

SUPERSYMMETRY TESTS AT FUTURE LINEAR COLLIDERS

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ABSTRACT

If new particles are discovered, it will be important to determine if they are the supersymmetric partners of standard model bosons and fermions. Supersymmetry predicts relations among the couplings and masses of these particles. We discuss the prospects for tests of these relations at a future e^+e^- linear collider.

1. Introduction

Supersymmetry (SUSY) predicts not only the existence of particles with the correct spin and quantum numbers to be superpartners of standard model particles, but also well-defined quantitative relations among the couplings and masses of these new particles. Even if only one or a few new particles are discovered, precise verification of quantitative SUSY relations could be taken as confirmation of SUSY. It is the prospects for such tests that we investigate in this study. Our tests will exploit the clean environment and polarizable beams of the proposed Next Linear Collider, a linear e^+e^- collider with $\sqrt{s} = 500 \text{ GeV}$ and a luminosity of $50 \text{ fb}^{-1}/\text{year}$. We will limit the discussion to the case in which charginos are produced, but slepton and squark pair production is beyond reach. Remarks about other scenarios may be found in an extended version of this work done with H. Murayama, M. E. Peskin, and X. Tata.¹

2. Regions of Parameter Space

This study will be conducted in the context of the minimal supersymmetric standard model (MSSM), the supersymmetric extension of the standard model with minimal field content. The charginos of the MSSM are mixtures of the charged Higgsinos and electroweak gauginos and have mass terms $(\psi^-)^T M_{\tilde{\chi}^\pm} \psi^+ + h.c.$, where

$$M_{\tilde{\chi}^\pm} = \begin{pmatrix} M_2 & \sqrt{2} M_W \sin \beta \\ \sqrt{2} M_W \cos \beta & \mu \end{pmatrix}, \quad (1)$$

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and $(\psi^\pm)^T = (-i\tilde{W}^\pm, \tilde{H}^\pm)$. The chargino mass eigenstates are $\tilde{\chi}_i^\pm = V_{ij}\psi_j^\pm$ and $\tilde{\chi}_i^- = U_{ij}\psi_j^-$. The matrices V and U are effectively orthogonal rotation matrices parametrized by the angles ϕ_+ and ϕ_- , respectively.

We assume that R-parity is conserved, the LSP is the lightest neutralino $\tilde{\chi}_1^0$, there is no intergenerational mixing in the sfermion sector, and sleptons and squarks are roughly degenerate with masses $m_{\tilde{l}}$ and $m_{\tilde{q}}$, respectively. (The last assumption may be partially relaxed.²⁾ With these assumptions, the parameters that enter chargino events are μ , M_2 , $\tan\beta$, $m_{\tilde{l}}$, M_1 , and $m_{\tilde{q}}$. The e^- differential cross section $d\sigma_L/d\cos\theta$ is governed by the first four parameters, while $d\sigma_R/d\cos\theta$ is dependent on only the first three. Charginos decay to LSPs through W bosons, virtual sleptons, and virtual squarks. All six parameters enter the decay process.

We now divide the parameter space into characteristic regions. The chargino masses and $\sigma_R \equiv \sigma(e_R^- e_L^+ \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp)$ depend only on μ , M_2 , and $\tan\beta$. In Fig. 1 we set $\tan\beta = 4$ as a representative case. The cross-hatched region is excluded by present experiments, and chargino production is inaccessible for $\sqrt{s} = 500 \text{ GeV}$ in the hatched region. In region 1, $\tilde{\chi}_1^\pm \tilde{\chi}_2^\mp$ production is possible, and so both chargino masses can be measured. Where $\tilde{\chi}_2^\pm$ is inaccessible, σ_R distinguishes regions 2 (shaded, $\sigma_R \approx 0$) and 3 (where, typically, $\sigma_R > 50 \text{ fb}$). We will consider case studies with $m_{\tilde{\chi}_1^\pm} \approx 170 \text{ GeV}$, which holds on the dashed contours in Fig. 1. Region 3 presents difficulties even for the identification of a SUSY signal, since $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ become nearly degenerate as M_2 increases, and we will not consider this case further.

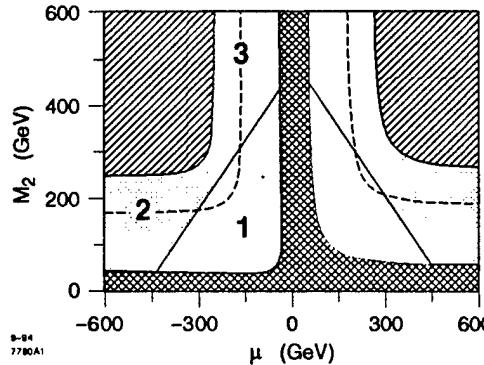


Fig. 1. The characteristic regions of parameter space.

3. Region 1

In region 1 we take the representative point in parameter space to be $(\mu, M_2, \tan\beta, M_1/M_2, m_{\tilde{l}}, m_{\tilde{q}}) = (-195, 210, 4, 0.5, 400, 700)$. For these parameters, $m_{\tilde{\chi}_1^\pm} = 172 \text{ GeV}$, $m_{\tilde{\chi}_1^0} = 105 \text{ GeV}$, and $m_{\tilde{\chi}_2^\pm} = 255 \text{ GeV}$. The uncertainty in determining these masses is small³ and will be unimportant for this study. The right-handed cross section $\sigma_R = 48 \text{ fb}$ is large enough to yield many events for study.

