ATLAS SUSY search in 0-lepton channel with boosted W bosons

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Introduction

Ongoing events:

- int note: (ATL-COM-PHYS-2013-1224)
- presented at Atlas Weekly: (https://indico.cern.ch/event/286459/)
- today’s open presentation: (https://indico.cern.ch/event/315963/)

In preparation:

- pMSSM legacy paper (RunI)
- prospects for RunII: (https://indico.cern.ch/event/315501/)
Supersymmetry

- symmetry of Lagrangian resulting to new particles and interactions
- has to be broken (similar to electroweak symmetry)

Theoretical motivations for SUSY searches:
- dark matter
- gauge coupling unification
- hierarchy problem

Motivation for SUSY searches with ATLAS:
- reachable sparticles production cross-section
- sensitivity to other theories (searching for discrepancy between SM and data in general)
Definition of "susy 0-lepton" analysis

- **0-lepton Signal Regions (SRs):**
  - jets: \( \tilde{q}, \tilde{g} \) decay to \( q \) and \( g \) making jets
  - MET: because of R-parity conservation, LSP does not decay further and contributes to MET
  - lepton veto: to be orthogonal to other SUSY analysis

- Aiming signals: mSUGRA, simplified models (gg-onestep on the left), MUED, NUHMG
Selection criteria

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2j</td>
</tr>
<tr>
<td>Targetted signal</td>
<td>θq direct</td>
</tr>
<tr>
<td></td>
<td>ñq direct</td>
</tr>
<tr>
<td></td>
<td>ñq</td>
</tr>
<tr>
<td>E_{miss} [GeV] &gt;</td>
<td>160</td>
</tr>
<tr>
<td>p_{T}(j_{1}) [GeV] &gt;</td>
<td>130</td>
</tr>
<tr>
<td>p_{T}(j_{2}) [GeV] &gt;</td>
<td>60</td>
</tr>
<tr>
<td>p_{T}(j_{3}) [GeV] &gt;</td>
<td>60</td>
</tr>
<tr>
<td>p_{T}(j_{4}) [GeV] &gt;</td>
<td>60</td>
</tr>
<tr>
<td>p_{T}(j_{5}) [GeV] &gt;</td>
<td>60</td>
</tr>
<tr>
<td>p_{T}(j_{6}) [GeV] &gt;</td>
<td>60</td>
</tr>
<tr>
<td>Δφ(j_{1}, j_{2}, E_{miss} &lt; 2jW) &gt;</td>
<td>0.4</td>
</tr>
<tr>
<td>Δφ(j_{i}, E_{miss} &lt; 4jW) &gt;</td>
<td>0.2</td>
</tr>
<tr>
<td>W candidates</td>
<td>2 W → j</td>
</tr>
<tr>
<td>E_{miss} / √H_{T} &gt;</td>
<td>8</td>
</tr>
<tr>
<td>E_{miss} / m_{eff}(Nj) &gt;</td>
<td>800</td>
</tr>
<tr>
<td>m_{eff}(incl.) [GeV] &gt;</td>
<td></td>
</tr>
</tbody>
</table>

Definition of W candidates will come later in this talk.

Powerful executing variables: $E_{T\text{miss}}, m_{\text{meff}} = \sum p_{T} + E_{T\text{miss}}, E_{T\text{miss}}/m_{\text{meff}}$

Two W signal regions SR2jW and SR4jW have been newly developed.
Hadronic boosted W Introduction

- There are two $W$s present in one-step simplified models.
- They mostly decay hadronically: $W \rightarrow q\bar{q}$ ($\sim 68\%$).
- They can be highly boosted for large values of $\Delta m(\tilde{\chi}^\pm - \tilde{\chi}^0)$ ($\Rightarrow x \sim 1$ for LSP=$60\text{GeV}$)
- We defined **resolved $W$** = 2 jets and **unresolved $W$** = 1 jet (AntiKt0.4) (right fig.)
- We try to reconstruct $W$s in the final state using the windows in the invariant mass of one or two jets (next slide).

**W-finder**

Find unresolved $W$s among the jets. Find resolved $W$s as a combination of two closest jets in $\Delta R$ among rest of the jets.
Hadronic boosted W Introduction

\[ \Delta R(q, \eta) \text{ vs. } P_T(W) \]

**ATLAS Work in progress**

\( m_g = 1200 \text{ GeV} \)
\( m_\chi = 360 \text{ GeV} \)
\( m_{\text{LSP}} = 60 \text{ GeV} \)

\[ \Delta R(q, \eta) \text{ vs. } P_T(W) \]

**ATLAS Work in progress**

\( m_g = 1200 \text{ GeV} \)
\( m_\chi = 1060 \text{ GeV} \)
\( m_{\text{LSP}} = 60 \text{ GeV} \)

**squark → chargino → LSP, \( m(\text{LSP}) = 60 \text{[GeV]} \)**

**gluino → chargino → LSP, \( m(\text{LSP}) = 60 \text{[GeV]} \)**

We have been using AntiKt0.4 jets so far to be consistent with previous 0-lepton analysis. The plan is to switch to AntiKt1.0
Hadronic boosted W Introduction

