

# Early Estimates of the Impact of W/Z pPb and PbPb LHC Data on nCTEQ15 PDFs



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# Outline



- Introduction to nCTEQ
- $W/Z$  Production at LHC
- Estimating Impact on nCTEQ15 PDFs
- Outlook

# Introduction to nCTEQ

# nCTEQ PDFs



Global fit to experimental data

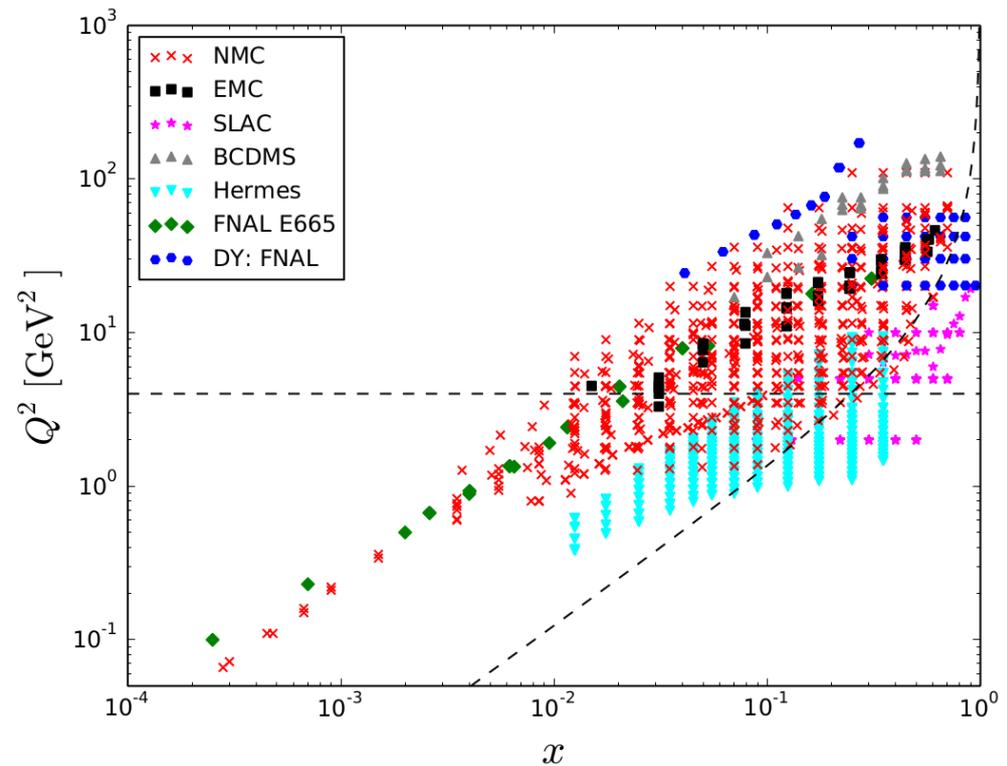
- Deep Inelastic Scattering
- Drell-Yan
- Pion Production Data

NO LHC data

740 nuclear data points after kinematic cuts

Error analysis with Hessian Method

- 16 Eigenvalues





## Formalism:

- Generalized A-Parameterization

- $$x f_i^{p/A}(x, Q^2) = c_0 x^{c_1} (1-x)^{c_2} e^{c_3 x} (1 + e^{c_4 x})^{c_5}$$

- $$c_k \rightarrow c_{k,0} + c_{k,1} (1 - A^{-c_{k,2}})$$

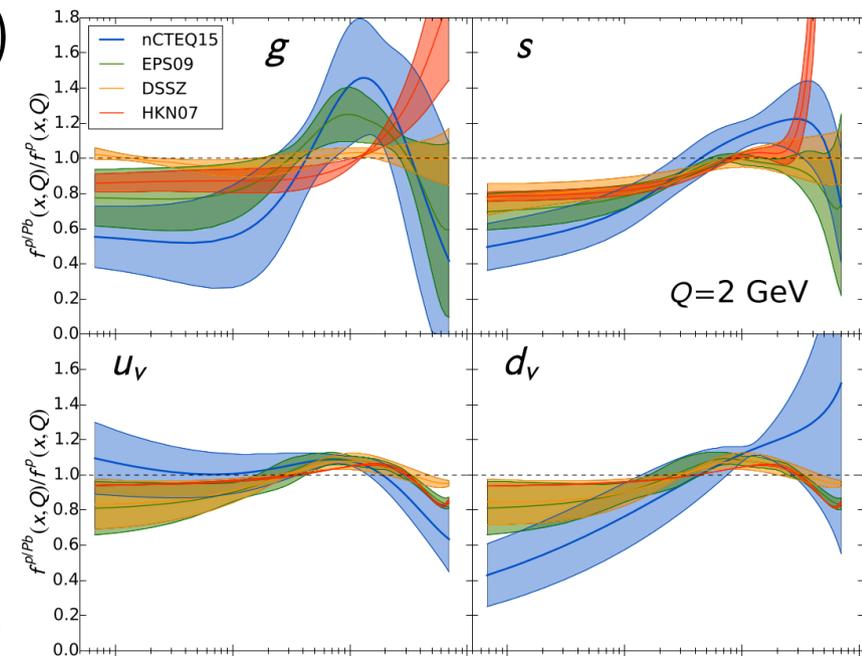
No multiplicative nuclear correction

- More parameters than proton fits

~ 3 times as many so we make assumptions

- Fewer data points

e.g 740 nuclear points for nCTEQ15 vs 2947 protons points for CT14<sup>[1]</sup>



# nCTEQ PDFs



Periodic Table of the Elements

1 IA H Hydrogen 1.00794	2 IIA He Helium 4.002602																	18 VIIIA He Helium 4.002602																
3 IIIA Li Lithium 6.941	4 IIIA Be Beryllium 9.0122																	10 VIIIA Ne Neon 20.180																
11 IA Na Sodium 22.990	12 IIA Mg Magnesium 24.305	13 IIIA B Boron 10.811	14 IVA C Carbon 12.011	15 VA N Nitrogen 14.007	16 VIA O Oxygen 15.999	17 VIIA F Fluorine 18.998	18 VIIIA Ar Argon 39.948																	18 VIIIA Ar Argon 39.948										
19 IA K Potassium 39.098	20 IIA Ca Calcium 40.078	21 IIIB Sc Scandium 44.956	22 IVB Ti Titanium 47.88	23 VB V Vanadium 50.942	24 VIB Cr Chromium 51.996	25 VIB Mn Manganese 54.938	26 VIII Fe Iron 55.933	27 VIII Co Cobalt 58.933	28 VIII Ni Nickel 58.693	29 IB Cu Copper 63.546	30 IIB Zn Zinc 65.39	31 IIIB Ga Gallium 69.723	32 IIIB Ge Germanium 72.64	33 IVB As Arsenic 74.922	34 VIB Se Selenium 78.972	35 VIIA Br Bromine 79.904	36 VIIIA Kr Krypton 83.798																	36 VIIIA Kr Krypton 83.798
37 IA Rb Rubidium 85.468	38 IIA Sr Strontium 87.62	39 IIIB Y Yttrium 88.906	40 IVB Zr Zirconium 91.224	41 VB Nb Niobium 92.906	42 VIB Mo Molybdenum 95.94	43 VIB Tc Technetium 98.907	44 VIII Ru Ruthenium 101.07	45 VIII Rh Rhodium 102.906	46 VIII Pd Palladium 106.42	47 IB Ag Silver 107.868	48 IIB Cd Cadmium 112.413	49 IIIB In Indium 114.818	50 IIIB Sn Tin 118.710	51 IVB Sb Antimony 121.760	52 VIB Te Tellurium 127.6	53 VIIA I Iodine 126.905	54 VIIIA Xe Xenon 131.29																	54 VIIIA Xe Xenon 131.29
55 IA Cs Cesium 132.905	56 IIA Ba Barium 137.327	57-71 IIIB La-Lu Lanthanides	72 IVB Hf Hafnium 178.49	73 VB Ta Tantalum 180.948	74 VIB W Tungsten 183.85	75 VIB Re Rhenium 186.207	76 VIB Os Osmium 190.23	77 VIII Ir Iridium 192.22	78 VIII Pt Platinum 195.08	79 IB Au Gold 196.967	80 IIB Hg Mercury 200.59	81 IIIB Tl Thallium 204.383	82 IIIB Pb Lead 207.2	83 IVB Bi Bismuth 208.980	84 VIB Po Polonium [209]	85 VIIA At Astatine [209]	86 VIIIA Rn Radon [222]																	86 VIIIA Rn Radon [222]
87 IA Fr Francium [223]	88 IIA Ra Radium [226]	89-103 IIIB Ac-Lr Actinides	104 IVB Rf Rutherfordium [261]	105 VB Db Dubnium [262]	106 VIB Sg Seaborgium [266]	107 VIB Bh Bohrium [264]	108 VIII Hs Hassium [265]	109 VIII Mt Meitnerium [268]	110 IB Ds Darmstadtium [271]	111 IB Rg Roentgenium [272]	112 IIB Cn Copernicium [285]	113 IIIB Uut Ununtrium [284]	114 IIIB Fl Flerovium [289]	115 IVB Uup Ununpentium [288]	116 VIB Lv Livermorium [293]	117 VIIA Uus Ununseptium [294]	118 VIIIA Uuo Ununoctium [294]																	118 VIIIA Uuo Ununoctium [294]

