Searches for the Third Generation: SUSY with b-jets in ATLAS

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Third generation squarks

Third generation squarks might be lighter than 1\textsuperscript{st}, 2\textsuperscript{nd} generation \rightarrow possibly high production cross sections:

- **gluino-mediated** or **direct pair** production:
  - if $m(\text{gluino})$ not too high, and $m(\text{gl}) > m(\tilde{b}) + m(b)$ or $m(\tilde{t}) + m(t)$, $\text{gl}-\text{gl}$ dominate
  
- Phenomenology depends on the SUSY particle mass hierarchy

- Final states with several $b$-jets are expected
Outline

*In this talk:*

Searches for gluino-mediated production of third generation squarks in R-parity conserving SUSY scenarios:

- in jets+MET (lepton veto) final states, (1 or 2 \(b\)-jet) for sbottom search using 0.83 fb\(^{-1}\) of data
- in jets+MET+1-lepton final states, (1 \(b\)-jet) for stop search using 1.03 fb\(^{-1}\) of data

→ update of analysis at 2010, integrated luminosity of 35 pb\(^{-1}\).
Object identifications

Common tools and requirements for ‘good events’ are used

Primary vertex
- At least 1 good vertex with $N_{\text{tracks}} > 4$

Electrons
- $p_T > 20$ GeV, $|\eta| < 2.47$
- If $\Delta R(\text{jet},e) < 0.2$, remove jet
- If $0.2 < \Delta R(\text{jet},e) < 0.4$, veto electron

Muons
- $p_T > 20$ GeV (10 GeV for veto), $|\eta| < 2.4$
- combined/extrapolated info from ID and Muon spectrometer
- Sum $p_T$ of tracks $< 1.8$ GeV in $\Delta R < 0.2$
- if $\Delta R(\text{jet},\mu) < 0.4$, veto muon

B-Jets
- $p_T > 50$ GeV
- Secondary vertex-based tagger with 50% b-tagging efficiency for MET+jets channel
- secondary vertex / impact parameter combined tagger with 60% b-tagging efficiency for 1-lepton tagger

Missing $E_T$
- Calculated from the vector sum of reconstructed jets with $p_T > 20$ GeV, $|\eta| < 4.5$, leptons and calorimeter clusters not belonging to reconstructed objects
Discriminating variables

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

\[
H_T = \sum_{i=1}^{3(4)} p_T^{jet_i} (+ p_T^l) \\
m_{\text{eff}} = H_T + E_T^{\text{Miss}}
\]

- $m_T$: missing transverse mass calculated from the lepton and missing transverse energy (1-lepton)

\[
m_T = \sqrt{2(P_{T\text{lepton}} E_{T\text{miss}} - P_{T\text{lepton}} \cdot E_{T\text{miss}})}
\]
Search in jets+MET (+b-jets)

Target → gluino-mediated ~b production
- At least 4 b-jets expected (+MET)

**Event selection:**
- Lepton-veto with $p_T > 20$ GeV(e), 10 GeV(μ)
- Jet $p_T > 130, 50, 50$ GeV
- MET $> 130$ GeV
- $\Delta \phi_{\text{min}}$, minimum $\Delta \phi$ between any of 3 leading jets and MET, $> 0.4$ rad
- $\text{MET}/m_{\text{eff}} > 0.25$

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

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Trigger-driven selections

QCD-multijet background rejection
designed to enhance sensitivity in different scenarios:
- low/high DM(g-b)
- low/high DM(g-LSP)
QCD-multijet background

- Smear $p_T$ of jets in data events with no MET to create sample of pseudo-events with large fake MET (*Jet Smearing Method*)
- Normalize pseudo-events to data in QCD-enriched control-region (reversal of $\Delta \phi_{\text{min}}$ cut).

Validated by checking $M_{\text{eff}}$ distributions for SM bkg and data in QCD CR

$\rightarrow$ 4-5% of total background depending on SR
Non-QCD background estimates

- Dominated by top pair production
- MC-driven estimate:
  - $t\bar{t}$bar, single top: use MC@NLO+HERWIG
  - W,Z+jets (light/HF): ALPGEN+HERWIG
- 1-lepton control region:

$$N_{SR0L, t\bar{t}} = \left( \frac{N_{CR1, data}^{t\bar{t}} - N_{MC}^{t\bar{t}, non-t\bar{t}}}{N_{MC}^{t\bar{t}}} \right) \cdot N_{CR1, t\bar{t}}^{MC}$$

**Transfer Factor**

Validated in control regions:
- lepton $p_T > 20$ GeV
- jet $p_T > 130, 50, 50$ GeV
- $40$ GeV < $m_T$ < $100$ GeV
- $m_{eff} > 600$ GeV
- 1 b-jet or 2 b-jet
Results (I)

- **Good agreement between data and SM expectations** within uncertainties
- **Systematic uncertainties dominated by:**
  - Jet energy scale and resolution
  - B-tagging (especially for 2-btags case)
  - Theoretical uncertainties
    - **Top pair** cross section, ISR/FSR variation, generator dependence, Parton shower and fragmentation models
    - **W/Z+jets**: uncertainties on N jets (√N×24% and HF rescale
    - **SUSY signals**: renormalization/factorization scale (20-30%), PDF(10-20%)
Results translated as model-independent exclusion limits

