Measurement of ZZ cross-sections in the four-lepton final state in pp collisions at $\sqrt{s} = 13.6$ TeV with the ATLAS experiment

Xingyu Wu

University of Science and Technology of China

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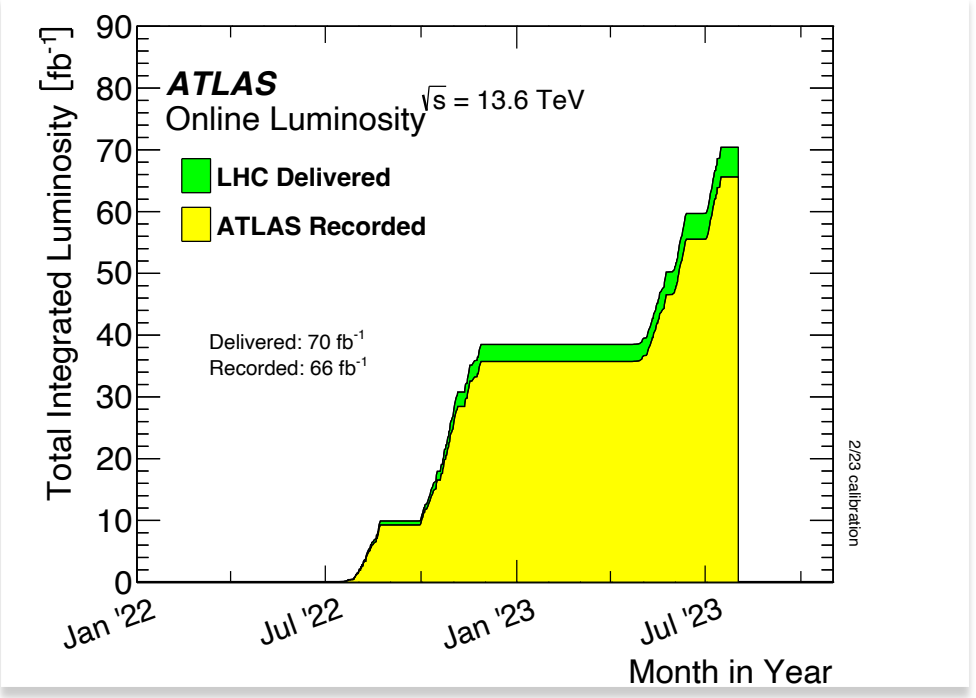
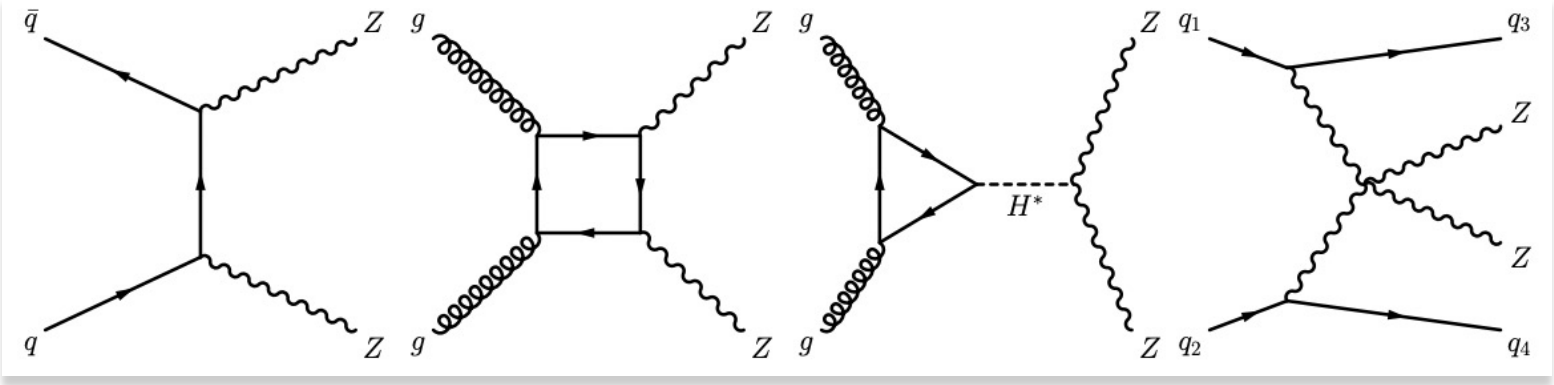
Introduction

