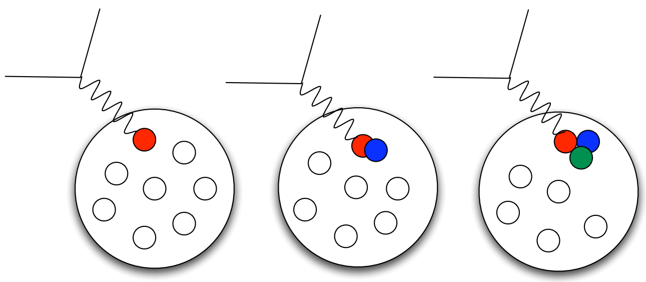
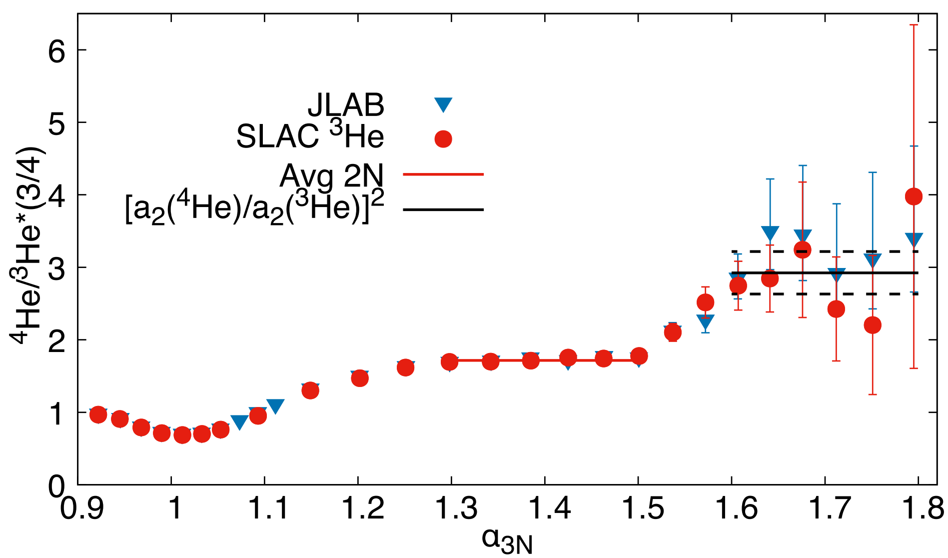
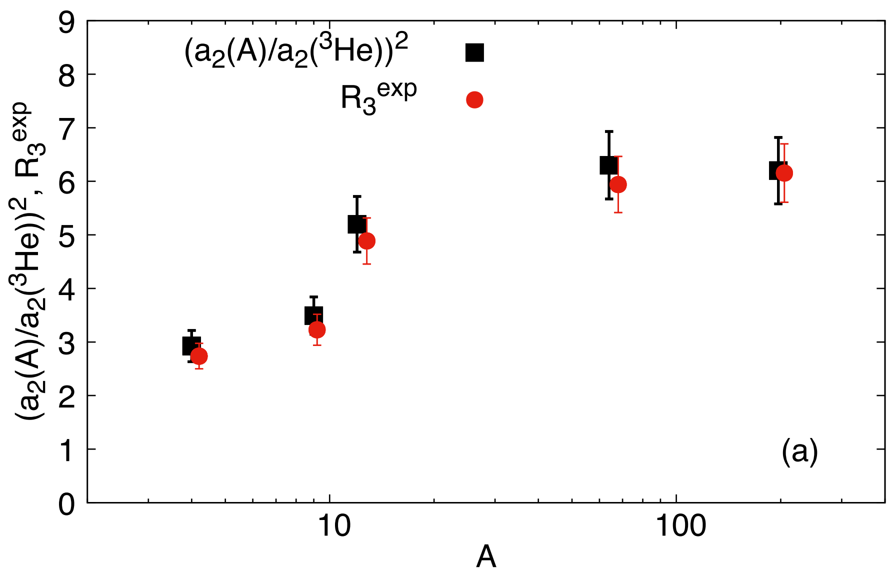
Searching for three-nucleon short-range correlations



Donal Day

Sargsian, Day, Frankfurt, Strikman, PRC 100, 044320 (2019)





University of Virginia

Searching for three-nucleon short-range correlations

Correlation, in nuclear physics, is a word that refers to effects that are beyond mean field theories.

- Long-range: Nuclear collective phenomena such as giant resonances, vibrations and rotations - very well known: Scales are MeV and nuclear radii
- Short-range: Subject of intensive studies in nuclear physics
    - Source is the strong repulsive core of the microscopic nucleon-nucleon interaction at short inter-nucleon distances. Attractive at long distances.
- Scales are nucleon radii and >> MeV

The search for nuclear phenomena exposing short-range correlations effects is one of the most discussed topics in the nuclear structure community today. In fact, the connection between SRCs and the EMC effect … have made it to Fox News!

Donal Day

University of Virginia

PHYSICS • **Published** January 6

There's a giant mystery hiding inside every atom in the universe

FOX NEWS .com

No one really knows what happens inside an atom. But two competing groups of scientists think they've figured it out. And both are racing to prove that their own vision is correct.

