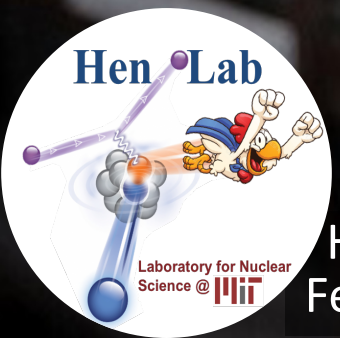
The LAD Experiment: "In Medium Nucleon Structure Functions, SRC, and the EMC effect"

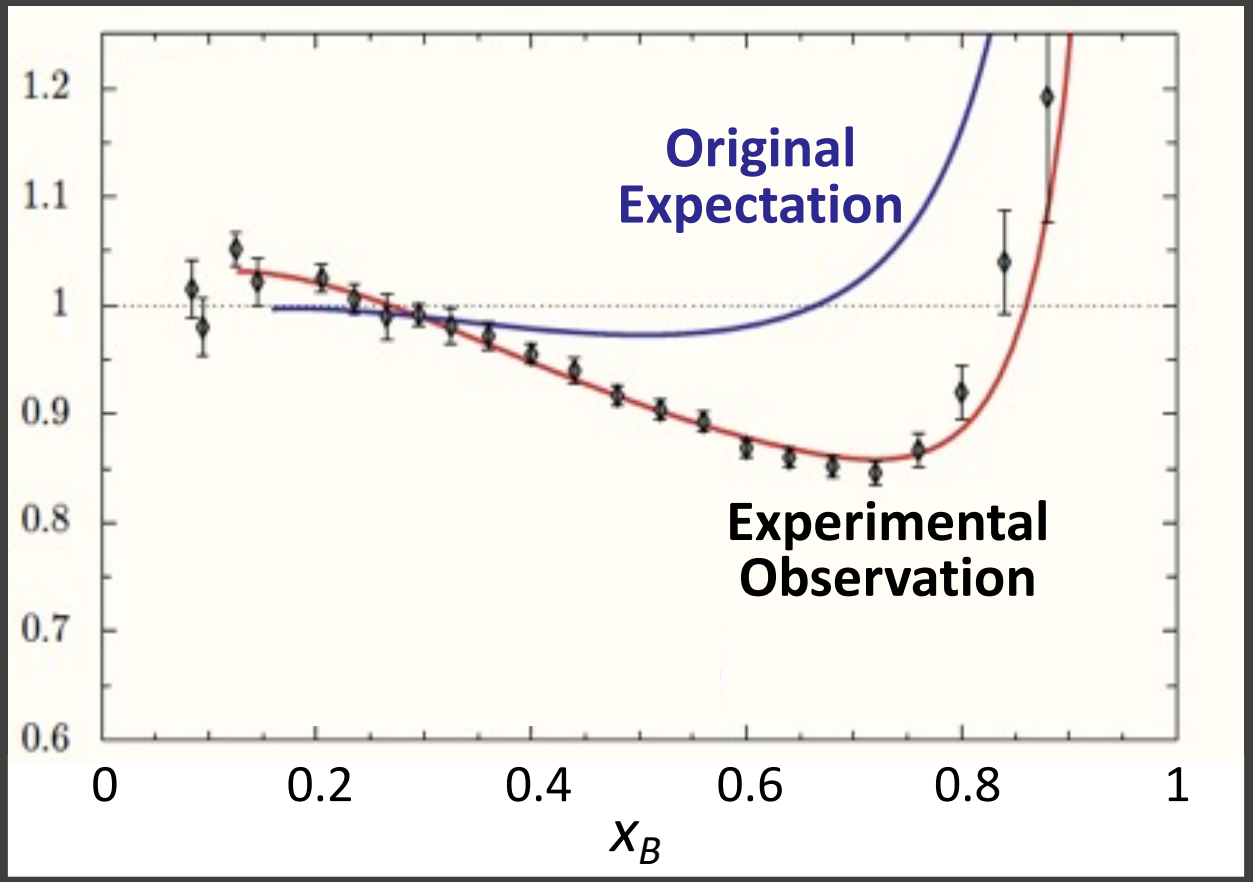
Or Hen
(MIT)



Hall-C Collaboration Meeting,
February 18th, 2022

EMC Effect:

Iron / Deuterium
Structure Function



Aubert et al., PLB (**1983**); Ashman et al., PLB (1988); Arneodo et al., PLB (1988); Allasia et al., PLB (1990); Gomez et al., PRD (1994); Seely et al., PRL (2009); Schmookler et al., Nature (**2019**)

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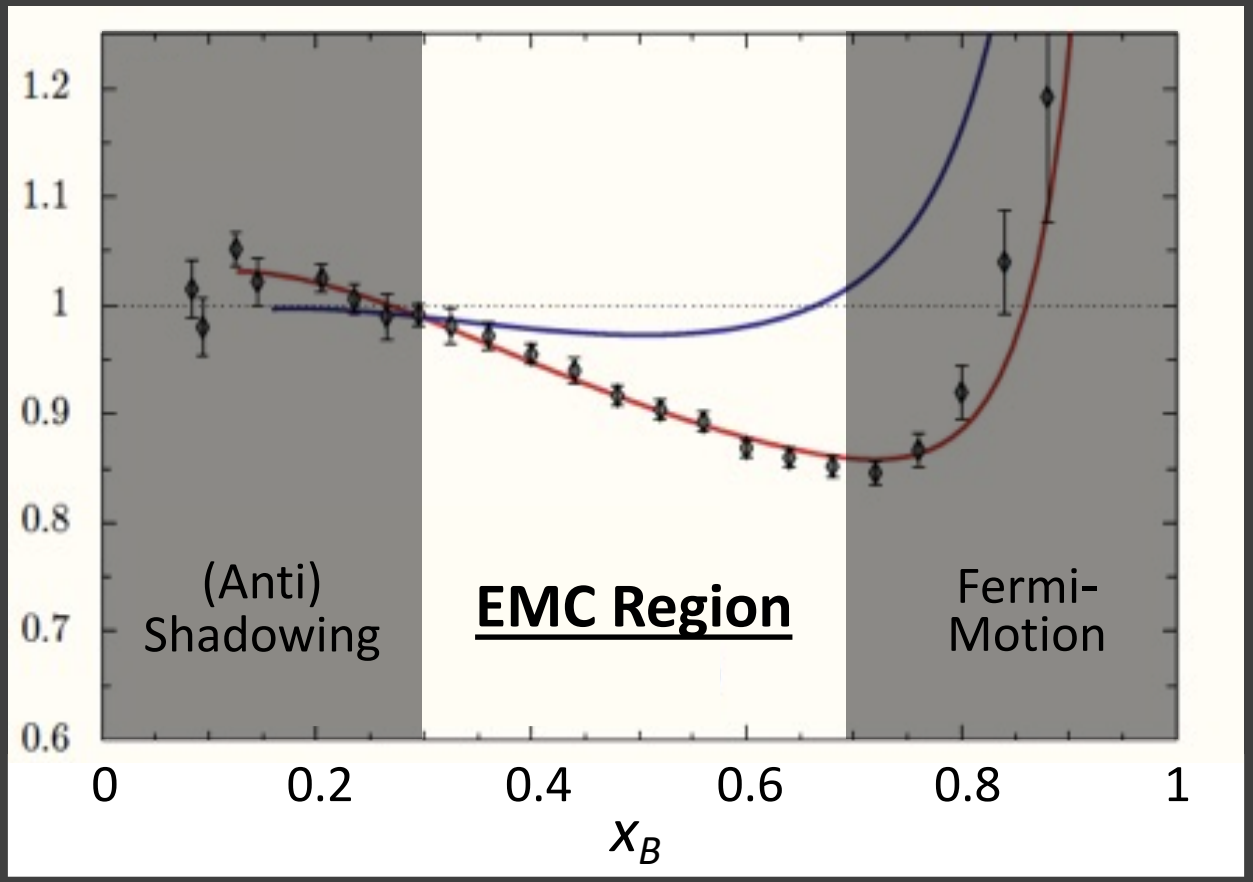

