R-parity violating SUSY model

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Abstract. This is a phenomenological review of R parity violating SUSY models, with particular emphasis on explicit R parity violation.

1. Introduction

The Minimal Supersymmetric Standard Model (MSSM) contains the particles of the Standard Model (SM) with two Higgs doublets as shown in the first row below and their supersymmetric partners as shown in the second [1]. They can be combined to form the corresponding super multiplets as shown in the third row.

$$\begin{pmatrix} \ell_i, \bar{e}_i, q_i, \bar{u}_i, \bar{d}_i, h_1, h_2, g, W, Z, \gamma \\ \tilde{\ell}_i, \tilde{\bar{e}}_i, \tilde{q}_i, \tilde{\bar{u}}_i, \tilde{\bar{d}}_i, \tilde{h}_1, \tilde{h}_2, \tilde{g}, \tilde{W}, \tilde{Z}, \tilde{\gamma} \end{pmatrix},$$

$$L_i, \bar{E}_i, Q_i, \bar{U}_i, \bar{D}_i, H_1, H_2, G, \cdots.$$

Thus $L_i(Q_i)$ and $\bar{E}_i(\bar{U}_i, \bar{D}_i)$ are the left-handed lepton (quark) doublet and antilepton (antiquark) singlet chiral superfields, where i refers to the generation index. Similarly $H_{1,2}$ are the chiral superfields representing the two Higgs doublets and G the vector superfield representing the gluon. The superpotential contains the Higgs Yukawa coupling terms responsible for the lepton and quark masses

$$W_1 = h_{ij} L_i H_2 \bar{E}_j + h'_{ij} Q_i H_2 \bar{D}_j + h''_{ij} Q_i H_1 \bar{U}_j. \tag{1}$$

However, these are not the only Yukawa couplings allowed by the $SU(3) \times SU(2) \times U(1)$ gauge invariance and supersymmetry. They allow three additional Yukawa coupling terms

$$W_2 = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{D}_i \bar{D}_j \bar{U}_k. \tag{2}$$

They can be rewritten in terms of the scalar and fermionic components of the chiral superfield, i.e.

$$W_2 = \lambda_{ijk} \ell_i \tilde{\ell}_j \bar{e}_k + \lambda'_{ijk} \ell_i \tilde{q}_j \bar{d}_k + \lambda''_{ijk} \bar{d}_i \tilde{\bar{d}}_j \bar{u}_k, \tag{3}$$

where the supertwiddle denotes the scalar partner of lepton and quark (i.e. the slepton and squark), and there are analogous terms from the permutation of the supertwiddle. Evidently, the 1st and 2nd terms of eq. (3) violate lepton number (L) and the 3rd term violates baryon number (B) conservation. Note that there were no such couplings in the Standard Model due to its particle content and Lorentz

invariance; i.e. absence of triple fermion coupling is simply ensured by angular momentum conservation. In the presence of scalar quarks and leptons, however, there is no basic principle of physics which would prohibit these lepton and baryon number violating couplings. Evidently the source of lepton and baryon number violation in the above couplings is the single emission (absorption) of a superparticle as denoted by the supertwiddle. Thus it is jointly referred to as R-parity violation, where

$$R = (-1)^{3B+L+2S} \tag{4}$$

is so defined that it is $+1$ for all the Standard Model particles and -1 for their superpartners, differing by 1/2 units of spin(S).

2. Properties of the $\not{R}$ Yukawa couplings

Let us consider some general properties of the above $\not{R}$ Yukawa couplings.

(i) The $SU(2)$ and $SU(3)$ gauge invariance of the superpotential require that the $\lambda_{ijk} L_i L_j \bar{E}_k$ and $\lambda''_{ijk} \bar{D}_i \bar{D}_j \bar{U}_k$ terms are antisymmetric combinations of the first two superfields in $SU(2)$ and $SU(3)$ respectively. Since the superfields satisfy Bose statistics, this implies that the couplings are antisymmetric in the first two indices

$$\lambda_{ijk} = -\lambda_{jik}, \quad \lambda''_{ijk} = -\lambda''_{jik}. \tag{5}$$

Thus there are 9 independent λ and λ'' coupling. Together with the 27 λ' couplings one has a total of 45 independent Yukawa couplings.

