Joint CTEQ Meeting and POETIC 7 - Temple University

# Vector boson production in pPb and PbPb collisions at the LHC and its impact on nCTEQ15 PDFs

arxiv: 1610.02925

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Southern Methodist University

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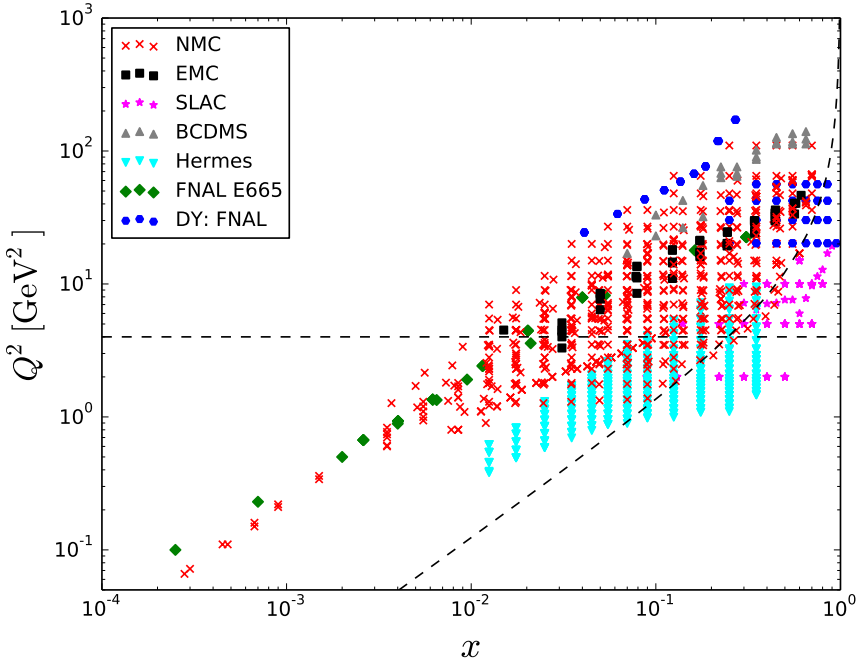
# nCTEQ

nuclear parton distribution functions

**Methodology:**

- Parametrization:
  - e.g. $xg^{p/A}(x,Q^2) = c_0 x^{c_1}(1-x)^{c_2} e^{c_3 x}(1+e^{c_4}x)^{c_5}$
  - $c_k \to c_{k,0} + c_{k,1}(1 - A^{-c_{k,2}})$

- Global **fit** to various experimental data
  - DIS
  - DY
  - Pion production




- $\mathbf{10^{-2} \leq x \leq 0.7}$

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## nCTEQ15

- A total of **740** points after kinematical cuts
  - $\chi^2 = 587.4 \Rightarrow \chi^2/d.o.f = 0.81$
- Error analysis via the **Hessian method**
  - **32** Eigenvalues

# nCTEQ

nuclear parton distribution functions

**To go further:**

- Include LHC data on $pP_b$ (and possibly $P_bP_b$) collisions
  - LHCb: $\sigma(Z \to \ell^+\ell^-)$
  - ALICE: $\sigma(W^{+(-)} \to \ell^{+(-)}\nu(\bar{\nu}))$
  - ATLAS: $d\sigma(Z \to \ell^+\ell^-)/dy$, $d\sigma(W^{+(-)} \to \ell^{+(-)}\nu(\bar{\nu}))/dy, A_\ell$
  - CMS: $d\sigma(Z \to \ell^+\ell^-)/dy$, $d\sigma(W^{+(-)} \to \ell^{+(-)}\nu(\bar{\nu}))/dy, A_\ell, A_{\mathrm{FB}}$
- $\sqrt{s_{pp}} = 7\ \mathrm{TeV} \Rightarrow \sqrt{s_{P_bP_b}} = 2.76\ \mathrm{TeV}$
- $\sqrt{s_{pp}} = 8\ \mathrm{TeV} \Rightarrow \sqrt{s_{pP_b}} = 5.02\ \mathrm{TeV}$

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$\Rightarrow$ **Vector boson production in $pP_b$ and $P_bP_b$ collisions at the LHC**

I) Introduction

II) LHC $pP_b$ and $P_bP_b$ data

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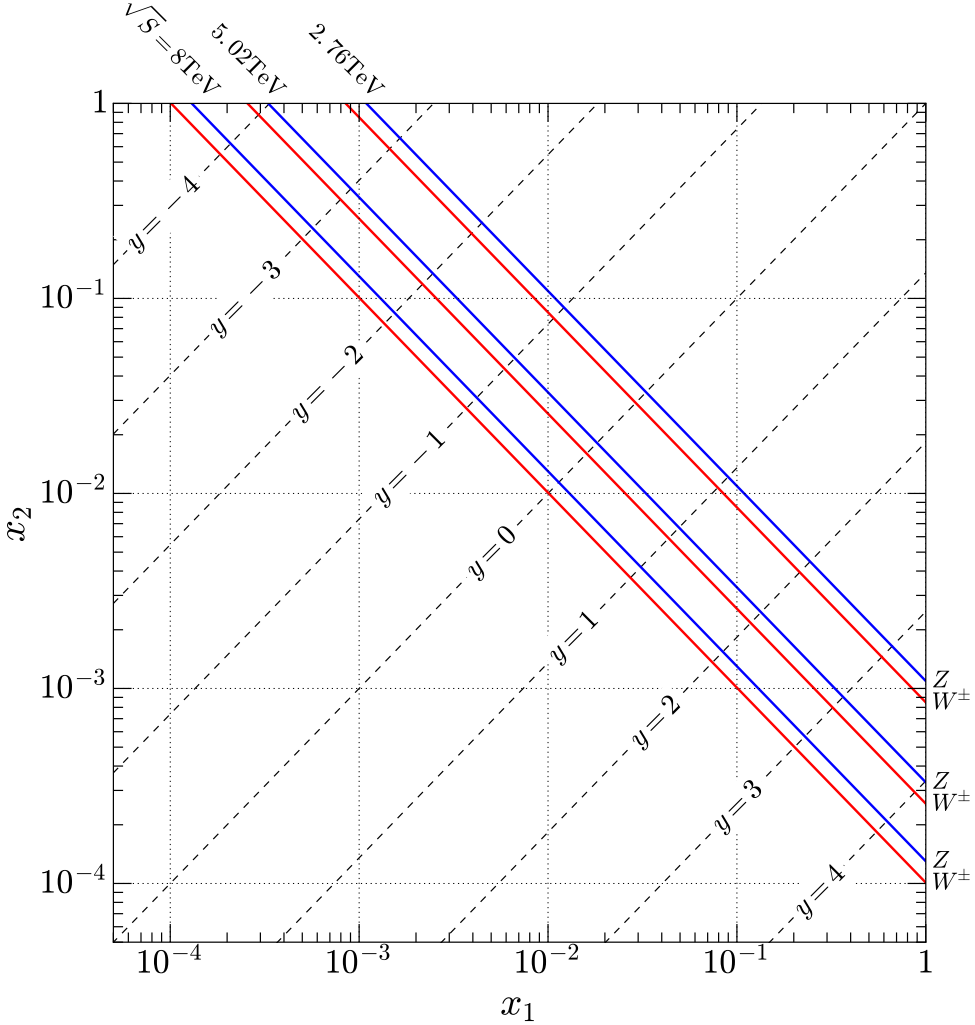
# Kinematics

- $x_2$ is the momentum fraction in the Lead nucleus



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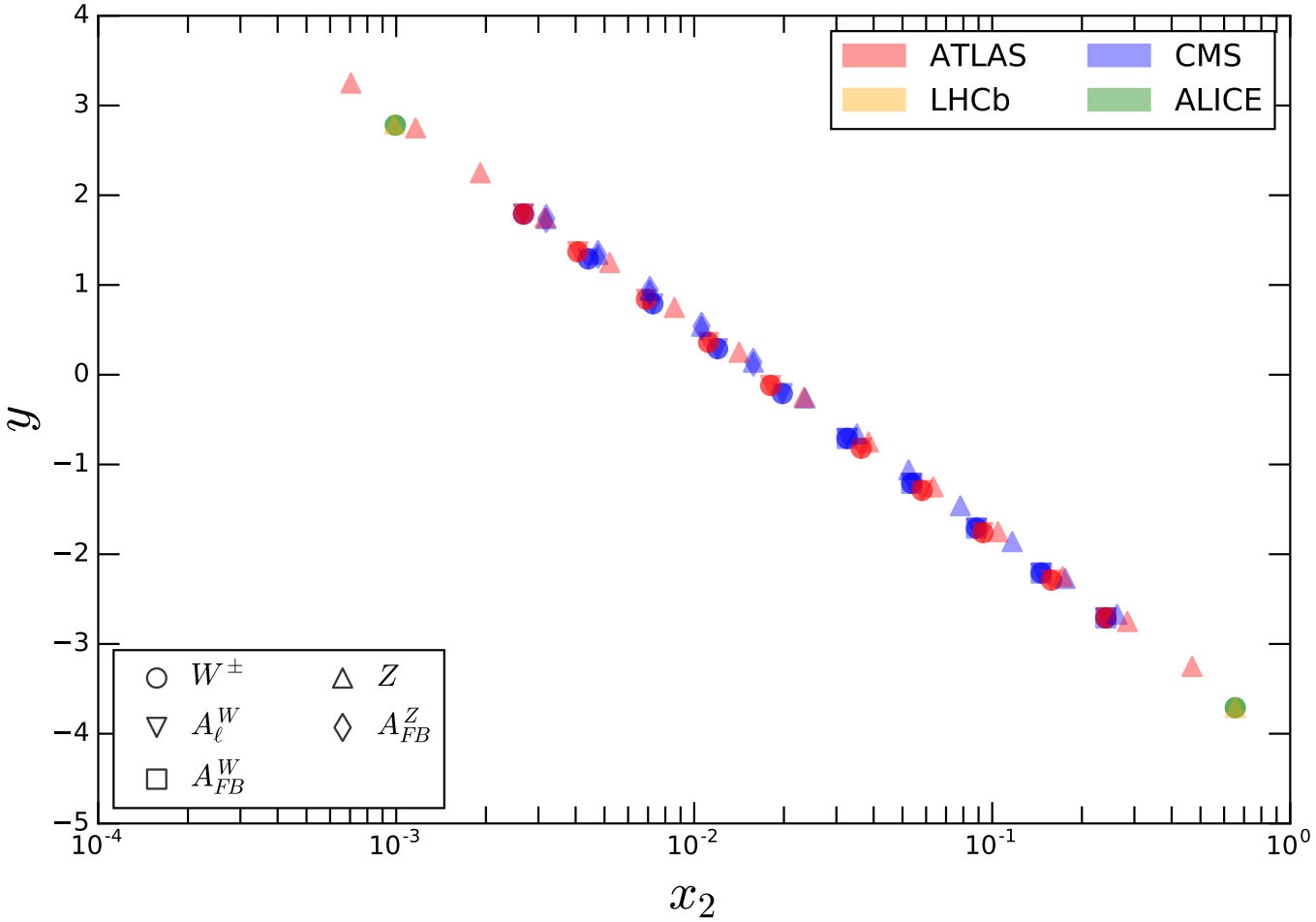


