Chargino-Neutralino Search

\[ p\bar{p} \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_2^0 \]

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For the CDF and DØ collaborations

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Supersymmetry solves the hierarchy problem
Also provides an excellent dark matter candidate ($R_p$ conservation $\rightarrow$ LSP)

Gauge couplings are unified much better
mSUGRA -- minimal SUper GRAvity grand unification

why? a) Widely used as a standard candle by Run I, LHC TDR's etc.
    b) Manageable due to five parameters

Defined by five parameters

\(m_0\) : common scalar mass at GUT scale
\(m_{\frac{1}{2}}\) : common gaugino mass at GUT scale
\(M_1(\text{GUT})=M_2(\text{GUT})=M_3(\text{GUT})=m_{\frac{1}{2}}\)
\(\tan(\beta)\) : ratio of Higgs vacuum expectation values
\(A_0\) : common trilinear scalar interaction at the GUT scale (Higgs-sfermion\(R\)-sfermion\(L\))
\(\text{sign}(\mu)\) : \(\mu\) is the Higgsino mass parameter
\(|\mu^2|\) determined by EWSB

Example: CDF Signal Benchmark Point
mSUGRA \(m_0=60\) GeV, \(m_{\frac{1}{2}}=190\) GeV,
\(\tan(\beta)=3, A_0=0, \mu>0\)
*Charginos & Neutralinos* are mixtures of the higgsino, binos and winos.

*There are four neutralinos and two charginos, we look for lightest chargino and next-to-lightest neutralino.*

*Produced via s-channel, destructive interference from t-channel*
Decaying Chargino/Neutralino

Chargino-Neutralino decays are good experimentally because they **decay to leptons** which makes identifying SUSY events easier. Presence of neutrino, and lightest-susy-particles (LSP's) in final state gives missing energy.
The Signature

\[ \Sigma E_T(\nu, \text{LSP}) \]

'missing' \( E_T \)

\[ M_0 = 60, \quad M_{1/2} = 190, \quad \tan(\beta) = 3, \quad A_0 = 0, \quad \mu > 0 \]

Supersymmetric Trilepton Event

\[ \begin{align*}
\tilde{\chi}_1^0 \to l^\pm l'^\pm \nu \quad \tilde{\chi}_1^0 \tilde{\chi}_2^0 \\
l = e, \mu, \tau
\end{align*} \]
Detectors: CDF & DØ

Multipurpose detectors:
- Central Tracker
- Electromagnetic (EM) & Hadronic (Had) Calorimeters
- Muon Systems

Chargino/Neutralino Search

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Identifying Leptons

Isolated tracks proxy for tau's 'single-prong' tau decays

Electrons:
- EM cal showers
- E/p ~ 1

Muons:
- MIP's, signal in muon systems

Hadronic calorimeter

Electromagnetic calorimeter

Central Tracker
The CDF analysis
Chargino/Neutralino Search

Channels & Backgrounds

Exclusive channels ordered by signal purity

Find three tight leptons
Else, two tight leptons(t) and a loose lepton(l).
Else, one tight and two loose leptons.
Else, two tight leptons and one track(T).
Else, one tight, one loose lepton and one track.

where lepton = e, μ

Dominant Backgrounds

![Pie charts showing dominant backgrounds]

Trilepton
Dilep+Trk

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

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

MET for \( 76 < M_{\mu} < 106 \text{ GeV/c}^2 \)

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

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

MET for \( \text{MET} < 10 \text{ GeV} \)

2 fb\(^{-1}\)

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**Selections**

\[ \mathbf{2 \; fb^{-1}} \]

- \( P_T > 15, 5, 5 \text{ GeV} \)
- Remove DY
- \( \text{MET} > 20 \text{ GeV} \)
- \( \Delta \varphi_{\text{os}} < 2.9 \text{ rad for trilepton} \)
- \( < 2.8 \text{ rad for dilep+trk} \)

**Resonance Cuts**

- \( M_{\text{os}}^1, M_{\text{os}}^2 > 20, 13 \text{ GeV/c}^2 \)
- Z-cut ( \( M_{\text{os}} < 76 \text{ or } > 106 \text{ GeV/c}^2 \) )