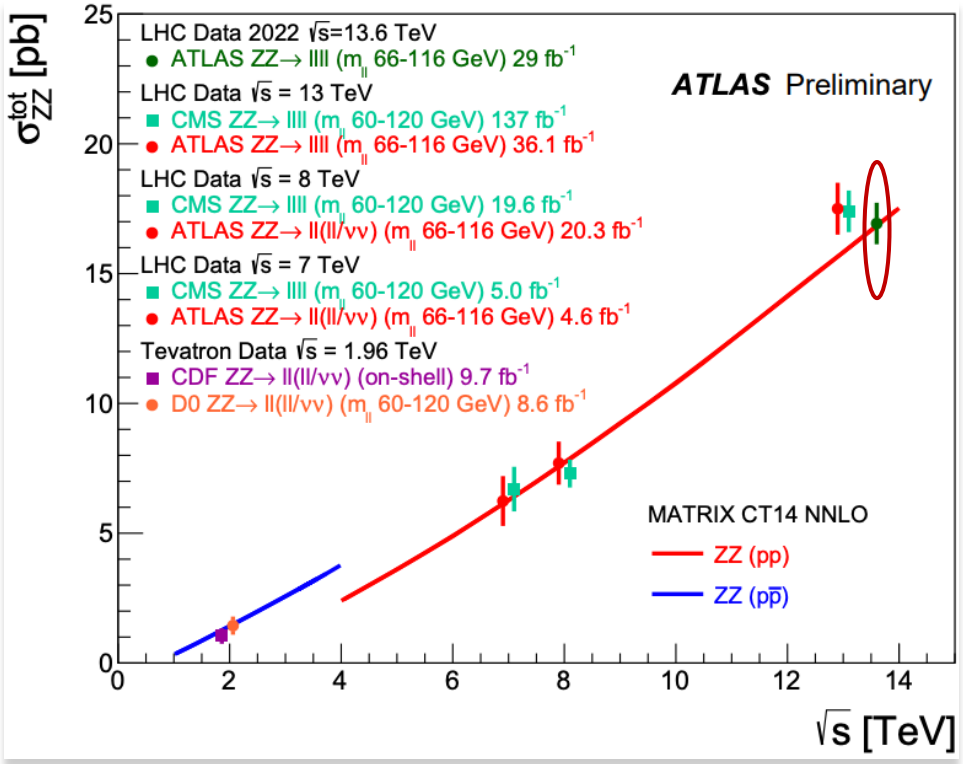
- The first look of diboson process with LHC Run-3 data.
  - Full 2022 LHC Run-3 data ($L = 29\ fb^{-1}$).
- Run-3 data taking status
  - Expected luminosity $\sim 60\ fb^{-1}$ good for physics.
- Measurement of on-shell $ZZ \rightarrow 4l$ production on LHC.
  - $q\bar{q} \rightarrow ZZ$
  - $gg \rightarrow ZZ$
  - EW $q\bar{q} \rightarrow ZZ + 2j$





Motivation

- Precision test of Standard Model under an unprecedented energy.
- 4-lepton clean final state, with low background (~5%).
- Precision measurement of on-shell $ZZ \rightarrow 4l$ $(l = e, \mu)$ decay mode.
  - Differential and inclusive fiducial cross sections
  - Total cross sections



First Run-3 ZZ results!
arxiv: 2311.09715

Fiducial & total phase space

- Forming the phase spaces with electrons and muons.
- Phase space definition highly rely on the detector acceptance.
- Focusing on the on-shell ZZ production.

Table 1: Definition of the fiducial and total lepton phase-space regions.

	Fiducial phase space	**Total lepton phase space**
Muon selection	Bare, $p_{\mathrm{T}} > 5$ GeV , $\lvert\eta\rvert < 2.5$	Born
Electron selection	Dressed, $p_{\mathrm{T}} > 7$ GeV , $\lvert\eta\rvert < 2.47$	Born
Four-lepton signature	≥ 2 SFOC pairs	≥ 2 SFOC pairs
Lepton kinematics	$p_{\mathrm{T}} > 27/10$ GeV	
Lepton separation	$\Delta R(\ell_i, \ell_j) > 0.05$	
Low-mass $\ell^+\ell^-$ veto	$m_{ij} > 5$ GeV	$m_{ij} > 5$ GeV
Z mass window	$66 < m_{\ell\ell,1}, m_{\ell\ell,2} < 116$ GeV	$66 < m_{\ell\ell,1}, m_{\ell\ell,2} < 116$ GeV
ZZ on-shell	$m_{4l} > 180$ GeV	

Define with born leptons

Remove lepton cut and ZZ on-shell cut

SFOC: same flavor opposite charge.

