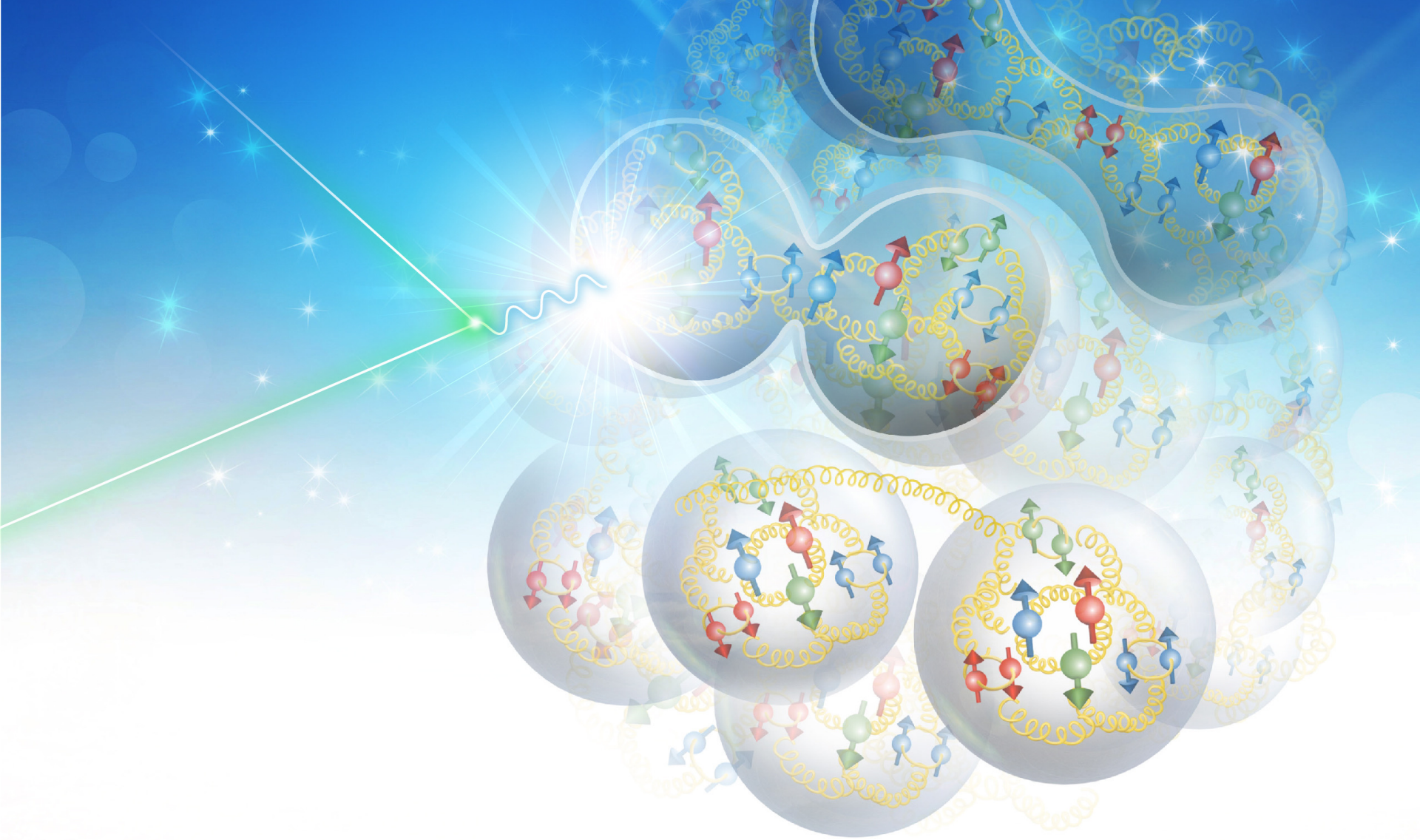


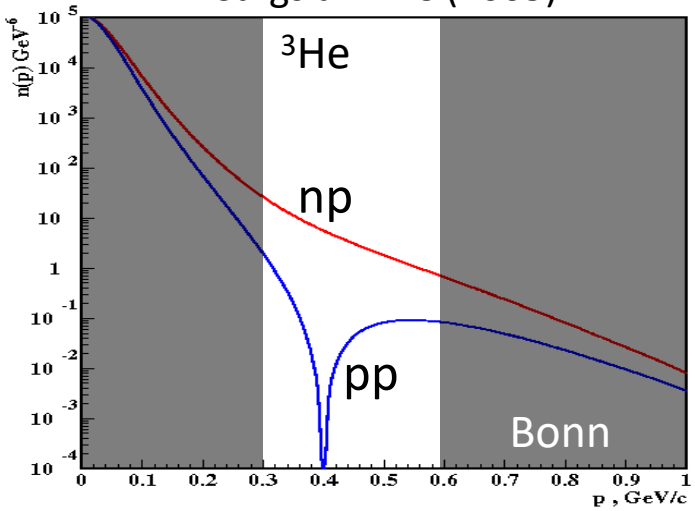
Hampton University Graduate School (HUGs)

June 2022, JLab, Newport News, VA.

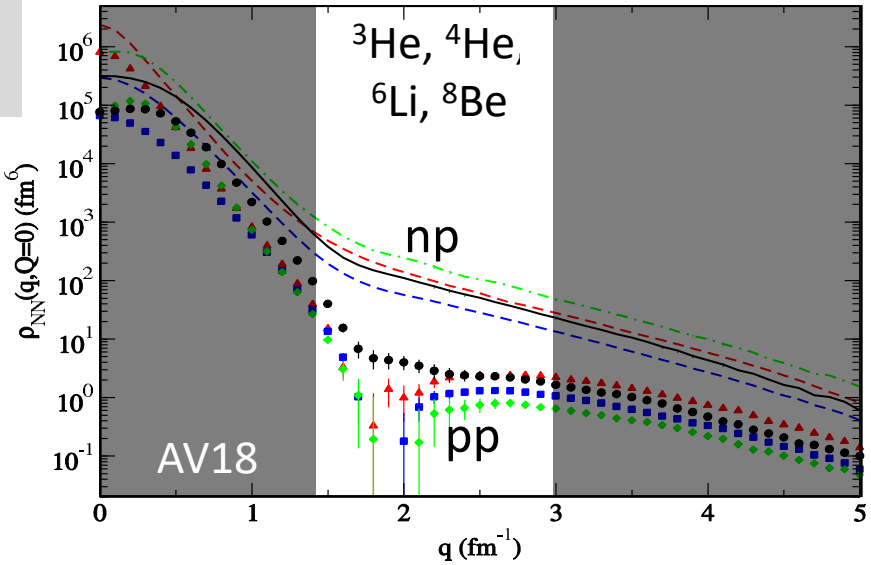
Also seen in ab-initio pair distributions

300 – 600 MeV/c Window

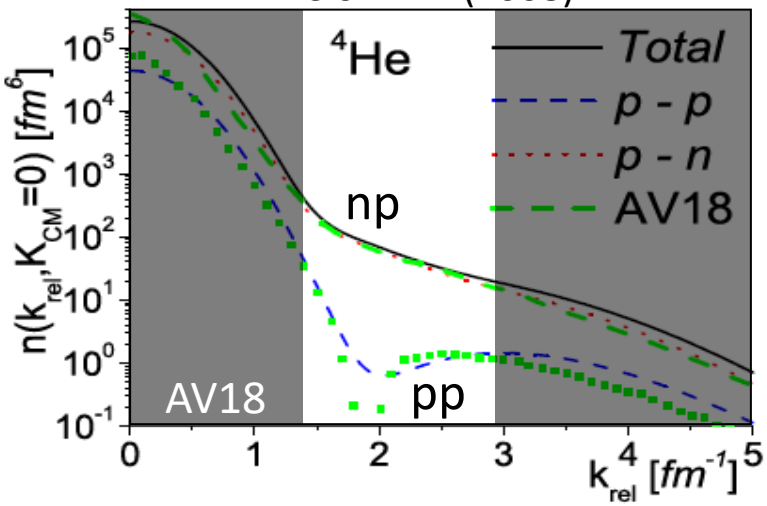
Sargsian PRC (2005)



Schiavilla PRL (2007)

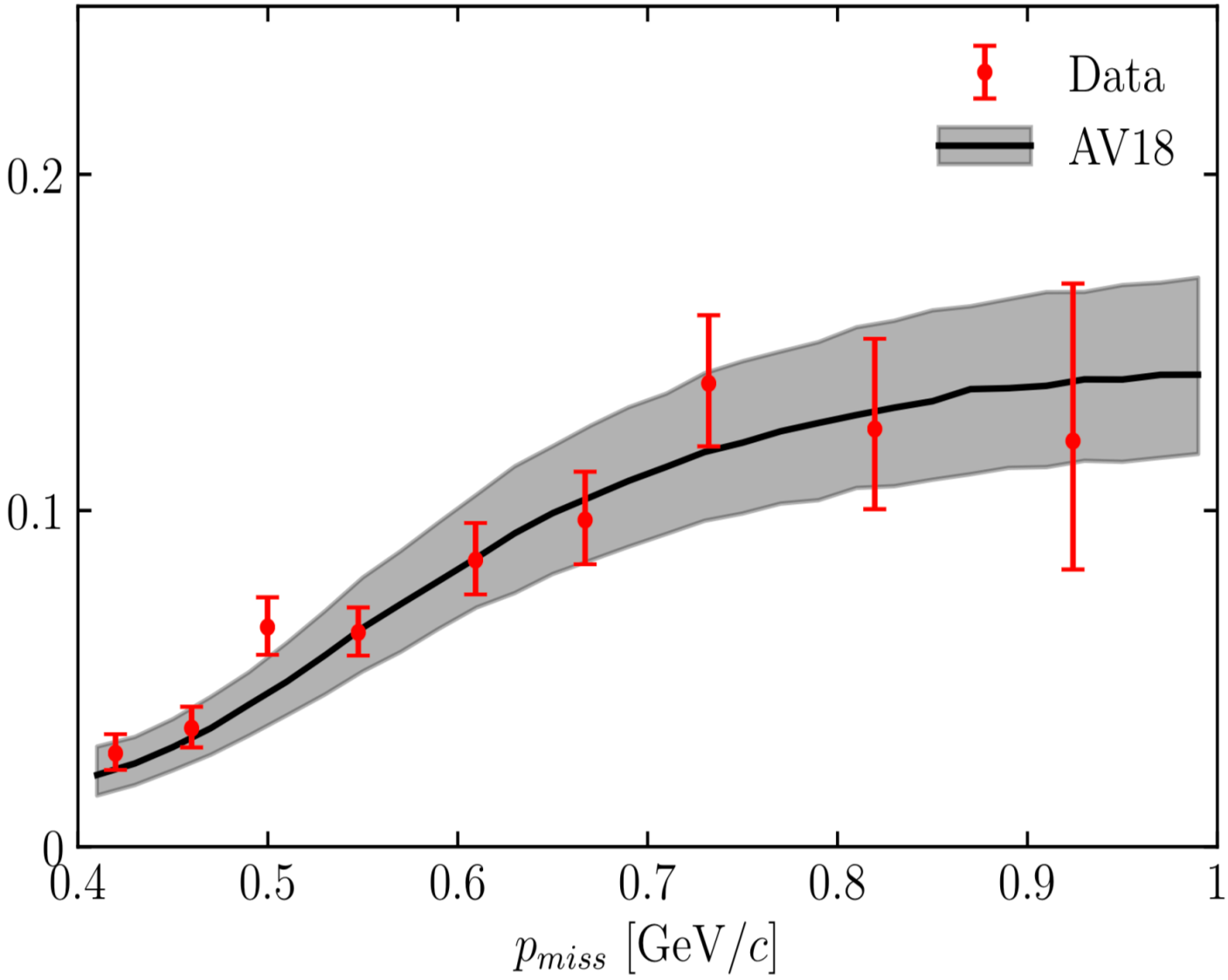


Ciofi PRL (2008)



