Search for heavy resonances with the ATLAS detector

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On behalf of the ATLAS Collaboration

Motivation

- The unification of fundamental interactions as well as some SM deficiencies have motivated the introduction of extended gauge symmetries, featured by several possible extensions of the SM
  - GUTs (E_6 model)
  - Extra-dimensions (Kaluza-Klein, Randall-Sundrum)
  - Technicolor (dynamic EWSB)
  - etc..

- Presenting in this talk the following signatures at 8TeV center-of-mass energy:

<table>
<thead>
<tr>
<th>Signature</th>
<th>Model</th>
<th>( \mathcal{L} ) at 8TeV</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e^+ e^- )</td>
<td>( Z' G^* )</td>
<td>20fb(^{-1} )</td>
<td>ATLAS-CONF-2013-017, ATLAS-CONF-2013-083</td>
</tr>
<tr>
<td>( jj )</td>
<td>( q^* )</td>
<td>13fb(^{-1} )</td>
<td>ATLAS-CONF-2012-148</td>
</tr>
<tr>
<td>( \omega' )</td>
<td>( \epsilon^* )</td>
<td>13fb(^{-1} )</td>
<td>ATLAS-CONF-2012-146</td>
</tr>
<tr>
<td>( WZ(-\rightarrow \ell \nu \ell \ell) )</td>
<td>( W', \rho_1 )</td>
<td>13fb(^{-1} )</td>
<td>ATLAS-CONF-2013-015</td>
</tr>
<tr>
<td>( ZZ(-\rightarrow \ell \ell jj) )</td>
<td>( G^* )</td>
<td>7.2fb(^{-1} )</td>
<td>ATLAS-CONF-2012-150</td>
</tr>
<tr>
<td>( \gamma j )</td>
<td>QBH, ( q^* )</td>
<td>20fb(^{-1} )</td>
<td>ATLAS-CONF-2013-059</td>
</tr>
</tbody>
</table>

- Other talks
  - **Searches for ttbar resonances with the ATLAS detector**: Diedi Hu
  - **Searches for resonant diboson production with the ATLAS detector**: Viviana Cavaliere

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Dilepton

$m(\mu\mu) = 1844\text{GeV}$
Dilepton ($\ell^+\ell^- : \ell = e, \mu$)

- Benchmark models: $Z'$, $G^*$
- Neutral gauge boson produced via Drell-Yan process: $pp \rightarrow Z'(G^*) \rightarrow \ell^+\ell^- (\ell = e, \mu)$
- Clean signature: $ee$ or $\mu^+\mu^-$
- Drell-Yan is irreducible background

**Backgrounds**

- Data-driven method: multi-jets and $W$+jets
- MC estimation: Drell-Yan, diboson and $t\bar{t}$

**Normalizing with the $Z$ peak ($80\text{GeV}-110\text{GeV}$)**

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**ATLAS Preliminary**

$Z' \rightarrow \mu\mu$ Search

$\int L \, dt = 20 \text{ fb}^{-1}$

$\sqrt{s} = 8 \text{ TeV}$

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**ATLAS Preliminary**

$G^* \rightarrow ee$ Search

$\int L \, dt = 20 \text{ fb}^{-1}$

$\sqrt{s} = 8 \text{ TeV}$

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Dilepton ($\ell^+\ell^- : \ell = e, \mu$)

- 95% C.L. limits on $\sigma \times B(Z' \rightarrow \ell\ell)$ and on $\sigma \times B(G^* \rightarrow \ell\ell)$

![Graph showing expected and observed limits for Z' and G* in dilepton channel](image)

- 95% C.L. limits on the $Z'/G^*$ mass

<table>
<thead>
<tr>
<th>Model</th>
<th>$Z'_{SSM}$</th>
<th>$Z'_{\psi}$</th>
<th>$Z'_N$</th>
<th>$Z'_\eta$</th>
<th>$Z'_I$</th>
<th>$Z'_S$</th>
<th>$Z'_\chi$</th>
<th>$G^* \rightarrow \ell^+\ell^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed mass limit [TeV]</td>
<td>2.86</td>
<td>2.38</td>
<td>2.39</td>
<td>2.44</td>
<td>2.42</td>
<td>2.47</td>
<td>2.54</td>
<td>2.47</td>
</tr>
<tr>
<td>Expected mass limit [TeV]</td>
<td>2.85</td>
<td>2.37</td>
<td>2.38</td>
<td>2.43</td>
<td>2.40</td>
<td>2.46</td>
<td>2.53</td>
<td>2.47</td>
</tr>
</tbody>
</table>
Dilepton ($\tau_{\text{had}}\tau_{\text{had}}$)

