New Phenomena at the EIC:

Exploring the limits of the strong interaction force

Fred Olness
SMU

Thanks for substantial input
from my friends & colleagues

nCTEQ
nuclear parton distribution functions

xFitter

C T E Q

New opportunities
for BSM searches at the EIC
22 July 2025

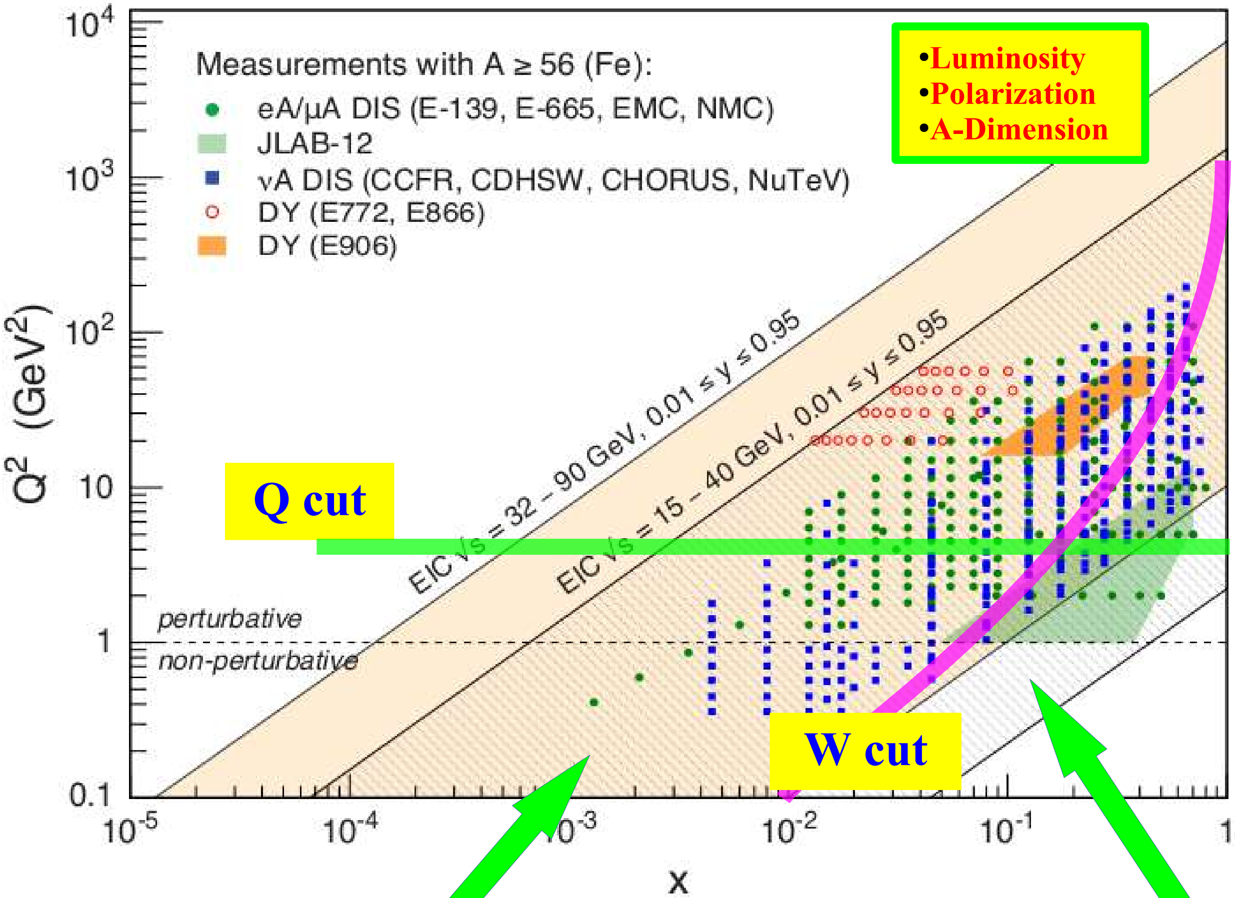
The most exciting phrase to hear in science,
the one that heralds new discoveries, is not "Eureka!" *(I found it!)*
but "That's funny ..."
— Isaac Asimov

Serendipitous scientific discoveries that are noteworthy

- **Penicillin**: Alexander Fleming's noticed a mold inhibiting bacterial growth in a neglected petri dish.
- **X-rays:** Wilhelm Roentgen observed a mysterious glow passing through objects and casting shadows.
- **Microwave Oven**: Percy Spencer, a Raytheon engineer, noticed a candy bar in his pocket melted while working with a magnetron.
- V**ulcanized Rubber**: Charles Goodyear accidentally spilled a rubber and sulfur mixture on a hot stove.
- **Post-it Notes**: Spencer Silver's attempt to create a super-strong adhesive at 3M.
- **Cosmic Microwave Background Radiation**: Arno Penzias and Robert Wilson were perplexed by persistent radio noise in their antenna.

Scientific progress isn't always a direct path ... often, it's about recognizing unexpected patterns found at the fringes of our expectations ...

To Boldly Go Beyond ... into the corners of the $\{x,Q^2\}$ Kinematic Plane



High-x:

Nuclear PDFs: x>1 allowed;

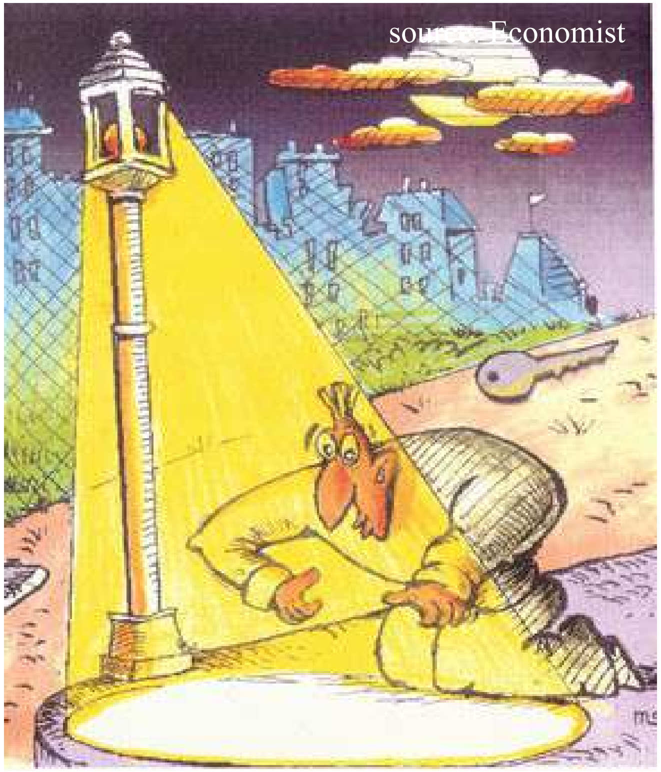
impacts F_2^{Nuc}/F_2^{Iso} in Fermi region

Target Mass Corrections

pick up M^2/Q^2 higher twist

Deuteron Corrections

impacts $F_2^{Nuc}/F_2^{Deuteron}$ ratio



Low-x:

Shadowing

Recombination

Resummation

BFKL

Saturation

Low-Q^2:

Non-Perturbative inteface

collective effects

Target Mass Corrections

pick up M^2/Q^2 higher twist

F_L at low Q^2 access to g(x)

Run at multiple energies

Future Opportunities with Lepton-Hadron Collisions*

Contact persons: Allen Caldwell[1], Silvia Dalla Torre[2], Rolf Ent[3], Aharon Levy[4], Paul Newman[5], Fred Olness[6] and Juan Rojo[7,8]

https://arxiv.org/abs/2503.18208
contributed to
2025 European Particle Physics Strategy Update.

Overview of selected DIS facilities.

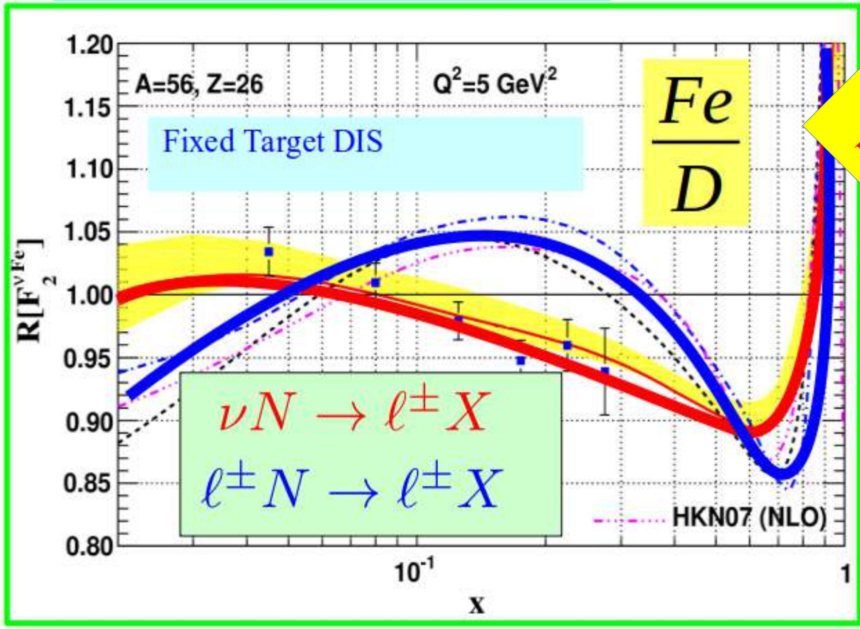
Facility	**Years**	E_{cm} (GeV)	**Luminosity** $(10^{33}/cm^2/s)$	**Ions** *(depends on)	**Polarisation**	**Status**
JLab 11 / JLab 22	Running / Late 2030's	4.5 — 6.5	10^2 — 10^6	p → Pb	e, p, Light nuclei	Running / Concept
FASER / FPF/AdvSND	Running / 2030's	30 — 90	0.3 — 10	W, Ar	no	Running / Advanced
EIC	> 2034	30 — 140	1 — 10	p → U	e,p,d,^{3}He	Approved
EicC	> Late 2030's	15—20	2 — 3	p → U	e,p,d,^{3}He	Concept
LHeC	> Late 2030's	1200	24	*LHC	e possible	Advanced
Plasma-based schemes	2040's	530 — 9000	10^{-5} — 10^{-1}	*SPS/LHC	e possible	Concept
FCC-eh	> 2050	3500	15	*FCC-hh	e possible	Concept

nCTEQ

nuclear parton distribution functions

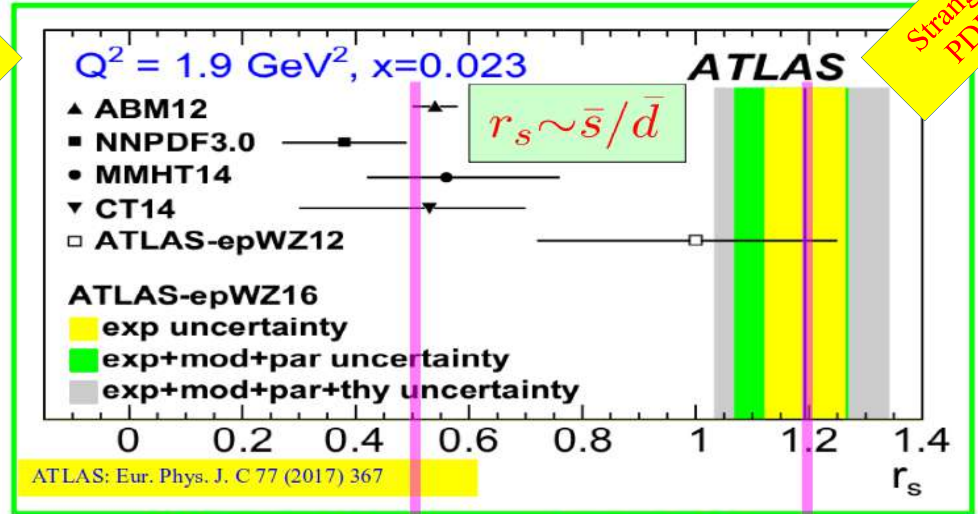
nCTEQ project is an extension of the CTEQ collaborative effort to determine nuclear parton distribution functions (nPDFs).

nCTEQ15ν



nCTEQ: arXiv: 2204.13157

nCTEQ15WZ

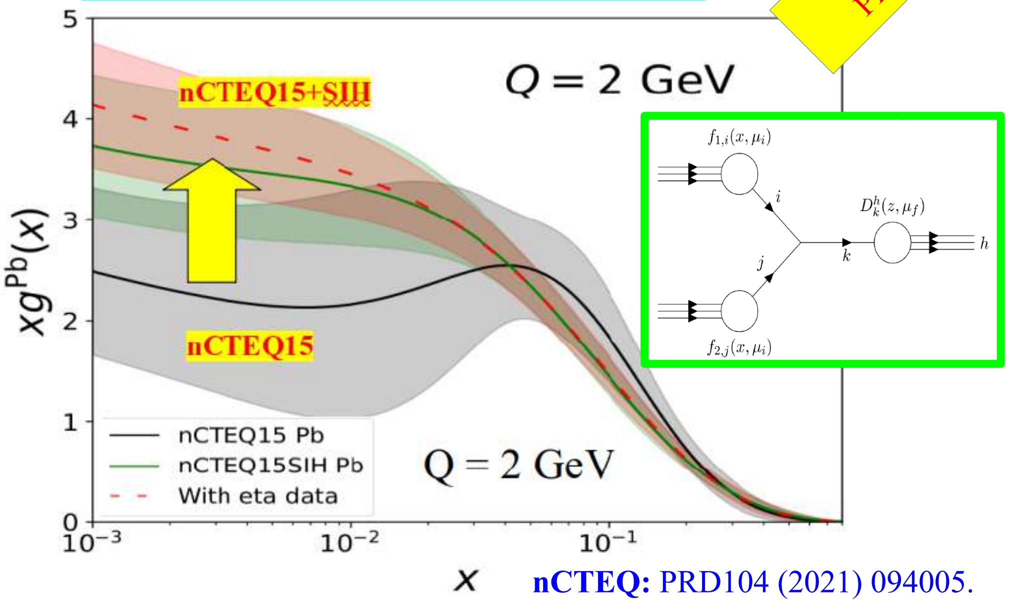


We expect: At the LHC:

nCTEQ: Phys.Rev.D 104 (2021) 094005

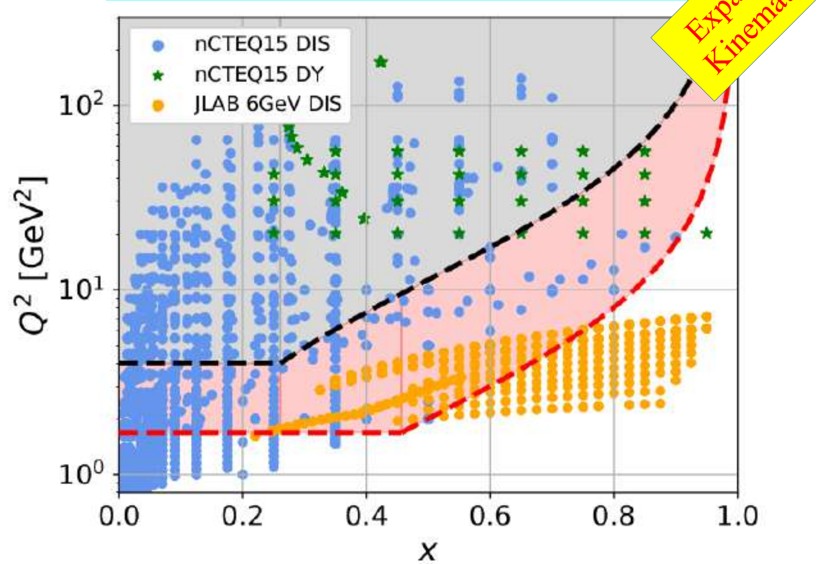
Key for **EIC**

nCTEQ15WZ+SIH



nCTEQ: PRD104 (2021) 094005.

nCTEQ15HIX



nCTEQ: Phys.Rev.D 103 (2021) 11, 114015

precision $f_A(x,Q)$ can serve as Boundary Condition for $f_A(x,Q,k_T,b_T,\sigma)$

QCD: Remarkably successful at describing High Energy Processes

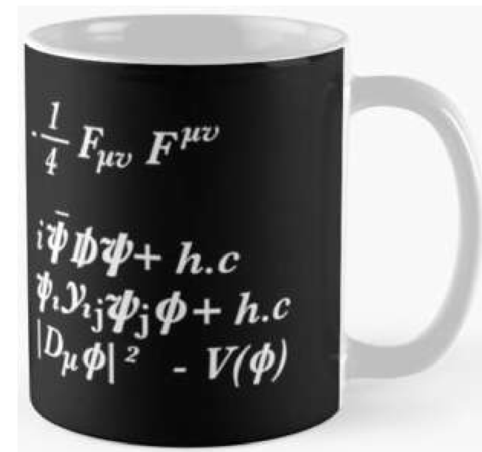
Quantum ChromoDynamics

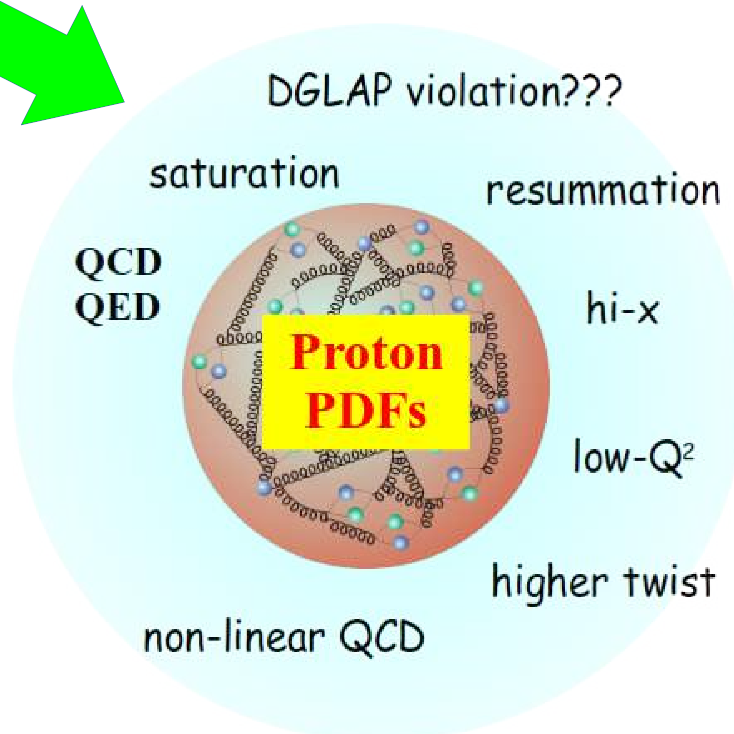
QCD

Lagrangian

$$\mathcal{L}_{QCD} = \overline{\psi}_q \left(i\gamma_\mu D^\mu - m_q\right)\psi_q - \frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a$$

Conjecture: A theory can't be fundamental unless it fits on a coffee mug.





