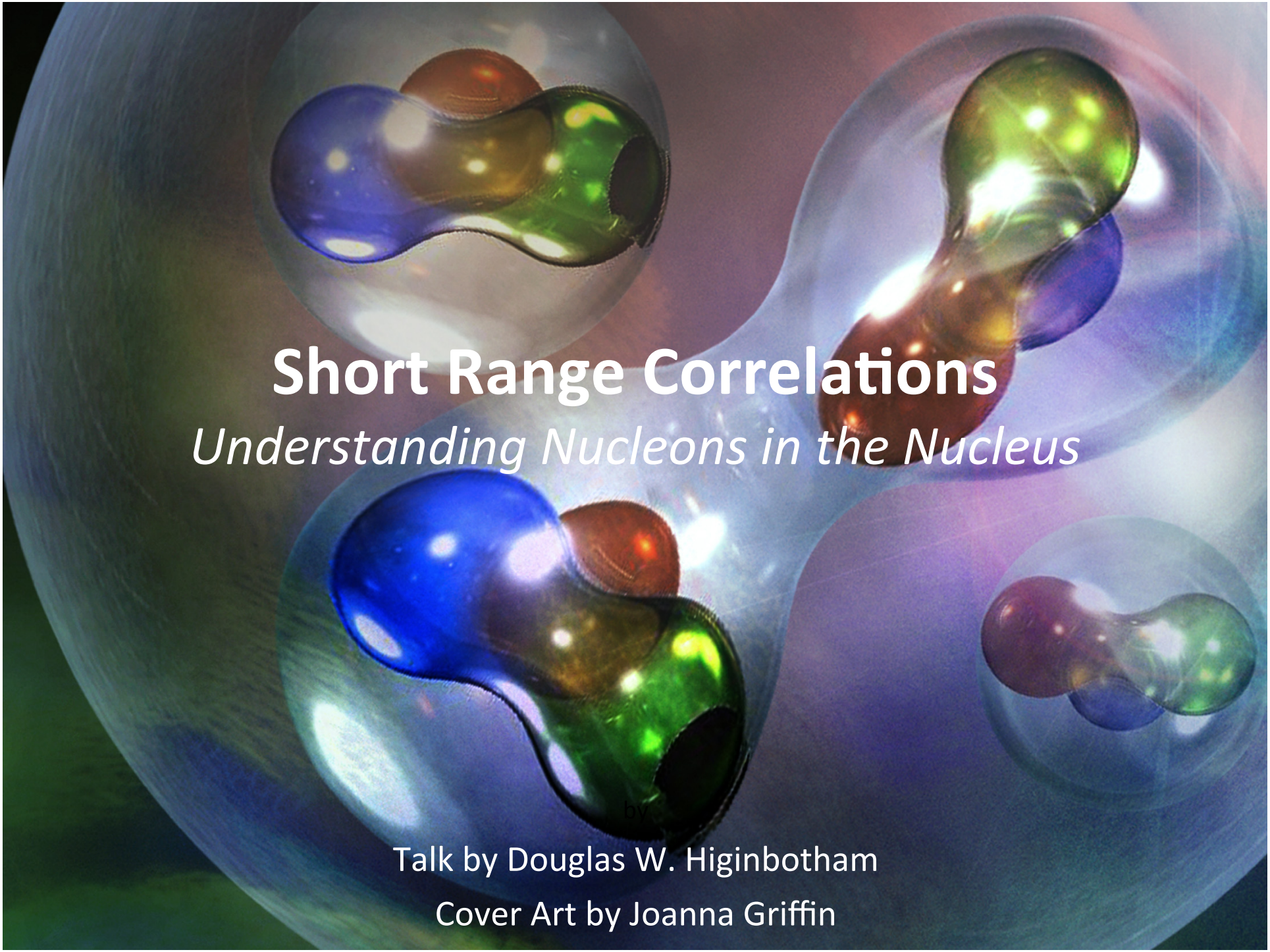


Short Range Correlations

Understanding Nucleons in the Nucleus

by

Talk by Douglas W. Higinbotham

Cover Art by Joanna Griffin

Many 12GeV SRC Related Proposals

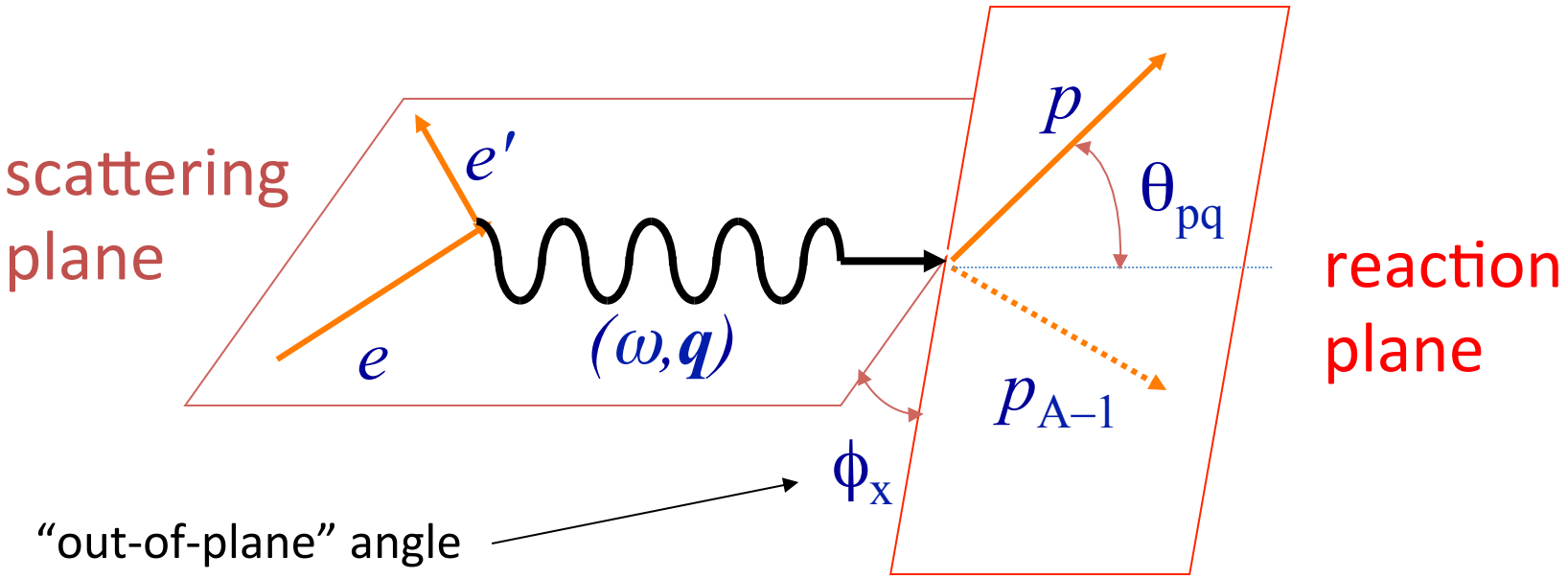
one example from each hall shown below.

- E12-14-011: Proton and Neutron Momentum Distributions in A = 3 Asymmetric Nuclei (Hall A) [**ran in April 2018**]
- PR12-17-006: Electrons for Neutrinos: Addressing Critical Neutrino-Nucleus Issues (Hall B)
- E12-17-005: The CaFe Experiment: Short-Range Pairing Mechanisms in Heavy Nuclei (Hall C)
- PR12-17-007: Probing QCD in the nuclear medium with real photons and nuclear targets at GlueX (Hall D)

My Goal Today Is To Provide You With A Quick History, Highlight Some 6GeV Highlights and Show You Of The Exciting Science That Is Already Approved for 12GeV

Background

Electron Scattering Kinematics



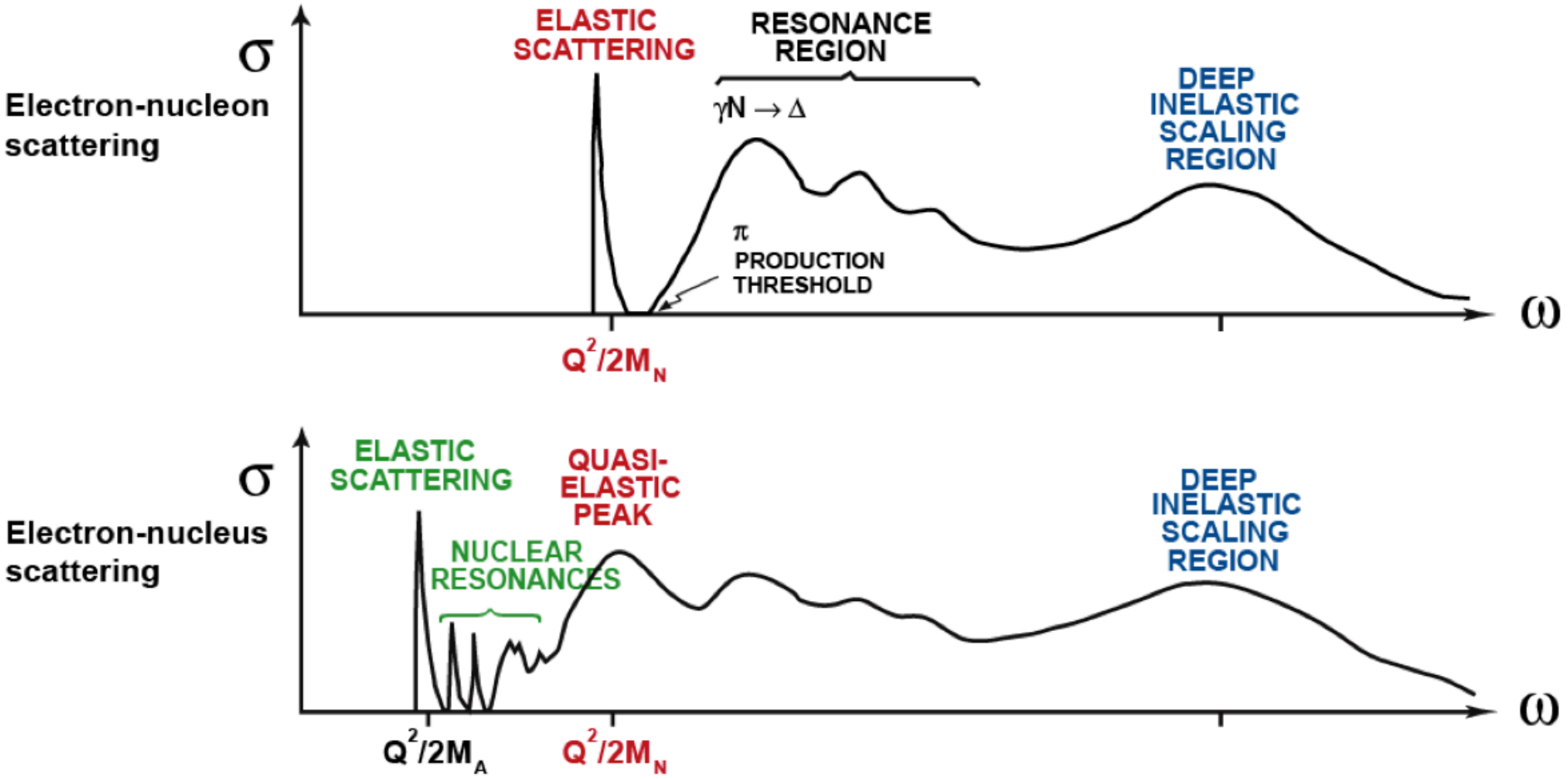
Energy transfer: $\omega = e - e'$

Four-momentum transfer: $Q^2 \equiv -q_\mu q^\mu = \boldsymbol{q}^2 - \omega^2$

Missing momentum: $\boldsymbol{p}_m = \boldsymbol{q} - \boldsymbol{p} = \boldsymbol{p}_{A-1}$

