

# Short-Range Structure of Nuclei

by

Douglas W. Higinbotham

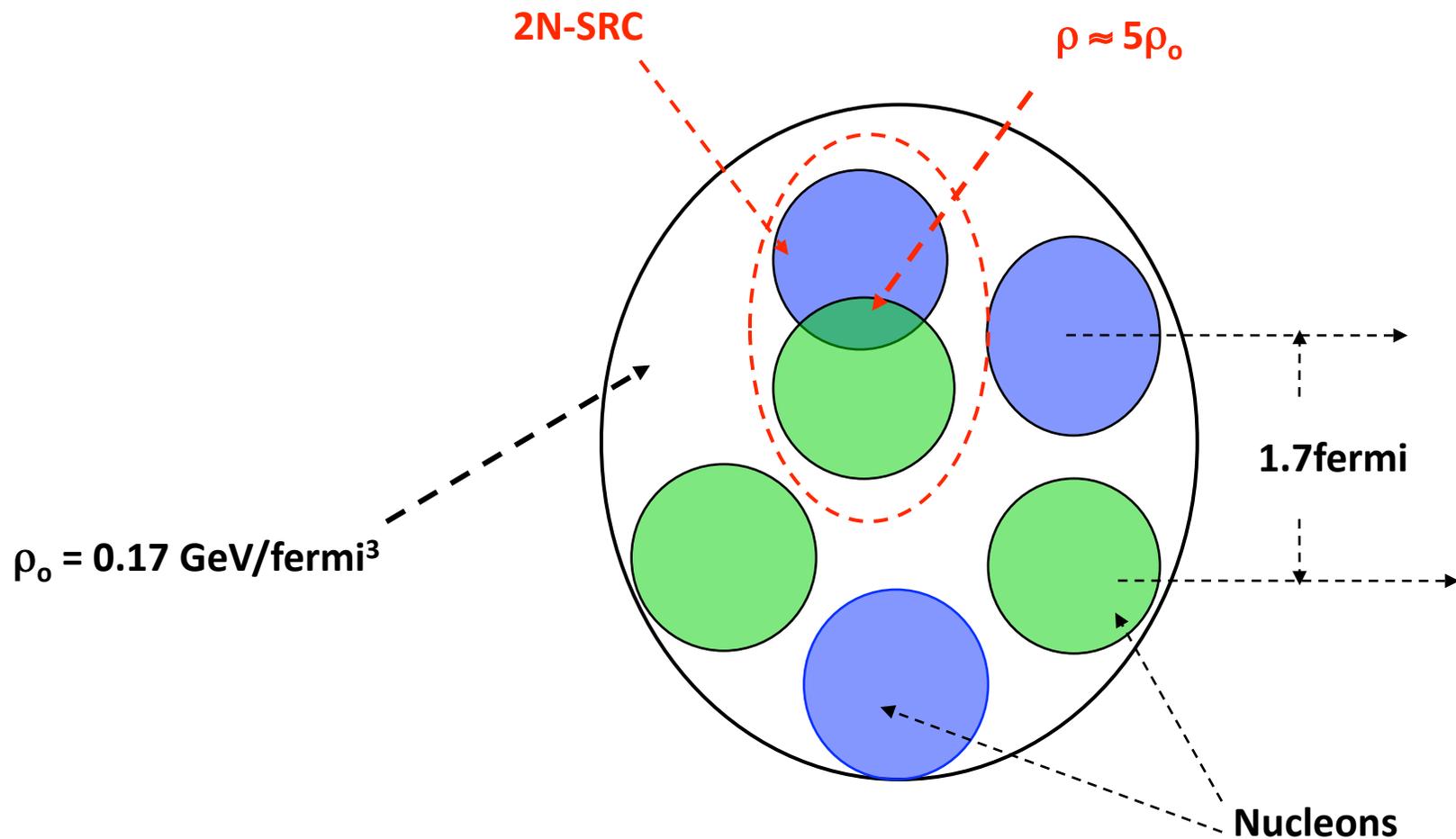
for the Jefferson Lab Hall A Collaboration

