Di-Boson production at ATLAS

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for the ATLAS collaboration

M. Aharrouche (Uni. Mainz)
Outline

• Introduction
  – Di-boson production at LHC
  – ATLAS detector
• W/Zγ Analysis
  – Event selection
  – Signal yield
  – Results
• WW Analysis
  – Event selection
  – Signal yield
  – Results
• Summary
Di-Boson Production

- Standard Model diagrams for di-boson production includes
  - t-channels: qqbar annihilation
  - s-channels: Triple Gauge Boson couplings
    * Due to non-abelian nature of SU(2)L x U(1)Y, SM predicts vector-boson self coupling
    * SM only allows WWγ and WWZ couplings in the s-channel
      - Neutral TGC forbidden in SM

\[
L_{g_{WWV}} = i g_S^V (W_{\mu V}^* W_{\mu V} - W_{\mu V}^* W_{\mu V}^* ) + i \kappa_V^V W_{\mu V}^* W_{\mu V}^* + \frac{\lambda_V}{M_W^2} W_{\mu \mu}^* W_{\mu V}^* W_{\mu V}^* 
\]

where \( V = Z, \gamma \).
In the Standard Model: \( g_1^V = \kappa_V = 1 \) and \( \lambda_V = 0 \).

**Wγ**

**WZ**

**WW**

**Zγ**

**ZZ**

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ATLAS detector

- Multi-purpose detector
  - coverage up to $|\eta| = 5$;
  - design to operate at $L = 10^{34} \text{cm}^{-2}\text{s}^{-1}$
- Inner Detector (tracker)
  - Si pixel & strip detectors + TRT;
  - 2 T magnetic field;
  - coverage up to $|\eta| < 2.5$.
- Calorimetry
  - highly granular LAr EM calorimeter ($|\eta| < 3.2$);
  - hadron calorimeter – scintillator til
    - LAr for endcap & forward ($|\eta| < 4.9$).
- Muon Spectrometer
  - air-core toroid system ($|\eta| < 2.7$)
W/Zγ production
Signal definition

• Signature
  – $W\gamma$
    * One isolated lepton + photon and missing ET.
  – $Z\gamma$
    * Two isolated leptons + photon

• Signal contributions
  – Initial State Radiation (ISR)
  – $WW\gamma$ Triple Gauge Coupling (TGC)
  – Final state photon radiation from $W(Z)$ inclusive production.
  – Photons from fragmentation of jets produced in association with a $W$ or a $Z$ boson.
    * consider only part of fragmentation photon that satistify
      – particle level truth isolation:
        \[ \sum E_T^{had} < 0.5 \cdot E_T^{\gamma} \]
Event Selection

- **W selection**
  - One lepton with ET > 20 GeV
  - $|\eta| < 2.47$ (e)  $|\eta| < 2.4$ (µ)
  - MET > 25 GeV
  - $m_T(W) > 40$ GeV
  - Veto on a second lepton

- **Z selection**
  - Two leptons with ET > 20 GeV
  - $|\eta| < 2.47$ (e)  $|\eta| < 2.4$ (µ)
  - $M_{ll} > 40$ GeV

- **Photon selection**
  - One photon with ET > 15 GeV and $|\eta| < 2.37$
  - $\Delta R(l, \gamma) > 0.7$
  - Isolation energy $E_t(\text{iso}) < 5$GeV

- **Number of Candidates in 35/pb**
  - $W\gamma$: 192
    - 95 (e$\nu\gamma$) + 97(µ $\nu\gamma$)
  - $Z\gamma$: 48
    - 25 (ee$\gamma$) + 23(µµ$\gamma$)

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Kinematic Distributions of the W/Zγ candidates

- Wγ candidates

- Zγ candidates

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Cross section calculation

• Fiducial cross section
  – Performed within phase space defined by kinematic cuts of event selection in analysis.
  
  \[
  \sigma_{pp \rightarrow l\nu\gamma(l^+l^-)}^{fid} = \frac{N_{W\gamma(Z\gamma)}^{sig}}{C_{W\gamma(Z\gamma)} \cdot L_{W\gamma(Z\gamma)}}
  \]

  – \( N_{\text{sig}} \) is the number of the extracted signal events
  – \( C_{W\gamma(Z\gamma)} \) summarizes the reconstruction and identification efficiency for signal events

• Total cross section
  – extraploting from fiducial phase space to full W/Z decay space.

  \[
  \sigma_{pp \rightarrow l\nu\gamma(pp \rightarrow l^+l^-\gamma)}^{total} = \frac{\sigma_{pp \rightarrow l\nu\gamma(pp \rightarrow l^+l^-\gamma)}^{fid}}{A_{W\gamma(Z\gamma)}}
  \]

