Nuclear corrections to Vector Boson production at the LHC

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Vector Boson Production

- High Energy proton-proton collisions at the LHC are capable of producing many electroweak bosons (W/Z) at high rapidity.
- Properties of these bosons are well constrained making them ideal "standard candle" measurements for detector calibration.
- The hadronic cross section for Drell-Yan pair production is written

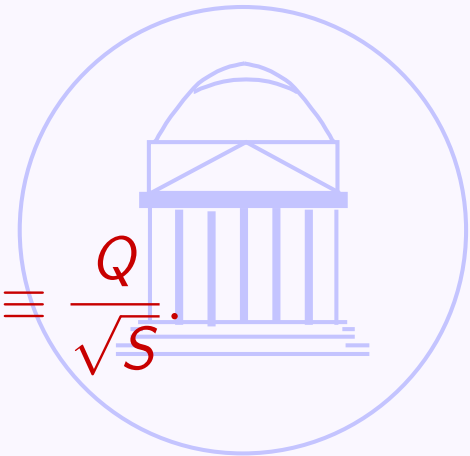
$$\frac{d\sigma}{dQ^2\,dy} = \sum_{a,b} \int_0^1 d\xi_1 \int_0^1 d\xi_2 \frac{d\hat{\sigma}}{dQ^2 dy} f_{a/A}(\xi_1) f_{b/B}(\xi_2)$$

- At LO we can make the approximation,

$$\xi_1 \approx x_1 \equiv \tau e^{y},$$
$$\xi_2 \approx x_2 \equiv \tau e^{-y},$$

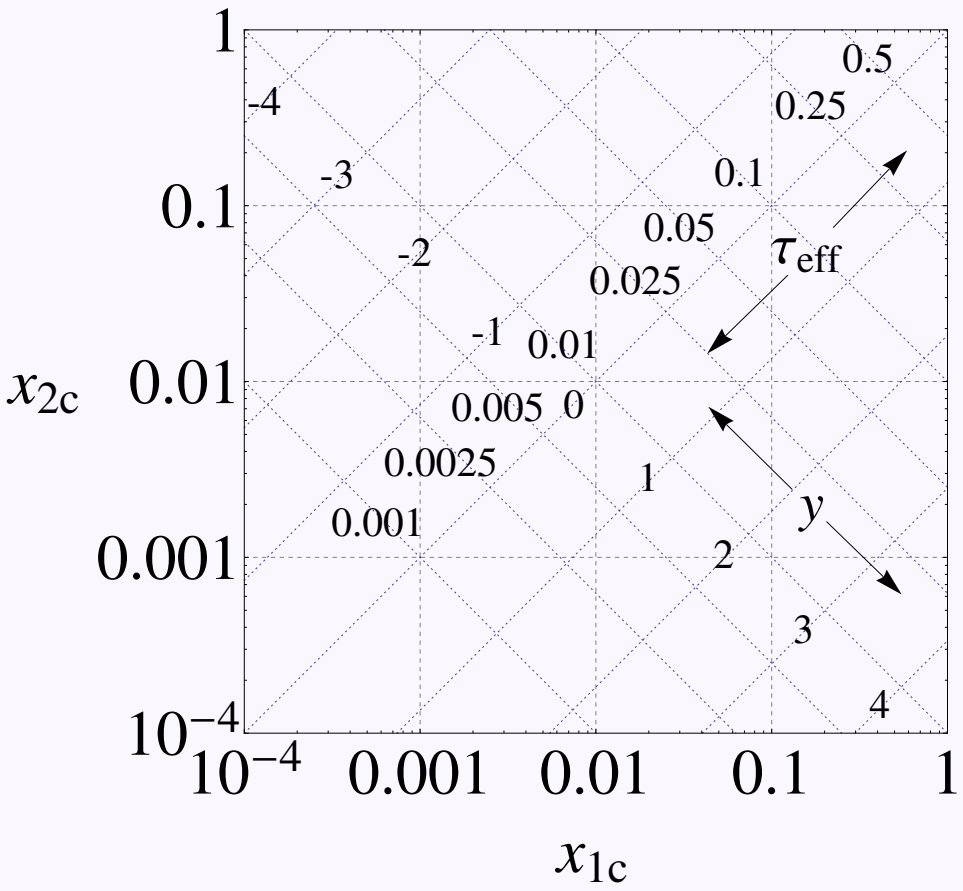
where

$$\tau \equiv \frac{Q}{\sqrt{S}}.$$



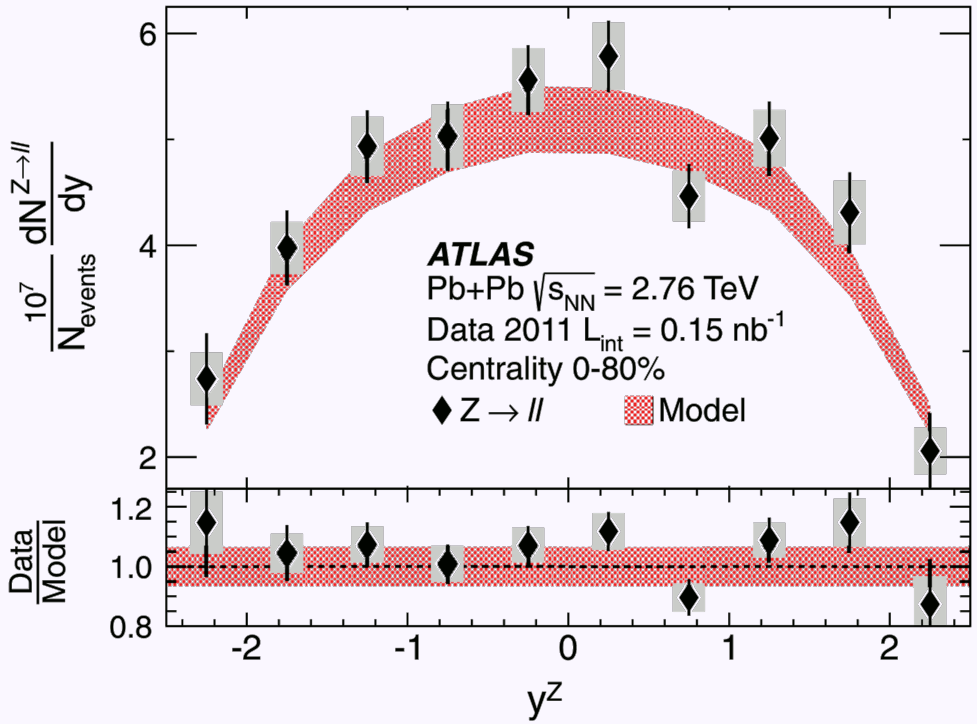
Vector Boson Production

- This means that rapidity measurements for on-shell vector boson production provide a method for probing the x dependence of the PDFs.



(Guzey,V. et al, arXiv:1212.5344v1))

