Short-range NN interactions: Experimental Past and Future

7th Workshop of the APS Topical Group on Hadronic Physics

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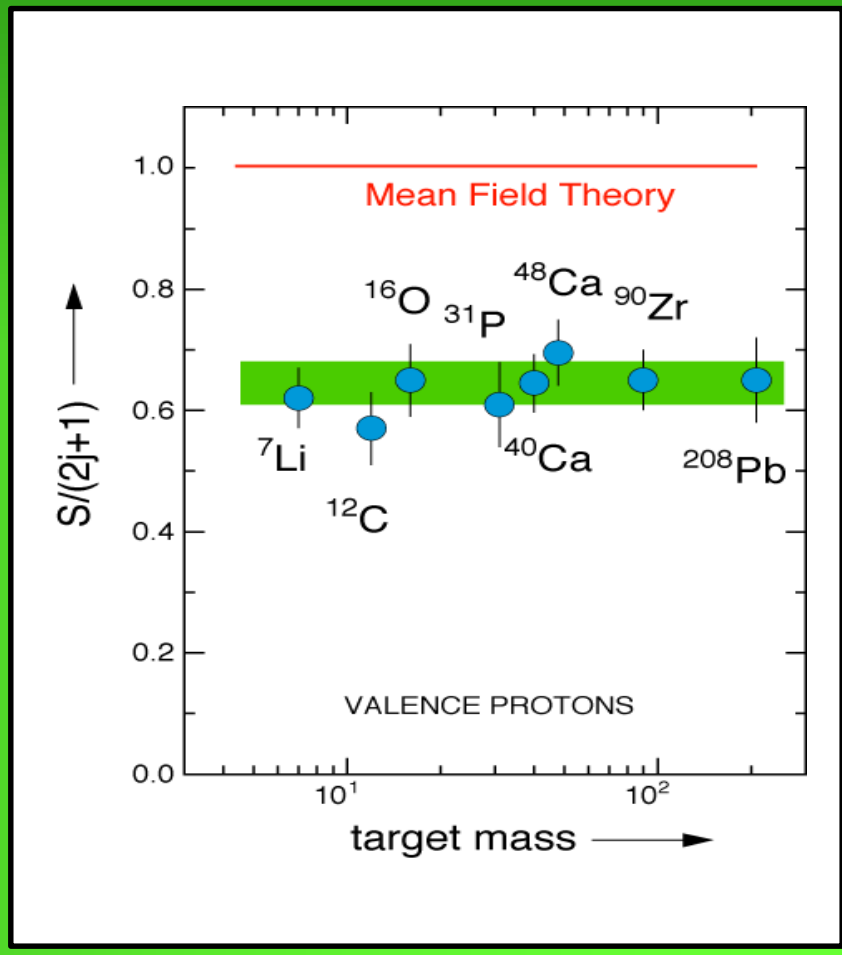
Independent Particle Shell Model :

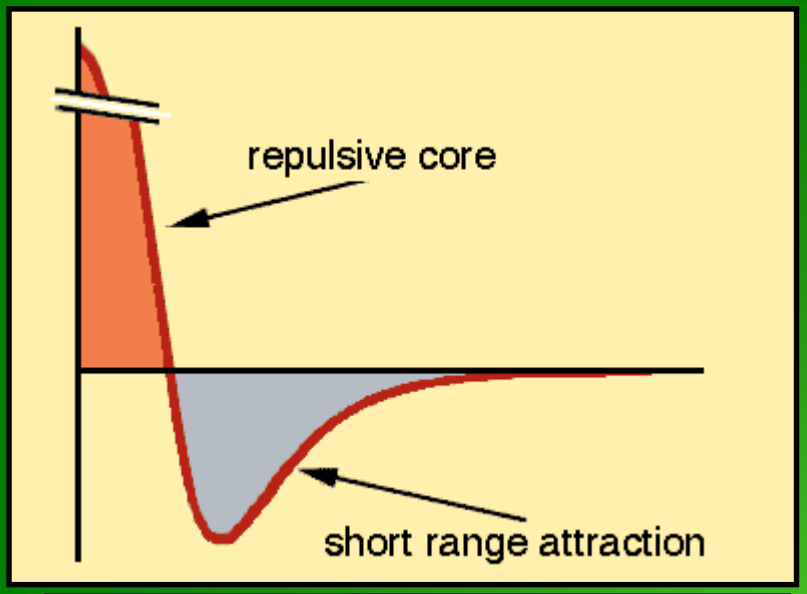
$$S_\alpha = 4\pi \int S(E_m, p_m) p_m^2 dp_m \delta(E_m - E_\alpha)$$

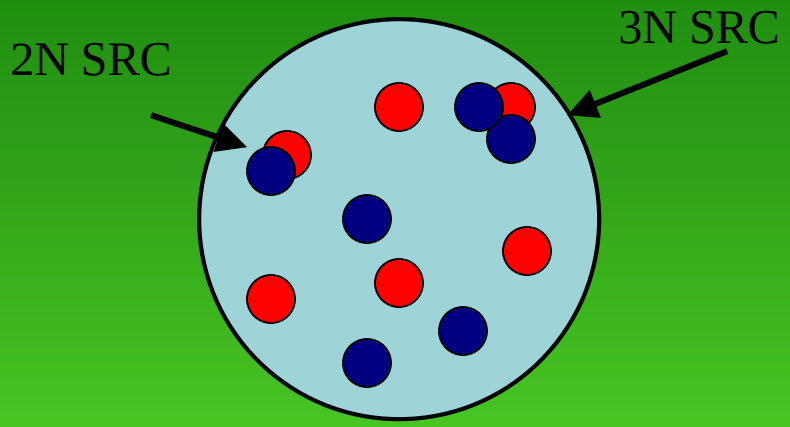
- For nuclei, S_α should be equal to ***2j+1*** => number of protons in a given orbital
- However, it as found to be only ~2/3 of the expected value
- The bulk of the missing strength it is thought to come from **short range correlations**

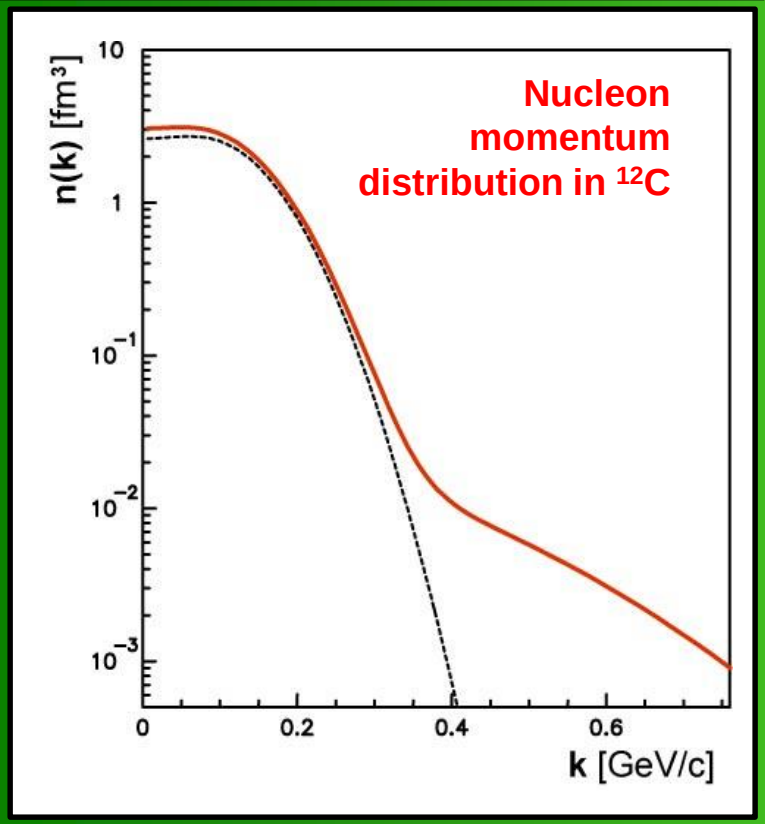


High momentum nucleons

- Short Range Correlations







High momentum tails in A(e,e'p)

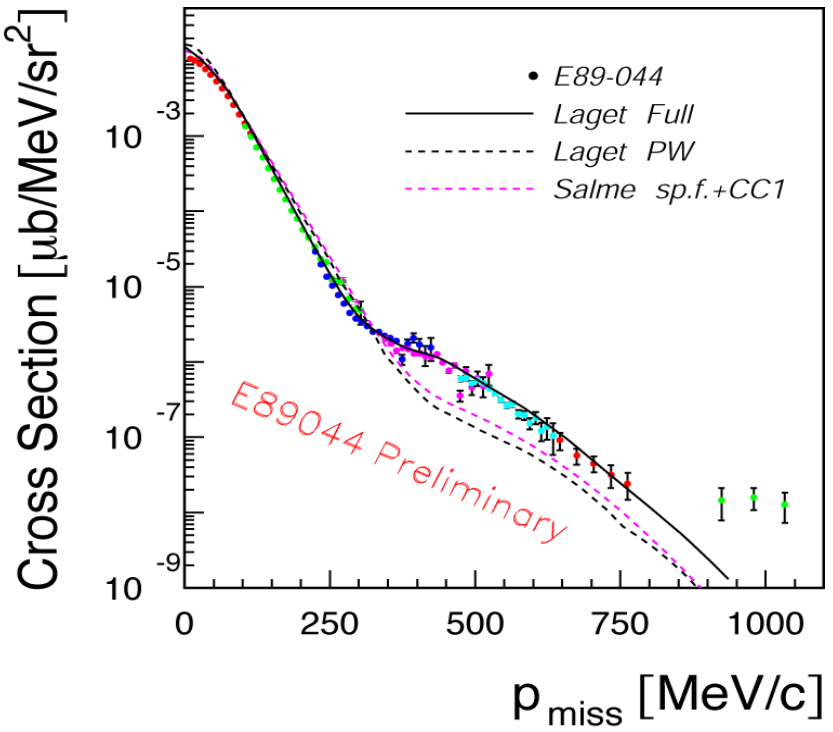
- E89-004: Measure of ^{3}He(e,e'p)d
- Measured far into high momentum tail: Cross section is ~5-10x expectation

Difficulty

- High momentum pair can come from SRC (initial state)

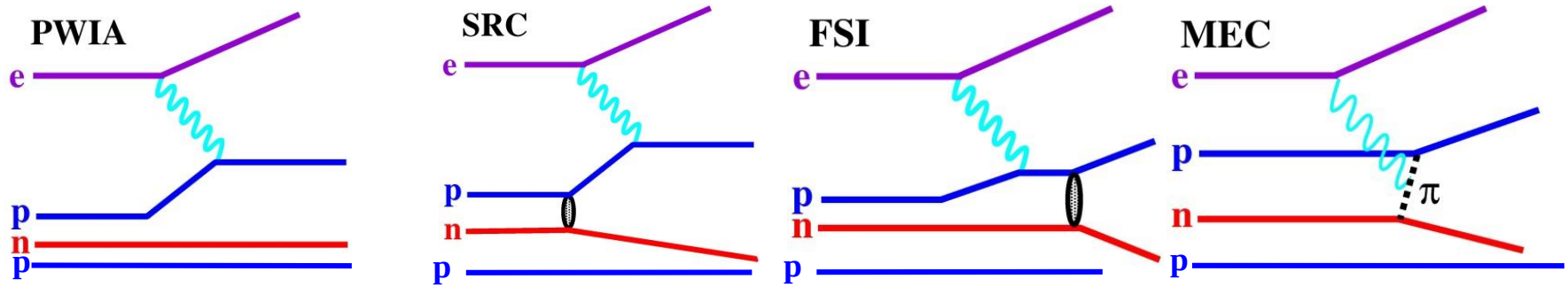
OR

- Final State Interactions (FSI) and Meson Exchange Contributions (MEC)



"slow" nucleons

"fast" nucleons



A(e,e'p)

^{2}H(e,e'p) Mainz
PRC 78 054001 (2008)

E =0.855 GeV
θ = 45^o
E'=0.657 GeV
Q^2=0.33 GeV^2
x=0.88

Unfortunately: FSI, MECs overwhelm the high momentum nucleons

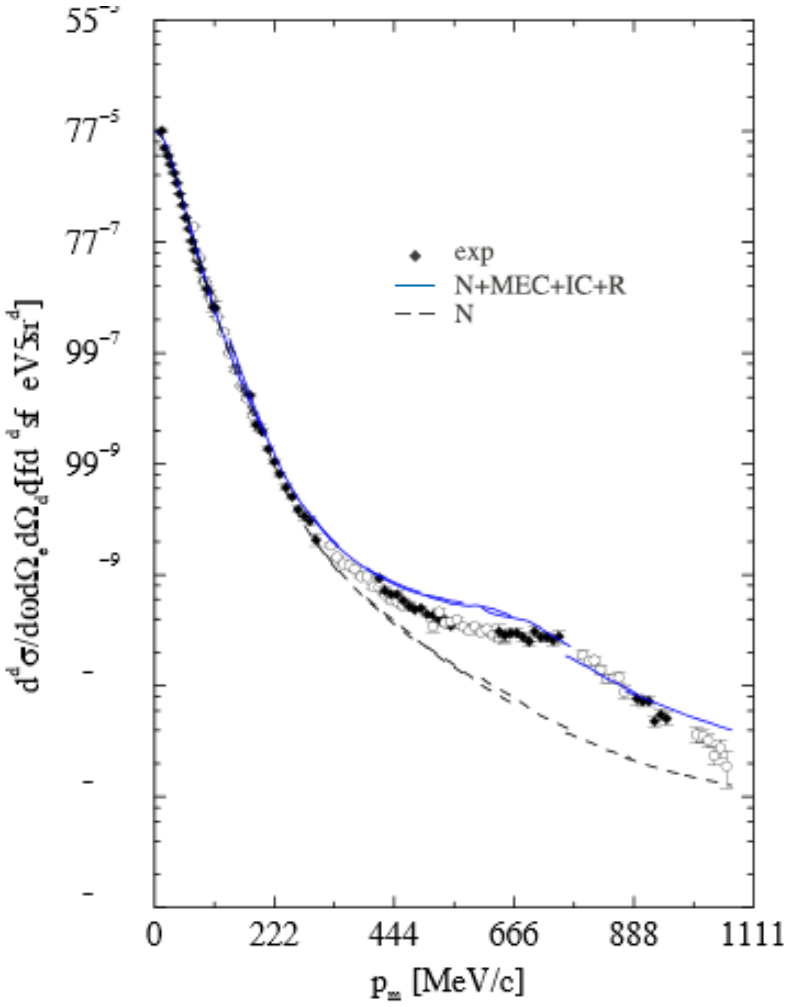
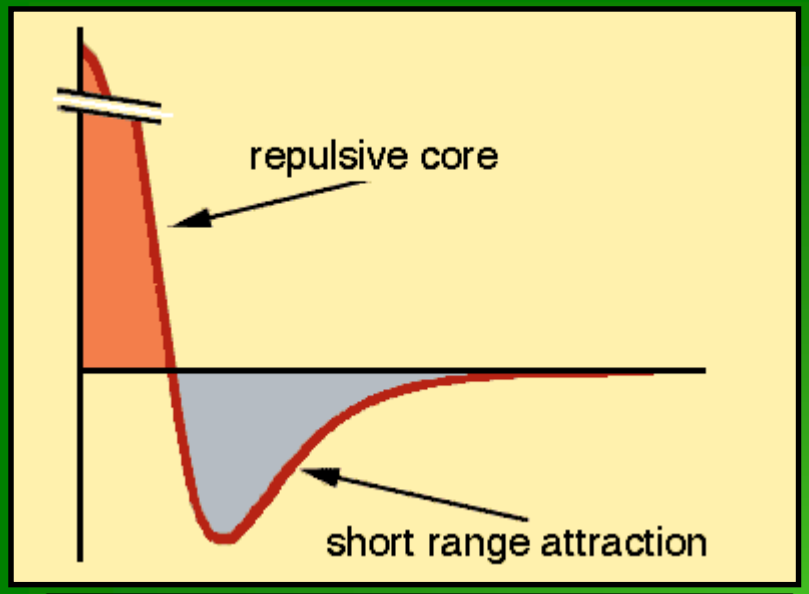
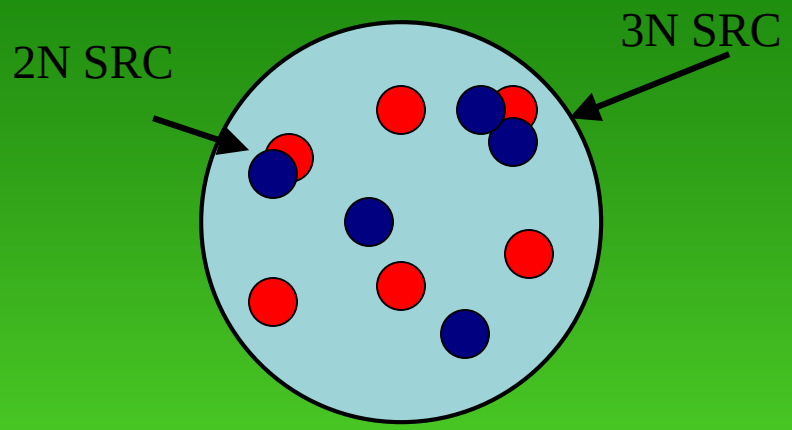