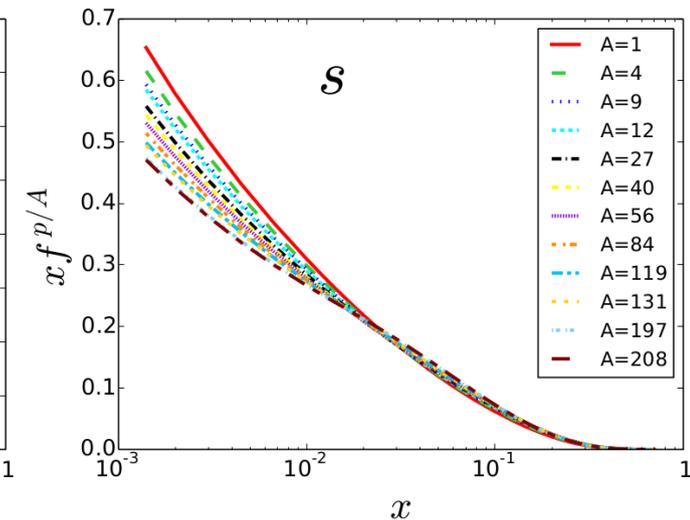
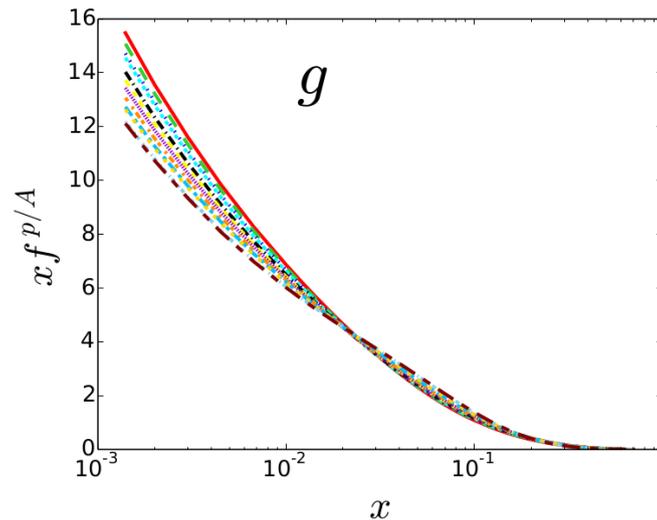
Nuclei with DIS data included in nCTEQ15

