Revealing the fundamental character of the strong force

From PDFs to the underlying QCD

Fred Olness
SMU

Thanks for substantial input
from my friends & colleagues

nCTEQ
nuclear parton distribution functions

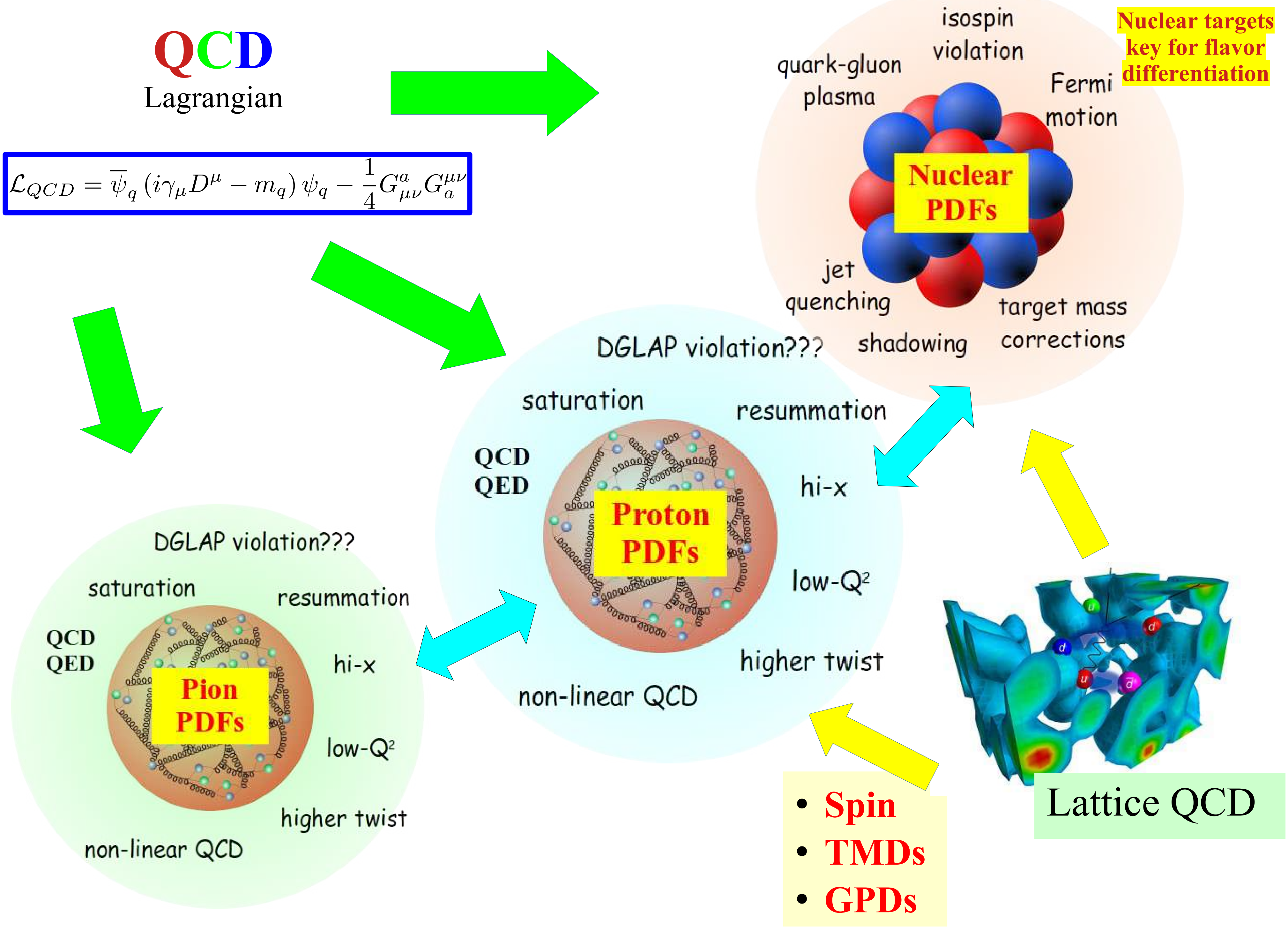
xFitter

SURGE
COLLABORATION

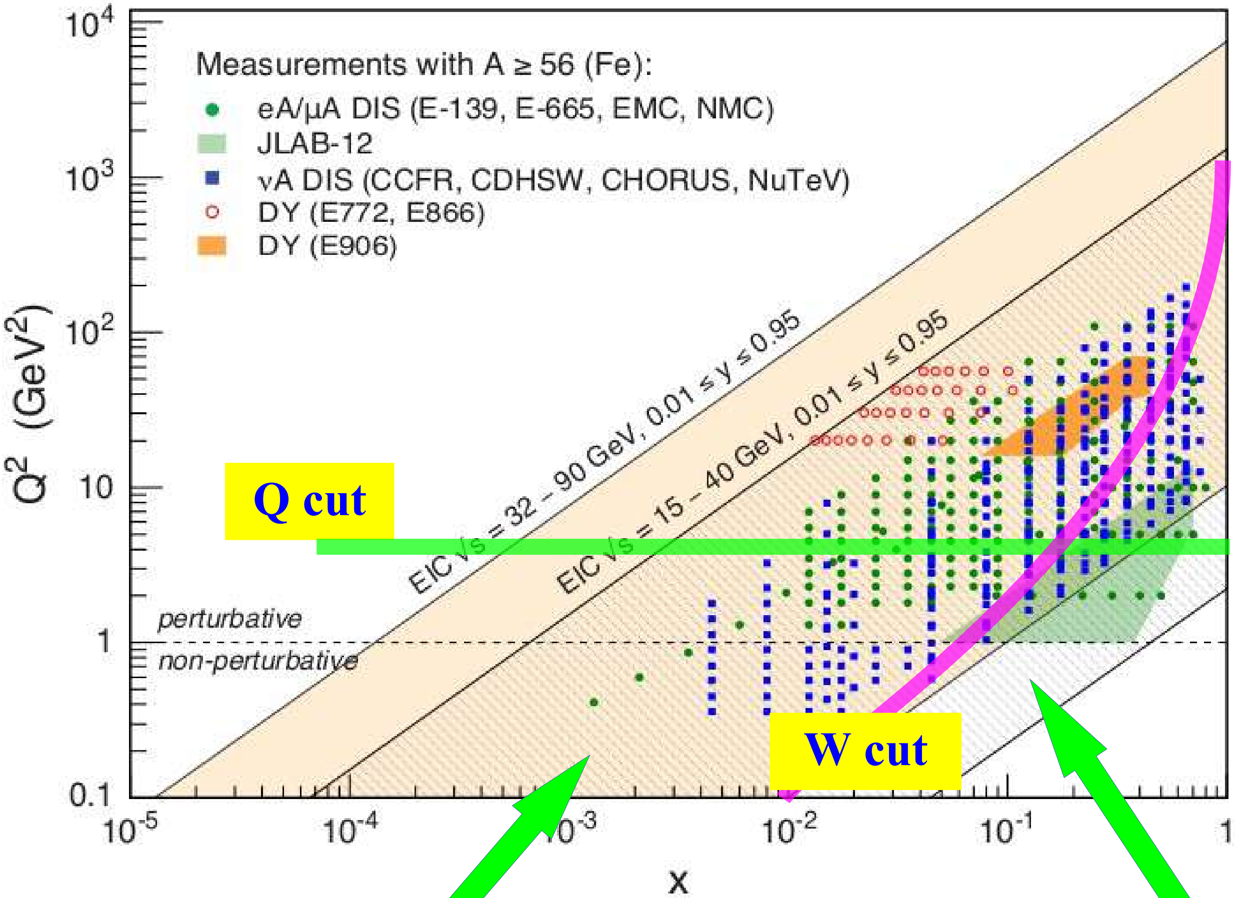
CTEQ

Pheno/DPF 2024
PITT PACC
14 May 2024

QCD: From PDFs to the underlying QCD



nPDFs: Extend Precision & Kinematic Reach in $\{x,Q^2\}$



High-x:

Nuclear PDFs: x>1 allowed;