Here's what we know for sure: Electrons whiz around "orbitals" in an atom's outer shell. Then there's a whole lot of empty space. And then, right in the center of that space, there's a tiny nucleus — a dense knot of protons and neutrons that give the atom most of its mass. Those protons and neutrons cluster together, bound by what's called the strong force. And the numbers of those protons and neutrons determine whether the atom is iron or oxygen or xenon, and whether it's radioactive or stable.

Still, no one knows how those protons and neutrons (together known as nucleons) behave inside an atom. Outside an atom, protons and neutrons have definite sizes and shapes. Each of them is made up of three smaller particles called quarks, and the interactions between those quarks are so intense that no external force should be able to deform them, not even the powerful forces between particles in a nucleus. But for decades, researchers have known that the theory is in some way wrong. Experiments have shown that, inside a nucleus, protons and neutrons appear much larger than they should be. Physicists have developed two competing theories that try to explain that weird mismatch, and the proponents of each are quite certain the other is incorrect. Both camps agree, however, that whatever the correct answer is, it must come from a field beyond their own.

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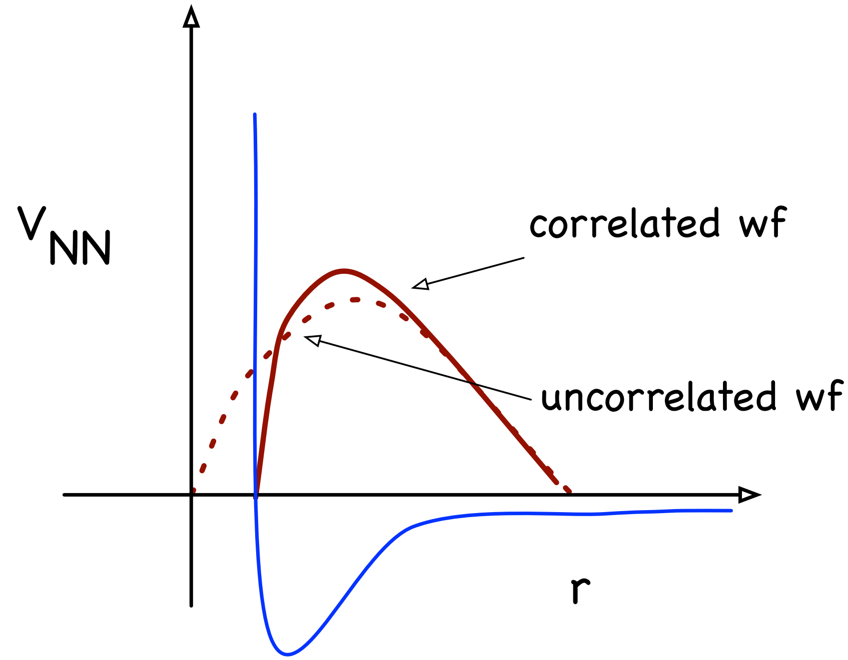
What we know about 2N-SRCs

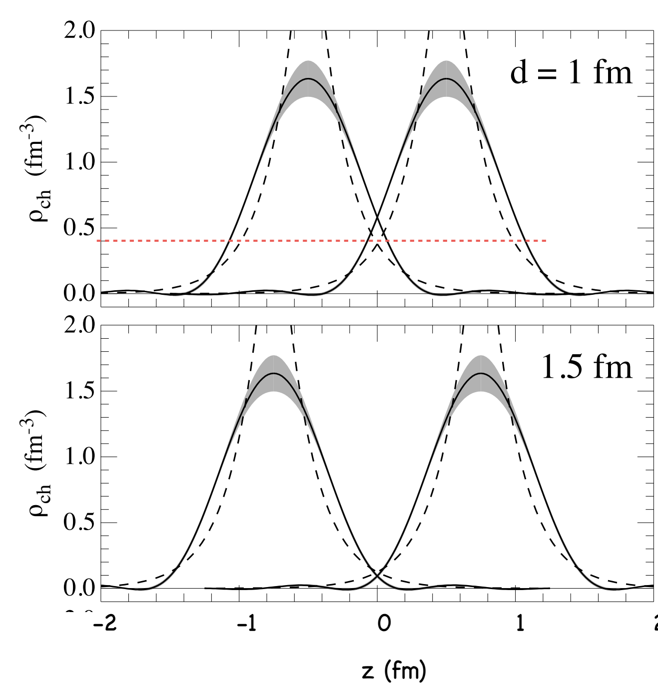
- Spawned inescapably from character of NN potential
  - the hard core and the tensor interaction
  - Identical structure of high momentum components in light and heavy nuclei - universality
  - Kinematic regions in (e,e'): $Q^2 \gtrsim 1.4$ GeV/c^2 and at large $x \gtrsim 1.5$ such that $p_{min} > k_F$; inelastic processes and MECs are minimized
  - Quantified as the strength relative to the deuteron, $a_2 = 2/A\ \sigma^A/\sigma^D$
- 2N-SRCs dominate the momentum distribution tail (300-600 MeV/c)
- Isospin dependence: 20 ± 5% 2N-SRCs - primarily np pairs (18:1 for pp) with large relative momenta and small com momentum
  - 80 ± 5% mean field; 10 - 20% long range correlations
- Simple average density dependence of a_2 violated - the local density - also seen in the EMC effect, dR/dx
- Short distance interactions (i.e. high density) plausibly lead to modification of nucleon pdfs and to a credible connection to the EMC effect
- Isospin dependence of SRC and EMC (e,e') - works in progress
- SRC-EMC connection is not fully understood.