In this region we generalize the chargino mass matrix to an arbitrary real 2×2

matrix by generalizing M_W to an arbitrary parameter M_W^χ in Eq. (1). Our goal is to test the SUSY relation $M_W^\chi = M_W$, that is, the equality of the Higgs boson and Higgsino couplings. Formally, this is a simple task. The four parameters M_2 , μ , $\tan \beta$ and M_W^χ may be exchanged for the parameters $m_{\tilde{\chi}_1^\pm}$, $m_{\tilde{\chi}_2^\pm}$, ϕ_+ and ϕ_- . By measuring $m_{\tilde{\chi}_1^\pm}$, $m_{\tilde{\chi}_2^\pm}$, and two quantities derived from $d\sigma_R/d\cos\theta$, we may restrict the variables (ϕ_+, ϕ_-) and may thereby bound M_W^χ . It is useful to work with the total cross section σ_R and the forward-backward asymmetry A_{FB}^R . Unfortunately, neither quantity may be observed directly. To determine the correlation of these quantities to experimental observables, we have performed Monte Carlo simulations for chargino events using the parton-level event generator of Feng and Strassler.² Using the cuts for mixed mode events presented by the JLC group³ and including both systematic and statistical errors, we find that for an integrated luminosity of $50 fb^{-1}$, the 1σ bounds on σ_R and A_{FB}^R constrain the (ϕ_+, ϕ_-) plane to the shaded region in Fig. 2. In the allowed region, $65 GeV < M_W^\chi < 100 GeV$, a significant quantitative confirmation of SUSY.

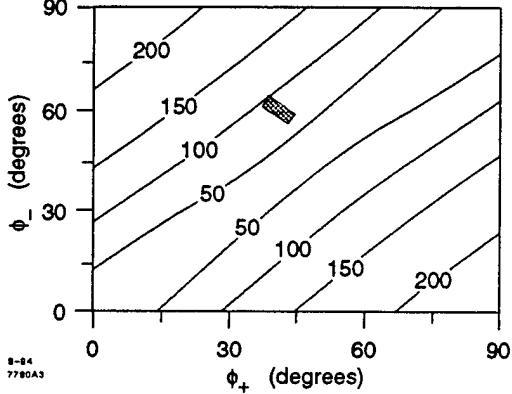


Fig. 2. The allowed region of the (ϕ_+, ϕ_-) plane. Contours of M_W^χ are plotted in GeV.

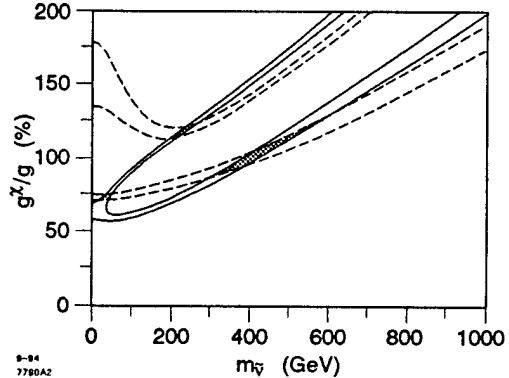


Fig. 3. Allowed $(m_{\tilde{\chi}}, g^\chi)$ regions. Solid (dotted) curves are σ_L (A_{FB}^L) constraints.

4. Region 2

In region 2 we take the representative point to be $(\mu, M_2, \tan \beta, M_1/M_2, m_{\tilde{l}}, m_{\tilde{q}}) = (-500, 170, 4, 0.5, 400, 700)$. For these parameters, $m_{\tilde{\chi}_1^\pm} = 172 GeV$, $m_{\tilde{\chi}_1^0} = 86 GeV$, $m_{\tilde{\chi}_2^\pm} = 512 GeV$, and $\sigma_R \approx 0$. Here we must rely on measurement of $d\sigma_L/d\cos\theta$, which introduces dependence on $m_{\tilde{\nu}}$. Fortunately, there is a compensating simplification: in region 2, $\phi_+, \phi_- \approx 0$, i.e., $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ are very nearly pure gauginos.

We will generalize the $\tilde{\chi}_1^\pm f\bar{f}$ coupling to $g^\chi V_{11}$ and test the SUSY relation $g^\chi = g$, that is, the equality of the W boson and wino couplings. The differential cross section $d\sigma_L/d\cos\theta$ is a function of $(m_{\tilde{\chi}_1^\pm}, \phi_+, \phi_-, m_{\tilde{\nu}}, g^\chi)$, but because we can measure $m_{\tilde{\chi}_1^\pm}$, and $\phi_+, \phi_- \approx 0$, we have only two unknowns. These may be constrained with two quantities formed from $d\sigma_L/d\cos\theta$, in particular, σ_L and A_{FB}^L . Following the procedure of the previous section, we find that, for an integrated luminosity of

50 fb^{-1} , the measurements constrain the allowed region of the $(m_{\tilde{\nu}}, g^X)$ plane to the three shaded areas shown in Fig. 3. If $m_{\tilde{\nu}} < 250\text{ GeV}$ can be excluded, the allowed region is only the largest of these shaded regions, in which $0.75g \leq g^X \leq 1.3g$. In addition to confirming the prediction of SUSY, it is clear from Fig. 3 that we have simultaneously bounded $m_{\tilde{\nu}}$, a useful result for future sparticle searches.

References

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