Fermi National Accelerator Laboratory

FERMILAB-Conf-98/246-E
CDF

Search for Supersymmetry at CDF

T. Kamon
For the CDF Collaboration

Texas A & M University
College Station, Texas 77843-4242

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

August 1998

Published Proceedings of the *Richard Arnoiwitt Fest*,
Texas A & M University, College Station, Texas, April 5-8, 1998

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

Search for Supersymmetry at CDF

Teruki Kamon
(CDF Collaboration)
Department of Physics, Texas A&M University,
College Station, TX 77843-4242, USA
E-mail: kamon@fnal.gov

We summarize results of a search for supersymmetry (SUSY) using a data sample of dileptons in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.8 TeV. The data represent an integrated luminosity of 107 pb^{-1} collected by the Collider Detector at Fermilab (CDF) during the 1992-93 and 1994-95 runs. We also briefly provide a prospect of the SUSY search at CDF in the next run of the Tevatron.

1 Introduction

The minimal supersymmetric standard model (MSSM)[1] is an extension of the standard model (SM) that adds a supersymmetric (SUSY) partner for each SM particle, and is constructed to conserve R parity (R_p).[2] For a particle of spin S, the multiplicative quantum number $R_p \equiv (-1)^{3B+L+2S}$ distinguishes particles ($R_p = +1$) from SUSY particles ($R_p = -1$). Here B and L are baryon and lepton number, respectively. With assumption of the gaugino unification provided by supergravity (SUGRA),[3] the MSSM framework has a simple mass relation between chargino ($\tilde{\chi}_1^\pm$) and neutralinos ($\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$): $M_{\tilde{\chi}_1^\pm} \approx M_{\tilde{\chi}_2^0} \approx 2\ M_{\tilde{\chi}_1^0}$.

Models with R_p conservation yield a natural candidate, the lightest neutralino ($\tilde{\chi}_1^0$), for the cold dard matter that astronomers now believe constitute the majority of matter in our galaxy and the universe. We assume the lightest neutralino is the lightest supersymmetric particle (LSP) and stable. This leads to experimental signatures with appreciable missing energy. Table 1 is a list of examples of R_p conserving SUSY signatures at the Tevatron. One of the most promising channels for the discovery of SUSY at a hadron collider is the trilepton final state[4] arising from $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ pair production with subsequent leptonic decays ($\tilde{\chi}_1^\pm \to \ell\nu\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to \ell^+\ell^-\tilde{\chi}_1^0$).

SUSY searches have been active in the CDF experiment at the Tevatron. One of important data samples for SUSY searches is a dilepton sample (Section 2.2), which is commonly used for:

- $\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to (\ell^\pm\nu\ \tilde{\chi}_1^0)\ (\ell^+\ell^-\ \tilde{\chi}_1^0)$
- $\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to (\tau^\pm\nu\ \tilde{\chi}_1^0)\ (\ell^+\ell^-\ \tilde{\chi}_1^0)$

Table 1: Examples of R_p conserving SUSY signatures at the Tevatron.

