Short Range Correlations: Present and Future

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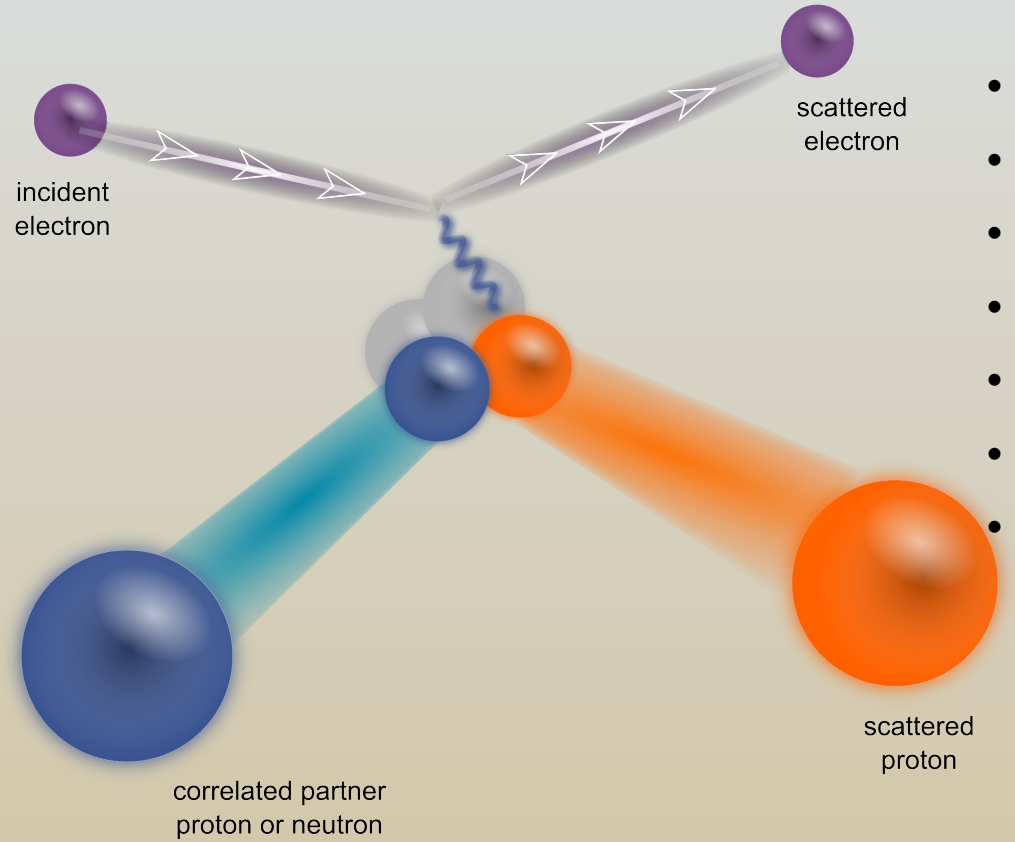
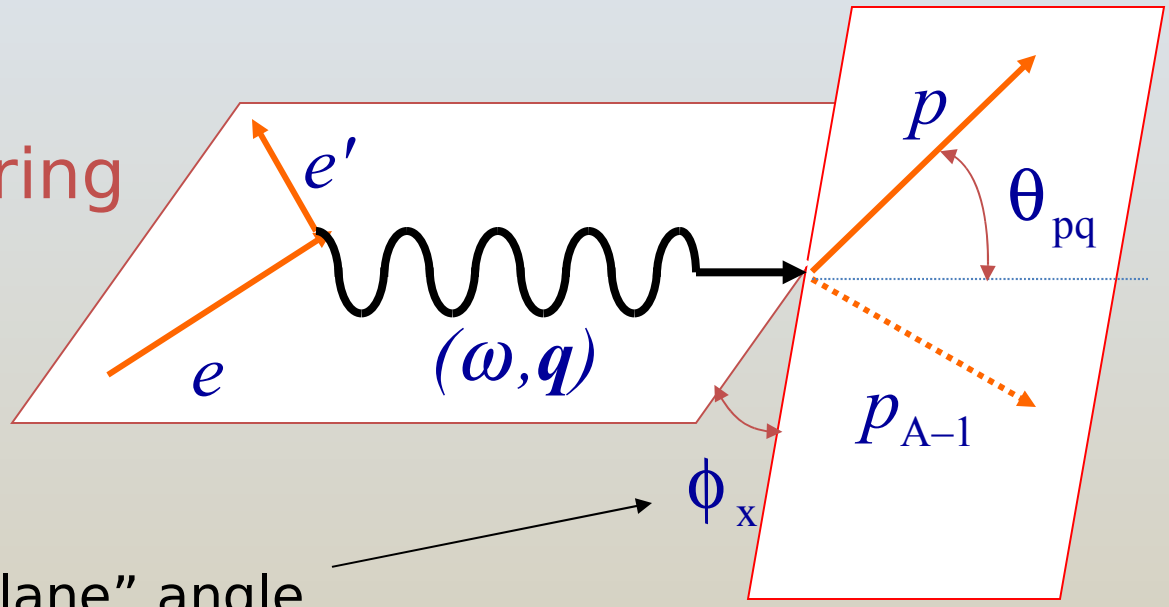


- Introduction
- Short Range Correlations
- Results from A(e,e') & A(e,e'p)
- Triple-coincidence experiments
- Future 6 GeV Experiments
- Future 12 GeV Experiments
- Summary

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



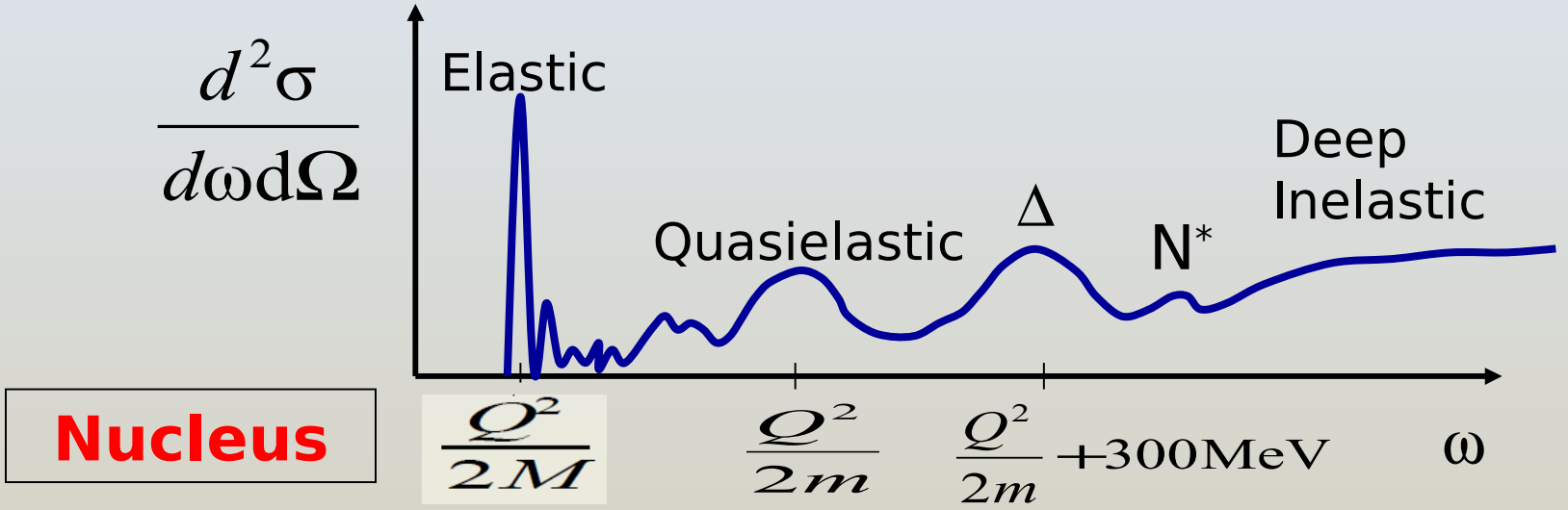
Four-momentum transfer: $Q^2 \equiv -q_\mu q^\mu = \boldsymbol{q}^2 - \omega^2$

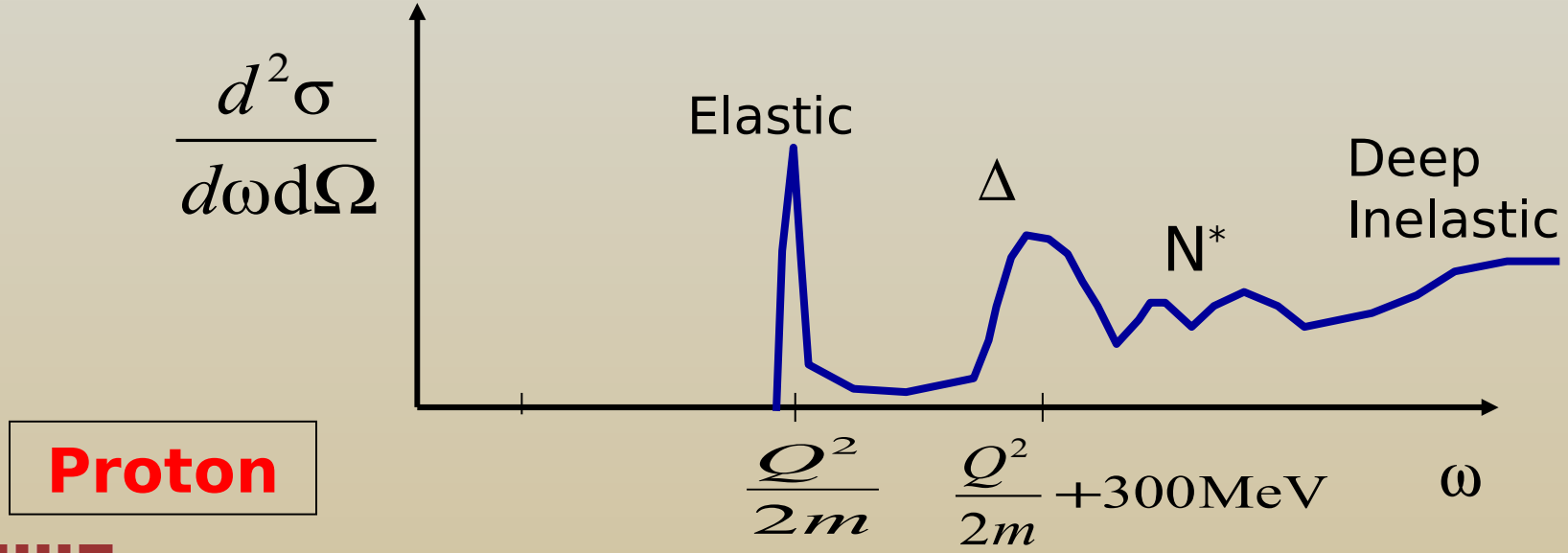
Missing momentum: $\boldsymbol{p}_m = \boldsymbol{q} - \boldsymbol{p} = \boldsymbol{p}_{A-1}$