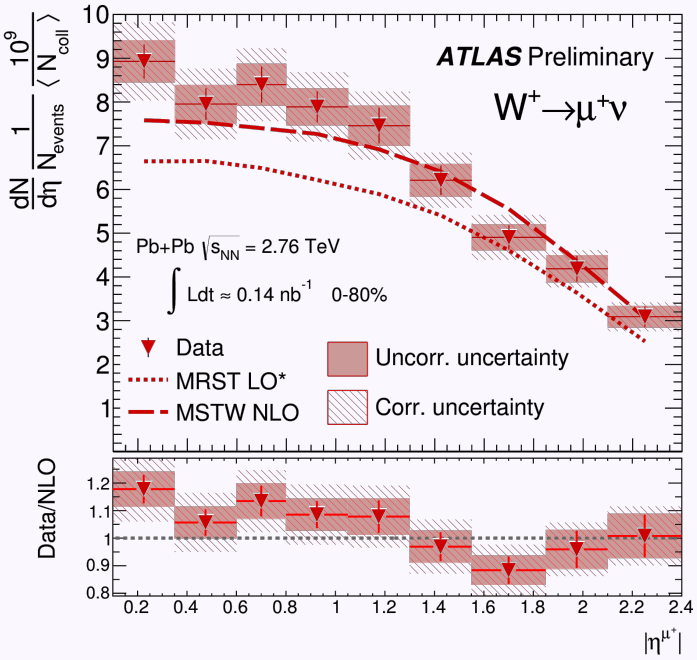
ATLAS measurement

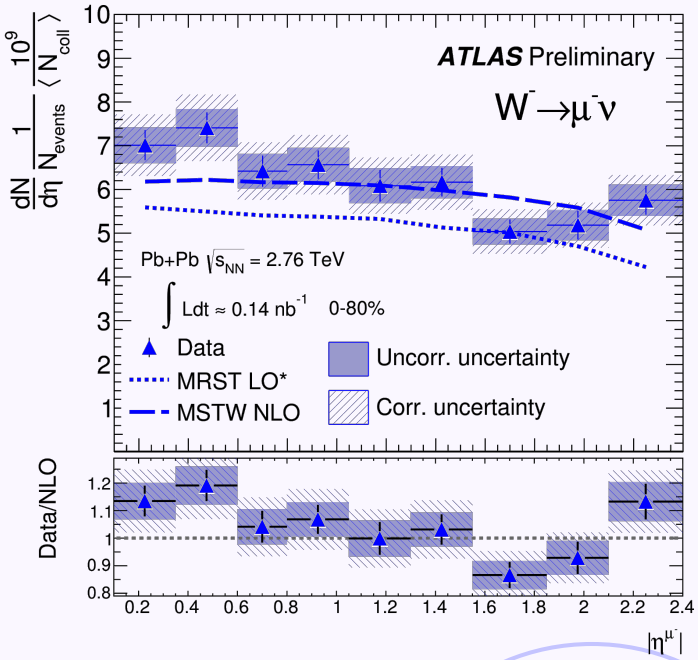


(ATLAS Collaboration, PRL 110,022301 92013))

- In January of 2013, ATLAS released the results of their Z boson rapidity distribution for Pb-Pb collisions at $2.76\mathrm{TeV}$.
- ATLAS observed 1995 candidate events corresponding to $0.15\mathrm{nb}^{-1}$ of integrated Luminosity.

ATLAS measurement





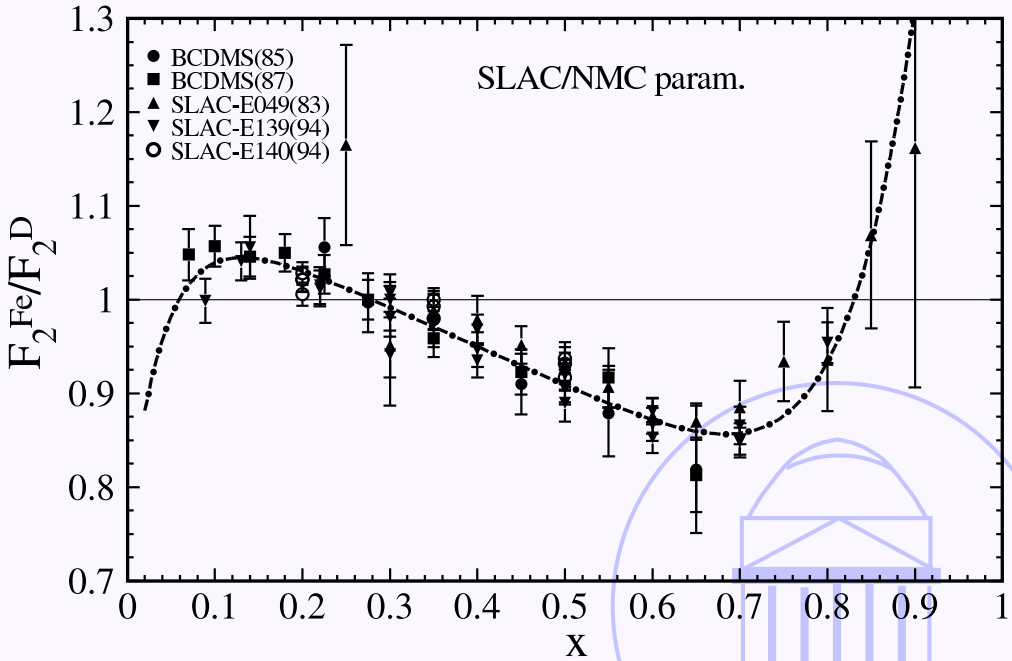
(ATLAS Collaboration, ATLAS-CONF-2013-106)

- In November of 2013, ATLAS released the result of their μ^+ and μ^- rapidity measurements.
- All of the heavy ion runs have been compared to predictions made with NLO PDFs.

Nuclear Modifications

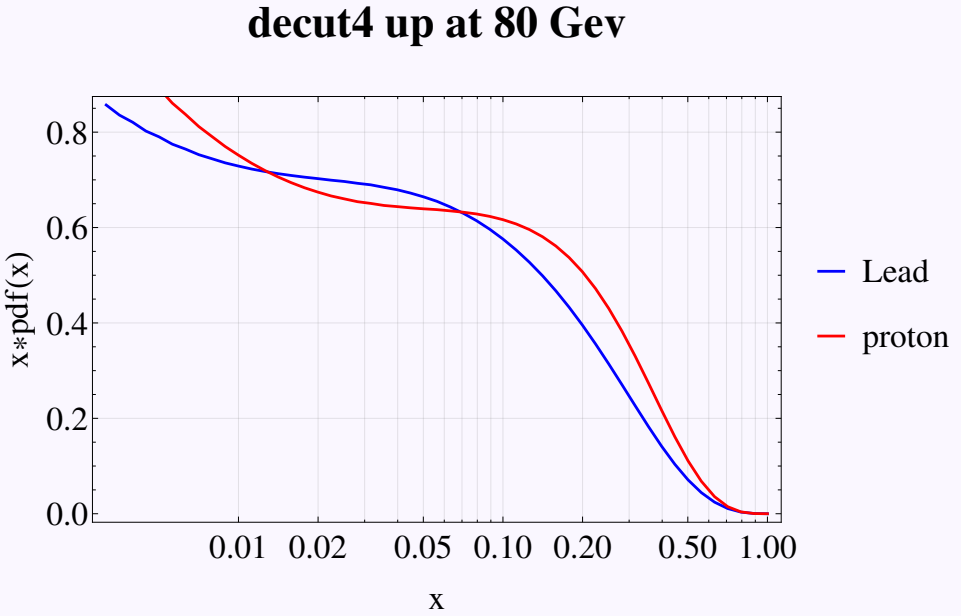
- Nuclear PDFs (nPDFs) can show significant modifications to the free proton PDFs.

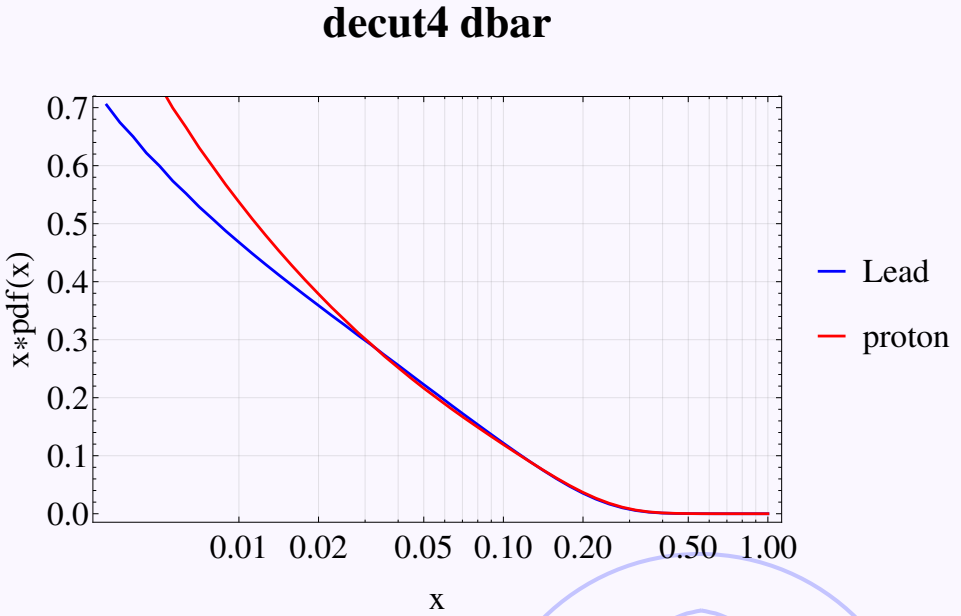
- DIS data suggest several types of corrections:
  - Shadowing
    $x < 0.05 - 0.1$
  - Anti-shadowing
    $0.1 \leq x \leq 0.3$
  - EMC effect
    $0.3 \leq x \leq 0.8$
  - Fermi motion
    $x > 0.8$