(ii) In analogy with the observed hierarchy of the Higgs Yukawa couplings, as reflected by the quark and lepton masses, it is reasonable to assume a hierachical structure for these additional Yukawa couplings as well [2-4]. Thus one expects one of these 45 independent Yukawa couplings to dominate over the others; but one does not know a priori which one.

(iii) Proton stability requires the λ' or λ'' coupling to be vanishingly small,

$$\lambda' \text{ or } \lambda'' \simeq 0 \text{ (i.e. } \ll 10^{-10}). \tag{6}$$

For these couplings would lead to proton decay via squark exchange as shown in Fig. 1. Since the SUSY solution to the gauge hierarchy problem requires

$$m_{\tilde{q}} \sim m_W \sim 100 \text{ GeV}, \tag{7}$$

this would imply a proton life time typical of the weak decay scale, i.e. $\tau_P \sim 10^{-8}$ sec! The experimental limit on the proton life time, $\tau_P > 10^{32}$ sec, implies the above constraint on λ' and/or λ''.

3. R conserving SUSY model and the missing-p_T signature

The traditional prescription for overcoming the proton decay problem has been to banish all the $\not{R}$ Yukawa couplings of eq. 2. This results in the standard R
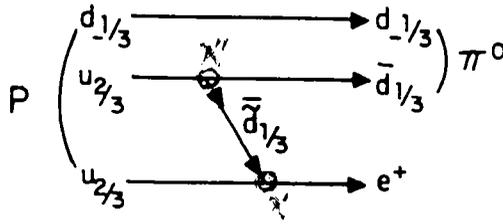
Figure 1. Proton decay via squark exchange in $\not{R}$ SUSY model.

conserving SUSY model. In particular the R conservation implies that (a) both baryon and lepton numbers are conserved, (b) the superparticles are produced in pair and (c) all of them decay into the lightest superparticle (LSP) which has to be stable. The stable LSP cannot carry any colour or electric charge for cosmological reasons. Thus the LSP can be either the sneutrino $\tilde{\nu}$ or the photino $\tilde{\gamma}$ – the latter being the case in most of the SUSY models in the market. Finally the photino interacts with ordinary matter as weakly as the neutrino, as shown in Fig. 2 (the same is true for sneutrino).
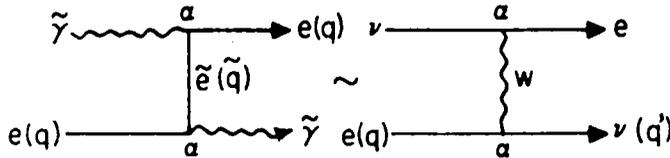

Figure 2. Comparison of photino and neutrino interaction rates with ordinary matter, i.e. electrons and quarks.

Thus it would escape the detector without a trace like the neutrino. The resulting imbalance in visible momentum provides the canonical missing transverse momentum signature for superparticle search (momentum balancing in the longitudinal direction is not possible in a collider due to loss of particles along the beam pipe).

The missing-p_T signature has been extensively used in the superparticle search at the $\bar{p}p$ colliders as well as LEP. Ofcourse the missing-p_T signature is not very crucial for the LEP results [5], most of which follow simply from the measurement of Z total width, i.e.

$$\Gamma_Z^{\text{Expt.}} = \Gamma_Z^{SM} \Rightarrow m_{\tilde{\ell},\tilde{q},\tilde{\nu},\tilde{h}} > \frac{1}{2}m_Z. \tag{8}$$

The only superparticles escaping this mass limit are the neutral gauginos $(\tilde{\gamma}, \tilde{Z}, \tilde{g})$, which do not couple to Z. On the other hand practically all the superparticle searches carried out at the $\bar{p}p$ colliders so far rely heavily on the missing-p_T signature [6]. One expects strong production of squark and gluino pairs followed by their

prompt decay into the LSP ($\tilde{\gamma}$), as shown in Fig. 3. The escaping photinos provide the missing-p_T signature for squark/gluino production at the $\bar{p}p$ collider.
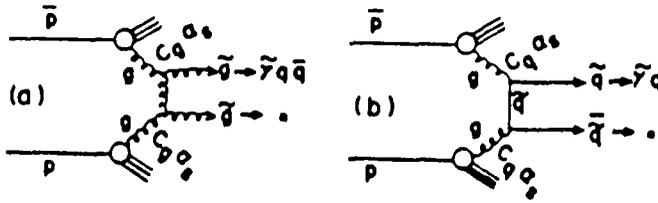

Figure 3. Strong production of gluino and squark pair, followed by their decay into the LSP ($\tilde{\gamma}$).

