Measurement of the W and Z cross-section in pp collisions at $\sqrt{s}$ = 13.6 TeV

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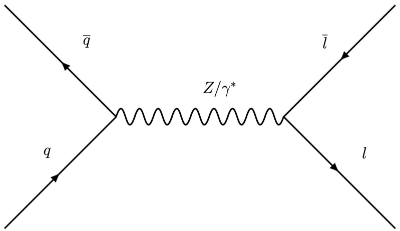
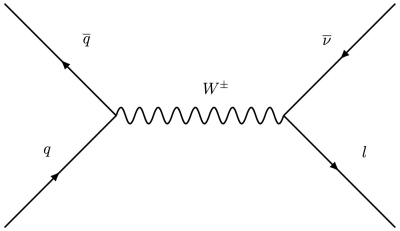
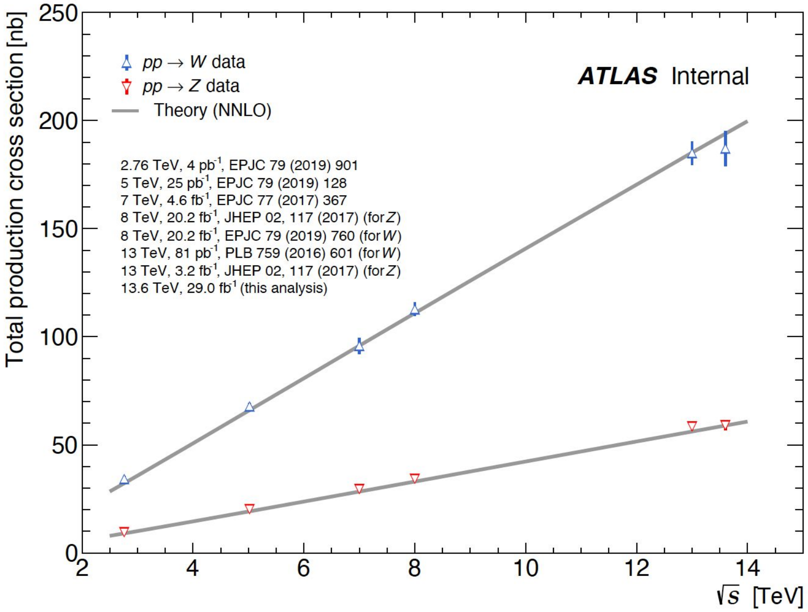
Introduction

- Measuring the W and Z boson cross sections provides a benchmark for our understanding of QCD and EW processes
- Test theoretical predictions at a new centre-of-mass energy of 13.6 TeV
- Large cross sections and easily identifiable leptonic decays of the W and Z bosons provide a clean experimental signature
    - Important for early validation of detector performance and software







Analysis overview

Measurement of vector boson production cross-sections and their ratios at 13.6 TeV

- Using 29 fb^{-1} of data collected in 2022
- The Z-boson fiducial cross section has been published together with ttbar results in arXiv:2308.09529
  - ttbar results used to measure ttbar/W ratio presented here

Event selection

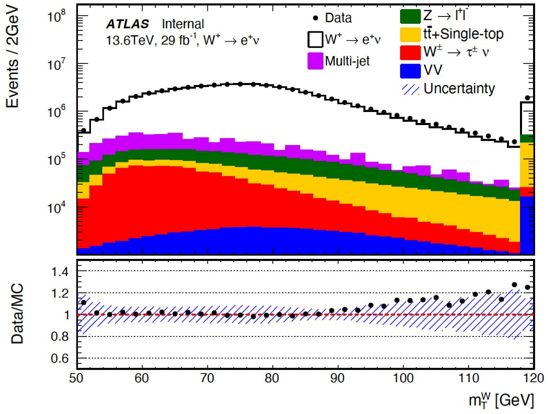
- Electrons and muons: $p_T^l > 27$ GeV, tight isolation
- **Z-boson selection:** 2 opposite sign, same flavour leptons, $66 < m_{ll} < 116$ GeV
- **W-boson selection:** only 1 lepton, $E_T^{miss} > 25$ GeV, $m_T^W > 50$ GeV