(Schienbein et. al. arXiv:0907.2357v2)

Nuclear Modifications





- The nuclear modifications are present in the PDFs and vary with A as well as x and Q.
- We expect modifications to any hadronic observable involving heavy nuclei.

nCTEQ PDFs

- The nCTEQ proton PDFs are parameterized according to the following prescription;

$$\begin{aligned} x\, f_k(x, Q_0) &= c_0 x^{c_1} (1-x)^{c_2} e^{c_3 x} (1 + e^{c_4} x)^{c_5} \\ k &= u_v, d_v, g, \bar{u} + \bar{d}, s, \bar{s}\,, \\ \bar{d}(x, Q_0)/\bar{u}(x, Q_0) &= c_0 x^{c_1} (1-x)^{c_2} + (1 + c_3 x)(1-x)^{c_4} \end{aligned}$$

- The nuclear A dependence is then applied to the coefficients in the parameterization.

$$c_k \to c_k(A) \equiv c_{k,0} + c_{k,1} \left(1 - A^{-c_{k,2}}\right), \quad k = \{1, \ldots, 5\}$$

(Schienbein et. al. arXiv:0907.2357v2)

nCTEQ PDFs

- The nCTEQ group has produced a several sets of nuclear nPDFs at NLO for public distribution.

(Schienbein et. al. arXiv:0907.2357v2)

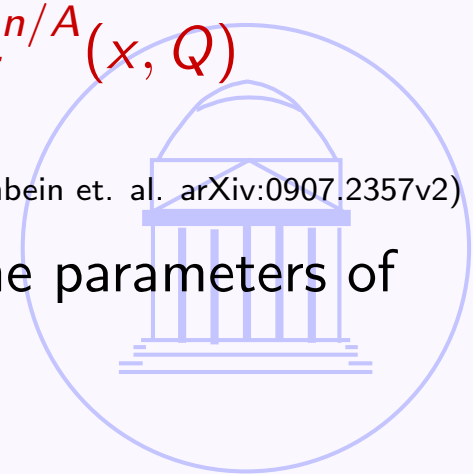
(Stavreva et. al. arXiv:1012.1178)

- These PDF sets are scaled down to the proton.
- The PDF for a general nucleus can be constructed as a linear combination of the PDFs,

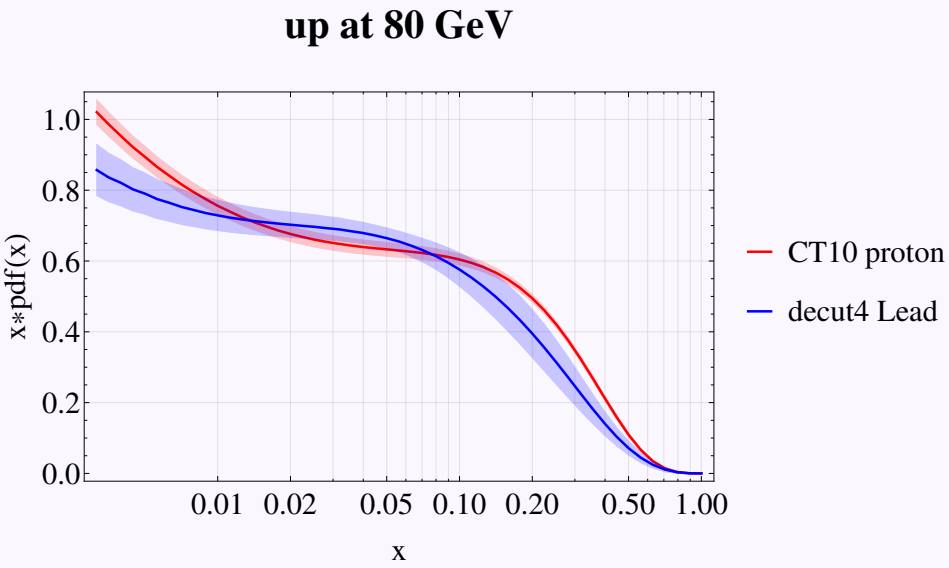
$$f_i^{(A,Z)}(x,Q) = \frac{Z}{A}\, f_i^{p/A}(x,Q) + \frac{(A-Z)}{A}\, f_i^{n/A}(x,Q)$$

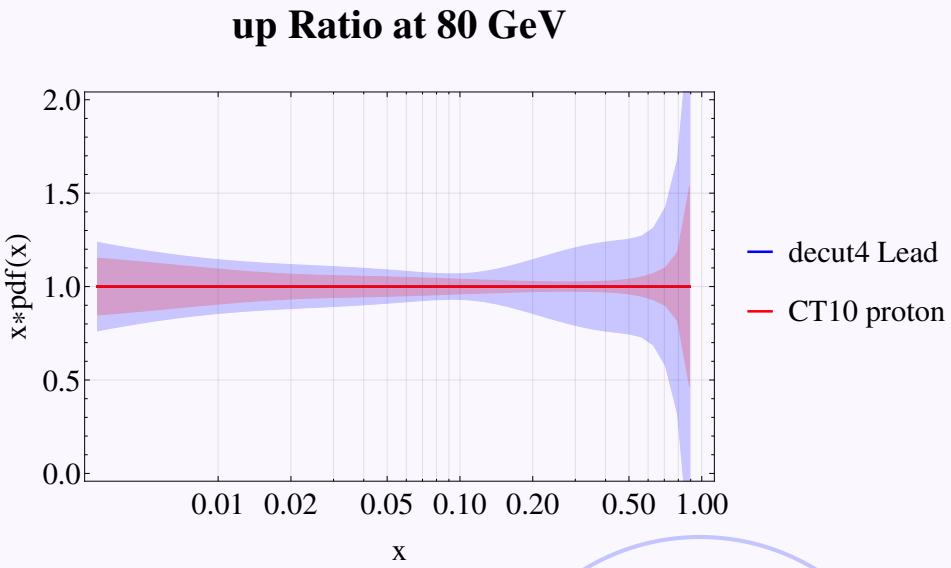
(Schienbein et. al. arXiv:0907.2357v2)

- Hessian error sets for the nPDFs are provided for the parameters of the nuclear correction.



