

Like Sign Dilepton Signature for Gluino Production at LHC with or without R Conservation

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Abstract

The isolated like sign dilepton signature for gluino production is investigated at the LHC energy for the R conserving as well as the L and B violating SUSY models over a wide range of the parameter space. One gets viable signals for gluino masses of 300 and 600 GeV for both R conserving and L violating models, while it is less promising for the B violating case. For a 1000 GeV gluino, the L violating signal should still be viable; but the R conserving signal becomes too small at least for the low luminosity option of LHC.

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I. Introduction

The hadron colliders offer by far the best discovery limit for superparticles because of their higher energy reach. The superparticles having the largest production cross section at hadron colliders are the strongly interacting ones – the squark \tilde{q} and gluino \tilde{g} . Therefore there has been a good deal of discussion on the search of these superparticles at the present and proposed hadron colliders [1,2]. So far the search programme has been largely based on the missing p_T signature assuming R conservation [3]. The latter implies pair production of superparticles followed by their decay into the lightest superparticle (LSP) which has to be stable. It is also required to be colourless and neutral for cosmological reasons [4]. The LSP escapes detection due to its feeble interaction with matter resulting in the missing p_T signature for superparticle production.

There is a growing realisation in recent years however that the multilepton signature, and in particular the like sign dilepton (LSD) signature, may play an equally important role in superparticle search for the following reasons. 1) The squark and gluino searches are expected to be carried over the mass range of several hundred GeV at LHC/SSC. The dominant decay mode for a squark or gluino in this mass range is not its direct decay into the LSP, which is generally assumed to be the lightest neutralino, but a cascade decay via the heavier neutralino and chargino states. The cascade decay proceeds through the emission of W or Z which have significant leptonic branching ratios. Thus one expects two (or more) leptons resulting from the cascade decay of the squark or gluino pair. More over, in the latter case the two leptons are expected have like sign half the time due to the Majorana nature of gluino [5-7]. 2) In the R violating (\bar{R}) SUSY models there is no missing p_T signature, since the LSP is no longer stable. Instead it decays into a leptonic or baryonic channel depending on whether the L or B violating Yukawa coupling is the dominant one [8-10]. In the former case one expects two (or more) leptons resulting from the decay of the LSP pair. Again the two leptons are expected to have like sign half the time due to the Majorana nature of the LSP. In the latter case there is no viable signature from the baryonic decay of LSP; the like sign dileptons coming from the cascade decay process provides by far the best signature for this case [9].

Thus there are two contributions to the like sign dilepton signature for gluino production – 1) from the cascade decay of gluino into LSP, which holds for R conserving as well as the \bar{L} and \bar{B} SUSY models, and 2) from the leptonic decay of LSP in the \bar{L} model. In the latter case the size of the like sign dilepton signal is expected to be large. In fact the Tevatron dilepton data is already known to give a gluino (squark) mass limit in the \bar{L} SUSY model [10], which is as large as that obtained from the corresponding missing- p_T data for the R conserving case [11]. On the other hand the LSD signal arising from the cascade decay process is suppressed by the leptonic branching fractions of the two vector bosons, and hence expected to be relatively small in size. Nonetheless it is expected to provide a useful alternative signature for gluino production in the R conserving SUSY model, since it has a smaller background compared to the missing- p_T channel. Moreover it provides the only signature for gluino production in the \bar{B} SUSY model as mentioned

above. Thus it is important to make a systematic study of the LSD signal, arising from both these sources, for the gluino mass range of interest to LHC/SSC along with the corresponding background. The present work is devoted to this exercise.

To be specific we shall concentrate on the LHC energy of

$$\sqrt{s} = 16 \text{ TeV}, \quad (1)$$

and assume a typical luminosity of 10 events/fb corresponding to the low luminosity option of LHC. Of course any viable signal here shall be even more viable at SSC or the high luminosity option of LHC. We shall study gluino production and decay under the assumption

$$m_{\tilde{g}} < m_{\tilde{q}} \quad (2)$$

in which case they provide the most important signal for superparticle search at hadron colliders. This inequality seems to be favoured by a large class of SUSY models. However, we shall briefly discuss how the results would change if the squarks are lighter than the gluino, in which case the dominant superparticle signal would come from the production and decay of squarks.

The paper is organised as follows. The standard model (SM) background for the like sign dilepton channel is briefly discussed in section II. Section III gives the formalism of gluino cascade decay into the LSP via the heavier neutralino and chargino states. It tabulates the masses and the compositions of the neutralino and chargino states, resulting from the diagonalisation of their mass matrices, for a wide range of gluino mass and the other SUSY parameters. It also gives the branching fractions of gluino decay into these states. Section IV describes the LSP decay in the \tilde{R} SUSY models. Section V compares the resulting like sign dilepton signals with the SM background. The main conclusions are summarised in section VI.

II. Standard Model Background for the Like Sign Dilepton Channel

The SM background to the like sign dilepton channel at LHC has been studied in detail in [12]. We shall only summarise the essential points here. The two main sources of LSD background are from

$$gg \rightarrow b\bar{b} (b\bar{b}g) \quad (3)$$

via $B\bar{B}$ mixing, and

$$gg \rightarrow t\bar{t} (t\bar{t}g) \quad (4)$$

followed by the sequential decay of one of the t quarks into b . In the first case both the leptons originate from B particle decay, $B \rightarrow \ell\nu D (D^*)$, while in the second case one of the leptons (the softer one) originates from B . Consequently both the contributions can be suppressed by imposing isolation cut on the leptons [13]. Moreover the isolation cut for the B decay lepton is known to become more powerful with the lepton p_T , resulting in a p_T cutoff for the isolated lepton [14]

$$p_T^\ell \lesssim E_T^{AC} \left(\frac{m_B^2 - m_{D(D^*)}^2}{m_{D(D^*)}^2} \right). \quad (5)$$

Substituting for the bottom and charm particle masses one sees that a typical isolation cut of

$$E_T^{AC} < 10 \text{ GeV} \quad (6)$$

at LHC [15] implies a lepton p_T cutoff

$$p_T^\ell \lesssim 60 \text{ GeV}. \quad (7)$$

Loss of visible E_T^{AC} due to semileptonic D decay and energy resolution leads to a small spill over of the isolated lepton background beyond this kinematic cutoff. On the other hand the contributions to E_T^{AC} from the fragmentation of b quark into B particle as well as the underlying event tend to strengthen the bound. All these effects are taken into account in the ISAJET [16] Monte Carlo calculation of this background in [12], which shows that the background becomes negligibly small beyond the lepton p_T of 60 GeV. This is evidently a powerful result, which can be exploited in the search of the gluino signal in the LSD channel. We shall use this result in our analysis. We shall also include the fake LSD background arising from the misidentification of one of the lepton charges in $t\bar{t} \rightarrow \ell^+ \ell^- X$.

