

Signatures of Gauge Mediated Supersymmetry Breaking Models at the Tevatron

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We consider the scenarios of the GMSB models in which the dominant signal for supersymmetry at the Tevatron are the events having two or three τ leptons with high p_T accompanied by large missing transverse energy. This signal is very different from the multijet or multileptons (involving e and/or μ only) in the usual supergravity models or the photonic signals in the GMSB models (where the lightest neutralino is the next to lightest supersymmetric particle (NLSP)). The parameter space where the lighter stau is the NLSP allows this possibility. We find that such a signal could be observable at the Tevatron Run II.
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1 Introduction

At the Tevatron, the dominant processes that give rise to multi τ signal in the GMSB models are the productions of chargino pairs ($\chi^+\chi^-$) and the chargino and the second neutralino pairs ($\chi^\pm\chi_2^0$). ($\sigma_{\chi^\pm\chi_2^0}$, where χ_0 is the lightest neutralino is very small compared to $\sigma_{\chi^\pm\chi_2^0}$). The chain of decays of χ^\pm and χ_2^0 lead to the observable high p_T τ 's and the missing neutrinos and the gravitinos. There are several mass hierarchies of these superparticles, (involving χ^\pm , χ_2^0 , χ_1^0 , $\tilde{\nu}_l(l=e, \mu, \tau)$, $\tilde{l}(l=e, \mu$ and $\tilde{\tau}_1)$) leading to the inclusive high p_T 2τ or 3τ final states plus \cancel{E}_T . Since these multi τ signatures appear in the parameter space where $\tilde{\tau}_1$ is the NLSP, we first briefly discuss the GMSB parameter space giving rise to $\tilde{\tau}_1$ as the NLSP¹.

2 parameter space

In GMSB models, with radiative EW symmetry breaking, all the sparticle masses and the mixing angles depend on five parameters, M , Λ , n , $\tan\beta$, and sign of μ . M is the messenger scale, and Λ is related to the SUSY breaking scale. The parameter n is fixed by the choice of the vector like messenger sector. The parameter $\tan\beta$ is the usual ratio of the up (H_u) and down (H_d) type Higgs VEVs. The parameter μ is the coefficient in the bilinear term, $\mu H_u H_d$ in the superpotential. The constraints coming from $b \rightarrow s\gamma$ demands μ to be mostly negative². For $n=1$, the parameter space where lighter stau is NLSP has large $\tan\beta$ (≥ 25) with lower values of Λ . For $n \geq 2$, $\tilde{\tau}_1$ is the NLSP even for the low

values of $\tan\beta$ (for example, $\tan\beta \geq 2$), and for $n \geq 3$, $\tilde{\tau}_1$ is again naturally the NLSP for most of the parameter space. The parameter space where $\tilde{\tau}_1$ is the NLSP gives rise to our proposed high p_T τ signals.

3 Productions and signatures

At the Tevatron, the chargino pair ($\chi^+\chi^-$) production takes place through the s-channel Z and γ exchange; while the $\chi_2^0\chi^\pm$ production is via the s channel W exchange. Squark exchange via the t-channel will also contribute to both processes. Since the squark masses are large in the GMSB models these contributions are negligible. The inclusive final states arising from both of processes are either 2τ or 3τ with high p_T plus \cancel{E}_T (due to the undetected neutrinos and gravitinos). The 2τ mode will be mostly of opposite sign charges, but a significant fraction will also have the same sign of charges. The details of the decays for the χ^\pm and χ_2^0 depend on the hierarchies of the superparticle masses, which in turn depend on the GMSB parameter space. There are roughly four possible cases to consider for EW gaugino production³:

$$\text{Case 1: } m_{\tilde{\nu}} > M_{\chi_2^0} \geq M_{\chi_1^\pm} > m_{\tilde{e}_1, \tilde{\mu}_1} > M_{\chi_1^0} > m_{\tilde{\tau}_1}$$

$$\text{Case 2: } M_{\chi_2^0} \geq M_{\chi_1^\pm} > m_{\tilde{\nu}} > M_{\chi_1^0} > m_{\tilde{e}_1, \tilde{\mu}_1} > m_{\tilde{\tau}_1}$$

$$\text{Case 3: } M_{\chi_2^0} \geq M_{\chi_1^\pm} > m_{\tilde{\nu}} > m_{\tilde{e}_1, \tilde{\mu}_1} > M_{\chi_1^0} > m_{\tilde{\tau}_1}$$

$$\text{Case 4: } m_{\tilde{\nu}} > M_{\chi_2^0} \geq M_{\chi_1^\pm} > M_{\chi_1^0} > m_{\tilde{e}_1, \tilde{\mu}_1} > m_{\tilde{\tau}_1}$$