A recent analysis of the missing-p_T data from the Tevatron collider has given a squark/gluino mass limit of [7]

$$m_{\tilde{q},\tilde{g}} \gtrsim 140 \text{ GeV}, \tag{9}$$

which represents the strongest experimental limit on any superparticle mass. But evidently it relies heavily on the assumption of R-parity conservation.

4. R violating SUSY model and the multilepton signature

The superparticle searches have been largely restricted so far to the missing-p_T channel due to the underlying assumption of R conservation. There is a growing realisation however that one should remove these blinkers and look for possible superparticle signals outside the missing-p_T channel, since there is no compelling reason for R conservation in the first place [4-6]. While R conservation implies proton stability the converse is not true – i.e. proton stability implies baryon or lepton number conservation, but not necessarily both. In particular it allows sizable values for either the $\not L$ Yukawa couplings $\lambda(\lambda')$ or the $\not B$ couplings λ''. Consequently one has two types of $\not R$ SUSY models consistent with proton stability, i.e.

$$\text{(a) } \lambda \text{ or } \lambda' \neq 0 \ (\not L \text{ Model}), \tag{10a}$$

$$\text{(b) } \lambda'' \neq 0 \ (\not B \text{ Model}). \tag{10b}$$

In either case the LSP is unstable, i.e. no missing-p_T signature. Assuming the LSP to be the lightest neutralino ($\tilde{\Lambda}$), one expects the decays (Fig. 4)

$$\tilde{\Lambda} \xrightarrow{\tilde{\ell}} \ell_i \ell_j \bar{e}_k, \quad \tilde{\Lambda} \xrightarrow{\tilde{q}} \ell_i q_j \bar{d}_k, \tag{11a}$$

or

$$\tilde{\Lambda} \xrightarrow{\tilde{q}} d_i d_j u_k, \tag{11b}$$

depending on whether the dominant $\not R$ Yukawa coupling is a $\lambda_{ijk}, \lambda'_{ijk}$ or λ''_{ijk} coupling.

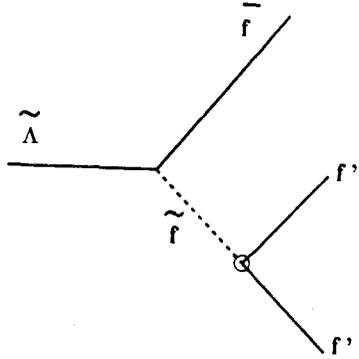**Figure 4.** $\not{R}$ decay of the LSP, assumed to be the lightest neutralino $\tilde\Lambda$, where f denotes either quark or lepton.

To be more precise, the LSP decays within the detector ($\sim$ 1 meter) if the dominant $\not{R}$ coupling is

$$\gtrsim 10^{-5}(m_{\tilde{\ell},\tilde{q}}/100 \text{ GeV})^2(m_{\tilde\Lambda}/30 \text{ GeV})^{-5/2}, \tag{12}$$

below which it would decay outside simulating the missing-p_T signature [4]. While $\not{B}$ decay of eq. 11b would correspond to a multijet final state which is indistinguishable from the QCD background, the $\not{L}$ decays of eq. 11a would result in a distinctive multilepton final state from the decay of the $\tilde\Lambda$ pair. More over $\tilde\Lambda$ being a Majorana particle, it decays into the final states of eq. 11 as well as their charge conjugate states with equal probability. This would lead to a distinctive final state with like sign dileptons. Thus the multilepton channel provides a superparticle signature in the $\not{L}$ SUSY model which is as viable as the missing-p_T signature for the R conserving case. Indeed we shall see below that the Tevatron dilepton data provides a squark/gluino mass limit for the $\not{L}$ SUSY model, which is comparable to eq. 9 above. Before discussing this result, however, it will be useful to briefly review the theoretical and phenomenological status of R parity breaking SUSY models.