Prod.	Signature	Comments
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	$(\ell^{\pm}\nu\ \tilde{\chi}_1^0)\ (\ell^+\ell^-\ \tilde{\chi}_1^0)$ $(\tau^{\pm}\nu\ \tilde{\chi}_1^0)\ (\ell^+\ell^-\ \tilde{\chi}_1^0)$ $(\tau^{\pm}\nu\ \tilde{\chi}_1^0)\ (\tau^+\tau^-\ \tilde{\chi}_1^0)$ $(q\bar{q}'\ \tilde{\chi}_1^0)\ (\ell^+\ell^-\ \tilde{\chi}_1^0)$ $(q\bar{q}'\ \tilde{\chi}_1^0)\ (\tau^+\tau^-\ \tilde{\chi}_1^0)$	
	$(\ell^{\pm}\nu\ \tilde{\chi}_1^0)\ (q\bar{q}\ \tilde{\chi}_1^0)$ $(\ell^{\pm}\nu\ \tilde{\chi}_1^0)\ (b\overline{b}\ \tilde{\chi}_1^0)$ $(\tau^{\pm}\nu\ \tilde{\chi}_1^0)\ (b\overline{b}\ \tilde{\chi}_1^0)$	
$\tilde{g}\tilde{g}, \tilde{q}\tilde{g}, \tilde{q}\tilde{q}$	$\not\!\!E_T + \geq$3,4 jets	
$\tilde{g}\tilde{g}$	$(q\bar{q}'\tilde{\chi}_1^{\pm})\ (q\bar{q}'\tilde{\chi}_1^{\pm}) \rightarrow \ell^{\pm}\ell^{\pm}$ + jets + $\not\!\!E_T$	
	$(\bar{b}\tilde{b})\ (\bar{b}\tilde{b}) \rightarrow (\bar{b}b\tilde{\chi}_1^0)(\bar{b}b\tilde{\chi}_1^0)$ $(\bar{b}\tilde{b})\ (\bar{b}\tilde{b}) \rightarrow (\bar{b}b\tilde{\chi}_2^0)(\bar{b}b\tilde{\chi}_2^0)$ $\rightarrow (b\overline{b}\ \ell^+\ell^-\tilde{\chi}_1^0)(b\overline{b}\ q\bar{q}\tilde{\chi}_1^0)$	$M_{\tilde{b}} < M_{\tilde{g}} - M_b$
$\tilde{t}_1\tilde{t}_1$	$(b\tilde{\chi}_1^+)\ (b\tilde{\chi}_1^-) \rightarrow (b\ell^+\nu\tilde{\chi}_1^0)\ (bq\bar{q}'\tilde{\chi}_1^0)$ $(b\tilde{\chi}_1^+)\ (\bar{b}\tilde{\chi}_1^-) \rightarrow (b\ell^+\nu\tilde{\chi}_1^0)\ (\bar{b}\ell^-\nu\tilde{\chi}_1^0)$	$M_{\tilde{\chi}_1^{\pm}} < M_{\tilde{t}_1} - M_b$
	$(c\tilde{\chi}_1^0)\ (\bar{c}\tilde{\chi}_1^0)$	$M_{\tilde{\chi}_1^{\pm}} > M_{\tilde{t}_1} - M_b$
	$(b\ell\tilde{\nu})\ (\bar{b}\ell\tilde{\nu}) \rightarrow (b\ell\nu\tilde{\chi}_1^0)\ (\bar{b}\ell\nu\tilde{\chi}_1^0)$ $(b\tau\tilde{\nu})\ (\bar{b}\tau\tilde{\nu}) \rightarrow \ell\ell + b\overline{b} + \not\!\!E_T$	$M_{\tilde{\nu}} < M_{\tilde{t}_1} - M_b$

- $\tilde{g}\tilde{g} \rightarrow (q\bar{q}'\tilde{\chi}_1^{\pm})\ (q\bar{q}'\tilde{\chi}_1^{\pm}) \rightarrow \ell^{\pm}\ell^{\pm}$ + jets + $\not\!\!E_T$

- $\tilde{g}\tilde{g} \rightarrow (\bar{b}\tilde{b})\ (\bar{b}\tilde{b}) \rightarrow (\bar{b}b\tilde{\chi}_2^0)(\bar{b}b\tilde{\chi}_2^0) \rightarrow (b\overline{b}\ \ell^+\ell^-\tilde{\chi}_1^0)(b\overline{b}\ q\bar{q}\tilde{\chi}_1^0)$

- $\tilde{t}_1\tilde{t}_1 \rightarrow (b\tilde{\chi}_1^+)\ (\bar{b}\tilde{\chi}_1^-) \rightarrow (b\ell^+\nu\tilde{\chi}_1^0)\ (\bar{b}\ell^-\nu\tilde{\chi}_1^0)$

- $\tilde{t}_1\tilde{t}_1 \rightarrow (b\ell\tilde{\nu})\ (\bar{b}\ell\tilde{\nu}) \rightarrow (b\ell\nu\tilde{\chi}_1^0)\ (\bar{b}\ell\nu\tilde{\chi}_1^0)$

- $\tilde{t}_1\tilde{t}_1 \rightarrow (b\tau\tilde{\nu})\ (\bar{b}\tau\tilde{\nu}) \rightarrow \ell\ell + b\overline{b} + \not\!\!E_T$

In this paper, we forcus on the trilepton analysis (Section 3), instead of systematically listing all SUSY searches at CDF.[5] Lastly, we discuss a prospect of SUSY searches in Run II (Section 4).

2 The CDF Experiment

2.1 The CDF Detector

The Collider Detector at Fermilab (CDF) is described in detail elsewhere.[6] The elements of the detector relevant to this analysis will be described briefly here. The location of the $p\overline{p}$ collision event vertex (z_{vertex}) is measured along the beam direction with a time projection chamber. The transverse momenta (p_T) of charged particles are measured in the pseudorapidity region $|\eta| < 1.1$ by the central tracking chamber, which is located in a 1.4 T solenoidal magnetic field. Here $p_T = p \sin\theta$ and $\eta = -\ln\tan(\theta/2)$.[7] The electromagnetic and hadronic calorimeters surround outside the tracking chambers, segmented in a projective tower geometry, and cover the central ($|\eta| < 1.1$) and plug ($1.1 < |\eta| < 2.4$) regions. Two central muon systems, located outside the hadronic calrorimeter, cover $|\eta| < 0.6$ and $0.6 < |\eta| < 1.0$, respectively.

