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Determination of sfermion parameters at an e^+e^- Linear Collider using polarized beams

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1 Introduction

The search for supersymmetric (SUSY) particles will be one of the main goals of a future e^+e^- linear collider with an energy range $\sqrt{s} = 0.5 - 1$ TeV [1]. Such an e^+e^- linear collider will also be very well suited for the precision determination of the parameters of the underlying SUSY model, in particular if polarized beams are available. The precise determination will be necessary to determine the mechanisms of SUSY breaking and electroweak symmetry breaking and eventually to reconstruct of the underlying high scale theory [2].

In this contribution we summarize the results of our recent phenomenological studies on the production of third generation sfermions in e^+e^- annihilation at $\sqrt{s} = 500$ GeV [3]. We take into account the effects of both e^- and e^+ beam polarizations. The main advantages of using polarized beams are: (i) larger cross sections can be obtained, (ii) background reactions can be suppressed, (iii) measurements of appropriate observables lead to additional information on the SUSY parameters. All calculations are performed within the Minimal Supersymmetric Standard Model (MSSM) with real parameters.

2 Sfermion Production

In the third generation, Yukawa terms give rise to mixing between the 'left' and 'right' states $\tilde{f}_L$ and $\tilde{f}_R$ ($\tilde{f} = \tilde{t}, \tilde{b}, \tilde{\tau}$). Neglecting the mixing between generations this mixing

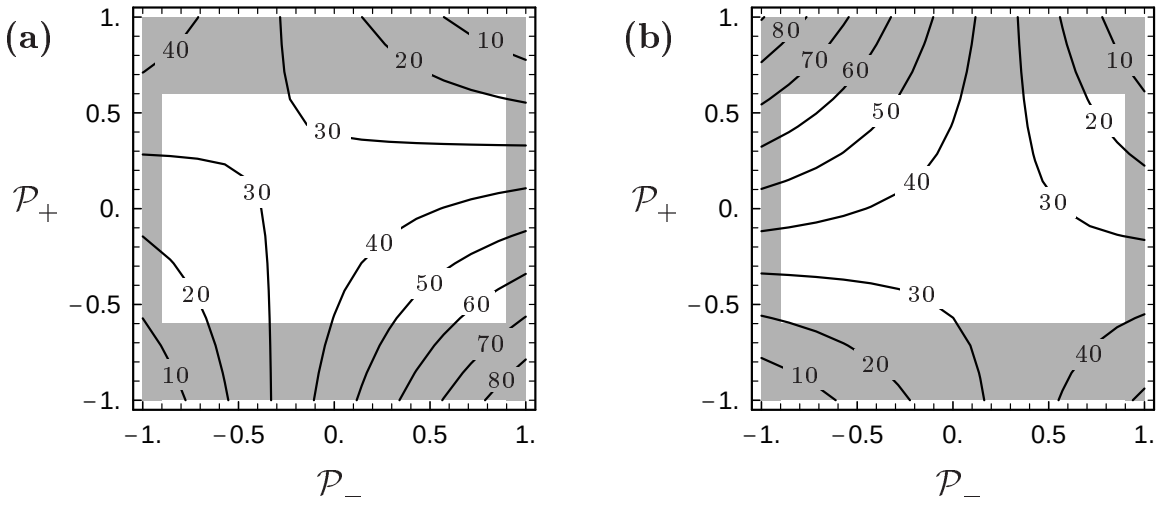

Figure 1: Dependence of $\sigma(e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1)$ on degree of electron and positron polarization at $\sqrt{s} = 500$ GeV, for $m_{\tilde{t}_1} = 200$ GeV, $\cos\theta_{\tilde{t}} = 0.4$ in (a) and $\cos\theta_{\tilde{t}} = 0.66$ in (b).

is described by a hermitian 2×2 mass matrix which depends on the soft SUSY–breaking mass parameters $M_{\tilde{Q}}$, $M_{\tilde{U}}$ etc., and the trilinear scalar coupling parameters A_t, A_b, A_τ. The mass eigenstates are $\tilde{f}_1 = \tilde{f}_L \cos\theta_{\tilde{f}} + \tilde{f}_R \sin\theta_{\tilde{f}}$, and $\tilde{f}_2 = \tilde{f}_R \cos\theta_{\tilde{f}} - \tilde{f}_L \sin\theta_{\tilde{f}}$, with $\theta_{\tilde{f}}$ the sfermion mixing angle. Information on the sfermion mixing angle can be obtained from measuring production cross sections using different combinations of beam polarizations as we discuss below taking the production of light stops as a particular example.