Bjorken x: $x_B = Q^2/2m\omega$ ***(just kinematics!)***

Electron Scattering from Nucleons in the Nucleus

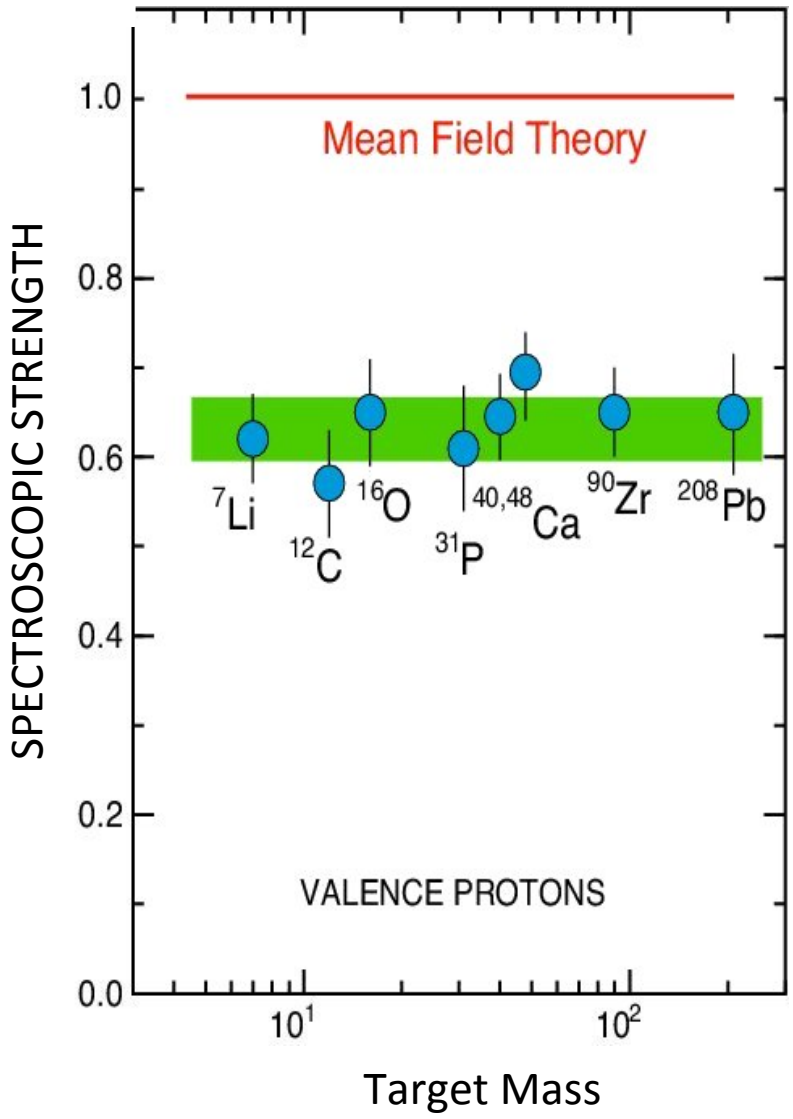


$x_B = Q^2/2m\omega$ $\quad x_B > 1$ $\quad x_B = 1$ $\quad x_B < 1$

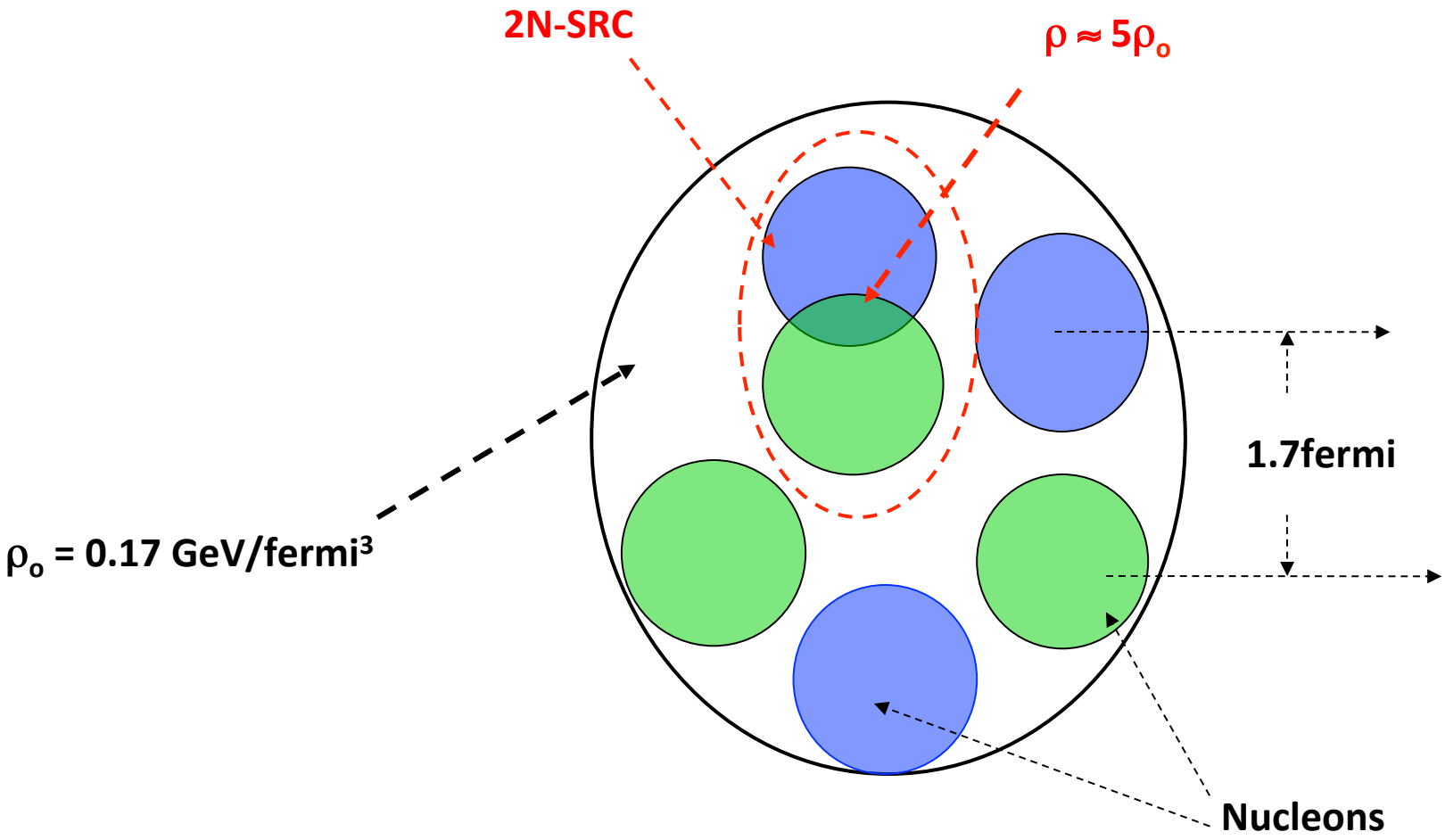
The Classic A(e,e'p)A-1 Problem

Independent-Particle Shell-Model is based upon the assumption that each nucleon moves independently in an average potential (mean field) induced by the surrounding nucleons

The (e,e'p) data for knockout of valence and deeply bound orbits in nuclei gives spectroscopic factors that are 60 – 70% of the mean field prediction.



Possible Answer: Short-Range Correlations

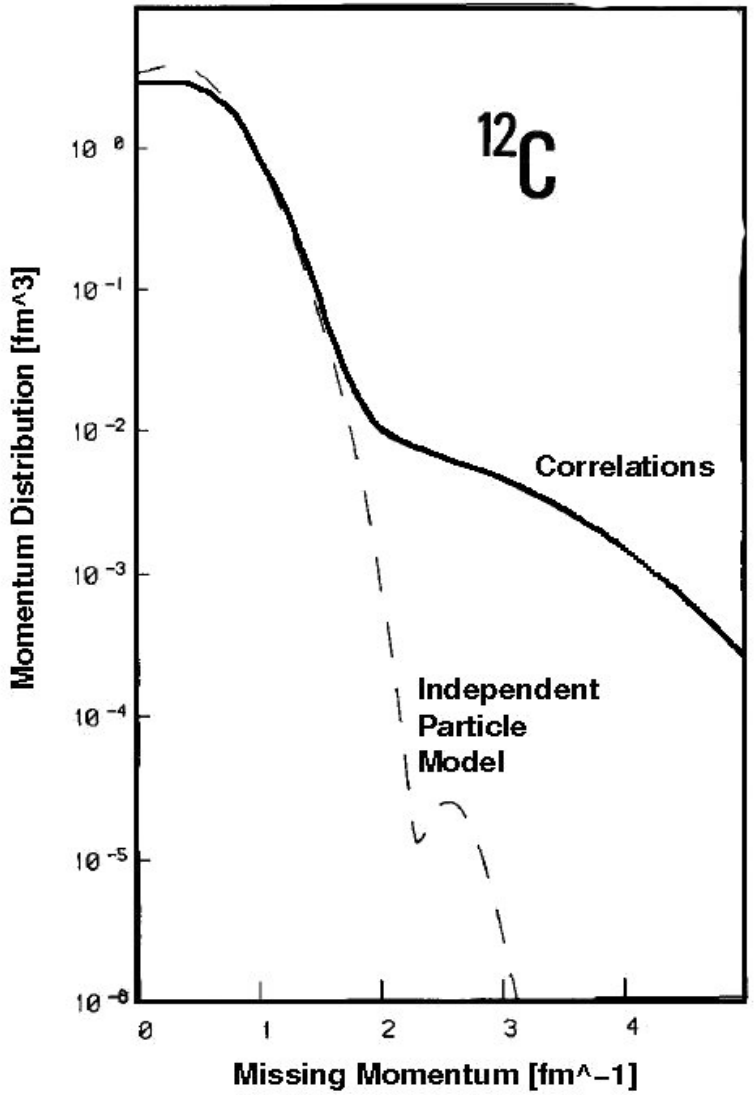


nucleons made up of Quarks, does NOT violate Pauli exclusion principle

If Correct Raises More Questions

- What fraction of the momentum distribution is due to 2N-SRC?
- What is the relative momentum between the nucleons in the pair?
- What is the ratio of pp to pn pairs?
- Are these nucleons different from free nucleons (e.g. size)?

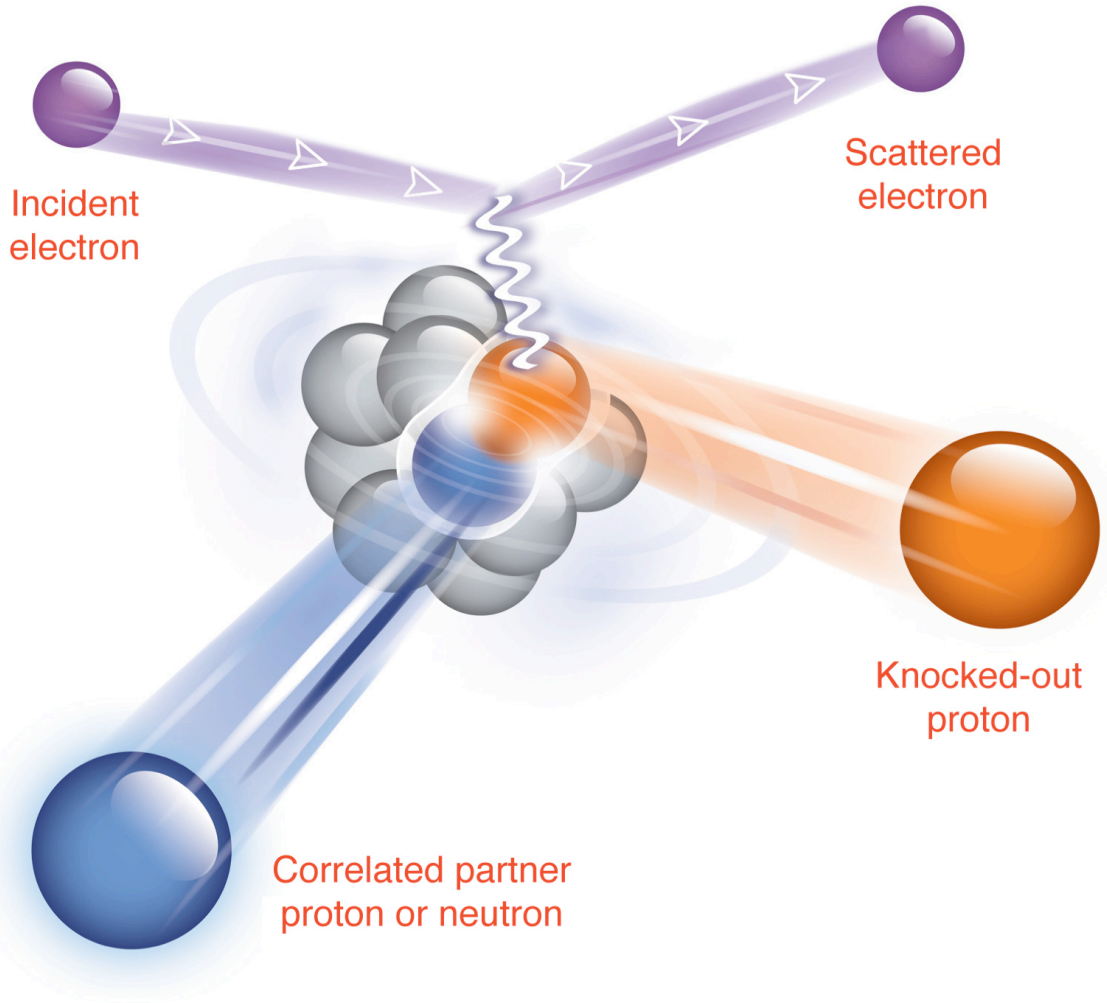
Benhar et al., Phys. Lett. **B** 177 (1986) 135.



Jefferson Lab 6 GeV Experimental Highlights

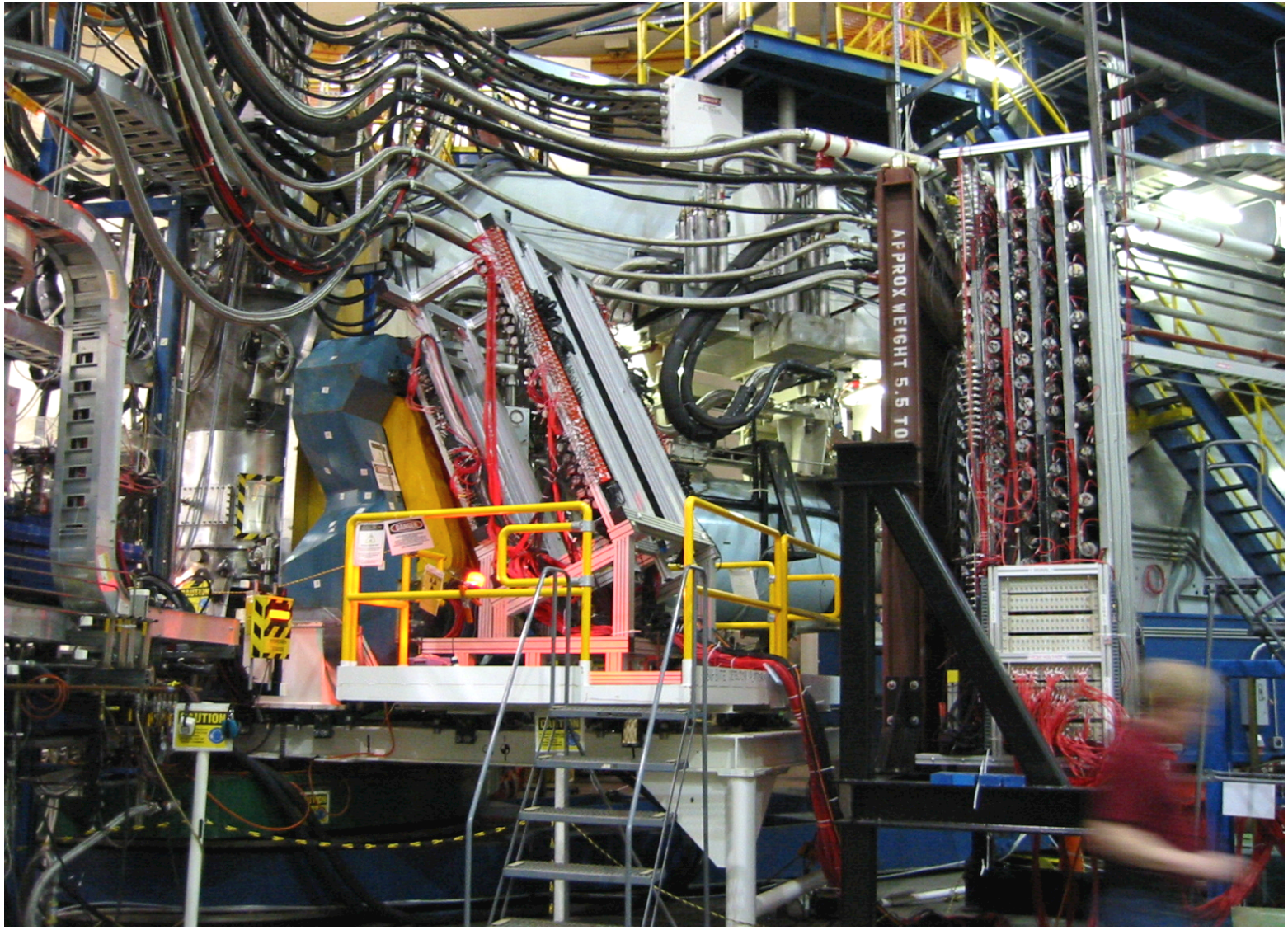
Coincidence (e,e'pN) Measurement

To study nucleon pairs and the fraction that contribute to momentum tail.



