DUALISM AND NON-DUALISM:
ELEMENTARY FORMS OF PHYSICS AT CERN

by

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ABSTRACT

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The dissertation critically examines the process of discovery, thought and language at the frontier of modern science. It is based on two and a half years of ethnographic research at the particle accelerator complex, the Large Hadron Collider (LHC) at CERN, Switzerland. In March 2010, the LHC began the world's highest energy experiments as a probe into the structure of matter and forces of nature. In the light of the LHC experiments, the dissertation investigates the relation of general beliefs and technical procedures of science with the principles of classification of knowledge, to show how they conjointly constitute a specific cultural or symbolic mode of apprehending the world, and to inquire how this mode is expressed, affirmed and maintained in everyday behavior.

Dwelling amongst the particle physics community at CERN, I observed that conceptions of matter and energy were derived from submerged assumptions about how the universe works. These assumptions took the form of proscriptions and dualisms: values do not affect physical reality, the mind does not participate in the universe, or conventions do not impinge on laws of physics. In spite of this, and perhaps more interesting, I found a few puzzling concepts in specific data-sets of theory, experiment and instrumentation, that confront and challenge, quite effectively to my mind, the separations of subject and object, or sign and thing, in a discipline that ostensibly proceeds from their strict separation.

The dissertation examines the classification of handedness (right and left) in particle interactions with the underlying question: Does physics admit of orientation? To characterize right or left presupposes an observer, and conventions. But if physics proceeds from the separation of subject and object, then how can it posit – as it does – a physical universe with a preferred orientation? The focus here shifts to the experimental concept of "signatures." Decays from particle collisions, such as a Higgs boson decaying into two photons, are termed signatures and constitute the unit of discovery in particle physics. Focusing on the physics signature, I inquire into the potential relevance of formal theories of semiotics in considering natural signs. Finally, my work explores the rich material culture of the laboratory through the lens of a concept of pure circulation – energy – as it flows in the magnetic fields and currents of the accelerator. By analyzing a concept that attempts to bring together Maxwell's equations of the field with the exigencies of machine parameters, the research arrives at a key moment in the life of a laboratory when the division of theory and practice stands critically exposed.

For Leibniz (1646-1716), and the physicists at CERN (2007-2009), to whose friendship I owe many happy hours

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Introduction

The dissertation is an ethnography of physics and physicists on the Large Hadron Collider (LHC) at CERN (Conseil Européen pour la Recherche Nucléaire), Switzerland, and a contribution to theory and method in anthropology. In March 2010 - fourteen years after it was approved - the LHC began the world's highest energy experiments as a probe into the structure of matter and forces of nature. The LHC experiments provide a fresh impetus to inquire what is the mode of existence of a work of science? What is the value of history and anthropology to that mode? Unlike previous studies that have sought the singularity of science in individual biographies or traced its generality in institutional practices, the dissertation explores the role of cognition in forming the social relation between subjects (the scientist) and objects of inquiry (the external world). By cognition, I mean the cosmological orientation (not the psychological orientation) of thought, whose relevance and character I shall examine as a problem in the theory of knowledge through an inquiry into the technical procedures of science.

Fieldwork was initiated in January 2007 at the Lawrence Berkeley National Laboratory (LBNL) at the thoughtful and kind invitation of Gil Gilchriese, Group Leader of LBNL-ATLAS. This generated enough interview, participant observation, and textual data on the nature of experimental work undertaken in contemporary physics and emerging forms of collaborative research to consider a laboratory as an object of study. In August 2007, I decided to move to CERN, Switzerland, where in all I resided for two and a half years, until December 2009. The bulk of my data comes from the site of the laboratory complex at CERN. My sincerest thanks go to the secretariat of LBNL, ATLAS and CERN User's Office for processing the paperwork for my long residence; and to my key informants Michael Doser, Malcolm John and Albert de Roeck (from experimental physics), Luis Alvarez-Gaume, Cesar Gomez and James Wells (from theoretical physics) and Gijsbert de Rijk and Francesco Bertinelli (from accelerator physics). At the conclusion of the active part of fieldwork, I returned to Berkeley and commenced with data-analysis and writing. Overall the research has aimed to examine the relation of general beliefs and technical procedures of science with the principles of classification of knowledge, to show how they conjointly constitute a specific cultural or symbolic mode of apprehending the world, and to inquire how this mode is expressed, affirmed and maintained in everyday behavior.

Initial observations revealed that the dualisms of (a) subject and object, (b) fact and value, and (c) theory and practice permeate and guide every aspect of the scientific process. The criteria for abstracting these three sets of dualisms was provided by the (i) *relations* they express, for instance, of differentiation and opposition; (ii) *forms* they participate in that are institutional with clearly established usage; and (iii) *values* they designate of superiority, integrity or fecundity.[1] Disclosing themselves as a consistent scheme, organizing an array of values, and prefiguring every native utterance and action meant that the dualisms selected were reliable signposts for the ethnographic inquiry.

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[1] Georges Dumezil, *Mitra-Varuna : An Essay on Two Indo-European Representations of Sovereignty* (New York: Zone Books, 1988); Louis Dumont, *Homo Hierarchicus; an Essay on the Caste System* ([Chicago: University of Chicago Press, 1970).

Binary classifications are a common feature of many cultures.[2] In some instances they encompass an entire social organization, for example, the division of a tribe into two exogamous moieties or clans. In the more prevalent cases, they apply to specific aspects of social life, like the opposition of State and Church, or the opposition of Royals and Commons. The most resilient form of binary classification, however, is one like the division of the universe between the sacred and the profane, which as Durkheim argued, is general, external and constraining. The sacred is *general* not because everyone believes in it but – and this is important – because even those who do not adhere to it, will not trespass it. It is *external* to the extent that any given individual recognizes it to be other than and greater than himself or herself. It is *constraining* because the nature of this opposition does not permit reciprocity or exchange between the categories involved, except by an alternation of the total social order.[3] For this absolute kind of binary classifications, I reserve the term dualisms.

To this category of dualisms belong the oppositions of fact and value, subject and object, and theory and practice. That they are "normal" to modern society – especially its science – is a commonplace in the history of ideas. Dwelling amongst the particle physics community at CERN, I observed in full strength how routine conceptions of matter, energy, luminosity, etc follow from submerged assumptions about how the universe works. These assumptions take the form of proscriptions and dualisms: values do not affect physical reality, the mind does not participate in the universe, or human conventions do not impinge on laws of physics. Two and a half years of continuous research at the CERN accelerator complex leads me to affirm the existence and significance of dualisms as a "total social fact" of scientific thought and conduct. By piecing together how physicists deal with binary terms and relations, I gained a sense of their main ideas on cosmology in which the dualisms fit so well but which they themselves find quite remarkable. Employing categorical oppositions and separations with enthusiasm and skill, as a common everyday matter, they are astonished and baffled when confronted with intellectual forces that suggest relationship, mediation, or unity between key categories. As a simple illustration, consider the relationship of mathematics and physics, which they present.

A popular paper written by the Physics Nobel laureate Eugene Wigner called, "*The Unreasonable Effectiveness of Mathematics in the Natural Sciences*,"[4] expresses every physicist's bewilderment at the metaphysics of congruence of the mind and the world. Physics is an exact science, pertaining to a mind-independent external reality. Exactitude in the natural sciences is achieved through the accuracy and precision of mathematics. Mathematics, however, is a feat of abstraction of the human mind. Then it is a mystery: How is it that the best description of physical reality is not provided by anything in physical reality but by something entirely non-physical, i.e., mathematics? As Einstein expressed it, "How can it be that mathematics, being after all a product of human thought which is independent of experience, is so admirably appropriate to the objects of reality?"[5] Take complex numbers, or expressions

[2] Claude Levi-Strauss, *Mythologiques* ([Paris: Plon, 1964); Rodney Needham, *Right & Left; Essays on Dual Symbolic Classification* (Chicago: University of Chicago Press, 1973).
[3] Emile Durkheim, *The Rules of Sociological Method* ([New York]: Free Press of Glencoe, 1964); ———, *The Elementary Forms of the Religious Life* (New York: Free Press, 1965).
[4] Eugene P. Wigner, "The Unreasonable Effectiveness of Mathematics in the Natural Sciences," *Communications in Pure and Applied Mathematics* 13, no. 1 (1960).
[5] Albert Einstein, "Geometry and Experience," in *An expanded form of an Address to the Prussian Academy of Sciences in Berlin* (January 27, 1921).

involving square root of negative numbers, for instance. How can complex numbers, of which there is no physical analog, formulate and correlate so effectively with physical phenomena? Or regard Hilbert Spaces of infinite dimensions, which play a decisive role in the precise formulations of Quantum Mechanics. How does physical reality responds so well to a language, which by far exceeds physical reality?

It is a serious puzzle to most informants. It is clear that the origins of the puzzle reach back to the metaphysical opposition and separation of the mind and the world. But it is also clear that the opposition does not lie outside of science, but is a part of its character. This is its interest for anthropology. We wish to interpret why are mathematics and physics, or the mind and the world, considered to be an opposition and why is their relationship, when ostensibly also useful, considered puzzling or baffling as well. "We do not understand the reasons of their usefulness."[6] This is how Wigner responds to the puzzle. Einstein offers a more shrewd observation: "In my opinion the answer to this question is, briefly, this: As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality."[7]

The accuracy of mathematics in describing the physical universe constitutes a formidable mystery of Western physics and philosophy.[8] I have no solution to the mystery save to note that *if* the mind and the world are habitually *presupposed* to be heterogeneous and separate, then anything that suggests their interlocution would seem mysterious. From an anthropological or a comparative cultures' perspective, one might speculate that the mystery would perhaps appear less exorbitant to the Amazonian Indians of Brazil who are not perplexed at the intimacies of the mind and the world[9] or the ancient Chinese who observed a rather sophisticated logic of oppositions and dualisms – however, thoroughly mediated and transcended.[10]

The success of mathematics is repeatedly invoked as the justification, legitimation and sanction behind the success of physics. Yet it is always understood as an enigma, as a puzzle. And this puzzle is not a limitation. Rather it constitutes the point of departure of all creative activity in modern science. In fact, to resolve it would mean the dissolution of science itself; the opposition and separation, or the dualism of the mind and the world must be irrevocable for science, as we know it, to take shape.[11] Here we begin to grasp and appreciate the significance of this dualism. The scientific formulation of laws of nature may be vague or ambiguous; measurements of "fundamental constants" may vary over time; models and theories may arise contingently.[12] But science is always certain about the definition of nature, the participation of

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[6] Wigner, "The Unreasonable Effectiveness of Mathematics in the Natural Sciences.", 1.
[7] Einstein, "Geometry and Experience."
[8] Dirac, "*The Relation between mathematics and physics*," in P. A. M. Dirac and R. H. Dalitz, *The Collected Works of P.A.M. Dirac, 1924-1948* (Cambridge; New York: Cambridge University Press, 1995); Richard Phillips Feynman, *The Character of Physical Law* (Cambridge: M.I.T. Press, 1965); Alfred North Whitehead, *Science and the Modern World. Lowell Lectures, 1925* (New York: Macmillan Co., 1925).
[9] Hugh Raffles, *In Amazonia : A Natural History* (Princeton, N.J.: Princeton University Press, 2002).
[10] Marcel Granet, *The Religion of the Chinese People* (New York: Harper & Row, 1975).
[11] This is the part which is expressed by the physicist's feeling of wonderment that "the miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve." Wigner, "The Unreasonable Effectiveness of Mathematics in the Natural Sciences.", 14.
[12] Nancy Cartwright, *How the Laws of Physics Lie* (Oxford; New York: Clarendon Press ; Oxford University Press, 1983); Andrew Pickering, *Constructing Quarks : A Sociological History of Particle Physics* (Chicago: University of

the mind, or the function of instrumentation. This decisive orientation distinguishes science from art, poetry or philosophy.

The development of the Western world is unintelligible in its unique importance without an understanding of its science, or its specialized theories of nature, in which physics occupies the pride of place. Physics claims to be the most fundamental science.[13] "Fundamental science is where new ideas and methods begin that later become commonplace - from the electric light, which originated in 19-century curiosity about electricity, to the World Wide Web, invented at CERN…. No amount of applied research on the candle would have brought us the electric light; no amount of R&D on the telephone would have brought about the Web."[14] The statement on CERN's website expresses the rule of positivistic reduction, hierarchy and autonomy, which the sciences inherited after the Enlightenment. What it amounts to is a hierarchical logic where every branch of knowledge is considered autonomous, governed by its own laws, but at the same time linked to the ones below it.[15] The impression prevails that the Jacob's ladder defining the classification of knowledge "is not a philosophical construct, but an empirical fact. Its existence is the reason why science could progress in the understanding of the particle world."[16]

For the sake of clarity let me state at once the general *problematique* of the present research: to inquire into the modern classification of knowledge, and specifically into the presuppositions of science, in order to grasp the content of scientific truth. The goal of researching discovery, thought and language is bound up with meting the challenge of a post-constructivist anthropology of science. The way I understand it, the classification of knowledge works in society at two levels: one instrumental, another expressive. At the instrumental level, the sanctions and guarantees of any intellectual classification or hierarchy are said to *derive* from empirical reality, the changes of "scale" and the endless heterogeneity of the universe. The motion of quarks, the properties of gasses, or the metabolism of cells necessitates different kinds or levels of scientific explanations. Here it is easily observed how variegated phenomena in physical reality are used to justify and sustain claims of different explanations or sciences. This has largely been the trajectory of the various constructivist approaches to science.

There is another way in which principles of classification of knowledge may be addressed. In this mode, principles of classifications are not understood as abstractions or constructions deriving from sensible reality, instead are ways of conceptualizing and ordering reality. What role does handedness play in crystal, molecular or organic structures? What is the

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Chicago Press, 1984); Rupert Sheldrake, *Seven Experiments That Could Change the World : A Do-It-Yourself Guide to Revolutionary Science* (London: Fourth Estate, 1995).

[13] Feynman, "*The Relation of Physics to Other Sciences*" in Richard P. Feynman, Robert B. Leighton, and Matthew L. Sands, *The Feynman Lectures on Physics* (Reading, Mass.: Addison-Wesley Pub. Co., 1963).

[14] http://public.web.cern.ch/public/en/about/Fundamental-en.html

[15] According to this hierarchy, the science of psychology must obey its own laws as well as the laws of physiology, chemistry and physics. Physiology must obey its own laws as well as all the laws of chemistry and physics, but not of psychology. Chemistry must obey its own laws as well as all the laws of physics, but none of physiology or of psychology. Physics is the fundamental science that must obey only its own laws and none of chemistry, physiology and psychology. "This classificatory system of knowledge and its hierarchy of explanation are what is meant by saying, with apparent modesty, that physics is the basis of chemistry, chemistry is the basis of biology and biology is the basis of psychology. J.P.S. Uberoi, "Mind and the World in Modern European Sociology," (2008)., 3.

[16] The observation is from Gian Giudice, a CERN Theoretical physicist who has recently written a book introducing LHC physics for the lay audience. Gian Francesco Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc* (Oxford; New York: Oxford University Press, 2010)., 85.

role of dimensionless physical constants in physics? Here the chief concern is with frontier zones of a classification, which exposes the relationships between different classes of phenomena through notions of symmetry, inversion or opposition, and requires no heterogeneous or hierarchical catalogues of explanation. This mode of symbolic algebra *confronts* reality by studying what it expresses, rather than simply analyzing what effects it achieves. Here the measure of truth is not imputed or derived from the outside, from reality. Not recognizing changes of physical scales, or emergence or reduction in existence, none but internal necessary relations, the notion of truth belongs to the systematic relation of the mind and the world, to reality as much as to possibility.

Adopting this second method, the present research aims to inquire into the *conditions*, which have made the world's greatest physics experiment possible at CERN. In order to analyze these conditions, we must retreat from external forms of observation and pause over the principles and presuppositions guiding the present classification of knowledge. So long as we are given to mere contemplation of observed reality, we cannot grasp how a mode of experimental inquiry, the pursuit of truth, a concept of nature or complex instrumentation is born. These questions have the widest and deepest relations, not with any observable reality, but with the logic of classification, the foundations of knowledge, the interface of physics and engineering, the relation of thing and sign, and so on. Therefore, it is useless to arrive at a luxuriant reproduction of the reality of science when the aim, as I conceptualize it, is more ascetic: to comprehend the source and direction of scientific activity as an intellectual problem.

The above lines should indicate that the present investigation into science would be made in a manner and form different from the methods of prevailing science. The natural scientist or the empirical social scientist may find the investigation ambiguous or strange owing to the lack of emphasis in describing the present state of science or in avoiding a personal history of remarkable moments of shared scientific life. But they need not be disconcerted for the emphasis will be in showing *the setting up of specific and concrete problems* in the intellectual content and the intellectual value of science. In the next two sections I shall outline some of the particular concerns and methods in the foundation and orientation of science – and here we must limit ourselves to a selection – that may provide us with an improved analytical understanding of the greatest physics experiment initiated at CERN.

Substantive Concerns

The dissertation is not a description of science, nor a prescription for a better science, but a look at some of its presuppositions. By presuppositions, I mean the class of beliefs that is collectively and unconsciously held by the participants of which they are themselves unaware but which informs every step of scientific discovery and proof. As mentioned in the beginning, the presuppositions I am abstracting converge on the dualisms of fact and value, subject and object, and theory and practice, which distinguish and mark out the limits of physics as a "modern" science. Historically, starting with the Enlightenment, the imprint of the dualisms stamp much of the thought and practices in Western Europe from 1650s onwards as uniquely modern. Like Evans-Pritchard's monograph on Zande witchcraft, where the manner in which beliefs relate to action opens a window onto key concerns of causation, rationality, or pluralism,[17] the main burden of this dissertation is to relate the technical procedures of particle physics to this category of cognitive beliefs, which I am calling its presuppositions. The presuppositions belong neither to science nor to art. They are neither innate to the mind. Nor do they arise from experience. They are logical, but also "practical", as Bourdieu uses the term,[18] since they are kept up and cultivated. In the final analysis, no physical exposition can free itself of these metaphysical presuppositions.

This last remark is made with the intent to underscore that metaphysics precedes physics. The function of precedence is not to be assumed in the sense of chronological stages of before and after or initial and later. The precedence is of logical priority and ordering. The categorical nature of physics as a branch of knowledge, which involves itself with matter, magnitudes, causation, etc., arises from a logically prior division of qualities into "primary" and "secondary."[19] The doctrine of subjectivity of sensible qualities such as those that pertain to colors, tones or smells is given by two factors: (i) the qualities are given by or produced by our consciousnesses through sensation and (ii) they depend on the vicissitudes of actually prevailing physical circumstances, for instance, illumination in the case of colors. In stark contrast to these are found properties that are considered intrinsic or self-subsisting to any object, such as extension or motion. "Extension in length, breadth and depth is what constitutes the nature of corporeal substance."[20] Since its incarnation as a modern science, the presuppositions on the eminence of extension or motion, which we perceive "clear and distinct" as opposed to the secondary qualities, has continued to embellish and dominate every aspect of physics.

If "the object of all behavioral sciences is to go behind the external forms of behavior and discover other information than that which is overtly expressed,"[21] the presuppositions provide a conspicuous vantage point for reflection into every native utterance or act that presents itself as self-evident. Everyone thinks they know what they can do in order to live long or remain in good health, and most recognize what role hygiene or diet play. But it is more difficult to say if it is desirable to live longer. Such a question involves the translation of common sense into the grid of suppositions informing any classification, which while recognizing the variations that communities display - without the triviality of relativism - keeps to a meticulous questioning outlook in analyzing problems of orientation and belief. This is the achievement of comparative ethnography and the discipline of social anthropology. In accordance with this strength, I wish to inflect the anthropological gaze towards the presuppositions of science in order to raise the key question: by what perspective and by what necessity does physical science gain knowledge of external reality?

The question demands that we immediately turn our attention to the science undertaken at the LHC. The LHC experiments are expected to address key questions pertaining to the origin of mass, the constitution of "dark matter," or matter that influences the evolution of the universe

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[17] E. E. Evans-Pritchard, *Witchcraft, Oracles and Magic among the Azande* (Oxford: Clarendon Press, 1968).
[18] Pierre Bourdieu, *Outline of a Theory of Practice* (Cambridge [England]; New York: Cambridge University Press, 1977).
[19] John Locke, *An Essay Concerning Human Understanding* (New York: Dover Publications, 1959). Book II, Chapter 8.
[20] RenÈ Descartes, *Principles of Philosophy* (Lewiston, N.Y., USA: E. Mellen Press, 1988)., 19.
[21] Mary Douglas, *Implicit Meanings : Essays in Anthropology* (London; Boston: Routledge & Paul, 1975)., 120.

gravitationally but is not visible, the existence of magnetic monopoles, and a host of unresolved issues in cosmology. All these questions are physical realizations of metaphysical presuppositions, and this relation is the chief object of our analysis. The physicist may be distressed to hear that there exists an intimate overlap between anthropology and physics on the subject of cosmology but anthropology boasts of a distinguished catalogue of studies on cosmology starting from Granet and Hocart to Levi-Strauss and Descola.[22] The difference is that while the investigation of the universe approached purely physically, shaped by mathematics and instrumentation, falls under the purview of physics or astrophysics, a conceptual approach to cosmology that includes the observer, or the community of observers and their view of the universe, is essential to anthropology.

In the 70s, Mary Douglas spiritedly revisited some of the debates on cosmology on the basis of case-studies from Purum (Leach), Dinka (Lienhardt) and Thailand (Tambiah) and expressly hoped that social anthropology would expand its horizons to include modern scientific cosmology.[23] Sadly, even as the scientific interest in cosmology has expanded, its neglect in the social sciences is near total and concerns of epistemology and ontology have instead moved to the foreground of critical considerations.[24] Almost every contemporary STS inspired study deals with the scrutiny of what is real, how is knowledge of reality obtained, how are findings certified, etc.[25] On the eve of the momentous LHC experiments it is fitting to follow Douglas' appeal and the present research is an attempt to revive from obscurity the subject of cosmology on which Durkheim and Mauss pioneered much of anthropological thought. Chapter Two, in particular, takes the argument of handedness out of its secluded "primitive" context and is bared to address in detail the origin and structure of the cosmos at the level of fundamental forces and interactions.

The provocation from cosmology, in general, will be raised in reference to formal abstractions of language and thought. One of the ways in which anthropology qualifies the social character of human life is by underscoring the social structuring of cognition. Outside the imperious scope of pure reason and transcendental disquisition, and without a reduction into local schemes or practices, cognition has been a worthy subject of anthropological analysis especially during the days of structuralism with the familiar refrain of "good to think." Throughout the dissertation when I allude to the mind or cognition, it is to indicate the durably established symbolic proclivities of classification. Among the symbolic vehicles that constitute a mode of thought are relations of abstraction and combination, identity and difference, or proximity and distance through which the mind, scientific or otherwise, organizes and generates a universe. Some of the symbolic operations are claimed to have an archetypal flavor such as

[22] Philippe Descola, *In the Society of Nature : A Native Ecology in Amazonia* (Cambridge [England]; New York: Cambridge University Press, 1994); Granet, *The Religion of the Chinese People*; A. M. Hocart, *The Life-Giving Myth, and Other Essays* (New York: Grove Press, 1953); Claude Levi-Strauss, *The Savage Mind* (Chicago: University of Chicago Press, 1966); R. G. Lienhardt, *Divinity and Experience; the Religion of the Dinka* (Oxford: Clarendon Press, 1961).

[23] Mary Douglas, *Natural Symbols; Explorations in Cosmology* (New York: Vintage Books, 1973); Douglas, *Implicit Meanings : Essays in Anthropology*.

[24] Ian Hacking, *Representing and Intervening : Introductory Topics in the Philosophy of Natural Science* (Cambridge [Cambridgeshire]; New York: Cambridge University Press, 1983); K. Knorr-Cetina, *The Manufacture of Knowledge : An Essay on the Constructivist and Contextual Nature of Science* (Oxford; New York: Pergamon Press, 1981).

[25] Mario Biagioli, *The Science Studies Reader* (New York: Routledge, 1999).

metaphors[26] or exemplars.[27] Although I do not have an individual preference for any particular operation, the general vein of the study is towards the scheme of unmediated oppositions, which gains extraordinary prominence in modern thought and practice.

To say that science is the expression of a particular community's thought exemplified by dual schemes is rhetorical unless the mode by which we discern this thought is also specified. The cognitive competence of physics is embodied in the language, and I mean the technical language, of mathematics, measurement and magnitudes. It is spoken by physicists worldwide, which implies a shared orientation. That, like any other language, it is imparted through socialization is a commonplace. The fact that this complex language allows them to be in conversation with each other as well as with Nature is where physics asserts its distinctive character.[28] The dissertation research has placed primary emphasis in attending to the grammar and syntax of physics in order to understand some of the conceptual transformations, which are taking place in its discourse.

To accomplish a dissertation on the social foundations of knowledge yet not to speak of trust, cohesion or consensus might seem an epic failing. On the contrary, this is where the dissertation diverges from varieties of structuralism, functionalism or hermeneutics, and their emphases on features of cohesion, consensus and shared understanding. What distinguishes science is the admissibility of debate, dissent and disagreement among scientists or between scientists and nature. In order to produce a breakthrough and earn a Nobel Prize nomination, the work of a physicist, or a team of physicists, must be different from their colleagues. Progress in inquiry would not be enlightening if it did not show where one went wrong before, and the remarkable possibilities of breakdown of trust or cohesion fill science with a dynamic tension and forward thrust.

Recently Shapin has provided us with an assessment of twentieth century techno-science with the insistence that there is not less but *more* of familiarity, trust and charisma.[29] The importance of his insight, and the cult of personality that sweeps science, can hardly be overstated. From my fieldwork experience, I am aware of how much physics abounds with fallen heroes, forgotten heroes, or true heroes. One's own success is always a case of in spite of others. Equally but inversely, one's inadequacy, like witchcraft accusations, is often perceived to be a result of others' malicious interventions. However, along with the personal universe of identity, trust and negotiations, there exists an impersonal universe. This is the universe of experiment, mathematics, measurement, instrumentation or peer review. The interlocution or the "essential tension" of these two opposed tropes is what makes physical science a distinctive language game. This is clear to Shapin. But somehow he elects to ignore the impersonal aspect and decides to concentrate one-sidedly on the advent and the changes in personal authority, identity or credibility of individual scientists. "I want to describe who the truth speakers are in late

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[26] George Lakoff and Mark Johnson, *Metaphors We Live By* (Chicago: University of Chicago Press, 1980).
[27] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago, IL: University of Chicago Press, 1996).
[28] Physics is not merely a physical science like any other, but, rather, one in which by far the greatest progress in mathematical elaboration and experimental method has been made. Its strength is this synthesis of the conceptual and the empirical mediated by the experiment. Incidentally I would like to mention, particularly for the benefit of the physics audience, that the synthesis of theory, data and the observing self, gives social anthropology its privileged position among the social sciences.
[29] Steven Shapin, *The Scientific Life : A Moral History of a Late Modern Vocation* (Chicago: University of Chicago Press, 2008).

modernity: what kinds of people, with what kind of attributed and acted-upon characteristics, are the bearers of our most potent forms of knowledge."[30] With the spotlight on the personas of scientists, the book loses sight of their science and it takes the problem - which a social science analysis has to work out - as already solved.

On the strength of my fieldwork, I wish to foreground the role of cognition, language and community, and circumscribe the role of action or agency, for a future anthropology of science. In particular, I wish to shift the accent from the individual scientist to the *impersonal* language of science. This is not an issue of my bias or the physicists' belief. The crux of the matter is that there are institutional forms of thought and conduct, which contribute to the specificity of science, and anthropology must take critical cognizance of them, instead of presupposing them. Without an experiment, it would not be particle physics. Without mathematical consistency, a model will not be accepted. Without crosschecking the magnitudes, the accelerator will not work. It is for a substantive contribution to science that the scientists have caught public attention and without subjecting that to critical discussion, it is useless to lavish attention on the personas of scientists, and find Richard Feynman juggling on the beach or James Watson complaining about his salary.[31]

If the reader feels I am being perverse or picking on Shapin, then I will come straight to the question: why are we again and again, in the social sciences, diffident in engaging with the merit of scientific work – its inner truth and falsity - rather than the virtues of scientists' personalities? What prevents us from entering the content of science and raise questions to it critically, rather than cursorily, or not at all? Are we not falling to the same error of respecting "the Great Divides"[32] while accusing the natural sciences of adhering to them? The failure to confront the impersonal domain of language, thought and usage vitiates many of the current claims in the anthropology of science. If we redress this hesitation, then anthropology might suggest the very consummation that physics requires.

Methodological Concerns

In the preceding section I simply laid out four shifts that the dissertation intends to track: (i) from questioning the findings of science to examining its presuppositions, (ii) from questions of epistemology or ontology to cosmology, (iii) from analyzing action or "inter-action" to cognition, and (iv) from focusing on personalities in science to the impersonal language of science. In order to accomplish the foregoing aims, I need to clear away some of the methodological constraints that apply to this field of inquiry. Here I will be making a few strong critical comments. At a distance criticism, which destroys any great work or idea, must always appear unpleasant. But I hope the reader will appreciate the constructive approach that underlies any criticism. Above all criticism implies the conviction that disciplinary engagements are of some consequence.

[30] Ibid., 6.
[31] Ibid., 218, 221.
[32] Bruno Latour, *We Have Never Been Modern* (Cambridge, Mass.: Harvard University Press, 1993).

Anthropology has been derided as a legacy of colonialism.[33] Most of it was carried out within the colonial territory. Some of its interests and aims coincided with those of the governments or missionaries. This problematical inception has inspired ethnography in particular to cast a critical look at itself. In the last few decades, ethics of fieldwork, politics of representation, privileges of race, class and gender, and more humane concerns with advocacy have been at the forefront of our agenda.[34] Indeed, the systematic reexamination of established institutional orders that impinge on the very process of ethnographic inquiry has much to recommend on grounds of methodological and humanistic considerations. Yet I cannot avoid feeling that they narrow the horizon more than they enlarge it. We are now advised to stay away from abstractions and universals.[35] Contentions mostly pertaining to ethics, politics and poetics are placed at the core of current "anthropological problems."[36]

Going against the grain of contemporary theorizing, the research attempts to take up the issue of knowledge formation in the foundations of thought through a consideration of the LHC experiments at CERN. "If concerning a science like theoretical physics or organic chemistry, one poses the problem of its relations with the political and economic structures of society, isn't one posing an excessively complicated question?.....Couldn't the interweaving of effects of power and knowledge be grasped with greater certainty in the case of a science as 'dubious' as psychiatry?"[37] I believe Foucault's appraisal is honest, but his proposal is unacceptable. We have examples of studies by Galison, Knorr-Cetina and Pickering, to name a few, that have brought before us the rise of post-War particle physics with a comprehensive consideration of technical details. Moreover, as I propose to show, the connection between power and knowledge need not be manifest or realized through political or economic structures alone. Experimentation carries its own power – the power of discovery, or instrumentation symbolizes unique pride – by showing human dominance over matter.

It is true that it is impossible to underestimate the significance of institutional factors, which have determined, or to use Freud's term, "overdetermined," the shape of particle physics. Almost every physicist I have spoken to underscores the role the Manhattan project and the Cold War played in fuelling the prospects for particle physics as well as the danger of decline that threatens the discipline given the disintegration of the Cold War. The present struggle by physicists to engage and impress the public of the value of physics betrays their anxiety. They are acutely aware that if the LHC fails to deliver on an exciting range of physics, they will suffer a huge loss in prestige, which will adversely affect government funding and public support for

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[33] Talal Asad, *Anthropology & the Colonial Encounter* (New York: Humanities Press, 1973).
[34] James Clifford et al., "Writing Culture : The Poetics and Politics of Ethnography" (Berkeley, Calif., 2010); George E. Marcus and Michael M. J. Fischer, *Anthropology as Cultural Critique : An Experimental Moment in the Human Sciences* (Chicago: University of Chicago Press, 1986); Kim Fortun, *Advocacy after Bhopal : Environmentalism, Disaster, New Global Orders* (Chicago: University of Chicago Press, 2001).
[35] "Stengers and Haraway generally agreed that a 'pragmatic and situated philosophy' was necessary in order to avoid abstractions and highlight corporeal/felt understanding irreducible to and incommunicable via language," from online blog entry on "*Donna Haraway, Richard Rorty, Isabelle Stengers in conversation on Whitehead and Science and Technology @ Stanford"*
http://traumwerk.stanford.edu/archaeolog/2006/04/donna_haraway_richard_rorty_is.html
[36] Aihwa Ong and Stephen J. Collier, *Global Assemblages : Technology, Politics, and Ethics as Anthropological Problems* (Malden, MA: Blackwell Pub., 2005).
[37] Michel Foucault and Colin Gordon, *Power/Knowledge : Selected Interviews and Other Writings, 1972-1977* (New York: Pantheon Books, 1980)., 109.

future particle physics projects. But the question concerning the limits of dealing with issues of power in the case of sciences such as mathematics or physics, which Foucault alludes to, is a theoretical problem. Power or prestige by itself does not disclose the specificity of physics, or knowledge, in general. Physicists often make this point against social-science charges of political economy or social constructivism. To express it philosophically, volition does not affect cognition. That is, action has no bearing on issues of thought.

Yet even this seemingly autonomous realm of cognition is socially constrained. This was the decisive departure that Durkheim and Mauss initiated and to which generations of notable anthropologists have added strength. What is the origin and source of some of the fundamental categories of thought? The question immediately recalls modes of classification prevalent in any society or community.[38] However, this strand of work has "increasingly grown remote from the main stream."[39] The decline is perplexing given the exuberant expansion we have achieved in recognizing reflexivity, multiplicity, situatedness, flux, and open-endedness as basic to issues of anthropological inquiry.[40]

The previous comment is made with the intent of arguing that it is not a social science challenge to re-discover a neat, ordered, and rational world to be inherently messy, fuzzy or chancy, find entanglements of humans and non-humans, demand agency from brute materiality, or celebrate the iconic or the affective in place of the cognitive.[41] These appear more like steps in distributive justice. To denounce universal principles of the sciences of nature while holding steadfast to the accomplishment of particulars for the sciences of culture does not dispel the opposition but rather intensifies it and does disservice to either side. Any moral yearning for achieving unity must be mediated by an understanding of the role and relevance of concepts, categories and classification. This inner relationship between the logic of classification and the problems of everyday practice that result from it has hardly ever been clearly understood. As a consequence much of the reflexive work undertaken in the social sciences lacks direction and vision.

To return to the relation of institutional settings and knowledge, upon reviewing the anthropological literature I find that the whole problem turns on two axes: (1) one approach is to claim a relation of correspondence, which implies some sort of parallel between a thought and a community. Most of the structuralist studies exemplify this position, for instance, starting with Durkheim, Levy-Bruhl to Evans-Pritchard, or Turner, to name a few. (2) The second position embraces a causal relation. Institutional orders of wealth, bureaucracy, or the state have "effects" on thoughts and representations. Political economy approaches generally exemplify this

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[38] Emile Durkheim and Marcel Mauss, *Primitive Classification* ([Chicago: University of Chicago Press, 1963).
[39] Malcolm R. Crick, "Anthropology of Knowledge," *Annual Review of Anthropology* 11(1982)., 287.
[40] George E. Marcus, "Ethnography in/of the World System: The Emergence of Multi-Sited Ethnography," *Annual Review of Anthropology* 24(1995).
[41] Karen Michelle. Barad, *Meeting the Universe Halfway : Quantum Physics and the Entanglement of Matter and Meaning* (Durham Duke University Press, 2006); Donna Jeanne Haraway, *Simians, Cyborgs, and Women : The Reinvention of Nature* (New York: Routledge, 1991); Evelyn Fox Keller, *A Feeling for the Organism : The Life and Work of Barbara Mcclintock* (New York: W.H. Freeman, 1993); Latour, *We Have Never Been Modern*.

approach and find the layering of interests, values, and knowledge in a "structural causality" with or without primacy to material factors.[42]

The first position (the correspondence approach) offers a weak theory of isomorphism. The participation of the two opposed orders is inherently unreciprocal: cognition expresses a social formation, but a society or an economy does not express cognition. This was precisely the juncture at which Durkheim and Mauss foundered when they contended in *Primitive Classification*, "the first classes of things were classes of men."[43] The second approach (the causal approach), while more rounded and dynamic, does not give an explanation on "first principles" or "final causes" and suffers the same problem as a functional or utilitarian explanation "which works when it works and doesn't when it doesn't."[44] Therefore, mapping changes in knowledge as a measure of changing institutional practices – albeit in tenuous, temporal, and contested ways - is also neither fecund nor far-reaching.

To return to the argument on the specificity of science, when a research analyst of the CMS experiment vehemently tells a fellow analyst upon the latter's insistence that a small peak in the graph is not a "Top" event or the community heatedly disputes Fermilab's evidence of a new kind of a "boson" with a mass energy of 144 GeV, the difference of opinion cannot be ascribed to individual intelligence, to differentials of power or to virtues of subjectivity or sovereignty. In order to be acquainted with this level of detail one has to explore the substrate of society or language inside science. It is to the exploration of this technical language - which is socially constituted like any other language - that my ethnography is seriously given to. It is within the critical scope of anthropology to interrogate the procedures, standards, and beliefs against which such truth claims are proximately admissible in the society of scientists and engineers. The coherence of these questions, their apparent failures, their explanations takes us to the source of how thought and knowledge are conceived and makes apparent the fascinating link between simple classification and complex vocabulary. It manifests in a full sense the underpinnings of what otherwise seems to be a self-sustaining paradigm.

The identity of this language inside science does not become apparent to us if we confine the term "social" to the privileges of the market and the state or to the dilemmas of inter-subjectivity. The language originates in the community, not as science's opposite, but as its culmination. In this - what I am going to call the third approach - we have moved away from a causal account of science[45] or eliciting a correspondence between epistemic concepts and social group[46] to the necessary interlocution, or mutual communication, of metaphysics and physics, or the mind and the world. How is a mind-independent reality accessible to scientists? What is the physical interpretation of a dimensionless coupling constant? How is a material collision

[42] Louis Althusser and Etienne Balibar, *Reading "Capital"* (London: NLB, 1970); Gary Lee Downey and Joseph Dumit, *Cyborgs & Citadels : Anthropological Interventions in Emerging Sciences and Technologies* (Santa Fe, N.M.; [Seattle, WA]: School of American Research Press ; Distributed by the University of Washington Press, 1997).
[43] Durkheim and Mauss, *Primitive Classification*.
[44] Geertz's entry on "*Functionalism*," from Edwin R. A. Seligman and Alvin Saunders Johnson, *Encyclopaedia of the Social Sciences* (New York: The Macmillan company, 1930)., 403.
[45] Robert King Merton, *Science, Technology and Society in Seventeenth Century England* (Bruges, Belgium: Saint Catherine Press, 1938).
[46] Sharon Traweek, *Beamtimes and Lifetimes : The World of High Energy Physicists* (Cambridge, Mass.: Harvard University Press, 1988).

transformed into a signal event? Is instrumentation possible without conventionally established units and magnitudes? Any such question inexorably leads to subterranean zones of a classification that crosscuts between the expressive and the instrumental, the physical and the conceptual. Between these there exists no relation of external influence or internal correspondence.

This third approach, which I am adopting, goes back to Leibniz who distinctly perceived the inadequacy of causality and correspondence as modes of explanation. Expressing dissatisfaction at Descartes' reduction of dynamics to the geometry of causes, Leibniz reflected, "I accept that all corpuscular phenomena can be traced back to mechanical efficient causes, but those mechanical laws as a whole must be understood as themselves deriving from higher reasons."[47] He then arrived at a critical moment in the theory of knowledge with his soul-like entities, the monads, which do not "interact" with each other, but "mirror" each other and the universe. "If anyone says that this effect is contained in the motions impressed on the atom,…it can be replied that not only must an effect in the atom result from all the impressions of the universe but conversely, the entire state of the universe must be gathered from the atom."[48] So if pure mechanics is deemed untenable, then there are also no more miracles. Rather the order of the universe itself is an enduring universal miracle. Thus the meaning of the world opens up to us when we view all being and change as rational and symbolic, thing and sign, at once.

Here the method of analysis is neither mechanical, nor organic. Against mechanical *cause and effect* and organic *holism*, what is being offered is the singularity of *form*, which expresses the principle of *integrity* and includes perspective and discrimination. The difference is subtle but entails a decisive shift. My research would not appear original if this subtlety is not appreciated, so I have gone into it in some detail. As is well known, Latour has provided us with an incisive critique of science, without reducing it completely to context or contingency. What is less incisive is his proposal of "anthropology as a model for describing our world,"[49] which he believes has the advantage of familiarizing "us to dealing calmly and straightforwardly with the seamless fabric of what I shall call 'nature-culture.'"[50]

No doubt Latour is moved by a desire to rehabilitate "seamless fabric" as an antidote to the perversions of modernity – its dualisms. However, the comparative record of ethnography abounds with oppositions, separations, and segregations, which demand our attention and an explanation as well. Outstanding anthropological monographs have chronicled a marvelous catalogue of immutable dual classifications. The separation of "upstream" and "downstream" among the Achuar of Amazonia (Descola), "mitra" and "varuna" in India (Dumezil), or "yin" and "yang" of Chinese cosmology (Granet) are well-known and do not offer us a template of a seamless social fabric.[51] What is attributed to modern science as a deficiency or a limitation actually seems the basis of primitive thought's richness and strength. The puzzle contains the

[47] Leibniz, "*Specimen Dynamicum*," in Gottfried Wilhelm Leibniz, Richard Francks, and R. S. Woolhouse, *Philosophical Texts* (Oxford; New York: Oxford University Press, 1998)., 163.
[48] Leibniz, "*First Truths*," in Gottfried Wilhelm Leibniz and Leroy E. Loemker, *Philosophical Papers and Letters; a Selection Translated and Edited, with an Introd* (Dordrecht: Reidel, 1969)., 203.
[49] Latour, *We Have Never Been Modern*., 91.
[50] Ibid., 7.
[51] Descola, *In the Society of Nature : A Native Ecology in Amazonia*; Dumezil, *Mitra-Varuna : An Essay on Two Indo-European Representations of Sovereignty*; Granet, *The Religion of the Chinese People*.

question: to what extent is it permissible to mark off a mode of existence by mere indication of characteristic features?

Any empirical list of features will fail without working out a methodological ground. What distinguishes a modern form of classification from non-modern ones is not any substance but the relations it establishes between differences. While non-modern forms make the recognition of differences the condition of their unity, modern predilections discover in them a ground of separation. Not by abolishing differences (homogeneity), nor by endless variety (heterogeneity), but by collecting perception in certain focal points, dualistic schemes of primitive thought create both the necessity and the possibility of centering and overcoming. Primitive thought has "no system of nature" or any interest in "holism". Their classification appeals to integrity, a principle by which it includes and excludes categories and events. The circle of anthropological reason forces the recognition that primitive thought is much more sophisticated than sometimes anthropologists acknowledge it.

The critical insights that Latour fastens on the ordering of phenomena in terms of *things* and *attributes*, that they are not pre-constituted in simple existence and facticity, he fails to extend to *relations*. Secondly, were he to extend those equally to the understanding of relations, he would have discovered that the apprehension of relations involves not any mode of *representation* but a mode of *evaluation*, that is, a language of distinctions. Thirdly, relations are of two kinds: of concurrence and comparison. The former include instances such as part and whole, like the relation of microcosm and macrocosm, and the latter includes relations based on resemblance and difference, like the relation of subject and object. While Latour speaks candidly of relations of scale, that is relations, which bring concurrence in size (or *quantity*) between inside and outside, local and global, micro and macro, he takes little cognizance of relations of comparison (or *difference*). Most of the intractable binary oppositions like that of matter and spirit, form and content, sacred and profane, or subject and object, involve relation of difference or comparison, the appraisal of which would throw into considerable jeopardy Latour's model of "translation and purification," and his claim of finding "expanded proliferation of hybrids" in modernity.[52]

If all that anthropology needs is a full-blown concept of an *object*, then we may be satisfied with Latour's proposal. On the other hand, if anthropology's model is human language, or the *relation* between *langue* and *parole*, then we step outside the ambit of reality into the terrain of possibilities. In order to subject science to a meaningful critique, we cannot confine our attention to the institutional power of science or to its dense presence in our lives. Either mode is merely an objection to the reality of science and leaves unexamined the decisive question of truth with which science is concerned. That truth should be a part of the orientation of a science is not indulging in any caprice or posturing. In conceiving and acknowledging truth, natural science shows it is surveying with pleasure the soil and expanse of its territory, without which it would remain, to use Kant's words, "mere acrobatics of reason."

The Field Site

[52] Latour, *We Have Never Been Modern*., 34.

CERN is a particle accelerator complex. The complex straddles across the French-Swiss border, although the primary site is in Meyrin, Switzerland, which is approximately eight kilometers from the Swiss cosmopolitan city of Geneva. As an international facility, it is officially neither under Swiss nor French jurisdiction and it is privileged with the status of diplomatic immunity. In September 1954, representatives of eleven European nations ratified the organization's convention and CERN formally came into being. At present, twenty Member States contribute towards CERN's annual budget, which equaled one billion Swiss Francs (or 0.85 billion USD) in 2010. Since Member States' financial contributions to the budget are pledged in advance, CERN can benefit from temporary financial borrowings for a fixed number of years, in order to aid the cost of large techno-science projects such as the construction of the Large Hadron Collider. Apart from the European member states, six countries have "observer" status, which include India, Israel, Japan, Russia, Turkey and the United States. In essence, CERN is a European laboratory hosting a global project. Although an academic establishment - with most people who pass through it holding doctorates - it has the underpinnings of a corporation with markers of worldly power, success and prestige. Given at once to relatively esoteric concerns of knowledge, discovery and truth, it is equally savvy with media blitz or CD-plated cars.[53]

The three main subcultures of particle physics - theory, experiment and instrumentation – are fully represented at CERN. The division and hierarchy of theory, experiment and instrumentation, is intact and clear. Equally clear is the functional interdependence between the three sub-cultures. "For obscure reasons, physicists - at CERN as everywhere else - like to categorize themselves in different classes, such as theorists, experimentalists, accelerator physicists, technicians...Of course, each class is convinced to be dominant over all the others, and that physics is best served by them. Worse! Theorists often think they do create physics with their theory, experimentalists often think they do discover or invent physics with their experiments, accelerator physicists often think they make it possible with their instruments...and they all think that the other categories exist only to provide them with the technicalities they either do not want - or are not able - to work out: long but straightforward calculations, subtle but repetitive measurements, powerful but dirty tools?"[54] Patrick Janot, from the CMS experiment at CERN, has expressed well the division of labor, which is seen as contributing to the overall success of particle physics.[55]

The total personnel employed by CERN is two thousand two hundred and fifty, out of which approximately twenty are from "Theory" division, fifty are "Research Physicists," that is, experimentalists who do the prestigious job of Physics Analysis, three hundred are "Applied Physicists" who deal with the R&D, construction, installation and commissioning of the detectors, and over a thousand technicians, mechanics, and engineers are involved with accelerator and beam instrumentation. The bulk of the workforce, however, does not come not from CERN directly but from worldwide universities and research centers, which are participating on the various experiments at CERN. Some eight thousand scientists, representing five hundred and eighty universities and eighty-five nationalities flock here for their research.

[53] Vehicles bearing CD or "Corps Diplomatique" license plates enjoy diplomatic immunity. Generally belonging to vehicles attached to foreign missions, they are also given to privileged personnel associated with international organizations such as the UN or CERN.
[54] http://public.web.cern.ch/public/en/People/Experimentalists-en.html
[55] The detailed investigation of the problem of division of labor has been taken up in Chapter Four.

That numbers is an issue at CERN one can observe from the constant expansions that are carried out by the Organization in office space, parking space, hostels, and cafeterias in order to accommodate the burgeoning work force, members of the press, attending dignitaries and curious visitors. English is the *lingua franca* at CERN, although it is surrounded by predominantly French-speaking areas.

The LHC or the Large Hadron Collider is the current flagship project of CERN. The term "hadron" refers to composite particles, or particles composed of more elementary matter called "quarks." Built at an approximate cost of 3.5 billion Swiss Francs, spread over fifteen years, the LHC is a discovery machine. It is set to explore and expand the existing range of physics, which for the last forty years has been stuck in a rut losing momentum and direction. A frenzied search for "new physics" went in air with the start-up of the LHC. On the morning of November 30, 2009 when it successfully accelerated two proton beams around the full 27 kilometers at 1.18 TeV (Tera Electron Volts), of energy, the LHC became the highest energy particle accelerator in the world, overtaking the Tevatron, the collider running at Fermilab, Illinois, USA at 1 TeV of energy. The Tevatron is presumed to cease operations in 2012 as it is made obsolete by the LHC. It is expected that for the next two decades, the LHC will be the sole major player in experimental particle physics.

The technology of the Large Hadron Collider is novel. A beam of protons is injected and accelerated in the LHC ring. Another beam of protons is introduced in the opposite direction. Giant superconducting magnets encircle the ring to bend and deflect the protons or to keep them going in circles because otherwise, according to Newtonian laws of motion, the particles will move in straight lines. Particle acceleration and collisions is predicated on the principle of mass-energy conversion ($E = mc^2$) in which fast-moving particles are collided with each other so that some of their energy is converted into the creation of new particles. At the site of each collision is a detector to record the data or the product of the collisions. The site of each detector is a distinct experiment pursuing specific physics goals managed by large-scale international collaborations. Out of the four big experiments, two are general-purpose experiments, ATLAS and CMS, designed to investigate general physics signatures possible, whereas LHCb and ALICE look closely at B-physics and quark-gluon plasma respectively. CERN also has a number of "Small and Medium Experiments" and its Department Head, Michael Doser, is one of my regular and key informants.

Some of the questions the LHC experiments are poised to tackle relate to fundamental laws governing particle interactions, the origin of mass, the nature of quark-gluon plasma in the early universe, along with confirming (or refuting) a number of predictions pertaining to the existence of "extra dimensions", "strings", or "grand unification" of all the forces of nature, among a host of others. These concerns in particle physics were ushered in with the paradigmatic rise of the Standard Model in the 1970s. The Standard Model is a theoretical explanation of the interactions between fundamental forces and elementary matter and is hailed as the crowning achievement of twentieth century particle physics. Some of the key contributions to the Standard Model were made by experiments done at SLAC, Brookhaven and Fermilab, laboratories in the U.S. The attention has now shifted across the Atlantic and CERN is self-conscious of its role and importance at the frontier of knowledge production.

In terms of the internal organization of the laboratory, the "PH" (PHysics) department is responsible for the basic research carried out in theoretical and experimental physics.

Instrumentation pertaining to the accelerator is covered by “BE” (BEams), “TE” (TEchnology) and “EN” (ENgineering) Departments. The other four departments are “IT” (Information Technology), “HR” (Human Resources), “FP” (Finance and Procurement), and “GS” (General Infrastructure Services). Each department has a “Head” and it is internally sub-divided into groups all of which have “Group Leaders”. To provide an illustration, the “PH” Department Leader is Phillipe Bloch, and the “TH” (THeoretical Physics) unit is led by Luis-Alvarez-Gaume, while each of the particular experiments is under a Group Leader, such as Giuseppe Mornacchi, for the ATLAS experiment, Monica Pepe-Altareli for LHCb, and so on. These department positions and offices are taken up on a rotation basis. During two and a half years, I made excellent contacts with over a hundred physicists, the division being more or less equal between theoretical and experimental physicists, a small number of engineers involved with beam instrumentation, computing and radiation safety, and a few members of the administrative staff.

The Director-General is the head of the CERN management. The present term of the Director-General, Rolf-Dieter Heuer, began on January 1, 2009 and will last for the next five years. The “CERN Council,” comprising of the European Member States, is the highest authority of the Organization. The Council is responsible for all of CERN’s activities in scientific, technical and administrative matters and is assisted by two Committees: (1) The Scientific Policy Committee, which evaluates the scientific merit of activities proposed by physicists, and (2) the Finance Committee which deals with issue relating to budget and expenditure. The CERN council meets periodically, and in particular some three to four times a year as a “Strategy Session” to formulate a comprehensive strategy on how to benefit from global enterprise while at the same time maintaining Europe’s lead in innovations. Termed the “European Strategy for Particle Physics,” it is formidable and thorough in harnessing future resources for European particle physics.