Case for Correlations

- The nucleon-nucleon (NN) interaction is singularly repulsive at short distances
  - Two nucleons rarely are at short distances
    Loss in configuration space components signals an increase of high-momentum components
- Both the correlation hole and the high-k components are absent in IPMs
- Taken together the loss of configuration space and the strengthening of high of momentum components are "correlations".
- The NN tensor force also provides high-momentum components; required to obtain the quadrupole moment of the deuteron and predicts a isospin dependence of SRCs.



$\rho_{NM} = 0.16$



Pandharipande, Pieper and Schiavilla

Densely packed -
at small distances multiples of NM density

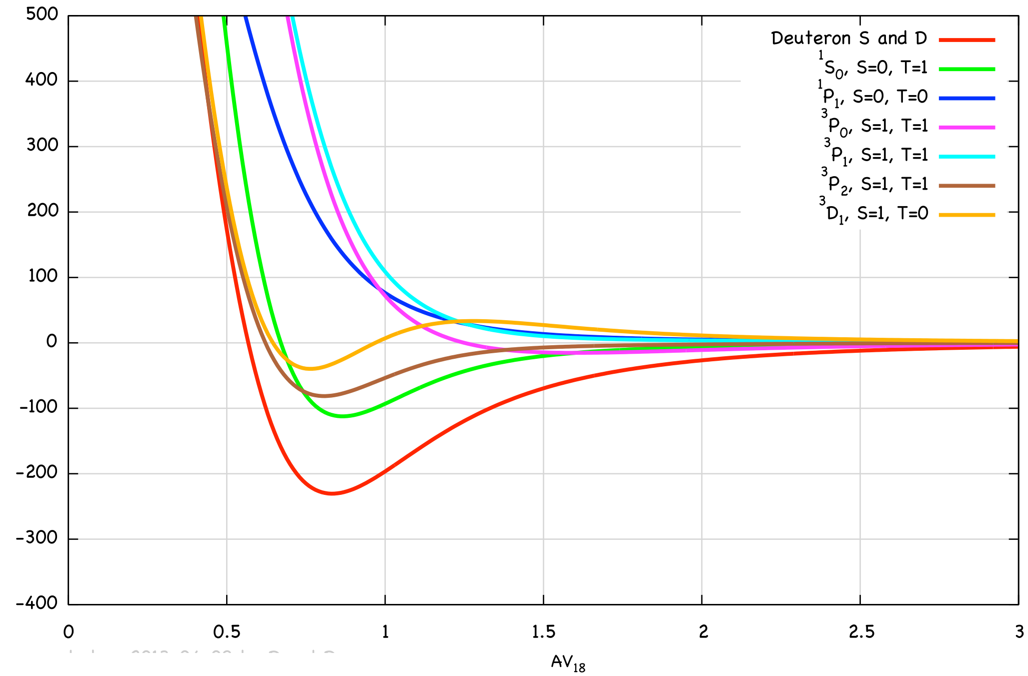
High enough to modify nucleon structure?

Possible Two Nucleon states

L	S	J	$\pi = -1^L$	T(L+S+T odd)	$^{2S+1}L_J$
0	0	0	+	1	$^1S_0$
0	1	1	+	0	$^3S_1$
1	0	1	-	0	$^1P_1$
1	1	0	-	1	$^3P_0$
1	1	1	-	1	$^3P_1$
1	1	2	-	1	$^3P_2$
2	0	2	+	1	$^1D_2$
2	1	1	+	0	$^3D_1$
2	1	2	+	0	$^3D_2$
2	1	3	+	0	$^3D_3$

