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# SUPERSYMMETRY SEARCHES AT THE TEVATRON

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FOR THE CDF AND D0 COLLABORATIONS

The CDF and D0 experiments have each collected over 110 $\mathrm{pb}^{-1}$ of proton-antiproton collision data with $\sqrt{s} = 1800$ GeV during the period 1992-1995. Limits on the production of supersymmetric particles are presented here.

## 1 Introduction

The Tevatron Collider experiments, CDF and D0, bring unique capabilities to the search for supersymmetric partners to the known Standard Model particles. Until the LHC turns on, the Tevatron is the highest energy accelerator in the world, with a center of mass energy of 1.8 TeV. Because it collides protons and antiprotons, both of which are composite particles, the partonic center of mass energy is lower and variable, reaching approximately 600 GeV for quark-antiquark collisions and 400 GeV for gluon-gluon collisions. This allows for production of heavier superparticles than at LEP, as well as enhanced production of colored superparticles (squarks and gluinos) via QCD processes.

With these advantages comes a price, and that is the increased backgrounds from Standard Model processes, particularly QCD. These backgrounds can be many orders of magnitude larger than the expected signals, so the experiments have to reduce this by concentrating on signatures that are unusual or rare in Standard Model processes. Some of these are high transverse momentum ($p_T$) leptons, heavy flavor quark jets, missing transverse energy ($\not{E}_T$) and energetic photons. In this paper I will discuss two categories of these signatures.

## 2 Events with Leptons

One of the cleanest signatures for supersymmetry is associated production of the lightest chargino and second-lightest neutralino via $q + \overline{q}' \to W^{*\pm} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ followed by the decays $\tilde{\chi}_1^{\pm} \to l^{\pm}\nu\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+ l^-$. In this model the $\tilde{\chi}_1^0$ is the lightest superparticle, and is stable, so manifests itself as missing energy. So the final signature is three isolated leptons.

Both experiments search for trilepton events, requiring minimum lepton transverse momenta between 5 and 11 GeV, not all with the same charge (CDF only) and with missing $\not{E}_T$ from the unseen $\tilde{\chi}_1^0$'s. Additionally, kinematic and topological requirements are imposed. Neither experiment sees any events[1], over an expected background of $1.2 \pm 0.2$ for CDF and $1.3 \pm 0.4$ for D0. This data allows the experiments to set limits on associated chargino-neutralino production (Figure 1) which are complimentary to limits set by the LEP experiments: the LEP limits exclude the low mass region, whereas the Tevatron limits exclude higher masses, provided the couplings are large enough for associated chargino-neutralino production to be significant.

A variation on this is trileptons from R-Parity violating (RPV) decays. R-Parity is defined to be even for particles and odd for superparticles, and in many models (such as

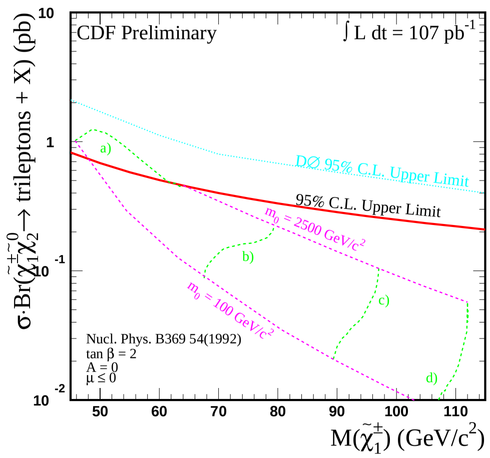


Figure 1. Tevatron limits on chargino and neutralino production from an analysis of trilepton events. The region to the left of the plot has been excluded by LEP.

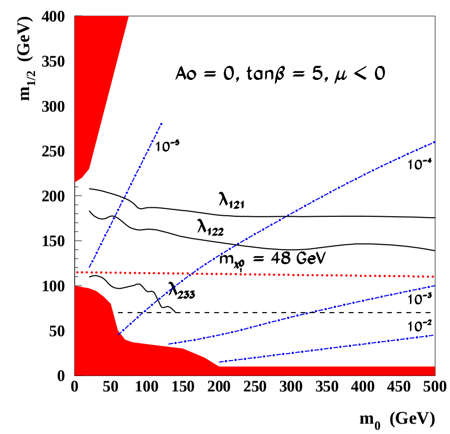


Figure 2. D0 limits on RPV 4-lepton events based on their trilepton limits.