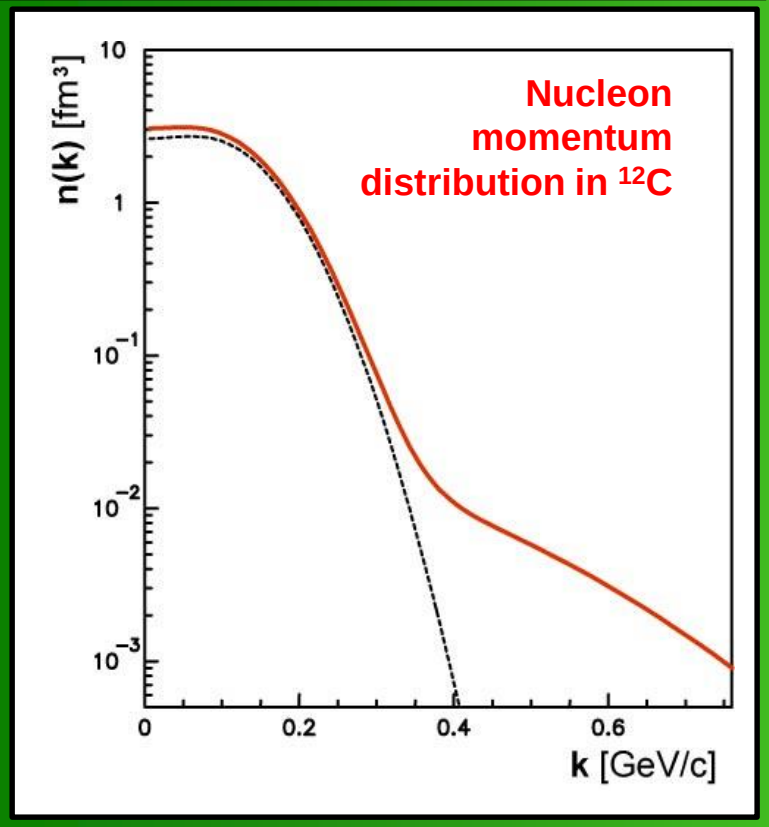
FIG. 1: The experimental D(e,e′p)n cross section as a function of missing momentum measured at MAMI for $Q^2 = 0.33$ $(\mathrm{GeV/c})^2$ [4] compared to calculations [7] with (solid curve) and without (dashed curve) MEC and IC. Both calculations include FSI. The low p_m data have been re-analyzed and used in this work to determine f_{LT} (color online).



High momentum nucleons

- Short Range Correlations





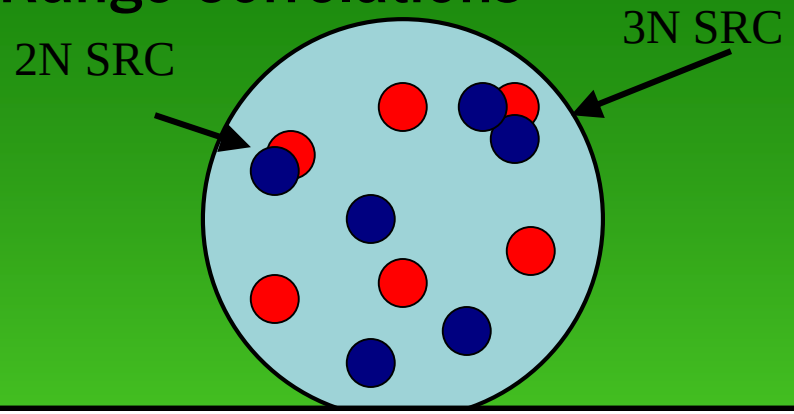
Try inclusive scattering!
Select kinematics such that the initial nucleon momentum $> k_f$

High momentum nucleons

- Short Range Correlations

$$\frac{d\sigma^{QE}}{d\Omega dE'} \propto \int d\vec{k} \int dE \sigma_{ei} S_i(k,E) \delta(Arg)$$

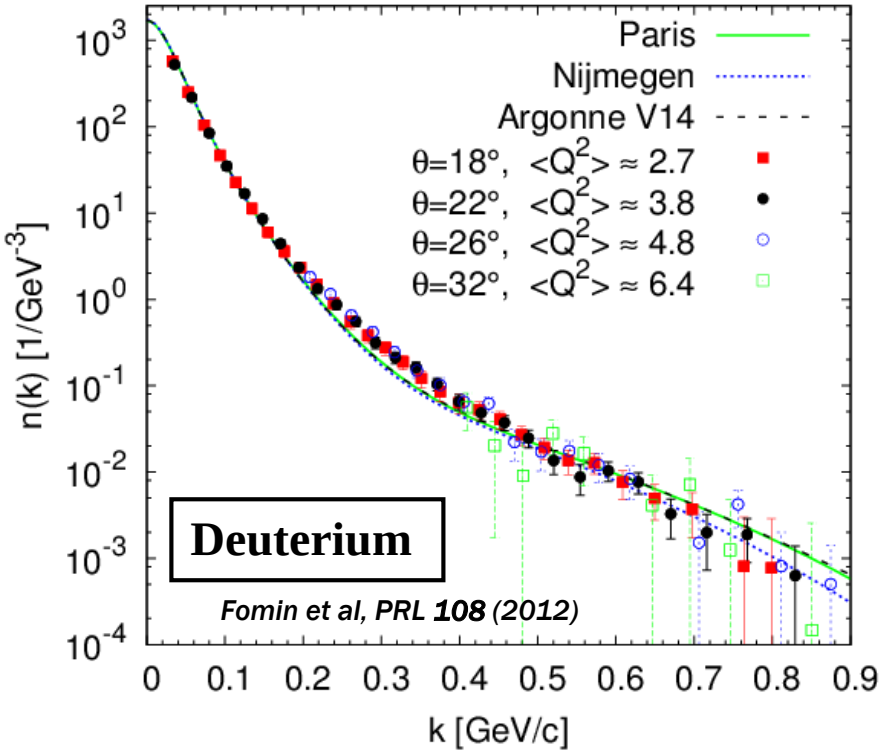
$$Arg = \nu + M_A - \sqrt{M^2 + p^2} - \sqrt{M^{*2}_{A-1} + k^2}$$



$$F(y,\mathbf{q}) = \frac{d^2\sigma}{d\Omega d\upsilon} \frac{1}{(Z\bar{\sigma}_p + N\bar{\sigma}_n)} \frac{\mathbf{q}}{\sqrt{M^2 + (y+q)^2}}$$

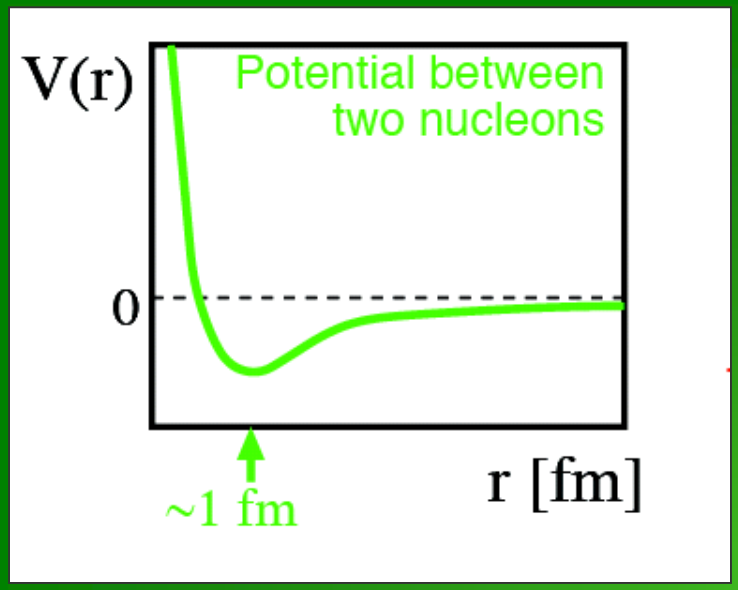
$$= 2\pi \int_{|y|}^{\infty} n(k) k dk$$