Two-nucleon states

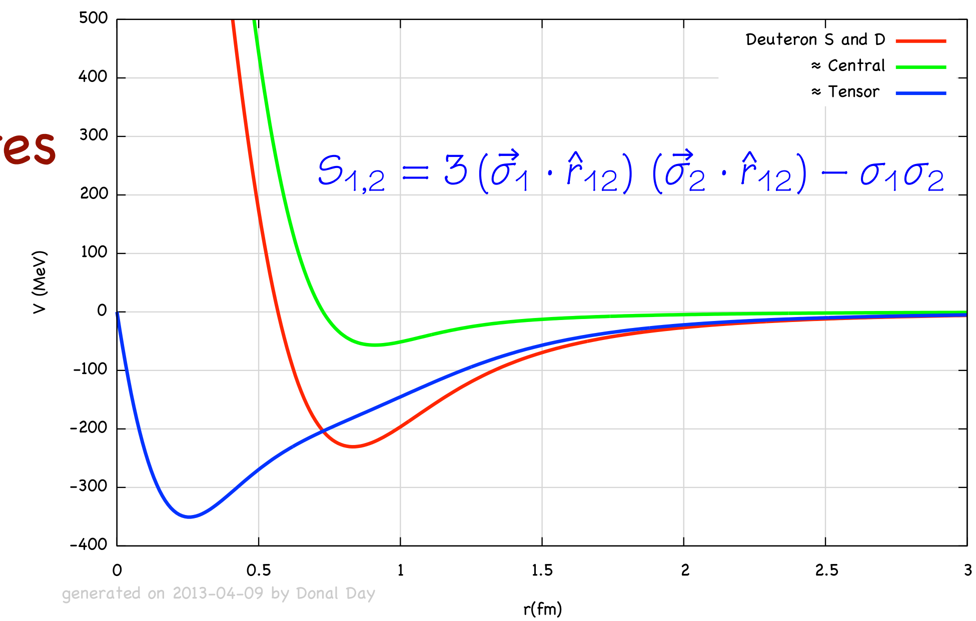
The Pauli principle requires that two-nucleon states be antisymmetric wrt to exchange of the nucleons' space, spin, and isospin coordinates



Without the tensor contribution the deuteron would not be bound

And it only contributes to T=0 2N states

Explains the SRC ratios, isospin asymmetry

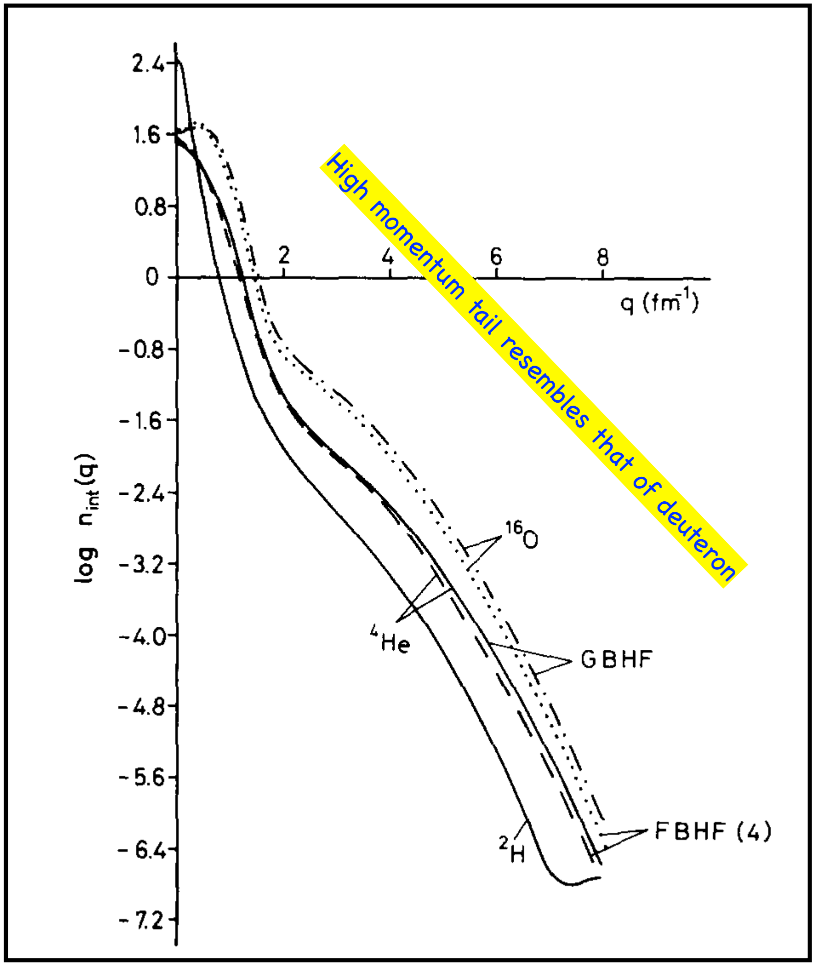


Long term quest for SRCs through n(k)

A repulsive core ⇒ spatial correlations (a hole) ⇒ a correlation in momentum space ⇒ high momentum components