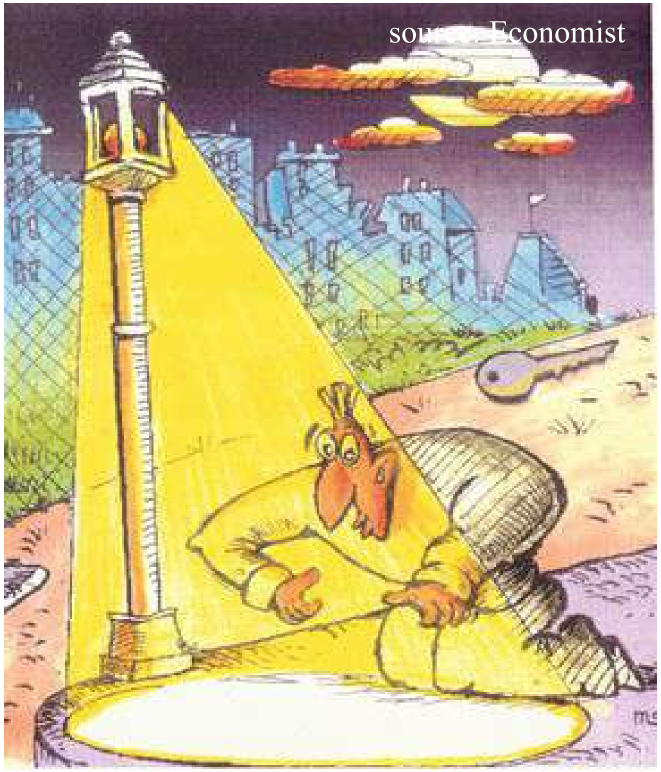
impacts F_2^{Nuc}/F_2^{Iso} in Fermi region

