Contraining nPDFs with electroweak bosons measurements in pPb collisions with CMS

Émilien Chapon
on behalf of the CMS Collaboration

CERN

Initial Stages 2019
June 24–28

Columbia University, New York City, USA

Nuclear Parton Distribution Functions

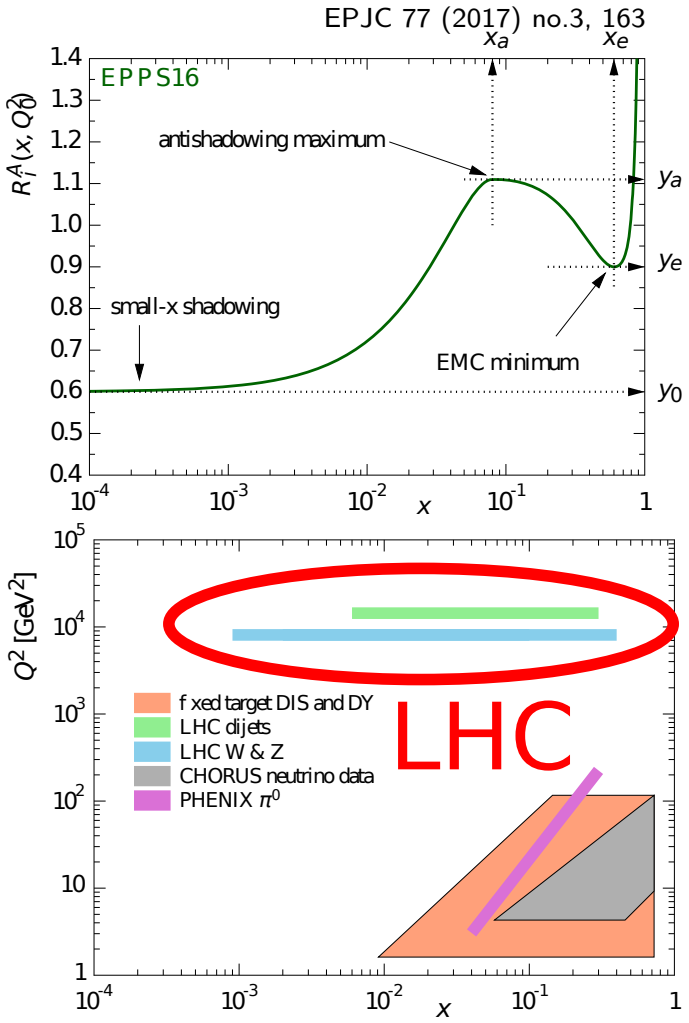
$$f_i^{p/A}(x, Q^2) = R_i^A(x, Q^2) f_i^p(x, Q^2)$$

Impact of nPDFs on LHC observables

- Important for most heavy-ion observables
- Up to $20 - 30\,\%$ modification compared to a free proton PDF

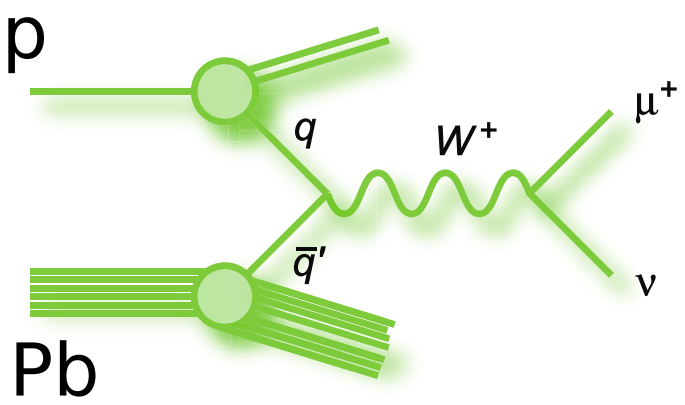
Impact of the LHC on nPDFs

- New range of (x, Q^2) accessible
- First nPDF to include LHC data: EPPS16

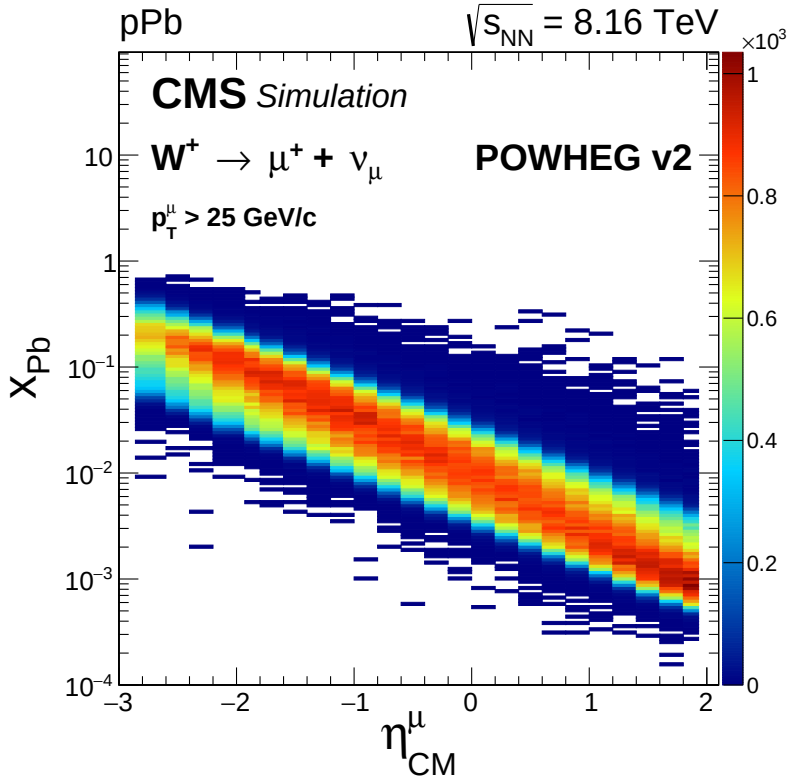


nPDF constraints with electroweak bosons in pPb

- Probing quarks and anti-quarks
- $10^{-3} \lesssim x_{\mathrm{Pb}} \lesssim 10^{-1}$: shadowing and anti-shadowing regions
- Asymmetric beams:
  laboratory frame $\neq$ centre-of-mass frame



