Measurement of the *WZ* production cross section at 8 TeV and 13 TeV and limits on anomalous TGCs with the ATLAS detector

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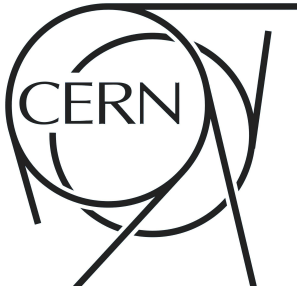


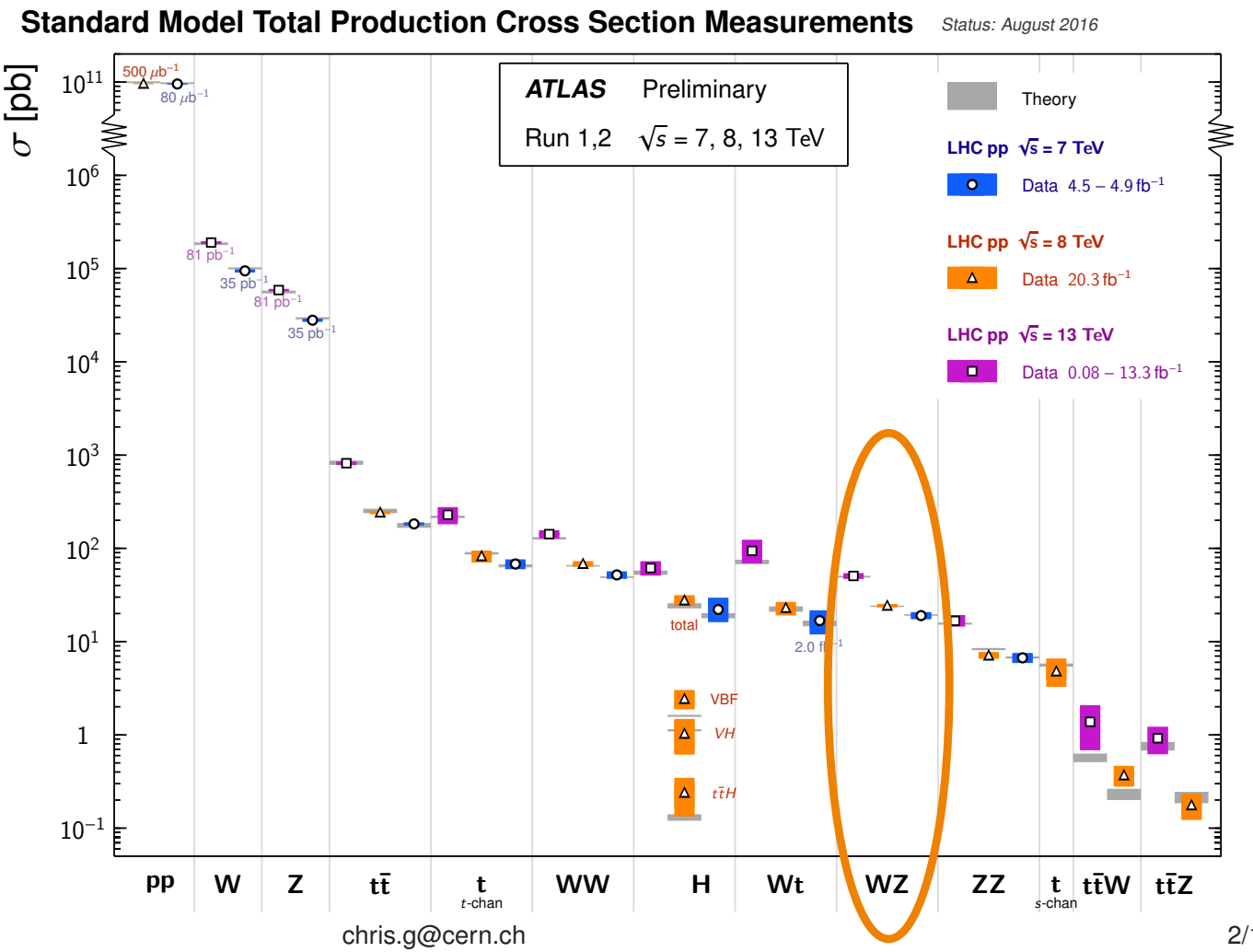
Overview

- measurements of rare electroweak processes are a crucial test of the Standard Model in extreme regions of phase space

- sensitivity to new physics via anomalous gauge couplings

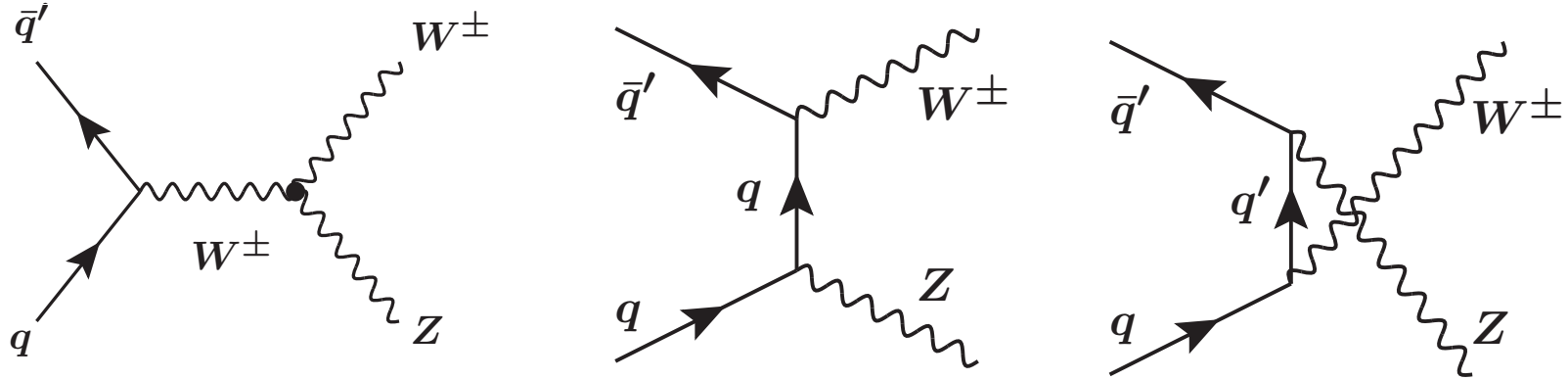
- valuable data to constrain generator modelling

- important backgrounds in many LHC new physics searches

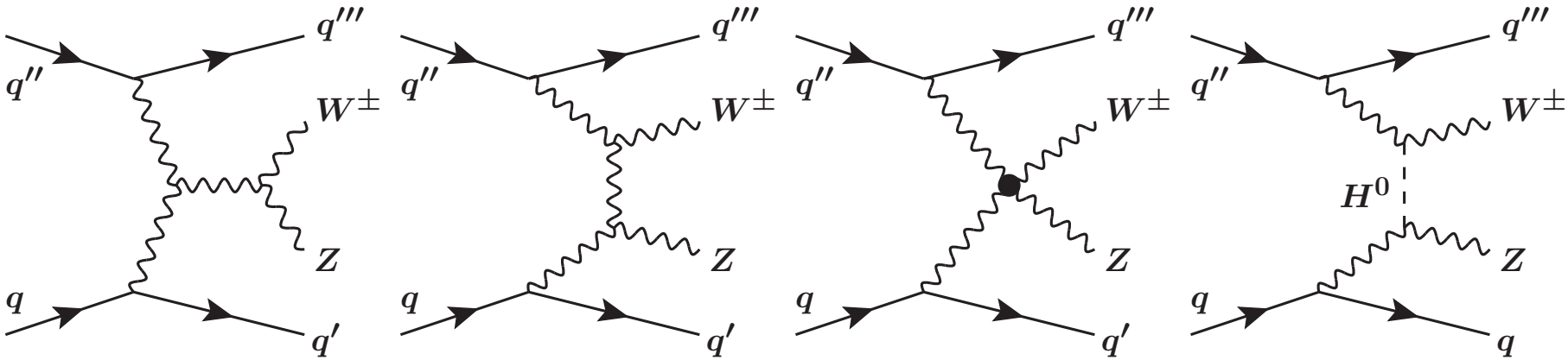


Signal characterisation

- QCD-initiated *WZ* production with four electroweak couplings at leading order



- electroweak *WZjj* production with six electroweak couplings at leading order, including vector boson scattering diagrams



