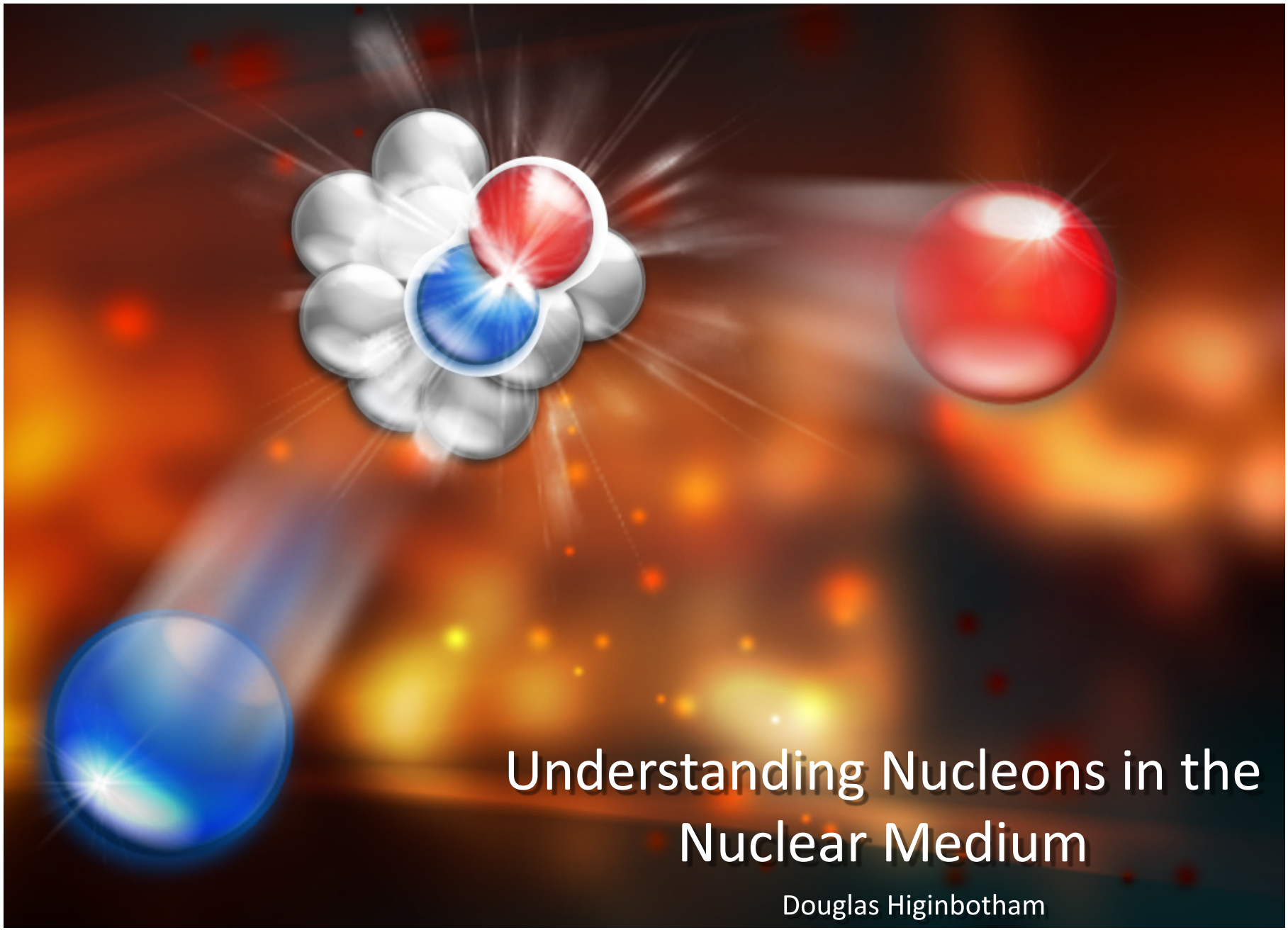
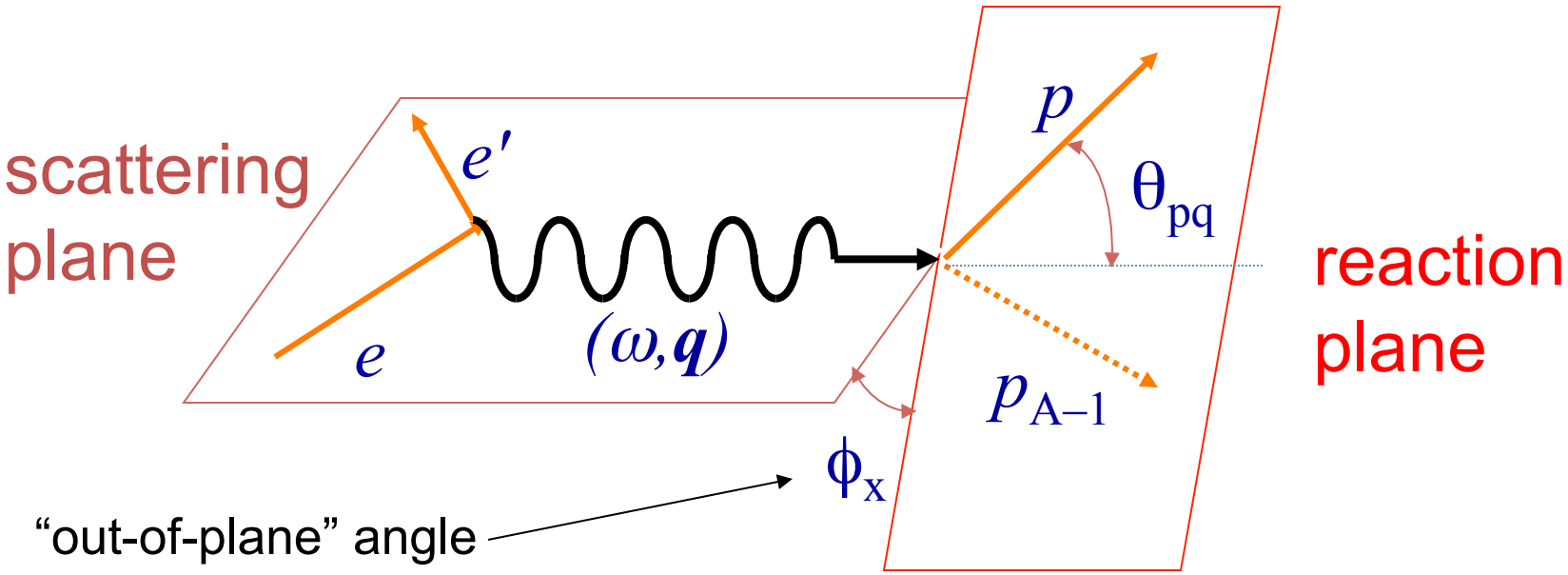


Understanding Nucleons in the Nuclear Medium

Douglas Higinbotham

A(e,e'p)A-1 Kinematics



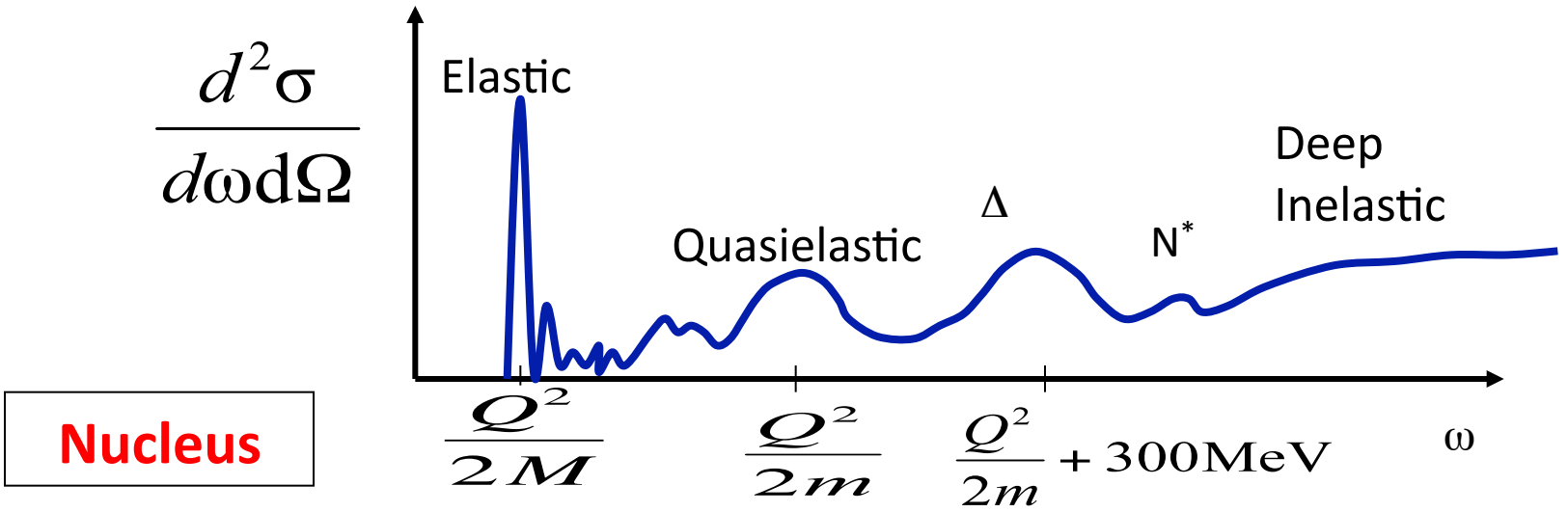
Four-momentum transfer: $Q^2 \equiv -q_\mu q^\mu = \boldsymbol{q}^2 - \omega^2$

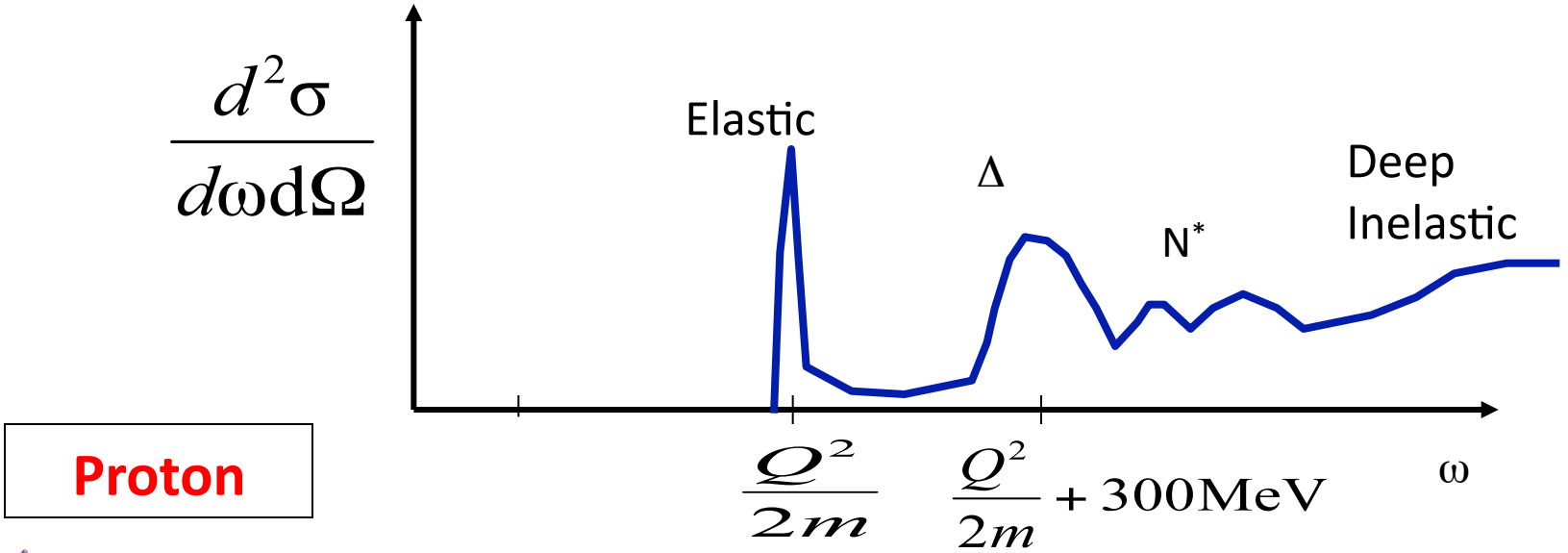
Missing momentum: $\boldsymbol{p}_m = \boldsymbol{q} - \boldsymbol{p} = \boldsymbol{p}_{A-1}$

