Measurement of the diboson production cross sections at 8TeV and 13TeV and limits on anomalous triple gauge couplings with the ATLAS detector

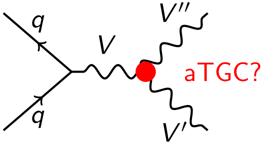
Angela Burger
LAPP Annecy

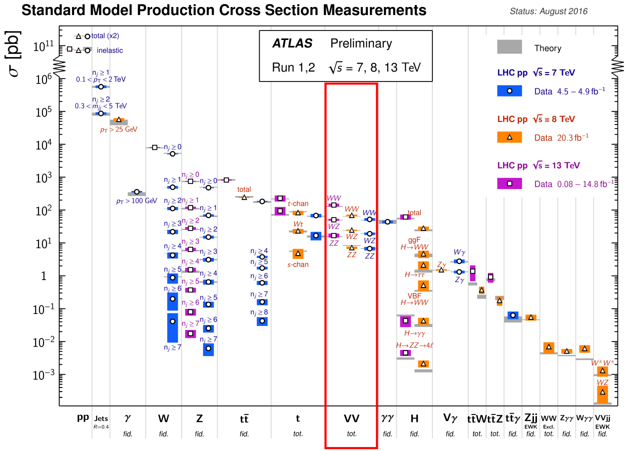
on behalf of the ATLAS collaboration

DIS 2017
Birmingham

06.04.17

- Test gauge structure of the Standard Model
- Check validity of Standard Model theory predictions
- Probe new physics beyond the reach of the LHC in a model-independent way via anomalous triple gauge couplings (aTGCs)





Focus on:

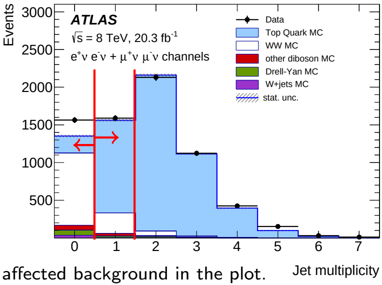
- WW @ 13 TeV (+0 jets), @ 8 TeV (0 and 1 jet associated production)
- WZ @ 8 and 13 TeV
- ZZ @ 8 and 13 TeV
- aTGC limits

W^+W^- cross section measurements @ 8 & 13 TeV

W^+W^- - Measurement strategy @ 8 TeV

- $W^+W^- \to \ell\nu\ell'\nu'$ $(\ell,\ell' = e,\mu)$
- Jet veto (p_T^{jet} >25 GeV) to suppress dominant top background ("0jet")
- Measure WW+1jet ("1jet"), decrease experimental uncertainty by combining "0&1jet" measurement and compare to improved theory predictions
- WW+1jet measurement only in $e\nu\mu\nu$ channel (lowest background, highest signal acceptance)
- Event selection in "0&1 jet" analyses very similar to facilitate combination ($\sigma_{fid}^{\leq 1jet}$)

Selection cut	$e\mu$		$ee/\mu\mu$
	"0jet"	"1jet"	"0jet"
Number of additional leptons ($p_T > 7$ GeV)	0	0	0
m_{ll} [GeV]	> 10	> 10	> 15
$\lvert m_Z - m_{ll}\rvert$[GeV]	-	-	> 15
$E_{T,Rel}^{miss}$ [GeV]	> 20	> 20	> 45
p_T^{miss} [GeV]	> 20	> 20	> 45
$\Delta\Phi_{E_T^{miss},p_T^{miss}}$	< 0.6	< 2.0	< 0.3
Number of jets (p_T >25 GeV)	0	1	0



Note: Color scheme of cuts on the table corresponds to color of affected background in the plot.

