LPSC 04-091

Slepton production in polarized hadron collisions

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Abstract

We calculate cross sections and asymmetries for slepton pair production through neutral and charged electroweak currents in polarized hadron collisions for general slepton masses and including mixing of the left- and right-handed interaction eigenstates relevant for third generation sleptons. Our analytical results confirm and extend a previous calculation. Numerically, we show that measurements of the longitudinal single-spin asymmetry at the existing polarized pp collider RHIC and at possible polarization upgrades of the Tevatron or the LHC would allow for a determination of the tau slepton mixing angle and/or the associated supersymmetry breaking parameters Λ for gauge mediation and A_0 for minimal supergravity. Furthermore, the Standard Model background from tau pair production can be clearly distinguished due to the opposite sign of the associated asymmetry.

Key words: Supersymmetry, hadron colliders, polarization, tau (s)leptons
PACS: 12.60.Jv, 13.85.Qk, 13.88.+e, 14.60.Fg, 14.80.Ly

1 Introduction

One of the most promising extensions of the Standard Model (SM) of particle physics is the Minimal Supersymmetric Standard Model (MSSM) [1,2], which postulates a symmetry between fermionic and bosonic degrees of freedom in nature and predicts the existence of a fermionic (bosonic) supersymmetric (SUSY) partner for each bosonic (fermionic) SM particle. Since SUSY and SM particles contribute to the quadratic divergence of the mass of the Higgs boson with equal strength, but opposite sign, the MSSM can, *inter alia*, stabilize the electroweak energy scale with respect to the Planck scale and thus propose a solution to the hierarchy problem.

Unfortunately, SUSY particles still remain to be discovered. Their masses must therefore be considerably larger than those of the corresponding SM particles, and the symmetry is bound to be broken. In order to remain a viable solution to the hiearchy problem, SUSY can, however, only be broken via soft mass terms in the Lagrangian, with the consequence that the SUSY particle masses should lie in the TeV range and thus within the discovery reach of current and future hadron colliders such as the Tevatron and the LHC.

Production cross sections for SUSY particles at hadron colliders have been extensively studied in the past at leading order (LO) [3,4,5] and also at next-to-leading order (NLO) of perturbative QCD [6,7,8,9,10,11,12]. In particular, the QCD [11] and full SUSY-QCD [12] corrections for slepton pair production are known to increase the hadronic cross sections by about 35 % at the Tevatron and 25% at the LHC, thus extending their discovery reaches by several tens of GeV.

Despite the first successful runs of the RHIC collider in the polarized *pp* mode, polarized SUSY production cross sections have received much less attention. Only the pioneering LO calculations for massless squark and gluino production [13,14] have recently been confirmed, extended to the massive case, and applied to current hadron colliders [15].

It is the aim of this work to verify the corresponding pioneering LO calculation for slepton pair production [16] and include the mixing effects relevant for third generation sleptons. Our analytical results for neutral (γ, Z^0) and charged ($W^\pm$) current slepton and lepton pair production will be presented in Sec. 2. In Sec. 3, numerical predictions will be made for unpolarized cross sections and longitudinal spin asymmetries at RHIC and possible upgrades of the Tevatron [17] and the LHC [18]. Particular emphasis will be put on the sensitivity of the asymmetry to the tau slepton mixing angle as predicted by various modern SUSY breaking mechanisms [19,20]. Possibilities to discriminate between the SUSY signal and the Drell-Yan SM background will also be discussed. We summarize our results in Sec. 4.

2 Analytical results

In order to be able to compare directly with the previously published LO cross sections for slepton pair production in unpolarized hadron collisions [3], we define the square of the weak coupling constant $g_W^2 = e^2/\sin^2\theta_W$ in terms of the electromagnetic fine structure constant $\alpha = e^2/(4\pi)$ and the squared sine of the electroweak mixing angle $x_W = \sin^2\theta_W$. The coupling strengths of left- and right-handed (s)fermions to the neutral electroweak current are then given by

$$L_f = 2\,T_f^3 - 2\,e_f\,x_W \quad \text{and} \quad R_f = -2\,e_f\,x_W, \tag{1}$$

where the weak isospin quantum numbers are $T_f^3 = \pm 1/2$ for left-handed and $T_f^3 = 0$ for right-handed up- and down-type (s)fermions, and their fractional electromagnetic charges are denoted by e_f.

In general SUSY breaking models, where the sfermion interaction eigenstates are not identical to the respective mass eigenstates, the coupling strenghts L_f and R_f must be multiplied by $S_{j1}S_{i1}^*$ and $S_{j2}S_{i2}^*$, respectively, where $i,j \in \{1,2\}$ label the sfermion mass eigenstates (conventionally $m_{\tilde{f}_1} < m_{\tilde{f}_2}$) and S represents the unitary matrix diagonalizing the sfermion mass matrix (see App. A). Including these slepton mixing effects in the polarized cross sections for the production of slepton pairs in hadron collisions represents our main analytical improvement over the previously published results in Ref. [16].

Our results for the electroweak $2 \to 2$ scattering process

$$q_{h_a}(p_a)\overline{q}_{h_b}(p_b) \to \tilde{l}_i(p_1)\tilde{l}_j^*(p_2) \tag{2}$$

will be expressed in terms of the conventional Mandelstam variables,

$$s = (p_a + p_b)^2 \quad , \quad t = (p_a - p_1)^2 \quad , \quad \text{and} \quad u = (p_a - p_2)^2 \tag{3}$$

and the masses of the neutral and charged electroweak gauge bosons m_Z and m_W.

