Trilepton Signal of Minimal Supergravity at the Tevatron Including $\tau$-lepton Contributions

V. Barger, Chung Kao and Tianjun Li

Department of Physics, University of Wisconsin, Madison, WI 53706, USA

Abstract

The trilepton signal with missing transverse energy ($3\ell + E_T$, with $\ell = e$ or $\mu$) from chargino-neutralino ($\chi^{\pm}_1 \chi^0_2$) associated production and decays is studied for the upgraded Fermilab Tevatron Collider with 2 TeV center of mass energy and integrated luminosity of $2 \text{fb}^{-1}$ (MI) to 20 fb$^{-1}$ (TeV33). In some regions of parameter space in the minimal supergravity model, $\chi^{\pm}_1$ and $\chi^0_2$ decay dominantly into final states with $\tau$ leptons via real or virtual $\tilde{\tau}_1$ sleptons. The contributions from $\tau$–leptonic decays increase the trilepton signal from $\chi^{\pm}_1 \chi^0_2$ by at least a factor of two when soft but realistic cuts on lepton transverse momenta are used. With the Main Injector, a trilepton signal can be detected at $\tan \beta \equiv v_2/v_1 \sim 3$ for universal masses $m_{1/2}, m_0 \lesssim 200 \text{GeV}$. 

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I. INTRODUCTION

In the near future, the Main Injector (MI) of the Fermilab Tevatron will run at 2 TeV center of mass energy and accumulate an integrated luminosity ($L$) of about 2 fb$^{-1}$ at each of the CDF and the DØ detectors. It has been proposed to further upgrade the Tevatron luminosity to $10^{33}$ cm$^{-2}$ s$^{-1}$ (TeV33) to obtain an integrated luminosity $L = 20$ fb$^{-1}$ \cite{1}. Such a great increase in luminosity will significantly improve the potential of Tevatron to discover new physics beyond the Standard Model (SM) before the CERN Large Hadron Collider (LHC) begins operation \cite{2}.

In this article, we assess the prospects for discovery of the trilepton signal of supersymmetry at the upgraded Tevatron. The source of this signal is associated production of the lightest chargino ($\chi^\pm_1$) and the second lightest neutralino ($\chi^0_2$) with decays to leptons \cite{3,4}. For definiteness, we base our analysis on supersymmetric particle masses and couplings of the minimal supergravity (mSUGRA) model \cite{5}. In the minimal supergravity model with gauge coupling unification, the sleptons ($\tilde{\ell}$), the lighter chargino ($\chi^\pm_1$) and the lighter neutralinos ($\chi^0_1, \chi^0_2$) are considerably less massive than the gluinos and squarks over most of the parameter space. Because of this, the trilepton signal with missing transverse energy ($3\ell + E_T$) from associated production of the lightest chargino ($\chi^\pm_1$) and the second lightest neutralino ($\chi^0_2$) \cite{3,4,6,7} is one of the most promising channels for supersymmetric particle searches at the Tevatron. The background to this signal from SM processes can be greatly reduced with suitable cuts. A principal departure of our analysis from previous studies is the inclusion of the contributions from $\tau$-lepton decays to leptons through the use of softer transverse momentum ($p_T$) acceptance cuts on leptons. The softer cuts increase the observable signal by at least a factor of two over results with conventional hard cuts \cite{4}. Our soft cuts are similar to those of a recent CDF analysis \cite{8} and should be realistic at the upgraded Tevatron as well \cite{9}.

A supersymmetry (SUSY) between fermions and bosons provides a natural explanation of the Higgs mechanism for electroweak symmetry breaking (EWSB) in the framework of a grand unified theory (GUT). For the particle content of the minimal supersymmetric standard model (MSSM) \cite{10}, the evolution of gauge couplings by renormalization group equations (RGEs) \cite{11} is consistent with a grand unified scale at $M_{\text{GUT}} \sim 2 \times 10^{16}$ GeV and an effective SUSY mass scale in the range $M_Z < M_{\text{SUSY}} \lesssim 10$ TeV \cite{12}. With a large top quark Yukawa coupling ($Y_t$) to a Higgs boson at the GUT scale, radiative corrections drive the corresponding Higgs boson mass squared parameter negative, spontaneously breaking the electroweak symmetry and naturally explaining the origin of the electroweak scale. In the minimal supersymmetric GUT with a large $Y_t$, there is a quasi-infrared fixed point (IRFP) \cite{13,14} at low $\tan \beta$; the top quark mass is correspondingly predicted to be $m_t = (200 \text{ GeV}) \sin \beta$ \cite{13}, and thus $\tan \beta \simeq 1.8$ for $m_t = 175$ GeV. At high $\tan \beta$, another IRFP solution ($dY_t/d\beta \simeq 0$) exists at $\tan \beta \sim 56$.