R. Shneor (Tel Aviv), R. Subedi (Kent State), P. Monaghan (MIT)

Ph.D Students



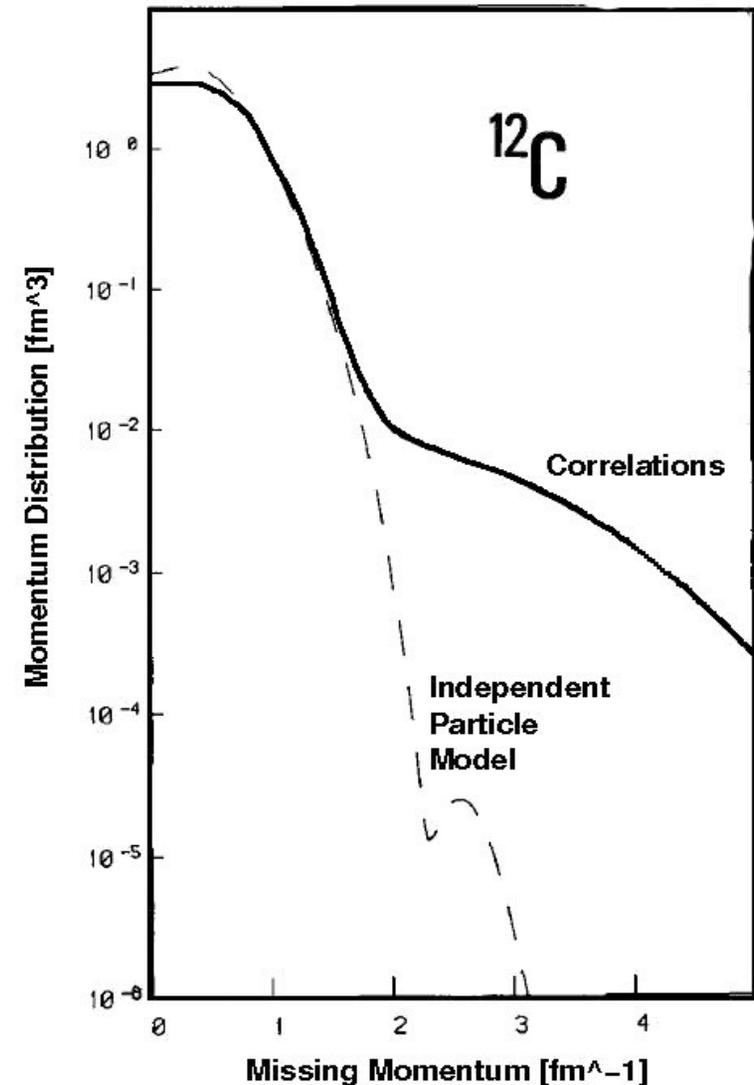
# Two Nucleon Short-Range Correlations



# 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)?

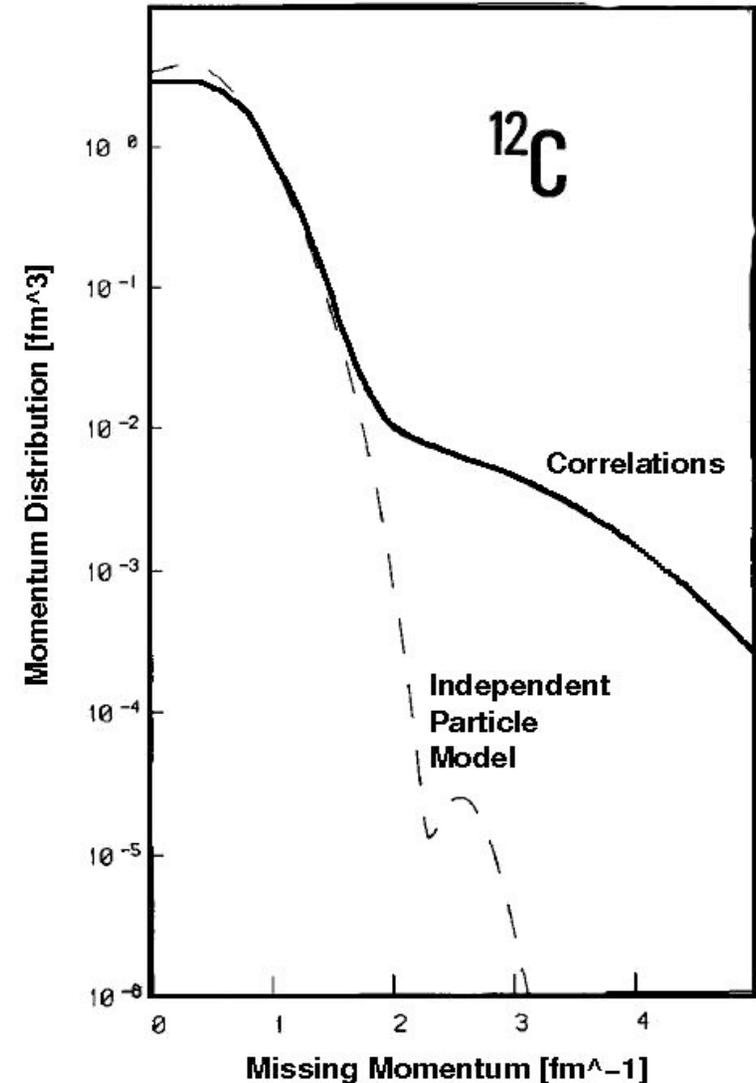
Benhar et al., Phys. Lett. **B** 177 (1986) 135.



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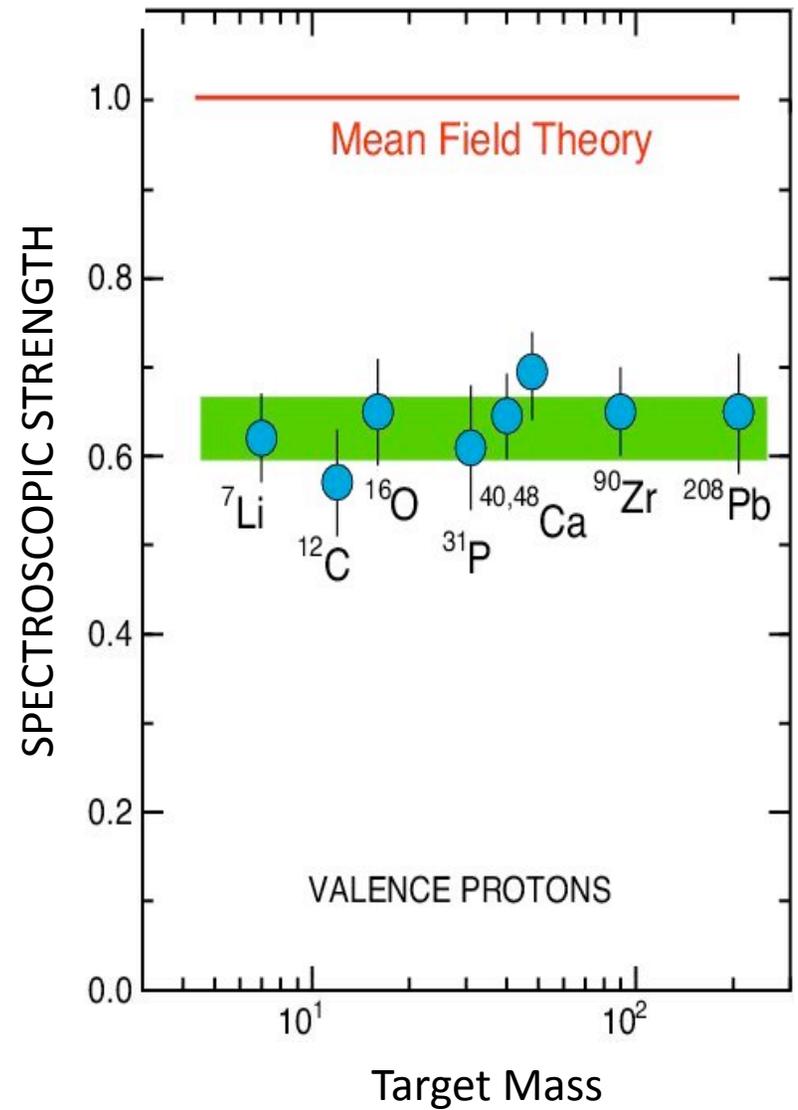
# Let's build a picture of nucleons in Carbon from $(e,e')$ , $(e,e'p)$ and $(e,e'pN)$ Reactions



# 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.

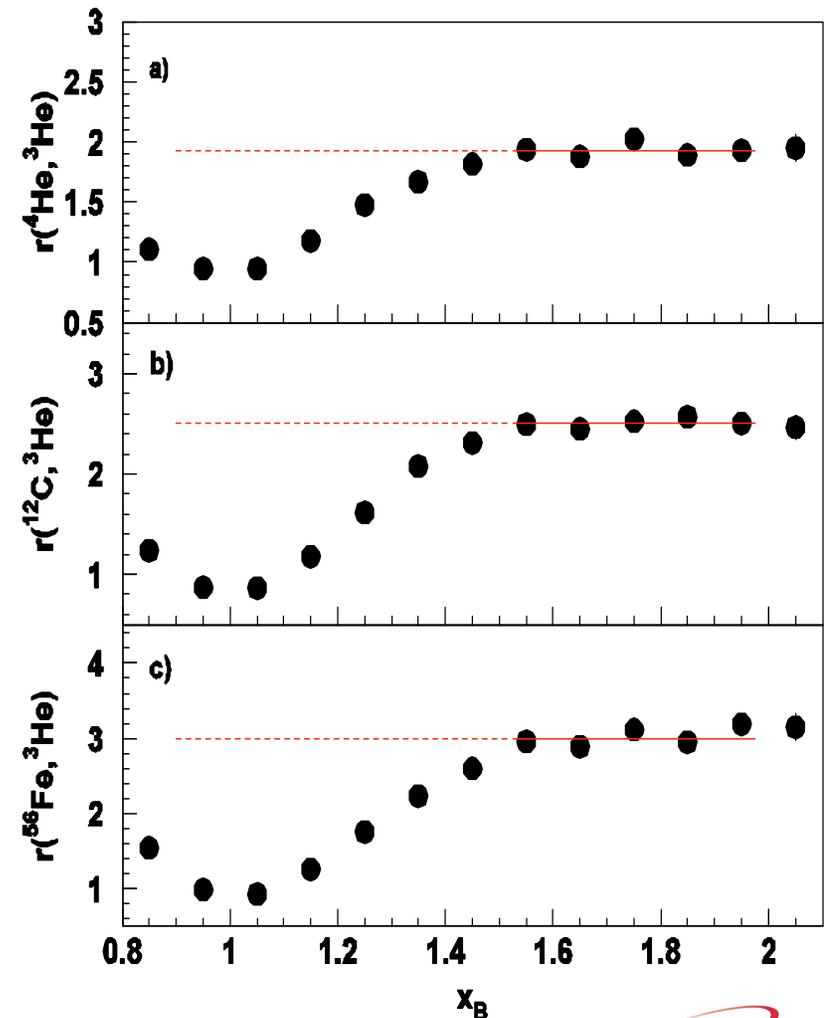
Originally done with SLAC data by D.B. Day *et al.*, Phys. Rev. Lett. 59 (1987) 427.

