Beyond the Standard Model: Summary

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1. INTRODUCTION

Well-known theoretical arguments indicate that, despite its impressive phenomenological success, the standard model (SM) of particle physics is incomplete. In particular, the mechanism of electroweak symmetry breaking most likely involves new particles and interactions, either in addition to or instead of the Higgs boson postulated by the standard model. The new physics is expected to enter at an energy scale of order a TeV, which will be accessible to the experiments at the Large Hadron Collider (LHC) and the International Linear Collider (ILC). Discovering and studying the new physics is the main goal of these machines. Understanding how the ILC can contribute to this goal under a variety of new physics scenarios is therefore an important part of the physics case for this project.

Many theoretical ideas about the possible form of new physics at the TeV scale are currently being discussed. The most popular idea is that the electroweak symmetry is broken by a fundamental Higgs boson and the weak scale is stabilized against radiative corrections by virtue of supersymmetry (SUSY). The phenomenology of this class of models has been studied extensively; one of the Physics working groups at the Snowmass 2005 workshop was dedicated exclusively to SUSY studies. In contrast, our working group concentrated on alternative, non-supersymmetric possibilities for physics at the TeV scale. Our discussions were by no means exhaustive; we built upon our subgroup participants' knowledge and interests that they brought to the workshop.

In the last few years, there has been a considerable effort to construct and study models with phenomenologically relevant extra dimensions of space. The two popular early proposals are the "large extra dimensions" model of Arkani-Hamed, Dimopoulos and Dvali (ADD) [1], and the model with a single warped extra dimension by Randall and Sundrum (RS) [2]. In both of these scenarios, the fields charged under the SM gauge groups are confined to four-dimensional "branes" within the higher-dimensional space-time, while gravity and possibly other SM singlet fields are free to propagate in the "bulk" of the extra dimensions. Subsequently, models with SM non-singlet fields propagating in the bulk have also been constructed. A well-known example in this class is the model with "universal" extra dimensions (UED), where all SM fields are assumed to propagate in one or more extra dimensions of toroidal shape [3]. Models with one warped extra dimension of the RS type with the SM fields propagating in the bulk have also been studied. Recent examples include the universal RS model (URSM) with all SM fields in the bulk [4], and models with the Higgs on the brane and the rest of the SM fields in the bulk (see, e.g., [5]). Finally, insights from model-building in extra dimensions, combined with the "deconstruction" technique [6], have led to construction of purely four-dimensional models with novel and interesting properties, such as the "Little Higgs" models [7]. Phenomenological analyses of the ILC potential to study each of these classes of models have been performed or refined in this workshop. The common thread running through many of these studies is the observation that the existing experimental constraints on most of the proposed non-SUSY models rule out the possibility of the direct production of predicted new particles at the initial stage of the ILC ($\sqrt{s} = 500$ GeV) and often even at the upgraded machine ($\sqrt{s} = 1$ TeV). However, the exquisitely precise measurements of the standard model processes possible at the ILC will allow to discern the *indirect*, or virtual, effects of the new particles, even if their masses are far above the collision energy. The expected effects include the modification of cross sections and angular distributions of the produced particles in reactions such as $e^+e^- \to f\bar{f}$ induced by heavy particle exchanges (see section 4), as well as shifts in the couplings such as WWH or ttZ due to mixing between the SM states and new TeV-scale states. In many cases, the discovery reach of the ILC in indirect channels was shown to be comparable or higher than that of the LHC. Even more importantly, a detailed study of the observed deviations from the standard model predictions may allow us to *distinguish* between the models of new physics, based purely on their virtual effects.

While the primary motivation for extending the standard model at the TeV scale comes from naturalness considerations, many proposed models contain a stable weakly interacting massive particle (WIMP) which generically has the correct relic abundance to play the role of dark matter. The WIMP hypothesis raises a tantalizing possibility that the particles responsible for dark matter can be observed and studied in detail in the upcoming terrestrial experiments at the LHC and the ILC. A variety of non-supersymmetric WIMP candidates, as well as other possible forms of dark matter, were discussed by our working group.