2.1 Sleptons

The neutral current cross section for the production of non-mixing slepton pairs in collisions of quarks with definite helicities $h_{a,b}$ is given by

$$\begin{aligned}
\frac{\mathrm{d}\hat{\sigma}_{h_a,h_b}}{\mathrm{d}t} = \frac{4\pi\alpha^2}{3s^2}\left[\frac{ut - m_i^2 m_j^2}{s^2}\right]\Big[& e_q^2 e_l^2 (1 - h_a h_b) \\
& + \frac{e_q e_l (L_l + R_l)[(1-h_a)(1+h_b)L_q + (1+h_a)(1-h_b)R_q]}{8x_W(1-x_W)(1-m_Z^2/s)} \\
& + \frac{(L_l^2 + R_l^2)[(1-h_a)(1+h_b)L_q^2 + (1+h_a)(1-h_b)R_q^2]}{64x_W^2(1-x_W)^2(1-m_Z^2/s)^2}\Big].
\end{aligned} \tag{4}$$

For the production of the slepton mass eigenstates i and j, the couplings L_l and R_l must be modified as described above. In addition, the first two lines in Eq. (4), representing the squared photon and photon-Z^0 interference contributions, receive additional factors of $\delta_{ij}/2$ and δ_{ij}, respectively, while in the third line, representing the squared Z^0 contribution, the factor $L_l^2 + R_l^2$ must be replaced by $(L_l + R_l)^2$.

The pure left-handed, charged current cross section

$$\frac{\mathrm{d}\hat{\sigma}_{h_a,h_b}}{\mathrm{d}t} = \frac{4\pi\alpha^2}{3s^2}\left[\frac{ut - m_i^2 m_j^2}{s^2}\right]\left[\frac{(1-h_a)(1+h_b)}{16x_W^2(1-m_W^2/s)^2}\right] \tag{5}$$

is easily derived from Eq. (4) by setting

$$m_Z \;\rightarrow\; m_W, \quad e_q = e_l = R_q = R_l = 0, \quad \text{and} \quad L_q = L_l = \sqrt{2}\cos\theta_W. \tag{6}$$

Averaging over initial helicities,

$$\mathrm{d}\hat{\sigma} = \frac{\mathrm{d}\hat{\sigma}_{1,1} + \mathrm{d}\hat{\sigma}_{1,-1} + \mathrm{d}\hat{\sigma}_{-1,1} + \mathrm{d}\hat{\sigma}_{-1,-1}}{4}, \tag{7}$$

we obtain the unpolarized partonic cross section

$$\begin{aligned}\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}t} &= \frac{4\pi\alpha^2}{3s^2}\left[\frac{ut - m_i^2 m_j^2}{s^2}\right] \\ &\times \left[e_q^2 e_l^2 + \frac{e_q e_l (L_q + R_q)(L_l + R_l)}{8x_W(1-x_W)(1-m_Z^2/s)} + \frac{(L_q^2 + R_q^2)(L_l^2 + R_l^2)}{64x_W^2(1-x_W)^2(1-m_Z^2/s)^2}\right],\end{aligned} \tag{8}$$

which agrees for non-mixing sleptons with the neutral current result of Ref. [3] in the limit of equal masses $m_L = m_R$ and with the charged current result of Ref. [5]. Note that for invariant final state masses close to the Z^0-pole, $s \simeq m_Z^2$, the Z^0-propagators must be modified to include the decay width of the Z^0 boson.

From Eq. (4), one can easily calculate the longitudinal double-spin asymmetry A_{LL} using the polarized differential cross section

$$\mathrm{d}\Delta\hat{\sigma}_{LL} = \frac{\mathrm{d}\hat{\sigma}_{1,1} - \mathrm{d}\hat{\sigma}_{1,-1} - \mathrm{d}\hat{\sigma}_{-1,1} + \mathrm{d}\hat{\sigma}_{-1,-1}}{4}. \tag{9}$$

However, the result

$$A_{LL} = \frac{\mathrm{d}\Delta\hat{\sigma}_{LL}}{\mathrm{d}\hat{\sigma}} = -1 \tag{10}$$

is totally independent of all SUSY breaking parameters.

It will thus be far more interesting to calculate the single-spin asymmetry $A_L = \mathrm{d}\Delta\hat{\sigma}_L/\mathrm{d}\hat{\sigma}$ from the polarized differential cross section

$$\mathrm{d}\Delta\hat{\sigma}_L = \frac{\mathrm{d}\hat{\sigma}_{1,1} + \mathrm{d}\hat{\sigma}_{1,-1} - \mathrm{d}\hat{\sigma}_{-1,1} - \mathrm{d}\hat{\sigma}_{-1,-1}}{4}, \tag{11}$$

i.e. for the case of only one polarized hadron beam. Not only does the neutral current cross section

$$\mathrm{d}\Delta\hat{\sigma}_L = \frac{4\pi\alpha^2}{3s^2}\left[\frac{ut - m_i^2 m_j^2}{s^2}\right] \times \left[-\frac{e_q e_l (L_l + R_l)(L_q - R_q)}{8x_W(1-x_W)(1-m_Z^2/s)} - \frac{(L_l^2 + R_l^2)(L_q - R_q)(L_q + R_q)}{64x_W^2(1-x_W)^2(1-m_Z^2/s)^2}\right] \tag{12}$$

remain sensitive to the SUSY breaking parameters, but even more the squared photon contribution, which is insensitive to these parameters, is eliminated. Finally, this scenario may also be easier to implement experimentally, *e.g.* at the Tevatron, since protons are much more easily polarized than antiprotons [17].

To conclude our analytical calculation of the polarized partonic slepton cross sections, we note that our neutral current result in Eq. (12) as well as our charged current result

$$\mathrm{d}\Delta\hat{\sigma}_L = \frac{4\pi\alpha^2}{3s^2}\left[\frac{ut - m_i^2 m_j^2}{s^2}\right]\left[\frac{-1}{16x_W^2(1-m_W^2/s)^2}\right] \tag{13}$$

agree [21] with those in Ref. [16] for non-mixing sleptons after integration over t in the interval

$$t_{\mathrm{min,max}} = -\frac{s + m_j^2 - m_i^2}{2} \mp \frac{\sqrt{(s - m_i^2 - m_j^2)^2 - 4m_i^2 m_j^2}}{2} + m_j^2. \tag{14}$$

2.2 Leptons

Due to their purely electroweak couplings, sleptons are among the lightest SUSY particles in many SUSY breaking scenarios [19,20] and often decay directly into the stable lightest SUSY particle (LSP), which may be the lightest neutralino in minimal supergravity (mSUGRA) models or the gravitino in gauge mediated SUSY breaking (GMSB) models. The slepton signal at hadron colliders will therefore consist in a lepton pair, which will be easily detectable, and associated missing (transverse) energy. This forces us to consider also the corresponding background of SM lepton pair production through Drell-Yan type processes.