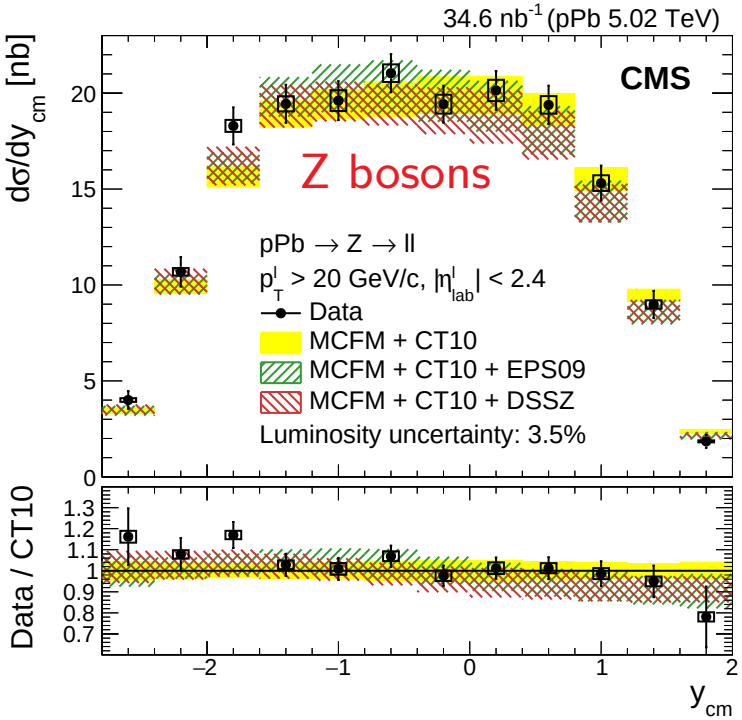
$$\eta_{\mathrm{CM}} = \eta_{\mathrm{lab}} - 0.465$$

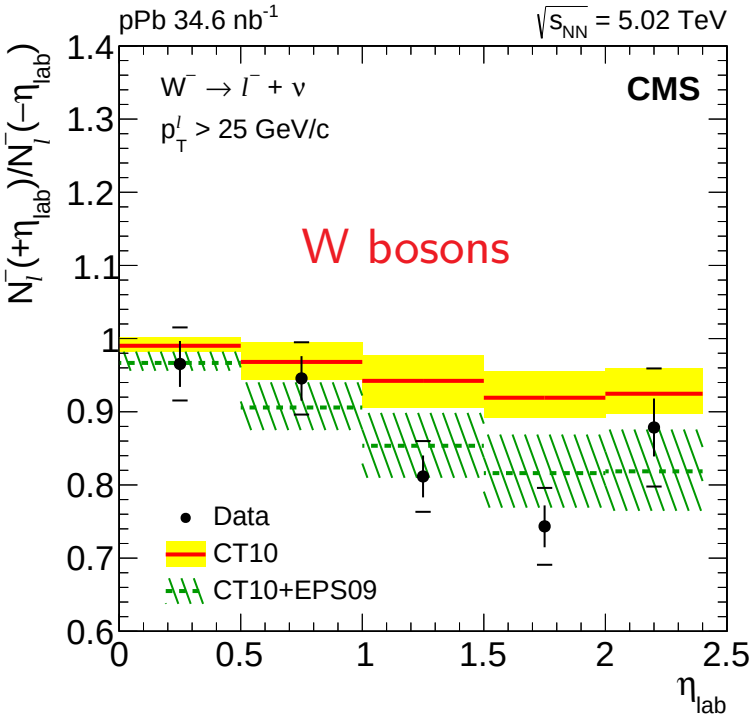


W and Z bosons in pPb at $\sqrt{s_{NN}} = 5.02$ TeV

PLB 759 (2016) 36, PLB 750 (2015) 565

- Both muon and electron channels
- Hints of shadowing (large $\eta > 0$) and anti-shadowing (large $\eta < 0$)
- Observables:
  - Cross sections $\mathrm{d}\sigma / \mathrm{d}y$
  - Forward-backward asymmetries $R_{\mathrm{FB}} = N(\eta > 0)/N(\eta < 0)$
  - Charge asymmetry (W bosons): $(N^+ - N^-)/(N^+ + N^-)$

