Measurements of Drell-Yan cross sections at 13 TeV with CMS

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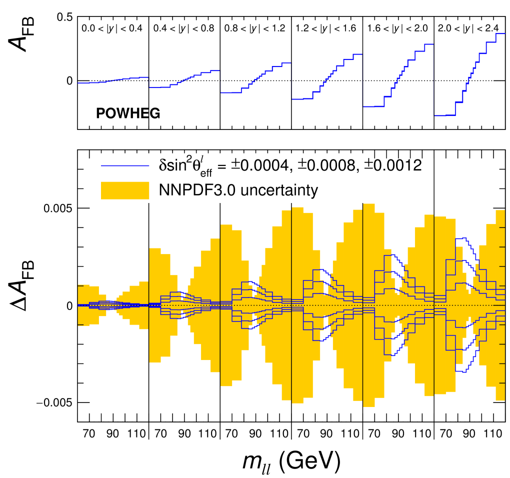
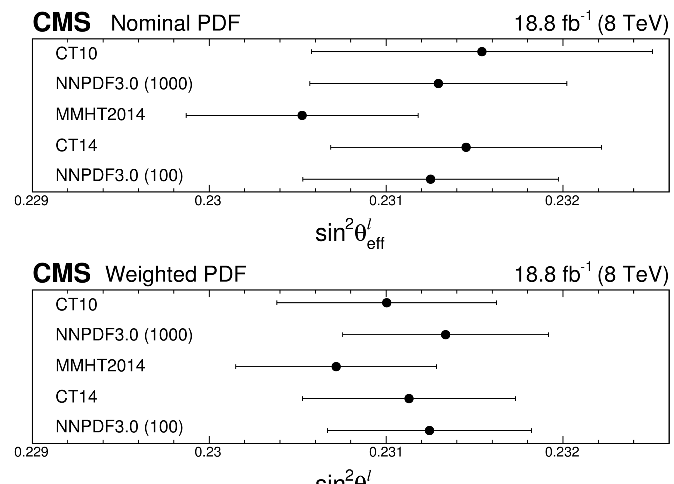
Introduction

- PDF’s are an important or dominant uncertainty to precision measurements at the LHC (e.g. $\sin^2\theta_W$ and W mass)
- Measurements of W and Z production at the LHC can constrain PDFs in the relevant phase space
    - In-situ constraints can also be used to constrain PDFs in the context of the measurements themselves (e.g. CMS weak mixing angle measurement)





Eur. Phys. J. C (2018) 78: 701 (CMS)

- Purpose of this talk is to show a short summary on the differential Drel-Yan cross section measurements using dilepton events in CMS with 13 TeV

Precise measurements of Z pT

- Precise measurements Z boson cross sections using dilepton events
  - Clean experimental signature
  - Very low background levels
- Recent CMS Z boson differential cross section measurement at 13 TeV
  - arXiv:1909.04133
  - $d\sigma/dpT$, $d\sigma/d|Y|$, $d^2\sigma/dpTd|Y|$, $d\sigma/d\varphi^*$
  - Making use of full 2016 dataset at 13 TeV (35.9 fb^{-1})
  - Unprecedented precision in CMS
- Measurement of the differential Drell-Yan cross section at 13 TeV
  - arXiv:1812.10529
  - $d\sigma/dM$
  - Making use of 2015 dataset at 13 TeV (up to 2.8 fb^{-1})
  - The range of x covered by this measurement is $10^{-4} < x < 1.0$

Fiducial definition

Fiducial definition at generation level (GEN):

- making use of so-called dressed leptons
  - accounting for photons in $\Delta R_{\ell,\gamma} < 0.1$
- two opposite-sign same-flavor leptons (electrons or muons)
- $p_{\mathrm{T}}^{\ell_1,\ell_2} > 25$ GeV, $|\eta^{\ell_1,\ell_2}| < 2.4$
- $|m_{\ell\ell} - m_{\mathrm{Z}}| < 15$ GeV
- tested that muon and electron cross sections agree better than the sample statistical precision with this definition

- Backgrounds
  - VV resonant background from simulation
  - Nonresonant background from data (top, W+jets, etc.)

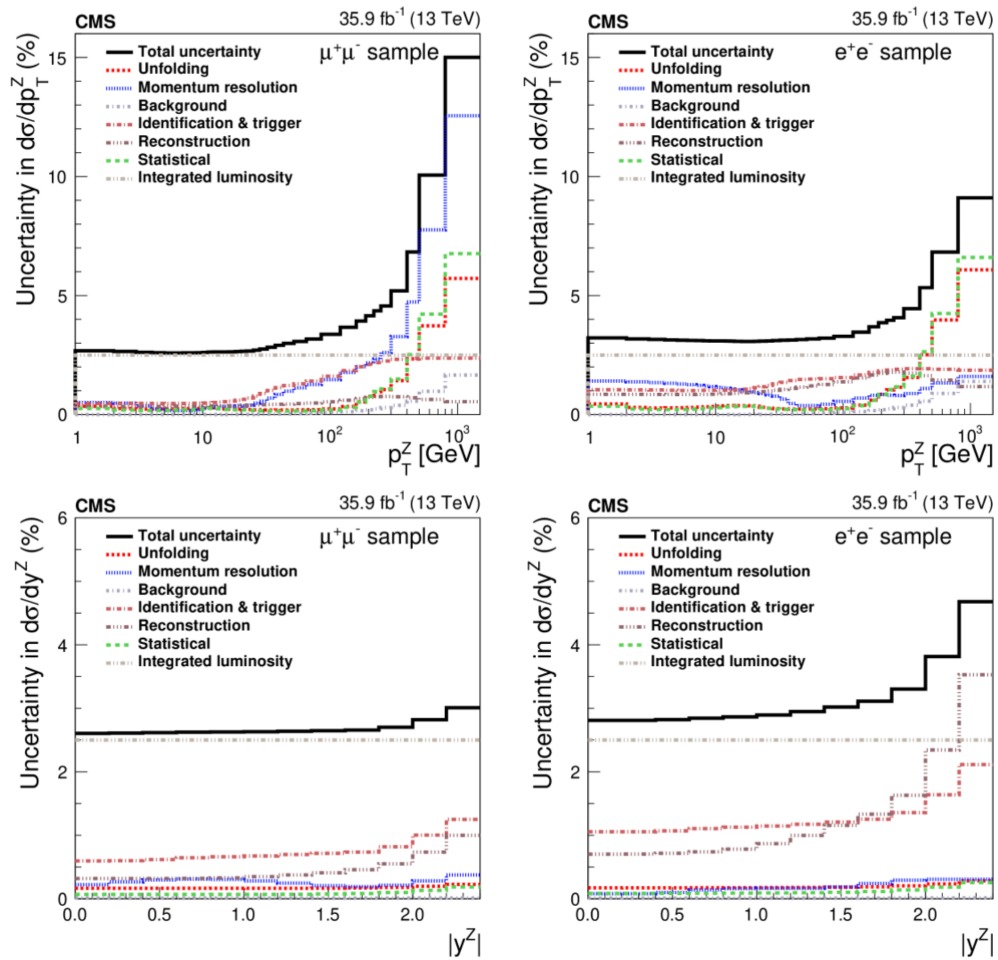
Final state	Data	$Z \to \ell\ell$	Resonant background	Nonresonant background
$\mu\mu$	20.4×10^6	20.7×10^6	30×10^3	41×10^3
ee	12.1×10^6	12.0×10^6	19×10^3	26×10^3