nCTEQ Errors vs CT10 Errors

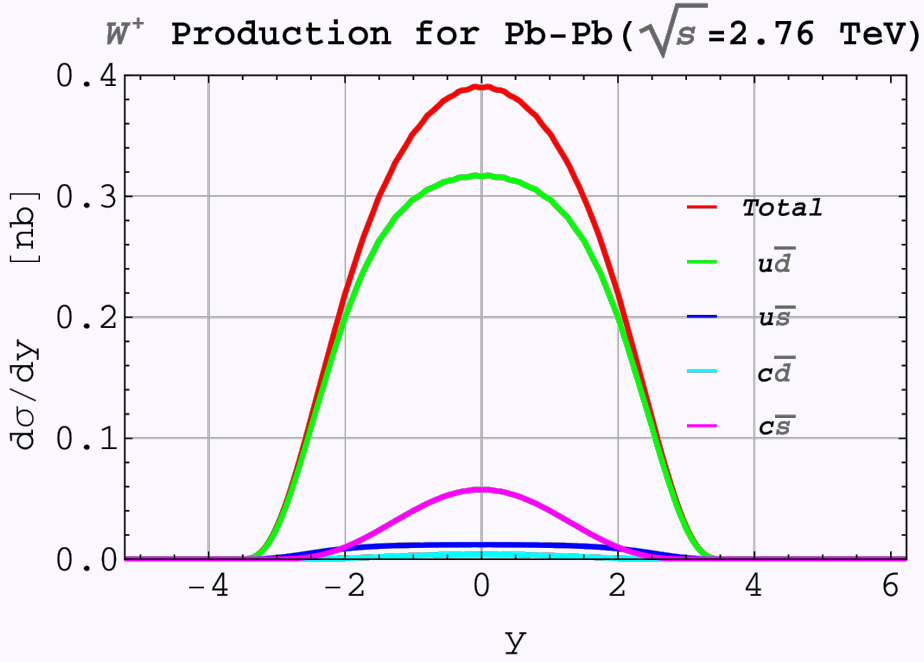




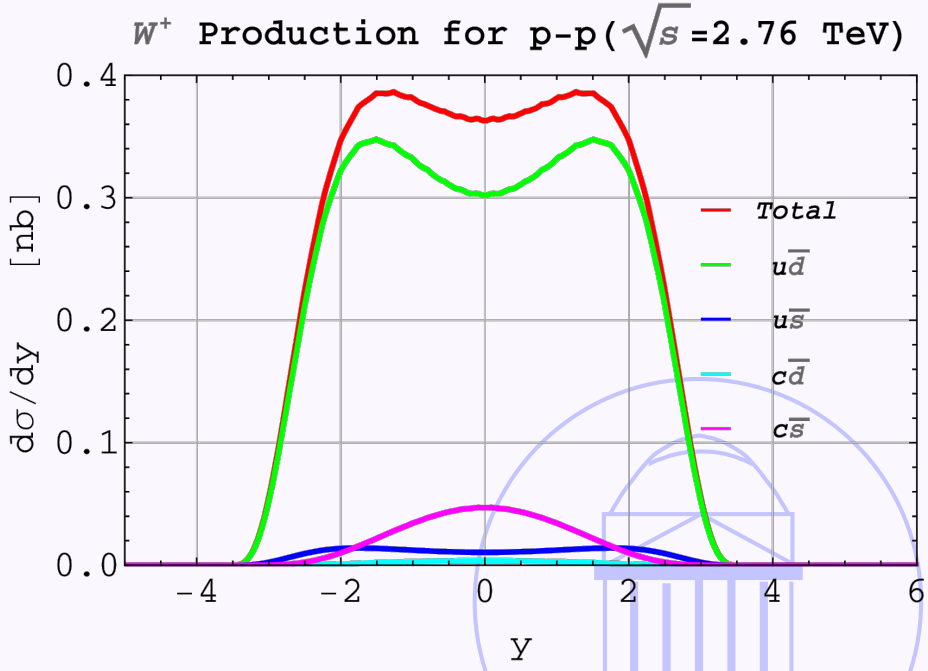
- Error sets have been created for the nCTEQ PDFs by Aleksander Kusina and Fred Olness.
- The error sets are over 17 eigenvectors. Each family contains 35 PDF sets.

LO Rapidity Calculation

- A LO calculation of rapidity shows shape changes due to the softening of the $u\ (x, Q)$ and $\bar{d}\ (x, Q)$ PDFs.



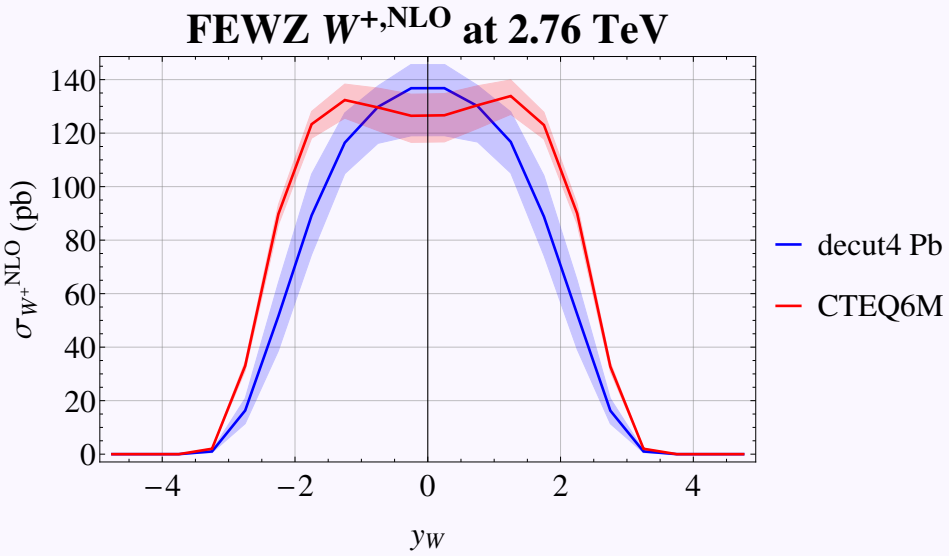
Pb-Pb

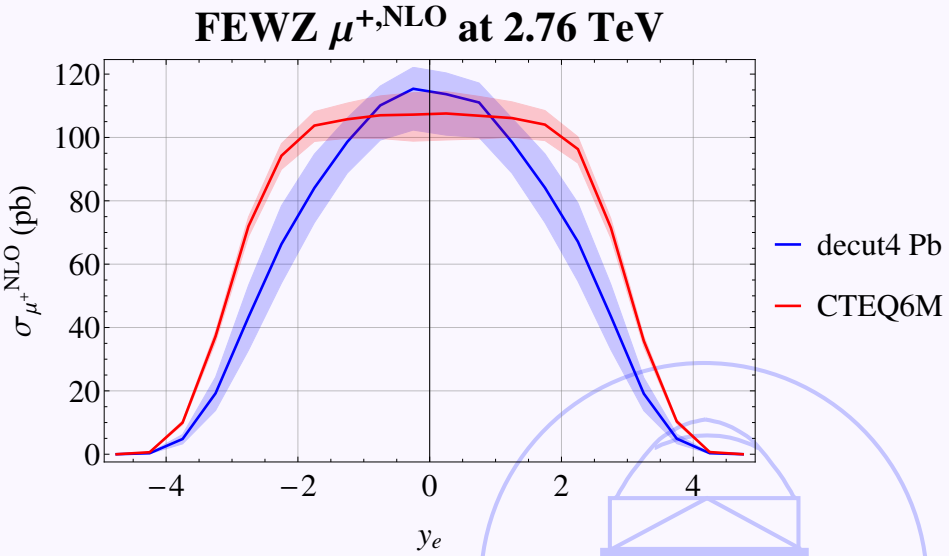


p-p

Pb-Pb vs. p-p rapidity

- There is an observable shape change for on-shell W^+ production. The difference is up to 20 % in some regions of parameter space.

