Short Range Correlations in Few Body Systems

Patricia Solvignon
UNH/JLab

6th Asia Pacific Few Body Conference
Handorf, Australia
April 7-11, 2014

Outline

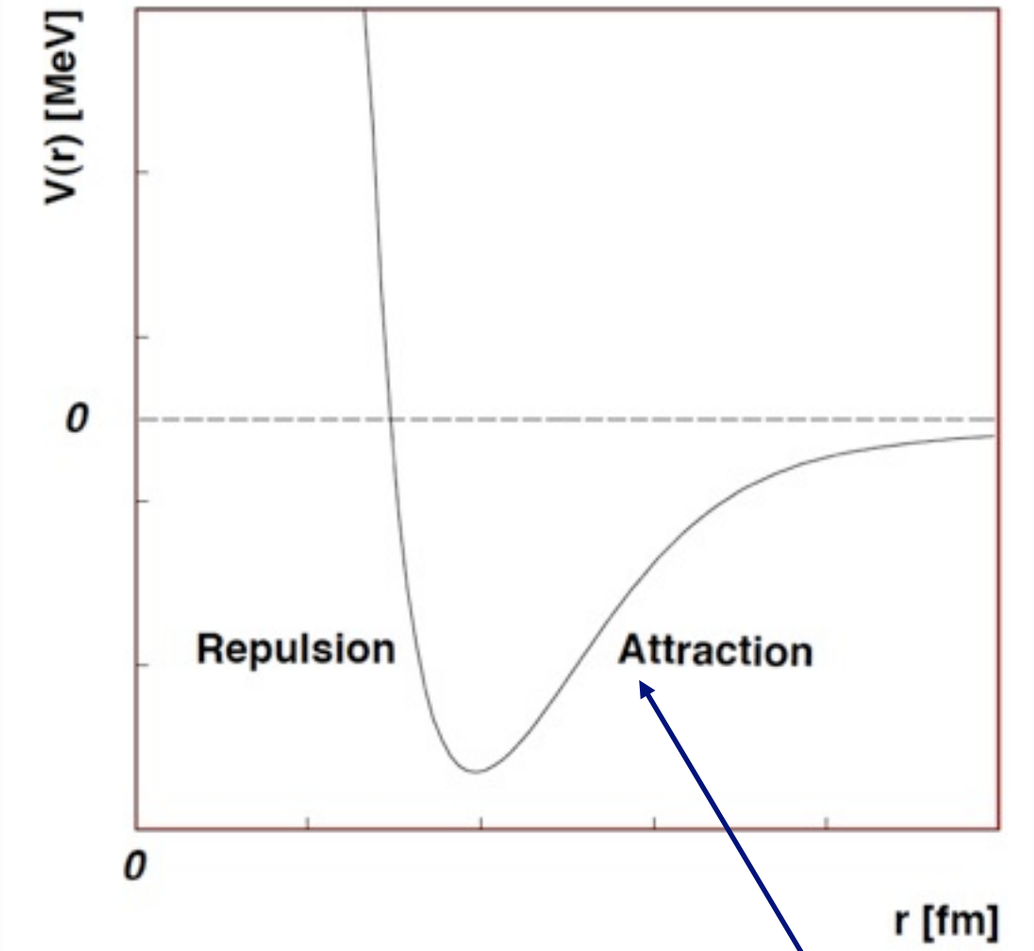
Introduction to short-range correlations

New results from Jefferson Lab

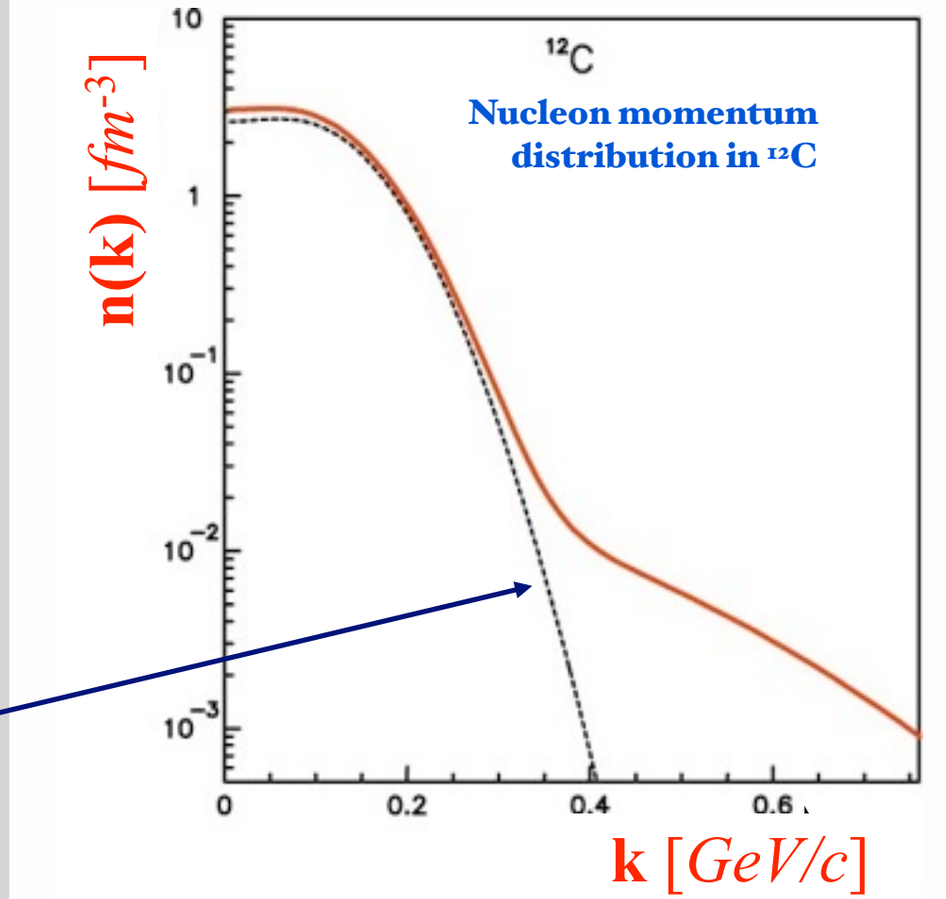
Future measurements

Summary

Nuclear Potential

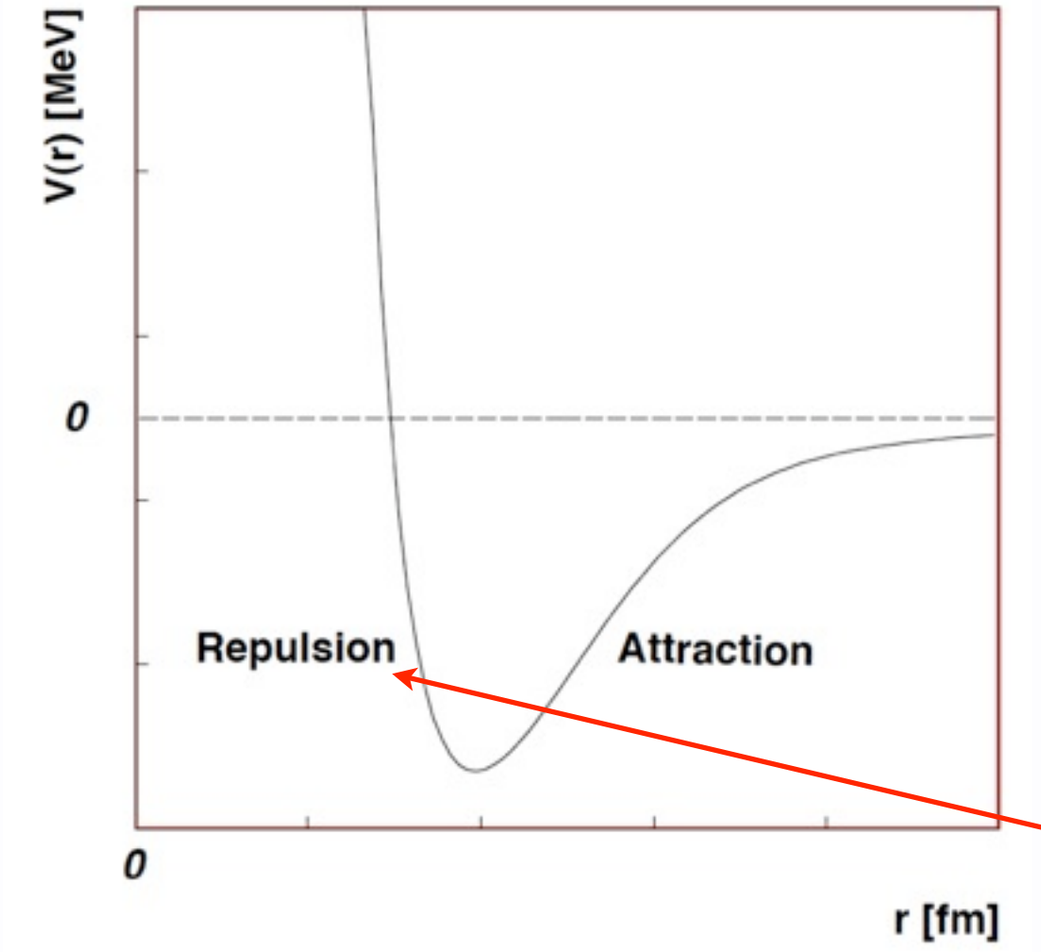


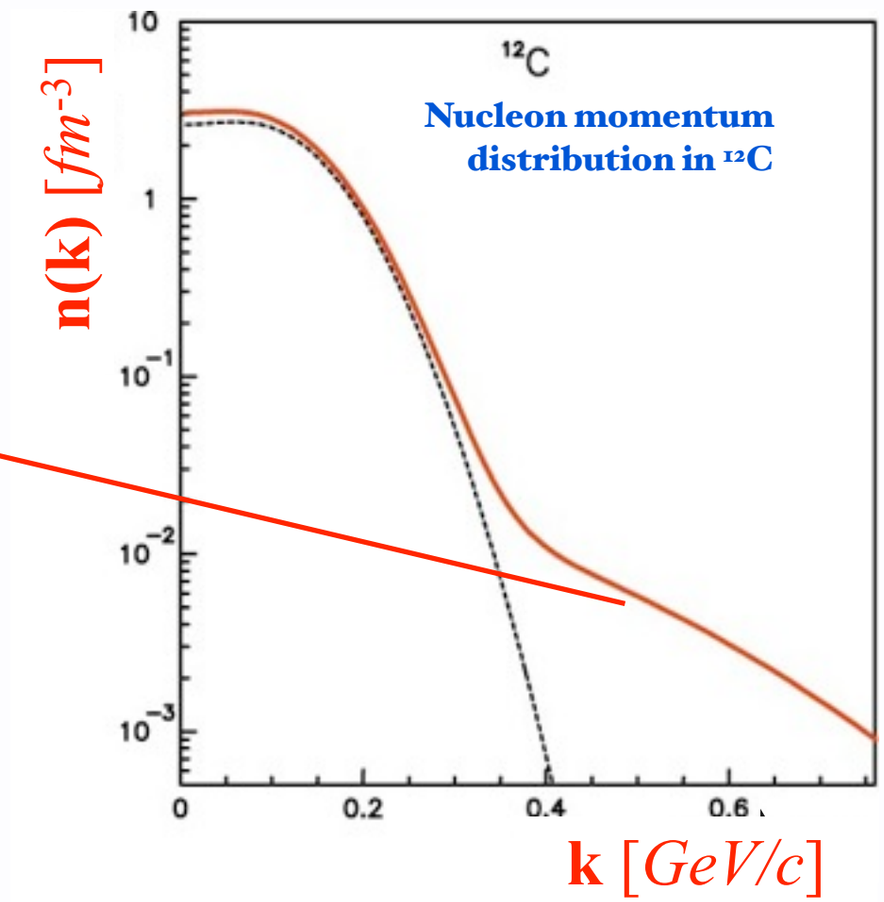
Mean field part



N-N interaction ⇨ **Hard interaction at short range**

Nuclear Potential



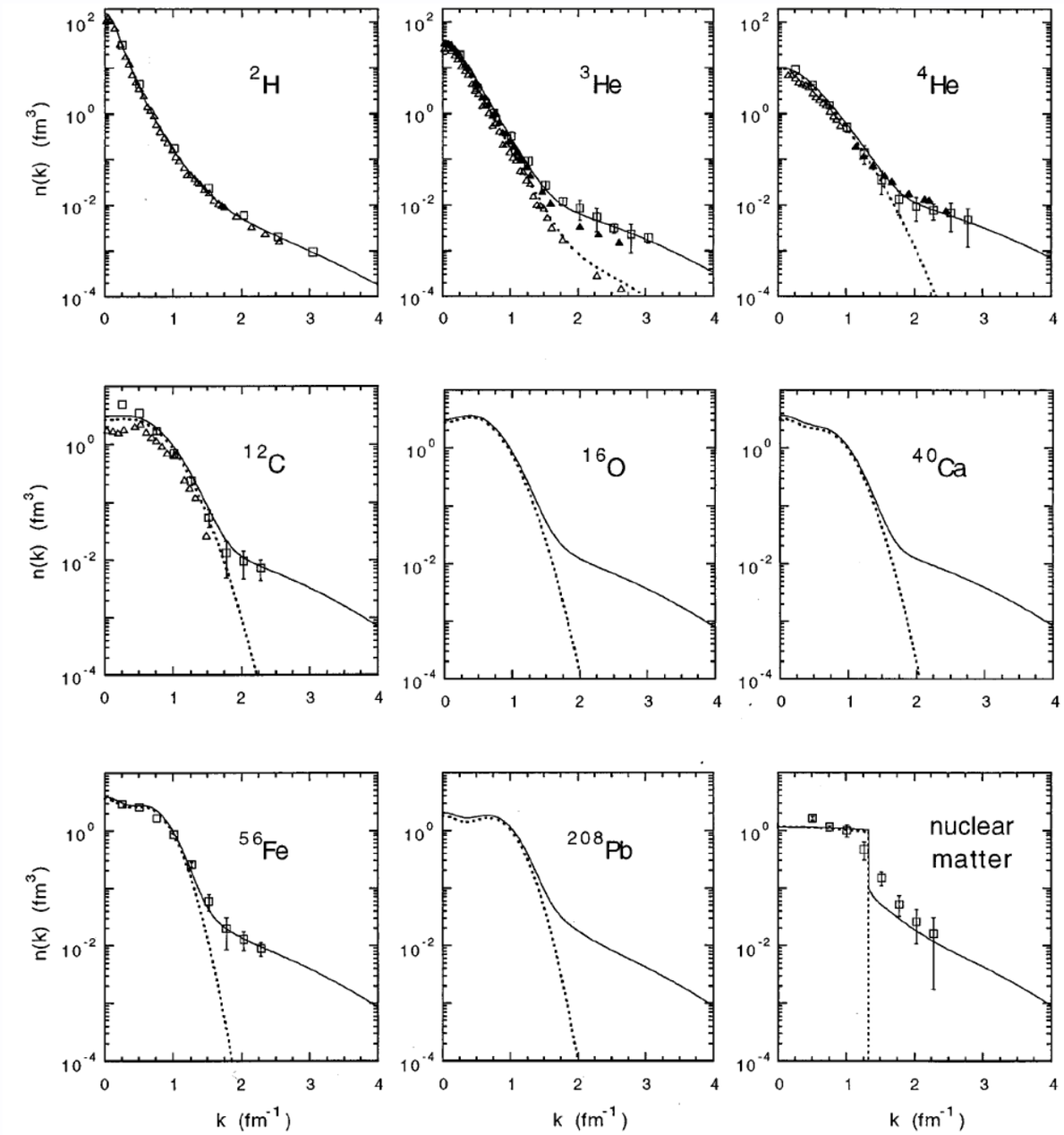


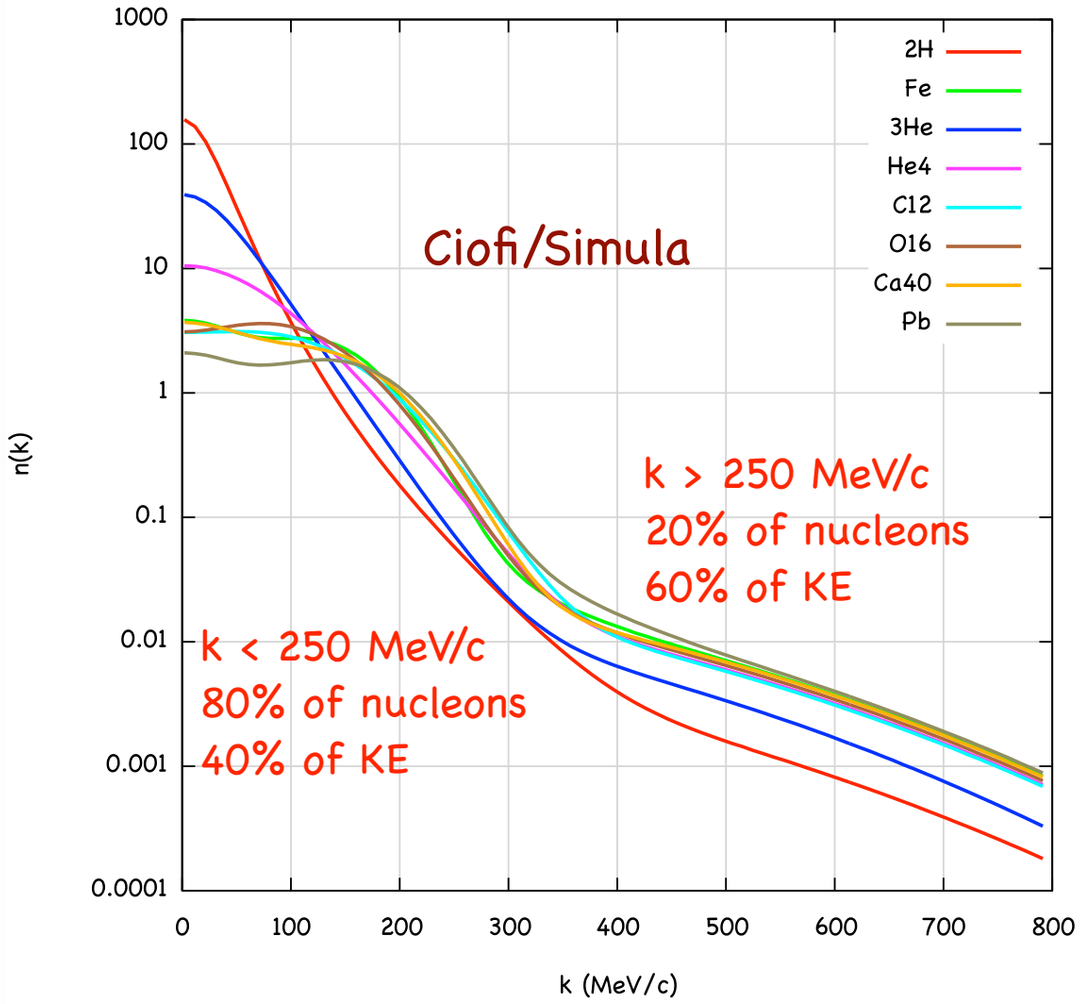
Short range/distance ⟺ **High relative momenta**

Momentum distribution

n(k) for k>k_{fermi} exhibits the same shape for all nuclei

Ciofi, Pace, Salmè et al., PRC 43, 1155 (1991)

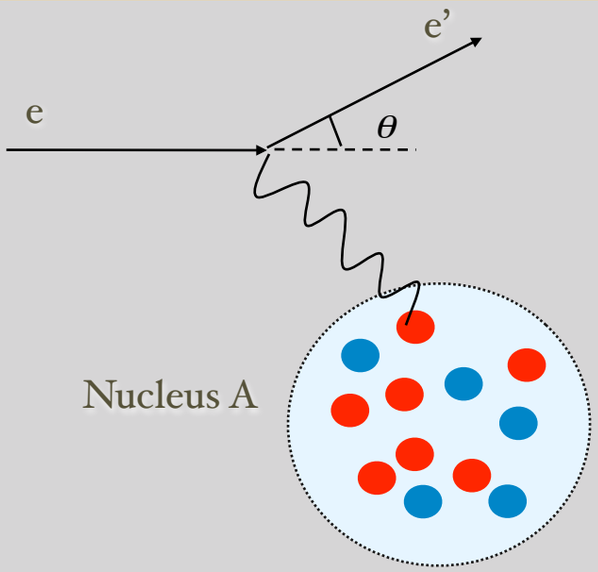




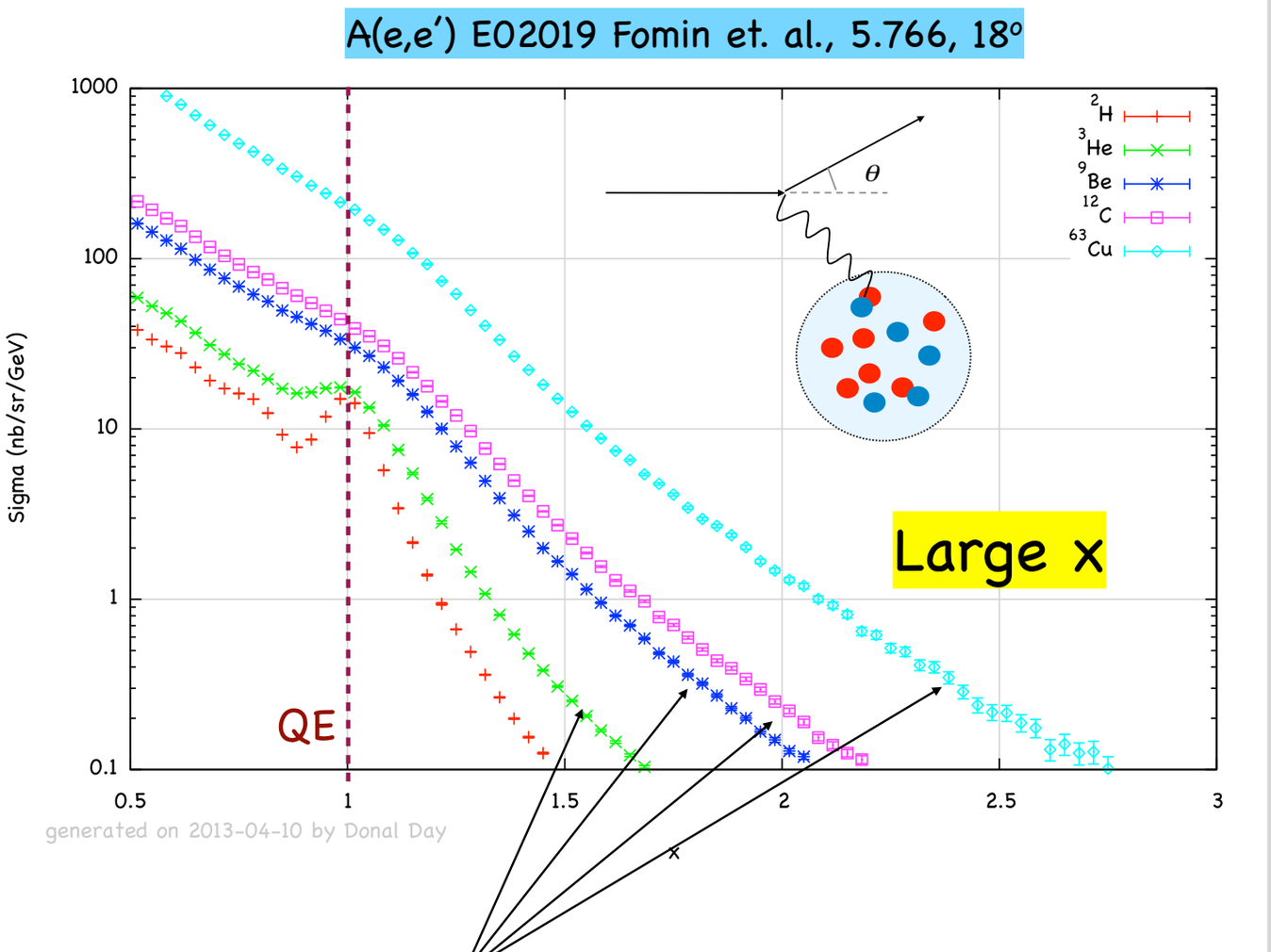
similar shape to deuteron:
NN interaction is isospin dependent

