

Drell-Yan measurements with CMS for PDF determinations



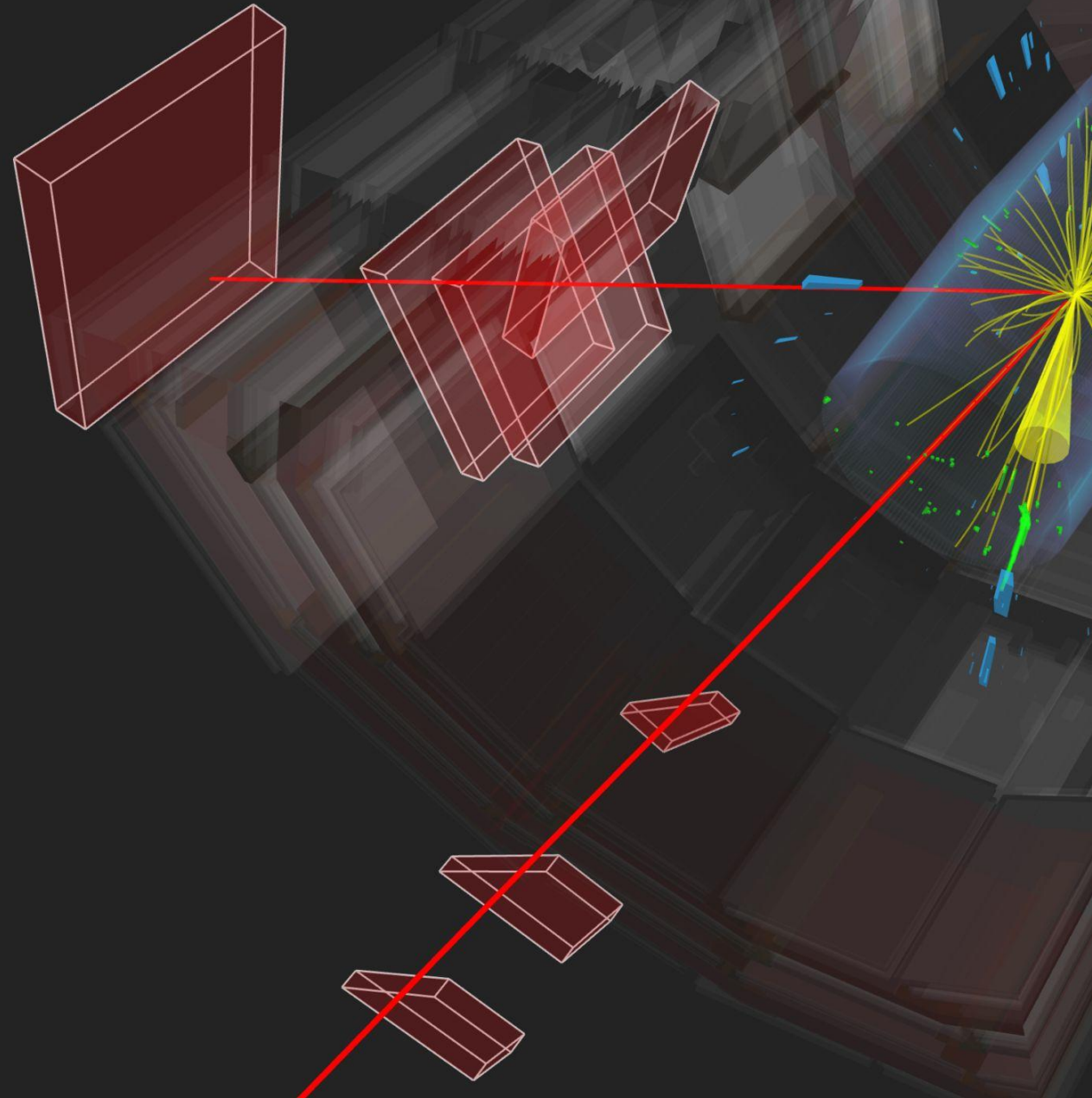
Cedric Verstege, Karlsruhe Institute of Technology
29. September 2026, QCD@LHC 2026, University of
Oxford



CMS Experiment at the LHC, CERN

Data recorded: 2016-Jun-17 18:17:18.774656 GMT

Run / Event / LS: 275310 / 216704991 / 115

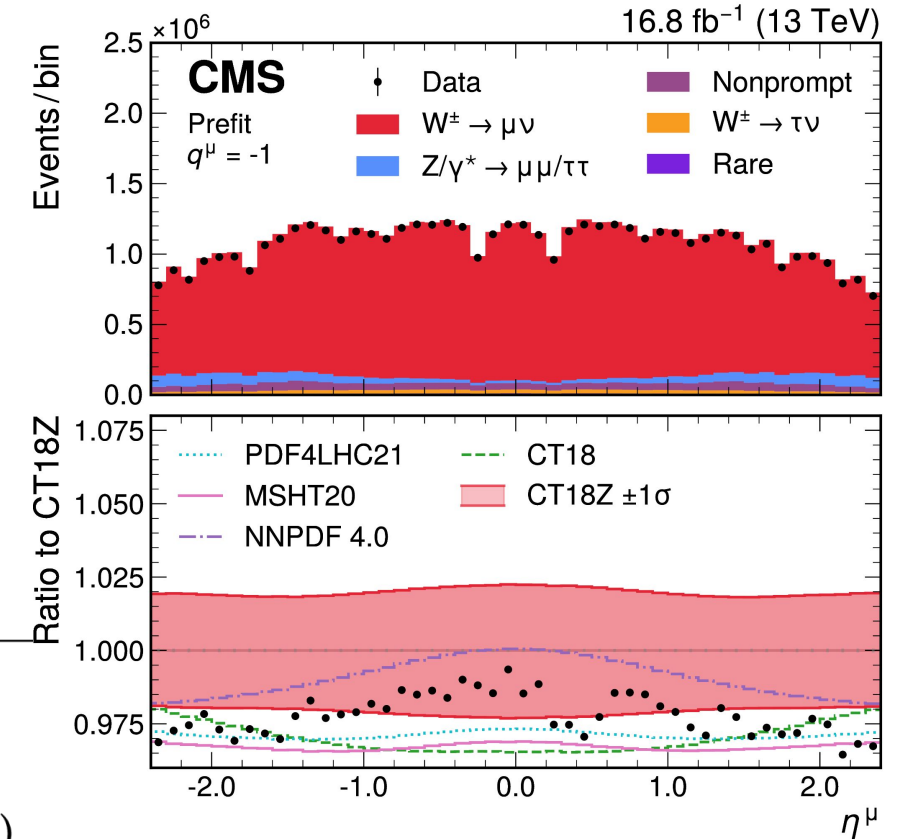


Precision Measurements limited by PDFs

Example: W boson mass (CMS-SMP-23-002)

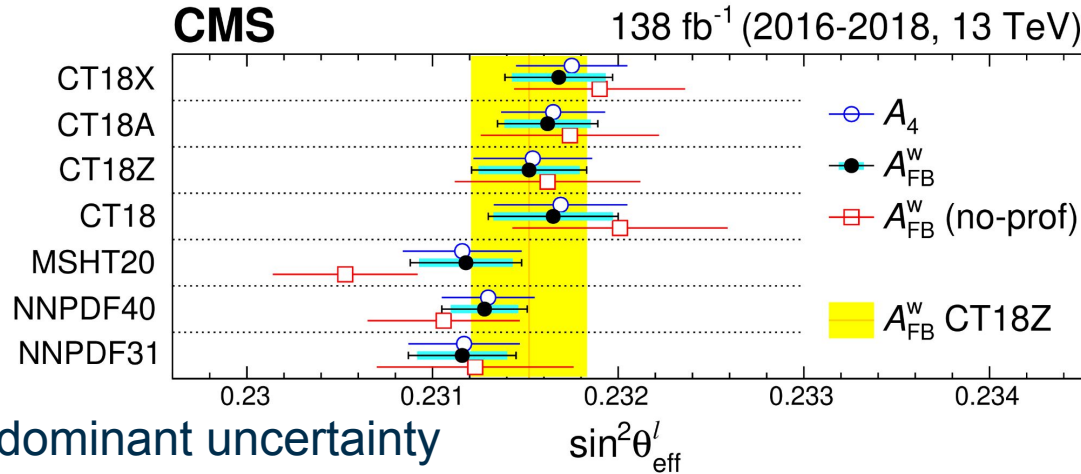
- PDFs are second-largest uncertainty
 - 4.4 of 9.9 MeV
- CT18Z eigenvectors profiled in situ
 - Muon (p_T , η , charge) distributions constrain PDFs, factor 2.5
- MSHT20/NNPDF priors too narrow to cover other sets
 - eigenvectors inflated by 1.5–5 before profiling

PDF set	σ_{PDF} scale fact.	Extracted m_W (σ_{PDF}) (MeV)	
		Original σ_{PDF}	Scaled σ_{PDF}
CT18Z	—	$80\,360.2 \pm 9.9$ (4.4)	
CT18	—	$80\,361.8 \pm 10.0$ (4.6)	
PDF4LHC21	—	$80\,363.2 \pm 9.9$ (4.1)	
MSHT20	1.5	$80\,361.4 \pm 10.0$ (4.3)	$80\,361.7 \pm 10.4$ (5.1)
MSHT20aN3LO	1.5	$80\,359.9 \pm 9.9$ (4.2)	$80\,359.8 \pm 10.3$ (4.9)
NNPDF3.1	3.0	$80\,359.3 \pm 9.5$ (3.2)	$80\,361.3 \pm 10.4$ (5.3)
NNPDF4.0	5.0	$80\,355.1 \pm 9.3$ (2.4)	$80\,357.0 \pm 10.8$ (6.0)



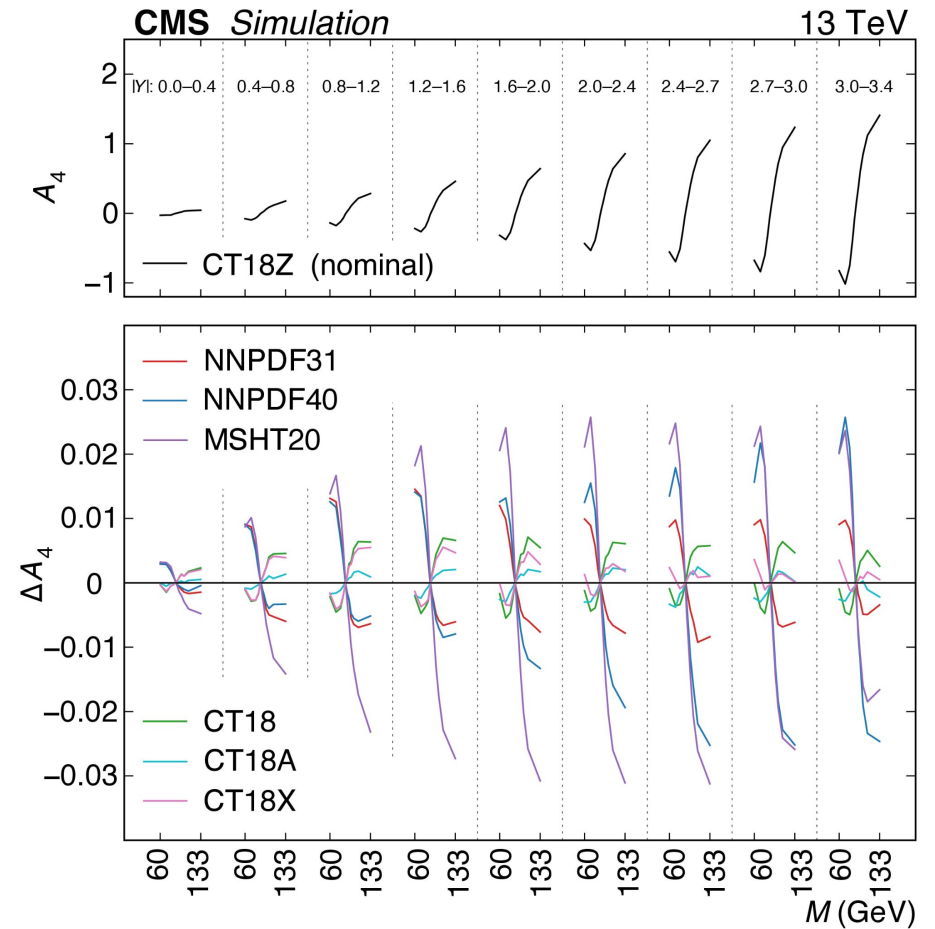
Precision Measurements limited by PDFs

Example: Weak mixing angle (CMS-SMP-22-010)



