Measurement of the top-quark pair to Z-boson production cross-section ratio at a centre-of-mass energy of 13.6 TeV with the ATLAS detector

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8th BCD ISHEP Cargèse School

Overview

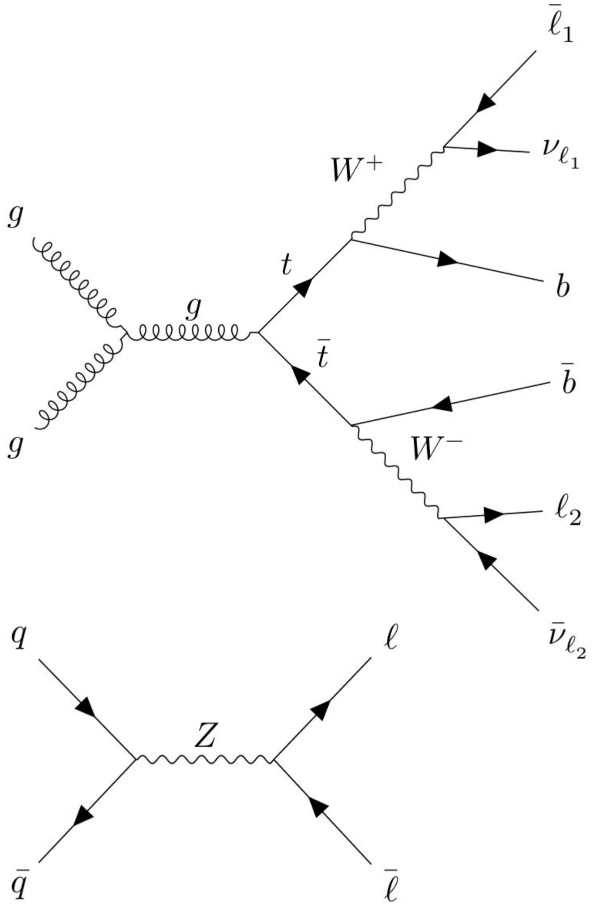
First ATLAS Run 3 physics result: **ATLAS-CONF-2022-070**

Cross-section ratio: top-antitop quark pair / Z-boson

- sensitive to
  - strong coupling constant
  - top-quark mass
  - parton distribution functions (PDF)

- LHC Run 3
  - validation of detector functionality, software, Monte Carlo simulation (MC), data
  - large cross-sections
  - clear signals in dilepton final state
  - low backgrounds

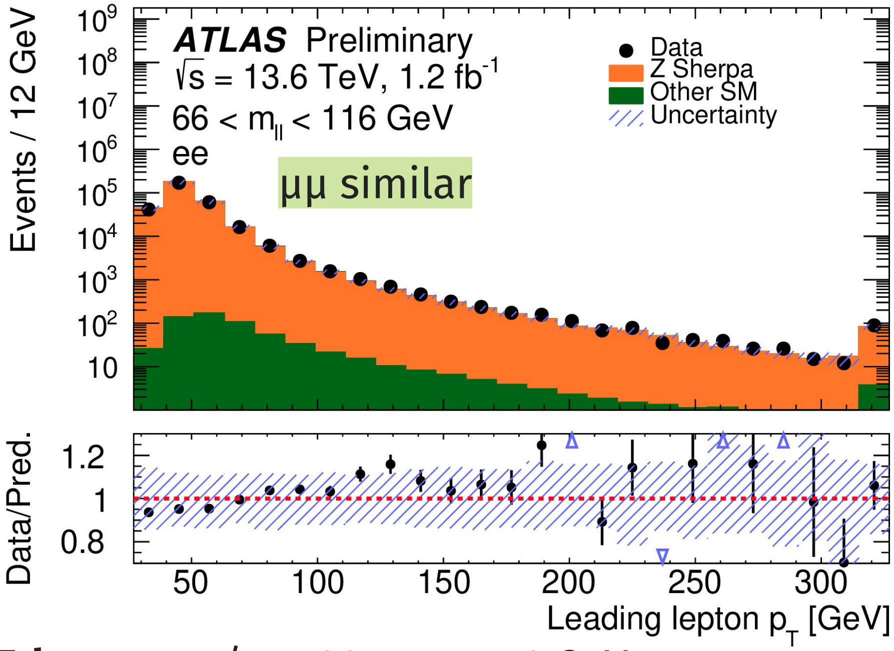
Data: 1.2 fb^{-1}, $\sqrt{s}$ = 13.6 TeV, pp-collisions

