Searches for the Supersymmetric Partner of the Bottom Quark

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Tsukuba, Japan, 2004
Sbottom Searches

\[ m_{b_{1,2}}^2 = \frac{1}{2} [m_{b_L}^2 + m_{b_R}^2 \pm \sqrt{(m_{b_L}^2 - m_{b_R}^2)^2 + 4m_b^2(A_b - \mu \tan \beta)^2}] \]

Sbottom could be light due to large mass splitting between the eigenstates (large \( \tan \beta \))

Assume:

- \( BR(\tilde{b}_1 \rightarrow b\tilde{\chi}^0_1) = 100\% \)
- R-parity conservation which leads to stable undetectable neutralino

LEP Limits

\( >92 \text{GeV}/c^2 \) for \( \Delta m > 10 \text{GeV}/c^2 \)

\[ m(\tilde{\chi}^0) > 46 \text{GeV}/c^2 \]
Sbottom Quark Production at the Tevatron

Direct Sbottom production: Gluino-pair production:

Large production cross section

Cross Section (pb)

Cross Section (pb)

Mass of the Sbottom (GeV/c^2)

Mass of the Gluino (GeV/c^2)
Sbottom quarks could be pair produced at the Tevatron or in a scenario where the gluino is heavier than the sbottom, through decays of gluinos. Consider here search for second case, it yields a richer signature

\[ \tilde{g}\tilde{g} \rightarrow (bb\tilde{b}_1)(bb\tilde{b}_1) \rightarrow (bb\tilde{\chi}_1^0)(bb\tilde{\chi}_1^0) \]

Assume:

- \( m_{\tilde{g}} > m_{\tilde{b}} > m_{\tilde{\chi}_1^0} \)
- \( m_t + m_{\tilde{\chi}_1^0} > m_{\tilde{b}_1} > m_{\tilde{\chi}_1} \)
- \( BR(\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0) = 100\% \)

Motivation

- Large cross section
- Very distinctive signature
- Accessible at Tevatron
$E_T$ at CDF

$E_T$ caused by particles escaping detection or by detector mis-measurement

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Real $E_T$
- from non-detectable $\nu, \tilde{\chi}_1^0, ...$

Fake $E_T$
- limited detector coverage
- reconstruction
- cosmics
B hadrons fly macroscopic distance: 
\[ \Delta L = c\tau \cdot \beta \gamma \text{ with } c\tau \approx 450 \text{ \(\mu m\)} \]

Can be detected using CDFs Silicon Vertex Detector

b-jets are identified using a secondary vertex tagging algorithm. Tracks with large impact parameter \(d_0\) are selected and a vertex fitting algorithm is used to reconstruct a displaced vertex.

B-tagging Efficiency per Jet
Search Strategy

Event kinematics depend on the mass differences:
\[ \Delta M = m(\text{gluino}) - m(\text{sbottom}) \] / \[ \Delta m = m(\text{sbottom}) - m(\text{neutralino}) \]

Assume fixed neutralino mass (60 GeV/c^2), \( \Delta m \) is large and consider different gluino/sbottom mass scenarios:

- \( \Delta M \) - large → b from gluino energetic
  - \( \chi \) boosted → moderate \( \pT \)
  - 3rd b-jet energetic

- \( \Delta M \) - small → b from sbottom decay energetic
  - \( \chi \) not boosted → larger \( \pT \)
  - 3rd b-jet non-energetic

Perform separate two analyses: Excl. single tagged / Inclusive double tagged
# Backgrounds

<table>
<thead>
<tr>
<th>Backgrounds</th>
<th>Description</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QCD</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td>$b\bar{b}, c\bar{c}, q\bar{q}$&lt;sup&gt;2&lt;/sup&gt;</td>
<td>• QCD heavy flavor production&lt;br&gt;• mismeasured jet energy&lt;br&gt;• semileptonic b-decay&lt;br&gt;• $\sigma$ large</td>
</tr>
<tr>
<td><strong>W/Z+jets</strong>&lt;sup&gt;3&lt;/sup&gt;</td>
<td>$W \rightarrow l\nu$&lt;br&gt;$Z \rightarrow ll, vv, b\bar{b}$</td>
<td>• mismeasured jet energy&lt;br&gt;• neutrinos</td>
</tr>
<tr>
<td><strong>Diboson</strong>&lt;sup&gt;4&lt;/sup&gt;</td>
<td>$W \rightarrow l\nu$&lt;br&gt;$Z \rightarrow ll, vv, b\bar{b}$</td>
<td>• neutrinos&lt;br&gt;• $\sigma$ small</td>
</tr>
<tr>
<td><strong>Top</strong>&lt;sup&gt;5&lt;/sup&gt;</td>
<td>$t \rightarrow Wb$&lt;br&gt;$L_l\nu$</td>
<td>• b-jets&lt;br&gt;• neutrinos&lt;br&gt;• very similar signature!</td>
</tr>
</tbody>
</table>

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**Event selection cuts**

- Inclusive three jets $P_T > 15$GeV<br>$|\eta| < 2$
- $\slash E_T > 35$GeV
- $\Delta \phi(\slash E_T, 1-3 \text{jet}) > 40^\circ$
- Heavy flavor tags

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**Use $E_T$ cut and lepton veto/requirement to define signal and control regions**
Define three control regions, based on $E_T$ and lepton requirement to provide cross-check for background predictions.

