PRECISION ACCESS TO SLEPTON MASSES AND NEUTRALINO PARAMETERS FROM $e^- e^-$ COLLISIONS.

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Abstract. Selectron pair production in the collision of highly polarized electrons permits a very precise definition of a number of highly informative SUSY parameters – masses, phases, couplings, and mixings. To reach an understanding of SUSY breaking mechanisms, this may be of paramount importance.

INTRODUCTION

Should Supersymmetry turn out to be Nature's choice of solving the hierarchy problem, we will be faced with the daunting task of determining a forbiddingly large number of parameters that characterize the vastly increased spectrum of basic particles and their interactions. It turns out that the easy accessibility of precisely defined incoming states for electron–electron collisions at the desired energies gives the observation of selectron pair production at Linear Collider energies a significant chance to grant us access to all of the parameters that define the lepton spectrum and interactions of the first generation of elementary particles. The fact that it takes a Majorana neutralino exchange to effect the transition from colliding electrons to ensuing selectron pairs that "remember" the chirality of the highly defined incoming state provides added insight into models of SUSY symmetry breaking.

The very fact that the mass matrix of the fermions that mediate the pair production process is vitally sensitive to the way in which Supersymmetry may be realized, including the possibility that it contain CP-violating phases, permits a determination of the relevant parameters in a way inaccessible to interactions which involve initial-state particles with uncertain chirality, such as positrons or even hadrons.

SELECTRON PAIR PRODUCTION AT THRESHOLD

The diagrams in Figs. 1a,b, when chosen to be realized in the Higgsino region of SUSY parameter space, lead to differential cross sections such as those illustrated in Fig. 2. This figure illustrates well two features we can exploit for precision measurements of relevant Supersymmetry parameters: interference effects between the s-channel and t-channel exchanges of Fig. 1a depress the cross sections in the e^+e^- case to much smaller values than the e^-e^--initiated ones. Worse, the impossibility of preparing highly polarized positrons will mix up the two curves of $e^+e^- \to \tilde{e}^+\tilde{e}^-$ in Fig. 2. This will impact on the mass measurement of selectrons by threshold production, which is much more precise than mass reconstruction from final-state observation. Fig. 3 illustrates this most tellingly, much helped by the fact that negative scalar selectrons are pair-produced in an S state when t- and u-channel neutralino exchanges are the relevant mechanisms, leading to very steep increases in cross section at threshold. $\tilde{e}^+\tilde{e}^-$ pairs, on the other hand, are largely produced by the annihilation diagram via s-channel photon exchange, which leads to an angular momentum barrier that permits only a slow rise of the cross section at threshold. Again, this slow rise is compounded in its information content by the fact that the positive selectrons have a chirality mix that manifests itself in a mass mix, further eroding the information content of the take-off at threshold.

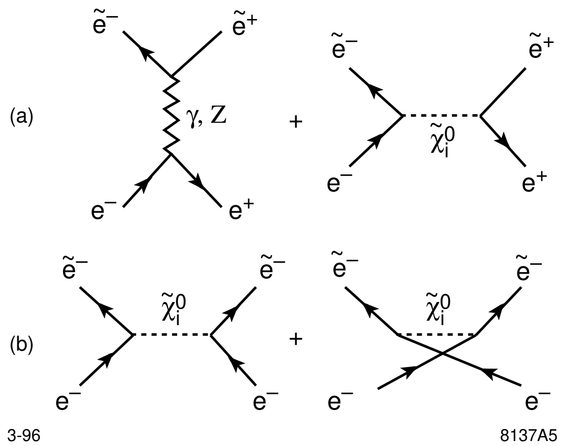

FIGURE 1. Feynman diagrams contributing to the reactions (a) $e^+e^- \to \tilde{e}^+\tilde{e}^-$, (b) $e^-e^- \to \tilde{e}^- + \tilde{e}^-$. From Ref. [1].

We stress that our illustration Fig. 3 neglects the effects of initial-state radiation, beamstrahlung, and particle widths; these effects are being investigated quantitatively both analytically and in simulations - but the resulting modifications of the threshold rise affect both modes in comparable ways (notwithstanding the stronger disruption effects in equal-charge collisions), so that the e^-e^- version retains an important edge.