- unitarisation restored through Higgs diagrams

Fiducial phase-space definition

- $N_\ell = 3$ with $|\eta^\ell| < 2.5$
- Z-decay leptons: $p_{\mathrm{T}}^\ell > 15\,\mathrm{GeV}$
- W-decay lepton: $p_{\mathrm{T}}^\ell > 20\,\mathrm{GeV}$
- $|m_{\ell\ell} - m_Z| < 10\,\mathrm{GeV}$
- $m_{\mathrm{T}}^W > 30\,\mathrm{GeV}$
- $\Delta R(\ell, \ell) > 0.3$ between the W-decay lepton and each of the Z-decay leptons
- $\Delta R(\ell, \ell) > 0.2$ between the Z-decay leptons

Process composition

- background processes with at least three prompt leptons estimated using dedicated Monte Carlo simulation
  - ZZ ($\sim 25\,\%$, dominant), VVV, tZ, $t\bar{t}V$

8 TeV

Channel	eee	μee	$e\mu\mu$	$\mu\mu\mu$	All
Data	406	483	539	663	2091
Total expected	336.7 ± 2.2	410.8 ± 2.4	469.1 ± 2.1	608.2 ± 3.5	1824.8 ± 7.0
WZ	255.7 ± 1.1	337.2 ± 1.0	367.0 ± 1.1	495.9 ± 2.3	1455.7 ± 5.5
Misid. leptons	43.7 ± 1.9	32.2 ± 2.1	50.2 ± 1.7	52.8 ± 2.6	178.9 ± 4.2
ZZ	25.9 ± 0.2	26.7 ± 0.3	36.1 ± 0.3	39.5 ± 0.3	128.2 ± 0.6
$t\bar{t}+V$	5.5 ± 0.2	6.7 ± 0.2	7.2 ± 0.3	9.1 ± 0.3	28.5 ± 0.5
tZ	4.2 ± 0.1	5.5 ± 0.2	6.0 ± 0.2	7.7 ± 0.2	23.3 ± 0.3
DPS	1.2 ± 0.1	1.9 ± 0.1	1.8 ± 0.1	2.3 ± 0.2	7.2 ± 0.3
VVV	0.5 ± 0.0	0.7 ± 0.0	0.8 ± 0.0	0.9 ± 0.0	3.0 ± 0.1

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- background processes with at least one fake leptons estimated using data-driven technique
  - dominant background ($> 50\,\%$) including $Z+$ jets, $Z\gamma$, $W\gamma$, $t\bar{t}$
  - fake lepton could be non-prompt, a misidentified jet or an electron from photon conversion

13 TeV ($3.2\,\text{fb}^{-1}$ dataset)

Channel	eee	μee	$e\mu\mu$	$\mu\mu\mu$	All
Data	98	122	166	183	569
Total Expected	102 ± 10	118 ± 9	126 ± 11	160 ± 12	506 ± 38
WZ	74 ± 6	96 ± 8	97 ± 8	129 ± 10	396 ± 32
$Z+j$, $Z\gamma$	16 ± 7	7 ± 5	14 ± 7	9 ± 5	45 ± 17
ZZ	6.7 ± 0.7	8.7 ± 1.0	8.5 ± 0.9	11.7 ± 1.2	36 ± 4
$t\bar{t}+V$	2.7 ± 0.4	3.2 ± 0.4	2.9 ± 0.4	3.4 ± 0.5	12.1 ± 1.6
$t\bar{t}$, Wt, $WW+j$	1.2 ± 0.8	2.0 ± 0.9	2.4 ± 0.9	3.6 ± 1.5	9.2 ± 3.1
tZ	1.28 ± 0.20	1.65 ± 0.26	1.63 ± 0.26	2.12 ± 0.34	6.7 ± 1.1
VVV	0.24 ± 0.04	0.29 ± 0.05	0.27 ± 0.04	0.34 ± 0.05	1.14 ± 0.18

arXiv:1606.04017 [hep-ex]

(2417 events in $13.3\,\text{fb}^{-1}$ dataset)

Systematic uncertainties

➜ dominant systematic uncertainties due to data-driven background estimation and electron identification efficiency

8 TeV

	eee	μee	$e\mu\mu$	$\mu\mu\mu$	combined
Source	Relative uncertainties [%]				
e energy scale	0.8	0.4	0.4	0.0	0.3
e id. efficiency	2.9	1.8	1.0	0.0	1.0
μ momentum scale	0.0	0.1	0.1	0.1	0.1
μ id. efficiency	0.0	0.7	1.3	2.0	1.4
$E_{\mathrm{T}}^{\mathrm{miss}}$ and jets	0.3	0.2	0.2	0.1	0.3
Trigger	0.1	0.1	0.2	0.3	0.2
Pileup	0.3	0.2	0.2	0.1	0.2
Misid. leptons background	2.9	0.9	3.1	0.9	1.3
ZZ background	0.6	0.5	0.6	0.5	0.5
Other backgrounds	0.7	0.7	0.7	0.7	0.7
Uncorrelated	0.7	0.6	0.5	0.5	0.3
Total systematics	4.5	2.6	3.7	2.5	2.4
Luminosity	2.2	2.2	2.2	2.2	2.2
Statistics	6.2	5.4	5.3	4.7	2.7
Total	8.0	6.3	6.8	5.7	4.2

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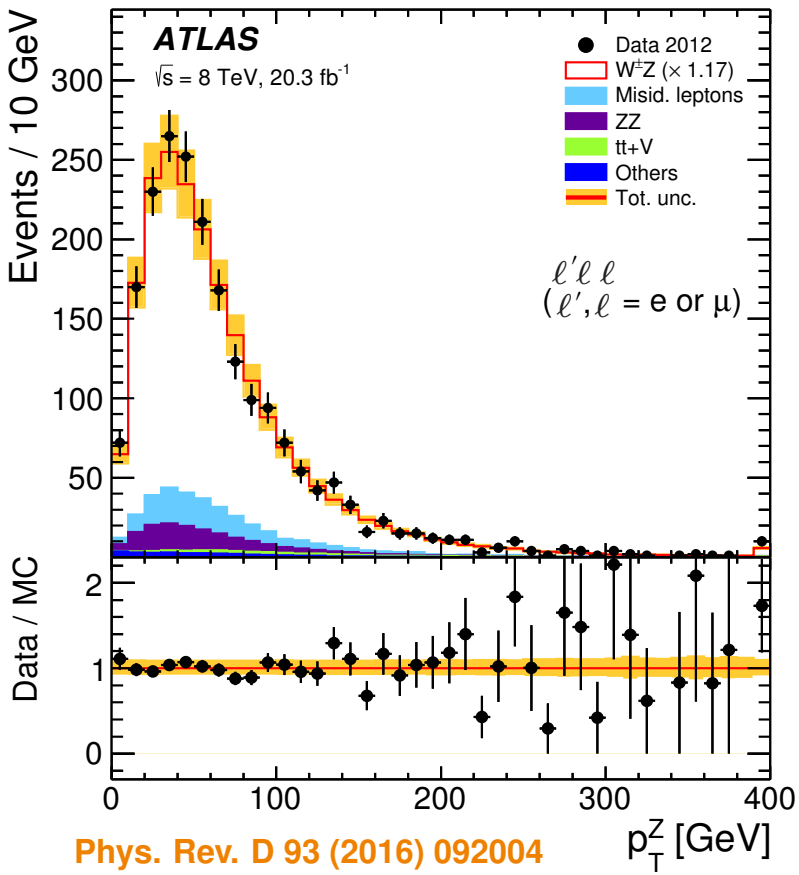
13 TeV

	eee	μee	$e\mu\mu$	$\mu\mu\mu$	combined
Relative uncertainties [%]					
e energy scale	0.5	0.2	0.3	< 0.1	0.2
e id. efficiency	1.4	1.1	0.6	—	0.7
μ momentum scale	< 0.1	< 0.1	< 0.1	0.1	< 0.1
μ id. efficiency	—	0.6	1.0	1.4	0.7
$E_{\mathrm{T}}^{\mathrm{miss}}$ and jets	0.3	0.4	0.8	0.7	0.6
Trigger	< 0.1	0.1	0.1	0.2	0.1
Pile-up	0.7	1.1	1.0	0.7	0.9
Misid. lepton background	10	4.6	4.8	3.2	3.6
ZZ background	1.0	0.7	0.6	0.7	0.7
Other backgrounds	0.5	0.5	0.3	0.3	0.4
Uncorrelated	2.2	1.3	1.4	1.7	0.8
Total sys. uncertainty	11	5.1	5.3	4.1	4.1
Luminosity	2.4	2.4	2.3	2.3	2.4
Statistics	14	11	10	8.8	5.1
Total	18	12	11	10	7.0

arXiv:1606.04017 [hep-ex]