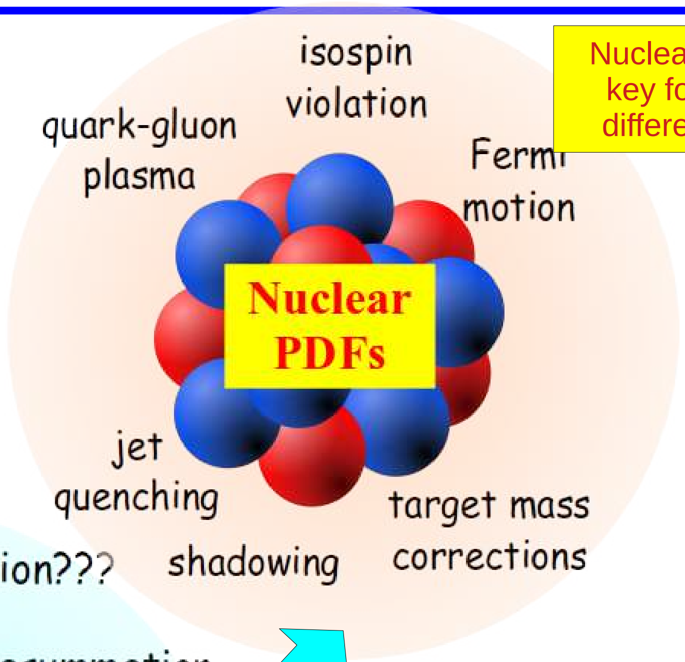
… we can go further

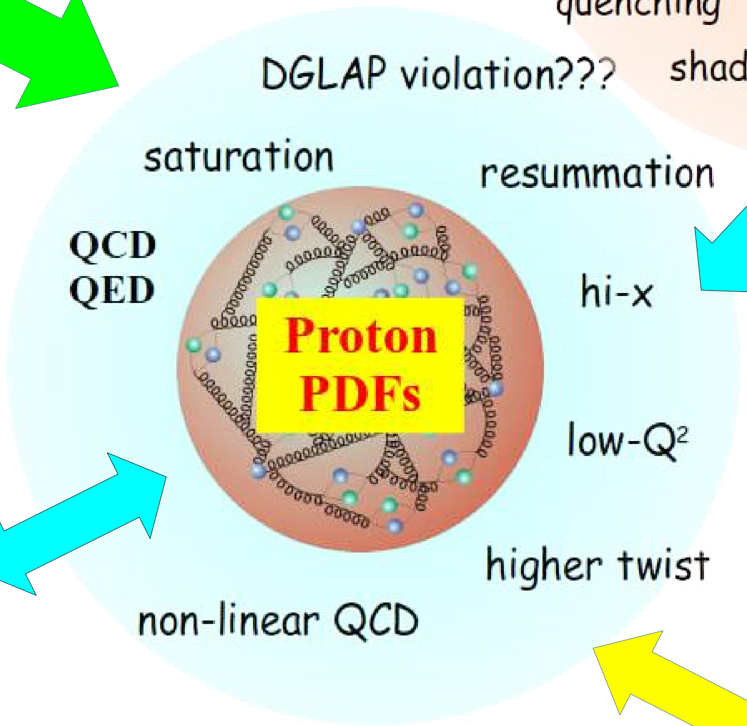
QCD: From PDFs to the underlying QCD

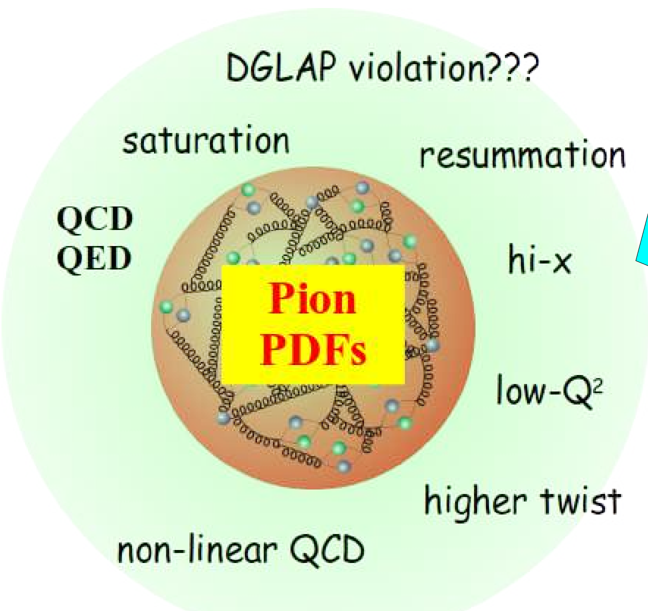
QCD Lagrangian

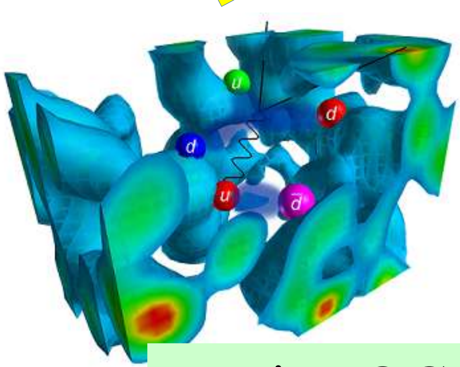
$$\mathcal{L}_{QCD} = \overline{\psi}_q \left(i\gamma_\mu D^\mu - m_q \right) \psi_q - \frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a$$

Nuclear targets key for flavor differentiation









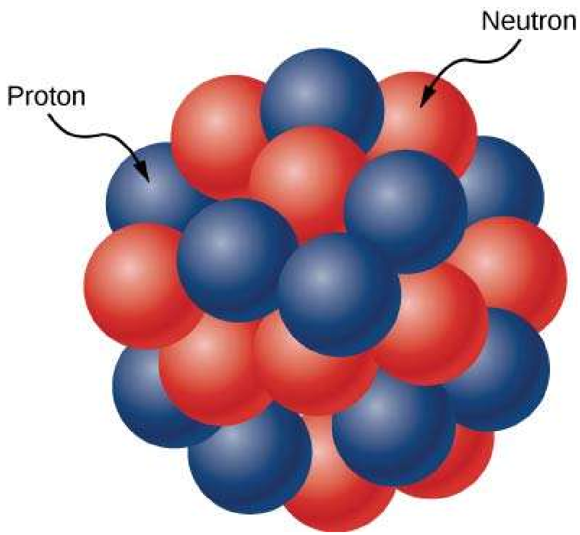
Lattice QCD

- **Spin**
- **TMDs**
- **GPDs**

precision $f_A(x,Q)$ can serve as Boundary Condition for $f_A(x,Q,k_T,b_T,\sigma)$

Nuclear PDFs

Parton Distribution Functions



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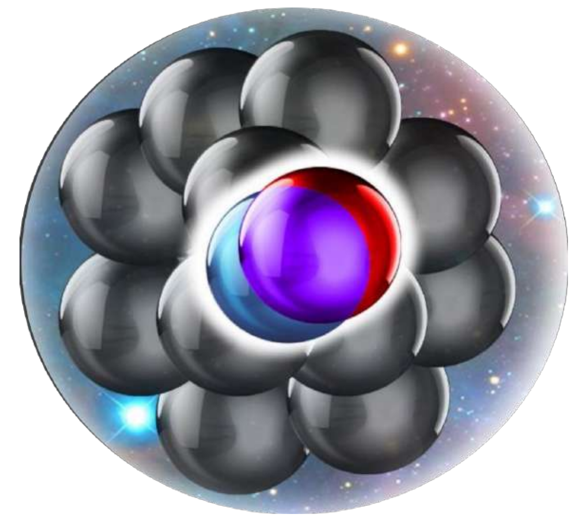


is it just a bag of protons & neutrons ???

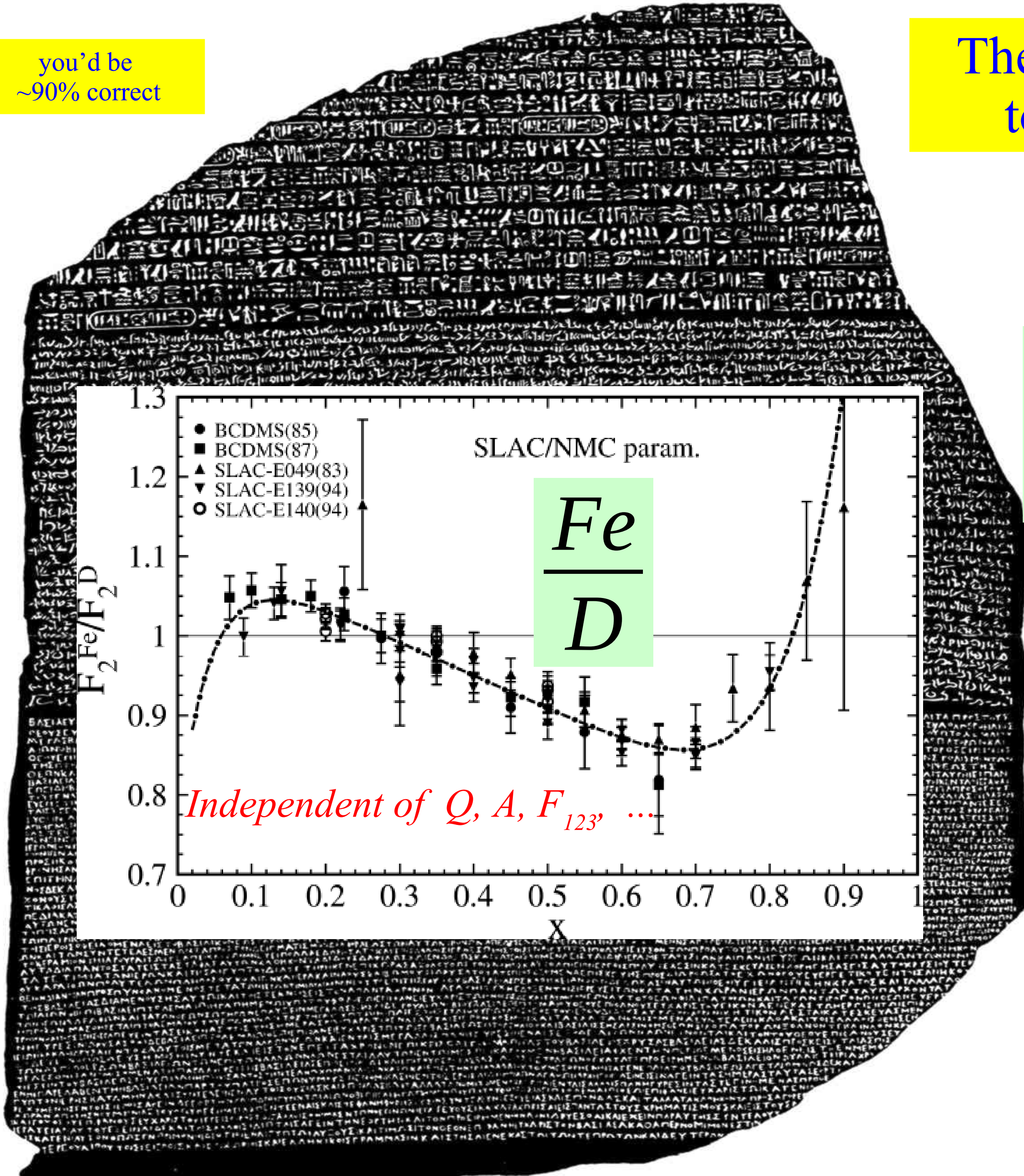
… is it just a bag of protons & neutrons ???

~90% correct

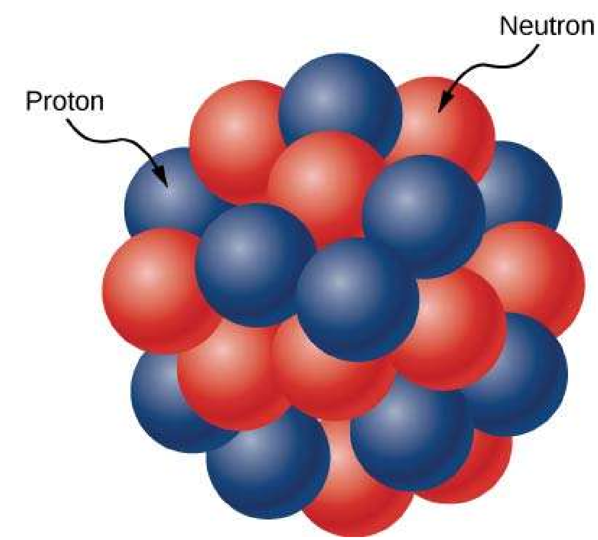
you'd be
~90% correct

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

$$\frac{Fe}{D}$$



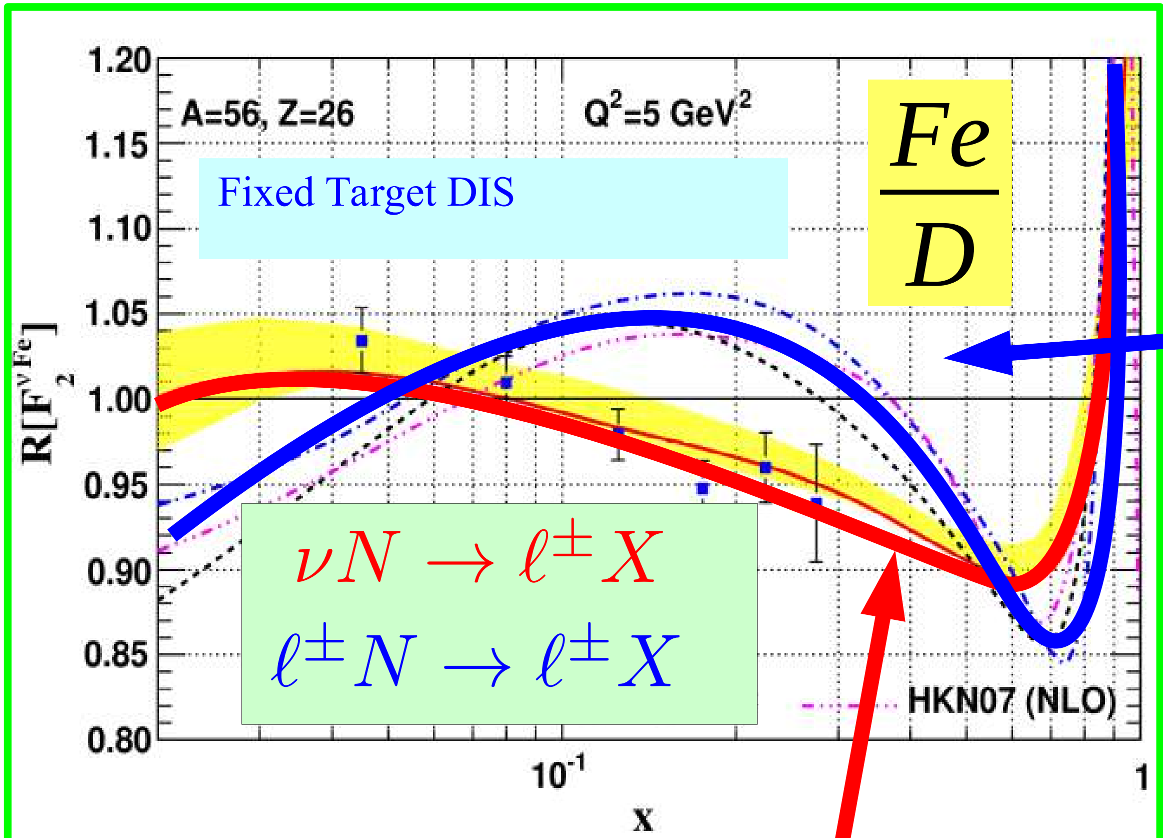
$$\frac{Iron}{(proton + neutron)}$$



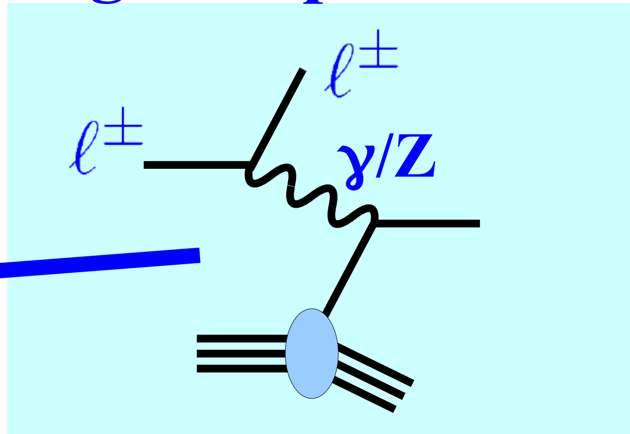
But ...

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.

Puzzle: Split Personality … *What is the correct Nuclear ratio*



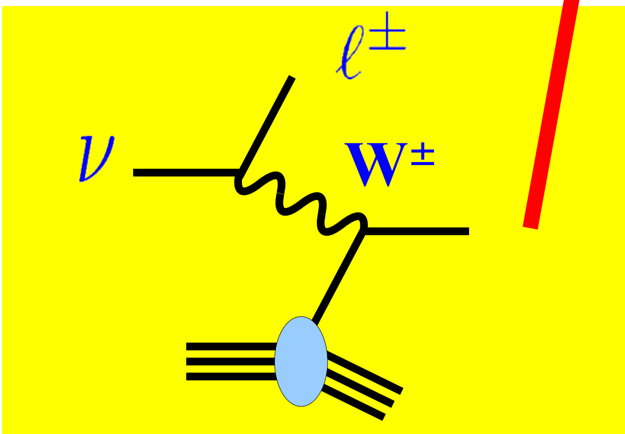
Charged Lepton DIS



some caveats
… correlated errors

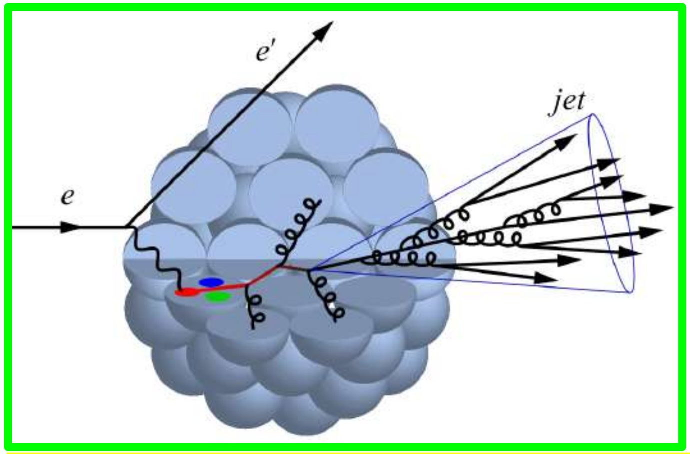
Ingo Schienbein, … (2007)

Karol Kovarik, … (2010)



Neutrino DIS

Depends on nuclear corrections



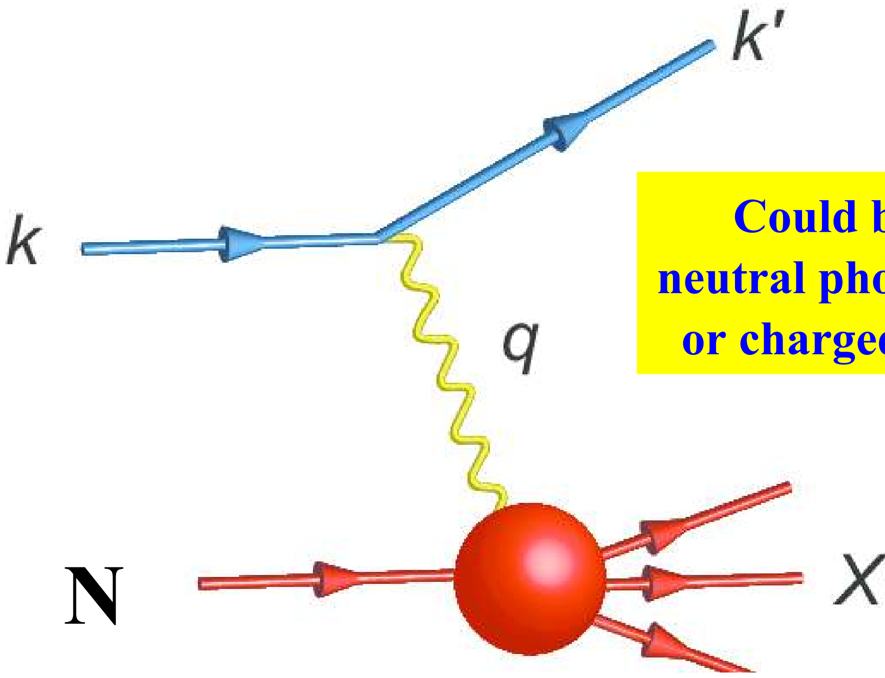
Propagation of γ/W thru nuclei

Neutrino
Deep Inelastic Scattering (DIS)

(nCTEQ) Faiq Muzakka, Karol Kovarik, ...

Phys.Rev.D 106 (2022) 7, 074004 • e-Print: 2204.13157 [hep-ph]

Nuclear Targets Important



Could be:
neutral photon γ
or charged $W^{\pm}$

Neutrino DIS

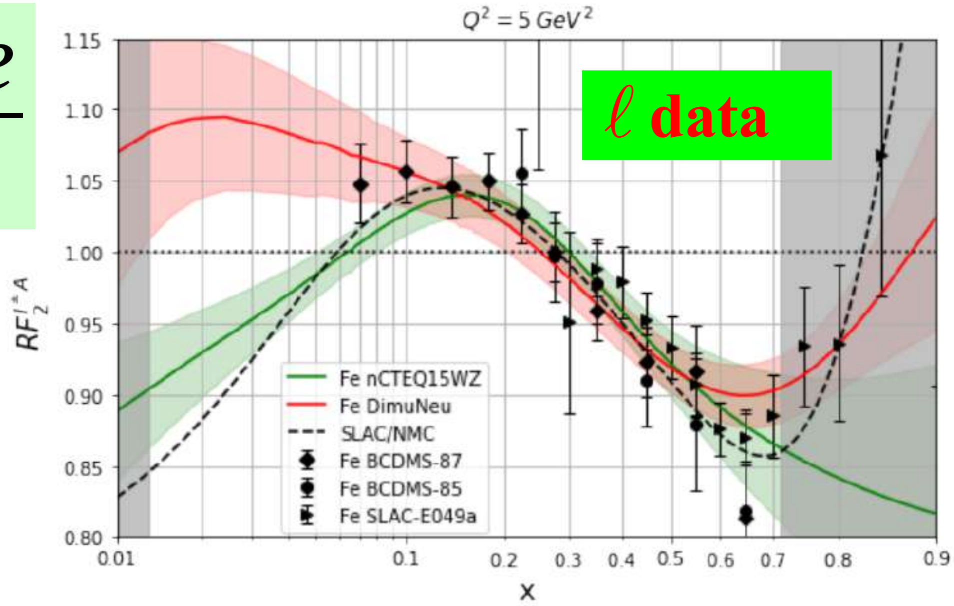
$$F_2^{\nu} \sim \left[d + s + \bar{u} + \bar{c}\right]$$
$$F_2^{\bar{\nu}} \sim \left[\bar{d} + \bar{s} + u + c\right]$$
$$F_3^{\nu} \sim 2\left[d + s - \bar{u} - \bar{c}\right]$$
$$F_3^{\bar{\nu}} \sim 2\left[u + c - \bar{d} - \bar{s}\right]$$

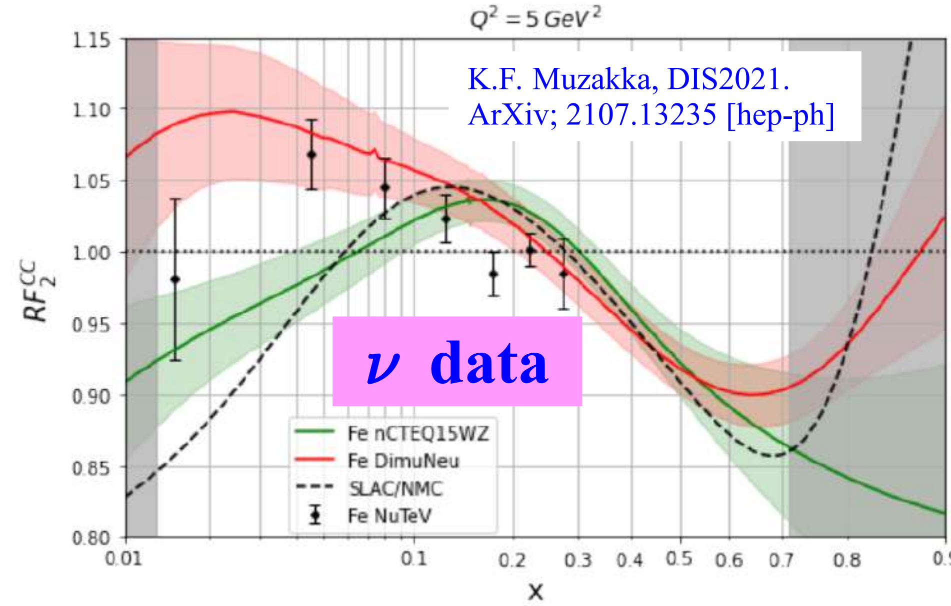
Differentiate flavors of free-proton PDFs:

Puzzle: **Split Personality …** *What is the correct Nuclear ratio*

Faiq Muzakka, Karol Kovarik, ...

$$\frac{Fe}{D}$$





$$\frac{Iron}{(proton + neutron)}$$

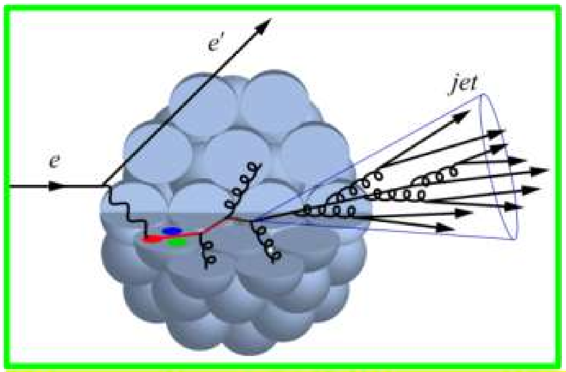
What is the correct nuclear correction ???

