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Abstract

We study the supersymmetry reach of the Tevatron in channels containing both isolated leptons and identified tau jets. In the most challenging case, where the tau branching ratios of the gauginos dominate, we find that searches for two isolated leptons, one identified tau jet and large amount of missing transverse energy have a much better reach than the classic clean trilepton signature. With total integrated luminosity of L $\gtrsim$ 4 fb^{-1}, the Tevatron will start extending the expected LEP-II reach for supersymmetry.

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1 Introduction

Searches for supersymmetry (SUSY) in Run I of the Tevatron have been done exclusively in channels involving some combination of leptons, jets, photons and missing transverse energy ($\not{E}_T$) [1]. At the same time, several Run I analyses have identified hadronic tau jets, e.g. in W-production [2] and top decays [3]. Hadronically decaying taus have also been used to place limits on a charged Higgs [4] and leptoquarks [5]. Since tau identification is expected to improve further in Run II, this raises the question whether SUSY searches in channels involving tau jets are feasible.

SUSY signatures with tau leptons are very well motivated, since they arise in a variety of models of low-energy supersymmetry, e.g. gravity-mediated [6, 7, 8] or the minimal gauge-mediated models [8, 9]. In this letter we shall study all possible *experimental* signatures with three identified objects (leptons or tau jets) plus $\not{E}_T$, and compare their reach to the clean trilepton channel [10, 11]. In evaluating the physics potential of the future Tevatron runs in these new tau channels, it is important to be aware not only of the physical backgrounds, but also of the experimental realities. Jets faking taus will comprise a significant fraction of the background, and it is crucial to have a reliable estimate of that rate, which requires a detailed Monte Carlo analysis. We use PYTHIA and TAUOLA for event generation and the SHW package [12], which provides the most realistic detector simulation available to theorists as of today.

2 Motivation

The classic SUSY signature at the Tevatron is the clean $3l\,\not{E}_T$ channel. It arises in the decays of gaugino-like chargino-neutralino pairs $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$. The reach is somewhat limited by the rather small leptonic branching fractions. In the limit where the squarks and sleptons are either very heavy, or comparable in mass, the leptonic branching ratios of $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ are W-like and Z-like, respectively. However, both gravity-mediated and gauge-mediated models of SUSY breaking allow the sleptons to be much lighter than the squarks, thus enhancing the leptonic branching fractions of the gauginos.

There are at least three generic reasons as to why one may expect light sleptons in the spectrum. First, the slepton masses at the high-energy (GUT or messenger) scale may be rather small to begin with. This is typical for gauge-mediated models, since the sleptons are colorless and do not receive large soft mass contributions proportional to the strong coupling constant α_s. This argument applies to all slepton flavors, including staus. The minimal gravity-mediated (mSUGRA) models, on the other hand, predict light sleptons if the universal scalar mass M_0 is much smaller than the universal gaugino mass $M_{1/2}$. Various effects (non-flat Kahler metric, renormalization group (RG) running above the unification scale $M_{\rm GUT}$, D-terms from extra $U(1)$ gauge factors, etc.) may induce nonuniversalities in the scalar masses at $M_{\rm GUT}$, in which case the slepton-squark mass hierarchy can be affected. In the absence of a specific model, we do not know which way these splittings will go, but as long as the soft scalar masses are small, the RG running down to the weak scale will naturally induce an additional splitting between the squarks and the sleptons, making the latter lighter. Second, the RG equations for the scalar soft masses contain terms proportional to Yukawa couplings, which tend to reduce the corresponding mass during the evolution down to low-energy scales. This effect is significant for third generation scalars, and for large values of $\tan\beta$ (the ratio of the Higgs vacuum expectation values v_2 and v_1) splits the staus from the first two generation sleptons. And finally, the mixing in the charged slepton mass matrix further reduces the mass of the lightest eigenstate. The slepton mixing is enhanced at large $\tan\beta$, since it is proportional to $\mu m_l \tan\beta/m_{\tilde{l}}^2$, where m_l ($m_{\tilde{l}}$) is the lepton (slepton) mass and μ is the supersymmetric Higgs mass parameter. Notice that this effect again only applies to the staus, since $m_\tau \gg m_{\mu,e}$.

