Probing dense nuclear matter

Updates from nCTEQ & SURGE

Fred Olness
SMU

Thanks for substantial input
from my friends & colleagues

Towards Improved Hadron Femtography
University of Virginia
20-24 July 2026

The SMU Campus

Ce n'est pas une rotonde

QCD: Remarkably successful at describing High Energy Processes

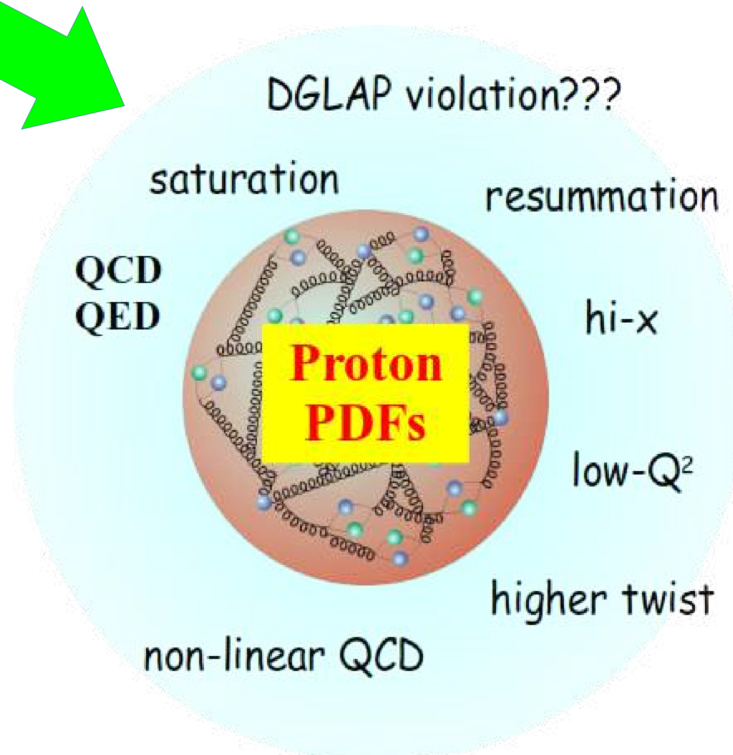
Quantum ChromoDynamics

QCD

Lagrangian

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

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



… we can go further

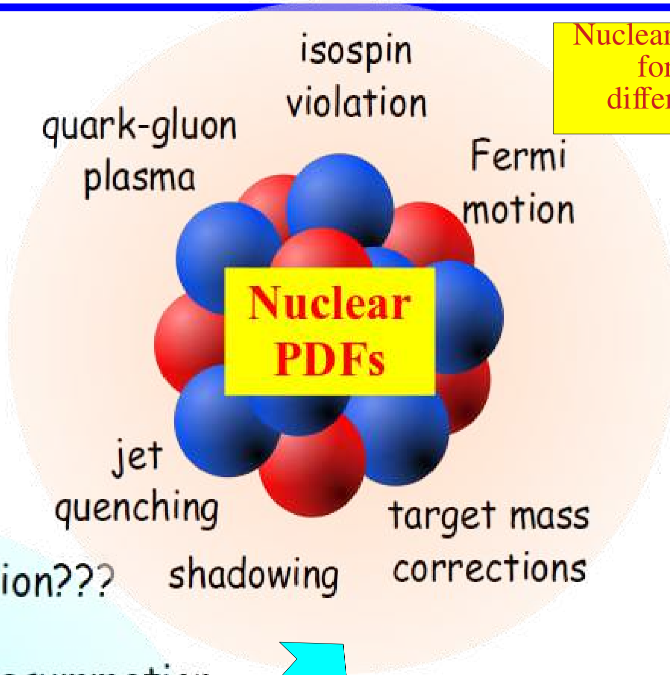
QCD: From PDFs to the underlying QCD

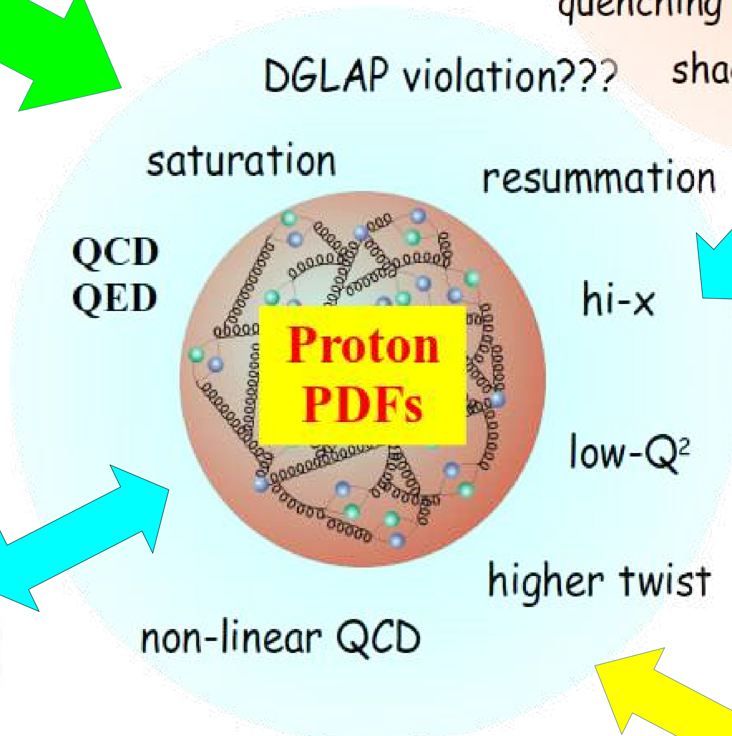
QCD

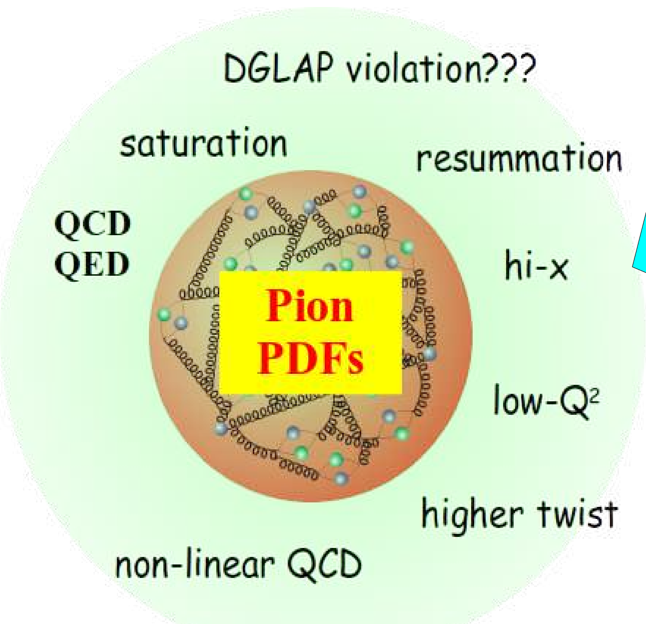
Lagrangian

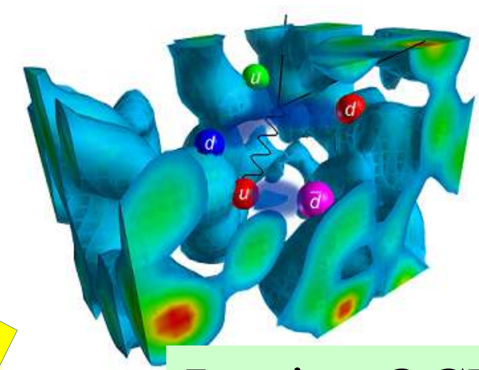
$$\mathcal{L}_{QCD} = \overline{\psi}_q \left(i\gamma_\mu D^\mu - m_q \right) \psi_q - \frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a$$

Nuclear targets key for flavor differentiation









Lattice QCD

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

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

Collinear (1D) PDFs can provide a benchmark and boundary condition for the more comprehensive **GPD** and **TMD** descriptions of hadron structure.

Synergistic Benefits:

Uncertainty Reduction: Methods developed to reduce uncertainties in collinear PDFs provide a foundation for improving the precision of more general partonic distributions, including GPDs, TMDs, spin-dependent PDFs, and related observables.

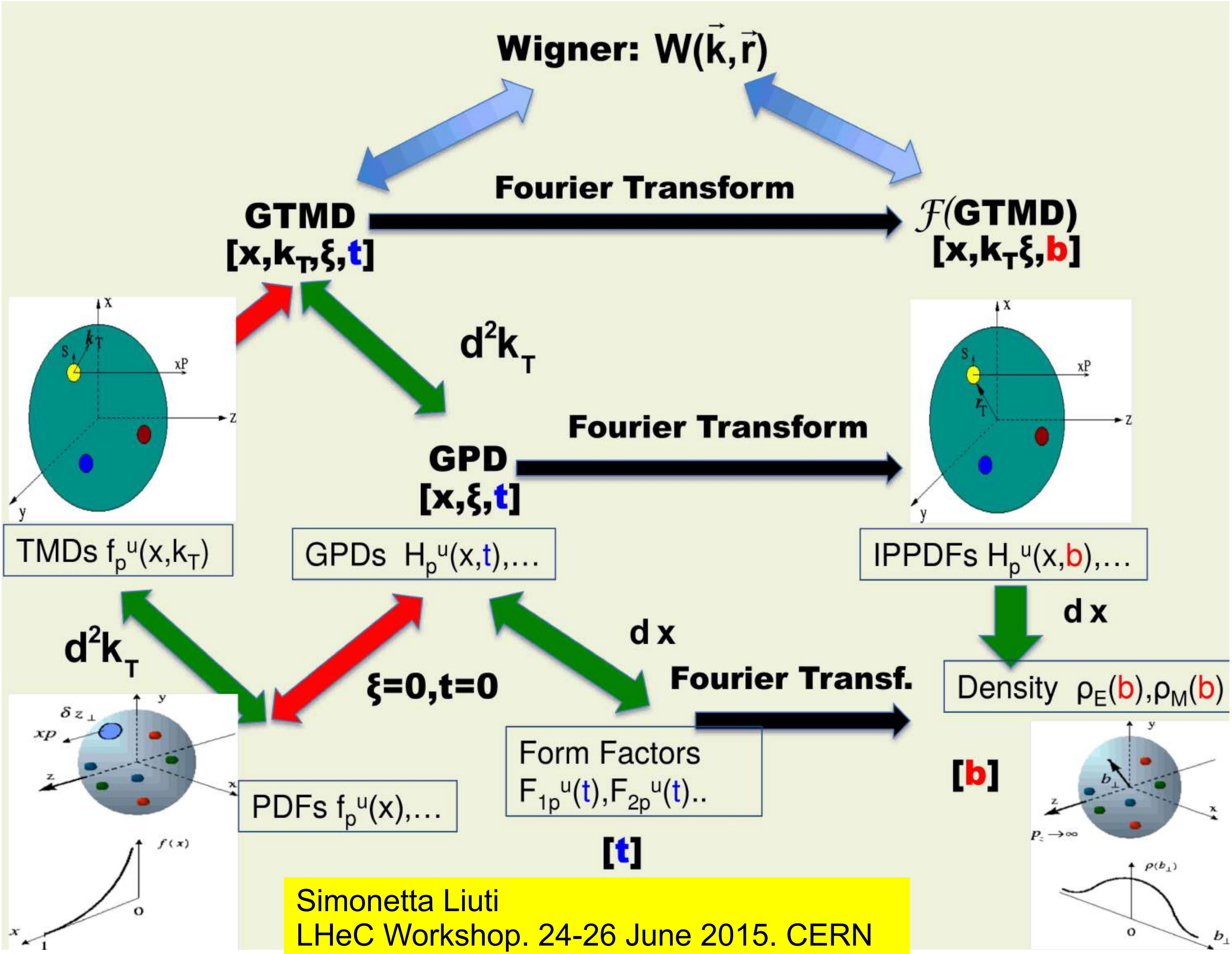
See Aurore's presentation

Evolution Equations: The DGLAP evolution equations serve as the archetype for more sophisticated evolution formalisms, including Collins–Soper, BFKL, BK, and JIMWLK evolution.

Experimental Optimization: By reducing the uncertainties of collinear PDFs, physicists can more effectively isolate the effects of transverse dynamics, essentially subtracting the well-constrained collinear contribution to reveal the richer structure encoded in TMDs and GPDs.

Global Analysis Synergy: The global-analysis methodology developed for collinear PDFs provides a robust framework for combining complementary measurements from diverse experimental facilities, yielding a coherent and consistent picture of hadronic structure across multiple observables and kinematic regimes.

Generalized Parton Distribution Functions



Simonetta Liuti
LHeC Workshop. 24-26 June 2015. CERN

nCTEQ

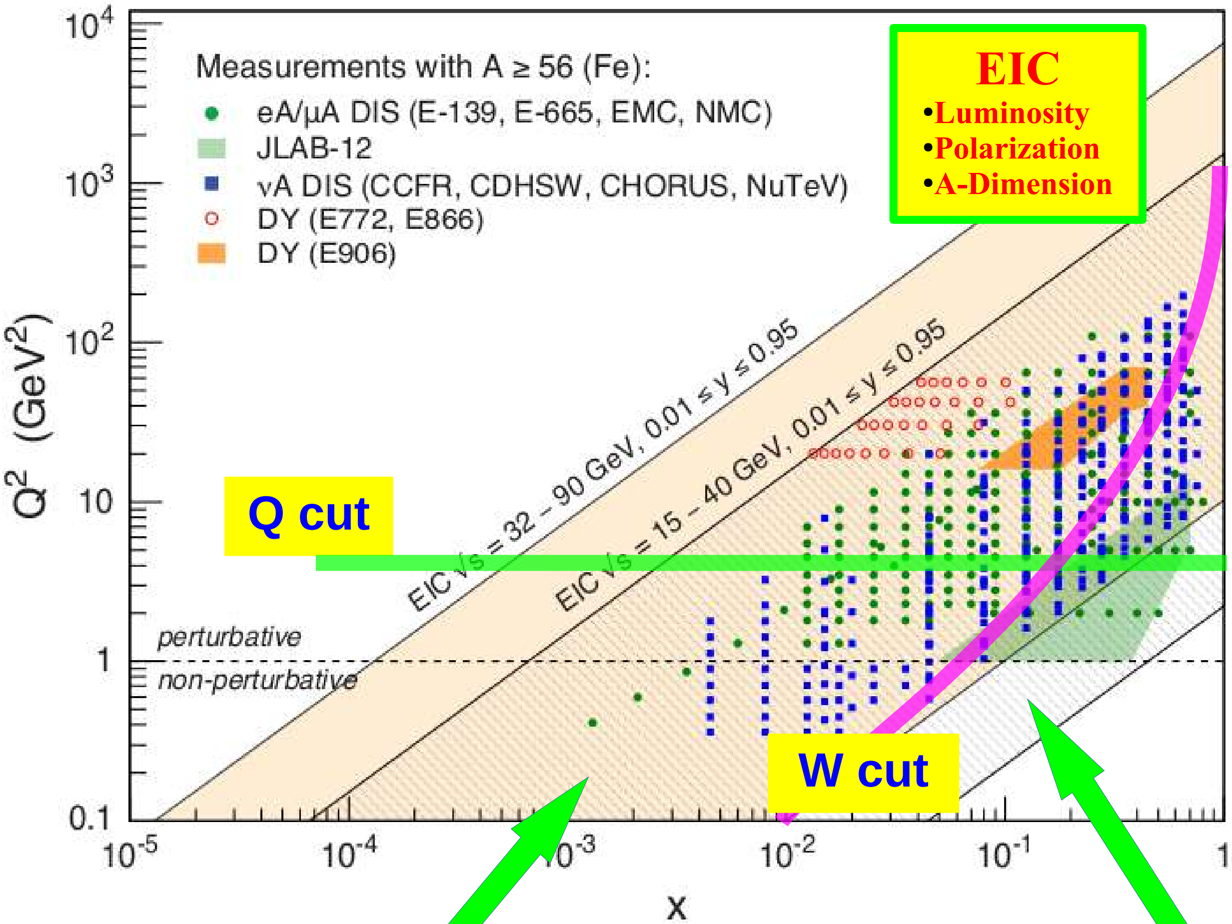
nuclear parton distribution functions

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

Comparison of available nPDFs

	KSASG20 PRD 104, 034010	TUJU21 PRD 105, 094031	EPPS21 EPJC 82, 413	nNNPDF3.0 EPJC 82, 507	nCTEQ25 arXiv:25XX.XXXX
lA NC DIS	✓	✓	✓	✓	✓
νA CC DIS	✓	✓	✓	✓	✓
pA Drell-Yan	✓		✓	✓	✓
πA Drell-Yan			✓		
RHIC dAu π			✓		✓
LHC pPb π, K					✓
LHC pPb W/Z		✓	✓	✓	✓
LHC pPb dijet			✓	✓	
LHC pPb HQ			✓ GMVFNS	✓ FO+PS(rew)	✓ ME fit/GMVFNS
LHC quarkonium					✓ ME fit
LHC pPb γ				✓	
Kinematic cuts	$Q > 1.3$ GeV	$Q > 1.87$ GeV $W > 3.5$ GeV	$Q > 1.3$ GeV $W > 1.8$ GeV $p_T^{HQ} > 3$ GeV	$Q > 1.87$ GeV $W > 3.5$ GeV	$Q > 1.3$GeV $W > 1.7$GeV $p_T^{HQ(SIH)} > 3$ GeV
No data points	4335	2410	2077	2188	3518
No free param.	9	16	24	256 (NN)	36
χ^2/dof	1.06(1.05)	0.94(0.84)	1.00	1.10	0.978
Error analysis	Hessian	Hessian	Hessian	Monte Carlo	Hessian
$\Delta\chi^2$ tol.	20 (68% CL)	50	35	N/A	40
Proton baseline	CT18	custom	CT18A	~NNPDF4.0	CJ15
Q_0 ini. scale	1.3 GeV	1.3 GeV	1.3 GeV	1.0 GeV	1.3 GeV
No flavours	3	4	6	6	5
Deuteron treat.	fitted	fitted	free	fitted	CJ15 correction
QCD order	**NLO & NNLO**	**NLO & NNLO**	**NLO**	**NLO**	**NLO**
HQ scheme	FONLL	FONLL	S-ACOT	FONLL	S-ACOT

To Boldly Go Beyond ... into the corners of the {x,Q²} Kinematic Plane



High-x:

Nuclear PDFs: x>1 allowed;