Are these data sets compatible???

Compatibility of neutrino DIS data and its impact on nuclear parton distribution functions

K.F. Muzakka,[1,*] P. Duwentäster,[1,†] T.J. Hobbs,[2,3,4] T. Ježo,[5,‡] M. Klasen,[1,§] K. Kovařík,[1,¶] A. Kusina,[6,**] J.G. Morfín,[7,††] F. I. Olness,[2,‡‡] R. Ruiz,[6] I. Schienbein,[8,§§]
[1]*Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster,*

Phys.Rev.D 106 (2022) 7, 074004 • e-Print: 2204.13157 [hep-ph]



Propagation of γ/W thru nuclei

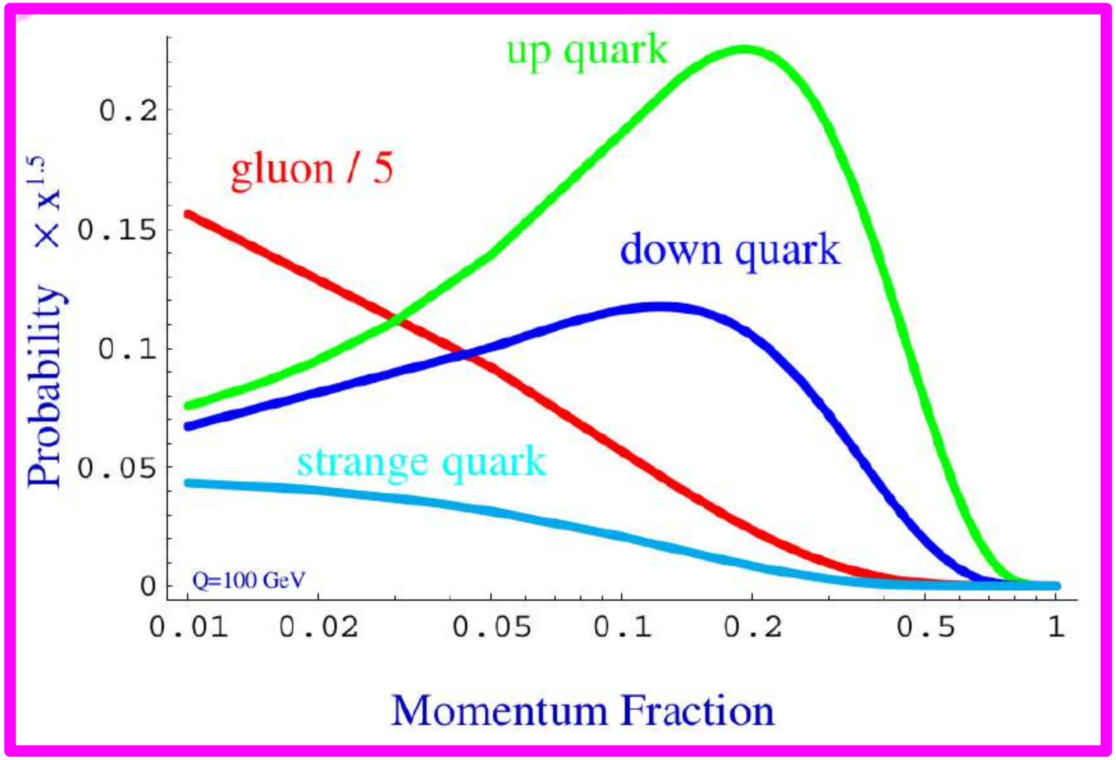
Strange PDF

Parton Distribution Functions

... this has a significant impact on the strange quark PDF

Strange PDF: ν Nucleon di-muon Production

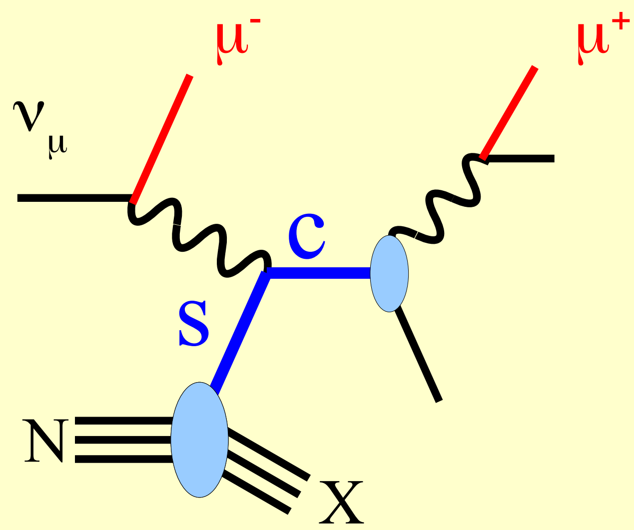
Need to "dig out" s(x) underneath d(x)



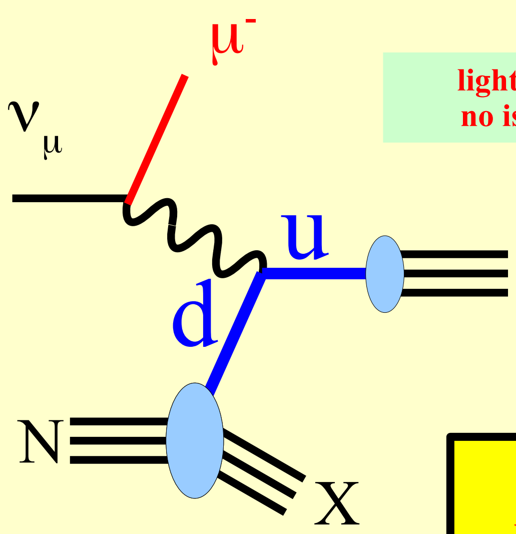
Result:

$$\bar{s}(x) \sim \frac{1}{2}\,\bar{d}(x)$$

Strange Quark



Down Quark



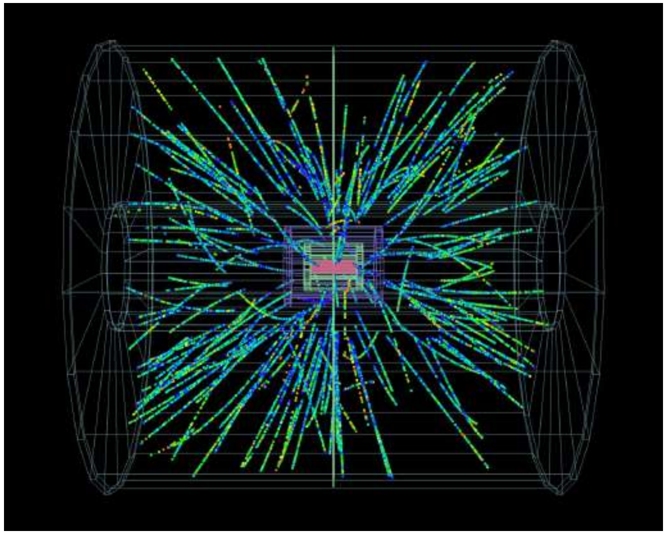
light u mass
no isolated μ

Depends on nuclear PDFs

W and Z Boson Production at the Large Hadron Collider (LHC)

(nCTEQ) Tomas Jezo, Aleksander Kusina, Fred Olness, ...

Independent of Nuclear Corrections



$$p\ p \to W, Z$$
$$p\,Pb \to W, Z$$

LHC Heavy Ion

… there's another way to measure the strange quark

nCTEQ: Eur.Phys.J.C 80 (2020) 10, 968

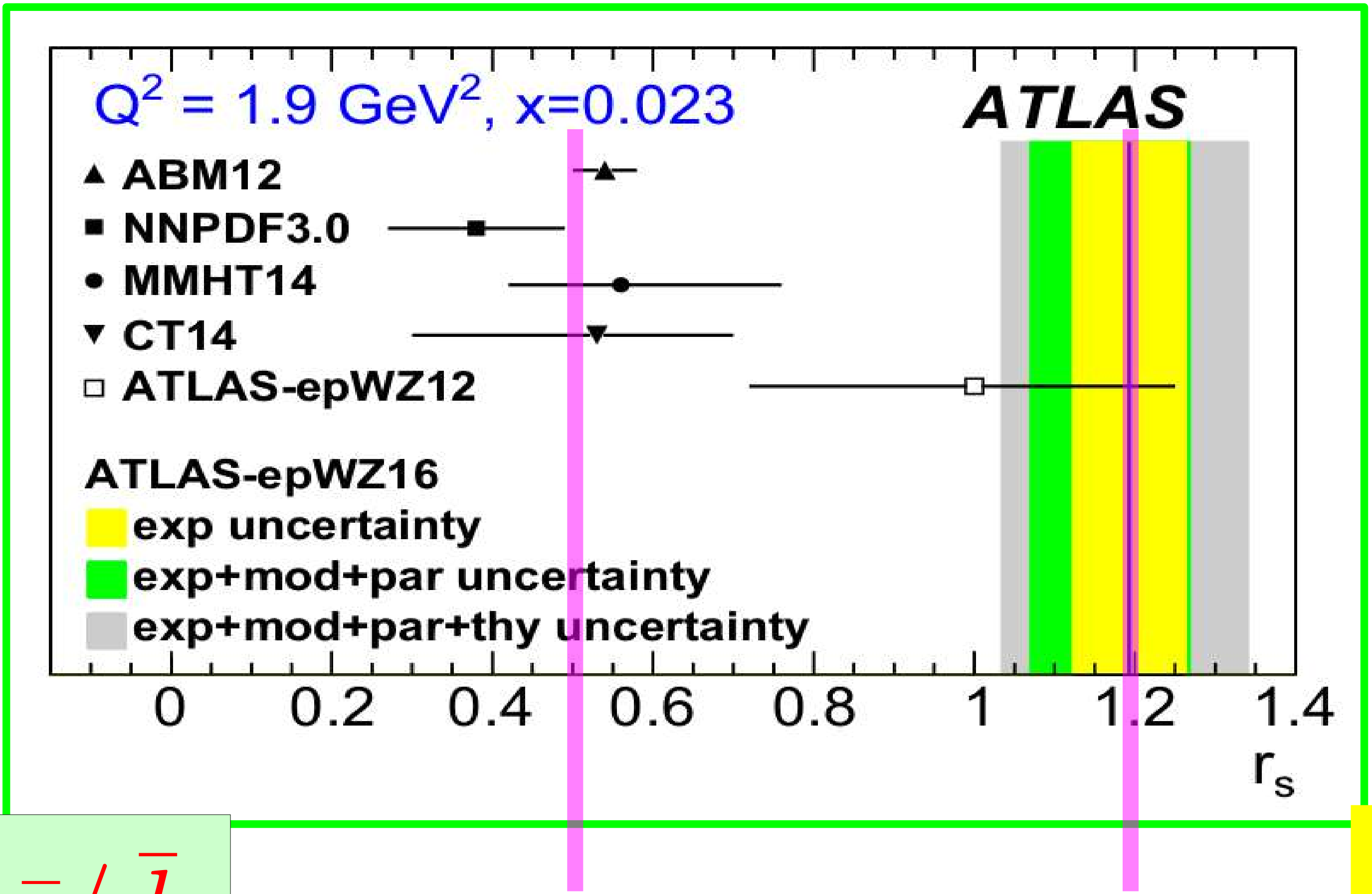
Surprise: … LHC sees more strange than expected

$$u\bar{d} + u\bar{s} + c\bar{d} + c\bar{s} \rightarrow W^+$$
$$\bar{u}d + \bar{u}s + \bar{c}d + \bar{c}s \rightarrow W^-$$
$$u\bar{u} + d\bar{d} + s\bar{s} + c\bar{c} \rightarrow Z$$

Surprise:

We expected $r_s = 1/2$

LHC finds $r_s > 1$



Proton case

$$r_s \sim \bar{s}/\bar{d}$$

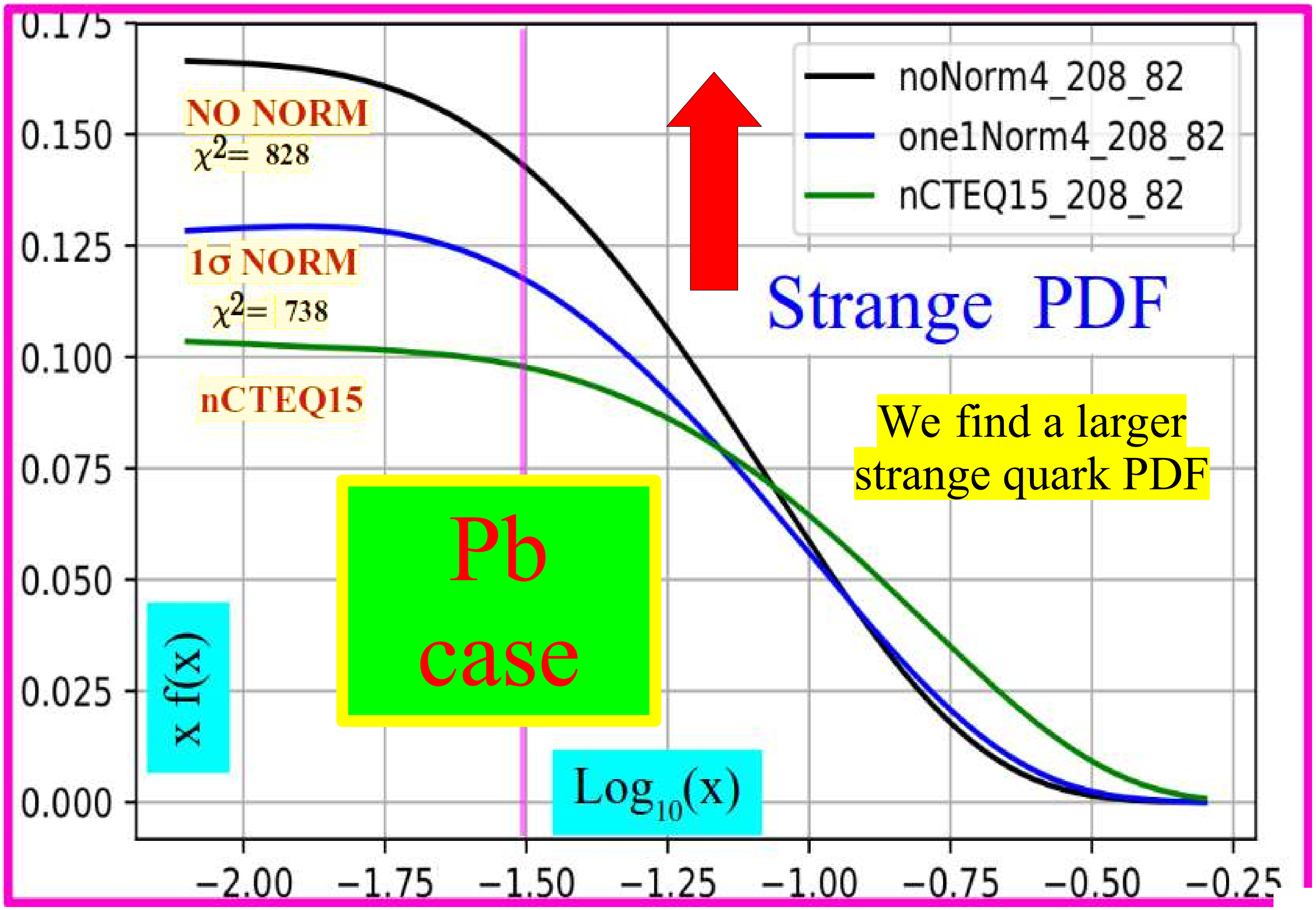
We expect:

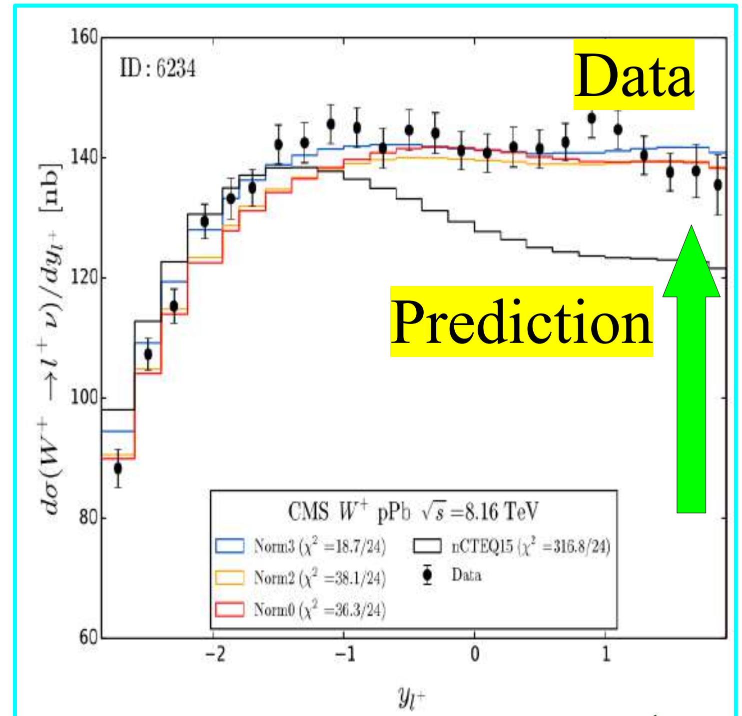
At the LHC:

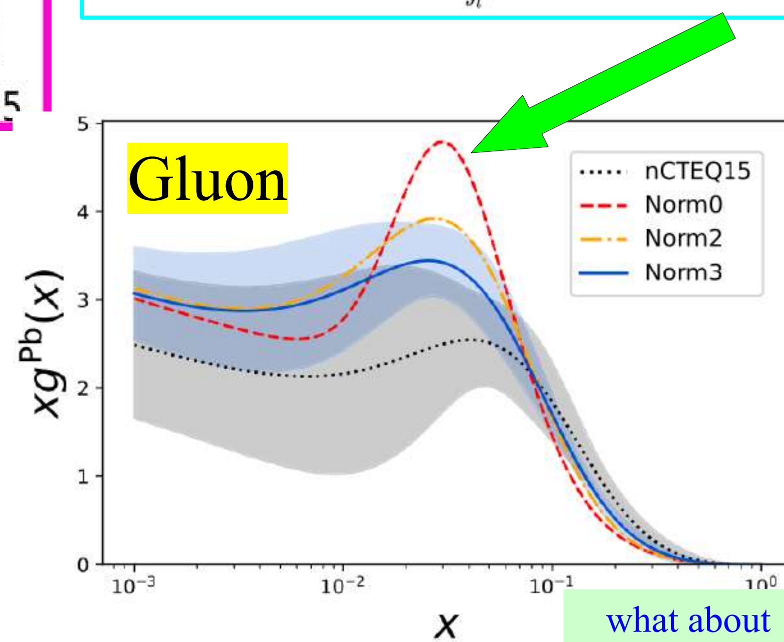
$$r_s = \frac{\bar{s} + s}{2\bar{d}}$$

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

Heavy Ion Case: … LHC STILL sees more strange than expected







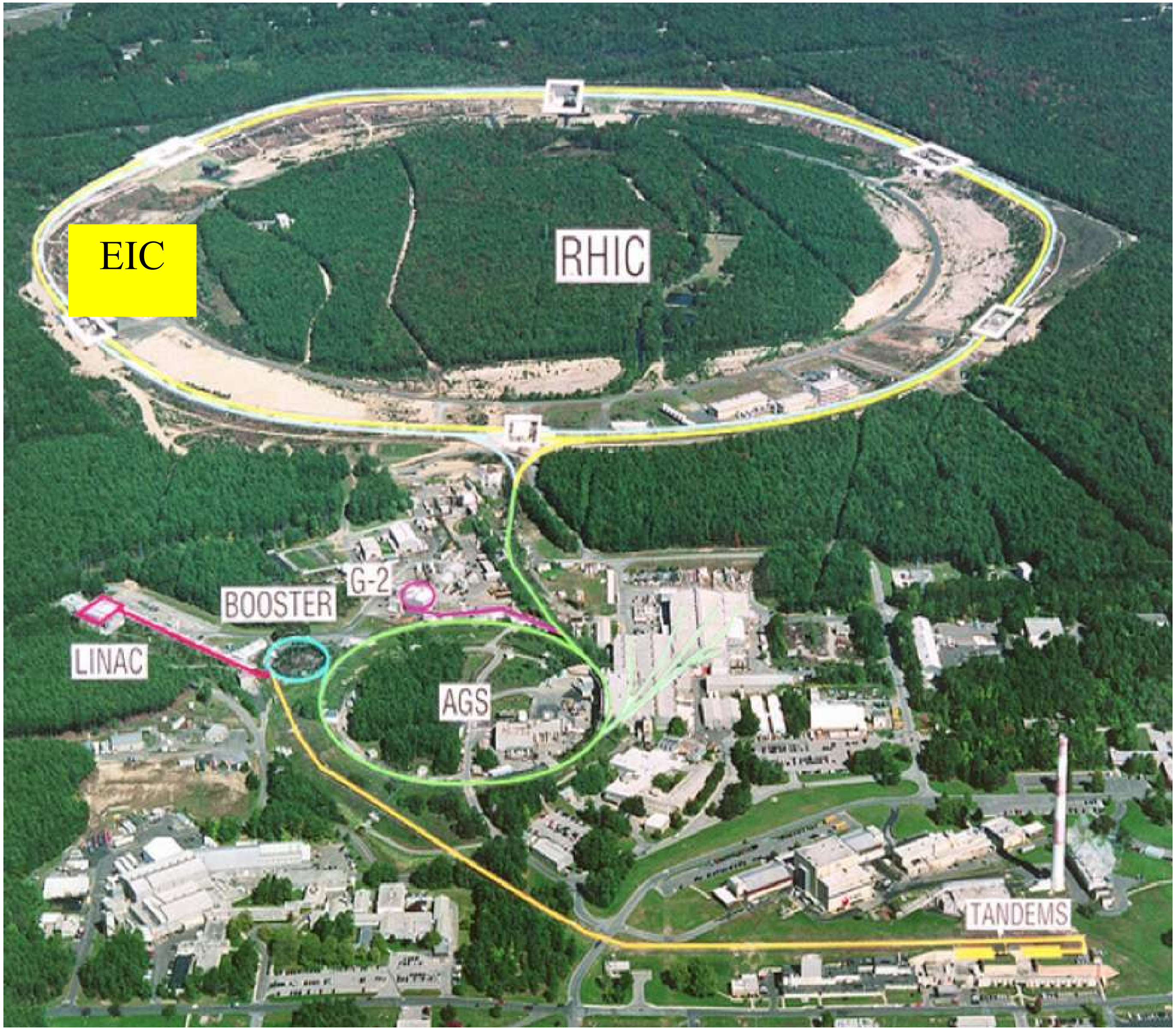
Is the strange PDF driving the data ...