In supergravity (SUGRA) models \cite{5}, supersymmetry is broken in a hidden sector with SUSY breaking communicated to the observable sector through gravitational interactions, leading naturally but not necessarily \cite{13} to a common scalar mass ($m_0$), a common gaugino mass ($m_{1/2}$), a common trilinear coupling ($A_0$) and a common bilinear coupling ($B_0$) at the GUT scale. Through minimization of the Higgs potential, the $B$ coupling parameter of the superpotential and the magnitude of the Higgs mixing parameter $\mu$ are related to the ratio
of Higgs-field vacuum expectation values (VEVs) \((\tan \beta \equiv v_2/v_1)\) and to the mass of the \(Z\) boson \((M_Z)\). The SUSY particle masses and couplings at the weak scale can be predicted by the evolution of RGEs from the unification scale \(\Lambda\). In most of the mSUGRA parameter space, the weak-scale gaugino masses are related to the universal gaugino mass parameter \(m_{1/2}\) by \(m_{\chi_1^0} \sim 0.44m_{1/2}\) and \(m_{\chi_2^0} \sim 0.88m_{1/2}\). Consequently, this discovery channel could provide valuable information about the value of \(m_{1/2}\).

Recent measurements of the \(b \to s\gamma\) decay rate by the CLEO \([14]\) and LEP collaborations \([15]\) place constraints on the parameter space of the minimal supergravity model \([16]\). It was found that \(b \to s\gamma\) excludes most of the minimal supergravity (mSUGRA) parameter space when \(\tan \beta\) is large and \(\mu > 0\) \([19]\). Therefore, we will choose \(\mu < 0\) in our analysis since we are particularly interested in large \(\tan \beta\). In our convention, \(-\mu\) appears in the chargino mass matrix and \(+\mu\) appears in the neutralino mass matrix.

The Yukawa couplings of the bottom quark \((b)\) and the tau lepton \((\tau)\) are proportional to \(\tan \beta\) and are thus greatly enhanced when \(\tan \beta\) is large. In SUSY GUTS, the masses of the third generation sfermions are consequently very sensitive to the value of \(\tan \beta\). As \(\tan \beta\) increases, the lighter tau slepton \((\tilde{\tau}_1)\) and the lighter bottom squark \((\tilde{b}_1)\) become lighter than charginos and neutralinos while other sleptons and squarks are heavy. Then, \(\chi_1^\pm\) and \(\chi_0^0\) can dominantly decay into final states with tau leptons via real or virtual \(\tilde{\tau}_1\). While these decays reduce the trilepton signal with hard cuts to suppress the backgrounds, they also open new discovery channels via \(\tau\) leptons.

One way to detect \(\tau\) leptons is through their one prong and three prong hadronic decays. The CDF and the DØ collaborations are currently investigating the efficiencies for detecting these modes and for implementing a \(\tau\) trigger. Recently, it has been suggested that the \(\tau\) leptons in the final state may be a promising way to search for \(\chi_1^+\chi_2^-\) production at the Tevatron if excellent \(\tau\) identification becomes feasible \([20,21]\).

Another way of exploiting the \(\tau\) signals, that we consider in this article, is to detect the soft electrons and muons from leptonic \(\tau\) decays by employing softer but realistic \(p_T\) cuts on the leptons than conventionally used. We find that this can improve the trilepton signal from \(\chi_1^+\chi_2^-\) production by at least a factor of two.

