Measurement of WW Production with the ATLAS detector at $\sqrt{s} = 8$ TeV

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On behalf of the ATLAS collaboration

Theory
Event Selection
Backgrounds
Results
Measurements of WW Production

- Proves non-Abelian structure of electroweak interaction
  → ZWW vertex fixes unitarity problem

- Important test of the Standard Model

- Sensitive to new physics due to triple gauge couplings

- Previous measurement from LHC showed slight enhancement of data over theoretical predictions

![Graph showing data compared to theoretical predictions]
Theoretical Predictions

MCFM NLO contains *triple gauge coupling* (enhanced cross section for high $p_T$ and new physics)

MCFM LO CT10 large k-factor?

NNLO MSTW2008 LHC Higgs XS WS

*Contributions neglected in this SM prediction*

- $qq \rightarrow WW$ (NLO → NNLO+NNLL k-factor) + 1.6 pb
- $gg \rightarrow WW$ (LO → NNLO+NNLL k-factor) + 1.4 up to +2.8 pb
- Electroweak corrections − 0.5 pb
- $\gamma\gamma$-induced $WW$ + 0.5 pb
- Vector boson scattering + 0.5 pb
- Double parton interaction + 0.04 pb

Total sum of: + 3.5 to 4.9 pb

Standard Model prediction: $58.7^{+1.0}_{-1.1}$ (PDF) $^{+3.1}_{-2.7}$ (total) pb
ATLAS Detector

4π-general purpose detector
excellent particle ID and missing ET performance

Data taken at \( \sqrt{s} = 8 \text{ TeV} \)
integrated luminosity \( \int L \, dt = 20.3 \text{ fb}^{-1} \)

muons and electrons identified and well-isolated
di- and single lepton trigger
\( p_T > 20 \) and 25 GeV
(subleading, leading)

Missing energy
vectorial sum of calorimeter deposits
\( E_{T,\text{Miss,rel}}>45 \text{ GeV} \) (ee,\( \mu\mu \))
\( E_{T,\text{Miss,rel}}>15 \text{ GeV} \) (e\( \mu \))

Missing momentum
vectorial sum of tracks
pileup-robust
\( p_T^{\text{Miss}}> 45 \) and 20 GeV
\( \Delta \phi(p_{T,\text{Miss}},E_{T,\text{Miss}})<0.3/0.6 \)

\[ E_{T,\text{Miss,rel}} = E_{T,\text{Miss}} \sin(\Delta \phi_{E_{T,\text{Miss}}-\text{jets,lep}}) \]
(if \( \Delta \phi < \pi/2 \) else \( E_{T,\text{Miss,rel}} = E_{T,\text{Miss}} \))

Event Selection
Event Selection

- Opposite sign requirement for leptons, outside $Z$ mass window
- Top background dominates, rejected by Jet Veto requirement
- No jets with $p_T>25$ GeV within $|\eta|<4.5$
- Data driven determination of $Z$, top and $W+$jets events
Data-driven Backgrounds

- **Top background (12 – 14 %):**
  Jet veto efficiency applied to MC events to obtain normalization determined from a data control sample of top events with large scalar sum of lepton and jet $p_T$

- **W+jets background (eμ 4% / ee+μμ 1%):**
  extract normalization and shape efficiencies for fake and real leptons for loose and tight cuts determine signal and background components with matrix method

- **Z+jets background (eμ 0.3% / ee+μμ 1%):**
  fit to data control region to extract normalization
Backgrounds from Dibosons

- Diboson background determined using MC simulation $WZ$, $ZZ$, $W\gamma$ and $W\gamma^*$

- Validation region of same sign events with large $W+jets$ contribution
Distributions

- 6636 WW candidate events observed after full selection (5067 eμ, 594 ee, 975 μμ)

- WW MC signal scaled to measured cross sections

- Shapes well described
Extraction of the cross section

\[
\sigma(pp \rightarrow WW) = \frac{N_{\text{data}} - N_{\text{bg}}}{A_{WW} \times C_{WW} \times \mathcal{L} \times \text{Br}}
\]

Total Cross section

Acceptance correction

\[
\begin{align*}
\text{ee: } 0.03 \\
\text{\(\mu\mu\): } 0.04 \\
\text{e\(\mu\): } 0.11
\end{align*}
\]

Branching ratio (0.108) \times (0.108)

Combination of channels performed using likelihood fit

\[
\begin{align*}
\text{E}_{T}^{\text{Miss}} \text{reconstruction} & \quad (2\text{-}4\%) \\
\text{Background} & \quad (3\text{-}6 \%) \\
\text{Jet energy} & \quad (2\%) \\
\text{Jet-veto requirement} & \quad (4\text{-}5\%) \\
\text{Luminosity} & \quad (2.5\%) \\
\text{Total:} & \quad \sim 7.5\%
\end{align*}
\]

<table>
<thead>
<tr>
<th>Channel</th>
<th>(\sigma_{WW}^{\text{total}} [\text{pb}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee</td>
<td>(68.6^{+4.2}<em>{-4.1} \text{ (stat)} +^{7.8}</em>{-6.7} \text{ (syst)} +^{2.1}_{-2.0} \text{ (lumi)})</td>
</tr>
<tr>
<td>(\mu\mu)</td>
<td>(68.6^{+3.1}<em>{-3.0} \text{ (stat)} +^{6.6}</em>{-5.6} \text{ (syst)} +^{2.1}_{-2.0} \text{ (lumi)})</td>
</tr>
<tr>
<td>e(\mu)</td>
<td>(71.4^{+1.3}<em>{-1.3} \text{ (stat)} +^{5.0}</em>{-4.4} \text{ (syst)} +^{2.1}_{-2.0} \text{ (lumi)})</td>
</tr>
<tr>
<td>Combined</td>
<td>(71.4^{+1.2}<em>{-1.2} \text{ (stat)} +^{5.0}</em>{-4.4} \text{ (syst)} +^{2.2}_{-2.1} \text{ (lumi)})</td>
</tr>
</tbody>
</table>
Combination

- Good agreement between the channels
- $e\mu$ dominates due to smaller uncertainty and larger statistics

Results

$$\sigma_{WW}^{\text{tot}} = 71.4^{+1.2}_{-1.2} \text{ (stat)} + 5.0^{+4.4}_{-4.4} \text{ (syst)} + 2.2^{+3.1}_{-2.1} \text{ (lumi)} \text{ pb}$$

Standard Model prediction: $58.7^{+1.0}_{-1.1} \text{ (PDF)} + 3.1^{+3.1}_{-2.7} \text{ (total)} \text{ pb}$
Results

- Some variations observed for different PDF predictions
- Global data CT10 PDF chosen for its generally good agreement with other LHC data
- PDF using LHC + HERA data only gives better agreement
Conclusion

- WW cross section measured at $\sqrt{s} = 8$ TeV using 20.3 fb$^{-1}$

- Robust measurement with data-driven background estimations

- Result somewhat higher than prediction

- Some contributions neglected: Missing higher order corrections
  Could amount to several pb

Results public under ATLAS-CONF-2014-033
http://cds.cern.ch/record/1728248
Thank you!