Cross sections for lepton- and baryon-number-violating processes from supersymmetry at $p\bar{p}$ colliders

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In the standard minimal low-energy supersymmetric model, superpartners are produced only in pairs and the lightest superpartner is stable. At hadron colliders missing transverse energy is the most important signature for this model. There are two other minimal supersymmetric models: one has lepton-number violation, the other baryon-number violation. In both models superpartners can be singly produced and the lightest superpartner is unstable. At hadron colliders missing transverse energy is a poor signature for these models. However, there are several important signatures. The most spectacular signatures have two charged leptons without jets. There are also events with two or more isolated charged leptons and jets. Superpartner masses may be reconstructed from combinations of lepton-lepton or lepton-jet invariant masses and from jet spectroscopy. Cross sections are presented for the most important single and pair superparticle production mechanisms in $p\bar{p}$ collisions. Present limits from CERN collider data are given and a variety of signatures, events, and backgrounds at $\sqrt{s} = 2$ TeV are discussed. For example, Drell-Yan fusion of a single superpartner gives a bump in the cross section for e^+e^- pairs or jet pairs with invariant mass at the superpartner mass. Squark pair production could yield events with two jets and two isolated charged leptons. If the lightest superpartner is long lived, it can give rise to secondary vertices or to signatures in stable-particle searches. A run of 10 pb^{-1} at $\sqrt{s} = 2$ TeV will enable a large region of the parameter space to be explored.

I. INTRODUCTION

Supersymmetry is currently an elegant mathematical theory desperately in need of experimental evidence. The majority of accelerator searches for supersymmetry assume that the lightest superpartner (LSP) is stable, and has neither strong nor electromagnetic interactions.¹ Therefore, the trademark for supersymmetry has been missing energy. Although such an LSP can arise in some minimal supersymmetric models, such models are constrained to have the fewest Yukawa-type interactions consistent with the known fermion masses. (We call a supersymmetric model minimal if it has the fewest number of particles possible. These include particles of the standard model, an extra Higgs doublet, and all the superpartners.) This constraint is nontrivial and it excludes those gauge-invariant interactions which allow the LSP to decay. More general models have lepton or baryon numbers violating Yukawa interactions and predict completely different accelerator signatures. For example,

they predict single superparticle production and leptonic signatures in hadron colliders.

In a previous paper,² Dimopoulos and Hall discussed various possible models, experimental tests, and limits on the strength of these Yukawa couplings. The reader is urged to review Ref. 2, especially for a discussion of the three minimal supersymmetry models. In this paper we present the cross sections for production of supersymmetric particles in $p\bar{p}$ colliders, arising in supersymmetric theories with lepton- or baryon-number-violating Yukawa interactions at the weak scale.

The standard minimal low-energy supergravity theory results when R parity or matter parity is imposed on the couplings. This constraint removes renormalizable baryon- and lepton-number-violating interactions. If baryon number is imposed, the couplings

$$q\bar{d}l, l\bar{l}\bar{e}, \Delta L \neq 0, \quad (1.1)$$

are allowed, giving a model which violates lepton number—the “ $\Delta L \neq 0$ ” model. If lepton number is im-

posed, the coupling

$$\bar{u}\bar{d}\bar{d}, \Delta B \neq 0, \quad (1.2)$$

is allowed, giving a model which violates baryon number—the “ $\Delta B \neq 0$ ” model.² Some vertices resulting from Eqs. (1.1) and (1.2) are drawn in Fig. 1. The flavor structure of the new interactions can be very rich. For our purposes, we will generally assume that the operator which gives the largest signal and does not violate any other laboratory results dominates. A good discussion of such laboratory bounds can be found in Refs. 2 and 3. While the couplings for all the $ll\bar{e}$ operators are constrained to be less than 0.1, the limits are not so stringent for most of the $q\bar{q}l$ operators. In fact some of the couplings can be of order 0.25 and larger. The limits depend of course on the flavor structure of the operators, and in general they are more relaxed when higher generations are involved.³ There are no published limits for the baryon-violating models, except for the lowest generation operator whose coupling has to be less than 10^{-6} (Ref. 2). We shall present all of our results assuming the relevant coupling is one, and then discuss how our results would differ for smaller values of λ . In the last section we shall discuss possible exotic signatures if λ is much smaller than 1.

We shall organize our work by the possible production channels: we will first discuss single supersymmetric-particle production and then mention pair production of gluinos, squarks, and sleptons. In each case we shall present the dominant interactions, the production cross section, the experimental signature, and the background. The general framework of our analysis is the same as Refs. 4 and 5; we integrate over the elementary tree-level production cross sections and the parton distribution functions of Ref. 4. For the distribution functions we use

FIG. 1. Yukawa interactions resulting from operators from Eqs. (1.1) and (1.2). Solid lines are fermions and dashed lines are scalars. Tilde denotes a superpartner. There are two more interactions for each operator obtained by permuting the position of each superpartner. Particles could be of any flavor.

set 2 of Ref. 4 where the QCD parameter is set equal to 0.29 GeV. The reader who is not interested in the formulas for the cross sections should only review the figures and then go directly to Sec. IV where we discuss some limits from existing data, prospects for detecting superpartners in the near future, and secondary vertices from LSP decay.

It is worth mentioning that there are a host of other experimental predictions of such models. There have already been studies of rare processes: K, π, ν decays, ν masses and oscillations,^{6–11} neutron oscillation, and heavy-nucleus decays.^{12,13} Other possibilities include signatures in e^+e^- machines, rare Z decays, or B decays. Dimopoulos and Hall have also proposed that such baryon-number-violating models are responsible for a low-energy (10-MeV) era of baryogenesis, which could account for the baryon asymmetry of the Universe.¹⁴

II. SINGLE SUPERPARTICLE PRODUCTION

An immediate consequence of including R -parity-violating processes is to lower the threshold for discovery of supersymmetry by allowing single production of superparticles. Sneutrinos, sleptons, and squarks are produced at resonance through the new interactions, while photino, gluino, and other gaugino single production require the new vertices and other appropriate gauge interactions. We shall start our discussion by introducing the necessary formalism of the parton model while considering the particular example of resonant production of sneutrinos. Once the reader is familiar with this formalism, we shall calculate the production rates for sleptons, squarks, photinos, gluinos, and other gauginos, respectively.