$x > 1$, $Q^2 = 1.5$ [GeV/c]^2 and missing momentum of 500 MeV/c

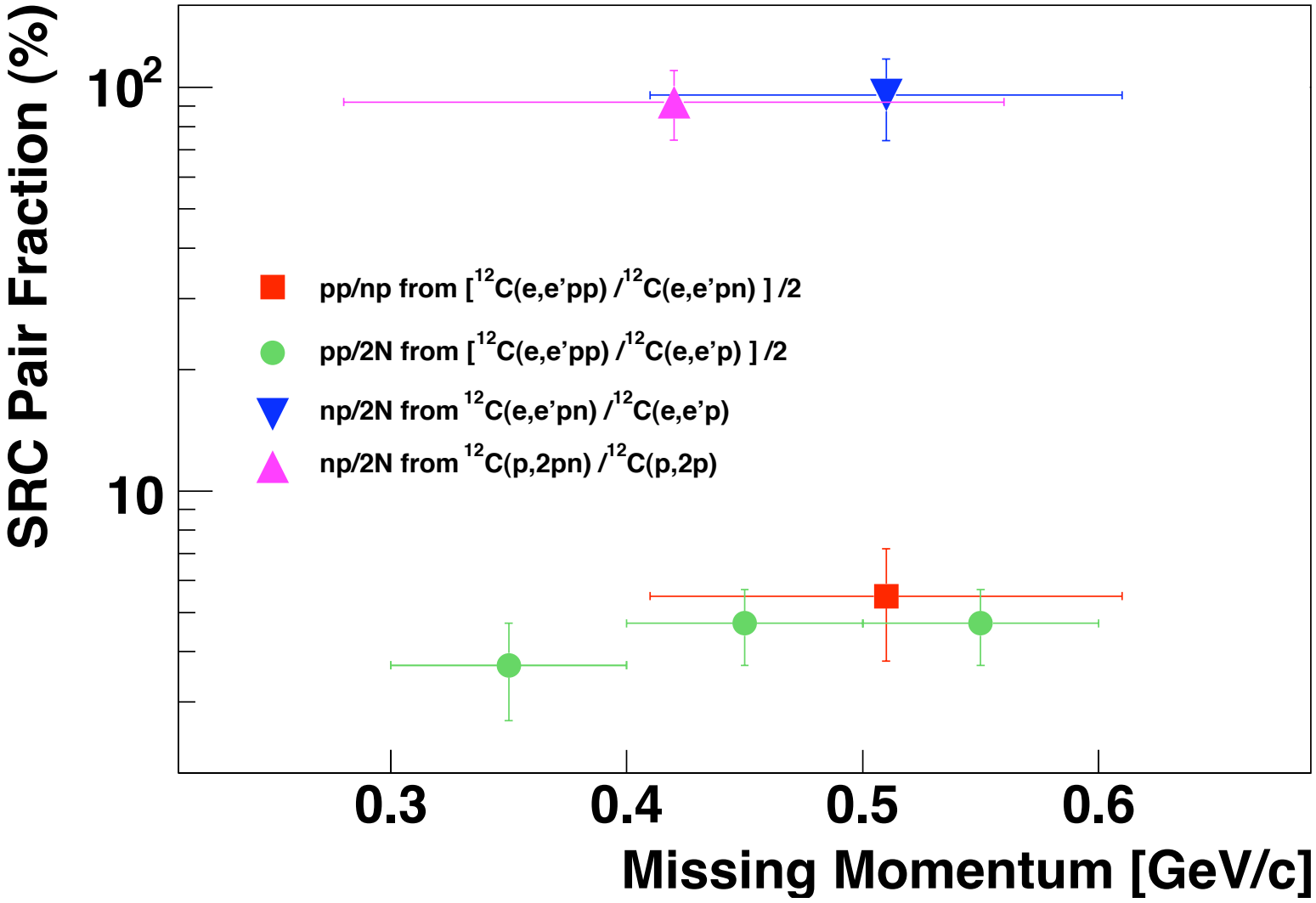
BigBite and Neutron Detector in Hall A



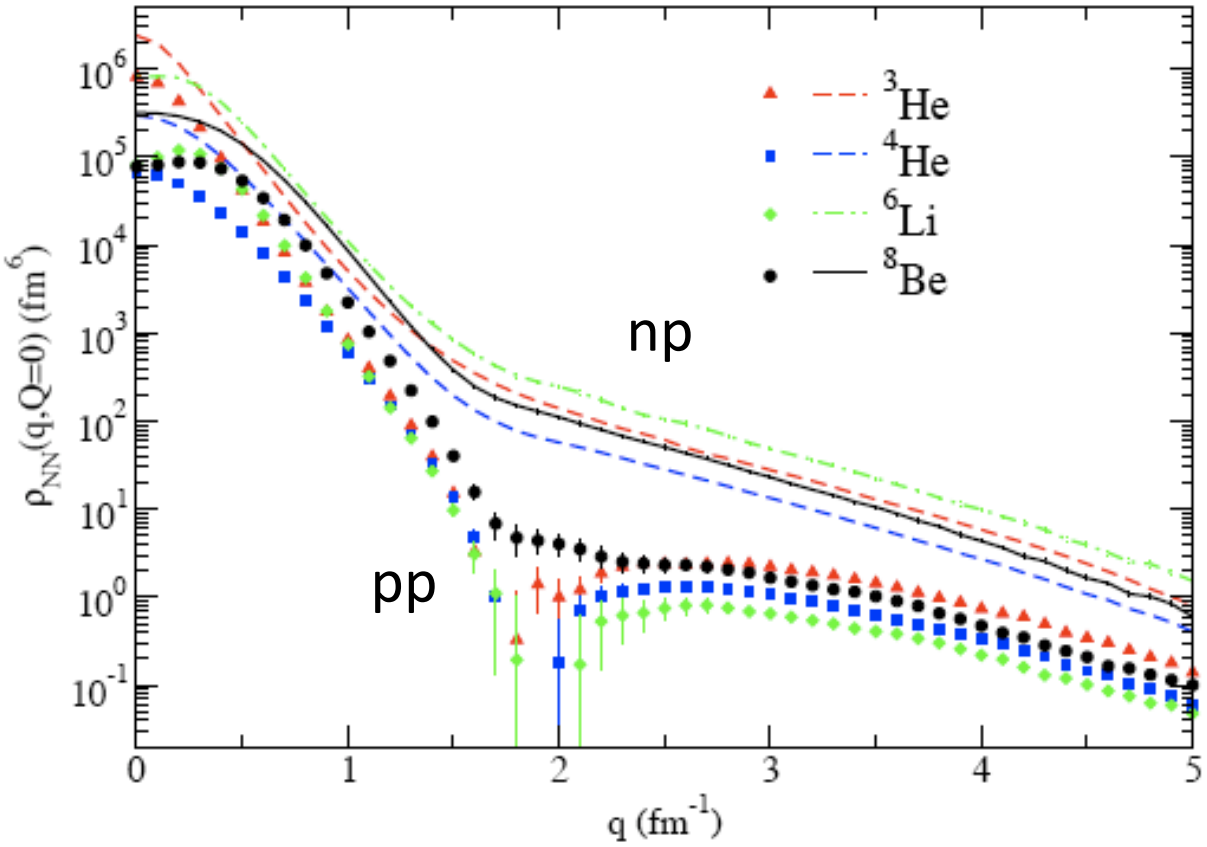
First step along the way to many successful high luminosity, large acceptance measurements

High p_m (e,e'p) events have recoiling neutrons.

R. Subedi *et al.*, Science **320** (2008) 1476.



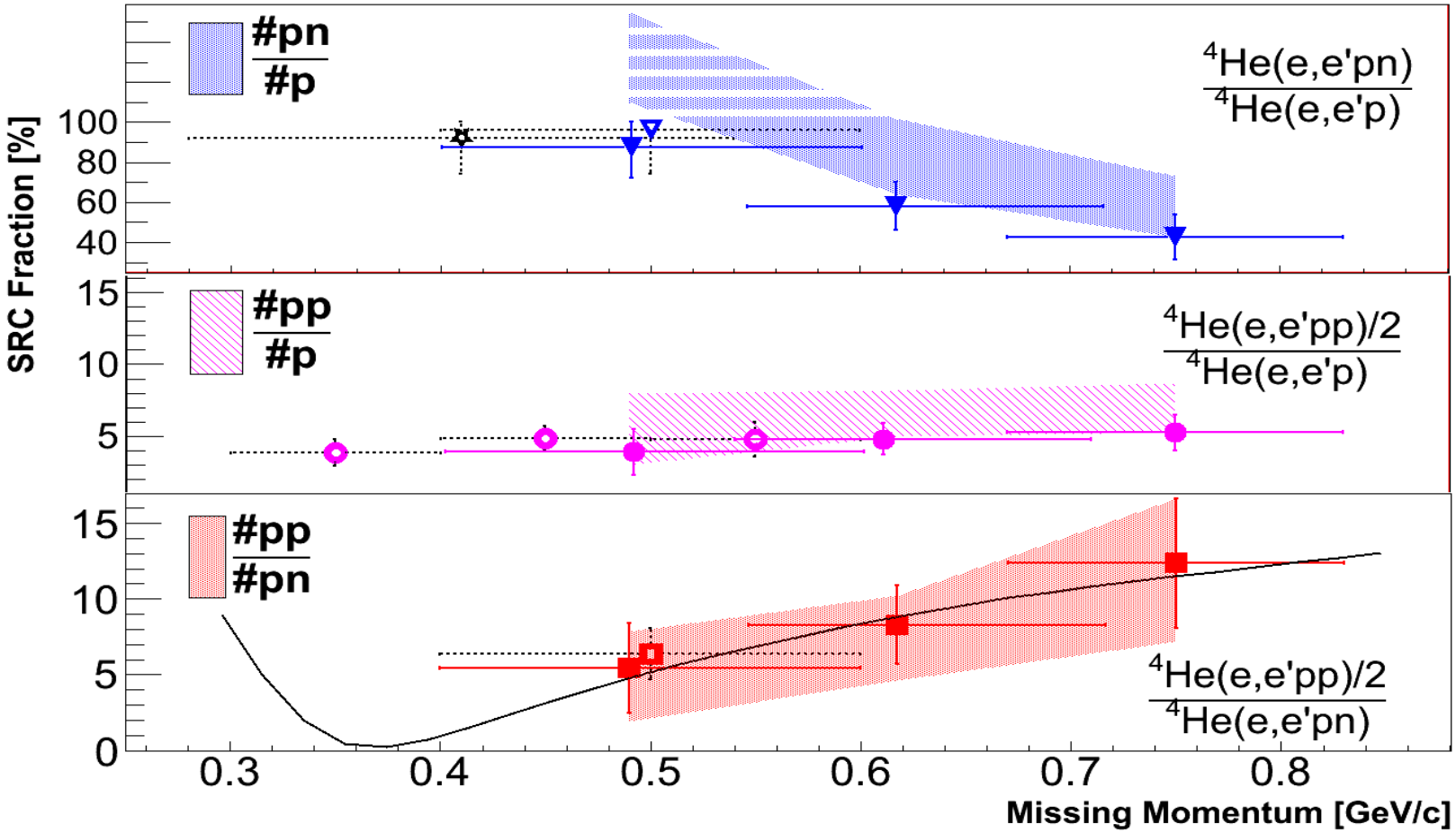
Importance of Correlations



- R. Schiavilla *et al.*, Phys. Rev. Lett. 98 (2007) 132501.
- M. Sargsian *et al.*, Phys. Rev. C (2005) 044615.
- M. Alvioli *et al.*, Phys. Rev. Lett. 100 (2008) 162503.

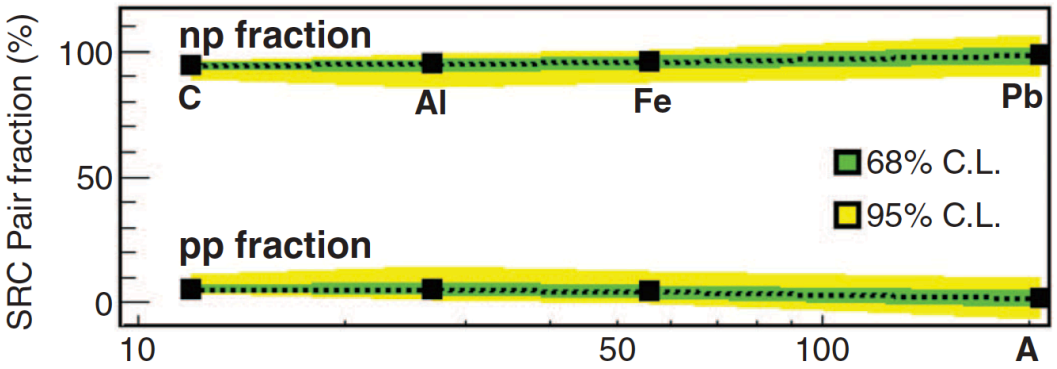
2nd Generation ^{4}He(e,e'pN) Results

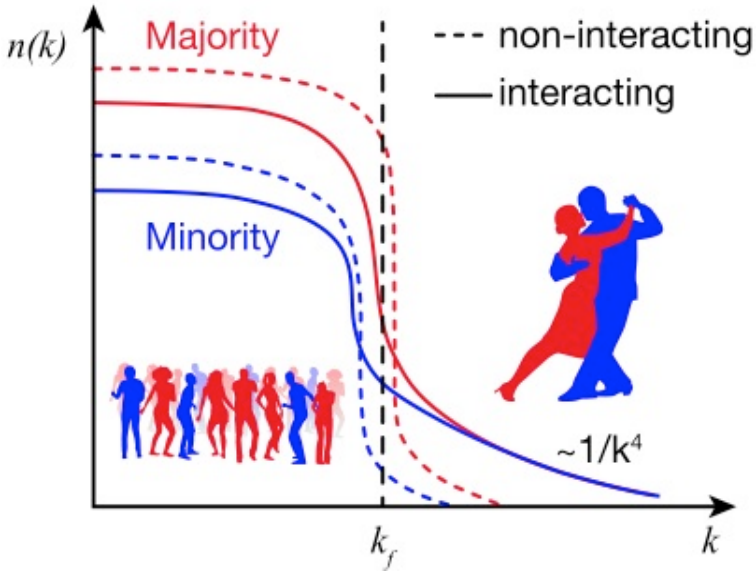
I. Korover *et al.*, Phys. Rev. Lett. **113** (2014) 022501.



Proton-Neutron Pairing In All Nuclei

Or Hen *et al.* (Jefferson Lab CLAS Collaboration) Science 346 (2014) 614.

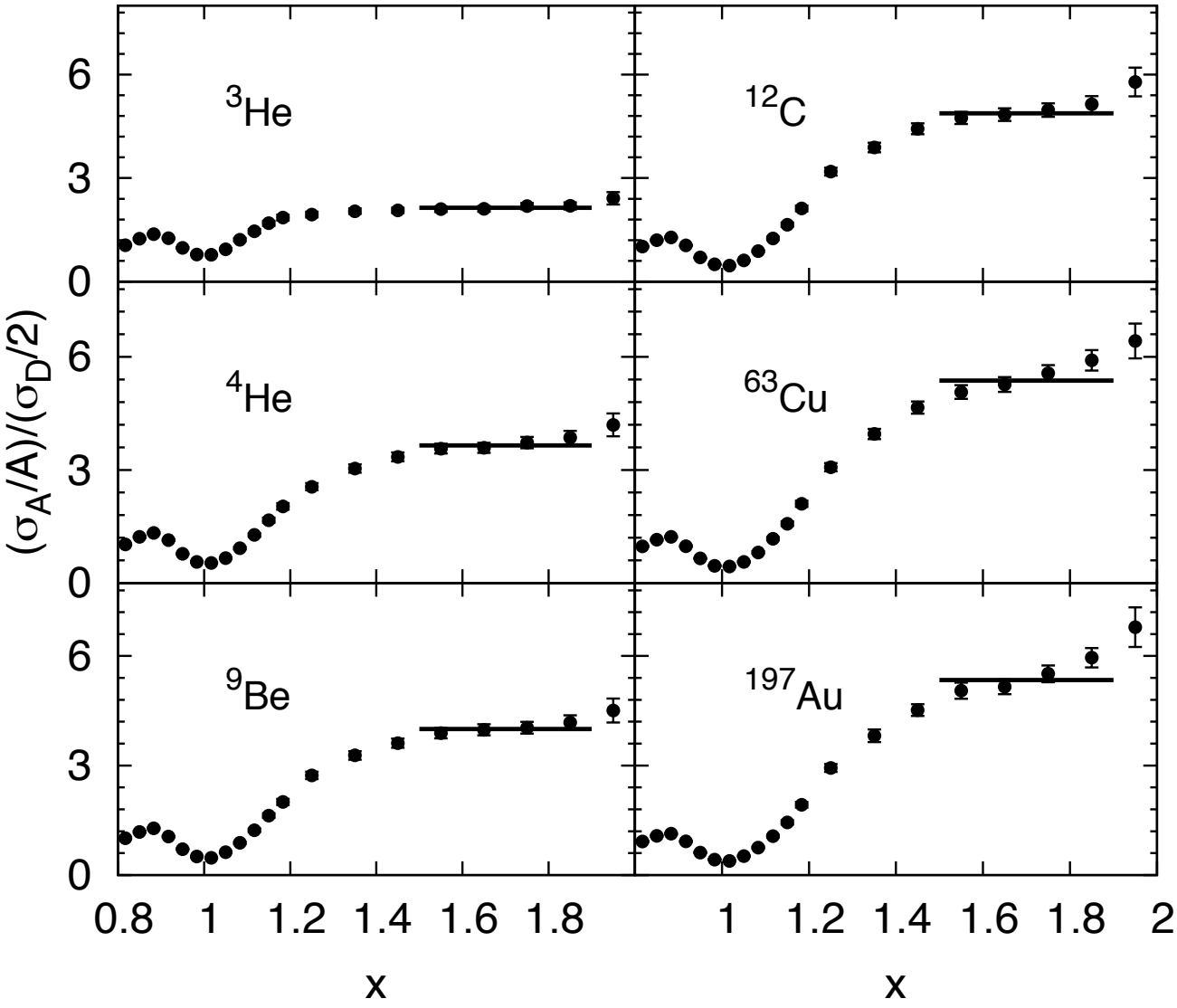




The minority particle will have a higher average kinetic energy then the majority particle.