Short-Range Correlations

At $x \approx 1$: Quasi-Elastic Scattering

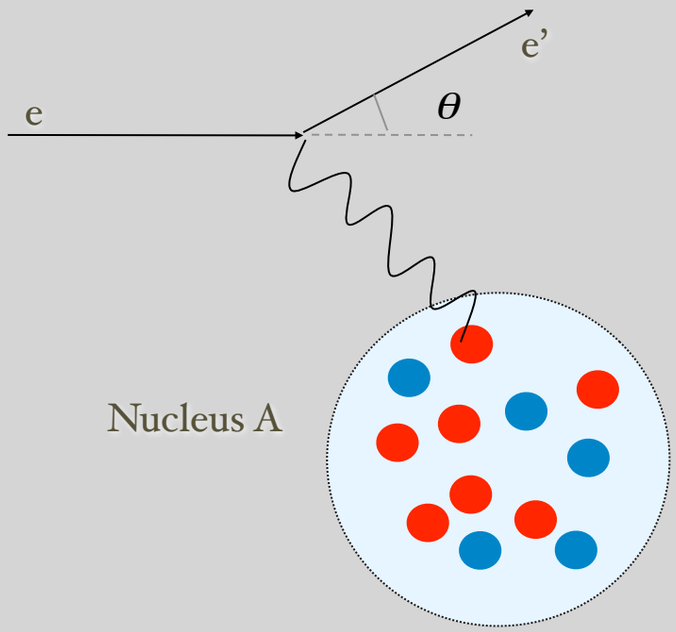


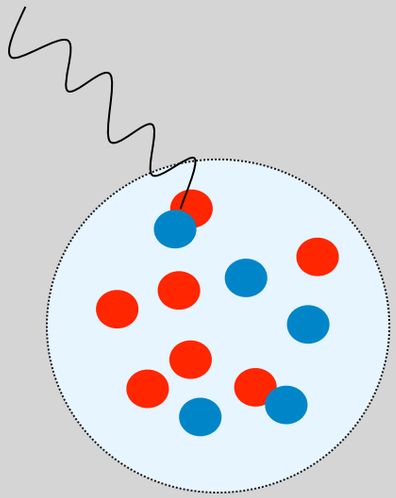
➡ Motion of nucleon in the nucleus broadens the peak.
➡ little strength from QE above x ≈ 1.3

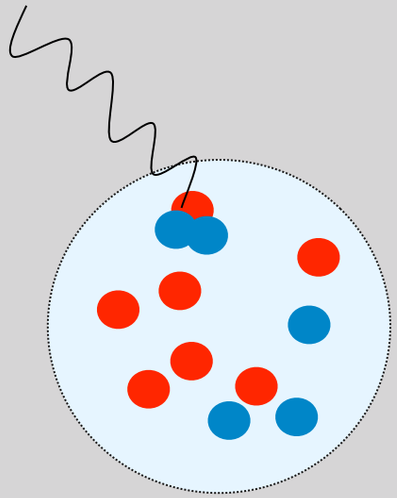


A(e,e') cross section ratios and SRC

Frankfurt & Strikman







...

QES
$x=1$

2N-SRC
$1<x<2$

3N-SRC
$2<x<3$

For $x \geq 1.3$:

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

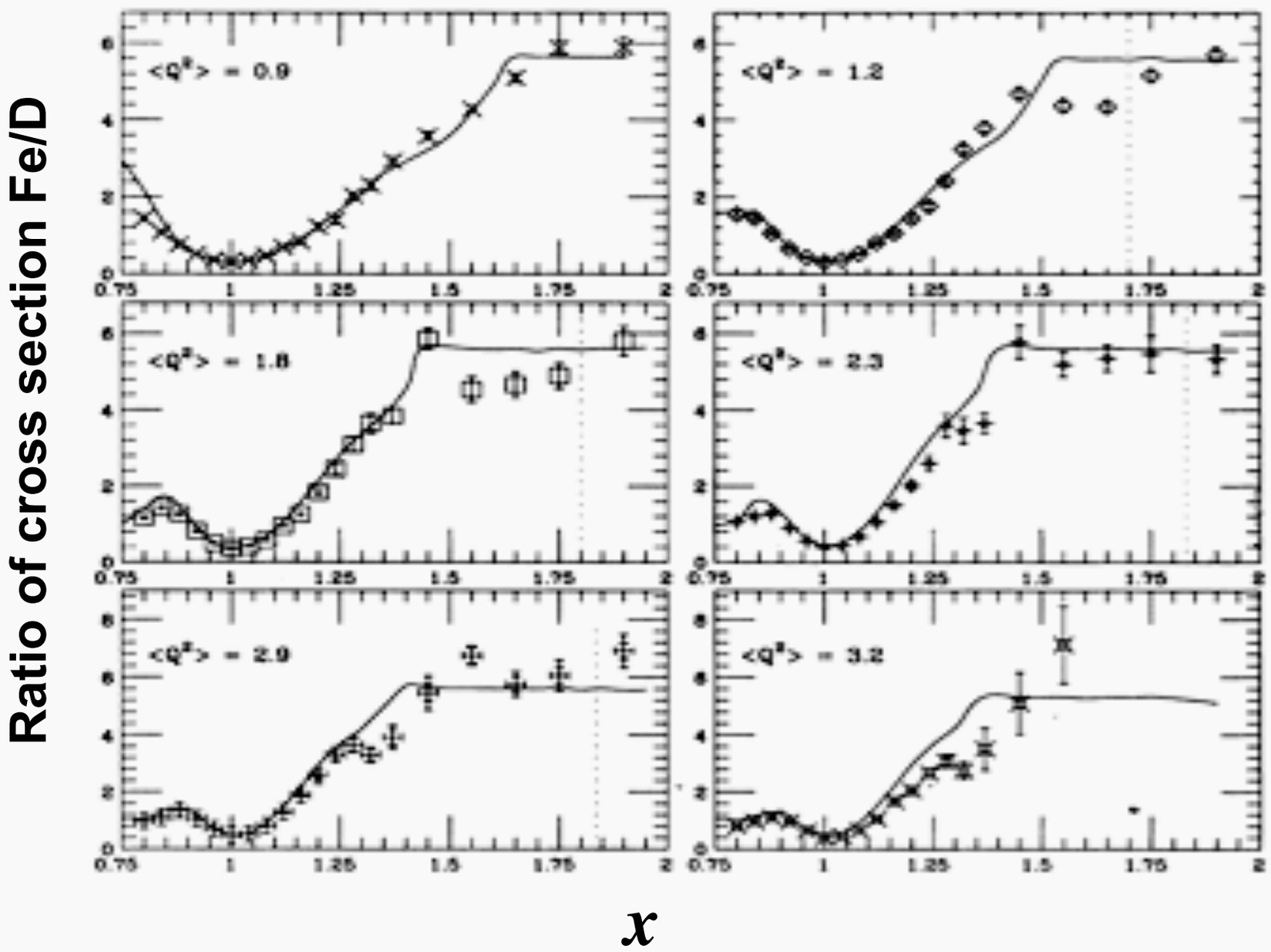
$$= \frac{A}{2} a_2(A) \sigma_2(x,Q^2) + \frac{A}{3} a_3(A) \sigma_3(x,Q^2) + \ldots$$

σ_j → cross section from a j-nucleon correlation

$a_j(A) \propto$ probability of finding a nucleon in a j-nucleon correlation

A(e,e') cross section ratios and SRC

Frankfurt, Strikman, Day, Sargsian, PRC48, 2451 (1993)



Ratio in plateau, proportional to the number of 2N SRCs

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

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

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

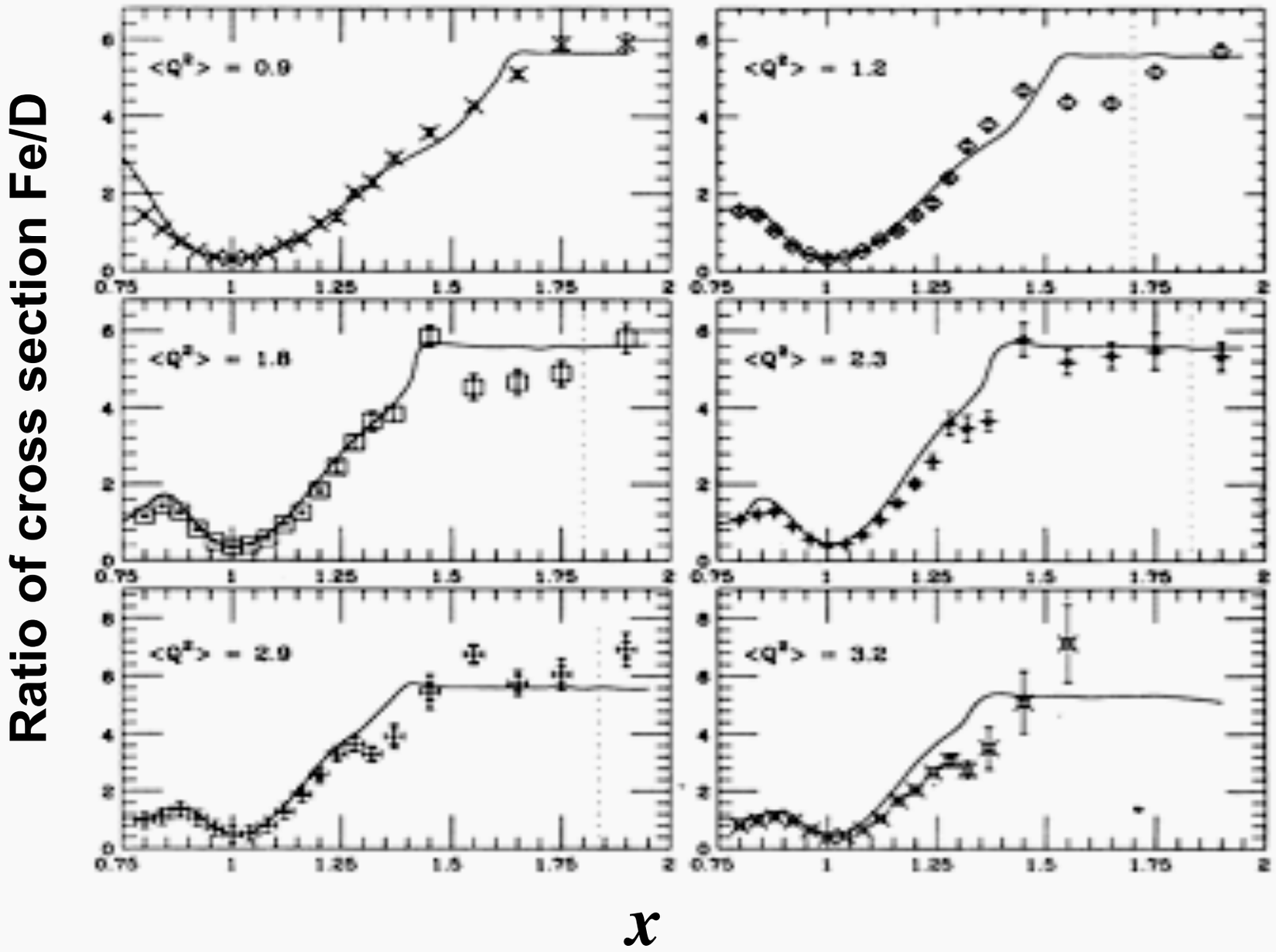
$a_2(^{27}Al)=5.3\pm0.6$

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

Evidence of 2N-SRC at x>1.5

A(e,e') cross section ratios and SRC

Frankfurt, Strikman, Day, Sargsian, PRC48, 2451 (1993)



Ratio in plateau, proportional to the number of 2N SRCs

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

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

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

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

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

Saturation

Evidence of 2N-SRC at x>1.5

A(e,e') cross section ratios and SRC

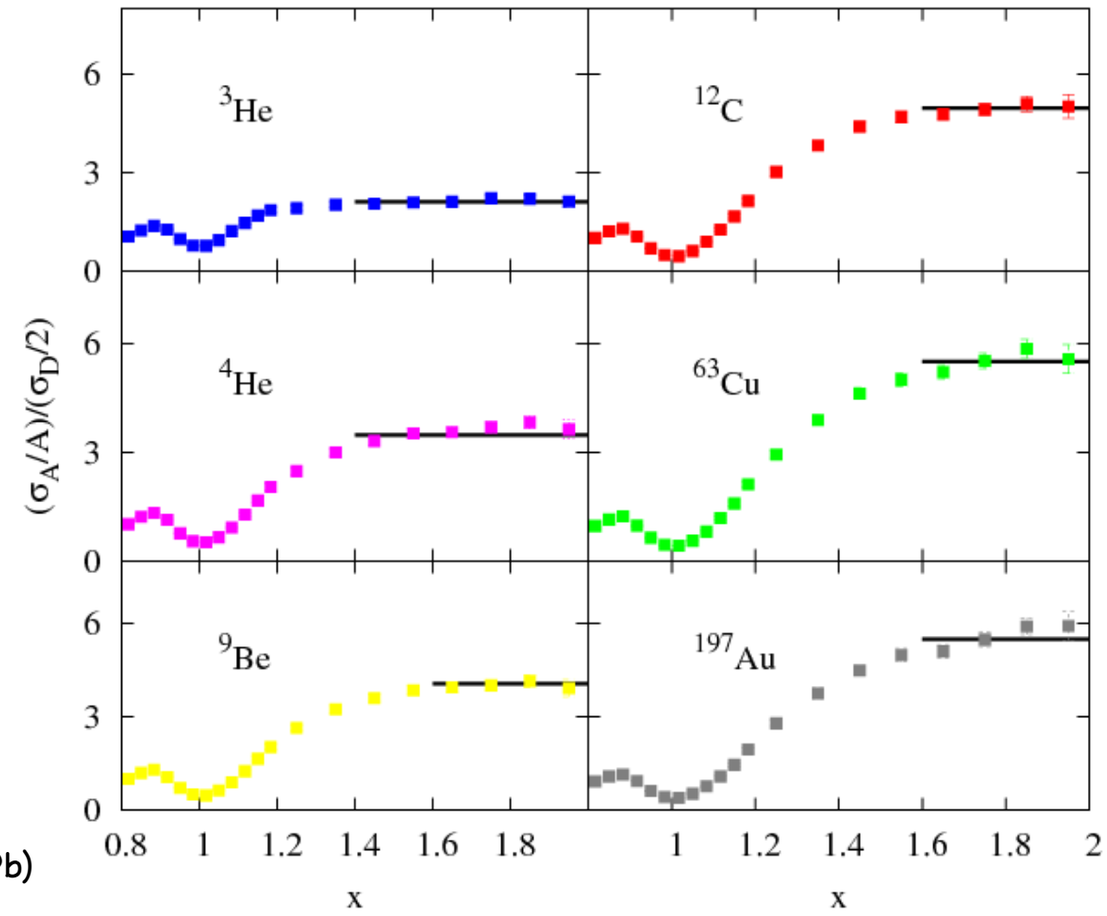
Dominance of np pairs in SRC region leads us to drop the isoscalar correction. We correct for COM motion of pair.

R_{2n} : number of np pairs relative to the deuteron

A	R_{2N} (E02-019)	SLAC	CLAS	F_{CM}	Ciofi/Simula
^{3}He	1.93 ± 0.10	1.8 ± 0.3	···	1.10 ± 0.05	1.9
^{4}He	3.02 ± 0.17	2.8 ± 0.4	2.80 ± 0.28	1.19 ± 0.06	3.8
Be	3.37 ± 0.17	···	···	1.16 ± 0.05	
C	4.00 ± 0.24	4.2 ± 0.5	3.50 ± 0.35	1.19 ± 0.06	4.0
Cu(Fe)	4.33 ± 0.28	(4.3 ± 0.8)	(3.90 ± 0.37)	1.20 ± 0.06 *	4.5
Au	4.26 ± 0.29	4.0 ± 0.6	···	1.21 ± 0.06	4.8 (^{208}Pb)
$\langle Q^2 \rangle$	~2.7 GeV^2	~1.2 GeV^2	~2 GeV^2		
x_{min}	1.5	···	1.5		
α_{min}	1.275	1.25	1.22–1.26		