Or is the data driving the strange ???

Tomas Jezo, Aleksander Kusina,

what about the gluon???

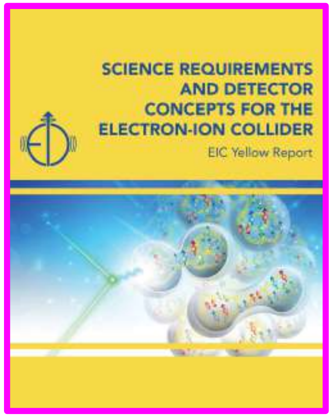
If only we had more DIS data



JLAB-PHY-20-3205, SMU-HEP-20-05

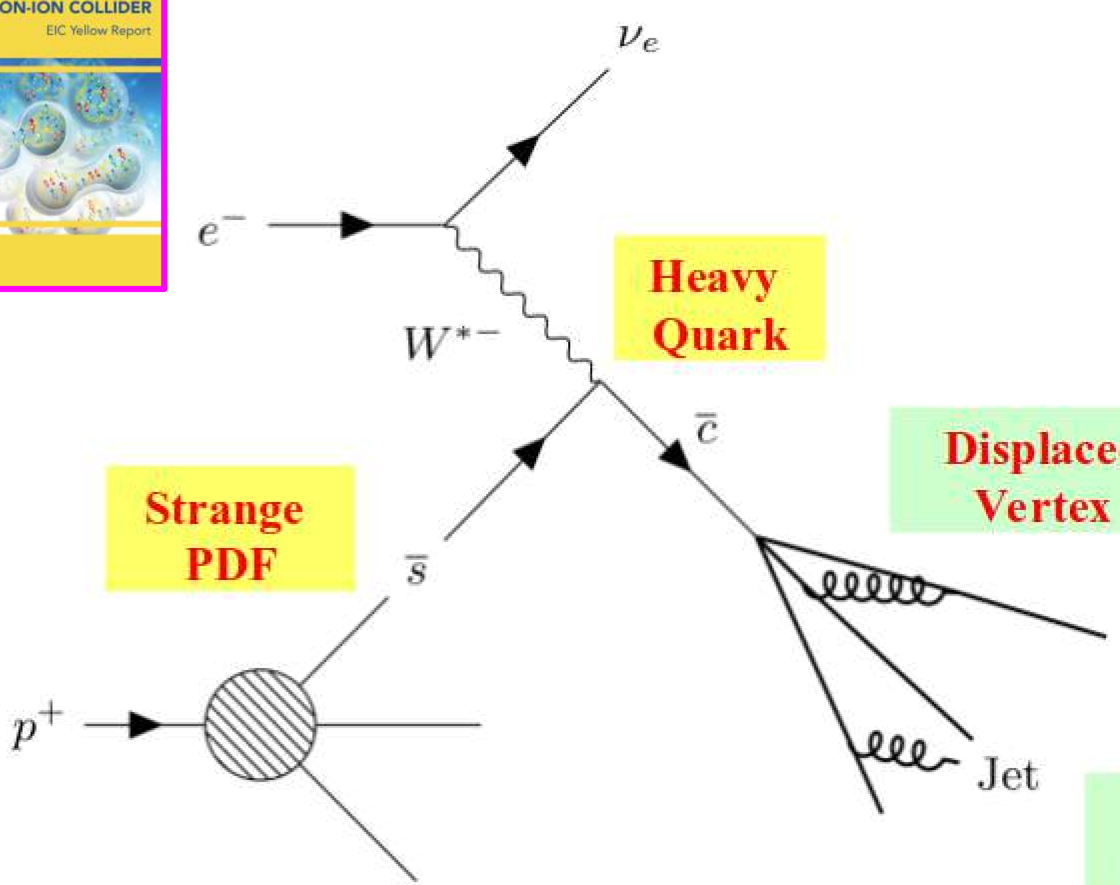
Charm jets as a probe for strangeness at the future Electron-Ion Collider

Miguel Arratia,[1,2] Yulia Furletova,[2] T. J. Hobbs,[3,4] Fredrick Olness,[3] and Stephen J. Sekula[3,*]



Missing E_T

Phys.Rev.D 103 (2021) 7, 074023



Heavy Quark

Displaced Vertex

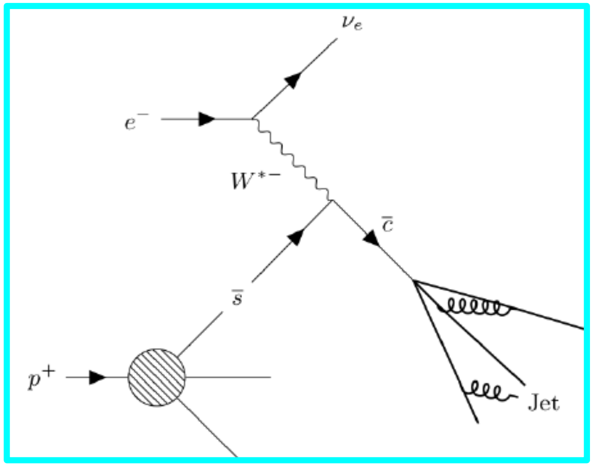
Strange PDF

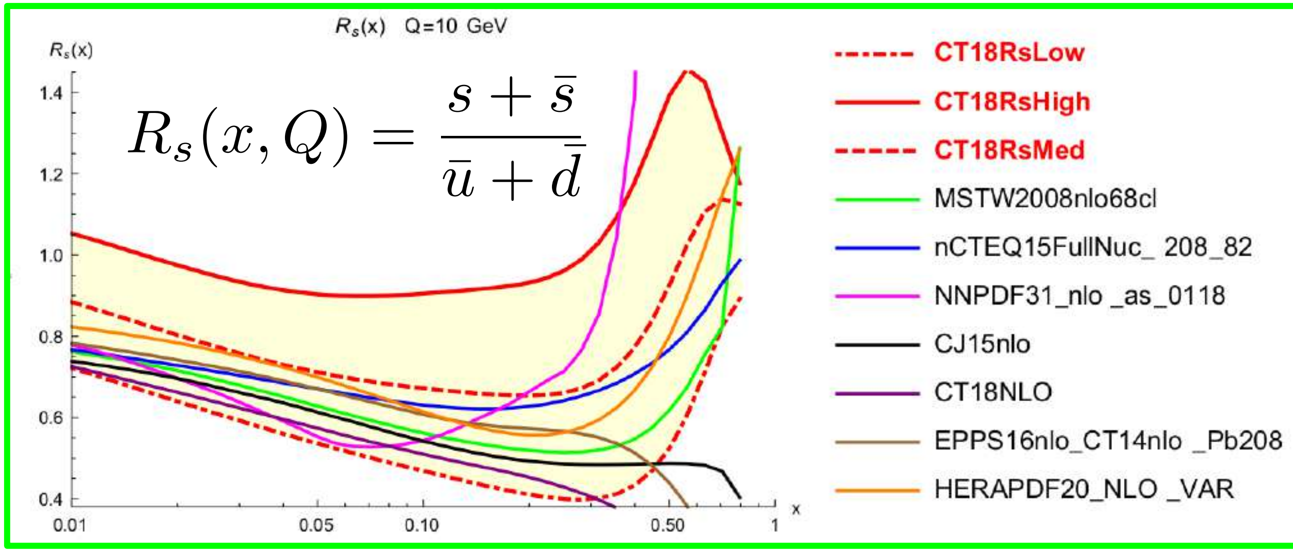
Jet Producton

Clear measure of Strange PDF beyond uncertainties

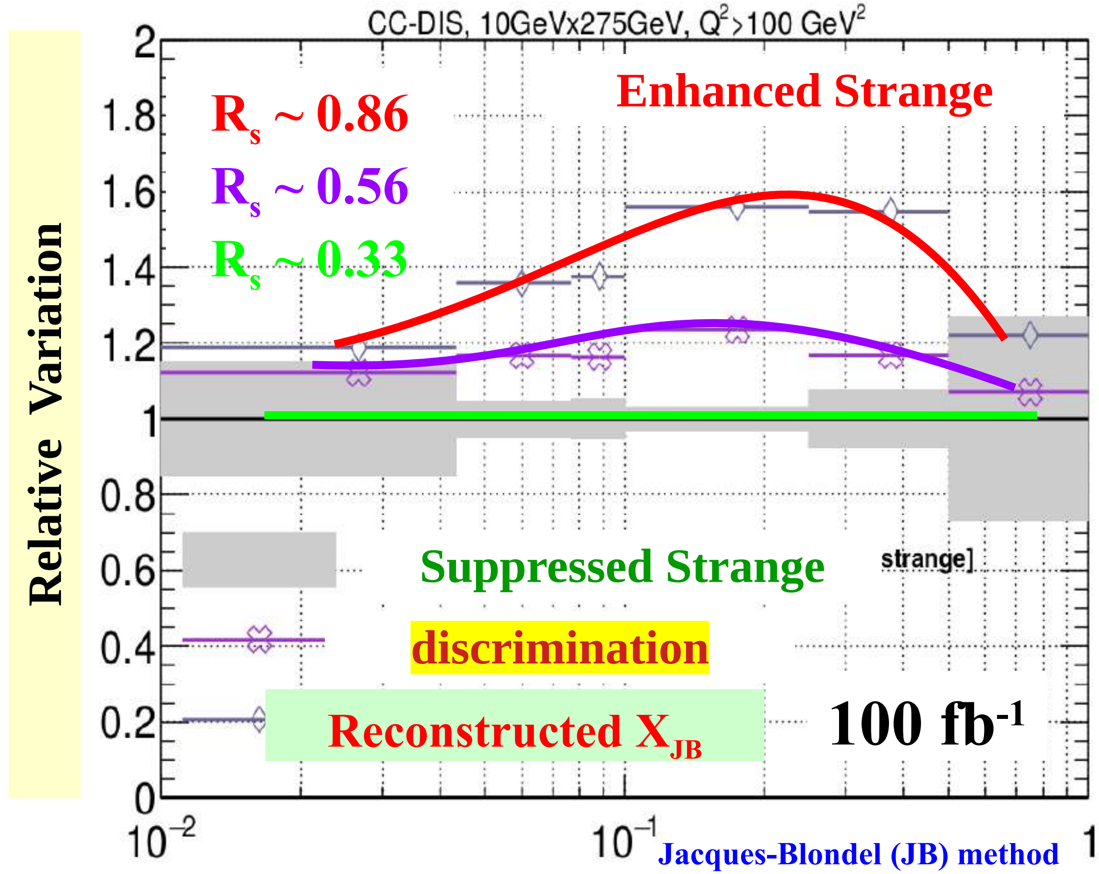
M. Arratia, Y. Furletova, T.J. Hobbs, F. Olness, S.J. Sekula, Phys.Rev.D 103 (2021) 7, 074023

Charm Jets at the EIC ⇒ The Strange PDF





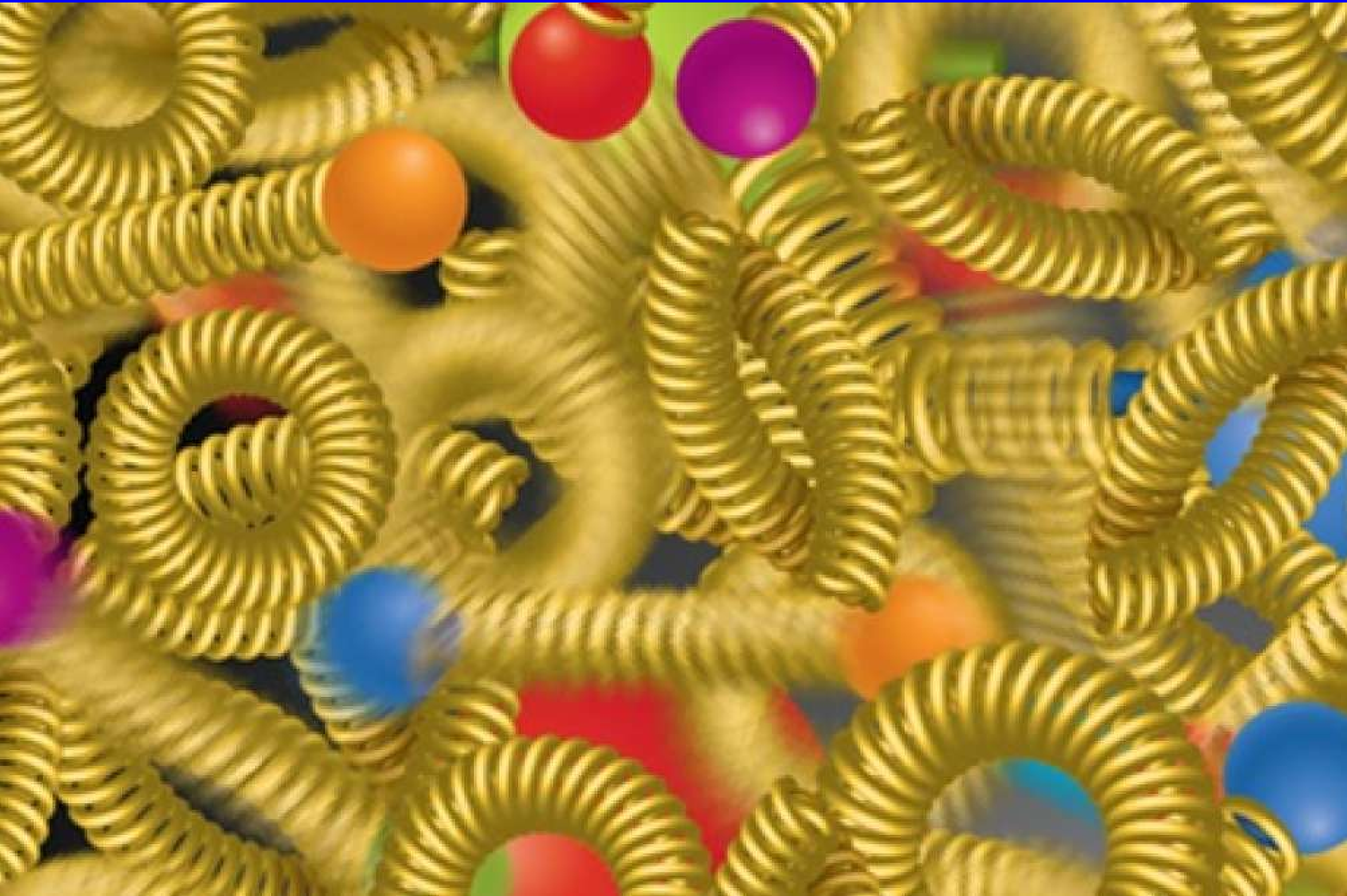
W+s → c_{jet}



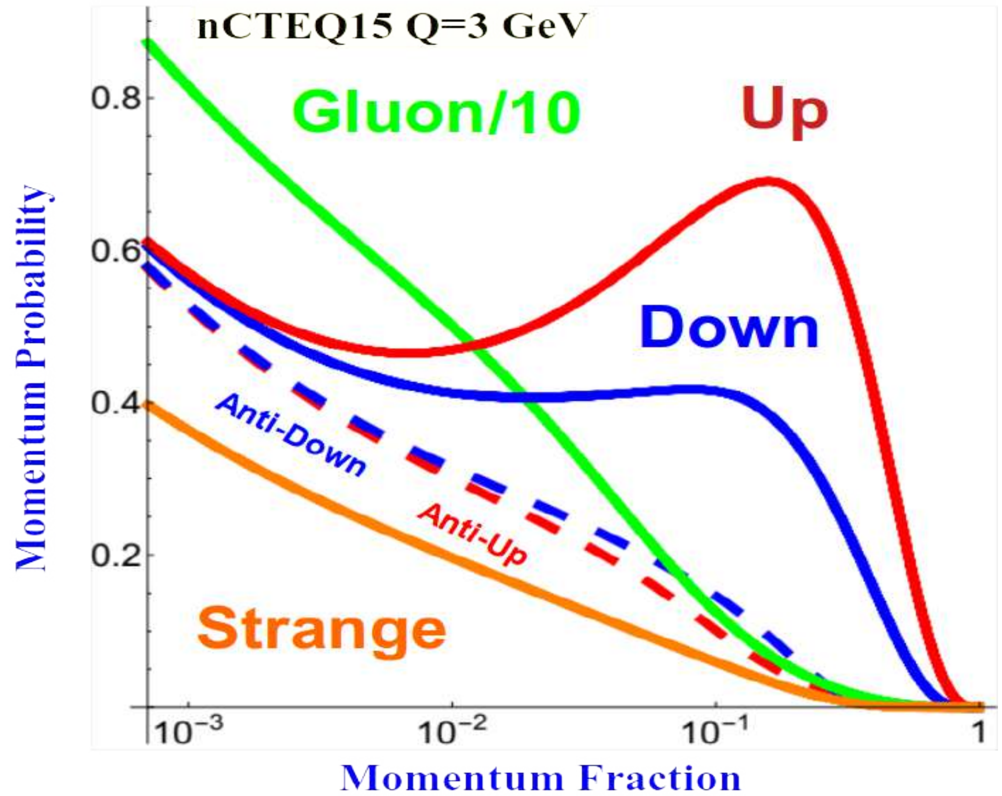
Clear measure of Strange PDF beyond uncertainties

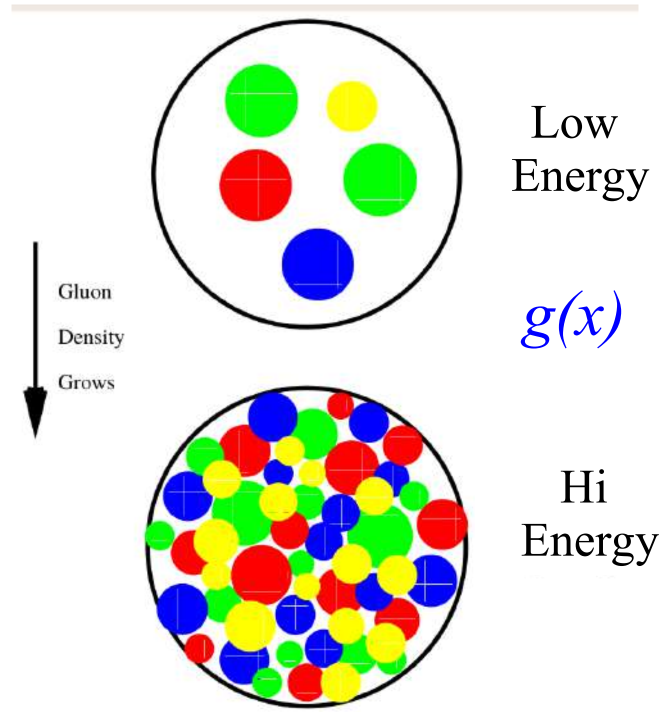
M. Arratia, Y. Furletova, T.J. Hobbs, F. Olness, S.J. Sekula, Phys.Rev.D 103 (2021) 7, 074023

