WW, WZ and Wγ Cross Section Measurements at ATLAS

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Argonne National Laboratory

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**Introduction**

- Why are we interested in the diboson cross section measurements?
  - Precision test of SM predictions -> **anomalous triple gauge couplings (aTGC)**?
  - Extended to search for new particles: heavy bosons, technicolor particles, graviton ...
  - Better understanding the diboson backgrounds for Higgs measurements and other BSM searches.

- **Diboson processes:**
Leptonic WZ Cross Section Measurement

- **Signature:** trileptons with a pair of leptons from Z and high missing transverse energy.
- **Selections:**
  - \( p_T \) cuts: 15 GeV (two leptons from Z), 20 GeV (lepton from W)
  - \( E_T^{\text{miss}} \) > 25 GeV
  - \( m_T^W \) > 20 GeV
  - Z mass cuts: \( |m_{ll}-m_Z| < 10 \) GeV
- **Backgrounds:** Z+jets (dominant), ZZ, W/Z+\( \gamma \), top...

### Final State

<table>
<thead>
<tr>
<th></th>
<th>eee</th>
<th>ee( \mu )</th>
<th>e( \mu )( \mu )</th>
<th>( \mu \mu \mu )</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed</strong></td>
<td>192</td>
<td>270</td>
<td>298</td>
<td>334</td>
<td>1094</td>
</tr>
<tr>
<td><strong>Background</strong></td>
<td>60 ( \pm 4 ) ( \pm 11 )</td>
<td>55 ( \pm 4 ) ( \pm 10 )</td>
<td>87 ( \pm 5 ) ( \pm 11 )</td>
<td>75 ( \pm 5 ) ( \pm 14 )</td>
<td>277 ( \pm 9 ) ( \pm 24 )</td>
</tr>
<tr>
<td><strong>Expected signal</strong></td>
<td>144 ( \pm 12 )</td>
<td>199 ( \pm 16 )</td>
<td>200 ( \pm 16 )</td>
<td>276 ( \pm 21 )</td>
<td>819 ( \pm 34 )</td>
</tr>
<tr>
<td><strong>Expected S/B</strong></td>
<td>2.4</td>
<td>3.7</td>
<td>2.3</td>
<td>3.7</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**13 fb\(^{-1}\), 8 TeV**

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**ATLAS Preliminary**
\( \sqrt{s} = 8 \) TeV, \( \int L dt = 13 \) fb\(^{-1}\)
Comparison with the SM prediction shows good agreement.

The unfolding technique, the measured quantity must be an estimate of the true variable distribution is correctly reproduced from a general expression for the effective Lagrangian for the Standard Model (SM). The data are therefore divided into six bins in m_{WZ} of width 30 GeV followed by a wide bin that includes 180–2000 GeV.

### Total cross sections:

<table>
<thead>
<tr>
<th></th>
<th>Measured (pb)</th>
<th>SM expectation (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>7 TeV</strong></td>
<td>19.0^{+1.4}_{-1.3}(stat.) ± 0.9(syst.) ± 0.4(lumi.)</td>
<td>17.6^{+1.1}_{-1.0}</td>
</tr>
<tr>
<td><strong>8 TeV</strong></td>
<td>20.3^{+0.8}<em>{-0.7}(stat.) +^{1.2}</em>{-1.1}(syst.) +^{0.7}_{-0.6}(lumi.)</td>
<td>20.3 ± 0.8</td>
</tr>
</tbody>
</table>
Leptonic WW Cross Section Measurements

- Candidate events: two opposite sign charged leptons and large missing transverse energy
- Backgrounds: dominated by Drell-Yan and tops
  - Drell-Yan: suppressed by modified missing transverse energy, Z mass and $p_T$(ll) cuts
  - Tops: reject events with at least one jet

![Graphs showing leptonic WW cross section measurements](image-url)
## WW Cross Sections

### Measured total cross section in good agreement with SM NLO prediction.

<table>
<thead>
<tr>
<th></th>
<th>Measured (pb)</th>
<th>SM prediction (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee</td>
<td>$46.9 \pm 5.7 \pm 8.2 \pm 1.8$</td>
<td>$44.7^{+2.1}_{-1.9}$</td>
</tr>
<tr>
<td>(\mu\mu)</td>
<td>$56.7 \pm 4.5 \pm 5.5 \pm 2.2$</td>
<td>$44.7^{+2.1}_{-1.9}$</td>
</tr>
<tr>
<td>e(\mu)</td>
<td>$51.1 \pm 2.4 \pm 4.2 \pm 2.0$</td>
<td>$44.7^{+2.1}_{-1.9}$</td>
</tr>
<tr>
<td>Combined</td>
<td>$51.9 \pm 2.0 \pm 3.9 \pm 2.0$</td>
<td>$44.7^{+2.1}_{-1.9}$</td>
</tr>
</tbody>
</table>
**WW+WZ Semileptonic Analysis**

- Require one lepton, high missing transverse energy and two jets
  - Measure combine WW+WZ cross section
  - Better σ x BR (~6 times compared to fully leptonic channel)
  - Similar signal to VH(bbar).

