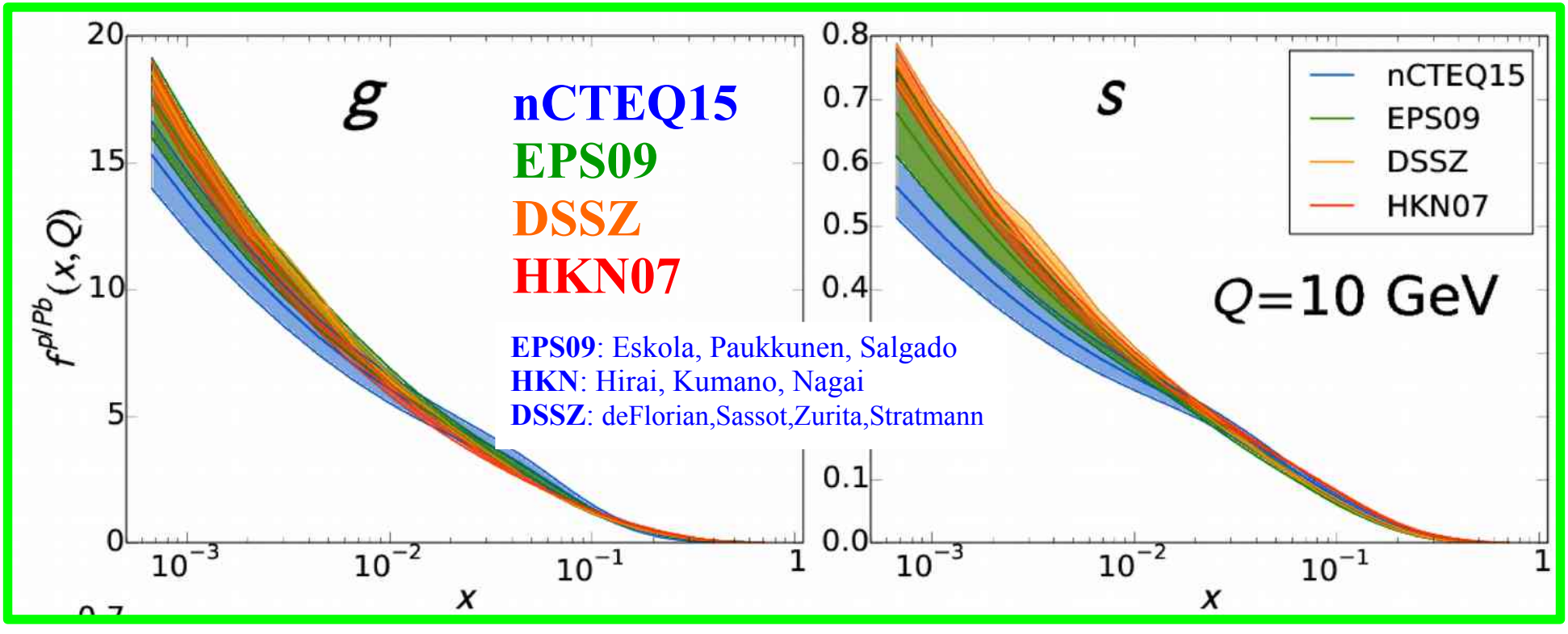
Nuclear PDF Discussion

Outline and discussion points from nCTEQ perspective

Fred Olness
SMU



Thanks to:
F. Lyonnet, B. Clark, E. Godat, A. Kusina,, I. Schienbein, K. Kovarik, J.Y. Yu, T. Jezo, J.G. Morfin, J.F. Owens, P. Nadolsky, M. Guzzi, V. Radescu, C. Keppel, C. Bertulani, J. Thomas

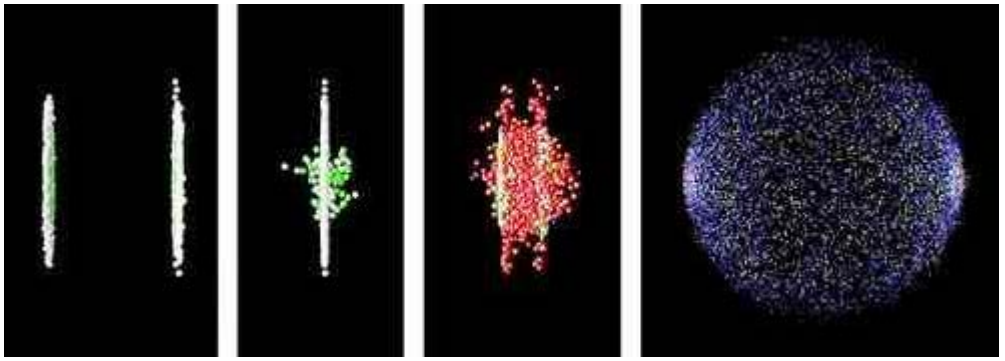
INT Workshop
15 February 2017

Motivation for nPDFs???

Make predictions for heavy ion collisions at:

RHIC (Al, Au, Cu, U, ...)

LHC (pPb, PbPb)



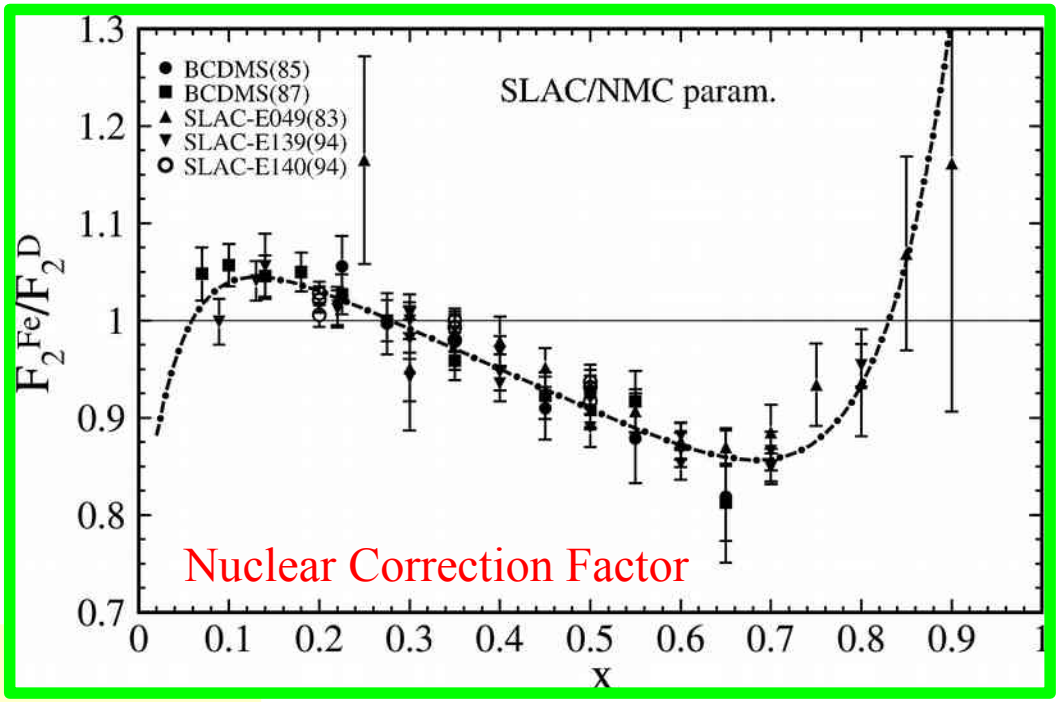
Differentiate flavors of free-proton PDFs:

neutrino DIS

$$F_2^{\nu} \sim \left[d + s + \bar{u} + \bar{c}\right]$$
$$F_2^{\bar{\nu}} \sim \left[\bar{d} + \bar{s} + u + c\right]$$
$$F_3^{\nu} \sim 2\left[d + s - \bar{u} - \bar{c}\right]$$
$$F_3^{\bar{\nu}} \sim 2\left[u + c - \bar{d} - \bar{s}\right]$$

charged lepton DIS

$$F_2^{l^{\pm}} \sim \left(\tfrac{1}{3}\right)^2 [d + s] + \left(\tfrac{2}{3}\right)^2 [u + c]$$

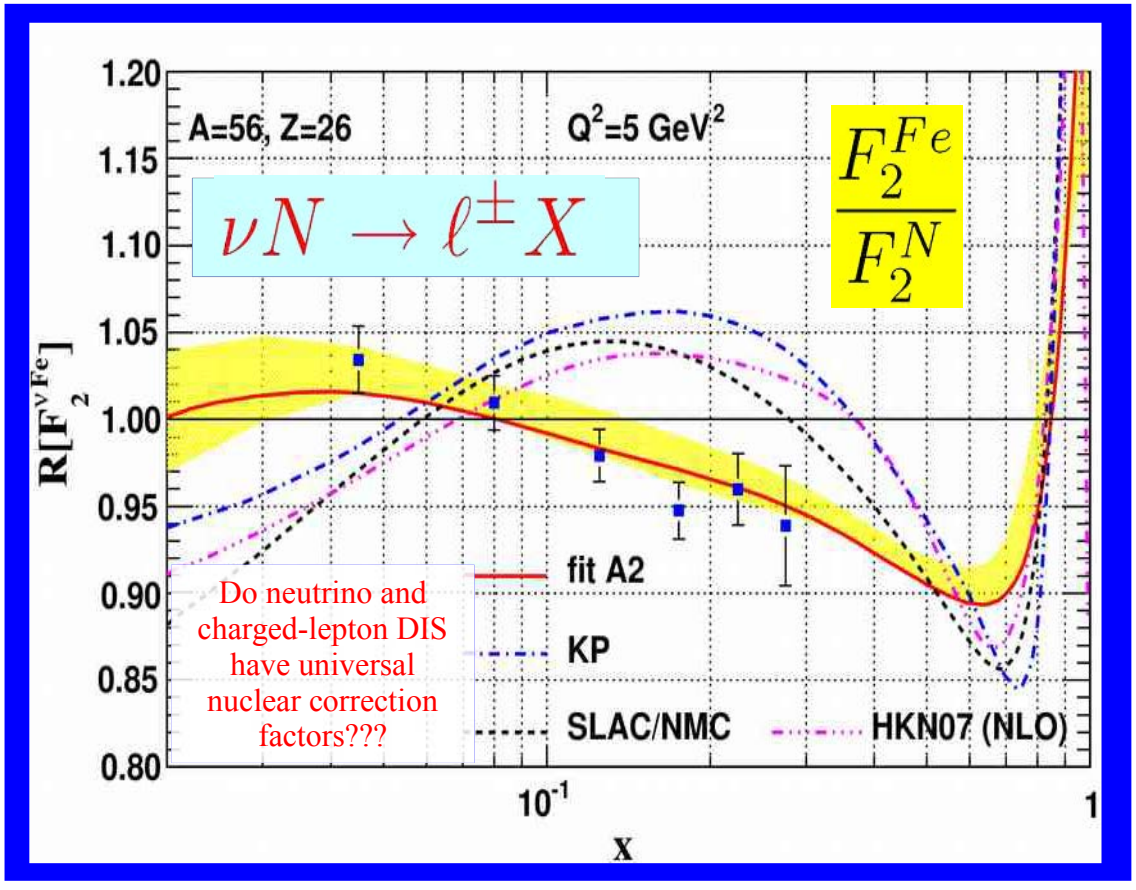


Can our Framework adequately/accurately describe all phenomena

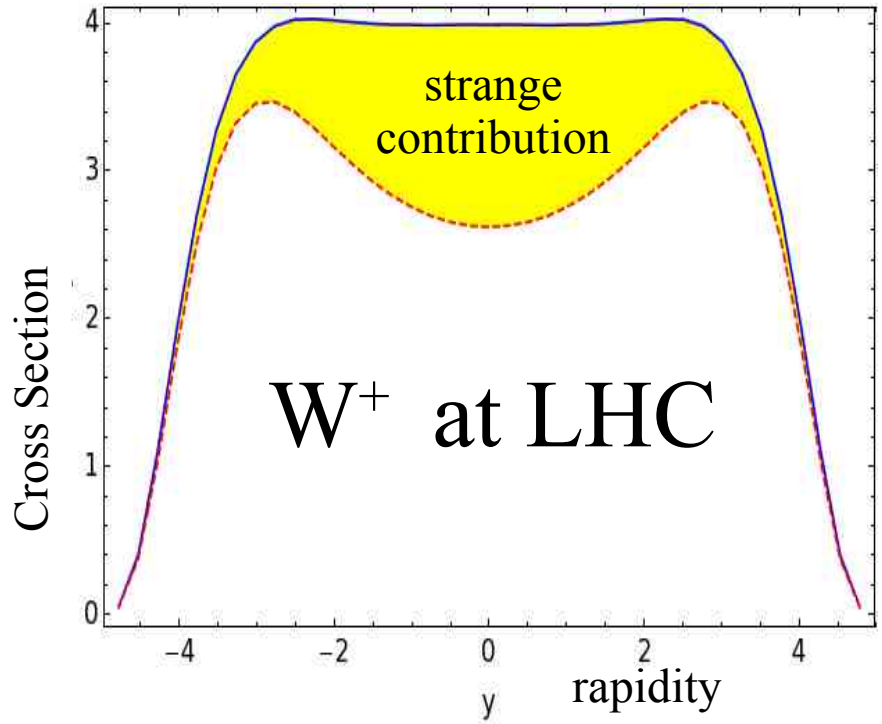
While in non-peripheral collisions between heavy ions the classification of centrality classes appears to be robust, in proton-lead collisions at the Large Hadron Collider (LHC) the situation is far more problematic. Whereas for both dijets and single jets the minimum bias results are well reproduced by standard pQCD with nuclear modification of parton densities, the centrality-selected results show a strong dependence on centrality that **cannot be accommodated by the existing ideas on the impact parameter dependence of nuclear parton densities.** There is an ongoing discussion on the definition of centrality in such asymmetric systems.