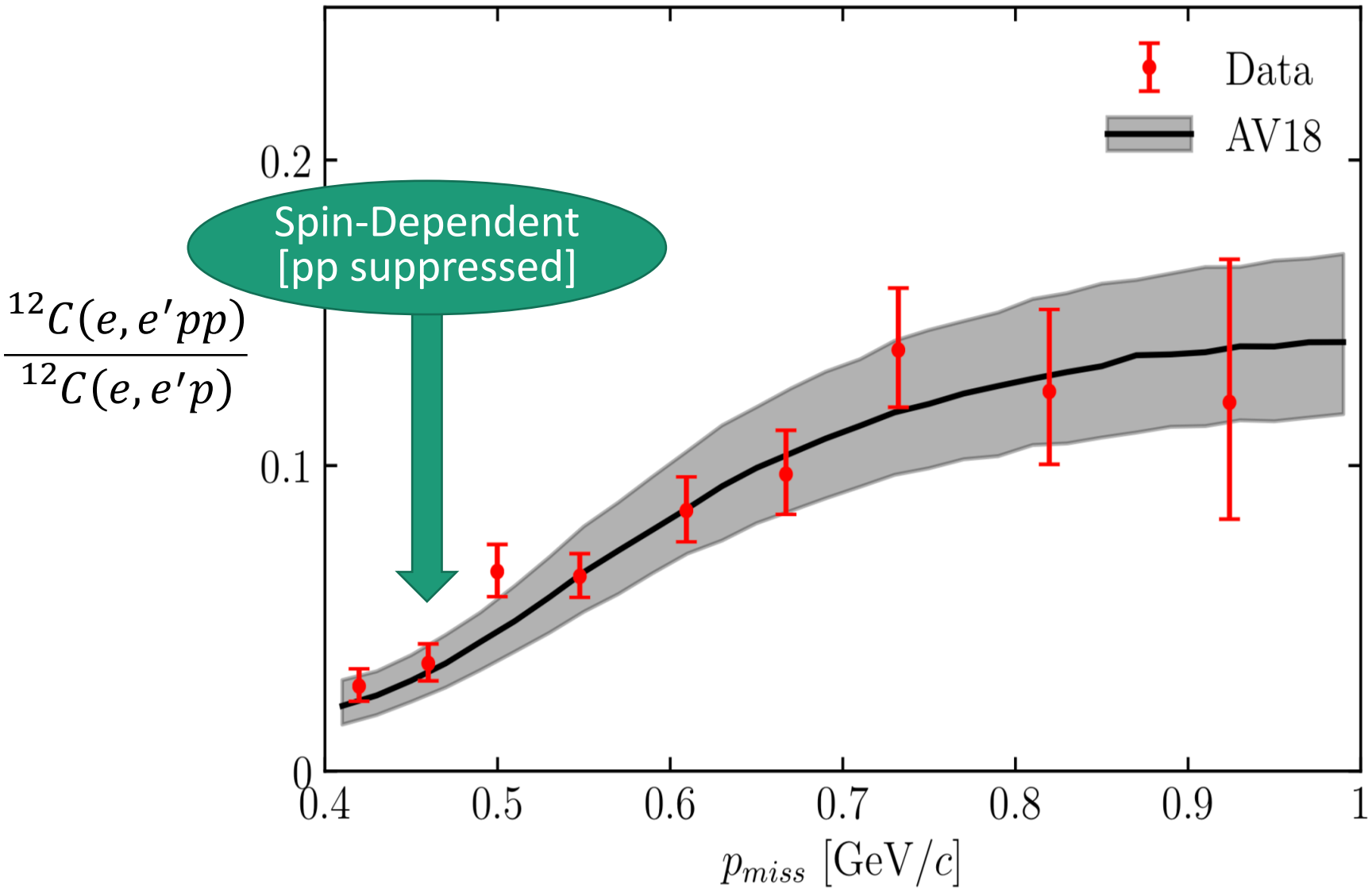
Reaching the Repulsive Core

$$\frac{^{12}C(e,e'pp)}{^{12}C(e,e'p)}$$



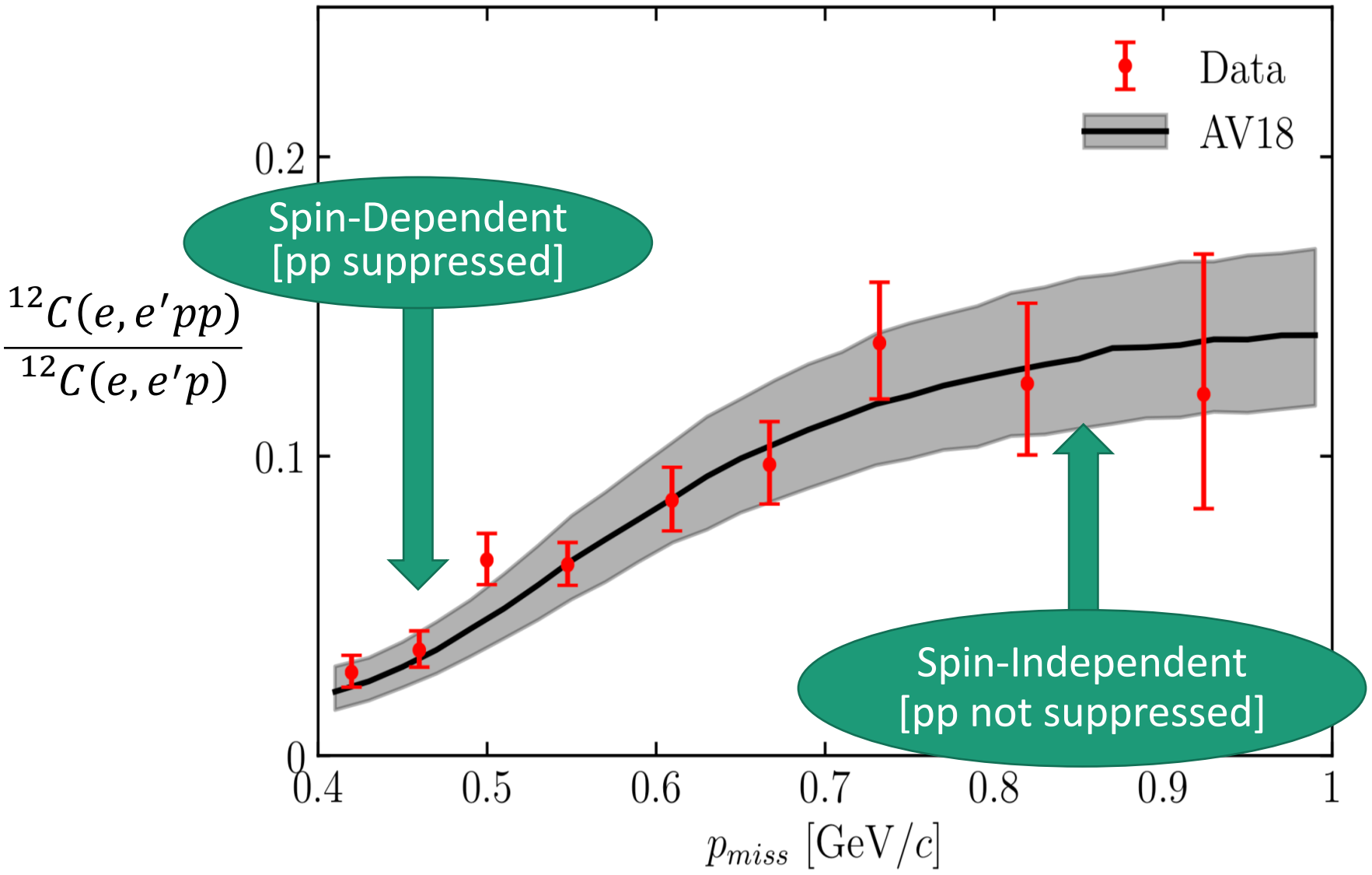
Schmidt et al., Nature (2020)

Reaching the Repulsive Core



Schmidt et al., Nature (2020)

Reaching the Repulsive Core



Schmidt et al., Nature (2020)

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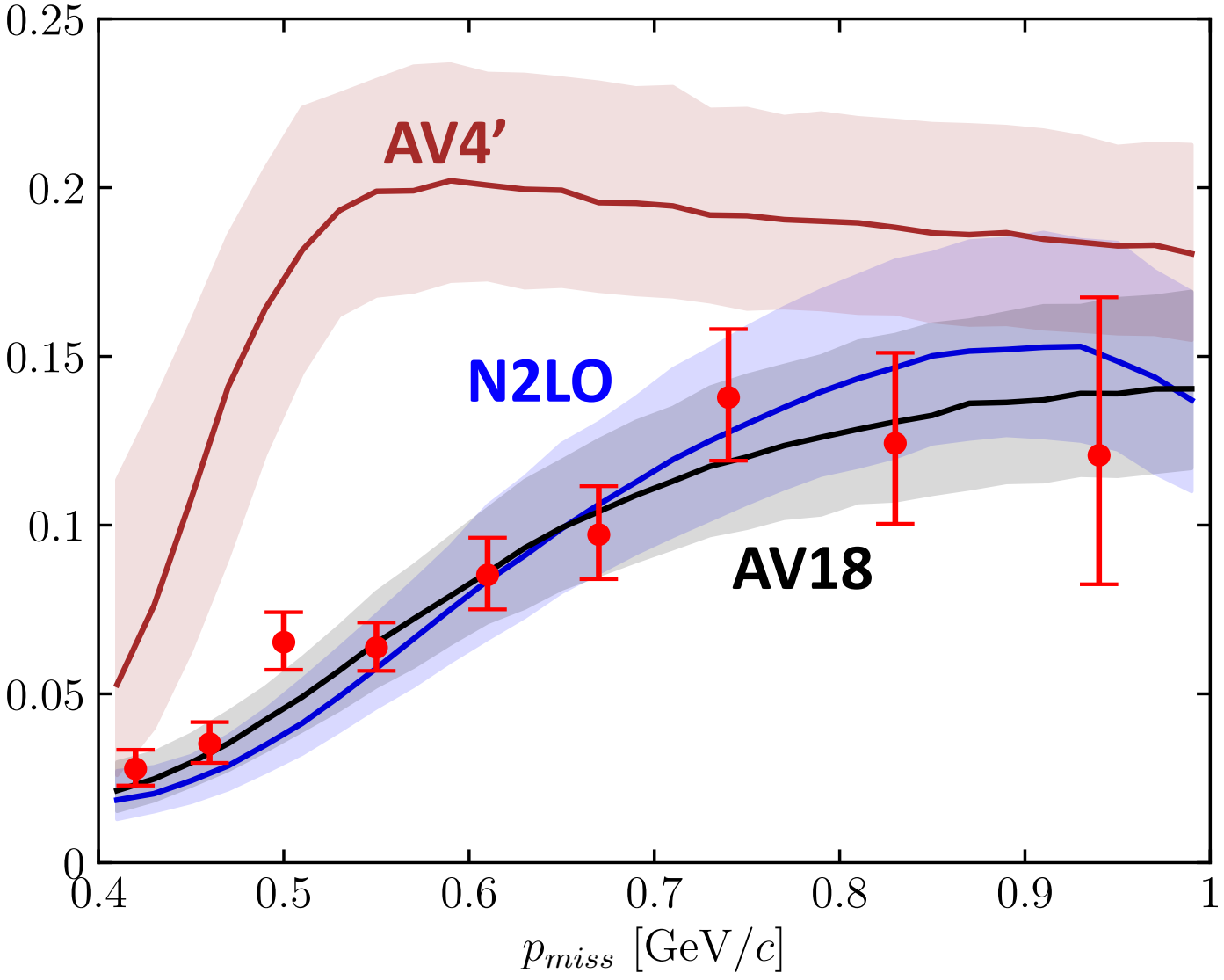
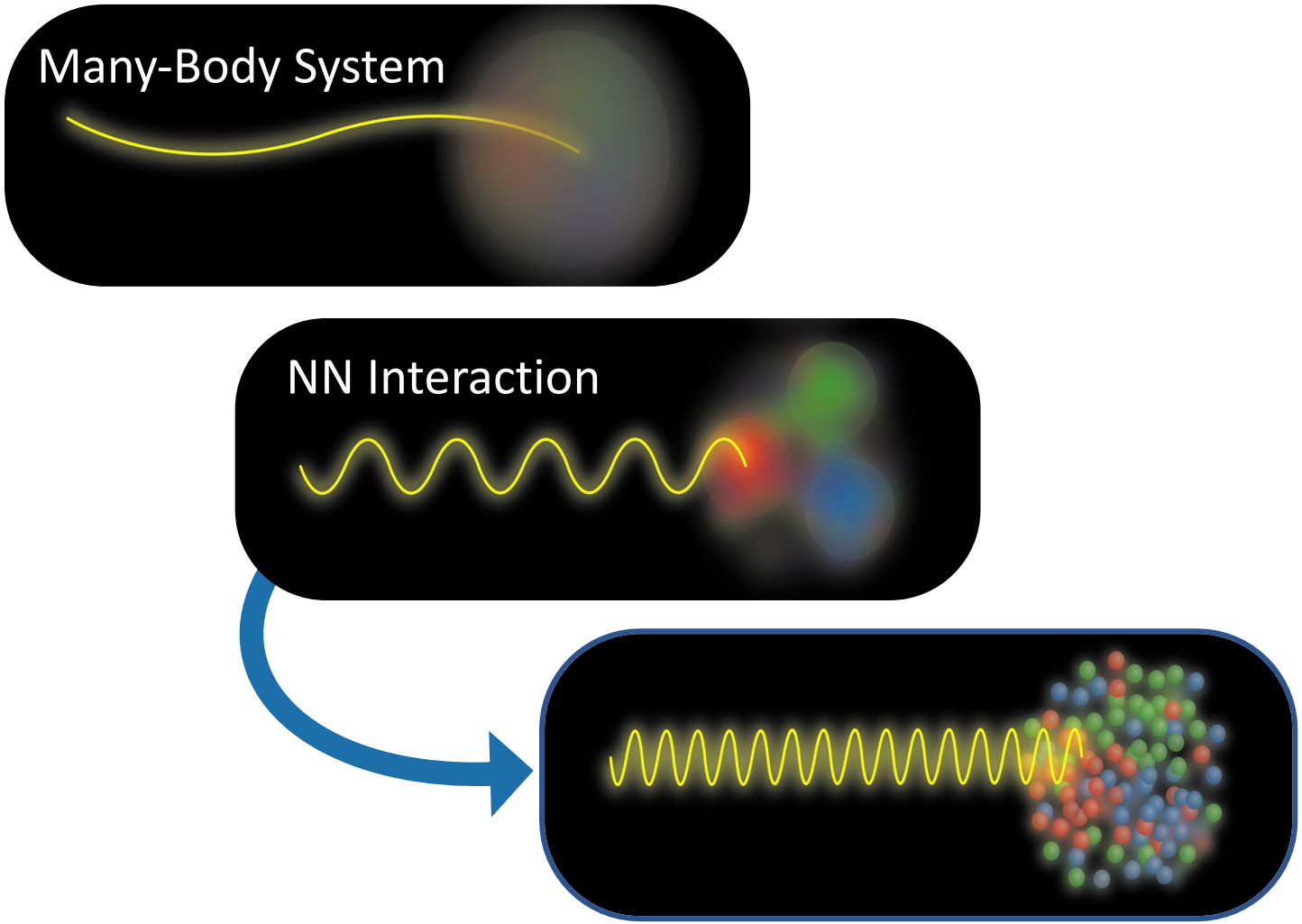
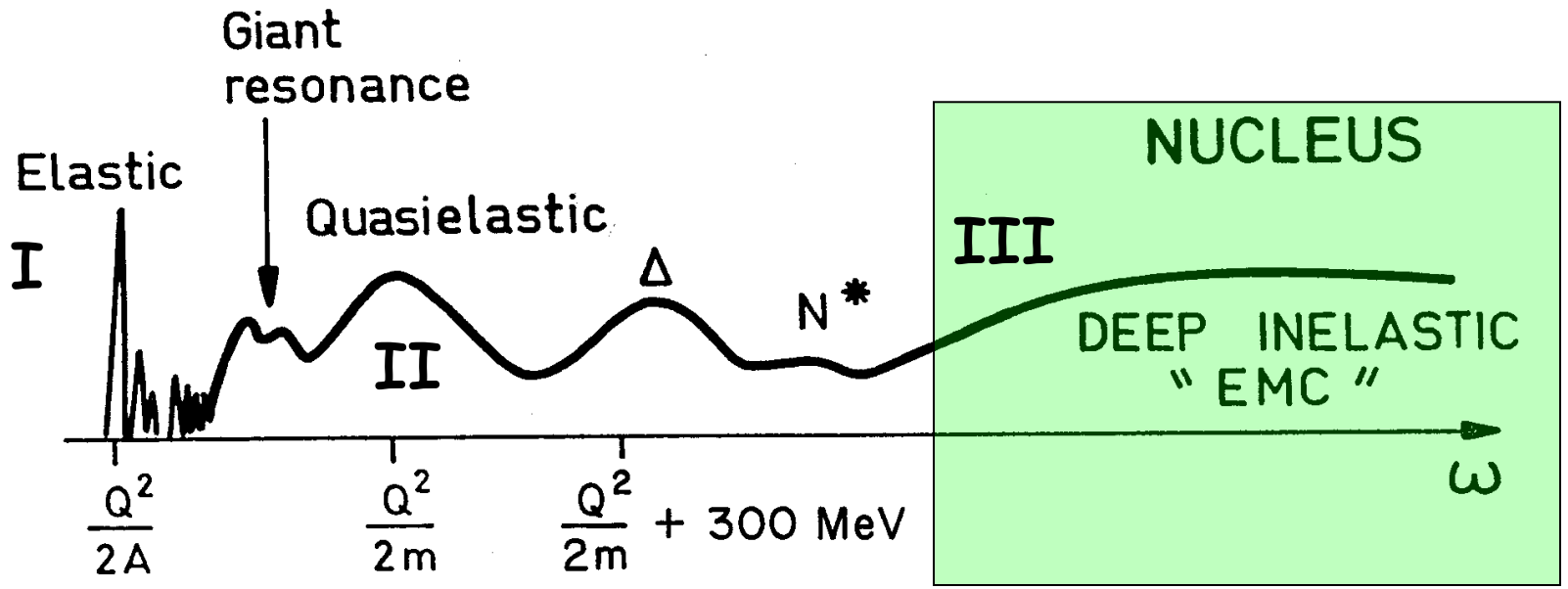


