JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Matthias Schott on behalf of the ATLAS Collaboration

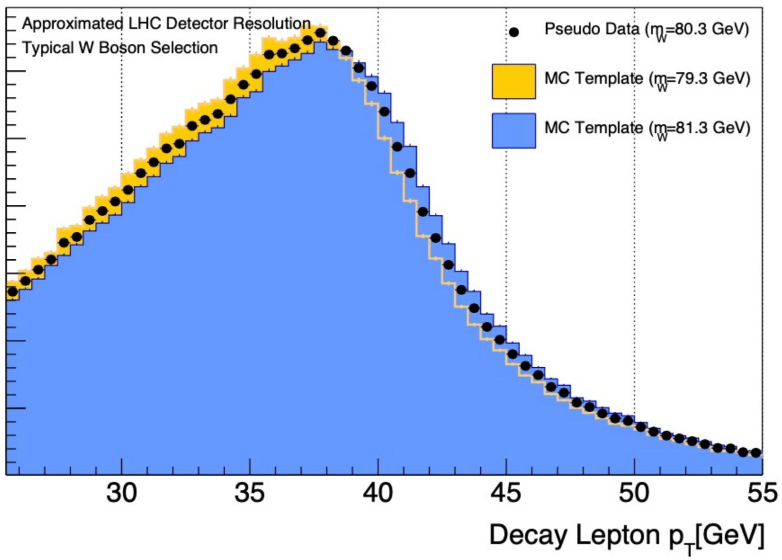
Measurements of W and Z boson production at ATLAS

(with a focus on $p_T(Z)$ and cross-experiment combination)

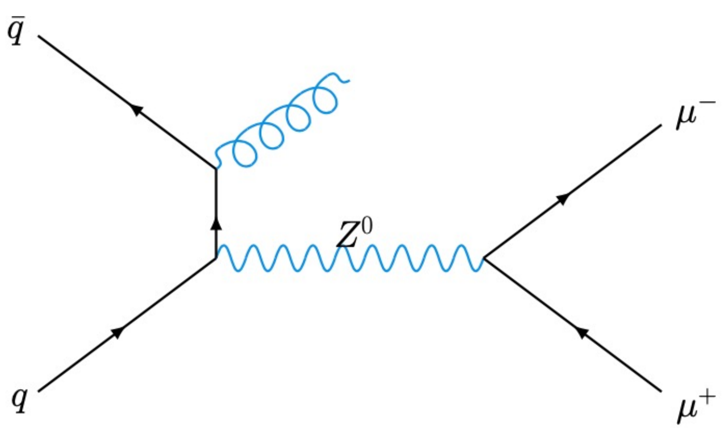
Prof. Dr. Matthias Schott

Goal of the Measurement

- Precision measurement of the transverse momentum as well as the ϕ* distribution of the Z boson
  - Eur. Phys. J. C 80 (2020) 616.
  - Based on 36.1 fb^{-1} (2015/2016 data-set) at 13 TeV
  - Important to model the $p_T(V)$ distribution, which is crucial for the W-Mass Measurement



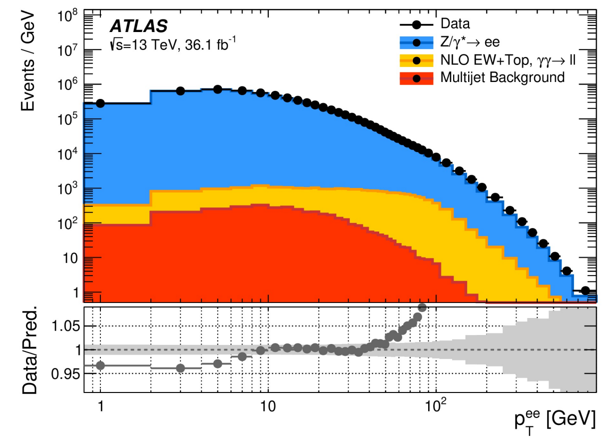
- Fiducial Volume
  - p_T(lepton) > 27 GeV,
  - $|\eta_{ll}| < 2.5$
  - m_{ll} = 66-116 GeV



