Search for New Phenomena at the Tevatron

John Strologas

University of New Mexico

For the CDF and D0 Collaborations
Why Physics Beyond the Standard Model?

Although extremely successful, the Standard Model does not answer all our basic questions about nature

- Why are the Planck scale and the electroweak scale 17 orders of magnitude apart (and how can we avoid the “fine-tuning”)?
- How is gravity incorporated?
- What is the origin of mass?
- What is the source of dark matter and dark energy?
- Why is there a boson/fermion asymmetry?
- Why is there a particle/antiparticle asymmetry?
- Why do we have several interactions instead of one unified one?
- ....

Our job as experimentalists is

- to perform experiments to discover new-physics effects that could give answers to the above questions
- to perform experiments to test current theories that offer answers to the above questions
Tevatron collides protons with antiprotons at 1.96 TeV center-of-mass energy

- Instantaneous luminosity exceeded $400 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$
- Delivered luminosity $\sim 9 \text{ fb}^{-1}$
- Recorded luminosity: $\sim 8 \text{ fb}^{-1}$ per experiment
- Presented in this talk up to $6.3 \text{ fb}^{-1}$
The CDF and D0 detectors

CDF

- Central silicon and drift tracking
- Lead/Steel+scintillator calorimeter
- Outer muon chambers
- Magnetic field of 1.4 Tesla

D0

- Central silicon and drift tracking
- Uranium/Steel+Liquid-argon calorimeter
- Outer muon chambers
- Magnetic field of 1.8 Tesla
Searches for new Phenomena

- Searches for phenomena predicted by specific current theories
  - SUSY
  - RS-gravitons
  - 4th generation
  - New gauge bosons
  - Universal Extra dimensions
  - Technicolor

- Searches for signatures inconsistent with the Standard Model
  - Mass resonances
  - Rare events
  - Not necessarily predicted by current theories

- Even searches that look for particles predicted by current theories can be generic enough to discover the unpredictable
Create an extension of the SM, where for each boson we have a fermion and vice versa (superpartners differ only in their spin)

Mixing gives $\pm_i$, $X^0_j$ (charginos and neutralinos)

gluino
Supersymmetry

- SUSY is obviously broken, which leads to a new mass-spectrum for sparticles. We study “soft” SUSY breaking
  - mSUGRA (LSP=neutralino), GMSB (LSP=gravitino)
- Removes fine tuning and offers ultra-violet completeness
  - Large radiative corrections of superpartners cancel each-other
- Offers possibility of force unification
  - Not exactly possible with SM
- Offers a cold dark matter candidate
  - If the lightest supersymmetric particle (LSP) is stable. This is the case if $R$-parity $= (-1)^{3(B-L)+2S}$ is conserved
- Possibility of radiative Electroweak symmetry breaking
  - As an alternative to spontaneous breaking
- Today I present searches for sbottom and stop quarks, $R$-parity violating sneutrinos, $R$-parity violating gluinos, GMSB models
  - Will also remind current limits for mSUGRA charginos/neutralinos and squark/gluinos
Charginos and neutralinos at the Tevatron

- **Golden chargino-neutralino signature:** trileptons + MET

- **Squark and gluinos are strongly produced and give jets + MET**

   If $M_{\tilde{g}} < M_{\tilde{g}}$

   If $M_{\tilde{g}} > M_{\tilde{g}}$

   If $M_{\tilde{g}} \approx M_{\tilde{g}}$ then additional contribution:
Current chargino-neutralino limits


- mSUGRA limit: Chargino mass > 165 GeV/c² @ 95% CL (for m₀=60 GeV/c²)
  -- expected limit 155 GeV/c²

**CDF public note 9817 (2009)**

**CDF Run II Preliminary, 3.2 fb⁻¹**

- mSugra tan β=3, A₀ = 0, μ > 0
- m(χ⁺₀) = m(χ₀)
- m(χ⁺₀), m(μ⁻) > m(t,j)

- LEP Chargino Limit
- LEP Sleppton Limit
- DØ observed limit (2.0 fb⁻¹)
- m(χ⁺₀) = M(χ₀)
- m(χ⁺₀) = M(χ₀)
- m(χ⁺₀) = M(χ₀)
- m(χ⁺₀) = M(χ₀)
Current squark-gluino limits

\[ M_{\text{gluino}} > 382-390 \text{ GeV}/c^2 \text{ (D0-CDF) if } M_{\text{squark}} = M_{\text{gluino}} \]


**Phys. Rev. Lett. 102, 121801 (2009)**
**Search for sbottom at the Tevatron**

- Investigate $\tilde{b} \rightarrow b + \tilde{\chi}_1^0$ (assume BR=1), signature from pair production: 2 b-jets and MET

| L = 5.2 fb$^{-1}$ |
| L = 2.65 fb$^{-1}$ |
| 2 or 3 jets, $E_T > 20$ GeV, at least 2 b-tagged (NN), leptons vetoed | 2 jets, at least one b-tagged, $\Delta \phi$(MET-jet$_{1,2}$)$>0.4, 0.7$ |
| $E_T^{\text{jet}1} > 20, 50$ GeV, MET$>40, 850$ GeV | $E_T^{\text{jet}1} > 80, 90$ GeV, $E_T^{\text{jet}2} > 25, 40$ GeV, |
| $H_T > 60, 220$ | MET$>60, 80$ GeV $H_T > 165, 300$ |
| - cuts optimized per mSUGRA point, based on $\Delta M$(sbottom-LSP)=$240$ and 45 GeV/c$^2$ | - cuts optimized per mSUGRA point, based on $\Delta M$(sbottom-LSP)$< \text{or} > 90$ GeV/c$^2$ |
| Point1: $N_{\text{obs}} = 901, N_{\text{SM}} = 971 \pm 152$ | $\Delta M<90 : N_{\text{obs}} = 139, N_{\text{SM}} = 134 \pm 25$ |
| Point2: $N_{\text{obs}} = 7, N_{\text{SM}} = 7 \pm 2$ | $\Delta M>90 : N_{\text{obs}} = 38; N_{\text{SM}} = 48 \pm 8$ |
| **Main backgrounds**: W/Z+jets, multi-jet with fake MET | **Main backgrounds**: light-flavor QCD with mistags and heavy-flavor QCD with high MET, W/Z+jets |

August 23, 2010

John Strologas, SUSY 10, Bonn
Search for sbottom at the Tevatron (2)

Kinematic distributions of MET and $H_T$ are consistent with SM background

$\Delta M < 90$ GeV/c$^2$
Search for sbottom at the Tevatron (3)

Limits on the Neutralino-mass vs Sbottom-mass are set

For neutralino mass < 70 GeV/c² observed sbottom mass limit is ~250 GeV/c²

For neutralino mass < 70 GeV/c² observed sbottom mass limit is ~240 GeV/c²
The jet+MET D0 analysis can be interpreted as a third-generation leptoquark limit.