III. Cascade Decay of Gluino into LSP

We shall work within the framework of the minimal supersymmetric standard model (MSSM) so as to have the minimum number of parameters [1,2]. The gluino cascade decay into the LSP proceeds via the heavier neutralino and chargino states. There are 4 neutralino states, which are mixtures of the 4 basic interaction states, i.e.

$$\chi_i^0 = N_{i1} \tilde{B} + N_{i2} \tilde{W}^3 + N_{i3} \tilde{H}_1^0 + N_{i4} \tilde{H}_2^0. \quad (8)$$

The masses and compositions of the neutralinos are obtained by diagonalising the mass matrix [1,2,5,17]

$$M_N = \begin{pmatrix} M_1 & 0 & -m_Z \sin \theta_W \cos \beta & m_Z \sin \theta_W \sin \beta \\ 0 & M_2 & m_Z \cos \theta_W \cos \beta & -m_Z \cos \theta_W \sin \beta \\ -m_Z \sin \theta_W \cos \beta & m_Z \cos \theta_W \cos \beta & 0 & -\mu \\ m_Z \sin \theta_W \sin \beta & -m_Z \cos \theta_W \sin \beta & -\mu & 0 \end{pmatrix}. \quad (9)$$

where M_1 and M_2 are the soft masses of the bino \tilde{B} and wino \tilde{W} respectively, μ is the supersymmetric higgsino mass parameter and $\tan \beta$ is the ratio of the two higgs vacuum expectation values. The two soft gaugino masses are related to that of the gluino in the MSSM, i.e.

$$M_2 = \frac{\alpha}{\sin^2 \theta_W \alpha_s} \cdot m_{\tilde{g}} \simeq 0.3 m_{\tilde{g}} \quad (10)$$

$$M_1 = \frac{5}{3} \tan^2 \theta_W M_2 \simeq 0.5 M_2. \quad (11)$$

Thus there are 3 independent parameters, $m_{\tilde{g}}$, μ and $\tan \beta$, defining the mass matrix. The Majorana nature of the neutralinos ensures that the mass matrix is in general complex symmetric and hence can be diagonalised by only one unitary matrix N , i.e.

$$N^* M_N N^{-1} = M_N^D. \quad (12)$$

We have followed the analytical prescription of diagonalising this mass matrix recently suggested in [18]. But we have also cross-checked our results extensively with the numerical diagonalisation program EISCH1.FOR of CERN library as well as the published results of [2,5,19].

The two chargino mass states are mixtures of the charged wino \tilde{W}^\pm and Higgsino \tilde{H}^\pm . Their masses and compositions are obtained by diagonalising

the corresponding chargino mass matrix

$$M_C = \begin{pmatrix} M_2 & \sqrt{2}m_W \sin \beta \\ \sqrt{2}m_W \cos \beta & \mu \end{pmatrix}. \quad (13)$$

This is done via the biunitary transformation

$$U M_C V^{-1} = M_C^D \quad (14)$$

where U and V are 2×2 unitary matrices, which diagonalise the hermitian (real symmetric) matrices $M_C M_C^\dagger$ and $M_C^\dagger M_C$ respectively. Explicit expressions for U and V may be found in [1,5] along with those of the mass eigenvalues. The corresponding chargino eigenstates are

$$\begin{aligned} \chi_{iL}^\pm &= V_{i1} \tilde{W}_L^\pm + V_{i2} \tilde{H}_L^\pm \\ \chi_{iR}^\pm &= U_{i1} \tilde{W}_R^\pm + U_{i2} \tilde{H}_R^\pm \end{aligned} \quad (15)$$

where L and R refer to the left and right handed helicity states. We shall use the real orthogonal representation for the unitary matrices U, V and N . Moreover the chargino and neutralino eigenstates shall be labelled in increasing order of mass, with

$$\chi_1^0 \equiv \chi \quad (16)$$

representing the LSP.

Table I (a,b,c) show the masses and compositions of the neutralino and chargino states for three representative values of the gluino mass which are of interest to LHC/SSC; i.e.

$$m_{\tilde{g}} = 300, 600 \text{ and } 1000 \text{ GeV}. \quad (17)$$

The results are not very sensitive to the variation of $\tan \beta$ over the range allowed by MSSM, i.e. $1 < \tan \beta < m_t/m_b$ ($\simeq 30$). We have chosen 2 representative values

$$\tan \beta = 2 \text{ and } 10; \quad (18)$$

the current lower mass bounds of top quark and neutral higgs boson do not seem to favour $\tan \beta = 1$ [2]. On the other hand, the results are quite sensitive to the variation of μ over the range $-M_2 < \mu < M_2$. Therefore we have chosen 5 representative values of this variable, i.e.

$$\mu = 0.1m_W, \pm m_W, \pm 4m_W \quad (19)$$

as in ref. [5]. This also helps us cross-check some of our results with theirs [20]. The SM parameters used are

$$m_W = 80 \text{ GeV}, m_Z = 91 \text{ GeV}, \sin^2 \theta_W = 0.233, \alpha = 1/128, \alpha_s = 0.115. \quad (20)$$

The masses and compositions of the neutralinos are shown in the 2nd and 3rd columns of Table I, while those of the charginos are shown in the 5th and 6th columns. The upper and lower entries of 6th column refer to the compositions of the left and right handed components of the chargino respectively. The sign of a mass affects the phases of the corresponding couplings [5]; these are irrelevant however in the approximation we shall be working in. One should note the following systematics in the masses and compositions of the neutralino and chargino states.

- 1) For $\mu = \pm 4 m_W$, the higgsino mass parameter is generally larger than M_1 and M_2 . Consequently the LSP (χ_1^0) is dominated by the bino \tilde{B} component, while the second lightest neutralino χ_2^0 and the lightest chargino χ_1^\pm are dominated by the wino \tilde{W} . These are clearly reflected

in their masses and compositions. Only at $m_{\tilde{g}} = 1000$ GeV, the χ_2^0 and χ_1^\pm acquire significant higgsino components as $M_2 \simeq |\mu|$. Evidently the gaugino dominance of χ_1^0 , χ_2^0 and χ_1^\pm is expected to hold even better at $|\mu| > 4 M_W$.

- 2) For $\mu = -m_W$, the higgsino mass parameter is comparable to M_1, M_2 at $m_{\tilde{g}} = 300$ GeV and smaller at $m_{\tilde{g}} = 600$ and 1000 GeV. Consequently the χ_1^0, χ_2^0 and χ_1^\pm contain significant admixtures of the gaugino and higgsino components at $m_{\tilde{g}} = 300$ GeV, while they are dominated by the higgsinos at $m_{\tilde{g}} = 600$ and 1000 GeV.
- 3) For $\mu = m_W$ and $0.1 m_W$, the χ_1^0, χ_2^0 and χ_1^\pm have large higgsino components as expected. However, this part of the parameter space is disallowed by the LEP data, which gives a lower mass limit of $\sim m_Z/2$ for the lightest chargino as well as higgs dominated neutralino [3,21]. Only at $m_{\tilde{g}} = 1000$ GeV does the $\mu = m_W$ value falls marginally within the allowed region.

Thus we see that the values of $\mu = \pm 4 m_W$ and $-m_W$ are generally representative of the two extreme cases where the lighter neutralino and chargino states are dominated by the gaugino and higgsino components respectively, while it is the opposite for the heavier ones. Note that for $m_{\tilde{g}} = 300$ GeV the lighter states have substantial gaugino components even at $\mu = -m_W$. Nonetheless the latter represents the extreme composition as it lies close to the boundary of the experimentally allowed region [3,19].

