Title

Report of the Subgroup on Alternative Models and New Ideas

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We summarize some of the work done by the P3 subgroup on Alternative Models and New Ideas. The working group covered a broad range of topics including a constrained Standard Model from an extra dimension, a discussion of recent ideas addressing the strong CP problem, searches for doubly charged higgs bosons in $e\gamma$ collisions, and an update on discovery limits for extra neutral gauge bosons at hadron colliders. The breadth of topics reflects the many ideas and approaches to physics beyond the Standard Model.

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I. INTRODUCTION

The search for physics beyond the Standard Model has become the "Holy Grail" of particle physics for the last twenty years. In addition to supersymmetry and dynamical symmetry breaking, which were examined by other groups at this workshop, there is a plethora of ideas to fulfill this quest. The most exciting new idea in recent years is the postulate of extra dimensions in addition to the standard four spacetime dimensions we are used to. In this context, Chertok *et al* examined the implications of a constrained Standard Model originating in five dimensions. In this model, the entire SM is supersymmetrized in five dimensions which leads to many new particles including a mirror set of supermultiplet fields and KK towers. A compelling feature of this model is that it makes an unambiguous prediction for the physical Higgs boson of $m_h = (127 \pm 8)$ GeV. In the next section we describe some of the phenomenology and experimental prospects for this model. Mohapatra and coworkers also took advantage of the possibility of extra dimensions to provide new approaches towards solving the strong CP problem, a longstanding problem of the Standard Model. This, along with some other ideas about the strong CP problem are summarized in section III of this report. In addition to these new developments in particle theory, more "conventional" variants of physics beyond the Standard Model were studied at the workshop. One of the most straightforward extensions of the Standard Model is the existence of larger Higgs representations. These arise naturally in the Left-Right symmetric model, for example, in addition to other models. A study using the $e\gamma$ mode of a high energy e^+e^- collider to search for doubly charged Higgs is summarized in section IV. Another common feature of many extensions of the Standard Model is the existence of extra neutral gauge bosons. Their discovery would have important implications for what lies beyond the SM. An update to discovery limits for the hadron colliders discussed at Snowmass is given in section V.

II. A CONSTRAINED STANDARD MODEL FROM AN EXTRA DIMENSION

This section represents a synopsis of a submission, Ref. [1], appearing in these proceedings.

Recently, a new approach to low energy supersymmetry breaking has been given by Barbieri, Hall, and Nomura [2]. Unlike the usual approach of postulating a low energy effective theory with so-called "soft" supersymmetry breaking terms added by hand, the entire SM is supersymmetrized in *five* dimensions. This means there are not only complete ($\mathcal{N} = 1$ in 4D) supermultiplets consisting of the SM fields and their superpartners, but also a "mirror" set SM fields and their superpartners. This is required since supersymmetry in 5D has

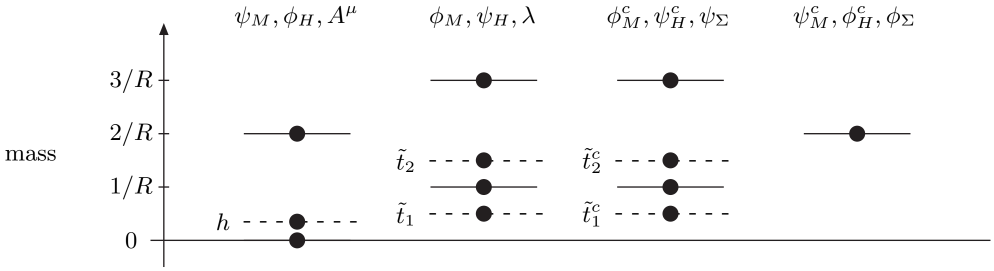

FIG. 1: Tree-level KK mass spectrum of the matter, Higgs and gauge multiplets. Physical light Higgs and top squarks mass eigenstates are shown in dashed lines.

double the number of supercharges than in 4D; i.e., an $\mathcal{N}=1$ supermultiplet in 5D has the field content of a single $\mathcal{N}=2$ supermultiplet in 4D, which is equivalent to *two* $\mathcal{N}=1$ supermultiplets in 4D.

The 5D spacetime is assumed to be compactified on an $S_1/(Z_2 \times Z_2')$ orbifold. Thus, the physical space is a line segment with two ends – the orbifold fixed points. At each fixed point the 5D fields can transform as either even or odd under the Z_2 symmetry associated with that fixed point. The field content is that of massless $\mathcal{N}=2$, 4D hypermultiplets and vector multiplets. The Kaluza-Klein (KK) reduction of this theory to 4D yields wave functions as sines and cosines of integer and half-integer multiplets of the size of the extra dimension, R, with a mass spectrum given in Fig. 1 (solid lines).

