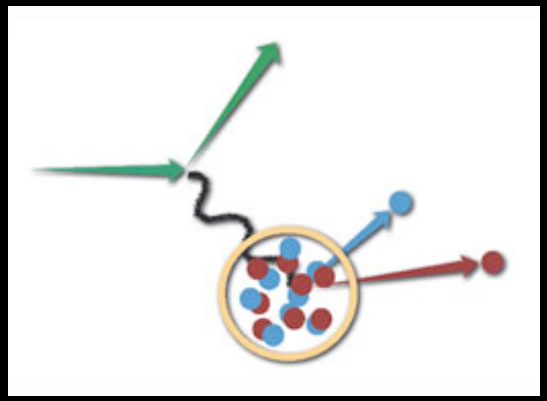
(e,e'pp) and (e,e'pn) and the role of correlations

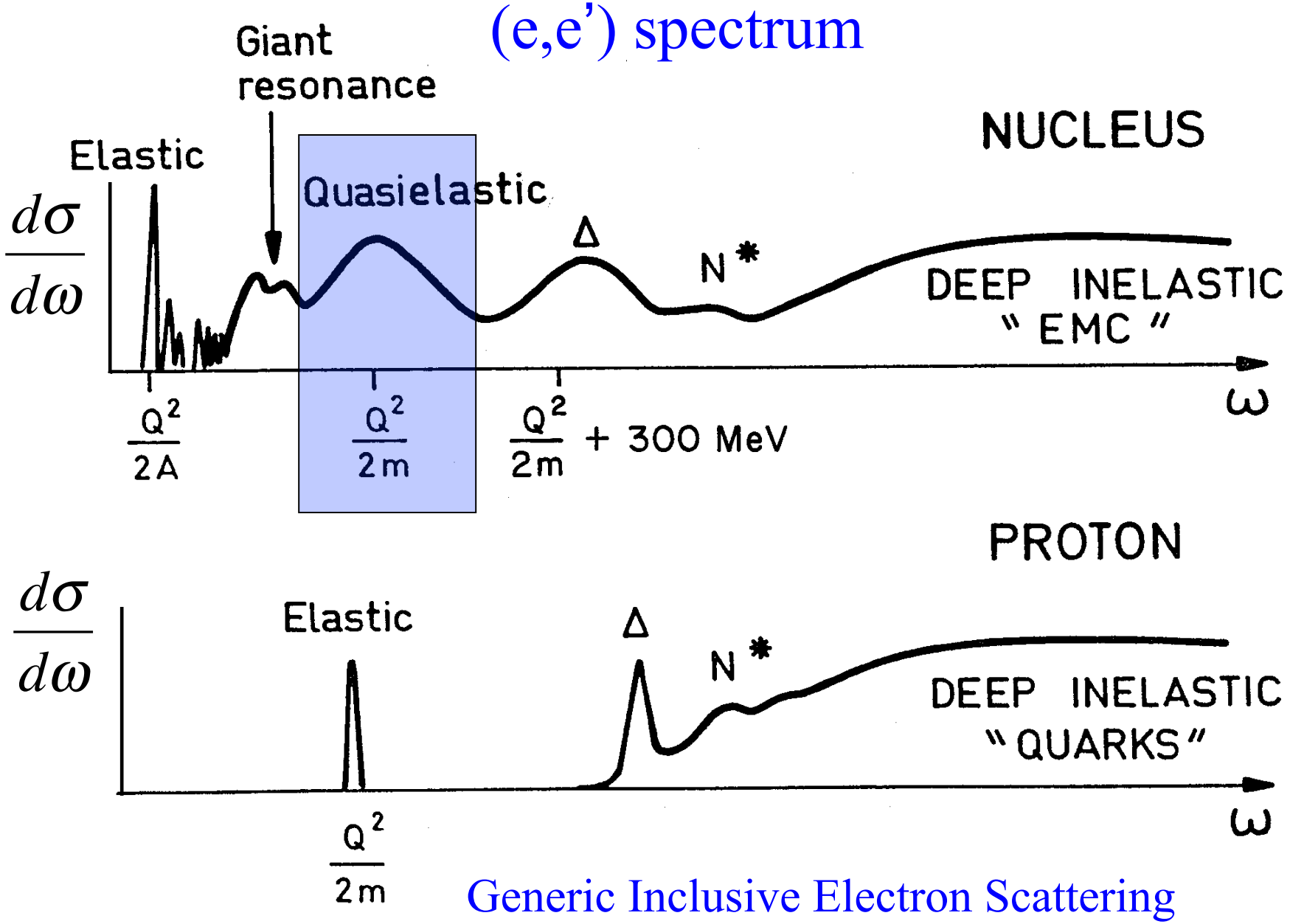
Lawrence Weinstein

Old Dominion University

- Nucleons One by One
- What are Correlations?
- How big are they?
- np vs pp pairs
- Summary



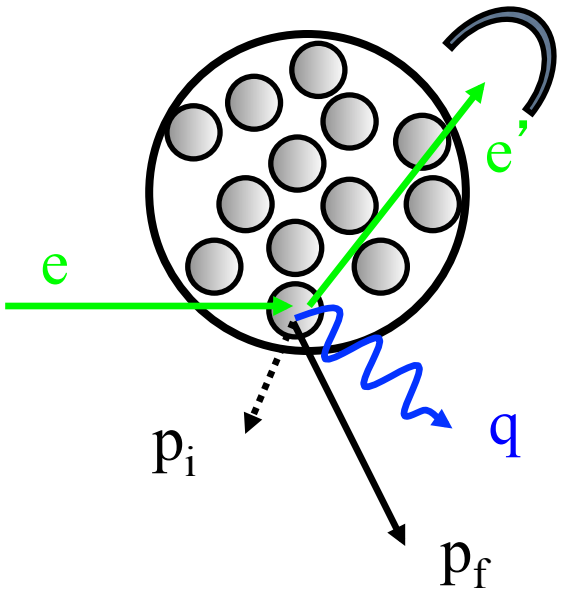
(e,e') spectrum



Generic Inclusive Electron Scattering
at fixed momentum transfer

Fermi gas model:

how simple a model can you make ?



Virtual photon:

Momentum q, energy ν

$$Q^2 = q_\mu q^\mu = |\vec{q}|^2 - \nu^2 > 0$$

Initial nucleon energy: $KE_i = p_i^2/2m$

Final nucleon energy: $KE_f = (\vec{q} + \vec{p}_i)^2/2m$

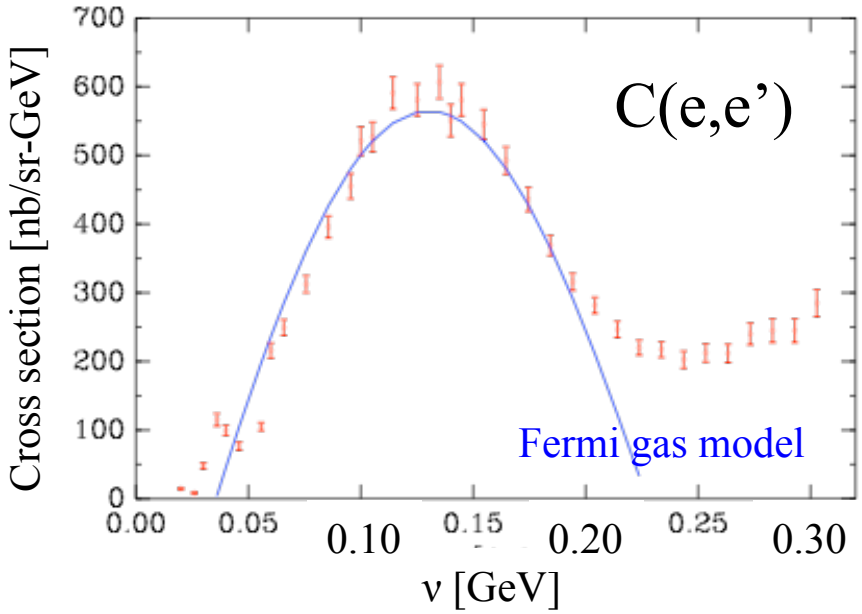
Energy transfer: $\nu = KE_f - KE_i = q^2/2m + (\vec{q}\cdot\vec{p}_i)/m$

➔Peak

Centroid: $\bar{\nu} = \vec{q}^2/2m$

Width: $\Delta\nu = (\vec{q}\cdot\vec{p}_i)/m$

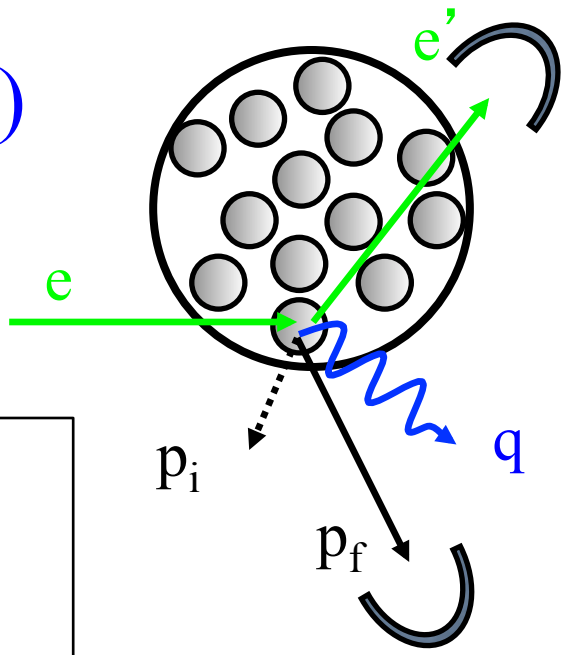
Cross section: $\sigma_{total} = Z\sigma_{ep} + N\sigma_{en}$



R.R. Whitney et al., PRC 9, 2230 (1974).

Get more information:

detect a knocked out nucleon (e,e'p)

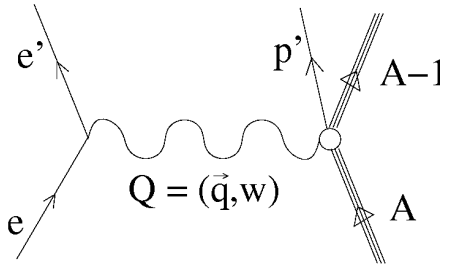


Missing energy: $E_{miss} = \nu - T_{p'} - T_{A-1}$

Missing momentum: $\vec{p}_{miss} = \vec{q} - \vec{p}_f$

No proton rescattering ➔ $\vec{p}_i = -\vec{p}_{miss}$

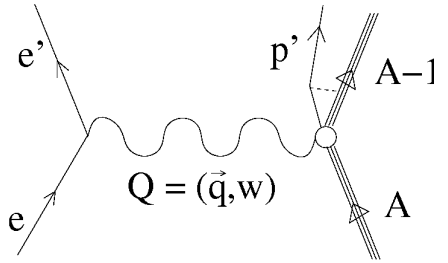
$$\frac{d\sigma}{d\nu d\Omega_e dE_{miss} d\Omega_p} = KS(p_i, E_{miss}) \frac{d\sigma_{ep}}{d\Omega}$$