- Challenging analysis with high background from W+jets (S/B < 3%)
- Need to understand the shape of invariant mass of two jets

### Results

**Sigma (WW+WZ):** $72 \pm 9$ (stat) $\pm 15$ (syst.) $\pm 13$ (MC stat) pb

**SM prediction:** $63.4 \pm 2.6$ pb

<table>
<thead>
<tr>
<th>Entries / 5 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>8000</td>
</tr>
<tr>
<td>Data</td>
</tr>
</tbody>
</table>

**Data - MC**

**Signal significance:**
- Observe: $3.3\sigma$
- Expected $3.0\sigma$

**Figure 4:** Di-jet invariant mass distribution of reconstructed events.

**Figure 5:** Background subtracted di-jet invariant mass distribution of reconstructed events.
**Wγ Cross Section Measurement**

- **Signature:** a lepton, high missing transverse energy and a gamma.
- **Major backgrounds** from $W$+jets, $γ$+jets and $Z$+X (electron channel).

Measure inclusive ($N_{\text{jet}} \geq 0$) and exclusive (no jets with $E_T > 30$ GeV and $|\eta| < 4.4$) cross sections -> better comparison to predicted cross section from MCFM.
Anomalous Triple Gauge Couplings

- Effective Lagrangian to describe anomalies at WWV vertex

\[ L/g_{WWV} = ig_1^V(W_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{*\mu} V^\nu) + ik^V W_{\mu}^* W_{V} V^{\mu\nu} + \frac{i\lambda^V}{M_W^2} W_{\rho\mu}^* W_{\rho} V^{\mu\nu} \]

- In SM:
  - \( g_1^Z = \kappa_Z = \kappa_\gamma = 1 \)
  - \( \lambda_Z = \lambda_\gamma = 0 \)

- Form factor to reserve the unitarity

\[ \alpha(\hat{s}) = \frac{\alpha_0}{(1 + \hat{s}/\Lambda^2)^n} \]

- aTGC effects enhance the rate at high scale (pT, invariant mass) or modify the angular distributions
Use reconstructed leading lepton $p_T$ distribution to obtain 95% CL cross section limits.

Compare 95% CL limits on the couplings between experiments
- Tighter than Tevatron (higher energy)
- Approaching the precision of LEP combined results
aTGC Limits from WZ Measurement

aTGC parameters constrained using 7 TeV data

- Comparable with Tevatron results
aTGC Limits from $W\gamma$ Measurement

- aTGC effect is shown at high gamma $E_T$ bins.
- Comparable to Tevatron results.

**ATLAS**

- ATLAS, $\sqrt{s} = 7$ TeV
- D0 ($W\gamma$), $\sqrt{s} = 1.96$ TeV

<table>
<thead>
<tr>
<th>Process</th>
<th>ATLAS</th>
<th>D0 ($W\gamma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \rightarrow l\nu\gamma$</td>
<td>$4.6$ fb$^{-1}$, $\Lambda = \infty$</td>
<td>$4.2$ fb$^{-1}$, $\Lambda = 2$ TeV</td>
</tr>
<tr>
<td>95% CL</td>
<td>ATLAS, $\sqrt{s} = 7$ TeV</td>
<td>D0 ($WW, WZ, W\gamma$), $\sqrt{s} = 1.96$ TeV</td>
</tr>
</tbody>
</table>

- $\Lambda = 6$ TeV
- $8.6$ fb$^{-1}$, $\Lambda = 2$ TeV

[Graph showing data points for $\lambda_\gamma$ and $\Delta \kappa_\gamma$]
Summary

- Cross section measurements of WW, WZ and Wγ are performed using 7 TeV and 8 TeV proton-proton collision data.
- No deviation from the SM expectation is found in these final states and the stringent limits on the aQGC couplings are set.
- More 8 TeV results are coming: update the cross sections and aTGC limits to full 2012 data.
Backup