Measurements of W and Z boson production at ATLAS

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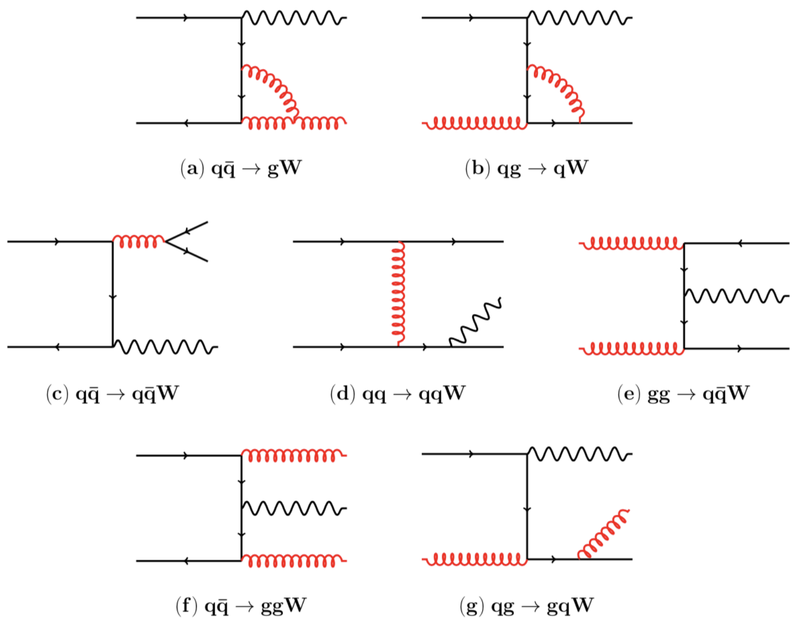
INTRODUCTION

- W and Z production allow to probe the SM Electroweak sector and to check the consistency of the SM
  - E.g. W mass, weak mixing angle, lepton universality
- Also allow to probe (non) perturbative QCD predictions
  - At lowest order in QCD: $q\bar{q}' \to W$ and $q\bar{q} \to Z$
  - Higher order QCD: non-zero p_T distribution
- Provides inputs to PDF profiling
- Two measurements presented in this talk :
  - Measurement of $W^{\pm}$ and Z cross-sections at 2.76 TeV
  - Measurement of Z pT at 13 TeV

Example NNLO diagrams for W production



- In this talk Z refers to Z/γ^* in the Drell-Yan process; considered decay channels are muon and electron only (Signal events: $W \to e\nu$, $W \to \mu\nu$, $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$)

ATLAS EXPERIMENT

EVENT TOPOLOGIES

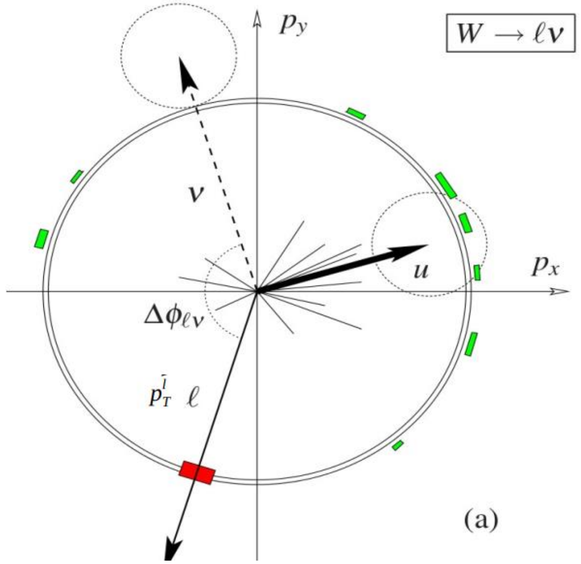
- W-decay topology:

1 lepton + $\mathbf{p_T^{miss}}$(neutrino)

$$\vec{p}_T^{miss} = -(\vec{p}_T^{l} + \vec{u}_T)$$

$$m_T = \sqrt{2 p_T^l E_T^{miss} \left(1 - \cos\left(\phi_l - \phi_{E_T^{miss}}\right)\right)}$$

$\vec{u}_T$ is the vector sum of all topo clusters excluding the ones from lepton

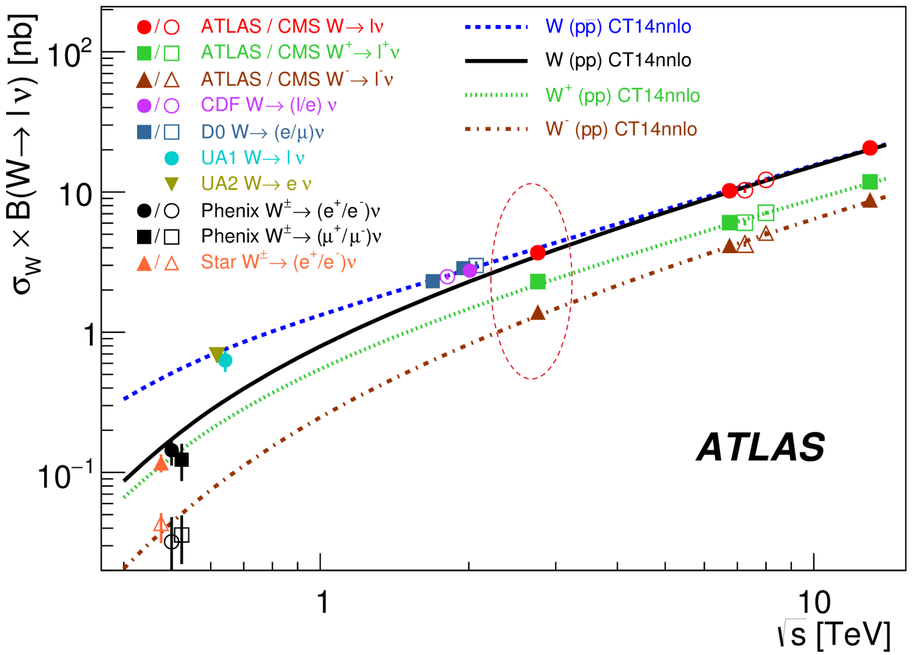


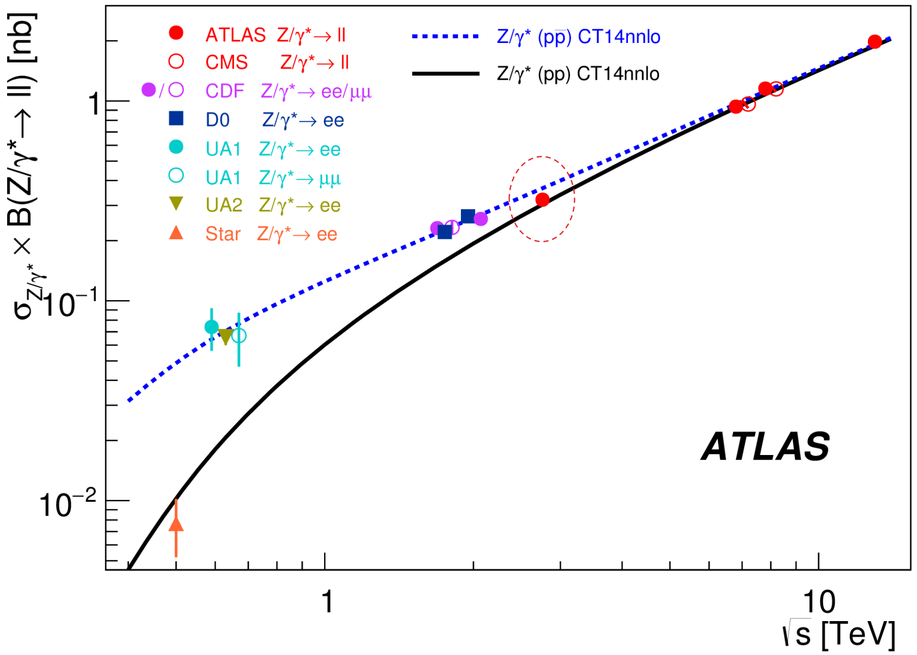
- Z-decay topology: 2 leptons with $\mathbf{m_{ll}}$ peaked around the Z mass.

Lepton is either electron or muon.

ATLAS EXPERIMENT

W/Z CROSS-SECTION VS $\sqrt{s}$





- ATLAS 7 TeV: doi.org/10.1140/epjc/s10052-017-4911-9
- ATLAS 8 TeV: doi.org/10.1140/epjc/s10052-016-4070-4
- ATLAS 13 TeV: doi.org/10.1016/j.physletb.2016.06.023
- The measurements at 2.76 TeV are indicated by the red circles.

ATLAS EXPERIMENT

- Measurement of $W^{\pm}$-boson and Z-boson production cross-sections in pp collisions at $\sqrt{s}$ = 2.76 TeV with the ATLAS detector

ATLAS Collaboration., Aad, G., Abbott, B. et al. Measurement of W±-boson and Z-boson production cross-sections in pp collisions at √s=2.76 TeV with the ATLAS detector. Eur. Phys. J. C 79, 901 (2019). https://doi.org/10.1140/epjc/s10052-019-7399-7

ATLAS EXPERIMENT

DATA AND SIMULATION SAMPLES

- Data:

February 2013 proton beams at LHC, $\sqrt{s}$=2.76 TeV, pile-up $\langle \mu \rangle$=0.3. Instantaneous luminosity: $1 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, integrated luminosity: 4.0 pb^{-1}.

- Baseline simulated samples

Process	Generator	Generator QCD precision
Signal Samples		
$W \to \ell\nu$	Powheg-Box +Pythia 8	NLO
$Z \to \ell^+\ell^-$	Powheg-Box +Pythia 8	NLO
Background Samples		
$W \to \tau\nu$	Powheg-Box +Pythia 8	NLO
$Z \to \tau^+\tau^-$	Powheg-Box +Pythia 8	NLO
$t\bar{t}$	Powheg-Box +Pythia 6	NLO
WW	Herwig	LO
ZZ	Herwig	LO
WZ	Herwig	LO
$b\bar{b}$	Pythia 8	LO
$c\bar{c}$	Pythia 8	LO

ATLAS EXPERIMENT

EVENT SELECTION

- Lepton selection

	Electron	Muon
Reconstruction	Clusters of energy in EM matched to ID tracks	Combining tracks in MS and ID
Lepton p_T	$p_T > 20$ GeV	$p_T > 20$ GeV
Lepton η	$\lvert\eta\rvert < 2.4$ excluding $1.37 < \lvert\eta\rvert < 1.52$	$\lvert\eta\rvert < 2.4$

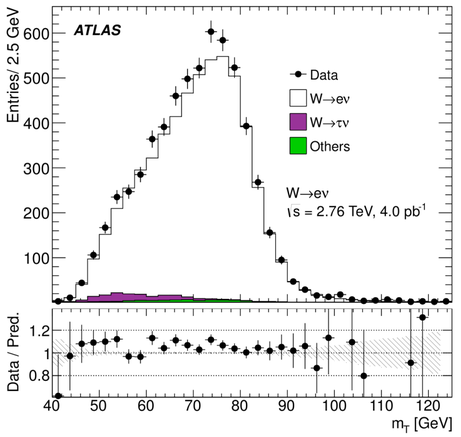
- W and Z fiducial volumes selection

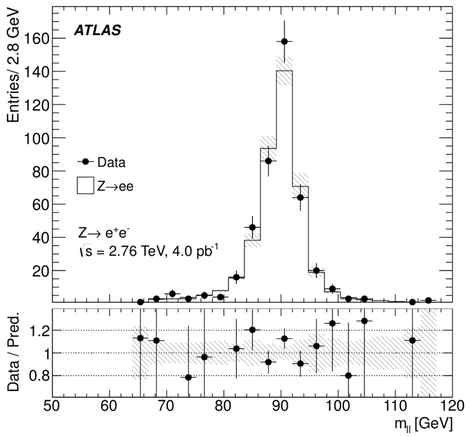
W-boson	Z-boson
$p_T^l > 20$ GeV $\lvert\eta^l\rvert < 2.4$ $E_T^{miss} > 25$ GeV $m_T > 40$ GeV	$p_T^{l^+,-} > 20$ GeV $\lvert\eta^{l^+,-}\rvert < 2.4$ $66 < m_{l^+l^-} < 116$ GeV

