MEASUREMENT OF TOTAL ZZ→4l PRODUCTION CROSS SECTION AND LIMITS ON ANOMALOUS TRIPLE GAUGE COUPLINGS WITH THE ATLAS DETECTOR

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Outline:

- Introduction to the measurement
- Analysis overview (Event selection, Background estimate, ZZ candidate distributions)
- ZZ Cross section result with 4.7 fb$^{-1}$
- Limits on aTGC with 1 fb$^{-1}$
- Conclusions and future perspectives
INTRODUCTION

• ZZ production is a rare process but with clear signature and very low background

• Irreducible background to the $H\rightarrow ZZ\rightarrow 4l$ channel

• Stringent SM test of the structure of the electroweak sector

• Gluon-gluon fusion contributions is 6.3% of the cross section

Public results on the topic:


4.7 fb$^{-1}$ measurement: ATLAS-CONF-2012-026 https://cdsweb.cern.ch/record/1430735
ATLAS DETECTOR & OBJECT SELECTION

- All main ATLAS subsystems are used to perform the measurement

**Muons**
- Combine Muon Spectrometer tracks with Inner Detector tracks
- Kinematic acceptance: $|\eta| < 2.7$, $p_T > 7$ GeV

**Electrons**
- Combine electromagnetic clusters with Inner Detector tracks
- Kinematic acceptance: $|\eta| < 2.47$, $p_T > 7$ GeV

- Apply requirements to leptons on ID track isolation, calorimeter isolation and longitudinal and transverse impact parameters to reject fake leptons

- Leading lepton must have $p_T > 25 (20)$ GeV for electrons (muons)
EVENT SELECTION

Trigger using single electron and muon triggers, with pT thresholds 18–22 GeV

Select events with exactly four leptons passing the object selection described previously.

Form two same-flavour opposite-sign pairs, choosing the pairing which minimises sum of distances from Z mass:

\[ |m_{12} - m_Z| + |m_{34} - m_Z| \]

Both pairs required to be on-shell: 66 < m_Z < 116 GeV

Display of a selected ZZ→μ⁺μ⁻μ⁺μ⁻ event with m⁴μ = 239.7 GeV and Pt⁴μ = 22.0 GeV
BACKGROUND ESTIMATE

Main backgrounds are $Z\rightarrow l^+l^-$ with additional jets or photons, $t\bar{t}$, single-top and other diboson processes ($WW$, $WZ$). All involve one or more fake leptons.

There are True Leptons (T) and objects that can Fake Leptons (F), with a probability $f$ for the fake object to be identified as a lepton.

We can measure the number of selected leptons ($L$) and number of lepton-like jets that fail one or two of the lepton ID cuts ($J$).

Fake Factors $FF$, the ratio of *selected* leptons to *lepton-like* jets in data, are measured using Z tag method.

The background is:

$$N_{4\ell}^{\text{fake}} = N_{TTFF} \times f \times f + N_{TTTF} \times f$$

The estimated background is:

$$N_{4\ell}^{\text{fake}} = (N_{LLLL} - N_{Z\gamma\gamma}) \times FF - N_{LLJJ} \times FF^2$$

<table>
<thead>
<tr>
<th>Final state</th>
<th>$\mu\mu\mu\mu$</th>
<th>$ee\mu\mu$</th>
<th>combined ($\ell\ell\ell\ell$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bkg(d.d.)</td>
<td>$0.6^{+0.7+0.8}_{-0.6-0.6}$</td>
<td>$&lt; 0.5^{+0.2}_{-0.3}$</td>
<td>$0.3^{+0.9+0.8}_{-0.3-0.3}$</td>
</tr>
<tr>
<td>Bkg(MC)</td>
<td>$0.3 \pm 0.3$</td>
<td>$&lt; 0.8$</td>
<td>$0.6 \pm 0.6$</td>
</tr>
</tbody>
</table>

Good agreement between Data Driven and MC background estimation.
• Observed candidate events in 4.7 fb$^{-1}$ of data:
  - 62 candidates:
    15 $\text{eee} \quad 21 \mu\mu\mu \quad 26 \text{ee} \mu\mu$
  - Predicted background:
    $0.7^{+1.3}_{-0.7} \text{ (stat)} +^{1.3}_{-0.7} \text{ (syst)}$
  - Predicted signal (MC):
    $53.2 \pm 1.1 \text{ (stat)} \pm 1.9 \text{ (syst)}$

• Sherpa (LO) used for signal predictions, scaled to predicted cross section of MCFM (NLO)
  - Cross checked with Pythia and gg2ZZ and found to be consistent

• Dominant systematics arise from uncertainty on lepton identification efficiencies
  - Evaluate using Tag and Probe measurements on large samples of Z$\rightarrow$ll events
CANDIDATE DISTRIBUTIONS

- Invariant mass (left) and transverse momentum (right) of the four lepton system
- Good agreement between data and Monte–Carlo
**ZZ→4l CROSS SECTION MEASUREMENT/1**

- First we measure cross section in a fiducial phase space close to experimental selection.

\[
\sigma_{ZZ\to4l}^{fid} = \frac{N_{obs} - N_{bkg}}{L \cdot C_{ZZ}}
\]

**Fiducial region:**
- \( ZZ\to l^+ l^- l'^+ l'^- \) (\( l = e, \mu \))
- Lepton Pt > 7 GeV
- Lepton \(|\eta| < 2.7\)
- Both Z: \( 66 < M_Z < 116 \) GeV

\[
C_{ZZ} = \frac{N_{MC \text{ Pass All Cuts Reconstructed } ZZ\to lll'l'} \times SF}{N_{MC \text{ Fiducial Volume Generated } ZZ\to lll'l'}}
\]

- First uncertainty is statistical, the second is systematics.