Missing energy: $\varepsilon_m = \omega - T_p - T_{A-1}$

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

Electron Scattering A(e,e') at Fixed Q^2





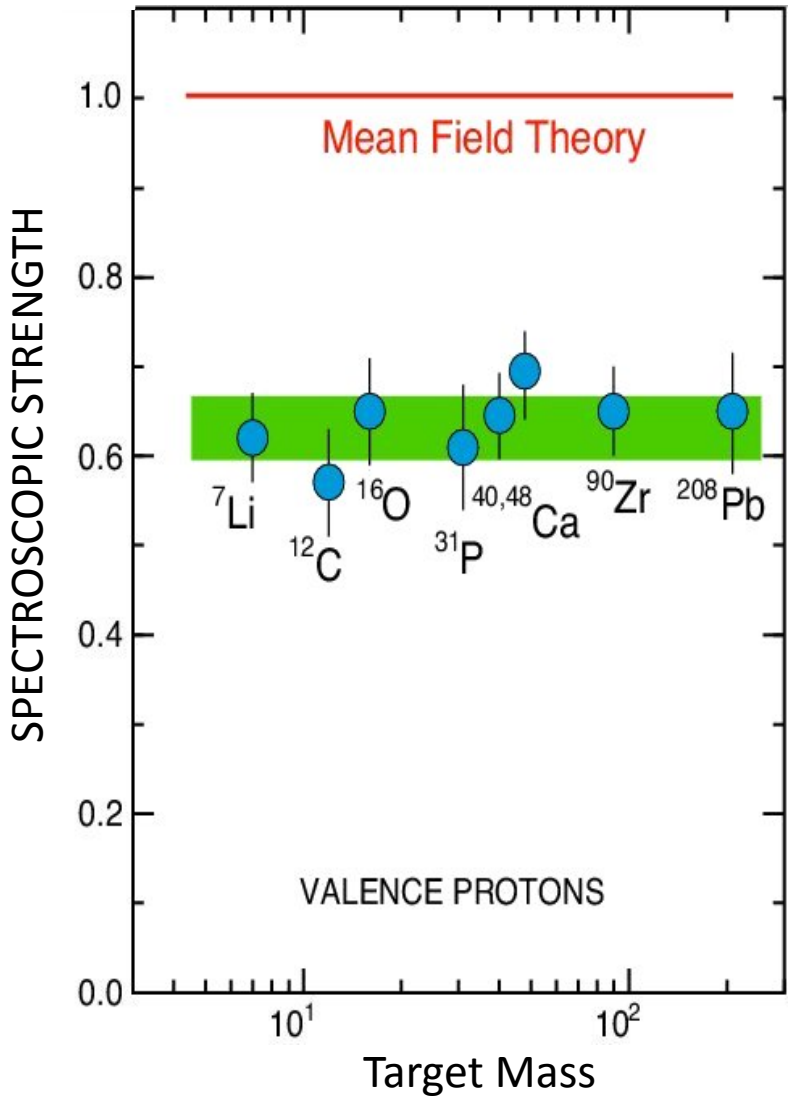
Classic Result from (e,e'p) Measurements

L. Lapikas, Nucl. Phys. A553 (1993) 297.

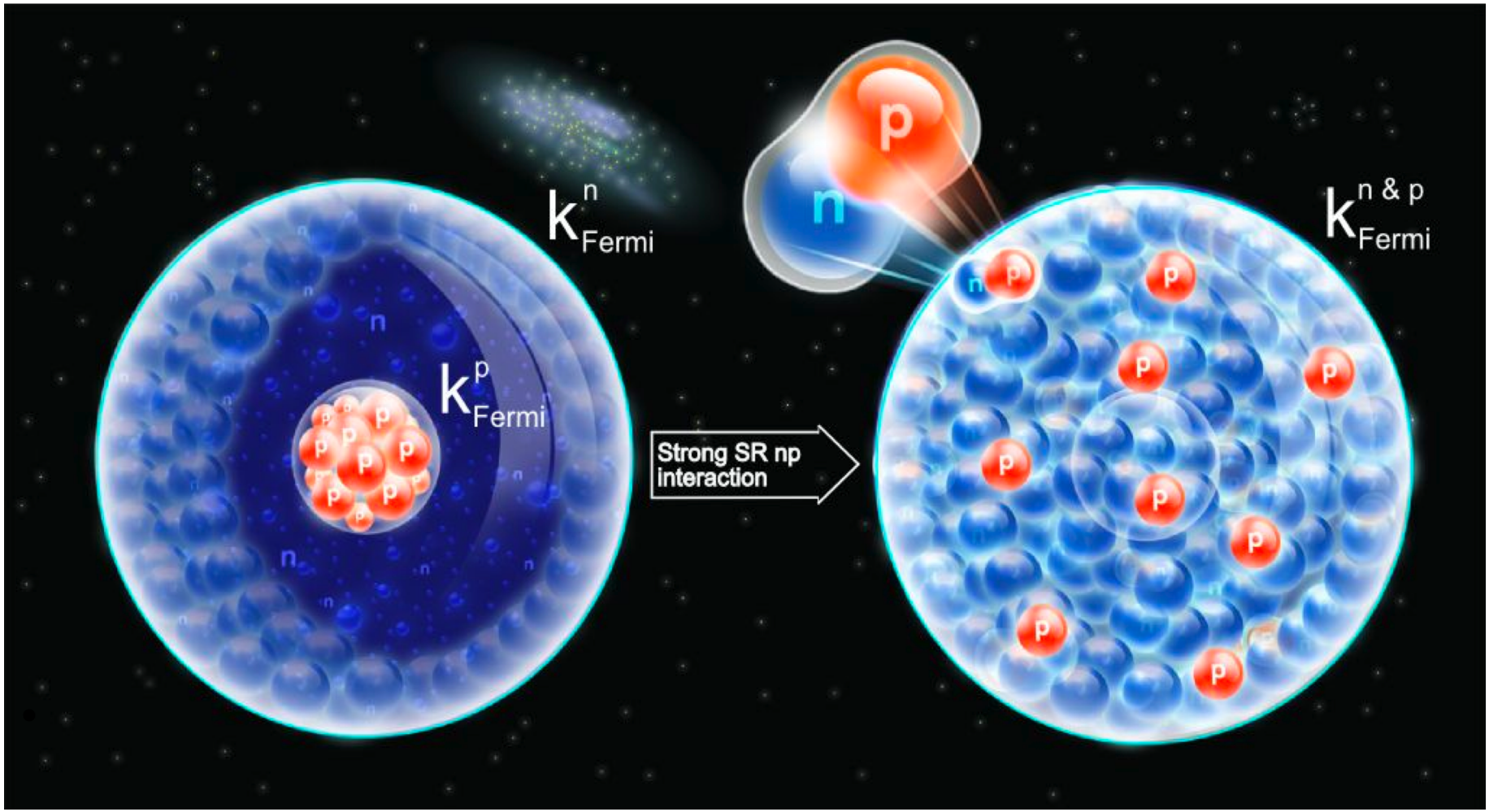
Independent-Particle Shell-Model is based upon the assumption that each nucleon moves independently in an average potential (mean field) induced by the surrounding nucleons

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.

Solution: Correlations Between Nucleons

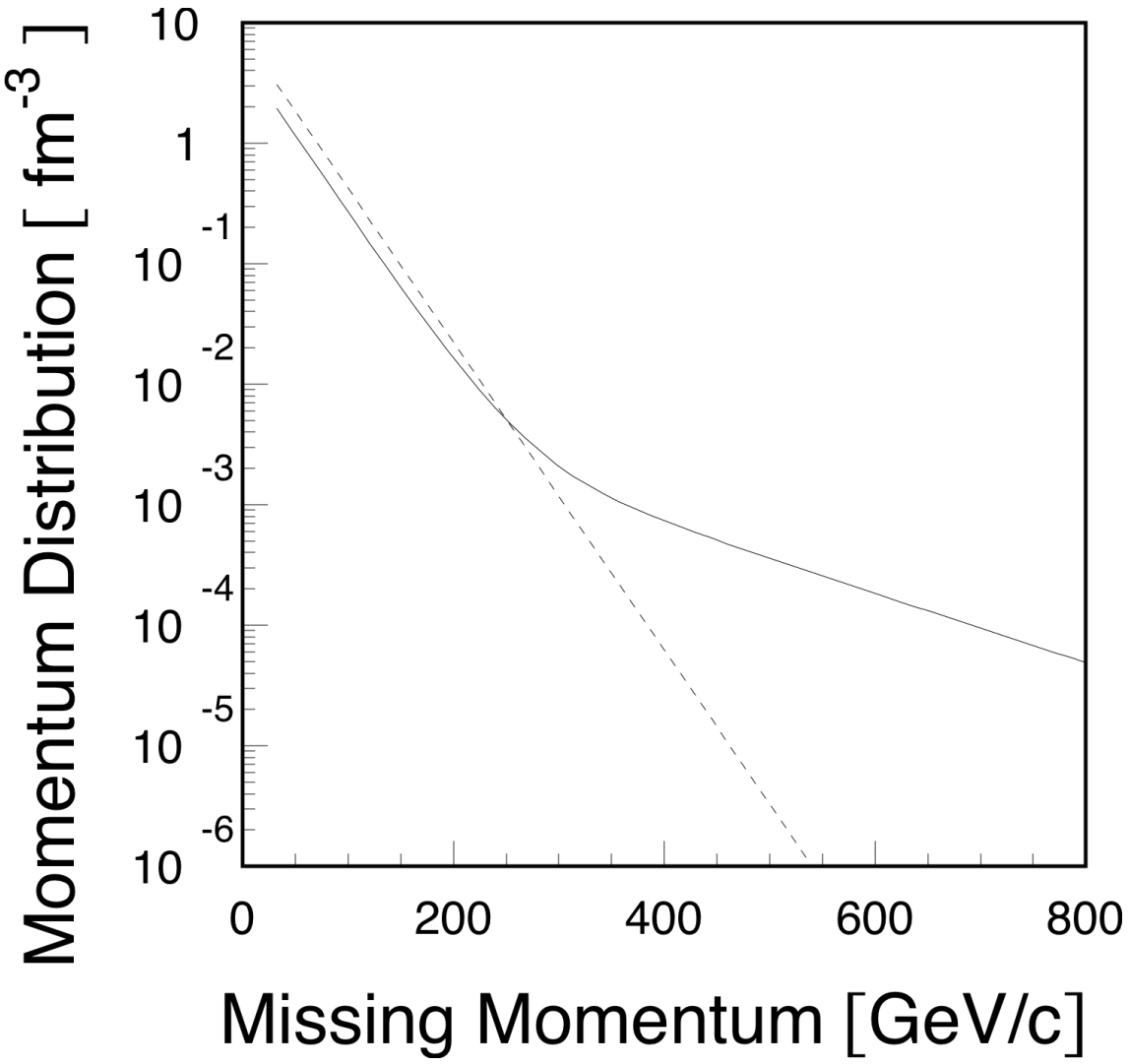


Implications for Neutron Stars



D.H., E. Piasetzky, M. Strikman , CERN Courier 49N1 (2009) 22.

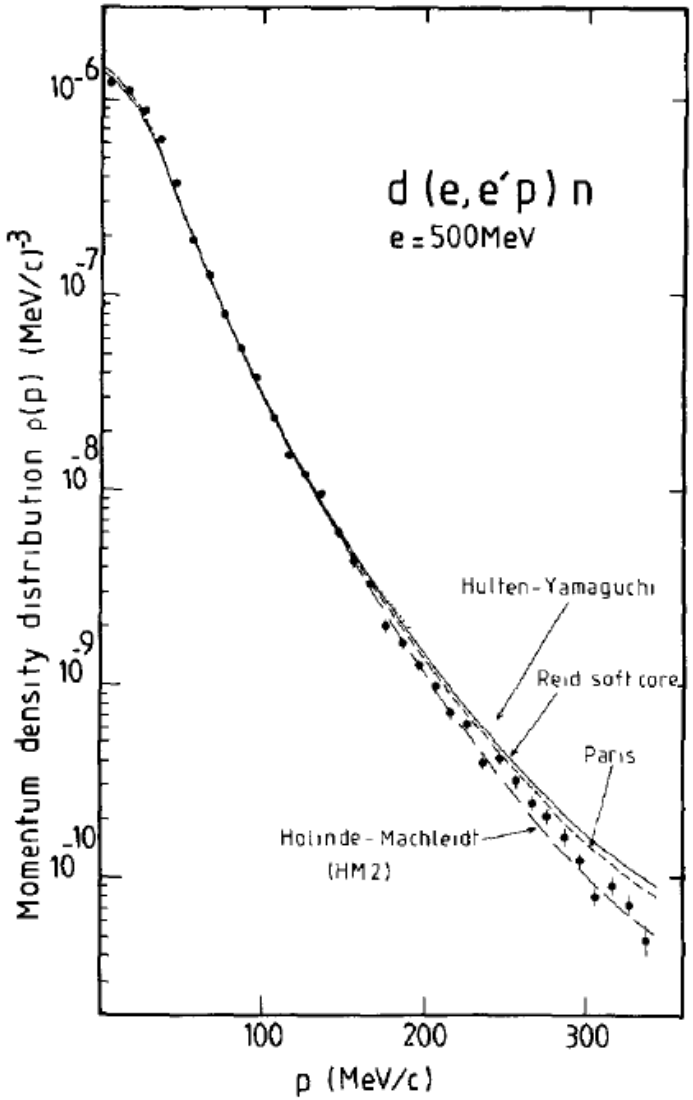
A Toy Model Momentum Distribution



By Uncertainty Principle High Momentum Region Dominated by Short Distance Phenomena