2. LITTLE HIGGS STUDIES

Precision electroweak measurements prefer a light Higgs boson, $m_h \lesssim 250$ GeV, which in turn indicates that in the absence of fine-tuning the cutoff of the SM (i.e. the scale where new physics appears) should not be much higher than 1 TeV. At the same time, assuming that all non-renormalizable operators consistent with the SM symmetries are generated at the cutoff with O(1) coefficients, precision electroweak fits put a *lower* bound on the cutoff scale of about 10 TeV. This tension is known as the "little hierarchy problem" of the SM. Little Higgs models provide an interesting approach to solve the little hierarchy problem. These models have an enlarged gauge group structure, which is broken near the TeV scale to the SM electroweak gauge group. The novel feature of little Higgs models is that there are approximate global symmetries that protect the Higgs mass from acquiring *one-loop* quadratic sensitivity to the cutoff. This happens because the approximate global symmetries ensure that the Higgs can acquire mass only through "collective breaking", or multiple interactions. In the limit that any single coupling goes to zero, the Higgs becomes an exact (massless) Goldstone boson. Quadratically divergent contributions are therefore postponed to two-loop order, thereby relaxing the tension between a light Higgs mass and a cutoff of order tens of TeV. The Higgs mass term is then dominated by the logarithmically divergent one-loop contribution from the top quark, which triggers electroweak symmetry breaking.

Many realistic models implementing the Little Higgs mechanism outlined above have been constructed [7]. Most phenomenological studies are performed in the context of the $SU(5)/SO(5)$ Littlest Higgs (LH) model [8]. The original version of this model suffers from strong constraints from precision electroweak data, which imply a significant amount of fine tuning [9]. However, slightly modified versions of the model avoid most of the constraints, at least in some small regions of the parameter space [10]. More interestingly, little Higgs models with an additional Z_2 discrete symmetry, named T-parity, were constructed [11] in which no corrections to low energy observables are generated at tree level. The Littlest Higgs model with T-parity satisfies precision electroweak constraints without fine tuning [12], albeit by significantly enlarging the particle content over the original Littlest Higgs models.

The new TeV-scale states predicted by Little Higgs models are typically beyond the kinematic reach of the ILC, and thus one must rely on indirect effects to study this sector[1]. In particular, all Little Higgs models contain a TeV-scale vector-like quark T of electric charge $+2/3$, which is required to cancel the one-loop quadratic divergence from the SM top loop. Typically, the T quark mixes with the SM top, leading to potentially observable shifts in the gauge and Yukawa couplings of the latter from their SM values. Berger *et. al.* [13] evaluated these shifts in two

[1]In models with T parity, it is possible that some of the new states are sufficiently light to be produced at a 1 TeV ILC. This possibility deserves further study.

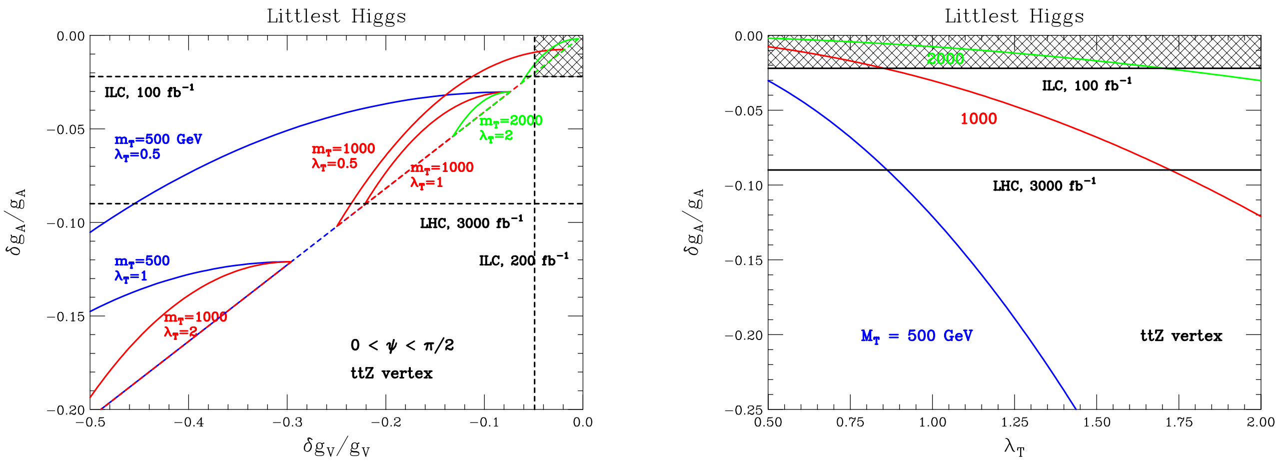

Figure 1: The corrections to the $t\bar{t}Z$ axial and vector couplings in the $SU(5)/SO(5)$ Littlest Higgs model (left panel), and the $t\bar{t}Z$ axial coupling in the Littlest Higgs model with T parity (right panel). (Vector and axial couplings receive equal shifts in the model with T parity.) The regions in which the ILC would observe no deviation from the SM are shaded. From Ref. [13].

versions of the Littlest Higgs model: the original model of [8] with the gauge group reduced to $SU(2) \times SU(2) \times U(1)$ to alleviate precision electroweak constraints, and the model with T parity [11, 12, 14]. It was found that the ILC will be able to observe the shifts throughout the natural range of model parameters, substantially improving upon the sensitivity expected at the LHC, even assuming very large integrated luminosity[2]. For example, the expected shifts in the ttZ couplings in these two versions of the Littlest Higgs, along with the LHC and ILC sensitivities, are shown in Fig. 1. The shift in the tbW coupling is also likely to be detected via a precise measurement of the SM top width.

