Search for Supersymmetry
Using the Trilepton Signature of
Chargino-Neutralino Production

Julian Glatzer
on behalf of the CDF collaboration
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1. Introduction
2. Analysis
3. Results
4. mSUGRA Interpretation
Chargino Neutralino Production

Cross section at benchmark point $\sigma = 0.5 \text{ pb}$
Decay of Chargino and Neutralino

Signature: 3 leptons and missing $E_T$
Decay of Chargino and Neutralino

Signature: 3 leptons and missing \( E_T \)

- \( p_T^1 > 15 \ldots 20 \text{ GeV} \)
- \( p_T^2 > 5 \ldots 10 \text{ GeV} \)
- \( p_T^3 > 5 \ldots 10 \text{ GeV} \)
- \( \text{MET} > 20 \text{ GeV} \)
The CDF Detector

Tracker | Electromagnetic Calorimeter | Hadronic Calorimeter | Muon System

Isolated tracks as a proxy for tau leptons.

This analysis is using $\int \mathcal{L} \, dt = 2.0 \, \text{fb}^{-1}$. 
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The Analysis

Unbiased counting experiment

Control Regions: also Dileptons

Find three tight leptons
Else, two tight and one loose lepton
Else, one tight and two loose leptons
Else, two tight leptons and one isolated track
Else, one tight, one loose lepton and one isolated track
# Standard Model Background

<table>
<thead>
<tr>
<th>Process</th>
<th>Signature</th>
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<tbody>
<tr>
<td><strong>Diboson</strong></td>
<td></td>
</tr>
<tr>
<td>ZZ</td>
<td>4 leptons</td>
</tr>
<tr>
<td>WZ</td>
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</tr>
<tr>
<td>WW</td>
<td>2 leptons + missing $E_T$</td>
</tr>
<tr>
<td>top-pair</td>
<td>3 leptons + missing $E_T$</td>
</tr>
<tr>
<td><strong>DY</strong></td>
<td>+γ, T</td>
</tr>
<tr>
<td></td>
<td>2 leptons</td>
</tr>
<tr>
<td><strong>Fake lepton</strong></td>
<td></td>
</tr>
<tr>
<td>DY</td>
<td>+h</td>
</tr>
<tr>
<td>W+jets</td>
<td>2 leptons</td>
</tr>
<tr>
<td>WW</td>
<td>1 lepton + missing $E_T$</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

h: hadron faking a lepton, T: Track, lepton=e,μ
Control Regions

CDF Run II Preliminary $\int L dt = 2.0 \text{ fb}^{-1}$

Search for $\chi^\pm_1 \chi^0_2$

Control Regions: Dileptons
2 tight leptons 1 tight + 1 loose leptons

CDF Run II Preliminary $\int L dt = 2.0 \text{ fb}^{-1}$

Search for $\chi^\pm_1 \chi^0_2$

Control Regions: Trileptons
All tight Two tight One tight Two tight One loose One loose One track One track

CDF Run II Preliminary $\int L dt = 2.0 \text{ fb}^{-1}$

Search for $\chi^\pm_1 \chi^0_2$
Signal Optimization

- Require missing \( E_T \)
  \[ E_T > 20 \text{ GeV} \]
- Remove Z, J/\( \psi \), \( \Upsilon \) contribution by cut on dilepton invariant mass
  \[ m_{OS}^{1,2} > 20, 13 \text{ GeV}/c^2 \]
  \[ m_{OS}^{1,2} \notin [76, 106] \text{ GeV}/c^2 \]
- Require low hadronic activity
  \[ N_{Jet} < 2 \]
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2. Analysis
3. Results
4. mSUGRA Interpretation
## Final Predictions