We shall estimate the branching fractions of gluino decay into the above chargino and neutralino states by neglecting the contributions of top quark ($\tilde{g} \rightarrow t\bar{t}\chi_i^0, t\bar{b}\chi_i^-$) as well as the loop induced processes ($\tilde{g} \rightarrow g\chi_i^0$). This seems to be a reasonable approximation for the bulk of the parameter space under investigation [2]. Thus the decay processes of interest are

$$\tilde{g} \xrightarrow{\tilde{q}} q\bar{q}\chi_i^0 \quad (21)$$

$$\tilde{g} \xrightarrow{\tilde{q}'} q'\bar{q}\chi_i^\pm \quad (22)$$

where q and q' are understood to represent the light quarks of a given generation. The relevant interaction terms for these processes are

$$\begin{aligned} \mathcal{L}_{q\tilde{q}\tilde{g}} &= \frac{ig_s}{\sqrt{2}}\tilde{q}_L^\dagger\tilde{g}_A\lambda_Aq_L + \frac{ig_s}{\sqrt{2}}\tilde{q}_R^\dagger\tilde{g}_A\lambda_Aq_R + h.c., \\ \mathcal{L}_{q\tilde{q}\chi_i^0} &= iA_{\chi_i^0}^q\tilde{q}_L^\dagger\bar{\chi}_i^0q_L + iB_{\chi_i^0}^q\tilde{q}_R^\dagger\bar{\chi}_i^0q_R + h.c., \\ \mathcal{L}_{q'\tilde{q}\chi_i^\pm} &= iA_{\chi_i^\pm}^d\tilde{u}_L^\dagger\bar{\chi}_i^-d_L + iA_{\chi_i^\pm}^u\tilde{d}_L^\dagger\bar{\chi}_i^+u_L + h.c., \end{aligned} \quad (23)$$

where g_s is the QCD coupling and λ_A are the generators of the colour $SU(3)$ group. In the absence of top quark one can safely neglect the small Yukawa couplings associated with the higgs sector, so that A and αOBB are simply the $SU(2) \times U(1)$ gauge couplings of left handed (doublet) and right handed (singlet) quarks [5] respectively. Moreover we shall ignore the phase factors associated with these couplings, since the interference terms between left and right handed squark exchanges are negligible for final states involving only light quarks [22]. Thus we have

$$A_{\chi_i^0}^\mu = \frac{g'}{3\sqrt{2}}N_{i1} + \frac{g}{\sqrt{2}}N_{i2}$$

$$\begin{aligned}
A_{\chi_i^0}^d &= \frac{g'}{3\sqrt{2}}N_{i1} - \frac{g}{\sqrt{2}}N_{i2} \\
B_{\chi_i^0}^u &= \frac{4}{3}\frac{g'}{\sqrt{2}}N_{i1} \\
B_{\chi_i^0}^d &= -\frac{2}{3}\frac{g'}{\sqrt{2}}N_{i1} \\
A_{\chi_i^\pm}^d &\equiv A_{\chi_{iR}^\pm} = gU_{i1} \\
A_{\chi_i^\pm}^u &\equiv A_{\chi_{iL}^\pm} = gV_{i1}
\end{aligned} \tag{24}$$

where g and g' are the standard $SU(2)$ and $U(1)$ couplings and u, d stand for up and down member of any quark generation. In terms of these couplings we have the following spin-averaged squared matrix elements for (21) and (22).

$$\bar{M}_{\tilde{g} \rightarrow q\bar{q}\chi_i^0}^2 = \left(A_{\chi_i^0}^{q^2} + B_{\chi_i^0}^{q^2} \right) \left[\frac{(\tilde{g} \cdot \bar{q})(\chi_i^0 \cdot q)}{(m_{\tilde{q}}^2 - (\tilde{g} - \bar{q})^2)^2} + \frac{(\tilde{g} \cdot q)(\chi_i^0 \cdot \bar{q})}{(m_{\tilde{q}}^2 - (\tilde{g} - q)^2)^2} \right] \tag{25}$$

$$\bar{M}_{\tilde{g} \rightarrow q'\bar{q}'\chi_i^\pm}^2 = \left(A_{\chi_i^\pm}^{u^2} + A_{\chi_i^\pm}^{d^2} \right) \left[\frac{(\tilde{g} \cdot \bar{q})(\chi_i^\pm \cdot q')}{(m_{\tilde{q}}^2 - (\tilde{g} - \bar{q})^2)^2} + \frac{(\tilde{g} \cdot q')(\chi_i^\pm \cdot \bar{q})}{(m_{\tilde{q}}^2 - (\tilde{g} - q')^2)^2} \right] \tag{26}$$

where particle indices have been used for their 4-momenta and we have ignored a common multiplicative constant involving the QCD coupling and colour factor, since it is not relevant for our calculation [22]. Note that in the limit $m_{\tilde{g}} \gg m_{\chi_i^0}, m_{\chi_i^\pm}$ the various partial widths are proportional to the respective factors in front of the square bracket. Thus one gets the following branching fractions as a simple first approximation.

$$B_{\tilde{g} \rightarrow \chi_i^0} \simeq \frac{\frac{5}{2}N_{i2}^2 + \frac{49}{18}\tan^2\theta_W N_{i1}^2 - \frac{2}{3}\tan\theta_W N_{i1}N_{i2}}{\frac{13}{2} + \frac{49}{18}\tan^2\theta_W} \simeq \frac{2.5N_{i2}^2 + 0.83N_{i1}^2 - 0.37N_{i1}N_{i2}}{7.33} \tag{27}$$

$$B_{\tilde{g} \rightarrow \chi_i^\pm} \simeq \frac{2U_{i1}^2 + 2V_{i1}^2}{\frac{13}{2} + \frac{49}{18}\tan^2\theta_W} \simeq \frac{2U_{i1}^2 + 2V_{i1}^2}{7.33}. \tag{28}$$

They show that the $SU(2)$ gauge interaction dominates over the $U(1)$ in gluino decay. Consequently the charginos account for a little over 50% of gluino decay and the neutralinos a little under 50%, of which only 12% goes into the \tilde{B} dominated neutralino and the remainder into the \tilde{W}^3 dominated one. The gluino branching fractions into the different neutralino and chargino states, resulting from (25) and (26), are shown in Table I for the allowed range of the parameter space. At $m_{\tilde{g}} = 1000$ GeV they are shown only for $\tan\beta = 2$, since in this case the loop induced decay processes are expected to become significant for $\tan\beta = 10$ [2]. The branching fractions have been obtained with a common squark mass

$$m_{\tilde{q}} = m_{\tilde{g}} + 200 \text{ GeV}, \tag{29}$$

but are insensitive to the choice of this parameter. In fact one can easily check that they are reasonably close to those obtained from the approximate formulae (27) and (28). One should note the following systematic features which will be useful for our subsequent analysis.

- 1) The branching fraction for direct gluino decay into the LSP has its

maximum value for \tilde{B} dominated LSP, i.e.

$$B_{\tilde{g} \rightarrow \chi(\tilde{B})} = .15 - .20. \quad (30)$$

It holds for most of the parameter space at $m_{\tilde{g}} = 300$ GeV and for $\mu \simeq \pm 4 m_W$ at the higher values of gluino mass.