Detector-level comparisons

- Z-boson transverse momentum
- signal prediction from POWHEG (CT10) + PYTHIA8 (CTEQ6L1+AZNLO)
  - 8 TeV predictions scaled by 1.17, 13 TeV predictions normalised to NNLO calculation



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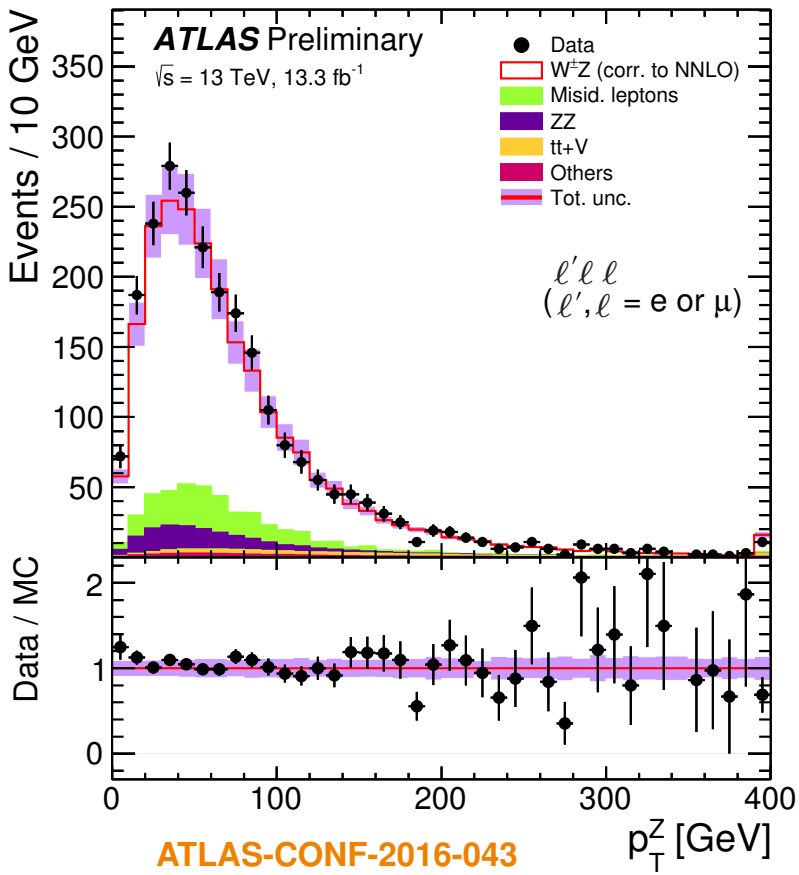

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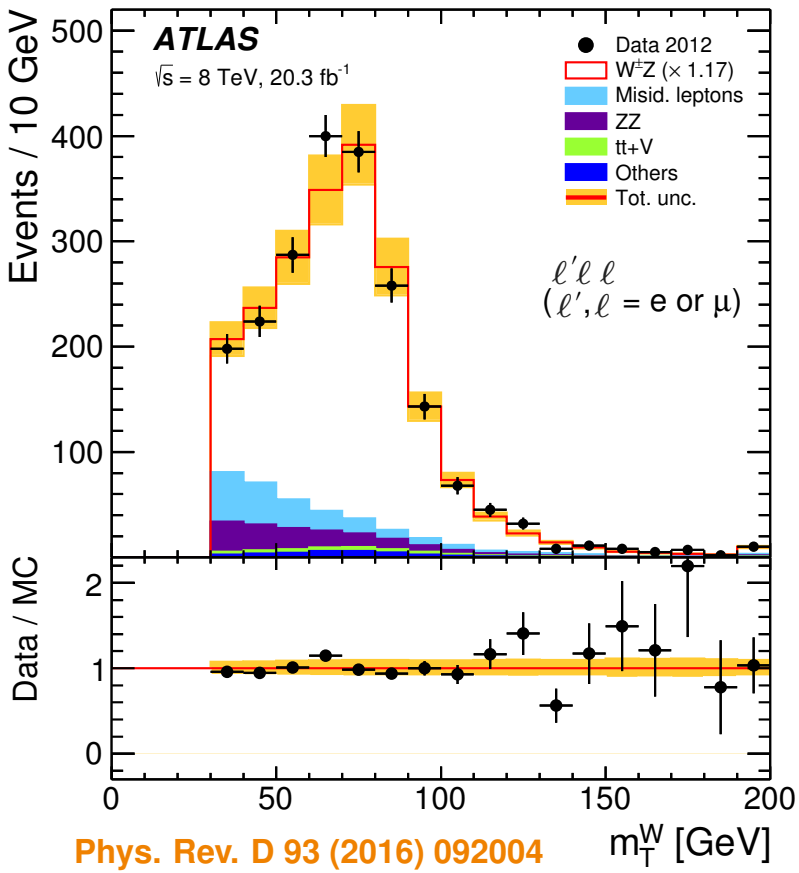
Detector-level comparisons

- *W*-boson transverse mass
- signal prediction from POWHEG (CT10) + PYTHIA8 (CTEQ6L1+AZNLO)
  - 8 TeV predictions scaled by 1.17, 13 TeV predictions normalised to NNLO calculation



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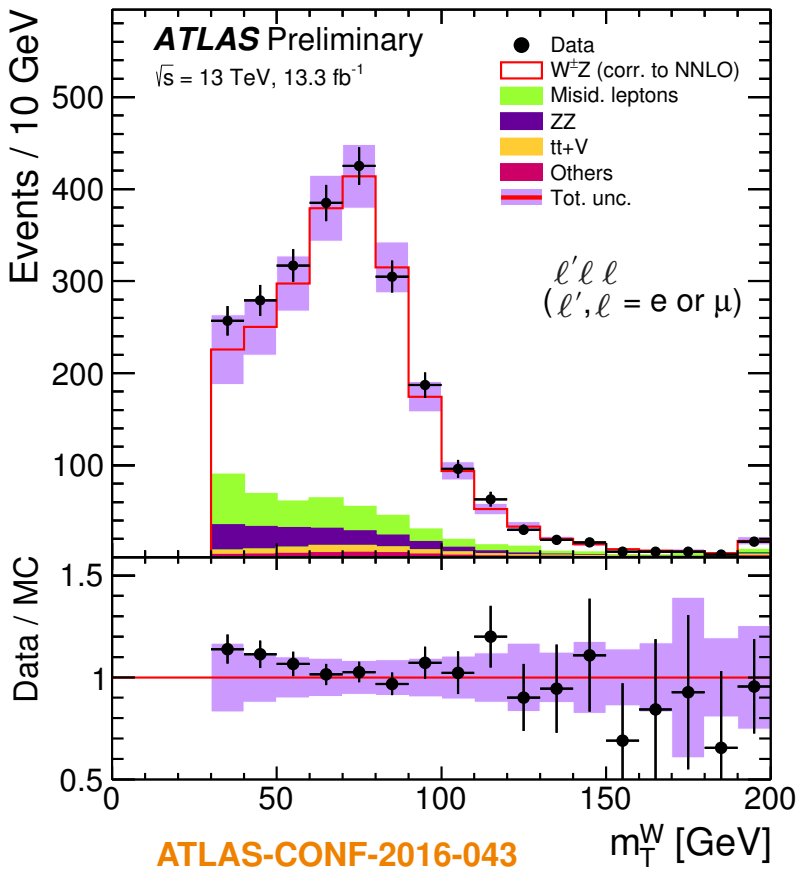

