Search for Supersymmetry at CDF using Trileptons

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Particle Physics Seminar
Brookhaven National Laboratory
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OUTLINE

- PART I : Introduction
- PART II : Data and Analysis
- PART III : Interpreting the Results
PART I
Introduction
Beyond Standard Model

Standard Model does fantastic job of explaining our world (up to EWK scales)
Precision tests upto few parts per million confirm SM

BUT,

- Including gravity
- What is Dark Matter/Dark Energy?
- Matter-Antimatter asymmetry in the universe
- Why three generations?
- Hierarchy problem
Supersymmetry

Proposes a new symmetry
Fermions ↔ Bosons

Every fermion has a boson superpartner & vice versa
R-parity: $R_p = (-1)^{3(B+L)+2s}$

- Electron $\rightarrow$ Selectron
  - $R_p = 1$  $R_p = -1$

- Photon $\rightarrow$ Photino
  - $R_p = 1$  $R_p = -1$
Supersymmetry solves the hierarchy problem
Also provides an excellent dark matter candidate ($R_p$ conservation $\rightarrow$ LSP)
Gauge couplings are unified much better

![Graphs showing renormalization scale vs. standard model couplings]

27 down, 73 to go!!

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Supersymmetry proposes a new symmetry
Fermions ↔ Bosons

Particles x 2

Standard particles

SUSY particles

Quarks
Leptons
Force Carriers
SQuarks
SLeptons
SUSY Force Carriers
mSUGRA

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

Signal Benchmark Point (BP) with parameters:
mSUGRA $m_0=60$, $m_{\frac{1}{2}}=190$, $\tan(\beta)=3$, $A_0=0$, $\mu>0$

Spectrum (at BP) GeV

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{\chi}_2^0$</td>
<td>124</td>
</tr>
<tr>
<td>$\tilde{\chi}_{1}^\pm$</td>
<td>122</td>
</tr>
<tr>
<td>$\tilde{\chi}_{1}^0$</td>
<td>66</td>
</tr>
<tr>
<td>$\tilde{e}_L$</td>
<td>149</td>
</tr>
<tr>
<td>$\tilde{e}_R$</td>
<td>101</td>
</tr>
<tr>
<td>$\tilde{\tau}_1$</td>
<td>100</td>
</tr>
<tr>
<td>$\tilde{\tau}_2$</td>
<td>150</td>
</tr>
<tr>
<td>$\tilde{g}$</td>
<td>477</td>
</tr>
<tr>
<td>$\tilde{u}_R$</td>
<td>421</td>
</tr>
<tr>
<td>$\tilde{d}_L$</td>
<td>439</td>
</tr>
</tbody>
</table>
Charginos and Neutralinos

☆ W's and Z's of Supersymmetry
☆ Charginos($\chi^\pm$) & Neutralinos ($\chi^0$) are mixtures of the higgsino, binos and winos.
☆ There are four neutralinos and two charginos.

W's and Z's of Supersymmetry

Charginos($\chi^\pm$) & Neutralinos ($\chi^0$) are mixtures of the higgsino, binos and winos.

There are four neutralinos and two charginos.
Supersymmetric Particles

One can (and does) look for all types of supersymmetric particles:
- Squarks ( trovare e Sbottoms)
- Gluinos
- Chargino-Neutralinos

But Chargino-Neutralino decays are good experimentally because they decay to leptons (among other things) which makes identifying them easier.
Chargino/Neutralino Production & Decay

We assume $R_p$ is conserved –
SUSY particles are produced in pairs, they decay to the lightest supersymmetric particle (LSP) which is stable

Production of chargino and neutralino via s-channel and t-channel

Decay of chargino/neutralino via
▶ virtual W,Z,sleptons (3-body)
▶ through intermediate slepton states(two 2-body decays)
Signature of Interest

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

'missing' \( E_T \)

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

Supersymmetric Trilepton Event

\[ \bar{p}, \rho, \chi_1, \chi_2, \chi_1^\pm \]