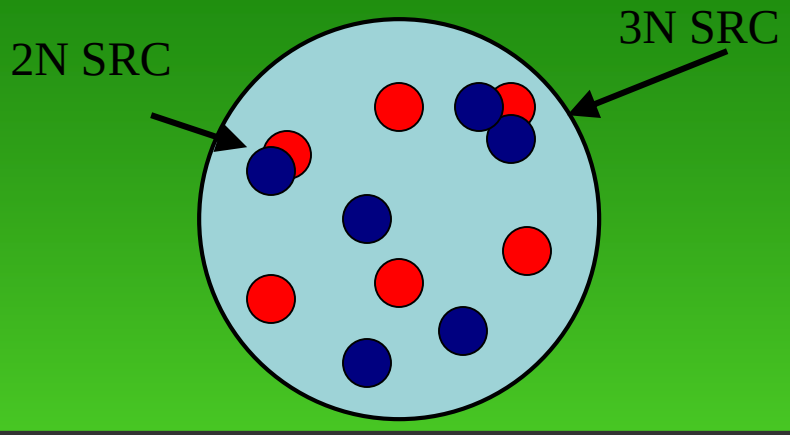
Ok for A=2

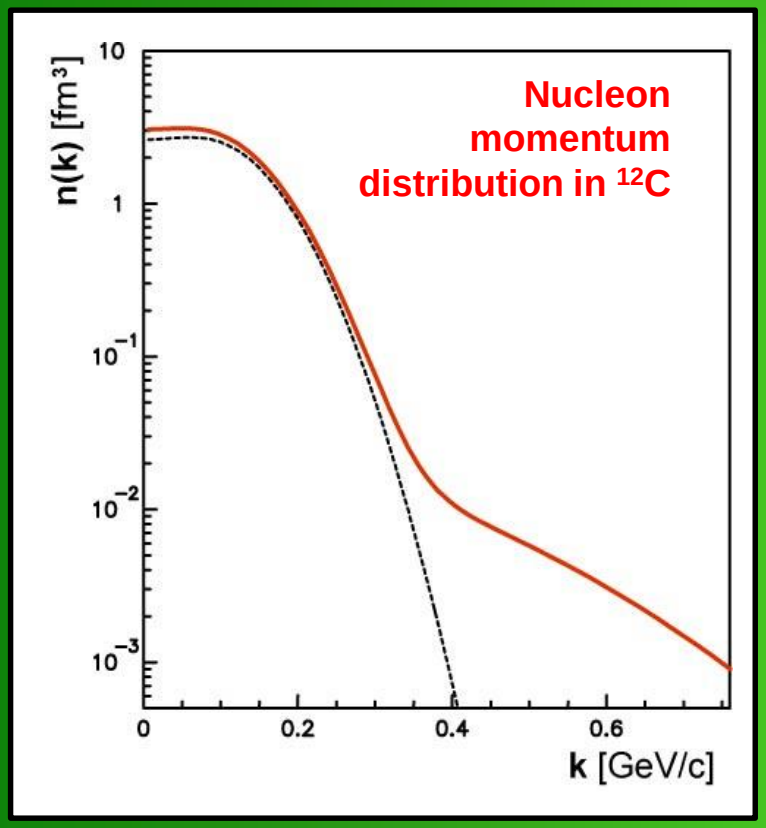


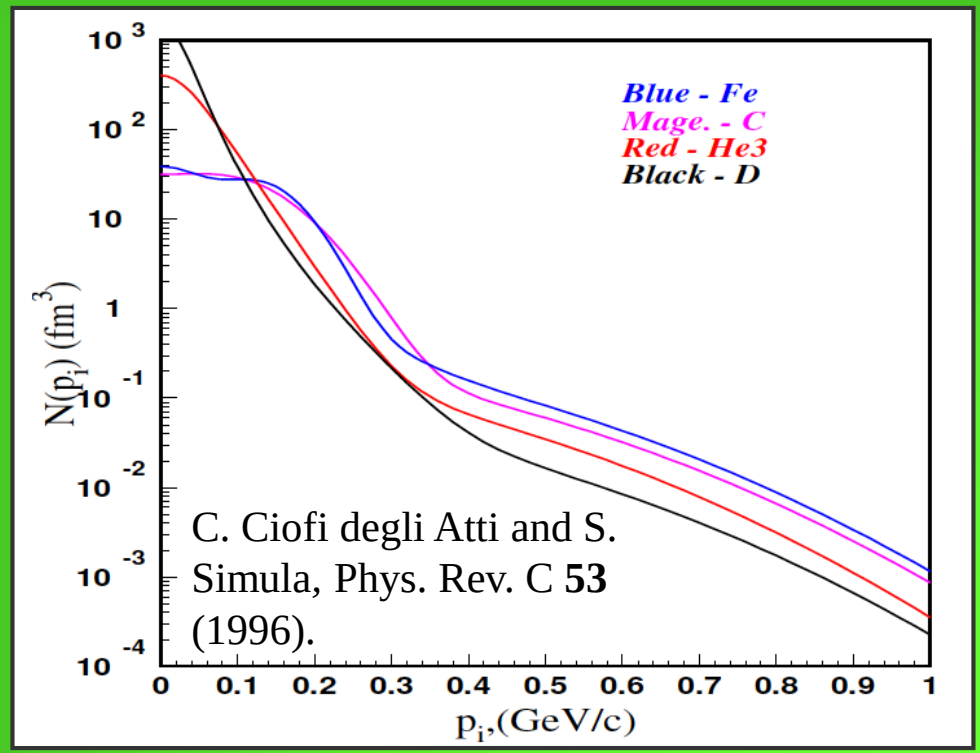
High momentum nucleons

- Short Range Correlations



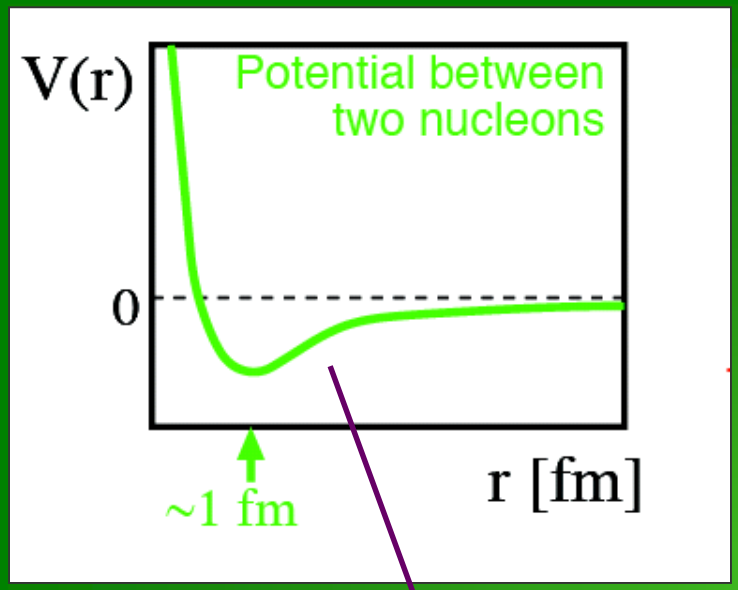


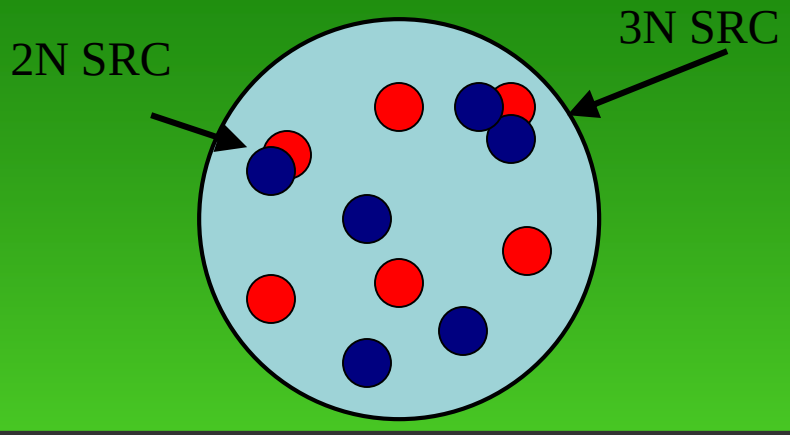


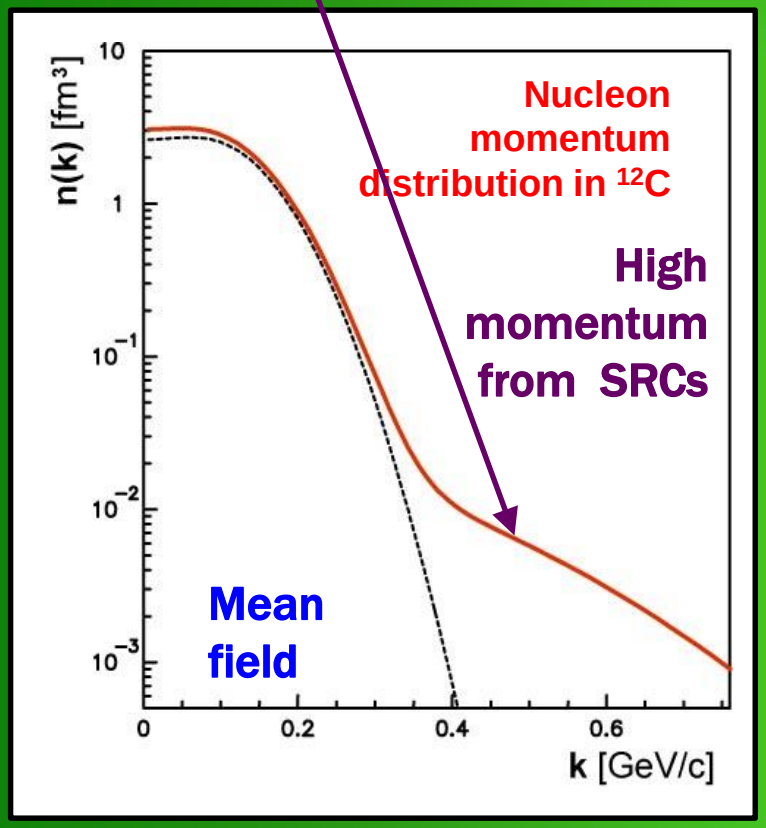


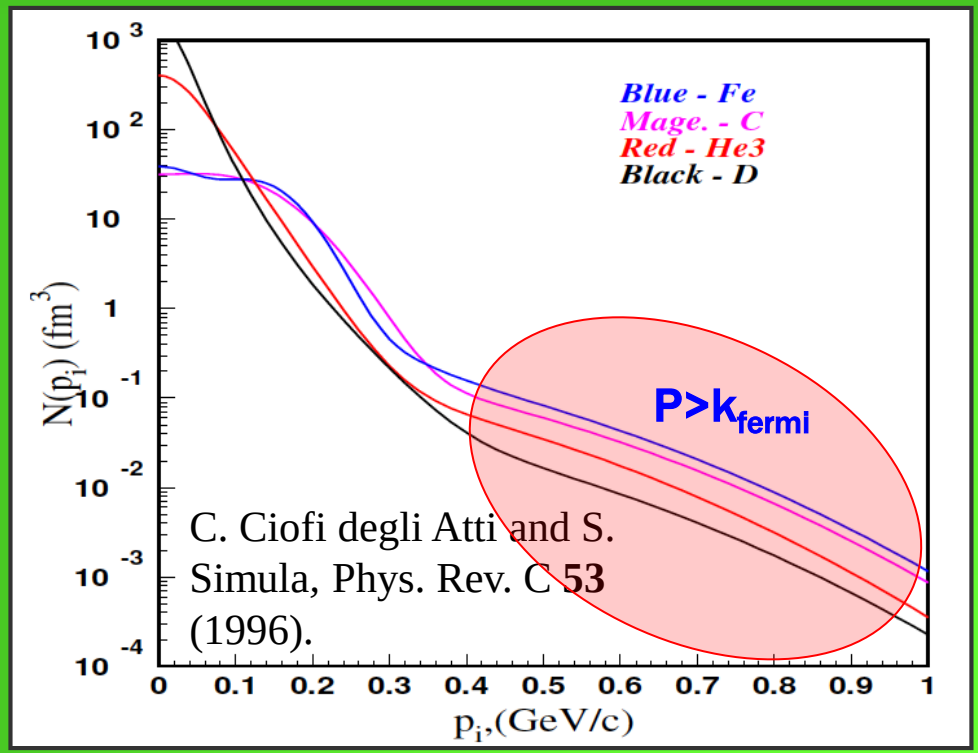
High momentum nucleons

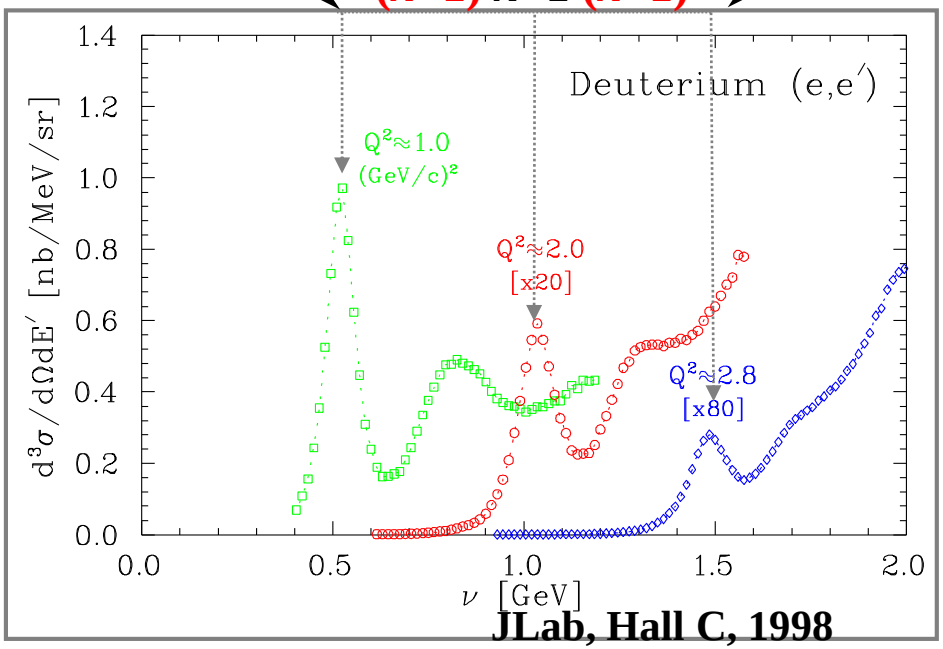
- Short Range Correlations



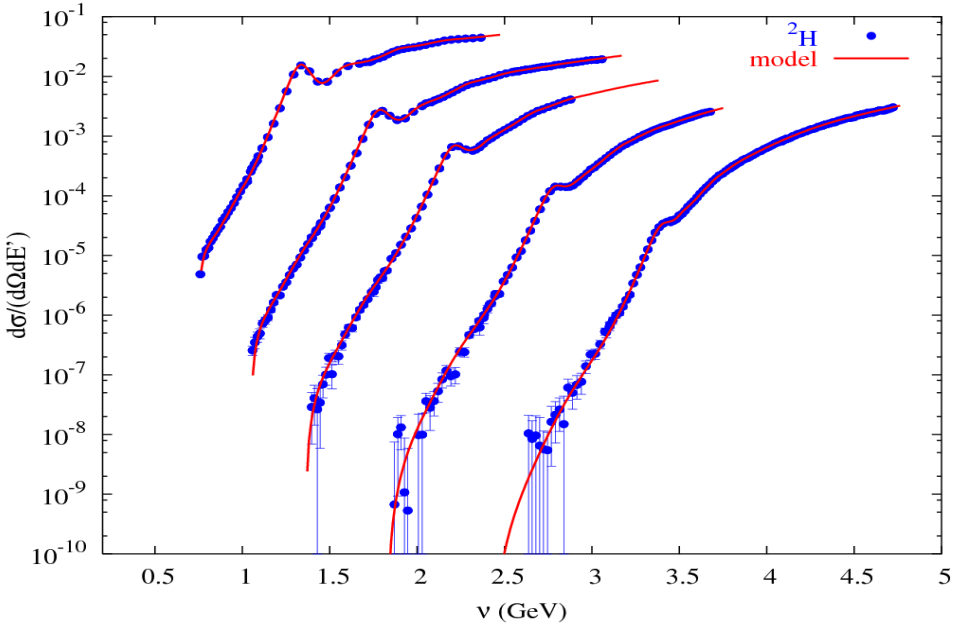


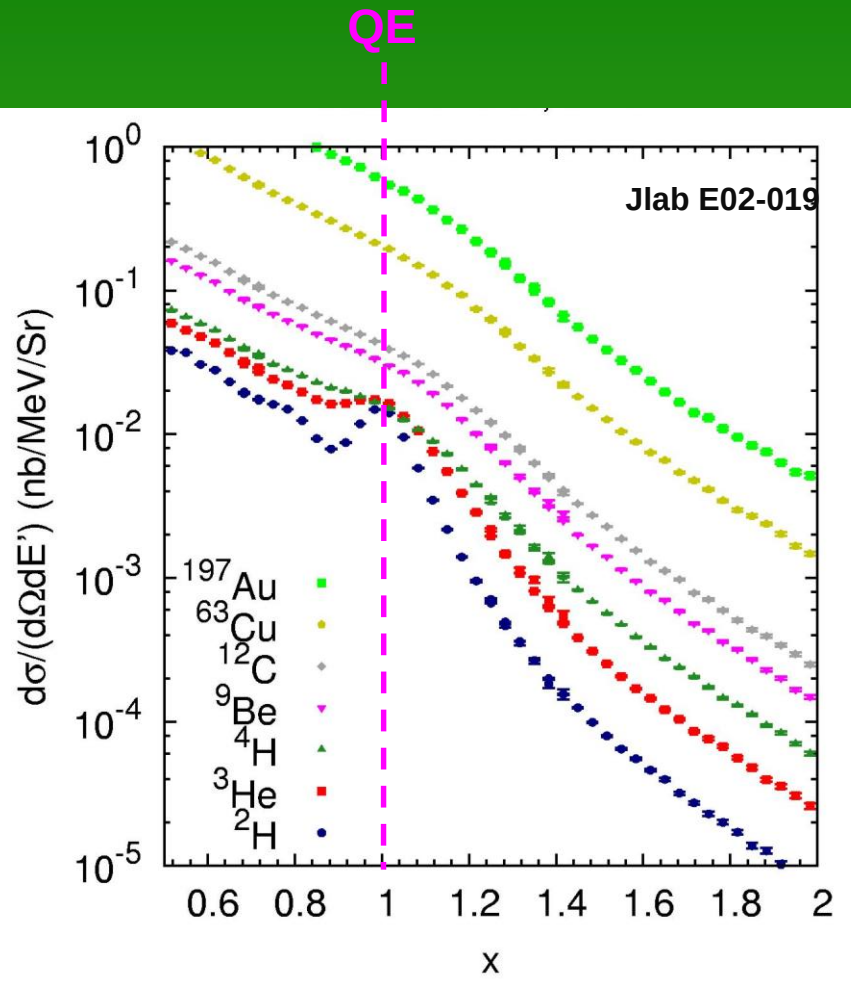






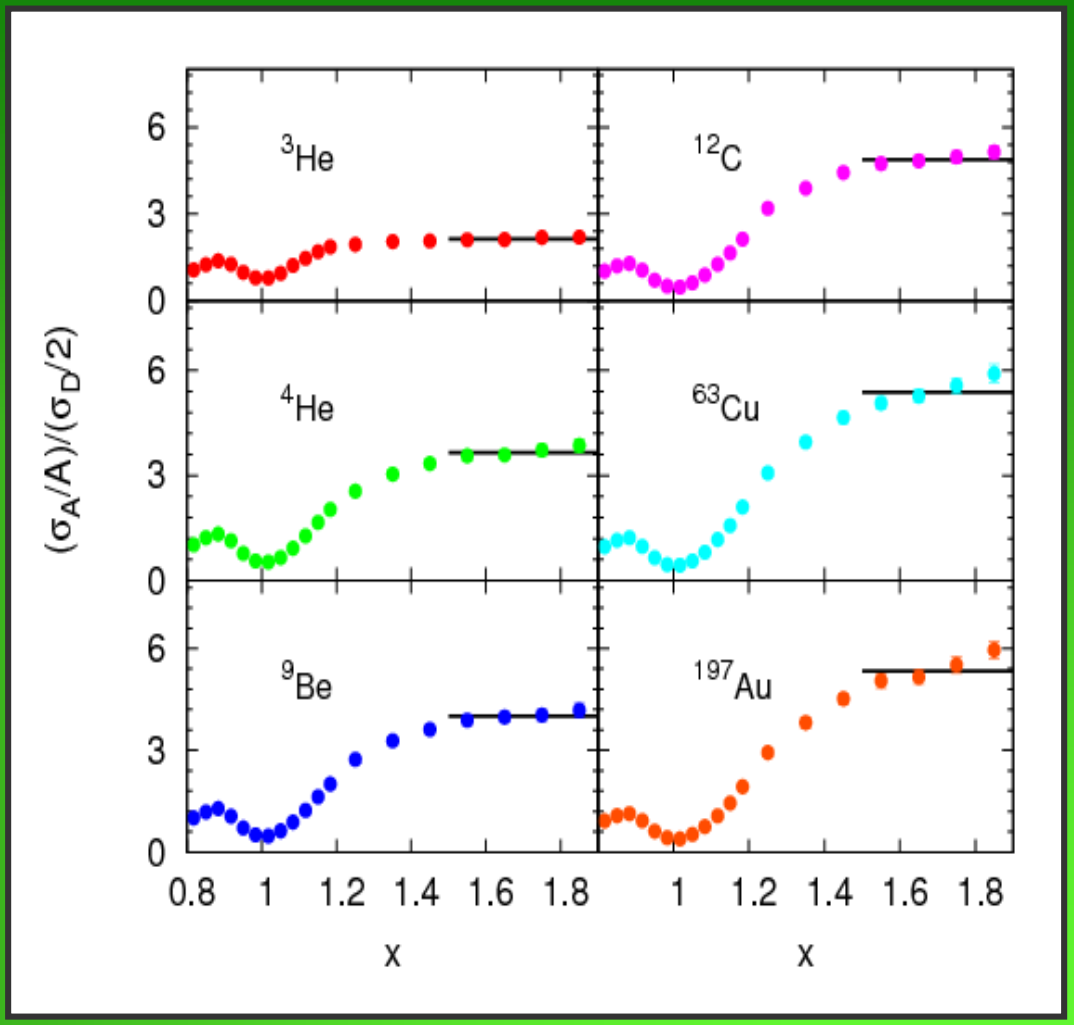
JLab, Hall C, 1998





E02-019: 2N correlations in A/D ratios

A	θ_e=18°
^{3}He	2.14±0.04
^{4}He	3.66±0.07
Be	4.00±0.08
C	4.88±0.10
Cu	5.37±0.11
Au	5.34±0.11
$\langle Q^2 \rangle$	2.7 GeV^2
x_{min}	1.5



*Fomin et al, PRL **108** (2012)*

Jlab E02-019

<Q^2>=2.7 GeV^2

Inclusive Scattering

- Relative measurement
- Reduced FSI
- Test scaling in x and Q^2
- No direct information on isospin structure
  - Only via target isospin structure
- No direct information on momentum distribution for A>2