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

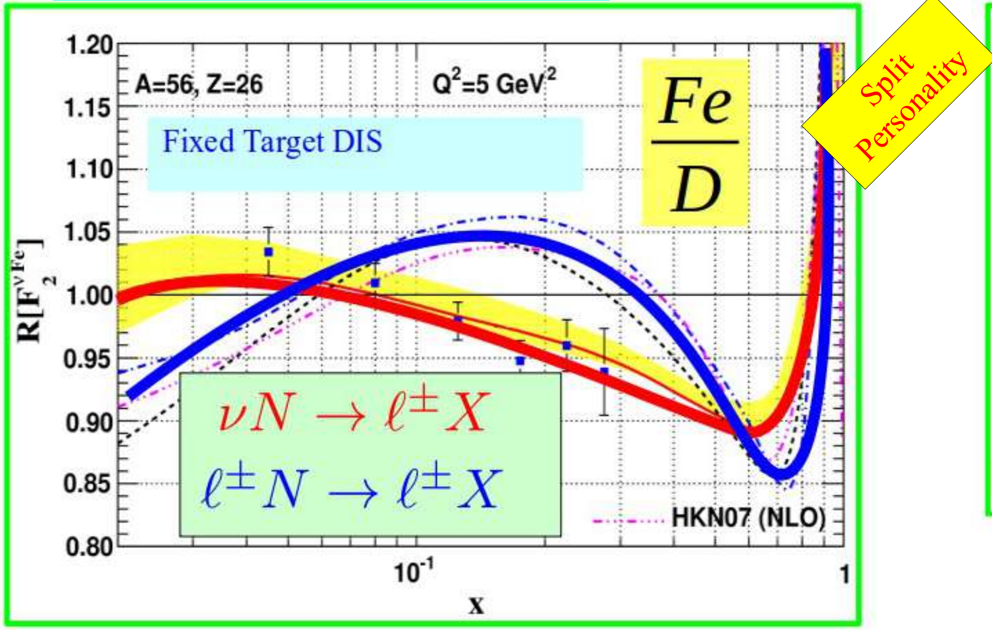
Target Mass Corrections

pick up M^2/Q^2 higher twist

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

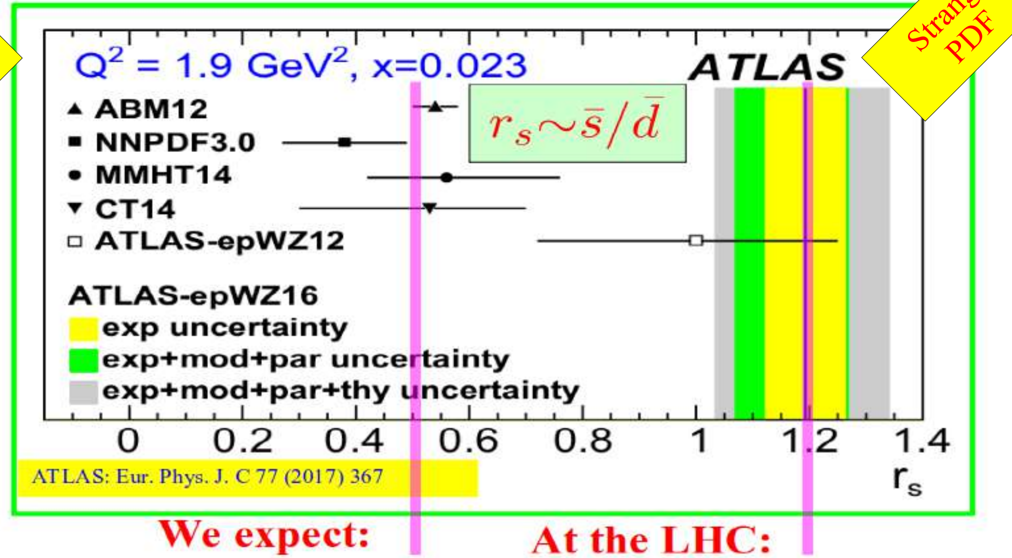
Run at multiple energies

nCTEQ15ν



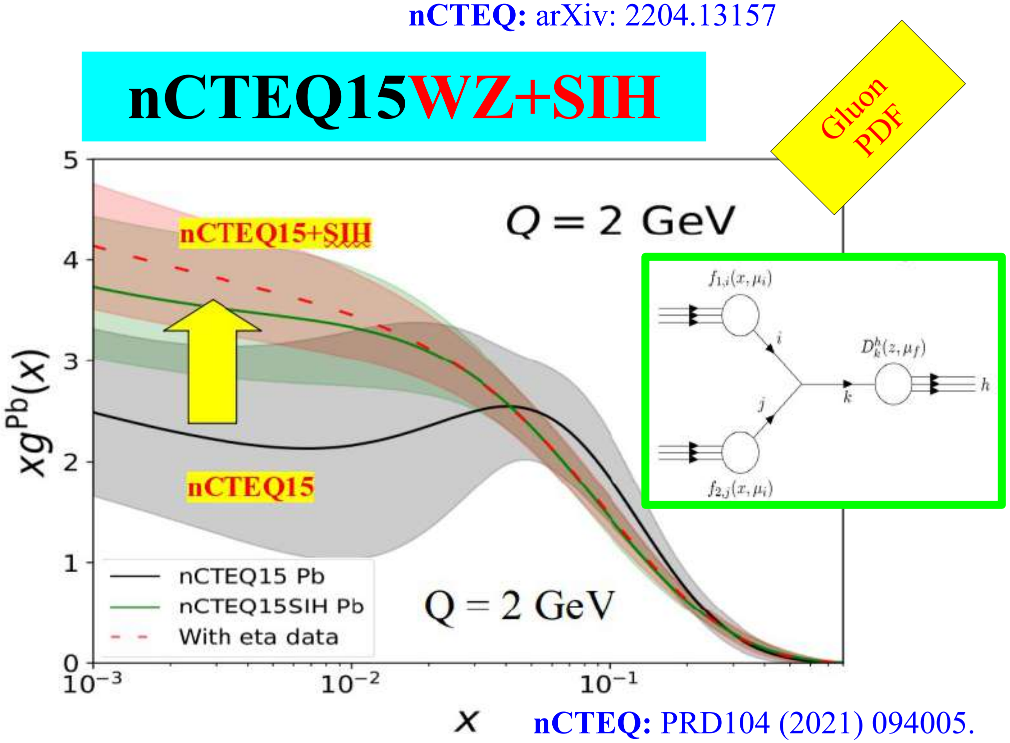
nCTEQ: arXiv: 2204.13157

nCTEQ15WZ



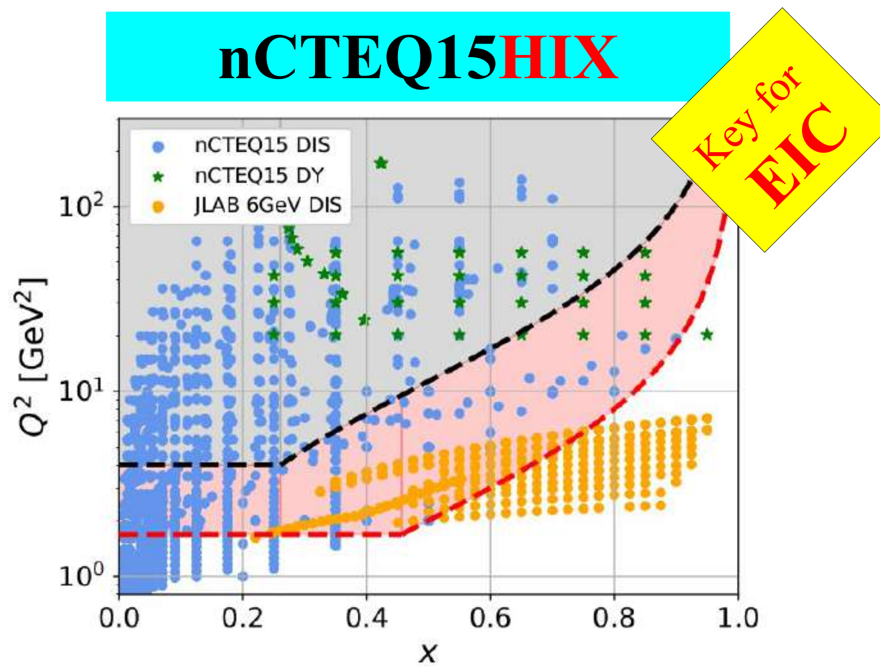
nCTEQ: Phys.Rev.D 104 (2021) 094005

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: From Parameterization to a Deeper Understanding

Proton PDF: $f_p(x,Q)$

generally NNLO; approaching ~1% precision; Boundary Conditions for nuclear PDF

Nuclear PDF: $f_A(x,Q)$

generally NLO; leverage proton PDF tools; recent progress encouraging *(e.g., PDG)*

evolve from parameterizing to deeper understanding of QCD

Extend kinematic {x,Q} range: … probe extreme regions of QCD

Low Q: non-perturbative region; correlation effects …

Low x: resummation; saturation; BFKL; …

Low W: resonance region; duality; …

TO DO LIST

Need theoretical guidance in these regions

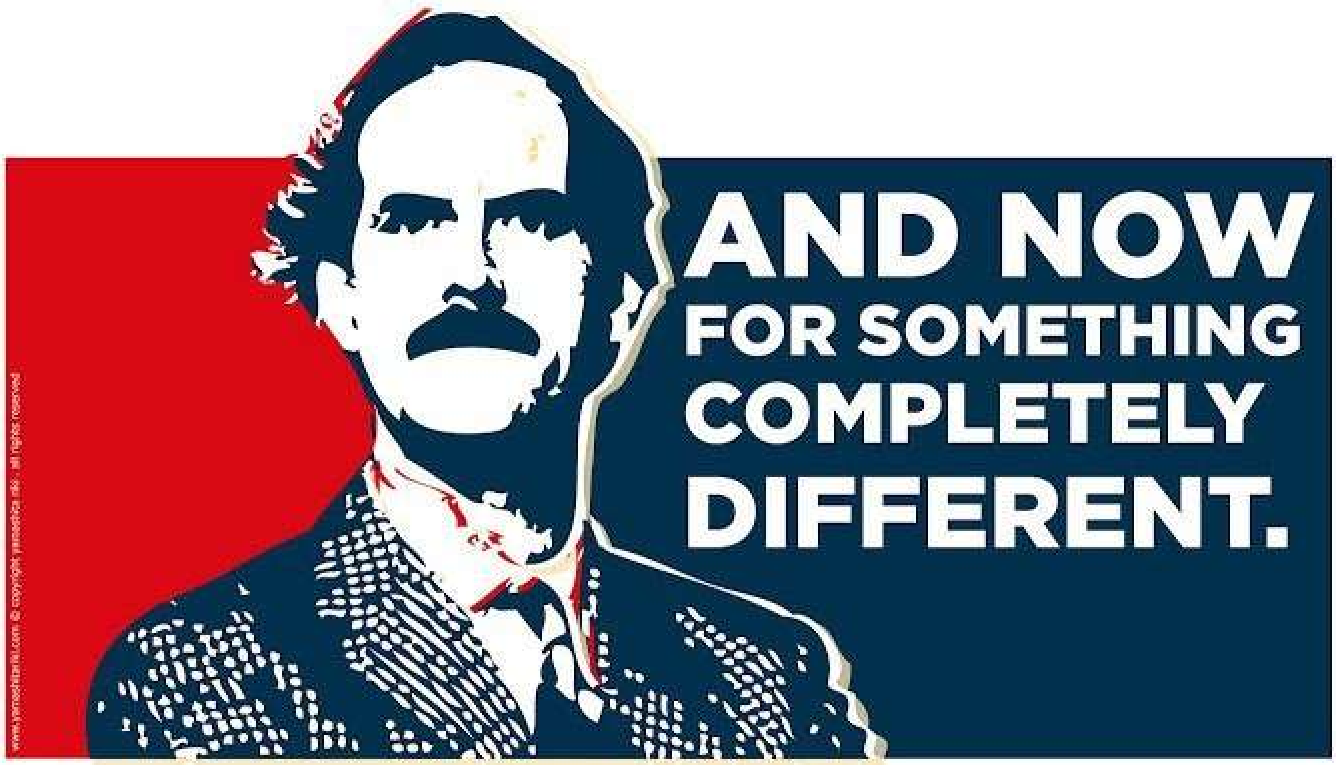
Extend Unpolarized Colinear to Spin, TMD & GPD

… explore full tomographic nuclear structure in spin, k_T, b_T

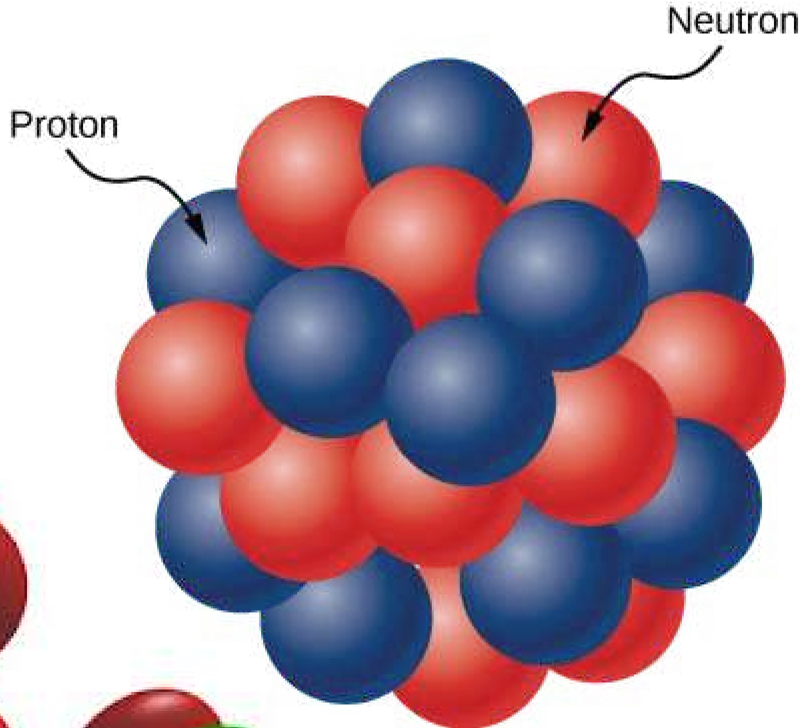
precision $f_A(x,Q)$ can serve as Boundary Condition for $f_A(x,Q,k_T,b_T,\sigma)$