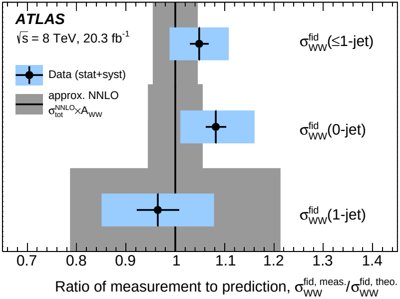
JHEP 09 (2016) 029, Phys. Lett.B763(2016)114

W^+W^- - Cross section results @ 8 TeV

- $\Delta\sigma_{fid}^{0jet}(e\mu)$: $\Delta_{stat.} = 1.8\%$, $\Delta_{sys.} = 6.7\%$
  Dominant uncertainties:
  - Experimental: Jet energy scale, W+jets bkg and luminosity
  - Modeling: jet veto requirement

- $\Delta\sigma_{fid}^{1jet}$: $\Delta_{stat.} = 4.5\%$, $\Delta_{sys.} = 11\%$
  Dominant uncertainties:
  - jet energy scale and top quark background

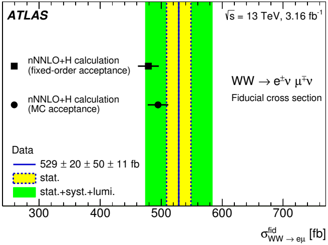
- $\Delta\sigma_{fid}^{\leq 1jet}$: $\Delta_{stat.} = 1.8\%$, $\Delta_{sys.} = 5.1\%$
  0+1 jet combination leads to reduced uncertainties

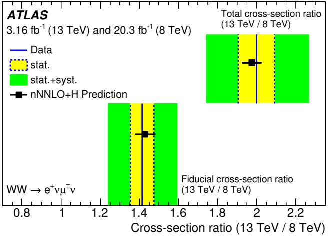


Measurements and ≈NNLO theory predictions in very good agreement

JHEP 09 (2016) 029, Phys. Lett.B763(2016)114

- Measurement performed in $WW \to e\nu\mu\nu$ decay channel, apply jet veto (WW+0jets)
- Event selection similar to WW+0jet @8TeV with minor differences





Good agreement with theory predictions

Dominant uncertainty:

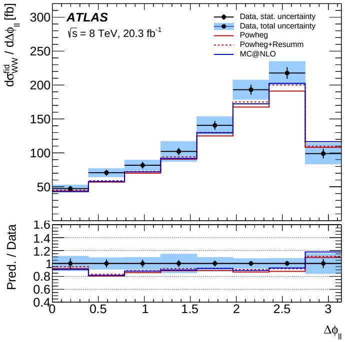
- Jet selection and calibration (7.3%)

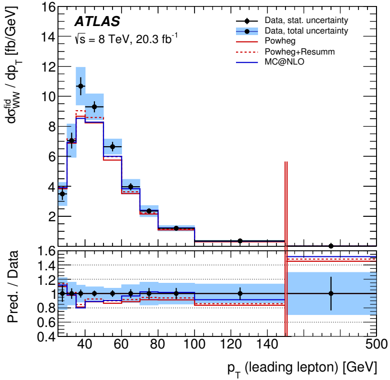
Total relative uncertainty on fiducial cross-section: 11% ($\Delta_{stat.} = 3.8\%$, $\Delta_{sys.} = 9.5\%$)

arXiv:1702.04519

W^+W^- @ 8 TeV: Differential cross sections

- Use WW+0jet$\rightarrow e\nu\mu\nu$
- Iterative Bayesian approach used to unfold differential distribution from detector to particle level
- Shapes well described by NLO, inclusive cross-section higher than prediction @NLO
- p_T^{lead} used to extract aTGCs (discussed later in the talk)