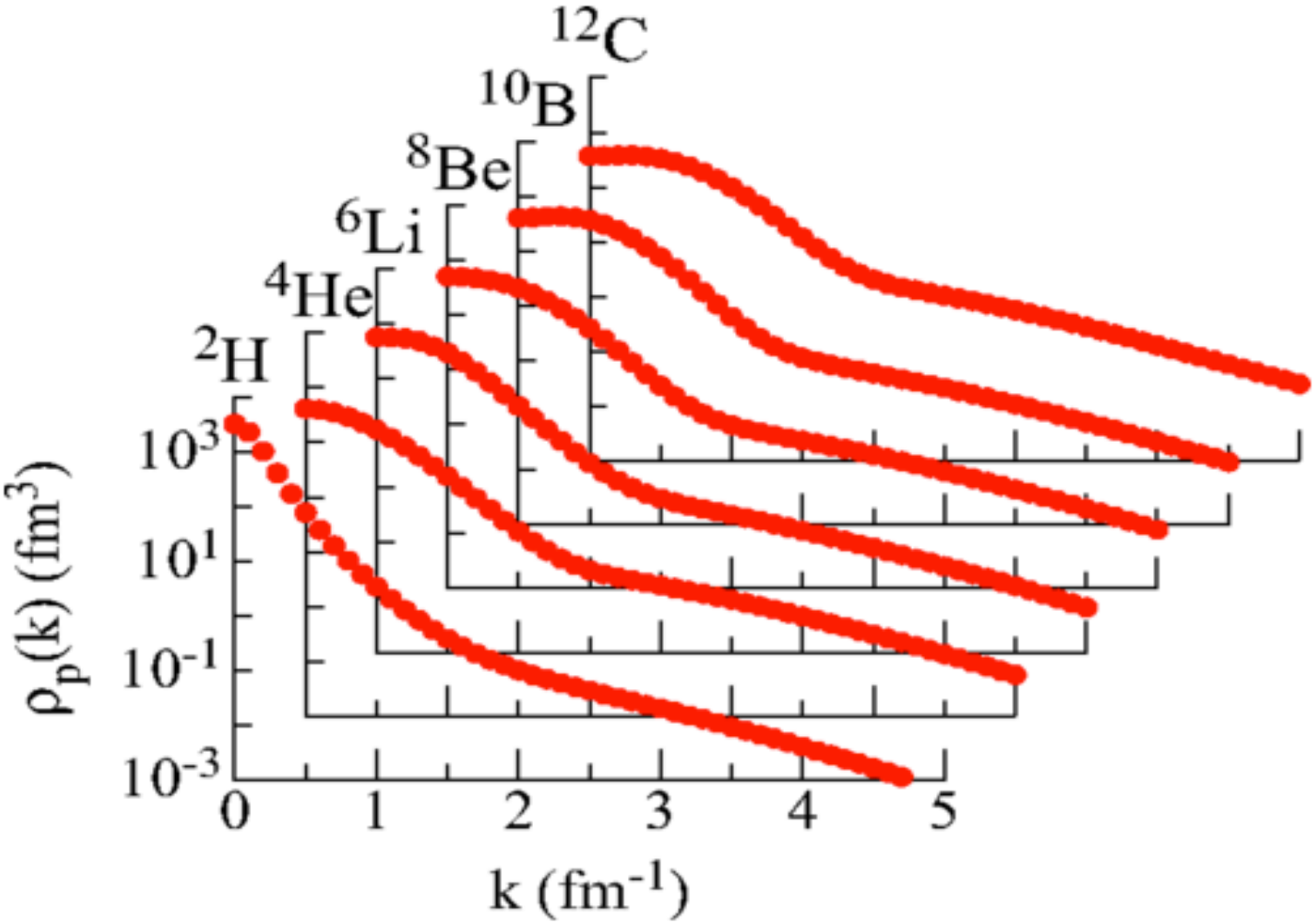
Precision (e,e') x>1 Cross Section Ratios

N. Fomin *et al.*, Phys. Rev. Lett. **108** (2012) 092502.



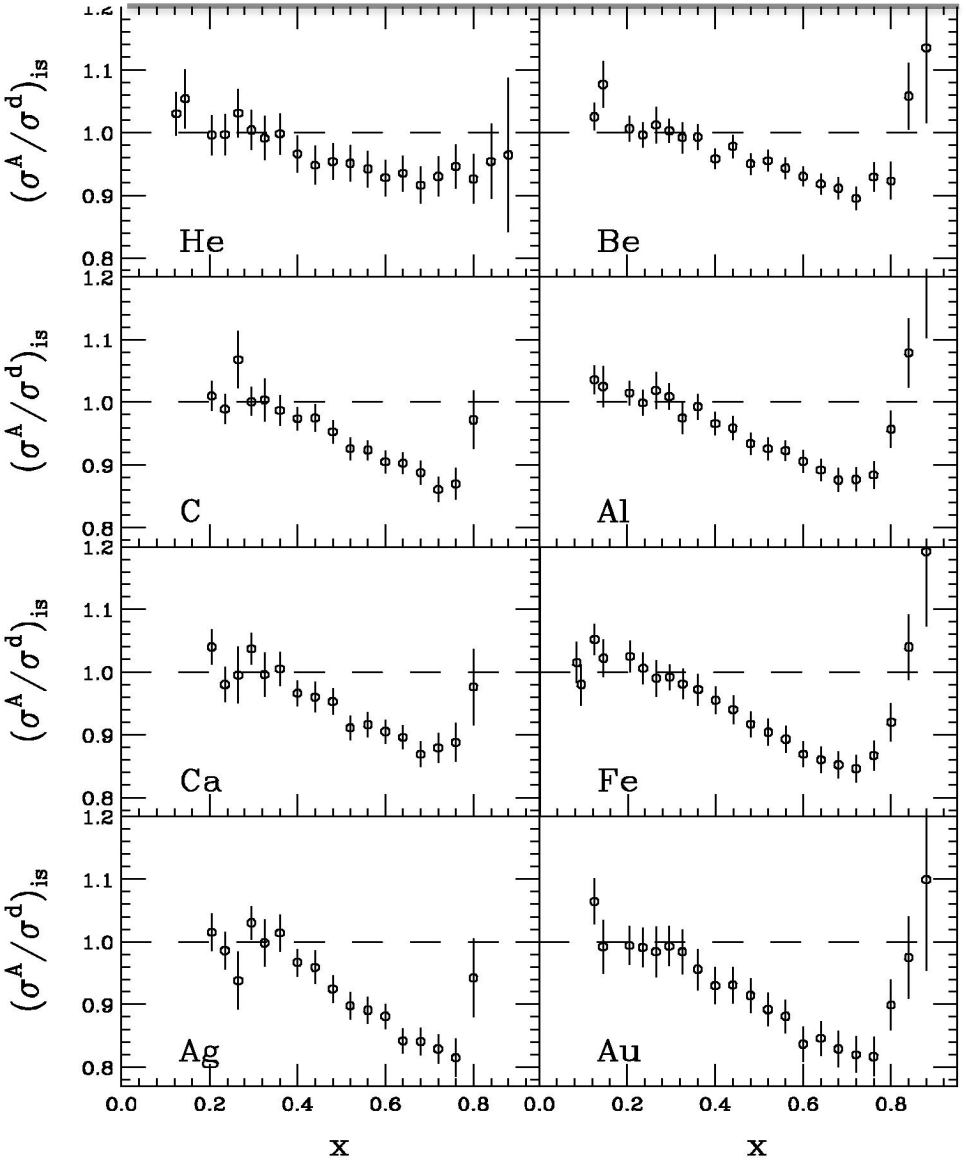
Modern AV18 and Urbana-X Results

R. Wiringa, R. Schiavilla, S. Pieper, and J. Carlson, Phys. Rev. C89 (2014) 024305.



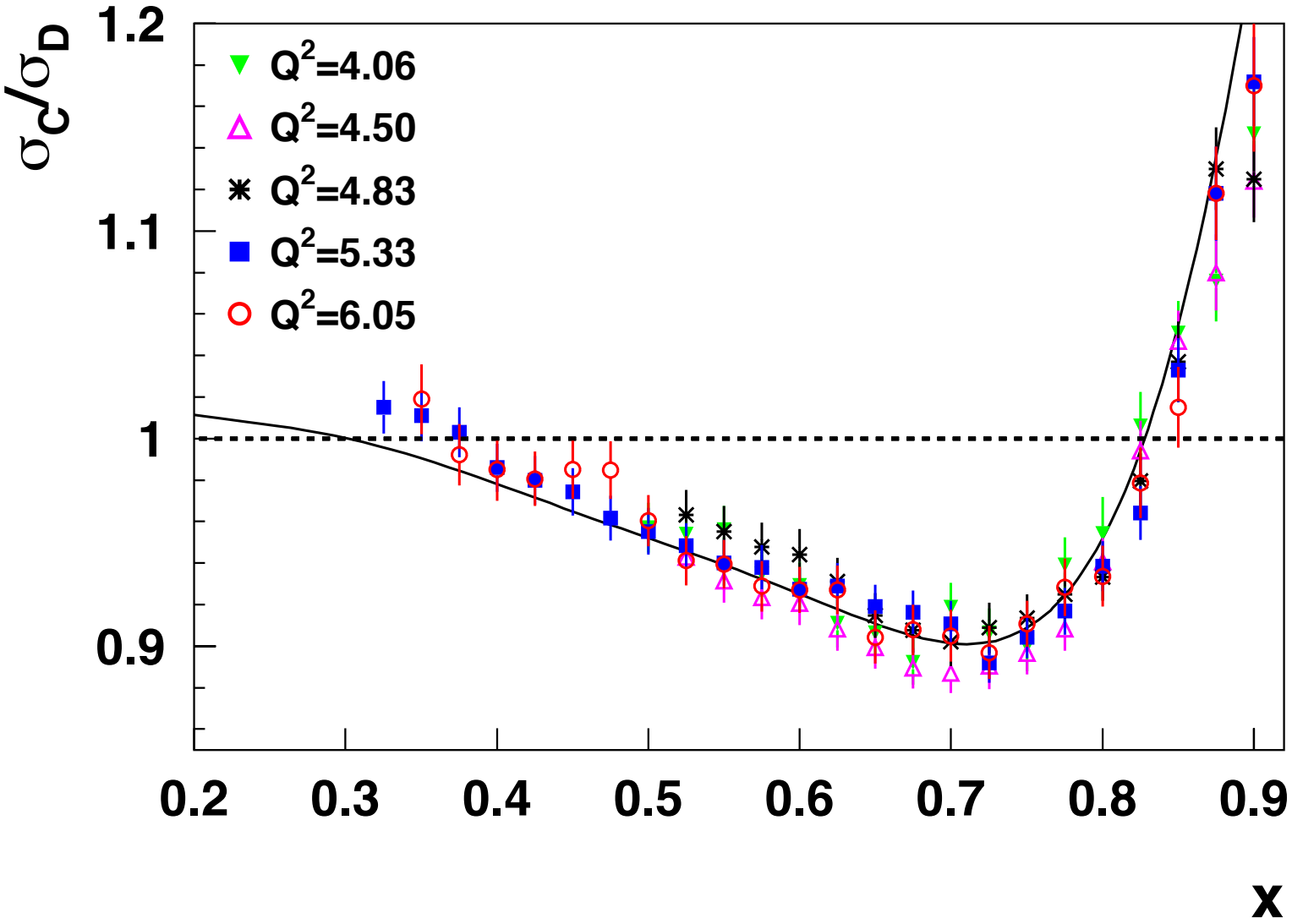
The Deep Inelastic EMC Effect

- **EMC effect is simply the fact the ratio of DIS cross sections is not one**
  - J.J. Aubert et al. PLB 123 (1983) 275.
  - Simple Parton Counting Expects One
  - **MANY Explanations**
- **SLAC E139**
  - J. Gomez et al., PRD 49 (1994) 4348.
  - Precise large-x data
  - Nuclei from A=4 to 197
- **Conclusions from SLAC data**
  - Q^2-independent
  - Universal x-dependence (shape)
  - Magnitude varies with A
  - Average Nuclear Density Effect



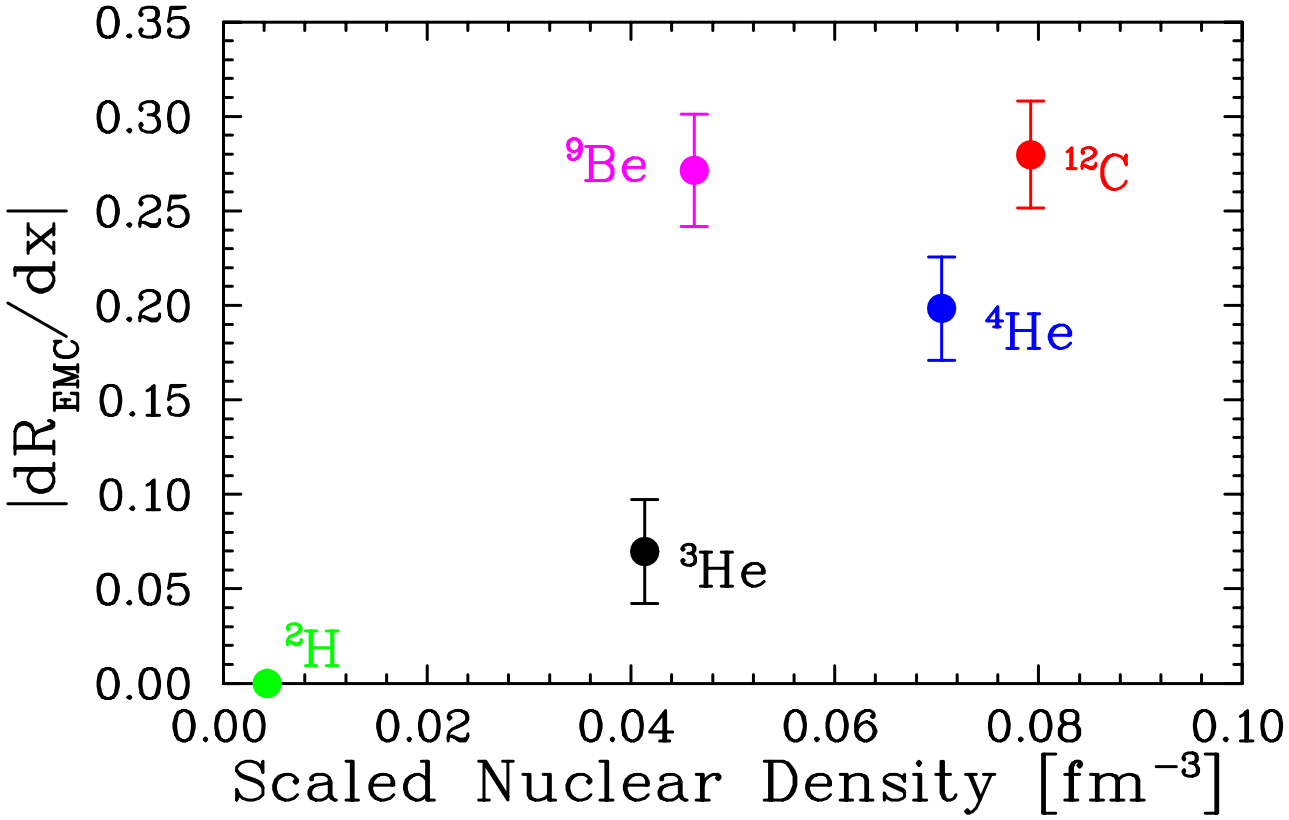
Jefferson Lab EMC Effect Data

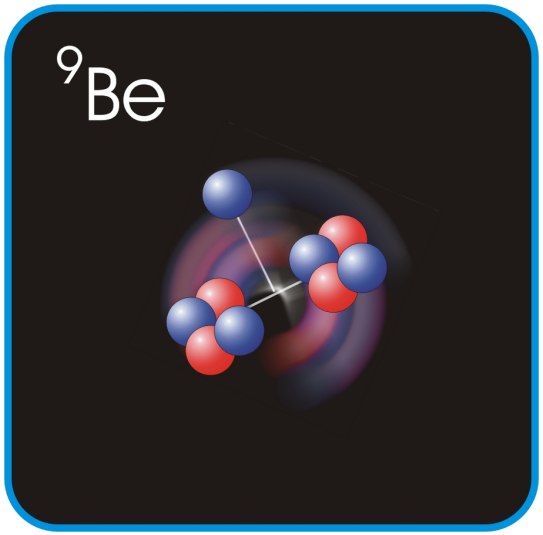
J. Seely *et al.*, Phys, Rev. Lett. **103** (2009) 202301.