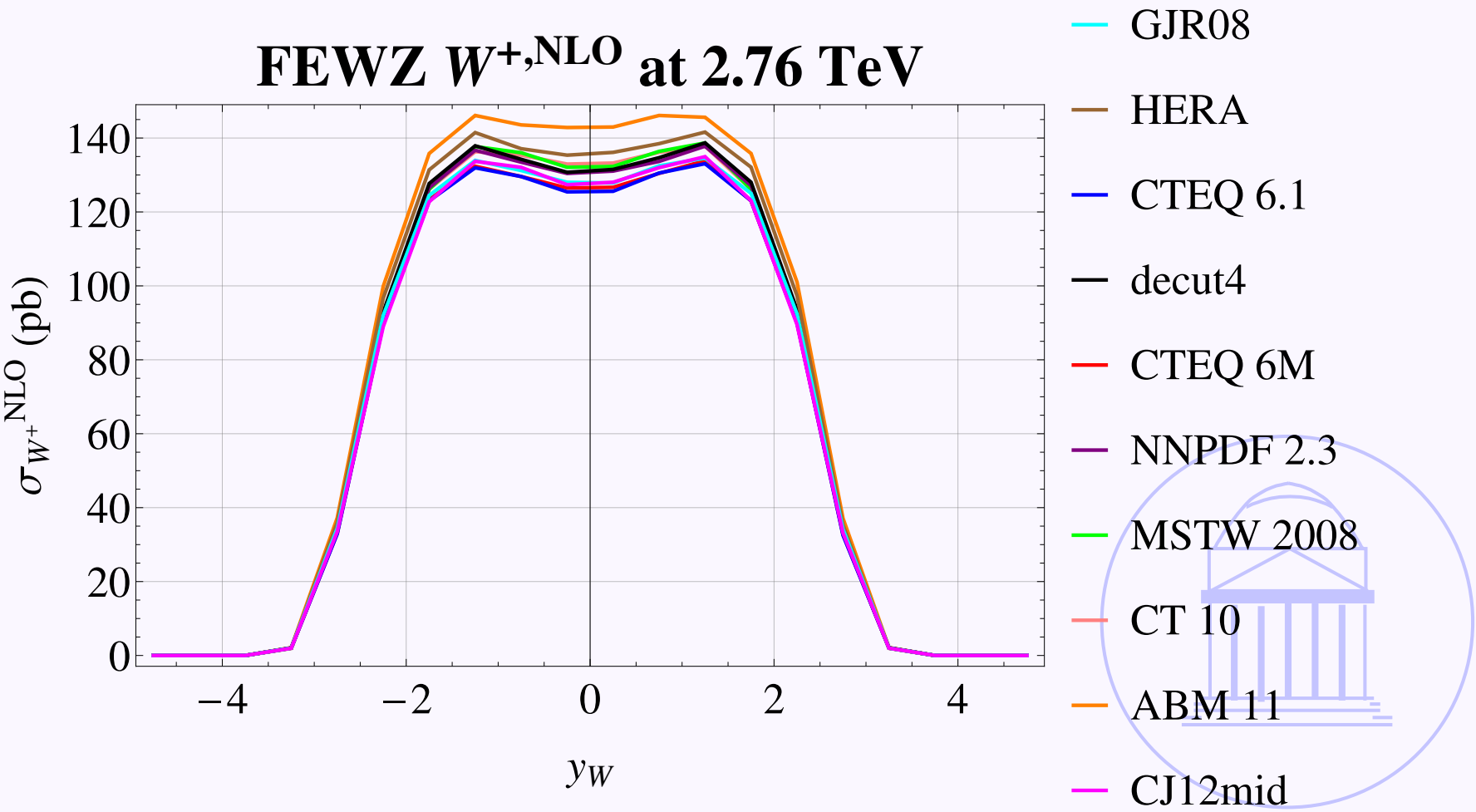




- These differences should be seen with a higher integrated luminosity for Pb-Pb collisions.

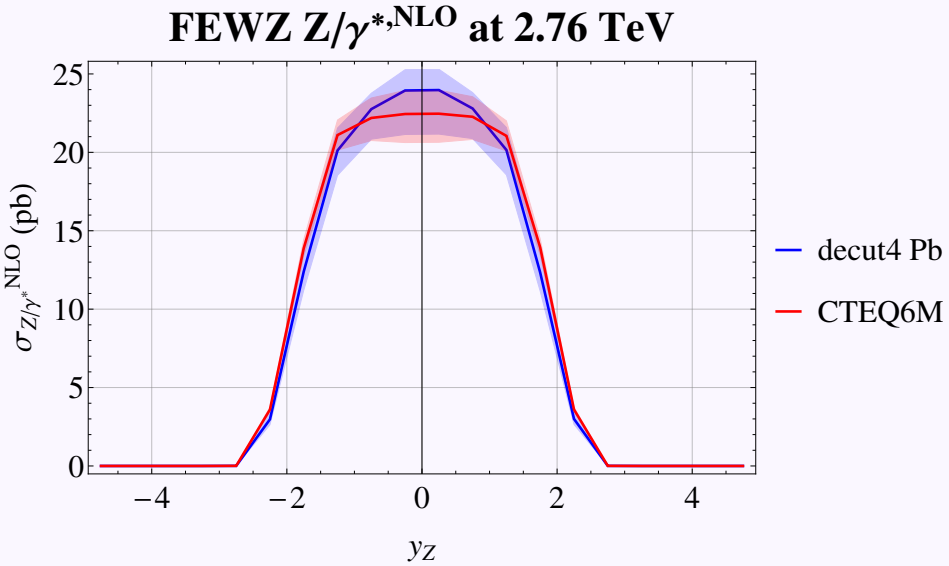
PDF Comparison

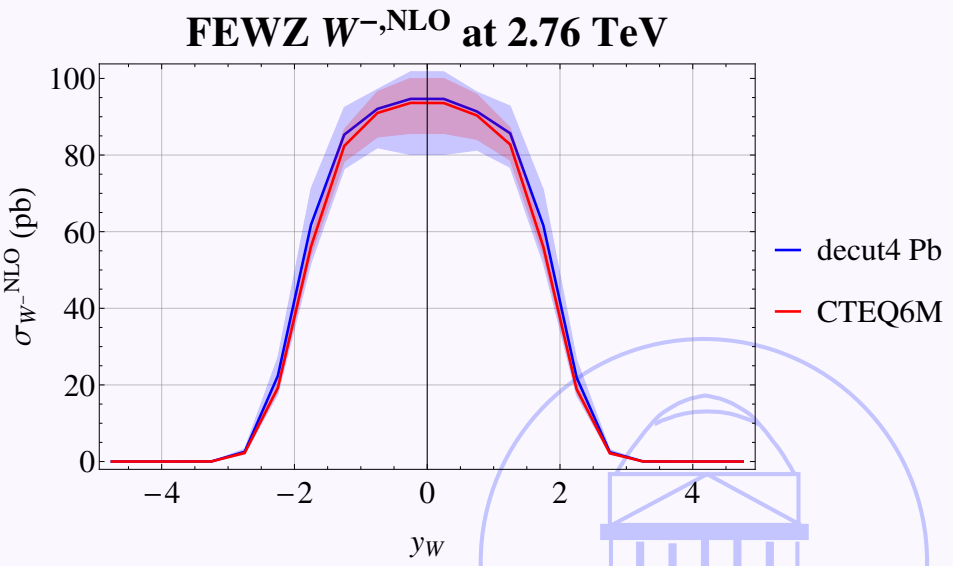
- The nCTEQ proton PDF set gives similar predictions to other commonly used sets.



Pb-Pb vs. p-p rapidity

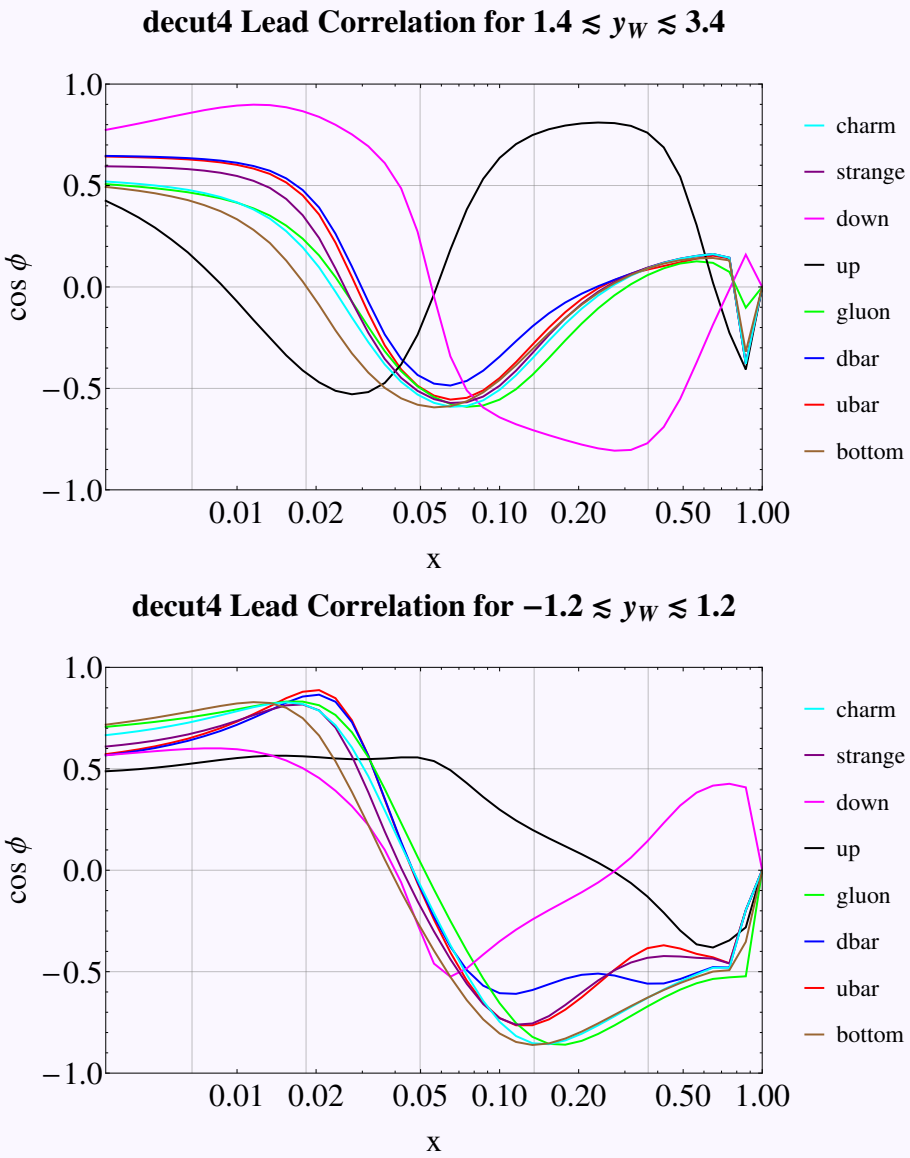
- No shape change for on-shell Z and W^- rapidity is found as we move from the proton PDFs to Lead.