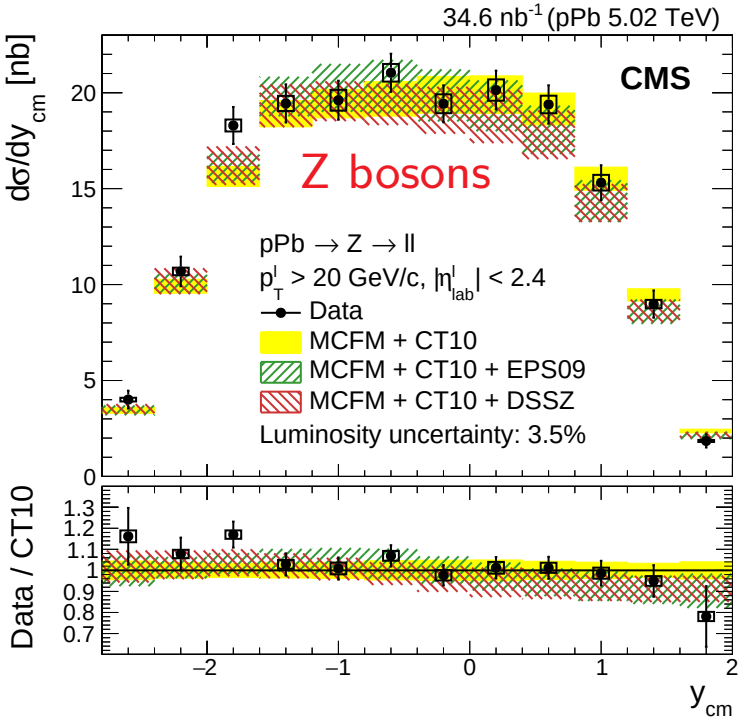




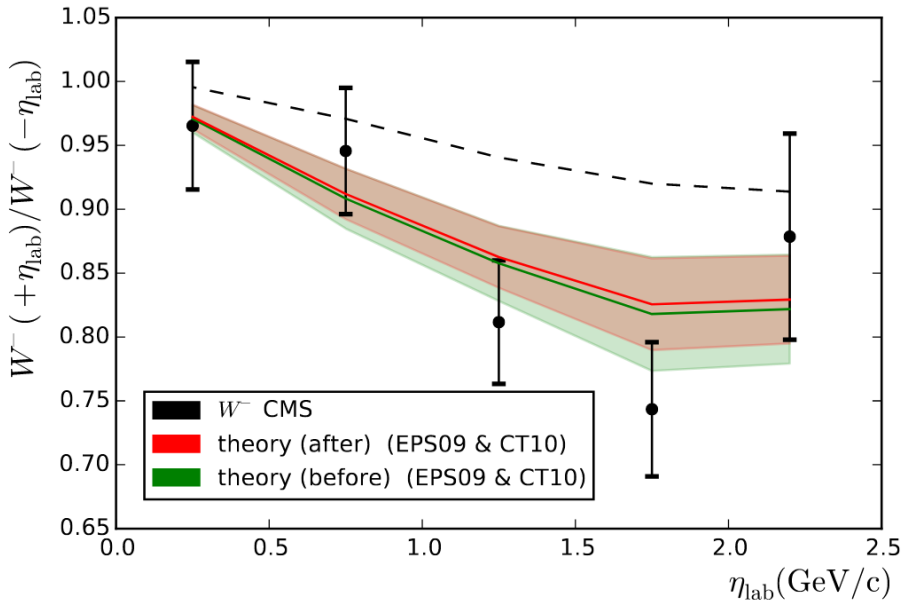
W and Z bosons in pPb at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$

PLB 759 (2016) 36, PLB 750 (2015) 565

- Both muon and electron channels
- Hints of shadowing (large $\eta > 0$) and anti-shadowing (large $\eta < 0$)
- Observables:
  - Cross sections $\mathrm{d}\sigma / \mathrm{d}y$
  - Forward-backward asymmetries $R_{\mathrm{FB}} = N(\eta > 0)/N(\eta < 0)$
  - Charge asymmetry (W bosons): $(N^+ - N^-)/(N^+ + N^-)$
- Data included in EPPS16



EPJC 76 (2016) no.4, 218



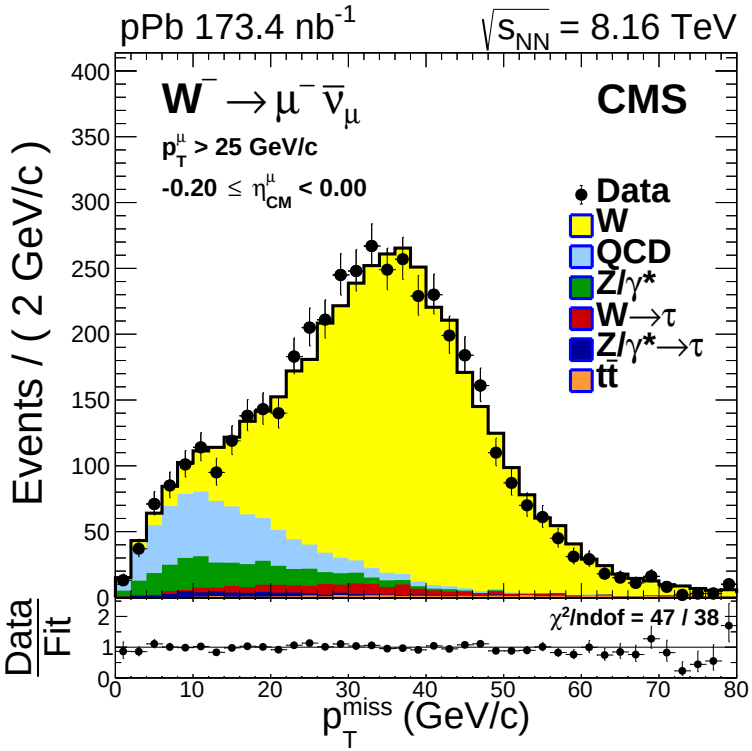
W bosons in pPb at $\sqrt{s_{NN}} = 8.16$ TeV