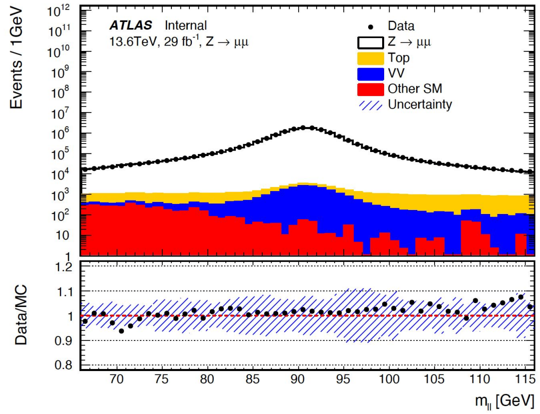
Background modelling

- Electroweak and top backgrounds evaluated using MC simulation
- Multijet background estimated using data-driven method

Cross-section measurement

- Fiducial cross sections are extracted with **binned profile likelihood fits** using 8 channels: 2 Z-boson channels (ee and μμ), 4 W-boson channels (e^+v, e^-v, μ^+v and μ^-v) and 2 ttbar channels (eμ, exactly 1 b-jet and eμ, exactly 2 b-jets)
- The total cross section: $\sigma^{tot} = \sigma^{fid}/A$, where A is the acceptance





Multijet background

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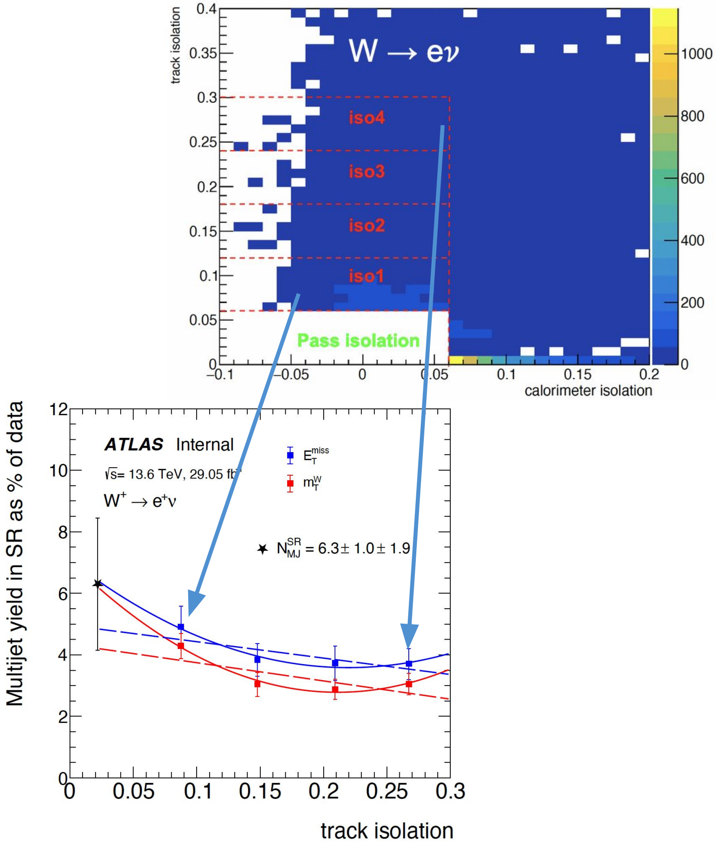
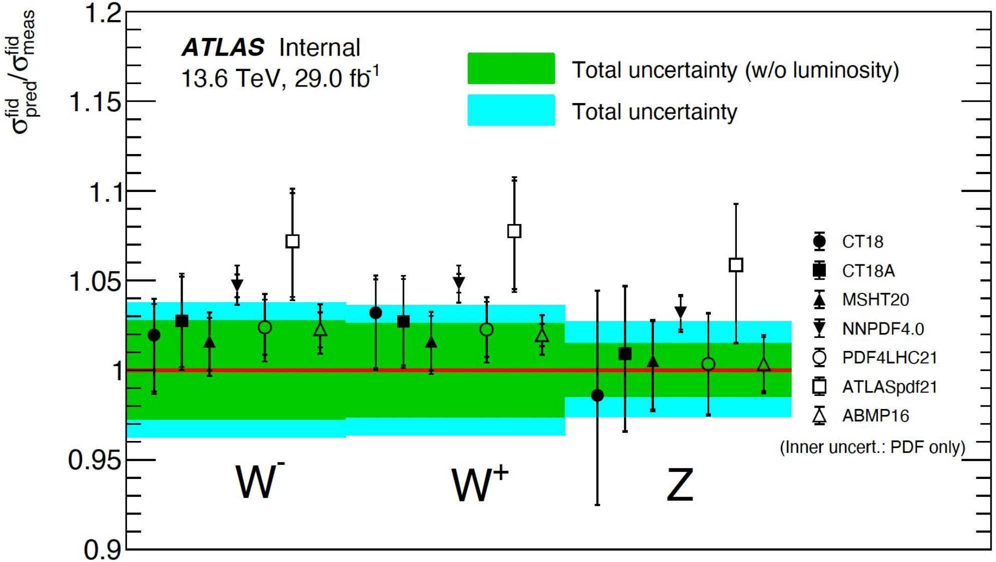


