

## SUPERSYMMETRY SEARCHES AT THE TEVATRON

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We present the current status of searches for supersymmetry performed at the Tevatron accelerator at Fermilab by the CDF and DØ collaborations using luminosity of up to  $2.1 \text{ fb}^{-1}$ . We focus on searches for charginos, neutralinos, squarks, gluinos and sneutrinos in several supersymmetric scenarios. No supersymmetric signal is detected and limits on the masses and production cross sections for the supersymmetric particles are set.

### 1 Introduction

Although the Standard Model (SM) is extremely successful in describing the known elementary particles and their interactions, it is not the final answer to our main questions about the physical world. Supersymmetry (SUSY), the theory that predicts the existence of a boson for every SM fermion and vice-versa, is one of the promising SM extensions. With the expense of doubling the known particles and introducing new interaction couplings, SUSY removes the fine tuning of radiative corrections making perturbative quantum field theory valid at arbitrarily high energies, offers the possibility of force unification, incorporates gravity through superstrings and provides a cold dark matter candidate, which is the lightest supersymmetric particle (LSP) if it is stable. In this paper, we concentrate on the recent searches at the Tevatron for squarks, gluinos, charginos, neutralinos and sneutrinos. The analyses assume that the breaking of SUSY is mediated either through gravity (mSUGRA scenario, where the LSP is the neutralino) or through gauge-bosons (GMSB scenario, where the LSP is the gravitino). Most analyses also assume  $R$ -parity conservation, according to which the supersymmetric particles must be produced in pairs and the LSP is stable and undetectable, resulting in missing transverse energy ( $\cancel{E}_T$ ).

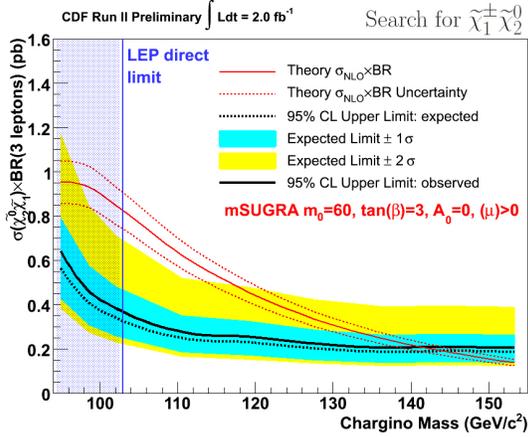


Figure 1: Exclusion plot for the CDF chargino-neutralino search.

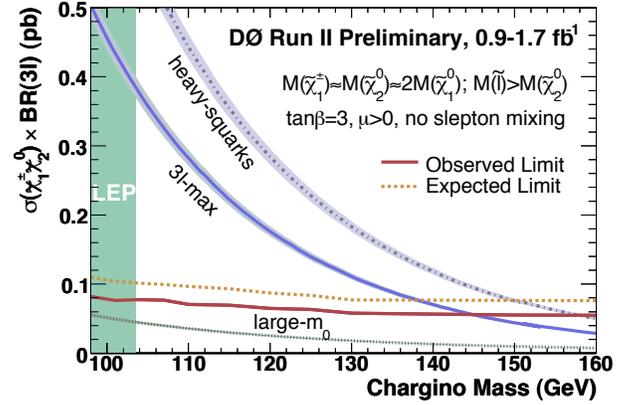


Figure 2: Exclusion plot for the D0 chargino-neutralino search.