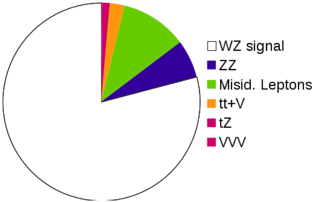


JHEP 09 (2016) 029

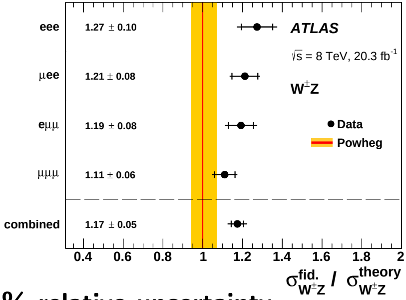
WZ cross section measurements @ 8 & 13 TeV

Inclusive *WZ* measurements: 8 and 13 TeV

- Use *WZ* lepton decays to e, μ
- Main background: misidentified leptons, *ZZ*
- Dominant uncertainties from:
  - Lepton reconstruction & identification
  - Misidentified lepton background

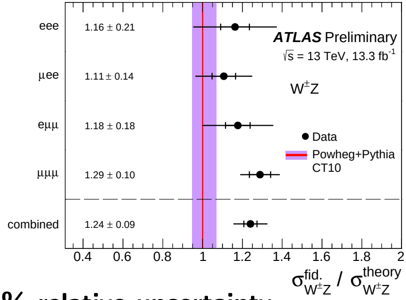


8 TeV



4% relative uncertainty

13 TeV



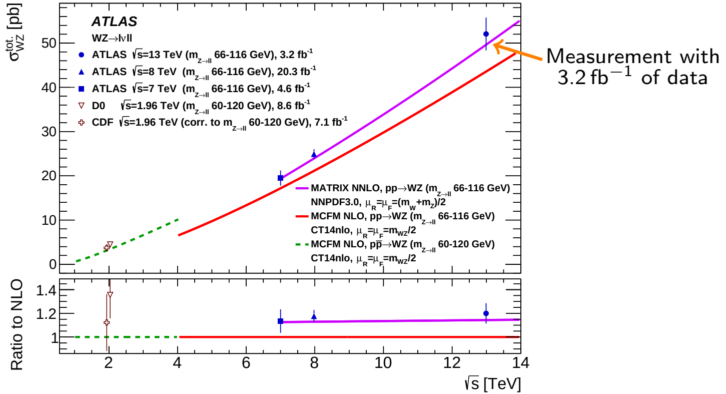
7% relative uncertainty

$\Rightarrow$ Measurements underestimated by NLO predictions

Phys.Rev.D93,092004(2016), Phys.Lett.B.752(2016) 1 & ATLAS-CONF-2016-043

WZ total cross section results

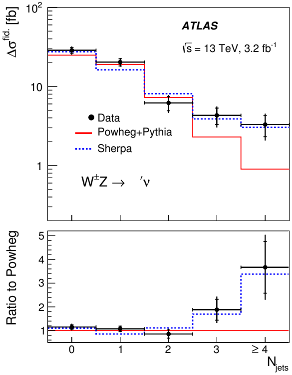
- NNLO predictions available now for WZ total cross section [Grazzini et al, arXiv:1604.08576]
- Good agreement between theory prediction @NNLO
- NNLO/NLO was not covered by theory scale uncertainty

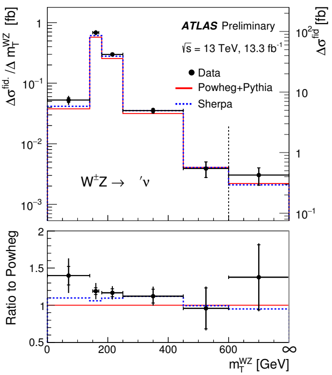


Phys.Rev.D93,092004(2016), Phys.Lett.B.752(2016) 1, ATLAS-CONF-2016-043

WZ differential cross sections

- Sherpa better describes high jet multiplicities (up to 3 jets at LO in Sherpa)
- m_T^{WZ} used to probe aTGCs, data & SM compatible ⇒ set limits