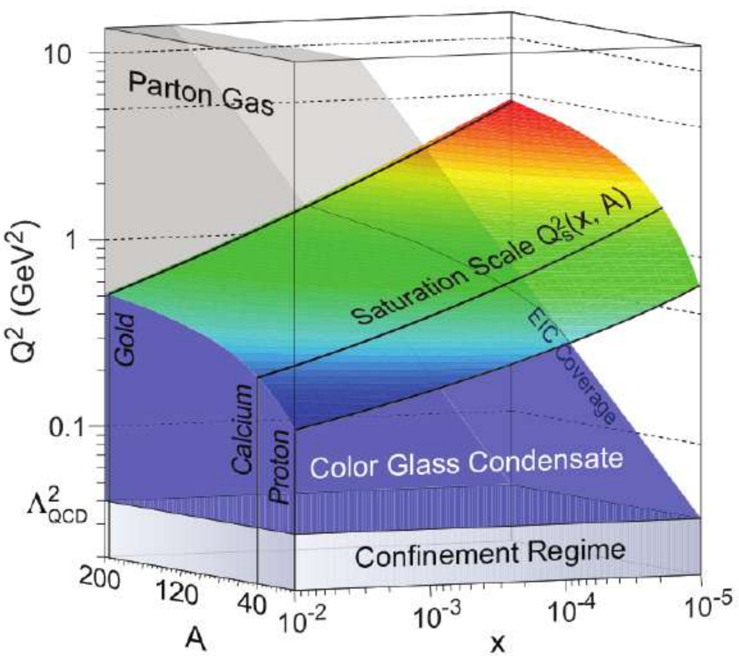
The Gluon



Nuclear Medium Effects at small momentum fraction (x)



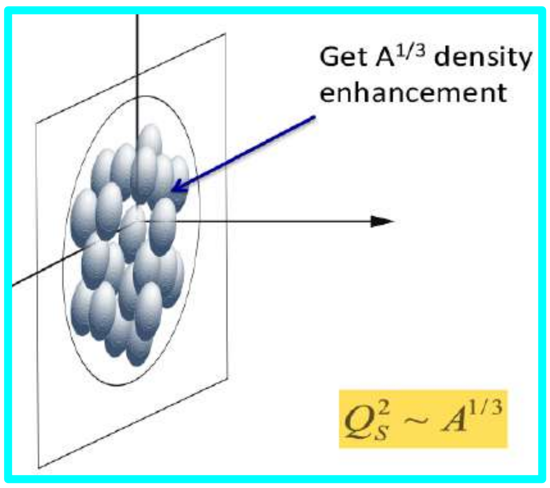




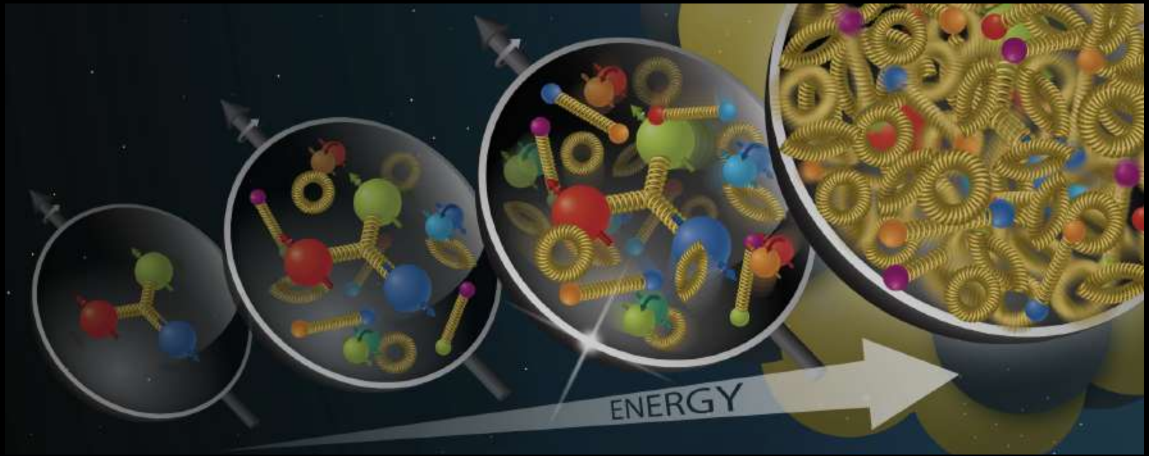
Nuclear medium effects:

- Quark Gluon Plasma
- Color Glass Condensate
- Recombination
- Saturation
- Resummation
- … *your theory here*

We gain a geometric factor of $A^{1/3}$



SURGE COLLABORATION



Discover and explore the gluon saturation regime of quantum chromodynamics

https://www.bnl.gov/physics/surge/

Members

Brookhaven National Laboratory
Y. Hatta, D. Kharzeev, Y. Mehtar-Tani, S. Mukherjee, P. Petreczky, R. Venugopalan

Old Dominion University / Thomas Jefferson Laboratory I. Balitsky

McGill University
S. Caron-Huot

CUNY, Baruch College
A. Dumitru, J. Jalilian-Marian

University of California, Los Angeles
Z. Kang

The Ohio State University
Y. Kovchegov

University of Connecticut
A. Kovner

University of Illinois at Urbana Champaign
J. Noronha-Hostler

Southern Methodist University
F. Olness

Lebanon Valley College
D. Pitonyak

New Mexico State University
M. Sievert

North Carolina State University
V. Skokov

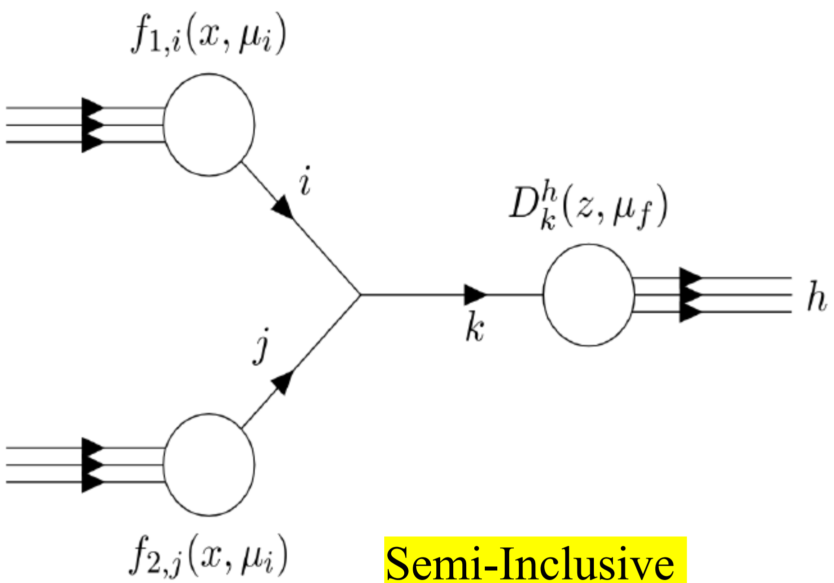
Penn State University
A. Stasto

University of California Berkeley / Lawrence Berkeley National Laboratory
X.-N. Wang

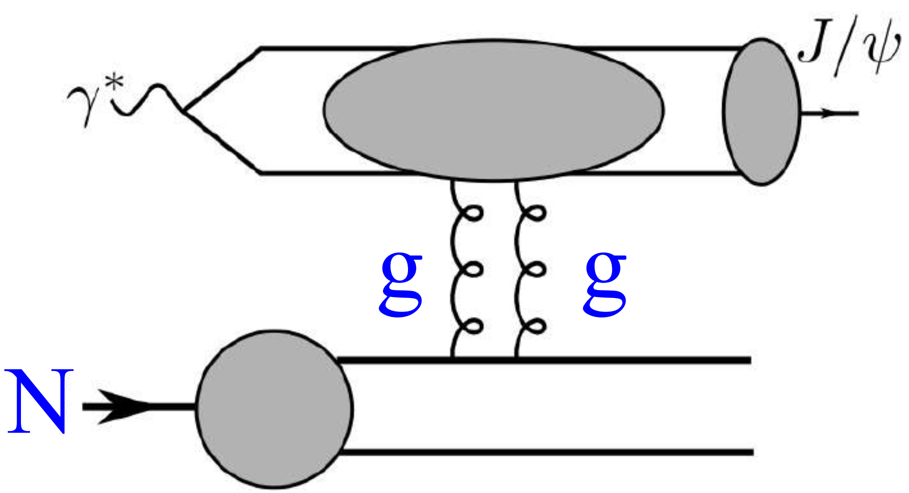
Measuring the nuclear Gluon PDF

Parton Distribution Functions

(nCTEQ) Pit Duwentaster, Michael Klasen, ...



Semi-Inclusive
Hadron Production

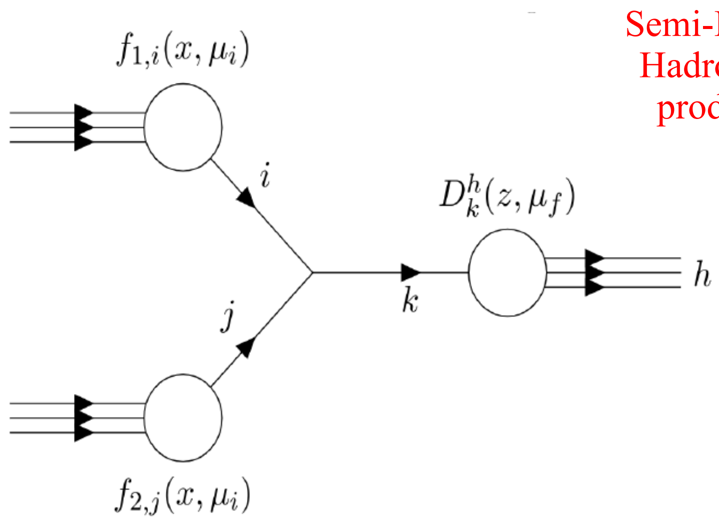


Quarkonia
Production

how can we determine
the gluon

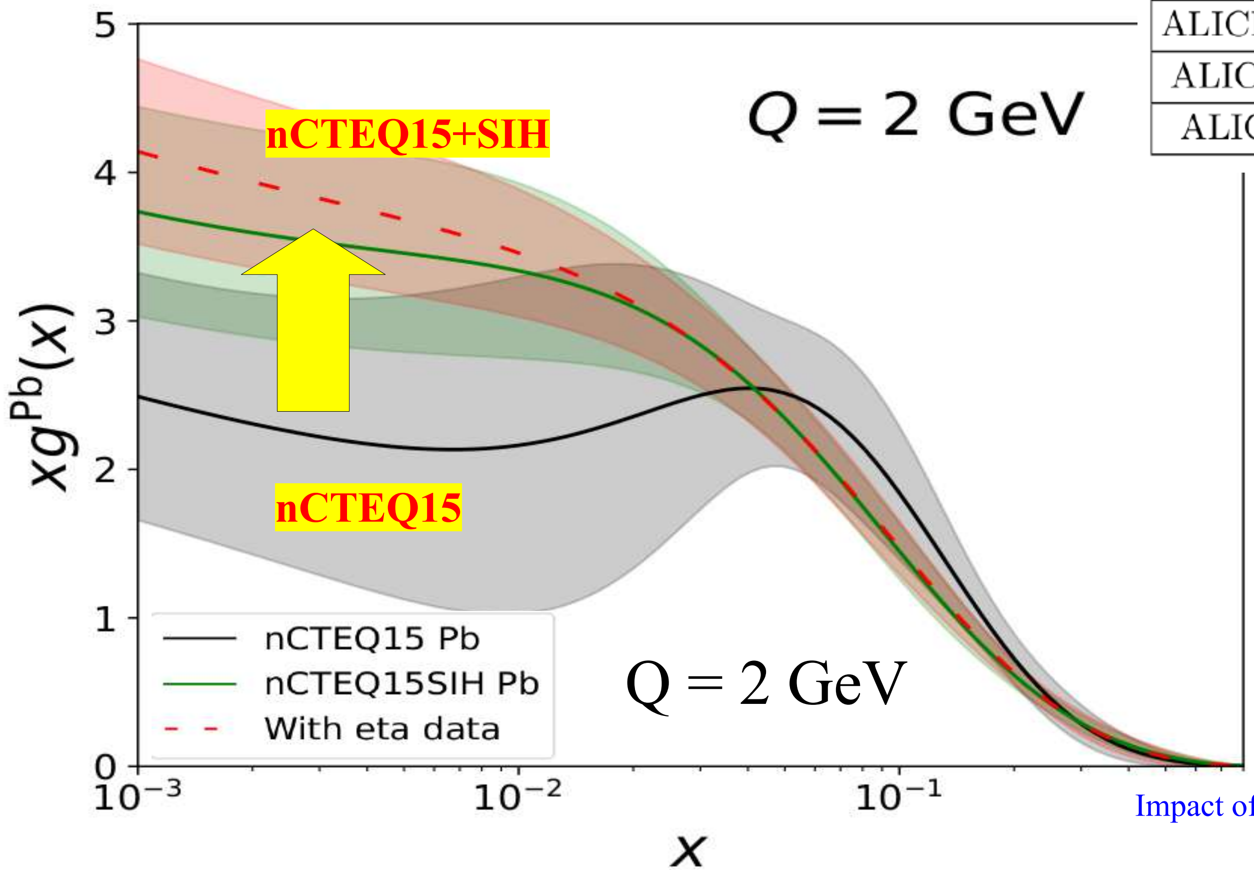
Precision Gluon can help study nuclear medium effects

Pit Duwentaster, Michael Klasen, ...



Semi-Inclusive Hadron (SIH) production

Data set	$\sqrt{s_{NN}}$ [GeV]	Observ.	No. points
PHENIX π^0	200	R_{dAu}	21
PHENIX η	200	R_{dAu}	12
PHENIX $\pi^\pm$	200	R_{dAu}	20
PHENIX $K^\pm$	200	R_{dAu}	15
STARπ^0	200	R_{dAu}	13
STAR η	200	R_{dAu}	7
STAR $\pi^\pm$	200	R_{dAu}	23
ALICE 5 TeV π^0	5020	R_{pPb}	31
ALICE 5 TeV η	5020	R_{pPb}	16
ALICE 5 TeV $\pi^\pm$	5020	R_{pPb}	58
ALICE 5 TeV $K^\pm$	5020	R_{pPb}	58
ALICE 8 TeV π^0	8160	R_{pPb}	30
ALICE 8 TeV η	8160	R_{pPb}	14

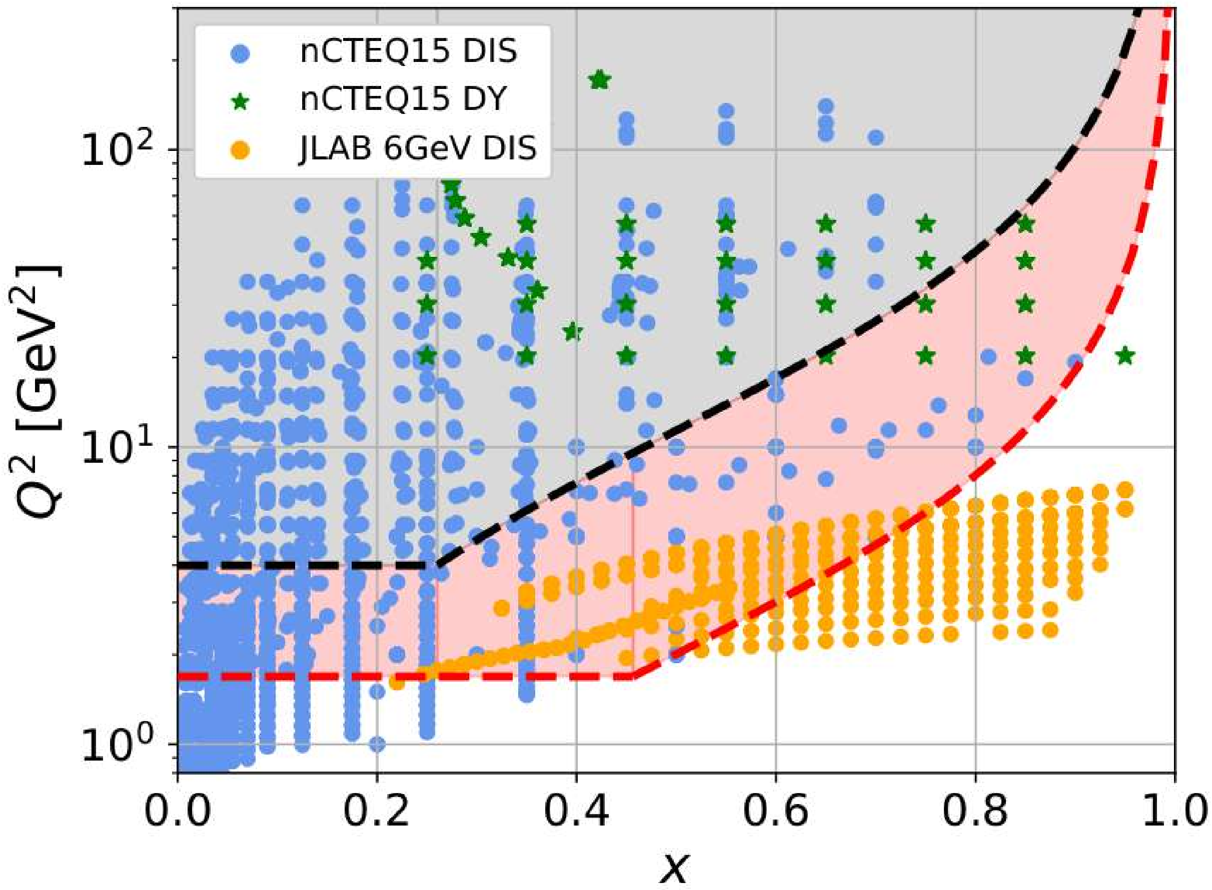


Semi-Inclusive Hadron (SIH) production

Determines gluon in small x region

Impact of inclusive hadron production data on nuclear gluon PDFs
nCTEQ: P. Duwentäster, et al., PRD104 (2021) 094005.

Extended $\{x, Q^2\}$ Kinematics



PHYSICAL REVIEW D **103,** 114015 (2021)

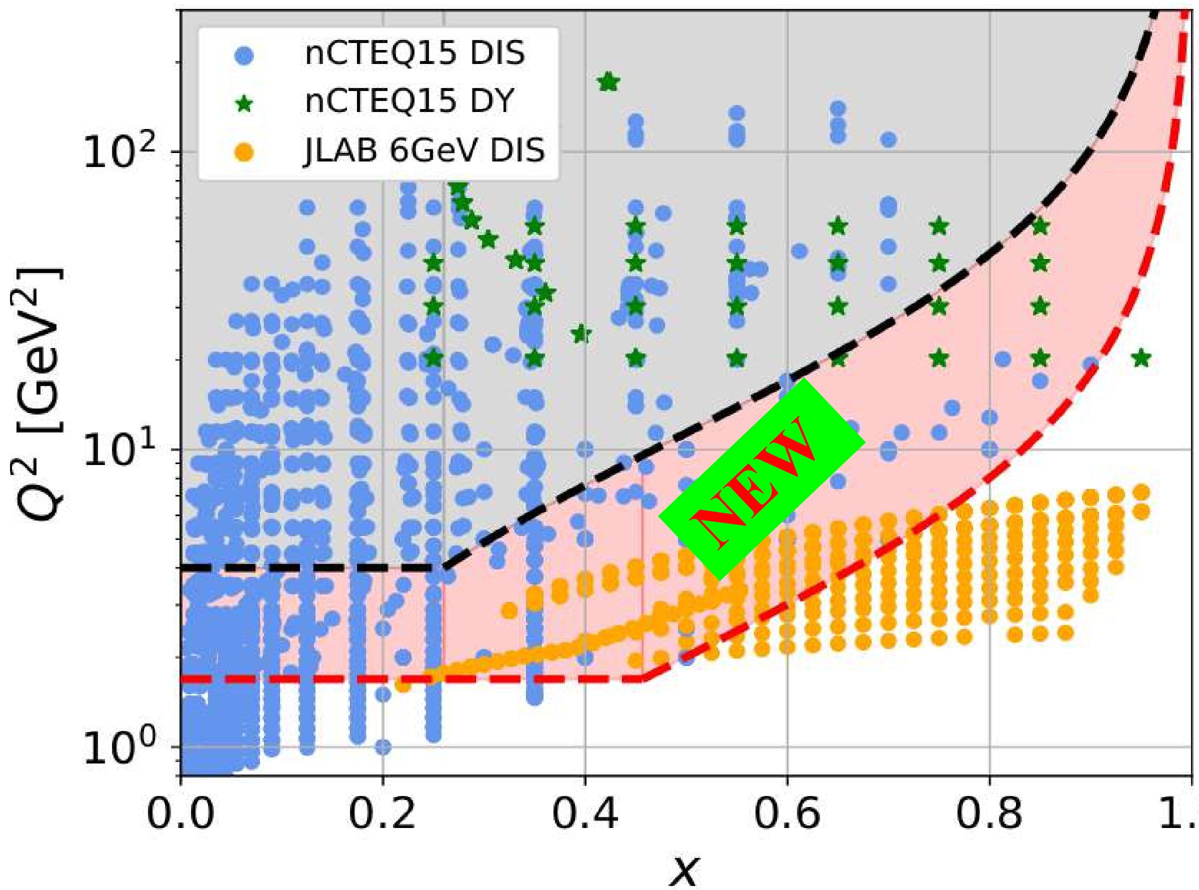
Extending nuclear PDF analyses into the high-x, low-Q^2 region

E. P. Segarra,[1,*] T. Ježo,[2,†] A. Accardi,[3,4] P. Duwentäster,[5] O. Hen,[1] T. J. Hobbs,[6,4,7] C. Keppel,[4] M. Klasen,[5] K. Kovařík,[5] A. Kusina,[8] J. G. Morfín,[9] K. F. Muzakka,[5] F. I. Olness,[6,‡] I. Schienbein,[10] and J. Y. Yu.[10]

Important effects:

- Deuteron Corrections
- Higher twist
- Target Mass Effects

Challenges at Large x & Low Q^2 & Low W^2:



Nuclear PDFs: x>1 allowed;

impacts F_2^{Nuc}/F_2^{Iso} in Fermi region

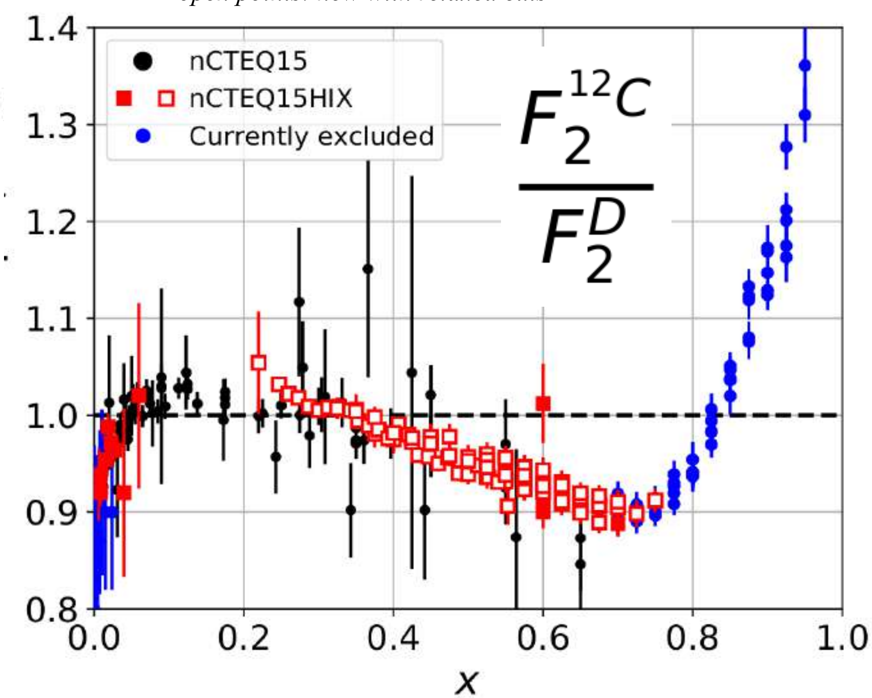
Target Mass Corrections

pick up M^2/Q^2 higher twist cont.