2.2 SUSY Dilepton Sample

A dilepton sample for various SUSY searches is created from an initial sample of events that fired the inclusive central lepton triggers with $E_T^e > 9.2$ GeV and $p_T^\mu > 9.2$ GeV/c in the 1992-93 run (Run Ia),[8] and with $E_T^e > 8$ (or 16) GeV and $p_T^\mu > 12$ (or 7.5) GeV/c in the 1994-95 run (Run Ib).[9] It contains 58,221 events from 1992-93 run and 457,478 events from 1994-95 run after requiring (i) at least one central lepton passing $E_T^e > 8$ GeV ($|\eta| < 1.1$) or $p_T^\mu > 7.5$ GeV/c ($|\eta| < 0.6$) and (ii) at least one additional lepton passing $E_T^e > 4$ GeV ($|\eta| < 2.4$) or $p_T^\mu > 1.4$ GeV/c ($|\eta| < 1.0$). A total integrated luminosity for events from the electron (muon) triggers is 107 (106) pb^{-1}.

3 Search for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ using Trilepton Events

Figure 1 shows diagrams for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production and decays of $\tilde{\chi}_1^\pm$ ($\rightarrow \tilde{\chi}_1^0 \ell^\pm \nu$) and $\tilde{\chi}_2^0$ ($\rightarrow \tilde{\chi}_1^0 \ell^+ \ell^-$). Here $\tilde{\chi}_1^0$ is the stable LSP. The ν and two LSPs do not interact with the detector and manifest themselves as missing transverse energy ($\not\!\!E_T$). The resulting final state is three isolated charged leptons plus missing energy.[4] We search for direct production of $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ in the trilepton channels (e^+e^-e, $e^+e^-\mu$, $e\mu^+\mu^-$ and $\mu^+\mu^-\mu$).

Trilepton event candidates are selected from our SUSY dilepton sample (Section 2.2). The lepton identifications are described in detail elsewhere.[8,9] We require: (i) at least one lepton (e or μ) with with $E_T^e > 11$ GeV ($|\eta| < 1.1$) or $p_T^\mu > 11$ GeV/c ($|\eta| < 0.6$), and additional two leptons (e or μ) with $E_T^e > 5$ GeV ($|\eta| < 2.4$) or $p_T^\mu > 4$ GeV/c ($|\eta| < 1.0$); (ii) all three leptons to be originated from a common event vertex ($|z_{vertex}| < 60$ cm); (iii) each lepton

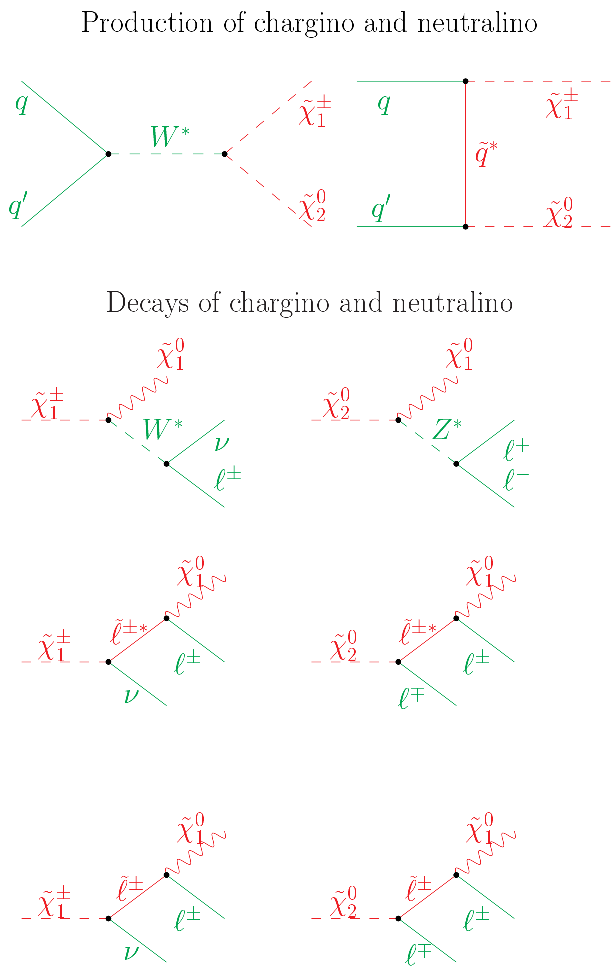


Figure 1: Chargino-neutralino pair production via virtual $W^\pm$ s-channel and virtual squark t-channel diagrams, and decays of charginos and neutralinos.

to pass $ISO < 2$ GeV, where ISO is the total calorimeter E_T inside an η-ϕ cone of radius $\Delta R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.4$ around the lepton, excluding the energy deposited by the lepton; (iv) at least one e^+e^- or $\mu^+\mu^-$ pair; (v) the η-ϕ distance between any two leptons ($\Delta R_{\ell\ell}$) to be greater than 0.4; (vi) the difference in azimuthal angle between the two highest p_T leptons ($\Delta\phi_{\ell_1\ell_2}$) in the event to be less than 170°. We are left with four events for the 1992-93 data (19 pb^{-1}) and eight events for the 1994-95 data (87 pb^{-1}).