Classic Deuteron Momentum Distribution

M. Bernheim *et al.*, Nuclear Physics **A365** (1981) 349.

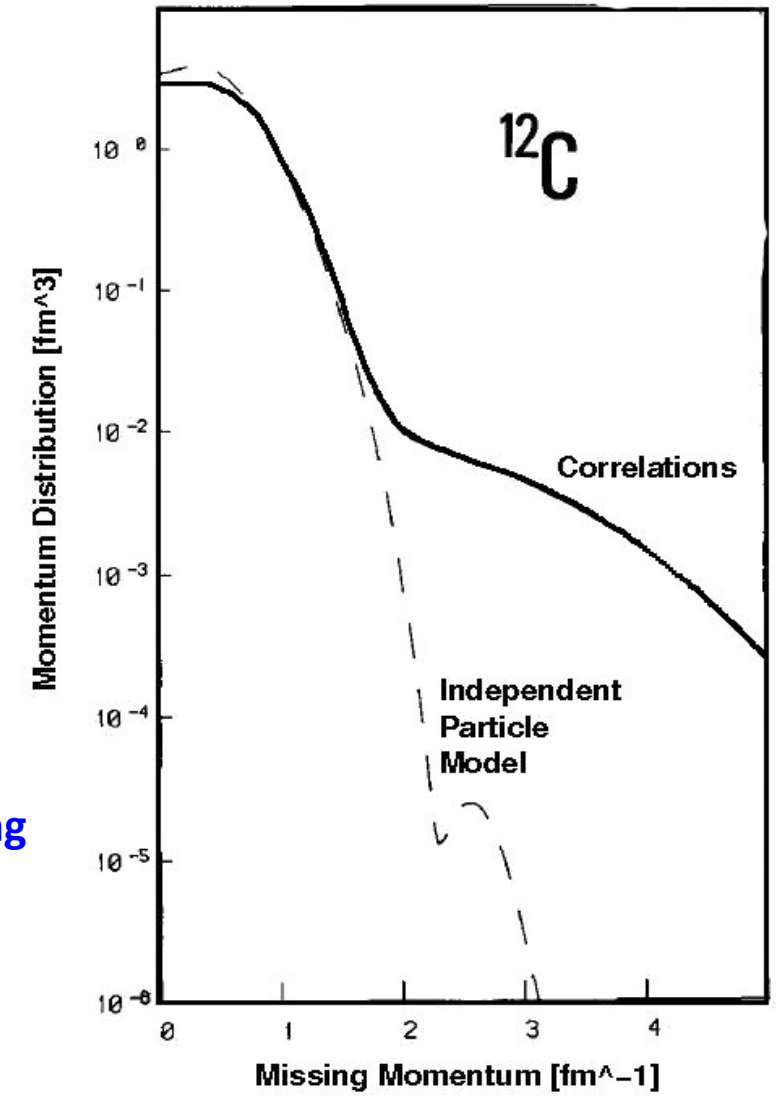


Short-Range Correlation Questions

- 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)?

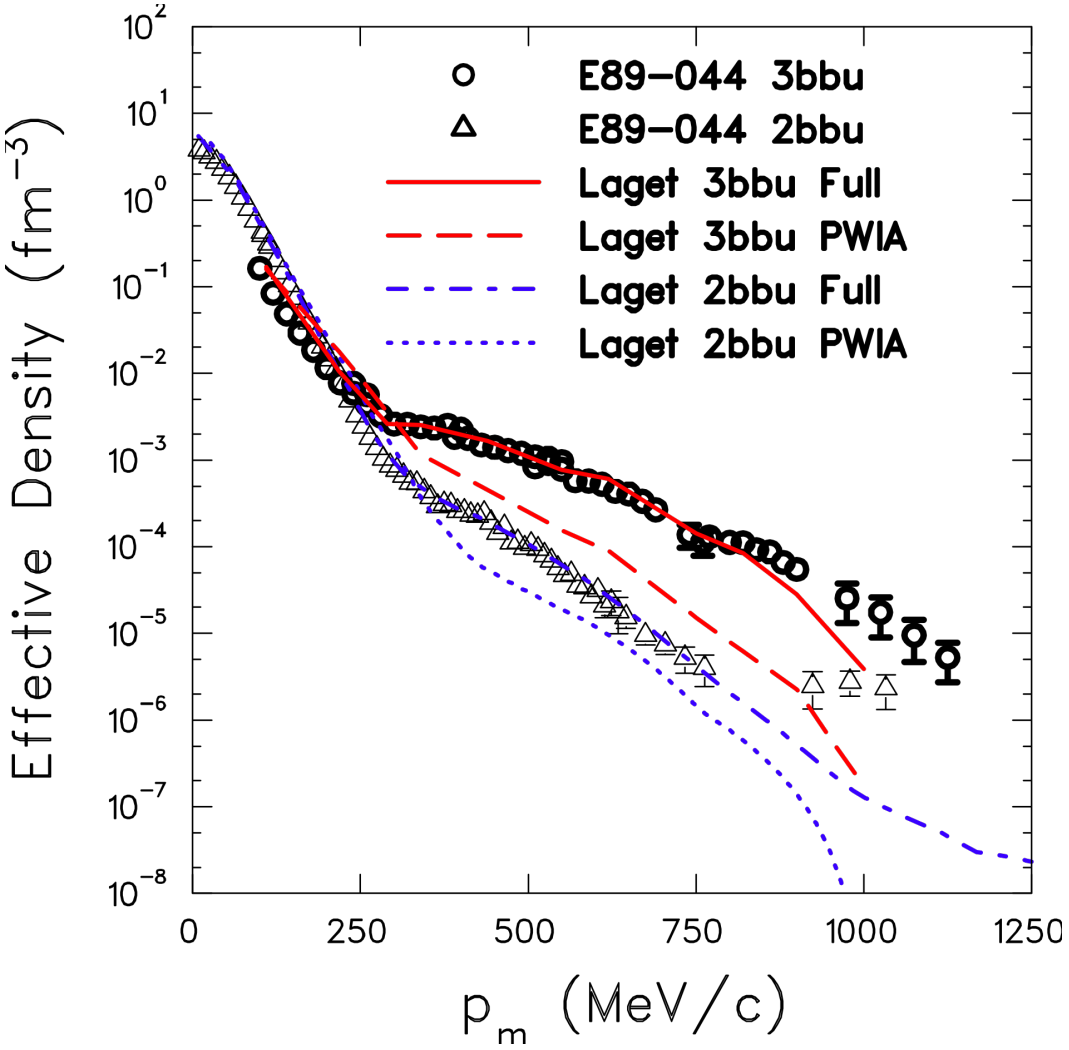
BUT Other Effects Such As A Final State Rescattering Have Masked The Signal In The Past.

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



^{3}He(e,e'p)d and ^{3}He(e,e'p)np

F. Benmokhtar *et al.*, Phys. Rev. Lett. **95** (2004) 082305.

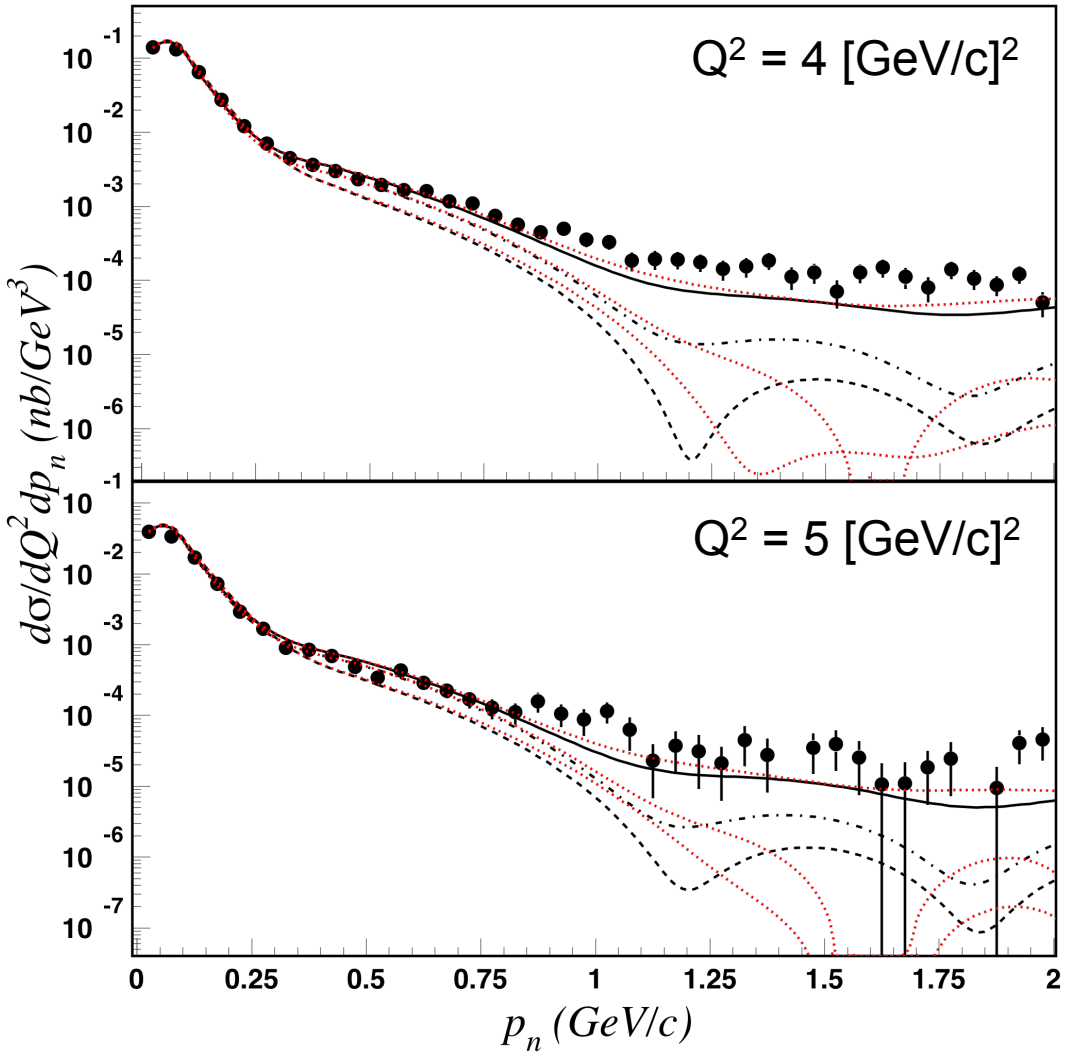


Q^2 = 1.5 [GeV/c]^2

x_B = 1 (Q.E. Peak)