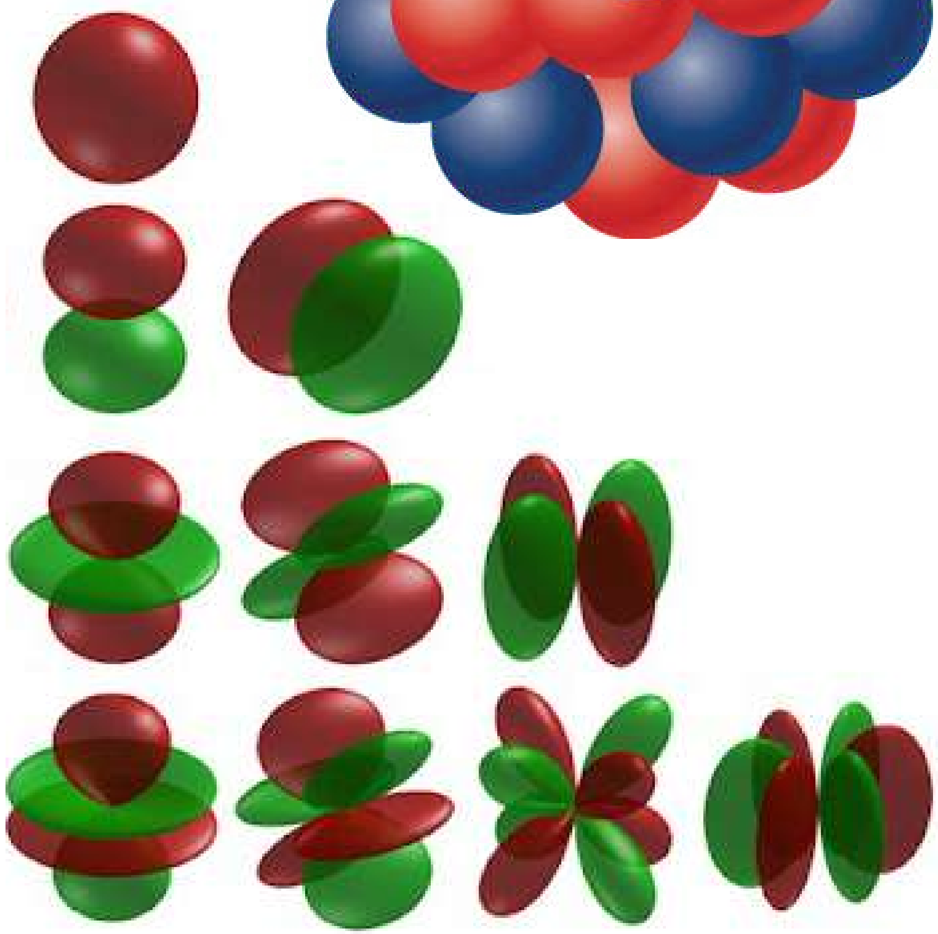
include Lattice QCD info on moments and quasi-PDFs

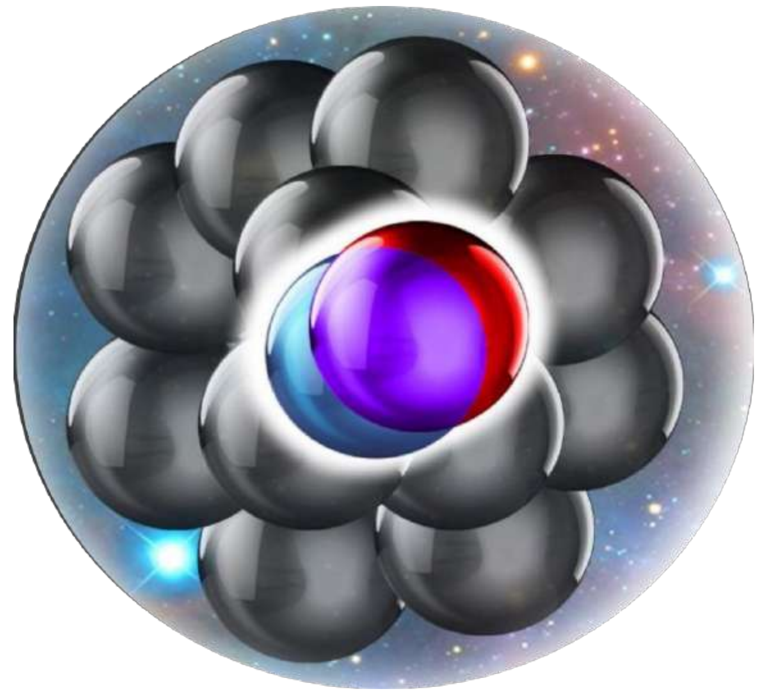
Need coordination/communication between efforts

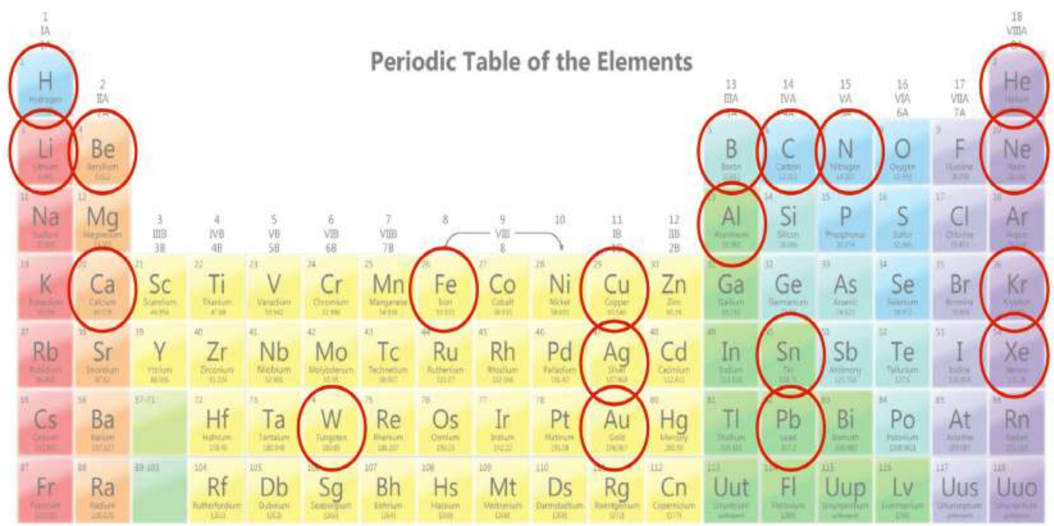

AND NOW
FOR SOMETHING
COMPLETELY
DIFFERENT.

… beyond parameterizations? … nearest neighbor interactions



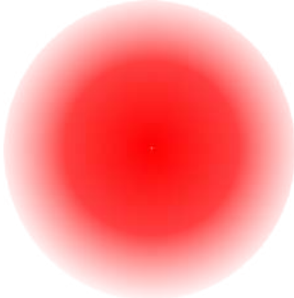




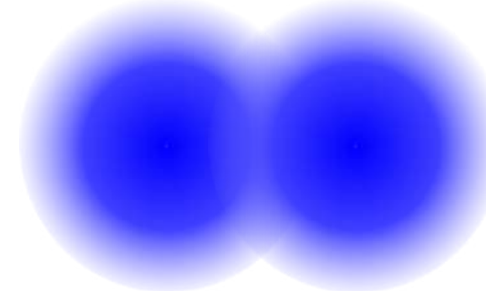


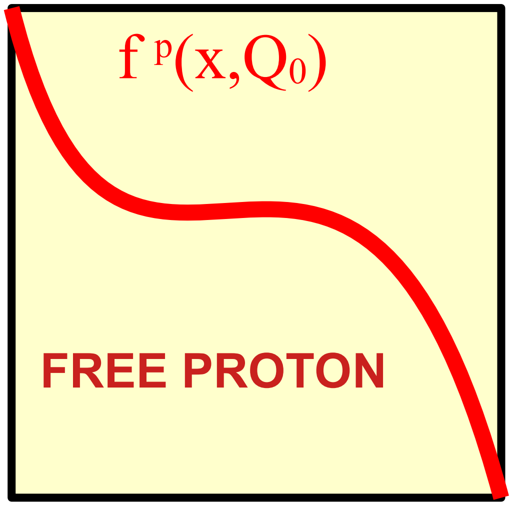
"Free nucleons" + "nucleon pairs"