An interesting feature of this model is that the Higgs effective potential can be calculated essentially in terms of a single free parameter R, which comes from the loop contribution through the top Yukawa coupling. The only scale in the model, $1/R$, can be determined by the minimization condition of the Higgs effective potential, which gives $1/R \sim 370$ GeV. This allows us to predict the physical Higgs boson mass as well as the superparticle and KK tower masses. The predicted Higgs mass is $m_h = (127 \pm 8)$ GeV. At the first excited level, there are two superparticles for each SM particle. Their masses shift from $1/R$ by the electroweak breaking effect through the expectation value of the Higgs field. The largest effect appears in the top squark sector, giving top squarks of masses $1/R \pm m_t \sim 210, 540$ GeV. The mass spectrum of the light Higgs and stops is also shown in Fig. 1 as dashed lines. Although possible additional brane localized interactions could shift the value of $1/R$ by as much as a few tens of percent, the Higgs and stop mass prediction is much less sensitive to the UV physics. The observation of the light stop, described below, and the measurement of its mass to be in the predicted range would be compelling evidence for this model.

A. Phenomenology

The low energy effective theory *below* $\sim 2/R$ consists of one Higgs doublet and two superpartners for each SM particle. The light Higgs has SM-like Yukawa couplings and WWh, ZZh gauge couplings. It can be produced at Tevatron RUN II via the usual associated production of Wh or Zh, with the Higgs decays into $b\bar{b}$ or $\tau\bar{\tau}$. At LHC, $gg \to h \to \gamma\gamma$ would be the discovery channel for the light Higgs. One particularly characteristic feature of this model is that the two degenerate light stops ($\tilde{t}_1$), with mass $m_{\tilde{t}_1} = 1/R - m_t$, are the LSPs, which are stable[1] if R-parity is exact. The lowest mass states [3] are $T^+ = \tilde{t}_1\bar{d}$, $T^0 = \tilde{t}_1\bar{u}$ and their charge conjugate states T^-, $\bar{T}^0$. The other supersymmetric particles (besides the heavier stop) are almost degenerate at a mass of $\sim 1/R$, with small mass splittings coming from electroweak corrections or additional unknown brane kinetic terms. All of them cascade decay into stop LSPs.

Squarks mostly decay via the channel $\tilde{q} \to q\tilde{g} \to q\tilde{t}_1 t \to q\tilde{t}_1 bW^\pm$. The b-jet from the top decay and the leptons/jets from the W decay are energetic, while q from the original $\tilde{q}$ decay is usually soft because of relatively small mass splitting between the squark and gluino. For $\tilde{q}_L$, another decay channel $\tilde{q}_L \to q'\tilde{W}^\pm \to q'\tilde{t}_1 b$ could be important (although suppressed by weak coupling) if the heavy gluino is off-shell in the first process.

For sleptons, decay can occur via the neutral Wino or Bino: $\tilde{l} \to l\tilde{W}^0/\tilde{B}^0 \to l\tilde{t}_1 t \to l\tilde{t}_1 bW^\pm$. However, for $\tilde{l}_L$, decay similar to that of $\tilde{q}_L$ is comparable to the neutral gaugino process for $m_{\tilde{W}} < m_{\tilde{l}}$, and dominates if $m_{\tilde{W}} > m_{\tilde{l}}$.

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[1] The cosmological constraints on an absolutely stable stop could be relaxed if we allow a small degree of R-parity violating.

The gluino can decay via $\tilde{g} \rightarrow t\tilde{t}_1$, $b\tilde{b}_L$, $q\tilde{q}_L$, $q\tilde{q}_R$, either on-shell or off-shell, with subsequent decays of the t, $\tilde{b}_L$, $\tilde{q}_L$ or $\tilde{q}_R$ as described above. The generic decay products would be $\tilde{t}_1$+b+($l\nu/jj'$)+soft jet/lepton.

There are three neutralinos and three charginos (all six *Dirac*), in contrast with the usual MSSM with four Majorana neutralinos and two Dirac charginos. The mass eigenstates are usually a mixture of gauginos and Higgsinos, with a small mass splitting of roughly 12 GeV (18 GeV) between the lightest one and the two heavier neutralinos (charginos). The dominant decay channel for charginos is $\chi^{\pm} \rightarrow b\tilde{t}_1$, leading to a clean signal of (track or missing energy)+b jet. Neutralinos decay similarly to gluinos or via $\chi^0 \rightarrow \chi^{\pm}W^{\mp}$ with subsequent decays of the $\chi^{\pm}$ and $W^{\mp}$.

The heavy Higgs, with mass $m_H \sim 2/R$, decays through $t\bar{t}$ like a usual heavy SM Higgs, while $H \rightarrow WW$ is forbidden due to the non-conservation of the fifth dimensional momentum. The discovery of the Kaluza-Klein tower of SM particles (heavy quarks, leptons, gauge bosons and their mirror partners) would be strong evidence for the existence of TeV-scale extra-dimensions. However, they are unlikely to be pair-produced at a TeV-scale e^+e^- collider. At a hadron collider the cascade decay chain is complicated and hard to distinguish from background. Thus, the phenomenology of these heavier states is not discussed here.