  – \( A_{W\gamma(Z\gamma)} \) is the acceptance of total phase space with respect to the fiducial one.
Signal yield

- Background for $W\gamma$: $W \rightarrow \tau\nu$, $t\bar{t}$, and $Z \rightarrow l^+l^-$ and $W+$jets.
- Background for $Z\gamma$: $t\bar{t}$ and $Z+$jets.
- $W+$jet background: data driven estimation
  - 2D sideband method is applied. The two dimensions are defined by the isolation energy on one axis, and the photon identification “quality” of the photon candidate on the other axis.
- $Z+$jets background contribution, as well as the non $W+$jets background, is estimated from Monte Carlo.

### Table

<table>
<thead>
<tr>
<th>Process</th>
<th>Observed events</th>
<th>non $W+$jets background</th>
<th>$W+$jet background</th>
<th>Extracted Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \rightarrow e\nu\gamma$</td>
<td>95</td>
<td>$10.1\pm0.8\pm1.2$</td>
<td>$16.9\pm6.4\pm7.3$</td>
<td>$67.9\pm9.5\pm7.3$</td>
</tr>
<tr>
<td>$pp \rightarrow \mu\nu\gamma$</td>
<td>97</td>
<td>$12.4\pm0.9\pm1.4$</td>
<td>$16.8\pm4.7\pm7.3$</td>
<td>$67.8\pm9.3\pm7.4$</td>
</tr>
<tr>
<td>$pp \rightarrow e^+e^-\gamma$</td>
<td>25</td>
<td>$3.8\pm3.8$</td>
<td></td>
<td>$21.2\pm5.8\pm5.8$</td>
</tr>
<tr>
<td>$pp \rightarrow \mu^+\mu^-\gamma$</td>
<td>23</td>
<td>$3.4\pm3.4$</td>
<td></td>
<td>$19.6\pm4.8\pm3.4$</td>
</tr>
</tbody>
</table>
Results

- Fiducial cross section

<table>
<thead>
<tr>
<th>reaction</th>
<th>experimental measurement</th>
<th>SM model prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma^{\text{fid}}[pb]$ (measured)</td>
<td>$\sigma^{\text{fid}}[pb]$ (predicted)</td>
</tr>
<tr>
<td>$pp \to e^+e^-\gamma$</td>
<td>$5.1 \pm 0.7(\text{stat}) \pm 0.9(\text{syst}) \pm 0.6(\text{lumi})$</td>
<td>$4.6 \pm 0.3(\text{syst})$</td>
</tr>
<tr>
<td>$pp \to \mu^+\mu^-\gamma$</td>
<td>$4.2 \pm 0.6(\text{stat}) \pm 0.7(\text{syst}) \pm 0.5(\text{lumi})$</td>
<td>$4.9 \pm 0.3(\text{syst})$</td>
</tr>
<tr>
<td>$pp \to e^+e^-\gamma$</td>
<td>$2.0 \pm 0.6(\text{stat}) \pm 0.5(\text{syst}) \pm 0.2(\text{lumi})$</td>
<td>$1.7 \pm 0.1(\text{syst})$</td>
</tr>
<tr>
<td>$pp \to \mu^+\mu^-\gamma$</td>
<td>$1.3 \pm 0.3(\text{stat}) \pm 0.3(\text{syst}) \pm 0.1(\text{lumi})$</td>
<td>$1.7 \pm 0.1(\text{syst})$</td>
</tr>
</tbody>
</table>

- Total cross section

<table>
<thead>
<tr>
<th>reaction</th>
<th>$\sigma^{\text{total}}[pb]$ (measured)</th>
<th>$\sigma^{\text{total}}[pb]$ (predicted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \to e^+e^-\gamma$</td>
<td>$73.9 \pm 10.5(\text{stat}) \pm 14.6(\text{syst}) \pm 8.1(\text{lumi})$</td>
<td>$69.0 \pm 4.6(\text{syst})$</td>
</tr>
<tr>
<td>$pp \to \mu^+\mu^-\gamma$</td>
<td>$58.6 \pm 8.2(\text{stat}) \pm 11.3(\text{syst}) \pm 6.4(\text{lumi})$</td>
<td>$69.0 \pm 4.6(\text{syst})$</td>
</tr>
<tr>
<td>$pp \to e^+e^-\gamma$</td>
<td>$16.4 \pm 4.5(\text{stat}) \pm 4.3(\text{syst}) \pm 1.8(\text{lumi})$</td>
<td>$13.8 \pm 0.9(\text{syst})$</td>
</tr>
<tr>
<td>$pp \to \mu^+\mu^-\gamma$</td>
<td>$10.6 \pm 2.6(\text{stat}) \pm 2.5(\text{syst}) \pm 1.2(\text{lumi})$</td>
<td>$13.8 \pm 0.9(\text{syst})$</td>
</tr>
</tbody>
</table>

