The nCTEQ PDFs:
Improved PDF precision with eA measurements

Fred Olness
SMU

Thanks for substantial input
from my friends & colleagues

CTEQ

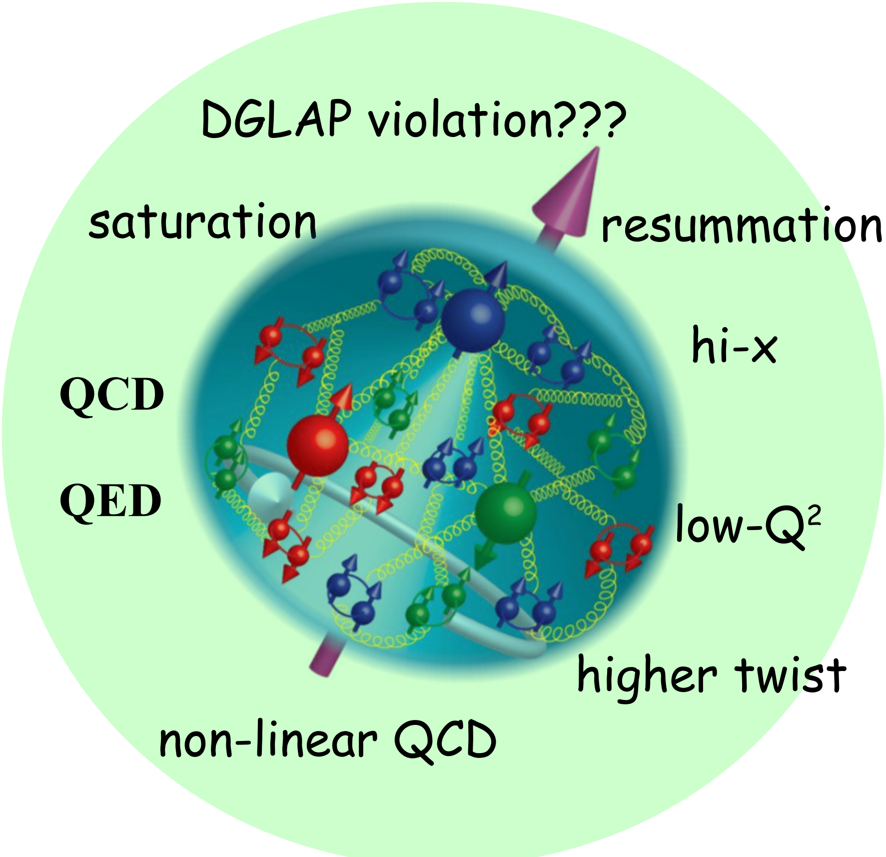
xFitter

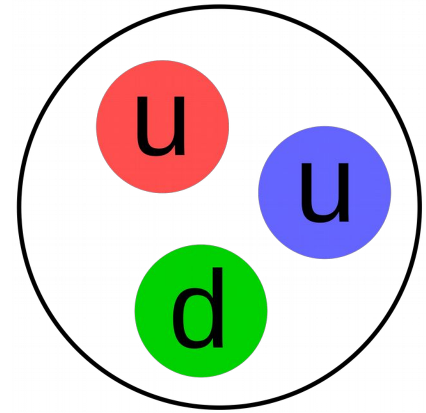
nCTEQ
nuclear parton distribution functions

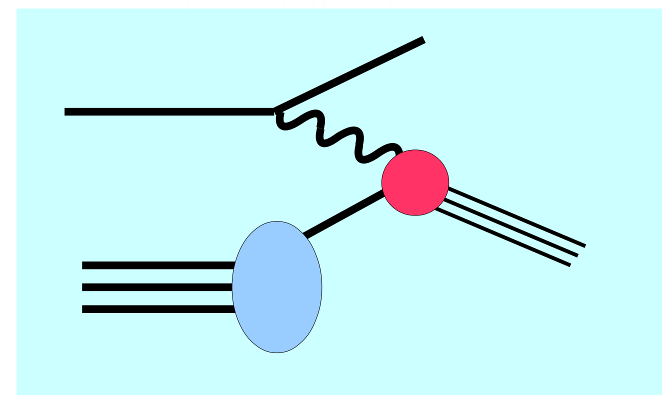
INT Workshop

22-26 October 2018

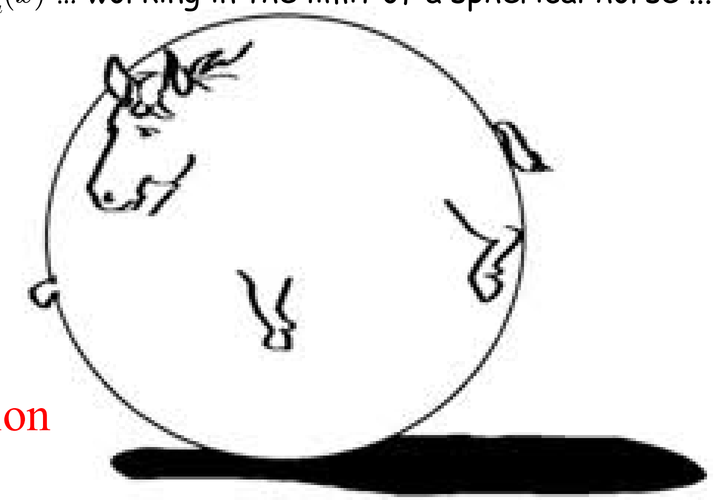

PDFs & the Parton Model … *a few simpifications*







$f_a(x)$ … working in the limit of a spherical horse …



The QCD Parton Model

$$d\sigma = f_a(x) \otimes \hat{\sigma}$$

Parameterized in terms of a single variable x, the momentum fraction

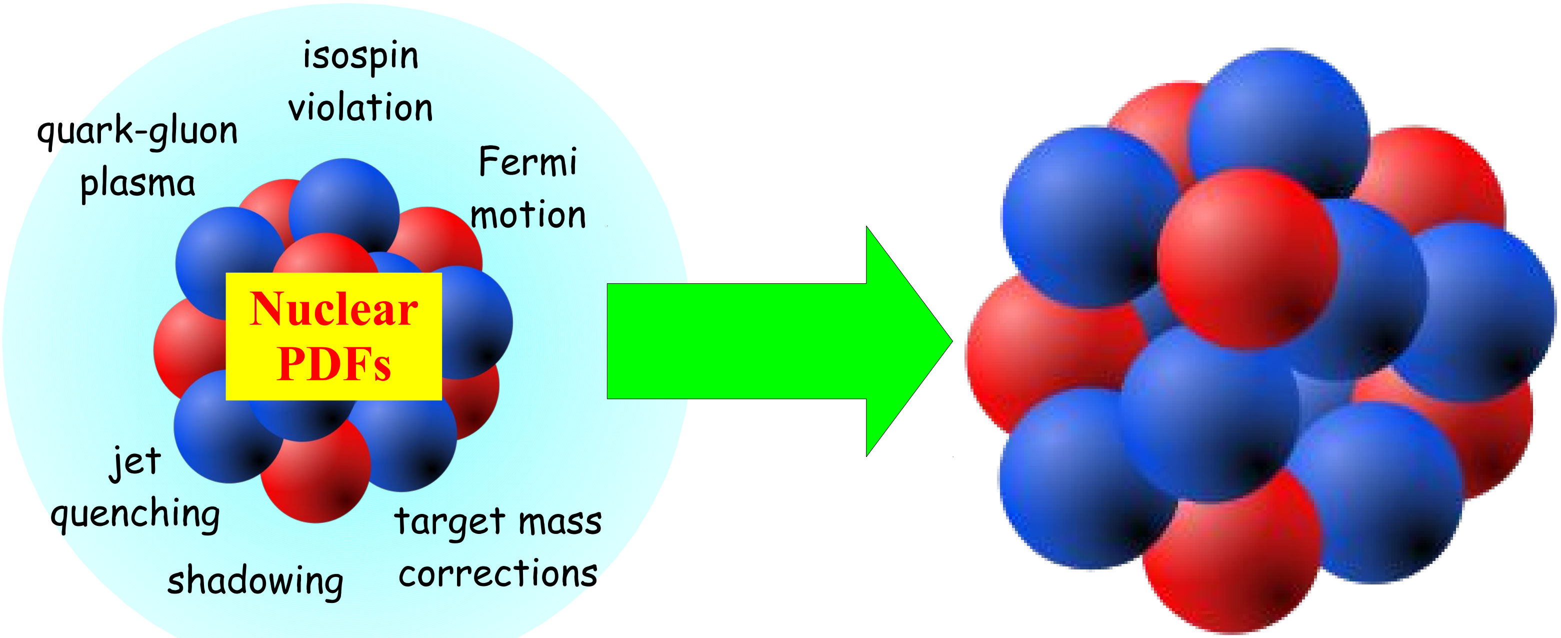
… use DGLAP to determine μ dependence

Nuclear PDFs

... a few simpifications

...

even more so with nPDFs



Limited data in nuclear dimension

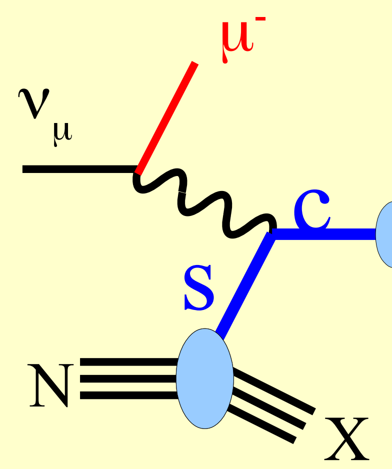
This is where EIC can contribute!!!

Nuclear PDFs are ESSENTIAL for proton PDFs

neutrino DIS

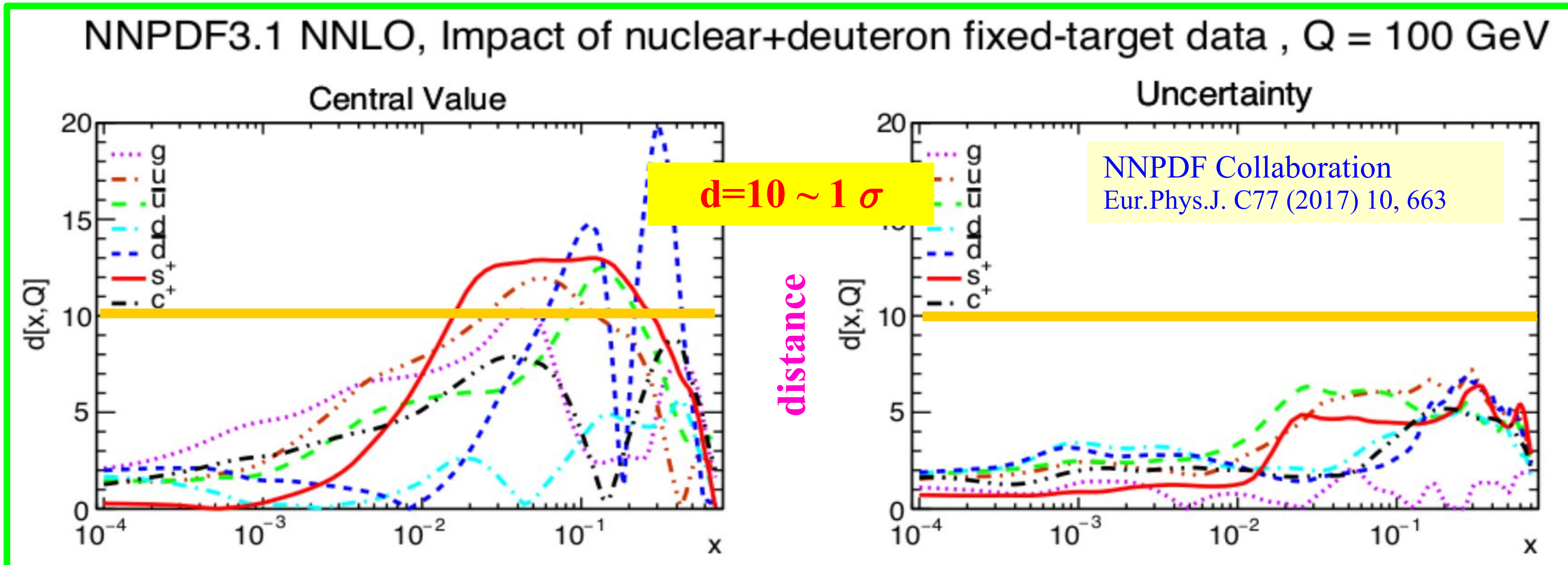
$$F_2^{\nu} \sim \left[d + s + \bar{u} + \bar{c}\right]$$
$$F_2^{\bar{\nu}} \sim \left[\bar{d} + \bar{s} + u + c\right]$$
$$F_3^{\nu} \sim 2\left[d + s - \bar{u} - \bar{c}\right]$$
$$F_3^{\bar{\nu}} \sim 2\left[u + c - \bar{d} - \bar{s}\right]$$

Neutrino DIS



Depends on nuclear corrections

Differentiate flavors of free-proton PDFs:



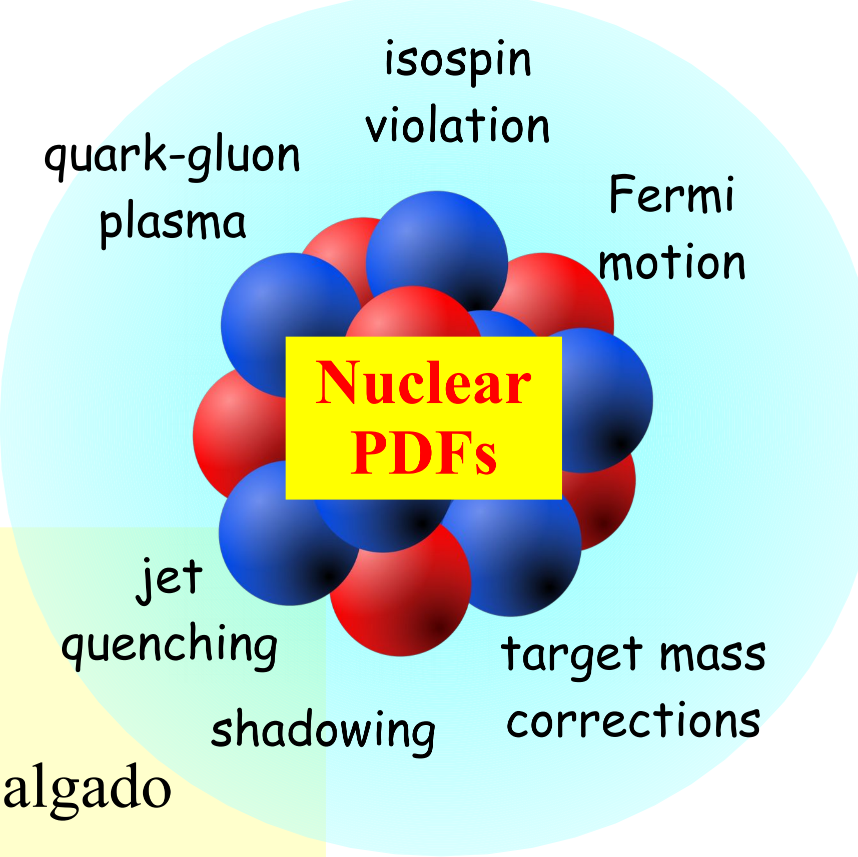
"... for the time being it is still appears advantageous to retain nuclear target data in the global dataset for general-purpose PDF determination"

Nuclear PDF

The Players
The Ingredients

nPDFs

nuclear parton distribution functions



HKN'07: Hirai, Kumano, Nagai
[PRC 76, 065207 (2007)]

EPPS'16: Eskola, Paakkinen, Paukkunen, Salgado
Eur.Phys.J. C77 (2017) no.3, 163
(supersedes EPS'09)

EPS'09: Eskola, Paukkunen, Salgado
[JHEP 04 (2009)]

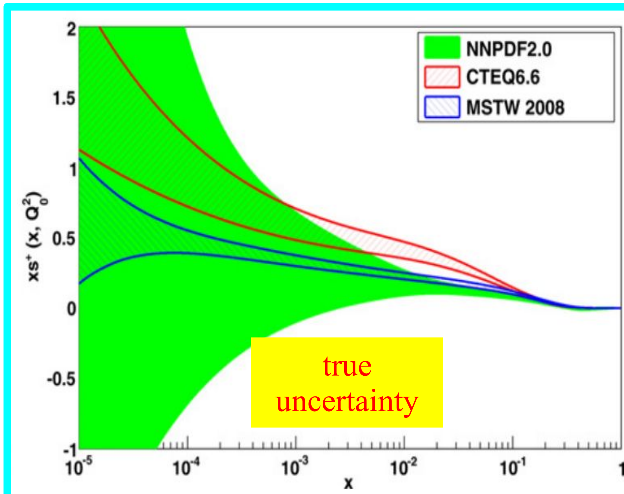
DSSZ'11: de Florian, Sassot, Stratmann, Zurita
[PRD 85, 074028 (2012)]

nCTEQ'15: nCTEQ Collaboration
[PRD 93, 085037 (2016)]

+ … a new group

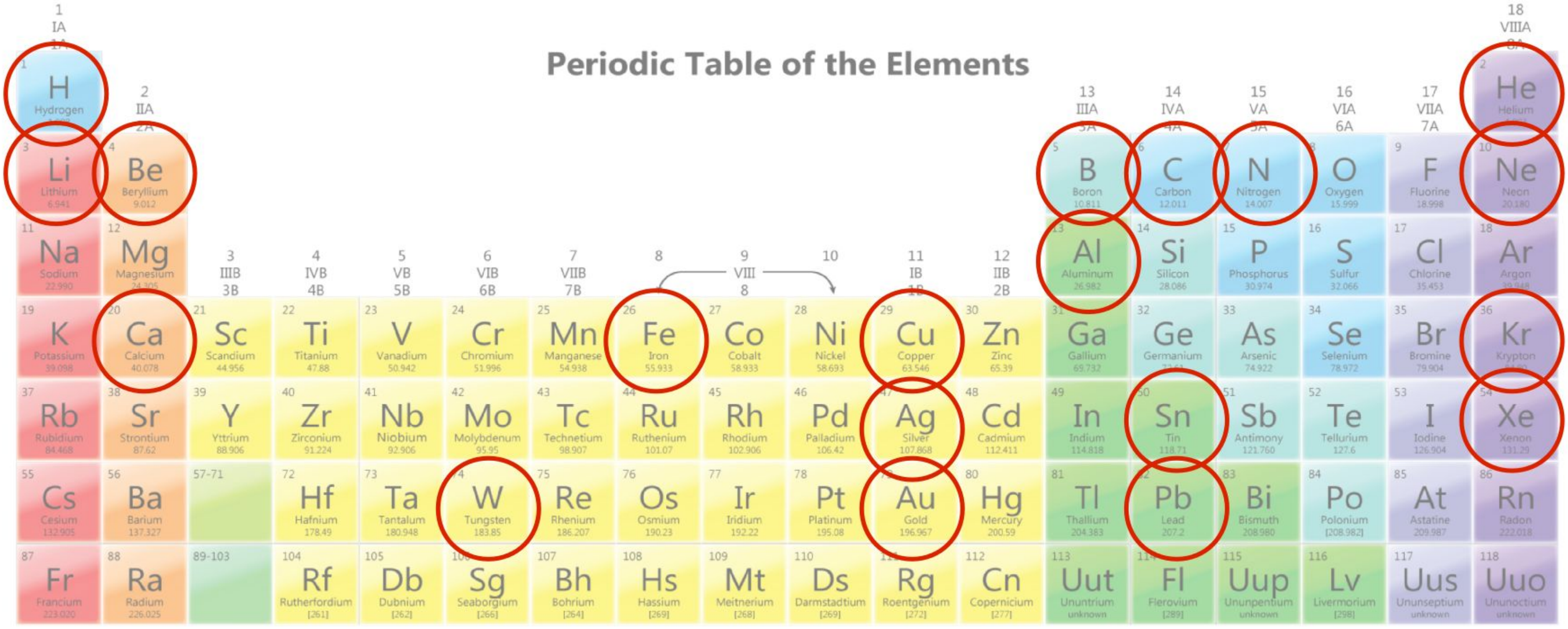
Towards a Neural Network determination of nuclear PDFs

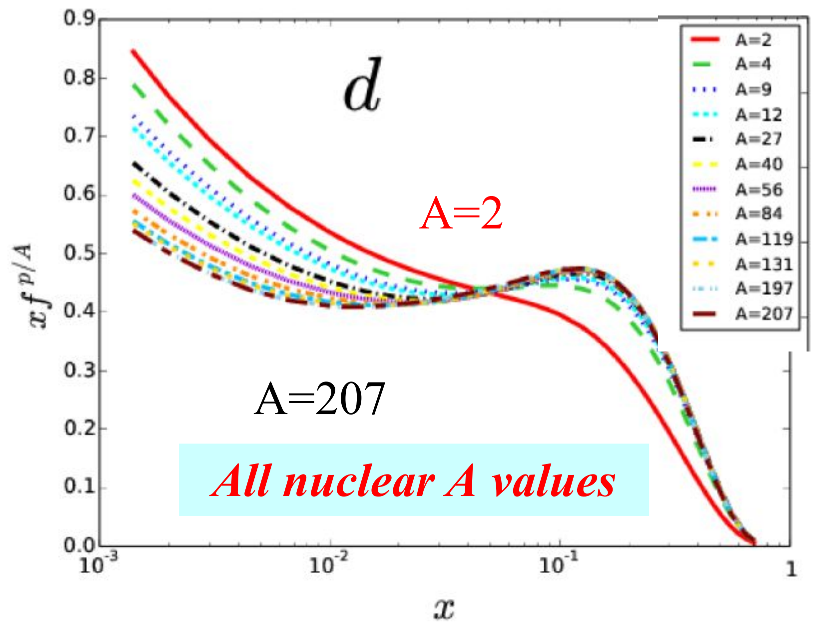
R. Abdul Khalek, J. Ethier, J. Rojo
Departement of Physics and Astronomy, Vrije Universiteit Amsterdam
Nikhef Theory Group

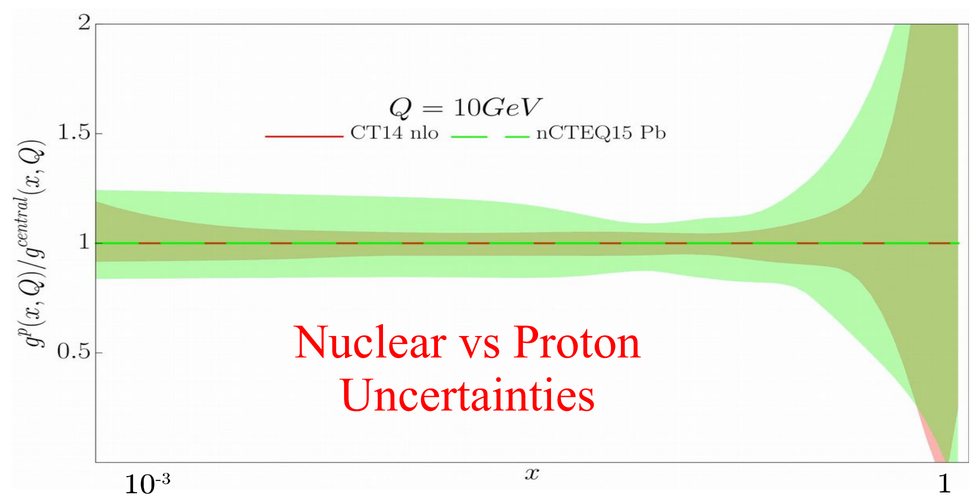


	EPS09	DSSZ12	KA15	NCTEQ15	EPPS16	nNNPDF1.0
Order in α_s	LO & NLO	NLO	NNLO	NLO	NLO	NLO
Neutral current DIS ℓ+A/ℓ+d	✓	✓	✓	✓	✓	✓
Drell-Yan dilepton p+A/p+d	✓	✓	✓	✓	✓	
RHIC pions d+Au/p+p	✓	✓		✓	✓	
Neutrino-nucleus DIS		✓			✓	
Drell-Yan dilepton $\pi+A$					✓	
LHC p+Pb jet data					✓	
LHC p+Pb W, Z data					✓	
Q cut in DIS	1.3 GeV	1 GeV	1 GeV	2 GeV	1.3 GeV	1.3 GeV
datapoints	929	1579	1479	708	1811	605
free parameters	15	25	16	17	20	73
error analysis	Hessian	Hessian	Hessian	Hessian	Hessian	Monte Carlo rep
error tolerance $\Delta\chi^2$	50	30	not given	35	52	
Free proton baseline PDFs	CTEQ6.1	MSTW2008	JR09	CTEQ6M-like	CT14NLO	NNPDF3.1
Heavy-quark effects		✓		✓	✓	✓
Flavor separation				some	✓	
Reference	[JHEP 0904 065]	[PR D85 074028]	[PR D93, 014026]	[PR D93 085037]	[EPJ C77 163]	Preliminary