NUMBER OF EVENTS

Summary of number of events in each channel

Measurement Channel	Observed candidates	Background (EW + top)	Background (Multijet)	Background-subtracted data N_W^{sig}	Background fraction
$W^+ \to e^+\nu$	3914	108 ± 6	30 ± 11	$3776 \pm 63 \pm 12$	3.5%
$W^- \to e^-\bar{\nu}$	2209	74.2 ± 3.3	30 ± 11	$2105 \pm 47 \pm 12$	4.7%
$W^+ \to \mu^+\nu$	4365	152 ± 7	2.5 ± 1.9	$4210 \pm 66 \pm 7$	3.5%
$W^- \to \mu^-\bar{\nu}$	2460	108 ± 4	2.5 ± 1.9	$2350 \pm 50 \pm 5$	4.5%
$Z \to e^+e^-$	430	1.3 ± 0.0	–	$428.7 \pm 20.7 \pm 0.0$	0.3%
$Z \to \mu^+\mu^-$	646	1.6 ± 0.1	–	$644.4 \pm 25.4 \pm 0.1$	0.2%





mT and mll distributions for $W \to e\nu$ and $Z \to e^+e^-$

- W→ τ ν , Z→l^+l^-, diboson production, $t\bar{t}$ production are estimated by simulation.
- Multijet background in W is estimated from data

ATLAS EXPERIMENT

MULTIJET BACKGROUND ESTIMATION

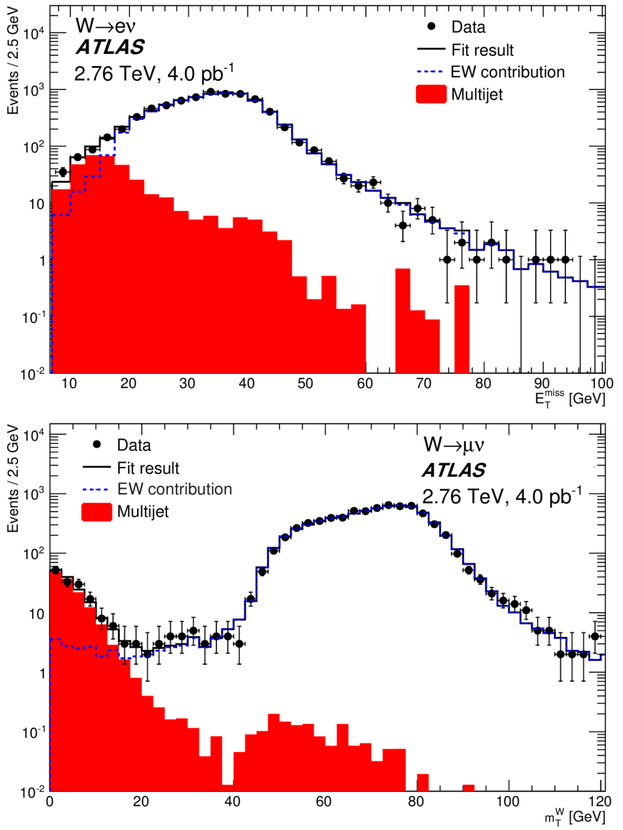
- CR for MJ templates

Electron: Revert electron identification and remove $\mathbf{E_T^{miss}}$ cut

Muon: Revert muon isolation and remove **mT** cut

- Shape of MJ template: $\mathbf{E_T^{miss}}$ or **mT** distribution in the control region after subtraction of expected contributions determined from MC samples.

- Normalization in SR : A χ^2 fit of $\mathbf{E_T^{miss}}$ or **mT** to the sum of template, signal and other backgrounds.



Overall number of MJ events estimated from a fit to the total W sample

CORRECTION FOR DETECTOR EFFECTS

- Fiducial production cross-section:

$$\sigma^{fid}_{W,Z\to l\nu,ll} = \frac{N^{sig}_{W,Z}}{C_{W,Z} \cdot L_{int}}$$

- Total production cross-section:

$$\sigma^{tot}_{W,Z\to l\nu,ll} = \sigma^{tot} \times B(W,Z \to l\nu, ll) = \frac{N^{sig}_{W,Z}}{A_{W,Z} \cdot C_{W,Z} \cdot L_{int}}$$

- Central values of acceptance $A_{W,Z}$: around 0.6

- Values of event detection efficiency $C_{W,Z}$:

$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
0.67	0.75	0.55	0.79

ATLAS EXPERIMENT

UNCERTAINTIES

- Systematic uncertainties in $C_{W,Z}$

$\delta C/C$[%]	$W^+\to e^+\nu$	$W^-\to e^-\nu$	$Z\to e^+e^-$	$W^+\to \mu^+\nu$	$W^-\to \mu^-\nu$	$Z\to \mu^+\mu^-$
Lepton trigger	0.14	0.13	< 0.01	1.07	1.07	0.03
Lepton reconstr. and ident.	2.31	2.33	4.55	0.30	0.32	0.62
Lepton isolation	0.71	0.71	1.41	0.51	0.51	1.01
Lepton scale and resolution	0.44	0.43	0.34	0.05	0.05	0.04
Recoil scale and resolution	0.25	0.20	–	0.22	0.22	–
PDF	0.22	0.29	0.11	0.11	0.20	0.06
MC statistical uncertainty	0.24	0.31	0.30	0.24	0.34	0.43
Total	2.5	2.5	4.8	1.3	1.3	1.3

Muon trigger, electron reconstruction and identification uncertainties are the dominant systematics.

- Systematics uncertainty in $A_{W,Z}$

Choice of PDF set: 1.0%(1.2%) for A_{W^+}(A_{W^-}), 1.4% for A_Z

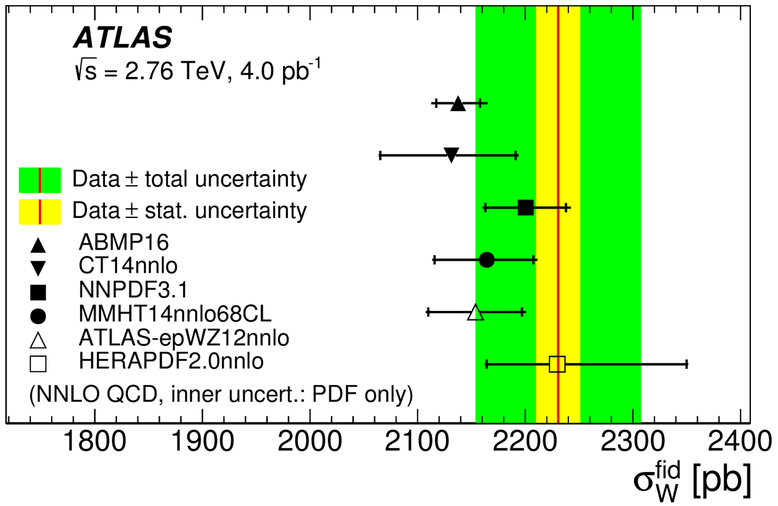
Choice of modelling: ~0.9%

ATLAS EXPERIMENT

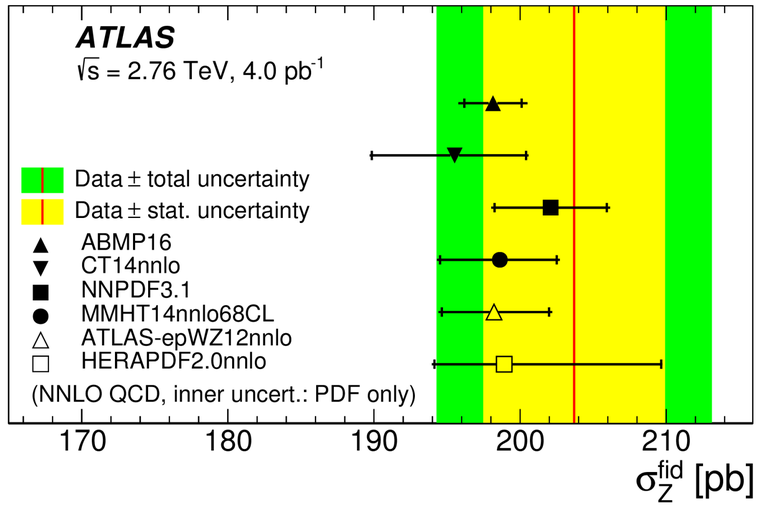
RESULTS

- Cross-section measurement

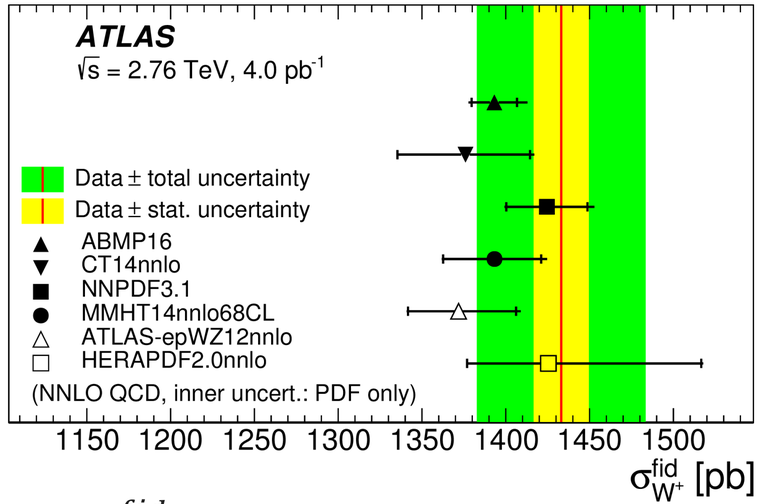
$$\sigma^{fid} = \text{value} \pm \text{stat.} \pm \text{syst.} \pm \text{lumi.}$$