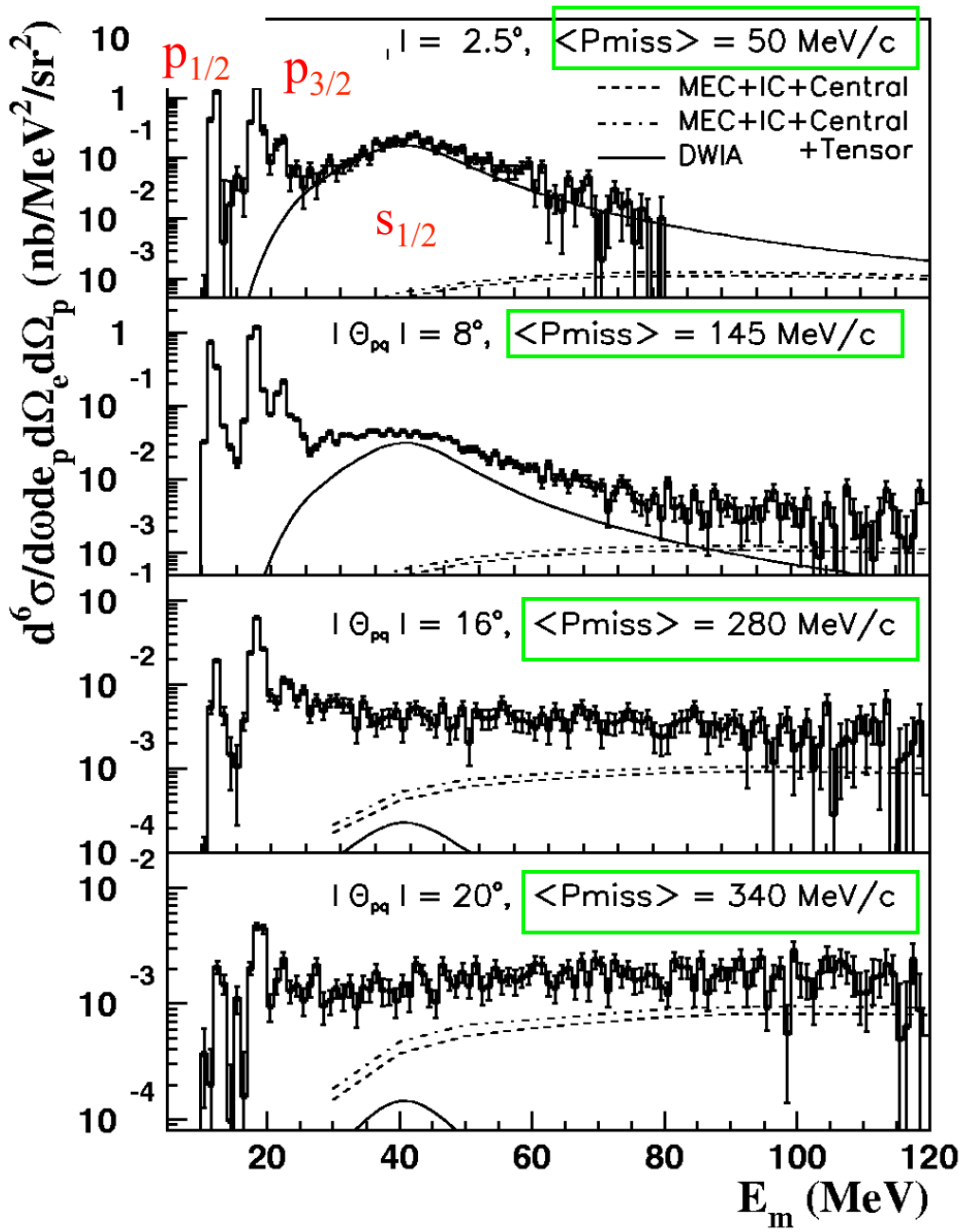
Spectral fn S = probability of finding a proton with momentum p_i and binding energy E_{miss}

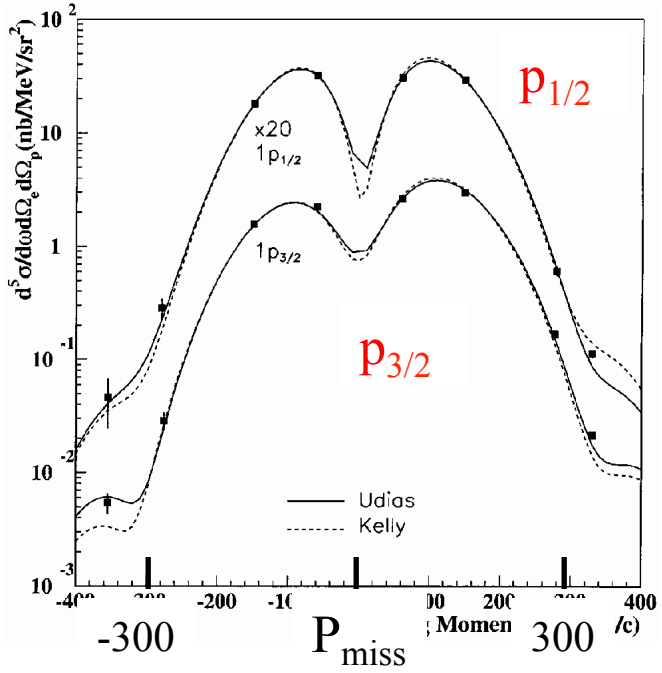
Proton rescattering $\vec{p}_i \approx -\vec{p}_{miss}$

➔ Distorted spectral fn



O(e,e'p) shells



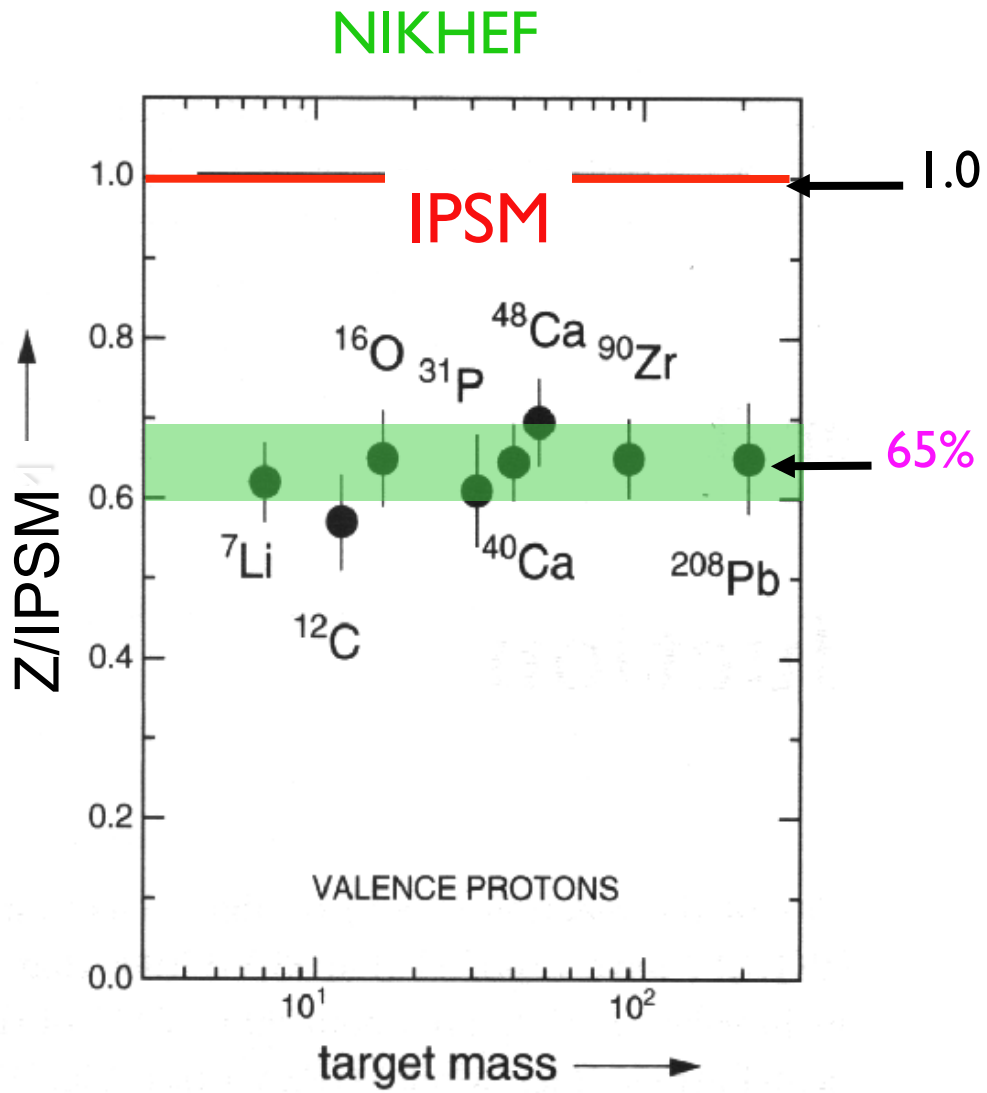


$1p_{1/2}$, $1p_{3/2}$ and $1s_{1/2}$ shells visible

Momentum distribution as expected for $L = 0, 1$

Fissum et al, PRC 70, 034606 (2003)

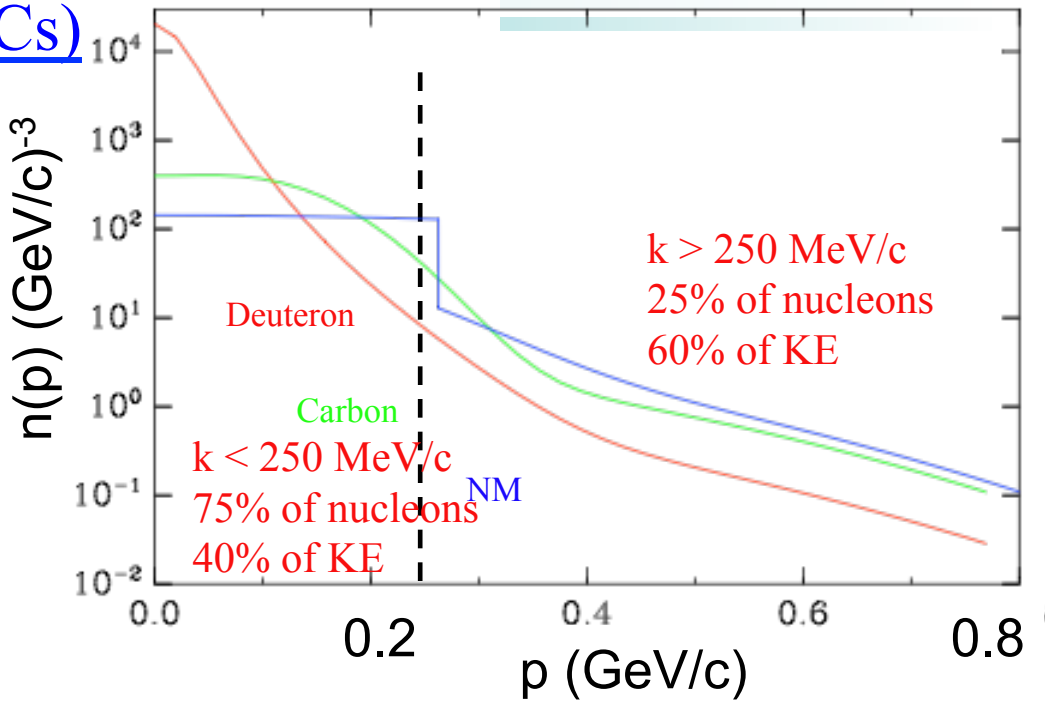
But we do not see enough protons!



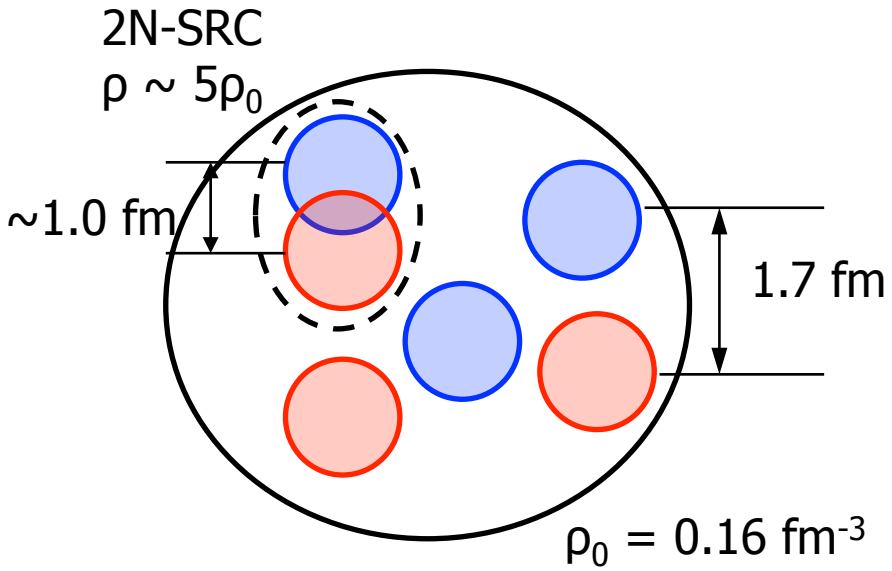
Short Range Correlations (SRCs)

➔High momentum tails: $k > k_F$

Calculable for $A \leq 12$ nuclei and nuclear matter.
Not well constrained at $k >> k_f$