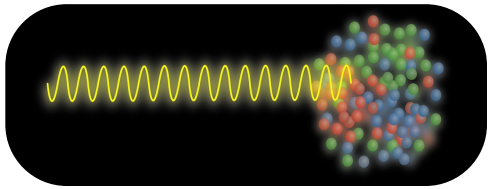
Schmidt et al., Nature (2020)


Many-Body System
NN Interaction

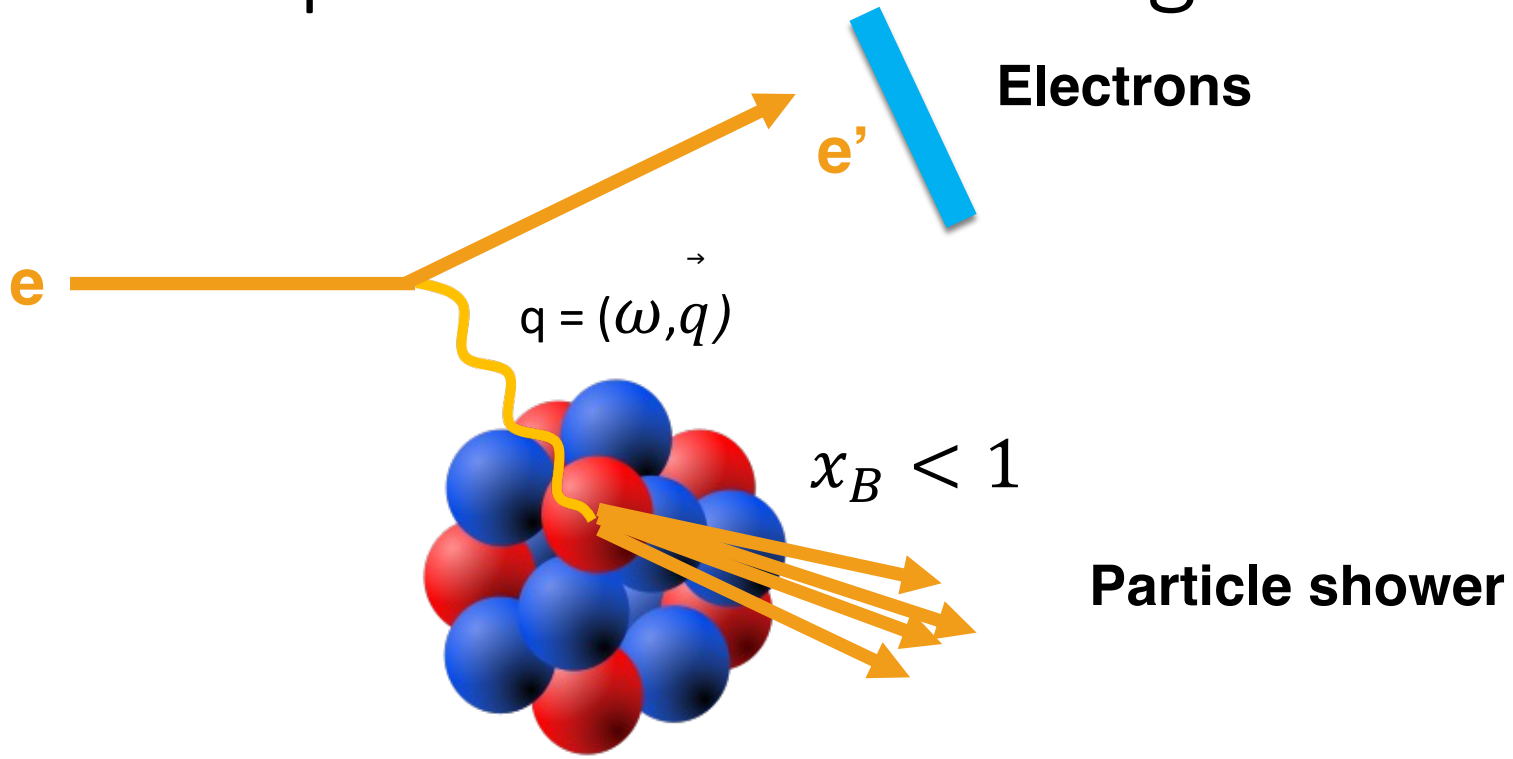
Overview: Deep Inelastic Scattering (DIS)



- ❑ Structure Functions
- ❑ EMC Effect



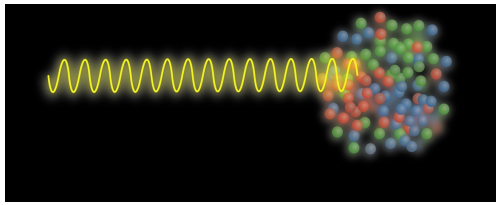
Deep Inelastic Scattering

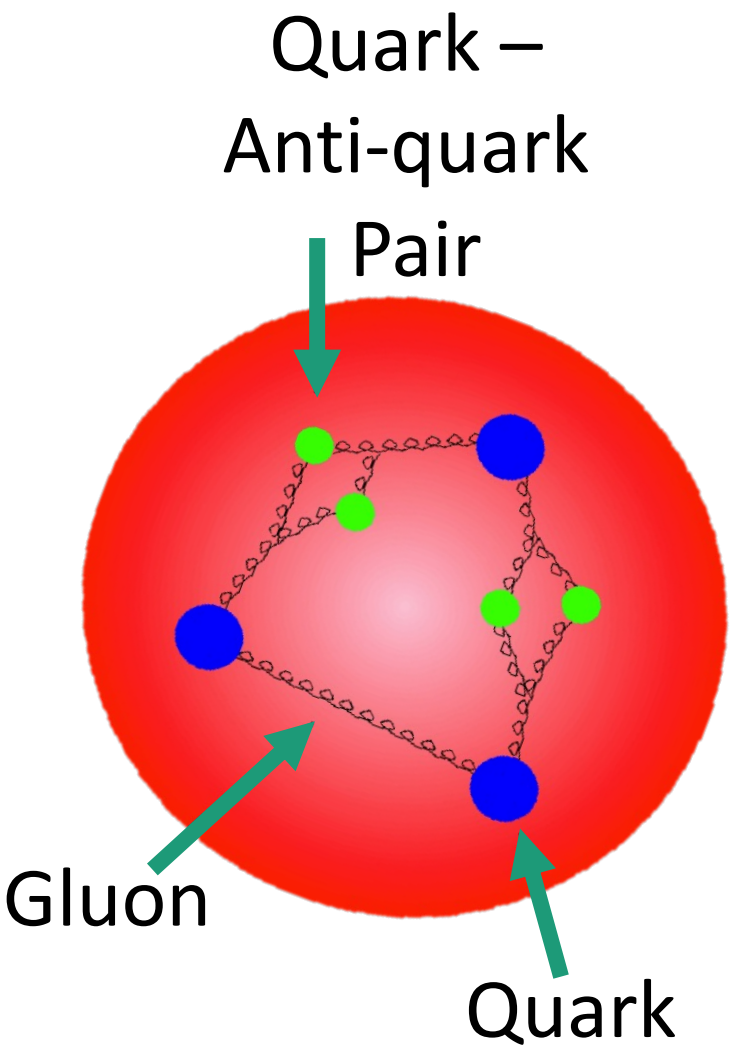


- Interacting nucleon destroyed
- Interaction with Parton (quark) inside the nucleon
- Cross-section depends on **Nucleon structure function F_2**

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_A = \frac{4\alpha^2 E'^2}{Q^4}\left[2\frac{F_1}{M}\sin^2\left(\frac{\theta}{2}\right) + \frac{F_2}{\nu}\cos^2\left(\frac{\theta}{2}\right)\right] \approx K(E,\theta,E')\,F_2(x)$$

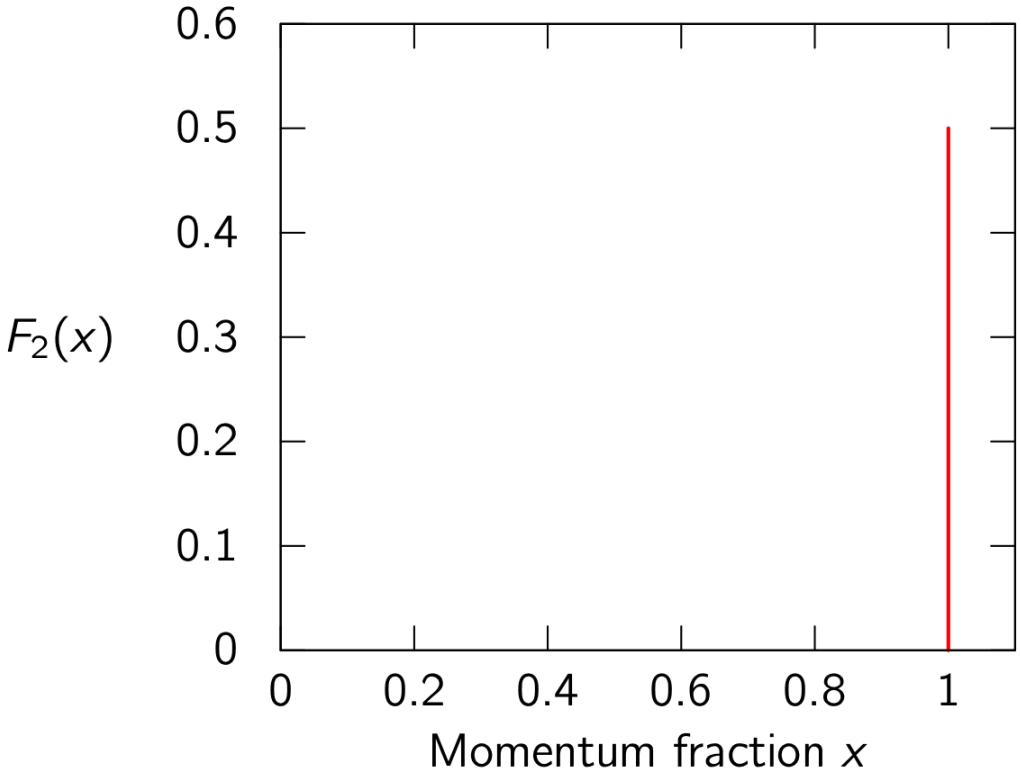
Partonic Structure



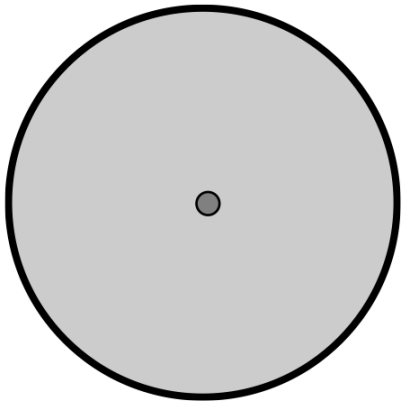


What F_2 can tell us about the nucleon

$$F_2\left(x,Q^2\right)=\sum_i e_i^2\cdot x\cdot f_i\left(x\right)$$



A quark



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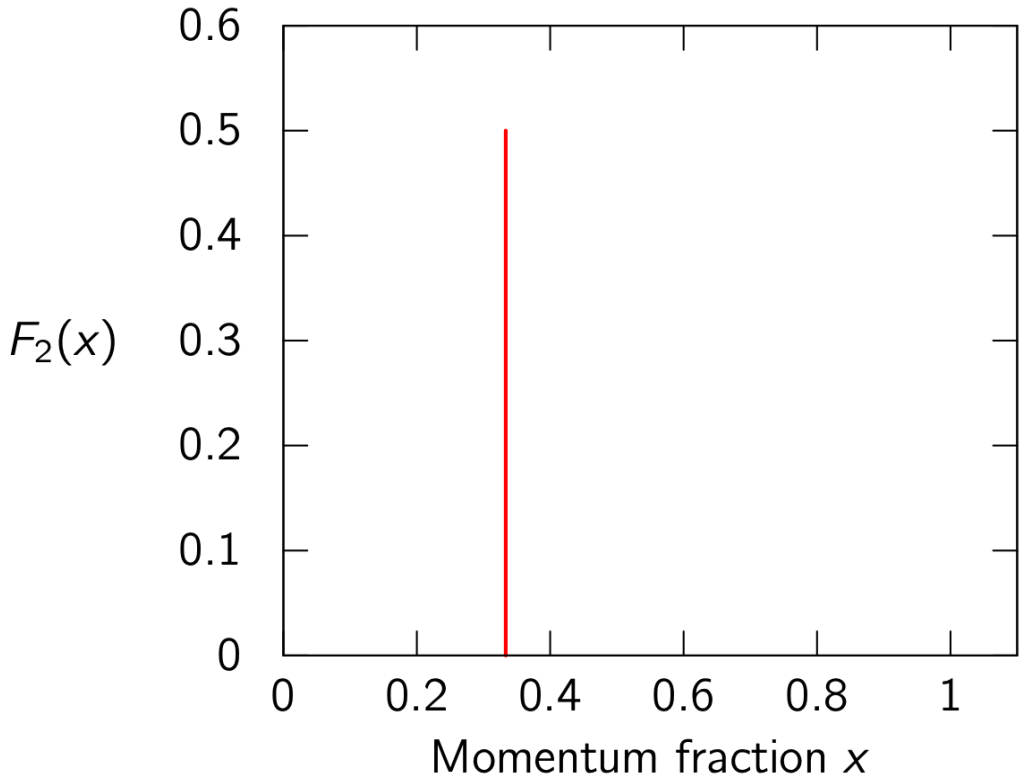
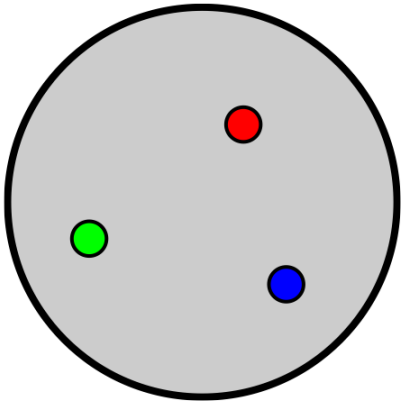