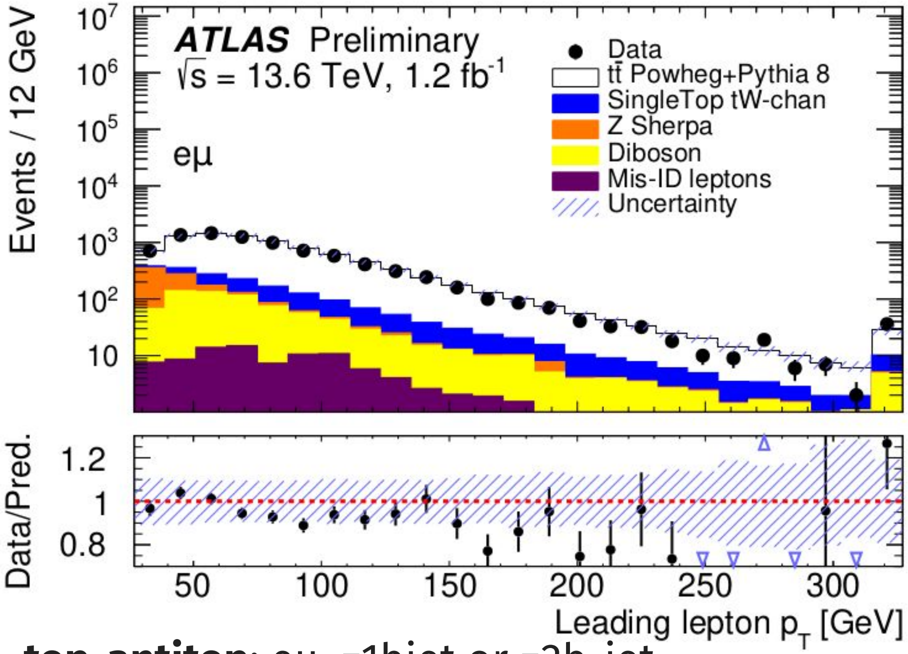


Signal Regions

Selections: opposite charge dileptons

Prefit plots





Z-boson: ee/μμ, 66 < m_{ll}< 116 GeV
➡ extrapol. to m_{ll}> 40 GeV fid. phase space

top-antitop: eμ, =1bjet or =2b-jet
(DNN tagger @77% efficiency WP)

Analysis Strategy

1. <u>In-situ measurement of efficiency to reconstruct+tag exactly 1 b-jet:</u> ϵ_b

tagging correlation factor

eμ events

with =1 b-tag: $$N_1 = L\sigma_{t\bar{t}}\epsilon_{e\mu}2\epsilon_b\,(1 - C_b\epsilon_b) + N_1^{\mathrm{bkg}}$$