With the help of the mass-subtracted Mandelstam variables

$$t_{i,j} \ = \ t - m_{i,j}^2 \quad \text{and} \quad u_{i,j} \ = \ u - m_{i,j}^2, \tag{15}$$

we can write the polarized neutral current cross section as

$$\begin{aligned} \frac{\mathrm{d}\hat{\sigma}_{h_a,h_b}}{\mathrm{d}t} = \frac{4\pi\alpha^2}{3s^2} \Bigg[& e_q^2 e_l^2 (1-h_a h_b) \frac{s(m_i+m_j)^2 + t^2 + u^2 - m_i^4 - m_j^4}{2s^2} \\ & + e_q e_l \frac{L_l[(1-h_a)(1+h_b)L_q(u_i u_j + m_i m_j s)] + R_l[t \leftrightarrow u]}{8x_W(1-x_W)s(s-m_Z^2)} \\ & + e_q e_l \frac{L_l[(1+h_a)(1-h_b)R_q(t_i t_j + m_i m_j s)] + R_l[t \leftrightarrow u]}{8x_W(1-x_W)s(s-m_Z^2)} \\ & + \frac{L_l^2[(1-h_a)(1+h_b)L_q^2 u_i u_j + (1+h_a)(1-h_b)R_q^2 t_i t_j] + R_l^2[t \leftrightarrow u]}{64x_W^2(1-x_W)^2(s-m_Z^2)^2} \\ & + \frac{2L_l R_l m_i m_j s[(1-h_a)(1+h_b)L_q^2 + (1+h_a)(1-h_b)R_q^2]}{64x_W^2(1-x_W)^2(s-m_Z^2)^2} \Bigg]. \end{aligned} \tag{16}$$

From this equation, the charged current cross section

$$\frac{\mathrm{d}\hat{\sigma}_{h_a,h_b}}{\mathrm{d}t} = \frac{4\pi\alpha^2}{3s^2} \frac{(1-h_a)(1+h_b)u_i u_j}{16x_W^2(s-m_W^2)^2} \tag{17}$$

can be obtained using again the substitions given in Eq. (6). For polarized quarks and unpolarized, massless leptons our results agree with Ref. [14] and, up to an overall sign in the analytical single-spin asymmetry, also with Ref. [22]. After averaging over initial spins and integration over t, our results also agree with Ref. [23].

3 Numerical Results

For the masses and widths of the electroweak gauge bosons, we use the current values of m_Z = 91.1876 GeV, m_W = 80.425 GeV, Γ_Z = 2.4952 GeV, and Γ_W = 2.124 GeV. The squared sine of the electroweak mixing angle

$$\sin^2\theta_W = 1 - m_W^2/m_Z^2 \tag{18}$$

and the electromagnetic fine structure constant

$$\alpha = \sqrt{2} G_F m_W^2 \sin^2\theta_W/\pi \tag{19}$$

can then be calculated in the improved Born approximation using the world average value of $G_F = 1.16637\cdot 10^{-5}$ GeV^{-2} for Fermi's coupling constant [24].

Since the mixing of left- and right-handed slepton interaction eigenstates is proportional to the mass of the corresponding SM partner (see App. A), it is numerically only important for third generation sleptons. Consequently, the lightest slepton is the lighter stau mass eigenstate $\tilde{\tau}_1$ in most SUSY breaking models [19,20], and we focus our numerical studies on its production.

The mass limits imposed by the four LEP experiments on the tau slepton vary between 52 and 95.9 GeV. They depend strongly on the assumed SUSY breaking meachanism, the mass difference between the stau and the LSP, and the stau mixing angle. The weakest limit of 52 GeV is found for GMSB models and stau decays to gravitinos, if no constraints on their mass difference are imposed [25]. This is the scenario that we will study for the RHIC collider, which has the most restricted hadronic center-of-mass energy range ($\sqrt{S} \leq 500$ GeV). For the Tevatron ($\sqrt{S} = 1.96$ TeV) and at the LHC ($\sqrt{S} = 14$ TeV) with their considerably larger center-of-mass energies, we will, however, impose the stricter mass limit of 81.9 GeV [26], which is valid for stau decays to neutralinos with a mass differences of at least 15 GeV and represents the current standard value [24]. The SM background will be evaluated using the physical tau mass of $m_\tau = 1.77699$ GeV.

Our numerical calculations of cross sections and asymmetries for the current (RHIC, Tevatron) and future (LHC) hadron colliders with up-to-date parton densities represent the main numerical improvement of this work over the previously published results in Ref. [16], which discussed only the case of the CERN $Sp\overline{p}S$ collider at $\sqrt{S} = 540$ GeV with nowadays obsolete parton densities.

3.1 Unpolarized cross sections for non-mixing sleptons

Thanks to the QCD factorization theorem, unpolarized hadronic cross sections

$$\sigma = \int_{m^2/S}^{1} \mathrm{d}\tau \int_{-1/2\ln\tau}^{1/2\ln\tau} \mathrm{d}y \int_{t_{\min}}^{t_{\max}} \mathrm{d}t \; f_{a/A}(x_a, M_a^2) \; f_{b/B}(x_b, M_b^2) \; \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}t} \tag{20}$$