B. Experimental Prospects

Both neutral and charged T mesons are stable inside the detector since the β-decay of T^+ into T^0 is suppressed by small mass splitting between them. $T^{\pm}$ appears as a stiff charged track with little hadron calorimeter activity, and passes through the muon chamber. A heavy $T^{\pm}$ can be distinguished from a muon via large dE/dx or time-of-flight (TOF). T^0 and $\bar{T}^0$ produced via cascade decays of higher-mass SUSY states can be identified via their missing energy as they traverse the detector with little interaction (T^0 and $\bar{T}^0$ from direct pair production will be difficult to trigger on).

The CDF Run I search [4] for these types of particles was based on the measurement of this energy loss by the tracking system. The search found no evidence for the production of heavy stable charged particles ('CHAMPs'), and lower mass limits of ~200 GeV were set in the context of a heavy quark model [5]. The limit in the context of supersymmetric models with a long-lived stop is currently being evaluated.

The CDF and D0 detectors have been upgraded in preparation for Run II. The CDF detector includes a TOF detector. Studies have been performed using Pythia [6] and the full CDF detector simulation to produce CHAMP Monte Carlo samples. Simulations of the upgrade high-p_T two-track trigger indicate a 37% efficiency for pair production of 200 GeV CHAMPs. Combining curvature and TOF information, the mass of 200 GeV CHAMPs can be measured with an event-by-event resolution of about 25 GeV. In the case of D0, dE/dx will be used at the trigger level, while the muon system will provide TOF information.

Given the 0.6 pb $\tilde{t}_1\tilde{t}_1$ cross section [7] of this model, CDF would expect over 100 events per year. The measurement of the light stop mass in the predicted range, with a rate consistent with twice the standard SUSY cross section, would be compelling evidence for this model. In addition, the scalar nature of the top squark could be inferred from its measured decay angular distribution.

The cross section for the production of $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$, $\tilde{g}\tilde{g}$ range from $0.1 - 1$ pb in this model [8]. The final decay products always include two $\tilde{t}_1$, which can be triggered on as discussed above. In addition, there will be other activity that can be used to distinguish these events from direct stop pair production. These generally include two energetic b jets, possible energetic leptons, missing E_T (from neutrinos), and jets coming from decays of the intermediate W. Alternative triggers based on this accompanying activity should be useful in selecting events containing two neutral T^0, although distinguishing the signal from backgrounds in this case will require further study. Finally, the observation of sleptons, gauginos and higher mass states are less promising for Run II of the Tevatron.

Given the factor of seven increase in center of mass energy over Tevatron Run II, the LHC experiments will substantially extend the search for phenomena predicted by this model. In particular, the heavier mass states should be accessible. Even for the heavier stop states, hundreds of events per year can be observed, given the clean signal of $\tilde{t}_2$ decay, and allowing confirmation of the robust prediction $m_{\tilde{t}_2} - m_{\tilde{t}_1} = 2m_t$. If the light Higgs is not discovered at the Tevatron it will be uncovered at the LHC in the usual channels. The heavy Higgs discovery should also be possible, as in the SM case, provided enough integrated luminosity is achieved [9]. However, prospects for identifying either of these Higgs as unique to this model requires more study. One strategy would search for the heavy Higgs decaying via some of the predicted SUSY states.

A high-energy electron-positron Linear Collider (LC), running at center-of-mass energies of up to 1 TeV, would permit a number of measurements which would be essential to the confirmation of this model. With a mass predicted to be less than 250 GeV, pair production of the light stop would be copious even at a 500 GeV LC. The factor-of-two enhancement of the stop production cross section (due to the presence of the degenerate mirror state $\tilde{t}_c$) could be measured to a statistical and systematic precision of order 1%. At higher energies, individual thresholds for the full spectrum of particles at the scale of $1/R$ could be detected. The resulting picture – a light stop plus a nearly-degenerate array of sfermions, Higgsino states, and gauginos, with each sfermion exhibiting a precise factor-of-two production rate enhancement – would represent an unambiguous signature for this model. Another unique characteristic of this model – the Dirac nature of the neutralinos and charginos – could be confirmed by studying the helicity dependence of their production cross-sections. The associated production of $\tilde{t}_1\tilde{t}_2$ is possible at a TeV LC via s-channel Z-exchange.

Several other checks of the model, which are not possible at a hadron machine, could be performed at a Linear Collider. The $O(10\%)$ deviation from the SM top Yukawa coupling could be measured to 1-2σ at a 1 TeV LC [10]. The chiral composition of the stop mass eigenstates could also be confirmed by exploiting the beam polarization. All in all, the ability to individually detect and precisely measure the properties of each of the 1/R-scale states, including those (such as sleptons) which are not accessible to hadron machines, makes the complementary information provided by the LC an essential component of the confirmation of the model's characteristic phenomenology.

III. THE STRONG CP PROBLEM

The vacuum of non-perturbative QCD seems to naturally support CP violation at a level clearly at odds with basic observation. The most well-known attempt to remove CP violation from the QCD vacuum is known as the Peccei-Quinn mechanism [11], and leads to the prediction of a massive goldstone-like boson known as the axion. While this particle has yet to be observed, experimental searches are only now reaching the sensitivity needed to rule them out in mass and coupling ranges allowed by astrophysical constraints.