Hall C

N. Fomin et al., Phys. Rev. Lett. 108, 092502 (2012)

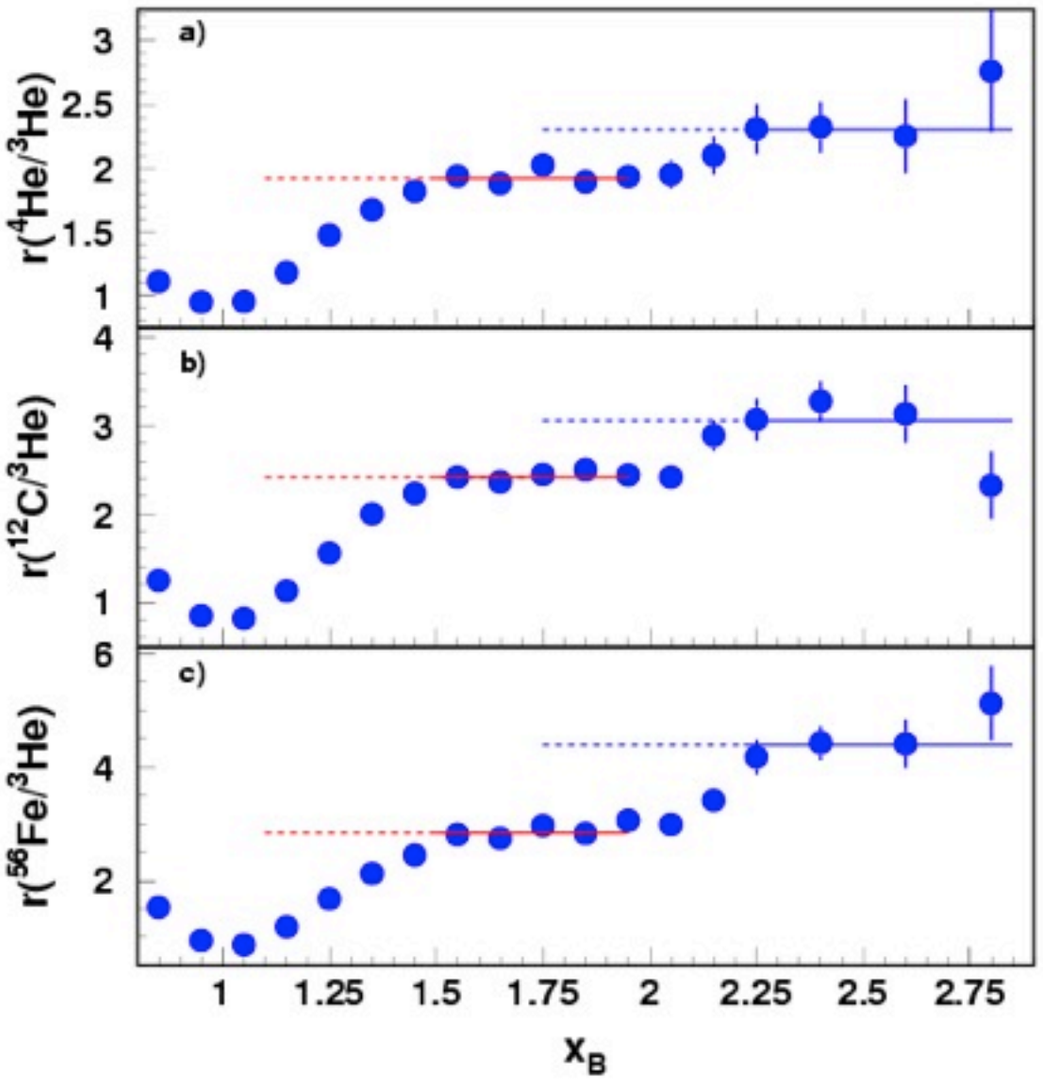


Evidence of 2N-SRC at x>1.5

A(e,e') cross section ratios and SRC

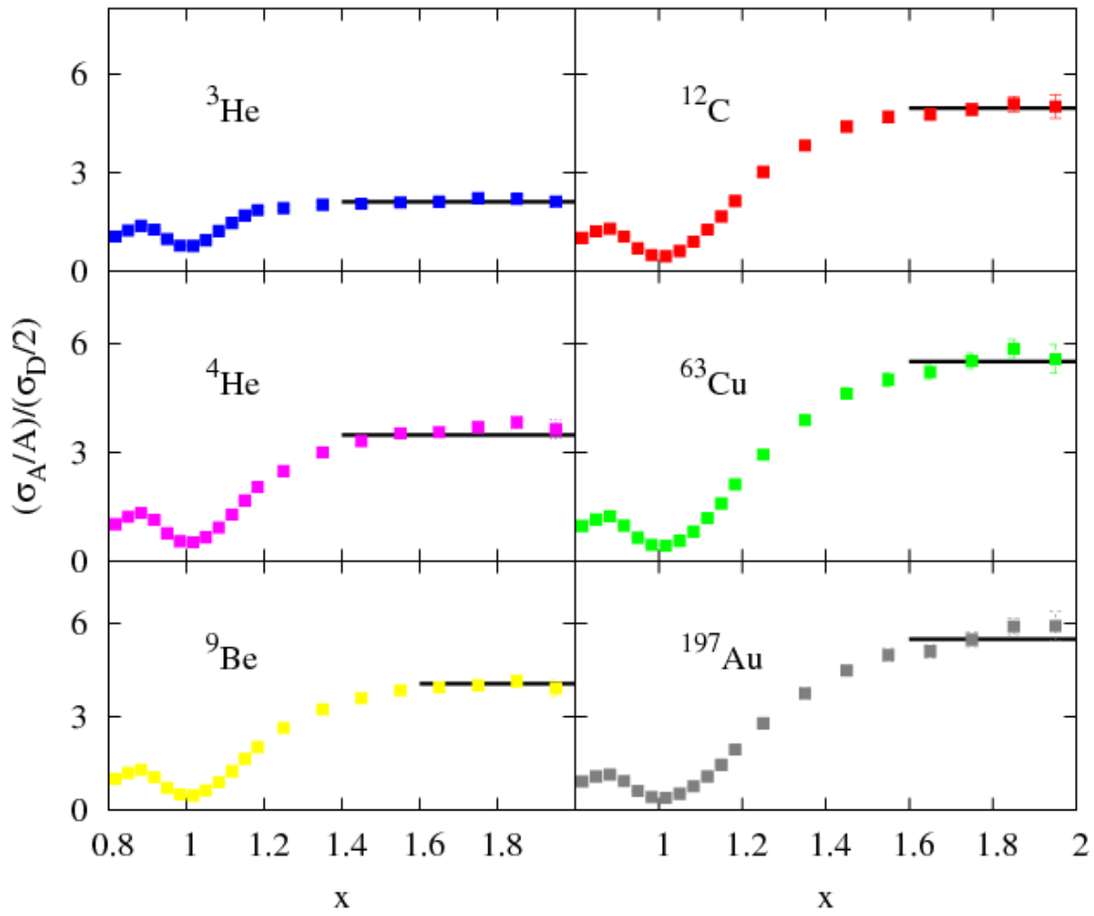
Hall B

K. S. Egiyan et al., Phys. Rev. Lett. 96, 082501 (2006)



Hall C

N. Fomin et al., Phys. Rev. Lett. 108, 092502 (2012)

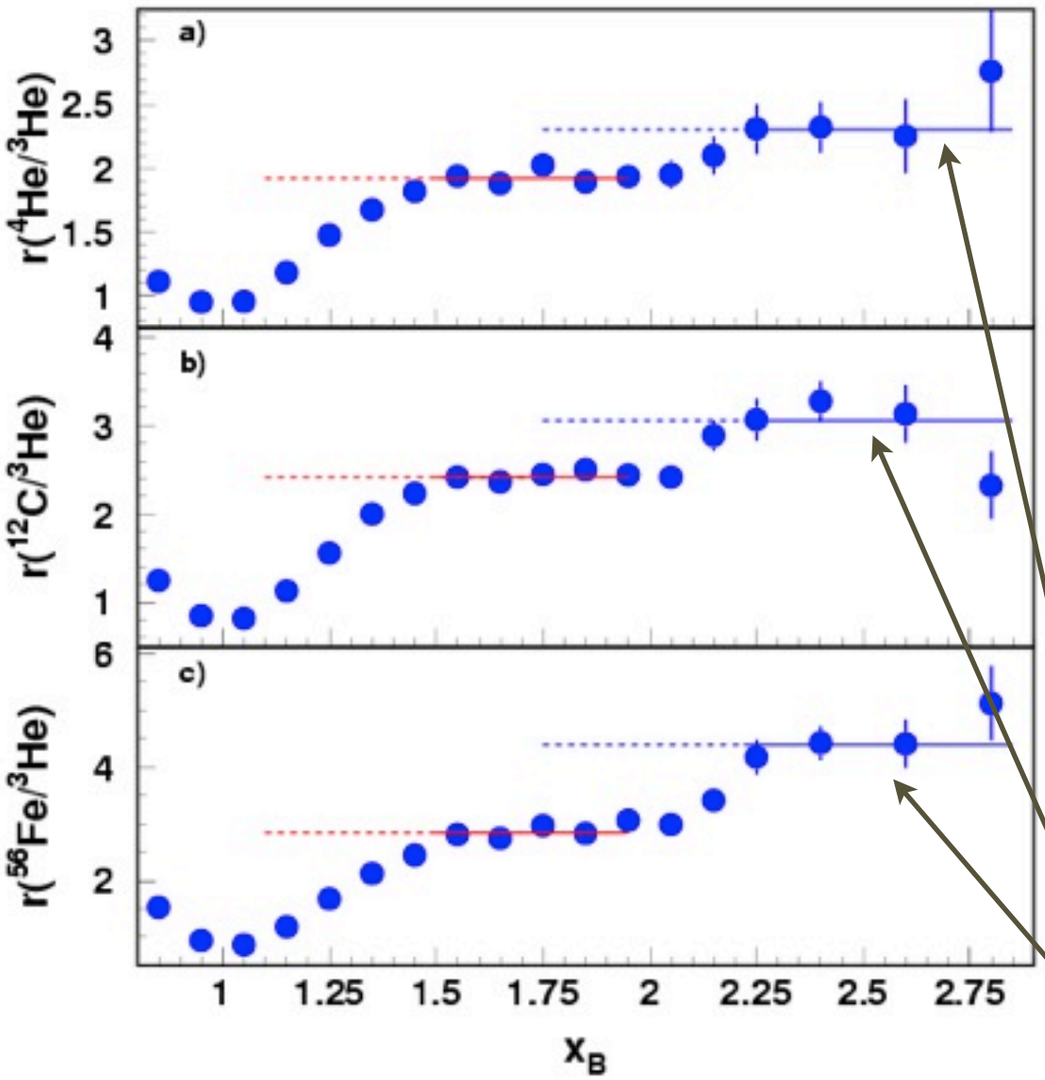


Evidence of 2N-SRC at x>1.5

A(e,e') cross section ratios and SRC

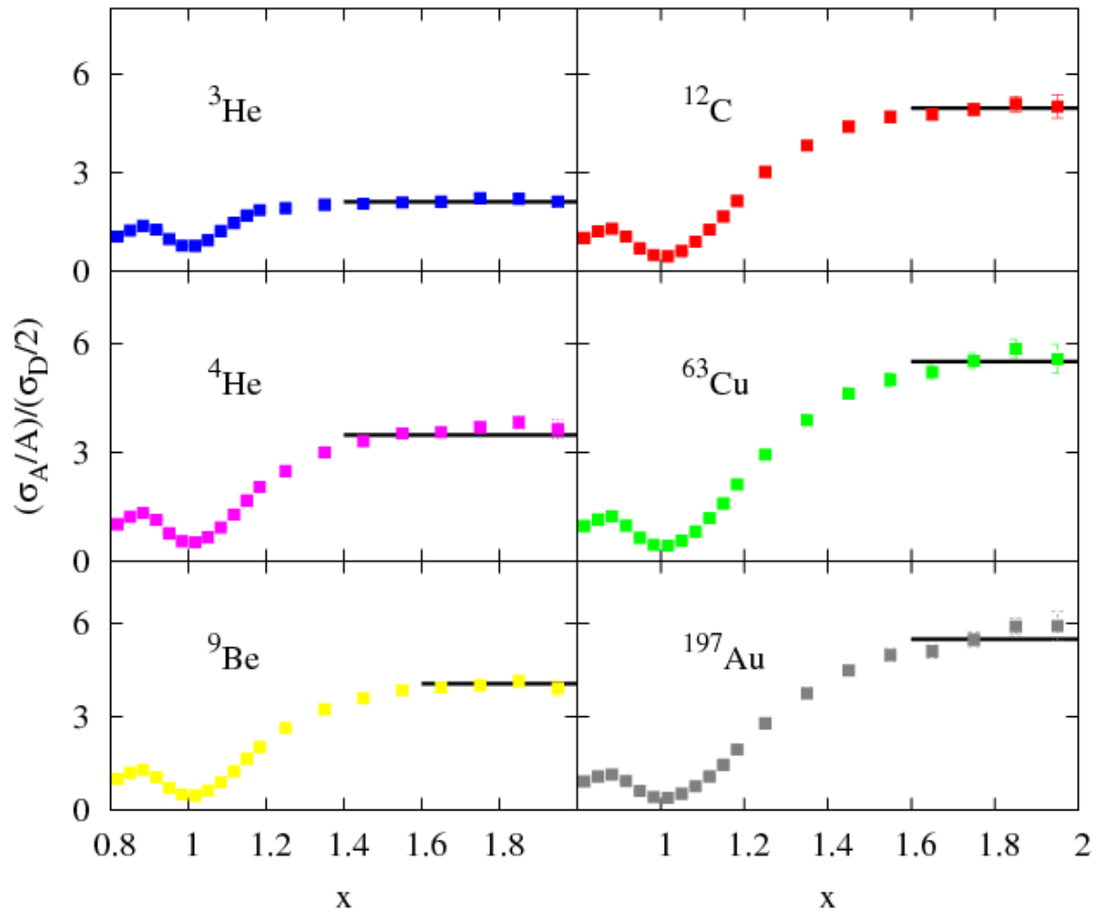
Hall B

K. S. Egiyan et al., Phys. Rev. Lett. 96, 082501 (2006)



Hall C

N. Fomin et al., Phys. Rev. Lett. 108, 092502 (2012)

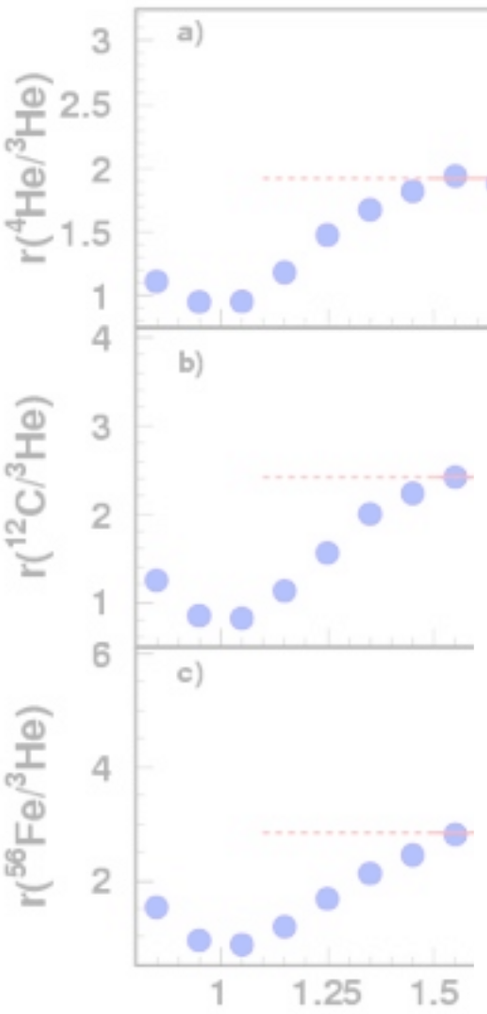


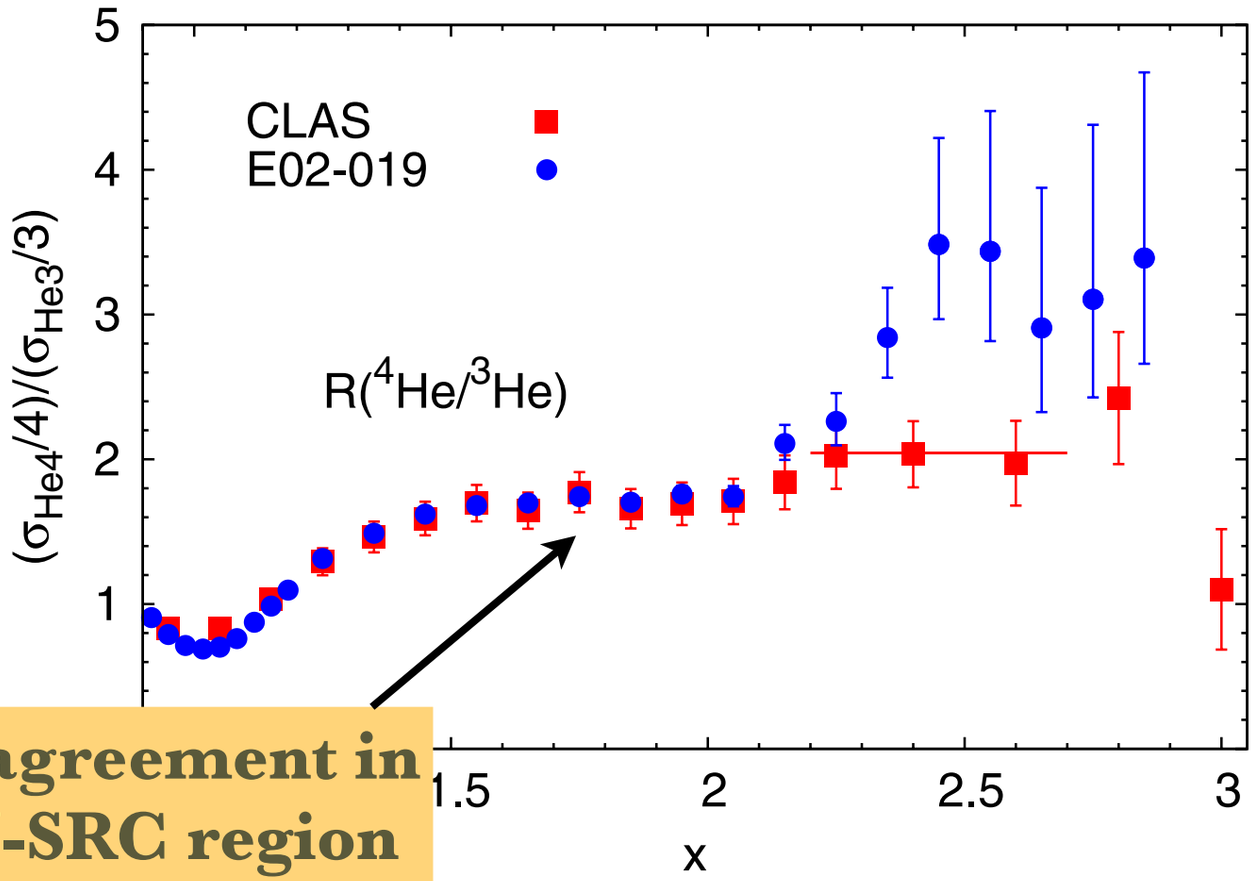
Hint of 3N-SRC at x>2 ?

A(e,e') cross section ratios and SRC

Hall B

K. S. Egiyan et al., Phys. Rev. Lett. 96, 082501 (2006)

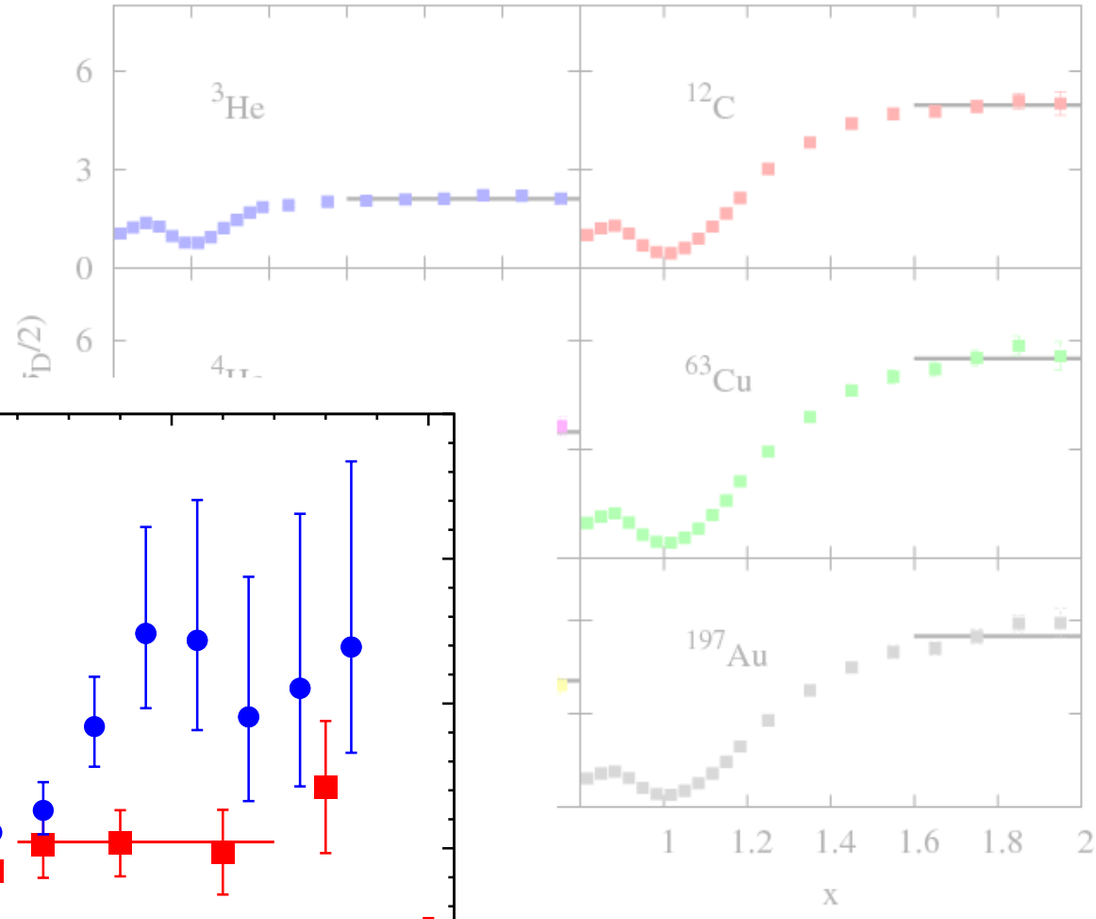




Good agreement in the 2N-SRC region

Hall C

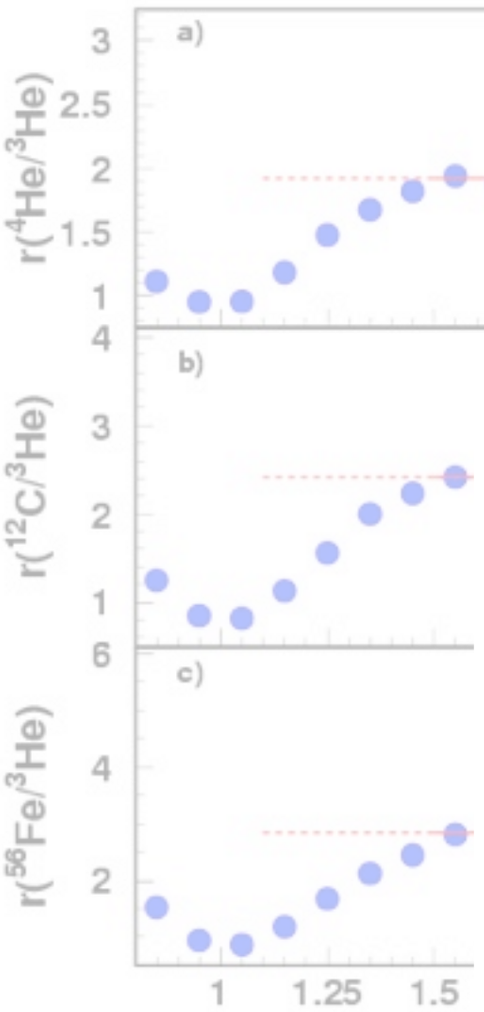
N. Fomin et al., Phys. Rev. Lett. 108, 092502 (2012)