nuclear parton distribution functions

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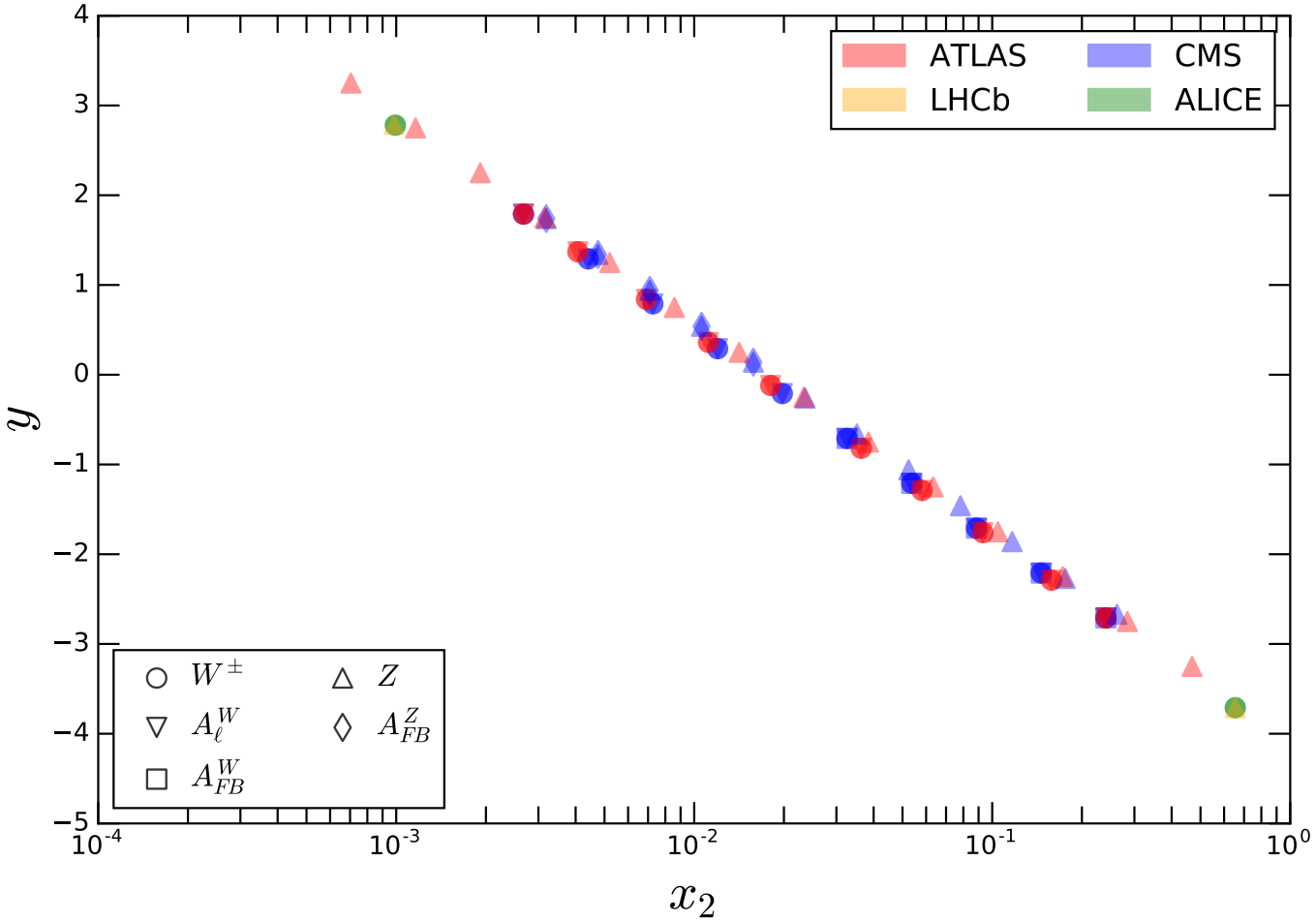
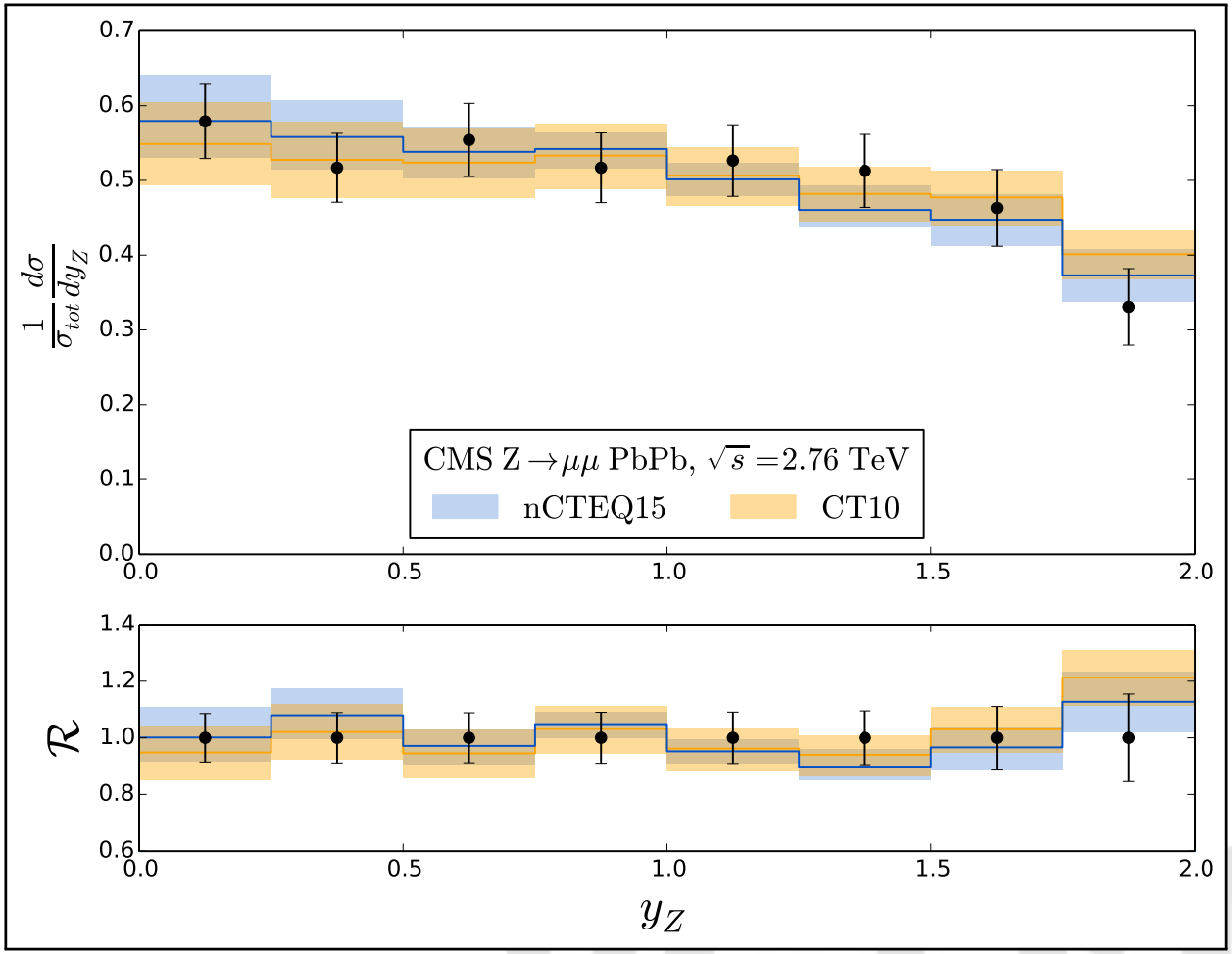


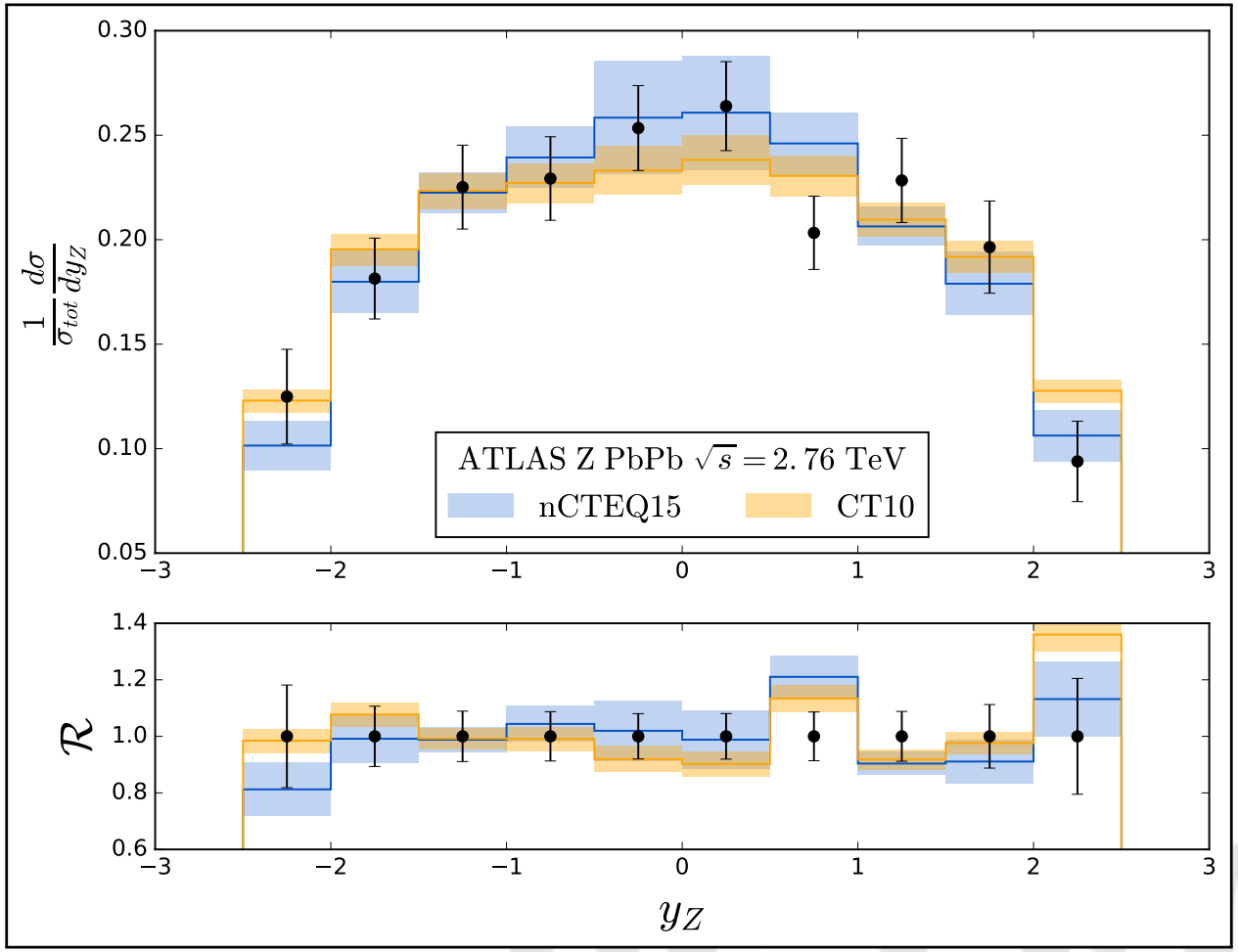

- All predictions @NLO using custom FEWZ (thanks F. Petriello)

# $P_b P_b$




- CT10: Lead nucleus made of CT10 protons

# $P_b P_b$

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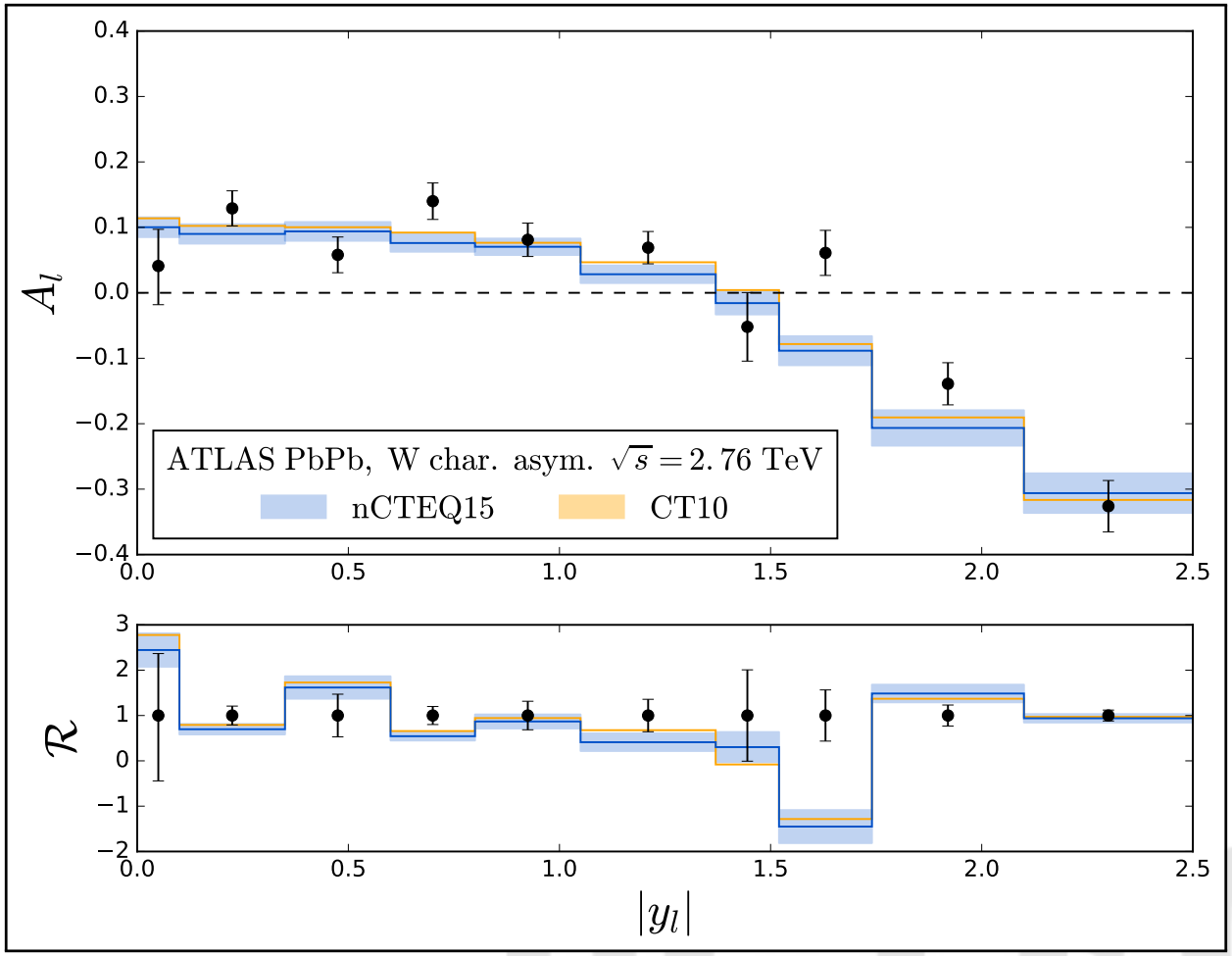