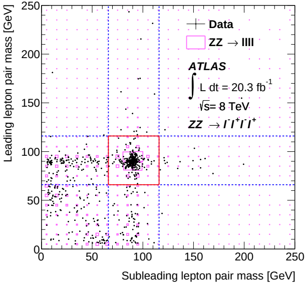




Phys.Lett.B.752(2016) 1, ATLAS-CONF-2016-043

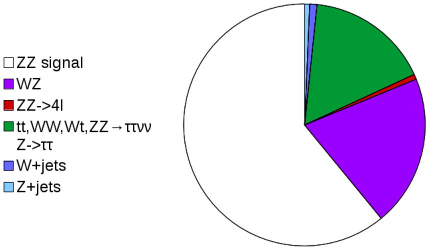
ZZ cross section measurements @ 8 & 13 TeV

ZZ measurements: 8& 13 TeV



- On-shell ZZ-production measured (66$< m_{\ell\ell} <$ 116 GeV)
- Two measured channels: $ZZ \to \ell\ell\ell'\ell'$ (8 &13 TeV), $ZZ \to \ell\ell\nu\nu$ (8 TeV), $\ell, \ell' = e, \mu$
- $ZZ \to 4\ell$: very clean channel ($\frac{S}{B} \approx 17$), main bkg from fake leptons

- $ZZ \to \ell\ell\nu\nu$: Background from:

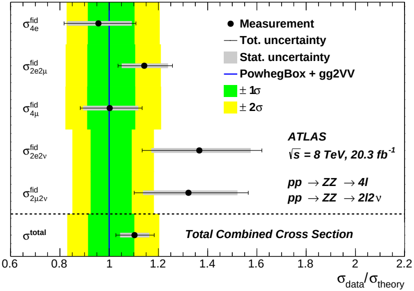


- Dominant uncertainties:
  - $ZZ \to 4\ell$: lepton reconstruction, isolation, @13 TeV: statistics
  - $ZZ \to 2\ell 2\nu$: jet modeling & veto, E_T^{miss} measurement

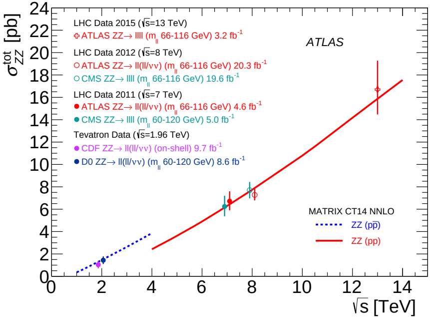
JHEP01(2017)099, Phys.Rev.Lett.116,101801(2016)

ZZ inclusive cross section

Fiducial cross sections @ 8 TeV



Total cross section



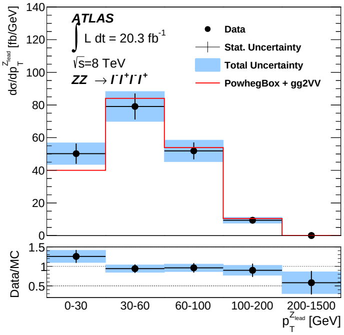
- 8% total uncertainty on measured cross section @ 8 TeV
- Good description of data by NNLO theory

JHEP01(2017)099, Phys.Rev.Lett.116,101801(2016)

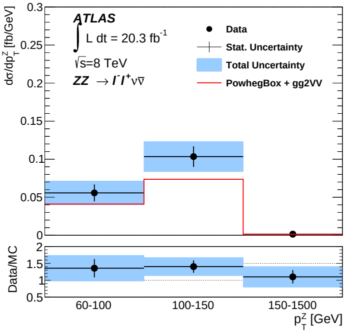
ZZ - Differential cross section

- 2 channels unfolded separately
- $p_T^{Z_{lead}}$ $(ZZ \to 4\ell)$ and p_T^Z $(ZZ \to 2\ell2\nu)$ used to obtain limits on aTGCs