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

then

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

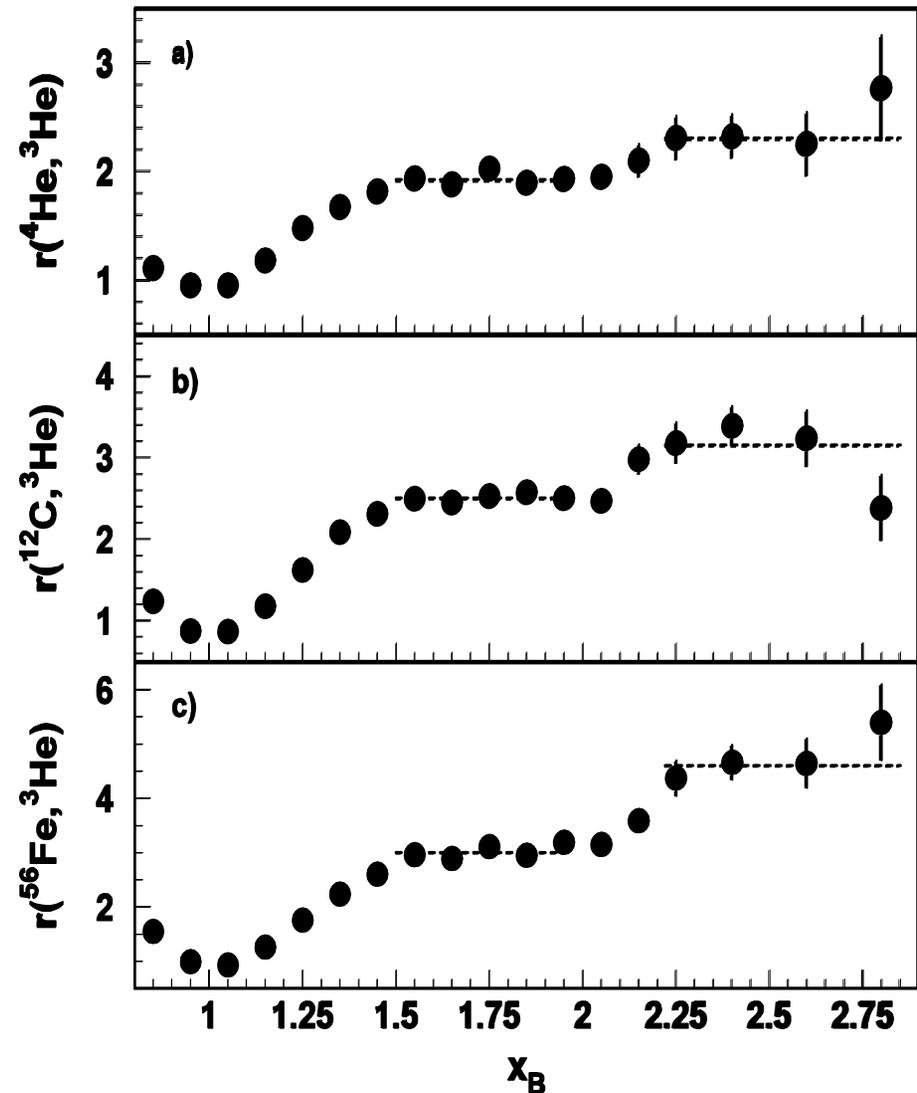
The observed *scaling* means that the electrons probe the high-momentum nucleons in the 2N-SRC phase, and the scaling factors determine the per-nucleon probability of the 2N-SRC phase in nuclei with  $A > 3$  relative to  ${}^3\text{He}$



# Estimate of $^{12}\text{C}$ 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  $r(^3\text{He},\text{D})$  results to find:
- $^{12}\text{C}$  20% two nucleon SRC
- $^{12}\text{C}$  <1% three nucleon SRC
- More in Donal Day's Talk