- Results based on the electron and muon decay channel
  - Dressed, bare and born-level results
  - Reaching a precision of <0.2% for <30 GeV

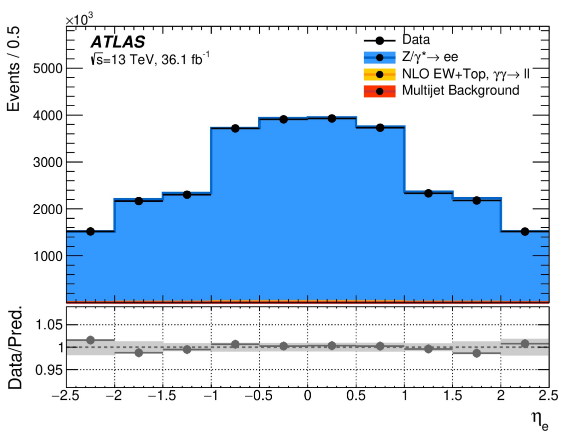
Basic Control Plots and Background Contributions

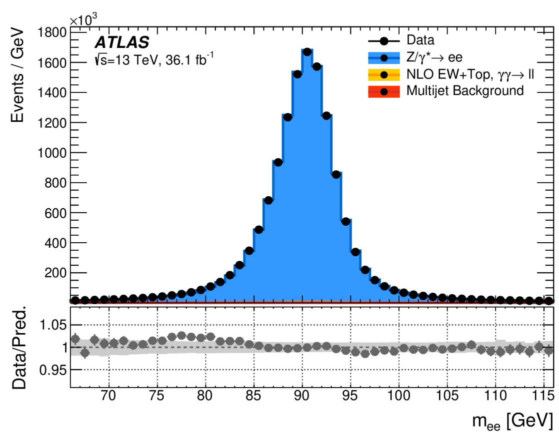
- Top- and electroweak background is estimated using MC predictions
  - Shape of top quark background verified using e/μ

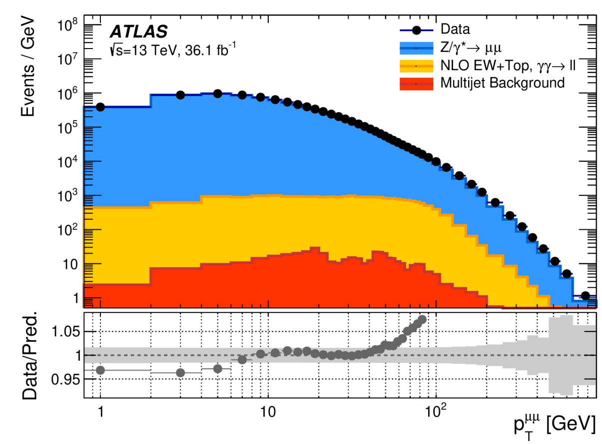


- Multijet background is estimated using a data-driven approach via (CR isolation and E_T^{Miss})
  - Overall background is very small

- Test lepton performance by comparing invariant mass and lepton-rapidity distributions







Inclusive Cross Section and Unfolding

- Measurement of the fiducial inclusive cross-section limited by
  - lepton identification
  - Many uncertainties highly correlated vs. lepton p_T
  - are reduced for normalized differential cross-section

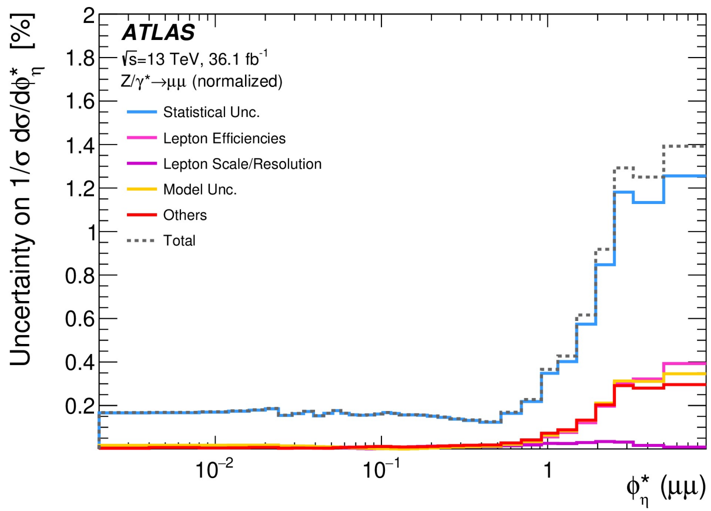
	Electron channel		Muon channel	
	Born	Dressed	Born	Dressed
C_Z	0.509 ± 0.005	0.522 ± 0.005	0.685 ± 0.011	0.702 ± 0.011
Trigger efficiencies	± 0.0004		± 0.0004	
Identification & reconstruction efficiencies	± 0.0049		± 0.0102	
Isolation efficiencies	± 0.0009		± 0.0029	
Energy/momentum scale and resolution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