Hall B (CLAS) D(e,e'p)n Q^2 x<1 Data

K. Sh. Egiyan *et al.,* Phys. Rev. Lett. **98** (2007) 262502.

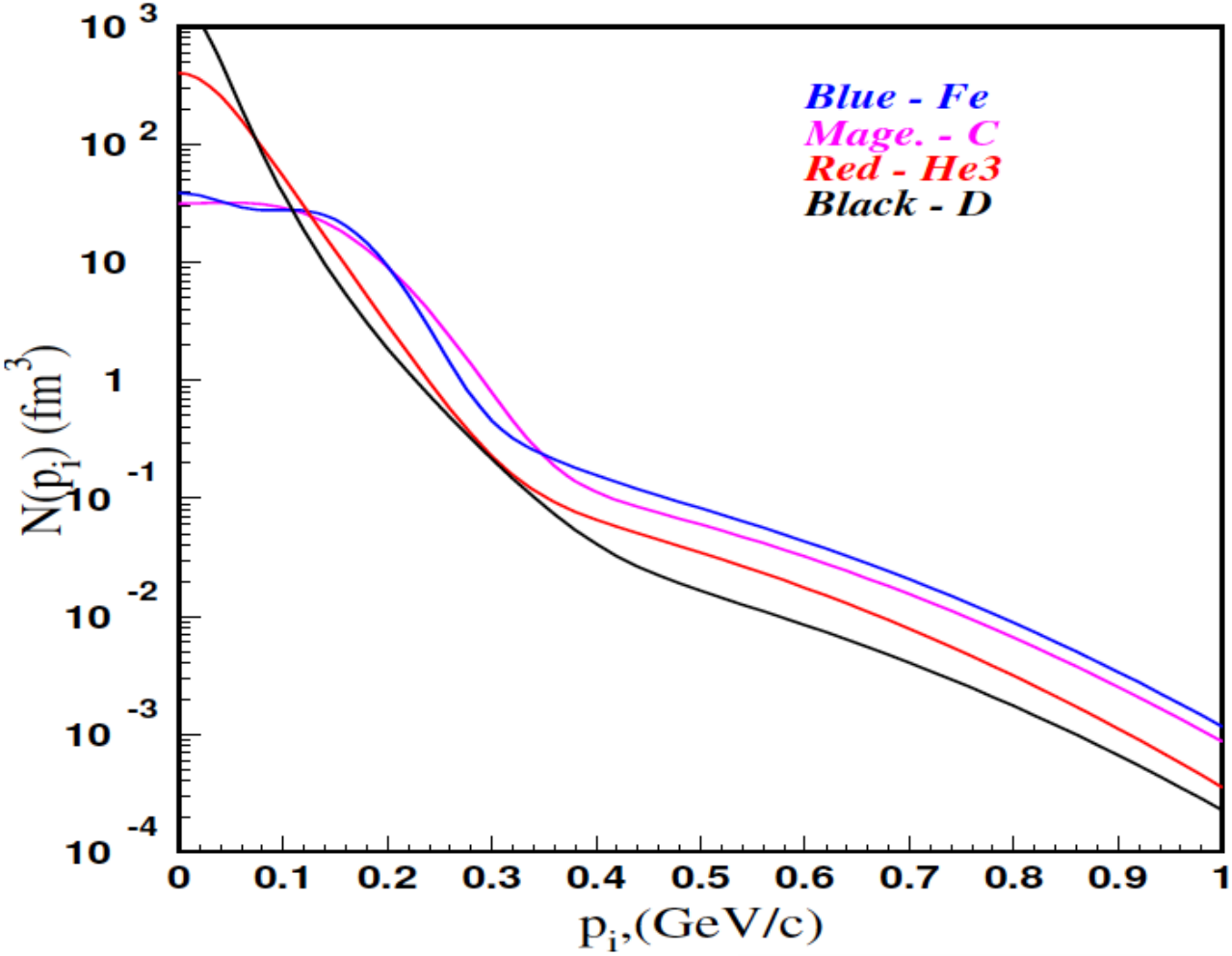


Black Paris Potential
Red AV-18 Potential

From Lowest To Highest
PWIA
PWIA+FSI
PWIA+FSI+MEC+NΔ

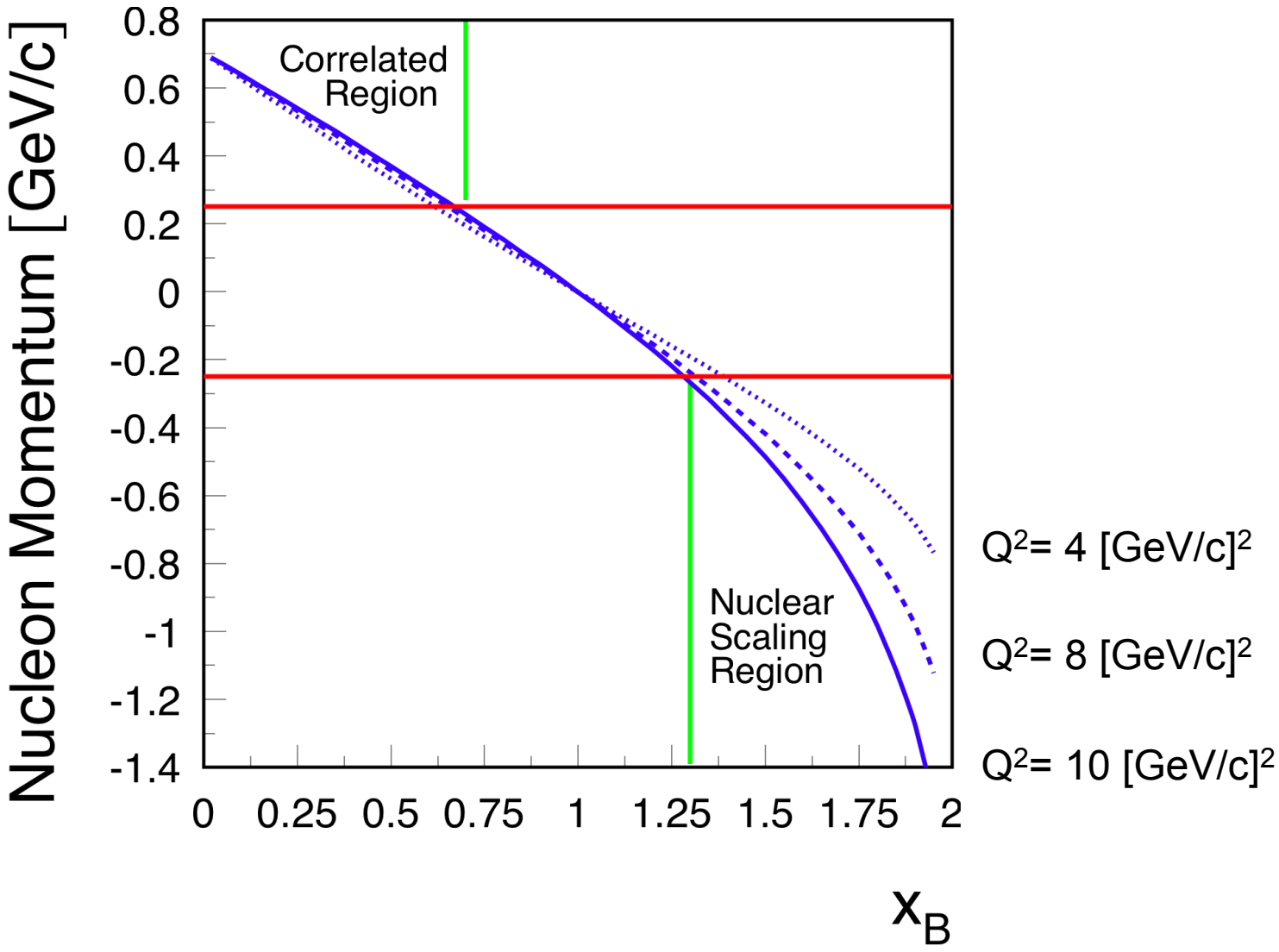
Calculation of Nucleon Initial Momentum

C. Ciofi degli Att and S. Simula, Phys. Rev. C **53** (1996) 1689.



Nuclear Scaling at High Initial Momentums: $n_A(k) = R\, n_D(k)$

D(e,e')pn Reaction As Function of x_B



CLAS A(e,e') x>1 Data

K. Sh. Egiyan *et al.,* Phys. Rev. C **68** (2003) 014313.

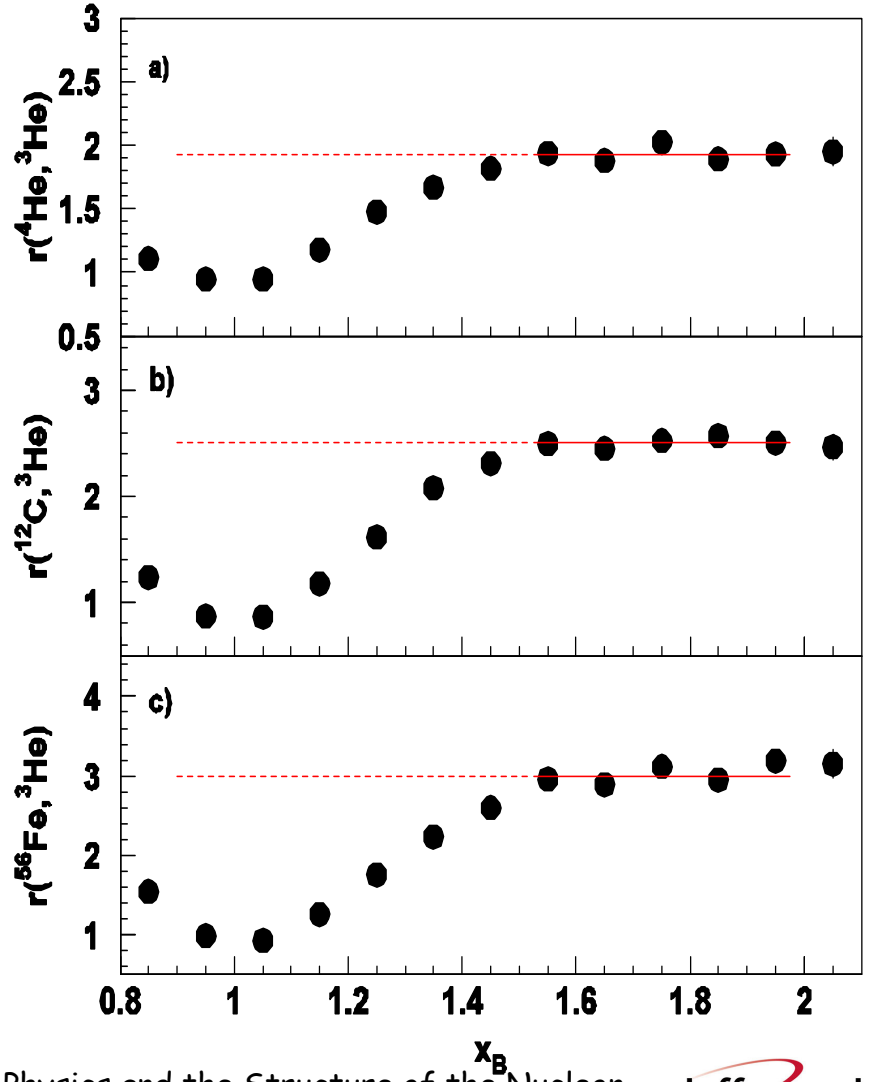
Originally done with SLAC data by D.B. Day *et al.*, Phys. Rev. Lett. 59 (1987) 427.

$$x = \frac{Q^2}{2M\omega} > 1.5 \quad \text{and} \quad Q^2 > 1.4\ [\text{GeV/c}]^2$$

then

$$r(A,{}^3He) = a_{2n}(A)/a_{2n}({}^3He)$$

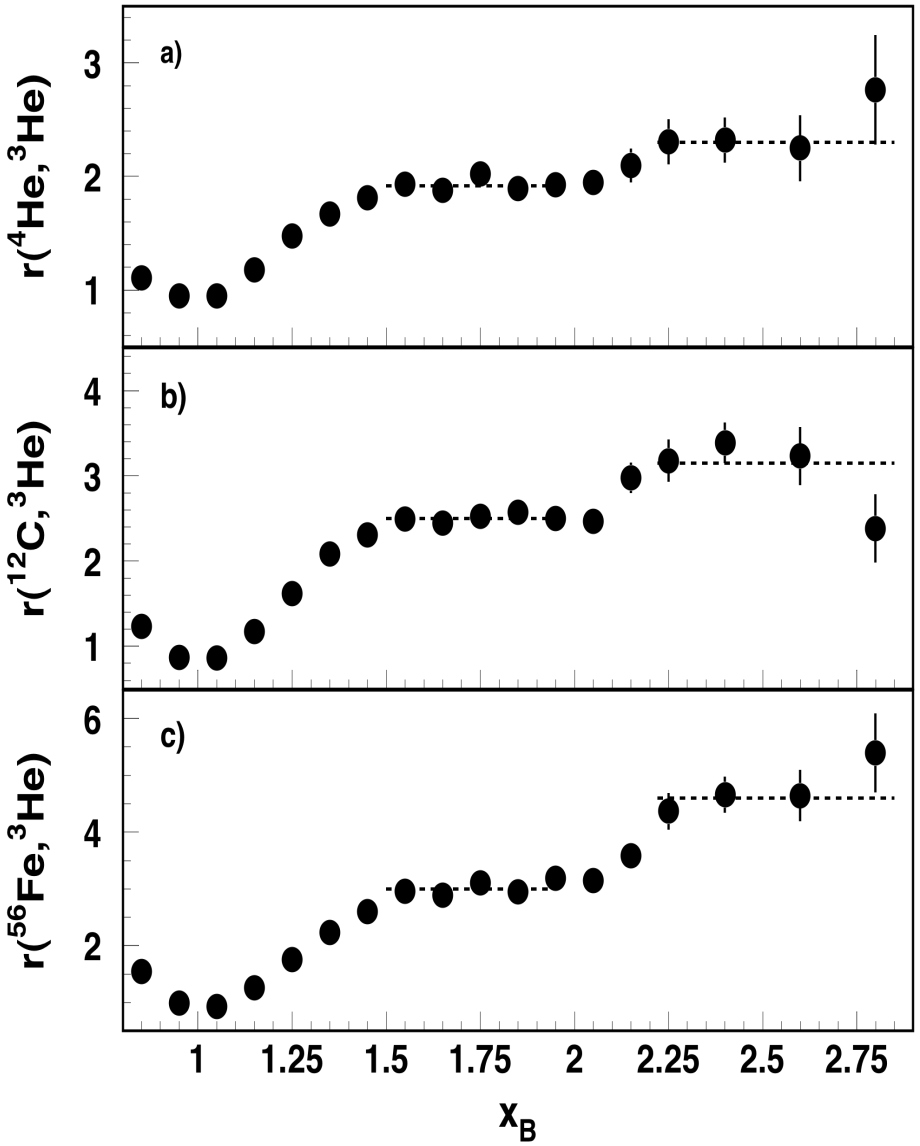
The observed *scaling* suggests that the electron is probing the high-momentum correlated nucleon; if so, the scaling factors determine the per-nucleon probability of the correlation in nuclei relative to ^{3}He.



Estimate of ^{12}C Two and Three Nucleon SRC

K. Sh. Egiyan *et al.,* Phys. Rev. Lett. **96** (2006) 082501.

- K. Egiyan *et al*. related the known correlations in deuterium and previous ^{3}He to D ratio results to find:
- ^{12}C 20% two nucleon SRC
  - ~5% Deuteron (from integral)
  - ^{3}He/D ratio ~2 (data & theory)
- ^{12}C <1% three nucleon SRC
  - ^{3}He Integral From Faddeev Cal.