The sneutrino resonance production occurs in hadron colliders through the lepton-number-violating operator $q\bar{d}l$. For the sake of clarity, let us assume for now that the dominant operator has the flavor structure $q_1\bar{d}_1l_k$, where k represents any generation. Then sneutrinos are produced through the fundamental interaction $d\bar{d} \rightarrow \tilde{\nu}_k$ (Fig. 2). Sneutrinos can decay to two quarks by the $q_1\bar{d}_1l_k$ operator, or to two leptons via $ll\bar{e}$, or could have cascade decays to lighter gauginos. The elementary cross section is given by Ref. 15:

$$\sigma(d\bar{d} \rightarrow \tilde{\nu} \rightarrow f) = \frac{1}{3} \frac{\frac{4}{3}\pi\Gamma_{d\bar{d}}\Gamma_f}{(\hat{s} - m^2)^2 + m^2\Gamma_t^2}, \quad (2.1)$$

where $\Gamma_{d\bar{d}}$ is the partial width of $\tilde{\nu}$ and is given by

$$\Gamma(\tilde{\nu} \rightarrow d\bar{d}) = \frac{3\alpha_\lambda}{4} m; \quad (2.2)$$

Γ_t is the total width of $\tilde{\nu}$, m is the mass, $\hat{s}$ is the square of

FIG. 2. The parton diagram for single sneutrino production.

the parton c.m. energy, and $\alpha_\lambda = \lambda^2/4\pi$. The factor of $\frac{1}{3}$ in front is from matching the initial colors.

To compute the interaction rate we follow the usual formalism of the parton model of hadrons (for more detail see Ref. 4). The cross section for any hadronic reaction

$$a + b \rightarrow c + \text{anything} \quad (2.3)$$

is given by

$$d\sigma(a + b \rightarrow c + X) = \sum_{i,j \text{ partons}} f_i^{(a)} f_j^{(b)} d\hat{\sigma}(i + j \rightarrow c + X'), \quad (2.4)$$

where $f_i^{(a)}$ is the probability of finding parton i in hadron a , and $\hat{\sigma}$ is the cross section for the elementary process resulting in the desired final state. The parton distributions are measured experimentally at a given scale, and then they are evolved to the very large momentum scales of interest via the Altarelli-Parisi equations. They are generally functions of the Bjorken scaling variable x and Q^2 , the square of the characteristic energy scale of the process under consideration.

A very useful quantity is the differential parton-parton luminosity

$$\tau \frac{d\mathcal{L}}{d\tau} \equiv \frac{\tau}{1 + \delta_{ij}} \int_\tau^1 dx [f_i^{(a)}(x) f_j^{(b)}(\tau/x) + f_j^{(a)}(x) f_i^{(b)}(\tau/x)] / x, \quad (2.5)$$

where τ is given by

$$\tau = \hat{s} / s \quad (2.6)$$

and $\sqrt{s}$ is the c.m. energy of the colliding hadrons. The differential luminosity is the number of parton collisions with c.m. energies between τ and $\tau + d\tau$ per hadron collision. Therefore, the cross section for the hadronic reaction [Eq. (2.3)] is given by

$$\frac{d\sigma}{d\tau}(ab \rightarrow cX) = \sum_{ij} \frac{d\mathcal{L}_{ij}}{d\tau} \hat{\sigma}(ij \rightarrow c), \quad (2.7)$$

where $\hat{\sigma}$ is the cross section for the elementary process.

Usually, one must integrate over τ , hence effectively integrating over all parton-parton c.m. energies, to compute the total hadronic cross section. In the case of resonance production of a particle, such as the $\tilde{\nu}$, we can make a further approximation. In the narrow resonance limit all the contribution to $p\bar{p} \rightarrow \tilde{\nu} + X$ essentially comes from the parton c.m. energies equal to the mass of $\tilde{\nu}$. Therefore we can replace the expression for the cross section by

$$\hat{\sigma} = \frac{4\pi^2}{9} \frac{\Gamma_{d\bar{d}} \Gamma_f}{m \Gamma_t} \delta(\hat{s} - m^2), \quad (2.8)$$

where now $\hat{\sigma}$ is the parton cross section and $\sqrt{\hat{s}}$ is the parton c.m. energy. This δ function removes the integral over τ and finally we get

FIG. 3. Quantity $(\tau/\hat{s})d\mathcal{L}/d\tau$ for $d\bar{d}$ interactions in proton-antiproton collisions. Collider energies $\sqrt{s}$ are given in TeV.

$$\sigma(p\bar{p} \rightarrow \tilde{\nu} X \rightarrow f) = \frac{4\pi^2}{9} \frac{\Gamma_{d\bar{d}} \Gamma_f}{m \Gamma_t} \times \left[\frac{\tau}{\hat{s}} \frac{d\mathcal{L}}{d\tau} \right] \Big|_{\tau=m^2/s}, \quad (2.9)$$

where $d\mathcal{L}/d\tau$ represents the differential $d\bar{d}$ luminosity in $p\bar{p}$ collisions evaluated at the mass of $\tilde{\nu}$. Figure 3 shows the values of $(\tau/\hat{s})d\mathcal{L}/d\tau$ as a function of $\sqrt{\hat{s}}$ in $p\bar{p}$ collisions for various collider energies $\sqrt{s}$. Now, using this graph it is easy to read off the cross section for $\tilde{\nu}$ production in $p\bar{p}$ collisions. In Fig. 4, we present the total cross section for $p\bar{p} \rightarrow \tilde{\nu} \rightarrow \text{anything}$ as a function of the collider c.m. energy, for various $\tilde{\nu}$ masses, with $\lambda_{q\bar{d}l} = 1$. The result is proportional to λ^2 .

So far we have assumed $q_1 \bar{d}_1 l_k$ is the dominant operator. If this is not the case, we must integrate over a different parton luminosity. These luminosity functions are given in Ref. 5 and will not be repeated here. We have already explained how to obtain the sneutrino production cross section given a particular luminosity function. Therefore, we will only present the results for some

FIG. 4. Total cross section for $p\bar{p} \rightarrow \tilde{\nu}$, with $\tilde{\nu}$ masses of 3, 50, 100, and 250 GeV, for the operator $q_1 \bar{d}_1 l_k$ with $\lambda_{q\bar{d}l} = 1$.

FIG. 5. Total cross section for $p\bar{p} \rightarrow \tilde{\nu}$, for the operator $q_1 \bar{d}_2 l_k$ with $\lambda_{q\bar{d}l} = 1$. Masses are as in Fig. 4.

of the other operators for comparison. Figures 5 and 6 contain the cross sections for sneutrino production if the operators $q_1 \bar{d}_2 l_k$ and $q_1 \bar{d}_3 l_k$ are dominant, respectively.