The reaction $e^+e^- \to \tilde{f}_i\bar{\tilde{f}}_j$ proceeds via γ and Z exchange in the s–channel. The $\tilde{f}_i$ couplings depend on the sfermion mixing angle $\theta_{\tilde{f}}$. In Figs. 1 a, b we show contour lines of the cross section $\sigma(e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1)$ as a function of the e^- and e^+ beam polarizations $\mathcal{P}_-$ and $\mathcal{P}_+$ at $\sqrt{s} = 500$ GeV for $m_{\tilde{t}_1} = 200$ GeV and (a) $\cos\theta_{\tilde{t}} = 0.4$ and (b) $\cos\theta_{\tilde{t}} = 0.66$. We have included initial–state radiation (ISR) and SUSY–QCD corrections (for details see [3, 4]). The white windows show the range of polarizations $|\mathcal{P}_-| < 0.9$ and $|\mathcal{P}_+| < 0.6$. As can be seen, one can significantly increase the cross section by using the highest possible e^- and e^+ polarization available. Moreover, beam polarization strengthens the $\cos\theta_{\tilde{t}}$ dependence and can thus be essential for determining the mixing angle. Corresponding cross sections for the production of sbottoms, staus and τ–sneutrinos are presented in [3].

3 Parameter Determination

We estimate the precision one may obtain for the parameters of the $\tilde{t}$ sector from cross section measurements using the parameter point $m_{\tilde{t}_1} = 200$ GeV, $\cos\theta_{\tilde{t}} = -0.66$ as an illustrative example: For $\mathcal{P}_- = -0.9$ we find $\sigma_L(\tilde{t}_1\bar{\tilde{t}}_1) = 44.88$ fb and for $\mathcal{P}_- = 0.9$ $\sigma_R(\tilde{t}_1\bar{\tilde{t}}_1) = 26.95$ fb (with $\mathcal{P}_+ = 0$) including SUSY–QCD, Yukawa coupling, and ISR corrections. According to the Monte Carlo study of [5] one can expect to measure the $\tilde{t}_1\bar{\tilde{t}}_1$ production cross sections with a statistical error of $\Delta\sigma_L/\sigma_L = 2.1\,\%$ and $\Delta\sigma_R/\sigma_R = 2.8\,\%$ in case of an integrated luminosity of $\mathcal{L} = 500\ \mathrm{fb}^{-1}$ (i.e. $\mathcal{L} = 250\ \mathrm{fb}^{-1}$ for each polarization). Scaling these values to $\mathcal{L} = 100\ \mathrm{fb}^{-1}$ leads to $\Delta\sigma_L/\sigma_L = 4.7\,\%$ and $\Delta\sigma_R/\sigma_R = 6.3\,\%$. Figure 2 a shows the corresponding error bands and error ellipses in the $m_{\tilde{t}_1}$ – $\cos\theta_{\tilde{t}}$ plane. The