Deuteron Corrections

impacts $F_2^{Nuc}/F_2^{Deuteron}$ ratio

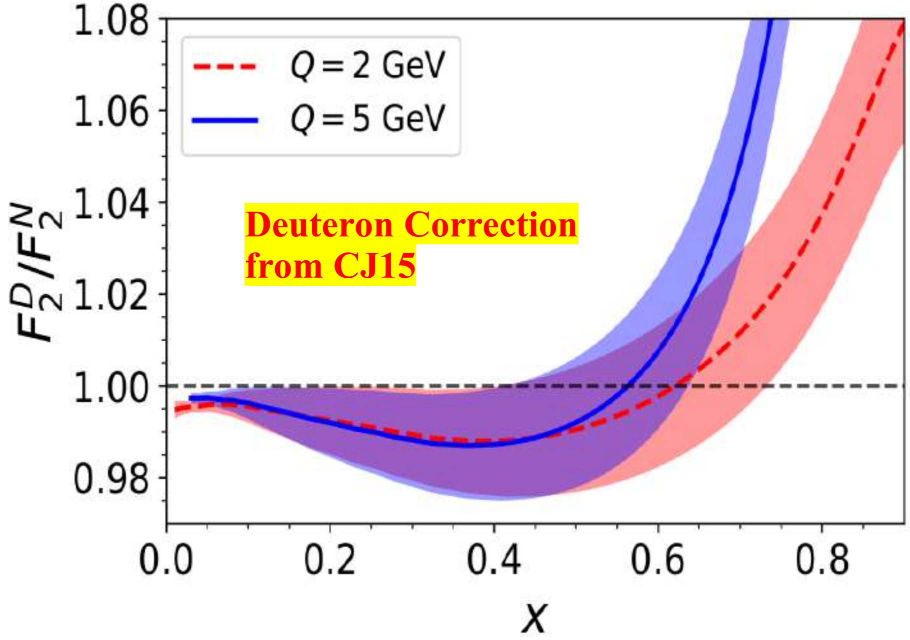
open points: new with relaxed cuts

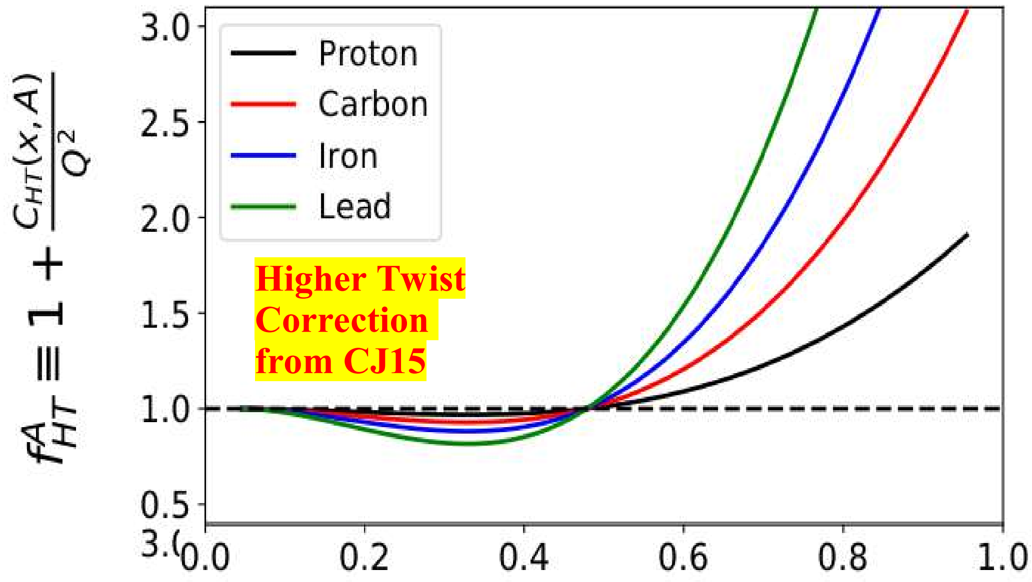


Extend nCTEQ framework
to accommodate this region
{Q,W}= {2, 3.5} ⇒ {1.3, 1.7}

nCTEQ15HIX -- Extending nPDF Analyses into the High-x, Low Q2 Region
E.P. Segarra, T. Ježo, et al., ***PRD 103, 114015 (2021)***

nCTEQ15HIX include large x JLab data





Fit	χ^2	N_{data}	χ^2/N_{dof}	Q_{cut}	W_{cut}
nCTEQ15	587	740	0.81	2.0	3.5
nCTEQ15*	2664	1564	1.70	1.3	1.7
BASE	1525	1564	0.99		
HT	1482	1564	0.96		
DEUT	1331	1564	0.85		
nCTEQ15HIX	1291	1564	0.83		

Reference

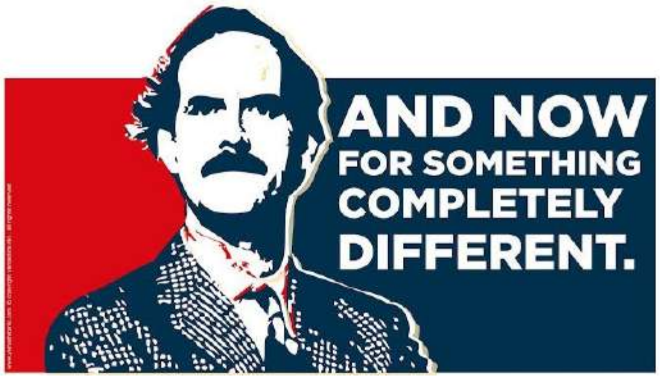
Higher Twist ~3%

Deuteron ~14%

Combined ~16%

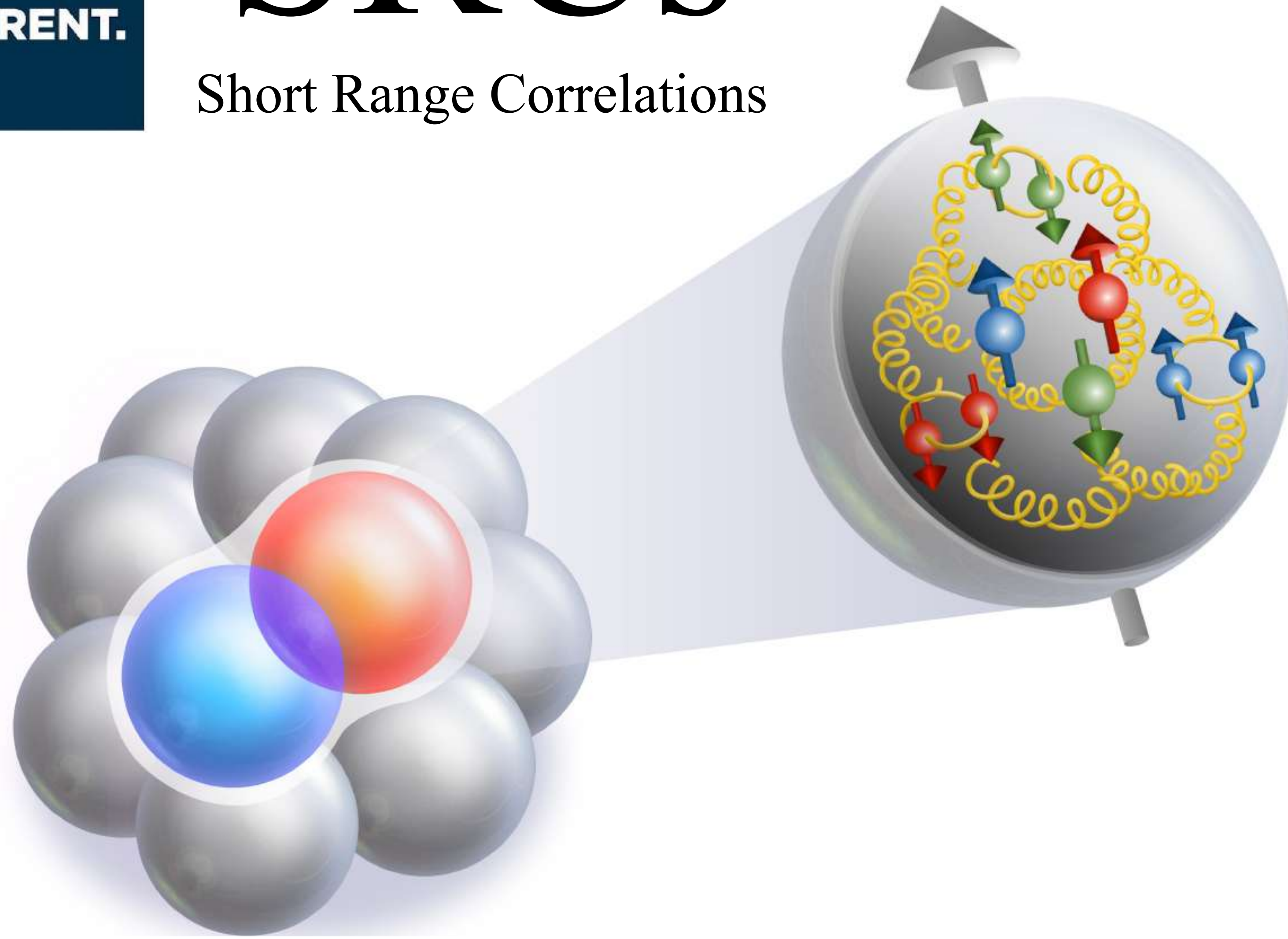
We can extend our kinematic reach in $\{x,Q^2\}$

what about mid x region



SRCs

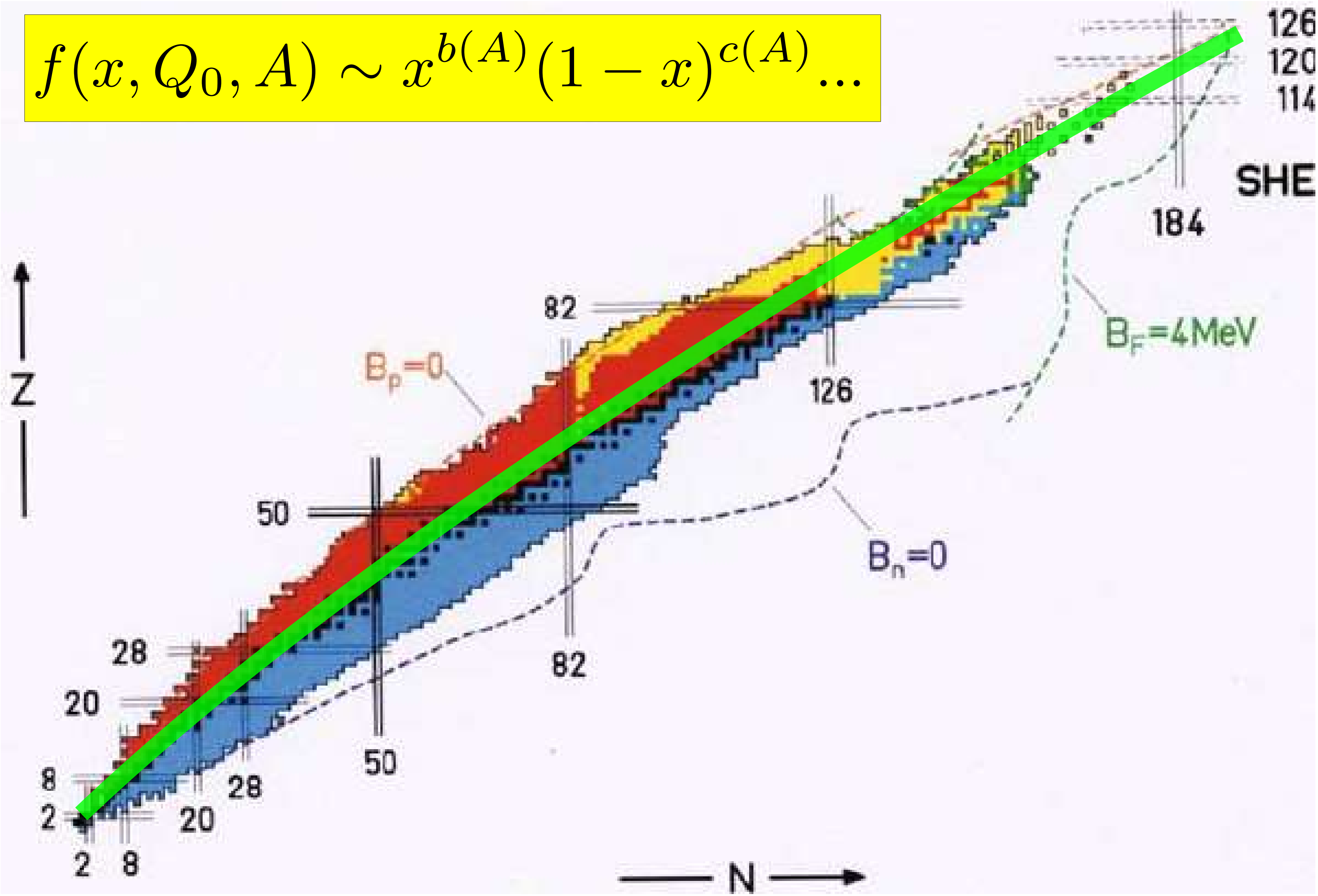
Short Range Correlations

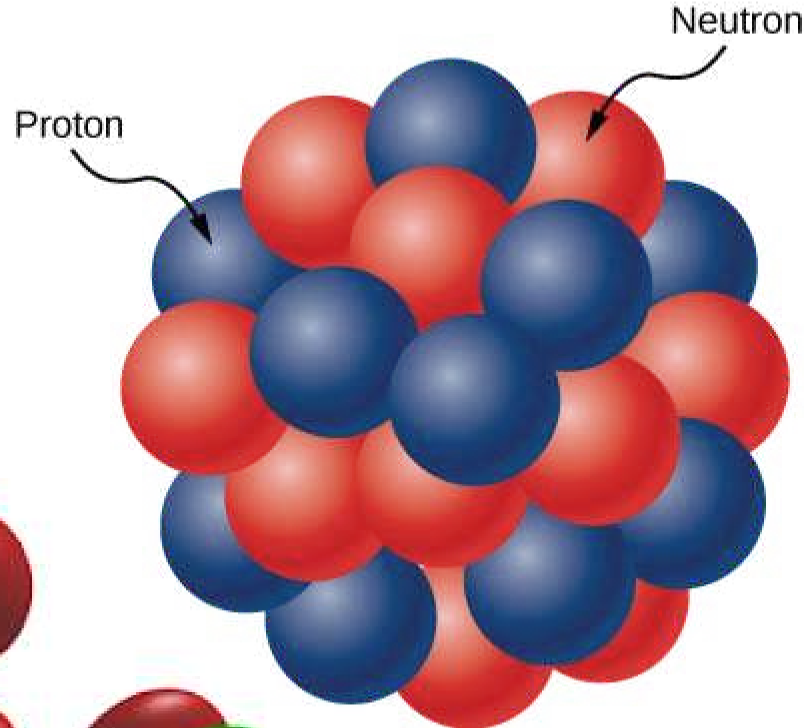


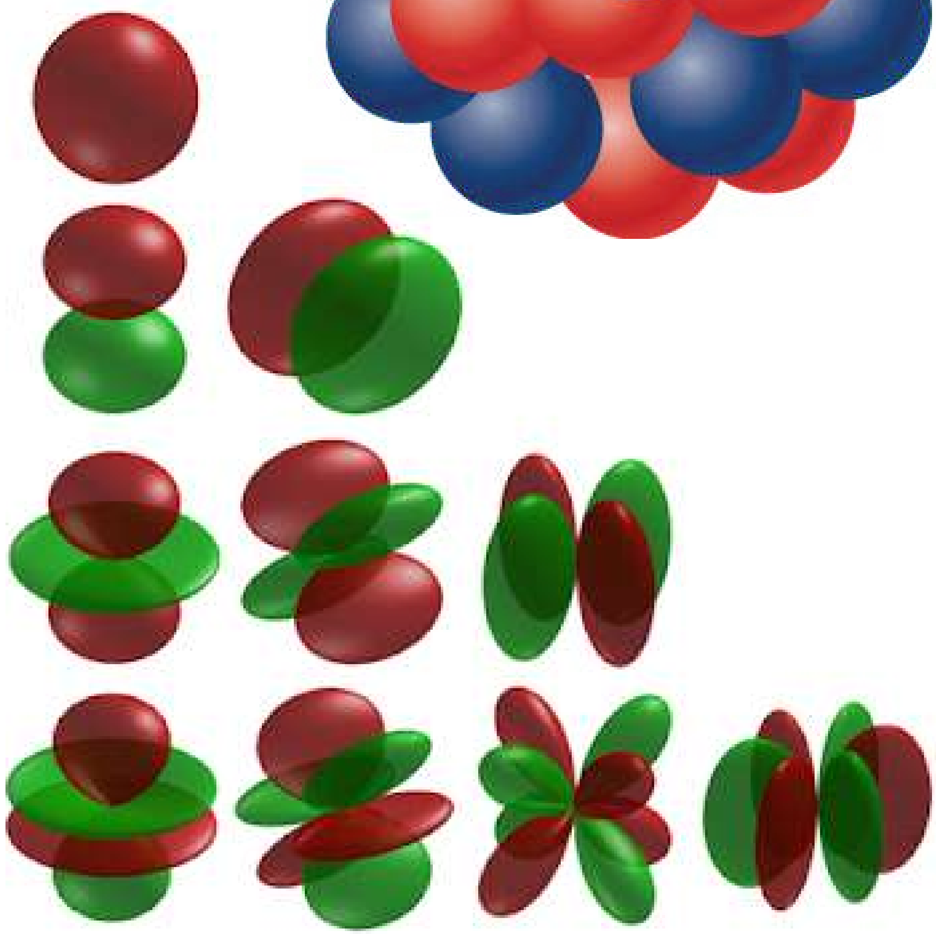
Connecting nuclear and partonic properties

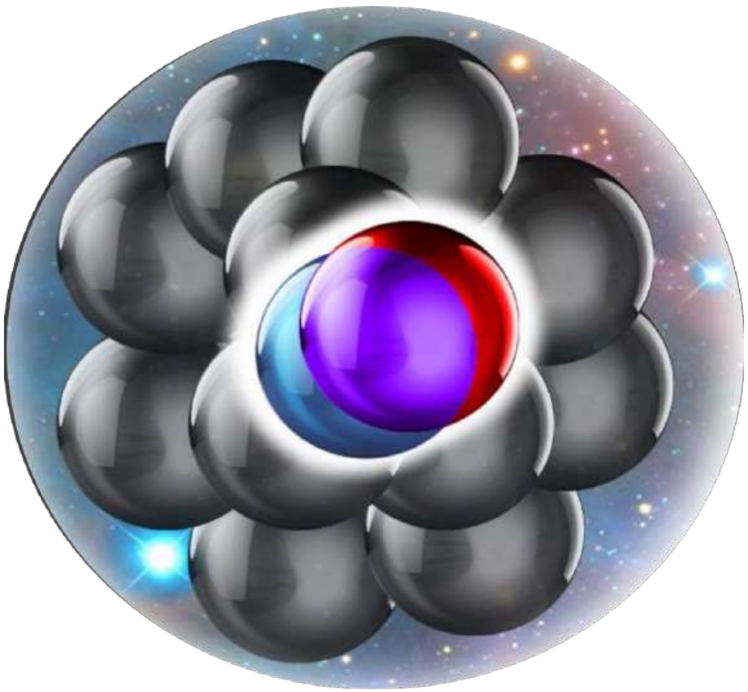
How do we characterize nuclei?

