THE SEARCH FOR SUSY AT THE TEVATRON

R. J. GENIK II[a]
Department of Physics and Astronomy
Michigan State University
East Lansing, MI, 48825, USA

We present results on searches for Supersymmetry (SUSY) using data from the 1992-96 Tevatron collider run. Included are stop and sbottom searches in heavy flavor tagged jet signatures for general SUSY models. Also, searches for R parity violating SUSY leptonic signatures are shown. Finally, a new result from DØ is presented on the search for squarks and gluinos in di-lepton signatures. No excess is observed above standard model background and we include plots of excluded parameter space for each model.

1 Introduction

The standard model has been very successful in describing the results of experiments to date. However, there are several theoretical problems that remain, namely, the required fine tuning of corrections to the scalar Higgs mass, the large hierarchy between the electroweak scale and the Planck scale, and the origin of electroweak symmetry breaking. This suggests that the standard model may be a subset of a larger theory, and that there exist undiscovered mass states near the TeV scale. Supersymmetry (SUSY) is one of the leading candidates for this larger theory.

SUSY is a symmetry between bosons and fermions. For every particle in the standard model, a SUSY partner, or sparticle, is proposed. In SUSY, there is an additional quantum number for all mass states denoted R. If R-parity is conserved, sparticles are produced in pairs and the final state will always contain at least two lightest supersymmetric particles (LSP). The LSP is assumed to be neutral and weakly interacting in such models, and is a candidate for cold dark matter. If R-parity is violated, then LSPs decay into ordinary matter.

The SUSY extension to the standard model that contains the fewest sparticles is called the Minimal Supersymmetric Standard Model (MSSM). Significant reduction in the 100 free

[a]For the DØ and CDF Collaborations

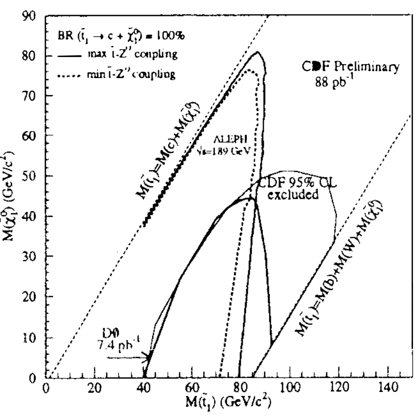

Figure 1: Excluded region for the CDF $\tilde{t}_1$ search.

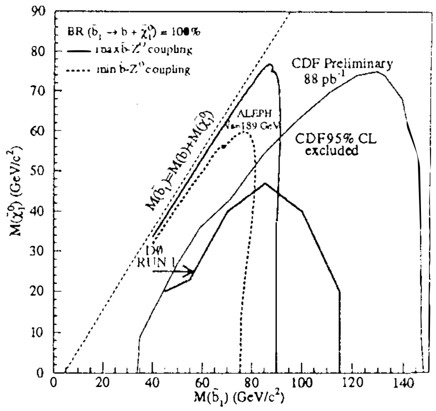

Figure 2: Excluded region for the CDF $\tilde{b}_1$ search.

parameters of the MSSM is possible with unification scenarios such as Supergravity (SUGRA), which has four free parameters, m_0, $m_{1/2}$, $\tan\beta$, and A_0. These represent, respectively, the common scalar and fermion sparticle masses, the ratio of the vacuum expectation values of the Higgs fields, and the common trilinear coupling. The sign of μ, the higgsino mass parameter, is also a free parameter in SUGRA.

The DØ and CDF detectors are described elsewhere.[1,2] The CDF detector emphasizes tracking and contains a silicon vertex detector that is used to tag heavy flavor decays. The DØ detector emphasizes calorimetry, providing hermetic coverage and excellent resolution for any imbalance in transverse momentum ($\not\!\!E_T$).

2 Recent Results on Stop, Sbottom, and Violation of R-parity.

In many SUSY scenarios, the lightest stop quark, $\tilde{t}_1$, can be significantly lighter than the other squarks. It can be so light that decays to t + LSP and $b + \tilde{\chi}_1^{\pm}$ (chargino) are kinematically forbidden. In this case, the dominant decay proceeds via one-loop diagrams, such as an off-shell $\tilde{\chi}_1^{\pm} + b$, to c + LSP. The signature of these decays corresponds to two acolinear charm jets and $\not\!\!E_T$. Using the assumption that $BR(\tilde{t}_1 \to c + \tilde{\chi}_1^0) = 100\%$, CDF has conducted a search selecting events with $\not\!\!E_T$, 2 or 3 jets, and requirements on $\not\!\!E_T$-jet and jet-jet correlations, no leptons, and at least one tagged c-jet. Backgrounds are from W and Z+jets, $t\bar{t}$, di-boson, and QCD multijet events. In 88 pb^{-1} of data, 11 events were observed with an expected background of 14 ± 4.2. The result was interpreted as a 95% confidence level (CL) exclusion of the region in the ($\tilde{\chi}_1^0$, $\tilde{t}_1$) mass plane shown in Fig. 1.