The relevance of \(\tau\) leptons in the production and decays of \(\chi_1^+\chi_2^-\), are illustrated in Figure 1, where the product of the cross section \(\sigma(p\bar{p} \to \chi_1^+\chi_2^- + X)\) and the branching fraction \(B(\chi_1^+\chi_2^- \to 3\) leptons \(+\not{\!E}_T)\) versus \(\tan \beta\) is presented with \(\mu < 0\), \(m_{1/2} = 200\) GeV, \(m_0 = 100\) and 200 GeV, for four final states \((a)\) \(\tau\tau\tau\), \((b)\) \(\tau\tau\ell\), \((c)\) \(\tau\tau\ell\) and \((d)\) \(\ell\ell\ell\) \(\ell\) \(= e\) or \(\mu\). For \(m_0 \lesssim 200\) GeV and/or \(\tan \beta \gtrsim 40\), channels with at least one \(\tau\) lepton are dominant.

II. PRODUCTION CROSS SECTION AND BRANCHING FRACTIONS

In hadron collisions, associated production of chargino and neutralino occurs via quark-antiquark annihilation in the \(s\)-channel through a virtual \(W\) boson \((q\bar{q} \to W^\pm \to \chi_1^\pm\chi_2^0)\) and in the \(t\) and \(u\)-channels through squark \((\tilde{q})\) exchanges. The \(pp \to \chi_1^+\chi_2^-\) cross section depends mainly on the masses of chargino \((m_{\pm})\) and neutralino \((m_{\chi^0})\). For squarks much heavier than the gauginos, the \(s\)-channel \(W\)-resonance amplitude dominates. If the squarks are light, a destructive interference between the \(W\) boson and the squark exchange amplitudes can suppress the cross section by as much as 40% compared to the \(s\)-channel
contribution alone. For larger squark masses, the effect of negative interference is reduced, and the cross section is enhanced.

In Figure 2, we present branching fractions of $\chi_2^0$ and $\chi_1^\pm$ versus $\tan\beta$ for $\mu < 0$, $m_{1/2} = 200$ GeV and several values of $m_0$. For $\tan\beta \lesssim 5$, the branching fractions are sensitive to the sign of $\mu$.

For $\mu < 0$ and $\tan\beta \sim 3$, we observe that:

- For $m_0 \lesssim 50$ GeV, $\chi_2^0$ decays dominantly to $\tilde{\nu}_L\nu, \tilde{\ell}_R\ell$ and $\tilde{\tau}_1\tau$, and $\chi_1^+$ decays into $\tilde{\nu}_L\ell$ and $\tilde{\tau}_1\nu$.
- For $60$ GeV $\lesssim m_0 \lesssim 110$ GeV, the $\chi_2^0 \to \tilde{\nu}_L\nu$ decay is kinematically suppressed; $\chi_2^0$ decays mainly to $\tilde{\ell}_R\ell$ and $\tilde{\tau}_1\tau$, and $\chi_1^+$ decays dominantly into $\tilde{\tau}_1\nu$.
- For $120$ GeV $\lesssim m_0 \lesssim 170$ GeV, all two-body $\chi$ decays to sleptons are closed. However, the $\chi_1^+\chi_2^0 \to 3\ell + E_T$ branching fractions is still significant due to relatively light virtual sleptons.
- For $m_0 \gtrsim 180$ GeV, $\chi_1^+$ and $\chi_2^0$ dominantly decay into $q\bar{q}'\chi_1^0$.

For $\mu > 0$ and $\tan\beta \sim 3$, we observe that:

- For $m_0 \lesssim 100$ GeV, $\tilde{\ell}_R, \tilde{\ell}_L$ and $\tilde{\nu}_L$ are all lighter than $\chi_1^+$ and $\chi_2^0$, $\chi_2^0$ dominantly decays to $\tilde{\nu}_L\nu$ and $\chi_1^+$ decays into $\tilde{\nu}_L\ell$.
- For $110$ GeV $\lesssim m_0 \lesssim 140$ GeV, $\tilde{\ell}_R$ and $\tilde{\tau}_1$ are lighter than $\chi_1^+$ and $\chi_2^0$, $\chi_2^0$ dominantly decays to $\tilde{\tau}_1\tau$ and $\chi_1^+$ decays into $\tilde{\tau}_1\nu$.
- For $140$ GeV $\lesssim m_0 \lesssim 160$ GeV, all two-body $\chi$ decays to sleptons are closed. However, the $\chi_1^+\chi_2^0 \to 3\ell + E_T$ branching fraction is still significant due to relatively light virtual sleptons.
- For $m_0 \gtrsim 170$ GeV, $\chi_1^+$ and $\chi_2^0$ dominantly decay into $q\bar{q}'\chi_1^0$.

