Search for supersymmetry in final states with b-jets and missing transverse energy with the ATLAS detector
Introduction

• Supersymmetry (SUSY) is one of the most compelling theories to describe physics beyond the Standard Model (SM).
  • $R$-parity conserving scenarios lead to signatures with unbalanced energy + jets / leptons.
  • Third generation scalar fermions can be lighter and stop and sbottom produced either via direct production or gluino decays.

→ Final states involving $b$-jets

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~g→ b~ b_1 decay diagram
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~g→ t ~t_1 decay diagram
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Analysis Strategy

• Two searches are presented.
  – lepton veto, 3-jet (1 or 2 $b$-jet) for sbottom search using 0.83 fb$^{-1}$ data
  – 1-lepton, 4-jet (1 $b$-jet) for stop search using 1.03 fb$^{-1}$ data

• This is the update of analysis at 2010, integrated luminosity of 35 pb$^{-1}$.
Object Definition (I)

- **jet**:  
  - reconstructed from anti-$k_t$ jet clustering algorithm,  
  - distance parameter $R=0.4$, $|\eta|<2.8$, $p_T>20$ GeV

- **$b$-tagged jet**:  
  - $p_T>50$ GeV  
  - secondary vertex-based tagger with 50% $b$-tagging efficiency (light jet rejection rate $\sim270$) for 0-lepton channel  
  - secondary vertex / impact parameter combined tagger with 60% $b$-tagging efficiency (light jet rejection rate $\sim350$) for 1-lepton channel

- **electron**:  
  - *medium* ID, $p_T>20$ GeV, $|\eta|<2.47$, $dR>0.4$ from jets

- **muon**:  
  - inner detector / muon spectrometer combined, track quality, $p_T>10$ GeV, $|\eta|<2.47$, $dR>0.4$ from jets
Object Definition (II)

- $E_T^{\text{miss}}$: missing transverse energy calculated from the vector sum of reconstructed jet with $p_T > 20$ GeV, $|\eta| < 4.5$, leptons and the calorimeter clusters not belonging to reconstructed objects.

- $\Delta \phi_{\text{min}}$: minimum $\Delta \phi$ between any of 3 leading jets and $E_T^{\text{miss}}$.

- $m_{\text{eff}}$: scalar sum of the $E_T^{\text{miss}}$ and up to
  - 3 leading jet $p_T$ (0-lepton)
  - 4 leading jet $p_T$ and identified lepton $p_T$ (1-lepton)

- $m_T$: missing transverse mass calculated from the lepton and missing transverse energy by the following equation,

$$m_T = \sqrt{2(p_T^{\text{lepton}} E_T^{\text{miss}} - \vec{p}_T^{\text{lepton}} \cdot \vec{E}_T^{\text{miss}})}$$
Event Selection (0-lepton)

- lepton veto with $p_T > 20$ GeV (electron), 10 GeV (muon)
- jet $p_T > 130, 50, 50$ GeV
- $E_T^{\text{miss}} > 130$ GeV
- $\Delta\phi_{\text{min}} > 0.4$ rad
- $E_T^{\text{miss}}/m_{\text{eff}} > 0.25$

Leading jet $p_T$ and $E_T^{\text{miss}}$ requirements are for trigger.

To reduce QCD multi-jet background

Prepare 4 signal regions
- 3JA ($\geq 1$ b-jet, $m_{\text{eff}} > 500$ GeV)
- 3JB ($\geq 1$ b-jet, $m_{\text{eff}} > 700$ GeV)
- 3JC ($\geq 2$ b-jet, $m_{\text{eff}} > 500$ GeV)
- 3JD ($\geq 2$ b-jet, $m_{\text{eff}} > 700$ GeV)

1 signal region is chosen to show the best sensitivity for each signal point.
Background Estimation (I)

- QCD multi-jet data-driven (d-d) estimation
  - Smearing method: smear the momentum of jets in clean data events with low $E_{T\text{miss}}$ to generate “pseudoevents”.
  - Normalization is taken from QCD dominant control region ($\Delta\phi_{\text{min}} < 0.4$ rad)