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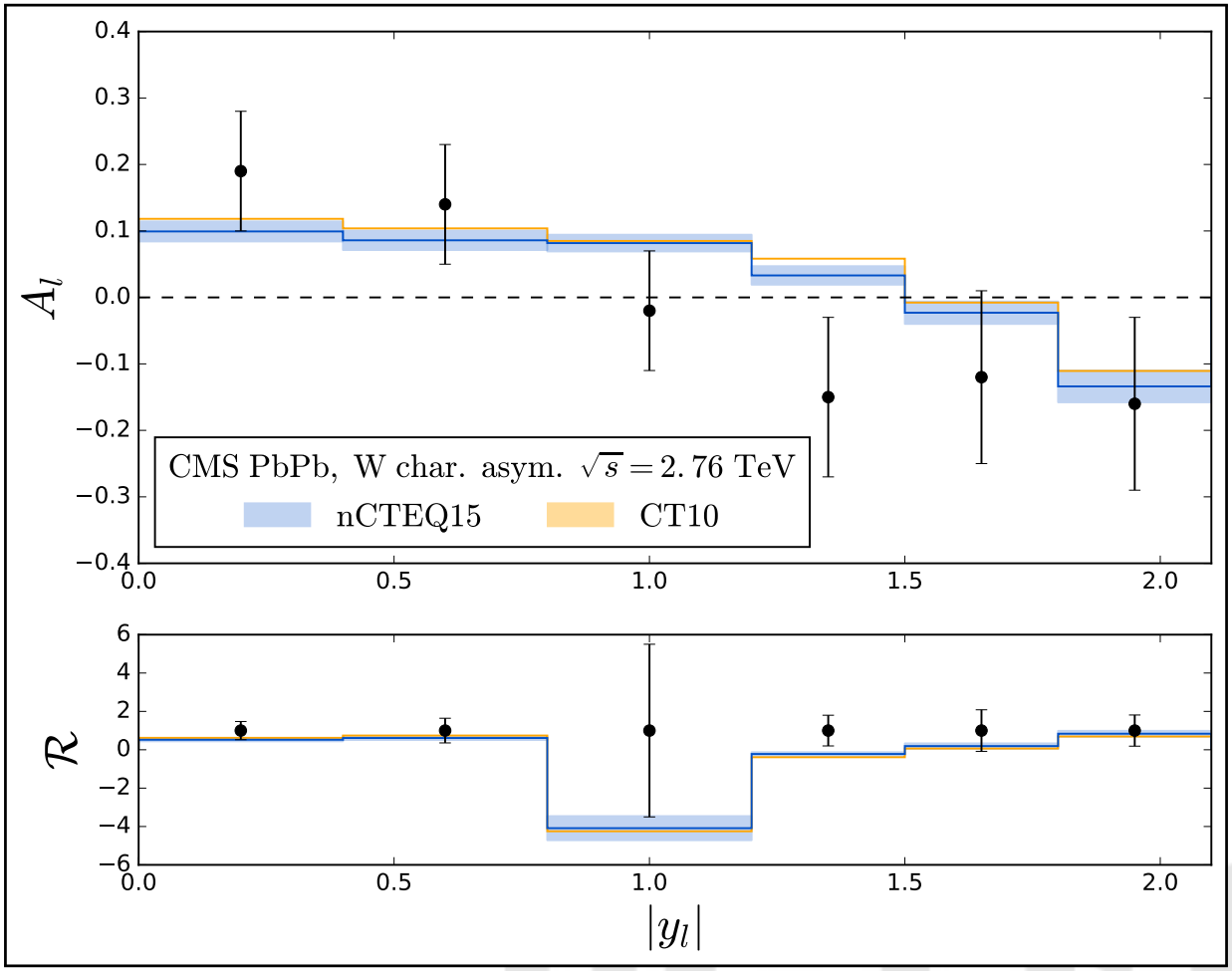


- CT10: Lead nucleus made of CT10 protons

# $P_b P_b$

## Comments

- Not really sensitive to nuclear corrections
- Uncertainties too large to bring constraints on nPDFs

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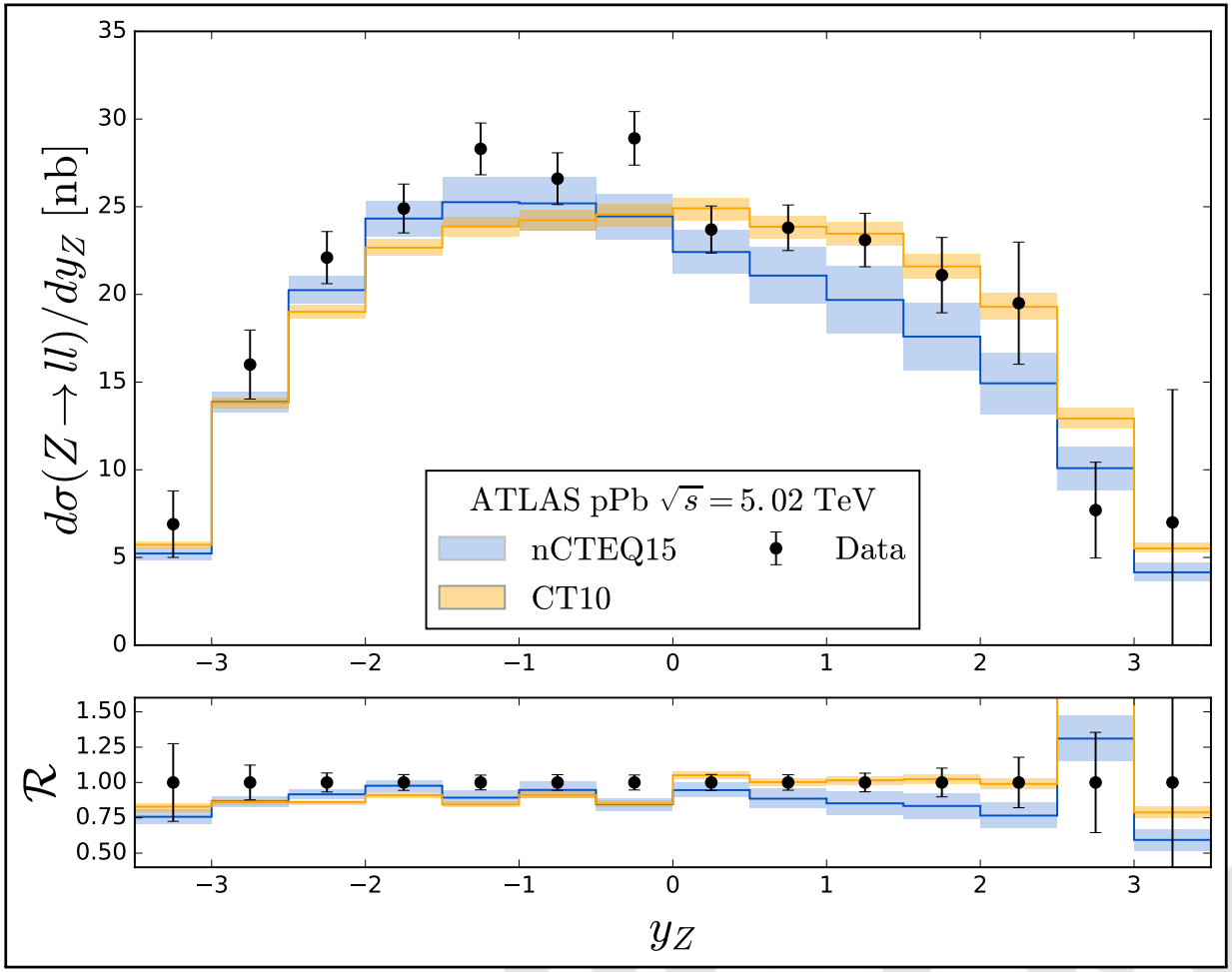
# $pP_b$ : $Z$

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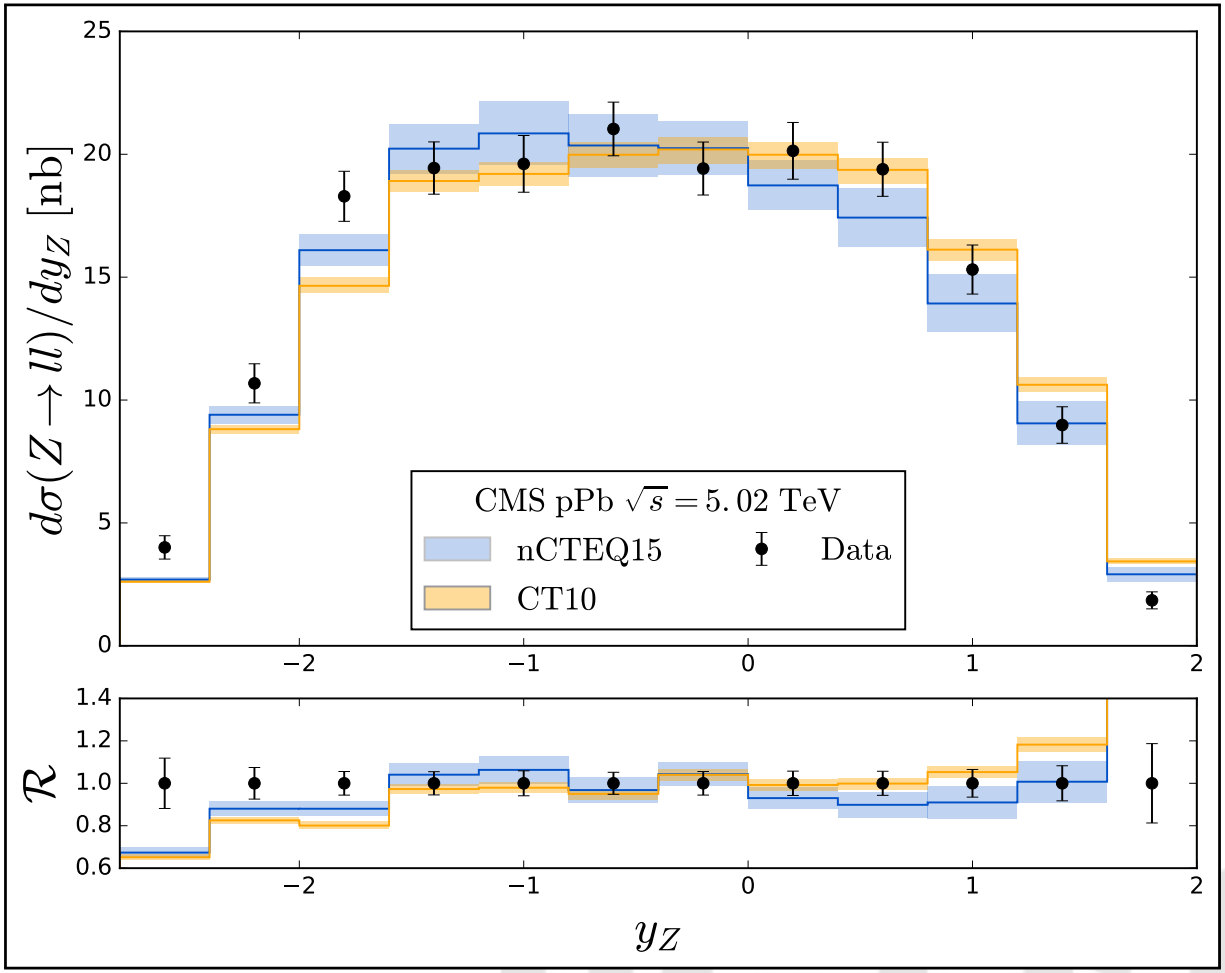