Nuclear PDFs: The Ingredients … ~19 nuclei





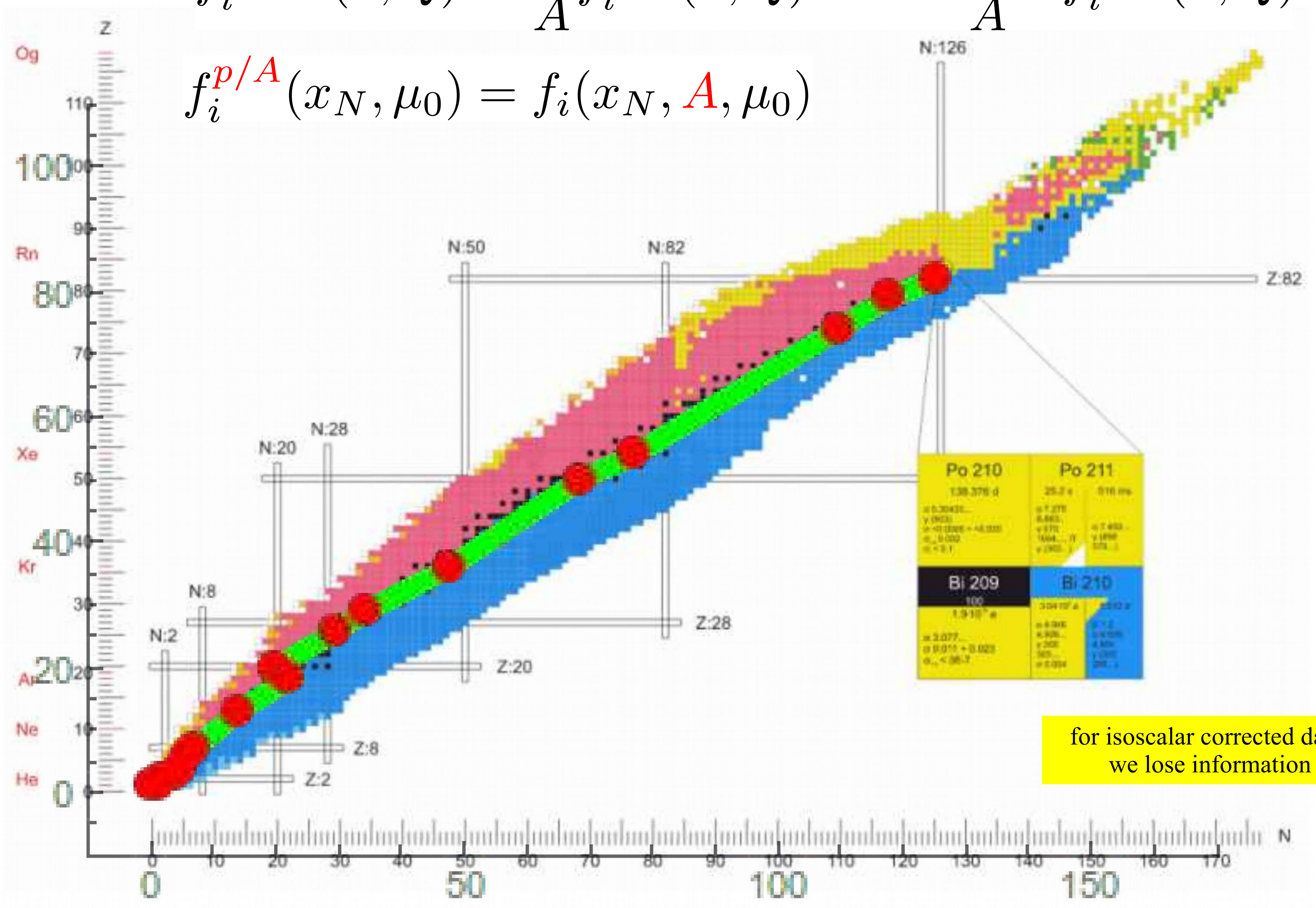


EIC can expand our knowledge of the nuclear A dimension

Nuclear PDFs: The Ingredients … ~19 nuclei

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

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

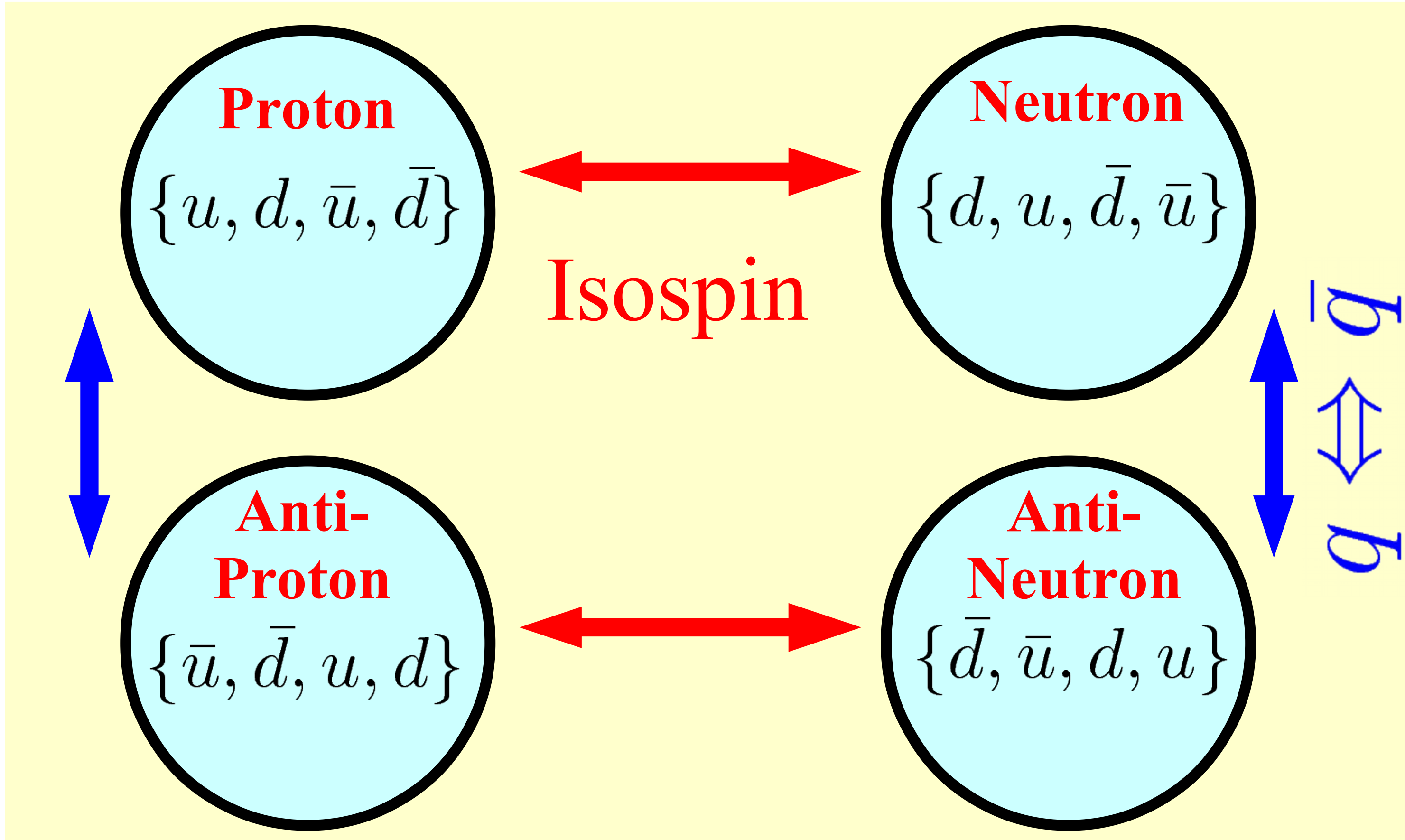


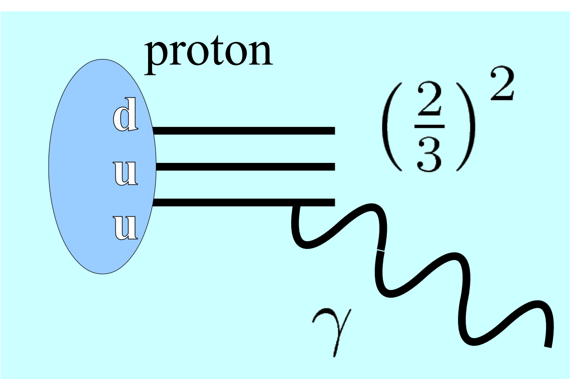
for isoscalar corrected data:
we lose information

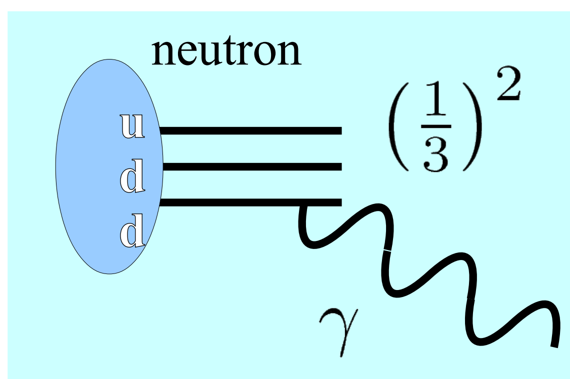
Isospin Symmetry used to generate nPDFs

$\alpha_s^2 \sim \alpha$

"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.

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*

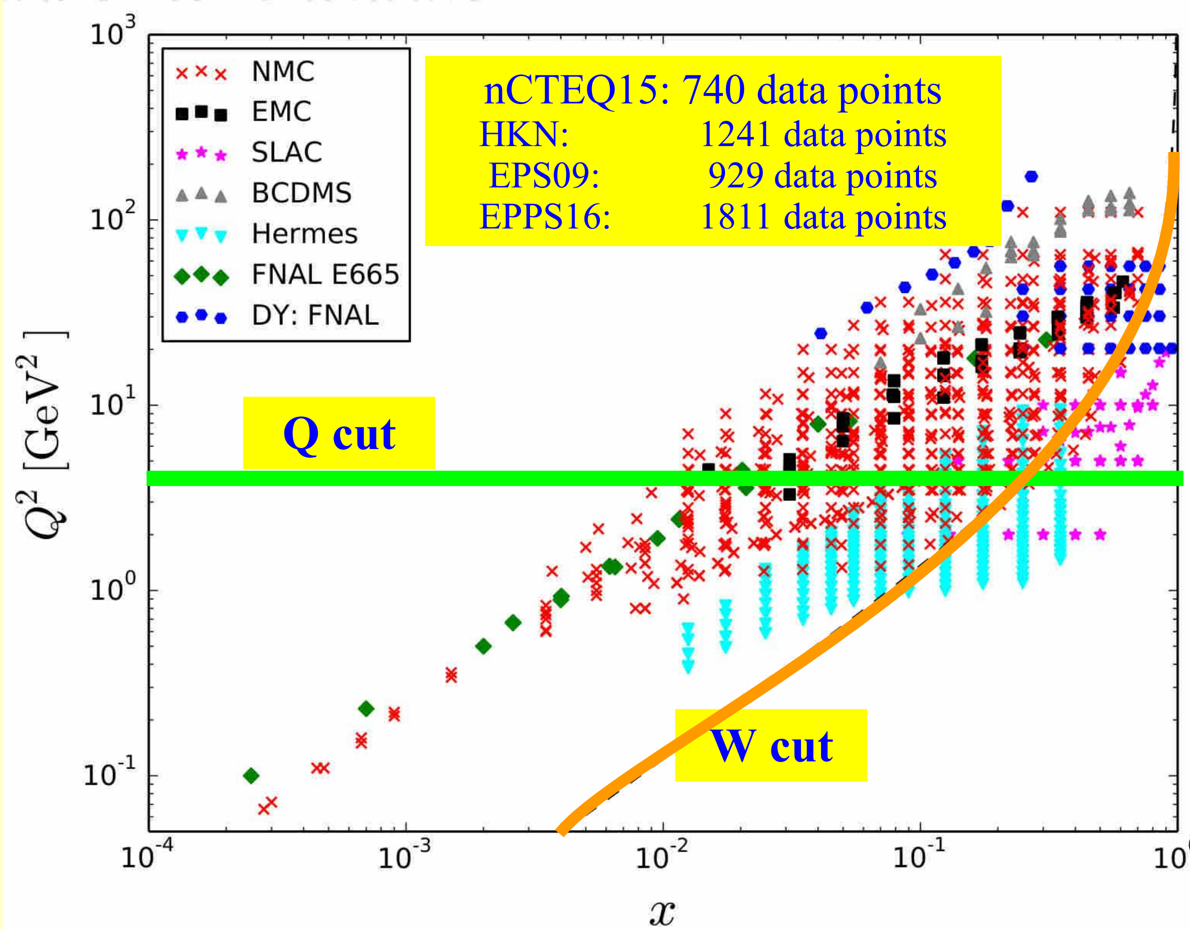
NuTeV CHORUS CCFR & NuTeV
N = Pb & Fe

Pion Production:

RHIC: PHENIX & STAR
N = Au

will show comparision w/ LHC pPb

DIS Cuts:
nCTEQ: Q>2.0 & W>3.5
EPPS16: Q>2.0 & W>3.5
EPS09: Q>1.3
HKN: Q>1.0
DSSZ: Q>1.0



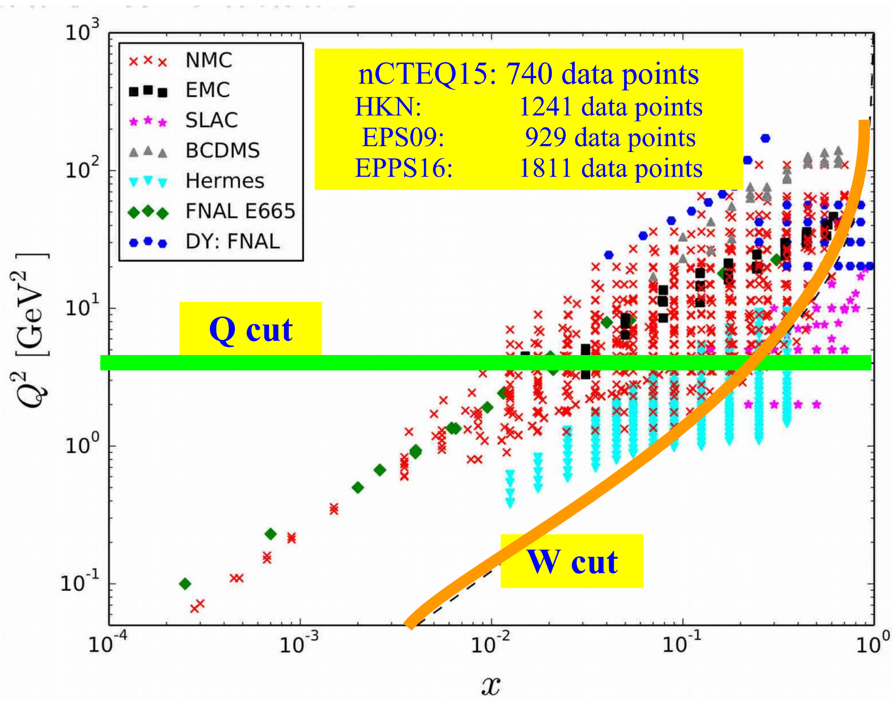
proton vs nuclear: fewer data and more DOF … impose assumptions on nPDFs

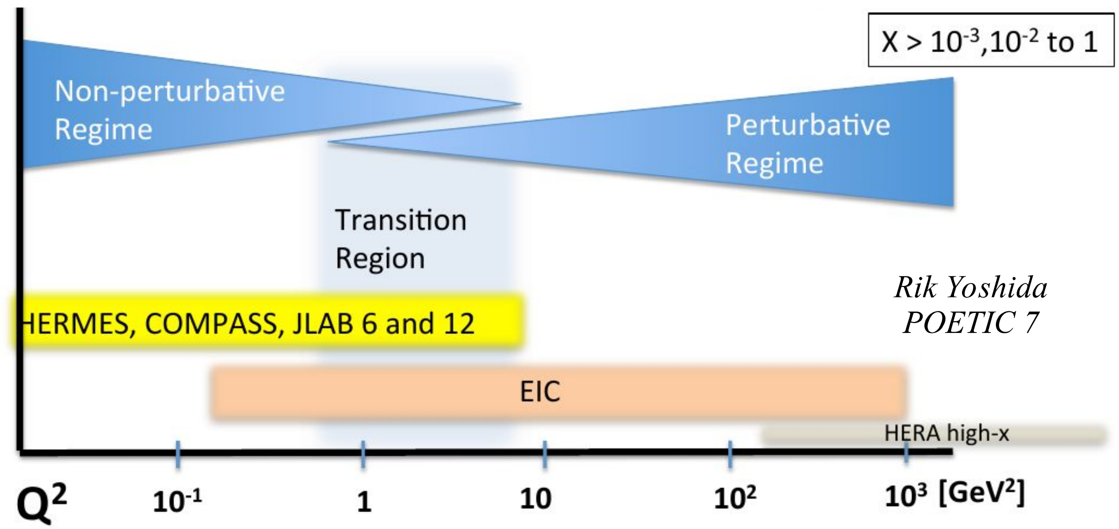
Low Q

Hi-X

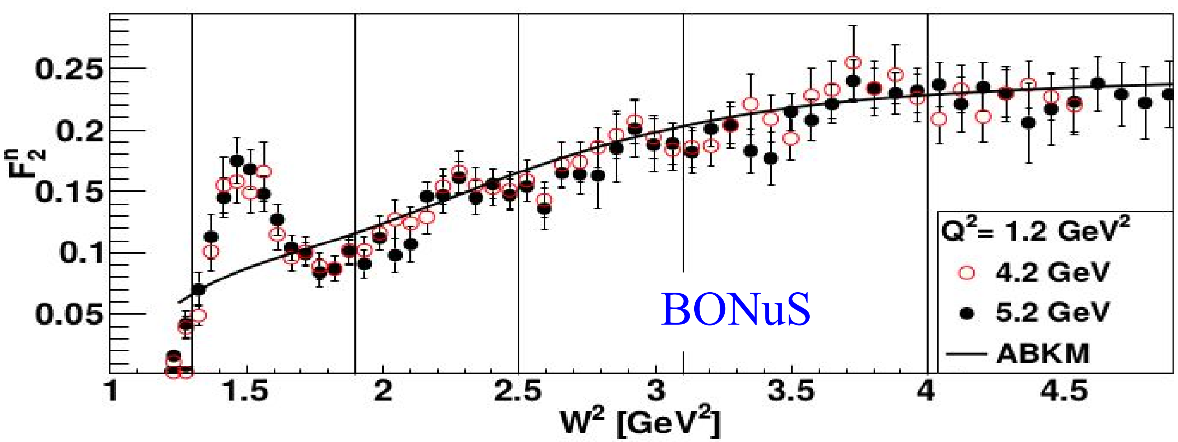
Low Q Region: Hadron / Parton Transition:

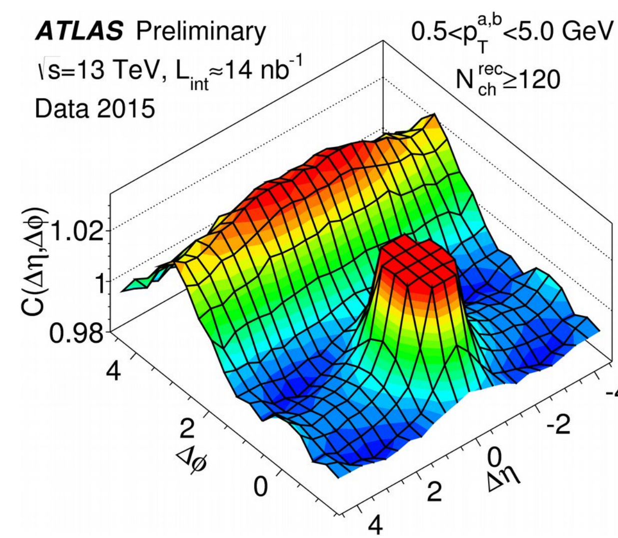
Higher Twist, many body problem, duality, hi-x, mass corrections ...





Rik Yoshida
POETIC 7





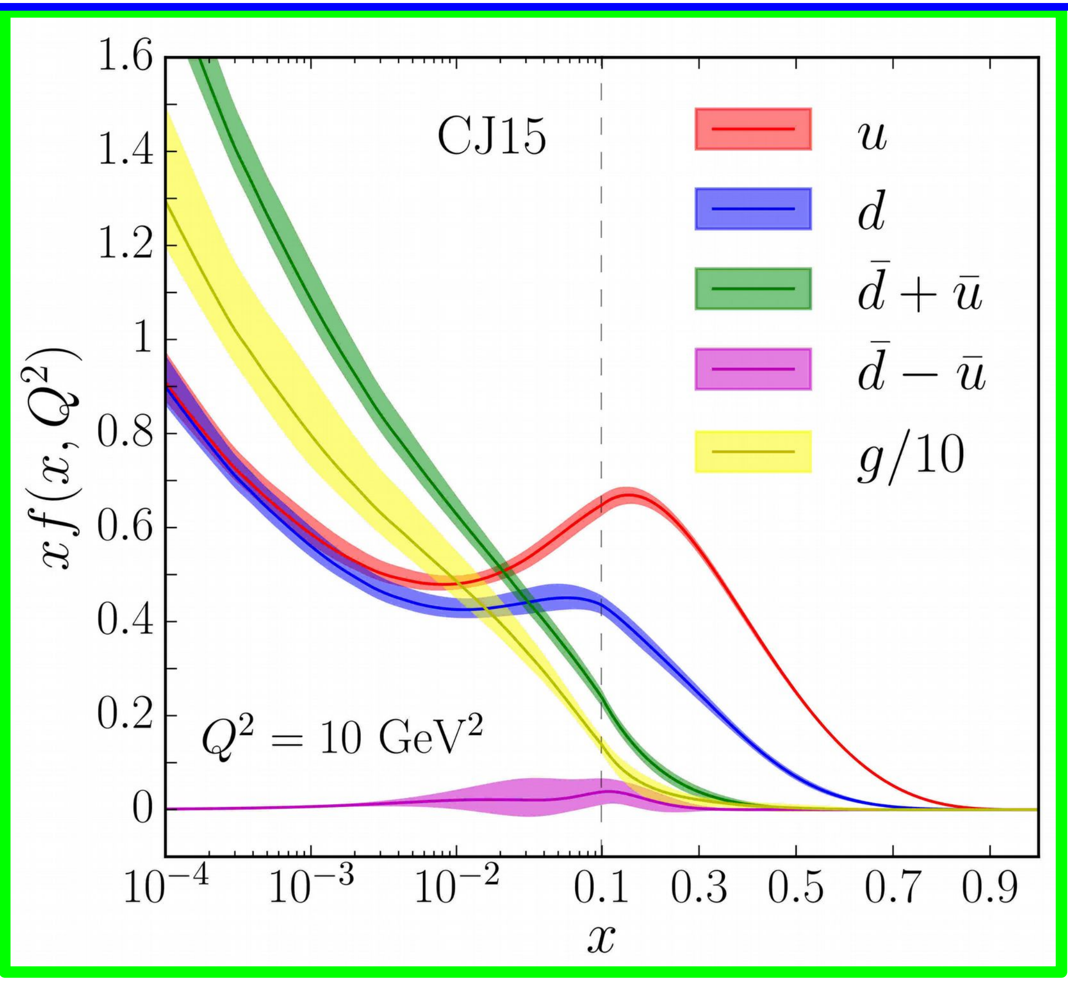
EIC can push these boundaries

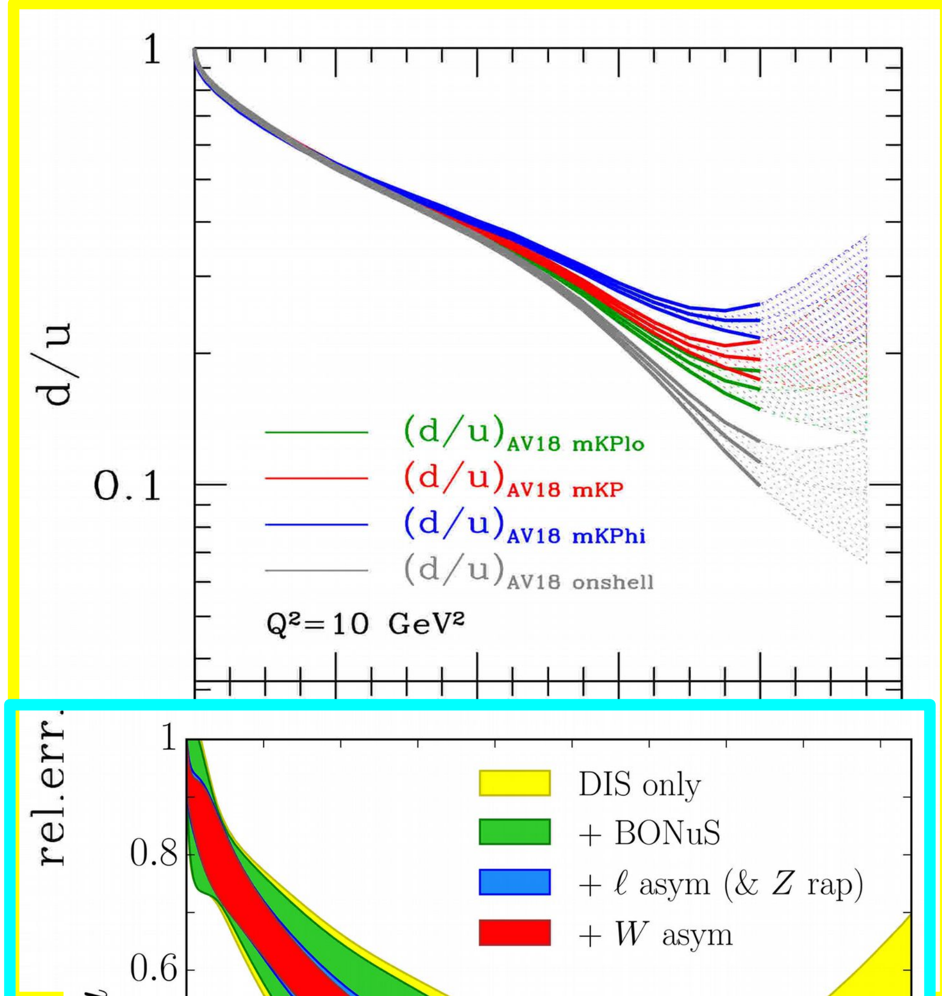
Hi-x

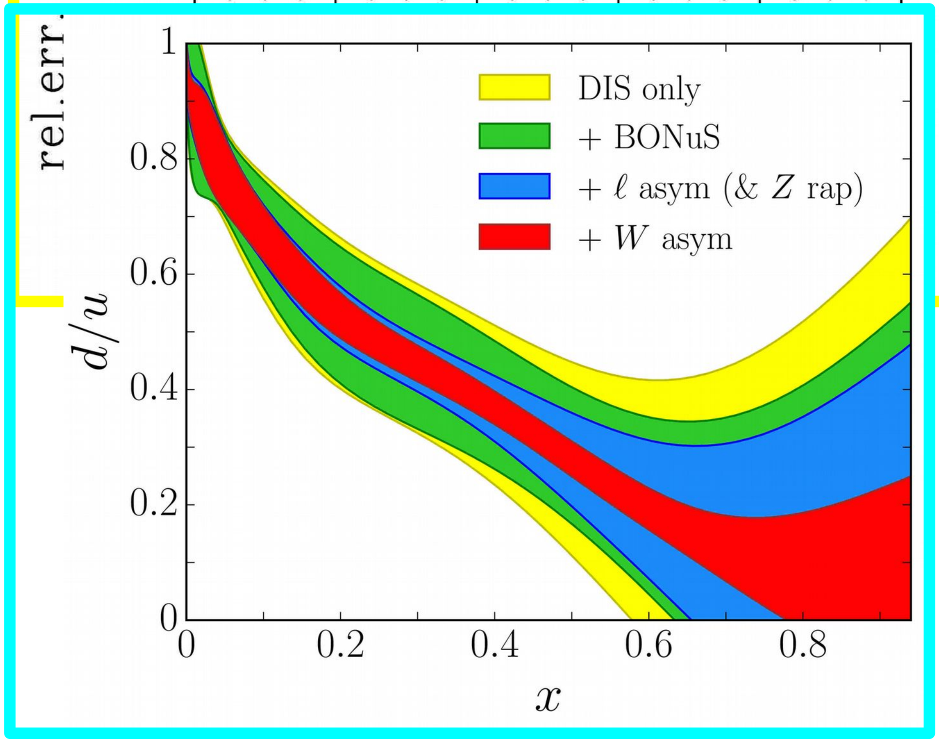
Higher twist
mass effects
limit $x \rightarrow 1$