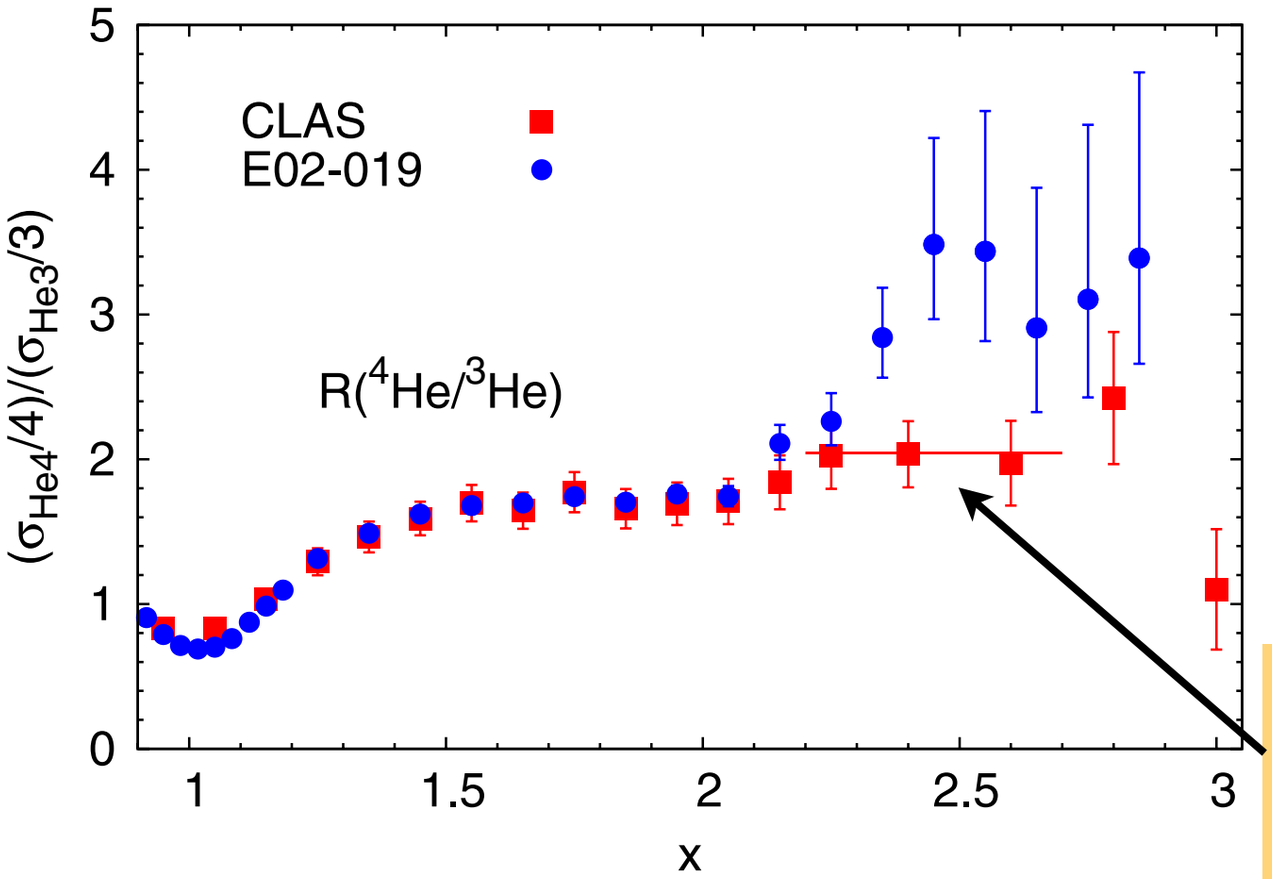


A(e,e') cross section ratios and SRC

Hall B

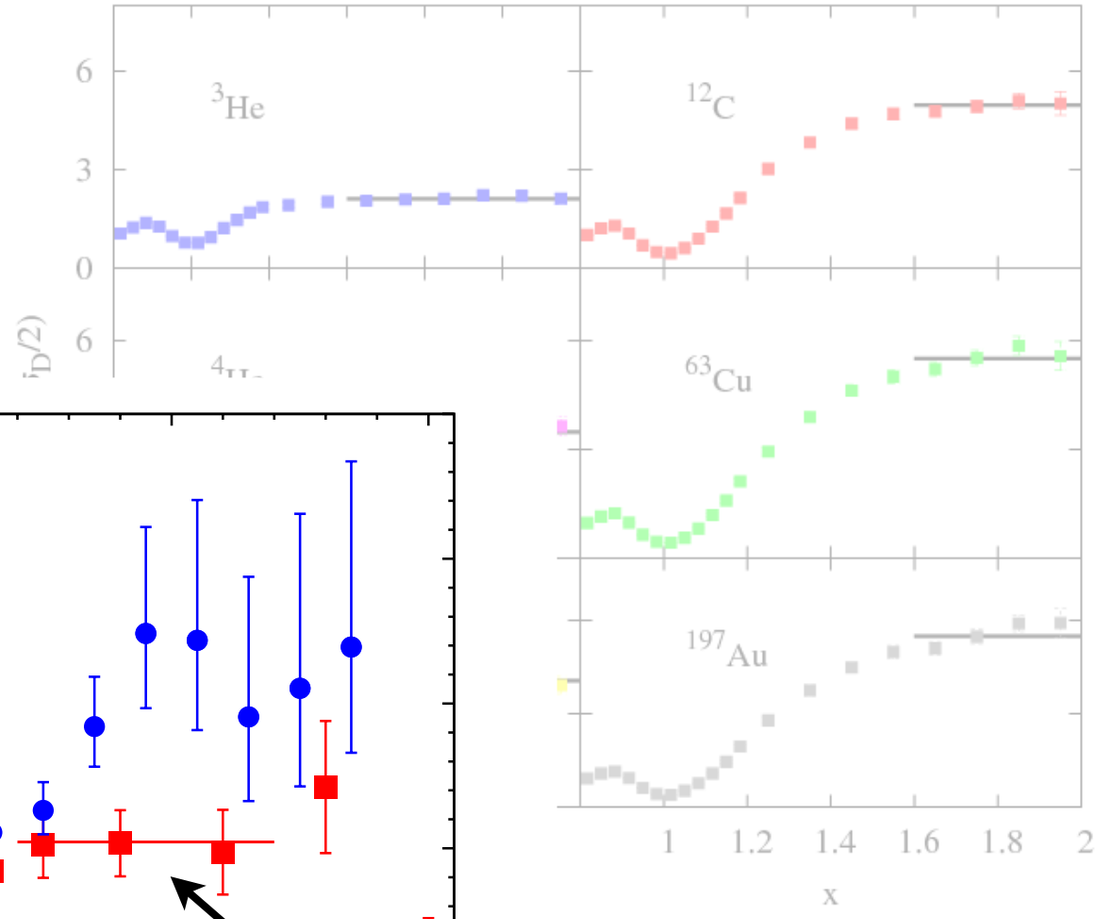
K. S. Egiyan et al., Phys. Rev. Lett. 96, 082501 (2006)





Hall C

N. Fomin et al., Phys. Rev. Lett. 108, 092502 (2012)



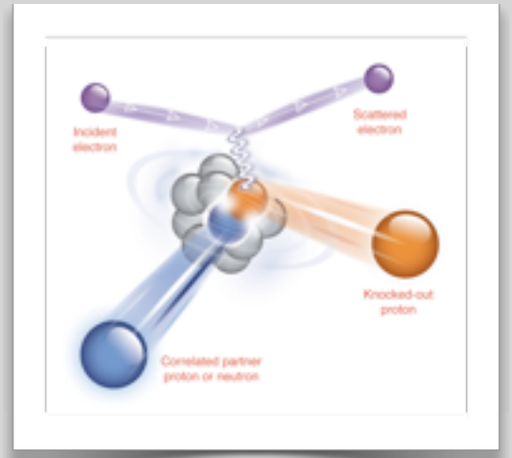
but
potential difference in the 3N-SRC region

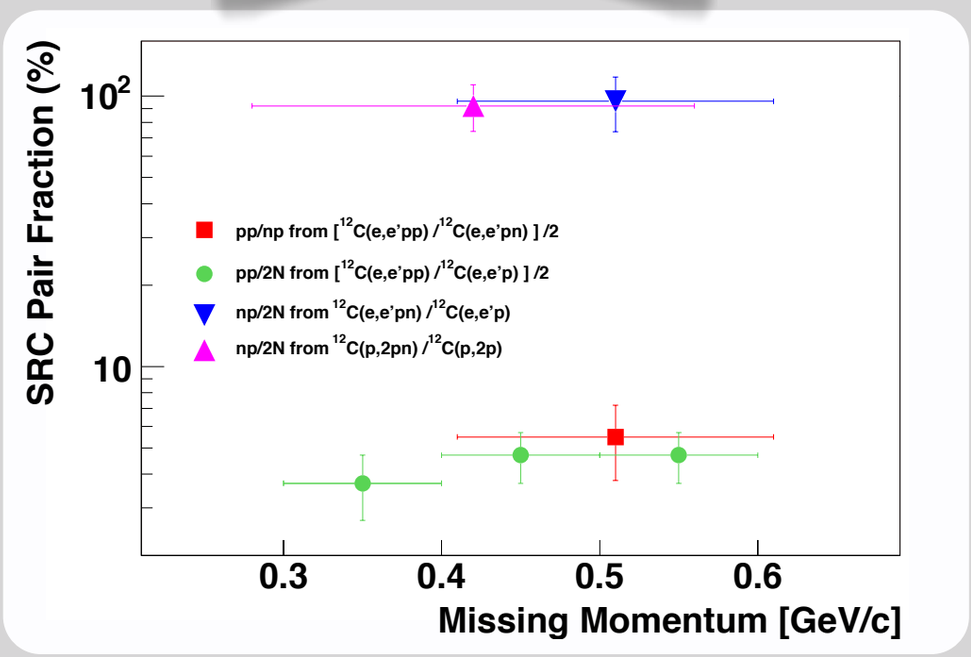
SRC: isospin dependence

Simple SRC model assumes isospin independence

Two-nucleon knock-out experiment

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

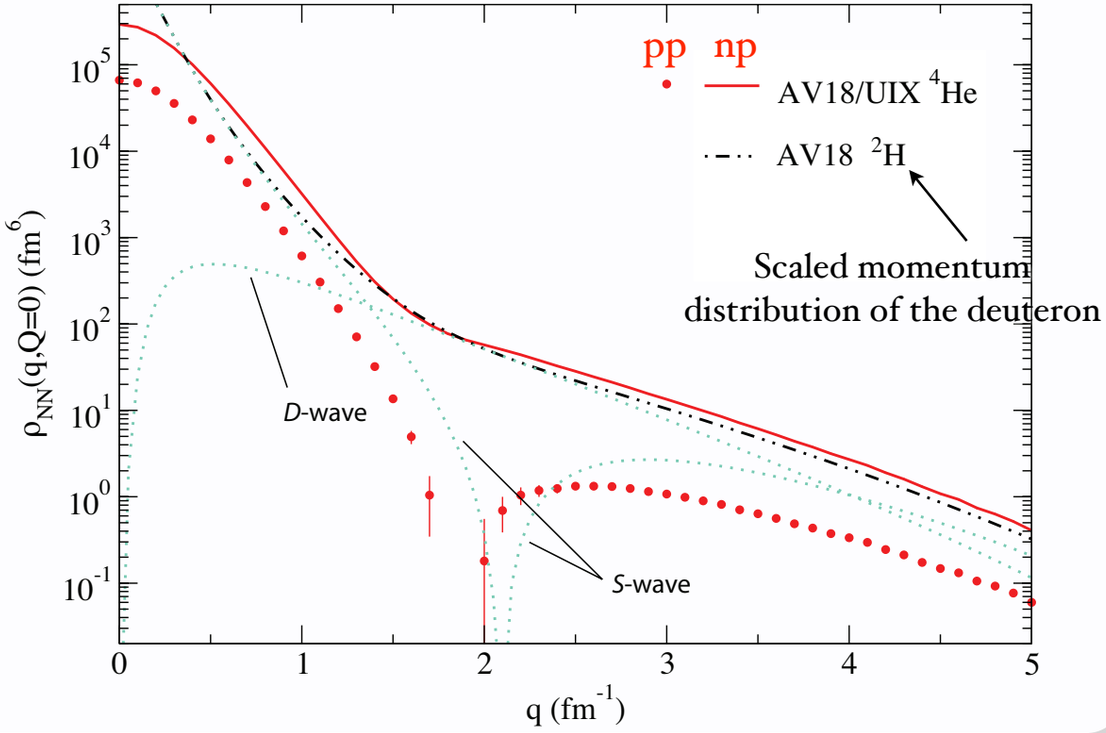




PRL **98,** 132501 (2007) PHYSICAL REVIEW LETTERS week ending 30 MARCH 2007

Tensor Forces and the Ground-State Structure of Nuclei

R. Schiavilla,[1,2] R. B. Wiringa,[3] Steven C. Pieper,[3] and J. Carlson[4]
[1]*Jefferson Laboratory, Newport News, Virginia 23606, USA*
[2]*Department of Physics, Old Dominion University, Norfolk, Virginia 23529, USA*
[3]*Physics Division, Argonne National Laboratory, Argonne, Illinois 61801, USA*
[4]*Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*
(Received 10 November 2006; published 27 March 2007)



Data show large asymmetry between np, pp pairs:

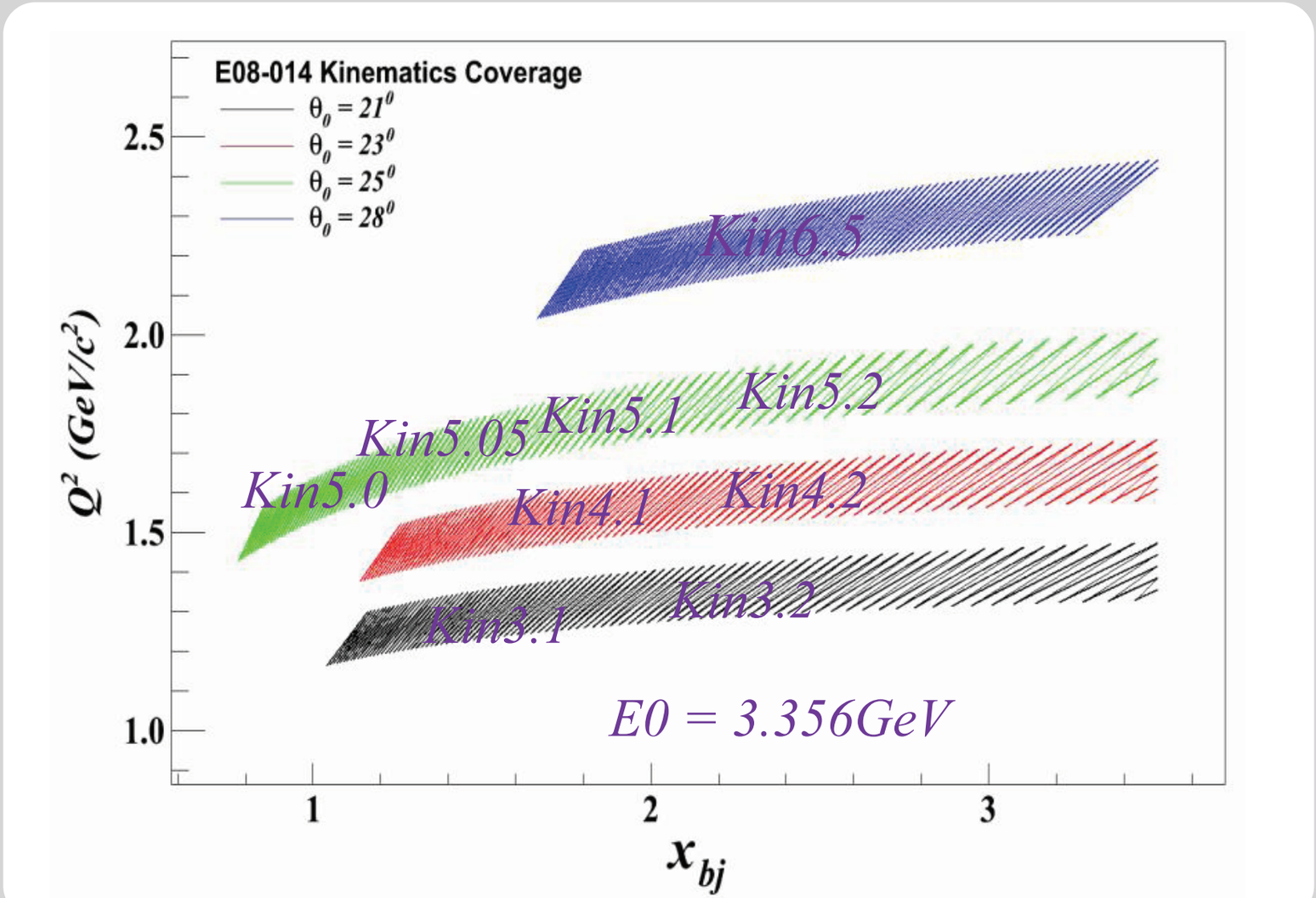
Qualitative agreement with calculations; effect of tensor force. Huge violation of often assumed isospin symmetry

