The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA

1942-51

Sixth International Conference on Perspectives in Hadronic Physics

12 - 16 May 2008

Short‐Range Structure of Nuclei.

D. Higinbotham
Jefferson Lab Hall A Collaboration
USA

R. Shneor (Ph.D Student)
Tel Aviv
Israel

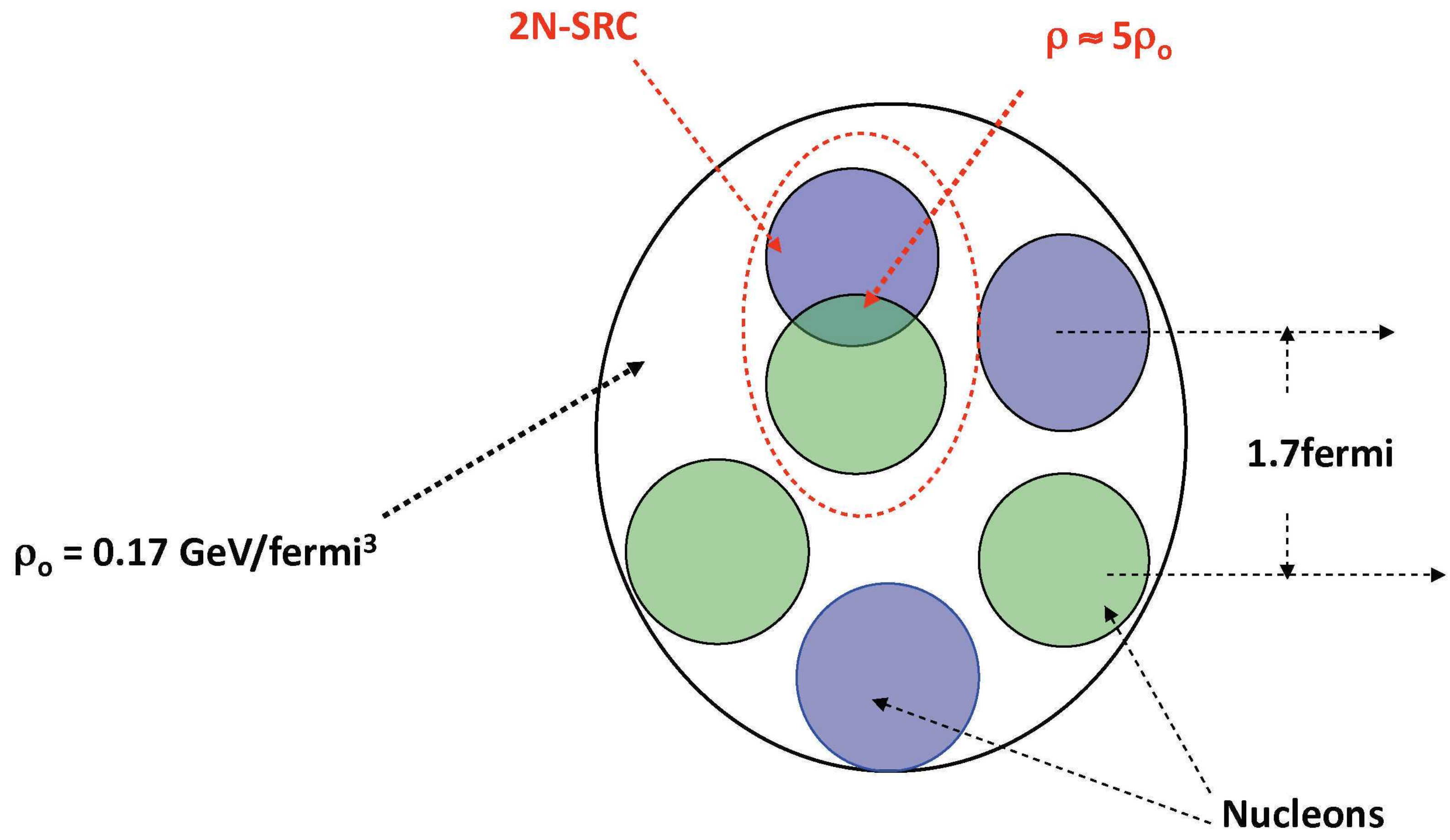
R. Subedi (Ph.D Student)
Kent State
USA

P. Monaghan (Ph.D Student)
MIT
USA

Short-Range Structure of Nuclei

by
Douglas W. Higinbotham
for the Jefferson Lab Hall A Collaboration
R. Shneor (Tel Aviv), R. Subedi (Kent State), P. Monaghan (MIT)
Ph.D Students

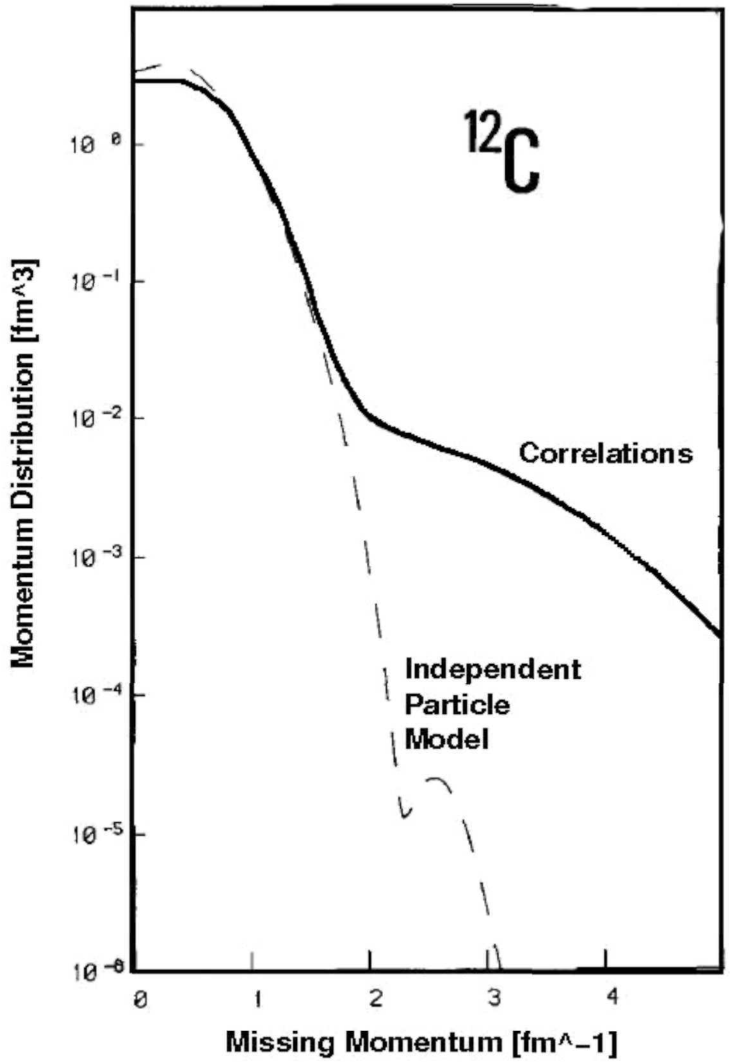
Two Nucleon Short-Range Correlations



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)?