<table>
<thead>
<tr>
<th>Channel</th>
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<th>Observed</th>
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<tbody>
<tr>
<td>3 tight</td>
<td>2.25 ± 0.32</td>
<td>0.49 ± 0.09</td>
<td></td>
</tr>
<tr>
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<td>1.61 ± 0.24</td>
<td>0.25 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>1 tight, 2 loose</td>
<td>0.68 ± 0.11</td>
<td>0.14 ± 0.03</td>
<td></td>
</tr>
<tr>
<td><strong>Total trilepton</strong></td>
<td>4.5 ± 0.6</td>
<td>0.88 ± 0.14</td>
<td></td>
</tr>
<tr>
<td>2 tight, 1 Track</td>
<td>4.44 ± 0.69</td>
<td>3.22 ± 0.72</td>
<td></td>
</tr>
<tr>
<td>1 tight, 1 loose, 1 Track</td>
<td>2.42 ± 0.35</td>
<td>2.28 ± 0.63</td>
<td></td>
</tr>
<tr>
<td><strong>Total Dilepton + Track</strong></td>
<td>6.9 ± 0.9</td>
<td>5.5 ± 1.1</td>
<td></td>
</tr>
</tbody>
</table>

Final Predictions: CDF Run II Preliminary $\int L dt = 2.0 \text{ fb}^{-1}$

Signal predictions for benchmark point.
## Final Predictions and Results

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Final Predictions: CDF Run II Preliminary $\int \mathcal{L}dt = 2.0 \text{ fb}^{-1}$

Signal predictions for benchmark point.
## Final Predictions and Results

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</table>

Final Predictions: CDF Run II Preliminary $\int \mathcal{L} dt = 2.0 \text{ fb}^{-1}$

Signal predictions for benchmark point.
Display of an Event
in the three tight leptons channel

Lepton e+
$\mathbf{p}_T = 17 \text{ GeV}/c$
$\eta = -0.82$

Lepton e-
$\mathbf{p}_T = 24 \text{ GeV}/c$
$\eta = 0.15$

Lepton e-
$\mathbf{p}_T = 5.8 \text{ GeV}/c$
$\eta = -0.67$

MET = 37 GeV

Jet
59 GeV
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4. mSUGRA Interpretation
Observed Limit on $\sigma \ast \text{BR}$
mSUGRA Exclusion Region

Excluded Region in mSUGRA

- CDF Run II Preliminary $\int L dt = 2.0$ fb$^{-1}$
- mSUGRA tan(β) = 3, $A_0 = 0, \mu > 0$
- $m(\tilde{e}_R), m(\tilde{\mu}_R) > m(\tilde{\tau}_1)$
- $m(\tilde{\chi}_2^0) \approx m(\tilde{\chi}_1^0)$

Search for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$

- Excluded at 95% C. L.
- LEP direct limit

Decay dominantly via on-shell sleptons

Decay dominantly via off-shell W/Z

LEP direct limit
mSUGRA Exclusion Region

Excluded Region in mSUGRA

CDF Run II Preliminary $\int L dt = 2.0$ fb$^{-1}$

mSUGRA $\tan(\beta)$=3, $A_0$=0, $\mu$>0

$\tilde{m}_{\tilde{e}_R}$, $\tilde{m}_{\tilde{\mu}_R}$ > $\tilde{m}_{\tilde{\tau}_1}$

$\tilde{m}_{\tilde{\chi}^0_2} \approx \tilde{m}_{\tilde{\chi}^\pm_1}$

LEP direct limit

Search for $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$

Excluded at 95% C. L.

Decay dominantly via on-shell sleptons

Decay dominantly via off-shell W/Z

LEP direct limit
A limit on the chargino mass for $m_0=60 \text{ GeV}/c^2$

CDF Run II Preliminary $\int L dt = 2.0 \text{ fb}^{-1}$

Search for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$

LEP direct limit

- Theory $\sigma_{\text{NLO}} \times \text{BR}$
- 95\% CL Upper Limit: expected
- Expected Limit $\pm 1\sigma$
- Expected Limit $\pm 2\sigma$
- 95\% CL Upper Limit: observed