\[ M_{LQ3} > 247 \text{ GeV/c}^2 \text{ at 95\% CL} \]
Search for $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm \rightarrow b\tilde{\chi}_1^0 l\nu$ assuming:

- $L = 2.7 \text{ fb}^{-1}$
- 2 leptons (e or $\mu$) >20 GeV and 2 jets >12-20 GeV
- MET >20 GeV
- Perform analysis with and without b-tag
- Genetic algorithm optimization
- Main background: top pairs, Z+jets (latter dies with b-tagging)
- Observation consistent with SM
Search for stop at the Tevatron (2)

Stop limits depend on the Branching Ratio of chargino

Chargino Mass of 105.8 GeV

Chargino Mass of 125.8 GeV

PRL 104, 251801 (2010)
Searches for GMSB at the Tevatron

- Under GMSB the lightest neutralino could decay to photon and gravitino.
- Signature of neutralino pair production will be **two photons and MET**
  - L = 6.3 fb⁻¹
  - 2 photons > 25 GeV, MET>50 GeV
  - \( \Delta \Phi \) separation between MET and \( \gamma \) or jets
- **Background:**
  - Fake MET: SM diphotons, \( \gamma \)+jets (estimate using dielectron/diphoton MET shape, fitted at MET<10,20 GeV)
  - Real MET: W+\( \gamma \), W+jet, W/Z+\( \gamma \)
- Observation consistent with SM

<table>
<thead>
<tr>
<th>MET (GeV)</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>35-50</td>
<td>20 ± 2</td>
<td>18</td>
</tr>
<tr>
<td>50-70</td>
<td>5 ± 1</td>
<td>3</td>
</tr>
<tr>
<td>&gt;70</td>
<td>0.9 ± 0.4</td>
<td>1</td>
</tr>
</tbody>
</table>
D0 result also interpreted in the universal-extra-dimensions model, setting limits on the compactification radius.

GMSB limit

\[ M_{\chi^0} > 170 \text{ GeV/c}^2 \text{ at 95\% CL} \]

Universal extra dimensions limit

\[ R_c^{-1} > 477 \text{ GeV/c}^2 \text{ at 95\% CL} \]

arXiv:1008.2133 [hep-ex]
Submitted August 12, 2010
R-parity violating (RPV) signals

- If R-parity is conserved, SUSY particles are produced in association.

- If R-parity is violated, we can have singly-produced SUSY particles decaying to SM-only particles and also lepton-number or/and baryon number violation.

\[
L_{RPV} = \frac{1}{2} \epsilon_{\alpha\beta} \lambda'_{ijk} L_i^a L_j^b E_k + \epsilon_{\alpha\beta} \lambda'_{ijk} L_i^a Q_j^b D_k + \\
\frac{1}{2} \epsilon_{\alpha\beta\gamma} \lambda''_{ijk} U_i^a D_j^b D_k^\gamma + \epsilon_{\alpha\beta} \mu_i L_i^a H_u^b
\]

- We present sneutrino production with lepton-number violating decay.

- We also present a multijet search that sets a limit on RPV gluino production.
Look for electron+muon production (lepton-number violation)

- \( L = 5.3 \text{ fb}^{-1} \)
- 1 electron > 35 GeV,
- 1 muon > 25 GeV/c, jet veto
- Neural-network based electron ID
- **Main Background:** \( Z \rightarrow \tau \tau \), diboson
- Main systematics: Cross-sections and luminosity
- Expect 410 \( \pm 38 \) from SM and observe 414
Look for electron+muon production (lepton-number violation)

arXiv:1007.4835 [hep-ex]
Submitted July 27, 2010
Search for RPV gluino at the Tevatron

- R-Parity violating pair of gluinos decays to 6 outgoing partons

- $L = 3.2 \text{ fb}^{-1}$
- 6 jets $>15 \text{ GeV}$, $\Sigma E_T > 250 \text{ GeV}$, jets coming from the same z-position
- MET $< 50 \text{ GeV}$
- Use all triplets of jets for each event
- Diagonal cut optimized for different gluino masses
- Main Background: multijets (use 5-jet bin to model the background)
Data consistent with SM (a 2 σ effect around the top mass)

CDF public note 10256 (2010)
Introduction to RS-gravitons

- In the Randall-Sundrum (RS) model the hierarchy is generated by introducing an extra dimension.
- 5-dimensional space-time -> 2 4-dimensional subspaces (branes).
- The SM particles are confined in the “TeV” brane, whereas gravity is localized on the “Planck” brane but can propagate in the bulk.
- The extra dimension is compactified with a radius $R_c$.

- Scale of physical phenomena is given by the warp factor $\Lambda = M_{Pl} \exp(-kR_c \pi)$, where $k$ is the curvature scale of the extra dimension.
- The compactification of the extra dimension gives rise to a tower of Kaluza-Klein graviton states with masses $m_n = x_n (k/M_{Pl}) \Lambda$.
- 2 parameters determine the graviton couplings and widths: $m_1$ and $k/M_{Pl}$. 

![Diagrams showing RS-gravitons interactions](image)
Search for RS-gravitons at the Tevatron

- Investigate the decays of RS-gravitons to pairs of electrons or photons \((BR(\gamma\gamma)\sim2BR(\text{ee}))\)

<table>
<thead>
<tr>
<th><strong>L = 5.4 fb(^{-1})</strong></th>
<th><strong>L = 5.4 fb(^{-1})</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2 central, isolated electrons or photons with</strong> (E_T&gt;25\text{ GeV})</td>
<td><strong>2 central, isolated photons with</strong> (E_T&gt;15\text{ GeV})</td>
</tr>
<tr>
<td>For (\gamma\gamma) Primary vertex selected with EM shower pointing</td>
<td><strong>Main backgrounds:</strong> SM (\gamma\gamma) and dijets (misidentification of a jet as a photon)</td>
</tr>
<tr>
<td><strong>Main backgrounds:</strong> DY(\rightarrow)ee / SM (\gamma\gamma)</td>
<td>Get a MC diphoton mass shape and fit it above 100 GeV/c(^2)</td>
</tr>
<tr>
<td>Background estimation is fitted to (60&lt;M_{ee}(M_{\gamma\gamma})&lt;200\text{ GeV/c}^2)</td>
<td>– <strong>The goodness of the fit is the actual result</strong></td>
</tr>
<tr>
<td><strong>Main systematics from cross sections (9-17%), EM energy resolution (6%), ISR and K-factors (5% each)</strong></td>
<td><strong>Main background systematics are</strong> ISR/FSR (4-8%) and luminosity (6%)</td>
</tr>
<tr>
<td><strong>Data consistent with SM</strong></td>
<td><strong>Data consistent with SM</strong></td>
</tr>
</tbody>
</table>
Dilepton and diphoton high masses are consistent with the SM

Probability of the $\gamma\gamma$ excess $\sim 450 \text{ GeV}/c^2$: 1.1% (2.3 $\sigma$)