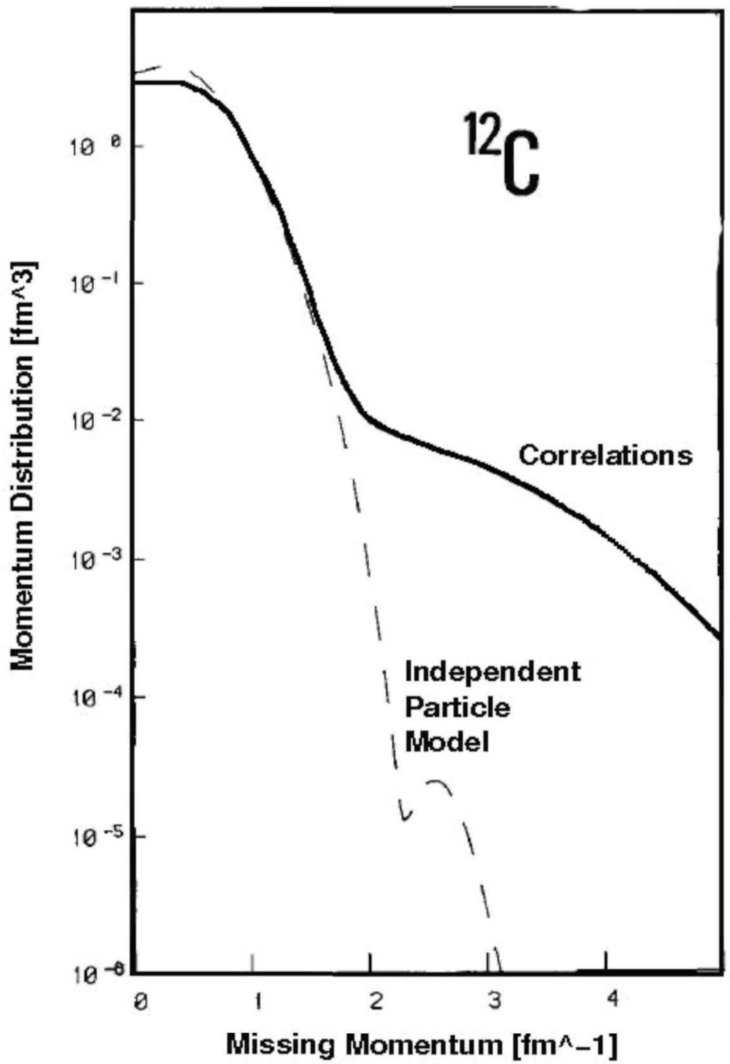
Benhar et al., Phys. Lett. **B** 177 (1986) 135.



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.

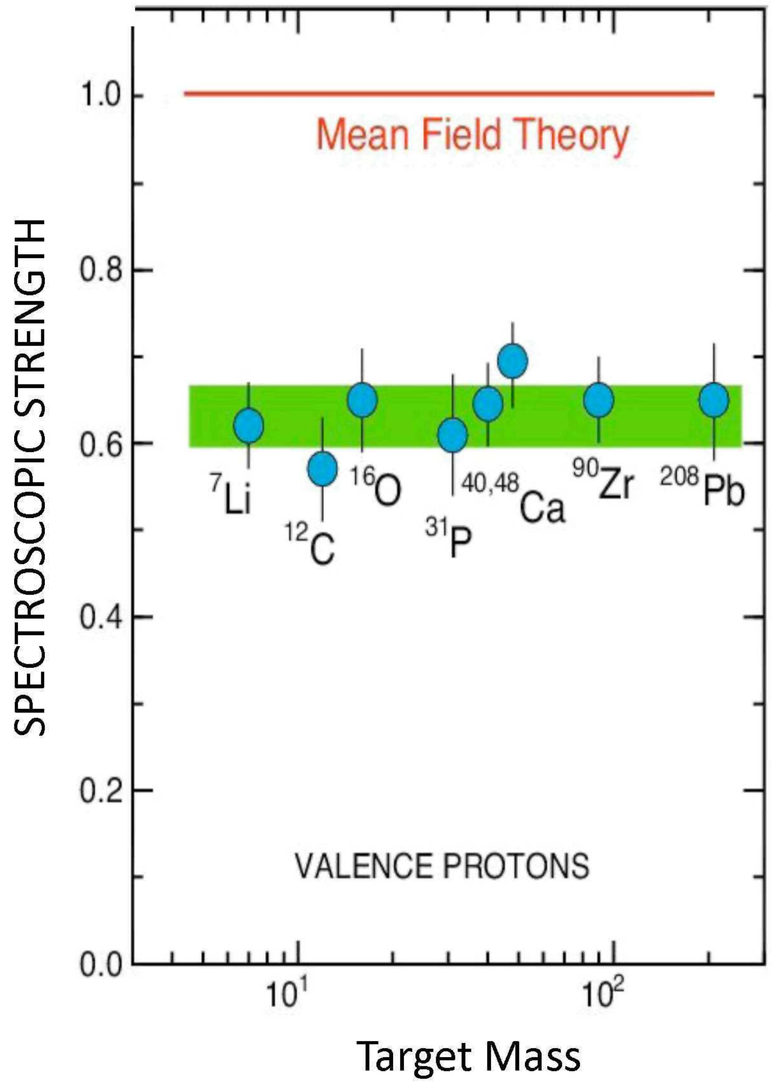


Let’s build a picture of nucleons in Carbon from (e,e’), (e,e’p) and (e,e’pN) Reactions

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.



CLAS A(e,e') Data

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

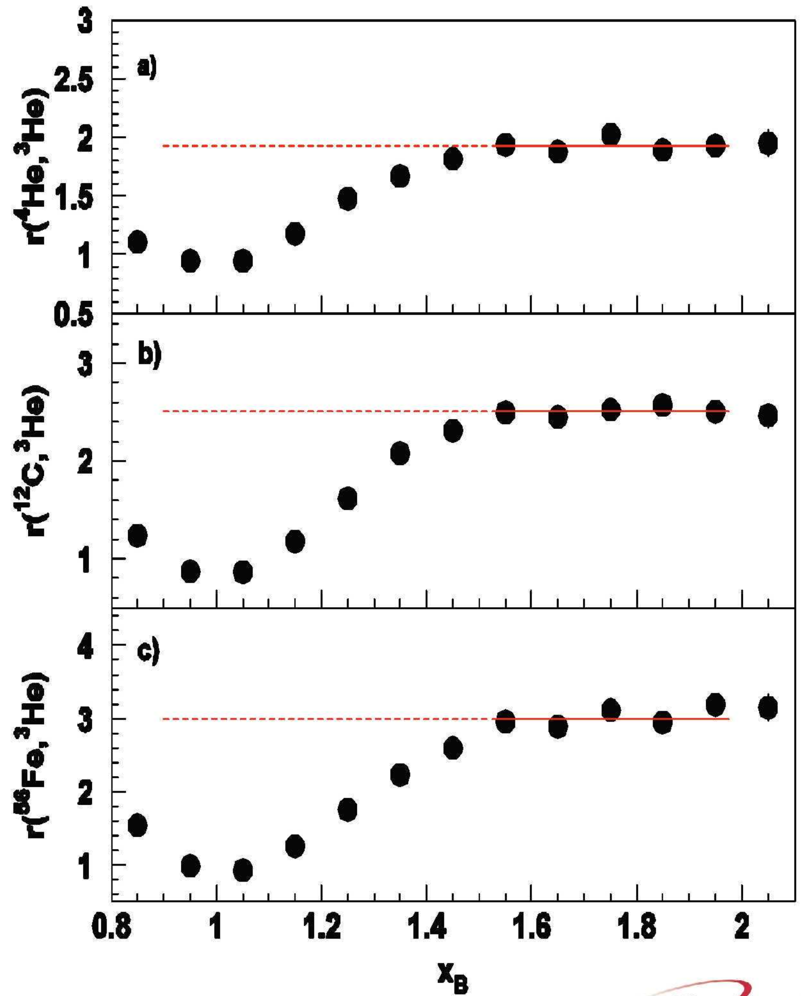
Originally done with SLAC data by D.B. Day *et al.*, Phys. Rev. Lett. 59 (1987) 427.