Nonetheless, in recent years substantial thought has been put forward in an attempt to explain the absence of strong CP violation without recourse to the Peccei-Quinn mechanism. Several such models are presented below.

A. Extra Dimensions and the Strong CP Problem

Over the past few years, the possibility that large extra spacetime dimensions might exist has received considerable attention. The main attraction of this idea is the observation that large extra dimensions have the potential to lower the fundamental energy scales of physics, such as the Planck scale [12], the GUT scale [13], and the string scale [14]. In this framework, one assumes that the observed four dimensions are merely a subspace within a p-dimensional membrane (or D-brane) which in turn floats in a higher-dimensional space. The extra compactified dimensions can therefore be of two types, either within the D-brane or transverse to it, and the phenomenology of both types of extra dimensions has been explored quite extensively in recent years.

One of the surprising aspects of extra dimensions is that they may provide a new approach towards solving the strong CP problem. One of the standard approaches to the strong CP problem is to introduce a Peccei-Quinn (PQ) symmetry with a corresponding axion. Unfortunately, the experimentally allowed parameter space for the mass and couplings of the axion have become very narrow, and it is not clear how to generate the high energy scale associated with the breaking of PQ symmetry or to explain the "invisibility" of the resulting QCD axion.

Within the framework afforded by large extra dimensions, however, this situation may be radically altered. The basic idea is that since the QCD axion is singlet under all Standard Model symmetries, the axion is free to leave the D-brane to which all Standard-Model particles are restricted and propagate into the higher-dimensional bulk. In other words, in theories with extra dimensions, the QCD axion can accrue an infinite tower of Kaluza-Klein axion states.

Can this be used to lower the fundamental PQ symmetry-breaking scale? This issue has been investigated in Refs. [15, 16]. As explicitly shown in Ref. [16] (and first proposed in Ref. [12]), it is possible to exploit the large volume factor associated with the extra dimensions in order to realize a large effective four-dimensional PQ scale from a smaller, higher-dimensional fundamental PQ scale. This is therefore one method of generating an *apparent* high PQ symmetry-breaking scale in a natural way.

However, as discussed in Ref. [16], the presence of the Kaluza-Klein axions can have important and unexpected effects on axion phenomenology. In theories with extra dimensions, it turns out [16] that the four-dimensional axion no longer is a mass eigenstate; instead, this axion mixes with the infinite tower of Kaluza-Klein axions, with a mass mixing matrix given in Ref. [16]. This mixing has a number of interesting phenomenological consequences.

First, as shown in Ref. [16], under certain circumstances the mass of the axion essentially *decouples* from the PQ scale, and instead is set by the radius of the extra spacetime dimension. Thus, axions in the 10^{-4} eV mass range are consistent with (sub-)millimeter extra dimensions. This decoupling implies that it may be possible to adjust the mass of the axion independently of its couplings to matter. This is not possible in four dimensions.

Second, as discussed in Ref. [16], the usual four-dimensional axion should undergo *laboratory oscillations* as it propagates since it is no longer a mass eigenstate. Such oscillations are entirely analogous to neutrino oscillations. Moreover, because the axion is now a higher-dimensional field, Standard-Model particles couple not only to the usual four-dimensional axion zero mode, but rather to the entire linear superposition $a' \sim \sum_n a_n$ (where a_n are the axion Kaluza-Klein modes). Therefore, the quantity of phenomenological interest is the probability $P_{a' \to a'}(t)$ that a' is preserved as a function of time. It turns out [13] that this probability drops rapidly from 1 (at the initial time $t = 0$) to extremely small values (expected to be $\approx 10^{-16}$ when an appropriately truncated set of 10^{16} Kaluza-Klein states are included in a'). At no future time does this probability regenerate. Thus, we see that in higher dimensions, the axion state a' rapidly "decoheres" and becomes invisible with respect to subsequent laboratory interactions. This decoherence is therefore a possible higher-dimensional mechanism contributing to an invisible axion.

Finally, one can investigate the effects of Kaluza-Klein axions on cosmological relic axion oscillations. In this regard it is important to understand whether the infinite towers of Kaluza-Klein axion states accelerate or retard the dissipation of the cosmological energy density associated with these relic oscillations. Remarkably, one finds [16] that the net effect of these coupled Kaluza-Klein axions is always either to *preserve* or to *enhance* the rate of energy dissipation. This implies that the usual relic oscillation bounds are loosened in higher dimensions, which suggests that it may be possible to raise the effective PQ symmetry-breaking scale beyond its usual four-dimensional value. This could therefore potentially serve as another factor contributing to axion invisibility.

Together, these results suggest that it may be possible to develop a new, higher-dimensional approach to axion phenomenology. Further details concerning these ideas can be found in Ref. [16], and other recent ideas along similar lines can be found in Ref. [17].

B. Strong CP and an Embedded MSSM

It has been shown [18] that a solution to the strong CP and SUSY phase problems can be obtained if the minimal supersymmetric model (MSSM) is embedded at high scale into a parity conserving gauge group such as $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ or $[SU(3)]^3$. These models are motivated independently by the seesaw mechanism for neutrino masses and due to high scale of parity restoration maintain the nice feature of gauge coupling unification in MSSM.