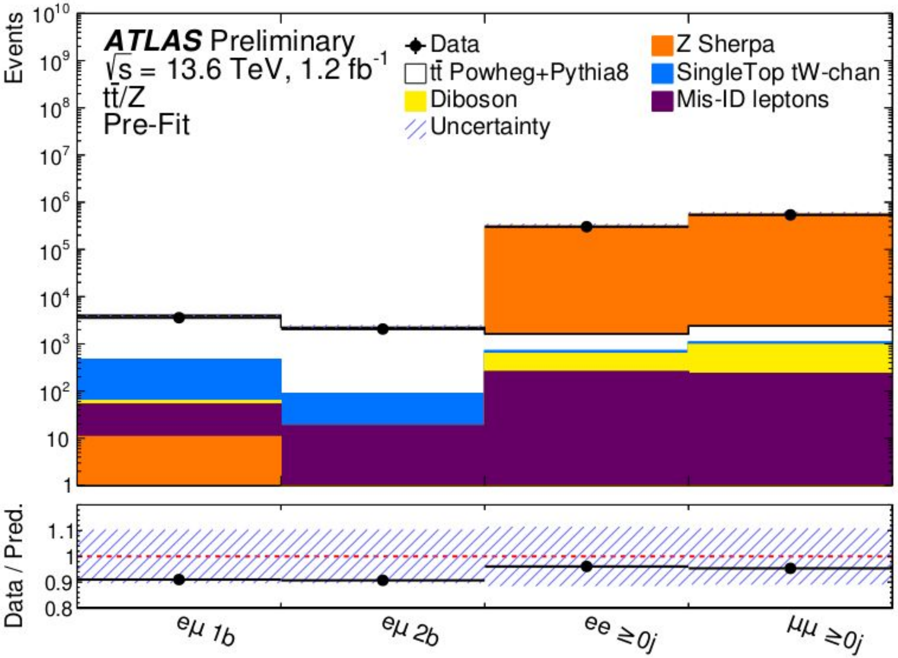
with =2 b-tags: $$N_2 = L\sigma_{t\bar{t}}\epsilon_{e\mu}C_b\epsilon_b^2 + N_2^{\mathrm{bkg}}$$

2. <u>Profile-likelihood fit</u>

- 3 free-floating parameters
  - ϵ_b top-antitop events in eμ region
  - μ_Z all top-antitop + all Z-boson events
  - $R_{t\bar{t}/Z}$ all top-antitop events → ratio strategy to achieve cancellation due to ±10% luminosity uncertainty

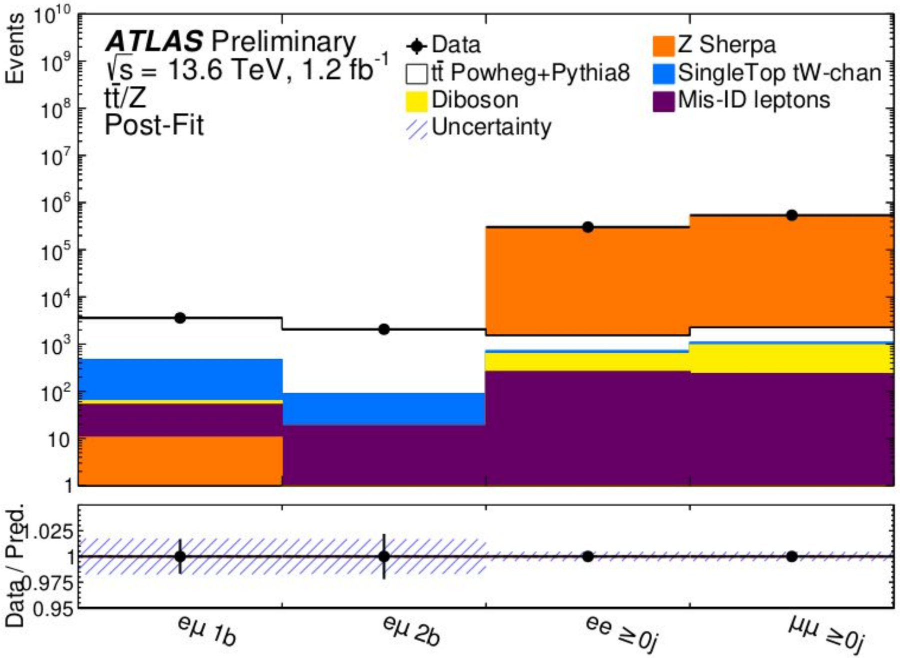
➡ $\mu_{t\bar{t}} = R_{t\bar{t}/Z} \cdot \mu_Z$

Prefit plot



- large overall uncertainty (luminosity)