CJ Project

Nuclear PDFs: Hi-x Region







CJ-15

arXiv: 1602.03154

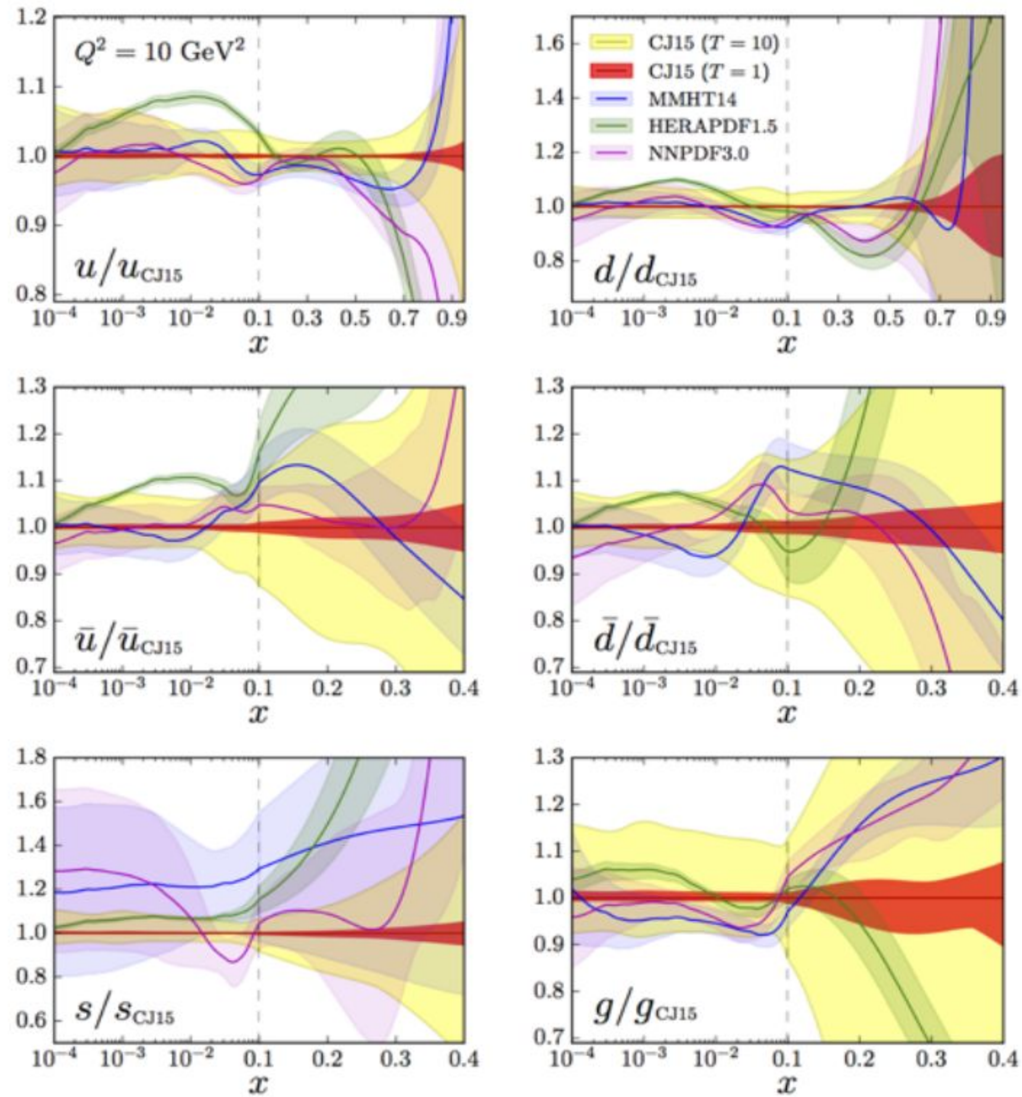
Partonic structure at high-x

- Partonic structure of nucleons/nuclei at high-x (x>0.5) poorly known:
  - >50% uncertainty on d(x) at x>0.6
  - >50% uncertainty on g(x) at x>0.2
  - very large uncertainties on quark sea
- Better understanding provides tests of models of hadron structure
  - d/u→1/2 : SU(6) Spin-Flavor symmetry
  - d/u→0 : Scalar diquark dominance
  - d/u→1/5 : pQCD power counting
  - Local quark hadron duality:

$$d/u \to \frac{4\mu_n^2/\mu_p^2 - 1}{4 - \mu_n^2/\mu_p^2} \simeq 0.42$$

- Better understanding important for BSM searches of new heavy states

CJ15 global fit, PRD93(2016)114017



Ingo Schienbein
2018 Trento Workshop

PDF Parameterization

Mechanics of nPDFs

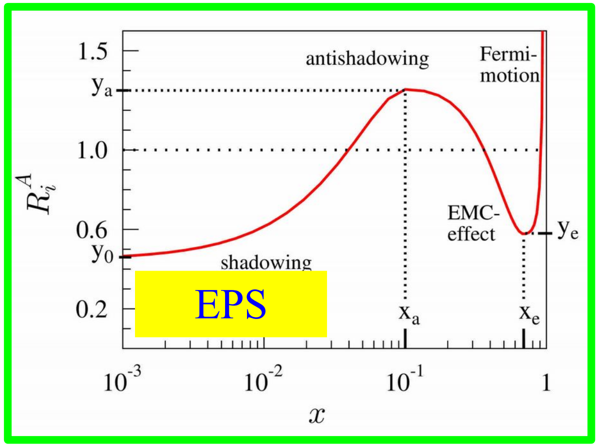
1) Multiplicative nuclear correction factors (HKN, EPPS, DSSZ)

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

... 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)

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

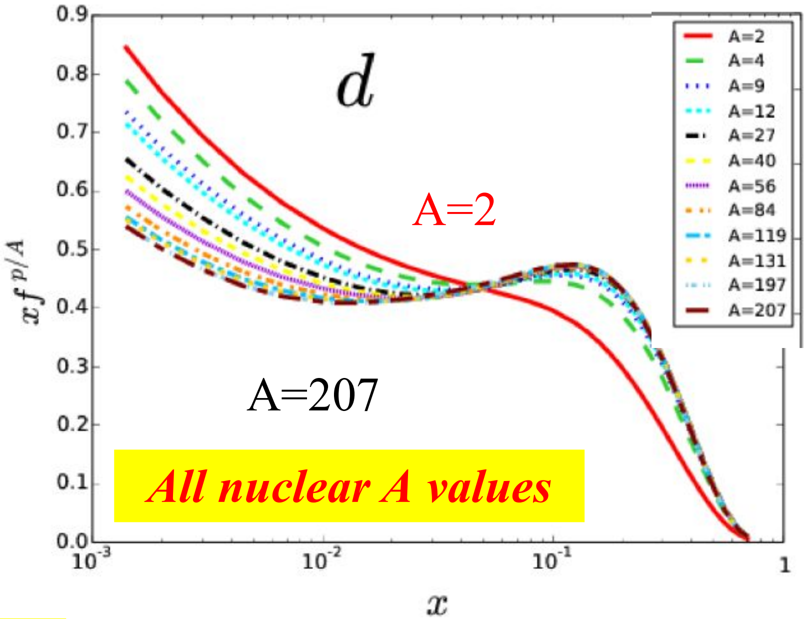
$$f \sim \ldots x^{c_1(A)} (1-x)^{c_2(A)} \ldots$$

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

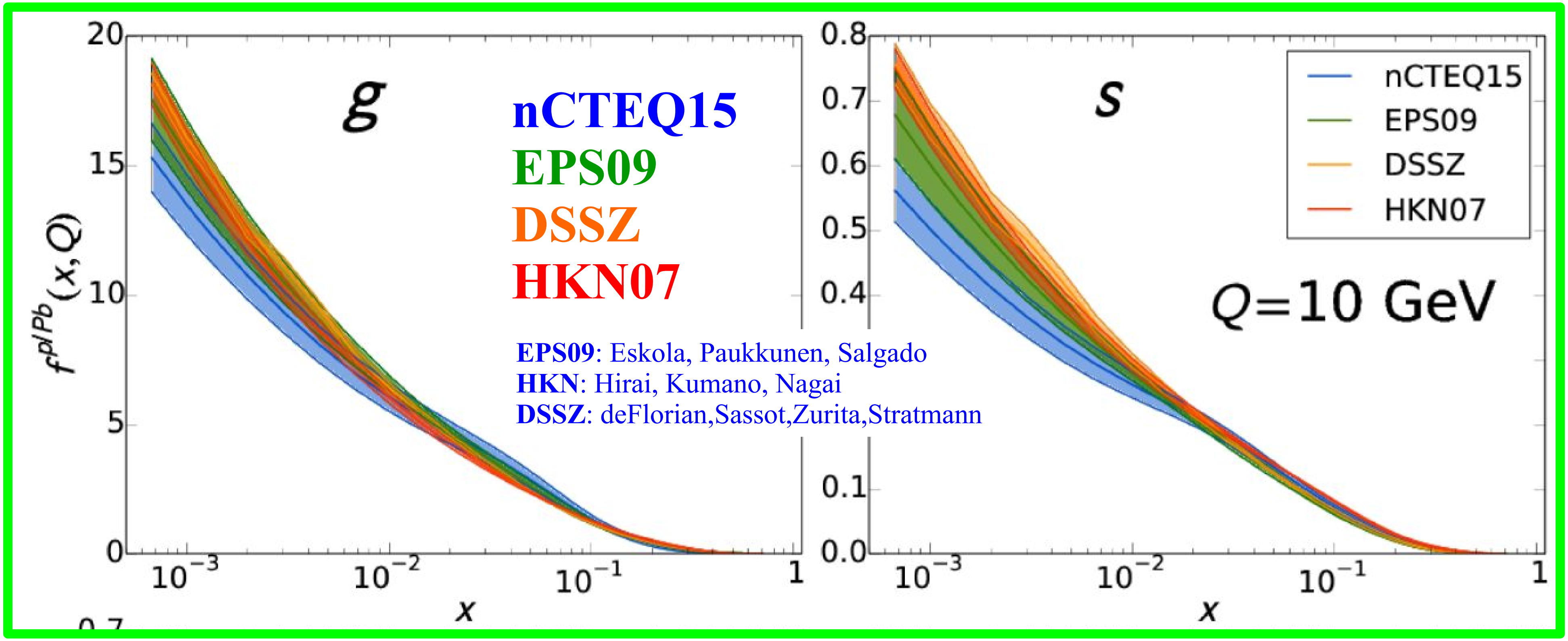
Proton → $c_{k,0}$

Nuclear → $c_{k,1}$, $c_{k,2}$

use proton as a Boundary Condition



Nuclear PDFs: Complementary efforts in general agreement



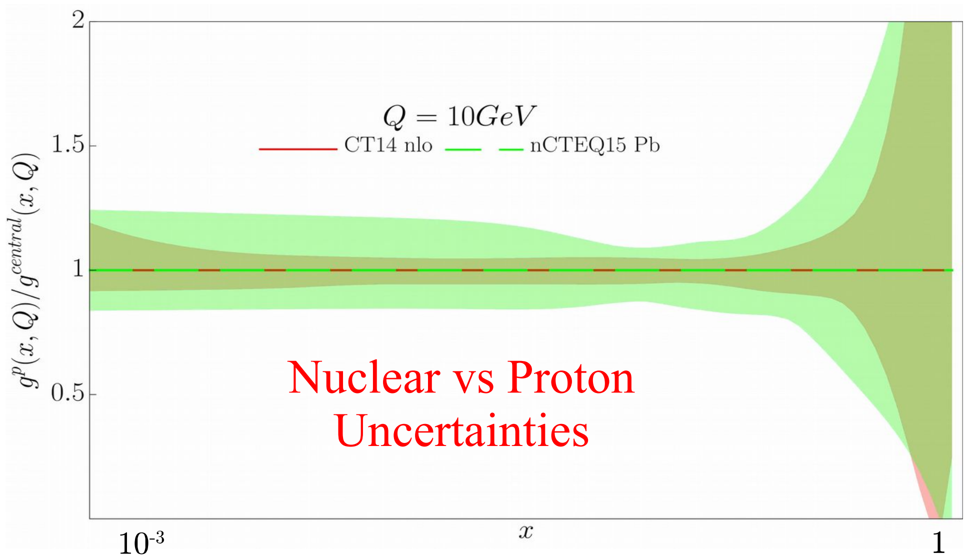
EPS09: Eskola, Paukkunen, Salgado
HKN: Hirai, Kumano, Nagai
DSSZ: deFlorian,Sassot,Zurita,Stratmann

Nuclear PDFs are more complex

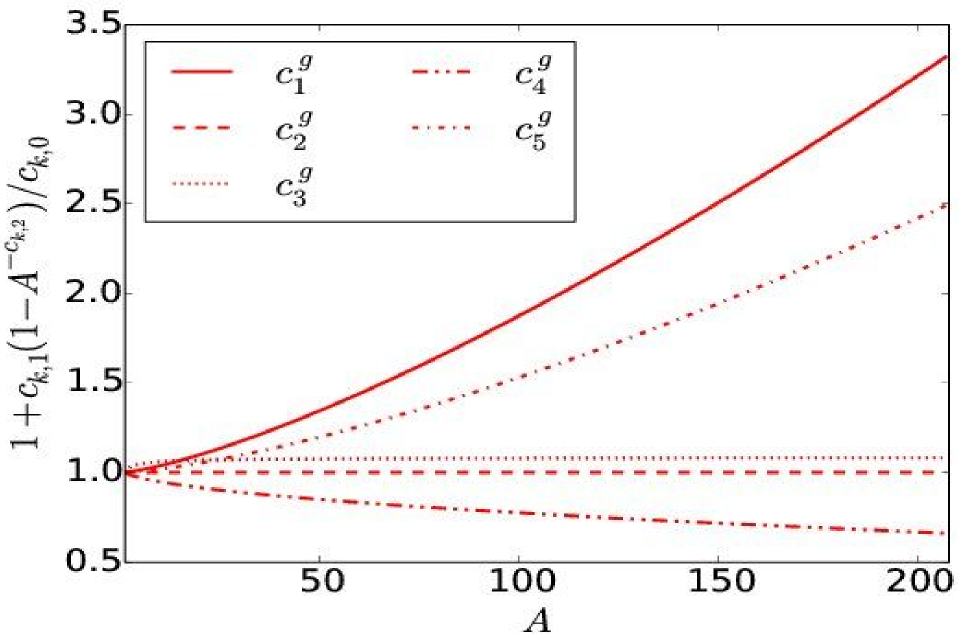
more DOF than Proton case

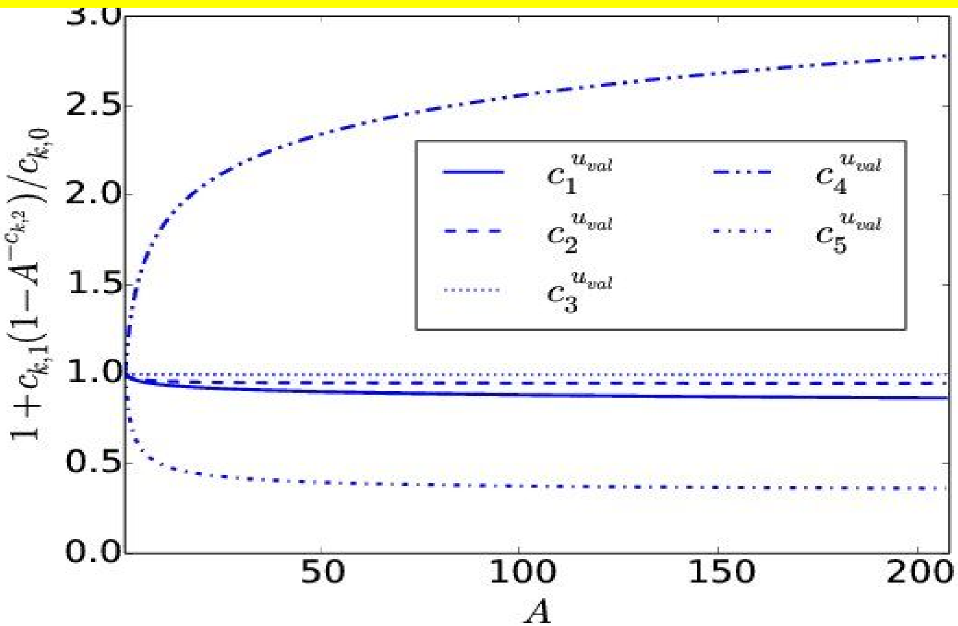
more "issues" to consider

more work to do ...



Nuclear PDFs: nCTEQ A-Dependence





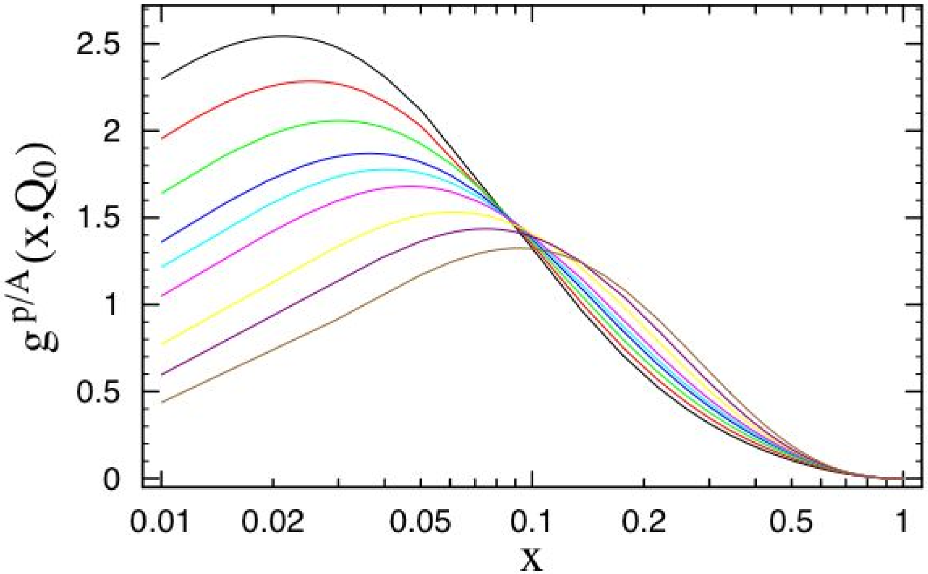
$$xf(x) = x^{a_1}(1-x)^{a_2} e^{a_3 x}(1+e^{a_4}x)^{a_5}$$

$$a_i \rightarrow a_i(A)$$

$$a_k = a_{k,0} + a_{k,1}\,(1-A^{-a_{k,2}})$$

Set by proton ($a_{k,0}$)

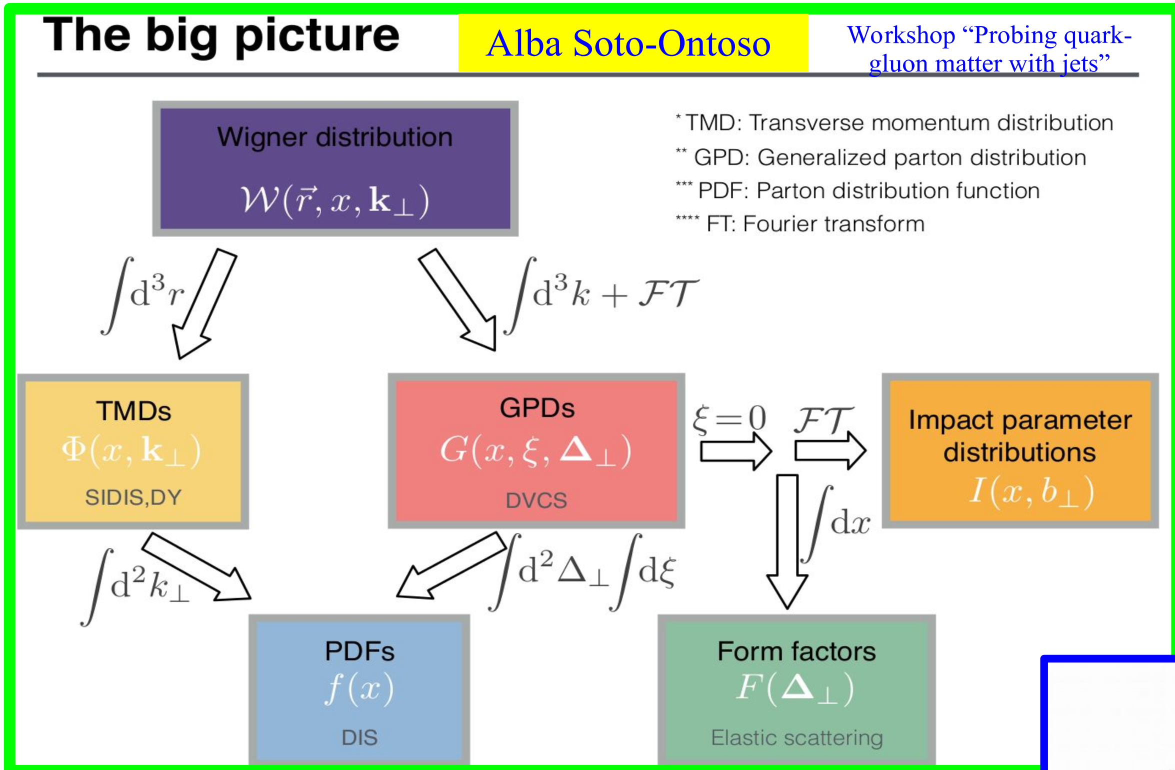
Nuclear dof ($a_{k,1}$, $a_{k,2}$)

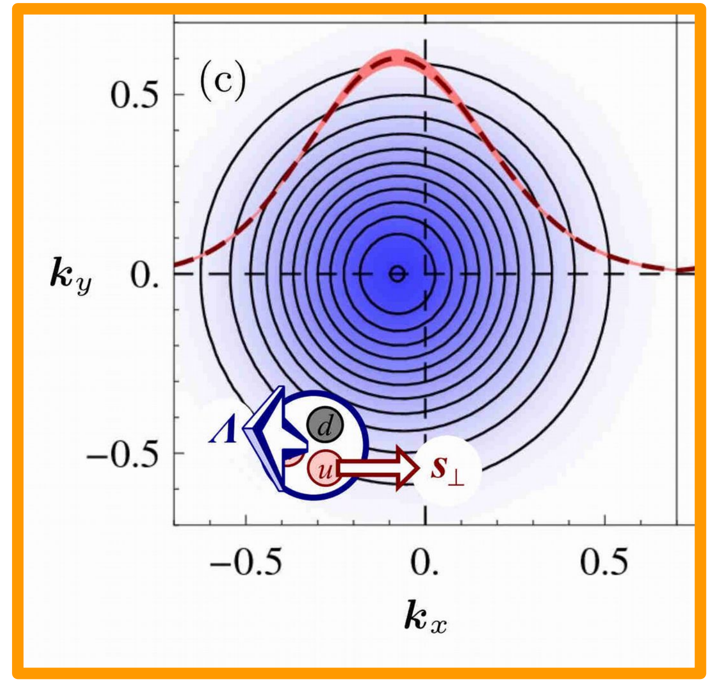


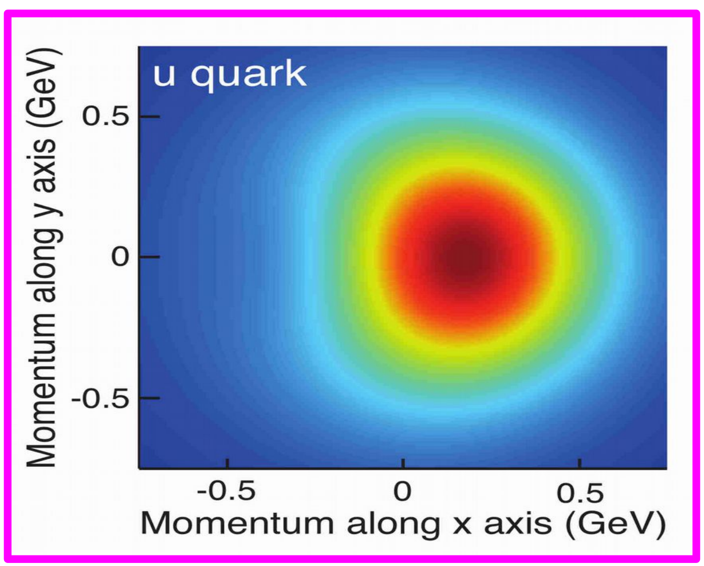
Generalized PDFs

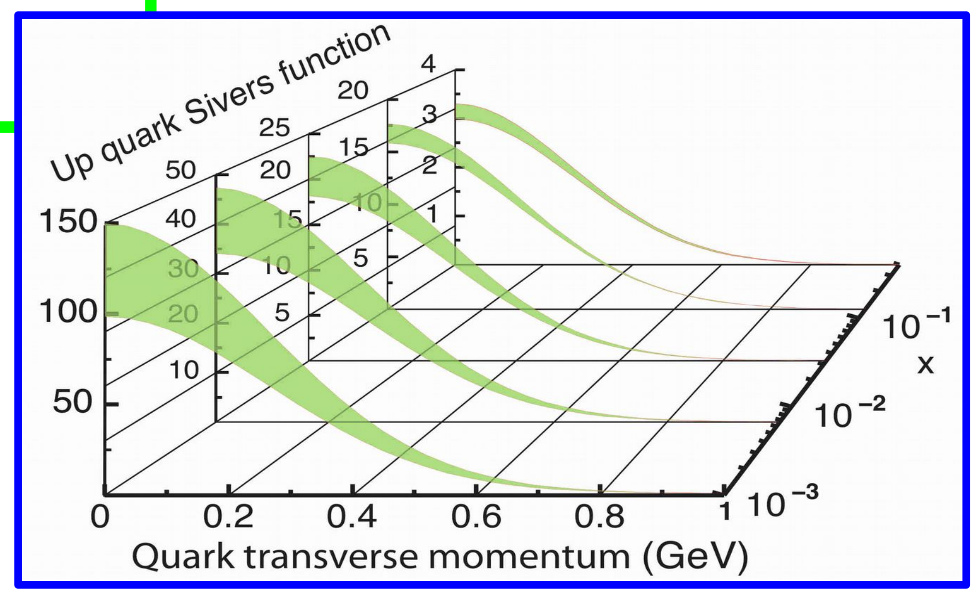
Nuclear Structure & Generalized PDFs

Hadron structure is much richer than f(x) conveys



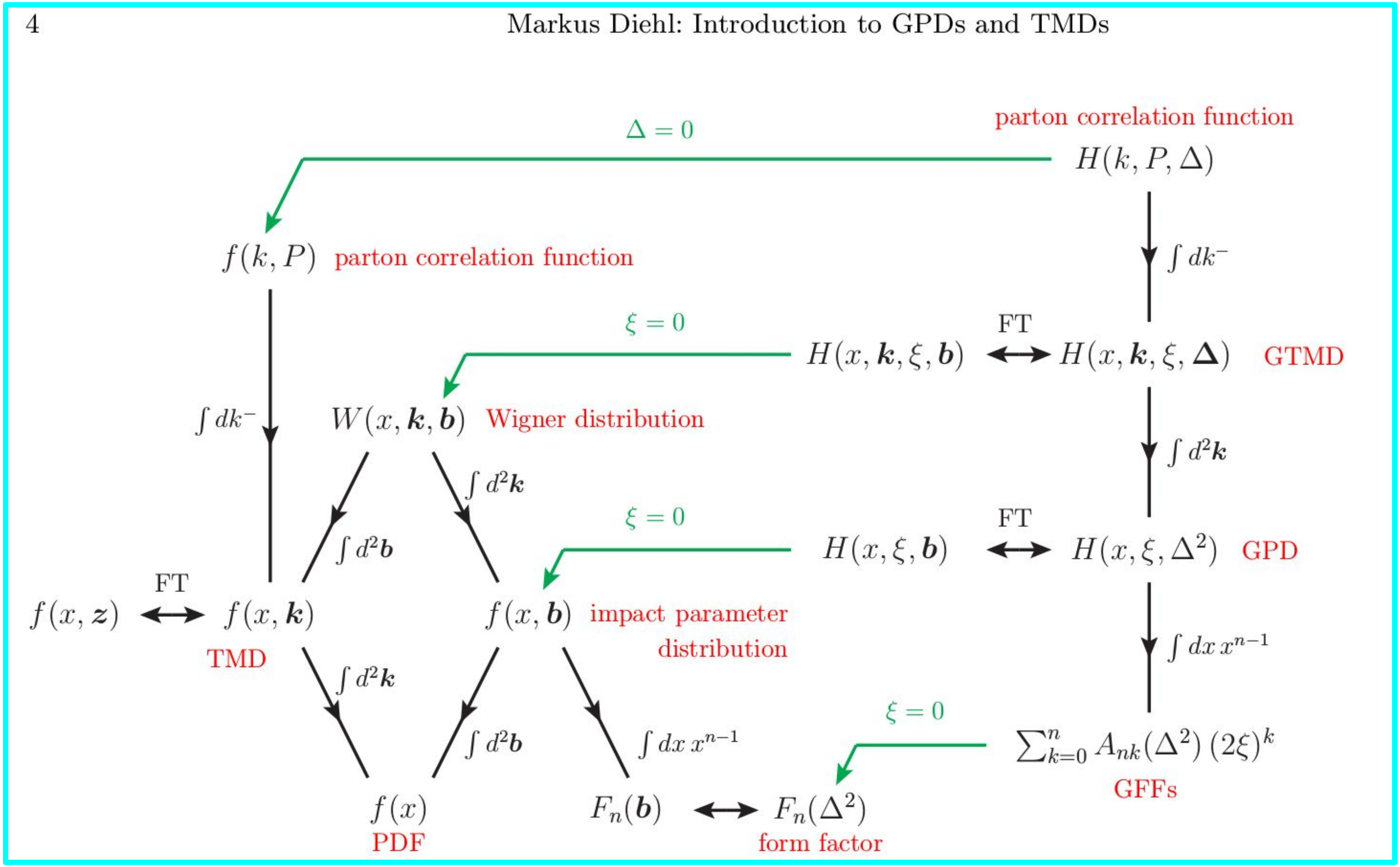






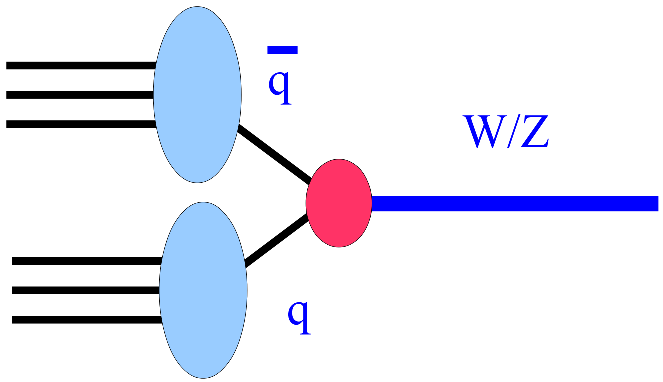
Conventional PDFs f(x) are the Boundary Conditions