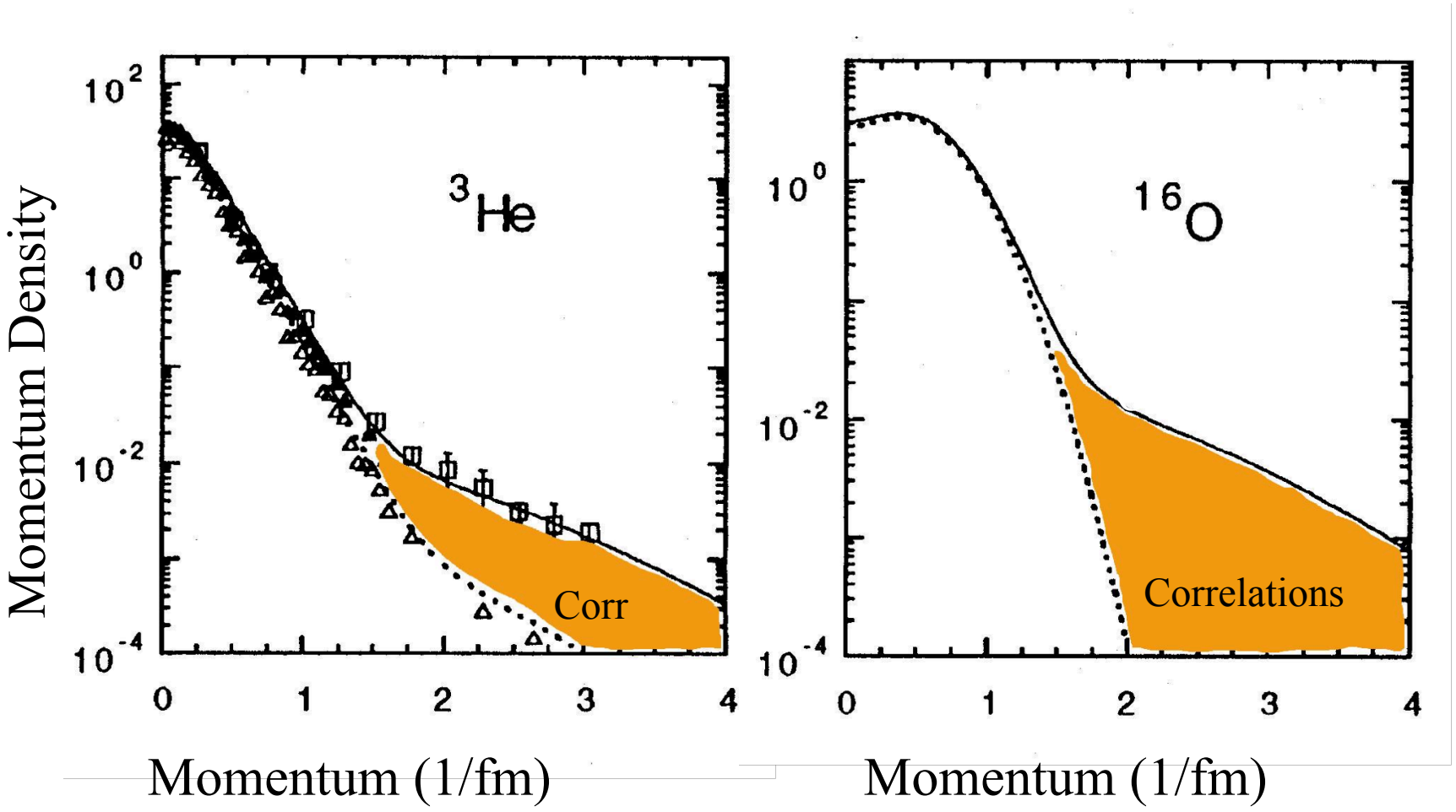


Effects:
- High momentum part of the nuclear wave function
- Short distance behavior of nucleons - modification??
- Cold dense nuclear matter
- Neutron Stars



Nucleons are like people …

Correlations and High Momentum

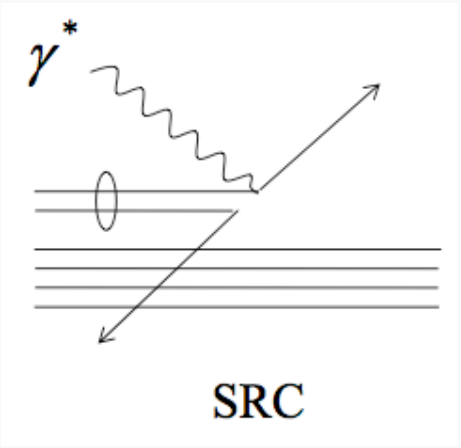


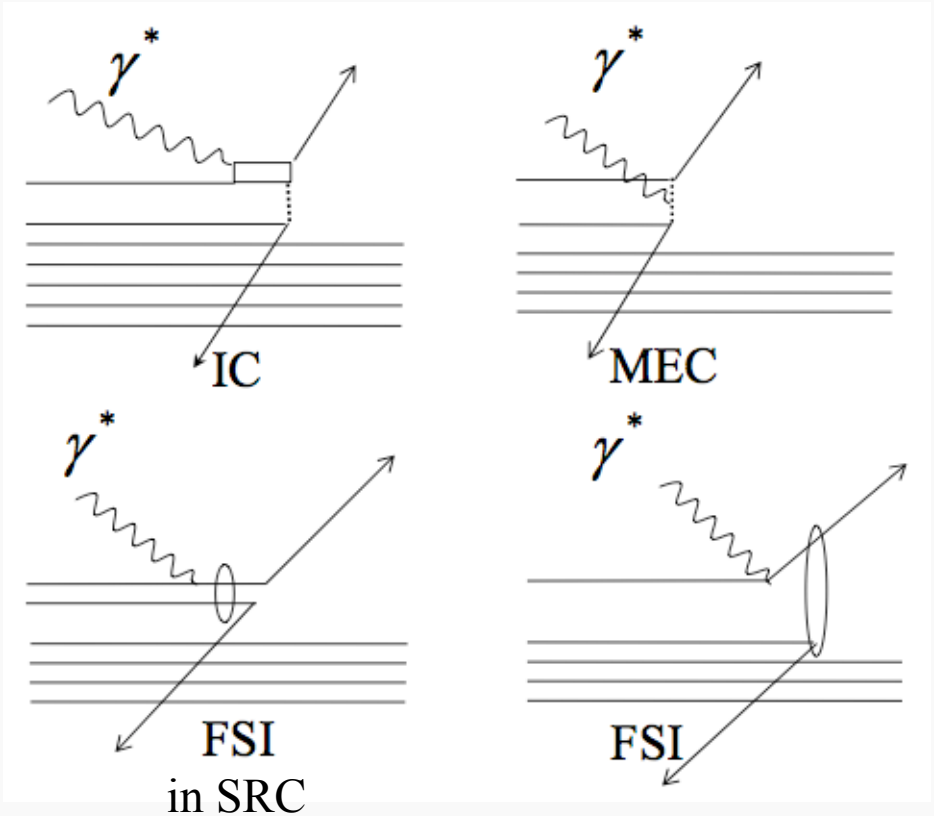
Ciofi degli Atti, PRC 53 (1996) 1689

What are correlations?

Average Two-Nucleon Properties in the Nuclear Ground State

Two-body currents are not Correlations
(but add coherently)

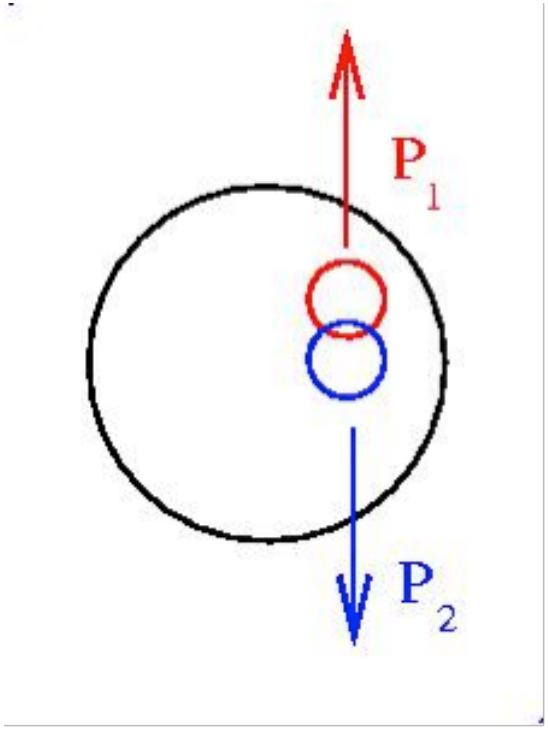




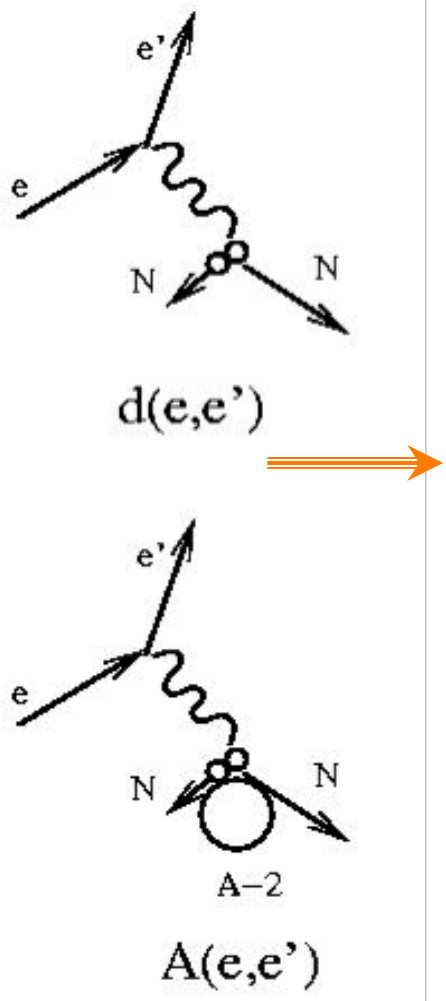
Signatures for Correlations

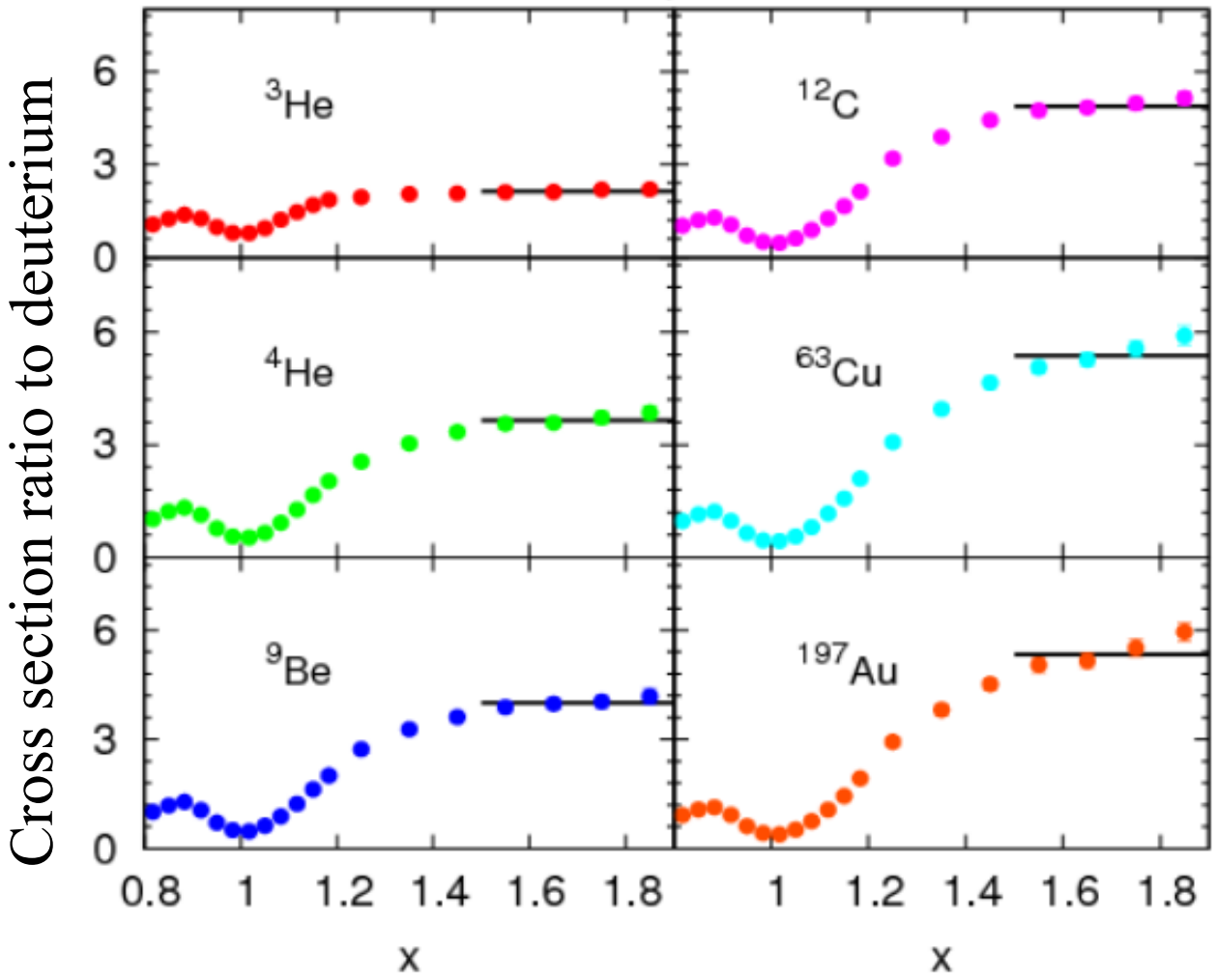
An Experimentalist's Definition:

- A high momentum nucleon whose momentum is balanced by **one** other nucleon
  - NN Pair with
    - Large Relative Momentum
    - Small Total Momentum



Correlations are Universal: A(e,e')





Scaling (flat ratios) indicates a common momentum distribution.