# 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.”

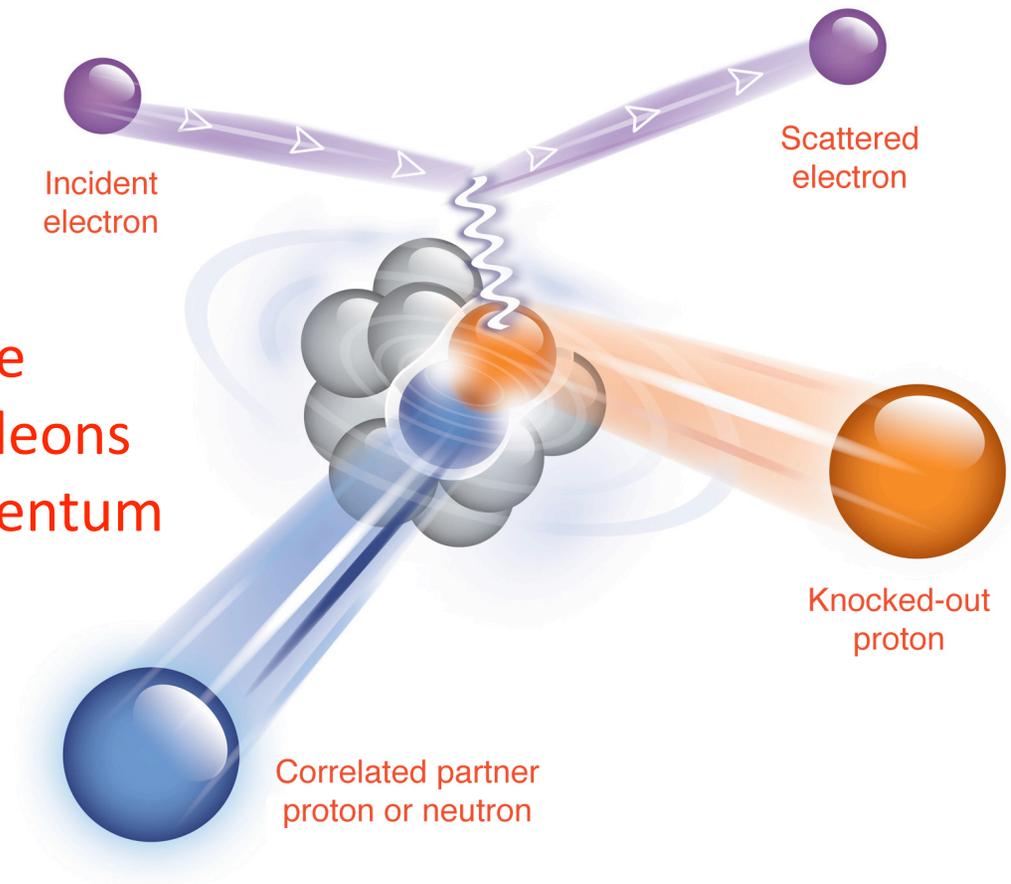
Rolf Ent's Ph.D. Thesis 1989



# Customized (e,e'pN) Measurement

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

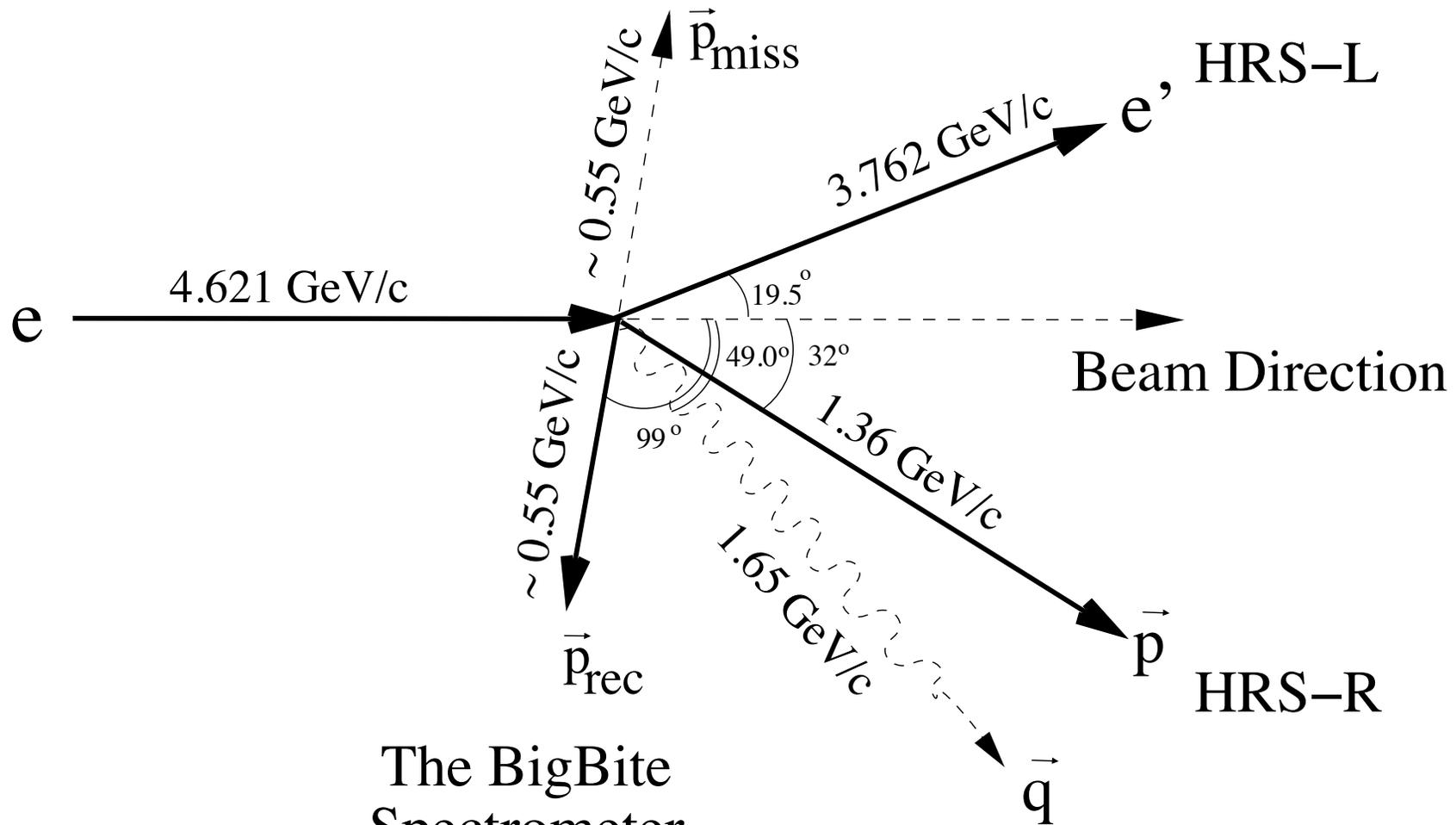
A pair with “large” relative momentum between the nucleons and small center of mass momentum