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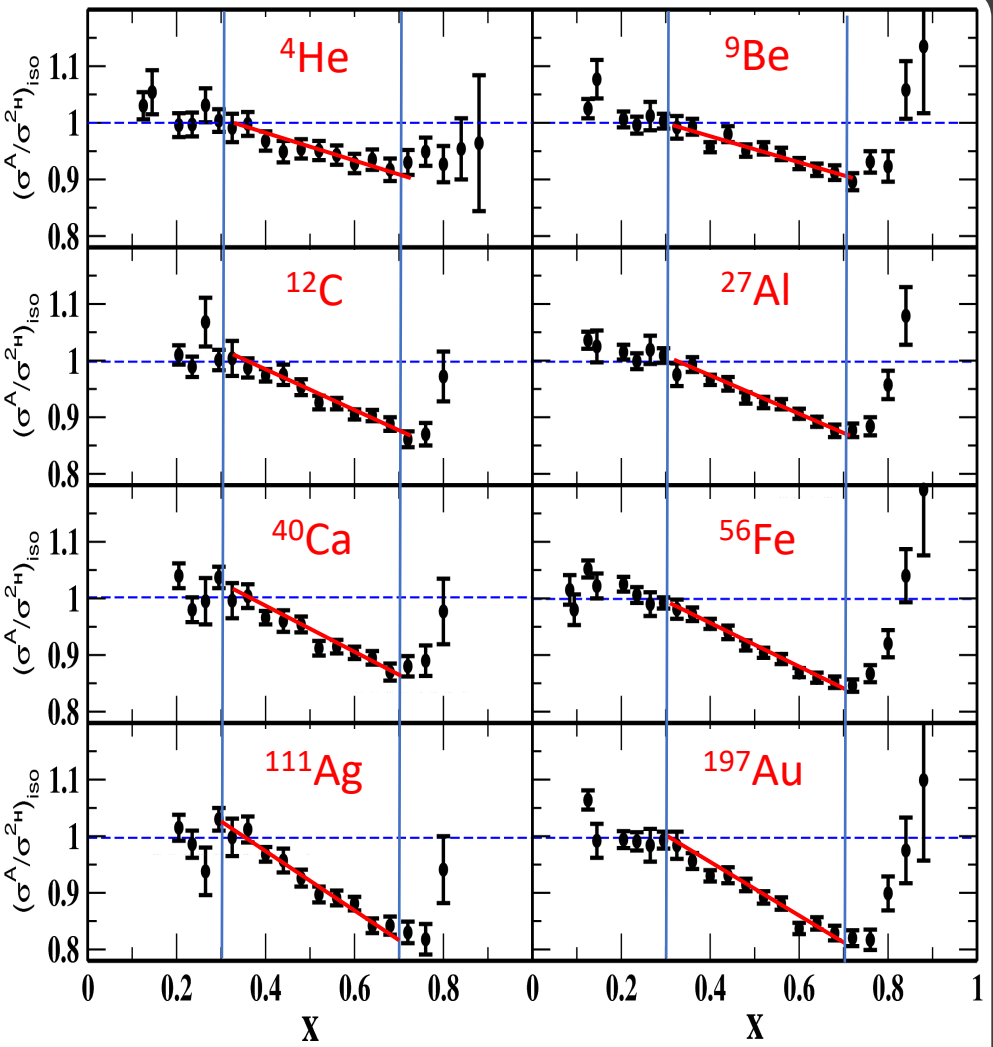
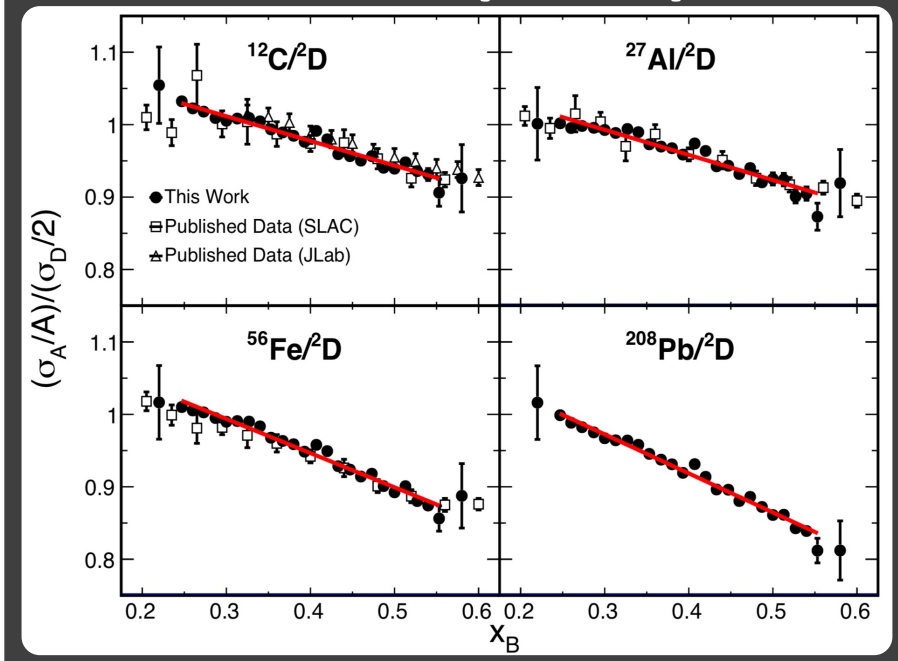
‘Global’ EMC Data



Gomez PRD (1994)

SLAC (1994)

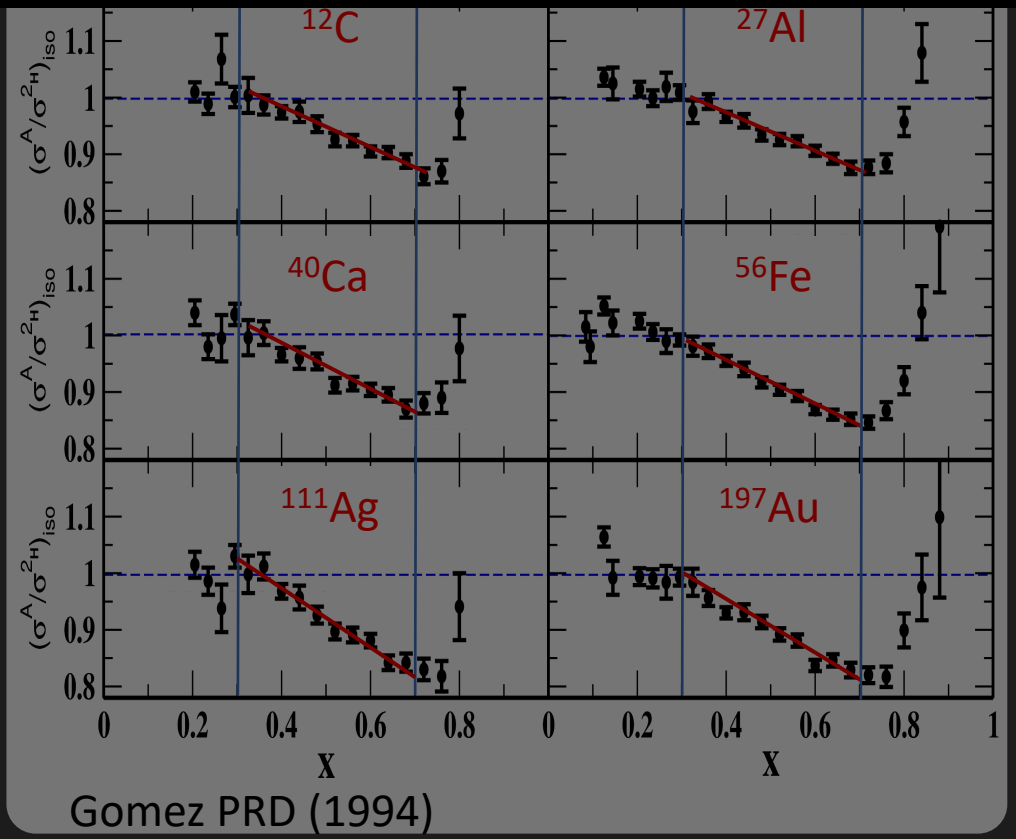
JLab (2019)



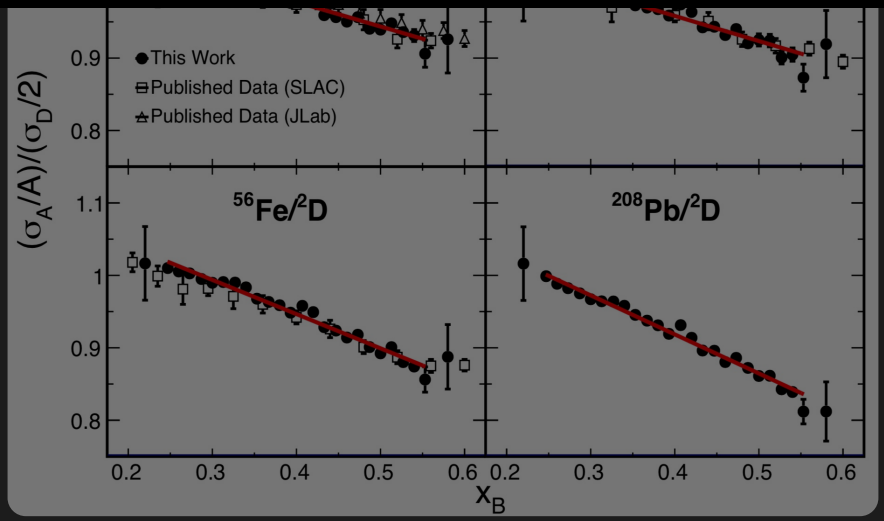
Schmookler, Nature (2019)

‘Global’ EMC Data

Effect driven by nuclear structure & dynamics



Gomez PRD (1994)



Schmookler, Nature (2019)

SLAC (1994)

38 years, >1000 papers, 3 Ideas

1. Proper treatment of ‘known’ nuclear effects
   - Nuclear Binding and Fermi motion, Pions, Coulomb Field.
   - **No modification of bound nucleon structure.**

2. Bound Nucleons are ‘larger’ than free nucleons.
   - Larger confinement volume => slower quarks.
   - Static, mean-field effect.

3. Short-Range Correlations
   - Beyond the mean-field.
   - **Dynamical.**

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PERSPECTIVES

Where Are the Nuclear Pions?

George F. Bertsch, Leonid Frankfurt, Mark Strikman

Unexpected results in a number of experiments in high-energy and medium-energy nuclear physics are chipping away one of the cornerstones of nuclear physics, namely the pi meson (or pion) as a dominant carrier of the nuclear force. In the 1930s, H. Yukawa suggested that nuclear forces would have particles associated with them, and the discovery of the pions in 1947 was a beautiful confirmation of his prediction. Since then, many more mesons have been found and our understanding of the nuclear force has been refined and modified to include contributions from all the meson exchanges that could occur. Nevertheless, the pion has special importance because it is the lightest of the mesons. According to the Yukawa theory, the smaller the mass of the particle, the larger the distance over which the force acts. The

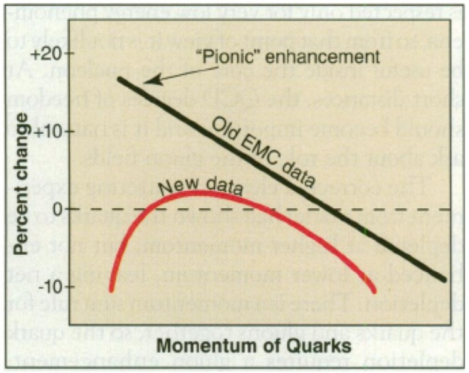

Fig. 1. The relative number of quarks in a heavy nucleus compared to those in an equal mass of deuterium. The upper curve shows the trend of the old muon scattering data, which found an enhancement of 15 to 20%. In the newer data, the enhancement has almost completely disappeared.

energies, the muons scatter from the quarks in the target. More quarks were found than could be accounted for by the number of nucleons in the nucleus. The interpretation (3) was that the extra quarks came from the pion field. As expected from the nuclear physics, the pion field would be enhanced by the interactions of the nucleons, giving in effect more virtual pions in a nucleus than for the same number of isolated nucleons. This experiment also showed the quarks to be depleted at higher momentum. According to the explanation by pions, this effect would be a consequence of the observed enhancement at lower momentum.