Due to these three effects, it may very well be that among all scalars, only the lightest sleptons from each generation (or just the lightest stau $\tilde{\tau}_1$) are lighter than $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$. Indeed, in both gravity-mediated and gauge-mediated models one readily finds regions of parameter space where either $m_{\tilde{\chi}_1^0} < m_{\tilde{\tau}_1} \sim m_{\tilde{\mu}_R} < m_{\tilde{\chi}_1^+}$ (typically at small $\tan\beta$) or $m_{\tilde{\chi}_1^0} < m_{\tilde{\tau}_1} < m_{\tilde{\chi}_1^+} < m_{\tilde{\mu}_R}$ (at large $\tan\beta$). Depending on the particular model, and the values of the parameters, the gaugino pair decay chain may then end up overwhelmingly in *any one* of the four final states: lll, $ll\tau$, $l\tau\tau$ or $\tau\tau\tau$.

2.1 Tau Jets

In order to make a final decision as to which experimental signatures are most promising, we have to factor in the tau branching ratios to leptons and jets. About two-thirds of the subsequent tau decays are hadronic, so it appears advantageous to consider signatures with tau jets in the final state as alternatives to the clean trilepton signal. (From now on, we shall use the following terminology: a "lepton" (l) is either a muon or an electron; a tau is a tau-lepton, which can later decay either leptonically, or to a hadronic tau jet, which we denote by τ_h.) We show the branching ratios for three leptons or undecayed taus into a final state containing leptons and tau jets, in Table 1. We see that the presence of

Experimental signature	Trilepton SUSY signal			
	$\tau\tau\tau$	$\tau\tau l$	$\tau l l$	lll
$\tau_h\tau_h\tau_h$	0.268	—	—	—
$l\ \ \tau_h\tau_h$	0.443	0.416	—	—
$l\ \ l\ \ \tau_h$	0.244	0.458	0.645	—
$l\ \ l\ \ l$	0.045	0.126	0.355	1.00

Table 1: Branching ratios of the four possible SUSY signals into the corresponding experimental signatures involving final state leptons l (electrons or muons) as well as identified tau jets (τ_h).

taus in the underlying SUSY signal always leads to an enhancement of the signatures with tau jets in comparison to the clean trileptons. This disparity is most striking for the case of $\tau\tau\tau$ decays, where $BR(\tau\tau\tau \to ll\tau_h)/BR(\tau\tau\tau \to lll) \sim 5.5$. An additional advantage of the tau jet channels is that the leptons from tau decays are much softer than the tau jets and as a result will have a relatively low reconstruction efficiency.

On the other hand, the tau jet channels suffer from larger backgrounds than the clean trileptons. The physical background (from *real* tau jets in the event) is actually smaller, but a significant part of the background is due to events containing narrow isolated QCD jets with the correct track multiplicity, which can be misidentified as taus. The jetty signatures are also hurt by the lower detector efficiency for tau jets than for leptons. The main goal of our study, therefore, will be to see what is the net effect of all these factors, on a channel by channel basis.