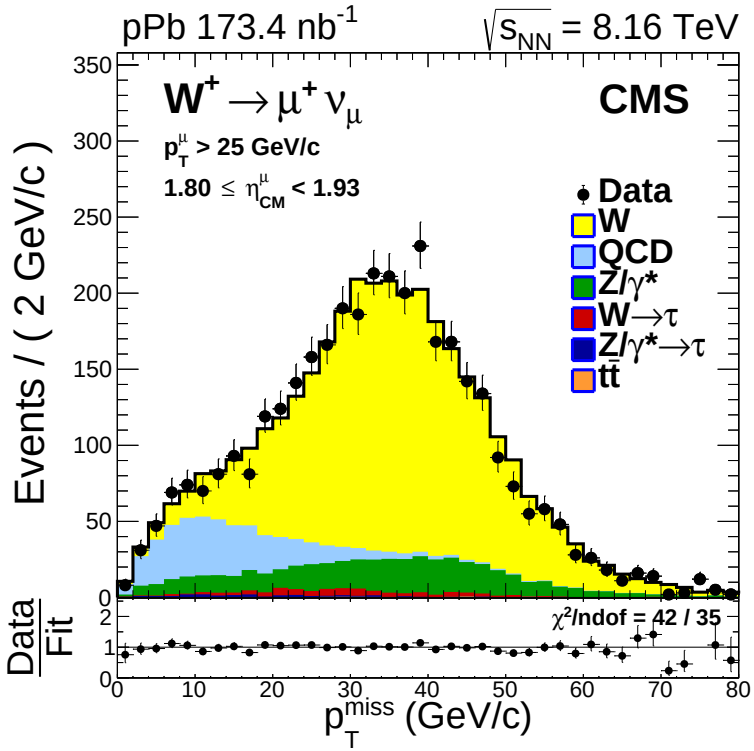
arXiv:1905.01486

- Muons: $p_T > 25$ GeV, $|\eta_{lab}| < 2.4$, isolated:

$$\left(\sum_{\Delta R < 0.3} p_T(\text{particle flow candidate}) \right) < 0.15 \times p_T(\mu)$$

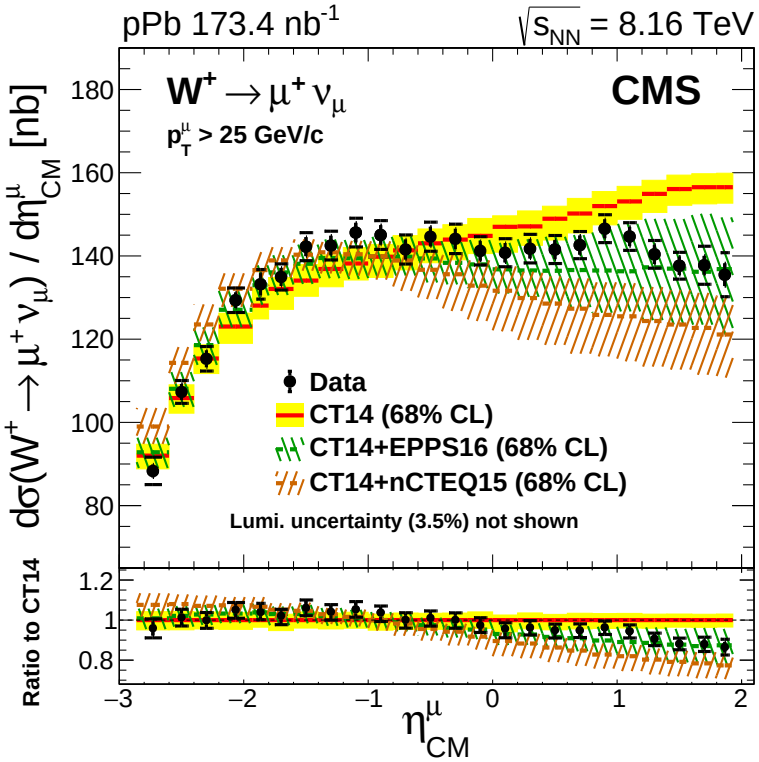
- No explicit p_T^{miss} cut: signal extracted using a p_T^{miss} fit
  - QCD multijet distribution estimated using non-isolated muons
  - Templates for other background estimated from MC
  - p_T^{miss} calibrated using Z boson events ("recoil corrections")