5. Theoretical ideas on R (non) conservation

There is no theoretical basis for any of the global symmetries, B, L or R, within the MSSM. Thus the origin of proton stability lies outside MSSM. One hopes this to be ensured by a discrete symmetry arising from the underlying string theory. In this context it has been recently shown by Ibanez and Ross [8] that there are only two such discrete symmetries which are discrete anomaly free and consistent with the particle content of MSSM. They are the Z_2 and Z_3 symmetries corresponding to R and B conservation respectively. More over the latter has been shown to have the advantage of eliminating the dimension 5 contribution to proton decay along with the dimension 4 contribution of Fig. 1. Thus from a theoretical standpoint the $\not{L}$ SUSY model seems to be no less attractive than the conventional R conserving model.

6. Cosmological constraint on $\not{R}$ couplings

GUT scale baryogenesis is expected to be washed away by a $\not{B}$ SUSY interaction occuring at a lower energy scale of ~ 100 GeV. Consequently the observed baryon asymmetry of the universe puts a severe constraint [9] on the $\not{B}$ Yukawa coupling of eq. 3, i.e.

$$\lambda'' < 10^{-7}. \tag{13}$$

This means that if at all the $\not{B}$ LSP decay occurs, it will be outside the detector (eq. 12) and hence indistinguishable from the missing-p_T signature. This is evidently a welcome result in the absence of a distinctive signature for the $\not{B}$ LSP decay. It has been further argued in [9] that the L violating SUSY interaction can combine with the $(B+L)$ violating nonperturbative electroweak interaction to wash out any previously generated baryon asymmetry. It should be noted however that the latter interaction conserves not only $B - L$ but also $B/3 - L_i$ for each lepton generation [10]. Consequently the preservation of the baryon asymmetry is ensured by the effective conservation of any one lepton generation. This implies the upperbound of eq. 13 for the smallest $\not{L}$ Yukawa couplings $\lambda_{ijk}(\lambda'_{ijk})$, while the $\not{L}$ LSP decay within the detector requires the lower bound of eq. 12 for the largest one. With the expected hierarchy among these Yukawa couplings it is evidently not difficult to satisfy both the requirements. Note that the quark generations are not conserved unlike the leptons, so that the upper bound of eq. 13 applies to all the indices of λ''_{ijk}. In summary, the observed baryon asymmetry of the Universe seems to imply severe restrictions for the $\not{B}$ LSP decay but not for the corresponding $\not{L}$ decay [10].

7. Laboratory constraints on $\not{R}$ couplings

Several phenomenological constraints on the $\not{B}$ and $\not{L}$ Yukawa couplings of eq. 3 have been obtained by considering virtual superparticle exchange contributions to various processes, measured in the laboratory. For the $\not{B}$ couplings there is only one serious constraint following from the absence of $n - \bar{n}$ oscillation (Fig. 5a) and the corresponding heavy nuclei decay [11]. One gets

$$\lambda''_{211} < 10^{-8}(m_{\tilde{q}}/100 \text{ GeV})^{5/2}. \tag{14}$$

For the $\not{L}$ Yukawa couplings, which are of greater interest to us, the constraints are more numerous but much weaker than above. The strongest constraints follow form the radiative contribution to the ν_e mass of Fig. 5b [2]

$$\lambda_{133}, \lambda'_{133} < 10^{-2}(m_{\tilde{l},\tilde{q}}/100 \text{ GeV})^{1/2} \tag{15}$$

and from the absence of neutrinoless double beta decay (Fig. 5c) [12]

$$\lambda'_{111} < 10^{-2}(m_{\tilde{l}}/100 \text{ GeV})^{5/2}. \tag{16}$$

There are weaker bounds from the observed charged current universality in muon and neutron beta decays (Figs. 5d and e) [13]

$$\lambda_{12k}, \lambda'_{11k} < 0.04, 0.03(m_{\tilde{l},\tilde{q}}/100 \text{ GeV}). \tag{17}$$

Under the assumption of hierarchy one of the two couplings dominates over the other, so that each one can be constrained from the ratio of the two decay rates. There are constraints on several other λ and λ' couplings; but they are still weaker that these ones [4].