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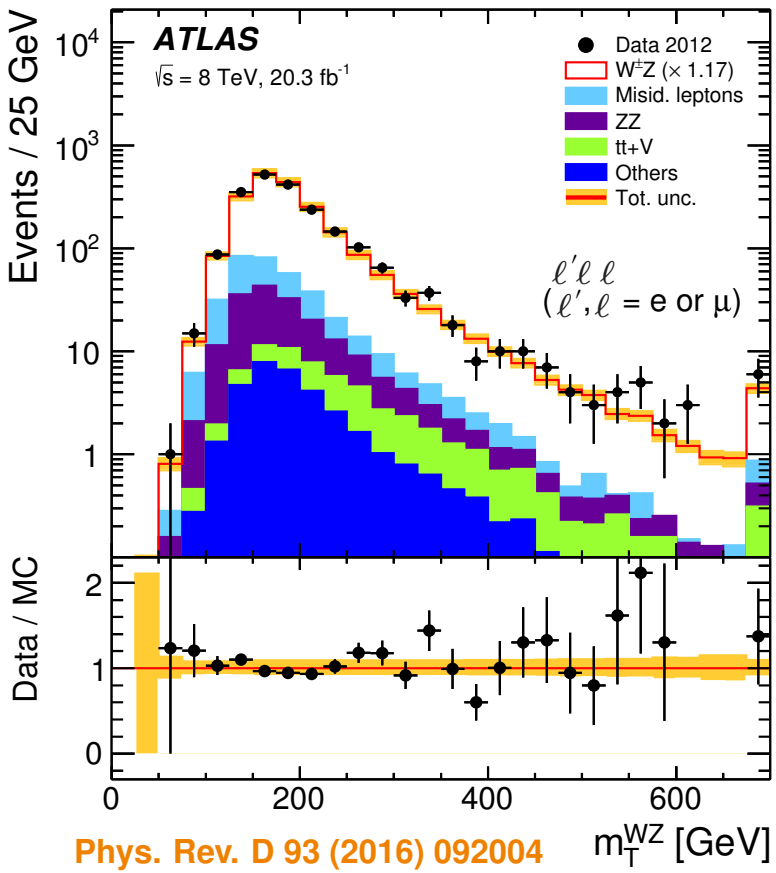
Detector-level comparisons

- diboson transverse mass
- signal prediction from POWHEG (CT10) + PYTHIA8 (CTEQ6L1+AZNLO)
  - 8 TeV predictions scaled by 1.17, 13 TeV predictions normalised to NNLO calculation



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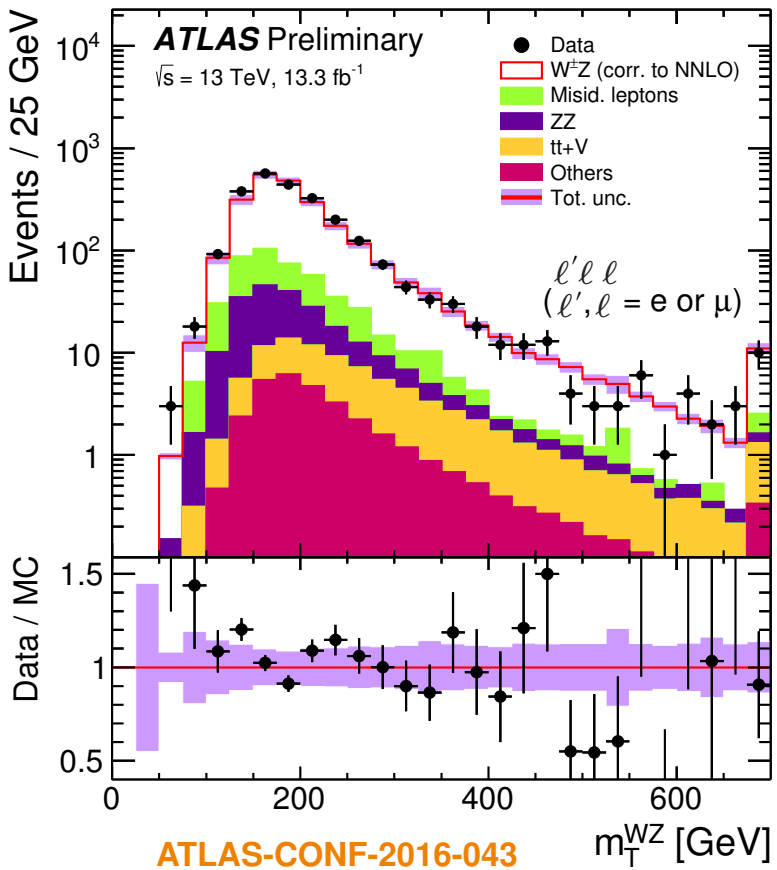

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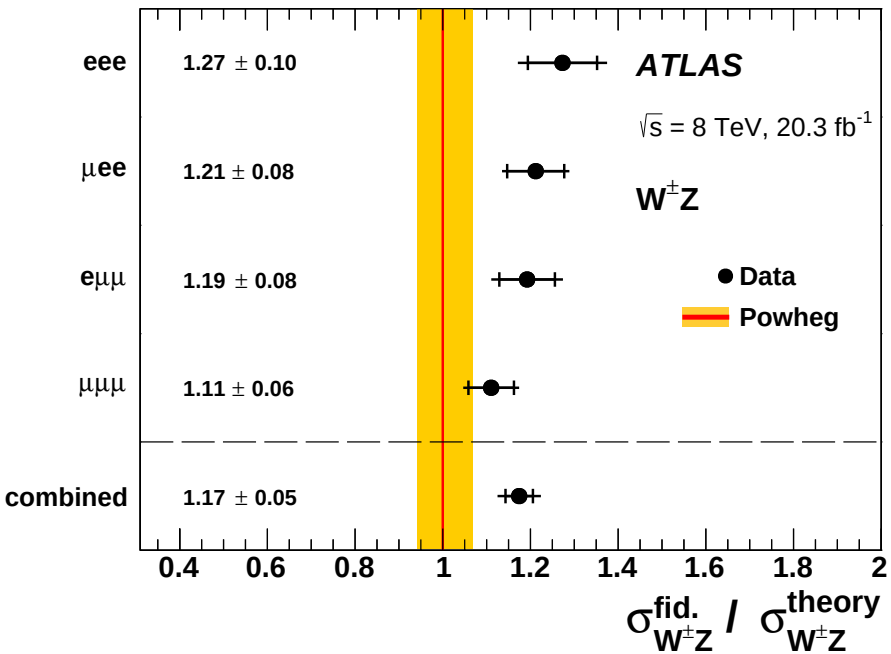
Fiducial cross sections

- *WZ* cross section broken down by lepton flavours
- signal prediction from POWHEG (CT10) + PYTHIA8 (CTEQ6L1+AZNLO)