the one used for the above analysis) is assumed to be conserved. However, it is not associated with a gauge symmetry, so it may not be conserved: there is no *a priori* reason to prefer R-parity conserving over R-parity violating models. In the RPV model investigated by D0, the lightest neutralinos are pair produced via an R-parity conserving process, and then decay via an R-parity violating process: $\tilde{\chi}_1^0 \to \nu l^+ l^-$. This therefore gives four leptons in the final state. D0 has reinterpreted their trilepton limits in the context of this model and the results are shown in figure 2.

CDF has taken a different approach to searching for the same process. They require identification of all four leptons, which lowers their efficiency, but allows them to recover it by relaxing their lepton selection requirements. For example only one lepton has to have $p_T$ above 12 GeV; the other three can be as low as 5 GeV. They see one signal event over an expected background of $1.2 \pm 0.2$. This event, an $ee\mu\mu$ event has both muons near jets - a topology more consistent with heavy flavor production than supersymmetry. Limits are shown in figure 3.

Another possible neutralino decay would be semileptonic: $\tilde{\chi}_1^0 \to e^+ d\overline{u}$. D0 searches for this decay, requiring two electrons not from $Z^0 \to e^+e^-$ and at least four jets, and they observe two events over an expected background of $1.8 \pm 0.4$. Limits are shown in figure 4. CDF looks for a similar signature (with somewhat different motivation) from the decays $\tilde{g} \to \overline{c}e^+d$ and $\tilde{q} \to qe^+q\overline{q}$ [4] and their limits are shown in figure 5.

## 3 Stop and Sbottom Squarks

There are a number of possible R-parity conserving decays of stop and sbottom squarks, such as:

- $\tilde{t} \to b + \tilde{\chi}_1^+ \to Wb + \tilde{\chi}_1^0$
- $\tilde{t} \to b + \tilde{\chi}_1^+ \to bl + \tilde{\nu}$
- $\tilde{t} \to t + \tilde{\chi}_1^0$
- $\tilde{t} \to c + \tilde{\chi}_1^0$
- $\tilde{b} \to b + \tilde{\chi}_1^0$

The signatures vary from mode to mode, and can include decays that look very much like Standard Model top quark decays; such decays will be difficult to separate from the $\overline{t}t$ background without substantially more data. Note the similarity of the last two decays: pair produced squarks will leave a signature

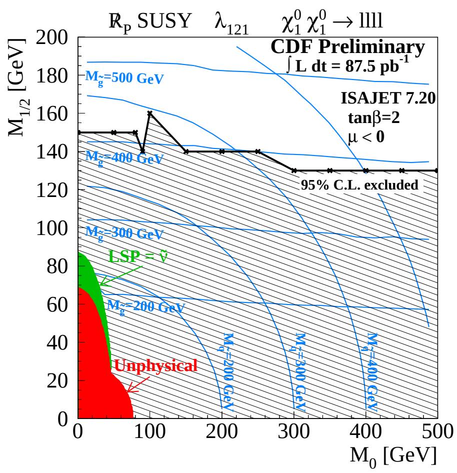


Figure 3. CDF limits on RPV 4-lepton events based on their direct search for such events.

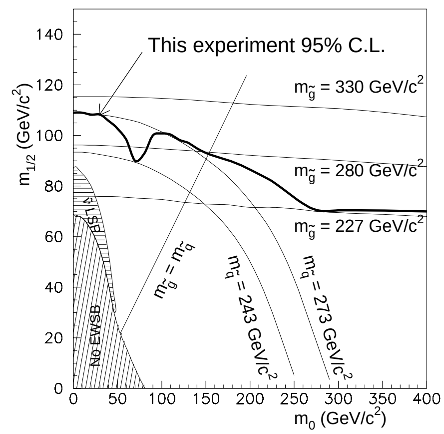


Figure 4. D0 limits on common scalar and fermion masses based on RPV dilepton events and the model described in the text.

of two heavy flavor jets (charm for $\bar{\tilde{t}}\tilde{t}$ production and bottom for $\bar{\tilde{b}}\tilde{b}$ production), plus missing $E_T$ carried off by the neutralinos.