Probability of the excess $\sim 200 \text{ GeV}/c^2$: 1.3% (2.2 $\sigma$)
Limits are set on the coupling vs. Graviton mass plane

- $M_G > 560 (1050) \text{ GeV}/c^2$ for $k/M_{PL} = 0.01 (0.1)$
- $M_G > 472 (976) \text{ GeV}/c^2$ for $k/M_{PL} = 0.01 (0.1)$


CDF public note 10207 (2010)
Search for diboson resonances at the Tevatron

Heavy $W'$ and $Z'$ or technicolor particles can decay to diboson pairs

- $L = 4.1 \text{ fb}^{-1}$
- Search for $WZ$ to leptons
- At least 3 isolated charged leptons ($e/\mu$) with $p_T > 20 \text{ GeV/c}$
- MET > 30 GeV
- Main backgrounds: SM dibosons, $Z$+jets, $Z$+$\gamma$ (latter 2 estimated with data)
- Main systematics from fake-rates, acceptances/efficiencies
- Expect 10.2 ± 1.6 SM events and see 9 (expect 4 from a 400 GeV/c$^2$ $W'$)

- $L = 2.9 \text{ fb}^{-1}$
- Search for $WW$ and $WZ$ decaying to electron+neutrino+2 jets
- $E_T$(electron) > 30 GeV, MET > 30 GeV
- 2 or 3 jets with $E_T > 30 \text{ GeV}$
- Total $H_T > 150 \text{ GeV}$
- Main backgrounds: $W$+jets, multijets
- Main systematics from jet energy-scale and theoretical cross-sections
- Data consistent with SM
- Limits set by additional optimization (higher $E_T$ cuts for higher masses)
Dibosons consistent with the Standard Model, $W'$ limits set

Exclude $188 < M_{W'} < 520$ GeV/c$^2$

Exclude $285 < M_{W'} < 516$ GeV/c$^2$
Using the diboson analyses we can set limits on technicolor and $Z'$

Exclude 208 $< M_{\rho_T} < 408$ GeV/c$^2$

PRL 104, 061801 (2010)

Exclude 247 $< M_{Z'} < 544$ GeV/c$^2$

PRL 104, 241801 (2010)
Dileptonic searches for $Z'$ at the Tevatron

Mainstream searches of $Z'$ to dileptons

<table>
<thead>
<tr>
<th>$L$</th>
<th>5.4 fb$^{-1}$</th>
<th>4.6 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Use of the dielectron analysis already presented</td>
<td>Two central muons &gt; 30 GeV/c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main background: Drell-Yan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main systematics from PDF, K-factor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data consistent with SM</td>
</tr>
</tbody>
</table>
Mainstream searches of $Z'$ to dileptons

- Dielectron mass spectrum consistent with SM
- Dimuon mass spectrum consistent with SM
Mainstream searches of $Z'$ to dileptons

- $M_{Z'} > 772 - 1023 \text{ GeV/c}^2$
  - arXiv:1008.2023 [hep-ex]
  - Submitted on August 11, 2010

- $M_{Z'} > 817 \text{ to } 1071 \text{ GeV/c}^2$
  - CDF Public note 10165 (2010)
t-tbar-enhanced technicolor Z'

- 4.8 fb$^{-1}$
- 1 e/\mu > 20 GeV, MET > 20 GeV, ≥4 15-GeV jets, 1 b-tagged
- Matrix-element reconstruction
- For each event observe a PDF of top-anti-top mass

95% CL exclusion of top-color-assisted technicolor Z' with $m_{Z'} < 900$ GeV for $\Gamma_{Z'} = 0.012M_{Z'}$
Searches for t’ and b’ at the Tevatron

4th generation is not excluded by electroweak precision measurements and could explain some forward-backward asymmetry in b-decays

<table>
<thead>
<tr>
<th>Search for b’ → Wt → WWb pair production</th>
<th>Search for t’ → Wq (not b’) pair production</th>
</tr>
</thead>
<tbody>
<tr>
<td>L = 4.8 fb⁻¹</td>
<td>L = 4.6 fb⁻¹</td>
</tr>
<tr>
<td>1 e/µ &gt; 20 GeV, MET&gt;20 GeV, ≥5 jets &gt;20 GeV (≥1 b tagged)</td>
<td>1 e/µ &gt; 25 GeV, MET&gt;20 GeV, ≥4 jets &gt;20 GeV (no b-tagging)</td>
</tr>
<tr>
<td>Main background: top pairs</td>
<td>Main background: W+jets, top pairs</td>
</tr>
<tr>
<td>Main systematics from Jet-energy scale</td>
<td>Fit the M_{reco} vs H_T distribution</td>
</tr>
<tr>
<td>Analysis performed for N_{jet}=5,6, ≥7 and for N_{b-tags}=0,1 ≥2</td>
<td>Main systematics from jet-energy scale</td>
</tr>
<tr>
<td>Some discrepancy compared to the SM for N_{jet}≥7 and ≥1 b-tags could be due to parton showering</td>
<td>Data consistent with SM</td>
</tr>
</tbody>
</table>
4th generation is not excluded by electroweak precision measurements

**b’ search**

**0-tag**

**1-tag**

**2-tag**

**t’ search**

*CDF Run II Preliminary L = 4.8 fb⁻¹*

*CDF Run 2 (4.6 fb⁻¹) Preliminary*

**Observed**

- **t’**
- **t**
- **W+jets, EW**
- **QCD**

**Events/25 GeV**

**M_reco (GeV)**
Searches for $t'$ and $b'$ at the Tevatron

4th generation is not excluded by electroweak precision measurements

**b' search**

CDF Run II Preliminary $L=4.8$ fb$^{-1}$

- $b' > 385$ GeV/c$^2$
- **CDF Public Note 10243 (2010)**

**t' search**

CDF Run 2 (4.6 fb$^{-1}$)

- Preliminary
- $t' \rightarrow Wq, \geq 4$ jets
- $H_T$ vs. $M_{reco}$ vs. $N_{jet}$

- $t' > 335$ GeV/c$^2$
- **CDF Internal Note 9846 (2010)**
Extra QCD-like SU(N) theories predict new kind of quarks. Parameters are the scale $\Lambda$ where “infracolor” becomes strong and the mass $M_\Delta$ of the “quirks”

Detect either strange tracks

Or detect highly-ionizing slow heavy particle

SUSY hidden sector $\gamma_D$ could give rise to “lepton jets” that are detectible at the Tevatron

Hanet al.,
Strassler and Zurek,

Kang and Luty (2008)
arXiv:0805.4642v3 [hep-ph]
Search for the ... Quirks

- Investigate $10 < \Lambda < 1 \text{ MeV/c}^2$ (mesoscopic range) and $60 < M_Q < 160 \text{ GeV/c}^2$
- $L = 2.4 \text{ fb}^{-1}$
- Look for slow, high-ionizing track
- Select an isolated track $> 40 \text{ GeV/c}$, a jet $> 75 \text{ GeV}$ and MET $> 50 \text{ GeV}$
- MET aligned with the track, jet opposite direction
- Expect large dE/dx, $\sim 15 \text{ MeV/cm}$
- **Main background**: W+jets and multijets
- Discriminating variable: dE/dx, measured with the tracking system
Hidden sector’s force carrier (dark photon $\gamma_D$) will decay to leptons