The parameter space is also restricted to those regions where $m_{\tilde{\tau}_1} \geq 70$ GeV. Ongoing LEP II analyses are expected to establish this bound soon. With this restriction, we did not find any examples for Cases 3 and 4.

Case 1: $m_{\tilde{\nu}} > M_{\chi_2^0} \approx M_{\chi_1^\pm} > m_{\tilde{e}_1, \tilde{\mu}_1} > M_{\chi_1^0} > m_{\tilde{\tau}_1}$

Let us consider a point where $\tan\beta = 20$, $\Lambda = 32$ TeV, $M = 480$ TeV, and $n = 2$. In the case of chargino pair production, $\chi_1^\pm \rightarrow \tilde{\tau}_1 \nu_\tau$ is the dominant decay mode. Thus in chargino pair production, two τ leptons are always produced. In the case of $\chi_1^\pm \chi_2^0$ production the main decay mode of the second heaviest neutralino is $\chi_2^0 \rightarrow \tilde{\tau}_1 \tau$ with a branching ratio (BR) of 85.3%, while the only other decay modes are $\chi_2^0 \rightarrow \tilde{e}_1 e$ and $\chi_2^0 \rightarrow \tilde{\mu}_1 \mu$. Thus the production probability for three τ leptons is high at 85.3% and the three τ -jet rate is correspondingly 27.2%. In this parameter point, the inclusive 3 τ -jet rate for combined $\chi_1^+ \chi_1^-$ and $\chi_1^\pm \chi_2^0$ production is 9.6 fb and the 2 τ -jets cross section is 62.8 fb at the RUN II.

Case 2: $M_{\chi_2^0} \approx M_{\chi_1^\pm} > m_{\tilde{\nu}} > M_{\chi_1^0} > m_{\tilde{e}_1, \tilde{\mu}_1} > m_{\tilde{\tau}_1}$

Due to the shifting of the sneutrino masses below that of χ_1^\pm and χ_2^0 and

also to the shifting of the selectron and smuon masses below the mass of the lightest neutralino, there are now many more decay modes for χ_1^\pm and χ_2^0 . The dominant decay mode of the lightest chargino is still $\chi_1^\pm \rightarrow \tilde{\tau}_1 \nu_\tau$, but now the decays to the sneutrinos are also important. In fact, the decay to the sneutrinos can have branching ratios approaching that of the decay to the stau: for example in a parameter space where $\tan \beta = 15$, $M = 400$ TeV, $\Lambda = 20$ TeV, and $n = 4$, we have $\text{BR}(\chi_1^\pm \rightarrow \tilde{\tau}_1 \nu_\tau) = 0.279$, while $\text{BR}(\chi_1^\pm \rightarrow \tilde{\nu}_\tau \tau) = 0.237$. For the second lightest neutralino, the dominant decay mode for these examples is $\chi_2^0 \rightarrow \tilde{\tau}_1 \tau$. But, as with the decays of the lightest chargino, here the decays to the sneutrinos are important. The branching ratio for the decays of the χ_2^0 to the sneutrinos tend to range from 10% to 20% each. In this parameter point the rate for inclusive production of 3 τ -jets is 8.3 fb and the inclusive 2 τ -jet rate is 26.2 fb at the RUN II.

4 Conclusion

We have considered the phenomenology of GMSB models where the lighter stau is the NLSP and decays within the detector. For this situation, the dominant SUSY production processes at the Tevatron are $\chi_1^+ \chi_1^-$ and $\chi_1^\pm \chi_2^0$. Their prompt decays lead to events containing 2 τ or 3 τ with high p_T plus large missing transverse energy. These signals are different from the photonic signals that have been investigated in GMSB models and the dilepton and trilepton signals in the usual supergravity models. The missing transverse energy associated with the events is quite large providing a good trigger for these events.

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