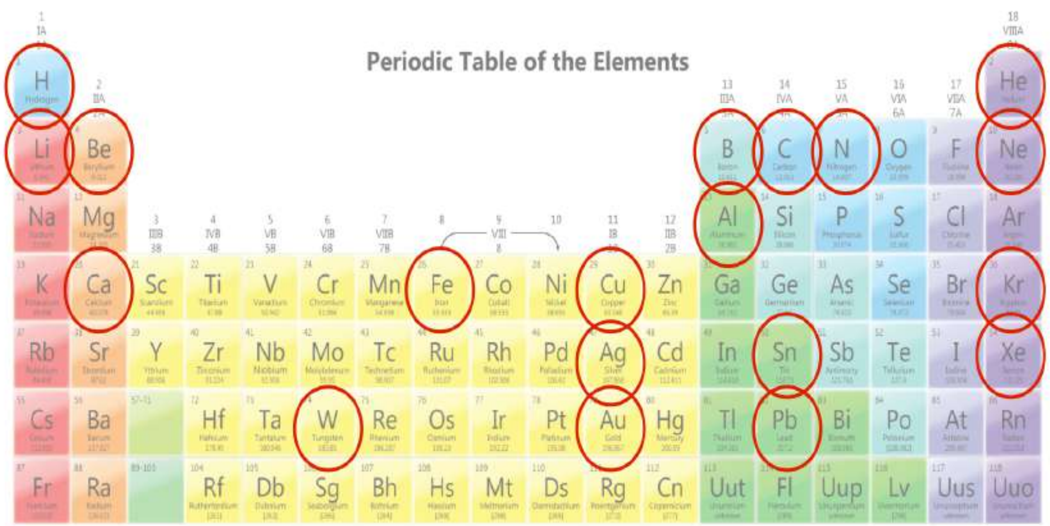
$$f(x, Q_0, A) \sim x^{b(A)}(1-x)^{c(A)}\ldots$$




Neutron
Proton

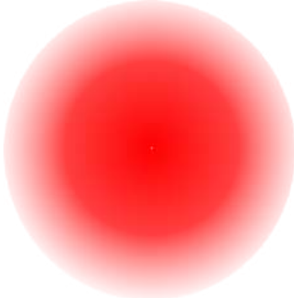




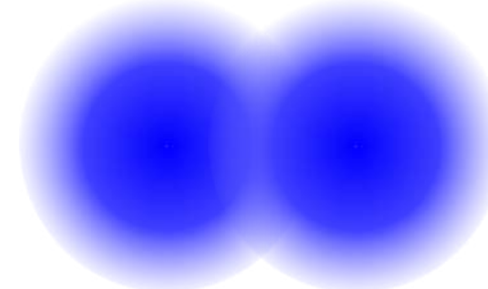

Periodic Table of the Elements
H He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra Rf Db Sg Bh Hs Mt Ds Rg Cn Uut Fl Uup Lv Uus Uuo

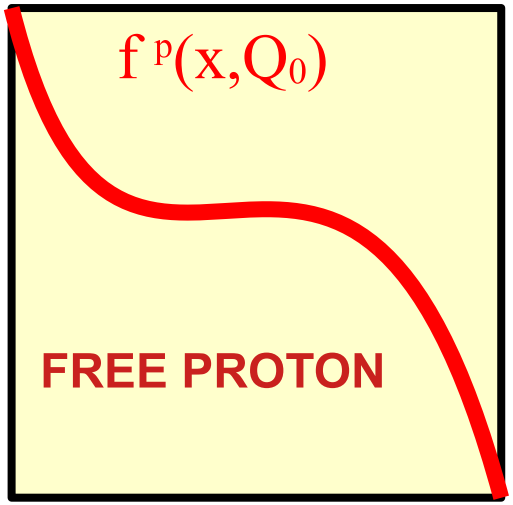
"Free nucleons" + "nucleon pairs"

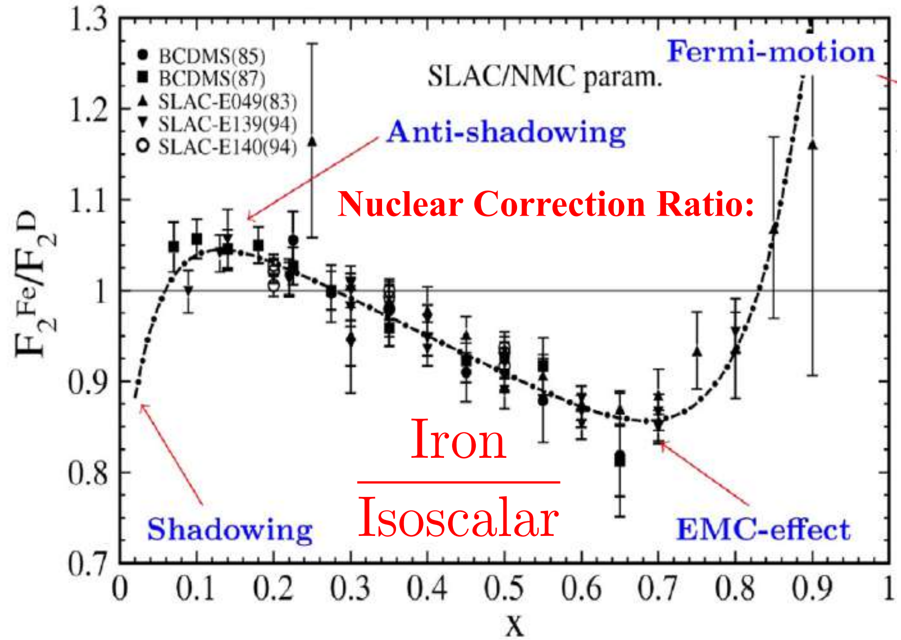
nucleon

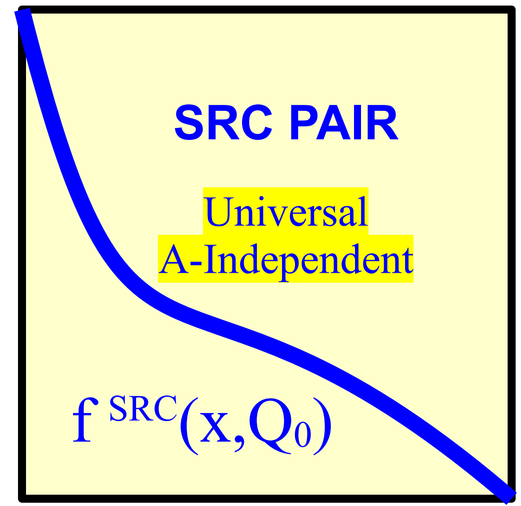


nucleon - nucleon









Linear Combination of 2 functions

$$f^{A}(x,Q_0) = (1-c_A)\, f^{p}(x,Q_0) + (c_A)\, f^{SRC}(x,Q_0)$$

Universal
A-Independent

Very different from standard parm. (e.g., nCTEQ)

Question: do C_A coefficients display any patterns???

Is the fit reasonable???

Improved fit compared to traditional approach

χ^2/N_{data}	DIS	DY	W/Z	JLab	χ^2_{tot}	$\frac{\chi^2_{\text{tot}}}{N_{\text{DOF}}}$
traditional	0.85	0.97	0.88	0.72	1408	0.85
baseSRC	0.84	0.75	1.11	0.41	1300	0.80
pnSRC	0.85	0.84	1.14	0.49	1350	0.82
N_{data}	1136	92	120	336	1684	

Standard

Free p & n

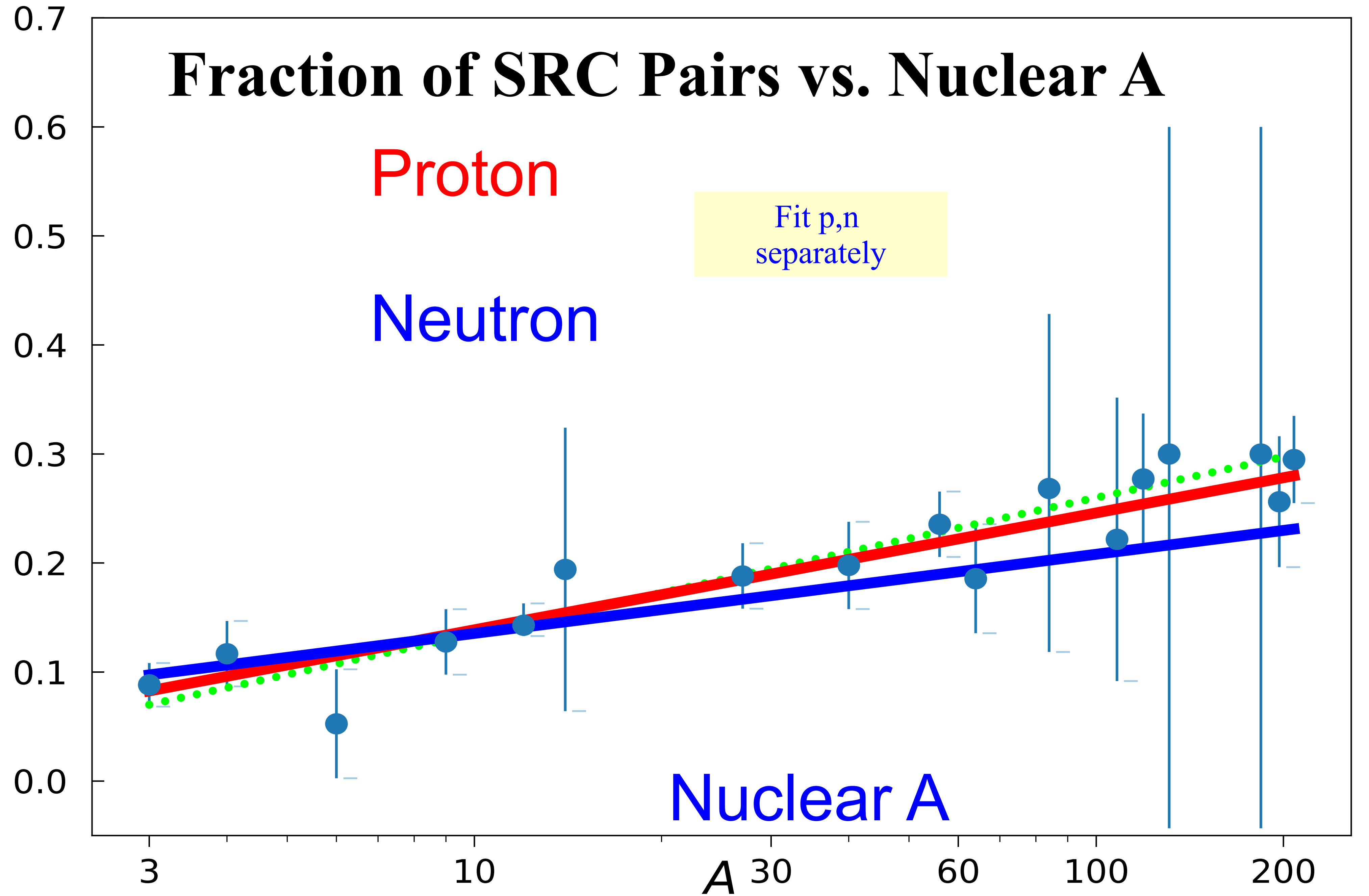
Link p & n

Fully accounts for all DOF

Evidence for Modified Quark-Gluon Distributions in Nuclei by Correlated Nucleon Pairs

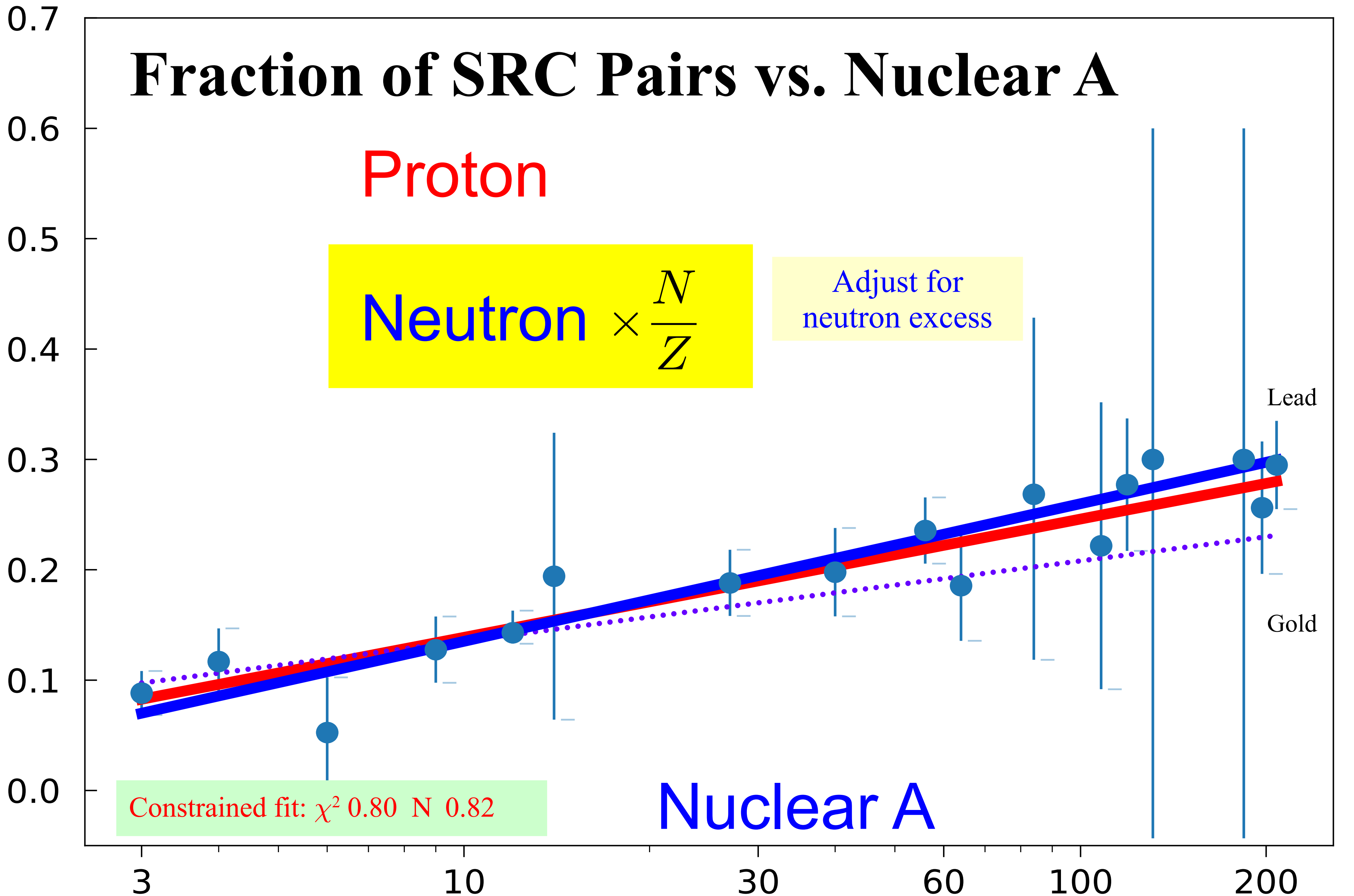
A.W. Denniston[1,*] T. Ježo[2,†] A. Kusina[3] N. Derakhshanian[3] P. Duwentäster[2,4,5] O. Hen[1] C. Keppel[6] M. Klasen[2,7] K. Kovařík[2] J.G. Morfín[8] K.F. Muzakka[2,9] F.I. Olness[10] E. Piasetzky[11] P. Risse[2] R. Ruiz[3] I. Schienbein[12] and J.Y. Yu.[12]

ArXiV:2312.16293



Nuclear A	2	3	4	6	9	12	14	27	40	56	64	84	108	119	131	184	197	208
# data	275	125	66	15	49	196	101	73	92	134	61	84	7	152	4	37	50	163

P, H2, HE3, HE4, LI6, LI7, BE9, C12, N14, AL27, CA40, FE56, CU64, KR84, AG108, SN119, XE131, W184, AU197, PB208



Nuclear A	2	3	4	6	9	12	14	27	40	56	64	84	108	119	131	184	197	208
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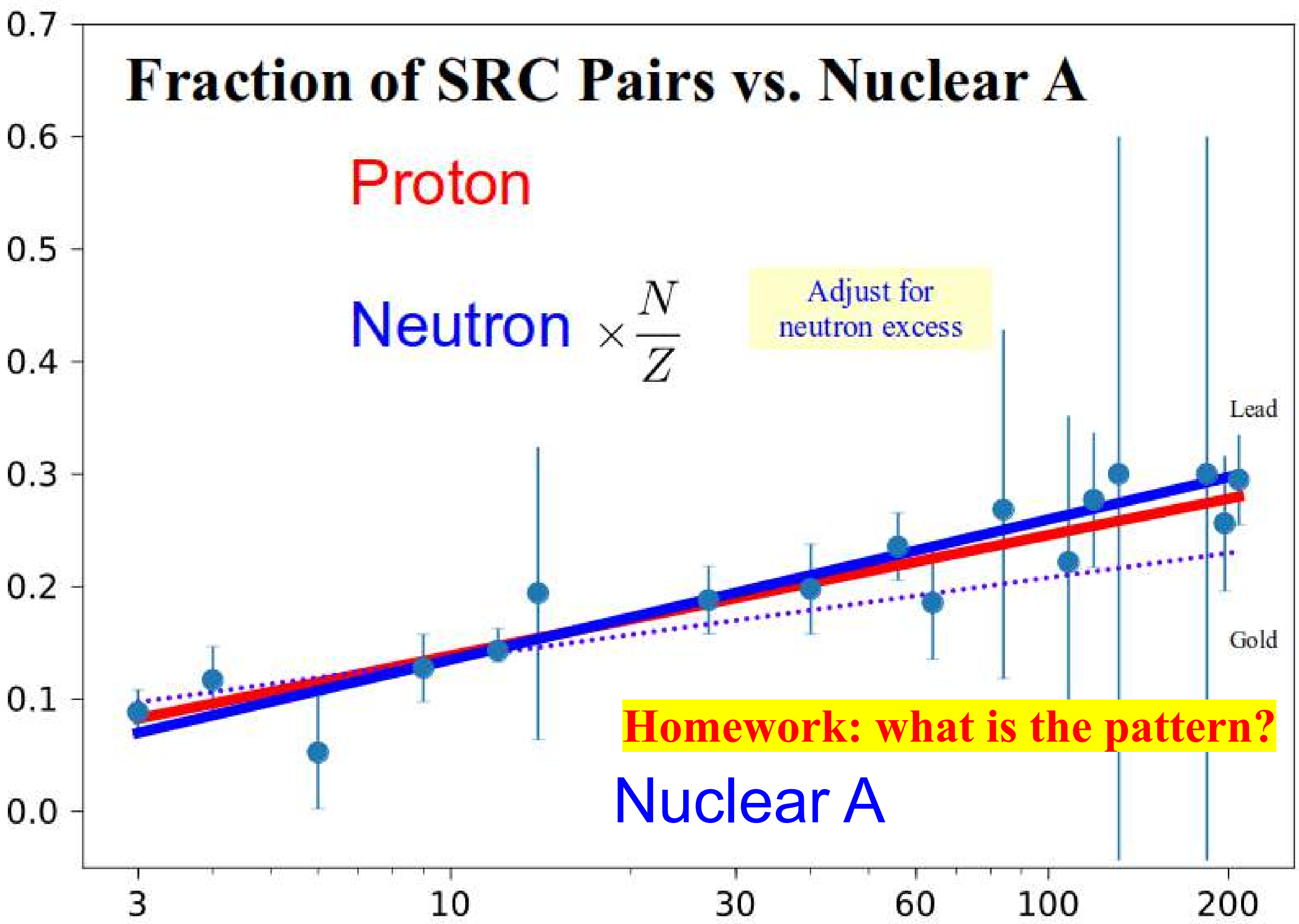
P, H2, HE3, HE4, LI6, LI7, BE9, C12, N14, AL27, CA40, FE56, CU64, KR84, AG108, SN119, XE131, W184, AU197, PB208

Fit Proton & Neutron Separately … a curious observation ..