LEPTONS

Missing Energy

\[ \\sim \bar{\nu}, \nu, l^+ \]

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

Events / GeV

Generated Lepton \( p_T \)
Signal and Background Cross sections

SIGNAL = 3 leptons + MET

\( \sigma(\text{Signal}) \approx 0.5 \text{pb} \), for benchmark point Mass(Chargino) = 120 GeV/c^2

MET = missing transverse energy

<table>
<thead>
<tr>
<th>Process</th>
<th>( \sigma(\text{bkg})/\sigma(\text{sig}) )</th>
<th>What it has</th>
<th>What it needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>WZ( \rightarrow \ell \ell \nu )</td>
<td>~ 1</td>
<td>3 leptons + MET</td>
<td>-</td>
</tr>
<tr>
<td>ZZ( \rightarrow \ell \ell \ell )</td>
<td>~ 10</td>
<td>\geq 3 leptons</td>
<td>MET</td>
</tr>
<tr>
<td>WW( \rightarrow \ell \ell \nu \nu )</td>
<td>~ 5000</td>
<td>2 leptons + MET</td>
<td>1 lepton</td>
</tr>
<tr>
<td>Top-pair</td>
<td>~ 10</td>
<td>3 leptons + MET</td>
<td>-</td>
</tr>
<tr>
<td>DY( \rightarrow \ell \ell )</td>
<td>~ 1000</td>
<td>2 leptons</td>
<td>1 lepton + MET</td>
</tr>
<tr>
<td>Z\gamma( \rightarrow \ell \ell \gamma )</td>
<td>~ 30</td>
<td>\geq 3 leptons</td>
<td>MET</td>
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<tr>
<td>W( \rightarrow \ell \nu )</td>
<td>~ 5000</td>
<td>1 lepton + MET</td>
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PART II
Data and Analysis
Proton-antiproton collisions at 1.96 TeV

Total Integrated Luminosity for this result is 2.0 fb$^{-1}$

Thanks to Accelerator Division!!
CDF Detector

- \( \eta = 0 \)
- \( \eta = 1 \)
- B field: 1.4 T

The CDF Detector includes:
- Muon system
- Drift Chamber
- EM Calorimeter
- Had Calorimeter

**Multipurpose Detector:** radially outward – silicon detector, tracking chamber, EM and Had Calorimeters, Muon systems
Three Leptons: Types

Electrons are a track [charged particle] + EM shower
Muons are a track + MIP + signal in muon systems
Tau-leptons decay to electrons or muons (see above) BR=35%
  decay hadronically single-prong (1 charged particle) BR=50%
  use an 'isolated' track to identify single-prong decays
Three 'Leptons' : Types

Leptons

Electrons

Tight gold plated

Loose

Muons

Tight gold plated

Tight

Loose

Tau leptons

Tracks

For example, Loose Electron has $E/p < 2$ and $\text{HadE}/\text{EmE} < 5\%$

Tight Electron has additional requirements based on shower shape of electron in calorimeter, pointing of track to calorimeter shower etc.
Tight Leptons

Loose Leptons

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

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

Events / 2 GeV

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

Electrons

Loose Electron $E_\tau$ (GeV)

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

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

Events / 2 GeV

Data
Drell-Yan
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Muons

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Events / 2 GeV

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

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Missing $E_T$

Missing energy known in transverse direction $\rightarrow$ missing $E_T$ or MET

MET is calorimeter based

Real MET $\rightarrow$ Neutrinos (and SUSY particles, if they exist)

**Instrumental MET** →
- mismeasurement of jet energies
- not accounting for muons

We correct MET
✓ for jets
✓ for muons
Setting up the Analysis

Perform an unbiased counting experiment:

- Define event selection
- Test predictive ability in a set of control regions
- Predict number of events in signal box
- Look at data and claim discovery or set limit.
Setting up the Analysis

Challenge: Overlapping datasets with multiple trigger paths.