- Remove top-pair
- \( \text{NJets } < 2 \)
Chargino/Neutralino Search

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Channel | Signal  | Bkgd   | Data
---------|---------|--------|-----

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<thead>
<tr>
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<tbody>
<tr>
<td>ttt</td>
<td>2.3±0.3</td>
<td>0.5±0.1</td>
<td>1</td>
</tr>
<tr>
<td>ttl</td>
<td>1.6±0.2</td>
<td>0.3±0.04</td>
<td>0</td>
</tr>
<tr>
<td>tll</td>
<td>0.7±0.1</td>
<td>0.1±0.03</td>
<td>0</td>
</tr>
</tbody>
</table>

3 leptons | 4.6±0.6 | 0.9±0.2 | 1

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</thead>
<tbody>
<tr>
<td>ttT</td>
<td>4.4±0.6</td>
<td>3.2±0.7</td>
<td>4</td>
</tr>
<tr>
<td>tlT</td>
<td>2.4±0.3</td>
<td>2.3±0.6</td>
<td>2</td>
</tr>
</tbody>
</table>

2 leptons + Track | 6.8±0.9 | 5.5±1.1 | 6

Signal mSUGRA with parameters
m_0=60, m_{½}=190, tan(β)=3, A_0=0, μ >0

No sign of SUSY!
The DØ analysis
Channels & Selections

Run IIa channels (with 1 fb$^{-1}$)
- $ee + \text{Track}$
- $\mu\mu + \text{Track}$
- $e\mu + \text{Track}$

Same-sign dimuons

Run IIb channel (with 0.6 fb$^{-1}$)
- $ee + \text{Track}$

Selections for new $ee + \text{Track}$:
- $p_T > 12, 8, 4 \text{ GeV}$
- $\text{MET} > 22 \text{ GeV}$
- $\Delta\phi(e,e) < 2.9 \text{ rad}$
- $18 < M_{ee} < 60 \text{ GeV/c}^2$
- $H_T < 80 \text{ GeV}$
- $\text{MET} \times \text{Trk} \geq 220 \text{ GeV}^2$
## Results

<table>
<thead>
<tr>
<th>Channel</th>
<th>Lum. (fb^{-1})</th>
<th>Signal</th>
<th>Bkgd</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee + T</td>
<td>0.6</td>
<td>0.5-2.1</td>
<td>1.0±0.3</td>
<td>0</td>
</tr>
<tr>
<td>ee + T</td>
<td>1</td>
<td>1.7-4.7</td>
<td>0.8±0.7</td>
<td>0</td>
</tr>
<tr>
<td>μμ + T</td>
<td>1.1</td>
<td>0.5-2.5</td>
<td>0.3^{+1.3}_{-0.3}</td>
<td>2</td>
</tr>
<tr>
<td>eμ + T</td>
<td>1.1</td>
<td>2.0-2.6</td>
<td>0.9±0.4</td>
<td>0</td>
</tr>
<tr>
<td>μ±μ±</td>
<td>0.9</td>
<td>0.6-3.8</td>
<td>1.1±0.4</td>
<td>1</td>
</tr>
</tbody>
</table>

Signal mSUGRA 'like' with no slepton mixing
m_0=88-121, m_{1/2}=182-221, tan(β)=3, A_0=0, μ >0

Data agrees with SM
The CDF analysis RESULTS
Excluded Region in mSUGRA

Dominated by

\[ \tilde{\chi}^0_2 \rightarrow \ell^\pm R \rightarrow \ell^\pm \]

Similar diagram for chargino

Small mass difference
\[ M(\text{Neutralino}) - M(\text{slepton}) \approx \Delta m \]

\[ \Rightarrow \text{soft lepton from Neutralino decay} \]

\[ \Rightarrow \text{loss in acceptance, no exclusion} \]
Mass limits for $m_0 = 60$ GeV/c$^2$

Fix $m_0 = 60$ GeV/c$^2$, vary $m_{1/2}$ along X-axis to get chargino mass.