Control regions in agreement with SM predictions.
## Control Regions

<table>
<thead>
<tr>
<th>$\mathcal{E}_T$:</th>
<th>35-50GeV</th>
<th>35-50GeV &gt;50GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lepton:</strong></td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>W/Z+jets/Diboson</td>
<td>3.9±0.8</td>
<td>11.0±1.2</td>
</tr>
<tr>
<td>Top</td>
<td>11.7±0.2</td>
<td>8.2±0.1</td>
</tr>
<tr>
<td>QCD-multijet</td>
<td>19.2±4.1</td>
<td>129.6±17.3</td>
</tr>
<tr>
<td><strong>Total background</strong></td>
<td>34.8±4.2</td>
<td>148.8±17.3</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>36</td>
<td>121</td>
</tr>
</tbody>
</table>

Comparison of standard model background predictions for inclusive single tagged events is in agreement with data.

**Statistical errors**

**Dominant systematics:**
- Tagging efficiency
- Energy scale
Signal Expectations

CDF Run II Preliminary, 156pb$^{-1}$

- QCD-multijet
- Top
- W/Z+jets, Diboson

$m_g=240, m_b=180, m_{\tilde{\chi}^0_i}=60$

Expected signal events:
- Inclusive Double B-Tag: 28.6
- Exclusive Single B-Tag: 0.61
- Inclusive Double B-Tag: 0.18

Expected events for signal:
- Inclusive Double B-Tag: 28.6
- Exclusive Single B-Tag: 2.63

Optimal sensitivity: $E_T > 80$ GeV

Similar signal acceptance for exclusive single tagged events and inclusive double tagged events

Large signal acceptance + small SM background
Results

Use 156\,pb$^{-1}$ of data taken 2002-2003

**Expected** 16.4±3.7
**Observed** 21

**Expected** 2.6±0.7
**Observed** 4
Sbottom Searches

Double tagged event in signal region

<table>
<thead>
<tr>
<th>Et</th>
<th>η</th>
<th>φ</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>85.3GeV</td>
<td>0.02</td>
<td>4.99</td>
<td>1</td>
</tr>
<tr>
<td>51.6GeV</td>
<td>0.84</td>
<td>5.97</td>
<td>1</td>
</tr>
<tr>
<td>30.0GeV</td>
<td>-0.83</td>
<td>1.42</td>
<td>0</td>
</tr>
</tbody>
</table>
Cross Section Limit

Gluino → b̅b', 95% C.L. Cross Section Limit

\[ \Delta M(\text{gluino}, s\text{bottom}) = 60 \text{GeV/c}^2 \]

Upper limit on signal events

\[ \sigma^{\text{Limit}} \cdot BR(\tilde{g} \rightarrow b\tilde{b}_1) = \frac{N^{\text{Limit}}}{\varepsilon \cdot L} \]

Assume branching ratio 100%

Signal selection efficiency

Luminosity

Now translate upper limit cross section to exclusion plane

Excl. single tag: Exclude 20.6 signal events at 95% C.L.
Incl. double tag: Exclude 8.7 signal events at 95% C.L.

\[ \Delta \sigma = \varepsilon \cdot L \cdot N^\text{Limit} \]

\[ \Delta \sigma^\text{Excl. Single B-Tag} \]

\[ \Delta \sigma^\text{Excl. Double B-Tag} \]
**Gluino/Sbottom Exclusion Plane**

- **CDF Gluino → b̅, 95% C.L. Exclusion Limit, 156 pb⁻¹**
  - BR(ĝ → b̅) = 100%
  - \( m(χ^0_b) = 60 \text{ GeV}/c^2 \)
  - \( m(\tilde{q}) = 500 \text{ GeV}/c^2 \)

**CDF Run II Preliminary**

- **Exclusive single tag analysis more sensitive for nearly mass degenerated scenario**

- **Include double tagged events, due to better background suppression by similar signal acceptance**

- **Similar limits expected also for larger neutralino mass scenarios**

**CDF Run I excluded**

\[ \tilde{g} \rightarrow b\tilde{b}, \text{ kinematically forbidden} \]

**Incl. double tag**

**Excl. single tag**

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*Carsten Rott (Purdue University)*
Conclusions

- Heavy flavor jets and $E_T$ exciting combination to look for new physics
- Performed search for sbottom quarks from gluino decays
- No excess found and new exclusion limit was set
- Vastly exceed Run I limits
- Searches beyond the standard model are ongoing ...

Gluino production allows significant extension of the best limits at high mass Sbottom and low mass neutralinos.