- 2) The largest branching fraction for gluino decay is into the \tilde{W} dominated chargino state, i.e.

$$B_{\tilde{g} \rightarrow \chi_i^\pm(\tilde{W})} \simeq 0.5. \quad (31)$$

It generally corresponds to the lighter (heavier) chargino state for $\mu \simeq \pm 4 m_W$ ($-m_W$); but it has a substantial admixture of the heavier (lighter) one at $m_{\tilde{g}} = 1000$ (300) GeV as discussed earlier.

- 3) The second largest branching fraction is into the corresponding \tilde{W} dominated neutralino, i.e.

$$B_{\tilde{g} \rightarrow \chi_i^0(\tilde{W})} \simeq 0.3. \quad (32)$$

It generally corresponds to the second lightest (heaviest) neutralino state for $\mu \simeq \pm 4 m_W$ ($-m_W$), but again with the same caveat as above.

- 4) Thus the \tilde{W} dominated chargino and neutralino states together account for $\sim 80\%$ of gluino decay. Note that these two states have nearly degenerate mass

$$m_{\chi_i^\pm(\tilde{W})} \simeq m_{\chi_i^0(\tilde{W})} \quad (33)$$

throughout the parameter space; and this common mass is also roughly equal to 1/3rd of the gluino mass, as expected from (10). The first equality implies very similar kinematics for the two major decay processes (31) and (32); while the second implies that the kinematics is mainly determined by the gluino mass and not by μ or $\tan\beta$. As a result one gets a fairly simple and robust signature as we shall see later.

- 5) The major decay modes of the \tilde{W} dominated chargino and neutralino states are

$$\chi_i^\pm(\tilde{W}) \xrightarrow{W} \chi_{1,2,3}^0 q' \bar{q}(\ell\nu), \quad (34)$$

$$\chi_i^0(\tilde{W}) \xrightarrow{Z} \chi_{1,2,3}^0 q \bar{q}(\ell\bar{\ell}). \quad (35)$$

Simple phase space considerations ensure that the decay into the LSP χ ($\equiv \chi_1^0$) dominates over most of the parameter space for $m_{\tilde{g}} = 300$ GeV and at $\mu \simeq \pm 4 m_W$ for heavier gluinos. Note that the leptonic branching fractions of (34) and (35) are about 20% and 6% respectively, where ℓ includes both e and μ . These are the primary sources of isolated leptons from cascade decay [23].

- 6) Finally since all the branching fractions and kinematics of gluino decay discussed above are very similar for $\mu = \pm 4 m_W$, we shall present the resulting signals for only one of these two values.

IV. LSP Decay in \tilde{R} SUSY Models

We shall concentrate on explicit R parity violation [8-10], where the LSP decay arises from one of the following \tilde{R} Yukawa interaction terms in the Lagrangian.

$$\mathcal{L}_{\tilde{R}} = \lambda_{ijk} \ell_i \tilde{\ell}_j \bar{e}_k + \lambda'_{ijk} \ell_i \tilde{q}_j \bar{d}_k + \lambda''_{ijk} \bar{d}_i \tilde{d}_j \bar{u}_k \quad (36)$$

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. The first two terms correspond to \tilde{L} and the third one to \tilde{B} Yukawa interaction. While proton stability prohibit simultaneous presence of both these interactions at any level of phenomenological significance, either one of them could be present at a significant level. Thus one has two types of models, corresponding to \tilde{L} and \tilde{B} . In the \tilde{B} model

$$\chi \rightarrow d_i d_j u_k, \quad (37)$$

so that the only leptons in the signal are those coming from the cascade decay. Moreover the decay quarks from (37) lead to a stronger isolation cut for these leptons, so that one expects a weaker signal in this case compared to the R conserving SUSY model. On the other hand the \tilde{L} model implies additional leptons from the LSP decay, resulting in a much stronger signal as we see below.

In analogy with the standard Yukawa coupling of quarks and leptons to the higgs boson one expects a hierarchical structure for these Yukawa couplings as well. Thus the dominant LSP decay process is

$$\chi \rightarrow \ell_i q_j \bar{d}_k (e_i u_j \bar{d}_k + \nu_i d_j \bar{d}_k) \quad (38)$$

or

$$\chi \rightarrow \ell_i \ell_j \bar{e}_k (e_i \nu_j \bar{e}_k + \nu_i e_j \bar{e}_k) \quad (39)$$

depending on whether the dominant \tilde{L} Yukawa coupling is one of the λ'_{ijk} or λ_{ijk} couplings (in the latter case particle identity requires $i \neq j$). The spin averaged and squared matrix element for the decay process (39) is

$$\begin{aligned} \bar{M}_{\chi \rightarrow e_i \nu_j \bar{e}_k}^2 &= \bar{M}_{\chi \rightarrow \nu_i e_j \bar{e}_k}^2 = \frac{A_\chi^{e^2} (\chi \cdot e) (\nu \cdot \bar{e})}{D_{\bar{e}}^2} + \frac{A_\chi^{\nu^2} (\chi \cdot \nu) (e \cdot \bar{e})}{D_{\bar{\nu}}^2} \\ &+ \frac{B_\chi^{e^2} (\chi \cdot \bar{e}) (e \cdot \nu)}{D_{\bar{e}}^2} - \frac{A_\chi^e A_\chi^\nu G(\chi, e, \bar{e}, \nu)}{D_{\bar{e}} D_{\bar{\nu}}} + \frac{A_\chi^e B_\chi^e G(\chi, e, \nu, \bar{e})}{D_{\bar{e}} D_{\bar{e}}} \\ &+ \frac{A_\chi^\nu B_\chi^e G(\chi, \nu, e, \bar{e})}{D_{\bar{\nu}} D_{\bar{e}}}, \end{aligned}$$

$$D_{\bar{e}} = m_{\bar{e}}^2 - (\chi - e)^2, \quad G(\chi, e, \nu, \bar{e}) = (\chi \cdot e) (\nu \cdot \bar{e}) - (\chi \cdot \nu) (e \cdot \bar{e}) + (\chi \cdot \bar{e}) (\nu \cdot e), \quad (40)$$

and

$$A_\chi^e = \frac{-g'}{\sqrt{2}} N_{11} - \frac{g}{\sqrt{2}} N_{12}, \quad A_\chi^\nu = \frac{-g'}{\sqrt{2}} N_{11} + \frac{g}{\sqrt{2}} N_{12}, \quad B_\chi^e = \frac{-2g'}{\sqrt{2}} N_{11}, \quad (41)$$

where we have dropped a common multiplicative factor involving the λ coupling, since it is not relevant for our calculation. Moreover, one can factor out a common denominator assuming a common slepton mass

$$m_{\bar{e}} = m_{\bar{\nu}} \gg m_\chi. \quad (42)$$

We shall be working in this limit.

For simplicity we shall present the like sign dilepton signal for the \mathbb{L} SUSY model assuming the leading Yukawa coupling to be λ_{123} . This corresponds to a lepton (i.e. e and μ) multiplicity of 1 for each LSP decay. The corresponding lepton multiplicities for the choices of different λ 's as the leading \mathbb{L} Yukawa coupling is listed in Table II. The corresponding LSD signals can be simply obtained by scaling the present signal by the squares of the lepton multiplicities; for the lepton spectrum is insensitive to the detailed structure of the squared matrix element.

