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Like Sign Dilepton Signature for R-Parity Violating SUSY Search at the Tevatron Collider

Monoranjan Guchait[1] and D.P. Roy[2]
Theoretical Physics Group
Tata Institute of Fundamental Research
Homi Bhabha Road, Colaba, Bombay 400 005

Abstract

The like sign dileptons provide the most promising signature for superparticle search in a large category of R-parity violating SUSY models. We estimate the like sign dilepton signals at the Tevatron collider, predicted by these models, over a wide region of the MSSM parameter space. One expects an unambiguous signal upto a gluino mass of $200 - 300$ GeV (≥ 500 GeV) with the present (proposed) accumulated luminosity of ~ 0.1 (1) fb^{-1}.

[1]e-mail: guchait@theory.tifr.res.in
[2]e-mail: dproy@theory.tifr.res.in

Introduction

The canonical signature for superparticle search at hadron colliders is the missing-p_T signature, which follows from R-parity conservation [1]. The latter implies that the superparticles are produced in pair; and the pair of lightest superparticles (LSP) resulting from their decays are stable. In the SUSY models of current interest the LSP happens to be the lightest neutralino $\tilde{Z}_1$. Being a weakly interacting particle, the LSP escapes detection like the neutrino. The resulting imbalance of visible transverse-momentum constitutes the missing-p_T signature for superparticle production. However, there is a growing interest now in possible signatures for superparticle production in R-violating SUSY models, since there is no compelling reason for R-parity conservation in supersymmetry. It is usually invoked to ensure proton stability via the conservation of lepton and baryon numbers, L and B. However proton stability requires the conservation of L or B, but not necessarily both. Thus one can have two types of R-violating SUSY models, corresponding to B or L violation, which are consistent with proton stability. The former implies LSP decay into a baryonic channel, which has a large QCD background. On the other hand the latter implies LSP decay into a leptonic channel, which can serve as a viable signature for superparticle search. In particular the Majorana nature of the LSP ($\tilde{Z}_1$) implies that the LSP pair decay into like and unlike sign dileptons with equal probability. This leads to a like sign dilepton (LSD) signature for superparticle production, which has very little background from the standard model (SM).

The dilepton data from an early Tevatron run [2], corresponding to an integrated luminosity of ~ 4 pb^{-1}, was analysed in [3] in terms of the above signature. This led to a lower bound on gluino and squark masses

$$m_{\tilde{g}}, m_{\tilde{q}} \; > \; 100 \text{ GeV}, \tag{1}$$

in the R-violating SUSY model. At present each Tevatron experiment has accumulated data, corresponding to an integrated luminosity of ~ 100 pb^{-1}. Moreover this is expected to go up by another order of magnitude following the main injector run (run II). Thus it is imperative to explore the prospect of extending the search to higher superparticle masses in the above mentioned R-violating SUSY model using these data. The present work is devoted to this exercise.

We shall work within the framework of the minimal supersymmetric standard model (MSSM), which is characterised by relatively few parameters [1]. For extending the analysis to $m_{\tilde{g}} \; > \; 100$ GeV, one has to include two additional features, which were not considered in [3]. Firstly one has to consider the cascade decay of gluino via the chargino and the heavier neutralino states, which dominate over its direct decay into the LSP for $m_{\tilde{g}} \geq 100$ GeV. Consequently the result will depend not only on the gluino mass, but on the two other MSSM parameters as well – i.e. the higgsino mass parameter (μ) and the ratio of the two higgs vacuum expectation values ($\tan\beta$). Secondly one has to include the contribution from the electroweak production of these chargino ($\tilde{W}_{1,2}$) and neutralino ($\tilde{Z}_{1-4}$) states [4]. As we shall see below, this contribution dominates over the gluino decay contribution for $m_{\tilde{g}} \; > \; 200$ GeV.

In the next section we summarise the R-violating decays of LSP, which will be relevant for our analysis. In the following section we shall briefly discuss the processes contributing to LSP production, i.e. the gluino cascade decay and the electroweak production of the chargino and neutralino states. The resulting signal cross-sections will be presented in the next section. We shall conclude with a summary of our results.