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

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

Electron Scattering at Fixed Q^2

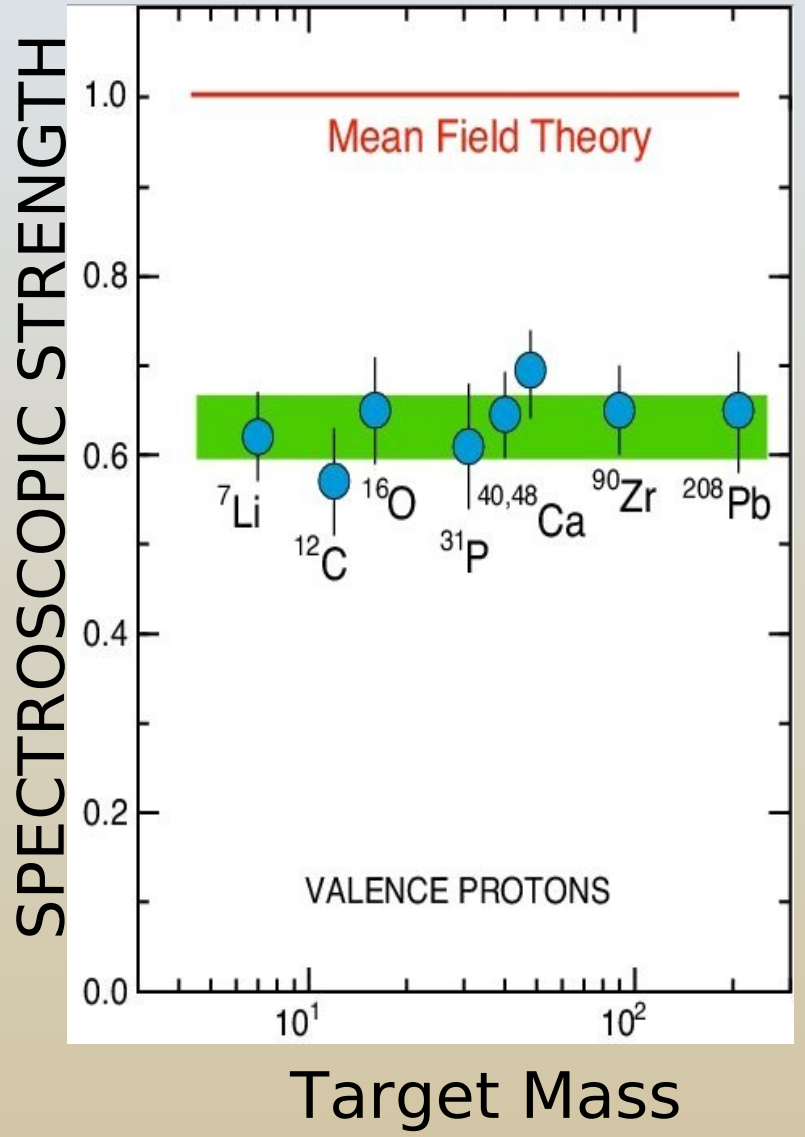




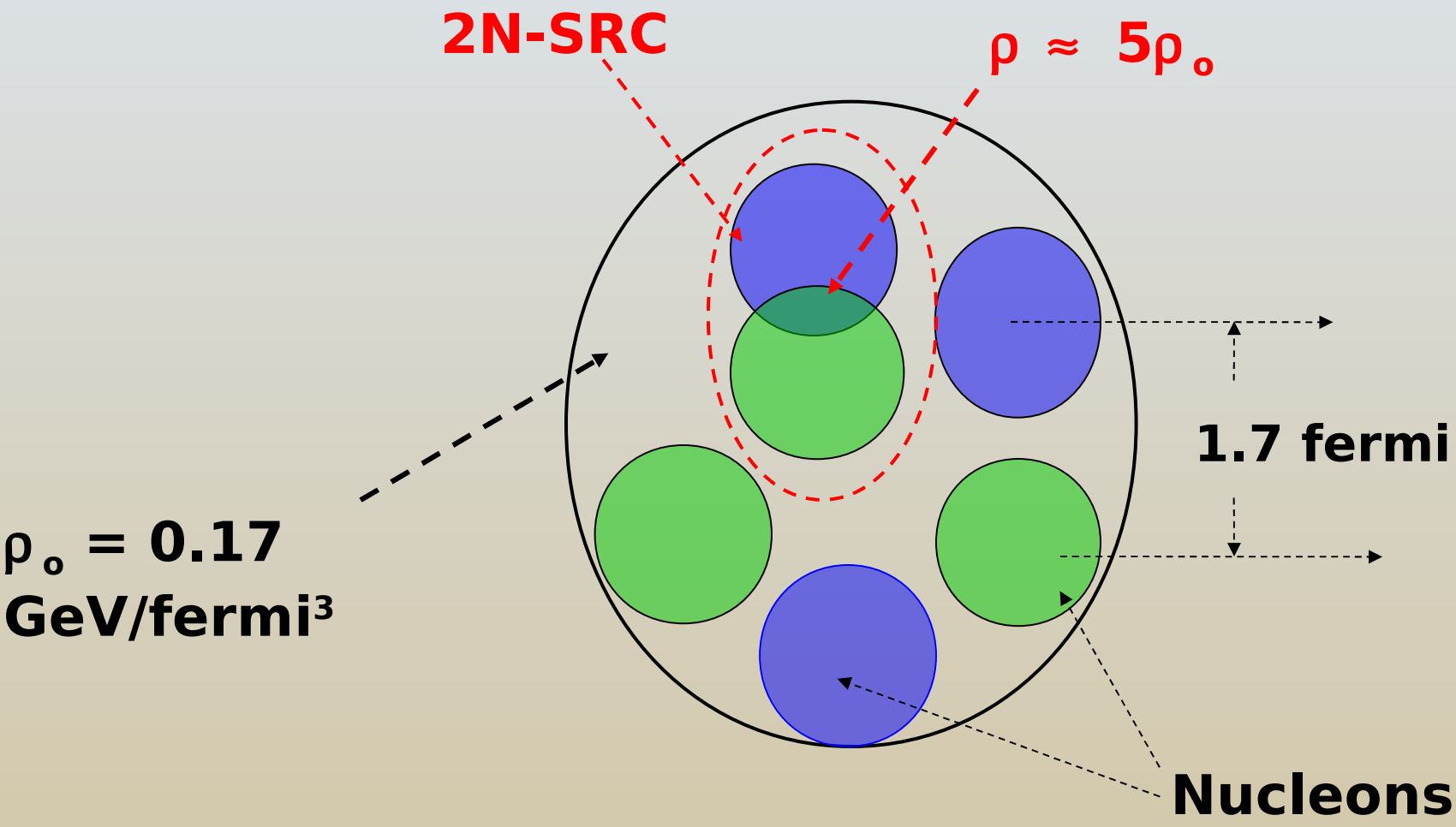
Results from (e,e'p) Measurements

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.



Short-Range Correlations

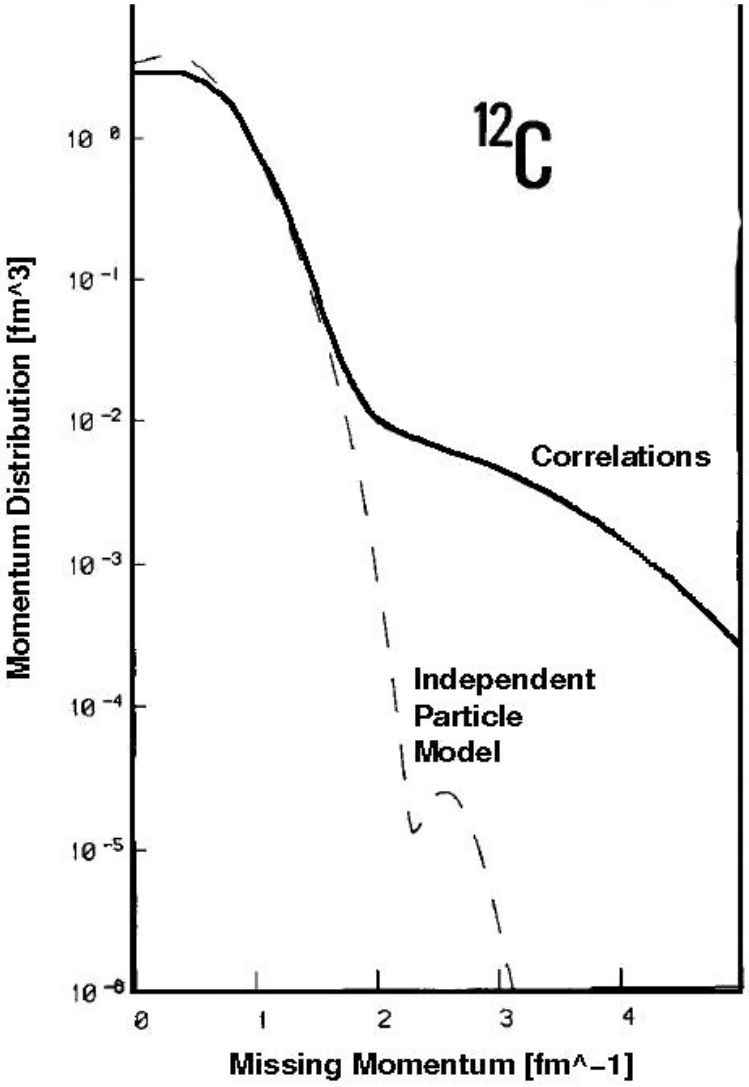


Questions

- 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)?

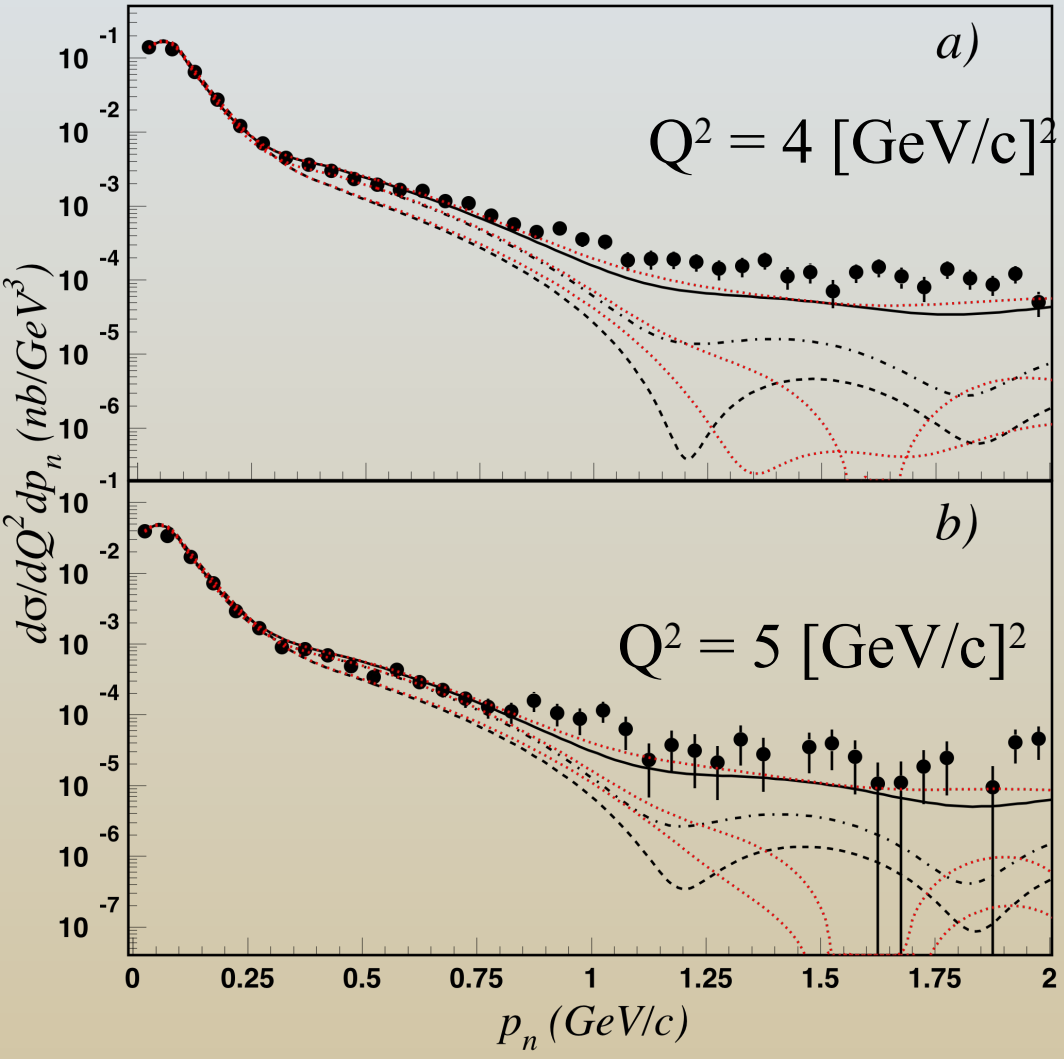
BUT Other Effects Such As A Final State Rescattering Can Mask The Signal…

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



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

CLAS A(e,e') Data

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

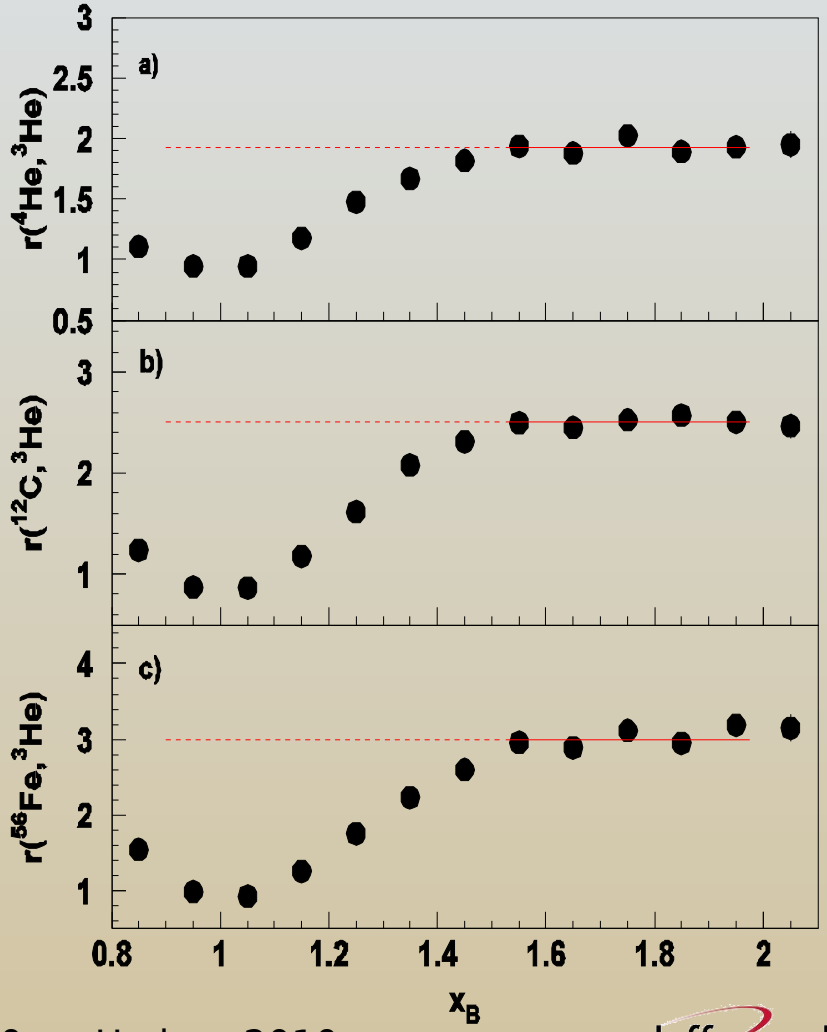
Originally done with SLAC data by D.B. Day *et al.*, Phys. Rev. Lett. 59 (1987) 427.