CERN is a pure science laboratory. Physicists frequently joke how hard it is for them to justify to funding agencies and the public the “spin-offs” or the benefits of particle physics for applications in technology or medicine. In conversations they underscore that they could easily have been rich if they had wanted, moved to more lucrative professions such as finance, business or engineering, but that their ambition is of another sort. There is a resonance with Weber’s depiction of science, as a “calling” rather than merely being a profession.[56]

As a pure intellectual endeavor, as a fundamental science, and in its capacity to address key questions relating to our universe, CERN attracts a great deal of press coverage, which the physicists seem to relish. Recognition and reward, particularly the Nobel Prize, is highly desired and sought after, resulting in a ruthlessly competitive milieu at times. The spirit of competition sits uneasily with the demand of collaboration or cooperation that an experimental science makes. The tension between competition and collaboration, while demoralizing at an individual level, is overall seen as good news for the field. Like any other community, the physics community exudes a strong sense of importance in the universe’s scheme of things. This belief in one’s importance is crucial to the narrative and action of what takes place at CERN and, among other reasons, makes it an exemplary site for an anthropological study.

[56] Max Weber, "Science as a Vocation," *Daedalus* 87, no. 1 (1958).

Map showing the area occupied by the Large Hadron Collider at CERN, Switzerland

Chapter One: Analysis of a Work of Science

Sometimes - history needs a push.

Lenin

What is the mode of existence of a work of science? What is the value of history and sociology to that mode?[1] Like every human endeavor, each aspect of science has certain unique characteristics. A theoretical proof, an experimental technique, an engineering design, each has an irreducible specificity. On the other hand, if we are interested in explanation, then we have to generalize from CERN's Hadron Collider, to particle physics, to all science. But in order to seek what is common, we arrive at another polarity: either we draw a list of distinctive features as we come across them (empiricism) or we select the form of inquiry as a precondition of what may be included in the analysis (rationalism).[2] The effort of the inquiry already sounds aimless, if not worthless. But that is the argument. An inquiry in the social sciences is not an invocation of pre-existing categories or a context of evaluation. On the contrary, it involves an interrogation of the categories themselves, into their constitution, scope and limits. To attempt a characterization of a problem is simultaneously a criticism, and sometimes even more - not just an admission of a failure to find any solution but even what is to count as a problem. In this restive spirit, the chapter explores the contributions of history and sociology to the mode of existence of science.

When speaking of history, I do not mean a developmental account. Instead of a chronological ordering, the logical ordering of science will be explored. From this standpoint, the relevant question to pose is not why things change but what form they take. Instead of tracing the construction and commissioning of the instrument, the Large Hadron Collider, the aim is to understand what drives the pursuit of experimental particle physics. By the same token, when speaking of sociology, the attempt is not to isolate factors of race, class or gender as they impinge on high-energy physics, or describe its organizational complexity and place in the emerging social order. Instead, I shall approach modern physical science as a form of knowledge that is specific to a community - its modes of thought and codes of conduct - that can be defined and critiqued. What is at stake is to understand how particle physics forms a language (of formulation) that begins with observed facts of physical states and processes, how it claims to explain these, and discloses or predicts new sets of facts. In its various modes of observation, description, explanation and prediction of physical reality, lies the specificity of physical science as an institution.

By the term "institution," I mean a socially standardized way of doing things. The term

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[1] These questions are modeled after Wellek and Warren's classic introduction to the analysis into "the mode of existence" of "a literary work of art." Rene Wellek and Austin Warren, *Theory of Literature* (New York: Harcourt, Brace, 1949)., 141.

[2] One of the ways of introducing the distinction between empiricism and rationalism is to consider Russell's treatment of a class, by "extension" and "intension." There are two approaches, he argues, to determine a class: one, by counting members one by one and grouping them as an aggregate (extension), and the other by stating a universal condition or characteristic, which all members of a class must fulfill (intension). The definition by intension clearly takes precedence over the grouping by extension for it is evident that before one proceeds to group elements of a class extensively by some sort of physical enumeration, a decision must be made as to which elements are to be regarded as belonging to the class. See for details Bertrand Russell, *The Principles of Mathematics* (Cambridge: Cambridge Universeity Press, 1903).

institution is frequently confused with the term organization. For instance, family and marriage are often spoken interchangeably, while marriage is an institution since it is a socially regulated way of establishing a family or a household, and the resulting unit, the family, is an organization, or a group, of people. From the standpoint of the definition adopted, a university or a bank is not an institution, but forms of organization, whereas the curriculum (followed in a university) or money (transacted in a bank) is an institution. Since the confusion is fairly common in anthropology, I have decided to clarify it at the outset. It also helps explain, in our particular case, the specificity of a laboratory mode of doing things, as opposed to unraveling its organizational structure or political agenda, which are not my particular concerns.

What relation, then, does this institution, which we call science, bear to society? The problem raised here received its first sharp and clear formulation in Durkheim's theory of knowledge. In order to demonstrate that cognition is a socially determined deed, he took the fundamental "categories of thought" such as space, time, force, substance, and causality and demonstrated how they coincided with forms of social groupings. For instance, it was argued that for the Australian Aboriginal tribe of Wotjobaluk, the orientation of space follows from the organization of their clans and moieties (and their social functions) or that the notion of force is the expression of an original concept in primitive cosmology, *mana*.[3] Although Durkheim introduced the social origin of concepts under the study of "primitive religion," he held that scientific concepts and classifications could not be immune or kept above the social control of thought, which he himself, however did not work out in any detail. Perhaps as a result, Durkheim's approach stands largely neglected today, especially in its relevance to modern knowledge or science.[4]

In occasional cases where scholars have attempted to resurrect and extend Durkheim's vision to science, such as David Bloor, they have followed a rather functional-normative approach in explaining knowledge claims, with the underlying assumption of a fit or a correspondence between nature and society.[5] From this perspective, language or concepts fulfill the requirement of generating "the coherence conditions" that keep collective representations or social networks intact and stable.[6] Such an approach is sympathetic, studious and reliable, but without imagination. It is Durkheimian in letter, rather than in spirit. The key question which preoccupies Durkheim is what contributes "to forming the intellect itself,"[7] and just like Hume's question of causation, philosophy or anthropology is to be studied not always for the sake of the answers to its questions, but rather for the sake of the questions themselves which open vistas onto unexpected and richer pursuits.

The approach opposite to Bloor's, also quite popular in academic sociology, begins by positing an external relation between categories such as laboratory and society. Bruno Latour, for instance, explores in depth the linkages appearing between nature and culture, or human and non-human, which generate diverse kinds of entities and artefacts. These "hybrid" entities render

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[3] Durkheim, *The Elementary Forms of the Religious Life*; Durkheim and Mauss, *Primitive Classification*.
[4] Please see Douglas for detailed explanations on the neglect of Durkheim in academic sociology and anthropology. Mary Douglas, *Implicit Meanings : Selected Essays in Anthropology* (London; New York: Routledge, 1999); ———, *How Institutions Think* (Syracuse, N.Y.: Syracuse University Press, 1986).
[5] David Bloor, "Durkheim and Mauss Revisited: Classification and the Sociology of Knowledge," *Studies In History and Philosophy of Science Part A* 13, no. 4 (1982).
[6] Ibid; Mary B. Hesse, *The Structure of Scientific Inference* (Berkeley: University of California Press, 1974).
[7] Durkheim, *The Elementary Forms of the Religious Life*., 21.

problematic most distinctions such as inside and outside, macro and micro or local and global. By pursuing these hybrids, Latour tries to grant a soothing benefit by persuading us that in spite of appearances, the world is really such as lacking in divides and segregations. He writes, "The Pythagorean theorem and Planck's constant spread into schools and rockets, machines and instruments, but they do not exit from their worlds any more than the Achuar leave their villages. The former constitute lengthened networks, the latter territories or loops: the difference is important and must be respected, but let us not use it to justify transforming the former into universals and the later into localities."[8] This spurious satisfaction is a disappointment. A question of difference is simply turned into a question of distance and propagation, i.e., metaphor is transformed into metonymy, and the value of science, or myths, becomes equivocal.

Latour and Bloor are caught in a heated exchange, given their antithetical methodological positions over the status of ontology, the role of interests in science, the locus of sociological analysis, etc.[9] The question that absorbs Latour is the "agency of things" such as how are electrons "allowed to cause our interpretations of them?"[10] His answer harps on the thesis he advocated twenty years earlier that under modernity, first we drive wedges ("purification") of nature and culture and then posit connections between the two realms ("translation"), whereby diverse material, social, and circumstantial entities simply become elaborations of various "networks."[11] While Bloor accuses Latour of making "no systematic distinction between nature and beliefs about, or accounts of, nature"[12], Bloor himself outlines a fairly standard or conventional view of sociology, namely that its aim "isn't to explain nature, but to explain shared beliefs about nature."[13]

Ultimately the fallout between the two scholars pivots on the distribution or the weight of the explanation between nature, society and language in the consideration of scientific metaphysics (ontology) and knowledge (epistemology). Like any exchange, it is fruitful, for together they have managed to pose critical questions regarding science, which they could not have done separately. However, in the end the criticisms have simply become supernumerary whose existence is justified, but whose significance is hardly explained. The criticisms, which had consisted of understanding and explicating between different facets or layers of scientific practice, have become a controversy incapable of discriminating between science and society or moving beyond idealism and/or realism.

I shall sidestep these approaches in my discussion, not because they are ineffectual, but because I wish to carry out an independent study of modern science not only in its relation to society, *but also in relation to itself* for "science is not only a *model of reality*, but simultaneously…*a model of truth*."[14] Let me explain this. The fundamental mission of a physical science lies in the conception of things or, what is generally understood as, reality. But when the

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[8] Latour, *We Have Never Been Modern*., 119.
[9] D. Bloor, "Anti-Latour," *Studies in history and philosophy of science* 30, no. 1 (1999); B. Latour, "For David Bloor...And Beyond: A Reply to David Bloor's Anti-Latour," *Studies in history and philosophy of science* 30, no. 1 (1999).
[10] Latour, "For David Bloor...And Beyond: A Reply to David Bloor's Anti-Latour." 119.
[11] ———, *We Have Never Been Modern*.
[12] Bloor, "Anti-Latour." 87.
[13] Ibid. 87.
[14] J. P. Singh Uberoi, *The Other Mind of Europe : Goethe as a Scientist* (Delhi; New York: Oxford University Press, 1984)., 11.

mould of judgment or evaluation is imposed upon reality, then the conviction of definite truth arises, and therein lies the ambition of science. After all physics is not simply a description of reality; it is also an explanation of reality by searching for causes, discovering laws, etc. Therefore, the principle adopted will be to regard science as a *symbol* as well as an *instrument* of knowledge, as both meaning and effect, so that even when the divergence between thing and sign is absolute, communication may be complete. How this happens is what I aim to inquire. From this viewpoint, it matters less if the content of science is considered fixed or flexible, as long as its orientation is adequately conceived. It matters less if the boundaries of science appear sketchy or exhaustive, while we understand its specificity. It matters less if its methods are one or many, as long as we grasp their integrity. These stipulations form the boundary conditions of the scope of my inquiry.

My plane of inquiry, without separating ontology (being), epistemology (knowledge) and cosmology (world), comprises of the prosaic concepts of physics, the concrete methods of experimentation, quantification and measurement, and the precision instruments and magnitudes, together which constitute a junction that produces with unprecedented limpidity a universe by proxy.[15] The force of intellect, the rigor of method, the sensation of objects in a mixed, but not indiscriminate way, lends to physics directness and vitality and suggests to us the possibility that a fresh scrutiny into its mission may still be valid. If we may then define physics, not in a formal sense of including criteria by which selective aspects of reality are identified or evaluated, but in the broader sense of determining its form and goal, we may say that physics moves back and forth between giving expression to a world that exists and the heralding of others which it conceives to be possible, which it does with metaphysical literalness but without practical efficacy.[16] In other words, its wisdom consists not in the dialectics of the real and the ideal, but of the real and the possible. Such is the intensity of particle physics as an experimental science.

In order to grasp it, we must examine it in the fanatical atmosphere of the laboratory where it takes shape. The sites of production (not the networks of transmission or dissemination) are where, like Marx, we can discover how surplus value is added to the outcomes of science so to speak.[17] To that extent, this dissertation is a genuine ethnography of a laboratory, of the *Conseil Européen pour la Recherche Nucléaire*, or CERN, headquartered in Switzerland. The fact that the direct source of a modern physical science is the laboratory has this consequence that ineffectual or immaterial things become objects of science when the instruments of science are active. But instruments and objects also rely on, just to continue with the Marxist vocabulary, a general medium of exchange that presupposes the objectification of relations and forms. The medium, which makes symbols and functions meaningful, is the society inside science that oversees the classification of knowledge. This notion of a society or a community within a laboratory is what I shall primarily explore in the text. A couple of points need elaboration here.

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[15] Proxy because the subject, that is the scientist, has minimal participation in the universe.

[16] In this conception of physics here what I have in mind are the mathematically possible worlds that physics routinely explores – extra dimensions, string theory landscape, chaotic inflation, etc - with little practical aim or motivation. These type of speculations are motivated by certain problems, some of them purely conceptual and unrelated to experimental facts.

[17] Marx accuses Ricardo of failing to understand the origin of surplus value since Ricardo was only concerned with the magnitude of value which he derives "from the act of exchange, from the product being sold above its value," thus overlooking the process of production where value and surplus value are *first* created. Hence, the decisive moment lies in production, according to Marx. Karl Marx and Friedrich Engels, *Capital; a Critique of Political Economy* (New York: International Publishers, 1967)., 516.

First, a brief word on the notion of a laboratory. Knorr-Cetina rightly urges that a physics laboratory should not be construed as a physical site or as an organizational setting.[18] A laboratory is not a physical site but a conceptual work-space, which provisions for the conduct of experiments, testing, manufacturing and assembling of instrumentation, preparation for collaboration on the development of techniques, theories, and models, and developing R&D (research and development) for future projects, and these distinctions are established foremost by principles of knowledge which makes it a function of intellectual classification. In other words, the laboratory forms a nodal point for the junction as well as the disjunction of three subcultures of high-energy physics, namely, theory, experiment and instrumentation. During the operation of an experiment, instrumentation or theory may step back or during the construction phase, engineering steps forward while experimental physics recedes in the background. It is in this dance of division and union of theory, instrumentation and experiment – as occupying a conceptual space in the classification of knowledge - that we find the foundation and significance of a laboratory, which is why I insist - the laboratory introduces us to the *source* of science.

Second, the notion of society inside the laboratory, which I aim to explore, represents the professional body of expertise. In approaching this body, the *impersonal* function, conceptual as well as instrumental, will be highlighted. The point of comparison by which this becomes clear is to say that my approach is not inclined towards individual scientists and inquire if they are dogmatic, pragmatic, strategic or reflexive.[19] It will not be towards collective or communitarian units such as collaborations, scientific papers, leadership functions, or information and gossip channels.[20] It will not address inventions at the confluence of industry and academy, or power, influence and expertise.[21] It will not be in the appropriation of metaphors and analogies used in scientific formulations.[22] These aspects of science – vital and richly fascinating - have received scholarly attention and little is gained by further dwelling on them. There is more reason to recognize, as I shall elaborate in the chapter, how a fundamental science makes it a matter of listening to the voice of nature by *suppressing* the voice of the scientist, while at the same time technology makes nature plastic by *intensifying* the action of the engineer. The concerted problem of the relation of subject and object with the relation of theory and practice in modern science remains untouched by digressions of post-modernism or doubts of political economy. Though a laboratory may have a precarious existence in the nebulous network of global capital, it is secure with an indomitable confidence in what it does, and with less financial or state support, science may then be better or worse, but not *false*. What is the secret of this resilience or inspiration? Let anthropology lead us to that.

Luhmann observes that modern society produces its own distinctiveness by way of stigmatizing the old. Therefore the problems of modern society are not problems in maintaining a heritage - the problem is to account for difference. The same, he argues, holds true for modern science with the overwhelming question of how to account for novelty or *innovation*. Novelty in the physical sciences is achieved by way of *experimentation*. The purpose of an experiment is to

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[18] K. Knorr-Cetina, *Epistemic Cultures : How the Sciences Make Knowledge* (Cambridge, Mass.: Harvard University Press, 1999).

[19] Shapin, *The Scientific Life : A Moral History of a Late Modern Vocation*.

[20] Knorr-Cetina, *Epistemic Cultures : How the Sciences Make Knowledge*.

[21] Paul Rabinow, *Making Pcr : A Story of Biotechnology* (Chicago: University of Chicago Press, 1996).

[22] Donna Jeanne Haraway, *Crystals, Fabrics, and Fields : Metaphors That Shape Embryos* (Berkeley, Calif.: North Atlantic Books, 2004).

amplify or exhibit entities that are revealed beyond experience, achieving in the process "a dialectical unity of reason and reality."[23] The possibility and necessity of an experiment is linked to the realization that science is not so much an ontological given as an epistemological construct; it refers not to things, but to our knowledge about things.[24] Germinal to knowledge are *problems*, or issues, which direct our attention to the *presuppositions* in the light of which science is done. Through these four aspects – of innovation, experimentation, problems, and presuppositions – I shall review the mode of existence specific to a physical science laboratory. The aim is not to seize science in its wholeness or spread but at its constitutive core.

1. The Logic of Innovations

In March 2010, the Large Hadron Collider (LHC) at CERN started its run of proton-proton collisions to search principally for the last remaining unobserved "standard model" particle, the Higgs boson.[25] The standard model is a theoretical explanation of the fundamental forces interacting between elementary particles. Aside from leaving gravity out, the standard model "covers everything else, from the reactions that fuel the sun to the forces that hold a snowflake together,"[26] and is hailed as the crowning achievement of twentieth century particle physics. If and when found, the Higgs particle would conclude the Standard Model. "Now the most urgent question in particle physics (maybe in physics as a whole) is: where is the Higgs?"[27]

When I arrived at CERN in August 2007, I asked the physicists if they looked forward to the discovery of the Higgs and the consequent validation of the Standard Model. To my utter surprise they replied in the negative. In so many different words, they all indicated that finding the Higgs would mean the end of particle physics! John Ellis, a prominent CERN theoretical physicist, has stated, "theorists are amusing themselves discussing which would be worse: to discover a Higgs boson with exactly the properties predicted in the standard model or to discover that there is no Higgs boson….The absence of a Higgs boson would be exciting for particle physicists, but it might not be so funny to explain to the politicians who have funded the LHC mainly to discover this particle."[28]

In one of my first scheduled interviews, I asked CERN's head of the Theoretical Physics division, Luis Alavarez-Gaume, about the fantastic possibility of a Higgs discovery on the LHC. He replied vehemently, "No, no we don't want to see the Higgs. The field will be totally dead. The press office has created this impression that the LHC has to do with the search for the Higgs. Most unfortunate. We wish to see 'new physics' not the Higgs." I was struck and baffled by his reply. The contrast between what the textbooks were proposing and the media was projecting, and what the physicists were saying couldn't be starker. While the search for the Higgs particle

[23] Gaston Bachelard, *The New Scientific Spirit* (Boston: Beacon Press, 1984).
[24] Ernst Cassirer, *Determinism and Indeterminism in Modern Physics; Historical and Systematic Studies of the Problem of Causality* (New Haven: Yale University Press, 1956).
[25] The Higgs boson is a massive elementary particle, which is responsible for endowing mass to other particles. It was postulated in 1964 by Peter Higgs, among others, and the LHC is expected to provide experimental evidence for the existence of the Higgs boson.
[26] David Kestenbaum, "What Is Electroweak Symmetry Breaking Anyway?," *FermiNews* 1998.
[27] Terry Wyatt, "High-Energy Colliders and the Rise of the Standard Model," *Nature* 448, no. 7151 (2007)., 277.
[28] John Ellis, "Beyond the Standard Model with the Lhc," *Nature* 448, no. 7151 (2007)., 298.

in order to complete the standard model seemed to scream from every poster, the particle physics community was eager to work out physics "Beyond the Standard Model" or "New Physics."

Of course there are compelling reasons why particle physicists are interested in probing a future of physics beyond the standard model. For in spite of the fact that all experimental tests have agreed fully and beautifully till date with standard model predictions, the model has some unresolved issues. It is not complete: it incorporates only three of the four fundamental forces, and leaves gravitational force out. It has a large number of arbitrary elements, termed "free parameters." It does not offer any explanation on differing masses. For example, why should the top quark, the heaviest known elementary particle, be something like 300,000 times heavier than the electron, another elementary particle?[29] It does not account for the observed phenomena of "neutrino oscillations."[30] All these open questions compel the community's efforts in exploring possibilities of "new physics" beyond Standard Model physics.

It was not just talk of "new physics" that was rampant when I arrived at CERN. One could observe the material manifestation of the concern with novelty in some of the scheduled instrumentation projects. Work was underway on the next set of accelerators and colliders like the International Linear Collider, or ILC, and the Compact Linear Collider, or CLIC, when the LHC had not even started. Since the time scale for building accelerators is so large, the R&D for the rival projects of ILC and the CLIC had commenced, and the design and prototyping stages were already completed. When I heard this in 2007, I was very surprised because at the time the LHC had not even started and yet everyone showed unmistakable signs of enthusiasm in the possibilities of exceeding the Standard Model. But, as I just said, the Model works and works fairly well. So what motivates the physics community to go beyond it?

"We have never found any deviation from these models, so we've been right for 30 years....It's sort of boring," celebrated CERN theoretical physicist, Alvaro de Rujula, reflects candidly in an interview.[31] de Rujula is not alone in citing boredom with standard (model) physics. I asked a leading string theorist, Cesar Gomez, "Why do you work on string theory?" "Because I don't know any other way of keeping myself entertained" came the prompt reply. Not the response the anthropologist was expecting, but whether uttered in jest or in earnest, one cannot disregard physicists' statements on boredom or ennui as motivating factors that propel scientific research. The conclusion one can draw is that while Standard Model physics is *important*, it is no longer *interesting*.

An explanation into this puzzling character of physics discloses that an expressive or a *symbolic* aspect, along with a purely *instrumental* aspect, is a defining moment of scientific enterprise. Innovations do not always proceed from any sense of failure or a desire to meet instrumental ends, but ideas or products may be replaced because they are "no longer considered acceptable as up-to-date."[32] Therefore, what marks science and technology in our times is not

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[29] An elementary particle is one without a substructure. Since an elementary particle is not made up of smaller particles, it forms one of the basic building blocks of the universe from which all matter is made.

[30] The phenomenon of neutrino oscillations implies that neutrinos have a non-zero mass, which is not part of the original standard model. Hence any explanation of neutrino oscillations has to be under the purview of new physics of some sort.

[31] David Kestenbaum, "Massive Particle Accelerator Revving Up."

[32] J. P. Singh Uberoi, *The European Modernity : Science, Truth, and Method* (New Delhi; New York: Oxford University Press, 2002)., 95.

simply an exponentially fast rate of growth, but in some peculiar twist, "*the rate of obsolescence overtakes the rate of depreciation*."[33] Ideas are phased out even before they get worn out. Uberoi illustrates this rationality with the case of pop star Madonna who refashions new personas even when previous ones were hugely successful: from "like a virgin", to "material girl" or "material mom" – her inventions of herself are not underwritten by any lack of success, but she moves from success to more success. The same underlying logic is found in the physics community's endeavor of creating new paradigms and rendering obsolete existing ones.[34]

Particle physics is eager to write a new future even when the contemporary state of affairs is a fairly satisfactory and successful one. In this quest for novelty, physics betrays that its goal is not that of finality, but of development and growth per se. While there is no consensus on the prognosis of the future that will emerge, the trend itself is seen as desirable, healthy and normal. "We have before us a situation in which the existence of new physics has been identified within a defined framework, but the answer itself is quite open. Such a circumstance is very attractive in targeting our scientific efforts."[35] The open and contingent future is a thrilling prospect and an indication that all is well. It is not entirely for the sake of a more complete picture that new physics prospects are being contemplated. In fact, the possibility that those may even challenge or undermine the Standard Model is admitted and not shied away from. The distinction between achieving useful solutions and exploring for the sake of intriguing possibilities becomes clear in this pursuit.

Max Weber poignantly recognizes that it is in the nature of science for accomplishments to be antiquated. "Every scientific 'fulfillment' raises new 'questions'; it *asks* to be 'surpassed' and outdated."[36] Weber's evaluation is that far from being extreme, which is how some of my informants delighted in presenting it, it is neither extreme nor idiosyncratic but profoundly symptomatic of modernity. To render oneself obsolete is not an exception or an aberration. It simply points to the chasm of fact and value that is achieved under modern life. The ability to think or act without regard to ultimate values is perfectly normal for modernity.[37]

It is here that we must pause and inquire into the meaning of science. It raises the question: what is science devoted to? Pure physics is an intellectual endeavor. It is devoted to increasing pure knowledge, with increase of knowledge as a value in itself. But the social scientist asks about the genealogy of knowledge. We ask: why is pure knowledge valuable or how can desire for knowledge be reconciled with the disinterestedness of science? The Large Hadron Collider presents us with the general problem of the dialectics of purpose and meaning.

An article in the Guardian titled "*Is the Large Hadron Collider worth its massive price tag?*" clamors: "what price society is willing to pay to understand the universe."**[38]** The LHC has been built at a staggering cost of $6.4 billion. The US has contributed approximately $521

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[33] Ibid., 95.
[34] Throughout this section, the terms novelty and innovation have been used interchangeably although there is a subtle distinction between the two. In the context of discovery, it is the sense of novelty, which predominates. When work concerns with techniques, models, theories, etc, then the sense of innovation is implied.
[35] U.S. ATLAS proposal, 2.
[36] Weber, "Science as a Vocation."
[37] Ibid.
[38] Ian Sample, "Http://Www.Guardian.Co.Uk/Science/Blog/2009/Sep/22/Particlephysics-Cern," (22 September 2009.).

million and the rest is borne by the twenty member states of CERN. A steady stream of media voices raise the concern that why must billions of dollars be spent to collide two tiny atoms in the hope of discovering a new particle. In other words, can't we do something more useful with that amount of money? In February 2008, the Science and Technology Facilities Council (STFC), which funds all of UK's particle physics and astronomy research, announced massive budget cuts to the Hadron Collider unless it could give convincing reasons why particle accelerators are productive. "In times of global financial meltdown and looming environmental problems, it's not unfair to wonder whether this kind of basic research is a luxury we can't afford. It's a question the physicists ponder and perhaps never fully answer."[39]

As Weber argues in his masterful essay, natural science gives us an answer to the question of what we must do if we wish to master life technically; our lives will be enriched, and our outlook will change by the growth of knowledge, but it is outside the purview of science to answer whether it is desirable to want a technical mastery over life, and whether it ultimately makes sense to do so.[40] Scientific analysis may answer accurately a great many of our questions about the world we live in, but it cannot answer our most important question, namely, how to live. Here Weber should not be read as rejecting science itself, rather he is rejecting science as a source of value claims.

If science is an ideal, which can never be reached, then why should everything in the world be subordinated to it? "Why should one do something which in reality never comes to an end and never can?"[41] Irrational as it may sound, the quest for novelty for its own sake is not illicit, but what defines progress. Science is nothing but open-ended inquiry sustained only by "continual self-correction."[42] In this spirit, it is typical that science should exceed its limits and does it ever so often. The emphasis on unceasing novelty distinguishes science from, say, religious dogma or philosophical doctrine.[43] The sprit of relentless discovery and innovation is best understood as Feynman famously put it, doing "physics is fun." "For me, physics is more fun than anything else or I couldn't be doing it."[44] Novelty is tinged with action and enthusiasm. If the Large Hadron Collider were unable to spout new particles, it would spell the end of accelerator physics. "The world would be too boring if the standard model is all us humans can ever uncover with accelerators."[45] The unreal or imaginary element plays a role in science by no means negligible. Without a doubt there is present a definite norm in the light of which physicists' expressions of excitement or ennui makes sense.

What about the opposite? Does physics involve practical efficacy? Innovations in physics rarely resolve practical problems in any direct way. When Bob Wilson, the first Director of

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[39] Ibid.
[40] Weber, "Science as a Vocation."
[41] Ibid.
[42] Hans-Georg Gadamer, *The Enigma of Health : The Art of Healing in a Scientific Age* (Stanford: Stanford University Press, 1996); Karl R. Popper, *Conjectures and Refutations; the Growth of Scientific Knowledge* (New York: Basic Books, 1962)., 3.
[43] Thomas S. Kuhn, *The Essential Tension : Selected Studies in Scientific Tradition and Change* (Chicago: University of Chicago Press, 1977); Popper, *Conjectures and Refutations; the Growth of Scientific Knowledge*.
[44] Leonard Mlodinow, *Feynman's Rainbow : A Search for Beauty in Physics and in Life* (New York: Warner Books, 2003).
[45] Posted by Joseph Smidt, "Http://Www.Theeternaluniverse.Com/2010/12/What-Would-Happen-to-Particle-Physics.Html," (December 29, 2010).

Fermilab at Batavia, Illinois, was asked by a Congressional Committee, "What will your lab contribute to the defense of the US?" he replied "Nothing, but it will make it worth defending."[46] While the overall power and prestige of high-energy physics decisively derives from past successes in the Manhattan project or the Cold War,[47] today's physics has no direct political or military benefits to offer. In CERN, the "spin-offs" of particle physics for industry and technology are lackadaisically mentioned. "When justifying particle physics, it is tempting to invoke spin-offs, such as the World Wide Web which was invented at CERN, but in my opinion they provide a secondary argument and the contribution to knowledge should be put first," according to Chris Llewellyn-Smith, physicist and former Director-General of CERN.[48] The Large Hadron Collider, CERN's latest flagship project, represents an extraordinarily complex and ambitious *intellectual* adventure.

> "The most fascinating aspect of the LHC is its journey towards the unknown…It is a search for unknown worlds which is carried out with complex cutting edge technologies and guided by theoretical speculations whose understanding requires knowledge of advanced physics and mathematics. These are the very aspects that have shrouded the work of physicists in a cloud of esoteric mystery, discouraging the interest of the uninitiated. But this book is intended to show that the issues raised by the results of the LHC are fascinating and of interest to anyone who believes it is worthwhile to ask fundamental questions about nature."[49]

The quote is from the Prologue of "*Zeptospace Odyssey*," a popular book by Gian Giudice that introduces LHC physics in a non-technical vocabulary. Giudice is a CERN theoretical physicist and his book is lucidly written with illustrative metaphors and imagery. However, I have selected it for mention here not because it is an outstanding literary feat but because it is a typical account of a physicist. Here I am using the term "typical" in a sociological sense to extract or highlight what are the standard modes of thought of the particle physics community. As Giudice skillfully makes the argument, there is no greater purpose or end that pure science serves, and as it feels its way towards the heart of things, which it never relinquishes, it also surpasses them in search of new questions and problems. In doing so, however, the symbols and significance of science become intelligible no less than its contradictions and troubles.

So while the Higgs hogs the popular imagination, the physicists are terrified that nothing but the Higgs will show up and conclude the Standard Model paradigm of particle physics. If physics today delivers on all the goals of explanation, then it would be dead. To be alive and in business in the present, it must constantly create futures that can be outclassed. During two and a half years of stay at the accelerator complex, I found over and over again expressions of hope and optimism on the possibilities of shocking discoveries on the LHC – exotic decays, sparticles, unparticles - alongside privately shared feelings of dread and anxiety: Will nature be perverse and stingy? Will she yield nothing but just a Standard Model Higgs?

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[46] C.H. Llewellyn Smith, "Http://Public.Web.Cern.Ch/Public/En/About/Basicscience3-En.Html."

[47] Hugh Gusterson, *People of the Bomb : Portraits of America's Nuclear Complex* (Minneapolis, Minn.: University of Minnesota Press, 2004); Joseph Masco, *The Nuclear Borderlands : The Manhattan Project in Post-Cold War New Mexico* (Princeton, N.J.: Princeton University Press, 2006).

[48] Smith, "Http://Public.Web.Cern.Ch/Public/En/About/Basicscience3-En.Html."

[49] Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*., 3.

> "If no new physics is seen beyond the standard model at the scale of 14 TeV, no expensive new project may be able to justify its existence…I hope that the LHC - i.e., ATLAS and CMS, including myself together with the other 2500 collaborators in my experiment - will indeed soon stumble in a host of new particles, magically turning on our detectors as a Christmas tree. Experimentalists will lose their sleep, theorists will go nuts, careers will be made overnight. Nobel prizes will pop up...."[50]

The Nobel Prize reward system is a singular temptation, even an obsession, of the particle physics community.[51] The annual prizes are recognition of the spirit of constant innovations - the milestones - in the development of science. Stories of major innovations and exemplary Nobel laureates percolate throughout the community. Thanks to my informants, Nobel laureates Paul Dirac, Enrico Fermi, Gerardus T'Hooft, Julian Schwinger and Steven Weinberg have become venerable and personable figures for me as well. I found that even the most hard-boiled physicist would reminisce with abandon the major turning points in physics. Heroic forms of narrative highlighting the endless quest for truth animate science.[52] "These stories are crucial to maintaining the values of the institution of science – the specificity and unique character of the knowledge it produces, for example, or the pivotal part played in its elaboration by the scientific method. They are essential to the smooth functioning and perpetuation of scientific communities."[53] There is a veritable myths and legends industry in physics, which exposes these endless possibilities where the merely mortal and the reasonable may easily be lost but radiating effects of outstanding originality and novelty are immortalized.

These stories also disclose the snares of politicking and ambition. The story of Carlo Rubbia's pursuit of a second Nobel Prize close on the heels of the first one, which at times bordered on unethical or opportunistic practices, is wildly cited and circulated in the community.[54] Or David Politzer's shrewd comments on the trauma of the "Yang-Mills beta function," a result with only two signs, a – or a +, which nonetheless had three contenders to the Nobel Prize (2004), is a remarkable public acknowledgement of aggression and deception that physics appears to breed.[55] Weberian or Marxist minded anthropologists might explore how people devoted to a pure esoteric science can at the same time display a maniacal inclination for worldly recognition. However, if our chief anxiety is not about what offends the sphere of moral sensibility, we begin to see that the depth and character of science becomes evident in its righteousness no less than in its fissures or disasters.

How then do things stand with this insistent demand of novelty? In this question, we implicitly recognize a caution often urged in fieldwork that ideals or myths should be compared with reality. There are two possibilities to this comparison: one, that reality mirrors myth, that

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[50] Tommaso Dorigo, "Particle Physics in 2020," in *A Quantum Diaries Survivor: Private thoughts of a physicist and chessplayer* (2010). Dorigo is an experimental physicist associated with the CMS experiment on the LHC. His online blog, addressed to the general public, is actually very popular among the physicists also because it is controversial at times.

[51] As a motivation to research and recognition, the Nobel Prize is not unique to the field of physics. See Rabinow, *Making Pcr : A Story of Biotechnology*.

[52] Dominique Pestre, "Commemorative Practices at Cern: Between Physicists' Memories and Historians' Narratives," *Osiris* 14(1999).

[53] Ibid. 205.

[54] Gary Taubes, *Nobel Dreams : Power, Deceit, and the Ultimate Experiment* (New York: Random House, 1986).

[55] H. David Politzer, "The Dilemma of Attribution," in *Nobel Lecture* (December 8, 2004).

there is a one-to-one correspondence such that myths of a society are expressive of its larger metaphysic (Durkheim, "a human institution cannot rest upon an error or a lie"). On the other hand, a comparison may well reveal a discrepancy between expressed sentiments and the actual situation (Marx, "all science would be superfluous if the outward appearance and the reality of things directly coincided"). In this reading, myths carry the dubious distinction of being illusory or false.

Illusions, however, need not be false, as Freud warned us. Levi-Strauss has made it amply evident that myths of a society are not false, although they may stand entirely inverted to reality. For instance, in the story of Asdiwal, all post-marriage residence is matrilocal, which, however, is in total contrast to the practice actually found which is patrilocal.[56] Myths do not serve in any straightforward sense as "charters for social action."[57] They may well function as a repository of a culture's values, expressions of dreams, personified abstractions of fallen gods and divine heroes, or, even prescriptions for behavior, but they are not simply functional or referential; they also indicate their own process of formation.[58] Anthropologists have worked out in elaborate length how myths convey meaning through logical order and empirical detail. The point where the structural aspects of myth combine with its more functional appropriation is best captured by Levi-Strauss when he suggests in oracular fashion: myths have no function except they permit a society to exist. They "have no intrinsic property other than that of establishing the necessary preconditions for the existence of the social system to which they belong."[59]

The myth most apposite to physics is perhaps that of Faust. The legendary Faust, at the summit of human excellence, is bored and dissatisfied and strikes a bargain with the Devil for unlimited knowledge.[60] Faust's spirit of insatiable inquiry finds expression in modern physics' unending quest for novelty. While the thought of anything mythical may be disclaimed and despised in physics, since it professes to be interested in physical reality, which it feels can be grasped only by rigorous procedures of observation and deduction, it delights in what amounts to an amiable representation of its overarching endeavor or spirit. With this window open to endless possibilities, science is made more fantastic than religion without being less irrational and vain. Thus, we find in the heart of Western rationality where we least expect to find – in a pure natural science - the scandal of myth and symbolism delighting in its own innocence and abundance.

However, the sense of unlimited possibilities, their spontaneity and their sweep, does not lead us to a sense of lurking absurdity because the physical sciences are found to yield constant and sufficient objects – from electrons to black holes. It is this conception, called truth, which becomes the intellectual measure of all pursuits that combine the attitude of distilled detachment with concrete conditions of experience. As the argument by Uberoi suggests, there is a certain rate at which novelty is introduced in the sciences, which implies that even pure possibility is condemned to rhythm and habit.[61] That is why we are far from the suggestion that the spirit of inventiveness that dominates physics is one of unbridled imagination.

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[56] Claude Levi-Strauss, *Structural Anthropology* (New York: Basic Books, 1963).
[57] Ibid.
[58] Bronislaw Malinowski, *Magic, Science and Religion, and Other Essays* (Garden City, N.Y.: Doubleday, 1954).
[59] Levi-Strauss, *Structural Anthropology*., 159.
[60] Johann Wolfgang von Goethe, *Faust*, The Temple Classics (London1902).
[61] Uberoi, *The European Modernity : Science, Truth, and Method*.

Bellah has superbly argued, in the study of religion, that outside the ambit of power and authority or interests and ends, which are often taken in sociology to be key factors providing legitimacy to a community's existence, symbols and myths have their own seriousness and integrity, which cannot be dismissed as something of *mere* ceremonial thrust.[62] In acknowledging the relentless spirit of innovation that takes reign over particle physics, we may abstract the independent status of narrative, symbolism and ideology, which has the privilege of structuring the conditions of experimentation in science. Rheinberger's rich account of scientific life in a laboratory in molecular biology highlights the constitution of novelty at two levels: (a) epistemic things, or the objects or the material artefacts that are produced and (b) the epistemic conditions, which form the background conditions to a scientific inquiry.[63] To these two levels, I wish to add a third level of metaphysical principles, which allow both epistemic things and experimental conditions to flourish. Given my observations so far, it is clear that if novel objects come into existence in an experimental science, they are not simply due to the inherent unpredictability of experimental systems, but also owing to the self-conscious desire for novelty.

In case my argument makes you wonder if anyone should take this literally, then I invite you to "the last word from the Director-General" in the closing issue of CERN's "Bulletin" in 2010. In a short article, meaningfully titled "*Foundations for the Future*," the Director-General, Rolf Heuer, notes that "the importance of scientific results are remarkable, but it's the political legacy of the LHC" that he wishes to reconsider. This includes the affirmation of "basic science," which "works on timescales far longer than any political cycle," and which therefore makes funding and support from the public sector necessary. "Science is now firmly on the popular agenda, and bright young people are being inspired to follow scientific careers. Continued innovation depends on this, just as it depends on the right balance of pure and applied research," Heuer concludes.[64]

The idea of constant novelty that enters into the innermost web of scientific thought and practice can now receive that anthropological interpretation which it so badly needs without making it seem subordinate, profligate or instrumental. For we know that fashion may not carry utilitarian justification, but it is not feeble for that reason. The untenability of fictions should not lead us to deny them, but to study them. Ethnography must take faithfully the vital forces of symbolism which science embodies, expressed in the posters and graphics decorating the walls of Physics departments, conveyed in the embellished stories of distinguished minds, and dramatized in the paranoia of stagnation. While disciplines such as history or philosophy of science may concisely evaluate how a speculative insight is integrated into standard theory, if it meets with empirical vindication or fails to win adequate support and ultimately falls into disarray, anthropology must seek the correspondence of human aspiration, physical application and metaphysical speculation which marks the dialectics of nature and history. To bewail the costs of intellectual pursuits or to combat the hype of scientific excellence is not the work of anthropology, which finds in this melodramatic rendition of ceaseless obsolescence and innovative stirrings the character of science most exceptionally manifested.

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[62] Robert Neelly Bellah, *Beyond Belief; Essays on Religion in a Post-Traditional World* (New York: Harper & Row, 1970).
[63] Hans-Jorg Rheinberger, *Toward a History of Epistemic Things : Synthesizing Proteins in the Test Tube* (Stanford, Calif.: Stanford University Press, 1997).
[64] Rolf Heuer, "Foundations for the Future," *The Bulletin* 13 December, 2010.

2. The Grammar of Experiment

Notwithstanding the talk around innovation and future, particle physics, like Tolstoy's every unhappy family, has been unhappy in its own way. There is a stark contradiction between the spirit of innovation and the inertia gripping particle physics, between desire and the prevailing state of affairs. "Since the late '70s, I'd say, particle physics has been in somewhat of a doldrums."[65] The observation comes from Steven Weinberg, Nobel laureate and a towering figure in contemporary particle physics. He, along with Sheldon Glashow and Abdus Salam, contributed to the unification of "weak" and "electromagnetic" interactions, which led decisively to the consolidation of the standard model and for which the three were jointly awarded the Nobel Prize in 1979. The times leading upto the establishment of the standard model were very exciting for the physics community, both theoretically and experimentally, with significant breakthroughs taking place one after another, such as the bewildering variety of particles, the understanding of the structure of strong interactions like asymptotic freedom, the discovery of neutral currents which led to the unification of "electromagnetism" and the "weak" force, the three-generational structure of matter, etc.

After this "golden age of modern particle physics,"[66] the situation began changing when physics entered a relative phase of stagnation. For an experimental science, particle physics has had no novelty in experimental data in the last forty years. Since the 70s, every new experimental finding has only corroborated Standard Model predictions. The sharp difference in the hope for novelty and the rut in the experimental situation must strike us. The last major experiment at CERN - in 1983 - obtained the W and Z bosons, the carrier of the weak force, which confirmed Standard Model predictions. In 1995, the Tevatron at the Fermi National Accelerator Laboratory, Illinois, found the Top quark, the last undiscovered particle of the six-member quark family, which was also a prediction of the Standard Model. In 2000, when the experiments on the Large Electron Positron Collider (LEP) at CERN were closed, they too showed tantalizing hints of a Standard Model Higgs particle. All the way for forty years, it has been a dreary long march of Standard Model physics.

The lack of novelty in data has been a major problem for theory in physics. Theoretical physicists have been twiddling their thumbs or rehashing the same frameworks of standard model or those in "supersymmetry" (known as SUSY in abbreviation and pronounced "Susie"). Jokes surrounding the detection of SUSY as being "just around the corner," with Nobel laureate Tini Veltman's refrain that, in fact, it has been hiding there for quite a long time, abound in the community.[67] Some of the problems are considered far more grave from the community's

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[65] NOVA, "Viewpoints on String Theory: Steven Weinberg," http://www.pbs.org/wgbh/nova/elegant/view-weinberg.html.

[66] J.D. Bjorken, "The Future and Its Alternatives," in *www.slac.stanford.edu/.../BJ_The%20Future%20and%20Its%20Alternatives.pdf*.

[67] Supersymmetry is motivated by the idea of symmetry of two different categories of particles, the "fermions" and the "bosons." Fermions are particles with half-integer spins, which obey Fermi-Dirac statistics. Bosons are particles of force carriers that are characterized by full integer spin, and obey Bose-Einstein statistics. No two fermions can occupy the same quantum state; they follow what is called the "Pauli exclusion principle". (It is this principle, which gives matter its materiality). Bosons in contrast cohere together. In spite of the difference in the behavior of fermions and bosons, the idea governing Supersymmetry is that equations of the primary theory will remain

perspective, for instance, the rise of string theory. As progress in fundamental physics came to a grinding halt, theoretical physics veered off from anything connected to direct experimentation into more esoteric terrains with mathematical speculative approaches predominating.[68] Drawing on the sharp-tongued Pauli's description of a poorly written student's paper as "not even wrong," implying that even a wrong idea can be valuable if it leads in a productive direction, Peter Woit in a well-known book asserts that string theory is not even wrong! Woit eloquently argues that string theory offers no possibility of experimental evidence and has led physicists astray from the ultimate norm of physics: experimental validation or falsification.[69]

During fieldwork, I observed string theory to be a near universal object of banter as it is destitute of immediate physical significance and hence considered by most to be outside the ballpark of physics. At the conclusion of "*Strings 2008*," the largest annual conference of string theory, organized in CERN, I met and befriended a few lively and engaging string theorists. Cliff Burgess, Keith Dienes, Wolfgang Lerche, and Fernando Quevido, friends from the conference, provided me with dramatic narrations of the dawn of string with Veneziano's work on the Euler-Beta function, then Nambu, Nielsen and Susskind's modeling of the strong nuclear force as one-dimensional strings, with the first superstring revolution ushered in by the cancellation of quantum-mechanical anomalies, and the second superstring revolution inaugurated by Edward Witten who gave birth to a 11-dimensional universe. At the time of this initiation, I knew little outside the area of flavor physics and CP violation, all terribly "dull stuff" as the string friends persuaded me, compared to AdS/CFT Correspondence and D-branes. In my newfound enthusiasm, I told Alvaro de Rujula as I ran into him one day, "I like string theory." He replied with withering contempt, "You would. It's close to sociology." For him as many others, string theory makes little connection with viable experimental data.

Some of the more exotic sounding aspects of physics make it quickly to the electronic media and become elements of science fiction or doomsday scenarios. The most familiar to the reader is perhaps the lethal role imputed to "anti-matter," produced at CERN and stolen with the intent of destroying the Vatican City, in Dan Brown's thriller "*Angels and Demons*." I recall Michael Doser, then deputy Director Physics division and an anti-matter specialist, saying wryly that CERN's annual production of antiprotons may at most suffice to light a 250-Watts bulb for approximately 1 minute! The increasing media attention to more sensational aspects of high-energy physics has led some physicists to observe a distinction between "blog physics" and "real physics." When string theorist Erik Verlinde came up with a paper claiming gravity does not exist, most members of the community showed exasperation.[70] Cesar Gomez said irritably, "These gimmicks will come to an end when the LHC starts." In his comment I recognized that the dramatic stir of innovations is made systematic by the order of experimentation.

The enduring problem of contemporary high-energy physics is not only that there has been no new experimental data but, in fact, that there has been little data, owing to the slow rate

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unchanged if fermions are replaced by bosons and vice versa. Governed by higher-order symmetry considerations, supersymmetry is believed to usher in a whole new physics.

[68] Lee Smolin, *The Trouble with Physics : The Rise of String Theory, the Fall of a Science, and What Comes Next* (Boston: Houghton Mifflin, 2006).

[69] Peter Woit, *Not Even Wrong : The Failure of String Theory and the Search for Unity in Physical Law* (New York: Basic Books, 2006).

[70] Erik P. Verlinde, "On the Origin of Gravity and the Laws of Newton," arXiv:1001.0785v1 [hep-th].

of development of accelerators since the decline of the Cold War.[71] In the last couple of decades, experimental physicists have been increasingly forced to work on "Monte Carlo" or computer simulations, rather than on actual particle collisions, or "real data." Lack of real data is a hurdle for budding careers in experimental physics. For instance, as a rule, United States institutions require students to use actual collision data, and doctorates are not awarded in experimental physics on the basis of Monte Carlo data. An article titled, "*LHC Students Face Data Drought,*" appearing in *Nature*, encapsulates the frustration and anxiety of students in experimental physics with respect to career prospects and the necessity of building accelerators and experiments.[72]

The last ten years have been especially difficult for the physics community awaiting the operation of the epic collider, the LHC. When CERN closed down its earlier collider LEP in 2000, its next collider, the LHC was still in its construction phase. The LHC was originally conceived in 1983-84 and approved for construction by the CERN Council in late 1994. In 1996, the first "technical proposals" of the ATLAS and CMS experiments were officially approved with an eventual project cost of 10 billion Swiss francs ($9.4 billion). In 1998, civil engineering work to excavate underground caverns to house the huge detectors for the experiments began. In 2000, after running for 11 years, LEP was closed, to allow for the construction of the Large Hadron Collider in the same tunnel. The original LHC Letter of Intent shows that the LHC was slated to be accomplished by 2002. Escalating problems with construction and installation, budgets, and faulty parts all led to a long delay of seven years in its completion, even as pressures on the LHC to start running kept mounting. Set to probe the structure of matter and forces of energy at highest ever energies achieved in a particle accelerator, the actual operation date kept getting pushed back every year.

Finally after a long wait, on 20th November 2009, two counter-rotating proton beams were successfully circulated in the LHC, with the first proton–proton collisions being recorded three days later at the injection energy of 450 GeV per beam. The event gathered worldwide media attention. On 30th November 2009, the LHC became the world's highest energy particle accelerator when protons in each beam reached an energy of 1.18 TeV. This exceeded the previous world record of 0.98 TeV, which had been held since 2001 by the Tevatron collider at the Fermi National Accelerator Laboratory, USA. "There's a great sense of anticipation here at CERN and at particle physics labs around the globe, and for good reason – we're about to open up the biggest range of potential new discovery that particle physics has seen in over a decade," announced Rolf Heuer, Director-General of CERN.[73]

Amidst the drama of extravagance and anticipation, the operation of the Large Hadron Collider puts the spotlight on experiment. As I indicated earlier, Kuhnian paradigm-changing revolutions are not avoided but greatly sought after in particle physics. But we would mistake the

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[71] See for texts documenting the close connection between high energy physics and war efforts Peter Galison and Bruce William Hevly, *Big Science : The Growth of Large-Scale Research* (Stanford, Calif.: Stanford University Press, 1992).; Hugh Gusterson, *Nuclear Rites : A Weapons Laboratory at the End of the Cold War* (Berkeley: University of California Press, 1996); Russell J. Dalton, *Critical Masses : Citizens, Nuclear Weapons Production, and Environmental Destruction in the United States and Russia* (Cambridge, Mass.: MIT Press, 1999); Mark Solovey, "Project Camelot and the 1960s Epistemological Revolution: Rethinking the Politics-Patronage-Social Science Nexus," *Social Studies of Science* 31, no. 2 (2001); Uberoi, *The European Modernity : Science, Truth, and Method*., Chapter Four.
[72] Geoff Brumfiel, "Lhc Students Face Data Drought," *Nature.* 460, no. 7255 (2009).
[73] Heuer email message March 9, 2010.

substance of this conception if we grasp it only as a quantitative expansion of knowledge. There is a qualitative notion that characterizes this growth, and it is encapsulated by the term "experiment." An experiment is more complex than any simple formula allows. It is not simply the assertion or denial of the external world. Koyre finds it absurd to compare experiment to experience. He says nothing can be further: "As for experience and experiment – two things which we must not only distinguish but even oppose to each other."[74] Experiment is a purposive intervention in the world. In Hacking's words the primary aim of science is not to understand the world ("representation") but to change it ("intervention").[75]

In modern science, experiment is the ultimate arbiter of truth. While all knowledge differs from common sense in virtue of its symbolic and relational character, physics in particular consists of confronting a body of knowledge, such as theories and models, with an experiment. What theories or models approach in *a priori* way, the experiment warrants their veracity empirically, without which theories do not receive legitimacy. "Without [experimental] data to help decide among competing ideas, or to convince theorists to take a particular approach seriously and explore its implications, the connection to nature that provides the criterion for what is correct is gone."[76] From the perspective of physics, it is in the active mode of confrontation of theoretical propositions and experimental results that scientific accuracy is constituted and on which rests the significance of experiment.[77]

From the perspective of social science, the experiment is significant because on its basis a *shift* is made from saying we see a pion to the further assertion that a pion exists. The predication of reality takes place in favor of the object in the indomitable sense of "there is." How does the attribution of objective reality take place? How is the perception, say, I see a pion, raised to a new awareness such as "The pion - really exists in nature,"[78] which conveys the reality of the pion independent of the observer? This philosophical problem encounters a more complicated question than any simple question of content in the understanding of nature. The question is not about the content of nature, but of its concept. Not of its experience but of its form. Viewed from this light, the substantive fact of an experiment should enable us to distinguish its significance not only for the results it achieves, but also in terms of its own logic and development. In this section, I shall attempt to sketch the concept and the form of nature that an experiment stakes.