## 2 Search for chargino-neutralino production

The charginos and the neutralinos are the supersymmetric partners of the gauge and Higgs bosons and, assuming mSUGRA and  $R$ -parity conservation, they are produced in pairs and decay to the lightest-neutralino which is the LSP. The golden signature of SUSY at the Tevatron comes from the decay of the lightest chargino ( $\tilde{\chi}_1^\pm$ ) and the next-to-lightest neutralino ( $\tilde{\chi}_2^0$ ) to three leptons as well as  $\cancel{E}_T$  resulting from the final-state lightest neutralino  $\tilde{\chi}_1^0$ s and neutrino(s). This signature is characterized by very low SM backgrounds while signal cross sections of the order of 0.1–1 pb, depending on the mSUGRA parameters, have not been excluded yet. CDF has recently completed a  $2 \text{ fb}^{-1}$  trilepton analysis<sup>1</sup>, which requires three leptons (or two leptons and an isolated track), with minimum  $p_T$  of 15/20, 5/10 and 5/10 GeV/ $c$  respectively (depending on the quality of the leptons),  $\cancel{E}_T$  above 20 GeV, low jet multiplicity (for reduction of the top background) and dilepton mass above 20 GeV/ $c^2$  (with the exclusion of  $Z$  mass window), for reduction of QCD background, low-mass Drell-Yan (DY) and meson resonances. After this selection, the dominant backgrounds are the production of dibosons (including  $Z + \gamma$ ) and the production of DY in association with a “fake” third lepton (jet (track) misidentified as electron (muon)). Overall,  $6.4 \pm 1.1$  SM events and  $11 \pm 1$  SUSY events ( $\tan\beta = 3$ ,  $m_0 = 60 \text{ GeV}/c^2$ ,  $m_{1/2} = 190 \text{ GeV}/c^2$ ,  $A_0 = 0$ ,  $\mu > 0$ ) are expected and 7 events are observed. The cross section and lightest chargino mass 95% confidence level (CL) exclusion limits are 0.2 pb and 140 GeV, for the above mSUGRA point with  $m_{1/2}$  varied, as shown in Figure 1. This is the first pure mSUGRA  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  limit at the Tevatron with no extra assumptions. D0 has analyzed  $590 \text{ pb}^{-1}$  of recently collected  $ee + \ell$  data<sup>1</sup>, with similar selection requirements, and the results are combined with previous analyses of  $\sim 0.9 - 1.1 \text{ fb}^{-1}$ . Overall,  $4 \pm 1$  SM events are expected and 3 are observed. Figure 2 shows the cross section vs. chargino mass exclusion for mSUGRA with several extra assumptions that include removal of slepton mixing for maximization of acceptance<sup>1</sup>.

## 3 Search for squarks and gluinos

The squarks and gluinos are strongly interacting particles and therefore could be copiously produced at the Tevatron. However, their production cross section is limited by their large mass in most of the non-excluded mSUGRA parameter space. In addition, they decay into jets and  $\cancel{E}_T$ , a signature that is dominated by large QCD multijet background. Therefore, careful optimization of the event selection is critical for the squark-gluinos searches. Here the light-flavored quarks are considered and are assumed to be heavy and almost degenerate in mass.

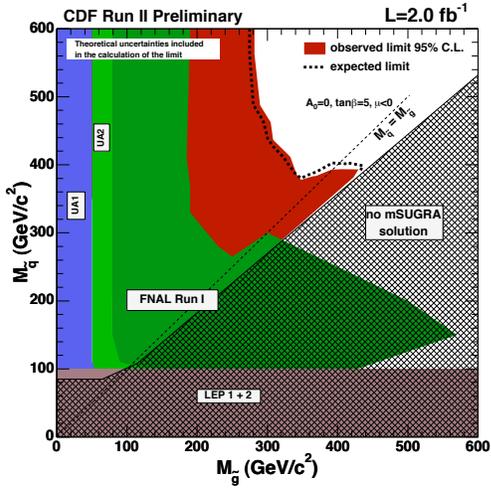


Figure 3: The exclusion plot for the CDF squark-gluino analysis.

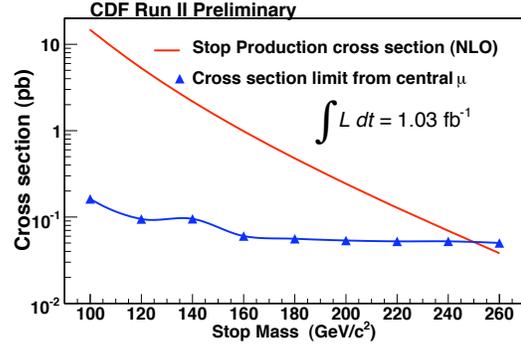


Figure 4: The exclusion plot for the CDF stable stop analysis.