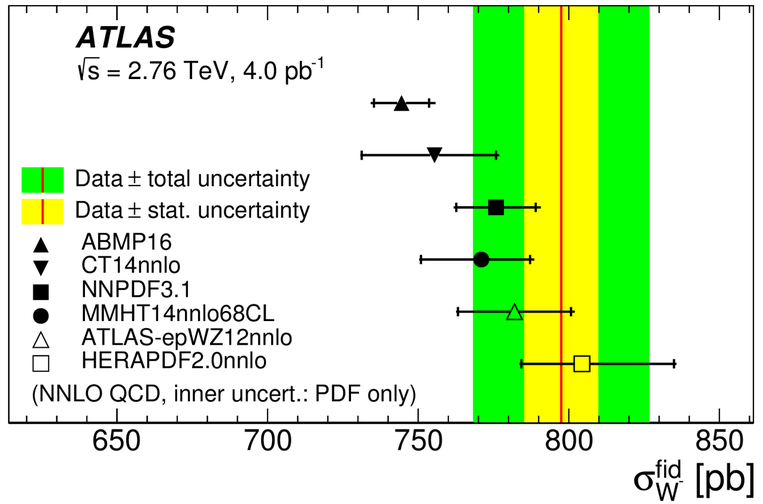
$$\sigma_W^{fid} = 2231 \pm 20 \pm 26 \pm 65 \text{ pb}$$



$$\sigma_Z^{fid} = 203.7 \pm 6.2 \pm 3.2 \pm 6.3 \text{ pb}$$



$$\sigma_{W^+}^{fid} = 1433 \pm 16 \pm 17 \pm 44 \text{ pb}$$



$$\sigma_{W^-}^{fid} = 798 \pm 12 \pm 10 \pm 25 \text{ pb}$$

RESULTS

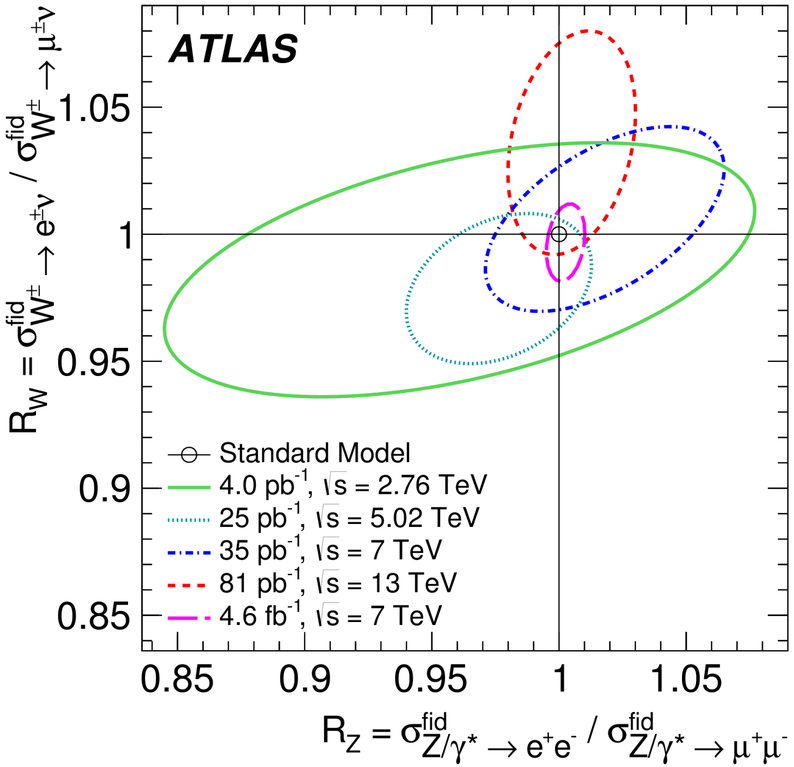
- The ratios of measured cross-sections (test of lepton universality)

$$R_{W^+} = \frac{\sigma^{fid}_{W^+\to e^+\nu}}{\sigma^{fid}_{W^+\to \mu^+\nu}} = 0.985 \pm 0.023(stat.) \pm 0.028(syst.)$$

$$R_{W^-} = \frac{\sigma^{fid}_{W^-\to e^-\nu}}{\sigma^{fid}_{W^-\to \mu^-\nu}} = 0.988 \pm 0.030(stat.) \pm 0.028(syst.)$$

$$R_{W} = \frac{\sigma^{fid}_{w\to e\nu}}{\sigma^{fid}_{w\to \mu\nu}} = 0.986 \pm 0.018(stat.) \pm 0.028(syst.)$$

$$R_{Z} = \frac{\sigma^{fid}_{Z\to e^+e^-}}{\sigma^{fid}_{Z\to \mu^+\mu^-}} = 0.96 \pm 0.06(stat.) \pm 0.05(syst.)$$



Taking ratios of the measurements benefits from full or partial cancellation of correlated systematics.

RESULTS

- The ratios of measured cross-sections:
- $R_{W/Z} = 10.95 \pm 0.35(\text{stat.}) \pm 0.10(\text{syst.})$

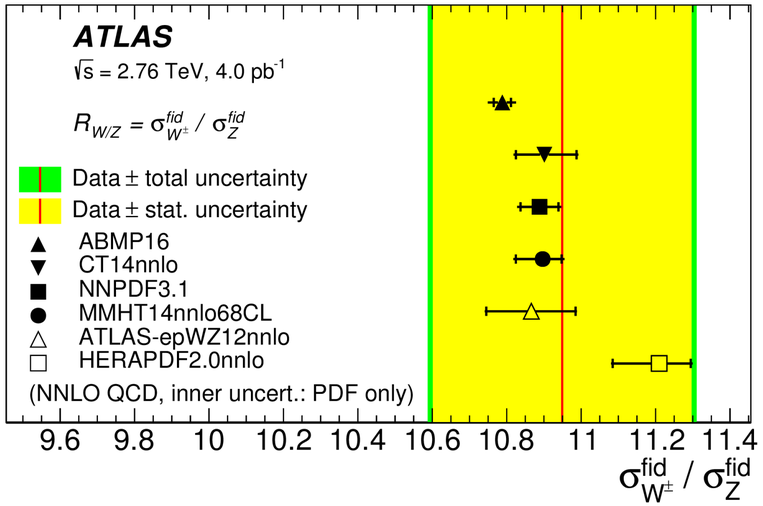
Constrains strange quark distribution.

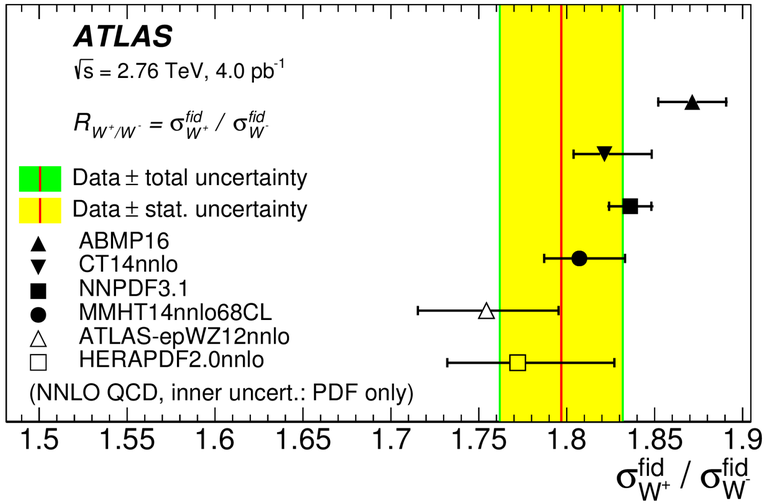
- $R_{W^+/W^-} = 1.797 \pm 0.034(\text{stat.}) \pm 0.009\ (\text{syst.})$

Constrains valence quark distributions.

- Alternatively, in terms of charge asymmetry:

$$A_l = \frac{\sigma^{fid}_{W^+} - \sigma^{fid}_{W^-}}{\sigma^{fid}_{W^+} + \sigma^{fid}_{W^-}} = 0.285 \pm 0.009(\text{stat.}) \pm 0.002(\text{syst.})$$





- Measurement of the transverse momentum distribution of Drell－Yan lepton pairs in proton－proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

Aad, G., Abbott, B., Abbott, D.C. et al. Measurement of the transverse momentum distribution of Drell－Yan lepton pairs in proton－proton collisions at √s=13TeV with the ATLAS detector. Eur. Phys. J. C 80, 616 (2020). https://doi.org/10.1140/epjc/s10052-020-8001-z

ATLAS EXPERIMENT

DEFINITIONS OF OBSERVABLES

The Z-boson differential cross-sections are measured as a function of p_T^{ll} and ϕ_η^*

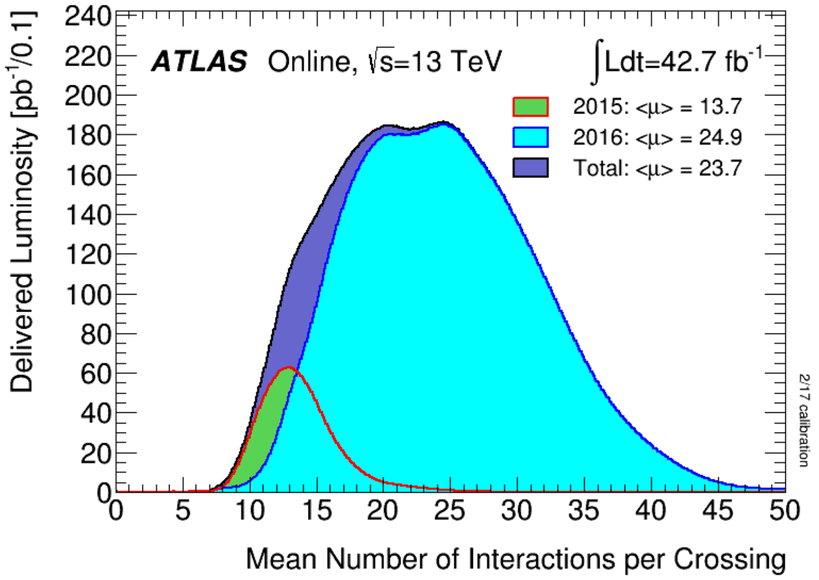
- A precise measurement of the p_T^{ll} provides an important input to the background prediction in searches for beyond SM processes (high p_T) as well as to SM precision measurement (low p_T).

- $\phi_\eta^* = tan\left(\frac{\pi - \Delta\phi}{2}\right) \times sin(\theta_\eta^*)$, with $\cos(\theta_\eta^*) = tanh\left(\frac{\eta^- - \eta^+}{2}\right)$. Since ϕ_η^* depends on the direction of leptons, it overcomes the limitation of lepton momentum resolution in low p_T^{ll}.

ATLAS EXPERIMENT

DATA AND SIMULATION SAMPLES

- Data: 2015+2016 pp collision at $\sqrt{s}$=13TeV, integrated luminosity of the sample: L_{int}=36.1 fb^{-1}
- MC Signal: Powheg-Box + Pythia8



Number of interactions per crossing for combined 13 TeV data from 2015 and 2016.