2.2 A Challenging Scenario

For our analysis we choose to examine one of the most challenging scenarios for SUSY discovery at the Tevatron. We shall assume the typical large $\tan\beta$ mass hierarchy $m_{\tilde{\chi}_1^0} < m_{\tilde{\tau}_1} < m_{\tilde{\chi}_1^+} < m_{\tilde{\mu}_R}$, so that $BR(\tilde{\chi}_1^+\tilde{\chi}_2^0 \to \tau\tau\tau + X) \simeq 100\%$. In order to shy away from specific model dependence, we shall ignore all SUSY production channels other than $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ pair production. The p_T spectrum of the taus resulting from the chargino and neutralino decays depends on the mass differences $m_{\tilde{\chi}_1^+} - m_{\tilde{\tau}_1}$ and $m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0}$. The larger they are, the harder the spectrum, and the better the detector efficiency. However, as the mass difference gets large, the $\tilde{\chi}_1^+$ and $\tilde{\chi}_2^0$ masses themselves become large too, so the production cross-section is severely suppressed. Therefore, at the Tevatron we can only explore regions with favorable mass ratios and at the same time small enough gaugino masses. This dictates our choice of SUSY mass ratios: for definiteness we fix $2m_{\tilde{\chi}_1^0} \sim (4/3)\ m_{\tilde{\tau}_1} \sim m_{\tilde{\chi}_1^+} (< m_{\tilde{\mu}_R})$ throughout the analysis, and vary the chargino mass. The rest of the superpartners have fixed masses corresponding to the mSUGRA point $M_0 = 180$ GeV, $M_{1/2} = 180$ GeV, $A_0 = 0$ GeV, $\tan\beta = 44$ and $\mu > 0$. With this choice we are not constrained to mSUGRA models only. Our analysis will apply equally to gauge-mediated models with a long-lived neutralino NLSP, as long as the relevant gaugino and slepton mass relations are similar. Note that our choice of heavy first two generation sleptons is very conservative. A more judicious choice of their masses, namely $m_{\tilde{\mu}_R} < m_{\tilde{\chi}_1^+}$, would lead to a larger fraction of trilepton events, and as a result, a higher reach. Furthermore, the gauginos would then decay via two-body modes to first generation sleptons, and the resulting lepton spectrum would be much harder, leading to a higher lepton efficiency. Notice also that the $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production cross-section is sensitive to the squark masses, but since this is the only production process we are considering, our results can be trivially rescaled to account for a different choice of squark masses, or to include other production processes as well.

Since the four experimental signatures in our analysis contain only soft leptons and tau jets, an important issue is whether one can develop efficient combinations of Level 1 and Level 2 triggers to accumulate these data sets without squandering all of the available bandwidth. We will not attempt to address this issue here; instead we will assume 100% trigger efficiency for those signal events *which pass all of our analysis and acceptance cuts*. A dedicated low p_T tau trigger for Run II, which may be suitable for the new tau jet channels, is now being considered by CDF [13].

3 Analysis

We used PYTHIA v6.115 and TAUOLA v2.5 for event generation. We used the SHW v2.2 detector simulation package, which simulates an average of the CDF and D0 Run II detector performance. In SHW tau objects are defined as jets with $|\eta| < 1.5$, net charge ± 1, one or three tracks in a 10 degree cone with no additional tracks in a 30 degree cone, $E_T > 5$ GeV, $p_T > 5$ GeV, plus an electron rejection cut. SHW electrons are required to have $|\eta| < 2.0$, $E_T > 5$ GeV, hadronic to electromagnetic energy deposit ratio $R_{h/e} < 0.125$, and satisfy standard isolation cuts. Muon objects are required to have $|\eta| < 1.5$, $E_T > 3$ GeV and are reconstructed using Run I efficiencies. We use standard isolation cuts for muons as well. Jets are required to have $|\eta| < 4$, $E_T > 15$ GeV. In addition we have added jet energy correction for muons and the rather loose id requirement $R_{h/e} > 0.1$. We have also modified the TAUOLA program in order to correctly account for the chirality of tau leptons coming from SUSY decays.

The reconstruction algorithms in SHW already include some basic cuts, so we can define an SHW reconstruction efficiency ϵ_{rec} for the various types of objects: electrons, muons, tau jets etc. We find that as we vary the chargino mass from 100 to 140 GeV the electron and tau jet reconstruction efficiencies for the signal range from 42 to 49 %, and from 29 to 36%, correspondingly. The lepton efficiency may seem surprisingly low, but this is because a lot of our leptons are very soft and fail the E_T cut. The tau efficiency is in good agreement with the results from Ref. [14] and [15], once we account for the different environment, as well as cuts used in those analyses.

The most important background issue in the new tau channels is the fake tau rate. Several experimental analyses try to estimate it using Run I data. Here we simulate the corresponding backgrounds to our signal and use SHW to obtain the fake rate, thus avoiding trigger bias [14]. We have also checked that the SHW tau fake rate in W production is in overall agreement with the findings of Refs. [14, 15].