Postfit plot

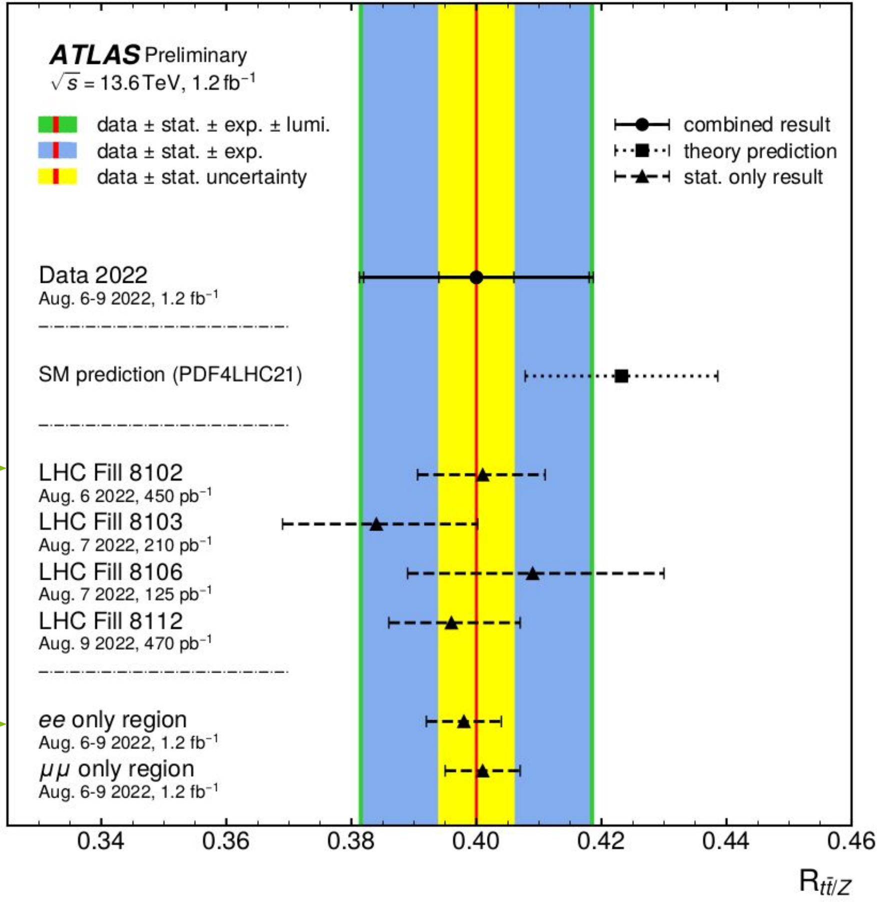


- strong reduction of uncertainty
  ➡ correlation of nuisance parameters

Results

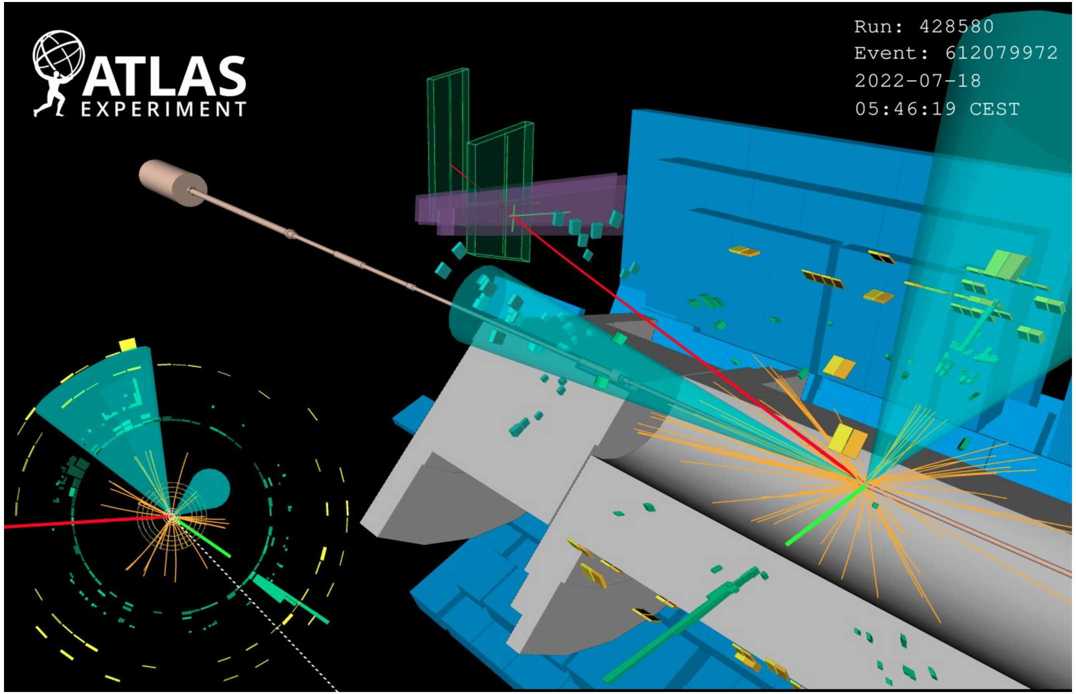
Checks

- measure Z→ee/Z→μμ ratio = 0.99 ± 0.05
- fit for increased lepton p_T selections at 30 GeV and 35 GeV: ~2% effect on result
- repeat ratio fit for each of the LHC fills
- only ee or μμ in the Z region



Conclusion

- cancellation of dominant uncertainty (luminosity)
- overall uncertainty of ±4.7% on ratio parameter
- dominated by
- systematic uncertainty
- result consistent with
- SM prediction