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2

ATLAS EXPERIMENT

EVENT SELECTION

- Lepton selection

	Electron	Muon
Reconstruction	Clusters of energy in EM matched to ID tracks	Combining tracks in MS and ID
Lepton p_T	$p_T > 27$ GeV	$p_T > 27$ GeV
Lepton η	$\lvert\eta\rvert < 2.47$ excluding $1.37 < \lvert\eta\rvert < 1.52$	$\lvert\eta\rvert < 2.5$

- Z-boson fiducial volume selection

Z-boson
$p_T^{l^+,-} > 27$ GeV
$\lvert\eta^{l^+,-}\rvert < 2.5$
$66 < m_{l^+l^-} < 116$ GeV

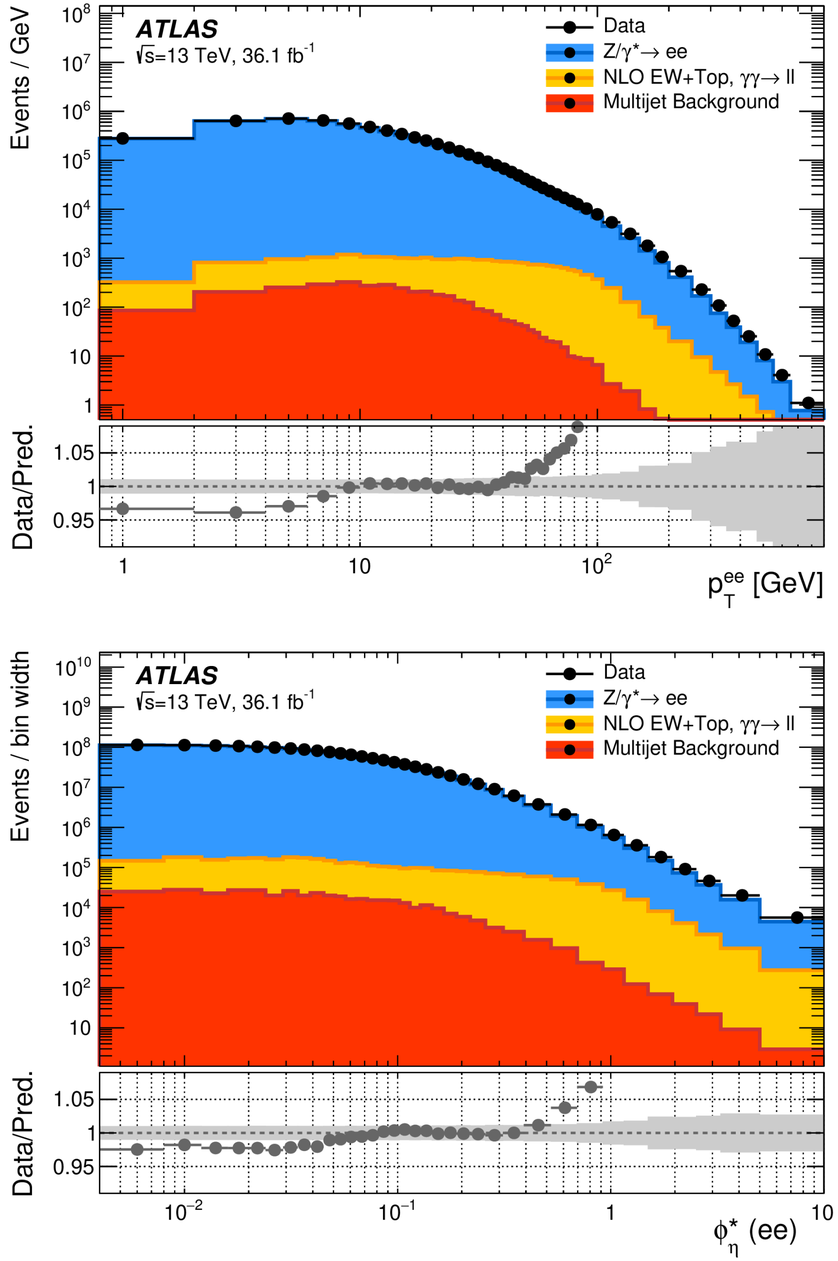
ATLAS EXPERIMENT

NUMBER OF EVENTS

- Signal events & estimated background

	$Z/\gamma^* \to ee$	$Z/\gamma^* \to \mu\mu$
Two reconstructed leptons within fiducial volume	13 649 239	18 162 641
Electroweak background ($Z \to \tau\tau$, WW, WZ, ZZ)	40 000 ± 2000	50 000 ± 2500
Photon-induced background	2900 ± 140	4100 ± 200
Top-quark background	38 000 ± 1900	45 400 ± 2200
Multijet background	8500 ± 4900	1000 ± 200
Total Background	89 400 ± 5600	100 500 ± 3300
Background fraction	0.7%	0.6%

- On the right: p_T^{ll} and ϕ_η^* for electron channel comparing data and MC predictions



CORRECTION FOR DETECTOR EFFECTS

- Measurement in fiducial volumes

$$\sigma^{fid}_{Z/\gamma^* \to ll} = \frac{N_{Data} - N_{Bkg}}{C_Z \cdot L_{int}}$$

C_Z is the correction for event detection efficiency

- Final differential distributions account for detector effects using Bayesian unfolding. The response matrix and correction for reconstruction efficiency are obtained from signal MC samples predictions.

ATLAS EXPERIMENT

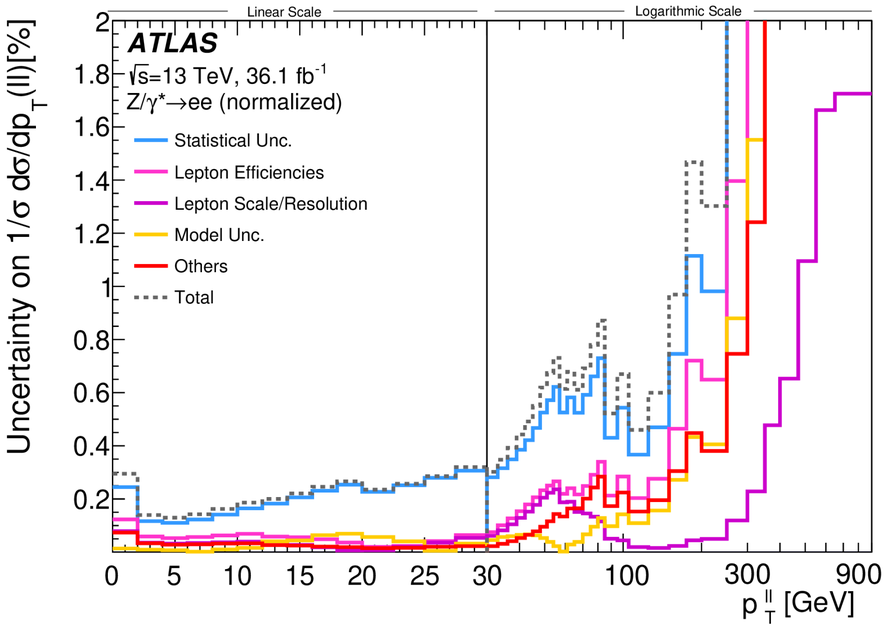
UNCERTAINTIES

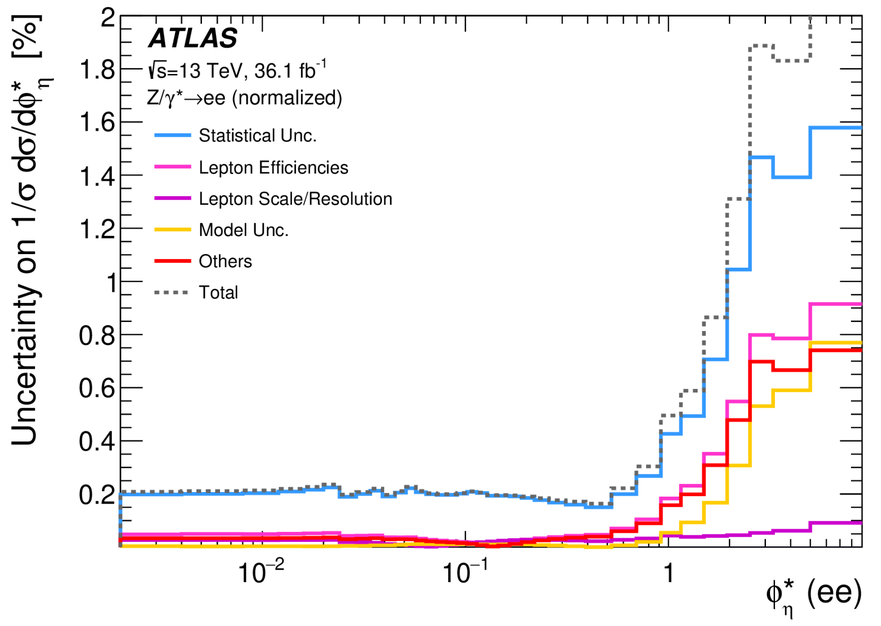
- Detection efficiency factors C_Z and their systematic uncertainties.

	Electron channel		Muon channel	
	Born	Dressed	Born	Dressed
C_Z	0.509 ± 0.005	0.522 ± 0.005	0.685 ± 0.011	0.702 ± 0.011
Trigger efficiencies	± 0.0004		± 0.0004	
Identification & reconstruction efficiencies	± 0.0049		± 0.0102	
Isolation efficiencies	± 0.0009		± 0.0029	
Energy/momentum scale and resolution	± 0.0014		± 0.0010	
Pile-up	± 0.0011		± 0.0019	
Model uncertainties	± 0.0001		± 0.0001	

Theory and modelling uncertainties are negligible.

- Systematic uncertainties in electron channel for p_T^{ll} and Φ_η^* are shown on the right.





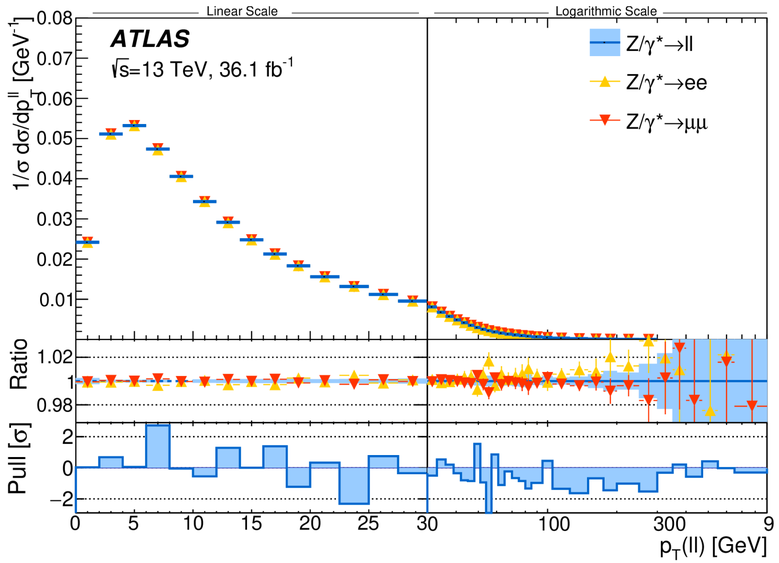
RESULTS

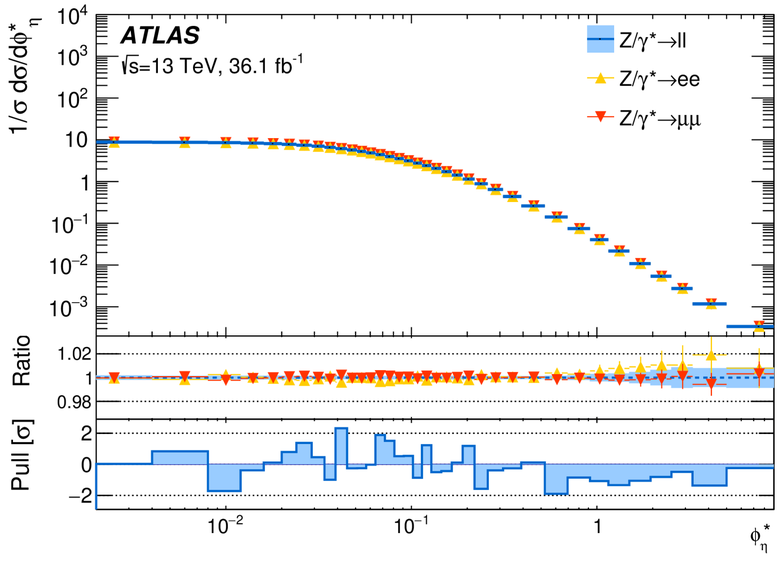
- Integrated cross-section

Channel	Measured cross-section $\times \mathcal{B}(Z/\gamma^* \to \ell\ell)$ (value ± stat. ± syst. ± lumi.)	Predicted cross-section $\times \mathcal{B}(Z/\gamma^* \to \ell\ell)$ (value ± PDF ± α_S ± scale ± intrinsic)
$Z/\gamma^* \to ee$	$738.3 \pm 0.2 \pm 7.7 \pm 15.5$ pb	
$Z/\gamma^* \to \mu\mu$	$731.7 \pm 0.2 \pm 11.3 \pm 15.3$ pb	
$Z/\gamma^* \to \ell\ell$	$736.2 \pm 0.2 \pm 6.4 \pm 15.5$ pb	$703^{+19\ +6\ +4\ +5}_{-24\ -8\ -6\ -5}$ pb (See Ref. below)

The prediction is at NNLO in α_S using CT14 PDF set.