- The measured data is unfolded to compare with the state-of-art prediction at fiducial level.

Bayesian unfolding method

Signal & background estimation

- Signal modellings
  - $q\bar{q} \rightarrow ZZ$ (Sherpa); $gg \rightarrow ZZ$ (Sherpa); EW $q\bar{q} \rightarrow ZZ + 2j$ (Powheg+Pythia) processes.
  - Using MC estimations.
- Irreducible background (~1%)
  - VVV (Sherpa) and $t\bar{t}Z$ (Sherpa) processes.
  - Using MC estimations.
- Fake background (~4%)
  - $lll\nu$ (Sherpa), Z + jets (Sherpa) and $t\bar{t}$ (Powheg+Pythia) processes.
  - Estimated with data-driven (fake factor) method.
  - Fake yields are validated in the validation region, in good agreement.

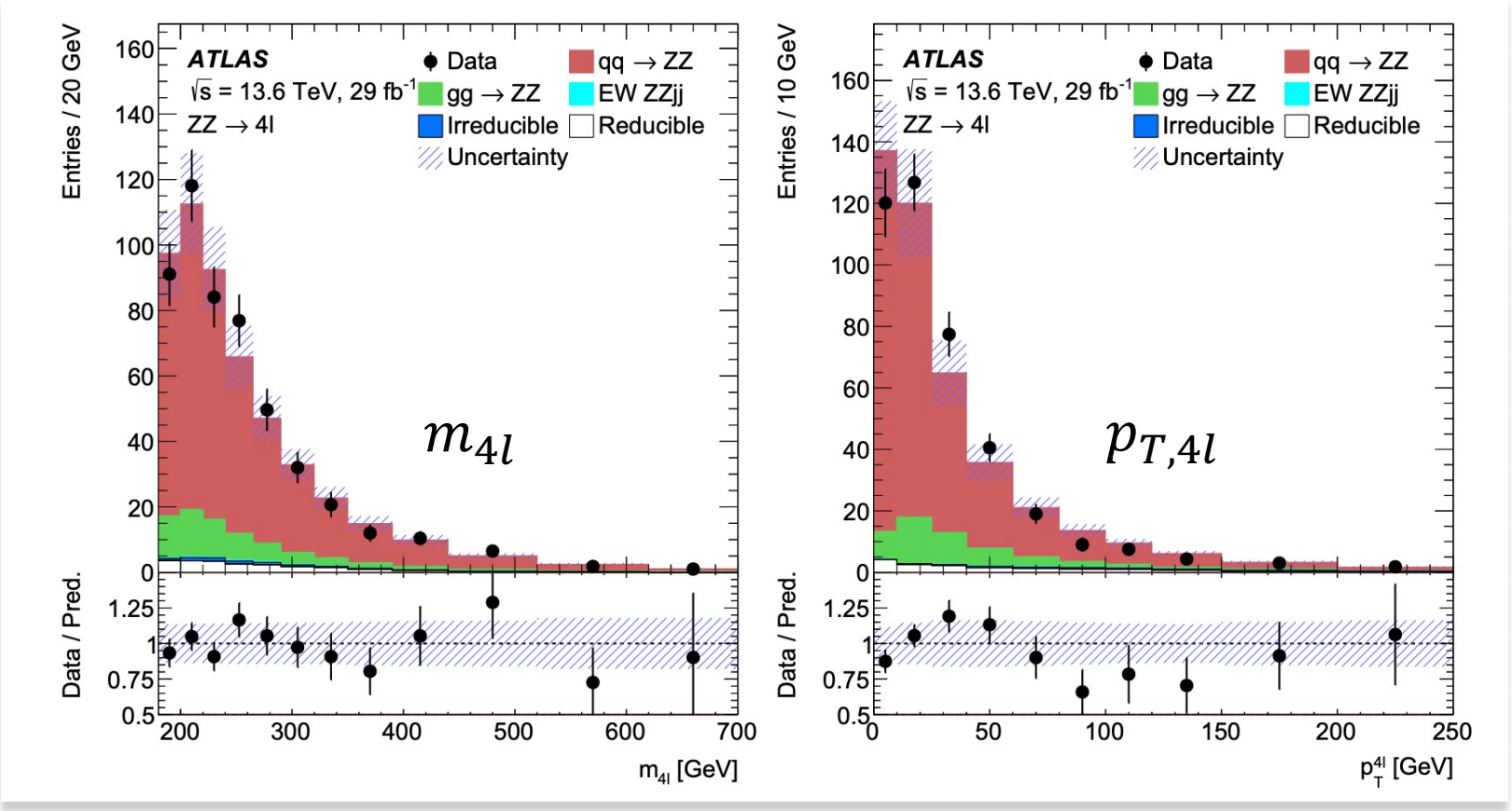
Systematics

- Theoretical uncertainties
  - PDF + α_s, QCD scale variations and parton shower uncertainties.