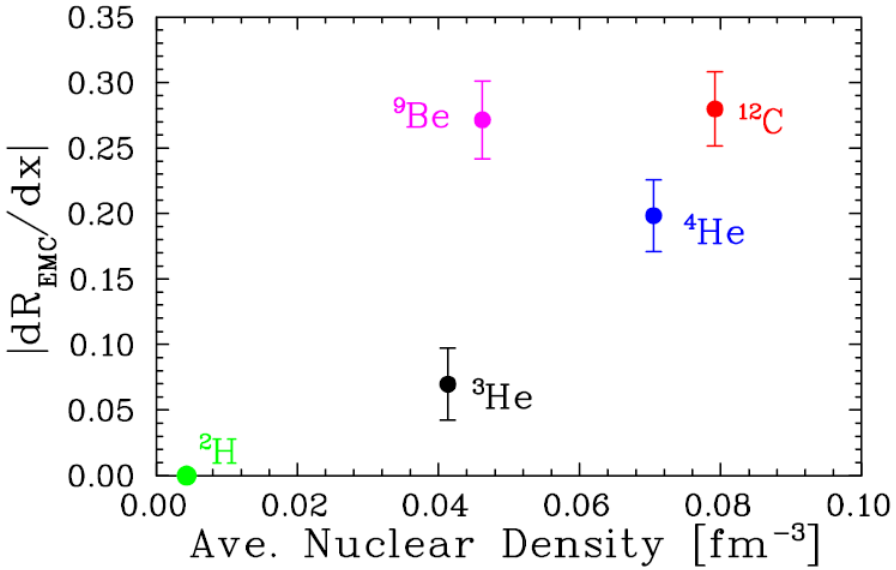


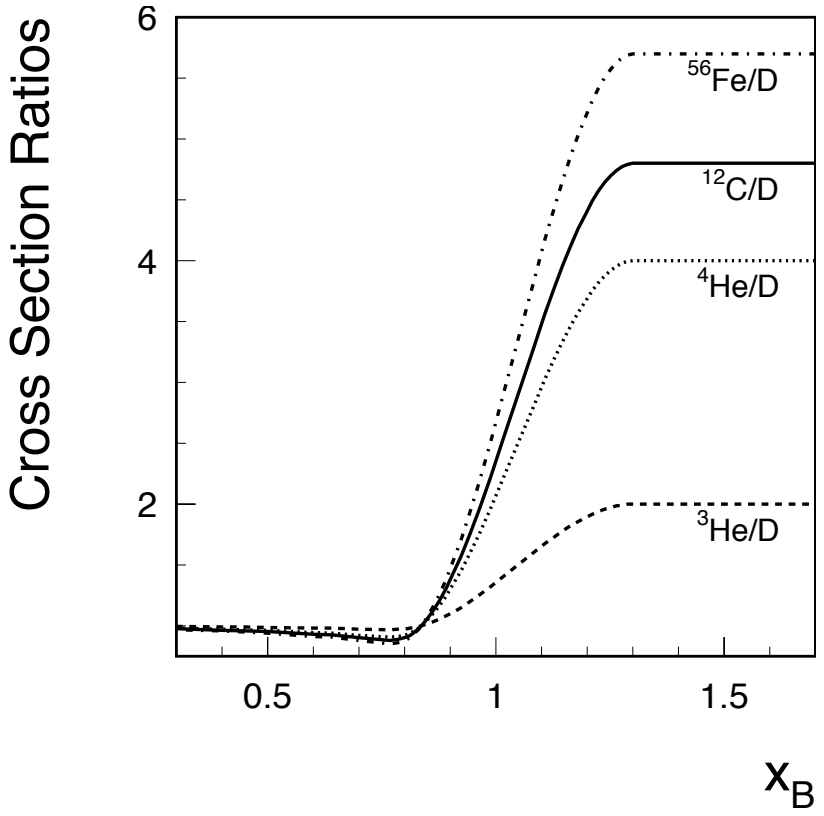
SRC Ratios and x>0.3 EMC Slopes

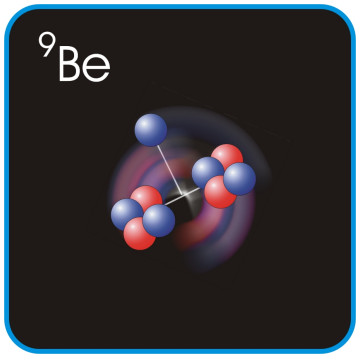
Both Local Density Effects?

Note: Q^2=50 GeV/c ^{56}Fe(e,e')/D(e,e') data extends smoothly into the x>1 region

A. C. Benvenuti, et al., Z. Phys. **C63** (1994) 29.







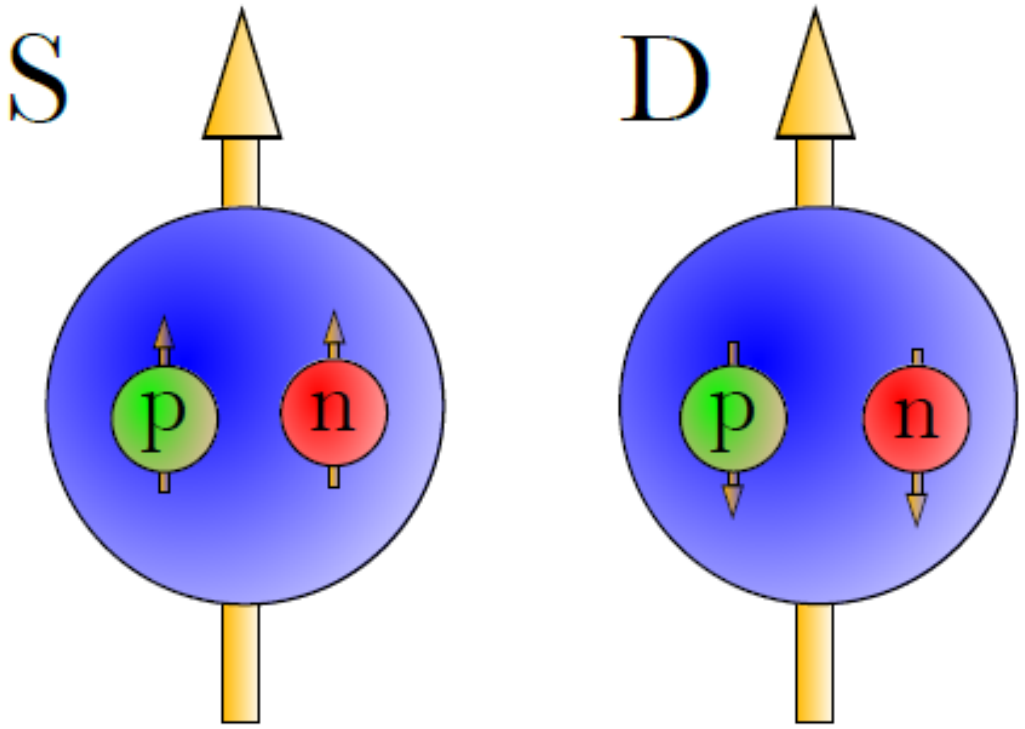
Ratio of EMC Slopes Seems To Follow Ratio of SRC Plateaus

^{12}C From the (e,e') and (e,e'p) Results

- 80 +/- 5% single particles moving in an average potential
  - 60 – 70% independent single particle in a shell model potential
  - 10 – 20% shell model long range correlations
- 20 +/- 5% two-nucleon short-range correlations
  - Hall C (e,e') Ratios Coming from Nadia Fomin
    - No Q^2 Dependence Of Ratio Magnitude Q^2 1 to 4 GeV to few percent
    - Plateaus Start When Minimum Missing Momentum > Fermi Momentum
- Less than 1% multi-nucleon correlations

Vector Polarized Deuterium

Spin-1 Particle, 2 spin-$^1/_2$ Nucleons (Proton and Neutron)