The effects of the extended gauge sector present in the Littlest Higgs model in the reactions $e^+e^- \to \bar{f}f$ and $e^+e^- \to Zh$ were examined by Conley *et. al.* in Ref. [16] and summarized in Ref. [17]. The main concern was with the extended neutral gauge sector, which can be parameterized by the symmetry breaking scale f and two mixing angles. For generic choices of the angles, $M_{A_H}/M_{Z_H} \simeq s_w M_Z/\sqrt{5}M_W \simeq 1/4$. This light A_H is responsible for the most stringent experimental constraints on the model [9]. As a result, phenomenologically viable variations of the Littlest Higgs models typically decouple the A_H by modifying the gauge structure of the theory. To gain some understanding of models in which the A_H decouples, two approaches were considered: one was to choose a parameter value ($s' = \sqrt{3/5}$) for which the coupling of A_H to fermions vanishes. Another was to artificially take $M_{A_H} \to \infty$ while letting all other quantities in the theory take on their usual, parameter-dependent values. While not theoretically consistent, this approach gives a more general picture of the behavior of models in which the A_H decouples.

First, the process $e^+e^- \to \bar{f}f$ was examined, where all of the LH neutral gauge bosons participate via s-channel exchange. The exclusion region at LEP II (taking $s' = s/2$) and the 5σ search reach at the ILC for various values of s' are shown in the left panel of Fig. 2. The search region at $\sqrt{s} = 1$ TeV extends to somewhat higher values of the parameter s, but has essentially the same reach for f as the 500 GeV collider. The 5σ discovery contour for the Z_H at the LHC, as computed by an ATLAS based analysis [18], is included in the figure for comparison.

Now, given the existence of an LH model with parameters in this accessible range, how accurately would the ILC be able to measure them? To answer this, a generic data point (s, s', M_{Z_H}) was used to calculate the observables, which was then fluctuated according to statistical error. (An integrated luminosity of 500 fb^{-1} was assumed.) It was assumed that the LHC would have determined M_{Z_H}, to of order a few percent for $M_{Z_H} < 5-6$ TeV, allowing a

[2]For a recent update of the LHC sensitivity projections, see [15].

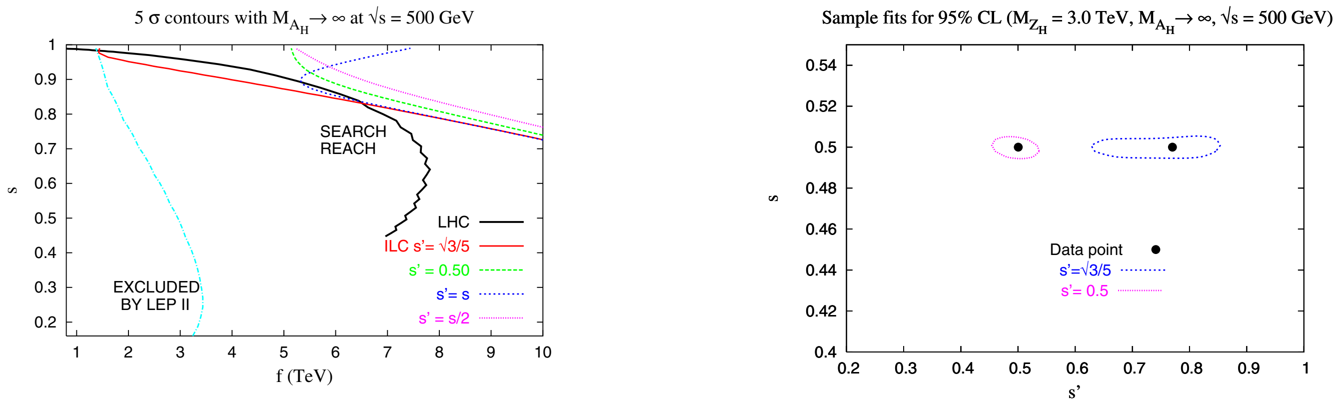

Figure 2: Left panel: LEP II exclusion region and ILC 5σ search reach in the $s-f$ parameter plane for various values of s'. The LHC result [18] is included for comparison. Right panel: 95% CL sample fits to the data points ($s=0.5$, $s'=0.5$) and ($s=0.5$, $s'=\sqrt{3/5}$) taking $M_{Z_H}=3.0$ TeV, at a 500 GeV ILC with 500 fb^{-1} integrated luminosity. From Ref. [17].