For $\mu < 0$ and $m_0 \sim 200$ GeV, $\chi_2^0$ dominantly decays (i) into $\tau\bar{\tau}\chi_1^0$ for $25 \lesssim \tan\beta \lesssim 40$, (ii) into $b\bar{b}\chi_1^0$ for $\tan\beta \simeq 40$, and (iii) into $\tau\tilde{\tau}_1$ for $\tan\beta \gtrsim 40$. For $m_0 \lesssim 300$ GeV and large $\tan\beta \gtrsim 35$, both $\tilde{\tau}_1$ and $b_1$ can be lighter than other sfermions, and $\chi_1^+$ and $\chi_2^0$ can decay dominantly into final states with $\tau$ leptons or $b$ quarks via virtual or real $\tilde{\tau}_1$ and $b_1$. For $m_0 \gtrsim 400$ GeV and $4 \lesssim \tan\beta \lesssim 40$, $B(\chi_2^0 \to \tau^+\tau^-\chi_1^0) \sim B(\chi_2^0 \to e^+e^-\chi_1^0) \sim 2\%$

III. DISCOVERY POTENTIAL AT THE TEVATRON

In this section, we present results from simulations with an event generator and a simple calorimeter including our acceptance cuts. The ISAJET 7.37 event generator program is employed to calculate the $3\ell + E_T$ signal from $\chi_1^+\chi_2^0$ and the dominant backgrounds from $t\bar{t}$ and $WZ$ at the upgraded Tevatron. A calorimeter with segmentation $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ extending to $|\eta| = 4$ is used. An energy resolution of $0.07\frac{\sqrt{E}}{E}$ for the hadronic calorimeter and $0.15\frac{\sqrt{E}}{E}$ for the electromagnetic calorimeter is assumed. Jets are defined to be hadron clusters with $E_T > 15$ GeV in a cone with $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.7$. Leptons with $p_T > 5$ GeV
and within $|\eta| < 2.5$ are considered to be isolated if the hadronic scalar $E_T$ in a cone with $\Delta R = 0.4$ about the lepton is smaller than 2 GeV.

The cuts we implement are very similar to those of recently employed CDF cuts [8].

(i) We require 3 isolated leptons in each event, with

$$p_T(\ell_1) > 12 \text{ GeV}, \ p_T(\ell_2, \ell_3) > 5 \text{ GeV}, \ \text{and}$$

$$|\eta(\ell_1)| < 1.0, \ |\eta(\ell_2, \ell_3)| < 2.4.$$  \hspace{1cm} (1)

(ii) We require $E_T > 25 \text{ GeV}$. This cut removes backgrounds from SM processes such as Drell-Yan dilepton production, where an accompanying jet may fake a lepton.

(iii) To reduce the background from $WZ$ production, we require that the invariant mass of any opposite-sign dilepton pair not reconstruct the $Z$ mass: $|m(\ell\bar{\ell}) - M_Z| > 10 \text{ GeV}$. This cut reduces $WZ$ background to below the 1 fb level.

The surviving total background cross section from $WZ$ and $t\bar{t}$ is about 0.47 fb. The background is mainly due to $WZ$ events, where $Z \rightarrow \tau\bar{\tau}$, with subsequent $\tau$ lepton decays.

The effect of cuts on the signal and background is demonstrated in Table I. The cross sections of the trilepton signal and background after cuts are shown versus $m_{\chi_2}$. The Poisson probability for the SM background to fluctuate to this level is less than 0.4%. For TeV33 with $L = 20 \text{ fb}^{-1}$, we expect about 9 events of background and a 5$\sigma$ signal would be 15 events, which corresponds to a signal cross section of 0.77 fb.