The basic idea that parity symmetry can provide a resolution of the strong CP problem goes back to the late 1970's [19] and is based on two observations: (i) the first is that the tree level θ term being parity violating automatically vanishes in a parity invariant theory and (ii) secondly, parity invariance makes the quark mass matrices hermitian, thereby making that contribution to $\overline{\theta}$ i.e. $\overline{\theta} = \theta + \mathrm{Arg}\{\mathrm{Det}(M_u M_d)\} = 0$.

The relevance of parity symmetry in solving the SUSY phase problem was noted in [20], where it was shown that many of the dangerous phases of MSSM such as the gluino mass phase, μ-term phase etc all vanish due to parity symmetry. It was then shown that loop corrections lead to a very tiny value for θ of order 10^{-8} to 10^{-16} depending on the structure of supersymmetry breaking terms.

C. Strong CP and SUSY Non-Renormalization

Recent developments also include a new mechanism for solving the strong CP problem which relies on the non-renormalization theorems of supersymmetry. The interested reader is referred to Ref. [21], the content of which is discussed very briefly here.

The strong CP problem has recently become more urgent because experimental data strongly favor a CKM phase of order one, 10 orders of magnitude larger than the upper bound on the strong CP phase. This represents a puzzle because both arise from the Yukawa couplings in the SM.

In this non-renormalization approach, CP is broken spontaneously and mediated to the SM by radiative corrections. Obtaining a large CKM phase requires the radiative corrections to be large, i.e. strong coupling of the CP violating physics to quarks.

Such models are very difficult if not impossible to build without SUSY, but the non-renormalization theorem of $\overline{\theta}$ in SUSY makes this solution to the strong CP problem very natural. In the absence of supersymmetry breaking $\overline{\theta}$ remains exactly zero while the CKM phase gets $O(1)$ contributions from renormalization. If supersymmetry breaking and mediation are flavor-universal and occur at a scale well below spontaneous CP violation (e.g. gauge-, anomaly-, or gaugino-mediation), then the radiatively generated $\overline{\theta}$ is much smaller than the experimental bounds. Predictions of the framework include supersymmetry with minimal flavor violation, no CP violation beyond the large CKM phase in B physics, and nearly degenerate first and second generation scalar masses.

Recent developments also include an explicit model for the CP messenger sector, but it should be stressed that the overall framework is more general because it is based on model-independent non-renormalization theorems.

IV. SENSITIVITY TO DOUBLY CHARGED HIGGS BOSONS IN THE PROCESS $e^-\gamma \to e^+\mu^-\mu^-$

Doubly charged Higgs bosons would have a distinct experimental signature. Such particles arise in many extensions of the Standard Model (SM) such as the Higgs triplet model of Gelmini and Roncadelli and the Left-right symmetric model. The signals for doubly charged Higgs bosons arising from an $SU(2)_L$ triplet were studied in the process $e^-\gamma \to e^+\mu^-\mu^-$. Details of the analysis are given in reference [22] and contribution P3-18 of these proceedings. The photon was assumed to be produced by backscattering a laser from the e^+ beam of an e^+e^- collider [23]. We consider e^+e^- centre of mass energies of $\sqrt{s} = 500$, 800, 1000, and 1500 GeV appropriate to the TESLA/NLC/JLC high energy colliders and $\sqrt{s} = 3$, 5, and 8 TeV for the CLIC proposal. In all cases an integrated luminosity of $\mathcal{L} = 500$ fb^{-1} was assumed. Because the signature of same sign muon pairs in the final state is so distinctive, with no SM background, the process can be sensitive to virtual Δ^{--}'s with masses in excess of the centre of mass energy, depending on the strength of the Yukawa coupling to leptons.

Indirect constraints on Δ masses and couplings have been obtained from lepton number violating processes [24]. Rare decay measurements [25] yield very stringent restrictions on the non-diagonal couplings $h_{e\mu}$ which were consequently neglected. Stringent limits on flavour diagonal couplings come from the muonium anti-muonium conversion measurement [26] which requires that the ratio of the Yukawa coupling, h, and Higgs mass, M_Δ, satisfy $h/M_\Delta < 0.44$ TeV^{-1} at 90% C.L.. These bounds allow the existence of low-mass doubly charged Higgs with a small coupling constant. Direct search strategies for the Δ^{--} have been explored for hadron colliders [27], with the mass reach at the LHC extending to ~ 850 GeV. Signatures have also been explored for various configurations of lepton colliders, including $e\gamma$ colliders.