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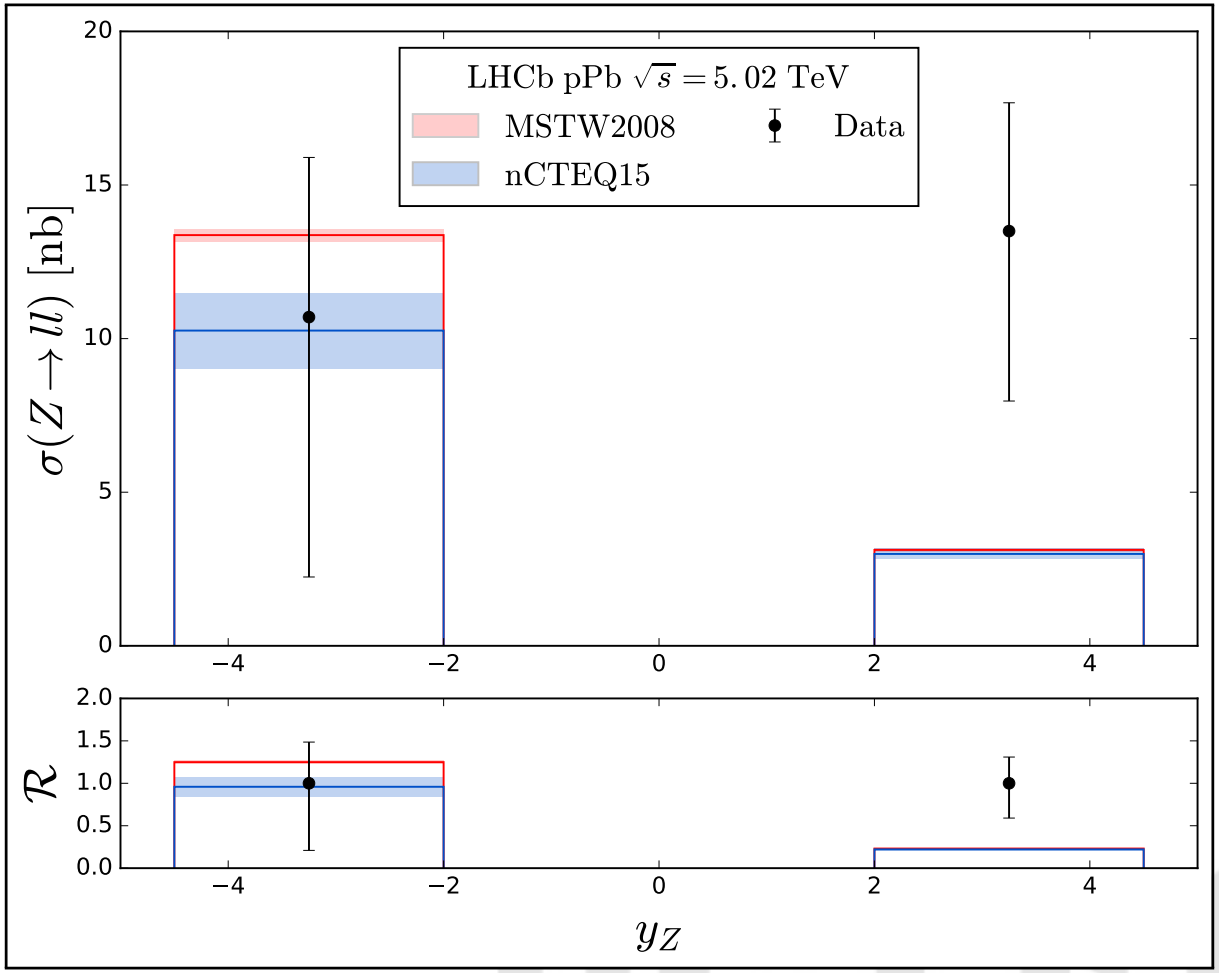
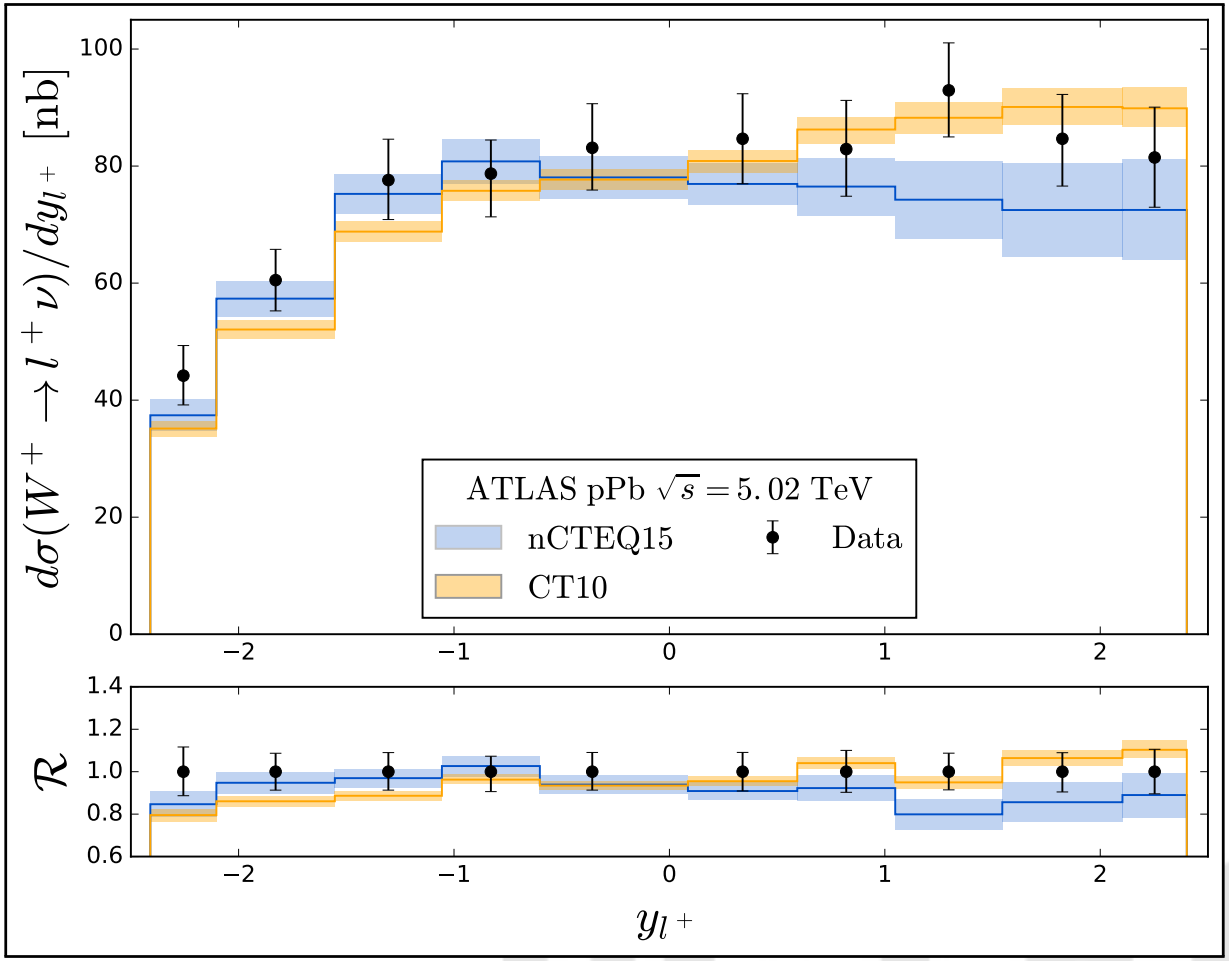
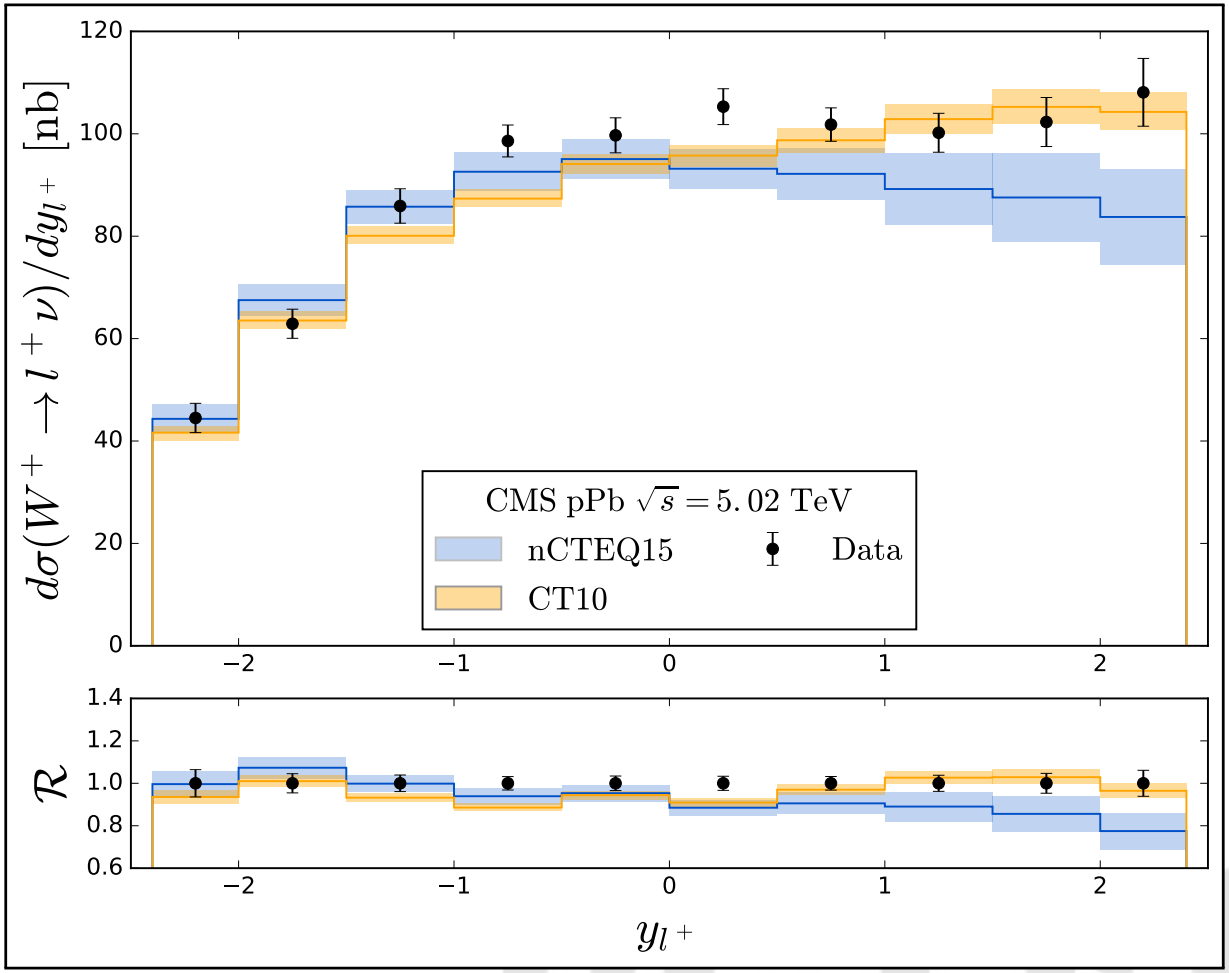

LHCb pPb $\sqrt{s} = 5.02$ TeV
MSTW2008
nCTEQ15
Data
$\sigma(Z \to ll)$ [nb]
$\mathcal{R}$
$y_Z$

# $pP_b$ : $W^+$




- CT10: Lead nucleus made of CT10 protons

# $pP_b : W^+$

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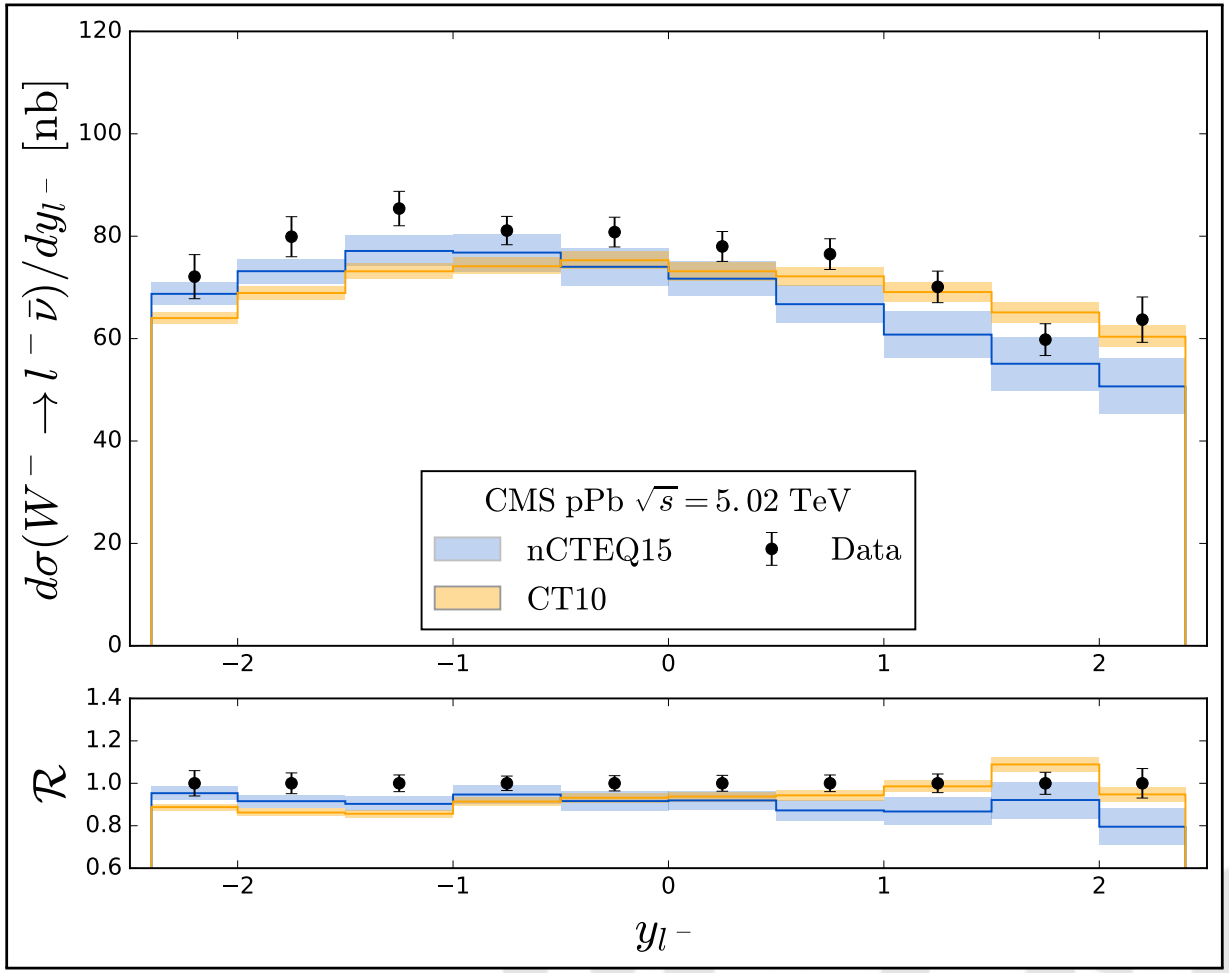