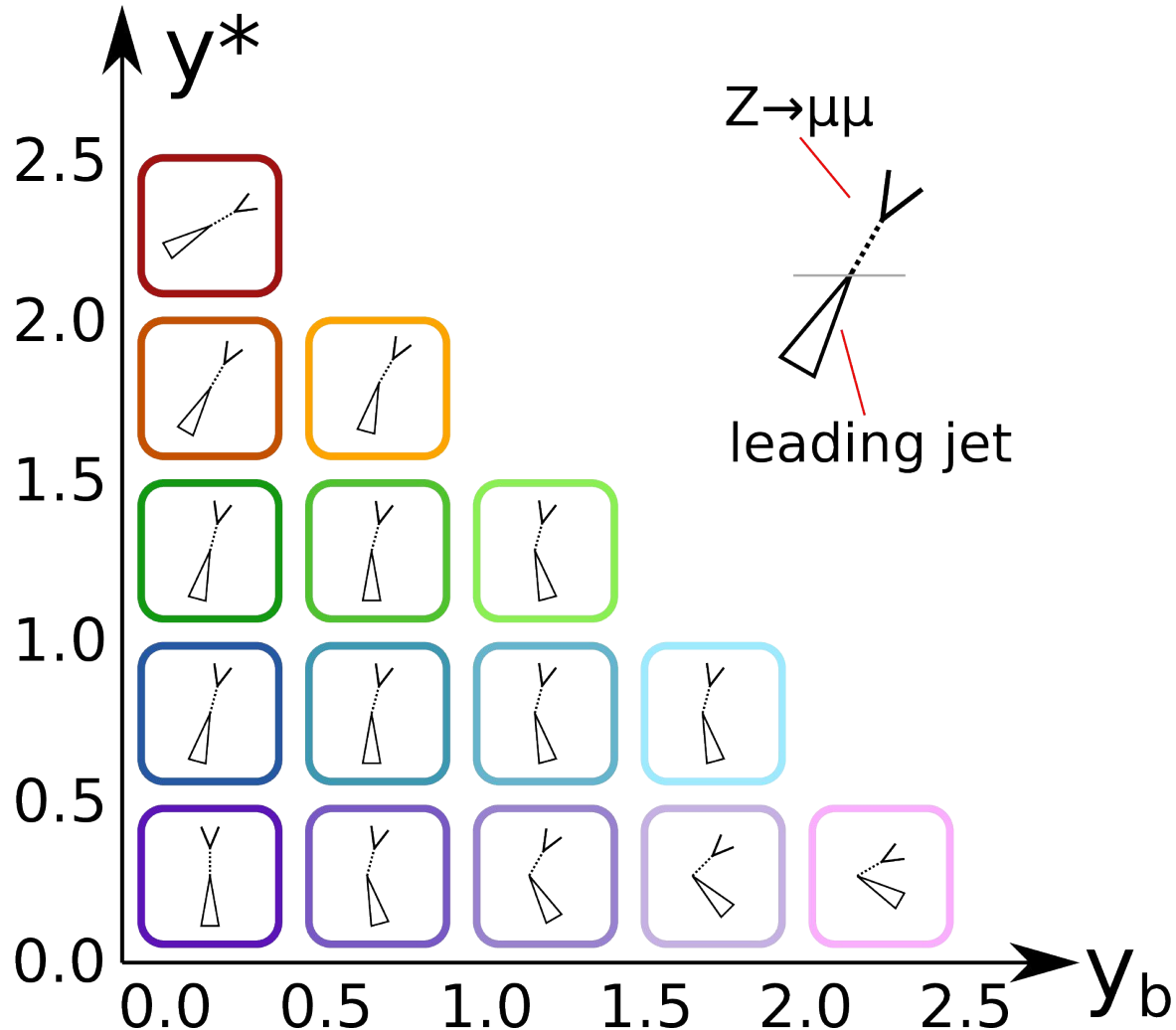
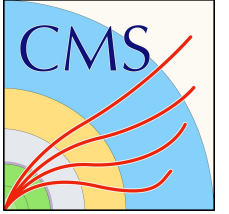
- PDFs are the dominant uncertainty
 - 0.00027 of 0.00031 total
- CT18Z eigenvectors profiled in situ
 - A_{FB} , mass and rapidity dependence constrain PDFs, factor 2
- Unfolded $A_4(|Y|, M)$ released with theory grids for PDF fits
 - simultaneous HERA + A_4 fit validates profiling
 - See next talk by K. Rabbertz for more details

$$\sin^2 \theta_{\text{eff}}^l = 0.23152 \pm 0.00010 (\text{stat}) \pm 0.00015 (\text{exp}) \pm 0.00008 (\text{theo}) \pm 0.00027 (\text{PDF}),$$



Triple-differential measurement of Z+jet production at 13 TeV

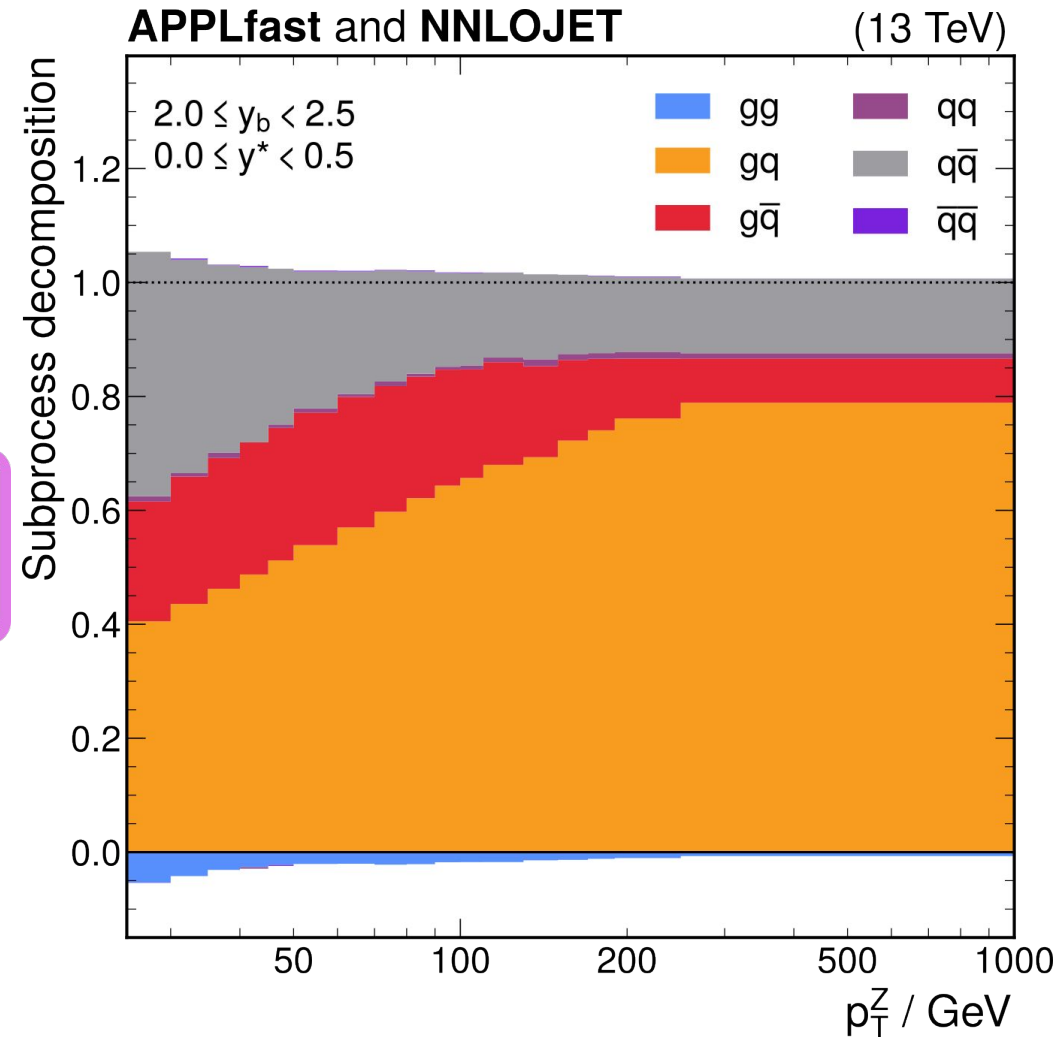
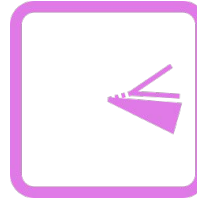
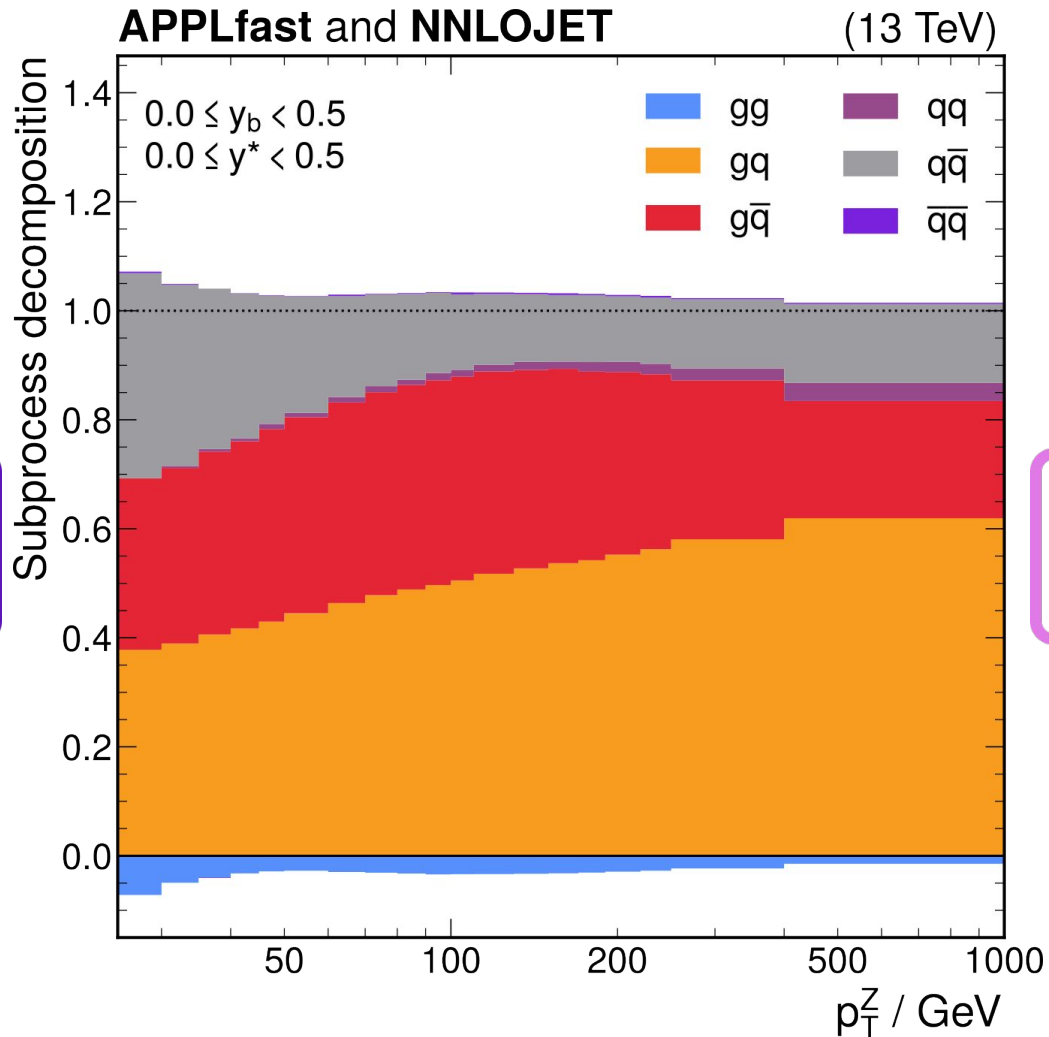
[CMS-SMP-24-010](#)