$m_{\text{eff}}$ distributions for QCD control region in 1 $b$-jet (left) and 2 $b$-jet channel.
Background Estimation (II)

- Non-QCD background (top, W/Z+jets)
  - MC-driven estimation
    - ttbar, single top: MC@NLO+HERWIG
    - W, Z+jets: ALPGEN+HERWIG
  - For validation of MC, similar kinematics region in 1-lepton channel is checked.
    - lepton $p_T > 20$ GeV
    - jet $p_T > 130, 50, 50$ GeV
    - $40$ GeV $< m_T < 100$ GeV
    - $m_{\text{eff}} > 600$ GeV
    - 1 $b$-jet or 2 $b$-jet

$m_{\text{eff}}$ distributions in 1-lepton control region. Electron (left) and muon (right) channel with 1 $b$-jet

<table>
<thead>
<tr>
<th></th>
<th>Top</th>
<th>W</th>
<th>Z</th>
<th>QCD</th>
<th>Total</th>
<th>Data(0.83fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td>7.3</td>
<td>0.46</td>
<td>0.05</td>
<td>negligible</td>
<td>7.8 ± 2.4</td>
<td>7</td>
</tr>
<tr>
<td>muon</td>
<td>11.2</td>
<td>0.57</td>
<td>0</td>
<td>negligible</td>
<td>11.9 ± 3.1</td>
<td>12</td>
</tr>
</tbody>
</table>
Systematic Uncertainties

- Pileup, jet energy scale and resolution
- $b$-tagging efficiency / light-jet fake rate
- Luminosity (3.7%)
- Theoretical uncertainties
  - $t\bar{t}$bar: cross section, ISR/FSR variation (using AcerMC), generator dependence (MC@NLO, POWHEG, ALPGEN), Parton shower and fragmentation model (HERWIG, PYTHIA)
  - single top: cross section
  - W/Z+jets: N jets uncertainty $\sqrt{N} \times 24\%$, heavy flavor rescale
  - SUSY signals: Renormalization/factorization scale, PDF (CTEQ6.6M PDFs)

<table>
<thead>
<tr>
<th></th>
<th>MC stat.</th>
<th>Jet</th>
<th>$b$-tag</th>
<th>Lumi</th>
<th>xsec</th>
<th>total w/o theory</th>
<th>theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>3JA($\geq 1$ b-jet, $m_{\text{eff}}&gt;500$ GeV)</td>
<td>± 4 %</td>
<td>± 23 %</td>
<td>± 10 %</td>
<td>± 3.7 %</td>
<td>± 8 %</td>
<td>± 27%</td>
<td>+28 % -17 %</td>
</tr>
<tr>
<td>3JB($\geq 1$ b-jet, $m_{\text{eff}}&gt;700$ GeV)</td>
<td>± 9 %</td>
<td>± 25 %</td>
<td>± 8 %</td>
<td>± 3.7 %</td>
<td>± 8 %</td>
<td>± 29%</td>
<td>+33% -18 %</td>
</tr>
<tr>
<td>3JC($\geq 2$ b-jet, $m_{\text{eff}}&gt;500$ GeV)</td>
<td>± 6 %</td>
<td>± 25 %</td>
<td>± 26 %</td>
<td>± 3.7 %</td>
<td>± 8 %</td>
<td>± 38%</td>
<td>+28% -17 %</td>
</tr>
<tr>
<td>3JD($\geq 2$ b-jet, $m_{\text{eff}}&gt;700$ GeV)</td>
<td>± 16 %</td>
<td>± 19 %</td>
<td>± 26 %</td>
<td>± 3.7 %</td>
<td>± 8 %</td>
<td>± 37%</td>
<td>+33% -18 %</td>
</tr>
</tbody>
</table>
Results (0-lepton)

- \(m_{\text{eff}}\) (top) and \(E_{\text{T}}^{\text{miss}}\) (bottom) distributions for 1 b-jet (left) and 2 b-jet (right)
- \(\sim g \rightarrow b \sim b_1\) signal is shown with stacked dotted line.