1 < x < 1.5: dominated by different mean field n(k)

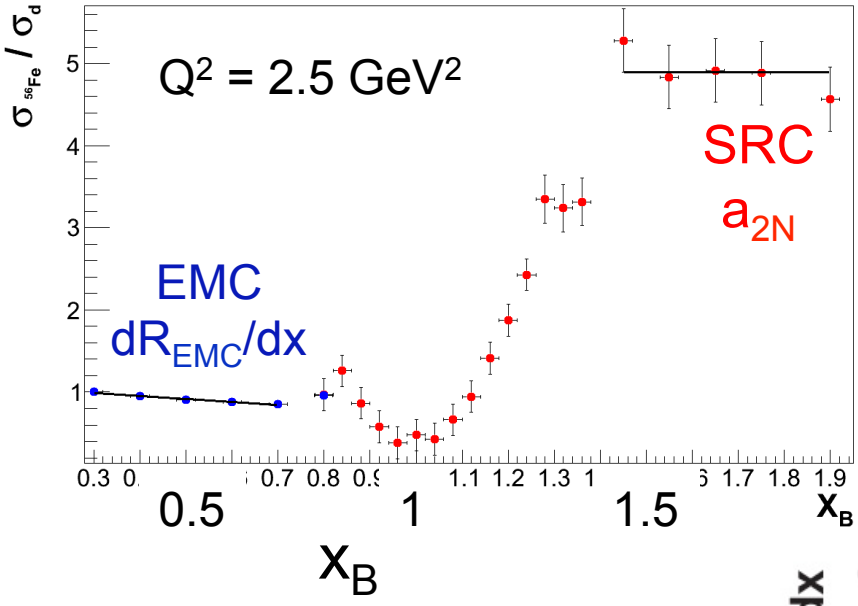
1.5 < x < 2: dominated by 2N SRC

$\alpha_{2N} \approx 20\%$

$x = Q^2 / 2m\nu$

N. Fomin et al, PRL 108, 092502 (2012)

SRC and the EMC Effect

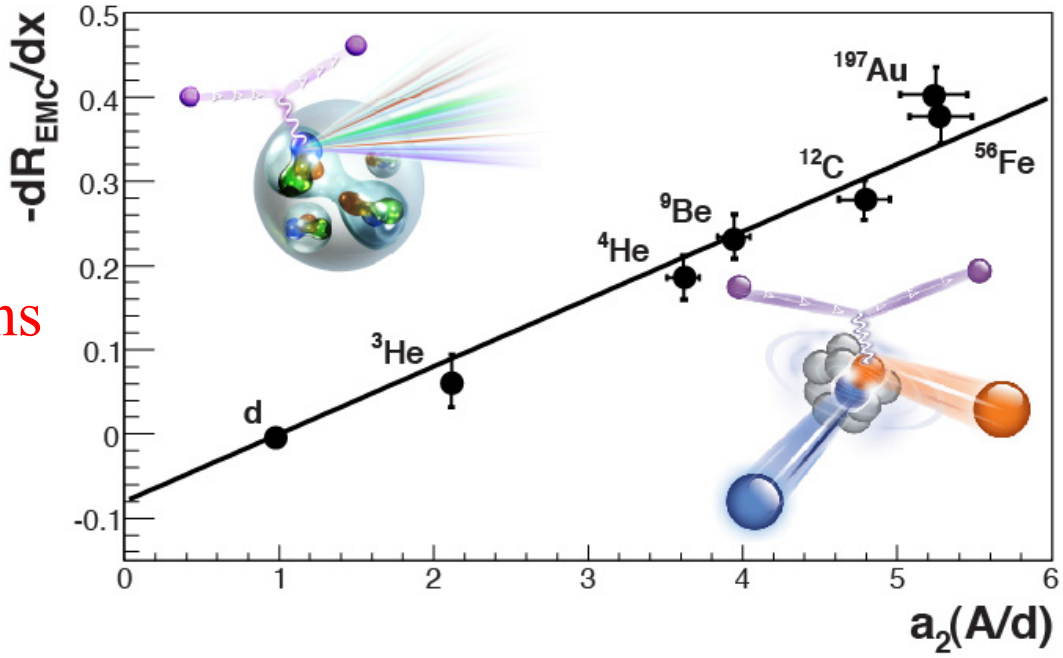


EMC effect: reduction of the per-nucleon DIS cross section relative to deuterium at $0.3 < x_B < 0.7$

- Implies nucleon modification

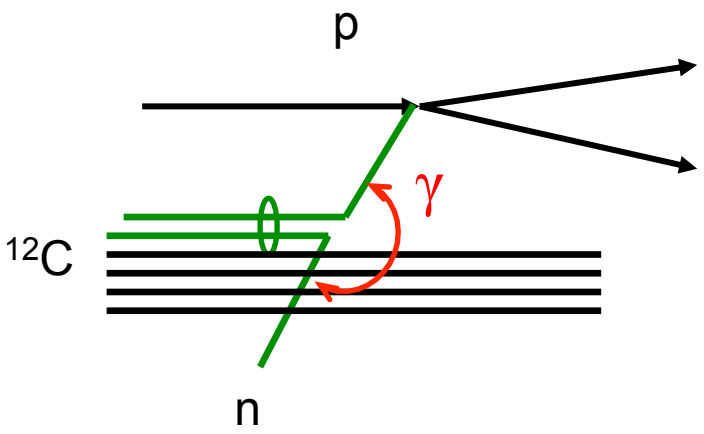
EMC effect and SRC are both due to high momentum nucleons

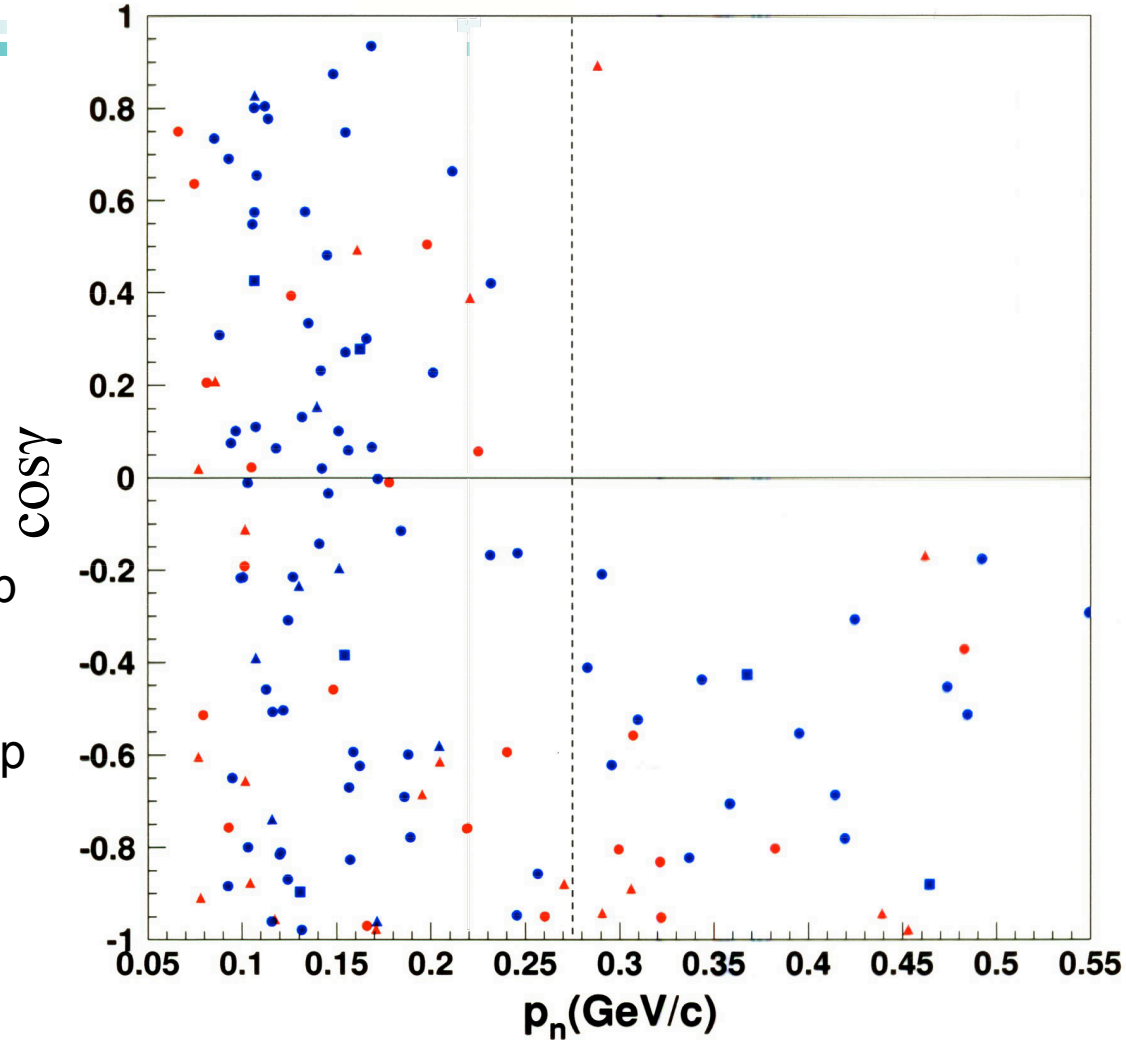
➢ nucleon modification due to nucleon motion?



PRL **106**, 052301 (2011)

^{12}C(p,ppn) EVA/BNL





Large neutron momentum ⟶ *n* opposite p_{init}

Small neutron momentum ⟶ *n* isotropic

High momentum nucleons are paired

Tang et al, PRL 90, 042301 (2003)

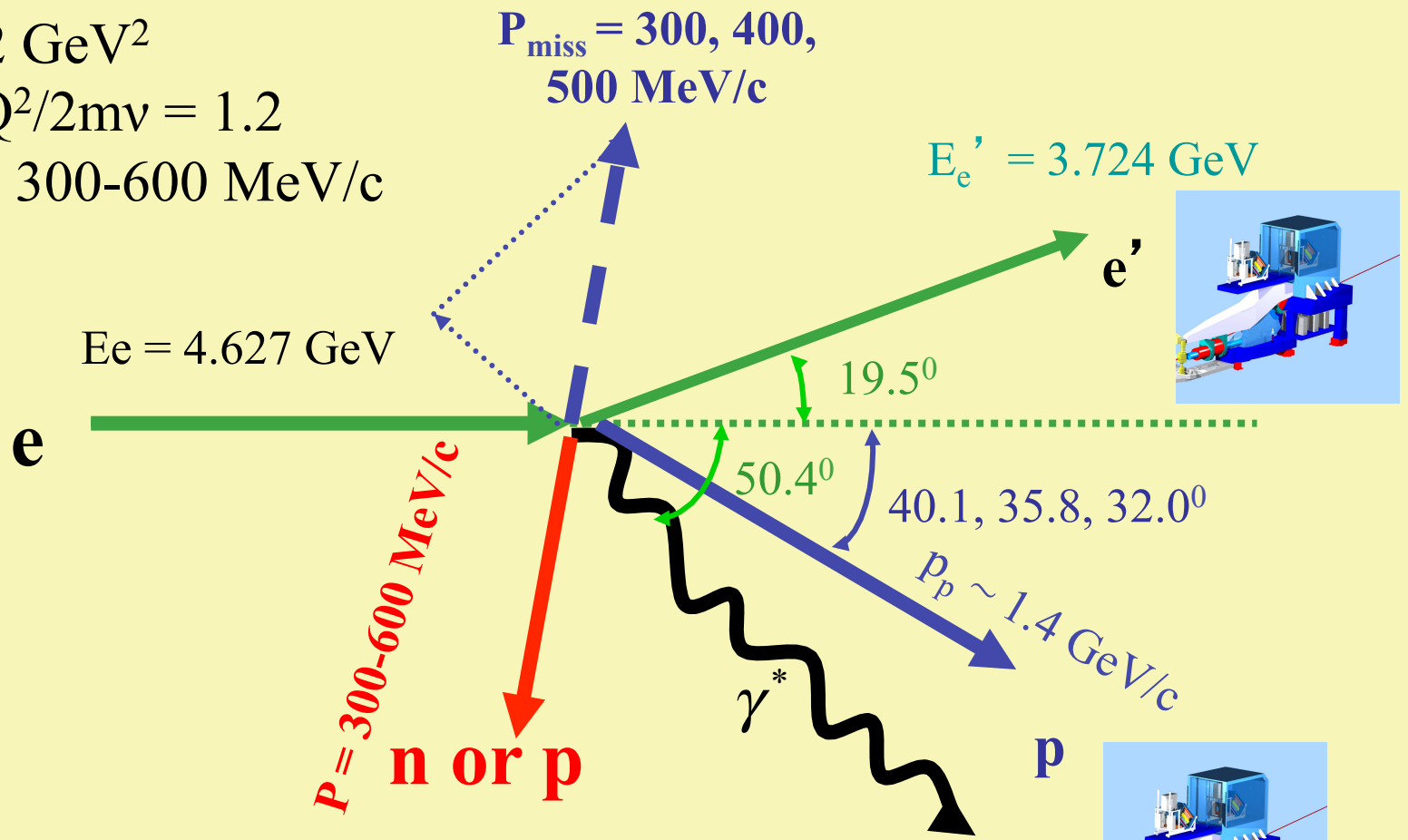
Jefferson Lab Site

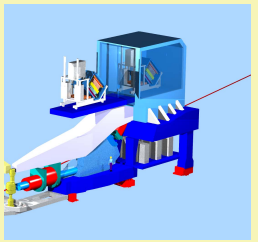
Now detect yet another nucleon
JLab Hall A C(e,e'pN) - selected kinematics