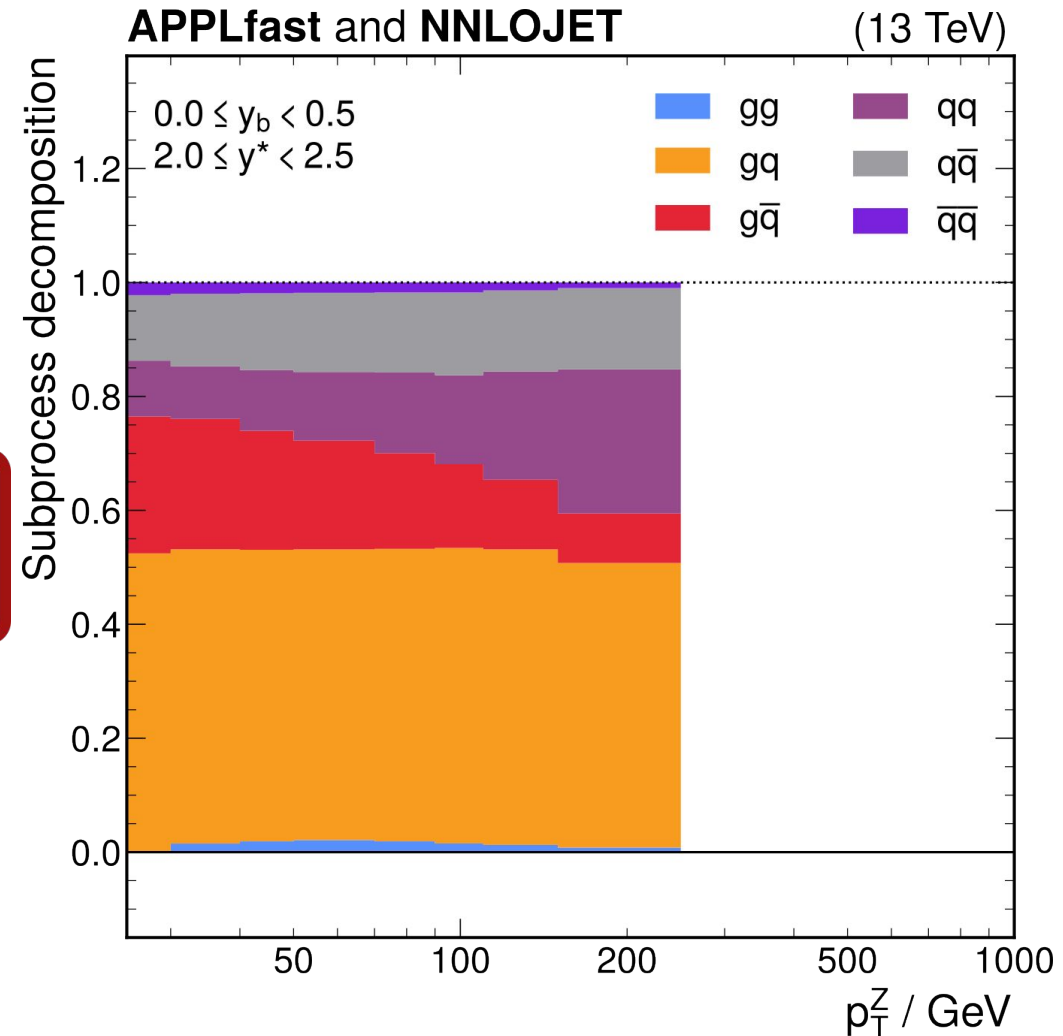
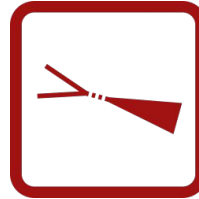
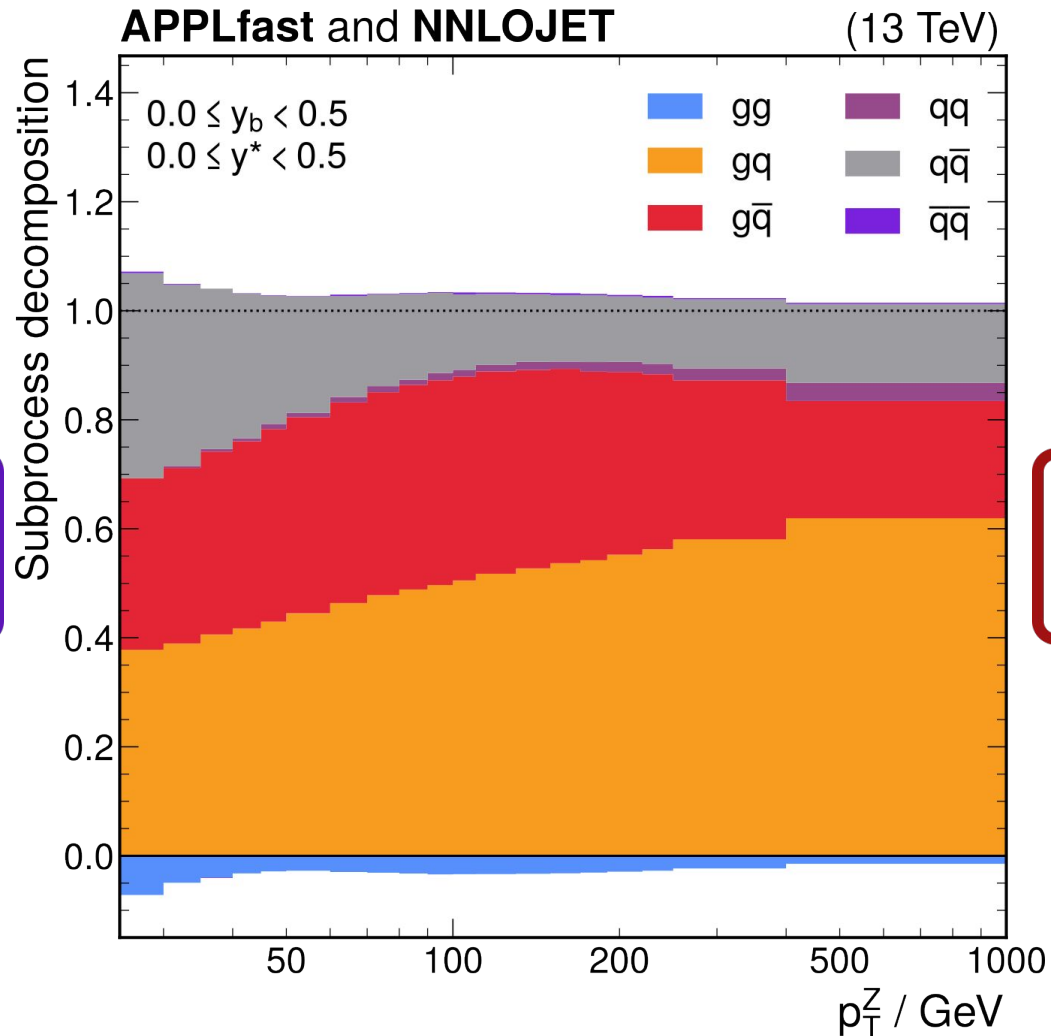
- Transverse momentum of di-muon system
 - p_T^Z
 - Scale of the hard interaction
- Boost of center-of-mass system
 - $y_b = \frac{1}{2} |y^Z + y^{\text{jet}}|$
 - Parton momentum fractions of the protons
 - Sensitive to x_1 and x_2
- Rapidity separation
 - $y^* = \frac{1}{2} |y^Z - y^{\text{jet}}|$
 - Scattering angle in center-of-mass system
 - Sensitive to changes in initial state contributions

Directly sensitive to PDFs and α_s
Complementary to 3D dijet [EPJC 85 \(2025\) 72](#)

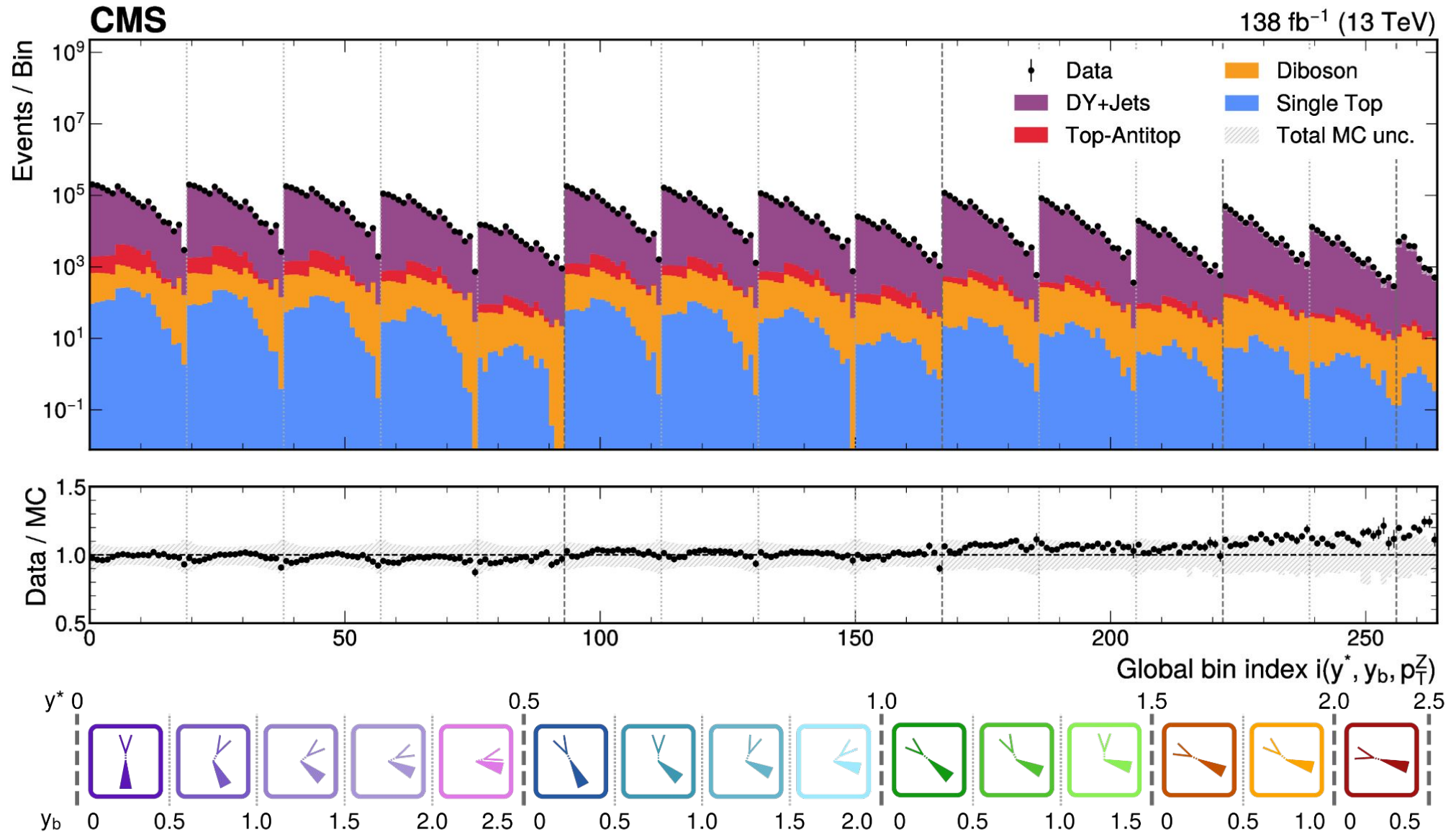
Parton contributions to Z+jet production



