Phenomenology of Stops, Sbottoms, \(\tau\)-Sneutrinos, and Staus at an \(e^+e^-\) Linear Collider*

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Abstract. We discuss production and decays of stops, sbottoms, \(\tau\)-sneutrinos, and staus in \(e^+e^-\) annihilation in the energy range \(\sqrt{s} = 0.5 – 1\) TeV. We present numerical predictions within the Minimal Supersymmetric Standard Model for cross sections and decay rates, including one-loop radiative corrections as well as initial state radiation. We also study the importance of beam polarization for the determination of the underlying SUSY parameters. Moreover, we make a comparison of the potential to study squarks and sleptons of the 3rd generation between Tevatron, LHC, and Linear Collider.

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1 Introduction

In supersymmetric (SUSY) extensions of the Standard Model (SM) squarks \(\tilde{q}_L\), \(\tilde{q}_R\), sleptons \(\tilde{\ell}_L\), \(\tilde{\ell}_R\), and sneutrinos \(\tilde{\nu}_\ell\) are introduced as the scalar partners of the quarks \(q_{L,R}\), leptons \(\ell_{L,R}\), and neutrinos \(\nu_\ell\) [1]. For each sfermion of definite flavour the states \(\tilde{f}_L\) and \(\tilde{f}_R\) are interaction states which are mixed by Yukawa terms. The mass eigenstates are denoted by \(\tilde{f}_1\) and \(\tilde{f}_2\) (with the convention \(m_{\tilde{f}_1} < m_{\tilde{f}_2}\)). Strong \(\tilde{f}_L - \tilde{f}_R\) mixing is expected for the third generation sfermions, because in this case the Yukawa couplings can be large. In particular, in the sector of the scalar top quarks these mixing effects will be large due to the large top quark mass. The lighter mass eigenstate \(\tilde{t}_1\) will presumably be the lightest squark state [2, 3]. If the SUSY parameter \(\tan \beta\) is large, \(\tan \beta \gtrsim 10\), then also \(\tilde{b}_L - \tilde{b}_R\) and \(\tilde{\tau}_L - \tilde{\tau}_R\) mixing has to be taken into account and will lead to observable effects [4, 5]. The experimental search for the third generation sfermions is an important issue at all present and future colliders. It will be particularly interesting at an \(e^+e^-\) Linear Collider with center of mass energy \(\sqrt{s} = 0.5 – 1.5\) TeV, where

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these states are expected to be pair produced. Moreover, at an $e^+e^-$ Linear Collider with this energy and an integrated luminosity of about 500 fb$^{-1}$ it will be possible to measure masses, cross sections and decay branching ratios with high precision [6]. This will allow us to obtain information on the fundamental soft SUSY breaking parameters. Therefore, it is necessary to investigate how this information can be extracted from the experimental data, and how precisely these parameters can be determined. In this way it will be possible to test our theoretical ideas about the underlying SUSY breaking mechanism.

Phenomenological studies on SUSY particle searches at the LHC have shown that the detection of the scalar top quark may be very difficult due to the overwhelming background from $t\bar{t}$ production [7, 8, 9, 10, 11]. This is in particular true for $m_{\tilde{t}_1} \lesssim 250$ GeV [7]. In principle, such a light stop could be discovered at the Tevatron. The actual mass reach, however, strongly depends on the luminosity, decay modes, and the available phase-space [12, 13]. Thus an $e^+e^-$ Linear Collider with $\sqrt{s} \sim 500$ GeV could even be a discovery machine for $\tilde{t}_1$.

In this contribution we summarize the phenomenology of $\tilde{t}$, $\tilde{b}$, $\tilde{\tau}$, and $\nu_e$ in $e^+e^-$ annihilation at energies between $\sqrt{s} = 500$ GeV and 1 TeV. We give numerical results for the production cross sections taking into account polarization of both the $e^-$ and $e^+$ beams. In particular, we show that by using polarized beams it will be possible to determine the fundamental SUSY parameters with higher precision than without polarization. Moreover, we discuss the decays of these particles. The production cross sections as well as the decay rates of the sfermions show a distinct dependence on the $f_L$--$f_R$ mixing angles. Squarks (sleptons) can decay into quarks (leptons) plus neutralinos or charginos. Squarks may also decay into gluinos. In addition, if the splitting between the different sfermion mass eigenstates is large enough, transitions between these states by emission of weak vector bosons or Higgs bosons are possible. These decay modes can be important for the higher mass eigenstates, and lead to complicated cascade decays. In the case of the lighter stop, however, all these tree-level two-body decays may be kinematically forbidden. Then the $\tilde{t}_1$ has more complicated higher-order decays [14, 15, 16].

The framework of our calculation is the Minimal Supersymmetric Standard Model (MSSM) [1] which contains the Standard Model (SM) particles plus the sleptons $\tilde{\ell}^\pm$, sneutrinos $\tilde{\nu}_i$, squarks $\tilde{q}$, gluinos $\tilde{g}$, two pairs of charginos $\tilde{\chi}_i^{\pm}$, $i = 1, 2$, four neutralinos, $\tilde{\chi}_i^0$, $i = 1, \ldots, 4$, and five Higgs bosons, $h^0$, $H^0$, $A^0$, $H^\pm$ [17].

In Section 2 we shortly review the basic features of left–right mixing of squarks and sleptons of the 3rd generation, and present formulae and numerical results for the production cross sections with polarized $e^-$ and $e^+$ beams. In Section 3 we discuss the decays of these particles and present numerical results for their branching ratios. In Section 4 we give an estimate of the errors to be expected for the fundamental soft SUSY–breaking parameters of the stop mixing matrix. In Section 5 we compare the situation concerning stop, sbottom, and stau searches at LHC and Tevatron with that at an $e^+e^-$ Linear Collider. Section 6 contains a short summary.