LSP Decay in R-violating SUSY Models

There can be explicit [5,6] as well as spontaneous [7] breaking of R-parity; but only the former is phenomenologically viable in the MSSM. Therefore we shall concentrate on explicit R-parity breaking, where the LSP decay arises from one of the following Yukawa interaction terms in the Lagrangian:

$$\mathcal{L}_{\not R} = \lambda_{ijk}\ell_i\tilde{\ell}_j\bar{e}_k + \lambda'_{ijk}\ell_i\tilde{q}_j\bar{d}_k + \lambda''_{ijk}\bar{d}_i\tilde{\bar{d}}_j\bar{u}_k \tag{2}$$

plus analogous terms from the permutation of the supertwiddle. Here ℓ and $\bar{e}$ (q and $\bar{u}, \bar{d}$) denote the left-handed lepton doublet and antilepton singlet (quark doublet and antiquark singlet) and i, j, k are the generation indices. Evidently the first two terms violate L and the third one violates B conservation. The λ and λ'' couplings are antisymmetric in the first two indices, so that there are 9 independent ones of each. Together with the 27 λ' couplings, there are 45 independent Yukawa coupling terms. In analogy with the standard higgs Yukawa couplings, one expects a hierarchical structure for these additional Yukawa couplings as well [5,6]. The decay channel of LSP is determined by the leading Yukawa coupling term.

The leptonic decay channels of LSP correspond to one of the λ or λ' couplings being the leading one, as shown below.

$$\lambda'_{3jk} \quad : \quad \tilde{Z}_1 \to \tau q\bar{q}'(\nu_\tau q\bar{q}'), \tag{3}$$

$$\lambda'_{13k,23k} \quad : \quad \tilde{Z}_1 \to \nu_\ell b\bar{q}', \tag{4}$$

$$\lambda'_{ijk}(i,j \neq 3) \quad : \quad \tilde{Z}_1 \to \ell q\bar{q}'(\nu_\ell q\bar{q}'), \tag{5}$$

$$\lambda_{133,233} \quad : \quad \tilde{Z}_1 \to \ell\nu_\tau\bar{\tau}(\nu_\ell\tau\bar{\tau}), \tag{6}$$

$$\lambda_{123} \quad : \quad \tilde{Z}_1 \to \ell\nu_{\ell'}\bar{\tau}(\nu_\ell\ell'\bar{\tau}), \tag{7}$$

$$\lambda_{311,322,312,321} \quad : \quad \tilde{Z}_1 \to \tau\nu_\ell\bar{\ell}'(\nu_\tau\ell\bar{\ell}'), \tag{8}$$

$$\lambda_{121,122} \quad : \quad \tilde{Z}_1 \to \ell\nu_{\ell'}\bar{\ell}''(\nu_\ell\ell'\bar{\ell}''), \tag{9}$$

where ℓ denotes e, μ and each of the above final states represents the corresponding charge conjugate state as well. Note that in 15 of these 36 cases, represented by (3) and (4), there is no e or μ in the final state. The $\ell t\bar{q}'$ final state in (4) is kinematically inaccessible for the $\tilde{Z}_1$ mass range of interest. Thus the leptonic decay channels of our interest correspond to the remaining 21 cases, represented by eqs. (5-9). The corresponding squared matrix elements are given in [8,9]. For the λ couplings, the pairs of final states shown in eqs. (6-9) have a branching fraction of 50% each, assuming a common selectron mass. For the λ' couplings of eq. (5), however, the branching fraction for the $\tilde{Z}_1 \to \ell q\bar{q}'$ decay is sensitive to the composition of $\tilde{Z}_1$. This is shown in Table I for different values of the MSSM parameters, where we have assumed a common sfermion mass $m_{\tilde{\ell}} = m_{\tilde{q}} \gg m_{\tilde{Z}_1}$.

It may be noted here that 15 of these 21 cases, represented by eqs. (5-7), lead to no more than two leptons in the decay of the LSP pair. Moreover for the 4 cases represented by eq. (8) the dilepton final state dominates over the 3-4 lepton state, as we shall see below. Thus in 19 of the 21 cases of interest, the LSD channel is the most viable channel for superparticle search. Only for the last two cases, represented by eq. (9), the trilepton final state dominates over the LSD [10]. Evidently they represent the most favourable case for the multilepton signal of superparticle production. We shall not present the signal cross-section for this case, since it has been covered in [10].