  - Conservative variations on ZZjj ($\pm 20\%$), VVV ($\pm 10\%$) and $t\bar{t}Z$ ($\pm 15\%$) cross sections.
- Experimental systematics
  - Lepton momentum resolution and energy scale.
  - Lepton identification, isolation, reconstruction and trigger efficiency.
  - Pileup reweighting.
  - Luminosity.
- Fake background
  - Statistical uncertainty.
  - Fake factor systematic uncertainty.
  - MC systematic uncertainty.

Largest contribution from electron ID.

Data/MC comparison in signal region

- The $m_{4l}, p_{T,4l}$ spectrums are derived at reconstructed level.
- Generally in good agreement with limited statistics.

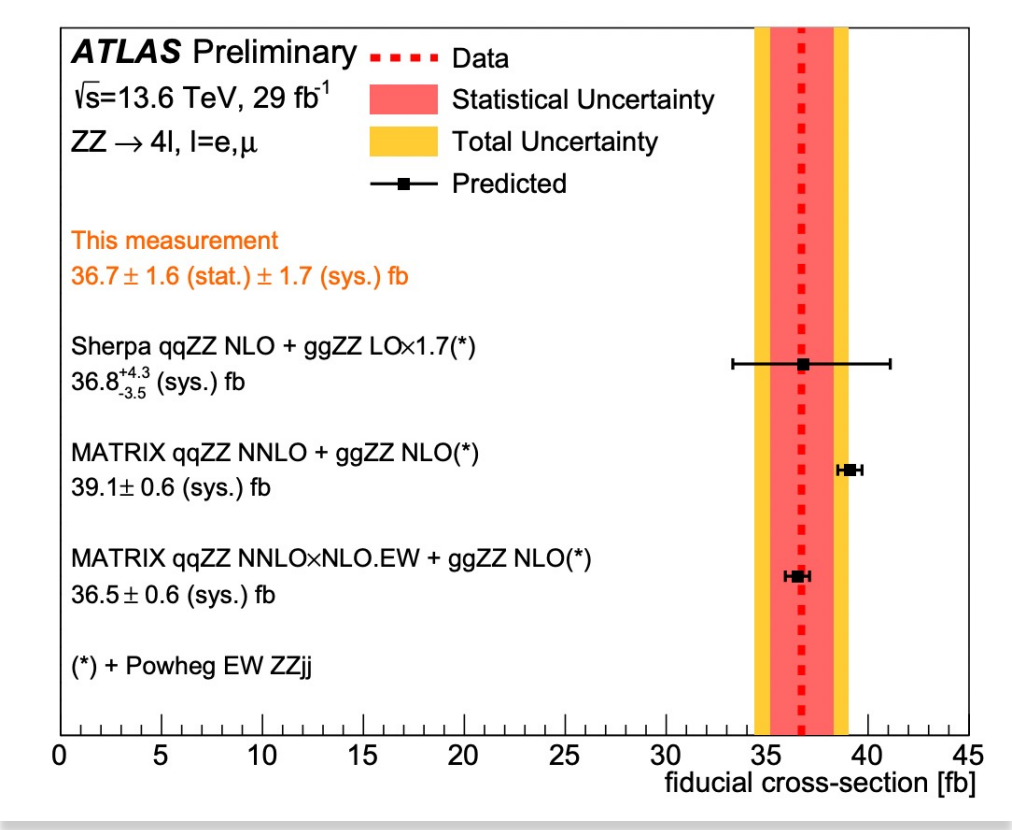


Reconstructed level yields comparison

Process	Yield
$qqZZ$	515 ± 50
$ggZZ$	74 ± 44
$ZZjj$	4.7 ± 1.0
$ttll$	5.5 ± 0.8
triboson	2.1 ± 0.2
Fake	25.4 ± 8.1
Total	626 ± 88
Data 2022	625