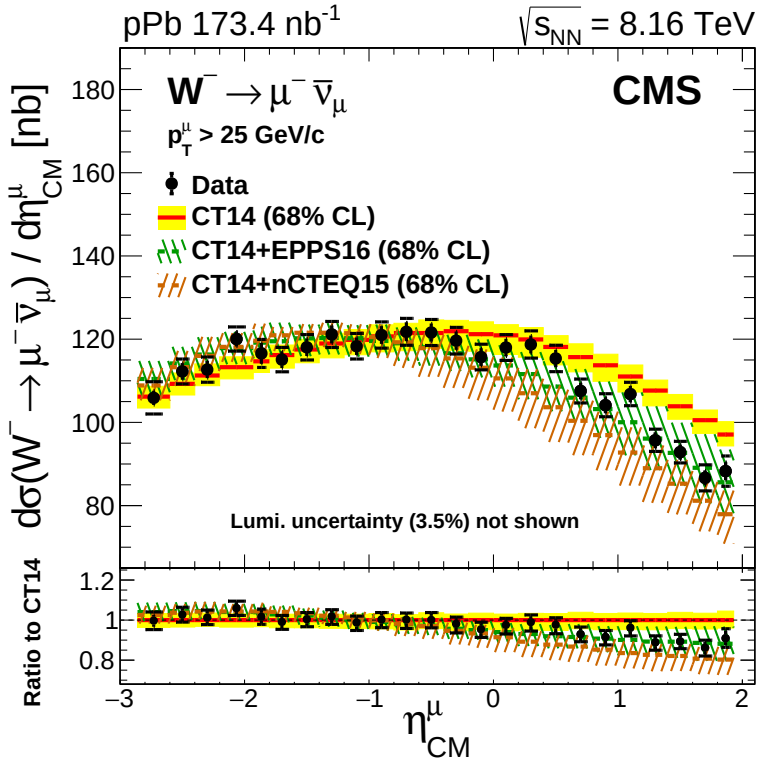




Cross sections

arXiv:1905.01486

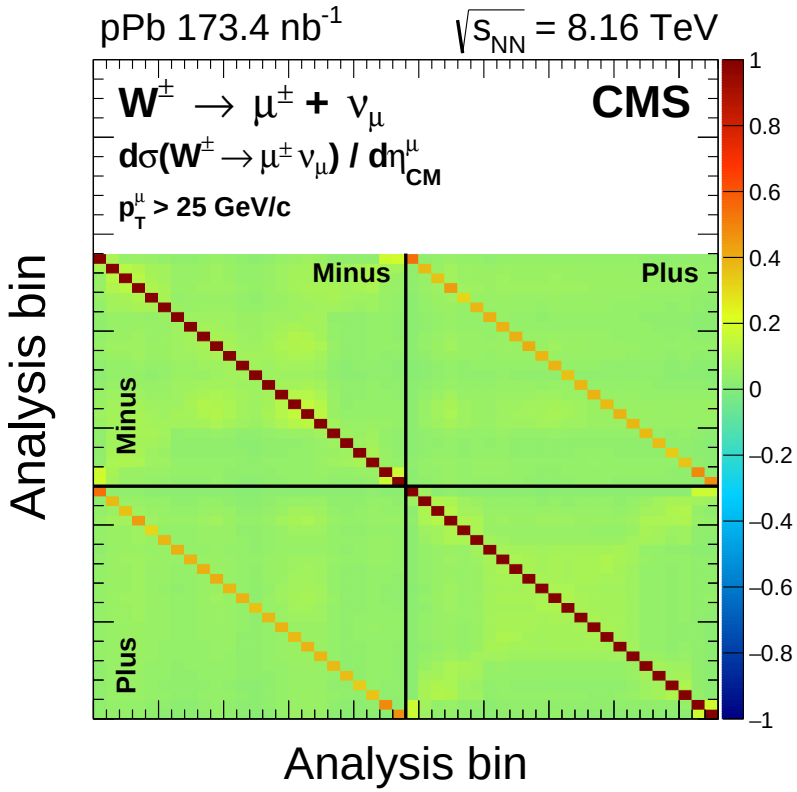




- Differential cross sections as a function of muon η_{CM}
- Compared to NLO calculations (Powheg)
- Smaller experimental than nPDF uncertainties!
- Negative rapidity: good description with all (n)nPDF
- Positive rapidity:
  - Bad description with CT14
  - Too strong shadowing in nCTEQ15
  - Good description with EPPS16 (note: includes W,Z data at 5.02 TeV)

Correlation matrix

arXiv:1905.01486

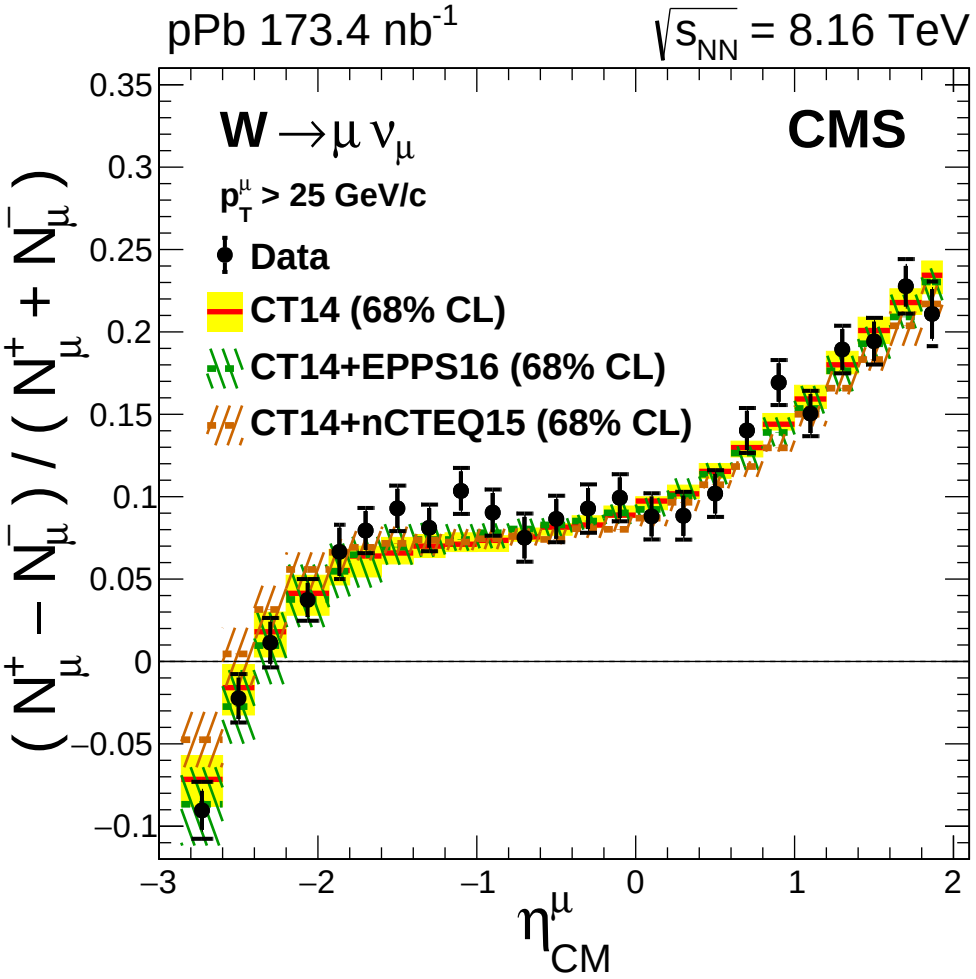


Full correlation matrix public in HepData

- Crucial for proper use in nPDF fits
- Sizeable correlation between μ^+ and μ^- at a given η
- Small correlation between different η