Events containing a same flavor $\ell^+ \ell^-$ pair with invariant mass in the regions of the resonances J/ψ (2.9-3.3 GeV/c^2), Υ (9-11 GeV/c^2) and Z^0 (75-105 GeV/c^2) are removed. These requirements select zero events for the 1992-93 data and six events for the 1994-95 data.

The dominant remaining backgrounds are $b\overline{b}$ production and the Drell-Yan process, which do not have significant $\not\!\!E_T$. Requiring $\not\!\!E_T > 15$ GeV reduces the background by 85% while more than 80% of the expected signal for $M_{\tilde{\chi}_1^\pm} \gtrsim 70$ GeV/c^2. No events pass the $\not\!\!E_T$ cut from 1992-93 and 1994-95 data.

The principal SM backgrounds to the $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ signature are real trilepton events from $W^\pm Z^0$, Z^0Z^0, $t\overline{t}$ and $b\overline{b}$ productions and dilepton events from W^+W^-, Z^0 and the Drell-Yan processes plus additional lepton [10] not from the primary process. We find the total expected background is 1.2±0.2 events in 106 pb^{-1}, which is consistent with zero observed events.

Theoretical prediction of of $\sigma(p\overline{p} \to \tilde{\chi}_1^\pm\tilde{\chi}_2^0 + X) \cdot Br(\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to 3\ell + X)$ is given by ISAJET [11] with CTEQ3L [12] parton distribution functions. Here $Br(\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to 3\ell + X) = Br(eee) + Br(ee\mu) + Br(e\mu\mu) + Br(\mu\mu\mu)$. With additional assumptions of SUGRA-inspired slepton/sneutrino mass constraints [13] and degeneracy of five of the squarks,[14] lead to models with six ISAJET MSSM parameters: the gluino mass ($M_{\tilde{g}}$),[15] the squark mass ($M_{\tilde{q}}$), the trilinear top squark coupling (A_t), the ratio of the Higgs vacuum expectation values ($\tan\beta$), the Higgsino mass parameter (μ), and the pseudoscalar Higgs mass (M_A). We scan SUSY parameter space as (a) 150 GeV/$c^2 \leq M_{\tilde{g}} \leq 340$ GeV/c^2 (*i.e.*, 50 GeV/$c^2 \lesssim M_{\tilde{\chi}_1^\pm} \lesssim 100$ GeV/c^2); (b) $1 \leq M_{\tilde{q}}/M_{\tilde{g}} \leq 2$ to avoid $\tilde{\chi}_2^0 \to \nu\tilde{\nu}$ ($M_{\tilde{q}}/M_{\tilde{g}} \lesssim 1$) and to enhance the branching ratio to leptons ($M_{\tilde{q}}/M_{\tilde{g}} \lesssim 2$); (c) $A_t = \mu/\tan\beta$ because the production and decay of $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ are independent of A_t; (d) $1.1 \leq \tan\beta \leq 8$ where $\tan\beta \gtrsim 8$ leads to higher branching ratios to τs; (e) -1000 GeV/c^2 $< \mu < -200$GeV/c^2 because the search is more sensitive to negative values of μ and small $|\mu|$ increases the Higgsino content of the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$, which decreases the branching ratio to leptons; (f) $M_A = 500$ GeV/c^2 to make the analysis more independent of details of the Higgs sector.[16]

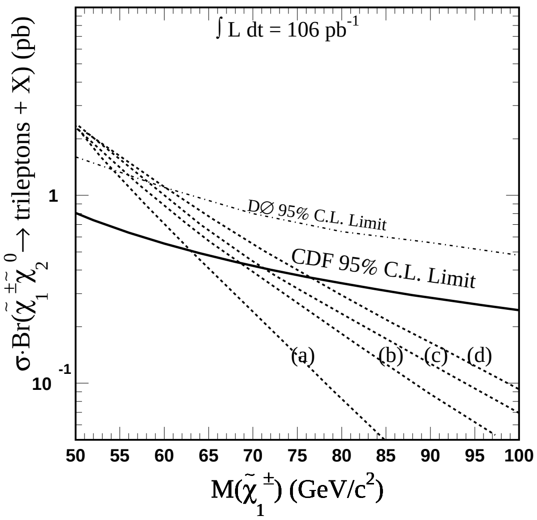


Figure 2: 95% C.L. upper limit (solid line) on $\sigma \cdot Br(\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to 3\ell + X)$ as a function of $M_{\tilde{\chi}_1^{\pm}}$, compared to predictions at four MSSM points at $\mu = -400$ GeV/c^2, tan $\beta = 2$ for $M_{\tilde{q}}/M_{\tilde{g}}$ = 2.0(a), 1.5(b), 1.2(c) and 1.0(d). The DØ limit [17] is also shown.