Suffice to say multiple responses have been suggested to the question of experiment from the "realism" of objects to "epistemic subjects," and to more middle level formulations affirming

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[74] Alexandre Koyre, *Newtonian Studies* (Cambridge: Harvard University Press, 1965)., 6.

[75] Hacking, *Representing and Intervening : Introductory Topics in the Philosophy of Natural Science*.

[76] G. L. Kane, *The Particle Garden : Our Universe as Understood by Particle Physicists* (Reading, Mass.: Addison-Wesley, 1995)., 131.

[77] In the initial stages of history of science, experimentation was often relegated to a subordinate role. The "neglect of the experiment" thereupon called into question why theories monopolize scholarly attention, when experiments clearly performed many vital roles. "One of its important roles is to test theories and to provide the basis for scientific knowledge. It can also call for a new theory, either by showing that an accepted theory is incorrect, or by exhibiting a new phenomenon that is in need of explanation. Experiment can provide hints toward the structure or mathematical form of a theory and it can provide evidence for the existence of the entities involved in our theories. Finally, it may also have a life of its own, independent of theory. Scientists may investigate a phenomenon just because it looks interesting. Such experiments may provide evidence for a future theory to explain." Allan Franklin, "Experiment in Physics," *The Stanford Encyclopedia of Philosophy*(2010).

[78] Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*., 48.

the material and semiotic nature of objects generated under experimental conditions.[79] These diverse lines of thought have generated new visions of science – with hints of greater plasticity of human agency and unthought-of entities to spring into view – virtual objects, assemblages, cyborgs.[80] However, most such visions are timid and partial, although not without charm, because human history had long before resolved the grammar of knowledge and circumscribed the general forms in which metaphysics and experience may be expressed. The grammar of these general forms, which I discuss below, has come down to us as the guiding principles of modern science, elementary in its expression but no less powerful in its effects.

The certitude of science in all its arrangements has its basis in a two-fold relation: (a) the absolute heterogeneity and separation of human nature and non-human nature, that is, non-human nature can speak only when the scientist suppresses her own nature, and (b) the absolute heterogeneity and separation of theory and practice, where this time the modesty of the scientist is counterbalanced by the arrogance of the engineer, who can manipulate non-human nature at pure will for any purpose or end. In these words I wish to re-state the incipient problem of *the mode of existence of science* with which I opened the chapter, which lays before us the exhaustive possibility that human will or agency may readily be admitted in scientific *practice*, where the agency of the *subject* is maximal, where as in scientific *thought*, it is the unqualified presence of the *object*, which must take over. This set of dual symmetrical relations encompassing the engagement of observer and nature was disclosed to me much later, after fieldwork, when from the data of ad hoc utterances to printed scientific texts, I began to perceive how physicists turn to a grid of contradictory but overlapping dichotomous divisions as a means of consistently approaching their work in the laboratory.

There must need be, it occurred to me as I began probing their conceptions of the universe, something felicitous and necessary that forms the immediate occasion, the general sanction and the source perhaps of all "manner of statements" or "enunciative modalities," to use Foucault's words.[81] Tentatively and reflexively, I gathered from the innumerable scientific presentations, the electronic preprints of scientific papers, weekly seminars, annual conferences, anniversary celebrations of major physicists, to family dinners, staff picnics and collaboration barbecues, the recognized and impersonal dogma of science – a dogma without images or allegory to illustrate the concepts, but where the concepts themselves are not confused. Perceiving and judging with forthright vision, modern science can rarely comprehend one thing to be another (*metaphor*) but it can unhesitatingly conceive the transformation of things in succession (*metamorphosis*): only with the subject in abeyance, nature runs boundless, provided the tools have been assembled, techniques have been mastered and materials have been ransacked. And when due allowance has been made for fraud or illicit human intervention,[82] there remains the half-innocent residuum of matter presiding over the mind and the half-arrogant resolve of the human will crafting the universe.

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[79] Barad, *Meeting the Universe Halfway : Quantum Physics and the Entanglement of Matter and Meaning*; Hacking, *Representing and Intervening : Introductory Topics in the Philosophy of Natural Science*; Knorr-Cetina, *Epistemic Cultures : How the Sciences Make Knowledge*.
[80] Haraway, *Simians, Cyborgs, and Women : The Reinvention of Nature*; Manuel De Landa, *Intensive Science and Virtual Philosophy* (London; New York: Continuum, 2002).
[81] Michel Foucault, *The Archaeology of Knowledge* (New York: Pantheon Books, 1972).
[82] Burton Feldman, *The Nobel Prize : A History of Genius, Controversy, and Prestige* (New York: Arcade Pub., 2000); Taubes, *Nobel Dreams : Power, Deceit, and the Ultimate Experiment*.

At no point do the two opposing currents of subject-object and theory-practice unite than in the experiment, and yet are they nowhere more clearly distinguishable. In an experiment, Gian Giudice, a CERN staff physicist writes, "one creates special situations, under controlled and reproducible conditions, to obtain quantitative information on nature's behavior."[83] But on the other hand, instead of obtaining information on nature's behavior, if by chance physics wants to comprehend the magic of "the human factor,"[84] then look to the "collaborations of about 2500 physicists [that] stand behind each of the two main detectors, and a slightly smaller number behind the other experiments put together. These people are ultimately responsible for the design, construction, and testing of every single component of these prodigious instruments."[85]

Dealing with the physicists' conception of knowledge, we are forced to ask (a) what is an experiment's relation to the scientific observer and (b) what is its relation to the engineer?[86] That these old and imperishable questions have lost none of their moral intensity or efficacy is something I intend to demonstrate from everyday particle phenomenology, or that branch of physics which deals with the behavior of particles and calculations pertaining to them such as their rates of production, patterns of decay, etc. Some of my explanations on these aspects of physics may appear labored since it is tedious to write in ordinary language what I now understand intuitively after two and a half years of being bombarded with technical terms, but I shall attempt to the best of my ability.

In experimental physics, ordinarily a distinction is observed between two core concepts, production cross-section and luminosity. Production cross-section simply means the occurrence of a certain number of interactions during collisions, and luminosity stands for the measure of the number of collisions per unit of area (microbarn) in per unit of time (second). The cross-section is always at a given centre-of-mass energy, a fixed number dependent on specific physics processes, while luminosity is a factor controlled by the parameters of the machine, hence dependent on the state of technology. The LHC accelerates bunches of protons to 7 TeV energies, colliding them head-on 40 million times a second, with each collision generating thousands of new particles at approximately the speed of light. The higher the energy, the more violent is the collision. But energy without luminosity is of little use to particle physicists. "Cars traveling at higher speed produce more spectacular crashes, but heavy traffic is needed to produce a sufficiently large number of accidents."[87]

Since experimental analyses critically depend on gathering as large a sample as possible, accelerators are designed to deliver as high a luminosity as they can. High machine luminosity can be achieved in a number of ways, for instance, by increasing the *number* of particles in the accelerator such as grouping particles into "bunches," by increasing the *frequency* at which collisions occur, by *focusing* the beam more tightly by applying strong magnetic fields, especially as it approaches the interaction point where the particles collide, etc. It is in the vital sense of technological efficiency, on which increased luminosity depends, which amplifies the cross-section for most particle interactions of interest, such as Higgs or supersymmetry, and leads to greater confidence in experimental results.

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[83] Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*., 30.
[84] Ibid., 142
[85] Ibid., 142.
[86] J. P. Singh Uberoi, *Science and Culture* (Delhi: Oxford University Press, 1978).
[87] Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*., 94.

The four major experiments convened and configured on the LHC, namely ALICE, ATLAS, CMS, and LHCb, are able to trace with consummate skill the comprehension of matter and energy through detailed studies of physical events and cross-sections produced in the collisions. The designs of the four experiments are different from each other as are their goals.[88] "A major goal of the ATLAS physics program for 2010 is the measurement of cross sections for Standard Model processes," is how a recent paper produced by the ATLAS collaboration, begins.[89] I have brought up the reference of the ATLAS paper simply to introduce to you how routine is the work of measuring cross-sections in experimental physics.

I was led to the concept of cross-sections when holding an interview with Ian Hinchliffe. Ian is a theoretical physicist, but a rare one, for his primary association is with the experiment and currently leads Berkeley National Laboratory's participation in the LHC's ATLAS experiment. He gave brisk answers to my questions on the relevance of the Top quark mass for Higgs measurements, the angle of bunch crossing on the LHC, the significance of muon calorimetry, etc. At some point in the interview he said, "You see there is a very small chance of the Higgs [particle] showing up in the first one or two years of data-taking [at the LHC]. But if SUSY [Suspersymmetry] exists, it will show up abundantly and right away." I did not follow why the Higgs should take time to "show up" or why would SUSY be abundant, but I felt timid asking him for I had heard that Ian had a reputation in the community for a sharp tongue.[90]

I resolved to ask Andreas Hoecker later who was the Convener of the Higgs Search on the ATLAS experiment, soft-spoken and who I had met a couple of times. Andreas laughed when I asked him, "Do you think Ian is correct in saying that *if* SUSY exists, it will show up before the Higgs? He replied, "Whatever else Ian maybe wrong about, on *that* he can't be." I was told that it was "fairly common knowledge" that

> the production cross-section for a low mass Higgs at 14 TeV energy is 100 picobarns (pb) whereas a low mass SUSY has a cross section of 50-100 picobarns (pb) at 14 TeV [energy]. Since we cannot change the production cross sections, which nature has given, we can only work on the luminosity. So here are two scenarios to show you how with a certain configuration of luminosity, discovery takes place. For example, if the cross section is 200 pb, the integrated luminosity sample 1000 pb-1, then we expect to have produced 200,000 Higgs particles. If the integrated luminosity is 10000 pb-1, i.e., 10 times larger we would expect 10 times more Higgses produced. For the example of 1000 pb-1, with 200,000 Higgses produced, 1 in 10,000 decays to 2 photons, so we expect in this sample only 20 photon pairs that come from a Higgs signal. Not too many.
>
> We want to make a discovery right. Can we do that with the above given data sample? A discovery is defined if the significance of a signal is larger than some number, typically 5. Significance is calculated from the number of signal events

[88] The differences in the design and conception of the four major LHC experiments are covered in detail later in Chapter Two.
[89] ATLAS Collaboration, "Luminosity Determination in Pp Collisions at √S = 7 Tev Using the Atlas Detector at the Lhc," arXiv:1101.2185v1 [hep-ex].
[90] As the ATLAS-LBNL group leader, Ian approved and signed two of my CERN extension forms which enabled me to stay for two years, and in subsequent meetings, I lost some of my initial trepidation.

divided by the fluctuation in the background. The number of signal events is what we determined above, i.e., 20 in our example. The background on the figure is larger. Typically the background is 5 times larger in number of events than the signal, so say 100 events. But what counts is the fluctuation of the background. The statistical fluctuation of the background is the square root of the number of background events, i.e., $\sqrt{100} = 10$.

So for our example of a luminosity of 1000 pb-1 the significance of the potential for a discovery is $20/\sqrt{100} = 20/10 = 2$. So not 5! We cannot discover the Higgs in this channel with only 1000 pb-1. What to do? Well we run the machine longer or improve the instantaneous luminosity with, for instance, more protons in the machine, so that we accumulate a data sample with 10 times more luminosity, i.e., 10,000 pb-1. What are the numbers now? The signal is now 200 events. The background is now 1000 events. The fluctuation on the background is $\sqrt{1000} \sim 30$. So the significance for the same channel with 10,000 pb-1, instead of 1,000 pb-1, the significance now becomes 200/30, which is about 6.5. Now we are above 5 sigma! We can claim a discovery.

In the discussion with Andreas what I absorbed was the distinct recognition that physicists can measure the cross-section of a given process, but they can't change it since it is given by nature. Inversely, what falls under human control is the performance of the machine, which therefore, can be consistently improved upon. "[The cross section is] fixed by nature and depends on the details of the interaction we wish to study. Only the luminosity, or number of collisions, is under our control. Since our analyses depend on gathering as large a sample as possible, we try to design an accelerator, which delivers as high a luminosity as we can."[91]

In no sphere of knowledge is the contrast clearer between physical nature and human control, in none perhaps has there been so much of both. Predicated on this distinction, collisions and interactions take place and leave indelible traces on the experiments, which the instruments, duly prepared can manage to capture, which are subsequently read off by the scientists. That such vibrant traces should exist is entirely consonant with reason and experience, but only *after* nature has made its mark, which leads to the reverence for such data and the reaffirmation of such methods as observation, quantification, measurement and analysis. Even as conventions of collaboration, rules of discourse and authorship, procedures of computing and transmission of data are internally debated and discussed, what is rarely asked is by what inward convention does human reason turn silent before the pure speech of nature in an experiment?

The human action, when it is admitted as a presence in the organization of the experiment, like getting the instrument ready, servicing the beams, or repairing faulty parts, is neither neglected nor considered insignificant. Nothing is farther from science than a desire to be primitive.[92] Human agency and technology are part of the form to solicit and conquer the world. Without the performance of the machine – its ability to achieve higher collisions – physics may

[91] Posted by Ted Kolberg on *21 Feb 2009* at http://blogs.uslhc.us/lhc-luminosity-and-energy
[92] See Rabinow's superb essay overturning the argument on the naturalness of nature in "Artificiality and Enlightenment: From Sociobiology to Biosociality," in Paul Rabinow, *Essays on the Anthropology of Reason* (Princeton, N.J.: Princeton University Press, 1996).

never have disclosed its oracles on matter and energy. So that in association with the manipulation of instruments in the conduct of the experiment, we find the fulfillment of science. Here is some data put together in a table-form from slides of regular seminar presentations at CERN to substantiate the claim that physics expressly and routinely acknowledges its reliance on engineering and instrumentation.

MEETING: LHC, week 1
chaired by Michelangelo Mangano (CERN)
Thursday 26 November 2009 from **16:00** to **17:30** (Europe/Zurich)
at CERN (500-1-001 - Main Auditorium)

16:00 - 16:30 LHC status report 30' Speaker: Steve Myers (CERN)	**On behalf of the LHC Team** "I'd like to express my heartfelt thanks and congratulations to all those who have done such a great job in bringing the LHC to life this week, and to all the unsung heroes who worked untiringly for the past 14 months to bring us from the dark days of late September last year, to where we are today. It has been a herculean effort, with no fewer than five distinct phases: repair; consolidation; hardware commissioning; preparing for beam; and finally operation"
16:30 – 16:45 ALICE report 15' Speaker: Federico Antinori (INFN Padova, Italy)	**On behalf of the ALICE Collaboration** "Thanks and congratulations to the machine teams for the outstanding performance"
16:45 –17:00 ATLAS report 15' Speaker: Andreas Hoecker (CERN)	**On behalf of the ATLAS Collaboration** "Big thanks to the machine team for a spectacular performance, and the excellent communication between ATLAS and CCC"
17:00 – 17:15 CMS report 15' Speaker: Ivan Mikulec (HEPHY)	**On behalf of the CMS Collaboration** "Many thanks to the LHC personnel for the collaborative spirit and patient response to all our questions and requests"
17:15 – 17:30 LHCb report 15' Speaker: Olivier Callot (LAL-Orsay)	**On behalf of the LHCb Collaboration** "A big THANK YOU to the LHC. To all the people who contributed to the design, construction, installation, commissioning and operation of the LHC. This machine is fantastic"

LHC Meeting **LHC report**

chaired by Massimiliano Ferro-Luzzi
Friday 18 December 2009 from **12:15** to **14:00** (Europe/Zurich)
at CERN (500-1-001 - Main Auditorium)

12:15 - 12:25 LHC report *10′* Speaker: Steve Myers (CERN)	**On behalf of the LHC Team** 26 days of highly successful beam commissioning due to meticulous planning
12:25 - 12:35 ALICE report *10′* Speaker: Juergen Schukraft (CERN)	**On behalf of the ALICE Collaboration** "The LHC accelerates, after concerted preparations and tense anticipations"
12:35 - 12:45 ATLAS report *10′* Speaker: Fabiola Gianotti (CERN)	**On behalf of the ATLAS Collaboration** Many thanks to the accelerator team for the excellent machine performance, for the impressive progress over a few days of operation, and the very pleasant and constructive interactions with ATLAS"
12:45 - 12:55 CMS report *10′* Speaker: Tejinder Virdee (CERN/Imperial College)	**On behalf of the CMS Collaboration** "Very encouraging collision data-taking start which augurs well for the future. Thanks to the LHC!!"
12:55 - 13:05 LHCb report *10′* Speaker: Andrei Golutvin (Imperial College London/(ITEP))	**On behalf of the LHCb Collaboration** "A few highlights from LHCb thanks to the outstanding LHC performance"

The tables have not been prepared with the purpose of showing that the majority of physicists are considerate or grateful beings. The ethnographic aim is to gather inversely from what is explicit and present to what is rare or absent. "If the anthropologically pertinent point is the fashioning of the particularity of practices,"[93] then it behooves us to ask what practice ordains why physicists abstain from acknowledging their presence when a shower of photons hits the detectors? In order to address the norms and practices central to the vocation of science, then surely it is relevant to ask why science cannot honor anything except nature as the source of its enterprise, even if out of pedantry or rhetoric? Scholars who harbor misgivings, quite rightly, about the status of intellect, the degree of disinterestedness or the role of impersonal values in science, cannot deny that to raise a question on the kinship or communion between man and nature is outside of anthropology's scope. On the other hand, those who admit the question, must

[93] Rabinow, *Making Pcr : A Story of Biotechnology*., 17.

they say that since science deceives itself about the rewards of nature in order to secure them, the exchange does not exist?[94]

That technology is the realm of pure play of human agency and which makes nature plastic is well documented. From our genes to our gender, technology can produce anything.[95] That science dominates and discriminates over the subject by the power of the object is also well known. From Bachelard to Daston & Galison we have the clear recognition of the presence of "objectivity" in science.[96] Equally familiar to us are their mutual relations of support. The dynamic advance of technology has progressively transformed physics. For example, the technological innovation of "stochastic cooling" led to the accumulation of proton beams that allowed experimentalists to produce the massive particles, W and Z bosons, in the 500 GeV proton-antiproton collisions at CERN. Likewise, science radically alters technology. The dual-use technology of Global Positioning System or GPS is a direct output of Einstein's theory of General Relativity. What remains obscure or undisclosed is the play and dynamism of agency and objectivity that must occur in *distinct* and clearly *separated* logbooks of engineering and science.

Most social science critiques are attentive either to the scientific impulse or the engineering impulse and fail to penetrate into the inner logic of science. They assert the "disunity of science"[97] and leave the matter at that without inquiring into the source, and the perpetual renewal, of dispersion and miscellany - in the double splinter of relations, i.e., the schism of subject and object across the schism of theory and practice, with one in forward gear and the other in reverse. Hence, the dissolution of the human-nonhuman divide that social science critiques clamor for[98] is easily accepted by a physical science as long as the human is understood as a factor in technological determination and not admitted in the content of science. So let there be no mistake: mere human presence itself is no indication of science's worth or worthlessness. Fact and value are as far apart as possible, but means and ends are as close to each other as possible. The two factors, of agency and objectivity, do not exist on the same register that they can cancel each other. The consequence is the strange doubling of a world where human presence is soundly acknowledged on the register of technology, which it is deprived in science, and while the voice of nature gains the elemental impetus in the experiment, in practice it can be subdued.

"Scientific practice is the only place where the object/subject distinction does not work."[99] Latour's candid assertion should be taken as an admission of impotence rather than of

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[94] Latour, *We Have Never Been Modern*.

[95] Adele Clarke and Virginia L. Olesen, *Revisioning Women, Health and Healing : Feminist, Cultural, and Technoscience Perspectives* (New York: Routledge, 1999).; Downey and Dumit, *Cyborgs & Citadels : Anthropological Interventions in Emerging Sciences and Technologies*.; Rabinow, *Making Pcr : A Story of Biotechnology*.

[96] Bachelard, *The New Scientific Spirit*; Lorraine Daston and Peter Galison, *Objectivity* (New York; Cambridge, Mass.: Zone Books ; Distributed by the MIT Press, 2007).

[97] Peter Galison and David J. Stump, *The Disunity of Science : Boundaries, Contexts, and Power* (Stanford, Calif.: Stanford University Press, 1996).

[98] I am not indicating that social science critiques are unified in their interrogation of science. To the contrary. For instance, Haraway's critique of science deals with the examination of the human-nonhuman divide, whereas Rabinow's critique questions the division of the pure and the applied in the sciences, to name a couple.

[99] Latour, "For David Bloor...And Beyond: A Reply to David Bloor's Anti-Latour." , 123.

pride. While it aims to acknowledge the failing of science in one vital quarter, and supplies the data for a critique, unintentionally it indicates the weakness of the critique and constitutes its chief difficulty. His critique fails to inquire how phenomena of nature are capable of a mathematical explanation as well as he inquires how they are capable of instrumental manipulation.[100] It fails to address the diversity of intellect and reality. Instead it hastens in the direction of manipulation of objects and practices as if anthropology has no stomach for mathematical proof or logical reasoning, which are in fact no less human for being more austere. The practical coupling of human and non-human is supposed to push further the hybridity of reason and action.[101] But it is not destined to succeed for the simple reason that the problem of subject and object remains to be investigated in the realm of scientific thought. From this perspective, the question stands, say, can we find human presence in the atom's character, which the physicists tell us is fixed by three quantities: (i) the electron's mass, (ii) the strength of the interaction that binds the electron to the nucleus, and (iii) and the value of Planck's constant.

The problem so plainly stated cannot be solved by searching for the materialism of practices, or criticizing the value of scientific evidence, or espousing hopeful alternatives, but must show at some point an appeal to direct evidence. To discredit science in its practice only brings at first a sigh of relief. But it is soon evident that neither thought nor practice can be substituted for each other because they run on oppositely wound tracks, and each errs if deploring the other and wishing itself to be omnivorous. Hence, science as practice is not perspicacious enough, as claimed, to grasp the character of scientific experiment: it points to subterfuges and stratagems incompatible with the professed separations literally taken, it explores the link between the tenets, their original meaning and function with their evolution, but it leaves unattended the elementary problem of separation of object and subject and how that is mediated in concept or thought, unless it is meant to imply that thought is not of much consequence.

I have instead decided to make the grammar of relations, of subject and object and theory and practice relative to the experiment, as my intellectual focus, as opposed to popular assumptions concerning the value or goal of science. Those who are troubled by the fact that an abstract grammar is considered a part of an ethnographic argument, and who find themselves obliged to attack it, may summon arguments in its disproof. This, however, is not my intention. Do we attack the cosmology of the fishermen in Kerala or the Indians of Amazonia? Indeed we seek to grasp their belief and understand their techniques which ethnography leads us to. If the objection is that grammar is an esoteric, unconscious structure, adhered by few or expressed by none, then we need look no further than ordinary language where grammar indicates our true habits and consciousness. Grammar is not a force reserved for only a part of our experience, or uncovered at the origin of a specific experience, but it is a relation pervading every part of our constitutive experience.

The problems and aspirations that haunt particle physics acquire their momentum in the set-up of the experiment. Here the desire for the absolutely universal combines with the power of the intellect to secure from objects of experience the impulse to fly into the land of possibilities, as this poster suggests (Figure 1). The experiment constitutes the meeting ground of the world of

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[100] ———, *We Have Never Been Modern*; Bruno Latour, "When Things Strike Back: A Possible Contribution Of "Science Studies" To the Social Sciences," *The British Journal of Sociology* 51, no. 1 (2000).
[101] P. Galison, "Ten Problems in History and Philosophy of Science," *ISIS* 99, no. 1 (2008).

possibilities with the world of reality. Skeptical or cynical researchers might have shown from the fieldwork data whether the intellect's potency or the realities described are illustrations of delusion or perception, or a combination of both. However, I do not claim prior or superior comprehension and have adhered to the assertions of each informant, moved by its dull throbbing character. I agree the account has left out – so far – the drama of science, which I now turn to, where the fault-lines, risks and triumphs of skepticism, of science and social science, shall appear in full measure.

Figure 1: A CMS Poster depicting the voyage of discovery between the real and the possible.

3. The Unit of Science is a Problem

Physics proceeds with the assumption that among a thousand different judgments concerning an object, one and only one is correct and true. The chief difficulty consists in determining this one true judgment. This leads to the interesting situation that while genuine inspiration is sought directly from nature, the total apprehension of it is derived from the community. As Kuhn pointed out, "The decision to reject one paradigm is always simultaneously the decision to accept another, and the judgment leading to that decision involves the comparison of both paradigms with nature *and* with each other."[102] Therefore, confronting every theory or technique against data from experiment would show physics to be a barren victory if it had not possessed another sort of substantial reality – the community – which supervenes and serves, in addition to the adjudication by the physical world, to constitute a conscious, independent order. The community is the body of expertise, which tries every problem of scientific research and decides the grounds of its ingenuity and applicability.

In doing so, the community brings together two opposed and separate orders of conception – the physical and the logical - and makes brute existence the object of its thought and makes discourse their measure. It is hard to decide if physics shows a bias in favor of one or the other. Galileo's assertion that nature's laws are expressed in the logical language of mathematics is not a childish mythology surviving as a figure of speech.[103] Computing with mathematical entities like integrals, limits and infinite series, or techniques of partial differential equations, or group theory (particularly Lie groups and algebra) constitutes the spine of scientific discourse. Equally found flourishing is Bacon's legacy of induction, with observation of interactions and collisions as the starting point of inquiry, which explains physics' obsession with data – plots (of cross-sections and various kinematical quantities), histograms (of likelihood analysis), analysis (of distributions and correlations), images of hits (of particles on the detector), jets (of strong interactions), or tracks (of electromagnetic charges). Critical to both mathematical and experimental outflow, is the support of hardware or instrumentation, which also includes practical and theoretical considerations. Together, the intense concentration of logical skill and physical effort are proclaimed as substantive evidence and sanction of expertise in physics.

It became redundant after a while to inquire into informants' formative years for they all spoke of being exemplary students from school or college onwards through university. With education from Caltech, MIT (Massachusetts Institute of Technology), EPFL (École Polytechnique Fédérale de Lausanne) or GGI (Galileo Galilei Institute, Florence), experience from laboratories of DESY (Deutsches Elektronen Synchrotron, Hamburg), Rutherford (Oxfordshire), SLAC (Stanford Linear Accelerator Center, California) or FNAL (Fermi National Accelerator Laboratory, Illinois), expertise in a scientific career becomes a glorious accomplishment and solving the mysteries of the universe an accredited passion. In spite of its boast, charm or unction, the fact is that science has risen as a technocracy. The community zealously guards the work it performs, its content and sphere of applicability, and is ready to sacrifice or subordinate itself at any turn to inner impulse and fact. What is the form of this inner impulse and fact, I will come to in a moment, but let me reiterate that its substance consists of the technical - theories, concepts, data, instruments and magnitudes – the "thought style" or the stock of knowledge of the community.[104]

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[102] Kuhn, *The Structure of Scientific Revolutions*., 77.
[103] Cartwright, *How the Laws of Physics Lie*.
[104] Ludwik Fleck, *Genesis and Development of a Scientific Fact* (Chicago: University of Chicago Press, 1979).

Only now, after postmodernism has exhausted the ingenuity of the bewildering forces of morals, perceptions, and narratives, and object theory's disclosure of the overpowering influence of things, which in the end prove rather trivial, that the principal fact, which is unheeded because so obvious, can be seriously availed that all knowledge in physics is consciously debated against empirical phenomena and logical principles. The two are different and opposed in character but can be mechanically combined in any number of ways. For instance, matter may be transformed and rearranged into logic and reflection. Technologies produce real and virtual objects. The intellect infers causes and connections between events. Abstract ideas and thoughts form the constituents of reality.

The medley of local and transitory co-ordinations encountered in the sciences has generated social science arguments which tend to emphasize the fluid and elastic character of science: "scientific judgment is best understood as situated within a continuing flow of practice" (Pickering),[105] "specialties within physics cannot be considered homogenous communities" (Galison),[106] "it construes, and accounts for, a new kind of epistemic subject, a procurer of knowledge that is collective and dispersed" (Knorr-Cetina),[107] and so on. In so far as these explanations are empirical generalizations, they are all verdicts of common sense, and appropriately so. But now arises a delicate question: Can common sense explain how do the dispersions arise and dissolve, how are they transformed into one another, or what is their principle of motion? As empirical or descriptive accounts, they share exactly the same problem as Pascal's wager, namely that the explanations can always be availed in partial form to be correct and to that extent they bear the satisfaction of being adequate if not the dignity of being true.

Peter Galison comprehends the issue in the strongest possible light and gives us three sorts of proposals on the meeting ground of "place, exchange and knowledge production" in high-energy physics. "The local continuities are intercalated – we do not expect to see the abrupt changes of theory, experimentation, and instrumentation occur simultaneously; in any case it is a matter of historical investigation to determine if they do line up."[108] In this register of reasoning, contingency prevails, but not in any drastic way for it is counterbalanced by functional stability. Besides only case-specific inquiries can lead us to any full picture. However, apart from historical circumstances of zone, place or periodization, things also have a logical character and origin. Here Galison invokes the language analogy - of pidgins and creoles and their trading zone - in the recognition of how coordination between heterogeneous groups and practices takes place. "I intend the term 'trading zone' to be taken seriously, as a social, material, and intellectual mortar binding together the disunified traditions of experimenting, theorizing, and instrument building."[109] Since hybrid forms of local coordination occur "according to no fixed rules," they necessitate a third level of conceptualization, the epistemological level. At this point Galison invokes Kant, and the metaphor of bricks and cables: while lining up bricks, we place them in an overlapping manner rather than sitting directly on top of each other; cables gain strength, not by having single unbroken threads, but by intertwined strands, no one of which holds all the weight.

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[105] Pickering, *Constructing Quarks : A Sociological History of Particle Physics*.
[106] Peter Galison, *Image and Logic : A Material Culture of Microphysics* (Chicago: University of Chicago Press, 1997).
[107] Knorr-Cetina, *Epistemic Cultures : How the Sciences Make Knowledge*.
[108] Galison, *Image and Logic : A Material Culture of Microphysics*., 799.
[109] Ibid. 803.

Now if we wish to inquire, as Galison does, what ties the strands of the cable together, here he professes, in a manner reminiscent of Wittgenstein: “All metaphors come to an end.”[110] Metaphors have to be discarded since the truth of science is what it is, as living and transitive, apart from every opinion. Such indeed is the conviction of an honest man.

However, outside of historical contingency, functional coordination or metaphorical unease, if we still wished to know what relation do things bear to belief or to knowledge in science, there is a possibility of an answer, one that requires an excursion beyond immediate reality, perhaps even beyond available rationality, as I dare suggest, into concepts, categories and method of the radical Enlightenment (of Leibniz or Spinoza), which glides equivocally from superstition or magic to criticism. In the presence of a dispersed and disparate field, where relations crisscross each other in contradictory and complementary modes, it will not help us to become more learned, immerse more deeply into the findings, or travel further, amass more detail and enlarge the picture. What we are after is a point or a “monad” which “expresses the whole universe in its own way, and that everything that happens to it is included in its own notion, with all the circumstances and the whole series of external things.”[111] This point is not some metaphysical essence of things or fixed patterns, nor totalizing forces or unifying ideals to which things strive. In short, not the Berkeleyan idea, Hegelian totality or Kantian possibility, but the Leibnizian “monad” that is conceived with perspective and rendered with abstraction.

In this method, we are not condemned to unwholesome rationality by finding a comprehensive determinate form to contingent facts. Nor do we disregard change or the slithering passage of one perception into another. The only axiom or postulate is to comprehend that each created substance has relations to every other and “consequently it is a perpetual living mirror of the universe.”[112] The method consists in locating the ground of particular existence in another particular existence without implying a physical correspondence or a causal relation, isolating instead a relation of mirroring or reflection, as if finding an alibi. In the consideration of real events and forces, even when they have a mental and moral accompaniment, we propose *not* to start with an analysis of things; instead we seek the negative after-images of things.[113] The concept and the method may seem less mysterious if conceptualized as a dynamic process, like the one that generates hexagonal figures in saturated limewater (calcium hydroxide), of forms attained in material processes, not contingent but restless, and more visible and alluring than the processes themselves. So far only topology or philosophy has been called upon to study the mechanism and movement of the substratum of formative processes, which I wish to avail for anthropology.

From the chief element of relations, what is conceived and understood is reflection. While the ground of this reflection lies in the irrevocable flux and idiosyncrasy of human nature and physical circumstances, the few relations that appear to us and fix our attention are necessary and eternal.[114] This is nothing paradoxical or arbitrary, but always happens when we, whether

[110] Ibid. 844.
[111] Gottfried Wilhelm Leibniz, *Discourse on Metaphysics* ([Manchester, Eng.: Manchester University Press, 1953)., § 9.
[112] ———, "The Monadology," Alex Catalogue ; NetLibrary., § 56.
[113] Johann Wolfgang von Goethe, *Theory of Colours* (Cambridge, Mass.: M.I.T. Press, 1970).
[114] David Hume, *An Inquiry Concerning Human Understanding : With a Supplement, an Abstract of a Treatise of Human Nature* (Indianapolis: Bobbs-Merrill Educational Pub., 1955); Gottfried Wilhelm Leibniz, *New Essays on Human Understanding*, trans. Peter Remnant and Jonathan Francis Bennett (Cambridge [Eng.]; New York:

self-consciously intellectual or not, become aware of anything at all. Since I wish to justify using Leibniz, not as a source of inspiration or analogy, but as a method of investigation in arriving at the framework of science, one that does not "synthesize" from discrete elements, but proceeds to find how "all things are conspirant,"[115] I will raise it with regard to my own ethnography. This is not easy.

Indeed an initial impulse may lead to the conclusion that science is heterogeneous and without a center. Yet in reflection, in a backward look, caring only for the bulk and perspective of things, first the proof itself emerges that reason, memory and classification are already working together. And then it appears that the most remarkable unit in science is a problem, an issue. With its latent impulse to isolation, spontaneity, and integrity, even as it is found in a matrix of material conditions, attached to myriad phenomena and fanned by volatile breezes of intellectual fashions, a problem, or an issue, is integral to science. Every other matter in science radiates from this relation to a problem: the set up of the experiments and the collaborations, the theoretical regeneration of the field, the formulation of error or truth, the building of colliders and future R&D, etc, and the relations are not of succession, but of simultaneity.

The day problem ceases, death ensues. The anxiety which informants express - that if the Standard Model Higgs is found the field will be dead - recalls us to the shock of habit and routine: in the wake of old problems, new ones must take their place. Intellectuals working on matter who can conceive success only in constant novelty are not disheartened even when nature is working against them. Their vitality is not superficial; it is inwardly prompted. Such is the dignity of problems in science, appearing familiar or mechanical when surveyed from the outside, and generative and spontaneous from within. If anthropology is vivified with humanism, it may find in the germinal scheme of problems the center of passion and concern in science, perpetually renewing its operation that makes it worthy of admiration. If anthropology is scientific, without the term scientific taken as eulogistic, then keeping as close to empirical data, consciousness discerns in the tread of problems, non-sensible, intellectual and applicable to a general class of things, the advance of knowledge, which possesses a certain value in the direction of truth-finding. This measure of truth- finding through the mundane march of problems shall now be put to examination with some "flesh and blood" of fieldwork data.[116]

After Charge and Parity (CP) were found experimentally violated in neutral kaon decays (1964), there was an interesting situation where the connection between quark mixing and CP violation had yet to be fathomed. "The terrain was open for speculations."[117] The concept of quark mixing, which means a quark transitioning to another quark of the same electric charge as allowed by the weak interaction, was developed by Nicola Cabibbo who introduced a single mixing angle to describe the transitions between "up," "down" and "strange" quarks. With the

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Cambridge University Press, 1981); Bertrand Russell, *The Collected Papers of Bertrand Russell*, ed. Kenneth Blackwell (London; Boston: G. Allen & Unwin, 1983)., Volume 2.

115 Leibniz, "The Monadology.", § 61.

116 Bronislaw Malinowski, *Argonauts of the Western Pacific : An Account of Native Enterprise and Adventure in the Archipelagoes of Melanisian New Guinea* (New York: Dutton, 1961)., 22.

117 Andreas Hoecker and Zoltan Ligeti, "Cp Violation and the Ckm Matrix," *arXiv:hep-ph/0605217v2* (2006)., 4.

discovery of the "charm" quark in 1974, this was extended to a "matrix" describing mixing between quarks of different generations.[118]

Kobayashi and Maskawa later generalized mixing for six quark flavors in a three-by-three matrix[119] (a matrix with three rows and three columns), which has come to be known as the Cabibo-Kobayashi-Maskawa matrix or the CKM matrix. What is considered exceptional is the fact that without knowledge of all the families of quarks, purely mathematical considerations, that in order to have real phases which cannot be eliminated one needs at least a matrix with 3 rows and 3 columns, led to the prediction of three families of quarks – up/down, strange/charm, top/bottom, which were discovered later. However, the discovery itself does not increase comprehension of why there should be three families of quarks, with the particular masses observed, or how is mass generated.

Now comes the most interesting part: the CKM Matrix cannot explain the observed matter/anti-matter asymmetry of the universe although it is posited as an explanation of matter/antimatter asymmetry. From the point of view of cosmology, the amount of CP violation indicated by the CKM matrix is much smaller than the asymmetry of matter and anti-matter actually found in the universe. Hence, the asymmetry of matter and antimatter in the universe necessitates some conditions, in particular some CP violating effects, at a more microscopic or fundamental level. Experimentally, this forms a critical hint that CP violating effects are worth looking for as possible indications of New Physics, or beyond Standard Model physics.

In March 2008, the "UTfit" collaboration announced "a clear (and clean) signal of New Physics (NP)" from sizable CP violation in the oscillation of Bs mesons (i.e., in b antiquarks and s quark bound states that transform or "oscillate" into their own anti-particles by involving the weak force). On 5th March 2008, the collaboration submitted its findings to the electronic pre-print site - the *arxive* - with the bold title, "First Evidence of New Physics in b <--> s Transitions." Their results were based on the combined data from the Tevatron's two major experiments currently running, CDF and DØ. In combining the data from these two experiments, the UTfit collaboration had to resort to "some wizardry"[120] because the two experiments have very different theoretical assumptions on the strong-CP phases and crucial differences in design and trigger in the experimental set-up. In spite of the steep challenges in combining data from two differently conceived experiments, the UTfit collaboration confidently claimed evidence of New Physics with more than 3 sigma deviations from Standard Model predictions.

On 19th March, in the weekly Theory Colloquium, Wednesday afternoons, one of the members of the UTfit collaboration, Maurizio Pierini, gave a talk summarizing their analysis and boldly announcing the advent of New Physics. The talk brought out incredulous gasp, especially from some of the senior members of the theoretical physics fraternity. Guido Altharelli in his inimitable Italian accent asked with pretended modesty, "can you teach me how the plots are

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[118] The six types of quarks are grouped into three generations: The first generation includes up and down quarks, the second charm and strange quarks, and the third top and bottom quarks. All searches for a fourth generation of quarks have failed.

[119] Matrix is a concept of algebra used widely in physics. The remarkable property of matrix multiplication is that it is non-commutative which implies A.B is not equal to B.A. This property is in marked contrast to real, rational or complex numbers, which makes matrices very useful for calculation of rotations and other transformations.

[120] Online blog entry of "resonances" http://resonaances.blogspot.com/2008/03/ut-fit-longo-magis-quam-acri-bello.html

consistent?" Alvaro de Rujula, with a little bit more sneer pronounced, "You just proved that statistics can prove anything!"

The next day, on 20th March, another member of the UTfit collaboration, Guillelmo Gomez-Ceballos from MIT, gave a talk, this time in the Main Auditorium, addressing the general audience of CERN. He also argued the case for New Physics in the B-S mixing based on the combined strength of continuous data, dedicated triggers, and robust analysis. The talk given in the Main Auditorium drew even more skepticism than the previous day's Theory colloquium.[121] Fierce questions were posed on the way the errors from "systematics," or variations in measurement owing to calibration in instrumentation, were being combined from the two differently organized experiments, CDF and DØ. The questions showed an overwhelming distrust of the data and the claim of New Physics. "How do you take into account the non-resonant background under the Φ peak?," "Don't the pT cuts that you have affect the angular distribution?," "You have half the statistics and yet you get the same number of events, one quote on the background and the same errors as DØ. How is that possible?" This last comment by Tatsuya Nakada, Deputy Spokesperson of LHC-b experiment, led to laughter in the auditorium even as the speaker struggled to give a cogent explanation.

The talks had all the elements and emotions associated with a Hindi film, from hype to bust. The speakers were tremendously in earnest about their analyses. The audience broke into hoots of laughter, even as it demanded rigor and standards. Where criticism is rife, orthodox scholastic character is no less obvious and the discussion turned on paradoxes, violations, errors and discrepancies in trying to reestablish order and truth to what gave every appearance of being false. Science is not alienated from everyday pursuits but prosecutes them with marked enthusiasm. In weeks of dull fieldwork, the Theory colloquium could almost always be counted upon for displays of verbal fireworks. Without deriding in the slightest, what I wish to describe is that in the most solemn undertakings of science, drama slips in, impulse and instinct take thrust, and questions of method and proof occupy the foreground. So enormous was the discrepancy between the analysis presented and the data accumulated that the desire for New Physics was stumped out of existence.[122] What remained was the irony of the problem: the CKM matrix, formulated as an explanation of the matter-asymmetry in the universe, is unable to explain the observed asymmetry. As I asked the audience coming out of the auditorium why do they need

[121] The members of the audience on this occasion consisted more of experimentalists than theorists and so the discrimination or skepticism accorded to data was higher. Einstein had once remarked that when it comes to a theoretical model, no one believes in it except its author who conceived it whereas with experimental results, everyone believes in it, except the physicist who conducted the experiment.

[122] In a thoughtful paper, Michelangelo Mangano, from CERN's Theory division, cautions the community that a discrepancy or deviation from Standard Model (SM) values by itself should not be treated as a sign of New Physics (NP). "One should think of two phases for a discovery: establishing the deviation from the SM, and understanding what this deviation corresponds to. It is crucial to maintain these two phases separate. The fact that a given anomaly is consistent with one possible interpretation does not increase its significance as an indication of new physics. If we see something odd in a given final state, it is not by appealing to, or freshly concocting, a new physics model that gives rise to precisely this anomaly that makes the signal more likely or more credible. The process of discovery, namely the detection of a deviation from the SM by more than, say, 5 standard deviations of combined statistical and systematic uncertainties, should be based solely on the careful examination of whether indeed the signal violates the SM expectation. Assigning this discrepancy to a slot in the space of possible BSM scenarios is a subsequent step." Michelangelo Mangano, "Understanding the Standard Model, as a Bridge to the Discovery of New Phenomena at the Lhc," *arXiv:0802.0026v2 [hep-ph]* (2008)., 2.

New Physics, or why do care for data on quark mixing, the answer was: "Everything depends on it." How are we to comprehend "it"?

In approaching this question, I am not concerned with repeating the explanations that the informants provide. I accept the cosmology rendered by them, as I accept the cosmology rendered by anthropology. But what remains beyond simple assertion is the point of view of the skeptic and the critic in judging the character of science as a form of valid knowledge. Therefore, what prompts anthropological recognition is the fact of a problem in the venture of science. The abstractness of this fact is overcome by its pervasiveness and perpetuity: (i) the dramatic intensity with which problems from quark-mixing, Unitarity triangle, or New Physics, prepare or succeed one another, and (ii) synchronically, in a single problem, models and analyses get cross-checked, criticized or consigned to oblivion; standards and methods come to be questioned (instead of remaining presupposed); and end values and goals are challenged and dethroned, even at the risk of discomfort and sorrow. All episodic activity in science is bound together and made relevant in a problem. It is of central importance to recognize that an intellectual issue understands nothing outside of it: it is a vibrating labor of endless effort which keeps the community alive. To these hardened professionals, the problem is the only thing that matters.

To the question then "What drives an experiment in physics?" the answer, without contradicting obvious empirical ones, such as money or collaboration, involves recognizing the conceptual element of a problem. When Rabinow suggests, "Without money and facilities there is no natural science,"[123] to that I would like to add that without a problem, there is no natural science. Money or facilities are no doubt necessary for science to take place, but they constitute its external determination. It is also not sufficient to remark, as Knorr-Cetina does, that the collaboration forms the key ingredient of high-energy physics since internally it makes all the relevant decisions on what to pursue.[124] If the CKM matrix is unable to explain the observed matter-antimatter asymmetry or if every experiment drearily vindicates Standard Model predictions, it is independent of what the collaboration wills or the money at its disposal. The forward thrust of a problem contains the inner germ of science, which lends it meaning and purpose, and from where its continuance and confidence are systematically affirmed.

What we must grasp – if we claim to comprehend as well as to critique science – is the dynamic substrate of society that exists inside science. The recognition sits uneasily with the current mood in the social sciences, which finds no demarcation between intrinsic and extrinsic interests or internal and external contexts. Bourdieu argues that owing to an idealist philosophy, which credits science with a power to develop in accordance with its immanent logic, which is both false and artificial, divisions between strictly scientific and strictly social determinations have been postulated. He believes it is pointless to distinguish between "intrinsic" and "extrinsic" interests. Instead we must recognize the inseparability of the political and the pure in the constitution of "the scientific field." The argument Bourdieu advances in support of his claim is the following: when a scientist discovers that someone else has published a conclusion which he was about to reach as a result of his own research, "almost invariably he feels upset by this

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[123] Paul Rabinow, *Anthropos Today : Reflections on Modern Equipment* (Princeton, N.J.; Oxford: Princeton University Press, 2003)., 5.
[124] Knorr-Cetina, *Epistemic Cultures : How the Sciences Make Knowledge*.

occurrence, although the *intrinsic interest* of his work has certainly not been affected."[125] As an argument it works only if one doesn't immediately inquire, what if the conclusion of the research was wrong? Work may be impersonal but it doesn't affect us less and to observe an error is of critical importance whether or not one is alone in erring.

There are a couple of fallacious assumptions in Bourdieu's argument that I wish to address as a way of stating some concrete observations on the subject of science. The diagnosis to the problem of what is social about science belongs to idealist philosophy only if one identifies some unique ethos to science, such as the set of Mertonian norms of universalism, disinterestedness, skepticism, etc. But these are foisted on science by the dogmatism of experience. It would be like foisting on society some norms of emotion, sympathy, morality, utility, or instrumentalism. The identification of science *and* society belongs to a different sphere - not to experience or perception but to implicit knowledge and judgment. What is unique to science is the conduct of experiment, the logic of innovations, the presuppositions or the grammar underlying the transaction with nature, as I have been arguing so far. If this world is arid or warm, discordant or peaceful are merely consequences and cannot be considered as the nerve of intellectual activity. The morphology of the scientific field is marked by certain principles of classification, and not by attitudes, ideas or ethos nor by power, interests, or domination. That both (ideal) attitudes and (real) power may be abundantly present is not denied but these aspects are no factors in its generation.

Secondly, it is mistaken to believe that the social character of science is best discerned because it is a *collective* enterprise involving thousands of people (in a closed space with money at their disposal and truth in their possession).[126] Marx made precisely the observation that the solitary scientist working by himself or herself in the laboratory is social: "When I am active scientifically – when I am engaged in activity which I can seldom perform in direct community with others – then I am *social*, because…not only is the material of my activity given to me as a social product (as is even the language in which the thinker is active): my *own* existence *is* social activity, and therefore that which I make of myself, I make of myself for society and with the consciousness of myself as a social being….The individual *is the social being*. His life, even if it may not appear in the direct form of a *communal* life carried out together with others – is an expression and conformation of *social life*."[127] The insight – that the social and the collective or the communal by no means coincide – is commonly taught but seldom understood.

In order to carry out a vigilant assessment of science, we must be cognizant to its uniqueness as a branch of knowledge. The point to bear in mind for an anthropological evaluation of the sciences is that the unit of society or culture is not configured extraneously by the poetics of publication or politics of authority nor manifest in its communitarian or collective structures such as collaborations, meetings, papers, or conventions. In the intellectual configuration of a problem resides the notion of society inside science, and which constitutes its conditions of existence. The cost of investing in the Hadron Collider or the growth of future colliders, the tedium of Standard Model physics, the changing protocols of authorship, the

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[125] Bourdieu, "*The Specificity of the Scientific Field and the Social Conditions of the Progress of Reason*," in Biagioli, *The Science Studies Reader*., 32.
[126] Bourdieu, "*The Specificity of the Scientific Field and the Social Conditions of the Progress of Reason*," in Ibid.
[127] Karl Marx and Friedrich Engels, *Economic and Philosophic Manuscripts of 1844*, Great Books in Philosophy (Amherst, New York: Prometheus Books, 1988)., 105. Italics in original.

mystery of the universe, and the degree of authority or autonomy accorded to these, are not just practical or moral questions, but also intellectual ones.

Its lack of interest in engaging the outside world shows that science is not a system. It does not need prophets to launch it, or skeptics to maul it to ground – as long as it has the intellectual import of a problem, it is secure in its confidence. Its intellectual issues is what renders physics prodigal, intense and relentless: after all what peace can be there in the double orientation that it is really right that something should be wrong, but that it is really wrong not to strive to right it? It is a shrewd position. Yet to wonder, interpret and critique the confidence of physics is the superior task of anthropology whose intrinsic character, never towards the easy or the perspicuous, deepens the apprehension of intellectual ardor by placing its development in the mundane march of problems, rendering it at once familiar and remote.

4. Presuppositions of Science

Now I have reached the culminating point of my exposition into the conditions of science at CERN. So far I have outlined three factors of equal prominence and longevity in the enterprise of science, to which I add a final abstraction, different in character from the previous three. The last section takes up the category of beliefs, or more specifically the presuppositions, which guide every step of the process of scientific inquiry. These form the metaphysical counterpoint to physical experience. While innovations, problems, and experimentation have an element of self-consciousness, the presuppositions lived by or adhered to come by inertia; they are followed without being justified. They have a subterraneous existence and a strange persistence. Thus, a problem may define a critical moment or redefine the field, experiment provides dramatic kinship and comprehension of nature, or an innovation may lead to the restoration of sapping spirits, beliefs and presuppositions simply endure the passage of time. Lacking clearness or consistency, and devoid of utility, what makes them durable and valuable is what I shall explore now.

The issue of beliefs is a vexing one in anthropology. Beliefs are precarious, obscure, diffuse, hidden and complicated. Needham refuses to accord any existence to a category, which has its source in nothing but mental or "interior states," and therefore he argues any claim to know them must be an illusion. "The concept of belief has no 'real' definition. If it has no such definition, it is the more unlikely to denote a real and specific experience."[128] The alleged incompetence in understanding beliefs is made on the grounds that they can only be expressed improperly, which can only be described inadequately. "Since the possibilities of misunderstanding that are inherent in the notion of belief are so great, I do indeed urge that in ethnographic reports, or in comparative epistemology, the use of the word should be quite abandoned."[129] I disagree with Needham's contention. If we experience any discomfort in the anthropological endeavor of defining belief, it does not come from a failure of recognizing its character or content. Rather it comes from a false conception of what would be a successful definition.

[128] Rodney Needham, *Belief, Language, and Experience* (Chicago: University of Chicago Press, 1972).
[129] Ibid., 193.

I shall attempt to outline an alternative account of beliefs that may be invoked with confidence and benefit. Of course, finding evidence for one's or others' belief is just as thorny as evidencing rules of grammar in actual speech.[130] When we first look at the everyday world, as it exists for the informants, in their science and in their lives, we confess that we cannot give a ready-made account of beliefs. For one, not everyone has the same uniform beliefs. The beliefs have a desultory character and a diffuse influence, and it defies comprehension on how they can be maintained or passed on. One may indeed be entirely without them in a self-conscious way. However, those who have them, hold them very strongly and cannot regard them as anything but as genuine expressions of truth. They struggle but find articulate grounds for their beliefs. Such grounds are sought in the character of everyday life, what seems self-evident. In this struggle and in the concrete, their beliefs are only too perceptible and too elaborate.

With obsessive fidelity for over thirty months, I observed the beliefs, which span the whole range from what can be fairly described as norms through more or less convictions, to what I am calling the unconscious and impersonal ones, the presuppositions. While the discussion aims at a general conception of belief, the class of beliefs that I shall abstract for attention is the presuppositions, which form a small, though perhaps the most striking part of the total repertoire. The concept of presuppositions is used extensively in philosophy.[131] When Saint Augustine queries what did God do before He created the universe, he answers that the question presupposes the existence of time before the creation of the universe. Presuppositions are unrecognizable from the point of view of actual or prevailing states of affairs. However, they form the necessary conditions for meaningfulness of utterances.[132] They should certainly not be confused with explicit premises or axiomatic principles. To formalize presuppositions is a difficult task and so let me proceed with the data and then return to its interpretation.