Jefferson Lab EMC Effect Data

J. Seely *et al.*, Phys, Rev. Lett. **103** (2009) 202301.

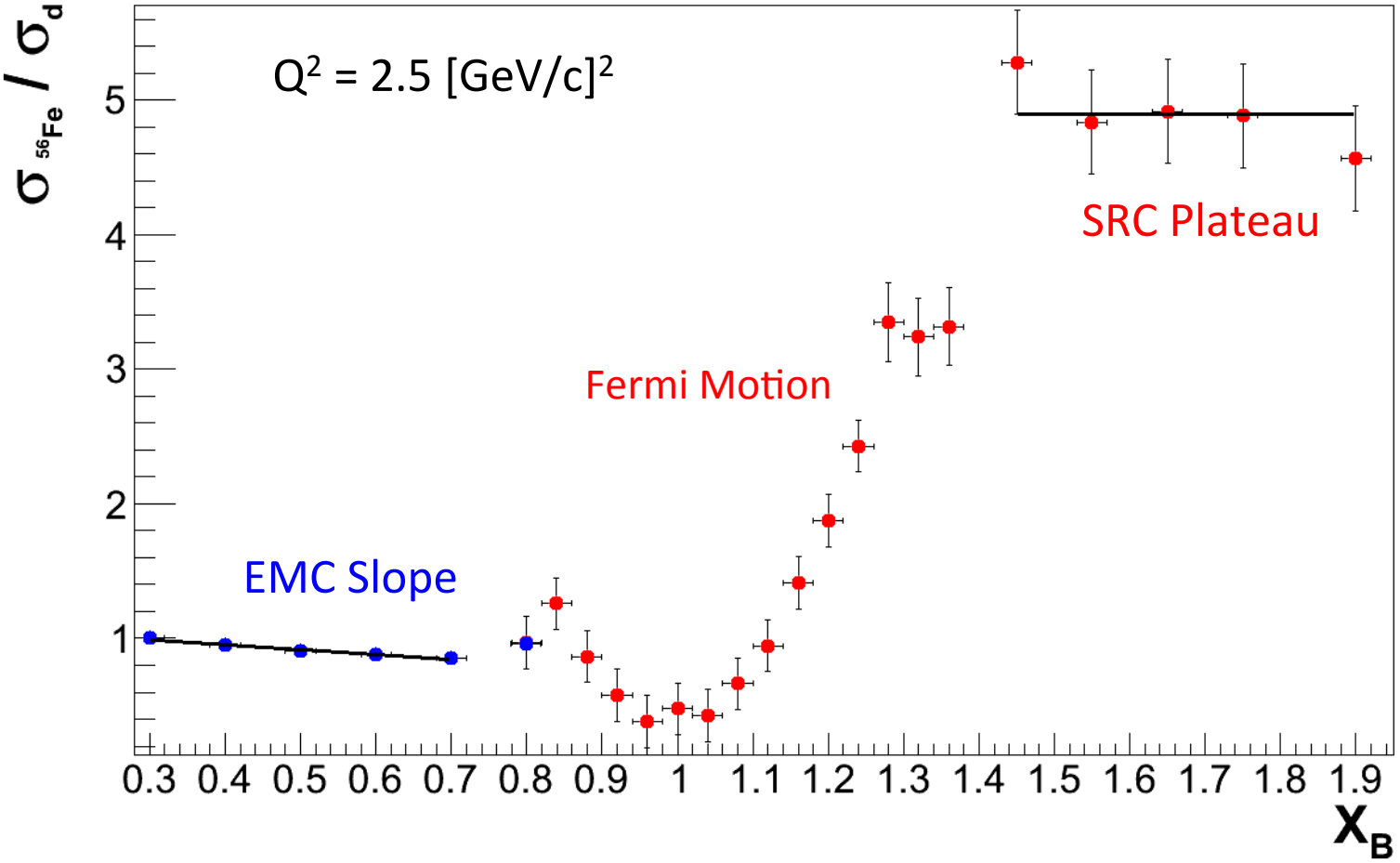




- Plot shows slope of ratio σ_A/σ_D at EMC region.
- EMC effect correlated with **local density** not average density.

Holistic View of inclusive EMC & SRC Data

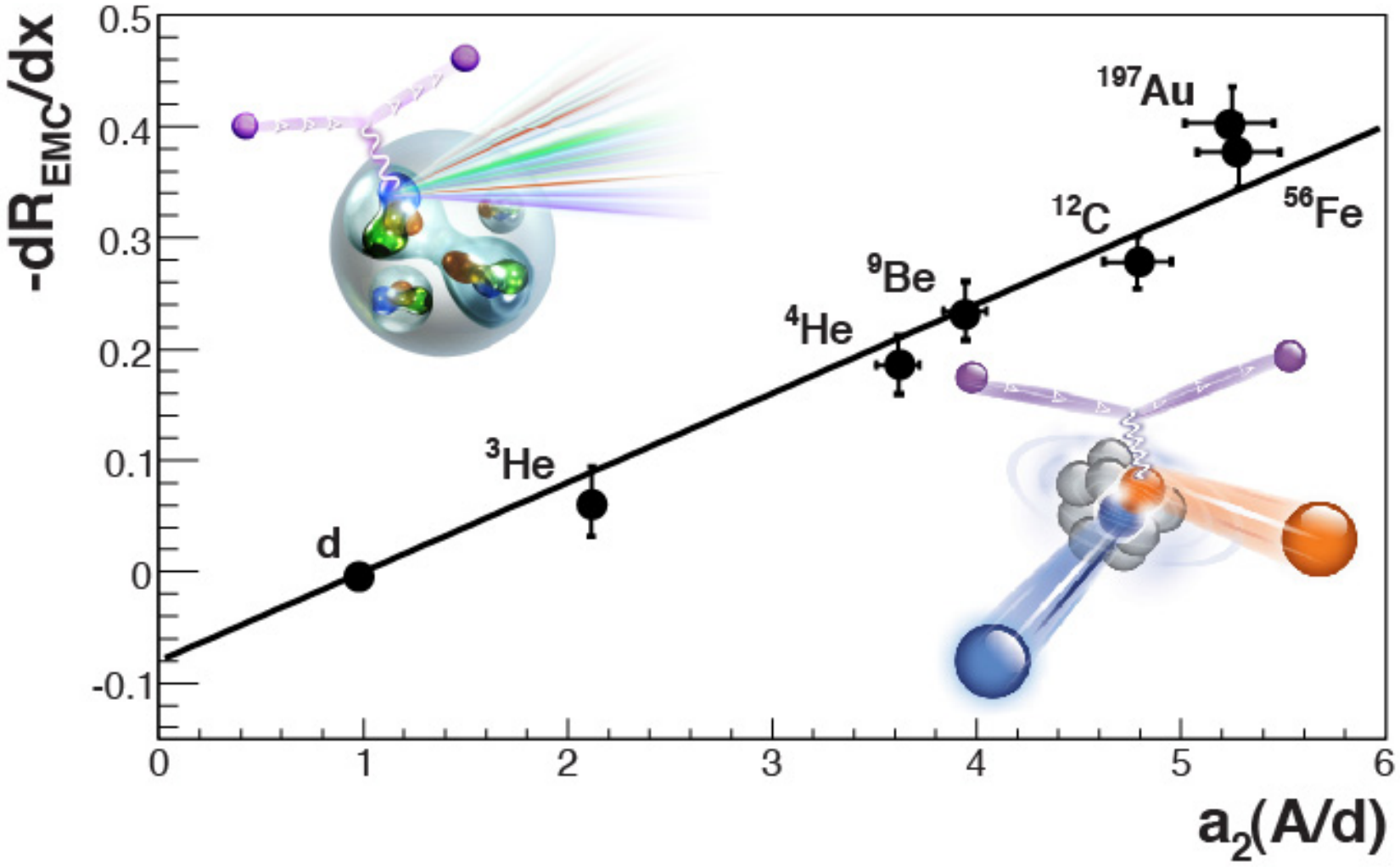
S. Malace, D. Gaskell, D.H., I. Cloet, Int. J. Mod. Phys. E **23** (2014) 1430013

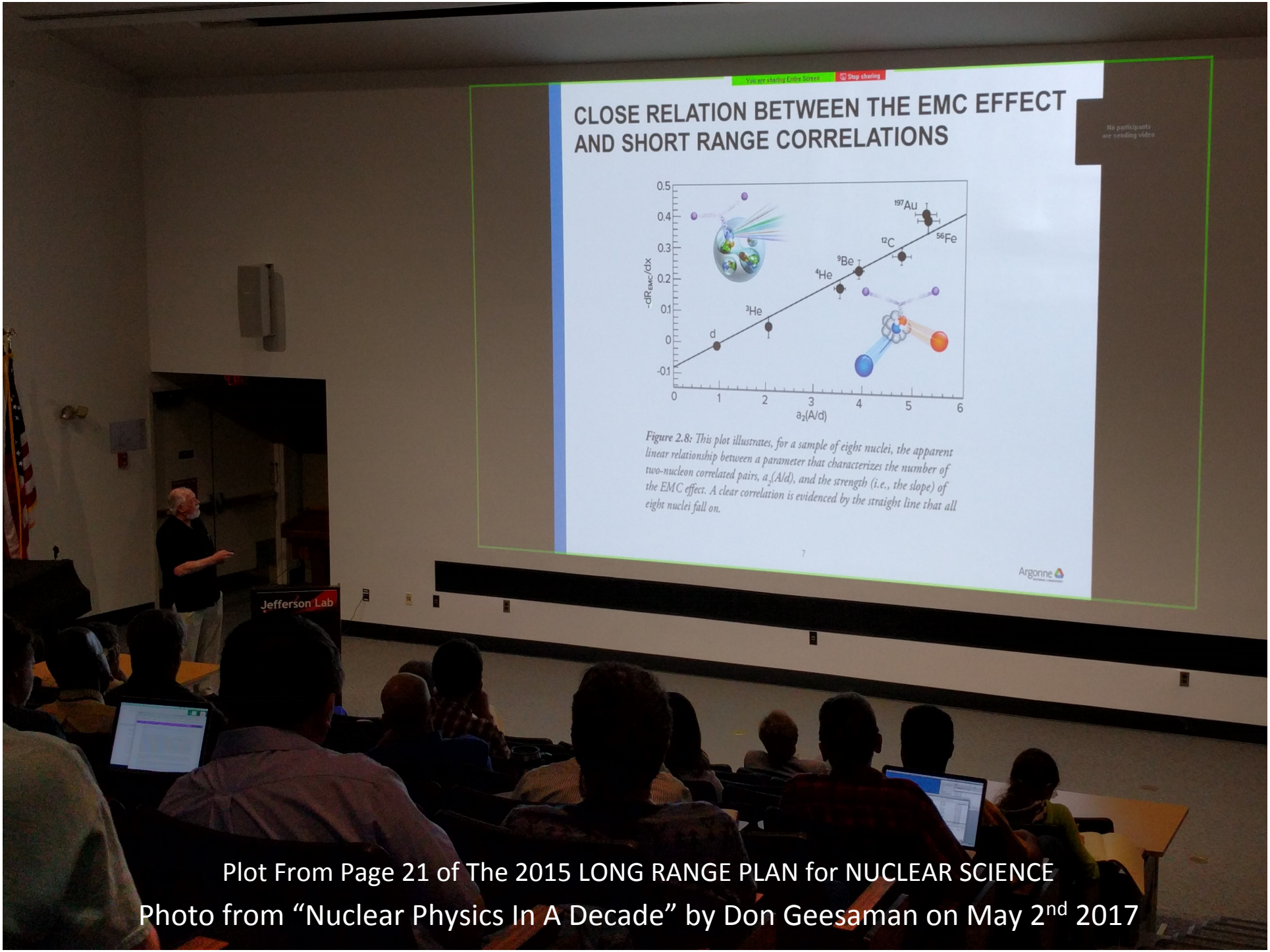


- Scaling plateaus are likely due to proton-nucleon **local density** correlations
- So could the **EMC** slopes (x_B<0.7) and **SRC plateaus** (x_B>1.5) correlated?!

x>1 Ratios and EMC Slope Correlation

L. Weinstein, E. Piasetzky, DH, J. Gomez, O. Hen, and R. Shneor, Phys. Rev. Lett. 106 (2011) 052301.





Plot From Page 21 of The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

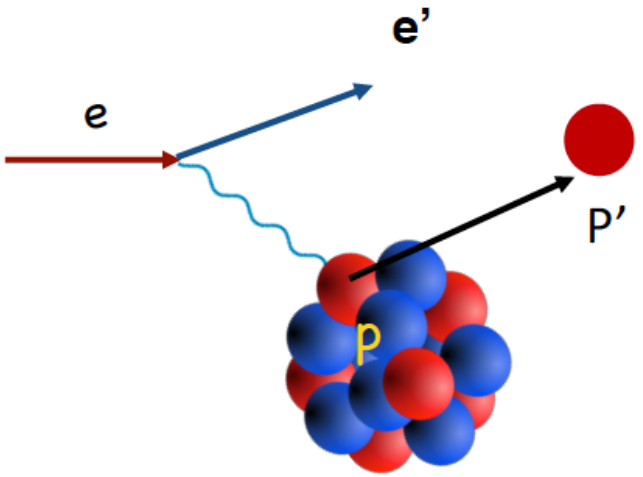
Photo from “Nuclear Physics In A Decade” by Don Geesaman on May 2nd 2017

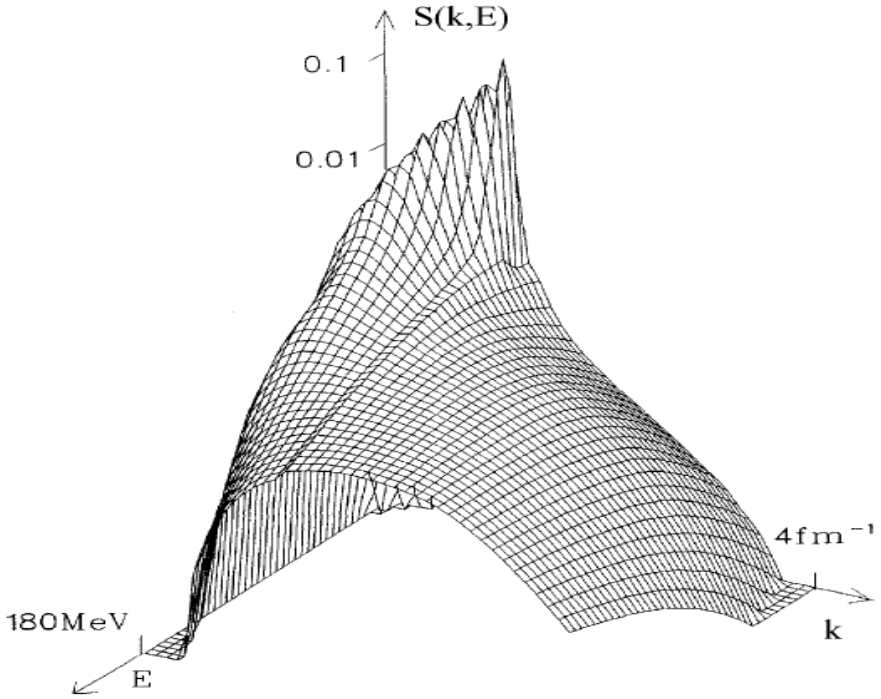
Recently Completed Argon Experiment

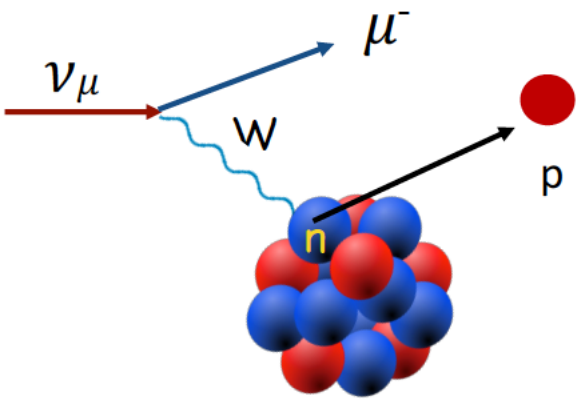
Collaboration with Neutrino Community

E12-14-012: Measurement of the Spectral Function of ^{40}Ar with the (e,e'p) reaction

- Precision neutrino experiments now require detailed understanding of nuclear structure and reaction mechanisms. This is particularly important as they don't know (event by event) the neutrino energy.
- Nice example of nuclear physics subfields coming together.
- Shown are Jefferson Lab ^{16}O(e,e'p) results from N. Liyanage *et al.*, Phys.Rev.Lett. 86 (2001) 5670.