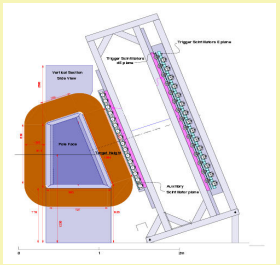
$Q^2 = 2$ GeV^2

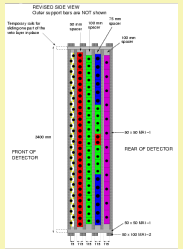
$x_B = Q^2/2m\nu = 1.2$

$P_{miss} = 300\text{-}600$ MeV/c









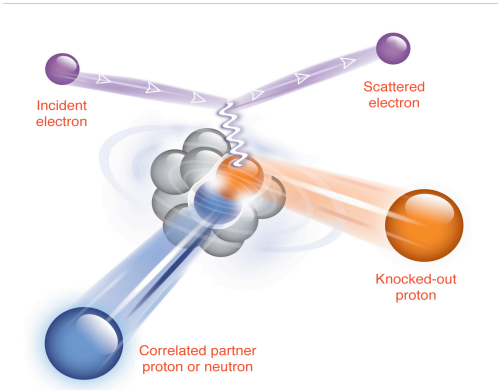
Detect the proton,
look for its partner nucleon

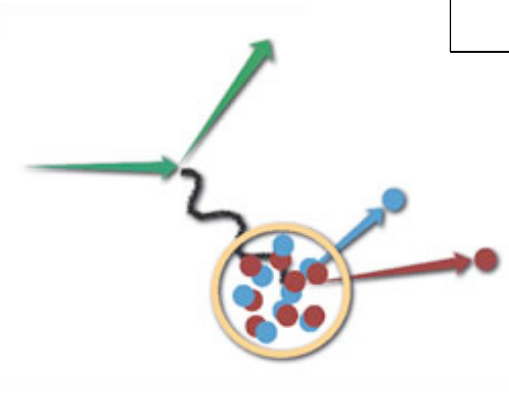
High momentum protons have partners
C(e,e'pN)

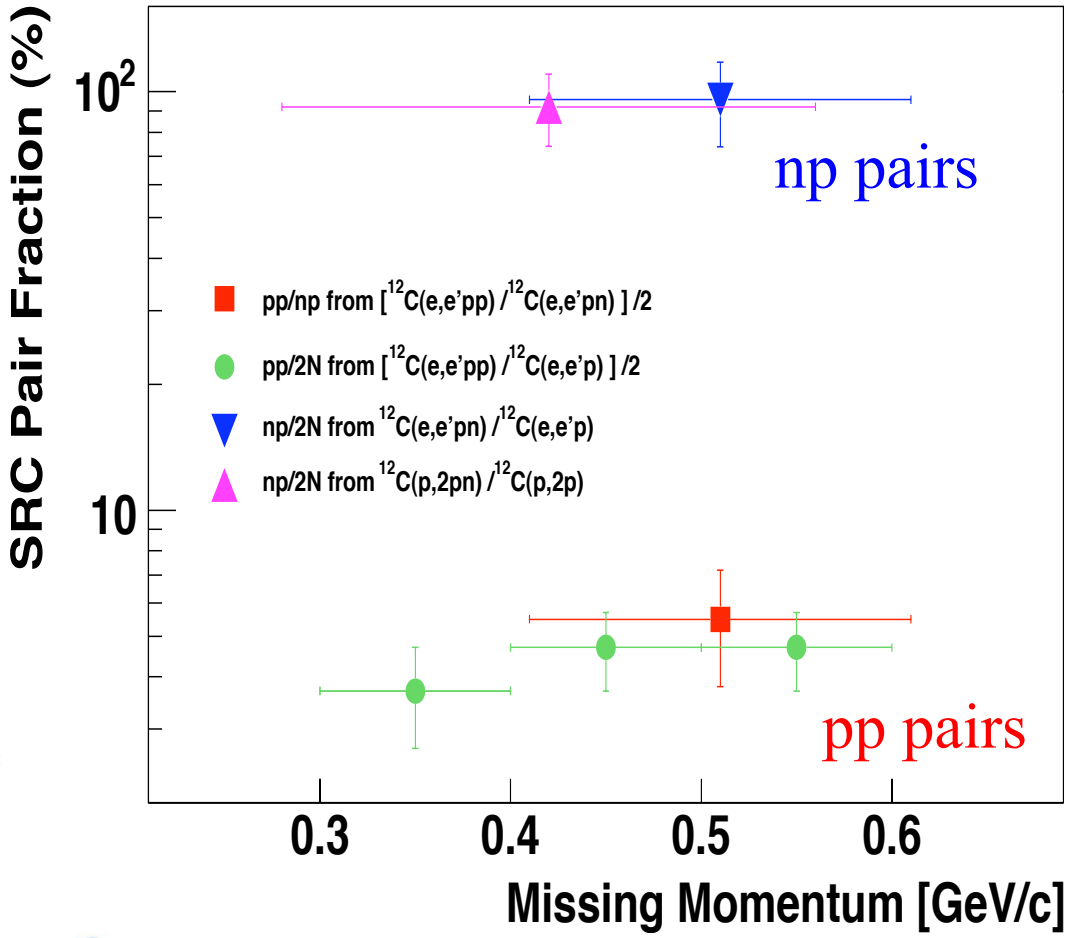
- Detect the knocked-out proton
- Look for its partner nucleon
- All high momentum protons have partners

➔ np pairs dominate at

$0.3 < p_i < 0.6$

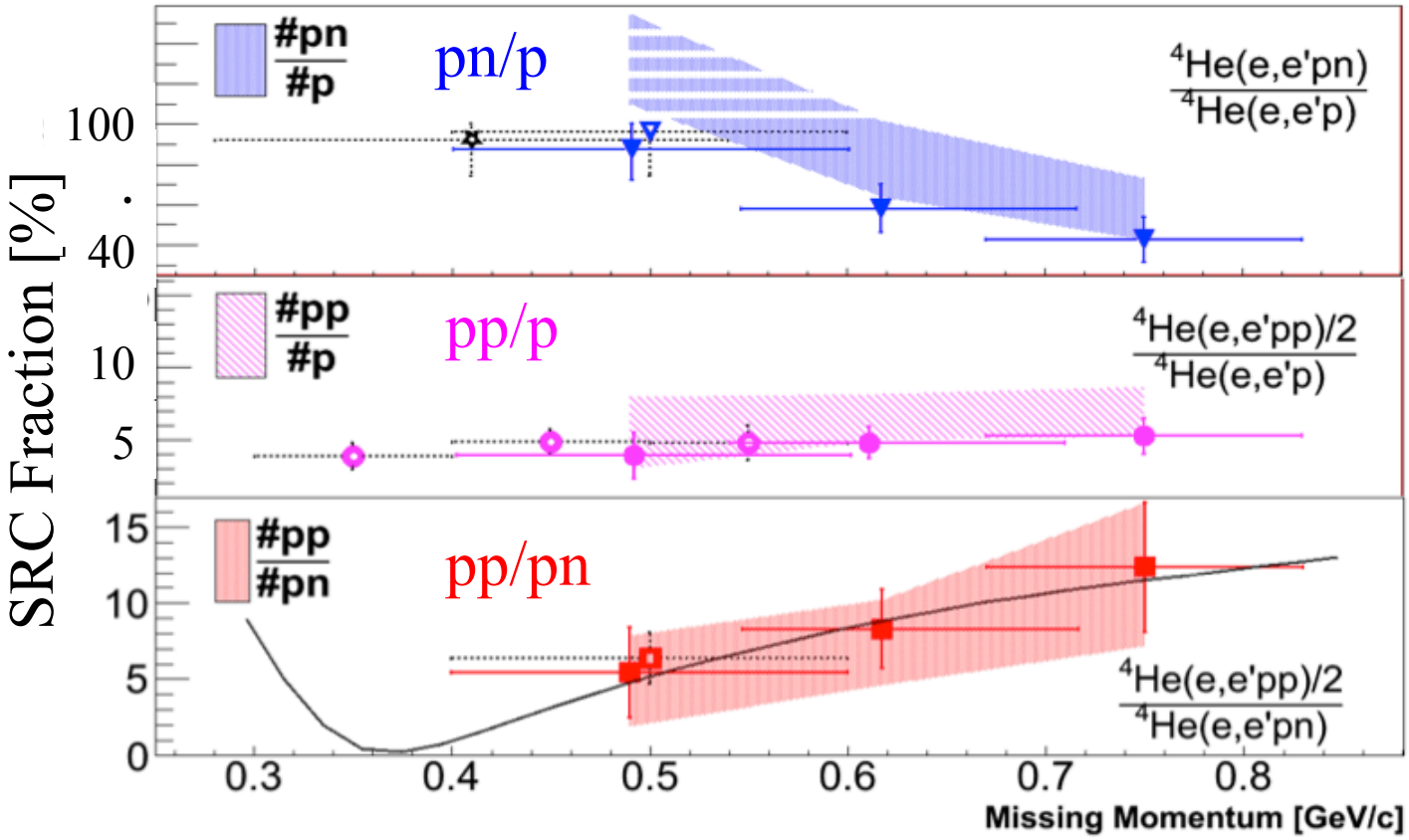






R. Subedi et al., Science 320, 1476 (2008)

Higher momentum protons?
^{4}He(e,e'pN)



- pp pairs still only 5% of high momentum protons
- np pairs decrease with missing momentum
- Three nucleon correlations???

I. Korover et al., arXiv:1401.6138

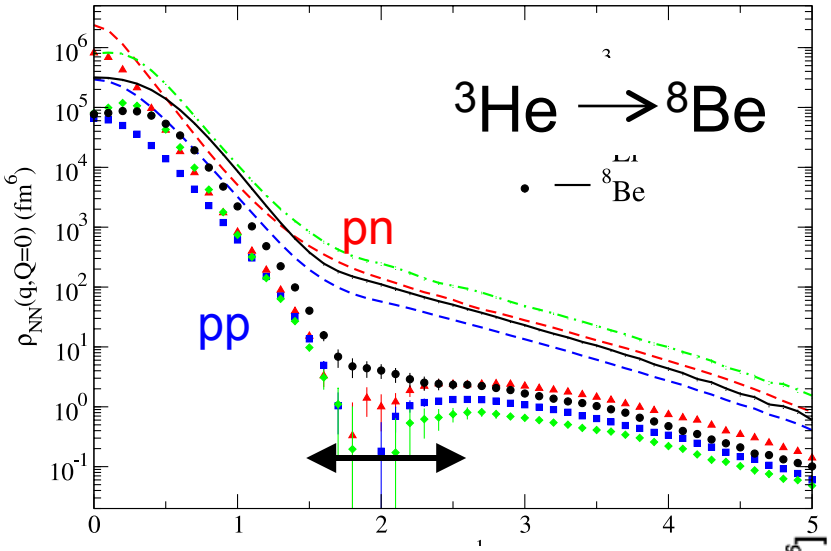
The ratio of pp-SRC / pn-SRC pairs in ^{12}C

There are 18 ± 2 times more np-SRC than pp-SRC pairs in ^{12}C.