Nuclear Structure & Generalized PDFs



Eur.Phys.J. A52 (2016) no.6, 149

TMD PDFS and Reorganizing the Perturbation Series



Fermi National Accelerator Laboratory

FERMILAB–Pub–91/22–T
January 24, 1991

Heavy quark production in very high energy hadron collisions

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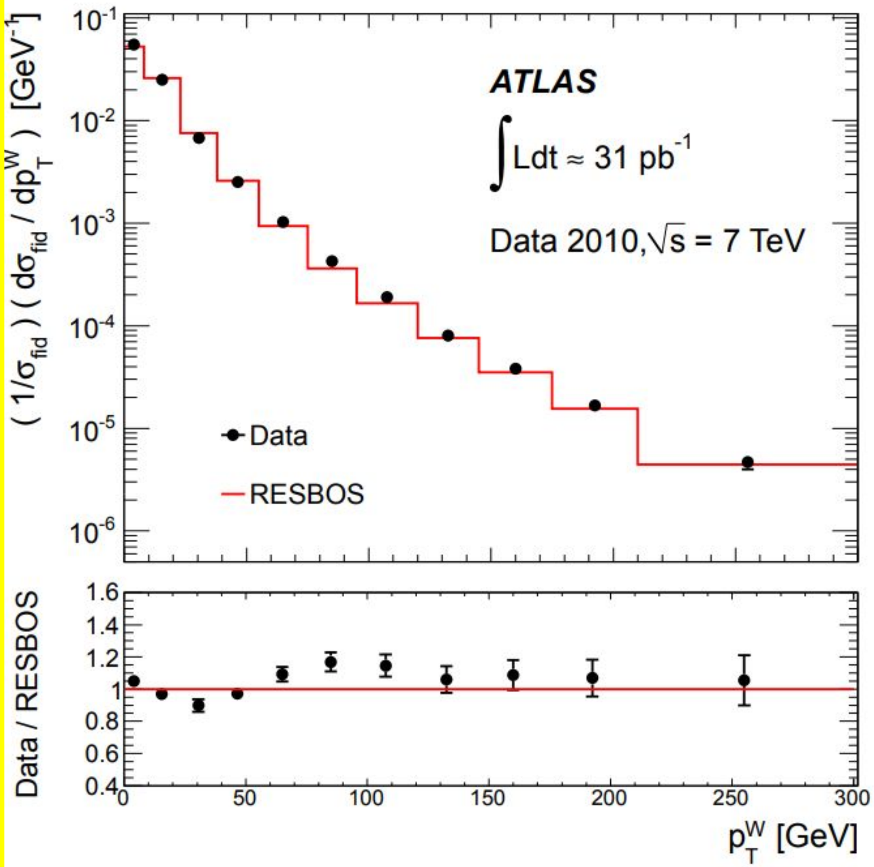

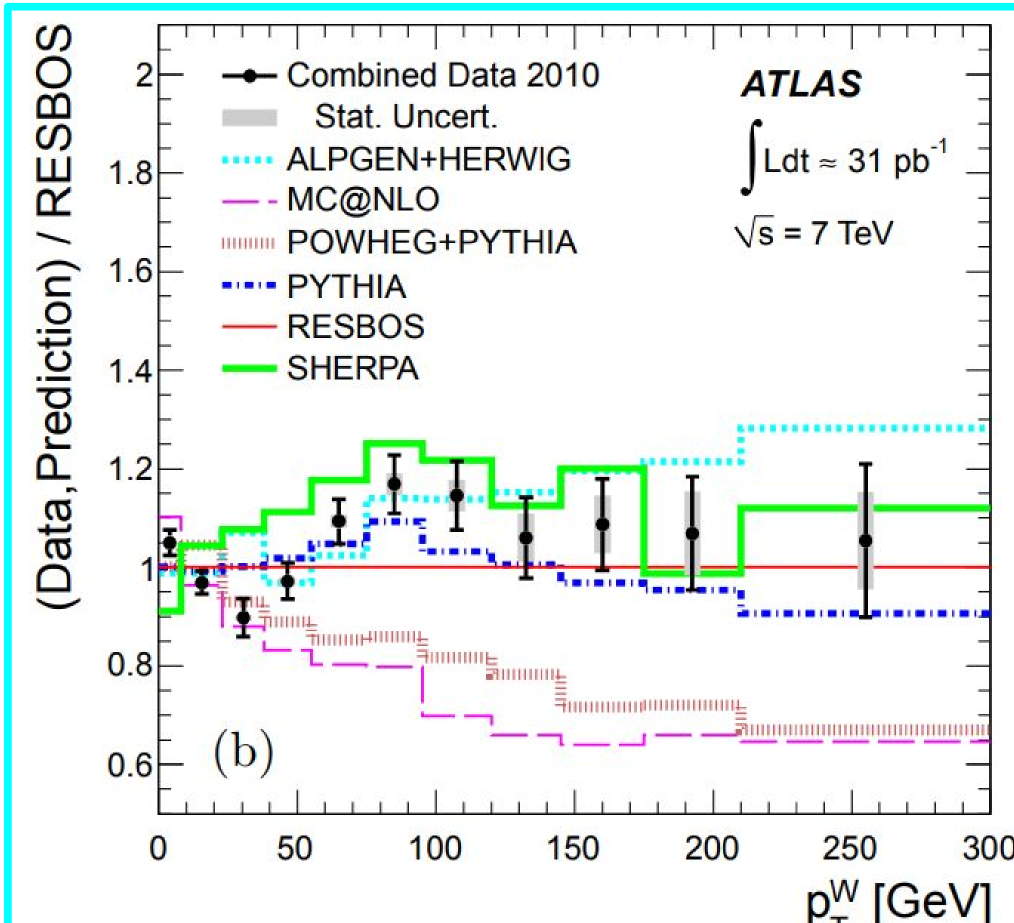

arxiv.org/1108.6308

PHYSICAL REVIEW D **96,** 054011 (2017)

Connecting different TMD factorization formalisms in QCD

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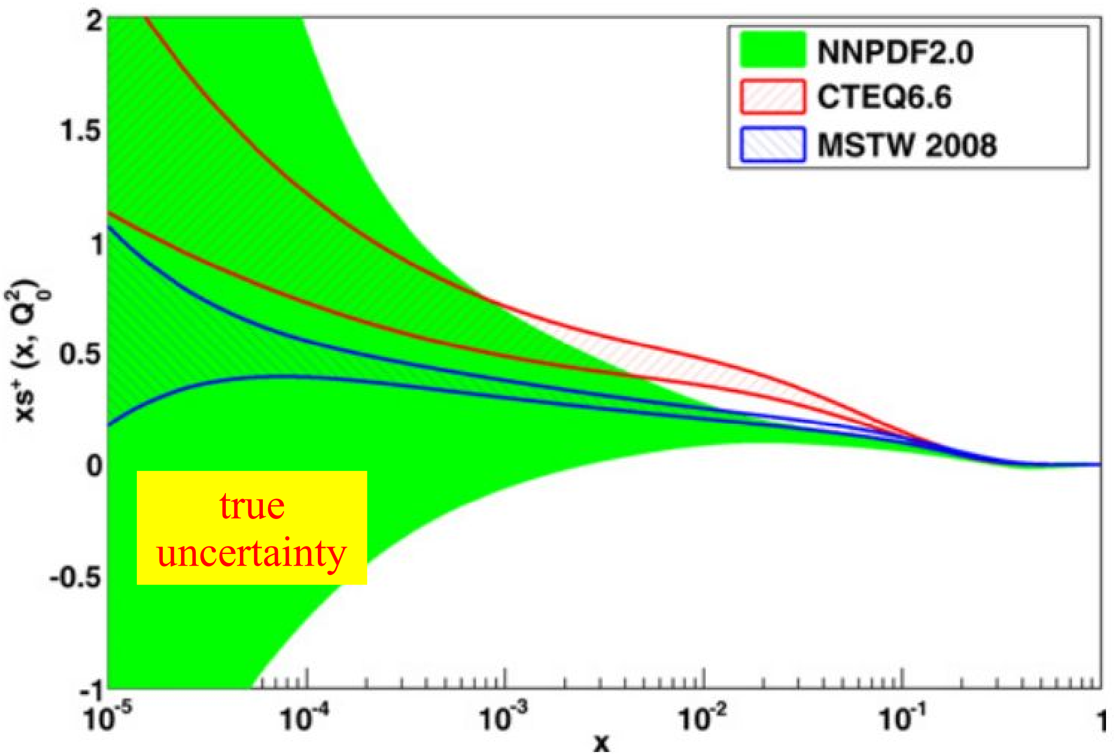
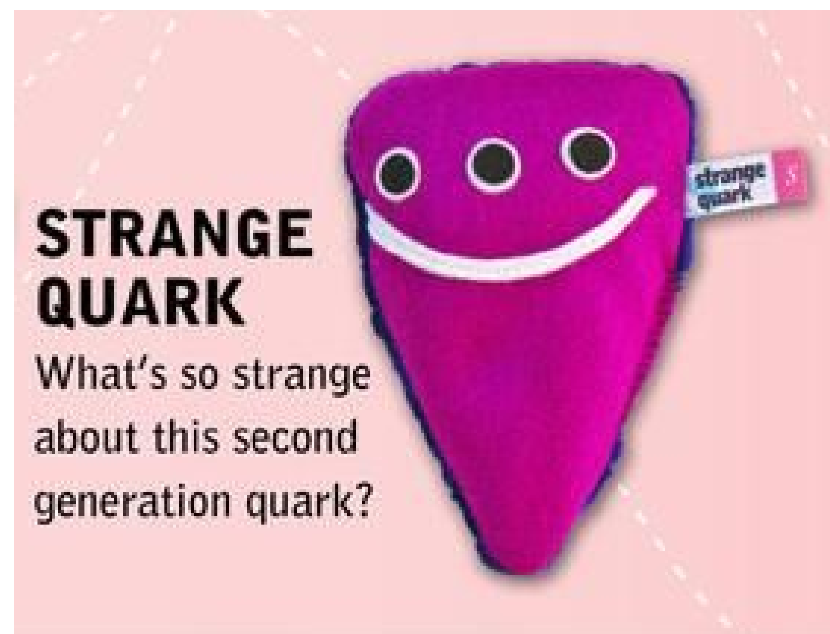
(Received 6 June 2017; published 11 September 2017)

In the original Collins-Soper-Sterman (CSS) presentation of the results of transverse-momentum-dependent (TMD) factorization for the Drell-Yan process, results for perturbative coefficients can be obtained from calculations for collinear factorization. Here we show how to use these results, plus known results for the quark form factor, to obtain coefficients for TMD factorization in more recent formulations, e.g., that due to Collins, and apply them to known results at order α_s^2 and α_s^3. We also show that the "nonperturbative" functions as obtained from fits to data are equal in the two schemes. We compile the higher-order perturbative inputs needed for the updated CSS scheme by appealing to results obtained in a variety of different formalisms. In addition, we derive the connection between both versions of the CSS formalism and several formalisms based in soft-collinear effective theory (SCET). Our work uses some important new results for factorization for the quark form factor, which we derive.

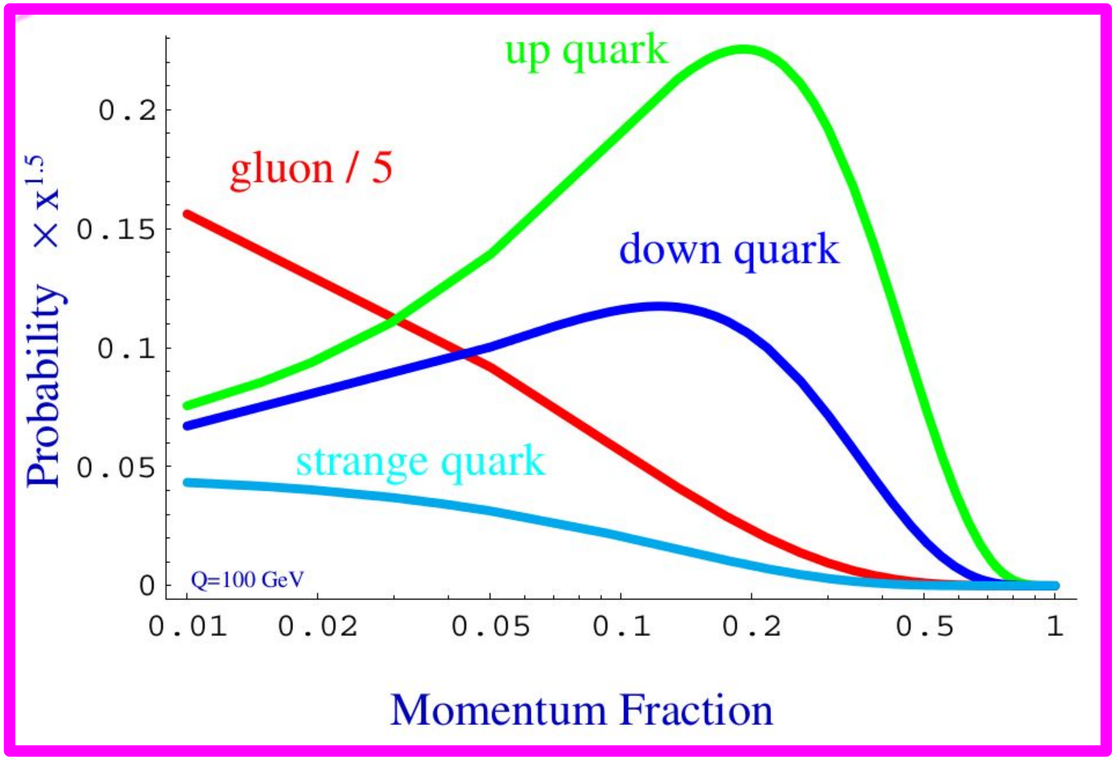
Strange PDF

Case Study: The Strange PDF

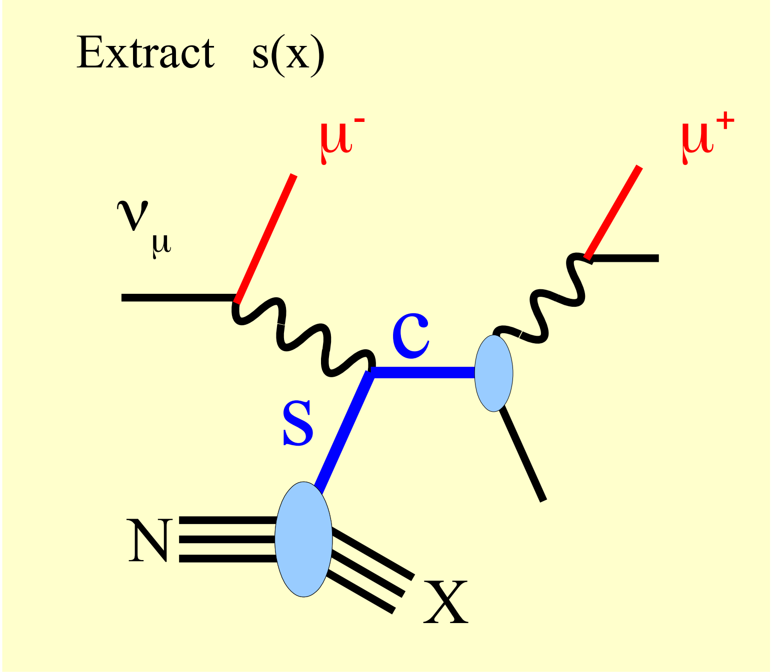


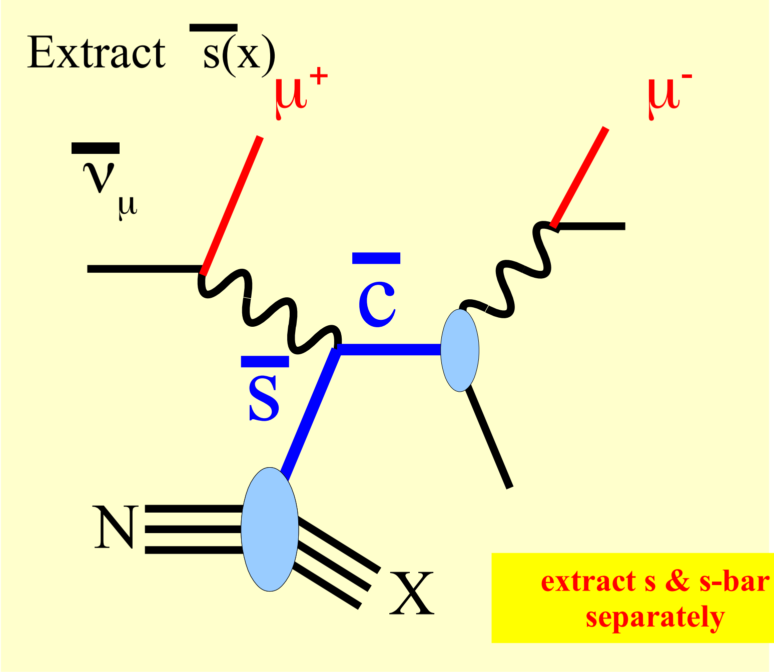


Strange PDF: ν N di-muon Production … (Fe,Pb)



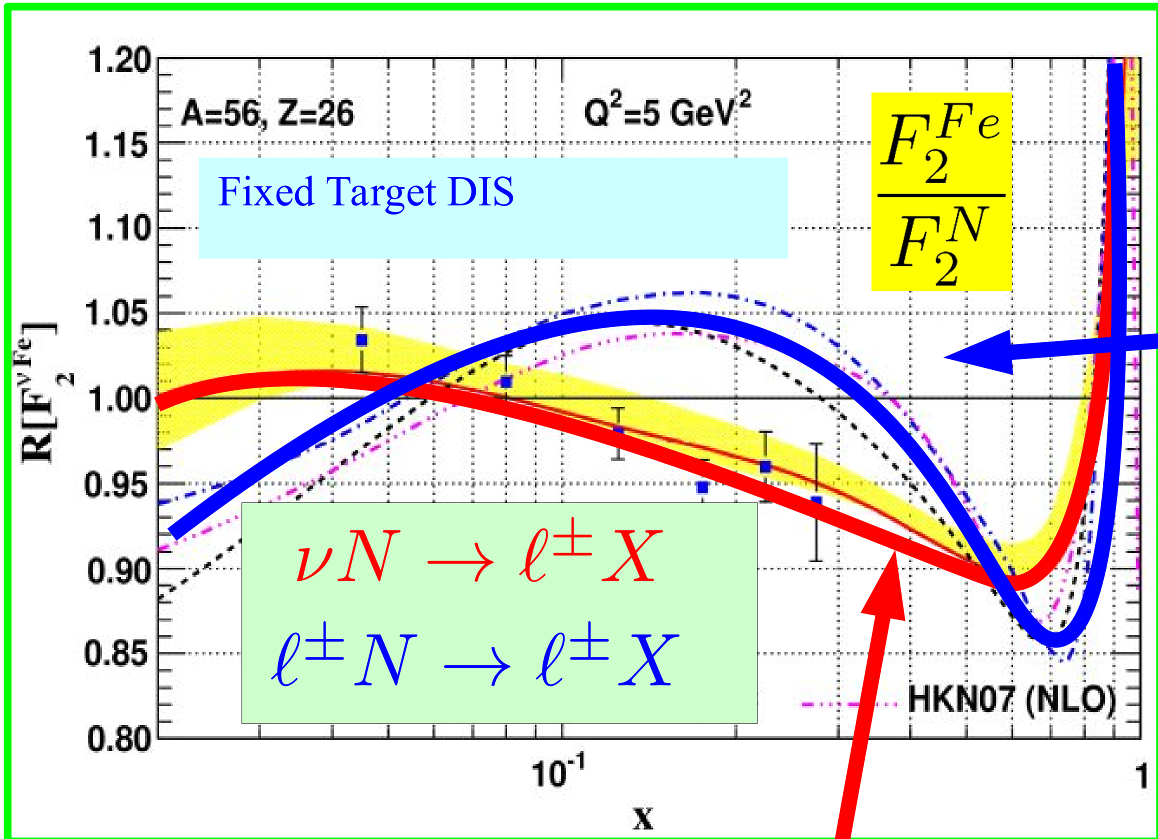
Need to "dig out" s(x) underneath d(x)