New results from Jefferson Lab

JLab experiment E08-014

Spokespeople: P. Solvignon, J. Arrington, D. Day, D. Higinbotham

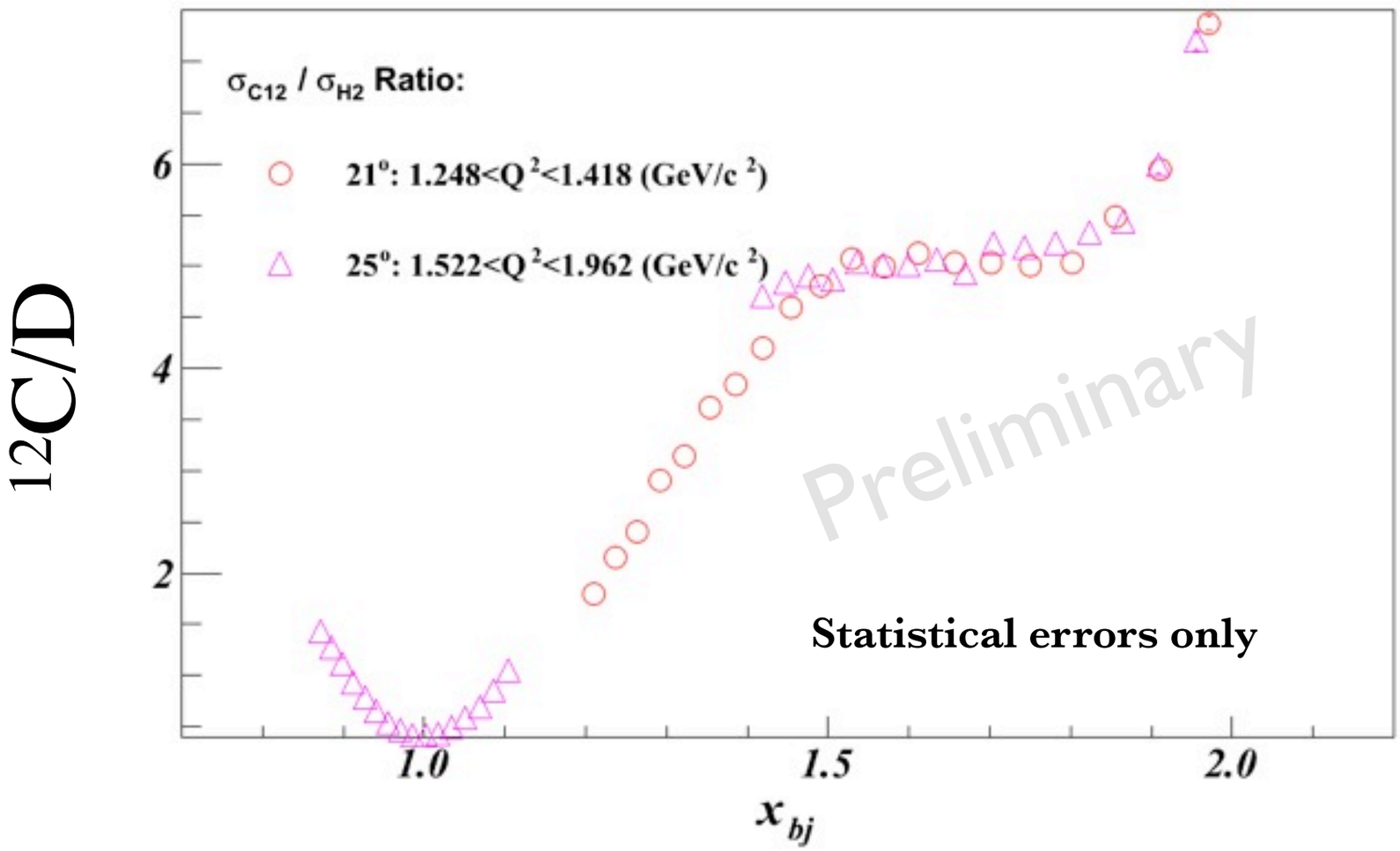
Ph.D student: Zhihong Ye



Verify and define scaling regime for 3N-SRC

Isospin effects on SRCs: ^{48}Ca vs. ^{40}Ca

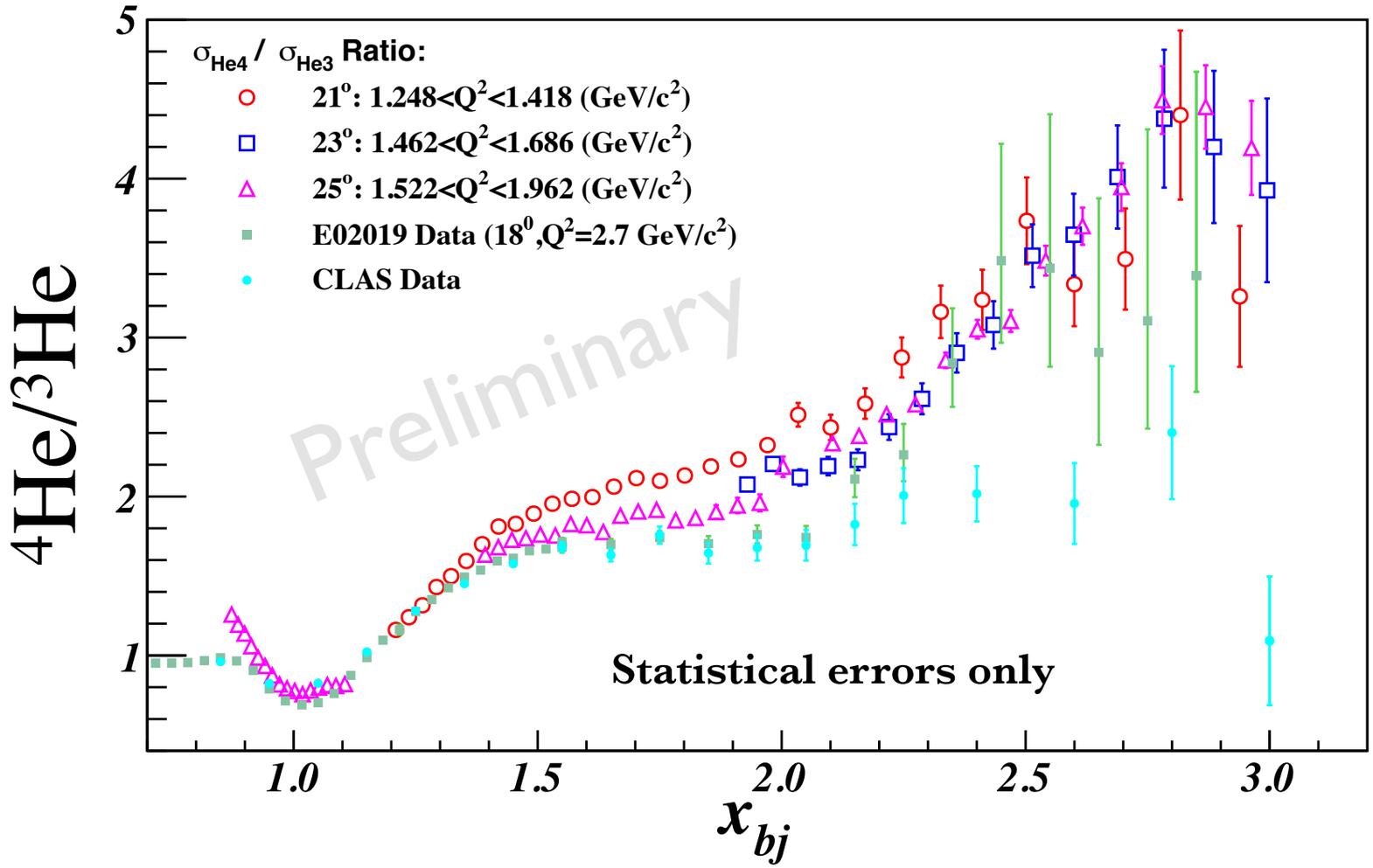
E08-014 result: $^{12}C/D$



a_{2n}=5.08+/-0.01

SLAC: $a_2(^{12}C)$=5.0±0.5

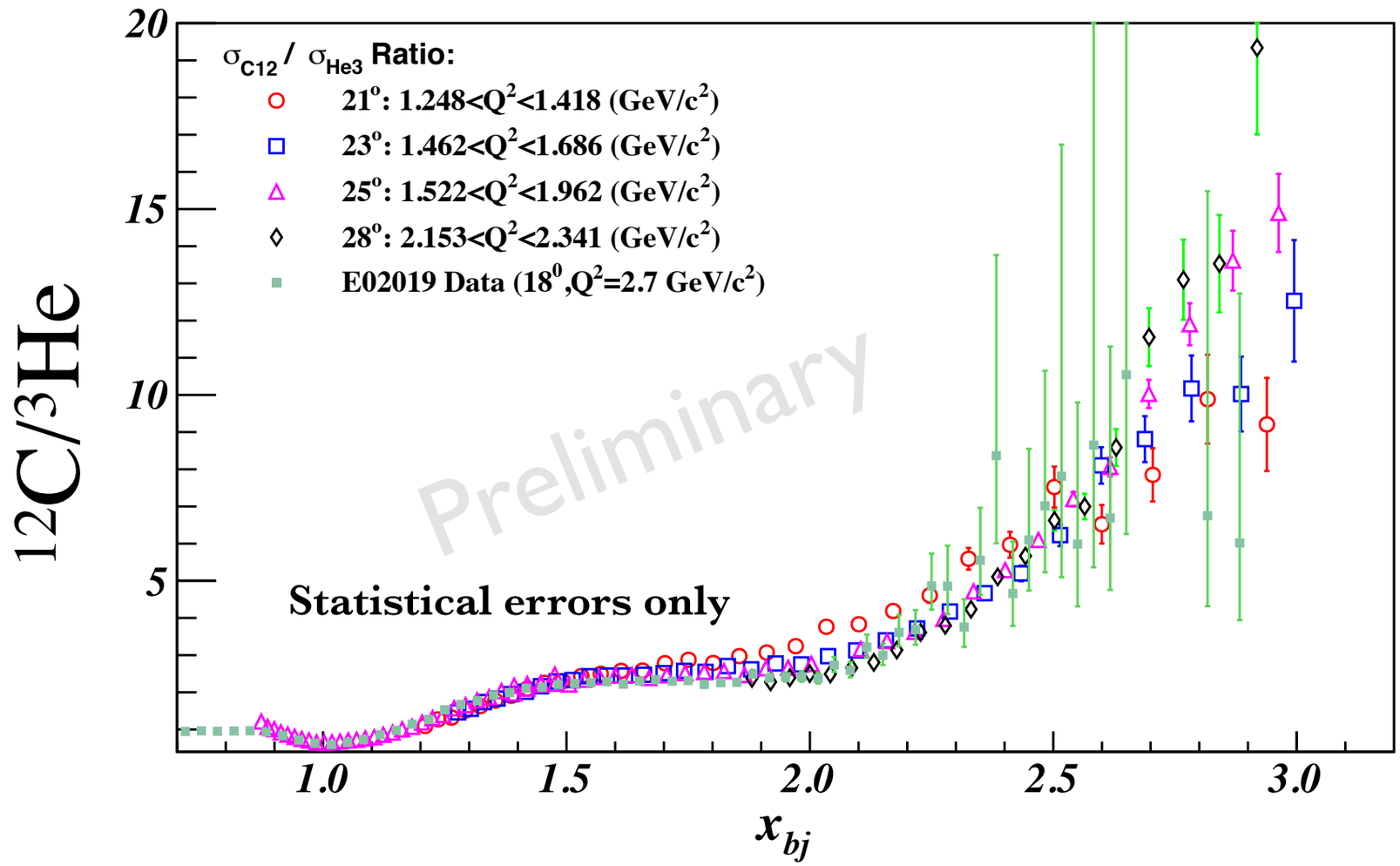
E08-014 results at x>2



Good agreement between the three experiments in the 2N-SRC region

3N-SRC region: very sensitive to acceptance edge effect and window contribution so no conclusion yet

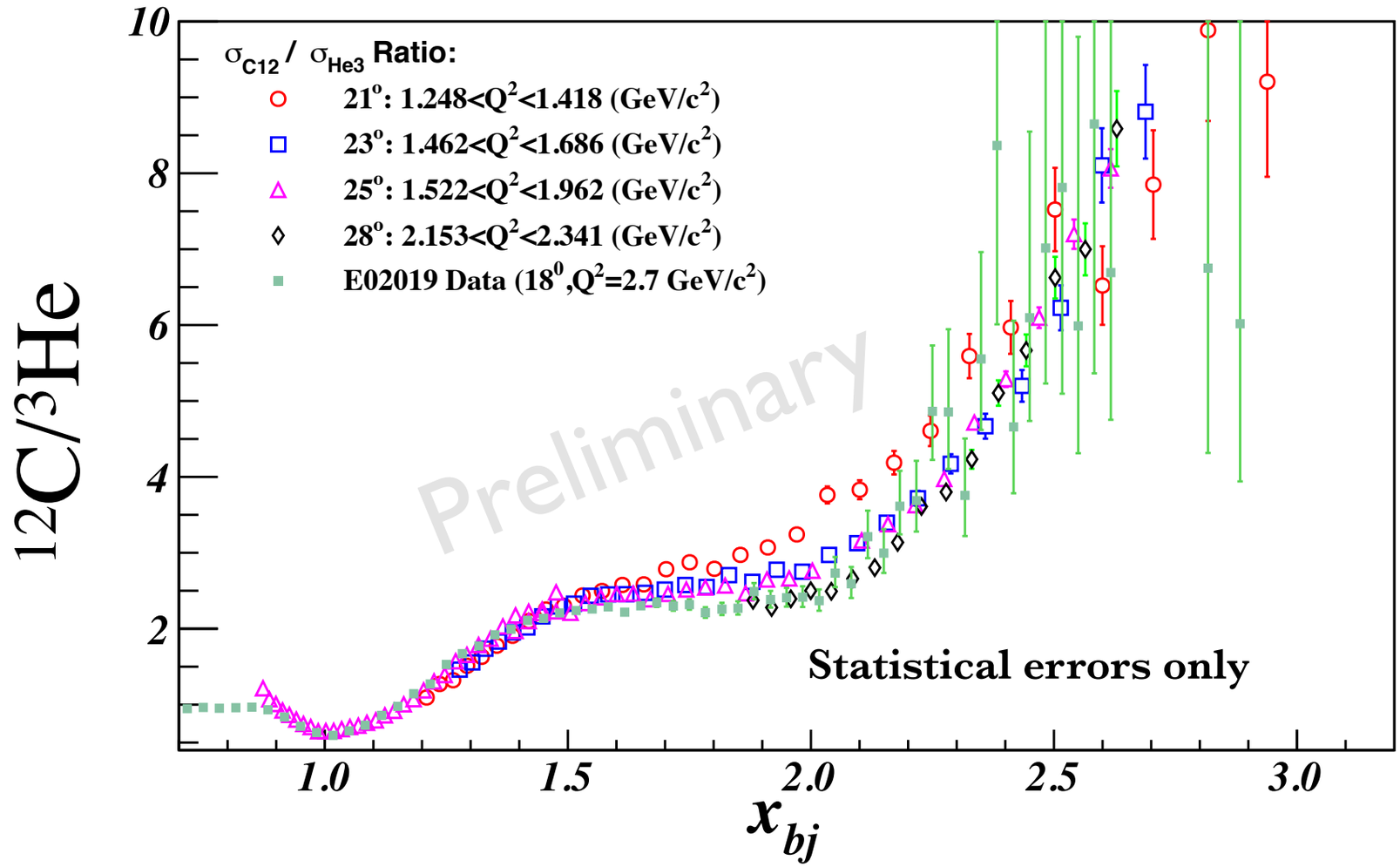
E08-014 results at x>2



Good agreement between the three experiments in the 2N-SRC region

3N-SRC region: very sensitive to acceptance edge effect and window contribution so no conclusion yet

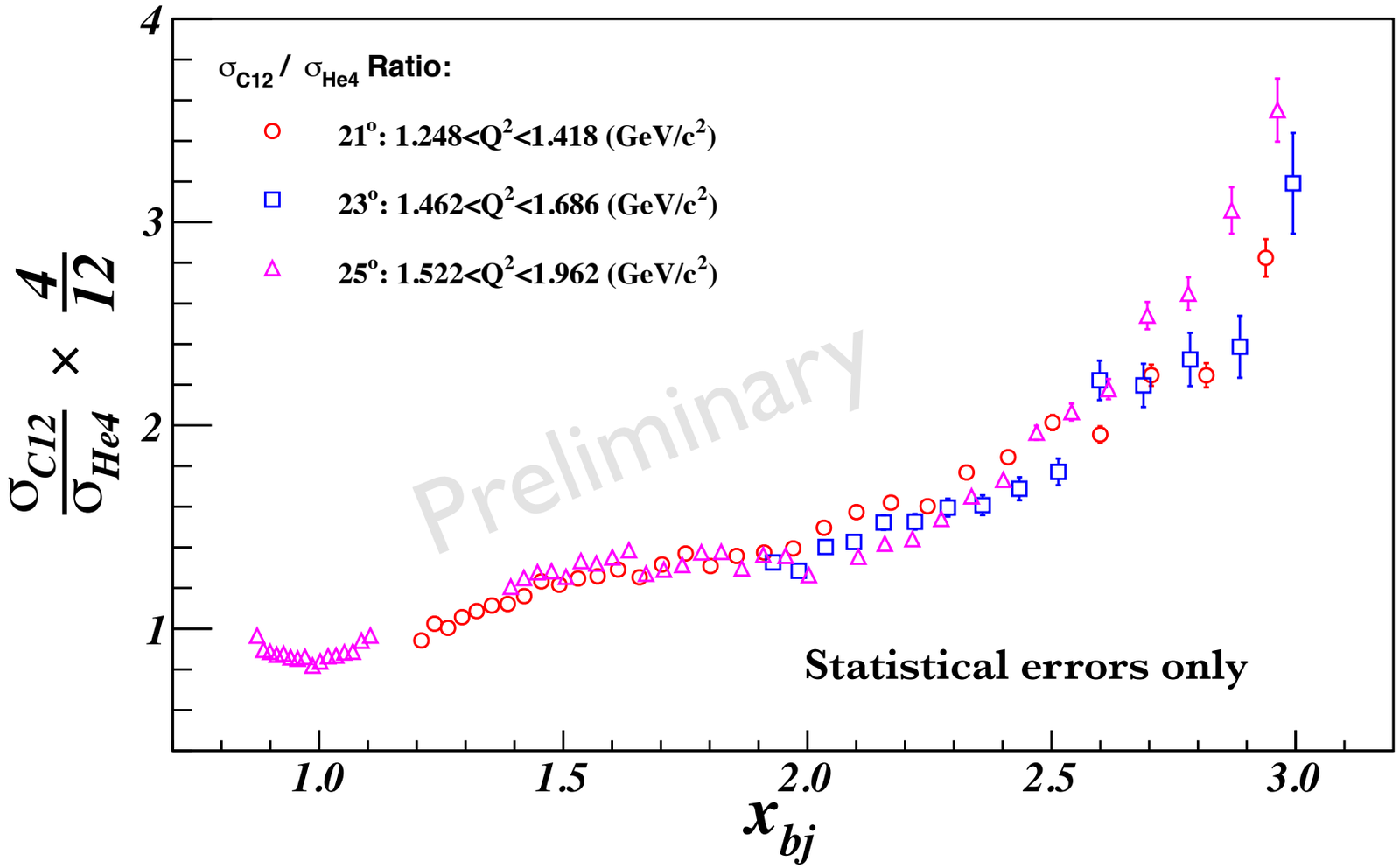
E08-014 results at x>2



Good agreement between the three experiments in the 2N-SRC region

3N-SRC region: very sensitive to acceptance edge effect and window contribution so no conclusion yet

E08-014 results at x>2

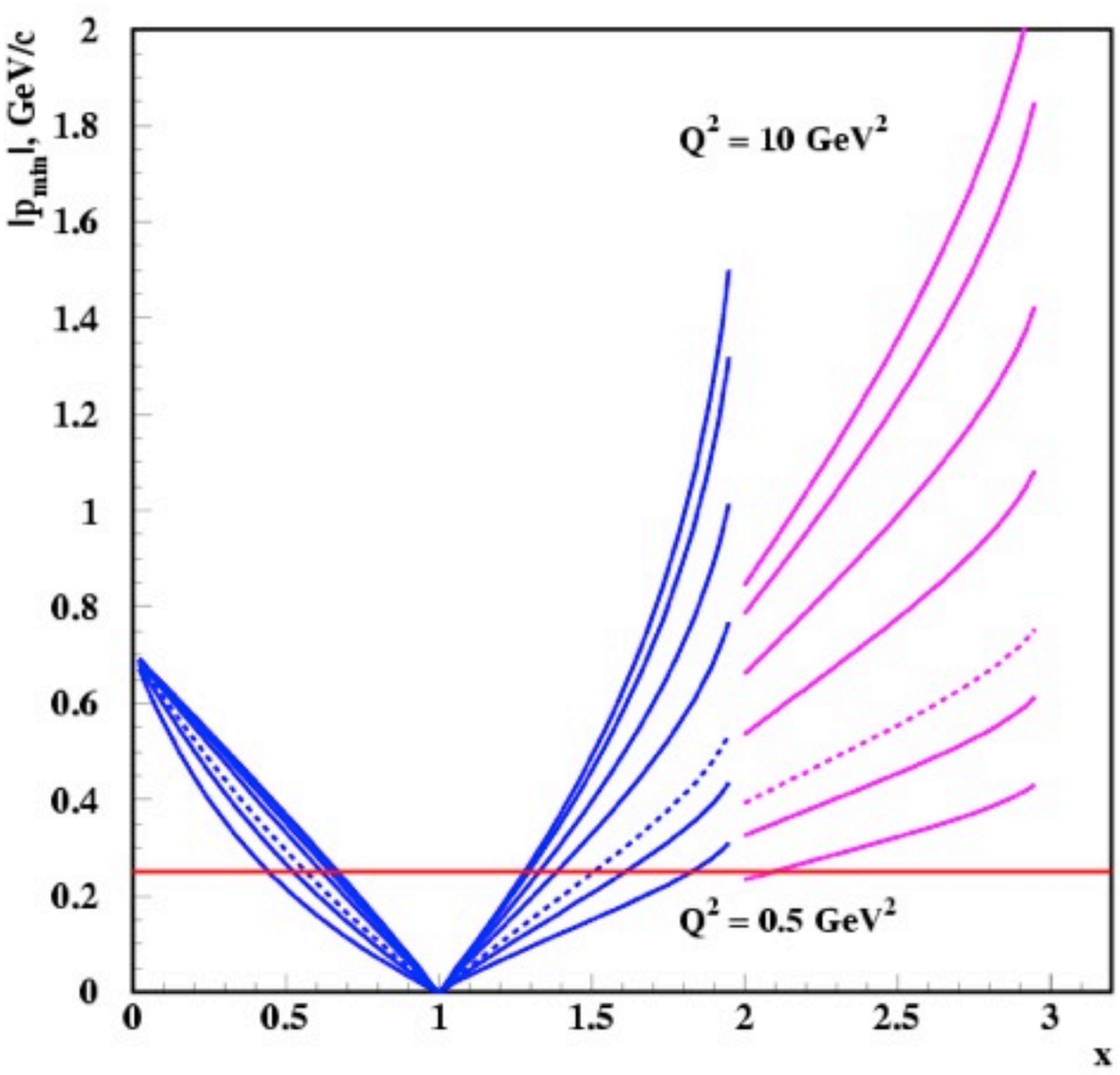


Advantages of this ratio:

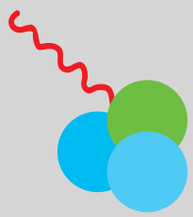
1) less sensitive to the window contribution
2) ^{4}He cross section doesn't go to zero at x=3
3) CM motion of the 3N mainly cancels in the ratio

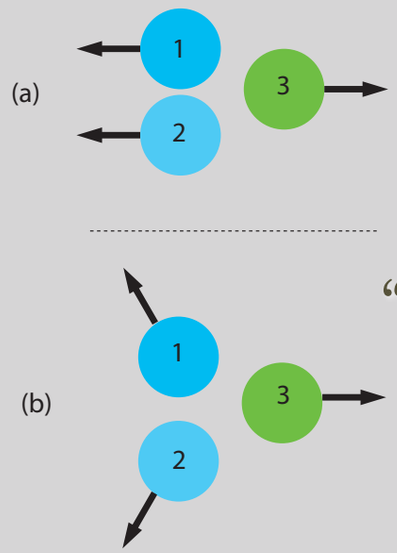
But still no sign of a 3N-SRC plateau !

