Fermi National Accelerator Laboratory

FERMILAB-Conf-98/156-E
CDF and D0

SUSY Searches at the Tevatron

Maxwell Chertok
For the CDF and D0 Collaborations
Texas A and M University

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

May 1998

Published Proceedings of the *33rd Rencontres de Moriond: QCD and High Energy Hadronic Interactions,* Les Arcs, France, March 21-28, 1998

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

Disclaimer

Distribution

SUSY SEARCHES AT THE TEVATRON

MAXWELL CHERTOK
Texas A&M University, CDF Group, MS 318, Fermilab
Batavia, IL 60510 USA

for the

CDF AND DØ *COLLABORATIONS*

CDF and DØ have performed searches for Supersymmetry with data collected at $\sqrt{s} = 1.8$ TeV during the years 1992-95. These searches are based on detector signatures: events with appreciable missing transverse energy plus jets with or without dileptons can signal squark and gluino production; the spectacular signature of trilepton events can result from the production of charginos and neutralinos; and the inclusion of R parity violation can produce events with like-sign dileptons and no missing transverse energy. Results from these analyses are presented.

1 Introduction

Supersymmetry (SUSY) [1] is an extension of the Standard Model (SM) with the appealing feature that it reduces the divergences in Quantum Field Theory and thus provides an elegant solution to the naturalness problem. This important effect occurs provided that the SUSY breaking mass scale is $\leq \mathcal{O}(1 \text{ TeV})$. Furthermore, the requirement of local gauge invariance in the theory immediately incorporates gravity; in the Minimal Supergravity (mSUGRA) extension [2] SUSY is broken at M_X, the scale of grand unification, by gravitational interactions. CDF and DØ have performed searches for SUSY particles (sparticles) that could be produced at the Tevatron.

If R parity (R_p) is conserved, then sparticles are pair produced, and the lightest sparticle (LSP) is stable. Furthermore, if the LSP is a neutralino ($\tilde{\chi}_1^0$), it exits the detector without interaction and thus produces events with unbalanced or "missing" transverse energy ($\not\!\!E_T$). If, on the other hand, R_p is violated in nature the resulting experimental signatures can differ substantially.