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- **Relative measurement**
- **Reduced FSI**
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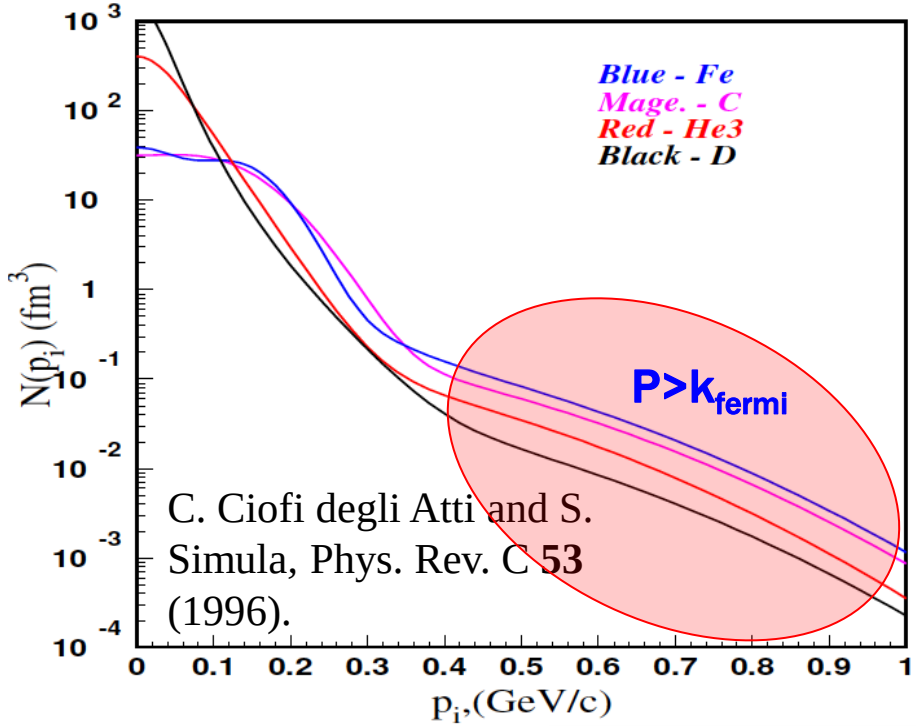
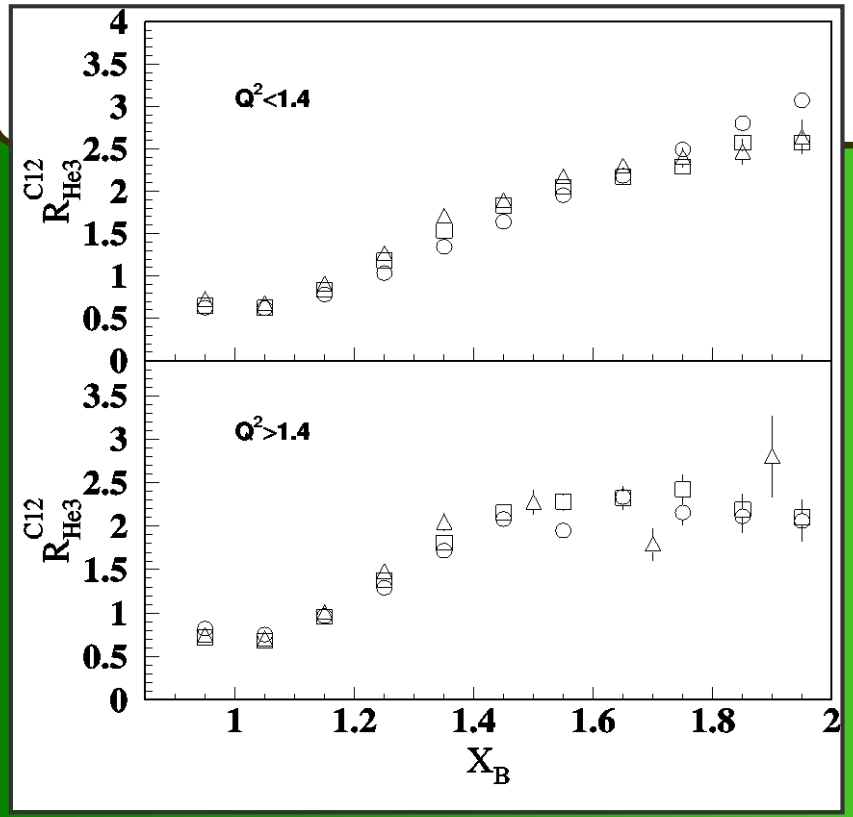
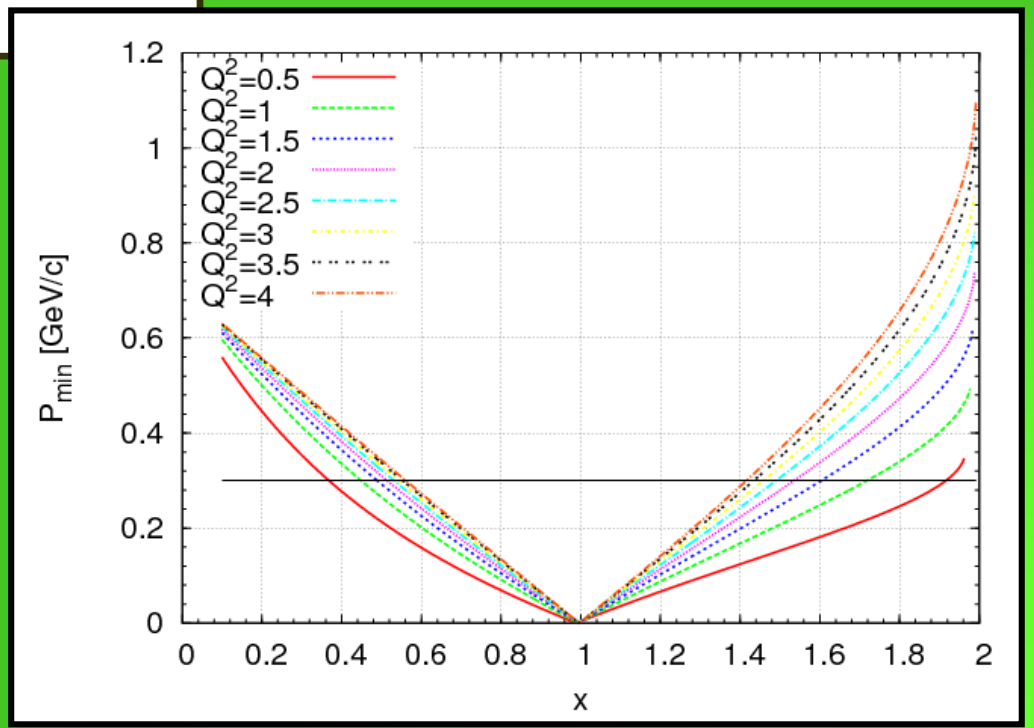


Inclusive Scattering

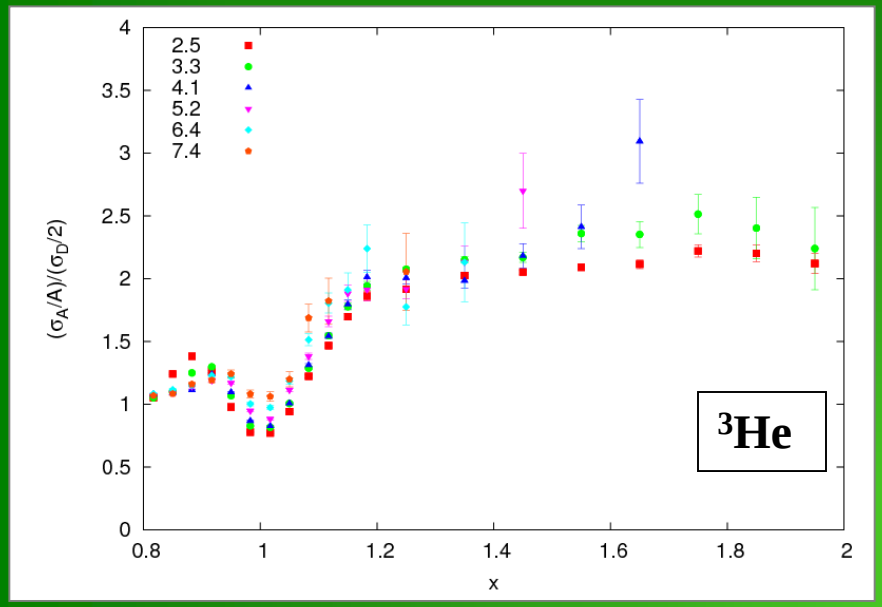
- Relative measurement
- Reduced FSI
- **Test scaling in x and Q^2**
- No direct information on isospin structure
  - Only via target isospin structure
- No direct information on momentum