We shall conservatively assume the leading R-violating Yukawa coupling to be significantly less than 1, so that the pair production of superparticles and their decays into LSP are not affected. In this case the signal does not depend on the value of the Yukawa coupling as long as it is large enough for LSP decay inside the detector, i.e. $\gtrsim 10^{-5}$ [3,6].

Production and Decay of Superparticles into LSP

The MSSM implies $m_{\tilde{q}} \gtrsim m_{\tilde{g}}$. In estimating the gluino and chargino/neutralino cross-sections we shall conservatively assume $m_{\tilde{q}}$ to be significantly larger than $m_{\tilde{g}}$. In that case the cross-sections are insensitive to $m_{\tilde{q}}$ [11]. The results presented below are obtained with

$$m_{\tilde{q}} = 2m_{\tilde{g}}. \tag{10}$$

The dominant processes for gluino production are the leading order QCD processes [12]

$$gg(q\bar{q}) \rightarrow \tilde{g}\tilde{g}. \tag{11}$$

In order to discuss the cascade decay of gluino, a brief summary of the chargino/neutralino sector is in order. The masses of the $SU(2)$ and $U(1)$ gauginos, M_2 and M_1, are related to the gluino mass in the MSSM [1], i.e.

$$M_2 = \frac{\alpha}{\sin^2\theta_W \alpha_s} m_{\tilde{g}} \simeq 0.3 m_{\tilde{g}}, \tag{12}$$

$$M_1 = \frac{5}{3}\tan^2\theta_W M_2 \simeq 0.5 M_2. \tag{13}$$

The physical neutralino states $\tilde{Z}_{1-4}$ are mixtures of these two gauginos and the two neutral higgsinos. Similarly the physical chargino states $\tilde{W}_{1,2}$ are mixtures of the charged $SU(2)$ gaugino and the charged higgsino. Their masses and compositions are obtained by diagonalising the corresponding mass matrices [1,13]. They are functions of $m_{\tilde{g}}$, μ and $\tan\beta$ [9,14]. It is important to include the QCD correction factor, which relates this running gluino mass with its physical (pole) mass, i.e. [15]

$$m_{\tilde{g}}\ (\text{pole}) \ = m_{\tilde{g}}(m_{\tilde{g}}) \left[1 + \frac{4.2\alpha_s}{\pi}\right]. \tag{14}$$

The signal cross-sections are presented below in terms of this pole mass.

It is worth mentioning here that for most of the MSSM parameter space of our interest the higgsino mass parameter μ is $> M_1, M_2$. Consequently the lightest neutralino ($\tilde{Z}_1$) is dominated by the $U(1)$ gaugino component, while the second lightest neutralino ($\tilde{Z}_2$) and the lighter chargino ($\tilde{W}_1$) are dominated by the $SU(2)$ gaugino. Thus their masses roughly correspond to

$$m_{\tilde{Z}_1} \simeq M_1, \tag{15}$$

$$m_{\tilde{Z}_2} \simeq m_{\tilde{W}_1} \simeq M_2. \tag{16}$$

Moreover, the gluino decays dominantly into these states, i.e.

$$\tilde{g} \xrightarrow{0.5} q\bar{q}'\tilde{W}_1, \tag{17}$$

$$\tilde{g} \xrightarrow{0.3} q\bar{q}\tilde{Z}_2, \tag{18}$$

$$\tilde{g} \xrightarrow{0.2} q\bar{q}\tilde{Z}_1, \tag{19}$$

where the larger branching fractions into $\tilde{W}_1$ and $\tilde{Z}_2$ reflect the larger $SU(2)$ gauge coupling relative to the $U(1)$ [9,14]. Of course our results are obtained with exact values of the masses and branching fractions, which show significant deviations from the approximate formulae (15-19) over parts of the parameter space.

