SUSY searches at the Tevatron

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For the CDF and D0 collaborations
Supersymmetry

- Theory that predicts a boson for any SM fermion and vice-versa
  - The superpartners differ only in their spin

- Removes fine tuning and offers ultra-violet completeness
  - Large radiative corrections of superpartners cancel each-other

- Possibility of force unification
  - Not exactly possible with SM

- Cold dark matter candidate
  - If the lightest supersymmetric particle (LSP) is stable

- Connections to superstrings
  - Incorporation of gravity

- Possibility of radiative Electroweak symmetry breaking
  - As an alternative to spontaneous breaking
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
Particles we (think we) look for

- There are scalar leptons (sleptons) and quarks (squarks)
  \[ l, \nu, q \rightarrow \tilde{l}, \tilde{\nu}, \tilde{q} \]

- There are fermionic gluons (gluinos) and fermionic gauge bosons and Higgses that mix to give charginos and neutralinos
  \[ g \rightarrow \tilde{g} \quad W, Z, \gamma, \text{higgs sector} \rightarrow \chi_1^{0}, \chi_1^{\pm} \]

- We present today direct searches for chargino-neutralino, squark, gluino, stop/sbottom production

- Of course, we may discover something completely unanticipated in the process!

Cartoons by Roz Chast
The Tevatron and its collider experiments

- Recorded luminosity /experiment $\sim 3 \text{ fb}^{-1}$
- Presented in this talk: up to $2 \text{ fb}^{-1}$
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 and neutrinos
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

$p_T$ of leptons can be really low (we consider momenta $> 5$ GeV/c)
Chargino-Neutralino

- $\mathcal{L} = 2.0 \text{ fb}^{-1}$
- **Signature:** (3 leptons or 2 leptons+track) +MET
- **Selection (signal region):**
  - $p_T (15,10/5,5)$ GeV/c
  - MET>20 GeV (DY and QCD rejection)
  - $N_{\text{jets}} \leq 1$ and $H_T < 80$ (top rejection)
  - Z-mass veto (DY rejection)
  - Dilepton Mass above 20 GeV/c$^2$ (QCD and resonance rejection)
- **Trilepton backgrounds:**
  - DY+fake, Z+$\gamma$, diboson

**Control regions in MET vs $M_{\ell\ell}$ phase-space**
- Both dilepton and trilepton control regions show excellent agreement between SM backgrounds and observation
Chargino-Neutralino

- Signal region is investigated only after validating backgrounds in control regions (a blind analysis)
- Good agreement with SM background
- Benchmark SUSY: $m_0 = 60$, $m_{1/2} = 190$, $\tan \beta = 3$

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

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Backg.</th>
<th>Signal</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trilepton</td>
<td>0.9 ± 0.1</td>
<td>4.5 ± 0.6</td>
<td>1</td>
</tr>
<tr>
<td>Dilepton+Track</td>
<td>6.9 ± 0.9</td>
<td>5.5 ± 1.1</td>
<td>6</td>
</tr>
</tbody>
</table>

First mSUGRA chargino-neutralino mass limit at the Tevatron

$$M(\chi_1^\pm) > 140 \text{ GeV/c}^2 \text{ at } 95\% \text{ CL}$$
Chargino-Neutralino to $eeX$

- $\mathcal{L} = 0.6 \text{ fb}^{-1}$
- **Signature:** $(ee+\text{track}) + \text{MET}$
- **Selection (signal region):**
  - 2 electrons with $p_T > 8,12$ GeV/c
  - Third lepton or Isolated track with $p_T > 4$ GeV/c
  - MET$>22$ GeV (DY and QCD rejection)
  - $H_T < 80$ GeV (top rejection)
  - $Z$-mass veto (DY rejection)
  - Dilepton Mass above $18$ GeV/c$^2$ (QCD and resonance rejection)

- **Backgrounds:**
  - DY+fake, diboson, QCD-multijet

**DØ Run II Preliminary, $\mathcal{L} = 0.6 \text{ fb}^{-1}$**

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Backg.</th>
<th>Signal</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ee+\ell$</td>
<td>$1.0 \pm 0.3$</td>
<td>$0.5 - 0.2$</td>
<td>$0$</td>
</tr>
</tbody>
</table>