3.1 Cuts

We use somewhat looser (compared to Run I) rapidity cuts on the central leptons and tau jets, since we expect that the tracking coverage will be better in Run II. Here we list our cuts for each channel.

As discussed earlier, we expect that the reach in the classic $lll\not{E}_T$ channel will be quite suppressed, due to the softness of the leptons. Therefore we apply the soft cuts advertised in Refs. [10]. We require a central lepton with $p_T > 11$ GeV and $|\eta| < 1.0$, and in addition two more leptons with $p_T(l_2) > 7$ GeV, $|\eta(l_2)| < 2.0$ and $p_T(l_3) > 5$ GeV, $|\eta(l_3)| < 2.0$. Leptons are required to be isolated: $I(l) < 2$ GeV, where I is the total transverse energy contained in a cone of size $\delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} = 0.4$ around the lepton. We impose a dilepton invariant mass cut for same flavor, opposite sign leptons: $|m_{ll} - M_Z| > 10$ GeV and $|m_{ll}| > 10$. Finally, we impose an optional veto on additional jets and require $\not{E}_T$ to be either more than 20 GeV, or 25 GeV. This gives us a total of four combinations of the $\not{E}_T$ cut and the jet veto (A: $\not{E}_T > 20$ GeV, no jet veto; B: $\not{E}_T > 25$ GeV, no jet veto; C: $\not{E}_T > 20$ GeV, with jet veto; D: $\not{E}_T > 25$ GeV, with jet veto), which we apply for all tau jet signatures later as well.

For our $ll\tau_h\ \not{E}_T$ analysis we impose cuts similar to the stop search analysis in the $l^+l^-j\ \not{E}_T$ channel [16]: two isolated ($I(l) < 2$ GeV) central ($|\eta| < 1.5$) leptons, with $p_T(l_1) > 8$ GeV and $p_T(l_2) > 5$ GeV; one identified hadronic tau jet with $|\eta| < 1.5$ and $p_T(\tau_h) > 15$ GeV. Again, we impose invariant mass cuts $|m_{ll} - m_Z| > 10$ GeV and $|m_{ll}| > 10$ for any same flavor, opposite sign dilepton pair.

A separate, very interesting signature arises if the two leptons have the same sign, since the background is greatly suppressed. In fact, we expect this background to be significantly smaller than the trilepton background! Roughly one third of the signal events in the general $ll\tau_h$ sample are expected to have like-sign leptons.

For our $l\tau_h\tau_h\ \not{E}_T$ analysis we use some basic identification cuts: two central ($|\eta(\tau)| < 1.5$) tau jets, with $p_T(\tau_1) > 15$ GeV and $p_T(\tau_2) > 10$ GeV; one isolated lepton with $p_T(l) > 7$ GeV and $|\eta| < 2.0$.

Finally, for the $\tau_h\tau_h\tau_h\ \not{E}_T$ signature we require three central ($|\eta| < 1.5$) tau jets, with $p_T(\tau_1) > 15$ GeV, $p_T(\tau_2) > 10$ GeV and $p_T(\tau_3) > 8$ GeV.

3.2 Signal

One can get a good idea of the relative importance of the different channels by looking at the corresponding signal samples after the analysis cuts have been applied. In Fig. 1 we show the signal cross-sections times the corresponding branching ratios times the total efficiency $\epsilon_{tot} \equiv \epsilon_{rec}\epsilon_{cuts}$, which accounts for both the detector acceptance ϵ_{rec} and the efficiency of the cuts ϵ_{cuts} (for each signal point we generated 10^5 events). We see that the lines are roughly ordered according to the branching ratios from Table 1. This can be understood as follows. The acceptance (which includes the basic ID cuts in SHW) is higher for leptons than for τ jets. Therefore, replacing a lepton with a tau jet in the experimental signature costs us a factor of ~ 1.5 in acceptance, due to the poorer reconstruction of tau jets, compared to leptons. Later, however, the cuts tend to reduce the leptonic signal more than the tau jet signal. This is mostly because the leptons are softer than the tau jets. Notice that we cannot improve the efficiency for leptons by further lowering the cuts – we are already using the most liberal cuts [10]. It turns out