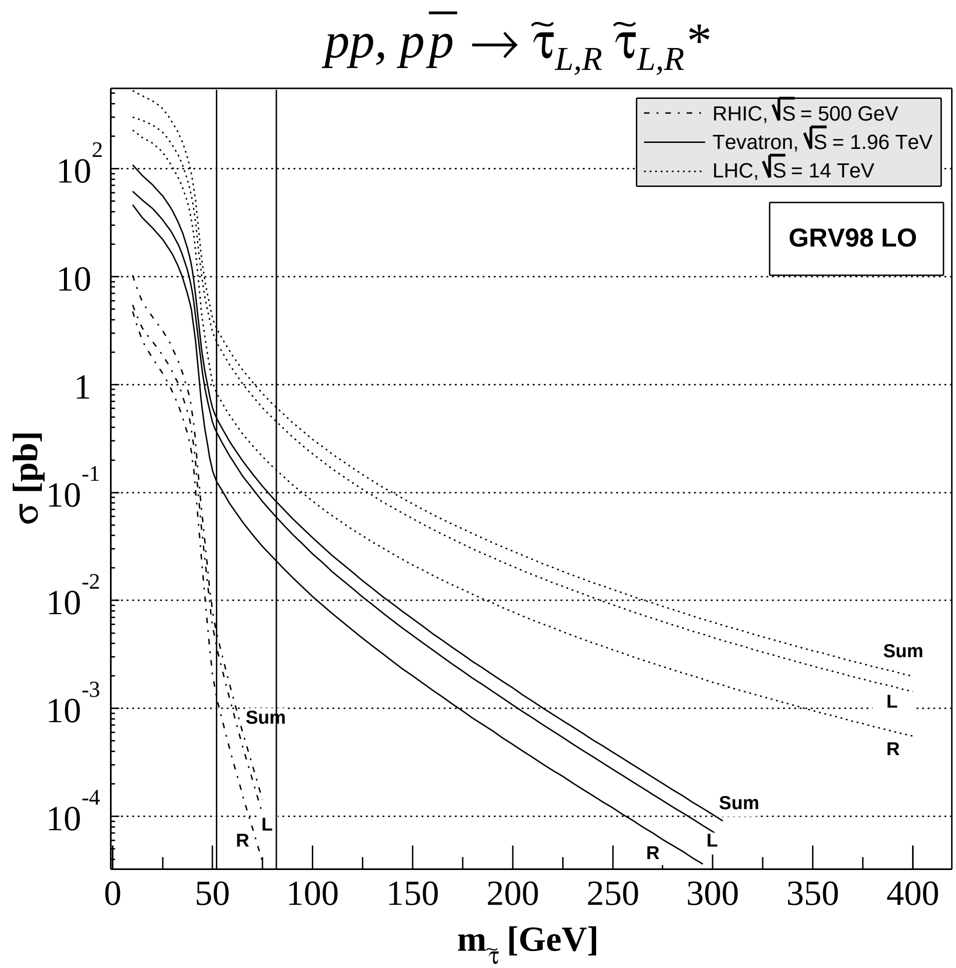

Fig. 1. Unpolarized hadronic cross sections for pair production of non-mixing tau sleptons at the RHIC, Tevatron, and LHC colliders as a function of their physical mass. For consistency with the polarized cross sections (see below), GRV98 LO parton densities have been used. The vertical lines indicate the two different stau mass limits of 52 [25] and 81.9 GeV [26].

can be calculated by convoluting the relevant partonic cross section $\hat{\sigma}$ with universal parton densities $f_{a/A}$ and $f_{b/B}$ of partons a, b in the hadrons A, B, which depend on the longitudinal momentum fractions of the two partons $x_{a,b} = \sqrt{\tau}e^{\pm y}$ and on the unphysical factorization scales $M_{a,b}$. In order to employ a consistent set of unpolarized and polarized parton densities (see below), we choose the LO set of GRV98 [27] for our unpolarized predictions at the factorization scale $M_a = M_b = m = (m_i + m_j)/2$.

In Fig. 1, we show the unpolarized hadronic cross sections for pair production of non-mixing tau sleptons at the RHIC, Tevatron, and LHC colliders as a function of their physical mass. Unfortunately, the observation of tau sleptons, as that of any SUSY particles, will be difficult at RHIC, which is the only existing polarized hadron collider. In contrast, tau sleptons will be detectable at the LHC over a large region of the viable SUSY parameter space up to stau masses of about 400 GeV. At the Tevatron, the discovery reach extends considerably beyond the current exclusion limits.

We have checked that the unpolarized cross sections change by at most 10 % if calculated with the more recent parton densities CTEQ6L1 [28]. Since the (sizeable) variations of the hadronic cross sections with the unknown factorization scale at LO are considerably reduced at NLO [11,12] and cancel to a large extent in the asymmetries, we refer the reader to these references for detailed estimates of factorization scale uncertainties.

Before application of any experimental cuts, the SUSY signal cross sections in Fig. 1 are at least three orders of magnitude smaller than the corresponding SM background cross sections from tau lepton pair production (1.7, 3.4, and 8.3 nb for the RHIC, Tevatron, and LHC colliders, respectively, using GRV98 LO parton densities at $M_a = M_b = m_\tau$). Imposing an invariant mass cut on the observed lepton pair and a minimal missing transverse energy will, however, greatly improve the signal-to-background ratio. In addition, as we will see in the next section, asymmetries may provide an important tool to further distinguish the SUSY signal from the SM background.

3.2 Single-spin asymmetries for mixing sleptons

Using again the QCD factorization theorem, we calculate the hadronic cross section for longitudinally polarized hadrons A with unpolarized hadrons B

$$\Delta\sigma_L = \int_{m^2/S}^{1} \mathrm{d}\tau \int_{-1/2\ln\tau}^{1/2\ln\tau} \mathrm{d}y \int_{t_{\min}}^{t_{\max}} \mathrm{d}t \; \Delta f_{a/A}(x_a, M_a^2) \; f_{b/B}(x_b, M_b^2) \, \frac{\mathrm{d}\Delta\hat{\sigma}_L}{\mathrm{d}t} \qquad (21)$$

through a convolution of polarized ($\Delta f_{a/A}$) and unpolarized ($f_{b/B}$) parton densities with the singly polarized partonic cross section $\Delta\hat{\sigma}_L$.

As mentioned above, we employ a consistent set of unpolarized [27] and polarized [29] LO parton densities. We estimate the theoretical uncertainty due to the less well known polarized parton densities by showing our numerical predictions for both the GRSV2000 LO standard (STD) and valence (VAL) parameterizations. Although these parton densities differ from the older parton densities employed in Ref. [16], we have checked that our numerical predictions for asymmetries of non-mixing sleptons and leptons are in reasonable agreement with Fig. 1 of Ref. [16].