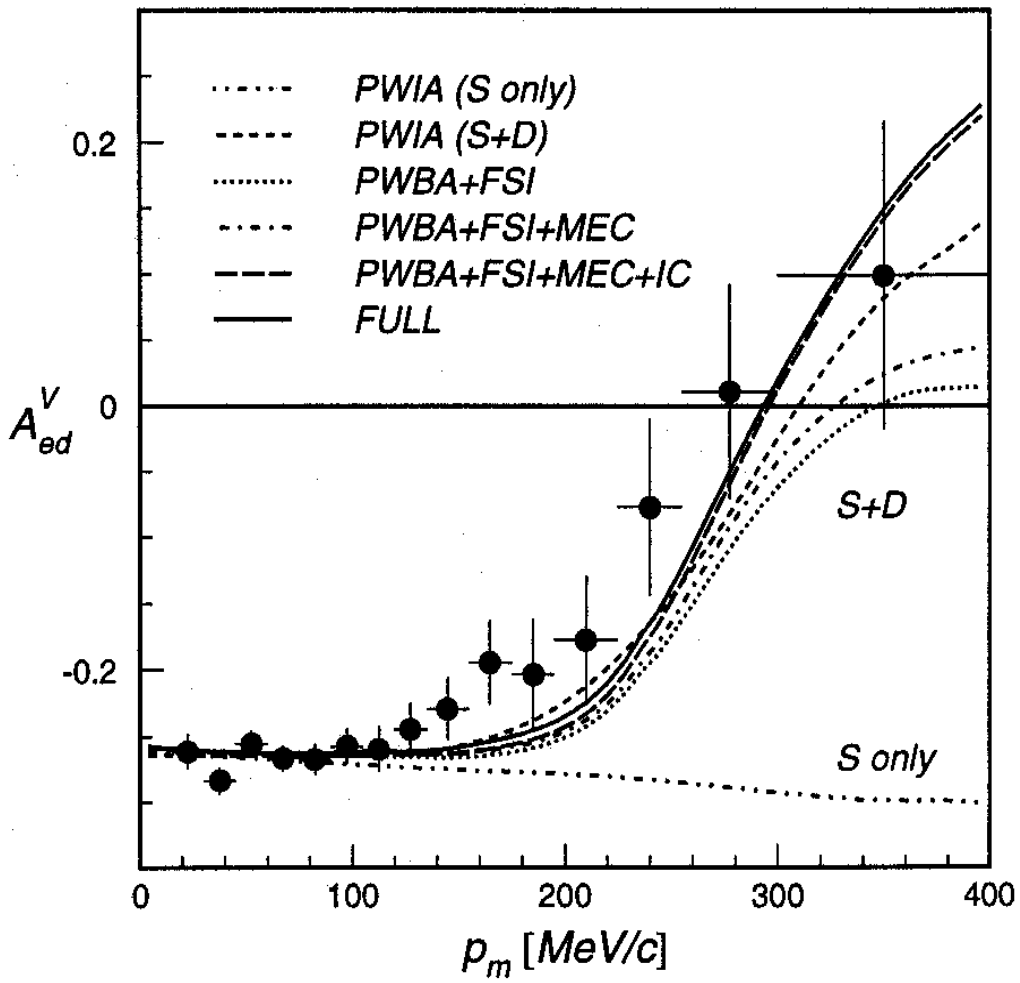


l=0
~90%

l=2
~10%

$^2\vec{\mathrm{H}}(\vec{e},e'p)$ Deuteron Asymmetry Data

I. Passchier *et al*., Phys. Rev. Lett. **88** (2002)102302.



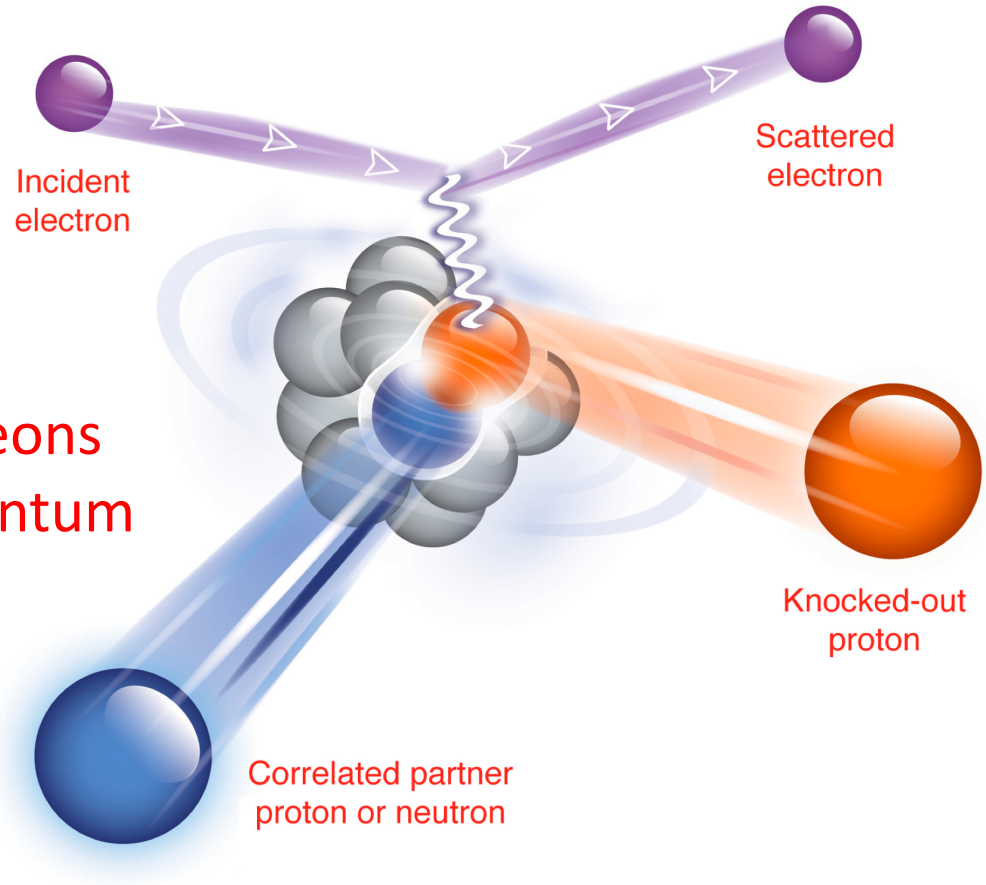
Q^2 = 0.2 GeV/c

x_B = 1

Customized (e,e'pN) Measurement

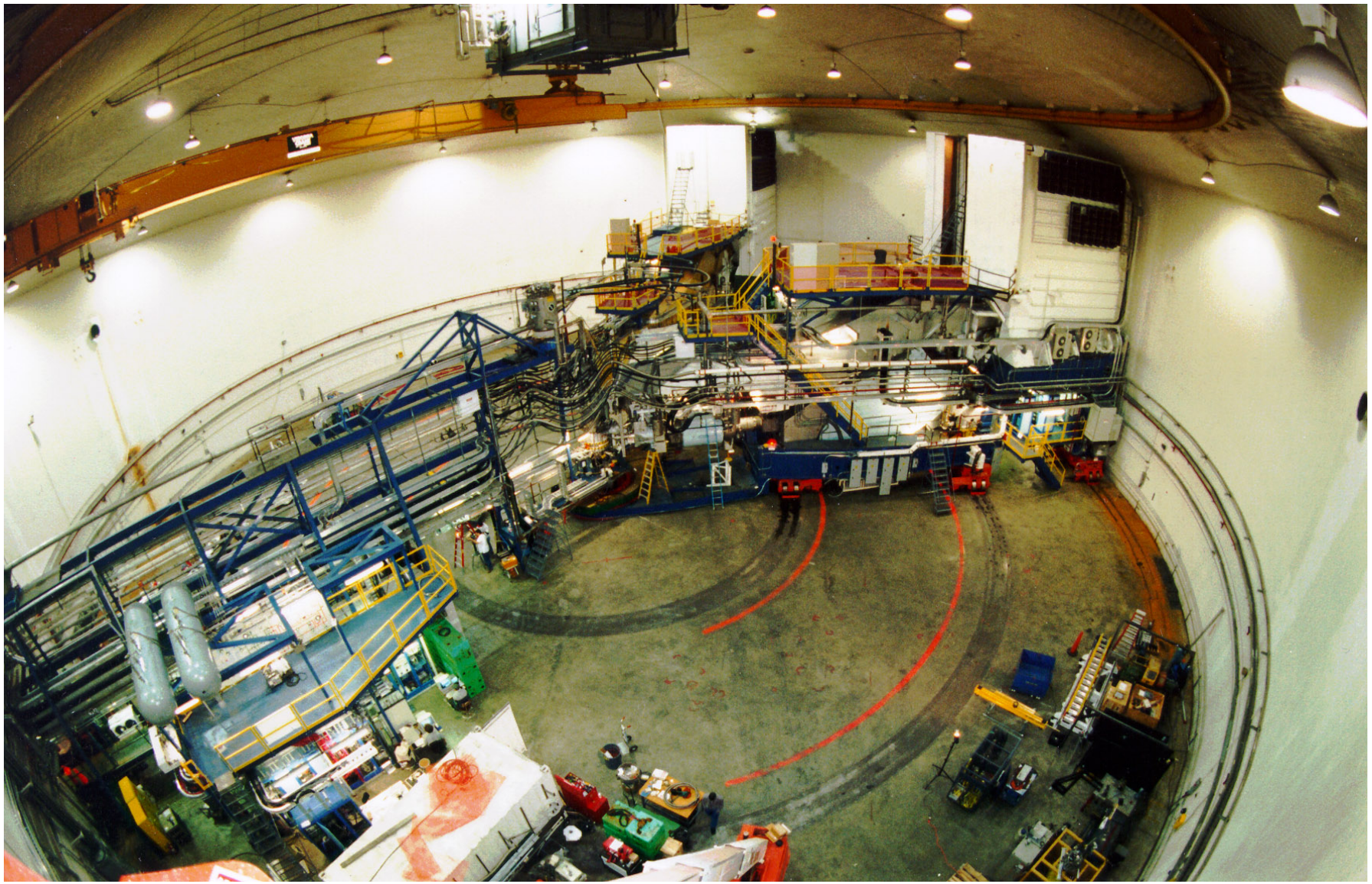
To study nucleon pairs at close proximity and their contributions to the large momentum tail of nucleons in nuclei.

A pair with "large" relative momentum between the nucleons and small center of mass momentum

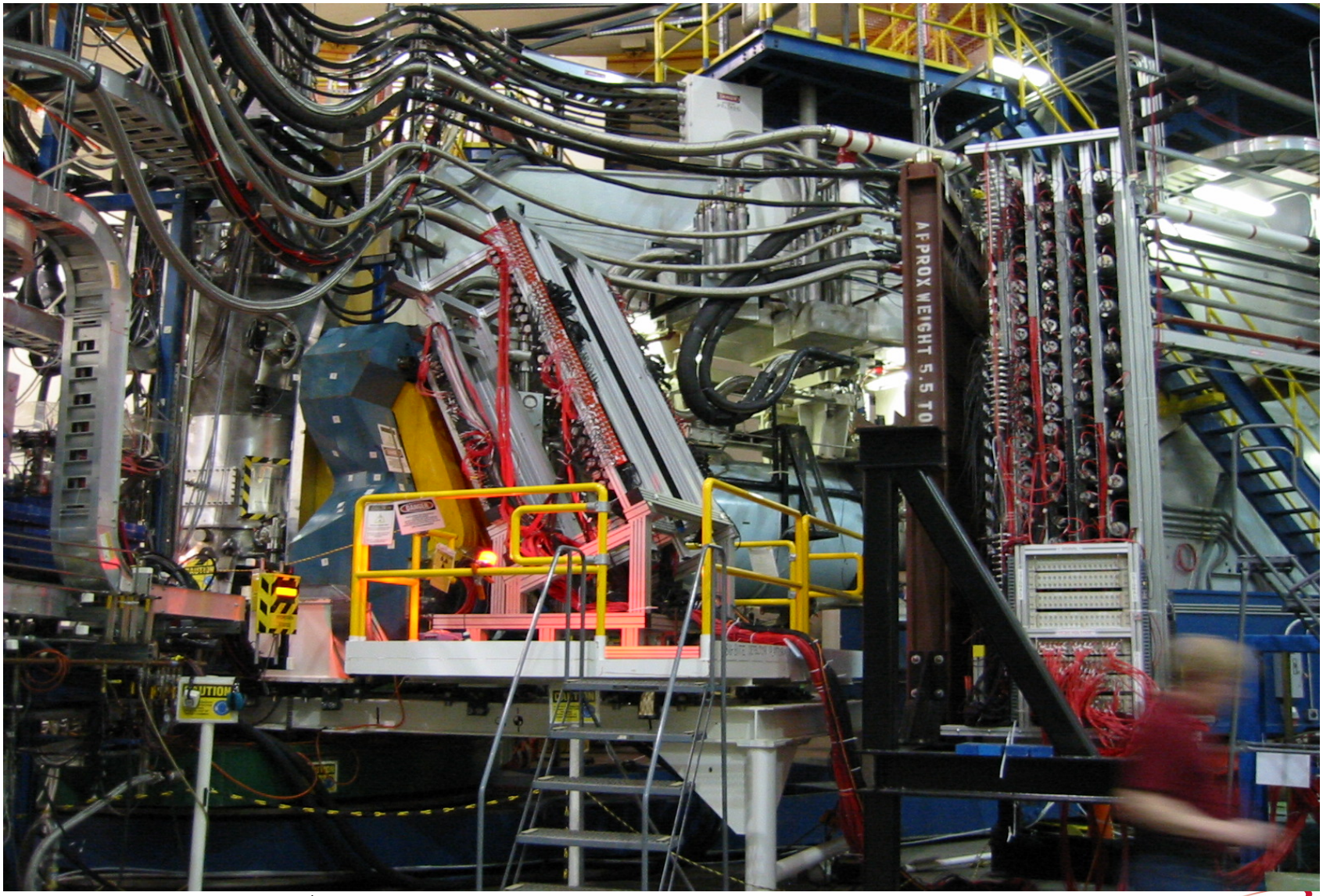


- high Q2 to minimize MEC
- x>1 to suppress isobar contributions
- anti-parallel kinematics to suppress FSI

Jefferson Lab's Hall A for (e,e'p)

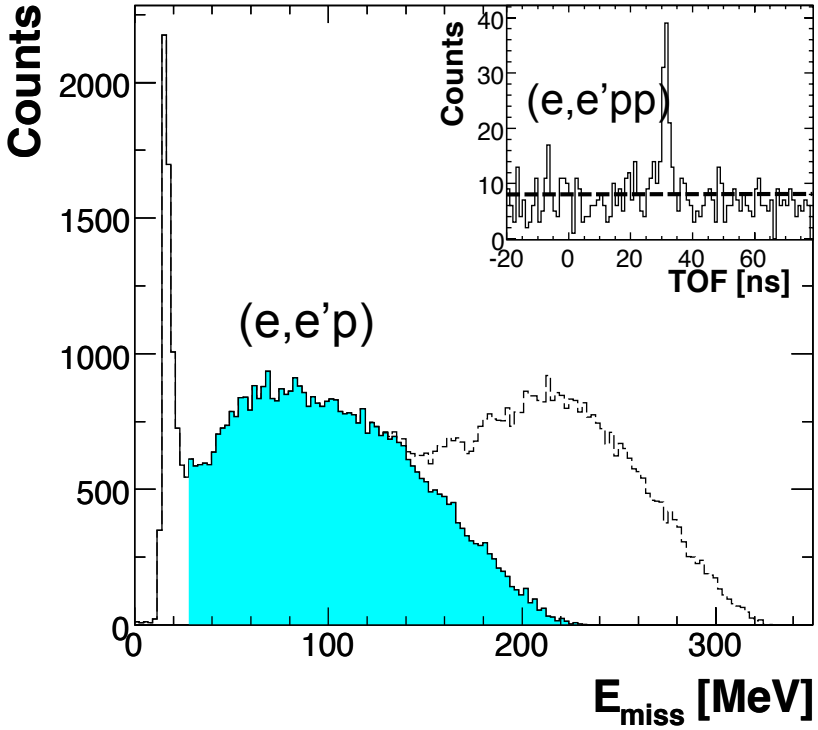


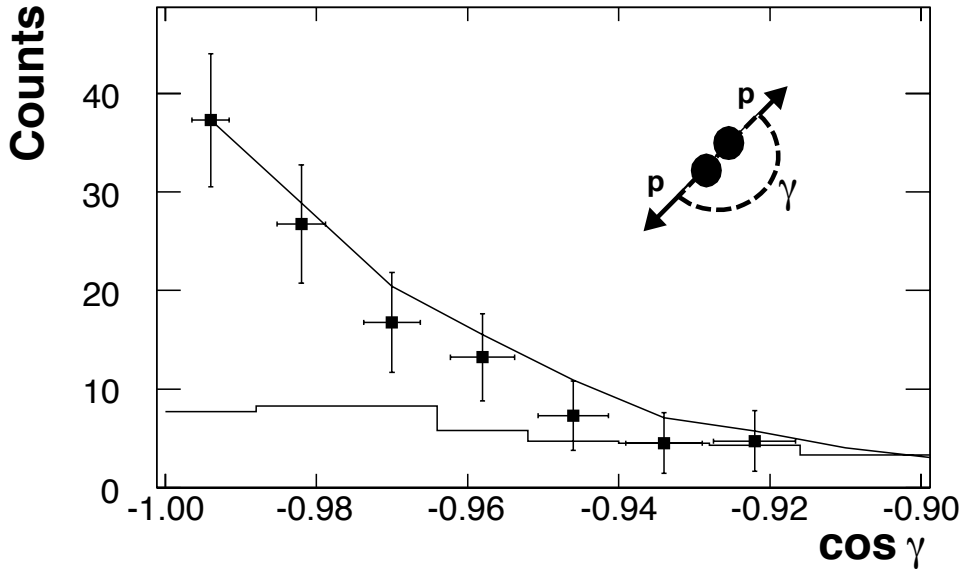
add BigBite and Neutron Detector for (e,e'pN)