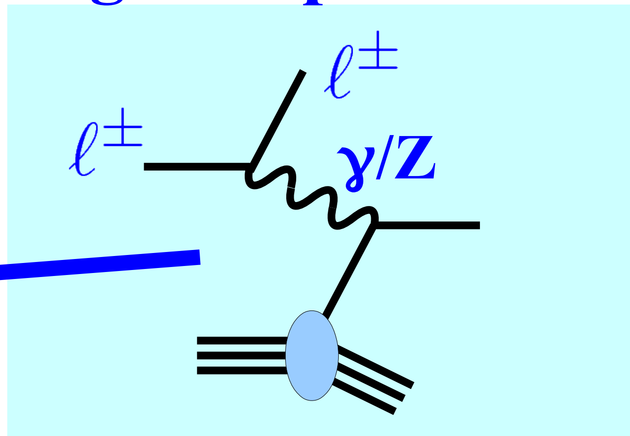


extract s & s-bar separately

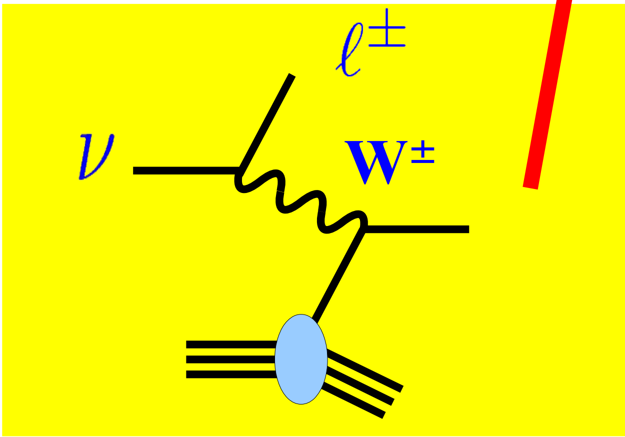
Puzzle: What is the Nuclear Correction



Charged Lepton DIS

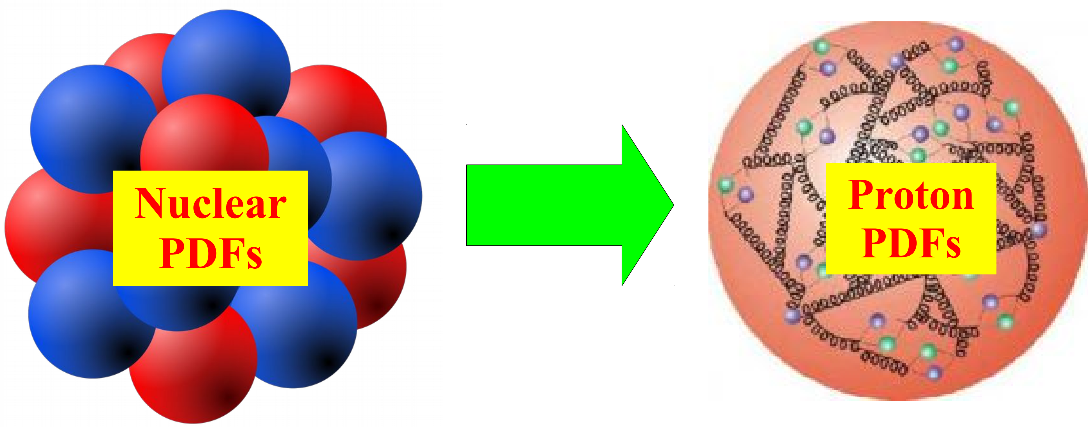


some caveats
... correlated errors



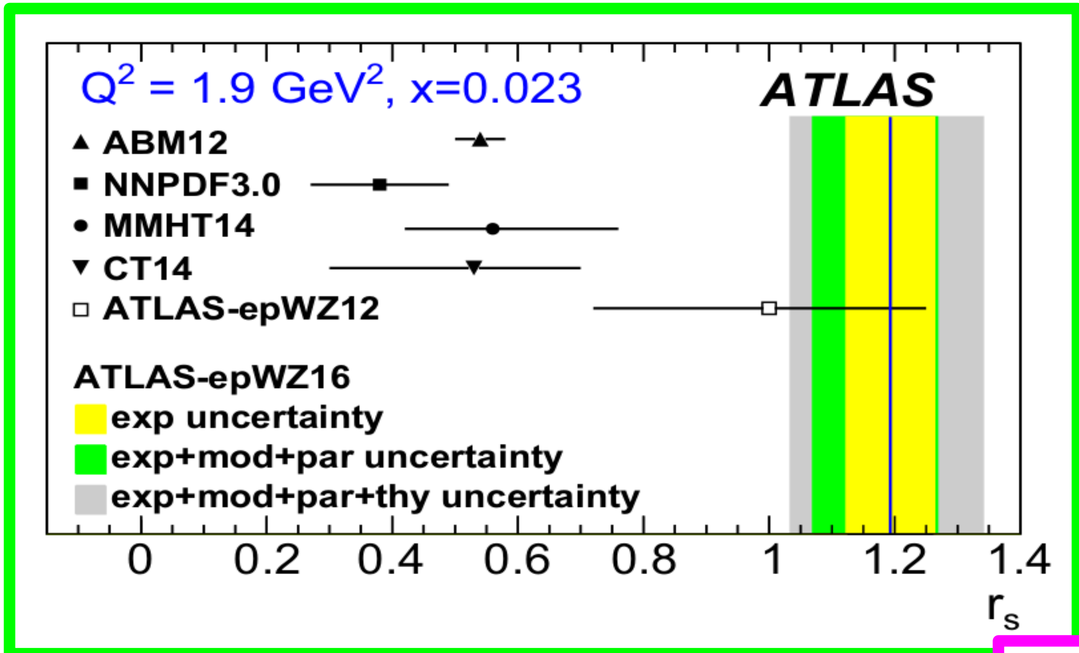
Neutrino DIS

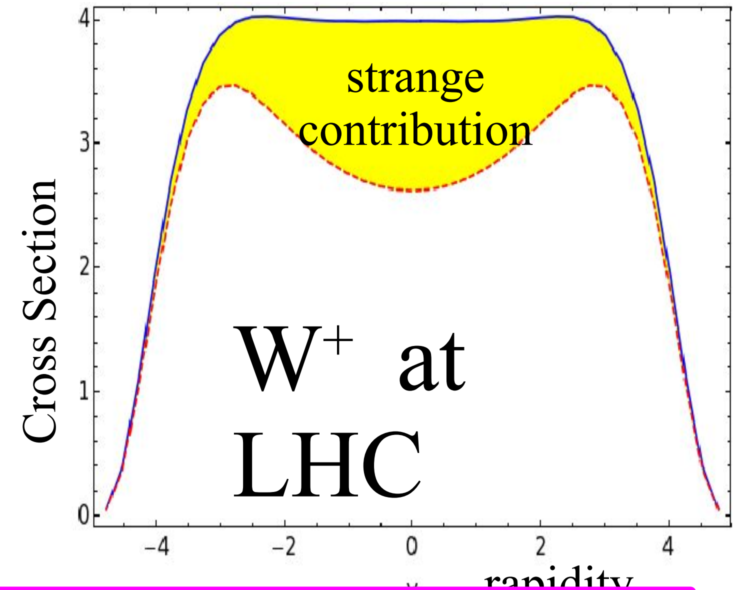
Depends on nuclear corrections

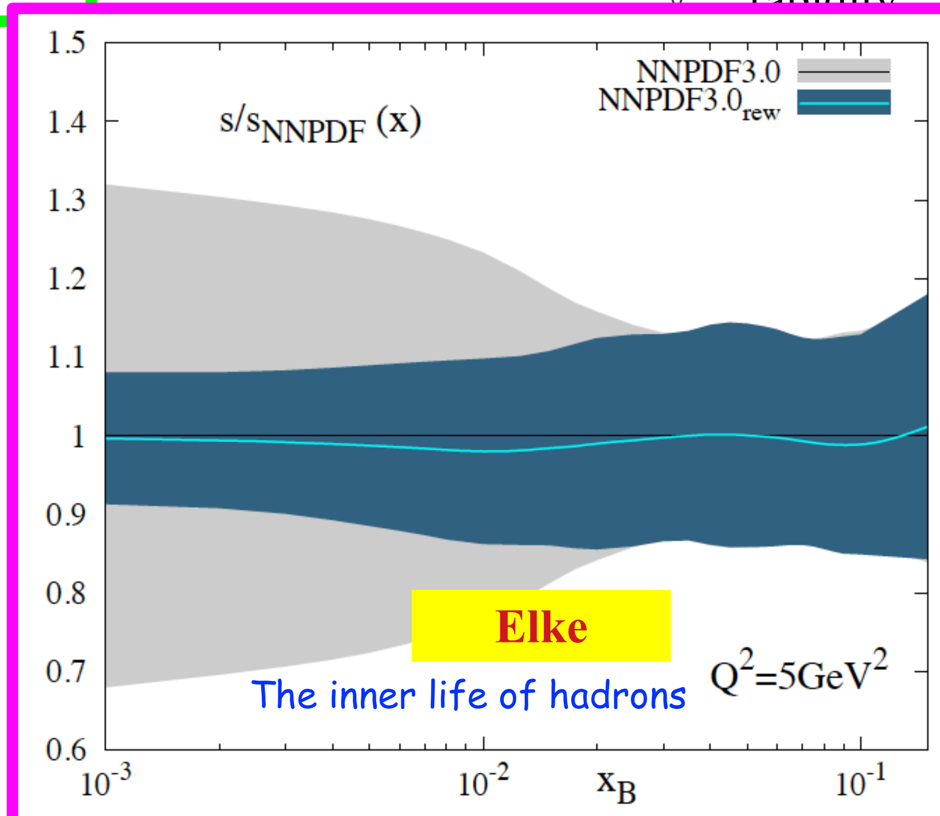


Propagation of γ/W thru nuclei

What's the Solution??? ... *high energy does not always help*







This is an area where EIC & LHeC are particularly suited to help

Combined Effort to Decipher

EIC can expand our knowledge of the nuclear A dimension

Heavy Quarks

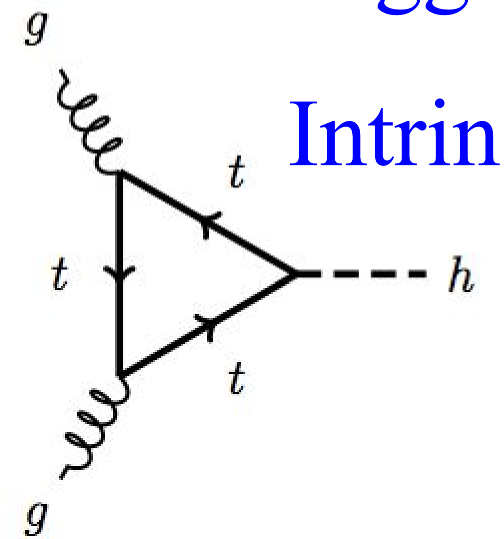
$$\alpha_S \ln\left(\frac{m}{Q}\right)$$

Multi-Scale Problem: {m, Q}

Higgs coupling proportional to mass

Intrinsic & Fitted Charm, F_2^c, F_L^c …

FFNS & VFNS

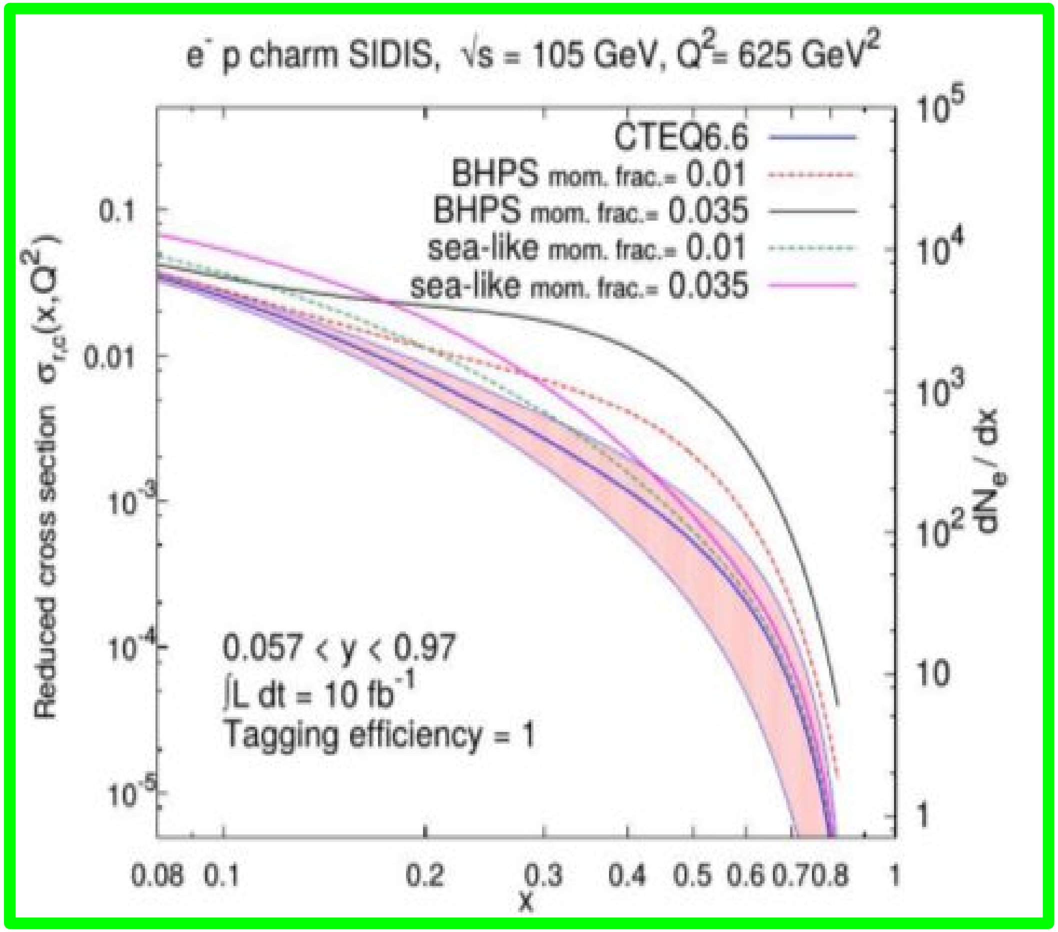


Intrinsic Charm (IC)

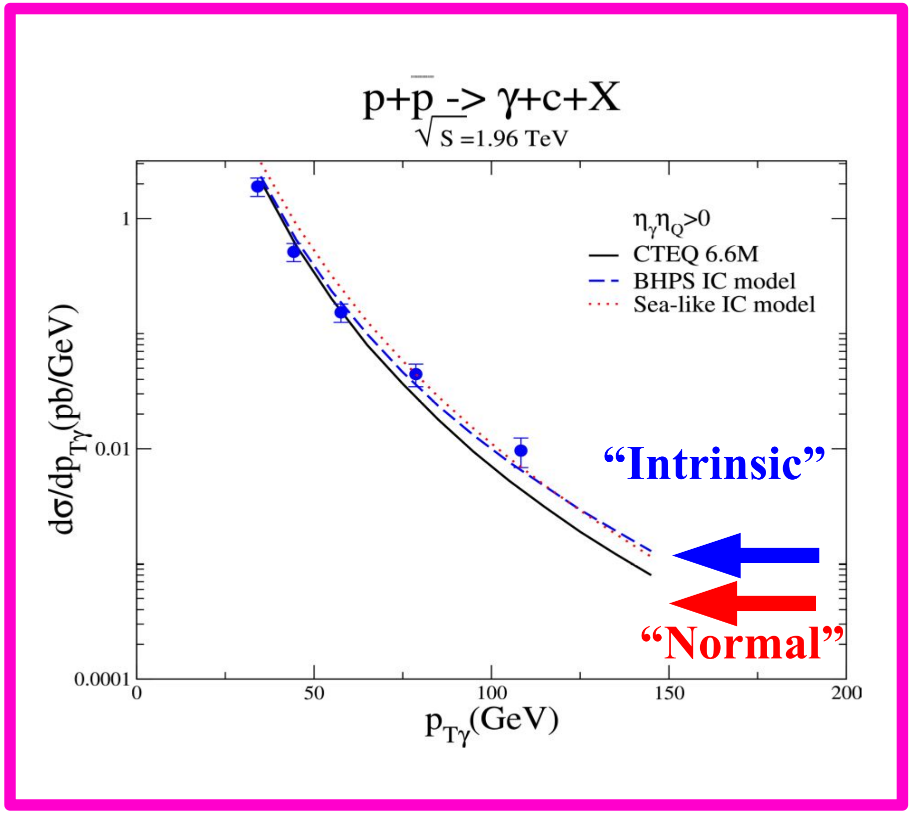
also F_2^c for charm PDF…

Probe IC via charm contributions to DIS σ, F_L^C, or angular distributions

… Tevatron excesss in γ c Production

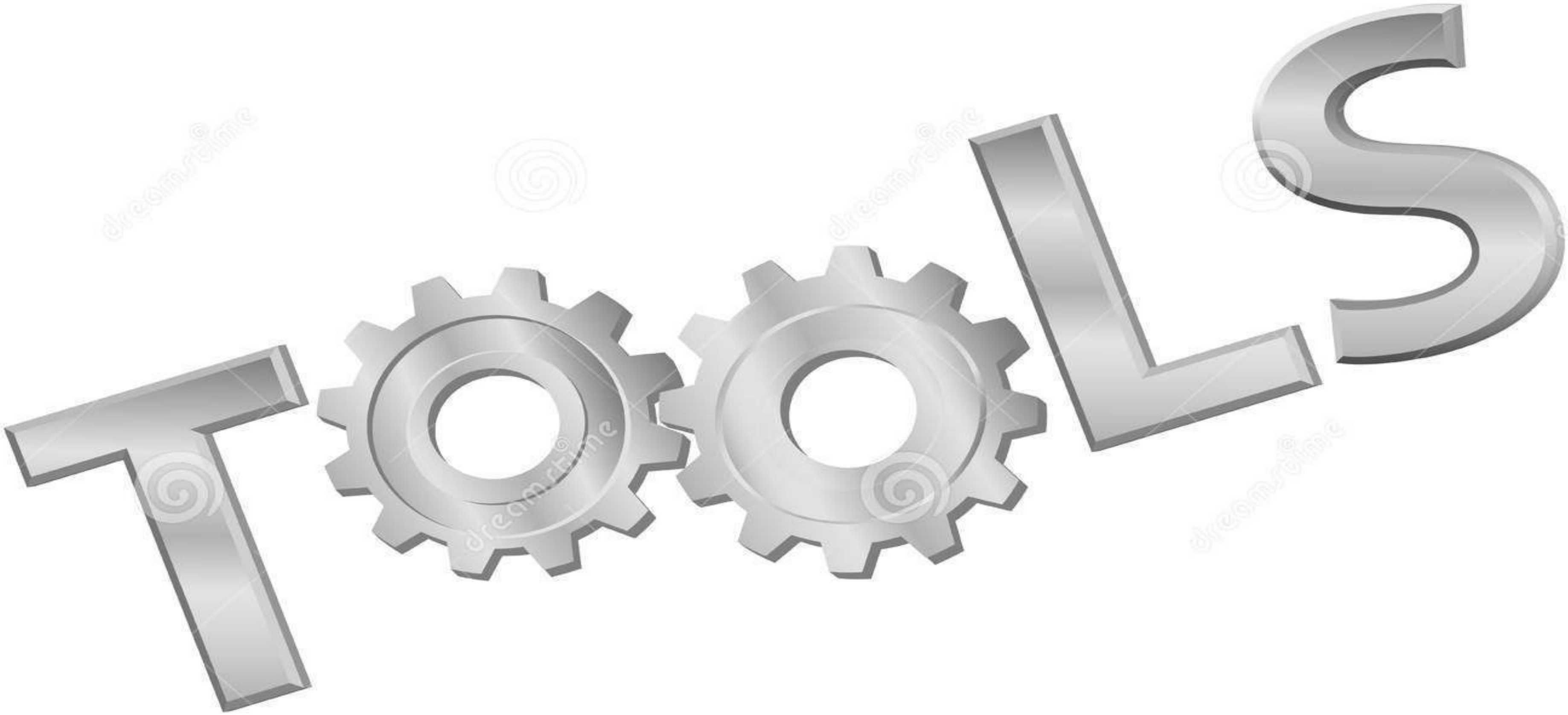


Gluons and the quark sea at high energies: distributions, polarization, tomography, D.Boer, et al., arXiv:1108.1713.



$gs \rightarrow cW$ at LHC and s(x)

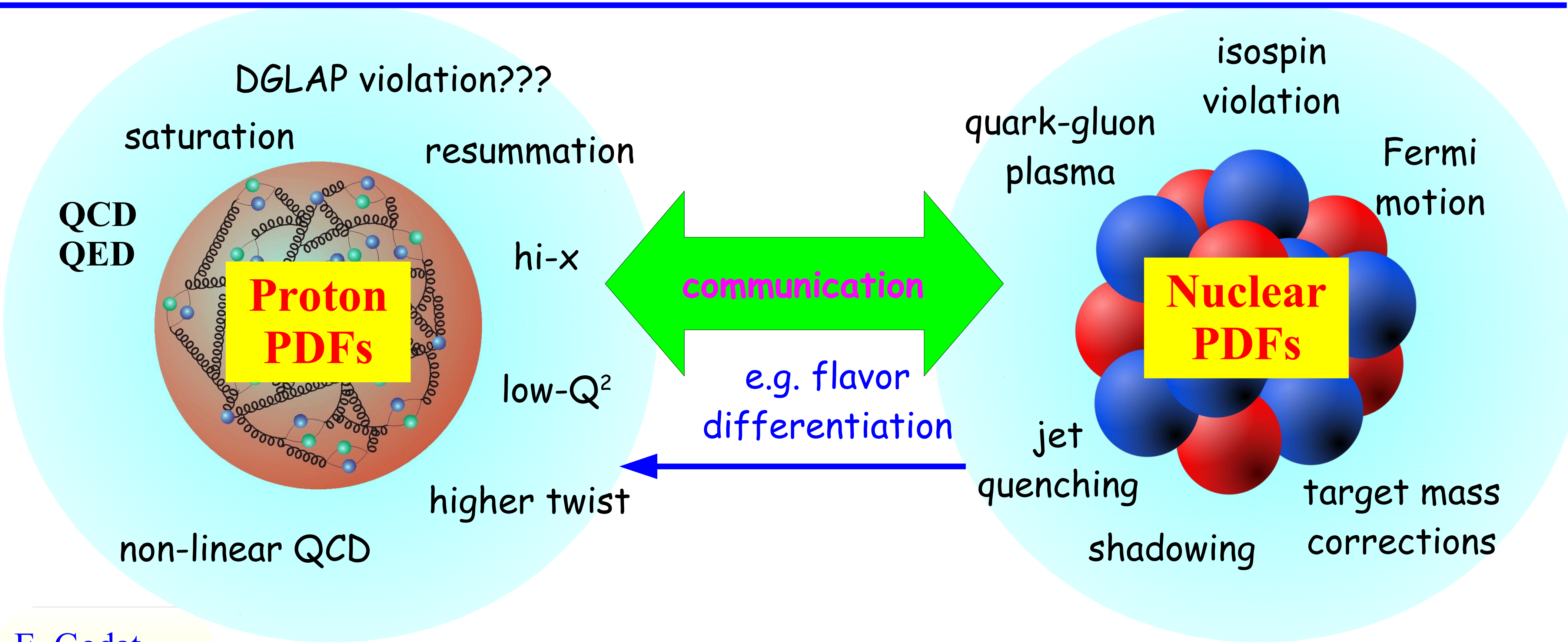
T. Stavreva, I. Schienbein, F. Arleo, K. Kovarik, F. Olness, J.Y. Yu, J.F. Owens, JHEP 1101 (2011) 152



nCTEQ++
xFitter
PDFSense

nCTEQ++

… the motivation for nCTEQ



E. Godat
T.J. Hobbs
T. Jezo,
C. Keppel,
K. Kovarik
A Kusina,
F. Lyonnet,
J. Morfin,
F. Olness
J. Owens,
I. Schienbein,
J. Yu

Data from nuclear targets play a key role in the flavor differentiation

nCTEQ

nuclear parton distribution functions

What is nCTEQ++?

- A complete rewrite of the nCTEQ FORTRAN fitting code in C++
- Changed the code to allow for modules when building a PDF

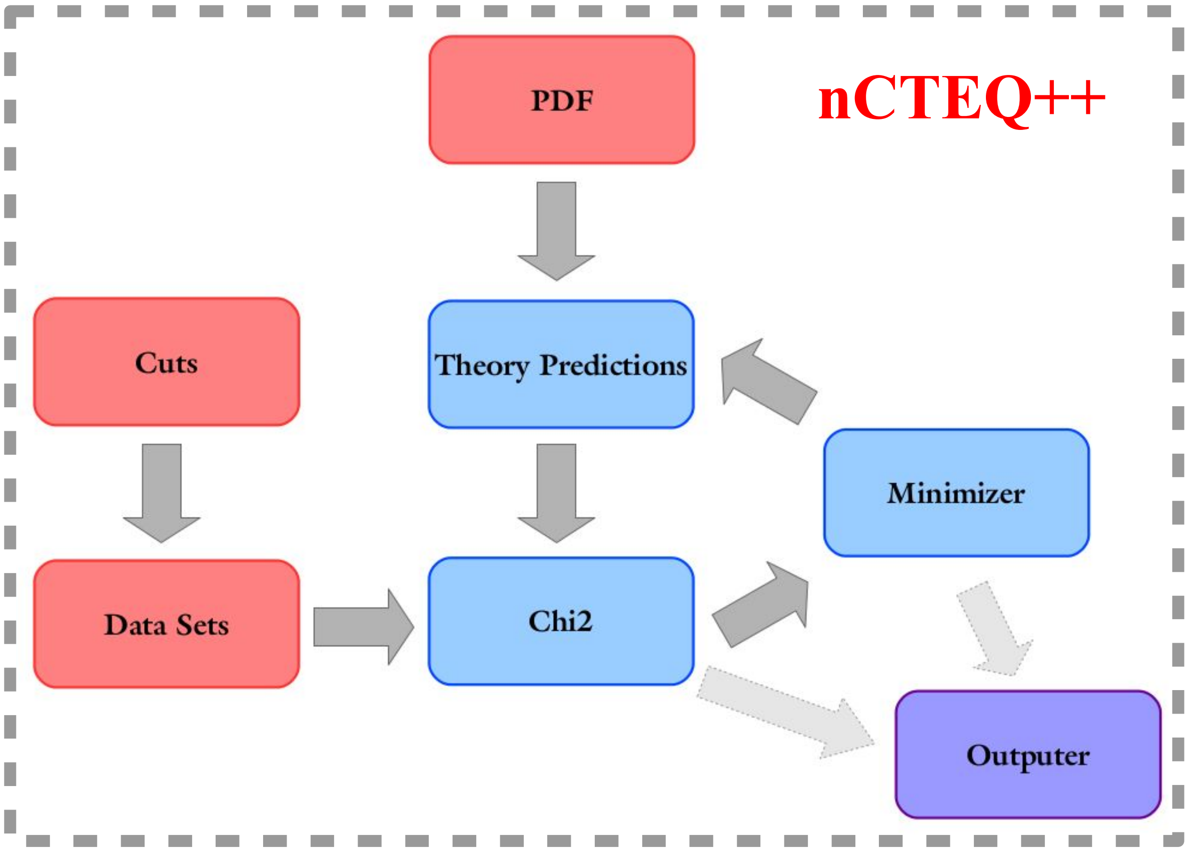
  Evolution

  Interpolation

  Parameterization

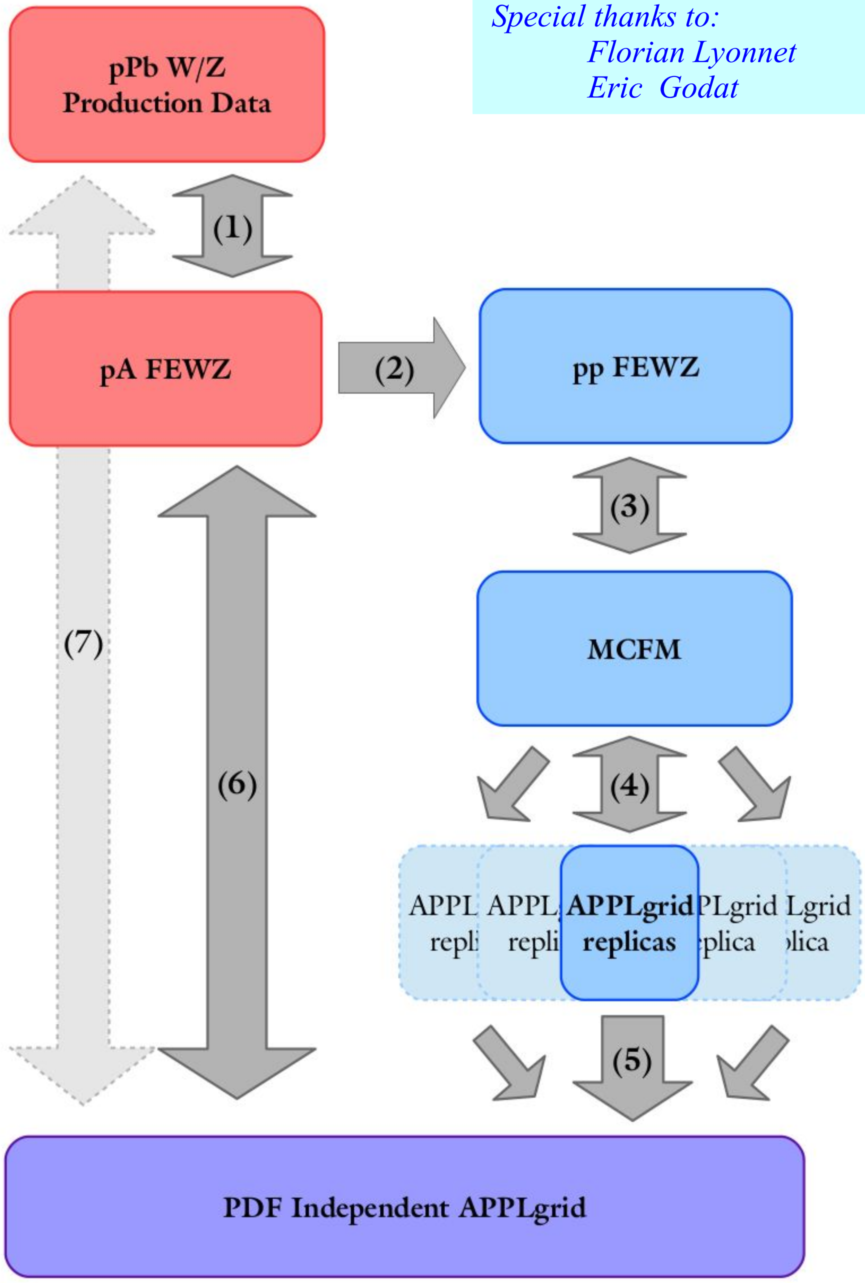
- Use external programs
  - Minuit
  - HOPPET
  - MCFM
  - APPLgrid

Special thanks to:
Eric Godat
Florian Lyonnet
Tomas Jezo
Aleksander Kusina



Use MCFM + APPLgrid for pPb

Special thanks to:
Florian Lyonnet
Eric Godat



(1) Data matched to pA-FEWZ in reweighting

(2) Run FEWZ in symmetric pp - mode

(3) Compare pp FEWZ to pp MCFM

(4) Generate APPLgrid grids

- Using mcfm-bridge
- Different Monte Carlo seeds

(5) Combine replica grids into a single PDF independent grid

- Using applgrid-combine

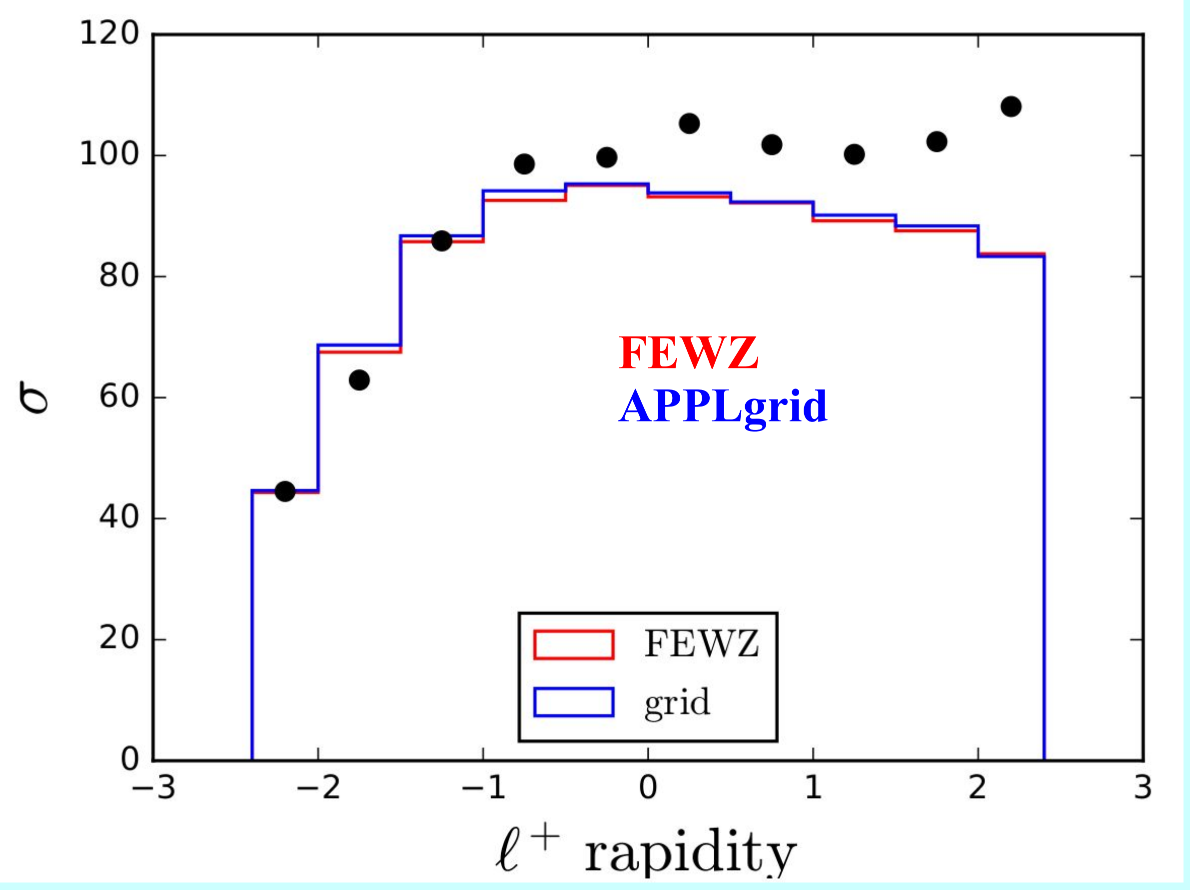
(6) Convolute PDF independent grid with asymmetric PDFs to compare to pAFEWZ

(7) Add data and grid in nCTEQ++ to fit W/Z LHC data

They Match !!!