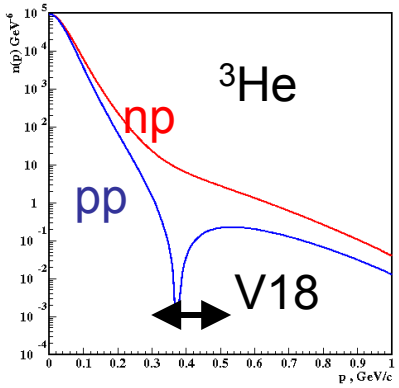
Why ?

At p_{rel} = 300-500 MeV/c the s-wave momentum distribution has a minimum

The *np* minimum is filled in by strong tensor correlations

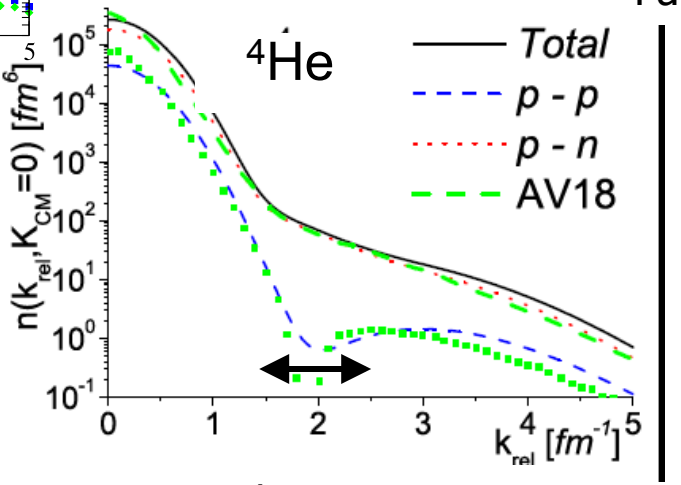


Pair relative momentum

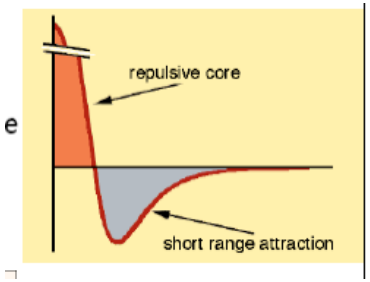


Pair relative momentum

Schiavilla, Wiringa, Pieper, Carlson, PRL **98**, 132501 (2007).



Pair relative momentum

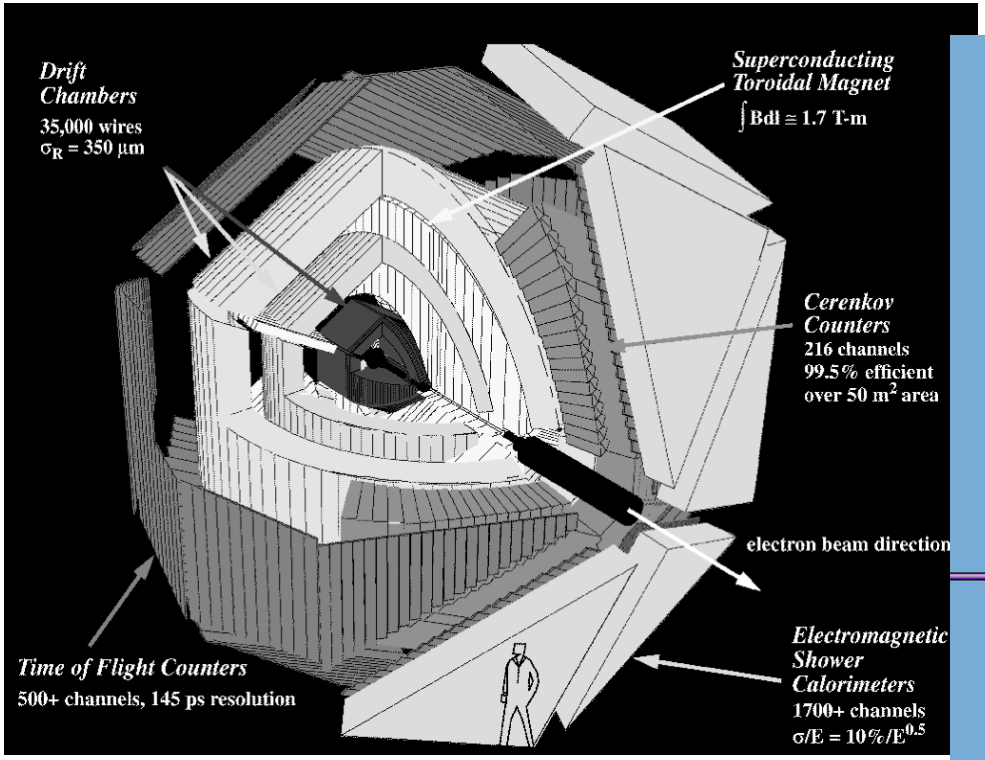


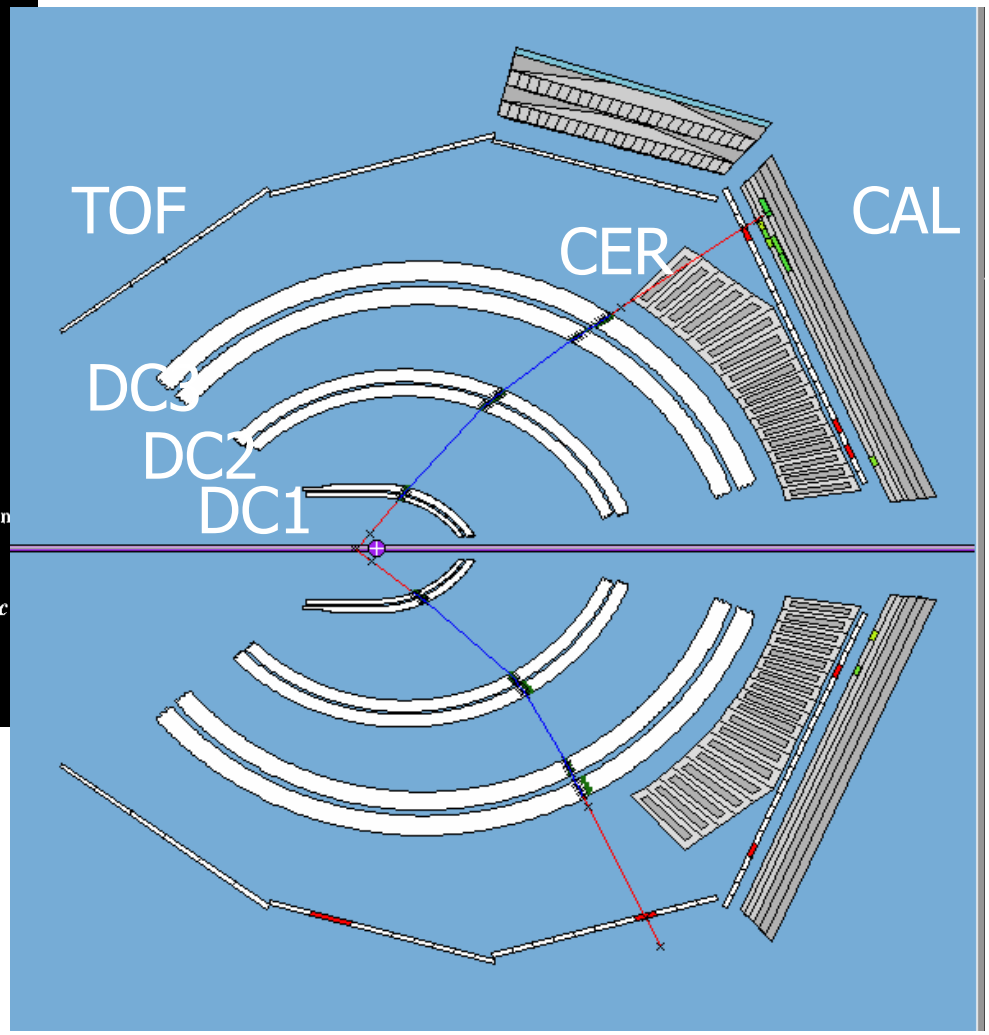
Ciofi and Alvioli
Gent workshop, Aug. 2007

Sargsian, Abrahamyan, Strikman, Frankfurt
PRC **71,** 044615 (2005).

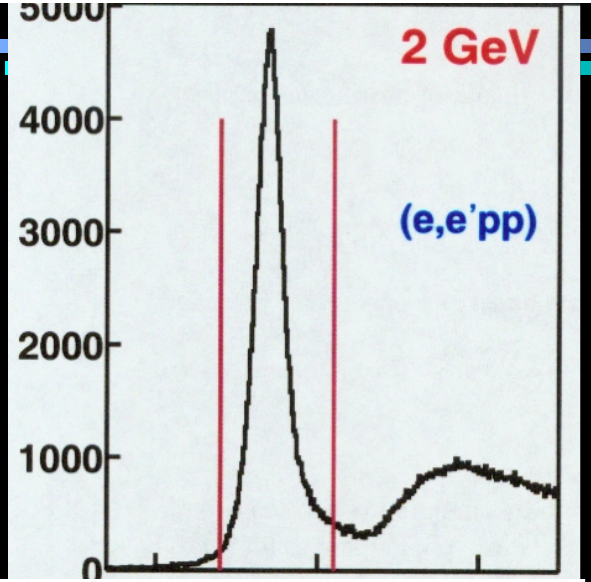
^{3}He(e,eX) in JLab CLAS

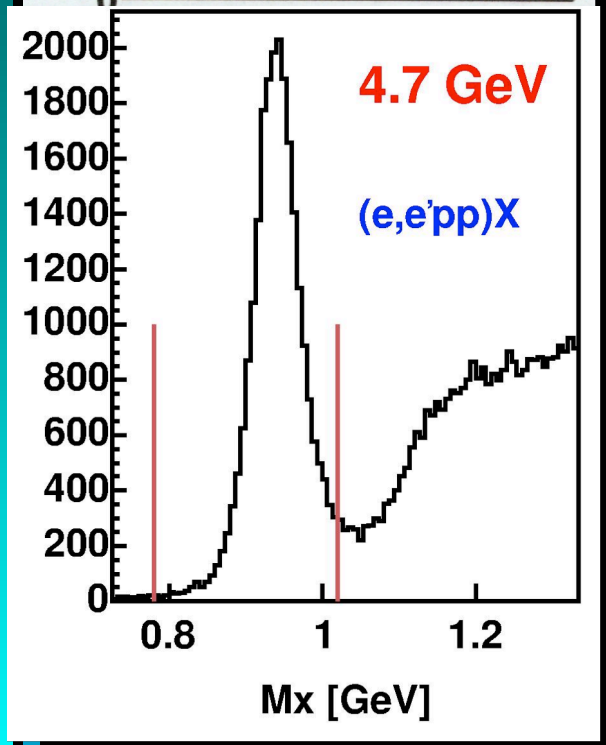
- 2.2 and 4.7 GeV electrons
- Inclusive trigger
- Almost 4π detector





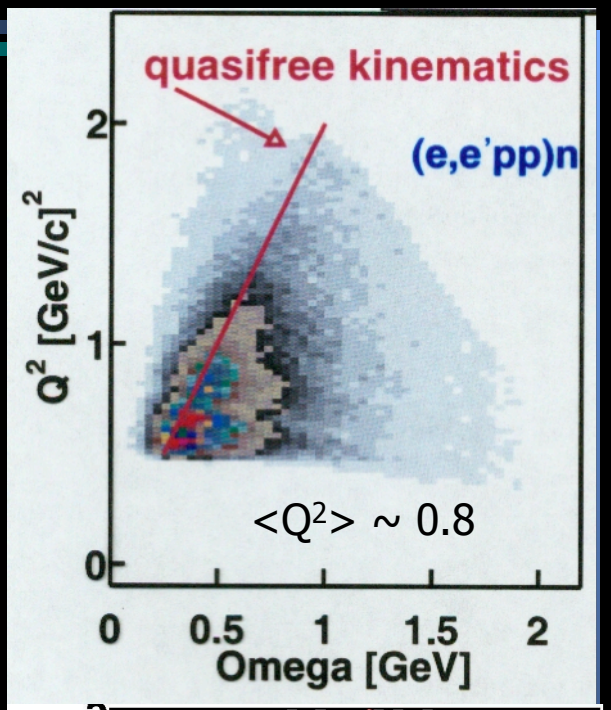
CLAS
^{3}He(e,e'pp)