$$f^N = \frac{Z}{A} f^{p/N} + \frac{A-Z}{A} f^{n/N}$$

Assume isospin symmetry

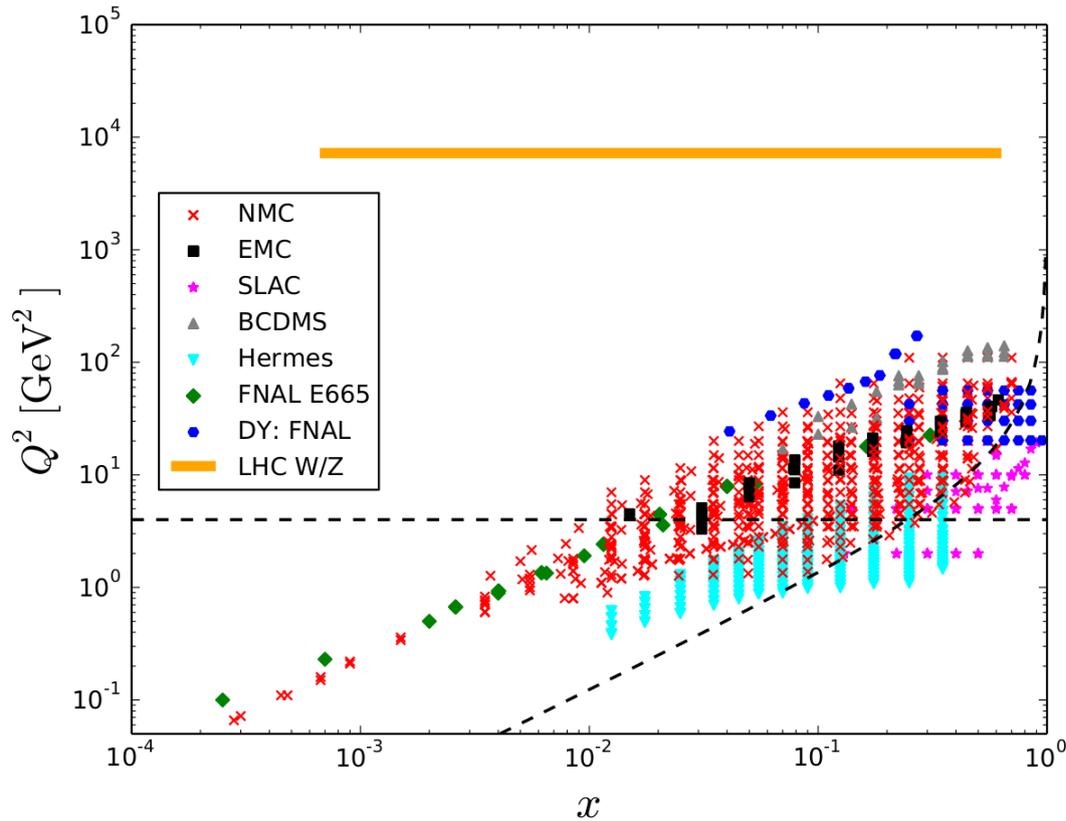
Currently at NLO

Parameterization allows for construction of any nuclei



# W/Z Production at LHC

# LHC Data for nCTEQ



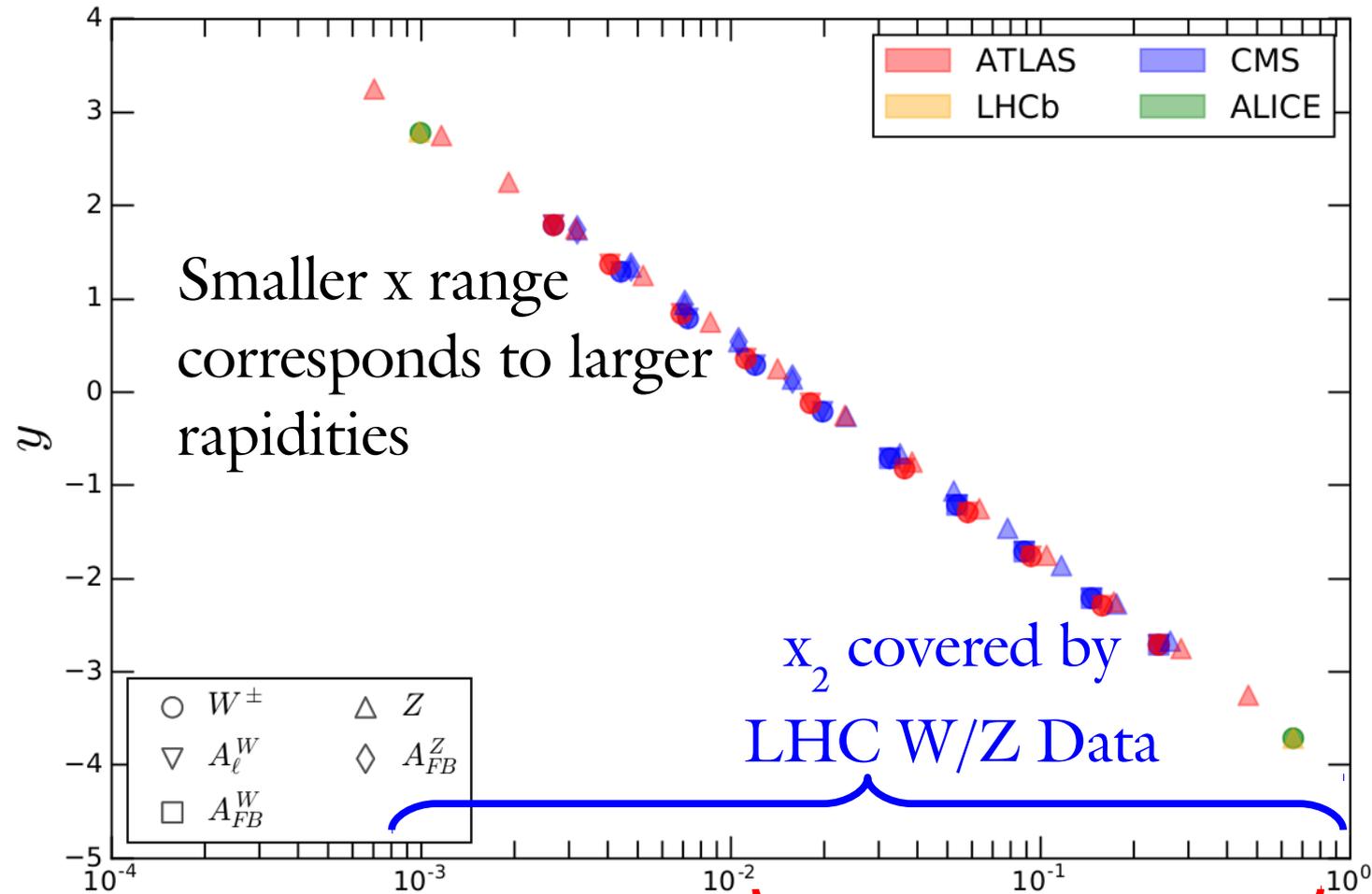
## pPb and PbPb collisions

- **LHCb:**  $\sigma(Z \rightarrow \ell^+ \ell^-)$
- **ALICE:**  $\sigma(W^\pm \rightarrow \ell^\pm \nu)$
- **ATLAS:**  $d\sigma(W^\pm \rightarrow \ell^\pm \nu)/dy$   
 $d\sigma(Z \rightarrow \ell^+ \ell^-)/dy$   
 $A_\ell$
- **CMS:**  $d\sigma(W^\pm \rightarrow \ell^\pm \nu)/dy$   
 $d\sigma(Z \rightarrow \ell^+ \ell^-)/dy$   
 $A_\ell$   
 $A_{FB}$