In addition to the above, one has to consider the electroweak processes for chargino/neutralino production [4,16]

$$q\bar{q} \rightarrow \tilde{W}_1\tilde{Z}_2, \tilde{W}_1\tilde{Z}_1, \tilde{W}_1^+\tilde{W}_1^-. \tag{20}$$

These are dominated by the s-channel W and Z exchanges. In spite of being electroweak processes they dominate over the QCD process (11) for $m_{\tilde{g}} > 200$ GeV because of the relatively low $\tilde{W}_1$ and $\tilde{Z}_{1,2}$ masses.

Finally the $\tilde{W}_1$ and $\tilde{Z}_2$ coming from (17), (18) and (20) decay into the LSP ($\tilde{Z}_1$) via W and Z exchanges, i.e.

$$\tilde{W}_1 \xrightarrow{W} q\bar{q}'\tilde{Z}_1(\ell\nu_\ell\tilde{Z}_1), \tag{21}$$

$$\tilde{Z}_2 \xrightarrow{Z} q\bar{q}\tilde{Z}_1(\ell^+\ell^-\tilde{Z}_1). \tag{22}$$

It may be noted that the leptonic decays of $\tilde{W}_1$ and $\tilde{Z}_2$ have branching fractions of 0.22 and 0.06 respectively. The former can give rise to a LSD signal for gluino production via (11) and (17) in the R-conserving SUSY model. Indeed this signal is expected to be as good as the canonical missing-p_T signal at the LHC energy [9,14]. For the Tevatron energy, however, the size of this LSD signal is rather small [17]. On the other hand, one expects a significant contribution to the LSD signal in the R-violating SUSY model from the cross-term, where one of the leptons comes from the $\tilde{W}_1$ (or $\tilde{Z}_2$) decay. This contribution is included in our estimate of the signal cross-section.

The cross-sections presented below are calculated for the Tevatron collider energy of

$$\sqrt{s} = 1.8 \text{ TeV}, \tag{23}$$

using the MRSD$'_-$ structure functions [18], with the QCD scale chosen as the sum of the produced superparticle masses.

Results and Discussion

We have calculated the signal cross-sections as functions of gluino mass for

$$\tan\beta = 2, 10 \text{ and } \mu = -100, -200, -300, +300 \text{ GeV}. \tag{24}$$

A large part of the interval $-100 < \mu < 300$ GeV is excluded by the LEP data for the low gluino mass range of our interest [19], while one expects no significant change in the cross-sections beyond $|\mu| = 300$ GeV.

Fig. 1 (a,b,c,d) shows the cross-sections for $\tilde{g}\tilde{g}, \tilde{W}_1\tilde{Z}_2, \tilde{W}_1^+\tilde{W}_1^-$ and $\tilde{W}_1\tilde{Z}_1$ production at $\tan\beta = 2$ and the four values of μ mentioned above. One can clearly see the electro-weak processes $\tilde{W}_1\tilde{Z}_2$ and $\tilde{W}_1\tilde{W}_1$ overtaking the QCD process $\tilde{g}\tilde{g}$ for $m_{\tilde{g}} > 200$ GeV at negative values of μ (Fig. 1a,b,c). The rapid increase in the $\tilde{W}_1\tilde{Z}_1$ cross-section as $m_{\tilde{g}}$ goes down to 150 GeV reflects production via on-shell W as $m_{\tilde{W}_1} + m_{\tilde{Z}_1}$ falls below m_W. This enhancement is visible for all the three electroweak processes at $\mu = 300$ GeV (Fig. 1d), as the $\tilde{Z}_1, \tilde{Z}_2$ and $\tilde{W}_1$ masses are all small for positive μ. This is why the region $m_{\tilde{g}} \lesssim 250$ GeV is excluded by LEP data for positive μ. It should be noted, however, that the electroweak processes dominate over the QCD process of superparticle production for any gluino mass at positive μ.