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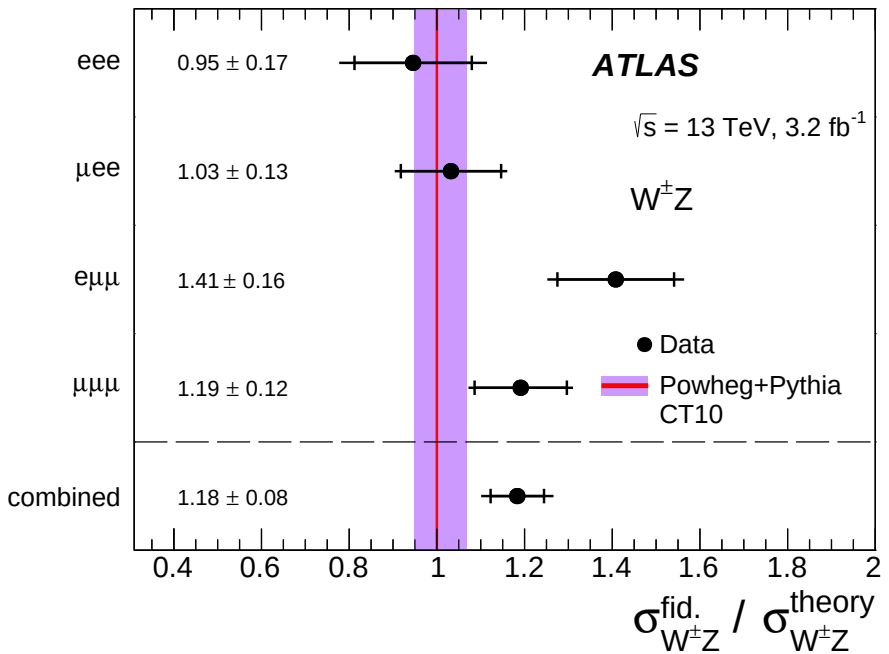
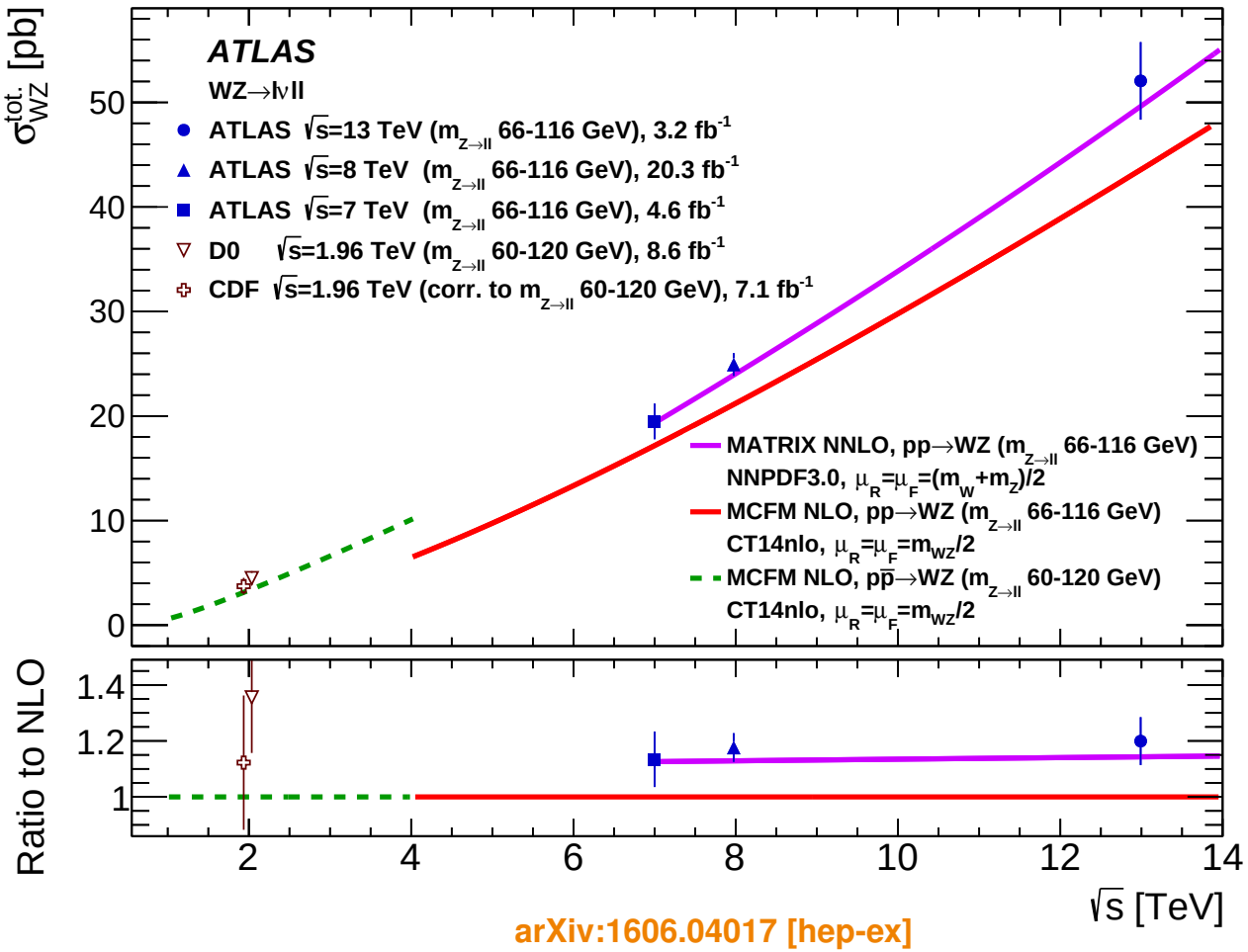


arXiv:1606.04017 [hep-ex]

Total cross sections

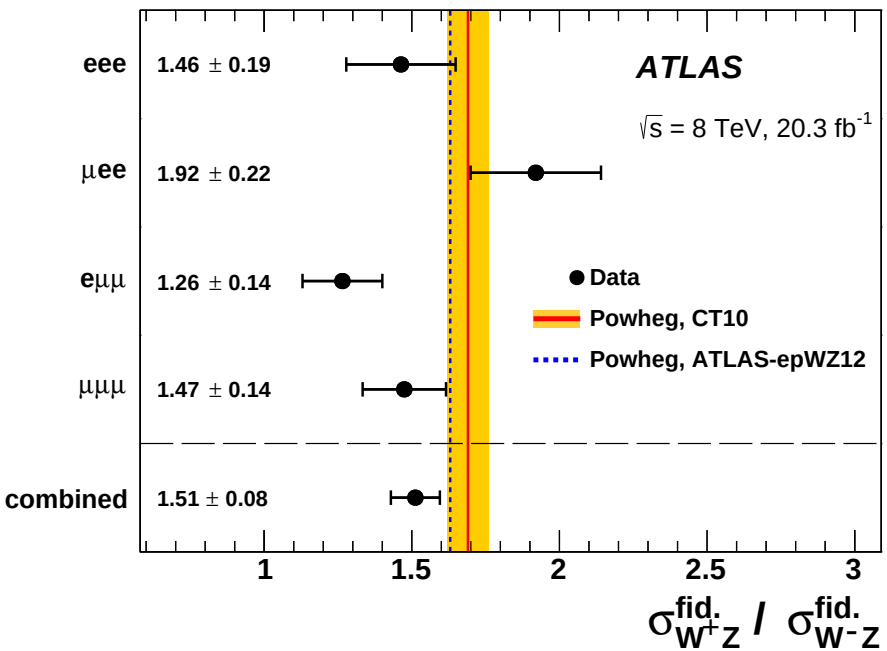
➜ comparison to recent NNLO calculation by Grazzini et al. (☞ ARXIV:1604.08576)



arXiv:1606.04017 [hep-ex]

Charge ratio measurements

- measured ratios of W^+Z-to-W^-Z production similar broken down by lepton flavours
- signal prediction from POWHEG (CT10) + PYTHIA8 (CTEQ6L1+AZNLO)



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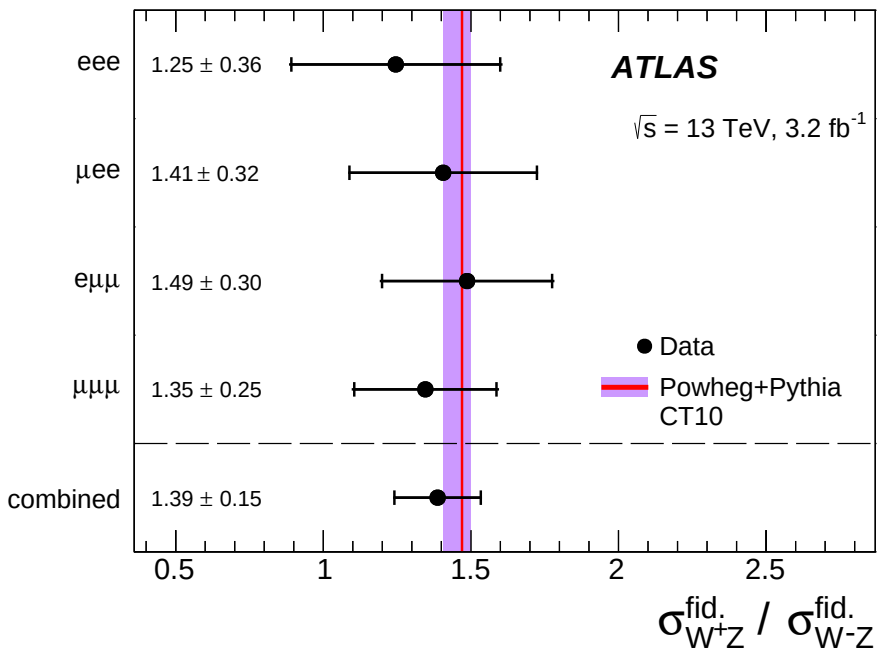
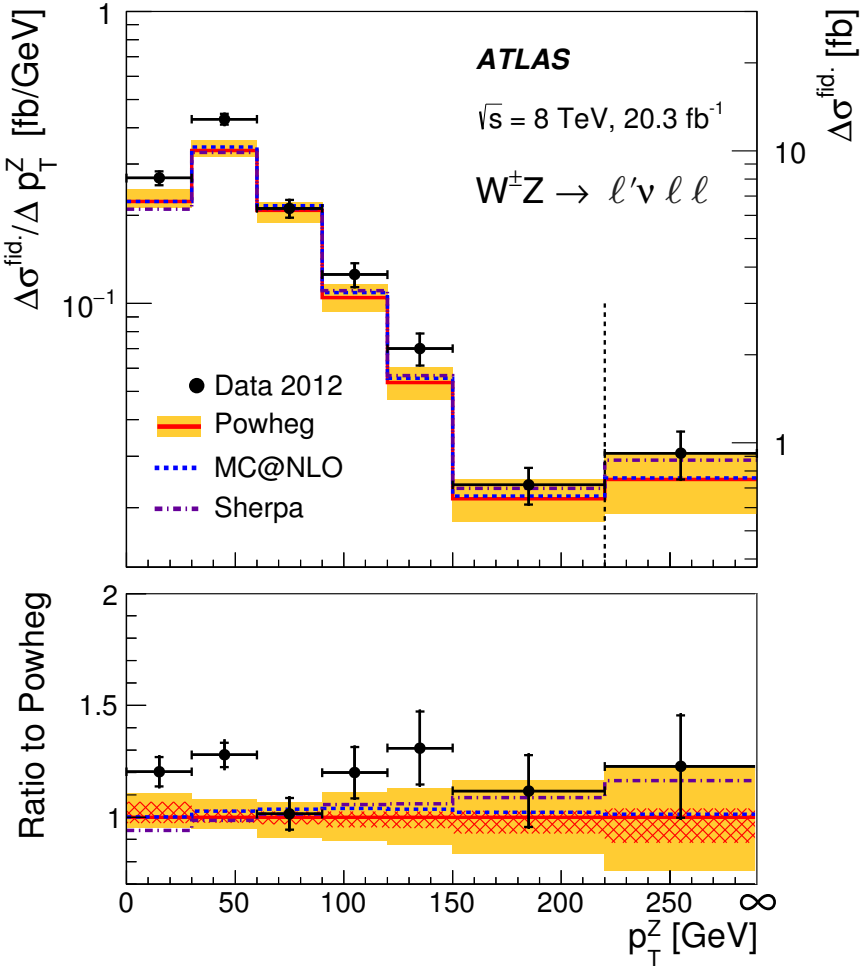