Nestor Armesto, Doga Can Gulhan, Jose Guilherme Milhano; arXiv:1502.02986

Can a "Nuclear Correction Factor" allow for all possible effects



Nuclear correction affects s(x)
Can we extract from LHC instead



Data sets & cuts for nPDF fits

NC DIS & DY

SLAC E-139 & E-049
N = (D, Ag, Al, Au, Be,C, Ca, Fe, He)

CERN BCDMS & EMC & NMC
N = (D, Al, Be, C, Ca, Cu, Fe, Li, Pb, Sn, W)

DESY Hermes
N = (D, He, N, Kr)

FNAL E-665
N = (D, C, Ca, Pb, Xe)

FNAL E-772 & E-886
N = (D, C, Ca, Fe,W)

Neutrino DIS

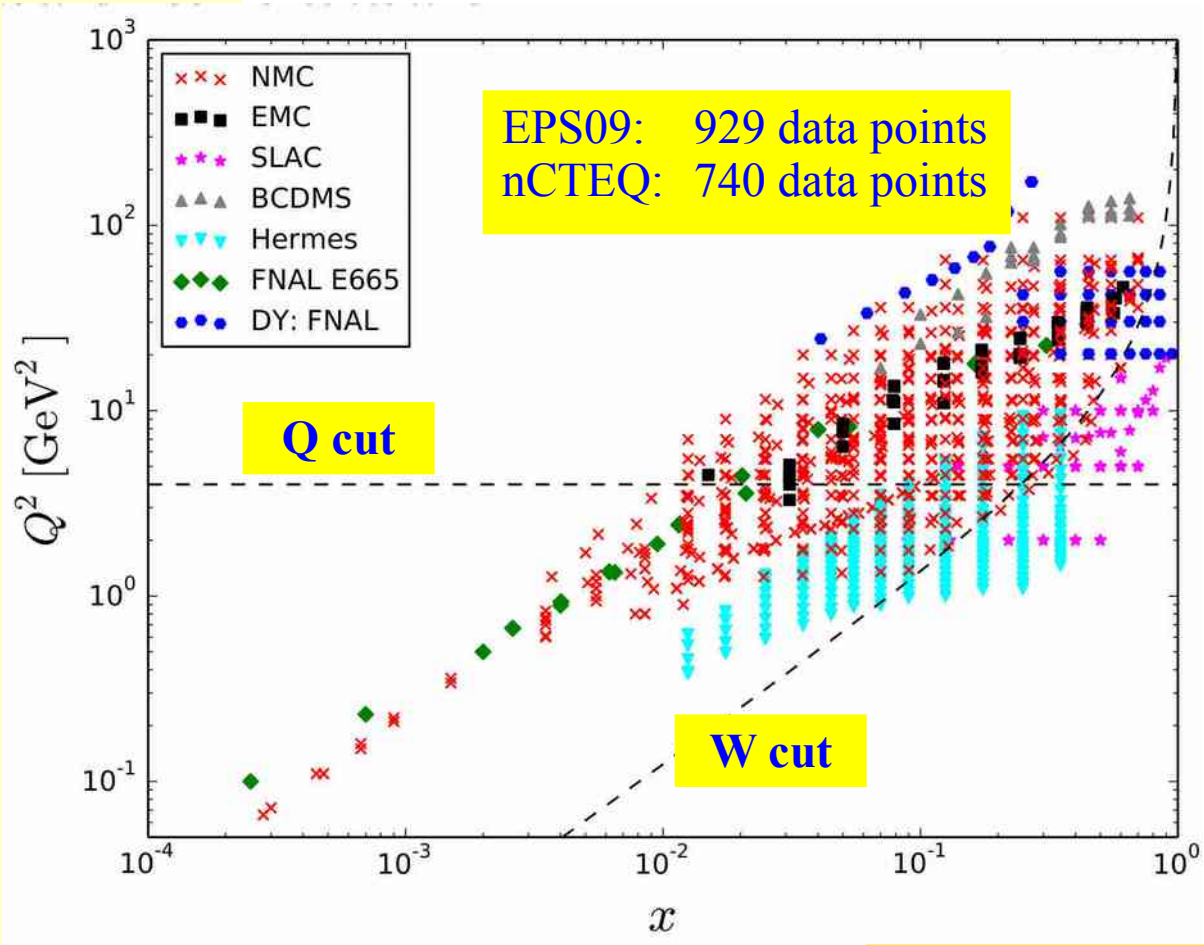
NuTeV CHORUS CCFR & NuTeV
N = Pb & Fe

Pion Production:

RHIC: PHENIX & STAR
N = Au

… near future: LHC pPb

DIS Cuts:
EPS: Q>1.3
HKN: Q>1.0
DSSZ: Q>1.0
nCTEQ: Q>2.0 & W>3.5



fewer data and more DOF … impose assumptions on nPDFs

(new: EPPS16)

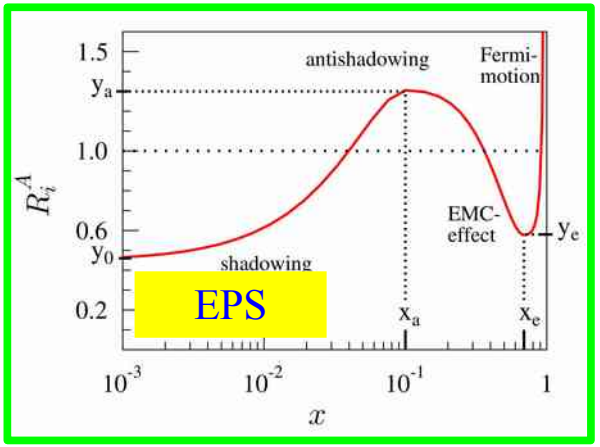
1) Multiplicative nuclear correction factors (HKN, EPS, DSSZ)

$$f_i^{p/A}(x_N, Q_0) = R_i(x_N, Q_0, A)\; f_i^{free\ proton}(x_N, Q_0)$$

... for example

HKN

$$R_i(x, Q_0, A) = 1 + \left(1 - \frac{1}{A^\alpha}\right) \frac{a_i + b_i x + c_i x^2 + d_i x^3}{(1-x)^{\beta_i}}$$



2) Generalized A-parameterization (nCTEQ)

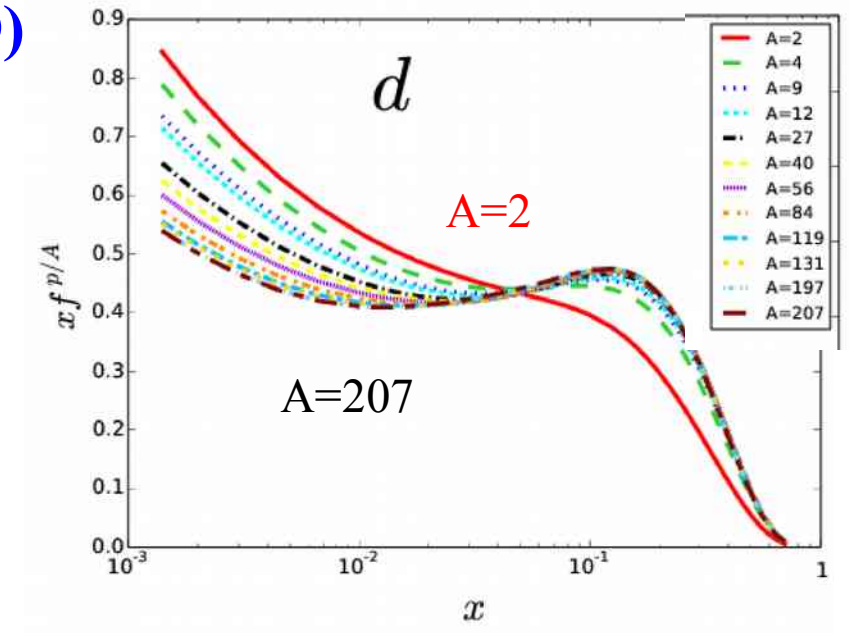
$$f_i^{p/A}(x_N, \mu_0) = f_i(x_N, A, \mu_0)$$

$$f \sim \ldots x^{c_1(A)}(1-x)^{c_2(A)}\ldots$$

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

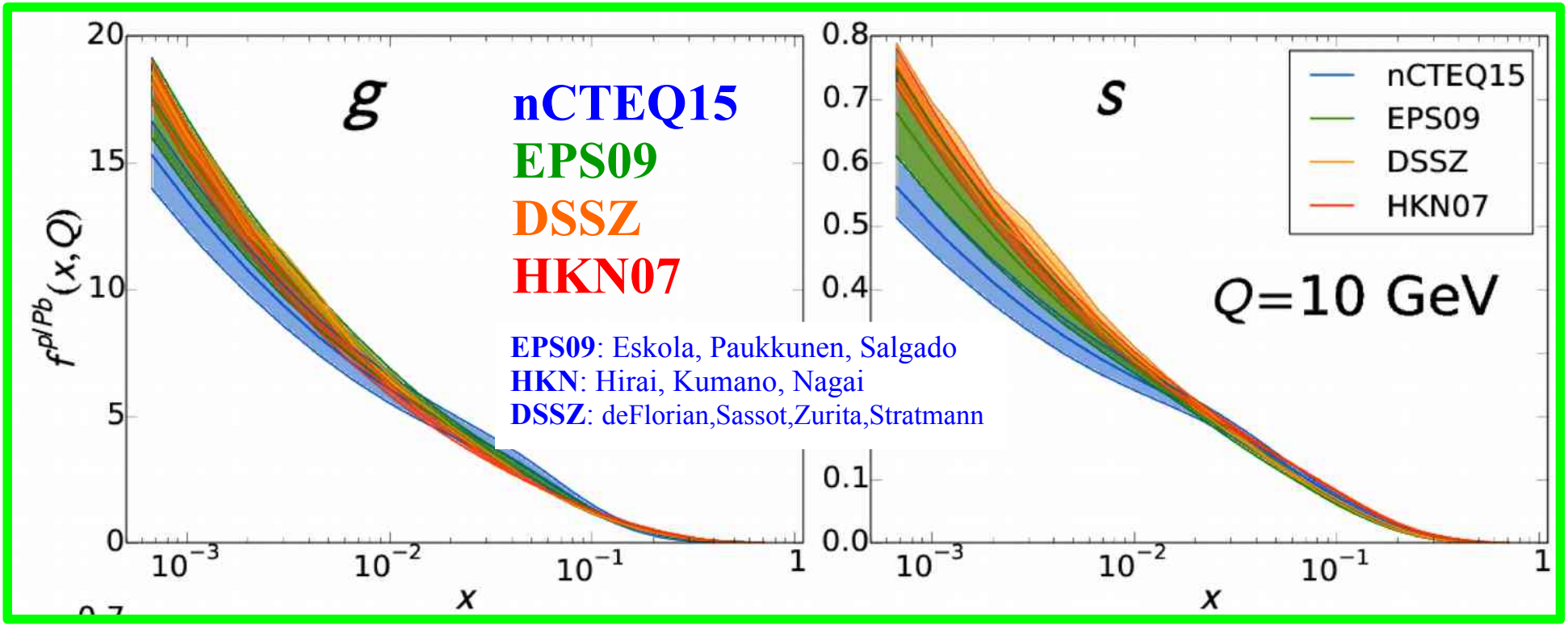
Proton

Nuclear



use proton as starting point

Nuclear PDFs: Complementary efforts in general agreement



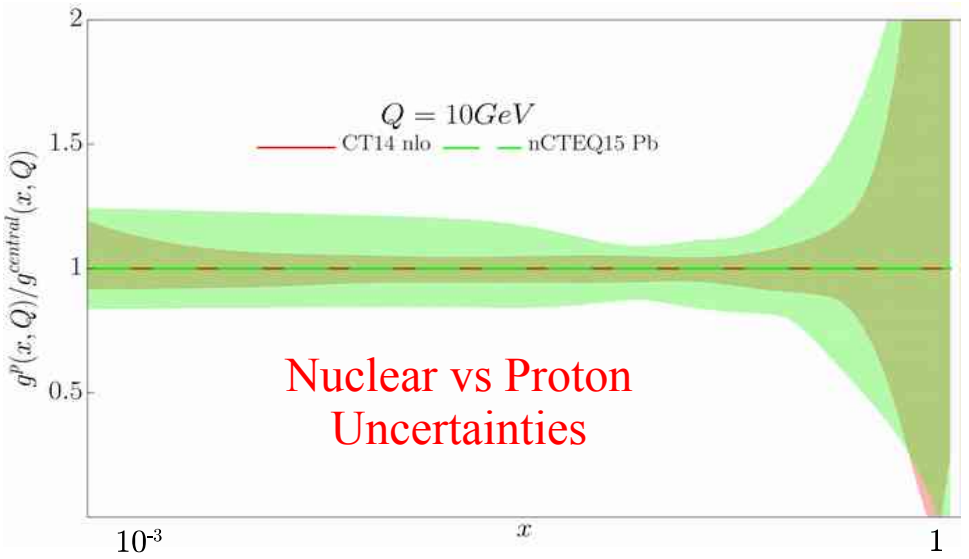
EPS09: Eskola, Paukkunen, Salgado
HKN: Hirai, Kumano, Nagai
DSSZ: deFlorian,Sassot,Zurita,Stratmann

Nuclear PDFs are more complex

more DOF than Proton case

more "issues" to consider

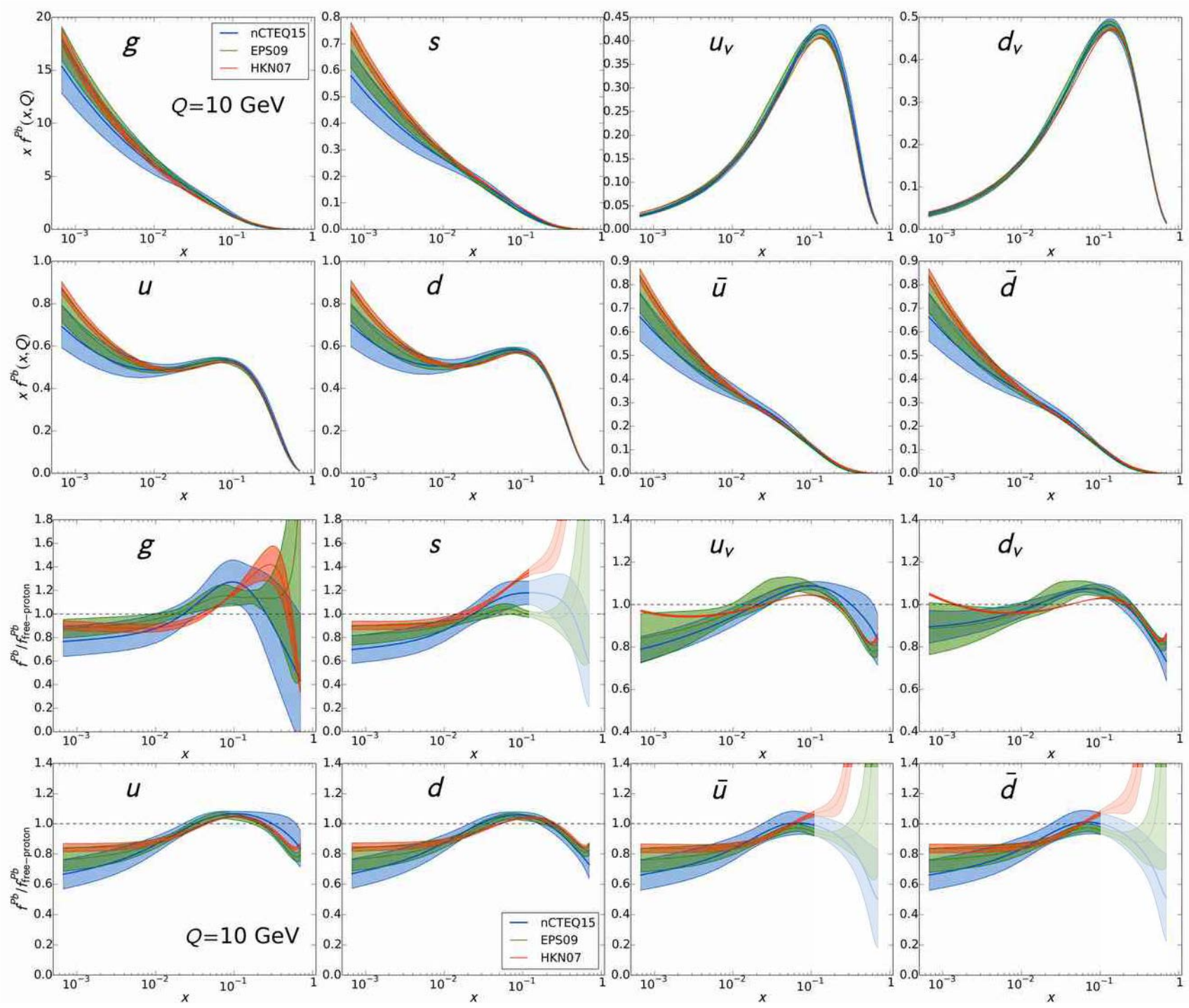
more work to do ...