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

then

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

The observed *scaling* means that the electrons probe the high-momentum nucleons in the 2N-SRC phase, and the scaling factors determine the per-nucleon probability of the 2N-SRC phase in nuclei with A>3 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 r(^{3}He,D) results to find:
- ^{12}C 20% two nucleon SRC
- ^{12}C <1% three nucleon SRC

$a_2(^3He)=1.7\pm0.3$

$a_2(^4He)=3.3\pm0.5$

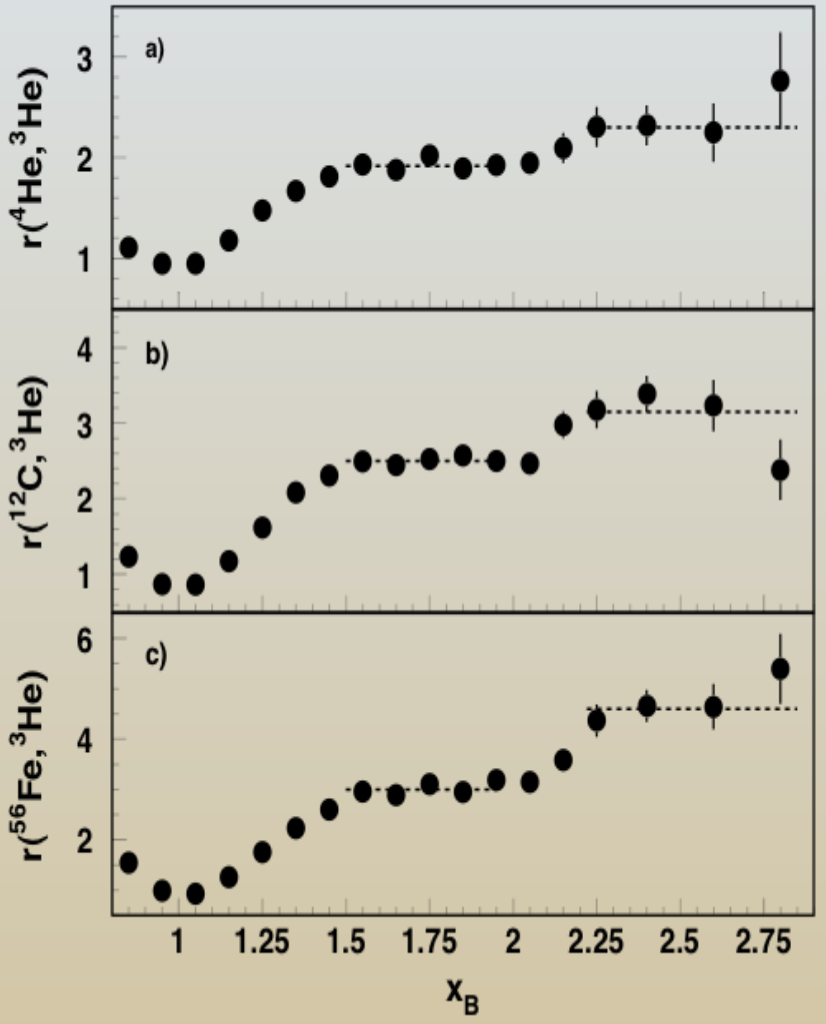
$a_2(^{12}C)=5.0\pm0.5$

$a_2(^{27}Al)=5.3\pm0.6$

$a_2(^{56}Fe)=5.2\pm0.9$

$a_2(^{197}Au)=4.8\pm0.7$

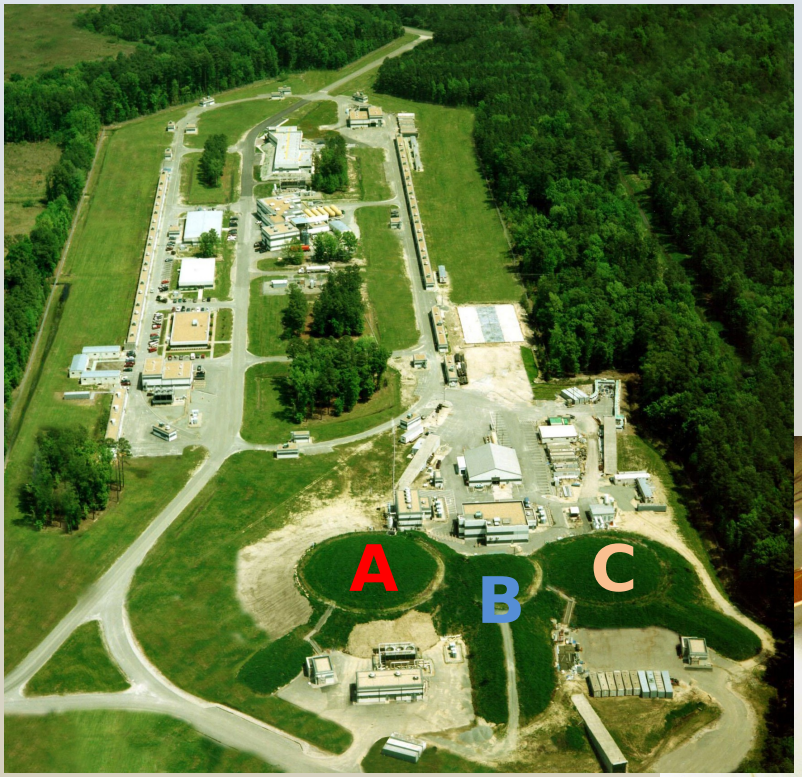
a_2=ratio in plateau represents probability of 2N SRC

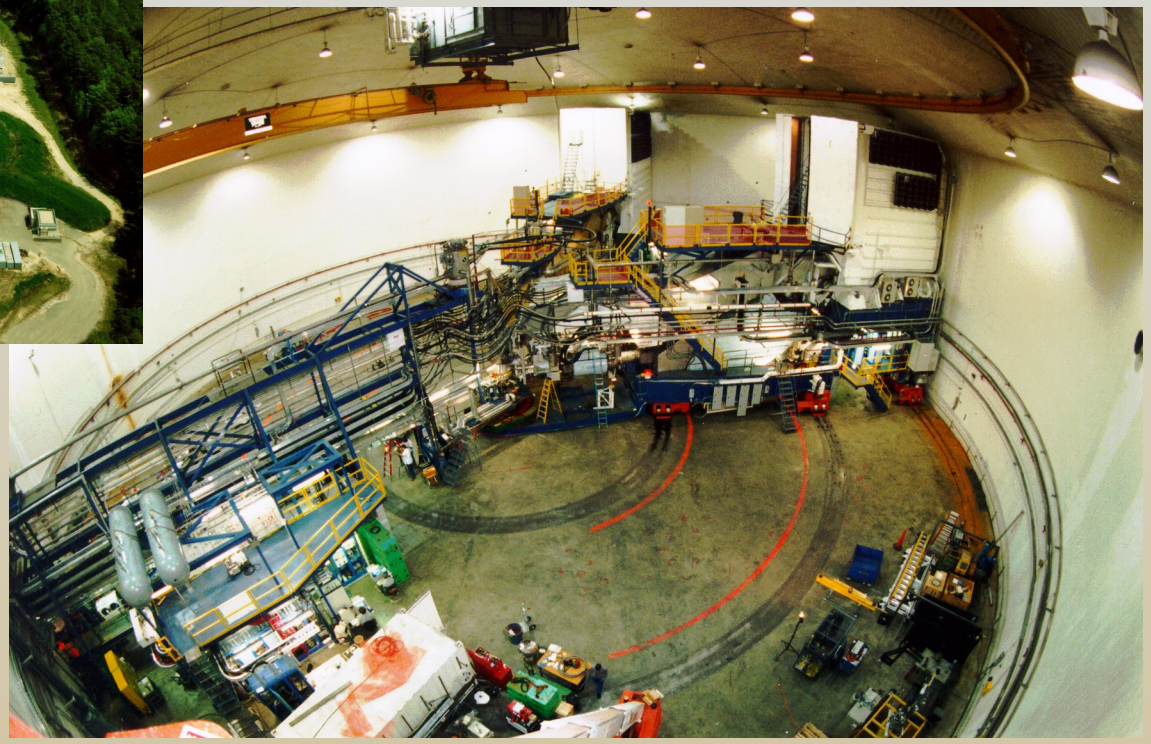


^{12}C From the (e,e') and (e,e'p) Results

- 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 for Q^2 = 1-4 GeV^2 within a few percent
    - Plateaus start when minimum missing momentum > Fermi momentum
- Less than 1% multi-nucleon correlations