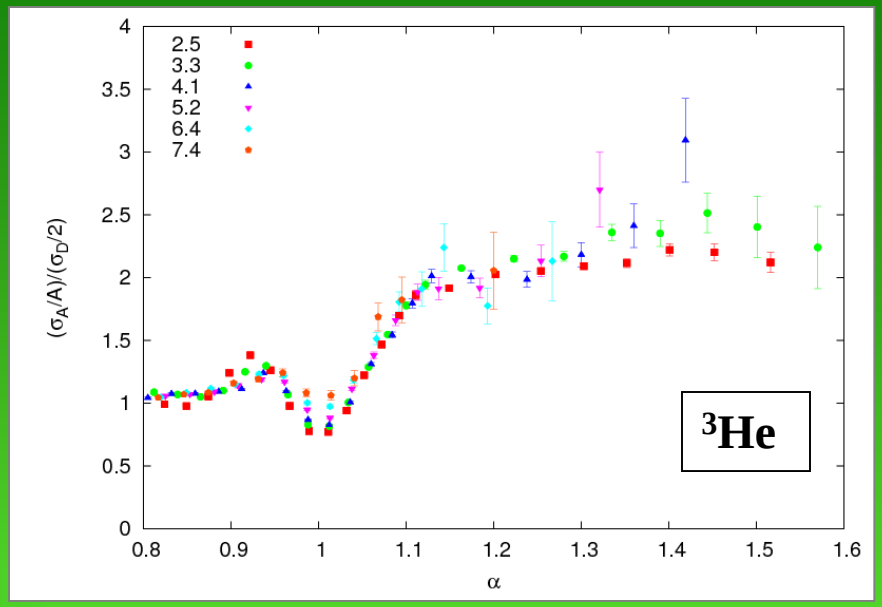


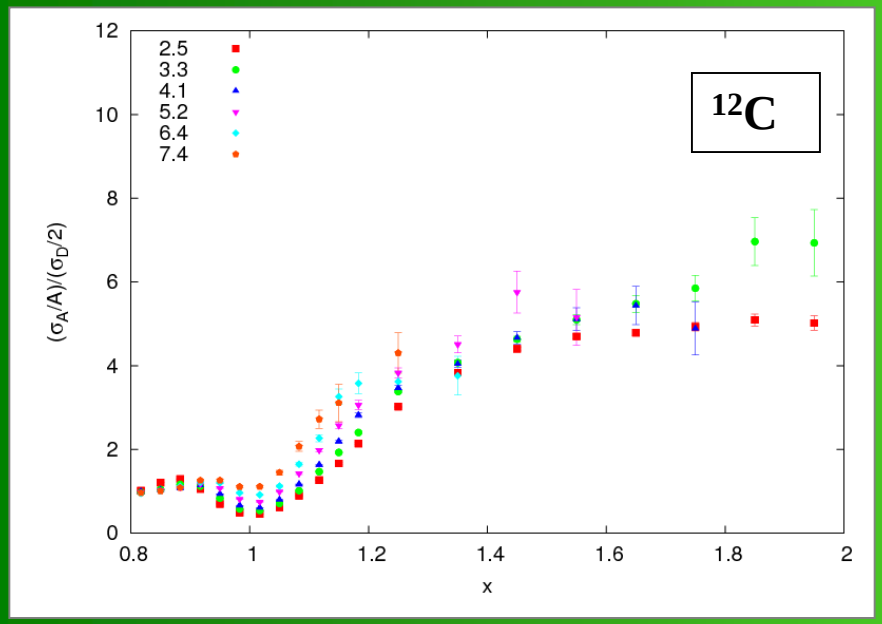


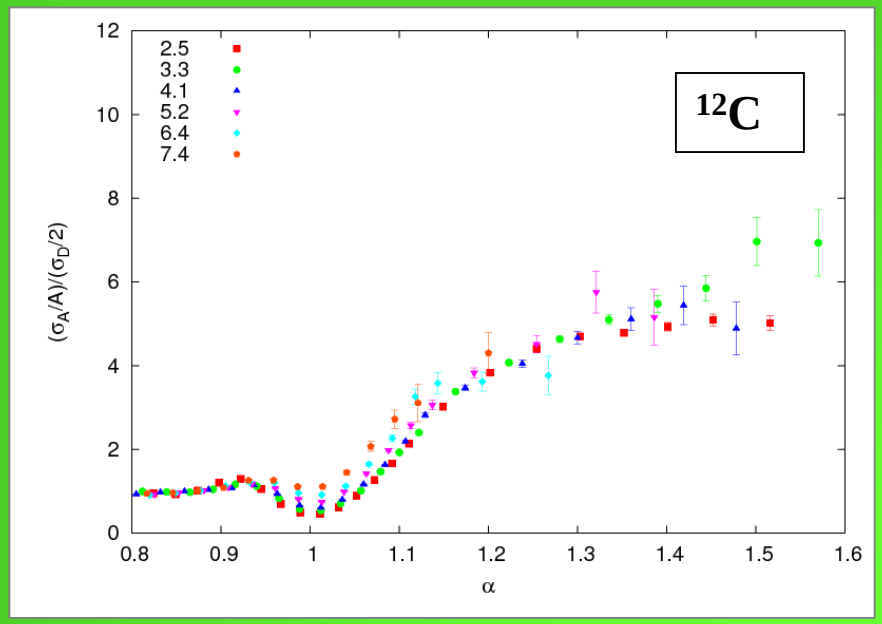
Test scaling in x and Q^2

$$\alpha = 2 - \frac{q^- + 2M}{2M}\left(1 + \frac{\sqrt{W^2 - 4M^2}}{W}\right)$$





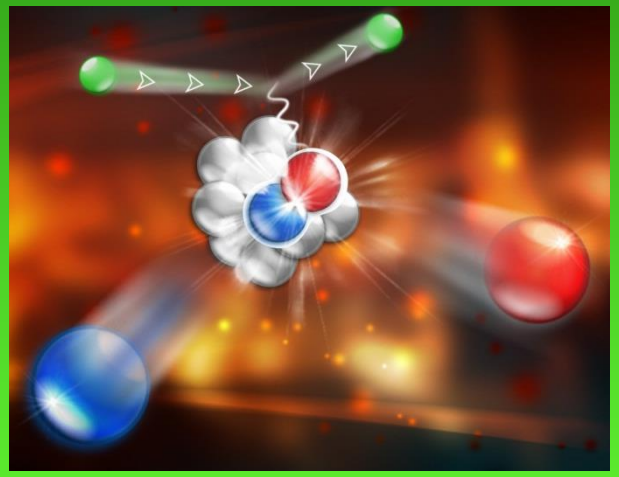




2N knockout experiments establish NP dominance

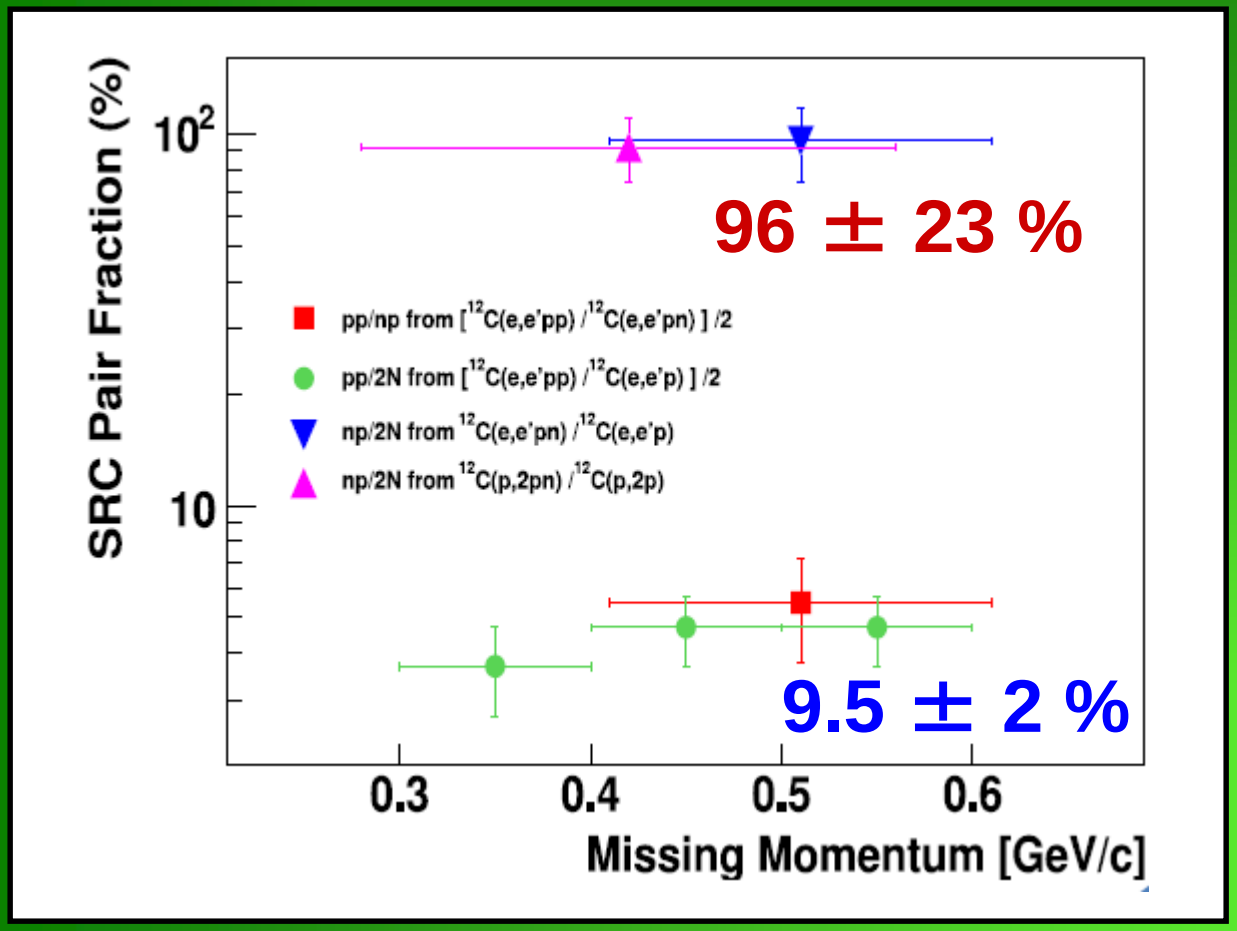
- Knockout high-initial-momentum proton, look for correlated nucleon partner.
- For $300 < P_{miss} < 600$ MeV/c all nucleons are part of 2N-SRC pairs: 90% np, 5% pp (nn)

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

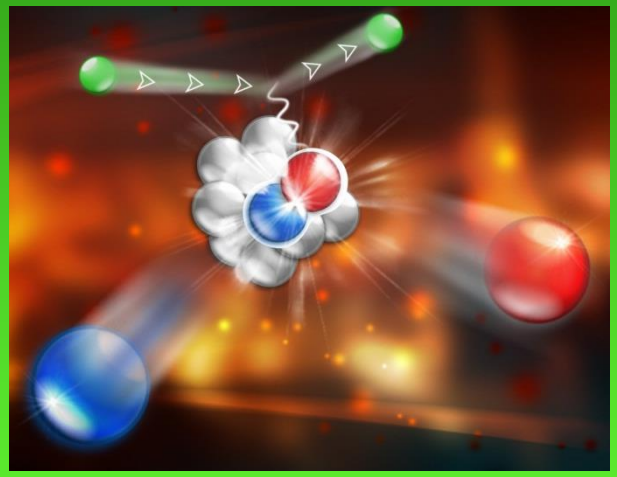


R. Shneor et al., PRL 99, 072501 (2007)

2N knockout experiments establish NP dominance

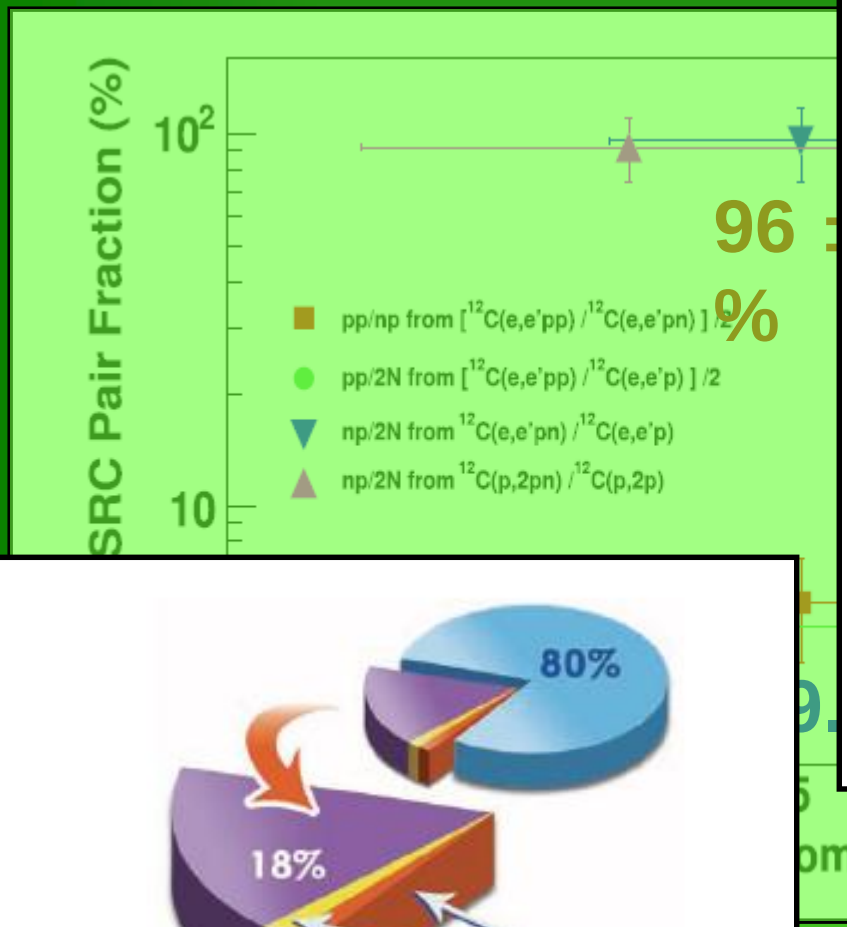


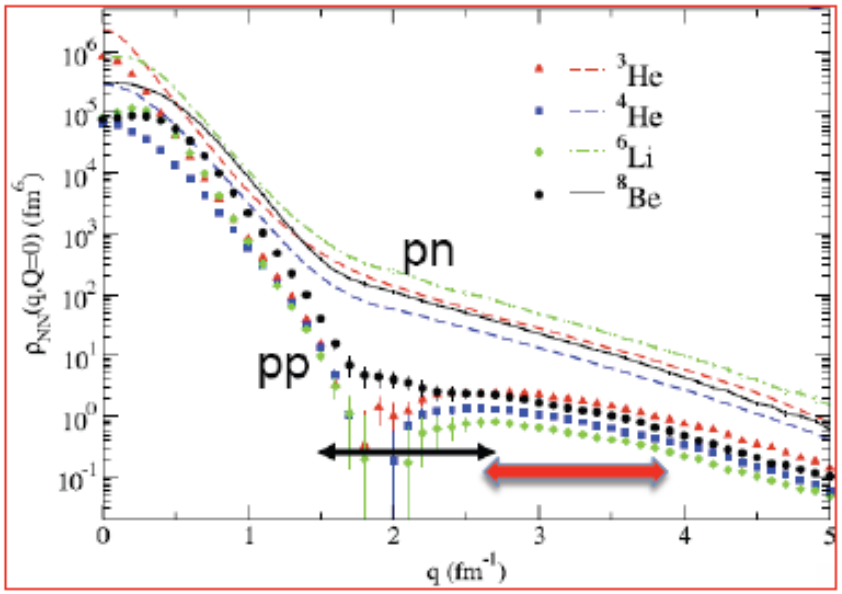
R. Subedi et al., Science 320, 1476 (2008)



R. Shneor et al., PRL 99, 072501 (2007)

NP dominance





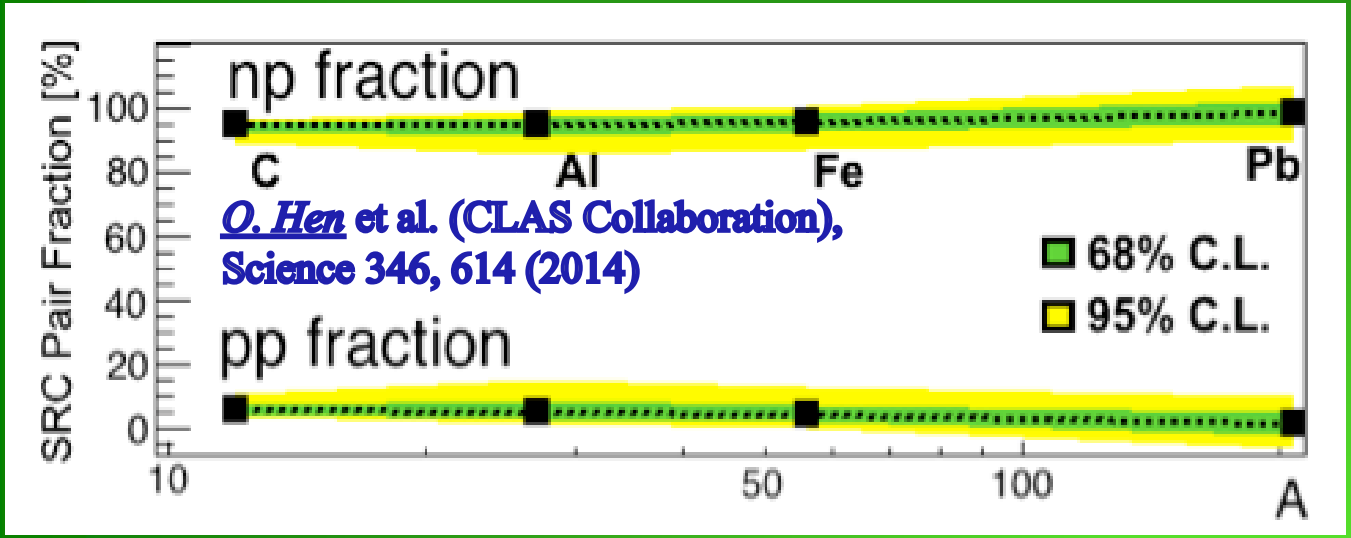
R. Schiavilla, R. B. Wiringa, S. C. Pieper, J. Carlson, Phys. Rev. Lett. **98** (2007) 132501

also

→ Ciofi and Alvioli PRL 100, 162503 (2008)

→Sargsian, Abrahamyan, Strikman, Frankfurt PR C71 044615 (2005)

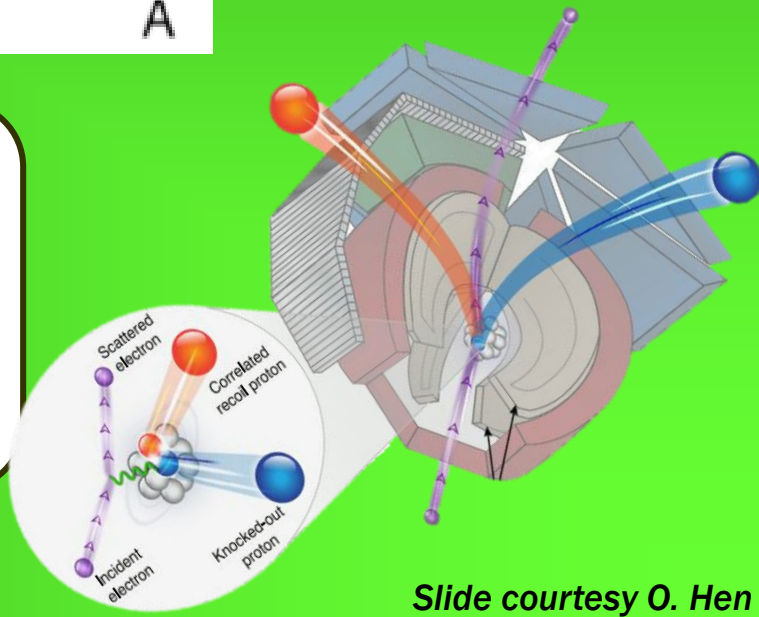
Data mining using CLAS
NP dominance continues for heavy nuclei



Assuming scattering off 2N-SRC pairs:

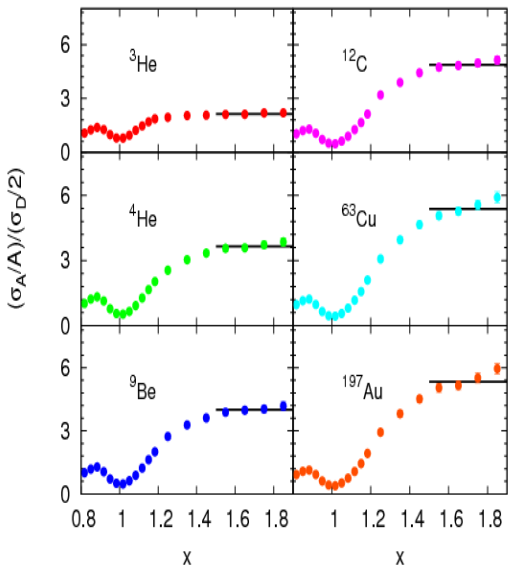
- **(e,e'p) is sensitive to *np* and *pp* pairs**
- **(e,e'pp) is sensitive to *pp* pairs alone**