Grids generated for pp can be used for pPb !!!

Convoluted grids can then be compared to data and used in nCTEQ++ as theory predictions



MCFM Processes Library (v6.8)

MCFM: Vector boson pair production at the LHC, J. M.Campbell, R. K.Ellis and C.Williams, JHEP 1107, 018 (2011)

The APPLGRID Project: Tancredi Carli, Dan Clements, Amanda Cooper-Sarkar, Claire Gwenlan, Gavin P. Salam, Frank Siegert, Pavel Starovoitov, Mark Sutton. Eur.Phys.J. C66 (2010) 503-524

nproc	$f(p_1) + f(p_2) \to \ldots$	Order
1	$W^+(\to \nu(p_3) + e^+(p_4))$	NLO
6	$W^-(\to e^-(p_3) + \bar{\nu}(p_4))$	NLO
11	$W^+(\to \nu(p_3) + e^+(p_4)) + f(p_5)$	NLO
12	$W^+(\to \nu(p_3) + e^+(p_4)) + \bar{b}(p_5)$	NLO
13	$W^+(\to \nu(p_3) + e^+(p_4)) + \bar{c}(p_5)$	NLO
14	$W^+(\to \nu(p_3) + e^+(p_4)) + \bar{c}(p_5)$[massless]	LO
16	$W^-(\to e^-(p_3) + \bar{\nu}(p_4)) + f(p_5)$	NLO
17	$W^-(\to e^-(p_3) + \bar{\nu}(p_4)) + b(p_5)$	NLO
18	$W^-(\to e^-(p_3) + \bar{\nu}(p_4)) + c(p_5)$	NLO
19	$W^-(\to e^-(p_3) + \bar{\nu}(p_4)) + c(p_5)$[massless]	LO

MCFM Processes Library (v6.8)

MCFM: Vector boson pair production at the LHC, J. M.Campbell, R. K.Ellis and C.Williams, JHEP 1107, 018 (2011)

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nproc	$f(p_1) + f(p_2) \to \dots$	Order
1	$W^+(\to \nu(p_3) + e^+(p_4))$	NLO
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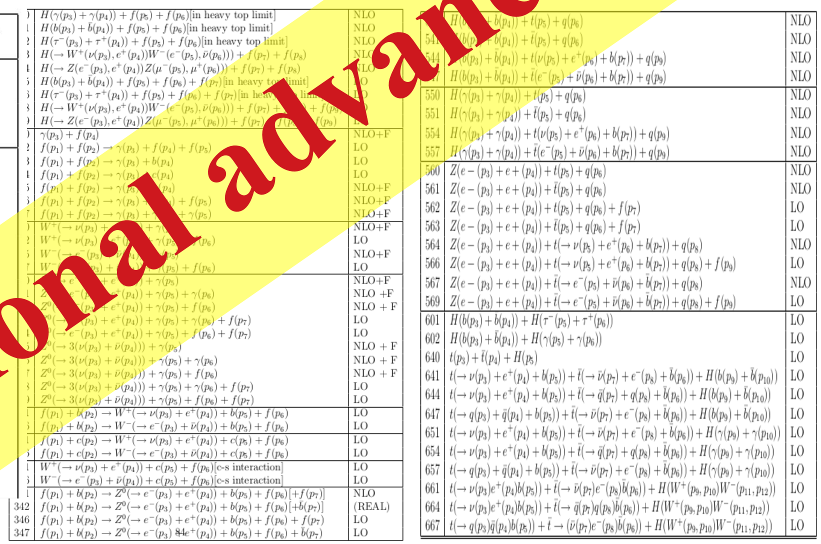
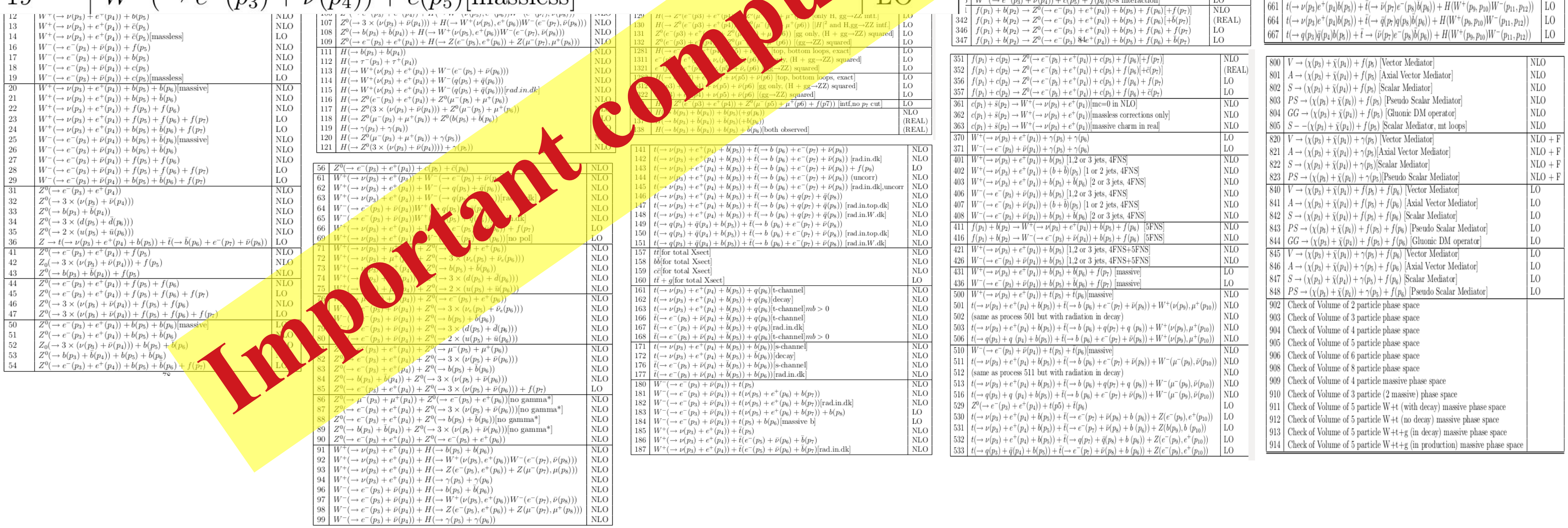
11	$W^+(\to \nu(p_3) + e^+(p_4)) + f(p_5)$	NLO
12	$W^+(\to \nu(p_3) + e^+(p_4)) + \bar{b}(p_5)$	NLO
13	$W^+(\to \nu(p_3) + e^+(p_4)) + \bar{c}(p_5)$	NLO
14	$W^+(\to \nu(p_3) + e^+(p_4)) + \bar{c}(p_5)$[massless]	LO
16	$W^-(\to e^-(p_3) + \bar{\nu}(p_4)) + f(p_5)$	NLO
17	$W^-(\to e^-(p_3) + \bar{\nu}(p_4)) + b(p_5)$	NLO
18	$W^-(\to e^-(p_3) + \bar{\nu}(p_4)) + c(p_5)$	NLO
19	$W^-(\to e^-(p_3) + \bar{\nu}(p_4)) + c(p_5)$[massless]	LO





xFitter

xFitter release xfitter-2.0.0

www.xFitter.org

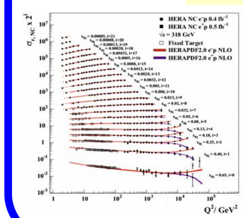
xFitter

xFitter/xFitterTalks » xFitter/../xFitterDevel.. » xFitter/../Meeting2017-.. » xFitter » xFitter/DownloadPage

Sample data files:

LHC: ATLAS, CMS, LHCb
Tevatron: CDF, D0
HERA: H1, ZEUS, Combined
Fixed Target: …
User Supplied: ...

Experimental Data



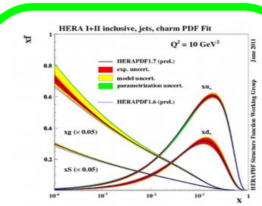
Data: HERA, Tevatron, LHC, fixed target experiments

Processes: Inclusive DIS, Jets, Drell-Yan, Diffraction, Top production, W and Z production

Theory Calculations

HQ Schemes:	MSTW, NNPDF, ABM, ACOT
Jets, W, Z:	FastNLO, ApplGrid
Top:	Hathor
Evolution:	QCDNUM, APFEL, k_T
Other:	NNPDF reweighting TMDs, Dipole Model, ...

xFitter



Parton Distribution Functions: PDF, Updf, TMD

$\alpha_S(M_Z)$, m_c, m_b, m_t ...

Theoretical Cross Sections

Comparisons to other PDFs (LHAPDF)

xFitter 2.0.0 FrozenFrog

Features & Recent Updates:

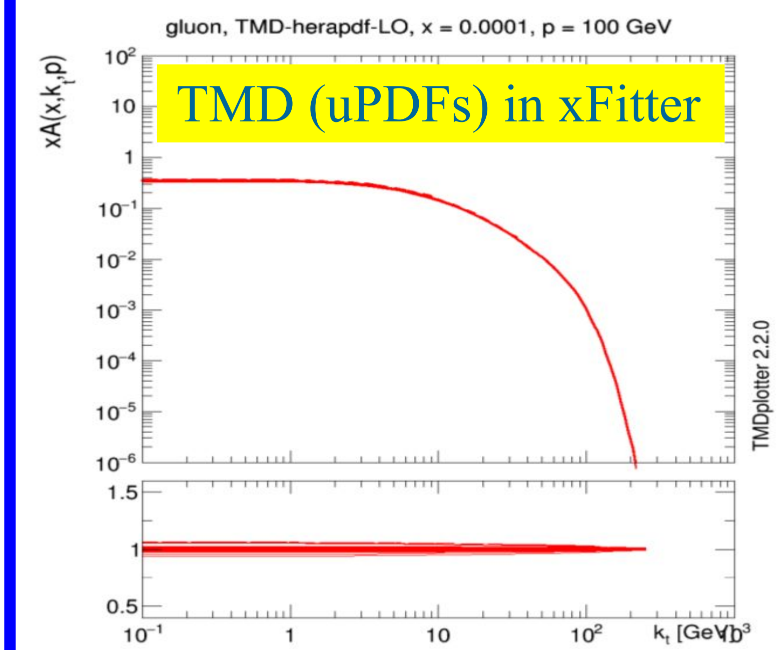
Photon PDF & QED
Pole & MS-bar masses
Profiling and Re-Weighting

Heavy Quark Variable Treshold
Improvements in χ^2 and correlations
TMD PDFs (uPDFs)
... and many other

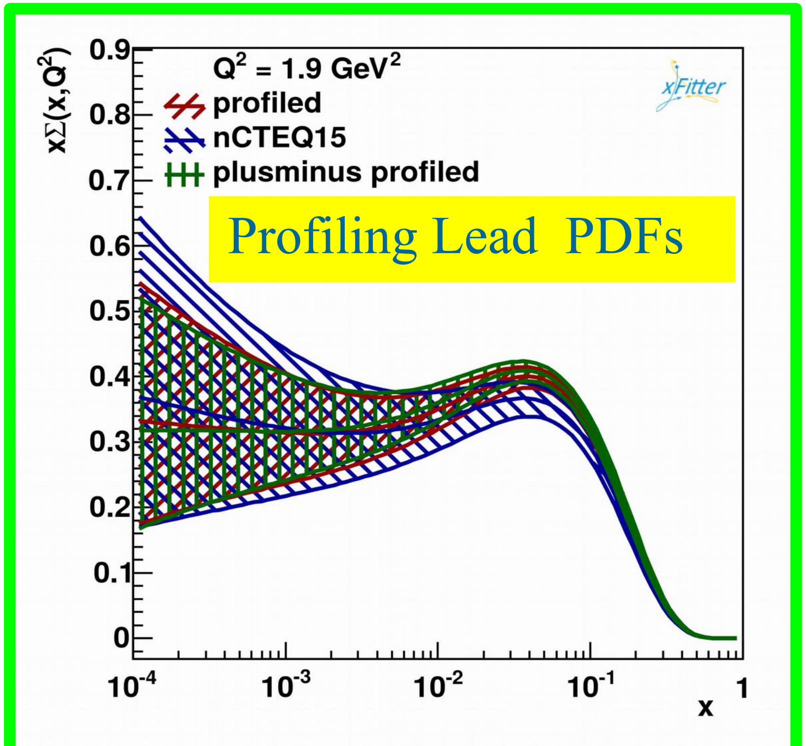
Versatility of xFitter

www.xFitter.org

TMDs from fits - comparison of LO and NLO

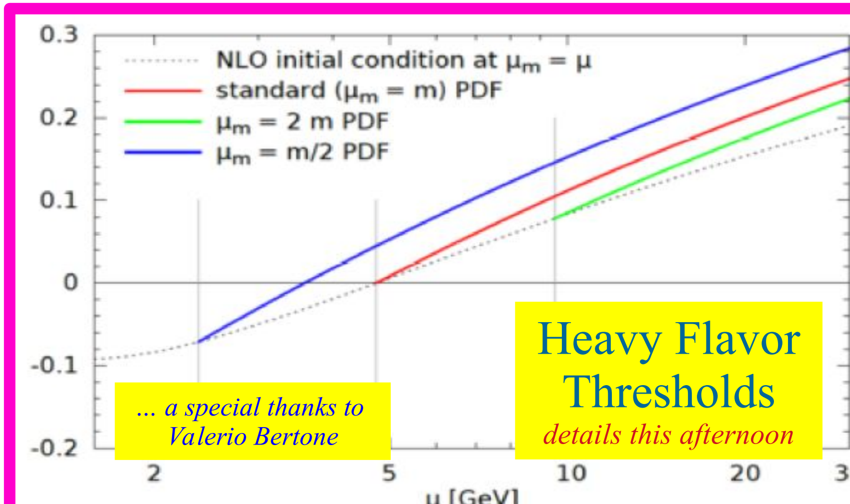


TMDs with experimental uncertainties.



nPDFs with xFitter
Marina Walt
U. Tuebingen

in progress
π / K PDFs

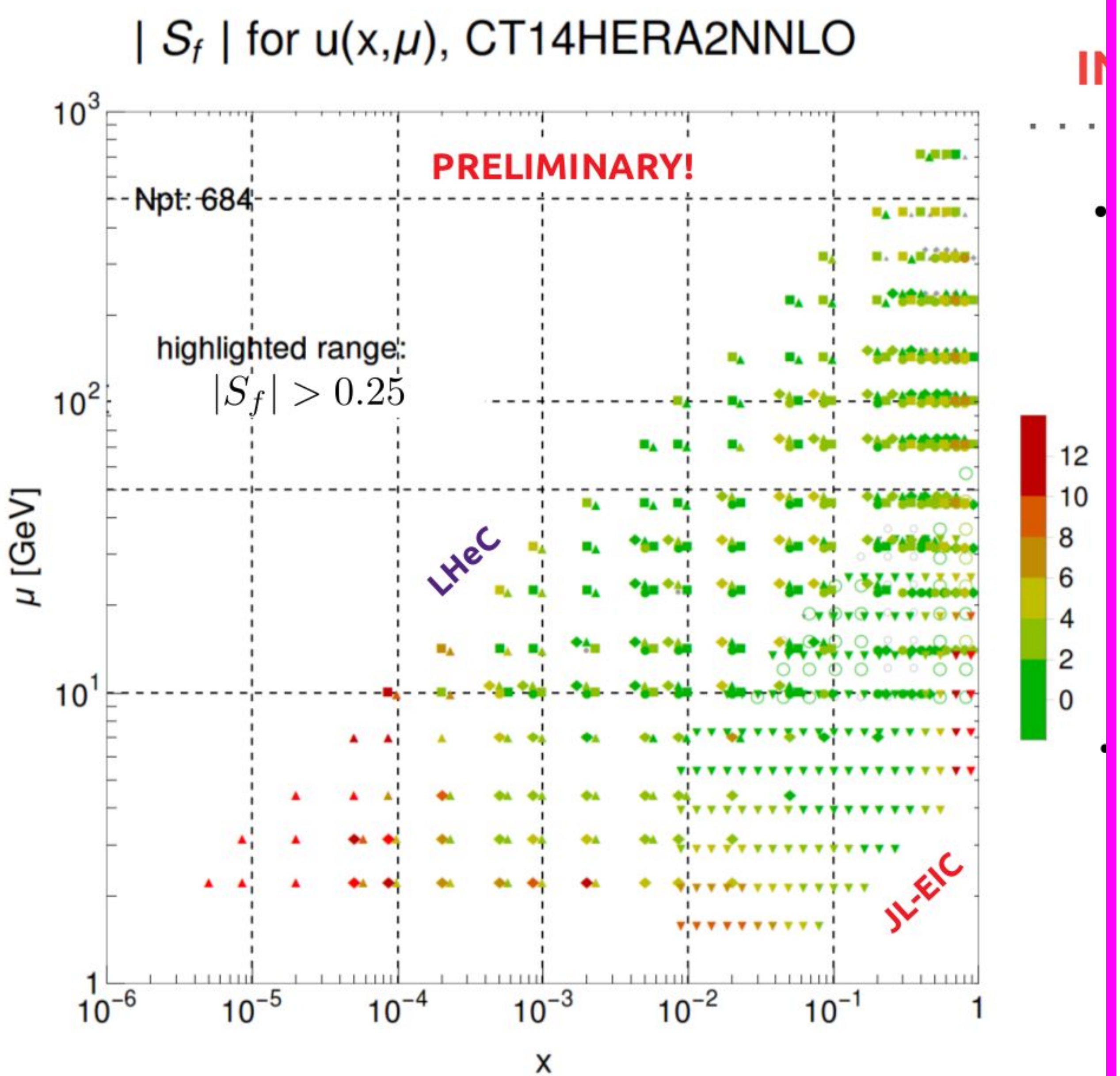


New Tools

PDFSense

&

… borrowing from AI



A new measure:

Sensitivity S_f

Extend concept of correlation (C) to include both pull and precision of experiment.

(Technically, weight by scaled residual.)

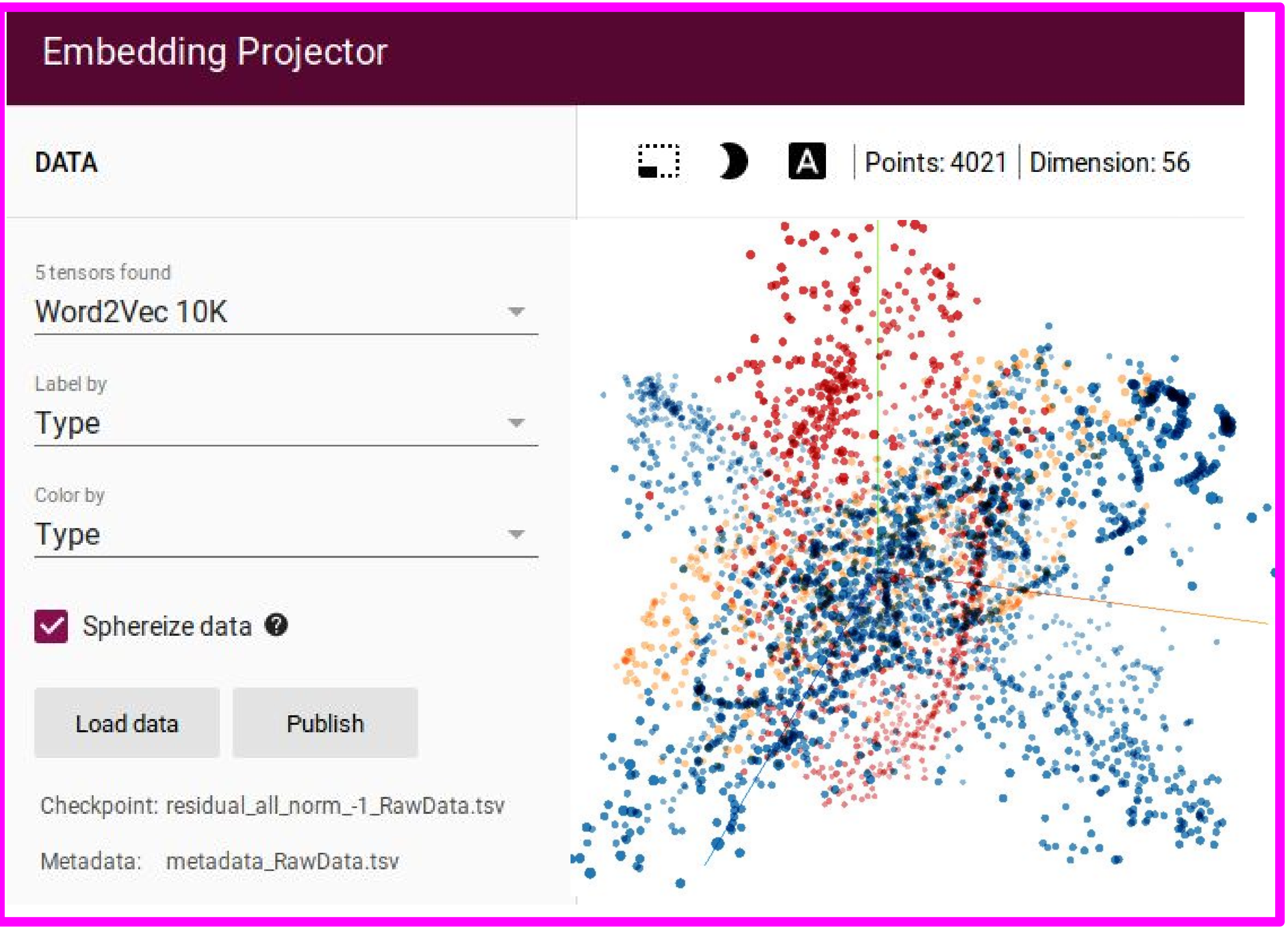
New insights on experimental impacts

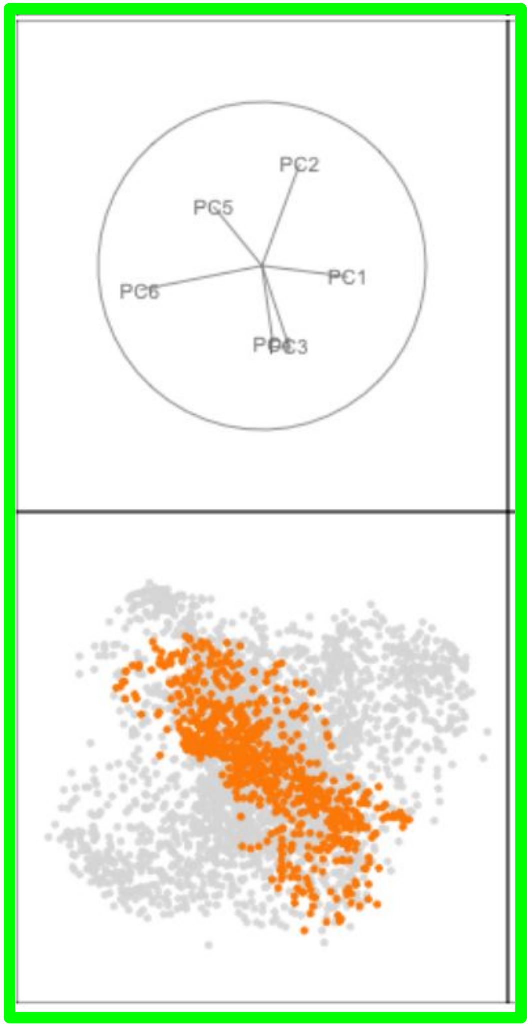
See Talk By:
Tim Hobbs (SMU)