$$\sqrt{s_{pp}} = 7 \text{ TeV} \rightarrow \sqrt{s_{PbPb}} = 2.76 \text{ TeV}$$

$$\sqrt{s_{pp}} = 8 \text{ TeV} \rightarrow \sqrt{s_{pPb}} = 5.02 \text{ TeV}$$

# nCTEQ PDFs at the LHC

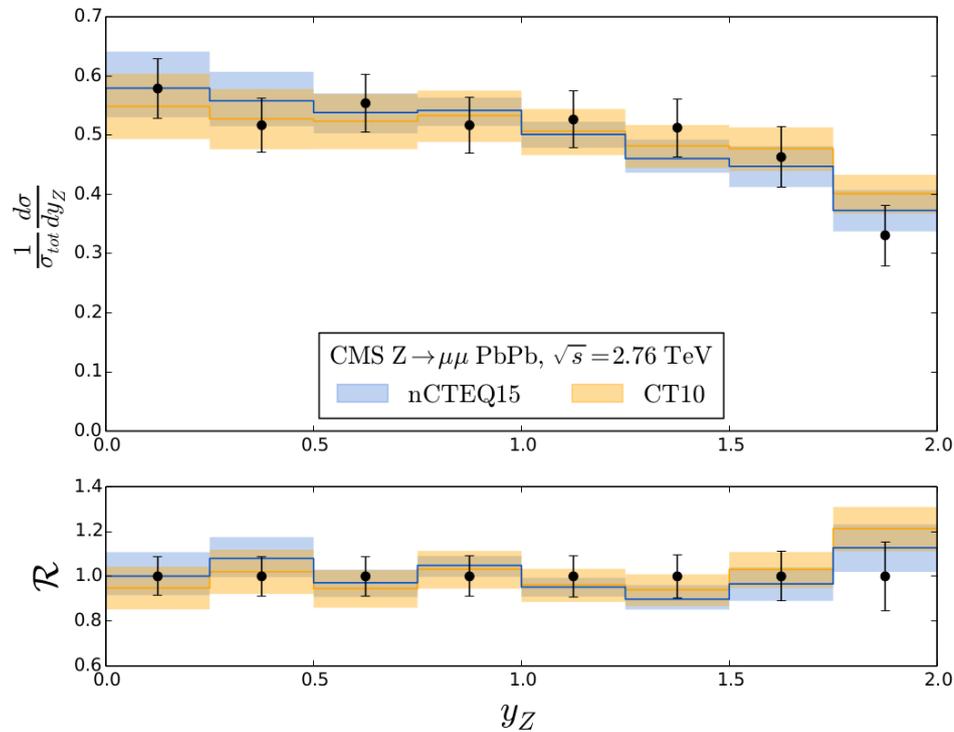


$x_2$  is the Lead PDF

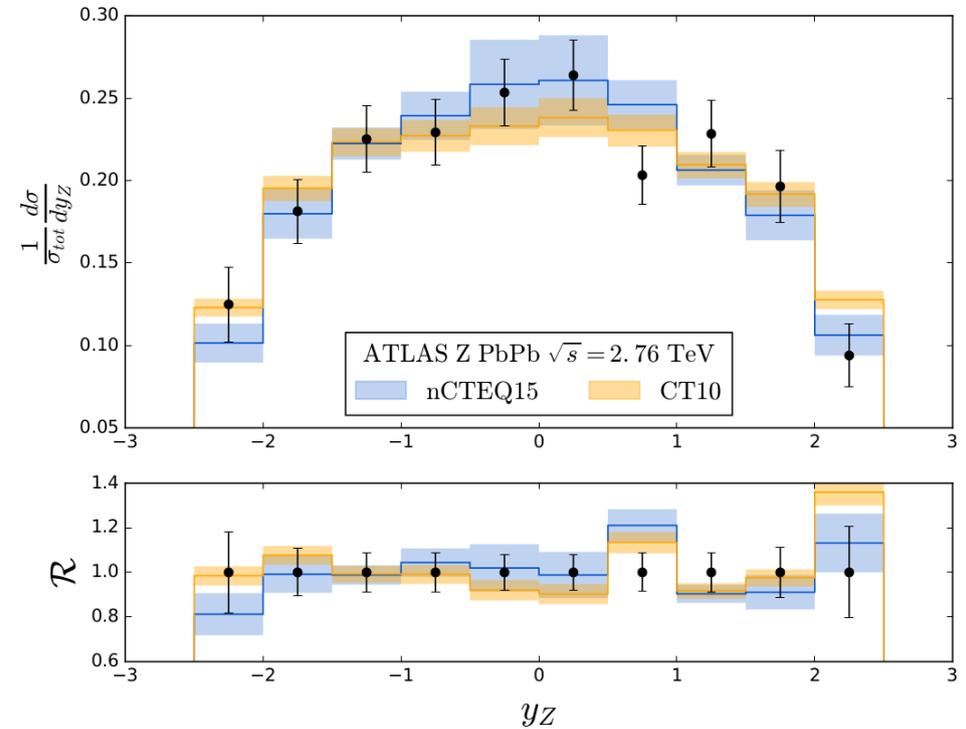
# W/Z Production



## CMS PbPb Z



## ATLAS PbPb Z



All predictions shown at NLO