Jefferson Lab's Hall A



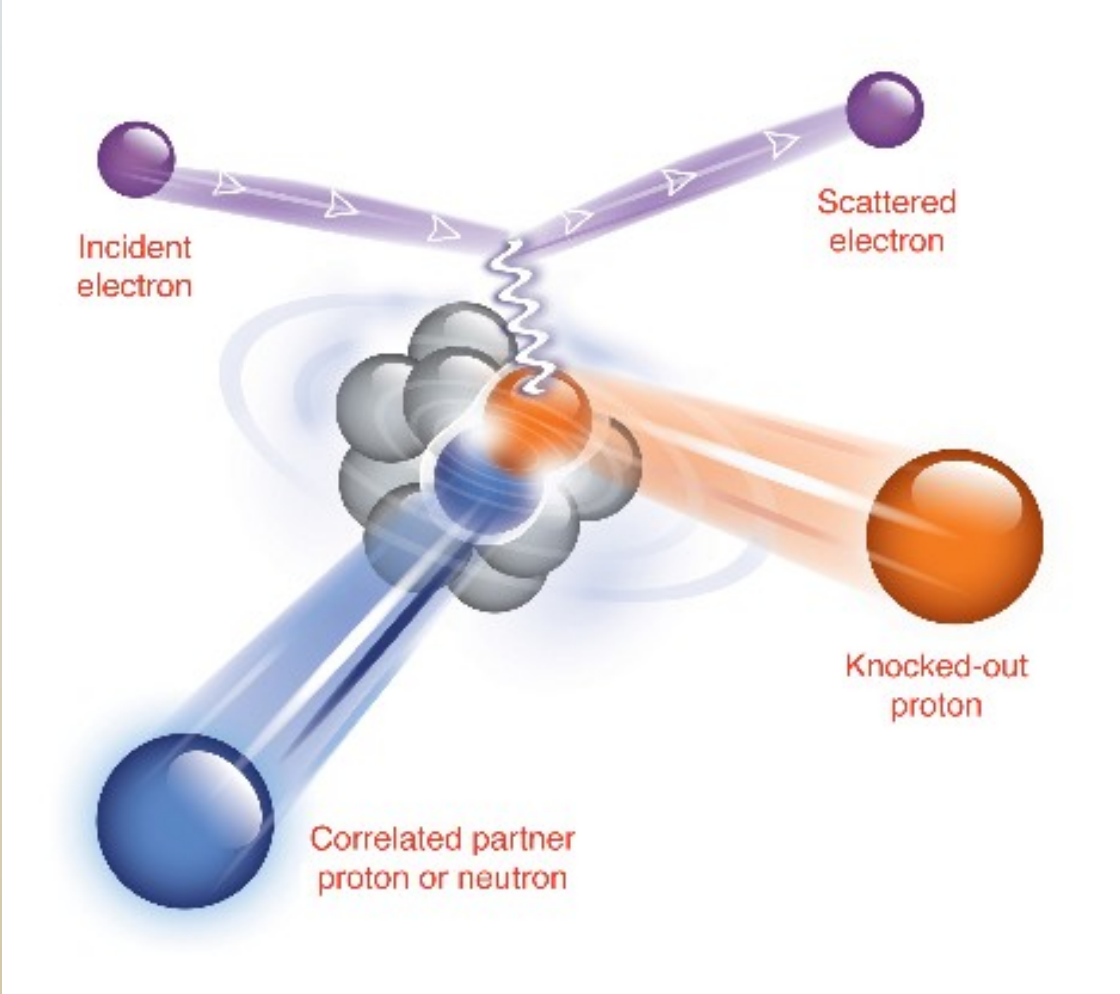


Customized (e,e'pN) Measurement

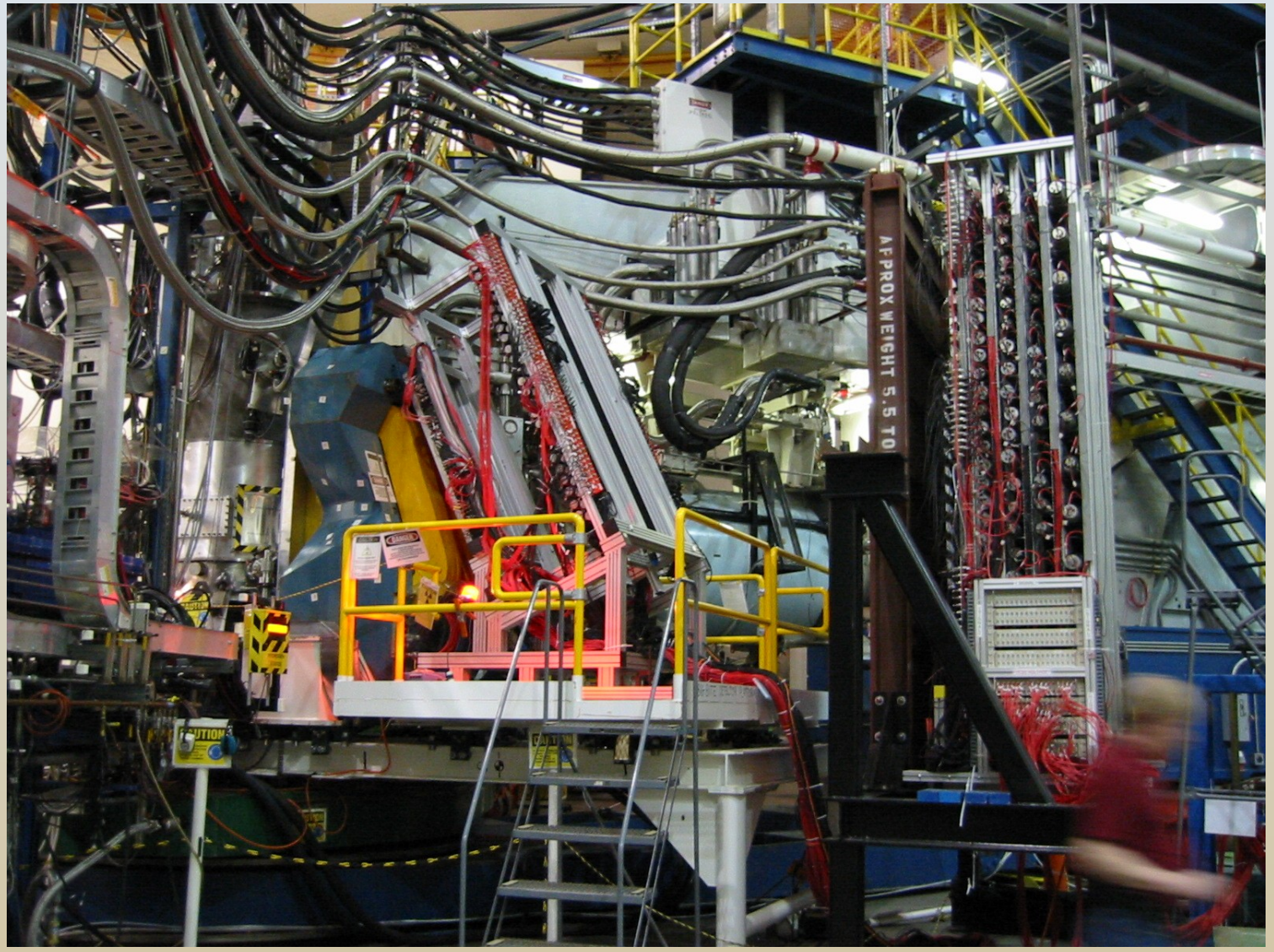
To study nucleon pairs at close proximity and their contributions to the large momentum tail of nucleons in nuclei.

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

- high Q^2 to minimize MEC
- x>1 to suppress isobar contributions
- anti-parallel kinematics to suppress FSI

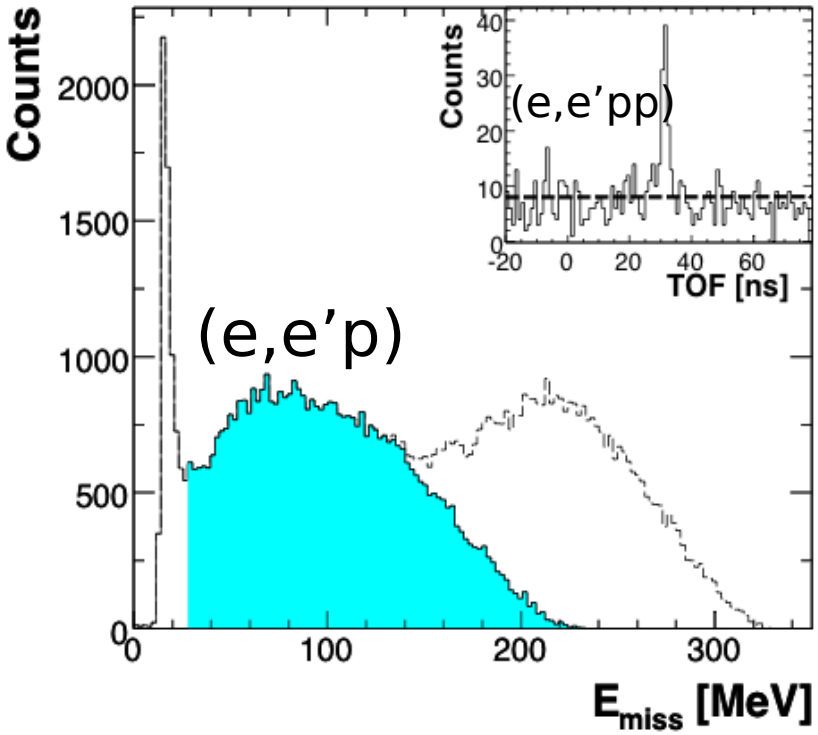


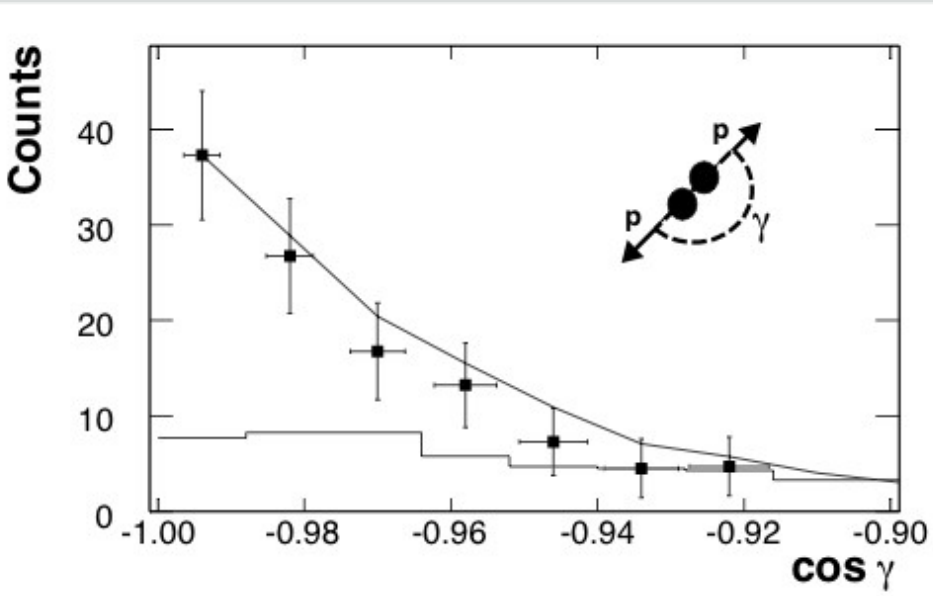
BigBite and Neutron Detector



^{12}C(e,e'p) & ^{12}C(e,e'pp) Data

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





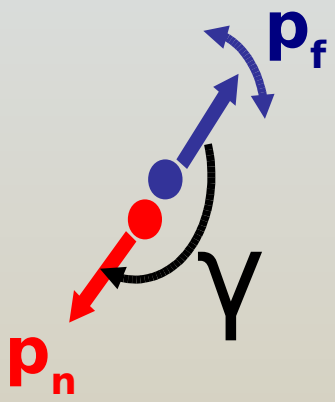
Strong back-to-back correlation!