=> (e,e'pp)/(e,e'p) ratio is sensitive to the *np*/*pp* ratio

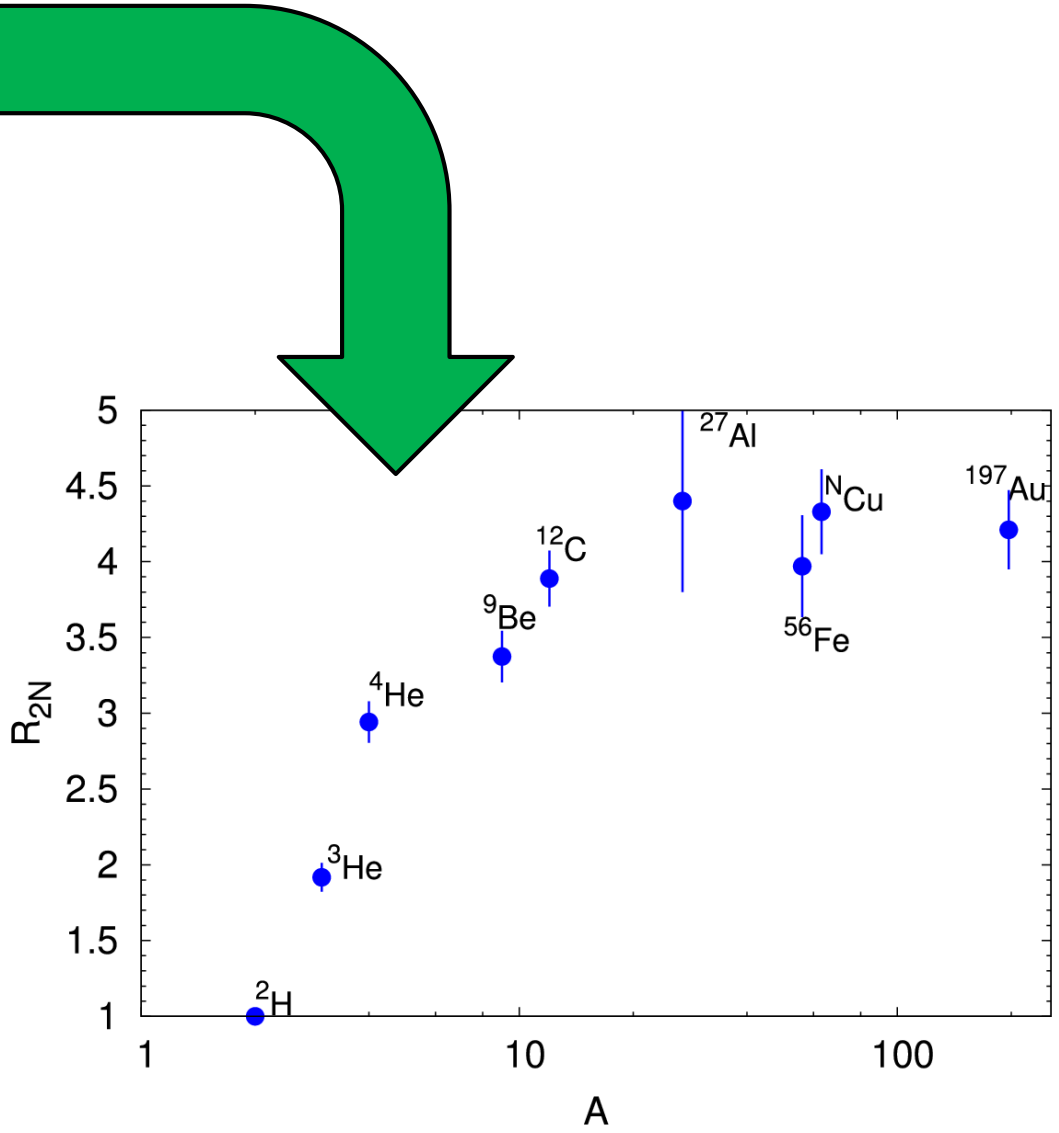


Slide courtesy O. Hen

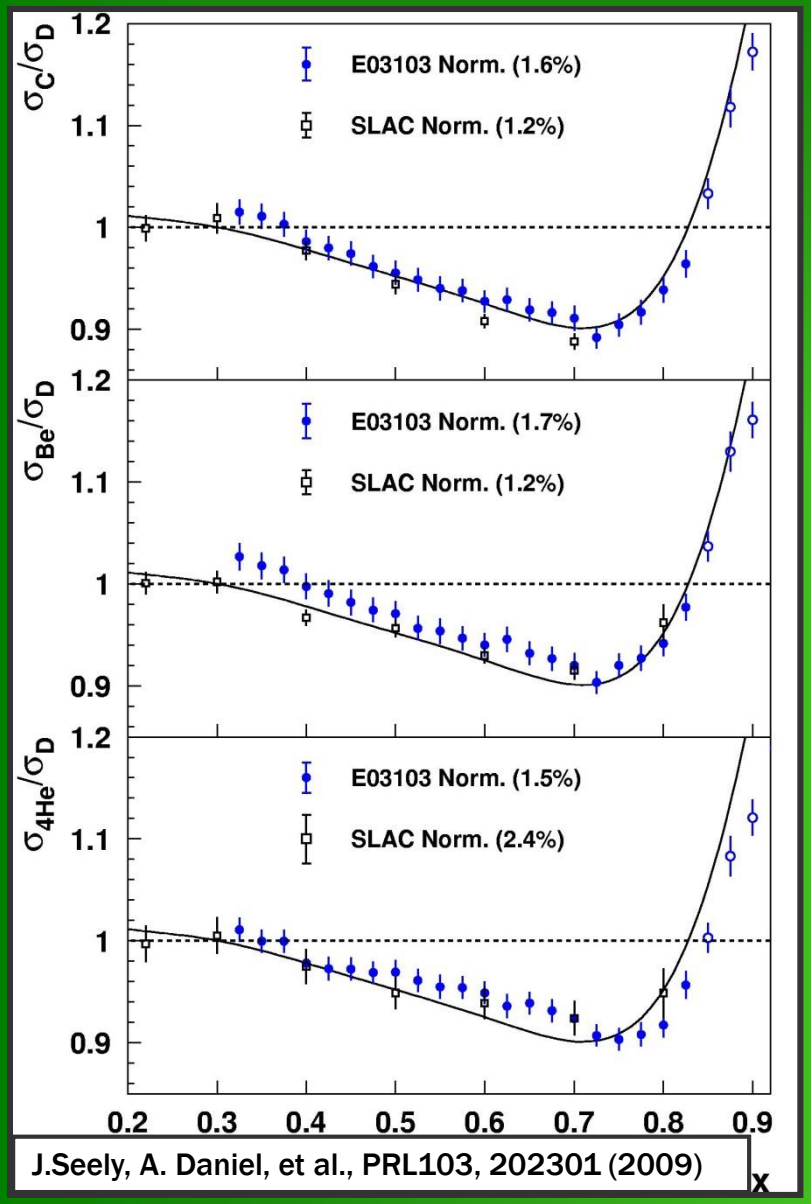
2N correlations



Have not solved the nuclear dependence



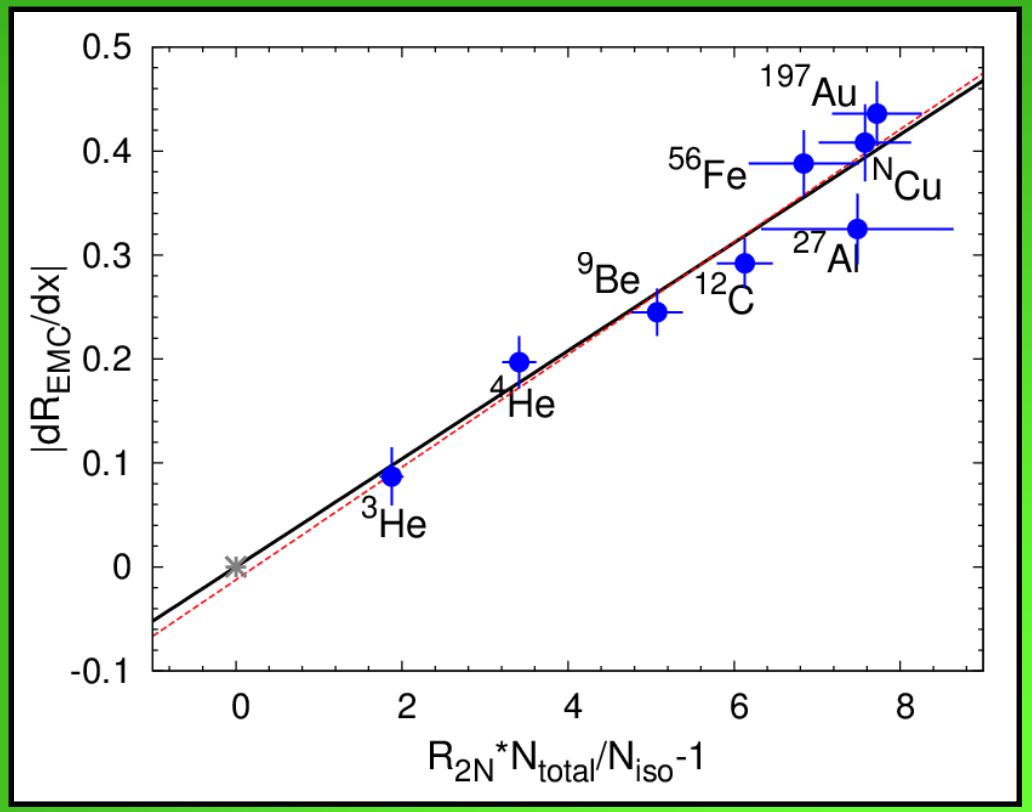
Linear relationship with EMC effect



J.Seely, A. Daniel, et al., PRL103, 202301 (2009)

- Fit the slope of the ratios for 0.3<x<0.7:

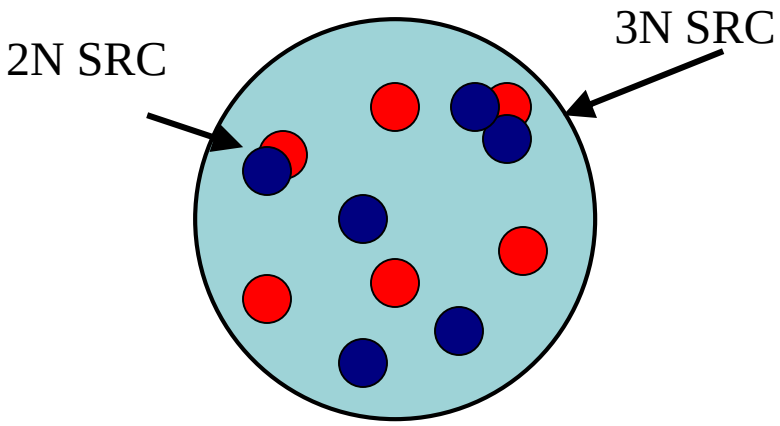
$$\frac{dR_{EMC}}{dx}$$



More nucleons in a correlation

1.4<x<2 => 2 nucleon correlation

2.4<x<3 => 3 nucleon correlation

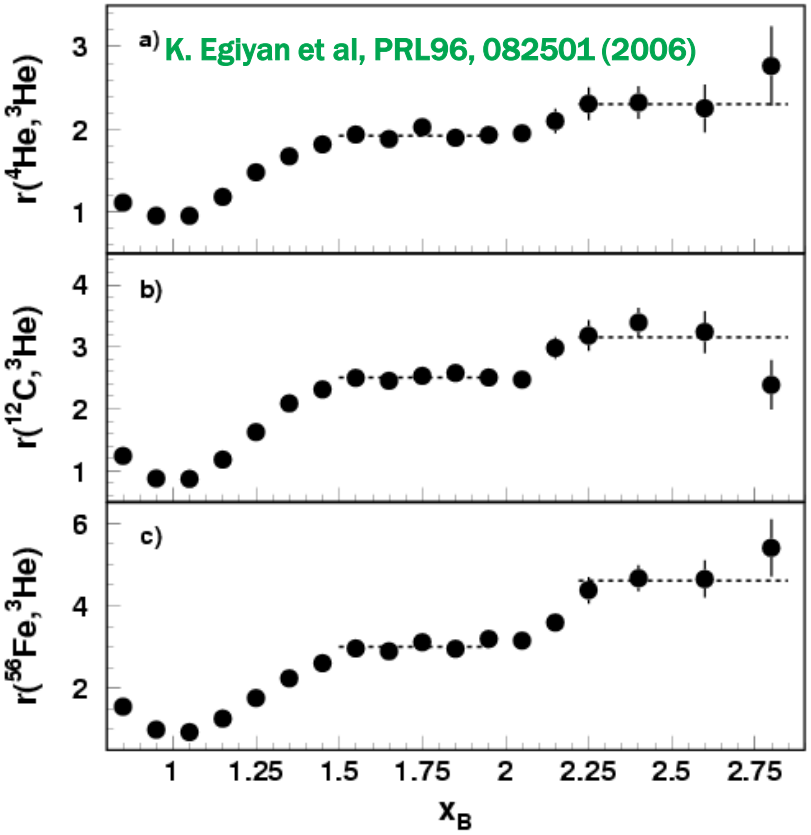


$$\sigma(x, Q^2) = \sum_{j=1}^{A} A \frac{1}{j} a_j(A)\sigma_j(x, Q^2)$$

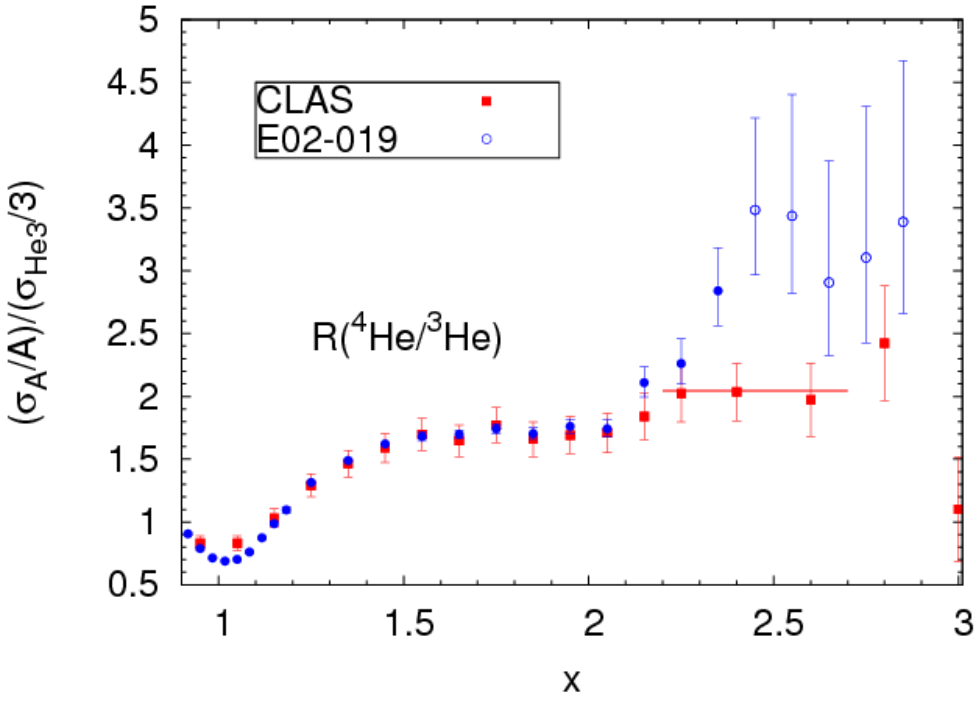
$$= \frac{A}{2} a_2(A)\sigma_2(x, Q^2) +$$

$$\frac{A}{3} a_3(A)\sigma_3(x, Q^2) + ...$$

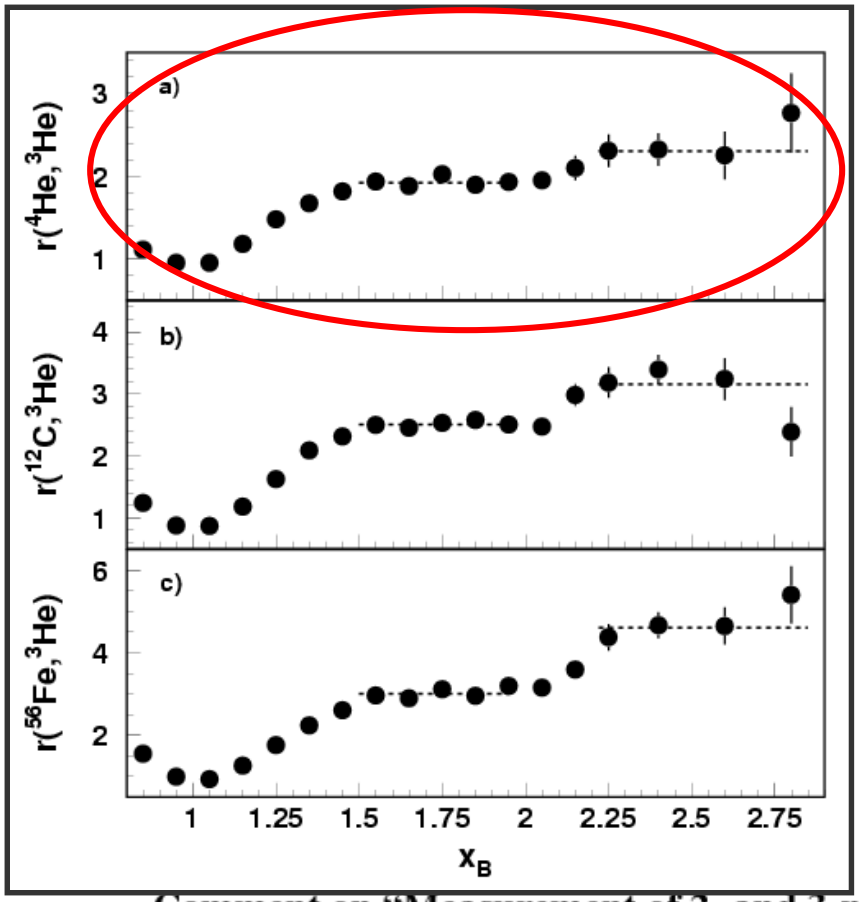
3N correlations (x>2 inclusive scattering)

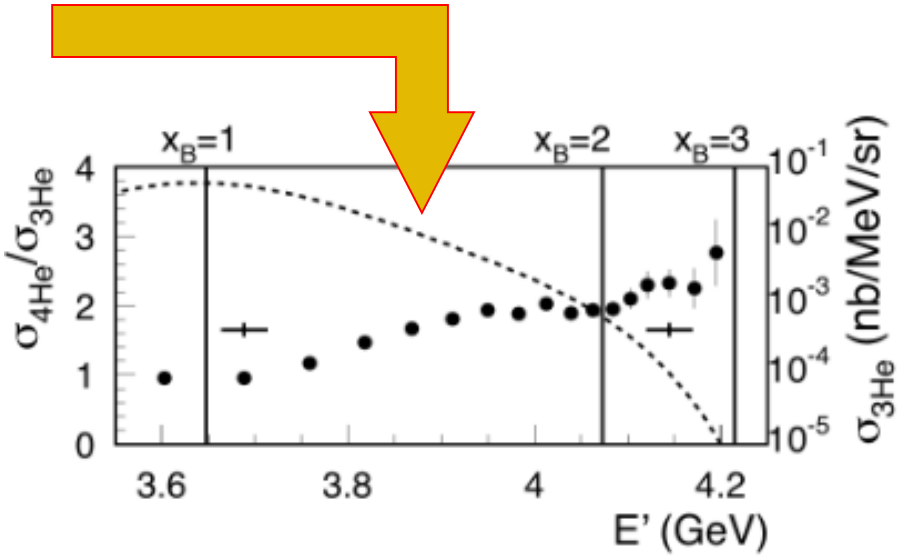


<Q²> (GeV²): ***CLAS: 1.6*** ***E02-019: 2.7***



Have we actually seen 3N SRC in ratios?