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>Top</th>
<th>W/Z</th>
<th>QCD</th>
<th>Total</th>
<th>Data(0.83fb^{-1})</th>
<th>95% CL N events</th>
<th>95% CL (\sigma)(pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3JA(1 b-jet, (m_{\text{eff}}&gt;500)GeV)</td>
<td>221^{+82}_{-68}</td>
<td>121±61</td>
<td>15±7</td>
<td>356^{+103}_{-92}</td>
<td>361</td>
<td>240</td>
<td>0.288</td>
</tr>
<tr>
<td>3JB(1 b-jet, (m_{\text{eff}}&gt;700)GeV)</td>
<td>37^{+15}_{-12}</td>
<td>31±19</td>
<td>1.9±0.9</td>
<td>70^{+24}_{-22}</td>
<td>63</td>
<td>51</td>
<td>0.061</td>
</tr>
<tr>
<td>3JC(2 b-jet, (m_{\text{eff}}&gt;500)GeV)</td>
<td>55^{+25}_{-22}</td>
<td>20±12</td>
<td>3.6±1.8</td>
<td>79^{+28}_{-25}</td>
<td>76</td>
<td>65</td>
<td>0.078</td>
</tr>
<tr>
<td>3JD(2 b-jet, (m_{\text{eff}}&gt;700)GeV)</td>
<td>7.8^{+3.5}_{-2.9}</td>
<td>5±4</td>
<td>0.5±0.3</td>
<td>13.0^{+5.6}_{-5.2}</td>
<td>12</td>
<td>14</td>
<td>0.017</td>
</tr>
</tbody>
</table>
Interpretation (0-lepton)

The gluino-sbottom plane exclusion limit with $m(\tilde{g}) > m(\tilde{b}_1)$. The lightest neutralino mass is set to 60 GeV.

The gluino mass below 720 GeV (and sbottom mass up to 600 GeV) is excluded with 95% CL.

The best selection is chosen from 3J A-D for each signal point.

gluino-neutralino plane exclusion limit in the $\tilde{g} \rightarrow b\bar{b} + \text{LSP}$ simplified model.

gluino mass below 660 GeV (and LSP up to 200 GeV) is excluded with 95% CL.
Interpretation in the $b$-jet enrich specific models:

- Grand Unification Theories based on the gauge group SO(10), D-term splitting model, DR3 and Higgs splitting model, HS (H. Baer, S. Kraml, A. Lessa, S. Sekmen, JHEP 1002 (2010) 055)
- In these models, squarks ($\sim$10 TeV) are much heavier than gluino. But third generation squarks ($\sim$1 TeV) are lighter than them, so gluino 3-body decay to $bb$ is enhanced.

95% CL limit on the production cross section for DR3 (left) and HS models (right) as a function of gluino mass.

Gluinos with masses below 570 GeV and 450 GeV are excluded for the DR3 and HS models.
Event Selection (1-lepton)

- exactly one lepton (electron or muon)
  - electron: \( p_T > 25 \text{ GeV} \) (requirement from electron trigger), track isolation
  - muon: \( p_T > 20 \text{ GeV} \) (requirement from muon trigger), track isolation
- 4 jet with \( p_T > 50 \text{ GeV} \)
- \( E_T^{\text{miss}} > 80 \text{ GeV} \)
- \( m_T > 100 \text{ GeV} \)
- at least 1 \( b \)-jet
- \( m_{\text{eff}} > 600 \text{ GeV} \)
Background Estimation

• QCD multi-jet data-driven (d-d) estimation
  – matrix method: decompose loose and tight selected leptons into real (EW) and fake (QCD).