Clearly none of the above bounds on $\not{L}$ Yukawa couplings is strong enough to inhibit the $\not{L}$ LSP decay within the detector (eq. 12). Thus the multilepton channels are relevant for superparticle search for a large part of the allowed coupling parameter space.

8. Squark and gluino search in $\not{R}$ SUSY model with the Tevatron dilepton data

We shall make two simplifying assumptions, leading to conservative mass limits for the superparticles [14].

1. The largest $\not{L}$ Yukawa coupling, responsible for the LSP decay, is assumed to be significantly smaller than 1. Thus we assume the superparticles to be produced in pair and to decay into the leptonic channel only via the LSP (Fig. 3). It is clear that contributions from single superparticle production and direct leptonic decay of squark via eq. 3 will only enhance the multilepton signal and hence lead to a stronger mass limit.

2. We shall explore gluino production by assuming it to be significantly lighter than the squark and vice versa. It is well known that relaxing these constraints increases the signal and the resulting mass limit [6,7]. Thus the squark (gluino) contribution to the dilepton cross-section comes from the corresponding diagram of Fig. 3, followed by the LSP decays into the dominant $\not{L}$ channel of eq. 11a. Consequently the squark (gluino) signal is independent of the gluino (squark) mass. It is also independent of the Yukawa coupling parameter since the LSP decays wit nearly 100% branching ratio in to the dominant $\not{L}$ channel ($\ell_i\ell_j\bar{e}_k$ or $\ell_i q_j \bar{d}_k$) with specific generation indices. Only one has to take care of the branching fractions into the 2 charge combinations of this channel, corresponding to ℓ_i being a neutrino or a charged lepton. They are equal for $\ell_i\ell_j\bar{e}_k$; but depend on the nature of the LSP for $\ell_i q_j \bar{d}_k$ [15]. One can see this by substituting the corresponding Yukawa coupling terms

$$
\lambda' \left[\tilde{e}_L \bar{d} u_L + \tilde{u}_L \bar{d} e_L + \tilde{\bar{d}}_L \bar{e}^c u_L \right.
$$
$$
\left. - \tilde{\nu}_L \bar{d} d_L - \tilde{d}_L \bar{d} \nu_L - \tilde{\bar{d}}_L \bar{d}^c \nu_L \right]
\tag{18}
$$

into the LSP decay of Fig. 4. In particular for photino decay one can see that the relative branching fractions of the neutrino and charged lepton channels are about 1:7. For simplicity one generally assumes the relative branching fractions to be equal [14;16], so that the branching fraction is 1/4 for the dilepton channel and 1/8 for the like sign dilepton. Note that the corresponding branching fractions for
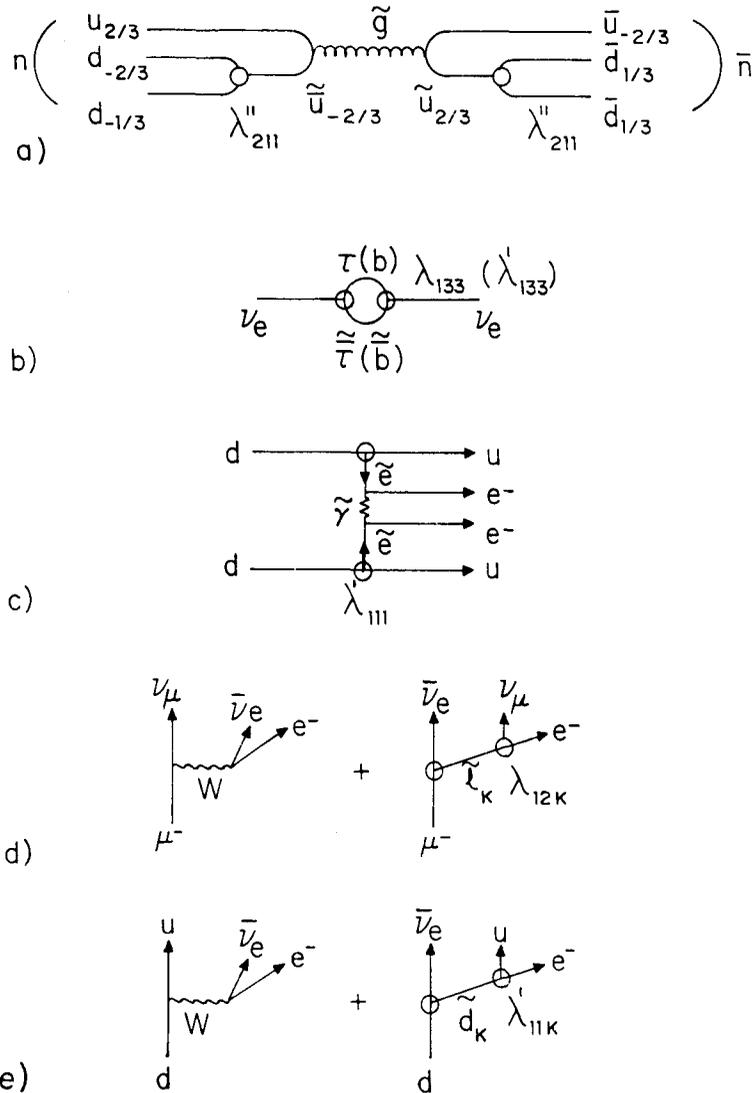
Figure 5. The R̸ SUSY model contribution to (a) neutron-antineutron oscillation, (b) ν_e mass, (c) neutrinoless double beta decay, (d) muon beta decay and (e) neutron beta decay.