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

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

LEP direct limit

Theory $\sigma_{\text{NLO}}^{\times \text{BR}}$

95% CL Upper Limit: expected

Expected Limit ± 1σ

Expected Limit ± 2σ

95% CL Upper Limit: observed

mSUGRA $m_0=60$, $\tan(\beta)=3$, $A_0=0$, $(\mu)>0$

Exclude Chargino with Mass < 145 GeV/c$^2$

Best direct mSUGRA limits on Chargino mass
Mass limits for $m_0 = 100$ GeV/c$^2$

Fix $m_0 = 100$ GeV/c$^2$, vary $m_{1/2}$ along X-axis to get chargino mass.

Excluded Region in mSUGRA

Excluded at 95% C. L. Ldt = 2.0 fb$^{-1}$

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

CDF Run II Preliminary

$\int L dt = 2.0$ fb$^{-1}$

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

mSUGRA $m_0 = 100$, $\tan(\beta) = 3$, $A_0 = 0$, $(\mu) > 0$

Exclude Chargino with Mass < 127.0 GeV/c$^2$
The DØ analysis
RESULTS
Three scenarios:

3l-max : Max BR to 3l

Heavy-squarks : squarks are set to high masses to reduce t-channel production (enhancing $\sigma$)

large-$m_0$ : slepton,squarks both very heavy, decays mainly via virtual W,Z

Exclude Chargino with Mass < 145 GeV/c$^2$

Best limits in no slepton mixing scenario
Mass limits in mSUGRA 'like' model

\[ \sigma(\chi^+_1, \chi^-_1) \times BR(3\ell) \text{ (pb)} \]

\[ \text{DØ Run II Preliminary, } 0.9-1.7 \text{ fb}^{-1} \]

\[ M(\chi^+_1) = 104 \text{ GeV}, \quad M(\chi^0_2) = 108 \text{ GeV} \]

\[ \tan \beta = 3, \quad \mu > 0, \quad \text{no slepton mixing} \]

- Observed Limit
- Expected Limit

- heavy-squarks
- no-mixing

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Summary

- CDF and DØ have searched for Charginos and Neutralinos with up to 2 fb$^{-1}$, no sign yet though!
- CDF rules out charginos up to masses of 145 GeV/c$^2$ in specific mSUGRA regions, and also provides an exclusion region in mSUGRA parameter space.
- DØ rules out charginos up to masses of 145 GeV/c$^2$ in an mSUGRA-'like' no slepton mixing scenario.
- Both results are well beyond LEP limits.

Expect more data soon

http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm
BACKUP
mSUGRA Features of interest: \( \sigma \)

\[
m(\tilde{\chi}_2^0) \approx m(\tilde{\chi}_1^\pm) \quad m(\tilde{e}_R) = m(\tilde{\mu}_R) \approx m(\tilde{\tau}_1)
\]

Cross section is a smooth function of chargino mass, hence \( m_{1/2} \)
mSUGRA Features of interest

\[ M(\tilde{\chi}_2^0, \tilde{\chi}_1^\pm) > M(\tilde{\ell}) \]
\[ \tilde{\chi}_2^0 \rightarrow \tilde{\ell}^\pm \ell^\mp, \tilde{\ell}^\pm \rightarrow \ell \tilde{\chi}_1^0 \quad \tilde{\chi}_1^\pm \rightarrow \tilde{\ell}^\pm \nu, \tilde{\ell}^\pm \rightarrow \ell \tilde{\chi}_1^0 \]

\[ M(\tilde{\chi}_2^0, \tilde{\chi}_1^\pm) < M(\tilde{\ell}) \]
\[ \tilde{\chi}_1^\pm - - - W^* \tilde{\chi}_1^0 - - - \ell^\pm \nu \tilde{\chi}_1^0 \]
\[ \tilde{\chi}_2^0 - - - Z^* \tilde{\chi}_1^0 - - - \ell^\pm \ell^\mp \tilde{\chi}_1^0 \]
$BR(\tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow 3\ell)$

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Observed Limits on $\sigma \times BR$

Observed Limit on $\sigma (\tilde{\chi}_2 \tilde{\chi}_1) \times BR(3$ leptons)

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

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

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

RED is bad

BLUE is good