Distribution of invariant mass for candidates on resolved W when 
\( N(\text{unres}.W) \geq 1 \)

\[ \Rightarrow 60\text{-}100 \text{ GeV window was used to reconstruct } W \]

\[ \Rightarrow \text{SR2jw: } N(\text{unres}.W) \geq 2 \]

\[ \Rightarrow \text{SR4jw: } N(\text{unres}.W) \geq 1, N(\text{res}.W) \geq 1 \]

**Alternative statistical treatment**

Background can be fitted by quadratic function and \( \chi^2 \)-test can be used to test hypothesis of signal.
Interesting distributions for 2jW region

mass of whichever jet in 2jet SRs

mass of whichever jet, 1 unresolved W required, 2jet SRs

$E_T^{miss}/m_{\text{eff}}$ distribution for 2jW region

$m_{\text{eff}}$ distribution for 2jW region
Interesting distributions for 4jW region

mass of whichever jet in 4jet SRs

mass of remaining di-jet combination, 1 unresolved W required, 4jet SRs

$E_T^{\text{miss}}/m_{\text{eff}}$ distribution for 4jW region

$m_{\text{eff}}$ distribution for 4jW region
Statistical treatment

Main background: Z,W+jets, Top, QCD, Diboson
Control regions (CR): CRY, CRQ, CRW, CRT
Signal regions (SR):

\[ N_{exp}^{SR} = N_{obs}^{CR} \frac{N_{raw}^{SR}}{N_{raw}^{CR}} \]

transfer factor
normalized through all CRs via likelihood fit

Likelihood: \( L(n|\mu,s,b,\theta) = P_{SR} \cdot P_{CRY} \cdot P_{CRQ} \cdot P_{CRT} \cdot P_{CRW} \cdot C_{syst} \)

<table>
<thead>
<tr>
<th>CR</th>
<th>SR Background</th>
<th>CR process</th>
<th>CR selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRY</td>
<td>( Z(\rightarrow \nu\nu) + \text{jets} )</td>
<td>( \gamma + \text{jets} )</td>
<td>Isolated photon</td>
</tr>
<tr>
<td>CRQ</td>
<td>Multijets</td>
<td>Multijets</td>
<td>Reversed ( \Delta \phi(j_i, E_{T}^{miss}) ) and ( E_{T}^{miss} / \sqrt{H_T} ) or ( E_{T}^{miss} / m_{\text{meff}}(N_j) ) cuts</td>
</tr>
<tr>
<td>CRW</td>
<td>( W(\rightarrow \ell \nu) + \text{jets} )</td>
<td>( W(\rightarrow \ell \nu) + \text{jets} )</td>
<td>30 GeV &lt; ( m_T(\ell, E_{T}^{miss}) &lt; 100 \text{ GeV, } b\text{-veto} )</td>
</tr>
<tr>
<td>CRT</td>
<td>( t\bar{t} ) and single-( t )</td>
<td>( t\bar{t} \rightarrow bbqq'\ell\nu )</td>
<td>30 GeV &lt; ( m_T(\ell, E_{T}^{miss}) &lt; 100 \text{ GeV, } b\text{-tag} )</td>
</tr>
</tbody>
</table>
Expected exclusion limits for one-step simplified models, \(m(\text{LSP}) = 60[\text{GeV}]\)

**Simplified model, \(\tilde{q} \tilde{q} \rightarrow q\tilde{\chi}_1^0 \rightarrow q\tilde{\chi}_0^+\tilde{\chi}_0^-\)**

- **Observed limit** (4.7 fb\(^{-1}\), \(\sqrt{s} = 8\) TeV)

- **ATLAS** Work in progress

\[
\int \text{L dt} = 20.3 \text{ fb}^{-1}, \quad \sqrt{s} = 8\text{ TeV}
\]

0-lepton combined

- \(m(\text{LSP}) = 60[\text{GeV}]\)

**Squark → Chargino → LSP, \(m(\text{LSP}) = 60[\text{GeV}]\)**

**Older results with 3jW. Boosted SRs improve exclusion limit for**

\[
x \equiv \frac{\Delta(m_{\tilde{g}, \text{LSP}})}{\Delta(m_{\tilde{\chi}_-^-, \text{LSP}})} \sim 1!
\]
Ongoing studies
Motivation for implementation of $\mathcal{M}_{T2}$ variable

$\mathcal{M}^2_{T2}$ def.

$$\min_{p_1+p_2=\text{MET}} [\max [\mathcal{M}^2_T(W_1, p_1), \mathcal{M}^2_T(W_2, p_2)]]$$

$\mathcal{M}_{T2}$ is designed to reconstruct mass of particle which is produced in pair and decays into invisible ($\nu, \tilde{\chi}^0$)

- in our case: target is to reconstruct mass of intermediate gauginos:
  - $\tilde{\chi}^- \rightarrow W^- \tilde{\chi}^0$
  - $\tilde{\chi}^0 \rightarrow H \tilde{\chi}_1^0$

and use $\mathcal{M}_{T2}$ to suppress the background
$M_{T2}$ distribution in unres-res + unres-unres $W$ channels

- **Selection:**
  - all preselection 0-lepton cuts used
  - $p_T(j_1) > 130 \text{GeV}$,
  - $p_T(j_2) > 60 \text{GeV}$, $E_T^{miss} > 160 \text{GeV}$
  - qcd redc.: $\Delta(\phi)(j_{1,2,3}) > 0.4$
  - $E_T^{miss}/m_{eff} > 0.3$ (only bottom fig.)