The cross sections of the trilepton signal and background after cuts are shown versus $m_0$ in Figure 3 for $m_{1/2} = 200 \text{ GeV}$ and $\tan \beta = 1.8, 10$ and 35. With $L = 2 \text{ fb}^{-1}$ and $m_{1/2} = 200 \text{ GeV}$, the trilepton signal may be observable for $m_0 \lesssim 350 \text{ GeV}$ with $\tan \beta \sim 1.8$ and for $m_0 \lesssim 150 \text{ GeV}$ with $\tan \beta \sim 10$. With $L = 20 \text{ fb}^{-1}$ and $m_{1/2} = 200 \text{ GeV}$, the trilepton signal may be observable for $m_0 \lesssim 550 \text{ GeV}$ with $\tan \beta \sim 1.8$ and for $m_0 \lesssim 500 \text{ GeV}$ with $\tan \beta \gtrsim 10$. For $180 \text{ GeV} \lesssim m_0 \lesssim 400 \text{ GeV}$ and $10 \lesssim \tan \beta \lesssim 40$, the $\chi_2^0$ decays dominantly into $q\bar{q}\chi_1^0$ and in these regions it will be difficult to establish a supersymmetry signal.

To further assess the discovery potential for the upgraded Tevatron, we present the cross sections of the trilepton signal and background after cuts versus $m_{1/2}$ in Figure 4 for $\mu < 0$, $\tan \beta = 3$ and 35 and $m_0 = 100, 200, 500$ and 1000 GeV. Also shown are the curves for (i) 4 signal events with $L = 2 \text{ fb}^{-1}$ and (ii) a 5$\sigma$ signal with $L = 20 \text{ fb}^{-1}$. The reach in $m_{1/2}$ at the MI and the TeV33 is presented in Tables II and III.

IV. CONCLUSIONS

In some regions of the mSUGRA parameter space, the $\chi_1^\pm$ and the $\chi_2^0$ decay dominantly to final states with $\tau$ leptons. The subsequent leptonic decays of these $\tau$ leptons contribute importantly to the trilepton signal from $\chi_1^\pm\chi_2^0$ associated production. With soft but realistic lepton $p_T$ acceptance cuts, these $\tau \rightarrow \ell$ contributions enhance the trilepton signal by at least
a factor of two. The branching fractions of $\chi_1^\pm$ and $\chi_2^0$ decays into $\tau$ leptons are dominant when the universal scalar mass $m_0$ is less than about 200 GeV and/or $\tan \beta > 40$.

The Tevatron trilepton searches are most sensitive to the region of mSUGRA parameter space with $m_0 \lesssim 100$ GeV and $\tan \beta \lesssim 10$.

- For $m_0 \sim 100$ GeV and $\tan \beta \sim 3$, the trilepton signal should be detectable (i) at the MI if $m_{1/2} \lesssim 260$ GeV, and (ii) at the TeV33 if $m_{1/2} \lesssim 290$ GeV.
- For $m_0 \sim 150$ GeV and $\tan \beta \sim 35$, the trilepton signal should be detectable at the TeV33 if $m_{1/2} \lesssim 170$ GeV.
- For $m_0 \gtrsim 500$ GeV and $\tan \beta \sim 35$, the trilepton signal should be detectable at the TeV33 if $m_{1/2} \lesssim 200$ GeV.

A difficult region for the trilepton search at the upgraded Tevatron is $180$ GeV $\lesssim m_0 \lesssim 400$ GeV with $10 \lesssim \tan \beta \lesssim 35$, because for these parameters $\chi_1^\pm$ and $\chi_2^0$ dominantly decay into $q\bar{q}\chi_1^0$.

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REFERENCES

[1] F.J. Gillman et al., Planning for the Future of U.S. High-Energy Physics, HEPAP Subpanel Report, February, 1998.

[2] D. Amidei and R. Brock et al., Future Electro Weak Physics at the Fermilab Tevatron, Report of the TeV2000 Study Group, April 1996.

