Searches for new phenomena in leptonic final states using the ATLAS detector

Giacomo Artoni on behalf of the ATLAS Collaboration
Isolated, high-$p_T$ leptons: a powerful probe for new physics!

- Electrons: exploit best resolution at high energies
- Muons: ensure reliable sagitta measurement using three-station tracks in the muon spectrometer

Many BSM models predicting heavy states, detectable at the LHC via their decays to electrons/muons/taus

$E_6$-motivated theories, Sequential Standard Model, Randall-Sundrum model, quantum black hole model, minimal walking technicolour, $R$-parity-violating supersymmetry, left-right symmetric models, Higgs triplet models, only to name a few!
Isolated, high-\(p_T\) leptons: a powerful probe for new physics!

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In this talk:

\[
W' \rightarrow e\nu/\mu\nu
\text{ arXiv:1706.04786} \\
2015+2016 data \\
36.1 \text{ fb}^{-1} \text{ at 13 TeV}
\]

\[
Z' \rightarrow e\nu/\mu\mu
\text{ ATLAS-CONF-2017-027} \\
2015+2016 data \\
36.1 \text{ fb}^{-1} \text{ at 13 TeV}
\]

\[
Z' \rightarrow \pi\pi
\text{ ATLAS-CONF-2017-050} \\
2015+2016 data \\
36.1 \text{ fb}^{-1} \text{ at 13 TeV}
\]

\[
Z' \rightarrow e\mu/e\tau/\mu\tau
2015 data \\
3.2 \text{ fb}^{-1} \text{ at 13 TeV}
\]
Looking for a $W'$: $e/\mu + \text{MET}$ search

- Select exactly one isolated electron (muon) with $p_T > 65$ (55) GeV and large missing transverse momentum
- Transverse mass of the system ($m_T$) used as discriminant
- Acceptance at 4 TeV: 47% for muons, 77% for electrons
- Minor backgrounds:
  - $t\bar{t}$: POWHEG+PYTHIA, cross-section normalised to NNLO in pQCD
  - Multi-jet background: data-driven estimate with “matrix method” using loose $\rightarrow$ tight ID probability

![Graph showing events vs. transverse mass with data and background contributions]
Looking for a $W'$: $e/\mu + \text{MET}$ search

- Irreducible background: $W \rightarrow l\nu$
- Generated using POWHEG (NLO in pQCD) with the CT10 PDF set (+Pythia8+Photos)
- Normalised to NNLO in pQCD (+CT14NNLO PDF) with mass-dependent $k$-factor
  - increasing cross-section by 5% (10%) for a 1 (5) TeV mass
- Also applying NLO EW mass-dependent $k$-factor
  - lowering predicted cross-section by 10% (20%) at 1 (5) TeV

$\sqrt{s} = 13$ TeV, $36.1$ fb$^{-1}$ at 13 TeV

Searches for new phenomena in leptonic final states using the ATLAS detector - G. Artoni (Oxford)
Looking for a $W'$: $e/\mu + \text{MET}$ search

- No significant excesses, excluding masses below 5.1 TeV (SSM $W'$)
- Main systematics (background):
  - PDF variation/choice: 90% CL
  - CT14NNLO uncertainty set/difference with NNPDF3.0
- EW corrections
- Main systematics (signal):
  - Electron energy scale and resolution
  - Muon identification and isolation efficiencies

```latex
\begin{align*}
\text{No significant excesses, excluding masses below 5.1 TeV (SSM $W'$)}
\end{align*}
```
Looking for a $Z'$: $ee/\mu\mu$ search

- Select one pair of isolated electrons (muons) with $p_T>30$ GeV
- Acceptance at 3 TeV: 40% for muons, 71% for electrons
- Irreducible DY from simulation:
  - POWHEG at NLO in pQCD, with NNLO (QCD) and NLO (EW) corrections
- Other backgrounds with real leptons from simulation (diboson/ttbar)
- Background from fakes ($ee$ only):
  - using again “matrix method” (extension to dilepton case)
Looking for a Z’: ee/µµ search

- No significant excesses, excluding masses below 4.5 TeV (SSM Z’)
- Comparable limits on E6-motivated models!
- Also setting:
  - limits on the ratio of coupling strengths between the Z’ boson and the Z boson, as a function of the Z’ mass in the context of minimal Z’ models
  - model-independent limits
    - fiducial cuts $p_T>30$ GeV, $|\eta|<2.5$, mass window 2x true signal width
    - anybody with a Z’ model outside ATLAS can re-interpret our results!