Reference: ATLAS Collaboration, Measurements of top-quark pair to Z-boson cross-section ratios at $\sqrt{s}$ = 13, 8, 7 TeV with the ATLAS detector, JHEP 02 (2017) 117, DOI: 10.1007/JHEP02(2017)117

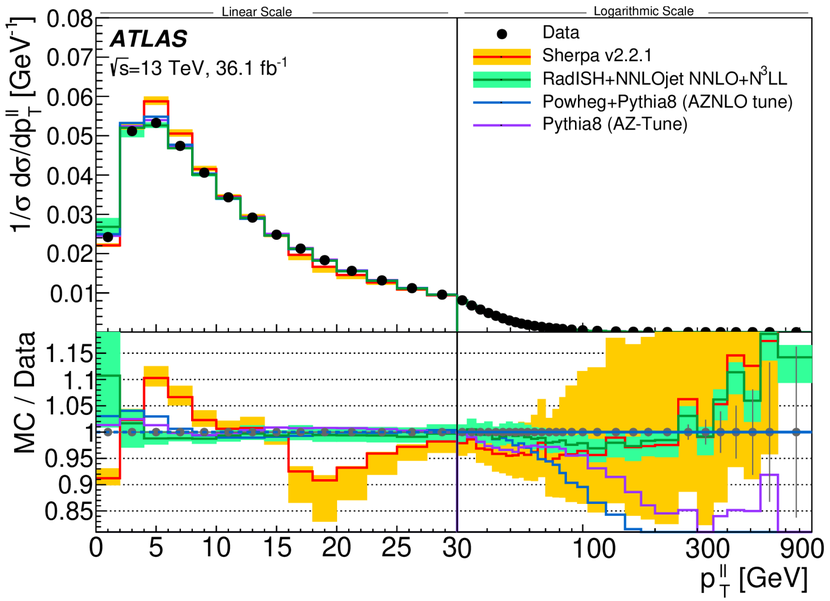


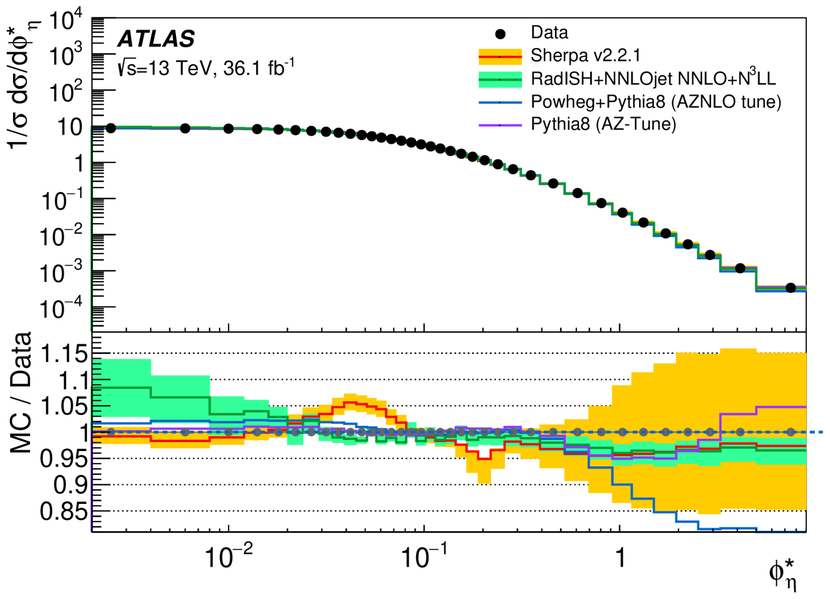


- Normalized cross-section

RESULTS

- Comparison of the normalized distributions predicted by various computations with the Born level combined measurement.





The RadISH prediction agrees with the data over the spectra of p_T^{ll} and ϕ_η^* within uncertainties of typically 1%~3% (larger in the low p_T^{ll} and ϕ_η^* regions).

SUMMARY

- The production cross-section for W and Z bosons are measured using ATLAS data at $\sqrt{s}$=2.76 TeV in fiducial region and extrapolated to the full phase space. Measured ratios and asymmetries are also reported, in agreement with NNLO QCD calculations.
- p_T^{ll} and ϕ_η^* distributions of Drell-Yan lepton pairs have been measured by ATLAS at $\sqrt{s}$=13 TeV. The data agrees with QCD prediction based on resummation approaches within uncertainties.

ATLAS EXPERIMENT

BACKUP

ATLAS DETECTOR

- **Sub-detector systems:**

Inner detector (ID)
EM calorimeter
Hadronic calorimeter
Muon spectrum (MS)

- **Magnet system:**

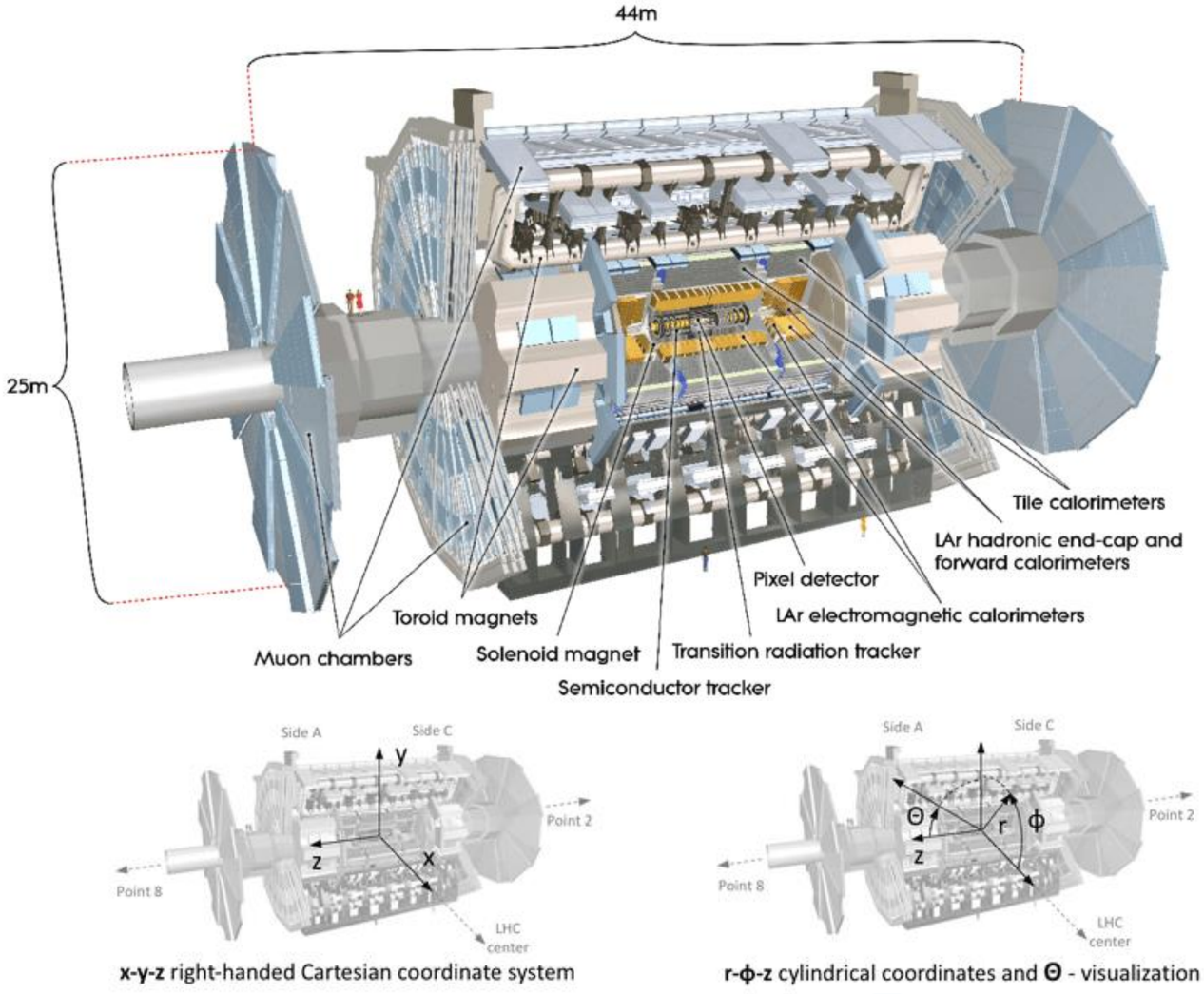
Central solenoid magnet
Barrel & end-cap toroids

- **Pseudo-rapidity:**

$\eta = \ln[\tan(\theta/2)]$

- **Angular distance:**

$\Delta R = \sqrt{\Delta\eta^2 + \Delta\theta^2}$



ANA-STDM-2018-06: EVENT SELECTION

- Event trigger : at least 1 electron (muon) with p_T^l > 15 GeV (10 GeV)
- Hard scatter vertex with at least 3 associated tracks
- Electrons : clusters of energy in EM matched to ID tracks, p_T > 20 GeV, $|\eta|$ < 2.4 excluding 1.37 < $|\eta|$ < 1.52, *medium* identification, isolated (Sum of transverse energies <10% of electron p_T within ΔR=0.2)
- Muons: combining tracks in MS and ID, p_T > 20 GeV, $|\eta|$ < 2.4 , isolated (p_T sum <80% of muon p_T within ΔR=0.8)
- W boson: hadronic recoil built from the vector sum of topo-clusters calibrated to the hadronic scale
- W selection : exactly one lepton matching the trigger, E_T^{miss} > 25 GeV, m_T > 40 GeV
- Z selection : exactly two opposite sign leptons fulfilling 66 < m_{ll} < 116 GeV, at least one matches the trigger

- Fiducial volumes selection

W-boson fiducial region	*Z*-boson fiducial region
$p_T^\ell > 20$ GeV	$p_T^{\ell^+,-} > 20$ GeV
$\lvert\eta^\ell\rvert < 2.4$	$\lvert\eta^{\ell^+,-}\rvert < 2.4$
$E_T^{miss} > 25$ GeV	$66 < m_{\ell^+\ell^-} < 116$ GeV
$m_T > 40$ GeV	

ATLAS EXPERIMENT

ANA-STDM-2018-06

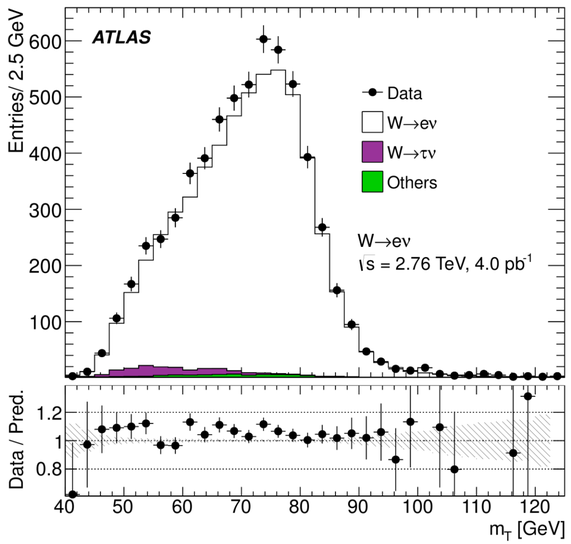
- Combined fiducial and total X-sections