The 95% confidence level (C.L.) upper limit on $\sigma \cdot Br$ is determined as

$$\sigma \cdot Br \ (95\% \text{ C.L.}) = \frac{N_{95\%}}{\epsilon^{tot} \cdot \int \mathcal{L} \, dt}, \tag{1}$$

where $N_{95\%}$ is the number of events expected at the 95% C.L. limit for zero observed events, ϵ^{tot} is the total detection efficiency, and $\int \mathcal{L} \, dt$ is the total integrated luminosity of (106 ± 7) pb^{-1}.

We find (i) ϵ^{tot}, which is a product of the trigger efficiency, the isolation efficiency, the lepton identification efficiency and a geometric and kinematic acceptance, is mainly a function of $M_{\tilde{\chi}_1^{\pm}}$, and increases linearly from 3% at 50 GeV/c^2 to 12% at 100 GeV/c^2; (ii) $N_{95\%} = 3.1$ by convolving the total systematic uncertainty of 15% as a Gaussian smearing with a Poisson distribution.[9]

Figure 2 shows the 95% C.L. upper limit on $\sigma \cdot Br$, compared to the DØ result.[17] We also overlay predictions at four representative MSSM points at $\mu = -400$ GeV/c^2 and $\tan\beta = 2$. The lower limit on $M_{\tilde{\chi}_1^{\pm}}$ is maximized at

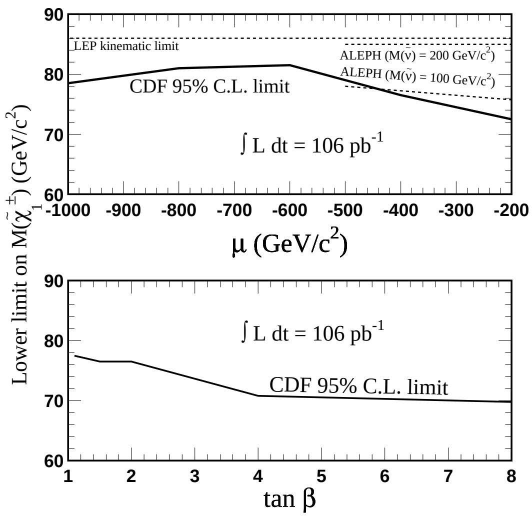


Figure 3: [Top] 95% C.L. lower limit on $M_{\tilde{\chi}_1^\pm}$ as a function of μ for $\tan\beta = 2$ and $M_{\tilde{q}} = M_{\tilde{g}}$. The ALEPH limits [18] are from a search for all possible final states. In this analysis $M_{\tilde{\nu}} \approx 100$ GeV/c^2. [Bottom] 95% C.L. lower limit on $M_{\tilde{\chi}_1^\pm}$ as a function of $tan\beta$ for $\mu = -400$ GeV/c^2 and $M_{\tilde{q}} = M_{\tilde{g}}$.

77.0 GeV/c^2 for $M_{\tilde{q}} = M_{\tilde{g}}$.

The lower limits on $M_{\tilde{\chi}_1^\pm}$ are also studied as a function of μ and $\tan\beta$. The results are shown in Figure 3. These limits are compared to the limits from ALEPH.[18] The OPAL, L3 and DELPHI collaborations report similar limits [19]. The strongest limit is $M_{\tilde{\chi}_1^\pm} > 81.5$ GeV/c^2 and $M_{\tilde{\chi}_2^0} > 82.2$ GeV/c^2 for $\tan\beta = 2$, $\mu = -600$ GeV/c^2 and $M_{\tilde{q}} = M_{\tilde{g}}$.

In SUGRA models,[3] $|\mu|$ value is determined by demanding the correct radiative electroweak symmetry breaking. Using ISAJET, we find a parameter point in minimal SUGRA model corresponding to a MSSM point of $M_{\tilde{\chi}_1^\pm} \simeq 80$ GeV/c^2, $M_{\tilde{q}} = M_{\tilde{g}}$, and $\tan\beta = 2$: $(m_0, m_{1/2}) = (130$ GeV/c^2, 75 GeV/$c^2)$ at $\mu < 0$ and $A_0 = 0$. The value of μ is -178 GeV/c^2, which is roughly a region with $|\mu| \approx 200$ GeV/c^2 in Figure 3. Thus, general limits for minimal SUGRA model are weaker than the strongest limit for our MSSM scenario.