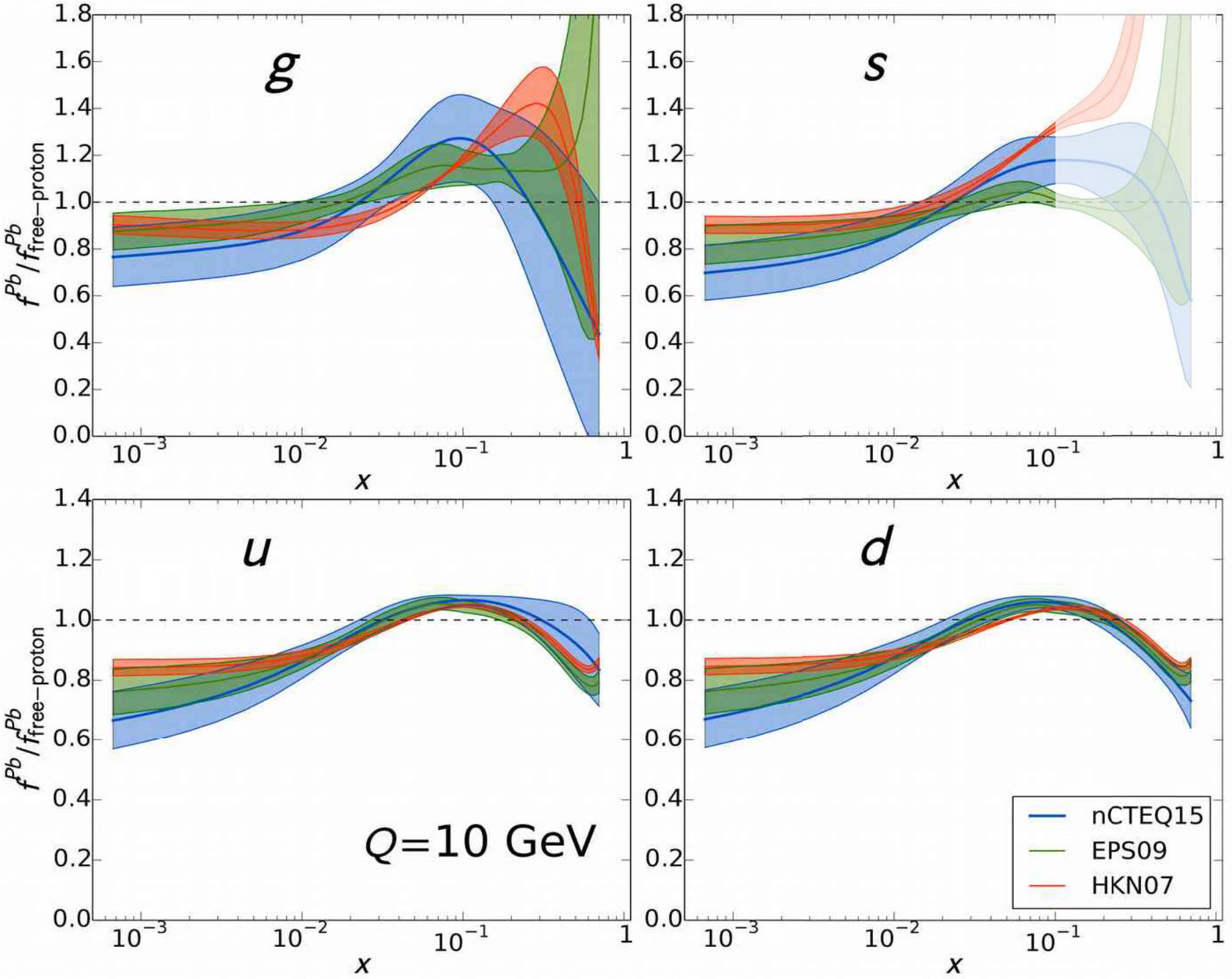
Nuclear

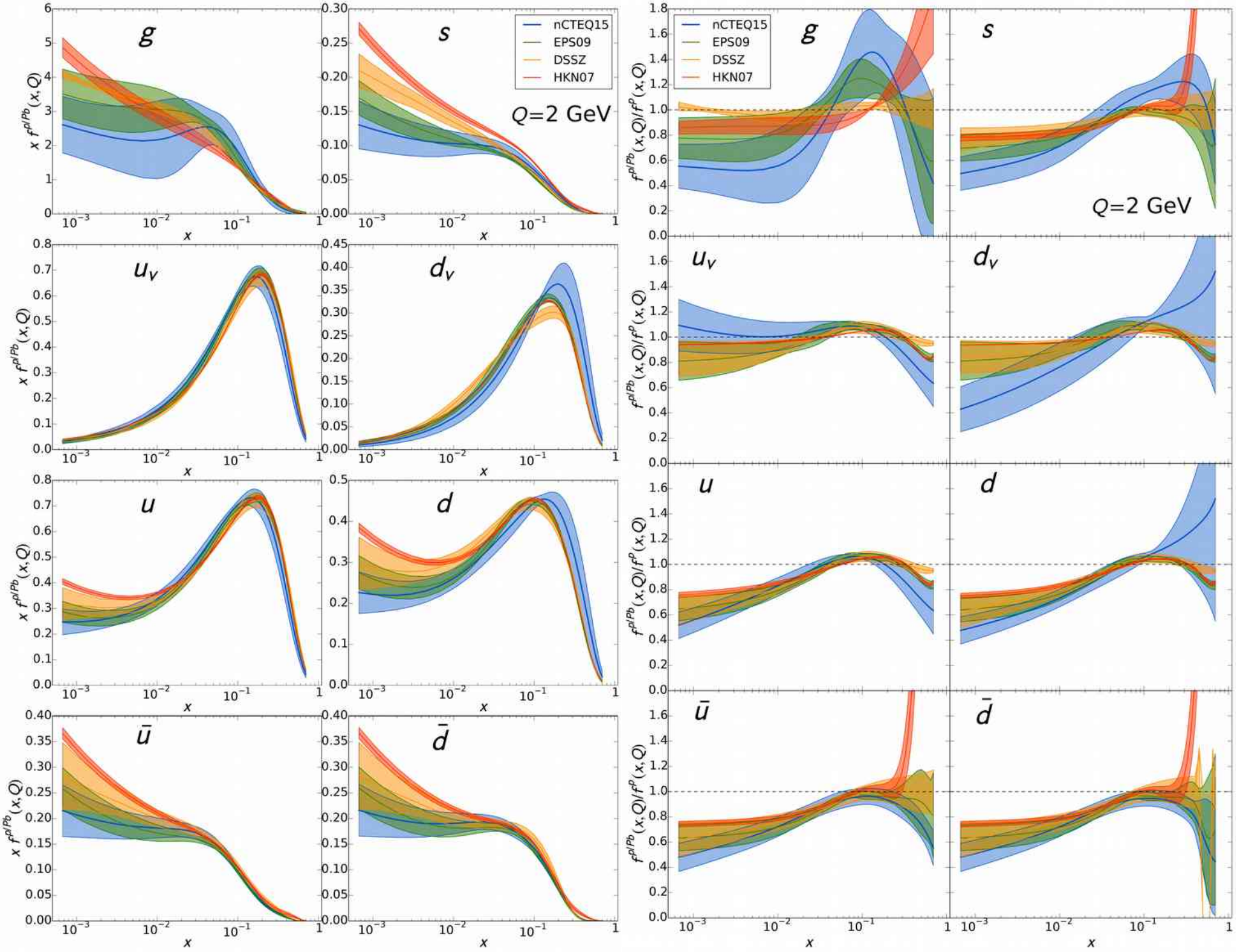
Corrections

Nuclear Corrections: Lead PDFs & Ratios to Proton

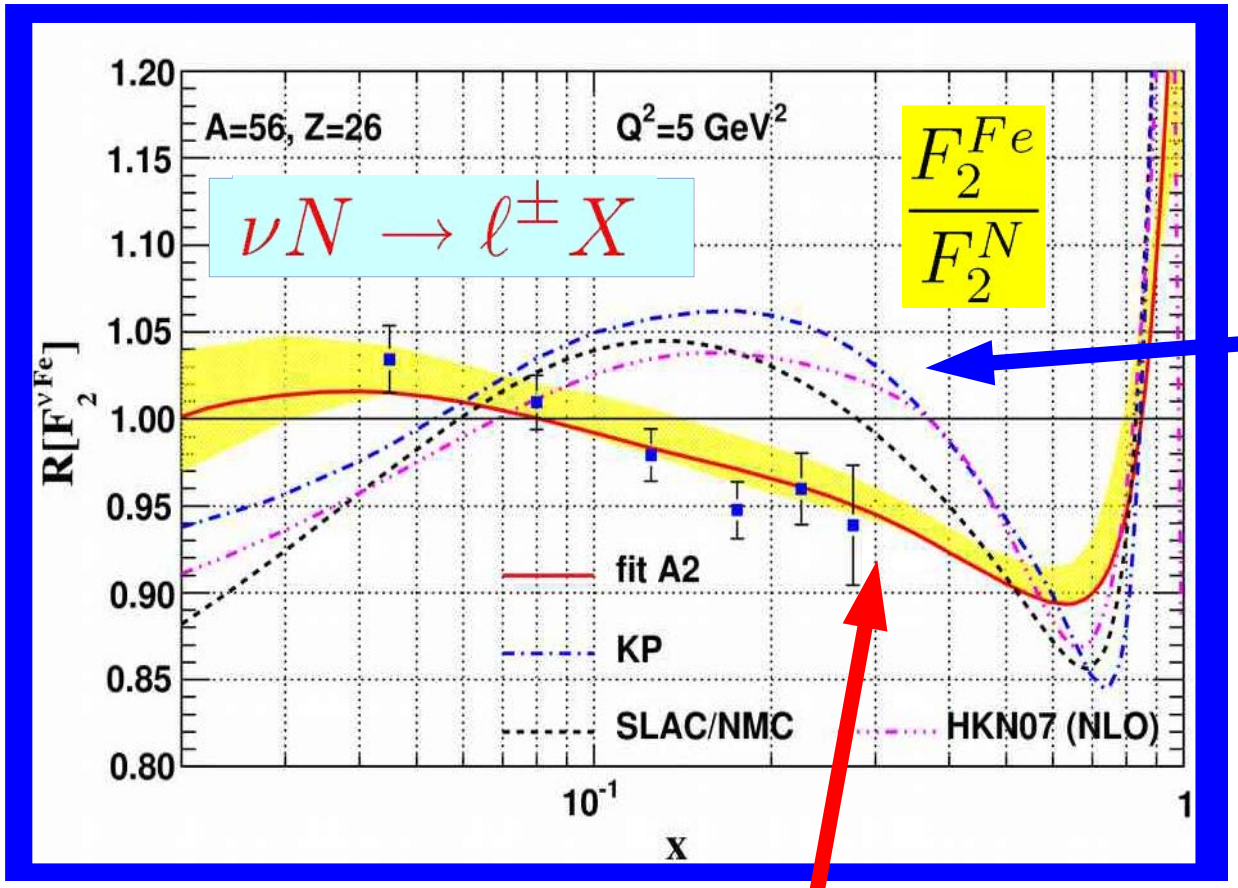


Nuclear Corrections: Lead PDFs & Ratios to Proton

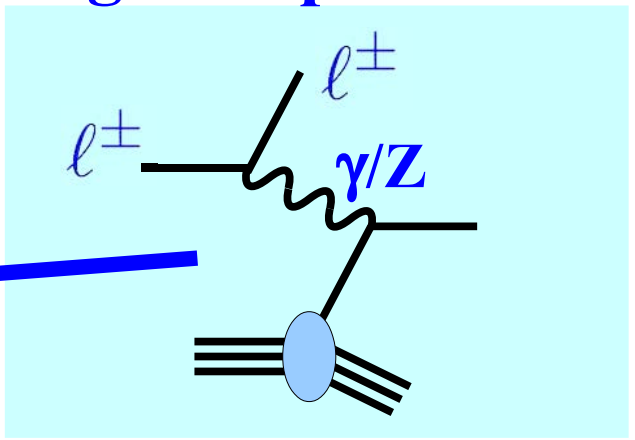


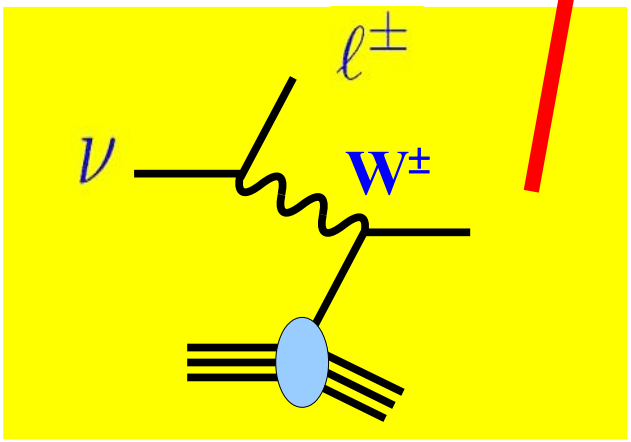

g
s
u_v
d_v
u
d
ū
d̄
nCTEQ15
EPS09
DSSZ
HKN07
Q=2 GeV
x f^{p/Pb}(x,Q)
f^{p/Pb}(x,Q)/f^{p}(x,Q)
x