I reproduce an abridged record of an exchange, fairly general, between two theoretical physicists and the anthropologist. During a lunch-hour conversation, one of the physicists, Thomas Mannel, is recollecting, how Supersymmetry, or "SUSY, has managed to keep a hold on particle physics without any basis in nature."

Thomas Mannel: SUSY is not a real theory. It is only an aesthetic consideration.

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[130] "Much of linguistic behavior lies on the level of unconscious thought. When we speak, we are not conscious of the syntactical and morphological laws of our language. Moreover, we are not ordinarily conscious of the phonemes that we employ to convey different meanings; and we are rarely, if ever, conscious of the phonological oppositions which reduce each phoneme to a bundle of distinctive features. This absence of consciousness, moreover, still holds when we do become aware of the grammar or the phonemics of our language. For, while this awareness is the privilege of the scholar, language, as a matter of fact, lives and develops only as a collective construct….We may say, then, that insofar as language is concerned we need not fear the influence of the observer on the observed phenomenon, because the observer cannot modify the phenomenon merely by becoming conscious of it." Levi-Strauss, *Structural Anthropology*., 56-57.

[131] Gottlob Frege, *Translations from the Philosophical Writings of Gottlob Frege*, trans. P. T. Geach (Oxford: B. Blackwell, 1952); Stephen C. Levinson, *Pragmatics* (Cambridge [England]; New York: Cambridge University Press, 1983); P. F. Strawson, *Introduction to Logical Theory* (London: Methuen, 1963).

[132] "Field-workers must learn to consider their research from two different perspectives. They are always in danger of confusing the natives' theories about their social organization (and the superficial form given to these institutions to make them consistent with theory) with the actual functioning of the society….The sociological representations of the natives are not merely a part or reflection of their social organization. The natives may, just as in more advanced societies, be unaware of certain elements of it, or contradict it completely." Levi-Strauss, *Structural Anthropology*., 130-31.

Robert Fleischer: Oh that is too much! How can you say that? It *is* one of our theories.

Thomas Mannel: No, it is not physics.

Anthropologist: What is physics?

Thomas Mannel: Physics is a real science. It works on evidence. The standard model was accepted after evidence was found for it. We have no evidence of SUSY so far.

Anthropologist: But you hold in respect the people who have produced these theories. String theory is not physics since it has no evidence but nobody says Ed Witten is a terrible physicist?

Thomas Mannel: Exactly. Evidence is separate from people. Witten is a genius. His contribution to physics is beyond comparison. He inaugurated a whole new field on his own. Nobody will disagree with me. But it is upto nature to prove Witten right or not. Before nature we are all equal, Witten, Lee Smolin or me.[133]

Anthropologist: Robert do you agree with Thomas?

Robert Fleischer: Yes of course. We would like things to be in a certain way but they have their own wish. We want to see maximal symmetry but nature may not work that way. What can we do?

Anthropologist: Then what is it that you do?

Thomas: We make predictions. Theory is the language of nature. We use models and theories to understand nature. Experimentalists do the calculations and test the theories and tell us if our predictions are right and engineers set up the instrument.

Anthropologist: This is what T.D Lee told me after his talk "we make predictions. Experiment is the point of contact with nature." Experimentalists often present results with 3-sigma evidence, then who decides if it is physics or a detector effect – nature or people?

Thomas Mannel: Look whatever they may say they know deep down that it is not evidence. LEP found some evidence of the Higgs. They didn't have good statistics but the ALEPH data showed some signs of the Higgs. For SUSY, nothing. In those days we could go to the experimentalists and get the numbers and include them. Now it is too much bureaucracy. Hundreds of groups analyzing every result, different results have to be integrated. They guard it like some secret. They don't just tell anyone. You should study that. That is sociology.

Anthropologist: You don't think this is sociology – that nature behaves one way, and humans another?

[133] Witten is a well-recognized physicist, 1990 Fields medalist, known as a person of great character and penetration. Lee Smolin, on the other hand, has gained notoriety for espousing odd theories (loop quantum gravity) and speculations on the laws of physics.

Thomas Mannel: Come on that is how the world is. What is there to study?

Anthropologist: I think it is an interesting sociological problem to investigate how you people can make predictions about things to which you say you have no connection.

Luis Alvarez-Gaume: What is going on? You are recording?

Anthropologist: Welcome. Yes! I am saying that it is interesting to study how you people find the relation or non-relation of mind and physical reality.

Luis Alvarez-Gaume: See mind is a tool that helps us to understand reality better. The source of reasoning is the mind; it does not come from outside. In that sense it is hardwired in the brain. But without a chair, the brain can't say there is a chair okay. The brain is in the body and the body is in the world. These are separate, and when you couple them, there is non-linearity.

Here in this conversation we have the strange phenomenon of a real presence of a set of beliefs of which at first no ready notion can be formed. And yet the feeling of reality attaches to the beliefs so strongly that one's perspectives and actions may be affected through and through by the content of the belief and yet that belief itself, for purpose of a definite description, can hardly be said to be there. Thomas and Robert are discussing, for the benefit of the anthropologist, the merits of a theory in physics, and the biases of the community. In doing this, they observe a difference and a separation between physics and physicists. While Thomas agrees that he has a "bias against SUSY," he will not admit that physics has a bias, which inclines towards evidence, measurement or non-human nature.

Luis speaks like the illustrious Helmholtz, the distinguished mathematician, physicist and physiologist but thoroughly positivistic. According to Luis, objects in the world stimulate the brain. There is a correspondence between the object and the sensation, established by means of reasoning. Reasoning cannot be learnt, since it is an inherent physical ability. The correspondence takes place in an organized, shared environment. In order for this correspondence to occur, it must be presupposed, as Thomas and Robert are trying to convey, that bodies, perceptions and minds exist independently of each other. While physics presents an inflated eloquence on every theme, from the presumed grandeur of its discoveries to the success of instrumentation, the presupposition on the total separation of different order of things is made with an unfailing literal earnestness. They stand like a rainbow over receding clouds. When a physicist says that nature acts independently of human beings, she does not mean it as a representation of an experience. Rather it is presented as information of an experience. The universe *is* like that. In this sense, the presuppositions have a clear and distinct physical character.

In addition to the physical aspect, the presuppositions have a moral force. Every physicist knows that the ideal of objectivity belonged more appropriately to classical than to quantum physics, but the separation of object and subject is the source or the premise of all physics, whether quantum or classical. To interject and ask if physics is less objective today would be a deeply disturbing question at CERN. Here, we find that while knowledge and rational inquiry have no difficulty in acknowledging historicity or change, the conviction of presuppositions does not admit of temporal change or cultural basis. Whereas the status of knowledge fluctuates, the presuppositions remain on rather unshakable grounds.

Before I take up the content of their claims and evaluations, it is useful to examine the distinction or juxtaposition of belief and knowledge. “From my initial explorations, it would appear that the term ‘belief’ as it is employed in anthropology does indeed connote error or falsehood, although it is seldom explicitly asserted.”[134] Byron Good explores the problematical assumptions of the analytic of belief in modernist anthropology. In questioning how the use of the term belief is related to the epistemological assumptions, he warns us that we must be alert us to the hazards of power in conducting research, and where the division between knowledge and belief becomes singularly pernicious. Previous ethnographic accounts, such as Evans-Pritchard’s or Rivers’, made knowledge the province of rationality and coherence, while inflecting the term belief with unsavory overtones of superstation, ignorance or irrationality. This led to a subtly instituted division of “what others believe to what we know.”[135] Fortunately, since “the place of the ethnographer as objective, scientific observer – both in research and in ethnographic texts – seems less and less available to us today,”[136] Good assures us that the unwholesome attitude of suspecting others of belief, while holding oneself privy to knowledge, is on the decline.

In addition to the problems of power and hegemony of the observer, the situation of the anthropological analysis of beliefs is supposedly complicated by the general post-modern angst of what can we know. How can we portray what others think? What is the “Other”? “It is clear, when describing beliefs and ideas in other cultures, that we must allow for the fact that males and females, old and young, rich and poor may understand different things by certain symbols; some may be ignorant of what is knowledge for others.”[137] Well it seems that the conceptualization of both belief and knowledge are problematical. Now we are exposed to the complex terrain of anthropology - and to its own troubled presuppositions - which have led to the ascendancy of “the local,” “the particular,” “the partial,” “the circumstantial,” “the sensuous,” “the material,” and “the practical” in every research and analysis. The preoccupations of a fanatical post-modernism have poisoned the freedom minimally allowed to writing and reflection and has turned anthropology, which should be a delightful venture, into burdensome circumlocutions.

To return to the analysis of science, we must go over the formation of its conceptions in its presuppositions. The beliefs and presuppositions of science are the existence of a mind-independent external world, the invariance of laws of nature, the adequacy of mathematics, and so on.[138] As is true of any belief system, the beliefs, which undergird the sense of physical reality, show variations, contradictions and confusions. From this amorphous group, I have, thus, selected a set of three presuppositions as fundamental to the cosmology of the physics community. These are the dualisms, or the absolute heterogeneity and separation, of (a) subject and object, (b) fact and value, and (c) theory and practice. Each term of the opposition is qualitatively different and hence not easily interchangeable and the terms themselves in each of

[134] Byron Good, *Medicine, Rationality, and Experience : An Anthropological Perspective* (Cambridge; New York: Cambridge University Press, 1994)., 17.
[135] Ibid., 18
[136] Ibid., 23.
[137] Crick, "Anthropology of Knowledge.", 295.
[138] E. F. Caldin, "Science and Philosophy: Implications or Presuppositions?," *The British Journal for the Philosophy of Science* 1, no. 3 (1950).

the three pairs are separated from each other. The intense incompatibility prescribes their separation. The asymmetry in the strength and dignity, which attaches to each term of the oppositional pair, is not unlike the opposition of scared and profane that Durkheim found in primitive cosmology.[139]

The dualisms have an enduring character in the community of physics. They are foundational because some of the other widespread beliefs are backed by these dualisms: objectivity is an observable property, causality is an external norm, experiments provide exact measurements, and so on. The dualisms perform effectively the task of analysis, developing one strand of belief from another, and then mechanically combine in synthesis the diverse planes of symbol and reality, mind and the world, external and internal. All non-dual motives are entirely foreign to physics and the difficulties that surround the tendencies of mediation or unity are long-standing and deep-rooted. Any suggestion of unity gives the appearance of the phenomena of continuous lines that approach one another, which must give at first sight give the certainty of intersecting. But the relation of the hyperbola to its asymptotes shows how deceptive the impression is. Hence, any discussion of unity is poetically, mystically or morally acceptable, but logically a mere hocus-pocus.

If the presuppositions, or the dualisms, can precipitate distinct forms of knowledge, it is because they are impersonal. They have an enduring quality to them independently of particular individuals. The subjects themselves hold the presuppositions neither as conceptions of the intellect (science) nor as sensible qualities that the senses can grasp (art). Sublime and impalpable, the dualisms reside in the physicists' minds and habits. Otherwise skeptical of every statement, which presents itself as a self-established fact, the informants rarely wondered if any one of their dualisms could be eliminated or displaced. It is the most vital and the most arbitrary part of their cosmology but for that very reason the most jealously guarded. If attacked on those, they become livid and the result is extreme unpleasantness on all sides. When I tried to expound on William James' "*Varieties of Religious Experience,*" together with my own personal experience of growing up in India in the sacred cosmos of Hinduism with little belief in the separation of the mind and the world, Luis (Alvarez-Gaume) savagely retorted: "why don't you go to the witchdoctor next time you are sick?"

In conclusion, the dualisms guide the conscious pursuits of physics, they lend strength to its ambitions, and they justify the set-up of the universe. To probe the presuppositions of physics is to inquire into the very conditions of its possibility. In the next three chapters I shall take up the specific dualisms with the conviction of mediation or unity, for knowledge could have set up a limit if it did not already contain a sense of being transgressed. So mediation or unity is an essential premise, of knowledge (epistemology), universe (cosmology), and being (ontology). Personally, I have the greatest satisfaction in carrying out the investigation into the dualism of subject and object in the phenomenon of handedness in quantum physics. It was the only time when informants' hubris seemed somewhat humbled as they reluctantly conceded that in handedness, conventions are integral to the constitution of a physical object, which puts into jeopardy the absolute opposition of subject and object. In the chapter after that, I attempt to interrogate the dualism of fact-value, not pursuing it backwards to some ultimate foundations but forward in the concrete configuration of signatures emerging in experimental physics. The fourth

[139] Durkheim, *The Elementary Forms of the Religious Life*. The sacred and the profane are so fundamentally opposed that they constitute two separate orders of the world.

chapter is an attempt to grasp the non-dualism of theory and practice in the operation of the instrument, which seemed to suggest a unity to the character of particle physics. The institutional force of the division of labor quickly dispelled the illusion.

I agree that the logic of dualisms is disconcerting for some of us. Yet we must be careful not to disregard them for analysis however crude or contingent they appear to us. In fact it is through these entrenched dualisms that the first principles or the most elementary forms of physics are disclosed and in the process we see how anthropological analysis becomes a masterpiece of characterization and insight. Through these we delve right into the society inside science, and relinquish the vulgar understanding of society as an extraneous entity adjacent to science and grasp the profound puzzle of how a group of people finds harmony with nature on the pivot of a wedge between microcosm and macrocosm. This is a question of classification, one that belongs equally to a scientific anthropology and a humanistic anthropology. It is upon this classification and cosmology that science reposes.

Chapter Two: Particle Physics and the Anthropology of Right and Left

I say, however: if you talk about essence, you are merely noting a convention. But here one would like to retort: there is no greater difference than that between a proposition about the depth of the essence and the one about - a mere convention. But what if I reply: to the depth that we see in the essence there corresponds the deep need for the convention.

Wittgenstein, Remarks on the Foundations of Mathematics

The chapter explores the genealogy of the concept of handedness in particle physics as a study in collective representations.[1] Handedness, or the designation of right or left, plays a critical role in explaining how subatomic particles interact with each other. "Electro-weak" interactions, such as nuclear beta decay, indicate that elementary particles do not conserve the symmetry, or parity, of right and left. In any such interaction more left-handed electrons are produced than right-handed ones. Since the observation of this intriguing asymmetry, it is claimed that quantum physics provides an "objective" basis to the classification of handedness, free from observer and social conventions.[2] This assertion of scientific thought forms the basis on which I interrogate the character and extent of knowledge that modern science stakes. On the basis of textual data and fieldwork at CERN, Switzerland, the text analyses what the objectivity of handedness says about the relation between the observer, the universe and conventions.[3]

Although the discussion of handedness, commencing with the groundbreaking analysis of Durkheim and Hertz, has been critical to the study of symbolic classifications, the work undertaken here is of a completely new kind. The novelty does not lie in the fact that handedness is being researched in the context of high-energy physics experiments at CERN, but the light it throws on a fundamental question of cosmology. The classification of handedness in particle physics enables us to posit afresh the problem of *orientation*. The characterization of a particle as "right-handed" or "left-handed" immediately raises the question: from whose point of view is it right or left? To designate handedness *presupposes* an observer, and conventions. But if physics proceeds from the strict separation of subject and object, then how can it posit – as it does – a physical universe with a preferred orientation?

Handedness, or rather the asymmetry of handedness, raises the singular possibility that the universe has a point of view, that the human observer is not a limitation of gaze but the source of vision for the universe. It undermines the separation of subject and object that science perpetuates, and shows that conventions are integral even to the formulations of a post-

[1] Collective representations are basic concepts or ideas, product of collective elaboration, through which a community or society expresses itself. These ideas are at once general and logical, like the "categories of thought" of causality, space, substance, etc, and specific and concrete to a social group's way of thinking and being. Ibid.
[2] John Earman, *World Enough and Space-Time : Absolute Versus Relational Theories of Space and Time* (Cambridge, Mass.: MIT Press, 1989); Martin Gardner, *The New Ambidextrous Universe : Symmetry and Asymmetry from Mirror Reflections to Superstrings* (New York, NY: W.H. Freeman, 1990).
[3] Professor Jit Singh Uberoi gave me this rich, generative problem of handedness to study; to him I am eternally beholden.

Enlightenment science. If the characterization of elementary matter as right or left depends on certain conventions of definition, the concept of objective science loses its meaning. My research not only extracts the concept of handedness out of its “primitive” context but also seeks to demonstrate the fundamental *unity* of intellect by finding all forms of thought, modern and primitive, rooted in a single function of *difference.* The seed and source of all intellectual activity resides in the principle of differentiation. The discussions of Durkheim, Hertz or Evans-Pritchard are steeped in the myriad differences that exist between the microcosm and the macrocosm, between the sacred and the profane, between magic and science. They inquired into the methodological significance of the principle of differentiation and found in it the foundation for unity – especially the unity of the mind and the world. This double movement of polarity and unity emerges with complete clarity in the investigation of handedness in quantum physics.

In what follows, I shall give a detailed exposition of the problem of handedness, particularly its relevance in classical anthropological thought. Some of the key issues to be addressed here are: What is the basis to the classification of handedness in cultural practices? How does such a system of classification order the universe? What is the relation between orientation, space and material extension? Once we delve into these questions, we shall then approach the problem of handedness in relativistic quantum physics with the aim of establishing what physical property determines handedness of a material particle. Is it an essential property of an elementary particle to be right- or left-handed? Or does a particular handedness depend on the observer and conventions of designation? After demonstrating what defines the logic of classification of particles’ handedness, I will briefly trace how the concept was introduced in the discipline of particle physics. Finally, I examine an empirical case - the observed experimental violation of the equality of right and left (or fall of parity) in particle interactions - in an attempt to cover ground on the form of explanation that science establishes. The case-study takes us to the very foundations of science and enables us to question: What are the presuppositions of physics in admitting an orientation category? What challenges does this pose for cosmology?

In the exploration of handedness, not only are particular concepts (of physics) like angular momentum, velocity or spin involved, but also other abstract ones of space, substance, relation and form. It is to this discussion that my research makes a contribution. The plea is not to argue for a hermeneutic understanding of the “hard” sciences, or to restore the subject’s position in so-called objective sciences, but to explore the knowledge of “form,” which as Plato held to be the goal of all logical explanation of the world. In outlining this genealogy, it is not my intention to reconstruct a historical trajectory of this concept, or to reconstitute the thought of twentieth century physics. Therefore it may not be an exposition faithful to accuracy in every historical detail. What I wish to describe, analyze and explain is the formulation of a concept in the space of knowledge that may elude the explicit consciousness of the individual scientist, yet forms part of the collective scientific consciousness. This is not to deny the presence or significance of intellectual biographies, which play a role in the articulation of scientific thought. Instead I will isolate the concept of handedness in physics as a problem or a puzzle in the theory of knowledge.

1. Exposition of the Problem

The presence of a concept like handedness in physics poses a puzzle for anthropology.

Handedness presupposes an observer, and conventions, to endow space with a particular orientation. As Reichenbach illustrates, the statement "Fifth Avenue is to the left of Fourth Avenue" is meaningless. It cannot be ascertained as true or false unless one specifies the direction from which one is looking at the streets.[4] For terms of handedness to make sense, the relation to the human subject can never be eliminated without losing the entire concept. But this is not to argue that handedness is a purely subjective phenomenon. For although identical in shape, size and structure, no matter how hard I try, I cannot wear the left glove on my right hand.[5] Its materiality places some constraints. This is indeed puzzling. It was this double-sided nature to handedness that drove Kant to exasperation.[6]

In particle physics, as I shall explain later, the terms right and left are two labels of particle behavior assigned on the basis of a particle's "spin" and motion. If a particle's spin is allied in the direction of motion, it is termed Right-handed and if the directions of spin and motion are oppositely aligned, the particle is called Left-handed. This definition of handedness is based on the "right hand rule," so a particle is considered carrying angular momentum along the thumb of the right hand when it is spinning in the direction in which the fingers curl. Clearly, using the right hand in defining the direction of the alignment of spin and motion is an arbitrary assignment. Well, the way any word stands for any entity is arbitrary or a matter of convention. That is not the issue here. What is being interrogated is would either of the handed objects make sense without an observer to endow them with a particular orientation?

One could, it may well be argued, describe left as "clockwise" or "anti-clockwise," or use other related concepts like spiraling "inside" or going "outside." But this displaces the opposition into other sets of oppositions. The crux of the matter is that we cannot give a verbal definition of any chiral term without using other chiral terms. As Feynman puts it, without establishing the convention first of what is right/left, clockwise/anticlockwise or positive/negative electric charges, we cannot shake hands with inhabitants of an alien universe.[7] Unless we share a common language of understanding of right and left with the alien inhabitants, there is no way it can be made clear what is in one's mind.[8] Since there is no inner difference between the right and left in enantimorphs of a given pair, like the human hands, it requires an arbitrary act of choice to determine what is right and what is left. Yet this determination is not haphazardly arbitrary. It is established by social conventions or custom.

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[4] Hans Reichenbach, *The Rise of Scientific Philosophy* (Berkeley: University of California Press, 1951)., 134.

[5] In proposition 6.36111 of the *Tractatus*, Wittgenstein argues that a right-hand glove can be worn on the left hand – simply by turning it inside out. The upshot is that in a Euclidean space of rigid rotations and translations, two hands cannot be mapped on each other. One requires an extra dimension in space – for a rotation in (n+1) dimension - to make them congruent. This is exactly what a Mobius strip achieves: two non-superimposable objects in a three-dimensional space become identical when one of them is rotated or turned over in a fourth, though physically unattainable, dimension. Ludwig Wittgenstein, *Tractatus Logico-Philosophicus*, trans. David Pears and Brian McGuinness (London; New York: Routledge, 2001)., 81.

[6] Between 1798 and 1786, Kant repeatedly pondered over the problem of handedness and what it indicates about the reality of space. After many attempts, he concluded that the incongruity of right and left could only be apprehended as a certain pure intuition. His arguments will be considered in detail in the next section. Kant, "*Concerning the Ultimate Ground of the Differentiation of Directions in Space*," [1768], in Immanuel Kant, *Theoretical Philosophy, 1755-1770*, trans. David Walford and Ralf Meerbote (Cambridge; New York: Cambridge University Press, 1992).

[7] Feynman, *The Character of Physical Law*., 107.

[8] This aspect of the problem is more familiarly known as the "Ozma problem", following Martin Gardner's popular and extensive discussion. Gardner, *The New Ambidextrous Universe : Symmetry and Asymmetry from Mirror Reflections to Superstrings*.

To admit of terms of orientation such as right and left in particle interactions, would imply that conventions are *intrinsic* to the constitution of a physical object, which flatly contradicts the assertion that the sciences are "destined to retain always a non-conventional kernel."[9] The phenomenon of handedness confronts and challenges the claim that physics deals with an impersonal universe. In discriminating between right and left, the impersonal universe shows it has discernment. The puzzle on handedness brings me to the core question at the heart of physics: what is the relationship of subject and object that modern physics posits? As the definition of handedness shows, is not the observer, or the community of observers, an integral part in the formulations of physics? If yes, then what sustains its claim of pure objectivity?

Modern physics proceeds by proclaiming the absolute separation and heterogeneity of the subject and the object as the precondition for all thought and determination of physical reality. There is a complete separation of inner nature from outer nature, or of the physicist's mind from the physical world. For physics to possess any reasonable criteria of validity, it must be assumed that the object is heterogeneous from and constituted independently of the subject. And from then on the task of analysis is to lay bare the form of physical object without any mediation. Even quantum mechanics, which generated a significant controversy into the role of the observer in physics, admits only a certain *physical* presence of the body of the observer and does not include the *mind* of the observer as necessary to experimental outcomes.[10] Heisenberg observes, "certainly quantum theory does not contain genuine subjective features, it does not introduce the mind of the physicist as a part of the atomic event."[11] From my fieldwork experience, I attest to the overwhelming concern of physicists' in maintaining objectivity as a distinctive feature of their thought and practice. At a lunch, I was once complaining that after two years of living amidst physicists my general outlook was getting prejudiced, to which Thomas Mannel, a theoretical physicist, immediately protested "But how can that be! We physicists are the most objective people on earth."

As a probe into properties of space-time, the vacuum and the origin of mass in the universe, handedness occupies a privileged place in contemporary particle physics and cosmology. The experimentally observed asymmetry of right and left, termed parity violation, is a critical ingredient in the explanation of how symmetrical rates of matter and anti-matter at the start of the universe have, over time, led to our asymmetrical or matter-dominated universe. Parity violation constitutes one of the three fundamental Sakharov conditions of "baryogenesis," or the generation of matter at the origin of the universe. The other two conditions for the generation of matter are violation of baryon number and interactions out of thermal equilibrium. Handedness has been enshrined in the current paradigm of physics, called the Standard Model, which is defined as a "chiral gauge" theory (Figure 1), which refers to the symmetry of right- and left-handed fermions,[12] which are treated differently in subatomic physical processes. For instance, right-handed fermions do not participate in the weak interactions whereas left-handed

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[9] W. V. Quine, *The Ways of Paradox, and Other Essays* (Cambridge, Mass.: Harvard University Press, 1976)., 77.

[10] Mara Beller, *Quantum Dialogue : The Making of a Revolution* (Chicago: University of Chicago Press, 1999). Karl Popper, "Quantum mechanics without 'the observer,'" in Mario Bunge, *Quantum Theory and Reality* (New York: Springer-Verlag, 1967).

[11] Werner Heisenberg, *Physics and Philosophy : The Revolution in Modern Science* (New York: Harper, 1958)., 29.

[12] Fermions, such as electrons, protons, etc, are particles that form the key building blocks of *matter.* They are contrasted with the bosons, or the force-carrier particles of radiations or *energy.*

fermions do. All these aspects in which handedness figures in contemporary particle physics will be examined in detail in the following sections.

$$\mathcal{L}_{E-W} = \mathcal{L}_g + \mathcal{L}_f + \mathcal{L}_H + \mathcal{L}_m$$

$$\mathcal{L}_g = -\frac{1}{4} G_a^{\mu\nu} G_{\mu\nu}^a - \frac{1}{4} B^{\mu\nu} B_{\mu\nu}$$

$$\mathcal{L}_f = \sum_i \overline{\Psi_{Li}}(i\partial\!\!\!/ + g' W\!\!\!/^a t_a + g B\!\!\!/_y)\Psi_{Li} + \sum_i \overline{\Psi_{Ri}}(i\partial\!\!\!/ + g B\!\!\!/_y)\Psi_{Ri}$$

$$\mathcal{L}_H = -(D_\nu \phi)^\dagger (D^\nu \phi) - \mu^2(\phi^\dagger \phi) + \lambda(\phi^\dagger \phi)^2$$

$$\mathcal{L}_m = -\sum_{i,j} C_{ij} \overline{\Psi_{Li}} \phi \Psi'_{Rj}$$

Figure 1: The standard model "Lagrangian," describing the fundamental forces and interactions of nature. The subscript R and L, in the third line of the equation, stand for terms of handedness.

Dealing with a relatively new and puzzling scientific concept brings to mind the relevant and long-standing issue of reality versus representation. Is there a reality to handedness pre-existing its fabrication as a concept (a "realist" account, e.g., Popper)[13] or does the conceptual elaboration create the entity ("social constructivist" interpretations e.g., Pickering).[14] Or, more generally, how robust are signs established by nature? Or how arbitrary is language and meaning? What is the context in which terms and objects acquire a particular usage? These are deep and outstanding questions. However, I do not wish to deny or contest the ontic status of phenomena, whether natural or social in origin. It would be sterile and unfair to analyze handedness in a one-sided formulation - of either representation or materiality alone – in order to expose the inherent limits of received truth without inquiring further into its foundations in knowledge and belief, not didactically as refuting old errors, recovering new truth, nor discursively as paradigm shifts and changing conceptions. The question of anthropological significance that I am attempting to raise is simply the following: what is the meaning of a concept of orientation in a discourse that claims to operate independently of observer and conventions? The discussion of the emergence of the concept of handedness in physics, and that bears the historicity of modern knowledge, takes me to the very foundations of modern science - to its presuppositions on the nature of space, substance, relation and form.

2. Handedness: Substance and Relation

[13] Karl R. Popper, *The Logic of Scientific Discovery* (New York: Basic Books, 1959).
[14] Pickering, *Constructing Quarks : A Sociological History of Particle Physics*.

Intense debates on the nature of space and substance took place on the eve of inauguration of modern science. Is space a substance in its own right independently of and prior to material objects that fill it? Or does it simply express relations between substances that can be identified independently of their spatial positions? Kant first posed and pondered over the problem of handedness in 1768 as a challenge to the then prevalent theories of space from which his whole critical philosophy of "transcendental idealism" was to evolve.[15] He reasoned as follows: two objects A and B, like the two hands, are similar in shape and equal in size. Yet there exists an inner difference between them, which consists in the fact that one hand cannot occupy the same portion of space as occupied by the other hand, although its reflection can. The difference lies in how the hands are oriented in space. Therefore, handedness, as a property of certain objects, relates to "universal space."[16] Kant then went on to claim that even a solitary hand in empty space would have a determinate identity of being a right or a left hand.

Weyl flatly refutes Kant's assertion that a solitary hand is determinate as to its particular handedness. Weyl contrasts Kant's view with Leibniz's approach arguing that, "Had God, rather than making first a left and then a right hand, started with a right hand and then formed another right hand, He would have changed the plan of the universe not in the first but in the second act, by bringing forth a hand which was equally rather than oppositely oriented to the first-created specimen."[17] In citing Leibniz's approach, Weyl is alluding to the relational nature of space that handedness expresses. Whether a hand is right or left cannot be determined by any of its own properties, but only by considering it in relation to other handed objects. Weyl goes on to argue that "scientific thinking" sides with Leibniz; "mythical thinking" subscribes to Kant's position "as is evinced by its usage of right and left as symbols for such polar opposites as good and evil."[18]

In mythic consciousness or ritual practices, the polarity of handedness is decisive to the organization of social life, as Robert Hertz first outlined in his seminal essay.[19] The two hands are almost identical and yet are accorded vastly different emphases: to the right are reserved all the values and virtues of the sacred, to the left are ascribed ideas of death, destruction and denial. The division of the entire cosmos takes places along lines of handedness - the right represents the sky, the clouds, and the heavens, the sky; left is the earth, the low, the netherworld, and so on.[20] Hertz's interest in the symbolism of right and left stemmed from an attempt to discover universals, or "near universals," of social thought and practice.

While these anthropological works are now largely forgotten, the anthropological attention to handedness in "primitive" thought indicates that the universe is set up according to a

[15] Immanuel Kant, *Critique of Pure Reason*, trans. Paul Guyer and Allen W. Wood (Cambridge; New York: Cambridge University Press, 1998).
[16] Kant, "*Concerning the Ultimate Ground of the Differentiation of Directions in Space*," [1768], in Kant, *Theoretical Philosophy, 1755-1770*., 365.
[17] Hermann Weyl, *Symmetry* (Princeton: Princeton University Press, 1952)., 21.
[18] Ibid., 22.
[19] Hertz, "*The Pre-eminence of the Right Hand: A Study in Religious Polarity*," [1909] in Needham, *Right & Left; Essays on Dual Symbolic Classification*.
[20] Ibid.

definite point of view.[21] Space is not a homogeneous whole. It is a qualitatively differentiated universe with clearly defined "regions" of above and below, inside and outside, right and left, etc which are not interchangeable since each region or direction is imbued with specific values of the sacred. The sacred provides orientation and meaning to an otherwise undifferentiated universe.[22] Durkheim invokes the *necessity of differentiation* since "to dispose things spatially there must be a possibility of placing them differently, of putting some at the right, others at the left, these above, those below, at the north of or at the south of, east or west of, etc., etc."[23]

Scientific articulation of space, on the other hand, commences with the *homogeneity* and *isotropy* of space, that is, space is the same in all locations and in all directions. Giordano Bruno was one of the first to assert unequivocally the homogeneity of the universe.[24] He put an end to the Aristotelian cosmos, each with its unique regions of up and down, or natural and violent motions.[25] Objects may be placed or shifted anywhere in space without altering any of their characteristics since the overall relations between objects remains unchanged. As Leibniz conjectured, if everything in the world were reflected East to West, retaining all the relations between bodies, the world would remain the same.[26] From this point of view, there is no fitness, no sufficient mathematical or physical reason to distinguish left from right. They form only relative, not absolute, conceptions. That is why, Buridan's ass, unable to choose between the two bales of hay kept on the right and the left, eventually starves to death!

Descartes dealt the ultimate blow and proceeded towards a thoroughgoing geometrization of space, whose essence is extension. "Extension in length, breadth and depth is what constitutes the nature of corporeal substance."[27] In defining matter solely through extension, Descartes lent support to the association of subjectivity with sense qualities (of tone, color or texture) and extension and motion being intrinsic or self-subsisting properties of objects themselves. The former are secondary in importance to the latter because in contrast to qualities, we recognize extension and motion "clear and distinct." And from this he deduced the fundamental tenet of his epistemology: truth is what we comprehend through extension.

Leibniz vehemently denied the Cartesian postulate that extension alone comprises the essence of matter. If matter were pure extension, Leibniz objected, then it would be incapable of

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[21] Ibid; Bourdieu, *Outline of a Theory of Practice*; Descola, *In the Society of Nature : A Native Ecology in Amazonia*; Mircea Eliade and Willard R. Trask, *The Sacred and the Profane : The Nature of Religion* (New York: Harcourt, Brace, 1959).
[22] The crux of the matter is the impossibility of a divorce between space and matter or between position and identity. Position is not something that can be detached from content, which leads to an intimate logic of associations connecting what an object is to what space it occupies. Ernst Cassirer, *The Philosophy of Symbolic Forms* (New Haven: Yale University Press, 1953). Volume II Mythical Thought, 84.
[23] Durkheim, *The Elementary Forms of the Religious Life*., 23.
[24] Alexandre Koyre, *From the Closed World to the Infinite Universe* (Baltimore: Johns Hopkins Press, 1957); Frances Amelia Yates, *Giordano Bruno and the Hermetic Tradition* ([Chicago: Univ. of Chicago Press, 1964).
[25] I should qualify that the distinction of "primitive" and "modern" does not work entirely. The contrast of a primitive conception of differentiated space and a modern one of homogenous space is to be found *within* scientific consciousness in Newton's advocacy of an absolute substantial space and Leibniz's assertion of space as the bearer of relations between material objects. Samuel Clarke et al., *The Leibniz-Clarke Correspondence : Together with Extracts from Newton's Principia and Opticks* (Manchester; New York: Manchester University Press ; Barnes & Noble, 1956).
[26] Ibid., 26.
[27] Descartes, *Principles of Philosophy*., 19.

grounding any dynamic feature of objects such as energy.[28] Strongly dissatisfied with Descartes' approach, which attempted to reduce dynamics to geometry and geometry to an abstract calculus of algebraic operations, Leibniz embarked, in 1679, on devising a topology based on situation rather than on metrics and magnitudes (*analysis situ*).

It was the radical initiative of Leibniz - and Euler's 1736 landmark paper titled "*The Seven Bridges of Königsberg*" - that fuelled Kant in 1768 to posit the problem of handedness as expressing an irreducibly qualitative element – of orientation. Kant put his finger on the precise problem that handedness brings to light: objects identical in shape, size and structure, cannot be spatially substituted. In other words, under a reflection, the metrical relations hold between the parts of a hand, all intrinsic properties are preserved; yet the two hands cannot be mapped onto each other. To have made a left hand, instead of a right hand, Kant argues, requires "a different action of the creative cause." This suggests another ground of determination for handed objects that is non-metric in character and invokes qualitative features of spatial configurations. The property of orientation in space is a property that is distinct from and irreducible to extension (of matter) or dimension (of space).[29]

The next step in Kant's argument – very important for its implications for anthropology - was that the ultimate ground on which orientation rests is the discerning subject. The description of an object's handedness can be arrived at only by someone confronting it. It is our awareness in feeling the discrimination of directions, mediated through our body, which is key to determining spatial orientation of objects.[30] Handedness presupposes perceiving, cognitive, corporeal beings. While scientific knowledge was increasingly reducing all sensuous distinctions to pure metric distinctions of extension and magnitude, Kant recognized that the concept of orientation resisted this reduction and re-introduces the necessity of considering quality, or form, along with magnitude or quantity. In his argument, it was by no means sufficient to investigate: What is an object? Or what is the relation between objects? The problem of handedness decisively showed that critical inquiry has to investigate a third point: What is the relation (or non-relation) between observers and objects? Kant then arrived at his famous "idealist" conception of space (and time) as *a priori* forms of sensibility given intuitively. Neither a substance, nor an attribute of a substance, space is a "form of sensibility" by means of which we organize our sensations.[31]

Since medieval scholasticism, the philosophical debate has centered on the categories of *substance* and *attribute*, with much of the discussion focusing on which is primary, with the near-total neglect of *relations*.[32] Empirical approaches tend to accord priority to substance over relations. They view relations as a creation of the mind, as unreal and groundless. For instance, Locke recognized that knowledge of relations constitutes the largest field of our knowledge but

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[28] Ibid.
[29] Kant, "*Concerning the Ultimate Ground of the Differentiation of Directions in Space*," [1768], in Kant, *Theoretical Philosophy, 1755-1770*.
[30] Ibid.
[31] Kant, *Critique of Pure Reason*.
[32] Gottlob Frege, *The Foundations of Arithmetic; a Logico-Mathematical Enquiry into the Concept of Number* (New York: Harper, 1960); Bertrand Russell and lectures Lowell Institute, *Our Knowledge of the External World as a Field for Scientific Method in Philosophy* (London, England: G. Allen & Unwin, 1926). For two thousand years, truth and logic were caught in the Scholastic frame of subject-predicate form, i.e., every proposition is about "substance" which carries "attributes." This made it impossible to admit the "reality" of relations, till Frege, Peano and Russell brought it to life in mathematical logic at the beginning of the twentieth century.

he denied them any significance in his theory of knowledge. He viewed them as "extraneous and superinduced," an artificial product of the human mind.[33] And Locke's entire theory sought the repudiation of understanding or mind in the conception of knowledge. Descartes had taken a similar but inverse route in the sense that he denied experience any formative principle but like Locke ended up positing a thoroughly dualistic universe with mind and body as two distinct and mutually exclusive substances. The problem of course is how to explain the interlocution of an immaterial, unextended, indivisible mind (*res cogitans*) with a material, extended, and divisible body (*res extensa*). Within the framework of either rationalist or empiricist thought, the problem is unsolvable in principle.

This is not a historical problem that Descartes faced in 1644 or Locke in 1690. The dualism of mind and matter is a problem in Western metaphysics and epistemology that keeps disappearing and reappearing.[34] And this problem lies at the core of the puzzle that handedness represents for us in physics: how does a concept that is by logic or necessity predicated on a relation of difference, embedded in the cognition of the subject, and the conventions of the community, be used in the formulation of purely objective knowledge? If physics presupposes the separation of mind from matter, or subject and object, then how can it base a physical universe with a preferred orientation? If it does not, then what is the meaning of handedness in its discourse?

3. Logic of a Concept: Chirality and Relativistic Quantum Mechanics

To address these questions I will review first, very briefly and simply, the formulation of handedness in relativistic quantum physics. What does a left-handed or a right-handed electron field mean? Does this characterization reflect an intrinsic property of sub-atomic matter? Here I should point out that in quantum field theory, particles have their own fields. That is, particles are regarded as excited states of a field (field quanta). A distinction is made between the force carrier particles, the "bosons" (e.g., photon, gluon, graviton, etc) and the particles of matter, the "fermions" (like the electron, quarks or the neutrinos) that make up most of the observable matter in the universe. The distinction between particles of matter and particles of electromagnetism will become salient for the discussion that follows.

As a prelude to understanding handedness in theoretical physics, we require the concept of spin. Spin is usually defined as internal angular momentum. Angular momentum is the magnitude used in physics to describe rotations, for instance, the rotation of a ball or a dancing figure. If one were to choose a point on the rotating dancer's body, this point would define a circle around the imagined axis as it is rotating, and the angular momentum informs us how fast this part of the dancer is rotating. It is reasonable to argue, however, that the rotation of an object like a ball is not an intrinsic property. For instance, the ball is not spinning when I simply leave it on the ground. However, in relativistic quantum mechanics, the idea of angular momentum is generalized to particles that are conceived to be "point-like," i.e., to something that does not take up any space, of zero dimensions. These material objects of modern physics - the point-like particles lacking in spatial extension - are said to possess *intrinsic* spin. In other words, akin to

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[33] John Locke, *An Essay Concerning Human Understanding* (Cleveland: Meridian Books, 1964)., 202.
[34] Uberoi, *The European Modernity : Science, Truth, and Method*.

mass or electric charge, spin is taken to be an intrinsic and indestructible property of all elementary particles.

The concept of intrinsic spin is a novelty of relativistic quantum mechanics. The epistemological problem underlining the concept of spin consists in generalizing the concept of angular momentum, which was intrinsically defined for extended objects in classical physics, to un-extended objects, the point-like particles, in relativistic quantum mechanics. It is reminiscent of Leibniz's attempt at working out a concept of "internal" force (*vis*) associated with every substance.[35] Recall that for Kant the problem of handedness was predicated on extended bodies, such as our hands or gloves, in three-dimensional space, where one of the gloves cannot occupy the same region of space as the other by any continuous motion like rotation. Extension-less objects surely do not have that problem. Then what is the basis to their handedness? Instead of reducing this question to a question of thing-like determinations, we should recognize in the question the conditions, which make it possible to posit such determinations. After the introduction of the concept of intrinsic spin, we can describe the rotation of elementary particles under the related notions of clockwise or anti-clockwise.

Consider the velocity of a particle. This is the everyday concept of velocity and one that can be represented by a vector indicating the direction of velocity (of the particle). When a particle spins in the direction of velocity (or counterclockwise), it is termed Right-handed. When spin and velocity are aligned in opposite directions (that is, clockwise) it is called Left-handed. Every particle has two possible ways to rotate, clockwise and anticlockwise. Since these two are physically different, the angular momentum is a different vector in each case. This description of clockwise and anti-clockwise actually refers to the concept of helicity - the projection of a particle's spin in the direction of motion. If spin is aligned the same way as the direction of motion, then the particle is said to possess positive helicity and is called right-handed; if spin and motion are oppositely aligned, the particle is assigned negative helicity, or termed left-handed.

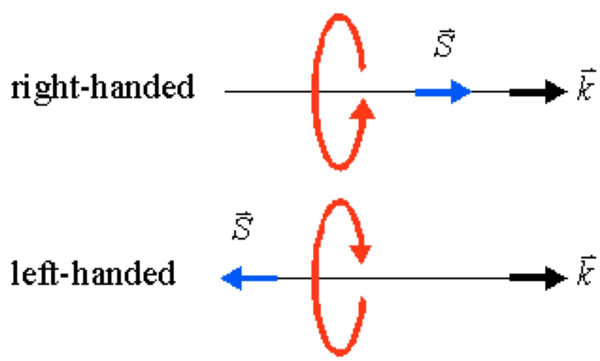

Figure 2: Particle "spin" in and against the direction of motion.

Yet I have explained only partially. The assignment of right-hand and left-hand to particle behavior is dependant on the particular definition of direction of spin, what the community terms as clockwise and anti-clockwise. It could have just as easily selected a different convention and the resulting definition of right- or left- handedness would have been different. Here the concept of spin has simply been displaced onto the notion of direction of velocity. And velocity, it will be objected, is a relational concept that depends on the observer

[35] Leibniz, "*Specimen Dynamicum,"* in Leibniz, Francks, and Woolhouse, *Philosophical Texts*.

relative to whom we are measuring that velocity. In which case handedness is not an intrinsic property of a particle. Then how can there be a measure of handedness that is intrinsic? The answer is derived from Einstein's relativity principle. In special relativity there exists a maximum velocity - the speed of light - and this velocity is the same for any observer or any frame of reference. It is not relative to any observer, but is absolute, and tied to the very structure of space-time. It is a "fundamental constant" of space-time such that no matter or information can travel faster than the speed of light.

Upon a mirror transformation, the direction of motion of every object with mass stands reversed, that is, it is seen as moving in the opposite direction. However, the direction of motion of massless objects, such as photons, or the force carrier particles of electromagnetism or light, cannot be reversed under mirror transformation. This is because massless particles are, as far as kinematical behavior is concerned, equivalent to particles of light and are moving at the speed of light. The speed of light is (a) the greatest possible speed and (b) independent of the reference frame. This is recognized as the principle of "Lorentz transformation." Once it is known that the direction of motion of massless objects cannot be reversed by a Lorentz transformation, an attempt is made to use this property to define a form of intrinsic or deterministic handedness.

Since a Lorentz transformation does not affect a massless particle's direction of motion, its helicity is absolute. It is fixed for all reference frames and stays invariant under the Lorentz group. For a massive particle, on the other hand, one could, in principle, "Lorentz boost" (change of viewpoint) by a large velocity, in the direction of the particle's motion and thus reverse its direction of motion while leaving its direction of spin intact. A massive particle has no definite chirality and looks different to different observers. This is what is meant in the physics literature when it says that the "helicity eigenstate" of a particle with mass involves both right- and left-handed components.

In essence, in relativistic quantum mechanics, handedness is defined with reference to the concepts of spin and velocity, and distributed in the twin notions of helicity and chirality.[36] Helicity comprises of spin (which is intrinsic) and velocity (which is relational). If a particle has mass, then the concept of right- or left-handed helicity is relational. If, on the contrary, a particle is massless, then left- or right-handed helicity is intrinsic and that is denoted as "chirality". The explanation is related to the deep structure of relativistic space-time. Massless particles are the only ones that move at the speed of light and in special relativity the speed of light is intrinsic and not relational. So a real observer - who must always travel at less speed than the speed of light - cannot be in a reference frame from where the particle can reverse its relative direction. Therefore all observers will see the same chirality for a massless particle. For a massless particle, right- or left-handedness is not a relational designation, but is *intrinsic* to it, and that is denoted as "chirality." To summarize:

Massive particles: Helicity = Spin (*intrinsic*) + velocity (*relational*) = *relational*;

[36] One of the chief difficulties involved in the understanding of handedness of particles/fields is the distinction of helicity and chirality. There is much that is confusing between chirality, which is deterministic and serves as the definition of orientation, and helicity, which is treated more as representing the direction of motion. Since the distinction is subtle and often easy to confuse, I have elaborated it at length.

Massless particles: Helicity = Spin (*intrinsic*) + velocity (now the velocity of light) (*intrinsic*) = *intrinsic* = Chirality

4. Evolution of a Concept: Chirality and Relativistic Quantum Mechanics

In the foregoing section I simply laid out the problematic of whether handedness is intrinsic or relative to particle-fields. Does handedness - not just the particular name or label - depend on a reference system or not? If a particle were left-handed for one observer, would another observer find the same handedness? Here I assume that all observers agree on what to denote as left and what to denote as right. Once it is decided which properties are absolute and which ones dependent on a system of reference, the principle of relativity is invoked to discern aspects of nature that are independent of the reference system.

This brings me to the notion of symmetry. Symmetry, in general, can be defined as a property that causes an object to remain *invariant* even under certain categories of *transformation*, such as, rotations, reflections, translations. If I say that the laws of physics do not change when I move to the next room, or if we lived in a mirror world, it indicates that the laws are symmetric under transformation in time and space. Lorentz transformation, mentioned in the previous section, for instance, is a fundamental symmetry of space-time. Symmetry considerations underlie some of the most profound results in modern physics.[37] When considering the role of symmetry in physics, it is worth keeping in mind two levels of the concept. One is the use of symmetry in a geometrical or physical sense. For instance, rotating an equilateral triangle by 120 degrees around its center results in complete identity. Secondly, symmetry properties may be attributed to laws, rather than to phenomena or objects. Some of the most fundamental symmetries in physics are the space-time symmetries where the laws of physics are unchanged under boosts and rotations.

In a certain sense, symmetry implies how an object may remain invariant under changes of subject.[38] This is a hint of why physics identifies symmetry as a good indication of objectivity. For example, the statement "body A has velocity V" cannot be a law of nature since for different observers in different frames, body A can have different velocities. However, the statement "the relation between force and acceleration of a body is its mass," can be a law of nature although different observers could measure different forces and different accelerations, since their ratio will be, in any reference frame, equal to the mass. Since symmetry is a sound epistemological principle to identify "objective" aspects of nature, the hope is, in the physical sciences, that once a definite symmetry is isolated, one can know what properties of a physical system are invariant or conserved.[39] The desire to generate final theories with maximal possible symmetry not only

[37] Katherine Brading and Elena Castellani, *Symmetries in Physics : Philosophical Reflections* (Cambridge, U.K.; New York: Cambridge University Press, 2003); Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*; L. V. Tarasov, *This Amazingly Symmetrical World* (Moscow: Mir Publishers, 1986).

[38] The identification of "objectivity" in the sense of conserved symmetry can be attributed to Hermann Weyl. Weyl, *Symmetry*.

[39] At the turn of the century, Emmy Noether (1882-1935) carried out groundbreaking work in connecting "conserved quantities" with observed symmetries of a physical system.

implies objectivity but also perfection, not merely a *factual* condition of what is as such, but a premise of a *value*, such that it ought to be.[40]

Handedness or chirality is an instance of a "discrete" symmetry. Discrete symmetry is another way of saying non-continuous transformations, such as a mirror reflection. The identity of laws under reflection symmetry constitutes one of the most fundamental and well-recognized symmetries of modern physics. However, their introduction in the discipline is a bit fuzzy. To understand how handedness is introduced into physics, we need to go back to the notion of intrinsic angular momentum or spin.

The situation was like this: In 1925, while working on the spectra of the hydrogen atom, its "fine structure," physicists Kronig, Uhlenbeck, and Goudsmit put forward a proposal for electron spin, a physical interpretation of particles spinning around their own axis.[41] They observed that the inclusion of spin gave a precise interpretation to the observed existence of "doublets," or pairs of closely spaced spectral lines from the hydrogen atom. Schrodinger had also been working on developing an equation that would explain the quantized energy states of the Hydrogen atom. But he failed. In the meantime, Klein and Gordon succeeded in obtaining an equation for a scalar field, but without taking into account electron spin, and so that too did not yield a prediction to the Hydrogen's fine structure. Many leading scientists at the time were working on deriving an equation that would accurately describe the hydrogen spectrum, which led Pauli to dub it as "the equation with many fathers."[42]

In 1927 Paul Dirac was attending the fifth Solvay Conference in Physics at Brussels when he was asked by Bohr what was he working on. Dirac replied that he was trying to produce a relativistic theory of the electron. Bohr told him that the theory had been worked out, referring to the work done by Klein and Gordon. Dirac disagreed and persisted. In a very short time, he produced a relativistic equation of the electron, which included the newly introduced concept of spin, and gave an accurate description of the splitting of the spectral lines of the Hydrogen atom. His quantum mechanical interpretation of Einstein's definition of energy for spin-half particle fields with a set of 4 X 4 matrices was considered a revolutionary product. Published in 1928, Dirac's work gave a theoretical meaning to chirality in terms of spin and its role in particle interactions.[43] What emerged from Dirac's work was how chirality was initially put forward as a mathematical formalism - the "gamma 5 matrices" - as a necessary consequence of marrying quantum mechanics with special relativity.

A year after Dirac's expression of the relativistic wave equation for the electron, Hermann Weyl observed that if one could formally imagine the mass of the electron to be zero,

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[40] Eugene Paul Wigner, *Symmetries and Reflections; Scientific Essays of Eugene P. Wigner* (Bloomington: Indiana University Press, 1967).

[41] The "fine structure" of the Hydrogen atom refers to the splitting of the spectral lines. The hydrogen atom has special significance in quantum mechanics, especially in the pattern of lines of the hydrogen spectrum.

[42] Jagdish Mehra and Helmut Rechenberg, *The Completion of Quantum Mechanics, 1926-1941* (New York: Springer, 2000).

[43] Incidentally, the Dirac paper is today more famously remembered for its prediction of the existence of anti-matter, which was confirmed four years later with the physical discovery of the positron – same mass and same lifetime as an electron but with an opposite electric charge (+1).

the four-component Dirac equation decouples or splits into two independent equations.[44] By taking the zero mass limit of the electron, he got two decoupled equations for the massless electron, the "left-handed" and the "right-handed" Weyl spinors.[45] Splitting the wave function into these different components was not self-evident immediately; calling them right or left also did not signify anything. There was no motivation for doing this from any experiment, or from nature or from any reflection on nature. It was motivated purely by the algebra of matrices. What Weyl's work accomplished was to connect the chiral components with spinors and the deep structure of space-time, and in the process, he raised the all-important question of origin of mass in relativistic quantum physics.