arXiv:1606.04017 [hep-ex]

Differential cross sections

➜ *Z*-boson transverse momentum



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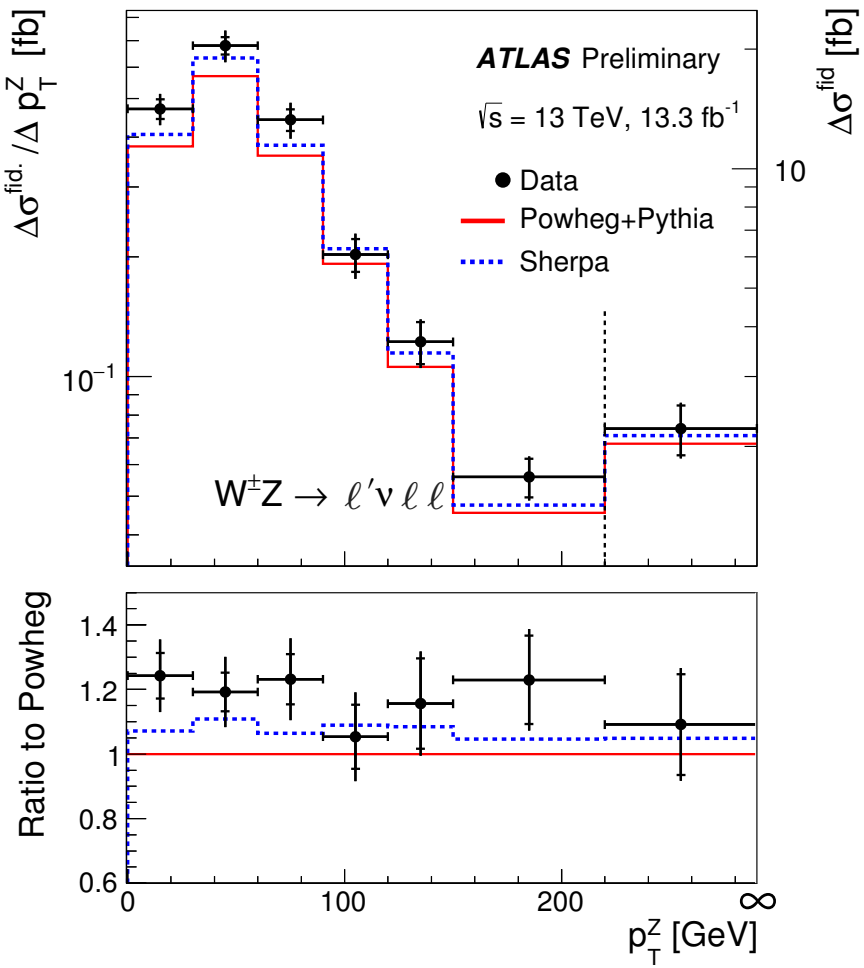

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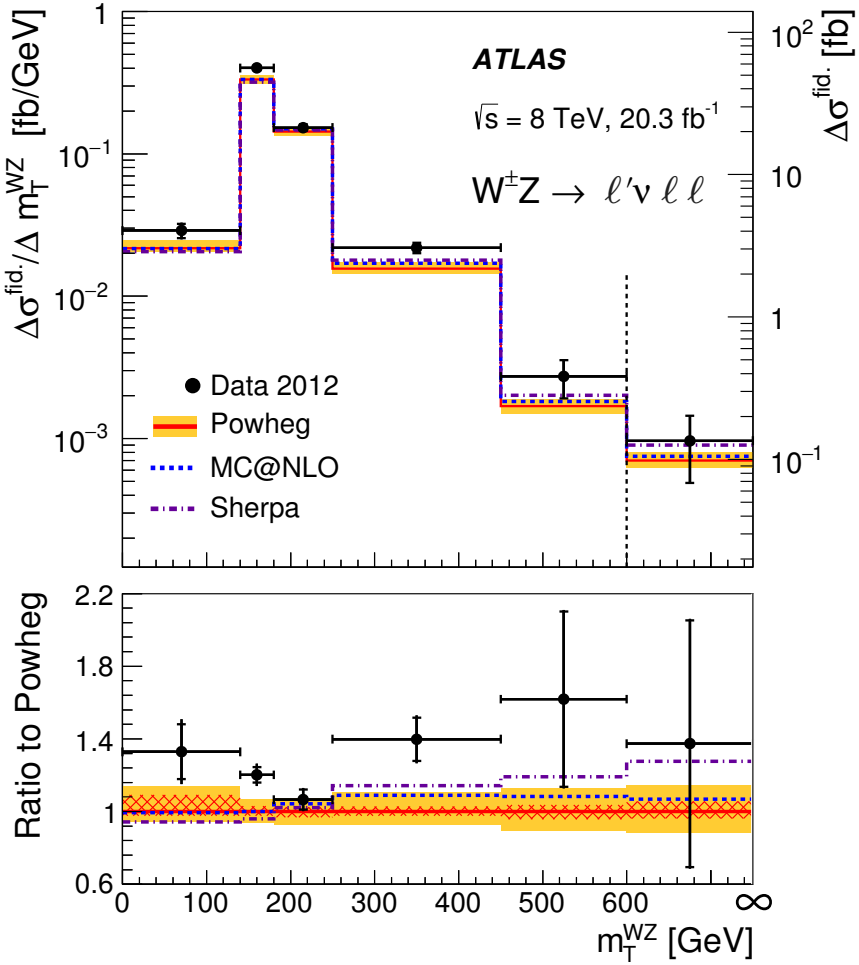
Differential cross sections