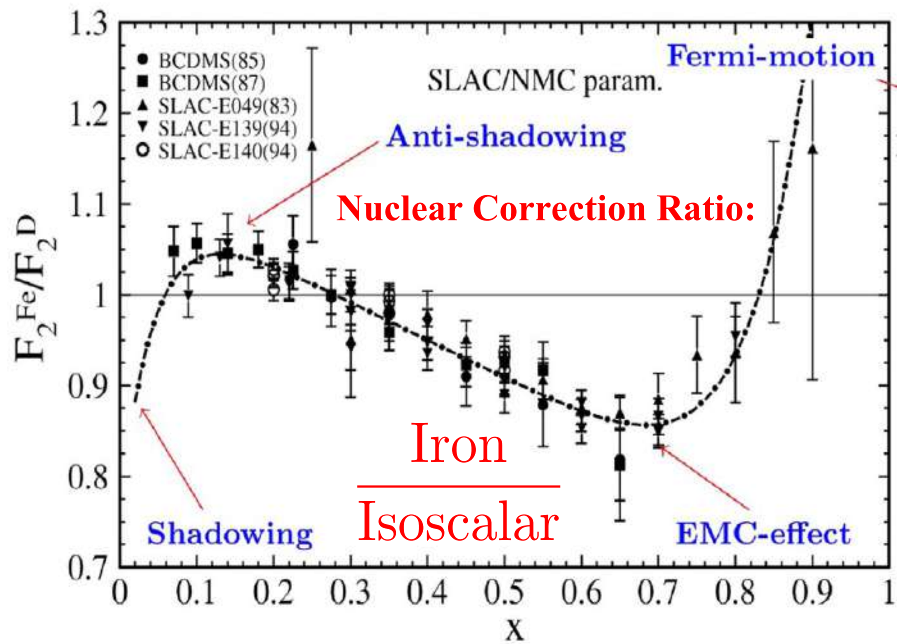
nucleon

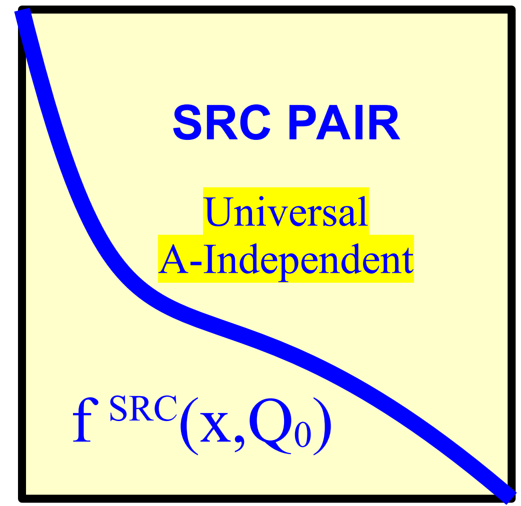


nucleon - nucleon









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}	$\frac{\chi^2_{\mathrm{tot}}}{N_{\mathrm{DOF}}}$
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

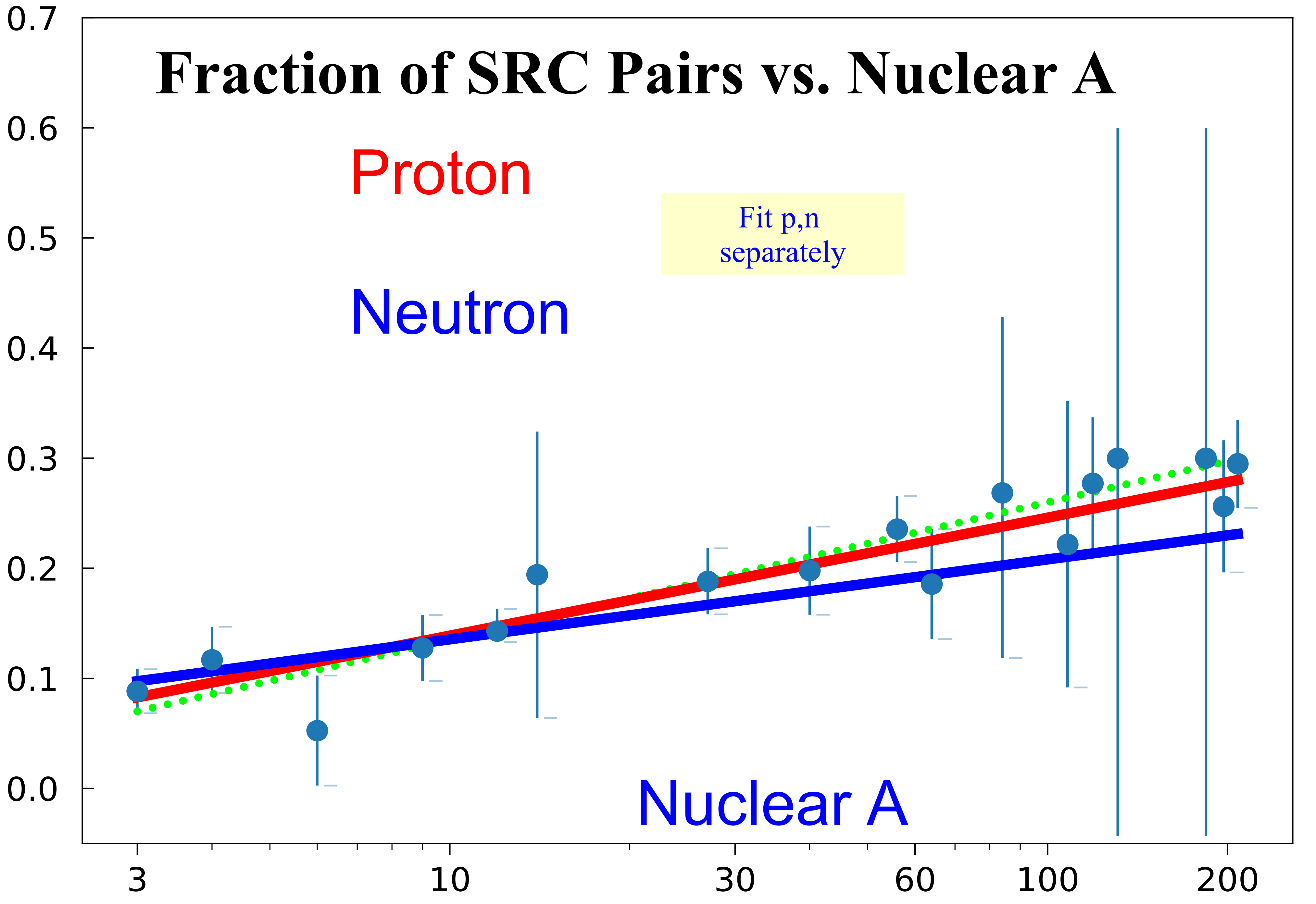
Evidence for Modified Quark-Gluon Distributions in Nuclei by Correlated Nucleon Pairs

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]