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

then

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

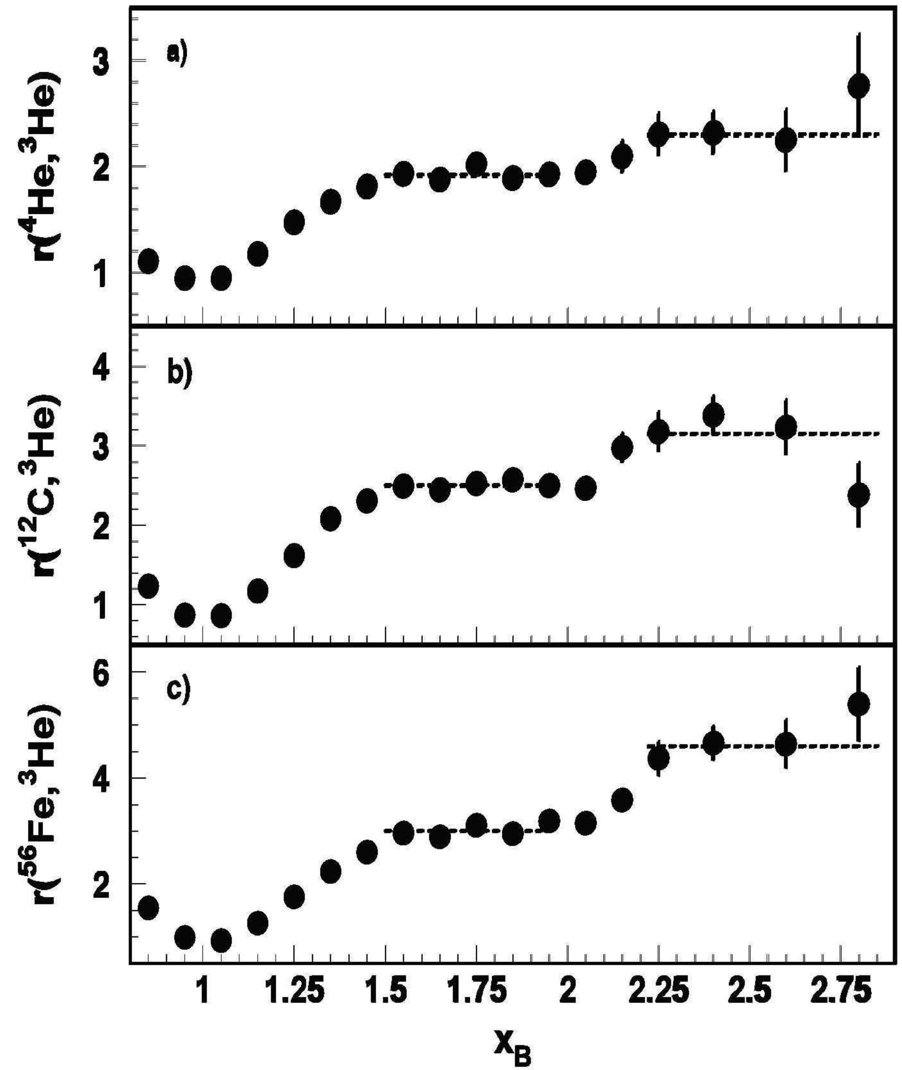
The observed *scaling* means that the electrons probe the high-momentum nucleons in the 2N-SRC phase, and the scaling factors determine the per-nucleon probability of the 2N-SRC phase in nuclei with A>3 relative to ^3He



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
- More in Donal Day's Talk



Jefferson Lab

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

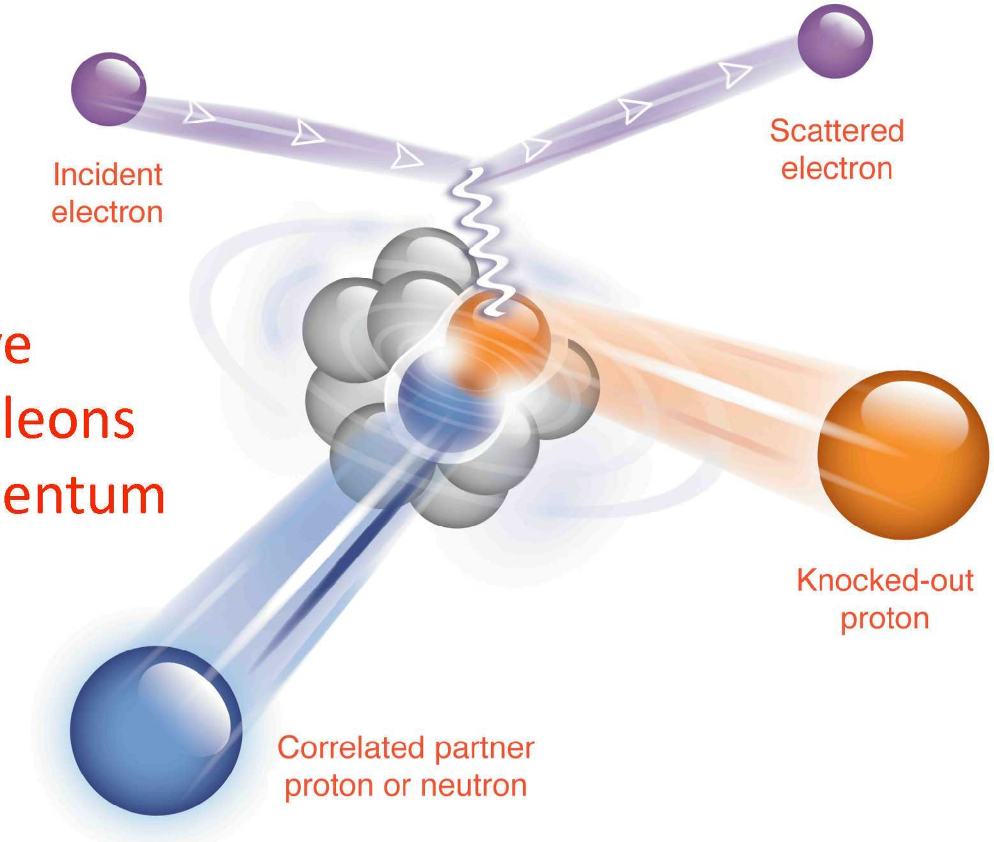
- 80 +/- 5% single particles moving in an average potential
  - 60 – 70% independent single particle in a shell model potential
  - 10 – 20% shell model long range correlations
- 20 +/- 5% two-nucleon short-range correlations
- Less than 1% multi-nucleon correlations

"A full investigation of two-nucleon correlations would require (e,e'NN) coincidence studies, but these are technically not yet feasible."