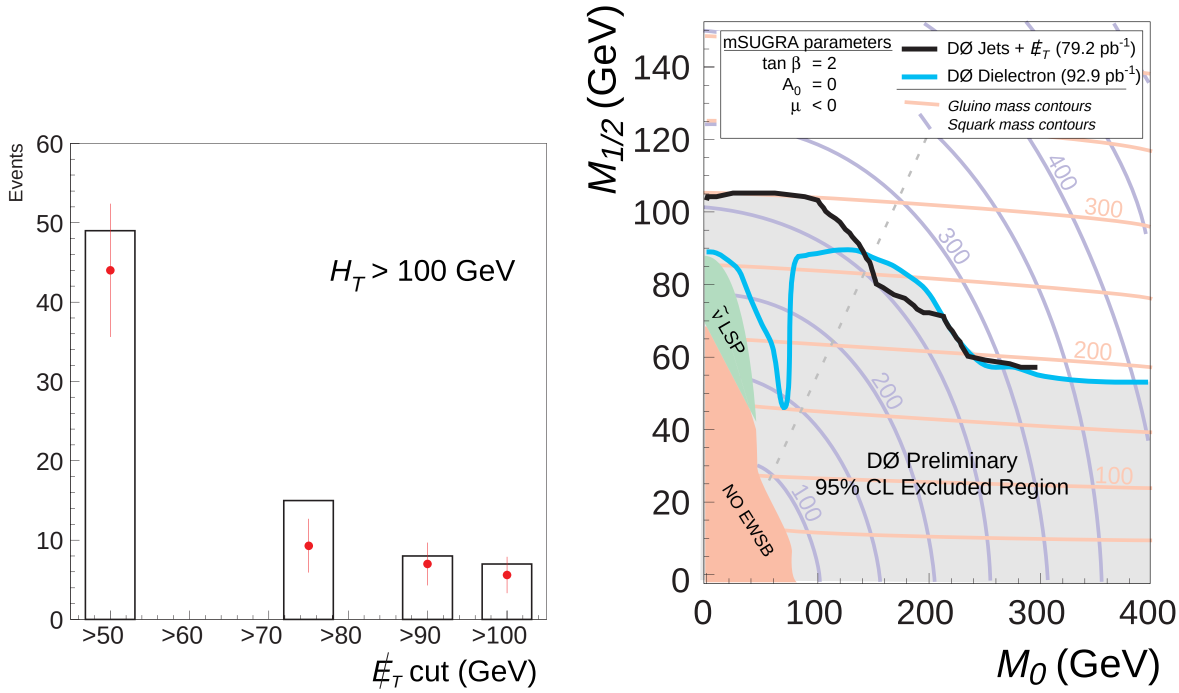

Figure 1: DØ squark and gluino search. Left: comparison of data and background MC after preliminary cuts as a function of $\not\!\!E_T$ cut for $\not\!\!E_T$ + jets analysis. Right: exclusion contour in the $M_0 - M_{1/2}$ plane for the $\not\!\!E_T$ + jets (black line) and dielectron analyses (grey line). Squark and gluino mass contours also are shown.

2 DØ search for squarks and gluinos

2.1 *Search in* $\not\!\!E_T$ *+ jets channel*

With the assumption of R_p conservation, squarks ($\tilde{q}$) and gluinos ($\tilde{g}$) are pair-produced in $p\overline{p}$ annihilations and decay, possibly via cascade decays, to LSPs, quarks, and gluons, leading to the experimental signature of $\not\!\!E_T$ plus jets. DØ has performed a search in this channel using 79 pb^{-1} of data. Preliminary data requirements include ≥ 3 jets with $E_T(j) > 25$ GeV, ≥ 1 jet traversing the central portion of the detector with $E_T > 115$ GeV, and $H_T > 100$ GeV, where $H_T \equiv \sum_{i=2}^{n} \left|\vec{E_T}(j_i)\right|$ and $E_T(j_i) > 15$ GeV.

SM backgrounds for this analysis include $t\bar{t}$ and W plus jets, where one lepton is misidentified or not observed, $Z^0 \to \nu\overline{\nu}$, and mismeasured QCD multijet events. A comparison of the number of data events that pass the preliminary cuts to the expected background shows no significant excess (see Figure 1). Accordingly, DØ sets limits on the mSUGRA parameters M_0 and $M_{1/2}$ after optimizing final $\not\!\!E_T$ $(50 - 150$ GeV) and H_T $(100 - 250$ GeV) cuts for each mass pair. The results are shown in Figure 1; this analysis excludes equal mass squarks and gluinos below 260 GeV.

2.2 *Search in dielectron +* $\not\!\!E_T$ *+ jets channel*

As a complement to the above search, DØ has analyzed the case in which the $\tilde{q}$ and $\tilde{g}$ decay to leptons via charginos ($\tilde{\chi}_1^{\pm}$) and neutralinos ($\tilde{\chi}_2^0$). The requirements for this search are ≥ 2 electrons with $E_T(e) > 15$ GeV, ≥ 2 jets with $E_T(j) > 20$ GeV, and $\not\!\!E_T > 25$ GeV. After Z^0 peak removal, 2 events survive with an expected background level of 3.0 ± 1.3 events. Dielectron decays of $t\bar{t}$ events present the largest source of background. The exclusion region from this analysis is shown in Figure 1. The dip in the contour around $M_0 = 70 - 80$ GeV$/c^2$ corresponds to the region where $M(\tilde{\nu}) < M(\tilde{\chi}_2^0) < M(\tilde{e})$. As a result the decay $\tilde{\chi}_2^0 \to \tilde{\nu}\nu \to \tilde{\chi}_1^0\nu\nu$ dominates,