In conclusion, we find no evidence for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production from 106 pb^{-1} data in 1.8 TeV $p\overline{p}$ collisions and measure upper limits on $\sigma \cdot Br$ as a function of $M_{\tilde{\chi}_1^{\pm}}$. In a MSSM framework of $M_{\tilde{\chi}_1^{\pm}} \approx M_{\tilde{\chi}_2^0} \approx 2\ M_{\tilde{\chi}_1^0}$ and three-body decays of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$, the strongest mass limit is $M_{\tilde{\chi}_1^{\pm}} > 81.5$ GeV/c^2 and $M_{\tilde{\chi}_2^0} > 82.2$ GeV/c^2 at $\tan\beta = 2$, $\mu = -600$ GeV/c^2 and $M_{\tilde{q}} = M_{\tilde{g}}$.

4 Prospect in Run II

Tevatron is currently being upgraded to provide a peak luminosity of 2×10^{32} cm^{-2}s^{-1} at $\sqrt{s} = 2$ TeV. The next run, called Run II, is expected to start in 2000 and to accumurate 2 fb^{-1} of data. In addtion to the upgraded Tevatron, the CDF detector is also being upgraded. The upgraded detector, called CDF-II,[20] should extend the coverage for electrons and muons with *tracking* to $|\eta|$ = 2 from $|\eta| = 1.1$ in the current CDF detector.

Both CDF and DØ collaborations formed four working groups to maximize the SUSY/Higgs search in Run II.[21] Four topics are (i) SUGRA, (ii) beyond the MSSM, (iii) Gauge-mediate SUSY breaking, and (iv) Higgs. Each group meets regularly to address the goal and to have a final report in November 1998.

For CDF, preliminary studies of Run II triggers were carried out based on SUGRA using the Run I data:

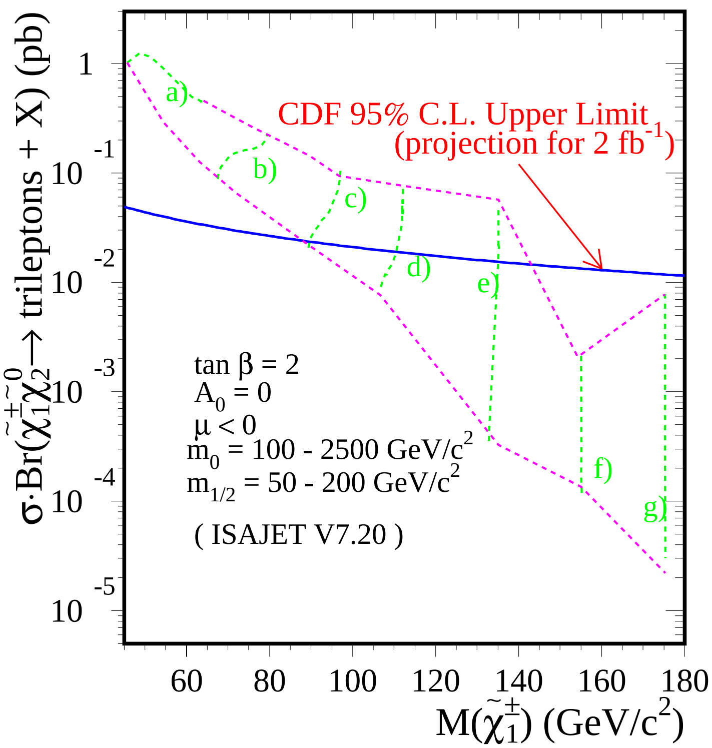
1. $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow \not{E}_T + (eee, ee\mu, e\mu\mu, \mu\mu\mu)$
2. $\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\bar{\tilde{q}} \rightarrow \not{E}_T$ + jets
3. $\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow \not{E}_T + cc,\ \not{E}_T + b\overline{b} + X$

From these channels, we designed low p_T dilepton trigger,[22] low $\not{E}_T$ (≥ 25 GeV) + $\geq$2-jets trigger,[23] low $\not{E}_T$ (≥ 20 GeV) + $b\overline{b}$ (or $c\overline{c}$) trigger.[24]

As an example of such analyses, we show an expected upper limit on $\sigma \cdot Br$ for SUSY trilepton search in Run II in Figure 4.[25] In this preliminary study, we raise the p_T cuts for second and third leptons to 7 GeV/c from 5 GeV/c. This is to reflect a preliminary desgin for dilepton $(ee, e\mu, \mu\mu)$ trigger.[22] The maximum reach on $M_{\tilde{\chi}_1^{\pm}}$ will be around 180 GeV/c^2 at $\tan\beta = 2$ and $\mu < 0$. Since the upgraded CDF detector has a better coverage for leptons (e and μ), it is expected we can explore larger SUGRA parameter space in Run II.

