Measurement of WW/WZ production in semileptonic decay channels and search for anomalous gauge couplings with the ATLAS detector at 8 TeV

Margherita Spalla, on behalf of the ATLAS Collaboration
Aims of the analysis:
- Diboson cross section measurement.
- Constrain new physics through limits on anomalous Triple Gauge Couplings (aTGC)
- We use 20.2 fb⁻¹ collision data at 8 TeV

Two separate analysis channels for two hadronic W/Z topologies:
- **Resolved topology:**
  » Hadronic W/Z decay: two “standard” jets (W/Z → jj)
  » Provides the largest significance in cross section measurement
- **Boosted topology:**
  » Hadronic W/Z decay: one single large-R jet (W/Z → J)
    - W/Z produced with a large Lorentz boost
Identifying $WW/WZ \rightarrow l \nu q\bar{q}$

1. **Select leptonic $W$**

   - Exactly one ELECTRON or MUON:
     - with large $p_T > 30$ GeV
     - in central $\eta$ region
     - isolated

   - Missing transverse energy:
     - $E_T^{\text{miss}} > 40$ GeV (resolved)

2. **Select hadronic $W/Z$**

   - Resolved channel: $R=0.4$ anti-$K_t$ jets
     - Exactly two separate jets of $p_T > 25$ GeV
     - Further cuts on di-jet and lepton kinematics

Event display reference:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplaysFromHiggsSearches
Identifying WW/WZ$\rightarrow$llνqq

1. **Select leptonic W**
   - Exactly one ELECTRON or MUON:
     - with large $p_T > 30$ GeV
     - in central $\eta$ region
     - isolated

2. **Select hadronic W/Z**
   - **Boosted channel**: $R=1$ anti-$K_t$ jet (*large-R jet*)
     - Exactly one large-R jet of high $p_T$: $p_T > 200$ GeV
     - No additional $R=0.4$ anti-$K_t$ jets (to reduce top background)

**Missing transverse energy**:
- $E_T^{\text{miss}} > 50$ GeV (boosted)

**NOTE**: Boosted and Resolved phase spaces are **not** orthogonal

Event display reference:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Physics

18/04/2017
Margherita Spalla
Contributions to final state

- **Signal:**
  - WW ~80%, WZ ~20%
  - Cannot separate the WW and WZ resonances

- **W/Z + jets (V+jets):**
  - Largest component
    » ~84% of total selected events

- **Top**
  - top/anti-top and single top
  - contributes to the visible peak

- **Minor backgrounds**
  - QCD multijet:
    » data-driven method based on modified event selection.
  - ZZ: ~ negligible
    » only considered for resolved

ATLAS Simulation Preliminary

\[ m_{jj} \text{ [GeV]} \]

- Shape normalised to unity
- Fraction of events / 5 GeV

\[ m_{JJ} \text{ [GeV]} \]

- Shape normalised to unity
- Fraction of events / 5 GeV

Figure 8:
(a) Comparison of the \( m_{jj} \) distributions for the WW and WZ processes, in the \( WV \rightarrow \nu j j \) channel.
(b) Comparison of the \( m_{JJ} \) distributions for the WW and WZ processes, in the \( WV \rightarrow \nu J \) channel.
Cross section measurement

Cross section is measured in the **fiducial phase space**.
- Kinematic acceptance of measurement.
- Defined from MonteCarlo particle-level objects.
  - Nonzero boosted/resolved overlap

Cross section extraction
- From Binned Maximum Likelihood fit
  - Resolved: di-jet invariant mass $m_{jj}$
  - Boosted: large-R jet mass $m_J$

Largest systematics
- MonteCarlo modelling: generator comparison
  - Resolved: Top, ~13%
  - Boosted: $W/Z+$jets, ~60%

Cross section

Cross section

Cross section

Cross section

Cross section

Cross section

Cross section
Cross section results

Resolved
Significance
Expected: 5.2 \( \sigma \)
Observed: 4.5 \( \sigma \)

Boosted
Significance
Expected: 2.3 \( \sigma \)
Observed: 1.3 \( \sigma \)

Resolved
Boosted

Cross section results

Resolved
Boosted

Resolved
Boosted

Resolved
Boosted

Resolved
Boosted

Resolved
Boosted

Resolved
Boosted

Resolved
Boosted
Cross section results

**Resolved**

Significance

Expected: 5.2 \( \sigma \)

Observed: 4.5 \( \sigma \)

\[ \sigma_{\text{fid}}(WV \rightarrow \ell \nu jj, \text{observed}) = 209 \pm 28(\text{stat}) \pm 45(\text{sys}) \text{ fb} \]

\[ \sigma_{\text{fid}}(WV \rightarrow \ell \nu jj, \text{theory}) = 225 \pm 13 \text{ fb} \]

**Boosted**

Significance

Expected: 2.3 \( \sigma \)

Observed: 1.3 \( \sigma \)

\[ \sigma_{\text{fid}}(WV \rightarrow \ell \nu J, \text{observed}) = 30 \pm 11(\text{stat}) \pm 22(\text{sys}) \text{ fb} \]

\[ \sigma_{\text{fid}}(WV \rightarrow \ell \nu J, \text{theory}) = 58 \pm 15 \text{ fb} \]
Search for anomalous Triple Gauge Couplings (aTGC)

- Contribution from new physics: vector boson couplings may deviate from Standard Model.
- Model independent interpretations
  - Here results in Effective Field Theory framework
    - Three free parameters
- aTGC tend to enhance the event rate at high $p_T$
- Strategy:
  - Cut on $65 \text{ GeV} < m_{jj}/m_J < 95 \text{ GeV}$
  - Maximum Likelihood fit of $p_T(jj)$ or $p_T(J)$
    - aTGC modelled with FullSim MonteCarlo
    - Resolved only: $m_{jj}$ sideband control region

\[ \Lambda = \text{new physics scale} \]
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aTGC limits: 95% Confidence Interval