the above case would be 3/4 and 3/8, resulting in a larger dilepton cross-section. We shall comment on this latter.

Since the lepton momentum spectrum from the LSP decay is sensitive to the LSP mass, a discussion of this assumption is in order. While exploring for gluino, we shall be interested in the mass range $m_{\tilde{g}} < 150$ GeV. With the MSSM mass relation [1,17]

$$m_{\tilde{\gamma}} = \frac{8}{3} \frac{\alpha(M_Z)}{\alpha_S(M_Z)} m_{\tilde{g}} \simeq \frac{1}{5} m_{\tilde{g}}, \tag{19}$$

this corresponds to a photino mass range $m_{\tilde{\gamma}} < 30$ GeV. As we saw in eq. 8 above, LEP constraints essentially all other superparticles to be heavier than 40 GeV [5]. Thus it is reasonable to assume the LSP to be photino in this case with

$$m_{\tilde{\lambda}} = m_{\tilde{g}}/5. \tag{20a}$$

Indeed, this agrees with the explicit calculation of LSP mass and composition incorporating the constraints of LEP and $m_{\tilde{g}} < 150$ GeV [17]. On the other hand, while exploring for squark over this mass range we shall assume

$$m_{\tilde{\lambda}} = 30 \text{ GeV}. \tag{20b}$$

This corresponds to a conservative lower limit consistent with our assumption of $m_{\tilde{g}}$ being significantly larger than $m_{\tilde{q}}$ for this case. However, this is adequate for our purpose, since a higher LSP mass would correspond to a harder decay lepton momentum and hence a larger signal.

The Tevatron dilepton (ee or $\mu\mu$) data [18] can probe all those $\not{L}$ SUSY models where the dominant Yukawa coupling has a lepton index 1 or 2. Let us start by considering

$$\lambda'_{1jk,2jk} \text{ (or equivalently } \lambda_{133,233}),$$

which leads to only one pair of electrons or muons and hence to the most conservative dilepton signal. Table 1 summarises the effect of various experimental cuts on the signal cross-section [14]. The effect of the lepton p_T cut, shown in the 1st column, is quite strong because of the sequencial decay. It is ofcourse relatively stronger for the gluino due to its 3-body decay. The 2nd and 3rd columns refer to lepton isolation and rapidity cuts. The 4th and 5th columns refer to cuts on the dilepton invariant mass and azimuthal angle to elliminate the Z decay background. The net detection efficiency is $\sim 1\%$ for gluino and $\sim 3\%$ for squark signal. Note that the last mentioned cut could be dispensed with for the like sign dilepton channel. Ofcourse the resulting gain ~ 2 in the acceptance factor will be compensated by a factor of 2 reduction in the cross-section.