The nuclear pions should also affect the scattering of nucleons from a nuclear target (4). The most sensitive method for probing the pion field with nuclear scattering is to use polarized beams and to measure the polarization transfer. The pions' interaction depends on the nucleon spin orientation with respect to the momentum transfer direction, giving a characteristic signature to the spin transfer cross section. An experiment (5) measuring the spin behavior of scattered protons in 1986 produced the surprising result that the scattering was independent of

Science (1993) AAAS

Precision EMC + Drell-Yan

38 years, >1000 papers, 3 Ideas

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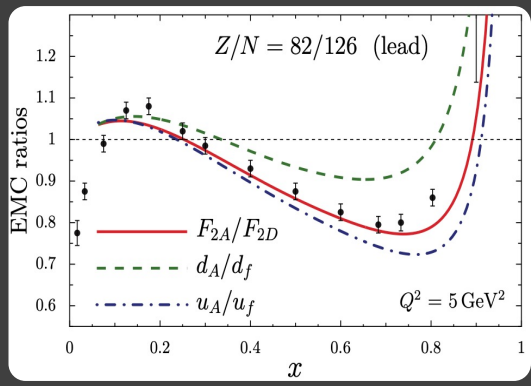

O. Hen et al., Rev. Mod. Phys. 89, 045002 (2017)

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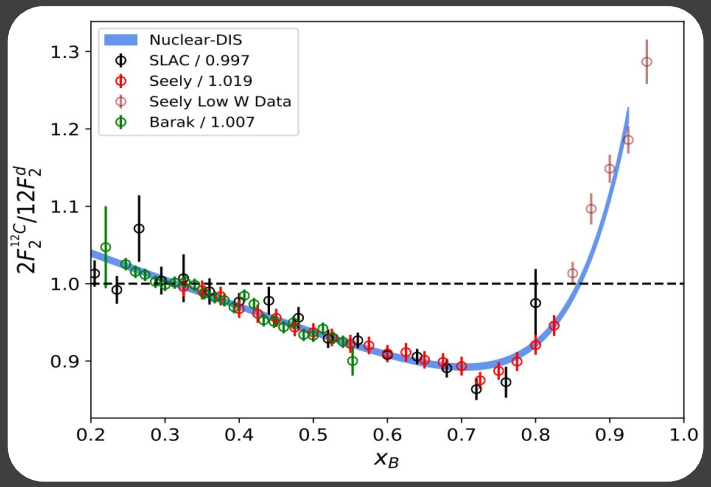
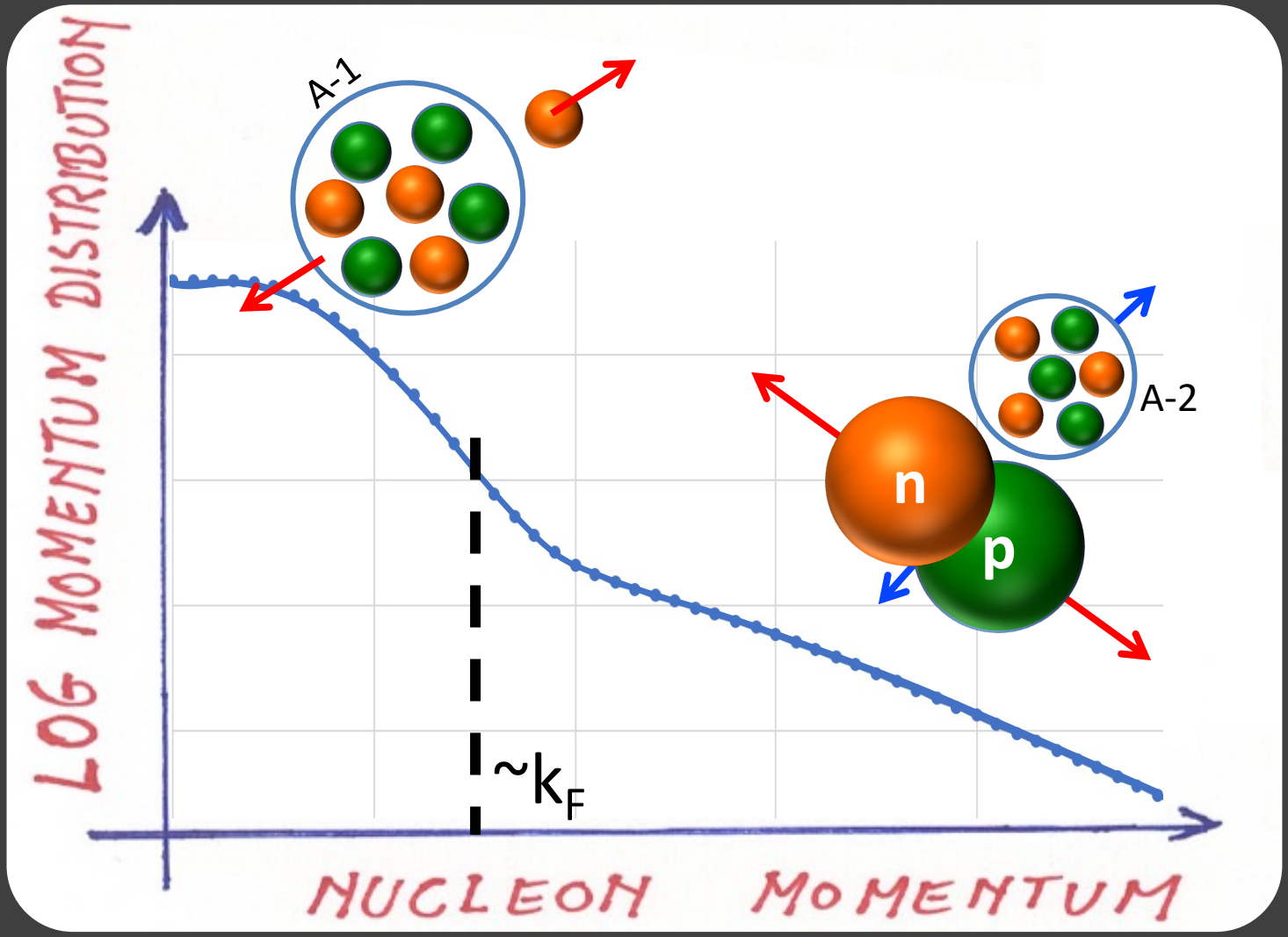
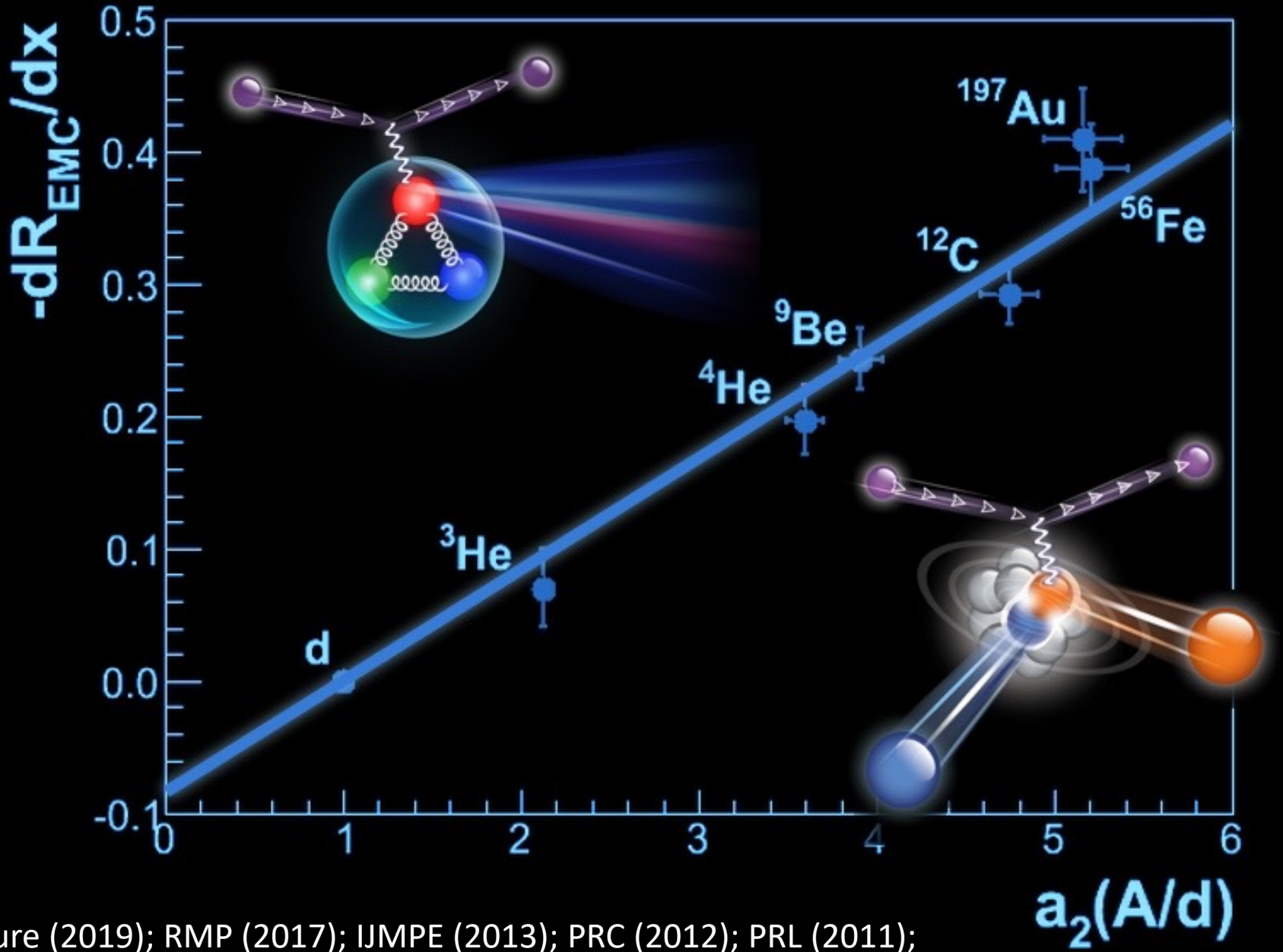