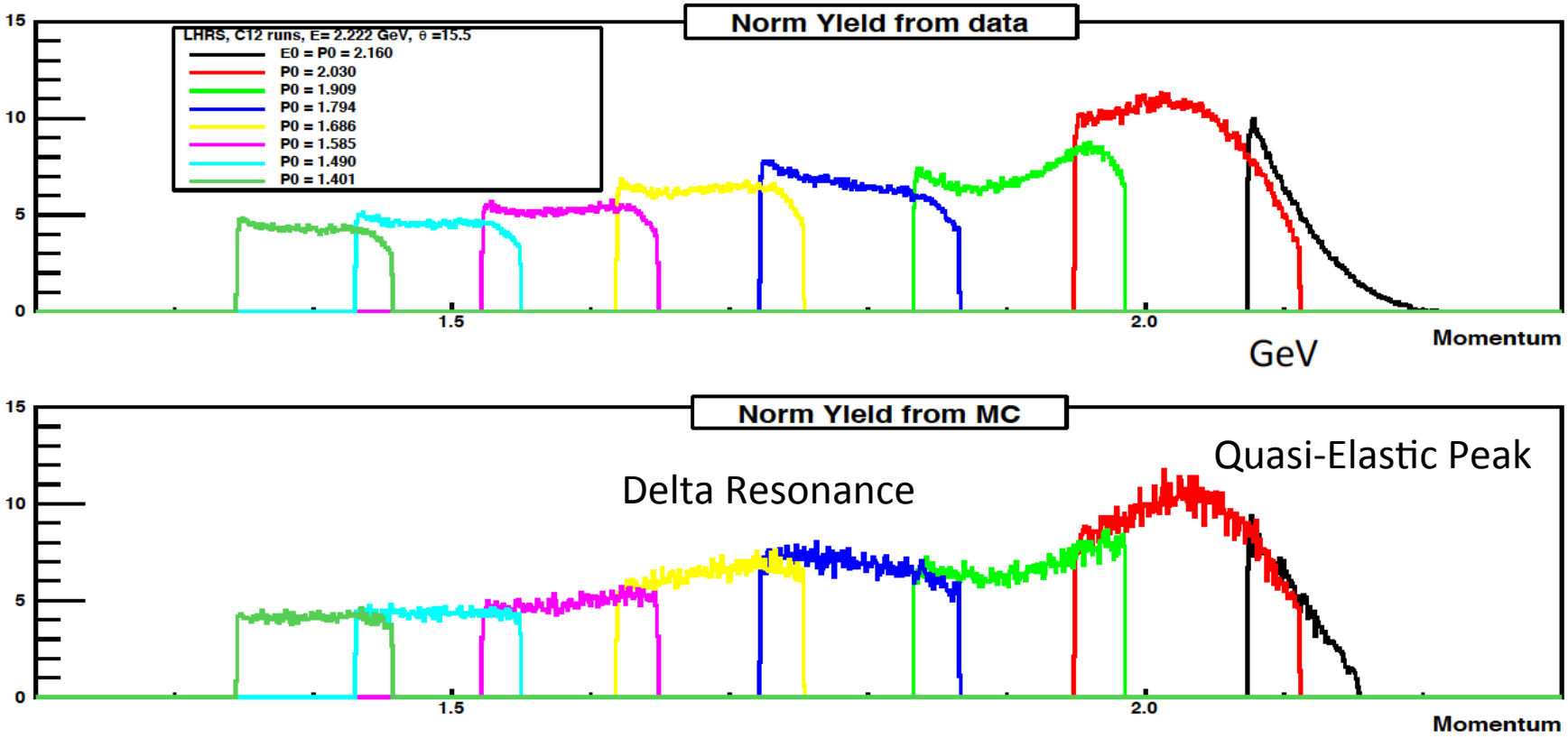




Analysis Underway

shown is the inclusive spectrum from data & simulation

Plot from Dien Nguyen (UVA) as presented at the Hall A/C Collaboration Meeting

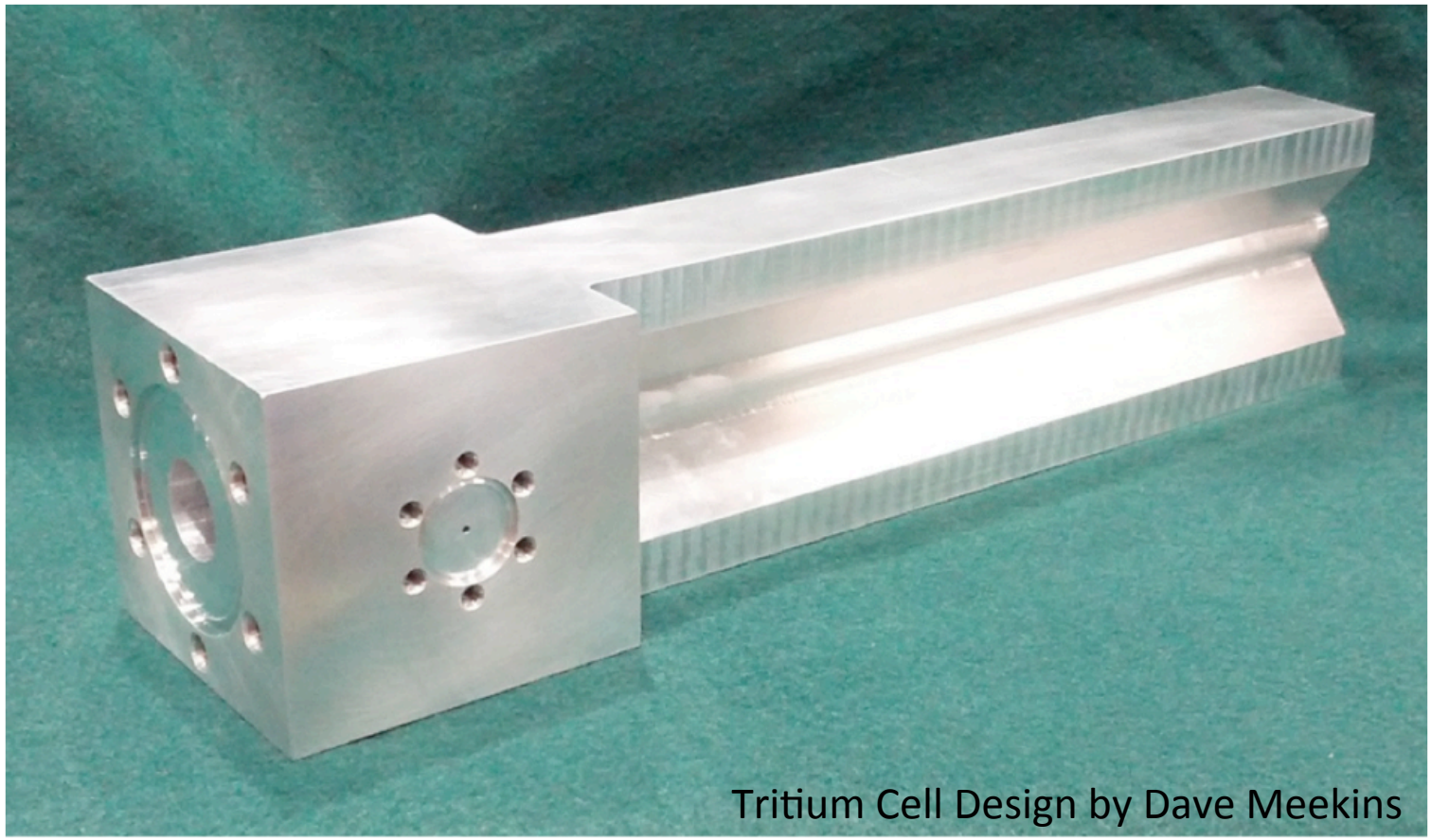


Final results can be found at: https://arxiv.org/pdf/1803.01910.pdf

Current Tritium Measurements

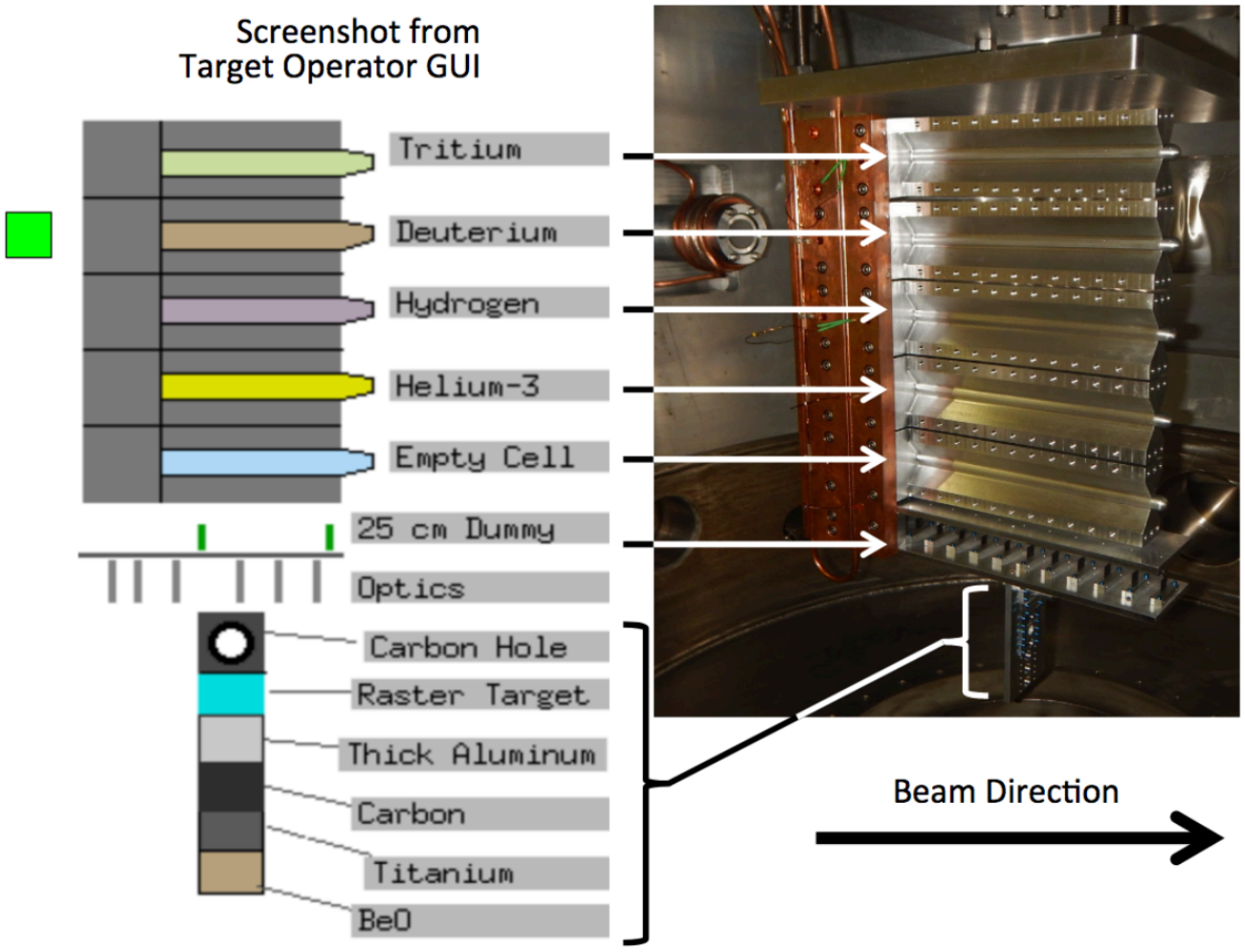
Triton (^{3}He & ^{3}H) Measurements

E12-10-103: Marathon u/d ratios from 3He(e,e')/3H(e,e') DIS measurements
E12-11-112: x>1 measurements of correlations
E12-14-001: elastic scattering measurement to better determine the charge radius
E12-14-012: (e,e'p) momentum distribution measurements
E12-17-003: Determining the Unknown Lambd-n Interaction



Relatively small amount of tritium (~1kC) in a cell machined from single block of Al.

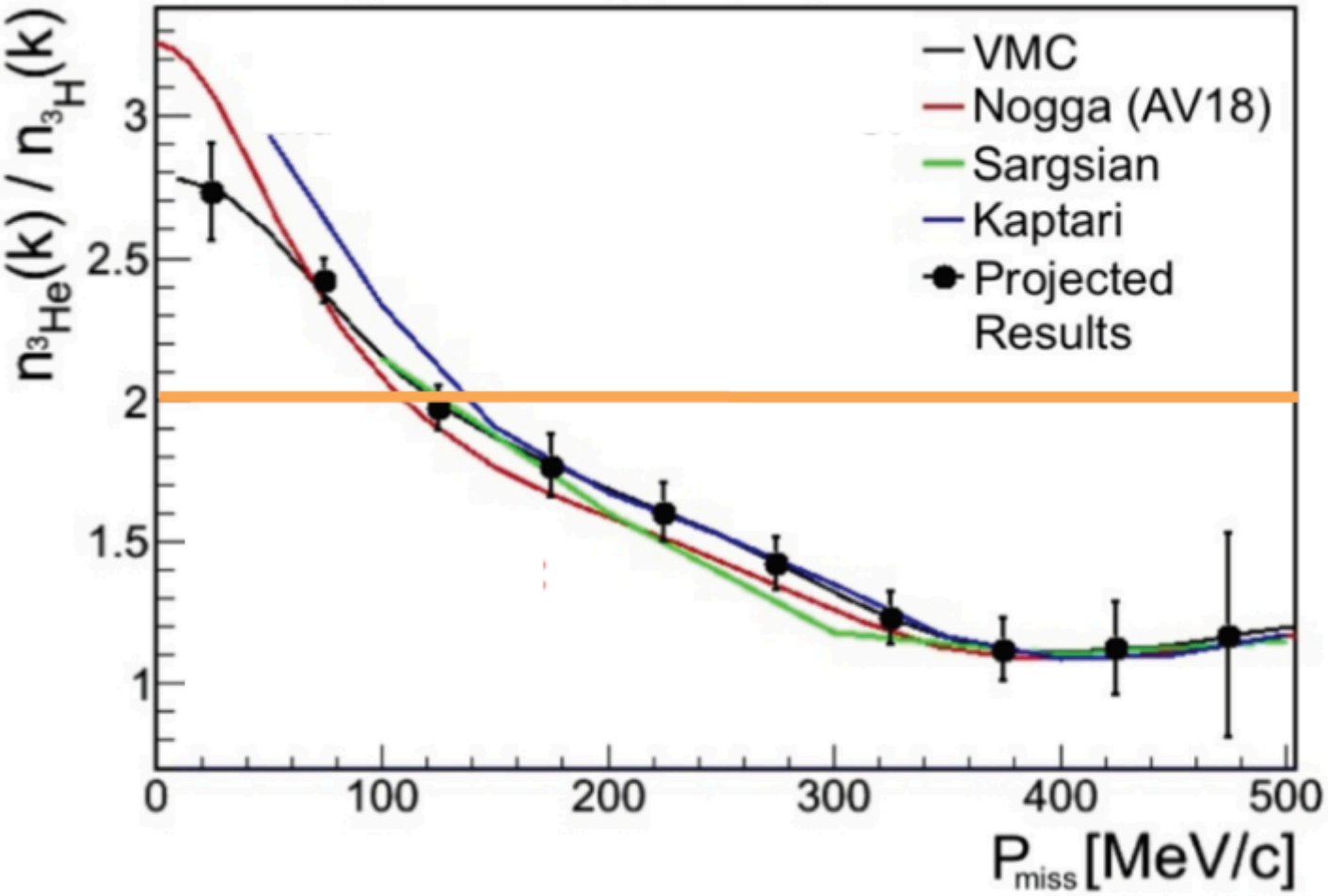
Tritium Target System In Hall A



^{3}He(e,e'p)/^{3}H(e,e'p) Is Two, Isn't It?!