Inclusive fiducial cross section

- $\sigma_{\text{fid.}} = 36.7 \pm 1.6\,(\text{stat.}) \pm 1.5(\text{sys.}) \pm 0.8\,(\text{lumi})$ fb
- Agree with the theoretical predictions within uncertainties.

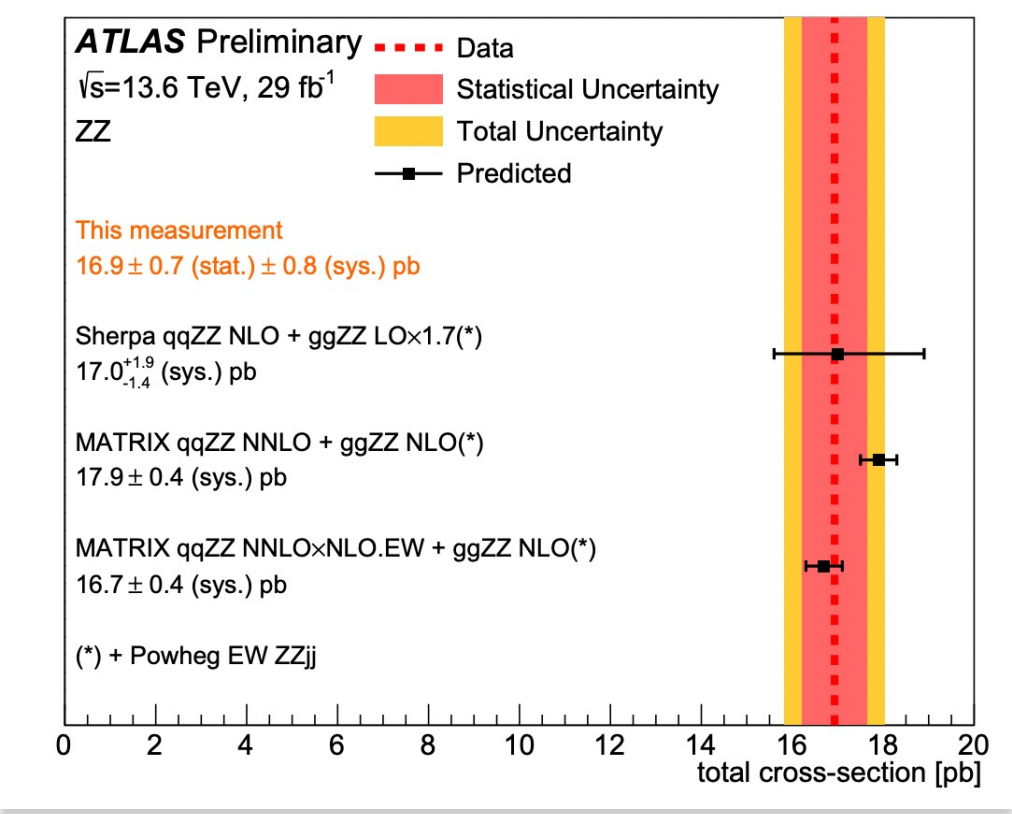