If the leading \mathbb{L} Yukawa coupling is a λ' coupling, then the relevant LSP decay is (38). The corresponding squared matrix elements are easily obtained from (40) by obvious substitutions (see eq. 34 of [24]). One should note however that in this case the squared matrix elements for $\chi \rightarrow e u \bar{d}$ and $\nu d \bar{d}$ are not identical. Consequently the lepton multiplicity for this LSP decay is 1/2 only if the LSP is a pure \tilde{B} or \tilde{W} , but not for a general composition of LSP. In the latter case it can be calculated from the relative rates of the two decay processes, i.e.

$$\frac{\Gamma_{\chi \rightarrow e u \bar{d}}}{\Gamma_{\chi \rightarrow \nu d \bar{d}}} = \frac{A_\chi^{e^2} + A_\chi^{u^2} + B_\chi^{d^2} - A_\chi^e A_\chi^u + A_\chi^e B_\chi^d + A_\chi^u B_\chi^d}{A_\chi^{\nu^2} + A_\chi^{d^2} + B_\chi^{d^2} - A_\chi^\nu A_\chi^d + A_\chi^\nu B_\chi^d + A_\chi^d B_\chi^d} \quad (43)$$

assuming $m_{\tilde{e}} \simeq m_{\tilde{q}} \gg m_\chi$. The resulting lepton multiplicities for the parameter values of our interest are shown in Table III. The corresponding LSD signals can again be obtained by scaling the ones presented here by the squares of these multiplicities. Although the lepton isolation cut is somewhat stronger in this case it would not degrade the signal substantially. One should note that there would be no e or μ in LSP decay if the leading \mathbb{L} coupling is a λ'_{3jk} or λ'_{i3k} [10]. The first decay proceeds through τ or ν_τ emission and the second through ν_i only due to the large top quark mass.

Finally it should be noted that we have conservatively assumed the leading R Yukawa coupling to be $\ll 1$, so that the pair production of superparticles and their decays into LSP are not affected [10].

V. The LSD Signal and Background

The gluino pair production cross-section has been calculated for the leading order QCD process [25]

$$gg \rightarrow \tilde{g}\tilde{g} \quad (44)$$

using the gluon structure functions of [26] with a QCD scale $Q = 2m_{\tilde{g}}$. Each of the gluinos is assumed to decay into the LSP via the cascade decay processes discussed above. The LSP escapes undetected in the R conserving SUSY model, while it decays in to a baryonic (leptonic) channel in the \tilde{B} (\mathbb{L}) violating models [8-10]. The resulting like sign dilepton signals have been calculated for the LHC energy using a parton level Monte Carlo program.

The isolated LSD signals are shown in Figs. 1-5 along with the SM background against the p_T of the 2nd (softer) lepton, with the isolation cut of eq. (6) and a rapidity cut of $|\eta| < 3$ on both the leptons. The SM background, arising from the $b\bar{b}$ production (crosses) and $t\bar{t}$ production (histogram), were calculated in [12] assuming $m_t = 150$ GeV [27]. The former dominates in the small p_T region, while the latter dominates in the large p_T region of our interest. But both are seen to become negligible for $p_{T2} \geq 60$ GeV. The dominant

background in this region is expected to arise from the misidentification of one of the lepton charges in

$$t\bar{t} \rightarrow \ell^+ \ell^- X. \quad (45)$$

We have calculated the resulting fake LSD background, assuming it to be about 1% of the above cross-section, i.e. a misidentification of one of the lepton charges at the 1/2% level. To avoid overcrowding, this background has been shown only in Figs. 4 and 5.

Fig. 1 shows the isolated LSD signals for a 300 GeV gluino at $\mu = 4 m_W$ and both values of $\tan\beta$. A brief discussion of the signal curves is in order.

- 1) R conserving Model: The main source of the signal in this case is the sequence

$$\tilde{g} \xrightarrow{0.5} \chi_i^\pm(\tilde{W}) \xrightarrow{0.2} \chi \ell^\pm \nu, \quad (46)$$

which has a leptonic branching fraction of 0.10. The corresponding branching fraction for the second largest source

$$\tilde{g} \xrightarrow{0.3} \chi_i^0(\tilde{W}) \xrightarrow{0.06} \chi \ell^+ \ell^- \quad (47)$$

is effectively 0.036. Moreover the degeneracy relation (33) along with $m_W \simeq m_Z$ imply very similar kinematic distributions for the two final states. Thus one can simply take account of the second source by increasing the branching fraction of the first by 36%. We have followed this prescription in obtaining the LSD signal. Following this procedure we have calculated the dilepton cross-section assuming the decay chain (46) for both the gluinos, with $\chi_i^\pm(\tilde{W}) = \chi_1^\pm$. The resulting dilepton branching fraction is $\simeq 2\%$. Deviding it by a factor of 2 gives the final LSD signal, shown as the dot-dashed lines.

- 2) B Model: The source of the dileptons in this case is the same as above. However, the quarks coming from the LSP decay (37) are included in the isolation cut of the leptons. This results in a substantial depletion of the LSD signal as shown by the short dashed lines.
- 3) L Model: The main source of the LSD signal in this case are the leptons from the LSP decay. The hardest component corresponds to the direct decay of each gluino into the LSP, i.e.

$$\tilde{g} \xrightarrow{17-20} \chi(\tilde{B}) \rightarrow \ell. \quad (48)$$

Thus the dilepton branching fraction is $\simeq 3-4\%$, i.e. roughly similar to the R conserving case. The resulting LSD signal, shown by the dotted lines, is similar to the later in both shape and size. However, the largest component comes from the decay sequence

$$\tilde{g} \xrightarrow{0.8} \chi_i^\pm(\tilde{W}), \quad \chi_i^0(\tilde{W}) \rightarrow \chi \rightarrow \ell \quad (49)$$

for each gluino. This can be combined with the cross-term between (48) and (49), since the 2nd (softer) lepton in either case comes from (49). Hence the combined dilepton branching fraction is $\simeq 1$. The resulting LSD signal is shown by the solid lines. Finally the cross-term between the combined decay sequence (48) and (49) for one gluino and (46) for the other has a dilepton branching fraction of $\simeq 0.2$, which is shown by the long dashed line [28]. There is negligible double counting in adding the above two components, since the probability of both the

decay leptons coming from the same gluino to populate the large p_T region of interest is negligible. As mentioned earlier, the \cancel{L} signals have been calculated for the LSP decay mode $\chi \rightarrow \ell\nu\tau$ having a leptonic multiplicity of 1. The corresponding signals for the other \cancel{L} decays of (38) and (39) can be obtained by multiplying them with the respective leptonic multiplicities of each LSP decay, shown in Tables II and III.