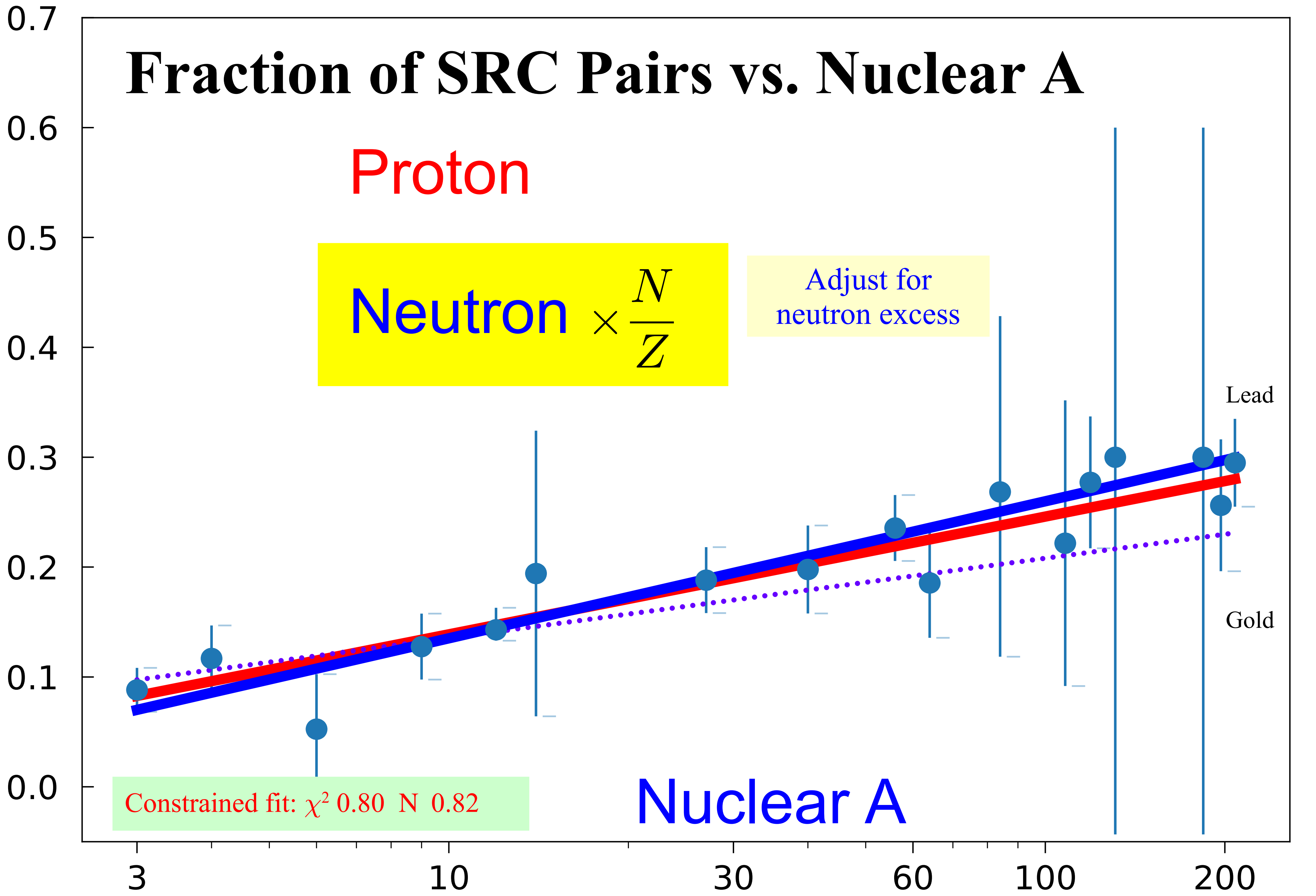
Hen Lab

Laboratory for Nuclear Science @ MIT

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



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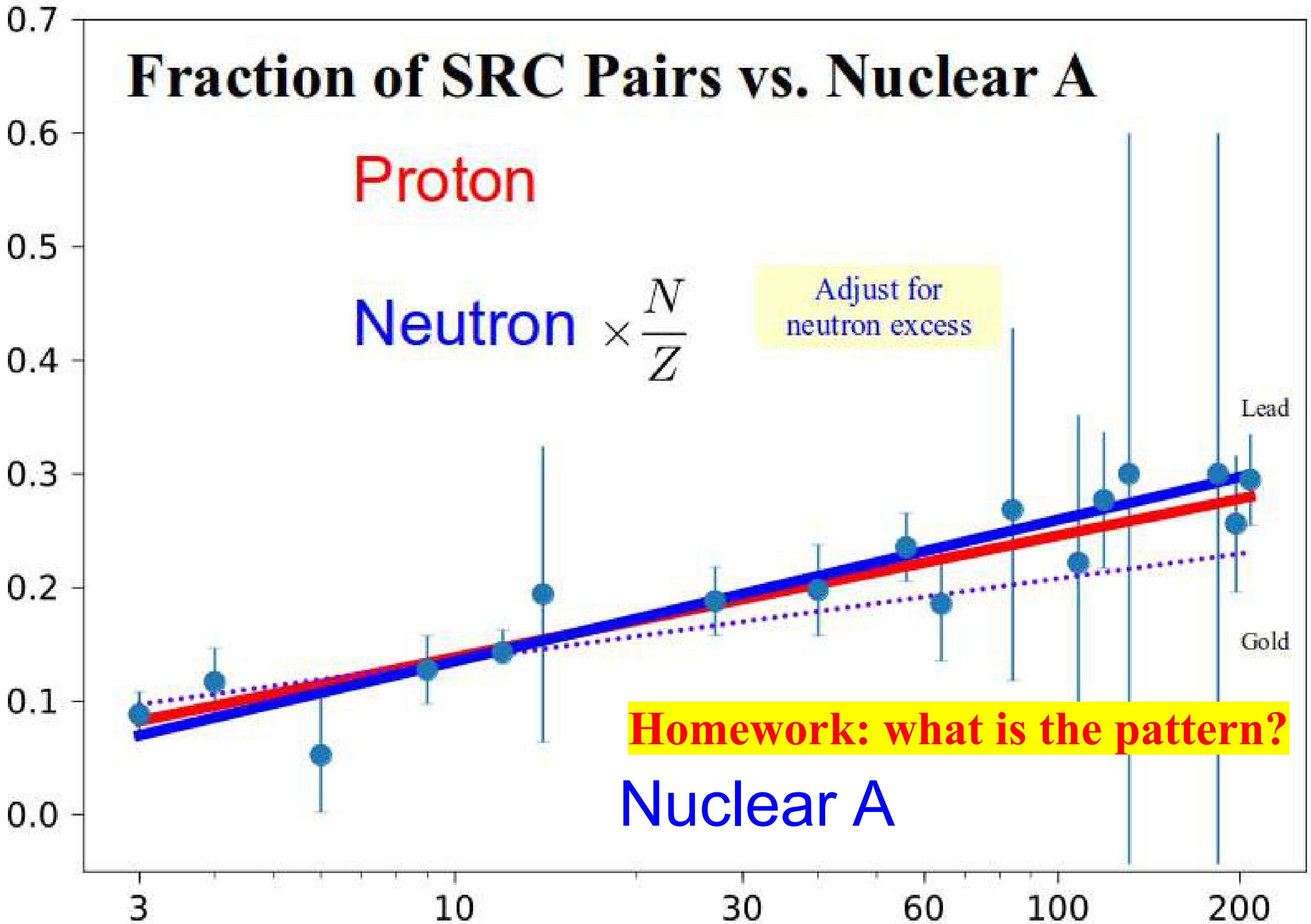
Fit Proton & Neutron Separately … a curious observation ..



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

Cp = 0.256
Cn = 0.177

A = 197
Z = 79
N = 118

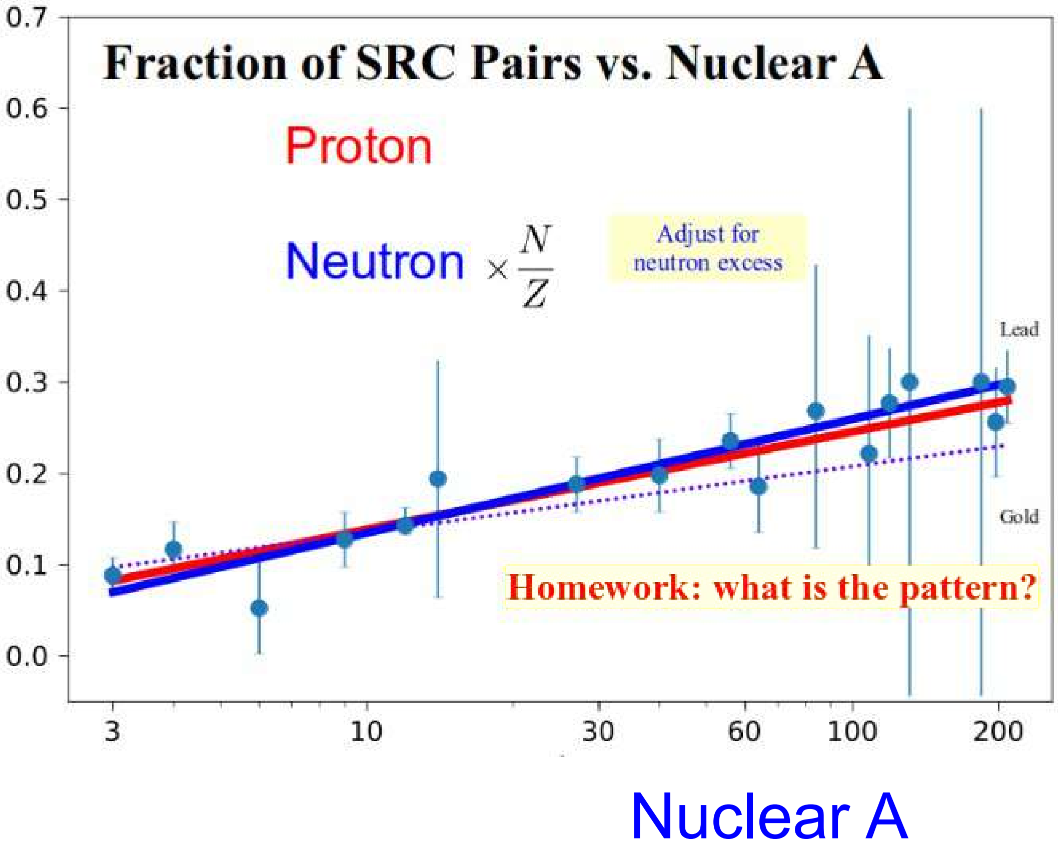
Cp × Z = **20.2**
Cn × N = **20.9**

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

Different Param. ⇒ i) NN / SRC and ii) nuclear character



- ➔ 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

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Nature is trying to tell us something