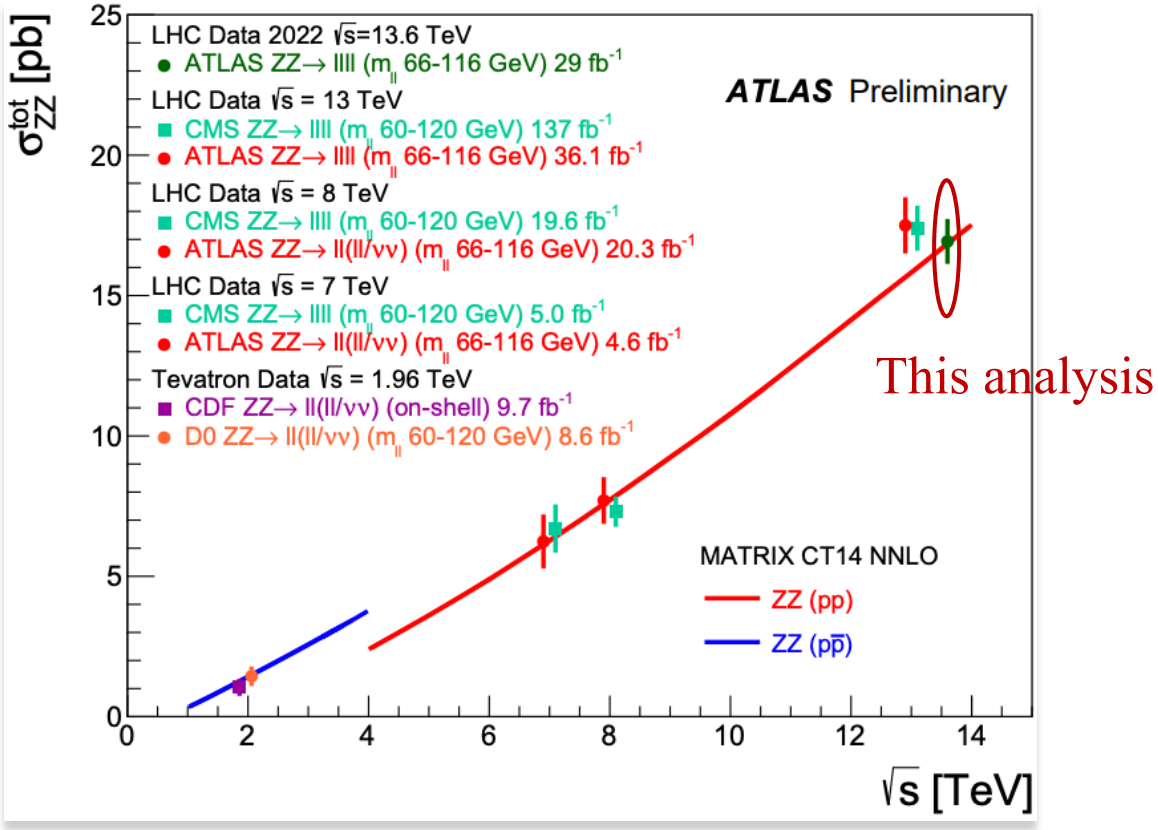
Source	Relative uncertainty(%)
Data statistical uncertainty	4.2
MC statistical uncertainty	0.3
Luminosity	2.2
Lepton momentum	0.2
Lepton efficiency	3.7
Background	1.6
Theoretical uncertainty	1.0
Total	6.3