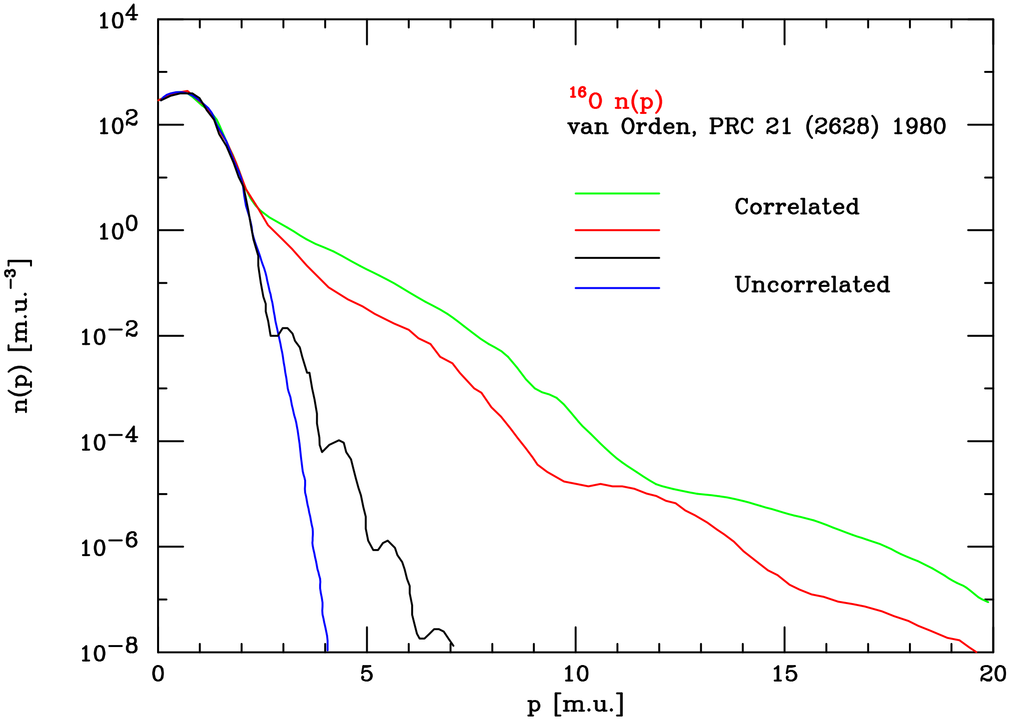
"For many years the quest for direct experimental evidence of nuclear correlations has not met much success."

Momentum Distributions Of Nucleons In Nuclei, Volume 76B, Physics Letters 3 July 1978, J.G. Zabolitzky and W. Ey

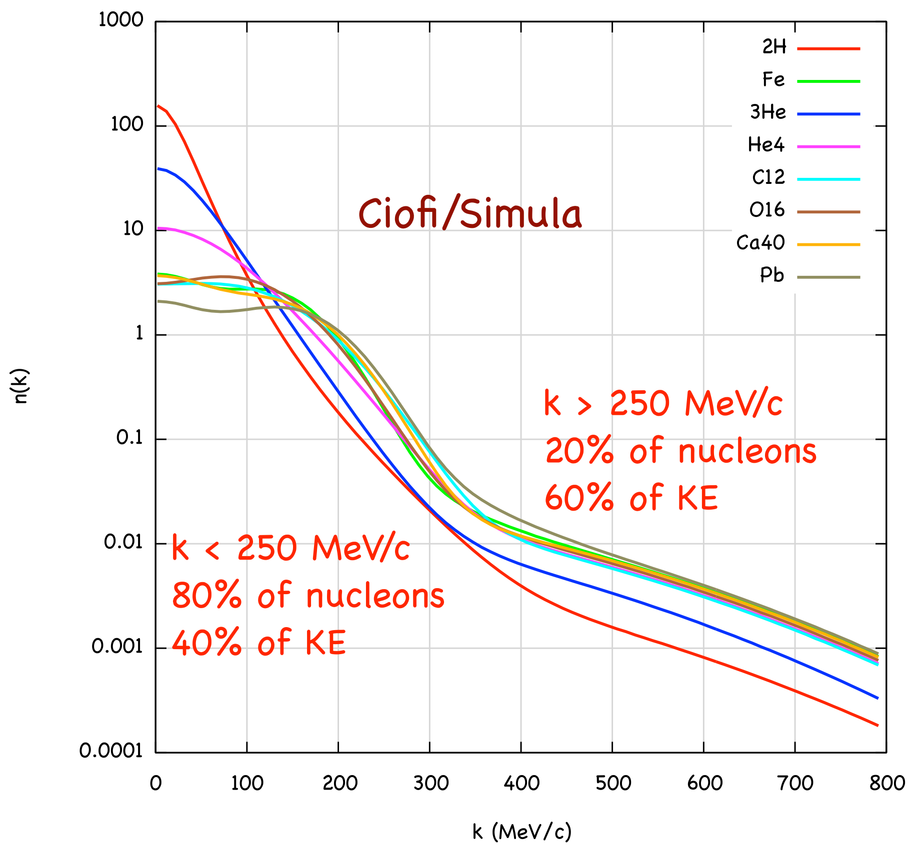


"The short-range correlations are found to modify significantly the independent particle shell model momentum density distribution for low momenta and to dominate it for high momenta"

Short-range correlations and the nuclear momentum density distribution for ^{16}O: Van Orden, Truex, Banerjee, PRC 21 (2628) 1980