- Signal is many “lepton jets”

- $L = 5.8 \text{ fb}^{-1}$

- Select a seed electron or muon track $>10 \text{ GeV/c}$ with a companion track of opposite charge of $>5 \text{ GeV/c}$

- MET $>30 \text{ GeV}$

- Both track and calorimeter isolation

- At least 2 such “lepton jets”

- Main background: multijet events and (for “electron jets”) conversions

- Results for $ee$, $e\mu, \mu\mu$ and combined

- Form invariant mass of dark photon from seed and companion track

---

August 23, 2010  John Strologas, SUSY 10, Bonn
Search for hidden valleys (2)

Limit on the cross-section vs dark-photon mass is set

[Graph showing cross-section limits vs dark-photon mass]

Evidence for an anomalous like-sign dimuon charge asymmetry

1. Dimuon charge asymmetry due to B-mixing:

\[
a_{sl}^b = \frac{\Gamma(B \to \mu^+ X) - \Gamma(B \to \mu^- X)}{\Gamma(B \to \mu^+ X) + \Gamma(B \to \mu^- X)} = A_{sl}^b
\]

2. The SM-expected asymmetry for the B_s and B_d produced at the Tevatron comes from CP-violating phase of the B mass matrix

\[
a_{sl}^q = \frac{\Delta \Gamma^q}{\Delta M_q} \tan(\phi_q)
\]

3. SM-expected asymmetry

\[
A_{sl}^b (SM) = (-0.023^{+0.005}_{-0.006})\%
\]

4. Measured by D0 is 3.2 σ higher:

\[
A_{sl}^b = (-0.957 \pm 0.251 \text{ (stat)} \pm 0.146 \text{ (syst)})\%
\]
Just blessed: lepton+gamma+MET+b-quark

- Signal could be due to t-tbar+photon with semileptonic decay or due to some new physics

- $L = 5.7 \, \text{fb}^{-1}$
- Select an electron or muon with $E_T > 20 \, \text{GeV}$, MET $> 20 \, \text{GeV}$, photon with $E_T > 12 \, \text{GeV}$
- b-tagged jet with $E_T > 20 \, \text{GeV}$
- Main background: t-tbar+$\gamma$ and W$\gamma$+jets
- Results consistent with the EM

**CDF Run II Preliminary, 5.74 fb$^{-1}$**

<table>
<thead>
<tr>
<th>Lepton + Photon + $E_T$ + b Events, Isolated Leptons</th>
<th>Total SM Prediction</th>
<th>Observed in Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>56.5 $\pm$ 7.9</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>29.8 $\pm$ 2.1</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>86.4 $\pm$ 8.5</td>
<td>84</td>
</tr>
</tbody>
</table>
More details about some of the analyses at the parallel sessions

Tevatron new-phenomena non-BSM-higgs parallel talks at SUSY 10

- **D0**

  Sudeshna Banerjee:
  
  Searches for physics beyond the standard mode in final states with two leptons and jets with the D0 detector

  Sudeshna Banerjee:
  
  Searches for physics beyond the standard model in final states with long lived particles.

  Mark Cooke:
  
  Searches for supersymmetry in ppbar collisions at sqrt(s) =1.96 TeV with the D0 detector

- **CDF**

  Maxwell Chertok:
  
  Searches in Same-Charge Dilepton Events at CDF and Searches for Supersymmetry Using the Trilepton Signature at CDF

  Gianluca de Lorenzo:
  
  Searches for Squarks and Gluinos in Jets and Missing Energy Final States at CDF
Conclusions

- The Tevatron experiments are extremely active in the search of new phenomena
- We try to test old and new theories without neglecting to perform model-independent searches
- We look at final states never investigated before
- We haven’t discovered new physics yet, but we keep expanding our kinematic and parameter space reach and we keep searching
- Our analyses improve continuously and the Tevatron performs extraordinarily, so we will keep increasing our discovery potential and limits-setting / theory-testing power
- Don’t forget to check the CDF and D0 public exotic pages: ...
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/wp.htm
Central tracker measures charged particle trajectories

These trajectories are matched to calorimeter energy depositions and hits in muon chambers to reconstruct electrons and muons

Hadronic Jets (from outgoing quarks and gluons) and imbalance in transverse momentum (MET) are also determined with the calorimeters
  - MET is indication of particles that do not interact with our detector
GMSB $\chi\chi \rightarrow \gamma\gamma + \text{MET}$

- $L = 2.6 \text{ fb}^{-1}$
- Selection: $2\gamma$ ($E_T > 13$ GeV)
  - MET significance $> 3$
  - $H_T > 200$ GeV, $\Delta \phi(\gamma, \gamma) < \pi - 0.15$
- SM backgrounds: electroweak with real MET (67%),
  QCD with fake MET (17%), non-collision
- Expect $1.2 \pm 0.4$ SM and observe none
- Set limits on lightest neutralino and its lifetime

![Graphs and diagrams showing data and cross section limits for GMSB events.](image-url)
GMSB $\chi\chi \rightarrow \gamma\gamma + \text{MET}$ (2)

**Expected exclusion region with $\gamma\gamma + \not{E}_T$ and 2.6 fb$^{-1}$**

**Observed exclusion region**

**Observed exclusion region with $\gamma + \not{E}_T + \text{Jet}$ and 570 pb$^{-1}$**

**ALEPH exclusion region**

**Cosmology favored region with $0.5 < M_{\tilde{g}} < 1.5 \text{ keV/c}^2$**

**GMSB $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{\chi}_1^0$**

$M_m = 2\Lambda$, $\tan(\beta) = 15$

$N_m = 1$, $\mu > 0$
Long-lived neutralinos

- \( L = 570 \, \text{pb}^{-1} \)
- Looking for neutralino to gamma+gravitino
- The photon is “delayed” since it is originated from the decay of the neutralino
- **Signature:** photon + jet + MET
- Investigated GMSB signal
  - \( M_{\text{mess}} = 2 \) Lambda, \( \tan\beta = 15 \), \( \mu > 0 \) \( N_{\text{mess}} = 1 \)
- **Backgrounds:**
  - Collision: \( \gamma + \text{jet+fake-MET, di-jet + fake-MET, } W \rightarrow e \nu \)
  - Non-collision: cosmic rays and beam effects
- **Preselection:**
  - Photon \( \text{ET} > 30 \), met \( \text{ET} > 30 \), jet \( \text{ET} > 30 \, \text{GeV} \)
  - Geometric separation of muon hits and gamma (cosmic reduction)
  - Delayed signal 2 ns – 10 ns
  - Selection optimized for neutralino mass of 100 GeV/c\(^2\) and lifetime of 5 ns
- **Optimization of final cuts**
  - MET>40, JET_\text{ET}>35, \( \Delta\phi(\text{Jet-met}) > 1 \) rad, 2 ns <\( t < 10 \) ns.
  - \( m(\text{neutralino}) > 101 \, \text{GeV} \) for lifetime of 5 ns.
- **References**
  - PRL 99, 121801 (2007)
t’ D0 result from Verzocchi’s wine+cheese

**t’ Search (I)**

- **Use 4.3 fb⁻¹**
- **Similar selection to top cross section measurement**
- **Use Hₜ and mₜ to build 2D discriminant**
- **Slight excess observed in data**
- **Set lower limit on t’ mass**
t’ D0 result from Verzocchi’s wine+cheese (2)

**t’ Search (II)**

- **Expected limit** $m_{t'} > 330$ GeV
- **Observed limit** $m_{t'} > 296$ GeV @ 95% C.L.