Three valence quarks



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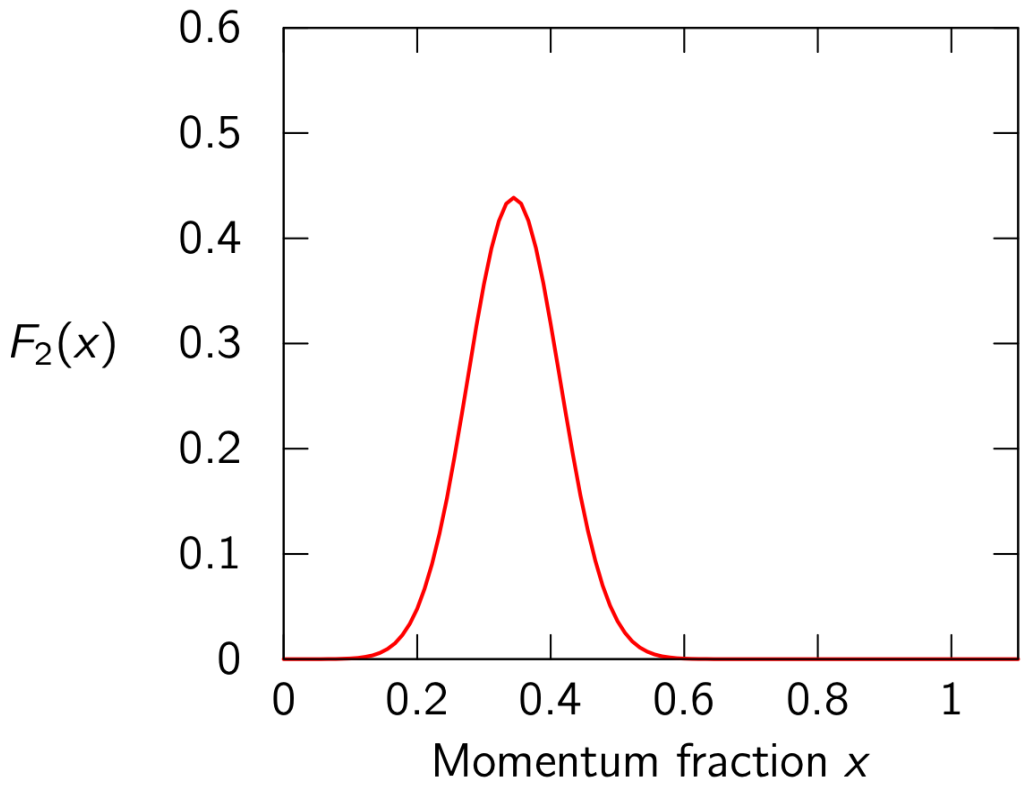
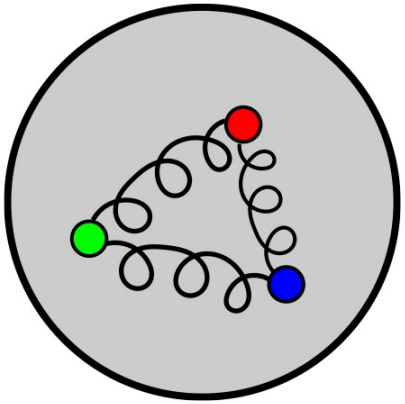
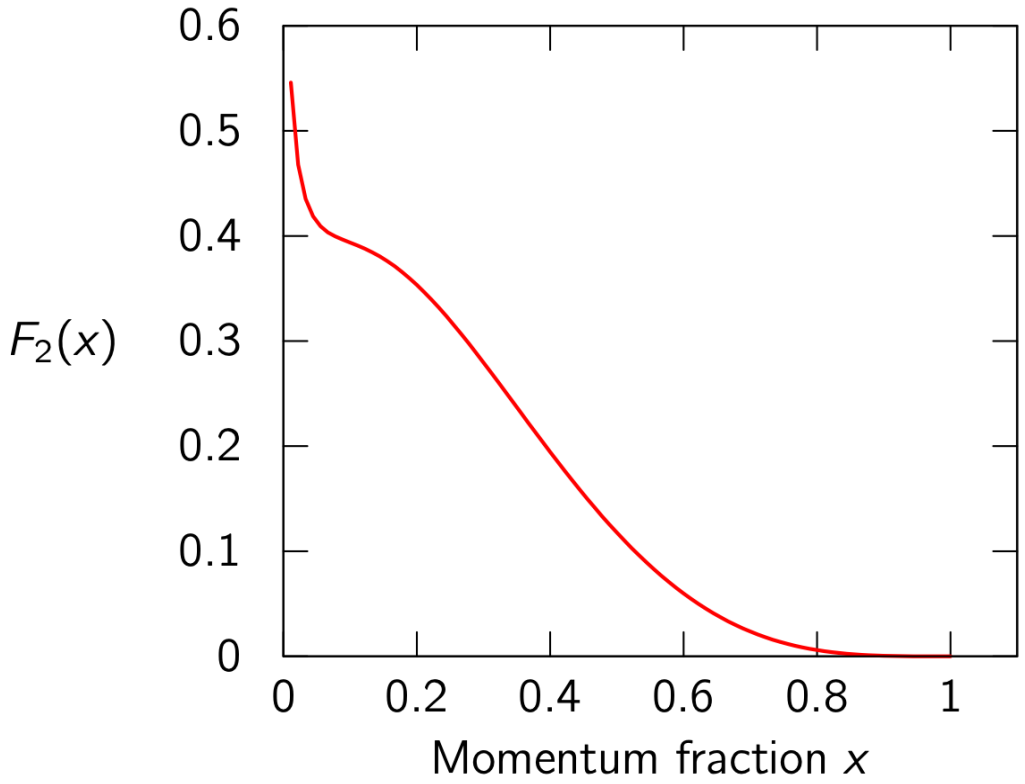


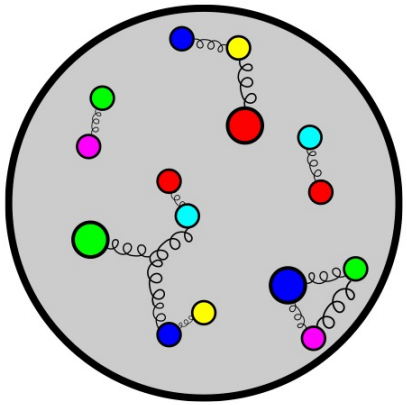
Three bound valance quarks



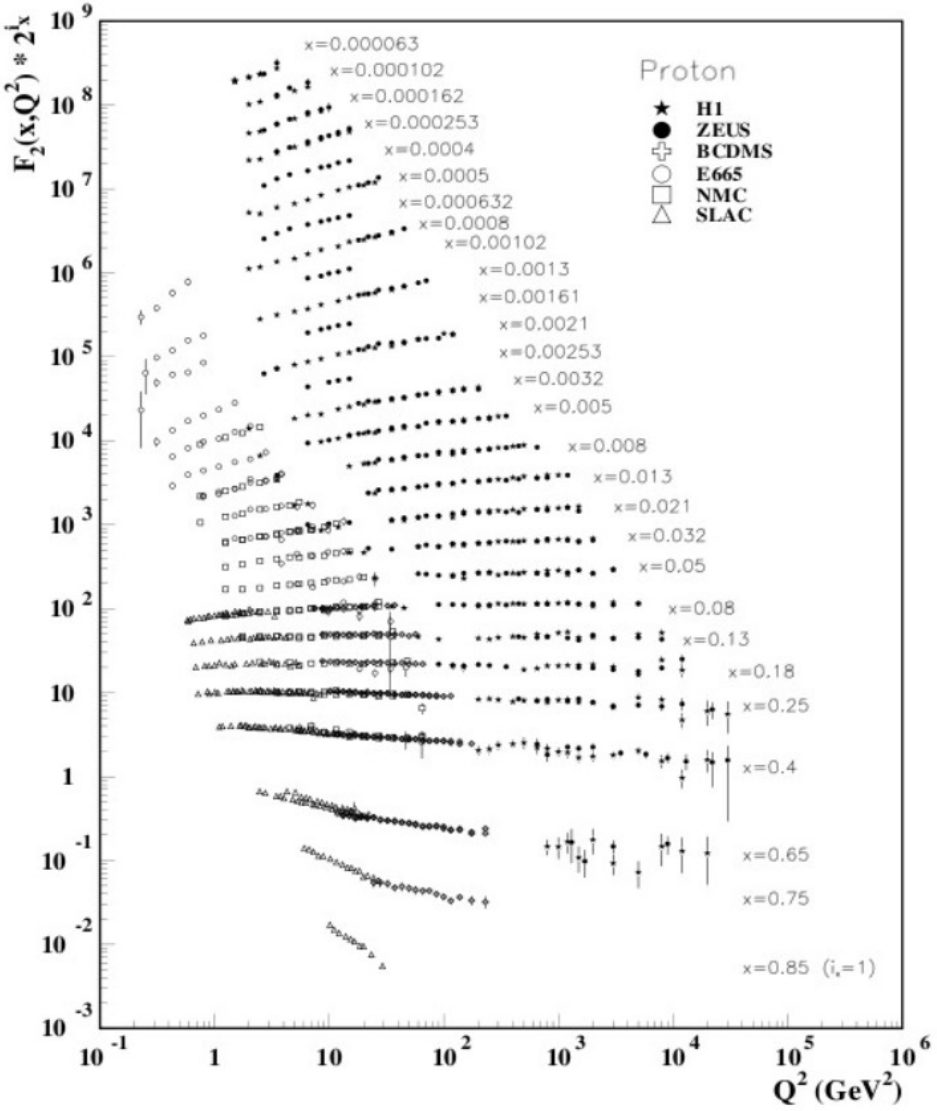
What F_2 can tell us about the nucleon

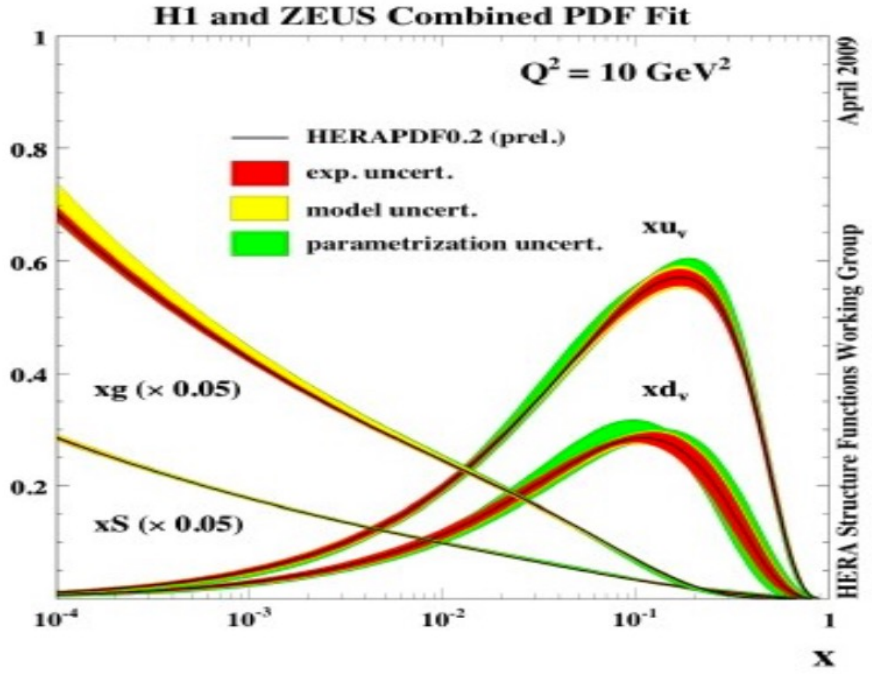
$$F_2\left(x,Q^2\right)=\sum_i e_i^2\cdot x\cdot f_i\left(x\right)$$





Decade of measurement gives us Proton‘s F_2 and PDFs





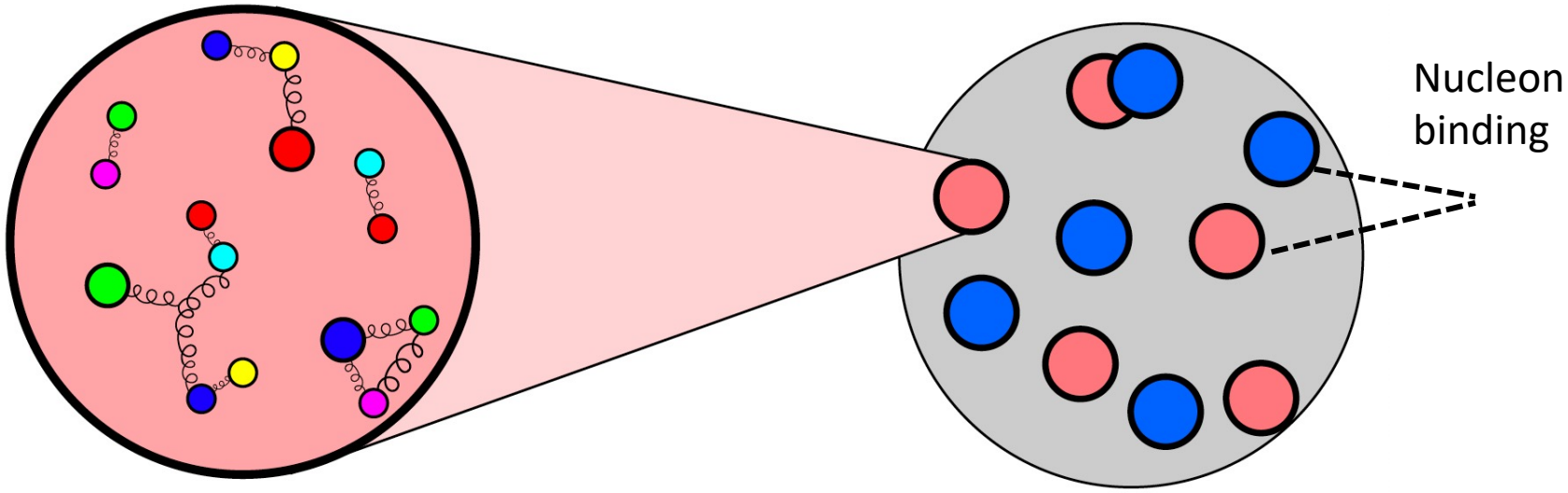
What is F_2 for a nucleus A

$$F_2^A = Z\,F_2^P + N\,F_2^N \;??$$

Questions:

1. Do quarks move differently in Nuclei?
2. Does the nuclear environment affect quark?

Quark and Nuclei are scale-separated



The scale of GeV

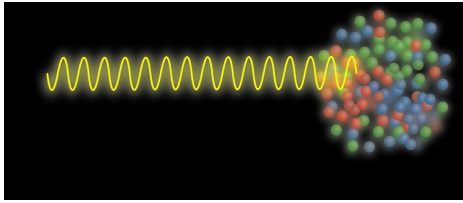
The scale of MeV

Naive expectation :

Bound nucleon ＝ Free nucleon

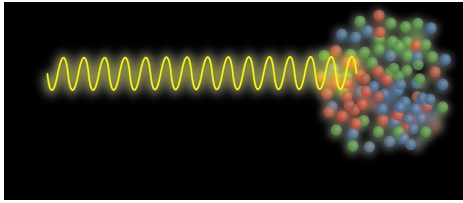
(Except some small Fermi motion correction)

Partonic – Nucleonic Interplay



<u>Question:</u> What is the *<u>simplest</u>* example of nuclear interaction affecting partonic properties?