➜ diboson transverse mass



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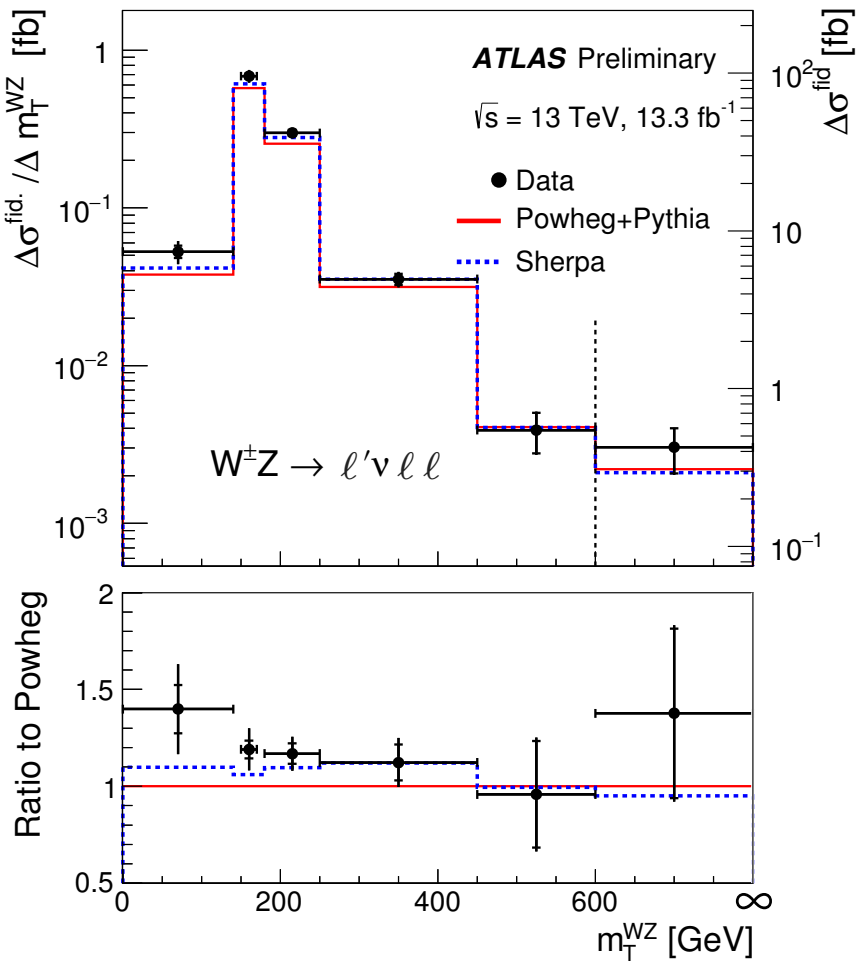

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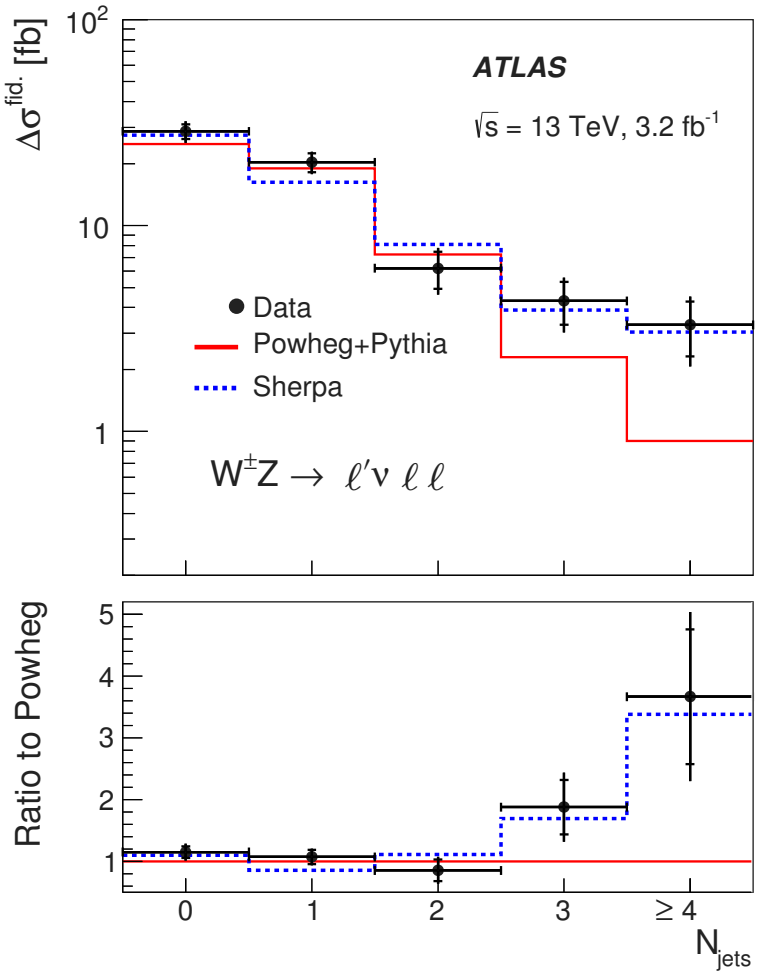
Differential cross section

- high jet multiplicities described inadequately by NLO+PS approach (here Powheg+Pythia8)
- excellent agreement between data and multi-leg formalism observed (here Sherpa 2.1)



arXiv:1606.04017 [hep-ex]

Cross section limits on *WZjj* production

- use 8 TeV data to put a cross section limit on electroweak *WZjj* production
- also require at least two jets with $p_T > 30$ GeV, $|\eta| < 4.5$, $m_{jj} > 500$ GeV and $\Delta R(j, \ell) > 0.3$
- place limits with and without the *tZj* contribution

8 TeV

95% CL upper limit on $\sigma^{\text{fid.}}_{W^\pm Zjj\text{-EW}\to\ell'\nu\ell\ell}$ [fb]		
	VBS only	VBS + tZj
VBS phase space		
Observed	0.63	0.67
Expected	0.45	0.49
$\pm1\sigma$ Expected	[0.28 ; 0.62]	[0.33 ; 0.67]
$\pm2\sigma$ Expected	[0.08 ; 0.80]	[0.19 ; 0.84]

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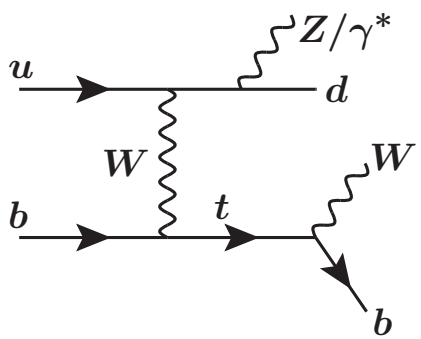
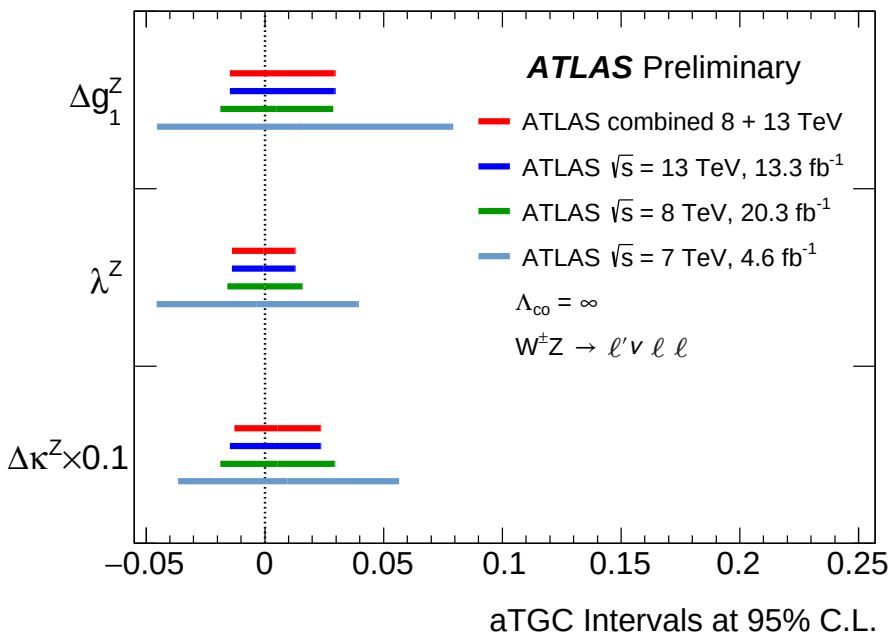


Limits on anomalous triple gauge couplings

- similar sensitivity between 8 and 13 TeV
- combine 8 and 13 TeV measurements to extract limits (no form factors applied)
- improves existing limits by up to 20 %