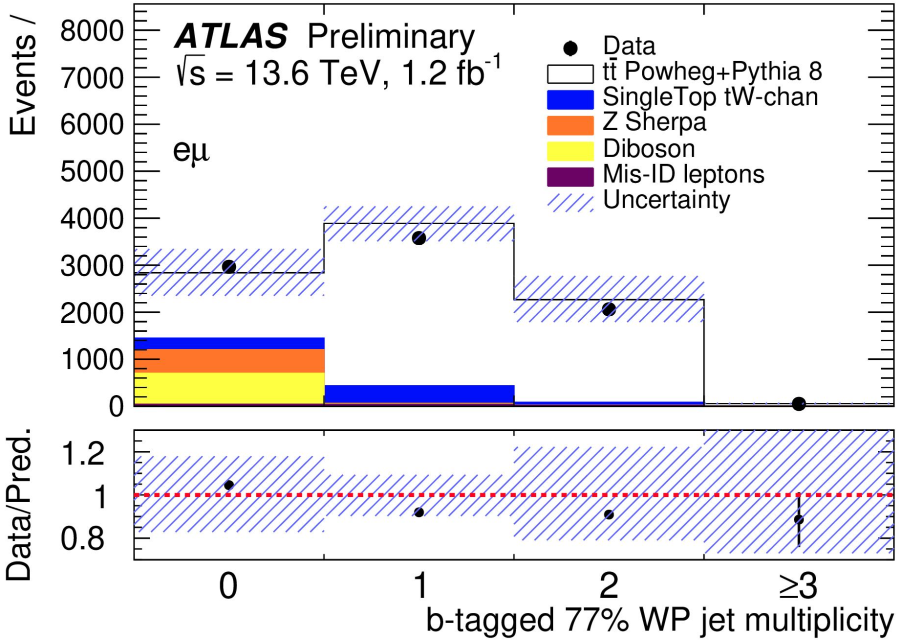
https://cds.cern.ch/record/2842591

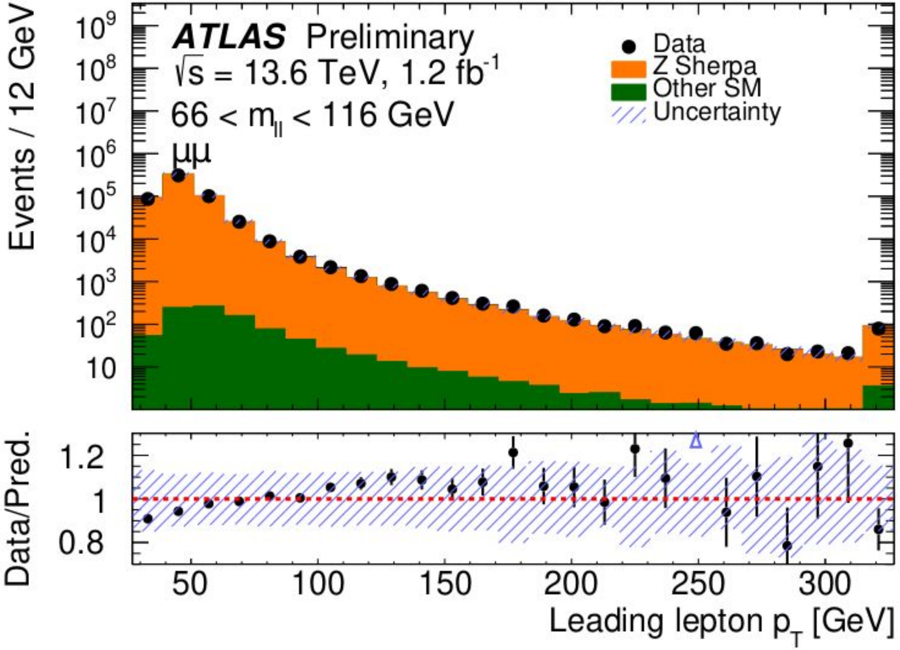
- first ATLAS Run 3 physics result: ATLAS-CONF-2022-070
- analysis extended for 11.3 fb^{-1}: more precise calibrations + fiducial treatment of Z-boson

Backup

SR additional plots

Prefit plots





Physics Objects

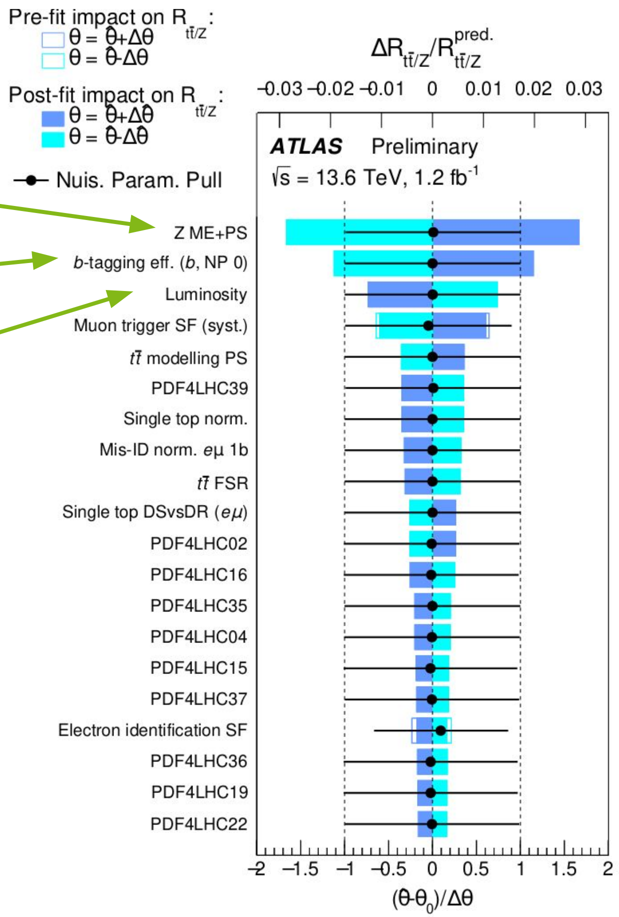
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun3

Physics Objects			
Electron	Muon	Jet	b-tagged jet
p_T > 27 GeV $\|\eta\|$ < 2.37	p_T > 27 GeV $\|\eta\|$ < 2.5	p_T > 30 GeV $\|\eta\|$ < 2.5	Deep Neural Network tagger for l/c/b-jets @ 77% efficiency WP

Results

Dominant uncertainties

- Matrix Element + Parton Shower variation in Z-boson events
- b-tagging efficiency
  ➡ single-top background
- luminosity
  ➡ total background



SRs, Important Systematics

Signal Regions

top-antitop		Z-boson	
eμ, =1b-jet	eμ, =2b-jets	ee, ≥0 jets	μμ, ≥0 jets

Systematic uncertainties

Modelling

- hadronisation, parton shower
- scale uncertainties
- PDFs
- normalisation uncertainties for backgrounds:
  - single-top
  - diboson
  - W+jets (fakes)