Systematic uncertainties

- Integrated luminosity
  - Current uncertainty is 2.5%
  - Possible room of improvement on this for ATLAS/CMS?
  - Negligible impact in normalized cross section measurements $1/\sigma \, d\sigma/dp_T$,…
- Lepton triggers reconstruction and identification
  - Largest experimental uncertainty at low-pT after luminosity
  - Measured using Tag&Probe techniques where the effects due to signal and background modeling are taken into account
  - Large effort to achieve the required precision
- Precise understanding of calibration and resolution of final state leptons
  - Relevant on differential measurements
- Simulated sample size
  - Relevant for unfolding at high-pT

Summary of systematic uncertainties

- Bin width of 1 GeV below 15 GeV for the pT measurement
- Limited by luminosity
- Identification and trigger
- Reconstruction
    - Detector trigger pre-fire
    - Mainly affects ee in forward region
- Momentum resolution
    - Large at high-pT for μμ
- Unfolding
    - Size of simulated sample
    - AMC@NLO/Powheg unfolding
- Background estimation
- Data statistics



Summary of systematic uncertainties

- Precise normalized cross sections/shape (limited by lepton efficiencies)
- Limited by luminosity
- Identification and trigger
- Reconstruction
    - Detector trigger pre-fire
    - Mainly affects ee in forwar region
- Momentum resolution
    - Large at high-pT for μμ
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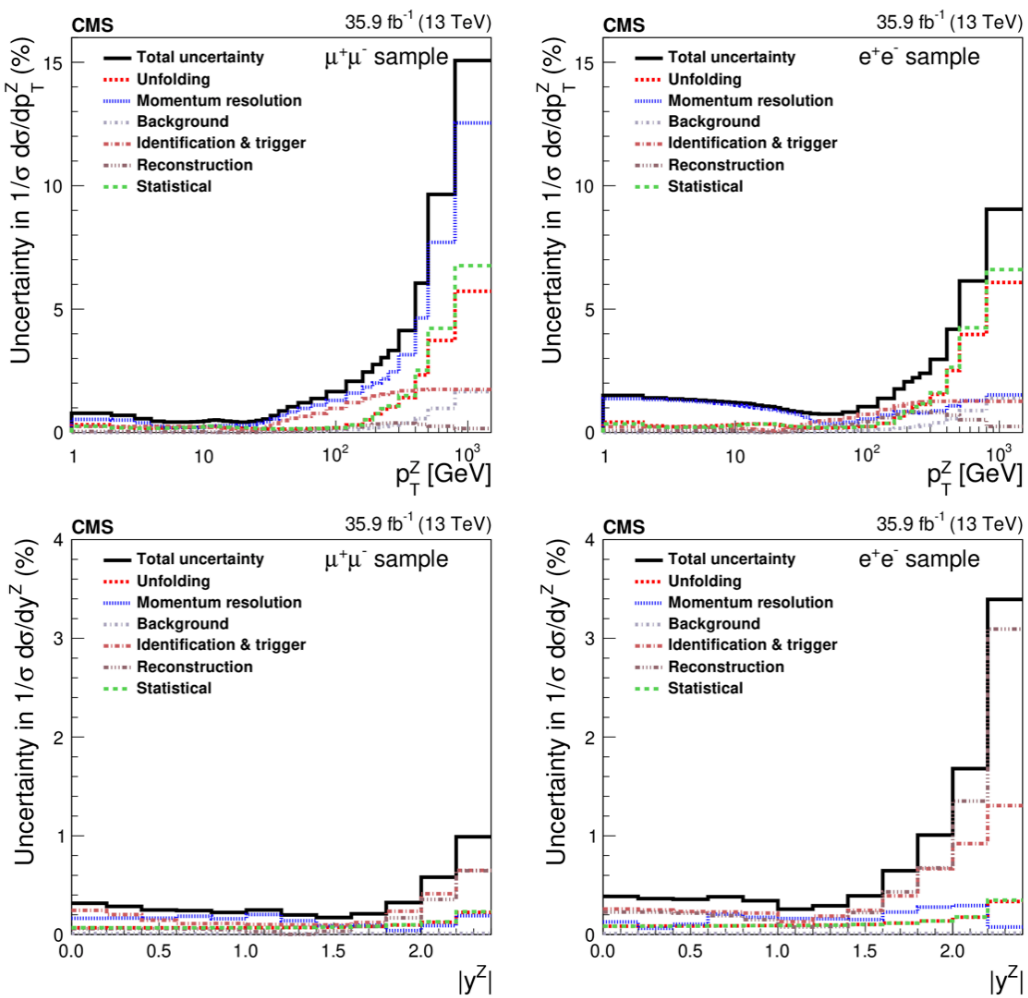