One of the most vital and yet unanswered questions in physics is the origin of mass in the universe. How does a particle acquire a (certain) mass? Without mass, the universe would be a chaotic sea of particles flying at the speed of light. The problem of mass generation in relativistic quantum mechanics comes down to finding a dynamical mechanism of marriage between right-handed and left-handed constituents of elementary particles. This is part of the famous "Higgs" physics - the Higgs mechanism of spontaneous symmetry breaking – which the experiments on the Large Hadron Collider are set to probe. If the Higgs vacuum expectation value is zero, we remain in a chiral and massless world. If the Higgs vacuum expectation value is non-zero, we get an effective right-left interaction, and land in our real, non-chiral world. It is this asymmetry, which makes understanding the problem of generation of mass, or the origin of matter, and the search for the Higgs particle, dubbed as the "God" particle, so momentous.

Here a purely theoretical formulation can lead us no further. Experimental particle physics provides us with the content through which the concept of handedness reveals not only what it *signifies*, but also what it *achieves*. Now we shall observe a decisive shift from chirality to parity, or from a question of simple difference to a radical asymmetry or polarity. The chiral representation of the gamma matrices given by Weyl becomes significant after it was experimentally established that only one of the two chiralities couples to the Weak force. This occurred years later. Without this observation from experiment, right- or left-handedness would remain a mathematical formalism without any physical significance. Instead of calling them right and left, had Weyl opted to call them black and white, it would have made little difference to the definition. What makes the definition or the terms of handedness substantial is the discovery of radical asymmetry or polarity of the terms.

Before moving onto the transition of handedness as a matter of a simple difference to a radical asymmetry, let me quickly state its relevance for anthropology. What I wish to evidence for anthropology is the singular point that without relations of difference and otherness, even a concept of physics does not acquire form, at least in a few rare instances as the concept of handedness shows us. It is to Durkheim's originality that we owe the significance of difference for a theory of knowledge.[46] The fact of contrast is universal for social morphology and thought. Symbol and reality open up only to the law of differentiation and unity. Durkheim's insight was taken up by Robert Hertz. In brilliant and compelling words, Hertz poses, "How could man's

[44] Hermann Weyl, "Gravitation and the Electron," *Proceedings of the National Academy of Sciences of the United States of America* 15, no. 4 (1929).
[45] Spinors are three-dimensional vectors whose components are "complex" numbers. Spinors have interesting properties that make them very handy in describing rotations, spin, etc.
[46] Durkheim, *The Elementary Forms of the Religious Life*.

body, the microcosm, escape the law of polarity which governs everything."[47] A few lines later he responds, "If organic asymmetry had not existed, it would have had to be invented!"[48]

Once this insight is embraced and recognition made that a relation of polarity is absolutely central to any question of cosmology, then all views of knowledge that proceed unhealthily or one-sidedly either by isolation and reduction into parts (mechanism), or by aggregation of parts into a whole (organicism), lose their validity and meaning. Instead they can be replaced by the method of differentiation and unity (dialectics). And now the last decisive step is taken: the most fundamental unit in the macrocosm, matter, discovers its essence in polarity - and at the same time - its unity with the mind. We are told, with hard experimental evidence, that the laws of physics treat fundamentally differently objects of opposite handedness. The final section will take up how a pure difference (chirality), as initially articulated in theory, is transformed into an experimentally observed asymmetry (violation of parity).

5. Parity Violation: Substance and Relation

Just to summarize, so far the discussion has framed the issue of handedness in the twin concepts of helicity and chirality, or motion and spin. Helicity is defined in terms of spin and its projection in the direction of motion. For massless particles, helicity and chirality are defined as being intrinsic, whereas for particles with mass, helicity is a relational attribute. This move is itself allowed when relational aspects are dubbed as "relativistic" that implies the presence of an observer or a reference frame, which from the perspective of modern physics could be isolated as a set of rulers and clocks. However, to displace the observer is not to dissolve it, for the mind of the observer is critical to the definition of orientation categories. So the problem persists: the act of defining any helicity, right or left, cannot be done without consciously choosing a particular orientation in space. Therefore, to sustain the argument of handedness as a meaningful concept in physics one must either assert that orientation of right and left is purely relative, therefore arbitrary, or it is intrinsic and determinate, and belongs to the order of things. I will examine this now with reference to the experimentally observed violation of parity in 1957.

Parity deals with the issue of how sub-atomic particles behave if the spatial configuration is changed under a reflection. Spatial inversion is one where a physical object or a process is described by a new set of coordinates that are just the negatives of the original set (x goes to $-x$, y goes to $-y$, and z goes to $-z$). Preserving parity implies that in replacing right-handed systems with left-handed ones, the result of a fundamental experiment will not change. While in classical physics, all known forces were acknowledged as preserving parity, in the 1950s a suspicion was raised whether it was positively known, if the "weak" force, one of the four fundamental forces of nature, the other three being gravitation, electromagnetism and strong interactions, preserve parity.[49]

Post-war physics received a boost from the particle accelerators being set up in laboratories at Berkeley (bevatron), Brookhaven (cosmotron), Birmingham (synchrotron), and

[47] Hertz, "*The Pre-eminence of the Right Hand: A Study in Religious Polarity*," [1909] in Needham, *Right & Left; Essays on Dual Symbolic Classification*., 10.
[48] Ibid. 10.
[49] The weak force is responsible for the disintegration and decay of matter such as radioactive particles.

CERN (proton synchrotron), in order to probe more deeply into the structure of matter. A plethora of sub-atomic particles was blasted out. The new particles also brought new problems. One such problem was the Tau-Theta ("τ-θ") puzzle, the seemingly indistinguishable K-mesons, which nonetheless decayed differently.[50] In 1949 Cecil Powell identified a cosmic ray particle that he dubbed the Tau meson. Another particle called the Theta meson was discovered in quick succession. The problem arose when the masses and the lifetimes of the Tau and Theta particles were considered. Every bit of evidence suggested that they were identical except their modes of decay: the Tau decayed into three Pions and the Theta into two. Yet the products of the two decays implied that the original particles had to be different. A number of experimental tests were carried out measuring the masses, lifetimes, branching ratios, production cross-section, and scattering properties, that would explain the tau-theta difference, but the results repeatedly came up with no differences.

In 1953 the physicist Richard Dalitz, famous as the creator of the "Dalitz plot," suggested that if conservation of parity holds, the Theta should have a parity of +1, and the Tau of -1, and they could not be the same particle. The clear difference of parity would explain their difference in decay modes. But to invoke a difference in parity for two particles identical in every other respect seemed poor practice. The way out of the predicament was provided by an innocuous question at a conference, which entailed significant unintended consequences. At the Rochester Conference in February 1956, Richard Feynman, at the behest of Martin Block, raised the question, "How do we know positively that weak interactions conserve parity?" To raise a question on the failure of invariance with respect to parity was a daring question because at the time parity conservation was an established credo, an *a priori* law of nature.

A few weeks after the conference, T.D. Lee, of Columbia University, and C.N. Yang from Brookhaven National Laboratory, got together and pondered over the problem. On June 22, 1956, Lee and Yang submitted a paper to the Physical Review journal titled, "Is Parity Conserved in Weak Interactions?" The editor of the journal, Samuel Goudsmit, protested against the use of question mark in the title! So the paper was published as "Question of Parity Conservation in Weak Interactions."[51] In this paper, Lee and Yang boldly argued that there was experimental evidence for parity conservation in strong and electromagnetic interactions, but no experimental evidence was available either confirming or refuting parity invariance in the weak interactions. They proposed two different solutions: one, that particles perhaps exist as "parity doublets," and secondly, much more revolutionary than the first, that the cherished conservation principle of parity may after all be violated in the weak interactions. To check they proposed a number of experimental tests, which would unequivocally determine if the weak interactions discriminate between right-handed and left-handed interactions in decay modes.

In a difficult and noteworthy experiment, assembled and performed by Madame Wu, at the Cryogenics Physics Laboratory at the National Bureau of Standards in Washington, involving nuclear radioactive decay of cobalt atoms, or "beta decay", the results strangely

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[50] Allan Franklin, *The Neglect of Experiment* (Cambridge [Cambridgeshire]; New York: Cambridge University Press, 1986).

[51] T.D. and C.N. Yang Lee, "Question of Parity Conservation in Weak Interactions," *Physical Review* 104(1956); A.K. Wroblewski, "The Downfall of Parity: The Revolution That Happened Fifty Years Ago," *Acta Physica Polonica* 39 no. 2 (2008). T.D. Lee colloquium at CERN, August 30 2007, "Symmetry and Asymmetry in Electro-weak Interaction: 50 Years after the Discovery of Parity Nonconservation."

showed that more electrons were emitted along the direction of nuclear spin than in the opposite direction. Conservation of parity demanded that the emitted electrons be equally distributed. The asymmetrical emergence of particles in one direction rather than the other, i.e., "anisotropy" in cobalt decay conclusively established handedness in the laws of nature. Two other experiments were performed almost at the same time, which confirmed Madame Wu's findings, and fetched for T.D. Lee and C.N. Yang the 1957 Nobel Prize "for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles."[52]

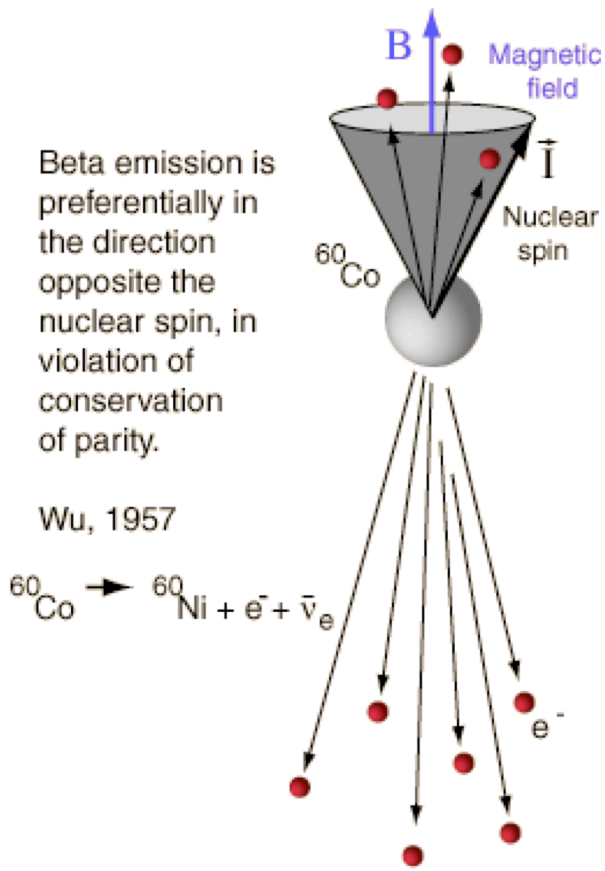

Figure 3: Diagrammatic representation of cobalt decay that established the "fact" of parity violation.

Parity violation was a major upset for the scientific community. Why does nature rebel against the symmetry of right and left? On hearing the news of parity violation, the indomitable Pauli dispatched a letter to Victor Weiskopf saying, "I do not believe that the Lord is a weak left-hander." Physicists even to this day express shock and disbelief in seeing the fall of a cherished and fundamental symmetry of physics. This is where the "disturbing character" of handedness surfaces, in the words of one of my informants, Raymond Stora, a distinguished mathematical physicist. Until the discovery of parity violation, it was held that there is nothing essential or intrinsic to a particle that makes it right- or left-handed, and the laws of nature would work the same way in the mirror-world as they do in the real world. In the absence of CP violation, there would be no way to distinguish left-handed physical processes from right-handed ones. After

[52] http://nobelprize.org/nobel_prizes/physics/laureates/1957/

parity violation, the difference in right or left is no more a case of arbitrary or conventional designation, but is absolute, grounded and substantial.[53] The discovery of CP violation recognizes the grounding of *conventions* of handedness into matters of *fact*.

Now that the difference of right and left has become a substantial or an asymmetrical difference, it is possible to give an "objective" definition of terms of handedness. Feynman made the famous argument that if we were in two-way contact with some alien species, but only through telegraph, i.e., light flashes or radio signals, we could tell the alien species how tall we are by expressing our height in mutually understood wavelengths of light. We could even describe to the alien how old we are as some number of ticks of a light-frequency clock. But if we wanted to shake hands and wanted to describe our right hand, we wouldn't be able to do so. Without sharing a handed object in common, we cannot describe what is right or left to them.[54] "Wait a moment!" says the alien. "What do you mean by 'right'?" Until 1957, there was no possibility of answering the question in a definite way. But now we can – simply by asking the alien species to carry out experiments with neutral kaon decays. If the distant civilization can produce in their laboratory long lived neutral kaons, they can distinguish unequivocally right from left observing the decay products. What seemed previously a difference established solely on the basis of human conventions now has the support from microscopic matter and unalterable laws of nature. [55] Parity violation has decisively solved the problem of communicating right and left, or the "Ozma problem."

A few years later, in 1964, neutral Kaon decays showed that weak interactions violate not only Parity (P) and the Charge-conjugation (C) symmetry, between particles and antiparticles, but also their combination (CP violation). As a consequence of parity violation, in weak interactions the couplings of the fermions to the vector bosons, W and Z, are dependent on their handedness or helicity. The $W^{\pm}$ couples only to left-handed (negative-helicity) fermions and right-handed (positive-helicity) anti-fermions. The Z couples to both left- and right-handed fermions, but with a different coupling constant in each case. The more striking illustration of parity violation is the case of the neutrino (and the anti-neutrino): nearly massless neutrinos with an intrinsic spin of ½, show a fixed left-handedness, that is their angular momentum always points in the direction opposite to its motion, whereas the anti-neutrinos always show up in the right-handed form. Performing a mirror transformation on the left-handed neutrino, would yield nothing because there are no right-handed neutrinos to flip into the left-handed one. This is a reason why neutrinos are said to be like vampires: they do not cast a mirror image!

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[53] Earman, *World Enough and Space-Time : Absolute Versus Relational Theories of Space and Time*; Gardner, *The New Ambidextrous Universe : Symmetry and Asymmetry from Mirror Reflections to Superstrings*.

[54] This is what Martin Gardener had identified as the "Ozma problem." Gardner, *The New Ambidextrous Universe : Symmetry and Asymmetry from Mirror Reflections to Superstrings*; Feynman, *The Character of Physical Law*.

[55] There is some contestation, however, as to whether differential handedness exhibited in electro-weak interactions is truly a reflection of a law of nature. Perhaps handedness is a reflection more appropriately of the system of co-ordinates chosen. "It turns out that the mathematics of parity violation does not involve treating being left-handed and being right-handed as different substantive and intrinsic properties…Left and right components of the fields are distinguished in terms of their differing congruence relations to the right-handed coordinate systems with respect to which the theory is standardly written." Pooley, "*Handedness, Parity Violation and the Reality of Space*," in Brading and Castellani, *Symmetries in Physics : Philosophical Reflections*., 267. The paradox resolves into one of terminology, but the tension - of how a purely relational attribute of handedness transforms into an asymmetry - persists.

The discovery of parity violation led to the consolidation of the chiral "V-A" structure of weak interactions, which yielded a two-component theory of left-handed neutrinos and it is CP invariant. Shortly thereafter, in 1967, it was pointed out by Andrei Sakharov that CP violation is no ordinary, isolated occurrence in bits of matter, but is a formative condition of the universe. It plays a fundamental role in the genesis of all matter, or "baryogenesis." Recall that the Dirac equation had predicted, as part of emerging relativistic quantum mechanics, the existence of anti-particles along with corresponding particles. Yet in the universe we do not find equal amounts of matter and anti-matter. If it were so, I would be annihilated by now producing a bunch of photons. So while at the microscopic level, matter and antimatter are always created together in 1:1 correspondence; in our universe there exists a conspicuous surplus of matter, of which our surroundings and we are made, over anti-matter. How did this happen?

Sakharov proposed that the observed asymmetry of matter and anti-matter in the universe is owing to CP violating effects found at the microscopic level. The universe was originally perfectly symmetric, but a set of phenomena contributed to the destruction of the initial symmetry of mater and anti-matter. For instance, B-mesons in the early universe might have decayed preferentially into protons rather than antiprotons, leading to the present day dominance of matter. Dedicated experiments at CERN (Switzerland), SLAC (Stanford) and KEK (Japan) are investigating precisely the problem of how handedness is related to the origin of the mass or matter in the universe. In order to posit the problem of the dynamical origin of mass, what is required is some intrinsic difference between massless and massive particles and this intrinsic difference is mediated by a concept as roving and elusive as differential handedness. It affirms a key lesson for anthropology: the strands that govern the innermost recesses of matter and which join it with the cosmos must pass through the human intermediary. Here the bond between concept and reality crafts a new direction, a new norm, for discourse, and one very significant for cosmology: the universe is not made by construction – disparate elements, combining together, and producing patterns, nor by deduction – a seamless whole breaking down into individual parts of decreasing complexity. By segmentation and differentiation, the universe is classified and known.[56]

The polarity of handedness dominates the universe of primitive people,[57] and in modern physics as well we find its decisive imprint.[58] In making this comparison, I do not wish to place the emphasis on the parallels of tradition and modernity, or religion and rationality. It is not my intent to explore or exploit holistic, epochal, oppositions across domains. The aim is more delicate. The exploration of handedness has been carried out with the intent of recognizing how "thought is the central organizing activity of cosmology."[59] To most physicists it seems an unnecessary excursion to attempt any reflection on scientific categories and concepts. They are bewildered at the suggestion of any further probe. "How can a philosopher or anthropologist teach a physicist more about space or time?" Wolfgang Lerche, a string theorist, remarked. They vehemently deny the prospects of any such examination. Much of my ethnographic encounter has been an effort to confront their disciplinary condemnation.

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[56] Douglas, *Implicit Meanings : Selected Essays in Anthropology*; Dumont, *Homo Hierarchicus; an Essay on the Caste System*; Levi-Strauss, *The Savage Mind*; Uberoi, *The Other Mind of Europe : Goethe as a Scientist*.
[57] Hertz *The Pre-eminence of the Right Hand: A Study in Religious Polarity*," [1909] in Needham, *Right & Left; Essays on Dual Symbolic Classification*.
[58] Feynman, *The Character of Physical Law*.
[59] Douglas, *Implicit Meanings : Essays in Anthropology*., 122.

I am not seeking to interrogate physicists' findings but simply trying to understand how much is explained by the findings and how much by the initial premises or the presuppositions. Every inquiry in physics, however radical and revolutionary, proceeds from and ends with the same professed heterogeneity and separation of mind and matter, or subject and object. The pre-eminence of matter, in the form of extension and motion, which we are able to perceive "clear and distinct," as opposed to the secondary qualities, has continued to embellish each and every aspect in physics. During my research, it was impressed upon me over and over again that concepts of physics express "essential," or self-subsisting, properties of objects. Indeed, concepts like mass, energy, momentum, etc provide little indication of human subjectivity. In the case of a concept of orientation, however, cognition (of the subject) and conventions (of the community) constitute its preconditions. To embrace and internalize such an antithetical concept, as a "fact," is exceptional for modern physics.

The problem of handedness yields conclusions, not trivial ones on the relation of theory and experiment in physics,[60] or the geometry of space in philosophy,[61] but on the origin of the universe (cosmology), the place of the observer (metaphysics), and principles of knowledge (epistemology). The asymmetry of handedness provides us with an astonishingly fertile ground to interrogate the claim of science on the chasm existing between thought and thing, symbol and reality, intention and cause, or mind and nature. Modern science has progressively striven to invalidate the subject and the mind. Yet it cannot annul them. The subject may be suppressed, but not abolished. Here we come to the end of skepticism, for the conventions that physics sought to deny as extraneous are now part of the very essence of matter. It teaches us "how deep are conventions."[62]

The concept of handedness underscores in a precise way the mind and its symbolic operations participate in the natural world. In his brilliant essay, "*Do Dual Organizations Exist*?" Levi-Strauss takes us on a tour of the Bororo village structure. The village is marked by an *east-west* axis, which divides it into two moieties and four clans, and a *north-south* axis, which splits up the eight clans of the two moieties into three endogamous classes. This division itself sits uneasily with several complex concentric and diametric structures such as male/female, scared/profane, wild/domestic, all of which mediate various aspects of social organization such as residence, marriage, ceremonial life, etc. If one survives this rather abstruse part of the essay, one is rewarded immeasurably, for towards the end, Levi-Strauss suddenly inquires: What is the function of the north-south axis in the Bororo social structure? It was not given any conspicuous function or explanation by the natives. He suggests that the north-south axis might be characterized by *zero value* – i.e., certain "institutions have no intrinsic property other than that of establishing the necessary preconditions for the existence of the social system to which they belong."[63] The tantalizing response is that the north-south axis has no function, "except that of permitting Bororo society to exist."[64] In the discourse of science, the humble concept of handedness has little function - except it permits the universe to come into existence.

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[60] Franklin, *The Neglect of Experiment*.
[61] Earman, *World Enough and Space-Time : Absolute Versus Relational Theories of Space and Time*.
[62] Ludwig Wittgenstein et al., *Remarks on the Foundations of Mathematics* (Cambridge: Mass, M.I.T. Press, 1967)., §74.
[63] Levi-Strauss, *Structural Anthropology*., 159.
[64] Ibid., 159.

Conclusion

Physics occupies a privileged position among the "hard sciences." It is not a physical science like any other, but, rather, one in which by far the greatest progress in mathematical elaboration and empirical method has been made. Its strength is this synthesis of the conceptual and the empirical. Chirality, or handedness is an expression of this strength. It is a concept of symmetry, characterized by a structure in which three factors are principal: (a) an object (*phenomenon*) under consideration, (b) its image formed under reflection (*transformation*) and (c) the conservation of its identity even after the transformation (*invariance*). The invariance may be purely geometrical like the conservation of geometrical shape upon reflection, e.g., the two hands. But it may be more substantial than simple geometry, like the conservation of dynamical properties, such as parity. In quantum physics, gauge symmetry principles are used to describe the transformations. These physically translate into constraints of probability distribution of possible outcomes that can be measured experimentally, like the rates of decay of various particle interactions.

In the last fifty years, particle physics has been faced with a reexamination of some of its most fundamental assumptions. The fall of parity, in particular, has important implications on the conceptualization of space-time and the origin of mass or matter in the universe. With parity violation, the nature of difference between right and left is grounded, substantial and absolute. Physics finds in this an absurdity of nature. The violation of parity subverts the physicist's vision of "a chilling impersonality" to the universe.[65] As a concept that presupposes the subject in the conception of the objective world, handedness seems curiously placed at the forefront of a science whose avowed aim is not human self-knowledge, but knowledge of physical reality independently of human presence.

In classical anthropology, the *dualism* of right and left is a striking illustration of the *unity* that that mind, body, community and cosmos form. For Hertz, nothing seems more paradoxical than the ascription of vastly different values to almost identically constituted objects such as our hands. The difference rests purely on grounds of conventions and customs, which links in an elaborate logic of symbolic classification every aspect of the cosmos with the fundamental polarity of handedness. My examination of the evidence of asymmetry of right and left from particle interactions finds the same correlation between the universe, the human mind and the conventions of the community that today's physics and physicists deny.

There are forms of systematic thoughts in the world, even as rigorous as physics, which cannot see their own boundaries. Anthropological reflection is critical in highlighting the premises that inform scientific outcomes. In this endeavor, it is inspiring to have a concept as robust as handedness that serves to undermine entrenched antinomies of modern thought. Extension, solidity, or motion, expressible in clear-cut magnitudes, defines scientific status. It was Kant's genius to highlight that orientation, as a problem in topology, overwhelmingly demonstrates the inadequacy of metric measures and magnitudes. More profoundly, handedness illustrates the predicament of the polarity *and* relation of microcosm and macrocosm or mind and the world, which a purely positivist science is unable to account for.

[65] Steven Weinberg, *Dreams of a Final Theory* (New York: Pantheon Books, 1992)., 245.

Chapter Three: Semiotics of the Sub-nuclear

The Lord whose oracle is at Delphi neither reveals nor conceals, but announces by a sign.

Heraclitus

Experimental physics confronts us with the givenness of things. It is what gives science its enduring concreteness. Cesar Gomez, a theoretical physicist and one of my rare insightful informants, said "physicists are Platonist only in credo. In actuality they profess an absolute trust in the reality of things." Under what conditions does experiment disclose this reality? I examine this question by way of the commonly used term *signature* among particle physics. Events produced in the debris of experimentally induced particle collisions, like a Higgs boson[1] decaying into two energetic photons, are termed signatures and constitute the unit of discovery in particle physics.

Fundamental to the generation of signatures is the *instrument*. The Large Hadron Collider (LHC) at CERN (Conseil Européen pour la Recherche Nucléaire), Switzerland, is the latest instrument generating experimental signatures. In March 2010, fourteen years after it was approved, the LHC started its experimental run of proton-to-proton collisions as a probe into the structure of matter and forces of nature. In a 27-kilometer underground tunnel, two proton beams at 7 Teraelectron Volt (TeV) of energy each are accelerated in opposite directions to induce collisions. At four points the beams are made to collide against each other. Each of these points forms the site of a distinct experiment whose goal is to find interesting "signatures" from the debris of collisions in order to "achieve robust and redundant physics measurements."[2]

Is it not a little paradoxical to approach things through signs, or the material through the mental? In positivistic thought nothing is more radical than the opposition of signs to things. Things are concrete, exemplified by a materiality, or, to use Hegel's word, immediacy, whereas signs are pure values, arbitrarily generated and differentially interpreted, as Saussure argued. The predicament of the signature is that it is a thing and a sign or a fact and a value at once. The LHC sees about 600 million proton-to-proton collisions per second. But the bare fact of a collision tells us nothing simply because it means nothing. The collision is made meaningful through the mediation of the sign, the signal. In the discrimination of a signal from the debris of collisions, the conceptual means of determination are not subsequently added to a pre-existing "brute fact." Nor is the signal a self-evident purposeful feature of a collision. Only the physicists' recognition gives it purpose and meaning. The unity of fact and value is intrinsic and executed in a single stroke: existence of a collision (fact or thing) with the attribution of meaning as a signal of discovery (value or sign) brings the physics signature into form.

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[1] The "Higgs boson" refers to the only remaining Standard Model particle yet to be observed. The Standard Model is a theoretical explanation of *fundamental forces* interacting between *elementary particles*. It is celebrated as the crowning achievement of twentieth century physics.

[2] ATLAS, "Technical Proposal," (1994)., 1.

Underlying the investigation is the aim to raise the signature from the interstices of the dichotomy between signs and things as an autonomous and subversive element in a semiotic triad. Emergent scientific projects compel our attention to forms of reasoning, everyday practices and ideological underpinnings that sustain large-scale, global collaborations. Most theoretical and ethnographic undertakings attentive to these projects stress the interconnections – rather than the separation – of categories.[3] They defiantly expose the contribution of values to factual evaluations,[4] the use of metaphors and analogies in pure science formulations,[5] or the entanglement of material-semiotic intermediaries in experimentation.[6] The overwhelming need to forge connections between humans and non-humans has led to the creation of novel non-dichotomous concepts such as "cyborgs," "hybrids" and "assemblages"[7] in re-thinking much of the work accomplished in the natural sciences. Varied in their focus, what the approaches have in common is the spotlight on the emergence of objects, how they take on fluid avatars and enter new assemblages. The connections linking heterogeneous objects and practices of science are principally observed to follow a logic of instrumentality and contingency. "The dominant (if not unique) mode of rationality guiding the life sciences today is instrumental."[8] Moving away from "the imaginary desire of historical narration for coherence, integrity, totality, and closure,…we are currently witnessing a lively debate concerning the contingent, contaminated, local and situated making of science."[9]

A critical analysis of modern techno-science, however, remains incomplete if we grasp the element of correspondence between nature and culture, or human and non-human, only in contingent practices or instrumental action. It remains one-sided because the strength of the relation derives not from within, but must be sought from the outside – the context – in the contingency of motivations that are at most provisional or "partial."[10] The problem most intriguing to me is the question found in Durkheim's framework namely, (a) how *concepts* are forms of symbolic classification and (b) what gives them their *necessary* or compulsive character. The importance of conceptual associations is "not to facilitate action, but to advance understanding….The Australian does not divide the universe between the totems of his tribe with a view to regulating his conduct or even to justify his practice, it is because, the idea of the totem being cardinal for him, he is under a necessity to place everything that he knows in relation to it."[11]

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[3] Barad, *Meeting the Universe Halfway : Quantum Physics and the Entanglement of Matter and Meaning*; Latour, *We Have Never Been Modern*.
[4] Michael Polanyi, *Personal Knowledge; Towards a Post-Critical Philosophy* (Chicago: University of Chicago Press, 1958); Hilary Putnam, *Ethics without Ontology* (Cambridge, Mass.: Harvard University Press, 2004).
[5] D. Bloor, "Durkheim and Mauss Revisited: Classification and the Sociology of Knowledge," *Studies in History and Philosophy of Science* 13, no. 4 (1982); Hesse, *The Structure of Scientific Inference*.
[6] Bruno Latour and Steve Woolgar, *Laboratory Life : The Social Construction of Scientific Facts* (Beverly Hills: Sage Publications, 1979); Steven Shapin, Simon Schaffer, and Thomas Hobbes, *Leviathan and the Air-Pump : Hobbes, Boyle, and the Experimental Life : Including a Translation of Thomas Hobbes, Dialogus Physicus De Natura Aeris by Simon Schaffer* (Princeton, N.J.: Princeton University Press, 1985).
[7] Haraway, *Simians, Cyborgs, and Women : The Reinvention of Nature*; Latour, *We Have Never Been Modern*; Rabinow, *Anthropos Today : Reflections on Modern Equipment*.
[8] G. & P. Rabinow Bennett, "Invitation: Synthetic Biology and Human Practices: A Problem,"(2008), http://cnx.org/content/m18812/latest/., 2.
[9] Rheinberger, *Toward a History of Epistemic Things : Synthesizing Proteins in the Test Tube*.,140.
[10] Marilyn Strathern, *Partial Connections* (Savage, Md.: Rowman & Littlefield Publishers, 1991).
[11] Durkheim and Mauss, *Primitive Classification*., 81-82.

Two and a half years of continuous ethnographic research, based on intensive participant-observation at CERN, leads me to affirm, on the one hand, the dichotomy of fact and value as a "total social fact" of scientific thought and conduct and, on the other hand, discover a puzzling concept of experimental physics that subverts this dichotomy and instead recalls its necessary unity. My argument is that the signature of physics is a necessary *unity of conception*. The unity of sign and thing is *not extraneously* forged through literary metaphors or pictorial analogies. An assorted mix of heterogeneous elements is *not contingently* assembled under the heading of a signature. Operating by means of conceptual interrelations, it organizes individual features under a "form." Not simply the charged tracks of electrons or the kinematics of decays of two photons, examining the form alone allows us to raise the question how do these constitute an integral taxonomy of signatures. Here both elements – fact and value – are so completely taken up into each other that, although admittedly they can be identified as different in reflection, they participate intrinsically together.[12]

What is the anthropological significance of my insistence on observing a distinction between a unity and a hybrid or an assemblage? The problem that confronts us while dealing with the hard sciences is that while mixtures or hybrids of humans and non-humans abound in their *practices,* few of their *concepts* give any indication of human presence, and which constitutes their strength.[13] Here we reach the constitutive limits of Latour or Haraway's claims of the "implosion" or proliferation of hybrids pervading the modern sciences.[14] It is to the strength of my fieldwork that I draw your attention to the notion of signatures flourishing in the most "exact" of post-Enlightenment science, when "the concept of signature disappears from Western science with the advent of the Enlightenment."[15] For no matter how one may judge its final contribution in the discourse of physics, its form is unmistakably rooted in a stratum of undivided concrescence where the opposition of fact and value, thing and sign, meaning and reference dissolves.

But more than it dazzles, the signature compels anthropological attention to the subject. What Peirce said for signs - they "address somebody" – is true of the physics signature. The signal is real – and this is absolutely crucial - not because it is materially present deriving from physical processes of collision. It is real because the physicist recognizes or receives it. Not like

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[12] A way to comprehend the notion of a unity is to consider it as form or principle. The principle of symmetry, for instance, defined as invariance under classes of transformation, is not a combination or a hybrid of a little bit of invariance and a little bit of transformation. It is a form that abstracts events or categories, which manifest a relation of invariance even while undergoing a transformation.

[13] In order to address the problem of subjectivity or objectivity in science we should distinguish two aspects of it. On the one hand, concepts are tools, which we use to understand nature. This trivial fact, however, does not imply that the meaning of a concept is subjective in the sense that it refers to properties that are subject-dependent. On the contrary, the concepts of physics are designed to be objective in the sense that they identify aspects of reality that are independent of the observer. It is one thing to say that we have chopped reality in certain pieces, like mountains, rivers, electrons, virus, etc, which *are* a human construction, dependent on our perceptual abilities and our pragmatic needs. But it is absurd to deduce from this that a mountain or an electron, for instance, expresses subjective features. This character of objectivity is true of all concepts in physics including those of quantum mechanics. Actually quantum mechanics reinforces the point of objectivity as evidenced in the rising trend of considering even "information" as an objective feature of nature.

[14] Donna Jeanne Haraway, *Modestwitness@Secondmillennium.Femalemanmeetsoncomouse : Feminism and Technoscience* (New York: Routledge, 1997).

[15] Giorgio Agamben, *The Signature of All Things : On Method*, trans. Luca detrans D'Isanto and Kevin Attell (New York; Cambridge, Mass.: Zone Books ; Distributed by the MIT Press, 2009).,68.

anything that science can describe, the physics signature revels in being itself (thing) and something other than itself (sign), and this bipolar orientation shifts modern metaphysics to a new light.

The signatures constitute the conditions for, not the consequences of, an experimental science. Through the specific instance of the physics signature, I propose to offer a paradigmatic formulation of the non-dualism of thing and sign, which forms the critical foundation on which experimental reality rests. To sustain the argument, I will show that the sign is necessary for the *conception* of things, and not just their *interpretation*. In proposition 5.53 of the *Tractatus*, Wittgenstein remarks that the identity of objects is expressed by the identity of signs.[16] What a thing is can be known only through signs. The grounding of the thing in the order of the sign, as given by the community, however, does not enervate the objective character of the signature. On the contrary, when things function as signs and we lose sight of their particular attributes, their individual concretion or reality opens up to the certainty of knowledge. Truth constitutes itself in this act of transgression of reality.

The chapter explores the mutual engagement of the symbol and the instrument, or the material and the mental, in the notion of the signature, and how it anchors the indisputable reality of nature. My ethnographic attention dovetails on Rabinow's "concept-centered" approach. Instead of a narrative or a description, I present an argument structured as follows: I start by laying out the material culture of the laboratory and the process by which experimental signatures are produced as meaningful entities. This involves paying attention to the technical competence and judgment that experimentalists bring to bear on the constitution of signatures. Next, I analyze how their import or significance is established. At this juncture I come to the core of what I seek to inquire: to dissect the internal unity of the signature from the point of view of its adequacy or efficacy. This is followed by a critical assessment of the signature in the light of the general theory of signs or semiotics. How relevant are formal theories of Saussure or Pierce in considering natural signs? Notwithstanding powerful critiques stipulating the demise of grandiose meta-narratives such as truth,[17] the last section takes up the concept of truth, which I believe is vital to any inquiry evaluating a claim in the field of knowledge.

1. Material Culture of the Laboratory

Amidst much fanfare and publicity on 10th September, 2008 at 10:28 a.m. the first beam in the Large Hadron Collider (LHC) went into circulation. It was a singular beam, sent at the injection energy of 450 Gigaelectron Volt (GeV), which was steered around the full 27 kilometers of the accelerator. The exercise was largely an opportunity for engineers and experimentalists to check the field-strength control of the "dipole" magnets (that keep the protons on a circular path), the "quadrapole" magnets (the focusing magnets that keep the protons from diverging), and the synchronization of the detectors with the accelerator. Although there were no collisions, the event of the first beam generated considerable excitement and crowds of physicists stood glued to screens watching the first LHC beam go around. A little later, at lunch, I ran into Michael Doser, an anti-matter experimentalist and deputy director,

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[16] Wittgenstein, *Tractatus Logico-Philosophicus*.
[17] Richard Rorty, *Philosophy and the Mirror of Nature* (Princeton: Princeton University Press, 1979).

CERN Physics division. He asked me sarcastically, “So how does the first step in the social construction of the Higgs look?”

Michael’s provocative comment was meant to indicate the spuriousness of the claim of construction of nature when faced with its tangible materiality. Like most particle physicists, Michael was aware of Pickering’s book, or certainly its title, *Constructing Quarks*.[18] He believes that theories of physics, which may well be social constructions, are nonetheless materially constraining. Images of the proton beam render fruitless any formulation of science as a purely social or contingent construction, although to be fair to Pickering, his work does not ignore materiality or experimental reality.

For Michael and his colleagues, beams, collisions, fields or tracks form the “facts” of physics. In the LHC ring, a beam of protons is injected and accelerated in one direction. Another beam of protons is circulated in the opposite direction. The protons for the most part just go past each other like swarms of mosquitoes. But some collide. At the site of each collision is a gigantic detector to record the “data,” or the product ensuing from the collisions. The site of each detector forms a distinct experiment pursuing particular physics goals. Out of the four major LHC experiments, “ATLAS” and “CMS” are “general purpose detectors,” designed to investigate the largest range of physics signatures possible, whereas “LHCb” and “ALICE” look closely at signatures of B-Physics and heavy ions respectively.

The robustness of a desired signature depends on three elements: (a) the design of the detector, (b) the trigger, and (c) the analysis. The detector is designed to identify specific features of particle interactions such as their momentum or electric charge. Most of the interactions taking place at present are considered “junk” because experimentalists have seen those millions of times in previous experiments. Now they are focusing on the unusual ones, which would be produced for the first time in the LHC since it is geared to unprecedented luminosity. In order to maximally obtain “interesting” or atypical physics interactions, special parameters are used to make a selection. This selection is called a “trigger,” which assorts events with a bias, like a “muon trigger,” i.e. selecting events from collisions that contain a muon or a “jet trigger,” etc. The complex electronics of readout channels integrates millions of individual signals into a coherent description called an “event” and transmits the data to the computing grid for physicists across the globe to view. “Analysis” is the stage of reconstructing the signal events, and where the prospects of a discovery become distinctly conspicuous. Then it is not surprising to observe that Physics Analysis forms the most distinguished stage of experimental physics. In the stage of analysis, all aspects of physics like the detector and its components, issues of alignment, calibration, and modeling all come together.

Using sensitive tracking and “calorimetry,” or energy-measuring devices, the detectors monitor the debris of protons colliding together in its center. The conceptual design of these detectors is generated by very specific motivations from physics and engineering. In general, the detectors are designed as “cylindrical onions” consisting of:

(i) an inner “*tracker*,” measuring the *momentum* of all charged particles emerging from the interaction vertex. Essentially, the tracker reconstructs curved tracks of all charged particles;

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[18] Pickering, *Constructing Quarks : A Sociological History of Particle Physics*.

(ii) an "*electromagnetic*" calorimeter (ECAL), which stops, absorbs and measures the *energy* of light particles such as electrons and photons;

(iii) a "*hadronic"* calorimeter (HCAL) which samples the *energy* of "hadrons," which interact via the strong nuclear force, such as protons or neutrons;

(iv) a "*muon"* tracker measuring the direction and *momenta* of energetic muons, which are the only particles that pass through the calorimeters and are therefore easy to identify.

The guiding principle behind the design of the detectors is that no particle of interest should escape unseen from an interaction point (except neutrinos, which are therefore of interest because their presence indicates the imbalance in the energy/momentum ratio of interactions). This is one reason why the detectors are called "hermetic," covering the full four "steradians" of solid angle (4π) around an interaction vertex. While the basic structure and layering of the calorimeters is common to all the detectors, each one is also unique and different from the other. For instance, the electromagnetic (ECAL) calorimeter of the CMS has a much better resolution than the one of ATLAS. This makes CMS more effective than ATLAS in distinguishing photons from "jets" of hadrons. On the other hand, the hadronic calorimeter (HCAL) of CMS has a much poorer resolution than that of ATLAS. The hadronic calorimeter is useful for detecting missing transverse energy for picking interesting physics channels, but it is the accuracy of electron and photon measurements that allow discrimination of various channels for "new" physics expected.

The difference in the approaches to the design of detectors is also governed by the choices and constraints of the magnet system. The CMS Collaboration chose a single solenoid magnet of 3.8 Tesla with a radius large enough to contain three of its main calorimeters (the Tracker, ECAL and HCAL). The choice of the single solenoid was based on the elegant idea of generating, with one magnet, a high magnetic field for all precision momentum measurements, and a high enough return flux in the iron outside the magnet, which makes it a very "compact" design and lends the experiment its name, the Compact Muon Solenoid or CMS. Employing a central solenoid of 2 Tesla and barrel toroid (doughnut-shaped) magnet system, the ATLAS experiment (or A Toroidal LHC ApparatuS) uses a different geometry. The eight race-track-shaped superconducting toroid magnet coils, each 25 meters long and placed symmetrically around the detector, supplies the magnetic field for the most posterior component of its detector, the muon trackers. This design requires no yoke and allows ATLAS to be almost eight times the size of CMS although weighing only a little over half as much (Figure 1).

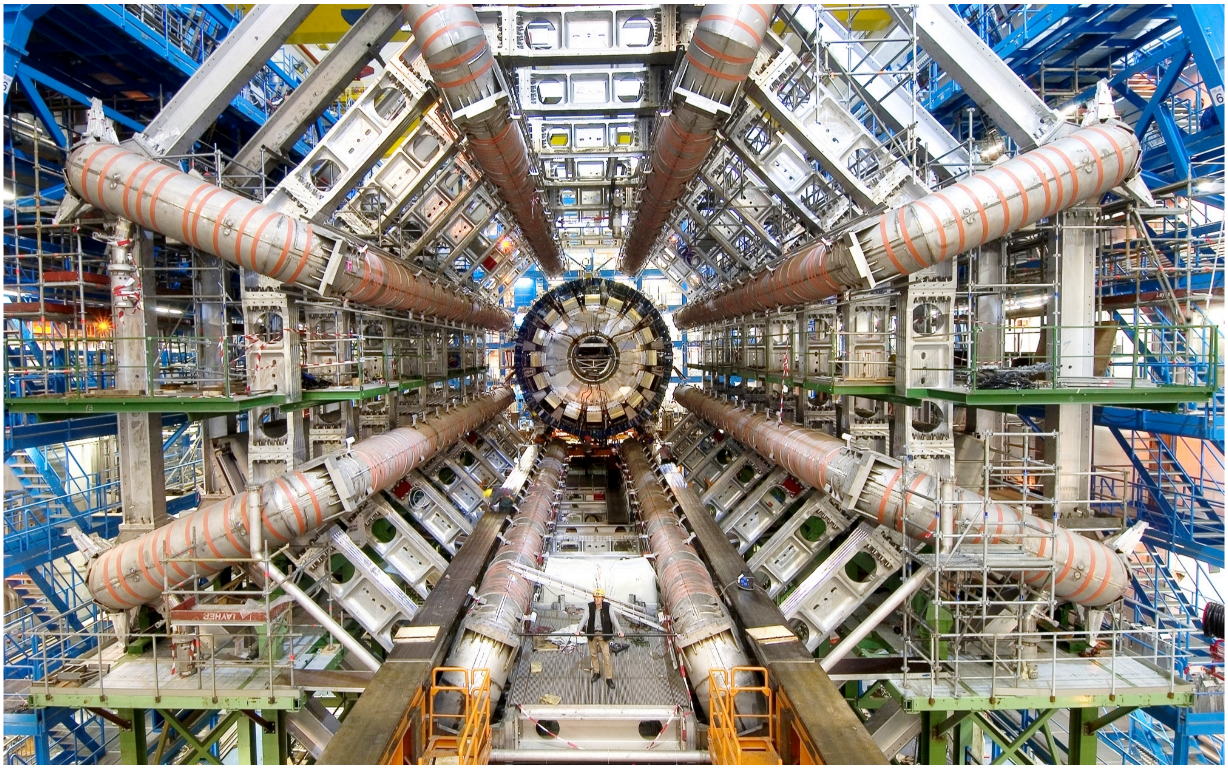

Figure1: Weighing over 7000 tonnes, ATLAS is the largest volume particle detector ever constructed. The proportion of its size can be gauged from the figure inside.

It should be clear by now that the desire to optimize the physics potential at the high energy frontier has motivated the different possibilities and strategies in the design of the LHC detectors. While the machine-experiment interface is provided by the performance of the detectors, the overall problematics of what is to be discovered straddles across the entire scope of an experiment, and instrumentation forms the embodiment or realization of these diverse possibilities. Under challenging conditions of operations, the different experiments complement one another in carrying out searches and discoveries in nature. No less marked is the element of competition, where each experiment attempts to outshine the others in claiming priority and securing attention of the community and beyond.

I began fieldwork in standard participant-observation fashion in the ATLAS Control Room tagging the "T/DAQ" (Trigger and Data Acquisition) group, headed by Livio Mapelli and later David Francis. Within months, well-meaning informants impressed upon me that the "real action" would begin once the data started to emerge and people who did "analysis" would be at the forefront of the game, which is where I should be if I wanted my research to capture the front line excitement. After some deliberation, I followed the informants' advice and the chapter is an outcome of that engagement. Since it deals with a specific and concrete inquiry, namely the constitution of a physics signature, the ethnographic data presented here (a) assimilates the work of "research physicists," more than, say, "detector physicists" or "theoretical physicists," and (b) focuses on the language of formulation used in physics, and not so much on its features of organization or hierarchy. To get to both these aspects, however, the material culture of the laboratory forms the point of departure.

In order to maximize collisions on the LHC, the counter-circulating proton beams are divided into "bunches." Each bunch contains 1.1 x 1011 protons, and there are 2,808 bunches per beam. Every 25 nano seconds, the proton bunches cross resulting in about 600 million collisions per second. There is an undeniable materiality or facticity to particle physics. But the assumption that naïve realism has so often set forth as self-evident – that materiality explains itself – is an exaggeration.[19] On this ground, the particle physicist will be in complete agreement with her archenemy, the sociologist. In the consideration of every single fact lies suppressed a prerequisite for its existence. This prerequisite is the gradation of relevance or significance. Why is the superconducting solenoid in front of the electromagnetic calorimeter or the muon chambers at the farthest end of a detector? The characterization of purpose and significance is an indication that a perspective has been imposed on matters of fact. In mentioning this, I am trying to highlight the intellectual character of physics.

But do also keep in mind that in the functioning of technology, facticity and purpose come together – or go apart – in accordance with exigency without any direct human input. I am not arguing that the operations of beams and collisions can exist or do away with human involvement. For sure, an engineer is needed to turn on the beams and build the machine. But when the beam is running, there is no engineer. Therefore, once a technology is instituted, it *functions* independently of the physicist or the engineer, whose presence becomes extraneous and relevant for maintenance, upkeep, repairs or safety. On the other hand, as I shall now elaborate, in the case of a signature, fact and significance are intrinsically bound together as a *unity at all stages and modes of operation*; the relation to the human subject cannot be eliminated at any stage of a signature without losing the entire concept.

2. A Physics Signature: Higgs $\Rightarrow \gamma\ \gamma$

What is a physics signature? "A two-body mass peak in the region of hundred GeV and above is the most robust signature one can hope for."[20] As a specific instance of a two-body mass peak signature, consider the decay process of a Higgs boson to two photons ($\gamma\gamma$) with a certain mass/momentum. A collision, *if* it is successful in producing a Higgs boson of a certain mass range, say between 80 and 120 GeV, may decay into two discernible photons. The photons identified must have a high transverse momentum – over 40 GeV. The momentum is deduced from the tracks of the curvature made by the speeding photons in the strong magnetic field. What this signature means can be understood by means of the following analogy. Supposing the reader imagines two balls, whose material composition is not known a priori, colliding head-on with each other. *If* the balls are made of crystal, say, of 100 pounds each, then we should have in the debris – according to the principle of conservation of momentum or mass – two conspicuous shards of glass of roughly 40 pounds each. Once we spot these two distinct pieces in the debris, we may deduce with some confidence that the original objects appearing in the collision were likely to be crystal balls with a mass of over 100 pounds.

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[19] Cassirer, *The Philosophy of Symbolic Forms*; Wilfrid Sellars, *Science, Perception and Reality* (London; New York: Routledge & K. Paul ; Humanities Press, 1963).

[20] Mangano, "Understanding the Standard Model, as a Bridge to the Discovery of New Phenomena at the Lhc.", 3.

The analogy is actually somewhat misleading because in the case of signatures in quantum physics, decays are processes where particles (such as a Higgs particle) *spontaneously* transform into other particles (like two photons) instead of simply dissolving or decomposing into constituent particles. When particles are produced in a collision, they are not particles that were somehow present inside the colliding ones. They are really created under the effect of field interactions by the conversion of collision energy into mass, as a result of the mass-energy relation ($E = mc^2$). This is a critical point, which I am merely mentioning here but will develop later, because I want to continue with the elaboration of the "Higgs to gamma-gamma" signature.

A signature, however, has to be extracted from the "background." Background refers to identical and competing processes that fake the signal. A potential source of background, as in this particular case of the Higgs decaying into two photons, are photons produced by "bremsstrahlung," or electromagnetic radiation given off by accelerated particles. When fast moving particles are forced to travel in a curved path, like in the circular accelerator, the LHC, they emit radiation in the form of photons. Thus, photons from bremsstrahlung are termed as "irreducible background."[21] The problem is the following: how to discriminate between photons which emerged as a consequence of bremsstrahlung, the irreducible background, and the photons produced from a possible Higgs, the signal? Speaking to the dashing "Convener of the Higgs Search on the ATLAS experiment," Andreas Hoecker, I asked him how he deals with this form of background in his analysis of the Higgs signature. He nonchalantly replied that he did not believe in the concept of irreducible background!

Andreas is a highly regarded figure in Physics Analysis, yet soon enough in the community I heard a few friendly murmurs of criticism of his approach to background. If he does not believe in the background, can he ever discern a signal? Skeptics were quick to suggest that Andreas had previously worked at SLAC, California, on the electron-positron accelerator, BaBar. It is well known that electron-positron collisions are "clean" compared to a hadron collider like the LHC, which is a "dirty" experiment since it generates a huge amount of particle debris, therefore a lot of background. This is owing to the fact that protons are composite particles, or "hadrons," and electrons are elementary particles. On a hadron collider, a sound experimentalist must have a complete understanding of the background, particularly the irreducible background, in order to discriminate and obtain a relevant signal.

I found the banter surrounding Andreas' approach to background disconcerting because he is at the top of the experimental physics hierarchy and enjoys a glowing reputation even among the somewhat distant and detached theoretical physicists. At this point it was clear to me that (i) there is continuity between experiments in the form of expertise and experience that physicists bring with them from previous experiments and laboratories. (ii) There is a multiplicity of views on how to do science even within a subculture of experimental physics. (iii) There is a distinct identity to the work one does even in collaborations involving thousands of individual scientists, and teams of scientists.[22] Anyhow, with this much clear I ran back to Andreas and put to him the same concern on the extraction of Higgs to $\gamma\gamma$ signal from the heap of background expected at CERN's hadron collider.

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[21] ATLAS, "Technical Proposal." 217.

[22] More than three thousand scientists, from hundred and seventy-two institutes, work on the ATLAS experiment alone.

Andreas confidently replied that he was aware of the "conservative view in the community," but argued that no matter what, "the topology of a signal event would always be different from the background." He then explained that while statistically plotting the decays, if a clear peak emerges from the "invariant masses of the energetic photons", it forms the "signal" that they are from a potential Higgs. On the other hand, the photons from bremsstrahlung with differing masses – the irreducible background – would be all over the graph, falling off in the tail regions of a quintessential Gaussian distribution (Figure 2). The overall shape of the distribution and the peak of invariant masses, from the two isolated photons in the final state, would lead Andreas to a clear signature of the much sought after Higgs boson.

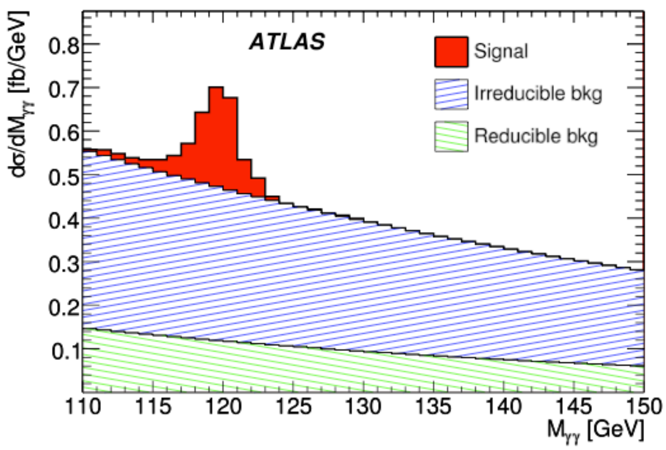

Figure 2: Diphoton invariant mass spectrum obtained from a Higgs boson.