Charge asymmetry

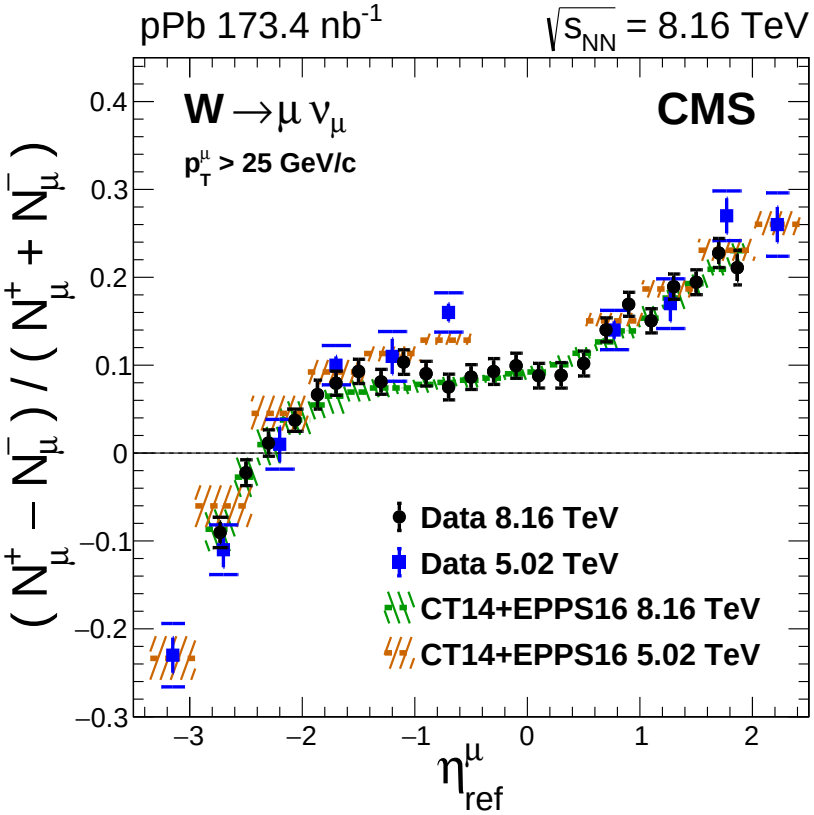
arXiv:1905.01486



- Large cancellation of experimental uncertainties
- Most nPDF uncertainties cancel too
- Sensitive to the flavour dependence of nPDF: R_{u_V}/R_{d_V}

Charge asymmetry: comparison with Run1

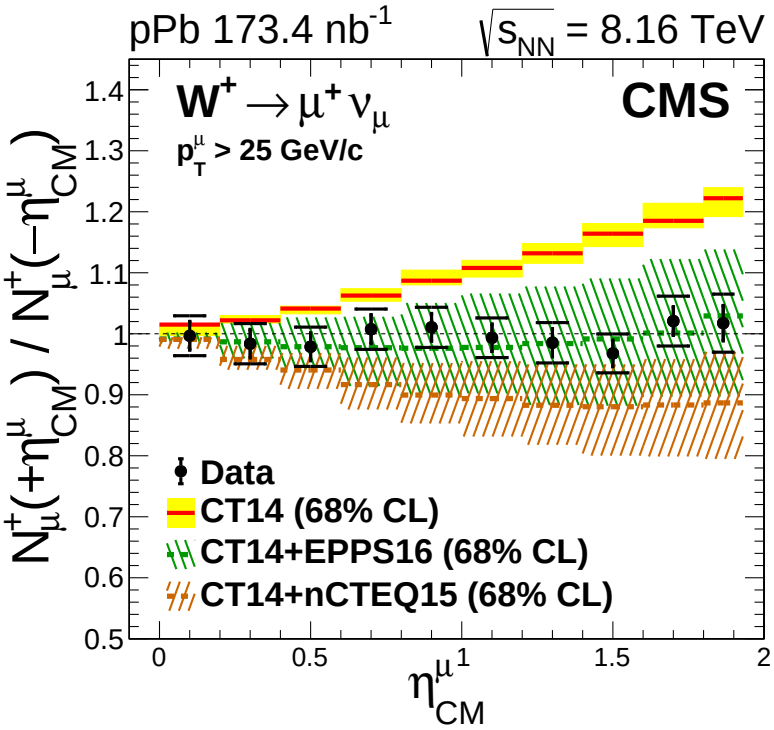
arXiv:1905.01486

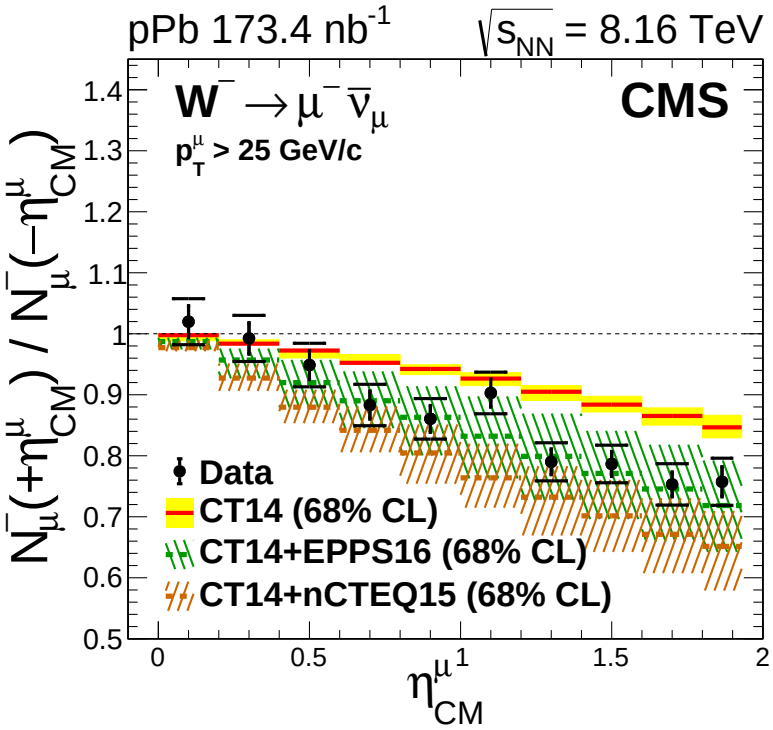


- Direct comparison with 5.02 TeV data using a scaling (EPJC 76 (2016), 214)
  - Applicable when one of the partons is at low enough x
- Good consistency between the two datasets
  - Scaling starts to break down at midrapidity
  - Small tension at large $\eta < 0$ seems to be gone
    - Change in proton PDF (CT10 $\rightarrow$ CT14), enlarged nPDF uncertainties