Just as for the case of stop, sbottom quarks can also be lighter than the other squarks, especially when $\tan\beta$ is large. The production cross section is the same as for stop, since it depends dominantly on the squark mass. Assuming that $BR(\tilde{b}_1 \to b + \tilde{\chi}_1^0) = 100\%$, the signature is two b-jets and $\not\!\!E_T$. The same data sample and selections are used as for the stop search, with the replacement of the c-tag requirement with a b-tag requirement, essentially a tighter cut on the displacement of tracks from the event vertex. Five events were observed, with an expected background of 5.8 ± 1.8. Again, the result was interpreted as a 95% CL region of exclusion in the ($\tilde{\chi}_1^0$, $\tilde{b}_1$) mass plane shown in Fig. 2. This figure also presents an earlier search using data from DØ.[3] The DØ measurement uses soft muons to tag b-jets, and a separate sample of two-jet + $\not\!\!E_T$ events.

In addition to R-parity conserving models, CDF also searched for R-parity violating signatures. The first of these searches assumes a small lepton-number-violating coupling within the SUGRA framework. Sparticles are produced and decay as in SUGRA, but each LSP decays via $\tilde{\chi}_1^0 \rightarrow l^+ l^- \bar{\nu}_l$. The final state has 4 leptons and small $\not{E}_T$. One event was observed, which was consistent with the prediction for background from the standard model. This result was also interpreted as a 95% CL region of exclusion in the $(m_{1/2}, m_0)$ plane (Fig. 3). For $\tan\beta = 2$, $\mu < 0$, and $A_0 = 0$, this translates into limits on the masses of various sparticles in this model: $m(\tilde{q}) > 350$, $m(\tilde{g}) > 380$, and $m(\tilde{\chi}_1^0) > 55$ GeV/c^2.

Finally, CDF has searched for signatures from the proposed R-parity violating scharm model of Choudhury and Raychaudhuri.[4] In this scenario, $p\bar{p}$ collisions would produce an excess of events with like-sign lepton pairs, two or more jets, and small $\not{E}_T$. No events in the like-sign di-electron signature were observed in the 107 pb^{-1} of data collected with the CDF detector, and this translates into a 95% CL exclusion for $\sigma \cdot BR > 180$ fb.

3 SUGRA with Di-leptons

DØ has conducted a new search for $\tilde{q}$ and $\tilde{g}$ production. R-parity conserving decays into leptons and jets form the basis for this search, with the signature being di-leptons, two or more jets, and $\not{E}_T$. The SUSY model is SUGRA, with $A_0 = 0$, $\mu < 0$, and stop production excluded.

The usual way to conduct a search is to generate signal and background events, and to optimize a single set of cuts that will yield the best discrimination. The problem with this method is that optimum thresholds vary substantially with input parameters, requiring the re-tuning of selection criteria at essentially every point in model space.

To approximate a continuous variation of cutoff parameters, DØ generated a grid of channel thresholds. For ee signatures, it was required to have $e_1 > 17$ and $e_2 > 15$ (all values correspond to E_T in GeV). In $e\mu$, $e > 17$ and $\mu > 4$, 7, or 10. In $\mu\mu$, $\mu_1 > 20$ and $\mu_2 > 10$. For all signatures, a minimum of two jets with $E_T > 20$ were required. The threshold for the leading jet was able to be raised to 45, and/or a third jet > 20 could also be required. Three $\not{E}_T$ thresholds were employed: 20, 30, and 40. Each unique combination of thresholds is called a *kinematic channel.* In all, there were 52 kinematic channels: 16 ee, 24 $e\mu$, and 12 $\mu\mu$.

To handle the large number of channels, a specialized fast Monte Carlo was written, FMCØ.[5] FMCØ incorporates SPYTHIA[6] as an event generator, a detector parameterization tuned from data, and a package that keeps track of the probability that produced events would be observed in any of the 52 kinematic channels.