Channels in this analysis are

A) Mutually exclusive and,
B) Ordered in terms of purity (S/B).
Setting up the Analysis

Challenge: Overlapping datasets with multiple trigger paths.

Channels in this analysis are

A) Mutually **exclusive** and,
B) Ordered in terms of purity (S/B).

**S/B**

- Find **three tight leptons**
  - Else, **two tight leptons and a 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**.
Setting up the Analysis

The five exclusive channels:

<table>
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<tr>
<th>Channel</th>
<th>E_T (P_T) GeV</th>
</tr>
</thead>
<tbody>
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<td>3 tight leptons OR 2 tight leptons + 1 loose electron</td>
<td>15, 5, 5</td>
</tr>
<tr>
<td>2 tight leptons + 1 loose muon</td>
<td>15, 5, 10</td>
</tr>
<tr>
<td>1 tight lepton + 2 loose leptons</td>
<td>20, 8, 5 (10 if loose muon)</td>
</tr>
<tr>
<td>2 tight leptons + 1 Track</td>
<td>15, 5, 5</td>
</tr>
<tr>
<td>1 tight lepton, 1 loose lepton, 1 Track</td>
<td>20, 8(10 if loose muon), 5</td>
</tr>
</tbody>
</table>

The five exclusive channels constitute five independent experiments within CDF
SM Backgrounds

Our signature is three leptons + missing energy –
What SM processes also look like this?

<table>
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<th>Process</th>
<th>Signature</th>
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<td>3 leptons + missing $E_T$</td>
</tr>
<tr>
<td>ZZ</td>
<td>4 leptons</td>
</tr>
<tr>
<td>Top-pair</td>
<td>3 leptons + missing $E_T$</td>
</tr>
<tr>
<td>DY</td>
<td>2 leptons</td>
</tr>
<tr>
<td>WW</td>
<td>2 leptons + missing $E_T$</td>
</tr>
<tr>
<td>W+jets</td>
<td>1 lepton + missing $E_T$</td>
</tr>
</tbody>
</table>

\[ a) + \gamma \text{ conversion} \]
\[ b) + \text{track from underlying event} \]
\[ c) + \text{hadron misidentified as lepton} \]

\[ \text{Three Real Leptons} \]

\[ \text{Two Leptons} + \text{'Fake'} \]

\[ \text{One Lepton} + \text{'Fake'} + \text{Track} \]
Estimating Backgrounds

Three real leptons:
Backgrounds from WZ, ZZ, top-pair are obtained from Monte Carlo (MC) simulations.

DY + γ:
also obtained from MC simulations.

Lepton identification efficiencies and trigger efficiencies used to get correct predictions in MC.
Estimating Backgrounds

Rate for Leptons:
DY  + (had→lep)
WW  + (had→lep)
W+jets + (had→lep)
Estimated in DATA

Rate for Candidate Tracks:
DY  + track
WW  + track
Estimated in MC
(but, normalized to data)
# Reducing Backgrounds

<table>
<thead>
<tr>
<th>Process</th>
<th>How to reduce?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drell-Yan + $\gamma$</td>
<td>low MET</td>
</tr>
<tr>
<td>Drell-Yan + track</td>
<td>make MET cut</td>
</tr>
<tr>
<td>top-pair production</td>
<td>has jets</td>
</tr>
<tr>
<td>hadrons faking leptons</td>
<td>require no more than 1 jet</td>
</tr>
<tr>
<td>Dibosons: WZ,ZZ</td>
<td>on-shell contribution of Z can be removed by a invariant mass cut for the Z.</td>
</tr>
<tr>
<td></td>
<td>off-shell contribution for ZZ $\rightarrow$ make MET cut</td>
</tr>
<tr>
<td></td>
<td>off-shell contribution is irreducible for WZ</td>
</tr>
</tbody>
</table>
Reducing Backgrounds: Drell-Yan, ZZ