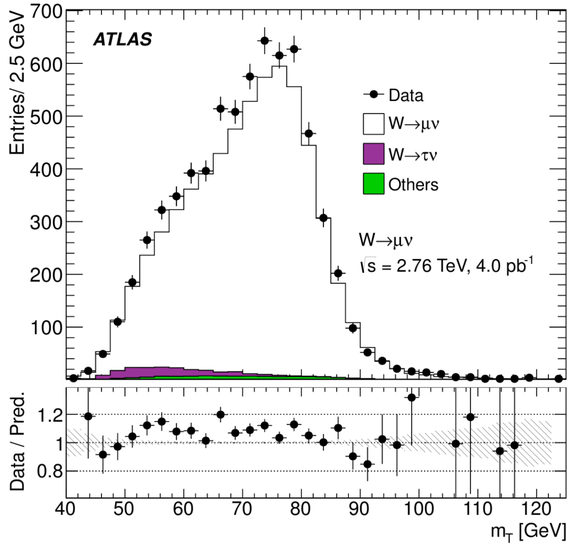
	Value ± stat. ± syst. ± lumi. (± extr.)	Value ± stat. ± syst. ± lumi. (± extr.)
	$W^+ \to \ell\nu$	$W^- \to \ell\nu$
σ_W^{fid} [pb]	$1433 \pm 16 \pm 17 \pm 44$	$798 \pm 12 \pm 10 \pm 25$
σ_W^{tot} [pb]	$2312 \pm 26 \pm 27 \pm 72$ (± 30)	$1399 \pm 21 \pm 17 \pm 43$ (± 21)
	$W \to \ell\nu$	
σ_W^{fid} [pb]	$2231 \pm 20 \pm 26 \pm 69$	
σ_W^{tot} [pb]	$3711 \pm 34 \pm 43 \pm 115$ (± 51)	
	$Z \to \ell\ell$	
σ_Z^{fid} [pb]	$203.7 \pm 6.2 \pm 3.2 \pm 6.3$	
σ_Z^{tot} [pb]	$323.4 \pm 9.8 \pm 5.0 \pm 10.0$ (± 5.5)	

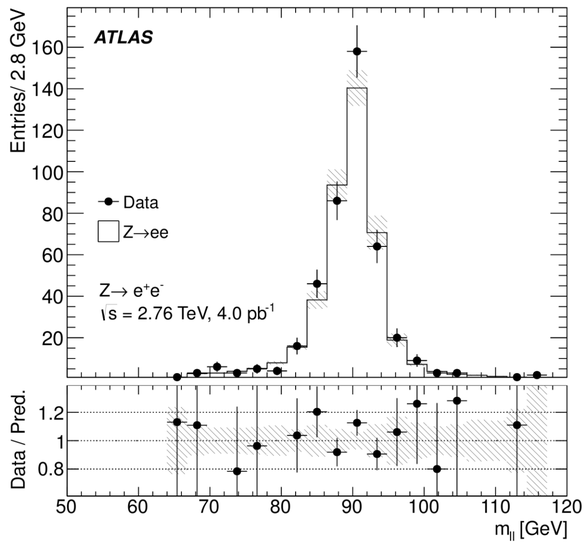
ATLAS EXPERIMENT

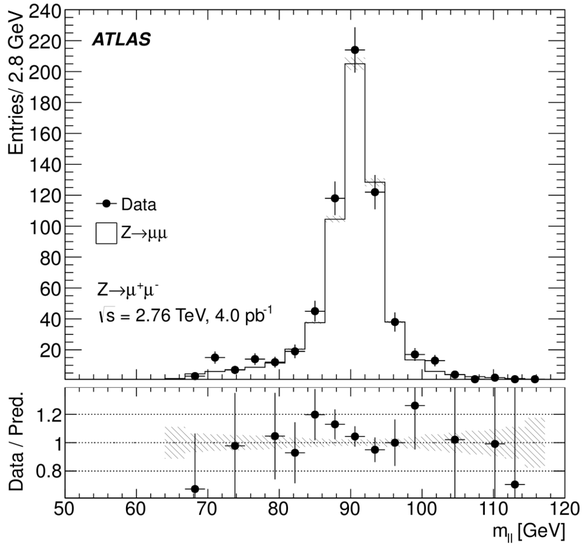
ANA-STDM-2018-06

- mT or m_ll candidate events









ATLAS EXPERIMENT

ANA-STDM-2018-06

- Uncertainties

Electron Reco&ID: tag-and-probe method in 8 TeV data, extrapolated to the 2.76 TeV dataset. (+2%)

Isolation corrections: tag-and-probe at 2.76 TeV. Uncertainty is set to the correction itself. (1% at low pT, 0.3% at high pT)

Electron energy scale: possible bias in the calibration method, the choice of generator, the presampler energy scale, and imperfect knowledge of the material in front of the EM calorimeter.

Muon trigger and isolation: tag-and-probe at 2.76 TeV (1.1%; 0.6%(0.5%) at low(high) pT)

Muon Reco&ID: tag-and-probe method at 8 TeV is applied

MET: smearing and bias corrections applied to obtain satisfactory modelling of the recoil

Luminosity: calibration of the luminosity scale derived from beam-separation scans performed during the 2.76 TeV operation (3.1%)

ATLAS EXPERIMENT

ANA-STDM-2018-06

- Uncertainties (correlations)

Source	Muon channel			Electron channel		
	Z	W^+	W^-	Z	W^+	W^-
Muon trigger	A	A	A	–	–	–
Muon reconstruction/ID	A	A	A	–	–	–
Muon energy scale/resolution	A	A	A	–	–	–
Muon isolation	A	A	A	–	–	–
Electron trigger	–	–	–	A*	A*	A*
Electron reconstruction/ID	–	–	–	A	A	A
Electron energy scale/resolution	–	–	–	A	A	A
Electron isolation	–	–	–	A	A	A
Recoil related	–	A	A	–	A	A
EW background	A	B	B	A	B	B
Top-quark background	A	A	A	A	A	A
Multijet background	–	A	A	–	A	A
PDF	A	A	A	A	A	A

Same letter in a row: fully correlated

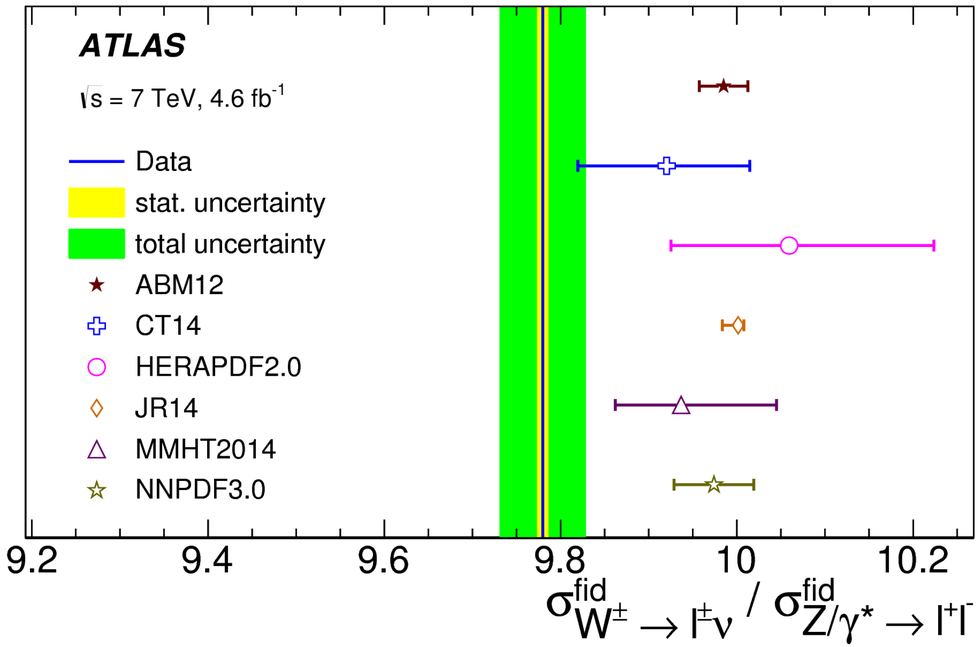
Starred letter: mostly correlated with the same letter in a row

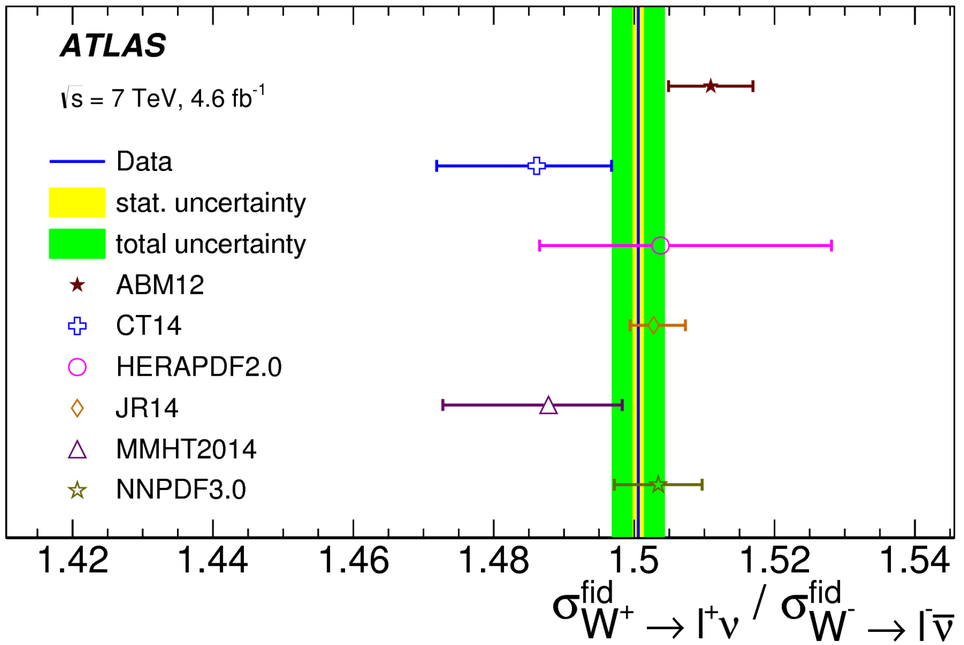
Different letters in a row: fully or mostly uncorrelated