Next, there is the resonance production of $\tilde{l}^\pm$ through the operator $q_1 \bar{d}_1 l_k$. With essentially the same assumptions as for the $\tilde{\nu}$, and the same analysis, we shall proceed to present the results. In Fig. 7, we show the parton luminosity resulting to $\tilde{l}^\pm$ production. The $\tilde{l}^\pm$ are produced by the elementary reactions $u\bar{d} \rightarrow l^+$ and $\bar{u}d \rightarrow l^-$. In Fig. 8, we present the total production cross section for $\tilde{l}^\pm$ production in $p\text{-}\bar{p}$ colliders for various collider energies. We shall refrain from presenting the results for other operators as we did for the case of the sneutrino, since a comparison of Figs. 4–6 and Fig. 8 should give the reader a feeling for what these cross sections are.

The presence of a baryon-number-violating Yukawa coupling ($\bar{u}\bar{d}\bar{d}$) can result in the production of single squarks (Fig. 9) which can decay into two quarks and produce two jets with an invariant mass equal to the mass

FIG. 6. Total cross section for $p\bar{p} \rightarrow \tilde{\nu}$, for the operator $q_1 \bar{d}_3 l_k$ with $\lambda_{q\bar{d}l} = 1$. Masses are as in Fig. 4.

FIG. 7. Quantity $(\tau/\hat{s})d\mathcal{L}/d\tau$ for $u\text{-}\bar{d}$ and $\bar{u}\text{-}d$ interactions in proton-antiproton collisions.

of the squark. The analysis is again similar to the $\tilde{\nu}$ and $\tilde{l}^\pm$; the formula (2.9) also applies to $\bar{q}$ production except for an extra factor of 2 from mismatch of initial color states, so that $4 \rightarrow 8$. Also, $d\mathcal{L}/d\tau$ now refers to a ud not a $d\bar{d}$ luminosity. Here we assumed the dominant operator has the flavor structure $\bar{u}\bar{d}\bar{d}_k$. Since the coefficient for the $\bar{u}\bar{d}\bar{s}$ must be necessarily small ($\leq 10^{-6}$) from neutron oscillations and nucleus decay, the superpartner is most likely a b -flavor squark. We present the results in Figs. 10 and 11.

Single gauginos can be produced both in the lepton-number- ($q\bar{d}l$) and the baryon-number-violating models ($\bar{u}\bar{d}\bar{d}$). Two quarks can exchange a squark in the t or the u channels; emitting a gaugino through an ordinary gauge interaction vertex and a quark or a lepton through a Yukawa vertex (Fig. 12).

As in Ref. 5, Eq. (3.3) through (3.9), we shall parametrize the relevant cross sections as follows. Let us define the convenient quantities

$$\xi = [s - (m_1 + m_2)^2]^{1/2} [s - (m_1 - m_2)^2]^{1/2}, \quad (2.10)$$

FIG. 8. Total cross section for $p\bar{p} \rightarrow \tilde{l}^\pm$, with $\tilde{l}^\pm$ masses of 20, 50, 100, and 250 GeV, for the operator $q_1 \bar{d}_1 l_k$ with $\lambda_{q\bar{d}l} = 1$.

FIG. 9. The parton diagram for single squark production.

$$\Delta_{ai} = M_a^2 - m_i^2, \quad (2.11)$$

$$\Lambda_a = \ln \left[\frac{s + \Delta_{a1} + \Delta_{a2} - \xi}{s + \Delta_{a1} + \Delta_{a2} + \xi} \right]. \quad (2.12)$$

The elementary cross section for single gaugino production is

$$\sigma(q'q \rightarrow \text{gaugino} + \text{fermion})$$

$$= \frac{\pi}{s^2} \left\{ A_t \left[\left[\xi + (\Delta_{t1} + \Delta_{t2})\Lambda_t + \frac{\xi\Delta_{t1}\Delta_{t2}}{M_t^4 + m_1^2 m_2^2 + M_t^2(s - m_1^2 - m_2^2)} \right] + (t \leftrightarrow u) \right] - A_{tu} \frac{2m_1 m_2 s}{s + \Delta_{t1} + \Delta_{u2}} (\Lambda_t + \Lambda_u) \right\} \quad (2.13)$$

where m_1 and m_2 are the masses of the outgoing particles, M_t is the mass of the t -channel-exchanged particle, etc., and A_t , A_u , and A_{tu} are numerical factors which depend on the gauge and the Yukawa couplings.

Let us start by considering single photino production. The photino could be accompanied by an ordinary neutrino or charged lepton of any flavor, or a quark depending on the model. In the first case, the photino could decay back into two quarks and a lepton of any charge, or if the lle operator is also present, it could decay into three leptons. In the second case, the photino would decay into three quarks.

FIG. 10. Quantity $(\tau/\hat{s})d\mathcal{L}/d\tau$ for u - d and $\bar{u}$ - $\bar{d}$ interactions in proton-antiproton collisions. FIG. 11. Total cross section for $p\bar{p} \rightarrow \bar{q}^{\pm 1/3}$, with $\bar{q}^{\pm 1/3}$ masses of 20, 50, 100, and 250 GeV, for the operator $\bar{u}_1 \bar{d}_1 \bar{d}_k$, with $\lambda \bar{u} \bar{d} \bar{d} = 1$.

For the case of $q'q \rightarrow \tilde{\gamma} + \text{lepton}$, we have

$$A_t = \frac{\alpha_\lambda \alpha e_q^2}{6}, \quad A_u = \frac{\alpha_\lambda \alpha e_{q'}^2}{6}, \quad A_{tu} = -\frac{\alpha_\lambda \alpha e_q e_{q'}^2}{3}.$$

Assuming the dominant operator is $q_1 \bar{d}_1 l_k$, if the lepton in the final state is neutral, then the elementary process is $d\bar{d} \rightarrow \tilde{\gamma} \nu$. Once we integrate over the appropriate parton distribution functions using the cross section (2.13), we get the total cross section for this process in a $p\bar{p}$ machine. In Fig. 13, we present the cross section for $p\bar{p} \rightarrow \tilde{\gamma} + \nu$ for various photino and squark masses. The analysis for a charged lepton in the final state is similar, although the squarks exchanged in the t and u channels have different charges. Assuming the same mass for the squarks, we present the cross section for $p\bar{p} \rightarrow \tilde{\gamma} l$ in Fig. 14.