Nuclear Corrections: Compare Neutrino and Charged Lepton DIS



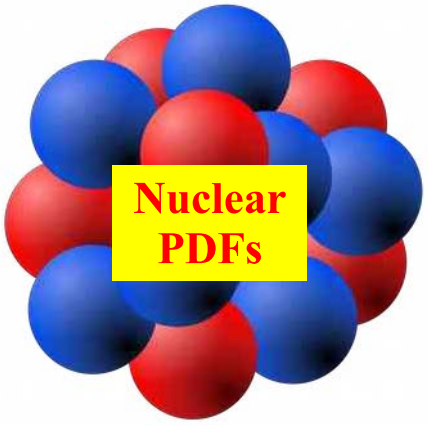
Charged Lepton DIS

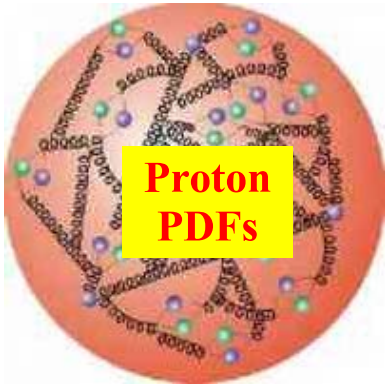




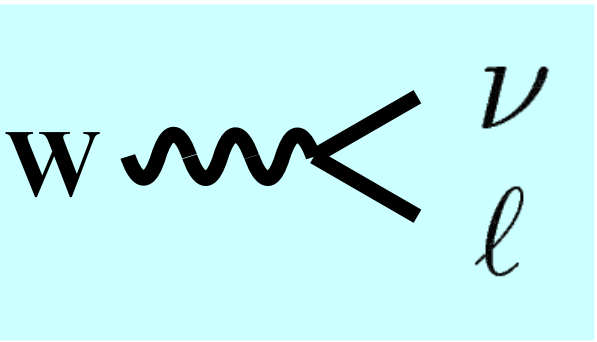
Neutrino DIS

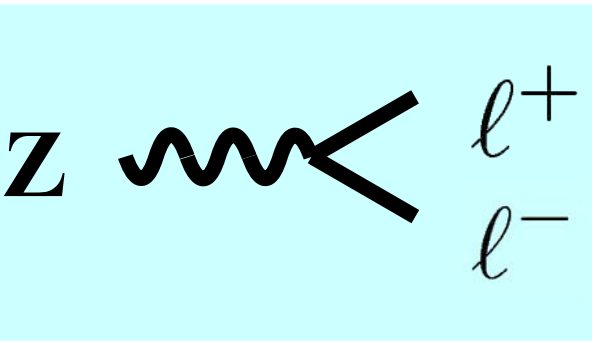
Depends on nuclear corrections





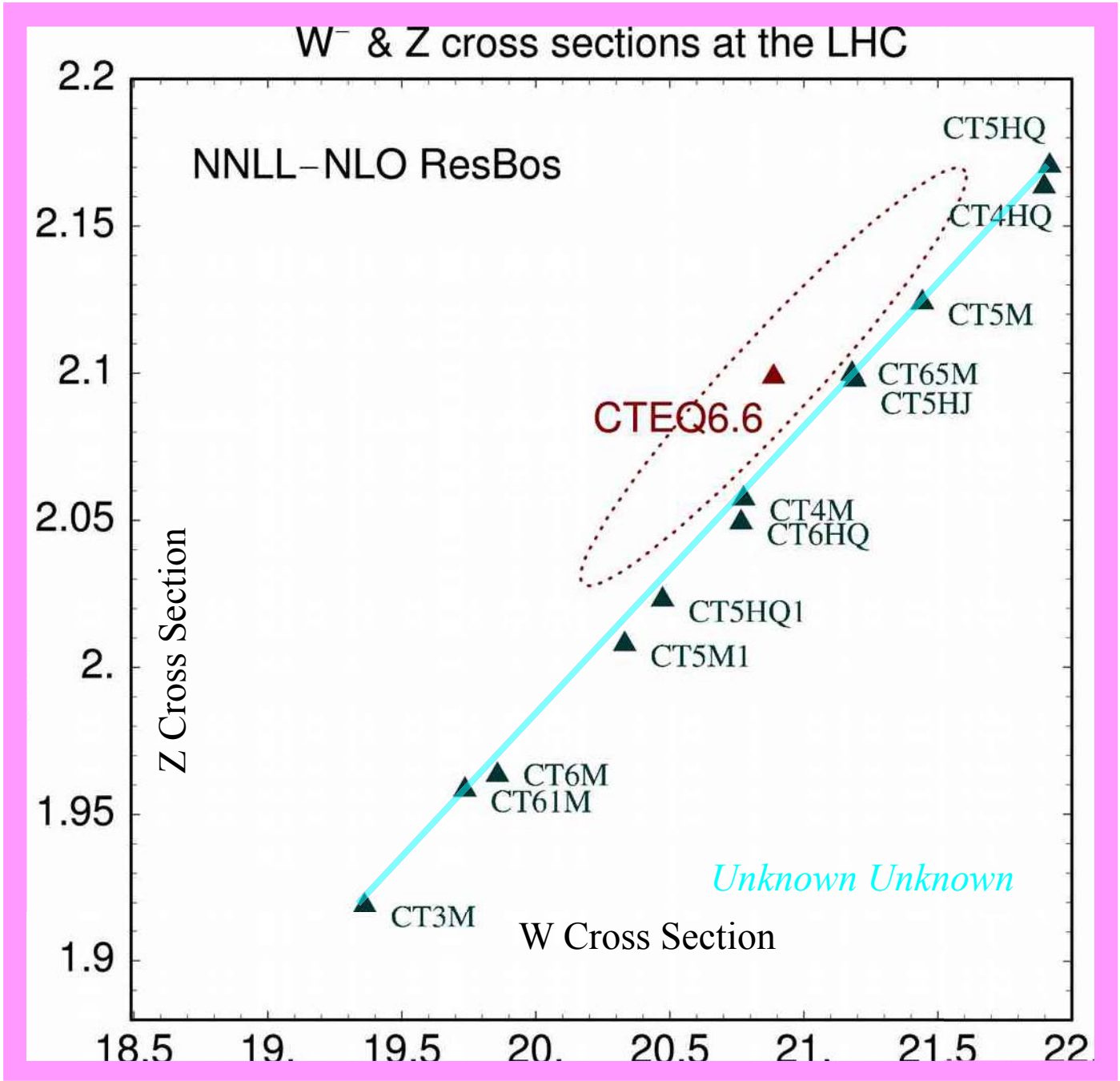
Strange Quark: Impact on LHC … W/Z correlation ⇒ M_W extraction





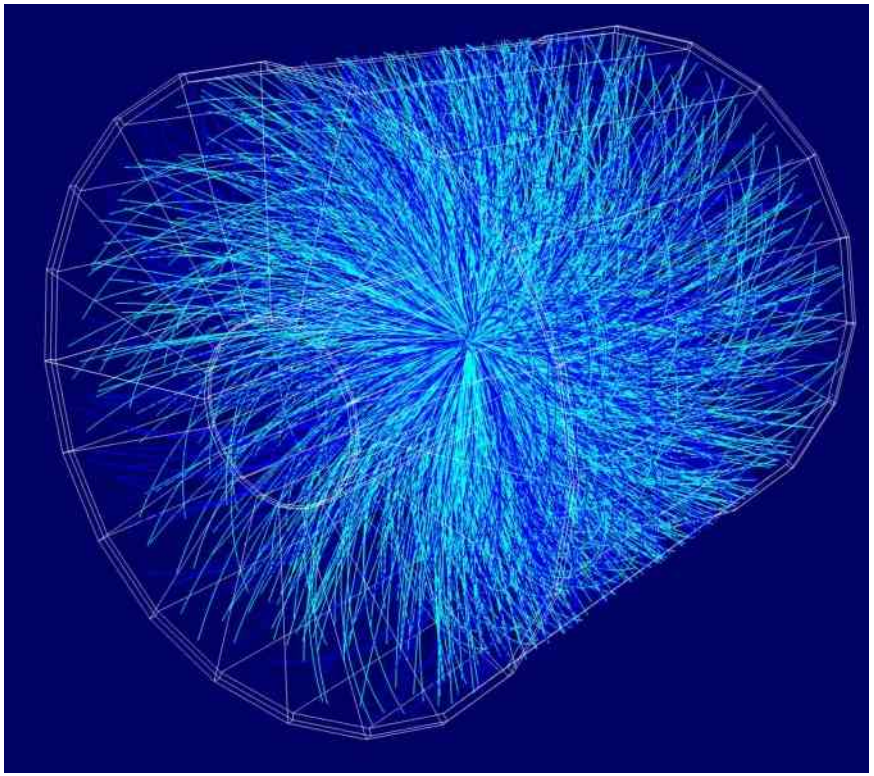
The W-Z correlation is intimately connected to the strange quark distribution

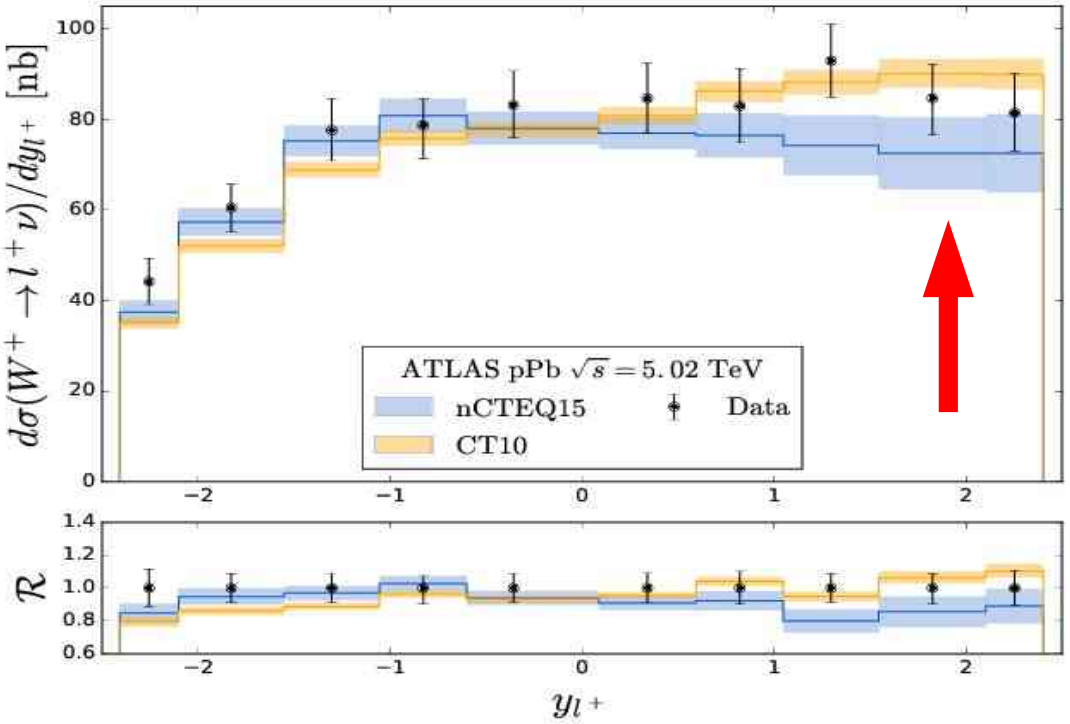
Key for M_W determination



W/Z Correlations & Flavor Determination

$p\ Pb \rightarrow W/Z$ and Nuclear Corrections





lead kinematics

larger x — **smaller x**

"OK" nuclear correction

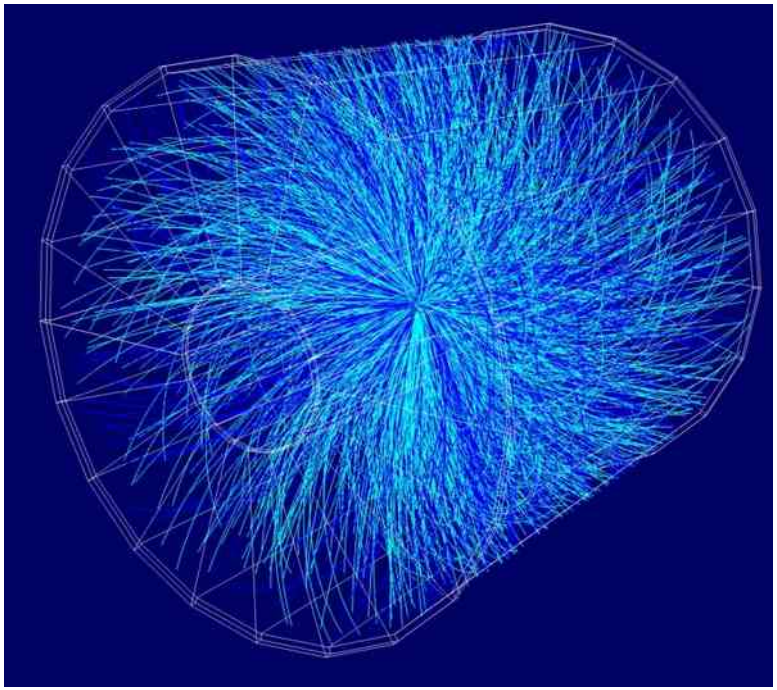
too much suppression

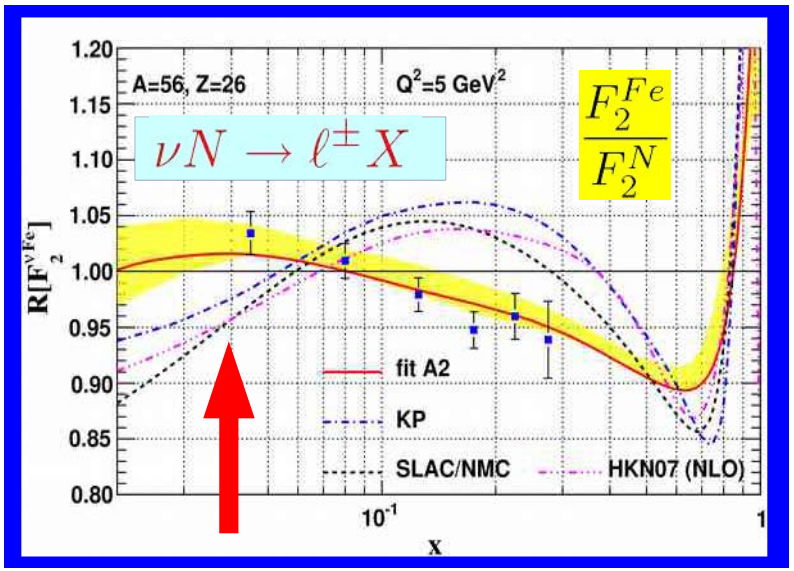
previous data constraints

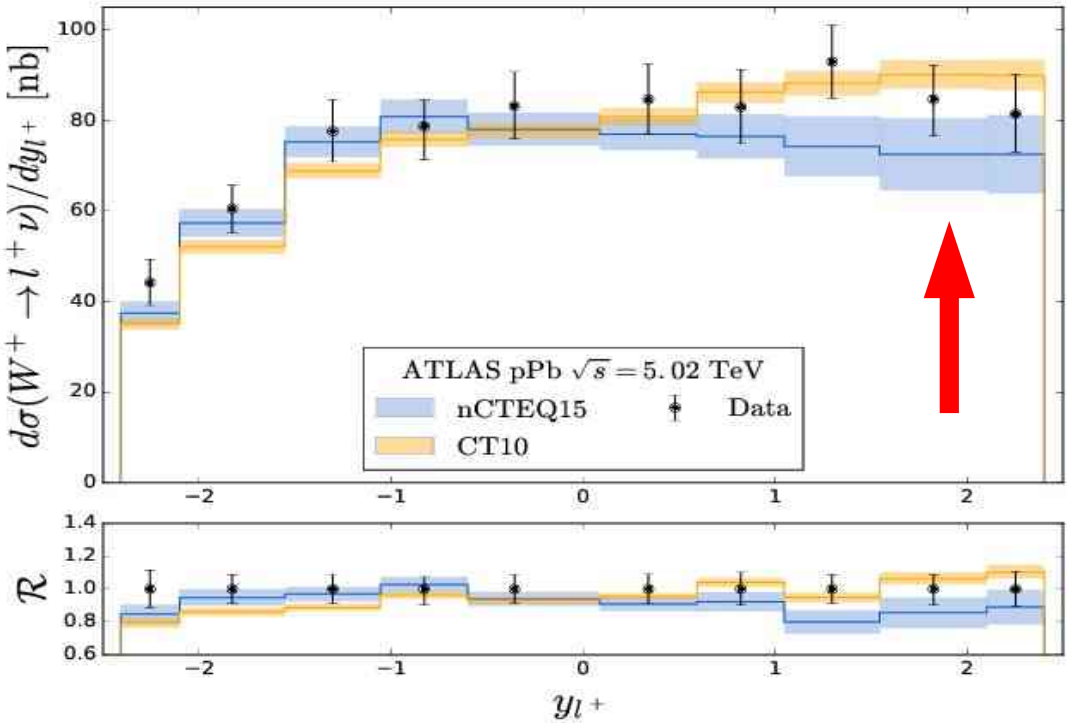
minimal data constraints

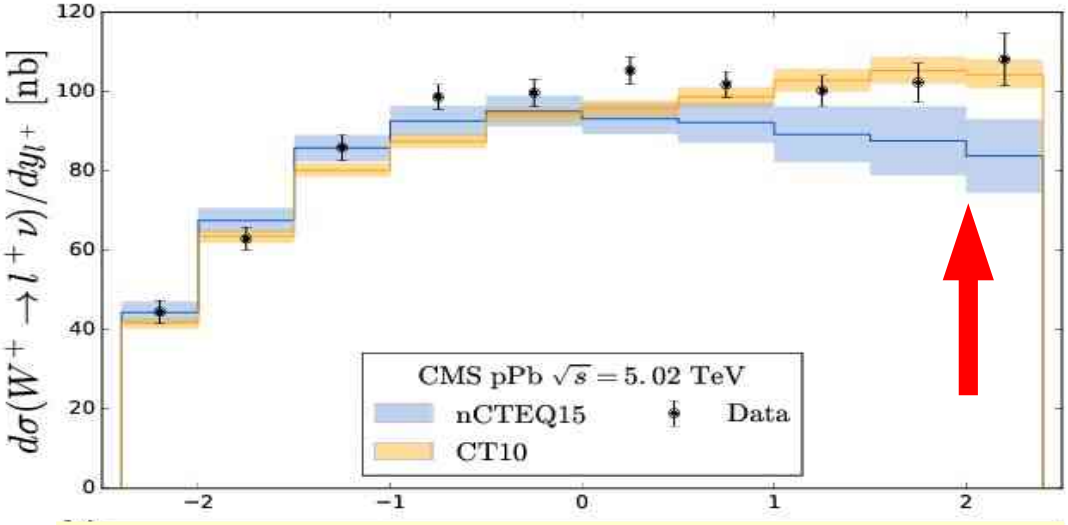
Vector boson production in pPb & PbPb
A. Kusina, F. Lyonnet, D. B. Clark, E. Godat, T. Jezo, K. Kovarik, F. I. Olness, I. Schienbein, J. Y. Yu, arXiv:1610.02925 [nucl-th]