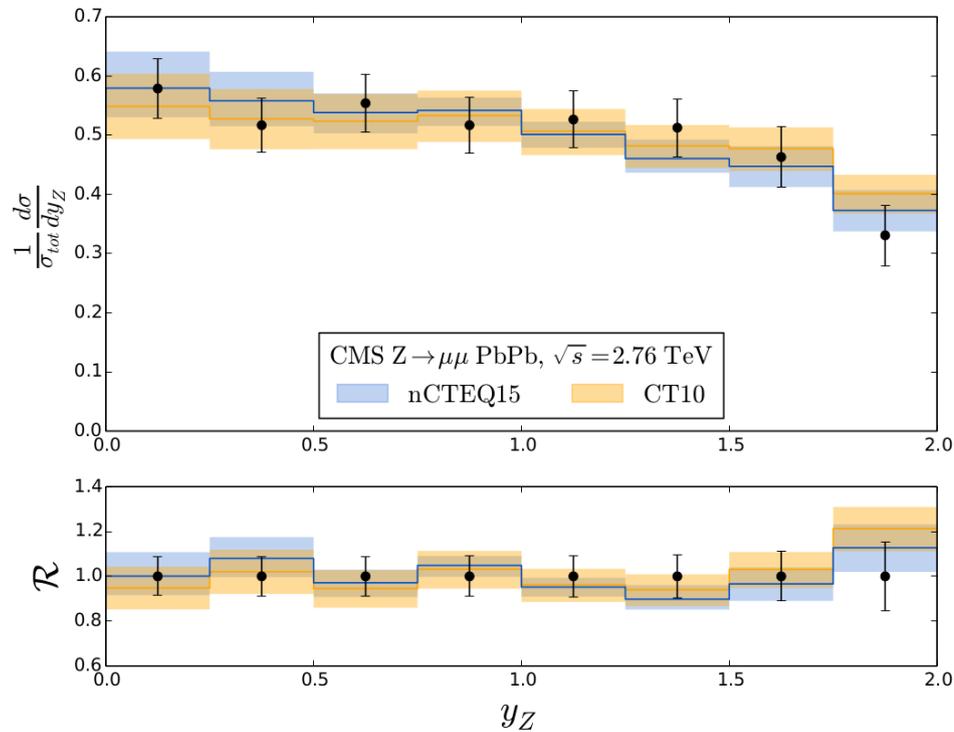
Done in modified FEWZ software which allows for pp, pPb, and PbPb collisions

CT10 nucleus constructed using CT10 free protons

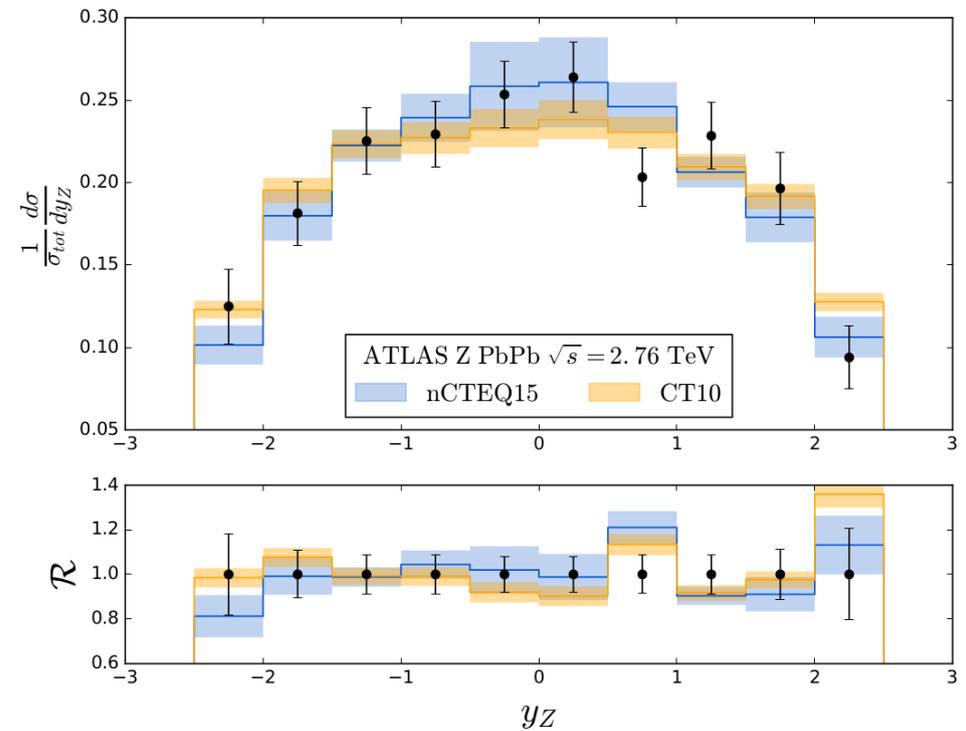
# W/Z Production



## CMS PbPb Z



## ATLAS PbPb Z



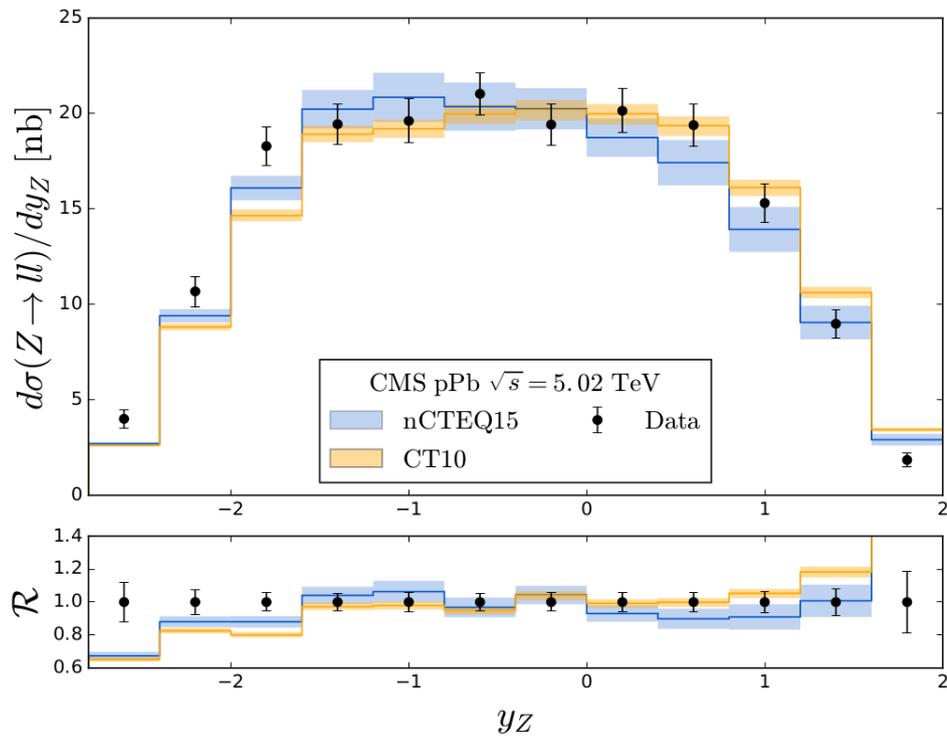
Good agreement between data and both sets