[3] H. Baer, K. Hagiwara and X. Tata, Phys. Rev. D35, 1598 (1987); R. Arnowitt and P. Nath, Mod. Phys. Lett. A2, 331 (1987); H. Baer and X. Tata, Phys. Rev. D47, 2739 (1993); T. Kamon, J. Lopez, P. McIntyre and J. T. White, Phys. Rev. D50, 5676 (1994); S. Mrenna, G. Kane, G. D. Kribs and J. D. Wells, Phys. Rev. D53, 1168 (1996).

[4] H. Baer, C. Kao and X. Tata Phys. Rev. D48 (1993) 5175; H. Baer, C-H. Chen, C. Kao and X. Tata Phys. Rev. D52 (1995) 1565; H. Baer, C-H. Chen, F. Paige and X. Tata, Phys. Rev. D54 (1996) 5866.

[5] A.H. Chamseddine, R. Arnowitt and P. Nath, Phys. Rev. Lett. 49 (1982) 970; L. Ibañez and G. Ross, Phys. Lett. B110 (1982) 215; J. Ellis, D. Nanopoulos and K. Tamvakis, Phys. Lett. B121 (1983) 123; L.J. Hall, J. Lykken and S. Weinberg, Phys. Rev. D27 (1983) 2359; L. Alvarez-Gaumé, J. Polchinski and M. Wise, Nucl. Phys. B121 (1983) 495.

[6] F. Abe et al., the CDF collaboration, Phys. Rev. Lett. 76 (1996) 2228.

[7] S. Abachi et al., the DØ collaboration, Phys. Rev. Lett. 76 (1996) 3207.

[8] F. Abe et al., the CDF collaboration, FERMILAB-PUB-98-084-E (1998), e-Print Archive: hep-ex/9803013.

[9] We thank Regina Demina and Teruki Kamon for this information.

[10] H.P. Nilles, Phys. Rep. 110 (1984) 1; H. Haber and G. Kane, Phys. Rep. 117 (1985) 75.

[11] K. Inoue, A. Kakuto, H. Komatsu and H. Takeshita, Prog. Theor. Phys. 68 (1982) 927 and 71 (1984) 413.

[12] P. Langacker and M. Luo, Phys. Rev. D44 (1991) 817; J. Ellis, S. Kelley and D. Nanopoulos, Phys. Lett. B260 (1991) 131; U. Amaldi, W. de Boer and H. Fürstenau, Phys. Lett. B260 (1991) 447; R. Barbieri, talk given at the 18th International Symposium on Lepton-Photon Interactions, Hamburg, Germany, July 1997, [hep-ph/9711233].

[13] V. Barger, M.S. Berger, P. Ohmann, Phys. Rev. D47 (1993) 1093; D49 (1994) 4908; V. Barger, M.S. Berger, P. Ohmann and R.J.N. Phillips, Phys. Lett. B314 (1993) 351.

[14] B. Pendleton and G.G. Ross, Phys. Lett. B98 (1981) 291; C.T. Hill, Phys. Rev. D24 (1981) 691; D.J. Froggatt, R.G. Moorhouse and I.G. Knowles, Phys. Lett. B298 (1993) 356; J. Bagger, S. Dimopoulos and E. Masso, Phys. Rev. Lett. 55 (1985) 920; H. Arason, et al., Phys. Rev. Lett. 67 (1991) 2933; and Phys. Rev. D46 (1992) 3945; P. Langacker, N. Polonsky, Phys. Rev. D50 (1994) 2199; W.A. Bardeen, M. Carena, S. Pokorski and C.E.M. Wagner, Phys. Lett. B320 (1994) 110; M. Carena, M. Olechowsk, S. Pokorski and C.E.M. Wagner Nucl. Phys. B419 (1994) 213; B. Schrempp, Phys. Lett. B344 (1995) 193; B. Schrempp and M. Wimmer, DESY-96-109 (1996), [hep-ph/9606386].

[15] V. Berezinskii et al., Astropart. Phys. 5 (1996) 1; P. Nath and R. Arnowitt, Northeastern Report No. NUB-TH-3151-97, (1997), [hep-ph/9701301].