Isolating 3N-SRCs



Onset of scaling for 2<x<3
at which p_{miss} ?





extremely large momentum

$p_3 = p_1 + p_2$

"Star-configuration"

$p_1 = p_2 = p_3$

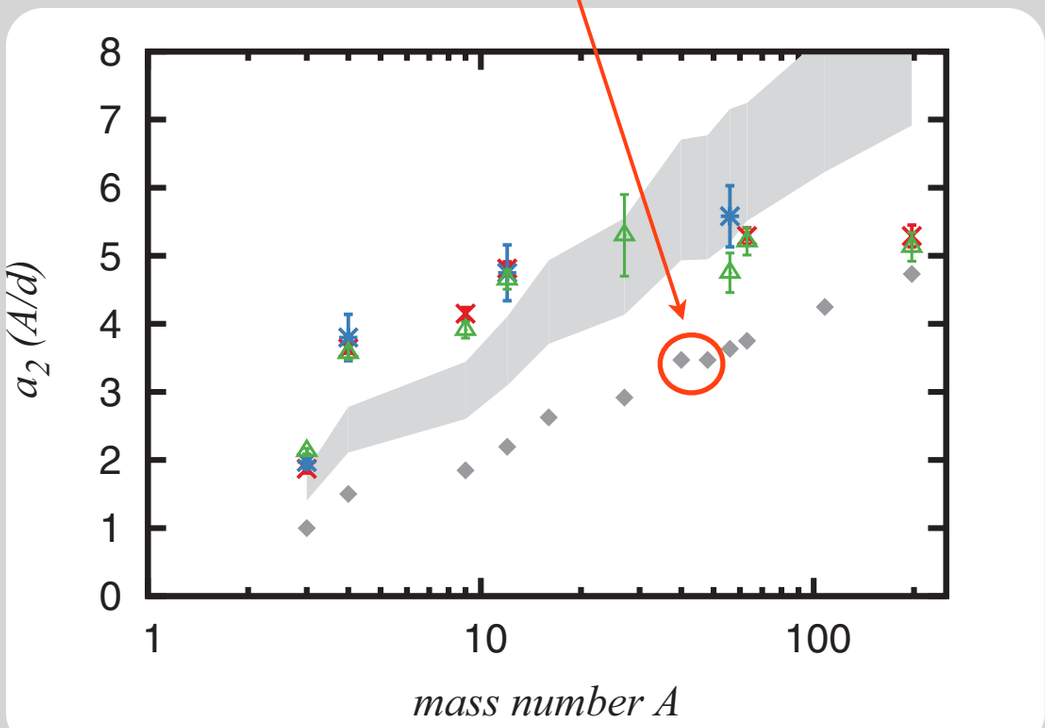
Isospin study from $^{48}Ca/^{40}Ca$ ratio

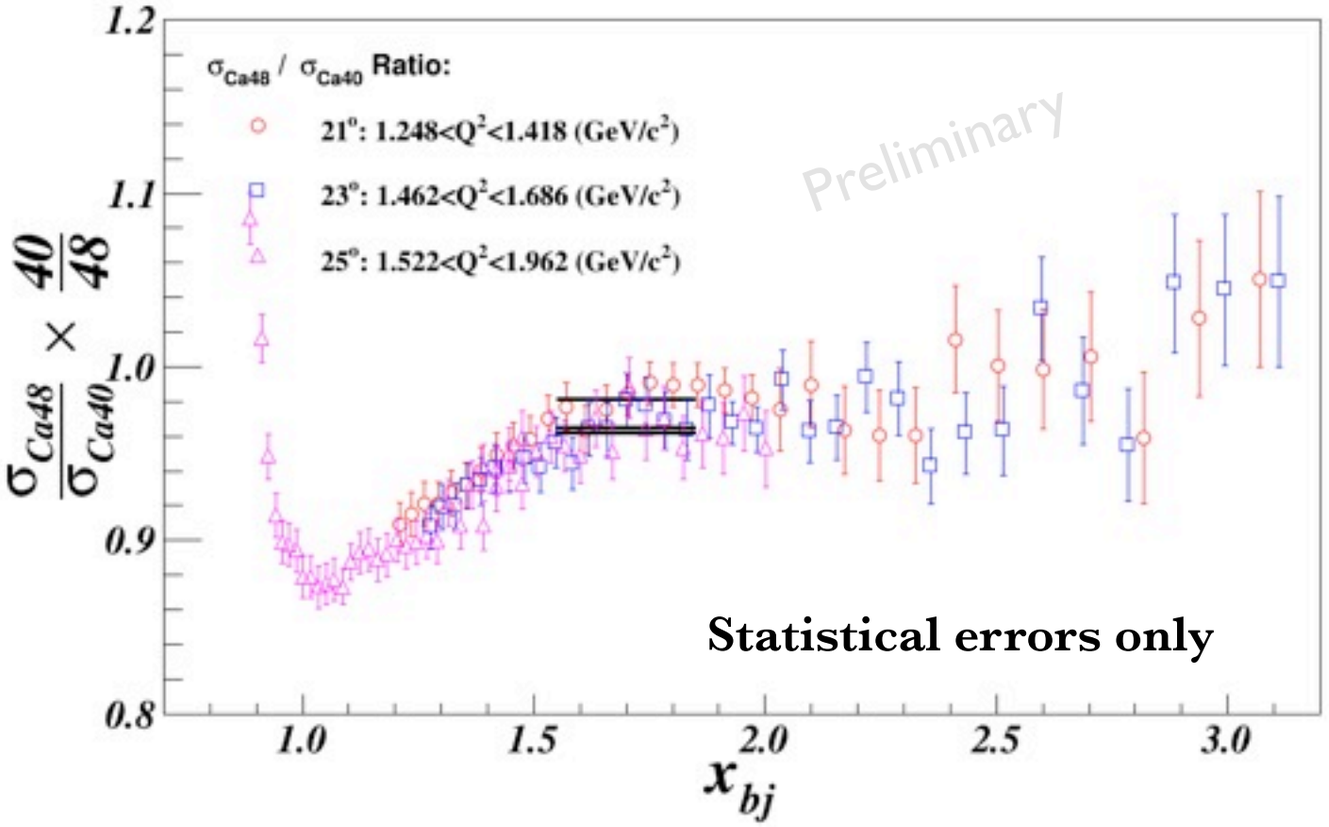
Theoretical predictions:

M. Vanhalst, J. Ryckebusch and W. Cosyn, PRC86, 044619 (2012)

"correlation operators generate the correlated part of the nuclear WF from that part of the mean-field WF where two nucleons are sufficiently close."

$a_2(^{40}Ca) \approx a_2(^{48}Ca)$





JLab experiment E07-006

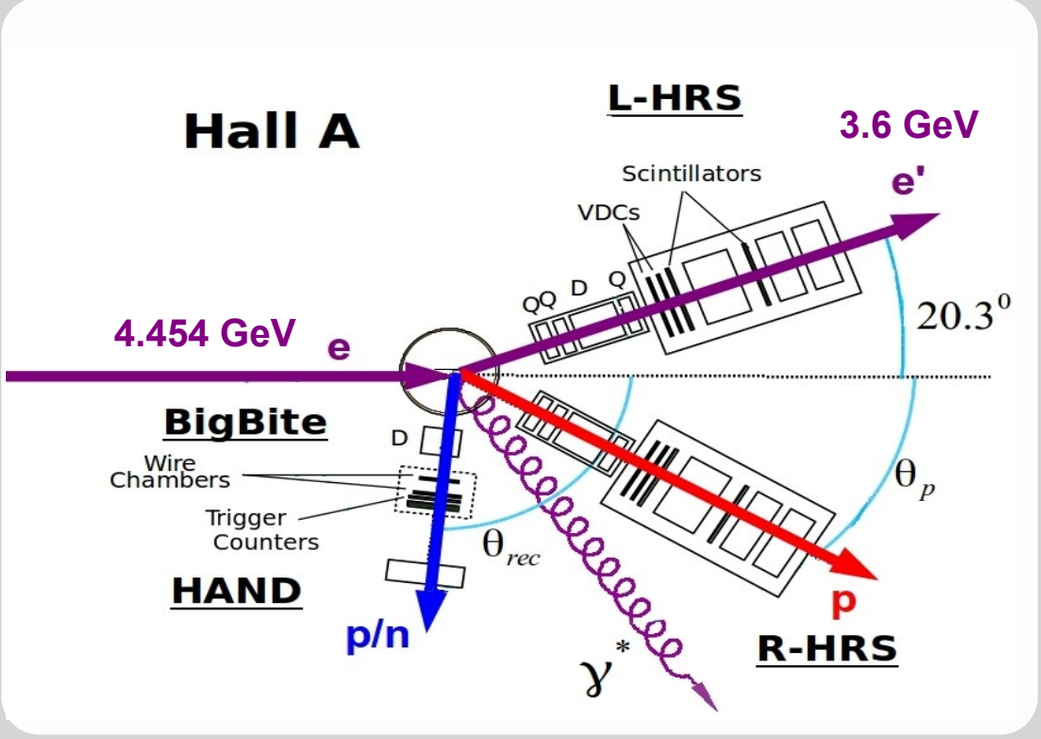
I. Korover et al., arXiv:1401.6138

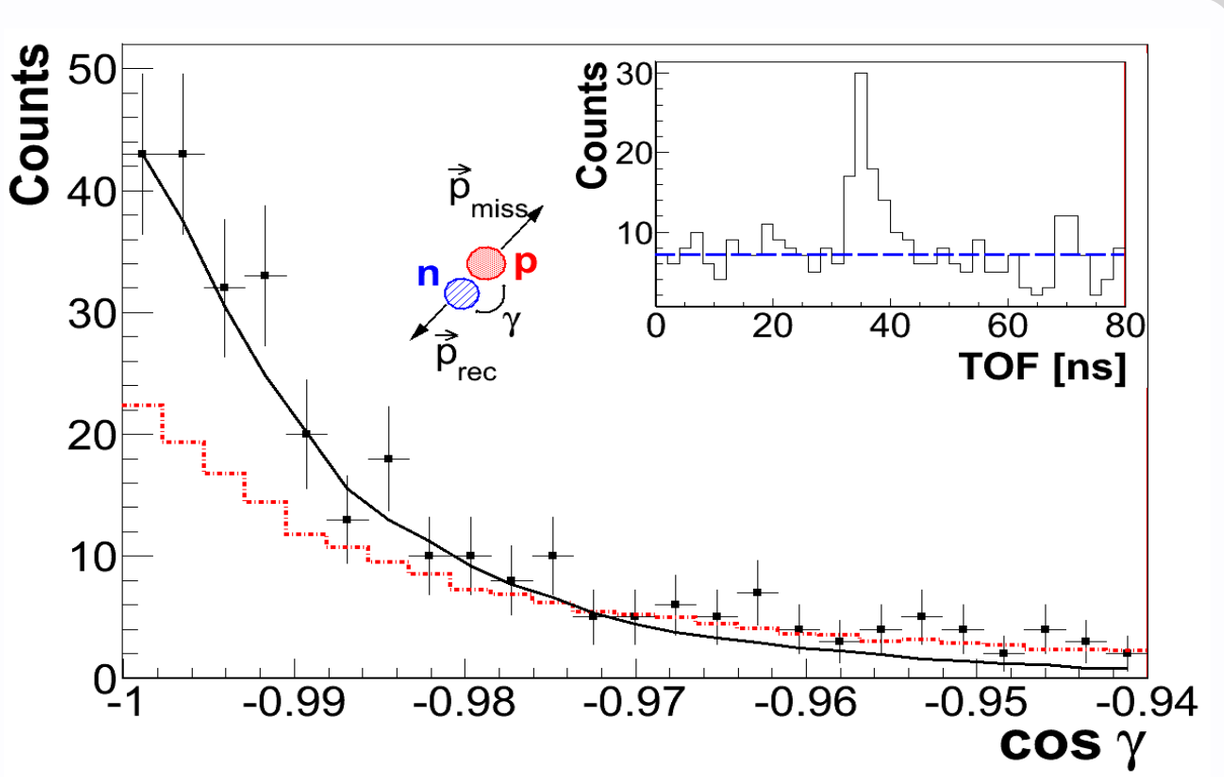
Approaching the nucleon-nucleon short-range repulsive core via the ^{4}He$(e,e'pN)$ triple-coincidence reaction.

I. Korover,[1] N. Muangma,[2] O. Hen,[1] R. Shneor,[1] V. Sulkosky,[2,3] A. Kelleher,[2] S. Gilad,[2] D.W. Higinbotham,[4] E. Piasetzky,[1] J. Watson,[5] S. Wood,[4] Abdurahim Rakhman,[6] P. Aguilera,[7] Z. Ahmed,[6] H. Albataineh,[8] K. Allada,[9] B.

Spokespeople: S. Gilad, D. Higinbotham, V. Sulkosky, E. Piasetzky, J. Watson, S. Wood

Ph.D students: O. Hen, I. Korover, N. Muangma





E07-006 results

I. Korover et al., arXiv:1401.6138

Approaching the nucleon-nucleon short-range repulsive core via the ^{4}He$(e, e'pN)$ triple-coincidence reaction.

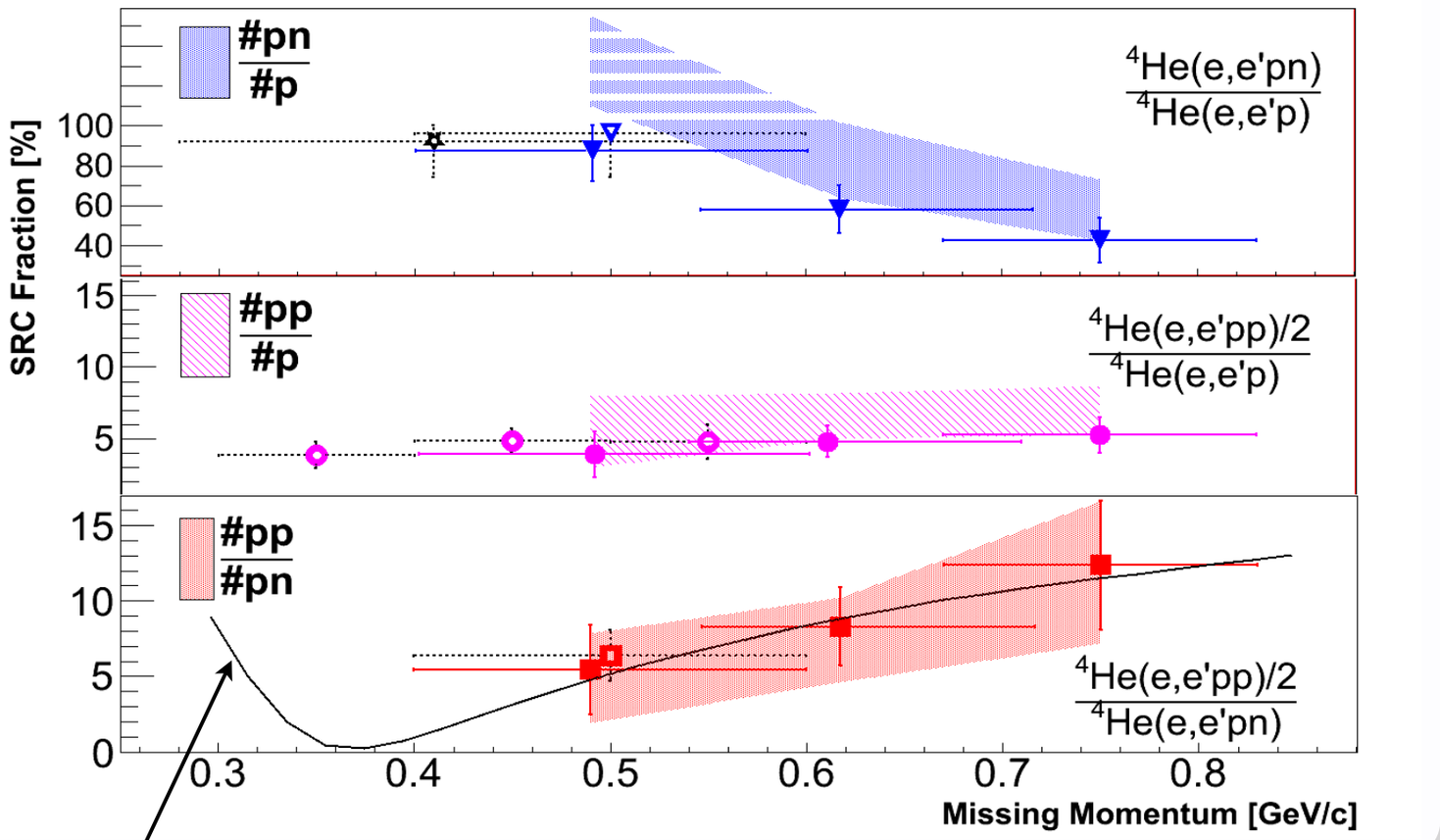
I. Korover,[1] N. Muangma,[2] O. Hen,[1] R. Shneor,[1] V. Sulkosky,[2,3] A. Kelleher,[2] S. Gilad,[2] D.W. Higinbotham,[4] E. Piasetzky,[1] J. Watson,[5] S. Wood,[4] Abdurahim Rakhman,[6] P. Aguilera,[7] Z. Ahmed,[6] H. Albataineh,[8] K. Allada,[9] B.

Observations:

#pp/#np increase with Pmiss
(as predicted by AV18)

#pp stays constant
(dominated by the repulsive core)

#np decrease with Pmiss
(FSI and/or 3N-SRC)



Wiringa, Schiavilla, Pieper, Carlson, arXiv: 1309.3794

Future experiments at Jefferson Lab

E12-11-112: ^{3}He/^{3}H at x>1

Precision measurement of the isospin dependence in the 2N and 3N short range correlation region

Spokespeople: P. Solvignon, J. Arrington, D. Day, D. Higinbotham

Main physics goals

Isospin-dependence

- ✓ Improved precision: extract R(T=1/T=0) to 3.8%
- ✓ FSI much smaller (inclusive) and expected to cancel in ratio

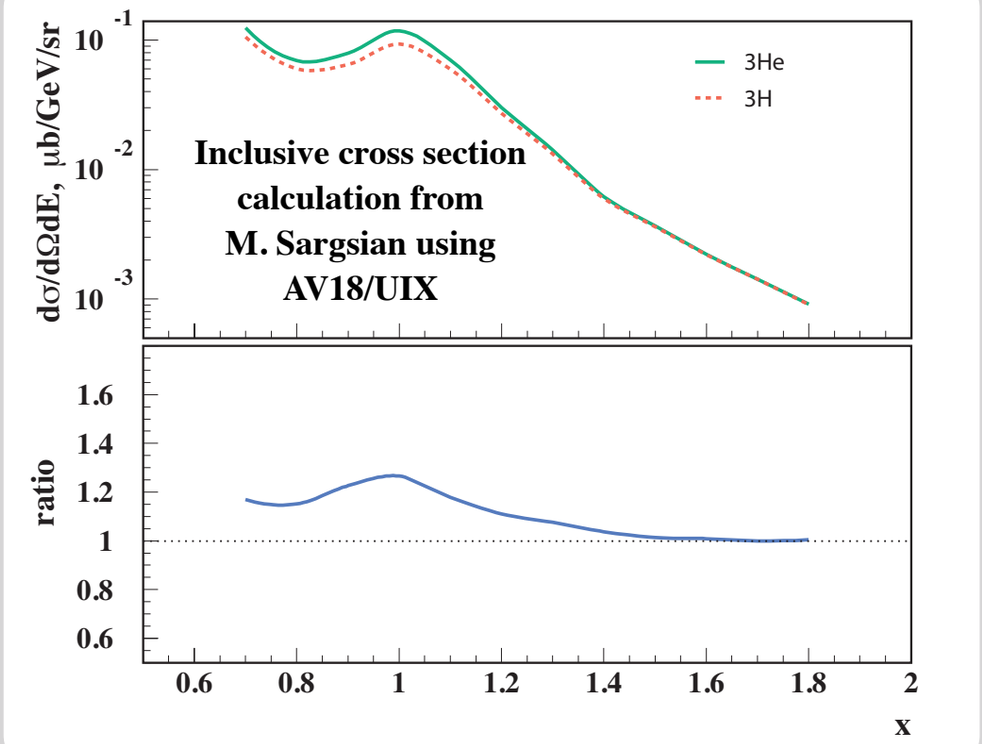
3N SRCs structure (momentum-sharing and isospin)

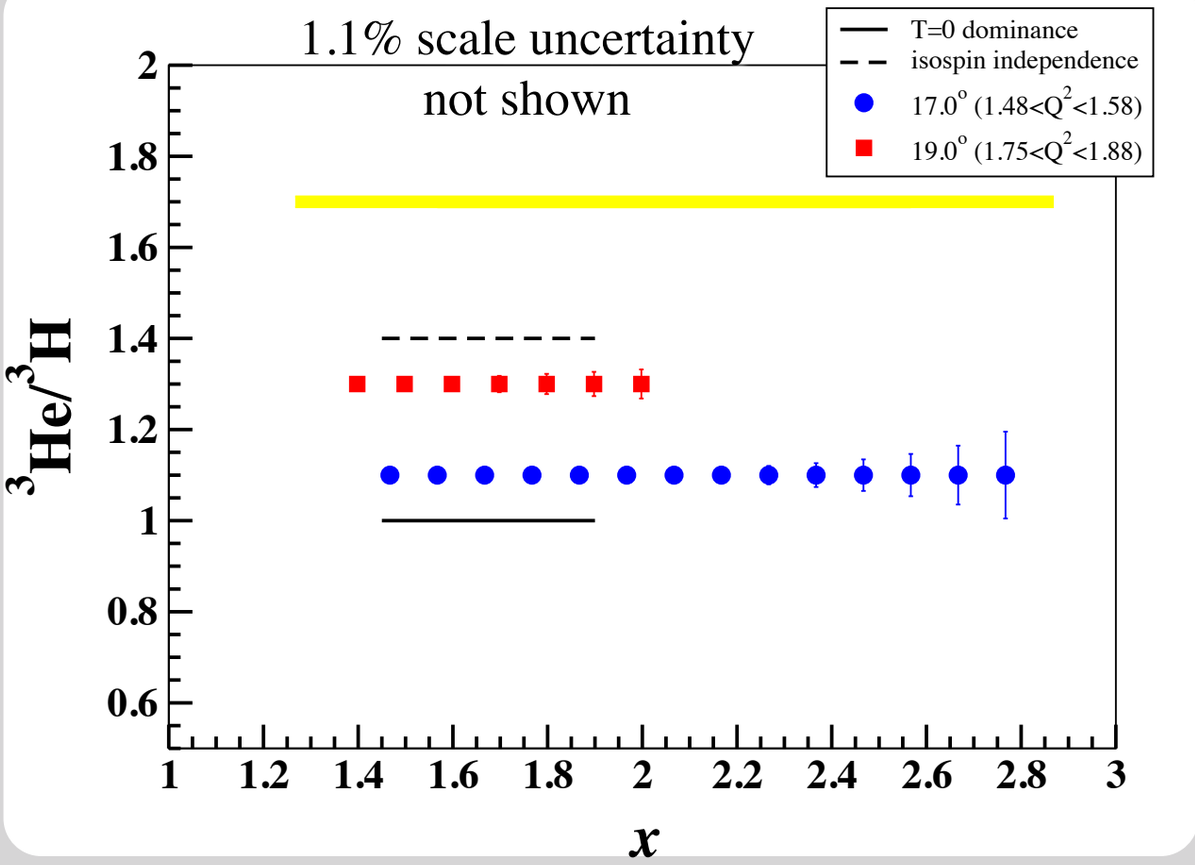
Improved A-dependence in light and heavy nuclei

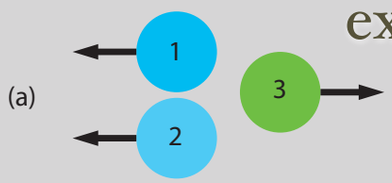
- ✓ Average of ^{3}H, ^{3}He --> A=3 "isoscalar" nucleus
- ✓ Determine isospin dependence --> improved correction for N>Z nuclei, extrapolation to nuclear matter

Absolute cross sections (and ratios) for ^{2}H, ^{3}H, ^{3}He: test calculations of FSI for simple, well-understood nuclei