- All cross section measurements are consistent within their uncertainties with the Standard Model expectations

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WW leptonic decay channels
**WW signature**

- **WW signal**
  - Two opposite-sign isolated high Pt leptons. Accordingly signal events are split into 3 channels:
    - $ee$, $\mu\mu$, $e\mu$
  - Large missing $E_T$ and less jet activity

- **WW Background**
  - $W$+jets, Drell-Yan, Top and Di-boson ($WZ, ZZ, W/Z\gamma$)

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Event selection

• Exactly two opposite-sign good leptons \((e, \mu)\)
  – To select di-lepton events
  – To suppress W+jets and di-boson events
• \(M_{ll}>15\text{GeV} \&\& |M_{ll}-M_Z|>10\text{GeV}\) for ee and \(\mu\mu\) channels
  – Mainly to remove Drell-Yan events
• \(E_T^{\text{miss}} > 40\text{GeV}\) in ee and \(\mu\mu\) channels, and >20GeV in em channel
  – To further remove Drell-Yan and di-boson events
• Jet veto : No jets (\(P_T>20\text{GeV}, |\eta|<3\)) present
  – To remove top events

• Number of Candidates in 35/pb
  – 8 (ee, \(\mu\mu, e\mu\) combined)
Kinematic Distributions of the W+W- candidates

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

- Data
- WW
- Drell-Yan
- Diboson
- W+jets
- top
- \( \sigma_{\text{stat+syst}} \)

\[ P_T(\text{second lepton}) \ [\text{GeV}] \]

\[ \Delta \phi(l^+l^-) \]

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

- Data
- WW
- Drell-Yan
- Diboson
- W+jets
- top
- \( \sigma_{\text{stat+syst}} \)

\[ P_T(l^+l^-) \ [\text{GeV}] \]

\[ M_T(l^+l^-E_T^{\text{miss}}) \ [\text{GeV}] \]

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Signal yield

- **Background estimation:**
  - W+jet: Data driven estimation
    * Using W+Jet control sample and di-jet sample in data
  - Drell-Yan
    * Central values are estimated using MC. Systematic uncertainties are estimated using a data driven method on Z control sample
  - Top background estimated using MC and crosschecked using data driven methods.
  - Di-boson (WZ, ZZ, W/Z+\gamma) backgrounds estimated using MC.

<table>
<thead>
<tr>
<th>Final State</th>
<th>(e^+e^-E_T^{\text{miss}})</th>
<th>(\mu^+\mu^-E_T^{\text{miss}})</th>
<th>(e^+\mu^-E_T^{\text{miss}})</th>
<th>combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed Events</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>MC WW Signal</td>
<td>0.85±0.02±0.13</td>
<td>1.74±0.04±0.24</td>
<td>4.81±0.06±0.68</td>
<td>7.40±0.07±1.05</td>
</tr>
<tr>
<td>Total Background</td>
<td>0.17±0.11±0.09</td>
<td>0.26±0.31±0.15</td>
<td>1.29±0.17±0.32</td>
<td>1.72±0.37±0.45</td>
</tr>
<tr>
<td>Signal / Background</td>
<td>5.0</td>
<td>6.7</td>
<td>3.7</td>
<td>4.3</td>
</tr>
</tbody>
</table>
Cross section

- The combined W+W- production cross-section is determined using the maximum likelihood method. The likelihood function based on Poisson statistics is constructed as

\[
F = \prod_{i=1}^{3} \frac{e^{-\left(N_{E}^{i}+N_{b}^{i}\right)}}{N_{obs}^{i}!} \left(N_{S}^{i} + N_{b}^{i}\right)^{N_{obs}^{i}}, \quad \text{where} \quad N_{S}^{i} = \sigma_{WW} \times Br^{i} \times L \times A^{i}
\]

\[
\sigma_{WW} = 40^{+20}_{-16} \text{(stat)} \pm 7 \text{(syst)} \text{ pb}
\]

- which is in good agreement with the SM NLO prediction of 46±3pb.
Conclusion

• First measurement of W/Zγ and WW production cross sections at 7 TeV performed by ATLAS using 35/pb of integrated luminosity

• The cross section measurements are in good agreement with SM NLO expectations

• The measurements are limited by statistics. The future analysis with larger dataset will be important for precision test of the SM and new physics searches.