Searches for new phenomena in leptonic final states using the ATLAS detector - G. Artoni (Oxford)

ATLAS-CONF-2017-027
2015+2016 data
36.1 fb$^{-1}$ at 13 TeV
Looking for a $Z'$: $\tau\tau$ search

- Re-interpretation of the MSSM Higgs search (see talk by G. Barone)
- Analysis split into $\tau_{\text{had}}\tau_{\text{had}}$ and $\tau_{\text{lep}}\tau_{\text{had}}$ final states (but no $b$-jets splitting), using total transverse mass as final discriminant
- $\tau_{\text{had}}\tau_{\text{had}}$ selection: use single-$\tau$ triggers, require opposite-charge, back-to-back $\tau_{\text{had}}$ pairs
- multijet background: use dijet control region by inverting identification on the $\tau_{\text{had}}$s and apply “fake-factor” parametrised as a function of $p_T$ and track multiplicity of the $\tau$
- non-multijet backgrounds: using simulation corrected with fake-rates extracted from $W$+jets and ttbar control regions

Searches for new phenomena in leptonic final states using the ATLAS detector - G. Artoni (Oxford)
Looking for a $Z'$: $\tau\tau$ search

- $\tau_{lep}\tau_{had}$ selection: use single-lepton triggers, require lepton ($\ell$) and $\tau_{had}$ to be back-to-back, veto $W+\text{jets}$ events with $m_T(\ell,\text{MET})$ cut and $Z+\text{jets}$ events with $m(\ell,\tau_{had-vis})$ cut

- $\tau_{lep}\tau_{had}$ backgrounds: jets mis-identified as $\tau_{had}$ using data-driven fake-factor technique, other contributions (real leptons) from simulation

- No excess found, limits set on a SSM $Z'$ and SFM $Z'$

- $\tau_{had}\tau_{had}$ dominating channel

Searches for new phenomena in leptonic final states using the ATLAS detector - G. Artoni (Oxford)
Looking for LFV: $e\mu$, $e\tau$, $\mu\tau$ search

- Requiring a pair of different-flavour leptons with $p_T > 65$ GeV (40 GeV for $\tau$), back-to-back in $\phi$ and no charge requirement
- Acc. x eff.: 50%, 25% and 20% ($e\mu$, $e\tau$, $\mu\tau$)
- Irreducible backgrounds: $DY \rightarrow \tau\tau$, $t\bar{t}$, diboson
- contribution estimated from simulation
- Reducible backgrounds: $W$+jets and multi-jet
  - matrix method for $e\mu$, MC corrected with measured $\tau$ fake-rate on data for $e\tau/\mu\tau$
- No significant excesses observed, limits extracted on the mass of a $Z'$ boson (with lepton-flavour-violating couplings) or a supersymmetric $\tau$ sneutrino (with $R$-parity violating couplings)
- results also interpreted as limits on the threshold mass for quantum black hole production
Conclusions

- Presented searches for new physics with leptonic final states
  - Small backgrounds/good resolution, ideal to look for new physics at the LHC!
- Most searches available with full 2015+2016 statistics
  - No significant excess found…
  - …setting more and more stringent limits
- Let’s stay positive!
  - A lot more data coming…
Presented searches for new physics with leptonic final states

Small backgrounds/good resolution, ideal to look for new physics at the LHC!

Most searches available with full 2015+2016 statistics

No significant excess found…

…setting more and more stringent limits

Let’s stay positive!