Instrumental

- pile-up, *luminosity* *(±10%)*

Other

- Electron, Muon Uncertainties
  - lepton fakes from MC: ~1% in eμ, <0.1% ee and μμ
- Jet uncertainties
- Flavor tagging
  - ±10% b-efficiency, c/l-inefficiencies

Numerical Results

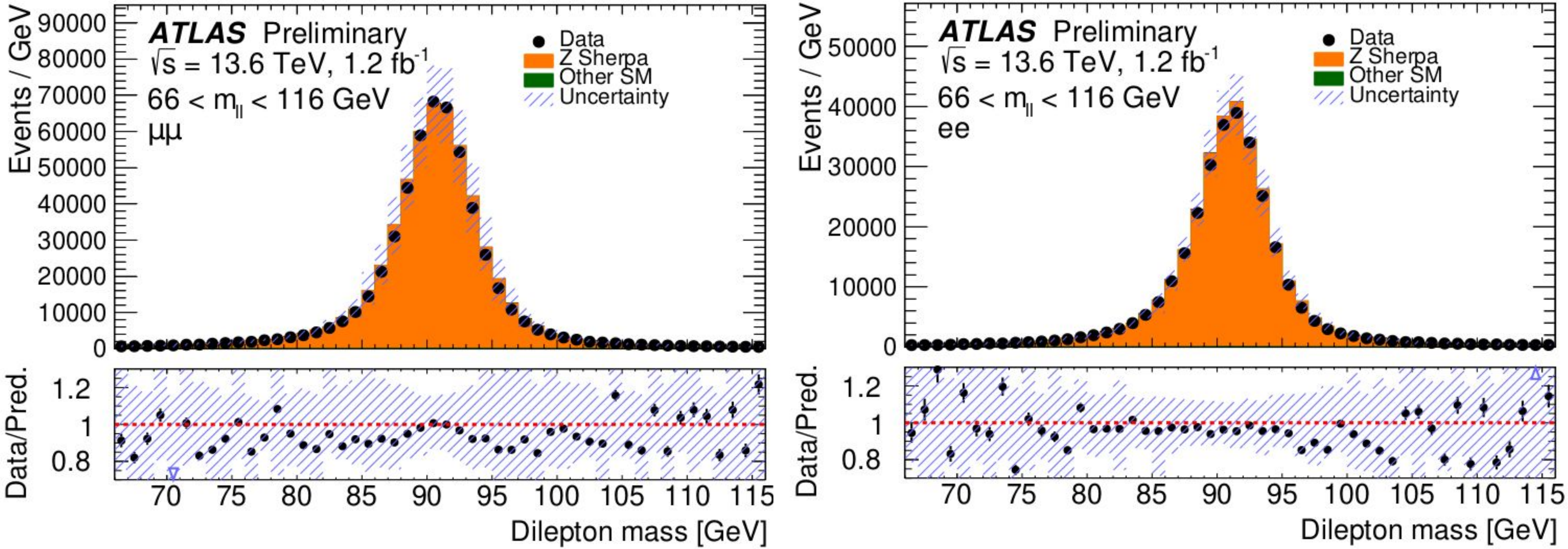
$$R_{t\bar{t}/Z}^{\text{theory}} = 0.423 \pm 0.015(\text{scale+PDF})$$
$$\sigma_{t\bar{t}}^{\text{theory}} = 924^{+32}_{-40}(\text{scale+PDF})\ \text{pb}$$
$$\sigma_{Z\to\ell\ell}^{m_{\ell\ell}>40,\text{theory}} = 2182^{+42}_{-45}(\text{scale+PDF})\ \text{pb}$$

$$R_{t\bar{t}/Z} = 0.400 \pm 0.006(\text{stat.}) \pm 0.017(\text{syst.}) \pm 0.005(\text{lumi.})$$
$$\sigma_{Z\to\ell\ell}^{m_{\ell\ell}>40} = 2075 \pm 2(\text{stat.}) \pm 98(\text{syst.}) \pm 199(\text{lumi.})\text{pb}$$
$$\epsilon_b = 0.553 \pm 0.007(\text{stat.}) \pm 0.005(\text{syst.}) \pm 0.001(\text{lumi.})$$