- Best sensitivity from boosted
- Boosted results similar to best previously published constraints
  - leptonic WW and WZ at 8 TeV (ATLAS/CMS)
  - CMS semileptonic WW/WZ at 8 TeV
Summary

- Analysis exploits both resolved and boosted topologies

- $4.5\,\sigma$ evidence of resolved WW/WZ
  - $1.3\,\sigma$ in boosted channel
- Measured fiducial cross sections in agreement with SM (NLO)

- Constraint on aTGC
  - Boosted signature provides limits similar to current best published limits

Ref. to shown plots: STDM-2015-23 (paper in preparation)
Backup
Data-driven corrections to MC: resolved channel

- Applied to W/Z+jets only
- Reweighting as a function of:
  - $\Delta \phi (jj)$
  - $p_T(j_1)$
- Order of 5-10%
- Derived in $m_{jj}$ sideband control region:
  
  $m'_{jj} \not\in [65, 95]\text{GeV}$
Data-driven corrections to MC: boosted channel

- Applied to top and W/Z+jets
- Constant Scale Factors (SF)
  - Top correction: order of 10%
  - W/Z+jets correction: order of 15%
  - each derived in specific control region

- W/Z + jets control region:
  - m_J sidebands.
  - m_J ≠ [65, 95] GeV

- Top control region:
  - at least one b-tagged small-R jet,
  - not overlapping with the large-R jet (ΔR(j,J)>1.)
QCD multijet estimation

- Template shape estimated from QCD control region
  » About 2.5% of total background

- Template normalization from \( E_{\text{Tmiss}} \) fit
  - multijet \( E_{\text{Tmiss}} \) template: from QCD control region
  - \( E_{\text{Tmiss}} \) templates for other processes:
    » WW/WZ, W/Z+jets, top
    » from MC
    » summed in a single template in the fit
  - Resulting normalization is scaled by efficiency of dropped cuts

QCD control region
- Electron channel: invert electron quality criteria and isolation
- Muon channel: invert muon impact parameter and isolation

<table>
<thead>
<tr>
<th>( E_{\text{Tmiss}} ) FIT REGION</th>
<th>Resolved</th>
<th>Boosted</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cuts but:</td>
<td></td>
<td></td>
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<tr>
<td>( E_{\text{Tmiss}} )</td>
<td></td>
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<tr>
<td>( \Delta \eta (j,j) )</td>
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<tr>
<td>( \Delta \phi (E_{\text{Tmiss}},j_1) ) (μ ch. only)</td>
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<tr>
<td>( m_T (μ ch. only) )</td>
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**NOTE:**
In boosted analysis, QCD multijet is negligible in muon channel
Cross section extraction

**Number of signal events**
- From Binned Maximum Likelihood fit
- Fit variable:
  - Resolved: di-jet invariant mass $m_{jj}$
  - Boosted: large-R jet mass $m_{j}$

$$\sigma_{\text{fid}} = \frac{N^{WV}}{L \cdot D_{\text{fid}}}$$

- **$L$: integrated luminosity**
- **$D_{\text{fid}}$: corrects for** the difference between fiducial phase space and the actual selection on reconstructed objects.

$$D_{\text{fid}} \sim \frac{N^{WV}[\text{reco, selected}]}{N^{WV}[WV \rightarrow \ell\nuqq, \text{inFiducial}]}$$
Systematic uncertainties

• Detector-related uncertainties
  • Larger component:
    » Resolved: small-R jet energy scale / resolution
    » Boosted: large-R jet energy and mass scale / resolution

• Modelling uncertainties
  » Generator comparison / theoretical uncertainties on process cross section
  » Data-driven SF where applicable
  • Larger contribution
    » Resolved: Top / signal modelling
    » Boosted Top / W/Z+jets modelling
aTGC parameters in Effective Field Theory

- EFT assumed to be valid below an energy scale $\Lambda$
- Introduces three CP-conserving dimension-six operators
  - Their coupling constants are the aTGC parameters of interest

\[
O_W = (D_\mu \Phi)\dagger W^{\mu\nu} (D_\nu \Phi),
\]
\[
O_B = (D_\mu \Phi)\dagger B^{\mu\nu} (D_\nu \Phi),
\]
\[
O_{WWW} = Tr[W_{\mu\nu} W^{\nu\rho} W^{\mu}_\rho].
\]

$\Phi = $ Higgs doublet
$B^{\mu\nu}, W^{\mu\nu} =$ combinations of derivatives of gauge-boson fields

$\Lambda =$ new physics scale

References

Annals Phys. 335 (2013) 21

Alternative description: effective Lagrangian, not discussed in this talk
aTGC results from ATLAS leptonic WW at 8 TeV

Figure 16: The expected and observed 95% confidence-level contours for limits in the plane of two simultaneously non-zero parameters in the effective field theory framework. In each case, only the two effective field theory couplings under study are allowed to differ from zero.

Ref: JHEP 09 (2016) 029
aTGC results from this analysis (for comparison)

Figure 7: The 95% confidence-level regions for combinations of two EFT parameters. (a) $c_{WWW}/\Lambda^2$ and $c_{B}/\Lambda^2$, (b) $c_{WWW}/\Lambda^2$ and $c_{W}/\Lambda^2$, (c) $c_{B}/\Lambda^2$ and $c_{W}/\Lambda^2$. The expected and observed confidence regions are shown for the $WV\rightarrow l\nu$ channel and the $WV\rightarrow lJ$ channel. When computing the confidence regions for two parameters, the third EFT parameter is held fixed to zero.