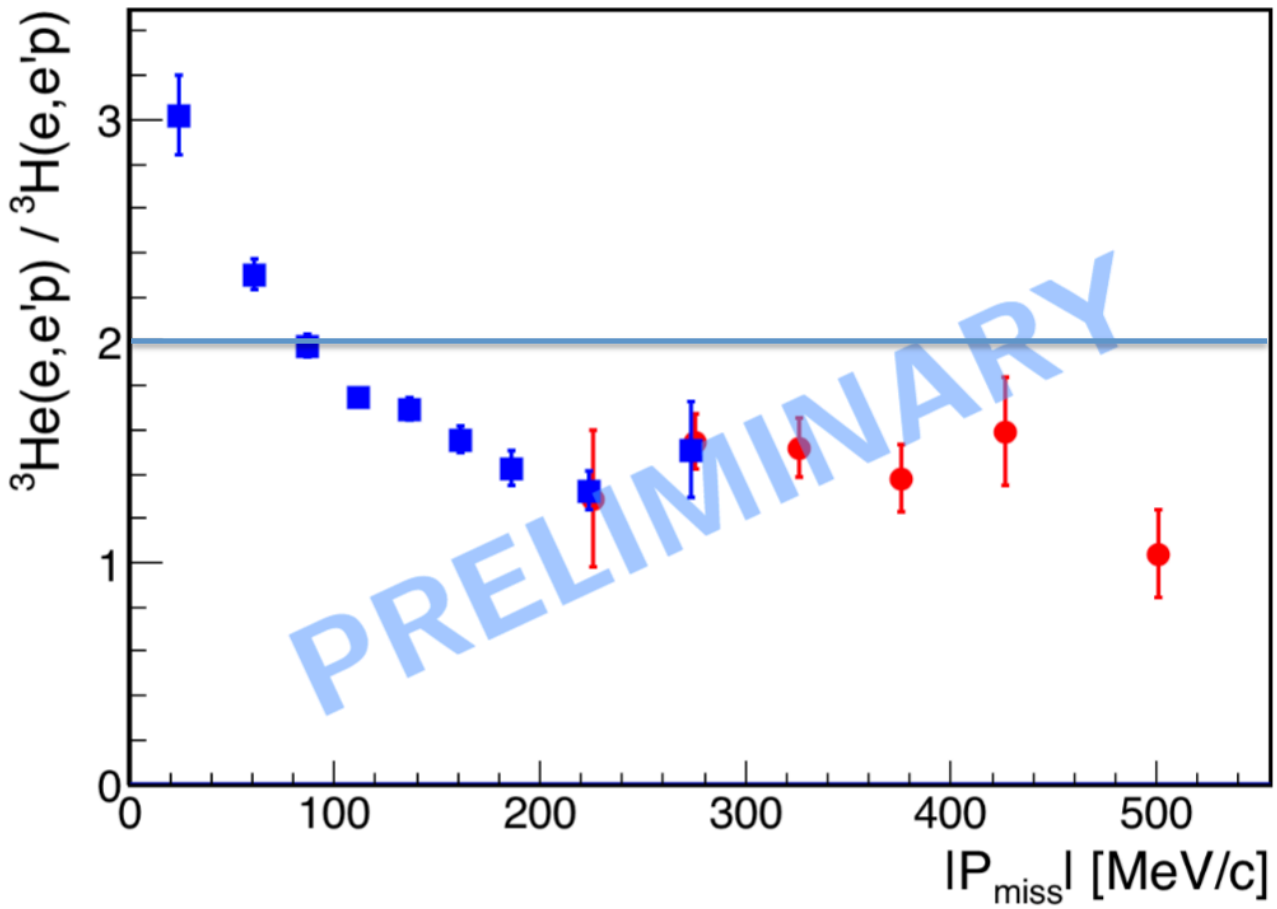
E12-14-011: Proton and Neutron Momentum Distributions in A = 3 Asymmetric Nuclei

arXiv:1409.1717



VERY Preliminary Results

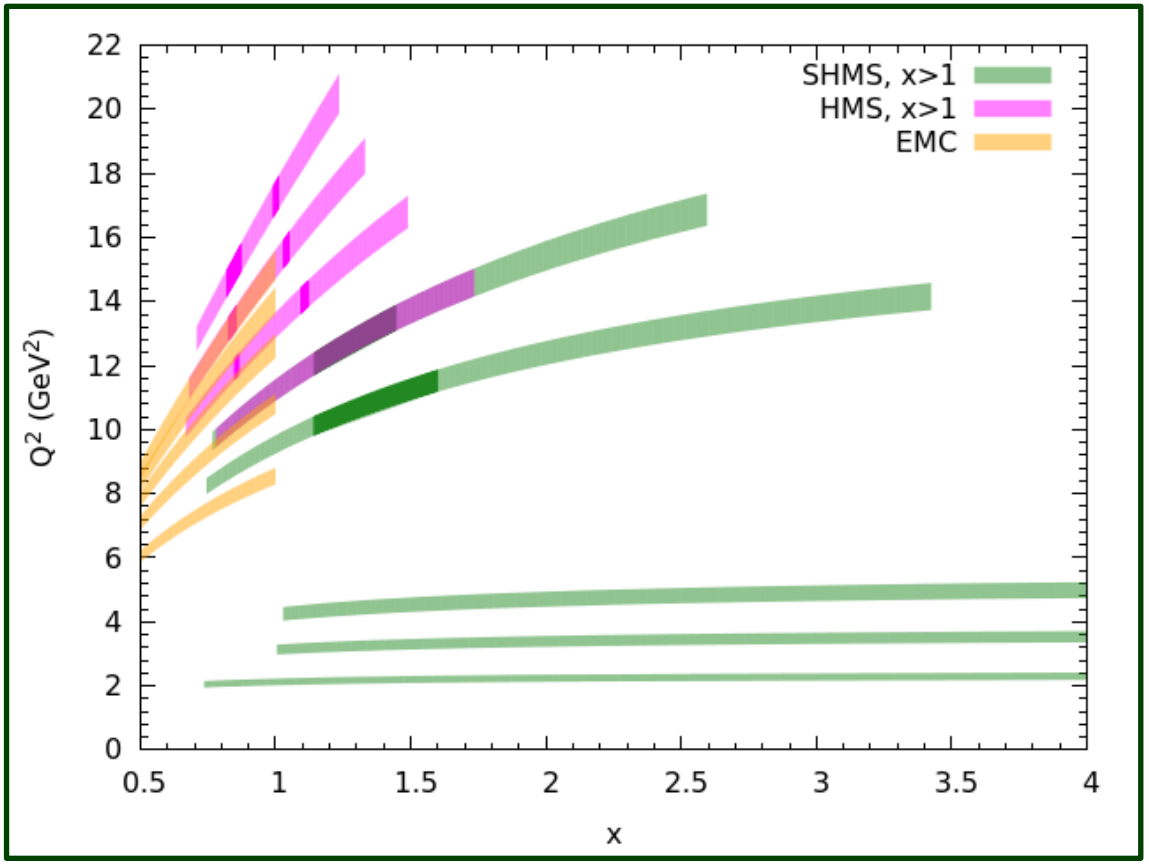
Thanks to Reynier Cruz Torres and Axel Schmidt (MIT)



Systematic Study of x>1 Region

E12-06-105: Inclusive Scattering from Nuclei at x > 1 in quasi-elastic & deeply inelastic regimes.

E12-11-112: Precision measurement of the isospin dependence in 2N & 3N SRC regions.

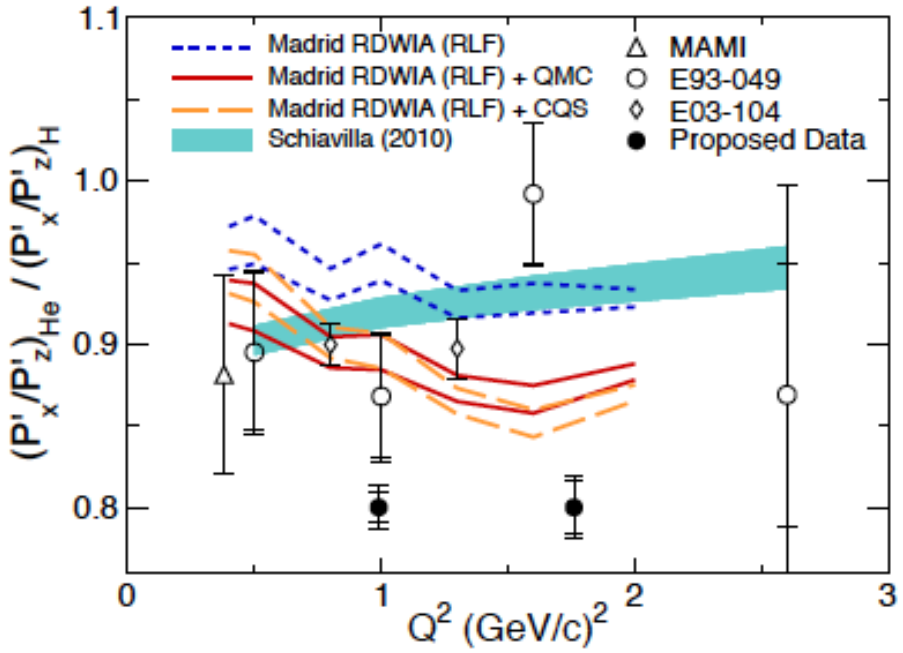


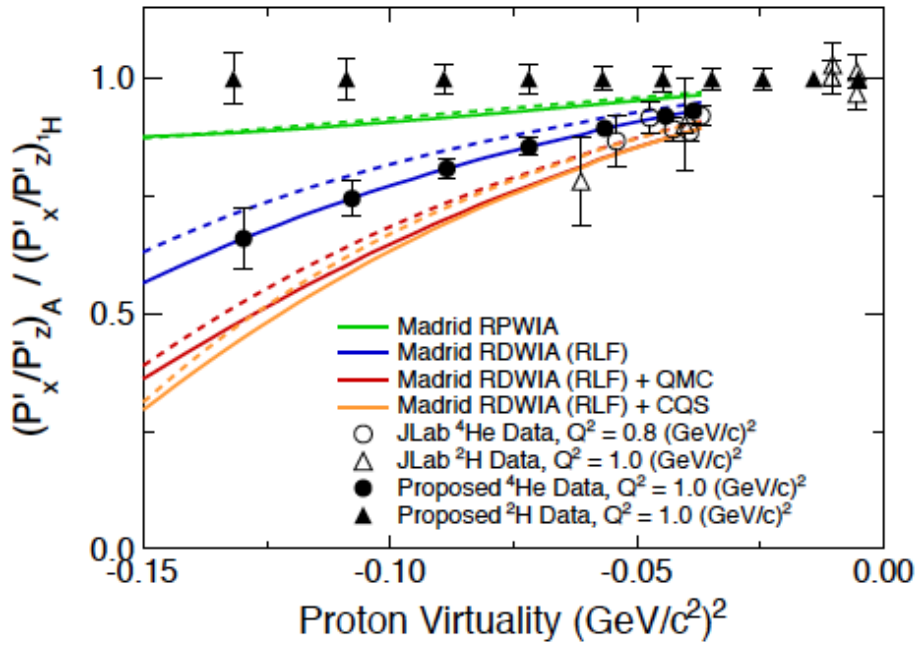
- Measure wide range of kinematics
- Measure with many targets: e.g. D2, H3, He3, He4, Be, C, Cu, Au
- Shown above is the kinematic reach of the Hall C E12-06-105 measurements

Upcoming Measurements

Search for Medium Modified Form Factors

E12-11-002: Recoil Polarization Measurements of ^{4}He(e,e'p)^{3}H, D(e,e'p)n, and H(e,e'p)

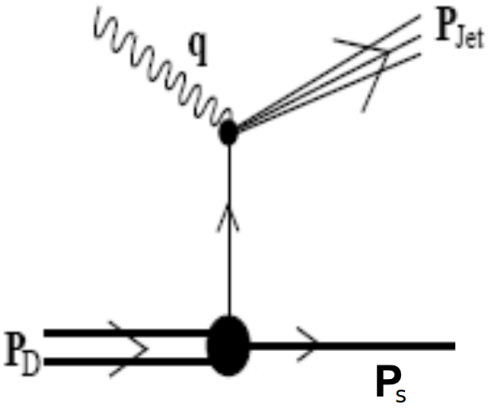


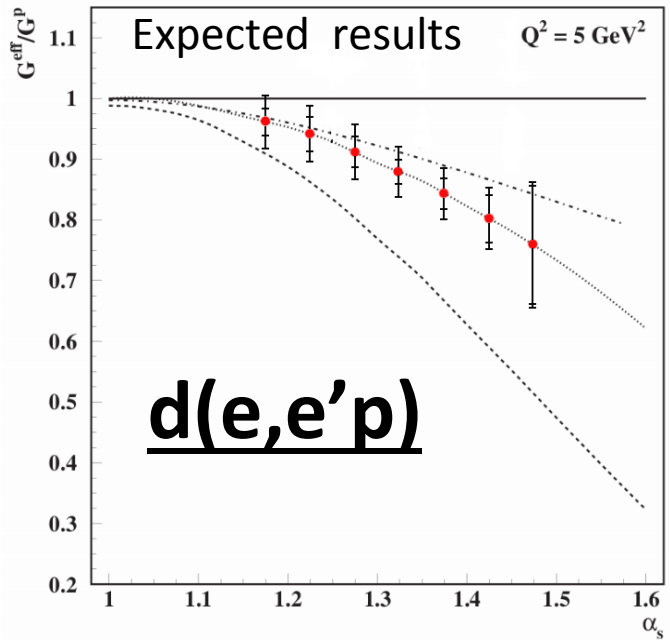


- Upcoming measurements will push the precision and reach of the these measurements and now include deuterium.