- Multijet templates derived from control regions requiring leptons to **fail isolation**
- Several multijet templates are created by defining **isolation slices** in the control regions
- Multijet normalisation estimated by performing profile-likelihood fits in a fitting region
  - Extract normalisation using multijet templates from 4 isolation slices and 2 discriminating variables (E_T^{miss} and m_T^{W}) in each channel
- Perform extrapolation in track isolation in order to reduce isolation bias on final multijet yield
  - Central value obtained from quadratic fit result with difference between linear and quadratic fit results as additional uncertainty

Results: W and Z fiducial cross sections

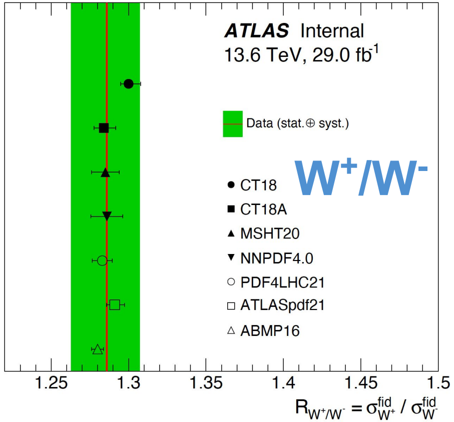
- Fiducial cross sections compared to theoretical predictions calculated with different PDFs
  - Theoretical predictions are calculated to NNLO + NNLL QCD and NLO EW accuracy
  - Good agreement between results and SM predictions

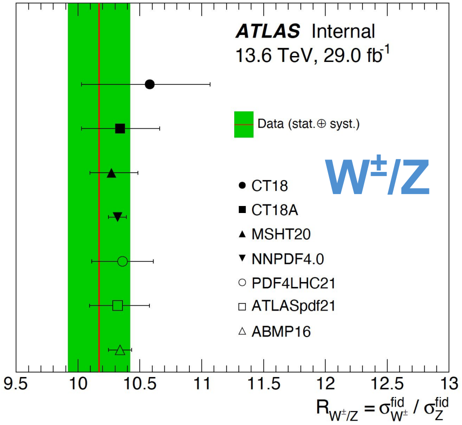


Channel	$\sigma^{\text{fid}} \pm \delta\sigma_{\text{stat.+syst.}}$ [pb]
$Z \rightarrow e^+e^-$	740 ± 22
$Z \rightarrow \mu^+\mu^-$	747 ± 23
$Z \rightarrow \ell^+\ell^-$	744 ± 20
$W^- \rightarrow e^-\bar{\nu}$	3380 ± 170
$W^- \rightarrow \mu^-\bar{\nu}$	3310 ± 130
$W^- \rightarrow \ell^-\bar{\nu}$	3310 ± 120
$W^+ \rightarrow e^+\nu$	4350 ± 200
$W^+ \rightarrow \mu^+\nu$	4240 ± 160
$W^+ \rightarrow \ell^+\nu$	4250 ± 150
$W^\pm \rightarrow \ell^\pm\nu$	7560 ± 270