This result is combined with the other DØ analyses.
Chargino-Neutralino DØ combination

- The ee+track results are combined with other tri-object analyses of DØ

- Results are interpreted in several models
  - an mSUGRA inspired model with no-slepton mixing
  - A large-m₀ model (suppressed decays to sleptons)
  - A heavy-squarks model (suppressed t-channel production)

### Table

<table>
<thead>
<tr>
<th>Analysis</th>
<th>( \mathcal{L} ) (fb)</th>
<th>Backg.</th>
<th>Signal</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee+(\ell)</td>
<td>0.6</td>
<td>1.0 ± 0.3</td>
<td>0.5 – 0.2</td>
<td>0</td>
</tr>
<tr>
<td>(\mu\mu+\ell)</td>
<td>1</td>
<td>0.3(^+0.7)(^{-0.03})</td>
<td>0.5 – 2.5</td>
<td>2</td>
</tr>
<tr>
<td>e(\mu+\ell)</td>
<td>1</td>
<td>0.9(^+0.4)(^{-0.1})</td>
<td>1 – 4</td>
<td>0</td>
</tr>
<tr>
<td>ee+(\ell)</td>
<td>1.1</td>
<td>0.8 ± 0.7</td>
<td>1.7 – 4.7</td>
<td>0</td>
</tr>
<tr>
<td>(\mu^+\mu^\pm)</td>
<td>0.9</td>
<td>1.1 ± 0.4</td>
<td>0.6 – 3.7</td>
<td>1</td>
</tr>
</tbody>
</table>

### Diagram

- DØ Run II Preliminary, 0.9-1.7 fb\(^{-1}\)
- \(\tau_1\tau_2\) \(\times\) BR(3) (pb)
- \(\tan\beta=3, \mu>0, \) no slepton mixing
- Observed Limit
- Expected Limit
- LEP
- 3l-max
- large-m₀
- heavy-squarks

March 10, 2008 John Strologas, XLIII Rencontres de Moriond - QCD
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 $M_q < M_{\tilde{g}}$

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

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

Result: 2 jets and MET

Result: 4 jets and MET

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 $E_T$)
Gluino-Squark

- \( \mathcal{L} = 2.1 \text{ fb}^{-1} \)
- Signature: Jets + MET
- QCD multijet background
  - estimated from data extrapolating the low-met distribution
  - Reduced with low \( \Delta \phi(\text{MET-jet}) \) and high MET cuts
- \( W/Z + \) jets, \( \text{ttbar}, \) diboson backgrounds (MC)
  - Reduced with lepton-vetos
- Backgrounds after selection: \( (Z \to \nu \nu) + \) jets, \( (W \to \ell \nu) + \) jets, \( \text{tt} \to \ell + \) jets

(hep-ex/0712.3805, PLB 660, 449 (2008))

<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>325</td>
<td>225</td>
<td>35,35</td>
<td>11 ± 1 +3/-2</td>
<td>11</td>
</tr>
<tr>
<td>Trijet</td>
<td>375</td>
<td>175</td>
<td>35,35,35</td>
<td>11 ± 1 +3/-2</td>
<td>9</td>
</tr>
<tr>
<td>4-jet</td>
<td>400</td>
<td>100</td>
<td>35,35,35,20</td>
<td>18 ± 1 +6/-3</td>
<td>20</td>
</tr>
</tbody>
</table>

March 10, 2008
John Strologas, XLIII Rencontres de Moriond - QCD
Gluino-Squark

- $\mathcal{L} = 2 \text{ fb}^{-1}$
- Signature: Jets + MET
- Selection:
  - MET>70 GeV (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)

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

<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>

March 10, 2008  
John Strologas, XLIII Rencontres de Moriond - QCD
Search for stop and sbottom

- We expect one of the stops and sbottoms to be light
- If \( m_c + m_{LSP} < m_t < m_b + m_W + m_{LSP} \) then the stop will decay to charm through flavor-changing loop processes

Light stop and sbottom production and decay

Other option is that stop does not decay in the detector (CHAMP)
Stops to charm

- $\mathcal{L} = 995 \text{ pb}^{-1}$

- Expected cross sections are 1-15 pb

- Selection
  - Exactly 2 jets (reduction of QCD)
  - Jet pt cuts (20,40 GeV/c) and angular separation of jets (reduces QCD and W+jets)
  - Angle between jets and met (reduction of QCD)
  - Flavor tagging using Neural Network (impact parameter, secondary vertex information)