In the baryon-number-violating scenario, a single photino is produced in conjunction with a quark. Assuming

FIG. 12. Feynman diagrams for single gaugino production in quark-quark scattering. $\tilde{g}$ represents any gaugino, and the final state could consist of a quark or a lepton depending on the model.

FIG. 13. Total cross section for $p\bar{p} \rightarrow \tilde{\gamma} + \nu$, for photino and squark masses 3, 20; 20, 50; 100, 100; 250, 250 GeV, and $\lambda_{q\tilde{d}l} = 1$.

FIG. 15. Total cross section for $p\bar{p} \rightarrow \tilde{\gamma} + q$. Masses are the same as Fig. 13, with $\lambda_{u\tilde{d}d} = 1$.

the flavor structure is $\bar{u}\bar{d}b$, the final-state quark is most likely a bottom quark. In this case again the t - and u -channel squarks have different charges, but we assume they have the same mass. The cross section is the same as the charged lepton, except for a factor of 2 which comes from the mismatch of initial color charges. The final result for $p\bar{p} \rightarrow \tilde{\gamma}b$ is presented in Fig. 15.

Single gluino production is very similar to single photino production; hence, we shall omit the details. In the case of the $\bar{u}\bar{d}d$ operator, the elementary cross section is as in Eq. (2.13), with

$$A_t = \frac{4\alpha_s\alpha_s}{9}, \quad A_u = A_t, \quad A_{tu} = -2A_t, \quad (2.14)$$

where α_s is the strong-coupling constant. In Fig. 16, we present the cross section for $p\bar{p} \rightarrow \tilde{g} + q$ or $\bar{q}$. Here we assumed the dominant operator has the flavor structure $\bar{u}\bar{d}b$. For comparison, we shall consider the operator $\bar{c}\bar{b}s$,

FIG. 14. Total cross section for $p\bar{p} \rightarrow \tilde{\gamma} + l$. Masses are the same as Fig. 13, with $\lambda_{q\tilde{d}l} = 1$.

in which case the decays $\tilde{g} \rightarrow qq\bar{q}$ will contain several $K, D, B, \dots$ mesons and frequently a Λ (Fig. 17). In Fig. 18, we present the total cross section for $p\bar{p} \rightarrow \tilde{g}q$ if the dominant operator is $\bar{c}\bar{b}s$.

In the $q\tilde{d}l$ models, a lepton will be produced with the gluino, then the gluino could decay into two jets and another lepton. The cross section is smaller than the B -number-violating model by a factor of 2 because of the matching of the initial colors of the quarks. We are going to leave this section by mentioning that the superpartners of W and Z^0 can also be singly produced. We will not present any calculations of their production rates, since the cross sections are very similar to the photino, except for multiplicative factors coming from various couplings and charges.

This concludes our presentation of single-

FIG. 16. Total cross section $p\bar{p} \rightarrow \tilde{g}q$, for gluino and squark masses 50, 50; 100, 100; and 250, 250 GeV, with $\lambda_{u\tilde{d}d} = 1$.

FIG. 17. Production and decay of a single gluino, if the dominant operator is $\bar{c}\bar{b}s$.

superpartner-particle production in $p\text{-}\bar{p}$ collisions. To summarize, squarks decay into two quarks producing two jets: the signature is a bump in the two-jet invariant-mass plot. Sleptons can decay into two jets or two leptons. In the latter case, the signature is a bump in the l^+l^- invariant mass. All gauginos can be singly produced. The gluino can decay into three quarks, producing up to four jets in the final state, some of which might contain a high number of higher-generation mesons and baryons. The photino can decay into two jets and a lepton, producing two leptons and two jets in the final state.

III. SUPERPARTICLE PAIR PRODUCTION

If the λ 's are small, the rates for single superparticle production will be low; however, superpartner pair production by gauge interactions will be present as in the minimal supersymmetric version of the standard model. The signatures, however, will be very different due to superpartner decays. The cross sections for superparticle pair production have been computed elsewhere (Ref. 5); for the sake of completeness we reproduce some of the results.

FIG. 18. Total cross section $p\bar{p} \rightarrow \tilde{g}q$, if the dominant “ $\Delta B \neq 0$ ” operator is $\bar{c}\bar{b}s$, for gluino and squark masses 50, 50; 100, 100; and 250, 250 GeV, and $\lambda_{\bar{c}\bar{b}s} = 1$.

FIG. 19. Total cross section for $p\bar{p} \rightarrow \tilde{g}\tilde{g}$. The masses of the gluinos and the squarks are 3, 20; 50, 50; and 100, 100 GeV. The plot is reproduced from Ref. 5.

Figures 19, 20, and 21, respectively, present the total cross sections for gluino, squark, and photino pair productions. We have already discussed the possible decays of the superparticles. In short, the $\Delta B \neq 0$ model gives multijet events with two or three jets with invariant mass equal to the mass of the superpartners. In the $\Delta L \neq 0$ models, there will be many isolated charged leptons in

FIG. 20. Total cross section for production of two squarks via the standard gauge couplings. The cross section is the same for an antisquark pair or a squark-antisquark pair. All masses are as in Fig. 19. The plot is reproduced from Ref. 5.

FIG. 21. Total cross section for photino pair production via the standard gauge couplings. The masses of the photinos and the squarks are 3, 20; 50, 50; 100, 100 GeV. The plot is reproduced from Ref. 5.

the final state. For example, if the decays are through the $ll\bar{e}$ operator, two sleptons could decay into two leptons each; or two photinos could decay into three leptons each, four of which could be charged.

IV. EXISTING LIMITS, FUTURE PROSPECTS, AND EXOTIC SIGNATURES

In this section we shall present some limits on the superpartner masses and the strength of the Yukawa operators coming from the data already published. We shall also discuss the prospects for detection of singly produced superpartners in a 2-TeV machine, e.g., the Fermilab Tevatron. In the final subsection, we shall enumerate the LSP decays in the presence of the B - and L -number-violating operators, and discuss what happens if the couplings for these operators are small ($\lambda \sim 10^{-8}$) and therefore the LSP is relatively long lived.

A. Limits from the CERN collider

It already is possible to set some very modest limits on the masses and the Yukawa couplings of the superpartners using the existing data from the CERN $p\bar{p}$ collider.