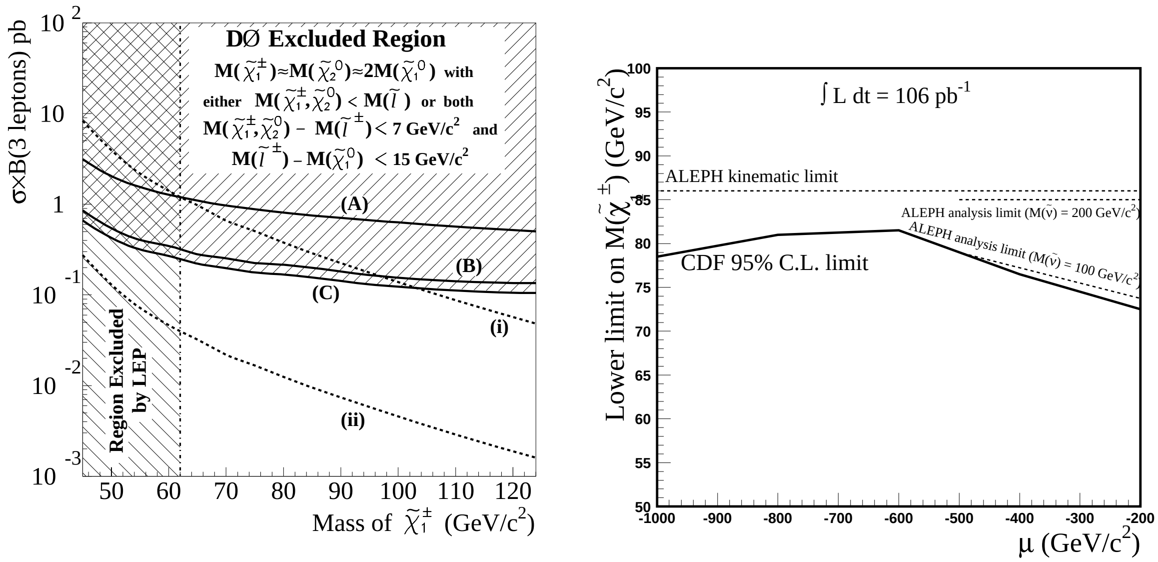

Figure 2: Tevatron trilepton searches. Left: DØ cross section times branching ratio limit versus $M(\tilde{\chi}_1^\pm)$. Curve "(C)" is the limit for the full 95 pb^{-1} data set. Two theoretical predictions are shown as dashed curves and are explained in the text. Right: CDF limit on $M(\tilde{\chi}_1^\pm)$ as a function of μ, the Higgsino mass parameter. Overlaid are the results from ALEPH for the general search $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$.

reducing the dielectron signal.

3 Tevatron trilepton searches for charginos and neutralinos

The lightest chargino ($\tilde{\chi}_1^\pm$) and second-lightest neutralino ($\tilde{\chi}_2^0$) can be lower in mass than other SUSY particles in SUGRA models,[2] and therefore may be discovered first.[3] Furthermore, the reaction $p\overline{p} \to \tilde{\chi}_1^\pm\tilde{\chi}_2^0$, where $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0\ell^\pm\nu$ and $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\ell^+\ell^-$ yields a spectacular trilepton signature. Here, $\tilde{\chi}_1^0$ is taken to be the LSP and adds appreciable $\not\!\!E_T$ to these events. DØ and CDF have performed searches for such trilepton + $\not\!\!E_T$ events, where $\ell = e, \mu$.

3.1 DØ trilepton search

DØ has searched for trileptons from chargino-neutralino production using 95 pb^{-1} of data.[4] This analysis requires events with 3 isolated[a] leptons ($\ell = e, \mu$) in the pseudorapidity ranges $0 < |\eta(e)| < 1.2$, $1.4 < |\eta(e)| < 3.5$, and $|\eta(\mu)| < 1.0$. Cuts on $E_T(\ell)$ and $\not\!\!E_T$ are tuned for each channel (eee, $ee\mu$, $e\mu\mu$, and $\mu\mu\mu$) separately. Events with dilepton mass consistent with Z^0 decay are removed for the eee channel.