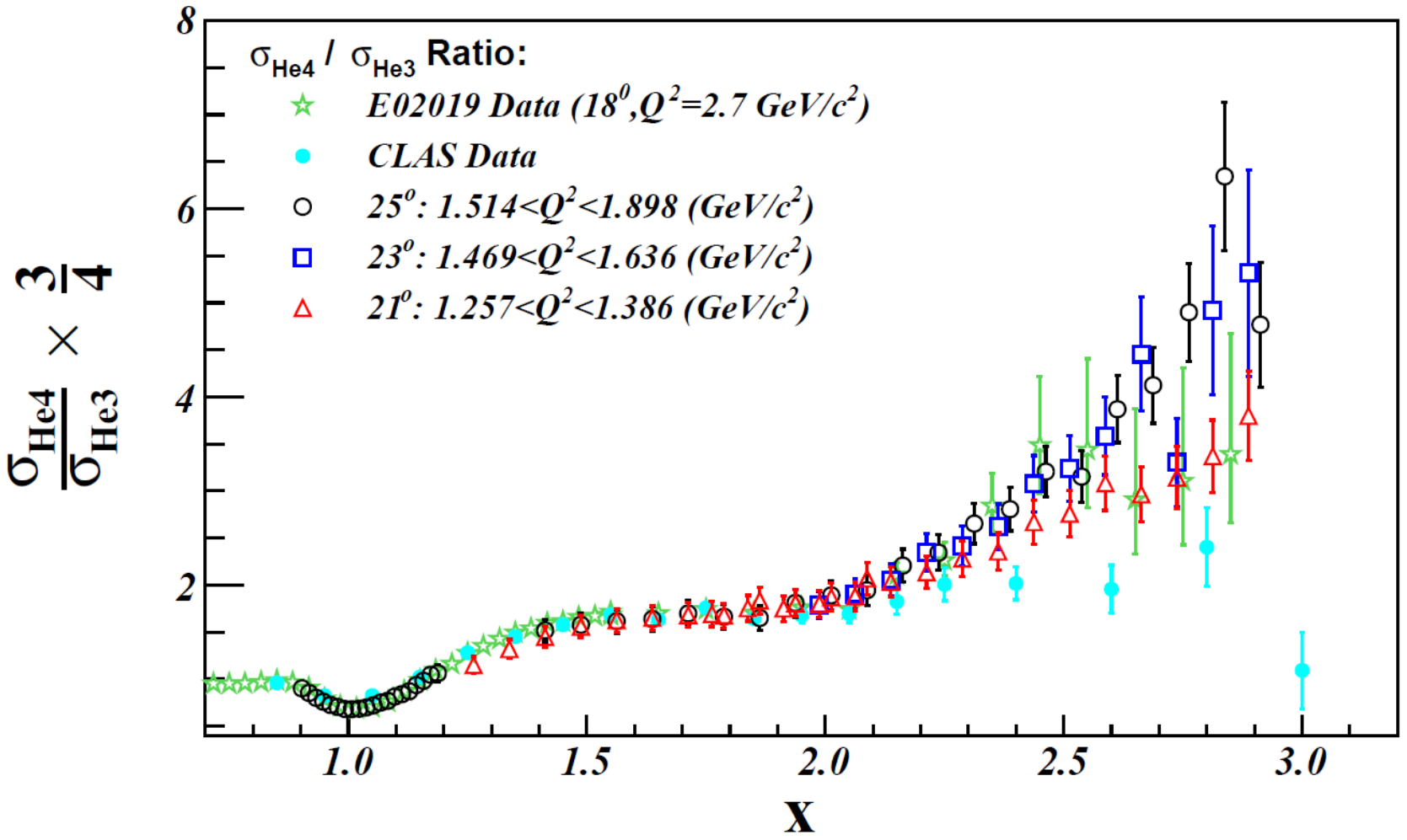




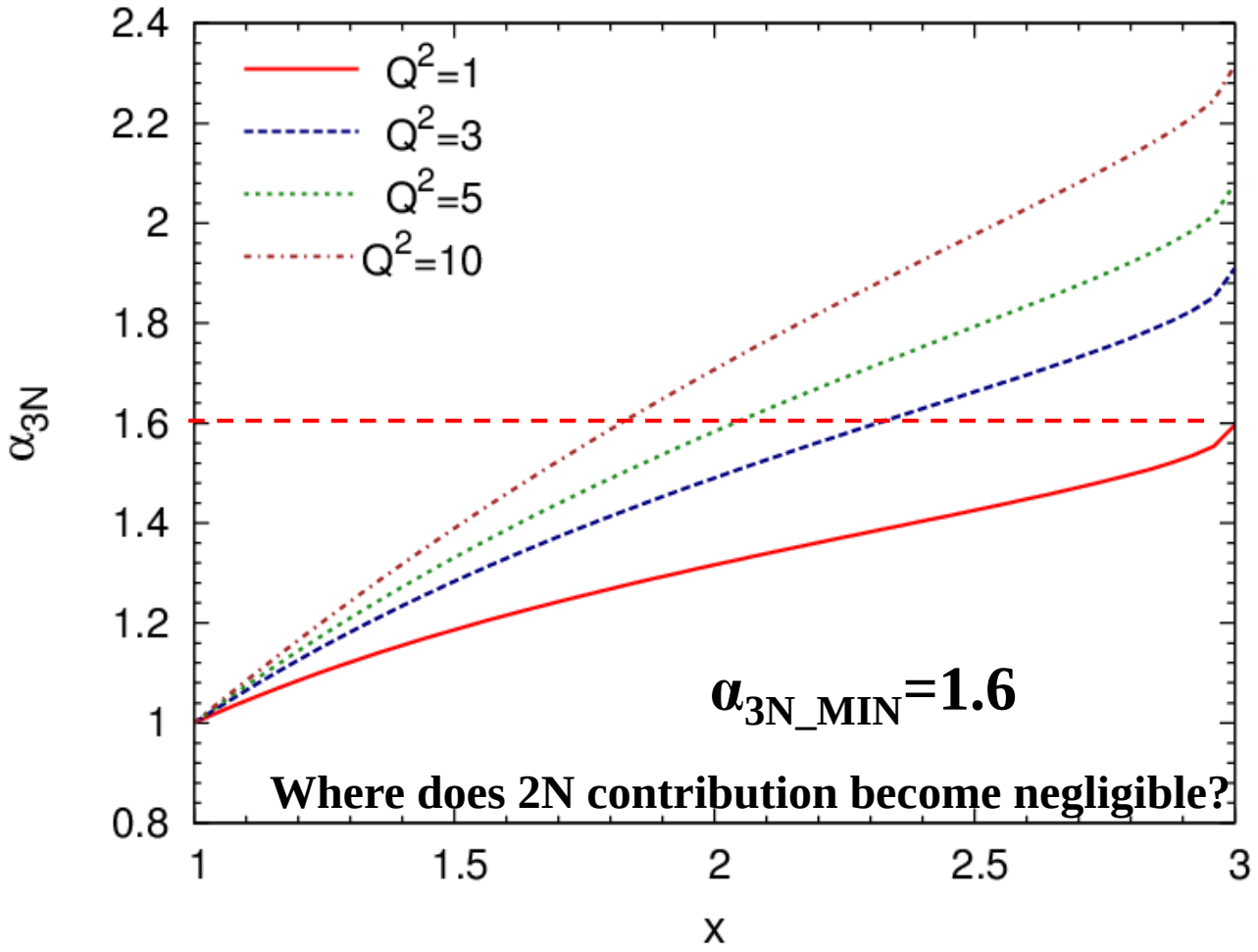
Comment on "Measurement of 2- and 3-nucleon short range correlation probabilities in nuclei"

Douglas W. Higinbotham[1] and Or Hen[2]

3N correlations



3N correlations – are we there yet?



Coming very soon: [Jlab E12-11-112]

- Quasielastic electron scattering with ^{3}H and ^{3}He
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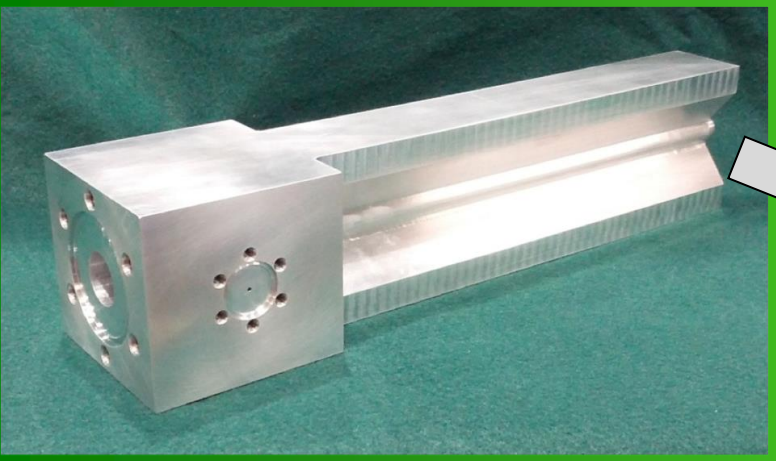
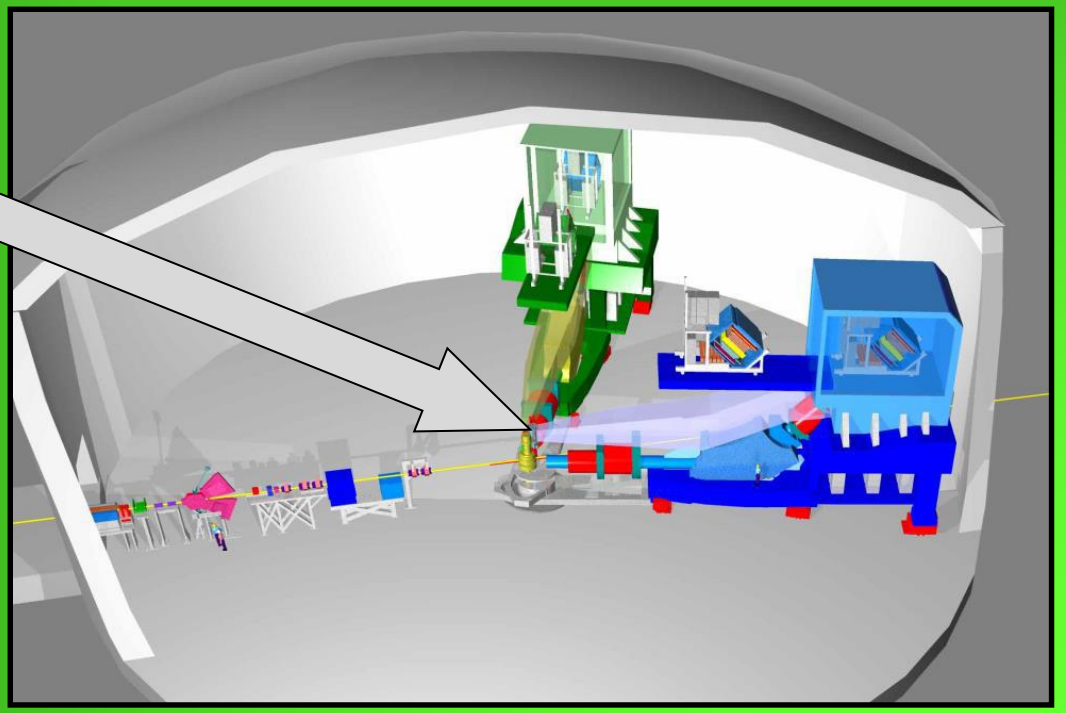
- Test calculations of FSI for well-understood nuclei