1. Limits from UA1

In a recent paper,¹⁶ upper limits are set on the cross section times the decay branching ratio for the production of any particle (a vector or a scalar) decaying into

FIG. 22. Our derived upper limits on the cross section times decay branching ratio for the production of a particle X decaying into two hadronic jets, shown as a function of mass M_X . The limits are shown for $\Gamma_X < 0.4M_X$. The broken lines show our predictions for the production of sneutrinos, squarks, and sleptons at the CERN collider ($\sqrt{s} = 630$ GeV), for $\lambda = 2.2$.

two hadronic jets. The limits are for a particle X with a width $\Gamma_X < 0.4M_X$, as a function of mass M_X for $M_X > 150$ GeV (Fig. 22). The data are from the CERN collider with the center-of-mass energy $\sqrt{s} = 630$ GeV. We also have shown in Fig. 22 the cross sections for sneutrino, squark, and lepton production as a function of the mass for the same center-of-mass energy, for $\lambda_{11k} = 2.2$ corresponding to Γ of $0.4m$, assuming a branching ratio of 1 into two jets. The predicted cross sections only lie in the excluded region for restricted masses and couplings for the single lepton production.

In the case of slepton and sneutrino production, the decays could be mainly into two leptons through the $ll\bar{e}$ operator and therefore, if single or double lepton final states are not observed, we could set limits on the product $\lambda_{q\bar{d}l}\lambda_{ll\bar{e}}$. We encourage the UA1 Collaboration to carry out such studies.

2. Limits from UA2

Limits for smaller masses can be obtained from the published results of the UA2 Collaboration. In Ref. 17, the invariance-mass distribution of jet pairs is examined in the search for decays of the $W^\pm$ and Z^0 bosons into quark-antiquark pairs. The UA2 results are shown in Fig. 23. Unfortunately, this data has not been converted into a limit on other scalar or vector particles decaying into two jets. To derive such a limit, one is required to carry on a Monte Carlo simulation of production and decay of X particles in the UA2 detector. Such a simulation must take into account the experimental efficiency and the geometrical acceptance of the detector, and also include all the experimental cuts for identifying the final jets and their invariant mass. While we encourage the UA2 Collaboration to carry on this program, we have derived certain limits without the use of a Monte Carlo program, based on the following procedure.

FIG. 23. The jet-pair mass distribution, for invariant masses between 45 and 175 GeV. Figure is taken from Ref. 17.

We assume that the efficiency of the detector to detect two-jet decays of X , i.e. the percentage of the two-jet events that are detected and pass all the experimental cuts, is independent of the mass of X and equivalent to that of the $W^\pm$ and Z^0 . To estimate this quantity, we first compute the number of jet pairs coming from the decays of these intermediate vector bosons (IVB's). The total integrated luminosity associated with the UA2 data is $L_i = 0.73 \text{ bp}^{-1}$. The total cross section for W production is predicted to be $\sigma_W(630 \text{ GeV}) = 5.8 \text{ nb}$, and for Z production $\sigma_Z(630 \text{ GeV}) = 1.7 \text{ nb}$ (Ref. 18). We also estimate the branching ratios $B(W \rightarrow qq) = 0.6$ and $B(Z \rightarrow qq) = 0.9$. Therefore, the expected number of jet pairs coming from the IVB decays is $730 \text{ nb}^{-1} \times (5.8 \text{ nb} \times 0.6 + 1.7 \text{ nb} \times 0.9) \approx 3.7 \times 10^3$. The UA2 Collabora-

FIG. 24. Upper limits on the cross section times decay branching ratio for the production of a particle X decaying into two hadronic jets, shown as a function of mass M_X , derived from the UA2 published results (Ref. 17). The limits are shown for $\Gamma_X < 0.1 M_X$. The broken lines show our predictions for the production of sneutrinos, squarks, and sleptons at the CERN collider ($\sqrt{s} = 630 \text{ GeV}$), for $\lambda = 1.3$.

FIG. 25. The excluded region of parameter space for single slepton, squark, and sneutrino production, using the UA1 and UA2 data. The dark region is excluded by our analysis, and we expect the shaded region to be excluded by a more detailed Monte Carlo simulation.

tion using a detailed Monte Carlo program predicts a total number 340 ± 80 two-jet events. Hence, the ratio of the number of two-jet events detected to the number of produced IVB's decaying into two jets is about $(340 \pm 80) / (3.7 \times 10^3) \approx (9 \pm 2)\%$. We shall take this ratio to be 7%, since this will give us the most confident bounds.

We also assume that a structure at the level of ≈ 5 standard deviations over the background is ruled out by the data. Consequently, we derive a limit on the production cross section times the branching ratio into quark-antiquark pairs, which is presented in Fig. 24. These limits match the UA1 reported limits in the mass region where the two data sets overlap. This makes us more confident that the limits we derived are similar to the true limits that are obtained by running Monte Carlo simulation.

The broken lines in Fig. 24 show the production cross sections for sleptons, squarks, and sneutrinos with $B = 1$ and $\lambda = 1.3$ corresponding to a width of $\Gamma = 0.1 M$. We restricted the analysis to X particle with width $\Gamma_X < 0.1 M_X$, since the best mass resolution achieved is about 10%. A particle with a larger width is harder to rule out because it produces a wider resonance which can be difficult to separate from the background. We do believe that some larger λ 's are ruled out; however, we leave the definite bounds to the detailed Monte Carlo simulation. In Fig. 25, the dark region in the m_X -vs- λ plane is excluded by the existing data. Obviously, experiments are just beginning to explore this domain. Tevatron data will allow a search for these particles over a wider range of parameters.

B. Prospects for detecting superpartner production at the Fermilab Tevatron

1. Single superparticle production: purely leptonic decays

The clearest signatures of the supersymmetric models we are advocating are the presence of charged leptons in the final decay products. We can have purely leptonic decays if the superpartners decay through the $l\bar{l}\bar{e}$ opera-

tor. The sneutrino would decay into two charged leptons of the same or different flavors, while the slepton would decay into a charged lepton and a neutrino, and the photino would decay into two charged leptons and a neutrino. Single squark or gluino production cannot lead to purely leptonic decays.