---

**Graph Details**

- **D0 Run II Preliminary 4.3 fb⁻¹**
- **Cross section [pb]**
- **t’ mass [GeV]**

- **Theory cross section**
- **Observed 95% CL upper limits**
- **Expected 95% CL upper limits**
- **Expected 95% CL limits ±1σ**
- **Expected 95% CL limits ±2σ**
R-parity violating sneutrino → eµ or eτ or µτ

- L = 1 fb⁻¹
- Selection: eµ, eτ, µτ
  (e,µ:pT>20, τ:pT>20 GeV/c)
- SM backgrounds: Z→ττ, diboson, tt, W/Z+ fakes
- Control regions: 50-110 GeV/c²
- Benchmark Signal regions: M_eµ>500, M_eτ>310, M_µτ>280 GeV/c²
- Observation consistent with SM expectation
- Set limits on RPV sneutrinos

<table>
<thead>
<tr>
<th>Channel</th>
<th>Mass cut (GeV/c²)</th>
<th>N_{exp}</th>
<th>N_{obs}</th>
</tr>
</thead>
<tbody>
<tr>
<td>eµ</td>
<td>500</td>
<td>0.1 ± 0.1</td>
<td>0</td>
</tr>
<tr>
<td>eτ</td>
<td>310</td>
<td>1.4 ± 0.3</td>
<td>2</td>
</tr>
<tr>
<td>µτ</td>
<td>280</td>
<td>1.0 ± 0.3</td>
<td>2</td>
</tr>
</tbody>
</table>
Large extra dimensions
Extra dimensions ($\gamma$+MET)

- $L = 2 \text{ fb}^{-1}$
- Signal: $G+\gamma \rightarrow \text{MET} + \gamma$
- Selection: $E_\gamma > 90 \text{ GeV}$  
  $\text{MET} > 50 \text{ GeV}$  
  No jets/tracks above 15(10) GeV
- SM backgrounds: $Z+\gamma \rightarrow \nu\nu\gamma(54\%)$,  
  cosmics (20%), $W+\gamma$ (10\%), $W \rightarrow \text{fake } \gamma$  
  (6\%), $\gamma\gamma$ (5\%)
- Expect $46.7 \pm 3$ SM and observe 40
- Set limits on number and mass-scale of Large extra dimensions (combined with the jet+MET analysis)

D0 Large extra dimensions

- 2.7 fb\(^{-1}\)
- Photon > 90 GeV
- MET > 70 GeV
- Jet veto

\[ q \rightarrow G_{KK} \]

\[ \bar{q} \rightarrow \gamma \]

\[ [\text{Graph} \text{diagram}] \]
CDF chargino/neutralino and squark/gluino
Gluino-Squark

- \( L = 2 \text{ fb}^{-1} \)
- Signature: Jets + MET
- Selection:
  - High MET (for QCD reduction)
  - lepton-veto (for top and boson reduction)
  - small jet-met angle (for QCD reduction)
  - separate optimized cuts for 3 analyses
- Backgrounds: QCD multijets, Z+jets, W+jets, top, diboson
  - (all MC, for QCD it is normalized to data at low-met)

95% CL: Mass of gluino > 392 GeV/c²

<table>
<thead>
<tr>
<th>Analysis</th>
<th>HT cut (GeV)</th>
<th>MET cut (GeV)</th>
<th>Jet Et (GeV)</th>
<th>Bckg.</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dijet</td>
<td>330</td>
<td>180</td>
<td>165,100</td>
<td>16 ± 5</td>
<td>18</td>
</tr>
<tr>
<td>Trijet</td>
<td>330</td>
<td>120</td>
<td>140,100,25</td>
<td>37± 12</td>
<td>38</td>
</tr>
<tr>
<td>4-jet</td>
<td>280</td>
<td>90</td>
<td>95,55,55,25</td>
<td>48 ± 17</td>
<td>45</td>
</tr>
</tbody>
</table>

arXiv:0811.2512 [hep-ex]
Result and limits

Our counting result is consistent with the Standard Model

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Backg.</th>
<th>Signal</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trilepton</td>
<td>1.5 ± 0.2</td>
<td>7.4 ± 0.7</td>
<td>1</td>
</tr>
<tr>
<td>Dilepton+Track</td>
<td>9.4 ± 1.4</td>
<td>11.2 ± 1.1</td>
<td>6</td>
</tr>
</tbody>
</table>

\[
(m_0=60 \text{ GeV}, \tan \beta=3, A_0=0, \mu>0)
\]

\[
M(\chi_1^\pm) > 164 \text{ GeV/c}^2 \text{ at 95\% CL}
\]

(expected 155)

\[
m_0=60 \text{ GeV},
m_{1/2}=190 \text{ GeV},
\tan \beta=3, A_0=0, \mu>0
\]
Older analyses
Search for high-mass $X \rightarrow ZZ$ resonance

- $L = 2.5-2.9 \text{ fb}^{-1}$
- Signature: $X \rightarrow ZZ \rightarrow llll$ or $lljj$, $l=e$ or $\mu$
- Selection: $ee(\mu\mu)$ of 5,20 (2 or 10, 20) GeV/$c$
- SM backgrounds: $W+\text{jets, Z+jets, QCD, diboson}$
- Signal region: based on the reconstructed $Z$-mass probability and $M_X > 300$ GeV/$c^2$
- Observation consistent with expectation
jet+jet+MET (CDF leptoquarks)

- # 2 Jets with ET > 30 GeV
- # No 3rd Jet with ET > 15 GeV
- # Scalar Jet HT > 125 GeV
- # Event Missing ET > 80 GeV
- Main backgrounds: Z→vv, W→lν

![Graphs showing Missing E_T for Low and High Kinematic Regions](image)

<table>
<thead>
<tr>
<th>Leptoquark Generation</th>
<th>Lower mass limit (GeV/c^2)</th>
<th>Higher cross-section limit (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st and 2nd</td>
<td>190</td>
<td>0.29</td>
</tr>
<tr>
<td>3rd</td>
<td>178</td>
<td>0.442</td>
</tr>
</tbody>
</table>
Sbottom to c + neutralino

Search for Direct Stop Production

- MSSM scenario with conserved $R_p$ with $\text{BR}(\tilde{t}_1 \to c \tilde{\chi}_1^0) = 100\%$.
- Final state with 2 c-jets and MET.
- NN-based flavor separator algorithm to enhance the c-tagging efficiency.
- QCD and mistags from DATA, other bkg from MC simulation.
- Sensitivity optimized with NN-based selection.
- No hint for SUSY, 95% CL limit:
  - $M_{\tilde{t}}>180$ GeV/$c^2$ (with $M_{\tilde{\chi}} \sim 90$ GeV/$c^2$)

Systematic uncertainties:
- 20% on bkg and 25% on signal dominated by the uncertainty on mistag rate and flavor separator algorithm.