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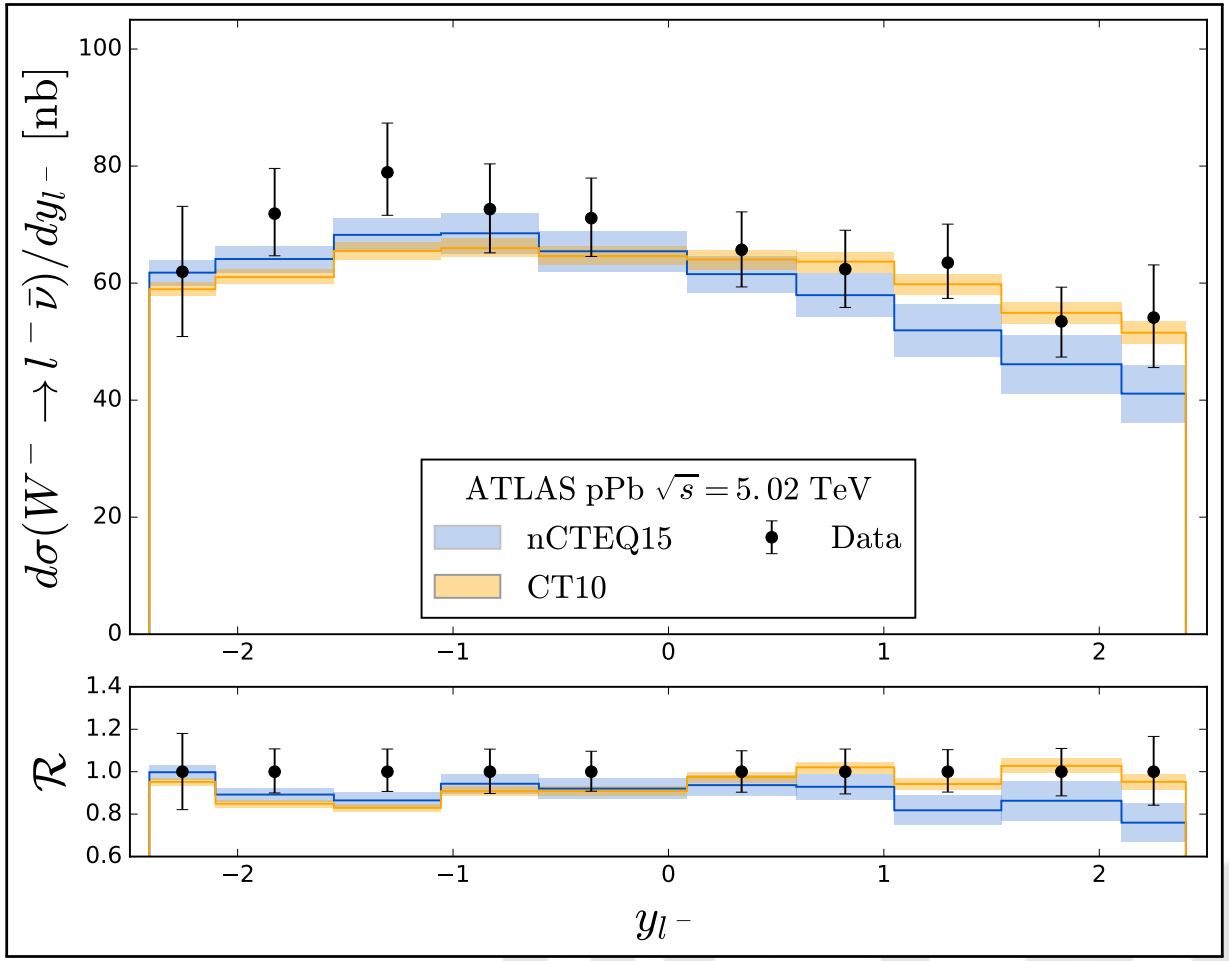


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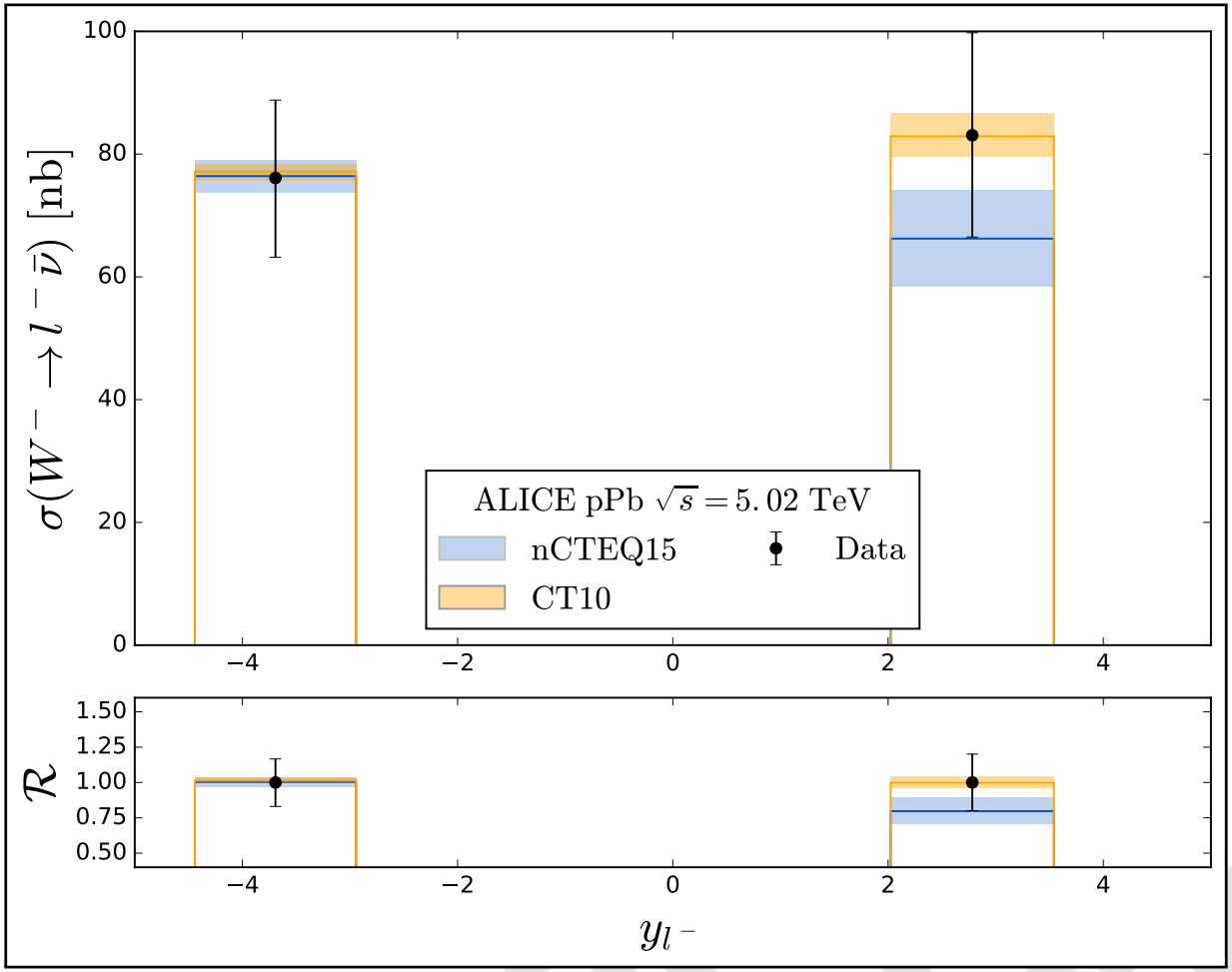


- CT10: Lead nucleus made of CT10 protons

## Remarks:

- Overall good description of the data
  - Very good for $y < 0$ where `nCTEQ15` has data.
  - Some leverage in the $y > 0$ (low $x$) region $\Rightarrow$ mainly extrapolation
- ALICE and LHCb $\Rightarrow$ interesting with more data
- Potential constraining power from the ATLAS and CMS $W^+$ rapidity distributions. In particular where we don't have data at the moment at $\boldsymbol{x \sim 3 \times 10^{-3}}$ $\Rightarrow$ shadowing region

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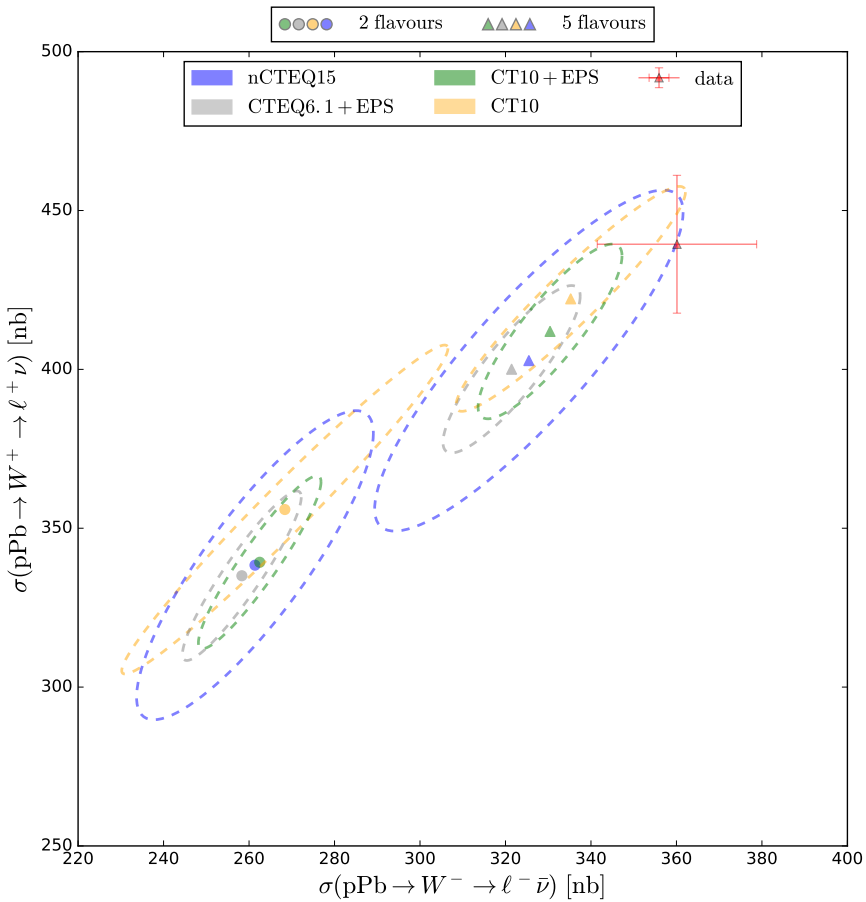
# Strange quark

Correlation of $W^+$ vs $W^-$ cross section with CMS ($pPb$)

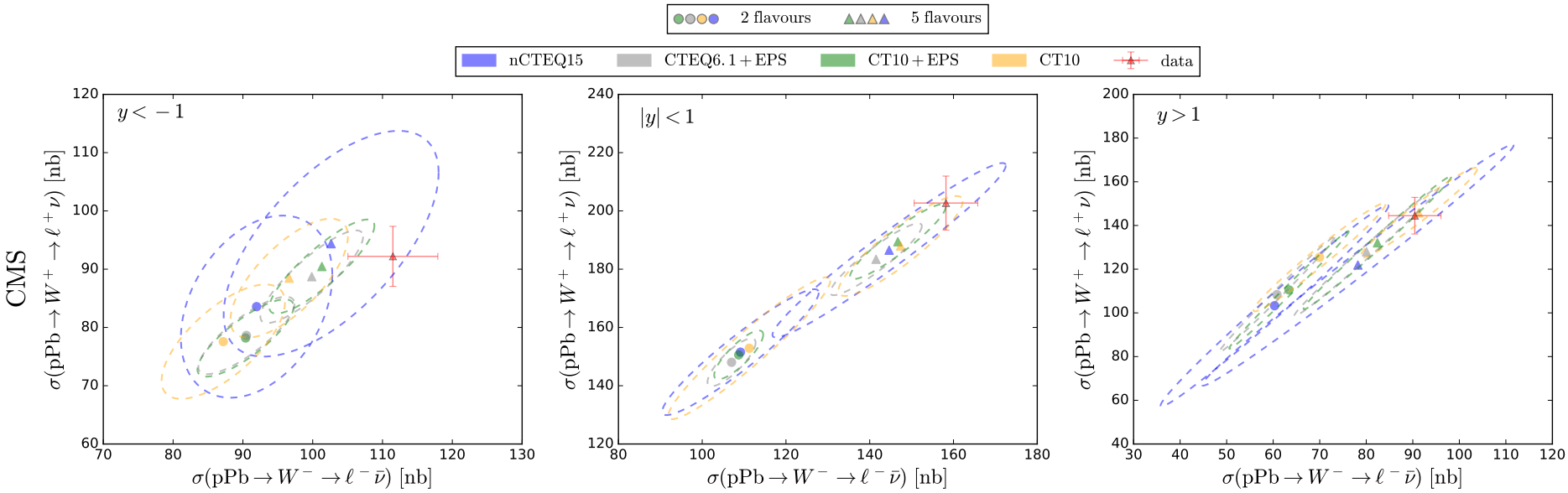
- Strange is fixed in `nCTEQ15`
- Compare 2 vs 5 flavours scenario




- The impact of the strange is $\sim 30\%$
- Most of the difference between **CT10+EPS09** and `nCTEQ15` is the underlying strange contribution in CT10
- Nuclear corrections very close to each other
  - Consistently lower than proton-proton results $\Rightarrow$ **shadowing** sets up too early ?