I must confess that I listened to his explanation fairly attentively but it took me almost a year to follow it, and not without the aid of many other experimental physicists at CERN. In fact, listening to his and other experimentalists' expositions on the way they extract signals from collision-data, as they filled my field-notebooks with rough, sketchy diagrams and plots, it was astonishing to observe how materiality turns away from itself while seeking itself. Their work illustrates a mode of thought, which lies at the conjunction of *matter* and *sign*. Collisions can be turned on, but signatures cannot be. The former is predicated on human presence while the latter is given by nature. On the other hand, collisions do not require continuous human presence, while signatures cannot exist a moment without physicists.

In her engaging study of the epistemic culture of high-energy physics, Knorr-Cetina describes it as moving "in the shadowland of mechanically, electrically and electronically produced negative images of the world – in a world of signs and often fictional reflections, of echoes, footprints, and the shimmering appearances of bygone events."[23] The decisive importance of her analysis lies in her recognition of the "sign processing machinery" as the distinguishing character of high-energy physics.[24] Her error lies, if I may put it that way, in consistently viewing signs as "fictions," "phantasms," or "chimeras," from which she deduces

[23] Knorr-Cetina, *Epistemic Cultures : How the Sciences Make Knowledge*., 146.
[24] Ibid. 46.

the world of high-energy physics to be a "ghostly self-enclosed system."[25] I am more inclined to distinguish the signatures of physics as an instantiation of a "logic of the concrete."[26] The signatures speak for a "science of the symbol" where *signs* function as *instruments*[27] and thus physics gains access to the external world. In my view, the question for anthropological significance is not so much "nature," "truth," "fact" or "theory" and to what extent they are to be viewed as constructed or described,[28] but *from what perspective and by what necessity does physics gain knowledge of external reality?*

3. Logical Form and Objectivity

In the previous sections, the notion of a physics signature was framed in terms of the source of its signification – beams and collisions - and the relevant parameters for its identification – momenta, invariant masses, contrast with background, etc. Collins' work on gravitational waves offers a first-rate exposition of the complexity of finding relevant signals, the costs of finding spurious signals, the time taken to extract signals, the derivation of signal-to-noise ratios, and so on.[29] I cannot give a more meticulously detailed account of signals in contemporary experimental science. What I am trying to attempt is what meaning does a physics signature holds for prospects of a general theory of knowledge.

In a recent paper Latour re-visits the problem of grasping and analyzing natural or material objects as part of a social science explanation.[30] There is much that is interesting and polemical in his essay, but the chief argument is fairly straightforward: restore the "rights of the object," recognize its ability to mobilize orders of existence, and reconfigure language and society. The result is "objectivity," which is "not a special quality of the mind, an inner state of justice and fairness" but simply the obduracy of objects, "how they object to what is told about them."[31] Latour recognizes the significant contribution of language in embedding objects in how and what can be said, or cannot be said of them, but decides to place the accent of explanation on "the thingness of the thing."

Undeniably, things form the stuff or substance of any laboratory science.[32] Hits (of particles), jets (of strong interactions), or tracks (of electromagnetic charges) traced on the detectors can force the most recalcitrant or Platonist physicist back to things. I have little to disagree with Latour on the pervasive presence of things in science, but I sharply disagree with him concerning their epistemological status, or their role in science, and the implications for social science. From my research, I wish to underscore that what distinguishes scientific objectivity more than the presence (or absence) of things, are the possibilities (or limitations) of thought. This central tenet yields the consequence that a doubt can be raised about the objectivity

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[25] Ibid. 52-53.
[26] Levi-Strauss, *The Savage Mind*.
[27] Uberoi, *The Other Mind of Europe : Goethe as a Scientist*.
[28] Knorr-Cetina, *The Manufacture of Knowledge : An Essay on the Constructivist and Contextual Nature of Science*.
[29] H. M. Collins, *Gravity's Shadow : The Search for Gravitational Waves* (Chicago: University of Chicago Press, 2004).
[30] Latour, "When Things Strike Back: A Possible Contribution Of "Science Studies" To the Social Sciences."
[31] Ibid. 115.
[32] Galison, *Image and Logic : A Material Culture of Microphysics*.

of a scientific fact other than as a doubt about the existence of an object in question. Here is an example to substantiate the claim.

In 1999, the “CDF” experimental collaboration on the collider Tevatron at Fermilab, Illinois, reported the claim of a discovery of “New Physics” from an event of “diphotons with a large missing transverse energy.”[33] In other words, an event was observed on the detectors with two photons and a huge amount of missing energy in the final state. Since they needed more data, they increased the statistics by a factor of fifty and still they had one event. According to the rules, the event qualifies as a discovery but “why do we not consider it as evidence of new physics? Because consensus built up in the community that…the evidence is not so compelling.”[34] For clarification I quizzed Albert de Roeck, Deputy Spokesperson of CMS experiment and one of my key informants, and he concluded his narration of the incident thus: “Yes, there was a case of di-photons but we don’t know what it was. Of course, it didn’t prevent theorists from going into a frenzy and proposing new models as possible explanations, but no attention was given [to those].” From Albert’s illustration it was clear to me: the physicist’s recognition does not convey simply an *interpretation* of a signal but is part of the *conception* of a signal. What does the event signal? Nothing! Since no meaning can be attributed to it, an object’s existence is illusory.

If we take seriously Latour’s proposal to demarcate between a “social sociology,” dealing with the “symbolic,” and a “physical sociology,” that is attentive to things,[35] I wonder on which side would a signature such as diphotons with missing energy be placed? If existence of an object alone were decisive, then science would have no category of “error.”[36] An object may exist or may not exist, it is there or not there; as such it cannot be true or false. Such a question can only be posed when the object is brought into a relation with judgment and knowledge. Objectivity is a term in a complex relation involving the subject, object, and a common language, which conjointly determine what *is* there, the thing, and what is *possible*, the judgment on a thing. That scientific objectivity embodies possibilities of thought needs to be emphasized.[37]

The point I am trying to convey more generally is the following: If anthropology has not fully extended its vision to science and technology, and if all that is needed is a full-blown concept of an *object*, then we may be satisfied with efforts that animate materiality by infusing it with agency and virtues of obduracy or pliancy.[38] On the other hand, if anthropology’s model is human *language*, or the relation between langue and parole, then we step outside the ambit of action and reality, into the terrain of thought and its possibilities. To put it another way, whereas

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[33] “Missing energy” stands for energy, which is not detected by a particle detector but is expected due to conservation of energy and momentum principles, and when it is in the direction transverse to the beam axis, it becomes a good signature for the evidence of “Supersymmetry,” for instance.

[34] Mangano, "Understanding the Standard Model, as a Bridge to the Discovery of New Phenomena at the Lhc." 9.

[35] Latour, "When Things Strike Back: A Possible Contribution Of "Science Studies" To the Social Sciences.", 121.

[36] Georges Canguilhem, *A Vital Rationalist : Selected Writings from Georges Canguilhem* (New York: Zone Books, 2000).

[37] The notion of truth or error is more relevant to questions of objectivity than the obstinate presence of an object. Objectivity is a feature of judgment or propositions that only bear on things by being about facts. Latour gives a resolutely empiricist interpretation which fails to refer to any science, physics or otherwise.

[38] Alfred Gell, *Art and Agency : An Anthropological Theory* (Oxford; New York: Clarendon Press, 1998); Knorr-Cetina, *Epistemic Cultures : How the Sciences Make Knowledge*; Latour, "When Things Strike Back: A Possible Contribution Of "Science Studies" To the Social Sciences."

the question that any attention to *objects* raises is *representation*, every apprehension of *relations* contains an evaluation, a *signification*. When we assign a relation of size, function, or position, we are not simply expressing or representing a simple datum to *consciousness* but we are bringing it in a dynamic relationship – of *judgment*. This is precisely what a signature achieves: What distinguishes a collision as a signal or how to extract a signal from the bulk of the background are questions that derive their validity and necessity, not from materiality or action, but from judgment and thought.

The realm of non-being, error or possibility assumes particular relevance because it holds a mirror on every object, which presents itself as self-evident. These categories disclose that a signature is meaningful by virtue of having a conception, a logical comprehension, and this makes it a fact and a value at once. If abstract categories and logical principles are key to a signature, there is certainly justification in insisting that the axis of meaning plays an equally important role as the criterion of causality or reference. Meaning is not secondary to the formation of the fact – as the physicists like to believe – but is co-constitutive with it. The principle of evaluation applies not only to the internal structure of a particular signature, but also to its relationship with the experimental tradition to which it belongs or which it resists, and further to the community and its thought.

4. Signal and Significance

The value of an experimental science consists not in summing up known empirical facts but in its potentiality to call forth new facts. Accordingly, the structure of matter is not simply to be looked at, but to be penetrated and probed. Physics provides not just a description of nature. It is also an explanation of nature, and explanation of a physical event is not simply the realization of its existence as it is. Rather the explanation consists in specifying the conditions under which it occurs. A case of discovery is particularly interesting and perplexing: how to recognize what is not known? This somewhat philosophical question may be tackled, for the purposes of this chapter, thus: how does the evaluation of a signature of discovery take place?

Let me address this issue by way of a controversy - the discovery of "leptoquarks." As a possible extension of physics beyond the standard Model, and inspired by the symmetry between "quarks" and "leptons," the existence of leptoquarks has been proposed in a number of theories. On the collider HERA at the DESY laboratory, Hamburg (Germany), with electron-proton collisions, two experiments called "H1" and "ZEUS" were running to look for something new. In November 1996 when the run ended, with 30 pb-1 of data,[39] the experimentalists looked at the data and selected a sample of collision events with the aim of finding a scattered electron with the highest transverse momentum ("a high pT electron"). The next step involved comparing the rate with standard model predictions and examining the result.

"The result - for ten-fifteen of us, out of the four hundred collaborators - took our breath away. There were too many events! Really too many!!" Albert de Roeck, now with CERN's CMS experiment, who was the "Physics Coordinator" of H1 at the time, exclaimed while

[39] Picobarn, or barn, is the unit of area that is used to measure the cross sections of any scattering process. Cross section is the effective area of a collision region.

narrating the experience. H1 had found twelve events for the high momentum electrons when standard model expectations gave between four and five events. Zeus had four events with a background of two, so was a little less spectacular than H1. Two questions immediately arose: (i) how well was the background understood, and (ii) did the identified electrons show a resonant behavior in the electron-quark mass around a well-defined value? The background appeared to be under control. The signal looked exciting. Could it be a discovery? The directorate of the lab organized an official hearing with each of the experiment representatives separately, and satisfied, asked for a joint paper to be submitted. A conference was soon planned to make the historical announcement of a discovery. However, slowly it started sinking in that the H1 and ZEUS data did not exactly match. They were off by 10% in the mass of the object spotted. That was a bad sign. In March, the collider started again with renewed hope for interesting results but found no luck with more such events. By July 1997 it was clear that the new data offered inadequate signals for "new physics" and a discovery was not claimed.

The aim in outlining the leptoquarks controversy is to emphasize that the character of a signature is important, but also its significance, to gauge which there is no strict mathematical rule. In addition to general principles of physics, physicists rely on tacit knowledge and craft skills in interpreting and evaluating a signature. There is no foolproof method that works under all circumstances that can be picked out from a textbook. Instead it is "a judgment call" on what procedure to follow in which circumstances. Every decision that goes in the recognition of a signature exposes the constraints that instrumentation, calculations, magnitudes, models and assumptions place. In borderline cases, it is not uncommon to observe a physics analyst conclude that the distribution has significant excess, while a group of colleagues radically disagree and say the opposite. The judgment, which establishes this significance, is not a sum or aggregate of particular instances but a form of thought, logical and mathematical.

The observation of a physics signature is considered valid in the community if a significance of "5-σ standard deviations" can be obtained. Five-sigma is the "Gold Standard" of discovery. Claims and counter-claims establishing a 5-σ discovery level are rampant as they are debated and (dis)solved. Highlighting differences of opinion among scientists "does not force one to take a radically relativist stance toward experimental conclusions."[40] Criticism and controversies are, in general, frequent in the community since every physicist lays claims to a novel approach and a revolutionary breakthrough. While claims to authority on the basis of privilege or fame is present, submission to authority is not present. Rather it is worth the challenge to discredit a model or a hypothesis of someone considered an authority.

In the structural configuration of the signature, co-present with the fact of collisions, is the judgment that experimentalists exercise which determines the character and significance of a signature. Armed with this technical competence, experimentalists are called upon to play a leading role in forging or validating discoveries. On the whole, extraordinary caution is urged in claiming signals of discovery. At seminars and conferences, I heard over and over: How well have you estimated the "errors from systematics?" Are you basing your evidence solely against Monte Carlo simulations? To what degree can you claim a Standard Model Higgs from "look-alikes?" Apart from background, experimentalists have to take care against "noise" generated by electronics such as amplification of small electrical signals, "statistical errors" from limited event

[40] Peter Galison, *How Experiments End* (Chicago: University of Chicago Press, 1987)., 227.

samples, "detector effects" like limited acceptance and resolution of the measurements, and so on. While there is a clear chain of tasks, recognition of skills, and specification of procedures, the ultimate extraction of a signature is a delicate and drawn-out process, like looking for a needle in a haystack, as informants often expressed it.

Derrida identifies a tension at the heart of the general concept of signature – how to reconcile difference with repetition.[41] In the essay, "*Signature Event Context*," he looks at signatures in the everyday context, and ascribes "iterability" as their primary specification. "In order to function, that is, in order to be legible, a signature must have a repeatable, iterable, imitable form, it must be able to detach itself from the present and singular intention of its production."[42] But equally the signature is a singularity, the bearer of a unique identity, which Derrida recognizes but fails to elaborate upon. What is the locus of its singularity? In the case of the physics signatures, to be sure, unless a signature is repeated enough times, it would be difficult to make recognition of it. It is never, properly speaking, one signal or one event that experimentalists invoke. It is the peak around which a cluster of events coheres. An interesting exception to the search for statistically recurring events is the discovery of the Ω- particle in 1964 which was based on a single compelling event. But even when a single fact is investigated and confirmed, the interest is not in its occurrence itself but its recurrence.

While it is true that without the support of iterability or repeatability, a signature would be less credible, recurrence is *not* a condition for its occurrence. Every experimentalist explicitly attests to the merit of statistical repeatability of signatures. However, what is not uttered in words but which constitutes or consumes the whole of their professional existence is the contrast of signal from background. The quest for a signal is pursued by *differentiation* and the signature takes form from this underlying relation. Contrary to Derrida's emphasis, I am arguing that it is not sameness or repetition as much as difference (and unity) that constitutes the singularity of a signature. Neither quantitative accumulation nor associative combination gives the signature its distinctive value. The relation of contrast posits and marks off a determinate sphere of collisions as signals and confers on the signature singularity and versatility.

5. Typology of Signs

So far I have established that the signature of physics is distinguished from the material instrument and is compelled by a determinate language. Now I briefly examine the signature in relation to the general theory of signs. Reviewing any modern typology of signs roughly discloses a dichotomy between signs considered *natural and necessary*, the reason of signification being contained in the very notion of things, and signs that are *cultural and arbitrary*, i.e., based upon social agreement. Cultural symbols are vehicles for the conception of objects, natural signs are proxy for their objects. If we consider Pierce's classification of signs, we find that a relationship between a sign and an object may be (i) iconic (based on resemblance) such as portraits, (ii) indexical (based on causality and context) for example, weathercocks or

[41] Jacques Derrida, *Margins of Philosophy* (Chicago: University of Chicago Press, 1982).
[42] Ibid., 328.

(iii) symbolical (based on conventions) and the best example is human language.[43] (1991). Let us consider a slightly more exhaustive classification of signs, for instance, that of the Port-Royal grammarians. There are four ways a sign could denote its object: (i) indexical signs (breathing as a sign of life), (ii) iconic signs (cross of Christianity), (iii) natural signs (fire and smoke), and (iv) conventional signs (words of a language).[44] In these typologies, one could, in principle, make a dyadic classification and assign indexical signs to natural signs and icons to cultural symbols.

Any dualism between cultural intent and the natural impulse leaves out the symptom or the signature. In a symptom, there is an intrinsic prior connection between the signifier and the signified but it requires a language for the intelligibility of this connection. Rashes on a baby's tummy would not occur without a natural impulse. But the physician must interpret the rashes to tell us if it is measles or chicken pox. The notion of a natural sign, such as a symptom or a signature, is extremely disruptive for any classification that observes a rigid dualism between signs, independent of the human will, and ones given by custom and convention.[45] This is especially true when we reach back to the occult tradition, which shows a remarkable tolerance towards natural signs, such as symptoms and signatures.

When we consider the work of Paracelsus we recognize immediately how aware he was of the opposition and tension between natural and conventional signs and how radically he strove to resolve it, in part mystical and part logical ways. In the treatise, "*Concerning the Signature of Natural Things,*" Paracelsus argues that signs reveal and conceal the order of things. From planets to minerals, "signatures" constitute the fountain and focus of classification and form. The human spirit is subjected to the stars and the body is subjected to the spirit. "So the star governs the man in his spirit, and the spirit governs the body in the flesh and blood….so, then, there is a certain conjunction of the star and the man, of the elements and the man. It is a single conjunction, and a single alliance of such a nature that no partition or separation can occur."[46] In mapping these relations between heterogeneous aspects of the cosmos, Paracelsus' vision operates on the twin tropes of difference and similarity (metaphor), and proximity and distance (metonymy). Uberoi explains, "The principle of causality or effectiveness at work here is then not simply that of resemblances or similitude as established between the four or five separate items or distinctive features…It is rather that the *systems of differences* found among the various specific diseases, organs of the human body, the planets, the metals and among chemical compounds as medicines all formally resemble each other *and they also form a single unbroken fabric of existence* in a field of correlation, pairing and sharing, e.g., by the principle of symmetry."[47]

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[43] Charles S. Peirce et al., *Writings of Charles S. Peirce : A Chronological Edition* (Bloomington: Indiana University Press, 1982).
[44] Winfried Noth, *Handbook of Semiotics* (Bloomington: Indiana University Press, 1990).
[45] Victor Witter Turner, *The Forest of Symbols; Aspects of Ndembu Ritual* (Ithaca, N.Y.: Cornell University Press, 1967); Uberoi, *The European Modernity : Science, Truth, and Method*.
[46] Paracelsus and Arthur Edward Waite, *The Hermetic and Alchemical Writings of Aureolus Philippus Theophrastus Bombast, of Hohenheim, Called Paracelsus the Great* (New Hyde Park, N.Y.: University Books, 1967)., 285.
[47] Uberoi, *The European Modernity : Science, Truth, and Method*., 17, italics in original. More recently, Agamben has provided a commentary on Paracelsus' work on signatures. Although he is careful to preface his comments by remarking that the nature of signatures is temporally varied and problematical, his reading of Paracelsus is wholly post-Enlightenment for it emphasizes the logic of "similitude" or "resemblance," like Baudrillard or Foucault, over difference. Only when he discusses modern semiology (and hermeneutics) that he discovers the decisive importance

If we resist the recognition of difference in reading the physics signatures, we deny relation its constitutive role in the signature, and instead erroneously adopt a thing-like characterization. The signature is a term of contrast. As I emphasized in the last section, the contrast to background, forms the constitutive core of a physics signature. Between the protons injected in the accelerator, the production of the Higgs boson and the emerging photons, there is no resemblance, neither on physical nor logical grounds. Multiple transformations, called "radiative corrections," which are a result of a particle's interactions with various fields, mark the initial and the final state of collisions and decays. What the field interactions produce during collisions are orders of differences.

At the same time, this difference does not lead to a separation; there is a necessary relation between sign and object, but it is not a causal relation. The Higgs is not an "effect" of colliding protons. The immediate suggestion would be that the link is metonymical, or based on context or proximity, such as indexicality, like rising smoke indicates fire. I am afraid even this explanation is partial because signatures are quantum events of discovery. For instance, consider the class of "exotic" signatures. "Exotic" refers to physics processes beyond the standard model, like that of extra dimensions, supersymmetry, etc. In most cases, their experimental signatures are given by large missing transverse energy (eT). The association between a large amount of missing eT and a new phenomenon of nature is an association based on meaning. Large missing eT simply signifies that some new process is taking place but we don't know exactly what. Efforts that try to reduce the signature to similarity-based features of semiology such as iconicity or indexicality are too quick.[48] The issue raised by physics signatures is more delicate.

In other words, a signature is not a way of denoting an event. It is not the usual case of sign and fact, as two self-subsisting units related by means of some representational mechanism, where only new information is added by us. A signature of physics is not the end point of a synthesis but the starting point for a metaphysical revelation. Like the enigmatic signatures of Paracelsus, the quantum physics signatures speak the kind of unity or union that *makes* nature expressive, and experiment the hunt for these expressive effects. To that extent, it is expression and effect in the same instance (Figure 3). This bi-polar character of the physics signature constitutes a radical mode of classification, and contributes to Durkheim's vision of non-dualism that refuses to "separate a mindless external world from the universes organized by the activity of the human mind."[49]

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of, in a sign's relation to other signs, difference. "If for the Renaissance episteme a signature thus refers to the resemblance between the sign and its designated thing, in modern science it is no longer a character of the individual sign but of its relation with other signs." Agamben, *The Signature of All Things : On Method*., 59.

[48] Nothnagel, "*The Reproduction of Nature in Contemporary High-Energy Physics,"* in Philippe Descola, P·lsson GÌsli, and Conference European Association of Social Anthropologists, "Nature and Society : Anthropological Perspectives" (London; New York, 1996).

[49] Douglas, *Implicit Meanings : Essays in Anthropology*.

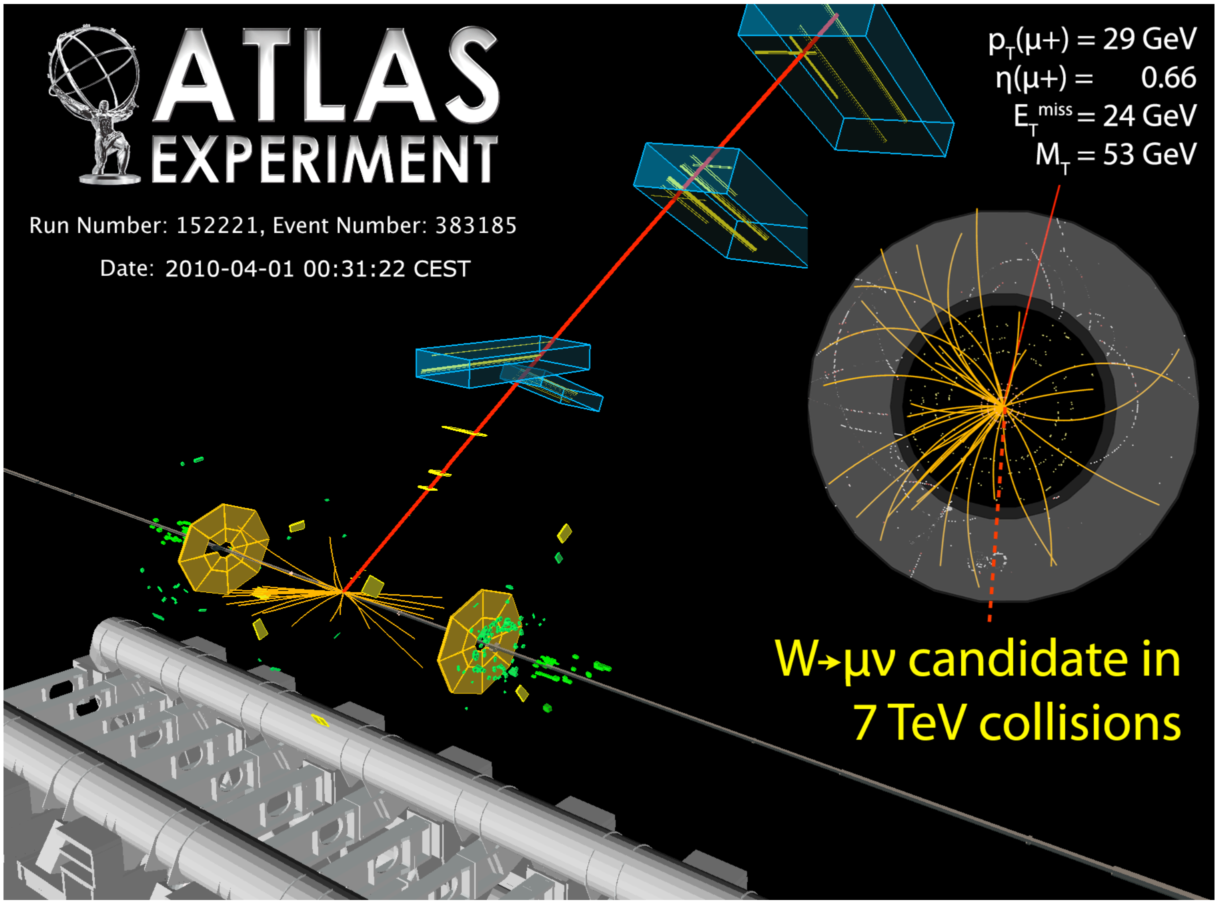

Figure 3: The extraction of a signature - a W boson decaying to two leptons - from a collision.

6. Measure of Reality

I started the essay with the utterance of Cesar Gomez on the trust they place on physical reality. Yet until now I have only stressed the paradoxical character of the physics signature that defies any notion of pure physical reality. The sheer act of identifying a signature comprises a change of form, an intellectual transposition. With this contention, I have attempted to undermine Latour's argument on the autonomy of things.[50] Signatures of particle physics defy brute materiality. On the other hand, they are not completely arbitrary assertions of signs or "fictions," as Knorr-Cetina contends,[51] without an embedding in the order of things. Then what is it that signatures disclose to us?

Evans-Pritchard cautions, "The most difficult task in social anthropological fieldwork is to determine the meanings of a few key words, upon an understanding of which the success of

[50] Latour, "When Things Strike Back: A Possible Contribution Of "Science Studies" To the Social Sciences."
[51] Knorr-Cetina, *Epistemic Cultures : How the Sciences Make Knowledge*.

the whole investigation depends."[52] Gaining this understanding is particularly tricky if informants can be credited with meaning in what they appear as saying. Here Victor Turner's insight into different levels of symbolic meanings and how they can be inferred serves as a useful guide for my ethnographic inquiry. Turner discerns a symbol's (i) *exegetical* meaning, obtained from questioning informants about observed ritual behavior, of which they are fully aware, (ii) an *operational meaning* which reveals its latent sense, of which the subjects are only marginally aware, and (iii) its *positional* meaning, which refers to a symbol's relationship with other symbols in the total ritual complex.[53] The "operational" level of symbolic meaning drew my attention to an aspect of signatures that its manifest usage did not.

During fieldwork, I observed that physicists frequently invoke the word truth. Discoveries and evidence are always debated against the standard of truth. CP violation in B mesons – is it true? Evidence of WIMP (Weakly Interacting Massive Particles) for cold dark matter – cannot be true? It was a familiar sight at CERN to see talks organized with titles, such as "The Truth of the Top Quark" (14 February, 2008) or "How Charming is the Truth: Search for Neutral Currents" (July 1, 2008). When news came in from the Tevatron, at Fermilab, on the exclusion of the Higgs mass in the window of 160 to 170 GeV, where the Higgs decays to two W bosons, it created a huge commotion. Michael Dittmar's presentation on the subject, "Why I Never Believed the Tevatron Higgs Sensitivity Claims for Run2A and B", on 19th March, 2009, was particularly interesting. The talk brought out the gamut of emotions that physicists are capable of – accusation (of fabricating the plots), defamation (of the Tevatron searches), erosion (of trust in scientific collegiality), but above all, skepticism, "Is this true?" Truth even entered coffee table conversations, often with bantering remarks aimed at the discipline of their "resident anthropologist" as not saying anything true about anything, "just a lot of words," as Alvaro de Rujula, a theoretical physicist, quipped. At a lunch, Luis Alvarez-Gaume, head of CERN Theoretical Physics, observed, "people from religion say that they have found the truth, while we are *still* searching for it."

In my informants' usage of the term, truth coincides with reality. Entities, which are really there, are true, and vice versa. Is that what truth is – a synonym or a description of reality? Or is it an imaginary, a utopia? For instance, originating in a common source and proximate in context, what makes experimentalists distinguish a signal from illusory events, the background? Well, what distinguishes real from illusion is truth. On this ground, truth is a criterion, a judgment. If I were to be satisfied with my informants' assertion of truth as a synonym or description of reality, their engagement with high-energy physics would show them to be servicing reality. But what they do in their appraisal of signatures, simultaneously addresses reality *and* their judgment of reality in the light of a certain knowledge that is held to be true. The import of signatures rests on this fact that they perfectly transcend reality. Therefore, if reality is a territory that is navigated with the aid of concepts as some sort of maps, then truth is the compass that orients their movement. The belief in truth prevents their, or any knowledge, from being haphazard or contingent. In other words, reality is not given to us, of which certain knowledge is thereby gained, but it is the certainty of knowledge as true, which forms the foundation for the quest of physical reality.

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[52] E. E. Evans-Pritchard and Corporation British Broadcasting, *Social Anthropology* (London: Cohen & West, 1951)., 80.
[53] Turner, *The Forest of Symbols; Aspects of Ndembu Ritual*., 50-52.

The peculiar character of the physics signature makes it quite understandable that while as physicists they are obviously concerned with physical reality – hence the reflexive utterance of Cesar Gomez – what they implicitly forge is the measure of reality. Wittgenstein makes a very puzzling observation in *Philosophical Investigations* §50: "There is *one* thing of which can say neither that it is one meter long, nor that it is not one meter long and that is the standard meter in Paris."[54] The philosophical puzzle gestures at something that is both itself and a sign, or a measure, for something other than itself. Through a few exceptional instances where things function as signs, such as symptoms or signatures, we discover the abolition of dualisms of fact and value, real and possible, meaning and effect, in a single stroke. It is in this dialectical sense that conundrums of rationality and logic of identity and association such as "twins are birds," "wine is blood," or "matter is quarks" seem no longer contrary to appearance and get their necessary and coherent character.

The concept of the physics signature affirms that the value with which physicists endow a fact, such as a discovery, goes beyond simple existence into meaningfulness and efficacy. However, from this investigation into signatures as natural signs with meanings, given by a community and comprising a value, I do not conclude that science is personal or that physicists have "a feeling for" science.[55] On the contrary, science is the proof that every person has an impersonal part, the impersonal love of truth. Physics does not require subjectivity of a subject, i.e., not a subject with feelings or "human nature" as understood by Locke or Hume. What distinguishes the scientific subject from all qualities of subjectivity is the intellectual renunciation it implies. Impartiality is not a negation of feeling, only an impersonal feeling. This is not a weak point. The subject is there to record the result. And to make a record is to imprint a judgment.

Conclusion

The articulation of science according to things and signs is by no means self-evident. The recognition of a signal from the data of collisions is an act of discrimination and an act of ordering. The consequence is the creation of an intelligible reality by epistemic values. It is not an accident that it requires a concept such as signatures, a primitive unity of fact and value, to disclose experimental reality. To this end, the chapter raises awareness of the judgment that experimental physicists bring to bear in their evaluation of a signature and underscores "the role of cognition in forming the social bond."[56]

Physics has systematically obliterated traces of the subject from the process of inquiry, except when propounding models or theories, for which personal credit is duly given or in assembling the experimental apparatus as an engineering feat where human presence is soundly acknowledged, and yet precisely at the juncture where "discoveries in nature" are claimed that one finds subversively enough a concept such as signatures, which enjoins on grounds of logical necessity (rather than, say, of ease of manipulation or functional need) a subject or, more appropriately, the community of subjects. Ultimately, if a signature of physics is stable it is not

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[54] Ludwig Wittgenstein, *Philosophical Investigations* (New York: Macmillan, 1953).
[55] Keller, *A Feeling for the Organism : The Life and Work of Barbara Mcclintock*.
[56] Douglas, *How Institutions Think*., 19.

because it is a thing, but because it is immersed in a determinate language from which it cannot be drawn apart.

Chapter Four: Instruments and Magnitudes

To terms of magnitude, and of direction, must we refer all our conceptions of Form.

D'Arcy Thompson, Growth and Form

The investigation of scientific concepts and categories of thought has so far taken place mainly in the branches of theoretical and experimental physics. Now the focus shifts to aspects of instrumentation with the aim of examining the broader interface of physics and engineering. The chapter approaches instrumentation and the material culture of the laboratory through a concept of pure circulation – energy – as it flows in the magnetic fields and currents of the collider. By analyzing a concept that attempts to bring together Maxwell's equations of the field with the exigencies of machine parameters, the research arrives at a key moment in the life of a laboratory when the division of theory and practice stands critically exposed.

In chapter 10 of *Capital*, "The Working Day,"[1] Marx discovers the mechanisms of capitalist exploitation in the rhythm of daily work, particularly, in the length of the working day. The formulation of a working day is the outcome of a struggle: the rights of the capitalist to prolong the working day to its maximum length and the rights of the proletariat to reduce it to a reasonable or "normal" duration. Marx reviews the historical data to support the correlation between the length of the working day and the accumulation of capital. He takes the evidence of the English Factory Acts from 1833 to 1864 to outline how through the struggle of capital and labor, an intrinsically dynamic or *variable* working day is set to a definite or a "normal" working day. However, the *absolute* limits to the working day are set within physical and social bounds. The work force can only work a definite quantity in a day and needs physical rest to replenish itself. Also social and intellectual aspirations have to be satisfied in order to be alive.

Now if we set aside the overwhelming issue of the tussle between the bourgeoisie and the proletariat, we succeed in extracting from Marx's analysis of a working day, the snapshot of a complex relation between productivity of labor and norms of life. The recognition between physical output and social norms is only an element in a great, comprehensive analysis, which however far from being exhausted or obliterated in relation to the total content of the analysis, serves as an indispensable methodological tool. We shall use this tool to investigate what constitutes the "normal" work life of a laboratory, with a simultaneous awareness of its other moment: whatever scope a laboratory may realize, it is constituted by limitations and problems.

1. The Normal and the Pathological

On Friday, 19 September, 2008, just nine days after a gala start-up of the Large Hadron Collider (LHC), an electrical fault brought the epic collider to a complete halt. An electrical connection between a "dipole" magnet (one of the 1232 magnets that bend the protons around the accelerator ring) and a neighboring "quadrupole" magnet (one of the 392 magnets that focus

[1] Marx and Engels, *Capital; a Critique of Political Economy*.

the proton beams) failed during a circuit test in sector 3-4 of the LHC. At the time, a current of 8.7 Kilo Amperes was being pushed through the superconducting cables, which generate the huge magnetic fields required to bend the protons at high energies. One of the “splices” linking the cables between two magnets suddenly developed a resistance and disintegrated – producing an electrical arc - which punctured the containers of liquid helium that keep the superconducting magnets at their 1.9 Kelvin operating temperature (Figure 1). Tonnes of helium gas were instantly released in the LHC tunnel and with such a force that some of the magnets broke their anchors to the concrete floor, and were displaced and damaged beyond recognition (Figure 2).

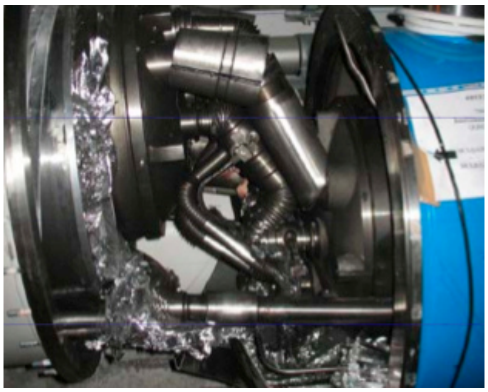

Figure 1: A severely damaged interconnect.

Figure 2: A broken magnet support.

Since August 20007 (until December 2009), I was conducting research at CERN in standard participant-observation fashion, interacting and interlocuting with physicists and engineers in order to interrogate and dissect their view of the universe. When the mishap occurred on September 19, I had spent a year among the community and was privy to some of the debates and discussions that took place at the time. Curiously enough, the word “accident” was never used to describe the electrical fault or the resulting damage in the CERN press releases or the media reports, presumably because there were no casualties, or because the word accident is more alarming than the term incident. I will keep to the term “incident” consistently throughout to isolate an interesting feature of diachrony of laboratory life.

As soon as preliminary news of the incident trickled in, speculations started on the causes and the extent of the damage, the amount of time needed for the repairs and what that meant for the schedule of the collider’s operation. In the first weeks surrounding the incident, CERN-management released little information, which created some discontent among some sections of scientists. An internal mail from Director-General Robert Aymar, on September 20, 2008, with the subject “incident in LHC sector 3-4” vaguely spoke of “a large helium leak” and “a faulty electrical connection between two magnets, which probably melted at high current leading to mechanical failure.” Some of the physicists grumbled that CERN was a research organization – not a diplomatic or a military establishment – and members of the personnel, i.e., the scientists, had a right to know what had caused the incident since their schedules were affected, and their students’ work was going to suffer, especially those who were anticipating to submit their dissertations on the basis of forthcoming LHC data. They argued how could there be secrecy in an academic environment? Yet others believed that secrecy was necessary so as not to dampen the general morale, or the management must have good reasons for withholding details of the damage, which it would disclose at an opportune moment, or more simply, that in an organization that big, everyone cannot know everything right away.

Soon intense rumors began circulating on the causes and the extent of the damage done to the accelerator. Masco has spoken insightfully, “secrecy, however, is also wildly productive: it creates not only hierarchies of power and repression, but also unpredictable social effects, including new kinds of desire, fantasy, paranoia, and—above all—gossip.”[2] And gossip does not occur in a vacuum; “it is almost always ‘plugged in’ to social drama.”[3] Conjectures and speculations on what had led to the accident, what kind of quality tests had been performed on the “interconnect splices,” or why weren’t there enough spare parts which would hasten the speed of repairs, prefigured most lunch-time conversations, as my field-notes indicate. It was not uncommon in that period to observe theoretical physicists striking conversations with accelerator physicists or engineers in the cafeteria, who had a better idea of what had befallen the accelerator, in attempts to extract information on the status of repairs than was officially available.

Eventually, the Director General’s office released a short report to all CERN personnel on the September incident, received via email on October 16, 2008:

> Dear Colleagues, We have today issued an analysis of the 19 September incident at the LHC. Investigations have confirmed that cause of the incident was a faulty electrical connection in a region between two of the accelerator’s magnets, which resulted in mechanical damage and release of helium from the magnet cold mass into the tunnel. Proper safety procedures were in force, the safety systems performed as expected, and no one was put at risk. Sufficient spare components are in hand to ensure that the LHC is able to restart in 2009, and measures to prevent a similar incident in the future are being put in place. This incident was unforeseen, but I am now confident that we can make the necessary repairs, ensure that a similar incident cannot happen in the future and move forward to achieving our research objectives. The full report is available here.
>
> https://edms.cern.ch/file/973073/1/Report_on_080919_incident_at_LHC__2_.pdf
>
> Best Regards,
>
> Robert Aymar[4]

The Director-General’s mail and the report disclosed the full extent of the damage to the LHC and immediately led to a general air of depression. The “faulty electrical connection,” which had induced the catastrophe, was nothing more than bad soldering![5] It also became clear

[2] Jospeh Masco, "Lie Detectors: On Secrets and Hypersecurity in Los Alamos," *Public Culture* 14, no. 3 (2002)., 451.

[3] Victor Turner, "Social Dramas and Stories About Them," *Critical Inquiry* 7, no. 1 (1980)., 149.

[4] Email sent by Robert Aymar, subject: Report on 19th Sept 2008 incident at LHC - rapport sur l'incident du 19 Sept 2008 au LHC.

[5] “During repair work in the damaged sector, inspection of the joints revealed systematic voids caused by the welding procedure,” in Mike Lamont’s “LHC status report,” dated April 23, 2010. Mike Lamont is the Leader of the Operations Group (Beams Department), which is responsible for the technical infrastructure and operation of all CERN present and future accelerators.

to everyone that the otherwise minor incident was going to cause a major delay in the re-operation of the machine. The chief reason for the delay was that sectors 3-4 of the LHC (Figure 3) would have to be warmed up for the inspections and the repairs to take place.[6] Since the LHC is a "superconducting" accelerator that operates at a horribly low temperature of 1.9 Kelvin (or -271 Celsius), it takes months for the 27-kilometer underground tunnel to regain room temperature. For a similar fault, not uncommon in a normally conducting machine, the repair time would merely be a matter of days.

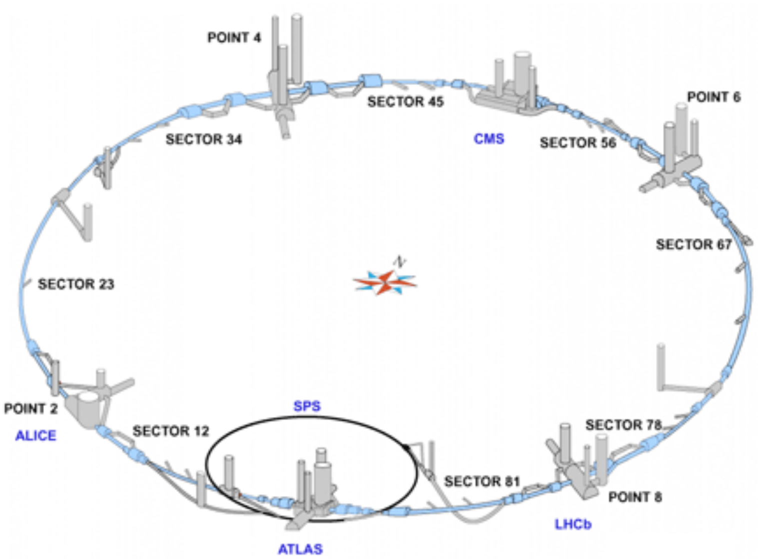

Figure 3: Schematic view of the sectors in the LHC ring.

The major repair work involved the severely damaged magnets. 24 "dipole" and 5 "quadrupole" damaged magnets had to be taken out of the tunnel and sent for repairs. The "splices" had to be inspected in the remaining sectors. Soot and debris had to be cleaned from the beam pipe. New safety systems and enhanced warning systems needed to be installed to prevent similar incidents from happening again. Finally, the repaired magnets had to be re-cooled. The magnets, however, cannot be cooled quickly; they must be "trained." The training process involves increasing the current gradually in the magnets so that the coils are not displaced or disturbed by the magnetic fields. After a few iterations, a stable configuration is reached where the magnets can reliably operate in a superconducting state. All this suggested a minimum of six months downtime for the LHC operation.

The engineering constraints, which decided the timeline of the repairs and the renewed operation, affected the physics situation decisively. The key factor motivating the endless rounds of discussion on spares and repairs was the question-mark placed on the LHC physics program and what that meant for the prospects of the rival proton-antiproton collider, the Tevatron at Fermi National Accelerator Laboratory, or Fermilab, Illinois, USA. Any setback in the LHC schedule implied an immediate advantage for the rival collider, the Tevatron. Operating since

[6] The LHC "ring" is not a perfect circle but is split into eight distinct parts, or sectors, comprising of eight arcs and eight straight sections. The sectors are the working units of the LHC: magnet installation, hardware commissioning, powering, etc all take place sector by sector.

1987, the Tevatron was working at peak performance and the September incident created a palpable possibility that it could overtake the LHC in staking the first claim to the Higgs boson.[7] For a "gold-plated, five-sigma-significance" discovery, to use the physicists' jargon, CERN's Hadron Collider had the edge. But when news trickled in March, 2009, that the Tevatron had excluded the Higgs mass in the window of 160-170 GeV, it created a commotion at CERN. Could the Americans snatch the prize of the Higgs right under the noses of the Europeans? The Tevatron had a head start, their technology was stable, and with three inverse femtobarns of collision data – the scientific unit that scientists use to count the number of collisions – they could use it to blow the LHC out of the water. "Coming immediately after the very successful start of LHC operation on 10 September, this is undoubtedly a psychological blow," lamented CERN's Director General, Robert Aymar.

The unforeseen incident of the electric fault and the resulting suspension of the machine invites us to examine the outstanding problem of classification of knowledge: how does a singular event, such as a crisis, lead to a renewed re-distribution of knowledge in the laboratory. Singular or specific events do not escape the regularity of established institutional divisions but combine with them to exhibit the unqualified normativity of social life and thought.[8] The distinction between what is exceptional and what is periodic appears to arise when we discriminate on grounds of temporality. However, the clear methodological distinction takes form when temporal occurrences are understood qualitatively in the source of norms of life. Durkheim takes the lead in this matter by breaking down the empirical structure of temporality and giving it a deductive explanation by tracing it to concepts of custom and usage.

According to Durkheim, the normal is what can be determined in relation to a given species or a social type. Taken in a literal sense, there appears nothing terribly exciting about Durkheim's conception. But when he takes up the phenomenon of crime, there he discerns an extraordinary riddle: most people regard crime as a problem. But Durkheim argues that some amount of crime seems to be present in all societies. So crime represents something of a condition of normality. What this implies is remarkable: A phenomenon is normal or pathological not in itself, or not even on account of what common sense prescribes; it is normal if we can ascertain its existence as a specific *rate* of occurrence. Hence, a phenomenon may be normal without being general. From this perspective, homicides or suicides are not exceptional events but linked to the basic conditions of social life.[9] No explanation from without can ever achieve the aim of explaining what is normal for society. At the same time, empirical enumeration or physical organization of occurrences by characteristics of experience will not disclose the conditions of normality.

The significance of Durkheim's formulation for general sociology need not be discussed here. In relation to our problem of the principles of classification of knowledge and action, it is important for showing the connection (a) between normality and pathology, and (b) between pathology and habit. Canguilhem has famously argued that the laws of normal development and growth appear in sharpest focus when seen in the light of their arrest. Norms are revealed to us

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[7] The BBC ran an article on February 17, 2009, under the title "*Race for God Particle Heats Up*."
[8] Max Gluckman, *Analysis of a Social Situation in Modern Zululand* (Manchester [England]: Published on behalf of the Rhodes-Livingstone Institute by the Manchester University Press, 1958); Turner, "Social Dramas and Stories About Them."
[9] Durkheim, *The Rules of Sociological Method*.

when they are broken; functions are revealed only when they fail.[10] Following Canguilhem, Foucault has introduced a novel conception of events.[11] He argued that events are not so much moments of eruption, or disruption, only to be reabsorbed in the institutional framework but, in some sense, problematize the assumptions of a normative order. To that extent, according to Foucault, crises and events are always present, only sometimes simmering below the surface and other times manifesting spectacularly.

2. Event and Liminality

Inspired by the literature, which makes crises central to the analysis of social processes, and triggered by the September incident, which had paralyzed the accelerator, I began paying attention to the life cycle of a laboratory, which I had not subject to any significant degree of scrutiny till then. While the informants bemoaned the suspension of work, I gained a remarkable opportunity: to observe nothing less than the origin and essence of everyday conditions of scientific-industrial life. Imagine what can be better for an anthropologist studying a political system if a coup takes place or elections break out. Likewise, the September 19th incident gave me a fantastic opportunity to observe the rhythms and routines of techno-scientific work life. It opened a window onto key anthropological concerns such as materiality, division of labor, *praxis*, performance, diachrony and the role of the symbolic.[12]

The productive transformation of nature according to prescriptions of *physis* (knowledge) and put into practice by *techne* (craft), has led to extreme specialization of work in projects of modern science. People who design the "detectors" are different from those who work on the magnets or the cryostats. There are myriad gradations of personnel regarding radiation, safety, electronics, computing or data-processing. Hacking comments on the "disunity of science" because of the proliferation of specializations, because each phenomena is produced by different techniques.[13] Stable laboratory science arises when theories and laboratory equipment evolve in such a way that they match each other and are mutually self-vindicating. Such symbiosis is a contingent fact about people, our scientific organizations, and nature.[14]

Peter Galison introduces the metaphor of "trading zone" to explain how theorists, experimentalists and engineers collaborate with each other, and in tandem produce some of the material artifacts of the laboratory. According to Galison, "Two groups can agree on rules of exchange even if they ascribe utterly different significance to the objects being exchanged; they may even disagree on the meaning of the exchange process itself. Nonetheless, the trading partners can hammer out a local coordination, despite vast global differences. In an even more

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[10] Georges Canguilhem, *The Normal and the Pathological* (New York: Zone Books, 1989).
[11] Michel Foucault et al., *The Foucault Effect : Studies in Governmentality : With Two Lectures by and an Interview with Michel Foucault* (Chicago: University of Chicago Press, 1991). 73-86.
[12] Prof J.P.S. Uberoi brought before my attention the critical significance of this moment of crisis and liminality that had affected the laboratory. It is his insight on temporality, and its singular importance to fieldwork, which I have developed in the present chapter.
[13] Hacking, *Representing and Intervening : Introductory Topics in the Philosophy of Natural Science*.
[14] Cartwright, *How the Laws of Physics Lie*; John DuprÈ, *The Disorder of Things : Metaphysical Foundations of the Disunity of Science* (Cambridge, Mass.: Harvard University Press, 1993); Galison and Stump, *The Disunity of Science : Boundaries, Contexts, and Power*.

sophisticated way, cultures in interaction frequently establish contact languages, systems of discourse that can vary from the most function-specific jargons, through semispecific pidgins, to full-fledged creoles rich enough to support activities as complex as poetry and metalinguistic reflection."[15]

A particularly interesting analysis of the relations between the three dominant sub-cultures of particle physics, theory, experiment and instrumentation, is to be found in Pickering's works. He insists on the recognition of temporal emergence and historicity of knowledge in evaluating the pursuits of science. For him the key question is: "How we should conceptualize temporally emergent phenomena?"[16] In taking cognizance of temporal emergence, Pickering discerns the structure of scientific practice to be a "mangle." The mangle extends to the realm of instruments, devices, substances, materials, actors and practices.[17] What emerges is a "kind of delicate material positioning or tuning" where alignments crisscross different branches of high-energy physics.[18]

In rich and substantiated ways, the emerging field of study called STS, or Science Technology and Society, acknowledges (a) the marked differences in the sub-cultures of physics and (b) the significance of periodization or temporality in mapping the culture of a laboratory. While it has given careful consideration to moments of emergence[19] and the end of experimental inquiry,[20] it has shed little light on the liminal stage as an autonomous periodization worthy of study. A "betwixt and between" moment, "liminality may perhaps be regarded as the Nay to all positive structural assertions, but as in some sense the source of them all, and, more than that, as a realm of pure possibility whence novel configurations of ideas and relations may arise."[21] Liminality is a socially and structurally ambiguous stage. It represents a midpoint, a transition in a sequence of two positions. By focusing on the liminal, Turner, like Van Gennep before him,[22] added a new dimension to our understanding of the stages of social processes. In the same vein, I am trying to argue that in discussing scientific work life we must pause and reflect on an incident's specificity, which accommodates its liminal status. Pronouncements on the general nature of relations binding or separating the different sub-cultures of physics are inadequate without an approach that incorporates the tempo of laboratory work, especially its liminal moments, which have something structurally puzzling to reveal.

The incident of September 19 discloses an interesting moment in the life of a laboratory: while efficient and successful organization of work accentuates the nature of coordination existing between various specialized units and groups, a failure or a crisis manifests how the collectivity disperses and each unit resolves or coheres into its own niche. In saying this I am not implying a sense of dysfunction. What it simply means is that at a liminal stage, relations

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[15] Galison, *Image and Logic : A Material Culture of Microphysics*., 783.
[16] Andrew Pickering, "The Mangle of Practice: Agency and Emergence in the Sociology of Science," *American Journal of Sociology* 99, no. 3 (1993)., 561.
[17] ———, *The Mangle of Practice : Time, Agency, and Science* (Chicago: University of Chicago Press, 1995); Pickering, *Constructing Quarks : A Sociological History of Particle Physics*.
[18] Pickering, "The Mangle of Practice: Agency and Emergence in the Sociology of Science.", 564.
[19] ———, *Constructing Quarks : A Sociological History of Particle Physics*.
[20] Galison, *How Experiments End*.
[21] Turner, *The Forest of Symbols; Aspects of Ndembu Ritual*., 97.
[22] Arnold van Gennep, *The Rites of Passage* ([Chicago: University of Chicago Press, 1960).

between various specialized units have decomposed, and they function separately and autonomously, each fulfilling the task it is responsible for.