- **Interesting:**
  - see gg-1step point (nice separation from background)
  - $M_{T2} > 500$. **suppress QCD**
  - see effect of $E_T^{miss}/m_{eff} > 0.3$
    (bottom figure on the left)
Correlation between $m_{\text{eff}}$ and $M_{T2}$

gg-onestep $m_{\tilde{g}} = 1200, m_{\tilde{\chi}^+} = 1190, m_{\text{lsp}} = 60$[GeV]

Sum of all SM backgrounds, $M_{T2} > 300$?
Significance, combination of cuts

\[ m_{\text{eff}}: \ m_{\text{eff}} > 1500 \text{[GeV]} \]
\[ E_T^{\text{miss}}/m_{\text{eff}}: \ E_T^{\text{miss}}/m_{\text{eff}} > 0.3 \]
\[ M_{T2}: \ M_{T2} > 500 \text{[GeV]} \]

<table>
<thead>
<tr>
<th></th>
<th>( m_{\text{eff}} )</th>
<th>( m_{\text{eff}},M_{T2} )</th>
<th>( E_T^{\text{miss}}/m_{\text{eff}} )</th>
<th>( E_T^{\text{miss}}/m_{\text{eff}},M_{T2} )</th>
<th>( E_T^{\text{miss}}/m_{\text{eff}},m_{\text{eff}} )</th>
<th>( E_T^{\text{miss}}/m_{\text{eff}},m_{\text{eff}},M_{T2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>allbg</td>
<td>21770</td>
<td>149.2</td>
<td>546.5</td>
<td>70.3</td>
<td>36.1</td>
<td>12.4</td>
</tr>
<tr>
<td>(q\bar{q})</td>
<td>14.3</td>
<td>8.2</td>
<td>16</td>
<td>11.3</td>
<td>8.1</td>
<td>7.0</td>
</tr>
<tr>
<td>(g\bar{g})</td>
<td>14</td>
<td>10.5</td>
<td>10.5</td>
<td>10.1</td>
<td>9.9</td>
<td>9.3</td>
</tr>
<tr>
<td>(s/\sqrt{b+s(q\bar{q})})</td>
<td>0</td>
<td>0.7</td>
<td>0.7</td>
<td>1.3</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>(s/\sqrt{b+s(g\bar{g})})</td>
<td>0</td>
<td>0.8</td>
<td>0.5</td>
<td>1.1</td>
<td>1.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Impact of combination of cuts on significance.
\(g\bar{g}\)-1step: \( m(gl) = 1200, m(char) = 1190, m(lsp) = 60 \).
\(\bar{q}\tilde{q}\)-1step: \( m(sq) = 800, m(char) = 790, m(lsp) = 60 \).
At least 1 unresolved and 1 resolved W or 2 unresolved W required. Selection same as on previous slides.

Best significancies achieved when combining all three cuts.
Conclusions & Plans

Conclusions:
- boosted $W$ regions have been developed
- data/MC ratio is fairly close to one for all distributions in SRs and CRs
- such new SRs improve expected exclusion limits

Plans:
- finishing 0-lepton paper and work on pMSSM paper
- preparing boosted 0-lepton analysis for 14 TeV
- studying possibility of using shape fits on $W$ mass peak
- studying jet substructure and $M_{T2}$
back-up
SUSY analysis using some boosted technique

- 0-lepton: ATL-COM-PHYS-2013-1224
- 0-lepton stop: ATL-COM-PHYS-2013-1092
- 1-lepton stop: ATL-COM-PHYS-2013-1490 (boosted top tagging, AntiKt10 Jets)
- boosted 3jet RPV: ATL-COM-PHYS-2012-793 (7TeV, 8TeV in progress)
$m_{\text{eff}}$ distribution in unres-res + unres-unres W channels

$m_{\text{eff}}$ distribution before $E_T^{\text{miss}} / m_{\text{eff}}$ cut with same selection as on previous slides

$E_T^{\text{miss}} / m_{\text{eff}} > 0.3$, $m_{\text{eff}}$ is unfortunately as powerful as $M_{T2}$, but their combination could give improvement!
Correlation between $MET/m_{eff}$ and $M_{T2}$

\[ \text{gg-onestep } m_{\tilde{g}} = 1200, m_{\tilde{\chi}^+} = 1190, m_{lsp} = 60 \text{[GeV]} \]

Sum of all background, $M_{T2} > 300$?