ATLAS EXPERIMENT

ANA-STDM-2018-06

- $R_{W/Z}$ and R_{W^+/W^-} at 7 TeV



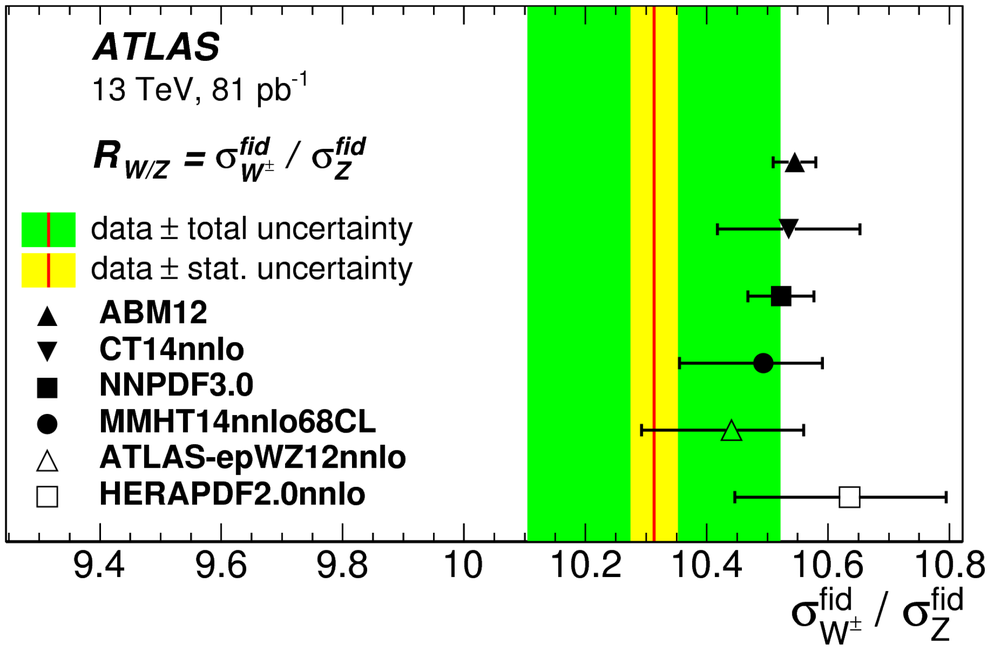


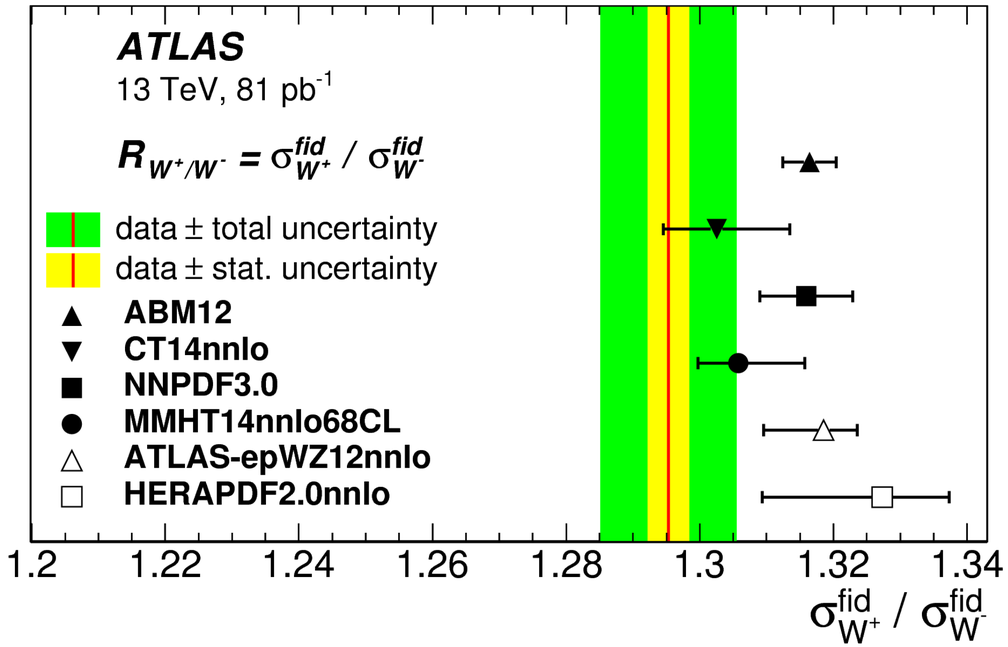
DOI: 10.1140/epjc/s10052-017-4911-9

ATLAS EXPERIMENT

ANA-STDM-2018-06

- $R_{W/Z}$ and R_{W^+/W^-} at 13 TeV





DOI: 10.1016/j.physletb.2016.06.023

ATLAS EXPERIMENT

ANA-STDM-2018-14: EVENT SELECTION

- $Z \to ee$ trigger: at least 1 isolated electron with p_T > 24GeV in 2015 and p_T > 26 GeV in 2016
- $Z \to \mu\mu$ trigger: at least 1 isolated muon with p_T > 20GeV in 2015 and p_T > 26GeV in 2016
- Primary vertex: at least 2 reconstructed tracks with p_T > 0.4 GeV
- Electron candidate: clusters of energy in EM matched to ID tracks, *medium* identification and *gradient* isolation
  - p_T > 27 GeV, $|\eta| < 2.47$ excluding $1.37 < |\eta| < 1.52$, impact parameter cuts
- Muon candidate: combining tracks in MS and ID, *medium* identification, *gradient* isolation
  - p_T > 27 GeV, $|\eta| < 2.5$, impact parameter cuts
- Exactly two opposite sign leptons fulfilling $66 < m_{ll} < 116$ GeV, at least one matches the trigger
- $Z/\gamma^* \to ll$ fiducial volume selection:

Exactly two OSSF leptons with p_T > 27GeV and $|\eta| < 2.5$ and $66 < m_{ll} < 116$ GeV

ATLAS EXPERIMENT

ANA-STDM-2018-14

- Background simulation: Powheg+Pythia8 for $Z \to \tau\tau$ and diboson, Powheg+Pythia6/Powheg+Pythia8 for top background, Pythia8 for $\gamma\gamma \to ll$

ANA-STDM-2018-14

- Uncertainties

Limited size of data & MC samples: pseudo-experiment variations

Dominant uncertainties in pTll: scale and resolution of electron energy scale and muon momentum scale

Dominant uncertainties in fiducial X-section: electron or muon Reco and ID (uncorrelated)

MC background estimations: independently varying the theory cross-sections used to normalize the corresponding samples and observing the effect

Luminosity: LUCID-2 for the primary luminosity measurements (2.1%)

ANA-STDM-2018-14

- Multijet-dominated samples

Electron: two same-charge electrons passing loose ID but not medium ID, collected by di-electron trigger without isolation.

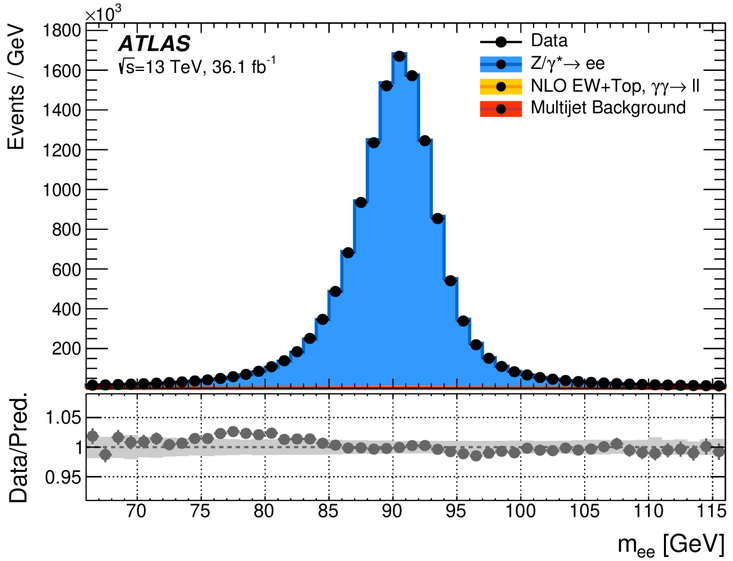
Muon: two same-charge muons.

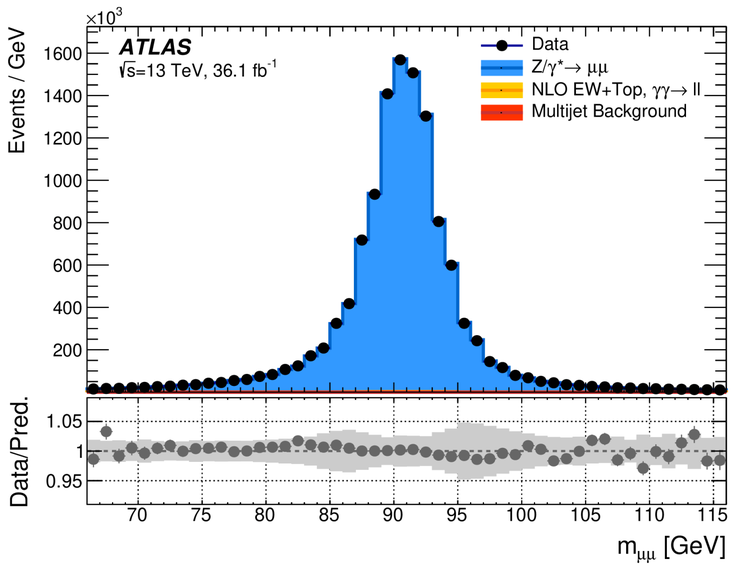
- Normalization of the template

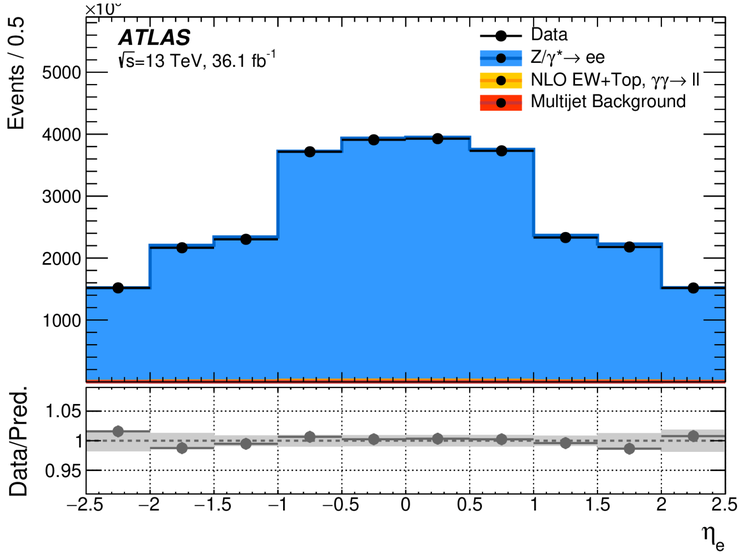
Electron: A fit to the distribution of the electron isolation using all event-selection criteria except the ones for isolation variables.

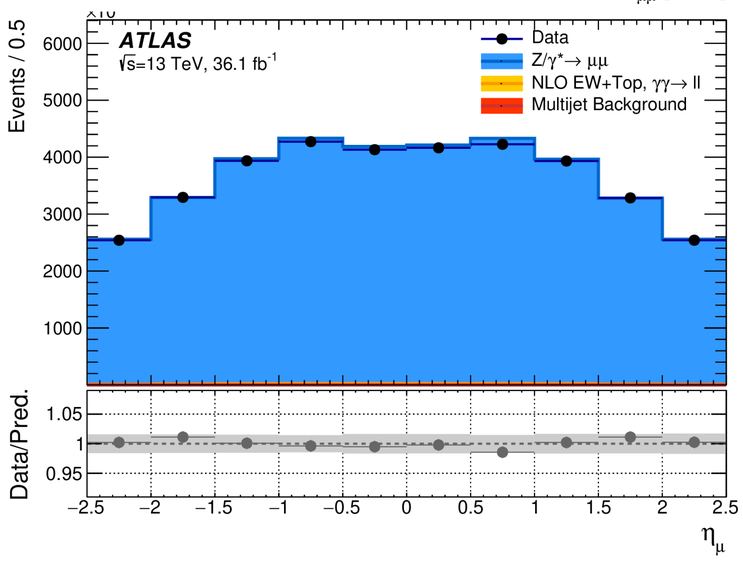
Muon: Using the ratio of number of opposite-charge dimuon events to the number of same-charge events where the muons don’t satisfy the isolation criteria.