No events passing these requirements are observed, so DØ sets limits on the product of the cross section and branching ratio to trileptons as a function of $M(\tilde{\chi}_1^\pm)$. The total efficiency for this analysis is determined with Monte Carlo data and ranges from 0.54% ($\mu\mu\mu$, $M(\tilde{\chi}_1^\pm) =$ 45 GeV/c^2) to 11% (eee, $M(\tilde{\chi}_1^\pm) = 124$ GeV/c^2), with systematic uncertainties in the range 10–20%. Results are plotted in Figure 2 for the data taking run ranges: (A) 1992-93, (B) 1994-95, (C) combined, and are compared to the LO cross section taken from ISAJET multiplied by the branching ratio to trileptons for two cases: (i) $M(\tilde{\ell}) < M(\tilde{\chi}_1^\pm), M(\tilde{\chi}_2^0) < M(\tilde{q})$ and the maximum

[a] An "isolated" lepton is one for which the E_T measured by the calorimeter inside an η-ϕ cone surrounding the lepton, excluding the lepton E_T, is less than a cut value. The pseudorapidity is defined $\eta \equiv -\ln\tan(\theta/2)$, where θ is the polar angle; ϕ is the azimuthal angle.

branching ratio $Br(3\ell) = 1/9$ for any single trilepton channel, and (ii) $M(\tilde{\chi}_1^{\pm}), M(\tilde{\chi}_2^0) < M(\tilde{\ell})$ with $Br(3\ell) = 0.0036$, assuming SM strength couplings.

3.2 CDF trilepton search

CDF has performed a search for trilepton events from $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production using 106 pb^{-1} of data.[5] Starting from a 460K dilepton event data sample, events with three isolated leptons are selected. The events must contain either e^+e^- or $\mu^+\mu^-$ with an addition electron or muon, and $\not{E}_T > 15$ GeV. After J/Ψ, Υ, and Z^0 removal no events remain, with an expected background level of 1.2 ± 0.2 events from $b\bar{b}$ and Drell-Yan plus fake leptons.[b] Consequently, CDF sets limits on the cross section times branching ratio for this process, along with limits on $M(\tilde{\chi}_1^{\pm})$.

Figure 2 shows this mass limit as a function of μ, the Higgsino mass parameter. This limit is determined for $\tan\beta = 2$, where $\tan\beta$ is defined as the ratio of the Higgs vacuum expectation values, and $M(\tilde{q}) = M(\tilde{g})$. Recent results from ALEPH[6] are overlaid for light (100 GeV/c^2) and heavy (200 GeV/c^2) $M(\tilde{\nu})$. As $M(\tilde{\nu})$ decreases, the negative interference to $\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-)$ increases thus reducing the limit. CDF also compares its results to a string-inspired "flipped" supergravity model[7] that requires $M(\tilde{\chi}_1^{\pm}) \simeq M(\tilde{\chi}_2^0) \leq 90$ GeV/c^2 and excludes much of it, setting limits $M(\tilde{\chi}_1^{\pm}) > 80.5$ GeV/c^2 and $M(\tilde{\chi}_2^0) > 87$ GeV/c^2.[5]

4 CDF search for R parity violating squarks and neutralinos

CDF has performed a search for like-sign dielectron plus multijet events which can arise in R_p violating ($\not{R}_p$) squark and neutralino decay. For a particle of baryon number B, lepton number L, and spin S, the multiplicative quantum number $R_p \equiv (-1)^{3B+L+2S}$ distinguishes particles ($R_p = +1$) from sparticles ($R_p = -1$). If R_p is conserved, sparticles must be produced in pairs, and the lightest sparticle (LSP) is stable. However, by adding explicit $\not{R}_p$ interactions to the theory, the LSP can be made to decay, which leads to experimental signatures without appreciable $\not{E}_T$.

One interpretation of the "excess" of high Q^2 events reported by the HERA experiments[8] in 1997 is $\not{R}_p$ $\tilde{q}$ production and decay via the reaction $e^+\, p \to \tilde{q} \to e^+\, d$, involving a non-zero value of the λ'_{1jk} coupling.[9] For this scenario, $\tilde{c}_L$ with mass $M(\tilde{c}_L) = 200$ GeV/c^2 [10] is a preferred squark flavor, because its associated coupling λ'_{121} is less constrained by experiment than the others.