In the process $e^-\gamma \to e^+\mu^-\mu^-$, the signal of like-sign muons is distinct and SM background free, offering excellent potential for doubly charged Higgs discovery. The process proceeds via the production of a positron along with a Δ^{--}, with the subsequent Δ decay into two muons as well as through additional non-resonant contributions. The cross section is a convolution of the backscattered laser photon spectrum, $f_{\gamma/e}(x)$ [23], with the subprocess cross section, $\hat{\sigma}(e^-\gamma \to e^+\mu^-\mu^-)$. Due to contributions to the final state that proceed via s-channel Δ^{--}'s, the doubly-charged Higgs boson width must be included. The Δ width, however, is dependent on the parameters of the model, which determine the size and relative importance of various decay modes. To account for the possible variation in width without restricting ourselves to specific scenarios, we calculated the width using $\Gamma(\Delta^{--}) = \Gamma_b + \Gamma_f$ where Γ_b is the partial width to final state bosons and Γ_f is the partial width into final state fermions. Two scenarios for the bosonic width were considered: a narrow width scenario with $\Gamma_b = 1.5$ GeV and a broad width scenario with $\Gamma_b = 10$ GeV. These choices represent a reasonable range for various values of the masses of the different Higgs bosons. The partial width to final state fermions is given by $\Gamma(\Delta^{--} \to \ell^-\ell^-) = \frac{1}{8\pi} h_{\ell\ell}^2 M_\Delta$. Since we assume $h_{ee} = h_{\mu\mu} = h_{\tau\tau} \equiv h$, we have $\Gamma_f = 3 \times \Gamma(\Delta^{--} \to \ell^-\ell^-)$. Many studies assume the Δ decay is entirely into leptons; for small values of the Yukawa coupling and relatively low M_Δ this leads to a width which is considerably narrower than our assumptions for the partial width into bosons.

We consider two possibilities for the Δ^{--} signal. We assume that either all three final state particles are observed and identified or that the positron is not observed, having been lost down the beam pipe. To take into account detector acceptance we restrict the angles of the observed particles relative to the beam, θ_μ, θ_{e^+}, to the ranges $|\cos\theta| \leq 0.9$. We restrict the particle energies E_μ, $E_{e^+} \geq 10$ GeV and assumed an identification efficiency for each of the detected final state particles of $\epsilon = 0.9$.

Given that the signal for doubly charged Higgs bosons is so distinctive and SM background free, discovery would be signaled by even one event. Because the value of the cross section for the process we consider is rather sensitive to the Δ width, the potential for discovery of the Δ is likewise sensitive to this model dependent parameter. Varying Γ_b, we find that, relative to $\Gamma_b = 10$ GeV, the case of zero bosonic width has a sensitivity to the Yukawa coupling h which is greater by a factor of about 5 [22].

In Fig. 2 we show 95% probability (3 event) contours in the $h - M_\Delta$ parameter space. In each case, we assume the narrow width $\Gamma = 1.5 + \Gamma_f$ GeV case. Figure 2a corresponds to the center of mass energies $\sqrt{s} = 500$, 800, 1000, and 1500 GeV, for the case of three observed particles in the final state, whereas Fig. 2b shows the case where only the two muons are observed. Figs. 2c and 2d correspond to the energies being considered for the CLIC e^+e^- collider, namely, $\sqrt{s} = 3$, 5, and 8 TeV, for the three body and two body final states, respectively. In each case, for $\sqrt{s}$ above the Δ production threshold, the process is sensitive to the existence of the Δ^{--} with relatively small Yukawa couplings. However, when the M_Δ becomes too massive to be produced the values of