Rolf Ent's Ph.D. Thesis 1989

Customized (e,e'pN) Measurement

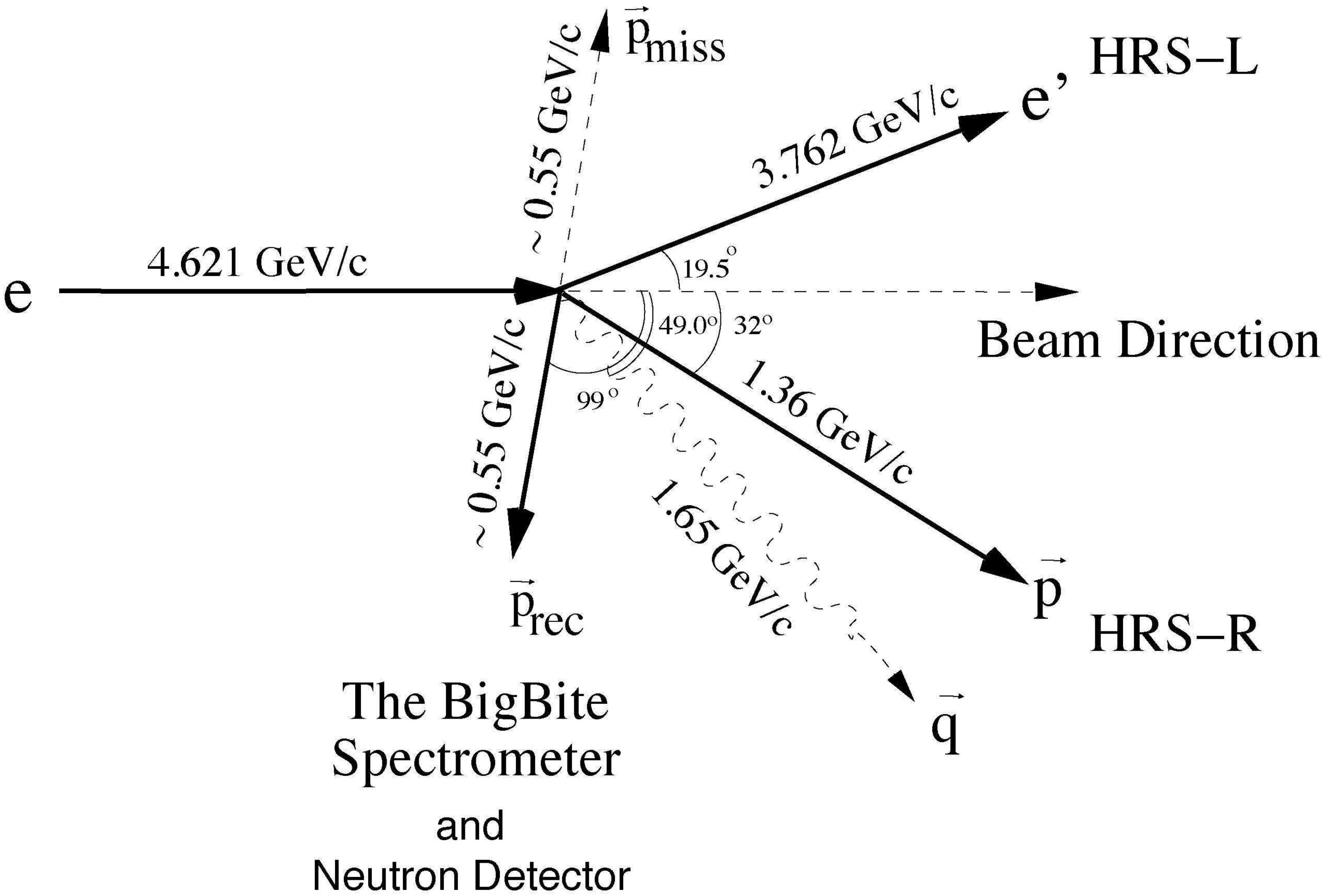
To study nucleon pairs at close proximity and their contributions to the large momentum tail of nucleons in nuclei.



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

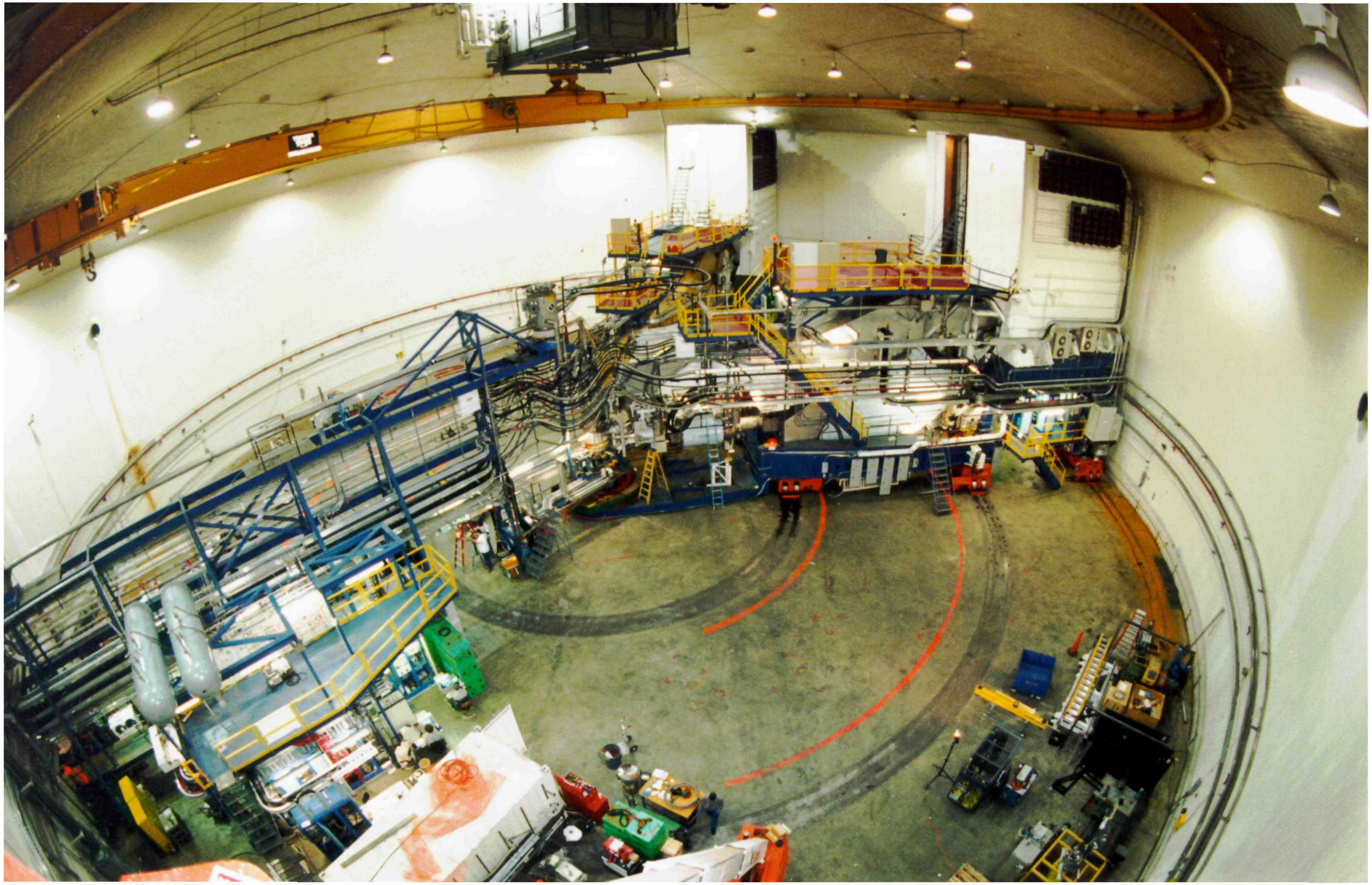
- high Q2 to minimize MEC
- x>1 to suppress isobar contributions
- anti-parallel kinematics to suppress FSI