- ^{12}C(e,e'p)
- Quasi-Elastic Shaded In Blue
- Resonance Even at x_B>1

Brookhaven EVA Collaboration Result

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

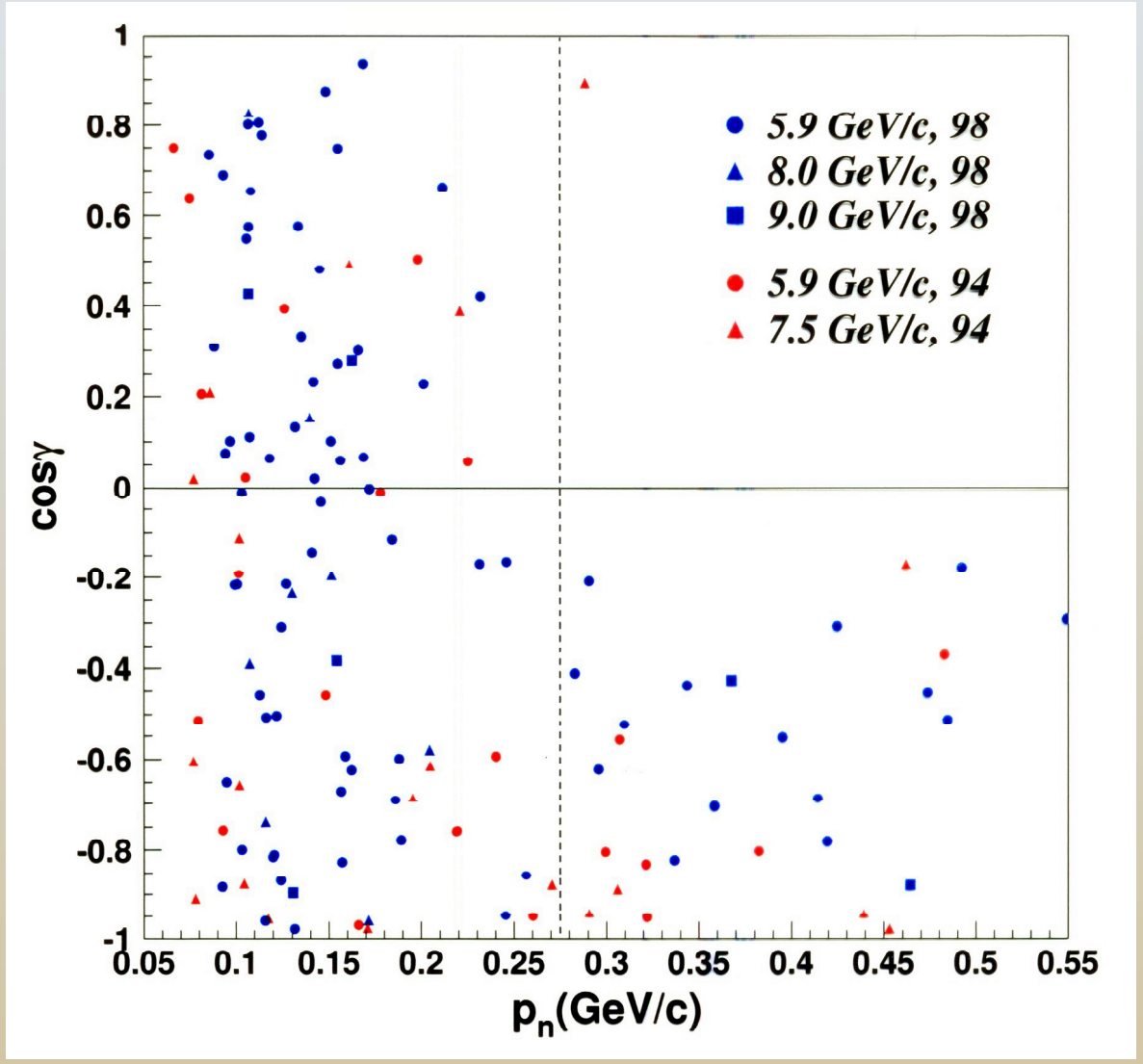
^{12}C(p,2p+n) Reaction



$p_f = p_1 + p_2 - p_0$

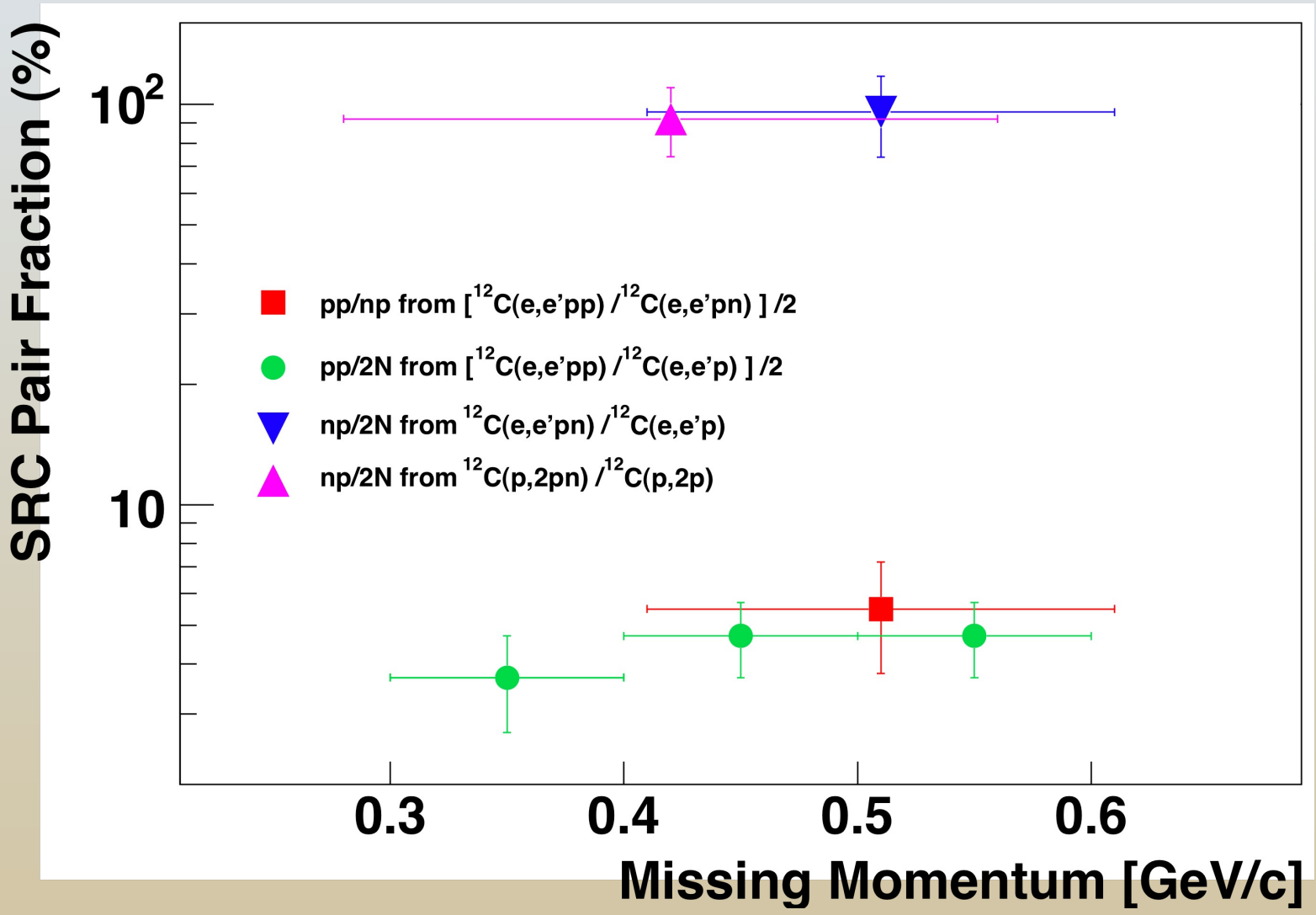
p_0 = incident proton

p1 and p2 are detected



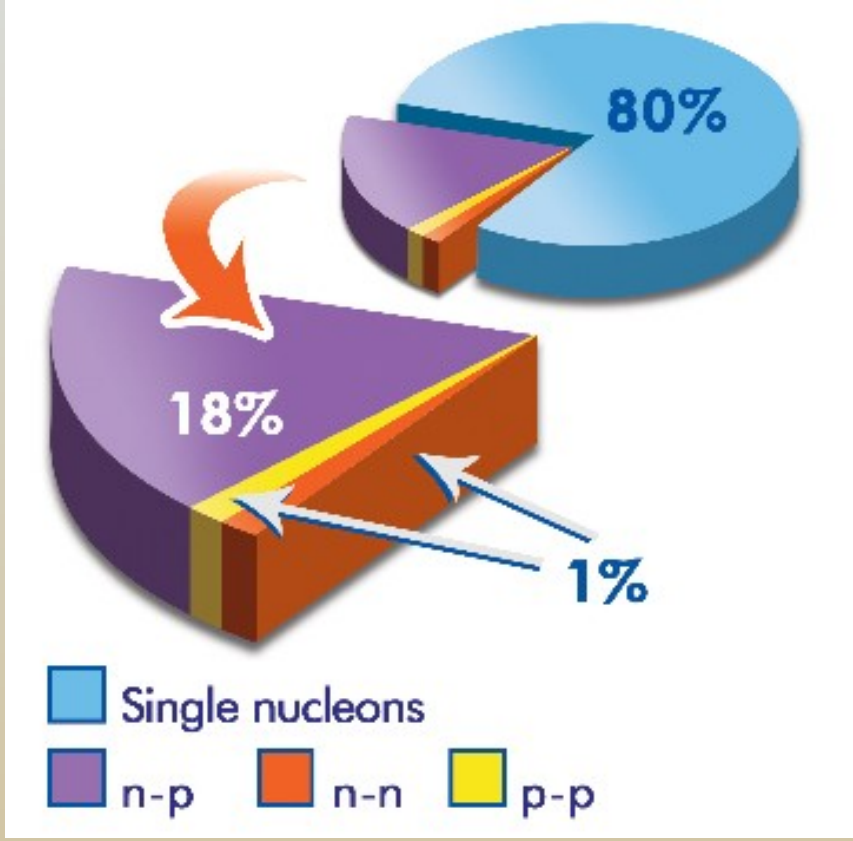
Correlated Pair Factions from ^{12}C

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

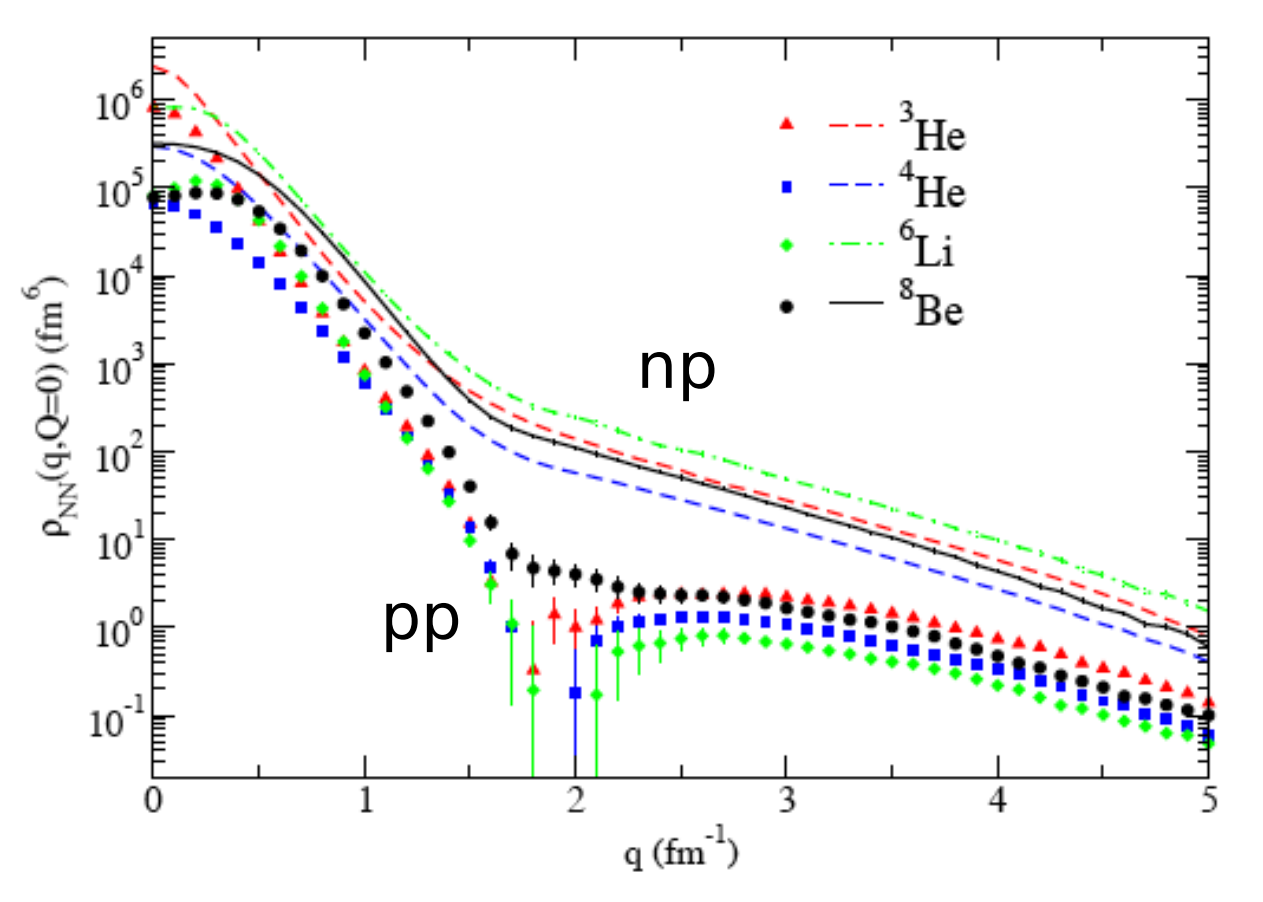


From the (e,e'), (e,e'p), and (e,e'pN) Results

- 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

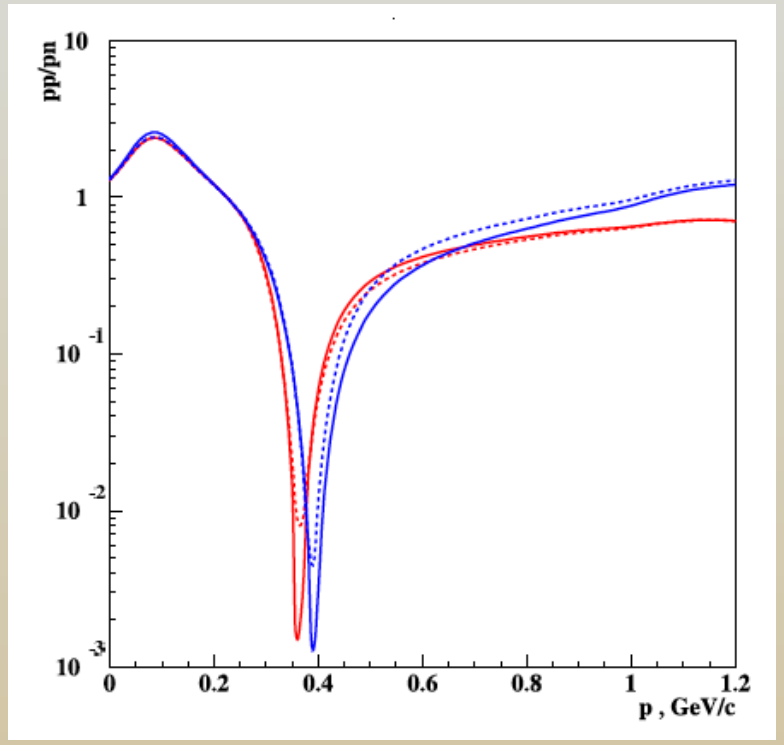


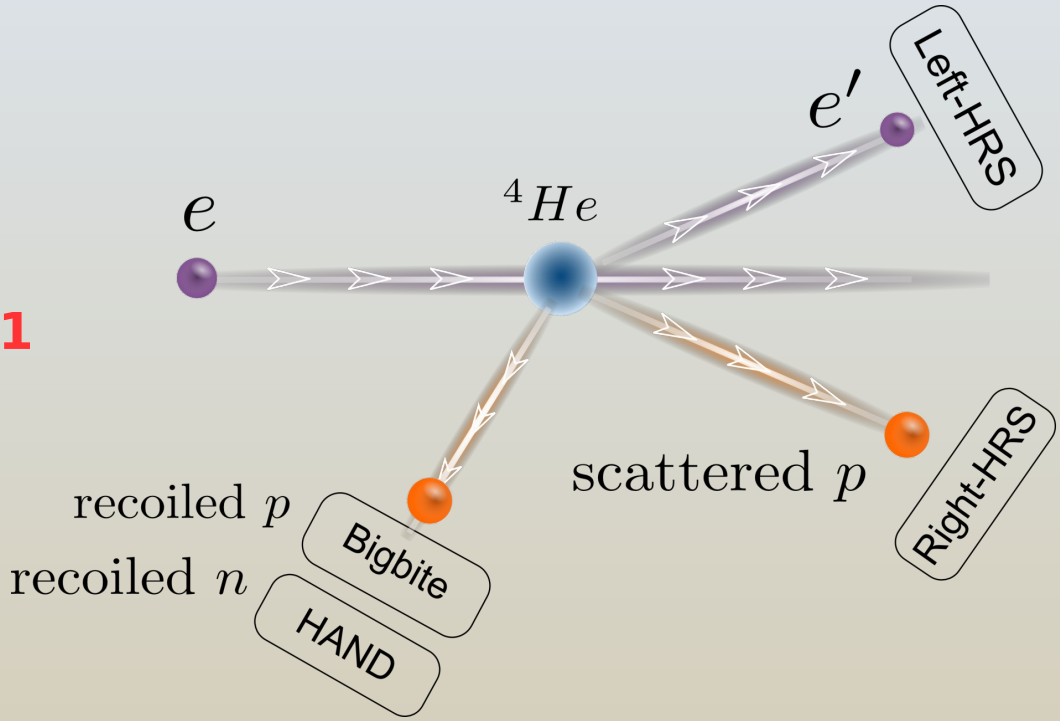
- R. Schiavilla et al., Phys. Rev. Lett. 98 (2007) 132501. [shown above]
- M. Sargsian et al., Phys. Rev. C (2005) 044615.
- M. Alvioli, C. Ciofi degli Atti, and H. Morita, Phys. Rev. Lett. 100 (2008) 162503.


Future 6 GeV Experiments

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