Uncertainty breakdown on $\sigma_{\text{fid.}}$

Total cross section

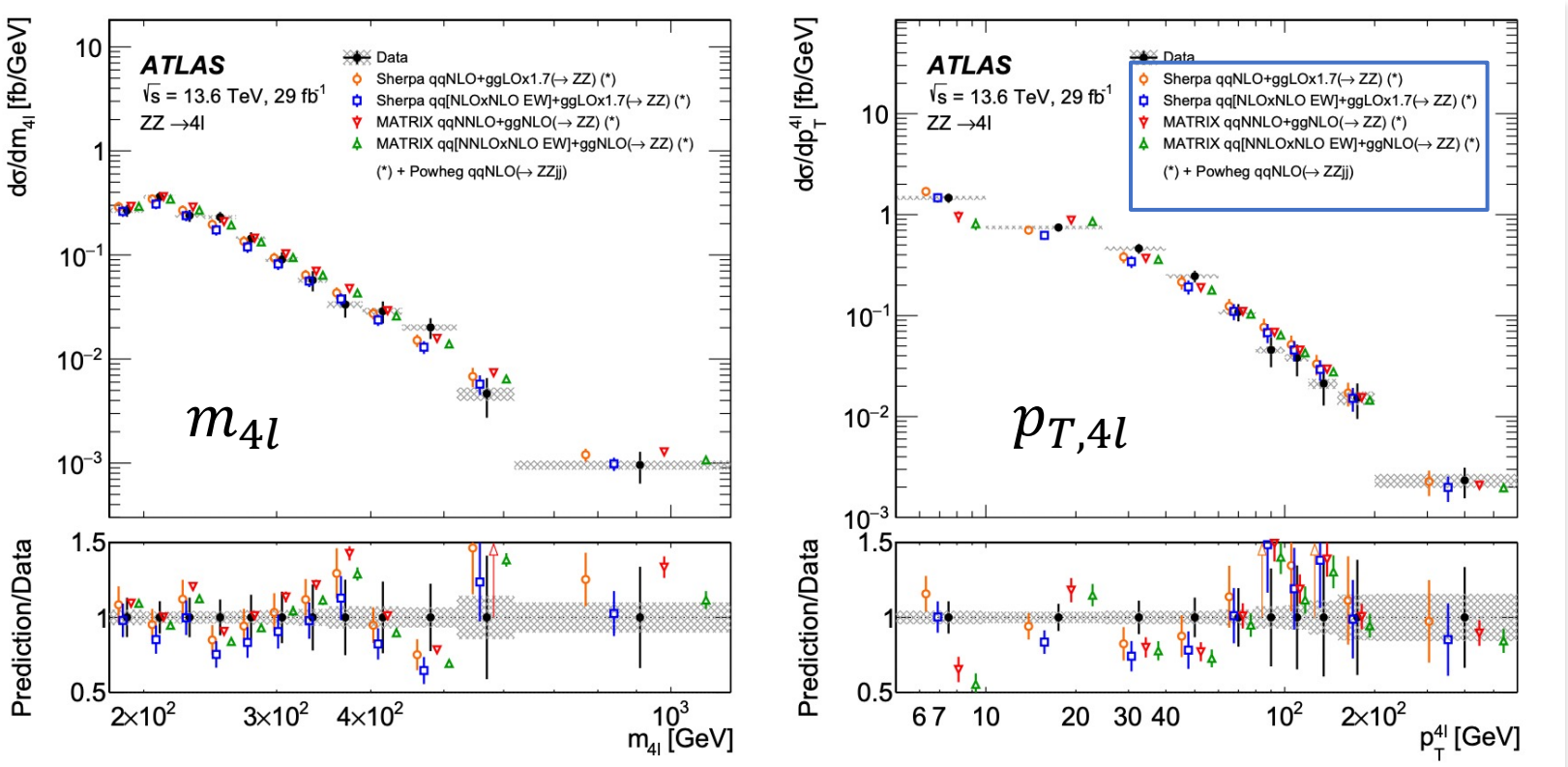
- Total phase space definition targeting on-shell ZZ with $66\text{GeV} < m_{12}, m_{34} < 116\text{GeV}$.
- $\sigma_{\text{total}} = 16.8 \pm 0.7\,(\text{stat.}) \pm 0.7(\text{sys.}) \pm 0.4\,(\text{lumi})\ \text{pb}$





Differential cross sections

- Using Bayesian unfolding method to correct the detector effects.
- Fiducial level data/MC comparison with 2 observables: m_{4l}, $p_{T,4l}$.
- Good agreement is shown at up to NNLO QCD + NLO EW order with limited statistics.
  - Different MC predictions at different accuracies are provided.



MC predictions provided with Sherpa/Powheg and MATRIX

Summary

- First Run-3 ZZ results are reported.
  - One of the few fresh Run-3 results.
  - ZZ differential fiducial cross-sections as a function of m_{4l} and $p_{T,\,4l}$ are measured.
  - ZZ inclusive fiducial and total cross sections are measured.
  - Good agreement is shown with the limited statistics.

13.6TeV!

- The observed data agree with the state-of-art MC simulation at up to NNLO QCD + NLO EW accuracy.

	Measurement	MC prediction	MATRIX prediction
Fiducial	$36.7 \pm 1.6(\text{stat}) \pm 1.5(\text{syst}) \pm 0.8(\text{lumi})$ fb	$36.8\ ^{+4.3}_{-3.5}$ fb	36.5 ± 0.7 fb
Total	$16.8 \pm 0.7(\text{stat}) \pm 0.7(\text{syst}) \pm 0.4(\text{lumi})$ pb	$17.0\ ^{+1.9}_{-1.4}$ pb	16.7 ± 0.5 pb

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Thanks!

Backup