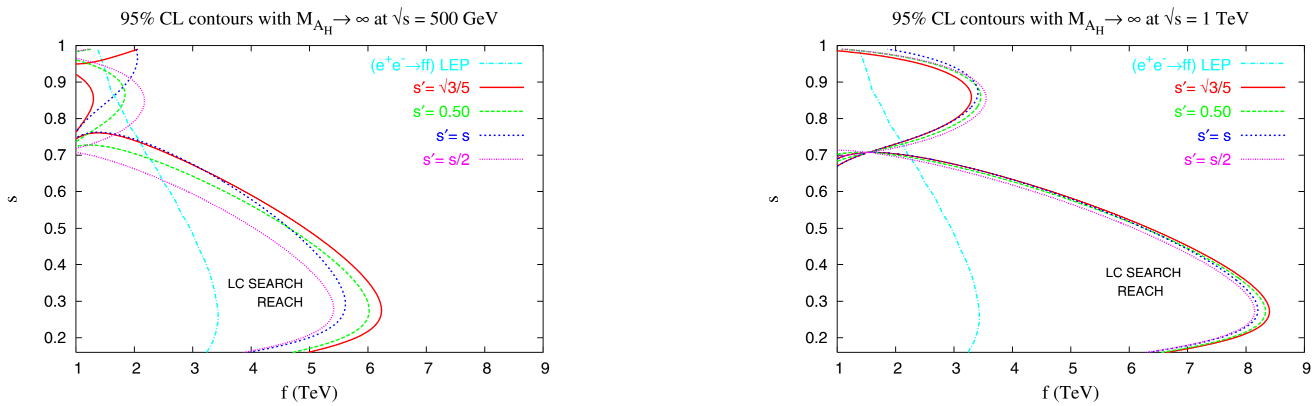

Figure 3: The ILC 95% CL search reach in the $s-f$ parameter plane from the process $e^+e^- \to Z_L h$ for various values of s', taking $\sqrt{s}=500$ GeV, and 1 TeV in the right and left panels, respectively. The LEP II exclusion region from $e^+e^- \to \bar{f}f$ is shown for comparison. From Ref. [17].

two-parameter fit on s and s' to be performed at the ILC. The right panel of Fig. 2 shows the results of this fit for two sample data points. For both cases, the determination of s is very accurate, due to the strong dependence of the $Z_H\bar{f}f$ couplings on this parameter.

Ref. [17] also studied the coupling of the Z_H to the Higgs boson using the process $e^+e^- \to Z_L h$. There are three sources for this process: Z_H and A_H exchange in the s-channel and the deviation of the $Z_L Z_L h$ coupling from its SM value. The dependence of the $Z_H Z h$ vertex on the $SU(2)$ mixing angle provides a smoking gun signature of the LH mechanism, as shown in Ref. [19]. A χ-squared analysis was carried out as before and the results for the ILC search reach in the LH parameter space are displayed in Fig. 3.

3. PROBING THE UNIVERSAL RANDALL-SUNDRUM MODEL AT THE ILC

The Universal Randall-Sundrum model (URSM), a five-dimensional theory with the geometry of the original Randall-Sundrum model and with all standard model fields, including the Higgs, assumed to propagate in the bulk, can be probed by precision measurements at the ILC. In particular, the couplings of the Higgs to the gauge bosons of the SM can be determined with high accuracy at the ILC. Deviations in these couplings from their SM values within the URSM were examined in Ref. [4] and summarized in the contribution by Davoudiasl *et. al.* [20].