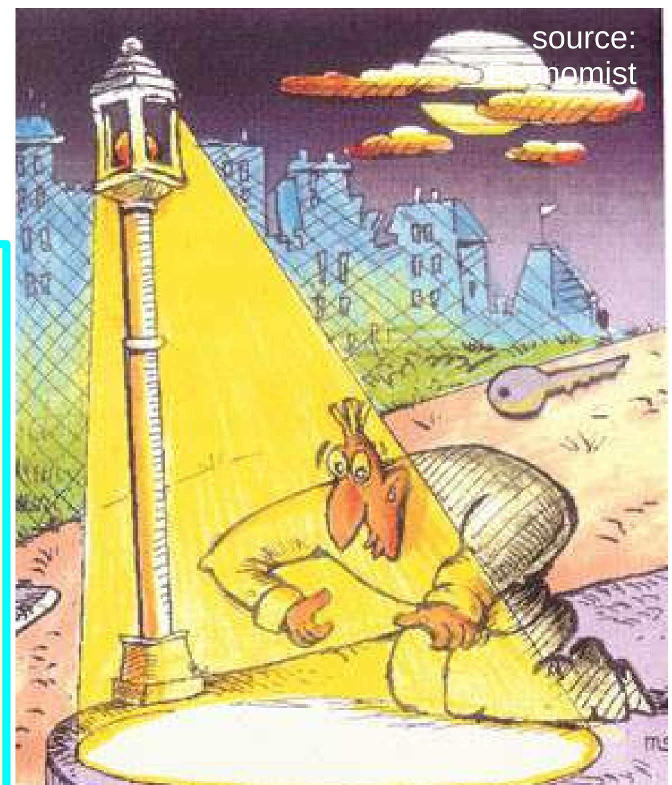
impacts F_2^{Nuc}/F_2^{Iso} in Fermi region

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-Q²:

Non-Perturbative inteface

collective effects

Target Mass Corrections

pick up M^2/Q^2 higher twist

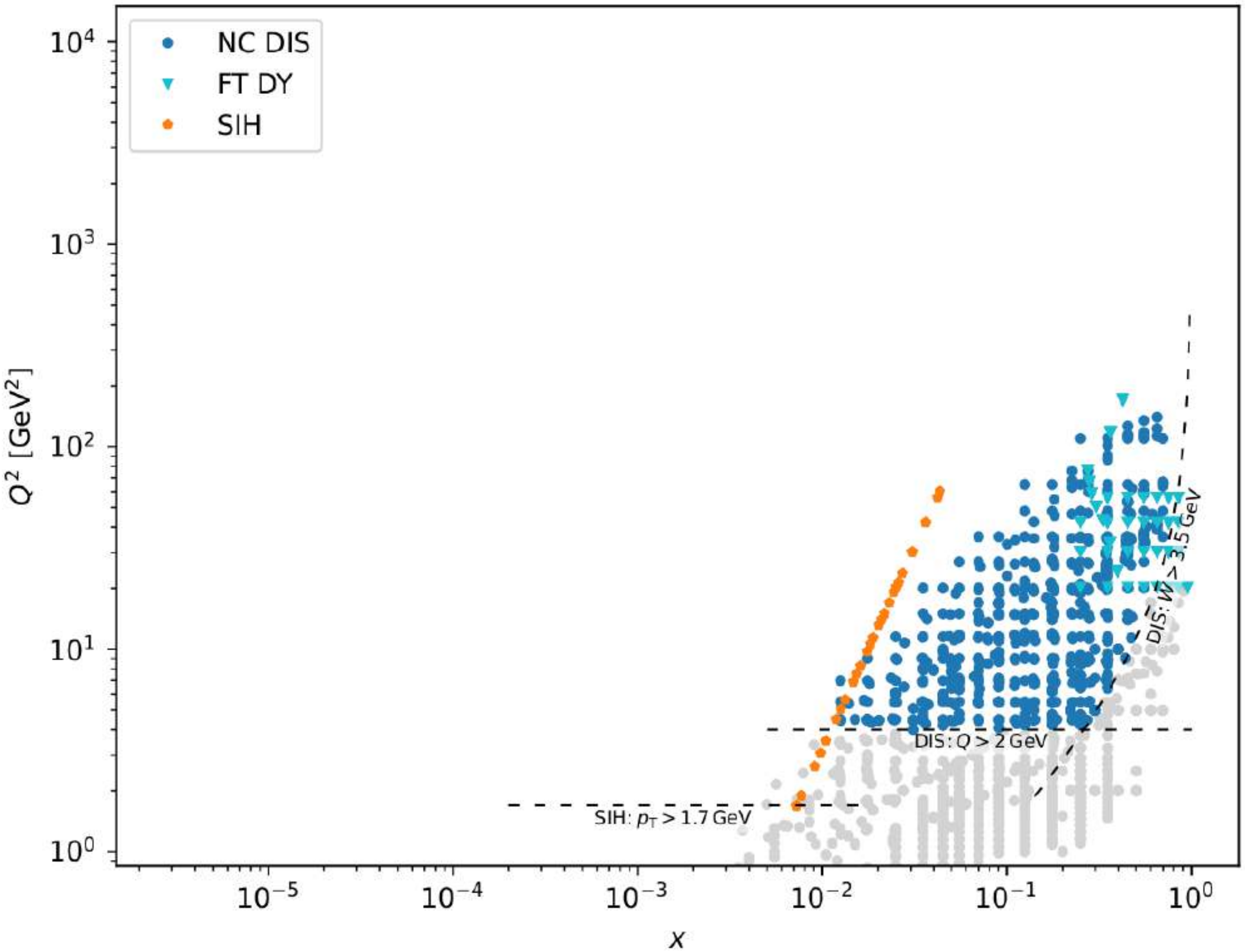
F_L at low Q^2 access to g(x)

Run at multiple energies

Towards nCTEQ26

- New nPDF release: **nCTEQ26** combines the previous analyses:
  - **nCTEQ15** [PRD 93, 085037 (2016)]
    - DIS NC data
    - fixed-target DY data
    - pion data from RHIC
  - **nCTEQ15WZ** [EPJC 80, 968 (2020)]
    - LHC W/Z data
    - constraints on *gluon* and *strange* nPDFs
  - **nCTEQ15HIX** [PRD 103, 114015 (2021); Prog.Part.Nucl.Phys. 136 (2024) 104096]
    - JLAB DIS data
    - constraints at high-x
    - theoretical corrections: TMC, HT, deuteron
  - **nCTEQ15SIH** [PRD 104 (2021) 9, 094005]
    - LHC & RHIC SIH data
    - constraints on *gluon* nPDF
  - **nCTEQ15neutrino** [PRD 106 (2022) 7, 074004]
    - DIS neutrino data (NuTeV, CHORUS, CDHSW, dimuons)
    - compatibility of NC & CC DIS
    - flavour separation
  - **nCTEQ15HQ** [PRL 121, 052004 (2018); PRD 105 (2022) 11, 114043]
    - LHC & RHIC HF data
    - constraints on low-x *gluon* nPDF
    - PDF-reweighting + full analysis

Data Overview: nCTEQ15

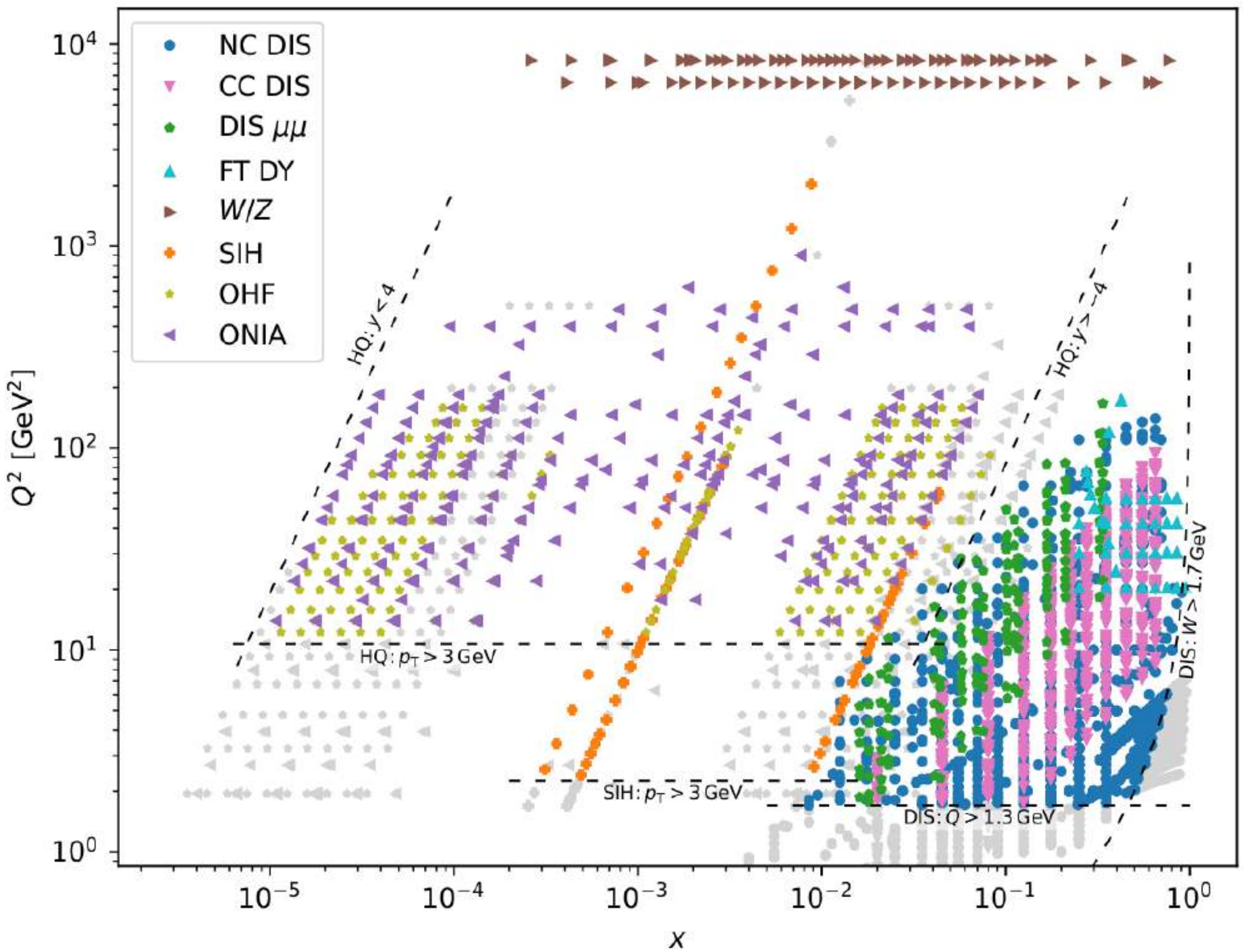


→ DIS, DY, SIH data

→ $N_{\text{data}} = 740$

nCTEQ
nuclear parton distribution functions

Data Overview: nCTEQ25



PRELIMINARY

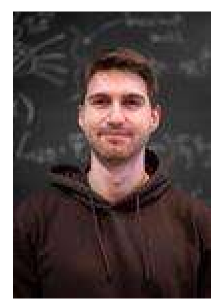
- → new CC DIS, DIS $\mu\mu$, DY W/Z, HQ data
- → $N_{\text{data}} = 3518$
- → looser cuts

nCTEQ

nuclear parton distribution functions


Tomas Jezo

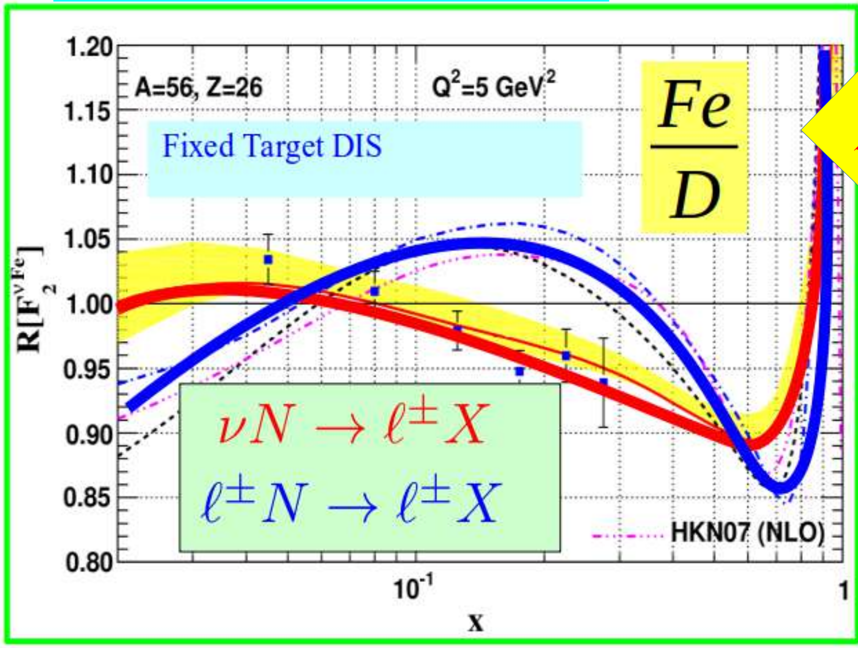

Katrin Greve


Jan Wissmann


Aleksander Kusina

nCTEQ15ν

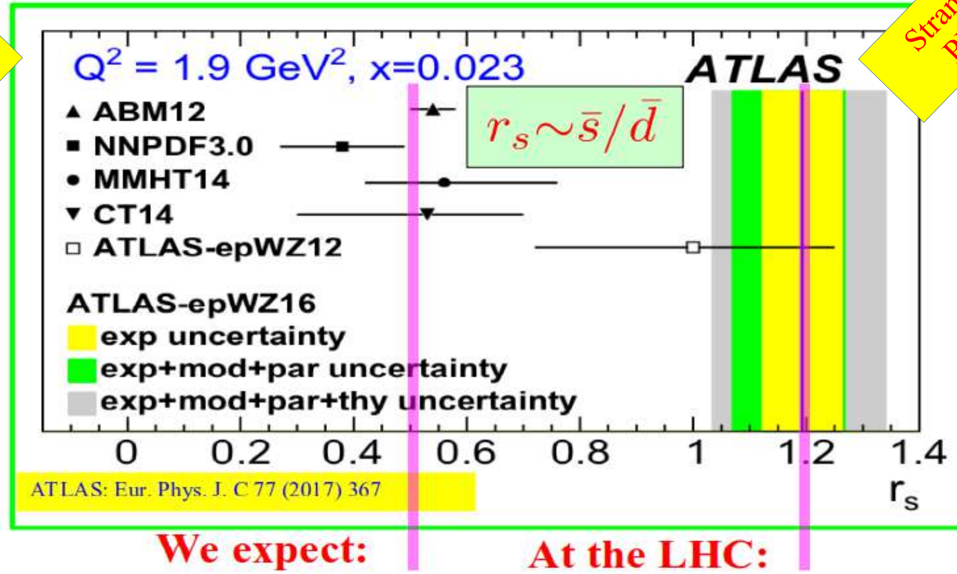
Split Personality



nCTEQ: arXiv: 2204.13157

nCTEQ15WZ

Strange PDF

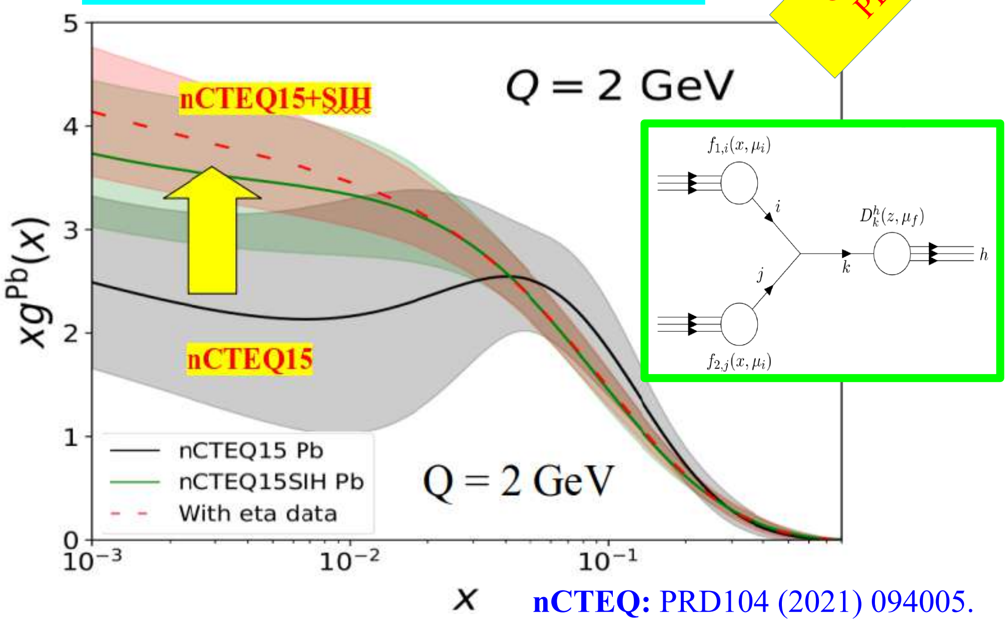


nCTEQ: Phys.Rev.D 104 (2021) 094005

Key for **EIC**

nCTEQ15WZ+SIH

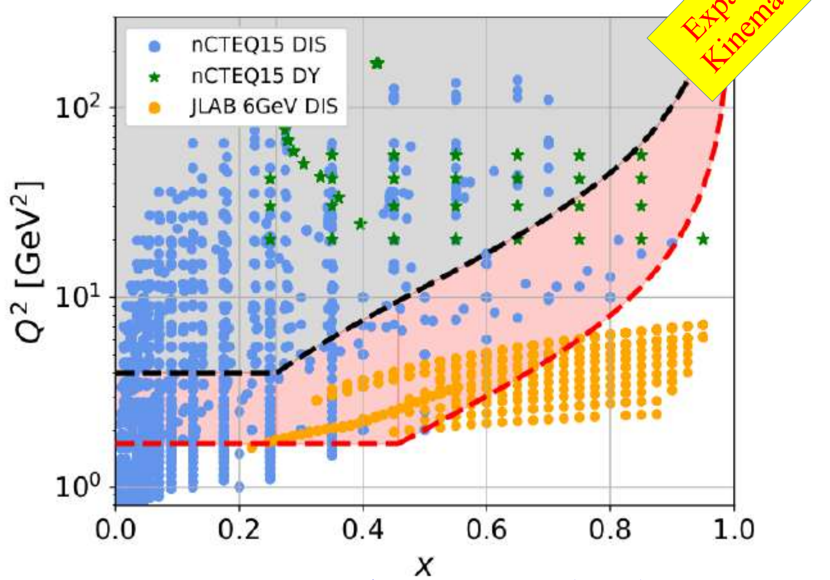
Gluon PDF



nCTEQ: PRD104 (2021) 094005.