Table 1: Expected and Observed events in the three jet multiplicity bins for CDF ( $2 \text{ fb}^{-1}$ ) and DØ ( $2.1 \text{ fb}^{-1}$ ).

Analysis	$H_T$ cut (GeV)	$\cancel{E}_T$ cut (GeV)	Jet $E_T$ cuts (GeV)	SM Background	Data
DØ dijet	325	225	35,35	$11^{+3}_{-2}$	11
DØ trijet	375	175	35,35,35	$11^{+3}_{-2}$	9
DØ 4-jet	400	100	35,35,35,20	$18^{+6}_{-3}$	20
CDF dijet	330	180	165,100	$16 \pm 5$	18
CDF trijet	330	120	140,100,25	$37 \pm 12$	38
CDF 4-jet	280	90	95,55,55,25	$48 \pm 17$	45

Squarks decay to quarks and the LSP  $\tilde{\chi}_1^0$  whereas the gluinos decay to two quarks and the LSP. The final signature depends on their relative masses and could be 2 jets and  $\cancel{E}_T$  (for  $M_{\tilde{q}} \ll M_{\tilde{g}}$ ), or 4 jets+ $\cancel{E}_T$  ( $M_{\tilde{q}} \gg M_{\tilde{g}}$ ) or 3 jets and  $\cancel{E}_T$  (if  $M_{\tilde{q}} \sim M_{\tilde{g}}$ ). The main backgrounds are  $W/Z$ +jets,  $t\bar{t}$ , dibosons and, most importantly, the QCD multijet. The optimization is done using jet  $E_T$ ,  $H_T$  (sum of jet  $E_T$ ) and  $\cancel{E}_T$ , separately for the three channels, because of the dependence of the QCD background and the SUSY signal on jet multiplicity. The final optimized cuts, expected background and observed data events for the three channels and for the two experiments can be seen in Table 1. The CDF  $M_{\tilde{q}}$  vs  $M_{\tilde{g}}$  exclusion plot for  $\tan\beta = 3$ ,  $A_0 = 0$ ,  $\mu < 0$ , and varied  $m_0$  and  $m_{1/2}$ , can be seen in Figure 3<sup>2</sup>. The DØ exclusion plot is very similar<sup>3</sup>.

One of the stop quarks may be much lighter than the other squarks and it may not be able to decay to the lightest neutralino and a quark. If its mass is such that  $m_c + m_{\tilde{\chi}_1^0} < m_{\tilde{t}} < m_b + m_W + m_{\tilde{\chi}_1^0}$  then it will decay to a charm quark through a flavor-changing loop process. A  $1 \text{ fb}^{-1}$  analysis of stop to charm is completed by DØ<sup>4</sup>. Exactly two jets (with  $E_T$  greater than 20 and 40 GeV) are required with proper angular separation from the  $\cancel{E}_T$  for reduction of the QCD and  $W$ +jet background. Heavy-flavor tagging is implemented with the use of a neural network. Using the  $H_T/\cancel{E}_T$ -optimized cuts at 140/70 GeV,  $64 \pm 3$  SM events are expected and 66 are observed. This result corresponds to exclusion of stop masses below 149  $\text{GeV}/c^2$  for neutralino masses below 63  $\text{GeV}/c^2$  at 95% CL.

If the stop is too light to decay to charm, it will not decay inside the detector and it will look like a CHarged Massive Particle (CHAMP). The CDF collaboration performed a search<sup>5</sup> for stable CHAMP-like top, which could be reconstructed as a heavy muon with possible energy

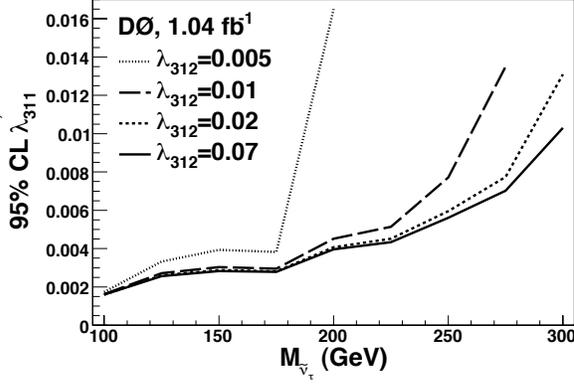


Figure 5: The exclusion plot for the  $D\bar{O}$  sneutrino analysis.

