

SEARCHES FOR SUPERSYMMETRY AT THE TEVATRON

ELSE LYTKEN

(for the CDF and DØ collaborations)

Department of Physics, Purdue University
525 Northwestern Avenue, West Lafayette, Indiana, USA



The results for searches for Supersymmetry at the Tevatron Collider are summarized in this paper. We focus here on searches for chargino/neutralino and the lightest stop, as well as scenarios with R-parity violation and split supersymmetry. No significant excesses with respect to the Standard Model were observed and constraints are set on the SUSY parameter space.

1 Introduction

Supersymmetry (SUSY), an attractive extension of the Standard Model (SM), is based on a new symmetry between fermions and bosons. Each Standard Model particle acquires a supersymmetric partner with $\Delta_{spin} = 1/2$. Most of the SUSY models considered assume the conservation of a quantum number, R-parity^a, resulting in a stable lightest supersymmetric particle, the LSP. This stable, weakly interacting particle would escape detection and give rise to missing transverse energy, \cancel{E}_T . In minimal supergravity models the lightest supersymmetric particle is usually the lightest neutralino, $\tilde{\chi}_1^0$. The non-excluded masses for the proposed superpartners are typically of the order of 100 GeV/ c^2 and above, thus potentially accessible at the Tevatron. The two Tevatron experiments, DØ and CDF have successfully been taking data at $\sqrt{s} = 1.96$ TeV. Results shown are based on 300 - 800 pb⁻¹ of data.

2 Squarks and gluinos

2.1 Searching for stop

Due to their strong couplings, squarks and gluinos are expected to be produced abundantly at hadron colliders. The lightest stop quark, \tilde{t}_1 , is in many scenarios expected to be the lightest of

^a $R_p = (1)^{3(B-L)+2s}$

all the squarks, thus making it very favorable to search for at the Tevatron. Recently a search for light stop quarks in final states with $e^\pm\mu^\mp + b\bar{b} + \cancel{E}_T$ was completed with the $D\mathcal{O}$ detector. This is the signature of \tilde{t}_1 pair production, followed by $\tilde{t}_1 \rightarrow b\ell\tilde{\nu}$, which is expected to be the dominant decay mode when $m_{\tilde{b}} \sim m_{\tilde{w}}$. The analysis defines 3 regions, each optimized for a particular mass difference, $\Delta M = m_{\tilde{t}_1} - m_{\tilde{b}}$. The results are shown in Table 1 below.

Table 1: $D\mathcal{O}$ results on the search for $\tilde{t}_1\tilde{t}_1 \rightarrow e^\pm\mu^\mp + b\bar{b} + \cancel{E}_T$ (350 pb^{-1})

| ΔM | SM expectation | Observed |
|---------------------------|------------------|----------|
| 20 – 40 GeV/c^2 | 22.99 ± 3.10 | 21 |
| 50 – 60 GeV/c^2 | 34.63 ± 3.96 | 34 |
| $\geq 70 \text{ GeV}/c^2$ | 40.66 ± 4.38 | 42 |

This result was combined with the previous result ¹, the $\mu^\pm\mu^\mp + b\bar{b} + \cancel{E}_T$ channel. No excess above the SM expectation was observed in any of the channels and the resulting combined limit is shown in figure 1.

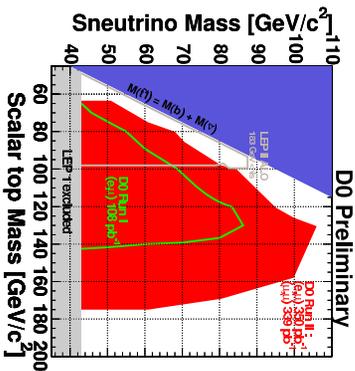


Figure 1: 95% CL excluded region in the stop search for the combination of $e\mu$ and $\mu\mu$ final states.

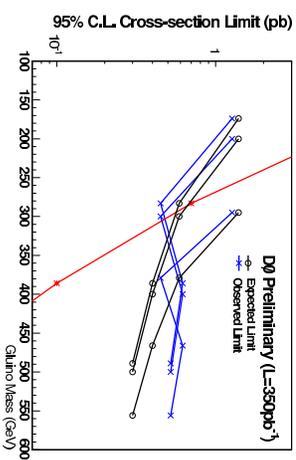


Figure 2: Stopped gluino search: 95% CL limits for expected (blue crosses) and observed (black, open) for 3 masses: $m_{\tilde{\chi}_1^0} = 50, 90, 200 \text{ GeV}/c^2$.