Parton contributions to Z+jet production



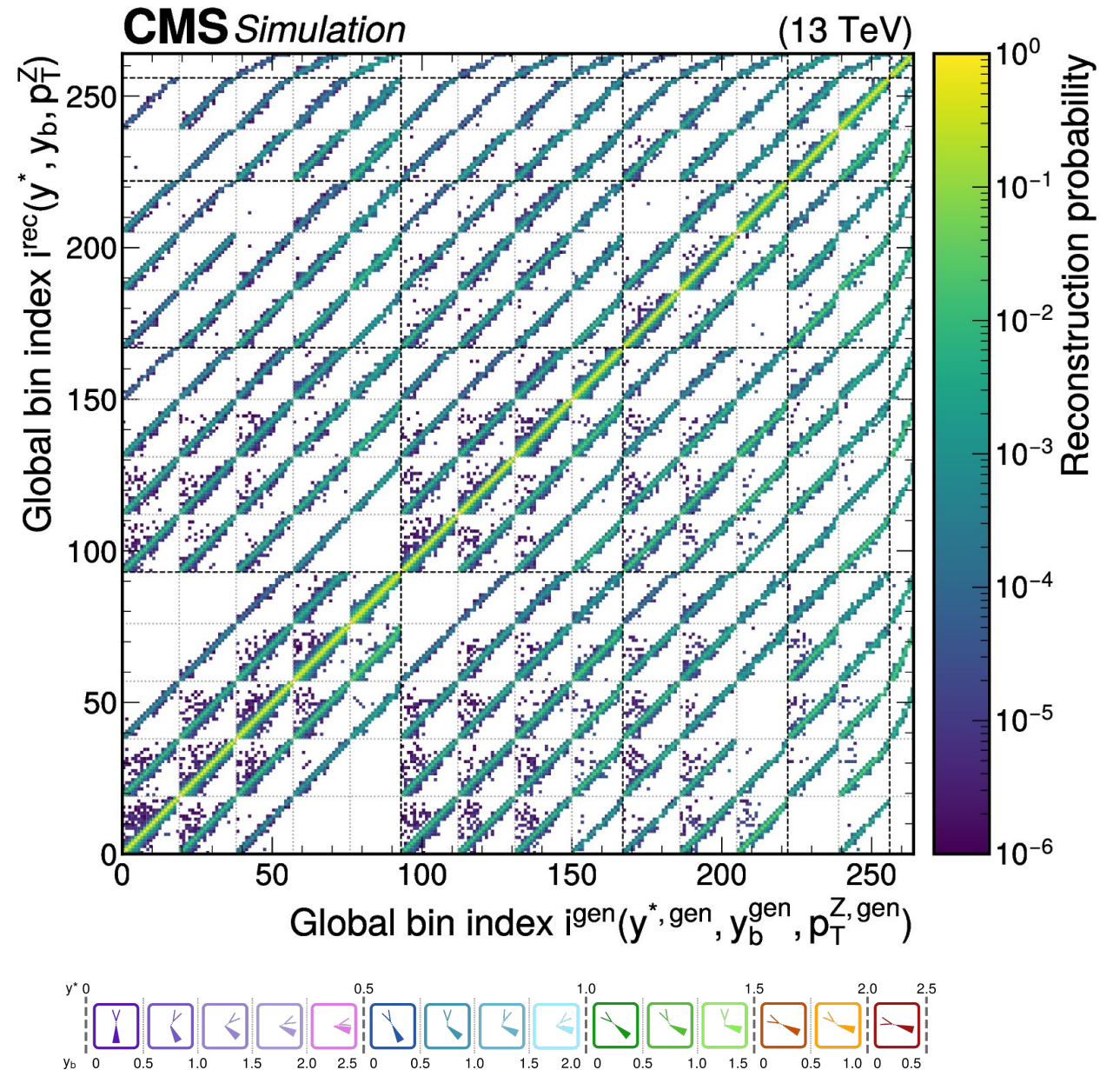
Unrolled distribution at detector level



Unfolding

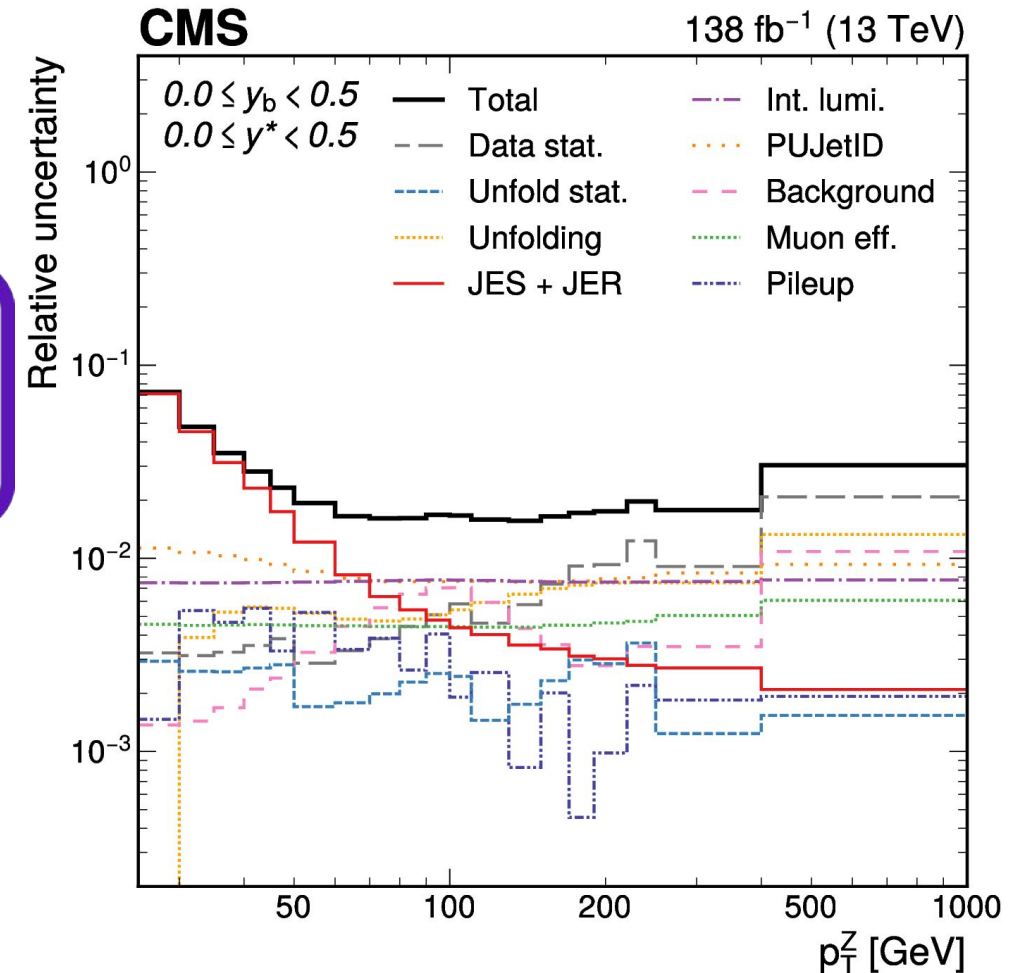
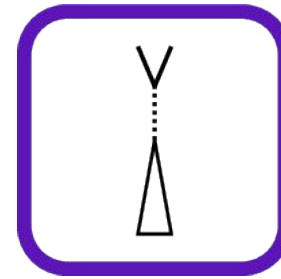
- Correct for detector effects
 - Final results at stable particle level
- Unfolding simultaneously in all three dimensions
 - Condition number 2.8
 - “Inverting” response matrix with TUnfold

$$\mathcal{L} = (y - Ax)^T V_y^{-1} (y - Ax)$$

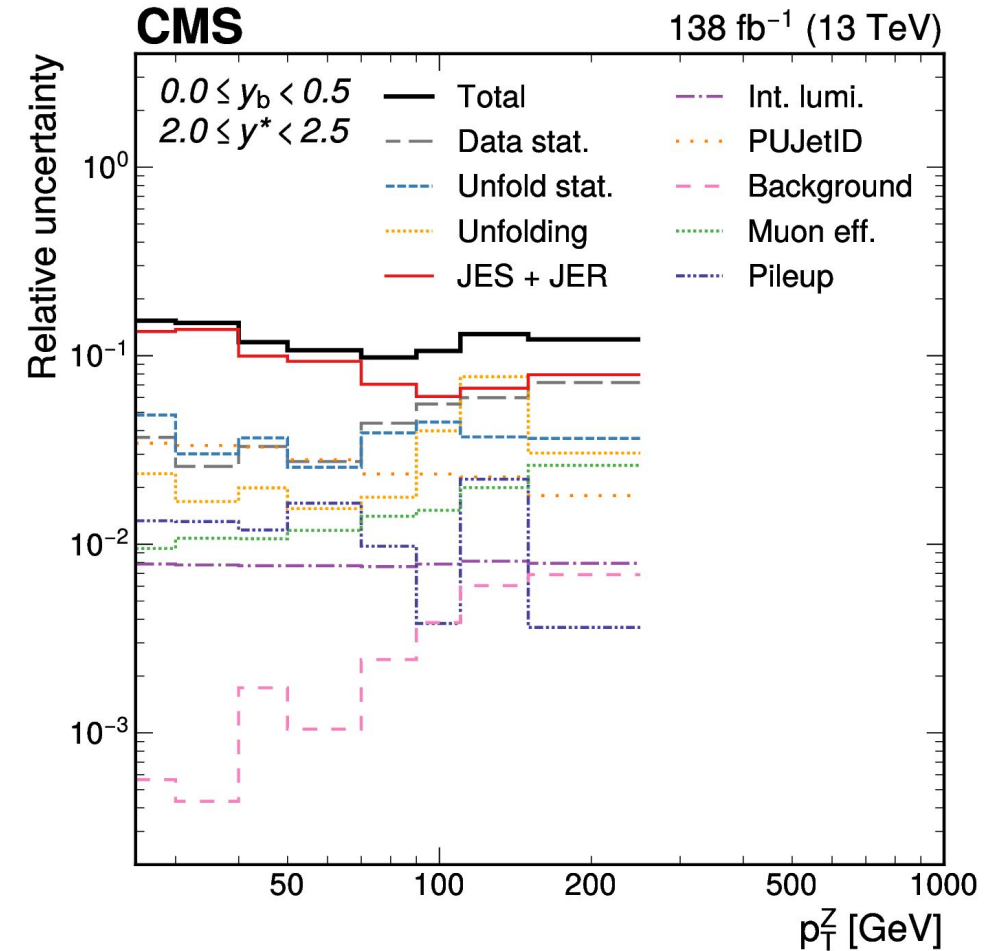
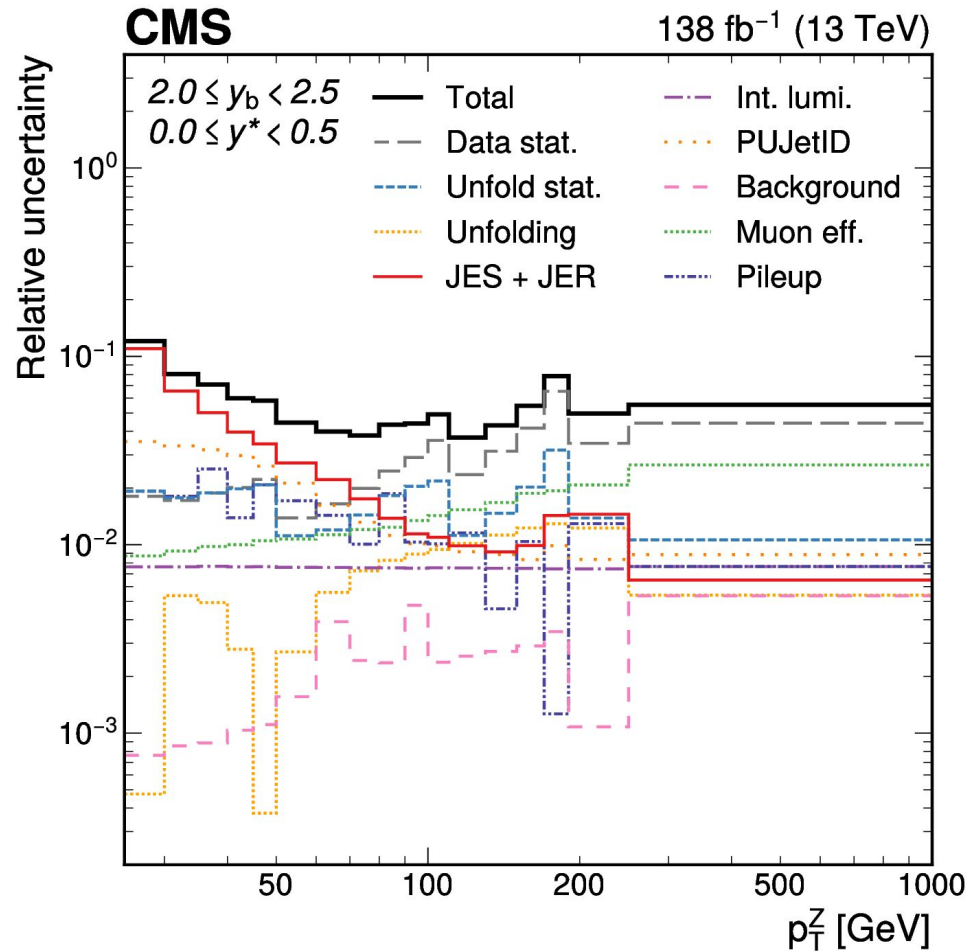


Uncertainty breakdown

- Unfolding in all 264 bins simultaneously
- Uncertainties vary greatly across phase space regions
 - Jet energy scale (**JES**) uncertainty dominates at low p_T^Z
 - Data statistics are limiting at high p_T^Z
 - Combination of other uncertainties (**Lumi**, PUJetID, Background, ...) in central regions
 - In outer rapidity regions uncertainty >10%
 - In central bins a precision of 1.5% is reached

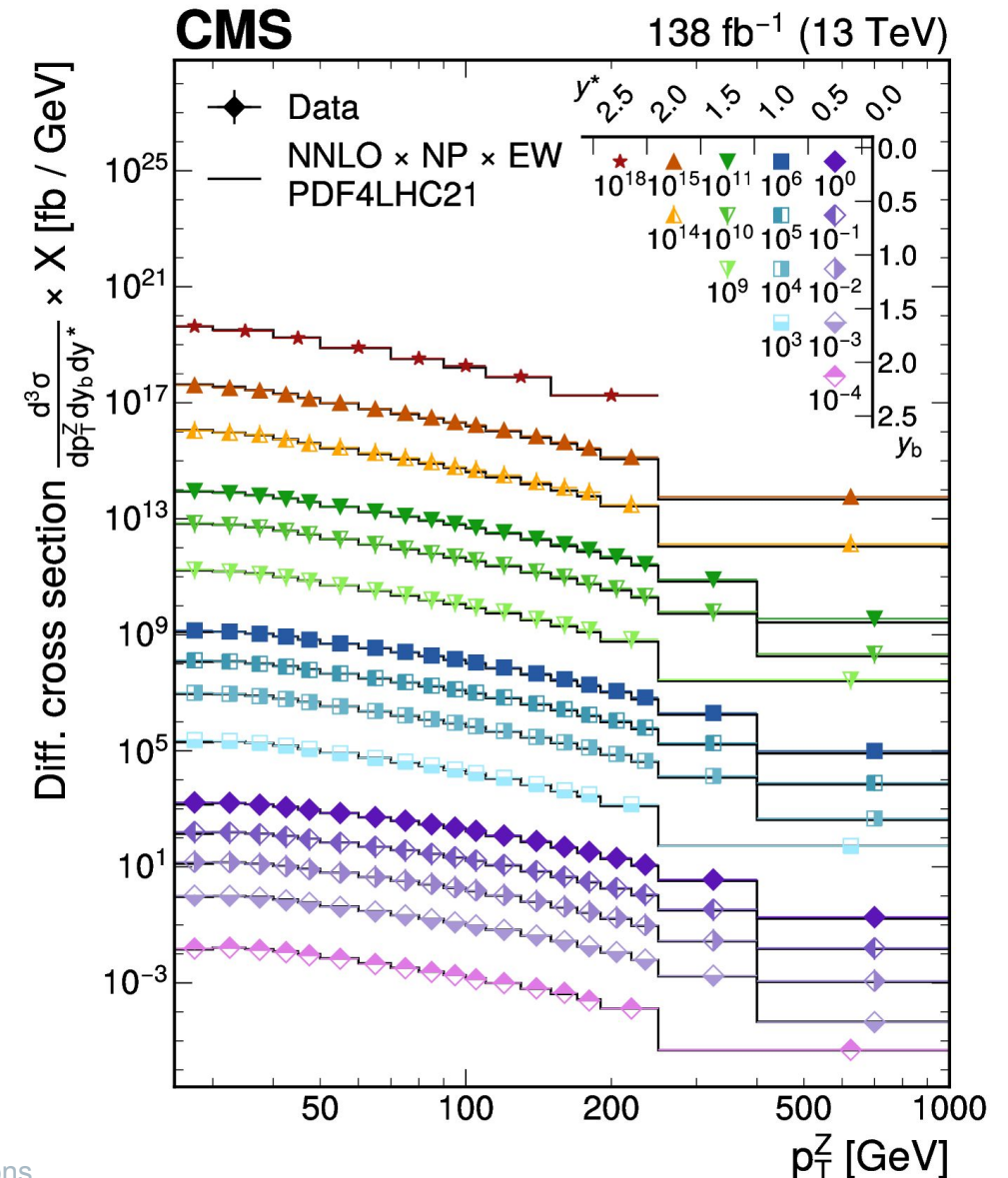
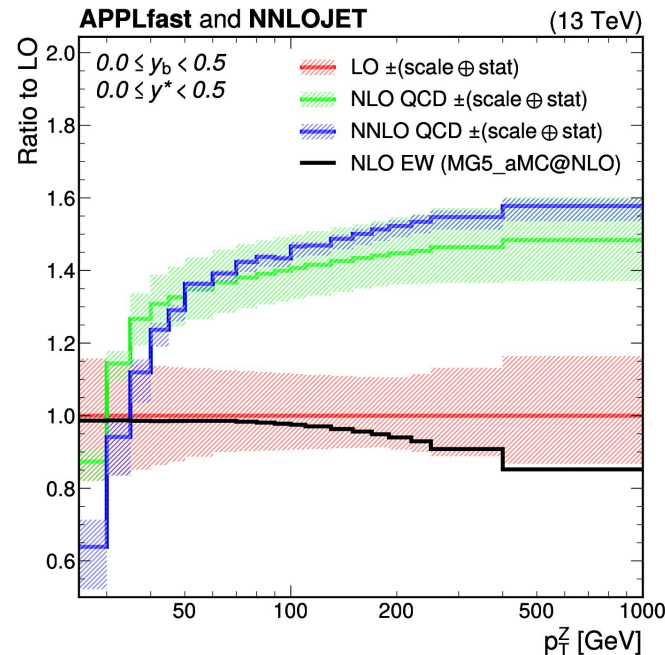
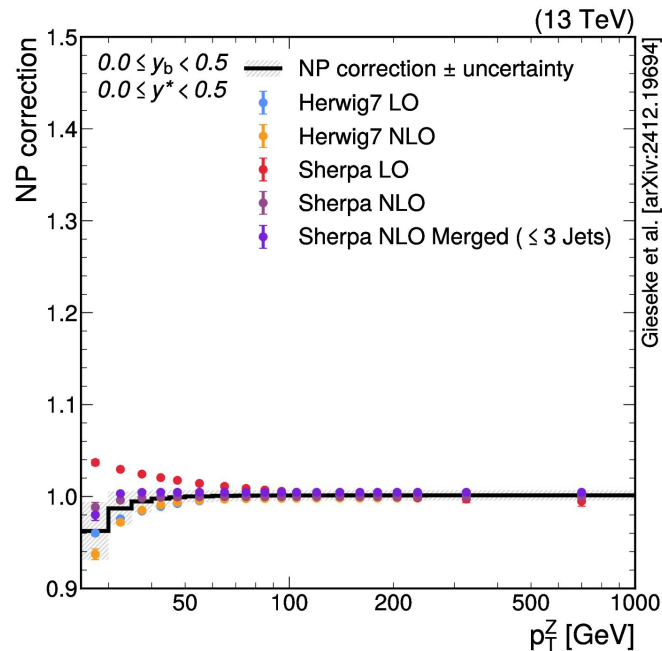