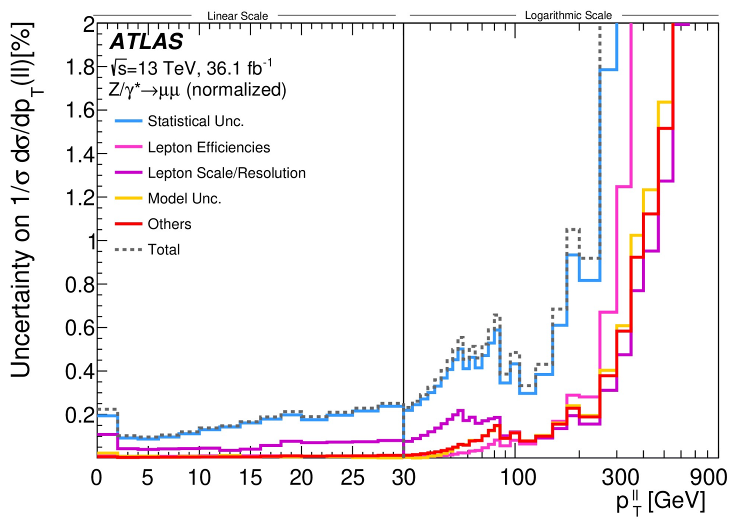
Channel	Measured cross-section $\times \mathcal{B}(Z/\gamma^* \to \ell\ell)$ (value $\pm$ stat. $\pm$ syst. $\pm$ lumi.)	Predicted cross-section $\times \mathcal{B}(Z/\gamma^* \to \ell\ell)$ (value $\pm$ PDF $\pm \alpha_S \pm$ scale $\pm$ intrinsic)
$Z/\gamma^* \to ee$	$738.3 \pm 0.2 \pm 7.7 \pm 15.5$ pb	CT14 PDF
$Z/\gamma^* \to \mu\mu$	$731.7 \pm 0.2 \pm 11.3 \pm 15.3$ pb	
$Z/\gamma^* \to \ell\ell$	$736.2 \pm 0.2 \pm 6.4 \pm 15.5$ pb	$703^{+19}_{-24}\,^{+6}_{-8}\,^{+4}_{-6}\,^{+5}_{-5}$ pb [**STDM-2016-02**]

- Measurement of differential cross-section via Unfolding
  - Iterative Bayesian Unfolding with 4 Iterations
  - Model uncertainty tested by reweighting the MC Truth Prior to the observed difference between data and MC on detector level
  - It was also shown that this uncertainty covers when taking an alternative MC Generator (Sherpa) as Pseudo Data
  - Statistical uncertainties are estimated with MC Toys
  - Systematic uncertainties are estimated by up- and down- variations of all uncorrelated nuisance parameters

Uncertainties on differential $P_T(Z)$ and ϕ^* Distributions

- Dominant uncertainties are statistical ones
  - While data statistics are dominant every-where, also limited MC statistics is not negligible
- Lepton efficiency uncertainties become important for the very high p_T regime
  - Lepton related uncertainties significantly reduced (by construction of ϕ^*)
- Lepton momentum/energy scale uncertainties are highly correlated vs. bins, i.e. can lead to an overall change of the spectrum
- The unfolding matrix for ϕ^* is very diagonal (high purity), hence very small model uncertainties are expected

