Searches for new Physics in Events with multiple Leptons with the ATLAS Detector

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On behalf of the ATLAS Collaboration
Introduction

• Leptons are clean probes for new physics at hadron colliders with a good Signal to Background ratio
• Many beyond Standard Model Models predict final states with three or more leptons

This talk covers:
- Model independent:
  • Search for new phenomena with multilepton events (20.3 fb⁻¹), ATLAS-CONF-2013-070
- Model dependent:
  • Search for Type-III Seesaw Model Heavy Fermions (5.8 fb⁻¹), ATLAS-CONF-2013-019
  • Search for excited electrons and muons (13 fb⁻¹), arXiv:1308.1364
  • Search for a WZ resonance (20.3 fb⁻¹), arXiv:1406.4456
Generic Multiple Leptons:

- Generic search for anomalous production of events with three or more charged leptons (e, μ, τ

  had)
- Probe for Beyond Standard Model Physics as: New Heavy Quarks, Doubly Charged Higgs, Excited Leptons, SUSY etc...

**Signal Regions**

1. 3e/μ, On-Z
2. 3e/μ, Off-Z
3. 2e/μ+1 τ had, On-Z
4. 2e/μ+1 τ had, Off-Z

**On-Z:** \(|m(ℓℓℓ)-m(Z)| < 20 \text{ GeV}^

### Selection Variables:

1. \(H_T^{\text{leptons}}\): Sum of 3 lepton \(p_T\)
2. \(H_T^{\text{jets}}\): Sum of all jet \(p_T\)
3. \(E_T^{\text{miss}}\): Missing transverse energy
4. \(m_{\text{eff}}\): \(H_T^{\text{leptons}} + H_T^{\text{jets}} + E_T^{\text{miss}}\)
5. Min. \(p_T(l)\): \(p_T\) of 3rd lepton
6. btags: number of btagged jets
7. \(m_T^W = \sqrt{(E_{T,l} + E_T^{\text{miss}})^2 - (\vec{p}_{T,l} + \vec{E}_T^{\text{miss}})^2}\)

### 94 Signal Regions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Signal Region Definition</th>
<th>Additional Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>(H_T^{\text{leptons}})</td>
<td>Inclusive (\geq 200 \text{ GeV})</td>
<td>(H_T^{\text{jets}} &lt; 150 \text{ GeV})</td>
</tr>
<tr>
<td>Min. (p_T^{\ell})</td>
<td>Inclusive (\geq 50 \text{ GeV})</td>
<td>(H_T^{\text{jets}} \geq 150 \text{ GeV})</td>
</tr>
<tr>
<td>(E_T^{\text{miss}})</td>
<td>Inclusive (\geq 100 \text{ GeV})</td>
<td>(E_T^{\text{miss}} \geq 100 \text{ GeV})</td>
</tr>
<tr>
<td>(m_{\text{eff}})</td>
<td>Inclusive (\geq 600 \text{ GeV})</td>
<td>(m_T^W \geq 100 \text{ GeV}, \text{on-Z})</td>
</tr>
<tr>
<td>(b)-tags</td>
<td>Inclusive (\geq 1)</td>
<td>(\geq 2)</td>
</tr>
</tbody>
</table>
Generic Multiple Leptons: Backgrounds & Results

Irreducible:

- Di-Boson Production (MC): WZ, ZZ, VVV
- Z\gamma (MC): photon conversion to electron

Reducible:

- Reducible: Z+jets, ttbar, W+jets
- Data Driven using fake-factor estimate
Deviations of observed yields from expected yields, in units of the total uncertainty on the expected yield

\[ \text{Inclusive \ 200} \, \text{N} \left( / \, \text{fb} \right) / \sigma_{95} \]

\[ \text{All \ 3 \ e/} \, \text{µ/} \, \text{τ/} \, \text{H leptons} \, / \text{m_{\text{miss}} [GeV]} / \text{\, E_{\text{T}} [GeV]} / \text{miss >100 GeV} / \text{m_{\text{off}} [GeV]} / \text{E_{\text{T}} miss [GeV]} / \text{H_{T} miss >150 GeV} / \text{H_{T} miss <150 GeV} \]

Figure 8: The observed- and median-expected 95% CL limit on the visible cross section (\[ \text{[GeV]} \]

\[ \text{All} \, / \text{3 e/} \, / \text{µ/} \, / \text{τ/} \, / \text{H leptons} \, / \text{m_{\text{eff}} [GeV]} / \text{E_{\text{T}} [GeV]} / \text{miss >100 GeV} / \text{m_{eff} [GeV]} / \text{E_{\text{T}} miss [GeV]} / \text{H_{T} miss >150 GeV} / \text{H_{T} miss <150 GeV} \]