Forward-backward asymmetries

arXiv:1905.01486

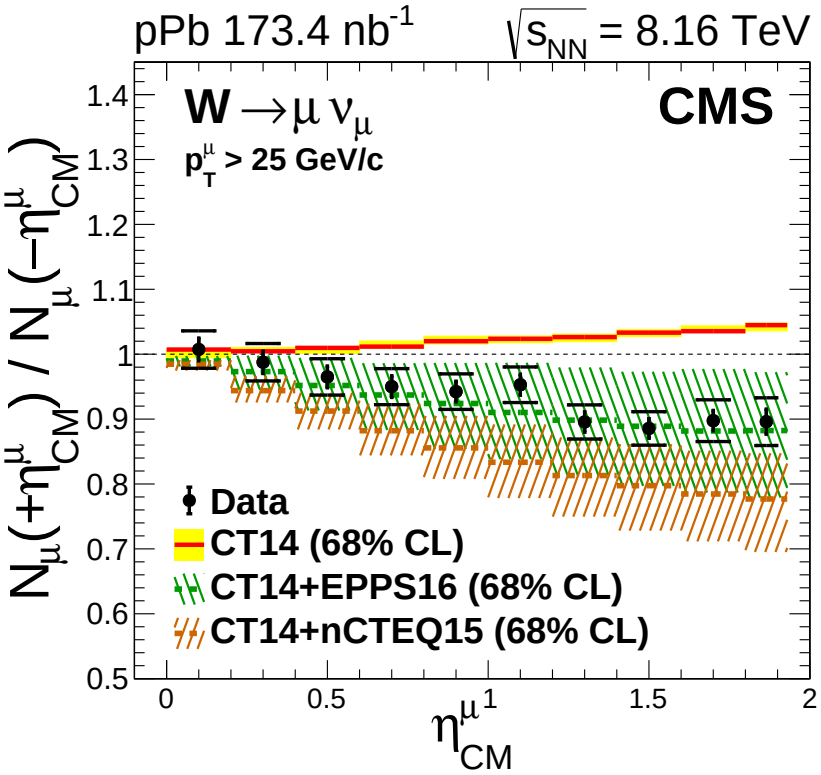




- Reduction of experimental uncertainties in the ratio
- (Shadowing) / (anti-shadowing): enhanced nuclear effects
- Best description with EPPS16, especially for W^+

Forward-backward asymmetrY, combined charges

arXiv:1905.01486



- Even reduced uncertainties
- Best description with EPPS16

Data-prediction agreement: χ^2 tests

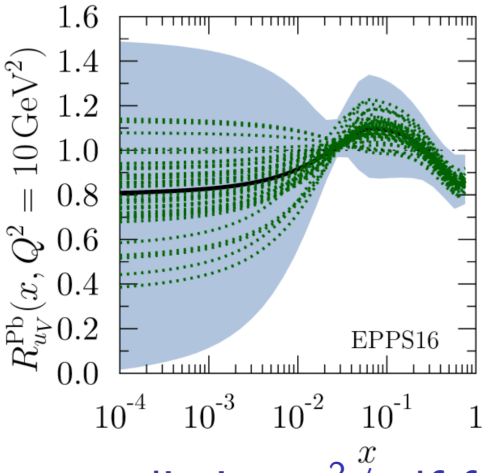
arXiv:1905.01486

Observable	CT14			CT14+EPPS16			CT14+nCTEQ15		
	χ^2	dof	Prob. [%]	χ^2	dof	Prob. [%]	χ^2	dof	Prob. [%]
$d\sigma/dy$	135	48	3×10^{-8}	32	48	96	40	48	79
Ch. asym.	23	24	54	18	24	80	29	24	23
$R_{FB}^{\pm}$	98	20	3×10^{-10}	11	20	95	14	20	83
R_{FB}	87	10	2×10^{-12}	3	10	99	5	10	90

- Account for bin-to-bin correlations of uncertainties (experimental and theoretical)
  - $\chi^2 = \sum_{i,j}(\text{data}_i - \text{theory}_i) V_{ij}^{-1} (\text{data}_j - \text{theory}_j)$
- **CT14**: very small χ^2 probability
- **EPPS16**: very large χ^2 probability
- **nCTEQ15**: good χ^2 probability
  - Central value off, but correlations help
  - In other words: model has degrees of freedom to accomodate for the data
- Charge asymmetry: good description by all models