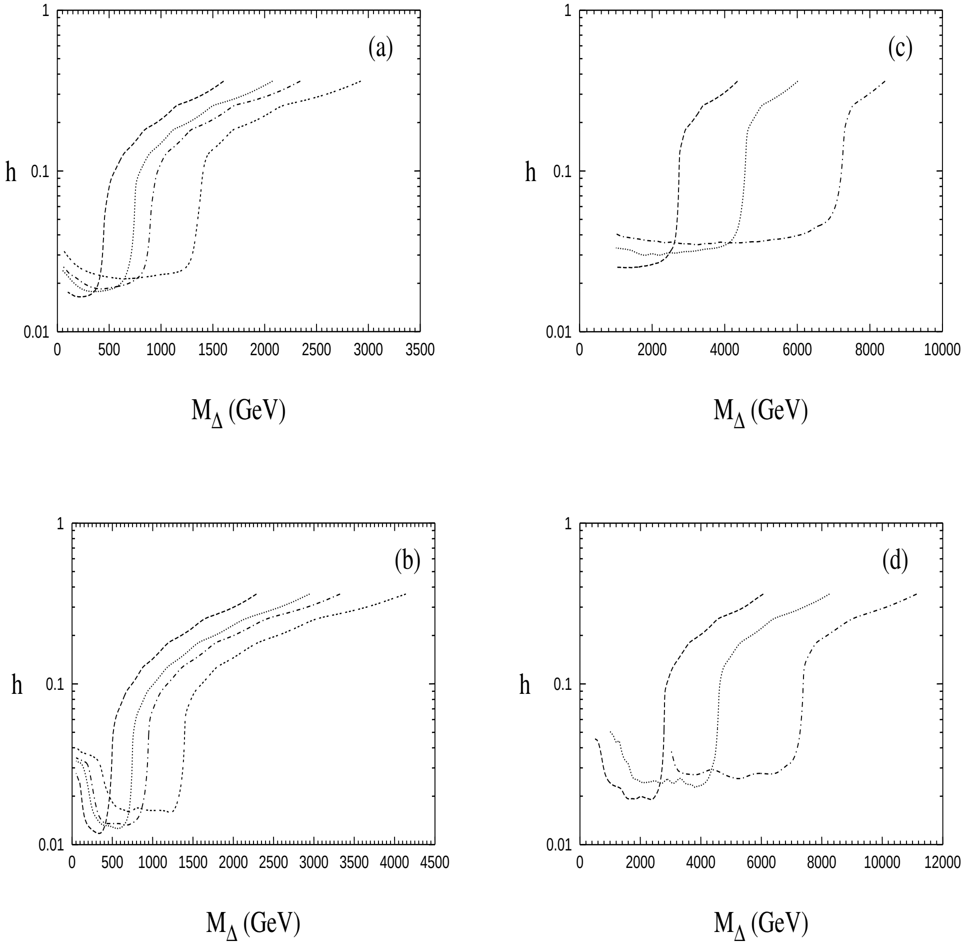

FIG. 2: Discovery limits for the charged Higgs bosons as a function of Yukawa coupling and M_Δ.

the Yukawa couplings which would allow discovery grow larger slowly.

The observation of doubly charged Higgs bosons would represent physics beyond the SM and, as such, searches for this type of particle should be part of the experimental program of any new high energy facility. We found that for $\sqrt{s_{e\gamma}} > M_\Delta$ doubly charged Higgs bosons could be discovered for even relatively small values of the Yukawa couplings; $h > 0.01$. For larger values of the Yukawa coupling the Δ should be produced in sufficient quantity to study its properties. For values of M_Δ greater than the production threshold, discovery is still possible due to the distinctive, background-free final state in the process $e\gamma \to e^+\mu^-\mu^-$ which can proceed via virtual contributions from intermediate Δ's. Thus, even an e^+e^- linear collider with modest energy has the potential to extend Δ search limits significantly higher than can be achieved at the LHC.

V. UPDATE OF DISCOVERY LIMITS FOR EXTRA NEUTRAL GAUGE BOSONS AT HADRON COLLIDERS

Following is a discussion of discovery limits for extra neutral gauge bosons at hadron colliders. The discovery of extra gauge bosons at future lepton colliders, particularly those arising from string and technicolor models, is presented in Ref. [28].

Extended gauge symmetries and the associated heavy neutral gauge bosons, Z', are a feature of many extensions of the Standard Model such as grand unified theories, Left-Right symmetric models, and superstring theories. If a Z' were discovered it would have important implications for what lies beyond the Standard Model. It is therefore important to study and compare the discovery reach for extra gauge bosons at the various facilities that are under consideration for the future [30, 31, 32, 33, 34, 35]. Included in the list of proposed facilities considered at the Snowmass'01 workshop are high energy hadron colliders. In this section we give the results of contribution P3-44 [29] which updates previous studies [30, 31, 32, 35] to include the high energy hadron colliders discussed at this meeting which range in $\sqrt{s}$ from 14 TeV to 200 TeV.

Many models that predict extra gauge bosons exist in the literature. We present search limits for several of these models that have received recent attention. Although far from exhaustive, the list forms a representative set for the purposes of comparison. The Effective Rank 5 E6 Model starts with the GUT group E_6 and breaks via the chain $E_6 \to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\chi \times U(1)_\psi$ with the Z' charges given by linear combinations of the $U(1)_\chi$ and $U(1)_\psi$ charges. Specific models are Z_χ corresponding to the extra Z' of $SO(10)$, Z_ψ corresponding to the extra Z' of E_6, and Z_η corresponding to the extra Z' arising in some superstring theories. The Left-Right symmetric model (LRM) is based on the gauge group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, which has right-handed charged currents and restores parity at high energy. The Alternative Left-Right Symmetric model (ALRM) is based on the same gauge group as the LRM but now arising from E_6 where the fermion assignments are different from those of the LRM due to an ambiguity in how they are embedded in the **27** representation. The Un-Unified model (UUM) is based on the gauge group $SU(2)_q \times SU(2)_l \times U(1)_Y$ where the quarks and leptons each transform under their own $SU(2)$ and the KK model (KK) contains the Kaluza-Klein excitations of the SM gauge bosons that are a possible consequence of theories with large extra dimensions. We also consider a Z' with SM couplings (SSM). Details of these models and references are given in Ref. [30].

The signal for a Z' at a hadron collider consists of Drell-Yan production of lepton pairs with high invariant mass via $pp \to Z' \to l^+l^-$. See Ref. [29, 31, 32, 36] for further details and references. The cross section for Z' production at hadron colliders is inversely proportional to the Z' width. If exotic decay modes are kinematically allowed, the Z' width will become larger and more significantly, the branching ratios to conventional fermions smaller. We will only consider the case that no new decay modes are allowed.