- ^{4}He Target
  - Dense Nuclear Matter
  - *MF & Exact* Calculations
- P_m from 400 – 800 MeV
- 25 PAC Days
- **Scheduled for March 2011**



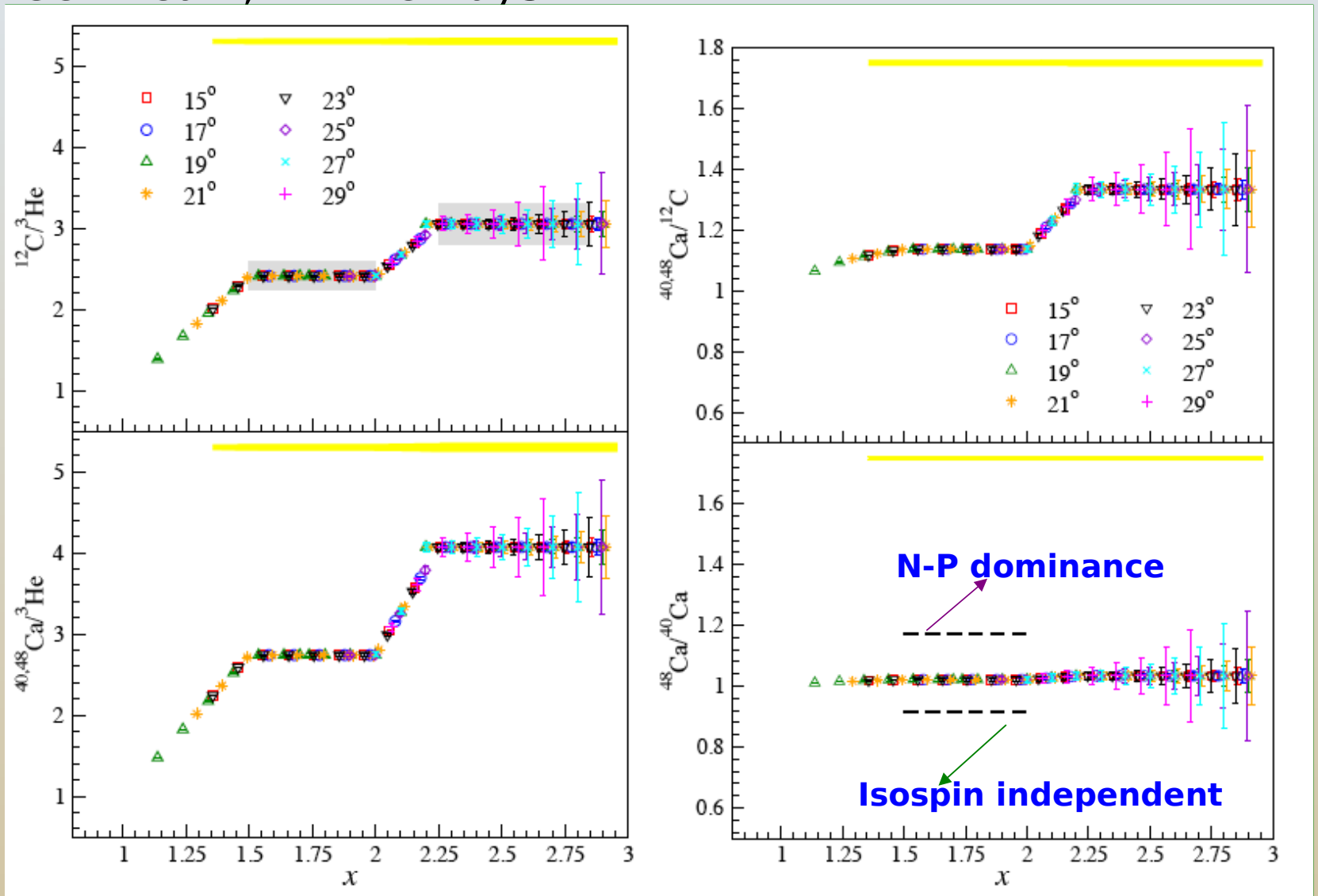


- Pushing Limits of NN Potential
  - Long range attraction
  - Short range repulsion

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

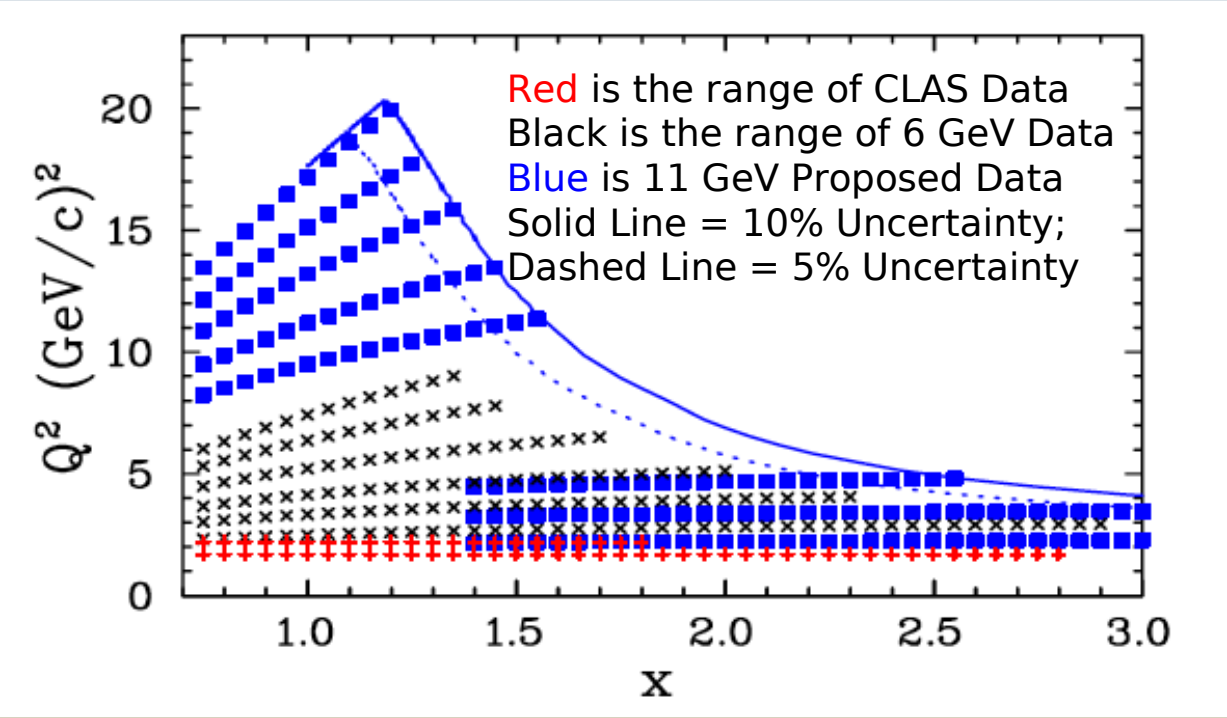
3.6 GeV Beam; 12 PAC DayS

Scheduled for April 2011




Future 12 GeV Experiments

E12-06-105: A(e,e') x>1 in QE and DIS regimes



11 GeV Beam

θ (deg)	E' settings (GeV)	x	Q^2 GeV^2
8.0	10.6	0.7-4.0	2.1-2.3
10.0	10.4	0.7-3.0	3.0-3.5
12.0	9.8	0.7-2.6	4.0-5.0
22.0	5.7,7.0	0.7-1.55	8.1-12
26.0	4.8,6.0	0.7-1.45	9.5-14
32.0	3.3,3.9,4.6	0.7-1.35	11-17
40.0	2.4,2.8,3.3	0.7-1.25	12-18
55.0	1.5,1.7,2.0	0.7-1.20	13-20

- Targets: D, ^{3}He, ^{4}He, Be, C, Cu and Au
- High Momentum Spectrometer (HMS): large Q^2 at large angles
- SHMS: intermediate Q^2 and angles

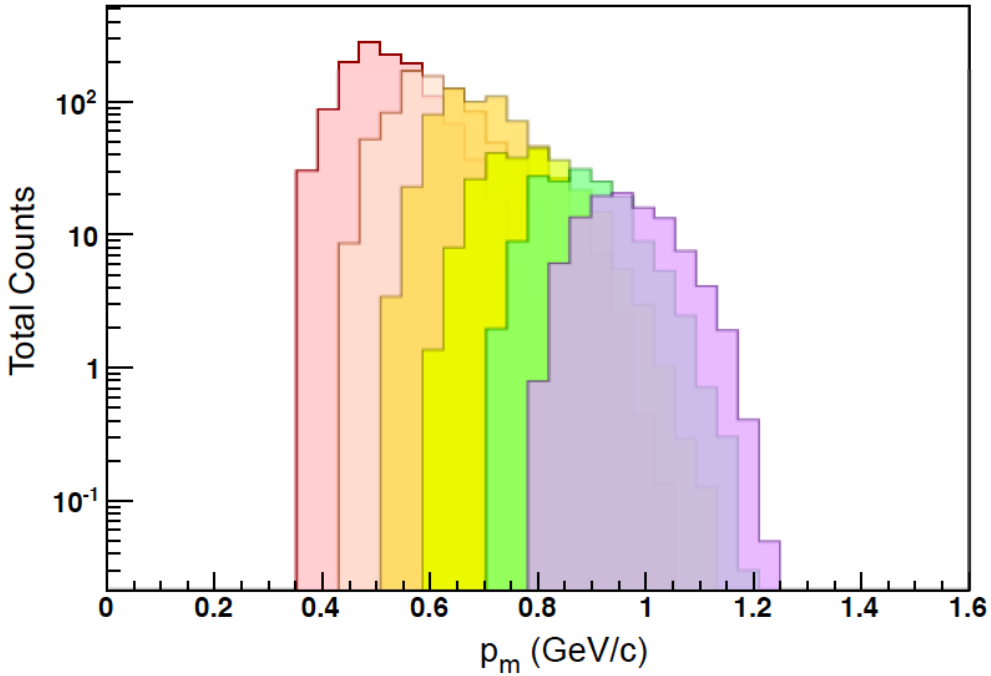
Goals:

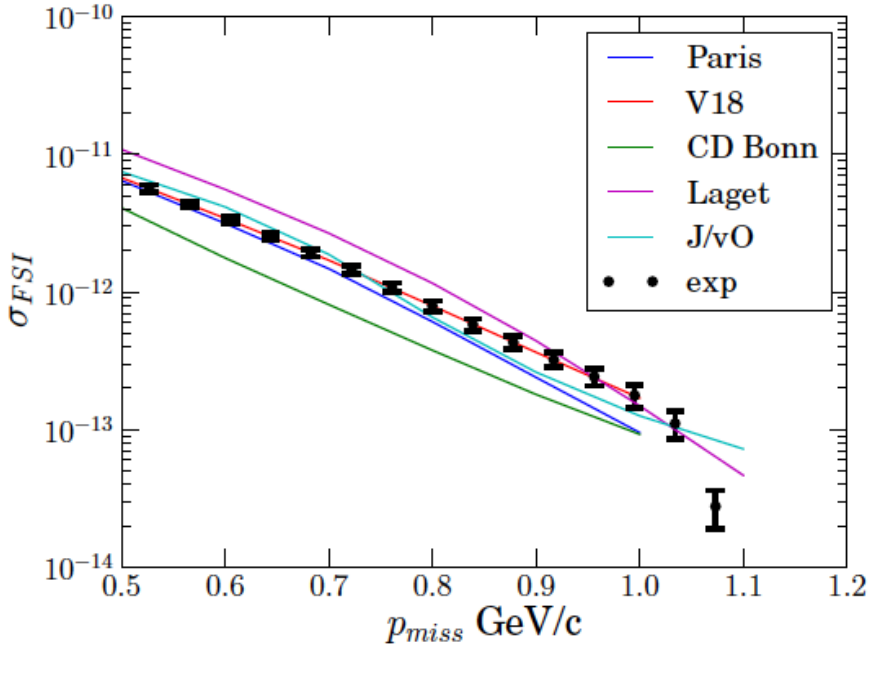
- Study A dependence in detail of strength of 2N and 3N SRCs
- Study size and importance of alpha-clusters in nuclei (4N SRCs).
- Extraction of structure functions and unseparated quark distributions at x >1
- Extended measurements of duality and scaling in nuclei

E12-10-003: D(e,e'p)n at x>1, Q^2=4.2 GeV/c

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

- Investigation of large relative momenta in the pn system
- Probe reaction dynamics, final state interactions and deuteron wave function
- Useful for interpretation of experiments that probe SRC in heavier nuclei





^{3}He(e,e'p)d deviated from conventional theory at around 0.8 GeV/c

PR12-09-010: Isospin Study of SRC with ^{3}He and ^{3}H

^{3}He/^{3}H is simple/straightforward case:

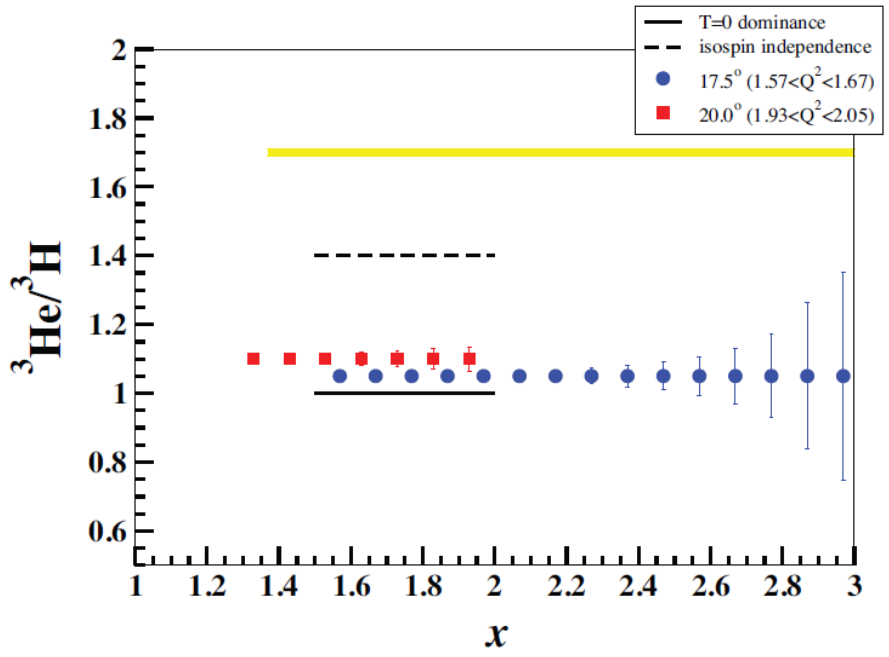
Simple mean field estimates for 2N-SRC

Isospin independent:

$$\frac{\sigma_{^3He}/3}{\sigma_{^3H}/3} = \frac{(2\sigma_p + 1\sigma_n)/3}{(1\sigma_p + 2\sigma_n)/3} \xrightarrow{\sigma_p \approx 3\sigma_n} 1.40$$

n-p (T=0) dominance:

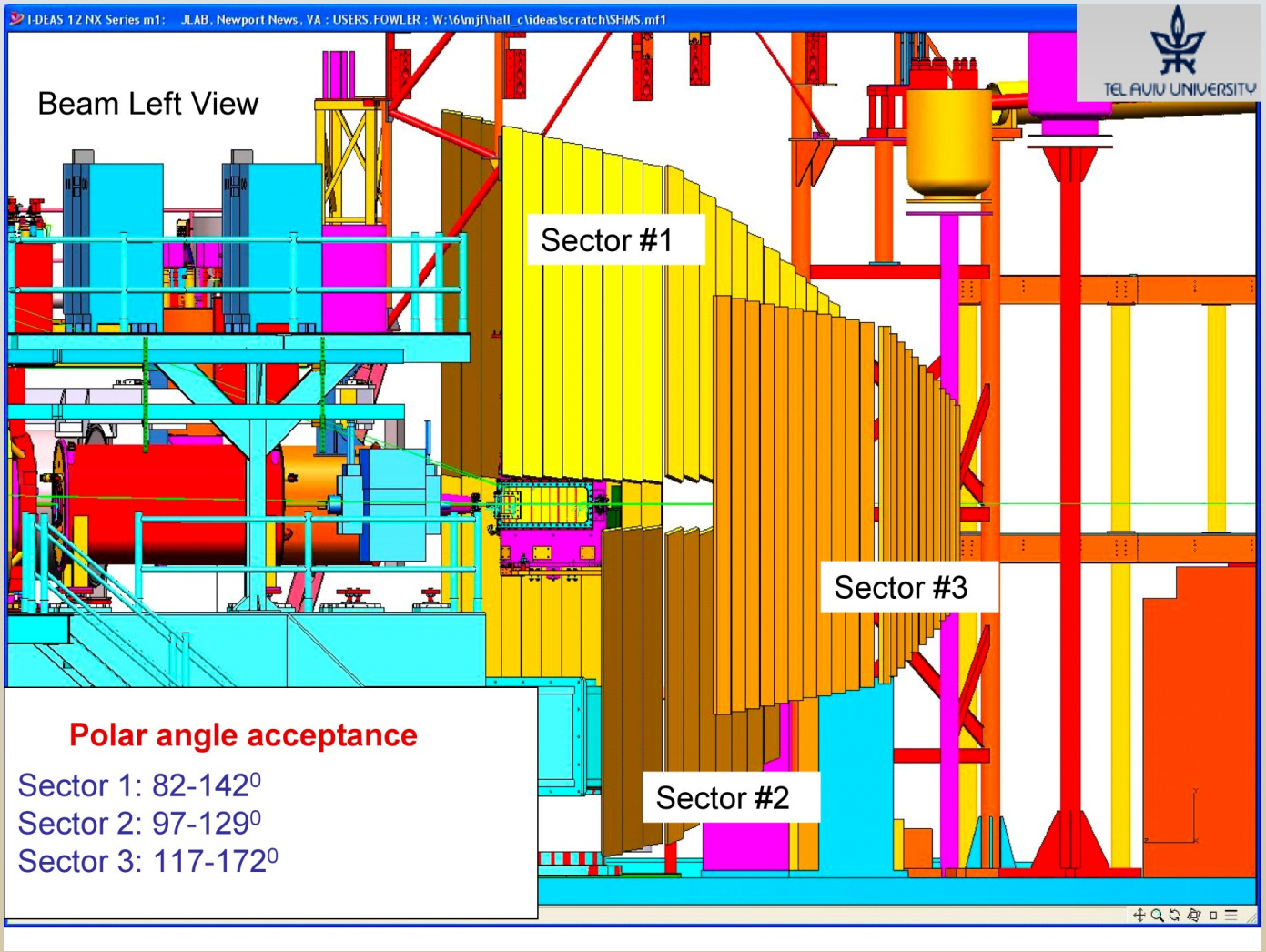
$$\frac{\sigma_{^3H}/3}{\sigma_{^3He}/3} = \frac{(2pn + 1\cancel{nn})/3}{(2pn + 1\cancel{pp})/3} = 1.0$$



- Requires a new ^{3}H and ^{3}He target system
- Target system design completed and reviewed in June
- Full report was expected this month (July 2010)