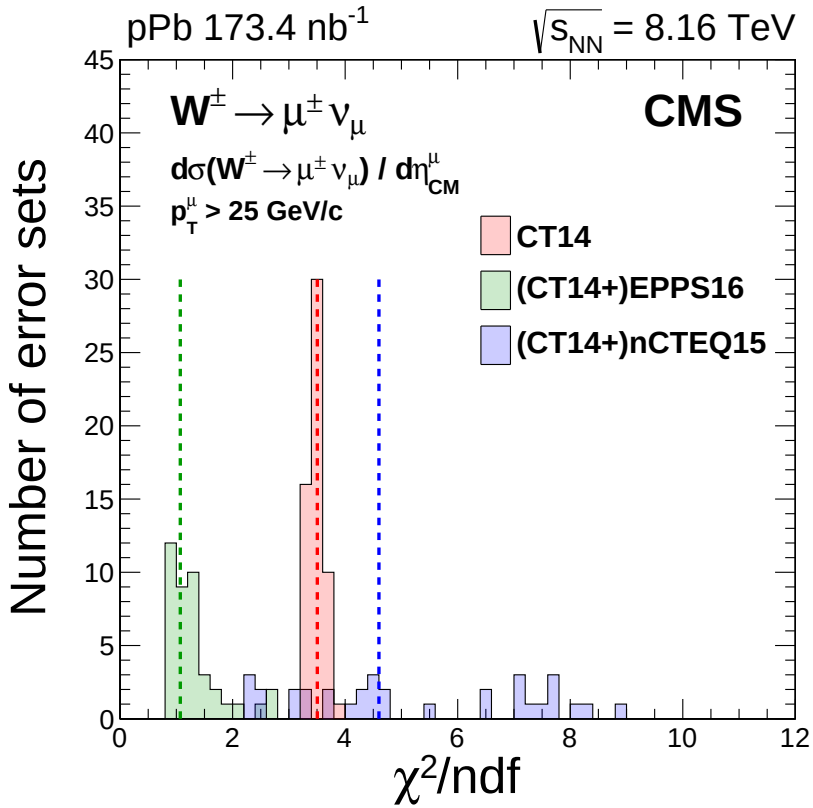
χ^2 for individual error sets

arXiv:1905.01486



What is the data-prediction χ^2/ndf for the PDF individual error sets?

- Data covariance taken into account
- No theory uncertainty, no theory correlation
- CT14: large χ^2/ndf, small spread
- EPPS16: small χ^2/ndf, larger spread
- nCTEQ15: large χ^2/ndf, even larger spread
- Interpretation: good description of the data provided by
  - most EPPS16 error sets,
  - some nCTEQ15 error sets,
  - none of the CT14 error sets



Summary and outlook

Electroweak bosons in 5.02 and 8.16 TeV data

- **Strong nPDF constraints** with W and Z boson production in pPb collisions with CMS
  - Quarks and antiquarks, $10^{-3} \lesssim x \lesssim 10^{-1}$
  - **Smaller experimental than nPDF uncertainties**
- Charge asymmetry well reproduced with and without nPDF effects

Summary and outlook

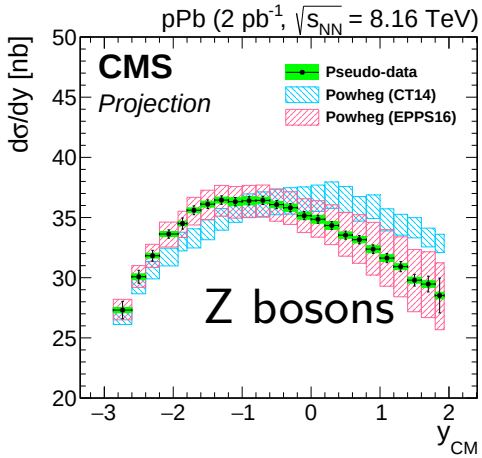
WG5 YR and references therein: CMS-PAS-FTR-17-002, CMS-PAS-FTR-18-027

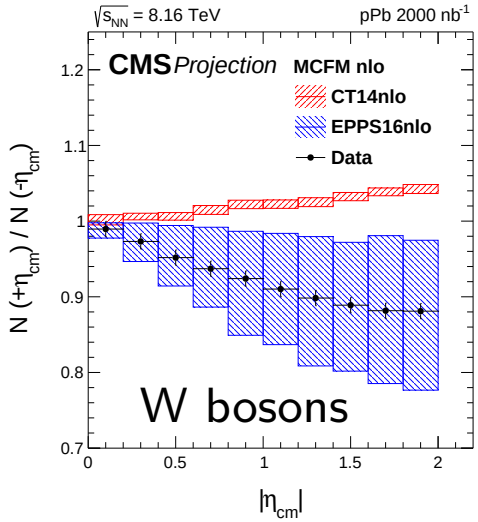
Electroweak bosons in 5.02 and 8.16 TeV data

- **Strong nPDF constraints** with W and Z boson production in pPb collisions with CMS
  - Quarks and antiquarks, $10^{-3} \lesssim x \lesssim 10^{-1}$
  - **Smaller experimental than nPDF uncertainties**
- Charge asymmetry well reproduced with and without nPDF effects

Outlook

- Expect ≈ 10 times more pPb data with future Runs 3–4 of the LHC
- Dominant systematic uncertainties will be reduced with more data
- Also planned: Z/γ^* in pPb, including mass and p_T dependence





Additional material

Systematic uncertainties

- Systematically limited (statistical uncertainty of a similar size)
  - For cross sections: additional 3.5% luminosity uncertainty
- Dominant uncertainties: efficiency, QCD background
  - Both dependent on the data sample size
- Reduced uncertainties in asymmetries because of correlations
  - Typical asymmetry magnitude: $R_{\mathrm{FB}} \approx 0.7$–$1.0$, $\frac{N_\mu^+ - N_\mu^-}{N_\mu^+ + N_\mu^-} \approx -0.1$–$0.2$

Source	$\frac{\mathrm{d}\sigma}{\mathrm{d}\eta}(\mathrm{W}^+)$ [%]	$R_{\mathrm{FB}}(\mathrm{W}^+)$	$\frac{N_\mu^+ - N_\mu^-}{N_\mu^+ + N_\mu^-}$
Boson p_{T} reweighing	0.5	0.001	0.001
EW background	0.4	0.002	0.000
POWHEG EW correction	0.9	0.007	0.003
Efficiency	3.0	0.026	0.011
Event activity reweighing	0.6	0.002	0.002
$p_{\mathrm{T}}^{\mathrm{miss}}$ template binning	0.1	0.002	0.001
QCD background	1.2	0.016	0.006
Hadronic recoil correction	0.2	0.002	0.002
Total systematic uncertainty	3.3	0.030	0.013
Statistical uncertainty	2.4	0.026	0.015