Kinematics

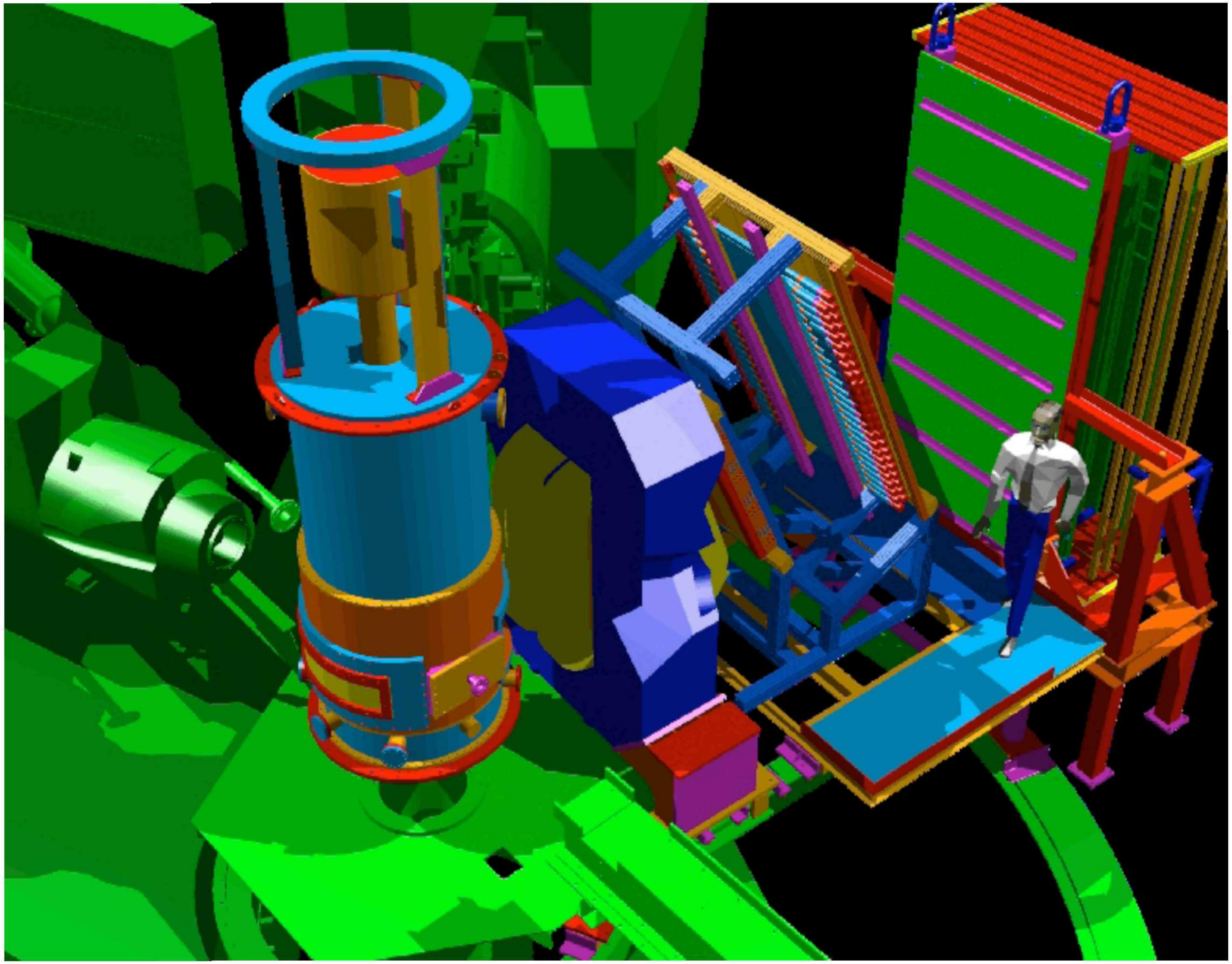


$\vec{p}_{miss}$
~ 0.55 GeV/c
e', HRS–L
3.762 GeV/c
e
4.621 GeV/c
19.5°
Beam Direction
49.0°
32°
~ 0.55 GeV/c
99°
1.36 GeV/c
1.65 GeV/c
$\vec{p}_{rec}$
$\vec{p}$
HRS–R
$\vec{q}$
The BigBite Spectrometer
and
Neutron Detector