- Benchmark model: $Z'$
- $\tau_{\text{had}}$ defined as reconstructed jet with 1 or 3 associated tracks in the inner detector.
- At least 2 taus (no $\mu$'s and e's). The 2 highest-$p_T$ taus must be opposite charged and back-to-back.

$$m_T^{\text{tot}} = \sqrt{2 p_{T1} p_{T2} C + 2 |E_T^{\text{miss}}| p_{T1} C_1 + 2 |E_T^{\text{miss}}| p_{T2} C_2}$$

$$C = 1 - \cos \Delta \phi_{12}, \quad C_{1(2)} = 1 - \cos \Delta \phi_{1(2),E_T^{\text{miss}}}$$

- Backgrounds
  - Data-driven method: multi-jets
  - MC estimation: Drell-Yan, diboson, ttbar and single top. The W/Z +jets are weighted with jet-to-tau fake rate

- 95% C.L. limits on $\sigma \times \text{BR}(Z' \rightarrow \tau \tau)$
Dijet

\[ m(jj) = 4.60 \text{ TeV} \]
Dijet

- Benchmark model: q*
- Events with at least 2 central jets
- The dijet invariant mass is computed with the highest $p_T$ jets (leading) and the second-highest $p_T$ (sub-leading).

### Data

<table>
<thead>
<tr>
<th>ATLAS Preliminary</th>
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</thead>
</table>

### Background

- Data-driven method used to estimate the dijet background.
- Using a functional form to fit the dijet background to avoid theoretical and systematic uncertainties using MC dijet background prediction.

$$f(x \equiv m_{jj} / \sqrt{s}) = p_1 (1 - x)^{p_2} x^{p_3} + p_4 \ln x$$
95% C.L. limits on $\sigma X A$ for $q^*$ and for a Gaussian resonance (Model independent)

95% C.L. limits on $q^*$ mass

**Model**

<table>
<thead>
<tr>
<th>$q^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed mass limit [TeV]</td>
</tr>
<tr>
<td>Expected mass limit [TeV]</td>
</tr>
</tbody>
</table>
Photon + jet

\[ m(\gamma j) = 2.57 \text{TeV} \]
Photon + jet

- Benchmark model: QBH, $q^*$

- Events with at least one $\gamma$ and one jet. $\gamma$ and jet are central.

- Events with more than one $\gamma$ or jet, the highest $p_T$ candidates are selected to compute $m_{\gamma j}$

Data-driven method to estimate the background

$$f(x = m_{\gamma j} / \sqrt{s}) = p_1 (1 - x)^{p_2} x^{-(p_3 + p_4 \ln x)}$$

Thorough checks of function behavior using the LO MC and NLO distributions of backgrounds

### Data at $\sqrt{s} = 8$ TeV

- $\int L\,dt = 20.3$ fb$^{-1}$

### Significance

- Data
- Fit
- $q^*$ (1.5 TeV)
- $q^*$ (2.5 TeV)
- $q^*$ (3.5 TeV)

### Events

- $m_{\gamma j}$ vs. Significance

- ATLAS Preliminary
- $\int L\,dt = 20.3$ fb$^{-1}$
Photon + jet

- 95% C.L. limits on $\sigma \times B(\text{QBH} \rightarrow \gamma j, q^* \rightarrow \gamma j) \times A \times \varepsilon$

**Observed and Expected Limits**

- **ATLAS** Preliminary
  - $\sqrt{s} = 8 \text{ TeV}$
  - $L dt = 20.3 \text{ fb}^{-1}$

**Table:**

<table>
<thead>
<tr>
<th>Model</th>
<th>QBH</th>
<th>$q^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed mass limit</td>
<td>4.6</td>
<td>3.5</td>
</tr>
<tr>
<td>Expected mass limit</td>
<td>4.6</td>
<td>3.4</td>
</tr>
</tbody>
</table>
Excited leptons