As one sees from Fig. 1, the \cancel{L} LSD signal is clearly large compared to the SM background at large p_T . It is also larger than the fake LSD background shown in Fig. 5. The R conserving signal is larger than the first but comparable to the second. Nonetheless it can be easily recognised by the large missing- p_T carried by the χ and ν of (46). This is shown in Fig. 6. The \cancel{B} signal is somewhat larger than the SM background but smaller than that coming from the fake LSD by a factor of ~ 5 . Thus identifying this signal would require identification of lepton charge to a 0.1% accuracy. Fig. 2 shows the corresponding signals for $\mu = -m_W$. In this case the gluino has significant branching fractions into both χ_1^\pm and χ_2^\pm ; but the former is still the larger one. Moreover if either of the gluinos decays via χ_1^\pm , the softer lepton p_T distribution would correspond to this decay mode. Therefore it is reasonable to approximate $\chi_i^\pm(\tilde{W})$ by χ_1^\pm as in the previous case. Thus the decay sequences and branching fractions are identical to (46-49), except for a marginal reduction of the dilepton branching fraction from (48) from 3 to 2% at $\tan\beta = 10$. A comparison of the signal curves with those of Fig. 1 shows that all of them are qualitatively similar. Thus the 300 GeV gluino signals are seen to be fairly insensitive to the choice of μ as well as $\tan\beta$.

Fig. 3 shows the LSD signals for a 600 GeV gluino at $\mu = 4 m_W$. Again in this case the LSP is dominated by \tilde{B} ; and the second lightest neutralino and the lighter chargino are dominated by \tilde{W} . Therefore we can use the gluino decays of (46-49) with the same branching fractions; the dilepton branching fraction from (48) is 3% for both values of $\tan\beta$. The resulting LSD signals are of course smaller and harder than the previous case. Nonetheless the \cancel{L} and R conserving signals are comfortably above the SM background for $p_{T2} \gtrsim 60$ GeV, while the \cancel{B} signal is comparable to this background. Moreover the \cancel{L} violating signal is larger than the fake LSD background as well. Although the R conserving signal is smaller than this background, it can again be distinguished by the large missing- p_T accompanying this signal (Fig. 6). But it would be difficult to identify the \cancel{B} signal unless the fake LSD background can be further suppressed by an order of magnitude. Fig. 4 presents the corresponding LSD signals for $\mu = -m_W$. Here the gaugino dominated states are the heavier chargino and neutralinos. Consequently the direct decay of gluino into LSP (48) is negligible, while the cascade decays (46) and (47) proceed via χ_2^\pm and χ_4^0 . The signals of Fig. 4 have been obtained with this substitution. One noticeable change is the enhancement of the \cancel{B} signal; the higher mass of χ_2^\pm (χ_4^0) ensures the isolation of the decay lepton even in the presence of (37). It should be added here that the χ_2^\pm (χ_4^0) decay has significant branching fraction into χ_2^0 [5], which has not been taken into account in these curves. However, we have checked its effect on the R conserving LSD signal by replacing χ by χ_2^0 in (46). It has negligible effect on the lepton momentum spectrum and hence the resulting LSD signal, since $m_{\chi_2^0} - m_\chi \ll m_{\chi_2^\pm} - m_{\chi_2^0}$. It may be noted here that this mass difference is also

small compared to $m_{\chi_2^0}$, particularly for $\tan\beta = 2$. Consequently χ should carry a large part of the χ_2^0 momentum in the cascade decay $\chi_2^\pm \rightarrow \chi_2^0 \rightarrow \chi$; and hence the resulting $\cancel{e}e$ LSD signal should not be substantially degraded. However, we have not checked this quantitatively since this signal is any way quite large. Finally, a comparison of the signal curves of Figs. 3 and 4 shows that they are quite similar for the $\cancel{e}e$ as well as the R conserving case. The reason of course is that the masses of the respective $\chi_i^\pm(\tilde{W})$ states are qualitatively similar, as remarked before.

Since the LSD signals for a 1000 GeV gluino are less promising, we have presented them in Fig. 5 for only one set of parameters, i.e. $\mu = 4 m_W$ and $\tan\beta = 2$. It also shows the SM as well as the fake LSD background. The $\cancel{e}e$ signal is larger than the first at large p_T but somewhat below the second. The latter can be reduced below the signal if one can identify lepton charge to within 0.2% accuracy. It should also be possible to separate the two via the accompanying \cancel{p}_T distribution. The size of the R conserving LSD signal is much too low, while the $\cancel{B}B$ signal lies below the scale of this figure. One hopes the size of the R conserving LSD signal to become viable at the SSC energy or the high luminosity option of LHC. Although the signal to background ratio is not expected to improve, the two can be separated via the accompanying \cancel{p}_T distribution (Fig. 6). Of course the canonical missing- p_T signal of a 1000 GeV gluino is expected to be observable even at the low luminosity option of LHC [2].

Let us conclude this section by looking at the fate of the LSD signal if squarks are lighter than gluinos. In this case the superparticle production would be dominated by pair production of squarks, in which singlet and doublet pairs occur with equal probability. Since the singlet squarks do not couple to \tilde{W} , the major decay mode is through \tilde{B} dominated neutralino. Consequently the direct decay into χ is expected to dominate over a large part of the parameter space [5]. The doublet squark decays are very similar to the gluino decays, except that the decay of the chargino pair would always lead to opposite sign dileptons. The largest source of LSD is the decay of one squark via $\chi_i^\pm(\tilde{W})$ (46) and the other via $\chi_i^0(\tilde{W})$ (47). The end result is a degradation of the R conserving LSD signal by a factor of ~ 5 , while the $\cancel{e}e$ signal is enhanced compared to the gluino case.

VI. Summary

We have investigated the isolated LSD signal for gluino production at the LHC energy in the R conserving as well as L and B violating SUSY models. The signals are investigated for representative values of gluino mass, μ and $\tan\beta$ assuming MSSM, against the standard model background as well as the fake LSD background coming from the misidentification of lepton charge. The main results are listed below.

- 1) The signals are fairly insensitive to the choice of $\tan\beta$ as well as the μ parameter. Thus for a given gluino mass one has fairly robust signals, which should hold for at least the bulk of the $\tan\beta$ and μ parameter space.
- 2) For the $\cancel{e}e$ SUSY model, the LSD signal is larger than both the SM and the fake LSD background for gluino masses of 300 and 600 GeV.

Although the R conserving signal is somewhat lower than the latter background, it can be identified via the large missing- p_T accompanying the LSD. The signal is less promising, however, for the \cancel{B} case.

- 3) For a gluino mass of 1000 GeV, the \cancel{L} LSD signal should still be viable. However the size of the R conserving LSD signal is too small in this case, at least for the low luminosity option of LHC.
- 4) In going from pair production of gluinos to that of squarks one expects a substantial degradation of the LSD signal for the R conserving model while it is expected to be enhanced for the \cancel{L} model.

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21. Only a gauge dominated neutralino is not seriously constrained by the LEP data [3] since it does not couple to Z .
22. There are also interference terms between the left handed squark and right handed antisquark exchanges (and vice versa) which vanish in the limit $m_{\chi_i^0}$ ($m_{\chi_i^\pm}$) $\ll m_{\tilde{g}}$. We shall neglect them since the gluino decays mainly into the gauge dominated chargino/neutralinos, for which this mass inequality is reasonably satisfied by eqs. (10) and (11). However we have checked that the gluino branching fractions evaluated by retaining these interference terms [5] agree with those shown in Table I to within 10%.
23. There is one exception to this however, which occurs for $m_{\tilde{\ell}} < m_{\chi_i^\pm(\tilde{W})} < m_\chi + m_W$. In this case the chargino decays dominantly into a lepton via the slepton, so that the resulting LSD signal is comparable in size to the canonical missing- p_T signal. This case has been recently investigated by R.M. Barnett, J.F. Gunion and H.E. Haber, LBL-34106 (1993); and H. Baer, C. Kao and X. Tata, FSU-HEP-930527 (1993).
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27. These LSD background are 8 time larger than the ones shown in [12], since they include both e and μ and both the charge combinations $++$ and $--$.
28. One could effectively include the decay sequence (47) along with (46) by increasing the dilepton branching fraction and hence the normalisation of the long dashed line by 36%, though we have not done this.