nCTEQ15HIX

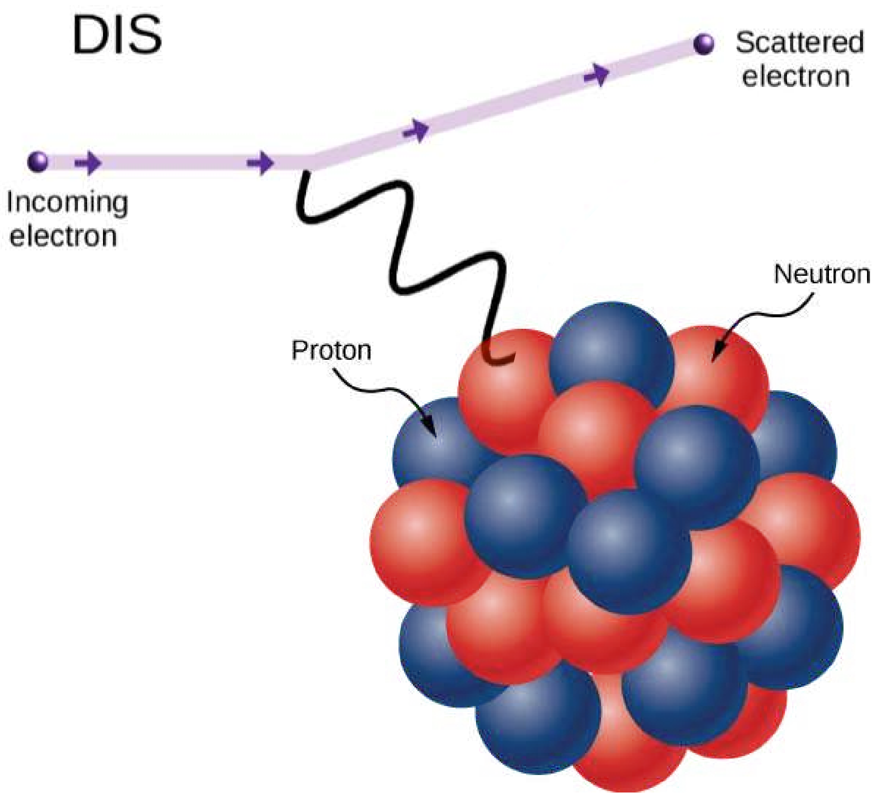
Expanded Kinematics

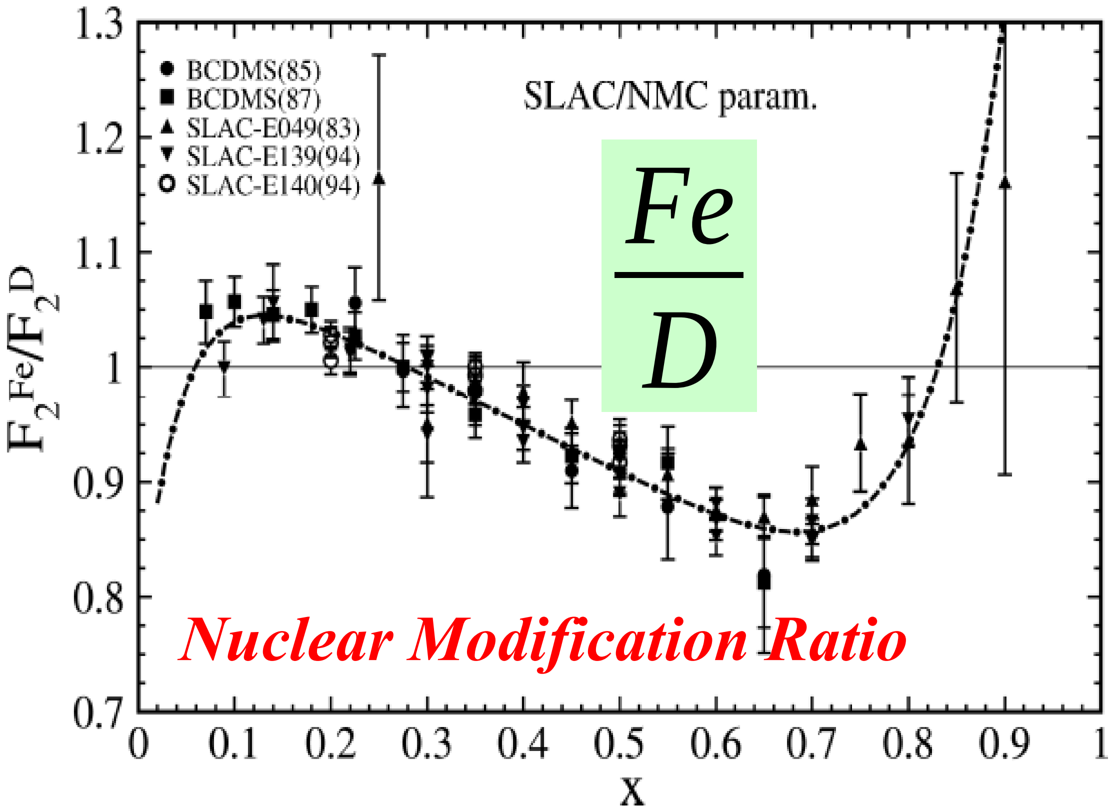


nCTEQ: Phys.Rev.D 103 (2021) 11, 114015

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

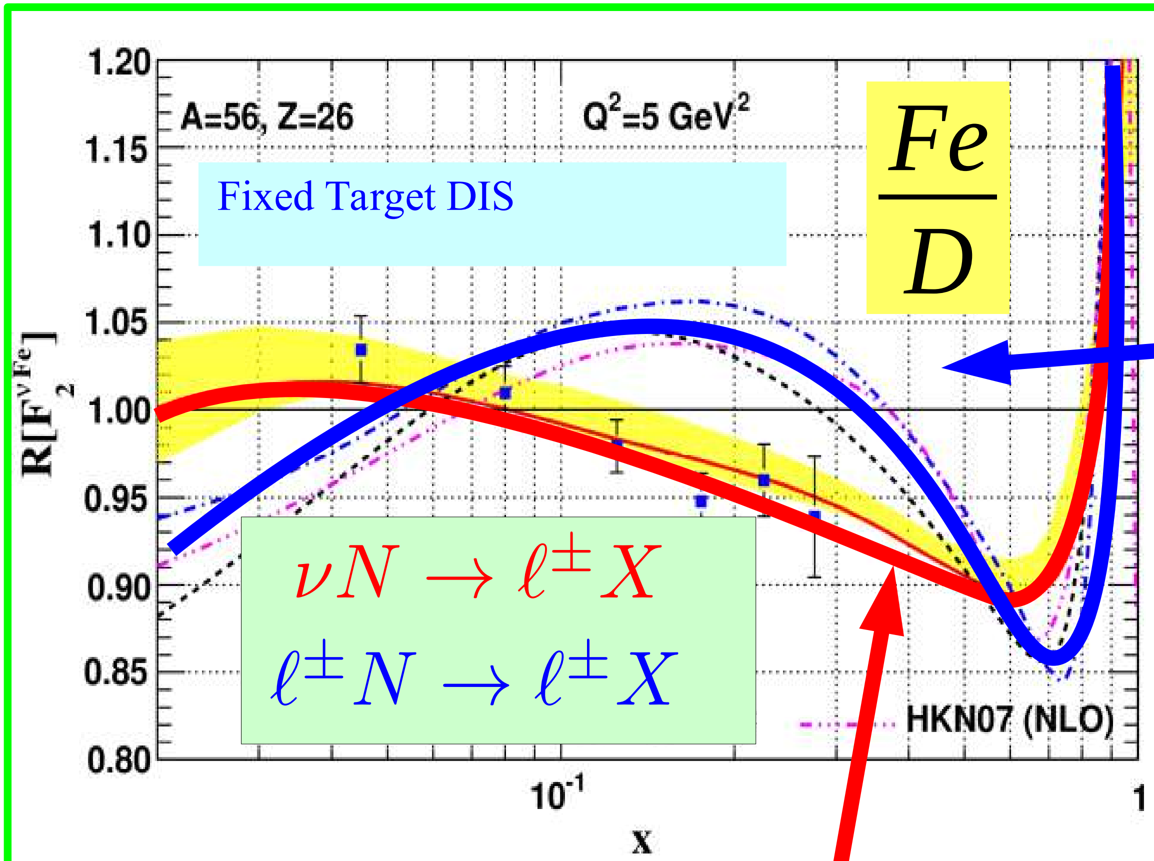
Nuclear Parton Distribution Functions from DIS

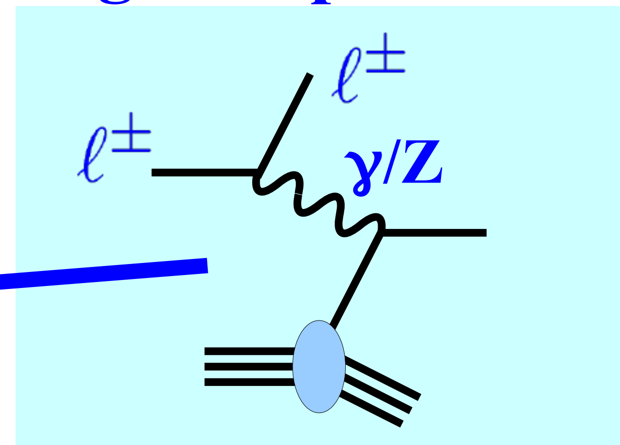




Puzzle: **Split Personality** … *What is the correct Nuclear ratio*

Charged Lepton DIS

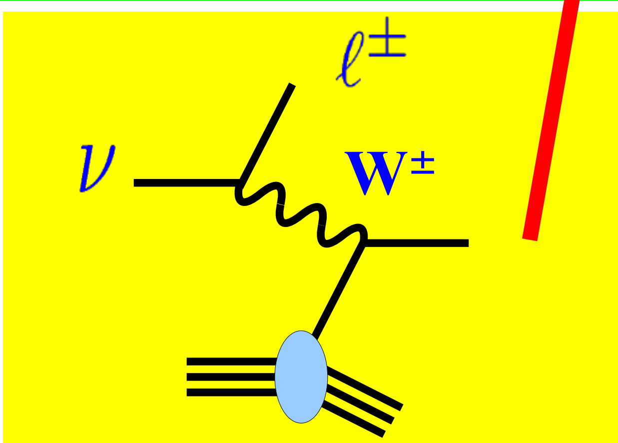




some caveats
… correlated errors

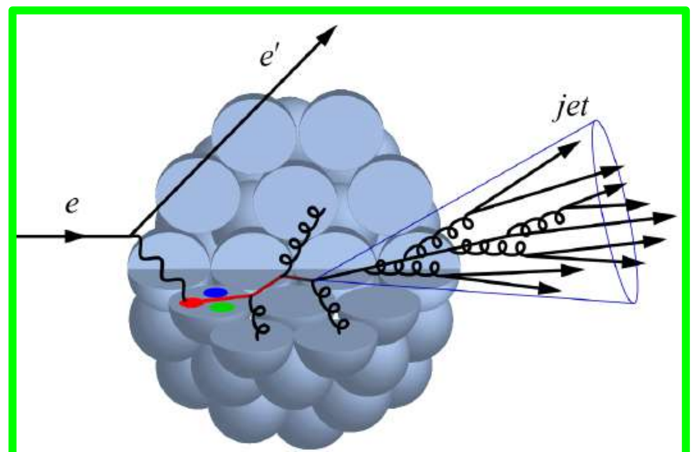
Ingo Schienbein, … (2007)

Karol Kovarik, … (2010)



Neutrino DIS

Depends on nuclear corrections

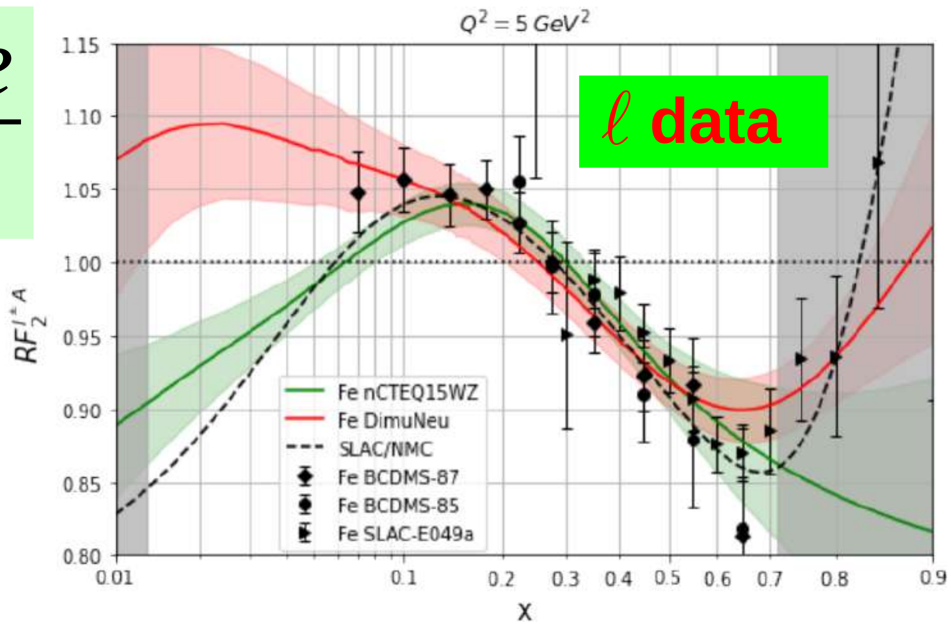


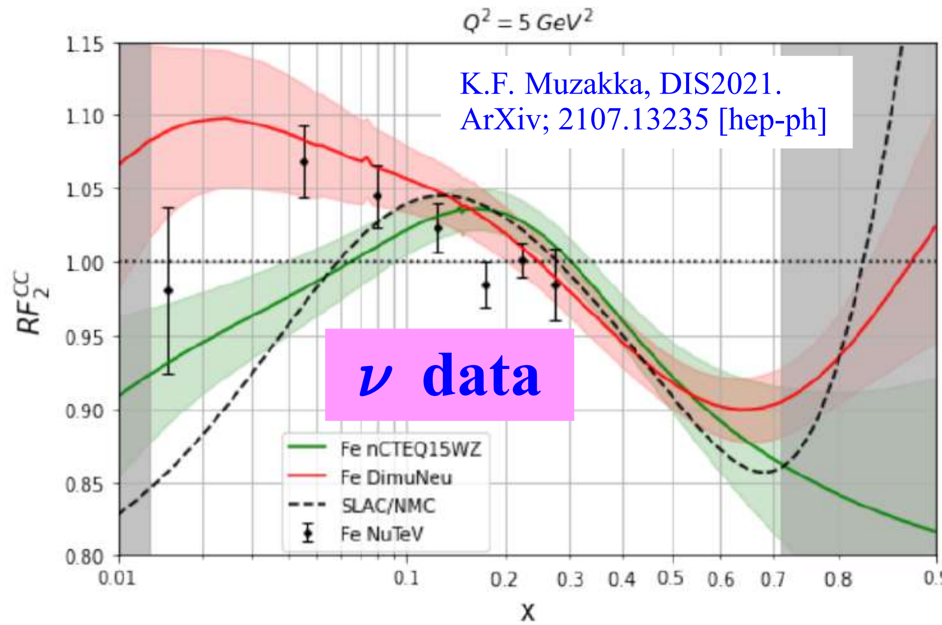
Propagation of γ/W thru nuclei

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 ???

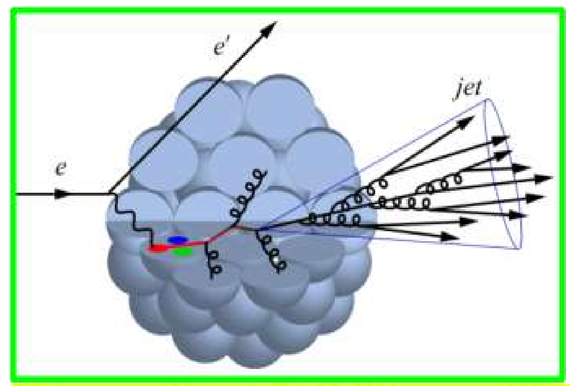
Are these data sets compatible???