φ* systematic uncertainties

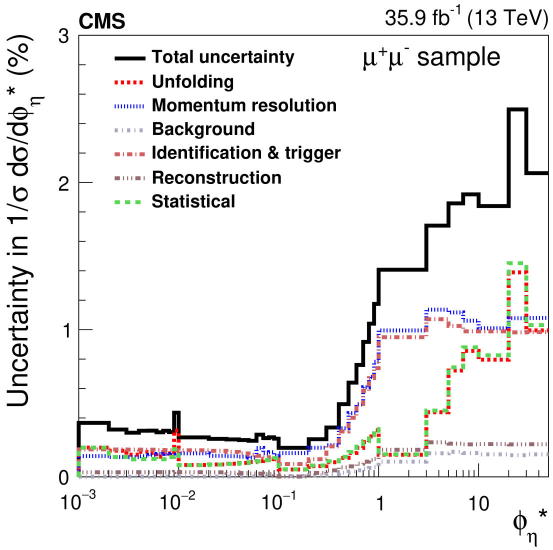
- An alternative probe of pT of the Z

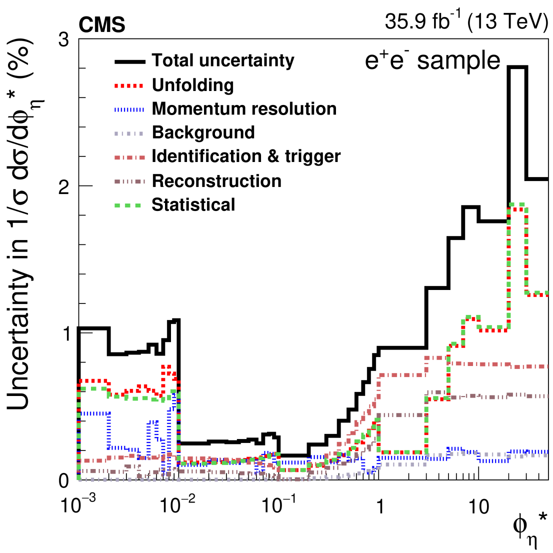
$$\phi^* = \tan\left(\frac{\pi-\Delta\phi}{2}\right)\sin(\theta^*_\eta)$$

$$\cos(\theta^*_\eta) = \tanh\left(\frac{\eta^- - \eta^+}{2}\right),$$

$$\phi^* \sim p_T^Z/m_{\ell\ell}$$

- φ* resolution better that of pT
  - Depends only on angular directions
  - Excellent spatial resolution of CMS inner tracking detector
  - Bin width of 10^{-3} roughly corresponds to 0.1 GeV bin width in Z pT





Inclusive results

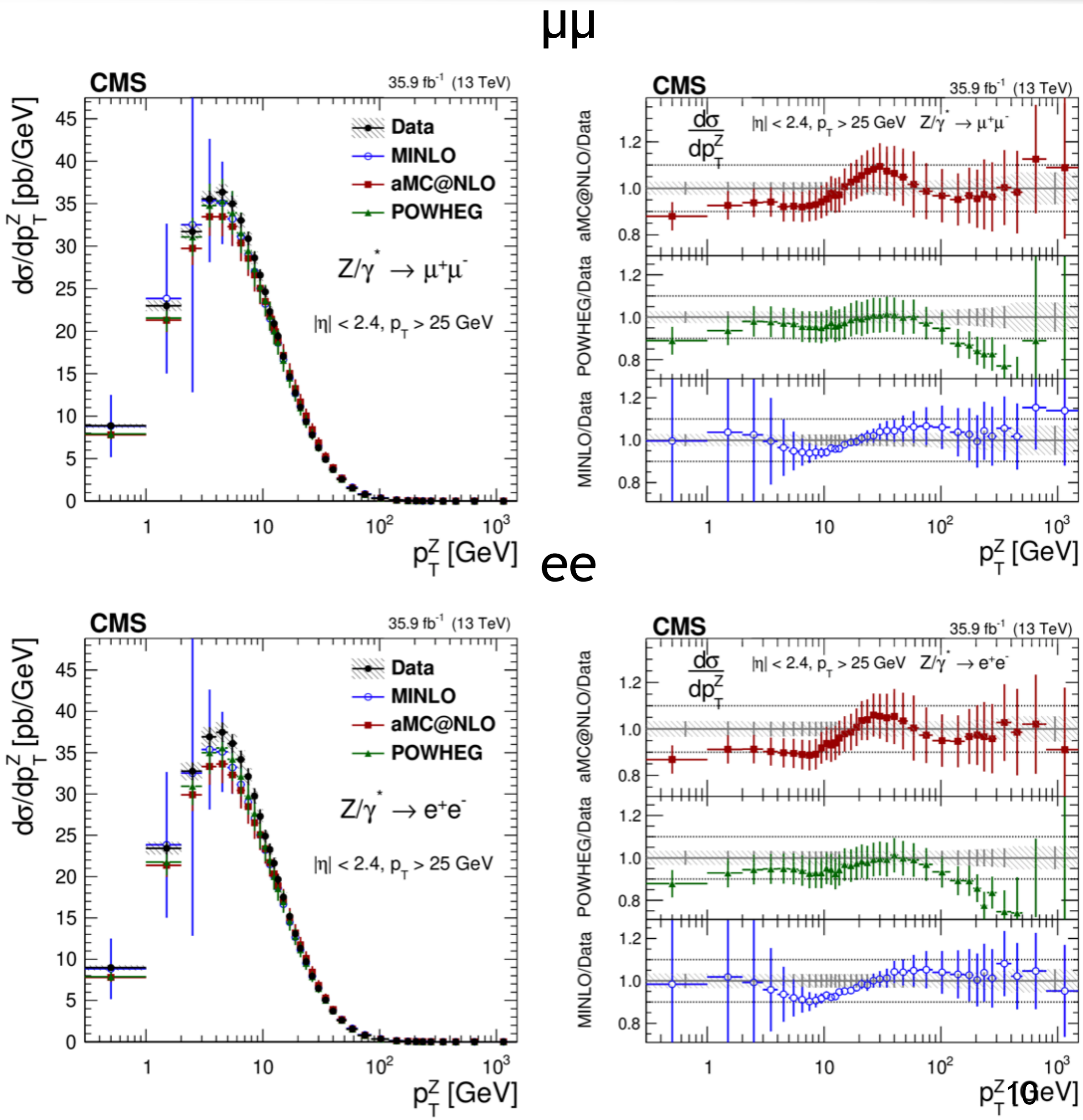
Source	$Z \to \mu\mu$ (%)	$Z \to ee$ (%)
Luminosity	2.5	2.5
Muon reconstruction efficiency	0.4	—
Muon selection efficiency	0.7	—
Muon momentum scale	0.1	—
Electron reconstruction efficiency	—	0.9
Electron selection efficiency	—	1.0
Electron momentum scale	—	0.2
Background estimation	0.1	0.1
Total (excluding luminosity)	0.8	1.4