Uncertainty breakdown

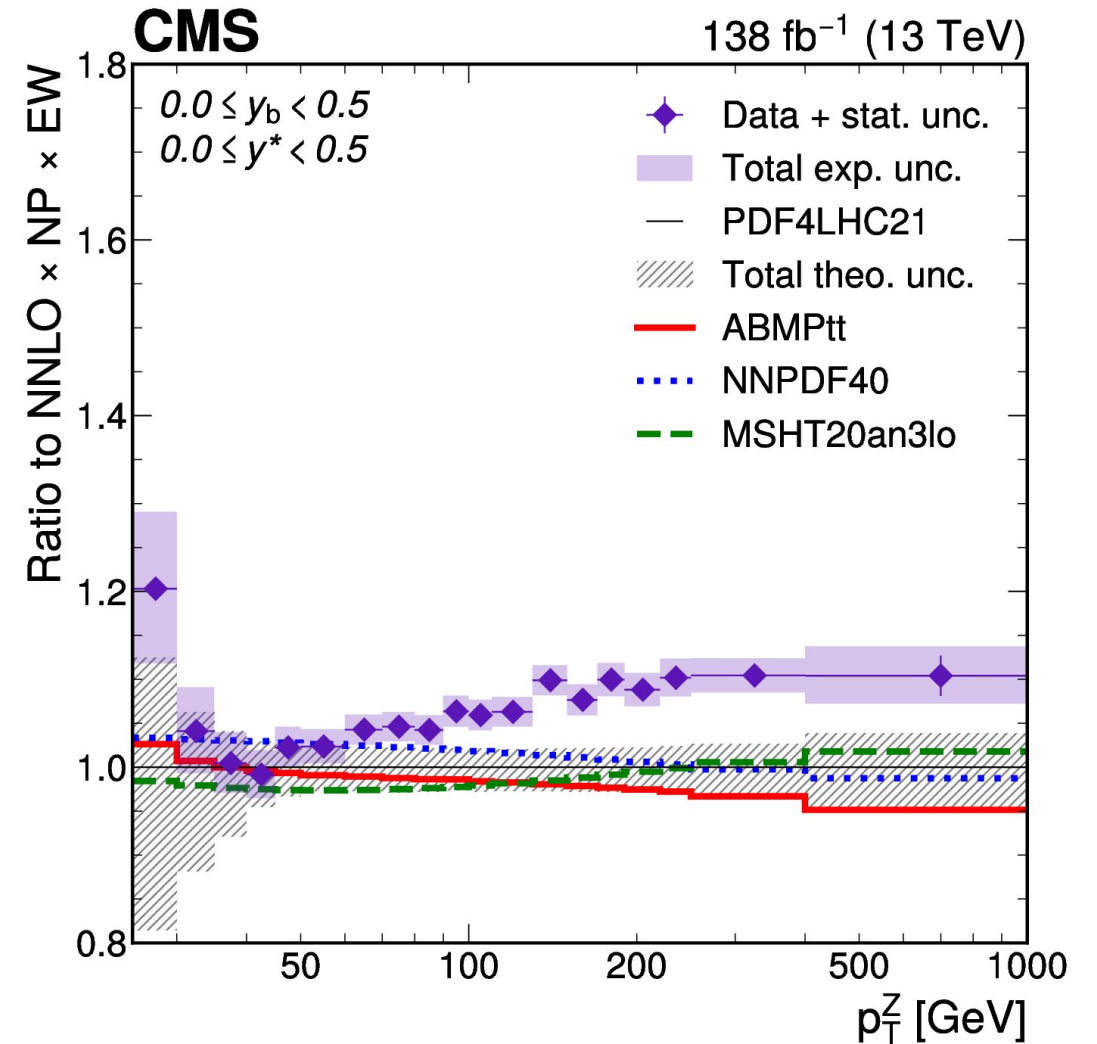
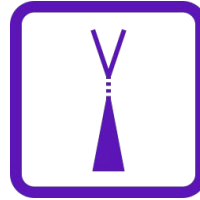
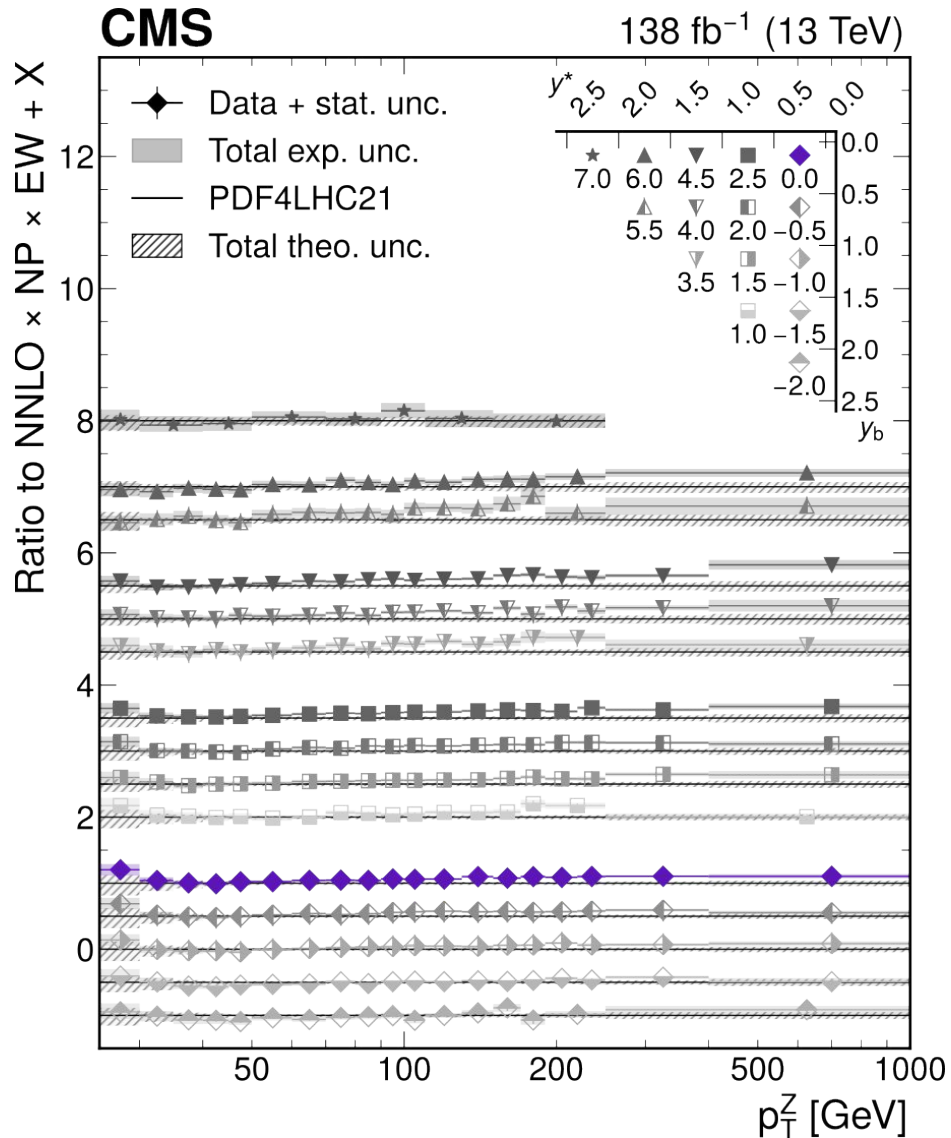