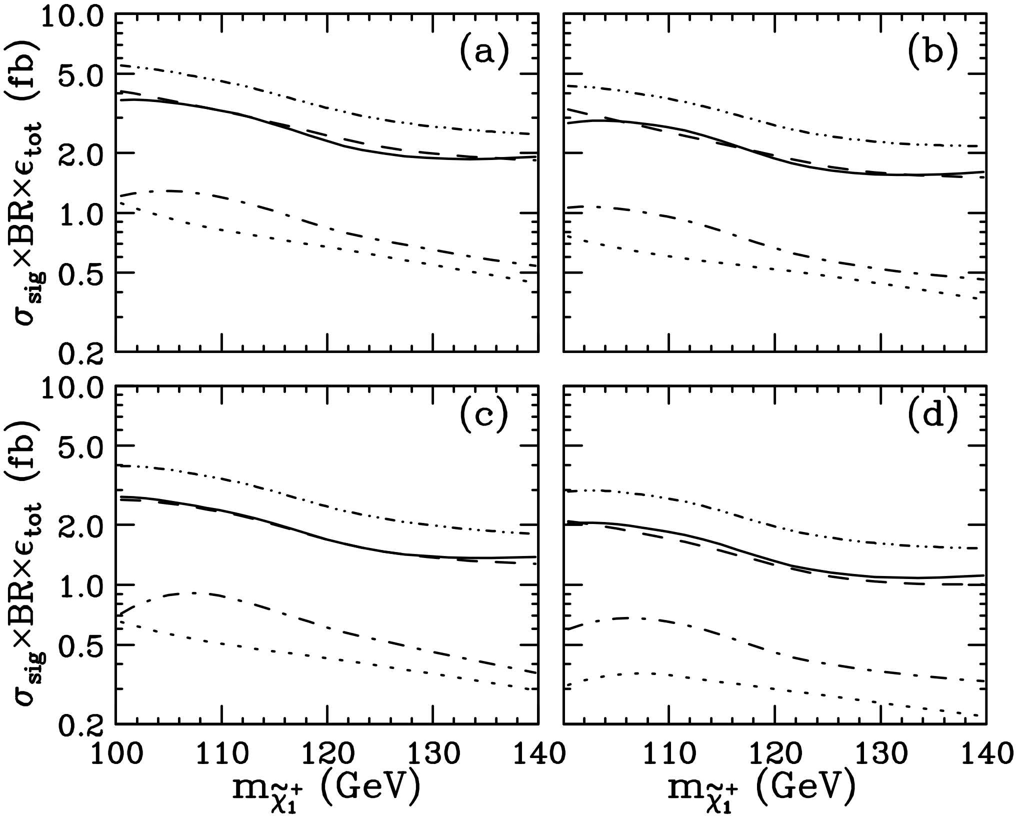

Figure 1: Signal cross-section times branching ratio after cuts for the five channels discussed in the text: $lll\ \not{E}_T$ (dotted), $ll\tau_h\ \not{E}_T$ (dashed), $l^+l^+\tau_h\ \not{E}_T$ (dot dashed), $l\tau_h\tau_h\not{E}_T$ (dot dot dashed) and $\tau_h\tau_h\tau_h\not{E}_T$ (solid); and for various sets of cuts: (a) cuts A, (b) cuts B, (c) cuts C and (d) cuts D.

that these two effects mostly cancel each other, and the total efficiency ϵ_{tot} is roughly the same for all channels. Therefore the relative importance of each channel will only depend on the tau branching ratios and the backgrounds. For example, in going from lll to $ll\tau_h$, one wins a factor of 5.5 from the branching ratio. Therefore the background to $l\tau_h\tau_h\not{E}_T$ must be at least $5.5^2 \sim 30$ times larger in order for the clean trilepton channel to be still preferred.

3.3 Backgrounds

We next turn to the discussion of the backgrounds involved. We have simulated the following physics background processes: ZZ, WZ, WW, $t\bar{t}$, $Z + jets$, and $W + jets$, generating 10^6, 10^6, 10^6, 10^6, 10^7 and 10^7 events, respectively. We list the results in Table 2, where we show the total background cross-section σ_{BG} for each case A-D, as well as the contributions from the individual processes, for case A. All errors are purely statistical. A few comments are in order.