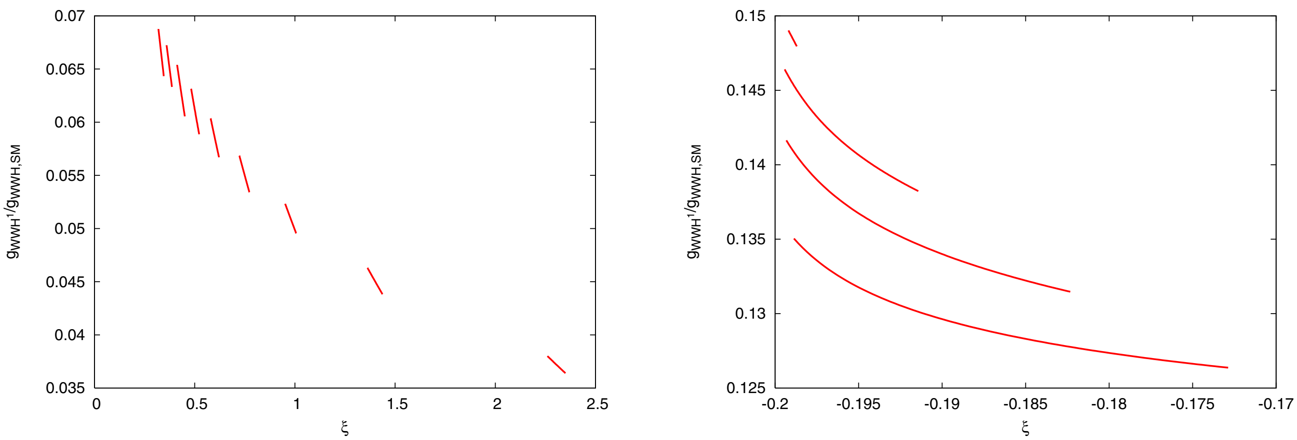

Figure 4: Values of the coupling ratio g_{WWH^1}/g^{SM}_{WWH} for the first Higgs KK excitation, scanned over the two theoretically consistent regions of the parameter ξ. The curves correspond to different values of β_H. For details, see Ref. [20].

The Randall-Sundrum (RS) model provides an interesting explanation of the hierarchy problem [2]. In the original RS model, the only 5-d field is the graviton. Subsequently, numerous works have extended the RS setup to include bulk fermions and gauge fields [21]. However, the fundamental Higgs field responsible for electroweak symmetry breaking (EWSB) has been kept on the TeV brane. Ref. [4] considered the possibility that all SM fields, including the Higgs, propagate in the bulk. The Higgs sector of the model is characterized by two dimensionless parameters: the bulk Higgs mass in units of the curvature scale k^{-1}, denoted by ξ, and the brane-localized mass, again in units of k^{-1}, denoted by β_H. (For precise definitions including numerical factors, see [4].) It was shown that by appropriate choices of these parameters, one can generate a single tachyonic Kaluza-Klein (KK) mode of the Higgs field in the low energy 4-d theory. This tachyonic mode can be identified as the SM Higgs field. Given a quartic bulk term for the Higgs, the tachyonic mode will lead to the usual 4-d Higgs mechanism and endow the electroweak gauge bosons with mass. Typical generic signatures of this scenario are the emergence of a tower of Higgs KK modes, as well as a modification of the WWH coupling which can be directly probed through precision measurements at the ILC.

How do the WWH couplings in the URSM compare to their SM values, *i.e.*, what are ratios g_{WWH}/g^{SM}_{WWH}? To address this question, Davoudiasl et. al. have performed a scan over the two theoretically allowed regions of the model parameter space. The results of such a scan suggest that, in units of v/v_{SM}, the deviation is expected to be O(1). With precision measurements at the ILC these predictions can be directly tested. The ratio v/v_{SM} itself can be independently determined by combining the Higgs mass measurement with that of the 4-d quartic coupling via the relation $\lambda_{4d} = m_H^2/(2v^2)$. The first KK Higgs excitation may be light enough to be produced at a 1 TeV ILC so that it is important to examine these couplings as well. The results (in units of the SM WWH coupling) are presented in Fig. 4 for both theoretically allowed regions of the parameter space. The reduced values of these couplings compared to the SM will lead to a substantial reduction in the production cross section for this state, making it difficult to produce at the LHC/ILC via the vector boson fusion process.

In the "gravity-induced" version of the URSM there are additional predictions which may be testable at the ILC. In this framework the parameter ξ controls the size of Higgs-radion mixing which is now directly correlated with the HWW coupling in the weak eigenstate basis. Measurements of radion properties will provide further tests of the URSM scenario.

4. CONTACT INTERACTIONS AND MODEL DISCRIMINATION AT THE ILC

Heavy new particles exchanged in fermion pair production at the ILC induce modifications of cross section and angular distribution of the final state fermions. The sensitivities to various models, especially Z′ models, have been studied extensively depending on the parameters of the ILC. The high precision measurements at the ILC may allow to discriminate the source of the deviations, and therefore to obtain valuable information about the nature of the underlying theory.

The description of new interactions by four-fermion contact terms is a simple but powerful tool to parameterize extensions of the standard model. The angular distribution of the final state fermions depends on the spin of the heavy particles exchanged in the $e^+e^- \to f\bar{f}$ reaction (see i.e. [23–29] and references therein). The contribution by Pankov *et al.* [30] (see also [31]) demonstrates the ILC potential to discriminate between the ADD large extra dimension scenario characterized by an angular-dependent contact term [23, 32] ($\sim \lambda/\Lambda_H^4$) and the dimension-6 contact interaction models [33] ($\sim \eta/\Lambda^2$) without additional angular dependence. For very large scales of new physics, the signal becomes too small to distinguish the models and a "confusion" region remains. Fig. 5 shows the confusion regions for the polarized and unpolarized beam cases [30]. This study only uses the $b\bar{b}$ final state; it would be interesting to see how combining information from different channels can improve the discriminating power.