$m_{\text{SUGRA}} m_0=60$, $\tan(\beta)=3$, $A_0=0$, $(\mu)>0$
A limit on the chargino mass for $m_0=60 \text{ GeV}/c^2$

We exclude chargino masses below $\sim 145 \text{ GeV}/c^2$.
mSUGRA Exclusion Region

Excluded Region in mSUGRA

CDF Run II Preliminary \( \int L dt = 2.0 \text{ fb}^{-1} \)

mSUGRA \( \tan(\beta) = 3, A_0 = 0, \mu > 0 \)

\( m(\tilde{e}_R), m(\tilde{\mu}_R) > m(\tilde{\tau}_1) \)

\( m(\tilde{\chi}_2^0) \approx m(\tilde{\chi}_1^\pm) \)

Decay dominantly via on-shell sleptons

Decay dominantly via off-shell W/Z

Search for \( \tilde{\chi}_1 \tilde{\chi}_2 \)

Excluded at 95% C. L.

LEP direct limit

m\(_{1/2}\) (GeV/c\(^2\))

m\(_0\) (GeV/c\(^2\))

12.11.2008

J. Glatzer: Search for Chargino-Neutralino Production using Leptons
A limit on the chargino mass for \( m_0 = 100 \text{ GeV/c}^2 \)
A limit on the chargino mass for $m_0=100$ GeV/c$^2$

We exclude chargino masses below $\sim 127$ GeV/c$^2$
Summary

- We looked for Chargino-Neutralino production in a trilepton + missing $E_T$ signature with 2.0 fb$^{-1}$ of data
- Observations are **consistent** with the standard model
- We have set a direct **exclusion** in mSugra for chargino/neutralino

Accepted by PRL
arXiv: 0808.2446
Thank you
Backup
Display of an Event
in the two tight one track channel

Track e/µ -
\( p_T = 9.2 \text{ GeV/c}^2 \)
\( \eta = 0.85 \)

Lepton µ -
\( p_T = 6 \text{ GeV/c}^2 \)
\( \eta = 0.80 \)

MET = 20.4 GeV

Lepton µ +
\( p_T = 34 \text{ GeV/c}^2 \)
\( \eta = 0.14 \)
## Candidate Events

CDF RUN II Preliminary $\int \mathcal{L} \, dt = 2.0 \text{ fb}^{-1}$: Search for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$

<table>
<thead>
<tr>
<th>Channel</th>
<th>Type</th>
<th>$E_T^1$ (GeV)</th>
<th>$E_T^2$ (GeV)</th>
<th>$E_T^3$ (GeV)</th>
<th>$M_{OS}^1$ (GeV/$c^2$)</th>
<th>$M_{OS}^2$ (GeV/$c^2$)</th>
<th>MET (GeV)</th>
<th>Jet$^1 E_T$ (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3tight</td>
<td>$e^-e^+e^-$</td>
<td>24</td>
<td>17</td>
<td>5.8</td>
<td>29</td>
<td>16</td>
<td>37</td>
<td>59</td>
</tr>
<tr>
<td>2tight, 1Track</td>
<td>$e^-e^+T^-$</td>
<td>27</td>
<td>9.7</td>
<td>8.5</td>
<td>41</td>
<td>19</td>
<td>28</td>
<td>24</td>
</tr>
<tr>
<td>2tight, 1Track</td>
<td>$e^-e^+T^+$</td>
<td>23</td>
<td>9.3</td>
<td>56</td>
<td>70</td>
<td>46</td>
<td>58</td>
<td>18</td>
</tr>
<tr>
<td>2tight, 1Track</td>
<td>$\mu^+\mu^-T^-$</td>
<td>34</td>
<td>6.2</td>
<td>9.2</td>
<td>33</td>
<td>28</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>2tight, 1Track</td>
<td>$\mu^-\mu^+T^-$</td>
<td>45</td>
<td>21</td>
<td>7.8</td>
<td>29</td>
<td>26</td>
<td>39</td>
<td>41</td>
</tr>
<tr>
<td>1tight, 1loose, 1Track</td>
<td>$\mu^+\mu^-T^+$</td>
<td>23</td>
<td>12.2</td>
<td>6.5</td>
<td>39</td>
<td>18</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>1tight, 1loose, 1Track</td>
<td>$\mu^+\mu^-T^-$</td>
<td>59</td>
<td>70</td>
<td>44</td>
<td>124</td>
<td>58</td>
<td>37</td>
<td>—</td>
</tr>
</tbody>
</table>
Results: 3 tight
mSUGRA Exclusion Region