Signal : mSUGRA $m_0=60$, $m_{\tilde{\chi}_1^0}=190$, $\tan(\beta)=3$, $A_0=0$, $\mu>0$, $M(\chi_{1\pm})=120$ GeV/c$^2$

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Reducing Backgrounds: WZ, ZZ on shell

Signal : mSUGRA $m_0=60$, $m_{\frac{1}{2}}=190$, $\tan(\beta)=3$, $A_0=0$, $\mu>0$, $M(\chi_1^\pm)=120$ GeV/c$^2$
Reducing Backgrounds: top-pair, fakes

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

Signal : mSUGRA $m_0=60$, $m_{1/2}=190$, $\tan(\beta)=3$, $A_0=0$, $\mu>0$, $M(\chi_1^\pm)=120 \text{ GeV/c}^2$

After all other selections are made

3 tight leptons

Require NJets < 2

Signal

Drell-Yan
Dibosons
$tt$
Fake lepton

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Reducing Backgrounds: residual DY

Signal: mSUGRA \( m_0 = 60, m_{1/2} = 190, \tan(\beta) = 3, A_0 = 0, \mu > 0, M(\chi_1^\pm) = 120 \text{ GeV}/c^2 \)

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Setting up the Analysis

Perform an unbiased counting experiment:

- Define event selection
- Test predictive ability in a set of control regions
- Predict number of events in signal box
- Look at data and claim discovery or set limit.
TEST WITH TWO LEPTONS FIRST
We will add third later in the talk
Two leptons before Three: High Stat Control Regions

Use Z events to test luminosity,
High $P_T$ leptons,
Use Z-veto to test low mass DY,
Low $P_T$ leptons

$Z : 76 < M_{ll} < 106 \text{ GeV/c}^2$

!$Z : 'not' Z or Z veto

Use MET distributions to test corrections to missing $E_T$
Use kinematic distributions to test agreements.
Split by flavor content (ee, $\mu\mu$, e$\mu$) to test agreements.
Control Regions: Dileptons

Missing Energy for Z selection

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

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

Dilepton Invariant Mass

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

MET

HIGH

IZ : Z veto

LOW

76 106

MASS
Control Regions : Dileptons

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

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

**Missing Energy for Z (ee) selection**

**Missing Energy for Z (µµ) selection**
Control Regions : Dileptons

Dilepton Invariant Mass

one tight, one loose

two tight

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

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

Events / 2 GeV/c^2

Invariant Mass (GeV/c^2)
Control Regions : Dileptons

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

<table>
<thead>
<tr>
<th>Name</th>
<th>$Z\rightarrow ee$</th>
<th>$Z\rightarrow \mu\mu$</th>
<th>$Z\rightarrow \tau\tau$</th>
<th>WW</th>
<th>WZ</th>
<th>ZZ</th>
<th>$t\bar{t}$</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>$!Z$</td>
<td>9847.8</td>
<td>5034.7</td>
<td>1310.2</td>
<td>93.3</td>
<td>1.6</td>
<td>7.1</td>
<td>57.1</td>
<td>16352 ± 716</td>
<td>15966</td>
</tr>
<tr>
<td>$!Zlo$</td>
<td>7705.6</td>
<td>4240.6</td>
<td>477.7</td>
<td>4.7</td>
<td>0.1</td>
<td>2.3</td>
<td>1.0</td>
<td>12432 ± 569</td>
<td>12352</td>
</tr>
<tr>
<td>$!Zhi$</td>
<td>858.4</td>
<td>205.5</td>
<td>550.3</td>
<td>83.5</td>
<td>1.4</td>
<td>3.6</td>
<td>55.0</td>
<td>1758 ± 80</td>
<td>1612</td>
</tr>
<tr>
<td>$Z$</td>
<td>31178.2</td>
<td>19870.4</td>
<td>21.9</td>
<td>22.4</td>
<td>6.3</td>
<td>35.8</td>
<td>15.0</td>
<td>51150 ± 2034</td>
<td>51042</td>
</tr>
<tr>
<td>$Zlo$</td>
<td>25577.6</td>
<td>16665.6</td>
<td>11.1</td>
<td>1.6</td>
<td>0.2</td>
<td>13.4</td>
<td>0.2</td>
<td>42270 ± 1682</td>
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</tr>
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<td>$Zhi$</td>
<td>1261.1</td>
<td>741.5</td>
<td>6.4</td>
<td>19.0</td>
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<td>15.9</td>
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<td>54445</td>
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<td>$Z(ee)$</td>
<td>31178.3</td>
<td>0.0</td>
<td>6.7</td>
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<td>31074</td>
</tr>
<tr>
<td>$Z(\mu\mu)$</td>
<td>0.0</td>
<td>19867.7</td>
<td>3.9</td>
<td>4.6</td>
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<td>4.3</td>
<td>18.3</td>
<td>10399 ± 617</td>
<td>10033</td>
</tr>
<tr>
<td>$e\mu$</td>
<td>0.0</td>
<td>21.9</td>
<td>580.4</td>
<td>56.5</td>
<td>0.1</td>
<td>0.5</td>
<td>35.1</td>
<td>694 ± 47</td>
<td>761</td>
</tr>
</tbody>
</table>
Control Regions : Dileptons