The resulting dimuon and dielectron cross-sections are shown against the gluino (squark) mass in Fig. 6 [14]. The right-hand scale shows the expected number of events corresponding to the integrated luminosity of 4.4 pb^{-1} of the CDF data [18]. The data contains only one dimuon and two dilepton events in the above kinematic region. The corresponding 95% CL limits are also shown in the figure. The resulting lower bound on squark and gluino masses are

$$m_{\tilde{q},\tilde{g}} > 100 \text{ GeV} \tag{21}$$

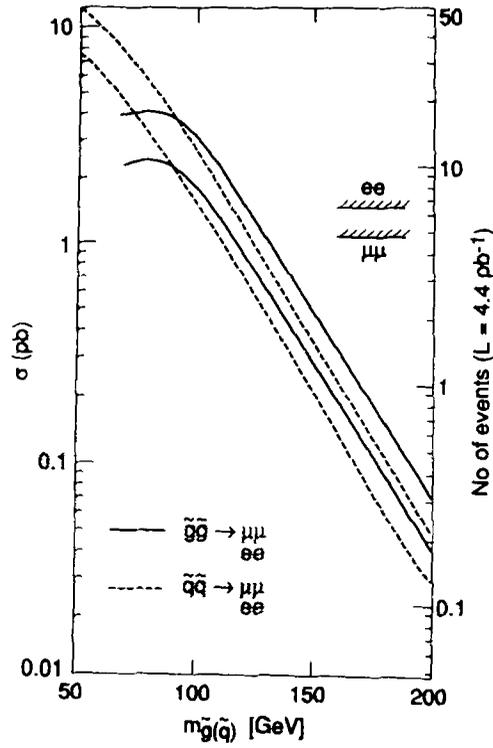for the dielectron and somewhat larger for the dimuon case.

Figure 6. The visibile dimuon and dielectron cross-sections, following the kinematic cuts of Table 1, are shown as functions of gluino (squark) mass. The right hand scale shows the expected number of events for the CDF luminosity of 4.4 pb^{-1}. The 95% CL limits shown correspond to 1 dimuon and 2 dielectron events remaining in the CDF data after these kinematic cuts.

Table 1. Acceptance factors for different kinematic cuts on dilepton events. (The net efficiency should be multiplied by a factor of 0.5 (0.7) for $ee(\mu\mu)$ events to take account of the geometrical acceptance and $e(\mu)$ selection efficiency.)

$m_{\tilde{g}(\tilde{q})}$ in GeV		Trans. mom. $p_\ell^T > 15\ GeV$	Isolation $p_{ac}^T < 5\ GeV$	Rapidity $|y_\ell| < 1$	Inv. mass $M_{\ell\ell} \neq$ 75−105 GeV	Azimuth. $\phi_{\ell\ell} =$ 20-120°	Net efficiency
$m_{\tilde{g}} =$	75	0.25	0.58	0.75	0.88	0.34	0.0035
	100	0.36	0.66	0.78	0.85	0.44	0.013
	150	0.53	0.72	0.80	0.82	0.48	0.037
$m_{\tilde{q}} =$	75	0.45	0.79	0.74	0.83	0.33	0.020
	100	0.53	0.73	0.75	0.80	0.43	0.030
	150	0.64	0.60	0.77	0.78	0.52	0.035

As mentioned above, the dilepton cross-section of Fig. 6 can be regarded as the like sign dilepton cross-section without the azimuthal cut. It seems one can be reasonably certain that there are no like sign dilepton events in the above data over the entire range of the azimuthal angle. The resulting 95% CL limit of 3 events, corresponding to 0 candidate events, is at least a factor of 2 lower than the predicted rate for $m_{\tilde{q},\tilde{g}} = 100$ GeV. This factor can take care of the uncertainty in the predicted rate, arising largely from the QCD parametrisation.