A lot more data coming…

Thanks for the attention!
Backup Slides
$W'$: limits split per channel

**ATLAS**

$\sqrt{s} = 13$ TeV, 36.1 fb$^{-1}$

$W' \rightarrow e\nu$

95% CL

$\sigma(pp \rightarrow W') \times BR(W' \rightarrow e\nu) [pb]$

- Expected limit
- Expected ± 1σ
- Expected ± 2σ
- Observed limit
- $W'_{SSM}$

$\sigma(pp \rightarrow W') \times BR(W' \rightarrow \mu\nu) [pb]$

- Expected limit
- Expected ± 1σ
- Expected ± 2σ
- Observed limit
- $W'_{SSM}$

Searches for new phenomena in leptonic final states using the ATLAS detector - G. Artoni (Oxford)
\(W':\) observed yields

### Electron channel

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Total SM</td>
<td>620 000 ± 70 000</td>
<td>168 000 ± 10 000</td>
<td>9700 ± 500</td>
<td>2010 ± 140</td>
<td>232 ± 24</td>
<td>5.9 ± 1.4</td>
<td>0.4 ± 0.4</td>
</tr>
<tr>
<td>(W') (2 TeV)</td>
<td>24.3 ± 0.9</td>
<td>126 ± 3</td>
<td>199 ± 5</td>
<td>614 ± 14</td>
<td>3280 ± 50</td>
<td>330 ± 70</td>
<td>0.85 ± 0.04</td>
</tr>
<tr>
<td>(W') (3 TeV)</td>
<td>3.83 ± 0.08</td>
<td>14.2 ± 0.2</td>
<td>16.1 ± 0.4</td>
<td>35.7 ± 0.4</td>
<td>122 ± 2</td>
<td>229 ± 4</td>
<td>24 ± 5</td>
</tr>
<tr>
<td>(W') (4 TeV)</td>
<td>1.18 ± 0.02</td>
<td>4.06 ± 0.03</td>
<td>3.58 ± 0.03</td>
<td>5.92 ± 0.03</td>
<td>12.1 ± 1</td>
<td>13.5 ± 0.2</td>
<td>23.3 ± 0.2</td>
</tr>
<tr>
<td>(W') (5 TeV)</td>
<td>0.476 ± 0.008</td>
<td>1.62 ± 0.01</td>
<td>1.35 ± 0.01</td>
<td>1.95 ± 0.01</td>
<td>2.64 ± 0.01</td>
<td>1.56 ± 0.01</td>
<td>3.72 ± 0.02</td>
</tr>
<tr>
<td>Data</td>
<td>671 128</td>
<td>169 338</td>
<td>9551</td>
<td>1931</td>
<td>246</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