Ethnographically, it invites our attention to the fact that while co-operation is usually carried out in a spirit of self-consciousness and propaganda, the work done alone is really a legitimate fulfillment of the same impulse, only not glaring to be somehow perceived by all. Cooperation and teamwork is sought as beneficial and propitious; it promotes harmony, the completion of tasks, and the growth of knowledge in acts of exchange. However, a crisis, when it occurs, triggers an awareness of the artificiality and the inadequacy of community and communication. This tendency came to a vivid expression when the accelerator came to a standstill. The sense of exigency, the strain of repair, to seize hold of the details, all justified by an immediate purposiveness or a goal in sight made it necessary for individual parts of the laboratory to function on their own with little connection to the whole or the neighboring parts.

In the "liminal period" between 19 September, 2008, the day when the collider paused, and 23rd October, 2009, when it resumed operation, each sub-culture of physics revolved on its own pivot. Theoretical physicists were involved in holding discussions and talks on New Physics without any exciting collision data, with a sense of despondency and "killing time." The conveners of "EP/PP" seminars (Experimental Physics subdivision, Particle Physics division) were organizing talks on issues peripheral to physics such as, "Evolution of Religious Beliefs" (August 13, 2009) or "The Strange Friendship of Pauli and Jung – When Physics Met Psychology" (December 10, 2009). Their justification was that "once the LHC starts, the entertainment would stop", as Luis Alavarez-Gaume made it clear. Till then they were fritting away time. Indeed most of my emails to theoretical physics friends from the period contain the subject, "playing squash today!"

As far as the experimental physicists were concerned, they went back disappointedly to Monte Carlo simulation-data and cosmic data, and to their shift duties in the control rooms. The few days of operation before the incident had offered them a glimpse of the potentiality of the machine, so they seemed particularly affected, haunted and dejected by the intervening delay. Their main concerns were the steady accumulation of data by the rival Tevatron collider, the delays in their students' careers, the possibility of other mishaps occurring in a machine so big and novel, and the dangers of losing support of funding agencies for future experiments.

The accelerator physicists and engineers, on the other hand, were energetically on their toes, removing, transporting and repairing the damaged magnets, manually checking the resistance of each of the splice connections, and carrying out cleaning operations in the vacuum chamber in sector 3–4, under the scrutinizing eyes of the entire organization. Key to the engineering work in this period was the installation of a new magnet "Quench Protection System" to prevent similar disasters in the future. The CERN web-pages daily published updates on the repair status. Even as the repair-work was being carried out, the attention was gradually shifting from ascertaining the causes of the incident in September 2008 to "The Incident in 2008 and its Consequences."[23] During the repairs and the tests, hitherto unforeseen flaws appeared, which could critically disrupt the future operation of the machine.[24] Overall in this phase, new features to the instrument were discovered, some were taken care of, and others left for later

[23] "Commissioning of the LHC Magnet Powering System in 2009," Proceedings of IPAC'10, Kyoto, Japan.
[24] CERN Annual Report, 2009.

when the LHC would need substantial upgrades for running at the optimum energy of 7 TeV per beam.

Most of the accelerator physicists and engineers I spoke to during this period unhesitatingly stated that the incident had given them a jolt. At the same time, it introduced them to the fragility and complexity of a hadron collider. "We always know that there is a lingering possibility that some technical problem, maybe even very small, can threaten operation anytime. The September incident was a critical and a painful lesson, but not without useful consequences," thought Gijsbert de Rijk, an accelerator physicist in the MSC group (Magnets, Superconductors and Cryostats), CERN, and my key informant from engineering. "The LHC is a unique, highly complex machine, and incidents of this kind are always a risk at the start of accelerator operations, as numerous accelerator experts have emphasized. The teams rallied to the challenge of repairing the machine and finding solutions to prevent any reoccurrence of an incident of this kind."[25]

3. The New Normal

Following the incident in September 08, repairs and subsequent consolidation work on the Hadron Collider took approximately a year. By 8th October 2009, the entire LHC had been cooled to its operating temperature of -271°C, just 1.9 degrees above absolute zero. On 23rd October, particles entered the LHC for the first time since September 2008 during tests to provide lead ions. On 23rd November, the LHC experiments began to see collisions for the first time at a total energy of 900 GeV. The early collisions were all obtained with a low-intensity "probe" beam, which nevertheless provided data for measurements of timings, tracking, missing energy and more, in all the four major LHC experiments. On 30th November 2009, the LHC became the world's highest energy particle accelerator when protons in each beam reached an energy of 1.18 TeV. This exceeded the previous world record of 0.98 TeV, which had been held since 2001 by the Tevatron collider at the Fermi National Accelerator Laboratory, USA. By the end of the year 2009, the transition had successfully been made from repair and commissioning of the LHC to its exploitation for physics.

A revised LHC plan was drawn up and unveiled on February 1, 2010 at the "Chamonix workshop." The LHC Performance Workshop in Chamonix, France, is an annual workshop, which "provides the teams operating CERN's accelerators a chance to retreat from the hustle and bustle of everyday work at the laboratory and focus on the near- and far-term future of the accelerator complex."[26] In the past, CERN – like Fermilab at Illinois, which also operates a superconducting particle collider – ran its accelerators on a one-year schedule, with an annual end-of-year shutdown in winter. Instead of the annual cycle, at the Chamonix workshop it was proposed the following: run the accelerator continuously for up to two years at energy of 3.5 TeV per beam. The continuous run would end by December 2011, which would be followed by a very long shutdown to prepare the accelerator to run at its full energy of 7 TeV per beam from the year 2013.

[25] CERN Annual Report, 2008, 25.
26 Katie Yurkewicz, "CERN's new LHC plan: Two years at 3.5 TeV," Symmetry, Volume 7, Issue 5, 2010.

The two main considerations to the change in the operation schedule were made by engineering and physics constraints. The new running cycle is an acknowledgment of the unique technology of the LHC, one that requires ultra-cooled superconducting magnets. Since the LHC takes at least a month to warm up, and another month to cool down, it makes sense to move to longer running times followed by longer shutdowns. The 2011-2012 longer shutdown, in particular, will be used to fix problems with the interconnect splices between superconducting magnets, which prevent the LHC right now from running at the energies it was designed for. During the long shutdown in 2012, all the necessary maintenance, repairs and upgrades will be performed that would enable the LHC from 2013 to operate at its maximum 14 TeV energy.

The physics motivation to change from the annual work-cycle and the decision to run the LHC at half the design energy – 3.5 TeV per beam – but for a longer running time, is to give the LHC experiments enough data to remain competitive with Fermilab's Tevatron experiments in the hunt for the big physics discoveries like the Higgs boson or supersymmetry. The goal for the next two years, 2011-2012, is that the LHC experiments should approximately collect one inverse femtobarn of data at 3.5 TeV per beam (Figure 4). With that amount of data at that energy, the LHC experiments would be well placed to make inroads into new territory, the possibility of significant discoveries, and to stay competitive with rival experiments at Fermilab's Tevatron. Once the physics goal is reached by December 2011, the accelerator and the experiments may peacefully shut down for upto a year to begin the long process of readying and upgrading the machine so that it can finally ramp up to its full energy of 7 TeV per beam in 2013.

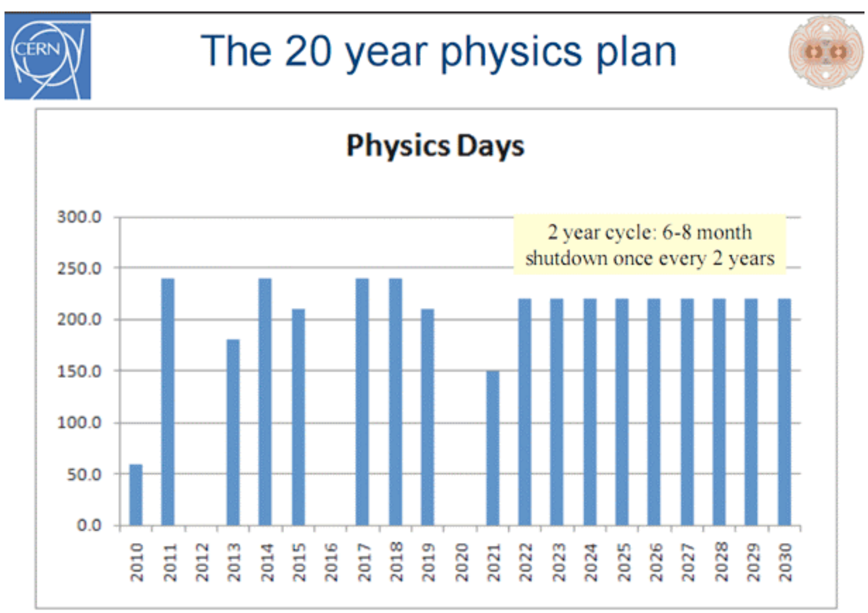

Figure 4: Speaking at the Paris physics conference, Steve Myers, CERN's director for accelerators and technology, presented this roadmap for LHC operation and shutdowns for the coming years.

2010 has been a momentous year for the CERN laboratory. The first collisions at energy of 3.5 TeV per beam took place on 30th March 2010. Since then, and well into nine months of operation in a new energy region, the experiments at the LHC are yielding a wealth of papers in physics. These include results aired at the premier summer conference called ICHEP, or International Conference on High-Energy Physics, in Paris (July 22-28, 2010). The ICHEP website presents rhetorically, “what is then so special about ICHEP 2010 conference? It was the first ICHEP conference where physics results obtained at the LHC were presented! New results about the elusive Higgs boson, or signals of physics beyond the standard model were therefore expected at this conference!”[27] At the end of September 2010, the CMS experimental collaboration announced the observation of intriguing angular correlations between particle pairs in high-multiplicity events, which might point to the creation of a “hot soup” of interacting particles called a quark–gluon plasma.[28] With the CMS collaboration’s announcement of this discovery, the LHC seems well on track for other potential discoveries. On 17th December 2010, the delegates attending the 157th session of the CERN Council congratulated the laboratory on the epic success of the LHC physics program after much waiting and anticipation.[29]

To conclude, the incident of September 2008 and the liminal period of repair and consolidation bring to sharp focus the following: the three main sub-cultures of physics namely, theory, experiment and instrumentation are distinctly marked off from each other. During “normal” times, the diverse sub-cultures work self-consciously in tandem, alongside each other. However, during a crisis, the organization of high-energy physics devolves into separate units, with each unit functioning largely on its own pivot. Therefore, any sociological analysis of the mutual relations and interactions of the different sub-cultures of physics must take into account the temporal frame in which diverse specializations come together or go apart. The subtle nature of the distinctions between the sub-cultures, together with their interrelations, appear more strikingly during the “betwixt and between” or liminal phases.

In the last few decades, the attention of the high-energy physics community has been consumed by the actual construction of the Large Hadron Collider and the four main detectors. This was followed by a sense of anticipation to the run-up to the physics and discovery potential. 2010 was the year of transition in the life of LHC when unstinting engineering efforts on repairs, consolidation, hardware commissioning and preparations for the beams finally came to an end and physics took the thrust. A switch has taken place. For the community as a whole, experimental physics has stolen the spotlight, with the instrument moving into the background. With clarity of hindsight, one may comment that the machine had after all delivered what it was aimed for. However, the incident in September 2008, occurring just days after a successful start-up, forced into consciousness the apprehension of the instrument as something vital and eternal. Once it goes into routine operation, it is easy to forget how the instrument undergirds the physics program. Without fetishizing, we can observe how the instrument becomes a symbol, which orchestrates the union and separation of the three sub-cultures of high-energy physics.

4. Division of Labor

[27] http://www.ichep2010.fr/

[28] The exact nature of the quark–gluon plasma is of great interest to physicists because the universe is believed to have been such a hot soup shortly after the Big Bang. arXiv:1009.4122v1 [hep-ex]

[29] CERN Press Release, 17.12.2010.

The discussion so far, revolving around the September 19th incident, is meant to emphasize that an entrenched division of labor marks the complex social activity of high-energy physics. The structural significance of this division of labor is the subject of our attention in the following pages. Marx and Engels suggested that "division of labor only becomes truly such from the moment when a division of material and mental labor appears."[30] But how, we may ask, is the division between *material labor* and *intellectual labor* sustained in a pure natural science? What place can a murky, powerful or exuberant materialism have in a pure science? Is there really a distinct labor process, a mode of production, which supports experimental inquiry in physics?

When we look at the organizational structure of CERN, we find a complex configuration. At present CERN is sub-divided into eight departments, listed below, with the names of the department heads:

- PH - Physics: Philippe Bloch
- IT - Information Technology: Frederic Hemmer
- BE - Beams: Paul Collier
- TE - Technology: Frédérick Bordry
- EN - Engineering: Roberto Saban
- HR - Human Resources: Anne-Sylvie Catherin
- FP - Finance and Procurement: Thierry Lagrange
- GS - General Infrastructure Services: Thomas Pettersson

The preeminent unit is Physics. It carries out basic scientific research in theoretical and experimental physics. Beams, Technology and Engineering departments are responsible for the infrastructure of the accelerator, in particular, the production and testing of magnets, cryogenics, vacuum and beam optics and related hardware such as, radio frequency, power converters, etc. The rest of the departments provide infrastructure support and services. There is an implicit hierarchy that most informants attest to. Theoretical physics stands at the top of the hierarchy, with experimental physics a close second, then accelerator physics and engineering, followed by the technical and the administrative staff. Underlying the hierarchy is a gradation of significance based on the nature of laboratory work. The demarcation between those who "think" and "those who use their hands," as one of my engineering informants, Francesco Bertinelli put it, is unmistakably made by the informants. At the heart of the pecking order lies the opposition of theory and practice, which designates and circumscribes the ambit of high-energy physics work culture. This opposition forms a key constitutive condition of scientific life.

The hierarchy of tasks and the division of labor is not really a single, linear, or all-encompassing one. One can trace multiple derivations of the same opposition of theory and practice in any stream or stage. Autonomous units may be isolated and sub-divided on these lines at any point. For instance, within theoretical physics, those who develop models, theoretical

[30] Karl Marx et al., *The German Ideology, Parts I & Iii* (International Publishers, 1947). 20.

frameworks, and mathematical techniques, which explain physical processes or make predictions for future experiments, are described as engaged in "model building" or "pure theory," and are distinguished from those who specialize in "computations," or the implementation of algorithms necessary for model building work, or "phenomenology," where the aim is to get an actual number which can be compared with current experimental data or conveyed to experimentalists so that they may design an experiment to test the validity of the predicted value. Phenomenology or computations are distinctly perceived to be in the zone of "application."

In the experimental physics community, which is numerically preponderant than the theory group, a distinction is commonly observed between those who work on the hardware of the detectors such as beams, targets or electronics, called "applied physicists," and those who do data analysis, termed "research physicists." Processing kinematics of decays or performing calculations is deemed more interesting than detector construction or conducting R&D on materials used in drift tubes and silicon pixels. The attribution of differential values to the kind of work one is engaged in is conveyed by a persistent worry of a number of informants working on the detectors, if they were ever going to make a transition to the more exciting task of "data analysis" once the experiments begin operation.

In 2009, after nineteen years of working on "end-cap B" of the CMS detector, David Cockerill, of Rutherford Appleton Laboratory, was happy and sad that the detector was completed and sealed. Happy because he had contributed in a significant measure towards its completion. Sad because what does he do now? When I met him a few months later, he beamed and told me, "I have moved to data analysis…not easy, but I have done it. I like working with young people. The data is exciting, people have fresh ideas, and I am learning new computing skills…" Not every detector physicist is able to make this career transition successfully. A few reluctantly admitted to being resigned to their positions. David Francis heads the T/DAQ (Trigger and Data Acquisition) group on the ATLAS experiment and believes that "it is too late to make a transition. Someone has to do the dull work….Someone has to bake the cake, others blow the candles [on it]." Working on detector hardware is commonly perceived to be a tedious, practical chore as compared to "data analysis," or searching for discoveries.

In the accelerator sector, it was impressed upon me that "TE" (Technology Department) was the leading arm since it deals with the star project, the LHC, and future projects, while the "EN" (Engineering) department provides technical coordination and infrastructure support to the accelerator and the experiments. Coordination, training and safety were considered "lower-end jobs, or what one does close to retirement," as a magnets engineer, whose name I shall not disclose, told me with some bitterness. "When one is young, one likes to tinker with materials, think about the mysteries of ordinary phenomena, play with ideas," he remarked. Conceptualization and development of technology is more challenging and rigorous than implementation of safety procedures or finding "applications" of a given technology. I agree.

Having said this much, I hasten to add that the feature of hierarchy itself is the least of my concerns. I have a rudimentary idea of the hierarchy with nothing substantial to offer by way of details on the factors that shape the division of labor or the functions it serves, if it promotes overall integration or expresses dubious power interests.[31] My particular interest lies in surveying the division of labor from the standpoint of the classification of knowledge. The opposition of theory and application forms the heart of the division of labor in science. The true value of this opposition lies not in utility or what the community accomplishes, as the scientific organization is eager to advertize or the sociologist keen to analyze, but in what it signifies as an instrument and symbol of knowledge. "The technical and practical interests of knowledge are not regulators of cognition which have to be eliminated for the sake of the objectivity of knowledge; instead they themselves determine the aspect under which reality is objectified, and can thus be made accessible to experience to begin with."[32]

The opposition of theory and practice is a tendency of genuine universality and depth that marks the particle physics worldview. The value of one may seem negative when measured by the other, but this does not indicate that the evaluation is false, only that a standard of evaluation exists. The dualism defines principal aspects in which creativity is exercised. Talents and tastes are a source, which in the course of time, must evolve into a distinction of manual activity or mental activity, i.e., those who work with their hands, and those who use their minds, or multifariously into modeling, calculating, designing, or fabricating. Since informants in the community perceive the opposition of theory and practice as important in itself, I have taken it up at some length.

What is the status of the theory-practice opposition in the social sciences? The intellectual premises of theory have, in the last few years, undergone momentous and traumatic changes leaving us to wonder what is theory, how can we know it.[33] Charles Taylor gives a pragmatic formulation of theory. He avers, "The stronger motive for making and adopting theories is the sense that our implicit understanding is in some way crucially inadequate or even wrong. Theories do not just make our constitutive self-understandings explicit, but extend, or criticize or even challenge them. It is in this sense that theory makes a claim to tell us what is really going on, to show us the real, hitherto unidentified course of events."[34] Even with a pragmatic thrust, Taylor concludes that theoretical analyses are too abstract for mapping satisfactorily complex social life, which should be more usefully undertaken as a study of practices. Reducing institutions of kinship or gift-giving to a set of rules does not convey the meaning that social actors attribute to marriage practices or acts of prestation.[35] Since the sixties, the study of social action and practices has become the central focus of anthropology, particularly in American anthropology.[36] A similar mood resonates in the history of science. The

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[31] Emile Durkheim, *The Division of Labor in Society* ([New York: Free Press of Glencoe, 1964); Dietrich Rueschemeyer, *Power and the Division of Labour* (Stanford, Calif.: Stanford University Press, 1986); Neil J. Smelser, *The Sociology of Economic Life* (Englewood Cliffs, N.J.: Prentice-Hall, 1963).
[32] Jurgen Habermas, *Theory and Practice* (Boston: Beacon Press, 1973)., 9.
[33] [33]Johannes Fabian, *Time and the Other : How Anthropology Makes Its Object* (New York: Columbia University Press, 1983); Marcus and Fischer, *Anthropology as Cultural Critique : An Experimental Moment in the Human Sciences*.
[34] Charles Taylor, *Philosophy and the Human Sciences* (Cambridge [Cambridgeshire]; New York: Cambridge University Press, 1985)., 94.
[35] Bourdieu, *Outline of a Theory of Practice*.
[36] In a well-known essay, Sherry Ortner predicted a great future for the study of practices, emerging as a backlash against Durkheimian analysis of solidarity and the static analysis of Levi-Strauss' kinship rules. I must add that in this essay, Sherry Ortner displays a feeble understanding of symbolism. The essay does not offer anything novel

interpretation of science as dominated by theory was the main pillar of the critique, launched by Kuhn, Quine, Hanson, and Feyerabend, against which the awareness that science is better described as a conglomerate of ad hoc procedures, oral traditions, and culturally specific practices has gained ascendancy.[37]

The painful inadequacy of pure thought has given prominence to the notion of practices, or everyday beliefs, the quotidian and the "taken for granted" assumptions that underlie and constitute human action. Much of the inspiration for "the practice turn" is credited to Marx and the later Wittgenstein. In the "*Theses on Feuerbach,*" Marx had proclaimed, "the question whether objective truth can be attributed to human thinking is not a question of theory but is a practical question."[38] It is a practical question because thinking does not occur in isolation; it is determined by concrete conditions of being. Hence any question of thought must be put against external reality. Wittgenstein placed a similar emphasis when insisting that language must be understood as an integral part of life, not as an abstract set of rules, but as usage. He demolished his own previous work, the *Tractatus*, for failing to acknowledge linguistic facts as elements embedded in systems of social practices.[39] "To obey a rule, to make a report, to give an order, to play a game of chess, are *customs* (uses, institutions)….'obeying a rule' is a *praxis*."[40]

Beginning by exalting materialism, and treating thought with impudent disdain, the practice turn in anthropology has bred a deep-seated contempt for theory. However, time and again it won't do to carry out a reversal of perspective. If the older critiques reified social constructs such as society or culture and bestowed on them a solidity or unity which they perhaps lack, the newer critiques liberate subjectivity and action and give them an autonomy which they do not possess. It is not enough to dissolve familiar methodological oppositions under a rubric of "blurring boundaries" or "shared contexts,"[41] which suggest the ideals of a popular philosophy rather than a systematic social science. What is required is not a complete reversal in the object or the content of analysis but a complete recognition of the problem.

As I indicated in Chapter One, the relation of science and technology is based on certain general principles. The technical mastery over nature demands solutions, which is a guiding factor in the entire process of reason and thought. This is technology. Technology "is a kind of knowledge which for the first time makes possible a novel relation to practice, namely, that of constructive projection and application."[42] Gadamer argues that modern experimental science, as it arose in the seventeenth century, is inherently incomplete. "The progress of science is sustained by its continual self-correction. And practice which is based on the application of science likewise requires that science further and further improve, by continual self-correction, the reliability of the expectations placed upon it."[43] The general knowledge which science

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besides the standard critique of knowledge that it ignores the operation of power. Sherry B. Ortner, "Theory in Anthropology since the Sixties," *Comparative Studies in Society and History* 26, no. 1 (1984).

[37] Biagioli, *The Science Studies Reader*.

[38] Karl Marx and Friedrich Engels, *The German Ideology : Including Theses on Feuerbach and Introduction to the Critique of Political Economy*, Great Books in Philosophy (Amherst, N.Y.: Prometheus Books, 1998).

[39] Wittgenstein, *Philosophical Investigations*.

[40] Ibid. §199, §202.

[41] S. E. Kirksey and S. Helmreich, "The Emergence of Multispecies Ethnography," *Cult. Anthropol. Cultural Anthropology* 25, no. 4 (2010).

[42] Gadamer, *The Enigma of Health : The Art of Healing in a Scientific Age*.

[43] Ibid. 3.

acquires takes place alongside practical legitimacy and "the entire content of what we call technology has this character of being applied science."[44]

In this recognition of the character and role of technology for modern science, we arrive at a question of decisive singularity. Is modern science incomplete without technology? The social sciences have done much to generate the impression that without technology, science is of little consequence. The claim, for instance, is particularly relevant in the emerging life sciences, such as synthetic biology, which seem to follow "the engineering ideal."[45] Steven Shapin makes the erroneous argument that owing to the widespread prevalence of the engineering attitude, the "massive distinction" between science and technology has faded with the result that the distinction between "the role of the scientist and that of the engineer makes less and less sense."[46] A week's fieldwork in a science laboratory would have brought correction. There is nothing new in the alliance of science and engineering as Shapin imagines it. The Manhattan project remains its best-known illustration, which employed more than a 100,000 physicists and engineers in order to manufacture the bomb. It was an outward alliance based on complete inner separation. That is, modern techno-science projects show a unity of means and ends, but not of fact and value, or subject and object. In the precincts of a laboratory, there is no confusion in the roles or positions of theoretical physicists from electronics engineers. The demarcation of theory and application does not depend on attitudes that individuals may or may not hold, but on grounds of professional discipline.

In a well-known essay, "*The Question Concerning Technology*," Heidegger claims to wrest technology from an unduly instrumentalist position to a more sublime function: "Technology is a mode of revealing. Technology comes to presence in the realm where revealing and unconcealment take place, where *alethia,* truth, happens."[47] In simpler words, it means that technology is a concrete way of revealing reality. Rather than emerging as a consequence of science, modern technology forms a possibility condition for science. "It is said that modern technology is something incomparably different from all earlier technologies because it is based on modern physics as an exact science. Meanwhile we have come to understand more clearly that the reverse holds true as well: Modern physics, as experimental, is dependent upon technical apparatus and upon progress in the building of apparatus."[48]

The functional dependence of science upon technology although constituting a mechanism of integration, carries with it the provision that it can never be consistently applied. It is a contingent alliance. That prospect alone makes it insufficient for any definition of unity. For we find mere juxtaposition when we meant to find a principle of unity. The fact of juxtaposition is expressed the institutionalized division of labor in modern organizations, which clearly

[44] Ibid. 17.Paul Rabinow and William M. Sullivan, *Interpretive Social Science : A Reader* (Berkeley: University of California Press, 1979).
[45] Paul Rabinow, "Prosperity, Amelioration, Flourishing: From a Logic of Practical Judgment to Reconstruction," *Law and Literature* 21, no. 3 (2009); ———, *Marking Time : On the Anthropology of the Contemporary* (Princeton: Princeton University Press, 2008).
[46] Shapin, "*Science and the Modern World,*" in Edward J. Hackett, *The Handbook of Science and Technology Studies* (Cambridge, Mass.: MIT Press : Published in cooperation with the Society for the Social Studies of Science, 2008)., 443.
[47] Martin Heidegger, *The Question Concerning Technology, and Other Essays* (New York: Harper & Row, 1977)., 13.
[48] Ibid. 14.

demarcates and separates the sphere of theory from practice. This fundamental recognition of the character of modern science I shall underscore from the phenomenon of particle acceleration in high-energy physics at CERN. Particle acceleration requires the coming together of accelerator physicists and engineers, in order to get the instrument running. However, for the phenomena, which emerge from the instrument, accelerator physicists and engineers, are not necessary or even relevant, who give way to theoretical and experimental physicists. The separation of theory and practice finds its entire tenor and orientation in the instrument, the accelerator, of high-energy physics.

5. Accelerator Physics: Machine Parameters

An accelerator is a tool for use. It is a tool of particle physics, just like the microscope is a tool for biology. Accelerators achieve the purpose of racing sub-atomic matter at approximately the speed of light and smashing them in order to probe the innards of matter as they interact with the field. If this concept seems too remote or esoteric to the reader, the engineer will remind her that the "cathode ray tube" of any TV or computer monitor is really a particle accelerator. The cathode ray tube (CRT) takes electrons from the cathode, speeds them up using electromagnets in a vacuum and then smashes them into phosphor molecules on the screen. The collision results in a lighted spot, or a pixel, on the TV or computer monitor. The same principle is at work in a particle accelerator, on a more grand and complex scale. Accelerators utilize many aspects of physics such as relativistic dynamics, electrodynamics, plasma physics and non-linear systems. They embrace a wide spectrum of technology such as superconductivity, radio-frequency cavities, optics, and cryogenics, to name a few.

There are two kinds of accelerators: linear and circular. Machines that accelerate particles as they travel in a straight line and hit against a fixed target are linear accelerators and are used for acceleration of low energy beams. An example of a linear accelerator is the "linac" at the Stanford Linear Accelerator Laboratory (SLAC) in California, which is about 1.8 miles (3 km) long. If particles are propelled around a circular track and oppositely circulating particles are made to collide against each other, we get a circular accelerator. Circular machines are geared to the production of high kinetic energy beams. The Large Hadron Collider is a circular accelerator, which covers 27 kilometers (17 miles) of underground area between France and Switzerland in Europe. The advantage of circular accelerators over linear accelerators is that the ring topology allows continuous acceleration, as particles can transit indefinitely. Another advantage is that a circular accelerator is able to achieve higher acceleration in less area using a power comparable to the linac. In other words, a linac would have to be extremely long in order to accelerate particles with the equivalent power of a circular accelerator. In this chapter I will principally discuss aspects of circular acceleration with reference to the Large Hadron Collider.

A brief excursion on the history of particle accelerators is perhaps necessary for the reader but I will skip it and instead direct them to a few references.[49] There is a point, however, that I wish to highlight from the chronology of the development of accelerators. The design and choice of accelerators follows an alternating logic. Informants often indicated that the Large

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[49] Gordon Fraser, *The Particle Century* (Bristol; Philadelphia: Institute of Physics Pub., 1998); Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*. A. M. Sessler and E. J. N. Wilson, *Engines of Discovery : A Century of Particle Accelerators* (New Jersey: World Scientific, 2007).

Hadron Collider is a "discovery" machine. Its aim is to push the energy frontier and gain new insights into the sub-nuclear world. In contrast, the proposed next-generation collider, the Compact Linear Collider, or CLIC, is a "precision" machine, which will explore in depth and substantiate in detail what the LHC discovers. The previous collider at CERN, the Large Electron Positron Collider, or LEP, had been designed to measure the masses of W and Z particles to a very high precision. The W and Z particles themselves had been discovered in 1983 at an earlier CERN collider, the Super Proton Synchrotron, or SPS. The alternating logic of expansion and consolidation, or discovery and validation, defines the development of accelerator systems. The LHC has been designed to attain unprecedented collision energies and event rates "to exploit the discovery potential,"[50] which require a range of novel features that stretch existing technologies to the limit. The design performance envisages roughly 30 million proton–proton collisions per second, spaced by intervals of 25 nanoseconds, with centre-of-mass collision energies of 14 TeV that are seven times larger than those of any previous accelerator. Its uniqueness among accelerators has earned it in the physics community, the epithet, "Lord of the Rings!"

Two parameters of fundamental significance in defining the structure and function of accelerators are energy and luminosity. Energy pertains to the accelerated particles inside the beam. The higher the energy, the more violent is the collision. With energies of 7 TeV in each beam, the LHC is the highest energy particle accelerator in the world. The unit used to express energy of a particle is an Electron Volt (eV). A particle with a charge equal to that of an electron gains the energy of one electron volt when accelerated in an energetic field whose potential difference is 1 V; thus 1 eV = 1.6 . 10 -19 J. Since one electron volt is a very small unit, the following derived units are used more commonly in charged particle acceleration:

1 Kiloelectron volt 1 keV = 10 3 eV

1 megalectron volt 1 MeV = 10 6 ev = 1000 keV,

1 gigaelectron volt 1 GeV = 10 9 e V = 10 6 kev

1 terraelectron volt 1 TeV = 10 12 eV = 10 9 kev

The other critical machine parameter is luminosity, which constitutes a measure of the intensity of the beams and, therefore, the rate at which particle collisions take place. Luminosity is a function of the number of particles spinning in the two directions. One can compute luminosity from the number of particles circulating in the two directions by taking their product N1.N2 and dividing it by the revolution frequency and the transverse section of the beam. One obtains a number whose units are inverse area (the beam size) times inverse time in seconds (the frequency), and is usually expressed in cgs units, cm^{-2} s^{-1}.[51]

An equally critical parameter, along with energy and luminosity, is the kind of particle species used for collisions. Energy and luminosity are concepts, which connote quantity, whereas

[50] Oliver Bruning and Paul Collier, "Building a Behemoth," *Nature.* 448, no. 7151 (2007).

[51] A popular blog online "A Quantum Diaries Survivor," by Italian physicist, Tomaaso Dorigo, mentions, "luminosity is not just a number with which machinists boast about their gadget. With it, you can actually compute the rate of production of any given process, if you know its cross section." Experimental physicists are almost always be found in discussions involving luminosity and production cross sections.

particle-species is a concept of a qualitative character. Colliders can, in principle, be designed for many different particle species. Electrons, positrons, protons, antiprotons, ions have all been exploited for collision purposes. The Tevatron at Fermilab operates with proton and antiproton beams. The Large Electron–Positron Collider (LEP), the last collider project at CERN, used leptons in the form of electron and positron beams, and the Large Hadron Collider (LHC), the present collider project at CERN, uses proton-to-proton collisions. By and large, electrons are the particles most frequently accelerated. Protons hold the second-rank as far as frequency in particle acceleration is concerned.

A disadvantage of accelerating electrons, or leptons, is that they lose a lot of energy due to "synchrotron radiation." When charged electrons are accelerated and forced to travel in a curved path by a magnetic field, they emit electromagnetic radiation in the form of photons (Figure 5). For relativistic particles, this radiated energy is proportional to the fourth power of the particle speed and is inversely proportional to the square of the radius of the path. Consequently, the energy lost in each revolution increases dramatically – with the fourth power – as the energy of the machine increases, which makes it virtually impossible for the accelerating system to replace it. This loss of energy becomes a severely limiting factor on the final energy of particles accelerated. Almost every physicist on the LHC who had previously worked on LEP, spoke of the haunting problem of synchrotron radiation at LEP, which was a lepton collider.

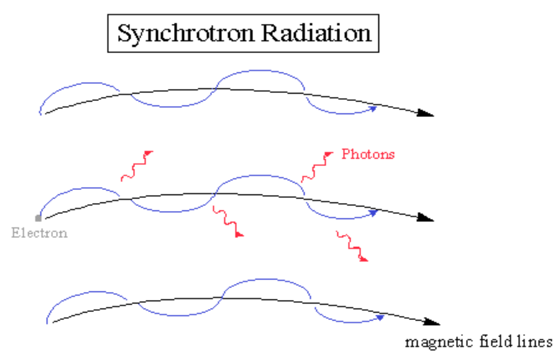


Figure 5: Synchrotron radiation in the form of photons.

Due to the problem of high synchrotron radiation with electrons (or leptons), protons (or hadrons) are preferred as particles for acceleration. The advantage of protons is that they do not lose energy in the form of synchrotron radiation since the energy loss per revolution varies as the inverse fourth power of the mass of the particle, and protons are 2000 times heavier than electrons. Protons are heavy and therefore lose less energy than leptons while following a curved trajectory in a strong magnetic field.

There is, however, a disadvantage of using protons or hadrons for purposes of collision. Protons are composite particles: each proton contains three or more fundamental particles called "quarks" that are held together by "gluons." In collider experiments, beams of equal but opposite momentum are brought together. The initial momentum is zero and so all the energy of the beams can, in principle, be converted into new particles. Since leptons are elementary particles, the centre-of-mass collision energies are precisely defined. In a lepton beam of known energy, each particle has this energy and so precision measurements of interactions in a detector are possible, balancing the energy before the event with the observed energy afterwards. On the other hand, when hadrons are smashed together, the collisions actually occur between constituent quarks and gluons, with each carrying only a proportion of the total proton energy. This is owing to the fact that hadrons are composite particles. In a hadron beam, each hadron's energy is shared out between its constituent particles in a constantly changing way and so the initial energy of the two colliding particles cannot be known very accurately. The centre-of-mass energy of these collisions can vary significantly, so they are not well suited for high-precision experiments.

Overall, the two types of particles generally used, namely leptons or hadrons, complement each other. Hadron colliders are useful for discovering new physics or searching for new particles as they explore the deeper constitution of matter. They offer a tremendous potential for the discovery of as-yet unknown particles, because they admit the possibility of collisions over a wide range of very high energies than is otherwise possible. Lepton machines can be used for precision measurements and in-depth probe of particles after their discovery. As I indicated a moment ago, colliders follow an alternating logic of discovery and validation. Now it should be clear to the readers the grounds on which CERN developed the Large Hadron Collider (LHC) right after the Large Electron Positron (LEP) collider.

This basic logic shows that the LHC is not a leap into the void but rather a development and deduction with systematic continuity of previous efforts. From this point of view, it becomes clear that a laboratory is best considered and evaluated only within a system of laboratories and not in isolation as an atomistic, or self-contained unit. In framing the inquiry into material culture, I have adhered to this fundamental insight of the social character of a laboratory, expressed through the feature of diachrony. The LHC has been built exactly in the 27-km-long LEP tunnel to make best possible use of the existing infrastructure at CERN. In the next section, I will outline the geometry of the tunnel and the constraints it placed on the technology of the LHC and the dynamics of particle acceleration.

6. Bending, Steering and Focusing via Magnetic fields

Accelerators accelerate particles under the effect of electromagnetic fields. During circulation, particles are permanently under a centripetal acceleration produced by the "Lorentz force." A particle with charge, q, velocity, v, and moving under an electric field, E, and magnetic field, B, will feel a Lorentz force (F)

$$F= q[E +(v \times B)]$$

given by the cross vector product, x. This is the general formula with which my discussions with accelerator physicists invariably began. What was subsequently pointed out was that the nature of magnetic force is different from the electrical force. Magnetic force is not linear, in the sense that it does not operate in the direction of the magnetic field. It acts perpendicular on a particle. This is unlike the electric force, which acts in the direction of the electric field applied. Therefore, the two effects work in two distinct directions, a longitudinal acceleration due to electric fields, and a largely transverse bending of the trajectory of particles due to magnetic fields. The cardinal concepts here are of field, direction, time dependent position and velocity of particles. For the most part, classical Maxwell's equations define the behavior of electromagnetic fields in the operation of particle accelerators. Apart from one or two quantum effects, such as superconductivity or synchrotron radiation, particle accelerators are completely classical. Overall, the distinct geometry of forces is responsible for the way particle acceleration takes place. Since magnetic force is perpendicular to the direction of velocity, it can only change the direction of motion – not its magnitude. In other words, magnetic force cannot alter the magnitude of velocity i.e. the speed of a charged particle, which is influenced by electric fields.

Now to revert to the LHC: the LHC consists of two interleaved synchrotron rings, 27 kilometers in total circumference. The main elements of the rings are superconducting "dipole" and "quadrupole" magnets, operating in superfluid helium at 1.9 Kelvin, which provide deflection to charged protons close to the speed of light. Different types of magnets, or windings of the superconducting coil, generate different kinds of fields. A field basically consists of flux lines in specific geometries. For instance, the image below (Figure 6) shows a typical dipole field of lines of magnetic flux with the arrows indicating the direction. Magnets with transverse fields make up the backbone of the accelerator and the beam transport system (Figure 7). They are called dipole magnets and are used for deflecting or bending the beams along the 27-kilometer circumference.

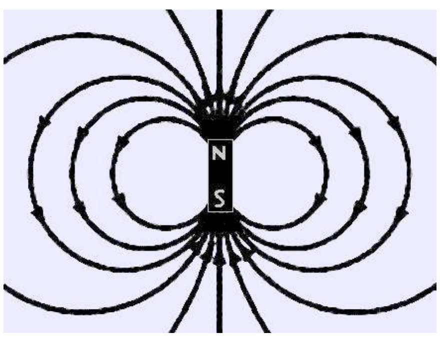


Figure 6: Field of a dipole magnet.

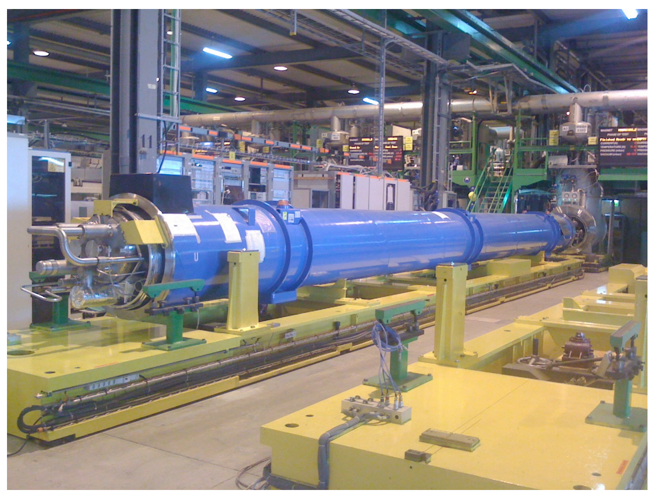
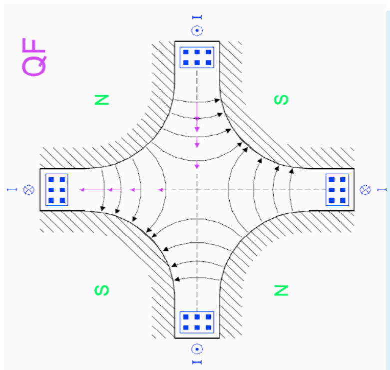


Figure 7: An LHC dipole.

Although particle motion under the influence of dipole magnets is "stable," it needs additionally extra focusing to force the particles to remain on the "central" trajectory. A particular type of magnets used to squeeze or focus the particles closer together to increase the chances of collisions, are termed "quadrupoles." Quadrupole magnets act on the beam of charged particles in exactly the same way as a lens would act on a beam of light. As the name suggests, a quadrupole has four poles, (two North and two South) arranged symmetrically around the beam (Figure 8). There is no field along the central axis. A single quadrupole focuses in one direction, defocuses in the orthogonal direction. Thus two lenses must always be paired and a series of alternatively focusing (called "QF") and defocusing quadrupoles (called "QD") provide the horizontal and vertical focusing needed to contain the beam in the transverse, X and Y, directions (Figure 9). By locating them right next to the collision detectors, physicists use quadrupoles to direct as many particles as possible to a tiny area at the center of their detectors, called the "interaction point."



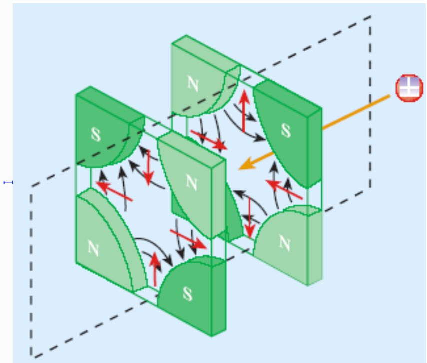


Figure 8: A quadrupole magnet. **Figure 9: Two quadrupoles together.**

In addition to the dipoles and quadrupoles, the LHC is equipped with hundreds of other, smaller, magnets for correction of dipole imperfections, synchronizing the optics and the final focus. Most of the LHC magnets are "superconducting." Superconductivity is the ability of certain materials, usually at very low temperatures, to conduct electric current without resistance and power losses, and are, therefore, able to produce high magnetic fields. The LHC superconducting cables are made of a special alloy of niobium-titanium (Nb-Ti). To keep them in a superconducting state, that is, efficiently conducting electricity without resistance or loss of energy, requires chilling the magnets to about -271°C – a temperature colder than outer space! For this reason, much of the accelerator is connected to a distribution system of superfluid liquid helium at a pressure of 1.3 atm (atmospheres).

In all there are 1232 dipole magnets located on the eight arcs of the ring, each of the dipoles having a length of 15 meters. "The 15 meter physical limit to the dipole length was determined by the maximum length allowed by regular transport on European roads."[52] On the other hand, the maximum operational field was fixed at 8.3 Tesla "which has its roots in the realm of quantum mechanics rather than in European Union regulations," Evans remarks in typical physicist fashion.[53] The construction, transportation, delivery and installation of the dipole magnets is a huge success story, since it had to cross a number of logistical, civil engineering, legal and financial hurdles. A number of issues of the *CERN Courier*, CERN's monthly journal since 1960, provide snapshots of the different phases of the LHC magnet design and development process.[54]

[52] Lyndon R. Evans, *The Large Hadron Collider : A Marvel of Technology* (Lausanne, Switzerland; [Boca Raton]: EPFL Press ; Distributed by CRC Press, 2009)., 74.
[53] Ibid. 74.
[54] Research European Organization for Nuclear, "Cern Courier," *CERN courier.* (1959). See in particular issues of Jan 26, 2004 "LHC dipole production begins to take off," Sep 7, 2006 "LHC dipole installation gets to half-way mark," Oct 5, 2006 "The longest journey: the LHC dipoles arrive on time," and Jun 4, 2007 "The last dipole makes its descent."

Now we arrive at an interesting juncture of the LHC saga, one where we find how engineering considerations work alongside local operational conditions. These conditions are negative in the sense that they designate less what the features are than what they are not. The problem facing the Hadron Collider during design and construction was the following: the maximum energy attainable in a circular accelerator depends on the product of the bending radius in the dipole magnets and the maximum field strength attainable. In order to bend two beams and generate field strengths in opposite directions, a large area is required. However, the diameter of the existing LEP tunnel at 3.8 meters posed a severe constraint. Due to the small transverse size of the tunnel, it was deemed impossible to fit two independent rings. Since the bending radius is constrained by the size of the tunnel, the aim was to have the magnetic field as high as possible. The challenge was how to confine two counter-rotating proton beams, two separate magnet apertures, with opposite field orientations squeezed into the 3.76-m diameter of the existing LEP tunnel?

The grave challenge of space limitations in the tunnel, and the need to keep costs down, led to the adoption of a novel and elegant "two-in-one magnet" design. Two-in-one magnets can have windings for two beam channels accommodated in a common cold mass cryostat since magnetic flux is circulating in opposite directions in the two channels. At the same time, the design provides a compact structure that fits two separate beam apertures into the relatively small existing machine tunnel. However, this makes the magnet structure far more complicated because the separation of the two beams has to be small enough so that they can be coupled both magnetically and mechanically. The two beam pipes are separated by a mere 19 cm inside a common iron yoke (which returns the magnetic field) and the cryostat.

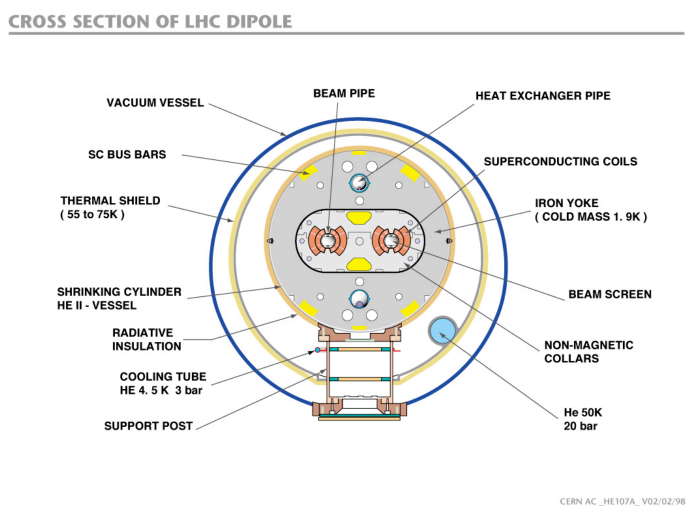


Figure 10: A cross-section of a two-in-one LHC bending magnet.

What we see in the image above (Figure 10) are the basic elements of a dipole magnet: the superconducting niobium-titanium coils, which are carefully arranged to achieve as pure a dipole field as possible, necessary to guide the two counter-rotating proton beams in separate magnetic channels. The superconducting coils are held in place by a mechanical structure called "collars," which keep the coils in position to prevent any movement during powering of the magnets. The coils and the collars are surrounded by a cylinder of iron, actually low carbon steel, called the "yoke," which carries the magnetic flux.

> "The LHC is very innovative, compared to the SSC [Superconducting Super Collider, the last collider project] which was based on a very conventional magnet design. This is the first time that the two-in-one magnet design has been built, so there is no existing experience to build on. The concept of a two-in-one magnet goes back to renowned accelerator physicist, Bob [Robert] Palmer, of Brookhaven. But nobody had used it. It was invented in Brookhaven but we developed it… In the late 70s we decided to use it. It made perfect sense for the LHC because it is a p-p [proton-to- proton] collider and so the magnetic field is up in one aperture and down in the other aperture. You couldn't get this to work with p - $\bar{p}$ [a proton-anti-proton collider]. The requirement that the fields must be in opposite directions in the two apertures [for a proton–proton collider] ensures that there is no saturation of the central part of the yoke. This simple geometry of flux lines makes possible the exquisite design of the LHC two-in-one dipole structure."

The innovation in the accelerator design was described by accelerator physicist and celebrated LHC Project Leader, Lyn Evans. For fourteen years he has been the principal person in charge from the conception through the prototype to the construction stages of the Large Hadron Collider. "It's a fantastic job that's been done to build it, an enormous effort of thousands of people in numerous laboratories," he said. "It's a triumph. The machine is working."

7. Particle Acceleration and Electric Fields

In the section above I reviewed how magnetic fields are able to provide deflection to particle trajectory. However, magnetic fields do *not* change the overall particle momentum. In this last section, I shall take up particle acceleration, or motion in the longitudinal plane. Electric fields (not electrostatic fields, but a dynamically changing field) guided by the "RF," or radio frequency, system is the technique used to accelerate and stabilize proton beams. A longitudinal oscillating electric field is introduced at a radio frequency of 400 Megahertz (MHz) in a set of resonant cavities. Radio frequency waves are selected because the electric field can be fed into cavities whose dimensions are chosen to support a resonant standing wave. The RF power creates an alternating electric field along the particle path, where radio waves push particles to ever-higher energies, much as ocean waves help a surfer gain speed.

The electric field in the cavities is extremely high, in excess of 5 million volts per meter. The cavity itself is basically a sphere with two openings to allow the beam to pass through. The key consideration here is that as the particle beam travels from one gap in the resonator to the next, it must stay "in phase" with the RF wave. If the RF frequency is an exact multiple of *h*, the revolution frequency, then the beam always arrives at the same amplitude and the correct polarity. In this way, radio-frequency cavities are capable of generating an extremely steep electric field gradient allowing for rapid acceleration.

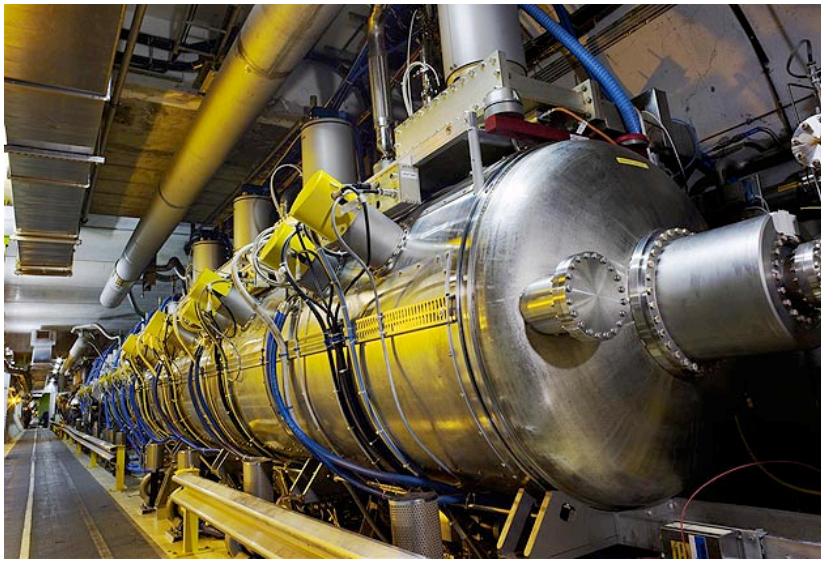


Figure 11: Superconducting radiofrequency cavity in the LHC tunnel.

The RF system of the LHC has 16 superconducting accelerating cavities, eight per beam, which generates an electric field oscillating at 400.8 MHz (Figure 11). The entire RF system of the LHC is located at Point 4. For RF acceleration, the beam has to be bunched in time and the bunches must be kept together as they travel through the accelerator. This condition requires that the RF frequency, *f*, and the magnetic field, B, must both be changed as the beam energy increases. B must be "ramped up" until the beam reaches its final energy. What occurs is the following: the beams are injected into the LHC in stages through four machines. The protons on the LHC start their journey when they are produced from a "duoplasmatron" device. Then, the protons enter the **"**LINAC," a machine from where they are transferred to the SPS (Super Proton Synchrotron), where they are further accelerated upto 450 GeV, and finally injected into the main LHC, first in one ring and then into the other. When the two rings are filled, the magnetic field of the LHC is slowly ramped up and the beams are simultaneously accelerated by the RF system, which keeps them in the center of the vacuum chamber as the magnetic field rises. After about 20 minutes the beams reach the nominal collision energy of 7 TeV. They are then steered into collision sites in each of the four detectors, where experimental physics and theoretical physics take over.

The contrast in the two key principles responsible for particle deflection and acceleration cannot be sharper and the synthesis cannot be neater. The RF cavities, which generate the electric fields, are responsible for the feat for acceleration of the beams. Magnetic fields provide deflection to the proton beams. This substantive determination follows from a simple difference: electric charges can be isolated and separated. They can be distributed or concentrated at a point to form positive (+) charges and negative (-) charges. On the other hand, the magnetic field is a dipole field. A magnet always has two poles, north and south. There is no magnetic monopole like electrical monopole i.e. point charge and the flux lines move continuously. This difference, due to the separation of electric charges and the non-separation of magnetic poles, takes care of two functions of paramount importance to a particle accelerator: accelerating and steering the beams.