Fig. 2 (a,b,c,d) shows the cross-sections for the three electroweak processes at $\tan\beta = 10$. They are significantly larger than the previous case at $\mu = -100$ GeV (Fig. 2a). This is due to a drop in the $\tilde{Z}_1, \tilde{Z}_2$ and $\tilde{W}_1$ masses in going from $\tan\beta = 2$ to 10 at negative μ, which is most significant at $\mu = -100$ GeV. Note that all the three cross-sections in Fig. 2a shoot up for $m_{\tilde{g}} \simeq 200$ GeV due to on-shell W and Z exchanges as the corresponding thresholds fall below the W and Z masses. For the same reason, however, this mass range is ruled out by the LEP data. On the other hand the cross-sections are clearly smaller than the previous case at $\mu = +300$ GeV (Fig. 2d). This reflects an increase in the above masses in going from $\tan\beta = 2$ to 10 at positive μ. Finally the suppression of $\tilde{W}_1\tilde{Z}_1$ relative to the $\tilde{W}_1\tilde{Z}_2$ and $\tilde{W}_1\tilde{W}_1$ cross-sections at $\mu = -200, -300$ and $+300$ GeV is due to the decoupling of the $SU(2)$ gaugino component from $\tilde{Z}_1$. All these features can be checked with the masses and compositions of these particles listed e.g. in [9].

Fortunately the wide variation of the chargino/neutralino cross-sections with μ and $\tan\beta$ parameters does not reflect in the resulting LSD signals. Lower chargino/neutralino masses correspond to softer decay leptons; and the resulting reduction in the detection efficiency compensates for the rise of the corresponding cross-section. Moreover the LSP ($\tilde{Z}_1$) coming out from on-shell W and Z decays carry very little p_T, so that its decay lepton seldom passes the required p_T cut. Thus the sharp peaks seen in some of these cross-sections at low $m_{\tilde{g}}$ has little effect on the resulting LSD signals, as we see below.

The LSD signal coming from the above superparticle decays has been estimated with the following p_T rapidity and isolation cuts on each lepton [2]:

$$p_T^\ell > 15 \text{ GeV}, \ |\eta_\ell| < 1, \ E_T^{ac} < 5 \text{ GeV}, \qquad (25)$$

where the last quantity refers to the transverse energy accompanying the lepton within a cone of $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$. Our estimates are based on a parton level Monte-Carlo programme, which should be adequate for the leptonic signal. The only place where hadronisation could play a significant role is in the isolation cut. We have checked that the efficiency factors obtained by our parton level programme for the isolation as well as the p_T and rapidity cuts agree with to those of ISAJET calculation [20].

The LSD background from the standard model has been calculated in [10]. The total background cross-section is only 2.4 fb, coming from WZ (2.1 fb) and $t\bar{t}$ (0.3 fb) [21]. This corresponds to a quarter of an event for the accumulated luminosity of ~ 0.1 fb^{-1} in the present Tevatron run, going upto 2.4 events for the projected luminosity of 1 fb^{-1} with the main injector. Thus the discovery pottential of the LSD signature is expected to be limited by the signal size rather than the SM background [10].

Fig. 3(a,b,c,d) shows the LSD signal cross-sections resulting from $\tilde{g}\tilde{g}, \tilde{W}_1\tilde{Z}_2, \tilde{W}_1^+\tilde{W}_1^-$ and $\tilde{W}_1\tilde{Z}_1$ production at $\tan\beta = 2$ and $\mu = -100, -200, -300$ and $+300$ GeV, assuming the λ' coupling of eq. (5) to be the leading R-violating Yukawa coupling. The relevant branching fractions for $\tilde{Z}_1 \rightarrow \ell q\bar{q}'$ decay are given in Table I. We see from Fig. 3 that the LSD signal cross-sections are less sensitive to μ than the corresponding raw cross-sections of Fig. 1 as remarked earlier. The $\tilde{W}_1\tilde{Z}_2$ and $\tilde{W}_1^+\tilde{W}_1^-$ contributions dominate over $\tilde{g}\tilde{g}$ at $m_{\tilde{g}} > 200$ GeV through out the negative μ region, while the $\tilde{W}_1\tilde{Z}_1$ contribution is very small. At $\mu = +300$ GeV, the electroweak contributions dominate over $\tilde{g}\tilde{g}$ for all values of $m_{\tilde{g}}$. Note that the size of the signal cross-section here is quite similar to that in the negative μ region. This is somewhat accidental as the larger cross-section at $\mu = +300$ GeV is compensated by a smaller branching fraction for the $\tilde{Z}_1 \rightarrow \ell q\bar{q}'$ decay (Table I).

