Interpretations of SUSY Searches in ATLAS with Simplified Models

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on behalf of the ATLAS Collaboration

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Where We Are

- ATLAS recorded ~2 fb\(^{-1}\) by early August (starting to have results with ~1 fb\(^{-1}\)).
- We are truly entering the TeV-scale.
- We want to be model-independent not to miss signals being too driven by specific SUSY models.
- **Simplified model approach** is one of the most promising (quasi-)model independent strategies for new physics searches.
- Widely gaining interests in the experimental/theoretical community (lhcnnewphysics.org).

5 jets with \(p_T > 40\) GeV (\(p_T = 528, 418, 233, 171\), and \(42\) GeV), \(E_T^{miss} = 460\) GeV; \(M_{eff}\) (scalar sum of \(E_T^{miss}\) & 4 leading jet \(p_T\)) = 1810 GeV.

An event with \(M_{eff} \sim 1.8\) TeV!!!
Simplified Models

• What are “Simplified Models”?  
  • Effective models with minimal particle contents  
  • Searches in the context of “particles”  
  • Model-independent results (upper limits on $\sigma \times \text{BR}$) : Interface to specific models; can also be extended to non-SUSY models

• Important additional features  
  • Can scan the whole sparticle mass plane (unlike mSUGRA)  
  • Disentangle assumptions on various couplings & branching ratios (complementary to pMSSM approach)
Simplified Models in ATLAS

Simplified Decay Chains

\[ \tilde{g} \rightarrow \tilde{q} \rightarrow \ldots \rightarrow \tilde{\chi}_1^{\pm} \tilde{\chi}_2^0 \rightarrow \tilde{l} \tilde{\nu} \]

- 2 - 4 mass parameters: subsets of gluino, squark, wino, slepton LSP masses
- Sparticles not relevant for the event topologies considered to be heavy (> a few TeV)
- Branching ratios can be free parameters, assume 1 or other realistic values

Simplified model interpretations in ATLAS

- No-lepton channel (1.04 fb\(^{-1}\))
- SS 2-lepton channel (35 pb\(^{-1}\))
- b-jet + MET channel (0.83 fb\(^{-1}\); see B. Butler’s talk)

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No-Lepton Search

- **Golden channel for SUSY search** → Has the largest coverage over possible R-parity conserving pMSSM phase space  
  (J. Conley et al., Supersymmetry Without Prejudice at the 7 TeV LHC, arXiv:1103.1697 (2011))

- Here, 3 diagrams considered, where gluinos/squarks directly decay down to the lightest supersymmetric particle (LSP)

  - 4 jet-like
  - 3 jet-like
  - 2 jet-like

\[ \tilde{g} \rightarrow \tilde{q} \tilde{q} j j \]

Dominant when \( m_{\text{squark}} \gg m_{\text{gluino}} \)

\[ \tilde{g} \rightarrow \tilde{q} j j \]

Dominant when \( m_{\text{squark}} \sim m_{\text{gluino}} \)

\[ \tilde{q} \rightarrow \tilde{q} LSP j j \]

Dominant when \( m_{\text{gluino}} \gg m_{\text{squark}} \)
No-Lepton Ev. Selections

- **Signature with large \( E_{T}^{\text{miss}} \) + multiple high-\( p_T \) jets**

- Using \( E_{T}^{\text{miss}} + \text{jet trigger} \)
  \( (E_{T}^{\text{miss}} 45 \text{ GeV}, \text{jet} \ p_T \ 75 \text{ GeV at raw EM scale}) \)

- 5 signal regions covering gluino/squark mass plane for various high-\( p_T \) jet multiplicities

- Additional cuts for QCD BG suppression

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>( \geq 2 \text{ jets} )</th>
<th>( \geq 3 \text{ jets} )</th>
<th>( \geq 4 \text{ jets} )</th>
<th>High mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_{T}^{\text{miss}} )</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
</tr>
<tr>
<td>Leading jet ( p_T )</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
</tr>
<tr>
<td>Second jet ( p_T )</td>
<td>&gt; 40</td>
<td>&gt; 40</td>
<td>&gt; 40</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>Third jet ( p_T )</td>
<td>–</td>
<td>&gt; 40</td>
<td>&gt; 40</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>Fourth jet ( p_T )</td>
<td>–</td>
<td>–</td>
<td>&gt; 40</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>( \Delta \phi(\text{jet}, E_{T}^{\text{miss}})_{\text{min}} )</td>
<td>&gt; 0.4</td>
<td>&gt; 0.4</td>
<td>&gt; 0.4</td>
<td>&gt; 0.4</td>
</tr>
<tr>
<td>( E_{T}^{\text{miss}}/m_{\text{eff}} )</td>
<td>&gt; 0.3</td>
<td>&gt; 0.25</td>
<td>&gt; 0.25</td>
<td>&gt; 0.2</td>
</tr>
<tr>
<td>( m_{\text{eff}} ) [GeV]</td>
<td>&gt; 1000</td>
<td>&gt; 1000</td>
<td>&gt; 500/1000</td>
<td>&gt; 1100</td>
</tr>
</tbody>
</table>

\[
m_{\text{eff}} = \sum_{i=1}^{n} |p_T^{\text{jet}(i)}| + E_{T}^{\text{miss}}
\]