Gianluca De Lorenzo, IFAE Barcelona
Gluino-mediated sbottom

- **L = 2.5 fb⁻¹**
- **Selection:** ≥2 jets (25,35) GeV
  - MET > 70 GeV
  - either 1 b-jet or ≥2 b-jets
- **Study of QCD and EWK control regions**
- **Two signal hypotheses used for optimization:**
  - **A:** Large Δm: M(gluino) = 335 GeV/c², M(sbottom) = 260 GeV/c², M(neutralino) = 60 GeV/c²
  - **B:** Small Δm: M(gluino) = 335 GeV/c², M(sbottom) = 315 GeV/c², M(neutralino) = 60 GeV/c²
- **SM backgrounds:** QCD (light and heavy flavor), top pair, W/Z+jets
- **For two-b-jet analysis:** For optimization A
  - (B) Expect 4.5 ± 1.4 (2.3 ± 0.8) SM events and observe 5 (2)
- **M(gluino) > 350 GeV at 95% CL**

---

**CDF Run II Preliminary**

- **Observed 95% CL limit**
- **Expected 95% CL limit**
- **g → bb (100% BR)**
- **M(χ) = 60 GeV/c²**
- **M(Ś) = 500 GeV/c²**

**CDF Run I excluded**

- **Run II 156 pb⁻¹**
- **DØ Run II 310 pb⁻¹**
- **Sbottom Pair Production Excluded Limit**

**Cross Section [pb]**

- **pP → ĝg at √s = 1.96 GeV**
- **Prospino NLO (CTEQ6M)**
- **M(Ś) = 500 GeV/c², M(χ) = 60 GeV/c²**
Search for high-mass $X \rightarrow ee$ or $\mu\mu$ resonance

- $L = 2.3-2.5$ fb$^{-1}$
- Possible signal investigated
  - Spin 0 (RPV sneutrino)
  - Spin 1 ($Z'$)
  - Spin 2 (Randall-Sundrum Graviton)
- Selection: 2 $\mu$ (2e), opposite charge, $p_T > 30$ (25) GeV/c
- Backgrounds Drell-Yan, diboson, tt, fakes

- $ee \rightarrow$ Observation consistent with expectation with the exception of the 241 GeV/c$^2$ window
  - “local” 3.8 $\sigma$
  - Probability to see that from 150 GeV - 1 TeV is 0.6% (2.5 $\sigma$)
- $\mu\mu \rightarrow$ Observation consistent with expectation

- Set limits for different bosons:
  - $M(Z'_{SM}) > 1030$ (966) GeV/c$^2$ using $\mu\mu$ (ee)
  - $M($Graviton$) > 921$ (850) GeV/c$^2$ for $k = 0.1M_{Pl}$ using $\mu\mu$ (ee)
  - $M($sneutrino$) > 866$ (397) GeV/c$^2$ for $\lambda BR = 0.01(0.0001)$

Phys. Rev. Lett. 102, 031801 (2009)

arXiv:0811.0053v1 [hep-ex]
Search for high-mass $X \rightarrow \mu\mu$ resonance

- $L = 2.3 \text{ fb}^{-1}$
- Possible signal investigated:
  - Spin 0 (RPV sneutrino)
  - Spin 1 ($Z'$)
  - Spin 2 (Randall-Sundrum Graviton)
- Selection: 2 $\mu$, opposite charge, $p_{\tau} > 30 \text{ GeV/c}$
- Backgrounds Drell-Yan, diboson, tt, fakes
- Strategy: Normalize dimuon background template to the data from 70-100 GeV/c$^2$ and look for resonance at the high mass tail ($> 100 \text{ GeV/c}^2$)
- Observation consistent with expectation
- Set limits for different bosons:
  - $M(\text{sneutrino}) > 866(397) \text{ GeV/c}^2$ for $\lambda BR = 0.01(0.0001)$
  - $M(Z') > 1 \text{ TeV/c}^2$
  - $M(\text{Graviton}) > 921(293) \text{ GeV/c}^2$ for $k = 0.1M_{\text{Pl}}(0.01M_{\text{Pl}})$
Search for high-mass $X \rightarrow ee$ resonance

- $L = 2 \text{ fb}^{-1}$
- Possible signal investigated
  - Spin 1 ($Z'$)
  - Spin 2 (Randall-Sundrum Graviton)
- Selection: 2 e, opposite charge, $p_T > 25$ GeV/c
- Backgrounds Drell-Yan, diboson, tt, fakes
- Scan procedure: Use likelihood ratio $L_b/L_{s+b}$ and scan the dielectron mass spectrum from 150 GeV/c$^2$ to 1 TeV/c$^2$
- Observation consistent with expectation with the exception of the 241 GeV/c$^2$ window
  - “local” 3.8 $\sigma$
  - Probability to see that from 150 GeV - 1 TeV is 0.6% (2.5 $\sigma$)
- Set limits for different bosons:
  - $M(Z') > 966$ GeV/c$^2$
  - $M(\text{Graviton}) > 850$ GeV/c$^2$ for $k=0.1 M_{Pl}(0.01 M_{Pl})$
Photon+jet+MET+b-jet

- $L = 2 \text{ fb}^{-1}$
  
  $$\tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow (\tilde{b}t)(\gamma \tilde{\chi}_1^0) \rightarrow (bc\tilde{\chi}_1^0)(\gamma \tilde{\chi}_1^0) \rightarrow (\gamma bc E_T^\gamma)$$

- Selection: 2 jets > 15 GeV (at least one b-tagged), 1 photon > 25 GeV, jet-jet and jet-photon separation of $\Delta R > 0.4$

- Backgrounds: multijets+(real/fake) photon+fake MET
  - b-tag can be real or fake
  - Estimate fake-$\gamma$ from shower shapes
  - Estimate real-$\gamma$/real-b from MC
  - Estimate real-$\gamma$/fake-b with mistag matrix

- Observation consistent with expectation
  - Expect $637 \pm 139$ from SM and observe 617
Long-lived top as CHAMP

- \( L = 1.0 \text{ fb}^{-1} \)