(e,e'p) & (e,e'pp) Data

R. Shneor *et al*., Phys. Rev. Lett. **99** (2007) 072501.



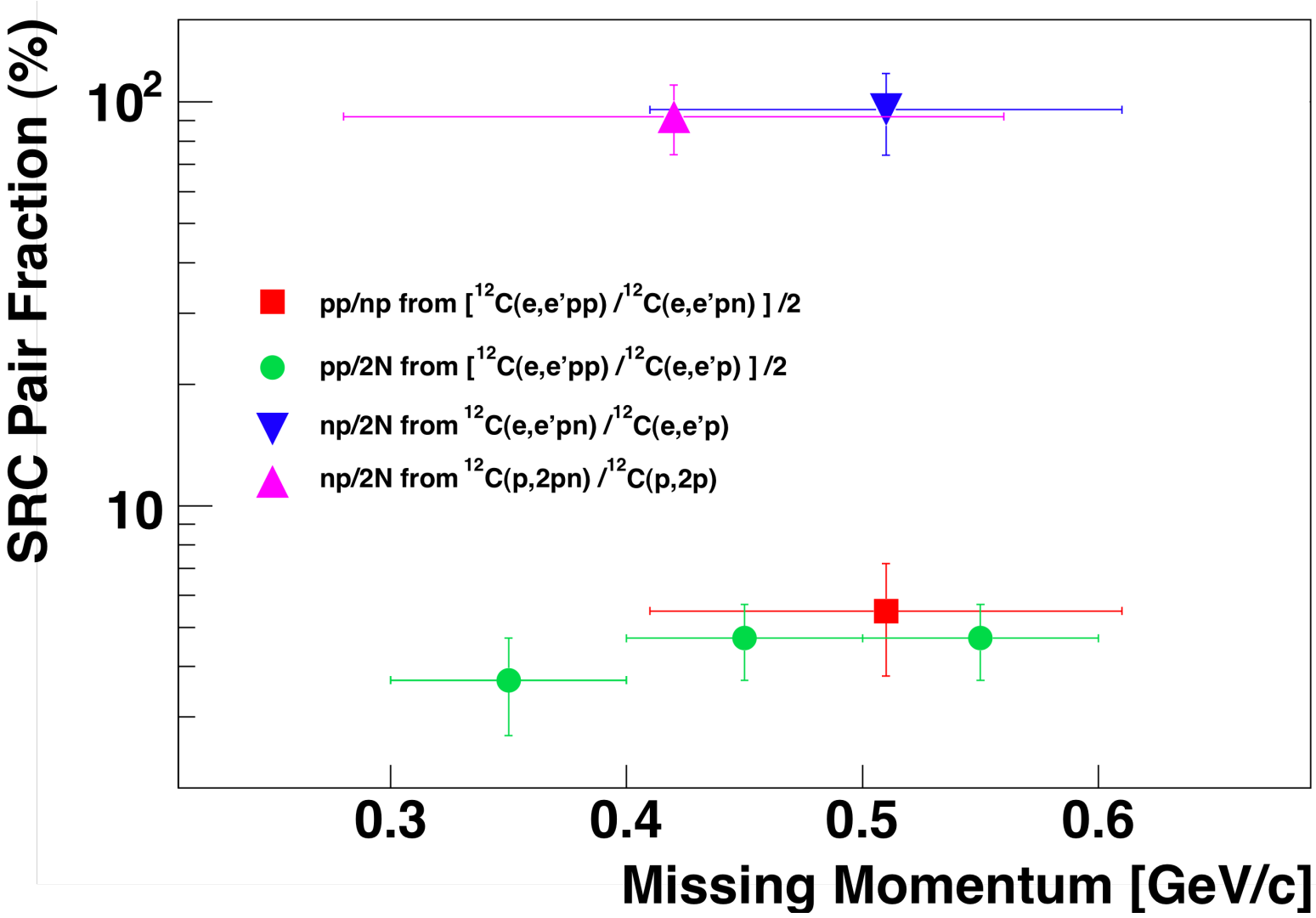


Strong back-to-back correlation!

- $^{12}C(e,e'p)^{11}B$ is the sharp peak at low E_{miss}
- Quasi-Elastic Shaded In Blue
- High E_{miss} Resonance Events

Correlated Pair Factions from ^{12}C

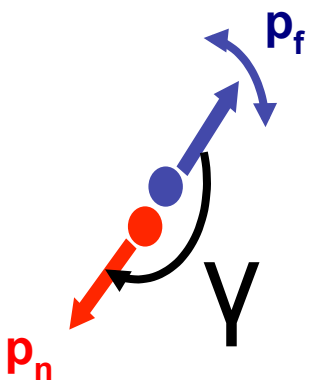
R. Subedi *et al.*, **Science 320** (2008) 1476.



Brookhaven EVA Collaboration Result

A. Tang *et al*., Phys. Rev. Lett. **90** (2003) 042301.

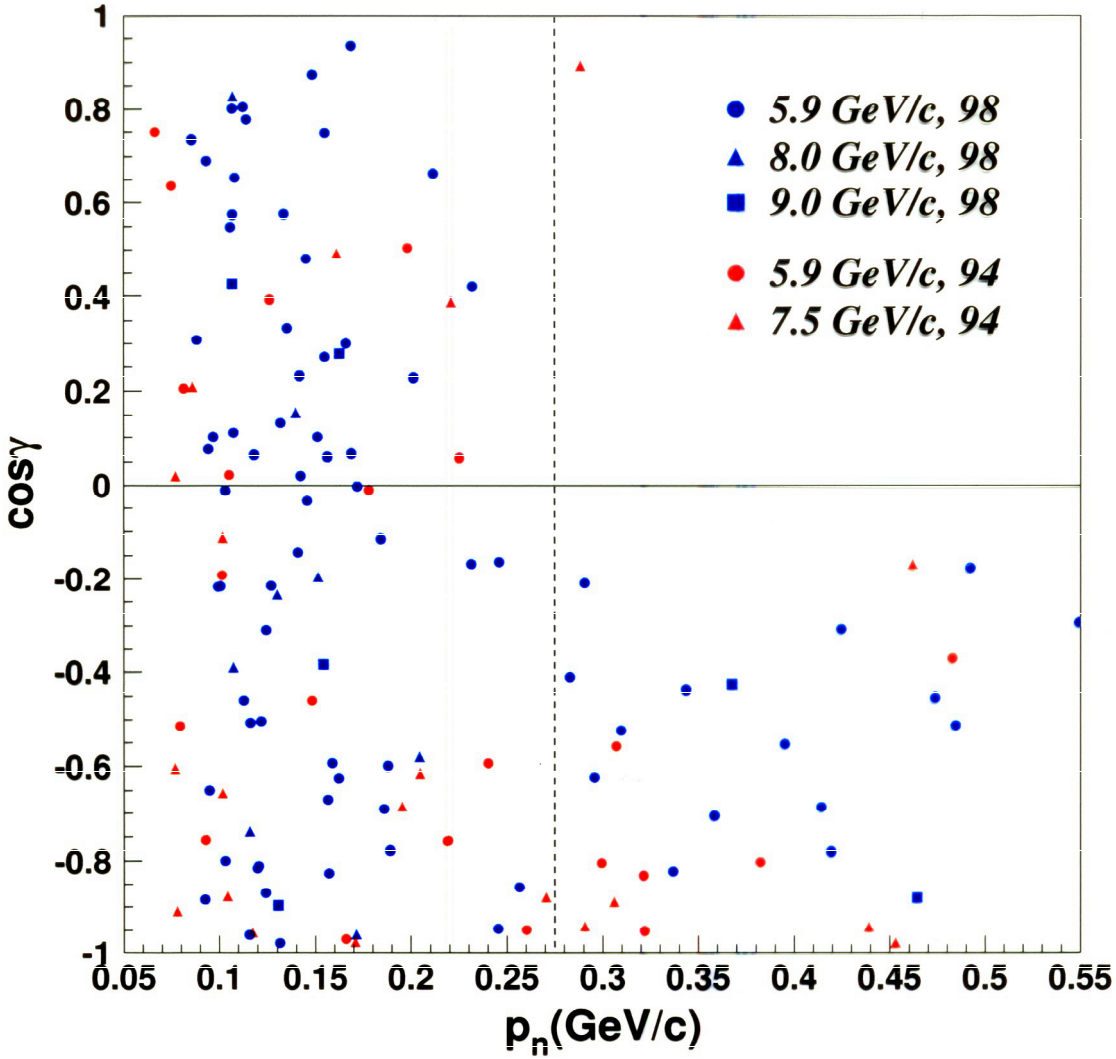
^{12}C(p,2p+n) Reaction



$p_f = p_1 + p_2 - p_0$

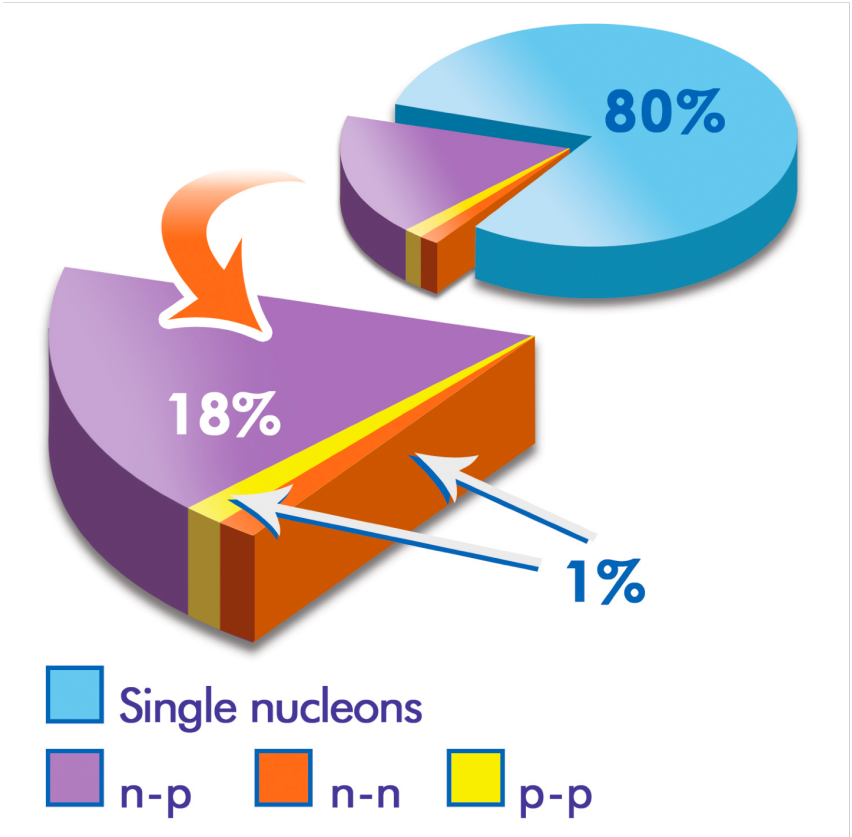
p_0 = incident proton

p1 and p2 are detected

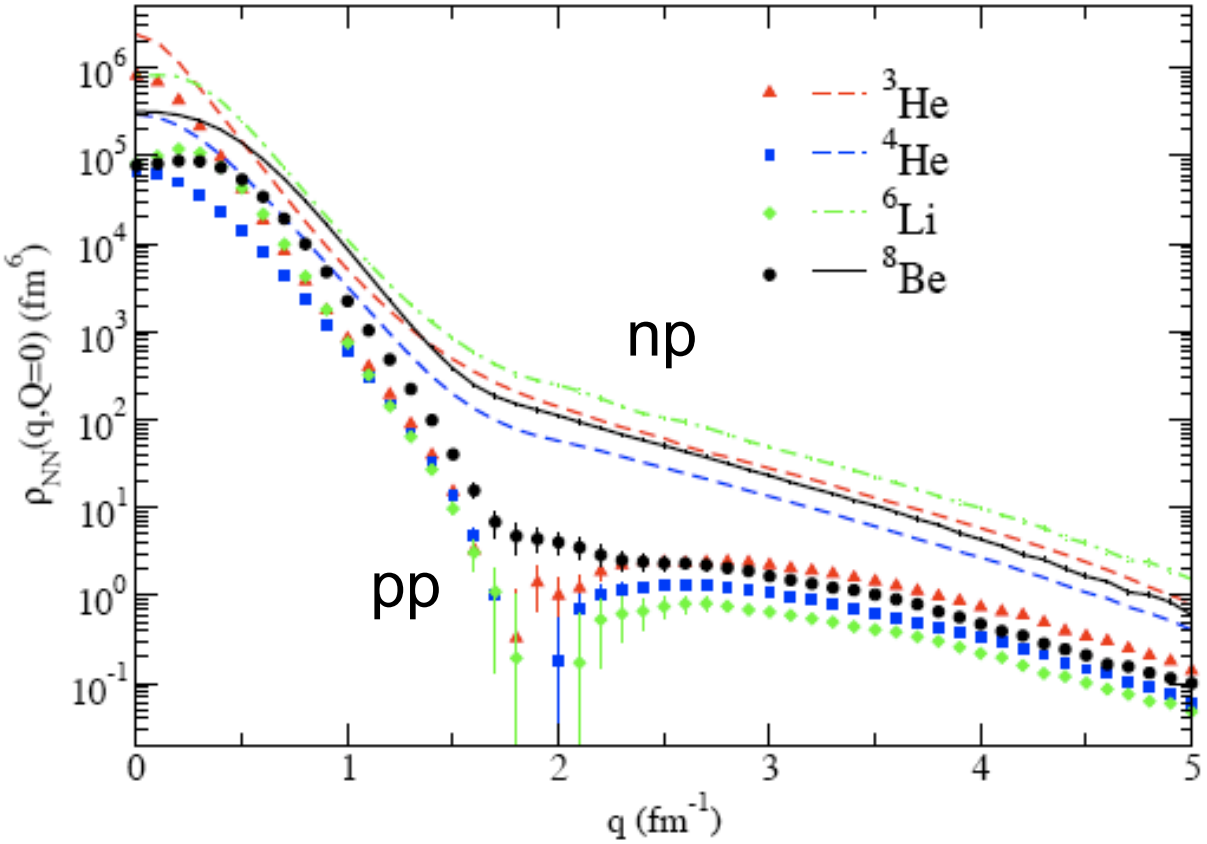


^{12}C From the (e,e'), (e,e'p), and (e,e'pN) Results

- 80 +/- 5% single particles moving in an average potential
  - 60 – 70% independent single particle in a shell model potential
  - 10 – 20% shell model long range correlations
- 20 +/- 5% two-nucleon short-range correlations
  - 18% np pairs
  - 1% pp pairs
  - 1% nn pairs (from isospin symmetry)
- Less than 1% multi-nucleon correlations