- The shapes of the lepton distributions for these bosons are also indistinguishable.

PDF Correlations (Preliminary)



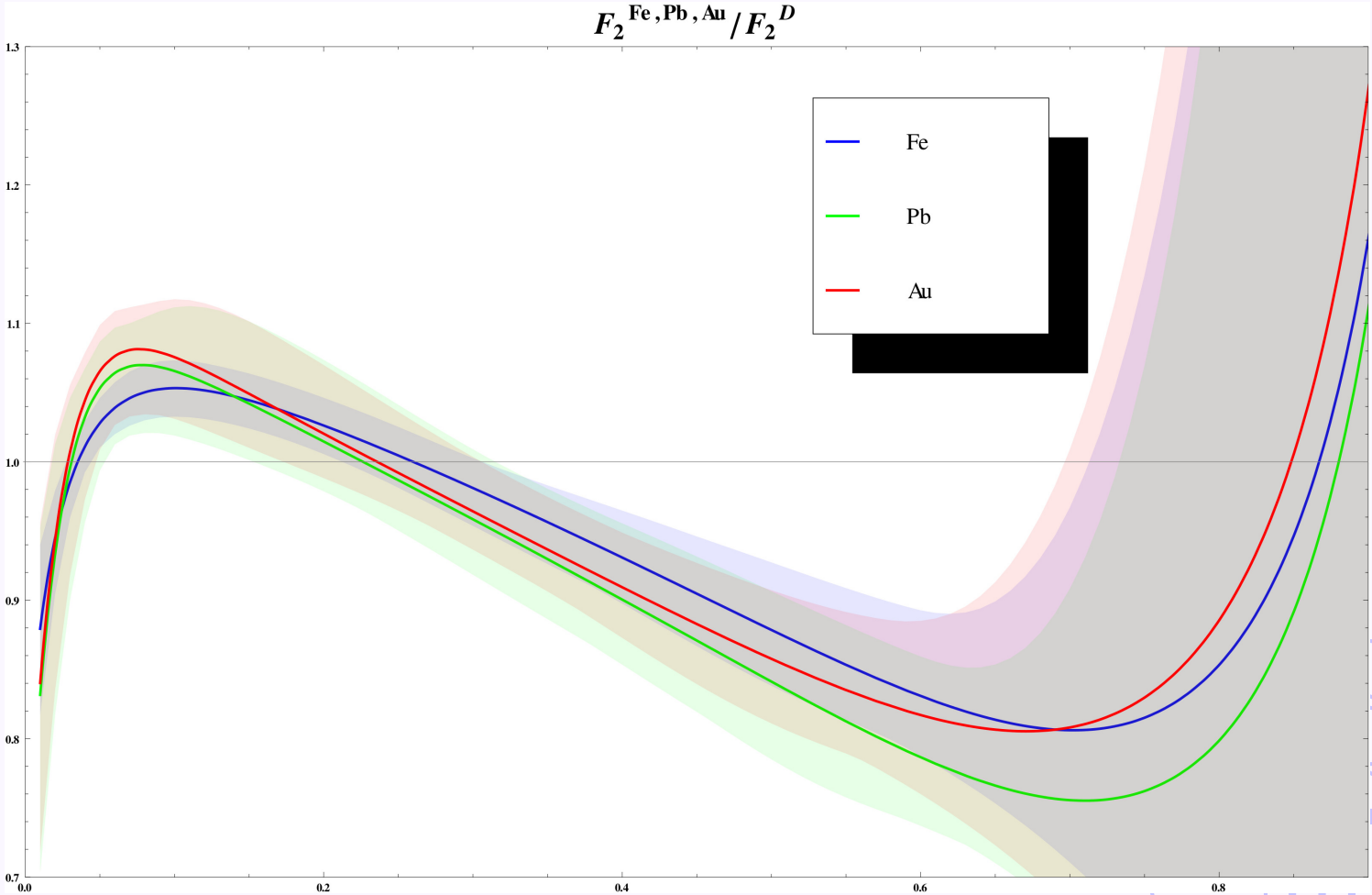
- In the high absolute rapidity region, the error is dominated by the uncertainty on the down PDF.
- In the central region, the $\bar{u}$ and $\bar{d}$ uncertainty provides the largest contribution but there is also a significant gluon contribution.
- Gluon data at low x values is needed to constrain the nCTEQ $g(x, Q)$ distribution.

Conclusions

- Nuclear modifications to the W^+ rapidity distributions may be observable in future heavy ion measurements at the LHC.
- W^- and Z boson production in $Pb-Pb$ collisions does not show significant modifications to the predictions made with proton PDFs.
- At low x in the central rapidity region, there is a large contribution due to the gluon PDF.
- Inclusion of these measurements in future PDF fits will help to constrain the gluon, as well as other poorly constrained PDFs.