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



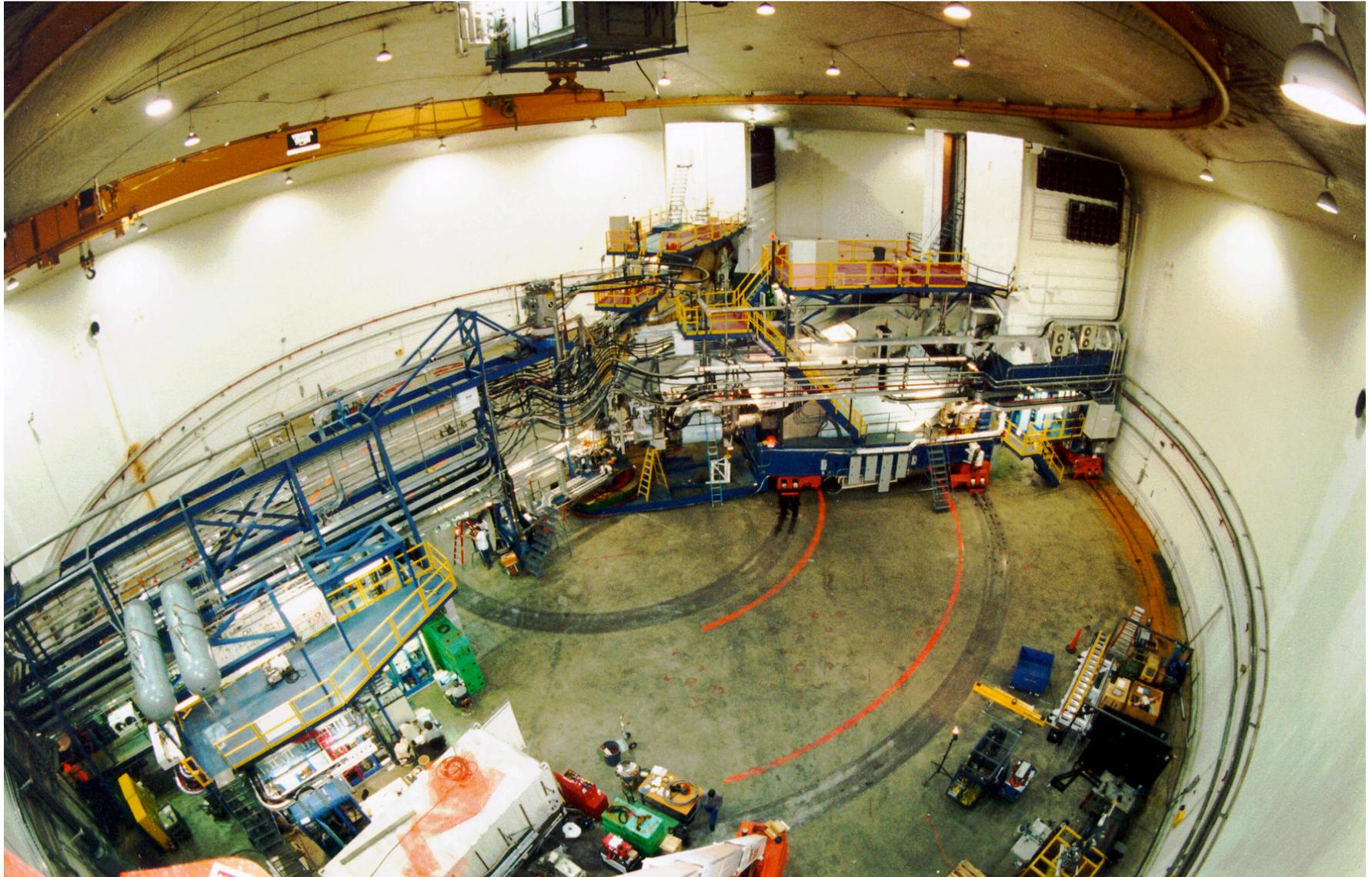
# Kinematics



The BigBite  
Spectrometer  
and  
Neutron Detector



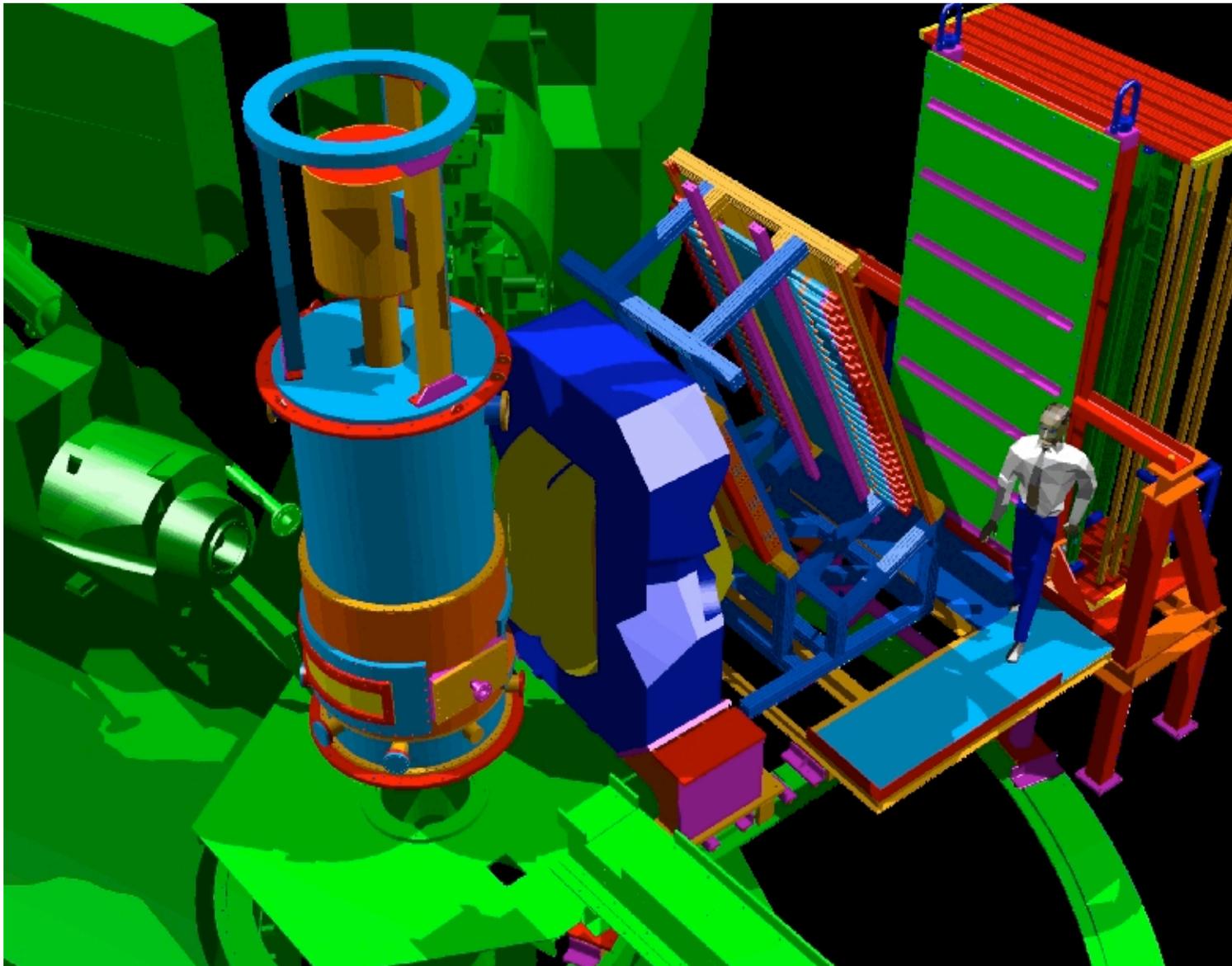
# Jefferson Lab's Hall A



Sixth International Conference on Perspectives in Hadronic Physics

Jefferson Lab

# New Equipment



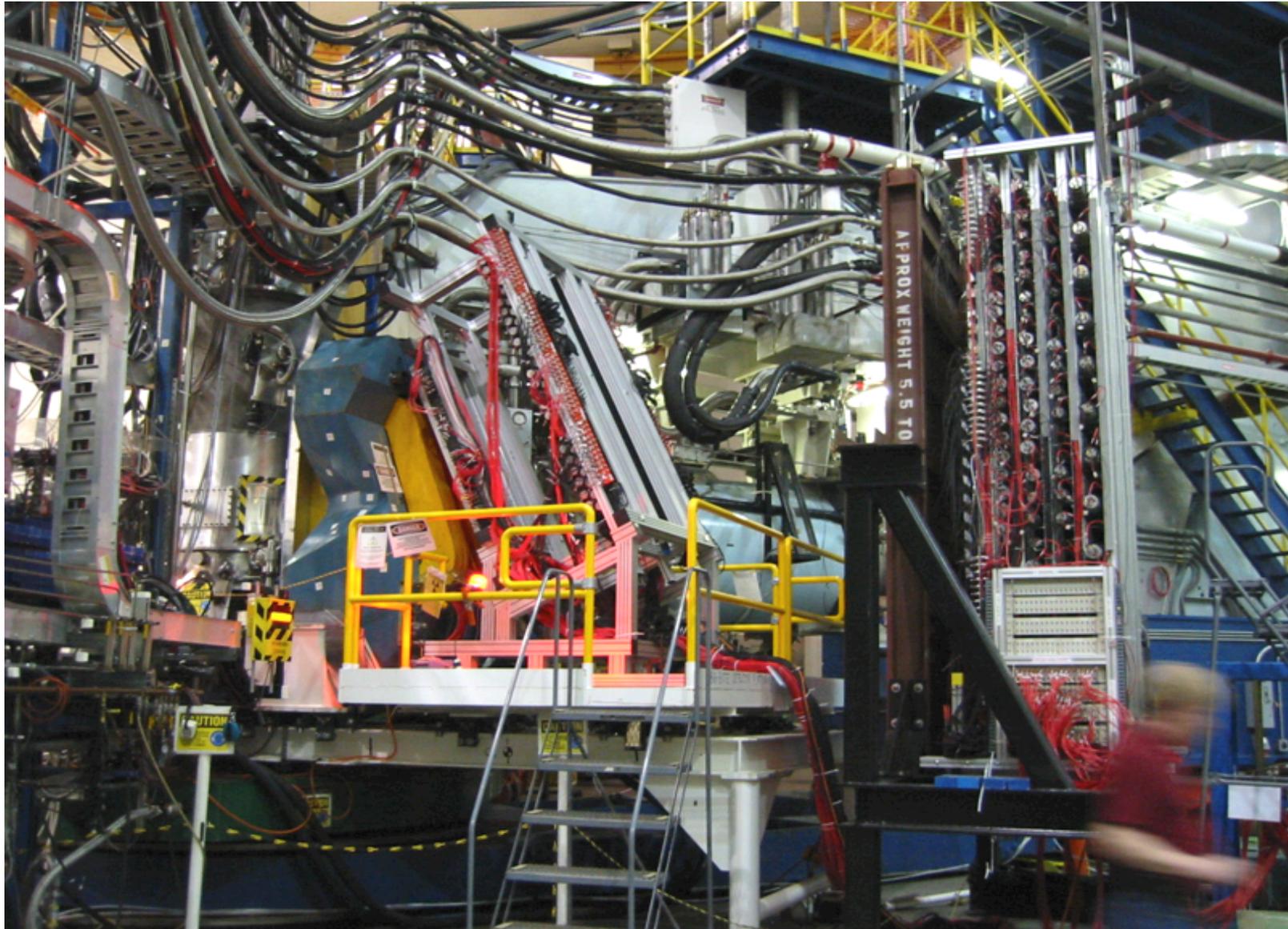
# Making BigBite & Neutron Detector



- 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*