σ_{BG} (fb)	$ll\not{E}_T$	$ll\tau_h\not{E}_T$	$l^+l^+\tau_h\not{E}_T$	$l\tau_h\tau_h\not{E}_T$	$\tau_h\tau_h\tau_h\not{E}_T$
ZZ	0.130 ± 0.012	0.199 ± 0.015	0.059 ± 0.008	0.181 ± 0.027	0.098 ± 0.020
WZ	1.058 ± 0.052	1.087 ± 0.053	0.447 ± 0.034	1.006 ± 0.051	0.248 ± 0.025
WW	—	0.416 ± 0.061	—	0.681 ± 0.078	0.177 ± 0.039
$t\bar{t}$	0.300 ± 0.057	1.543 ± 0.128	0.139 ± 0.038	1.039 ± 0.105	0.161 ± 0.041
$Z + jets$	0.062 ± 0.044	4.09 ± 0.36	0.094 ± 0.054	11.34 ± 0.59	10.0 ± 0.56
$W + jets$	—	—	—	37.2 ± 2.9	6.1 ± 1.2
total (A)	1.55 ± 0.09	7.3 ± 0.4	0.74 ± 0.07	51 ± 3	16.8 ± 1.3
total (B)	1.39 ± 0.09	5.7 ± 0.3	0.67 ± 0.07	42 ± 3	12.6 ± 1.2
total (C)	0.91 ± 0.06	4.1 ± 0.3	0.41 ± 0.04	34 ± 2	9.2 ± 1.0
total (D)	0.79 ± 0.04	3.0 ± 0.2	0.35 ± 0.03	28 ± 2	6.9 ± 0.9

Table 2: Total background cross-section after cuts σ_{BG} (in fb) for the various channels in cases A-D, as well as the breakdown of the individual contributions for case A.

1. WZ is indeed the major source of background for the trilepton channel. About half of the background events contain a leptonically decaying off-shell Z/γ and pass the invariant dilepton mass cut. The rest of the WZ background comes from $Z \to \tau^+\tau^- \to l^+l^- \not{E}_T$. Then, as we move to the channels with tau jets, the number of events with *real* taus decreases: first, because of the smaller branching ratios of W and Z to taus; and second, because the tau jets are *softer* than the leptons from W and Z decays. This is to be contrasted with the signal, where, conversely, the tau jets are harder than the leptons. However, the contribution from events with fake taus (from hadronically decaying W's and Z's or from initial and final state jet radiation) increases, and for the 3τ channel events with fake taus are the dominant part of the WZ background.

2. Notice that the WZ background to the same-sign dilepton channel is smaller (by a factor of two) than for the trilepton channel. As expected, it is also about a half of the total contribution to $ll\tau$ (recall that for the signal this ratio is only a third). Indeed, one third of the events have opposite sign leptons coming from the Z-decay and are cut away by the dilepton mass cut.

3. Vetoing a fourth lepton in the event reduces the ZZ background to the trilepton channel only by 4–8 % (depending on the sample A–D). The ZZ trilepton background is due to one Z decaying as $Z \to \tau\tau$, thus providing the missing energy in the event, and the other (off-shell) Z decaying to leptons: $Z \to l^+l^-$. More often, both of these leptons are reconstructed, and the third lepton comes from a leptonic tau decay. Then, however, it is about 6 times more probable that the second tau would decay hadronically and will not give a fourth lepton. In the rest of the ZZ background events one of the leptons from the Z is missed, and the invariant mass cut does not apply. For those events, there is obviously no fourth lepton.

4. The jet veto is very effective in eliminating the $t\bar{t}$ background for the first three channels. However, it also reduces the signal (see Fig. 1).

5. In all channels, a higher $\not{E}_T$ cut did not help to get rid of the major backgrounds. Indeed, WZ, $t\bar{t}$ and/or $W + jets$ tend to have a lot of missing energy, due to the leptonic W-decays.