Jefferson Lab's Hall A



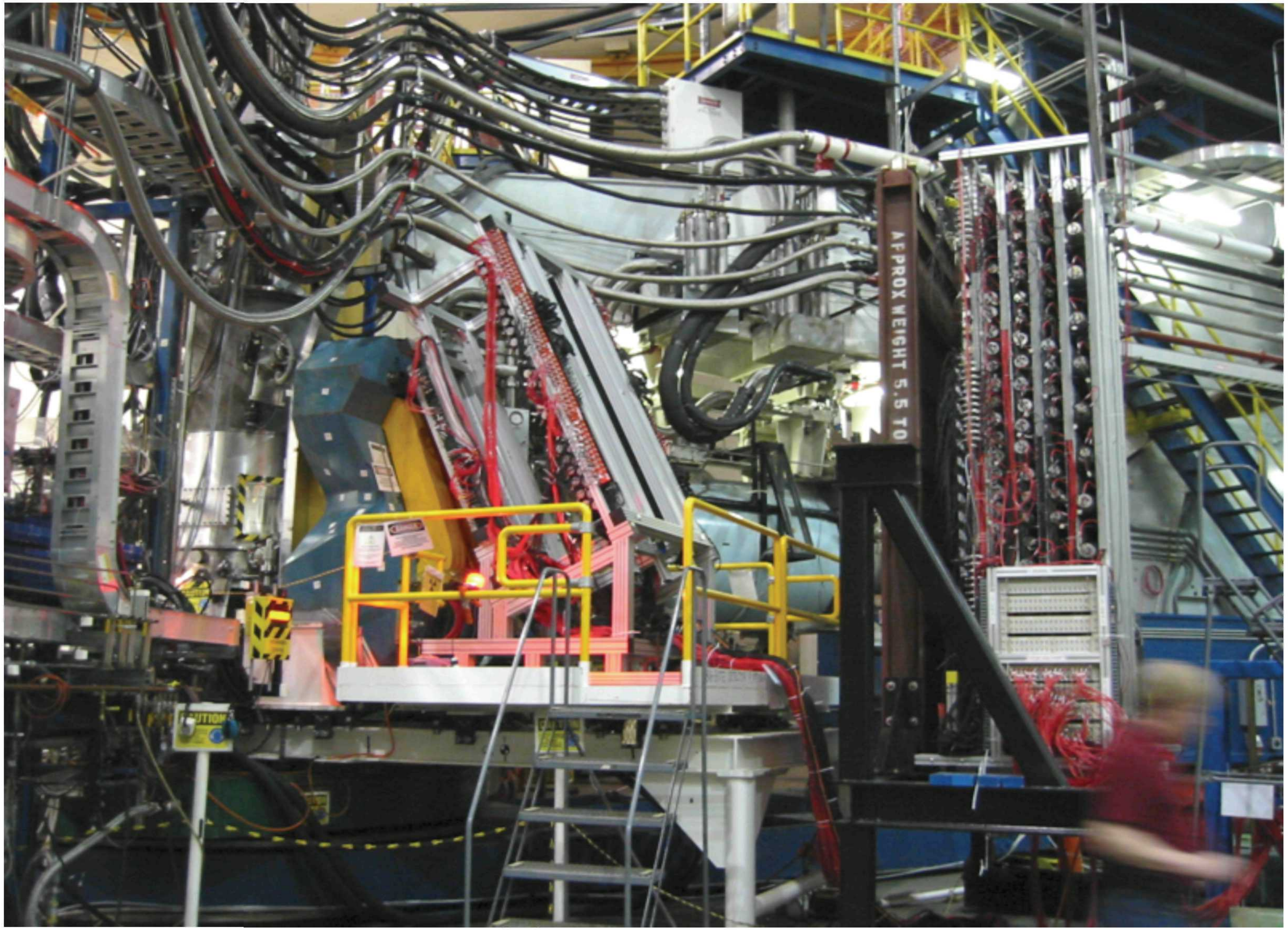
New Equipment



Making BigBite & Neutron Detector

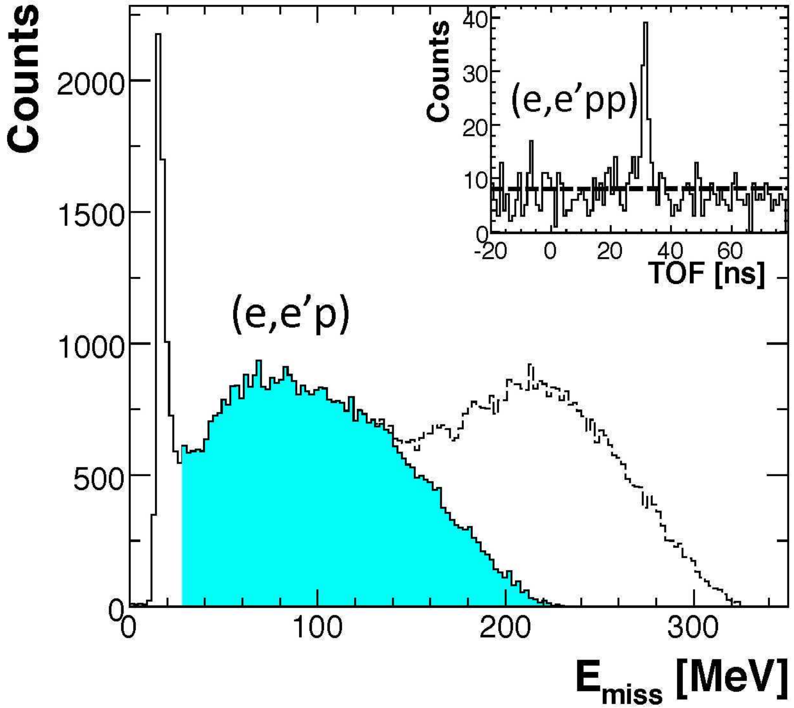
- Jlab from NIKHEF – BigBite Magnet
- Tel Aviv - Auxiliary Plane
- Glasgow - Trigger Plane
- UVa MRI - Scattering Chamber
- Kent State – Most of the Neutron Detectors
- *future Wire Chambers also from UVa MRI*

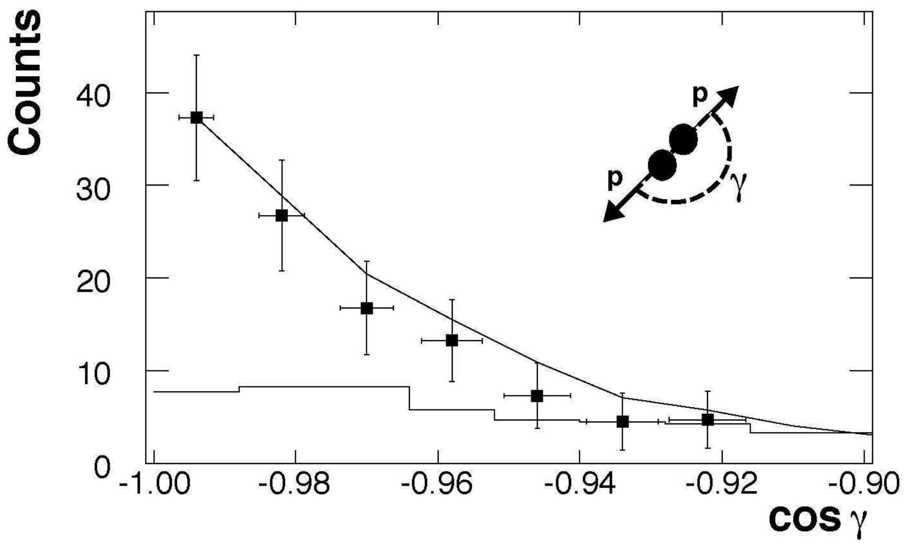
Final Assembly



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

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





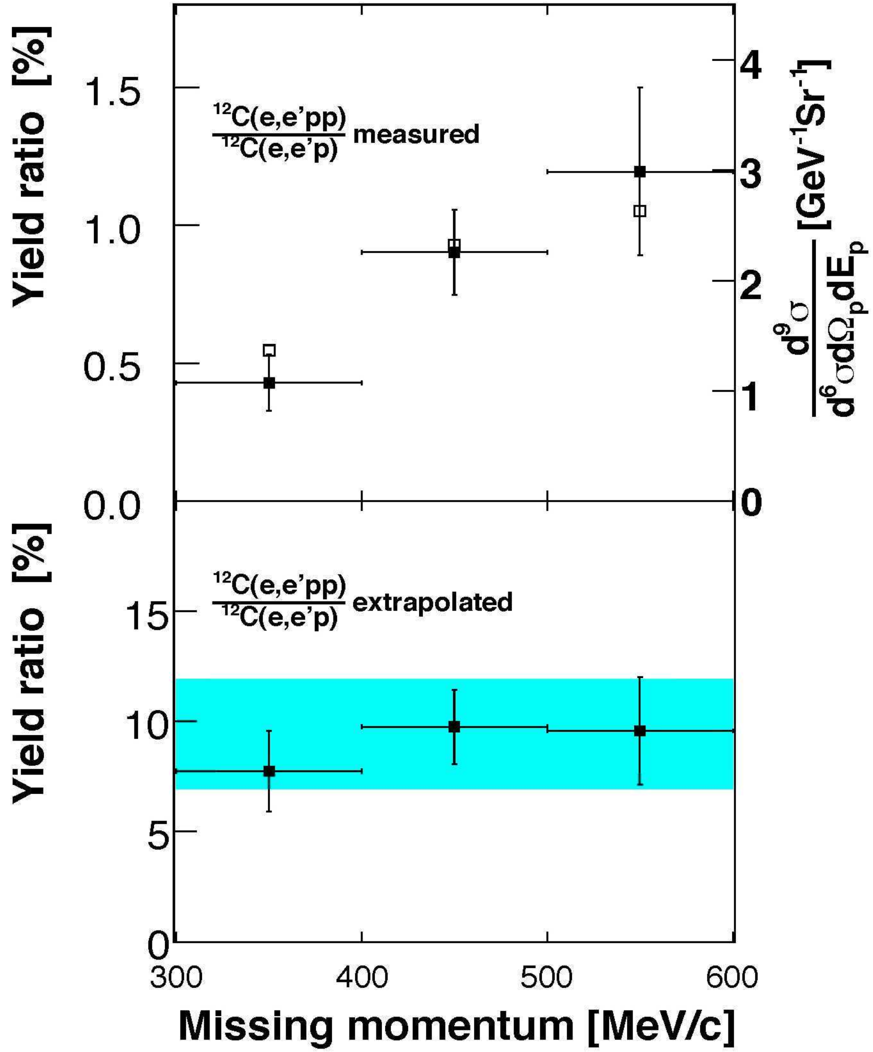
Strong back-to-back correlation!