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]

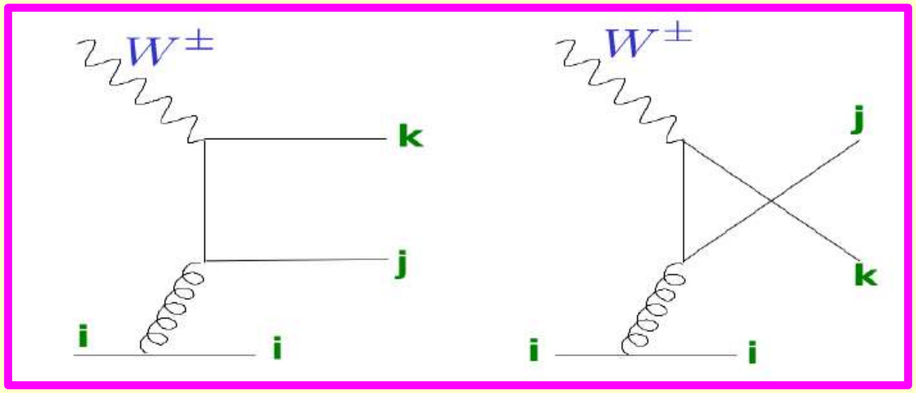


Propagation of γ/W thru nuclei

Fast Evaluation of Complex (N2LO) Amplitudes: … *e.g. APFEL++ Library*

Fast evaluation of heavy-quark contributions to DIS in APFEL++

P. Risse[a,†], V. Bertone[b], T. Ježo[a], M. Klasen[a], K. Kovařík[a], F.I. Olness[c], I. Schienbein[d]



APFEL++ – A PDF evolution library in c++

APFEL++

Bertone, arXiv:1708.00911

Valerio Bertone

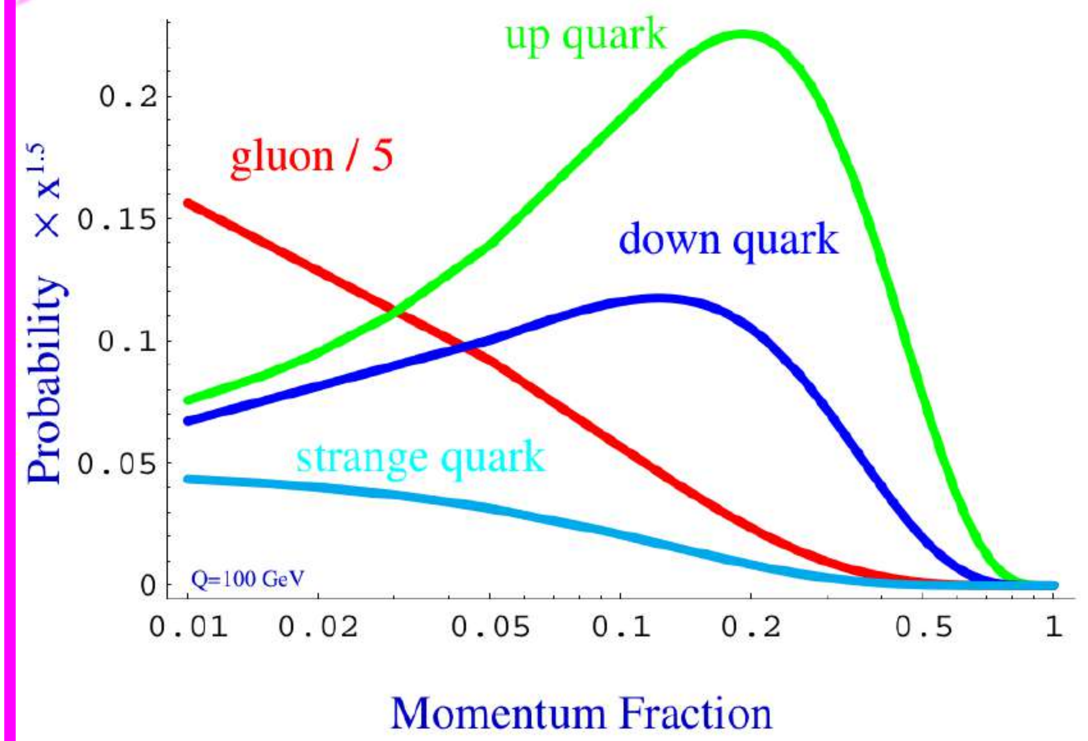
Peter Risse

Available schemes in APFEL++

scheme	$\mathcal{O}(\alpha_s)$	NC: F_2	NC: F_3	NC: F_L		CC: F_2	CC: F_3	CC: F_L
ZM	N2LO	✓	✓	✓		✓	✓	✓
FONLL-C	N2LO	✓	✗	✓		✗	✗	✗
ACOT	NLO	✓	✓	✓		✗	✗	✗
sACOT-χ	NLO	✓	✓	✓		✓	✓	✓
approx. sACOT-χ	N2LO	✓	✓	✓		✓	✓	✓

Strange PDF: ν Nucleon di-muon Production

Strange PDF

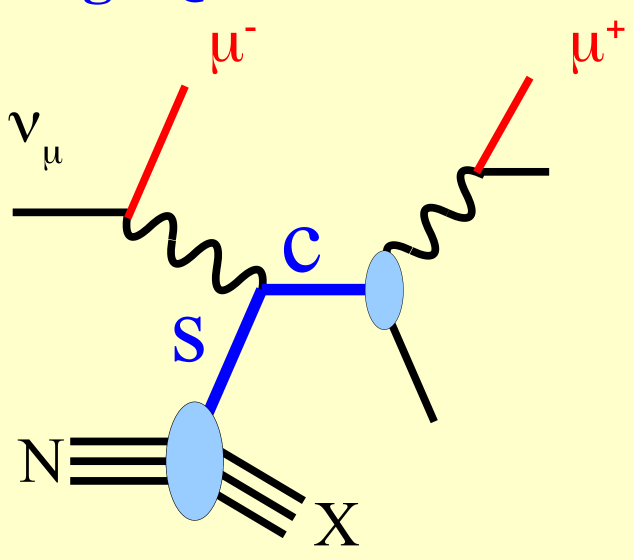


Result:

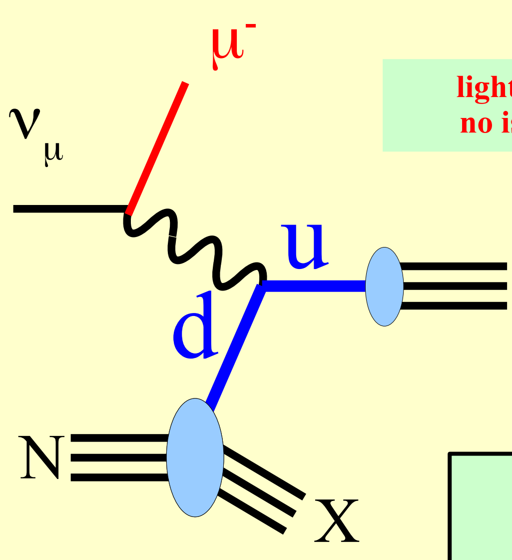
$$\bar{s}(x) \sim \frac{1}{2}\,\bar{d}(x)$$

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

Strange Quark



Down Quark



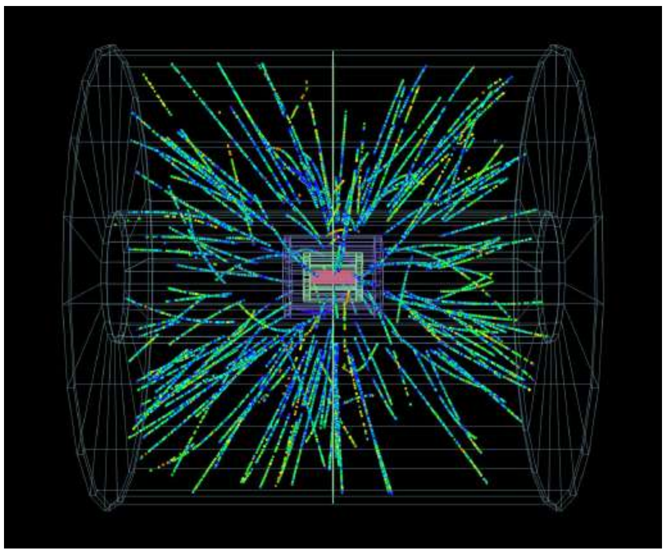
light u mass
no isolated μ

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

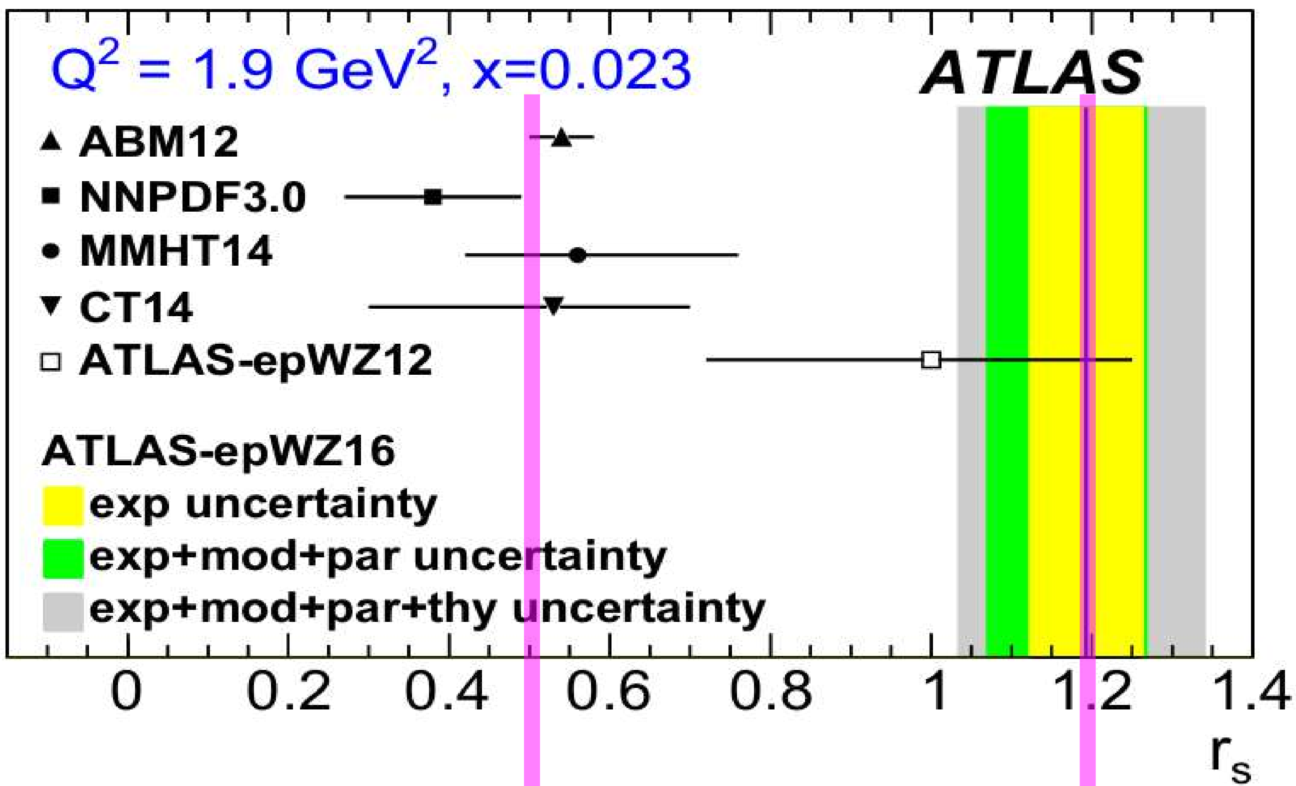
Surprise: … LHC sees more strange than expected

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

Surprise:

We expected $r_s = 1/2$

LHC finds $r_s > 1$



Proton case

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

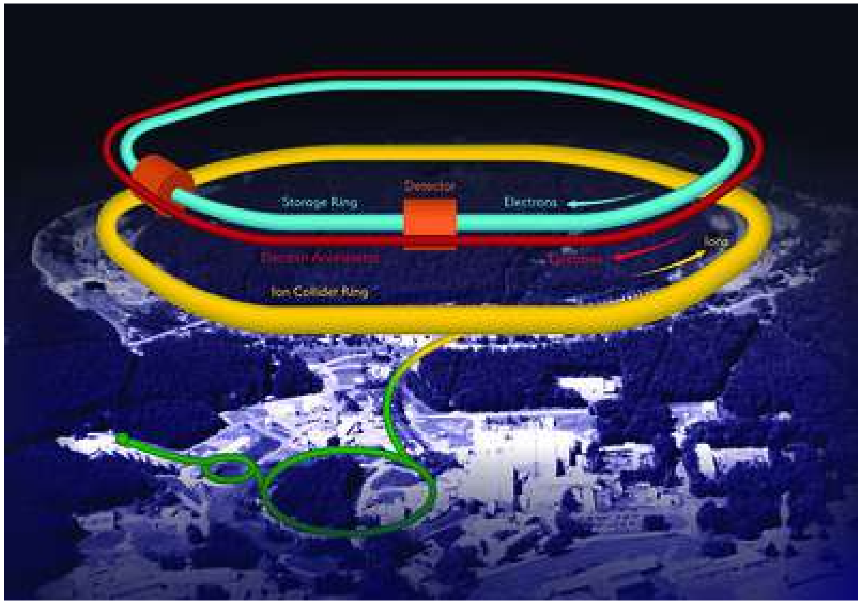
We expect:

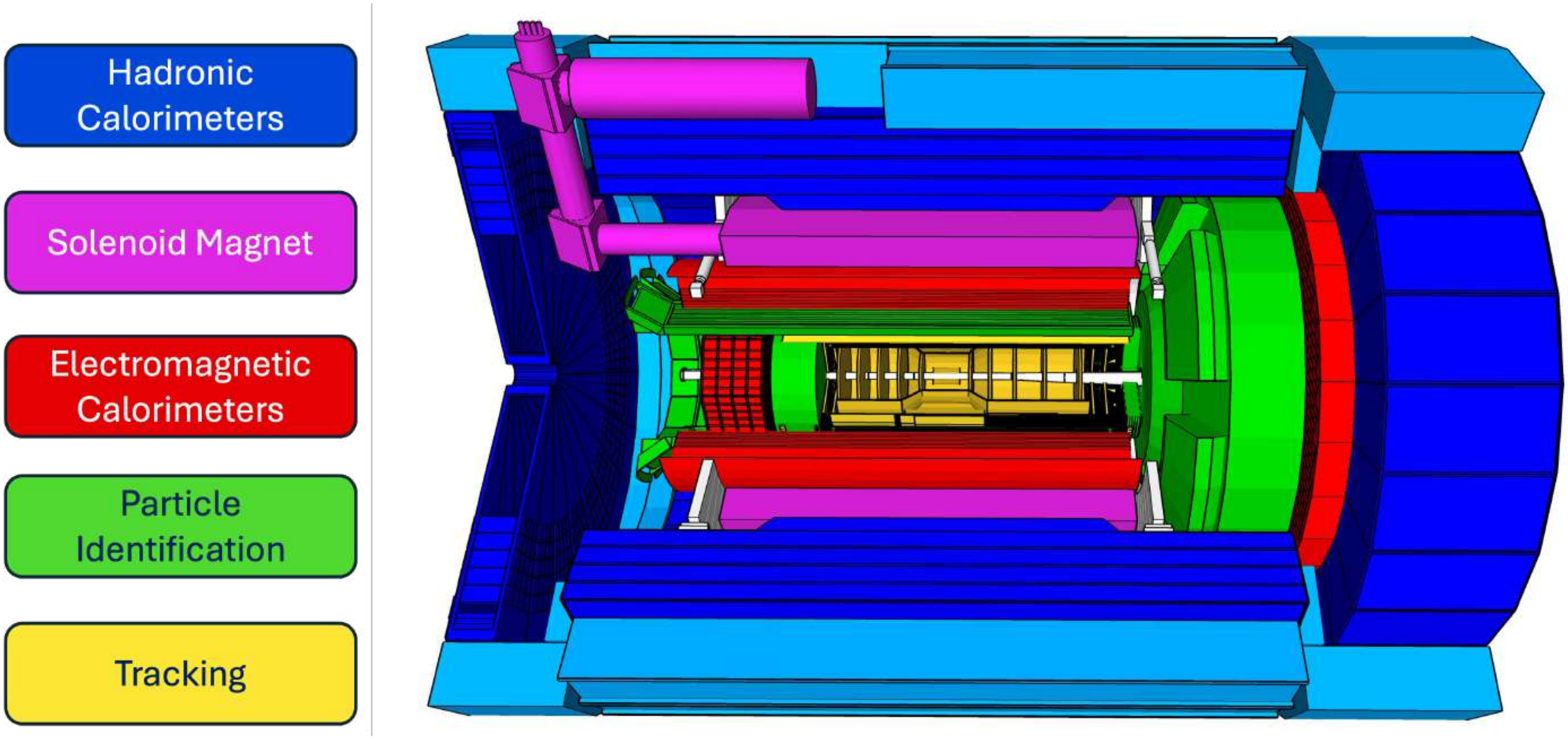
At the LHC:

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

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

If only we had more DIS data



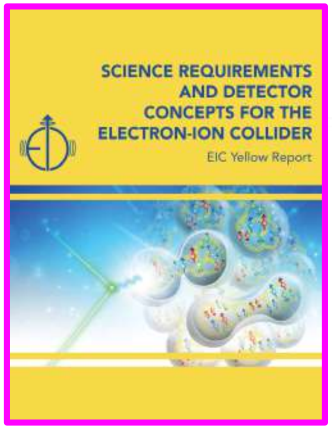


Charm Jets at the EIC:

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

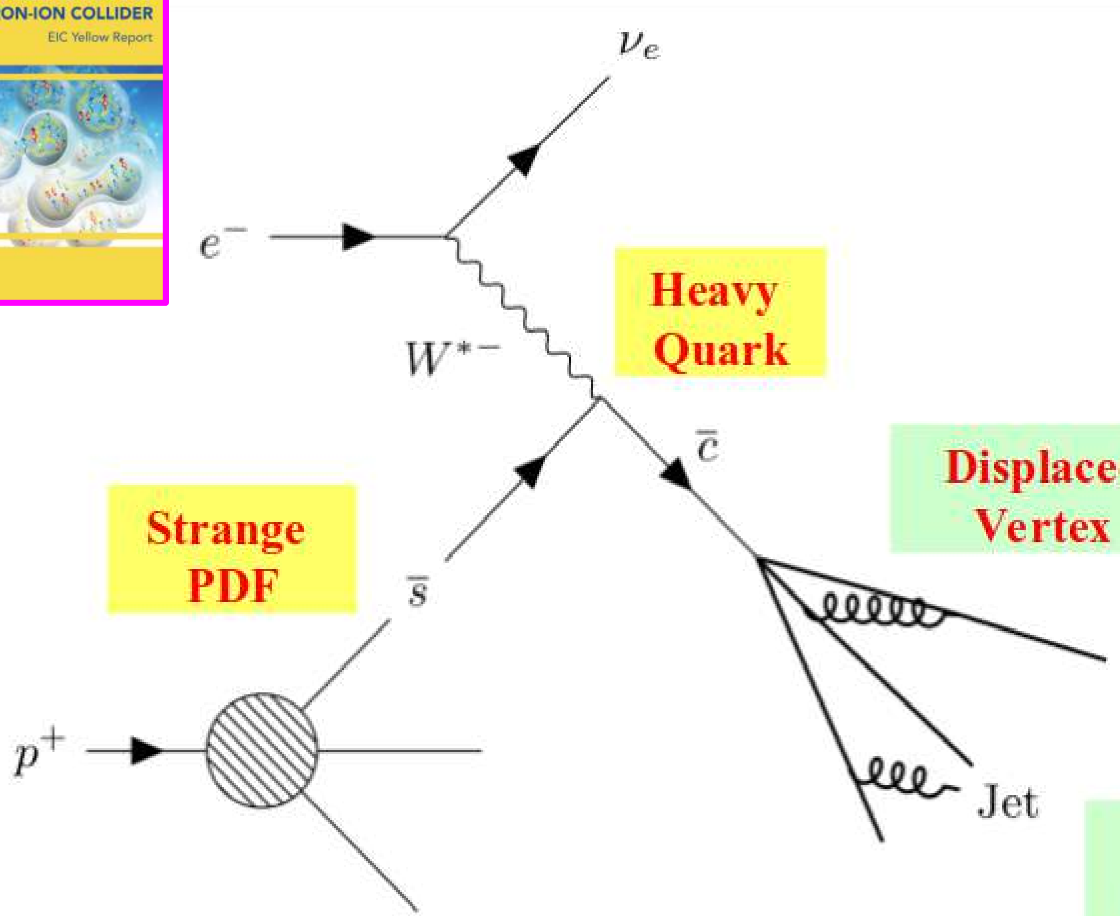
Charm jets as a probe for strangeness at the future Electron-Ion Collider