ANA-STDM-2018-14





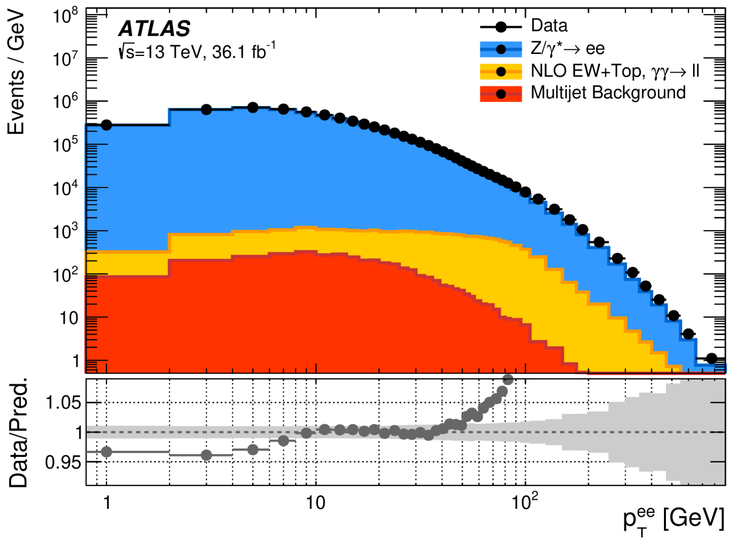


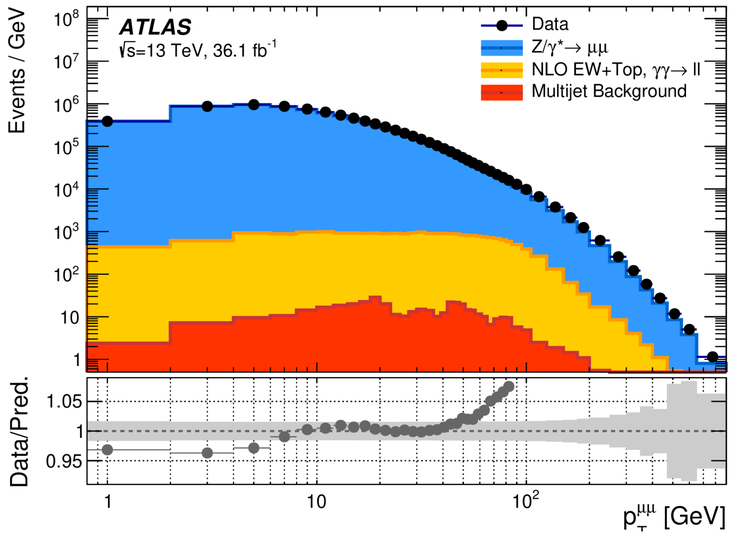


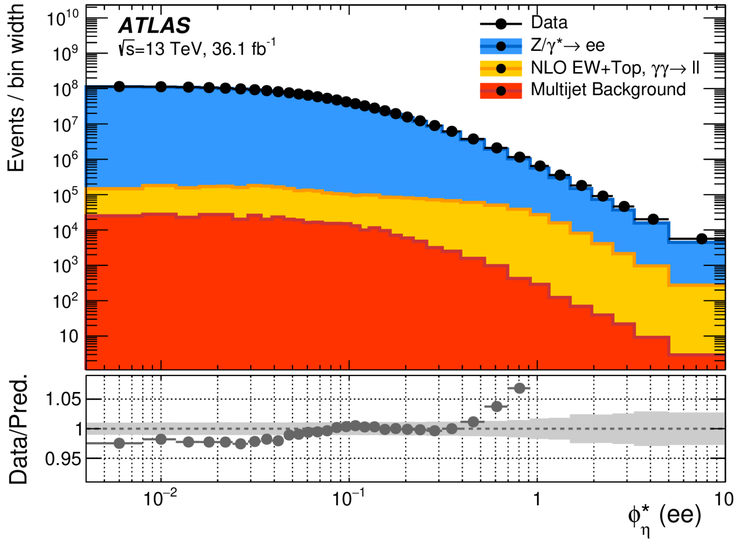
- m_{ll} and η_l for both channels.

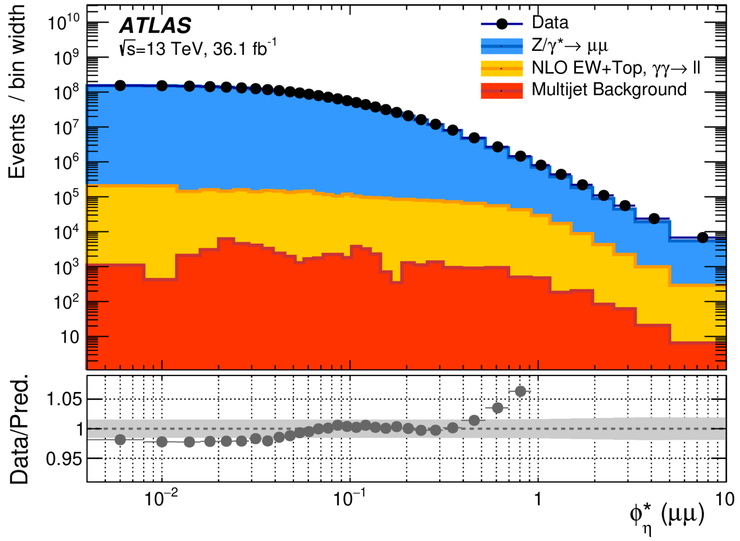
ATLAS EXPERIMENT

ANA-STDM-2018-14





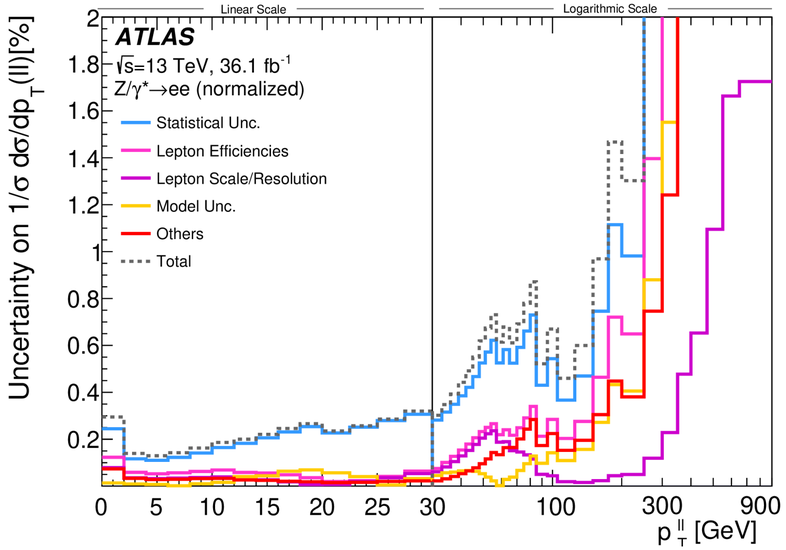


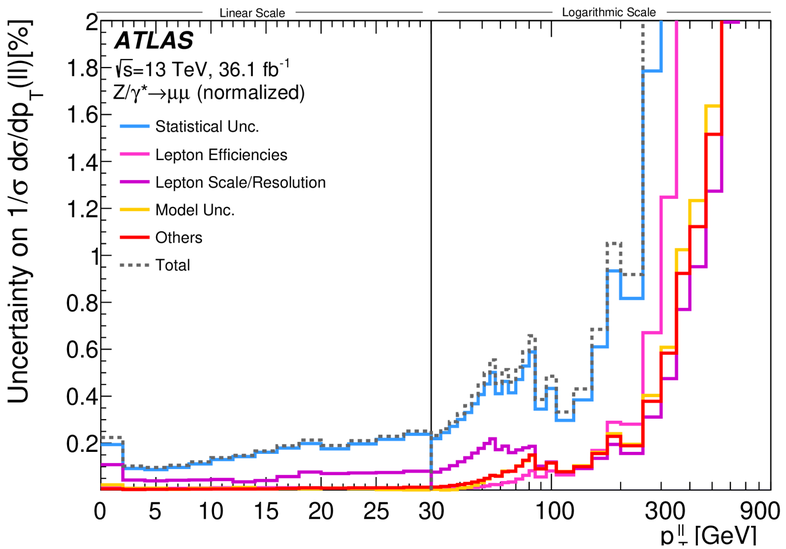


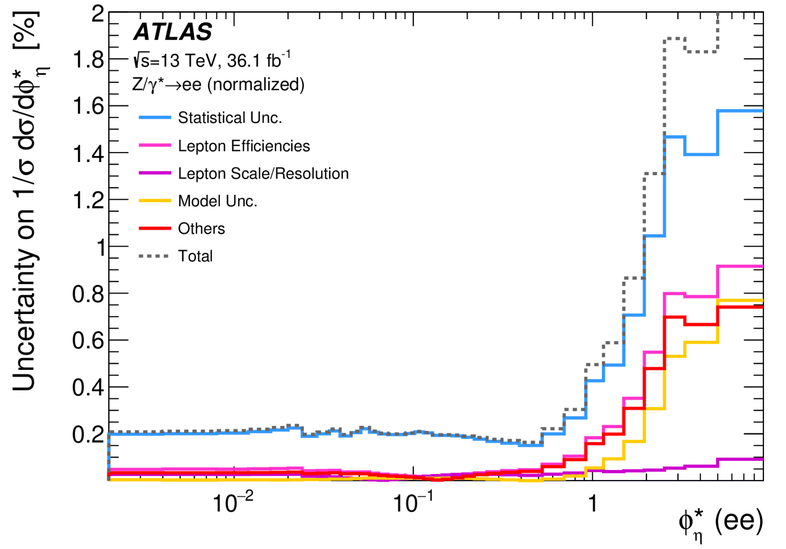
- p_T^{ll} and ϕ_η^* for both channels

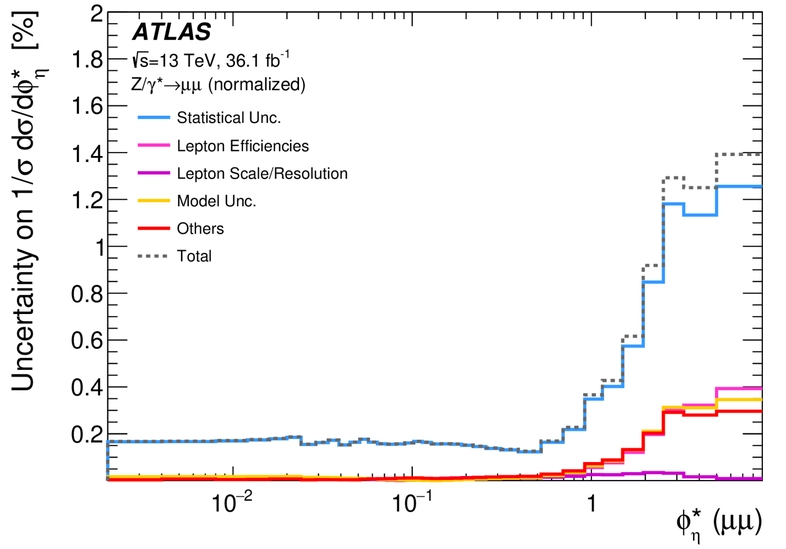
ATLAS EXPERIMENT

ANA-STDM-2018-14









- p_T^{ll} and ϕ_η^* uncertainties

ATLAS EXPERIMENT