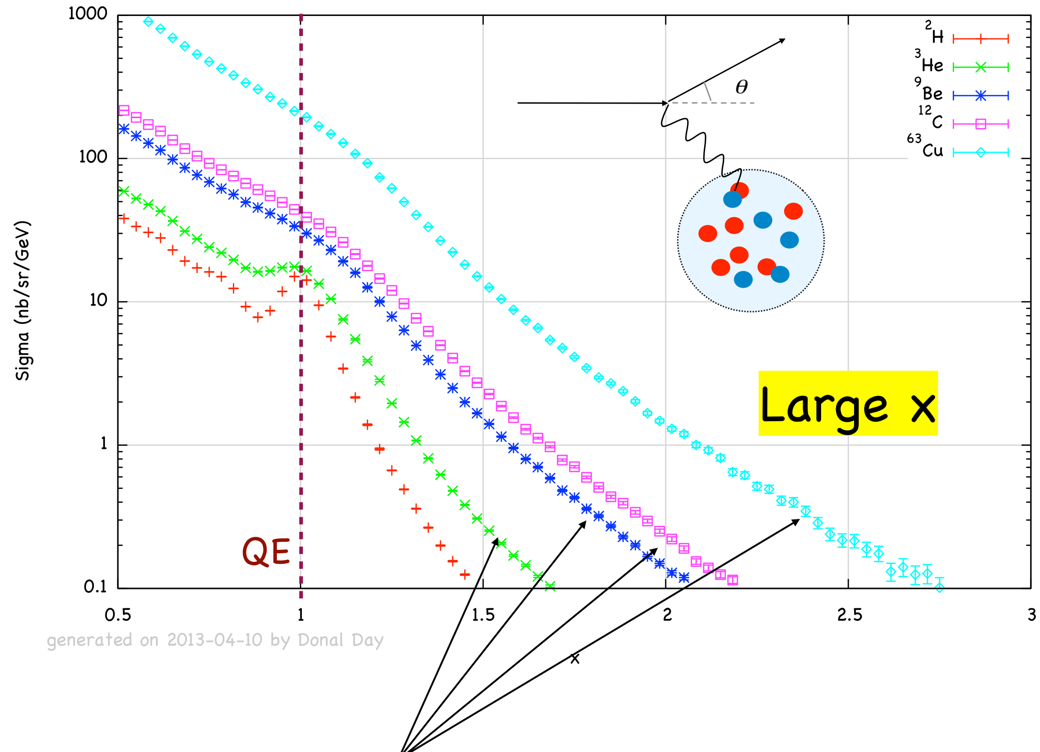


Cross sections mirror aspects of n(k)



C. Ciofi degli Atti and S. Simula, Phys. Rev. C **53** (1996) 1689

A(e,e') E02019 Fomin et. al., 5.766, 18°



High momentum tails accessible AND should yield constant ratio if seeing SRC

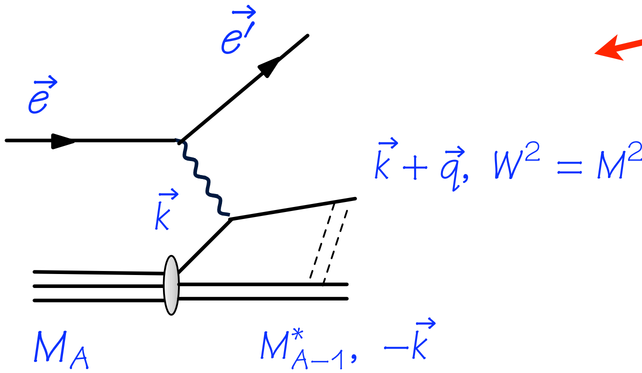
a plateau in ratios

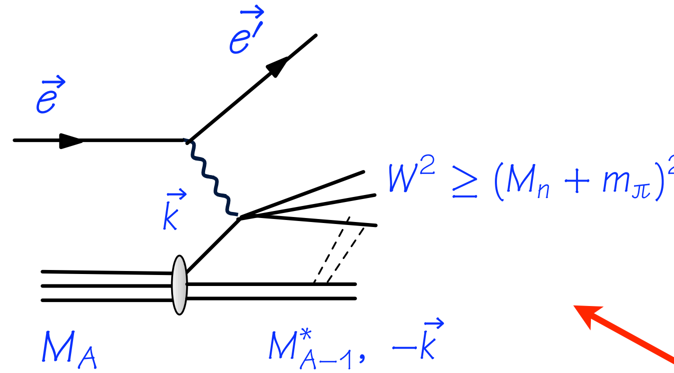
n(k) is A dependent at $k < k_f$ yet has a universal shape at large k, reflecting the details of the NN interaction.