6. Our result for the $Z+jets$ background should be taken with a grain of salt, in spite of the relatively small statistical errors. Events with fake leptons are expected to comprise a major part of this background, and SHW does not provide a realistic simulation of those. In fact, the most reliable way to estimate this background will be from Run II data, e.g. by estimating the probability for an isolated track from Drell-Yan events, and the lepton fake rate per isolated track from minimum bias data [17].

7. We have underestimated the total background to the three-jet channel by considering only processes with at least one real tau in the event. We expect sizable contributions from pure QCD multijet events, or $Wj \to jjj$, where *all three* tau jets are fake.

Our simulated background in the trilepton channel is higher than the values found in Refs. [7, 10], which employed ISAJET instead of PYTHIA.

3.4 Tevatron reach

A 3σ exclusion limit would require a total integrated luminosity

$$L = \frac{9\sigma_{BG}}{\left(\sigma_{sig}\ BR(\tilde{\chi}_1^+\tilde{\chi}_2^0 \to X)\ \epsilon_{tot}\right)^2}. \qquad (1)$$

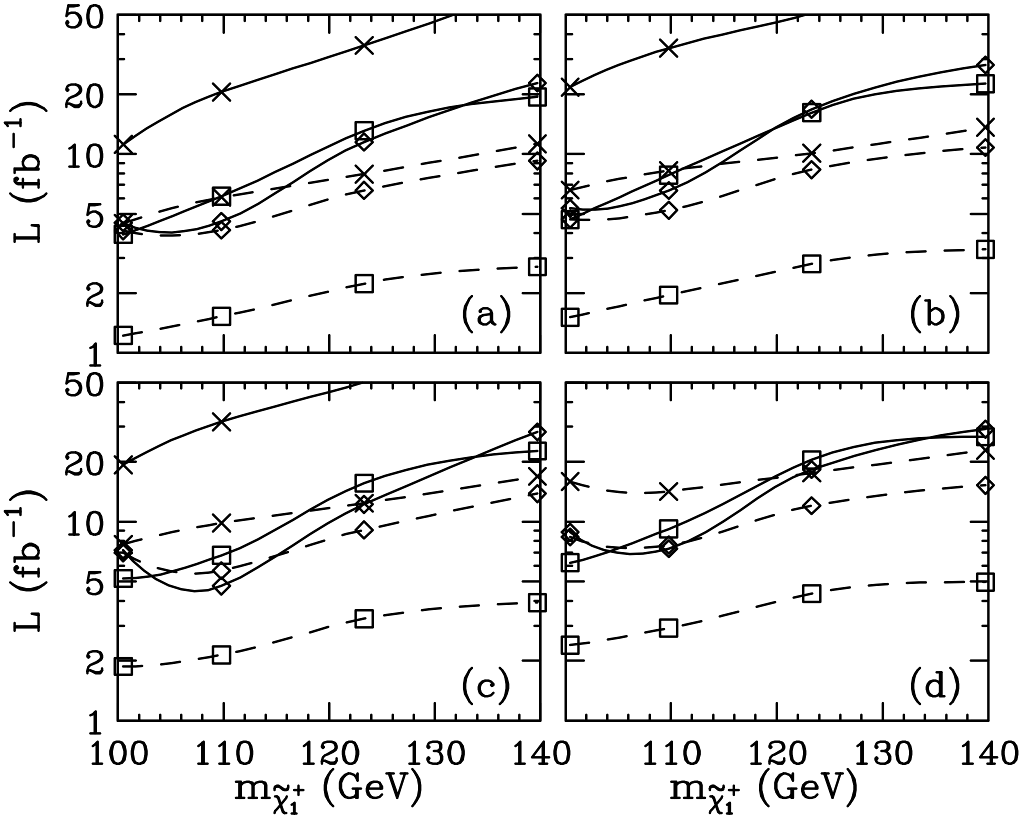

Figure 2: The total integrated luminosity L needed for a 3σ exclusion (solid lines) or observation of 5 signal events (dashed lines), as a function of the chargino mass $m_{\tilde{\chi}_1^+}$, for the three channels: $lll\ \not{E}_T$ ($\times$), $ll\tau_h\ \not{E}_T$ ($\square$) and $l^+l^+\tau_h\not{E}_T$ ($\diamond$); and for various sets of cuts: (a) cuts A; (b) cuts B; (c) cuts C and (d) cuts D.