Finally, let us consider the cases where the dominant $\not{L}$ coupling is one of the remaining λs. Evidently the higher lepton multiplicity will lead to a higher visible dilepton cross-section. Indeed, in view of the small detection efficiency for each lepton one expects the dilepton cross-section to be roughly propertional to the multiplicity of the appropriate lepton in each LSP decay. More over, e and μ detection efficiencies being similar, one can treat them jointly by combining the $ee, \mu\mu$ and $e\mu$ channels (none of which has any like sign dilepton events). In this way one can relate the size of the visible (like-sign) dilepton cross-section for each case to that of Fig. 6 and derieve the corresponding mass limits. The results are summarised in Table 2. The Table also shows the above mentioned enhancement of the dilepton branching fraction from 1/4 to 3/4, corresponding to the decay of the photino pair via $\lambda'_{1jk,2jk}$, and the resulting increase of the mass limit from 100 to 130 GeV.

One sees from Table 2 that for most of the choices of the dominant $\not{L}$ Yukawa coupling one gets a squark/gluino mass bound comparable to that of the R-conserving SUSY model (eq. 9). The least of these bounds, 100 GeV, holds for all but two choices of the dominant $\not{L}$ coupling. While this is effective for all values of this coupling larger than eq. 12, the R-conserving bound coming from the missing-p_T channel is valid for the complimentary region of this coupling parameter. Combining the two, gives a lower squark/gluino mass bound of 100 GeV, which is valid for all values of the $\not{L}$ Yukawa couplings[1] with these two exceptions. The two exceptions correspond to the dominant $\not{L}$ coupling being λ'_{3jk} or λ'_{i3k}. The former corresponds

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[1]An important by product is a corresponding photino mass bound of $m_{\tilde{\gamma}} > 20$ GeV.

Table 2: Relative size of the like-sign or total dilepton cross-section for different choices of the leading Yukawa coupling and the corresponding limit on gluino/squark masses.

Leading Yukawa coupling	Relative size of $\sigma_{(\mu\mu+ee+e\mu)}$	Limit of $m_{\tilde{q},\tilde{g}}$
$\lambda'_{3jk,i3k}$	0	–
$\lambda'_{ijk}(i,j \neq 3)$	1	100 GeV
"	3	130 GeV
$\lambda_{133,233}$	1	100 GeV
123	4	140 GeV
311,322,312,321	9	160 GeV
121,122	16	175 GeV

to the $\tau q\bar{q}$ decay of LSP and the latter to the $\nu b\bar{q}$ decay, since the corresponding charged lepton decay is inhibited by the large top quark mass. It would be hard to probe these channels in a hadron collider since the τ identification is dificult in a multijet environment and the missing-p_T resulting from the ν is degraded by the long decay chain. These channels may be probed at LEP II upto a squark/gluino mass of 100 GeV [19].

In summary, for almost all choices of the dominant $\not{L}$ Yukawa coupling one gets a squark/gluino mass bound from the CDF dilepton data, which is comparable to that obtained from their missing-p_T data. Combining the two gives a squark/gluino mass bound of $\sim$ 100 GeV, which is valid for all values of the corresponding $\not{L}$ Yukawa coupling parameters.

9. Spontaneously R violating SUSY model

Finally, let me comment on the alternative type of $\not{R}$ SUSY model, where the R-parity is spontaneously broken via a vacum expectation value of the sneutrino [20]. This is not phenomenologically viable for the MSSM.[2] However, there are phenomenologically viable models of spontaneous R-parity breaking involving nonminimal SUSY models with singlet $\nu(\tilde{\nu})$ [21]. In these models, the LSP can decay either into the leptonic channels considered above or into a neutrino and Majoron, which is indistinguishable from the missing-p_T channel. Thus the above squark/gluino mass bound, obtained by combining these two channels, should be valid for these models as well.

Acknowledgement

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[2]In the MSSM the $\tilde{\nu}$ vacum expectation value generates $SU(2)$ doublet Majorons, which are ruled out by the LEP measurement of Z invisible width as well as by astrophysical constraints.

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Discussion

U. Sarkar : Baryon number violating couplings are not studied since they can wash away the baryon asymmetry of the universe, which is true if there are no additional sources of CP violation other than the KM matrix. If one can have a scenario in which new sources of CP violation make the TeV range baryon number violating couplings consistent, can one study the consequences?

D.P. Roy : Looking for LSP decay into a baryonic channel would be impossible in a hadron collider. As far as I know the chances are pretty bleak even in an electron-positron machine.

R. Raja : Perhaps it is worthwhile pointing out that the photino may be so weakly unstable that its decay vertex may be defectable at the Tevatron.