$p\ Pb \rightarrow W/Z$ and Nuclear Corrections









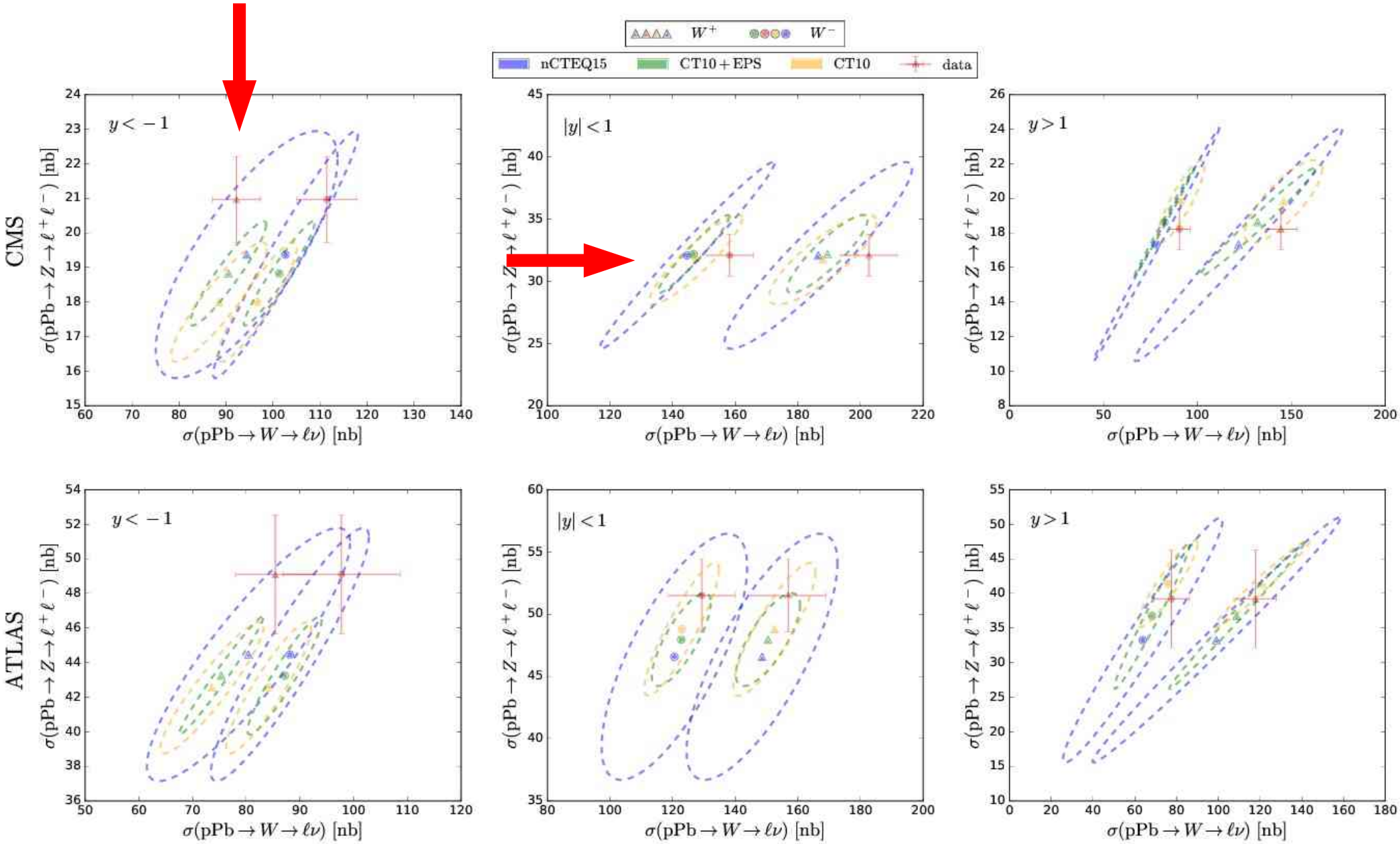
$\mathcal{R}$

lead kinematics

larger x **smaller x**

A. Kusina, et al., arXiv:1610.02925 [nucl-th]

σ Correlations: Scan in "x" and flavor combinations



lead kinematics

larger x **smaller x**

A. Kusina, et al., arXiv:1610.02925 [nucl-th]

QED+QCD for PDFs

CONF-8

ANL-HEP-CP--86-104

DE87 001562

Received OCT 2 9 1986

ANL-HEP-CP-86-104

Intrinsic Polarization of the High Energy W-Boson Structure Functions*

JOHN P. RALSTON[a,b] AND FREDRICK OLNESS[c]

[a] *High Energy Physics Division, Argonne National Laboratory, Argonne, IL 60439*

[b] *Department of Physics and Astronomy, University of Kansas, Lawrence, KS 66045*

and

[c] *Department of Physics, Illinois Institute of Technology, Chicago, IL 60616*

ABSTRACT

We present several new issues to be incorporated into a consistent treatment of high-energy transverse effective-W boson structure functions. The issues include the numerical importance of the proper choice of scale, and the q^2 evolution of the boson structure functions in an Altarelli-Parisi framework. We investigate a novel effect of the V-A coupling which produces a sizable intrinsic polarization of the W distributions. A preliminary estimate yields a left- to right-helicity structure function ratio $W_L^+/W_R^+ \simeq 1 - 21/(1-x) + 21/(1-x)^2$. For $x \gtrsim 0.06$, there are two left-handed W^+'s for every right-handed one in an unpolarized proton. Here are 3 more 2 figures.

To appear in the proceedings of the *1986 Summer Study on the Physics of the Superconducting Supercollider*, Snowmass, Colorado, June 23–July 11, 1986; edited by Rene Donaldson.

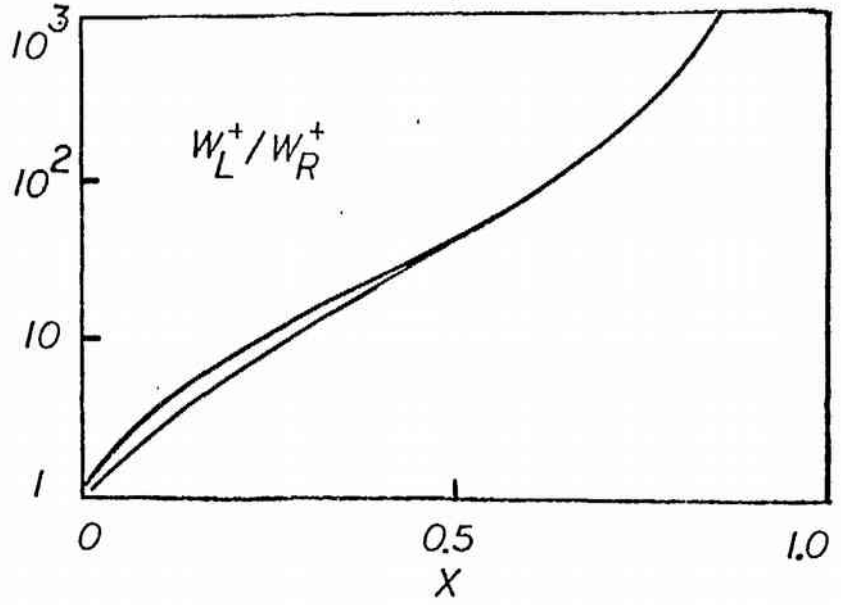
* This work was supported in part by the U.S. Department of Energy under contracts DE-FG02-85ER-40214.A002 and DE-FG02-85ER-40235.

MASTER

Electroweak DOF in Proton

$$W_\lambda(x,\hat{s}) = \frac{\alpha_W}{2\pi} \int_{M_W^2}^{\hat{s}} d\,\ln\mu^2 \int_x^1 \frac{dx'}{x'} \sum_i q_i(x',\mu^2)\, P^i_{W_\lambda/q}\left(\frac{x}{x'}\right),$$

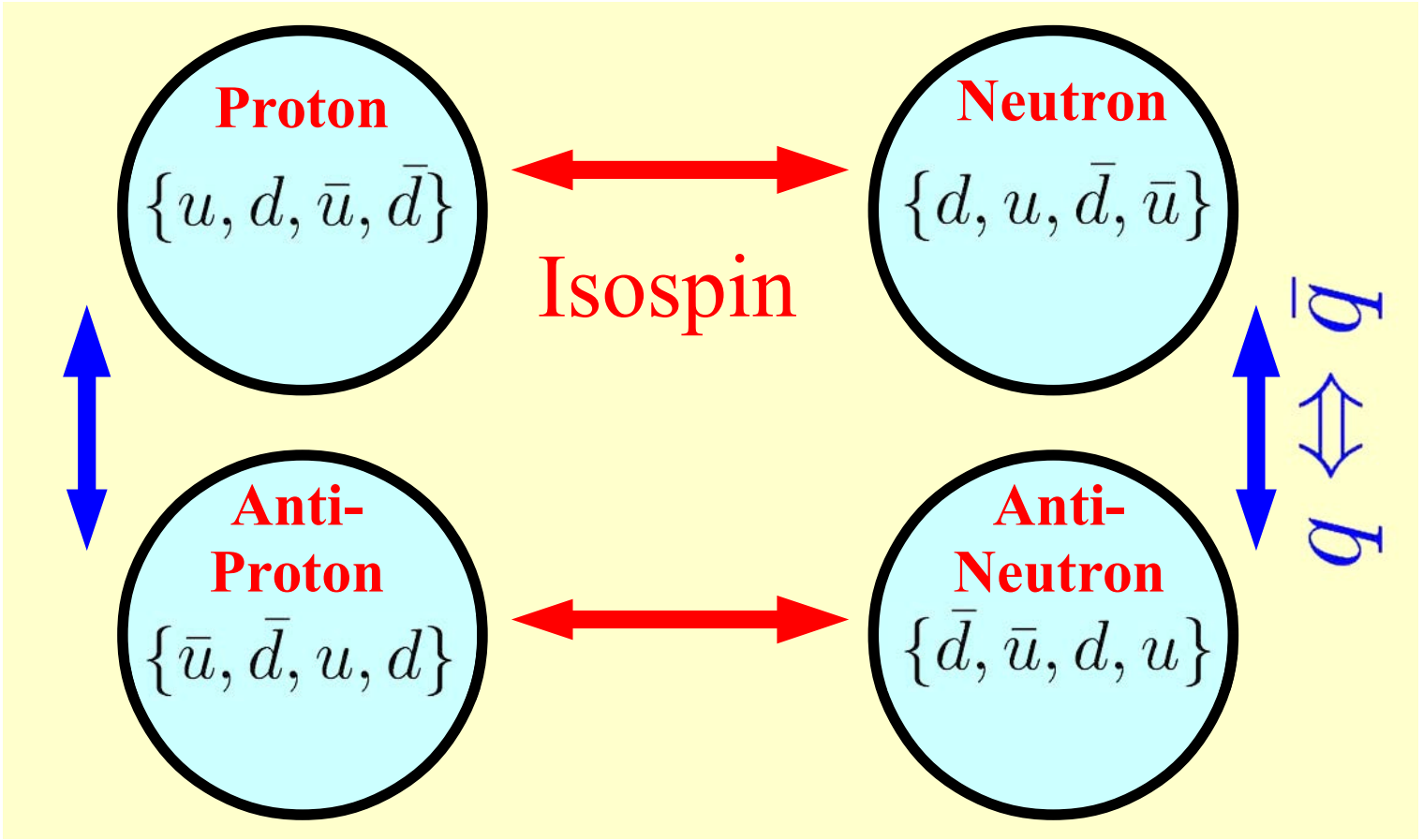
where $\lambda = L, R$.