A brief comment on the effect of kimatic cuts is in order. At $m_{\tilde{g}} = 300$ GeV and negative μ the suppression factors from the lepton p_T, rapidity and isolation cuts are around $5, 2$ and 2 respectively, resulting in an overall suppression factor of ~ 20. This goes up (down) by a factor of 2 at $m_{\tilde{g}} = 200$ (400) GeV. The corresponding suppression factors at $\mu = +300$ GeV are about twice as large because of the low chargino/neutralino masses.

Fig. 4 shows the net LSD signal cross-sections for different choices of the leading R-violating Yukawa coupling at $\tan\beta = 2$. Let us first consider the negative μ region (Fig. 4a,b,c). For the λ' and the unfavourable λ couplings of eqs. (5) and (6) one expects a LSD signal cross-section ≥ 100 fb for $m_{\tilde{g}} = 200$ GeV. For the more favourable λ couplings of eqs. (7) and (8) the LSD cross-section remains ≥ 100 fb upto $m_{\tilde{g}} = 300$ GeV. This corresponds to at least 10 isolated LSD events for the current Tevatron luminosity of 0.1 fb^{-1}. Thus the current CDF data is capable of probing for R-violating SUSY signal upto a gluino mass of atleast 200 GeV in the former case and 300 GeV in the latter. With the expected luminosity of ~ 1 fb^{-1} at the main injector run, the probe can be extended upto 500 GeV in the former case and ~ 600 GeV in the latter. Turning to the $\mu = +300$ GeV region (Fig. 4d), one sees that the λ' coupling predicts no viable LSD signal for the current luminosity of 0.1 fb^{-1}. However the λ coupling of eq. (6) predicts a viable signal for $m_{\tilde{g}} = 300$ GeV, while for the more favourable couplings of eqs. (7) and (8) it remains viable upto 500 GeV. With a luminosity of 1 fb^{-1} of course one expects a viable signal upto 500 GeV even for the λ' coupling, while for the λ couplings the discovery limit is significantly larger. It should be noted here that the four λ couplings of eq. (8) can lead to 3 and 4 lepton final states as well. For this case the trilepton signal, corresponding to 3 leptons passing the kinematic cut (25), is also shown in Fig. 4. It is comparable to the corresponding LSD signal in the negative μ region. But it is relatively small at $\mu = +300$ GeV, as the low chargino/neutralino masses make it harder for the 3rd lepton to pass the kinematic cut. The 4 lepton signal (not shown) is negligible.

Finally Fig. 5 shows the signal cross-sections for different choices of the leading R-violating Yukawa coupling at $\tan\beta = 10$. The most noticable feature in this case is the drop in the signal cross-section for the λ' coupling at $\mu = -100$ GeV (Fig. 5a). This is due to the fall in the $\tilde{Z}_1 \to \ell q \bar{q}'$ branching fraction shown in Table I [22]. Apart from this the signal cross-sections are generally insensitive to the choice of μ. With the current luminosity of ~ 0.1 fb^{-1}, one expects a viable LSD signal for $m_{\tilde{g}} = 200$ GeV for the λ' and the unfavourable λ couplings of eqs. (5) and (6), while for the more favourable λ couplings of eqs. (7) and (8) it remains viable upto $m_{\tilde{g}} = 400$ GeV. With a luminosity of ~ 1 fb^{-1}, the discovery limit goes upto $m_{\tilde{g}} = 500$ GeV in the former cases and much beyond in the latter. Note that for the λ couplings of eq. (8) one also expects a trilepton signal of similar size.

It may be added here that for the most favourable λ couplings of eq. (9), the multilepton signals studied in [10] are somewhat larger than the ones shown above. Although these signals were studied in [10] only for one set of μ and $\tan\beta$, they are expected to remain comfortably large for other values of these parameters as well.