We obtain the discovery limits for this process based on 10 events in the $e^+e^- + \mu^+\mu^-$ channels using the EHLQ quark distribution functions [36] set 1, taking $\alpha = 1/128.5$, $\sin^2\theta_w = 0.23$, and including a 1-loop K-factor in the Z' production. Using different quark distribution functions results in a roughly 10% variation in the Z' cross sections [35] with the subsequent change in discovery limits. Lowering the number of events in the $e^+e^- + \mu^+\mu^-$ channels to 6 raises the discovery reach about 10% while lowering the luminosity by a factor of ten reduces the reach by about a factor of 3 [32]. Detailed detector simulations for the Tevatron and LHC validated our approximations as a good estimator of the true search reach. Furthermore, the results of our previous studies following this approach are totally consistent with subsequent experimental limits obtained at the Tevatron.

In our calculations we assumed that the Z' only decays into the three conventional fermion families. If other decay channels were possible, such as to exotic fermions filling out larger fermion representations or supersymmetric partners, the Z' width would be larger, lowering the discovery limits. On the other hand, if decays to exotic fermions were kinematically allowed, the discovery of exotic fermions would be an important discovery in itself; the study of the corresponding decay modes would provide additional information on the nature of the extended gauge structure.

The discovery limits for various models at hadron colliders are shown in Fig. 3. These bounds are relatively insensitive to specific models. In addition, since they are based on a distinct signal with little background they are relatively robust limits. Typical search limits for pp colliders are $\sim 0.25 - 0.30 \times \sqrt{s}$ assuming 100 fb^{-1} to 1 ab^{-1} of integrated luminosity with some variation due to differences of fermion couplings in the different models. The Tevatron, a $p\bar{p}$ collider, has a 50% higher discovery reach than this rough guideline, indicating that valence quark contributions to the Drell-Yan production process are still important at these energies.

VI. PARTING THOUGHTS

In this working group summary we have surveyed some of the topics explored by the Alternative Models and New Ideas subgroup. While some of the topics are updates of previous studies, many of the topics are related to ideas barely imagined during the last Snowmass workshop in 1996. Clearly, the bounds of our creativity are challenged only by nature itself. Until clear experimental evidence for new physics points us in the right direction, we must have the capability to explore as many avenues of new physics as our imaginations can conceive.

The work presented hear barely scratches the surface of the volume of alternative ideas that are currently being pursued, and which will no doubt continue to expand to encompass further insights and approaches. The challenge ahead is not only to construct models that purport to extend our understanding of the workings of nature, but also to develop methods by which the predictions of these models can be tested by experiment. Hopefully, in the not so distant future, a combination of theoretical creativity, phenomenological insight, and

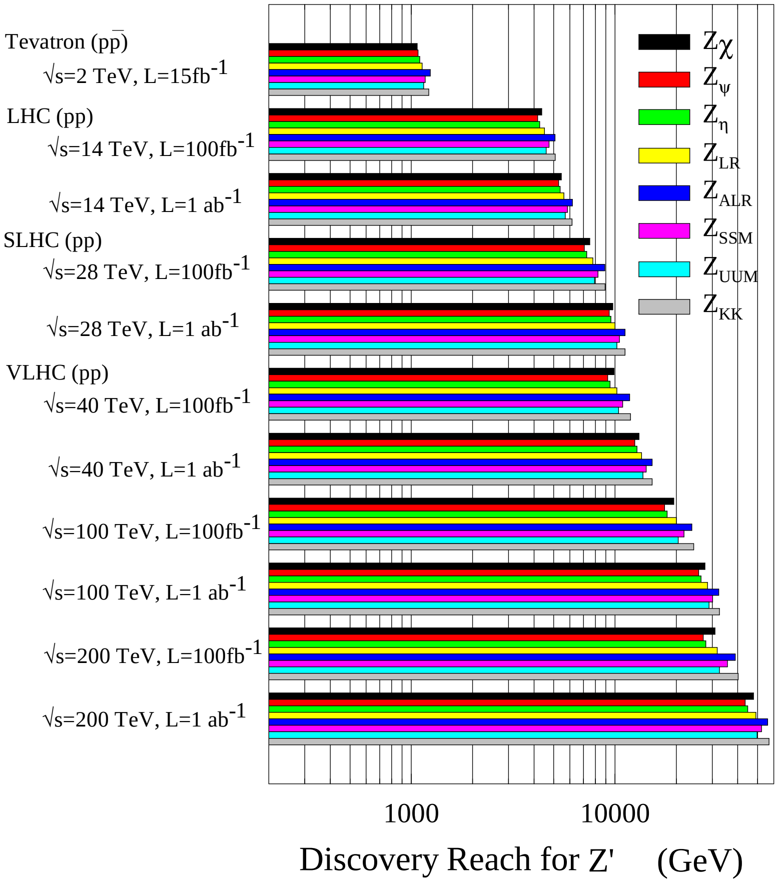

FIG. 3: Discovery limits for extra neutral gauge bosons (Z') for the models described in the text based on 10 events in the e^+e^- + $\mu^+\mu^-$ channels.

experimental progress will peel back the next layer in our understanding of the universe in which we live.

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