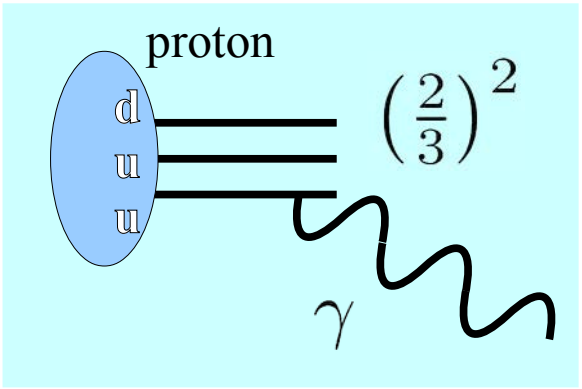


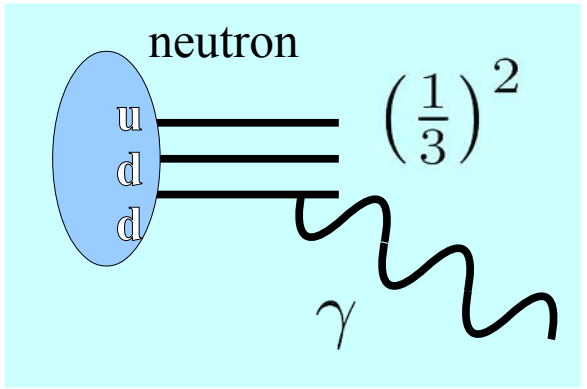
Isospin Symmetry used to relate PDFs

$\alpha_s^2 \sim \alpha$

"New" Photon PDFs







Isospin terms are comparable to NNLO QCD

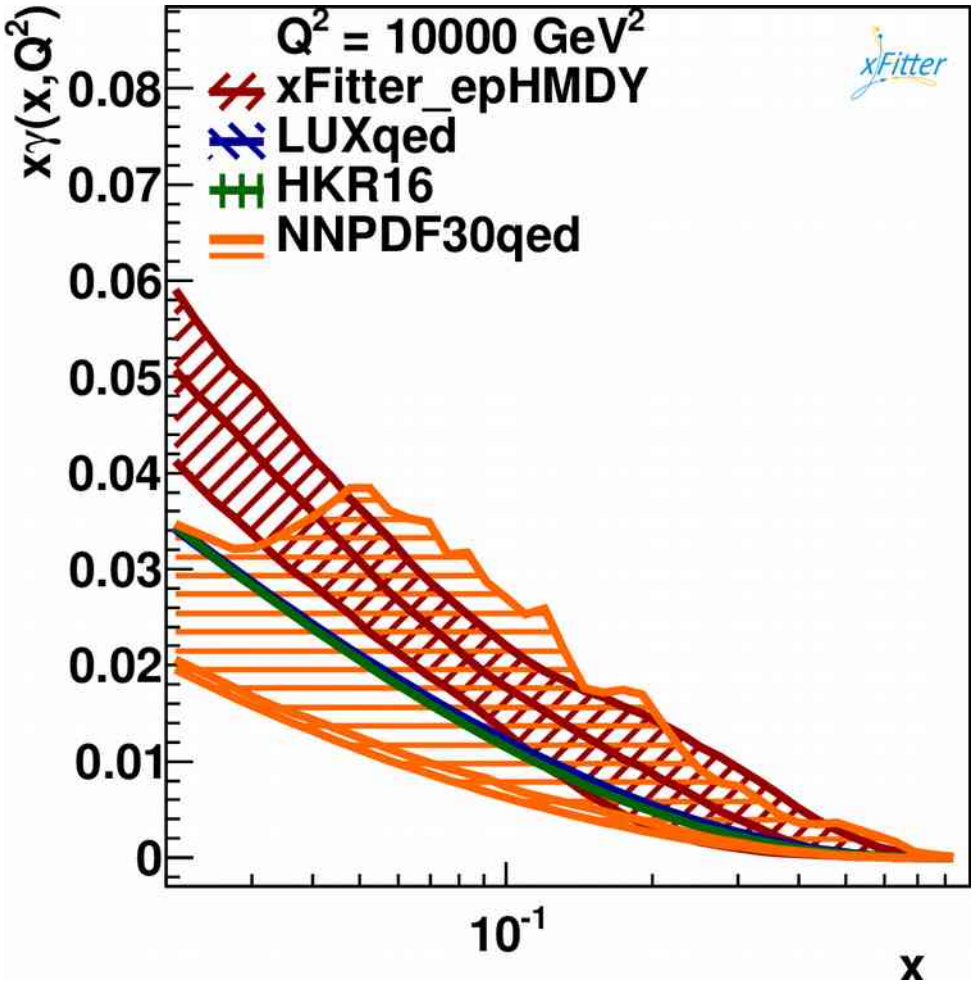
QCD & EW Corrections do NOT factorize

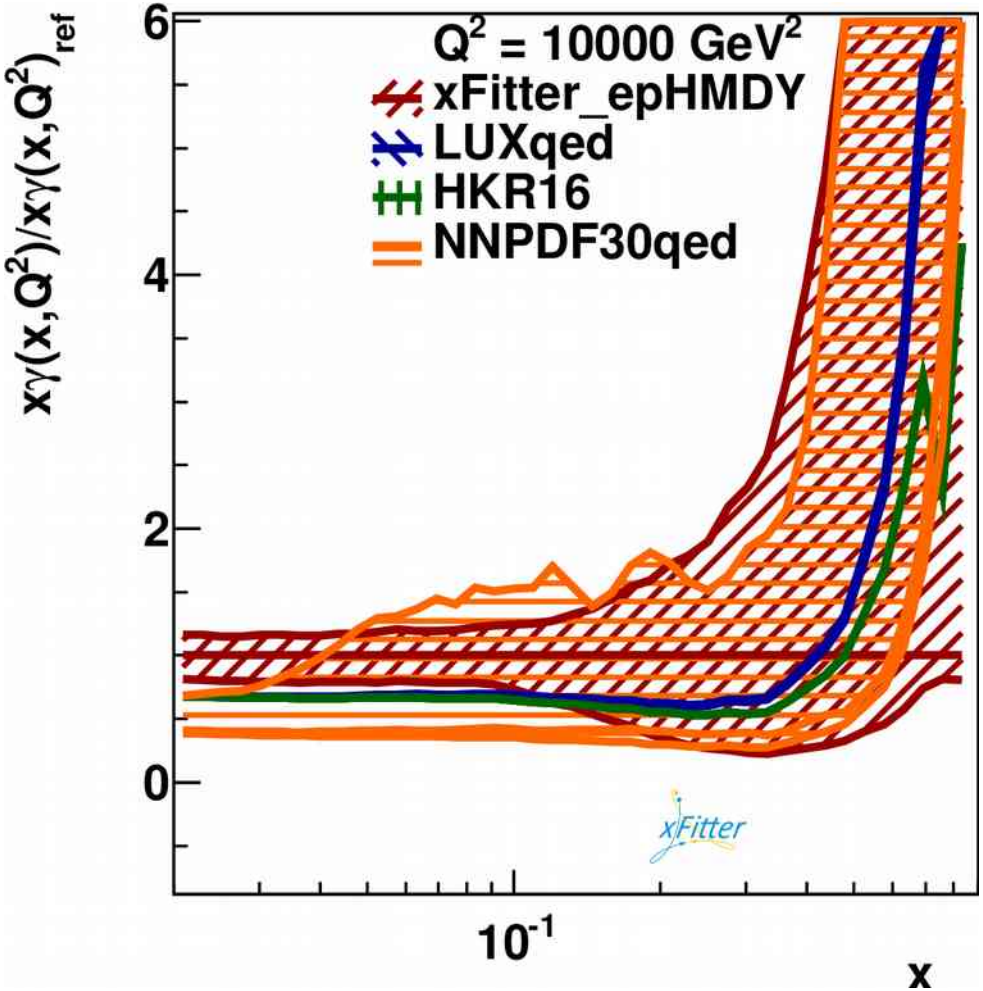
A Review of Target Mass Corrections.
Ingo Schienbein et al,
J.Phys.G35:053101,2008.

Photon PDF using xFitter

Determination of the photon PDF from fits to recent ATLAS measurements of high-mass Drell-Yan dilepton production at √s=8 TeV

Fit photon PDF at Q_0 $\quad x\gamma(x) = A_\gamma\, x^{B_\gamma} (1-x)^{C_\gamma} (1 + D_\gamma\, x + E_\gamma\, x^2)$

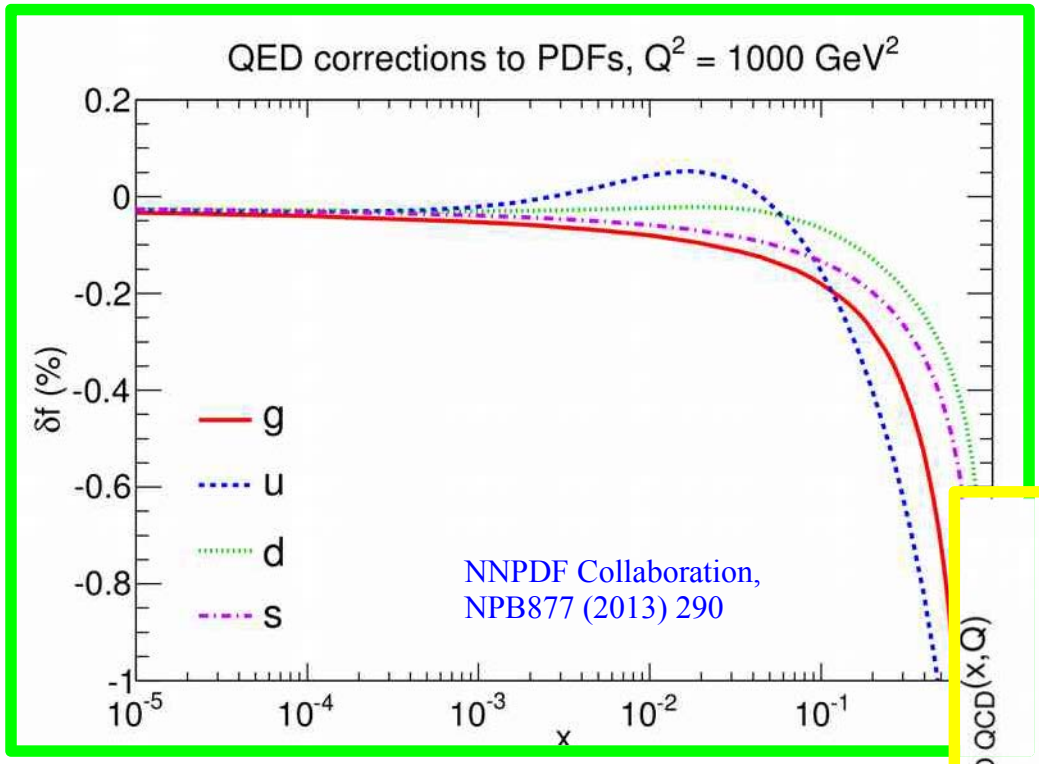


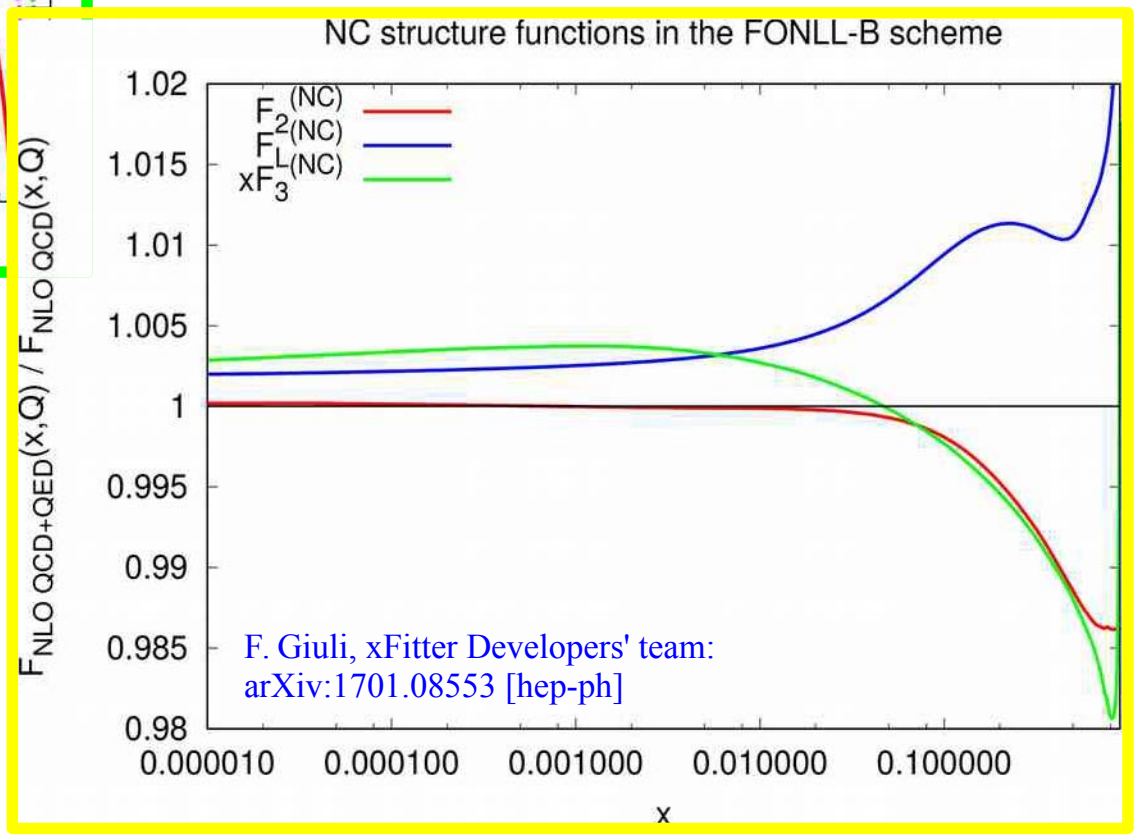


The photon PDF from high-mass Drell Yan data at the LHC
F. Giuli, et al., xFitter Developers' team
arXiv:1701.08553 [hep-ph]

V. Bertone and S. Carrazza, arXiv:1606.07130.
NNPDF Collaboration, JHEP 04 (2015) 040
A. Manohar, P. Nason, G. P. Salam, and G. Zanderighi, arXiv:1607.04266.
L. A. Harland-Lang, V. A. Khoze, and M. G. Ryskin, Eur. Phys. J. C76 (2016)

Impact of Photon PDF & QED Corrections

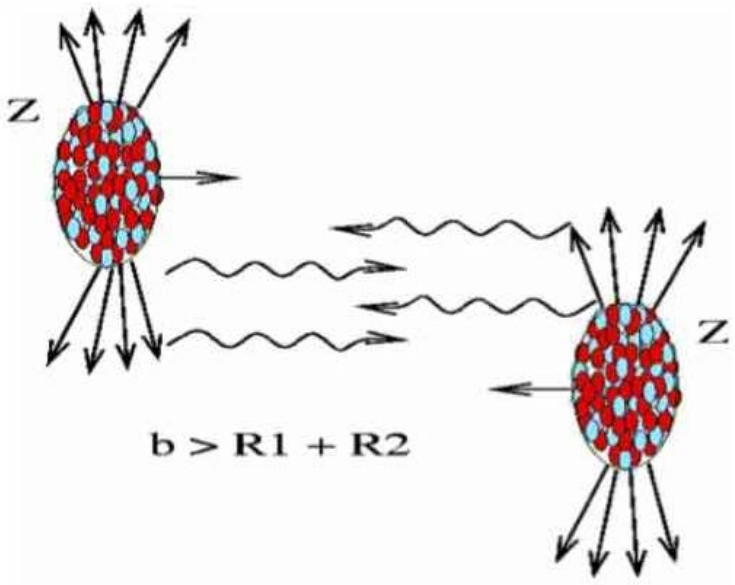


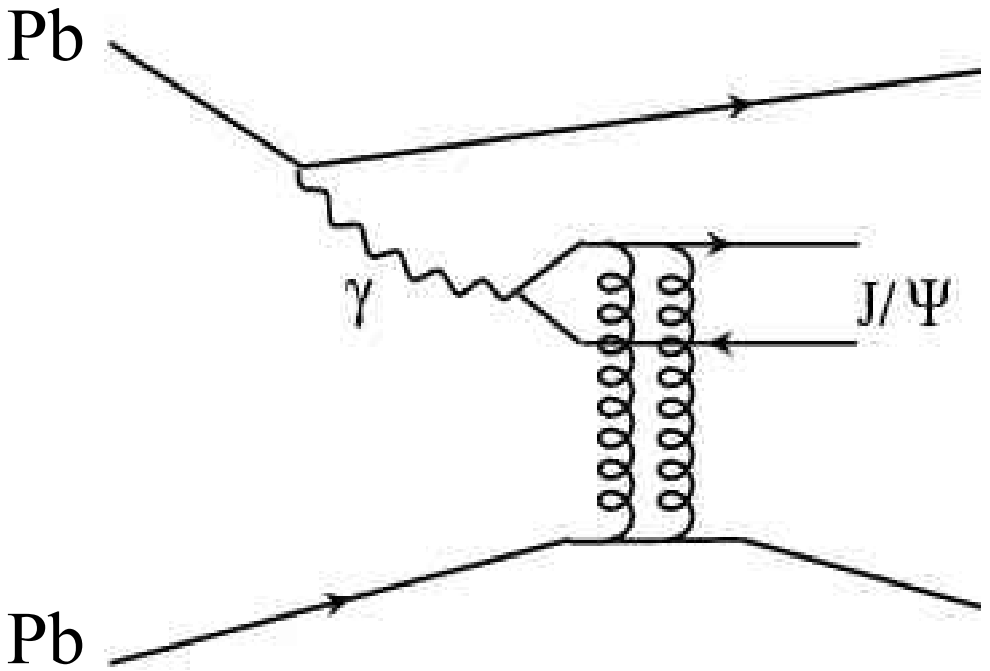


The photon PDF from high-mass Drell Yan data at the LHC
F. Giuli, et al., xFitter Developers' team
arXiv:1701.08553 [hep-ph]