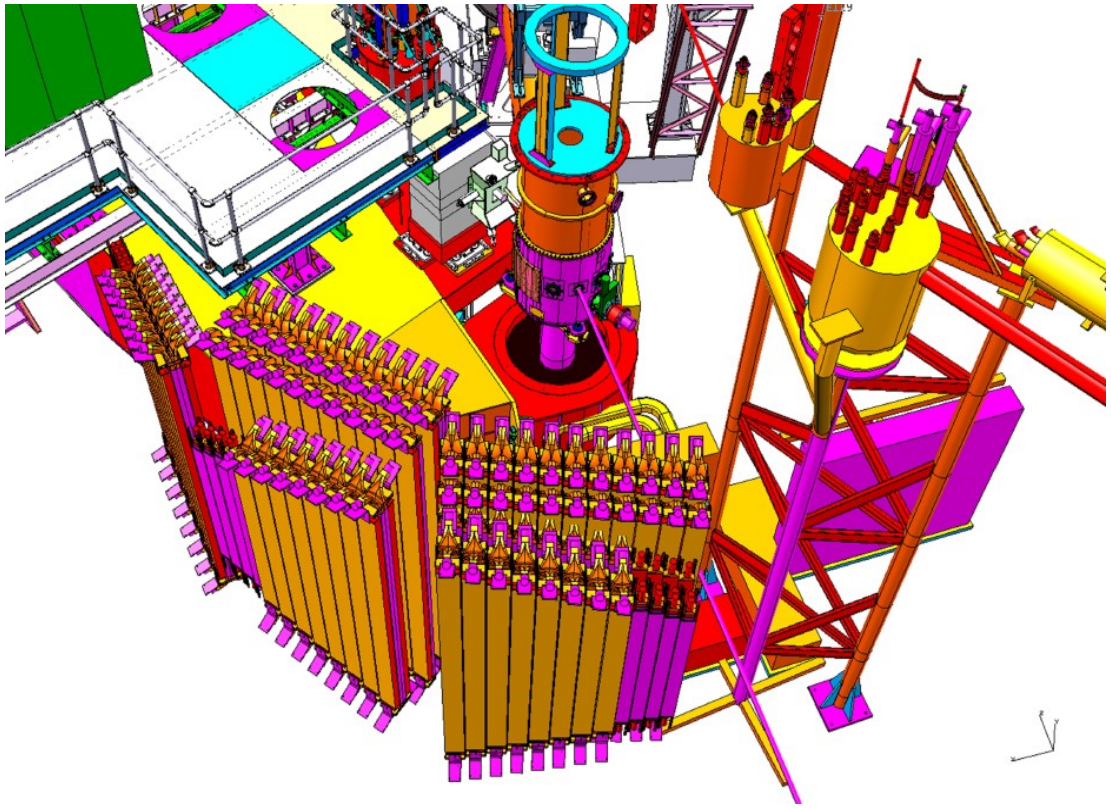
In-Medium Structure Functions with LAD

E12-11-107: In Medium Nucleon Structure Functions, SRC, and the EMC effect





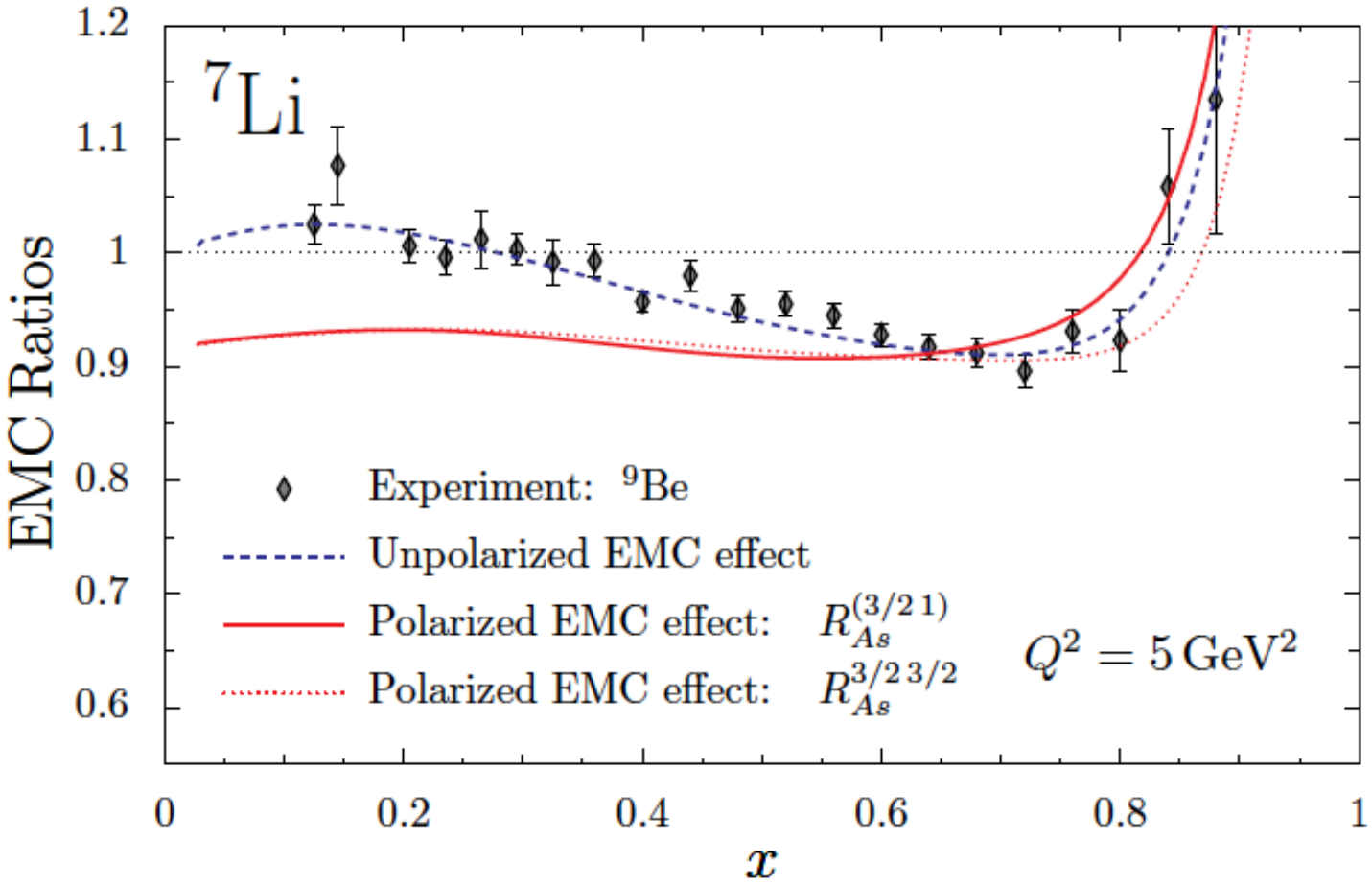
Large Acceptance Detector for Jefferson Lab Hall C



Spectator Tagging with Bonus, E12-06-113: The Structure of the Free Neutron at Large x.

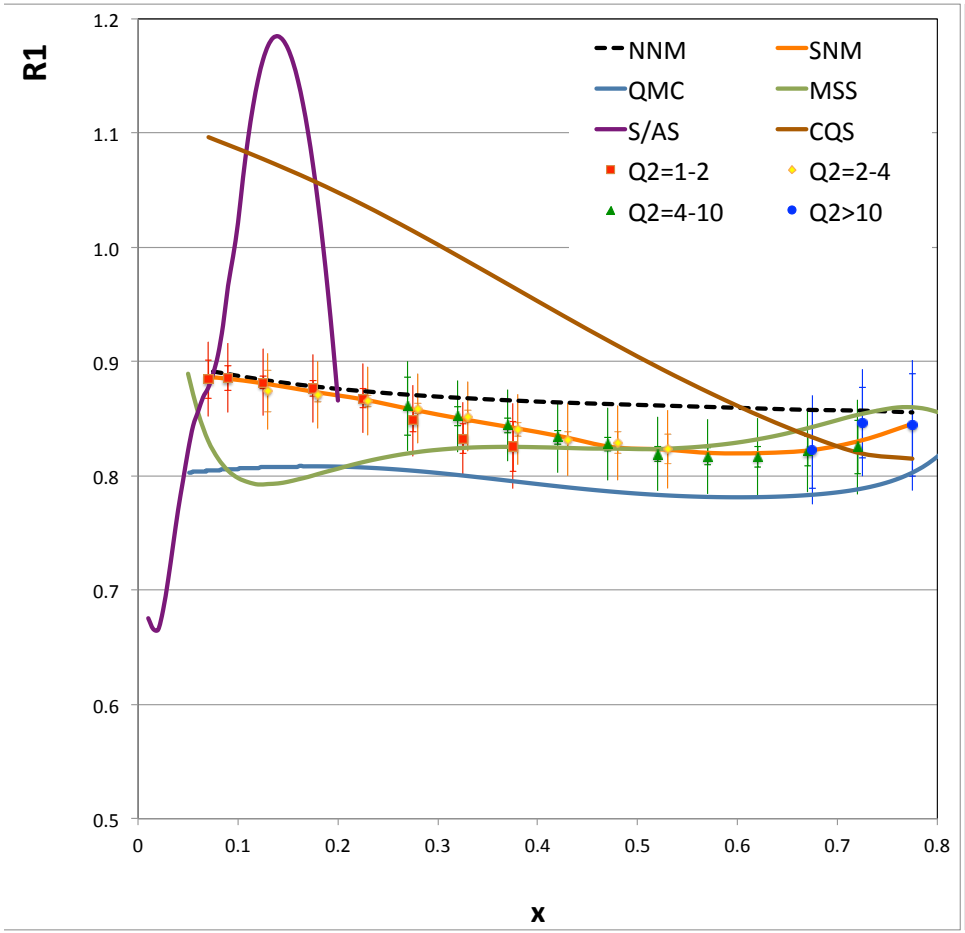
Polarized EMC Effect

I. C. Cloet, W. Bentz and A. W. Thomas, Phys.Lett.B **642** (2006) 210-217.

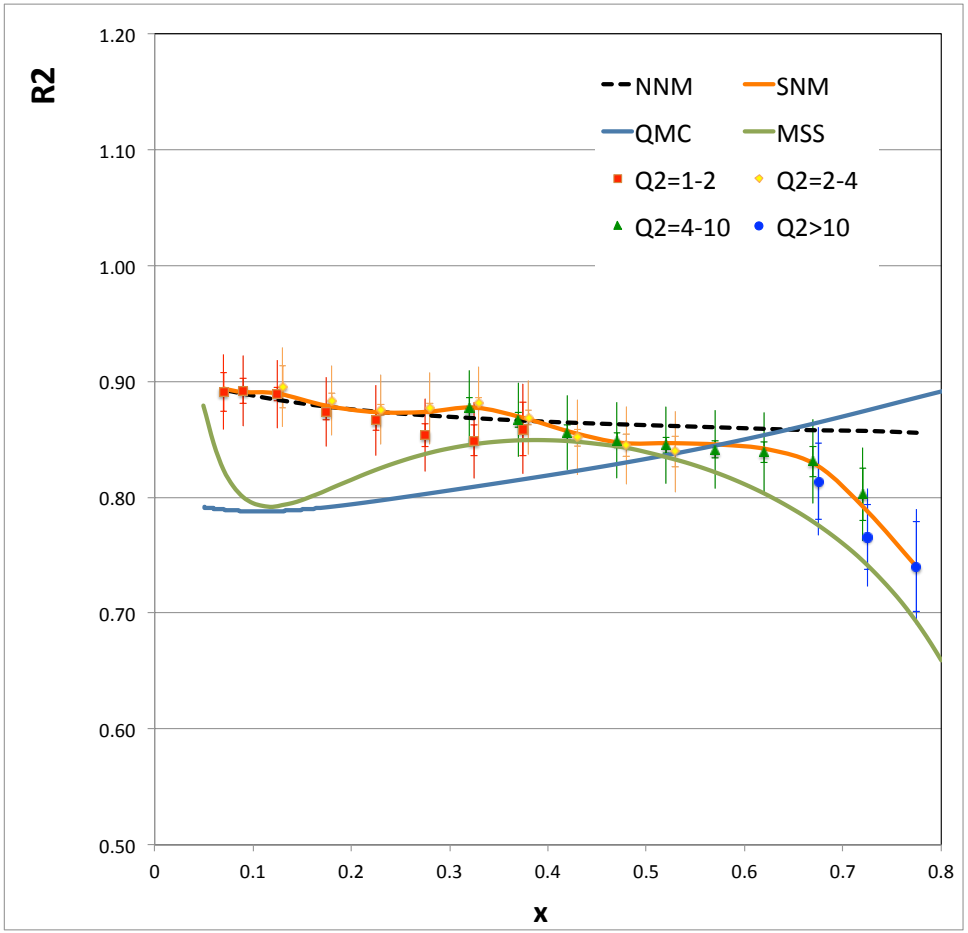


Polarized EMC = Every Model Cannot

E12-14-001: The EMC Effect in Spin Structure Functions



$\Delta\sigma$ Ratio



$A_{||}$ Ratio

Changing Picture Of Nuclear Matter

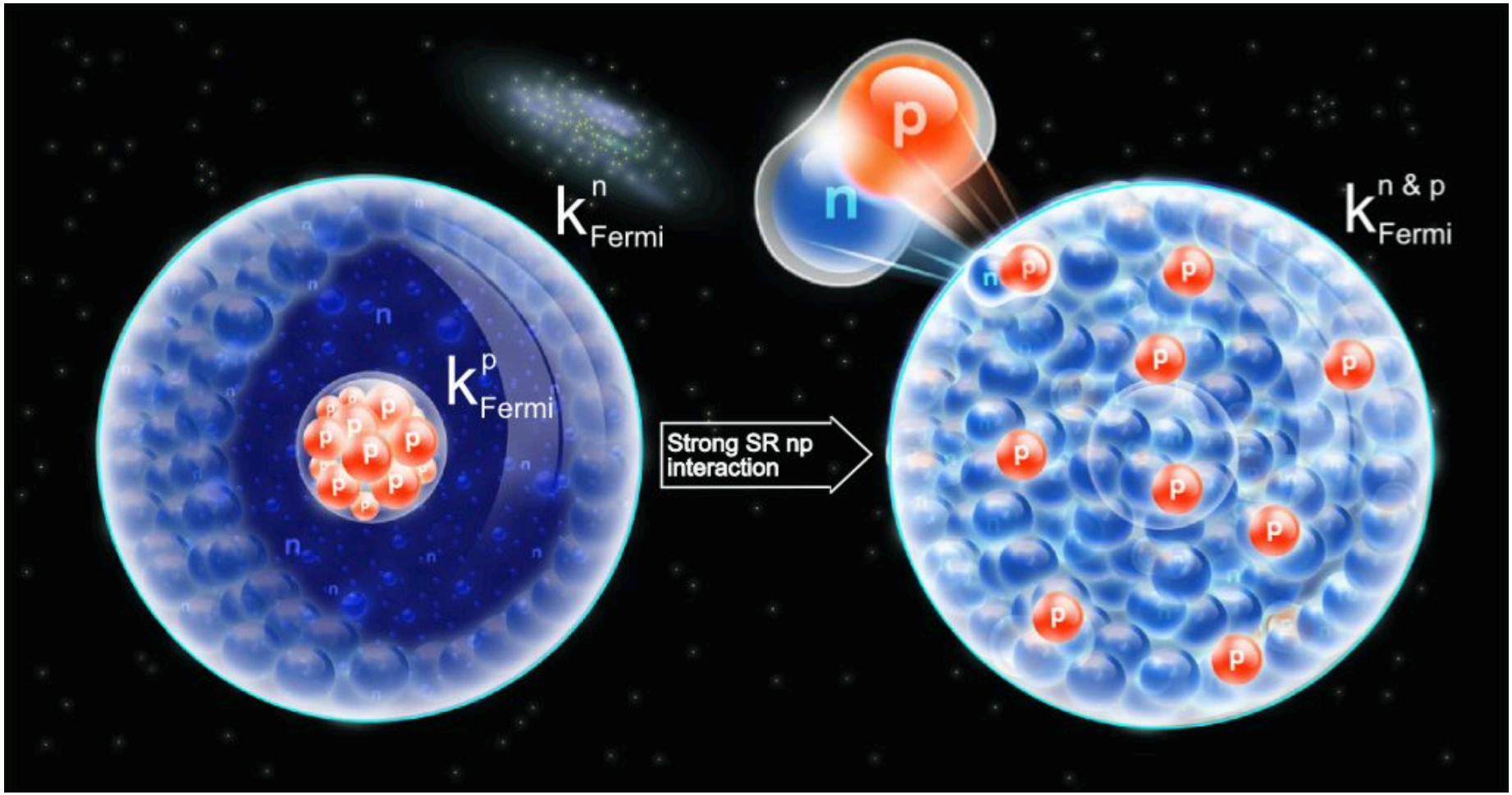


Image from CERN Courier **49N1** (2009) 22-24.

List Of Discussed 12GeV Experiments

Jefferson Lab Hall A

* E12-11-112 3He/3H x>1 (*High Impact Proposal*)
* E12-14-011 3He/3H (e,e'p)
* E12-14-012 40Ar(e,e'p) in collaboration with neutrino community

Jefferson Lab Hall B

* E12-06-113 Spectator Tagging (*High Impact Proposal*)
* E12-14-001 Polarized EMC

Jefferson Lab Hall C

* E12-06-105 x>1 *(High Impact Proposal*)
* E12-11-002 polarization transfer
* E12-11-107 (e,e'p) EMC-SRC
* E12-17-005: The CaFe Experiment

http://www.jlab.org/exp_prog/PACpage/High_Impact_Proposals.pdf