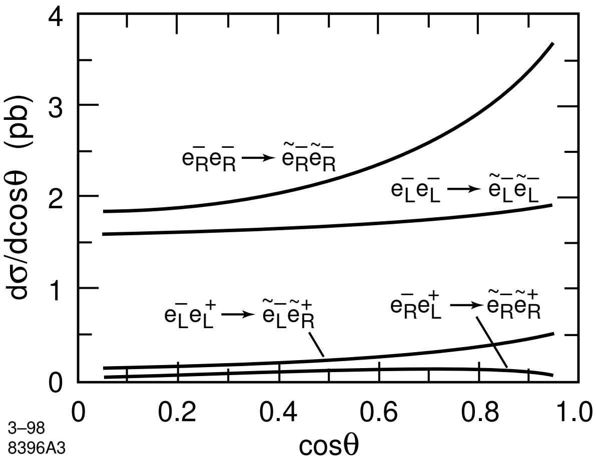

FIGURE 2. Differential cross sections for four slepton production processes, computed at a point in the Higgsino region, with $m_2/\mu = -5$ for $\tan\beta = 4$. $M_1 = 50, m(e_R) = 150$, $m(e_L) = 200$, $\sqrt{s} = 500$ GeV. From Ref. [1].

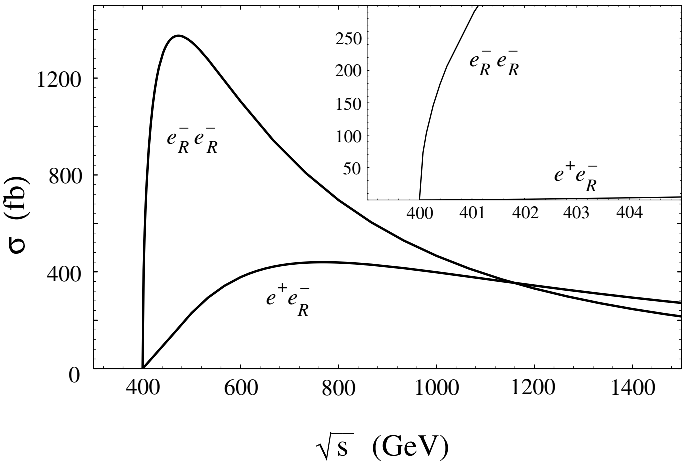

FIGURE 3. Cross sections $\sigma(e^-_R e^-_R \to \tilde{e}^-_R \tilde{e}^-_R)$ and $\sigma(e^+_R e^-_R \to \tilde{e}^+_R \tilde{e}^-_R)$ for $m_{\tilde{e}_R} = 200$ GeV and $M_{\tilde{B}} = 100$ GeV. The inset is a magnified view for $\sqrt{s}$ near threshold. Effects of initial state radiation, beamstrahlung, and the selectron width are not included. From Ref. [2].

ACCESS TO THE NEUTRALINO MASS MATRIX

Neutralino exchange in the selectron pair production diagram of Fig. 1 has, as we saw, the virtue of leading to large cross sections that depend vitally on the mass of that exchange. J. Feng [2] showed how a measurement of the total cross section can then serve as a means to pin down the bino mass M_1, as illustrated for a given parameter set in Fig. 4. How strongly that mass dependence hinges on the selectron mass is further shown in Fig. 5: again, the virtues of knowing the slepton mass precisely from threshold measurement are tellingly illustrated. These features are obviously non-existent in selectron pair production from e^+e^-, mostly via the annihilation graph.

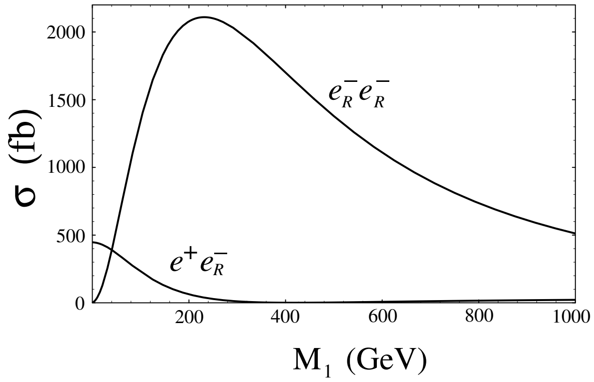

FIGURE 4. Cross sections $\sigma(e_R^- e_R^- \to \tilde{e}_R^- \tilde{e}_R^-)$ and $\sigma(e_R^+ e_R^- \to \tilde{e}_R^+ \tilde{e}_R^-)$ as functions of the bino mass M_1 for $m_{\tilde{e}_R} = 200$ GeV and $\sqrt{s} = 500$ GeV. The t-channel mass insertion for the $e^- e^-$ case leads to large cross sections, even for $M_1 \sim \mathcal{O}(1 \text{ TeV})$. From Ref. [2.]