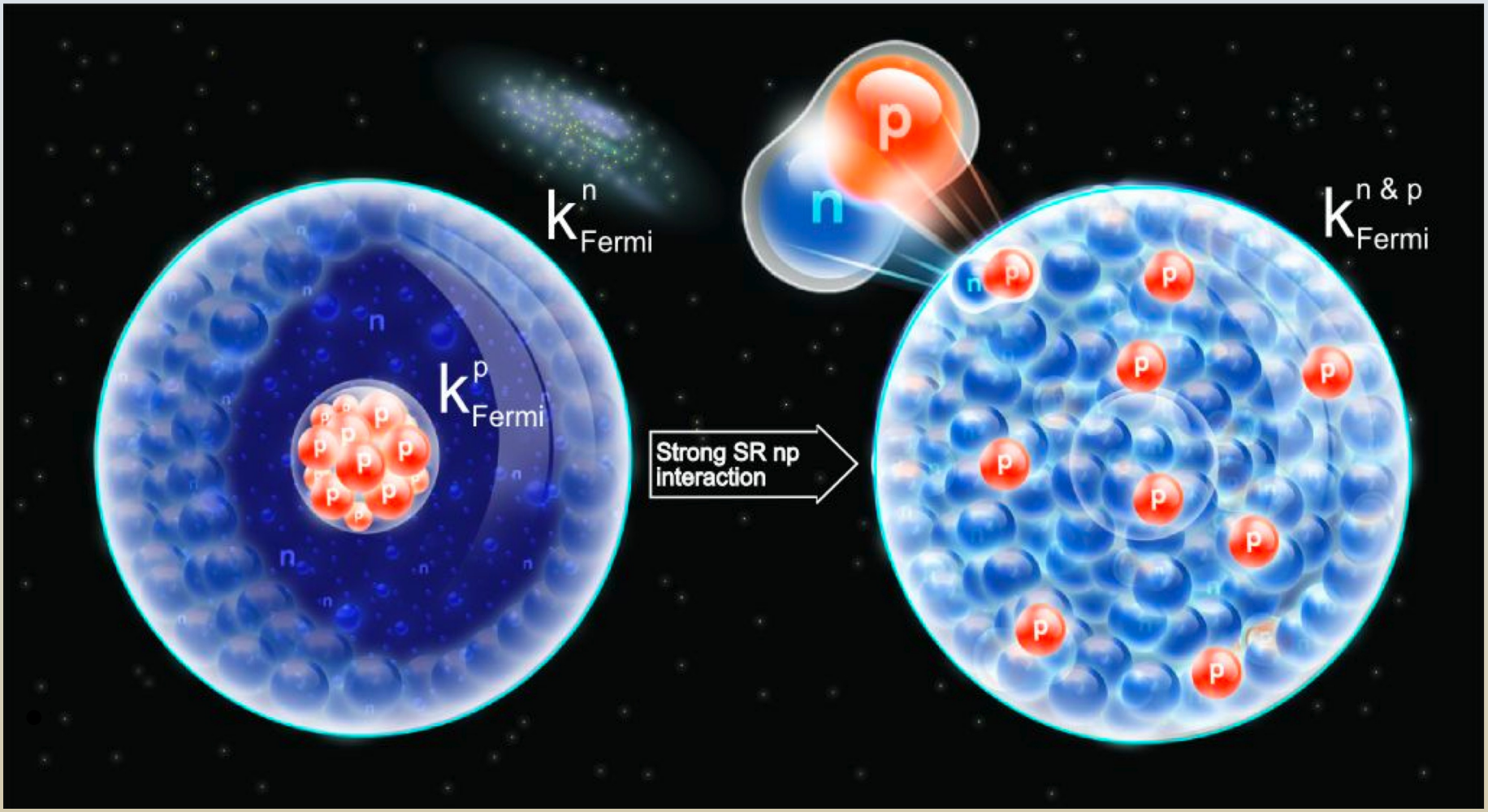
New Idea: Large Acceptance Device

Letter of Intent at Most Recent Jefferson Lab Program Advisory Committee Meeting



Look for EMC type of effect for nucleons which are a member of a 2N-SRC

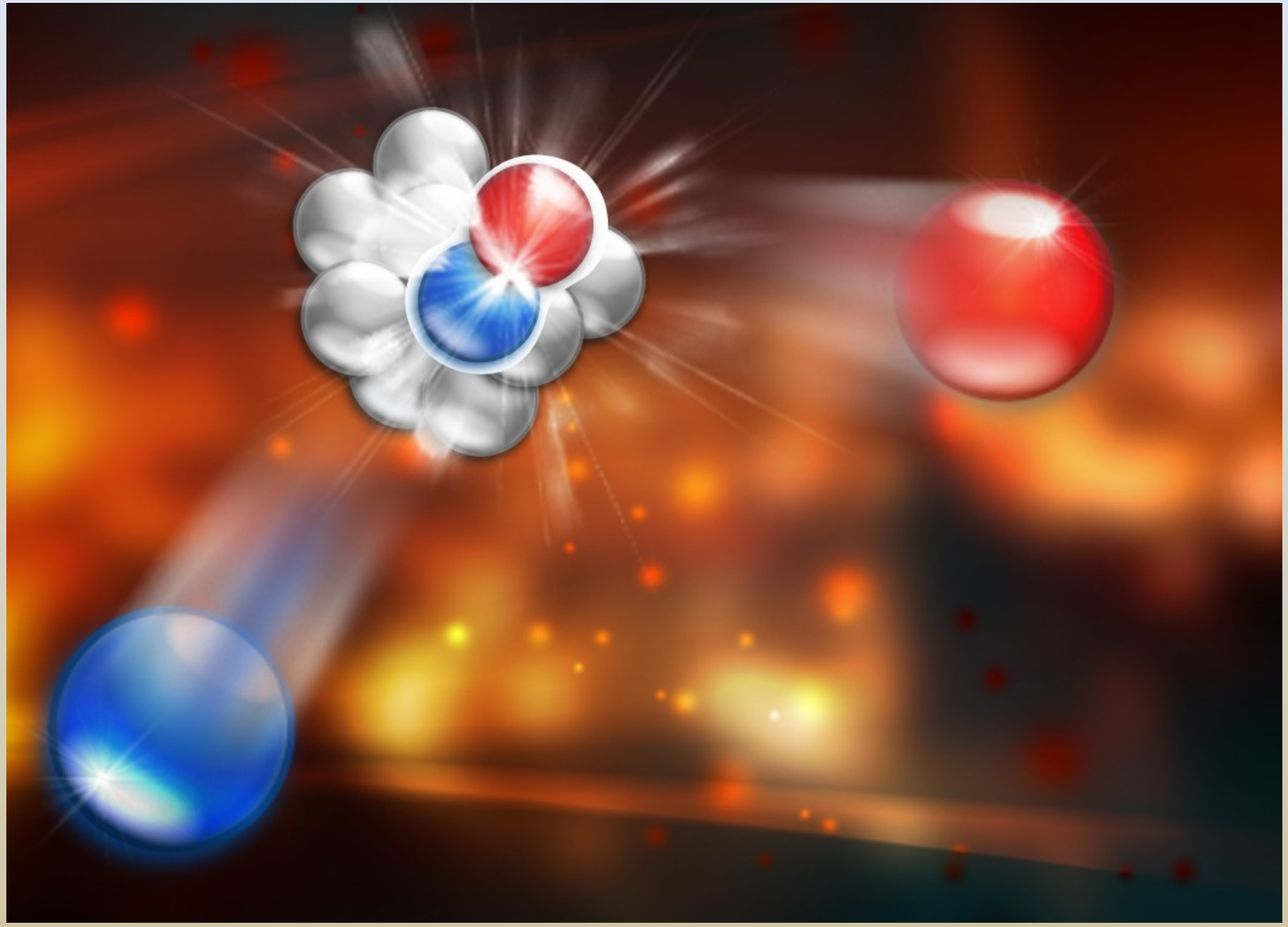
Implications for Neutron Stars



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

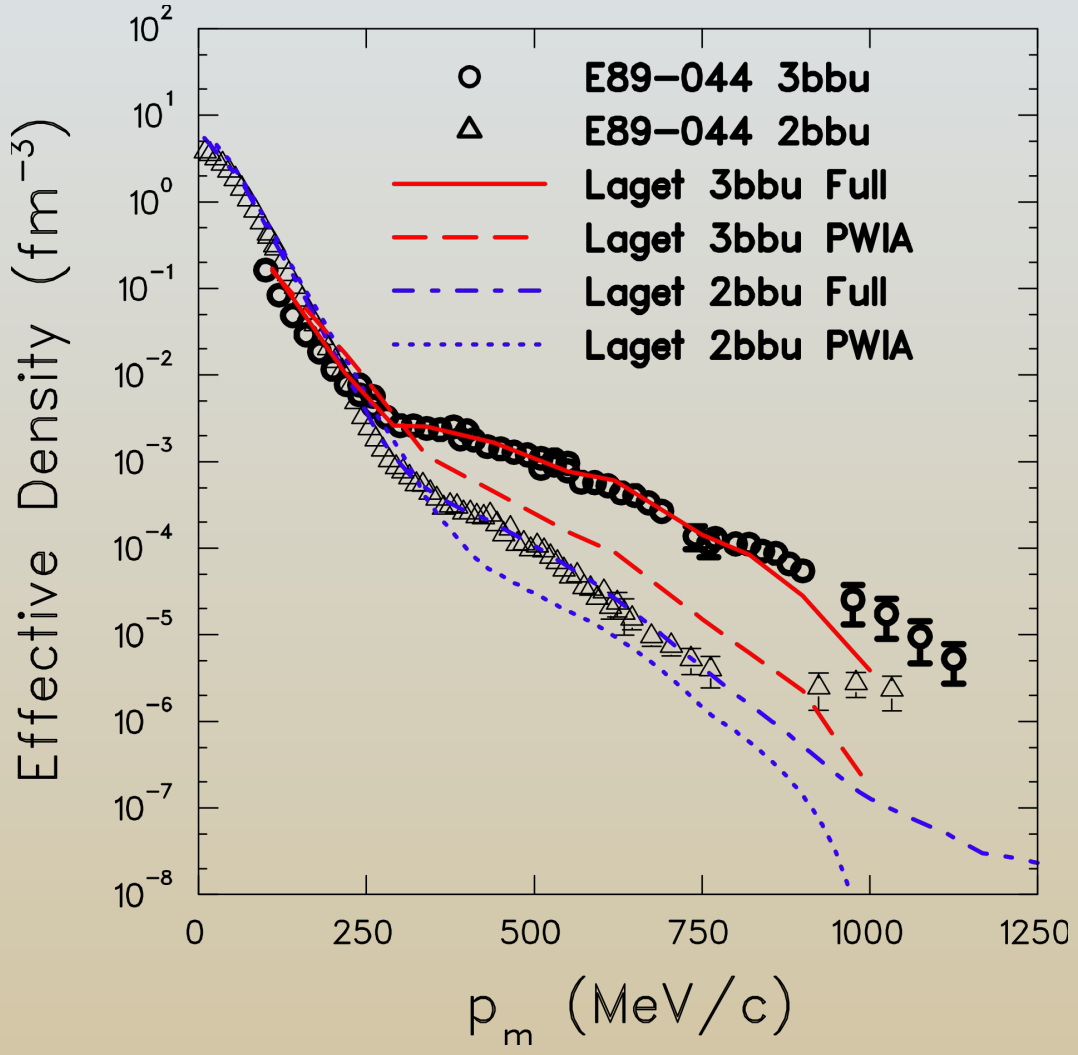
Summary and Outlook

- 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 what 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).
- New collaborators are welcome!



^{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)

Inclusive scattering at large x

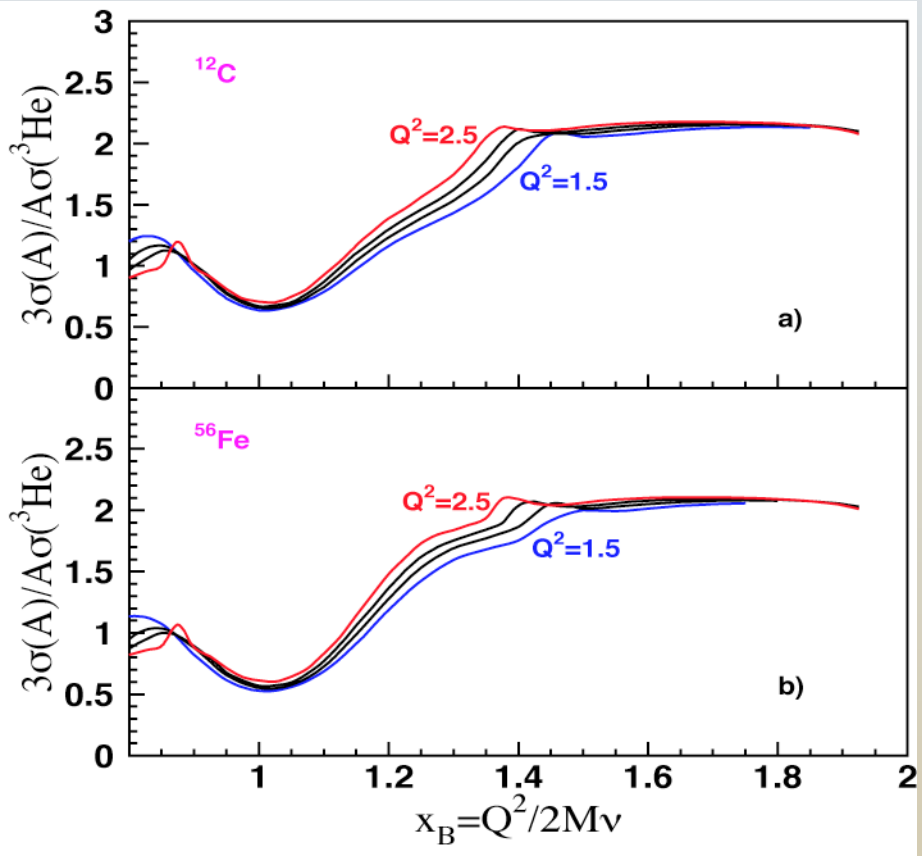
Define y as the x_B-value at which the minimum p_{miss} exceeds p_{Fermi}

SRC model predicts:

- Scaling for $x_B > y$ and $Q^2 > 1.5$ GeV^2
- No scaling for $Q^2 < 1$ GeV^2
- In scaling regime ratio Q^2-independent and only weakly A-dependent

Glauber Approximation predicts:

- No scaling for $x_B < 2$ and $Q^2 > 1$ GeV^2
- Nuclear ratios should vary with A and Q^2



Ratio of $^{12}C(e,e'pp)$ to $^{12}C(e,e'p)$

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

- Top plot shows the raw measured ratio
- Bottom plot shows the extrapolated where the finite acceptance of BigBite and pair center of mass motion has been taken into account.
- Determined pair cm motion to be 136+/-20 MeV/c and blue band indication two-sigma around this value.
- Note Brookhaven found 143+/-17 MeV/c