With further restrictions to minimal SUGRA models from various measurements of $M_{\tilde{\chi}_1^{\pm}}$, M_t, $Br(b \rightarrow s\gamma)$, proton decay lifetime, and relic density of $\tilde{\chi}_1^0$ as cold dark matter candidate, one generally expects a restriction of

Projected Limits for Run II



e) increase in trilepton signal from $\tilde{\chi}_2^0 \rightarrow \tilde{e}e, \tilde{\mu}\mu$

f) decrease in trilepton signal from $\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0$

g) increase in trilepton signal from $\tilde{\chi}_2^0 \rightarrow \tilde{e}e, \tilde{\mu}\mu$;

also have $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm}\tilde{\chi}_1^0$

Figure 4: CDF preliminary projection of 95% C.L. upper limit on $\sigma \cdot Br$ for Run II. The branching ratio (Br) is the sum of four trilepton modes. Curves (a) - (g) represent SUGRA predictions of $\sigma \cdot Br$ for various values of m_0 between 100 GeV/c^2 and 2500 GeV/c^2 at $m_{1/2}$ = 50 GeV/c^2 - 200 GeV/c^2, incremented by 25 GeV/c^2. Upper and lower dashed curves represent the theoretical predictions at m_0 = 100 GeV/c^2 and 2500 GeV/c^2 for 50 GeV/c^2 $< m_{1/2} <$ 200 GeV/c^2.

$M_{\tilde{g}} \lesssim 500$ GeV/c^2 and hence $M_{\tilde{\chi}_1^\pm} \lesssim 120$ GeV/c^2 ($M_{\tilde{\chi}_1^0} \lesssim 65$ GeV/c^2) for the minimal SU(5) type model.[26] Therefore, the upgraded Tevatron is accessible to the chargino and the gluino marginally.[27]

However, it is pointed out by H. Baer *et al.*[28] and V. Barger *et al.*[29] that the CDF search based on eee, $ee\mu$, $e\mu\mu$, and $\mu\mu\mu$ will not be sensitive to SUSY parameter space with large values of $\tan\beta$, where the branching ratios to $\ell\tau\tau$ and $\tau\tau\tau$ are dominant final states. Furthermore, p_T of τ's is generally smaller compared to those from decays of $W^\pm$ and Z^0 bosons. In Run I analyses, we only identified τ's with $p_T \gtrsim 20$ GeV/c. Therefore, it is crucial for the SUGRA group to design a low-threshold trigger for hadronic decay τ's with $p_T \gtrsim 10$ GeV/c.[30]

5 Summary

We show the SUSY trilepton search at CDF in Run I data, which have the benefit of small SM backgrounds. In general, multilepton channels will be one of promissing experimental signatures for SUSY discovery in Run II. There has been a great effort in other SUSY searches using Run I data to cover the wide range of possible experimental signatures.

The experience from Run I analyses will greatly help us to design new triggers for previously inaccessible channels, particularly those involving τ's and heavy flavor. This will increase the quality of the Run II searches.

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Science and Culture of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; and the A. P. Sloan Foundation.

References

1. For reviews on SUSY and the MSSM, see H.P. Nilles, *Phys. Rev.* **110**, 1 (1984), and H.E. Haber and G.L. Kane, *Phys. Rev.* **117**, 75 (1995).
2. A. Salam and J. Strathdee, *Nucl. Phys.* B**87**, 85 (1975); P. Fayet, *Nucl. Phys.* B**90**, 104 (1975); G. Farrar and P. Fayet, *Phys. Lett.* B**76**, 575 (1978).