\[
\begin{align*}
N_{\text{loose}} &= N_{\text{real}}^{\text{loose}} + N_{\text{fake}}^{\text{loose}} \\
N_{\text{tight}} &= \varepsilon_{\text{real}} N_{\text{real}} + \varepsilon_{\text{fake}} N_{\text{fake}} \\
N_{\text{tight}}^{\text{fake}} &= \frac{\varepsilon_{\text{real}}}{\varepsilon_{\text{real}} - \varepsilon_{\text{fake}}} (\varepsilon_{\text{real}} N_{\text{loose}} + N_{\text{tight}})
\end{align*}
\]

$m_T$ distributions for QCD control region in electron (left) and muon (right) channel
Background Estimation

• ttbar, single top, W/Z+jets semi-data-driven estimation
  – Obtain scale factor in control region (CR) defined by $40 \text{ GeV} < m_T < 100 \text{ GeV}$ and $m_{\text{eff}} > 600 \text{ GeV}$.
  – Then propagate it to signal region (SR).

$$N_{\text{data}}^{\text{SR}} = N_{\text{data}}^{\text{CR}} \frac{N_{\text{MC}}^{\text{SR}}}{N_{\text{MC}}^{\text{CR}}} = N_{\text{data}}^{\text{CR}} T_{\text{MC}}$$

Other control regions are also checked for validation and reasonable agreement is obtained.

$m_{\text{eff}}$ distributions for control region in electron (left) and muon (right) channel
Results (1-lepton)

- $m_{\text{eff}}$ (top) and $m_T$ (bottom) distributions for electron (left) and muon (right) channels
- $\sim g \rightarrow t^\ast t_1$ signal are shown.
- Model independent 95% CL upper limit on the effective cross-section
  
  31 fb (expected)
  46 fb (observed)

<table>
<thead>
<tr>
<th></th>
<th>Top</th>
<th>W/Z</th>
<th>QCD(d-d)</th>
<th>Total(MC)</th>
<th>Total(d-d)</th>
<th>Data (1.03 fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td>24 ± 14</td>
<td>0.6 ± 0.9</td>
<td>0.9 ± 1.0</td>
<td>26 ± 14</td>
<td>25.5 ± 5.3</td>
<td>37</td>
</tr>
<tr>
<td>muon</td>
<td>24 ± 13</td>
<td>1.4 ± 1.4</td>
<td>&lt; 0.6</td>
<td>25 ± 14</td>
<td>27.3 ± 8.7</td>
<td>37</td>
</tr>
</tbody>
</table>
Interpretation (1-lepton)

- gluino-stop plane exclusion limit with $m(\tilde{g}) > m(\tilde{t}_1)$. The lightest neutralino mass is set to 60 GeV and 2nd lightest neutralino and lightest chargino masses are 120 GeV.
- gluino mass below 500 GeV is excluded with 95% CL.
- gluino-neutralino plane exclusion limit in $\tilde{g}\rightarrow tt + \text{LSP}$ simplified model.
- gluino mass below 570 GeV (and up to LSP mass 40 GeV) is excluded with 95% CL.
Conclusion

• Updates on the search for supersymmetry in final states with missing transverse momentum, $b$-jet and 0/1-lepton are presented.
  – In the $pp$ collision of 7 TeV at LHC with the ATLAS detector, integrated luminosity of 0.83 fb\(^{-1}\)/1.03 fb\(^{-1}\)

• The results are used to set limits on the models of gluino$\rightarrow$sbottom or gluino$\rightarrow$stop cascade decay.
  – In sbottom case, gluino masses below 720 GeV are excluded at 95% CL.
  – In stop case, gluino masses below 570 GeV for LSP masses below 40 GeV are excluded at 95% CL.

• Note: mSUGRA/CMSSM interpretation will be done with the full 2011 dataset.
Backup
mSUGRA Limit at 35pb$^{-1}$

**b-tagging Performance**

- IP3D+JetFitter means secondary vertex- / impact parameter-based tagger combined
- SV0 means secondary vertex-based tagger

*b-tagging algorithm performances based on simulated ttbar events*

SO(10) Models

BR for gluino decays in DR3 (left) and HS models (right).