Not sensitive to nuclear corrections

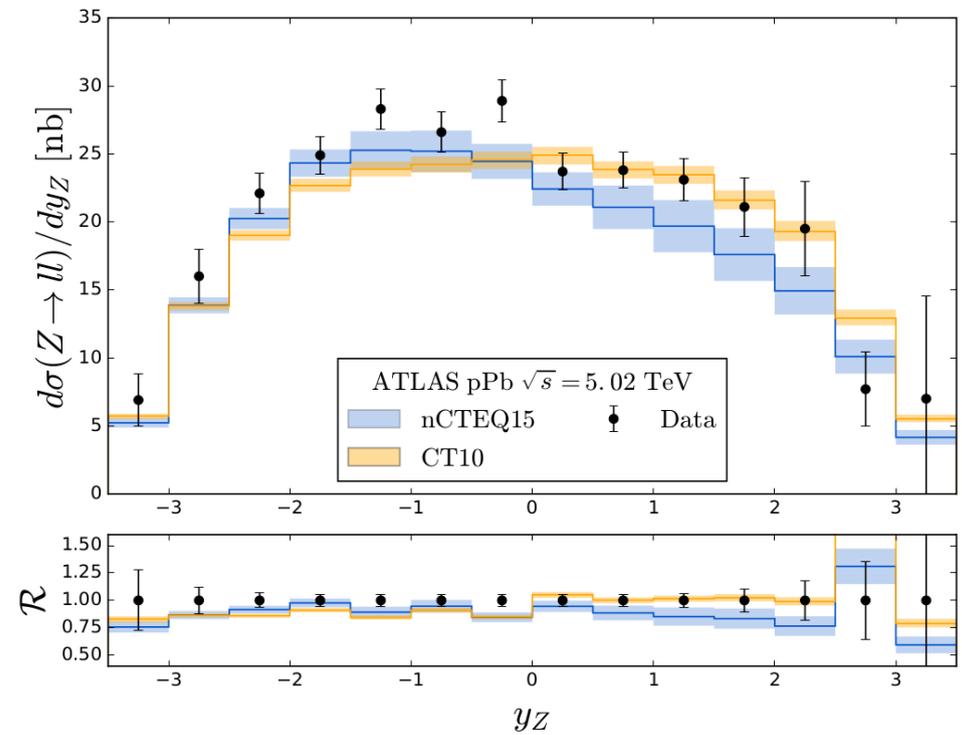
# W/Z Production



## CMS pPb Z



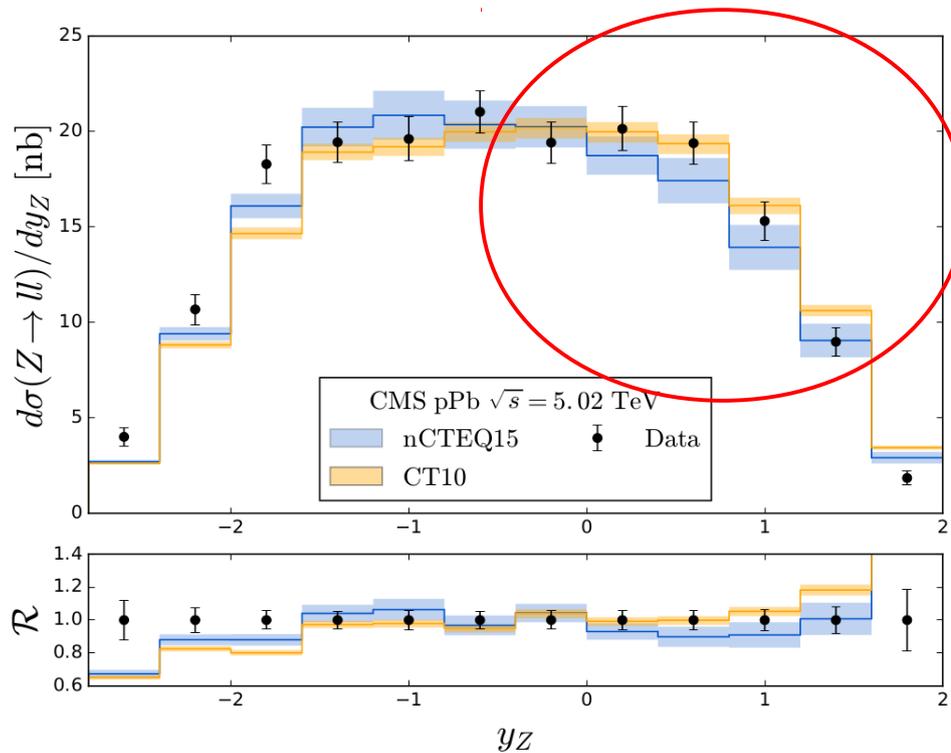
## ATLAS pPb Z



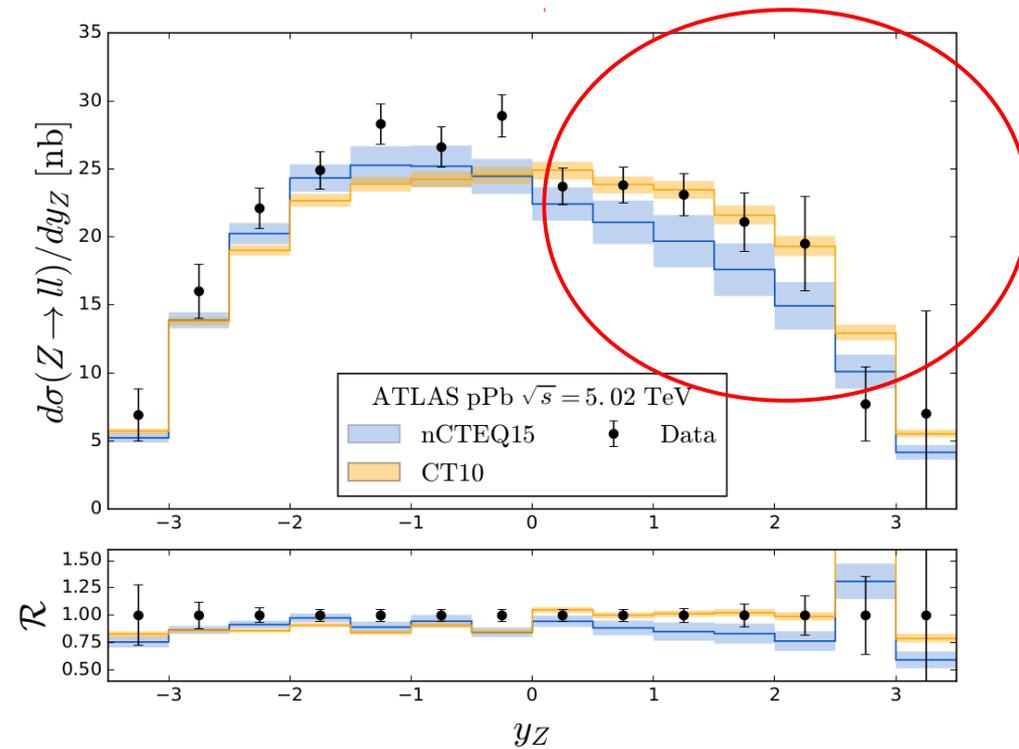
# W/Z Production



## CMS pPb Z



## ATLAS pPb Z



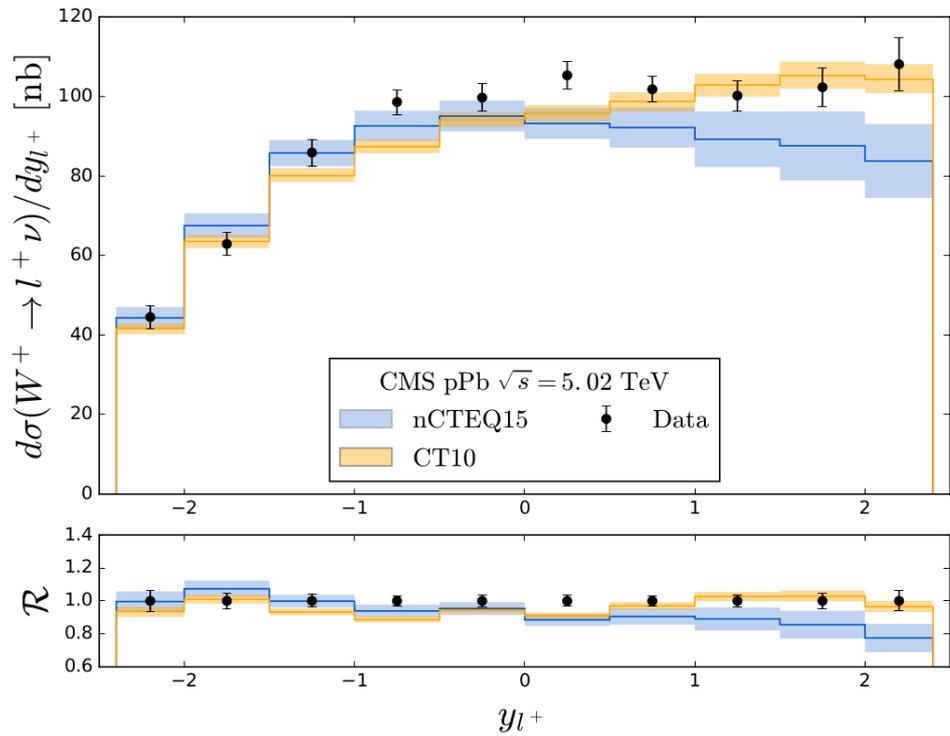
Slight deviance between data and CT10 from nCTEQ15

Good agreement for negative rapidities, the region we have data to constrain the PDF