- Final optimization: $H_T$ and MET

Exclusion: stop mass $<149 \text{ GeV/c}^2$ for neutralino mass of 63 GeV/c$^2$
Long-lived top as CHAMP

- \( \mathcal{L} = 1.0 \text{ fb}^{-1} \)
- 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 2 Preliminary**

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

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

R-parity violating part of Lagrangian

\[ L_{RPV} = \frac{1}{2} \varepsilon_{\alpha \beta} \lambda_{ijk} L^i L^b E_k + \varepsilon_{\alpha \beta} \lambda'_{ijk} L^i Q^b D_k + \]
\[ \frac{1}{2} \varepsilon_{\alpha \beta \gamma} \lambda''_{ijk} U^\alpha D^b D^\gamma_k + \varepsilon_{\alpha \beta} \mu L^\alpha H^b_u \]

- \( \mu L \rightarrow \) neutrino masses
- LLE and LQD \( \rightarrow \) lepton number violation
- UDD \( \rightarrow \) baryon number violation

We set limits on the couplings \( \lambda, \lambda' \)
R-parity violating sneutrinos

- $\mathcal{L} = 1 \text{ fb}^{-1}$
- Assumption: sneutrino is the LSP
- Signature: $e^{+}\mu$ (resonance at the $M_{e\mu}$)
- Backgrounds: $Z/\gamma \rightarrow \tau\tau$, diboson, $t\bar{t}$
  - (W+\gamma, W+jets, QCD negligible)
- Selection:
  - $E_T^{\text{ele}} > 30$, $p_T^{\text{muon}} > 25$
  - $\text{MET} < 15$ (top rejection)
  - No extra leptons (diboson rejection)

<table>
<thead>
<tr>
<th>Process</th>
<th>Number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z/\gamma \rightarrow \tau\tau$</td>
<td>$43 \pm 4$</td>
</tr>
<tr>
<td>$WW$</td>
<td>$14 \pm 2$</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>$1.4 \pm 0.3$</td>
</tr>
<tr>
<td>$WZ$</td>
<td>$1.2 \pm 0.2$</td>
</tr>
<tr>
<td>Total SM</td>
<td>$59 \pm 5$</td>
</tr>
<tr>
<td>DATA</td>
<td>68</td>
</tr>
</tbody>
</table>

hep-ex/0711.3207 (submitted to PRL)
R parity violation with multileptons

**PRL 98, 131804 (2007)**

- **$\mathcal{L} = 346 \text{ pb}^{-1}$**
- Search for anomalous production of 3 or $\geq 4$ leptons
- Both electrons and muons are used

<table>
<thead>
<tr>
<th>SUSY Scenario</th>
<th>Expected $M_{\tilde{\chi}_1^0} (\text{GeV}/c^2)$</th>
<th>Observed $M_{\tilde{\chi}_1^0} (\text{GeV}/c^2)$</th>
<th>Expected $M_{\tilde{\chi}_1^\pm} (\text{GeV}/c^2)$</th>
<th>Observed $M_{\tilde{\chi}_1^\pm} (\text{GeV}/c^2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{121}$ and $\mu &gt; 0$</td>
<td>105.0</td>
<td>101.5</td>
<td>191.9</td>
<td>185.3</td>
</tr>
<tr>
<td>$\lambda_{121}$ and $\mu &lt; 0$</td>
<td>101.1</td>
<td>97.7</td>
<td>192.2</td>
<td>185.6</td>
</tr>
<tr>
<td>$\lambda_{122}$ and $\mu &gt; 0$</td>
<td>107.7</td>
<td>110.4</td>
<td>197.5</td>
<td>202.7</td>
</tr>
<tr>
<td>$\lambda_{122}$ and $\mu &lt; 0$</td>
<td>102.7</td>
<td>106.3</td>
<td>195.3</td>
<td>201.9</td>
</tr>
</tbody>
</table>
Neutralinos to diphotons