# Strange quark

- As we move from $y < 0$ to $y > 0 \Rightarrow$ high-$x$ to low-$x$
  - I.e. from well constrained to less constrained




- At $y < 0$ nuclear corrections $> 0 \Rightarrow$ pull results toward data
- As we move to higher $y$ it seems we are little short $\Rightarrow$ **shadowing region**
- Hypothetic: small negative $s - \bar{s}$ asymmetry at high-$x$ ?

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# Reweighting Technique

- We study the impact of the data set via a Baysian Reweighting Technique

## General Idea

(i) Generate Replica: $f_k(x) = f_0 + \sum_i \frac{1}{2}\left(f_i^+ - f_i^-\right)\mathcal{R}_{ik}$

(ii) Calculate Giele-Keller weights: $w_k = \frac{\exp -\frac{1}{2}\chi_k^2}{\frac{1}{N_{rep}}\sum_i \exp -\frac{1}{2}\chi_i^2}$

(iii) Then one can estimate the **weighted average** and **standard deviation**: $< \mathcal{O} >= \frac{1}{N_{rep}} \sum_k w_k \mathcal{O}(f_k)$

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

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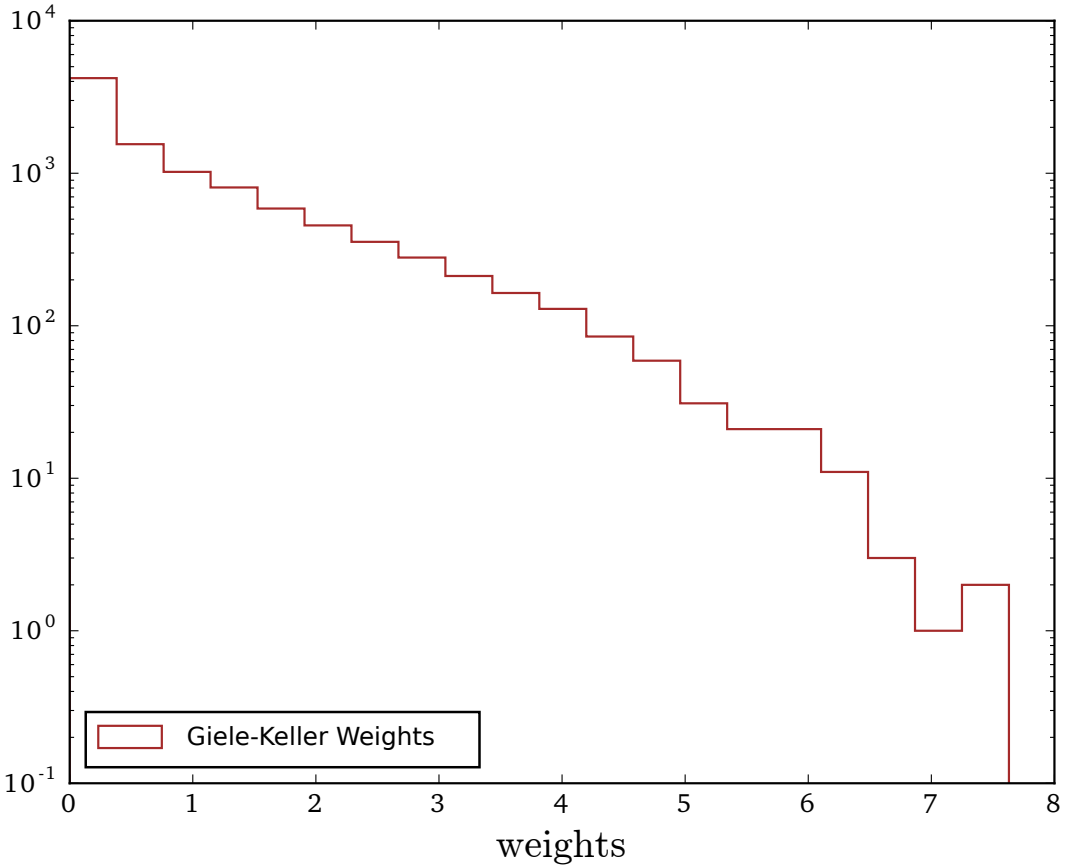
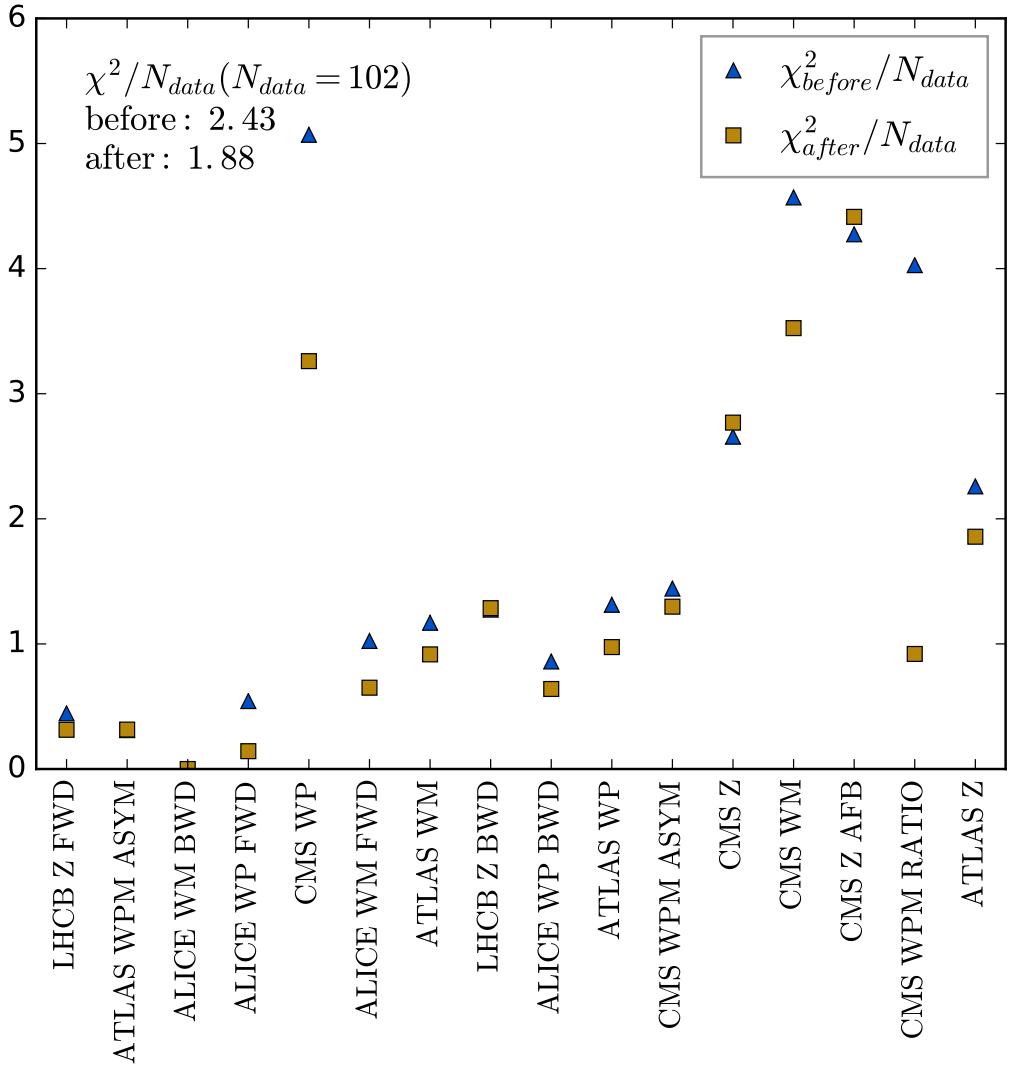
# All Data on $pP_b$

- Perform reweighting of the previously presented data on $p - P_b$ collisions
- Using $10^4$ replicas



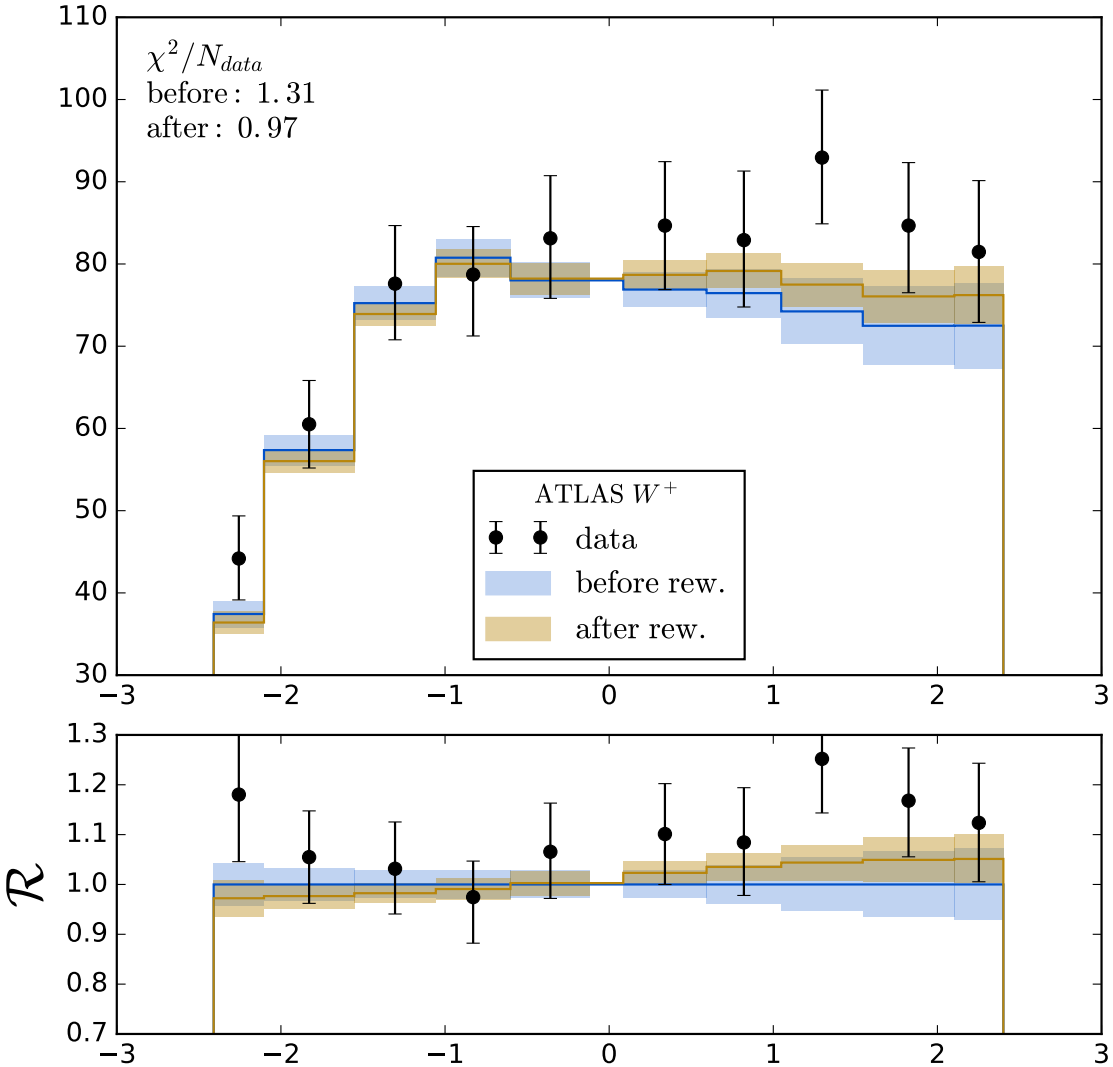

- Reasonable weights, regular fall down distribution of weights
- No excessive values or irregular paterns