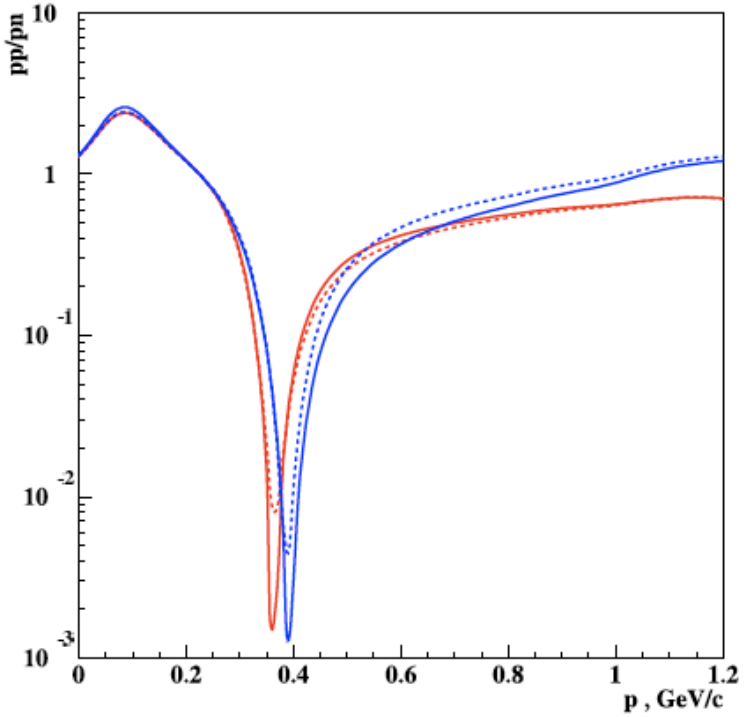
Importance of Tensor Correlations

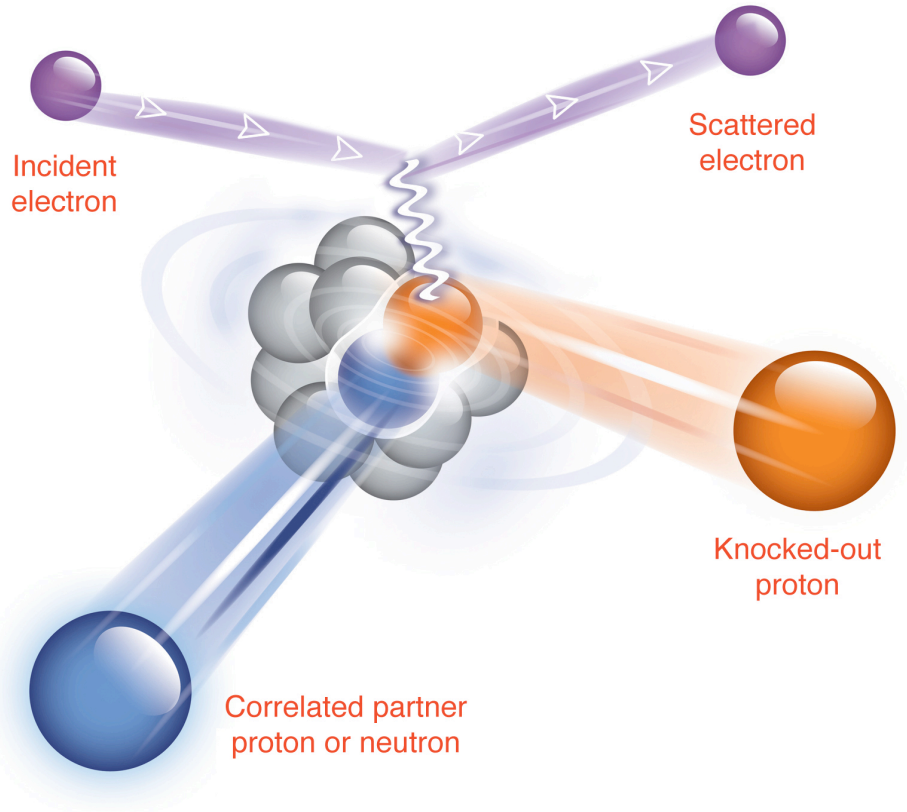


- R. Schiavilla et al., Phys. Rev. Lett. 98 (2007) 132501. [shown above]
- M. Sargsian et al., Phys. Rev. C (2005) 044615.
- M. Alvioli, C. Ciofi degli Atti, and H. Morita, Phys. Rev. Lett. 100 (2008) 162503.

E07-006: ^{4}He(e,e'pN)pn in 2011

- ^{4}He Target
  - Dense Nuclear Matter
  - *MF & Exact* Calculations
- P_m from 400 – 800 MeV
- 25 PAC Days

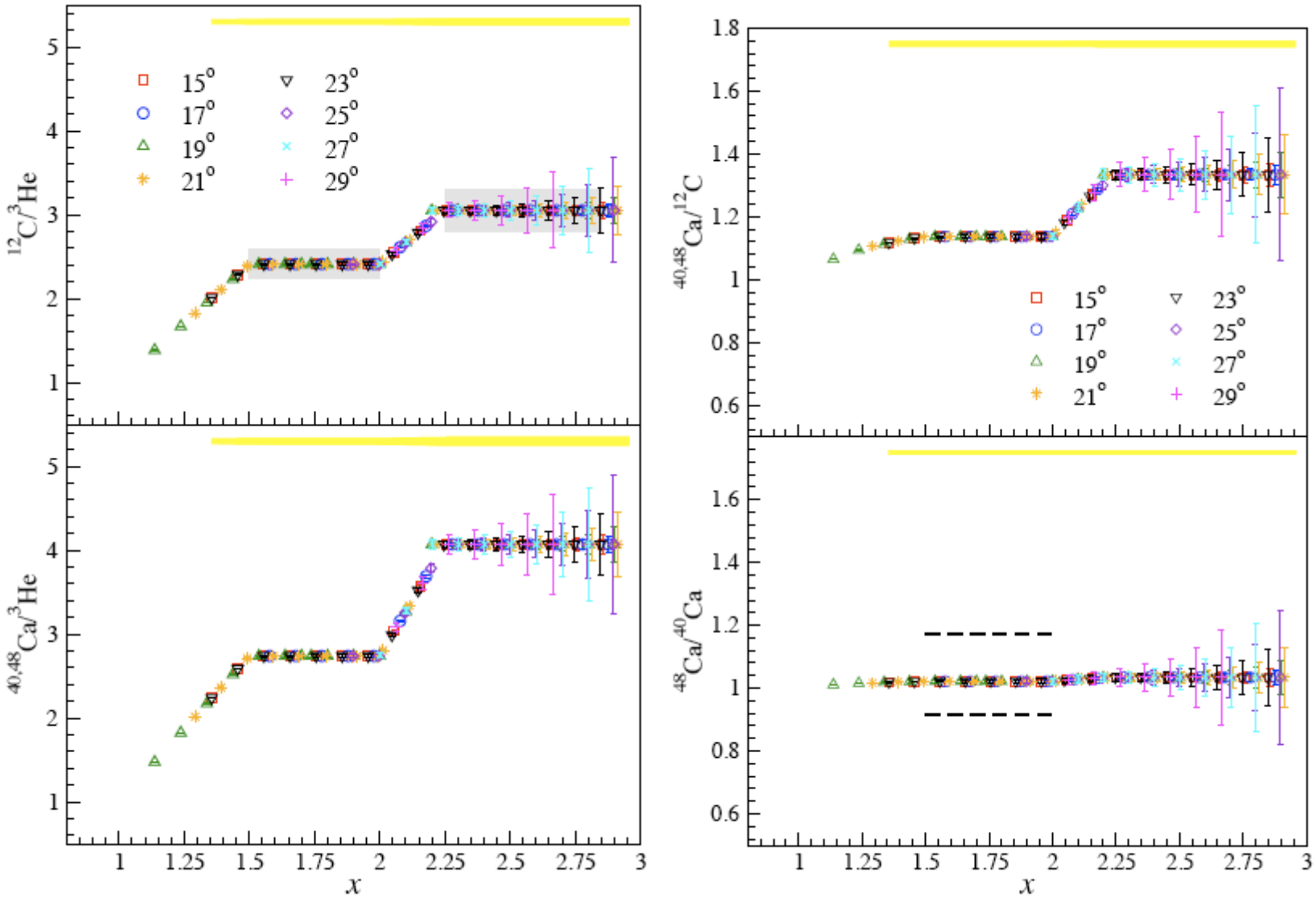




- Pushing Limits of NN Potential
  - Long range attraction
  - Short range repulsion

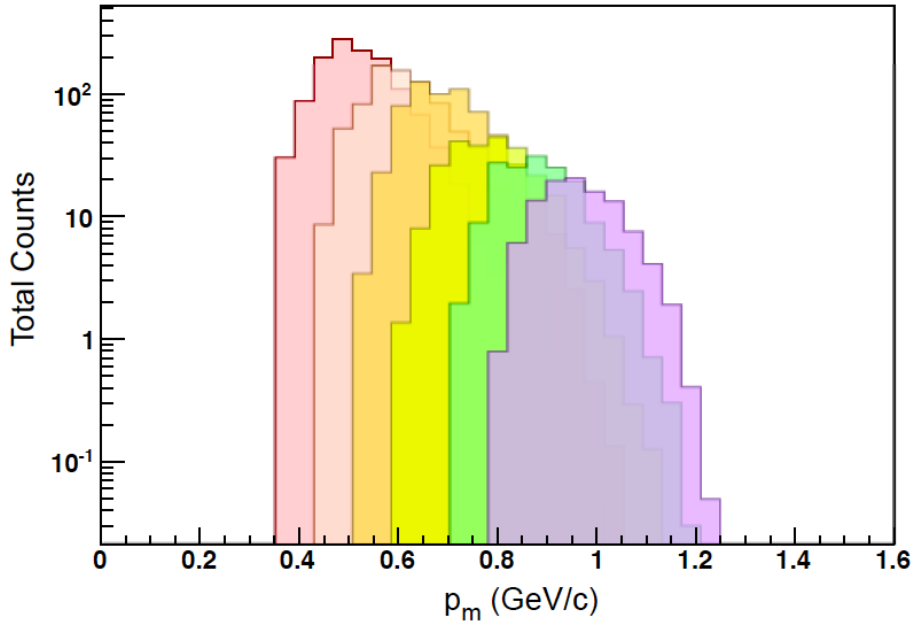
E08-014: A(e,e') x>2 High Stat. in 2011

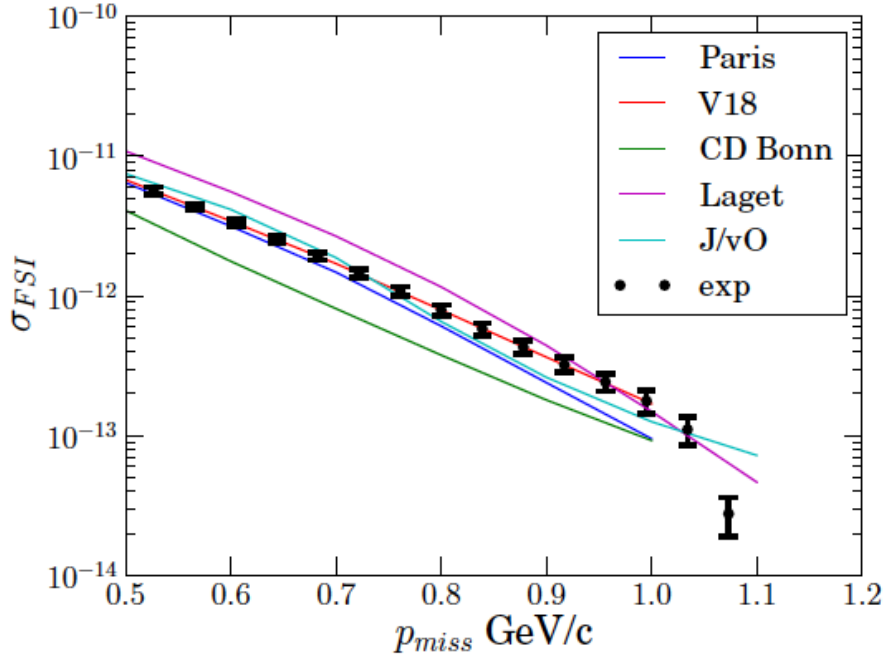
D, ^{3}He, ^{4}He, C, ^{40}Ca, ^{48}Ca Targets (^{9}Be ?!)



PR12-10-003: D(e,e'p)n at x>1 & Q^2=4 GeV/c

21 PAC Days, 11 GeV beam and Hall C with 6 settings of the spectrometers





^{3}He(e,e'p)d deviated from conventional theory at around 800 MeV/c

Summary and Outlook

- Shell Model (the mean behavior of nucleons in nucleus)
- Short-Range Nucleon-Nucleon Correlation Experiments
  - Goal to probe the repulsive part of the nucleon-nucleon potential
  - Long History of Reaction Mechanisms Dominating Cross Section
- With high luminosity, x_B>1 and Q^2>1 [GeV/c]2 we seem to finally be cleanly probing short distance behavior.
- Many other new results compliment want has been shown.
- With JLab 12 GeV, with high Q^2 $[GeV/c]^2$ in x>1 kinematics, experiments will push the limits of modern NN potentials and understand if these correlations are Hadronic, Partonic or Both (i.e. Duality).