Partonic – Nucleonic Interplay



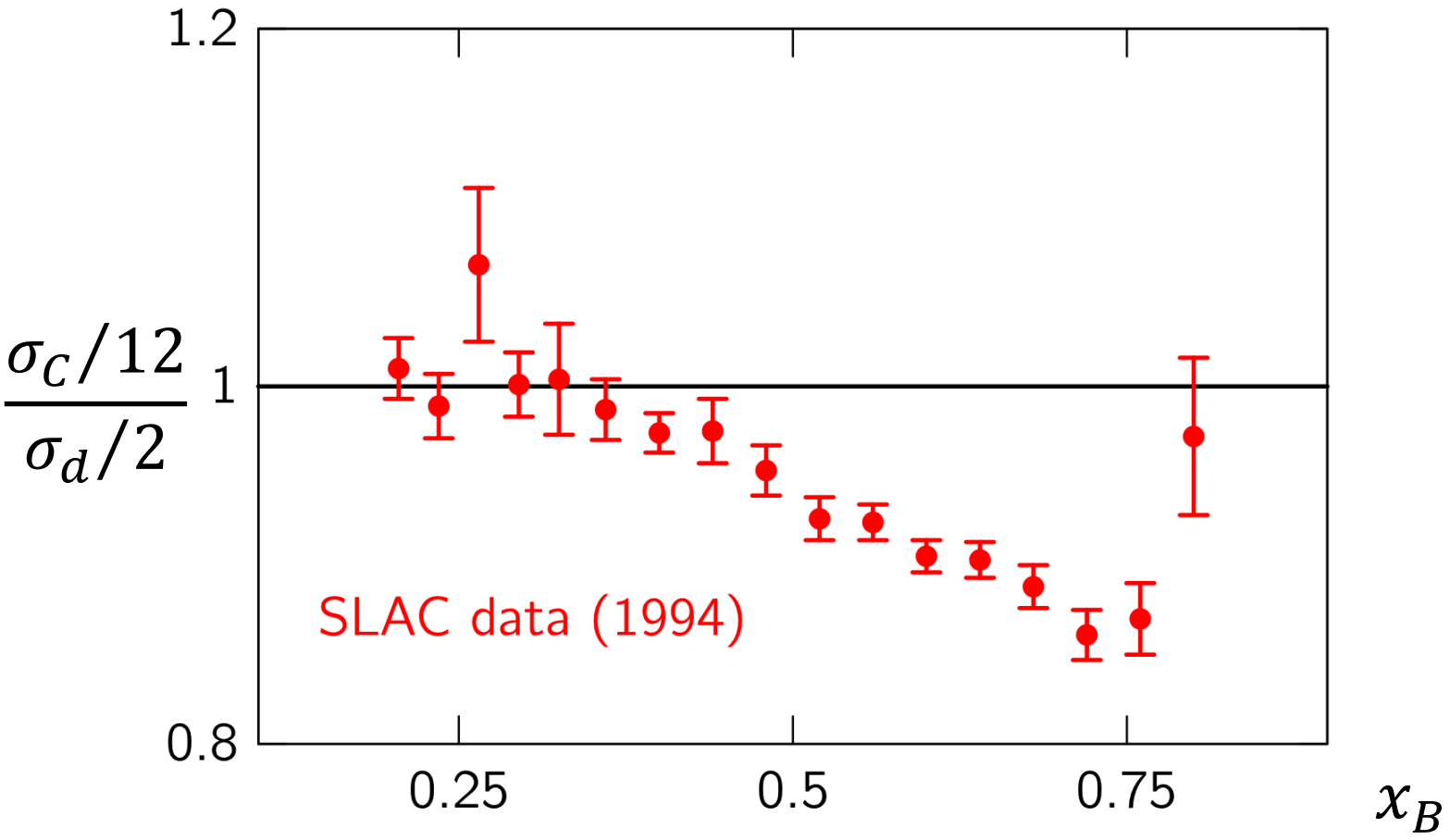
Question: What is the *simplest* example of nuclear interaction affecting partonic properties?

Answer:

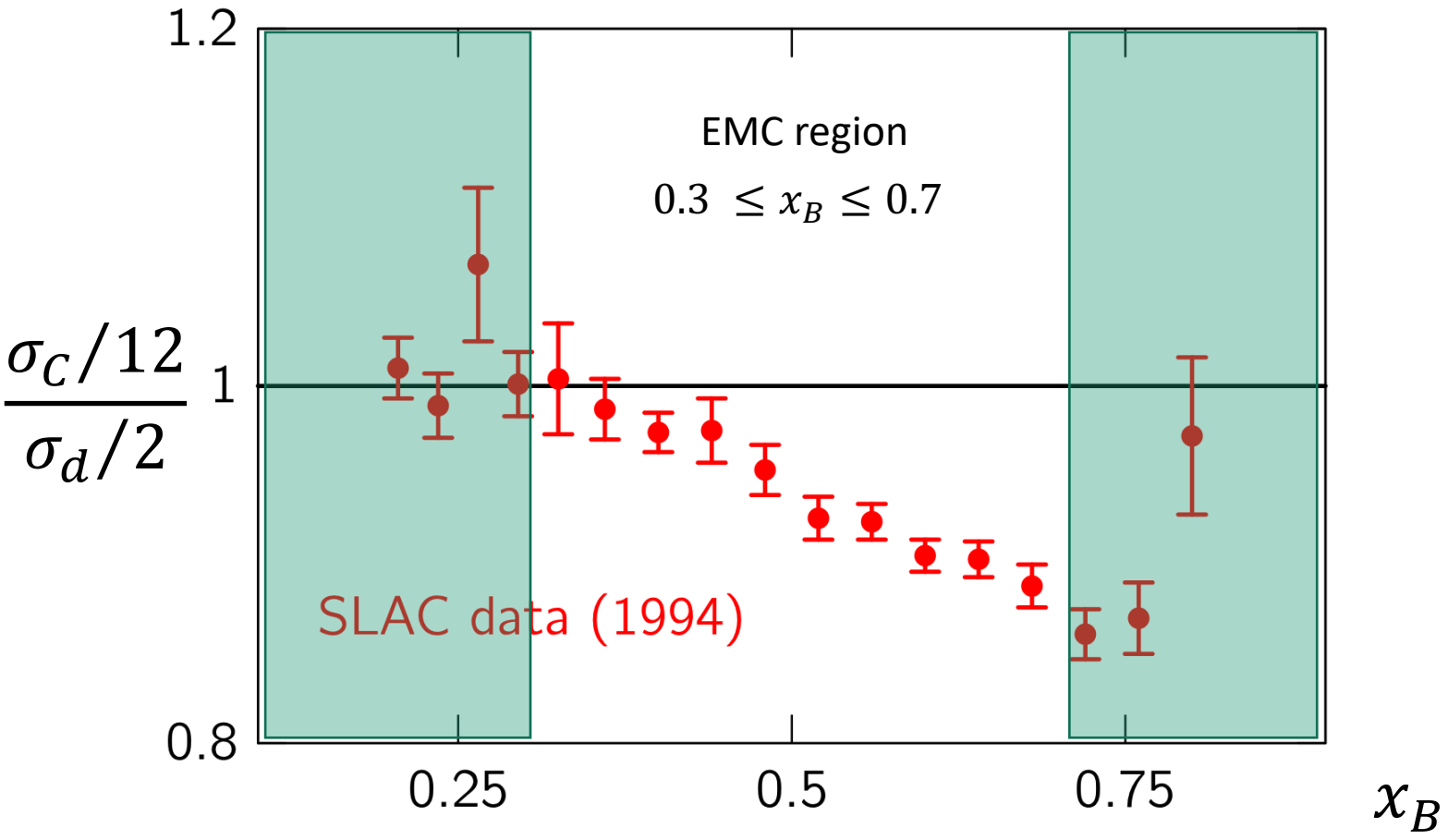
The nuclear interaction that binds the deuteron also makes the neutron stable.

- Simplest nuclear system = Deuteron,
- Free neutron is unstable: decays in ~ 10 minuets,
- Bound in the Deuteron, a neutron can live forever!

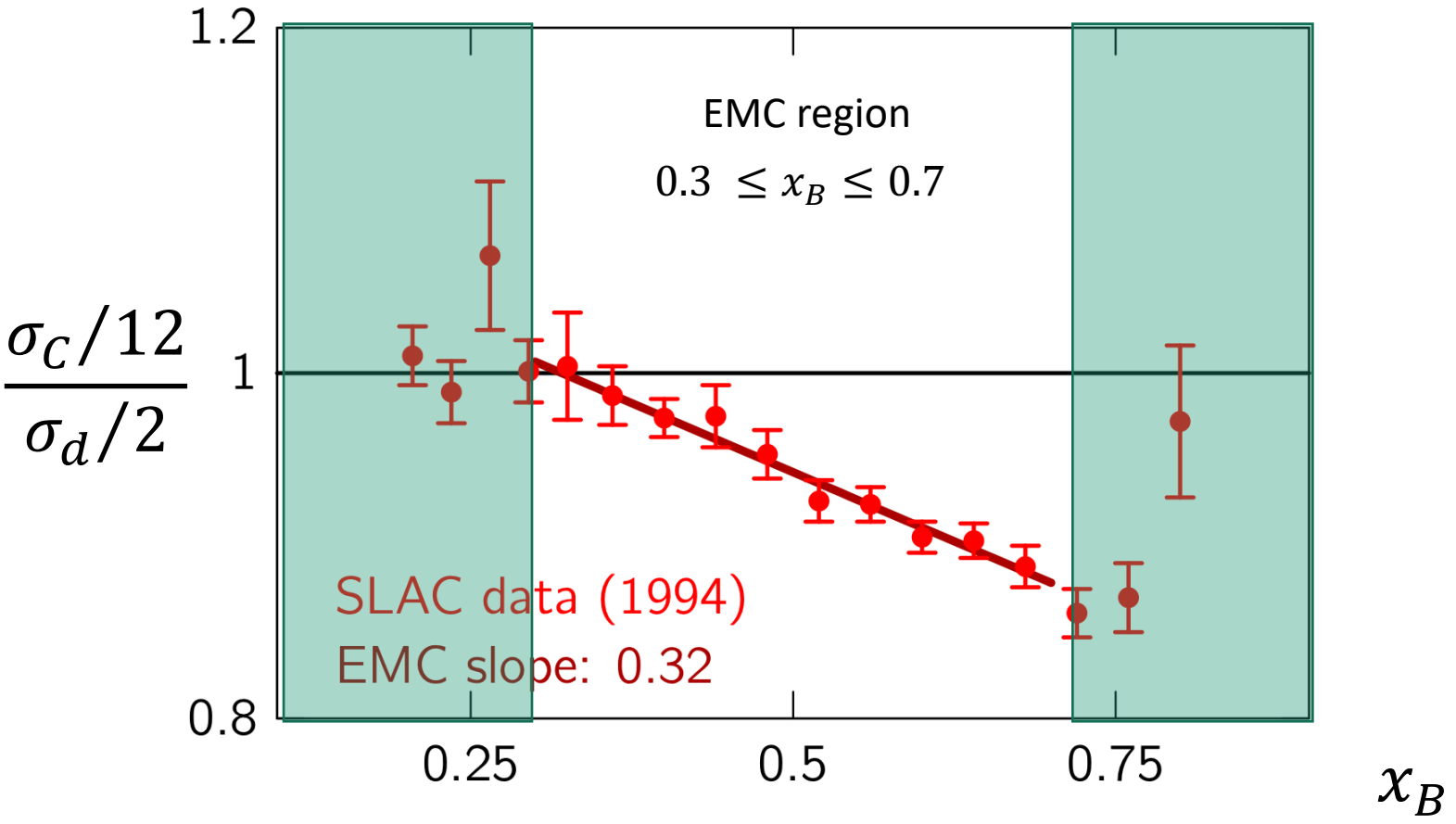
The nuclear environment affects quarks!



The nuclear environment affects quarks!

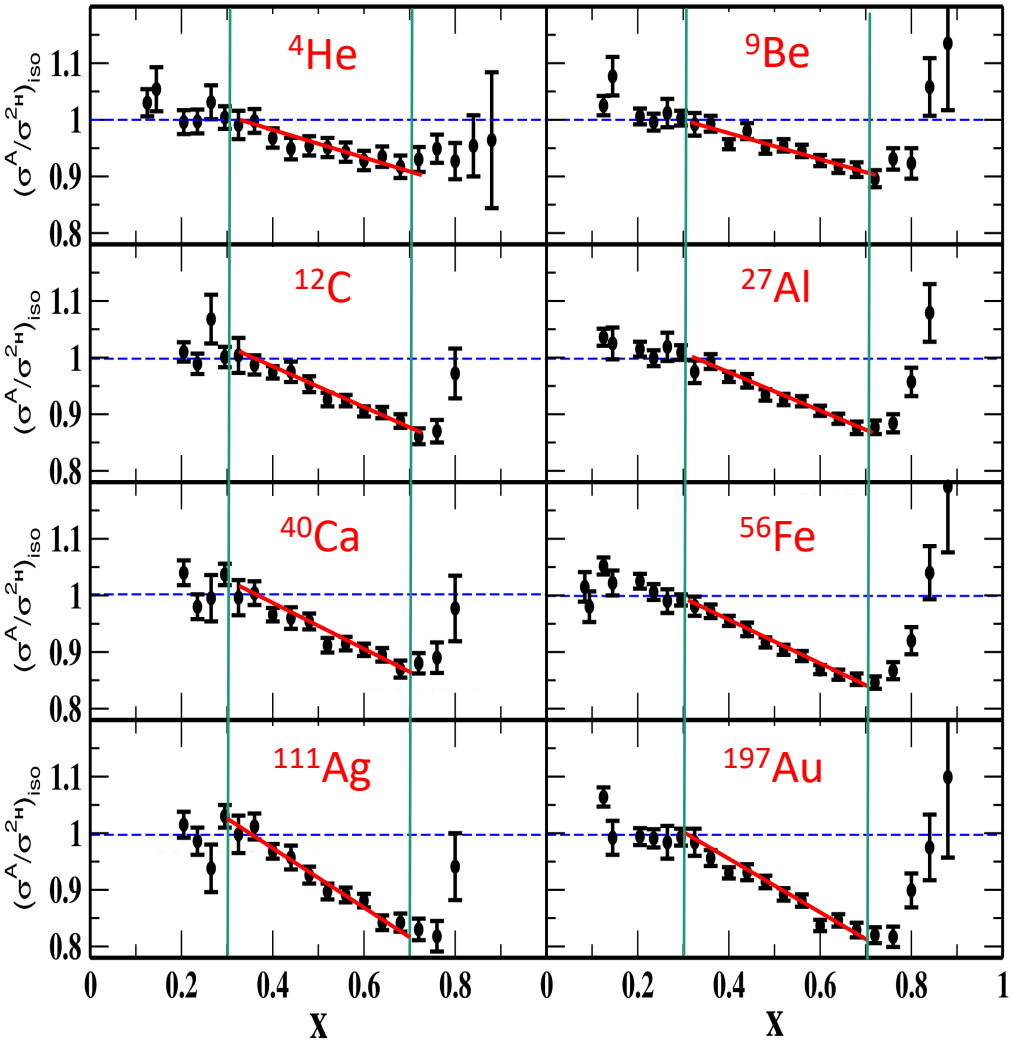


The EMC effect!