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



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

Missing E_T



Heavy Quark

Strange PDF

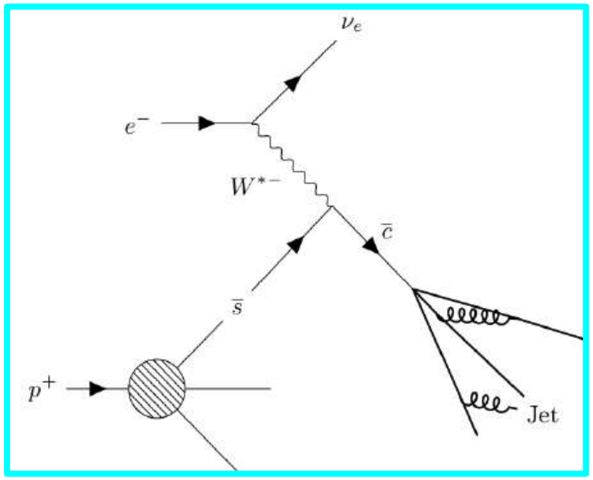
Displaced Vertex

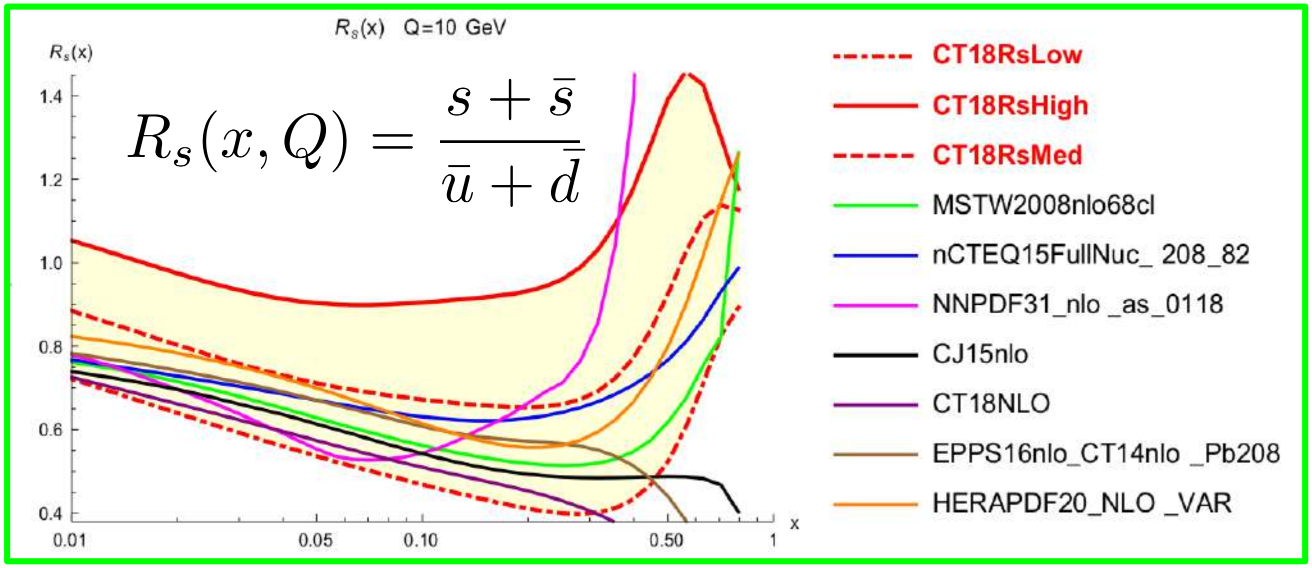
Jet Producton

Clear measure of Strange PDF beyond uncertainties

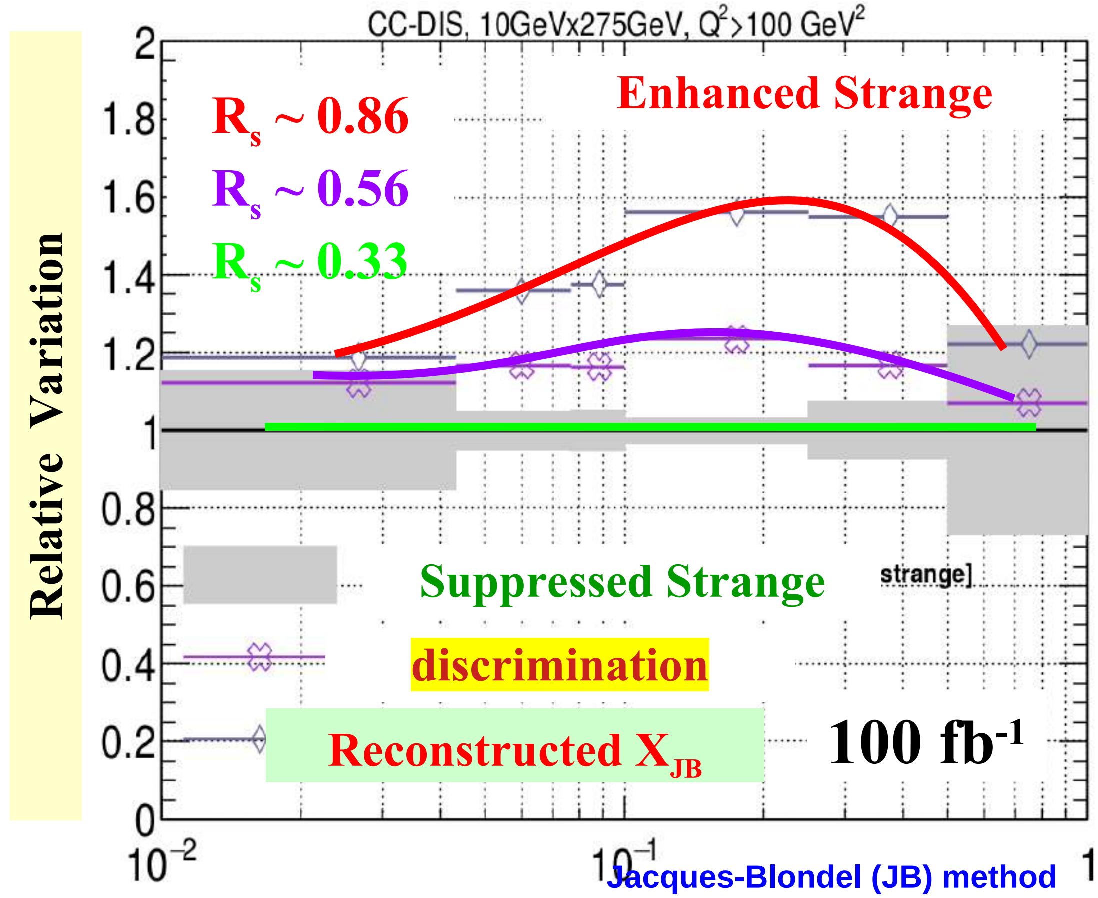
M. Arratia, Y. Furletova, T.J. Hobbs,
F. Olness, S.J. Sekula,
Phys.Rev.D 103 (2021) 7, 074023

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

PDF Tools
xFitter

xFitter Collaboration Meeting
February 2020, DESY

xFitter

PROTON

NUCLEON

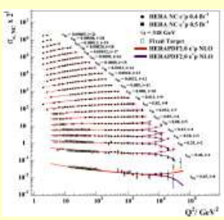
MESON

www.xFitter.org

Sample data files:

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

Experimental Data



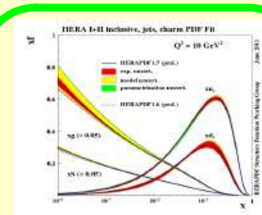
Data: HERA, Tevatron, LHC, fixed target experiments

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

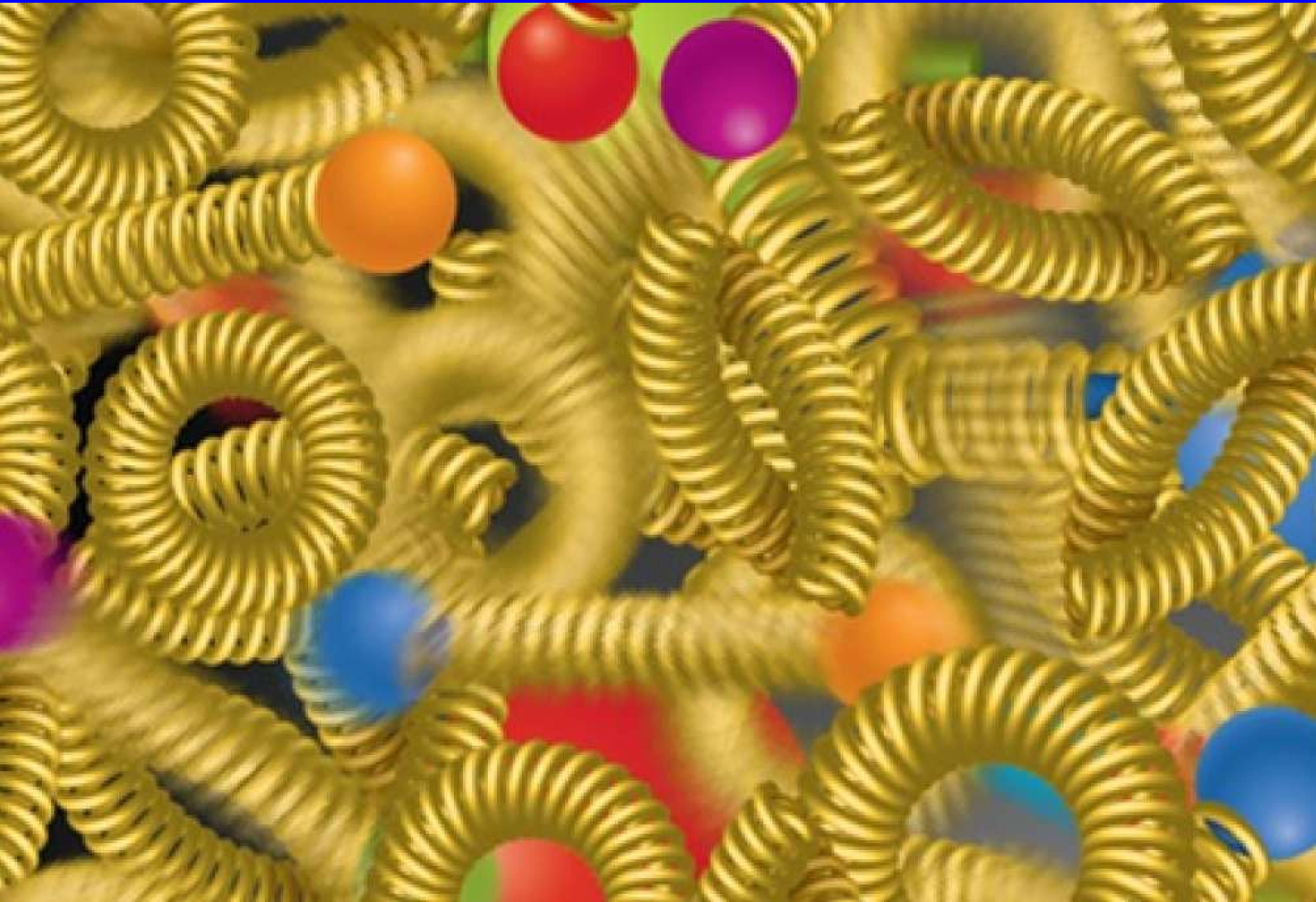
Features & Recent Updates:

NNLO DGLAP
Photon PDF & **QED**
Pole & MS-bar masses
Profiling and Re-Weighting
BFKL interface

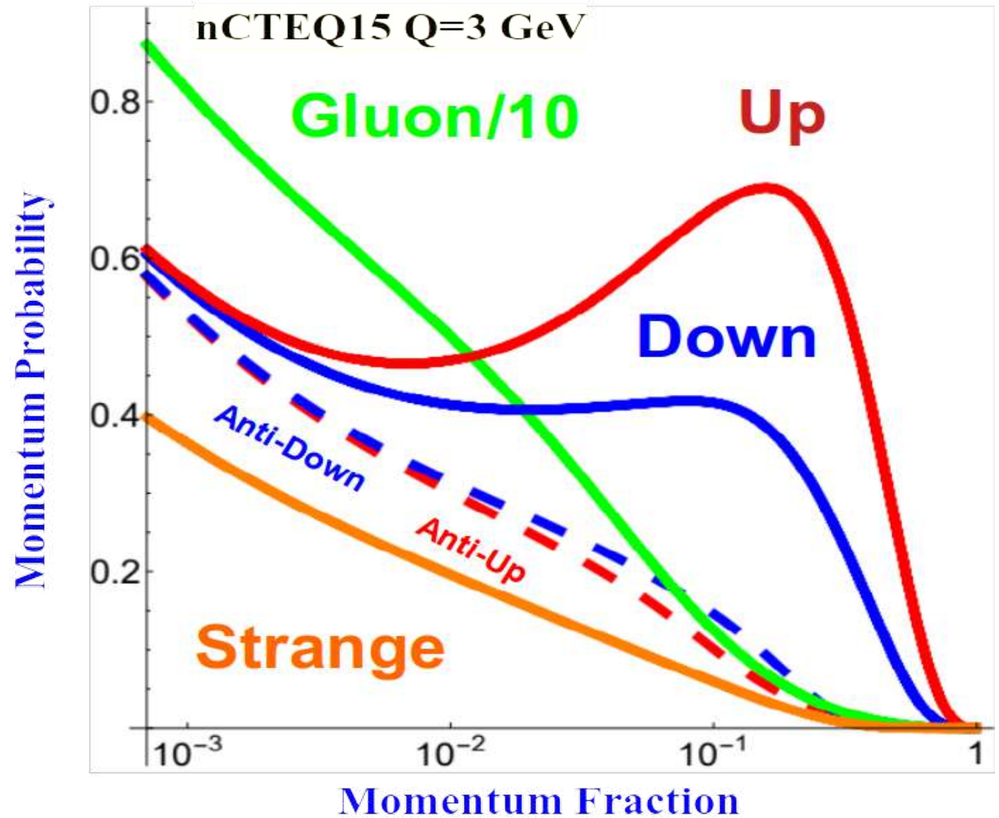
Heavy Quark Variable Treshold
Improvements in χ^2 and correlations
TMD PDFs (uPDFs)
… and many other

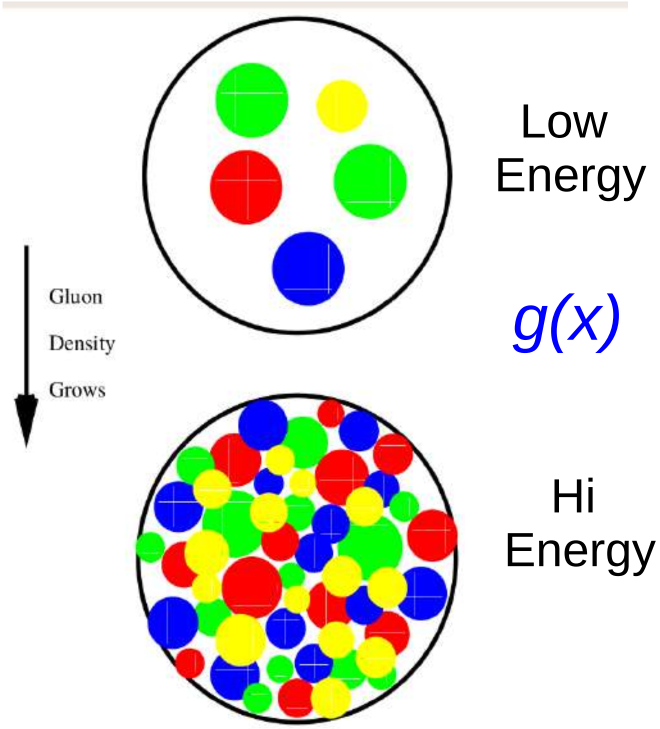
xFitter 2.2.0
Future Freeze

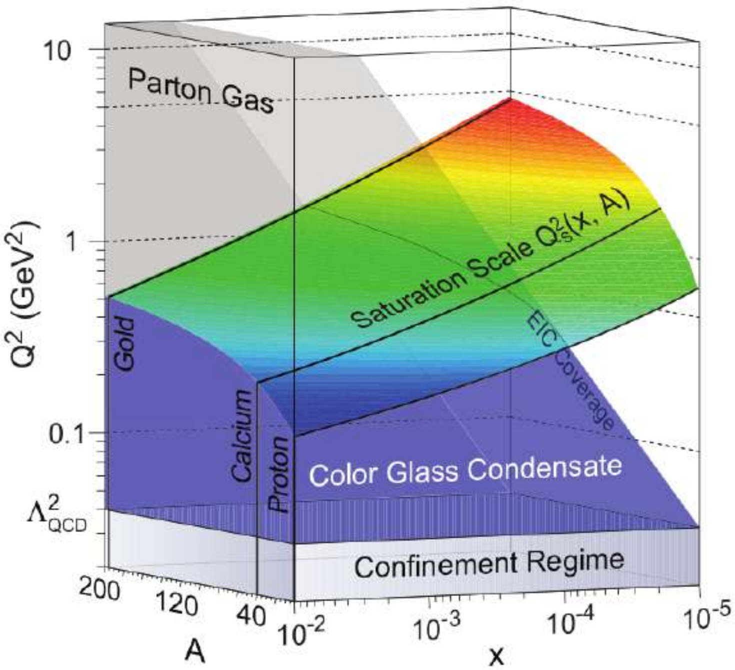
The Gluon



Nuclear Medium Effects at small momentum fraction (x)



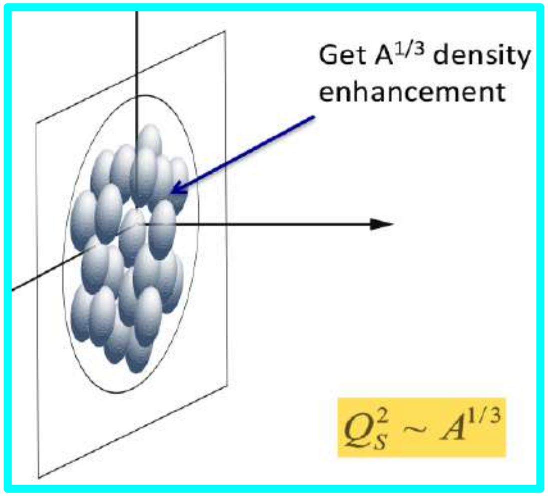




Nuclear medium effects:

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

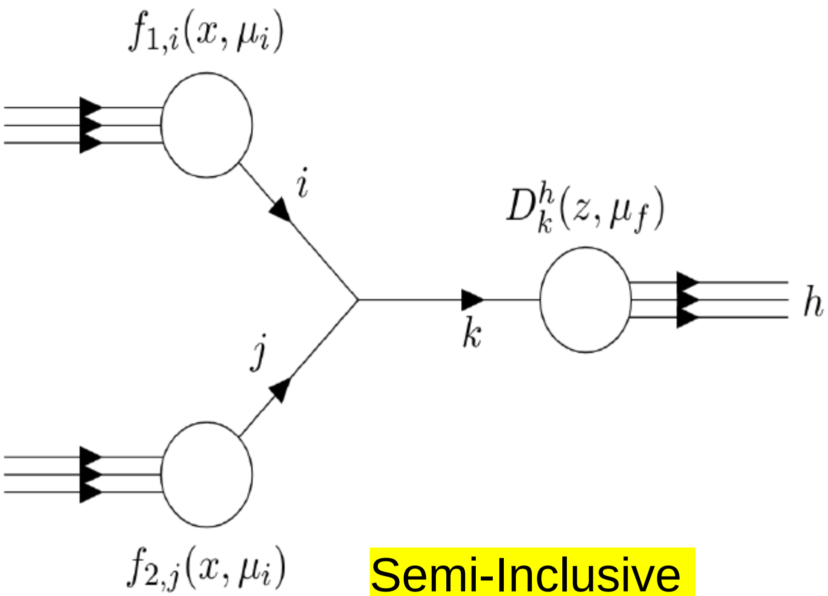
We gain a geometric factor of $A^{1/3}$



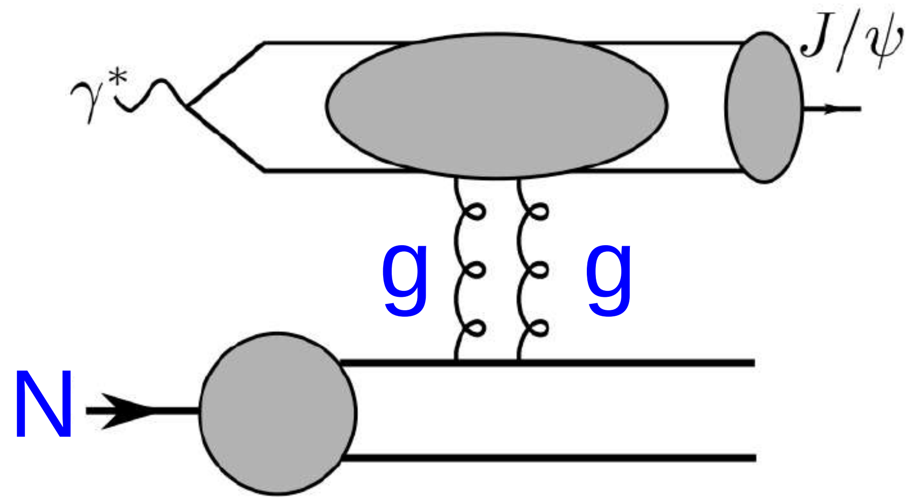
Measuring the nuclear Gluon PDF

Parton Distribution Functions

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



Semi-Inclusive
Hadron Production

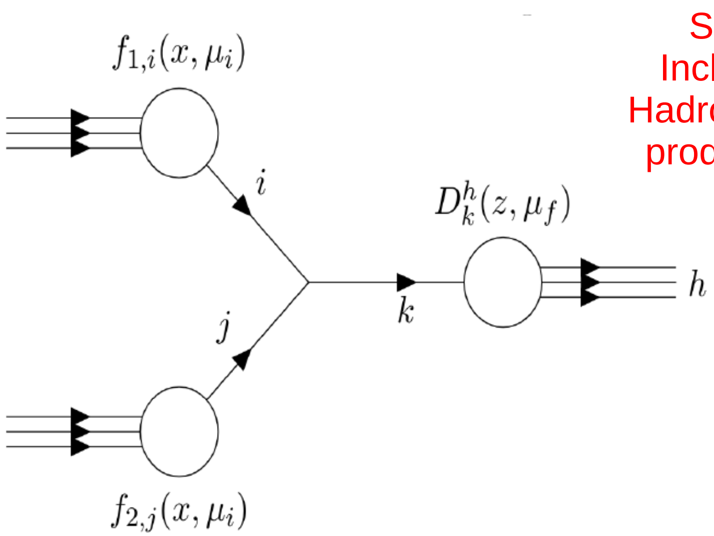


Quarkonia
Production

how can we
determine the gluon

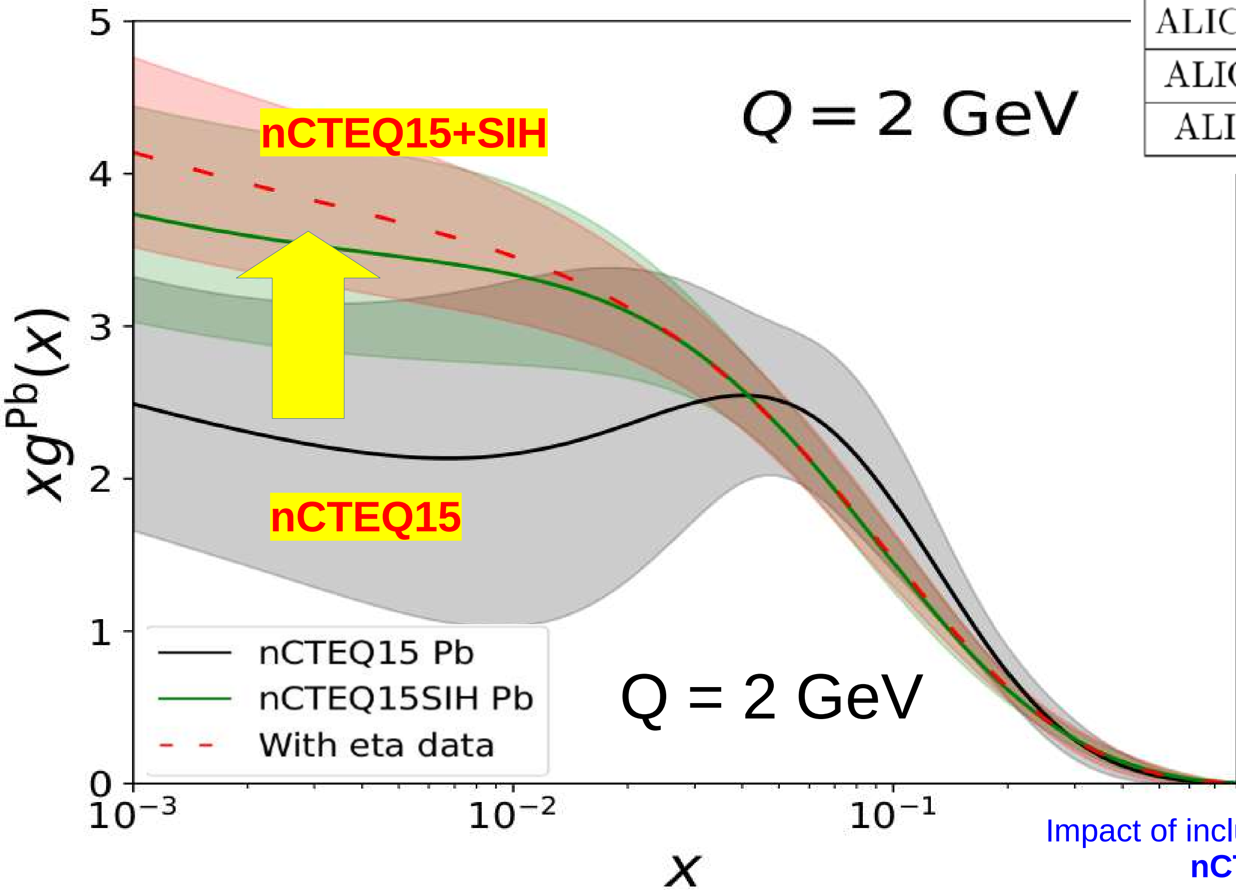
Precision Gluon can help study nuclear medium effects

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



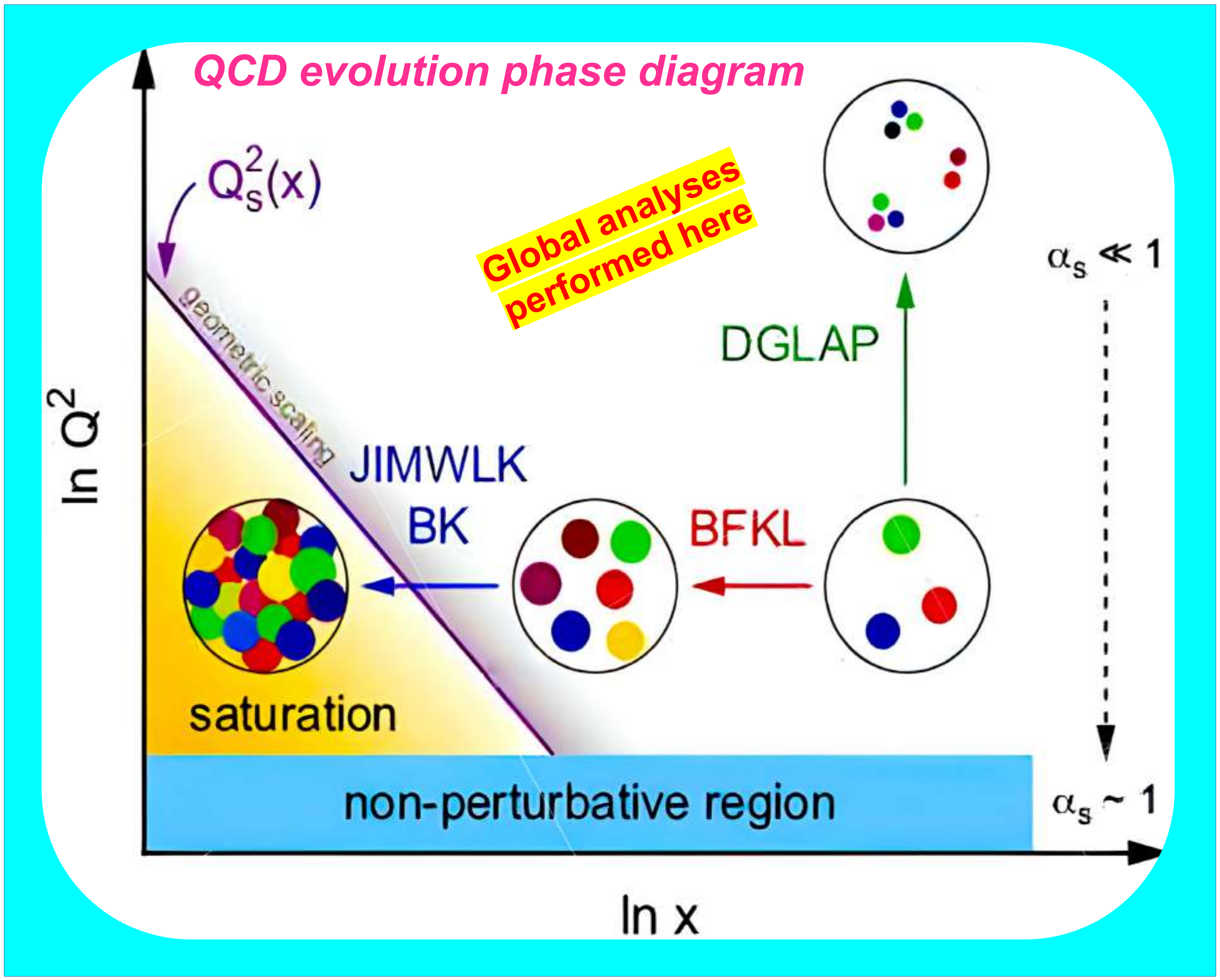
Semi-Inclusive Hadron (SIH) production

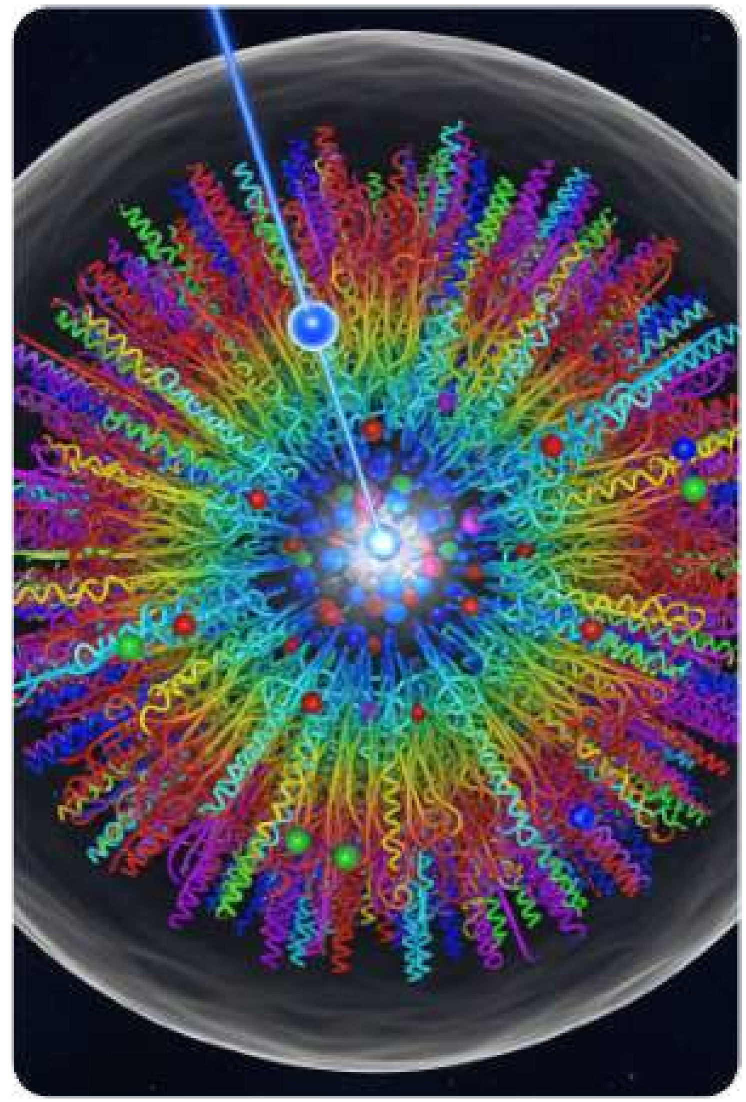
Determines gluon in small x region

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

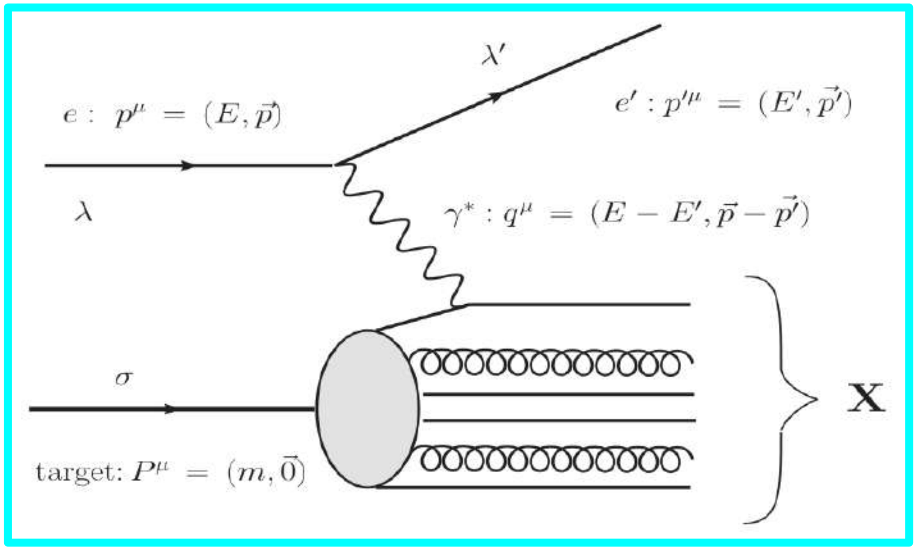
SURGE Topical Collaboration

Mission statement: Discover and explore the gluon saturation regime of quantum chromodynamics by advancing calculations to high precision and developing a comprehensive framework to compute observables and compare to a wide range of experimental data, including predictions for the Electron Ion Collider (EIC).





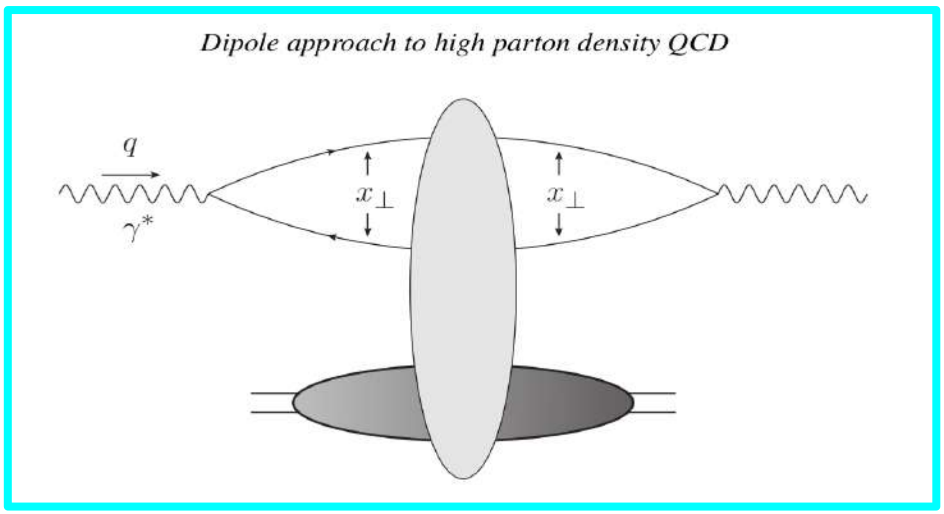
Paradigm Choice: Parton Model & Dipole Model



Parton Model

$$\sigma = f_{P\to a}(x,Q) \otimes \widehat{\sigma}_{a\gamma\to X}(x,\hat{s})$$

Implemented in **xFitter**
uses several numerical "tricks"
for efficient computation



Dipole Model

GOAL: Develop flexible
framework to test
initial/final-state, spin, NLO ...