CDF analyzes two $\not{R}_p$ processes that involve the same λ'_{121} coupling: (1) $p\bar{p} \to \tilde{g}\tilde{g} \to (c\,\tilde{c}_L)\,(c\,\tilde{c}_L) \to c\,(e^{\pm}d)\,c\,(e^{\pm}d)$; and (2) $p\bar{p} \to \tilde{q}\bar{\tilde{q}} \to (q\tilde{\chi}_1^0)\,(\bar{q}\tilde{\chi}_1^0) \to q\,(dce^{\pm})\,\bar{q}\,(dce^{\pm})$. For process (1), the relation $M(\tilde{q}) > M(\tilde{g}) > M(\tilde{c}_L) = 200$ GeV/c^2 is assumed, using a mass relation to fix the "degenerate" squark masses.[10] For process (2), $\tilde{q}\bar{\tilde{q}}$ production (5 degenerate squark flavors) and $\tilde{t}_1\bar{\tilde{t}}_1$ production are considered separately. Given the Majorana nature of the gluino and neutralino, these decays yield like-sign (LS) and opposite-sign (OS) dileptons with equal probability. Since LS dilepton events have the benefit of small SM backgrounds, for both processes CDF searches for events with LS electrons (e^+e^+ or e^-e^-) plus two or more jets.

The data analysis starts with the same dilepton sample used in the CDF trilepton search[5] and imposes similar identification and isolation requirements. In Figure 3 the dielectron invariant mass is plotted for events with LS or OS ee, satisfying $E_T(e_1) > 11$ GeV, $E_T(e_2) > 5$ GeV, and $|\eta_e| < 1.1$, plus two or more jets with $E_T(j) > 15$ GeV and $|\eta_j| < 2.4$. Final requirements are imposed after Monte Carlo studies of signal and background events: $E_T(e) > 15$ GeV, LS ee only, and no significant $\not{E}_T$ in the event: $\sigma(\not{E}_T) \equiv \not{E}_T/\sqrt{\Sigma E_T} < 5$ GeV$^{1/2}$. After these requirements, no events survive in 107 pb^{-1} of data. Backgrounds to these processes from $t\bar{t}$

[b] "Fake leptons" include electrons from muon decay and non-leptonic objects that pass leptonic identification requirements.