- Benchmark model: $\ell^*$
- Events with 2 same flavor leptons ($e/\mu$) and a photon
- Backgrounds
  - MC estimation: $Z+\gamma$, $Z+$jets, ttbar and diboson
  - Scale factor applied to $Z+$jets in a region of (70GeV,110GeV)
- Fitted the $Z+\gamma$ and $Z+$jets backgrounds to extrapolate in a region of $150\mathrm{GeV}<m_{\ell\ell}\gamma<1050\mathrm{GeV}$

![Graph showing 95% C.L. limits on $\sigma XB(\ell^*\rightarrow\ell\gamma)$](image)

*Observed limit*
*Expected limit*
*Expected $\pm$1 $\sigma$
*Expected $\pm$2 $\sigma$

$\Lambda = 2.5$ TeV
$\Lambda = 5.0$ TeV
$\Lambda = 12.0$ TeV

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Diboson

WZ→ℓνℓℓ

\[ m(jj) = 2.9\text{TeV} \]

ZZ→ℓℓqq

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**WZ->lνll**

- **Benchmark model:** $W'$, $\rho_T$

- **Exactly 3 leptons with 2 opposite sign, same flavor leptons to reconstruct $W(l^+\nu)$ and $Z(l^-l^+)$**

- **Backgrounds**
  - Data-driven method: $Z$+jets (Z+jets, ttbar and Wt)
  - MC estimation: WZ/ZZ, $Z^+\gamma$, $W^+\gamma$

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**Model**

<table>
<thead>
<tr>
<th>$W'$</th>
<th>$\rho_T$</th>
</tr>
</thead>
</table>
| Obs. mass limit [TeV] | 1.18
| Exp. mass limit [TeV] | ~1.07

$\rho_T: m_{\rho_T} = m_{\pi^T} + m_W$,

$m_{\pi^T} = 1.1 m_{\rho_T} (> m_{\rho_T})$, $\sin \chi = 1/3$

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**95% C.L. limits on $\sigma \times B(W'\rightarrow WZ)$**

- **Expected 95% CL Limit**
- **Observed Limit**
- **W EGM Cross Section**
- **ATLAS Preliminary**

**Exclusion mass regions on ($\pi^T$, $\rho_T$) plane**

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**Obs. mass limit [TeV] 1.18**

**Exp. mass limit [TeV] ~1.07**
**ZZ --> llqq**

- Benchmark model: bulk RS G*
- Exactly 2 leptons and $m_{ll}$ is between (66GeV, 116GeV) (μ: ee or μ⁺μ⁻)
- 2 Signals regions for good acceptance over the wide mass range:
  - $m_{ll}$ for signal below 1TeV
  - $m_{ll}$ for signal above 1TeV
- Data-driven method used to estimate the background
- Resonance signal is searched for by making a smooth function fit to the $m_{ll}$ and $m_{jj}$ spectra in data

<table>
<thead>
<tr>
<th>Model</th>
<th><strong>Bulk RS G</strong>* $(\kappa/m_p = 1.0)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs. mass limit [TeV]</td>
<td>0.85</td>
</tr>
<tr>
<td>Exp. mass limit [TeV]</td>
<td>0.87</td>
</tr>
</tbody>
</table>

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Summary

- The 8TeV running was successful, and the ATLAS Collaboration continues search for the physics beyond the Standard Model (BSM)

- In this talk we presented six different signatures at 8TeV center-of-mass energy constraining nine BSM models with the ATLAS detector

- Much improved reach with $\sqrt{s}=14$TeV
  - Expecting parton luminosities will increase
Backup
Benchmark models

- Sequential Standard Model\(^{1}\): \(Z'_{SSM}\)
- \(E_6\) model Grand Unification Theories (GUT's)\(^{2}\): \(Z'_{(\psi, N, \eta, I, S, X)}\)
- Randall-Sundrum Model\(^{3}\): (RS \(G^*\))
- Excited quark and leptons\(^{4,5,6}\): (\(q^*, \ell^*\))
- New vector boson\(^{7}\): \(g_{W'WZ} = g_{WWZ} \times (m_W m_Z / m_{W'}^2)\)
- Low-scale Technicolor\(^{8,9}\)
- Bulk Randall-Sundrum model\(^{10}\): (Bulk RS \(G^*\))
- Low-scale quantum gravity\(^{11,12}\): (QBH)
References

1) P. Langacker, Rev. Mod. Phys. **81** (2009) 1199-1228
References