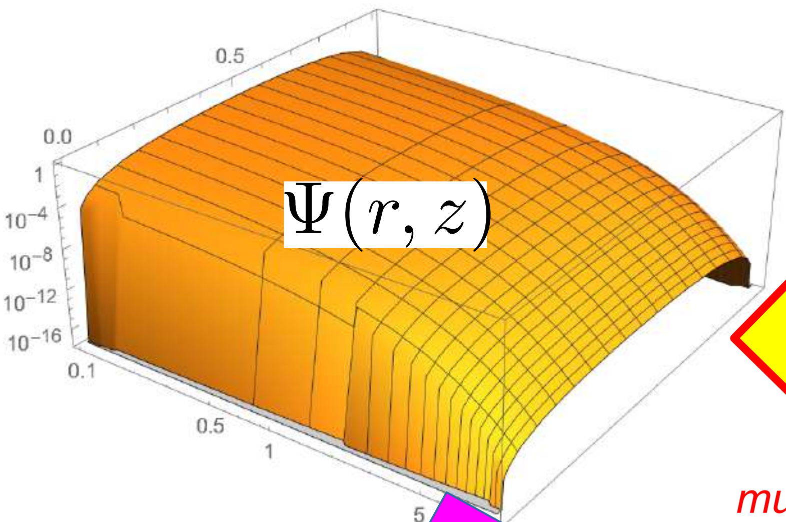
The dipole model excels at small-x and
describes the transition between perturbative
and non-perturbative QCD regime.
Incorporates "shadowing" or "saturation"
which is key for dense gluon configurations.

$$\sigma_{tot}^{\gamma^* A}(x,Q^2) \simeq \iint |\Psi^{\gamma^*\to q\bar{q}}(\vec{x_\perp},z))|^2 \otimes \sigma_{tot}^{q\bar{q}A}(\vec{x_\perp},Y)$$

Photon light-front wave function

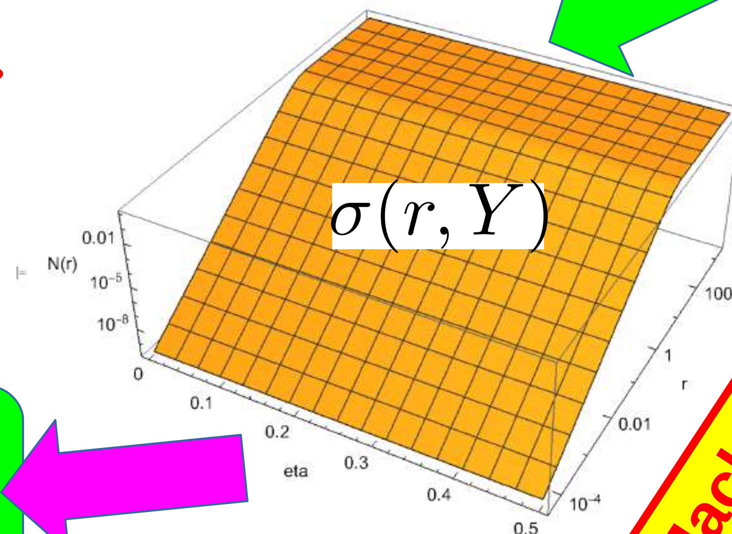
Dipole–nucleus cross section

$$\sigma_{tot}^{\gamma^* A}(x, Q^2) = \int \frac{d^2 x_\perp}{4\pi} \int_0^1 \frac{dz}{z(1-z)} |\Psi^{\gamma^* \to q\bar{q}}(\vec{x}_\perp, z)|^2 \sigma_{tot}^{q\bar{q}A}(\vec{x}_\perp, Y).$$



Grid Method

must be fast!!!



Machine Learning

Convolution

2D Grid-based calc

$$\sigma_{tot}^{\gamma^* A}(x, Q^2)$$

… F_2 & F_L

$$\chi^2 = \frac{(D-T)^2}{\sigma^2}$$

xFitter

Machine Learning: MLP (Multi-Layer Perceptron) Model


Junaid Khan


Brandon Stevenson

Neural Network Setup

- **Input features**: **x, r, C, Qs0, γ**
- **Input model: McLerran-Venugopalan**
- **Target**: N(x,r) dipole cross section
- **Architecture**: 3 hidden layers (64, 64, 32 neurons) with ReLU activation
- **Output layer**: Linear

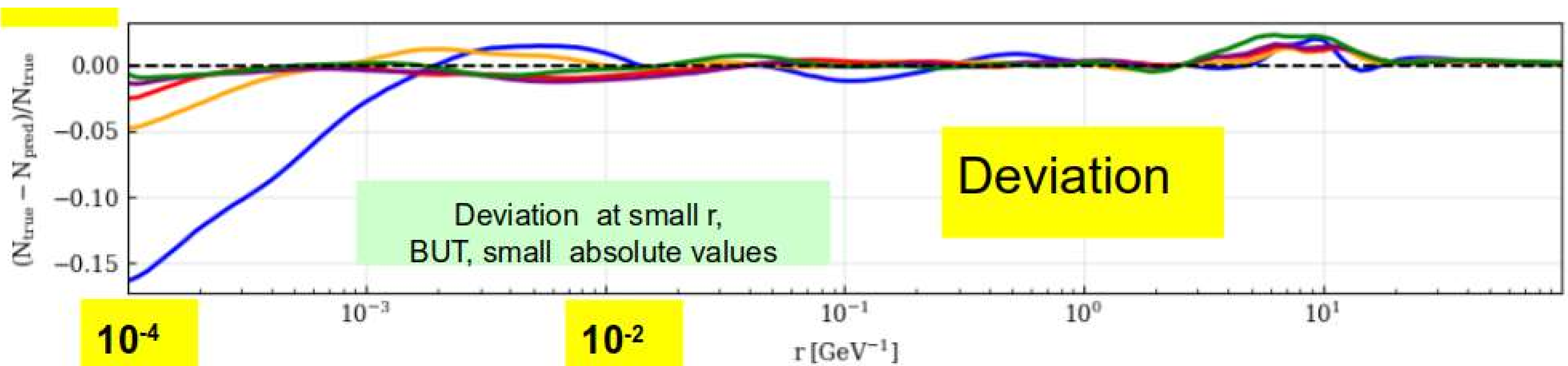
Training Details

- Optimizer: **AdamW**
- Learning rate: **Exponentially decaying**
- Loss function: **Custom** **(scaled MSE: Mean Absolute Error.)**

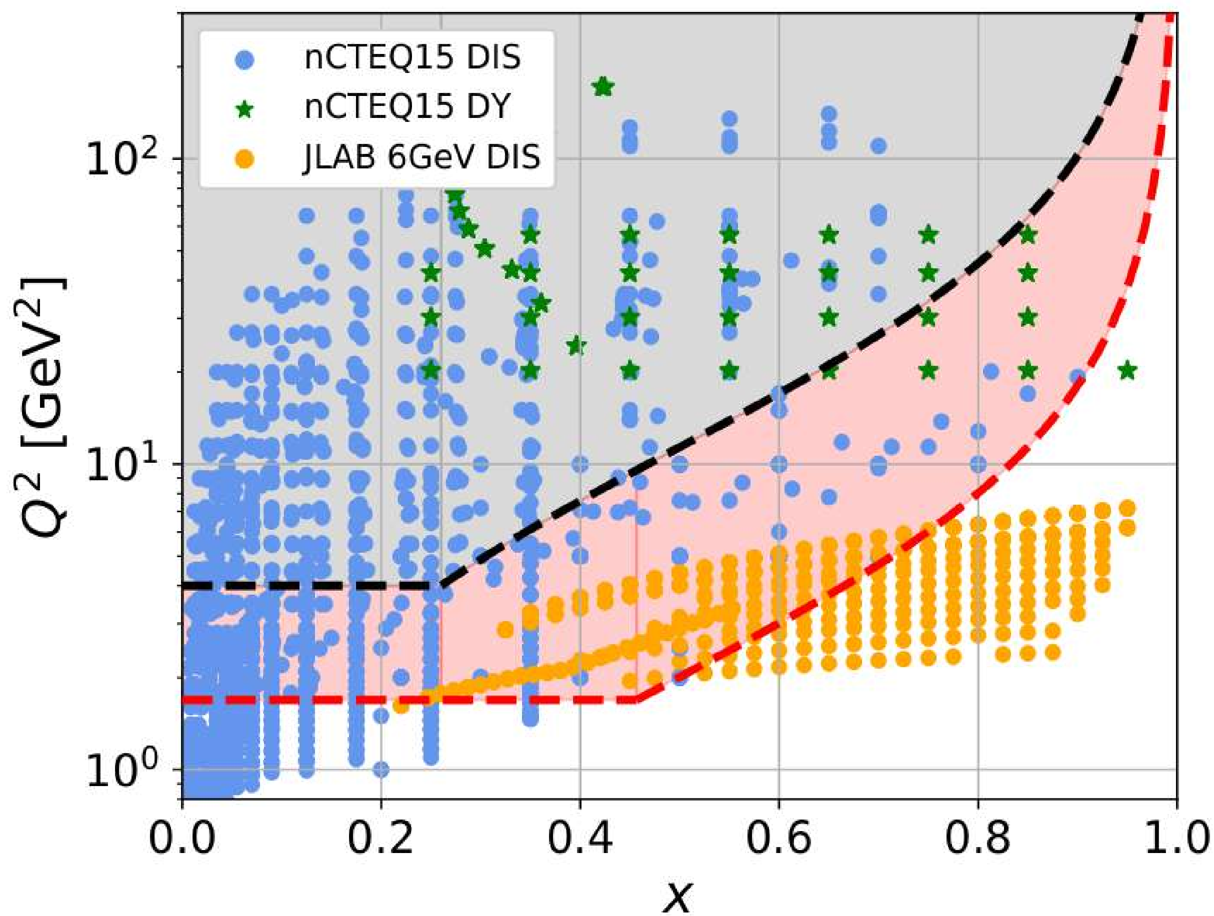
Dataset split: **80/10/10** (train/validation/test)

$$\mathrm{MSE} = \frac{1}{N}\sum_{i=1}^{N}\left(y_i^{\mathrm{pred}} - y_i^{\mathrm{true}}\right)^2$$

$$L = \frac{1}{N}\sum_{i=1}^{N}\frac{\mathrm{MSE}}{(0.01\, y_i^{\mathrm{true}} + \varepsilon)^2}$$



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



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

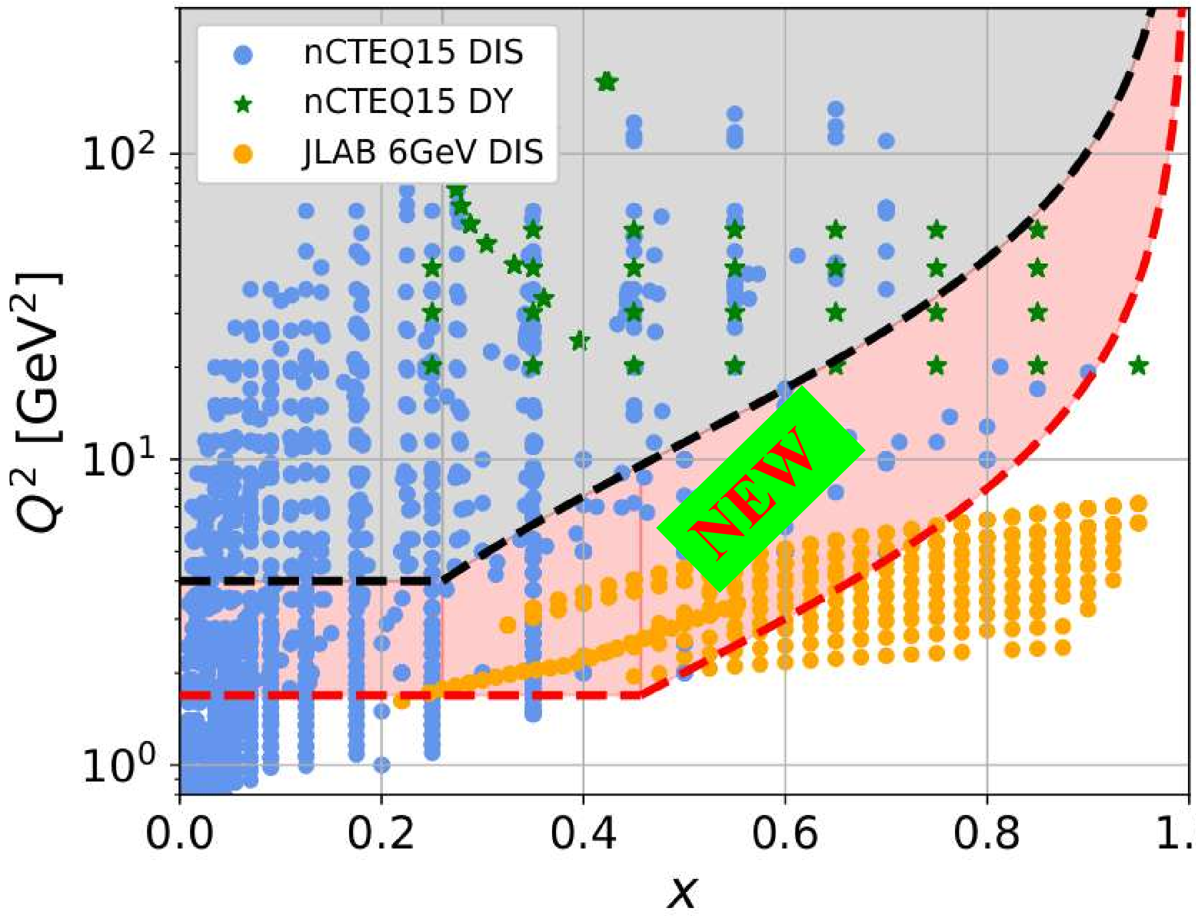
Extending nuclear PDF analyses into the high-x, low-Q^2 region

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:

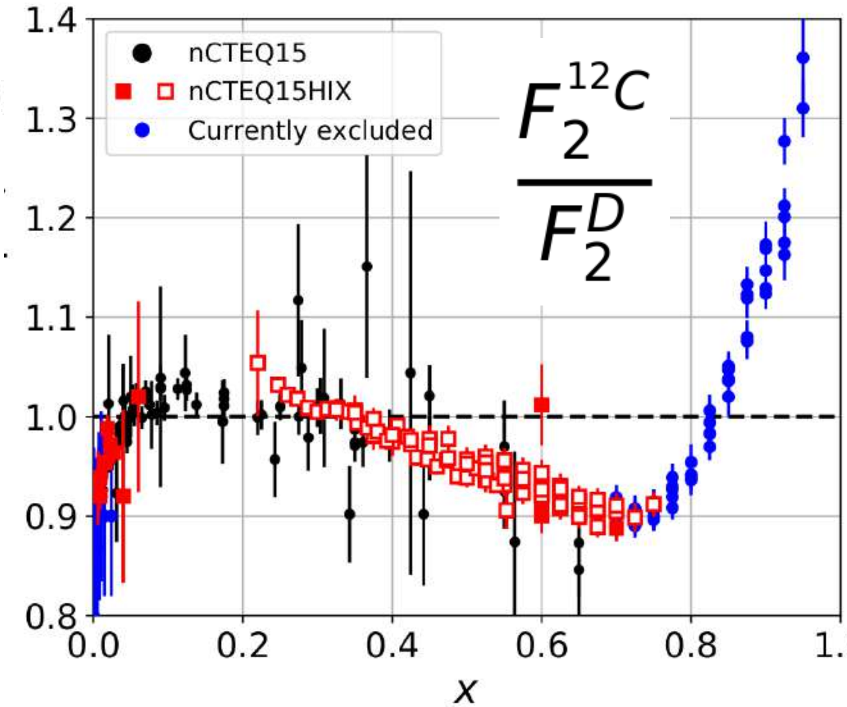
- Deuteron Corrections
- Higher twist
- Target Mass Effects

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

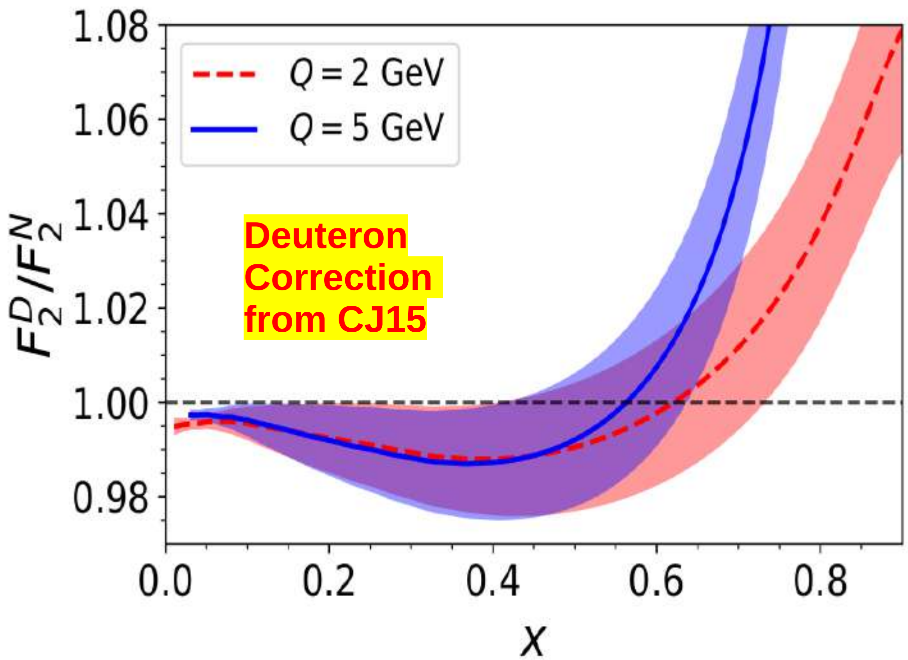
open points: new with relaxed cuts

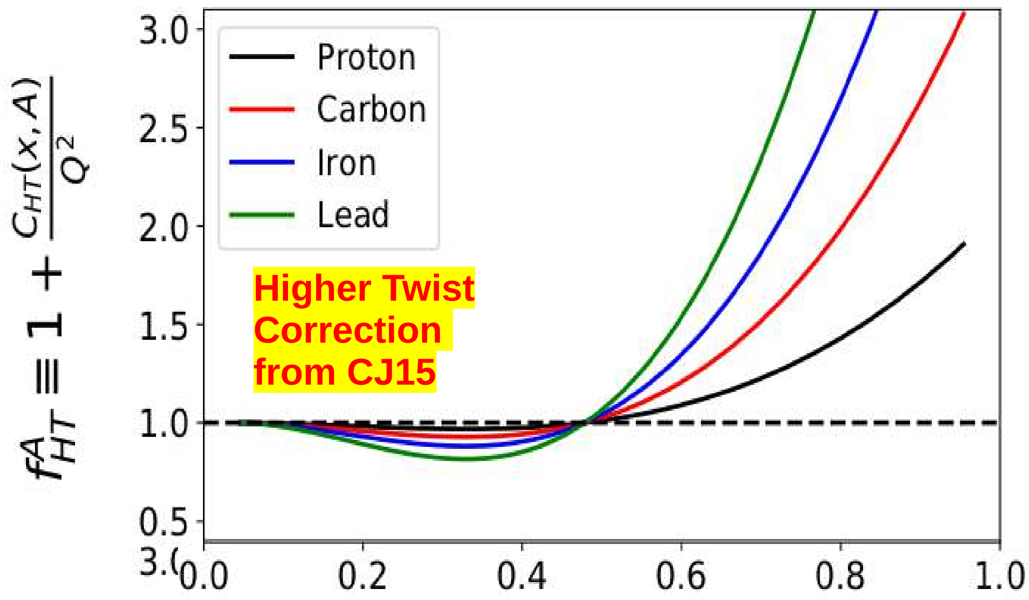


Extend nCTEQ framework
to accommodate this region
{Q,W}= {2, 3.5} ⇒ {1.3, 1.7}

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





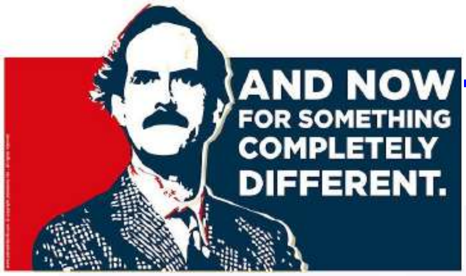
Fit	χ^2	N_{data}	χ^2/N_{dof}	Q_{cut}	W_{cut}
nCTEQ15	587	740	0.81	2.0	3.5
nCTEQ15*	2664	1564	1.70	1.3	1.7
BASE	1525	1564	0.99		
HT	1482	1564	0.96		
DEUT	1331	1564	0.85		
nCTEQ15HIX	1291	1564	0.83		