Inclusive Electron Scattering from Nuclei

Two distinct processes

Quasielastic from the nucleons in the nucleus





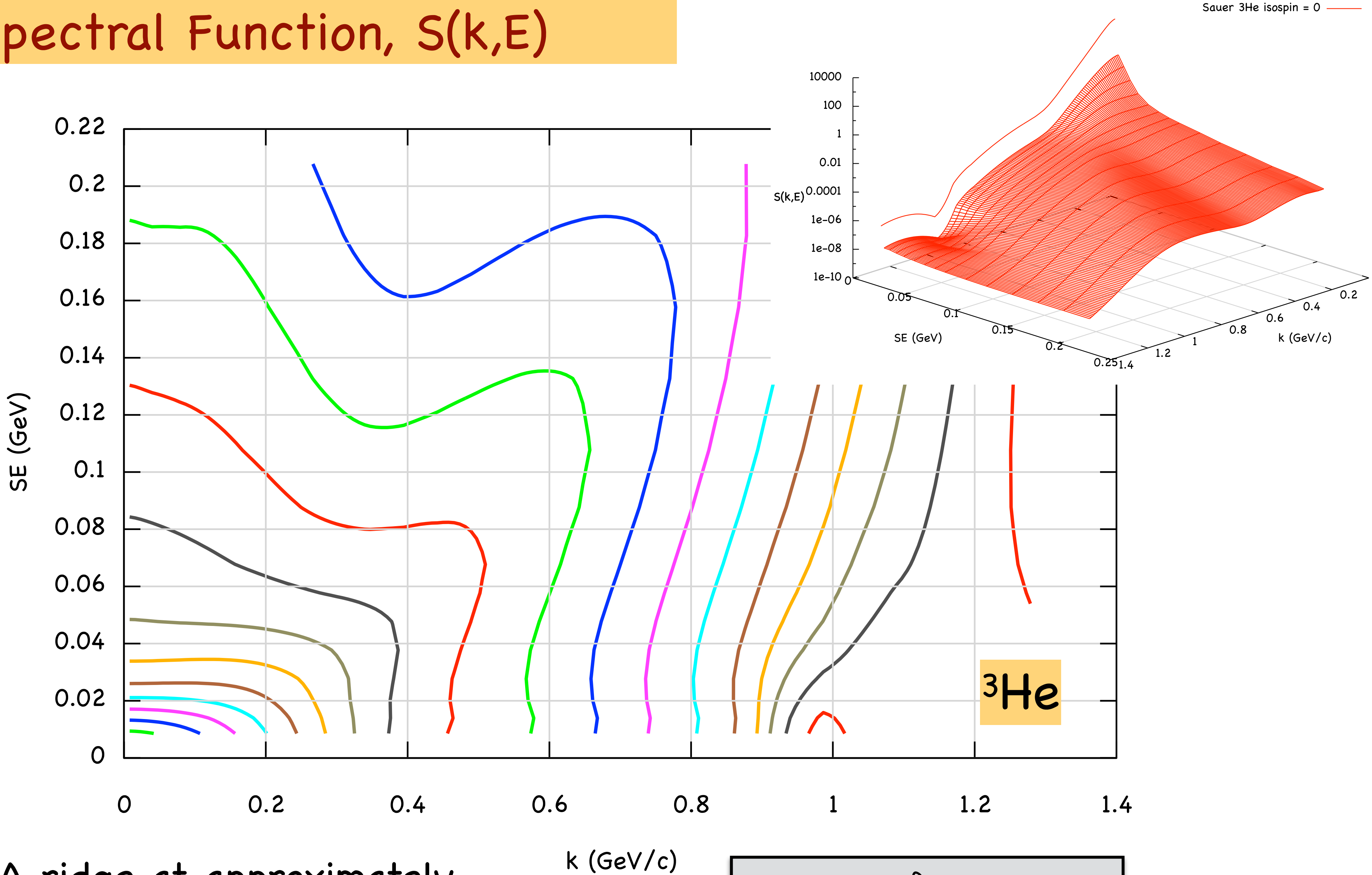
Inelastic and DIS from the quark constituents of the nucleon.

$$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE \sigma_{ei} \underbrace{S_i(k,E)}_{\text{Spectral function}} \delta()$$

$$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE\ W_{1,2}^{(p,n)} \underbrace{S_i(k,E)}_{\text{Spectral function}}$$

In IA, S(k,E) describes the probability of finding a struck nucleon in the nucleus initially having missing momentum k and missing energy E.

Spectral Function, S(k,E)



A ridge at approximately $E = k^2/(2m)$ reflects correlations in the gs

$$n(k) = \int dE\, S(k,E)$$

CS Ratios and SRC

The cross section in inclusive electron scattering at high Q^2 is factorized in the form

$$\sigma_{eA} \approx \sum_N \sigma_{eN} \rho_A^N(a_N)$$

where σ_{eN} is the elementary cross section and $\rho_A^N(\alpha)$ is the light-front density matrix at LC momentum fraction α_N of probed nucleon.
Starting from the above (see references below) we can predict the following.

$$\Rightarrow \qquad \frac{2}{A}\frac{\sigma_A(x,Q^2)}{\sigma_D(x,Q^2)} = a_2(A)\Big|_{1<x\leq 2}$$

$$\frac{3}{A}\frac{\sigma_A(x,Q^2)}{\sigma_{A=3}(x,Q^2)} = a_3(A)\Big|_{2<x\leq 3}$$

In the ratios, off-shell effects and FSI largely cancel.