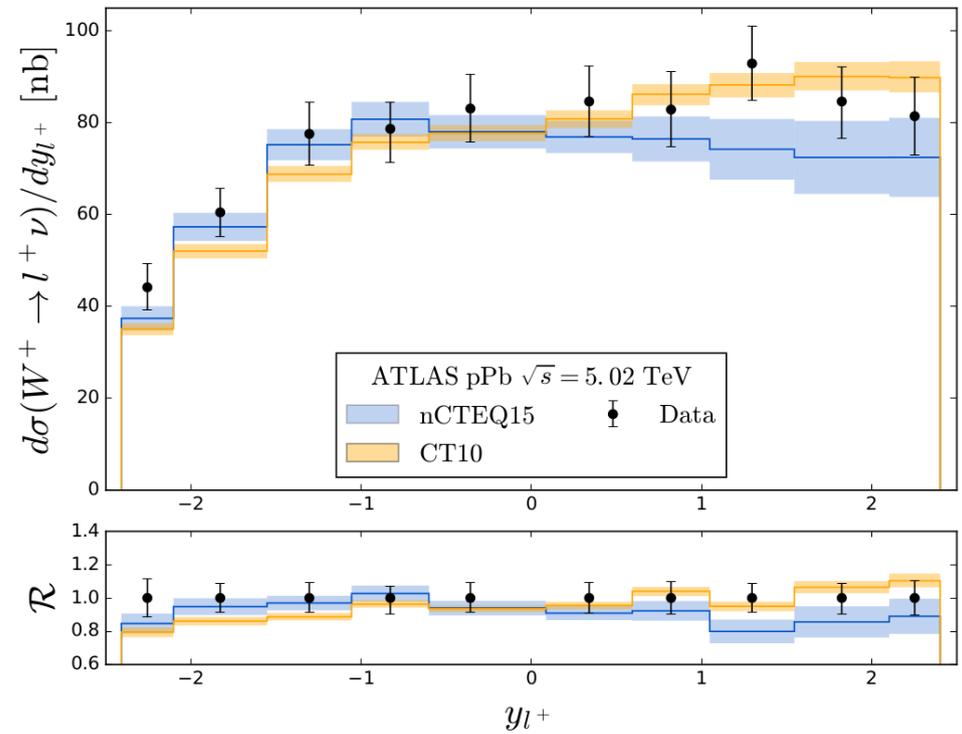
# W/Z Production



## CMS pPb $W^+$



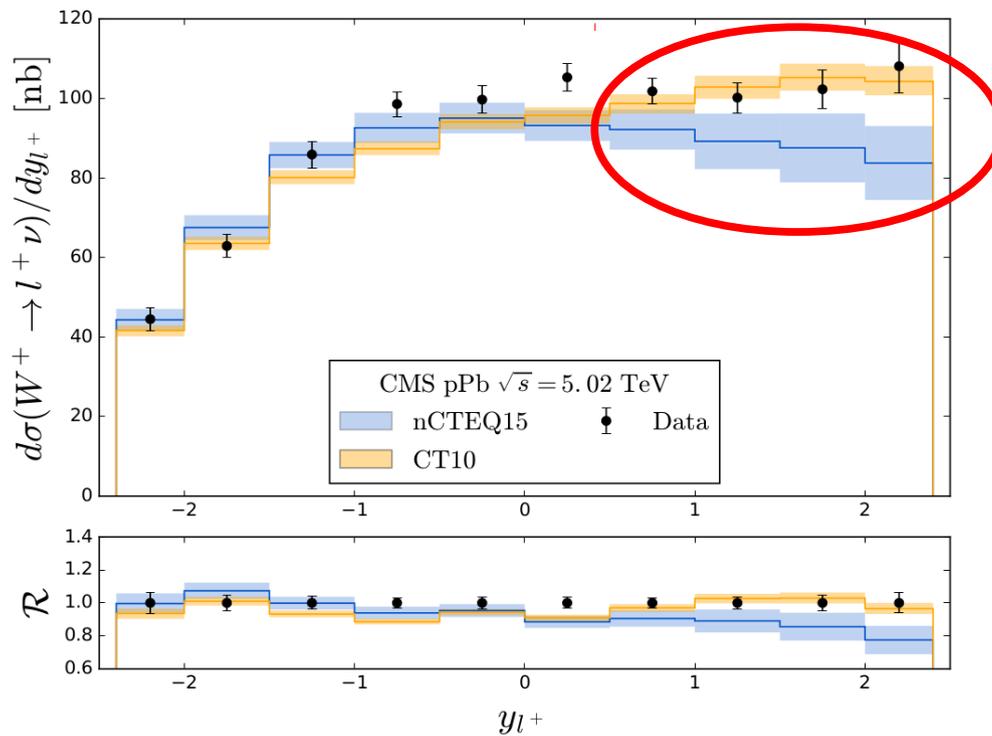
## ATLAS pPb $W^+$



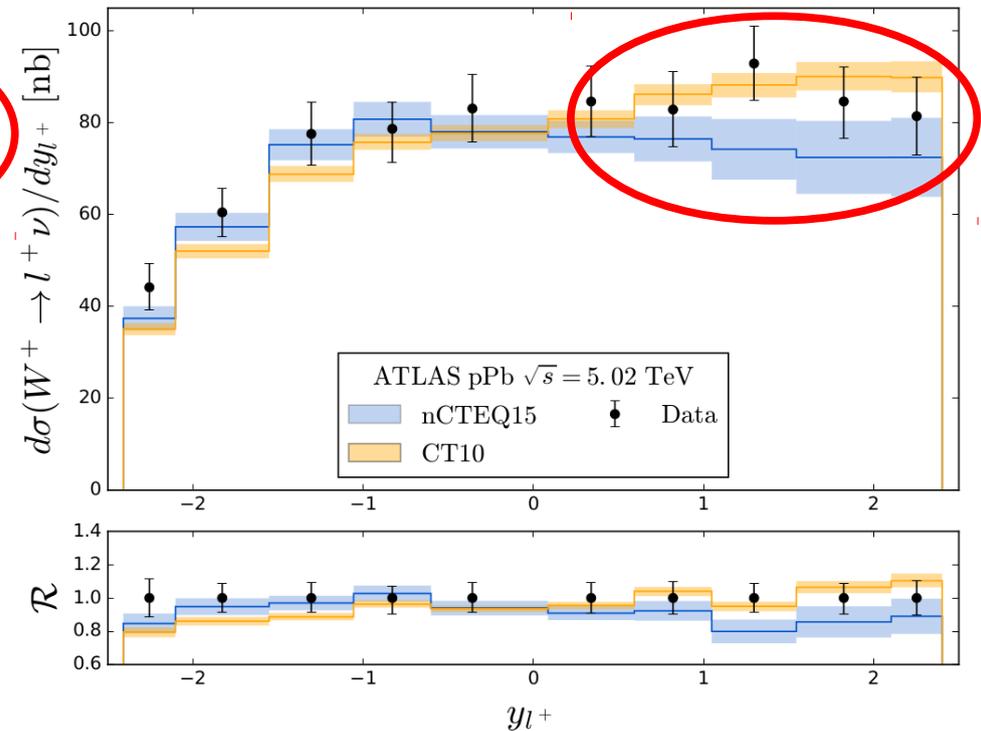
# W/Z Production



## CMS pPb $W^+$



## ATLAS pPb $W^+$



Definite separation between data and CT10 from nCTEQ15

Indicates this data could be useful in constraining PDFs in this region

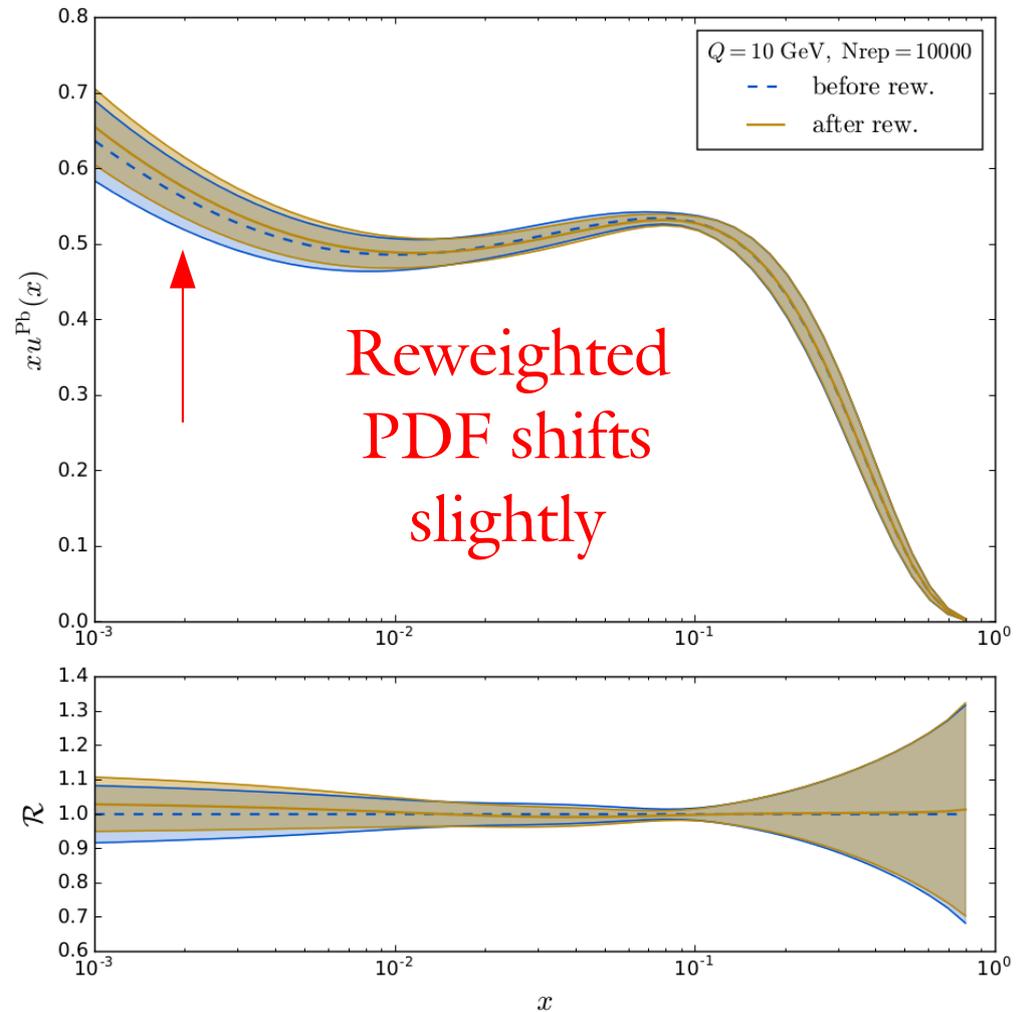
# Estimating Impact on nCTEQ15 PDFs

# Reweighting



Reweighting study<sup>[1]</sup>  
performed to analyze the  
potential impact of LHC  
pPb W/Z data on  
nCTEQ15 PDFs