Table I(a)

Masses (in GeV) and compositions of the neutralino χ_i^0 and chargino χ_i^\pm states along with the corresponding gluino branching fractions for $m_{\tilde{g}} = 300$ GeV.

μ	$m_{\chi_i^0}$	N_{ij}	$B_{\tilde{g} \rightarrow \chi_i^0}$	$m_{\chi_i^\pm}$	V_{ij}/U_{ij}	$B_{\tilde{g} \rightarrow \chi_i^\pm}$	
$\tan \beta = 2$							
$4m_W$	42.3	-.94,.24,-.18,.10	.20	77.7	-.97,.23	.47	
	81.8	-.29,.92,-.20,.13	.32		-.93,.35		
$-4m_W$	-326.4	-.03,.06,.69,.71	0	349.8	.23,.97	0	
	352.9	-.13,.28,.66,-.68	0		.35,.93		
	53.6	-.98,-.11,.08,-.03	.20	110.6	.99,.06	.47	
	110.7	-.10,.97,.21,-.04	.32		.95,.28		
$-m_W$	328.0	-.05,.11,-.68,-.71	0	340.8	-.06,.99	0	
	-341.9	-.10,.16,-.68,.69	0		.28,-.95		
	54.9	-.90,-.14,.38,.09	.20	91.5	.81,-.57	.30	
	73.1	.28,.42,.69,.50	.11		.25,.96		
m_W	-118.4	-.23,.32,-.60,.68	.04	146.2	.57,.81	.19	
	141.3	-.20,.83,-.52,-.50	.16		.96,-.25		
	-0.1	-.05,.46,-.65,.32		16.6	-.75,.65		
	63.3	.82,.51,-.18,.17			-.55,.83		
$0.1m_W$	-87.5	-.13,.17,.60,.76		171.6	.65,.75		
	175.0	-.23,.70,.41,-.53			.83,.55		
	-6.2	-.04,.04,-.92,-.38		29.8	.67,-.74		
	-53.9	-.34,.42,-.29,.77			-.29,.95		
$0.1m_W$	59.8	-.90,-.37,.09,-.16		149.4	.74,.67		
	150.9	-.22,.82,.24,-.46			.95,.29		
	$\tan \beta = 10$						
	$4m_W$	48.2	-.98,.08,-.15,.04	.17	89.8	-.99,.13	.52
90.6		.12,.95,-.24,.08	.31		-.93,.36		
$-4m_W$	-332.5	-.07,.01,.68,.71	0	346.9	.13,.99	0	
	344.3	-.11,.24,.66,-.69	0		.36,.93		
	50.9	-.99,-.01,.13,.01	.18	97.9	.99,-.07	.50	
	97.8	.02,.96,.24,.05	.31		.93,.34		
$-m_W$	-336.3	-.08,.14,-.68,.70	0	344.7	.07,.99	0	
	338.2	-.09,.21,-.66,-.70	0		.34,-.93		
	37.2	-.62,.24,.69,.26	.15	58.0	.83,-.54	.42	
	65.0	.71,.53,.35,.27	.22		.38,.92		
m_W	-109.0	-.21,.29,-.57,.73	.04	162.4	.54,.83	.10	
	157.5	-.22,.75,-.24,-.56	.08		.92,-.38		
	23.3	-.54,.35,-.71,.26		40.6	-.82,.56		
	63.9	.78,.52,-.25,.21			-.43,.89		
$0.1m_W$	-101.8	-.19,.27,.56,.75		167.6	.56,.82		
	165.3	-.22,.72,.31,-.56			.89,.43		
	-0.1	-.06,.06,-.99,-.01		3.2	.74,-.66		
	57.6	-.33,.42,.03,.84			-.08,.99		
$0.1m_W$	-59.7	-.91,-.36,.04,-.18		152.3	.66,.74		
	149.7	-.22,.82,.07,-.50			.99,.08		

Table I(b)

Masses (in GeV) and compositions of the neutralino χ_i^0 and chargino χ_i^\pm states along with the corresponding gluino branching fractions for $m_{\tilde{g}} = 600$ GeV.

μ	$m_{\chi_i^0}$	N_{ij}	$B_{\tilde{g} \rightarrow \chi_i^0}$	$m_{\chi_i^\pm}$	V_{ij}/U_{ij}	$B_{\tilde{g} \rightarrow \chi_i^\pm}$
$\tan \beta = 2$						
$4m_W$	92.3	-.96,.14,-.18,.12	.18	164.5	-.92,.38	.49
	169.3	.22,.89,-.29,.23	.30		-.88,.47	
	-326.1	-.03,.05,.70,.70	0	362.4	.38,.92	.02
	365.8	-.14,.41,.62,-.64	.01		.47,.88	
$-4m_W$	104.1	-.99,-.05,.10,-.11	.20	206.0	.99,-.05	.49
	205.5	-.03,.96,.24,.05	.30		.94,.33	
	330.6	-.06,.20,-.67,-.71	.01	340.5	.05,.99	.01
	-339.0	-.09,.13,-.69,.70	0		.33,-.94	
$-m_W$	74.0	-.28,.11,.75,.57	.03	95.5	.43,-.89	.08
	-108.4	-.19,.23,-.64,.70	.04		-.04,.99	
	111.1	-.93,-.18,-.10,-.28	.19	225.0	.89,.43	.41
	224.6	-.10,.94,.05,-.30	.25		.99,.04	
m_W	27.4	-.43,.34,-.67,.48		45.6	-.51,.85	
	-85.1	-.09,.10,.64,.74			-.35,.93	
	117.7	-.88,-.32,.22,.25		240.1	.85,.51	
	241.1	-.14,.87,.26,-.37			.93,.35	
$0.1m_W$	-5.8	-.05,.05,-.94,-.31		15.8	.44,-.89	
	-35.5	-.28,.30,.26,.86			-.21,.97	
	112.1	-.99,-.21,.11,.20		230.2	.89,.44	
	230.5	-.12,.92,.16,-.31			.97,.21	
$\tan \beta = 10$						
$4m_W$	97.6	-.98,.06,-.16,.06	.18	178.8	-.95,.29	.48
	180.2	.12,.91,-.31,.19	.31		-.88,.47	
	-331.1	-.06,.09,.69,.71	0	355.5	.29,.95	.01
	354.5	-.12,.37,.62,-.67	.01		.47,.88	
$-4m_W$	100.5	-.98,.01,.14,.03	.19	188.9	.97,-.22	.49
	189.0	.06,.93,.31,.16	.30		.89,.44	
	334.3	-.07,.11,-.69,.70	0	350.3	.22,.97	.01
	346.0	-.11,.33,-.63,-.68	.01		.44,-.89	
$-m_W$	55.9	-.38,.22,.75,.47	.06	75.4	.53,-.84	.14
	-100.8	-.17,.21,-.61,.73	.03		.14,.98	
	114.9	-.89,-.26,-.19,-.29	.18	232.5	.84,.53	.35
	231.3	-.12,.91,-.09,-.37	.23		.98,.14	
m_W	44.8	-.41,.27,-.74,.45		63.2	-.54,.83	
	-95.2	-.15,.18,.61,.74			-.22,.97	
	116.3	-.88,-.28,.21,-.28		236.1	.83,.54	
	235.4	-.13,.89,.16,-.38			.97,.22	
$0.1m_W$	-0.3	-.06,.06,-.99,.06		1.4	-.49,.86	
	-40.2	-.27,.29,.09,.90			-.06,.99	
	111.9	-.95,-.20,.04,-.22		230.7	.86,.49	
	229.9	-.11,.92,.05,-.34			.99,.06	