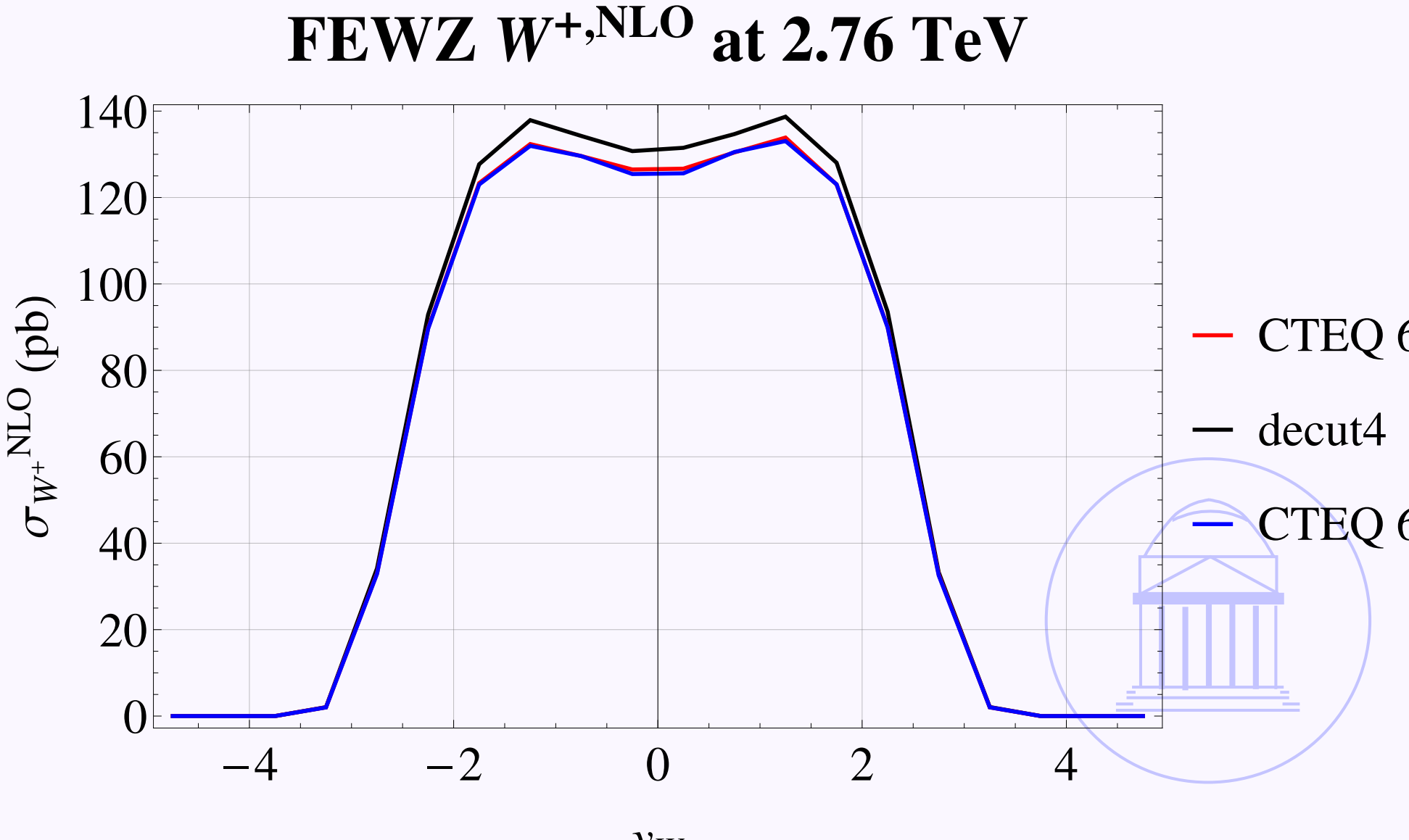
Backup Slides

Constraints on PDFs

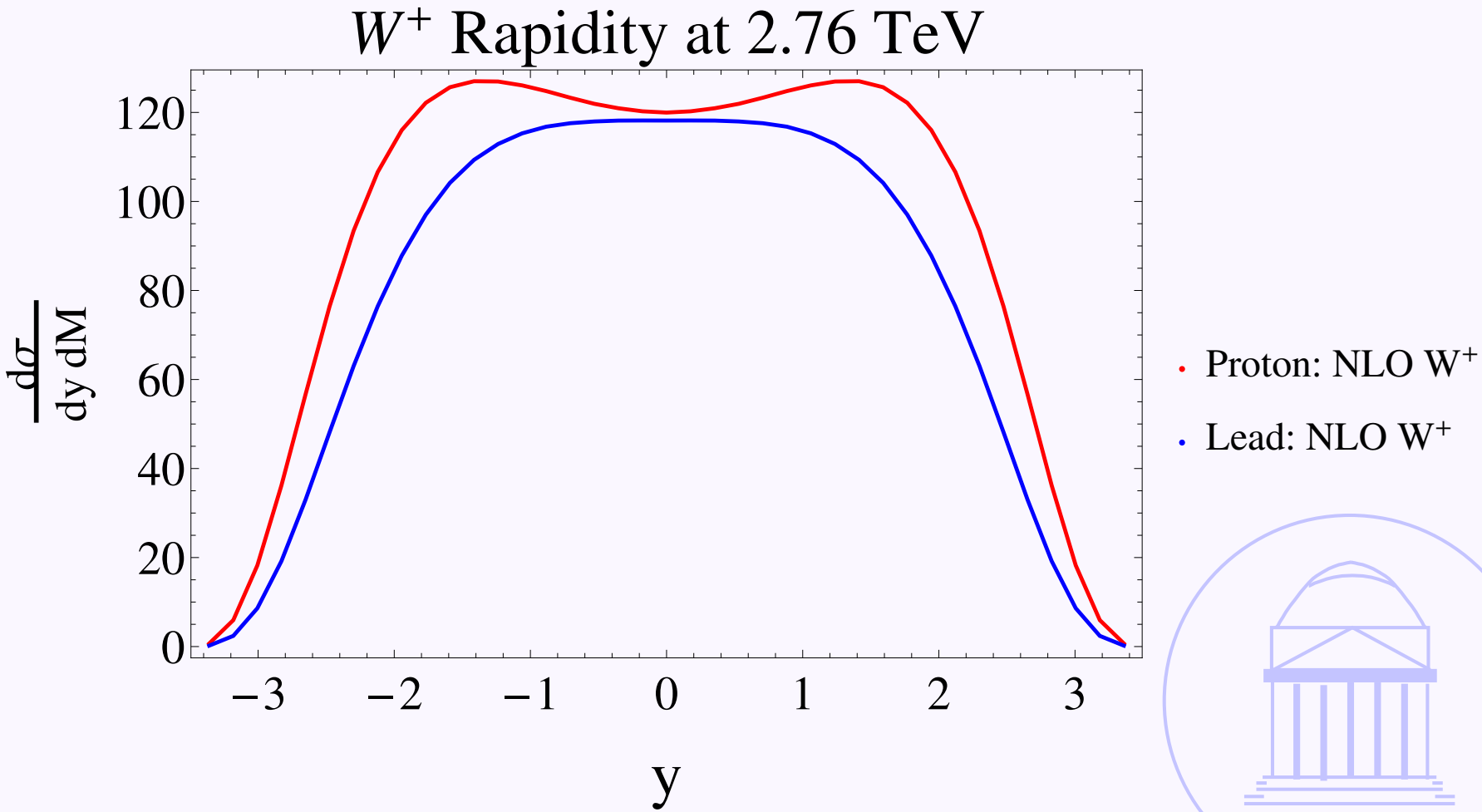


- The inclusion of LHC data from heavy ion collisions will help to further constrain the nPDFs.