$ZZ \to 4\ell$ @ 8 TeV

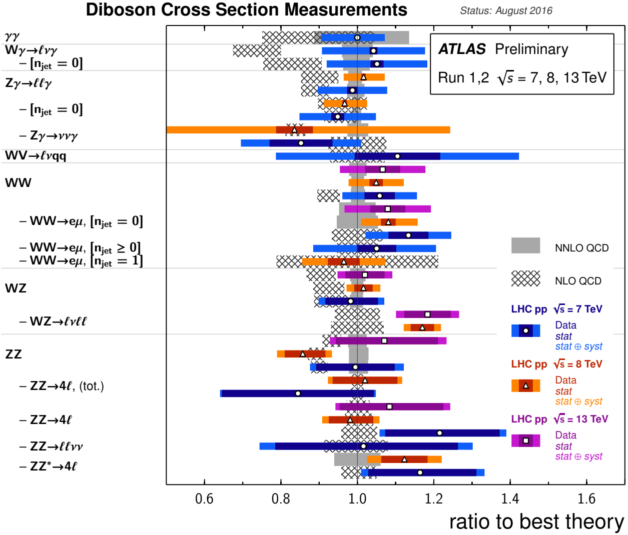


$ZZ \to 2\ell2\nu$ @ 8 TeV



doi:10.1007/JHEP01(2017)099

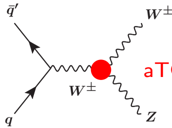
Diboson cross section measurement - Summary



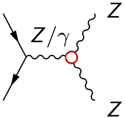
Limits on aTGCs

Short introduction to aTGCs

Several theoretical approaches with different parameterisations:



- **Effective Lagrangian**
  $\mathcal{L} = ig_{WWV}[g_1^V(W^+_{\mu\nu}W^{-\nu} - W^{+\mu}W^-_{\mu\nu})V^\nu + \kappa^V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2} W^{+\nu}_\mu W^{-\rho}_\nu V^{-\mu}_\rho]$
  in SM, $g_1^V = \kappa^V = 1$ and λ^V=0,
  parameterise deviations using $\Delta g_1^V = g_1^V - 1$, $\Delta\kappa^V = \kappa^V - 1$ and λ^V



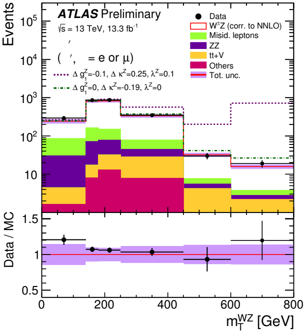
Vertex function approach for neutral aTGCs:
Parameterise deviations from the SM using two CP violating parameters f_4^V ($V = Z, \gamma$) and two CP-conserving parameters f_5^V (0 in SM)

- **Effective field theory (EFT) approach:**
  Add linear combinations of higher dimension operators to SM:
  $\mathcal{L} = \mathcal{L}_{SM} + \sum_{d=5}^{\text{inf}} \frac{1}{\Lambda^{d-4}} \sum_i c_i \mathcal{O}_i^{(d)}$ ("Λ": scale of new physics)

$$\mathcal{O}_{WWW} = \frac{c_{WWW}}{\Lambda^2} Tr[W_{\mu\nu}W^{\nu\rho}W_\rho^\mu]$$
$$\mathcal{O}_W = \frac{c_W}{\Lambda^2}(D_\mu\Phi)^\dagger W^{\mu\nu}(D_\nu\Phi)$$
$$\mathcal{O}_B = \frac{c_B}{\Lambda^2}(D_\mu\Phi)B^{\mu\nu}(D_\nu\Phi)$$