2.2 Stopped gluinos

$D\mathcal{O}$ has also looked into a possible signature for split supersymmetry ², where the new SUSY scalars can be much heavier than the fermions. In that case the decay of the gluino into squarks would be heavily suppressed and the gluino therefore could have a lifetime long enough to stop in the calorimeters and decay to $g + \tilde{\chi}_1^0$. This would appear as an event with one high E_T shower and thereby implicit large \cancel{E}_T , out of time with a collision, due to the long lifetime of the gluino. The data used for the search is collected by a trigger for diffractive physics, and the energy spectrum of the shower is studied for signal and backgrounds. The analysis finds no hints of stopped gluinos in the measured spectrum and thus proceeds to set a limit on the gluino mass. Figure 2 shows the resulting exclusion region.

3 Chargino-neutralino

3.1 Multilepton final states

The cross section for the associated production of $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ is expected to be significant at the Tevatron due to the light masses. In the case where both decay leptonically, $\tilde{\chi}_1^\pm \rightarrow \ell^\pm\nu\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \rightarrow \ell^\pm\ell^\mp\tilde{\chi}_1^0$, one can have very clean final states of 3 leptons, plus \cancel{E}_T caused by the

$\tilde{\chi}_1^0$'s and the neutrino. Very few SM processes contribute to such a signature, the dominant being Drell-Yan plus a misidentified jet or a $\gamma \rightarrow e^+e^-$ conversion, and real WZ production. CDF presented new results on trileptons looking at many different decay channels. Results are summarized in Table 2. The $E_{T\ell}$ spectrum for the $\mu\mu$ channel is illustrated in Figure 3. No significant excess is observed and limits are set on the χ_1^\pm mass in minimal models. A previous $D\bar{O}$ analysis³ sets a limit of $m_{\chi_1^\pm} \geq 117$ GeV/ c^2 for $m_{\tilde{g}} \sim m_{\tilde{\chi}_2^0}$.

Table 2: CDF results of search for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow \ell\ell + X$ (* = low p_T triggers)

| Channel | $ee + \ell$ | $\mu\mu + \ell$ | $\mu e + \ell$ | $*ee + tracks$ | $*\mu\mu + \ell$ | $\ell^\pm\ell^\pm$ |
|----------------|----------------------|----------------------|-----------------------------|----------------------|----------------------|----------------------|
| \mathcal{L} | 346 pb ⁻¹ | 745 pb ⁻¹ | ~ 700 pb ⁻¹ | 607 pb ⁻¹ | 312 pb ⁻¹ | 704 pb ⁻¹ |
| SM expectation | 0.17 ± 0.05 | 0.64 ± 0.18 | 0.78 ± 0.11 | 0.49 ± 0.10 | 0.13 ± 0.03 | 6.8 ± 1.0 |
| Observed | 0 | 1 | 0 | 1 | 0 | 9 |

3.2 Diphotons

In another popular SUSY model, Gauge Mediated Supersymmetry Breaking (GMSB), the LSP is the gravitino, the super partner of the graviton. Each of the $\tilde{\chi}_1^0$'s from chargino-neutralino production will decay into a gravitino and a photon. Independently of the decays of the charginos and other neutralinos, each pair produced set of gauginos will therefore have a final state with two photons and $E_{T\ell}$. $D\bar{O}$ has searched for this signature in 760 pb⁻¹ of data. Four events are observed with an expected background of 2.1 ± 0.7 events. The resulting limits are shown in Figure 4.

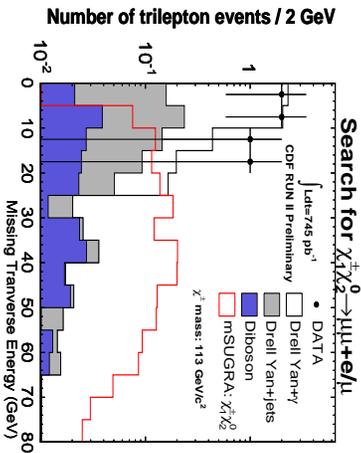


Figure 3: $E_{T\ell}$ spectrum before the cut of the trilepton $\mu\mu + \ell$ channel.