### Muon channel

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total SM</td>
<td>1640 000 ± 200 000</td>
<td>122 000 ± 8000</td>
<td>6460 ± 330</td>
<td>1320 ± 90</td>
<td>150 ± 13</td>
<td>4.7 ± 0.6</td>
<td>0.63 ± 0.13</td>
</tr>
<tr>
<td>(W') (2 TeV)</td>
<td>25.0 ± 1.5</td>
<td>102 ± 6</td>
<td>143 ± 9</td>
<td>420 ± 22</td>
<td>1720 ± 90</td>
<td>369 ± 28</td>
<td>17 ± 4</td>
</tr>
<tr>
<td>(W') (3 TeV)</td>
<td>3.98 ± 0.12</td>
<td>10.3 ± 0.3</td>
<td>10.7 ± 0.5</td>
<td>26.3 ± 1.5</td>
<td>84 ± 5</td>
<td>98 ± 6</td>
<td>39.3 ± 3.4</td>
</tr>
<tr>
<td>(W') (4 TeV)</td>
<td>1.20 ± 0.03</td>
<td>2.80 ± 0.07</td>
<td>2.36 ± 0.09</td>
<td>4.07 ± 0.19</td>
<td>8.1 ± 0.5</td>
<td>8.8 ± 0.6</td>
<td>11.1 ± 0.9</td>
</tr>
<tr>
<td>(W') (5 TeV)</td>
<td>0.485 ± 0.012</td>
<td>1.12 ± 0.03</td>
<td>0.88 ± 0.03</td>
<td>1.27 ± 0.05</td>
<td>1.7 ± 0.1</td>
<td>0.99 ± 0.07</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td>Data</td>
<td>1862 326</td>
<td>128 155</td>
<td>6772</td>
<td>1392</td>
<td>177</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
### $W'$: main systematic uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>Electron channel</th>
<th>Muon channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Background</td>
<td>Signal</td>
</tr>
<tr>
<td>Trigger</td>
<td>negl. (negl.)</td>
<td>negl. (negl.)</td>
</tr>
<tr>
<td>Lepton reconstruction and identification</td>
<td>negl. (negl.)</td>
<td>negl. (negl.)</td>
</tr>
<tr>
<td>Lepton momentum scale and resolution</td>
<td>3% (3%)</td>
<td>4% (3%)</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ resolution and scale</td>
<td>&lt; 0.5% (&lt; 0.5%)</td>
<td>&lt; 0.5% (&lt; 0.5%)</td>
</tr>
<tr>
<td>Jet energy resolution</td>
<td>&lt; 0.5% (&lt; 0.5%)</td>
<td>&lt; 0.5% (&lt; 0.5%)</td>
</tr>
<tr>
<td>Pile-up</td>
<td>1% (&lt; 0.5%)</td>
<td>1% (&lt; 0.5%)</td>
</tr>
<tr>
<td>Multijet background</td>
<td>7% (70%)</td>
<td>N/A (N/A)</td>
</tr>
<tr>
<td>Top extrapolation</td>
<td>1% (1%)</td>
<td>N/A (N/A)</td>
</tr>
<tr>
<td>Diboson extrapolation</td>
<td>4% (20%)</td>
<td>N/A (N/A)</td>
</tr>
<tr>
<td>PDF choice for DY</td>
<td>1% (13%)</td>
<td>N/A (N/A)</td>
</tr>
<tr>
<td>PDF variation for DY</td>
<td>8% (15%)</td>
<td>N/A (N/A)</td>
</tr>
<tr>
<td>EW corrections for DY</td>
<td>4% (7%)</td>
<td>N/A (N/A)</td>
</tr>
<tr>
<td>Luminosity</td>
<td>3% (3%)</td>
<td>3% (3%)</td>
</tr>
<tr>
<td>Total</td>
<td>13% (76%)</td>
<td>5% (5%)</td>
</tr>
</tbody>
</table>
Z’: more limits

\[ \gamma' \]

\[
\begin{align*}
\text{Exp. } & \quad \text{Obs.} \\
M_{Z'} & = 5.0 \text{ TeV} \\
M_{Z'} & = 4.5 \text{ TeV} \\
M_{Z'} & = 4.0 \text{ TeV} \\
M_{Z'} & = 3.5 \text{ TeV} \\
M_{Z'} & = 3.0 \text{ TeV} \\
M_{Z'} & = 2.5 \text{ TeV} \\
M_{Z'} & = 2.0 \text{ TeV} \\
M_{Z'} & = 1.5 \text{ TeV} \\
M_{Z'} & = 1.0 \text{ TeV} \\
M_{Z'} & = 0.5 \text{ TeV}
\end{align*}
\]

ATLAS Preliminary
\[ \sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1} \]

\( Z'_{\text{Min}} \rightarrow ee \)
$Z'$: model independent limits

\[ \text{ATLAS Preliminary} \]
\[ \sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1} \]
\[ Z' \rightarrow \ell \ell \]

observed limits

<table>
<thead>
<tr>
<th>Width</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>orange</td>
</tr>
<tr>
<td>2%</td>
<td>red</td>
</tr>
<tr>
<td>4%</td>
<td>purple</td>
</tr>
<tr>
<td>8%</td>
<td>blue</td>
</tr>
<tr>
<td>16%</td>
<td>green</td>
</tr>
<tr>
<td>32%</td>
<td>black</td>
</tr>
</tbody>
</table>
$Z'$: CI limits

**ATLAS** Preliminary

$\sqrt{s} = 13$ TeV, 36.1 fb$^{-1}$

Prior: $1/\Lambda^2$

CI $\rightarrow$ II

Chiral Structure

- **Observed**
- **Expected**
- **Expected ± 1 $\sigma$**
- **Expected ± 2 $\sigma$**

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