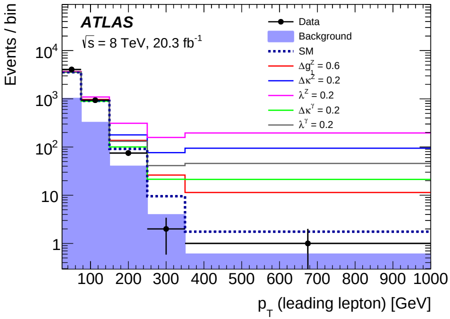
Charged aTGCs - *WW* and *WZ*: Results

WZ @ 8& 13 TeV: m_T^{WZ}



Dataset	Coupling	Expected [TeV^{-2}]	Observed [TeV^{-2}]
8 and 13 TeV	c_W/Λ^2	[-3.4;6.9]	[-3.6;7.3]
	c_B/Λ^2	[-221;166]	[-253;136]
	c_{WWW}/Λ^2	[-3.2;3.0]	[-3.3;3.2]

WW @ 8 TeV (0 jets): p_T^{lead}



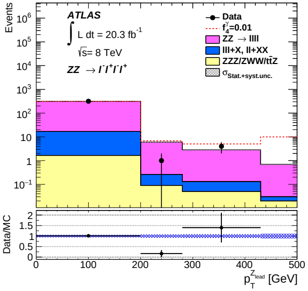
Dataset	Coupling	Expected [TeV^{-2}]	Observed [TeV^{-2}]
8 TeV	c_W/Λ^2	[-12.58;14.32]	[-5.87;10.54]
	c_B/Λ^2	[-35.8;38.4]	[-20.9;26.3]
	c_{WWW}/Λ^2	[-7.62;7.38]	[-4.61;4.60]

- *WW* more sensitive to c_B as also sensitive to vertex involving γ
- *WZ* measurement gives stricter limits on c_W and c_{WWW} but less sensitive to c_B

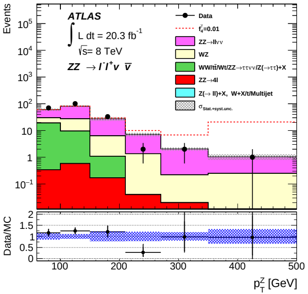
JHEP 09 (2016) 029, Phys.Rev.D93,092004(2016), ATLAS-CONF-2016-043

Neutral aTGCs - ZZ

$ZZ \to 4\ell$ @8 TeV: $p_T^{Z_{lead}}$



$ZZ \to 2\ell 2\nu$ @8 TeV: p_T^Z



Coupling	Expected (10^{-3})	Observed (10^{-3})
f_4^γ	$[-4.6,\ 4.8]$	$[-3.8,\ 3.8]$
f_4^Z	$[-4.0,\ 4.1]$	$[-3.3,\ 3.2]$
f_5^γ	$[-4.8,\ 4.8]$	$[-3.8,\ 3.8]$
f_5^Z	$[-4.1,\ 4.1]$	$[-3.3,\ 3.3]$

- No indications for neutral aTGCs
- Limits were derived using last two bins of $p_T^{Z_{lead}}$-distributions ($Z \to 4\ell$) and p_T^Z-distribution ($Z \to 2\nu 2\ell$)

JHEP01(2017)099

Summary & Conclusion

- In past year, precise measurements on dibosons were published which pushed theorists to improve their calculations
- Several recent diboson results from ATLAS for WW, ZZ and WZ
- All measurements show good agreement with NNLO theory predictions
- No hints for aTGCs found yet
- aTGC limits derived, more stringent than previous limits from ATLAS due to higher center-of-mass energy and luminosity
- Larger 13 TeV dataset will even further improve experimental precision

Back-up

Cross section measurement methodology

$\sigma_{fid}^{VV'}$: Measurement in fiducial phase space defined by detector acceptance

$$\sigma_{fid}^{VV'} = \frac{N_{obs} - N_{bkg}}{C_{VV'} \times \mathcal{L}}$$

- N_{obs} = Observed data event number after applying selection cuts
- N_{bkg} = Total number of estimated background events
- $\mathcal{L}$ = Luminosity
- $C_{VV'}$ = Factor correcting for detector effects (estimated using MC)

To compare with other experiments, extrapolate to total phase space:

- $A_{VV'}$ = Acceptance factor to extrapolate from fiducial PS to total PS (estimated using MC)
- Br = Branching fraction of measured final state for $\sigma_{fid}^{VV'}$

$$\sigma_{tot}^{VV'} = \frac{\sigma_{fid}^{VV'}}{A_{VV'} \times Br}$$

W^+W^- cross section measurement

Title	$\sqrt{s}$, lumi	Measured quantities	Link
Measurement of total and differential W^+W^- production cross sections in proton-proton collisions at $\sqrt{s}$=8 TeV with the ATLAS detector and limits on anomalous triple-gauge--boson couplings	8 TeV, 20.3 fb^{-1} (2012 data)	σ_{fid} (0jets), σ_{tot}, aTGC limits, Differential σ	JHEP 09 (2016) 029 (Published 03/2016)
Measurement of W^+W^- production in association with one jet in proton-proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector	8 TeV, 20.3 fb^{-1} (2012 data)	σ_{fid} (+1jets), σ_{tot}, $\sigma_{fid}^{\leq 1jet}$, $\frac{\sigma_{fid}^{1jet}}{\sigma_{fid}^{0jet}}$	Phys. Lett.B763(2016)114 (Published 08/2016)
Measurement of W^+W^- production cross section in pp collisions at a centre-of-mass energy of $\sqrt{s}$=13 TeV with the ATLAS experiment	13 TeV, 3.16 fb^{-1} (2015 data)	σ_{fid} (0jets), $\frac{\sigma_{fid}^{13\text{ TeV}}}{\sigma_{fid}^{8\text{ TeV}}}$	arXiv:1702.04519 (Published 02/2017)

Inclusive WZ measurement at 8 and 13 TeV

Title	$\sqrt{s}$, lumi	Measured quantities	Link
Measurements of $W^{\pm}Z$ production cross sectionsin pp collisions at $\sqrt{s}$ =8 TeV with the ATLAS detector and limits on anomalous gauge boson self-couplings	8 TeV, 20.3fb^{-1} (2012 data)	σ_{fid}, σ_{tot} , $\frac{W^+Z}{W^-Z}$, Differential σ, limits on aTGCs, (VBS & aQGC)	Phys.Rev.D93,092004(2016) (Published 03/2016)
Measurement of the WZ boson pair-production cross section in pp collisions at $\sqrt{s}$ =13 TeV with the ATLAS Detector	13 TeV, 3.2fb^{-1} (2015 data)	σ_{fid}, σ_{tot} , $\frac{W^+Z}{W^-Z}$, $\frac{WZ_{13\,\text{TeV}}}{WZ_{8\,\text{TeV}}}$, Differential σ	Phys.Lett.B.752(2016) 1 (Published 06/2016)
Measurement of $W^{\pm}Z$ boson pair-production in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS Detector and confidence intervals for anomalous triple gauge boson couplings	13 TeV, 13.3fb^{-1} (2015+part of 2016 data)	Differential σ aTGC limits	ATLAS-CONF-2016-043 (Published 07/2016)

Measurement of the ZZ production cross section at 8 and 13 TeV

Title	$\sqrt{s}$, lumi	Measured quantities	Link
Measurement of the ZZ production cross section in proton-proton collisions at $\sqrt{s}$=8 TeV using the $ZZ \to llll$ and $ZZ \to ll\nu\nu$ decay channels with the ATLAS detector	8 TeV, 20.3 fb^{-1} (2012 data)	σ_{fid}, σ_{tot} ($ZZ \to llll$, & $ZZ \to ll\nu\nu$) aTGC limits, Differential σ	doi:10.1007/JHEP01(2017)099 (Published 10/2016)
Measurement of the ZZ production cross section in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	13 TeV, 3.2 fb^{-1} (2015 data)	σ_{tot}, σ_{fid} ($ZZ \to llll$ channel)	Phys.Rev.Lett.116,101801(2016) (Published 12/2015)