O. Hen et al., Rev. Mod. Phys. 89, 045002 (2017)

‘SRC picture’ of Nuclei

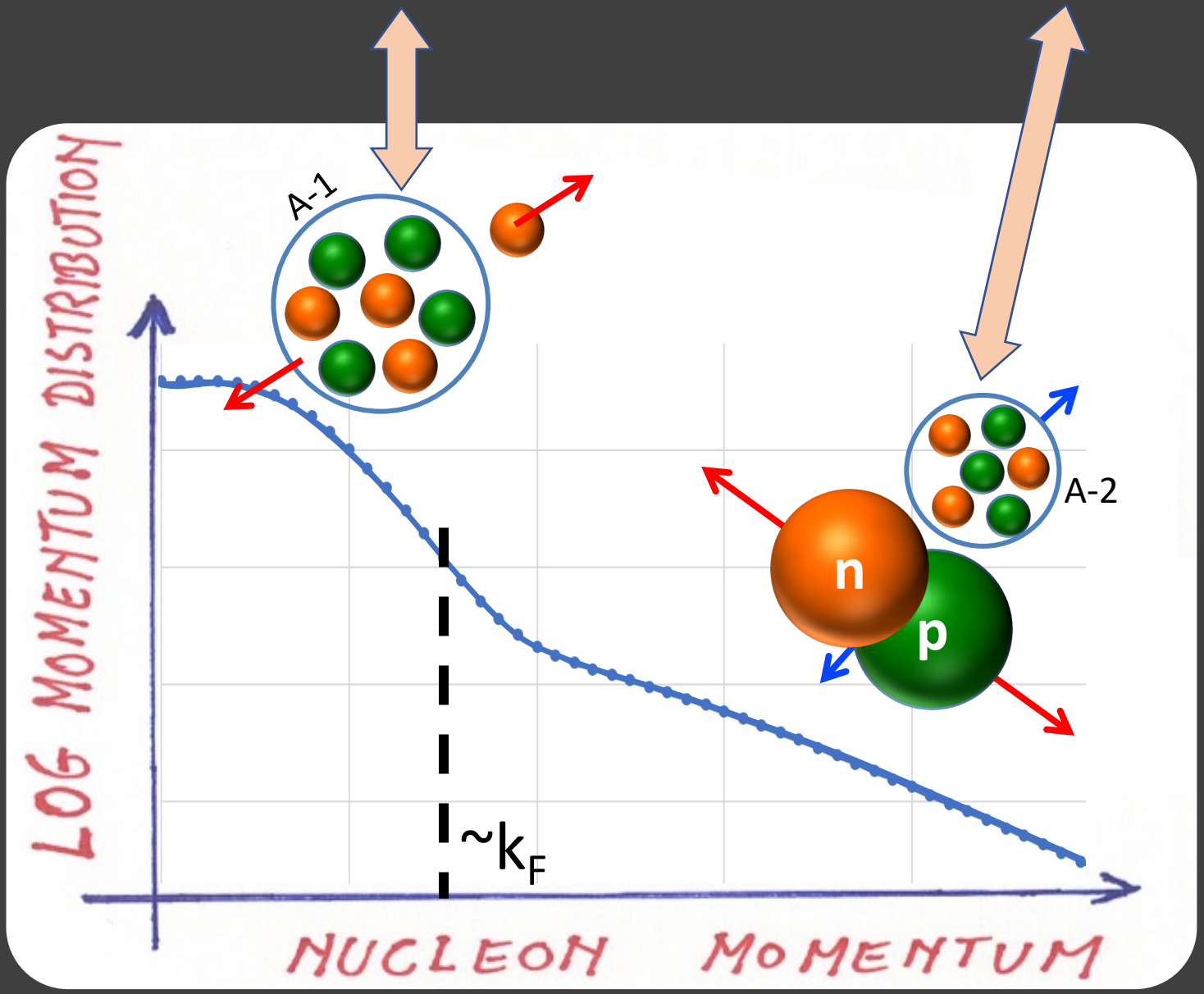


EMC – SRC Correlation



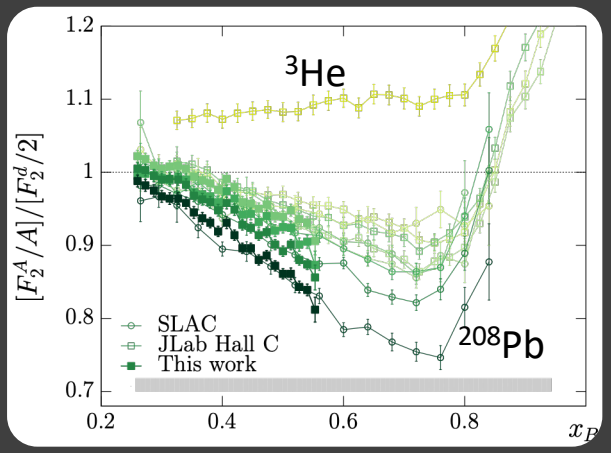
Nature (2019); RMP (2017); IJMPE (2013); PRC (2012); PRL (2011);

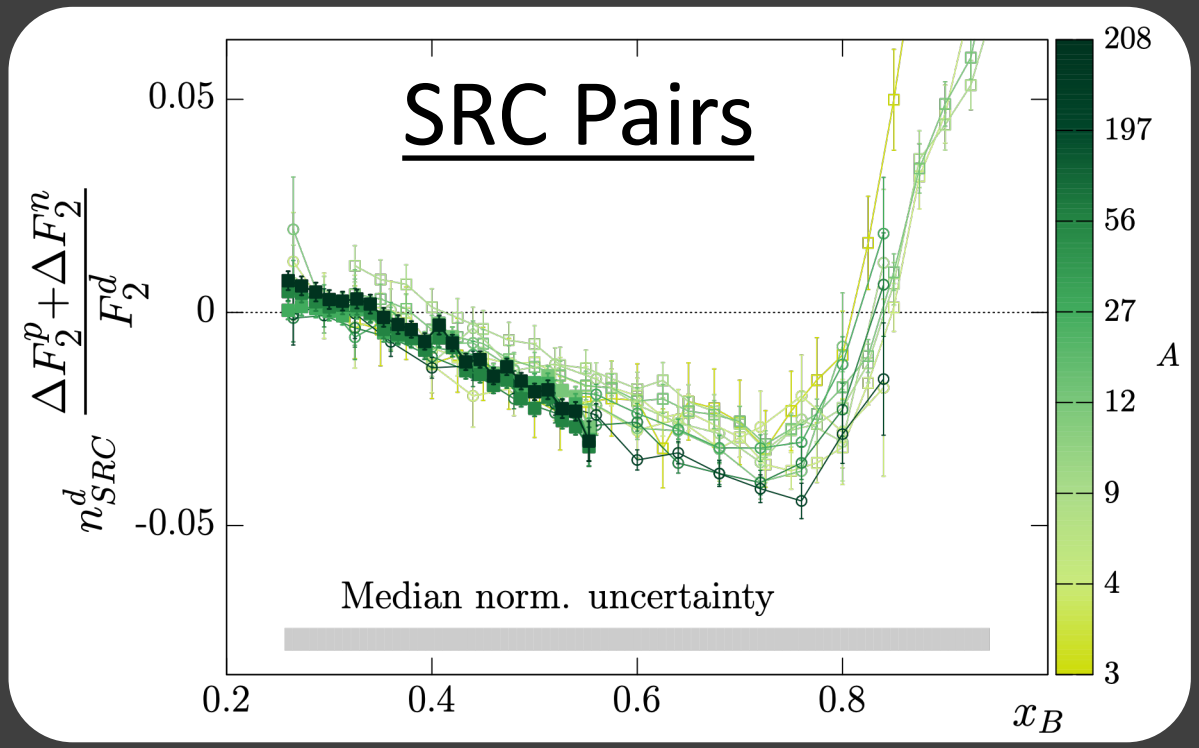
Bound = ‘quasi Free’ + Modified SRCs



SRC Universality!

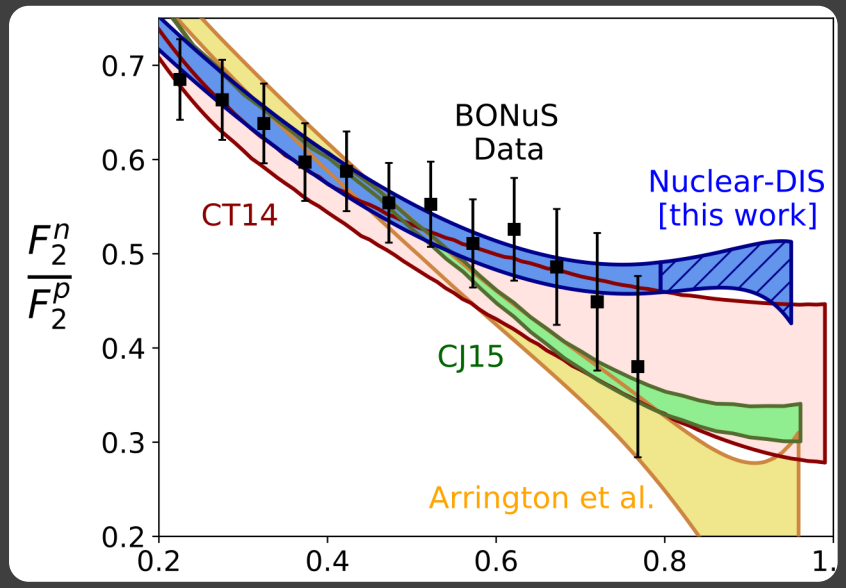
All Nucleons





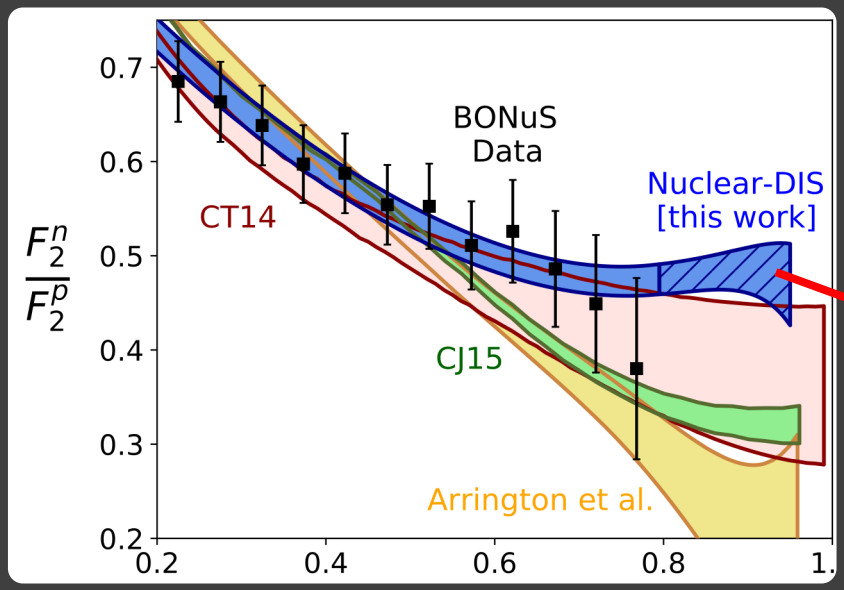
Schmookler et al., Nature (2019)

SRCs can affect our extraction of free neutron structure.