- Study suggested data had significant pull to warrant inclusion in full fit

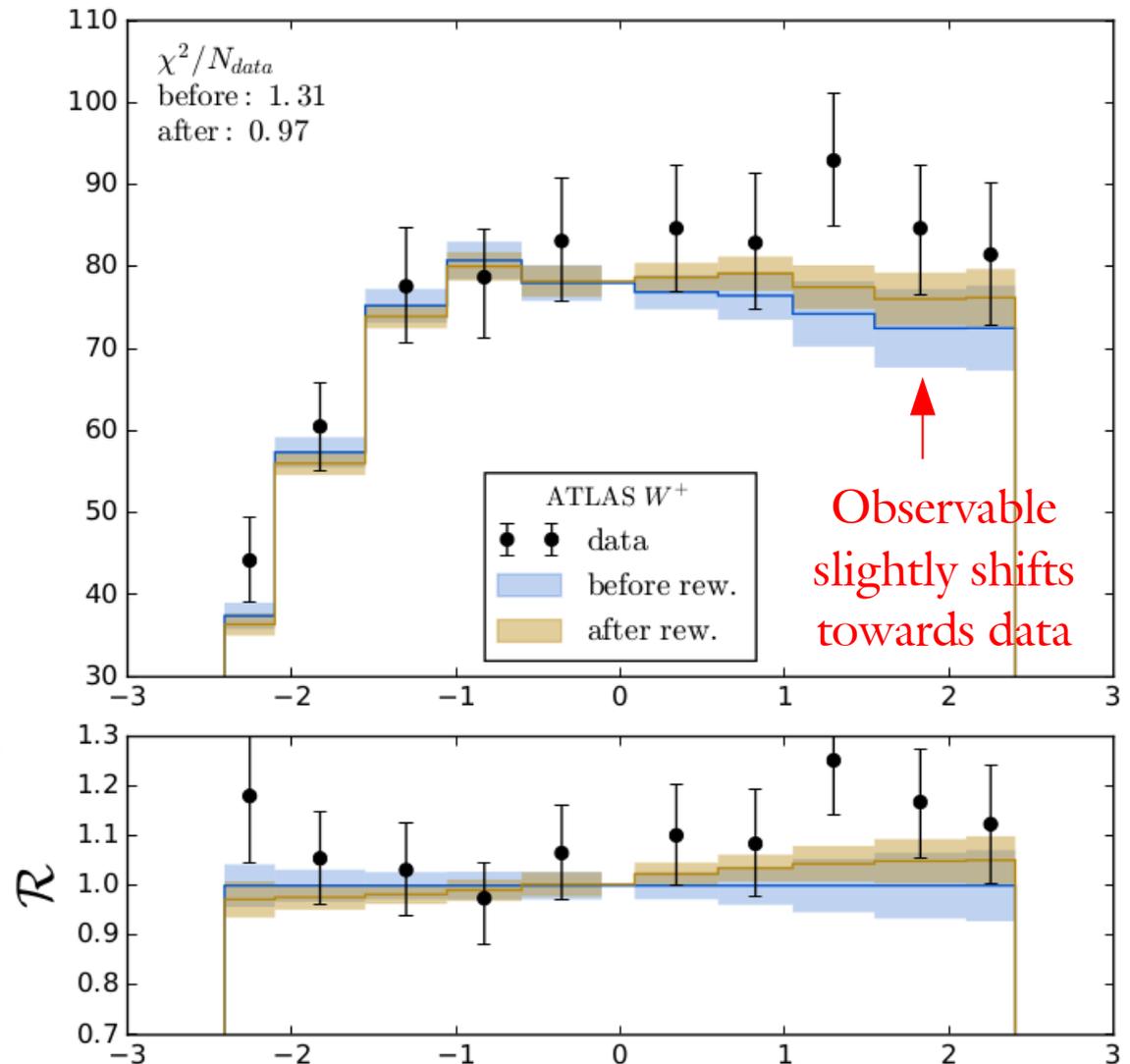


# Reweighting



Results indicated parameterization is inflexible

- Extrapolation in  $x_2$  region corresponding to positive rapidity
  - Previously lacked data in this range
- Strange quark parameter could be opened
  - Currently fixed to up and down quarks



# Outlook

# Outlook



- Currently working on including LHC W/Z pPb data in new fit of nCTEQ15 PDFs
  - Utilizing:
    - APPLGrid
    - pAFEWZ
    - MCFM
- Free up parameterization
  - Strange quark (preliminary study)

Thank you to:

A. Kusina

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I. Schienbein

K. Kovarik

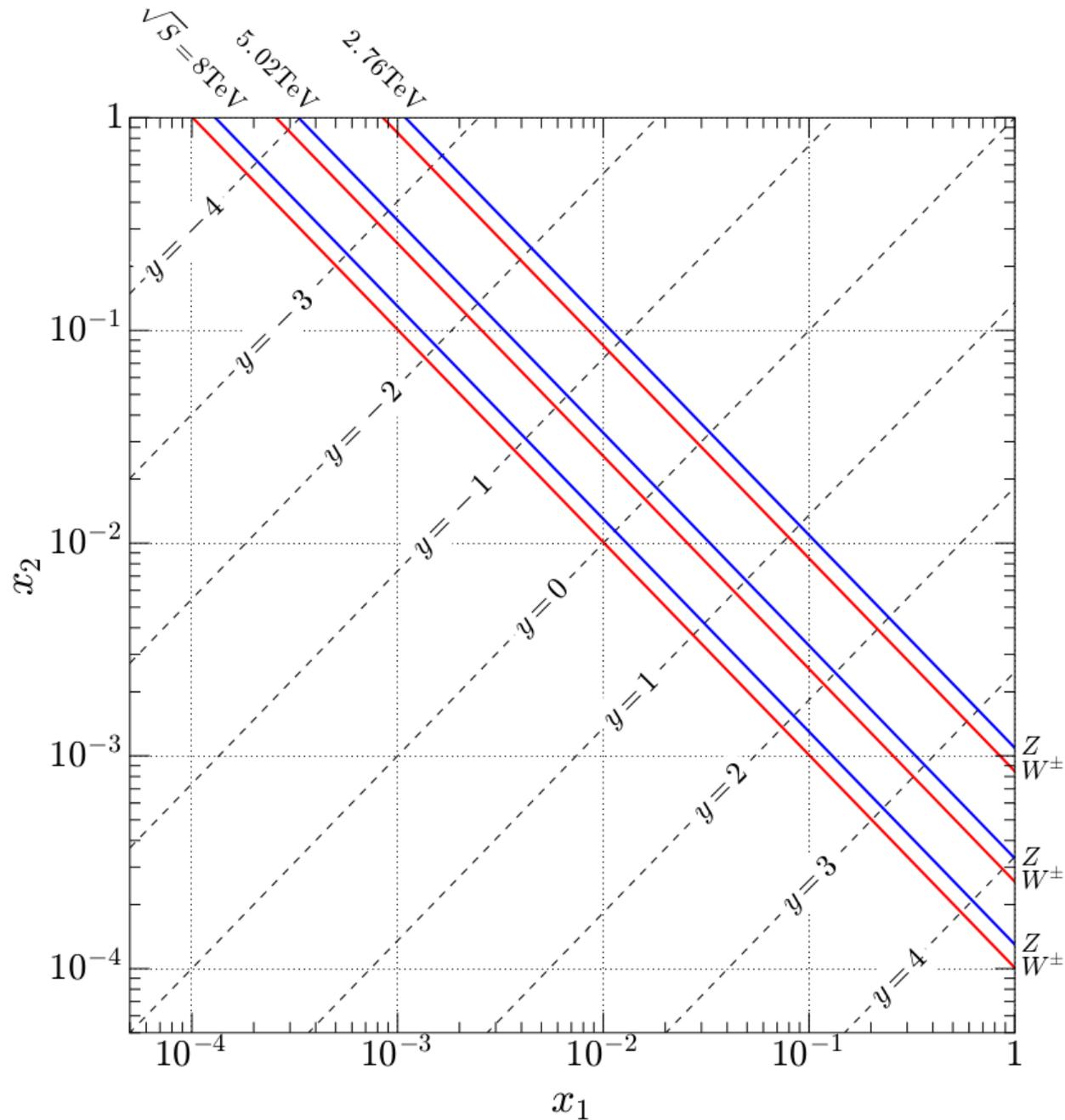
J.Y. Yu

Additional Slides

# nCTEQ PDFs at the LHC



$x_2$  is the  
Lead PDF



# Reweighting Formalism



## Bayesian Reweighting Technique

- **Generate Replica:**  $f_k(x) = f_0 + \sum_i \frac{1}{2} (f_i^+ - f_i^-) R_{ik}$

- **Calculate Giele-Keller weights:**  $w_k = \frac{e^{-\frac{1}{2} \chi_k^2}}{\frac{1}{N_{rep}} \sum_i e^{-\frac{1}{2} \chi_i^2}}$

- **Estimate weighted average and standard deviation:**

$$\langle O \rangle = \frac{1}{N_{rep}} \sum_k w_k O(f_k)$$

$$\delta \langle O \rangle = \sqrt{\frac{1}{N_{rep}} \sum_k w_k (O(f_k) - \langle O \rangle)^2}$$

# LHC Data vs Current Data

## Cuts