Linked from:
https://metapdf.hepforge.org/

Applications of PDFSense:

Artificial Intelligence Tools: Projector tool of Google TensorFlow





Dynamical projections for the visualization of PDFSense data

Dianne Cook, Ursula Laa, German Valencia arXiv:1806.09742

Conclusion

Thanks to my nCTEQ & xFitter colleagues

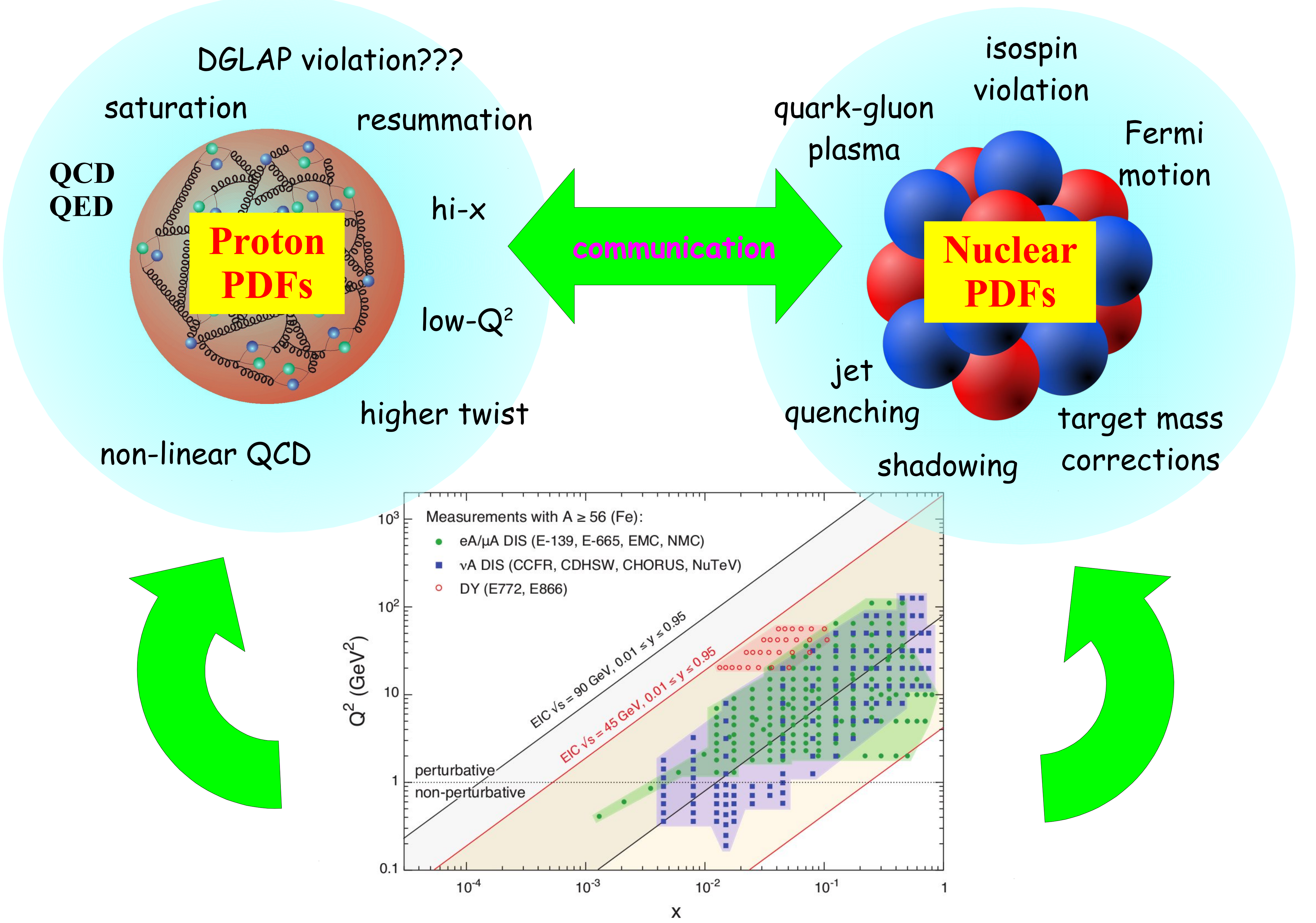
nCTEQ
nuclear parton distribution functions

nCTEQ & friends @ Grenoble 2017

xFitter Meeting: Krakow March 2018

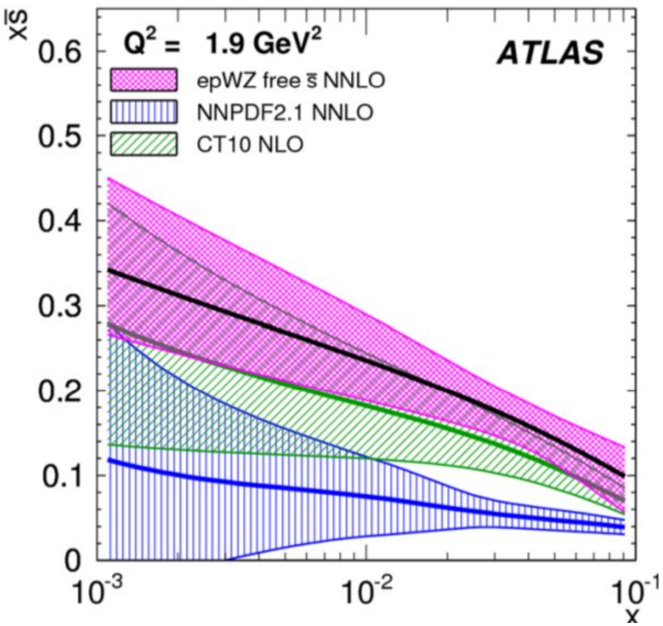
xFitter

"EIC would unlock scientific mysteries" *NAP Report*



What is s(x) … I want a second opinion, ...

$$\kappa(Q) = \frac{\int_0^1 x\,[s(x,Q)+\bar{s}(x,Q)]\;dx}{\int_0^1 x\,[\bar{u}(x,Q)+\bar{d}(x,Q)]\;dx} \qquad r^s(x,Q) = \frac{\bar{s}(x,Q)+s(x,Q)}{2\bar{d}(x,Q)} \qquad R^s(x,Q) = \frac{s(x,Q)+\bar{s}(x,Q)}{\bar{u}(x,Q)+\bar{d}(x,Q)}$$



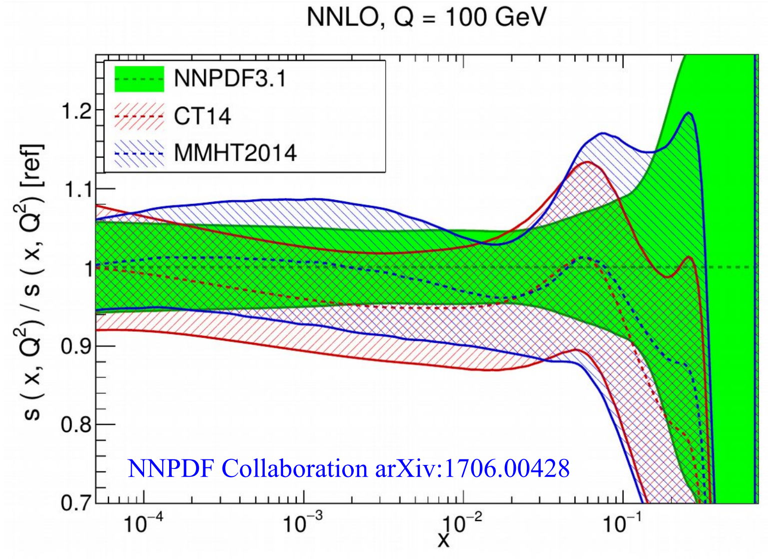
HERAFitter, Open Source QCD Fit Project
Eur. Phys. J. C (2015) 75: 304.

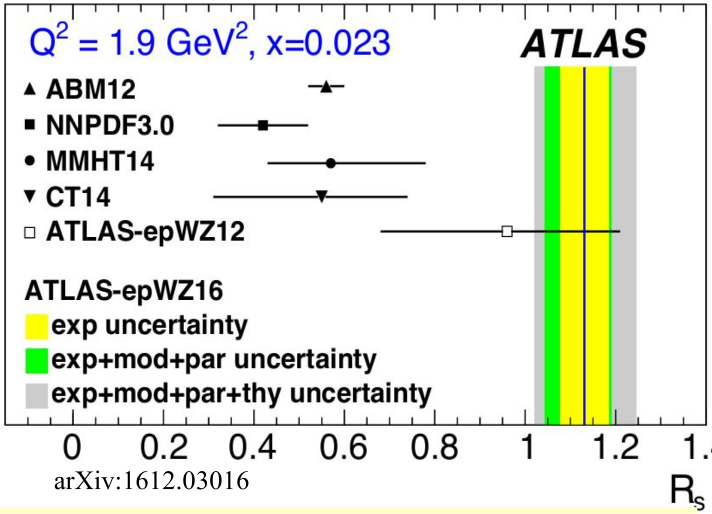
$$\kappa^s_{CT14NNLO} = 0.62 \pm 0.14$$

$$\kappa^s_{CT10NNLO} = 0.73 \pm 0.11$$

Carl Schmidt October 2015: INT Workshop

… whatever you want it to be





arXiv:1612.03016

… yes, details depend on {x,Q²}

$$\text{NuTeV}\ \kappa = 0.477^{+0.063}_{-0.053}$$ Z.Phys.C65:189-198,1995

$$\text{NOMAD}\ \kappa = 0.591 \pm 0.019$$ arXiv:1308.4750

$$\text{CMS}\ \kappa = 0.52^{+0.12}_{-0.10}{}^{+0.05}_{-0.06}{}^{+0.13}_{-0.10}$$ Q^2=20 GeV^2

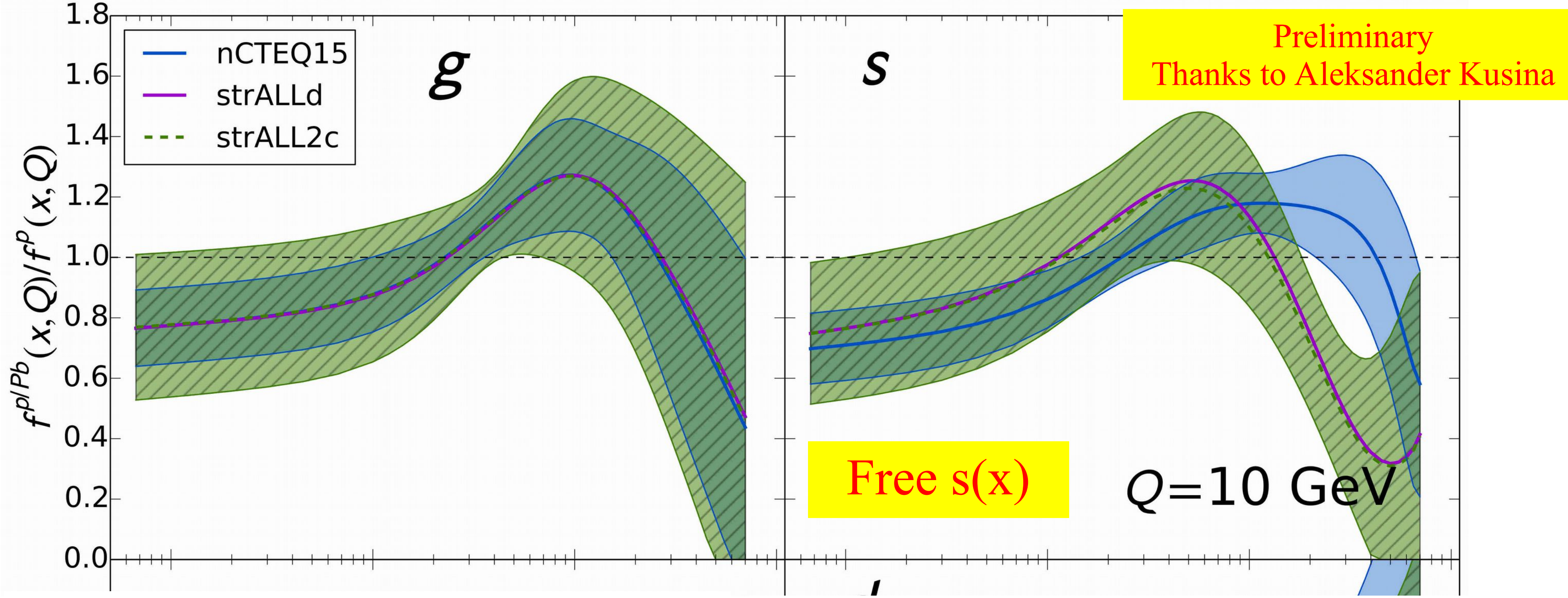
PhysRevD.90.032004
(exp)(model)(param)

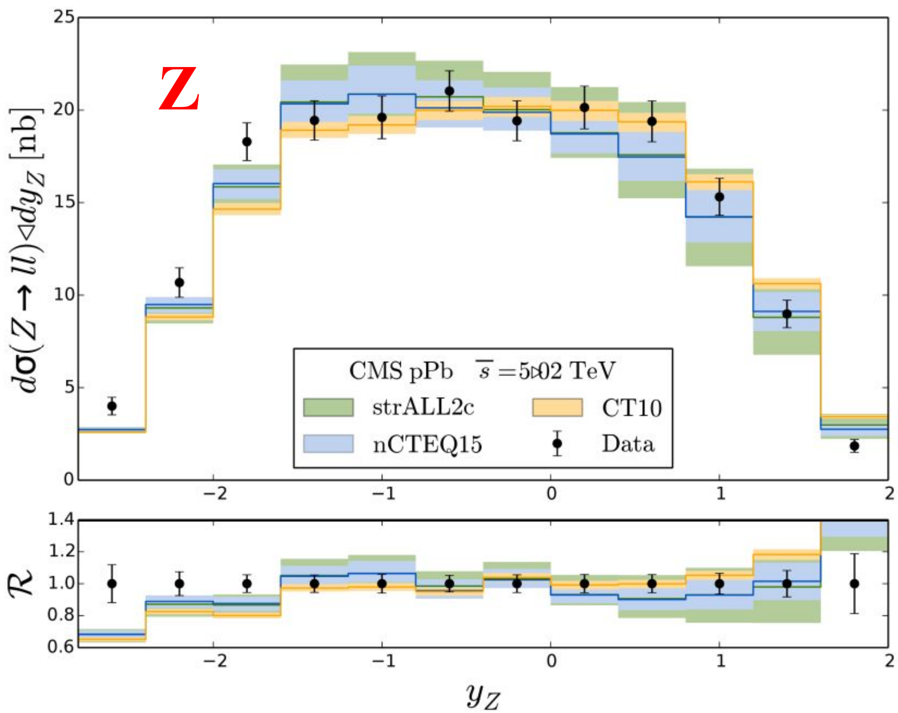
$$\text{ATLAS}\ r_s = 1.19 \pm 0.07 \pm 0.02^{+0.02}_{-0.10}$$

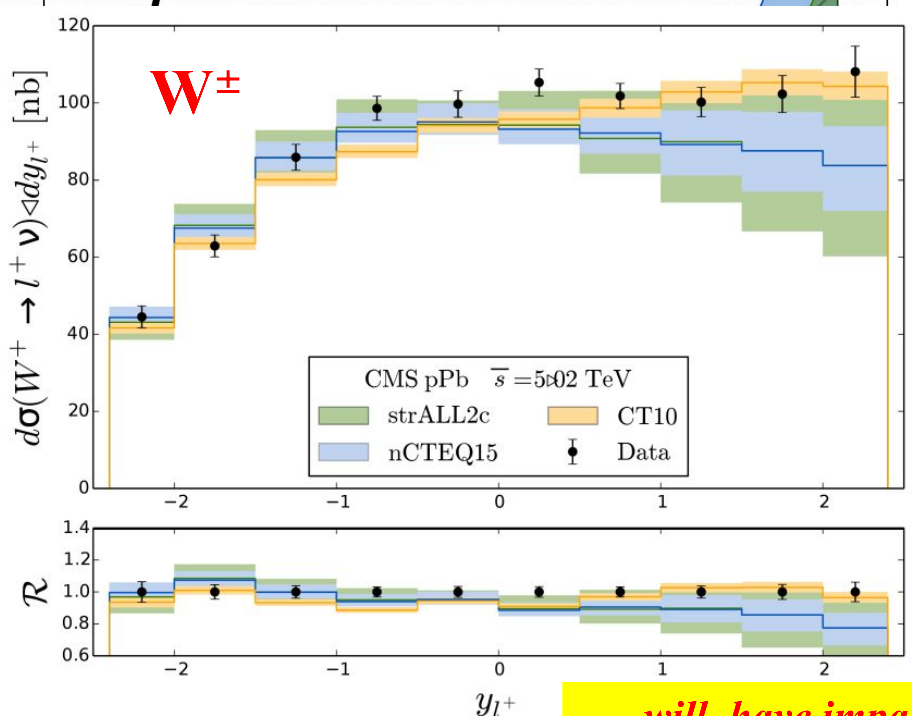
Q_0^2=1.9 GeV^2 at x=0.023

EPJC (2107) 77:367
(exp)(model)(param)

Reweighting: Add $p\,Pb \to W/Z$

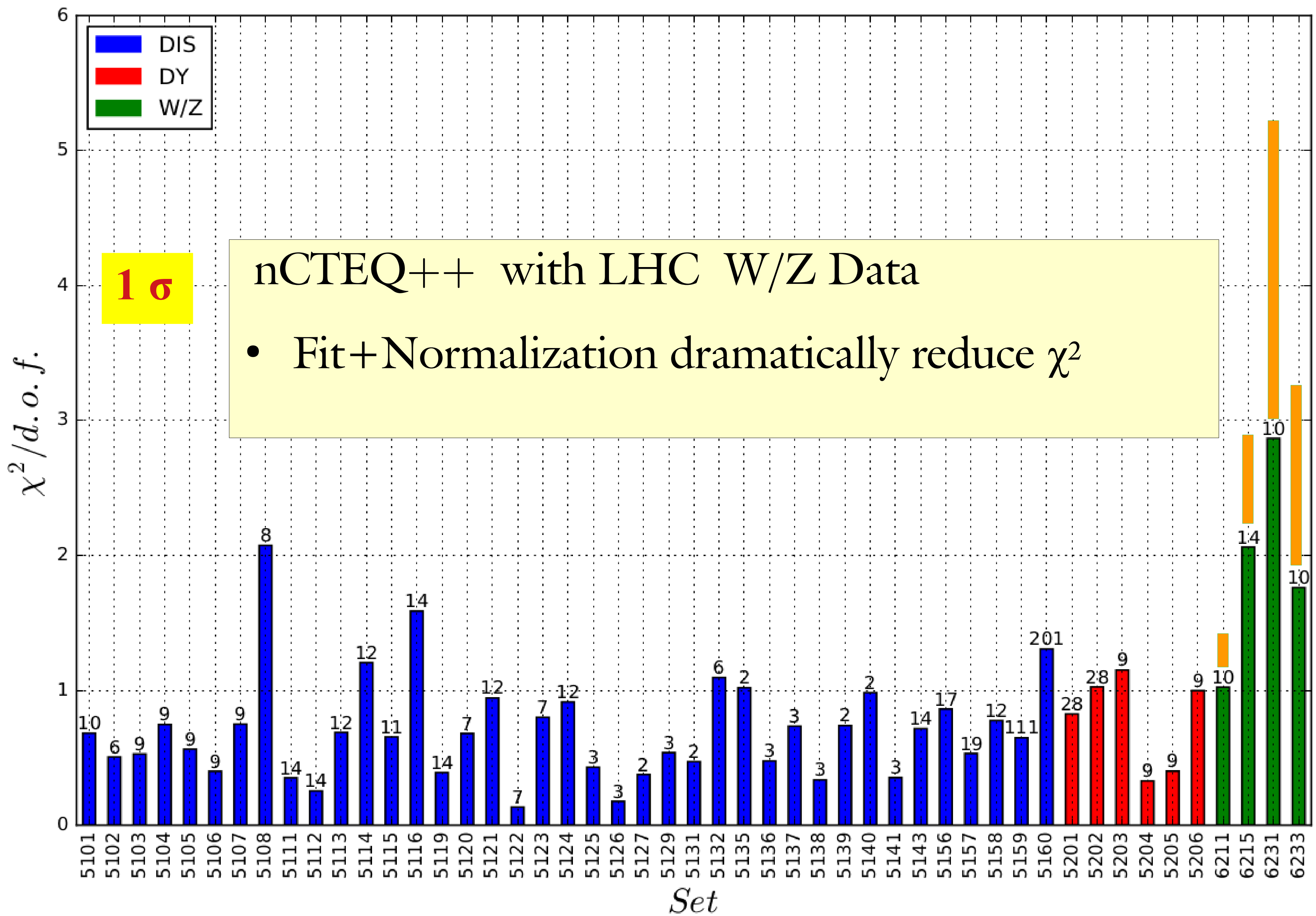






...will have impact!!!

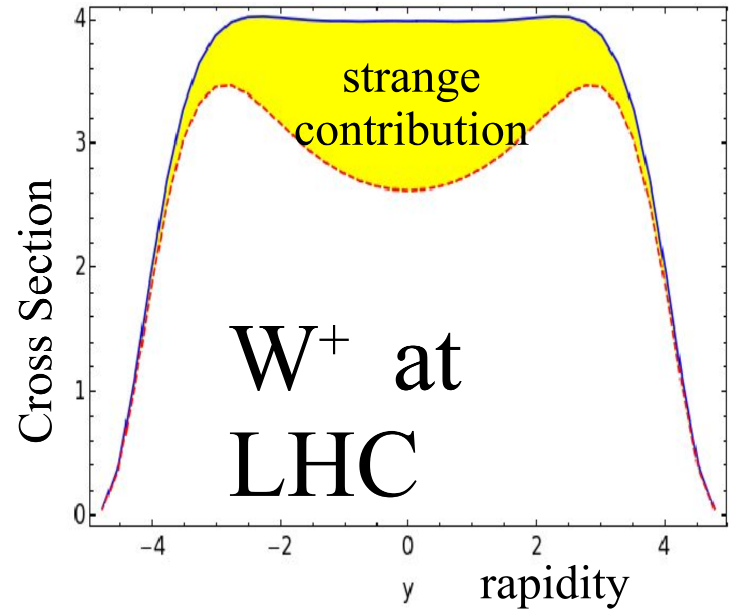
Fit to LHC W/Z Data w/ Normalization

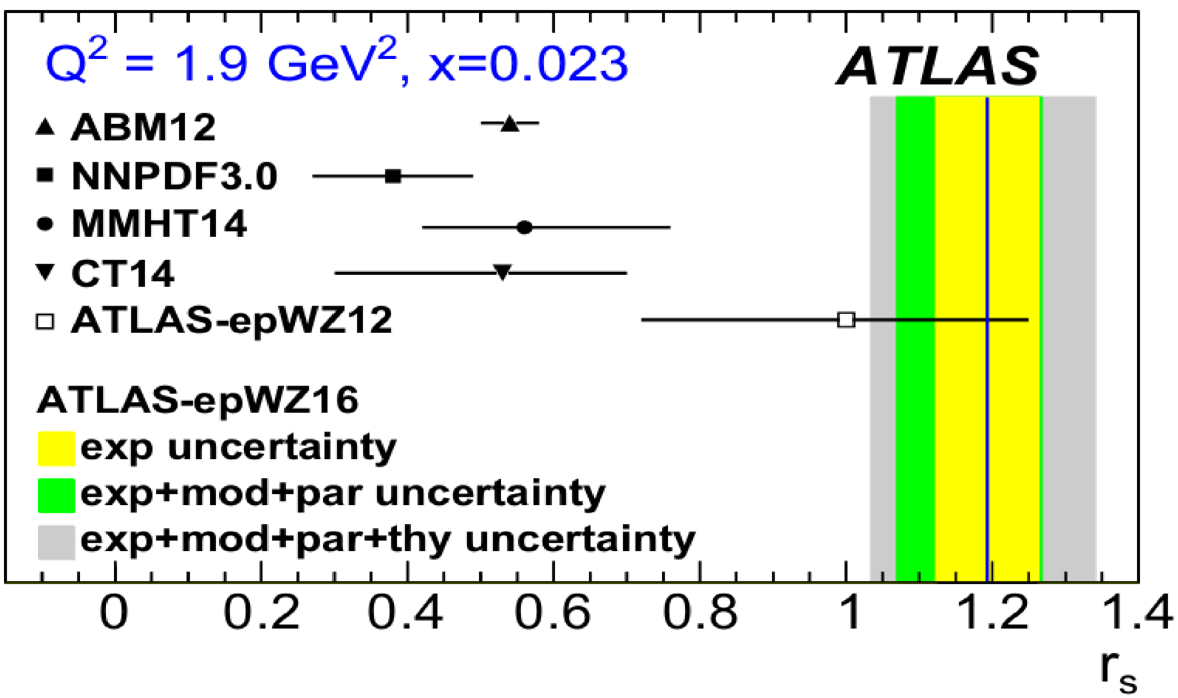


nCTEQ++ with LHC W/Z Data

- Fit+Normalization dramatically reduce χ^2

$$
\begin{aligned}
u\bar{d} + u\bar{s} + c\bar{d} + c\bar{s} &\rightarrow W^{+} \\
\bar{u}d + \bar{u}s + \bar{c}d + \bar{c}s &\rightarrow W^{-} \\
u\bar{u} + d\bar{d} + s\bar{s} + c\bar{c} &\rightarrow Z
\end{aligned}
$$