Notice that the luminosity limit depends linearly on the background σ_{BG} after cuts, but *quadratically* on the signal branching ratios. This allows the jetty channels to compete very successfully with the clean trilepton signature, whose branching ratio is quite small (see table 1). In Fig. 2 we show the Tevatron reach in the three channels: trileptons ($\times$), dileptons plus a tau jet ($\square$) and like-sign dileptons plus a tau jet ($\diamond$). We see that the two channels with tau jets have a much better sensitivity compared to the usual trilepton signature. Assuming that efficient triggers can be implemented, the Tevatron reach will start exceeding LEP II limits as soon as Run II is completed. Considering the intrinsic difficulty of the SUSY scenario we are contemplating, the mass reach for Run III is quite impressive. One should also keep in mind that we did not attempt to optimize our cuts for the new channels. For example, one could use angular correlation cuts to suppress Drell-Yan, which is the major source of background for $ll\tau_h\not{E}_T$, or use (chargino) mass–dependent p_T cuts for the leptons and tau jets, to squeeze out some extra reach.

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References

[1] For a review, see M. Carena, R. Culbertson, S. Eno, H. Frisch and S. Mrenna, preprint ANL-HEP-PR-97-98, `hep-ex/9712022`.

[2] F. Abe *et al.*, Phys. Rev. Lett. **68**, 3398 (1992); A. Kotwal, ICHEP'98 Proceedings, Vancouver, Canada, July 23-29, 1998; S. Protopopescu, preprint FERMILAB-CONF-98-376-E.

[3] M. Hohlmann, preprint FERMILAB-CONF-96-330-E; F. Abe *et al.*, Phys. Rev. Lett. **79**, 3585 (1997).

[4] F. Abe *et al.*, Phys. Rev. **D54**, 735 (1996); Phys. Rev. Lett. **79**, 357 (1997).

[5] F. Abe *et al.*, Phys. Rev. Lett. **78**, 2906 (1997); preprint FERMILAB-PUB-98-352-E.

[6] H. Baer, C.-H. Chen, M. Drees, F. Paige and X. Tata, Phys. Rev. Lett. **79**, 986 (1997).

[7] H. Baer, C.-H. Chen, M. Drees, F. Paige and X. Tata, Phys. Rev. **D58**, 075008 (1998).

[8] J. Wells, Mod. Phys. Lett. **A13**, 1923 (1998).

[9] B. Dutta, D. J. Muller and S. Nandi, preprint OSU-HEP-98-4; D. Muller and S. Nandi, preprint OSU-HEP-98-8,

[10] V. Barger, C. P. Kao and T.-J. Li, Phys. Lett. **B433**, 328 (1998); V. Barger and C. P. Kao, preprint FERMILAB-PUB-98-342-T, `hep-ph/9811489`.

[11] F. Abe *et al.*, preprint FERMILAB-PUB-98/084-E, `hep-ex/9803015`; B. Abbott *et al.*, Phys. Rev. Lett. **80**, 1591 (1998).

[12] J. Conway, talk given at the SUSY/Higgs Workshop meeting, Fermilab, May 14-16, 1998 , additional information available at `www.physics.rutgers.edu/~jconway/soft/shw/shw.html`.

[13] Y. Seiya, talk given at the SUGRA working group meeting as part of the SUSY/Higgs Workshop, Fermilab, September 3, 1998; A. Savoy-Navarro, talk given at the SUSY/Higgs Workshop meeting, Fermilab, November 19-21, 1998.

[14] M. Hohlmann, Univ. of Chicago Ph.D. Thesis, 1997.

[15] L. Groer, Rutgers University Ph.D. Thesis, 1998.

[16] R. Demina, talk given at the SUSY/Higgs Workshop meeting, Fermilab, November 19-21, 1998.

[17] J. Nachtman, private communication.