Since we are primarily interested in the possible impact of slepton pair produc-

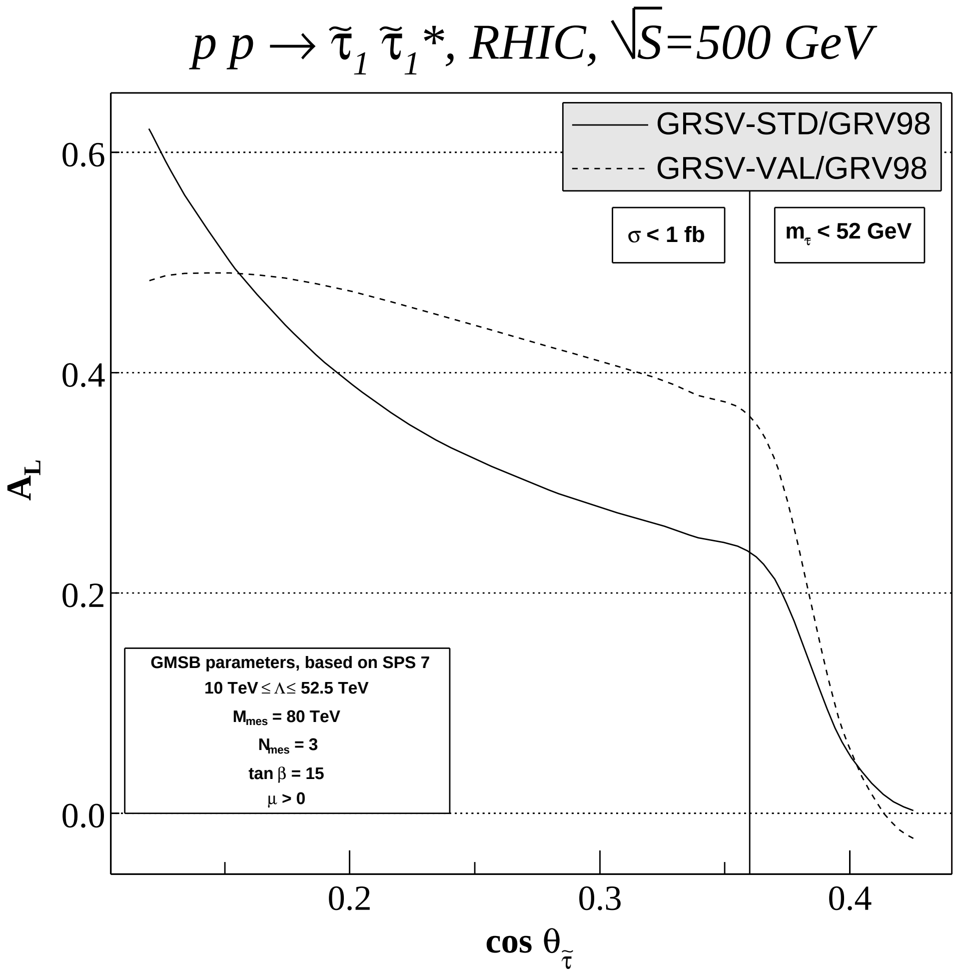

Fig. 2. Dependence of the longitudinal single-spin asymmetry A_L on the cosine of the stau mixing angle for $\tilde{\tau}_1$ pair production in a GMSB model at RHIC. Although the asymmetry is large and depends strongly on the stau mixing angle, its determination will be difficult due to the limited center-of-mass energy and luminosity at RHIC.

tion with polarized hadron beams on the determination of the mixing angle for third generation sleptons in realistic SUSY breaking scenarios, we choose for the three hadron colliders three of the ten benchmark points introduced in Ref. [19]: The GMSB point SPS 7 with a light tau slepton decaying to a gravitino for RHIC and its very limited mass range, the typical mSUGRA point SPS 1a' with an intermediate value of $\tan\beta = 10$ and a slightly reduced common scalar mass of $m_0 = 70$ GeV [20] for the Tevatron, and the mSUGRA point SPS 4 with a large scalar mass of $m_0 = 400$ GeV and large $\tan\beta = 50$, which enhances mixing for tau sleptons, for the LHC with its larger mass range.

The physical mass of the pair produced light tau slepton mass eigenstate and the mixing angle are calculated using the recently updated computer program SUSPECT [30]. Its Version 2.3 includes now a consistent calculation of the Higgs mass, with all one-loop and the dominant two-loop radiative corrections,