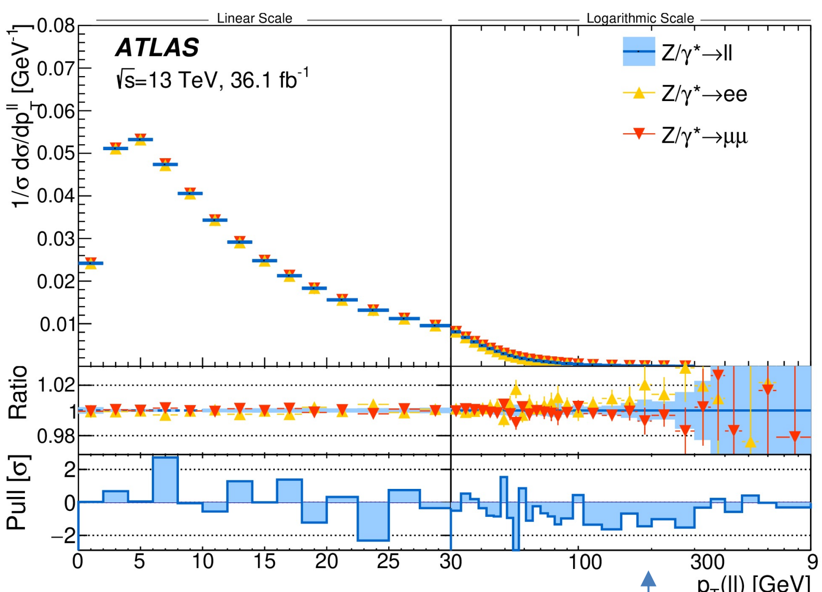


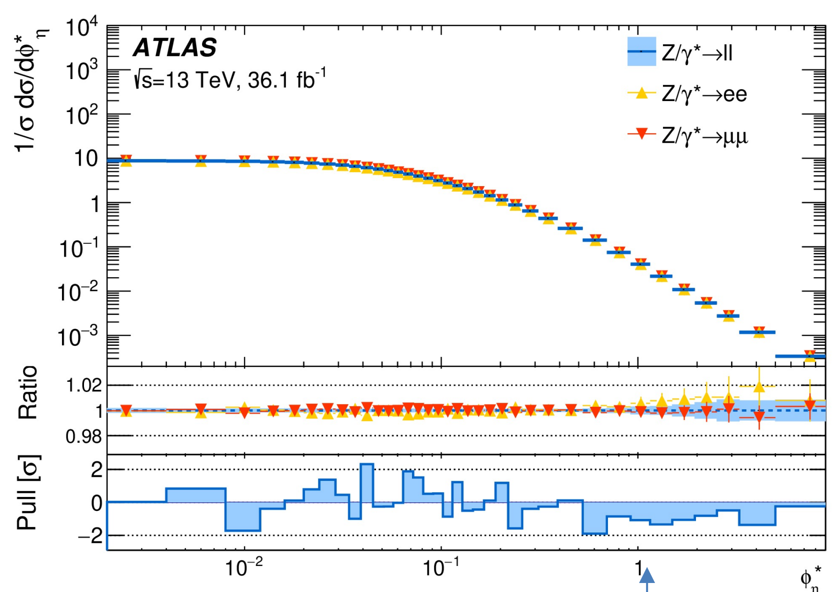


Combination

- Treat statistical uncertainties uncorrelated between channels (and nearly uncorrelated vs. bins)
  - Split efficiency systematics in bin-to-bin uncorrelated and correlated components
  - Several uncertainties are also correlated vs channels, e.g. z-positioning, pile-up, model-uncertainties