Reference
Higher Twist ~3%
Deuteron ~14%
Combined ~16%

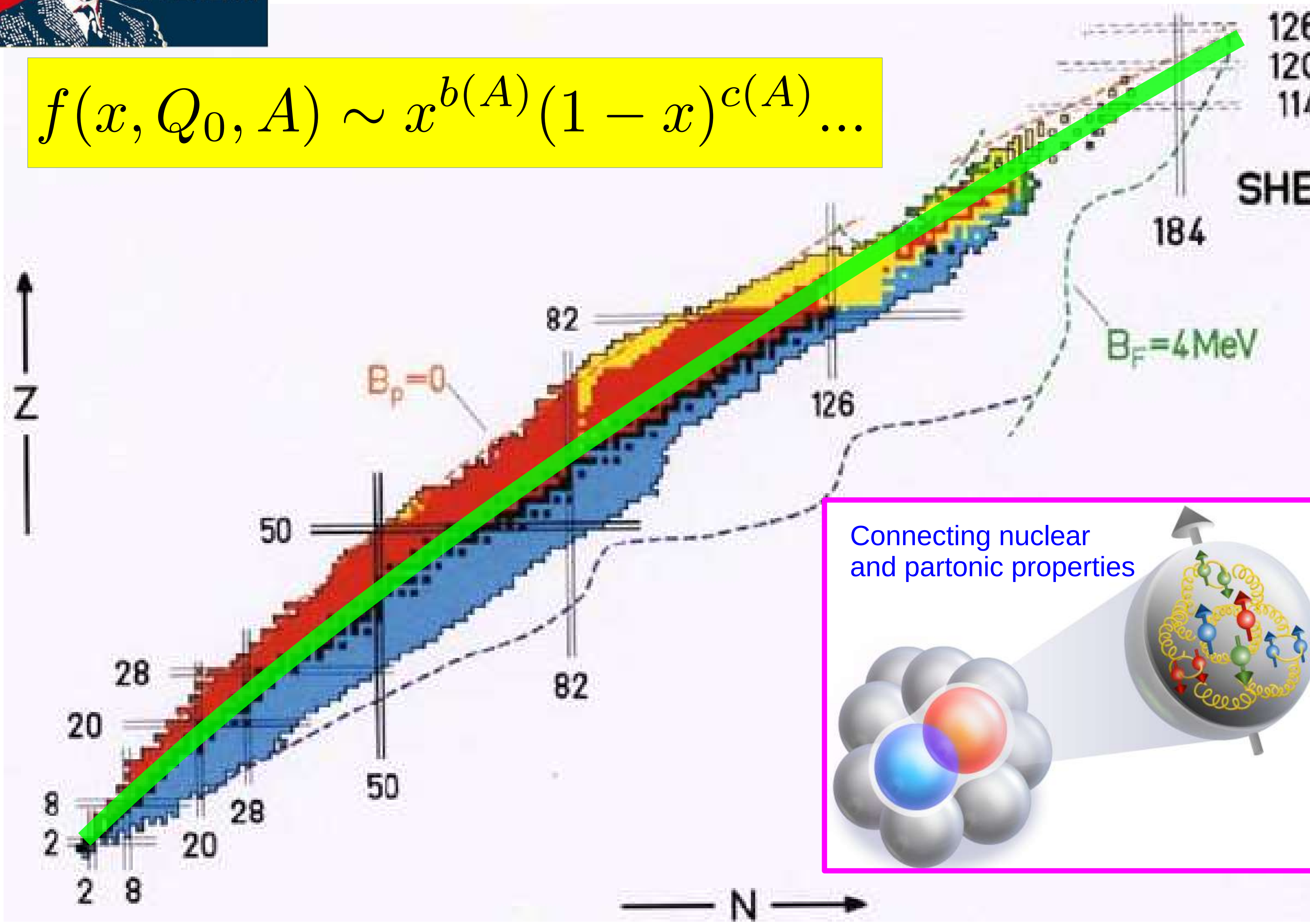
We can extend our kinematic reach in {x,Q²}

what about mid x region

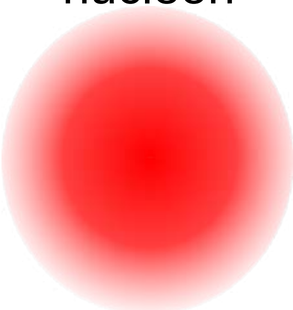
How do we characterize nuclei?



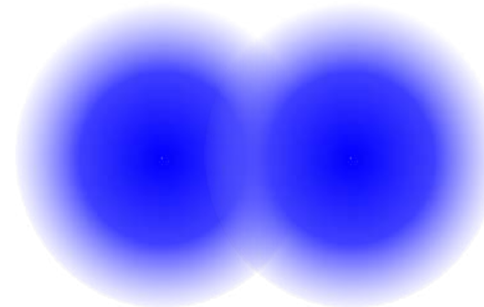
$$f(x, Q_0, A) \sim x^{b(A)}(1-x)^{c(A)} \ldots$$

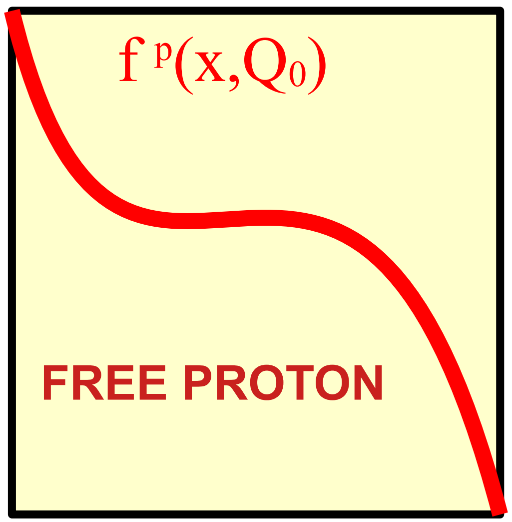


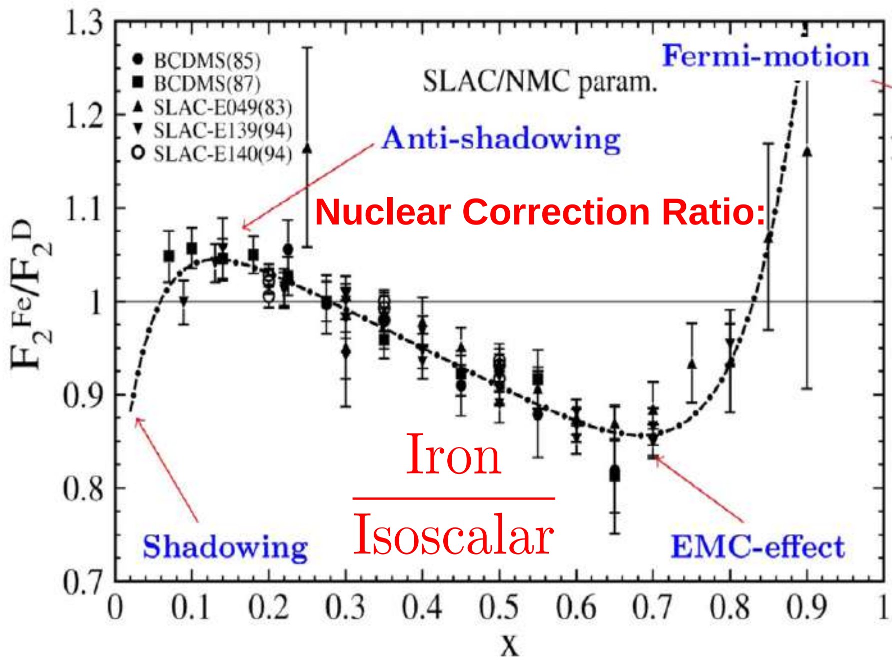
nucleon

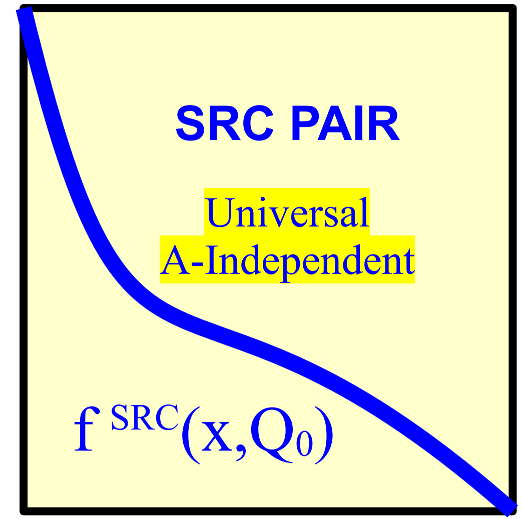


nucleon - nucleon









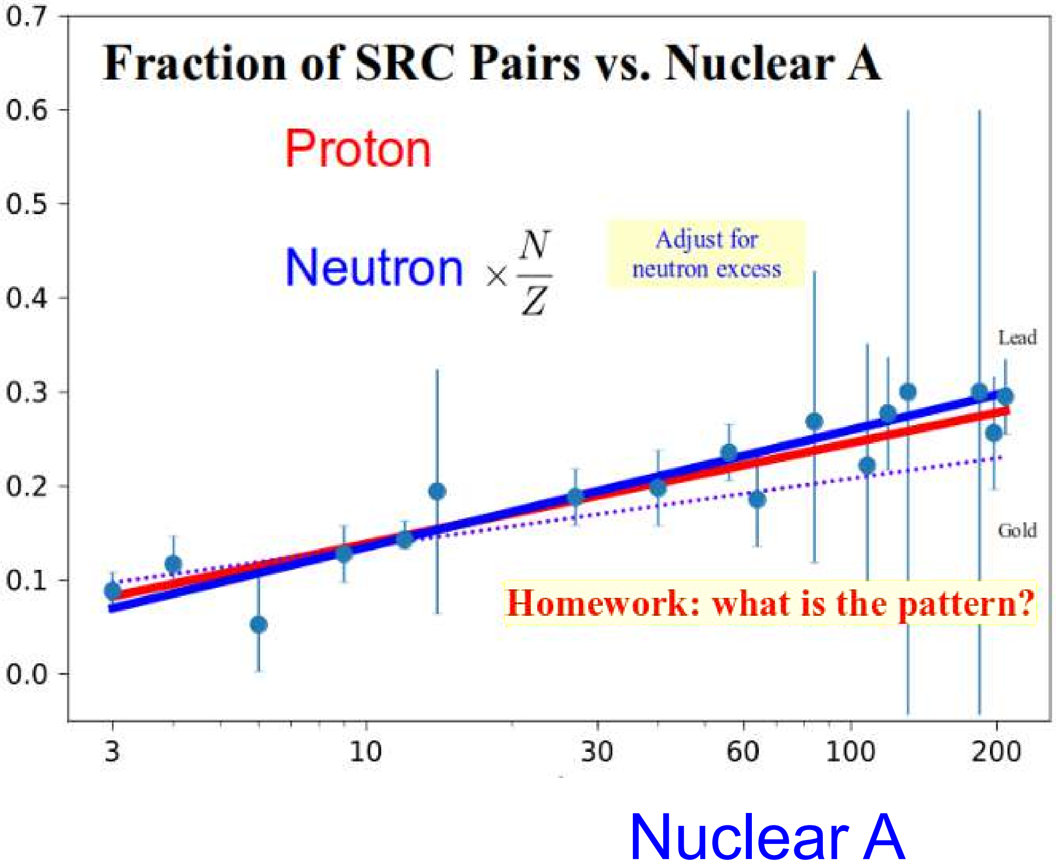
Linear Combination of 2 functions

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

Universal
A-Independent

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

Question: do C_A coefficients display any patterns???

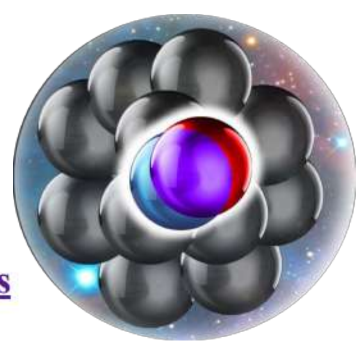


➔ Simple Nearest-Neighbor (SRC) inspired form yields remarkably good fit

➔ Comparable/better than traditional approach

➔ Coefficients scale with **ln(A)**

➔ Separate p,n fits are consistent with (pn) SRC pairs



Relate nuclear to particle properties

physicsworld TOP 10 BREAKTHROUGH 2024

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.

This parameter form connects to new concepts

CONCLUSIONS

FONDAZIONE BRUNO KESSLER

ECT*
EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS

WORKSHOP

QUARK-GLUON DYNAMICS IN THE NUCLEAR MEDIUM

9 - 13 November 2026

ECT* - Villa Tambosi, Villazzano

This workshop will bring together experimentalists and theorists to discuss recent progress and open questions in understanding how quark and gluon dynamics are modified in the nuclear environment. The workshop aims to foster focused discussion across subfields and to identify key directions for future measurements and theoretical work.

Topics will cover related developments in theory, phenomenology, and experiment in the areas of gluonic components in nuclei, hadronization, partonic structure, nuclear medium effects, short-range correlations, 3D nucleon/nuclear structure, vector mesons, hypernuclei, and connections to the future electron ion collider.

ORGANIZERS

Holly **Szumila-Vance**, Florida International University
Cynthia **Keppel**, 3q Scientific Consulting
Fredrick **Olness**, Southern Methodist University
Matteo **Rinaldi**, INFN Perugia
Misak **Sargsian**, Florida International University

ECT* Director: Prof. Ubirajara van Kolck

The ECT* is part of the Fondazione Bruno Kessler. The Centre is funded by the Autonomous Province of Trento, funding agencies of EU Member and Associated states, and by INFN-TIFPA and has the support of the Department of Physics of the University of Trento.

For the organization please contact: Barbara Gazzolii – ECT* Secretariat - Villa Tambosi - Strada delle Tabarelle 286 | 38123 Villazzano (Trento) – Italy
Tel.:(+39-0461) 314763, E-mail: gazzoli@ectstar.eu or visit http://www.ectstar.eu

SUPPORTING INSTITUTIONS

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QUARK-GLUON DYNAMICS IN THE NUCLEAR MEDIUM

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https://indico.ectstar.eu/event/276/

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 …"

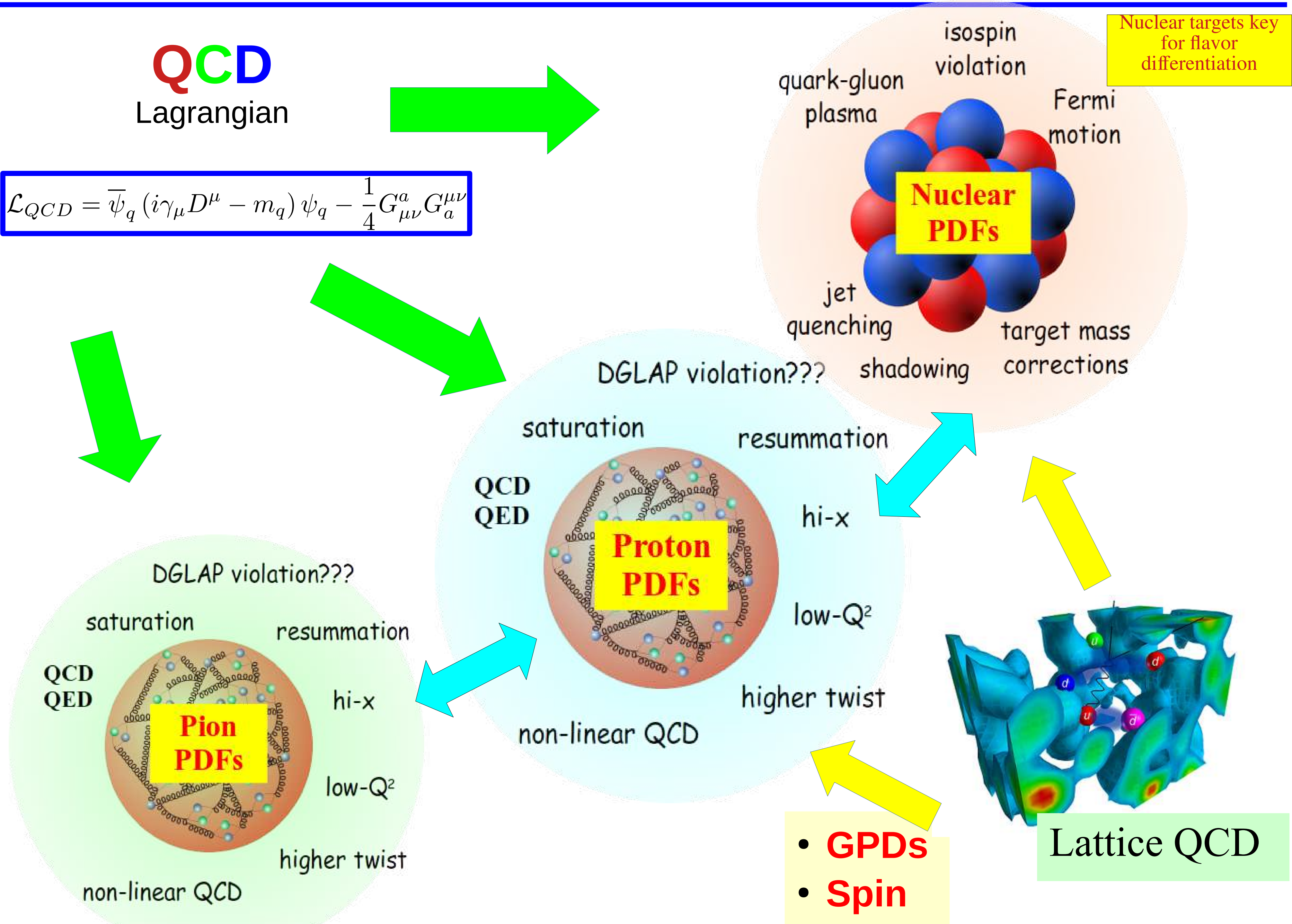
— Isaac Asimov

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



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

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