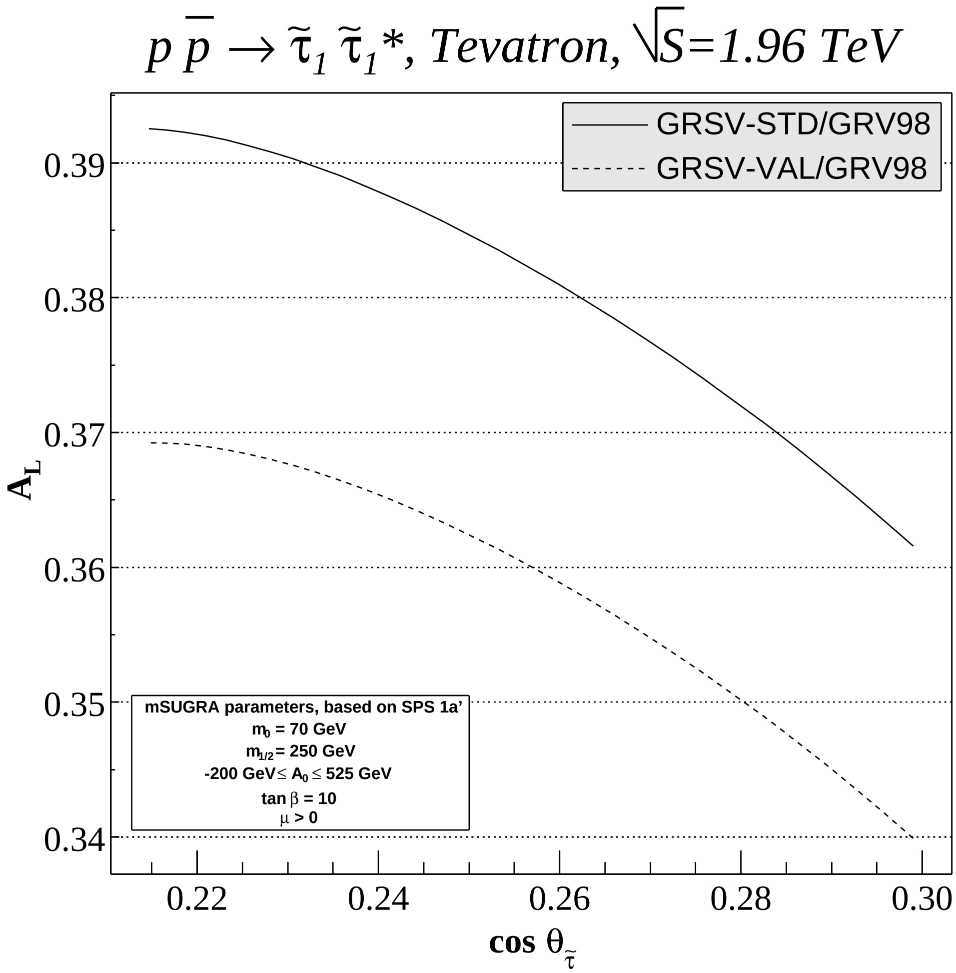

Fig. 3. Dependence of the longitudinal single-spin asymmetry A_L on the cosine of the stau mixing angle for $\tilde{\tau}_1$ pair production in a typical mSUGRA model at the Tevatron. While the unpolarized cross section is nearly independent of A_0 and the stau mixing angle, these parameters could well be determined in an asymmetry measurement, provided the polarized parton densities are better constrained.

in the renormalization group equations, that link the restricted set of SUSY breaking parameters at the gauge coupling unification scale to the complete set of observable SUSY masses and mixing angles at the electroweak scale.

The stau mixing angle depends directly on the universal soft SUSY breaking mass scale Λ in the GMSB model and on the trilinear coupling A_0 in the mSUGRA models. We test the sensitivity of the single-spin asymmetry on these parameters by varying them within their allowed ranges (see Figs. 2-4). We note in passing that the reduced value of $A_0 = -300$ GeV proposed in Ref. [20] for the mSUGRA point SPS 1a' leads in SUSPECT to a Higgs potential that is unbounded from below.

For the only existing polarized hadron collider RHIC, which will be operating at a center-of-mass energy of $\sqrt{S} = 500$ GeV in the near future, and in the

GMSB model with a light tau slepton, we show the single-spin asymmetry in Fig. 2 as a function of the cosine of the stau mixing angle. The asymmetry is quite large and depends strongly on the stau mixing angle. However, very large values of $\cos\theta_{\tilde{\tau}}$ and stau masses below 52 GeV may already be excluded by LEP [25], while small values of $\cos\theta_{\tilde{\tau}}$ may be unaccessible at RHIC due to its limited luminosity, which is not expected to exceed 1 fb^{-1}. Polarization of the proton beam will also not be perfect, and the calculated asymmetries should be multiplied by the degree of beam polarization $P_L \simeq 0.7$. The uncertainty introduced by the polarized parton densities increases considerably to the left of the plot, where the stau mass 41 GeV $\leq m_{\tilde{\tau}} \leq$ 156 GeV and the associated values of the parton momentum fractions $x_{a,b} \simeq 2m_{\tilde{\tau}}/\sqrt{S}$ become large.

As mentioned above, the SM background cross section can be reduced by imposing an invariant mass cut on the observed tau lepton pair, *e.g.* of 2·52 GeV. While the cross section of 0.13 pb is then still two orders of magnitude larger than the SUSY signal cross section of 1 fb, the SM asymmetry of -0.04 for standard polarized parton densities or -0.10 for the valence-type polarized parton densities can clearly be distinguished from the SUSY signal due to its different sign.

While the variation of the parameter Λ in the GMSB model introduced not only a variation of the stau mixing angle, but also of the stau mass, variation of the parameter A_0 in mSUGRA leaves the stau mass almost invariant. In the SPS 1a' model, its value varies only between 114 and 119 GeV, and the corresponding unpolarized cross section at the Tevatron is nearly constant ($\sim 5.8 \pm 0.5$ fb).

This would make an asymmetry measurement at an upgraded Tevatron extremely valuable, as one can see in Fig. 3. The predicted asymmetry is very sizeable in the entire viable SUSY parameter range, and it depends strongly on the parameter A_0 and the stau mixing angle. Unfortunately, the parton density uncertainty is still large, but it will be reduced considerably in the future through more precise measurements at the COMPASS, HERMES, PHENIX, and STAR experiments. As a recent experimental study demonstrates, events with tau lepton pairs or tau leptons with associated missing energy larger than 20 GeV can be identified with the CDF-II detector in events with hadronic tau decays [31].

The SM background cross section after an invariant mass cut of 2·119 GeV is 0.16 pb and thus only about 25 times larger than the SUSY signal. As in the case of RHIC, the SM asymmetry of -0.09 (for both polarized parton densities) would be clearly distinguishable due to its opposite sign.

For the LHC, where first feasibility studies of tau slepton identification with the ATLAS detector [32] and tau tagging with the CMS detector [33] have