- **Main BG: \( W/Z+\text{jets} \), top, QCD multijets.** Estimated with (quasi-)data-driven methods using various control regions (CR’s)

\[
N(SR, \text{est}, \text{proc}) = N(CR, \text{obs}, \text{proc}) \times \frac{N(SR,raw,proc)}{N(CR,raw,proc)}
\]

Common systematics
- JES/JER (~15% effect on transfer function)
- Pileup
- MC (generator, PDF, scale; ~25% effect)
• Z(→ν¯ν)+jets is the dominant component in Z+jets BG

• 2 CR’s: γ+jets & Z(→e⁺e⁻, μ⁺μ⁻)+jets from single photon or lepton triggered events; bosons are replaced with E_T^miss

• Transfer functions: p_T-dependent cross section ratio between Z/γ etc. for γ+jets; acceptance effects, etc. for Z(→e⁺e⁻, μ⁺μ⁻)+jets

CR-specific systematics

• Photon/lepton trigger efficiency, reconstruction efficiency, energy scale and resolution

• Photon acceptance & BG

• MC statistics
W+jets & Top BG

• 1 lepton + \(E_T^{\text{miss}}\) + jets CR’s with 30<\(M_T<100\) GeV are used for W+jets/Top

• CR’s were further separated to W+jets & Top-dominant regions using b-tagging

• Lepton is replaced as “jet,” since no-lepton BG dominantly comes from hadronic \(\tau\)’s

CR systematics

• Lepton trigger eff., reconstruction eff., energy scale and resolution

• b-tag/veto eff.

• MC statistics
Fake $E_{T\text{miss}}$ originates in multijet events from jet mismeasurement and heavy flavors.

Low $E_{T\text{miss}}$ region used for CR. Jets are smeared using response function measured from data (systematics arise from modeling of non-Gaussian tail).

Three Jet Channel

Four Jet Channel
• Limits on the simplified models with LSP mass at 0. Combined from 5 channels

• $m \leq 1.075$ TeV excluded when $m_{\text{gluino}} = m_{\text{squark}}$ at 95% confidence level

• $m_{\text{gluino}} \leq 800\text{GeV}$, $m_{\text{squark}} \leq 850\text{GeV}$ are excluded respectively

• Exclusion limit is not sensitive to the LSP mass up to $\sim 200$ GeV
• Very small Standard Model BG $\rightarrow$ clear channel for SUSY search 
  \( (M. \text{ Barnett et al.}, \text{Phys. Lett. B} 315, 349) \)

• Simplified models with same-sign same-flavor squark production considered in particular 
  \( (H. \text{Okawa, presentation at Characterization of new physics at the LHC II, Nov. 2011; ATLAS Collaboration, ATLAS Note, ATLAS-CONF-2011-091}) \)

Masses (3 parameters): squark, \( \chi_1^\pm/\chi_2^0 \), LSP (\( m_{\chi_1^\pm} = m_{\chi_2^0} \) assumed)

Branching ratios: \( \text{BR}(sq \rightarrow q\chi_1^\pm), \text{BR}(sq \rightarrow q\chi_2^0), \text{BR}(\chi_1^\pm \rightarrow l\nu\chi_1^0), \text{BR}(\chi_2^0 \rightarrow l^+l^-\chi_1^0) \)
**BG in SS 2-Lepton**

- Fake BG: 2 fake leptons from $b\bar{b}$, $c\bar{c}$, multijet. 1 real + 1 fake lepton from $W/Z$+jets & Top. Estimated from data-driven method using loose & tight lepton selection.

- Diboson: $WW$, $WZ$, $ZZ$. Estimated purely from MC.

- Charge flip: electron undergoing brems/pair creation (“trident events”) & reconstructed with wrong sign (other softer electrons are not identified). Mostly $t\bar{t}$.

- Cosmic BG: muons from cosmics

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**Table:**

<table>
<thead>
<tr>
<th></th>
<th>Same Sign, $E_T^{miss} &gt; 100$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$e^±e^±$</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Fakes</strong></td>
<td>0.12 ± 0.13</td>
</tr>
<tr>
<td><strong>Di-bosons</strong></td>
<td>0.015 ± 0.005</td>
</tr>
<tr>
<td><strong>Charge-flip</strong></td>
<td>0.019 ± 0.008</td>
</tr>
<tr>
<td><strong>Cosmics</strong></td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.15 ± 0.13</td>
</tr>
</tbody>
</table>

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**Notes:**

- FAKE BG: 2 fake leptons from $b\bar{b}$, $c\bar{c}$, multijet. 1 real + 1 fake lepton from $W/Z$+jets & Top. Estimated from data-driven method using loose & tight lepton selection.

- DIBOSON: $WW$, $WZ$, $ZZ$. Estimated purely from MC.