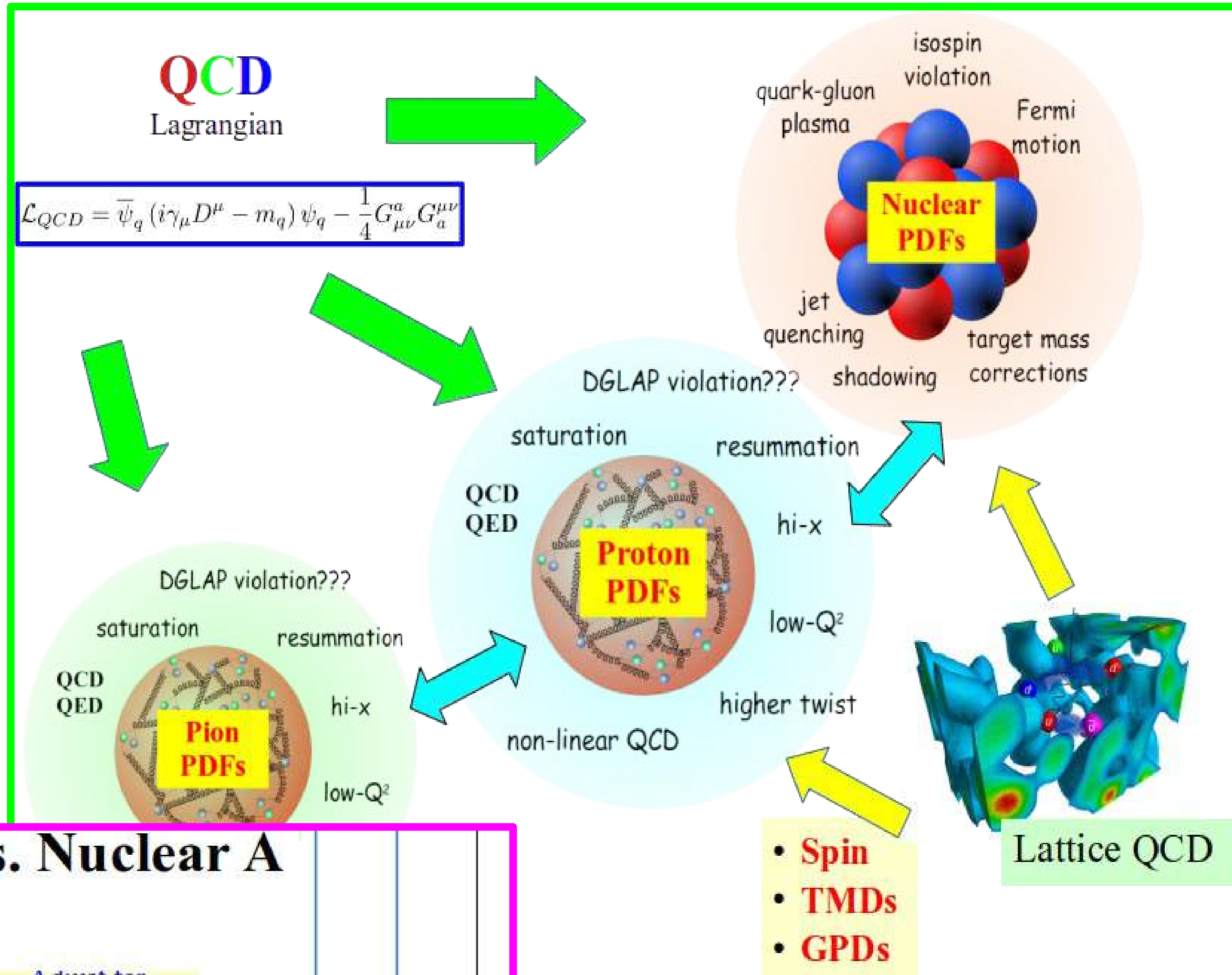
This parameter form connects to new concepts

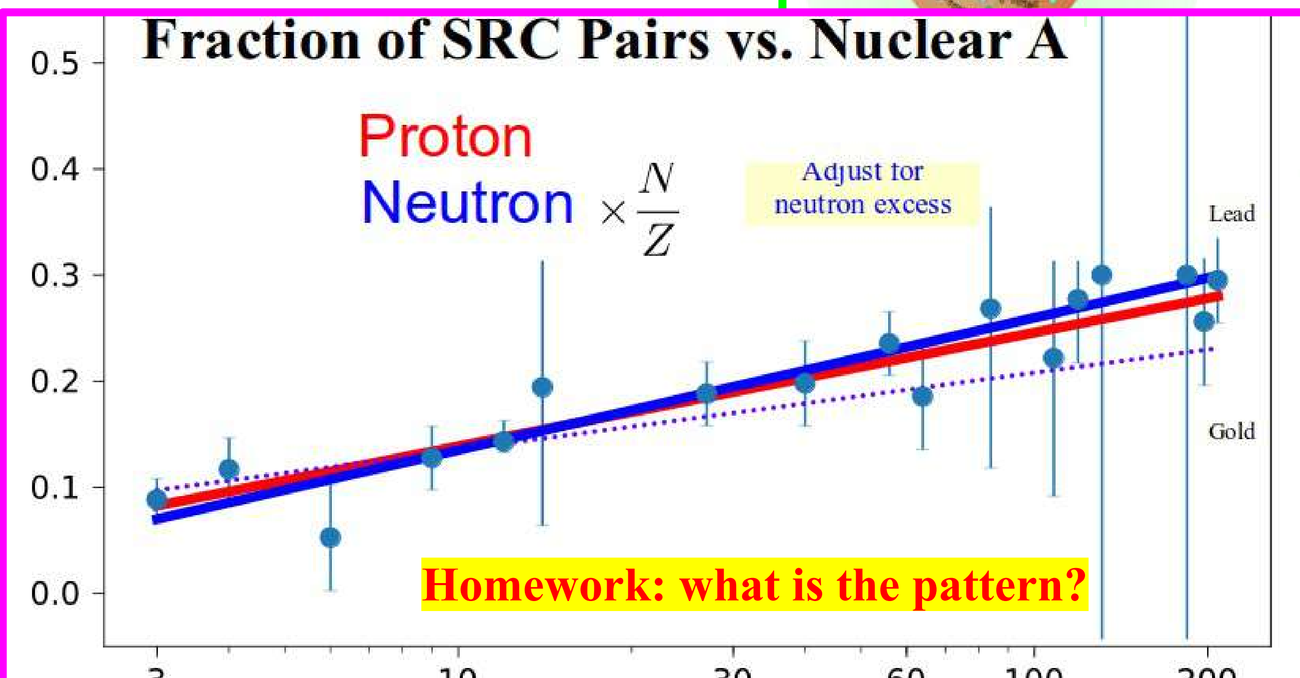
CONCLUSIONS:

Assembling the puzzle pieces

Interdisciplinary …
Use tools from
HEP, Nuclear,
& Lattice QCD

… to really understand the
strong force

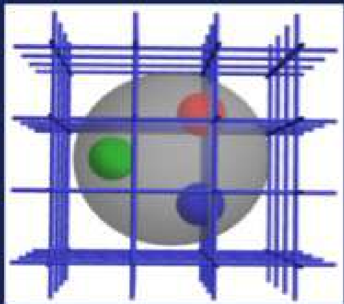


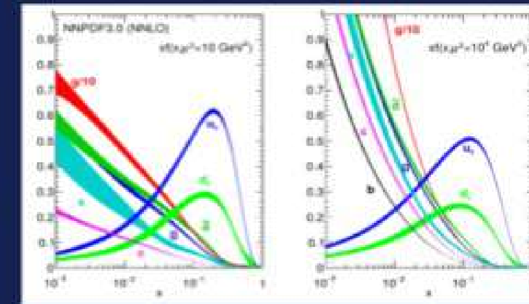


Nature is telling us ...

Why (pn) pairs?

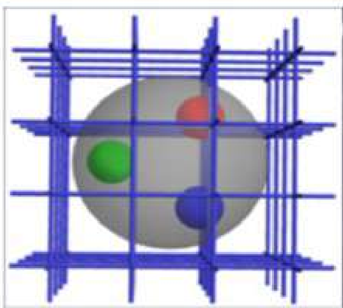
What drives this pattern?