- $\mathcal{L} = 1.1 \text{ fb}^{-1}$
- Signature: 2 photons plus MET (GMSB)
- Selection:
  - Photons: $E_T > 25$ GeV, $\text{eta} < 1.1$
  - EM cluster pointing algorithm to the vertex within 2 cm
  - Jet-met separation

Instrumental Backgrounds (fake photons)
- $W\gamma$, $W+$jet, $t\bar{t}$bar, QCD multijet, $Z \rightarrow ee$
- $e\gamma$ sample used for normalizations

Physics backgrounds
- $W\gamma\gamma \rightarrow l\gamma\nu\nu$ and $Z\gamma\gamma \rightarrow \nu\nu\gamma\gamma$ (MC)

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Bckg.</th>
<th>$\Lambda = 75$ TeV</th>
<th>$\Lambda = 90$ TeV</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>MET &gt; 30 GeV</td>
<td>$11 \pm 1$</td>
<td>$28 \pm 4$</td>
<td>$9 \pm 1$</td>
<td>16</td>
</tr>
<tr>
<td>MET &gt; 60 GeV</td>
<td>$1.6 \pm 0.4$</td>
<td>$18 \pm 3$</td>
<td>$6 \pm 1$</td>
<td>3</td>
</tr>
</tbody>
</table>

(hep-ex/0710.3946, PLB 659, 856 (2008))
Summary

- SUSY has not been observed yet
- At Tevatron we work hard trying to either discover it or set stringent limits

Current state of the art:

<table>
<thead>
<tr>
<th>Sparticle</th>
<th>Low mass limit (GeV/c²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chargino (mSUGRA)</td>
<td>~140-150</td>
</tr>
<tr>
<td>NL Neutralino (mSUGRA)</td>
<td>~140-150</td>
</tr>
<tr>
<td>Chargino (GMSB)</td>
<td>~230</td>
</tr>
<tr>
<td>LSP Neutralino (GMSB)</td>
<td>~125</td>
</tr>
<tr>
<td>Chargino mSUGRA, RPV</td>
<td>~200</td>
</tr>
<tr>
<td>Neutralino mSUGRA, RPV</td>
<td>~100</td>
</tr>
<tr>
<td>Squark</td>
<td>~400</td>
</tr>
<tr>
<td>Gluino</td>
<td>~300</td>
</tr>
<tr>
<td>Light stop or RPV stop</td>
<td>~150</td>
</tr>
<tr>
<td>Stop as CHAMP</td>
<td>~250</td>
</tr>
</tbody>
</table>

http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm
http://www-cdf.fnal.gov/physics/exotic/exotic.html
Additional analyses
RPV stop to tau + b

- $\mathcal{L} = 322 \text{ pb}^{-1}$
- Process: two stops produced, each of which decay to tau + b with a BR $\sim \beta$
  - Selection for one hadronic and one leptonic tau
- Signature: lepton + narrow jet + 2 jets
- SM Backgrounds: QCD (bb, $\gamma+$jet) and W/Z+jets
- Selection:
  - Electron or muon with $p_T > 10 \text{ GeV/c}$
  - Hadronic tau with $p_T > 15 \text{ GeV/c}$
  - Conversion, cosmic removal and $Z \rightarrow \tau \tau$ vetos
  - Signal region (blind) $N_{\text{jets}} > 2$ and $M_T(\ell, \text{MET}) < 35$
- Expected $\sim 2 \pm 0.5 \text{ e+}\tau_h$ and observed 1
- Expected $\sim 1 \pm 0.5 \mu+\tau_h$ and observed 1
- For $\beta = 1$, $m_{\text{stop}} > 151 \text{ GeV/c}^2$ at 95% CL

arXiv:0711.3161 (submitted to PRL)
Squark to taus

- $\mathcal{L} = 960 \text{ pb}^{-1}$
- Objects: Jets + MET + hadronic taus
  - Hadronic tau $\rightarrow$ narrow isolated jet with low track multiplicity
  - Three kinds of taus (with or without $\pi^0$)
- Require at least one tau, separated from jets, with $p_T(\text{tau}) > 15$ GeV
  - Neural Networks for tau-jet separation
- Main backgrounds after optimization: ttbar, W+jet
- Expect 1.7 $\pm 0.6/-0.4$ and we observe 2 events (expected $\sigma \sim 0.3$ pb)
Stop dileptons