- No significant excess above background is found
- 95% CL limits using CL_{S} are set on the non-SM-Signal Yields
- Fiducial efficiencies are provided for model testing

\[ \sigma_{95}^{\text{fid}} = \frac{N_{95}}{\epsilon_{\text{fid}} \int L \, dt} = \frac{\sigma_{95}^{\text{vis}}}{\epsilon_{\text{fid}}} \]

All tables available in HEPDATA and Analysis in RIVET
Type-III Seesaw Model

Motivation:

• Neutrino Mass Generation

Seesaw Mechanism:

• Introduce dim. 5 Operator

• Type III: fermionic triplet: neutral Majorana $N^0$ and Dirac $N^\pm$

Event Selection: $N^\pm N^0 \rightarrow Z(\ell\ell)l^\pm W^\pm l^\mp$

• At least 4 isolated leptons $p_T>10$ GeV, trigger lepton $p_T>25$ GeV

Main Backgrounds

• ZZ, VVV, Z+jets

$\ell^+\ell^-$

• Z Veto: $|M(l_3 l_4) - M(Z)| > 10$ GeV

• Z candidate: $|M(l^+ l^-) - M(Z)| < 10$ GeV

• Third “bachelor” lepton, min. $d\phi$ to Z candidate
Seesaw-III: Control Regions

- 2 same flavour opposite sign pairs
- Invert Z veto for bachelor and fourth lepton into Z selection: $|M(\ell\ell) - M(Z)| < 10$ GeV
- Good data and MC agreement

- Invert isolation and impact parameter requirements on bachelor lepton
- Good agreement between MC and data
- Scale sideband distribution according to MC estimate in signal region
Seesaw-III: Results

- No significant excess observed
- Derive 95% CL limits on mass limits on heavy leptons as a function of $\text{BR}(N^\pm \to Zl^\pm)\times \text{BR}(N^0 \to W^\pm l^\mp)$
  - For nominal BR $m_N$ is excluded up to 245 GeV
  - For BR=1 $m_N$ is excluded up to 350 GeV
Excited Leptons: Introduction

Motivation:
• Standard Model does not explain mass hierarchy or generational structure of quarks and fermions
• Could be explained by fermion compositeness
• Substructure of leptons:
  ● Standard Model leptons are ground state
  ● excited states $\ell^*$ could be observed

Effective Theory:
• Production of $\ell^*$ via four fermion contact interaction
• Decay of $\ell^*$ via gauge field interaction

Final State:
• $pp \rightarrow \ell\ell^* \rightarrow \ell\ell\gamma$
• $\ell^*$ mass must be less than compositeness scale $\Lambda$.

Event Selection:
• 2 same flavour, opposite sign leptons and a photon, $m_{\ell\ell} > 110$ GeV (Z Veto)
• Signal regions
  • $m_{\ell\ell\gamma} > m_{\ell^*} + 150$ GeV if $m_{\ell^*} < 900$ GeV
  • $m_{\ell\ell\gamma} > 1050$ GeV if $m_{\ell^*} > 900$ GeV
Excited Leptons: Backgrounds

Main SM Background:

- $Z+\gamma$, Dominant Background, irreducible (MC)
- $tt\bar{t}$ and DiBoson processes (MC)
- $Z+jets$ (MC, normalised in CR to account for misidentification of jets as photons)
- $W+\gamma+jets$, (MC sample normalised with likelihood fit to account for misidentified jets as electrons)

Control Region: $70 < m_{\ell\ell} < 110$ GeV
Excited Leptons: Results

- No significant excess is observed in the eeγ and μμγ channel

**ATLAS**

\[ \int L \text{ } dt = 13 \text{ fb}^{-1} \]

\[ \sqrt{s} = 8 \text{ TeV} \]

- Data 2012
- Z + γ
- Z + jets, diboson, t+t
- Z + jets, diboson, tót
- Bkg. uncertainty
- \((m_{\ell'}, \Lambda) = (0.2, 10) \text{ TeV}\)
- \((m_{\ell'}, \Lambda) = (0.5, 10) \text{ TeV}\)
- \((m_{\ell'}, \Lambda) = (0.8, 10) \text{ TeV}\)