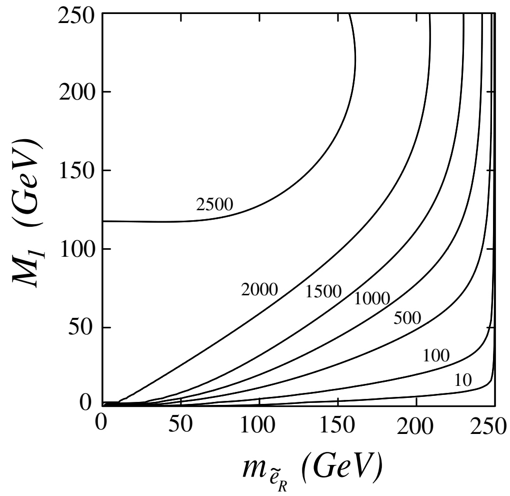

FIGURE 5. Contours of constant $\sigma_R = \sigma(e_R^- e_R^- \to \tilde{e}_R^- \tilde{e}_R^-)$ in fb in the $(m_{\tilde{e}_R}, M_1)$ plane for $\sqrt{s} = 500$ GeV. From Ref. [3].

Finally, it was pointed out by S. Thomas [4] that CP-violating phases, which may well be present in the neutralino mass matrix, will manifest themselves in the cross section values of selectron pair production: the total cross section for $e_L e_L$ varies quite strongly as a function of a relative phase between, say, wino and bino, as Fig. 6 shows for a given parameter choice; $e_R e_R$ production shows no such effect.

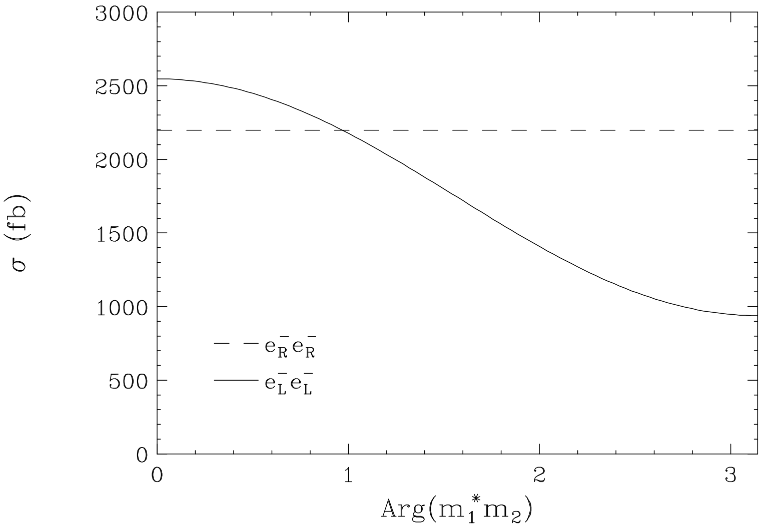

FIGURE 6. Total cross sections for $e_R^- e_R^- \to \tilde{e}_R^- \tilde{e}_R^-$ and $e_L^- e_L^- \to \tilde{e}_L^- \tilde{e}_L^-$ in the pure gaugino or Higgsino limit, as a function of $\mathrm{Arg}(m_1^* m_2)$. The parameters are $\sqrt{s} = 500$ GeV, $|m_1| = 100$ GeV, $|m_2| = 200$ GeV, $m_{\tilde{e}_R} = 130$ GeV, and $m_{\tilde{e}_L} = 180$ GeV. For reference, $R \simeq 400$ fb at this center of mass energy. From Ref. [4].

CONCLUSION

We chose a small number of very telling Supersymmetry parameters that will spring from careful measurements of selectron pair production in $e^- e^-$ collisions. Notably, this pure incoming state has the virtue of isolating individual diagrams that contribute to the process, in a way inaccessible to $e^+ e^-$ collisions. High degrees of polarizability and easy helicity reversal of the incoming leptons are a key feature, together with large cross sections.

There have been questions whether the attainable precision is really all that important, quite apart from a very general need for optimal access to the many new parameters of SUSY phenomenology. It has to be stressed in this context that in the case of anomaly-mediated SUSY breaking, there is a fair chance that the mass differences between right-chirality and left-chirality selectrons become very small [5,6]. This implies a further potential task for an optimal mass measurement as an indicator for the prevalent SUSY breaking mechanism.

Clearly, the electron-electron version of the Linear Collider is the machine of choice for much of what we want to accomplish in the search for a clear identification of Supersymmetry phenomenology. Both its exotic quantum numbers and its clean initial state with optimal definition of its chirality parameters provide the means to accomplish this task.

REFERENCES

1. M.E. Peskin, *Int. J. Mod. Phys.* **A13**, 2299 (1998)
2. J.L. Feng, ibidem, 2319.
3. H.C. Cheng, ibidem, 2329.
4. S. Thomas, ibidem, 2307.
5. T. Gherghetta, G.F. Giudice, J.D. Wells, hep-ph/9904378.
6. J.L. Feng, Pakeo Moroi, *Phys. Rev.* **D61**, 095004 (2000).