- \( \mathcal{L} = 400 \text{ pb}^{-1} \)
- Signature: Two isolated leptons, met and jets
- QCD multijet background is estimated from data
  - by reversing the \( \mu \)-isolation or e-likelihood function for \( e\mu \)
  - by investigating SS dimuons for \( \mu\mu \)
- Main backgrounds: QCD, \( Z/\gamma \to \tau \tau \), WW
- \( \mu\mu \) Selection
  - 2 track-isolated muons
  - \( p_T \) (muons) > 6, 8 GeV/c2, MET>20 GeV+
  - \( N_{jets} \geq 1 \) (to reduce \( Z/\gamma \to \mu\mu \) + ISR)
  - High jet-probability
  - \( Z \)-veto
  - top dominates after the above selection
- \( e\mu \) Selection
  - 2 isolated leptons with \( p_T \) (leptons) > 8, 10 GeV/c2
  - MET>15 GeV
  - Lepton-MET and lepton-jet separation
  - \( MT(\mu+\text{MET})>15 \text{ GeV/c2} \), for \( Z \to \tau \tau \) reduction
  - After the above selection, main background is WW and ttbar

<table>
<thead>
<tr>
<th>Channel</th>
<th>QCD</th>
<th>( Z \to \ell\ell )</th>
<th>( t\bar{t} )</th>
<th>Diboson</th>
<th>Total Bckg.</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu\mu )</td>
<td>0.1</td>
<td>2.3</td>
<td>( 2.9 \pm 0.4 \pm 0.1 )</td>
<td>( 1 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

hep-ex/0707.2864, PLB 659, 500 (2008)
Long-lived neutralinos

\( \mathcal{L} = 570 \text{ pb}^{-1} \)

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: \( \gamma + \text{jet} + \text{fake-MET}, \text{di-jet} + \text{fake-MET}, W \to e \nu \)
- Non-collision: cosmic rays and beam effects

**Preselection:**
- photon \( E_T > 30 \), met \( E_T > 30 \) GeV
- Geometric separation of muon hits and gamma (cosmic reduction)
- Delayed signal \( 2 \text{ ns} - 10 \text{ ns} \)
- Selection optimized for neutralino mass of 100 GeV/c² and lifetime of 5 ns

**Optimization of final cuts**
- \( \text{MET} > 40, \text{JET} _{ET} > 35, \Delta \phi (\text{Jet-met}) > 1 \text{ rad}, 2 \text{ ns} < t < 10 \text{ ns} \)
- \( m(\text{neutralino}) > 101 \text{ GeV} \) for lifetime of 5 ns.

**PRL 99, 121801 (2007)**
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/c$^2$
- **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>
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<tr>
<td></td>
<td>&lt;100</td>
<td>100-120</td>
<td>&gt;120</td>
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<tr>
<td>SM</td>
<td>137±16</td>
<td>95 ± 11</td>
<td>43 ± 5</td>
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<td>DATA</td>
<td>151</td>
<td>108</td>
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<td>&lt;140</td>
<td>140-180</td>
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<tr>
<td>SM</td>
<td>55 ± 7</td>
<td>18 ± 2</td>
<td>4.7 +2.2/-0.7</td>
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<td>DATA</td>
<td>60</td>
<td>18</td>
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</tbody>
</table>

**PRD 76, 072010 (2007)**

**Selection:**
- Charged particle and EM fraction cut (reduces cosmics beam-halo, 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

March 10, 2008
John Strologas, XLIII Rencontres de Moriond - QCD
Sbottom

- \( \mathcal{L} = 310 \text{ pb}^{-1} \)

- **Backgrounds:**
  - QCD multijet (estimated by fitting data with \( \text{MET} < 60 \) GeV and extrapolating
  - W/Z+jets, diboson, top

- **Selection:**
  - Charged particle multiplicity (reject fake jets)
  - Azimuthal-angle jet-jet and jet-MET cuts (to reduce QCD)
  - \( \text{MET} > 60 \) and \( \text{jet ET} > 60,20 \) GeV (to reduce QCD)
  - Isolated lepton veto and jet-met not back-to-back (to reduce W/Z)
  - No more than 3 jets (to reduce top)
  - One heavy-flavor tagged jet (30\% efficient for b, 5\% for c)

- After selection, QCD and diboson are negligible.