- We observe a chi2/ndf=47/44 and 32/36 for $P_T(Z)$ and ϕ^*, respectively

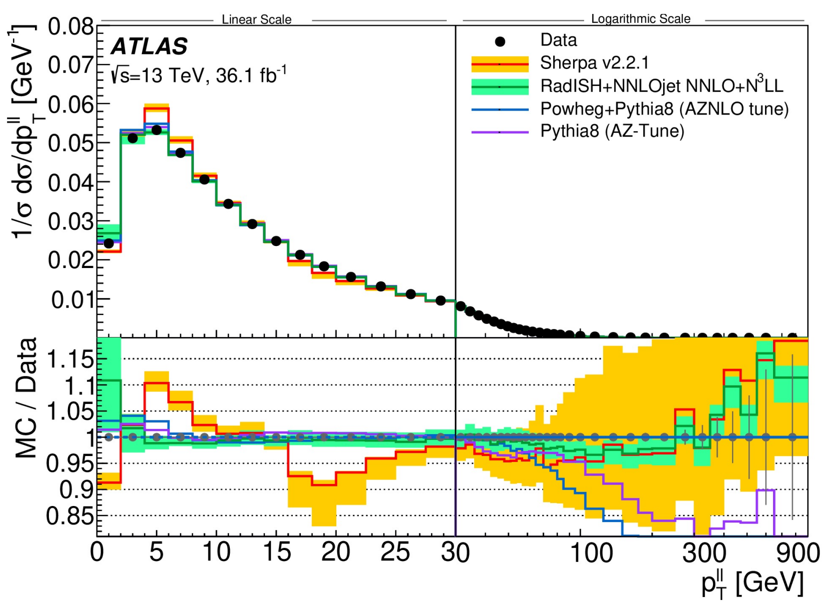


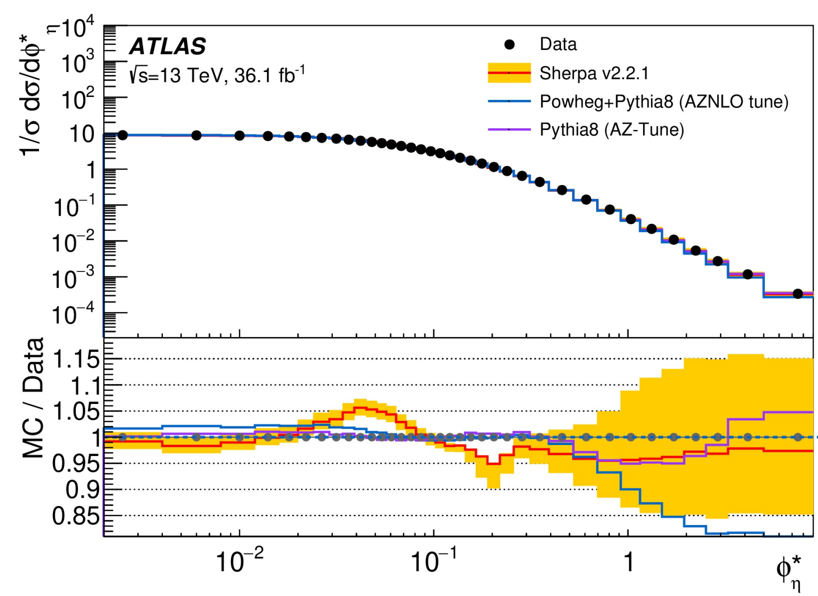


This discrepancy is not significant when taking correlations into account

Comparison to Theory

- Comparison to Powheg+Pythia (Baseline MC), Sherpa2.2.1, Pythia8, RadISH+NNLOjet+N2LL
  - As expected, similar trends for $p_T(Z)$ and ϕ^*
  - Good description with RadISH over the full spectrum (prediction for ϕ^* in preparation)
  - Pythia8 with AZ tune (as used for the W mass measurement) describes the data well at low pT
  - Theory uncertainties significantly larger than experimental uncertainties
    - We have tiny uncertainties <0.5%!