The backgrounds predicted in the standard model for all of these events are insignificant for a large area of the parameter space of masses and couplings. We shall not attempt to give a complete account of all the signatures and backgrounds here; however, we would like to point out an example of a sneutrino decaying into two leptons of the same flavor. The standard-model background arises from the lowest-order Drell-Yan mechanism,¹⁹

$$q\bar{q} \rightarrow \gamma^* \rightarrow l^+ l^- ,$$

which has been computed in Ref. 5 and is given by

$$\frac{d\sigma}{dM} = \frac{8\pi\alpha^2}{9M^3} \sum_i e_i^2 \left[\tau \frac{d\mathcal{L}}{d\tau} \right]_{i\bar{i}} ,$$

where M is the invariant mass of the dileptons. At higher masses, comparable to the Z mass, it is necessary to include the contributions of a real or a virtual Z^0 , which may be easily done by making the replacement

$$e_i^2 \rightarrow e_i^2 - \frac{M^2(M^2 - M_Z^2)(L_e + R_e)(L_q + R_q)}{8x_W(1 - x_W)[(M^2 - M_Z^2)^2 + M_Z^2\Gamma_Z^2]} e_i \\ + \frac{M^4(L_e^2 + R_e^2)(L_q^2 + R_q^2)}{64x_W^2(1 - x_W)^2[(M^2 - M_Z^2)^2 + M_Z^2\Gamma_Z^2]} .$$

As usual, we have

$$L_e = 2x_W - 1, \quad R_e = 2x_W$$

for the leptons and

$$L_q = \tau_3 - 2e_q x_W, \quad R_q = -2e_q x_W$$

for the quarks, where we take $x_W = 0.22$, $M_Z \sim 90$ GeV, and $\Gamma_Z = 2.6$ GeV. This invariant-mass spectrum of two leptons is presented in Fig. 26 for collision energy $\sqrt{s} = 2$ TeV. To simplify our discussion of what type of signal we should expect, let us assume that the sneutrino has the same branching ratio into two leptons as to two jets. In effect we are assuming that the $q_1 \bar{d}_1 l_k$ and $l_k l_i \bar{e}_i$ operators are present with the same strength λ , such that $\Gamma_{d\bar{d}} \sim \Gamma_{l+l} \sim 1/2\Gamma_t$. Then the signal for single sneutrino production has a peak with a height $\propto 1/m^2$ which is independent of λ , and a width $\propto \lambda^2 m$, and is given by

$$\left. \frac{d\sigma}{dM} \right|_{\text{peak}} = \frac{\pi}{9} \frac{1}{m} \times \left[\frac{\tau}{\hat{s}} \frac{d\mathcal{L}}{d\tau} \right] \Big|_{\tau=m^2/\hat{s}} , \quad (4.1)$$

where $(\tau/\hat{s})d\mathcal{L}/d\tau$ is the parton-parton luminosity depicted in Fig. 3; For comparison, we have plotted this function on Fig. 26 (dashed line). From this figure, it is clear that the peak of the signal is generally about three orders of magnitude higher than the background. Therefore, if the width of the sneutrino is not very much smaller than the experimental resolution of the dilepton invari-

FIG. 26. Invariant-mass spectrum for dileptonic events produced in proton-antiproton collisions at $\sqrt{s} = 2$ TeV. The dashed line shows the peak of the signal for sneutrino decay into two leptons.

ant energy, we should see the signal before the background. Assuming the energy resolution is about 10% of the invariant mass, let us estimate for what values of λ the signal is larger than the background. For a given total luminosity, L_t , the number of sneutrinos that decay into a pair of leptons is

$$N = \frac{\Gamma_{\tilde{\nu}}}{2} \left. \frac{d\sigma}{dM} \right|_{\text{peak}} \times L_t , \quad (4.2)$$

where $\Gamma_{\tilde{\nu}} = 3/2\alpha_\lambda m$, while the number of events in the background for the same luminosity is

$$B = 0.1 M_{\tilde{\nu}} \times \left. \frac{d\sigma}{dM} \right|_{\text{dileptons}} \times L_t . \quad (4.3)$$

Therefore, we have $N > B$ as long as $\alpha_\lambda > 4/3 \times 0.1/10^3$, or $\lambda > 0.05$. In this case, we conjecture that only 30 such events would constitute a positive signature for the sneutrino decays into a pair of leptons. It should be stressed that here we have made no attempt to calculate the detector's efficiency for such events and feel that 30 is a conservative number. Figure 27 shows the sneutrino masses and couplings λ , for which at least 30 pairs of leptons from sneutrino decays would be detected at the Tevatron for an integrated luminosity of 10 pb^{-1} . Clearly, if such leptonic decays do exist, Tevatron data will allow a search for single superparticle production over a considerable range of masses and for values of λ down to 10^{-2} .

Two-jet decays. If the dominant mechanism for $\tilde{\nu}, \tilde{l}$, and $\tilde{q}$ decay is into two quarks forming two jets, the signature is a bump in the two-jet invariant-mass plot. Let us discuss the possibility of seeing this signal in a 2-TeV machine. The invariant-mass spectrum for two-jet events produced in $p\bar{p}$ collisions has been computed in Ref. 4, and is presented in Fig. 28 for collision energy $\sqrt{s} = 2$ TeV. This jet-jet mass spectrum represents the background for any of the superparticles which decay into two jets. Our discussion here closely resembles the case

FIG. 27. For these sneutrino masses and couplings (λ_{qdl}), at least 30 sneutrinos are going to be produced at the c.m. energy of 2 TeV at the Fermilab Tevatron, for a total integrated luminosity of 10 pb^{-1} .

of the dileptonic decays of the sneutrino. The signal has a peak with a height $\propto 1/m^2$ which is independent of λ , and a width $\propto \lambda^2 m$. For example, in the case of $\tilde{\nu}$ production, the height of the signal in the two-jet invariant-mass spectrum is equal to

$$\left. \frac{d\sigma}{dM} \right|_{\text{peak}} = \frac{8\pi}{9} \frac{1}{m} \times \left. \left(\frac{\tau}{\hat{s}} \frac{d\mathcal{L}}{d\tau} \right) \right|_{\tau=m^2/s}, \quad (4.4)$$

where $(\tau/\hat{s})d\mathcal{L}/d\tau$ is the parton-parton luminosity depicted in Fig. 3; M , the invariant mass of two jets is a variable; and m is the mass of the $\tilde{\nu}$. For comparison, we have plotted this function on Fig. 28 (dashed line). The

FIG. 28. Invariant-mass spectrum for two-jet events produced in proton-antiproton collisions at $\sqrt{s} = 2 \text{ TeV}$. Both jets must satisfy the rapidity cut $|y| < 0.85$. The dashed line shows the peak of the signal for sneutrino decay into two jets.