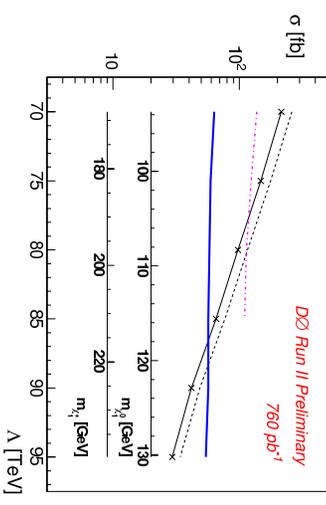


Figure 4: Results of search for GMSB $\tilde{\chi}_1^\pm \tilde{\chi}_1^\pm$ production. Full blue line is current result, pink dashed-dotted line is the previous result from $D\bar{O}$.

4 R-parity violation

4.1 $\tilde{\chi}_1^0 \rightarrow \mu\mu\nu$

Imposing R_P conservation is not a necessity in supersymmetry. The Tevatron experiments therefore also look for signatures that could arise from decays where R-parity is violated. R-parity violation would add more terms to the supersymmetric Lagrangian, for instance for lepton flavor violation:

$$W_{RP} = \lambda_{ijk} L_i L_j \bar{E}_k \quad (1)$$

A non-zero λ would cause decays of the lightest neutralino into neutrinos and charged leptons. A CDF analysis looking for an excess of $e\ell(l)$ and $\mu\mu(l)$ final states, with $l = e, \mu$, is sensitive

to both λ_{121} and λ_{122} couplings. The observation is compatible with expectation given the uncertainties in 346 pb^{-1} of data. Both the 3 and 4 lepton signatures were investigated and combined to set limits on the couplings: $\sigma < 0.21 \text{ pb}$ for $\lambda_{121} > 0$ and 0.11 pb for $\lambda_{122} > 0$.

4.2 Long-lived LSP

DØ looked for the decay of the neutralino to leptons and a neutrino in 383 pb^{-1} of data. The analysis focuses on the scenario where the R_P coupling is weak and the LSP would travel $\geq 5 \text{ cm}$ before decaying. This possibility was inspired by an excess in dimuon events reported by NuTeV⁴. No events are observed with an expectation of $0.8 \pm 1.1 \pm 1.1$ from backgrounds and the limit set (Figure 5) excludes the possibility that the NuTeV events are due to neutralino decay.

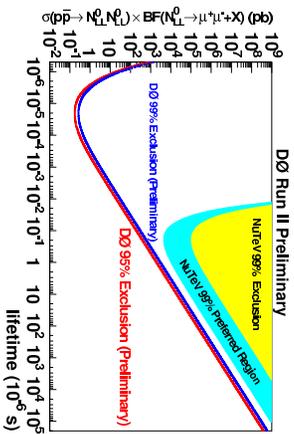


Figure 5: Red curve is the 95 % CL limit on pair production of neutral, long-lived particles.

| | Expected | Obs | Expected | Obs |
|--------------------------|-----------------|-----|-----------------|-----|
| $B_s \rightarrow \mu\mu$ | 0.88 ± 0.30 | 1 | 0.39 ± 0.21 | 0 |
| $B_d \rightarrow \mu\mu$ | 1.86 ± 0.34 | 2 | 0.59 ± 0.21 | 0 |

Table 3: CDF results from $B_s \rightarrow \mu\mu$ search. The left and right parts correspond to different muon selections.

5 B_s to $\mu^\pm \mu^\mp$

In addition to the direct searches for supersymmetry the Tevatron experiments are also trying to constrain supersymmetry by searching for rare decays, such as $B_s \rightarrow \mu\mu$. This decay is heavily suppressed in the SM but can be enhanced orders of magnitude if new particle loops (like SUSY) exist. The latest CDF analysis looks for opposite-sign $\mu\mu$ pairs in the B_s and B_d mass windows, using sidebands to estimate the expected backgrounds. Results with 780 pb^{-1} of data are shown in table 3. The observations are in agreement with background expectations, and the new limits, $\text{BR}(B_s \rightarrow \mu\mu) < 1.0 \cdot 10^{-7}$, and $\text{BR}(B_d \rightarrow \mu\mu) < 3.0 \cdot 10^{-8}$, improve the latest published result⁵ by a factor of 2.

6 Conclusions

CDF and DØ have searched for new physics in the form of supersymmetry and find no evidence for such new physics. The limits presented are the worlds best at this time. With the Tevatron and the experiments now working optimally we expect to chart much more uncovered territory in the coming few years.

References

1. DØ Collaboration, <http://www-d0.fnal.gov/Run2Physics/WWW/results/mp.htm> (2005)
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