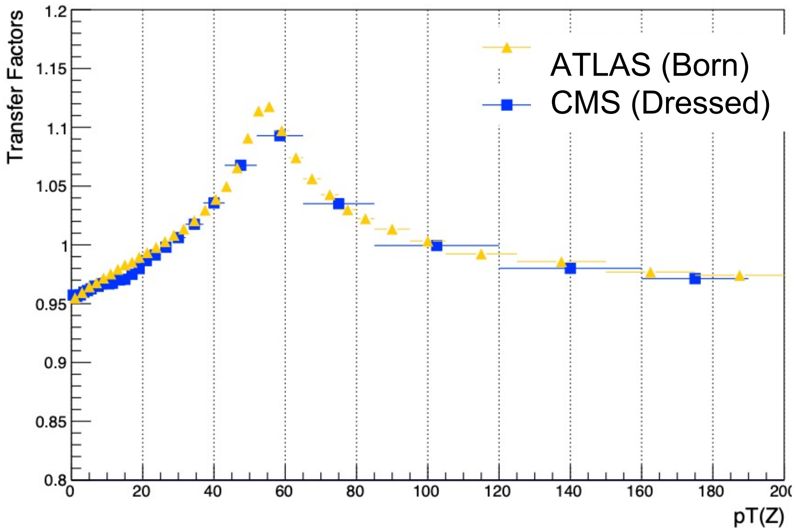


Can we trust our high precision?

- Can we trust our small uncertainties?
  - We need to test the consistency across the LHC experiments
  - The LHC (EW) Working Groups are the natural place for this effort

- Discuss in the following the comparison of $p_T(Z)$ between ATLAS and CMS (JHEP 12 (2019) 061)
  - Detailed discussion can be found in https://indico.cern.ch/event/955878/

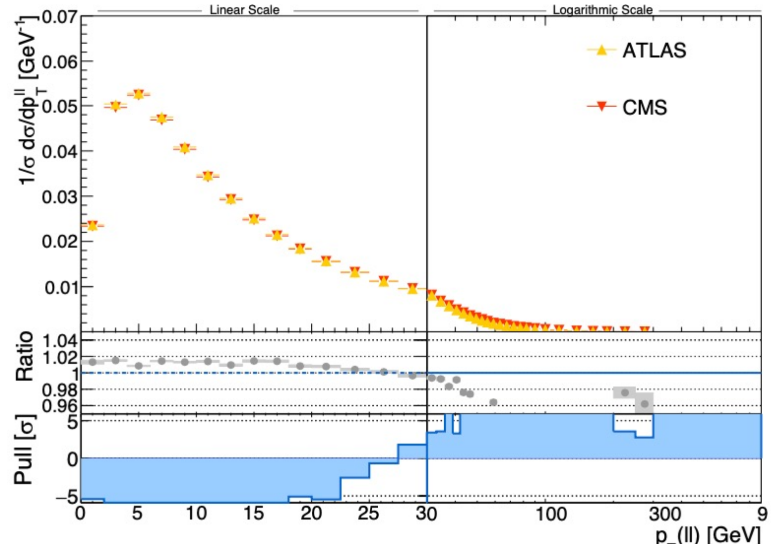
- Workflow
  - Concentrate on dressed level definition
  - Correct for differences in fiducial volume definition using transfer factors
  - Use TGraph Linear interpolation to rebin CMS results in ATLAS Binning