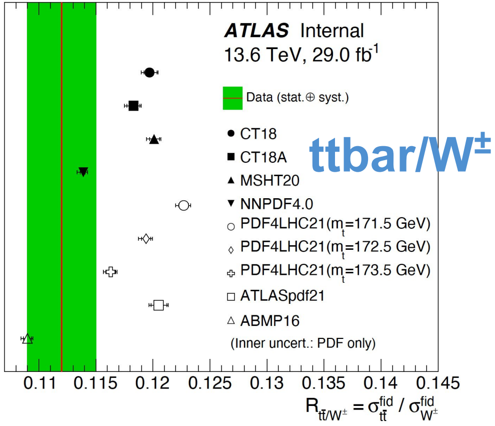
- Dominant sources of uncertainties:
  - $W^\pm$: luminosity, jet and multi-jet background
  - Z: luminosity, lepton efficiency

Results: cross-section ratios





- Cross-section ratios benefit from cancellations of some of the experimental uncertainties
- Good agreement between W/Z results and SM predictions
  - ttbar/$W^{\pm}$ ratio shows slight deviations from the theoretical predictions

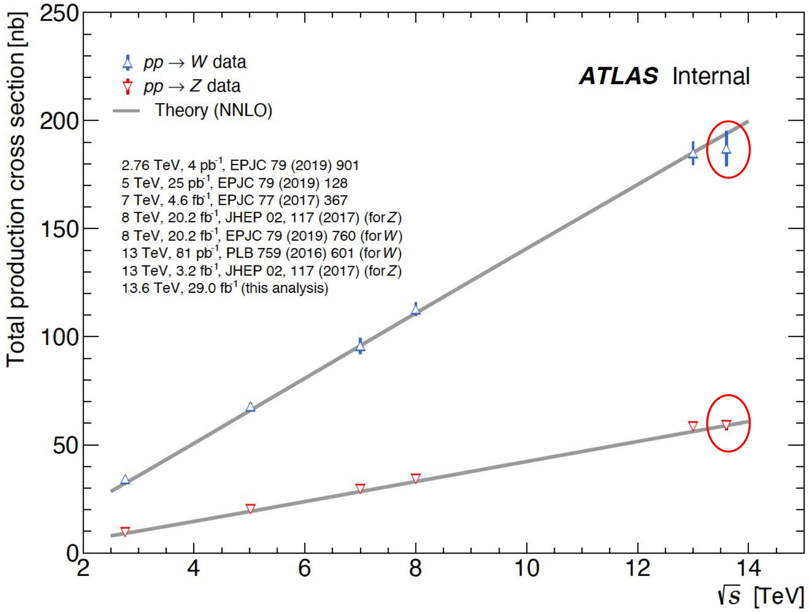


Ratio	$R \pm \delta R_{stat.+syst.}$
W^+/W^-	1.286 ± 0.022
$W^\pm/Z$	10.17 ± 0.25
$t\bar{t}/W^-$	0.256 ± 0.008
$t\bar{t}/W^+$	0.199 ± 0.006
$t\bar{t}/W^\pm$	0.112 ± 0.003

- Dominant sources of uncertainties:
  - W^+/W^-: multi-jet background
  - $W^\pm/Z$: jet related uncertainty
  - ttbar/$W^\pm$: ttbar modelling, jet and multi-jet background

Conclusion

- Results for vector boson cross sections and their ratios at √s = 13.6 TeV are presented using 29 fb^{-1} collected in 2022
  - Important for testing the SM at the new centre-of mass energy and providing early validation for detector performance
  - First ttbar/W± cross-section ratio measurement using the same dataset in ATLAS
- Good agreement between results and theoretical predictions for W/Z measurements
  - ttbar/$W^{\pm}$ ratio shows slight deviations from the theoretical predictions