Cross section	$\sigma\mathcal{B}$ [pb]
$\sigma_{Z\to\mu\mu}$	694 $\pm$ 6 (syst) $\pm$ 17 (lumi)
$\sigma_{Z\to ee}$	712 $\pm$ 10 (syst) $\pm$ 18 (lumi)
$\sigma_{Z\to\ell\ell}$	699 $\pm$ 5 (syst) $\pm$ 17 (lumi)

- Theoretical predictions (uncertainties include QCD scale and PDF):
  - 682 ± 55 pb (AMC@NLO with NNPDF3.0), NLO in QCD
  - 719 ± 8 pb (FEWZ with NNPDF3.1), NNLO in QCD

pT measurements

- Measurement compared to several theory predictions
- AMC@NLO with NNPDF3.0
  - Up to 2 hard parton emissions at matrix element
- Powheg with NNPDF3.0
  - Up to 1 hard parton emissions at matrix element
- MINLO with NNPDF3.1
  - JHEP05, (2013) 082
  - 7-point scale variation
  - Large uncertainties confirmed by authors (fundamentally different scale prescription)



|Y| measurements

- Measurement compared to several theory predictions
- AMC@NLO with NNPDF3.0
  - Up to 2 hard parton emissions at matrix element
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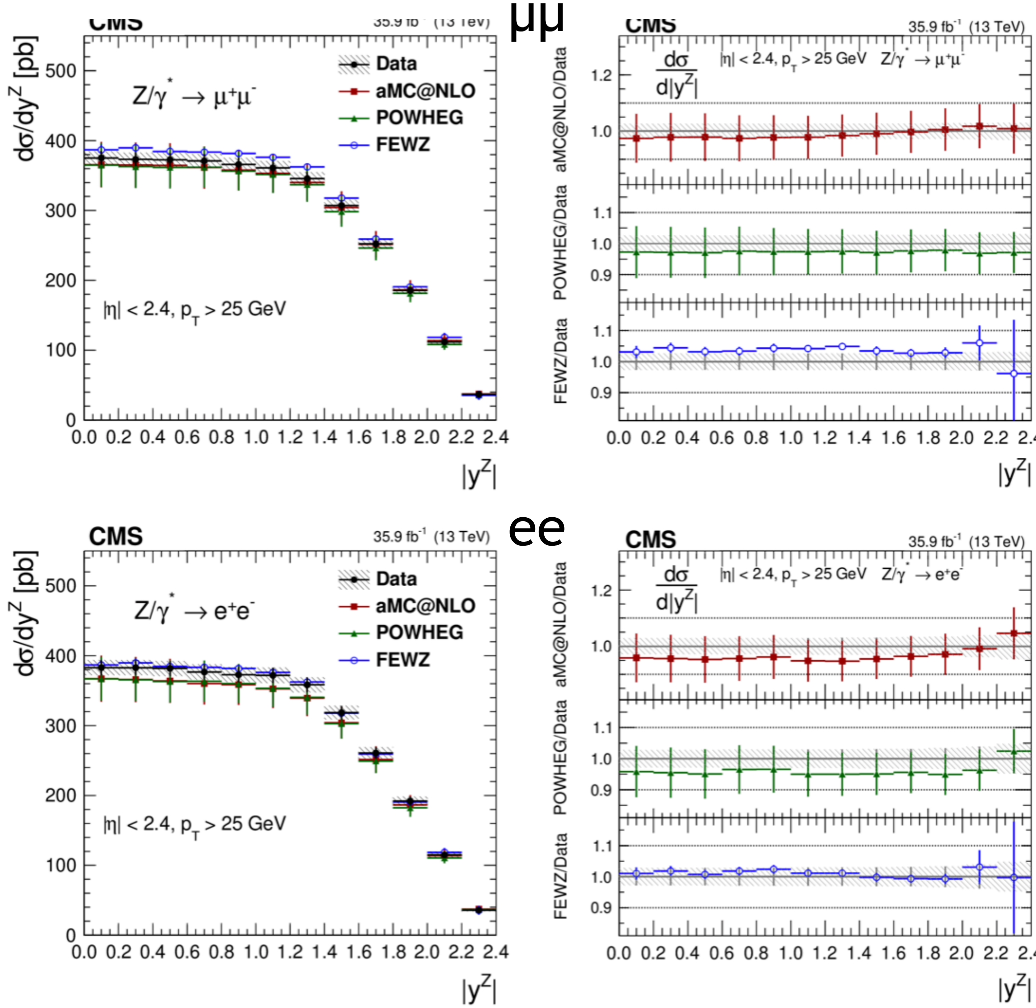
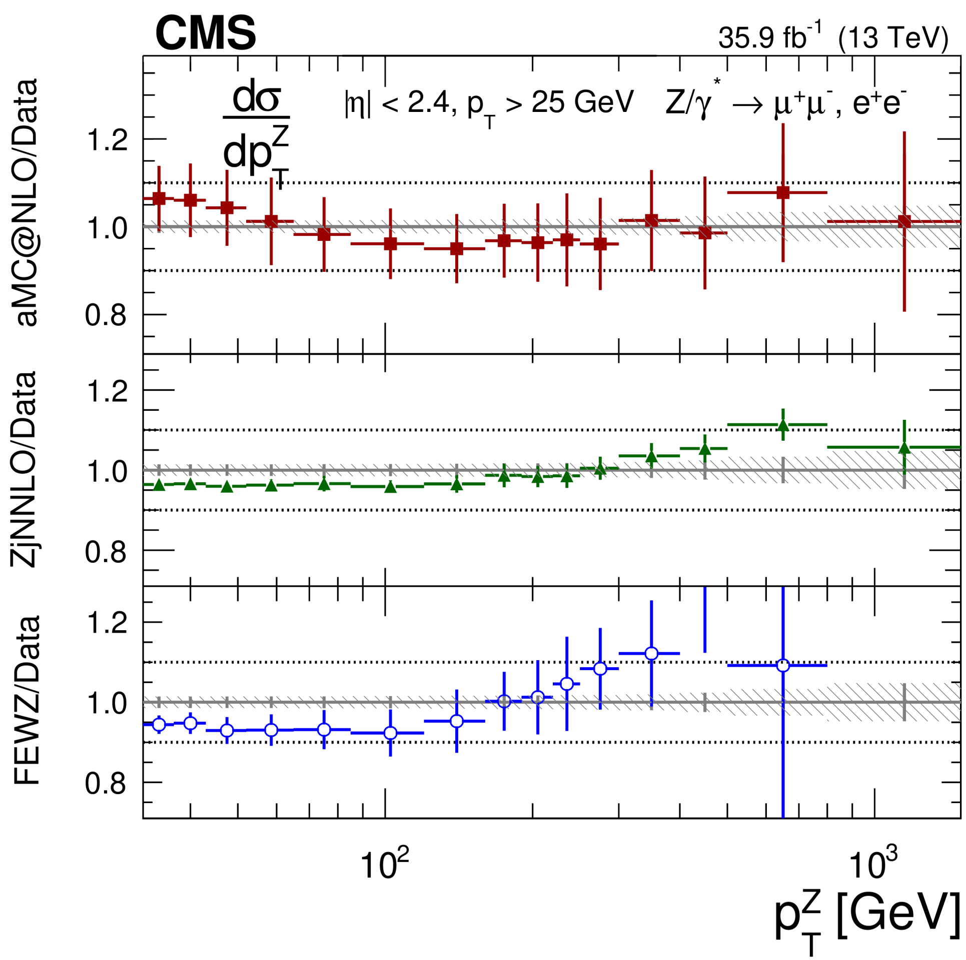
- FEWZ with NNPDF3.1
  - Fixed order prediction
  - NNLO accuracy