signal is about an order of magnitude smaller than the background for all $\tilde{\nu}$ masses. The situation is very similar to the decays of $W^\pm$ and Z^0 into quark-antiquark pairs, where such a signature has been observed by the UA2 Collaboration (Ref. 17). To get an idea of what sort of total luminosity is needed to “discover” the sneutrinos, let us assume the following criterion: if the signal is five times the statistical error in the background, then this could constitute a positive signature. Let us assume that the best jet energy resolution that can be achieved is about 10% of the total jet energy. We also assume that the width of the $\tilde{\nu}$ resonance is smaller than this resolution, i.e., $\Gamma_{\tilde{\nu}} < 0.1 M_{\tilde{\nu}}$. If N is the number of $\tilde{\nu}$'s produced, and B is the number of events in the background in a bin of size $0.1 M_{\tilde{\nu}}$ around the sneutrino mass, then we require as our “discovery criterion” that $N/\sqrt{B} = 5$. The number of events in the background is given by

$$B = 0.1 M_{\tilde{\nu}} \times \left. \frac{d\sigma}{dM} \right|_{\text{jet-jet}} \times L_t, \quad (4.5)$$

where L_t is the total integrated luminosity. The number of $\tilde{\nu}$'s, produced with the same total luminosity is given as

$$N = \frac{\Gamma_{\tilde{\nu}}}{2} \left. \frac{d\sigma}{dM} \right|_{\text{peak}} \times L_t. \quad (4.6)$$

Again assuming that the QCD background is about an order of magnitude larger than the peak of the $\tilde{\nu}$ resonance, we can solve for the minimum total luminosity required to satisfy our “discovery” criterion:

$$L_t = (0.5 \text{ pb}^{-1}) \left[\frac{0.1 M_{\tilde{\nu}}}{\Gamma_{\tilde{\nu}}} \right] \left[\frac{1 \text{ nb}}{\sigma_{\tilde{\nu}}} \right]. \quad (4.7)$$

Figure 29 shows the integrated luminosity necessary to satisfy our condition for collider energy of 2 TeV, assuming $\lambda = 1$. We must stress that these numbers are just simple estimates and we encourage future Monte Carlo simulations to take care accurately of a detector's geometry and design specifications.

From Eq. (4.7), we know that L_t scales as $1/\lambda^4$ since both the width and the production cross section are proportional to α_λ . This rule with Fig. 29 allows one to estimate the luminosity needed for any mass and coupling. If λ is less than 0.1, it is unlikely that single superparticle production would be detected as a resonant bump in the two-jet mass spectrum. However, one could look for other decay modes of a singly produced superparticle which are not drowned by a large QCD background. Such decays include prominent leptonic decays, some of which we have already mentioned, and decays of a singly produced gluino or a photino, which we shall discuss in the next subsections.

Three-jet decays. We already have presented the cross sections for single production of gluinos and photinos in the presence of the $\bar{u}dd$ operator; the final state contains four jets, three of which come from the decay of the gaugino and therefore have the invariant mass equal to the gluino mass. The four-jet QCD background, for $\sqrt{s} = 2 \text{ TeV}$, is estimated to be about 10 nb (Ref. 20), where each

FIG. 29. The total integrated luminosity necessary to discover a sneutrino for $\sqrt{s} = 2$ TeV, in the $q\bar{d}l$ model for $\lambda = 1$.

jet energy must be more than 15 GeV and the sum of all the jet energies must be greater than 70 GeV. Let us take the gluino as an example. The gluino production cross section is 4 nb for $m_{\tilde{g}} = 50$ GeV and $m_{\tilde{q}} = 50$ GeV; assuming $\lambda_{\tilde{u}\tilde{d}\tilde{d}} = 1$. For larger gluino masses, one can put tighter cuts on the jet energies and reduce the background considerably. Therefore, the signal is larger than the background for some combinations of couplings and masses, and it can also be enhanced considerably by looking at the mass distribution of the jets: the QCD four-jets are produced relatively uncorrelated, while the trijet mass distribution of the signal should peak around the gluino mass. Although the analysis is harder in this case than the two-jet mass distribution, the signal-to-noise ratio is much larger. Such jet spectroscopy is a challenge; frequently one of the three jets will be too soft to be measured as such and at other times jet coalescence would occur, especially for small values of the gluino mass. For large gluino masses, it is expected that the fourth jet will have little transverse energy.

Cascade decays and other gaugino decays. If the singly produced superpartner is not the LSP, it could first decay into the LSP via the usual gauge couplings. For example, $\tilde{t} \rightarrow t\tilde{\gamma}$ could dominate $\tilde{t} \rightarrow \tilde{q}_i q_j$, where the photino would decay into a lepton and a pair of quarks. These events produce a striking signal. The topology of the event consists of an isolated lepton in one hemisphere balanced by a lepton plus two jets in the other hemisphere with no missing energy. This signature, with two leptons and two jets in the final state, is easier to see than a bump in the invariant-mass plot. In fact, the background for this process is negligible. The standard-model background arises from the production and decay of one Z^0 plus two jets: $Z^0(\rightarrow l^+ l^-) + \text{two jets}$. The cross section times the branching ratio is of the order of 10^{-3} nb (Ref. 4) and can be greatly reduced by excluding lepton pairs with an invariant mass equal to the Z^0 mass. Another source of background could be the Drell-Yan mechanism producing two leptons, accompanied by two jets. This process is suppressed by a factor $\alpha_c^2 \alpha_s^2 / \alpha_\lambda \simeq 10^{-6} / \alpha_\lambda$, compared to

the single production of sleptons. This is not a severe background. Moreover, the signal can be enhanced greatly by looking at the invariant mass of the two jets and the lepton in the same hemisphere, which should peak around the photino mass. We therefore conclude that in the absence of any significant background, a minimum of 30 such events should constitute a clear signal for the production of the slepton. Again we are ignoring the detector's efficiency for such events. Since the production rate of sneutrinos and sleptons is about the same, Figure 27 also represents the slepton masses and the values for the couplings of the $q\bar{d}l$ operator, for which at least 30 sleptons will be produced at the Tevatron for the total integrated luminosity of 10 pb^{-1} .

In the $q\bar{d}l$ model, single production and decay of gauginos could result in similar events as the cascade events of the sneutrino. A gaugino is produced along with a lepton and the decay is into two jets and a lepton. The leptons can have any charge or they could be neutral. In fact, the most interesting events would be when both leptons have the same charge. Again, the background is insignificant for the parameter space of interest.