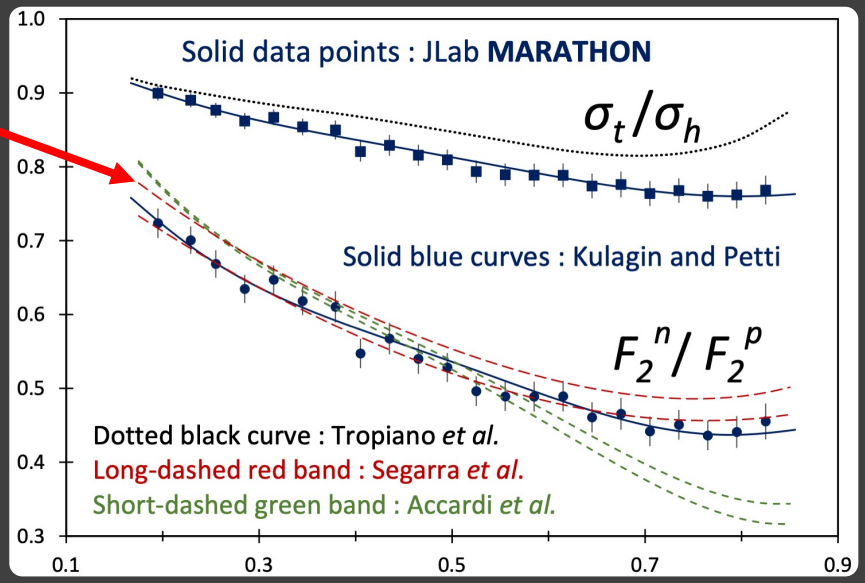
E. P. Segarra et al., PRL (2020)

SRCs can affect our extraction of free neutron structure.



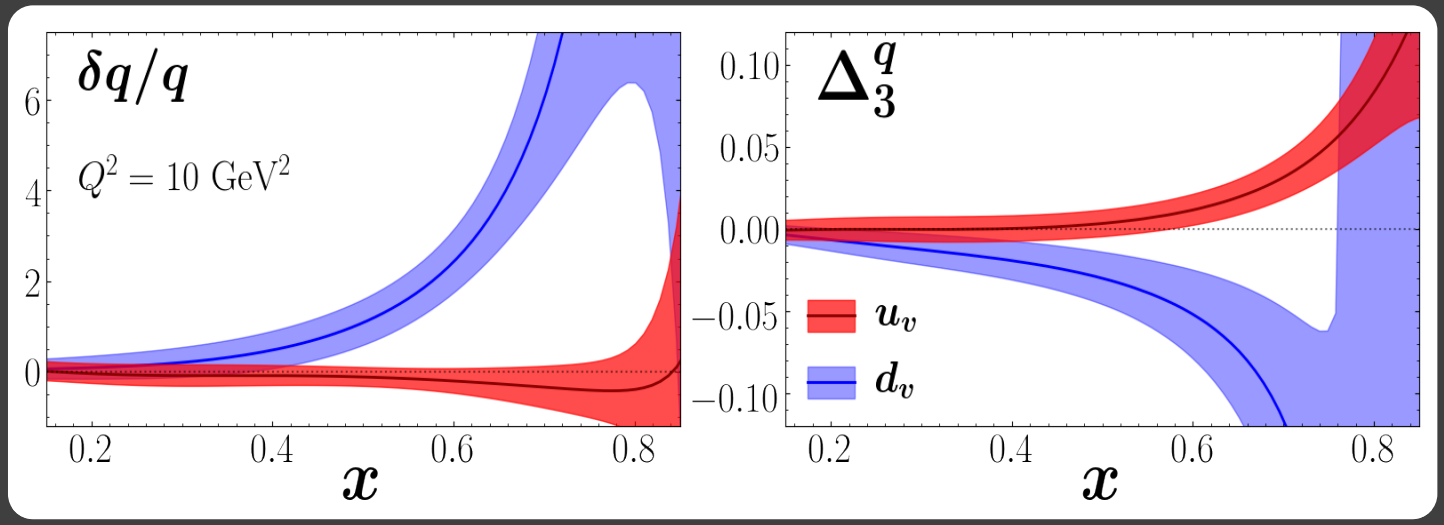
E. P. Segarra et al., PRL (2020)

SRC-EMC Model



MARATHON PRL (2022)

SRCs can affect our extraction of free neutron structure.



Our … analysis [including MARATHON data] reveals the first indication for an isovector nuclear EMC effect in light nuclei.

JAM Collaboration, arXiv:2104.06946 (2021)

052301 (2011) PHYSICAL REVIEW LETTERS

Short Range Correlations and the EMC Effect

L. B. Weinstein,[1,*] E. Piasetzky,[2] D. W. Higinbotham,[3] J. Gomez,[3] O. Hen,[2] and R. Shneor[2]

PHYSICAL REVIEW LETTERS **124,** 092002 (2020)

Neutron Valence Structure from Nuclear Deep Inelastic Scattering

E. P. Segarra,[1] A. Schmidt,[1,2] T. Kutz,[1,2] D. W. Higinbotham,[3] E. Piasetzky,[4] M. Strikman,[5] L. B. Weinstein,[6] and O. Hen[1,*]

PHYSICAL REVIEW C **85,** 047301 (2012)

strengthen the connection between short range correlations and the EMC

O. Hen,[1] E. Piasetzky,[1] and L. B. Weinstein[2]

PHYSICAL REVIEW D **84,** 117501 (2011)

Constraints on the large-x d/u ratio from electron-nucleus scattering at $x > 1$

O. Hen,[1] A. Accardi,[2,3] W. Melnitchouk,[3] and E. Piasetzky[1]

NUCLEAR PHYSICS A

Short range correlations and the EMC effect

tzky[a], L.B. Weinstein[b], D.W. Higinbotham[c], J. Gomez[c], O. Hen[a]

International Journal of Modern Physics E
Vol. 22, No. 7 (2013) 1330017 (30 pages)

THE EMC EFFECT AND HIG
NUCLEONS IN NU

O. Hen, D.W. Higinbotham, G.A. Miller, Piasetzky

REVIEWS OF MODERN PHYSICS, VOLUME 89, OCTOBER–DECEMBER

Nucleon-nucleon correlations, short-lived excitations, and the quarks within

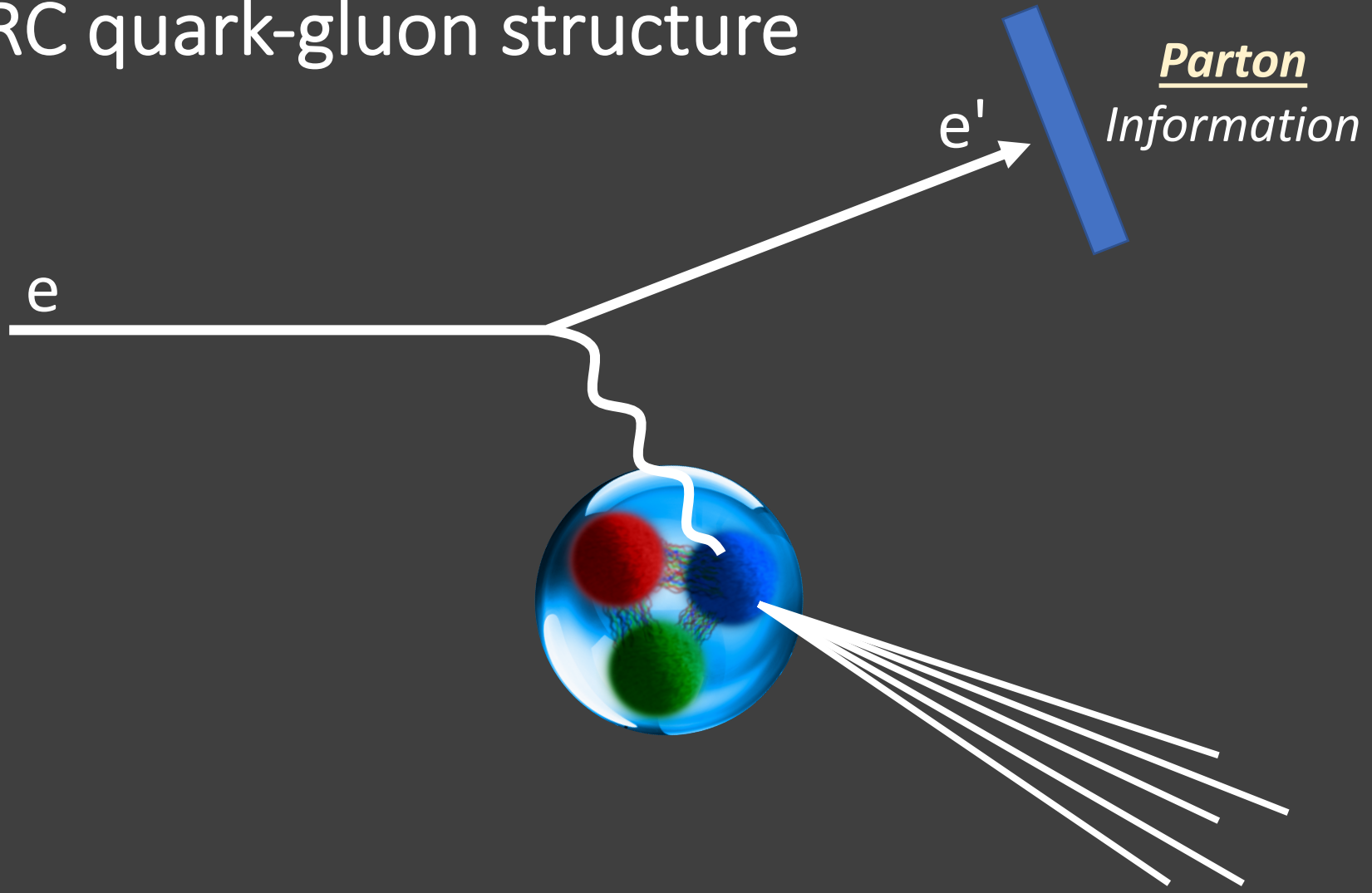
Or Hen Gerald A. Miller Eli Piasetzky Lawrence B. Weinstein

Interest in the EMC Effect and on the SRC-EMC hypothesis is very large

Subset of recent theory/phenom, 2019 – present:

- **E. P. Segarra et al., arXiv:2104.07130 (2021)**
- C. Cocuzza et al., arXiv:2104.06946 (2021)
- J. Rittenhouse-West, arXiv:2009.06968 (2021)
- **E. P. Segarra et al., PRR 3 (2021)**
- H. Szumila-Vance et al., PRC 103 (2021)
- W. Detmold et al., PRL 126 (2020)
- X. G. Wang et al., PRL 125 (2020)
- S. Fucini et al., PRD 101 (2020)
- **E. P. Segarra et al., PRL 124 (2020)**
- J. E. Lynn et al., JPG 47 (2020)
- J. Arrington, N. Fomin, PRL 123 (2019)
- I.C. Cloët et al., JPG 46 (2019)
- **B. Schmookler et al., Nature 566 (2019)**

SRC quark-gluon structure



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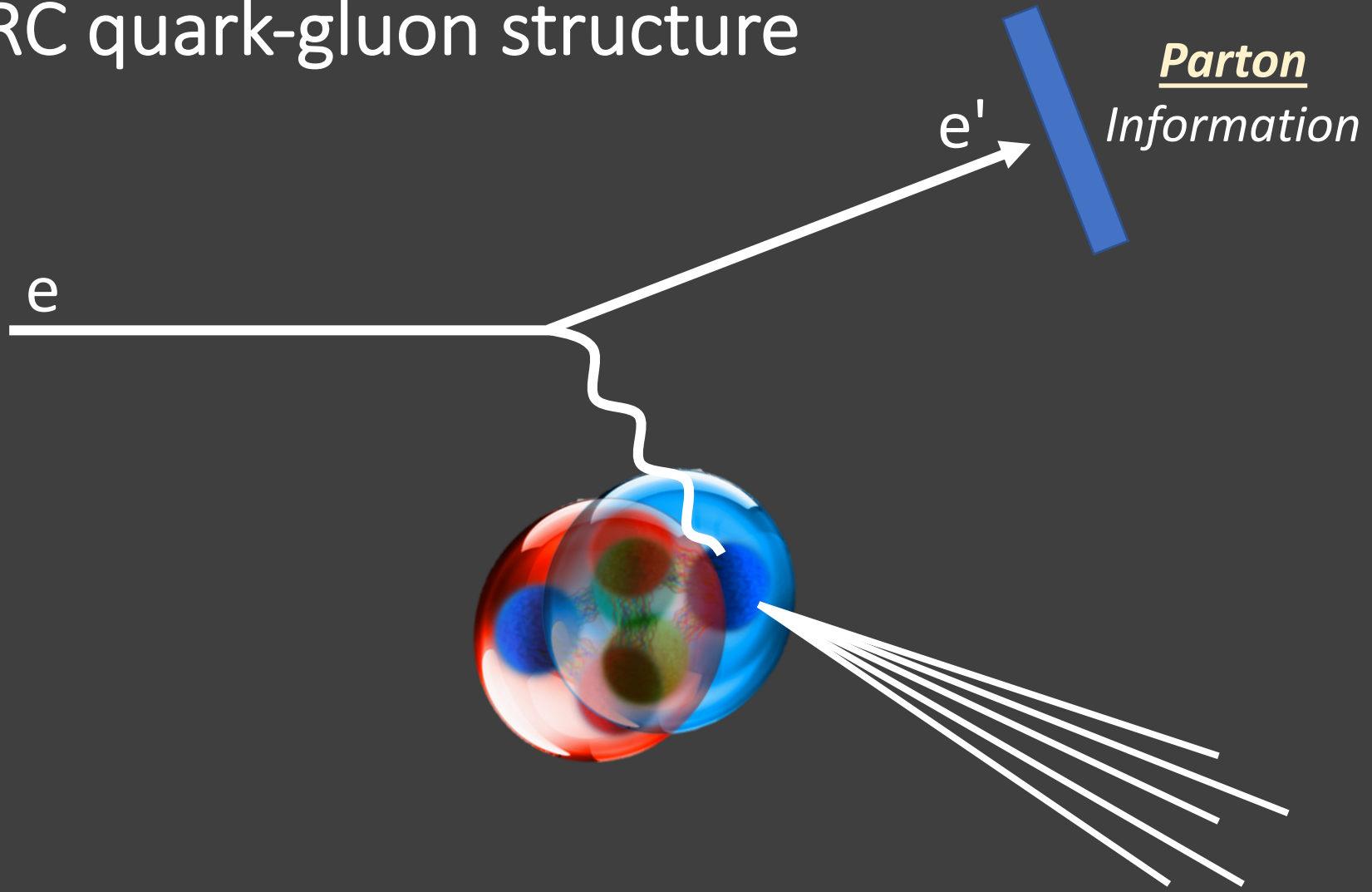

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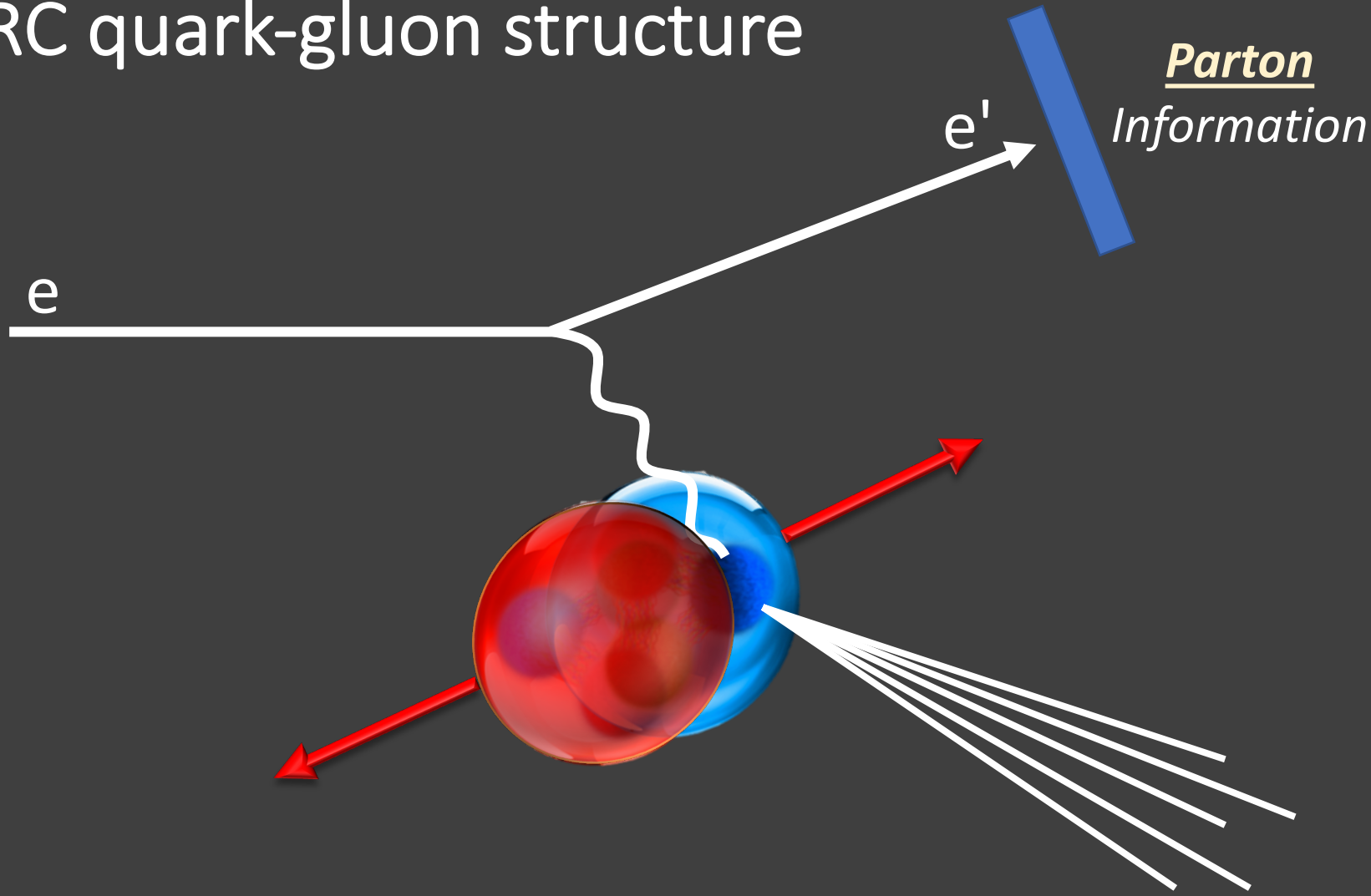