Comparison to NNLO QCD

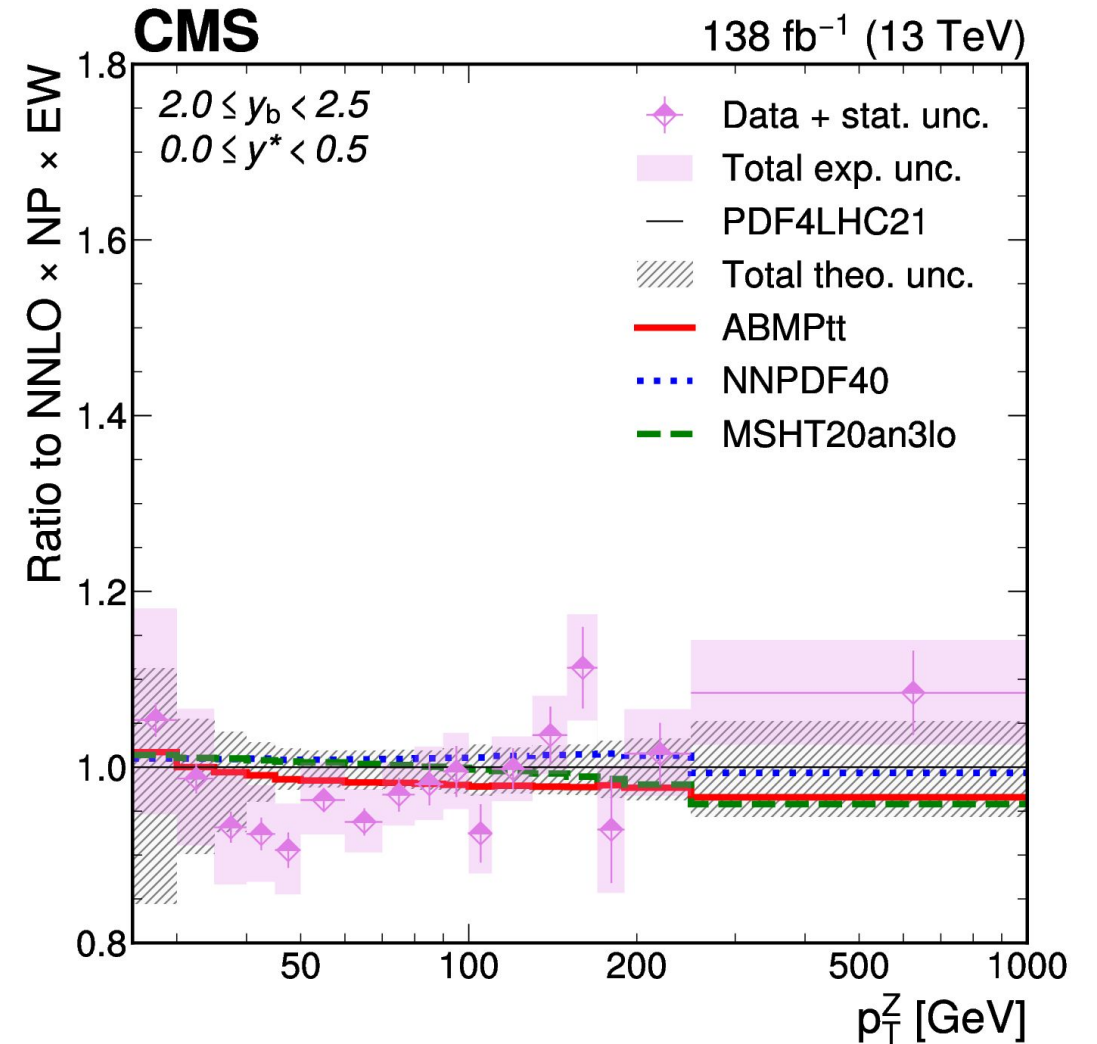
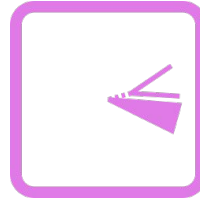
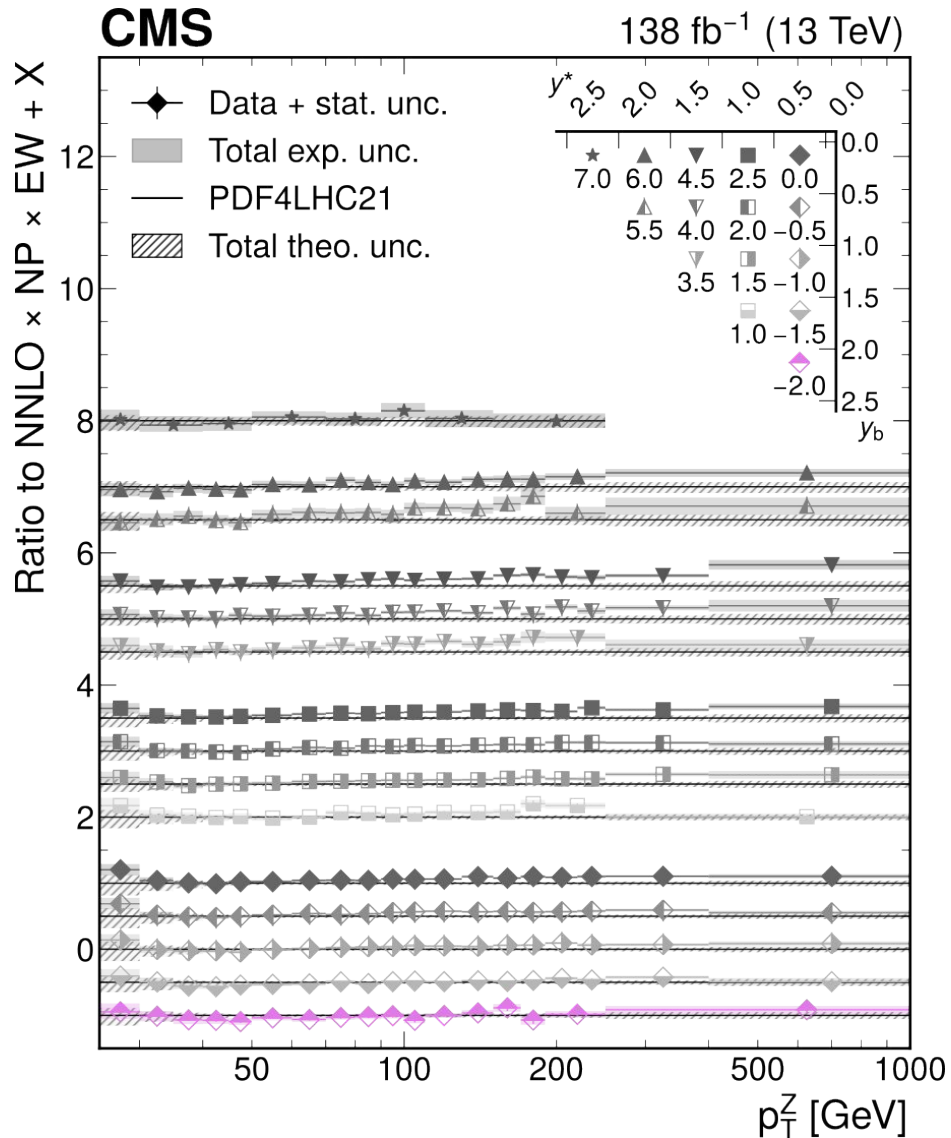
- Fixed Order for Z+jet available at NNLO QCD
 - Calculated using NNLOJet and FastNLO
- Non-perturbative (NP) corrections
 - Derived with Sherpa and Herwig in [arXiv:2412.19694 \[hep-ph\]](https://arxiv.org/abs/2412.19694)
- Electroweak (EW) corrections
 - NLO EW corrections with MadGraph5 aMC@NLO



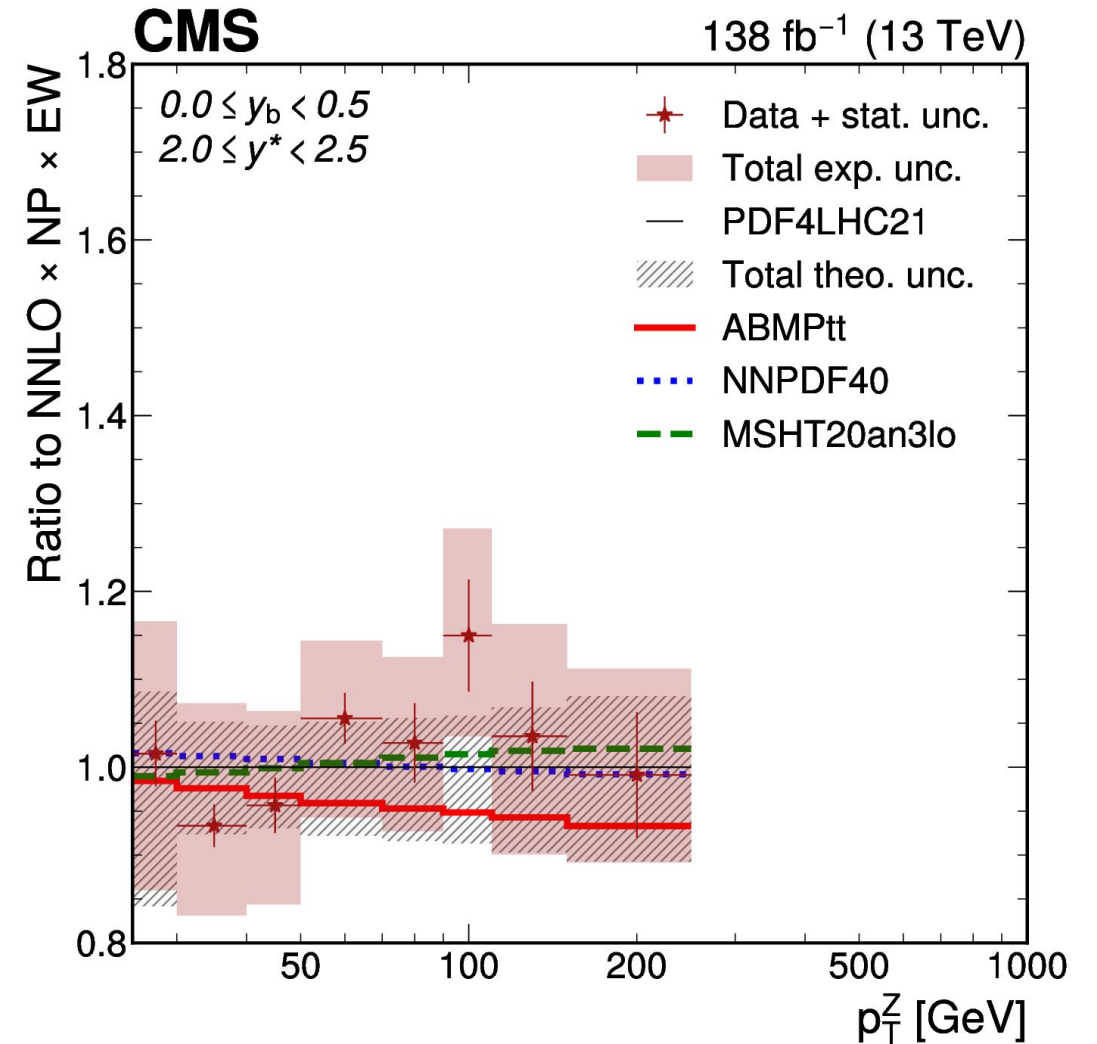
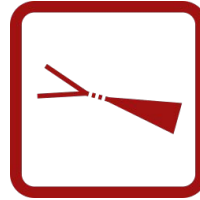
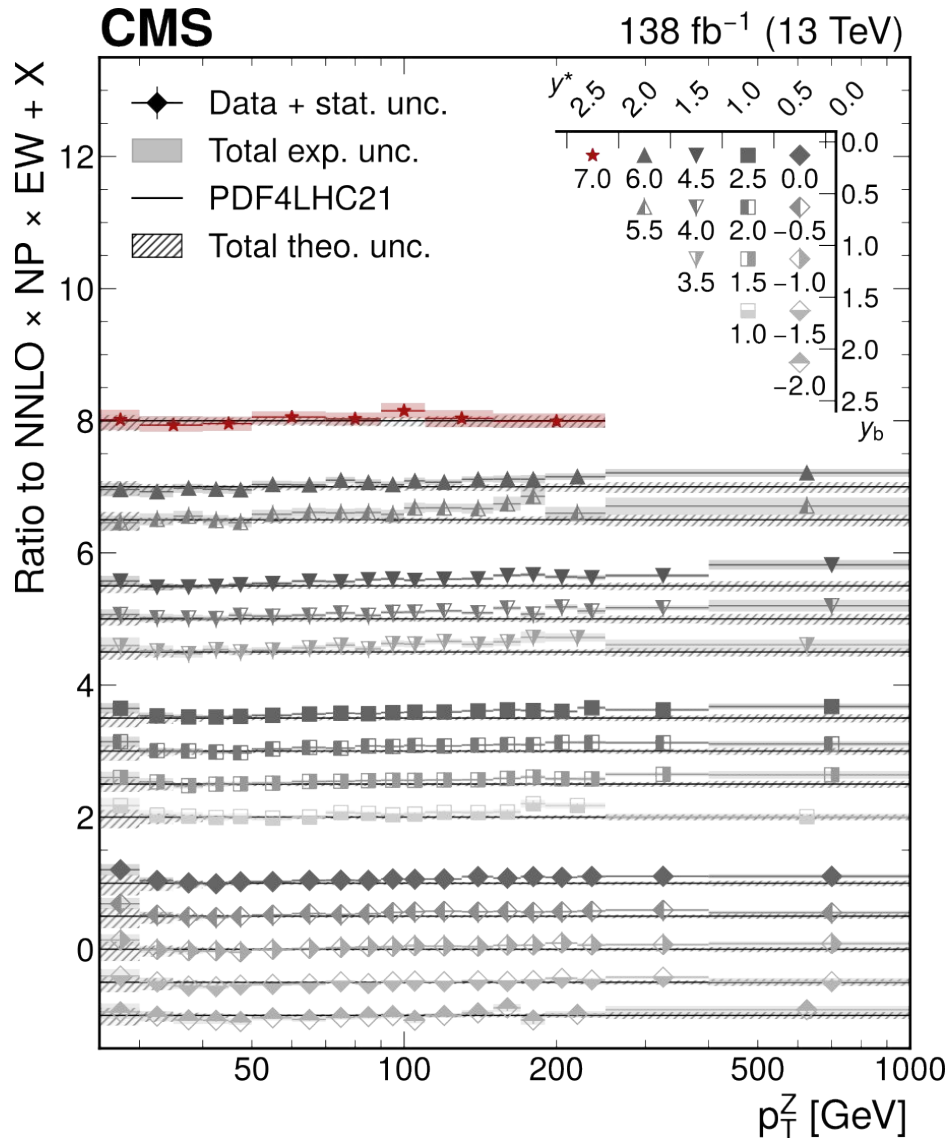
Comparison to NNLO QCD



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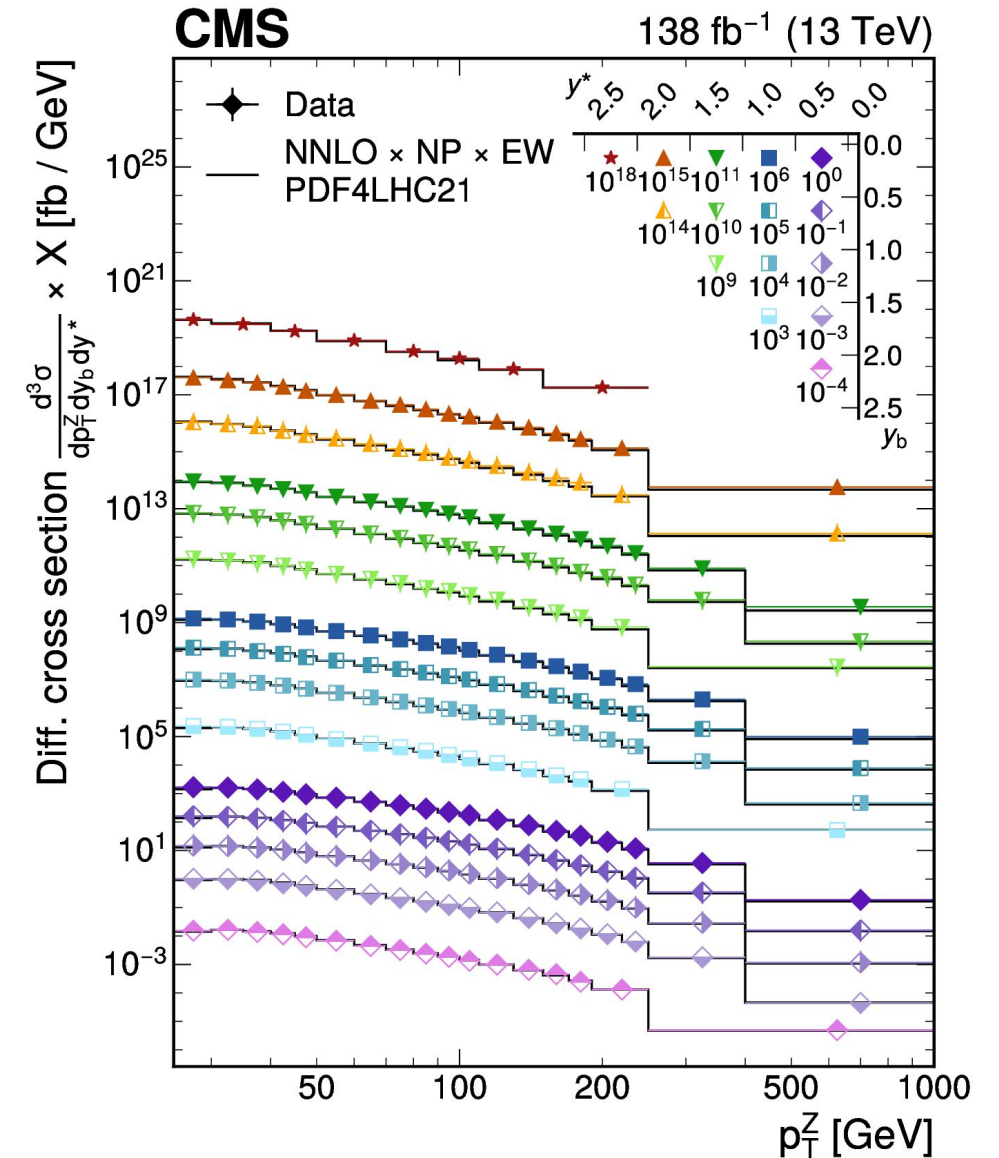
Comparison to NNLO QCD