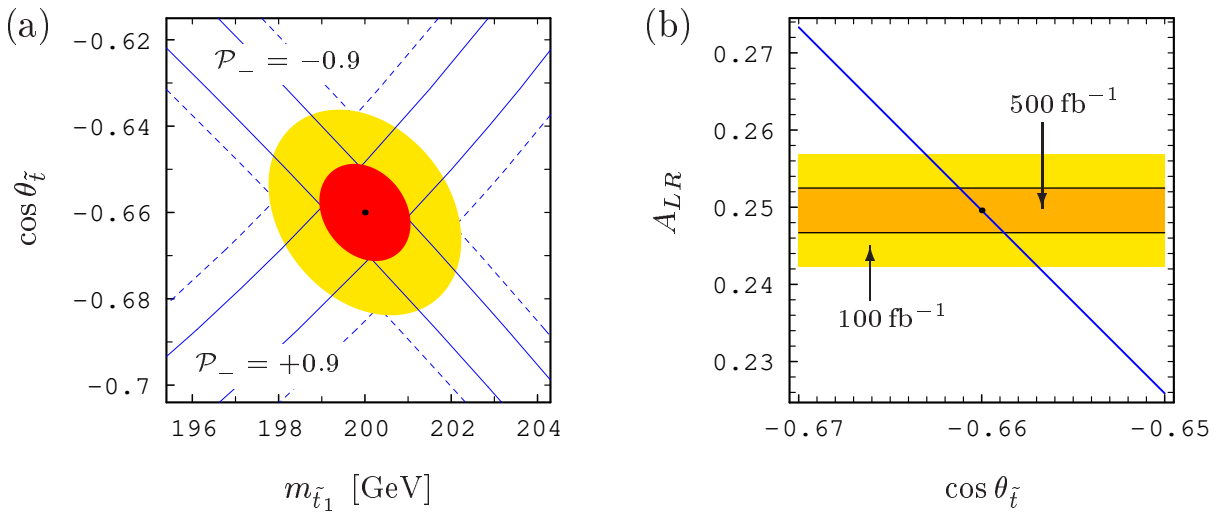

Figure 2: (a) Error bands and 68% CL error ellipse for determining $m_{\tilde{t}_1}$ and $\cos\theta_{\tilde{t}}$ from cross section measurements; the dashed lines are for $\mathcal{L} = 100$ fb^{-1} and the full lines for $\mathcal{L} = 500$ fb^{-1}. (b) Error bands for the determination of $\cos\theta_{\tilde{t}}$ from A_{LR}. In both plots $m_{\tilde{t}_1} = 200$ GeV, $\cos\theta_{\tilde{t}} = -0.66$, $\sqrt{s} = 500$ GeV, $\mathcal{P}_- = \pm 0.9$, $\mathcal{P}_+ = 0$.

resulting errors on the stop mass and mixing angle are: $\Delta m_{\tilde{t}_1} = 2.2$ GeV, $\Delta\cos\theta_{\tilde{t}} = 0.02$ ($\Delta m_{\tilde{t}_1} = 1.1$ GeV, $\Delta\cos\theta_{\tilde{t}} = 0.01$) for $\mathcal{L} = 100$ fb^{-1} ($\mathcal{L} = 500$ fb^{-1}). If in addition the e^+ beam is 60% polarized these values can be improved by $\sim 25\%$.

For the determination of the mixing angle, one can also make use of the left–right asymmetry $A_{LR} \equiv [\sigma(-|\mathcal{P}_-|, |\mathcal{P}_+|) - \sigma(|\mathcal{P}_-|, -|\mathcal{P}_+|)]/[\sigma(-|\mathcal{P}_-|, |\mathcal{P}_+|) + \sigma(|\mathcal{P}_-|, -|\mathcal{P}_+|)]$. We get $A_{LR}(e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1) = 0.2496$ for $m_{\tilde{t}_1} = 200$ GeV, $\cos\theta_{\tilde{t}} = -0.66$, $\sqrt{s} = 500$ GeV, $\mathcal{P}_- = 0.9$, and $\mathcal{P}_+ = 0$. Taking into account experimental errors as determined in [5], a theoretical uncertainty of 1%, and $\Delta P/P = 10^{-2}$ we get $\Delta A_{LR} = 2.92\%$ (1.16%) for $\mathcal{L} = 100\,\text{fb}^{-1}$ ($500\,\text{fb}^{-1}$). This corresponds to $\Delta\cos\theta_{\tilde{t}} = 0.0031$ (0.0012). This is most likely the most precise method to determine the stop mixing angle. The corresponding error bands are shown in Fig. 2 b.

Once produced, sfermions will decay into e.g., $\tilde{t}_1 \to b\tilde{\chi}_1^+$, $\tilde{b}_1 \to b\tilde{\chi}_1^0$, $\tilde{\tau}_1 \to \tau\tilde{\chi}_1^0$, etc. Information on the polarization of the fermions in the final states can be used to further improve the precision on the SUSY parameters [6,7]. The basic SUSY breaking parameters of the sfermion mass matrix can be extracted if both masses and the mixing angle are known. In particular, A_t is given by $A_t = \mu\cot\beta + (m^2_{\tilde{t}_1} - m^2_{\tilde{t}_2})\sin 2\theta_{\tilde{t}}/(2m_t)$, and likewise for A_b and A_τ where $\cot\beta$ has to be replaced by $\tan\beta$. The precise determination of these parameters is in particular important for reconstruction of the high scale theory and for the determination of the SUSY breaking mechanism [2]. Moreover, it allows for cross checks with the determination of A_t from the Higgs sector [8].

Acknowledgements

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