3. A.H. Chamseddine *et al.*, *Phys. Rev. Lett.* **49**, 970 (1982); R. Barbieri *et al.*, *Phys. Lett.* B**119**, 343 (1982); L. Hall *et al.*, *Phys. Rev.* D**27**, 2359 (1983). For a review, see R. Arnowitt and P. Nath, "Supersymmetry and Supergravity," VIIth Swieca Summer School, Campos de Jordao, Brazil, (World Scientific, Singapore, 1994).
4. P. Nath and R. Arnowitt, *Mod. Phys. Lett.* A**2**, 331 (1987); R. Barbieri *et al.*, *Nucl. Phys.* B**367**, 28 (1991); J.L. Lopez *et al.*, *Phys. Rev.* D**48**, 2062 (1993); H. Baer and X. Tata, *Phys. Rev.* D**48**, 5175 (1993).
5. For a review of the SUSY searches at CDF and DØ, see M. Carena *et al.*, hep-ex/9712022 (1997).
6. F. Abe *et al.* (CDF Collaboration), *Nucl. Instrum. Methods* A**271**, 387 (1988), and references therein; D. Amidei *et al.*, *Nucl. Instrum. Methods* A**350**, 73 (1994); F. Abe *et al.* (CDF Collaboration), *Phys. Rev.* D**50**, 2966 (1994).
7. In the CDF coordinate system, θ and ϕ are the polar and azimuthal angles with respect to the proton beam direction.
8. F. Abe *et al.* (CDF Collaboration), *Phys. Rev. Lett.* **76**, 4307 (1996).
9. F. Abe *et al.* (CDF Collaboration), *Phys. Rev. Lett.* **80**, 5280 (1998).
10. The lepton includes both decay-in-flight muon and non-leptonic object passing the lepton identification cuts as well as real lepton from semileptonic b decay in associated gluon jet ($g \to b\bar{b}$).
11. H. Baer *et al.*, "Simulating Supersymmetry with ISAJET 7.0/ISASUSY 1.0," Proc. of Workshop on Physics at Current Accelerators and the Supercollider, (Argonne Nat. Lab., 1993). We use ISAJET V7.20.
12. H.L. Lai *et al.* (CTEQ Collaboration), *Phys. Rev.* D**51**, 4763 (1995).
13. L.E. Ibañez *et al.*, *Nucl. Phys.* B**256**, 218 (1985); G.G. Ross and R.G. Roberts, *Nucl. Phys.* B**377**, 571 (1992); R. Arnowitt and P. Nath, *Phys. Rev. Lett.* **69**, 725 (1992); S. Kelley *et al.*, *Nucl. Phys.* B**398**, 31 (1993); G.L. Kane *et al.*, *Phys. Rev.* D**49**, 6173 (1994). In this analysis we use formulae in H. Baer *et al.*, *Phys. Rev.* D**47**, 2739 (1993) to determine $M_{\tilde{\ell}}$ and $M_{\tilde{\nu}}$ from $M_{\tilde{g}}$ and $M_{\tilde{q}}$. The formulae have solutions for $M_{\tilde{q}} \gtrsim 0.9 M_{\tilde{g}}$.
14. In SUGRA, five lighter squarks are approximately degenerate for small values of $\tan\beta$.
15. In the $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ search, it is not necessary to assume gluino mass unification. However, the gluino mass is an input in the ISAJET program to calculate chargino/neutralino masses with gaugino unification hypothesis.
16. We consider a region in the MSSM where there is no significant chargino or neutralino branching fraction into Higgs particles.

17. B. Abbott *et al.* (DØ Collaboration), *Phys. Rev. Lett.* **80**, 1591 (1998). The upper limit on $\sigma \cdot Br$ is given for a single trilepton mode. To compare to the CDF result, the DØ limit should be scaled up by 4.
18. R. Barate *et al.* (ALEPH Collaboration), CERN-PPE-97-128 (1997).
19. K. Ackerstaff *et al.* (OPAL Collaboration), CERN-PPE-97-083 (1997); M. Acciarri *et al.* (L3 Collaboration), CERN-PPE/97-130 (1997); P. Abreu *et al.* (DELPHI Collaboration), *Eur. Phys. J.* C**1**, 1 (1998).
20. R. Blair *et al.* (CDF II Collaboration), "The CDF II Detector - Technical Design Report," Fermilab-Pub-96/390-E (November 1996).
21. For details, see http://fnth37.fnal.gov/run2.html.
22. J.P. Done, "The Run II SUSY Dilepton Trigger at CDF," talk at SUGRA meeting, Fermilab, Batavia, IL, May 13, 1998.
23. M. Spiropulu, "SUSY search in the $\not\!\!E_T$ + jets channel at CDF," talk at SUGRA meeting, Fermilab, Batavia, IL, May 13, 1998.
24. R. Demina, "Search for Stops at CDF," talk at Physics at Run II - Workshop on Supersymmetry/Higgs: First General Meeting, Fermilab, Batavia, IL. May 14-16, 1998.
25. Jane Nachtman, "Search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ at CDF," talk at Physics at Run II - Workshop on Supersymmetry/Higgs: First General Meeting, Fermilab, Batavia, IL. May 14-16, 1998.
26. R. Arnowitt, "Cold Dark Matter and Proton Decay Constraints on Accelerator Predictions of mSUGRA," talk at Physics at Run II - Workshop on Supersymmetry/Higgs: First General Meeting, Fermilab, Batavia, IL. May 14-16, 1998.
27. TeV2000 Group, "Future ElectroWeak Physics at the Fermilab Tevatron: Report of the TeV2000 Study Group," Fermilab-Pub-96/082 (1996).
28. H. Baer *et al.*, hep-ph/9802441 (1998).
29. V. Barger *et al.*, hep-ph/9804451 (1998).
30. T. Kamon, "SUGRA-CDF/DØ Working Group Report," talk at Physics at Run II - Workshop on Supersymmetry/Higgs: First General Meeting, Fermilab, Batavia, IL. May 14-16, 1998.