Let us compare single gaugino production and decay in these models to slepton production and decay. In the absence of $l\bar{l}\tilde{e}$ operators, the slepton will not have purely leptonic decays and will decay into two jets. As we discussed before, the signal is difficult to see because of the large QCD two-jet background. Which signature is going to be detected first? For comparable masses of gauginos, squarks, and sleptons, single resonant production of sleptons has a cross section which in general is about two orders of magnitude larger than single gluino production, and about three orders of magnitude larger than single photino production. However, the cross section for single gauginos is proportional to square of the coupling constant $\lambda_{q\bar{d}l}$, while the total luminosity required to detect a bump in the two-jet invariant-mass plot is proportional to four powers of $\lambda_{q\bar{d}l}$. Therefore, it seems most likely that single gauginos will be discovered first. In fact we can compare the total luminosity required to produce 30 gauginos, $L_{\tilde{g}}$, to the luminosity $L_{\tilde{\nu}}$ required to see a bump given in Eq. (4.7):

$$\frac{L_{\tilde{\nu}}}{L_{\tilde{g}}} \sim 20 \times \frac{1}{\lambda^2} \frac{\sigma_{\tilde{g}}}{\sigma_{\tilde{\nu}}} . \quad (4.8)$$

From this equation, it becomes clear that for most values of $\lambda_{q\bar{d}l}$, if gauginos are lighter than sleptons and squarks or have comparable masses, their final states of two jets and two leptons will constitute a much better signature than a bump in the two-jet mass invariant plot, while for large values of the coupling, both signatures should be observed simultaneously. For smaller values of the coupling constants ($\lambda < 10^{-2}$), the only observable evidence for superparticle decay in hadron colliders would be squark or gluino pair production and the subsequent decay of the LSP due to the B - and L -number-violating operators. In the next subsection we are going to discuss some of the signatures arising from the pair production of superparticles. We shall see that there is a wealth of interesting possibilities.

TABLE I. In this table, q represents a quark or an antiquark, and l could be a lepton of any charge.

LSP	$\bar{u}\bar{d}\bar{d}$	$q\bar{d}l$	$ll\bar{e}$
Charged, strongly interacting	$\bar{q} \rightarrow qq$	$\bar{q} \rightarrow ql$	$\bar{q} \rightarrow qlll$
Neutral, strongly interacting	$\bar{g} \rightarrow qq\bar{q}$	$\bar{g} \rightarrow qq\bar{l}$	$\bar{g} \rightarrow qqlll$
Charged, weakly interacting	$\bar{l}^\pm \rightarrow lqq\bar{q}$	$\bar{l}^\pm \rightarrow ql$	$\bar{l}^\pm \rightarrow ll$
Neutral, weakly interacting	$\bar{\nu} \rightarrow lqq\bar{q}$	$\bar{\nu} \rightarrow ql$	$\bar{\nu} \rightarrow ll$
	$\bar{\gamma} \text{ or } \bar{Z} \rightarrow qq\bar{q}$	$\bar{\gamma} \text{ or } \bar{Z} \rightarrow lqq$	$\bar{\gamma} \text{ or } \bar{Z} \rightarrow lll$

2. Superparticle pair production and decay

For small λ ($\lambda \lesssim 10^{-2}$), the dominant production mechanism for the superpartners is the pair production of squarks and gluinos via the usual gauge couplings. If the pair-produced superparticle is the LSP, it will decay via the B - or L -number-violating interactions. If it is not the LSP, it will first decay into the LSP, and then the LSP will decay. In Table I, we enumerate various candidates for the LSP and their decay modes in the presence of any of the Yukawa interactions. We must stress again the significance of leptons in the final states. The majority of events with singly or doubly produced superpartners can contain single isolated leptons. For example, if a squark is the LSP decaying via the $q\bar{d}l$ operator, the signal consists of two jets and two leptons, with the invariant mass of the jet-lepton system strongly peaked around the squark mass. We have already mentioned that the background for such events is very small, making these lepton decays the best signatures to look for.

The production cross sections for gluino pairs and squark pairs are relatively large (Figs. 19 and 20). For example, the gluino pair production is about 0.3 nb at Tevatron energies, for $m_{\tilde{g}} = m_{\tilde{q}} = 100$ GeV, which means about 3000 such pairs can be produced with an integrated total luminosity of 10 pb^{-1} . With such a large rate of production, the prospects of detecting superparticles through their B - and L -number-violating decays are great.

C. Searches for gaps, secondary vertices and stable particles

In the previous sections we assumed that the strength of the Yukawa couplings are large ($\lambda \gtrsim 10^{-2}$). All the results can be rescaled for new λ 's if this is not the case. However, a small coupling means that perhaps the LSP is long lived, which suggests a new set of possibilities for accelerator signatures. The LSP can travel a macroscopic distance and decay inside the detector; and if charged, it can leave a track. For example, assume the squark is the LSP. Its lifetime is

$$\tau_q = (10^{-9} \text{ sec}) \left[\frac{100 \text{ GeV}}{m_q} \right] \left[\frac{10^{-8}}{\lambda} \right]^2.$$

For $\lambda \lesssim 10^{-8}$, a squark, after being pair produced, can either decay in the tracking chambers leaving a secondary vertex, or may be stopped in the hadronic calorimeter and produce hadronic showers when it decays. If the LSP is neutral, there would be a gap between the primary and the secondary vertices. Such events are so prominent

that only a few would constitute a clean signal. This gives sensitivity to smaller couplings all the way down to 10^{-10} for the sneutrinos; the small fraction of sneutrinos which decay in the detector before escaping would be sufficient to give a signal. Larger couplings, $\lambda \sim 10^{-7}$ for a 100 GeV superpartner, could be probed in future runs with a vertex detector.

V. CONCLUSION

To summarize, we have stressed the possibility that the LSP can decay even in supersymmetric models with the minimal field content. We have presented the production cross sections for supersymmetric particles from B - and L -violating Yukawa couplings. We were able to set some limits on the strength of these couplings and the masses of some superpartners using existing data from the CERN collider. We discussed the prospects for detecting these processes at the Fermilab Tevatron, and find that a run of 10 pb^{-1} will enable a large new region of the parameter space to be explored. For the spectacular dilepton events, this region can be seen from Fig. 27. Events with a pair of leptons (possibly the same sign) and two jets also provide an excellent signature. In some cases the only signatures at the Tevatron are the multijet events which are harder to observe.

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