- Slow particle signature: slowly-moving highly-ionizing highly-penetrating particle
  - Will look like muon with possible calorimetry energy deposition

- Goal: Measure Time of Flight mass of tracks

- Shape of TOF mass determined by beta-resolution, measured with \( W \rightarrow \text{ev} \)

- Backgrounds: Cosmics, multiple interactions

<table>
<thead>
<tr>
<th>Stop Mass (GeV/c^2)</th>
<th>Bckg.</th>
<th>DATA</th>
<th>( \sigma_{95%} ) (fb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>4.7±0.3</td>
<td>4</td>
<td>160</td>
</tr>
<tr>
<td>120</td>
<td>1.9±0.2</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td>260</td>
<td>(2.6±0.5) \times 10^{-2}</td>
<td>0</td>
<td>50</td>
</tr>
</tbody>
</table>

CDF Run II Preliminary (1.0 fb^-1)

\[ \int L \, dt = 1.03 \text{ fb}^{-1} \]

Stable stop mass > 250 GeV/c^2 at 95% CL
R parity violation with multileptons

![Graphs showing cross section vs. mass for CDF Run II Preliminary data with mass limits for SUSY particles.](image)

**PRL 98, 131804 (2007)**

- **L** = 346 pb⁻¹
- Search for anomalous production of 3 or ≥ 4 leptons
- Both electrons and muons are used

<table>
<thead>
<tr>
<th>SUSY Scenario</th>
<th>Expected (GeV/c²)</th>
<th>Observed (GeV/c²)</th>
<th>Expected (GeV/c²)</th>
<th>Observed (GeV/c²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M⁻χ⁻¹</td>
<td>105.0</td>
<td>101.5</td>
<td>191.9</td>
<td>185.3</td>
</tr>
<tr>
<td>M⁺χ⁻¹</td>
<td>101.1</td>
<td>97.7</td>
<td>192.2</td>
<td>185.6</td>
</tr>
<tr>
<td>M⁻χ⁻¹</td>
<td>107.7</td>
<td>110.4</td>
<td>197.5</td>
<td>202.7</td>
</tr>
<tr>
<td>M⁺χ⁻¹</td>
<td>102.7</td>
<td>106.3</td>
<td>195.3</td>
<td>201.9</td>
</tr>
</tbody>
</table>
RPV stop to tau + b

- L = 322 pb⁻¹
- Process: two stops produced, each of which decay to tau + b with a BR~β
  - Selection for one hadronic and one leptonic tau
- Signature: lepton + narrow jet + 2 jets
- SM Backgrounds: QCD (bb, γ+jet) and W/Z+jets
- Selection:
  - Electron or muon with p_T > 10 GeV/c
  - Hadronic tau with p_T > 15 GeV/c
  - Conversion, cosmic removal and Z → τ τ vetos
  - Signal region (blind) N_jets >2 and M_T(ℓ, MET)<35
- Expected ~2±0.5 e+τ_h and observed 1
- Expected ~1±0.5 μ+τ_h and observed 1
- For β=1, m_stop >151 GeV/c² at 95% CL

CDF Run II Preliminary (322 pb⁻¹)

σ_NLO (pp → τ̄_τ̄_1) ± √σ_{PDF}² + σ_{scale}²

95% C.L. upper limit:

- Observed
- Expected (±σ)

m > 155 GeV/c²

Stop-sbottom

- \( L = 295 \text{ pb}^{-1} \)
- Expected \( \sigma \) of 50 pb to 0.25 pb for stop and sbottom masses from 80 to 200 GeV/c²
- Signature: c+cbar+MET and b+bbar+MET
- Three mass ranges for each of the sbottom and stop analyses
- Backgrounds:
  - QCD multijet (from data, normalized to low-MET and MET//jet regions)
  - W/Z+jet, single top, ttbar, diboson.

<table>
<thead>
<tr>
<th></th>
<th>( M_{\text{stop}} )</th>
<th>( M_{\text{stop}} )</th>
<th>( M_{\text{stop}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;100</td>
<td>100-120</td>
<td>&gt;120</td>
</tr>
<tr>
<td>SM</td>
<td>137±1</td>
<td>95 ± 11</td>
<td>43 ± 5</td>
</tr>
<tr>
<td></td>
<td>( M_{\text{sbottom}} )</td>
<td>( M_{\text{sbottom}} )</td>
<td>( M_{\text{sbottom}} )</td>
</tr>
<tr>
<td></td>
<td>&lt;140</td>
<td>140-180</td>
<td>&gt;180</td>
</tr>
<tr>
<td>SM</td>
<td>55 ± 7</td>
<td>18 ± 2</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+2.2/-0.7</td>
</tr>
<tr>
<td>DATA</td>
<td>60</td>
<td>18</td>
<td>3</td>
</tr>
</tbody>
</table>

Selection:
- Charged particle and EM fraction cut (reduces cosmics, beam-halos, fake jets, wrong PV selection)
- MET>50 GeV, no additional jets, no collinear jet and met and jets not collinear or back-to-back (for QCD reduction)
- Lepton veto and high jet track multiplicity (for W/Z+jets reduction)
- HF tagger (efficiency 40% and 17% for b and c – 1% and 5% mistag)

After cuts the highest source of background is
Mistag and HF multi-jet
- the latter goes to zero for the high mass region of search
Extra material
Graviton Branching Ratios

Same for all KK modes

\[ M_H = 200 \text{ GeV} \]
Feeling about the SM cross-sections

- But generic production is not enough:

- We care about the branching ratios to leptons
  - \(\approx 11\% / \text{flavor for } W\)
  - \(\approx 3.5\% / \text{flavor for } Z\)

- We care about the probability for jets to be mis-reconstructed as leptons
  - Depends on the jet and lepton identification requirements
    - \(10^{-2} - 10^{-4}\)

- And we care about the trigger and reconstruction efficiency and detector acceptance
Why chargino-neutralino, why trileptons?

- The non-excluded chargino-neutralino production cross-section at the Tevatron is of the order of 0.1-1 pb, depending on the SUSY parameters

![Graph showing production cross-section vs. mg (GeV)](attachment)

- The leptonic decays of the chargino and the next-to-lightest neutralino give **3 leptons and MET**, a signature with low SM backgrounds.