Summary

The multilepton signals provide the most viable signature for a large category of R-parity violating SUSY models, where the LSP undergoes leptonic decay via one of the Yukawa couplings of eqs. (5-9). In all but 2 of these 21 cases the like sign dileptons constitute the dominant SUSY signal. We have done a systematic analysis of these LSD signals at the Tevatron collider energy covering a wide range of the MSSM parameters. The contributions from the gluino cascade decay as well as the electroweak production of chargino/neutralino pairs are taken into account. For the λ' and the unfavourable λ couplings of eqs. (5) and (6) one expects an unambiguous LSD signal upto a gluino mass of at least 200 GeV with the current accumulated luminosity of ~ 0.1 fb^{-1}. For the projected luminosity of ~ 1 fb^{-1} from the main injector run, the signal is expected to remain viable upto a gluino mass of 500 GeV. For the more favourable λ couplings of eqs. (7) and (8) one expects viable signals upto a gluino mass of 300 GeV and at least 600 GeV for integrated luminosities of 0.1 and 1 fb^{-1} respectively. It may be added here that the most favourable λ couplings of eq. (9), for which the trilepton signal dominates over the LSD, has been already investigated in ref [10]. The signal cross-section in this case is somewhat larger than above.

At present only the CDF experiment can probe for the LSD signal. But the DØ experiment can also probe for this signal in the main injector run, since it is scheduled to install a central magnet for lepton charge identification. Finally the increase of the energy from 1.8 to 2 TeV in the main injector run will push up the corresponding discovery limits somewhat higher.

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21. The kinematic cuts used in [10] are $p_T^\ell > 15$ GeV, $|\eta_\ell| < 3$ and $E_T^{ac} < p_T^\ell/4$. The isolation cut is essentially the same as ours, while the larger rapidity interval means a somewhat higher estimate of the LSD background.

22. This table shows a continueing fall in the $\tilde{Z}_1 \to \ell q \bar{q}'$ branching fraction as $\tan\beta$ goes up to 30. Thus there may be a hole in the parameter space at $\mu = -100$ GeV and large $\tan\beta$, where the LSP decay via the λ' coupling gives no viable LSD signal.

Table I

The Branching Fraction for LSP decay ($\tilde{Z}_1 \to \ell q \bar{q}'$) via the R-violating Yukawa coupling λ'_{ijk} $(i, j \neq 3)$

$m_{\tilde{q}}$	μ	$\tan\beta = 2$	$\tan\beta = 10$	$\tan\beta = 30$
250	-100	.87	.54	.21
	-200	.85	.63	.46
	-300	.82	.61	.50
	+300	.15	.24	.36
200	-100	.85	.40	.18
	-200	.82	.57	.43
	-300	.77	.58	.49
	+300	.126	.28	.38
300	-100	.81	.27	.16
	-200	.77	.51	.41
	-300	.73	.53	.47
	+300	.132	.33	.40
400	-100	.76	.20	.14
	-200	.72	.47	.39
	-300	.685	.51	.46
	+300	.166	.35	.40
500	-100	.68	.16	.13
	-200	.68	.45	.38
	-300	.65	.49	.45
	+300	.20	.37	.41

Figure Captions

Fig. 1. The QCD cross-section for gluino pair production shown along with the electroweak cross-sections for chargino/neutralino production as functions of gluino mass for $\tan\beta = 2$ and $\mu = -100, -200, -300$ and $+300$ GeV.

Fig. 2. Electroweak cross-sections for chargino/neutralino production shown as functions of gluino mass for $\tan\beta = 10$ and $\mu = -100, -200, -300$ and $+300$ GeV.

Fig. 3. The gluino and the chargino/neutralino contributions to the LSD signal cross-section shown for the R-violating Yukawa couplings of eq. (5) at $\tan\beta = 2$ and different values of μ.

Fig. 4. The LSD signal cross-sections shown at $\tan\beta = 2$ and $\mu = -100, -200, -300$ and $+300$ GeV for various R-violating Yukawa couplings. The solid, dot-dashed, long dashed and short dashed lines correspond to the couplings of eqs. (5), (6), (7) and (8) respectively. The trilepton signal cross-section for the last case is shown as crosses.

Fig. 5. Same as Fig. 4 at $\tan\beta = 10$.