E12-11-112: ^{3}He/^{3}H at x>1

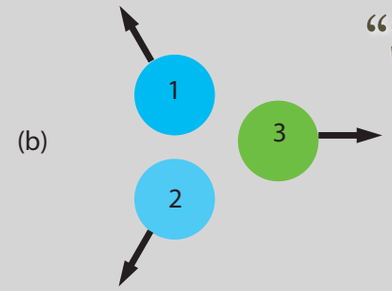






extremely large momentum

$p_3 = p_1 + p_2$



"Star-configuration"

$p_1 = p_2 = p_3$

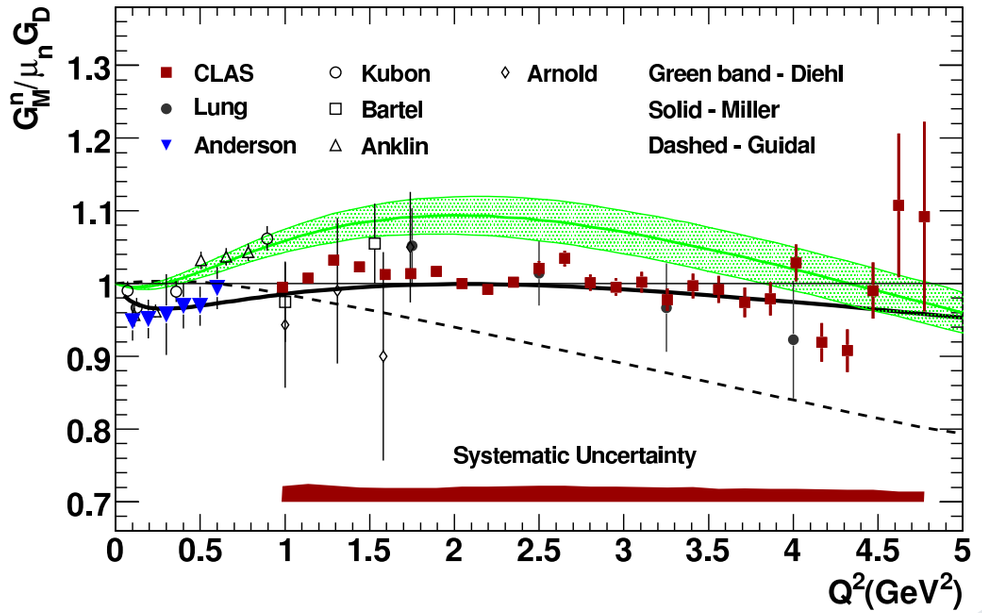
At x>2, ^{3}He/^{3}H ≠ 1.4 implies isospin dependence AND non-symmetric momentum sharing

QE data and Neutron Magnetic FF

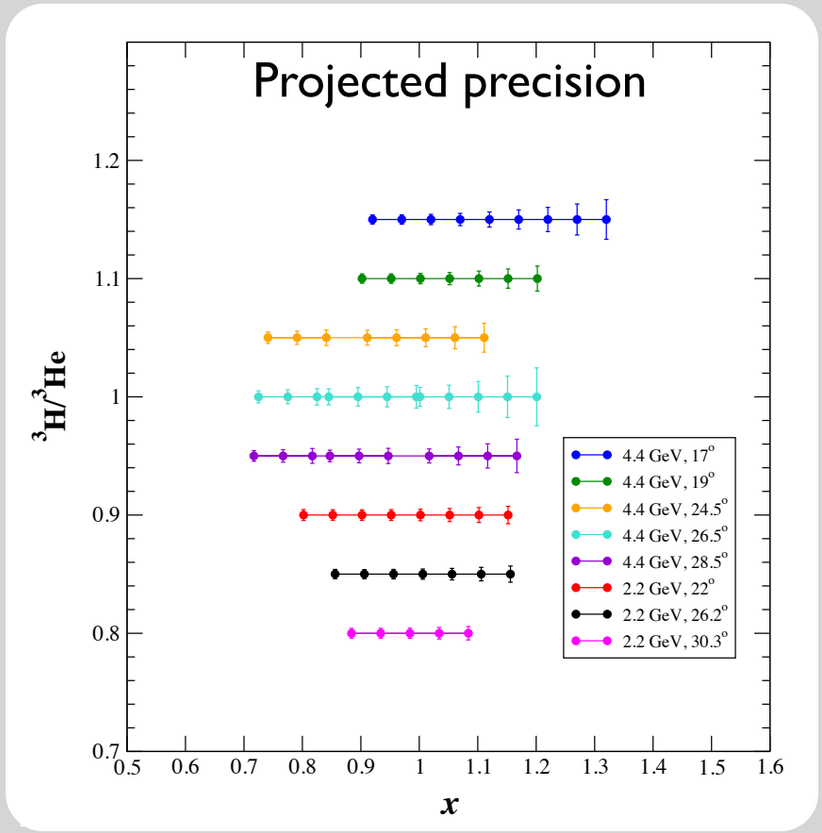
In PWIA, ^{3}He/^{3}H with 1.5% uncertainty corresponds to 3% on G_M^n

- Limited to $Q^2 \leq 1$ GeV^2, where QE peak has minimal inelastic contribution
- This is the region with ~8% discrepancy between the Ankin, Kubon data and the CLAS ratio and the Hall A polarized ^{3}He extraction.

Nuclear effects expected to be small, largely cancel in ratio



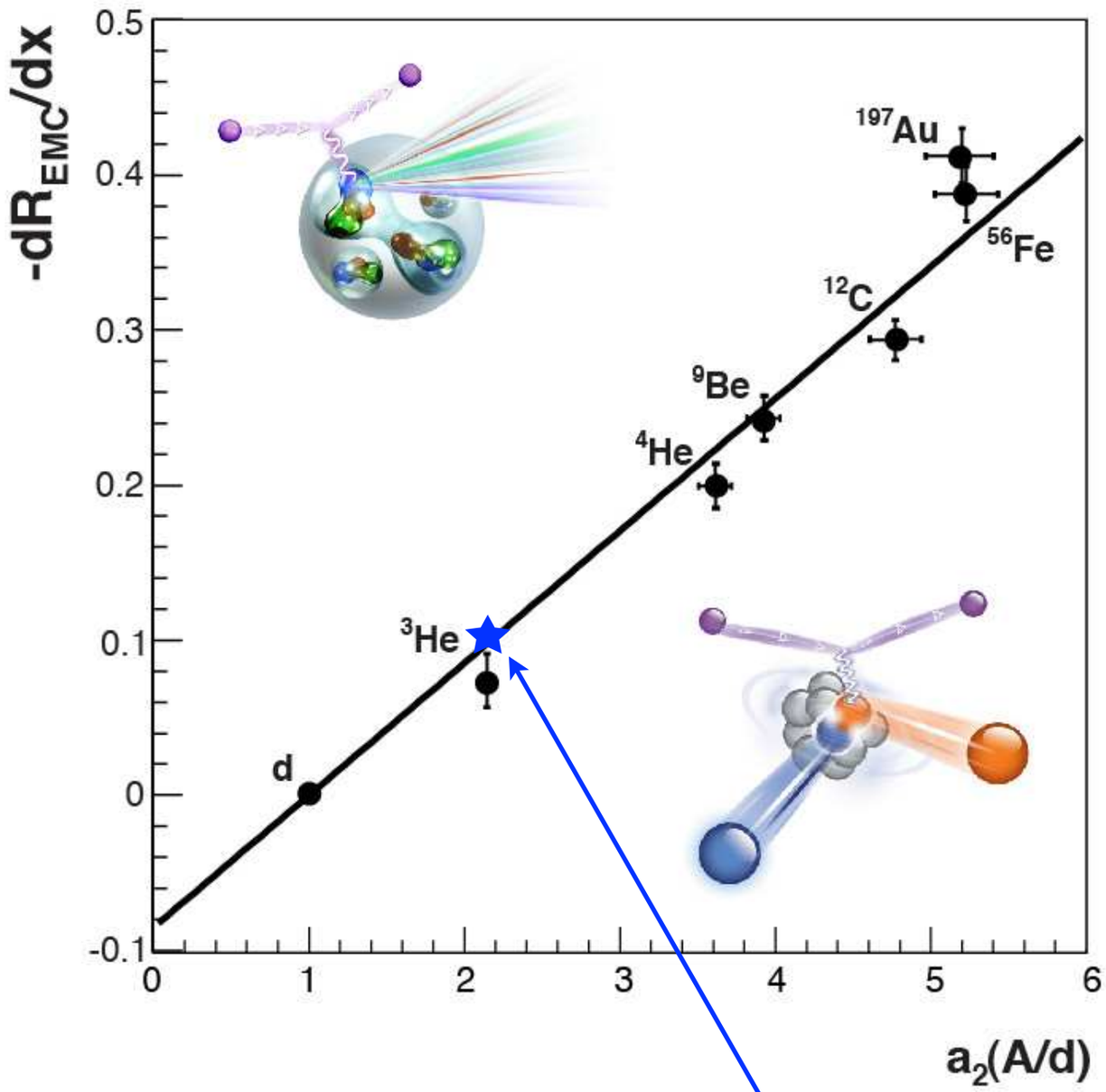
World ^{3}H QE data:
$Q^2 \leq 0.9$GeV^2



This experiment:
0.6, 0.8, 1.0, 1.4, 1.7, 2.4, 2.7 and 3.0 GeV^2

EMC vs. SRC

O. Hen, et al, PRC 85, 047301 (2012)
L. Weinstein, et al., PRL 106, 052301 (2011)



EMC effect due to:
high virtuality
or
local density
???

J. Arrington, A. Daniel, D. Day,
N. Fomin, D. Gaskell and P. Solvignon,
PRC 86, 065204 (2012)

No clear conclusion.
Needs more data !

After combining results from E12-11-112 and MARATHON experiments (no error bar projected at this time)

E12-06-105

Inclusive Scattering from Nuclei at $x > 1$ in the quasielastic and deeply inelastic regimes.

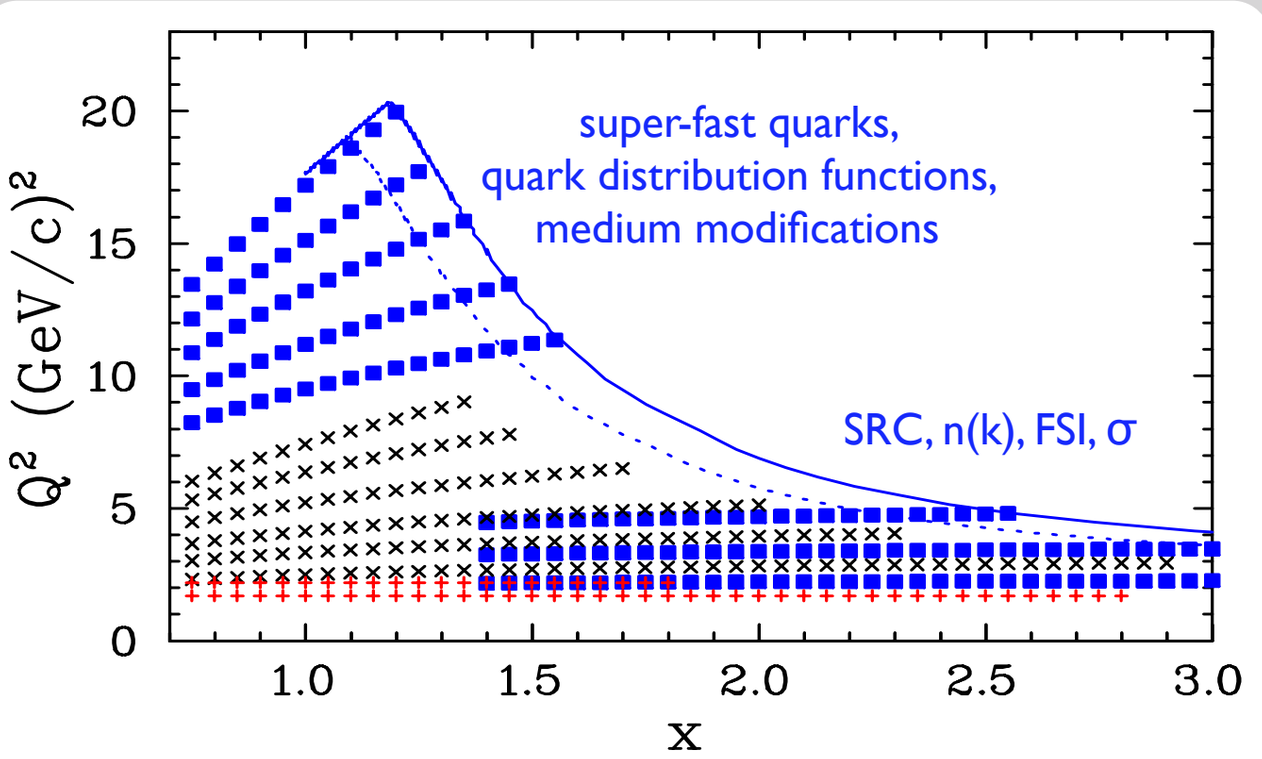
Spokespeople: J. Arrington, D. Day, N. Fomin, P. Solvignon

Main physics goals

A-dependence of 2N and 3N-SRCs at moderate Q^2 values for large x

First studies of the size and importance of α-clusters in nuclei

Distribution of superfast quarks in nuclei: high sensitivity to non-hadronic components (6-q bags)

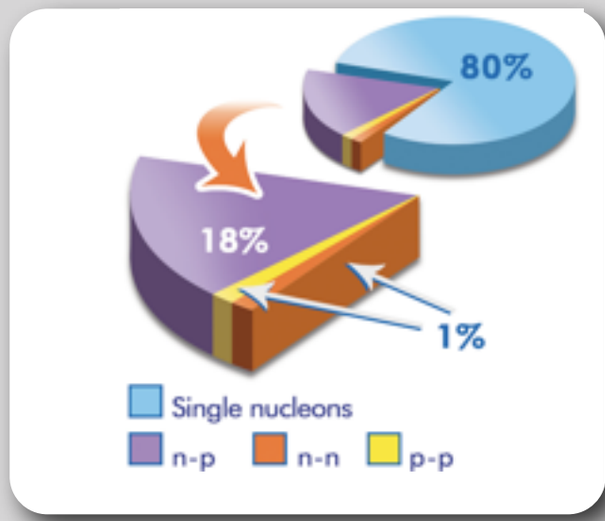


Summary

SRCs are an important component to nuclear structure:

~20% of nucleons in SRC

Very few (~1%) p-p, n-n pairs



Inclusive scattering measurements from E08-014 and E12-11-112 will map out the 2N- and 3N-SRCs and produce a detailed study of their isospin dependence

--> E08-014: too early to conclude on the 3N-SRC and the isospin test

--> E12-11-112 is scheduled to run in Spring 2016

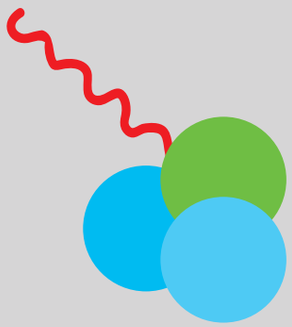
E12-06-105 will probe quark distribution in SRC = EMC effect in SRCs

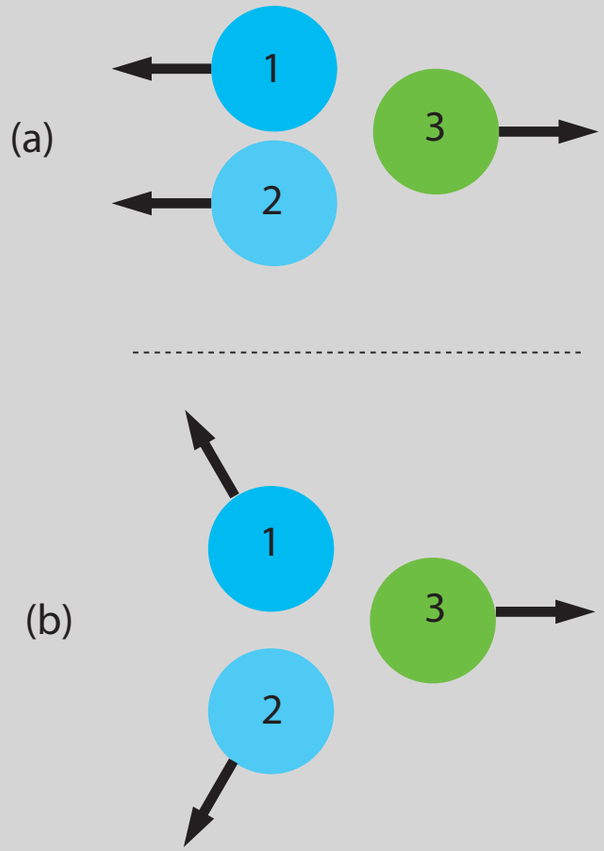
--> A part of the experiment is scheduled to run in 2017

Several other experiments at 12 GeV to look at SRC and EMC and their possible link.

EXTRA SLIDES

3N-configuration





extremely large momentum

$p_3 = p_1 + p_2$

"Star-configuration"

$p_1 = p_2 = p_3$

(a) yields $R(^3He/^3H) \approx 3.0$ if nucleon #3 is always the doubly-occurring nucleon
(a) yields $R(^3He/^3H) \approx 0.3$ if nucleon #3 is always the singly-occurring nucleon
(a) yields $R(^3He/^3H) \approx 1.4$ if configuration is isospin-independent, as does (b)

$R \neq 1.4$ implies isospin dependence AND non-symmetric momentum sharing

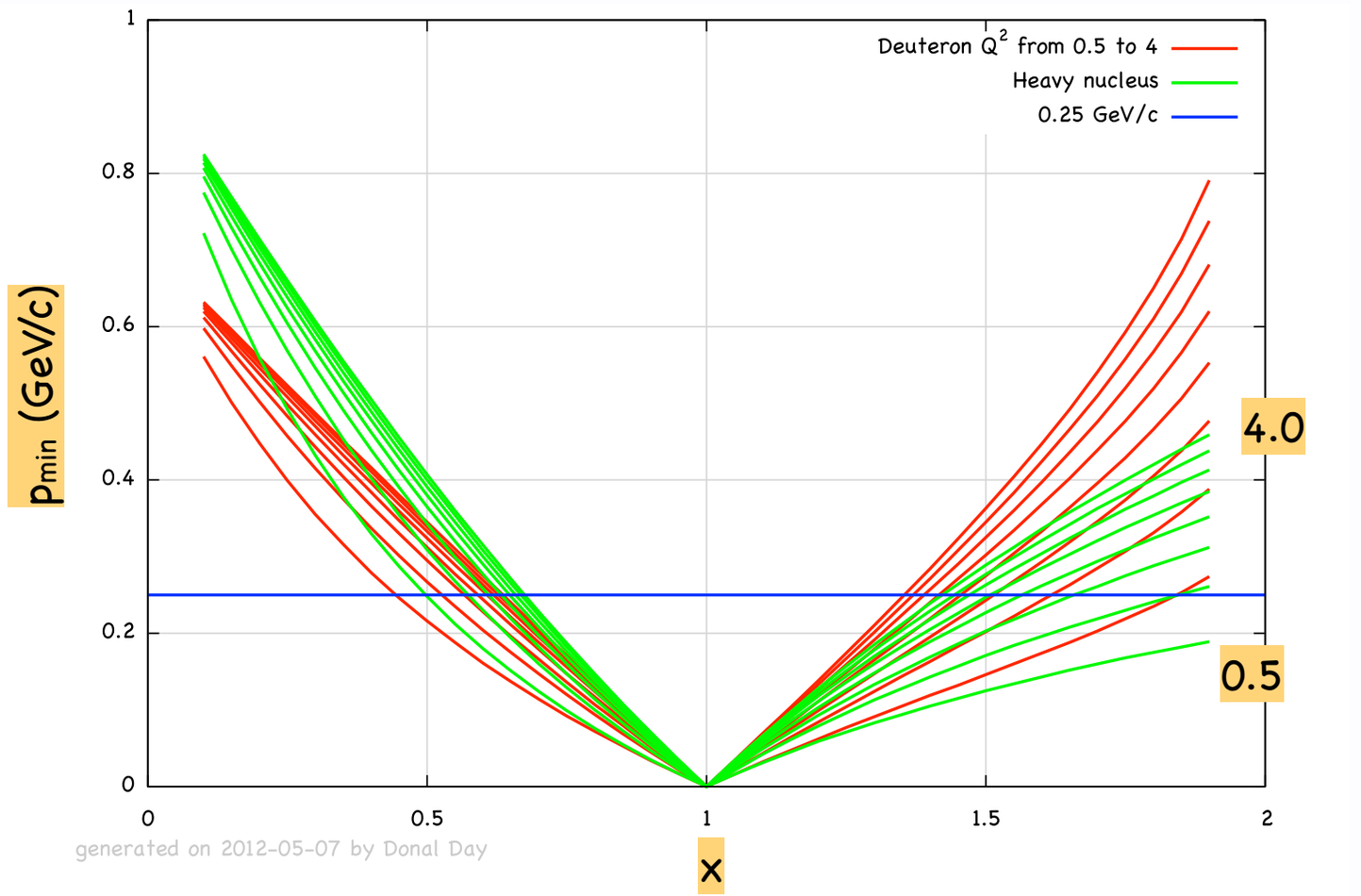
Isolating 2N-SRCs

Onset of plateaus is A dependent

Heavier recoil systems do not require as much energy to balance momentum of struck: p_{min} for a given x and Q^2 is smaller

Mean field part in heavy nuclei persist in x to larger values

Have to go to higher x or Q^2 to insure scattering is not from mean-field nucleon