- Good agreement between electron and muon final states
  - Only the combined results shown henceforth

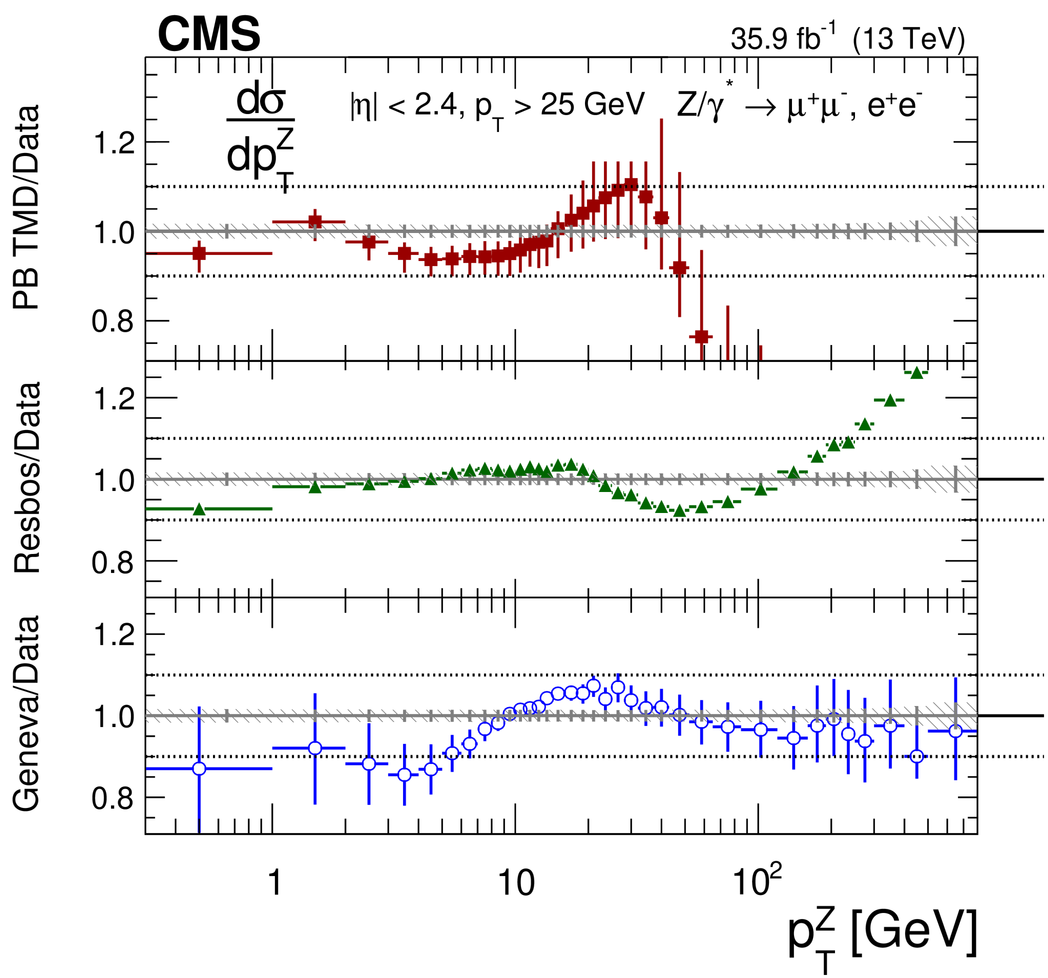
High-pT comparisons

- Measurement compared to fixed order calculations
- High-pT sensitive to EW corrections
  - ~0.9 at pT=500 GeV and ~0.8 at pT=800 GeV
- Z+1jet NNLO predictions
  - Phys. Rev. Lett. (2016), 152001
  - Accuracy at O(α_s^3)
  - Using N-jettiness subtraction scheme
- FEWZ predictions at NNLO QCD
  - EW corrections included (no FSR)