Summary

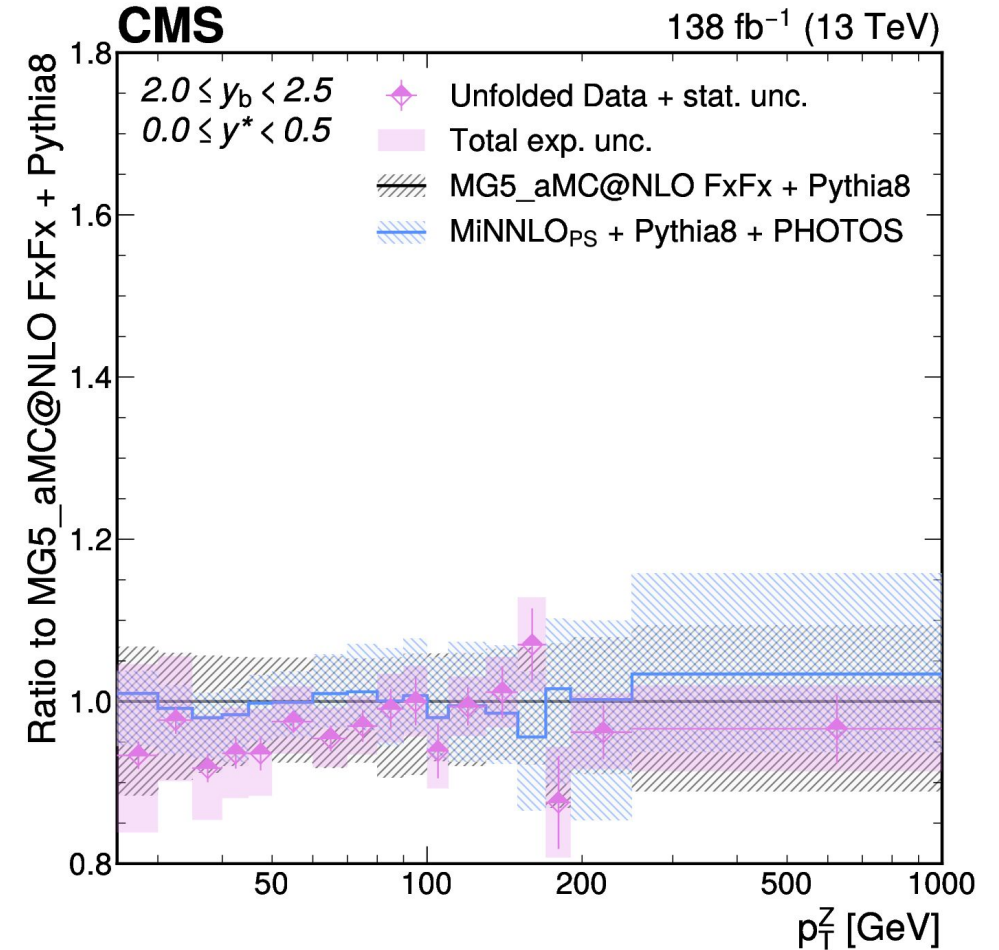
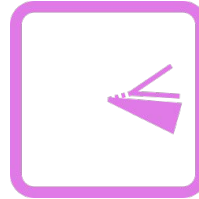
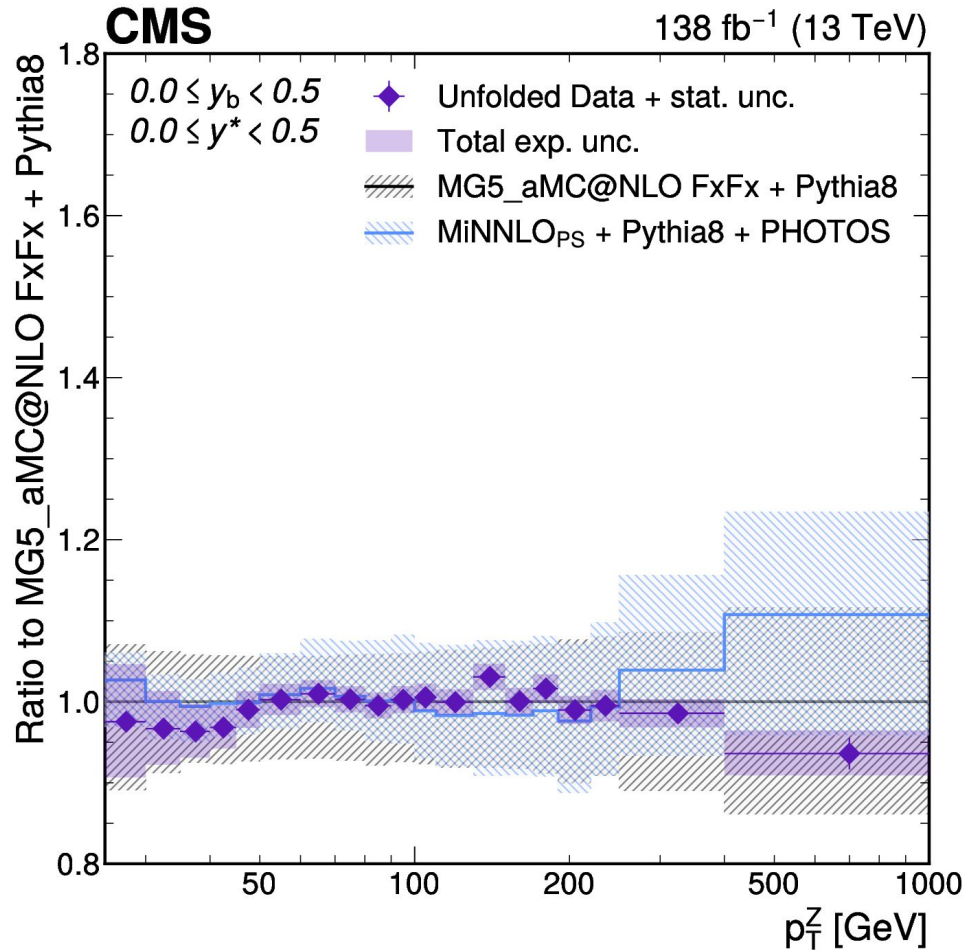
- First triple-differential Z+jet cross section measurement unfolded simultaneously in p_T^Z , y_b and y^*
([CMS-SMP-24-010](#))
 - Directly sensitive to PDFs
 - Complementary to triple-differential dijet ([CMS-SMP-21-008](#))
- Theory predictions at NNLO in QCD
 - NLO electroweak corrections
 - Nonperturbative corrections
- Precision up to 1.5% in central detector region

To be submitted to the arXiv in the coming days
[HEPData](#) with full covariance matrix

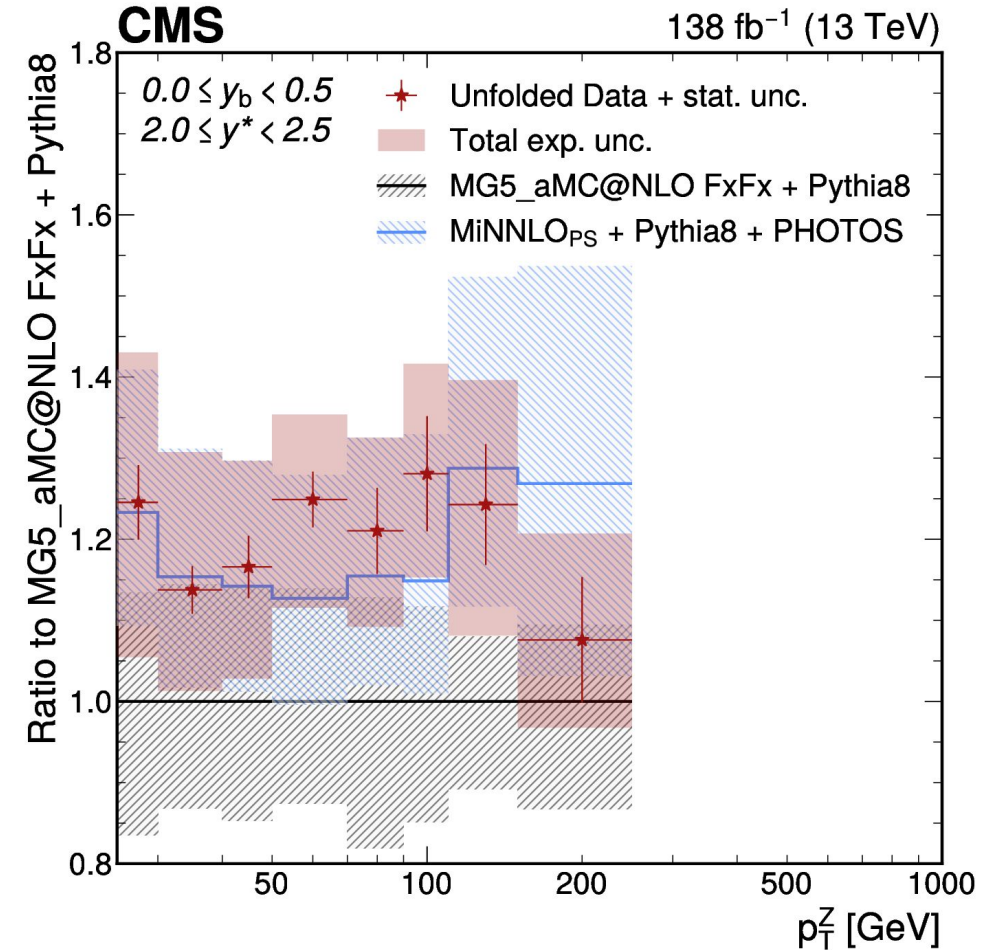
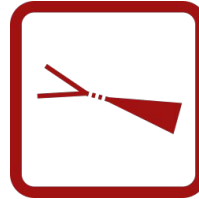
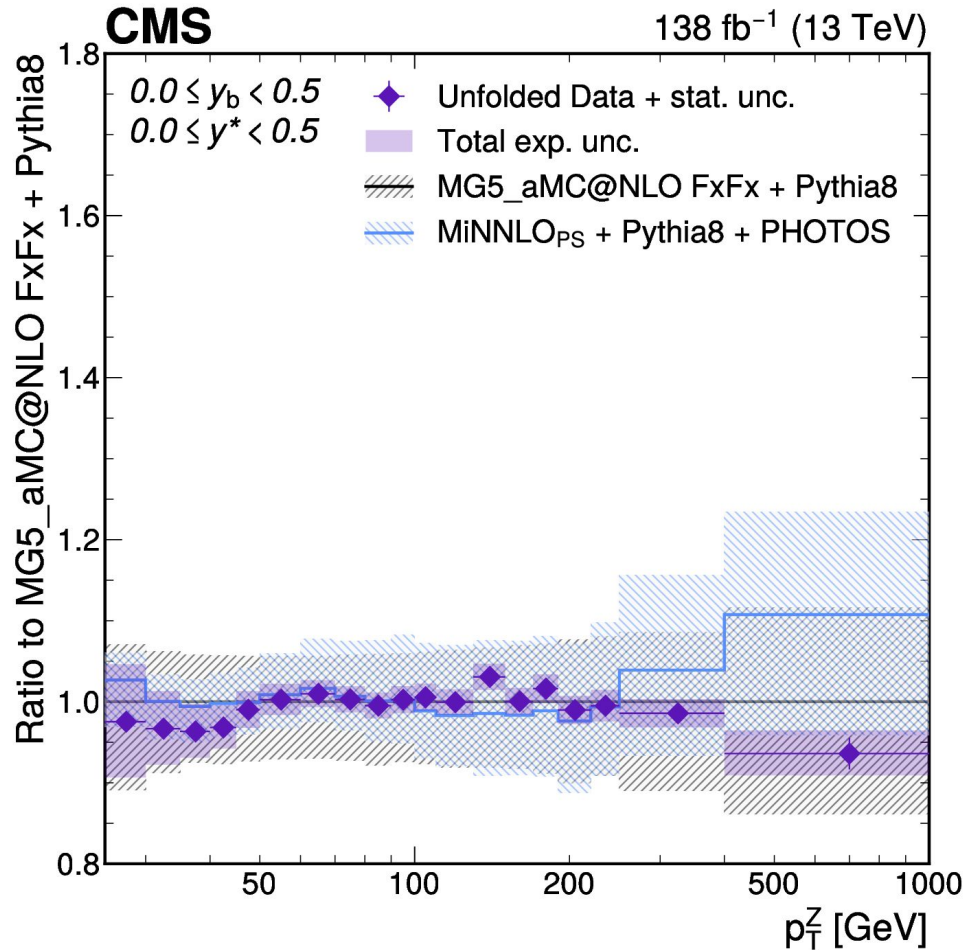