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- \((m_{\ell'}, \Lambda) = (0.8, 10) \text{ TeV}\)
• Exclusion limit set on 95% Credibility Level on $(\ell \ell^*) \times (\ell^+ \ell^- \gamma)$
• Present limit as a function of $m_{\ell^*}$ and $\Lambda$.
• Filled area excluded at 95% CL
• For $m_{\ell^*} = \Lambda$, $m_{\ell^*} < 2.2$ TeV is excluded
WZ Resonance: Introduction

Motivation:
- Predicted by many SM extensions: GUT, Little Higgs, Technicolor, Composite Higgs and some extra dimension models
- Possible Signal in many non-SUSY models of electroweak symmetry breaking

Event Selection: $WZ \rightarrow lnu(l''l')$, $l''=e,\mu$
- Three Leptons ($e,\mu$), $E_{T,\text{miss}} > 25$ GeV
- Z Candidate: same flavour opposite sign lepton pair: $|M(l^{+}l^{-}) - M(Z)| < 20$ GeV
- $\Delta y(W,Z) < 1.5$
- Regions separated by W boost
  - Low Mass region: $\Delta \phi(l, E_{T,\text{miss}}) > 1.5$
  - High Mass region: $\Delta \phi(l, E_{T,\text{miss}}) < 1.5$

Models:
- extended gauge model with spin-1 $W'$
- phenomenological Lagrangian for Heavy Vector Triplets (HVT)
Main SM Background:
- Di-Boson Production, WZ, ZZ (MC)
- Zγ (MC)
- t\bar{t}, Z+jets and other sources where a jet is misidentified as a lepton (ll’+jets)
  - Data Driven, fake factor, using reversed ID cuts

Result:
- Good agreement between data and predictions in the signal regions.
- No significant excess is observed
WZ Resonance: Results

- 95% Confidence Limits are set as a function of $m_{WZ}$
- $W' \rightarrow WZ$ limit and Heavy Vector Triplet (HVT) are explicitly derived:
  - $M_{W'} > 1.52$ TeV @ 95% CL
- HVT mass limits for the 3 chosen benchmark models
Conclusion

• Searches for prompt isolated leptonic final states are invaluable probes to new physics

• Three model dependent searches and one model independent search were presented

• No significant deviation from Standard Model observed so far
Backup Slides
Characterize reducible leptons with fake factors:

\[ f(p_t, \eta, ...) = \frac{\#\text{numerators}}{\#\text{denominators}} \]

where numerators are full signal leptons, and denominators invert kinematic quantities sensitive to reducible backgrounds.

\( f \) measured in reducible background-enriched control regions.

Prompt contamination accounted for with MC throughout.
## Multilepton

<table>
<thead>
<tr>
<th>ID</th>
<th>e</th>
<th>μ</th>
<th>τ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leading/Trigger $E_T$</td>
<td>$E_T \geq 26$ GeV</td>
<td>$p_T \geq 26$ GeV</td>
<td>$p_T \geq 20$ GeV</td>
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<tr>
<td>Subleading $E_T$</td>
<td>$E_T \geq 15$ GeV</td>
<td>$p_T \geq 15$ GeV</td>
<td>$</td>
</tr>
<tr>
<td>Acceptance</td>
<td>$(</td>
<td>\eta</td>
<td>&lt; 1.37)$</td>
</tr>
<tr>
<td></td>
<td>$(1.52 \leq</td>
<td>\eta</td>
<td>\leq 2.47)$</td>
</tr>
<tr>
<td>Calo Iso</td>
<td>$\frac{E_T^{(\text{TopoCone30})}}{E_T} &lt; 0.10$</td>
<td>$\frac{E_T^{(\text{cone30})}}{p_T} &lt; 0.10$</td>
<td>-</td>
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<tr>
<td>Track Iso</td>
<td>$\frac{p_T^{(\text{cone30})}}{p_T} &lt; 0.10$</td>
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<tr>
<td>$</td>
<td>d_0^0</td>
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<td>$&lt; 3$</td>
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<td>$</td>
<td>\sigma d_0</td>
<td>$</td>
<td>$&lt; 0.5$ mm</td>
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<td>$</td>
<td>z_0 \sin \theta</td>
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<td>-</td>
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</tbody>
</table>
WZ Resonance

\[ \frac{g^2}{q} c_F \]

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

\[ A_{B_{\ell^\pm}} \]

\[ A_{B_{\ell^\pm}} = 3 \]

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Backup Slides: Control Regions Multiple Leptons