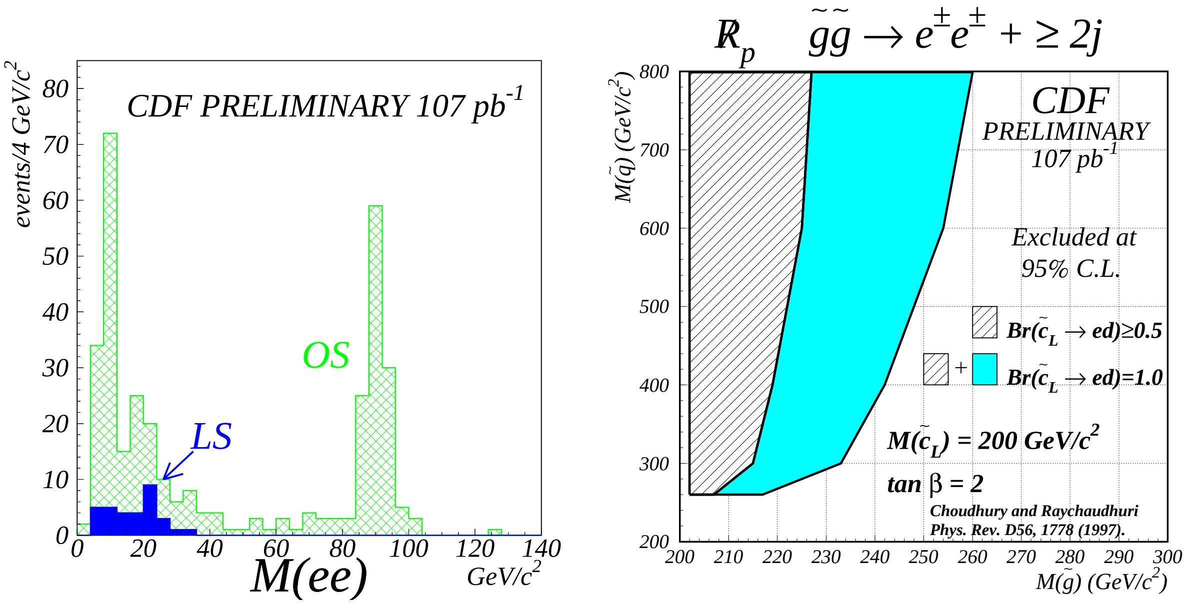

Figure 3: CDF R_p violation search. Left: the dielectron invariant mass for events in the $ee+ \geq 2$ jets sample. Clear peaks at the Υ and Z^0 masses are visible for events with OS ee. There is one OS ee + 2 jet event with $M(ee) = 263$ GeV$/c^2$. Right: exclusion region in the $M(\tilde{g})$ - $M(\tilde{q})$ mass plane from the gluino decay analysis. The combined hatched plus shaded region is excluded for $Br(\tilde{c}_L \to ed) = 1.0$, while the hatched region alone is excluded for $Br(\tilde{c}_L \to ed) \geq 0.5$. $M(\tilde{c}_L)$ is fixed at 200 GeV$/c^2$.

and $b\overline{b}/c\overline{c}$ are removed effectively with the lepton isolation cuts, $\not\!\!E_T$ signficance cut, and electron E_T cut. Systematic uncertainties are dominated by the uncertainty on the integrated luminosity and from gluon radiation effects on the acceptance and are in the range $10-16\%$.

Consequently, CDF sets limits on these two processes. For process (1), the product $\sigma(p\overline{p} \to \tilde{g}\tilde{g}) \cdot Br(\tilde{g}\tilde{g} \to e^{\pm}e^{\pm} + \ \geq 2j) \geq 0.18$ pb is excluded independent of $M(\tilde{g})$, giving the exclusion contours shown in Figure 3, using the NLO cross section $\sigma(p\overline{p} \to \tilde{g}\tilde{g})$.[11] For process (2), the cross section times branching ratio limit is a function of $M(\tilde{q})$ and $M(\tilde{\chi}_1^0)$ in the range $0.81-0.20$ pb. Figure 4 shows the resulting limit plots for the cases of $\tilde{t}_1\bar{\tilde{t}}_1$ and $\tilde{q}\bar{\tilde{q}}$ production, using the NLO cross sections $\sigma(p\overline{p} \to \tilde{t}_1\bar{\tilde{t}}_1)$ and $\sigma(p\overline{p} \to \tilde{q}\bar{\tilde{q}})$.[12,13] For the latter, the cross section has a $M(\tilde{g})$ dependence. In each case, a better limit is set for a heavy $M(\tilde{\chi}_1^0)$, since this yields higher E_T electrons.

References

1. For reviews on SUSY, see H.P. Nilles, *Phys. Rep.* **110**, 1 (1984), and H.E. Haber and G.L. Kane, *Phys. Rep.* **117**, 75 (1985).
2. For a recent review, see R. Arnowitt and P. Nath, "Supersymmetry and Supergravity: Phenomenology and Grand Unification," Proceedings of VIIth J.A. Swieca Summer School, Campos de Jordao, Brazil, 1993 (World Scientific, Singapore, 1994).
3. P. Nath and R. Arnowitt, *Mod. Phys. Lett.* A **2**, 331 (1987); R. Barbieri, F. Caravaglios, M. Frigeni and M. Mangano, *Nucl. Phys.* B **367**, 28 (1991); H. Baer and X. Tata, *Phys. Rev.* D **47**, 2739 (1993); J.L. Lopez, D.V. Nanopoulos, X. Wang and A. Zichichi, *Phys. Rev.* D **48**, 2062 (1993); H. Baer, C. Kao, and X. Tata, *Phys. Rev.* D **48**, 5175 (1993).
4. B. Abbott *et al.* (DØ Collaboration), *Phys. Rev. Lett.* **80**, 1591 (1998).
5. F. Abe *et al.* (CDF Collaboration), To be published in *Phys. Rev. Lett.*, Fermilab-Pub-98/084-E and hep-ex/9803015 (1998).
6. R. Barate *et al.* (ALEPH Collaboration), CERN-PPE-97-128 (1997).