[16] J. Ellis and F. Zwirner, Nucl. Phys. B338 (1990) 317; G. Ross and R.G. Roberts, Nucl. Phys. B377 (1992) 571; R. Arnowitt and P. Nath, Phys. Rev. Lett. 69 (1992) 725; M. Drees and M.M. Nojiri, Nucl. Phys. B369 (1993) 54; S. Kelley et. al., Nucl. Phys.
B398 (1993) 3; M. Olechowski and S. Pokorski, Nucl. Phys. B404 (1993) 590; G. Kane, C. Kolda, L. Roszkowski and J. Wells, Phys. Rev. D49 (1994) 6173; D.J. Castaño, E. Piard and P. Ramond, Phys. Rev. D49 (1994) 4882; W. de Boer, R. Ehret and D. Kazakov, Z. Phys. 67 (1995) 647; H. Baer, M. Drees, C. Kao, M. Nojiri and X. Tata, Phys. Rev. D 50 (1994) 2148; H. Baer, C.-H. Chen, R. Munroe, F. Paige and X. Tata, Phys. Rev. D 51 (1995) 1046.

[17] M.S. Alam et al., the CLEO Collaboration, Phys. Rev. Lett. 74 (1995) 2885.

[18] R. Barate et al., the ALEPH Collaboration, CERN Report CERN-EP-98-044 (1998).

[19] P. Nath and R. Arnowitt, Phys. Lett. B336 (1994) 395; Phys. Rev. Lett. 74 (1995) 4592; Phys. Rev. D54 (1996) 2374; F. Borzumati, M. Drees and M. Nojiri, Phys. Rev. D51 (1995) 341; H. Baer and M. Brhlik, Phys. Rev. D55 (1997) 3201; H. Baer, M. BrhliK, D. Castano and X. Tata, Florida State University Report FSU-HEP-971104 (1997), e-Print Archive: hep-ph/9711230.

[20] H. Baer, C.-H. Chen, M. Drees, F. Paige and X. Tata, Florida State University Report FSU-HEP-980204 (1998), e-Print Archive: hep-ph/9802441.

[21] J.D. Wells, Stanford Linear Accelerator Center Report SLAC-PUB-7788 (1998), e-Print Archive: hep-ph/9804242.

[22] F. Paige and S. Protopopescu, in Supercollider Physics, ed. D. Soper (World Scientific, 1986); H. Baer, F. Paige, S. Protopopescu and X. Tata, in Proceedings of the Workshop on Physics at Current Accelerators and Supercolliders, ed. J. Hewett, A. White and D. Zeppenfeld, (Argonne National Laboratory, 1993), hep-ph/9305312; ISAJET 7.37: A Monte Carlo Event Generator for pp, pp, and e+e− Reactions, Bookhaven National Laboratory Report BNL-HET-98-18 (1998), e-Print Archive: hep-ph/9804321.
TABLE I. The effect of cuts on the trilepton signal (with $m_{1/2} = 200$ GeV, $m_0 = 100$ GeV) and the background from $WZ$ and $t\bar{t}$ at the upgraded Tevatron: (a) No Cuts; (b) Soft Cuts: $p_T(\ell_1) > 12$ GeV, $\eta(\ell_1) < 1.0$, $p_T(\ell_2, \ell_3) > 5$ GeV, $\eta(\ell_2, \ell_3) < 2.4$, $|E_T| < 2$ GeV, and $|M_\ell - M_Z| > 10$ GeV; (c) Hard Cuts: $p_T(\ell_1) > 20$ GeV, $p_T(\ell_2) > 15$ GeV, $p_T(\ell_3) > 10$ GeV, $|\eta(\ell')| < 2.5$, $|E_T| < p_T(\ell)/4$, and $|M_\ell - M_Z| > 10$ GeV.

| Case \ $\tan\beta$ | 3  | 10 | 15 | 20 | 25 | $WZ$ | $t\bar{t}$ |
|---------------------|----|----|----|----|----|------|----------|
| No Cuts             | 40 | 14 | 8.9| 7.4| 6.9| 37   | -        |
| Soft Cuts           | 12 | 2.6| 1.1| 0.67|0.21|0.40 | 0.073   |
| Hard Cuts           | 6.1| 1.2| 0.44|0.16|0.0028|0.28 | 0.041   |