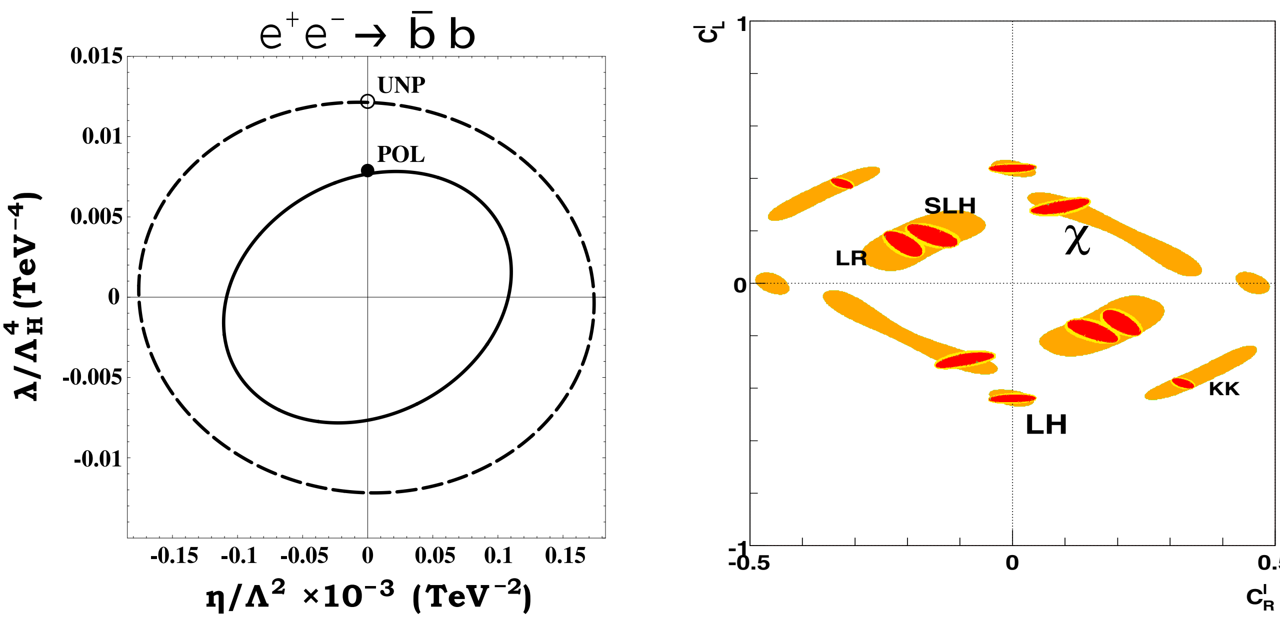

Figure 5: Left (from Ref. [30]): Confusion region (95% C.L.) for the ADD and the vector-like contact interaction model, VV, from $e^+e^- \to b\bar{b}$ with $\mathcal{L}_{int} = 100$ fb^{-1}. Right (from [34]): Resolving power (95% C.L.) for $M_{Z'} = 2$ TeV and $\sqrt{s} = 500$ GeV, $\mathcal{L}_{int} = 1$ ab^{-1} for leptonic couplings based on the leptonic observables, $\sigma^{\mu}_{P_{e^-} P_{e^+}}$, $A^{\mu}_{LR}$and A^{μ}_{FB}. The largest allowed regions correspond to the unpolarized case, the smallest regions correspond to electron and positron polarization of 80% and 60% respectively, and the middle regions correspond to electron polarization only.

Godfrey *et al.* [34] focus on discriminating between Z′ models, models with extra dimensions, and Little Higgs models. They point out the need for polarized beams and the examination of all final states to increase the resolving power between new physics models. It should be mentioned that the analysis of the Kaluza-Klein (KK) models is problematic: both photon and Standard Z KK excitations have to be taken into account and they are roughly degenerate in mass. The couplings resulting from fits do not correspond to the "initial" KK couplings but the example shows that KK models can be distinguished from other scenarios.

Finally, it should be emphasized that while the discovery reach is not increased substantially in the case when both the electron and the positron beam are polarized, polarizing both beams is extremely useful in distinguishing between models of new physics. The potential angular dependence of new physics effects has to be included by considering differential instead of the integrated cross sections.