- Further optimize the MET and jet ET values.

- sbottom mass > 222 GeV at 95\% CL.

**PRL 97, 171806 (2006)**

<table>
<thead>
<tr>
<th>Process</th>
<th>Number of events</th>
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<tbody>
<tr>
<td>( W \rightarrow e/\mu \nu + \text{jets} )</td>
<td>2.7 ± 0.2</td>
</tr>
<tr>
<td>( W \rightarrow \tau \nu + \text{LF jets} )</td>
<td>4.1 ± 0.6</td>
</tr>
<tr>
<td>( Z \rightarrow \nu\nu + \text{jets} )</td>
<td>8.8 ± 0.3</td>
</tr>
<tr>
<td>Diboson</td>
<td>0.9 ± 0.2</td>
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<tr>
<td>( t\bar{t} )</td>
<td>3.8 ± 0.2</td>
</tr>
<tr>
<td><strong>Total Background</strong></td>
<td><strong>22 ± 1</strong></td>
</tr>
<tr>
<td><strong>DATA</strong></td>
<td><strong>22</strong></td>
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### $B_s \rightarrow \mu\mu$ (CDF and D0)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Luminosity</th>
<th>BR($B_s \rightarrow \mu\mu$)</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td>CDF Run 2</td>
<td>1.9 fb$^{-1}$</td>
<td>$&lt;5.8 \times 10^{-8}$ @95% CL</td>
<td>Recent CDF result</td>
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<td>Comb CDF/D0</td>
<td></td>
<td>$&lt;1.5 \times 10^{-7}$ @95% CL</td>
<td>hep-ex/0508058</td>
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<td>CDF Run 2</td>
<td>364 pb$^{-1}$</td>
<td>$&lt;2.0 \times 10^{-7}$ @95% CL</td>
<td>Phys. Rev. Letters 95, 221805 2005</td>
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<tr>
<td>D0 Run 2</td>
<td>300 pb$^{-1}$</td>
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<tr>
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<td>171 pb$^{-1}$</td>
<td>$&lt;7.5 \times 10^{-7}$ @95% CL</td>
<td>Phys. Rev. Letters 93, 032001 2004</td>
</tr>
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</table>

### B_d → μμ (CDF and D0)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Luminosity (fb^{-1})</th>
<th>BR( B_d → μμ ) &lt; ( \text{value} ) @90% CL</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF Run 2</td>
<td>1.9</td>
<td>( 1.5 \times 10^{-8} )</td>
<td>Recent CDF result</td>
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<td>364</td>
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<td>Phys. Rev. Letters 95, 221805 2005</td>
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<td>BaBar</td>
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<td>Phys. Rev. Letters 94, 221803 2005</td>
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<td>Phys. Rev. Letters 93, 032001 2004</td>
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<td>Belle</td>
<td>78</td>
<td>( 1.6 \times 10^{-7} )</td>
<td>Phys. Rev. D RC 68, 111101 2003</td>
</tr>
</tbody>
</table>

How to get SUSY MC signal

Assuming on shell produced SUSY particles, use only \(2 \rightarrow 2\) decays:
- Select a SUSY point (e.g., mSUGRA)
- Get the spectrum (e.g., using SOFTSUSY)
- Get Branching Ratios (e.g., using SDECY)
- Feed spectrum and BR to generator with fragmentation (e.g., PYTHIA)
- Feed PYTHIA generated events to detector simulator (e.g., GEANT)
- Correct using the NLO cross-section (e.g., from PROSPINO)

Assuming the whole \(2 \rightarrow 6\) decays of most processes (e.g., chargino-neutralino), which is more accurate:
- Use the complete \(2 \rightarrow 6\) matrix element (e.g., from MADGRAPH)
- Get the spectrum (e.g., using SOFTSUSY)
- Integrate using proper phase-space to generate events (e.g., using MADEVENT)
- Feed the generated events to program with fragmentation (e.g., PYTHIA)
- Feed PYTHIA generated events to detector simulator (e.g., GEANT)
- Correct using the NLO cross-section (e.g., from PROSPINO)