Light-cone fraction

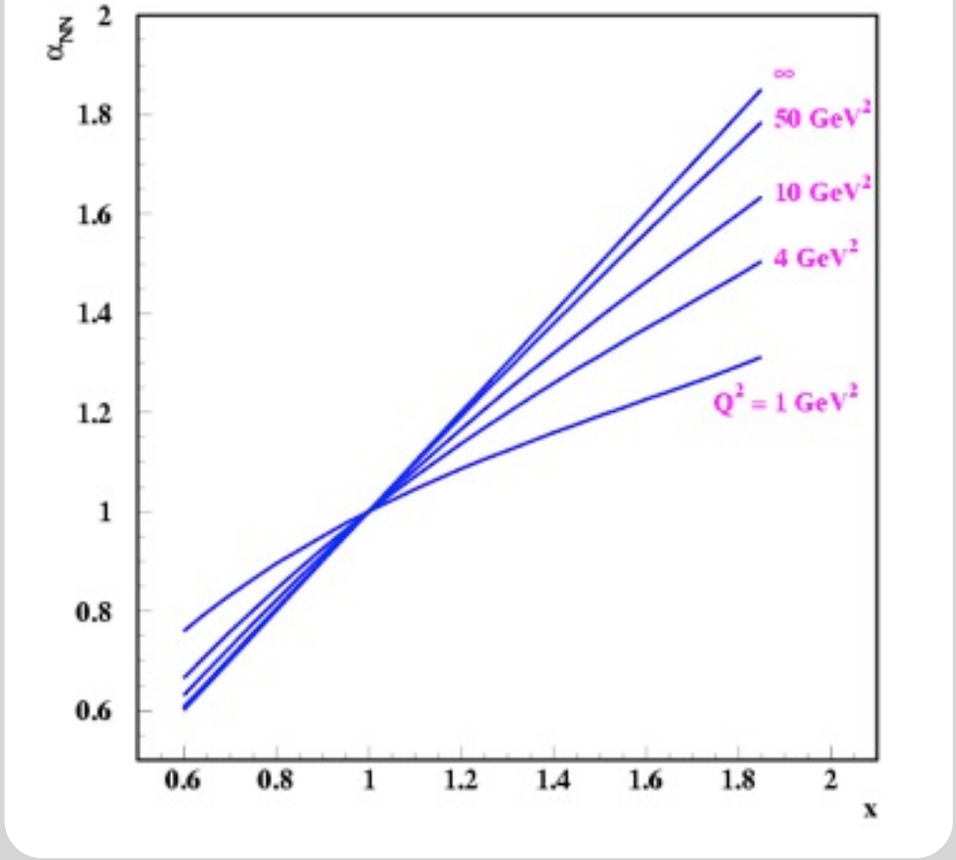
SRC model: 1N, 2N, 3N, …, contributions at x≤1,2,3,…

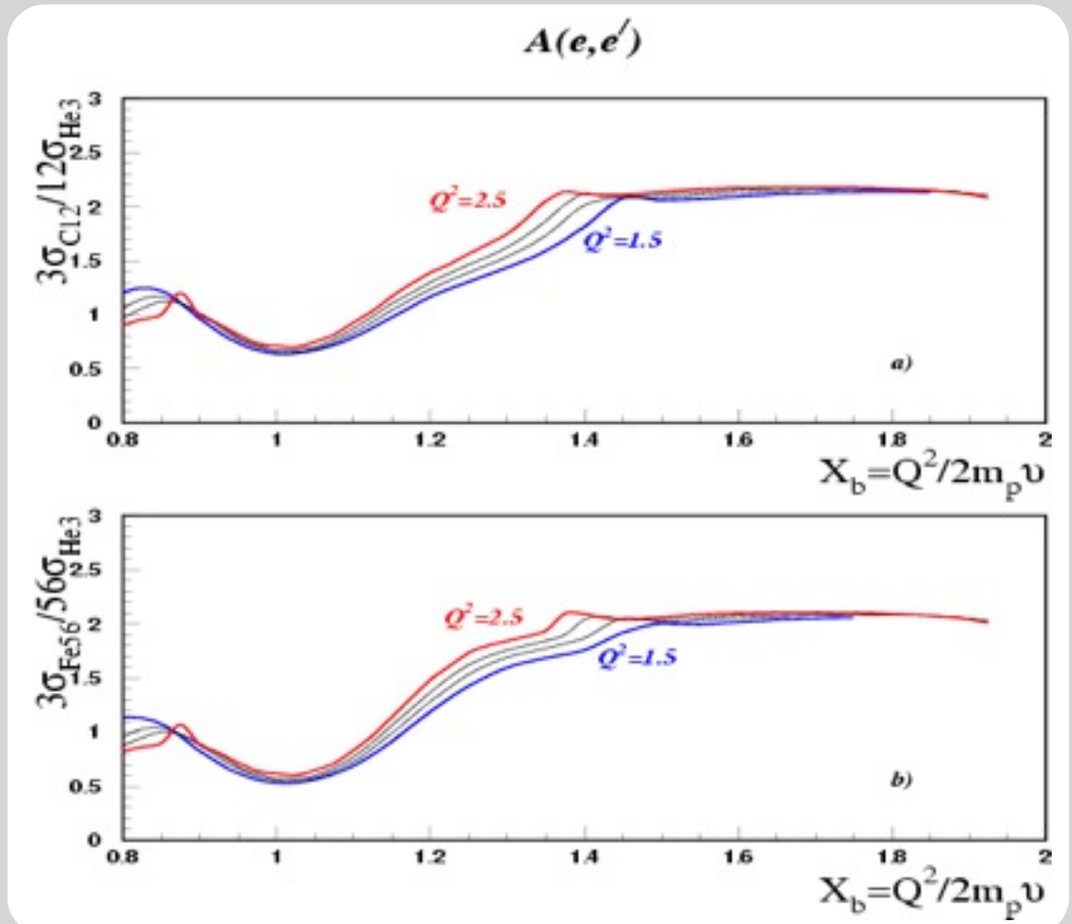
Motion of SRCs: broaden the range of contribution

$$\alpha_{2N} = 2 - \frac{q_- + 2m}{2m}\left(1 + \frac{\sqrt{W^2 - 4m^2}}{W}\right)$$

Relativistic: x ⟶ α_{2N}

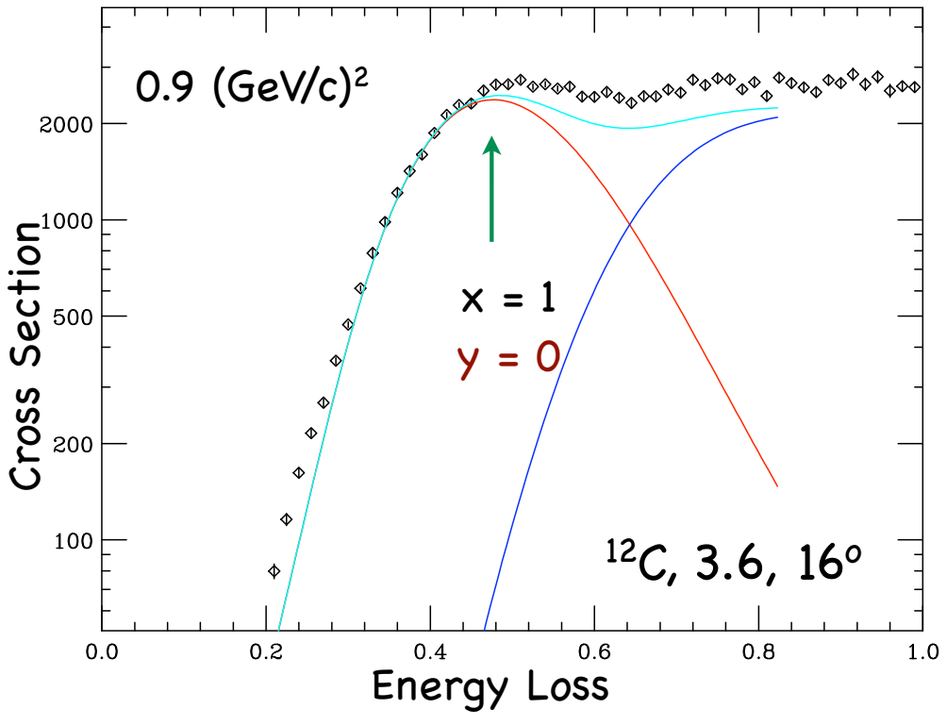
α_{2N} is the light-cone variable for the interacting nucleon of the correlated nucleon pair

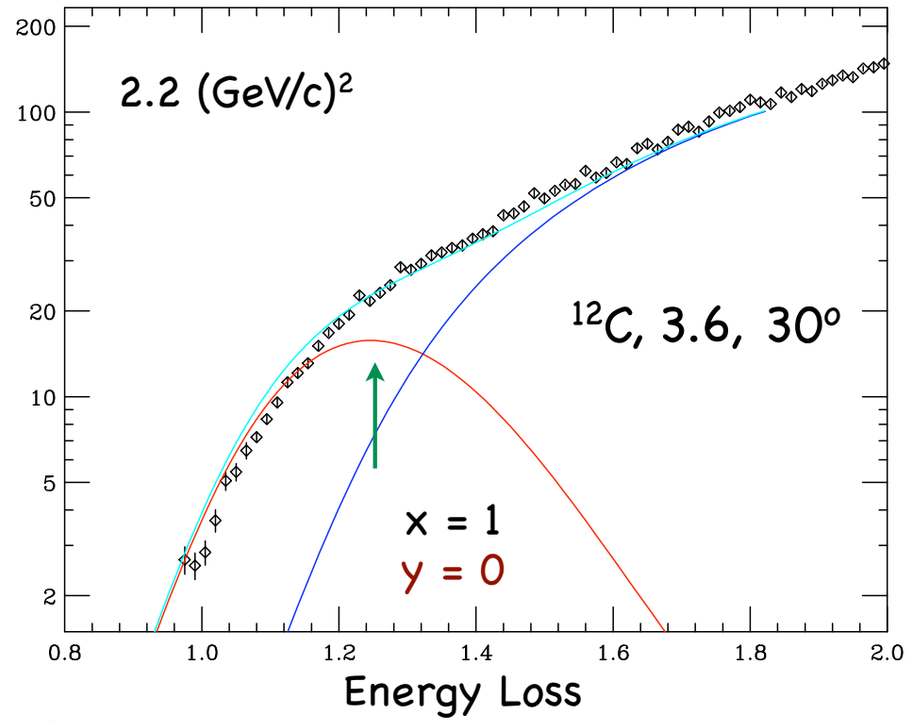




E12-06-105

Return to A(e,e') Inelastic contribution increases with Q^2

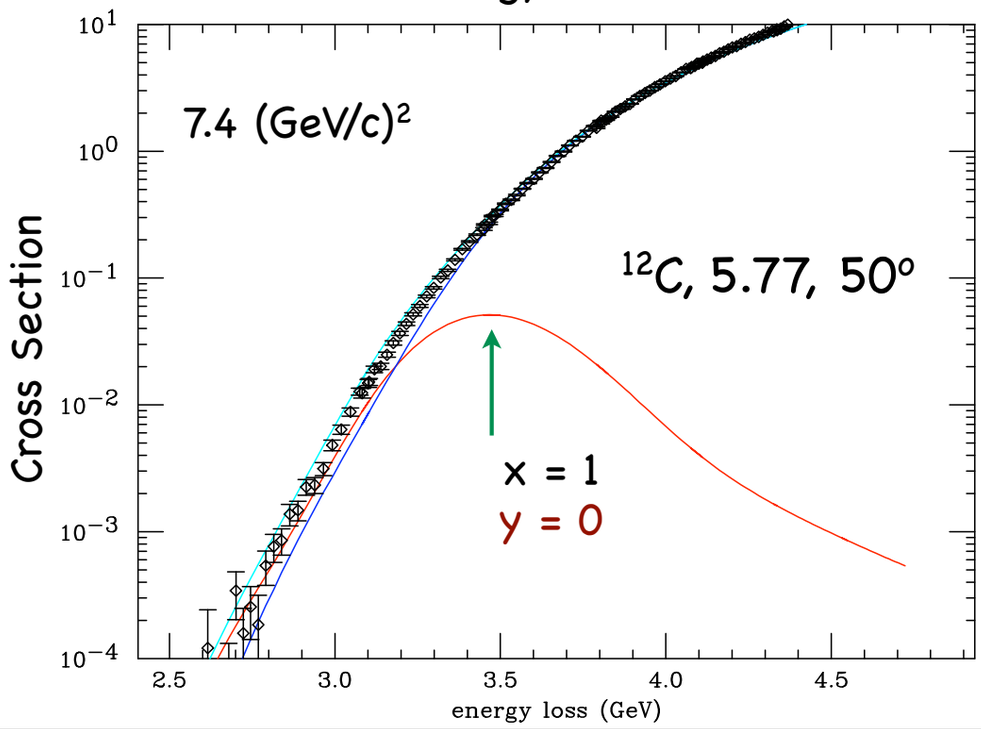




DIS begins to contribute at x > 1

Convolution model

We expect that as Q^2 increases to see evidence (x-scaling) that we are scattering from a quark at x > 1



Isospin study from $^3He/^3H$ ratio

Simple mean field estimates for 2N-SRC

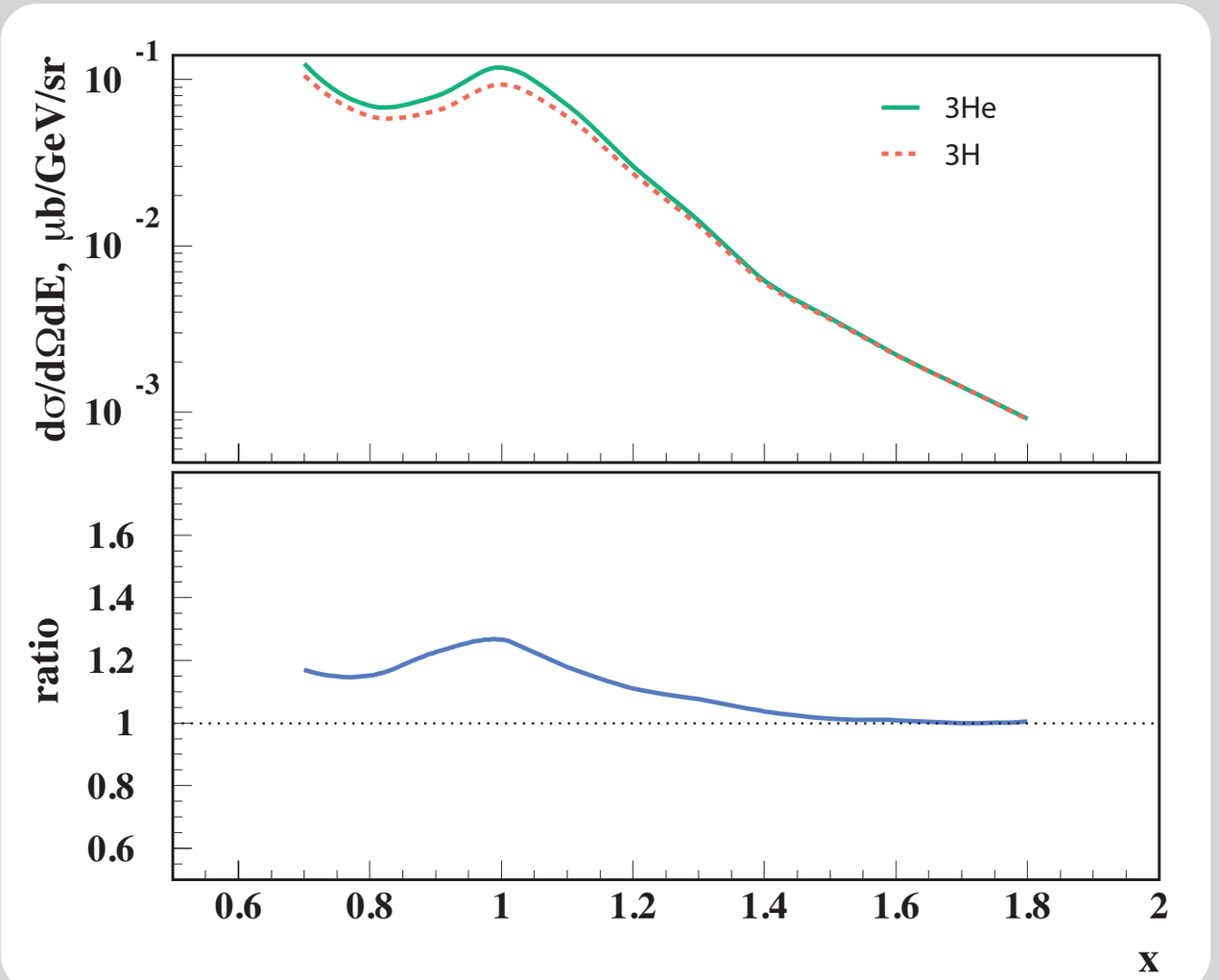
Isospin independent:

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

n-p (T=0) dominance:

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

Inclusive cross section calculation from M. Sargsian using AV18/UIX



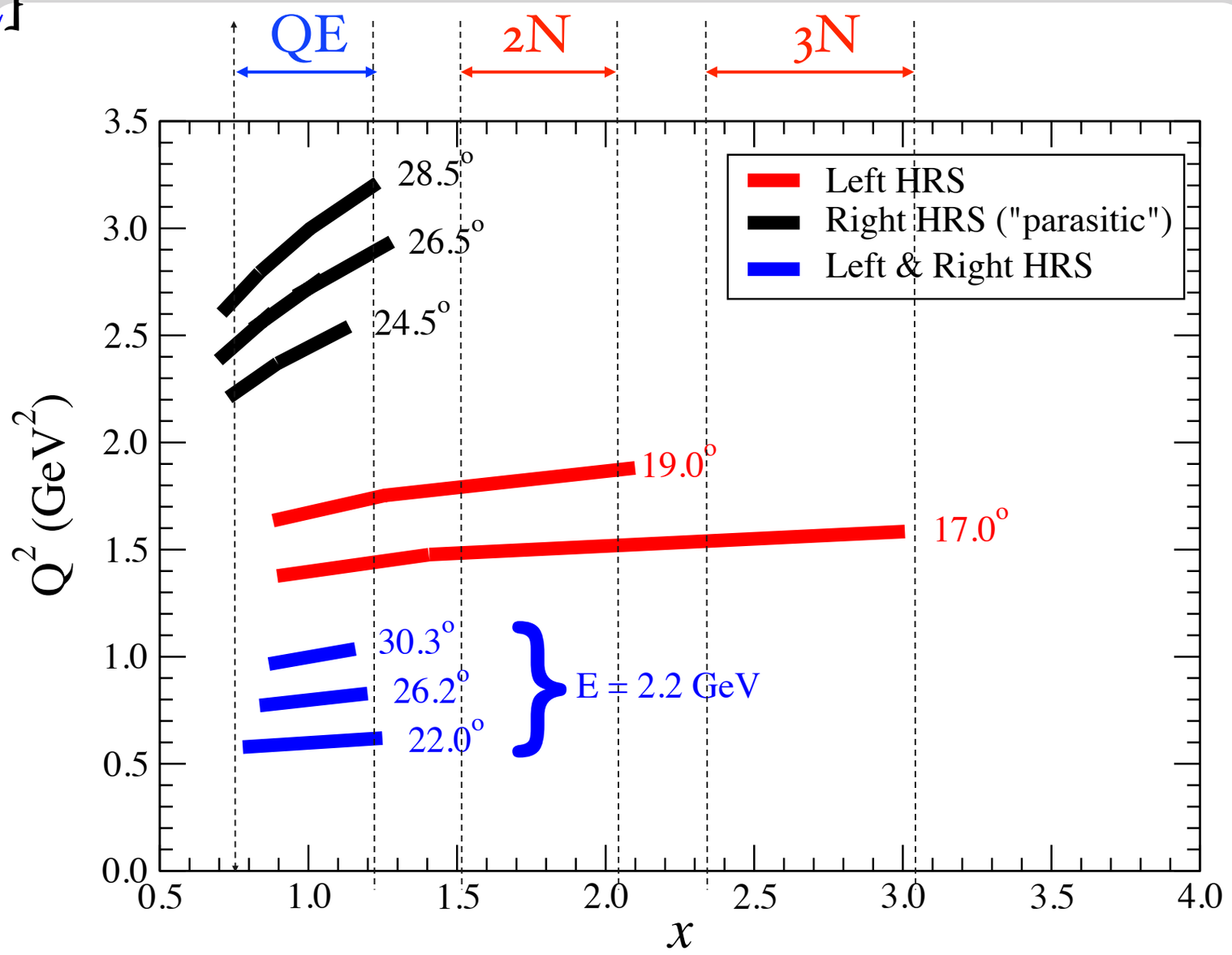
E12-11-112: kinematics

Beam current: 25 μA, unpolarized, Raster interlock

Beam energy:

17.5 Days 4.4 GeV [main production]

1.5 days 2.2 GeV [checkout+QE]



Isospin study from $^{48}Ca/^{40}Ca$ ratio

Simple mean field estimates for 2N-SRC

1) Isospin independent: $\frac{\sigma_{48}/48}{\sigma_{40}/40} = \frac{(20\sigma_p + 28\sigma_n)/48}{(20\sigma_p + 20\sigma_n)/40} \xrightarrow{\sigma_p \approx 3\sigma_n} 0.92$

2) n-p (T=0) dominance: $\frac{\sigma_{48}/48}{\sigma_{40}/40} = \frac{(20*28)/48}{(20*20)/40} = 1.17$

25% difference isospin indep. vs. pn-only (compare to 40% for $^3He/^3H$)

3)For no extra T=0 pairs with f7/2 neutron: $\frac{\sigma_{48}/48}{\sigma_{40}/40} = \frac{\sigma_{40}/48}{\sigma_{40}/40} = 0.83$

Other predictions:

M. Vanhalst, J. Ryckebusch and W. Cosyn, PRC86, 044619 (2012)

$a_2(^{40}Ca) \approx a_2(^{48}Ca)$