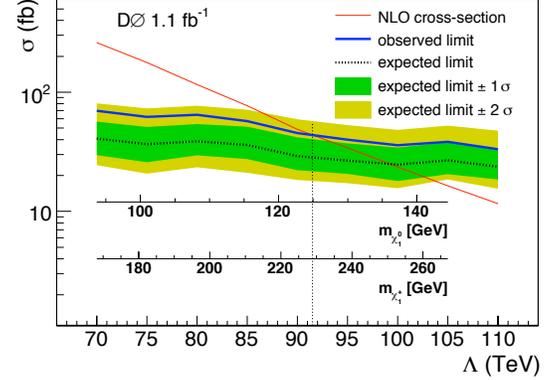


Figure 6: The exclusion plot for the  $D\bar{O}$  GMSB diphoton analysis.

deposition in the calorimeter. The measurement is performed by reconstructing the mass of the slow massive particle using its  $\beta$ , measured with the Time of Flight system and the momentum of its corresponding track. The backgrounds come from cosmic rays and multiple interactions both of which would create fake delayed signals. In the  $1 \text{ fb}^{-1}$  analysis,  $4.7 \pm 0.3$  SM events are expected and 4 are observed. A stable stop is excluded below  $250 \text{ GeV}/c^2$  at 95% CL.

#### 4 $R$ -parity violation signals

If we do not demand  $R$ -parity conservation then lepton- and baryon-number violating terms are allowed in the soft SUSY-breaking sector of the lagrangian.  $D\bar{O}$  performed a  $1 \text{ fb}^{-1}$  analysis<sup>6</sup> looking for lepton-number-violating sneutrinos decaying to  $e + \mu$ . An electron ( $30 < E_T < 100 \text{ GeV}$ ), a muon ( $p_T > 25 \text{ GeV}/c$ ) and  $\cancel{E}_T < 15 \text{ GeV}$  and no extra leptons are required. The main backgrounds come from  $Z/\gamma \rightarrow \tau\tau$  and  $WW$  production. Overall,  $59 \pm 5$  SM events are expected and 68 observed. Figure 5 shows the 95% CL exclusion limits for  $\lambda'$  as a function of the sneutrino mass for several  $\lambda$  values, where  $\lambda$  and  $\lambda'$  are the lepton-violating couplings. CDF has performed a search for  $R$ -parity violation with multileptons at  $346 \text{ fb}^{-1}$ , using at least 3 leptons (electrons or muons)<sup>7</sup>. The lower 95% CL mass limits for  $\tilde{\chi}_1^0$  and  $\tilde{\chi}_1^\pm$  are set to  $98 - 110$  and  $185 - 202 \text{ GeV}/c^2$  respectively, depending on the  $\lambda$  assumptions.

#### 5 Search for GMSB neutralinos

In the GMSB scenario, the pair production of neutralinos would result to 2 gravitinos (LSPs) and 2 photons. A  $1.1 \text{ fb}^{-1}$   $D\bar{O}$  analysis<sup>8</sup> searched for two prompt photons above  $25 \text{ GeV}$  and  $\cancel{E}_T > 30$  or  $60 \text{ GeV}$ , with angular separation between any present jet and the  $\cancel{E}_T$ . The background comes from processes with no real diphotons ( $W\gamma$ ,  $W + \text{jet}$ ,  $t\bar{t}$ , QCD-multijet) and at a lesser degree from processes with real diphotons ( $W\gamma\gamma$  and  $Z\gamma\gamma$ ). Overall,  $11 \pm 1$  SM events for  $\cancel{E}_T > 30$  and  $1.6 \pm 0.4$  SM events for  $\cancel{E}_T > 60$  are expected and 16 and 3 are observed respectively. Figure 6 shows the cross section limit as a function of the GMSB  $\Lambda$  parameter and the  $\tilde{\chi}_1^+$  and  $\tilde{\chi}_1^0$  masses.

#### References

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