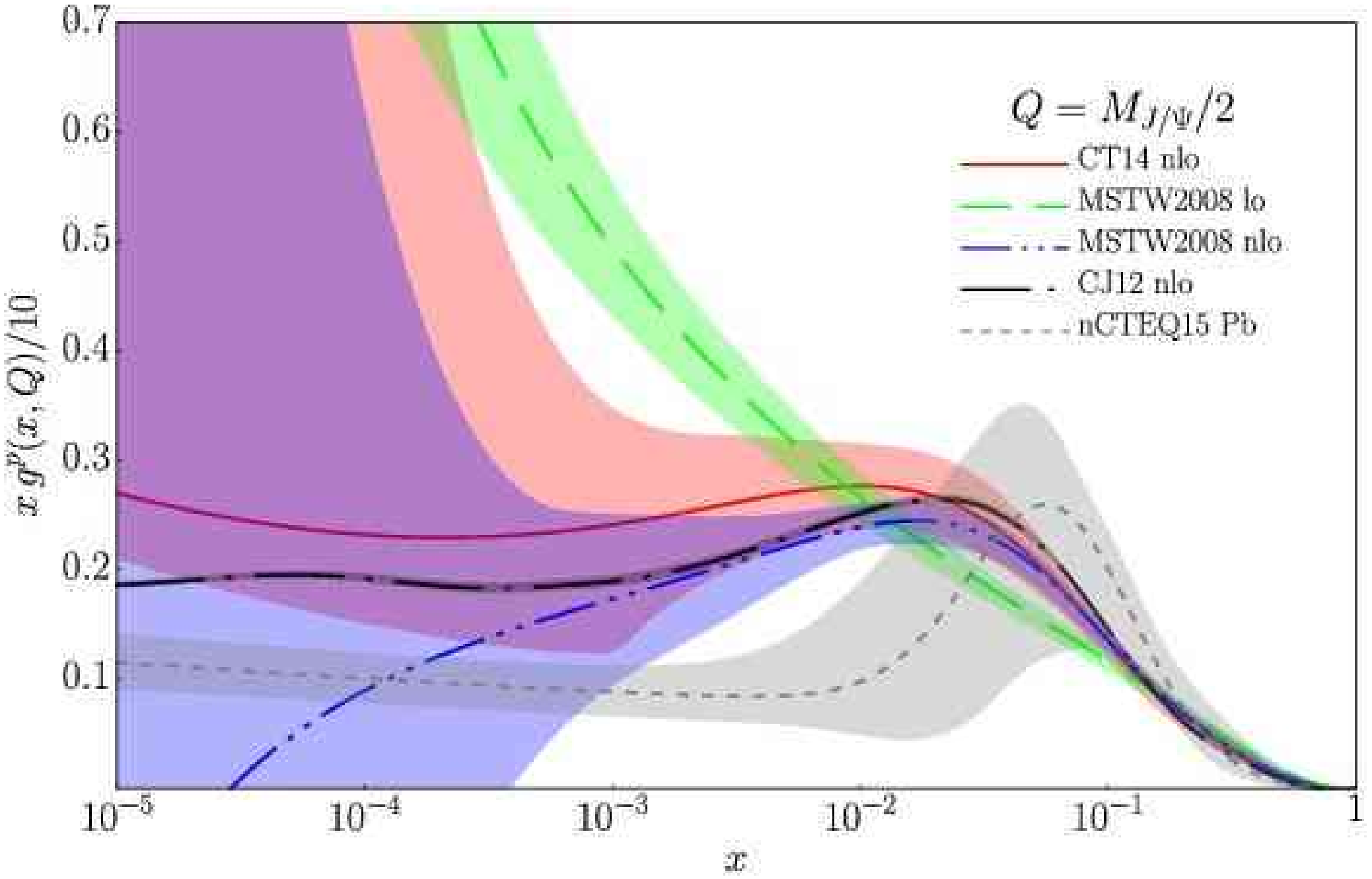
UPC & nPDFs

Ultra-peripheral collisions

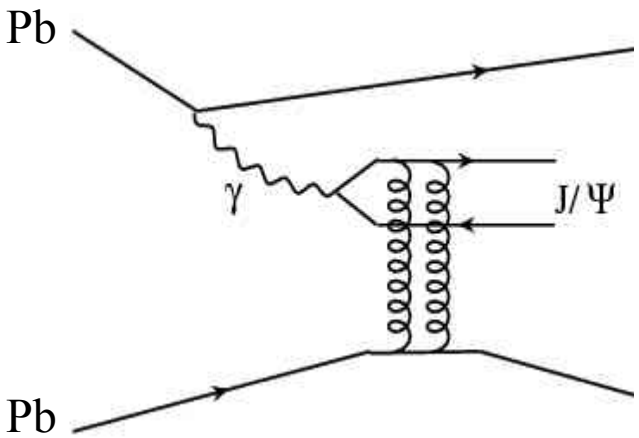


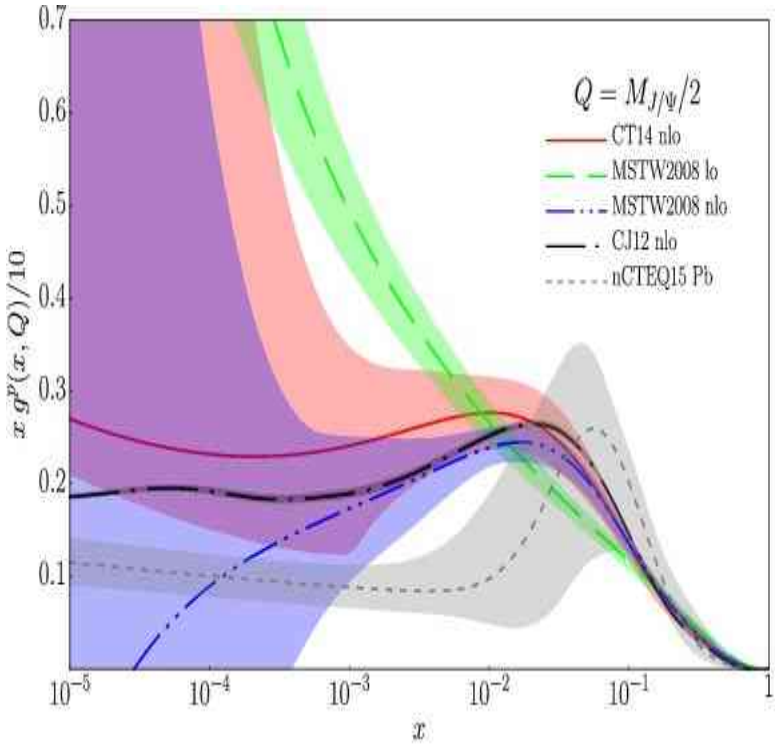


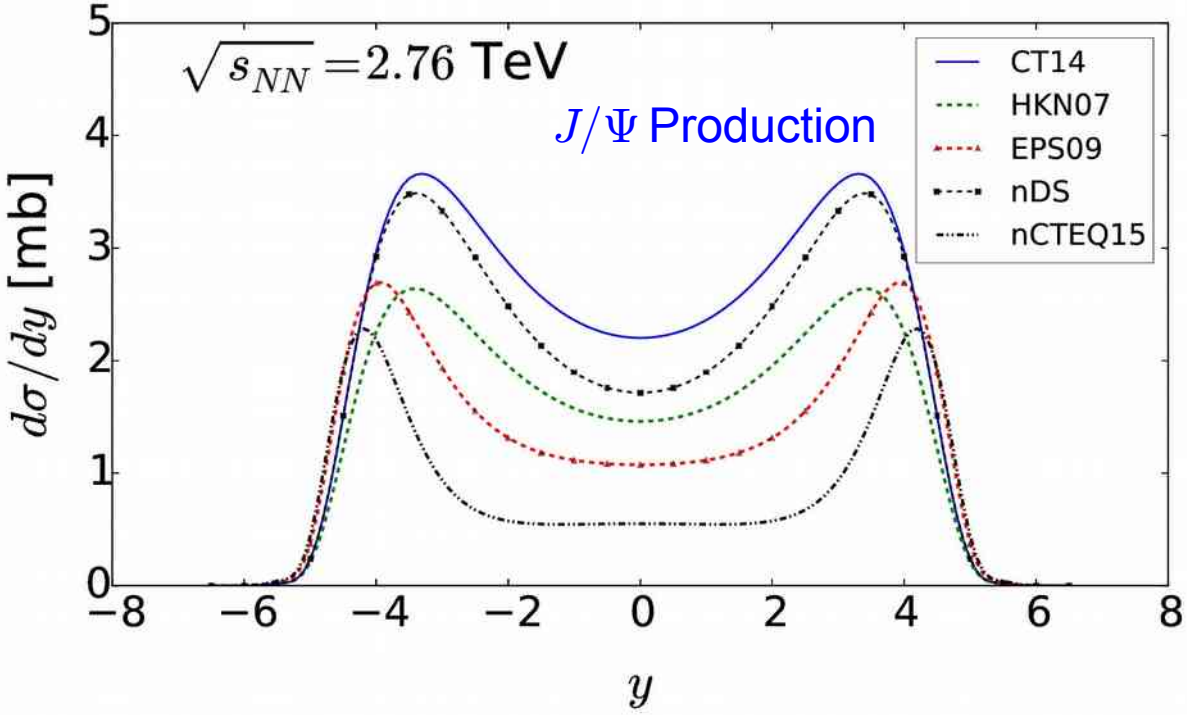
Key ingredient: Gluon nPDF

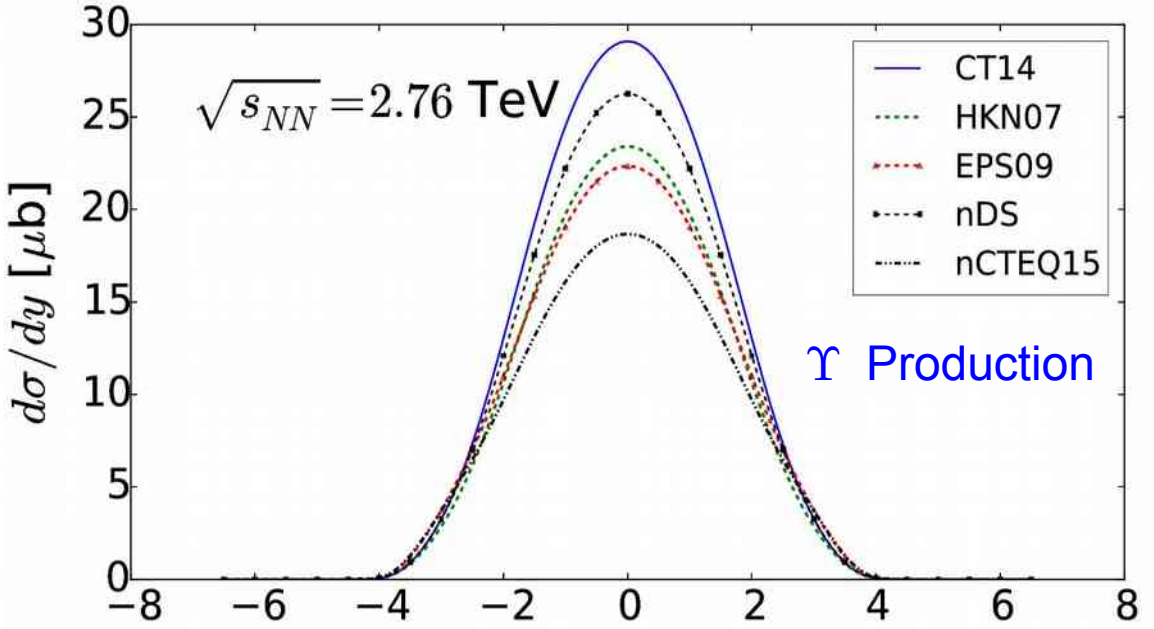


nPDF uncertainties ⇔ UPC Production









J. Thomas, C.A. Bertulani, N. Brady, D. B. Clark, E. Godat, F. Olness, arXiv:1603.01919 [hep-ph]

Nuclear & Proton PDFs;

- Intimately connected
- Flavor differentiation dependent on nuclear corrections

Nuclear Correction Factors;

- Can new LHC data help here
- Can W/Z rapidity correlations allow us to "scan" in x

Other issues:

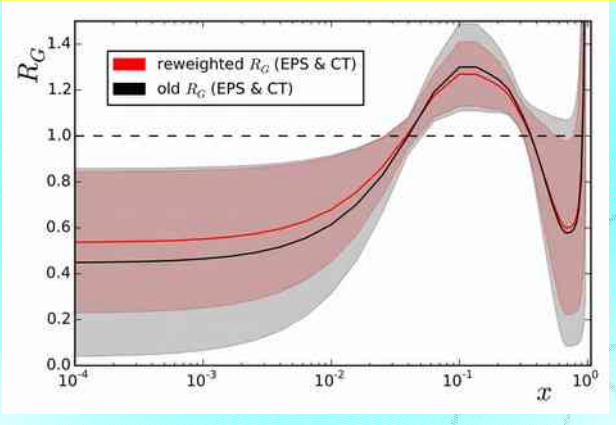
- Kinematic cuts: Q, W dependence, extend to low scales
- Where do we see breakdown of DLGAP, saturation, BFLK
- Is our framework sufficiently general to accommodate ...

QED Dimension:

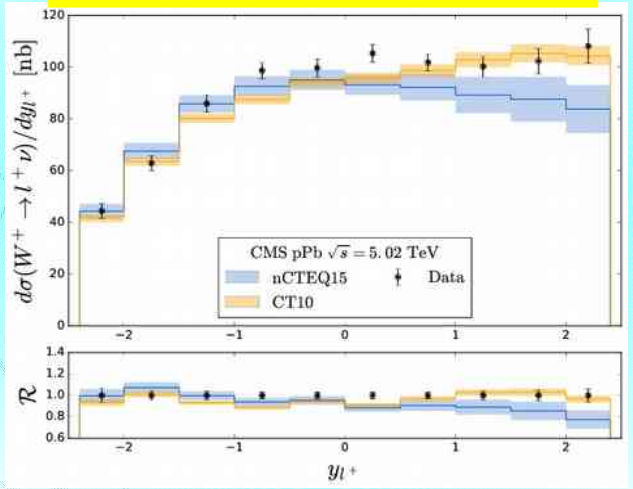
- Photon PDF
- Isospin violation

... *what did we forget ...*

Nuclear Correction Factor



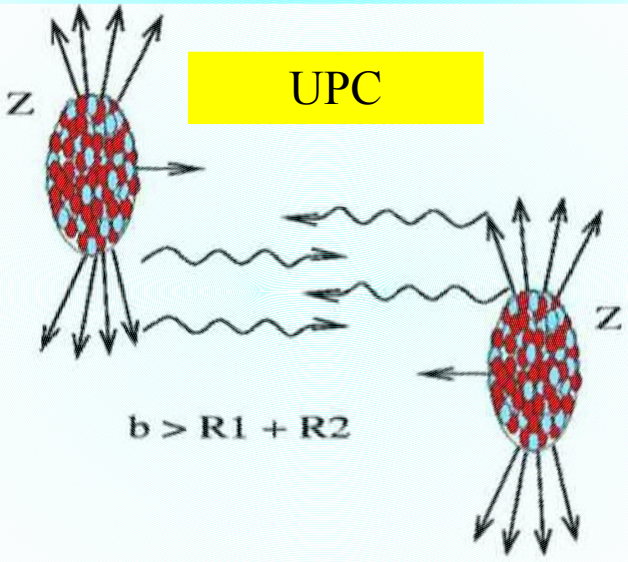
W/Z @ LHC w/ pPb & PbPb



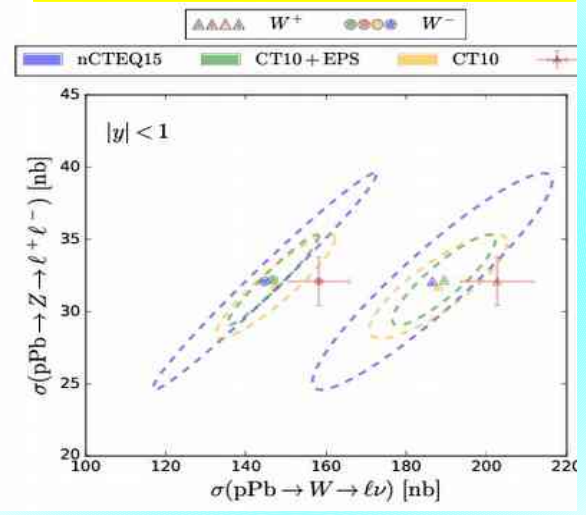
Nuclear PDFs

Proton PDFs

UPC

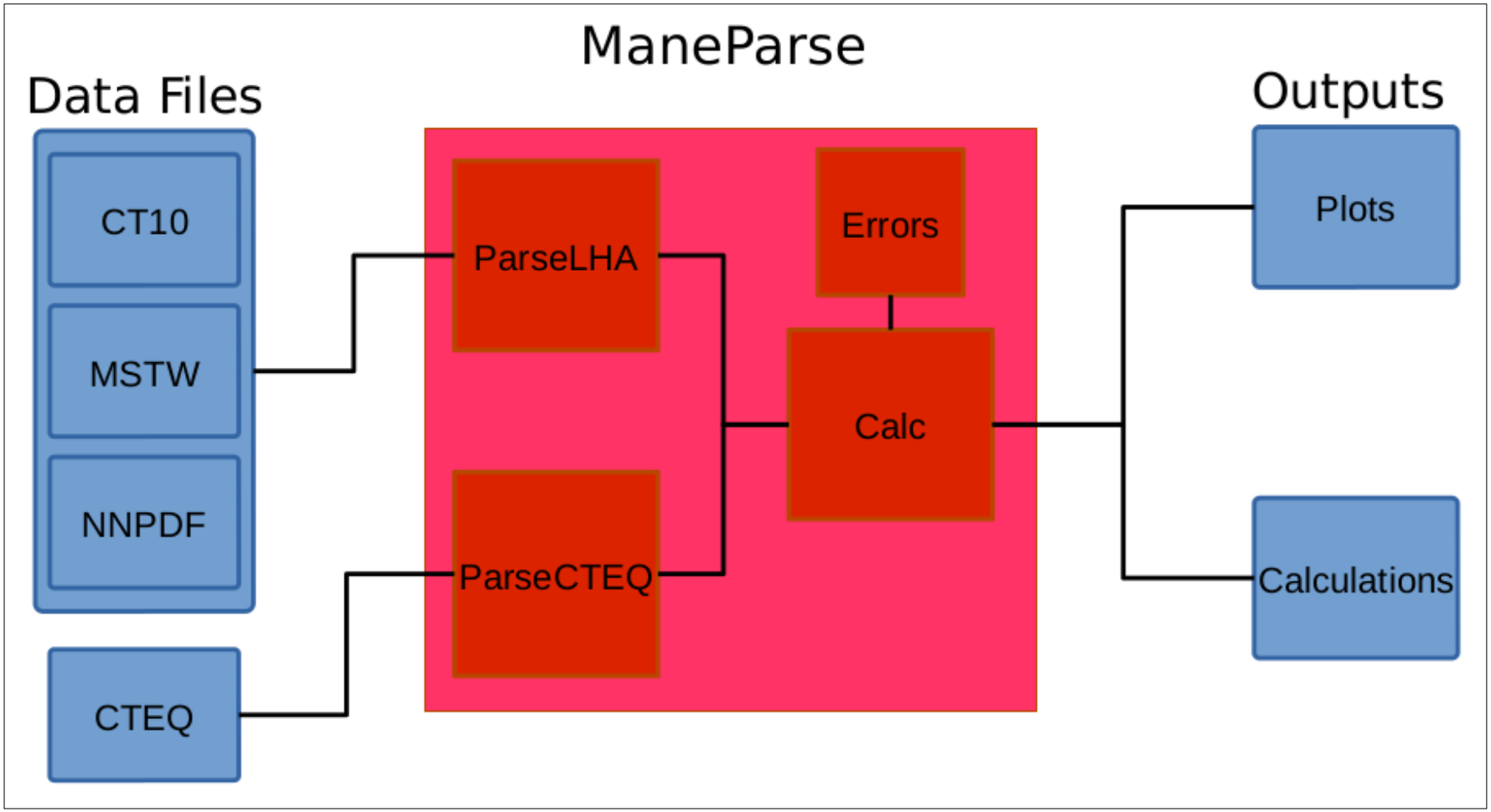


W/Z Correlations



Auxiliary Reference Material

ManeParse



Download data sets

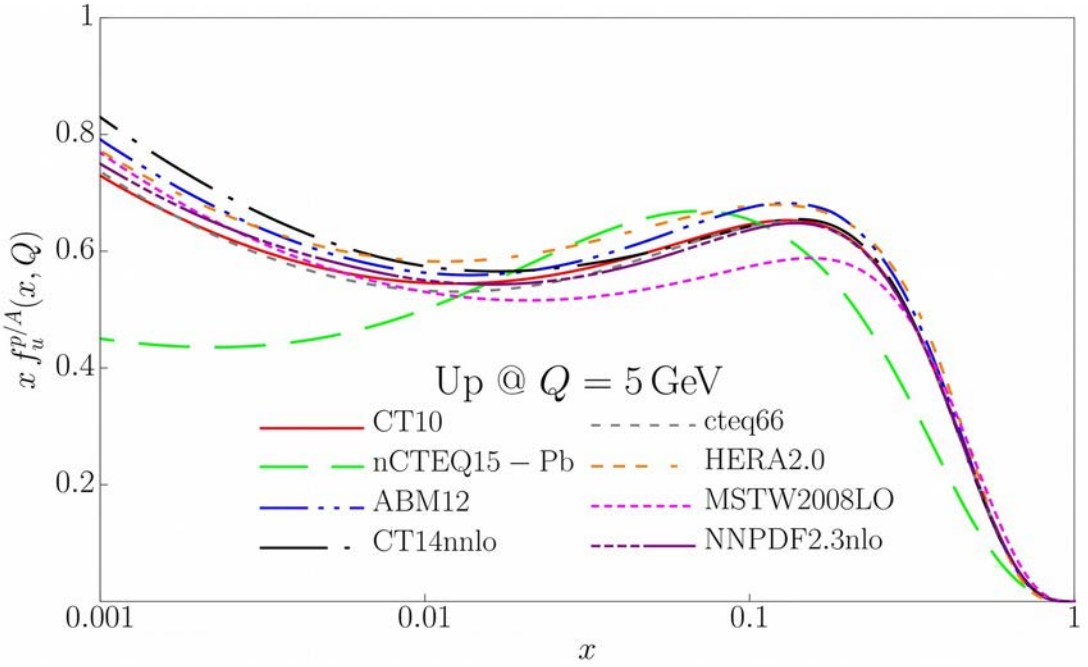
Load parser that matches your files

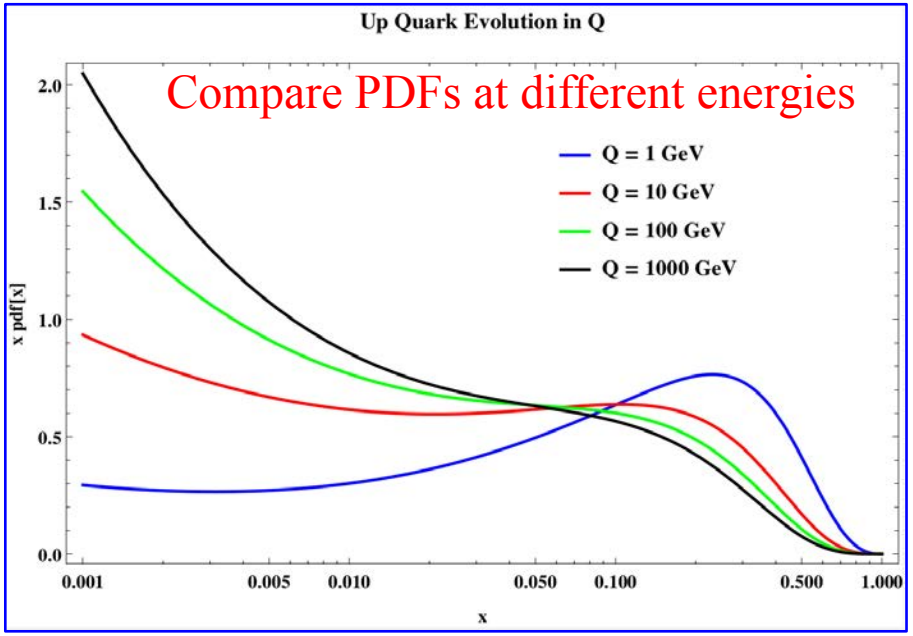
Interpolate and

Error functions

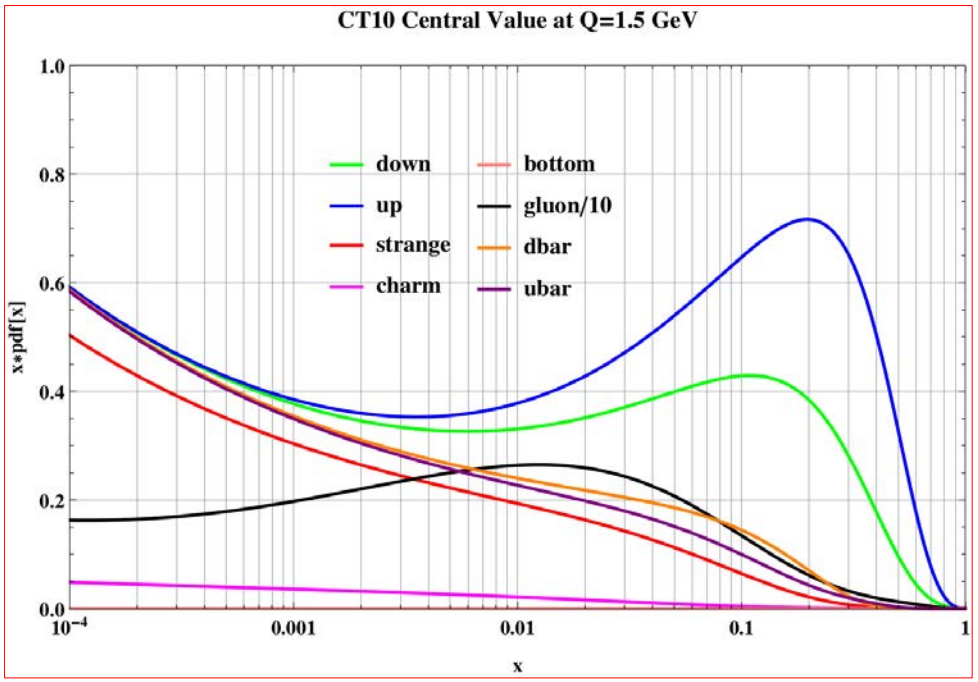
Mathematica provides plotting and integration

Examples: I

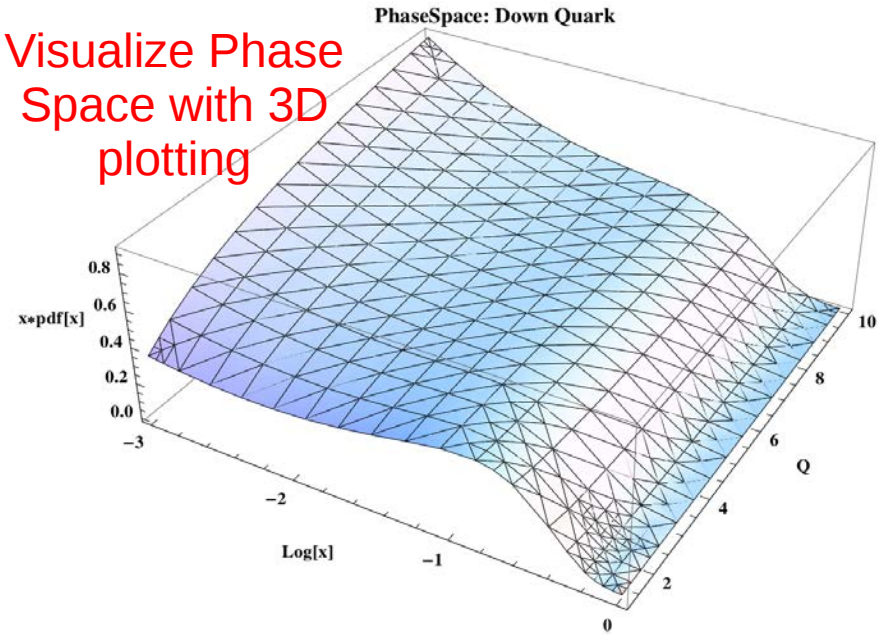




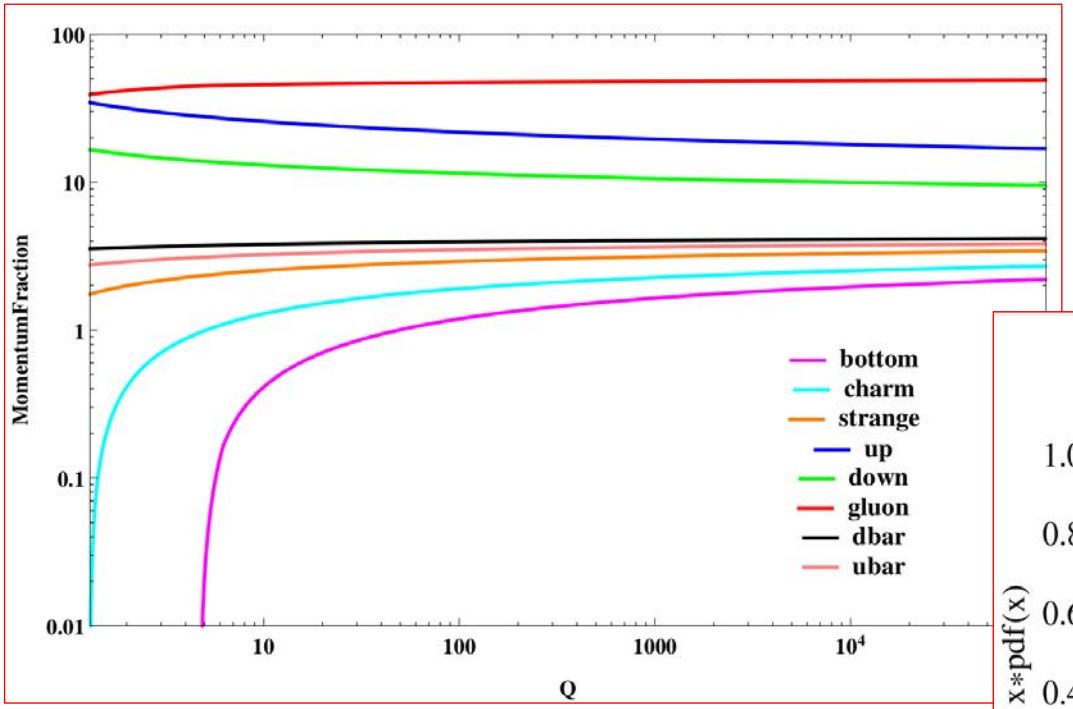
Plot of Multiple Partons for a Single PDF



Visualize Phase Space with 3D plotting

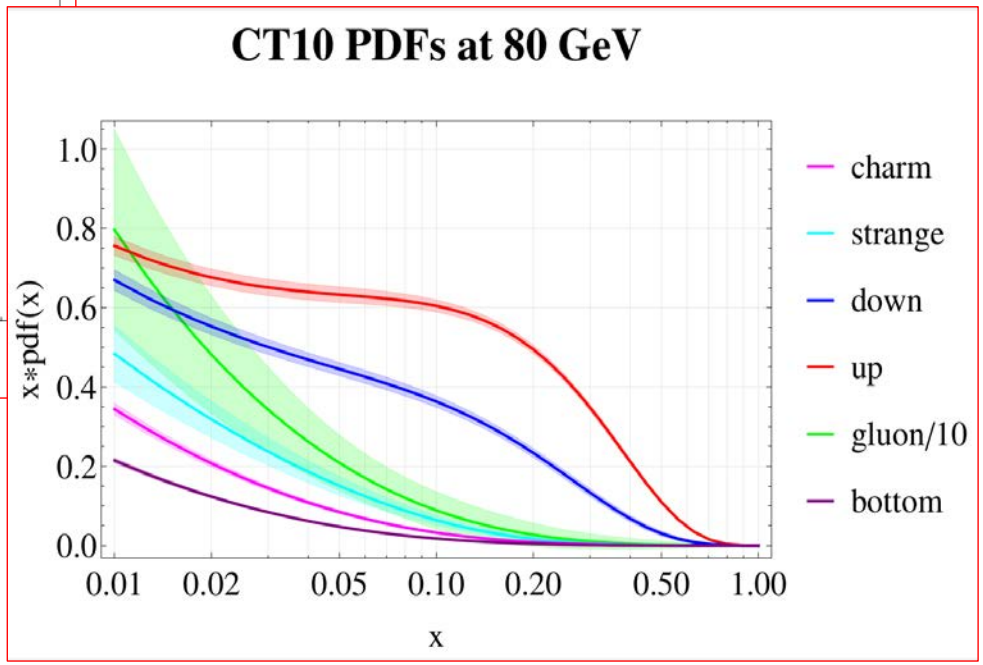


Examples: II



Full sets of PDFs inside Mathematica

Easy to manipulate



Momentum Sum Rule provides a good check for interpolation errors

$$1 = \sum_i \int_0^1 x \cdot pdf_i(x, Q)\, dx$$

Proper α_s is essential for NLO+ calculations