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

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<td>$Z_{(ee)}$</td>
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</table>
Control Regions : Dileptons

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

Search for $\tilde{\chi}^\pm_1 \tilde{\chi}^0_2$

2 tight leptons

1 tight + 1 loose leptons
Ready for Three Leptons

High MET, Z-veto is now signal box

Use Z events to test MET

Use high MET Z region to test dibosons (WZ,WW)

Test 'fake' estimations in Z events and low-mass, low-MET events.

Trileptons = two opposite charge pairs. Take higher to define control regions.
Control Regions: Trileptons

Highest Invariant Mass

Missing Energy for Z selection

Selection:
2 tight leptons + 1 Track
Control Regions: Trileptons

Selection: 2 tight leptons + 1 Track
Control Regions : Trileptons

Leading Lepton $E_T$ for Z selection

Selection : 3 Tight Leptons

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

Search for $\tilde{\chi}^\pm_1 \tilde{\chi}^0_2$

Highest Invariant Mass

NEvents / 8 GeV$^2$

NEvents / 4 GeV
Control Regions : Trileptons

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Control Regions : Trileptons

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

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

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

Obs-Exp vs Exp
Pull for 25 uncorrelated control regions shown, overall 51 control regions, split by lepton flavor, purity and hundreds of distributions

This is where we spent most time and effort.

Ready to open the Signal Box, but first - a look at the systematic uncertainties
Systematic Uncertainties

**Backgrounds**
- hadrons faking leptons
- underlying event → tracks
- Lepton identification ~ 2%
- Jet energy scale ~ 2 to 5%
- Process Cross-section ~ 5%

**Signal**
- Signal cross section ~ 10%
- Lepton identification ~ 4%
- Initial/Final State radiation ~ 4%

Common to both
- Luminosity ~ 6%
- PDF ~ 2%
## FINAL PREDICTIONS

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

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<tr>
<td>2tight,1loose</td>
<td>1.6±0.1±0.2</td>
<td>0.3±0.03±0.03</td>
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<td>0.7±0.1±0.1</td>
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<tr>
<td><strong>Total trilepton</strong></td>
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FINAL PREDICTIONS
Breakdown of Backgrounds

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

ALL THREE LEPTONS
Total $\sim 1$ event

TWO LEPTONS AND A TRACK
Total $\sim 5.5$ events
**FINAL PREDICTIONS**

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

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**TOTAL EXPECTED SIGNAL = 11.4 events**

Signal: mSUGRA $m_0=60$, $m_{1/2}=190$, $\tan(\beta)=3$, $A_0=0$, $\mu>0$, $M(\chi_1^\pm)=120$ GeV/c$^2$
### FINAL PREDICTIONS