- Size of EMC effect is characterized by the slope

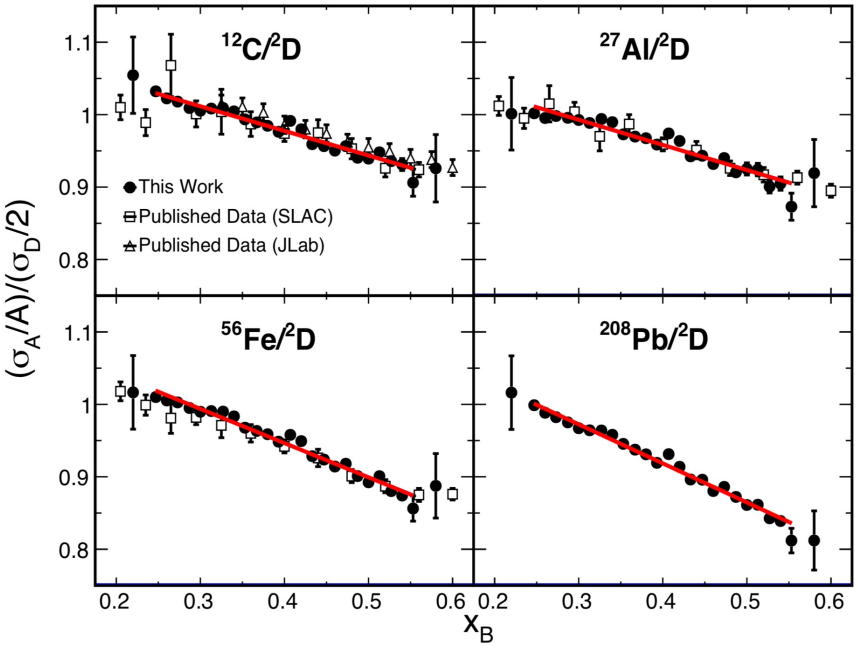
‘Global’ EMC Data



Gomez PRD (1994)

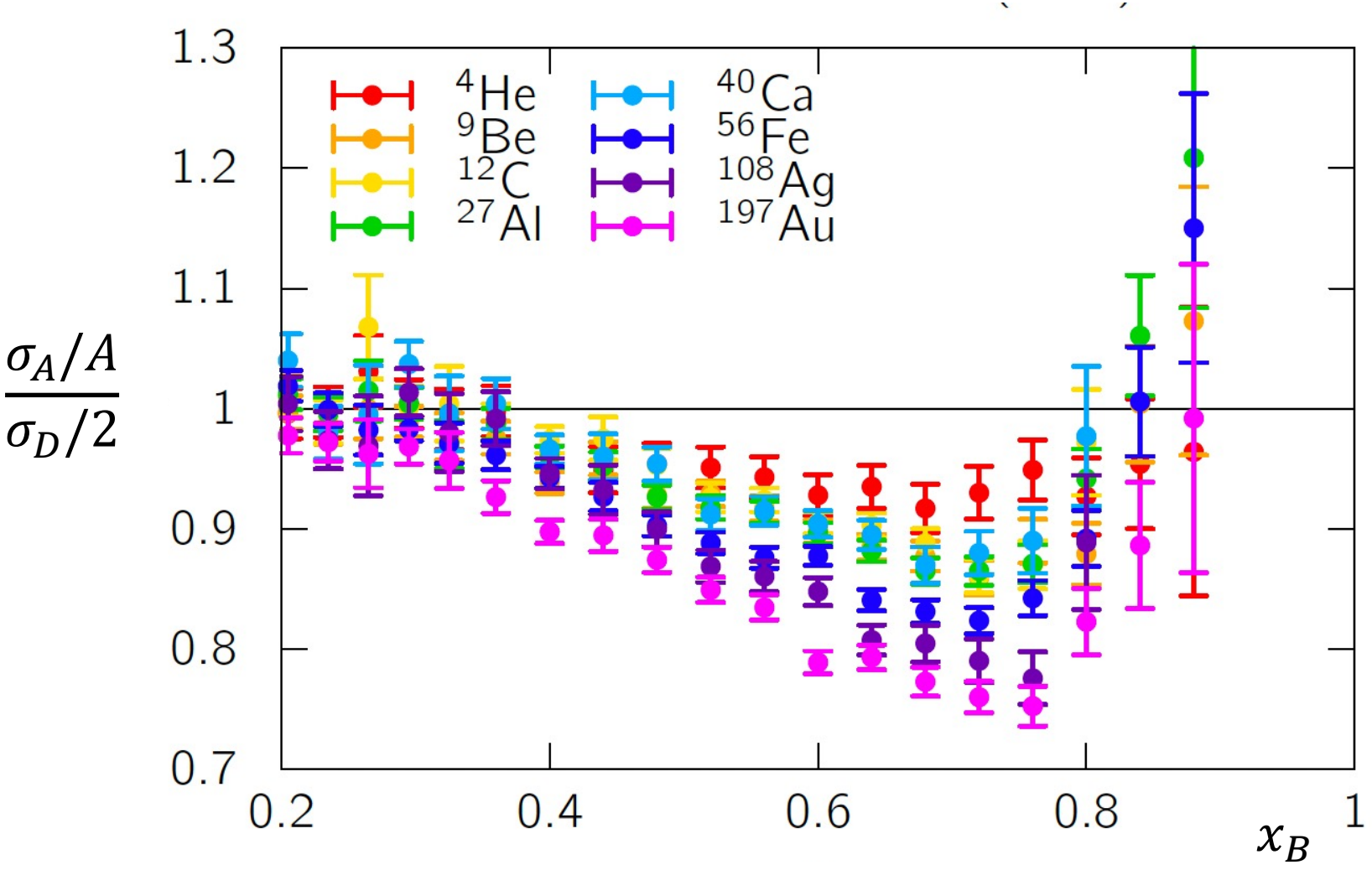
SLAC (1994)

JLab (2019)



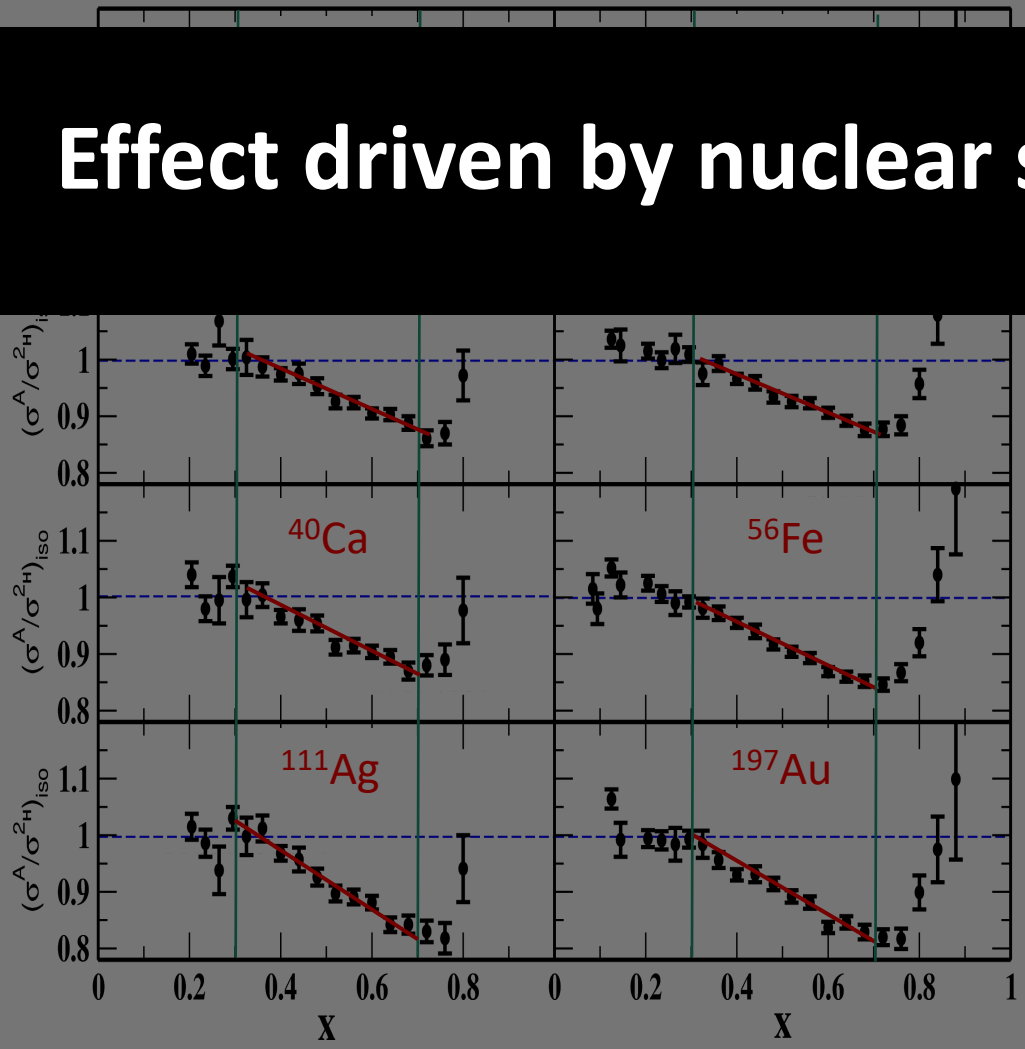
Schmookler, Nature (2019)

EMC Effect increases with Nuclear Size



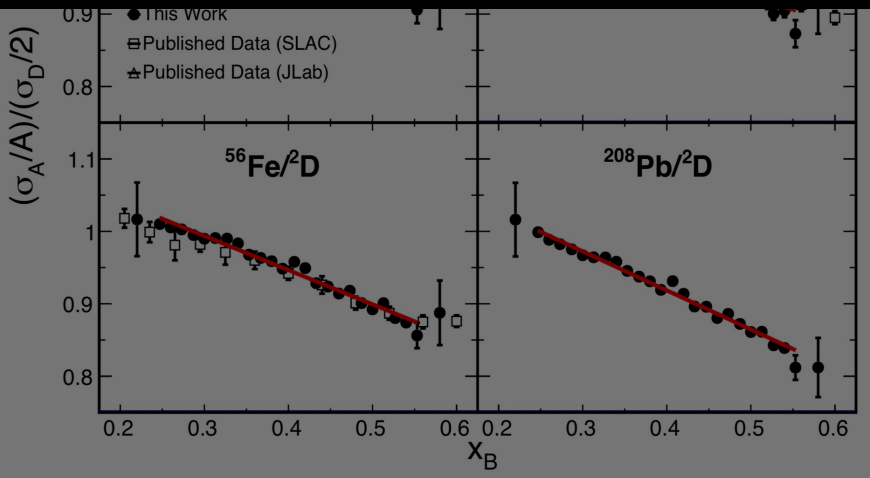
‘Global’ EMC Data

Effect driven by nuclear structure & dynamics



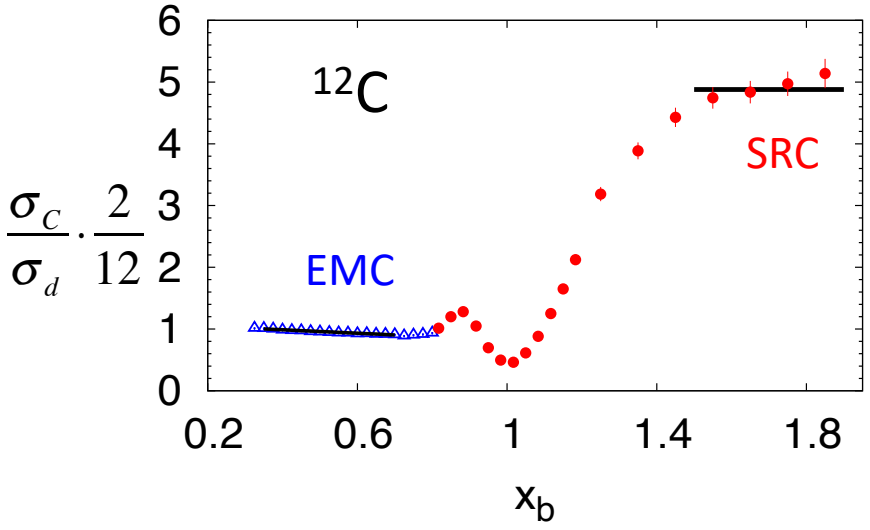
Gomez PRD (1994)

SLAC (1994)



Schmookler, Nature (2019)

Correlations Between EMC and SRC

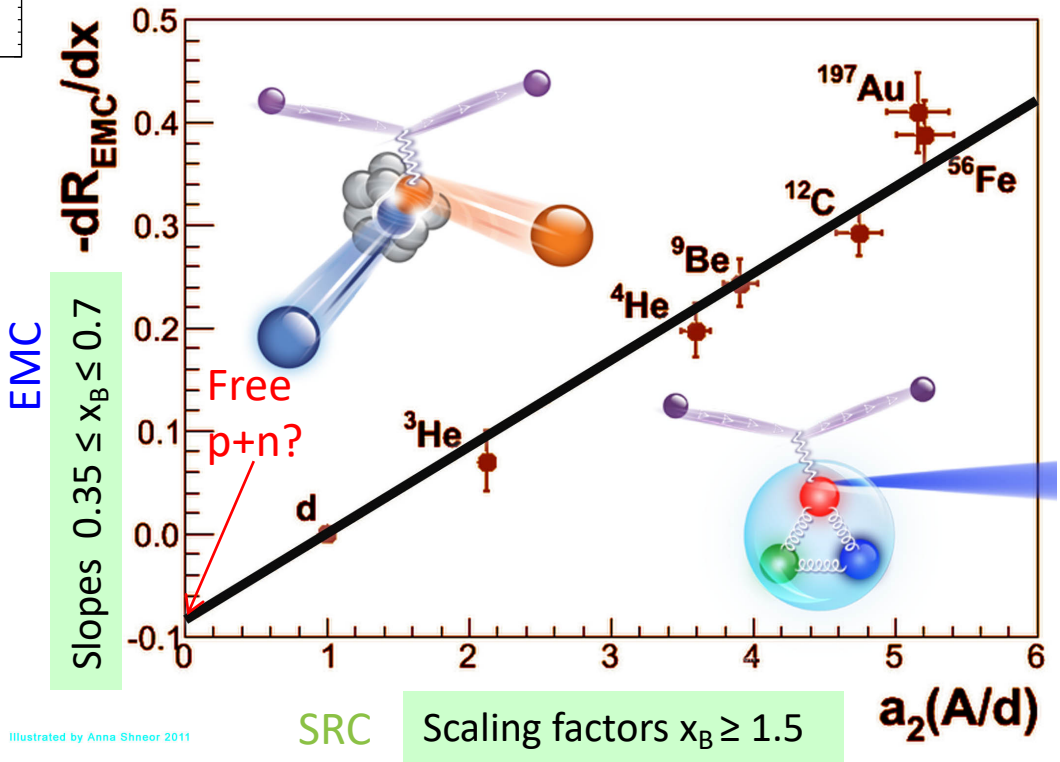


SRC

- High nucleon momenta

JLab data

J. Seely *et al.*, PRL **103** (2009) 202301
N. Fomin et al., Phys. Rev. Lett. **108** (2012) 092502

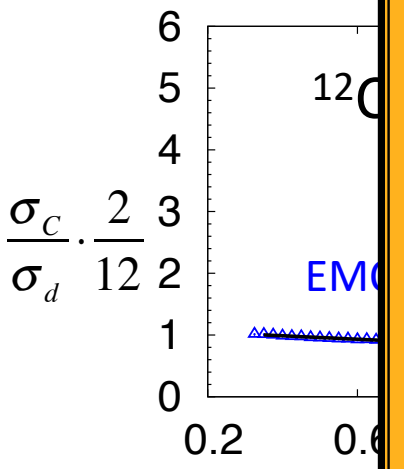


EMC

- Is EMC related to high-momentum nucleons?
- Are high-momentum nucleons modified?