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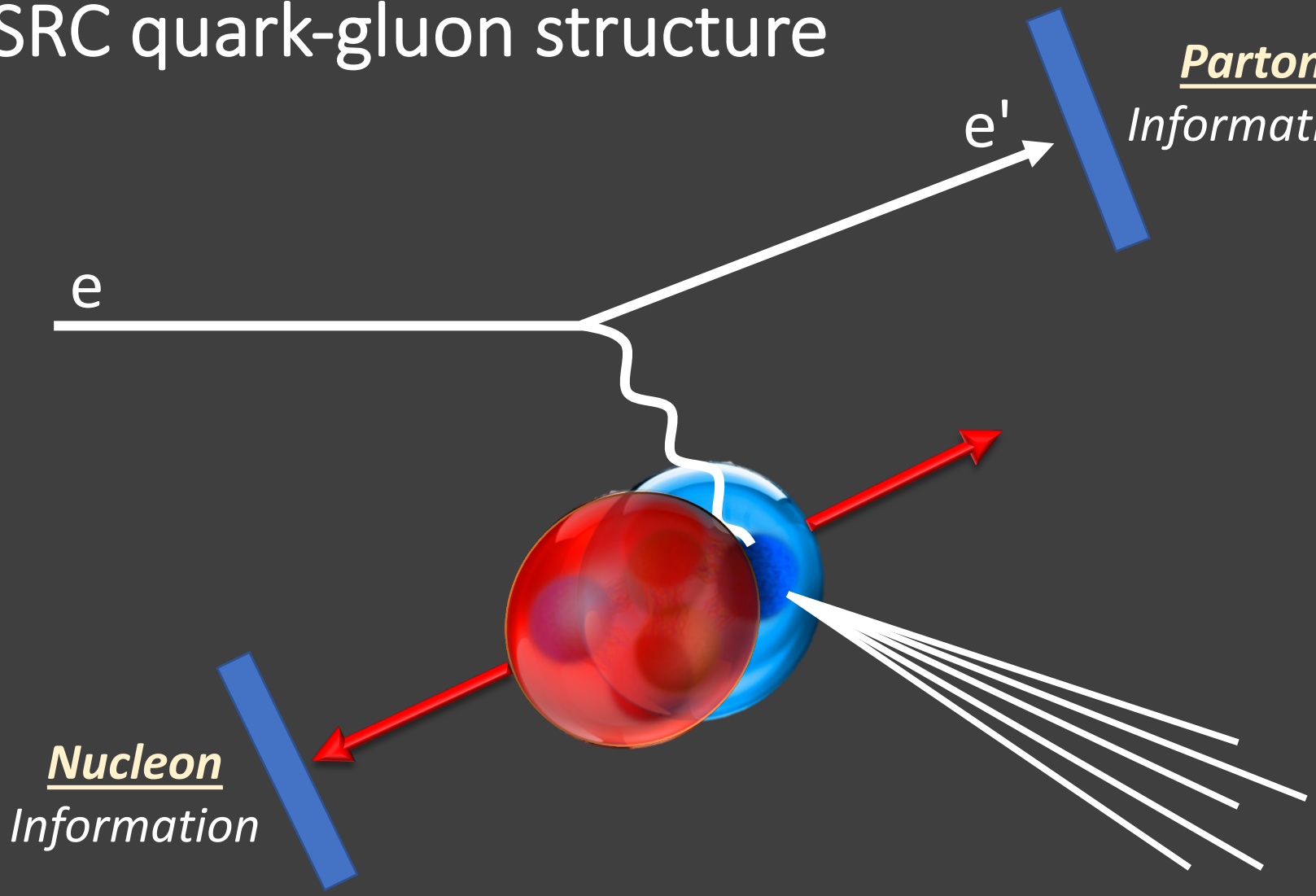
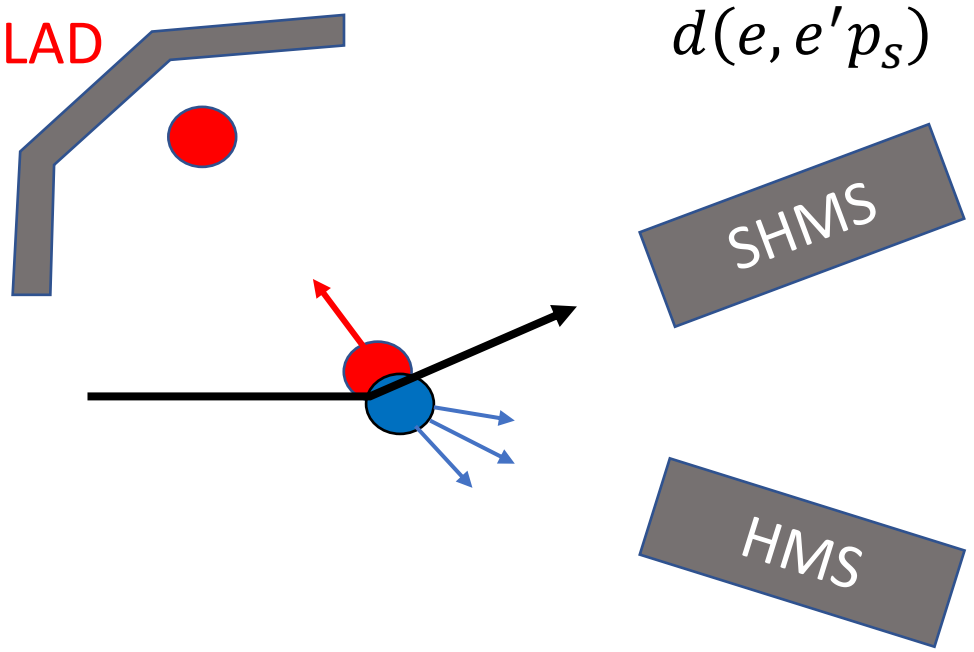


E12-11-107: The LAD Experiment

Spectator-tagged deep inelastic scattering:

- Bound neutron structure modification
- LAD will detect spectator protons 200 – 700 MeV/c
- Approved by PAC 38, for 40 days
- **Passed ERR in 2020**
- **Passed Jeopardy in 2021**



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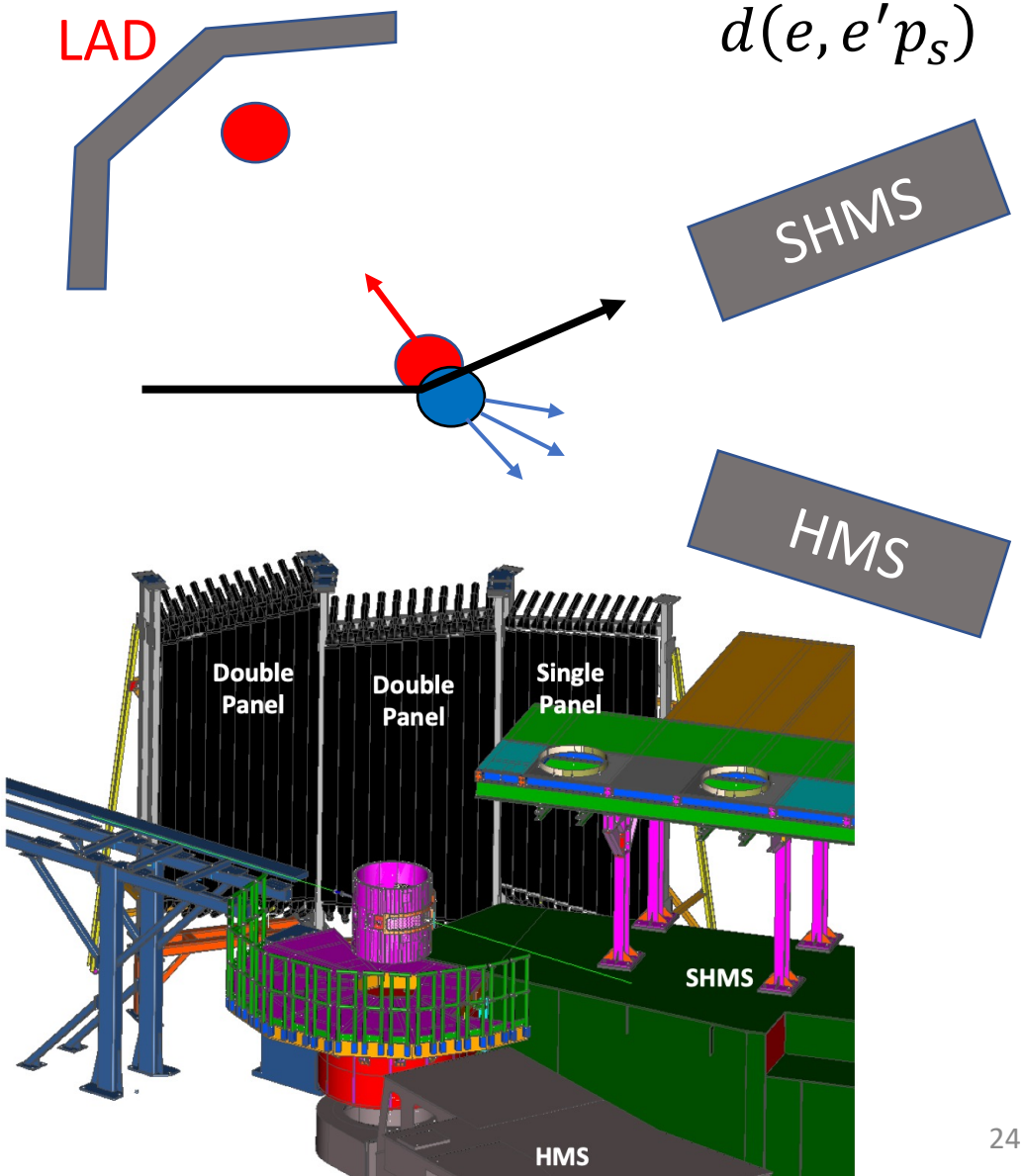