Table I(c)

Masses (in GeV) and compositions of the neutralino χ_i^0 and chargino χ_i^\pm states along with the corresponding gluino branching fractions for $m_{\tilde{g}} = 1000$ GeV.

μ	$m_{\chi_i^0}$	N_{ij}	$B_{\tilde{g} \rightarrow \chi_i^0}$	$m_{\chi_i^\pm}$	V_{ij}/U_{ij}	$B_{\tilde{g} \rightarrow \chi_i^\pm}$
$\tan \beta = 2$						
$4m_W$	156.5	-.94,.12,-.22,.18	.17	252.8	-.71,.70	.31
	262.6	.28,.69,-.48,.44	.19		-.65,.75	
$-4m_W$	-325.8	-.03,.04,.70,.71	0	406.9	.70,.71	.20
	408.7	-.12,.70,.47,-.51	.12		.75,.65	
	170.9	-.99,-.02,.11,.004	.17	311.7	.72,-.68	.23
$-m_W$	307.1	.06,.58,.61,.52	.12		.55,.83	
	-336.4	-.08,.11,-.69,.70	.01	363.8	.68,.72	.27
	360.5	-.06,.80,-.34,-.47	.19		.83,-.55	
m_W	77.5	-.12,.08,.74,.64	.01	92.3	.27,-.96	
	101.0	-.15,.17,-.66,.71	.02		-.08,.99	
	176.2	-.97,-.08,.01,-.18	.15	349.7	.96,.27	
	349.4	-.05,.97,.06,-.19	.30		.99,.08	
$0.1m_W$	47.7	-.03,.24,-.70,.59		61.1	-.32,.94	
	-83.7	-.01,.01,.66,.73			-.21,.97	
	181.7	-.94,-.14,.17,-.22		356.5	.94,.32	
	356.4	-.06,.95,.15,-.23			.97,.21	
$0.1m_W$	-5.1	.90,-.37,-.10,.17		7.3	.29,-.95	
	22.9	-.42,-.87,-.11,.20			-.14,.98	
	177.9	.003,-.08,.97,.20		352.5	.95,.29	
	352.3	.08,-.28,.16,-.94			.98,.14	
$\tan \beta = 10$						
$4m_W$	162.5	-.96,.06,-.20,.11		269.9	-.73,.67	
	274.1	.21,.68,-.52,.45			-.62,.78	
$-4m_W$	-329.9	-.056,.076,.69,.71		395.8	.67,.73	
	395.4	-.10,.72,.44,-.52			.78,.62	
	166.1	-.98,.03,.18,.07		283.3	.74,-.67	
$-m_W$	283.9	-.06,.92,-.69,.70			.60,.79	
	-332.5	-.07,.09,-.07,.70		386.3	.67,.74	
	384.6	-.09,.73,-.42,-.51			.79,-.60	
m_W	66.5	-.22,.15,.75,.59		80.3	.33,-.94	
	-95.0	-.13,.15,-.64,.73			.05,.99	
	178.6	-.96,-.11,-.08,-.22		352.7	.94,.33	
	352.1	-.05,.97,-.03,-.23			.99,-.05	
$0.1m_W$	59.2	-.26,.18,-.74,.57		72.6	-.34,.93	
	-90.9	-.11,.12,.64,.74			-.11,.99	
	179.9	-.95,-.12,.12,-.23		354.3	.93,.34	
	353.8	-.06,.96,.08,-.24			.99,.11	
$0.1m_W$	.05	-.06,.06,-.98,.15		4.0	-.32,.94	
	-28.2	-.20,.20,.18,.94			-.04,.99	
	177.7	-.97,-.10,.03,-.20		352.6	.94,.32	
	352.1	-.05,.97,.03,.22			.99,.04	

Table II

Multiplicity of lepton (e, μ) per LSP decay for leading \not{R} Yukawa coupling λ_{ijk} , valid for any gauge composition of LSP.

Leading coupling	λ_{123}	$\lambda_{1(2)33}$	$\lambda_{1(2)31(2)}$	$\lambda_{121(2)}$
Multiplicity of $e(\mu)$	1	1/2	3/2	2

Table III

Multiplicity of lepton (e, μ) per LSP decay for leading \not{R} Yukawa coupling $\lambda'_{ijk}(i, j \neq 3)$ and different gauge composition of LSP.

$m_{\tilde{g}}$	300 GeV		600 GeV	
$\tan \beta$	2	10	2	10
$\mu = -4m_W$	.67	.52	.58	.48
$\mu = 4m_W$	.20	.38	.30	.41
$\mu = -m_W$	.72	.13	.13	.13

Figure Captions

- Fig. 1. The LSD signals for 300 GeV gluino production at LHC at $\mu = 4 m_W$ and $\tan\beta = 2, 10$ shown against the p_T of the 2nd (softer) lepton. The dot-dashed and short dashed lines represent the signals in the R conserving and B violating SUSY models, while the solid, long dashed and dotted lines are three components of the signal in the L violating model. The SM background from $t\bar{t}$ via sequential decay and from $b\bar{b}$ via mixing are shown by the histogram and the crosses respectively.
- Fig. 2. The LSD signals for 300 GeV gluino production at $\mu = -m_W$ shown along with the SM background. The conventions are the same as in Fig. 1.
- Fig. 3. The LSD signal for 600 GeV gluino production at $\mu = 4 m_W$ shown along with the SM background. The conventions are the same as in Fig. 1.
- Fig. 4. The LSD signal for 600 GeV gluino production at $\mu = -m_W$ shown along with the SM background, with the same convention as in Fig. 1. The circles denote the fake LSD background from misidentification of one of the lepton charges.
- Fig. 5. The LSD signal for 1000 GeV gluino production at $\mu = 4 m_W$ and $\tan\beta = 2$ shown along with the SM background, with the same convention as in Fig. 1. The circles denote the fake LSD background.
- Fig. 6. The missing- p_T (\cancel{p}_T) distribution of the LSD signals for the R conserving model are shown for gluino masses of 300, 600 and 1000 GeV with $p_T^\ell > 20$ GeV (solid lines) along with the fake LSD background (dashed line). The \cancel{p}_T distribution of the SM background from $t\bar{t}$ is marginally softer than the latter, while that from $b\bar{b}$ is extremely soft.

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