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

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

Search for $\chi_{2\chi_1}^\pm$

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

**Missing $E_T$**

3 tight $\rightarrow$ 1 event

2 tight, 1 Track $\rightarrow$ 4 events

1 tight, 1 loose, 1 Track $\rightarrow$ 2 events
PART III
Interpreting the Results
Present State of Knowledge

We place limits on production cross section times branching ratio as a function of parameters of interest in mSUGRA

**LEP results**: directly applicable
Charginos must have mass $> 103.5 \text{ GeV/c}^2$
mSUGRA

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

Spectrum (at BP) GeV

\( \tilde{\chi}_2 \) 124
\( \tilde{\chi}_1^+ \) 122
\( \tilde{\chi}_1^0 \) 66
\( \tilde{e}_L \) 149
\( \tilde{e}_R \) 101
\( \tilde{\tau}_1 \) 100
\( \tilde{\tau}_2 \) 150
\( \tilde{g} \) 477
\( \tilde{u}_R \) 421
\( \tilde{d}_L \) 439

Signal Benchmark Point (BP) with parameters:
mSUGRA \( m_0=60, \) \( m_{\frac{1}{2}}=190, \) \( \tan(\beta)=3, A_0=0, \mu>0 \)
mSUGRA -- minimal SUper GRAvity grand unification

why?  
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  b) Manageable due to five parameters

Defined by five parameters:

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

Signal Benchmark Point (BP) with parameters:

- mSUGRA $m_0=60$, $m_{1/2}=190$, $\tan(\beta)=3$, $A_0=0$, $\mu>0$

We fix:

- $\tan(\beta) = 3$
- $A_0 = 0$
- $\mu > 0$
mSUGRA Features of interest : $\sigma$

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

$\sigma(p\bar{p} \rightarrow \tilde{\chi}_2^0\tilde{\chi}_1^{\pm})$

Cross section is a smooth function of chargino mass, hence $m_{1/2}$

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mSUGRA Features of interest

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

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

\[ M(\tilde{\chi}_2^0, \tilde{\chi}_1^\pm) < M(\tilde{\ell}) \]

\[ \tilde{\chi}_1^\pm \rightarrow - - - W^* \tilde{\chi}_1^0 \rightarrow - - - \ell^\pm \nu \tilde{\chi}_1^0 \]

\[ \tilde{\chi}_2^0 \rightarrow - - - Z^* \tilde{\chi}_1^0 \rightarrow - - - \ell^\pm \ell^\mp \tilde{\chi}_1^0 \]
$BR(\tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow 3\ell)$
Observed Limits on $\sigma \times \text{BR}$

- RED is bad
- BLUE is good
Observed Exclusion

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

Search for $\chi_1\chi_2$:
- Excluded at 95% C. L.
- LEP direct limit

$m(\tilde{\tau}_1) < m(\tilde{\chi}_2^0)$

$m(\tilde{\tau}_1) > m(\tilde{\chi}_2^0)$

$m_0 (\text{GeV/c}^2)$

$m_{1/2} (\text{GeV/c}^2)$
Mass limits for $m_0 = 60$ GeV/$c^2$

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

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

LEP direct limit

- Theory $\sigma_{NLO} \times$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 < 145.4 GeV/$c^2$
Mass limits for $m_0=60 \text{ GeV/c}^2$

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

**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

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

Exclude Chargino with Mass $< 127.0 \text{ GeV/c}^2$
Summary

- We analyzed 2 fb\(^{-1}\) of 1.96 TeV p-pbar collisions at CDF. For benchmark mSUGRA parameters, we expected \(~12\) SUSY events.

- We have a unified analysis – channels with all combinations of leptons (e,\(\mu\)) in parallel; channels with two leptons and track to add sensitivity to tau leptons.

- Our observation of 7 events is consistent with the standard model expectation of 6.4 events.

We present an exclusion region in mSUGRA plane

We now have first mSUGRA chargino mass limits since LEP
Outlook

- We are working on making our results less model-dependent. For example, what does $\tan(\beta)$ dependence imply for experimental limits?