# All Data on $pP_b$



# All Data on $pP_b$

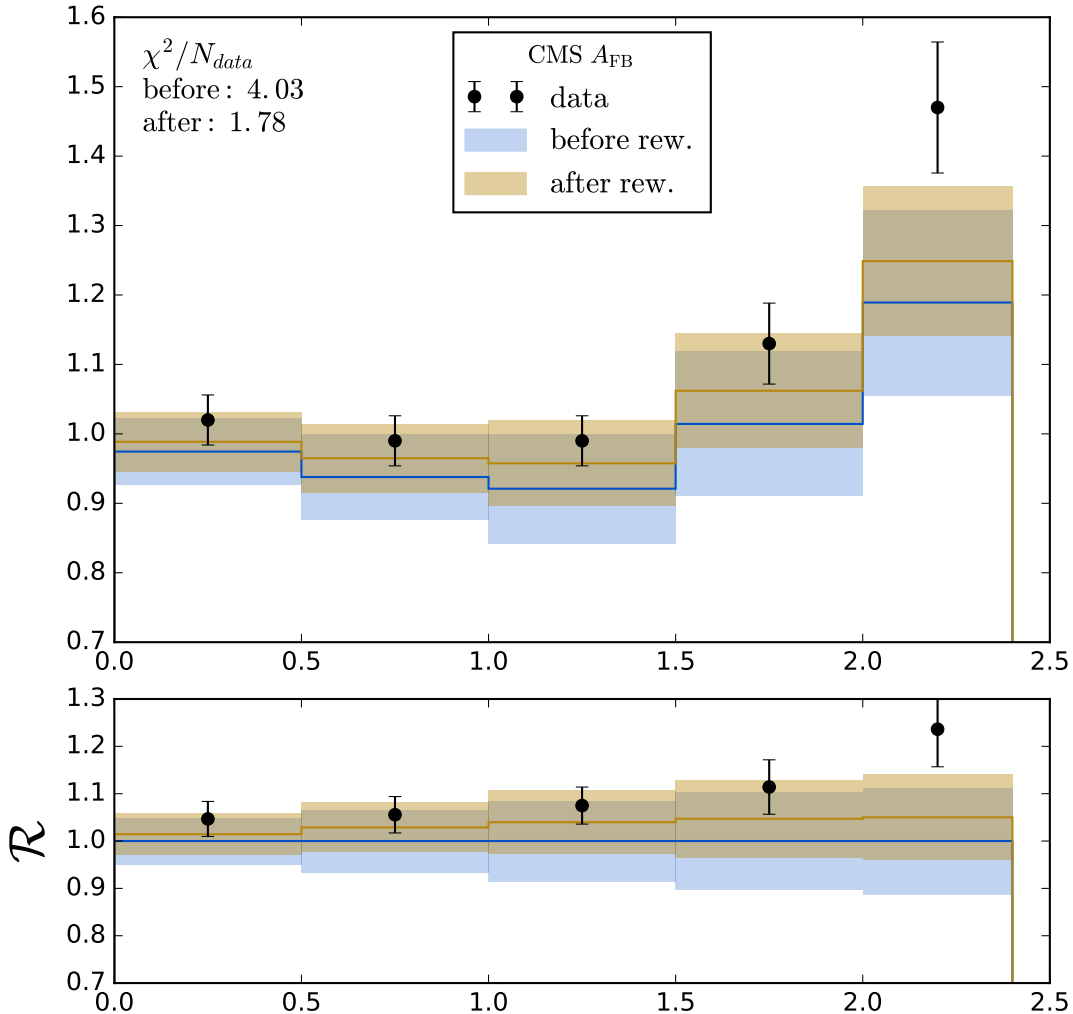
ATLAS reweighted distribution:




- $\chi^2/N_{data}$ decreases from **1.31** to **0.97**
- As expected, distribution is **pulled toward** the data at $y > 0$
- Not so much at $y < 0 \Rightarrow$ limit of the parametrization?

# All Data on $pP_b$

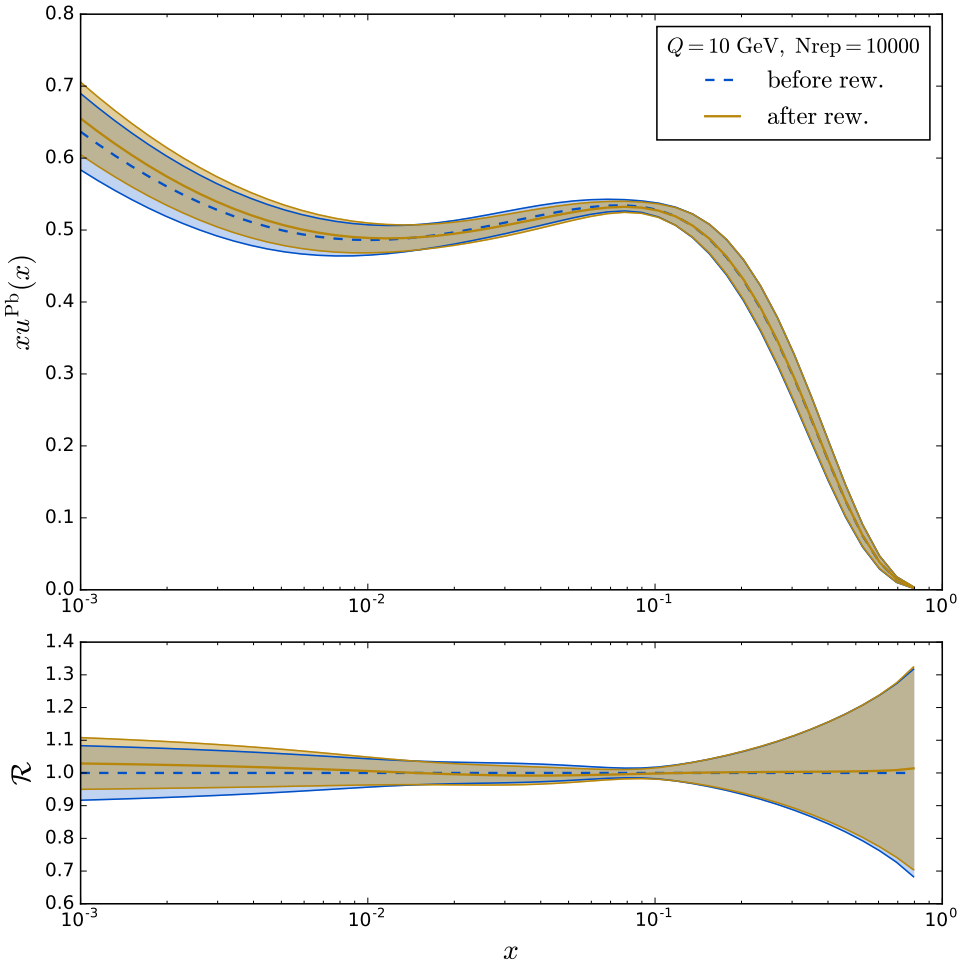
CMS Forward Backward: $A_{\mathrm{FB}}(y_\ell) = \dfrac{dN_{\ell\pm}(+y_{\mathrm{lab}})}{dN_{\ell\pm}(-y_{\mathrm{lab}})}$




- As expected, distribution is **pulled toward** the data
- $\chi^2/N_{data}$ decreases from **4.01** to **1.78**

# Impact on the PDFs

- **up quark** distribution at $Q = 10$ GeV




- Impact of data still limited

**Remarks:**

- Results obtained once these data in the fit may be different
  - Might be able to open more parameters ⇒ fit strange

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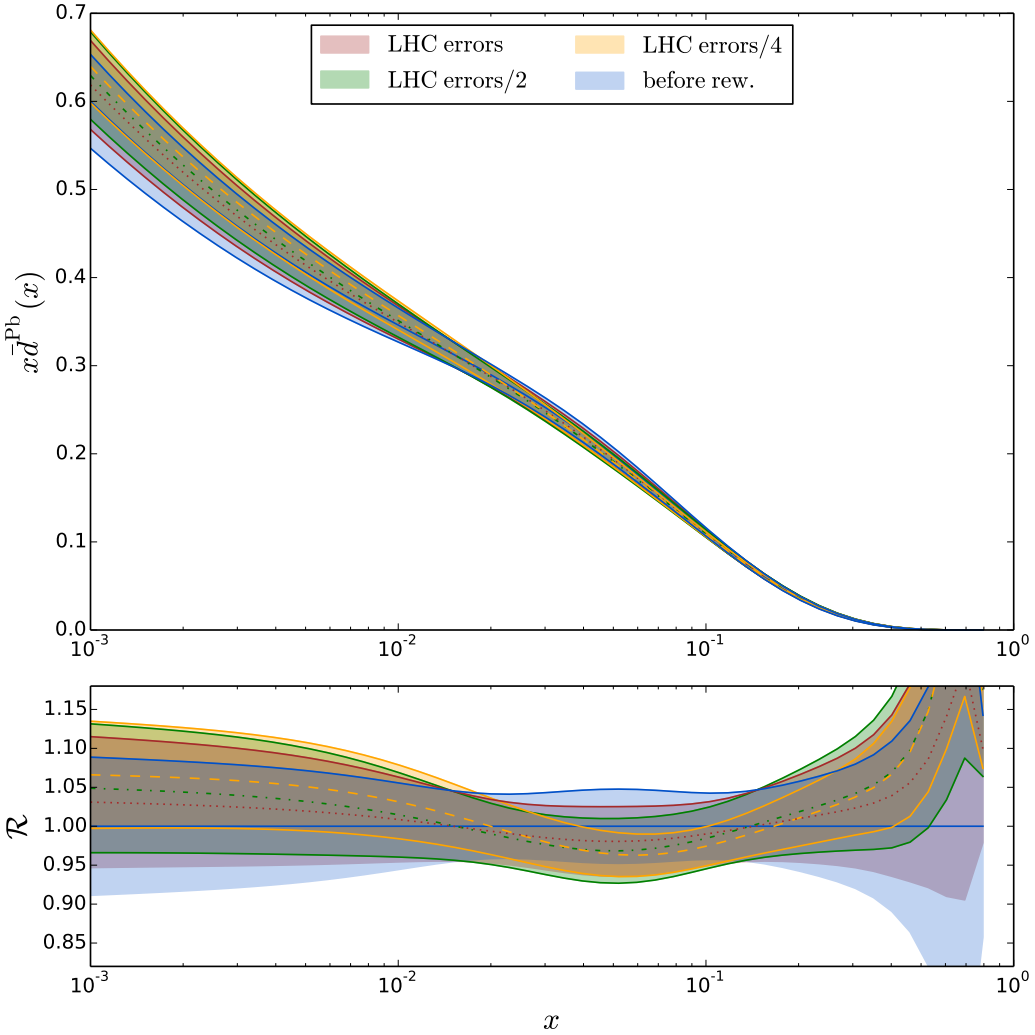
- Also looked at reduced errors



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# Conclusion

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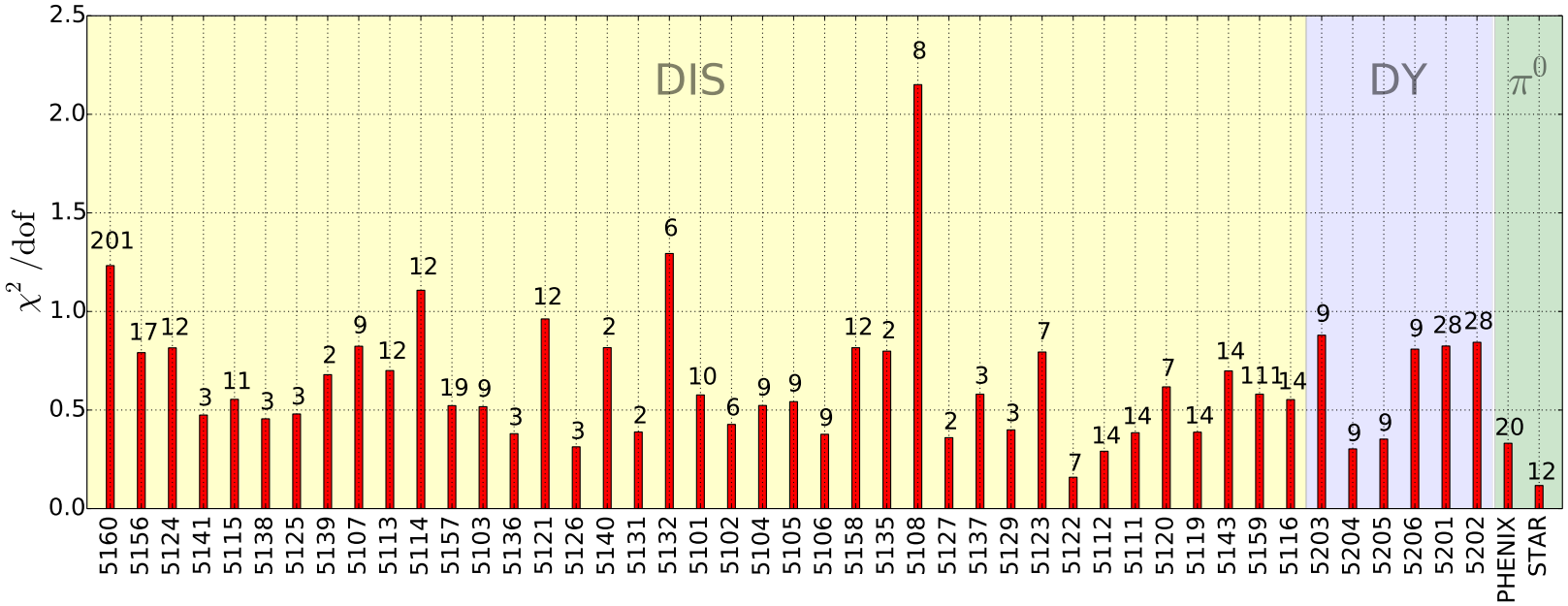
- nCTEQ project is moving fast
  - Publish new fit, nCTEQ15 with **Hessian** error analysis ⇒ PDFs for **any nuclei**
  - In the process of including LHC $W/Z$ production data
- First step: performed detailed study of the nCTEQ15 predictions for these observables
- Investigated **reweighting** technique to assess the power of this data
  - Seems that the impact is **limited** in this setup
  - Could still open possibilities and in particular to **fit strange** quark PDF
  - Will also be interesting to compare reweighting vs actual fits