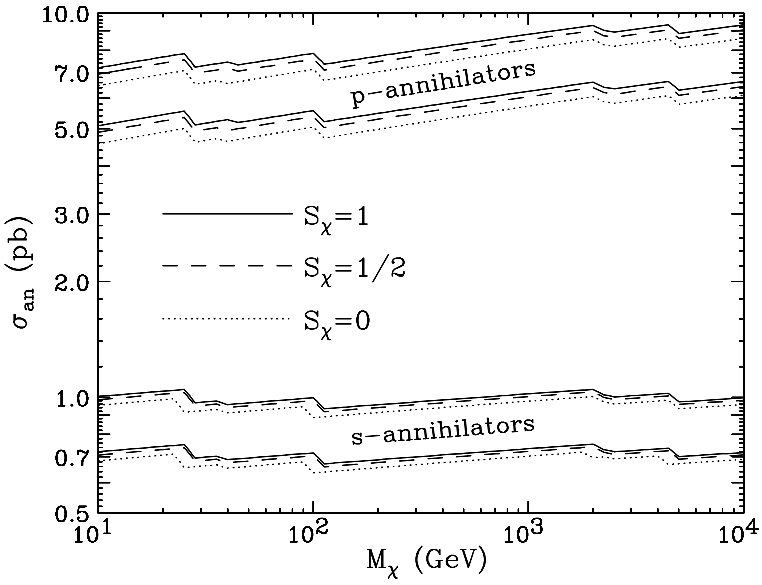

Figure 6: Values of the $\chi + \chi \to$ SM annihilation cross section allowed at 2σ level by the WMAP dark matter density determination, as a function of the χ mass. The lower (upper) band is for models where s-wave (p-wave) annihilation dominates. From Ref. [40].

5. DARK MATTER IN MANY FORMS

It has now been firmly established that about 25% of the energy density in the universe exists in the form of nonrelativistic, non-baryonic, non-luminous matter, so called "dark matter" [35]. However the microscopic composition of dark matter remains a mystery, and a large number of possibilities have been discussed in the literature [36]. Many of the suggested candidates belong to the class of "thermal relics", stable elementary particles which were in thermal equilibrium with ordinary matter in the early universe and subsequently decoupled. If all of the observed dark matter consists of a thermal relic χ, the total pair annihilation cross section of χ's into the SM species is determined by the measured dark matter density, see Fig. 6. Intriguingly, the inferred value of the cross section is within the range typical for weak-scale processes, giving rise to the popular conjecture that the dark matter is made out of weakly interacting massive particles (WIMPs). Many models of TeV-scale physics naturally contain WIMP candidates, typically stable due to being the lightest state charged under a new discrete symmetry G. The best known example is the neutralino of the supersymmetric models, where R parity plays the role of G; however, other models such as UED [37] and Little Higgs models with T-parity [14] contain WIMP dark matter candidates as well. Another, closely related possibility is that the WIMP is not stable, and decays into another, stable G-odd particle (the "superWIMP") which only interacts gravitationally with ordinary matter and plays the role of dark matter [38]. On the other hand, a variety of non-thermal relic candidates also exist. The axion is probably the best motivated candidate in this class. Rosner's contribution [39] emphasized that many of these possibilities are not mutually exclusive, and the observed dark matter may consist of more than one type of object. Indeed, the ordinary matter is made out of a variety of particles: protons, neutrons, electrons, neutrinos, photons and gravitons, which are light and stable due to a variety of symmetries (exact and accidental, gauge and global) of the standard model. Likewise, dark matter may be a mixture of several stable species: for example, neutralinos (or some other WIMPs), axions, and microscopic black holes can all contribute. Dark matter search experiments should be prepared for this possibility. In particular, given the variety of candidates, it is useful to obtain theoretical predictions for quantities relevant for dark matter searches in a way that minimizes the dependence on the underlying particle physics model. While no completely model-independent statement can be made concerning non-gravitational interactions of dark matter, an approach based only on the generic assumption of a thermal relic dark matter was successfully pursued in [40], where the photon+missing energy signature of the direct production of dark matter particles at the ILC was considered. The same approach was applied to predict the anomalous gamma ray fluxes from the dark matter annihilation in the galactic center, followed by final state radiation [41].

Several dark matter candidates in extra-dimensional theories were also discussed and reviewed in the contribution by Cembranos *et. al.* [42]. KK gravitons, for example, exist in all UED models and these may be viable dark matter candidates. Given the general formalism for analyzing the dynamics of gravitons in UED theories [43], one can find the widths for decays of KK fermions and KK gauge bosons into KK gravitons. These results are of special relevance when a KK graviton is the lightest KK particle and a superWIMP candidate [44], as they determine the observable implications of KK graviton dark matter for Big Bang nucleosynthesis, the cosmic microwave background, the diffuse photon flux [43] and structure formation [45]. The possibility of populating a large number of graviton states at different KK levels implies that the production of gravitons after reheating is extremely efficient and extremely sensitive to the reheat temperature T_{RH}. The constraints on T_{RH} presented in [42] are rather stringent: the reheat temperature is generally required to be below about 10 TeV.