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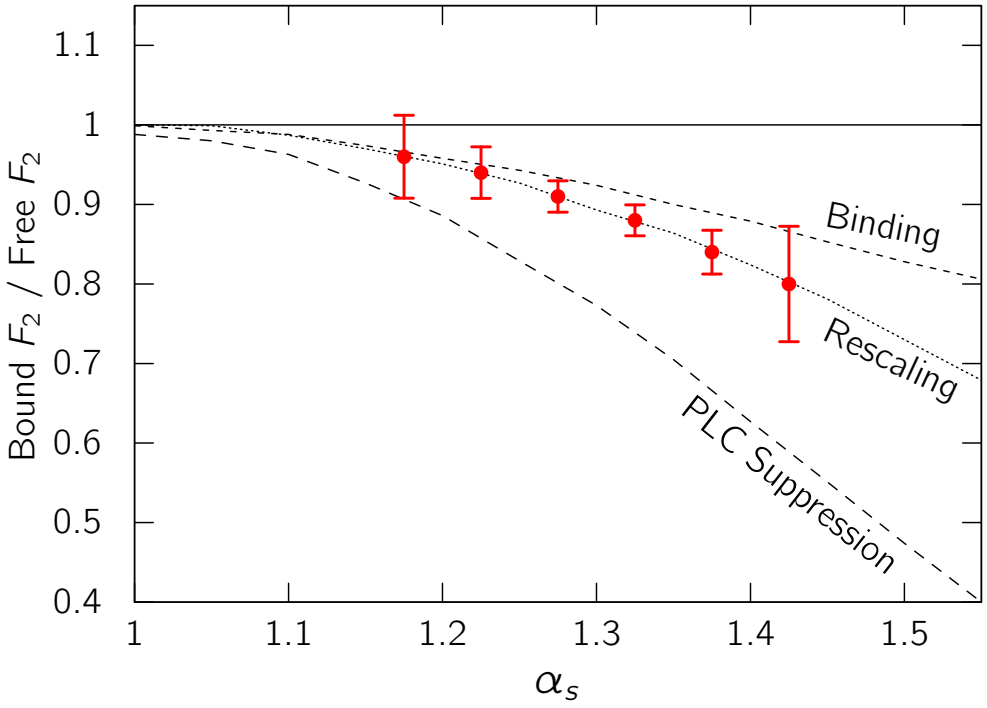
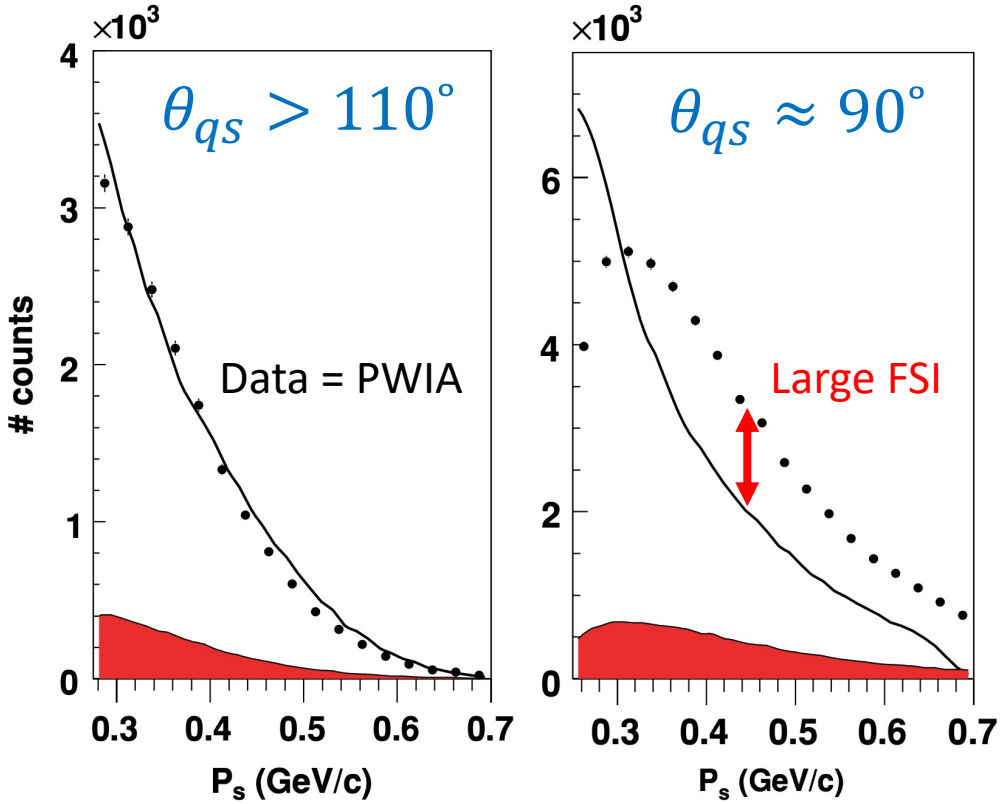


LAD will cover kinematics where FSI are small and where FSI are large.



A. V. Klimenko et al., PRC 73, 035212 (2006)

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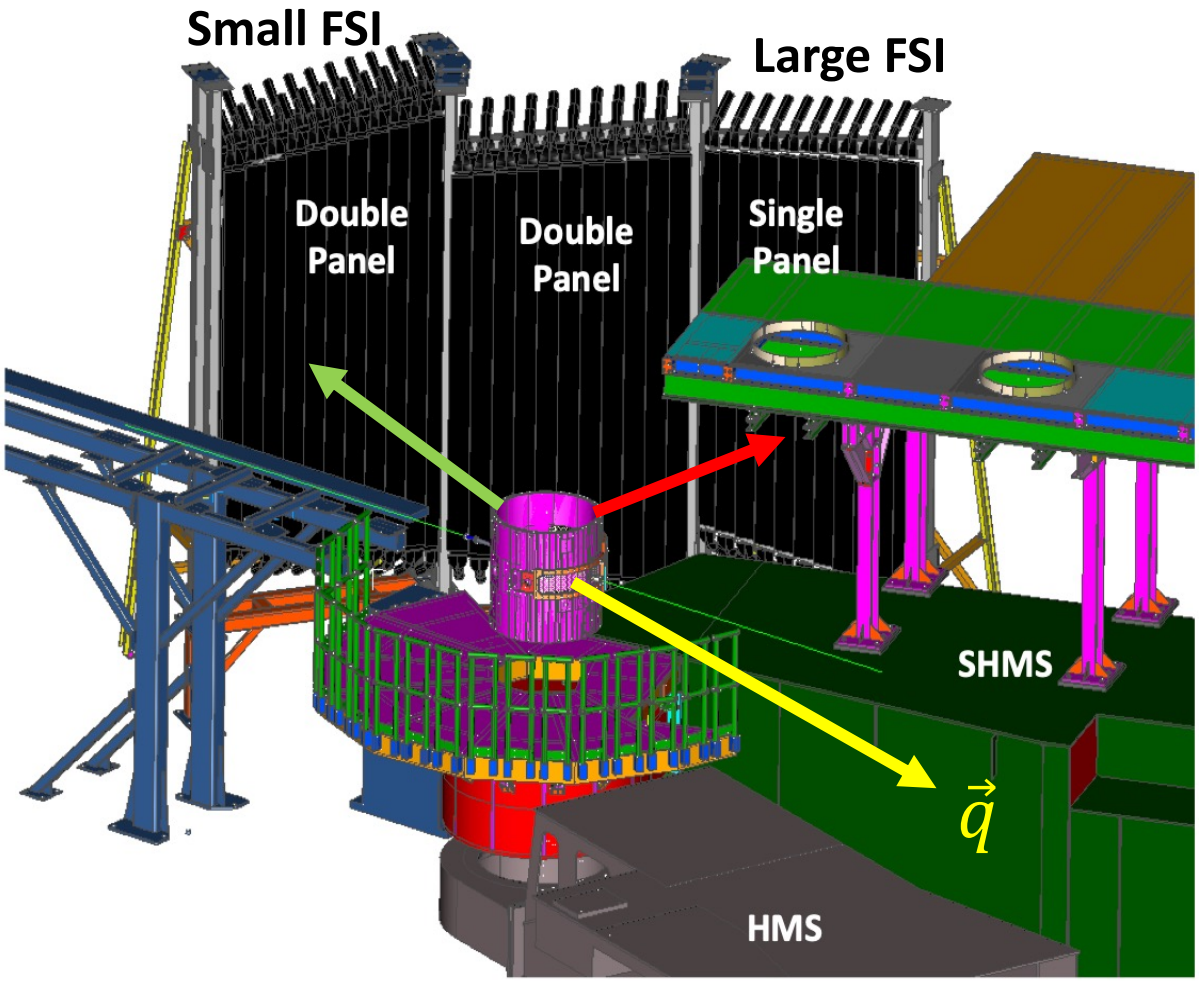


Theory support for LAD is strong.

- New calculations of FSI in tagged DIS
  - W. Cosyn, M. Sargsian, "Nuclear final-state interactions in deep inelastic scattering off the lightest nuclei," Int.J.Mod.Phys.E 26, 1730004 (2017)
  - M. Strikman, C. Weiss, "Electron-deuteron deep-inelastic scattering with spectator nucleon tagging and final-state interactions at intermediate x," Phys. Rev. C 97 035209 (2018)
- JLAB LDRD: "Spectator Tagging Project"
- 3rd workshop on quantitative challenges in EMC and SRC Research
  - https://indico.jlab.org/event/428/overview

Tagged DIS is become an important technique, and will be a major part of the EIC

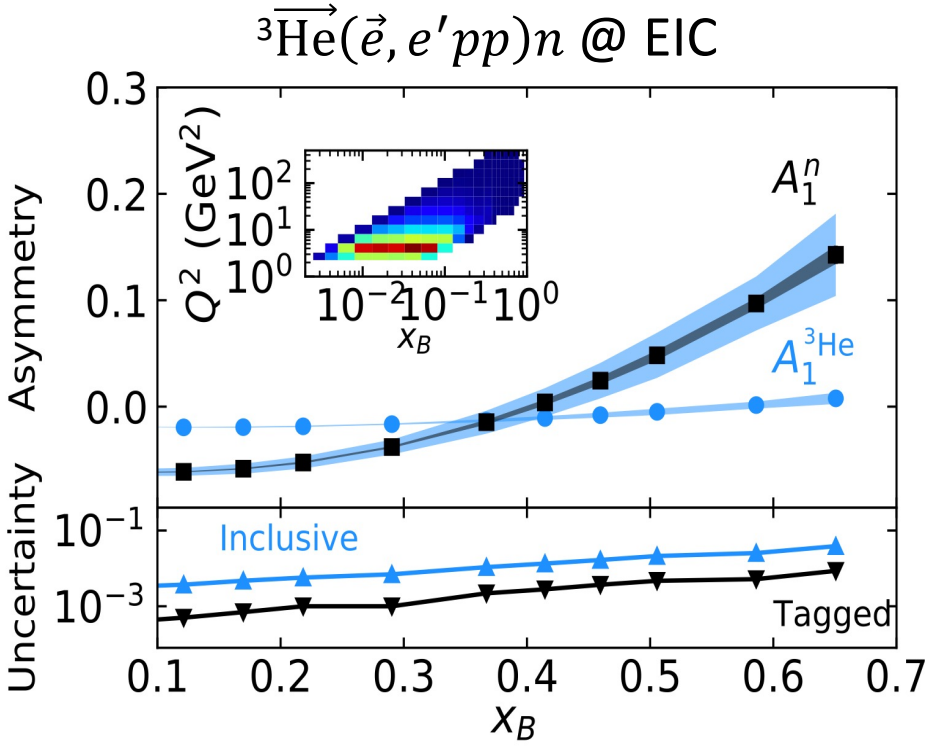
At JLab:

- Bonus
- ALERT
- TDIS @ SBS
- BAND

Low-momentum recoils

EIC:

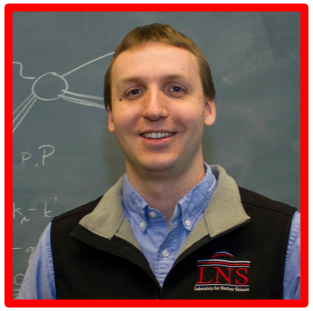
- Friscic and Naguyen et al., PLB (2021)
- Z. Tu et al., PLB (2020)
- Cosyn and Weiss, PLB (2019)
- Strikman and Weiss, PRC (2018)
- …



Friscic and Naguyen et al., PLB (2021)

A new generation of young people is enthusiastic about LAD.

Axel Schmidt



Tyler Kutz

Dien Nguyen

Holly Szumila-Vance

Sara Ratliff

Natalie Wright

Jason Phelan

Florian Hauenstein