PRL **106**, 052301 (2011) RMP **89**, 045002 (2017)
PRC **85**, 047301 (2012) Nature **566**, 354 (2019)

Correlations Between EMC and SRC



SRC

- High nuc

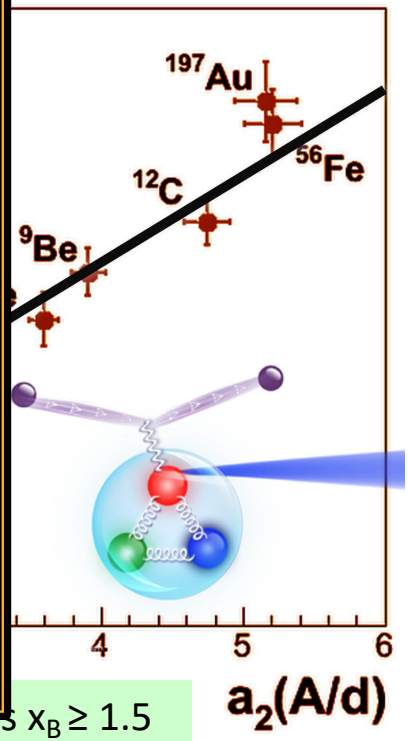
- Is EMC r
  moment
- Are high-momentum nucleons modified?

The Big EMC Effect Question:

Are **all** the nucleons each modified **a little bit** by the mean field?

or

Are the **few** high-momentum nucleons each modified **a lot** by the short range interaction?



Illustrated by Anna Shneor 2011

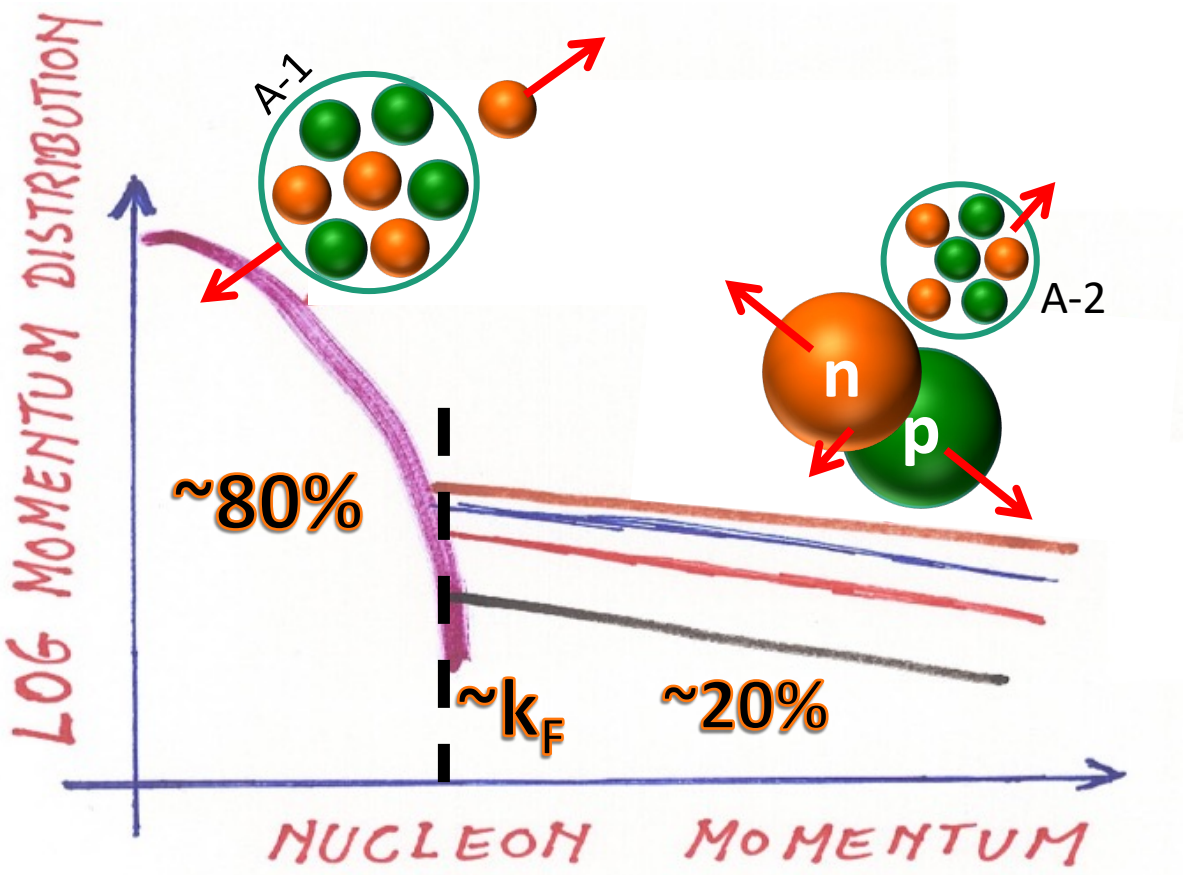
SRC Scaling factors $x_B \geq 1.5$

PRL **106**, 052301 (2011) RMP **89**, 045002 (2017)
PRC **85**, 047301 (2012) Nature **566**, 354 (2019)

EMC-SRC model

Hypothesis:

- EMC effect as being due entirely to the modification of SRC-pair
- Based on the isospin dominance of SRCs => Modification of np-SRC pair



EMC-SRC model predicts that the modification of SRCs should be universal!

$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A\left(\Delta F_2^p + \Delta F_2^n\right)$$

$$F_2^d = F_2^p + F_2^n + n_{SRC}^d\left(\Delta F_2^p + \Delta F_2^n\right)$$

EMC ratio

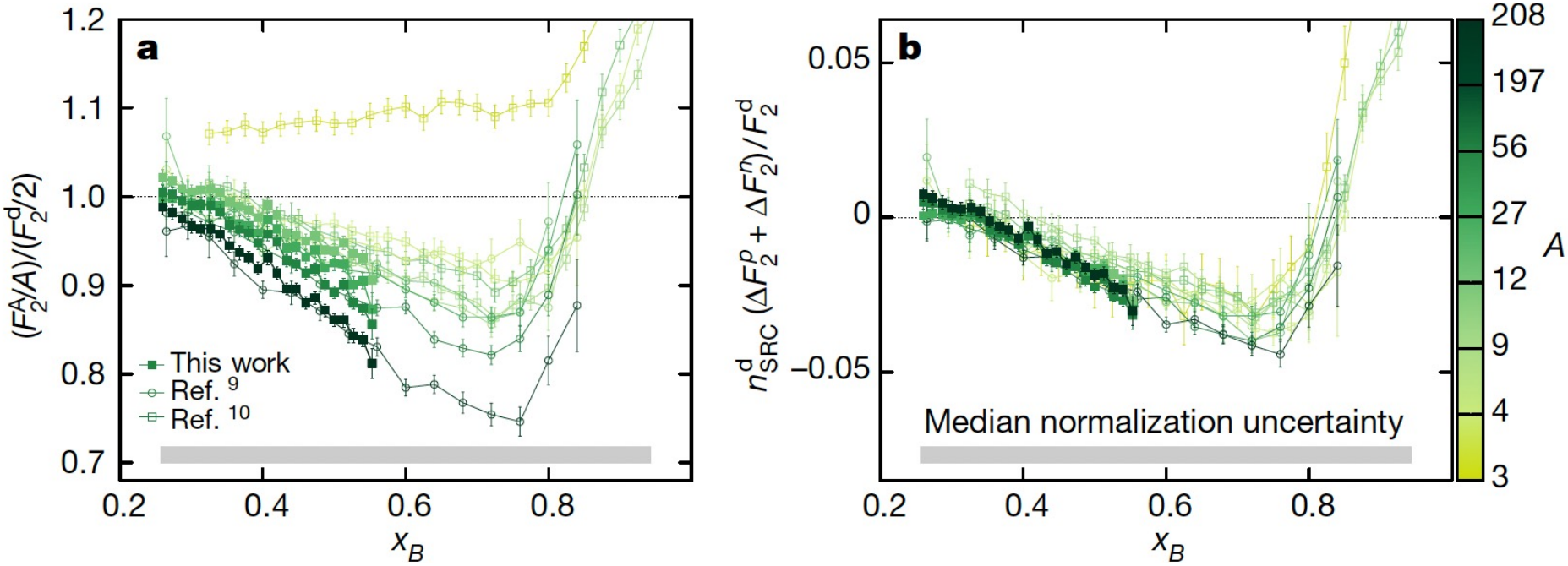
$$\frac{F_2^A/A}{F_2^d/2} = (a_2 - 2\frac{N}{A})\left(n_{SRC}^d \frac{\Delta F_2^p + \Delta F_2^n}{F_2^d}\right) + 2 \cdot \frac{Z-N}{Z+N} \cdot \frac{F_2^p}{F_2^d} + 2\frac{N}{A}, \quad \text{where} \quad a_2 = \frac{n_{SRC}^A/A}{n_{SRC}^d/2}.$$

Nucleus-independent

$$\Rightarrow \quad n_{SRC}^d \frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} = \frac{\frac{F_2^A}{F_2^d} - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}.$$

Schmookler, Nature (2019)

EMC-SRC model predicts that the modification of SRCs should be universal!

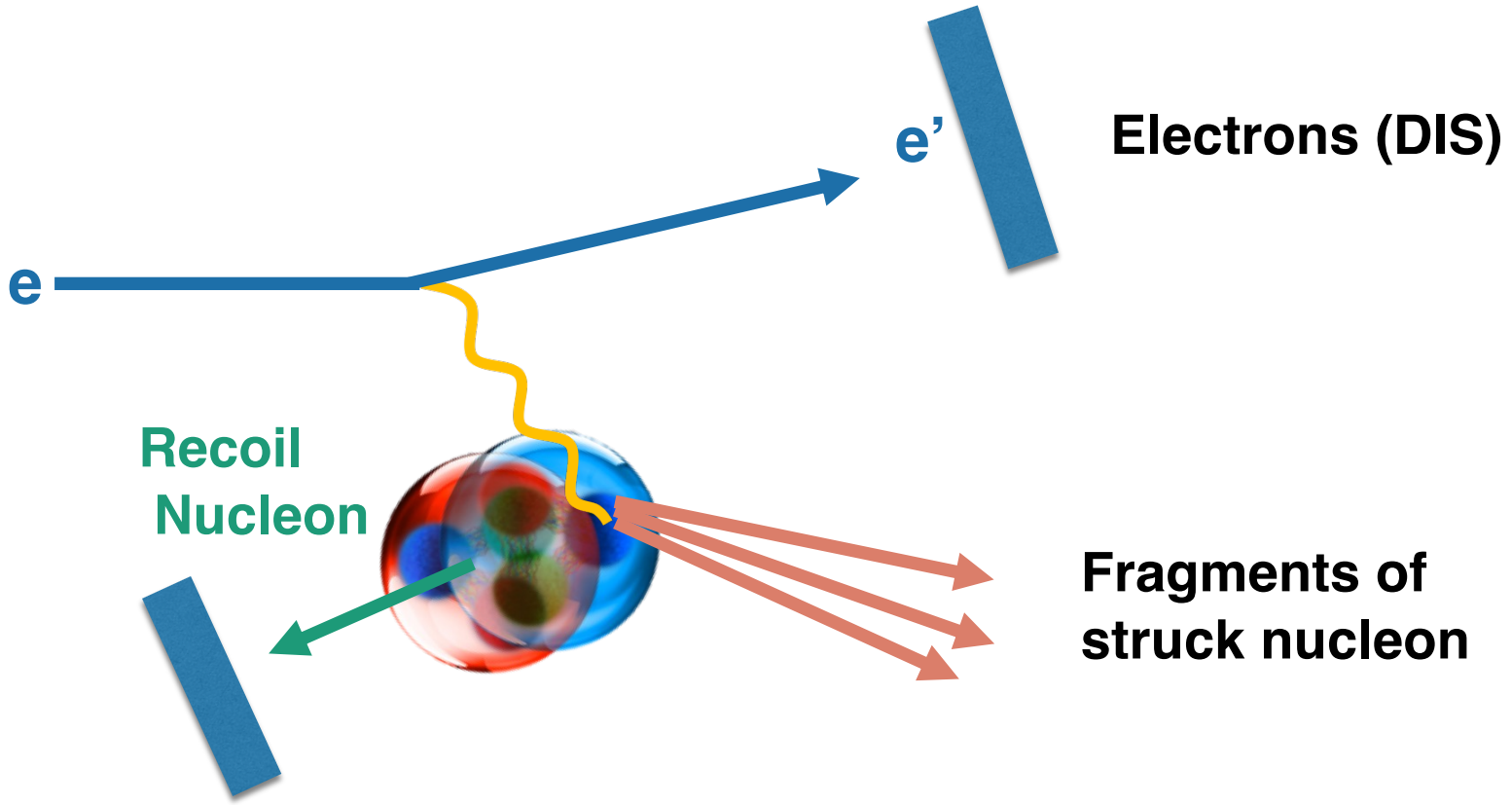


$$R_{\mathrm{EMC}} = \frac{2F_2^A}{AF_2^d} = \frac{2N}{A} + \frac{2(Z-N)}{A}\frac{F_2^p}{F_2^d} + \frac{2}{A}\left(\frac{n_{\mathrm{SRC}}^A}{n_{\mathrm{SRC}}^d} - N\right)\cdot U$$

The EMC effect can be described by the universal modification of SRC pairs

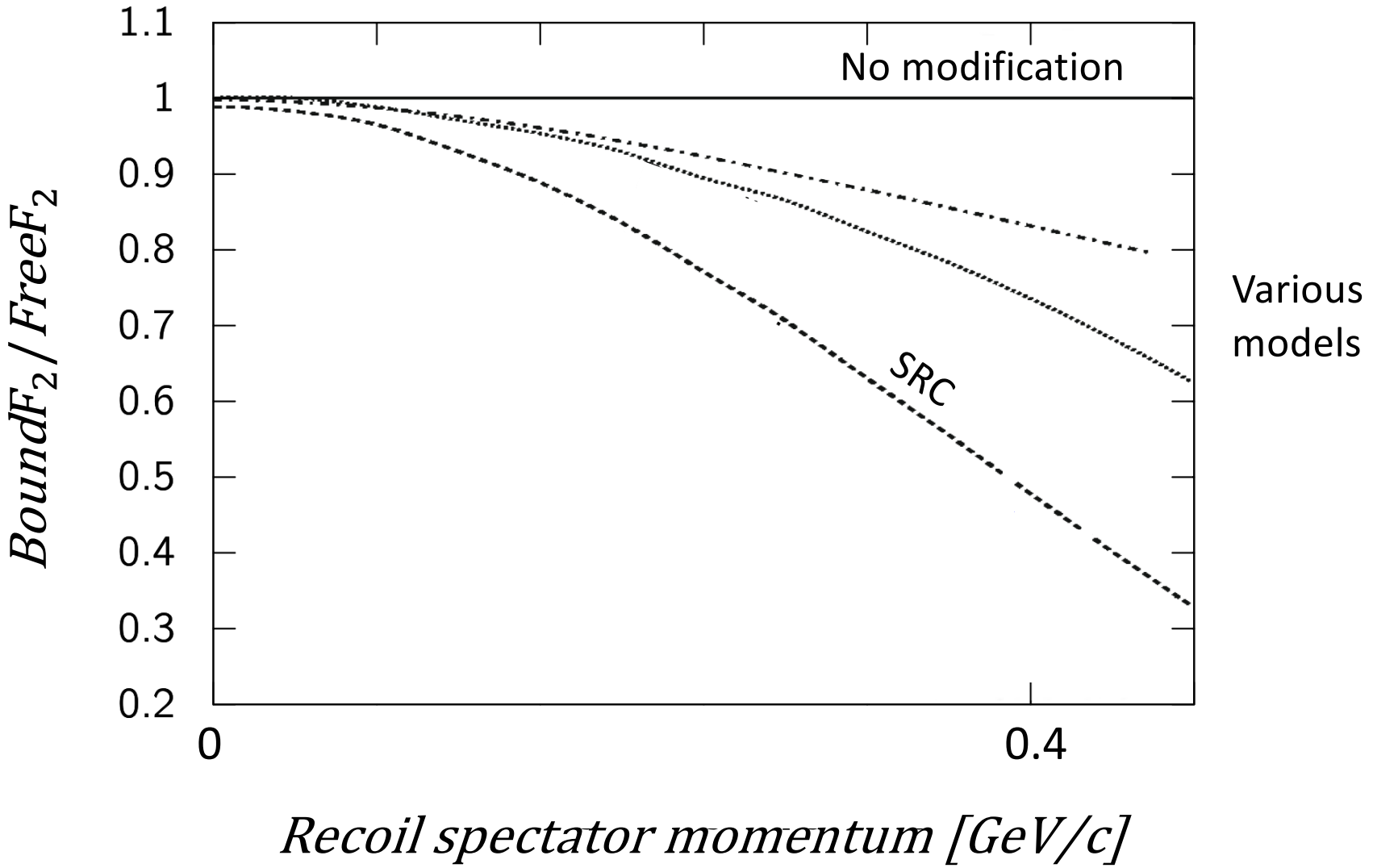
Schmookler, Nature (2019)