Cembranos *et. al.* also emphasized that the UED scenario with KK graviton superWIMPs can be probed in collider experiments. Decays of KK leptons, which are the next-to-lightest KK particles in this scenario and are long-lived, to KK gravitons may be observed by trapping the KK leptons in water tanks placed just outside collider detectors. By draining these tanks periodically to underground reservoirs, KK lepton decays may be observed in quiet environments as in the case of supersymmetric models with gravitino LSP studied in [46–51]. Precision studies of KK lepton decays are therefore possible and can provide a direct observation of gravitational effects at colliders, measurements of the size of the extra dimensions and Newton's constant, and a precise determination of the KK gravitons' contribution to dark matter abundance.

Another dark matter candidate, discussed both in [42] and in the contribution by Cembranos, Dobado and Maroto [52], is the branon. In flexible braneworld models, where the brane tension is much smaller than the D dimensional or fundamental gravitational scale M_D, the branons are the only new relevant low-energy degrees of freedom [53]. Branons interact by pairs with the SM energy-momentum tensor and their couplings are suppressed by the brane tension f^4. In fact, they can be generically stable and weakly interacting, and thus interesting WIMP dark matter candidates [54, 55]. In collider experiments, the events with direct branon production are charecterized by apparent missing energy. Branon production in association with a single jet or a photon at hadron colliders, or a single Z or photon in e^+e^- collisions [56], provides potentially observable signatures. The photon+missing energy has been studied experimentally by L3 [57], who found the tightest bound on the brane tension, $f > 180$ GeV, for light branons. Branon radiative corrections [58] also modify four body interactions, electroweak precision observables, anomalous magnetic moments and Higgs boson phenomenology. Nevertheless, the resulting constraints do not rule out the possibility that the branons make all or part of the observed dark matter.

6. CONCLUSIONS

While naturalness considerations provide a strong theoretical reason to expect new physics at the TeV scale, they are not sufficient to determine what this new physics will be. Supersymmetric models are well motivated and attracted much attention; however, in the last few years, a host of new, non-supesymmetric candidate theories have been proposed. Most of these theories involve extra compact dimensions of space, large enough to be relevant at the TeV scale; others, such as the Little Higgs, are four-dimensional theories with novel properties, constructed using insights from the analysis of models with extra dimensions. All these theories predict new particles that will be observable, either via direct production or indirect effects on low-energy processes, at the LHC and the ILC. During the Snowmass 2005 workshop, our working group discussed the potential of the ILC to discover and study the new physics under a variety of non-supersymmetric scenarios. In every scenario, we found that the ILC will be able to perform interesting measurements, and in many cases, we found that the ILC sensitivity to new physics exceeds the capabilities of the LHC. This is mostly due to the precise measurements of the SM processes possible at the ILC. The high precision allows to discern and study the effects of new physics even if, as is the case in many of the models we studied, the new particles are too heavy to be directly produced. For example, if a new resonance appears in the $e^+e^- \to f\bar{f}$ channels, a study of the reaction rate and angular distribution of the final state fermions will allow to determine the spin of the resonance and its couplings to fermions, even if the resonance mass is in a few-TeV range. Electron and positron beam polarizations can play an important role in this determination. Another example is provided by the shifts in the ttZ and tbW couplings predicted in Little Higgs models, which can be probed only in a small corner of the model parameter space at the LHC but throughout the parameter space at the ILC. In the future, it would be interesting to identify and study further examples of the LHC-ILC complementarity within the non-supersymmetric new physics scenarios.

Our working group also discussed a variety of non-supersymmetric candidates for dark matter. WIMP or super-WIMP dark matter candidates are contained in many interesting non-SUSY new physics models: examples include KK photons or KK gravitons in the UED models, T-odd heavy photons in the Littlest Higgs model with T parity, and branons in braneworld theories. The LHC and especially the ILC can provide a direct and precise determination of the properties of these new particles, such as their masses and couplings. If enough information is collected to provide a precise theoretical calculation of the WIMP pair-annihilation and co-annihilation cross sections, confronting this prediction with the observed cosmological abundance of WIMPs will provide a quantitative test of the early universe cosmology at the epoch of WIMP decoupling, well before the Big Bang nucleosynthesis. This exciting possibility is being studied in detail in the context of SUSY models. It would be interesting to perform analogous analyses for the various non-supersymmetric dark matter candidates mentioned above.

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