Theory $\sigma(\chi_2\chi_1) \times BR(3\text{ leptons})$

CDF Run II Preliminary $\int L dt = 2.0\text{ fb}^{-1}$

mSUGRA $\tan(\beta)=3$, $A_0=0$, $\mu>0$

- Excluded at 95% C. L.
- LEP direct limit
- $m(\tilde{\tau}, m(\chi_2) = m(\tilde{\chi}_1)$
- $m(\tilde{e}_R), m(\tilde{\mu}_R) > m(\tilde{\tau})$
**mSUGRA**

minimal supergravity grand unification

---

5 free parameters:

- $m_0$: common scalar mass at GUT scale
- $m_{1/2}$: common gaugino mass at GUT scale
- $\tan(\beta)$: Ratio of the Higgs VEV
- $A_0$: common trilinear coupling at GUT scale
- $\text{sign}(\mu)$: $\mu$ is the Higgsino mass parameter

Our benchmark point: $m_0 = 60 \text{ GeV/c}^2$, $m_{1/2} = 190 \text{ GeV/c}^2$, $\tan(\beta) = 3$, $A_0 = 0$, $\mu > 0$
Five different channels

are defined as five different, **mutually exclusive** experiments.

**Why do we do this?** Combining channels with different signal over background gives more significant results than one channel with average S/B.

- Find **three tight leptons**
  - Else, **two tight and one loose lepton**
    - Else, **one tight and two loose leptons**
      - Else, **two tight leptons and one isolated track**
        - Else, **one tight, one loose lepton and one isolated track**

Decreasing purity

Lepton $p_T$

- $(15,5,5)$
- $(15,5,10)$
- $(20,8,5/10)$
- $(15,5,5)$
- $(20,8/10,5)$
## Standard Model Background

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</tr>
<tr>
<td><strong>top-pair</strong></td>
<td></td>
</tr>
<tr>
<td><strong>DY</strong></td>
<td>2 leptons</td>
</tr>
<tr>
<td>Fake lepton</td>
<td></td>
</tr>
<tr>
<td>DY</td>
<td>2 leptons</td>
</tr>
<tr>
<td>W+jets</td>
<td>1 lepton + missing $E_T$</td>
</tr>
<tr>
<td>WW</td>
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</tr>
<tr>
<td><strong>top-pair</strong></td>
<td></td>
</tr>
</tbody>
</table>

h: hadron faking a lepton, T: Track, lepton=e,μ
Reducing Backgrounds

- Require missing $E_T$ 
  $\not E_T > 20 \text{ GeV}$
- Remove $Z, J/\psi, \gamma$ 
  contribution by cut on 
  dilepton invariant mass
  $$m_{OS}^{1,2} > 20, 13 \text{ GeV}/c^2$$
  $$m_{OS}^{1,2} \not\in [76, 106] \text{ GeV}/c^2$$
- Require low hadronic 
  activity
  $$N_{Jet} < 2$$
Control Regions

CDF Run II Preliminary, $\int L dt = 2.0 \text{ fb}^{-1}$

- Data
- Drell-Yan
- Dibosons
- $t\bar{t}$

Search for $\tilde{\chi}^0_2\tilde{\chi}^0_1$

- Data
- Drell-Yan
- Dibosons
- $t\bar{t}$
- Fake lepton

12.11.2008  J. Glatzer: Search for Chargino-Neutralino Production using Leptons
## Methods for the Estimation of Backgrounds

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<tbody>
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<td>FR</td>
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h: hadron faking a lepton, T: Track, lepton=e,μ
Background Estimation:

The Isolated Track Rate
Getting the isolated track rate:
• Use data from $p_T$ lepton lepton triggers
• Select $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ by cut on invariant mass of dileptons
  $|M_{ll} - 91.2| < 15 \text{ GeV}/c^2$
• Count the number of events with at least one extra isolated track as a function of number of "good" tracks.