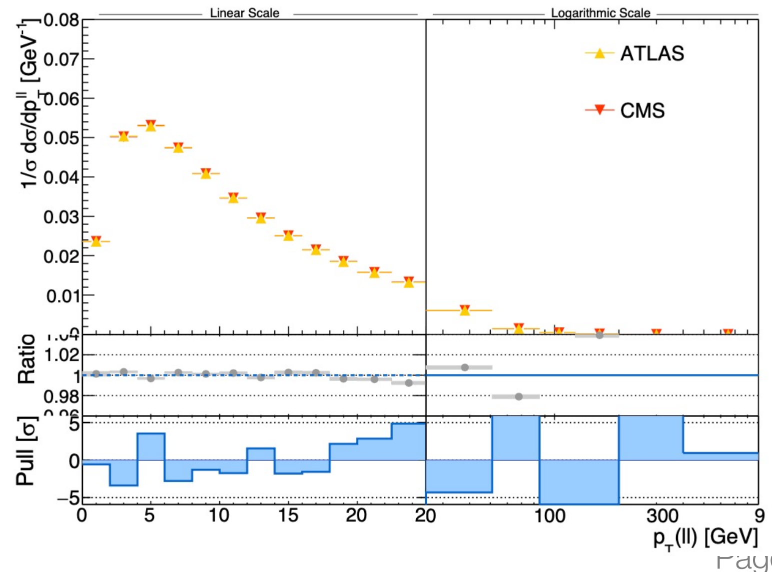


Comparison between ATLAS and CMS

- Preliminary Results
  - Good news: We observe consistent shape for $p_T(Z)<25$ GeV, i.e. in the high precision regime
  - Bad news: We see differences up to 10% between 50-200 GeV
    - Unlikely that there is an experimental problem: in the energy/momentum scales, as we see the same behaviour in PT(Z) and PhiStar, In the efficiencies, as they should not be so localized
  - Difficult to imagine a background that explains 10% differences
    - However, ATLAS substracts yy->ll background, while CMS does not. 0.5% effect in the first bin

- Most likely solution: Interpolation introduces a significant bias
  - When calculating only 2 bins, we see. a good agreement
  - When using wider bins for $p_T(Z)>25$ GeV, we see indeed a quite good agreement.





Lessons learnt and a wishlist for Run-3

- The comparison of $P_T(Z)$ is just a test case.
  - Comparisons are not easy!
- But some simple measures could help before we start with Run-3
  - Agree on at least one common binning
    - We can still keep the “detector” optimized versions
  - Define a common fiducial volume
    - Again, we can keep the “detector” optimized versions for the publications, but at least provide a “supporting” measurement
  - Agree on “what is signal and what is backgrounds”
  - All this is trivial when you still do the analysis – it is nearly impossible after publication

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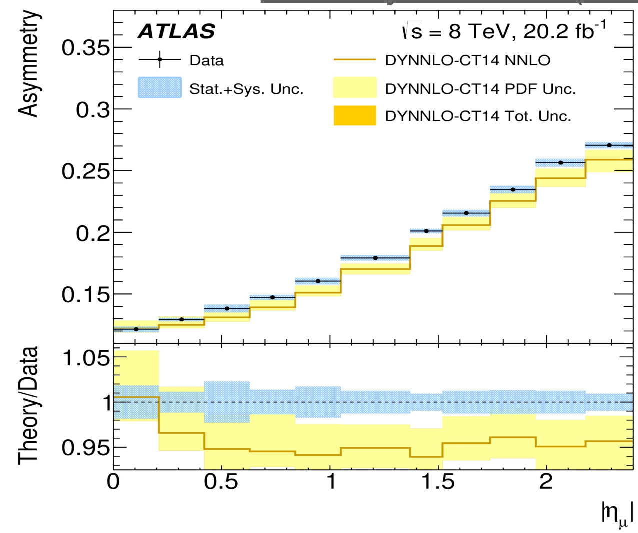

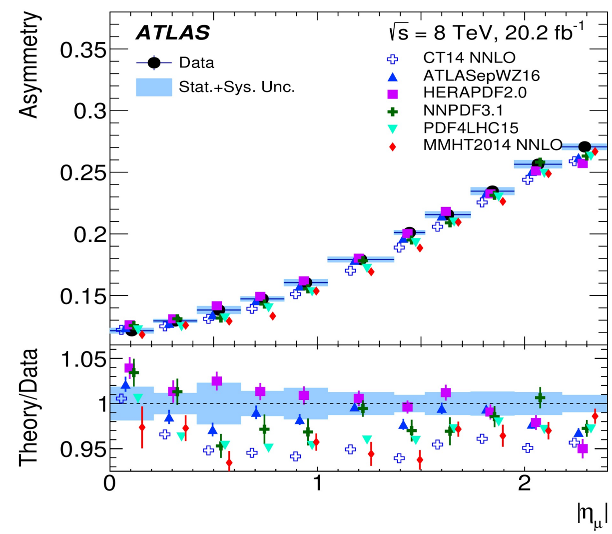

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Summary

- First ATLAS measurement of $p_T(Z)$ and ϕ^* at 13 TeV based on the 2015/2016 data-set
- Measurement performed in the electron and the muon decay channel
- Combination yields a precision of 0.2% and better for $P_T(Z)$<30 GeV
- Let's improve in the analysis design between the LHC experiments, before Run-3