- For these reasons, the trileptons are **the golden channel for the discovery of SUSY at the Tevatron**
R-parity violation

- R-parity violating part of Lagrangian

\[ L_{RPV} = \frac{1}{2} \varepsilon_{\alpha\beta} \lambda_{ijk} L_i^{\alpha} L_j^{b} E_k + \varepsilon_{\alpha\beta} \tilde{\lambda}_{ijk} L_i^{\alpha} Q_j^{b} D_k + \]

\[ + \frac{1}{2} \varepsilon_{\alpha\beta\gamma} \lambda^{\prime\prime}_{ijk} U_i^{\alpha} D_j^{b} D_k^{\gamma} + \varepsilon_{\alpha\beta} m_i L_i^{\alpha} H_u^{b} \]

- $\mu LH \rightarrow$ neutrino masses
- LLE and LQD $\rightarrow$ lepton number violation
- UDD $\rightarrow$ baryon number violation
- We set limits on the couplings $\lambda, \lambda'$
The free parameters are

- $m_0$, the common sfermion mass
- $M_{1/2}$, the common gaugino mass
- $\tan\beta$, the ratio of higgs vacuum expectation values
- $A$, the trilinear sfermion-sfermion-higgs coupling
- Sign of $\mu$, the higgs parameter scale
Checking one SUSY benchmark point

- This is point $m_0=60 \text{ GeV}/c^2$, $m_{1/2}=190 \text{ GeV}/c^2$, $\tan\beta=3$, $A_0=0$, $\mu>0$

- Spectrum created with Isajet 7.79

- The decay to leptons is really good and our acceptance even better
  - Neutralino goes 30% to selectron, 30% to smuon, 40% to stau
  - Chargino goes 2% to electron, 2% to muon, 2% to tau, 92% to stau

- Cross section (prospino) equals to 0.47 pb.

- Masses:
  - Lightest chargino $\sim 122 \text{ GeV}/c^2$
  - Next to-lightest chargino $\sim 325 \text{ GeV}/c^2$
  - Lightest neutralino $\sim 67 \text{ GeV}/c^2$
  - Next-to-lightest chargino $\sim 125 \text{ GeV}/c^2$
  - Lightest higgsion $\sim 100 \text{ GeV}/c^2$
  - Heavy higgsinos $\sim 350 \text{ GeV}/c^2$
Chargino – Neutralino to Trileptons

Chargino-Neutralino production and decay to trileptons is a golden SUSY signature

- Very low SM backgrounds, cross sections of the order of 0.1-1 pb have not been excluded yet

Decays through W/Z favorable for heavy sleptons, but BR to leptons low

Decays through sleptons guarantee final leptons, but also preference to $\tilde{\tau} \rightarrow \tau$

- **Signature of interest:** *Three leptons and Missing Transverse Energy* (MET) due undetected neutralinos (LSP in mSUGRA with R-parity conservation) and neutrinos
Squark-Gluino production and decay

- The dominant squark-gluino production process depends on their mass ($\sigma \sim 0.1$-0.2 pb for our sensitivity region)

If $M_{\tilde{q}} < M_{\tilde{g}}$

- Result: 2 jets and MET

If $M_{\tilde{q}} > M_{\tilde{g}}$

- Result: 4 jets and MET

If $M_{\tilde{q}} \approx M_{\tilde{g}}$ then additional contribution:

- Result: 3 jets and MET

- Although the production is strong, the analyses are challenging due to QCD-multijet and W/Z+jet backgrounds

- Solution: break-down analyses in jet-multiplicity bins and optimize separately (using MET and HT, Sum of jet $E_T$)
Supersymmetry breaking and spectrum

“Minor detail”: We haven’t discovered new particles with same masses as our known SM particles and only a spin difference.

So if SUSY is a symmetry of nature, it has to be broken at a higher energy-scale and the effects are mediated to the electroweak scale.

In Minimal SUSY (MSSM), supersymmetry is broken by introduction of extra Lagrangian terms
  – Soft SUSY Breaking

Minimal Supergravity (mSUGRA) is MSSM with some extra boundary conditions and assumptions
  – SUSY breaking is mediated by gravity
  – LSP is the Neutralino
  – Only 4 parameters and a sign ($m_0$, $m_{1/2}$, $\tan\beta$, $A$, $\mu$)

Alternatively, in Gauge Mediated SUSY Breaking (GMSB), SUSY breaking is mediated by gauge fields
  – LSP is the Gravitino
Staus are expected to be the lightest sleptons

- They will decay to one or three charged hadrons resulting to one or three tracks
- Or, they will decay to soft leptons

For this reason, we include isolated tracks to reconstruct some of the “hadronic” taus

\[ p_T \text{ of leptons can be really low (we consider momenta } > 5 \text{ GeV/c) } \]
Current trilepton analysis improvements

- We are in the process of extending/improving the chargino-neutralino analysis (in addition to adding more data, currently 4 fb\(^{-1}\) in total, and new triggers)

- We expand geometrically
  - We include forward (\(|\eta|>1\)) regions of the detector

- We expand kinematically
  - Low-\(p_T\) and low-\(M_{\tau\tau}\)

- We include new objects
  - tau leptons

- Our goal is the completion of the most sensitive CDF analysis
  - For the greatest discovery potential
  - For the best limits settings
  - For setting benchmarks for the current LHC experiments
Increase coverage for muons and electrons

- We will use the full CDF detector, including the forward calorimeters and muon systems.
- The forward objects roughly double (triple) our dilepton (trilepton) acceptance.
Lower lepton $p_T$ and dilepton mass

- Lowest $p_T$ value for most objects will be 5 GeV/c and lowest dilepton mass will be 10.5 GeV/$c^2$. Also looser cuts for low-$p_T$ leptons will be used.

- **Motivation:** the signal is most probably there !!
  - Due to cascade SUSY decays and the preferable production of staus that decay to taus that decay to soft leptons.

- This way we fully utilize the low-$p_T$ dilepton triggers.

- **Extra backgrounds: Heavy-flavor.** We have developed and tested a method that estimates the HF with data.

**Example: 1 fb$^{-1}$ dimuons**

Inclusion of tau leptons

- For many SUSY scenarios and parameters the staus are the lightest sleptons
  - Especially for high $\tan\beta$

- As a result, we expect many tau final states

- We catch the leptonic decays of taus through the soft leptons (>5 GeV/c)

- We want to catch the hadronic decays of taus, by using tau objects
  - Initially for $\ell\ell\tau$, eventually for $\tau\tau X$ decays

- We define a tau using 1 or 3 tracks (for 1 or 3 prong decays) isolated from extra hadronic activity

- For the $[m_0=60\text{ GeV}, m_{1/2}=190\text{ GeV}, \tan\beta=3, A_0=0, \mu>0]$ benchmark, our sensitivity to third taus is better than that of third electrons!
Event Display (1)
Event display (2)

- $e^-$ $E_T = 20$ GeV
- Track $P_T = 5.8$ GeV/
- $\mu^-$ $P_T = 17$ GeV/
- MET = 20.4 GeV

- Track $P_T = 5.8$ GeV/
- MET = 20.4 GeV
- $e^-$ $E_T = 20$ GeV
Hadronic Tau reconstruction

- $|\eta| < 1$
- $E > 20$ GeV
- $M < 1.8$ GeV/$c^2$
- $N_{\text{tracks (inner cone)}} = 1$ or $3$
- $N_{\text{tracks (between inner and outer cone)}} = 0$
- $N_{\text{towers}} \leq 6$
- good tracking for seed track
- $d0$ cut on seed track
- track-EMcalorimeter matching with seed track