Low-pT comparisons

- Measurement compared to predictions with analytic resummation
- Resbos CP with CT14 PDF set
    - NNLL accuracy
    - Only statistical uncertainties are shown for the prediction
- Geneva predictions
    - Phys. Rev. D 92 (2015), 094020
    - NNLL+NNLO matched with Parton shower
    - Dedicated parton shower tune needed for very low pT



φ* results

- Measurement compared to several theory predictions
- AMC@NLO with NNPDF3.0
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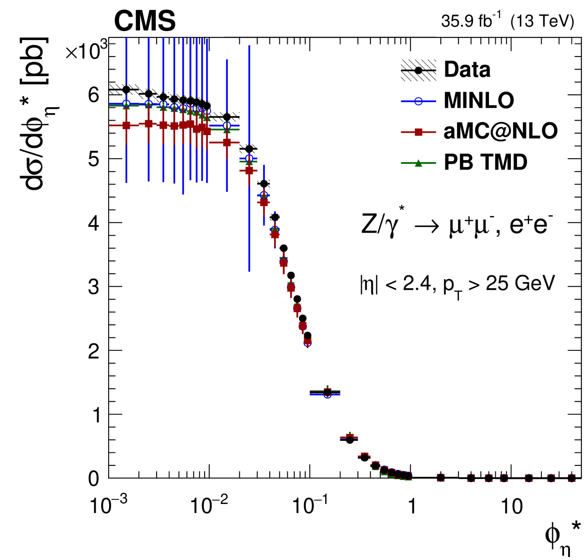
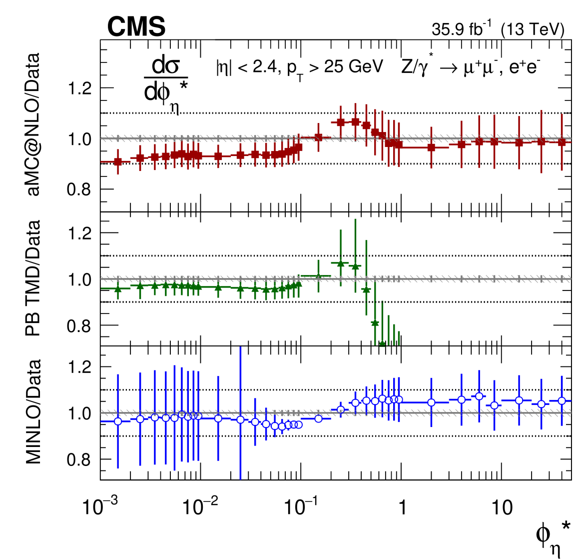
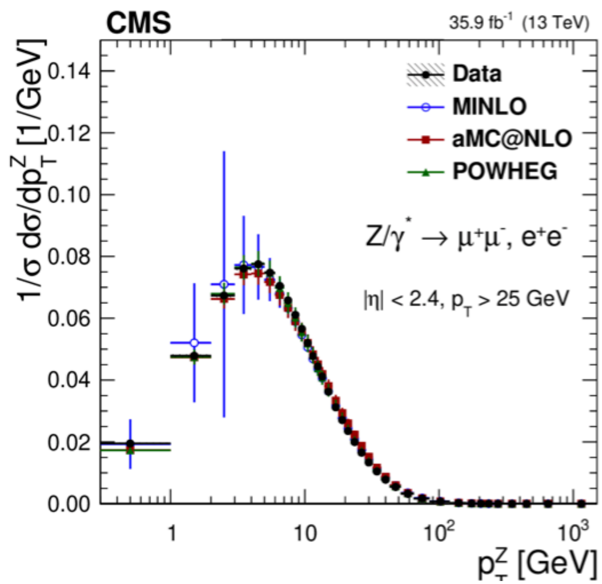
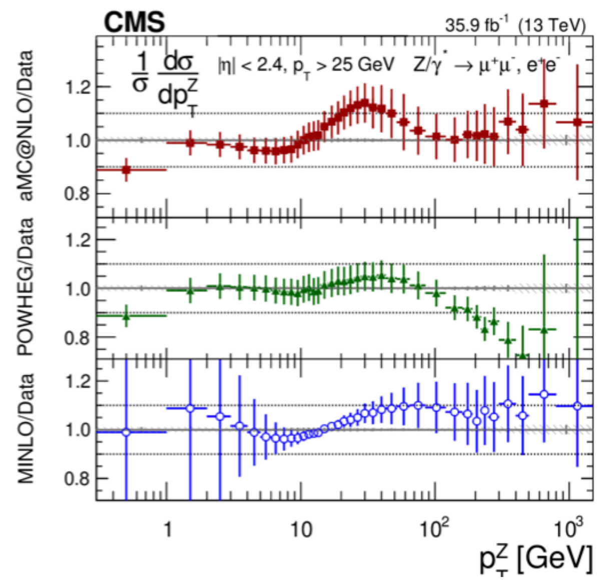