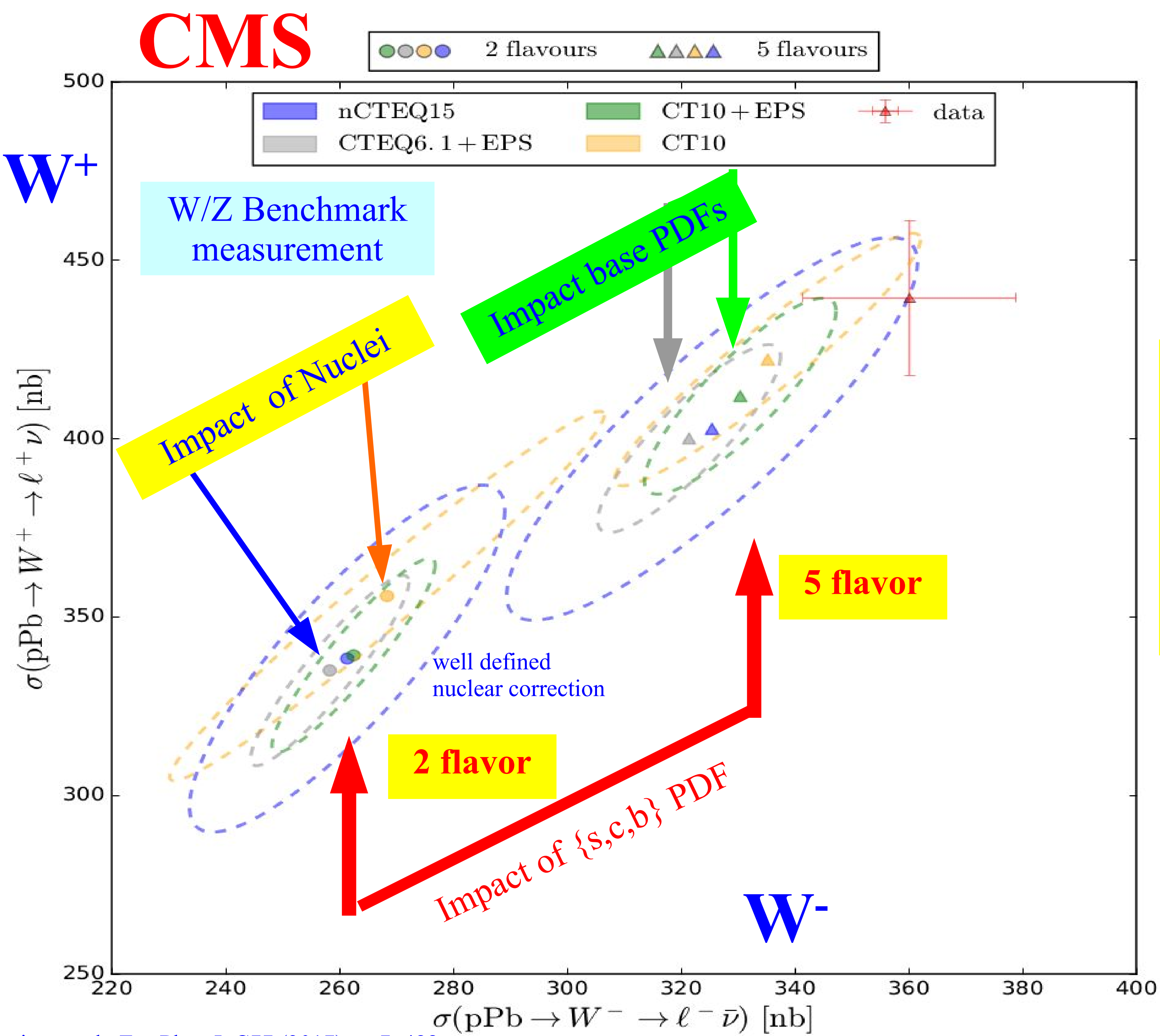


$$
r^{s}(x,Q) = \frac{\bar{s}(x,Q) + s(x,Q)}{2\bar{d}(x,Q)}
$$

Do it yourself!!!
Try xFitter

ATLAS: Eur. Phys. J. C 77 (2017) 367

Add LHC Heavy Ion: $p\ Pb \rightarrow W/Z$



Entangled:

- Nuc Corrections
- Base PDF
- PDF Flavors

LHC: data at A={1,208}

A. Kusina, et al., Eur.Phys.J. C77 (2017) no.7, 488

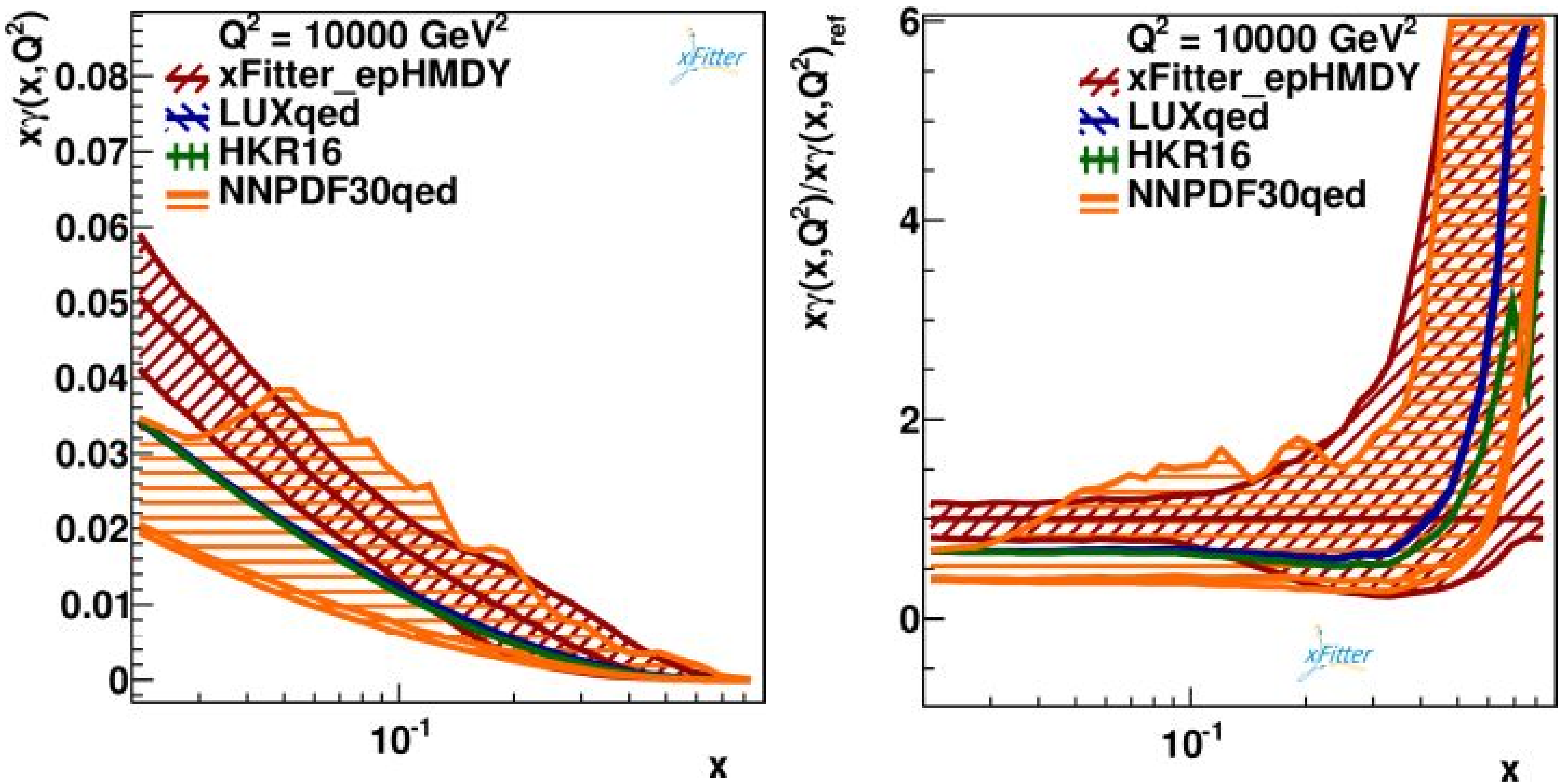
Photon

PDFs

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 $$x\gamma(x) = A_\gamma\, x^{B_\gamma}(1-x)^{C_\gamma}(1 + D_\gamma\, x + E_\gamma\, x^2)$$



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)

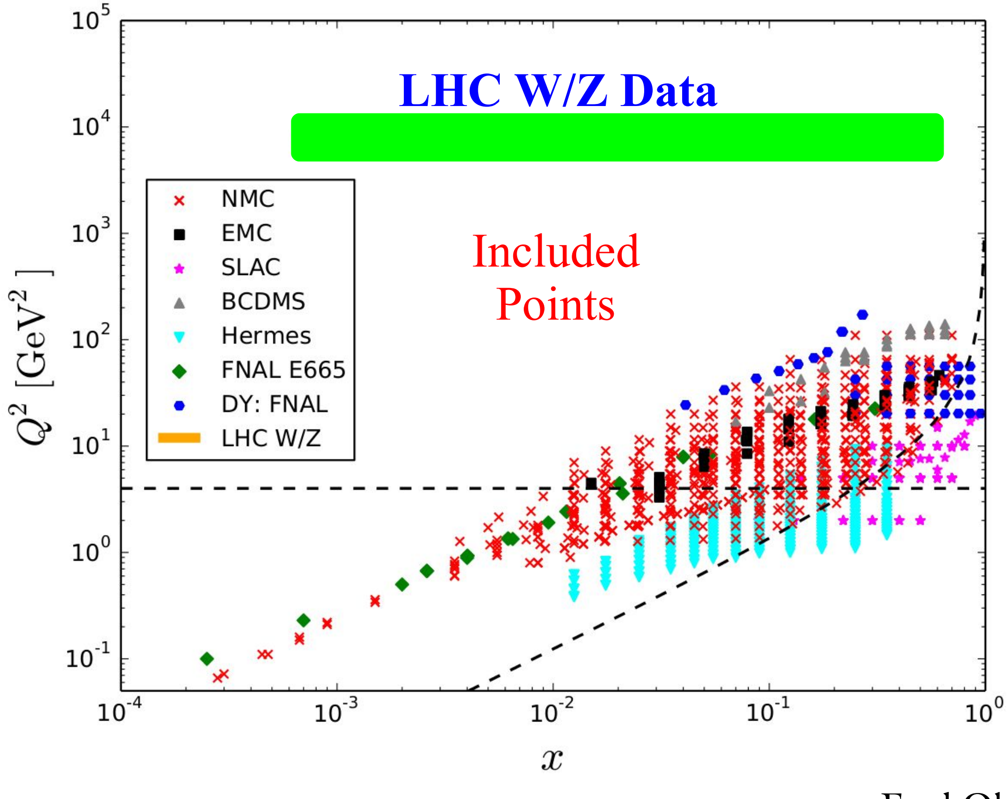
Let's include LHC data into the fit directly

nCTEQ+LHC

pPb Data for nCTEQ+LHC

No LHC data in any previous nCTEQ fit

- New gridded theory predictions make this possible



ATLAS:

- $d\sigma(W^- \to \ell^- \nu)/dy$

  ID: 6211 Npts: 10

- $d\sigma(Z \to \ell^+ \ell^-)/dy$

  ID: 6215 Npts: 14

CMS:

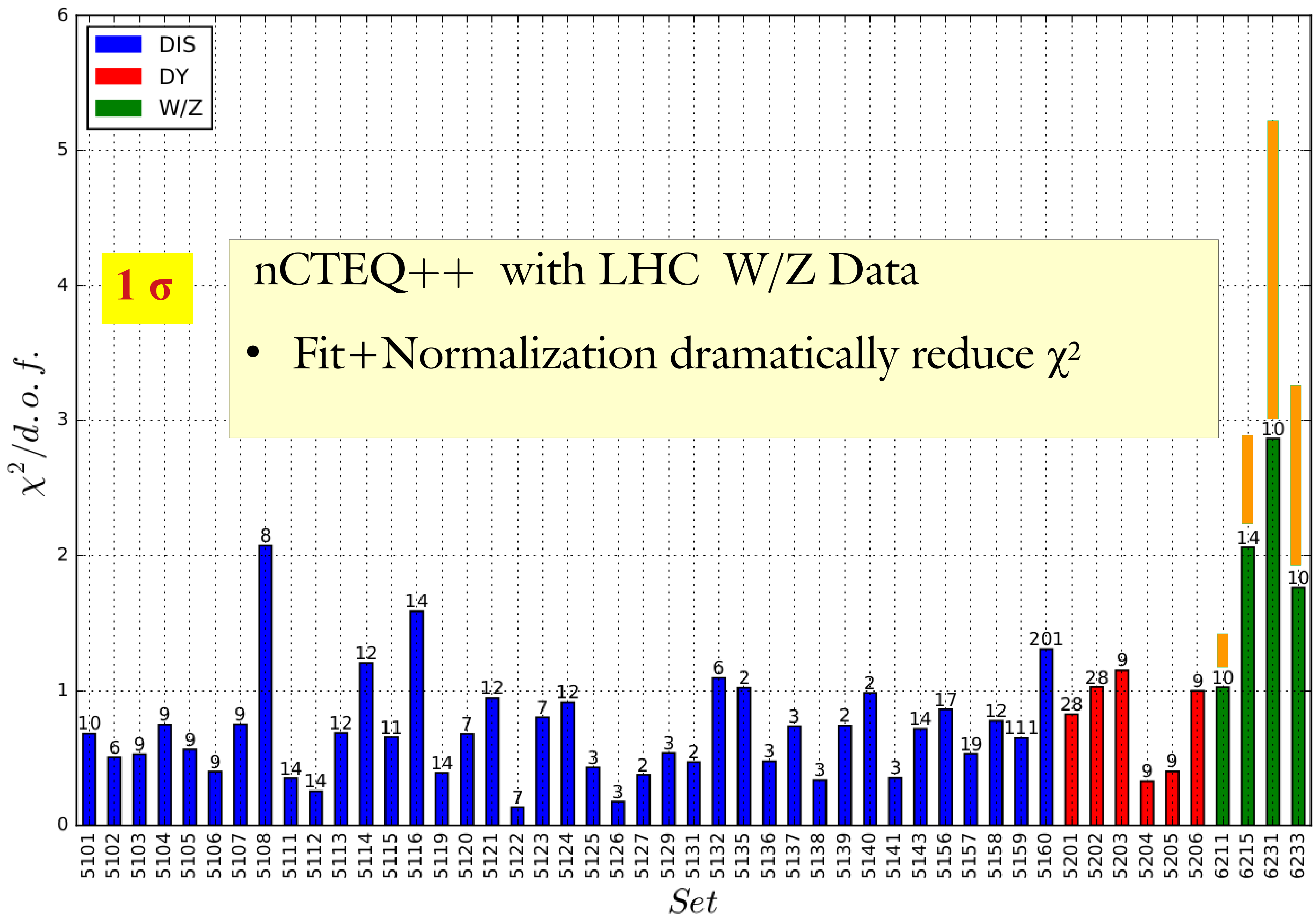
- $d\sigma(W^- \to \ell^- \nu)/dy$

  ID: 6231 Npts: 10

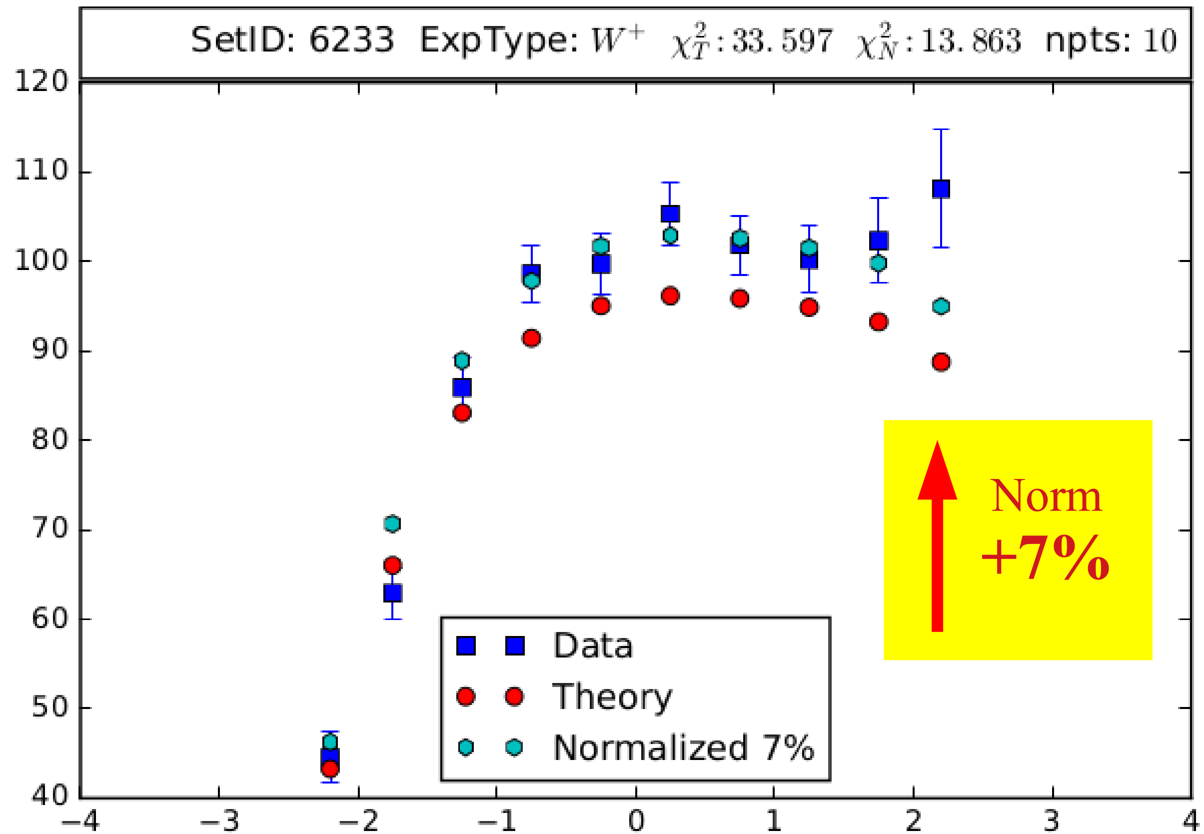
- $d\sigma(W^+ \to \ell^+ \nu)/dy$

  ID: 6233 Npts: 10

Fit to LHC W/Z Data w/ Normalization



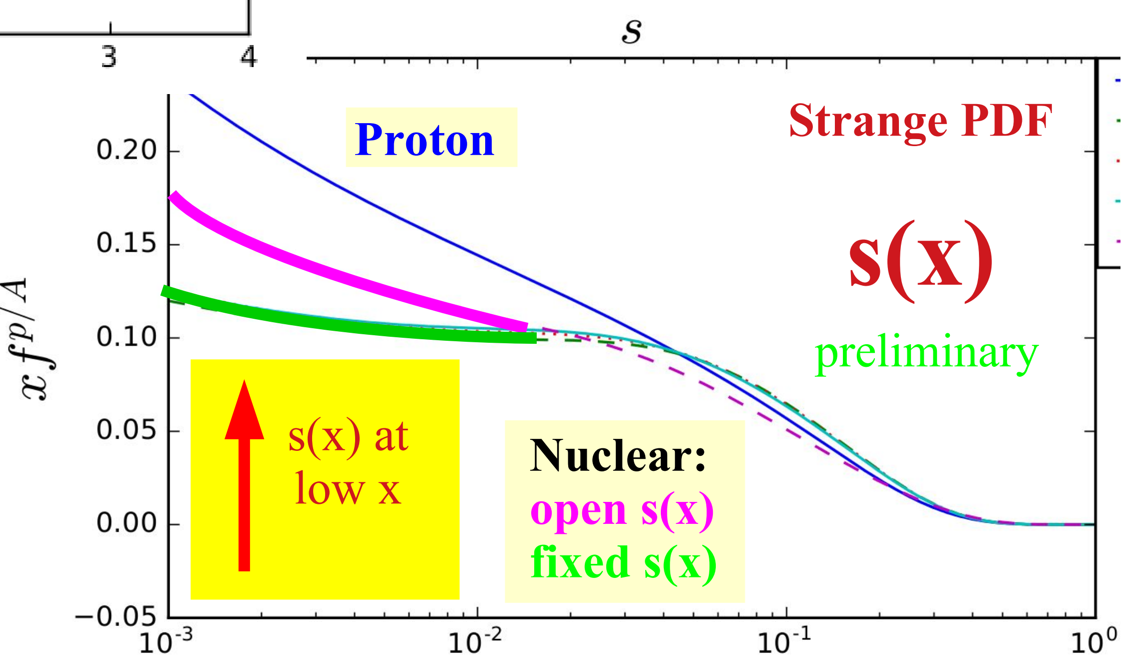
Fit to LHC W/Z Data w/ Normalization



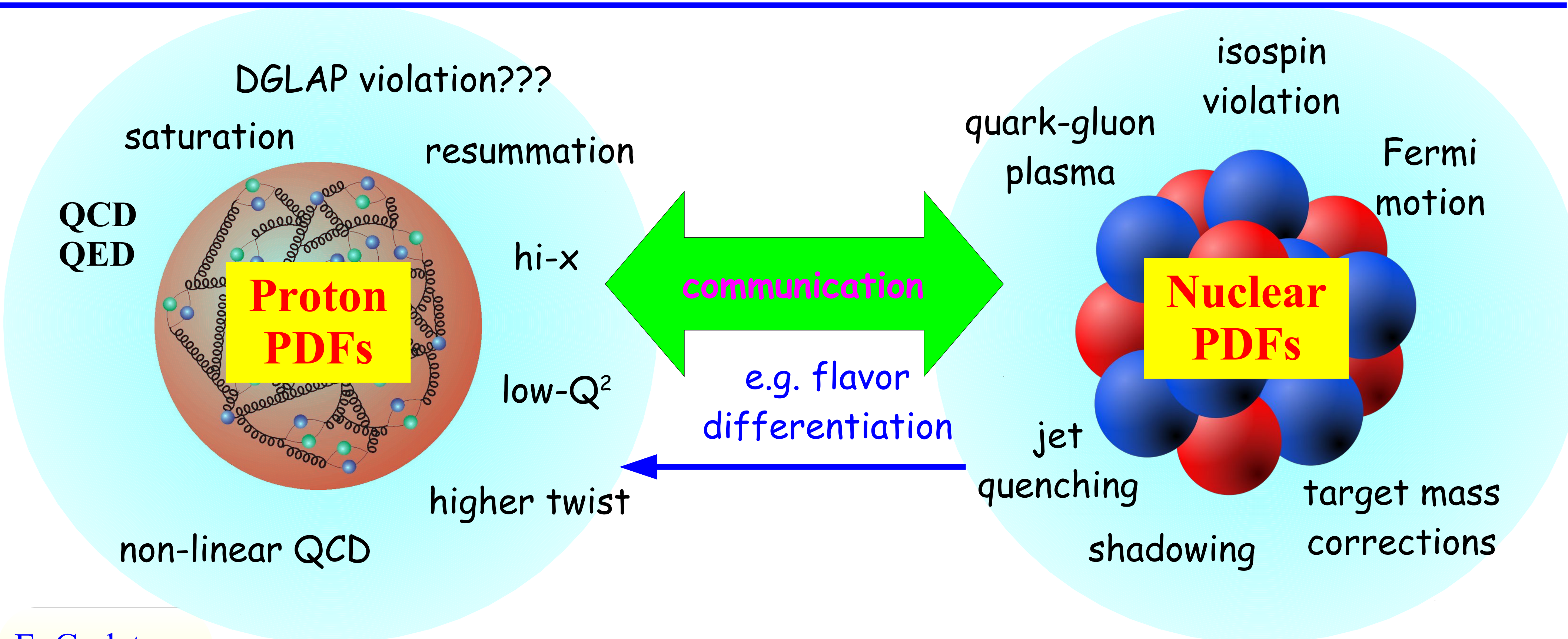
Fit + Normalization

- Improved χ^2/d.o.f.
- Seems to prefer larger strange PDF

The preliminary result is
if we fit strange,
the data prefers a larger s(x)



… the motivation for nCTEQ



E. Godat
T.J. Hobbs
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K. Kovarik
A Kusina,
F. Lyonnet,
J. Morfin,
F. Olness
J. Owens,
I. Schienbein,
J. Yu

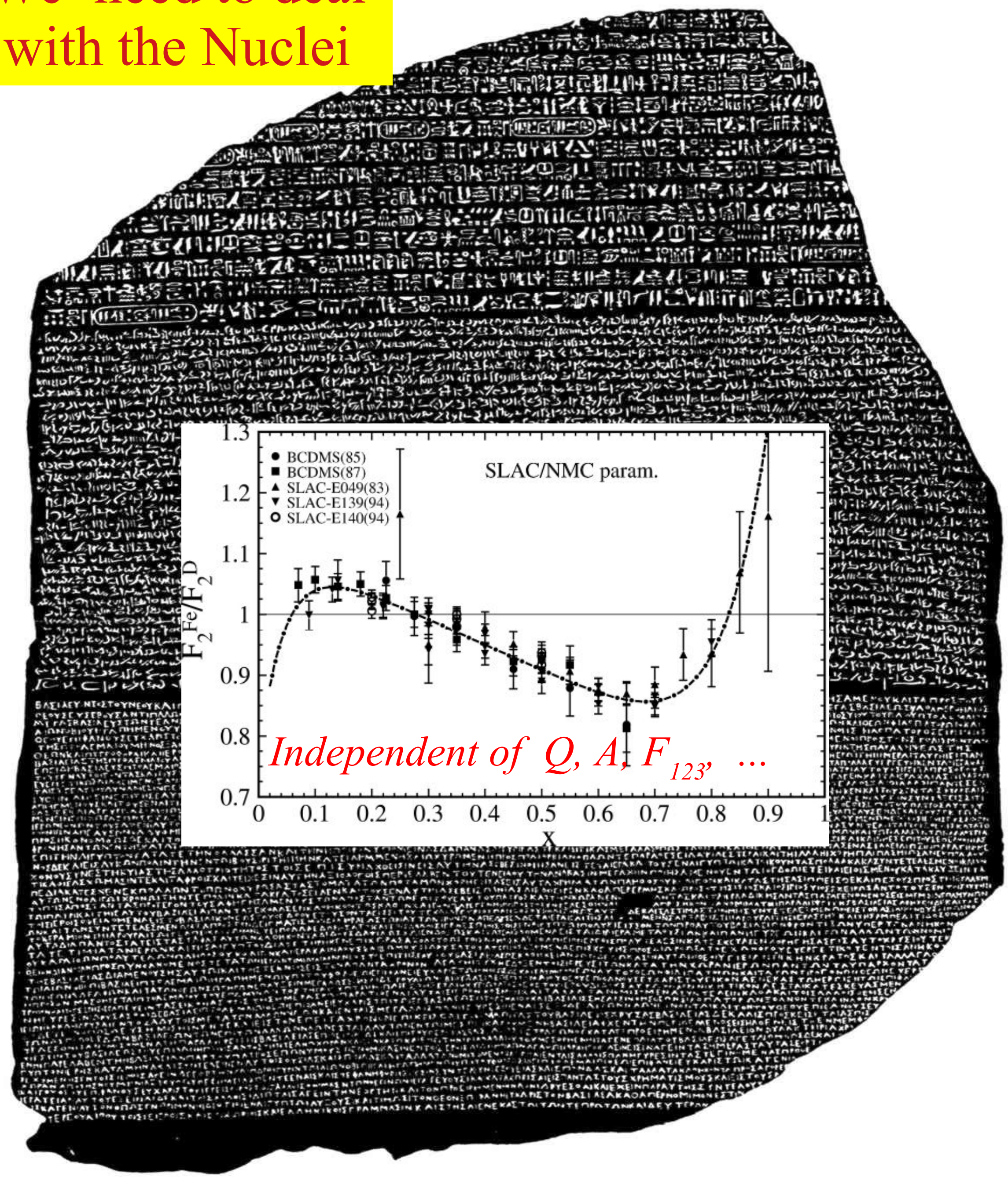
Data from nuclear targets play a key role in the flavor differentiation

nCTEQ

nuclear parton distribution functions

Where do nuclear corrections come from ????

We need to deal with the Nuclei



The ratio of iron (Fe) to Deuterium (D)

$$\frac{F_2^{Fe}}{F_2^{D}}$$

Discovered by the French in 1799 at Rosetta, a harbor on the Mediterranean coast in Egypt. Comparative translation of the stone assisted in understanding many previously undecipherable examples of hieroglyphics.

"EIC would unlock scientific mysteries" *NAP Report*

Ideally suited to " ... glean the fundamental insights into QCD"

Nucleon Structure:

protons, hadrons, nuclear tomography, …

Hadron/Parton Transition:

Higher Twist, many body, duality, ...