- in N events and $\sigma$

<table>
<thead>
<tr>
<th>95% C.L. N events ($CL_s$ (PCL))</th>
<th>95% C.L. $\sigma_{eff}$ (pb) ($CL_s$ (PCL))</th>
</tr>
</thead>
<tbody>
<tr>
<td>3JA 240 (206)</td>
<td>0.288 (0.247)</td>
</tr>
<tr>
<td>3JB 51 (40)</td>
<td>0.061 (0.048)</td>
</tr>
<tr>
<td>3JC 65 (53)</td>
<td>0.078 (0.064)</td>
</tr>
<tr>
<td>3JD 14 (11)</td>
<td>0.017 (0.014)</td>
</tr>
</tbody>
</table>
Interpretation of the results (I)

- **Two phenomenological interpretations**
  - Gluino-sbottom decays on-shell or off-shell, sbottom in b+LSP in both cases
- **$m(\text{gl}) > 720 (660) \text{ GeV}$** excluded depending on gluino – sbottom - neutralino mass hierarchy

Upper cross section limits also provided in case of simplified models
Interpretation of the results (II)

- Interpretation in GUT 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 (~10 TeV) much heavier than gluino.
- Third generation squarks (~1 TeV), gluino 3-body decay to $bb+LSP/NLSP$ is enhanced.
Search in jets+MET+1-lepton (b-jets)

Target → gluino-mediated ~t production

- At least 2 tops and b-jets expected, or 4 tops

\[ \tilde{t}_1 \rightarrow b + \tilde{\chi}_1^\pm \text{ or } \tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0 \]

Event selection:

- Exactly one lepton (electron or muon):
  - Electron: \( p_T > 25 \text{ GeV} \), track isolation
  - Muon: \( p_T > 20 \text{ GeV} \), track isolation

- 4 Jets with \( p_T > 50 \text{ GeV} \)
- MET > 80 GeV
- At least 1 b-jet

Signal region:

\( m_T > 100 \text{ GeV} \) and \( m_{\text{eff}} > 600 \text{ GeV} \)
QCD-multijet background

- QCD multi-jet data-driven estimation
  - So-called Matrix Method: decompose “loose” and “tight” selected leptons into real (EW) and fake (QCD).

\[
N^{\text{loose}} = N^{\text{loose}}_{\text{real}} + N^{\text{loose}}_{\text{fake}}
\]
\[
N^{\text{tight}} = \varepsilon_{\text{real}} N^{\text{loose}}_{\text{real}} + \varepsilon_{\text{fake}} N^{\text{loose}}_{\text{fake}}
\]

\[
N^{\text{tight}}_{\text{fake}} = \frac{\varepsilon_{\text{real}}}{\varepsilon_{\text{real}} - \varepsilon_{\text{fake}}} (N^{\text{loose}}_{\text{real}} + N^{\text{tight}})
\]

\[m_T\] distributions for QCD control region
Non-QCD background

- ttbar and single top estimated using a semi-data-driven estimation
- Define $m_T$ vs $m_{\text{eff}}$ plane
  - Obtain Transfer Factor (T) in control region (CR) defined by $40 \text{ GeV} < m_T < 100 \text{ GeV}$ and $m_{\text{eff}} > 600 \text{ GeV}$.

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

Good agreement in other CR verified as further cross check
Results (I)

- Systematic uncertainties dominated by:
  - Jet energy scale and resolution and b-tagging
  - Theoretical uncertainties (partially reduced by semi-data driven method)
  - **SUSY signals**: renormalization/factorization scale (20-30%), PDF(10-20%)
Results (II)

Model independent upper cross section limits:

Exp: 31 fb
Obs: 46 fb
Interpretation of the results

- Two phenomenological interpretations depending on mass hierarchy and stop decay mode

\[ \tilde{t}_1 \rightarrow b + \tilde{\chi}_1^0 \]

- Gluino-stop plane: \( m(\tilde{g}) > m(\tilde{t}_1) \).
- Lightest neutralino mass \( \rightarrow 60 \) GeV,
- \( m(\text{chargino}) \sim 2 \times m(\text{neut}) \)

**Gluino masses below 520 GeV is excluded @ 95% CL.**

**Gluino masses below 570 GeV (and up to LSP mass 40 GeV) excluded @ 95% CL.**
Conclusions

- Updates on the search for supersymmetry in final states with missing transverse momentum, \textit{b-jet and 0/1-lepton are presented}.
  - In the \textit{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-sbottom or gluino-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.

- Updates with 2 / 5 fb-1 in preparation
- Analyses targeting direct sbottom/stop pair production will follow soon → stay tuned for more results!
Back-up
mSUGRA interpretation (35 pb$^{-1}$)

MSUGRA/CMSSM: $\tan \beta = 40$, $A_0 = 0$, $\mu > 0$.

ATLAS

$\int L \, dt = 35 \text{ pb}^{-1}$, $\sqrt{s} = 7$ TeV

95% C.L. limit
- obs. - 0 lepton
- exp. - 0 lepton
- obs. - 1 lepton
- exp. - 1 lepton
- obs. - Combined
- exp. - Combined

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

LEP2 $\tilde{\tau}$

LEP2 $\tilde{\chi}_1^\pm$

$m_{0}$ [GeV]

$m_{1/2}$ [GeV]
mSUGRA interpretation (35 pb^{-1})

MSUGRA/CMSSM: tan\(\beta\) = 40, A\(\_0\) = -500 GeV, \(\mu > 0\).

ATLAS Preliminary

\[ \int L dt = 35 \text{ pb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]

95% C.L. limit

- obs. - 0 lepton
- exp. - 0 lepton
- obs. - 1 lepton
- exp. - 1 lepton
- obs. - Combined
- exp. - Combined

- m(\(\tau\)) < m(\(\tilde{\chi}\_1^0\))
- LEP \(\tilde{\chi}\_1^0\) limit