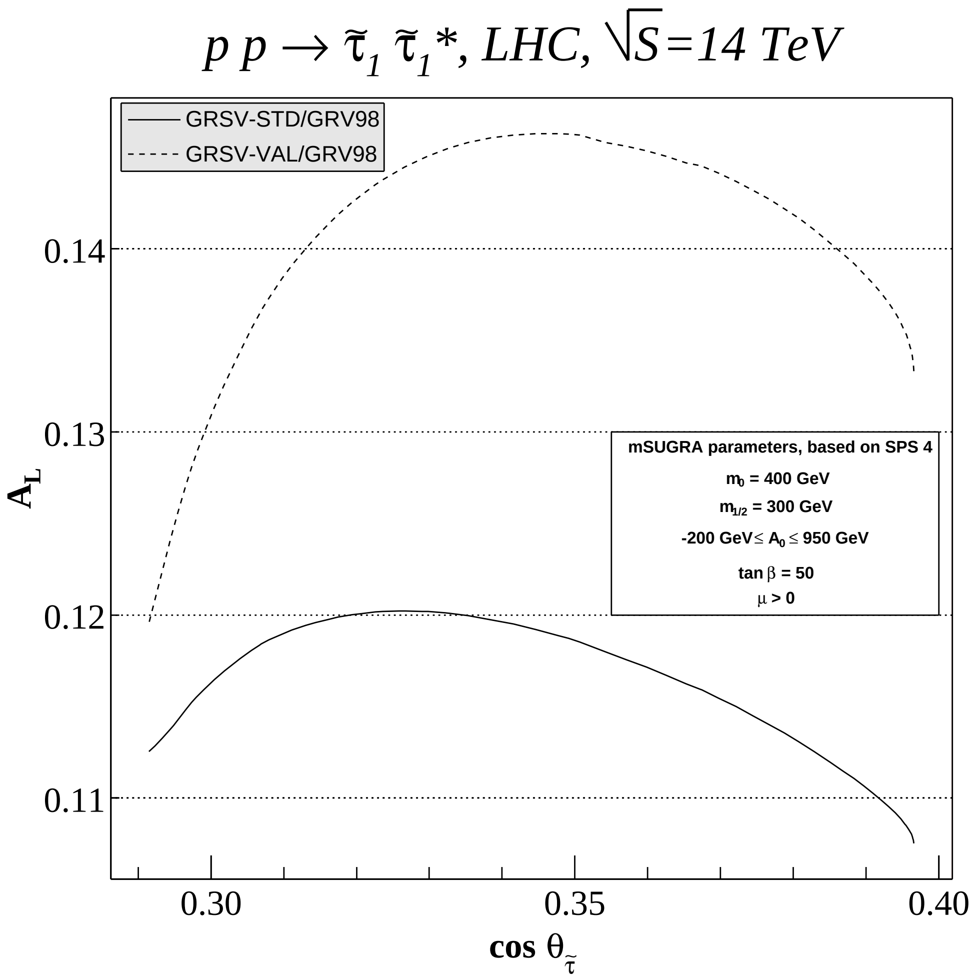

Fig. 4. Dependence of the longitudinal single-spin asymmetry A_L on the cosine of the stau mixing angle for $\tilde{\tau}_1$ pair production in an mSUGRA model with large m_0 and $\tan\beta$ at the LHC. A determination of the SUSY breaking parameter A_0 and the stau mixing angle would require an improved knowledge of the polarized parton densities at small x.

recently been performed and SUSY masses should in general be observable up to the TeV range, we choose an mSUGRA model with elevated scalar mass $m_0 = 400$ GeV and a large value of $\tan\beta = 50$, which enhances mixing in the stau sector. While the predicted asymmetry for a possible polarization upgrade of the LHC in Fig. 4 is slightly smaller than in the previous two cases, it is still comfortably large and has again the opposite sign with respect to the SM asymmetry of -0.02 (for both polarized parton densities). The dependence of the asymmetry on the stau mixing angle is, however, also reduced, while the uncertainties from the polarized parton densities, which are not yet well known at the small x values relevant for the large LHC center-of-mass energy, are quite enhanced.

4 Conclusion

In this Letter, we have presented a new calculation of cross sections and asymmetries for slepton pair production through neutral and charged electroweak currents in polarized hadron collisions. Our analytical results are valid for general slepton masses and include the mixing of the left- and right-handed interaction eigenstates relevant for third generation sleptons. They confirm and extend in these respects an earlier pioneering calculation [16].

Numerically, we have studied in detail the dependence of the longitudinal single-spin asymmetry on the tau slepton mixing angle for pair production of the lighter tau slepton mass eigenstate. Its physical mass and the mixing angle at the electroweak scale have been calculated with the help of renormalization group equations after imposing restricted sets of SUSY breaking parameters at the unification scale.

The determination of these parameters in measurements of the longitudinal single-spin asymmetry at the only existing polarized *pp* collider RHIC was found to be difficult due to its limited center-of-mass energy and luminosity, even in a gauge mediated SUSY breaking model with a very light tau slepton.

In contrast, a polarization upgrade for the proton beam of the Tevatron would give direct access to the trilinear coupling A_0 in a typical minimal supergravity model, independently of the tau slepton mass and the unpolarized cross section.

At the LHC, where larger masses are easily accessible and where we have studied an alternative minimal supergravity model with enhanced tau slepton masses and mixings, the sensitivity of the longitudinal single-spin asymmetry to the mixing angle and the trilinear coupling A_0 is found to be reduced and hampered by a large uncertainty from the not well-known polarized parton densities at small values of their longitudinal momentum fractions in the proton.

For all colliders, an asymmetry measurement would allow for a straightforward discrimination of the SUSY signal from the associated SM background of tau lepton pair production due to the opposite sign of SUSY and SM asymmetries.

Acknowledgments

We thank A. de Roeck and G. Polesello for interesting discussions and encouragement at the Frascati meeting of the Euro-GDR on *Supersymmetry*. This work was supported by a postdoctoral and a Ph.D. fellowship of the French ministry for education and research.

A Slepton Mixing

The (generally complex) soft SUSY-breaking terms A_l of the trilinear Higgs-slepton-slepton interaction and the (also generally complex) off-diagonal Higgs mass parameter μ in the MSSM Lagrangian induce mixings of the left- and right-handed slepton eigenstates $\tilde{l}_{L,R}$ of the electroweak interaction into mass eigenstates $\tilde{l}_{1,2}$. The slepton mass matrix [2]

$$\mathcal{M}^2 = \begin{pmatrix} m_{LL}^2 + m_l^2 & m_l m_{LR}^* \\ m_l m_{LR} & m_{RR}^2 + m_l^2 \end{pmatrix} \tag{A.1}$$

with

$$m_{LL}^2 = (T_l^3 - e_l \sin^2\theta_W) m_Z^2 \cos 2\beta + m_{\tilde{L}}^2, \tag{A.2}$$

$$m_{RR}^2 = e_l \sin^2\theta_W m_Z^2 \cos 2\beta + \begin{cases} m_{\tilde{\nu}}^2 & \text{for sneutrinos,} \\ m_{\tilde{l}}^2 & \text{for charged sleptons,} \end{cases} \tag{A.3}$$

$$m_{LR} = A_l - \mu^* \begin{cases} \cot\beta & \text{for sneutrinos} \\ \tan\beta & \text{for charged sleptons} \end{cases} \tag{A.4}$$

is diagonalized by a unitary matrix S, $S\mathcal{M}^2 S^\dagger = \mathrm{diag}\,(m_1^2, m_2^2)$, and has the squared mass eigenvalues

$$m_{1,2}^2 = m_l^2 + \frac{1}{2}\left(m_{LL}^2 + m_{RR}^2 \mp \sqrt{(m_{LL}^2 - m_{RR}^2)^2 + 4m_l^2 |m_{LR}|^2}\right). \tag{A.5}$$