Backup

Systematic uncertainties

- Table shows the observed impact of the different sources of uncertainty on the measured W/Z cross sections and their ratios

Category	$\sigma(Z \to ee)$	$\sigma(Z \to \mu\mu)$	$\sigma(Z \to \ell\ell)$	$\sigma(W^- \to e^-\bar{\nu})$	$\sigma(W^+ \to e^+\nu)$	$\sigma(W^- \to \mu^-\bar{\nu})$	$\sigma(W^+ \to \mu^+\nu)$
Luminosity	2.2	2.2	2.2	2.5	2.5	2.5	2.4
Pile-up	1.2	0.3	0.8	1.1	1.1	0.3	0.4
MC statistics	< 0.2	< 0.2	< 0.2	< 0.2	0.4	< 0.2	0.4
Lepton trigger	0.2	0.4	0.2	1.2	1.3	1.0	1.0
Electron reconstruction	1.4	–	0.9	0.7	0.8	–	–
Muon reconstruction	–	2.1	1.4	–	–	1.0	1.0
Multi-jet	–	–	–	2.9	2.4	1.3	1.1
Other background modelling	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.5	0.4
Jet energy scale	–	–	–	1.4	1.4	1.3	1.4
Jet energy resolution	–	–	–	< 0.2	0.3	0.2	0.2
Jet vertex tagger	–	–	–	1.6	1.5	1.3	1.3
$E_{\mathrm{T}}^{\mathrm{miss}}$ track soft term	–	–	–	< 0.2	0.4	< 0.2	< 0.2
PDF	0.2	0.2	< 0.2	0.8	0.8	0.6	0.5
QCD scale (ME and PS)	0.6	< 0.2	0.3	1.3	1.2	0.6	0.6
Flavour tagging	–	–	–	–	–	–	–
$t\bar{t}$ modelling	–	–	–	–	–	–	–
Total systematic impact	3.0	3.1	2.7	5.0	4.5	3.8	3.6
Statistical impact	0.04	0.03	0.02	0.02	0.01	0.01	0.01

Category	$\sigma(W^- \to \ell^-\bar{\nu})$	$\sigma(W^+ \to \ell^+\nu)$	$\sigma(W^\pm \to \ell\nu)$	R_{W^+/W^-}	$R_{W^\pm/Z}$	$R_{t\bar{t}/W^\pm}$
Luminosity	2.5	2.4	2.4	< 0.2	0.3	< 0.2
Pile-up	0.5	0.7	0.6	< 0.2	< 0.2	< 0.2
MC statistics	< 0.2	0.2	< 0.2	< 0.2	< 0.2	< 0.2
Lepton trigger	1.0	0.9	0.9	< 0.2	0.7	0.8
Electron reconstruction	0.4	0.5	0.4	< 0.2	0.5	0.4
Muon reconstruction	0.6	0.6	0.6	0.2	0.8	0.6
Multi-jet	1.2	1.2	1.2	1.6	1.1	1.0
Other background modelling	0.4	0.4	0.4	< 0.2	0.3	0.9
Jet energy scale	1.3	1.3	1.3	< 0.2	1.3	1.3
Jet energy resolution	< 0.2	0.2	< 0.2	< 0.2	< 0.2	< 0.2
Jet vertex tagger	1.4	1.3	1.3	< 0.2	1.3	< 0.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ track soft term	< 0.2	0.3	0.3	< 0.2	0.3	0.3
PDF	0.5	0.5	0.3	0.5	0.2	0.4
QCD scale (ME and PS)	0.8	0.7	0.6	< 0.2	0.7	0.7
Flavour tagging	–	–	–	–	–	< 0.2
$t\bar{t}$ modelling	–	–	–	–	–	1.1
Total systematic impact	3.7	3.5	3.5	1.7	2.4	2.5
Statistical impact	0.01	0.01	0.01	0.01	0.02	0.32