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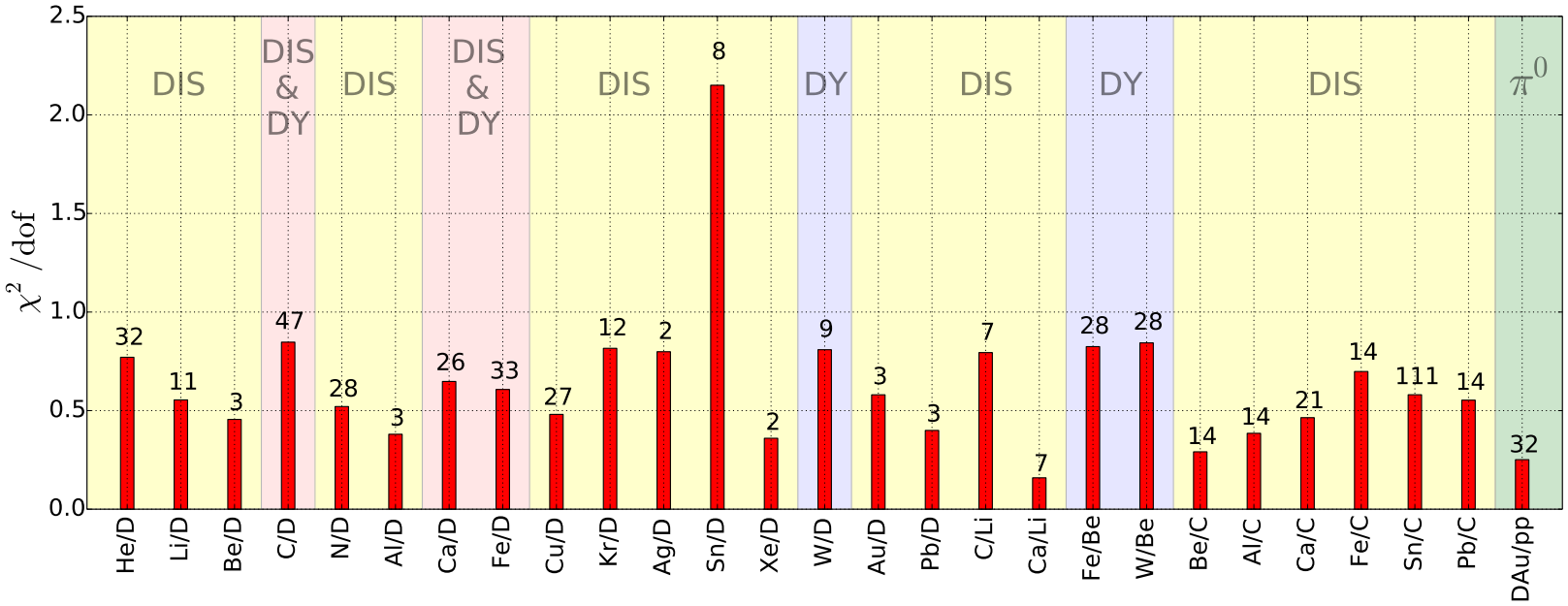


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| $\mathbf{F_2^A/F_2^D}$ : Observable | Experiment | ID | Ref. | # data | # data after cuts | $\chi^2$ |
|---|---|---|---|---|---|---|
| D | NMC-97 | 5160 | [48] | 292 | 201 | 247.73 |
| He/D | Hermes | 5156 | [49] | 182 | 17 | 13.45 |
| | NMC-95,re | 5124 | [50] | 18 | 12 | 9.78 |
| | SLAC-E139 | 5141 | [51] | 18 | 3 | 1.42 |
| Li/D | NMC-95 | 5115 | [52] | 24 | 11 | 6.10 |
| Be/D | SLAC-E139 | 5138 | [51] | 17 | 3 | 1.37 |
| C/D | FNAL-E665-95 | 5125 | [53] | 11 | 3 | 1.44 |
| | SLAC-E139 | 5139 | [51] | 7 | 2 | 1.36 |
| | EMC-88 | 5107 | [54] | 9 | 9 | 7.41 |
| | EMC-90 | 5110 | [55] | 9 | 0 | 0.00 |
| | NMC-95 | 5113 | [52] | 24 | 12 | 8.40 |
| | NMC-95,re | 5114 | [50] | 18 | 12 | 13.29 |
| N/D | Hermes | 5157 | [49] | 175 | 19 | 9.92 |
| | BCDMS-85 | 5103 | [56] | 9 | 9 | 4.65 |
| Al/D | SLAC-E049 | 5134 | [57] | 18 | 0 | 0.00 |
| | SLAC-E139 | 5136 | [51] | 17 | 3 | 1.14 |
| Ca/D | NMC-95,re | 5121 | [50] | 18 | 12 | 11.54 |
| | FNAL-E665-95 | 5126 | [53] | 11 | 3 | 0.94 |
| | SLAC-E139 | 5140 | [51] | 7 | 2 | 1.63 |
| | EMC-90 | 5109 | [55] | 9 | 0 | 0.00 |
| Fe/D | SLAC-E049 | 5131 | [58] | 14 | 2 | 0.78 |
| | SLAC-E139 | 5132 | [51] | 23 | 6 | 7.76 |
| | SLAC-E140 | 5133 | [59] | 10 | 0 | 0.00 |
| | BCDMS-87 | 5101 | [60] | 10 | 10 | 5.77 |
| | BCDMS-85 | 5102 | [56] | 6 | 6 | 2.56 |
| Cu/D | EMC-93 | 5104 | [61] | 10 | 9 | 4.71 |
| | EMC-93(chariot) | 5105 | [61] | 9 | 9 | 4.88 |
| | EMC-88 | 5106 | [54] | 9 | 9 | 3.39 |
| Kr/D | Hermes | 5158 | [49] | 167 | 12 | 9.79 |
| Ag/D | SLAC-E139 | 5135 | [51] | 7 | 2 | 1.60 |
| Sn/D | EMC-88 | 5108 | [54] | 8 | 8 | 17.20 |
| Xe/D | FNAL-E665-92 | 5127 | [62] | 10 | 2 | 0.72 |
| Au/D | SLAC-E139 | 5137 | [51] | 18 | 3 | 1.74 |
| Pb/D | FNAL-E665-95 | 5129 | [53] | 11 | 3 | 1.20 |
| **Total:** | | | | 1205 | 414 | 403.70 |

Table I: The DIS $F_2^A/F_2^D$ data sets used in the `nCTEQ15` fit. The table details values of $\chi^2$ for each experiment, the specific nuclear targets, references, and the number of data points with and without kinematic cuts.

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| $\mathbf{F_2^A/F_2^{A'}}$ : Observable | Experiment | ID | Ref. | # data | # data after cuts | $\chi^2$ |
|---|---|---|---|---|---|---|
| C/Li | NMC-95,re | 5123 | [50] | 25 | 7 | 5.56 |
| Ca/Li | NMC-95,re | 5122 | [50] | 25 | 7 | 1.11 |
| Be/C | NMC-96 | 5112 | [63] | 15 | 14 | 4.08 |
| Al/C | NMC-96 | 5111 | [63] | 15 | 14 | 5.39 |
| Ca/C | NMC-95,re | 5120 | [50] | 25 | 7 | 4.32 |
| | NMC-96 | 5119 | [63] | 15 | 14 | 5.43 |
| Fe/C | NMC-96 | 5143 | [63] | 15 | 14 | 9.78 |
| Sn/C | NMC-96 | 5159 | [64] | 146 | 111 | 64.44 |
| Pb/C | NMC-96 | 5116 | [63] | 15 | 14 | 7.74 |
| **Total:** | | | | 296 | 202 | 107.85 |

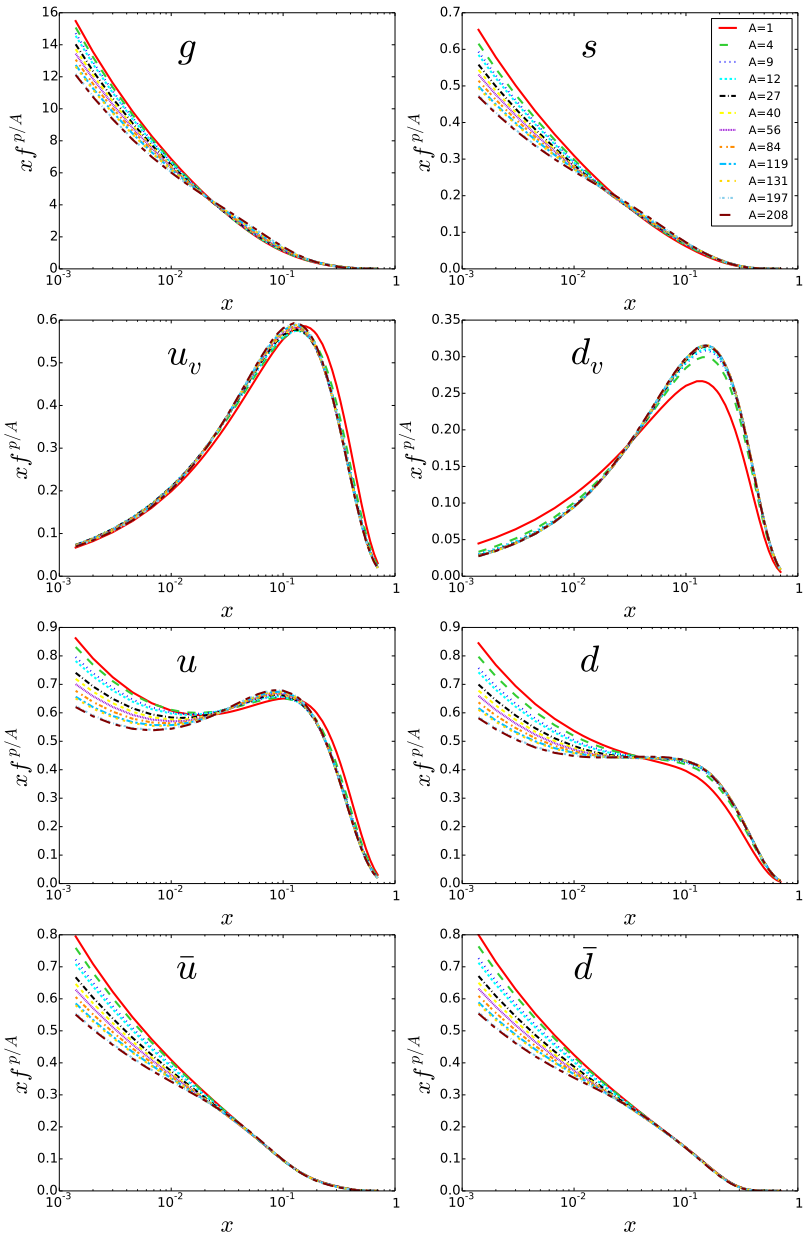
Table II: The DIS $F_2^A/F_2^{A'}$ data sets used in the nCTEQ15 fit. We list the same details for each data set as in Tab. I.

nCTEQ
nuclear parton distribution functions

| $\sigma_{DY}^{pA}/\sigma_{DY}^{pA'}$ : Observable | Experiment | ID | Ref. | # data | # data after cuts | $\chi^2$ |
|---|---|---|---|---|---|---|
| C/H2 | FNAL-E772-90 | 5203 | [65] | 9 | 9 | 7.92 |
| Ca/H2 | FNAL-E772-90 | 5204 | [65] | 9 | 9 | 2.73 |
| Fe/H2 | FNAL-E772-90 | 5205 | [65] | 9 | 9 | 3.17 |
| W/H2 | FNAL-E772-90 | 5206 | [65] | 9 | 9 | 7.28 |
| Fe/Be | FNAL-E886-99 | 5201 | [66] | 28 | 28 | 23.09 |
| W/Be | FNAL-E886-99 | 5202 | [66] | 28 | 28 | 23.62 |
| **Total:** | | | | 92 | 92 | 67.81 |

Table III: The Drell-Yan process data sets used in the nCTEQ15 fit. We list the same details for each data set as in Tab. I.

nCTEQ
nuclear parton distribution functions


g
s
u_v
d_v
u
d
ū
d̄
x f^{p/A}
x
A=1
A=4
A=9
A=12
A=27
A=40
A=56
A=84
A=119
A=131
A=197
A=208