For real values of m_{LR}, the slepton mixing angle $\theta_{\tilde{l}}$, $0 \le \theta_{\tilde{l}} \le \pi/2$, in

$$S = \begin{pmatrix} \cos\theta_{\tilde{l}} & \sin\theta_{\tilde{l}} \\ -\sin\theta_{\tilde{l}} & \cos\theta_{\tilde{l}} \end{pmatrix} \quad \text{with} \quad \begin{pmatrix} \tilde{l}_1 \\ \tilde{l}_2 \end{pmatrix} = S \begin{pmatrix} \tilde{l}_L \\ \tilde{l}_R \end{pmatrix} \tag{A.6}$$

can be obtained from

$$\tan 2\theta_{\tilde{l}} = \frac{2 m_l m_{LR}}{m_{LL}^2 - m_{RR}^2}. \tag{A.7}$$

If m_{LR} is complex, one may first choose a suitable phase rotation $\tilde{l}'_R = e^{i\phi}\tilde{l}_R$ to make the mass matrix real and then diagonalize it for $\tilde{l}_L$ and $\tilde{l}'_R$. $\tan\beta$ is the (real) ratio of the vacuum expectation values of the two Higgs fields. The soft SUSY-breaking mass terms for left- and right-handed sleptons are $m_{\tilde{L}}$ and $m_{\tilde{\nu}}$, $m_{\tilde{l}}$, respectively.

References

[1] H. P. Nilles, Phys. Rept. **110** (1984) 1.

[2] H. E. Haber and G. L. Kane, Phys. Rept. **117**, 75 (1985).

[3] S. Dawson, E. Eichten and C. Quigg, Phys. Rev. D **31** (1985) 1581.

[4] F. del Aguila and L. Ametller, Phys. Lett. B **261** (1991) 326.

[5] H. Baer, C. H. Chen, F. Paige and X. Tata, Phys. Rev. D **49** (1994) 3283.

[6] W. Beenakker, R. Höpker, M. Spira and P. M. Zerwas, Nucl. Phys. B **492** (1997) 51.

[7] W. Beenakker, M. Krämer, T. Plehn, M. Spira and P. M. Zerwas, Nucl. Phys. B **515** (1998) 3.

[8] E. L. Berger, M. Klasen and T. Tait, Phys. Rev. D **59** (1999) 074024.

[9] E. L. Berger, M. Klasen and T. Tait, Phys. Lett. B **459** (1999) 165.

[10] E. L. Berger, M. Klasen and T. Tait, Phys. Rev. D **62** (2000) 095014 [Erratum-ibid. D **67** (2003) 099901].

[11] H. Baer, B. W. Harris and M. H. Reno, Phys. Rev. D **57** (1998) 5871.

[12] W. Beenakker, M. Klasen, M. Krämer, T. Plehn, M. Spira and P. M. Zerwas, Phys. Rev. Lett. **83** (1999) 3780.

[13] N. S. Craigie, K. Hidaka and P. Ratcliffe, Phys. Lett. B **129** (1983) 310.

[14] N. S. Craigie, K. Hidaka, M. Jacob and F. M. Renard, Phys. Rept. **99** (1983) 69.

[15] T. Gehrmann, D. Maitre and D. Wyler, arXiv:hep-ph/0406222.

[16] P. Chiappetta, J. Soffer and P. Taxil, Phys. Lett. B **162** (1985) 192.

[17] R. Baiod, P. S. Martin and A. D. Russell [SPIN Collaboration], "Polarized Protons in the Tevatron Collider," contribution to the *10th Topical Workshop on Proton-Antiproton Collider Physics*, Batavia, Illinois (1995).

[18] A. de Roeck, private communication.

[19] B. C. Allanach *et al.*, Eur. Phys. J. C **25** (2002) 113.

[20] P. M. Zerwas, "Supersymmetry Parameter Analsysis: SPA Convention and Project," talk given at the ECFA Study on *Physics and Detectors for a Linear Collider*, Durham, UK (2004), http://www.desy.de/~zerwas/SPA.draft.ps.

[21] The different electroweak coupling strengths are related by

$$(a_q, b_q) \;=\; \frac{L_q \pm R_q}{4\sin\theta_W\cos\theta_W} \quad \text{and} \quad a_l \pm b_l \;=\; \frac{(L_l, R_l)}{2\sin\theta_W\cos\theta_W}.$$

Note that in Eqs. (5) and (7) of Ref. [16], parentheses must be put around the $\hat{s}|D_Z|^2$ terms, and in Eq. (7) of Ref. [16] the index q should be replaced by e in the first occurence of $(a_q + \epsilon b_q)$.

[22] P. Chiappetta and J. Soffer, Phys. Lett. B **152** (1985) 126.

[23] R. K. Ellis, W. J. Stirling and B. R. Webber, "QCD and collider physics," Cambridge Monogr. Part. Phys. Nucl. Phys. Cosmol. **8** (1996) 1.

[24] S. Eidelman *et al.* [Particle Data Group Collaboration], Phys. Lett. B **592** (2004) 1.

[25] R. Barate *et al.* [ALEPH Collaboration], Phys. Lett. B **433** (1998) 176.

[26] J. Abdallah *et al.* [DELPHI Collaboration], Eur. Phys. J. C **31** (2004) 421.

[27] M. Glück, E. Reya and A. Vogt, Eur. Phys. J. C **5** (1998) 461.

[28] J. Pumplin, D. R. Stump, J. Huston, H. L. Lai, P. Nadolsky and W. K. Tung, JHEP **0207** (2002) 012.

[29] M. Glück, E. Reya, M. Stratmann and W. Vogelsang, Phys. Rev. D **63** (2001) 094005.

[30] A. Djouadi, J. L. Kneur and G. Moultaka, arXiv:hep-ph/0211331.

[31] A. Anastassov *et al.* [CDF Collaboration], Nucl. Instrum. Meth. A **518** (2004) 609.

[32] I. Hinchliffe, Nucl. Phys. Proc. Suppl. **123** (2003) 229.

[33] S. Gennai, Nucl. Phys. Proc. Suppl. **123** (2003) 244.