- CHARGE FLIP: electron undergoing brems/pair creation (“trident events”) & reconstructed with wrong sign (other softer electrons are not identified). Mostly $t\bar{t}$.

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**Also see T. Sarangi’s talk**
Observed upper limits (95% CL) on $\sigma \times \text{Br}$ as a function of squark, weakino, and LSP masses

Tighter upper limits for 2-lepton final state due to the acceptance

These results can also be considered for other BSM models contributing to the same event topologies
Summary

- No excess was found in no-lepton & SS 2-lepton searches
- The results were interpreted with simplified models
- Provides interface to map the results to specific models
- Also provides information about which phase space of sparticle masses are currently covered.
- Interplay between different search channels is becoming more important & currently under way.
- More simplified model results are coming for wider range of channels with larger dataset! Stay tuned!
BACKUPS
ATLAS Detector

- Toroid magnets
- Muon chambers
- Solenoid magnet
- Transition radiation tracker
- Semiconductor tracker
- Pixel detector
- LAr electromagnetic calorimeters
- LAr hadronic end-cap and forward calorimeters
- Tile calorimeters

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<table>
<thead>
<tr>
<th>Process</th>
<th>≥ 2-jet</th>
<th>≥ 3-jet</th>
<th>≥ 4-jet, $m_{eff} &gt; 500$ GeV</th>
<th>≥ 4-jet, $m_{eff} &gt; 1000$ GeV</th>
<th>High mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z/\gamma$+jets</td>
<td>32.5 ± 2.6 ± 6.8</td>
<td>25.8 ± 2.6 ± 4.9</td>
<td>208 ± 9 ± 37</td>
<td>16.2 ± 2.1 ± 3.6</td>
<td>3.3 ± 1.0 ± 1.3</td>
</tr>
<tr>
<td>W+jets</td>
<td>26.2 ± 3.9 ± 6.7</td>
<td>22.7 ± 3.5 ± 5.8</td>
<td>367 ± 30 ± 126</td>
<td>12.7 ± 2.1 ± 4.7</td>
<td>2.2 ± 0.9 ± 1.2</td>
</tr>
<tr>
<td>$t\bar{t}$ Single Top</td>
<td>3.4 ± 1.5 ± 1.6</td>
<td>5.6 ± 2.0 ± 2.2</td>
<td>375 ± 37 ± 74</td>
<td>3.7 ± 1.2 ± 2.0</td>
<td>5.6 ± 1.7 ± 2.1</td>
</tr>
<tr>
<td>QCD jets</td>
<td>0.22 ± 0.06 ± 0.24</td>
<td>0.92 ± 0.12 ± 0.46</td>
<td>34 ± 2 ± 29</td>
<td>0.74 ± 0.14 ± 0.51</td>
<td>2.10 ± 0.37 ± 0.83</td>
</tr>
<tr>
<td>Total</td>
<td>62.3 ± 4.3 ± 9.2</td>
<td>55 ± 3.8 ± 7.3</td>
<td>984 ± 39 ± 145</td>
<td>33.4 ± 2.9 ± 6.3</td>
<td>13.2 ± 1.9 ± 2.6</td>
</tr>
<tr>
<td>Data</td>
<td>58</td>
<td>59</td>
<td>1118</td>
<td>40</td>
<td>18</td>
</tr>
</tbody>
</table>
SS 2-lepton Limits
SS 2-lepton Limits

ATLAS Preliminary

\begin{align*}
\int L &= 35 \text{ pb}^{-1} \\
m_{\chi_1} &= 50 \text{ GeV} \quad \bar{q}q \to \chi_1^0 \chi_2^0 \to qqW^+Z_{\chi_1} \chi_1 \\
m_{\chi_1} &= 100 \text{ GeV} \quad \bar{q}q \to \chi_1^0 \chi_2^0 \to qqW^+Z_{\chi_1} \chi_1 \\
m_{\chi_1} &= 200 \text{ GeV} \quad \bar{q}q \to \chi_1^0 \chi_2^0 \to qqW^+Z_{\chi_1} \chi_1
\end{align*}
SS 2-lepton Limits

\[ \int L = 35 \text{ pb}^{-1} \]

- For \( m_{\tilde{\chi}_1^\pm, \tilde{\chi}_2^0} = 50 \text{ GeV} \) and \( q \bar{q} \rightarrow q\tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow q\bar{q}Z\tilde{\chi}_1^0 \tilde{\chi}_1^0 \), the limit is 1.3 pb.

- For \( m_{\tilde{\chi}_1^\pm, \tilde{\chi}_2^0} = 100 \text{ GeV} \) and \( q \bar{q} \rightarrow q\tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow q\bar{q}Z\tilde{\chi}_1^0 \tilde{\chi}_1^0 \), the limit is 1.7 pb.

- For \( m_{\tilde{\chi}_1^\pm, \tilde{\chi}_2^0} = 200 \text{ GeV} \) and \( q \bar{q} \rightarrow q\tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow q\bar{q}Z\tilde{\chi}_1^0 \tilde{\chi}_1^0 \), the limit is 1.3 pb.

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