Tagged DIS on Deuterium



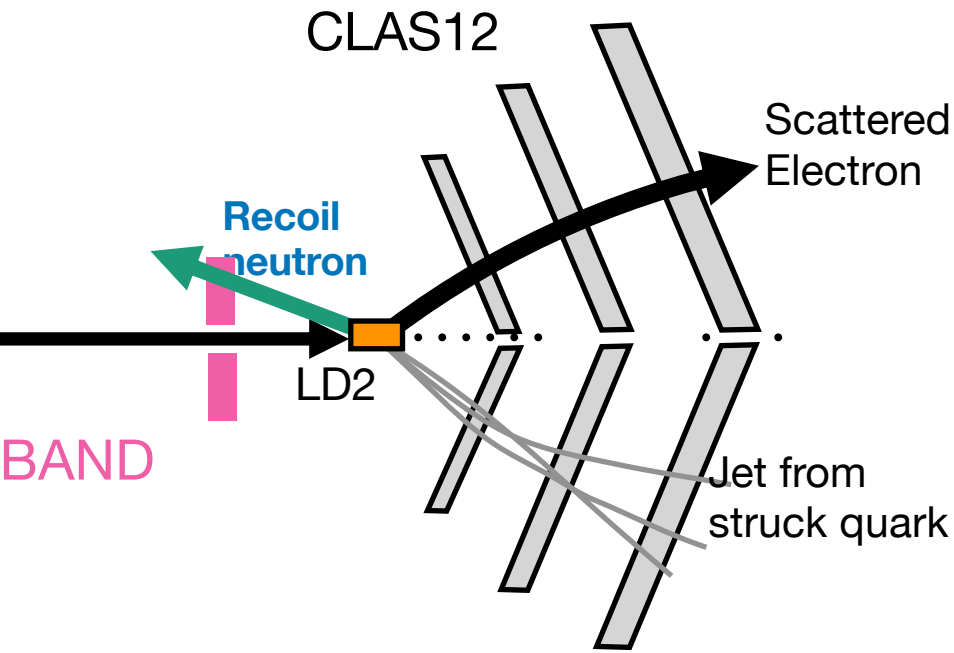
- "Tag" interacting nucleon by measuring recoil spectator
- Measure dependence of bound nucleon structure function on nucleon momentum

DIS Recoil Tagging d(e,e'N)X - Expected Results



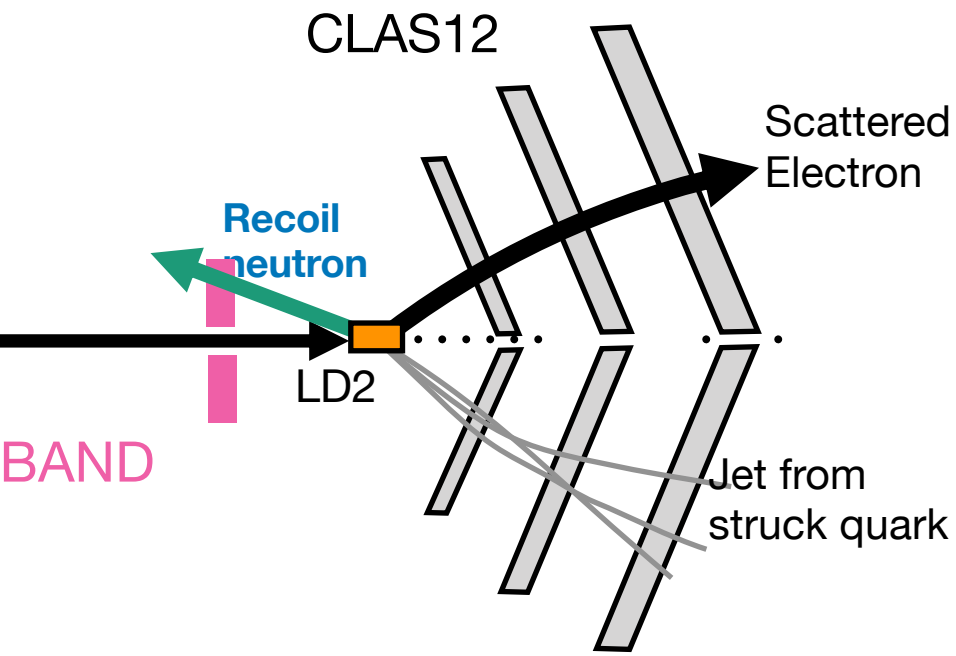
Tagged DIS at JLab

Hall B:
CLAS 12 + Backward Angle
Neutron Detector (BAND)

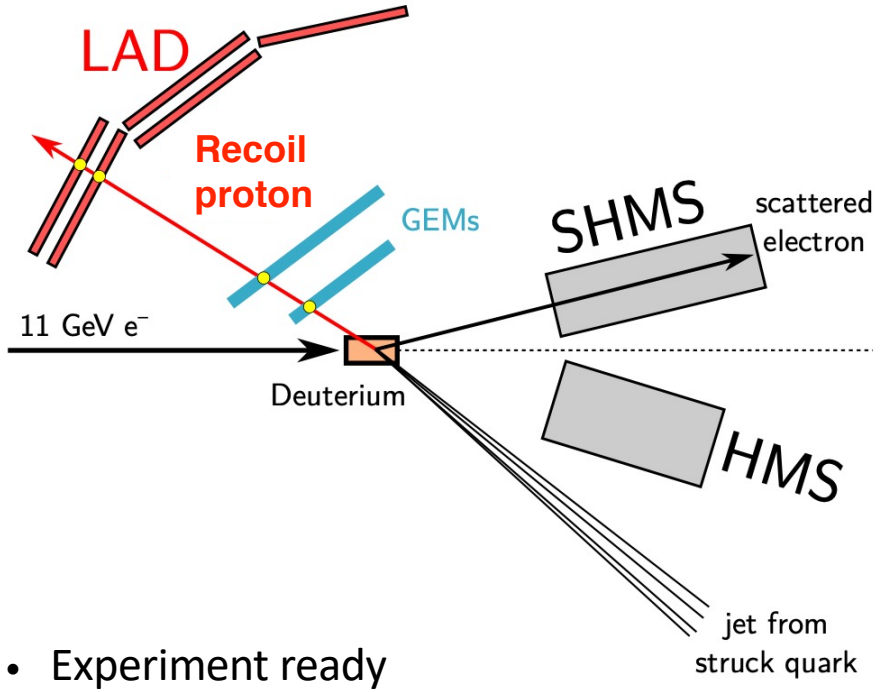


Tagged DIS at JLab

Hall B:
CLAS 12 + Backward Angle Neutron Detector (BAND)

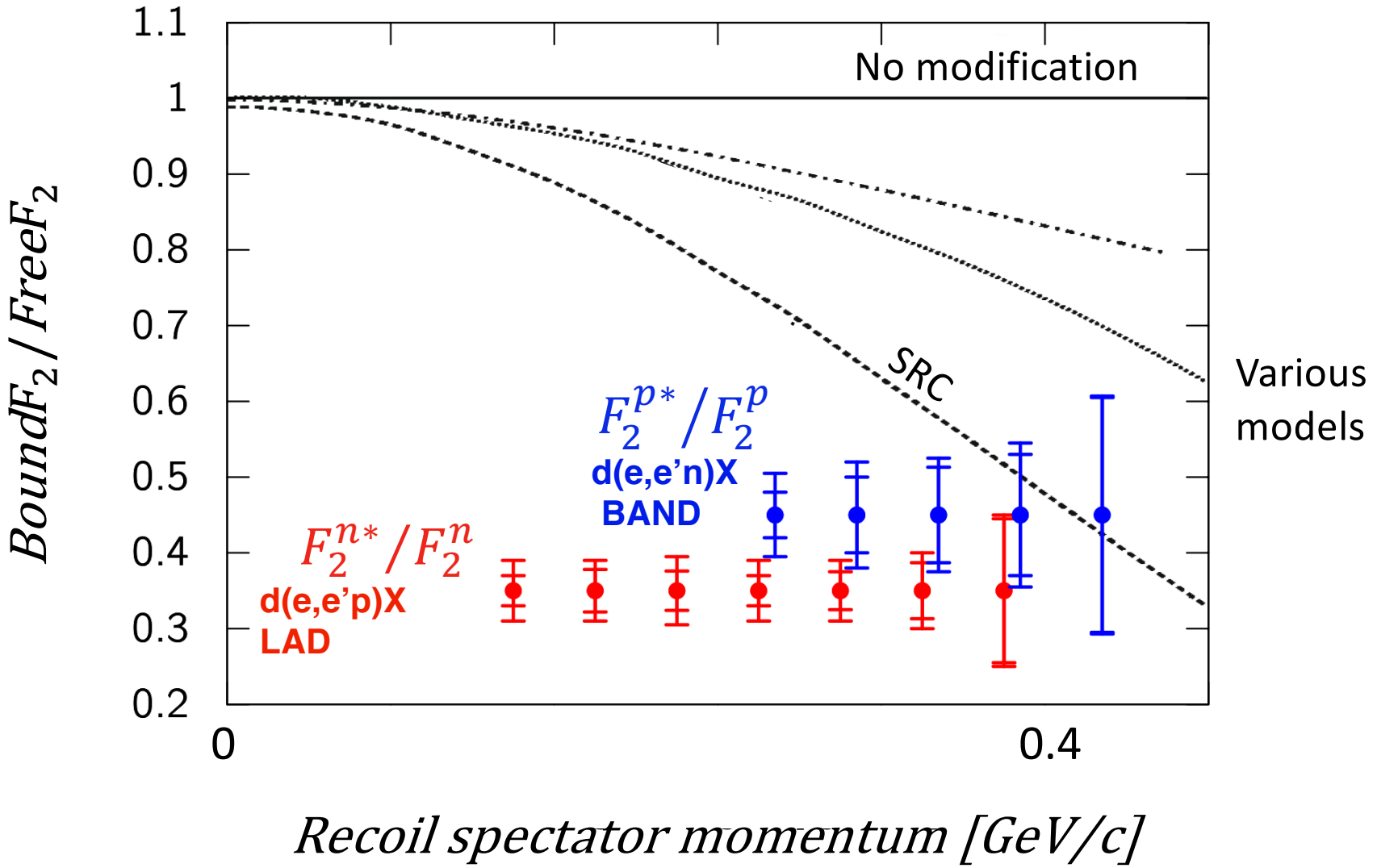


Hall C:
SHMS/HMS + Large Angle Detector (LAD)

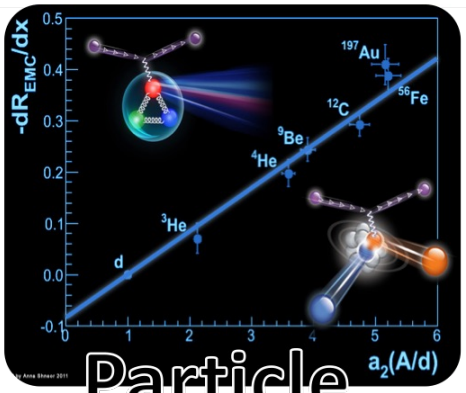


- Experiment ready
- GEMs track particle direction
- Run in 2023?

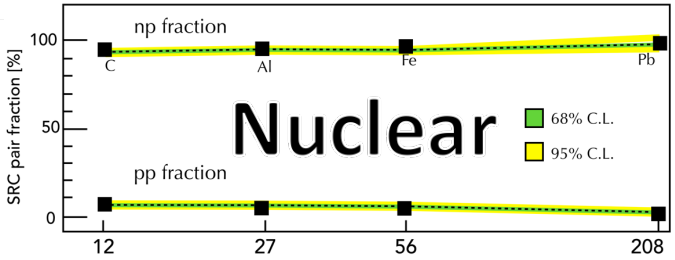
DIS Recoil Tagging d(e,e'N)X - Expected Results



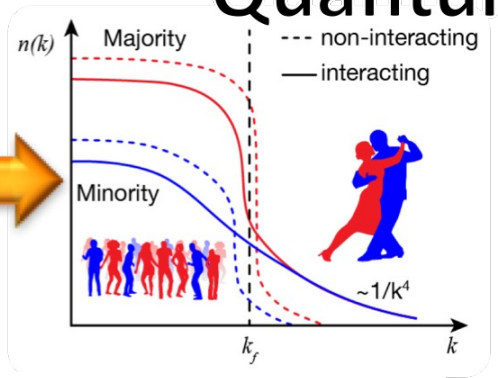
SRCs has many implication

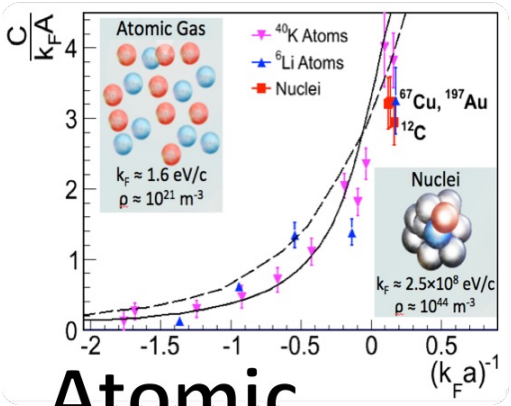


Particle

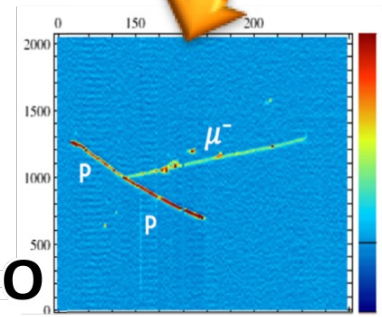


Quantum

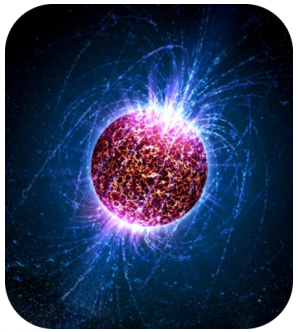




Atomic



Neutrino



Astro

Proton visualization

https://www.youtube.com/watch?v=G-9I0buDi4s