TABLE II. The anticipated $m_{1/2}$ reach (in GeV) from a trilepton search at the upgraded Tevatron with $L = 2$ fb$^{-1}$ (MI) for various values of $\tan\beta$ and $m_0$. Note that, for $m_0 < 400$ GeV, the trilepton cross section is too small for discovery, especially if $10 < \tan\beta < 40$.

| $\tan\beta$ | $m_0$(GeV) = 100 | 200 | 500 | 1000 |
|--------------|------------------|-----|-----|------|
| 3            | $m_{1/2}$(GeV) = 260 | 200 | 130 | 150  |
| 35           | $m_{1/2}$(GeV) = < 100 | < 100 | 160 | 190  |

TABLE III. The anticipated $m_{1/2}$ reach (in GeV) from a trilepton search at the upgraded Tevatron with $L = 20$ fb$^{-1}$ (TeV33) for various values of $\tan\beta$ and $m_0$.

| $\tan\beta$ | $m_0$(GeV) = 100 | 200 | 500 | 1000 |
|--------------|------------------|-----|-----|------|
| 3            | $m_{1/2}$(GeV) = 290 | 230 | 170 | 200  |
| 35           | $m_{1/2}$(GeV) = 160 | 110 | 200 | 230  |
FIG. 1. Cross section of $p\bar{p} \rightarrow \chi^+ \chi^- \rightarrow 3\ell's + X$ without cuts at $\sqrt{s} = 2$ TeV verses $\tan\beta$, with $\mu < 0$, $m_{1/2} = 200$ GeV, $m_0 = 100$ GeV for 4 final states: (a) $\tau\tau\tau$ (solid), (b) $\tau\tau\ell$ (dot-dash), (c) $\tau\ell\ell$ (dash) and (d) $\ell\ell\ell$ (dot), where $\ell = e$ or $\mu$. 

$\sqrt{s} = 2.0$ TeV, $\mu < 0$, $m_{1/2} = 200$ GeV

(a) $m_0 = 100$ GeV

(b) $m_0 = 200$ GeV
FIG. 2. Branching fractions of $\chi_0^2$ and $\chi_1^\pm$ decays into various channels versus $\tan \beta$ with $m_{1/2} = 200$ GeV, for $m_0 = 100$ GeV [(a) and (c)] as well as $m_0 = 200$ GeV [(b) and (d)].
$\sqrt{s} = 2.0$ TeV, $\mu < 0$, $m_{1/2} = 200$ GeV, with cuts

\[ \sigma(\bar{p}p \rightarrow \chi_1^\pm \chi_2^0 \rightarrow 3\ell + X) \text{ (fb)} \]

\[ \tan \beta = 1.8 \quad \text{TeV33: } 5\sigma \quad \text{Background: } W^+Z^0 \]

\[ \tan \beta = 35 \quad \tan \beta = 10 \]

\[ \text{MI: } 4 \text{ events} \]

FIG. 3. Cross section of $\bar{p}p \rightarrow \chi_1^\pm \chi_2^0 \rightarrow 3\ell + X$ at $\sqrt{s} = 2$ TeV versus $m_0$, with soft cuts (Eq. [1]), for $m_{1/2} = 200$ GeV, $\mu < 0$ and $\tan \beta = 1.8$ (solid), 10 (dash) and 35 (dot-dash). Also noted is the cross section of background from $WZ$ (dot-dash), for 5 events with $L = 2$ fb$^{-1}$ (dot) and for 5 $\sigma$ with $L = 20$ fb$^{-1}$ (dash).
$\sqrt{s} = 2.0$ TeV, $\mu < 0$, with cuts

(a) $\tan \beta = 3$  
(b) $\tan \beta = 35$

FIG. 4. Cross section of $p\bar{p} \rightarrow \chi_1^\pm \chi_2^0 \rightarrow 3\ell + X$ at $\sqrt{s} = 2$ TeV, with soft cuts versus $m_{1/2}$, with (a) $\tan \beta = 3$ and (b) $\tan \beta = 35$, for $m_0 = 100$ GeV (solid), 200 GeV (dot-dash), 500 GeV (dash) and 1000 GeV (dot). Also noted is the cross section for 5 events with $L = 2$ fb$^{-1}$ (dot) and 5 $\sigma$ for $L = 20$ fb$^{-1}$ (dash).