Generators, Cross-sections

Sample	Generator+PS	Cross-section
top-antitop	Powheg v2 + Pythia 8.307	NNLO+NNLL @ 13.6 TeV
single-top	Powheg v2 + Pythia 8.307	tW: NLO+NNLL, t-, s-channel: NLO
V+jets	Sherpa 2.2.12	MATRIX: NNLO (QCD) + NLO (EW)
Diboson	Sherpa 2.2.12	<= 1 additional parton: NLO (QCD), <= 3 additional parton: LO (QCD)

Z-boson Mass Peak



Overview of Systematics

Modelling

- hadronisation, parton shower
- scale uncertainties on
  - initial/final state radiation
  - renormalisation
  - factorisation
- PDF variations
- diagram removal vs. diagram subtraction
- different normalisation uncertainties

Instrumental

- pile-up, <u>luminosity (±10%)</u>

Electrons and Muons

- different trigger, energy, momentum, identification, reconstruction, isolation and track-to-vertex association uncertainties

Jets

- energy scale, energy resolution, vertex tagger uncertainties (discriminate pile-up jets from jets of interest)

Flavor tagging

- ±10% b-efficiency,
  ±20% c–mistag-efficiency,
  ±40% light–mistag-efficiency

Complete Systematics

Modelling

- top-antitop
  - PS + hadronisation model (Herwig 7.2.3)
  - h_damp parameter (controls matching of Powheg elements to PS and regulates high p_T radiation)
- top-antitop and Z
  - Variations of μ_R / μ_F, ISR and FSR
  - PDF uncertainties
- single-top: normalisation (3.5%), ME, ISR, FSR, DR vs. DS
- lepton fakes: normalisation (50% for 1b eμ, 100% for other channels)
- diboson: normalisation (50%)

Instrumental

- pile-up reweighting (average μ varied by 3% in MC)
- luminosity (10%)

Leptons

- electron energy, muon momentum: from Run 2 Z→ll + extrapolation to Run 3; simulation vs. data in Run 3
- electron identification, muon reconstruction, ID, isolation, track-to-vertex association: Tag and Probe method (Z→μu events in Run 3 and MC Run 2 vs. Run 3)
- Trigger efficiencies from Run 3 data + difference of MC simulation vs. data

Jet energy scale, jet energy resolution

- JES, JER, jet-vertex tagger (like in Run 2 + coverage of difference in reconstruction in Run 2 vs. Run 3 (from MC))

Flavor tagging

- 10% b-efficiency, 20% c–mistag-efficiency, 40% light–mistag-efficiency

Post-fit Uncertainty Overview

Category		Uncert. [%]		
		$\sigma_{t\bar{t}}$	$\sigma_{Z\to\ell\ell}^{m_{\ell\ell}>40}$	$R_{t\bar{t}/Z}$
$t\bar{t}$	$t\bar{t}$ parton shower/hadronisation	0.6	0.2	0.7
	$t\bar{t}$ scale variations	0.5	0.1	0.5
Z	Z scale variations	0.2	2.9	2.9
Bkg.	Single top modelling	0.6	< 0.01	0.6
	Diboson modelling	0.1	< 0.01	0.5
	Mis-Id leptons	0.6	< 0.01	0.6
Lept.	Electron reconstruction	1.6	2.3	1.1
	Muon reconstruction	1.3	2.4	0.3
	Lepton trigger	0.2	1.3	1.1
Jets/tagging	Jet reconstruction	0.2	< 0.01	0.2
	Flavour tagging	1.9	< 0.01	1.9
	PDFs	0.5	1.4	1.3
	Luminosity	10.3	9.6	1.3
	Systematic Uncertainty	10.8	10.7	4.4
	Statistical Uncertainty	1.5	0.1	1.5
	Total Uncertainty	11	10.7	4.7