- Systematics uncertainty is mostly due to e and mu reconstruction ID and isolation efficiencies (~3.5 %)

<table>
<thead>
<tr>
<th>Channel</th>
<th>( C_{ZZ} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>eeee</td>
<td>0.4661 ± 0.0163 ± 0.0361</td>
</tr>
<tr>
<td>μμμμμ</td>
<td>0.8097 ± 0.0135 ± 0.0158</td>
</tr>
<tr>
<td>eεμμμ</td>
<td>0.6036 ± 0.0112 ± 0.0232</td>
</tr>
<tr>
<td>llll</td>
<td>0.6190 ± 0.0160 ± 0.0215</td>
</tr>
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</table>
**ZZ→4l CROSS SECTION MEASUREMENT/2**

- Then we extrapolate to the total cross-section, correcting for the acceptance ($A_{ZZ}$) of the fiducial cuts estimated using the MCFM NLO generator and the $Z\rightarrow ll$ branching ratios.

$$
\sigma_{ZZ→4l}^{fid} = \frac{N_{obs} - N_{bkg}}{L \cdot C_{ZZ}}
$$

$$
\sigma_{ZZ}^{tot} = \frac{N_{obs} - N_{bkg}}{L \cdot BR(ZZ→4l) \cdot A_{ZZ} \cdot C_{ZZ}}
$$

$$
A_{ZZ} = \frac{N_{MC \ Fiducial \ Volume \ Generated \ ZZ→\ell\ell\ell\ell'}}{N_{MC \ All \ Generated \ ZZ→\ell\ell\ell\ell'}}
$$

Fiducial Volume is the same for each channel so $A_{ZZ}$ is the same:

$$
A_{ZZ} = 0.6484 \pm 0.0117
$$

(systematic uncertainty 1.8%)

$$
\sigma_{ZZ→\ell^+\ell^-\ell^+\ell^-}^{fid} = 21.2^{+3.2}_{-2.7} \text{ (stat)}^{+1.0}_{-0.9} \text{ (syst)} \pm 0.8 \text{ (lumi) fb}
$$

$$
\sigma_{ZZ}^{tot} = 7.2^{+1.1}_{-0.9} \text{ (stat)}^{+0.4}_{-0.3} \text{ (syst)} \pm 0.3 \text{ (lumi) pb}
$$

Observed total cross section is consistent with the Standard Model cross section, calculated with MCFM and PDF set MSTW2008, of $6.5^{+0.3}_{-0.2} \text{ pb}$.
Anomalous Triple Gauge Coupling (aTGC)

Search for general $ZZV$ couplings where $V = (Z, γ)$, introduced using an effective Lagrangian

$$L = -\frac{e}{M_Z^2} \left[ f_4^V (\partial_\mu V^{\mu \beta}) Z_\alpha (\partial^\alpha Z_\beta) + f_5^V (\partial^\sigma V_{\sigma \mu}) \tilde{Z}^{\mu \beta} Z_\beta \right]$$

- Couplings parameterised by two CP-violating ($f_4^V$) and two CP-conserving ($f_5^V$) complex parameters. All are zero in the SM.

- Signature for aTGCs is enhanced cross section at high energies and large scattering angles $\Rightarrow$ observables proportional to $M_{ZZ}$, $P_{T, ZZ}$ sensitive to aTGCs.
- Limits on aTGCs set using \( ZZ \rightarrow 4l \) cross section measured with the first \( 1 \text{ fb}^{-1} \) of the 2011 dataset using the observed number of events only.

- Limits are comparable with, or tighter than, those derived with measurements from LEP and the Tevatron.

<table>
<thead>
<tr>
<th>Coupling 95% CI</th>
<th>( f_4^Y )</th>
<th>( f_4^Z )</th>
<th>( f_5^Y )</th>
<th>( f_5^Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Lambda = 2 \text{ TeV} )</td>
<td>([-0.15, 0.15])</td>
<td>([-0.12, 0.12])</td>
<td>([-0.15, 0.15])</td>
<td>([-0.13, 0.13])</td>
</tr>
<tr>
<td>( \Lambda = \infty )</td>
<td>([-0.08, 0.08])</td>
<td>([-0.07, 0.07])</td>
<td>([-0.08, 0.08])</td>
<td>([-0.07, 0.07])</td>
</tr>
</tbody>
</table>
Conclusions and Future Perspectives

- ZZ cross section measurement provides a stringent SM test in the electroweak sector

- ZZ→4l cross section measurement with 4.7 fb⁻¹ of data using the ATLAS detector has been presented. Value obtained is consistent with SM prediction

- Limits on aTGC set using cross-section measured with 1 fb⁻¹ statistics show no deviation from SM prediction

- Differential cross-section measurements

- Update aTGC using full 2011 dataset and differential distributions

- Push detector acceptance even further including forward electrons and calorimeter tagged muons