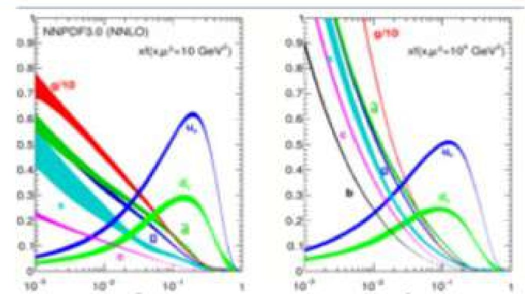
Parton Distributions and Lattice Calculations in the LHC era (PDFLattice 2017)

22-24 March 2017, Oxford, UK

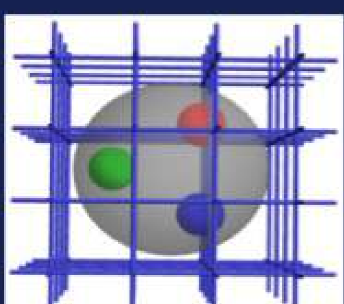


W. K . Kellogg Biological Station

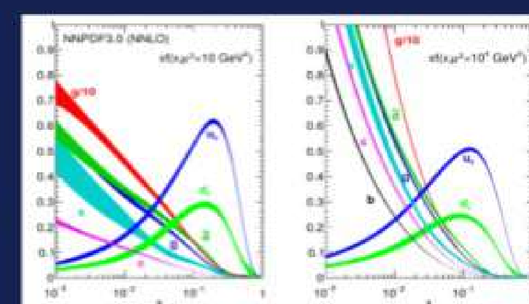
MICHIGAN STATE UNIVERSITY



Parton Distributions and Lattice Calculations (PDFLattice 2019)



Jefferson Lab



Parton Distributions and Lattice Calculations (PDF Lattice 2024) **18-20 November 2024**

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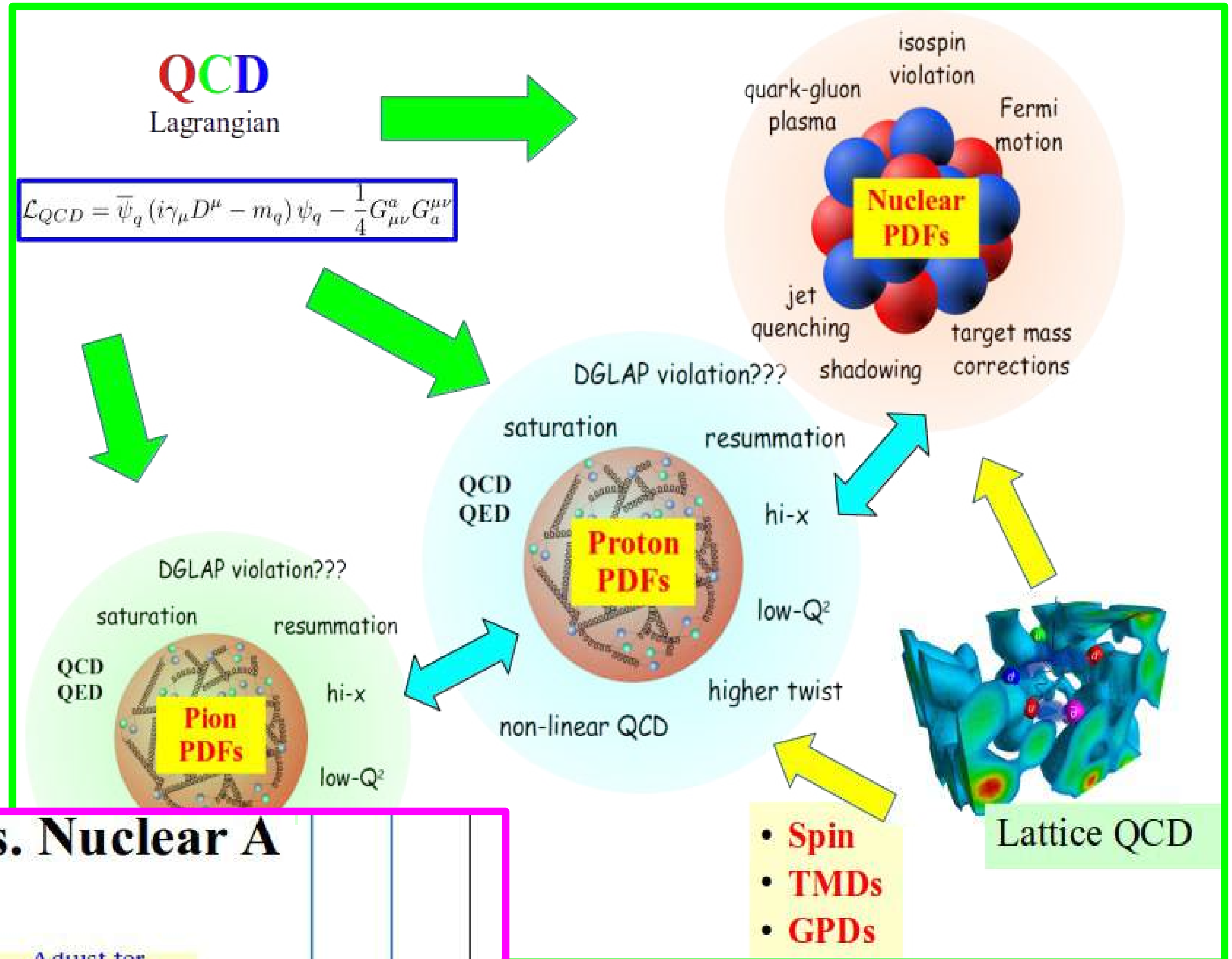

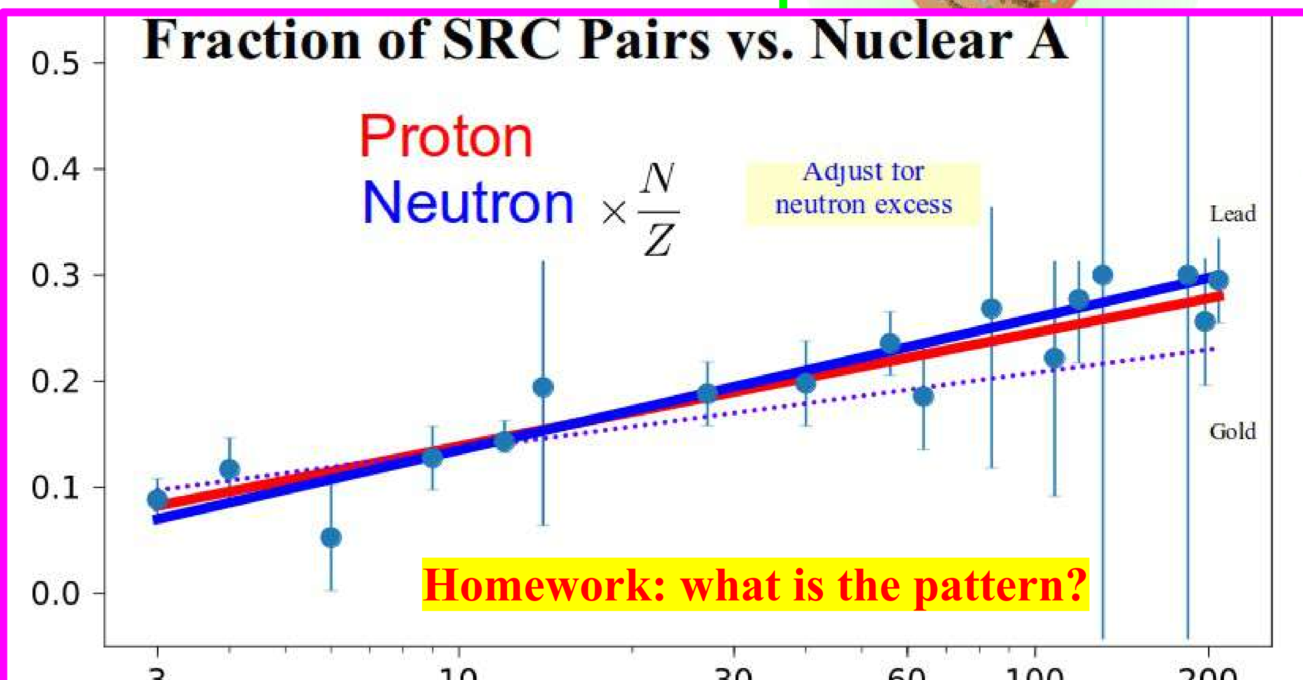

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