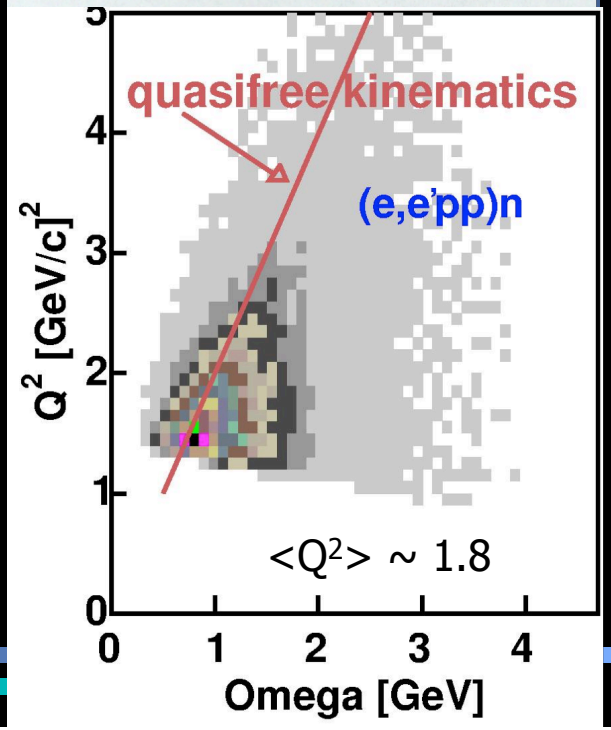




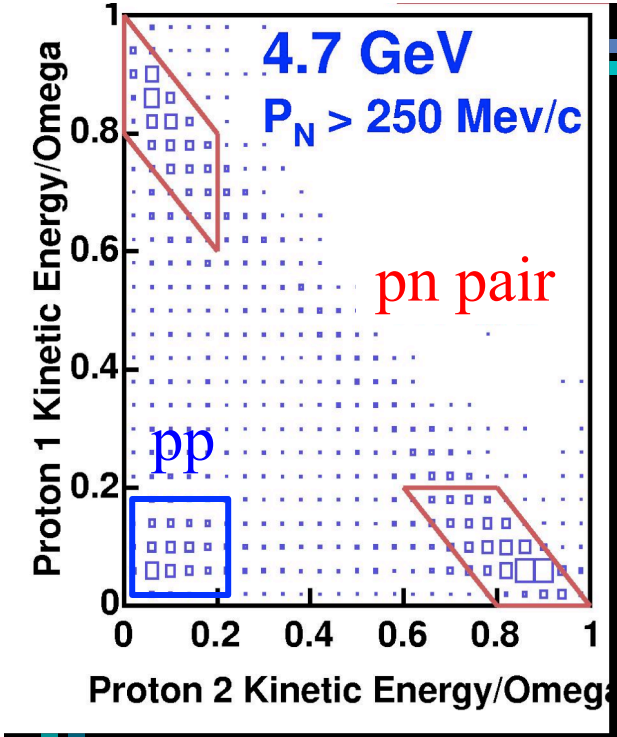
Detect 2 protons, reconstruct the neutron

Huge electron acceptance

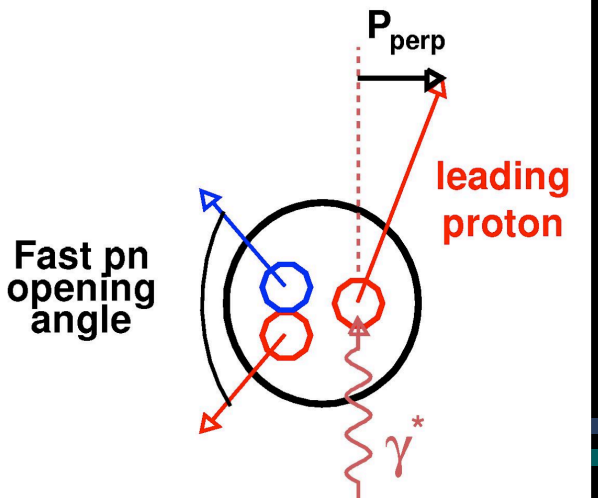


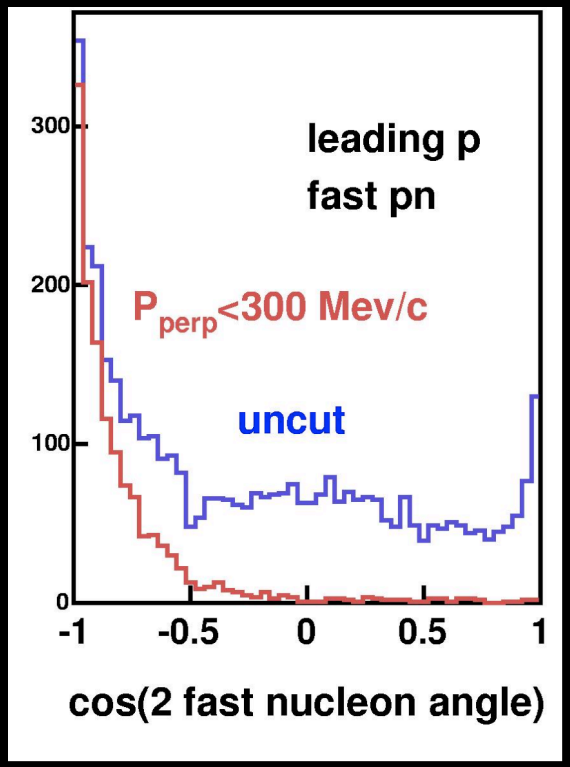


3He(e,e'pp)n nucleon energy balance

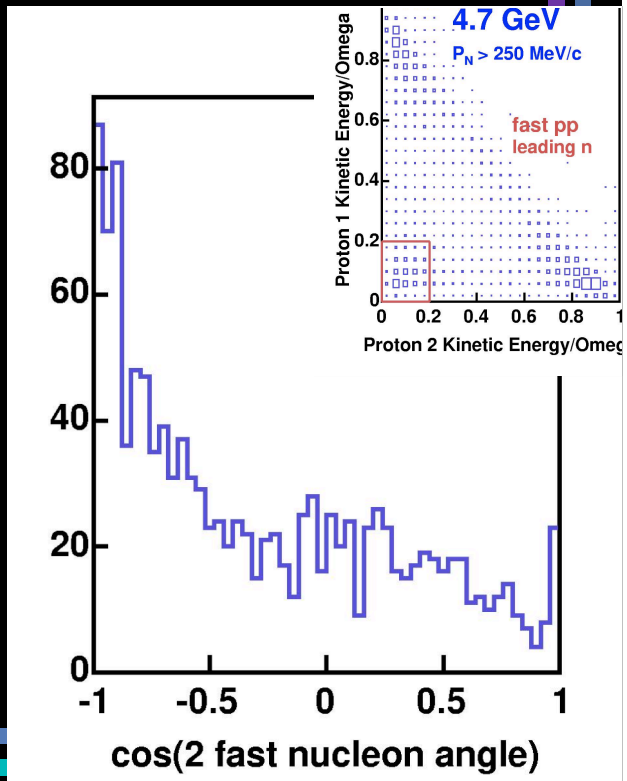


Select peaks in Dalitz plot





Pair has back-to-back peak!

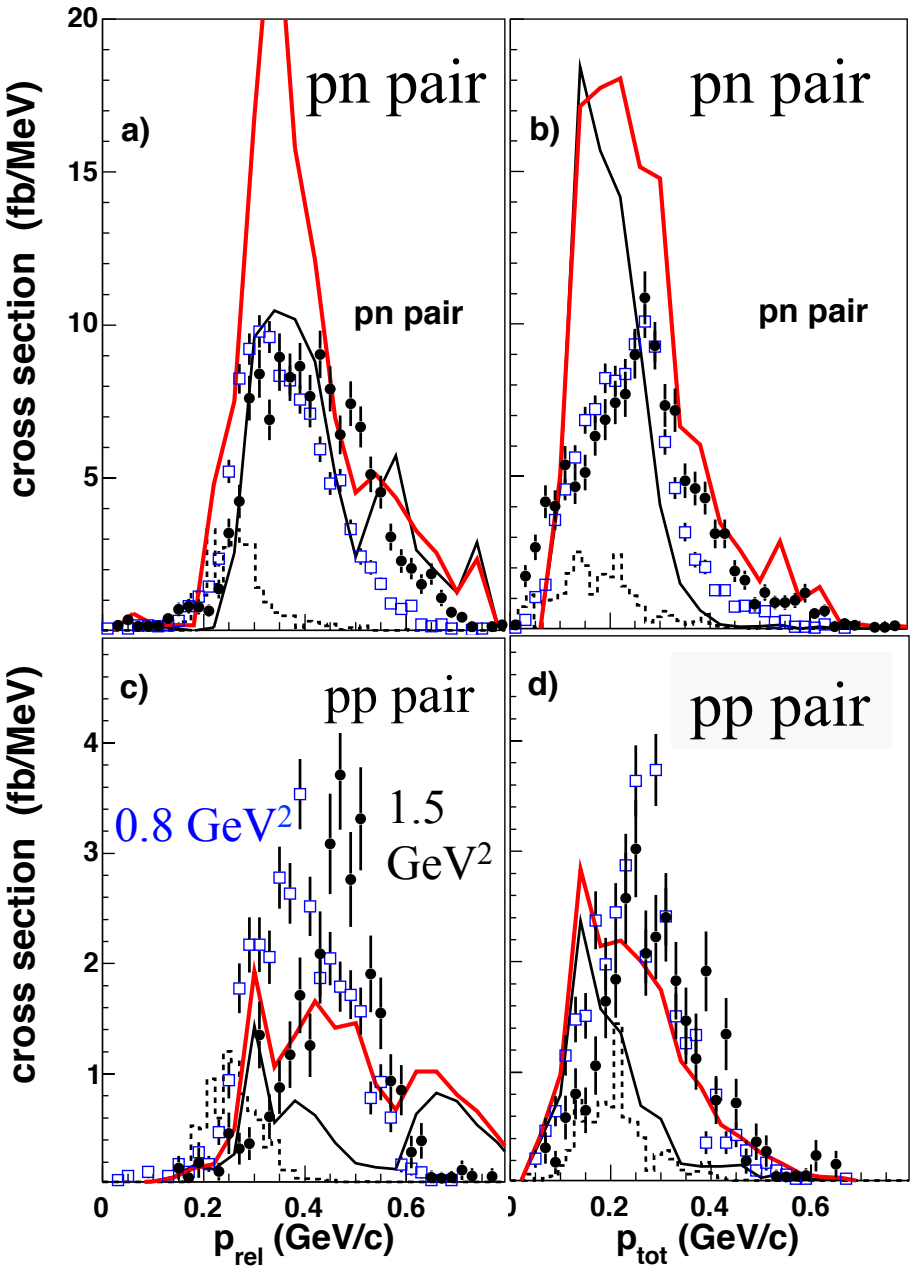


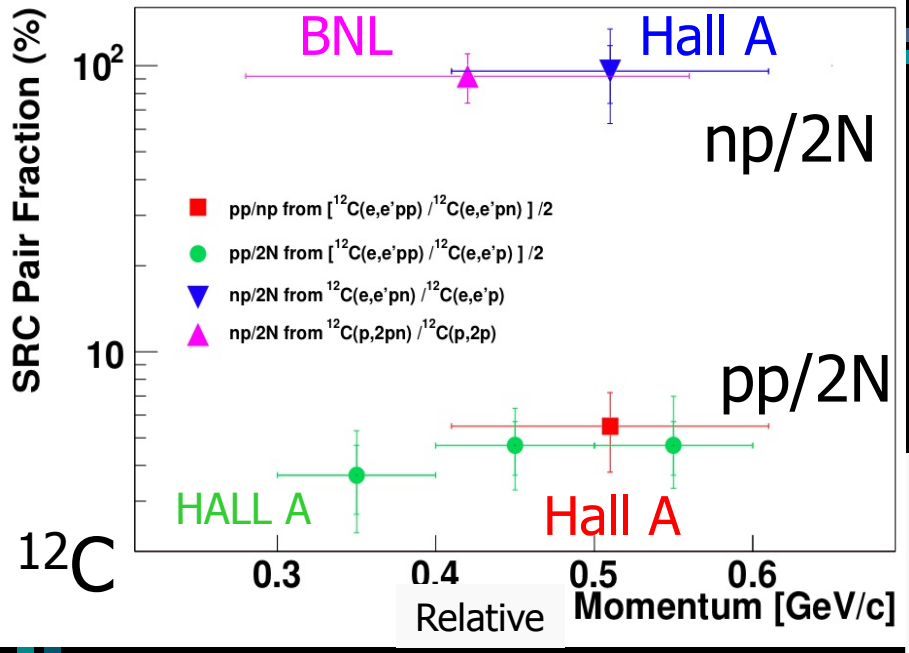
Results:

Similar momentum distributions
- Relative
- Total

pn / pp ratio ~ 4

$Q^2 \approx 0.8$ GeV^2 reduced by 5.3

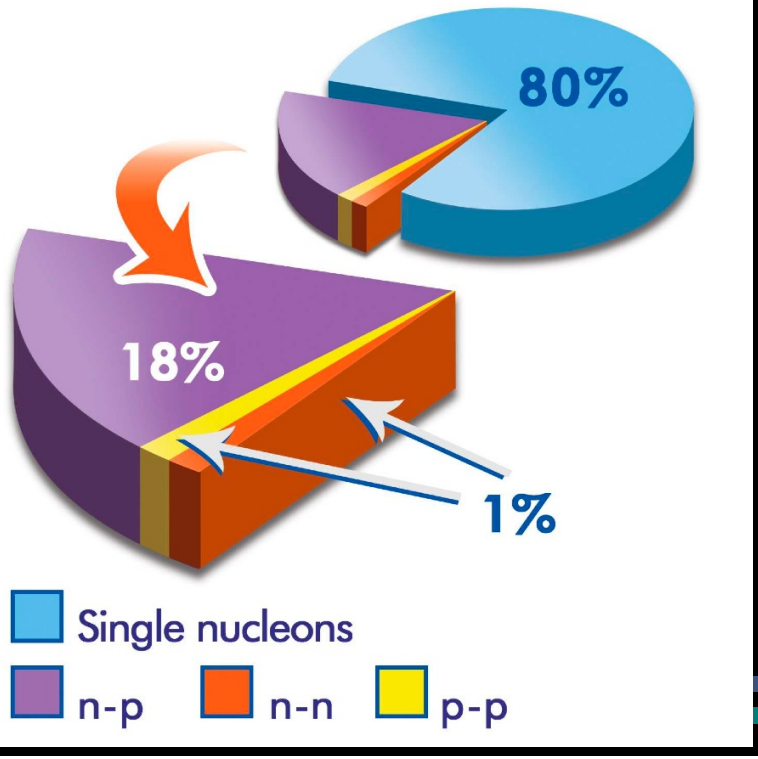




pp to pn comparison

Subedi et al, Science (2008)

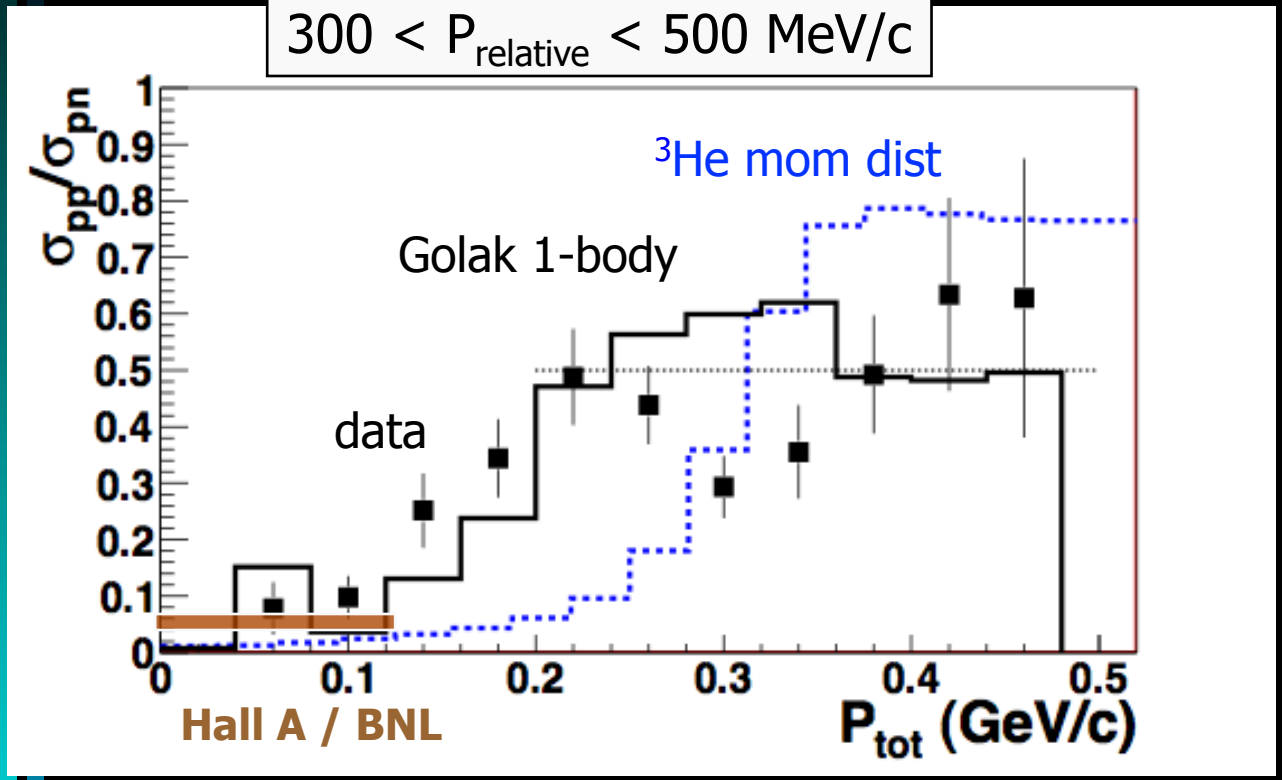
E_{beam}	$<Q^2>$	pn to pp ratio
Hall A / BNL	2 / ??	18
Hall B	0.8 – 1.5	4



Contradiction???

pp to pn resolution:

pp/pn ratio increases with pair total momentum P_{tot}



Tensor Correlations!

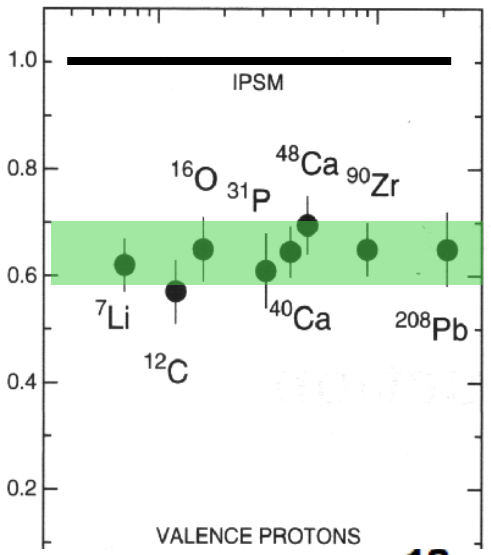
Small P_{tot} ➔ pp pair in s-wave (no tensor)
➔ wave fn minimum at p_{rel}=400 MeV/c

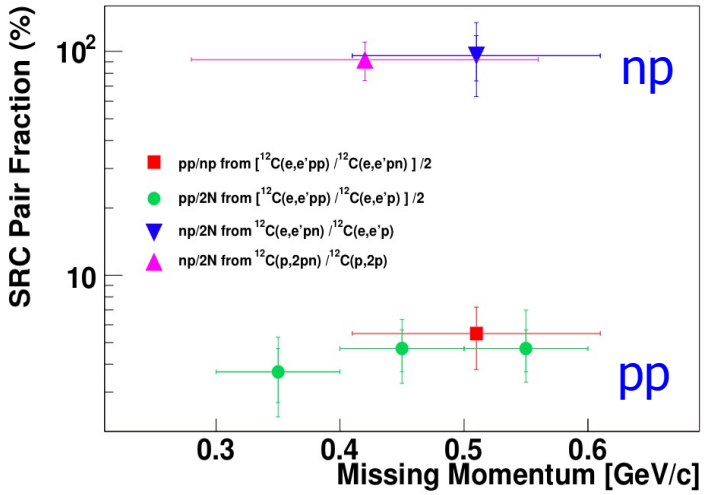
PRL 105, 222501 (2010)

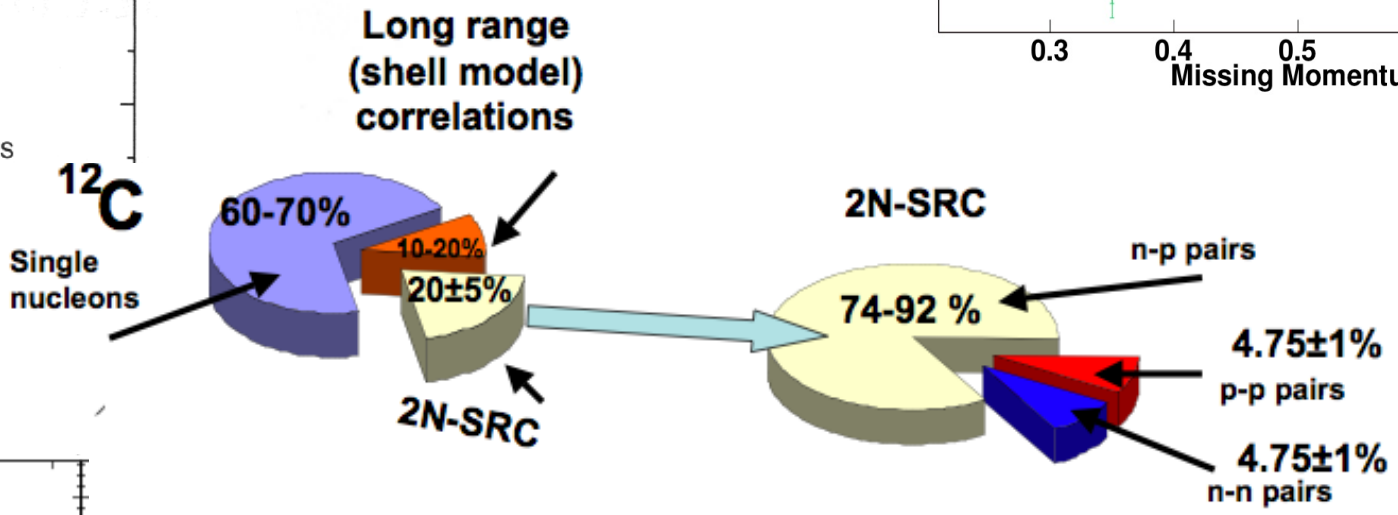
Hall A: small P_{tot} ➔ less pp
Hall B: large P_{tot} ➔ more pp

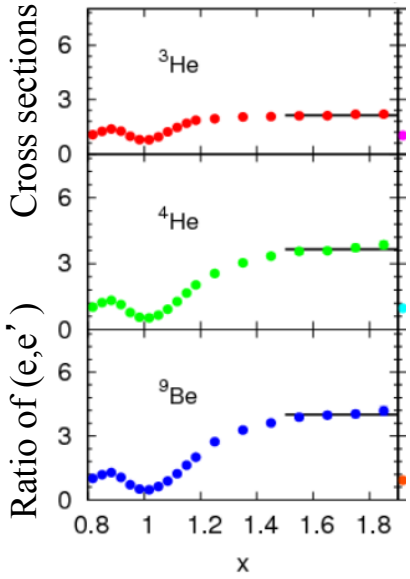
Summary

(e,e' p) Shell occ

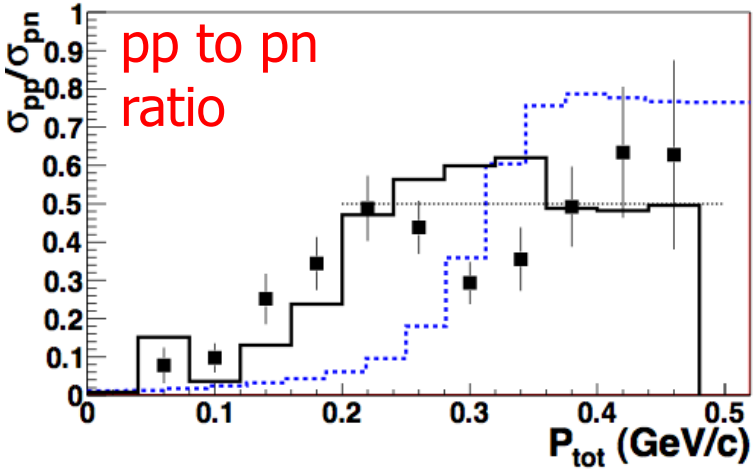








A(e,e') ratios



~25% SRC pairs
- ~90% np pairs
- Tensor correlated