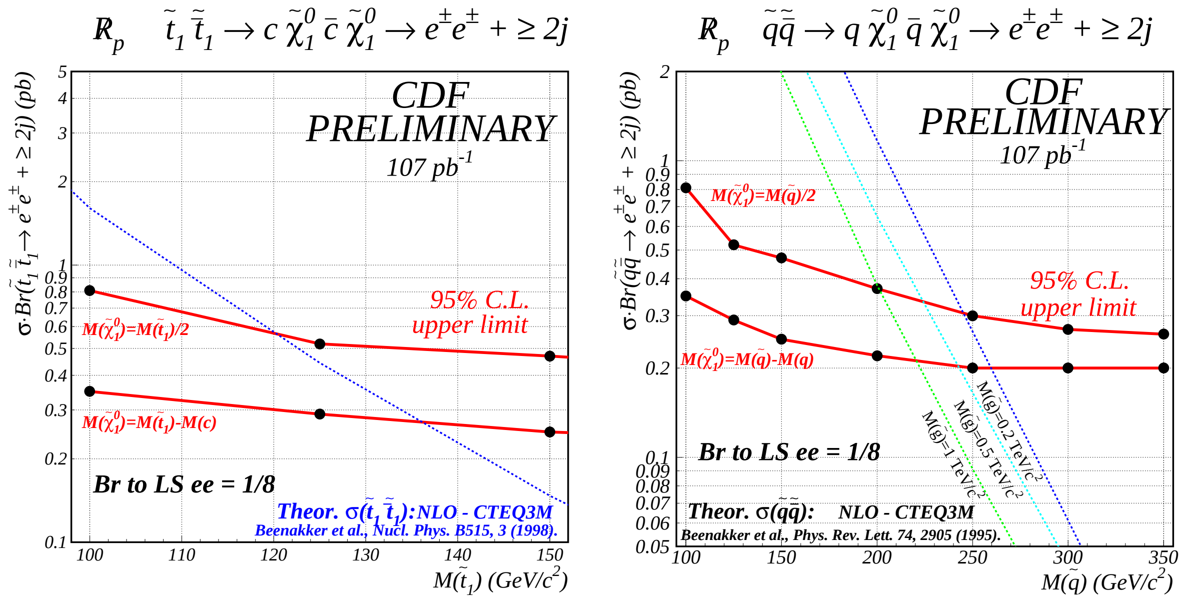

Figure 4: CDF R_p violation search. Left: cross section times branching ratio upper limit for stop-antistop production decaying to neutralinos. The theoretical curve is the NLO $\tilde{t}_1\bar{\tilde{t}}_1$ cross section multiplied by a branching ratio of 1/8. The branching ratio $Br(\tilde{t}_1 \to c\tilde{\chi}_1^0)$ is taken to be 1.0. Right: cross section times branching ratio upper limit assuming 5 degenerate squark flavors decaying to neutralinos. The theoretical curves are the NLO total cross section multiplied by a branching ratio of 1/8. The branching ratio $Br(\tilde{q} \to q\,\tilde{\chi}_1^0)$ is taken to be 1.0.

7. J. Lopez *et al.*, *Phys. Rev.* D **52**, 4178 (1995) and *Phys. Rev.* D **53**, 5253 (1996).
8. C. Adloff *et al.* (H1 Collaboration), *Z. Phys.* C **74**, 191 (1997); J. Breitweg *et al.* (ZEUS Collaboration), *Z. Phys.* C **74**, 207 (1997).
9. D. Choudhury and S. Raychaudhuri, *Phys. Lett.* B **401**, 54 (1997); G. Altarelli *et al.*, *Nucl. Phys.* B **506**, 3 (1997); H. Dreiner and P. Morawitz, *Nucl. Phys.* B **503**, 55 (1997); J. Kalinowski *et al.*, *Z. Phys.* C **74**, 595 (1997); T. Kon and T. Kobayashi, *Phys. Lett.* B **409**, 265 (1997).
10. D. Choudhury and S. Raychaudhuri, *Phys. Rev.* D **56**, 1778 (1997).
11. W. Beenakker, R. Höpker, M. Spira, and P. M. Zerwas, *Z. Phys.* C **69**, 163 (1995).
12. W. Beenakker, M. Krämer, T. Plehn, M. Spira, and P. M. Zerwas, *Nucl. Phys.* B **515**, 3 (1998).
13. W. Beenakker, R. Höpker, M. Spira, and P. M. Zerwas, *Phys. Rev. Lett.* **74**, 2905 (1995).