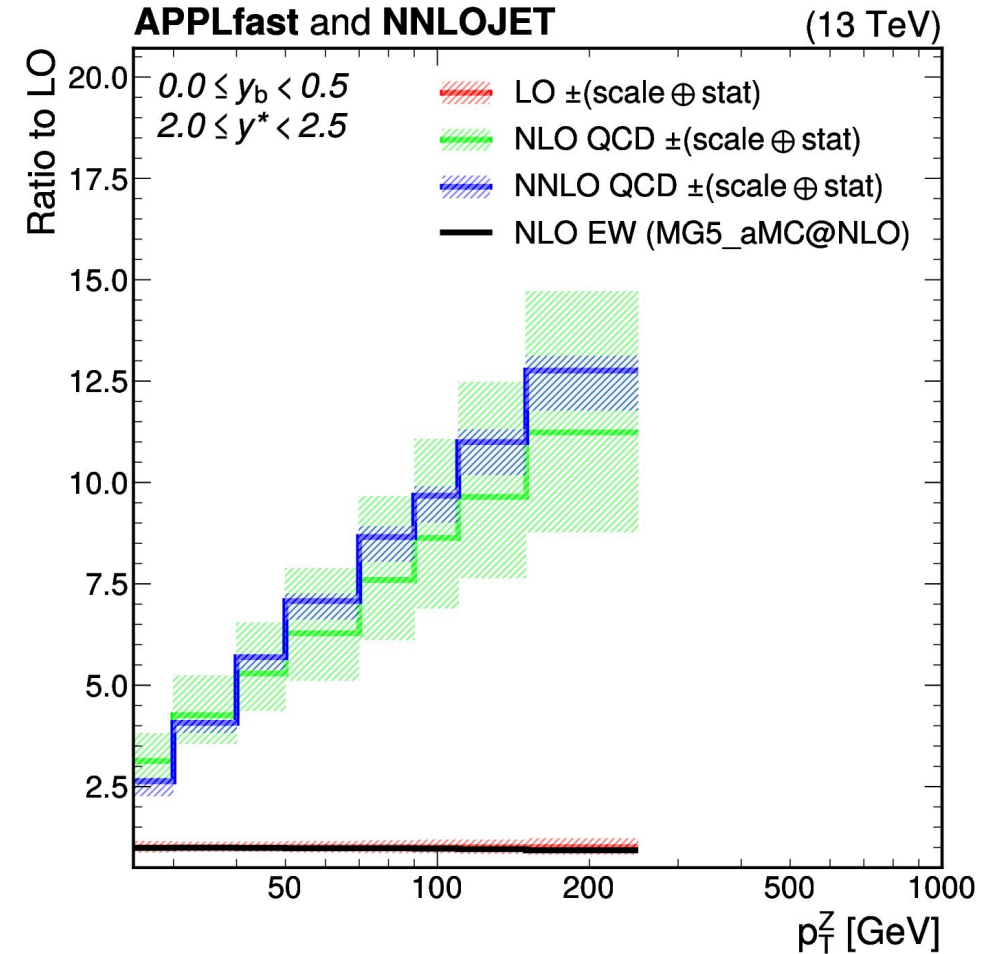
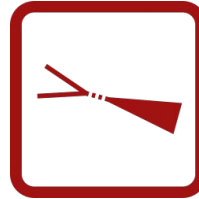
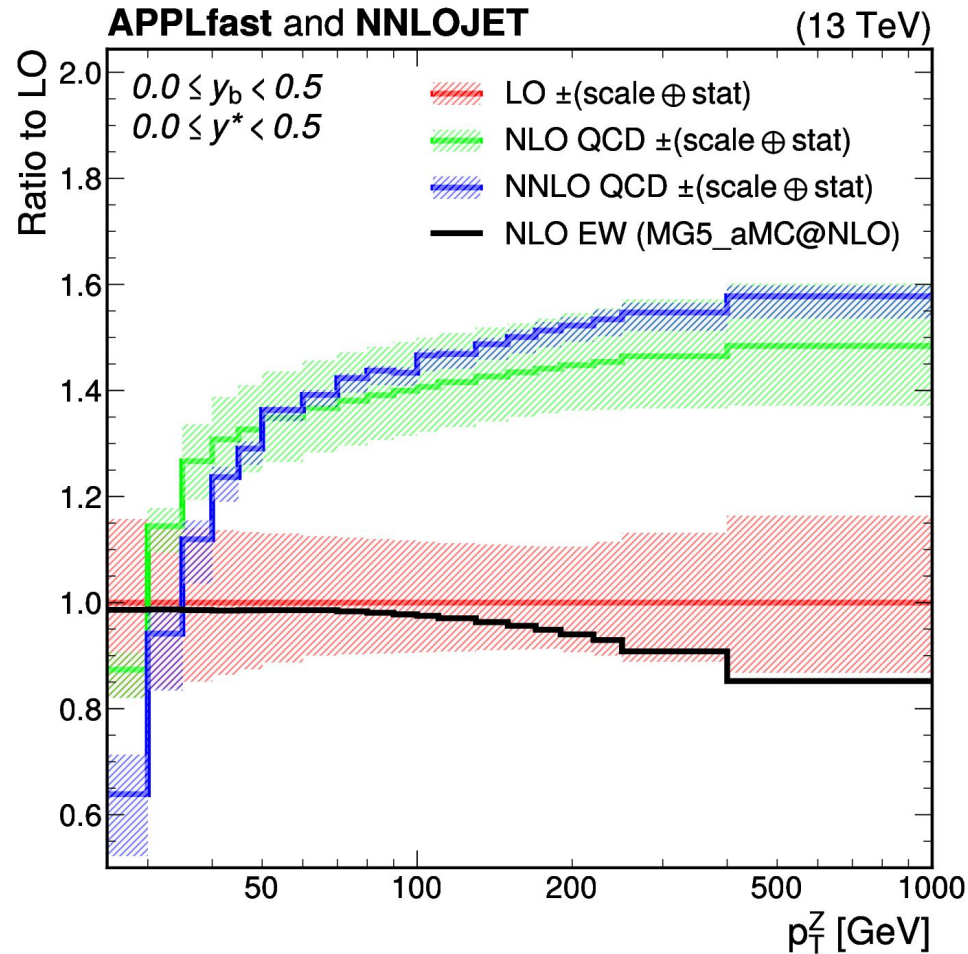
Comparison to MC generators at NLO



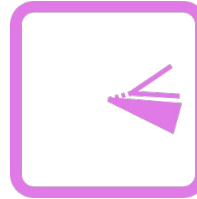
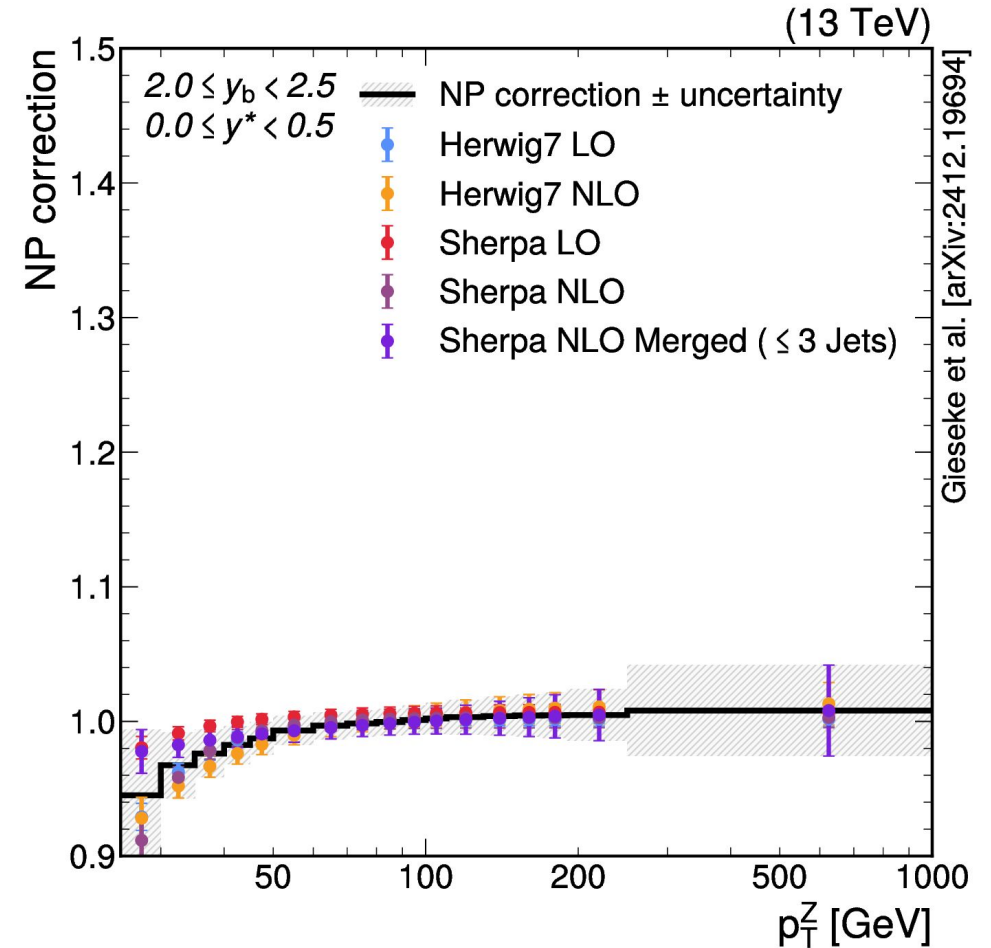
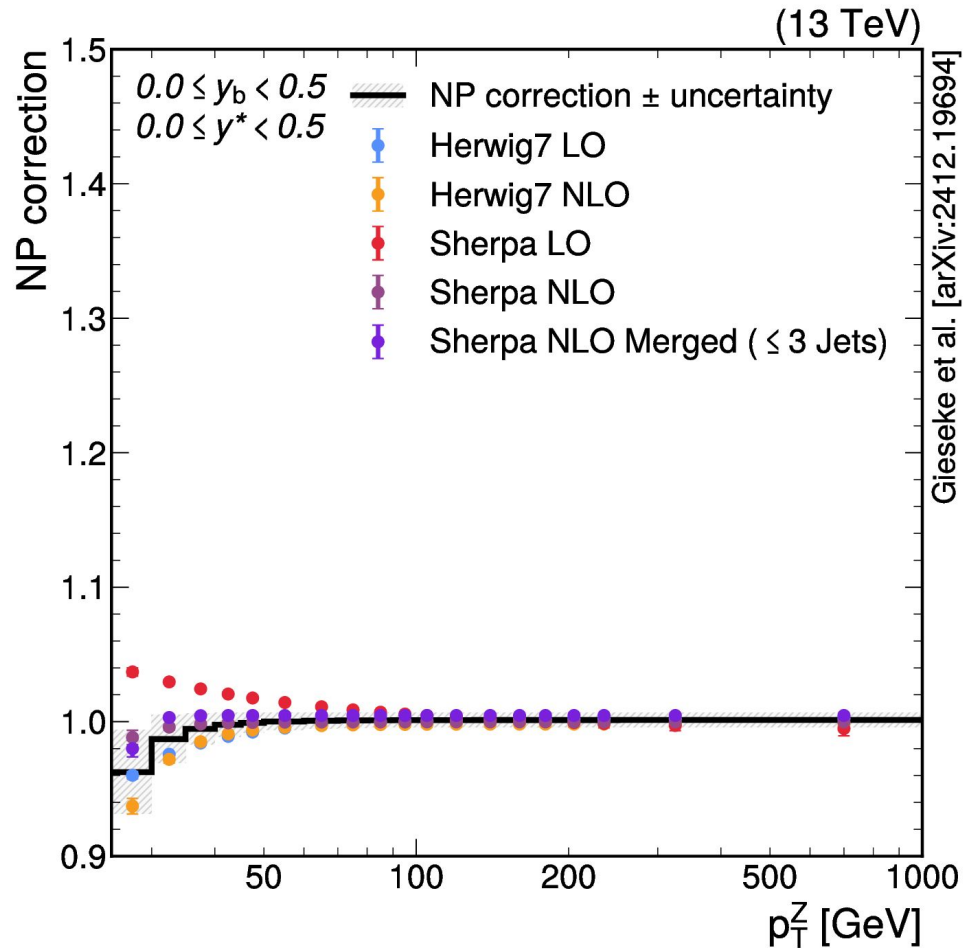
Comparison to MC generators at NLO



Fixed Order predictions



Nonperturbative corrections



Nonperturbative corrections

