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Relativistic Heavy Ion Physics

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The main objective of relativistic heavy ion physics is to study nuclei under conditions far from normal nuclear densities and excitations. Properties of nuclei such as binding energy, radius, deformation, and level structure have been studied extensively. However, basic macroscopic information is missing concerning what happens when a nucleus is compressed to several times normal density or excited to several hundreds of MeV/nucleon. Theoretical speculations abound about exotic behavior, such as superdense nuclear matter, density isomers,[1] pion condensates,[2] hydrodynamical flow,[3] and production of quark matter. Another objective in relativistic heavy ion physics is to study "conventional" nuclear properties such as the limits of nuclear stability, ground state correlations, and the excitation of high multipole giant resonances.

Presently the lofty goals of producing exotic phenomena have not been reached. However, much basic understanding has been gained about the underlying, "background" phenomena involved in these reactions. Some glimpses of exotic phenomena have been observed. Also, some of the more readily accomplished goals have been reached.

The quantities measured in experiments to date include single particle inclusive, two particle inclusive, and multiplicity distributions. Also, the single and two particle inclusive measurements have been carried out while simultaneously measuring the associated charged particle multiplicity. The single particle data have provided most of the basic information while the multiparticle inclusive data hold the promise for future experiments.

The accomplishments toward the understanding of the basic reaction mechanism include insights into the role of geometry and the population of momentum space by various classes of reactions characterized by impact parameter.[4] Correlation measurements[5] have established that there is a substantial contribution from direct nucleon-nucleon scattering in addition to a component which seems to be completely thermalized. Final state interactions such as coulomb effects[6] and shadowing[7] have been shown to have strong effects. Light nuclei emitted in these reactions[8] make up a large fraction (up to 70%) of the measured cross section. The multiplicity distribution of negative pions can be understood from geometrical agreements and may provide a method of isolating impact parameters.[9] The size and lifetime of the interaction region has been estimated using pion-pion interferometry.[10]

Glimmers of the sought-after exotic effects have been observed in recent experiments. A peak has been observed in the angular distribution of protons from high multiplicity events which may be interpreted in terms of a collective hydrodynamical flow.[11] The difference between the observed "temperatures" of pions and protons may be the signature of a collective "blast wave".[12] Positive pions have been observed to peak anomalously at 90° in the center of mass hinting at a possible "sidesplashing".[13]

Recent experiments have produced results that give information concerning "conventional" nuclear physics. Fifteen new neutron-rich nuclei have been discovered.[14] Reaction mechanism studies have attempted to shed light on ground state correlations in nuclei.[15]

Five years from the present picture, which is dominated by the Bevalac, will contain many new accelerators in the energy range of 50-2000 MeV/nucleon. There will be accelerators at Saclay, GSI, MSU, INS-University of Tokyo, GANIL, Oak Ridge, Argonne, Chalk River, Khurchatov, and Dubna. Also, the Bevalac will have been upgraded to produce uranium beams at 1 GeV/nucleon. Experiments will have progressed past the present single particle inclusive stage to multiparticle exclusive measurements. These searches require new, sophisticated detection systems. "Conventional" nuclear physics will be studied by fragmenting the heavy beams to produce neutron rich nuclei out to the limits of nuclear stability. The transition from low energy phenomena to the fragmentation region will be mapped out.

Ten to fifteen years from now the possibility exists that colliding heavy ion beams of ~ 20 GeV/nucleon will be available at Berkeley (VENUS) and possibly at GSI (SUSA). Using beams of these energies, it is possible to study quark matter, the hadronic mass spectrum, and new heavy bosons. The study of quark matter formed in relativistic heavy ion collisions has the advantage over nucleon-nucleon interactions that a large bulk of quark matter could be created, simulating the early stages of the Big Bang.

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