- $^{12}C(e,e'p)^{11}B$
- Quasi-Elastic Shaded In Blue
- Resonance Even at $x_B>1$

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

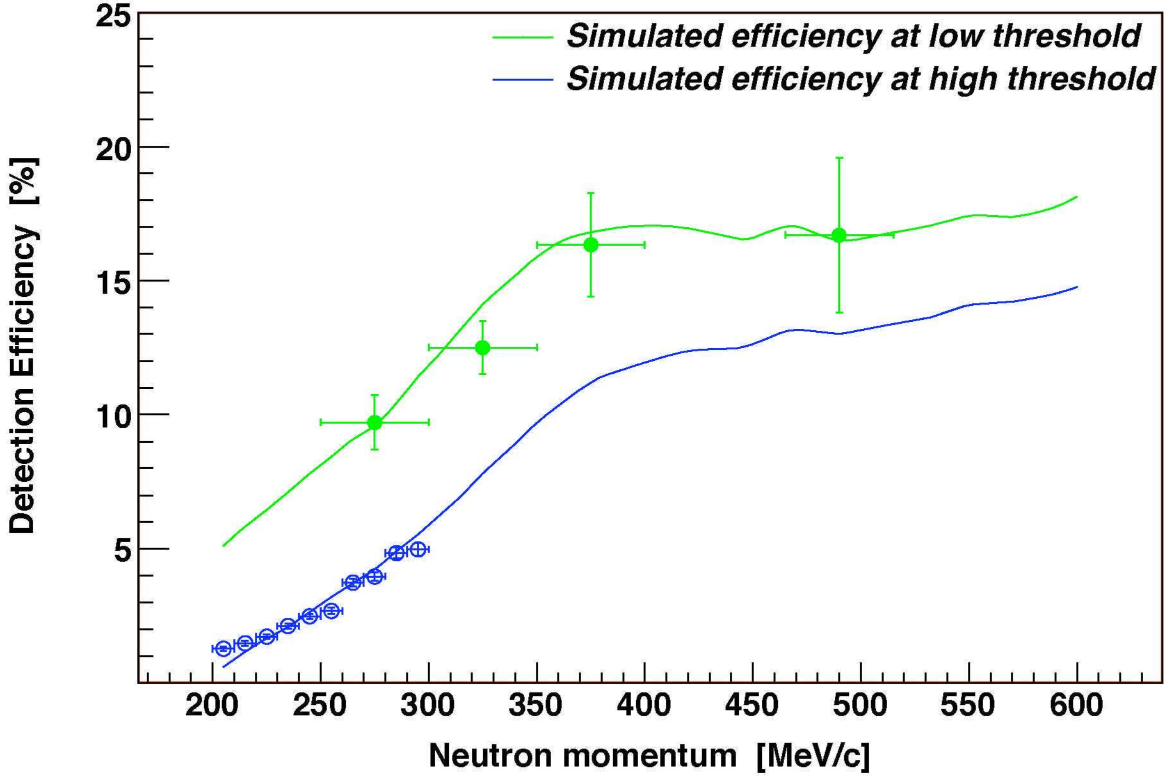
R. Shneor *et al.*, Phys. Rev. Lett. **99** (2007) 072501.

- 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



(e,e'n): Absolute Neutron Detector Efficiency

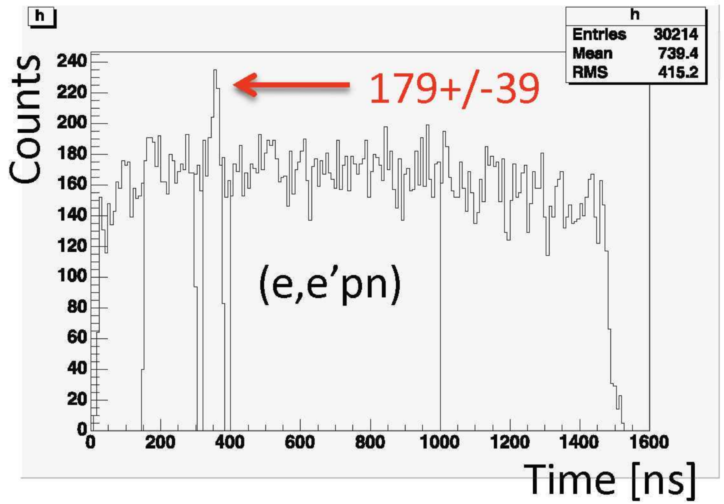
- Used HRS quasi-elastic D(e,e'p)n to tag neutrons
- Tested Result Against Neutron Efficiency Code
  - R. A. Cecil, B. D. Anderson, R. Madey, Nucl. Instrum. Meth. 161 (1979) 430.
  - Blue data using 2.3 GeV beam, Green data with 4.6 GeV beam

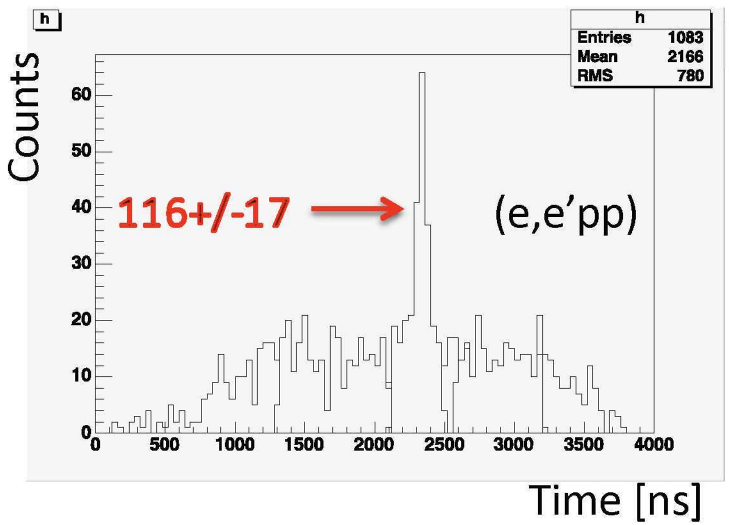


Jefferson Lab

Ratio of np-SRC/pp-SRC

R. Subedi et al., Accept for publication by Science.





Corrected for detection efficiency:

$$\frac{^{12}C(e,e'\,pn)}{^{12}C(e,e'\,pp)} = 8.2 \pm 2.2$$

Corrected for SCX (using Glauber):

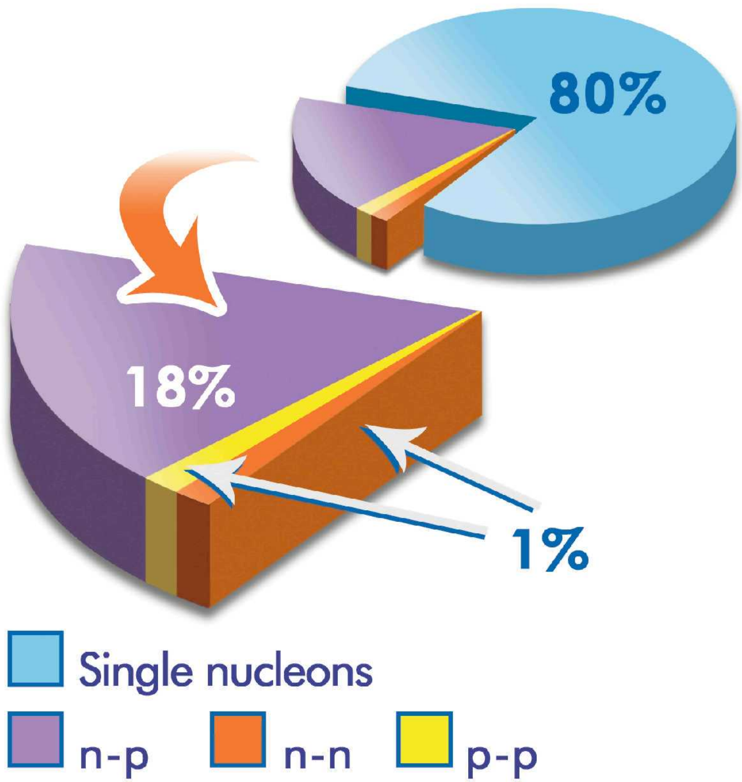
$$\frac{^{12}C(e,e'\,pn)}{^{12}C(e,e'\,pp)} = 9.1 \pm 2.5$$

In Carbon:

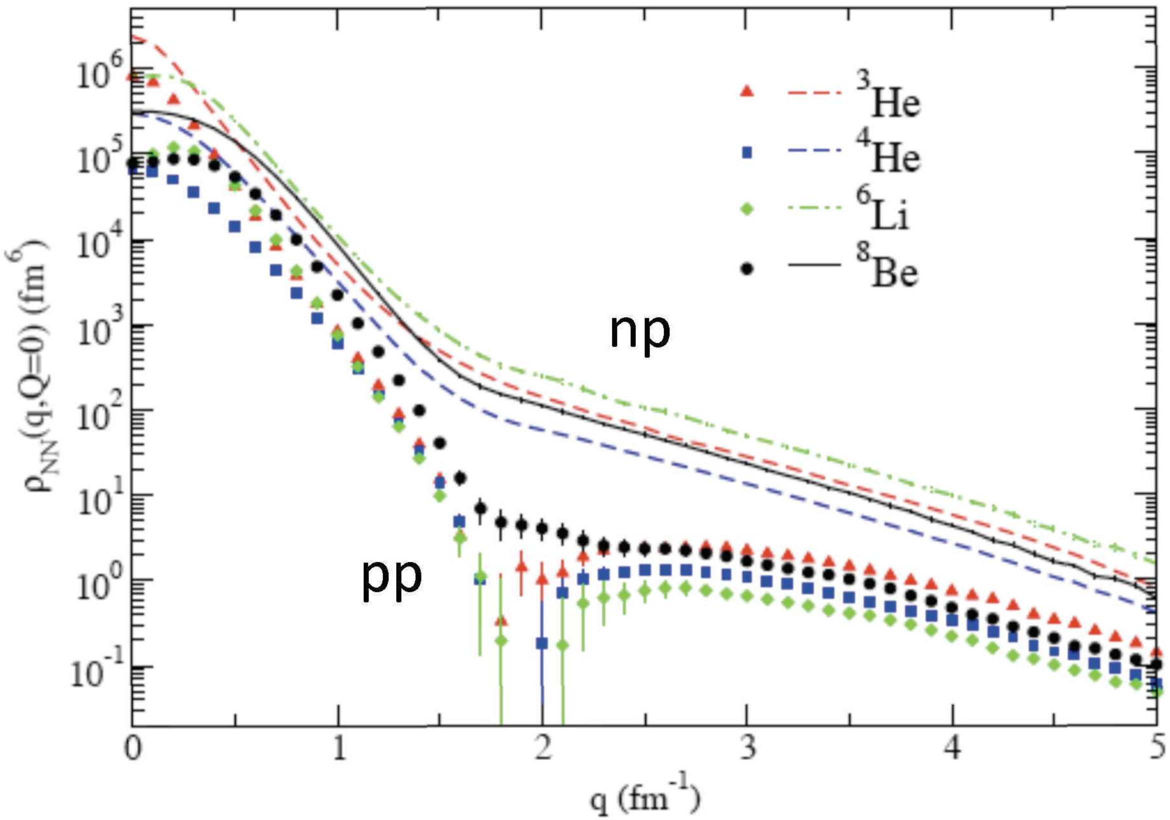
$$\frac{np - SRC}{pp - SRC} = 18.2 \pm 5$$

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% np pairs
  - 1% nn pairs (from isospin symmetry)
- Less than 1% multi-nucleon correlations

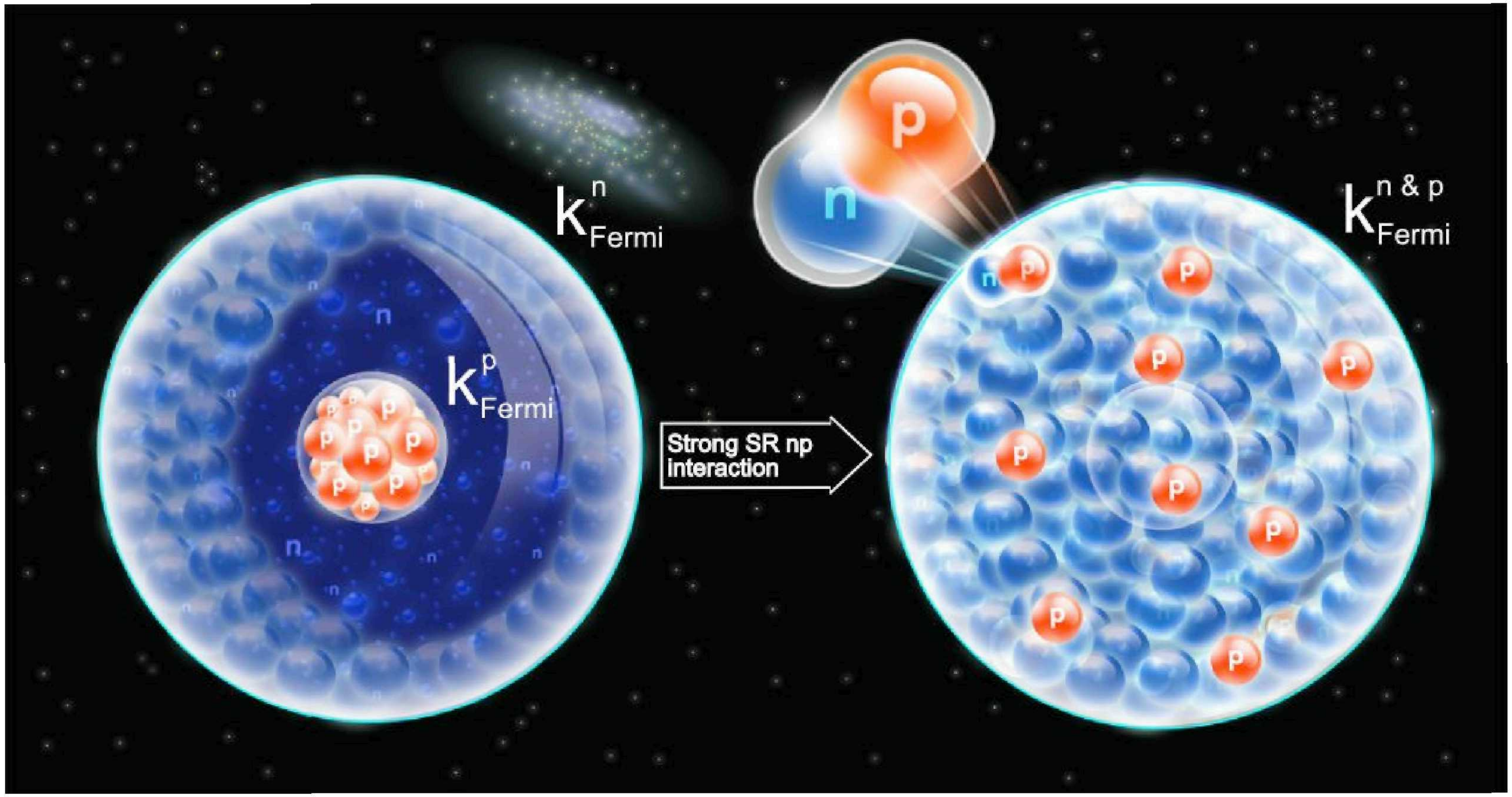


Importance of Tensor Correlations



- R. Schiavilla et al., Phys. Rev. Lett. 98 (2007) 132501.
- M. Sargsian et al., Phys. Rev. C (2005) 044615.
- M. Alvioli, C. Ciofi degli Atti, and H. Morita, arXiv:0709.3989.

Implications for Neutron Stars



- At the core of neutron stars, most accepted models assume :~95% neutrons, ~5% protons
- Neglecting the np-SRC interactions, one can assume two separate Fermi gases
- Since np interaction is large compared to nn, n gas heats the p gas
- This could effect the upper limit on mass of neutron and allow the neutrons in the star decay