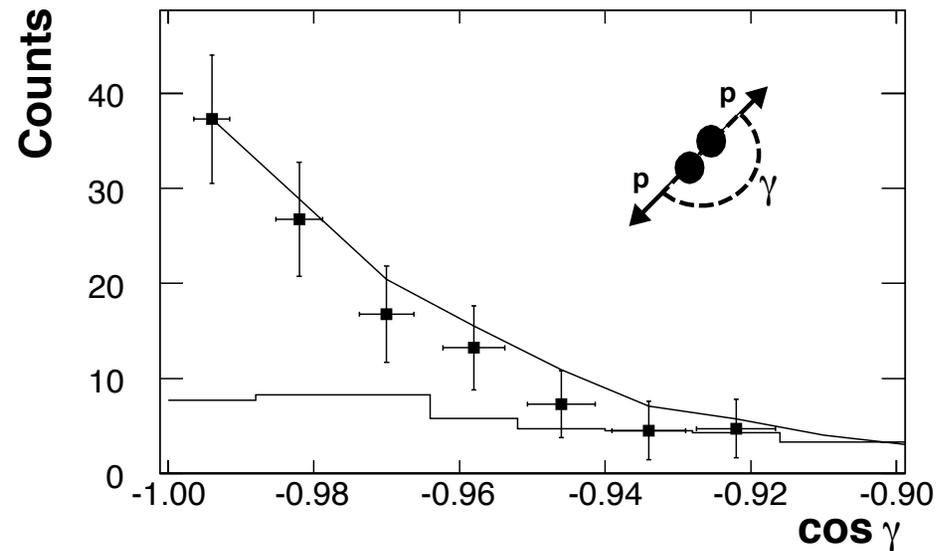
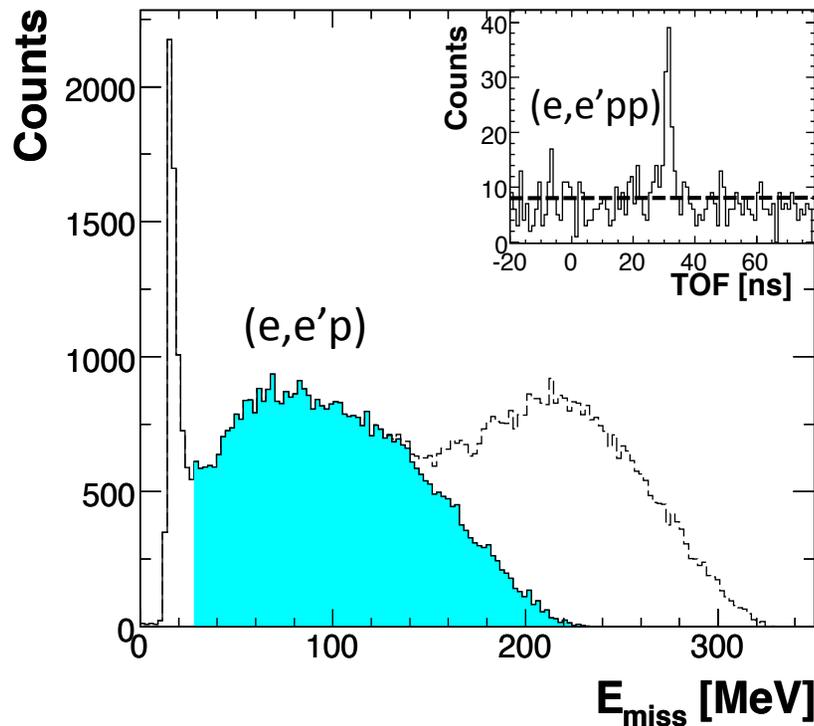


# Final Assembly



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

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



Strong back-to-back correlation!

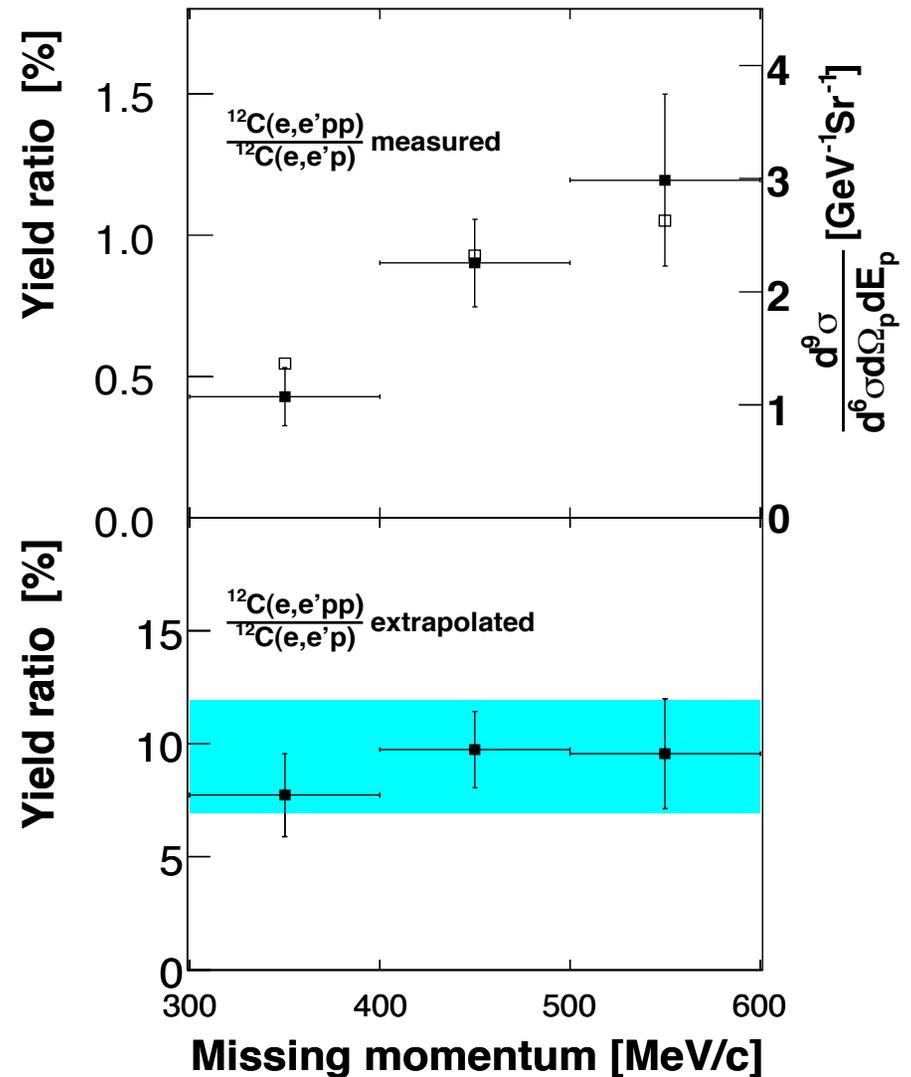
- $^{12}\text{C}(e,e'p)^{11}\text{B}$
- Quasi-Elastic Shaded In Blue
- Resonance Even at  $x_B > 1$