Backgrounds are from 4 sources: $t\bar{t}$, $W + jets$, $Z + jets$, and QCD multijet events. Top and Z backgrounds were calculated using FMCØ and the measured cross sections. QCD multijet and $W + jet$ backgrounds were calculated using a data-based estimate.

The data sample was collected in the 1994-96 Tevatron collider run. The trigger required an electron, jet, and $\not{E}_T$ for ee and $e\mu$ signatures, and a muon and jet for the $\mu\mu$ signatures. There was no significant excess observed in 108 pb^{-1} (103 pb^{-1} for $\mu\mu$), and the results were used to exclude SUGRA parameter space.

The kinematic channels within a given signature are correlated, that is, loosening cutoffs yield event samples that are supersets of tighter requirements. To avoid bias, one channel in each of the three signatures (determined for each point in parameter space) was chosen to determine exclusion. Input parameters were selected and events generated to determine the expected signal in all kinematic channels, s_i. Using the background prediction, b_i, the *expected significance* was calculated as: $\overline{S}_i = \sum_{N=0}^{\infty} P(s_i + b_i|N) \cdot S(b|N)$, where P is the (Poisson) probability that signal and background produce N observed events, and S is the (Gaussian) significance, that is, the number of standard deviations that background must fluctuate to produce N events.[7] The three kinematic channels with the highest $\overline{S}_i$ were then selected: one ee, one $e\mu$, and one

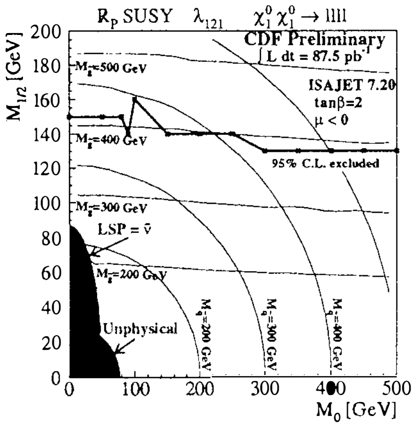

Figure 3: Region excluded at 95% CL for R-parity violating SUGRA multilepton signatures (CDF).

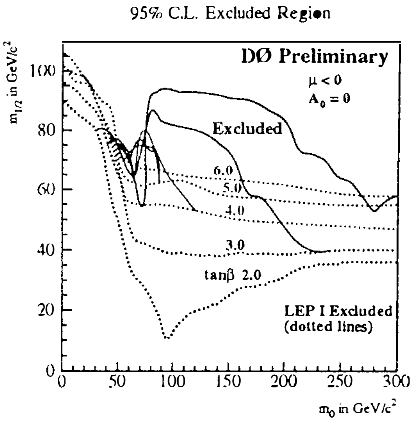

Figure 4: Exclusion for various $\tan\beta$ values from the DØ (R-parity conserving) di-lepton search.

$\mu\mu$ (the three independent channels). In addition, the combination (two- or three-channel) with the highest $\overline{S}_i$ was determined. The number of observed events in the four channels, the three independent and the one combination, were used to determine whether the point is excluded at the 95% confidence level, employing a standard Bayesian prescription.[8] A smooth demarcation was observed between points that could and could not be excluded, and this defined the contour of exclusion (Fig. 4).

4 Conclusions

We have presented results on the search for Supersymmetry at the Tevatron collider. Included were searches for stop and sbottom, as well as searches for R-parity violating Supersymmetry from the CDF Collaboration. We presented a new result from the DØ Collaboration searching for evidence of squarks and gluinos in di-lepton events. No excess above standard model background has been observed in either experiment. DØ and CDF are currently undergoing major detector upgrades, and eagerly await more data from the Tevatron at an energy of 2 TeV.

References

1. S. Abachi, *et al.*, DØ Collaboration, *Nucl. Instr. Meth.* **A338**, 185 (1994).
2. F. Abe, *et al.*, CDF Collaboration, *Nucl. Instr. Meth.* **A271**, 387 (1988).
3. B. Abbott, *et al.*, DØ Collaboration, hep-ex/9903025.
4. D. Choudhury and S. Raychaudhuri, hep-ph/9703369.
5. R. J. Genik II, Ph.D. Thesis, Michigan State University, 1998 (unpublished).
6. S. Mrenna, ANL-HEP-PR-96-63 (unpublished).
7. J. Linnemann, at Computing in High Energy Physics, Rio De Janiero, September 1995. World Scientific (1996), pp. 205-209.
8. I. Bertram *et al.*, DØ Note 2775a (unpublished); also see Particle Data Group, R. M. Barnett *et al.*, *Phys. Rev.* D **54**, 165 (1996).