While the principles of electric fields and magnetic fields work in different ways, and require completely different skills and personnel, they are brought together in the instrument. The geometry of continuous magnetic fields makes it possible especially for the LHC – a proton-to-proton collider – to accommodate electromagnetic fields in a single mechanical structure without saturating the field in the yoke. Gijsbert de Rijk's insistence that one should comprehend the phenomenon of particle acceleration "as an absolute realization of Maxwell's unification of electromagnetism" finally begins to make sense. The material foundations, the civil engineering constraints, the costs of design, and the optimization of machine parameters are crucial and enduring elements in a mode of practice, which remain separate from the processes and outcomes of the instrument.

The engineering mode of accomplishing, with its principles of precision and excellence, conveys a prodigious conception of ideals crafted in the concrete. It corresponds to a notion of work that is personal and perfect, and is finished but never complete. The execution of work follows to the end point where aspiration and grease meet. It exemplifies Aristotle's characterization of *praxis*: action that does not have an end, it is an end. Accelerator physics and engineering has a literalness and an earnestness, which no other branch of knowledge can rival. We may well doubt the arbitrary character of units or the neatness of abstract principles. However, when faced with the efficacy of the instrument, the distinction of science (nature) and fable (history) dissolves. The whole endeavor is made human and superhuman at once by the same principle of idealization and perfection.

Chapter Five: Science Criticism

I remember Menard used to assert that censure and praise were sentimental operations which had nothing to do with criticism.

Jorge Luis Borgess

Few ventures have suffered more by popularization than the enterprise of science. The public perceives in the pursuits of pure science impractical minds that divert attention from pressing concerns. Online wikis, blogs, and forums deplore the drain of money in the advancement of "Big" science when the world gropes with survival issues. The humanist finds in science an intellectual arrogance that conceals the emptiness of its endeavors. The protest includes an interrogation of the foundations of truth and reason in what is essentially perceived as a will to power. The scientist bemoans the loss of a vocation into a profession especially as the demand to accommodate public interests appears at odds with the preoccupations of experimental inquiry. All these facets of perception – decadent intellectualism, manipulative vaingloriousness or impoverishing professionalization –disclose that the meaning and purpose of knowledge have diverged once again.

Yet nothing is of greater interest to anthropology than the mood that popularization encloses, which provokes rather than satisfies any systematic explanation. For popular verdict knows no barriers of disciplines. It seizes with a sudden vision and intuition and questions the positive determination of the physical world that the sciences provide. Seen from this perspective, popular questioning does not equip us with new insights or elaboration but affords instead a resolution of existing problems and methods of science. On the one hand, any effort to divest scientific positivism of progress, to assault technical or specious arguments or to encourage public participation in expert cultures, constitutes a critical response and, upto a certain point, forms a vital function of intellectual life. On the other hand, it constitutes an insurrection from beneath, a refutation of exiting categories in favor of new ways of imagining the world, which alert us to the possibilities of a different world.

The trouble, however, of such efforts is not their motivation for reform but their misrecognition of the very divided foundations from which they spring and which they must overthrow in order to succeed. In the organization of every modern institution there runs a systematic duality of the symbol and the instrument, or culture and power. Against this duality, the public's outcry is doomed to defeat not because science defends a knowledge that is powerful and glorious to which an enlightened public lacks access, but because the public does not question the content of science, merely its utility or application. The popular protest against natural science must avail not only the freedom to debate its practical use or moral worth, but also the freedom to renounce all the prepossessions of our thought, and to debate afresh how the world can be grasped or known.

Yet so strong is the pull of passions over the intelligence that even anthropology, whose special task is to question and oppose any accepted classification of knowledge and seek instead the basis of a classification and normative order, overlooks the distinction inscribed in the heart of modernity, as the popular imagination does, of symbol and power, communication and domination. For instance most critiques of science remain caught within this dualistic framework. In order to challenge the theory of quarks or blackbody radiation, it must find them to be constructed across language-games and paradigms. In opposing the bomb, on the other hand, we are up against real power and real effects. I do not mention this paradox in order to jeer at social constructivism or political protest, but to show that behind the process of modern thought and practice to shift from one register to the other, between symbols and effects, there remains for anthropology the task of critiquing science with a different set of assumptions which may lead us to new forms of classification.

In the present time when we are witnessing a declining constructivism and an ascendant positivism, we can give form to a third mode of critical inquiry, a post-constructivist anthropology of science. The new mode has to fight against the opposite forces of constructivism and positivism as well as provide a new methodological foundation to nature, truth and society, if it is to be more than a compromise. In occupying completely new ground, we must not be weary of attacking the truth and credibility of science. No matter how powerful and efficacious science may be, it consistently transforms as real not only what is ideal, but also what is purely symbolic. The exchange between subject and object, transacted entirely in favor of the object, cannot take place without the acrobatics of mathematics. To grasp and adopt facts of measurement and experiment works only because human judgment forms the dynamic center of this activity. These conclusions against the content and status of science have been drawn with full blaze and force. Now is the time to take the decisive step and combine the critique of science with the problematique of knowledge. I shall term this labor "science criticism."

Close as the relationship may seem between criticism and science, the two remain sharply distinguished in their outlook on the meaning and task of science. Whether and to what extent can science and science criticism unite despite their opposition is what shall be explored in the next few pages. In undertaking this venture, I shall fall upon the evidence of my fieldwork, and my own understanding, and the shortcomings of either will occasion the intrusion into some other discipline such as philosophy or history. A note on the organization of the chapter. I had to decide if it is wiser to start with fieldwork data, which is vague, complex and indeterminate, or with the foundations of knowledge, such as logical principles and relations by which the intellect organizes the world. After some thought, I decided to begin with the relationship of art and science – an act of classification - that connects to the principles and presuppositions of knowledge. Recently CERN initiated a move to bring together art and science under the same roof. In this orientation, a number of interesting questions arise. The foremost among them to my mind, is the question of how to understand or resolve the logical notion of difference. Are art and science intrinsically alike or inherently different?

I shall begin the chapter with the question: how do art and science comprehend their relation to human and non-human nature? In considering this question, the emphasis will be the complete contrast or difference of scientific observation and aesthetic contemplation. Instead of resolving it here, I will raise the relation of art and science to another level – to symmetry and form. Here again the key element is the concept of difference, but in this case, difference produces true unity. So we have on the one hand, a difference of perception, such as between art and science, which leads to complementarity, and in another instance, the perception of difference, as in symmetry considerations, which leads to unity. However, the aim of counter posing these two instances is not to show some simple or steady progress but to show in a mode of reversal that while the differences between science and art generate their proximity or complementarity, the differences of science and social science prescribe their mutual separation and competition. Therefore, true participation, not mere conditioning or influence, is only possible when relations of difference are affirmed and acknowledged, as in the middle ground of symmetry considerations, which constitute the spine of physics.

The objection might be that such participation does not affect the reality of experience or that science may in future forfeit symmetry principles and make claims to truth on some other basis. Well what can be of more interest to the anthropologist seeking the genealogy of science as the shadowy form of a problem which makes science seem noble when dealing with matters of facts and makes it absurd when approached as an object of intellectual classification. The tortures of pretension or expediency of facts, which should be a burden to any human sensibility, intellectual or otherwise, become for us elements of interest because they allow us to inquire how is the relation of signs and things set up. In other words, the purpose of the exercise is to establish an adequate formulation of the principles of knowledge, which does not cut through the nerve of everyday experience or scientific truth, but guarantees the validity of experience or truth as such. The method is not unlike Platonic cosmology where objects are perhaps diffuse and vague to begin with, but become useful and abundant in their suggestions.

1. Pure Science and Fine Art @ CERN

"CERN has a new cultural policy." The *CERN Bulletin*[1] boldly informs its readers of a new policy, which represents "the first official framework for CERN's engagement with the arts." The new cultural policy features four main activities: (1) the creation of an honorary advisory board, (2) the launch of an "Artist-in-Residence" program, (3) support for the various cultural events developed at CERN, and (4) a new website which will showcase CERN's significant cultural activities and provide relevant information for both artists and people working at CERN. The new Cultural Advisory Board comprises of internationally recognized figures in the arts, including "Serge Dorny, Director-General of the Lyon National Opera, Frank Madlener, Director of IRCAM, and Beatrix Ruf, Director of the Kunsthalle in Zurich and listed in Art Review's Top 20 Most Influential people in the Arts." The board will provide expert advice to the Director-General and CERN staff, judge artists' applications utilizing a formal commissioning process, and provide professional guidance for CERN's larger initiatives on missions of art and culture.

Essential to the new cultural policy is the inauguration of "*Collide*" – an international Artist-in-Residence plan - in which "artists will come every year from different art forms to engage with scientists in a mutual exchange of knowledge and understanding through workshops, lectures and informal talks, and to begin to make new work."[2] Ariane Koek, CERN's Communication Group's cultural specialist, has been key to this project. She has been fundraising and building partnerships with external art agencies and organizations to help materialize the Artist-in-Residence scheme. The effort builds on the immediate event of Josef Kristofoletti, an artist, who painted a part of the Large Hadron Collider on a mural at CERN in October 2009. Kristofoletti is an artist drawn to hard science. In order to gain access, the artist had to cross "a labyrinth of red tape and bureaucracy: Funding limitations. Safety clearances.

[1] Katarina Anthony, "Cern Has a New Cultural Policy," *The Bulletin* 13 December, 2010.
[2] Ariane Koek, "Viewpoint: Collide – a Cultural Revolution," *CERN Courier* July 7, 2010.

Legal hurdles. Training courses."[3] He worked closely with the scientists on the design and painted a three story tall mural of the ATLAS experiment. "It was a long process, Kristofoletti said, but thrilling to have a subject so epic in both scale and concept, a 'cathedral of science,' he calls it."[4] And now with the ATLAS experiment no longer open to visitors, since the experiment is running, the mural has become a stopping place on CERN tours for the public.

In keeping with its professional character, CERN is not satisfied with any unsystematic attempt or informal arrangement but seeks a formal expression and commitment in its invitation to art. It is emphasized that the engagement with art would involve no tampering with the instrument, the LHC or the experiments. Critical to the official engagement of art and science is transparency and accountability. Collaborations between CERN and dancers, writers, artists and film-makers have been ongoing, but more or less on an ad-hoc basis. As Koek explains, "Artists normally visit because they know someone who works at CERN. So the process isn't very transparent – which is in contrast to the way the rest of CERN works."[5] Her aim is to set up an efficient and open system to bring artists to CERN, which is why a board of experts has been set up who will select the projects and the individuals. The goal is to invite artists who dare to think about the invisible, "and the impossible", and make it visible and possible.

The movement between the visible and the invisible, which reveals an inner kinship of mind and reality, is viewed as a particularly potent common ground between science and art. This is something that informants often allude to. For instance, in astro-particle physics the hypothesis of "dark matter," or matter that is not visible but is inferred as existing, is used to explain the anisotropies observed in cosmic microwave background or the anomalies observed in galactic rotation. Or consider the postulate of neutrinos advanced by Pauli in 1930 to explain the principle of energy conservation in beta decay. He theorized that an invisible particle - the massless chargeless neutrino – had to be present in the reaction, which was carrying away the observed differences between the energy, momentum and angular momentum of the initial and final particles. Such invocations of the invisible are also believed to have a strong parallel in art. For example, Dali's painting titled "Surrealist composition with invisible figures," show the lack of a concrete figure of the human body which is simply indicated by the shape left on the bed[6] or Picasso's painting "fruit bowl, violin and bottle," discloses fragments of a newspaper or the wineglass indicates a table top in much the same way as the deflection of radiation is inferred from the motion of galaxies. These sorts of explorations into the invisible, prefiguring much of modern physics and art, shows an inner kinship of art and science, that goes beyond simple presence or reality.[7]

The unorthodox effort of CERN in creating a partnership of artists and scientists - unorthodox or extravagant from the perspective of a pure science laboratory - is based on the critical premise that art and science are not distinguished, not even opposed, but harmonious and united. Awe, imagination, obsession, passion, defiance are cited as some of the attitudes which

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[3] Jenny Marder, "At Cern, Art Collides with Science," http://www.pbs.org/newshour/updates/science/july-dec10/cern_12-01.html.

[4] Ibid.

[5] "Where Science and Art Collide," *The Bulletin* 7 September, 2009.

[6] Michelangelo Mangano, "Visible and Invisible in Modern Physics," (2010).

[7] Of course while mental processes such as methods of deduction and reasoning are admitted, the mind is denied any presence in science, which makes it exceptional and different from any undertaking in art. I will get to the exception shortly.

are common to both vocations and which makes artists and scientists the perfect partners. The selection of projects and people in both follow institutionalized peer-review procedures. There are strict criteria in judging and evaluating both works of art and science. Lastly, the arts and the sciences both pursue "nature" with intense effort and longing. "The arts and science are kissing cousins. Their practitioners love knowledge and discovering how and why we exist in the world. They just express it in different ways."[8] Given the essential similarities in their outlook and goals, the partnership of art and science, carried out through the scheme of Artist-in-Residence, is deemed mutually sustaining and rewarding.

The reader will likely recognize in the new cultural policy and the artist-in-residence scheme an element of celebration and propaganda for it is meant to showcase "how much CERN values its significant role in culture."[9] "The director-general, Rolf Heuer, has the vision and the wish to express the crucial inter-relationship of arts and science that makes culture." The discourse operates on the explicit recognition and commemoration of science. Science is approached from the point of view of an enthusiast or an aficionado, i.e., someone who is impressed by the "impact of science" in our lives. The argument usually takes the form of what can be more significant in science today than the highest-energy collisions of the Large Hadron Collider, a project that has been in the making for decades, in which case it is only fitting that paintings are made depicting the accelerator and the detectors, capturing the process, vision and power of science. Such events of commemoration are not unknown in history and show continuity with the best or the highest in artistic tradition, such as da Vinci's Last Supper or Diego Riviera's Mexican Revolutions.[10]

The formalization and the launch of the Artist-in-Residence program took place just when I was wrapping up and preparing to leave the field, in the winter of 2009. I had the opportunity however of meeting Arianne Koeck during a couple of lunches, owing to Michael Doser, an anti-matter experimentalist and my key informant, who is also involved with the launching the program. I got to know Michael very well in the course of two and a half years and know of his passion and hobby for art, as well as his wife, a renowned artist, Sylvia Wyder. Arianne holds a degree in English literature and journalism, and has a long and distinguished history working as a producer of television and radio programs for the BBC. Before joining CERN as a cultural specialist, she was the CEO of a creative writing foundation in Britain.

In December 2009, on the occasion of Arthur Miller's visit to CERN, a special lunch was held in the cafeteria's "glass box."[11] About a dozen people were invited.[12] During lunch, the similarities and differences between art and science came up in conversation. The discussion followed the by-now familiar (to me) pattern with comparisons alluded to between two

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[8] Koek, "Viewpoint: Collide – a Cultural Revolution."
[9] Anthony, "Cern Has a New Cultural Policy."
[10] The comparison of paintings of the Large Hadron Collider with Leonardo Da Vinci's Last Supper. Diego Rivera's Mexican revolutions is from Ariane's online blog. Ariane Koeck, "It's Only a Matter of Time..." in *http://wwwbeautyquark-beautyquark.blogspot.com/* (19 August, 2010).
[11] These "glass box" lunches – named owing to a portion of the main cafeteria marked off by glass walls - were organized when high ranking dignitaries, notable scientists, and other luminaries came visiting CERN for talks, book launches, meetings etc. Arthur Miller, a historian of science, was visiting CERN to give a talk on 10 December 2009 titled, "The Strange Friendship of Pauli and Jung – When Physics Met Psychology."
[12] Arianne Koeck, Beatrice and a couple of others from the Press Office, along with physicists Luis Alvarez-Gaume, Michael Doser (and his artist wife, Sylvia Wyder), Cesar Gomez, and Mike Lamont were present.

extraordinary figures or “geniuses” of the twentieth century, Einstein and Picasso, how art and science explore nature, and the dismay of physicists at the prices paintings fetch in the market. When the discussion shifted from this general level to the specific plan of the Artist-in-Residence at CERN, the attitude quickly changed from pedantic orations to banter and laughter. “We should have a chef-in-residence. That is more needed at CERN.” “Who will the artist observe? What will be his muse – particles or people?” This sort of banter is fairly common at mealtime conversations, since the work environment of the laboratory is conservative. New ventures, if they not concerned directly to physics, do not get easy acceptance as serious proposals, such as my own presence, and become occasions for the display of wit and humor. Apart from the lunch discussion, the event of the Artist-in-Residence at the time did not elicit widespread response, although, as I said, that was the time when it was just being launched. So most of the physicists didn’t know about it and when I shared the details, they didn’t seem to care about it.

Here in this initiative of CERN we find an institutionalized effort of bringing together professional artists and scientists in close proximity. There is a board of experts to regulate and monitor the process. It is not merely a token relation, but one involving monetary investment and reward. There is an obvious element of mutual interest and propaganda. But above all, the exercise is recommended as a precursor to future initiatives involving the relationship of a “fundamental science” with other disciplines. In keeping with the trends of dialogue and engagement in contemporary intellectual life, the venture is touted as favorable and desirable. With these last observations we are in a position to move beyond the immediate reality of the cultural and art policy unveiled at CERN. The question really is: what are the assumptions or the ideals of classification of knowledge of modern thought and practice, which enable a laboratory of pure science to engage meaningfully with art? On what methodological grounds are art and science considered worthy partners? Would science be equally enthusiastic about engaging with the social sciences?

As I see it, two problems arise at the outset of the discussion: the first, which I shall not probe in any detail, involves the problematical use of the concept of culture. In the policy, the term culture is considered as a synonym of higher forms of creativity, as though culture is the same as being cultured or civilized. On these grounds of consideration, the definition would exclude significant segments of any population as having a culture. Again prior to the launch of the new cultural policy, the only time an explicit recognition of culture was made by the laboratory was in the routine serving of food in “Restaurant 1,” its main cafeteria, on Mondays and Tuesdays. Every Monday, in the vast dining hall, the menu features “kebabs” for which one of the chefs dons a Turkish hat while handing out the kebab plates to impatient and long queues. On Tuesdays, the menu features “Asian curry” and a woman, sporting a dress with a Chinese collar, stands behind the counter to serve the people. Note that on Wednesdays or Thursdays the two chefs are not serving. Instead they can be found inside the kitchen, cooking European meals, this time without the “ethnic” hat or the dress. Scarcely has the imagination worked in more standard ways than the discovery of culture in customs of food and dress. Yet this insipid display is not meaningless. A scientific community that can rarely admit culture in any immediate or meaningful way should do so in the daily round of commensality shows that there is an understanding between matter and spirit. Were the notion of spirit not fused with that of living substance, it could never carry out the suggestion of detachment with inert matter. Here it is interesting to observe that after forfeiting human nature from the significant part of their working lives, they became conscious of it in the humble variations of dining and dress.

The second, and more significant, concerns the engagement of fine arts with experimental science, and the *exclusion* of industrial arts from this exercise. Undeniably, the fine arts are the most cultivated of all the art forms. But so far as giving form to matter is concerned, the industrial arts give a more propitious form than the fine arts. Then it is surprising to find that not only is the distinction and separation of fine art and mechanical art, elsewhere in the scholarly literature attacked and eliminated,[13] tout court accepted as valid in CERN's venture, but why should the new policy completely overlook the mechanical arts from its program or vision? This is a very revealing oversight. It indicates how entrenched the opposition of theory and practice is, and serves to affirm the significance of grammar and habits, or the sphere of unconscious intellectual presuppositions, as I have been emphasizing so far. If practices are all there is to study for social anthropology, we should be left wholly in the dark on the oversight of applied arts in a laboratory of pure science. I will have more to say on this subject in the next section but here I simply wanted to highlight the general orientation of CERN's "new cultural policy."

During the time I was engaged in fieldwork, my impression was that science is not weary of engaging with art. On the surface, they appear as different as chalk and cheese, but a little reflection also reveals their inner harmony and unity. The extraneous exploration of nature in physics goes well with the manifestation and celebration of its inner pulse contributed by art. In fact, there is very little that is challenging or confrontational in the relation of art and science, although some of the wives of the physicists tried to convince me otherwise, that at home it was *battle royale* between them, their artistic temperaments, and their husbands, steeped in the scientific temper. Certainly the way in which the Artist-in-residence program has been conceived and executed, points to commonality and cohabitation rather than conflict or discord, which is why within a few months, the creative team had launched the program at CERN with utter seriousness and success. How do we understand the intellectual nerve of this engagement of art and science is what I propose to address next.

2. Nature, Aesthetics and Science

The ambitious title of this section leads me immediately to the recognition of limitations that such a task must involve.[14] The aim is not to give a historical account or a philosophical perspective, although elements from both are present, but only to the extent that they aid in formulating the question: how can art find a spot in a pure science laboratory? In responding to the question, we need not go over the ones that informants give – that the cohabitation of art and science is desirable owing to their temperamental similarities, their productive symbiosis, or at any rate, to their possibility, as an experiment. Instead the aim is to analyze, as a problem of classification, what enables this experiment or what makes them complementary. In other words, diagnostics, not therapeutics, shall provide the thrust to the inquiry. The emphasis will be on the form, not features, of differences, similarities, proximity or separation in the consideration of art and science. To this end, I shall use the analysis and explanation provided by Kant. I have opted

[13] Arthur Coleman Danto, *Beyond the Brillo Box : The Visual Arts in Post-Historical Perspective* (New York: Farrar Straus Giroux, 1992); George Santayana, *The Life of Reason; or, the Phases of Human Progress* (New York: C. Scribner's sons, 1905). Reason in Art.

[14] In these pages I have relied extensively on commentaries by Cassirer and Santayana for the comprehension of art in different historical periods and perspectives and on Russell and Weyl likewise for science.

for Kant, rather than Hegel or Goethe, since Kant is the first to make a serious and systematic attempt in illustrating how aesthetics is not an isolated experience but equips us to have any experience in the world.

In the following paragraphs, I shall give a summary of Kant's inquiry into aesthetics, his explanation on the faculty of reflective judgment, and the objects about which such judgment is made ("fine art"). Kant's *Critique of Judgment* is a response to the question: is art a sign of truth or a sign of illusion? Is it an imitation or a free creation? In finding a garden or a painting beautiful, what sort of a judgment is involved? Kant finds four criteria at the basis of our sense of beauty.[15] First, the contemplation of beauty is disinterested. It does not gratify our senses and passions. The impersonality of enjoyment implies that art is indifferent to the real existence of the object of representation. However, this should not lead us to think that art is wayward or subjective. Here Kant furnishes an argument that seems radically counter-intuitive, namely, that the essence of aesthetics is its universality. He recognizes that in no area of life do we come across greater disagreements between people than in aesthetic matters. Yet he maintains that the experience of beauty is universal. This occurs in the following way: with aesthetics we enter a new realm where we shift from desire into pleasure, from concepts into rules, and from autonomy into society. Contrary to the universality underlying the categorical imperative, aesthetics is not grounded in the conceptual exercise of reason but in the social community of pleasure, undergird by rules by which it becomes universal. The universality of aesthetic appreciation passes into the third characteristic – that of finality without an end, or purposiveness without a definite purpose. Beauty is equivalent neither to utility nor perfection but is still purposive. Lastly, the experience of beauty is necessary since it presupposes principles of universal validity such as found in common sense (*sensus communis)*.

From Book I of *Critique of Judgment*, we can extract the chief argument of aesthetic creation, that it is a process of pure spontaneity. Art does not mimic or imitate an existing relation to given objects, but posits or recasts these objects in a whole new light and sensibility. In that sense, art requires no object. While alive to everything, it is indifferent to the real existence of the object of representation. Everything turns on the meaning and coherence, which the artists can bestow to this representation relying on their faculties of imagination and understanding.[16] The content of art requires neither a ground nor a goal outside itself. In a crucial respect, fine art, although produced with a definite design must not seem to be designed. Instead, Kant believes, it "must look like" nature. This leads to a perplexing observation, one that I have not understood or resolved fully. The confusion is the following: in what sense is there a difference between natural beauty and artistic beauty? There is no doubt that there exists a difference because Kant introduces the "genius" as the one who mediates between nature and art: "Genius is the talent (natural endowment) which gives the rule to art. Since talent, as an innate productive faculty of the artist, belongs itself to nature, we may put it this way: genius is the innate mental aptitude through which nature gives the rule to art."

[15] Immanuel Kant, *The Critique of Judgement*, trans. James Creed Meredith (Oxford: Clarendon Press, 1952).

[16] This part of Kant's argument has been attacked from all sides. It is argued that the cultivation of taste is not justifiable on autonomous grounds, that art is an objective or ontological vision that constitutes the climax of the history of the human spirit (Hegel) or that the value of art is extrinsic, directed to the purpose of life (Nietzsche), and so on.

Here Kant's argument appears to emphasize the *difference* between art and nature. Although art may have nature as an object of representation, the form and the mode of representing this object follow from the power and freedom of the mind. Art is not an imitation of nature; nor is the artist a craftsman copying the beauty of nature. Nature is a force that pulses through all living beings. It is autonomous. However, it speaks in the language of symbols and bewitches and engages humans. Art becomes the expression of the longing for unity with nature. The work of art obeys conventions, which have no counterpart in nature. In art we move away from depiction or representation to construction or conscious formation. Instead of reproducing outer nature, art is a reproduction of inner nature. These aspects of Kant's treatment of the aesthetics were to have a profound influence on later Romanticism. Romanticism too dismantled the notion of art as simply imitating nature and explored in detail how the notion of art goes hand in hand with a total reevaluation of the concept of nature, and how it connects to the generative activities of the mind.[17]

By now the complete contrast of art and science should be evident. Artistic production is stamped through and through by the signature of its author. It follows from the imagination of its creator, the spontaneous overflow of feelings. On the other hand, in order to be valid, modern science must reproduce nature without participating in it. Einstein said it plainly, "The belief in an external world independent of the percipient subject is the foundation of all science."[18] Science conveys the objective concept of nature: the record of empirical detail, the causal connections, comparisons and measurements, without the perceiving subject. Somehow to see this process in all its richness and from within becomes the privilege of art. Art presents experience in its immediacy and apparent groundlessness. There is no possible totality in the aesthetic experience for there is no known ground.[19] Turn to science and the difference is glaring. It is object, substance and ground all along. All other features of a comparison between art and science go by the wayside beside this singular difference of the two.

Now the question arises: is this contrast the reason why art and science can be complementary? Here also the point of view of Kant, and the Romantics who later followed him, is interesting and important. But before we consider their views, we must note that curiously enough the finest romantics avoided giving a one-sided interpretation of art as an emotional outpouring, or carrying the germ of limitless subjectivity. Aesthetics is not simply emotive or expressive. It is formative. And the formation is carried out in a certain medium and material. The formative principles are not to be sought in our emotional constitution, although it is true that without being capable of deep emotions, an artist can never produce great art, but in the structural aspects of perception – in design, techniques, form, and colors. The orientation of purposiveness is necessary for artistic production, as Kant reminds us.

Therefore, what explains the complementarity of art and science is the link between aesthetics and teleology, as Kant posited. Kant's interest in the faculty of judgment is not prompted by concrete characteristics of particular objects. For him the problem is not of explaining the occurrence of purposive objects in art or nature. What he wants to discover is the orientation of knowledge when it judges something as purposive. In art we make a judgment

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[17] Tzvetan Todorov, *Theories of the Symbol* (Ithaca, N.Y.: Cornell University Press, 1982)., Chapter Six.
[18] Einstein, "*Maxwell's Influence on the Development of the Conception of Physical Reality*," in J. J. Thomson, *James Clerk Maxwell; a Commemoration Volume, 1831-1931* (Cambridge [Eng.: University Press, 1931)., 66.
[19] As Kant said, art is "indifferent" to the real existence of the object of representation.

about sensibility or intellect itself rather than about the objects disclosed to the senses or the intellect. The justification and the objective validity of such judgment is all that is in question. "The assignment of the teleological and the aesthetic problem to a unitary critique of judgment finds its deeper explanation and foundation only here."[20] By occupying this meeting ground, where judgment forms the "middle term" between understanding and reason, the theoretical and the practical, the universal and the singular, art becomes more central to human self-understanding, more than either philosophy or anthropology.[21]

The initial attempt to invoke Kant to resolve the relation of art and science configured at CERN may seem far-fetched on empirical grounds and dubious on rational grounds. For isn't it the case that modern physical science is without *telos*, its truth is conceived in terms of conventions of internal coherence and the only finality admitted is that of calculability and predictability? The value and proof of this suspect attempt to abide by Kant's approach and method will be explained in two different steps. On the one hand, the synthesis of art and science will be taken up in the content of science itself, in the realm of theoretical physics in the concept of symmetry. On the other hand, it will be tried in the critique of science, in the social classification of knowledge. In these different steps, it will be shown that the substantive and methodological operations of art, science and society, can be (a) reduced to judgment, which (b) consists of a very basic relation, of contrast or difference. The relation of contrast is so potent that it not only infuses physics, aesthetics, culture or politics with their specific form but it also sets up their mutual exchange and interrelations.

3. Symmetry: Aesthetics in Science

Since the revolution in the seventeenth century, which ushered in modern science, there has been a complete refashioning of the content of physical science. The relativity of space, the concept of matter-fields, the unification of forces, etc stand far, far away from the geometry of space, matter and extension or luminiferous ether. But so far as the applicability of scientific methods is concerned, such as its methods of observation, deduction, experimentation, measurement, they remain largely in accordance with the seventeenth century.[22] As a consequence of its victorious methodological orientation, knowledge of nature even today does not imply encompassing every object in the universe, but rather "the identification of the fundamental laws that determine the behavior of the physical world."[23] This is exactly consonant with Galileo or Bacon's vision of science. Perception and phenomena form the starting point of physics; analysis and explanation constitute its goal.

In this goal, certain aesthetic notions such as symmetry, simplicity, elegance or perfection

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[20] Ernst Cassirer, *Kant's Life and Thought* (New Haven: Yale University Press, 1981)., 284.
[21] This is a very interesting point, which I will take up in the fourth section.
[22] The only significant controversy in method has been between the rival processes of observation and measurement provoked by quantum physics. Both, however, have been resolved in favor of the object. So there is not much that is really disturbing to the basic orientation of science. See for details Hermann Weyl, *Mind and Nature Selected Writings on Philosophy, Mathematics, and Physics* (Princeton: Princeton University Press, 2009).
[23] Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*., 146.

come to occupy a salient place.[24] Science shows the greatest respect for simplicity, harmony and proportion. In the presence of competing theories, each one equally compatible with evidence, the one with greatest simplicity is likely be selected or esteemed. The respect for simplicity or symmetry is historically said to follow from the principle of Ockham's razor or Leibniz's principle of sufficient reason. These are principles of mathematical elegance, aesthetic economy and logical efficiency. In modern times, Russell's advocacy of simplicity as the basis of scientific construction or Einstein's faith in the simplicity of nature are well known dogmas of science.[25] Associated with the principles of simplicity and elegance is the sister concept of truth. There is singular beauty in the simple figures of geometry or the infinitely small in the universe and many a physicist or a philosopher finds in these the occasion for feelings of joy and a diffuse sense of "this is truth." Of course, "beauty does not automatically ensure truth, but it helps."[26]

Although in philosophy and history of science much has been written on the notion of aesthetic simplicity or mathematical beauty and the role it plays in the formulation of physical theories, let me not fall into the extreme of aesthetics of taste as an issue of perception alone. There is danger indeed of carrying out too far the inspiration that beauty or economy may provide in evaluating works of science. The insights into nature's behavior or observer's preference (for elegance or harmony) leads to the possibility of combining perception and object in a concept, based on firm ground, which becomes the framework for the discussion of aesthetic appeal and scientific reasoning in a systematic way. That concept is symmetry.

"If mathematics is the language of nature, symmetry is its syntax."[27] In modern theoretical physics, symmetry is enshrined as the most dominant concept in the exploration and formulation of laws of nature.[28] Symmetry is a property, which defines invariance under certain categories of transformation, such as rotation, reflection or repetition. For instance, turning a tennis ball does not alter the ball's appearance. It is said to have rotational symmetry. Or the letter "H" possesses reflection symmetry because it looks the same when viewed in the mirror. These are instances of physical symmetries describing operations with objects. On the other hand, symmetry considerations can apply to laws and dynamical equations, for instance, the postulate of special relativity that the speed of light is the same for different observers. The presupposition of certain symmetries, such as the isotropy of space (that nature has no preferred direction), or the invariance of laws of mechanics in time, constitutes the foundations of physics. While physical symmetries are a matter of visual perception, symmetry principles are more abstract and conceptual. They have a precise mathematical definition, in particular involving the concept of "groups," which describes permutations or automorphisms among abstract algebraic structures.[29] Symmetry considerations are singularly useful in physics, as a source of explanatory or predictive power.

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[24] Dirac, "*The Relation between Mathematics and Physics,"* in The collected works of P.A.M. Dirac, 1924-1948 / edited by R.H. Dalitz. Frank Wilczek, *The Lightness of Being : Mass, Ether, and the Unification of Forces* (New York, NY: Basic Books, 2008).
[25] Gerald James Holton, *Thematic Origins of Scientific Thought; Kepler to Einstein* (Cambridge, Mass.: Harvard University Press, 1973).
[26] Ian Stewart, *Why Beauty Is Truth : A History of Symmetry* (New York: Basic Books, a member of the Perseus Books Group, 2007); Wilczek, *The Lightness of Being : Mass, Ether, and the Unification of Forces*.
[27] Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*., 147.
[28] David J. Gross, "The Role of Symmetry in Fundamental Physics," *Proceedings of the National Academy of Sciences of the United States of America* 93, no. 25 (1996).
[29] Weyl, *Symmetry*.

The first major case where a prediction was made using symmetry considerations is the postulate of anti-matter made by Dirac in an equation describing the quantum mechanics of particles with spin-half. The equation does not change when the sign of the charge is reversed and from this symmetry Dirac postulated the existence of anti-matter, or matter with an opposite sign. The transformation of particles under interactions, which does not alter the structure of the interaction, is a novel interpretation of symmetry. For instance, the result of a physics process remains the same if neutrons replace protons, but this is not a visually perceived symmetry. It is an abstract, logical one. While particles may undergo transformations, the basic structure, i.e., the "symmetry group," which dominates the transformations, remains unchanged.

In twentieth century theoretical physics, the approach has been to study the symmetry groups and then deductively search for dynamical properties. Wigner credits Einstein for starting the trend of deriving "the laws of nature and to test their validity by means of the laws of invariance, rather than to derive the laws of invariance from what we believe to be the laws of nature."[30] By positing global continuous spacetime symmetries in the special theory of relativity, Einstein marks the radical departure from classical physics where it had been the other way around: physical laws are the primary element which determine the symmetries.[31] The theory of general relativity is likewise grounded in symmetry, or the condition of invariance under arbitrary motion of the observer, and gravity is simply a consequence of this invariance principle.

Symmetry principles define the tenor and orientation of contemporary standard model physics, like the Standard Model. While the Standard Model teaches that all physical reality subsists and exhausts itself within matter and forces, it is itself guided neither by matter nor forces, but by the mathematical principle of gauge symmetry. Weyl formulated the principle of gauge symmetry, or local symmetry in a gauge field. Here the contribution of symmetry is remarkable in availing and enriching physics with the concept of field. "The punch line is that the electromagnetic force is just the consequence of a gauge symmetry of nature. Once the symmetry principle has been enunciated, the interactions between particles are completely determined, and the existence of the photon is an inescapable consequence. This is the conceptual revolution of the gauge principle: not force, but symmetry is the primeval notion."[32]

Weyl notes that symmetry is one idea by which man through the ages has tried to comprehend and create order, beauty, and perfection.[33] The Last Supper or the Arnolfini Portrait expresses something solemn and dynamic owing to the compositions' adherence to principles of symmetry (and harmony of colors). Yet Weyl takes the first step in identifying symmetry explicitly as the bearer of scientific objectivity: "objectivity means invariance with respect to the group of automorphisms."[34] He finds the common ground of symmetry, expressed in diverse domains such as art or nature, in mathematics. According to Weyl, the fact that something which is more qualitative is also capable of a precise mathematical treatment is what explains the

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30 Eugene P. Wigner, *Symmetries and Reflections* (Bloomington1967).
31 Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*; Wigner, *Symmetries and Reflections*.
32 Giudice, *A Zeptospace Odyssey : A Journey into the Physics of the Lhc*. 156. The prior generation of quantum physicists, e.g., Heisenberg, Pauli, etc did much in showing how particles and forces are manifestations of a deeper notion of quantum fields. In present day quantum field theory, almost all particles are bundles of energy of various fields: the photons of the electromagnetic field, the electrons of the electron field, and so on.Weinberg, *Dreams of a Final Theory*.
33 Weyl, *Symmetry*.
34 Ibid., 112.

strength and its use in physics. While beauty, harmony, simplicity and elegance are connotations of symmetry, physics assimilates the use of symmetry as a precise heuristic mathematical tool to deduce properties of the physical world.

"The whole point of symmetry," as Wilczek observes, "is that it's not supposed to change the behavior of the things it transforms. We want to have a distinction *without* a difference."[35] Here beauty, solidity, or reality is not conceived as a fixed static form but considered as the dynamic mutability of forms. Bodies and facts are superseded in favor of relations and transformations. From the perspective of history of science, it is a remarkable achievement that not only is the physical world superseded by the symbolic, but also the symbol itself expresses relations and relations of relations.[36] On all these grounds, it is clear that symmetry gives physics a chance to stand on an independent basis, and not under the complete domination of reality or brute facts. In the concept of symmetry, scientists can experience art that is serious in its aim although pleasurable in its means.

At this point we are in a position to present the main conclusions of the relation of art and science, which were discussed in a general theoretical form in the previous section. Here the connection between the metaphysical as well as the epistemological meaning of symbiosis between objective facts and aesthetic values, as expounded by Kant, becomes clear. When a physicist encounters relations between diverse phenomena, it usually produces a feeling of being in the proximity of truth. As Kant says in the *Critique of Judgment*, the recognition of finality of nature, which arises when science discovers that widely different phenomena are bound into a beautiful, unified picture is coupled with the feeling of pleasure. This feeling, however, is not based on principles of "pure reason," but in a more primitive feeling of subjective pleasure. Contrary to the archaic Aristotelian conception where finality is interpreted as an ingredient of nature with dynamical power in the development of natural changes, the Kantian conception of finality, and the associated feeling of aesthetic pleasure, is not something out there to be discovered, but a necessary ingredient in transforming an autistic form of experience of nature into the social form of experience that we call science. Here it is the capacity of the soul in feeling pleasure that makes possible the transformation of an objective experience into scientific knowledge.

In other words, it is art that transforms experience into science and the rules of art - the universalization of taste – is what makes science a social activity. Science can be viewed as the paradigmatic example of the universalization of taste! With the notion of Kantian judgment as the necessary link between understanding and reason, Kant initiates what we may denote as the social constitution of subjectivity. The importance of considering (in a Kantian frame) the interplay between science and art comes from the fact that science is the social understanding of facts and the instruments which make this social understanding possible is judgment, at the root of which is the capacity of the soul in feeling pleasure. The social component of science is the shared recognition of finality in nature. Finality, aim or *telos* may not be a part of the laws of science but it is determining in transforming science into a social activity.

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[35] Wilczek, *The Lightness of Being : Mass, Ether, and the Unification of Forces*.

[36] Cassirer makes the same point on the symbolic character of physical science. This is affirmed by the latest and the most abstract contribution in mathematics and mathematical physics, called "category theory," which has no objects so to speak but only arrows, homomorphisms and relations between objects. It is increasingly used in quantum mechanics, mainly in string theory formulations.

The foregoing conclusions are better understood with an example, such as the suggestion of extra dimensions, so popular these days. Extra dimensions appear for two completely different reasons. On the one hand, they are necessary due to mathematical consistency of string theory, which requires additional dimensions of space, such as 10 or 11. On the other hand, and unrelated to string theory, extra dimensions are a way of explaining the huge hierarchy between the electroweak scale of the standard model and the scale of gravity. *A priori* there is nothing unusual about the hierarchy of scales. However, scientists find it unnatural that such a huge difference should exist without an explanation. Looking for this explanation leads to the invention of scenarios such as extra dimensions. This is a fantastic illustration of what Kant mentions in the third Critique. People find aesthetic satisfaction or pleasure if they are able to find a certain end or finality underlying the facts of nature.

The reduction or disintegration that nature undergoes in methods of isolation, measurement, quantification finds an antidote in the concepts of symmetry and unification. The concept of symmetry connects the subject's ability to know with the object of perception, the external world. It enables one to distinguish appearance from reality or what remains invariant even under a transformation. This double orientation constitutes its essence. To be sure, the mathematical idiom blurs the distinction and tries to convert the qualitative aspects of transformations into purely quantitative ones. After all it is in the abstract mathematical treatment that symmetry is most generally availed in theoretical physics. But once mathematical techniques are used for understanding or explaining laws of nature, the qualitative criteria of economy, simplicity, elegance or finality again become compelling. After seeing its decisive presence in physics, it would not be wrong to conclude that the significance of symmetry, as a concept of proportion and perspective, in grasping the physical worldview, given in part by methodological and in part by metaphysical considerations, belongs equally to art and to science, or to neither, but to higher forms of reflection and judgment.

4. Critique and Anthropology

The unity achieved by art and science in the notion of symmetry brings us to the general and basic philosophical problem of the relation of subject and object. The intellectual currents that nourish our age flow decisively into this central problem. We have before us two distinct instances of the relation of subject and object, expressed in the classification and relation of art and science. In the first illustration, i.e., in the case of formal engagement of art and science as initiated in CERN's Artist-in-Residence program, art is held as fulfilling a function of representation. The invited artists will be given an opportunity to respond to certain ideas and practices in physics. Physics is meant to provide an inspiration or impetus to art. Such a mode of engagement enjoys a long legacy in twentieth century art, such as, kinetic art, op art, appropriation art, etc.[37] Here the association of art and science is purely extraneous. While mindful of the division of the two domains, it looks for fusion by moving from one to the other.

Underlying the external arrangement of fusion of art and science, there lies, however, completely different points of departure. In order to carry out with fidelity the description of external nature, scientific truth must be divested of the presence of the subject, whereas in order to have a sympathetic vision of nature, artistic truth must organize and route it through the subject. Art is interlaced through and through with the producer, which is why works of art are

[37] Cyril Stanley Smith and Martyl, *Science and Art* (Chicago: Educational Foundation for Nuclear Science, 1959).

signed. Science on the other hand, must, in the final analysis, remove all traces of the producer from the view. Every concept, every project, every outcome of science must speak purely and entirely in favor of the object, or external physical reality. In my view, this critical difference is able to harmonize perfectly well the reciprocal (and formal) relation of art and science. In confronting each other, art and science mutually sustain and influence each other.

In the second instance of symmetry, science has internalized the aesthetic impulse and the distance between the two is properly speaking abolished. The outward resemblance of similarity of forms has given way to the possession of an identical creative force, which includes the subject. In the second case, we have moved away from extraneous association and perceptible appearance, to productive principles and "a thinking" perspective. Here aesthetics is not sought outside of one branch of knowledge in another medium, but becomes one of the internally determining conditions of physical knowledge itself. In one case, art is description, in the other a prescription. The difference of subject and object is resolved in the same frame, in the same proposition, and not on different registers or media. In its highest form, symmetry is no longer related to an individual's perception, but to the general form of perception. Here the mind becomes like the world it conceives. There is no external dissociation, nor extraneous correspondence, of the mind and the world. The power of the mind in seizing and grasping the world is only possible by overcoming the separation of subject and object.

These two illustrations of the relation of art and science that I have outlined so far, one empirical and the other logical, are not answers to a problem but the problem itself. The basic problem of how art and science resolve the relation of subject and object is the crux, as far as the theory of knowledge is concerned. In modern times, an artist's work – and by this I do not refer to any specific aspect of artistic style or content – is based on the acknowledgement of the self in relation to the object, and their necessary mutual inter-relations. A scientist's work – whether theoretical or experimental – is based on the (intellectual) renunciation of the self and the complete suspension of their mutual relations. The possibility of formal and institutionalized *complementarity* of art and science rests on the recognition of this difference. The possibility of *unity* of the mind and the world forms the basis of the notion of symmetry, and is found equally and abundantly in both art and science.

Yet what we have learnt from the foregoing discussion is only how wrong it would be to assign aesthetics an isolated jurisdiction. In the broadest possible sense, whether conceived as imitation, representation, proportion or creation, art possesses the value of reflection. It gives us a dynamic awareness of the form of things. Art readily participates in the processes of transformation. Now the question arises: can transformation and reflection lead to criticism? If spontaneity, creation and abstraction have given way to contemplation and reflection, can it also offer some grounds for criticism? In a certain sense, the question before us now is, not what is the relationship between art and science, but between art and art criticism. In discerning this relationship, we will gain a much deeper conception of something else - the character of anthropology or the social sciences.

In February 2009, the "*LHC Performance Workshop*" was held in Chamonix in particular to determine the physics potential of a LHC run at a reduced beam energy. The question was: Should the LHC run during the winter months when it is traditionally shut down in order to obtain physics data? Alternative scenarios were presented. Scenario one involved the installation of "DN 200" pressure relief valves in the 4 (warm) sectors, the machine running at 3.5

TeV/beam, accumulating 1 fb^{-1} of data, then a year-long shutdown in 2012 to conclude all the repairs and installations before moving to 7 TeV/beam. Scenario two would be to install the relief valves in all the 8 sectors right away, check the whole machine, have a delayed start but at 8 or 9 TeV/beam.

The motivations to the two scenarios crosscut various pros and cons. How to balance machine safety with the desire for data? Are there funds for the electricity bill for a winter run? Is it possible to stay in competition with the Tevatron? Accelerator physicists and experimental physicists met and debated before and during the Workshop. Experimentalists were largely in favor of immediate running of the machine, so they have some data to work with, while accelerator physicists preferred carrying out the necessary repairs first so that future problems do not occur. However, the battle lines were not drawn rigidly. Steve Myers, the chair of the workshop and machine in-charge, remarked that midway through the workshop he switched from the second scenario to the first and again back. The workshop ended with "no consensus in Chamonix."[38]

The controversy is interesting because it shows how the formation of scientists takes place and how discourse arises with certain forms of arguments impelled, and others excluded. The debate was generated not by interests or personal dispositions (although both could be present) but by the positions occupied by the subjects in relation to their objects. Structurally, it involved the relations of the subcultures, the opposition primarily being between engineers and scientists, or accelerator physicists and detector physicists. Ideologically, it relied on the trans-Atlantic rivalry between the two running colliders, the Tevatron and the LHC. Science is not a bloodless affair, without strife or feeling. What makes it bloody is not the introduction of power necessarily, as Michel Foucault believes.[39]

The standard critique of knowledge for ignoring power is an important criticism but an abdication as far as science is concerned. Even when science shows no consensus, highlighting differentials of power or authority would add little to our awareness of the generative possibilities of the discourse. Decrying science on grounds of emotion and attitude is also feeble. In this terrain, art can competently rebel against science. Passion, pleasure or power may find environments congenial to their existence or may encounter violent oppositions, which would thwart or obstruct their existence. In either case, art would have an object of representation. But art would be incapable of understanding the conditions of generation. Instead of immersing itself in the feeling or enjoyment of science, could art carve new principle or bases of science? The question is not being raised in order to deny the significance of sensible perception or belittle the contribution of ornamentation and representation, but to make the observation that felicity in expressing an undertaking can hardly reveal the source of the undertaking. Therefore it occurs to me art is incapable of criticizing science.

The concept of criticism begins with the premise that it knows what holds an idea together, as it evaluates its claim. Critique is oriented to something, as stressed by Foucault and Butler. Indeed it is oriented to something - but as different. The power to criticize lies in the ability to grasp a difference between prevailing and possible states of affairs. Criticism is an intellectual resistance. In order o be effective, it requires materials, modes, and apprehension

[38] From Steve Myers' slide/talk on 24th February, 2009.
[39] Foucault and Gordon, *Power/Knowledge : Selected Interviews and Other Writings, 1972-1977.*, 115.

different from existing ones. It also requires training, effort to reassemble impressions, and the ability to alienate reality.[40] Marx writes that for criticism "the point is not whether the opponent is a noble, equal, *interesting* opponent, the point is to *strike* him."[41] If the Marxist spirit of criticism is too strong, one can adopt the Kantian expression of critique: Criticism frees us from illusions. It is a safeguard of freedom. It is in criticism that the power of intellect is truly evaluated.

Sense perception and considerations of beauty may be used propitiously to embellish science and the charm of such a representation is undeniable. The delight felt in observing a work of art, to see the invisible processes of nature, or the satisfaction of symmetry in physical theory all deepen our sense of cultural life. Art can see science in dimensions that science itself cannot. But in the same way, art does not chasten the science. Art appears to say science is equally true or false, or doesn't matter, but we have a richer apprehension of it in our lives. To know the conditions of knowledge is not the business of art. In fact, its ignorance allows it to represent science. For scientists themselves ignorance of science is better than the illusion of knowledge. That is why I believe art and science may be found together rather than separate.

Only critical insight can transform reflection on the outcomes of science to its conditions of existence. Unlike art, the social sciences recognize the purpose as well as the limits of science because they have a scaffolding of concepts, categories, method, and analysis. The hostility between science and social science is owing to both their similarities and differences. From C.P. Snow's "two cultures" to the "Sokal affair," the opposition between sciences and social sciences is well documented. During fieldwork it was clear that the real strife was not between science and religion, or science and art, but between science and social science. All principles of metaphysics and higher understanding are vehemently opposed by physics. The challenge that the social sciences pose to scientific thought and practice is considerable.

Criticism is one of the dearest possessions of the anthropological spirit. Yet this deeper possibility should be remembered with the contradiction of power and symbol, which runs through all of modernity. As symbol, science expresses the separation of human and non-human nature. As power, it wields and thrusts on us all the applications of its knowledge, good and bad. With this contradiction before us, we must comprehend how to fight against two different and opposed forces. Therefore, critiques that deal with the "politics of knowledge" without involving the content of knowledge, and those that assail the symbols of knowledge without dealing with change and conflict are both limited or feeble attempts. Feeble because the resources of the critique are not commensurate with the ambitions. As disconnected attempts, they become displays of the triviality of our perception and age. To challenge science, in both its authority and content, requires that critical efforts embrace the higher unity of symbol and instrument, culture and power.

Conclusion

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[40] Butler, "*What is Critique? An essay on Foucault's Virtue*," in Judith Butler and Sara Salih, *The Judith Butler Reader* (Malden, MA: Blackwell Pub., 2003).; Foucault, "*What is Critique?*" in Michel Foucault, SylvËre Lotringer, and Lysa Hochroth, *The Politics of Truth* (New York: Semiotext(e) : Distributed by the MIT Press, 1997).
[41] A Contribution to the Critique of Hegel's Philosophy of Right

The mutual positioning of art and science indicates that they can be mixed, the essence of one goes into the other quite easily, and scarcely has a boundary worked in more porous ways. Art completes science. Art is not the opposite of science but rather forms the ground of its fulfillment. This is illustrated and elaborated in unmistakable form in the courtship of art and science that CERN has presented before us. My sense of CERN's art and science engagement is that although the balancing of different perspectives may be an attractive intellectual pastime, it can furnish little evidence of any strength in respect to scientific pursuit. The program is not superfluous, but can be expected to yield little more than a prodigious description of science. On the whole if the problem of engagement between the different sciences is to be assigned a rightful inquiry, then knowledge *and* critique cannot be abandoned. In that regard, the real hiatus is not between science and art but between science and social science. In the distinction of art and the theory of art, or of physics and metaphysics, the separation is nearly irrevocable. Of course doubts are raised on the strength of the separation and novel possibilities explored now and then but the basic view remains unaffected by most proposals.

The dissertation has no authentic history of CERN to present, much less of the present state of particle physics, or what its future prospects looks like. My task, the way I conceived it, included the responsibility of clarifying the form of knowledge that science stakes, or to use Wittgenstein's words, its grammar. Consequently, the task of fieldwork was to grasp the language of physics in order to understand how it approaches nature. Humble rules of concept construction and laboratory practice turn out to be intimately connected with the scientific cosmos. To traverse this inner relationship between systems of classification and problems of everyday practice, to grasp each of these forms and their contradictions, and to join abstraction to vision are the highest aims of anthropological inquiry. While it may not be capable of reconciling all oppositions, it sets them up with the greatest precision and rigor. And far from it constituting a limitation, it becomes instead our discourse's surest asset and confirmation.

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