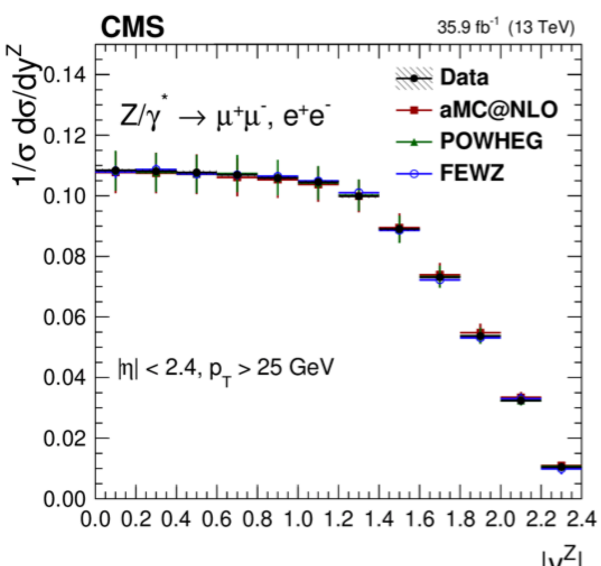
Normalized results

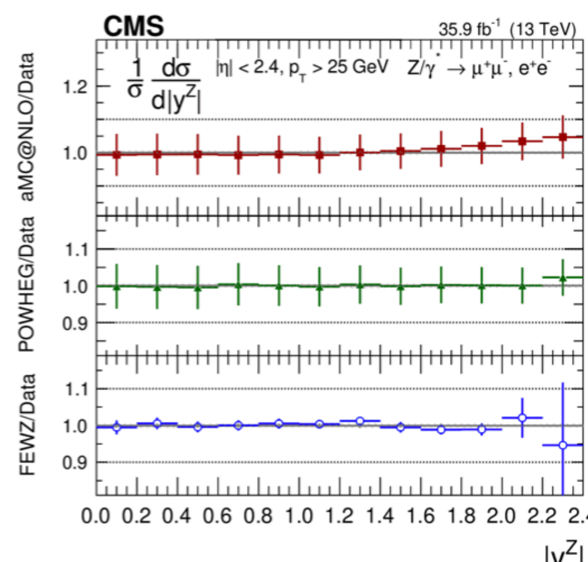
pT





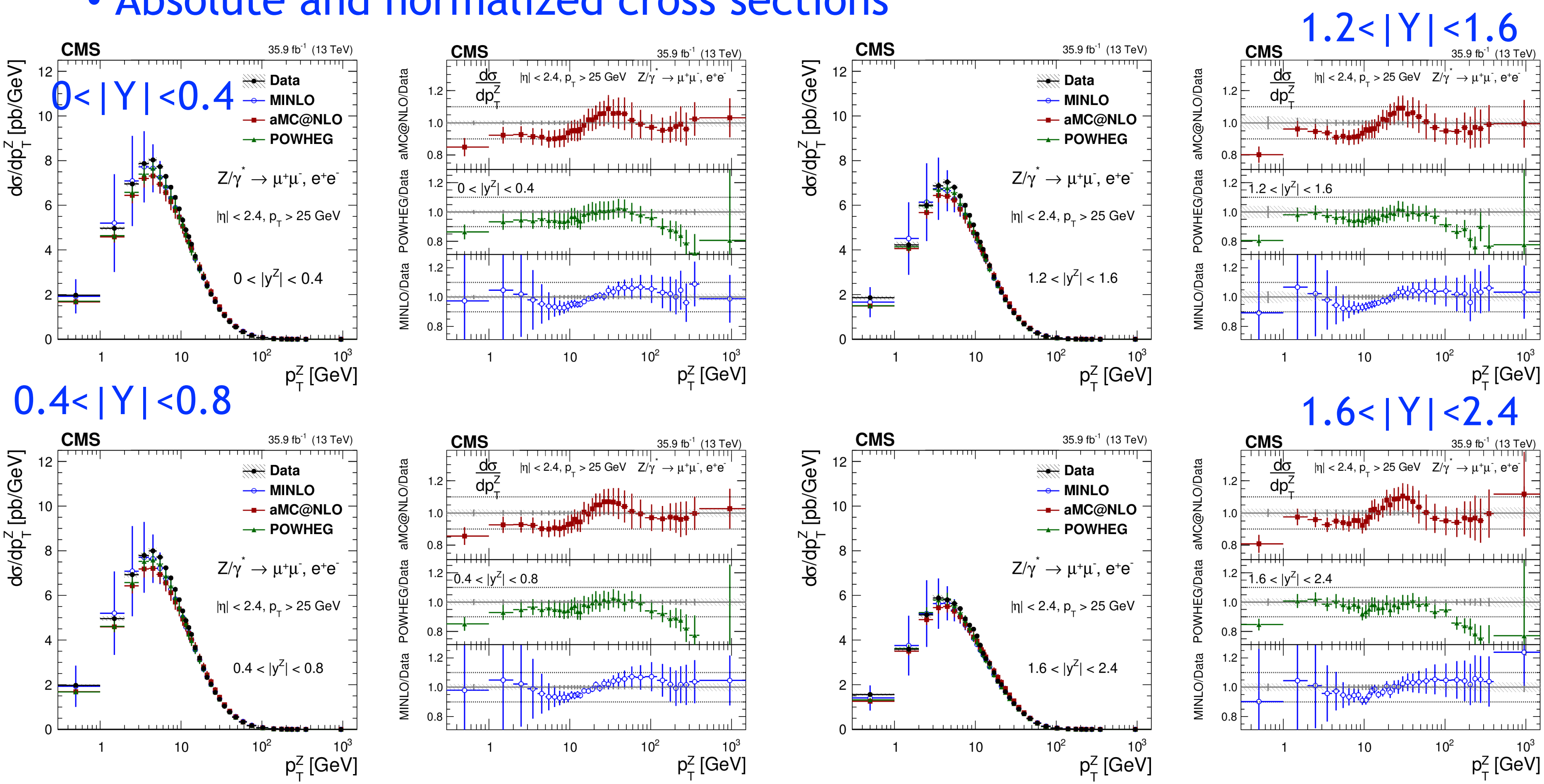
|Y|





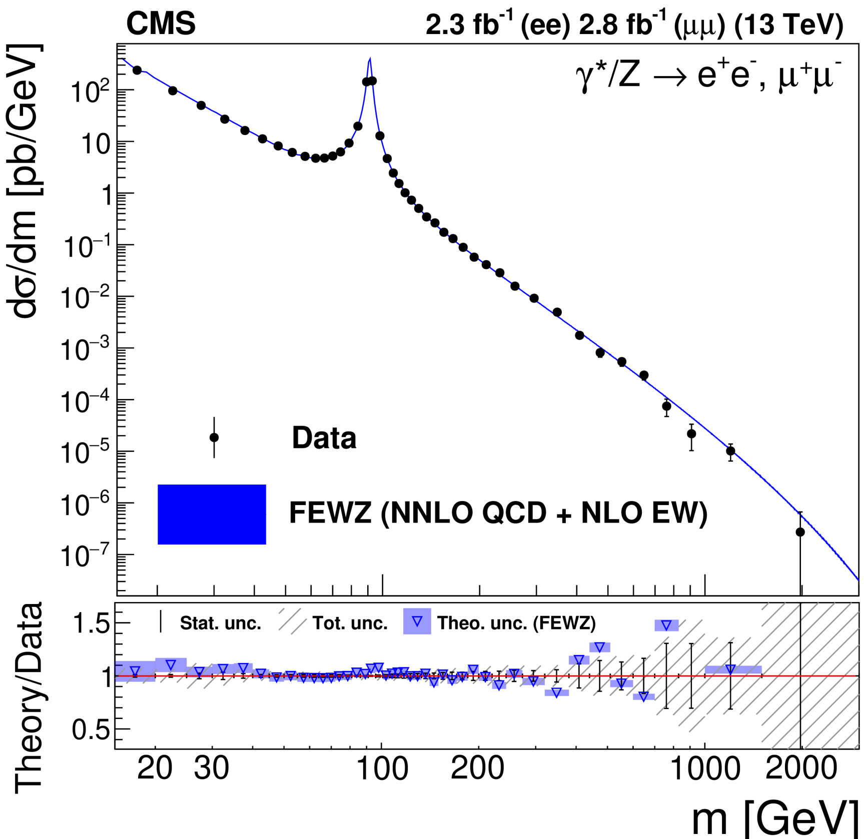
pT vs. |Y| measurements

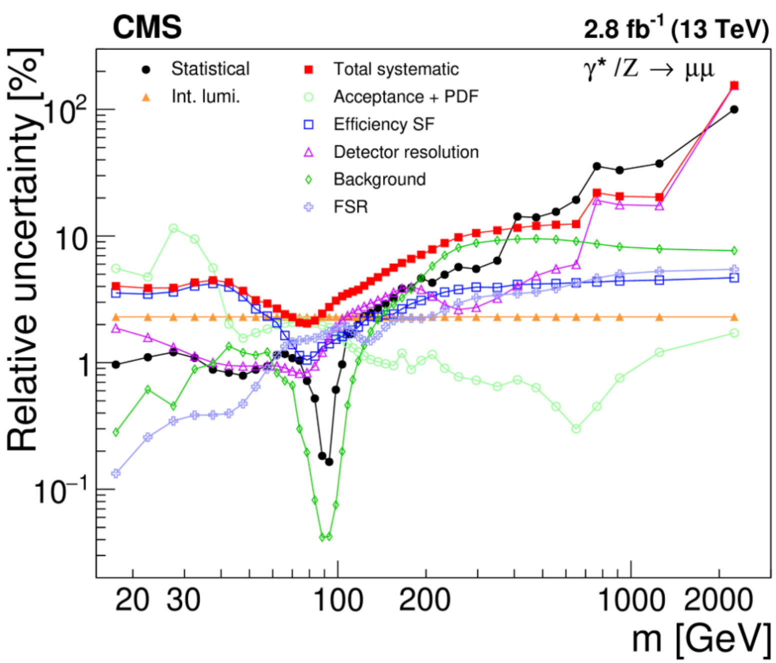
- Measurement of pT in bins of |Y|
    - 0<|Y|<0.4, 0.4<|Y|<0.8, 0.8<|Y|<1.2, 1.2<|Y|<1.6, 1.6<|Y|<2.4
    - Absolute and normalized cross sections



Drell-Yan measurement

- Measurement of the differential Drell-Yan cross section at 13 TeV
  - arXiv:1812.10529, dσ/dM
  - Dilepton invariant mass in the range 15 to 3000 GeV (leading lepton pT>22 (30) GeV and subheading lepton pT > 10 GeV





Summary

- Measurements of W and Z production cross sections with CMS
  - Targeting constraints on PDFs in the relevant phase space for precision electroweak measurements
- Precise measurements of the Z differential cross sections with CMS
  - $d\sigma/dp_T$, $d\sigma/d|Y|$, $d^2\sigma/dp_Td|Y|$, $d\sigma/d\varphi^*$
  - Normalized cross section uncertainties are smaller than ~0.5% for $\varphi^*<0.5$ and $p_T<50$ GeV
  - The paper is submitted to JHEP and the HepData (including dressed and born level results) will come in time of publication