Application of the isolated track rate:
• Select event with 2 leptons and no third isolated track
• Apply isolated track rate as an event weight

The Fake Rate
A hadron is faking a lepton
• Events with more than one fake are negligible
• In "Jet-Triggered" events the number of identified leptons per jet (electron) or isolated track (muon) as a function of the transverse energy of the denominator object is measured.
• The fake rate is applied as a weight to fakeable events in data.
• Measured and applied in data
Results

<table>
<thead>
<tr>
<th>Channel</th>
<th>$l_tl_{l_t}$</th>
<th>$l_tl_{l_l}$</th>
<th>$l_tl_{l_l}$</th>
<th>$l_tl_{l_T}$</th>
<th>$l_tl_{l_T}$</th>
<th>$\sum$ channels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signal at BP1</strong></td>
<td>2.25</td>
<td>1.61</td>
<td>0.68</td>
<td>4.44</td>
<td>2.42</td>
<td>11.40</td>
</tr>
<tr>
<td>Statistical Uncertainty</td>
<td>±0.13</td>
<td>±0.11</td>
<td>±0.07</td>
<td>±0.19</td>
<td>±0.14</td>
<td>±0.30</td>
</tr>
<tr>
<td>Systematic Uncertainty</td>
<td>±0.29</td>
<td>±0.21</td>
<td>±0.09</td>
<td>±0.58</td>
<td>±0.32</td>
<td>±0.76</td>
</tr>
<tr>
<td><strong>Background</strong></td>
<td>0.49</td>
<td>0.25</td>
<td>0.14</td>
<td>3.22</td>
<td>2.28</td>
<td>6.38</td>
</tr>
<tr>
<td>Statistical Uncertainty</td>
<td>±0.04</td>
<td>±0.03</td>
<td>±0.02</td>
<td>±0.48</td>
<td>±0.47</td>
<td>±0.67</td>
</tr>
<tr>
<td>Systematic Uncertainty</td>
<td>±0.08</td>
<td>±0.03</td>
<td>±0.02</td>
<td>±0.53</td>
<td>±0.42</td>
<td>±0.68</td>
</tr>
<tr>
<td><strong>Observed</strong></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 4.10: Final number of expected signal and background events in the different analysis channels together with the observed number of events in data. The signal predictions are for benchmark point BP1.
# Systematics

CDF RUN II Preliminary $\int L dt = 2.0$ fb$^{-1}$: Search for $\tilde{\chi}_1^{\pm} \tilde{\chi}_2^0$

<table>
<thead>
<tr>
<th>Channel/Source</th>
<th>ID (%)</th>
<th>Trig (%)</th>
<th>JES (%)</th>
<th>X-sec (%)</th>
<th>PDF (%)</th>
<th>ISR/FSR (%)</th>
<th>Conv (%)</th>
<th>ITR(nom) (%)</th>
<th>ITR(alt) (%)</th>
<th>Fake (%)</th>
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<td>-</td>
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<td>1.7</td>
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mSUGRA Branching Ratio

Branching Ratio of $\tilde{\chi}_2\tilde{\chi}_1$ into 3 Leptons

- $m(\tilde{\chi}_2) > m(\tilde{\nu}) > m(\tilde{l}_R)$
- $m(\tilde{\chi}_2) < m(\tilde{l}_R)$

mSUGRA $\tan(\beta)=3$, $A_0=0$, $\mu>0$

$m_{1/2}$ (GeV/c²)

$m_0$ (GeV/c²)