Gold $^{197}_{79}\mathrm{Au}$

Cp = 0.256
Cn = 0.177

A = 197
Z = 79
N = 118

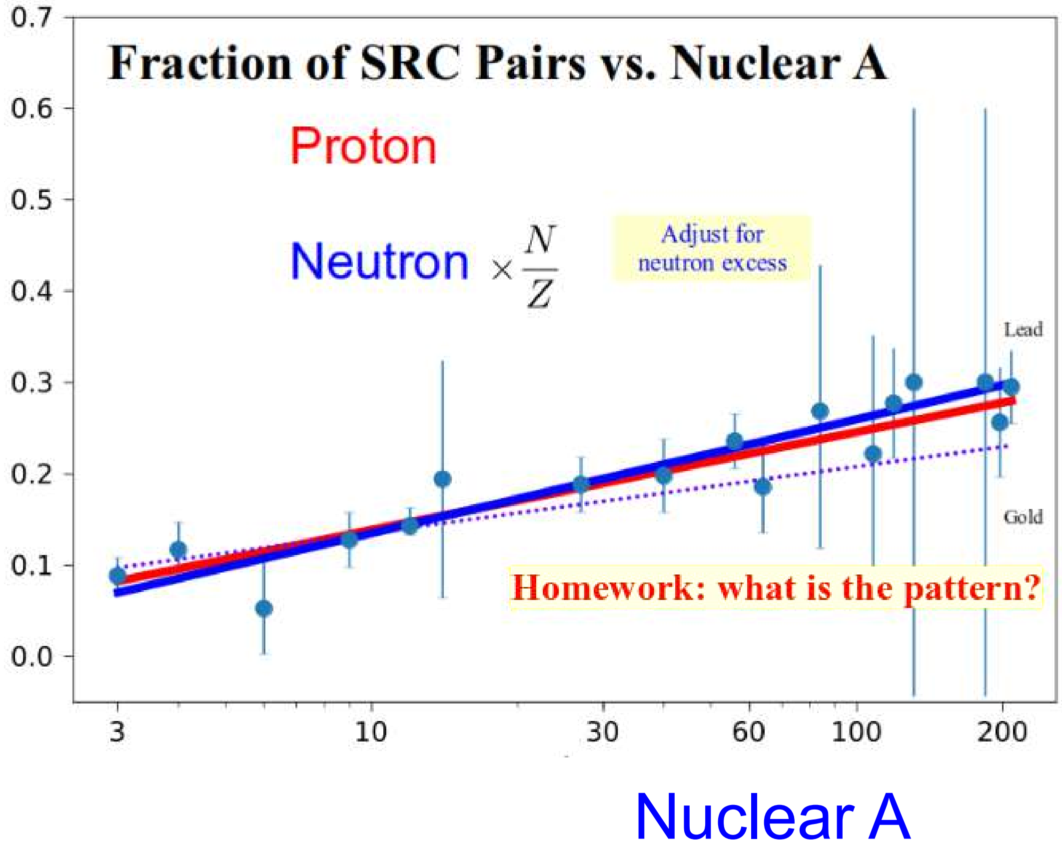
Cp × Z = **20.2**
Cn × N = **20.9**

The fit suggests equal # of protons & neutrons participate

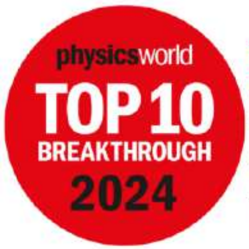
Consistent with hypothesis that SRCs are (pn) pairs

Nuclear A	2	3	4	6	9	12	14	27	40	56	64	84	108	119	131	184	197	208
# data	275	125	66	15	49	196	101	73	92	134	61	84	7	152	4	37	50	163

Nature is trying to tell us something



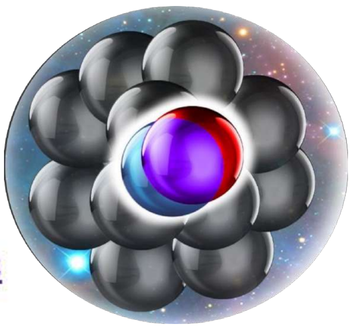
- ➔ Simple Nearest-Neighbor (SRC) inspired form yields remarkably good fit
- ➔ Comparable/better than traditional approach
- ➔ Coefficients scale with **ln(A)**
- ➔ Separate p,n fits are consistent with (pn) SRC pairs



Physics World 2024:
Top 10 Breakthroughs of the Year in Physics

Press Release: "Two distinct descriptions of nuclei unified for the first time"

This nCTEQ project partnered SMU with JLab, MIT, and Muenster, to produce the new analysis published in Physical Review Letters.



Relate nuclear to particle properties

This parameter form connects to new concepts

Current Tools

xFitter

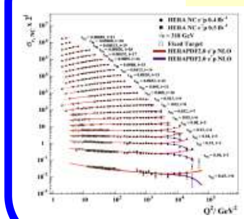
xFitter

PROTON NUCLEON MESON

www.xFitter.org

Sample data files:
- **LHC:** ATLAS, CMS, LHCb
- **Tevatron:** CDF, D0
- **HERA:** H1, ZEUS, Combined
- **Fixed Target:** …
- **User Supplied:** ...

Experimental Data



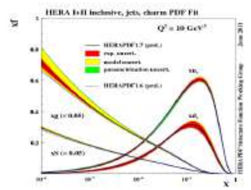
Data: HERA, Tevatron, LHC, fixed target experiments

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)

extensions include nuclear PDFs

Features & Recent Updates:
- **NNLO DGLAP**
- Photon PDF & **QED**
- Pole & MS-bar masses
- Profiling and Re-Weighting
- **BFKL interface**
- Heavy Quark Variable Treshold
- Improvements in χ^2 and correlations
- **TMD** PDFs (uPDFs)
- *... and many other*

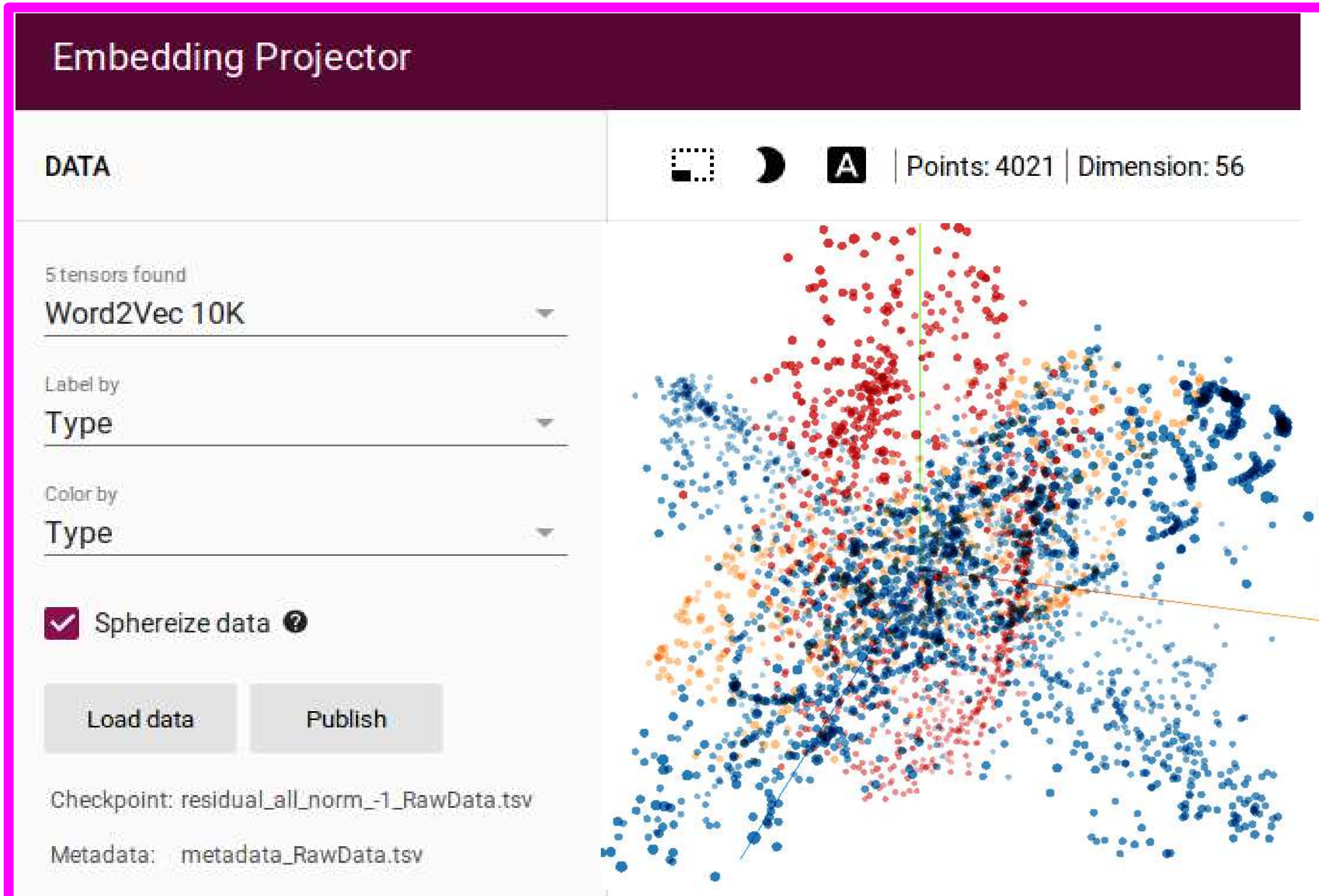
xFitter 2.2.0 Future Freeze

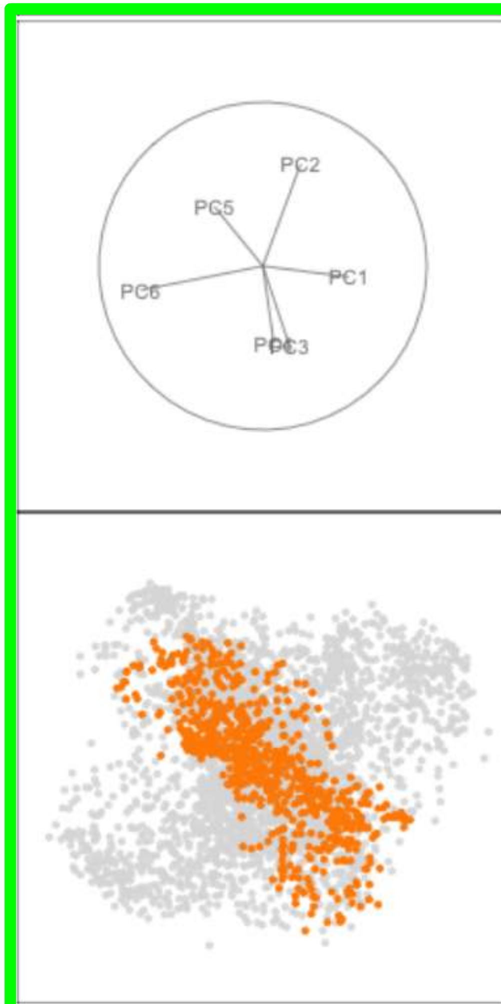
New Tools

PDFSense
&
… borrowing from AI

Applications of PDFSense:

Artificial Intelligence Tools: **Projector Tool** of Google TensorFlow





https://metapdf.hepforge.org/PDFSense/

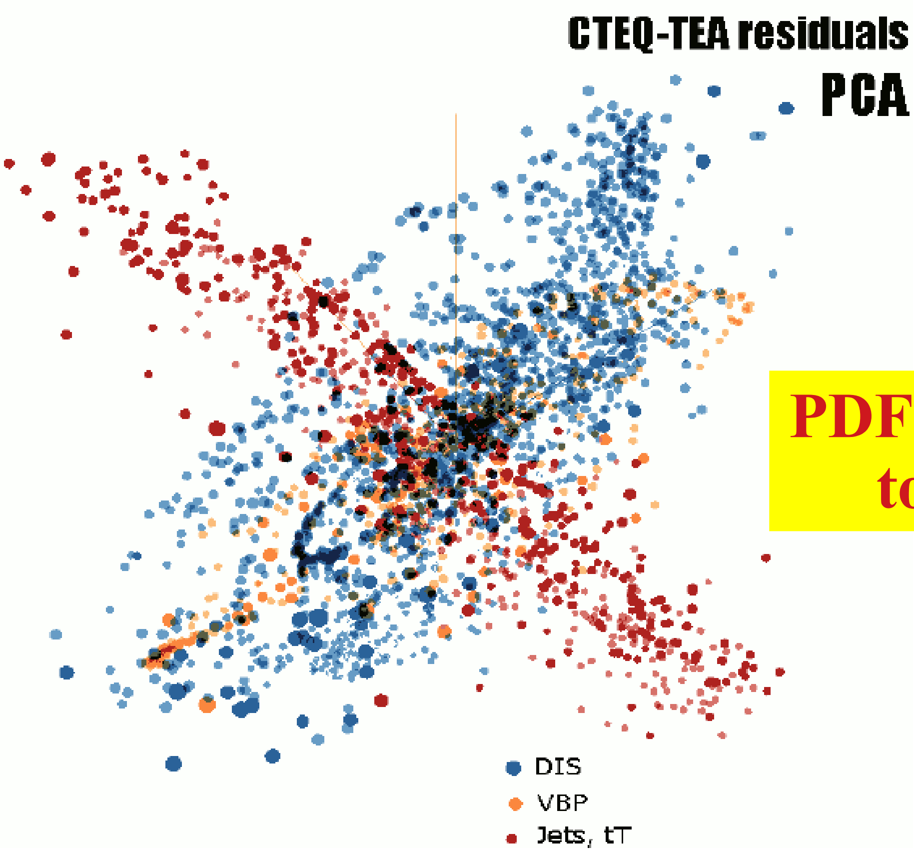
$$r_i(\vec{a}) = \frac{1}{s_i}\left(T_i(\vec{a}) - D_{i,sh}(\vec{a})\right)$$

Mapping the sensitivity of hadronic experiments to nucleon structure
B.T. Wang, T.J. Hobbs, S. Doyle, J. Gao, T.J. Hou, P. Nadolsky, F. Olness
https://arxiv.org/abs/1803.02777 Phys. Rev. D 98, 094030 (2018)

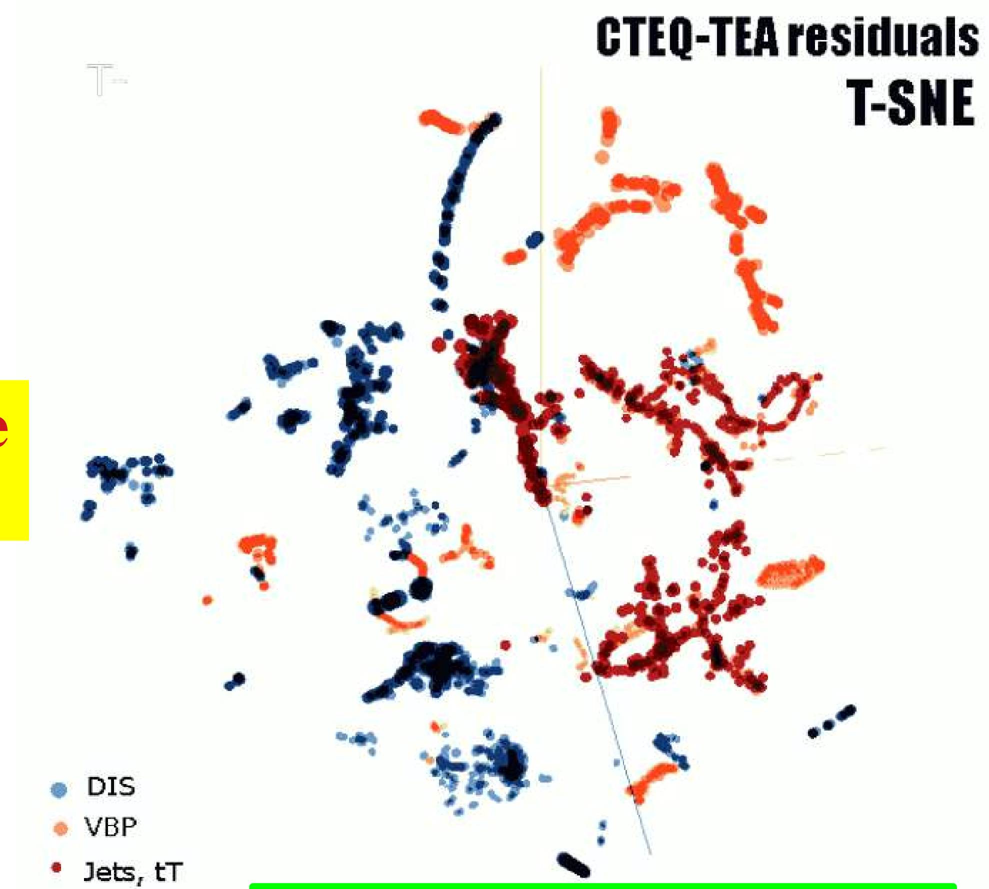
Dynamical projections for the visualization of PDFSense data
Dianne Cook, Ursula Laa, German Valencia arXiv:1806.09742

TensorFlow Embedding Projector

https://metapdf.hepforge.org/PDFSense/



PDFSense tool



Principal Component Analysis (PCA) visualizes the 56-dim. manifold by reducing it to 10 dimensions

t-distributed stochastic neighbor embedding (**t-SNE**) sorts vectors according to their similarity

$$r_i(\vec{a}) = \frac{1}{s_i}\left(T_i(\vec{a}) - D_{i,sh}(\vec{a})\right)$$

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https://arxiv.org/abs/1803.02777 Phys. Rev. D 98, 094030 (2018)

http://projector.tensorflow.org

CONCLUSIONS

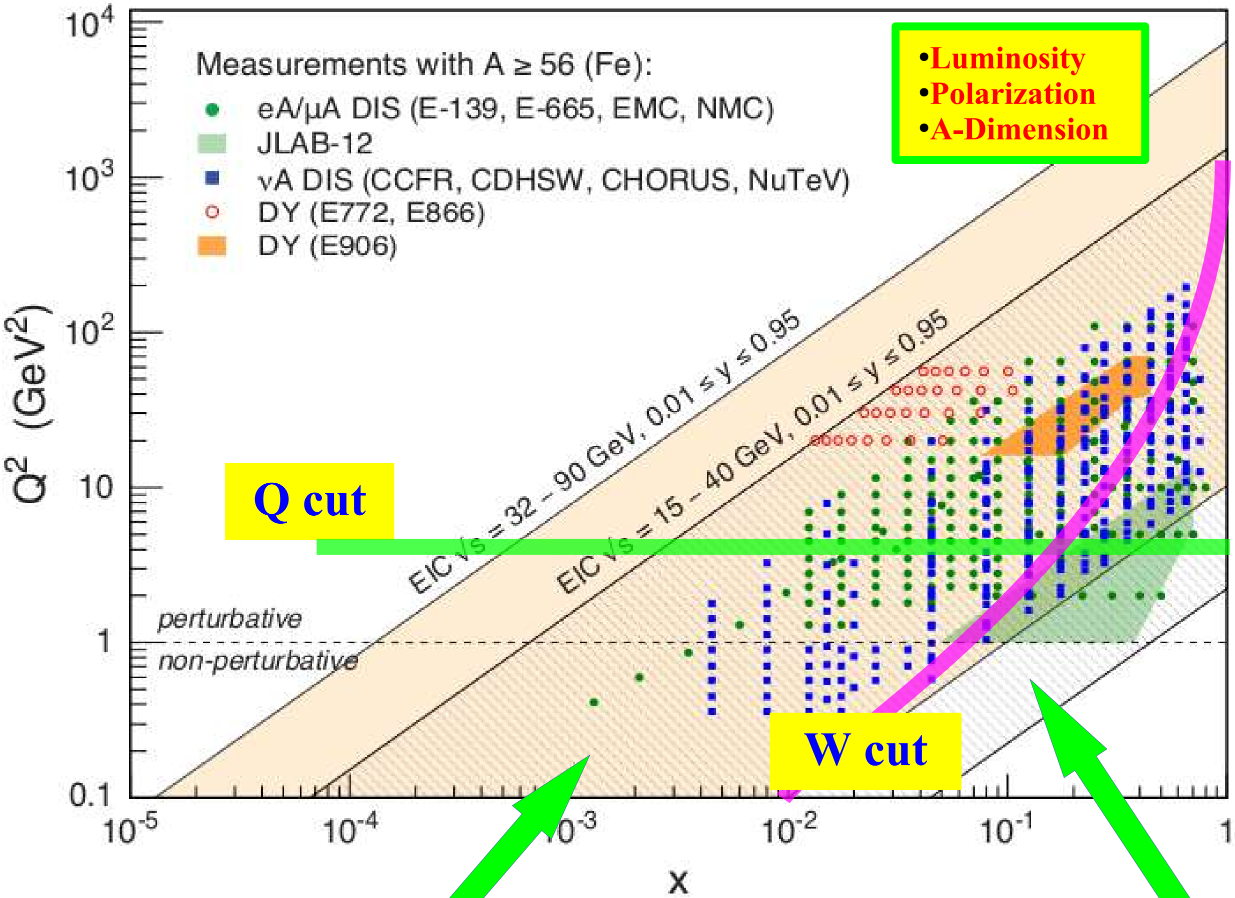
The most exciting phrase to hear in science,
the one that heralds new discoveries, is not "Eureka!" *(I found it!)*
but "That's funny …"

— Isaac Asimov

Chance favors the prepared mind

Louis Pasteur

To Boldly Go Beyond ... into the corners of the {x,Q^2} Kinematic Plane



High-x:

Nuclear PDFs: x>1 allowed;

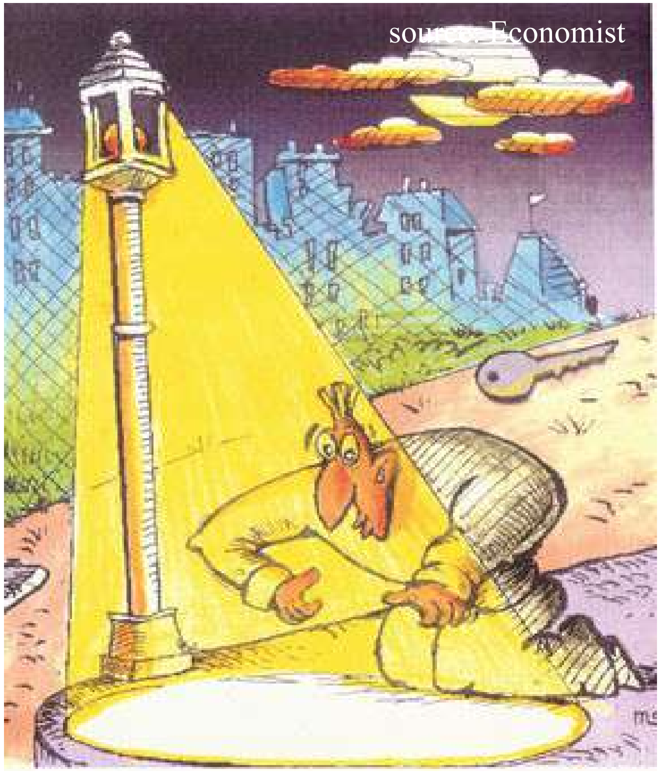
impacts F_2^{Nuc}/F_2^{Iso} in Fermi region

Target Mass Corrections

pick up M^2/Q^2 higher twist

Deuteron Corrections

impacts $F_2^{Nuc}/F_2^{Deuteron}$ ratio



Low-x:

Shadowing

Recombination

Resummation

BFKL

Saturation

Low-Q^2:

Non-Perturbative inteface

collective effects

Target Mass Corrections

pick up M^2/Q^2 higher twist

F_L at low Q^2 access to g(x)

Run at multiple energies