- Interesting new measurements at 13 TeV are expected in the coming months and years
  - Stay tuned...

ADDITIONAL MATERIAL

Unfolding and binning

Using TUnfold method to perform the unfolding, as officially suggested

- $p_{\mathrm{T}}^{\mathrm{Z}}$ (in GeV): {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 18, 20, 22, 25, 28, 32, 37, 43, 52, 65, 85, 120, 160, 190, 220, 250, 300, 400, 500, 800, 1500}
- $|y^{\mathrm{Z}}|$: {0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4}
- $\phi^{\star}$: $\{1 \cdot 10^{-3}, 2 \cdot 10^{-3}, 3 \cdot 10^{-3}, 4 \cdot 10^{-3}, 5 \cdot 10^{-3}, 6 \cdot 10^{-3}, 7 \cdot 10^{-3}, 8 \cdot 10^{-3}, 9 \cdot 10^{-3}, 1 \cdot 10^{-2}, 2 \cdot 10^{-2}, 3 \cdot 10^{-2}, 4 \cdot 10^{-2}, 5 \cdot 10^{-2}, 6 \cdot 10^{-2}, 7 \cdot 10^{-2}, 8 \cdot 10^{-2}, 9 \cdot 10^{-2}, 1 \cdot 10^{-1}, 2 \cdot 10^{-1}, 3 \cdot 10^{-1}, 4 \cdot 10^{-1}, 5 \cdot 10^{-1}, 6 \cdot 10^{-1}, 7 \cdot 10^{-1}, 8 \cdot 10^{-1}, 9 \cdot 10^{-1}, 1, 3, 5, 7, 10, 20, 30, 50\}$
- $p_{\mathrm{T}}^{\mathrm{Z}}$ in $|y^{\mathrm{Z}}|$ regions (in GeV): {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 18, 20, 22, 25, 28, 32, 37, 43, 52, 65, 85, 120, 160, 190, 220, 250, 300, 400, 1500}