Both experiments search for these decays. The CDF search involves looking for 2 (or 3) acolinear jets with at least 40 GeV of missing $E_T$. Leptons are removed, and then the jets are searched for secondary vertices using the silicon detector. They observe 11 charm jets over a background of $15 \pm 4$, and 5 bottom jets over a background of $6 \pm 2$. From these events, limits (shown in Figures 6 and 7) can be extracted.[2] The CDF limits are more stringent than the D0 limits, because they used a larger dataset, but also because their secondary vertex detector improves their heavy flavor identification. The $\tilde{b}$ limits are better than the $\tilde{t}$ limits because identifying bottom is easier than identifying charm.

An interesting possibility for future stop searches is to consider R-Parity violating *production* of stop squarks.[3] This allows production of a single stop squark via a process like $d + s \rightarrow \tilde{t}$. Of course, you pay the price of the coupling constant (which could potentially still be large without being in disagreement with the data), but you gain in terms of phase space by having to produce only one squark instead of a pair. This could potentially increase the cross section by a factor of 100.

## 4 The Future

The results of these searches have so far been negative, but inconclusive: there is still a sizable fraction of SUSY parameter space available. In March of 2001 the Tevatron will begin Run II, an ambitious program to deliver at least 20 times (and possibly as much as 150 times) the data to the two experiments as in Run I. Additionally, both experiments will be running with substantially improved detectors: D0 will have (for the first time) a central magnetic tracker and a silicon vertex detector, and CDF will have a completely new tracker, additional silicon, and improved lepton identification. It's not an accident that the two experiments are growing more similar - each is incorporating the best features of the other. Together, these two experiments provide the best discovery potential before the LHC.

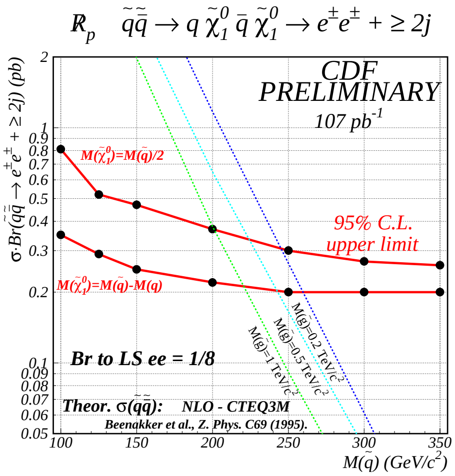


Figure 5. CDF limits on common squark masses based on the RPV model described in the text.

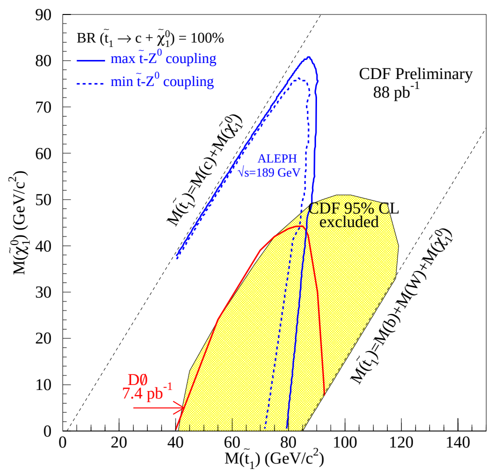


Figure 6. Tevatron limits on stop squark production, overlaid on LEP limits. The region in the top left is kinematically disallowed.

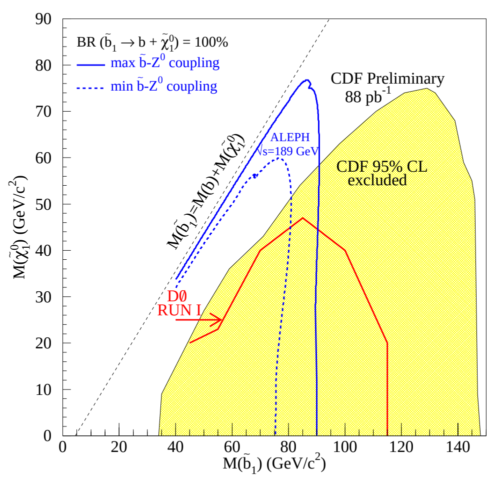


Figure 7. Tevatron limits on sbottom squark production, overlaid on LEP limits. The regions in the top left and bottom right are kinematically disallowed.

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