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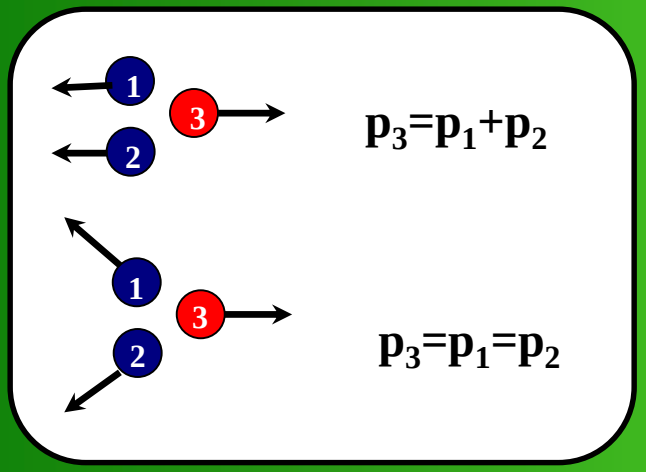
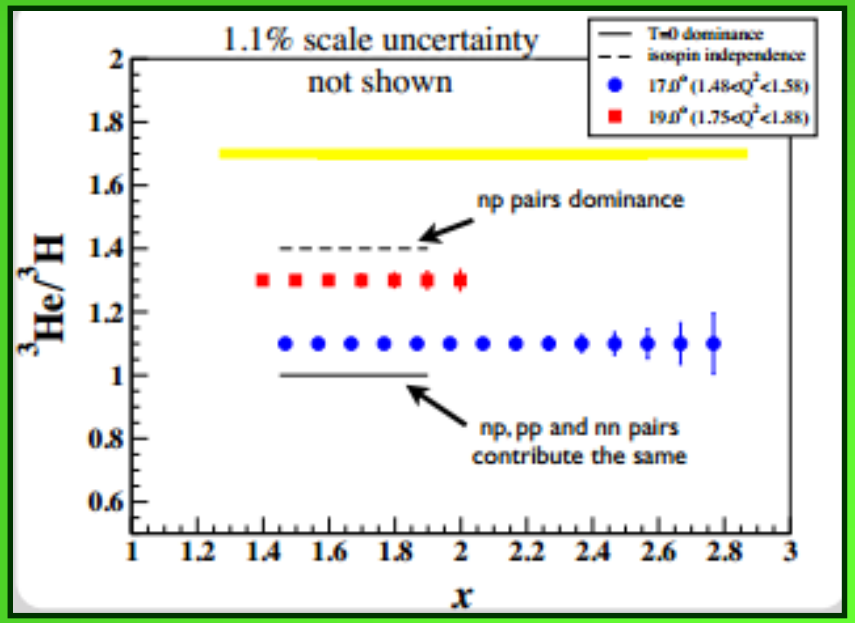
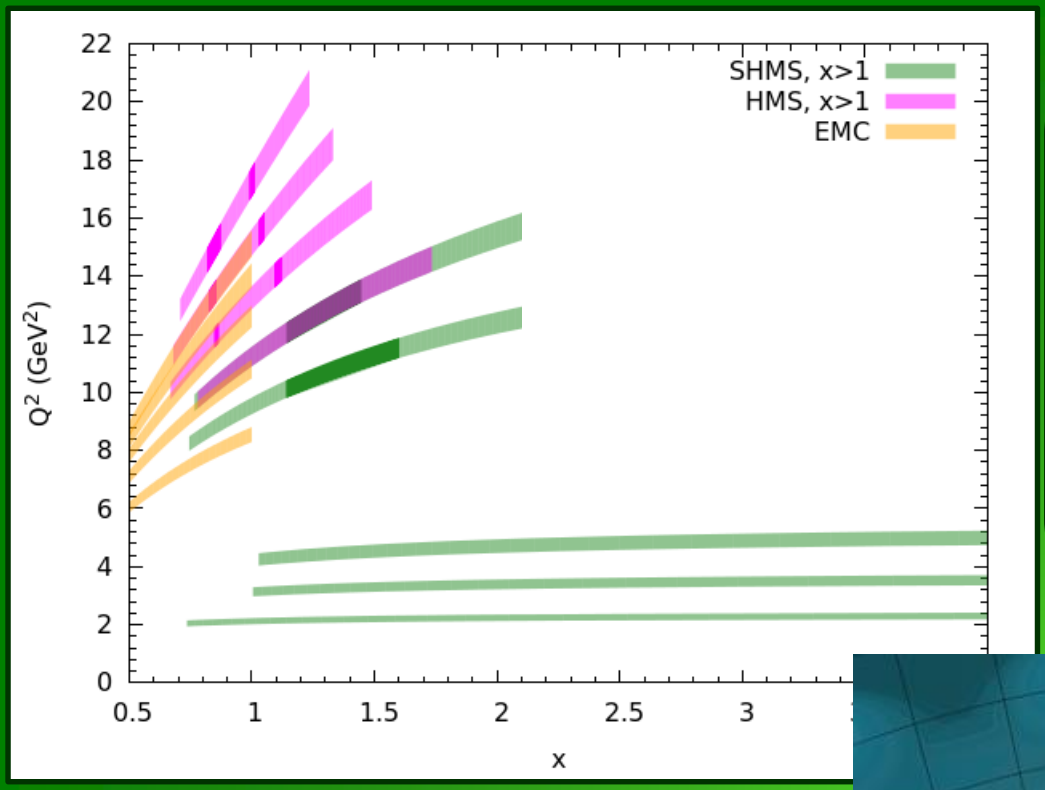
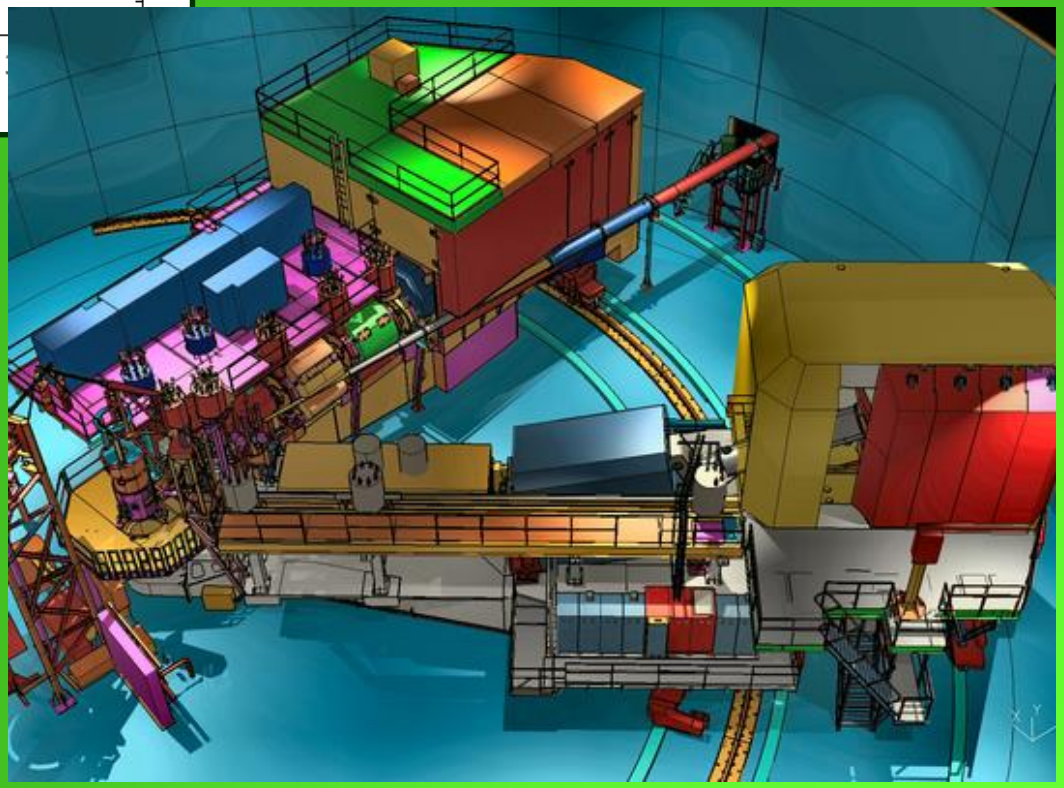


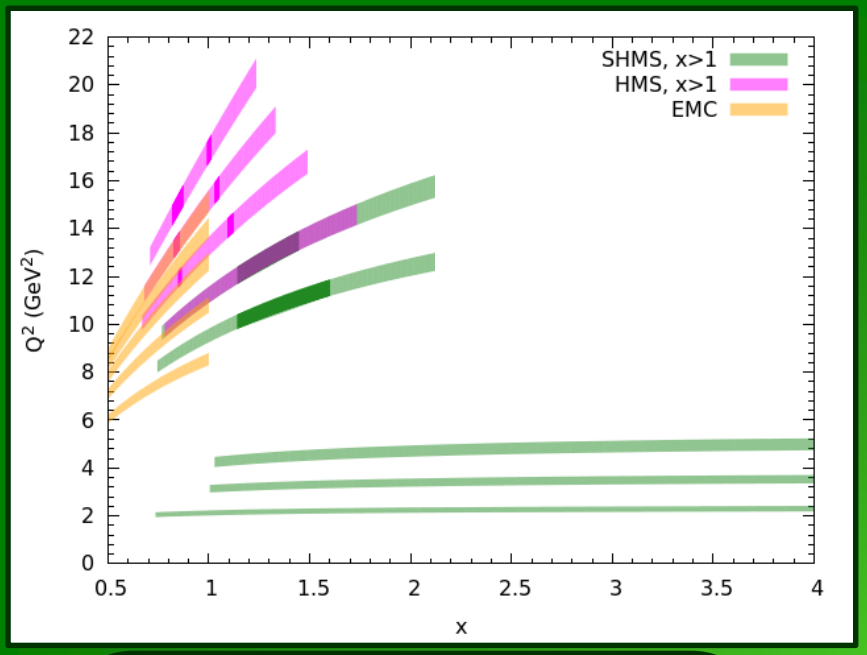




Jlab E12-06-105 && E12-10-008

- short-range nuclear structure
  - Isospin dependence
  - A-dependence
- Super-fast quarks





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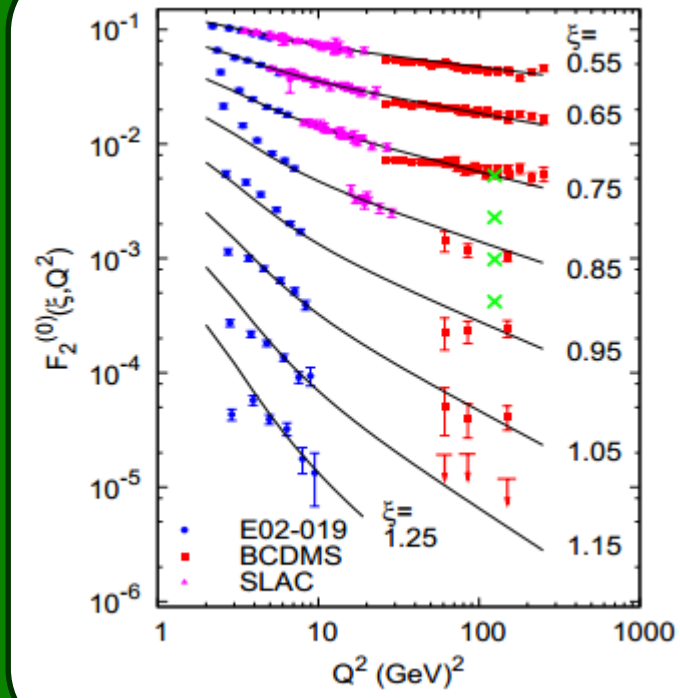
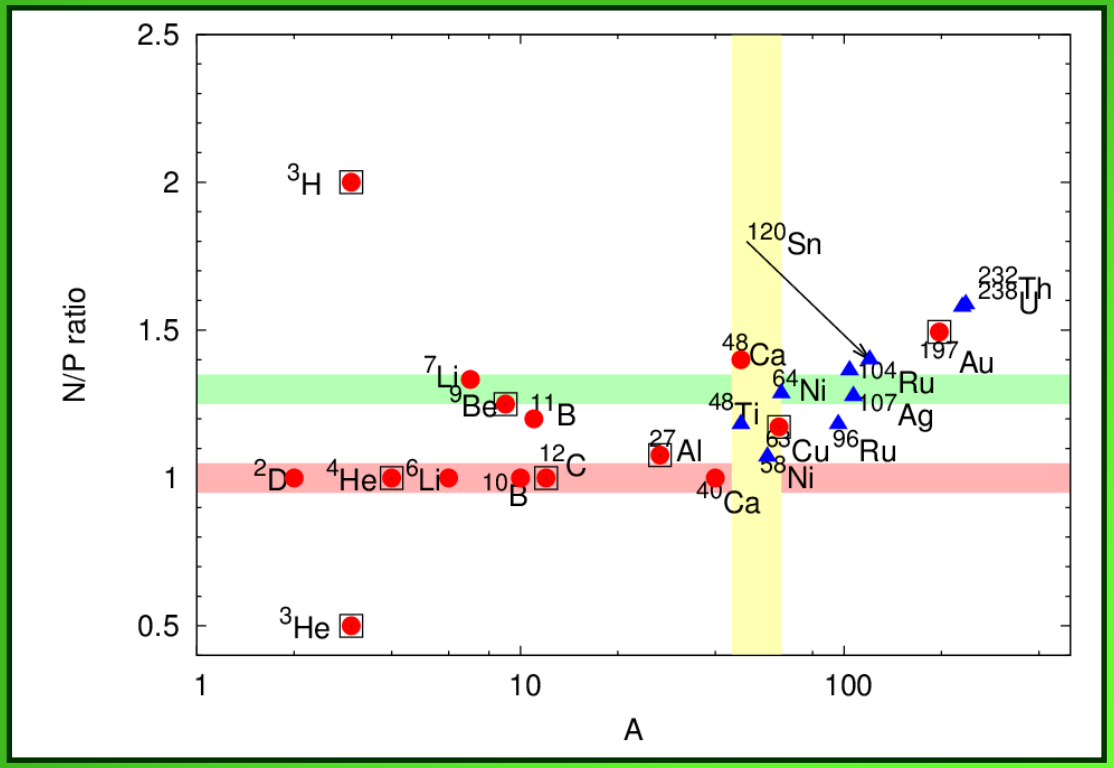
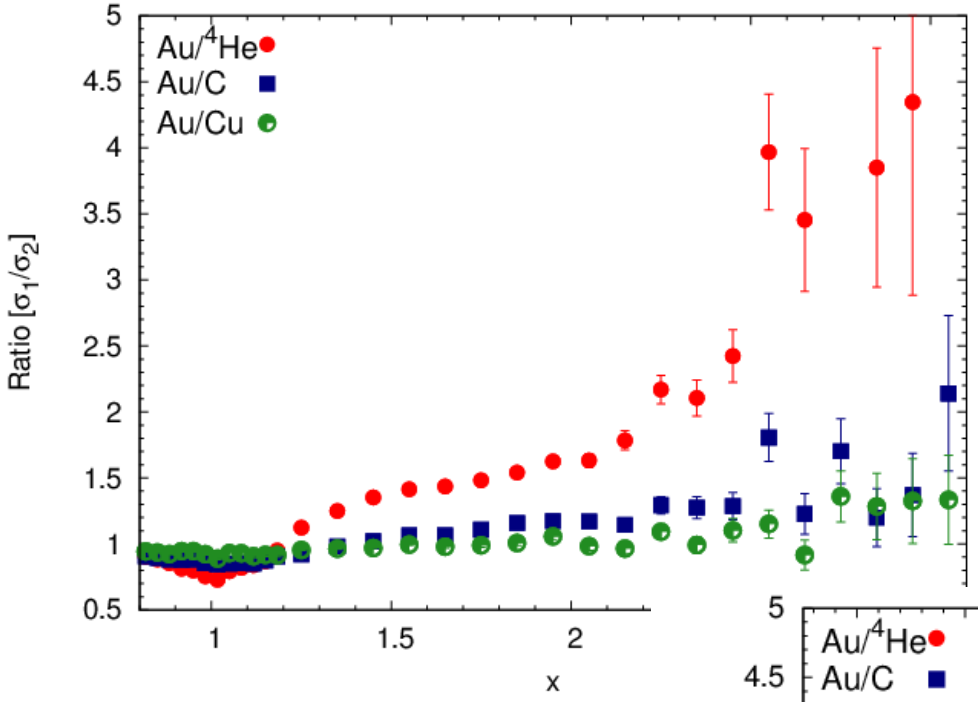


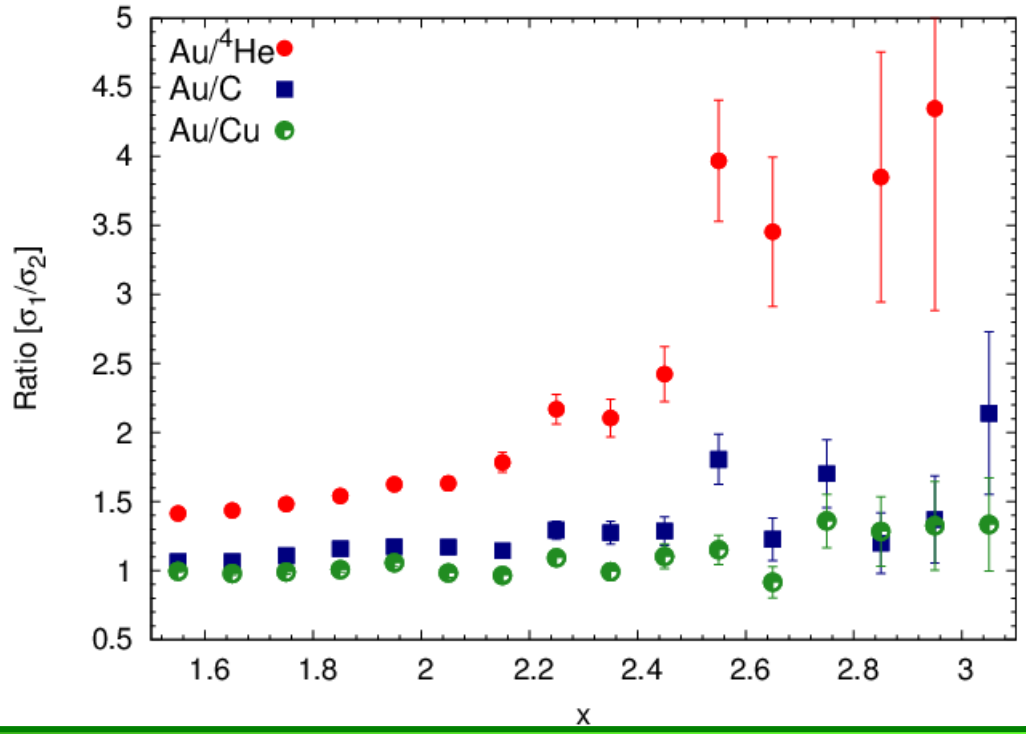


Summary

- SRCs and EMC effect have been under the microscope for many decades – 6GeV era at Jlab has yielded interesting data
- 12 GeV experiments continue the search
- Upcoming experiments in Halls A/C
  - → Study short range correlations in 3He/3H
  - → Map out nuclear dependencies of clustering
  - → Study how quark distributions are modified in nuclei over free nucleons
- New results in the next few years!



By popular demand σ_{A1}/σ_{A2}



No hint of a second plateau at x>1.6 for Au/(A>=12)