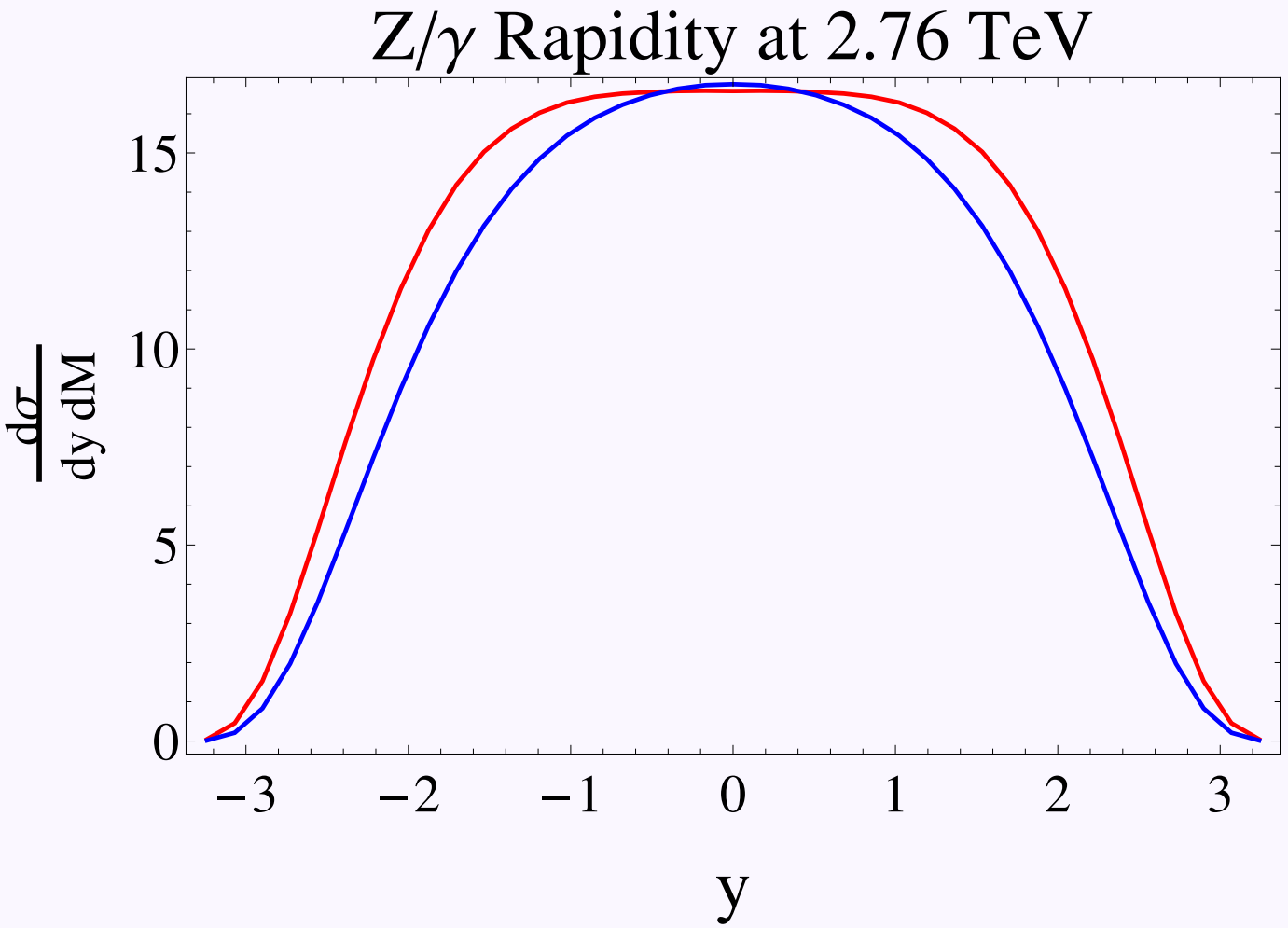
CTEQ PDF Comparison



decut3 Comparison

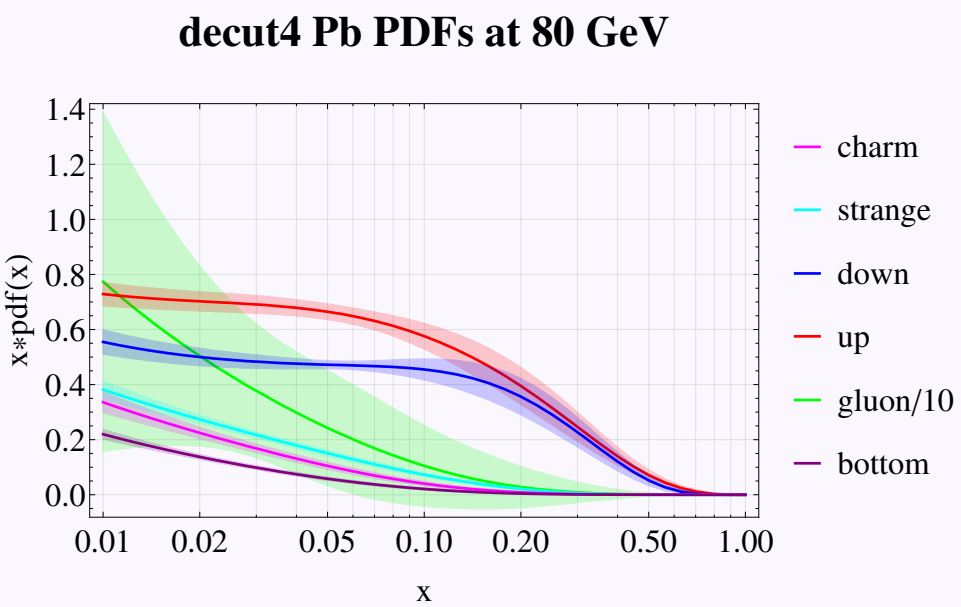


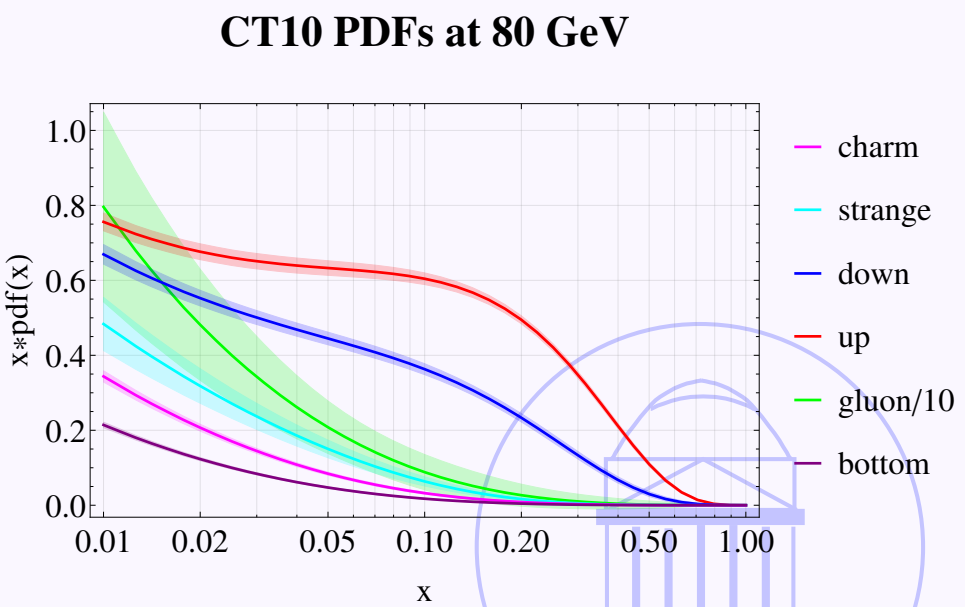
decut3 Comparison



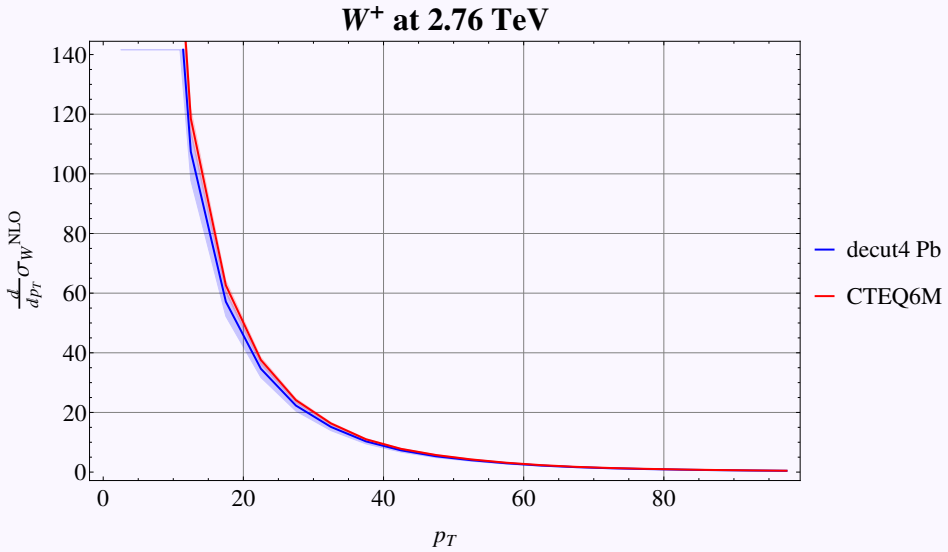
PDF Comparison

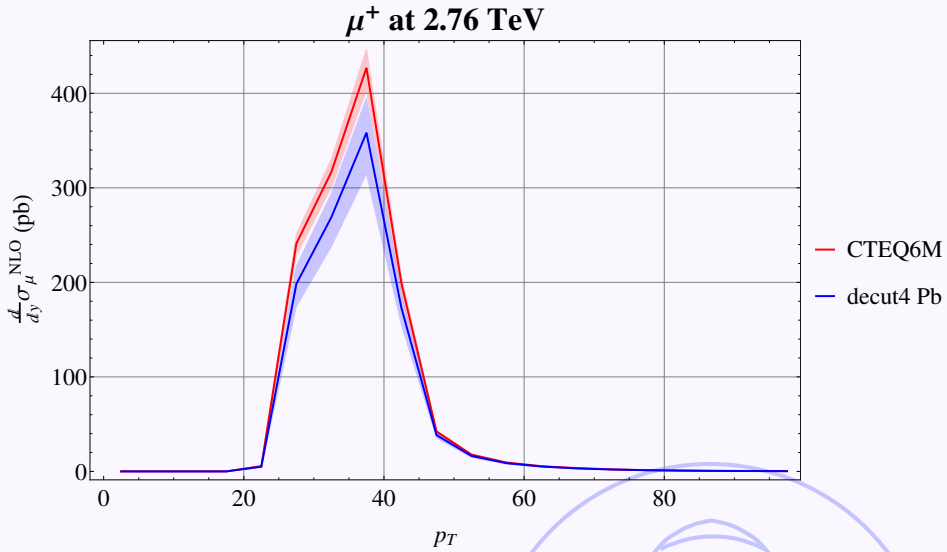
- The nuclear PDFs are not as well constrained as the proton fits.





Transverse Momentum





- The transverse momenta of the lead and proton predictions are very similar.