- We can take our understanding and then try and apply it to LHC (CMS & ATLAS). This will be a good way for me to learn about LHC as well!
BACKUP
Observed Exclusion

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
- \( m(\tilde{\tau}_i) \approx m(\tilde{\chi}_0^0) \approx m(\tilde{\chi}_1^0) \)
- \( m(\tilde{e}_R), m(\tilde{\mu}_R) > m(\tilde{\tau}_i) \)
3 Tight Lepton Event

Lepton e+
- $p_T = 17 \text{ GeV}/c^2$
- $\eta = -0.82$

Lepton e-
- $p_T = 5.8 \text{ GeV}/c^2$
- $\eta = -0.67$

Lepton e-
- $p_T = 24 \text{ GeV}/c^2$
- $\eta = 0.15$

$E_T = 24, 17, 6 \text{ GeV}$

MET = 37 GeV

One jet, Jet $E_T = 60 \text{ GeV}$
3 tight electron event
$E_T = 24, 17, 6 \text{ GeV}$
$\text{MET} = 37 \text{ GeV}$
One jet, Jet $E_T = 60 \text{ GeV}$
EVENTS

2 tight muons + 1 Track
$E_T = 34, 6, 9$ GeV
MET = 20.4 GeV
One jet, Jet $E_T = 22$ GeV

Track e/μ -
$p_T = 9.2$ GeV/c
$\eta = 0.85$

Lepton μ-
$p_T = 6$ GeV/c
$\eta = 0.80$

MET = 20.4 GeV

Lepton μ+
$p_T = 34$ GeV/c
$\eta = 0.14$
EVENTS

2 tight muons + 1 Track
\( E_T = 34, 6, 9 \text{ GeV} \)
\( \text{MET} = 20.4 \text{ GeV} \)
One jet, Jet \( E_T = 22 \text{ GeV} \)
Signal Plots: Acceptances by Channel

Acceptances by Channel

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

Acceptance [%]

- Trilepton
- Dilepton+Track

Chargino Mass (GeV/c²)

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Signal Plots : Large $m_0$

Large $m_0$ in mSUGRA

$\sigma \times BR$

- $\tan(\beta)=30, M(\tilde{\chi}^+_1)\sim 136$
- $\tan(\beta)=3, M(\tilde{\chi}^+_1)\sim 138-144$

- $\tan(\beta) = 30$
- $\tan(\beta) = 3$

$m_{1/2} = 190, A_0 = 0, \mu > 0$
Signal Plots
\[ \tan(\beta) \text{ variation} \]

\[ \sigma(\bar{\chi}_2^0\chi_1^\pm), \ BR(3 \text{ leptons}) \]

\[ \text{mSUGRA } m_0 = 60, \ m_{1/2} = 190, \ A_0 = 0, \ (\mu) > 0 \]

\[ \text{Chargino Mass (GeV/c^2)} \]

\[ \text{Chargino Mass (GeV/c^2)} \]

\[ \text{mSUGRA } m_0 = 60, \ m_{1/2} = 190, \ A_0 = 0, \ (\mu) > 0 \]
Cross Sections: Tevatron & LHC

\[ \sigma_{\text{tot}} \text{[pb]}: \bar{p}p \rightarrow g\bar{g}, q\bar{q}, t\bar{t}, \chi^0_1, \chi^+_1, \nu\bar{\nu}, \chi^0_1 g, \chi^+_1 q \]

\( \sqrt{S} = 2 \text{ TeV} \)

NLO

LO

T. Plehn, PROSPINO

Prospino2 (T. Plehn)

\[ \sigma_{\text{tot}} \text{[pb]}: \bar{p}p \rightarrow g\bar{g}, q\bar{q}, t\bar{t}, \chi^0_1, \chi^+_1, \nu\bar{\nu}, \chi^0_2 g, \chi^+_2 q \]

\( \sqrt{S} = 14 \text{ TeV} \)

NLO

LO

m [GeV]