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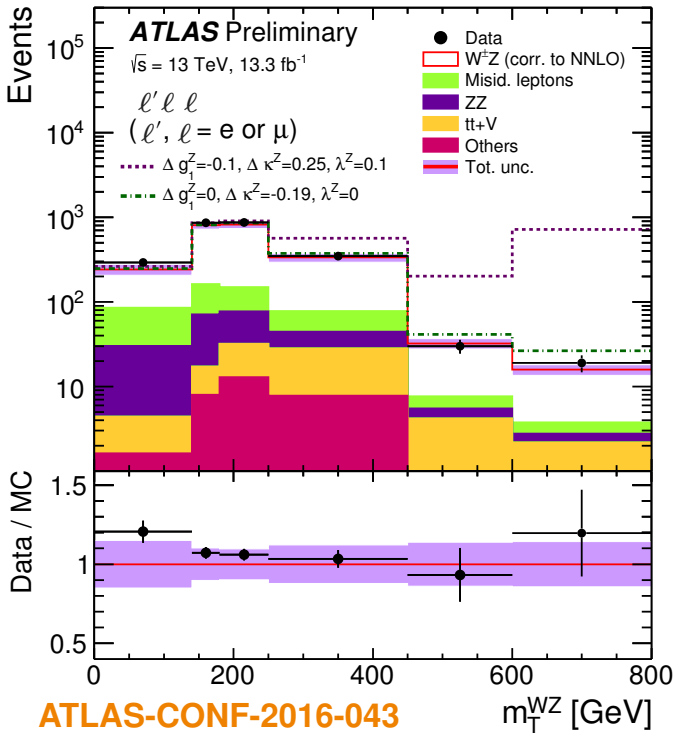

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Dataset	Coupling	Expected	Observed
13 TeV	Δg_1^Z	[-0.017; 0.032]	[-0.016; 0.036]
	$\Delta\kappa_1^Z$	[-0.18; 0.24]	[-0.15; 0.26]
	λ^Z	[-0.015; 0.014]	[-0.016; 0.015]
8 and 13 TeV	Δg_1^Z	[-0.014; 0.029]	[-0.015; 0.030]
	$\Delta\kappa_1^Z$	[-0.15; 0.21]	[-0.13; 0.24]
	λ^Z	[-0.013; 0.012]	[-0.014; 0.013]

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Limits on EFT coefficients

➜ to allow for a direct comparison with limits extracted in *WW* measurement, interpret aTGC coupling parameters in terms of EFT coefficients:

$$\frac{c_{WWW}}{\Lambda^2} = \frac{2}{3g^2 m_W^2}\lambda_Z$$

$$\frac{c_W}{\Lambda^2} = \frac{2}{m_Z^2}\Delta g_1^Z$$

$$\frac{c_B}{\Lambda^2} = \frac{2\Delta g_1^Z}{\tan^2\theta_W m_Z^2} - \frac{2\Delta\kappa_Z}{\sin^2\theta_W m_Z^2}$$

Dataset	Coupling	Expected [TeV^{-2}]	Observed [TeV^{-2}]
13 TeV	$c_W/\Lambda^2_{\mathrm{NP}}$	[-4.1; 7.6]	[-3.8; 8.6]
	$c_B/\Lambda^2_{\mathrm{NP}}$	[-261; 193]	[-280; 163]
	$c_{WWW}/\Lambda^2_{\mathrm{NP}}$	[-3.6; 3.4]	[-3.9; 3.7]
8 and 13 TeV	$c_W/\Lambda^2_{\mathrm{NP}}$	[-3.4; 6.9]	[-3.6; 7.3]
	$c_B/\Lambda^2_{\mathrm{NP}}$	[-221; 166]	[-253; 136]
	$c_{WWW}/\Lambda^2_{\mathrm{NP}}$	[-3.2; 3.0]	[-3.3; 3.2]

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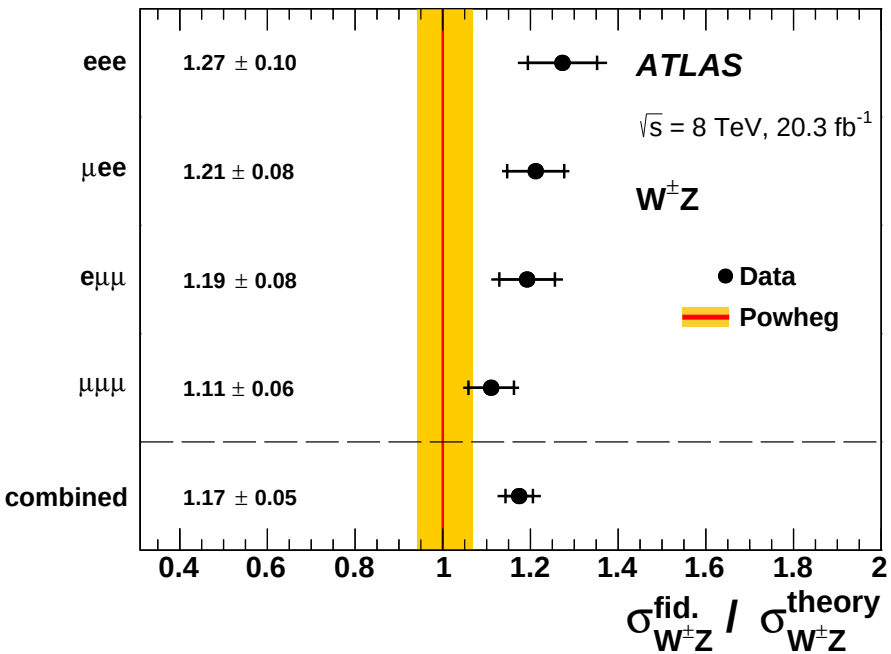
Summary

- ATLAS have measured the *WZ* production cross section at 8 TeV and 13 TeV
  - $20.3\,\text{fb}^{-1}$ of 2012 data at 8 TeV (**Phys. Rev. D 93 (2016) 092004**)
  - $3.2\,\text{fb}^{-1}$ of 2015 data at 13 TeV (**arXiv:1606.04017 [hep-ex]**)
  - $13.3\,\text{fb}^{-1}$ of 2015+2016 data at 13 TeV (**ATLAS-CONF-2016-043**)
- first measurement of differential cross sections as a function of p_{T}^{Z} and m_{T}^{WZ} at 13 TeV
- extracted limits on anomalous triple gauge couplings improve existing limits by up to 20 %

Backup

Fiducial cross sections

- *WZ* cross section broken down by lepton flavours
- signal prediction from POWHEG (CT10) + PYTHIA8 (CTEQ6L1+AZNLO)



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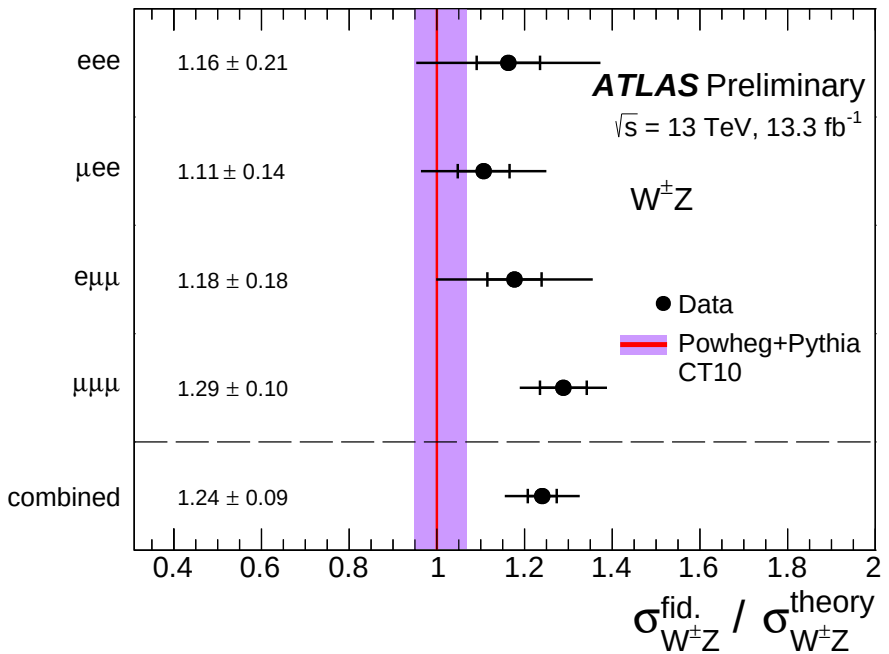

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