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

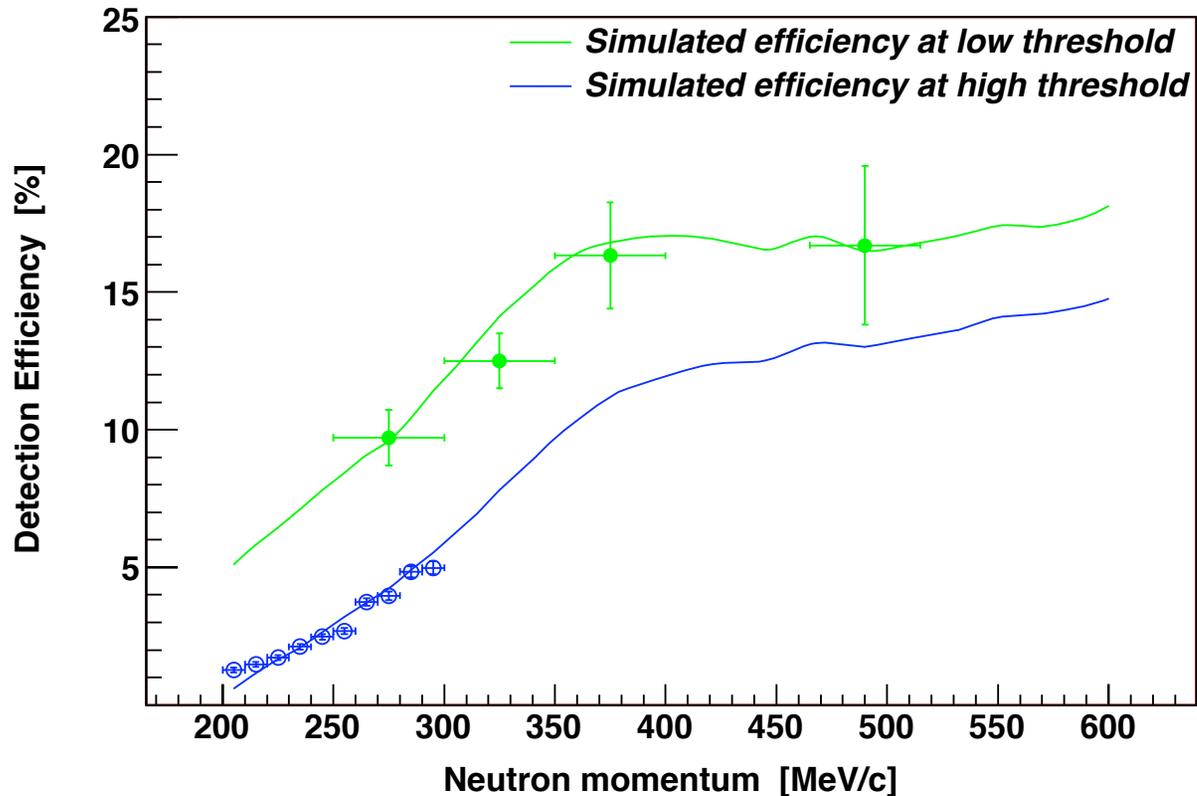
R. Shneor *et al.*, Phys. Rev. Lett. **99** (2007) 072501.

- 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  $136 \pm 20$  MeV/c and blue band indication two-sigma around this value.
- Note Brookhaven found  $143 \pm 17$  MeV/c



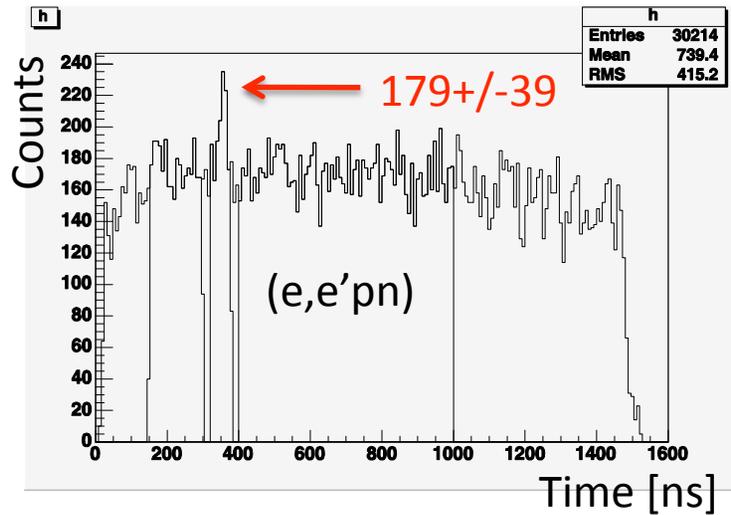
# (e,e'n): Absolute Neutron Detector Efficiency

- 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



# Ratio of np-SRC/pp-SRC

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

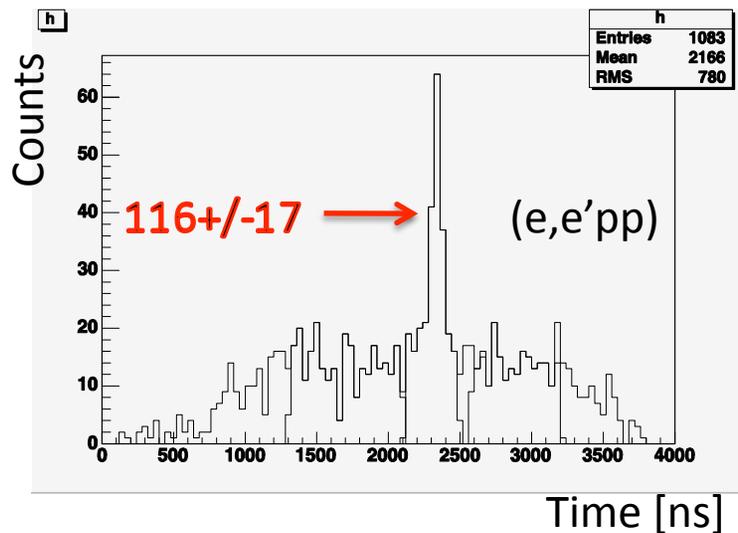


Corrected for detection efficiency:

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

Corrected for SCX (using Glauber):

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



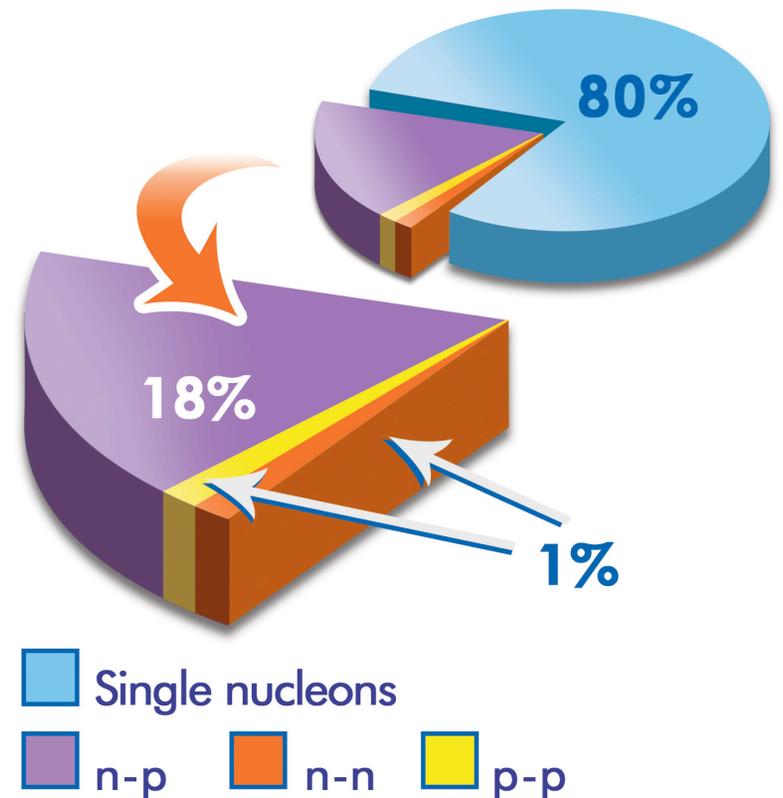
In Carbon:

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

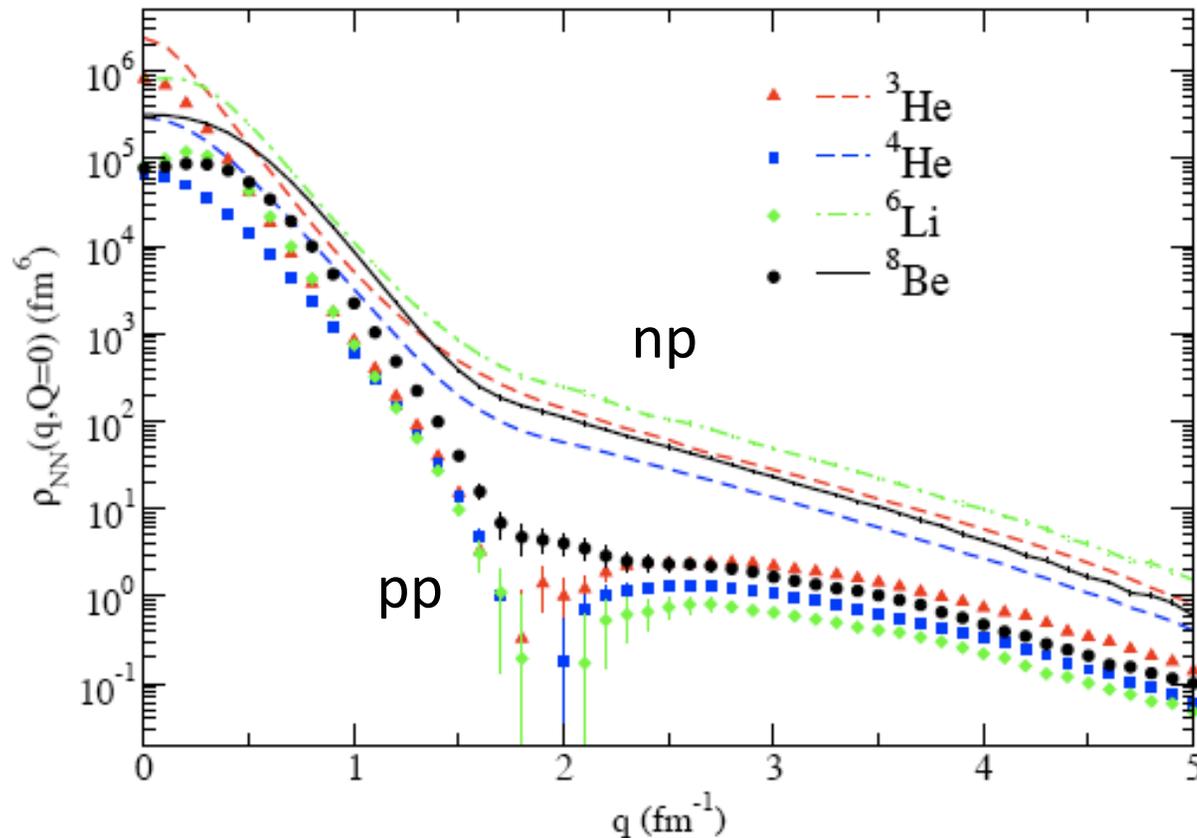


# From the $(e,e')$ , $(e,e'p)$ , and $(e,e'pN)$ Results

- 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



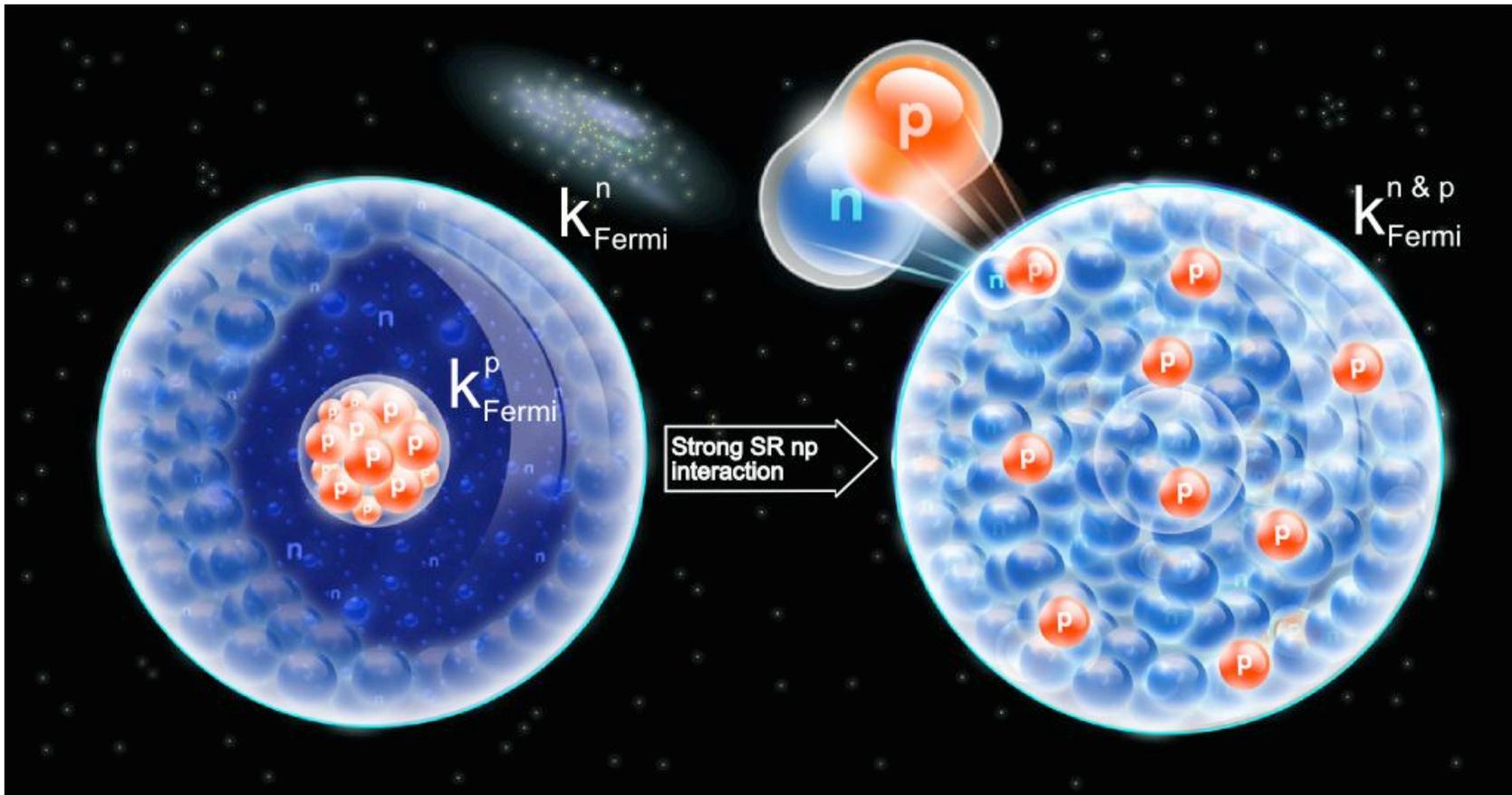
# Importance of Tensor Correlations



- 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