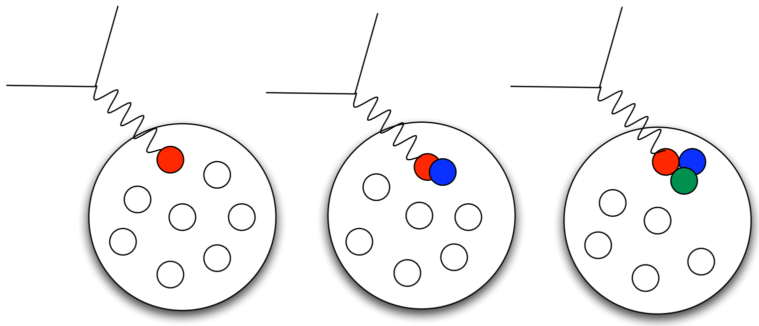
$a_j(A)$ is proportional to probability of finding a j-nucleon correlation

L.L. Frankfurt and M.I. Strikman, Phys. Rep. 160, 235 (1988)

L. Frankfurt, M. I. Strikman, D. B. Day, and M. Sargsyan, Phys. Rev. C 48, 2451 (1993).

Ratios and SRC

In the region where correlations should dominate, large x,



$a_j(A)$ is proportional to probability of finding a j-nucleon correlation

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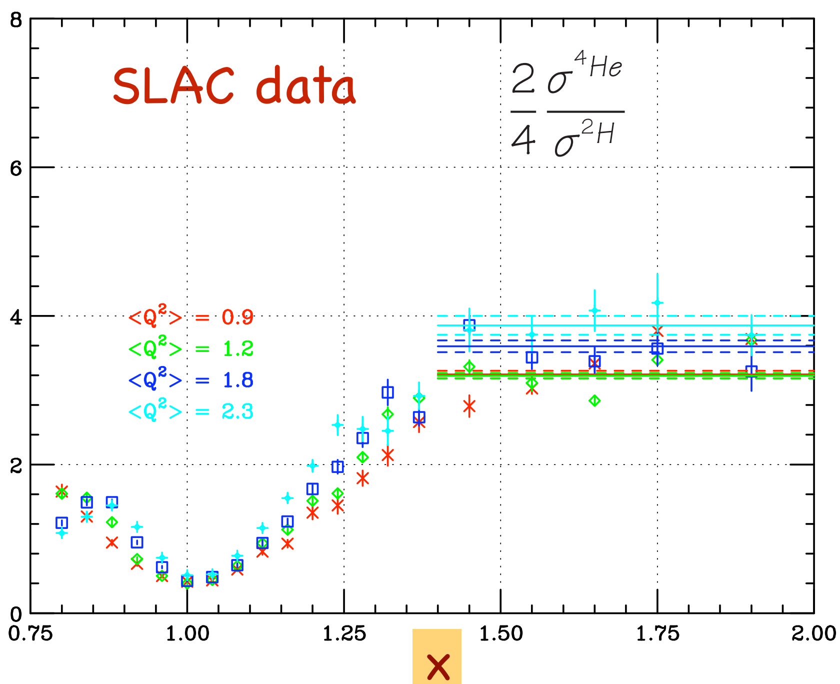
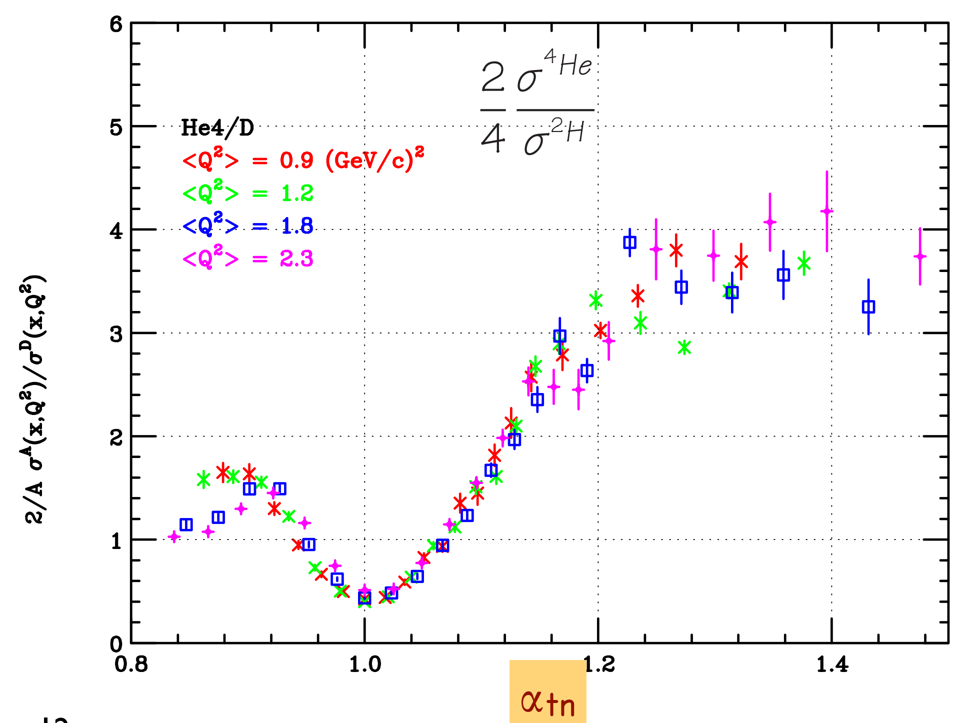
$$\frac{3}{A}\frac{\sigma_A(x,Q^2)}{\sigma_{A=3}(x,Q^2)} = a_3(A)\Big|_{2<x\leq 3}$$

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

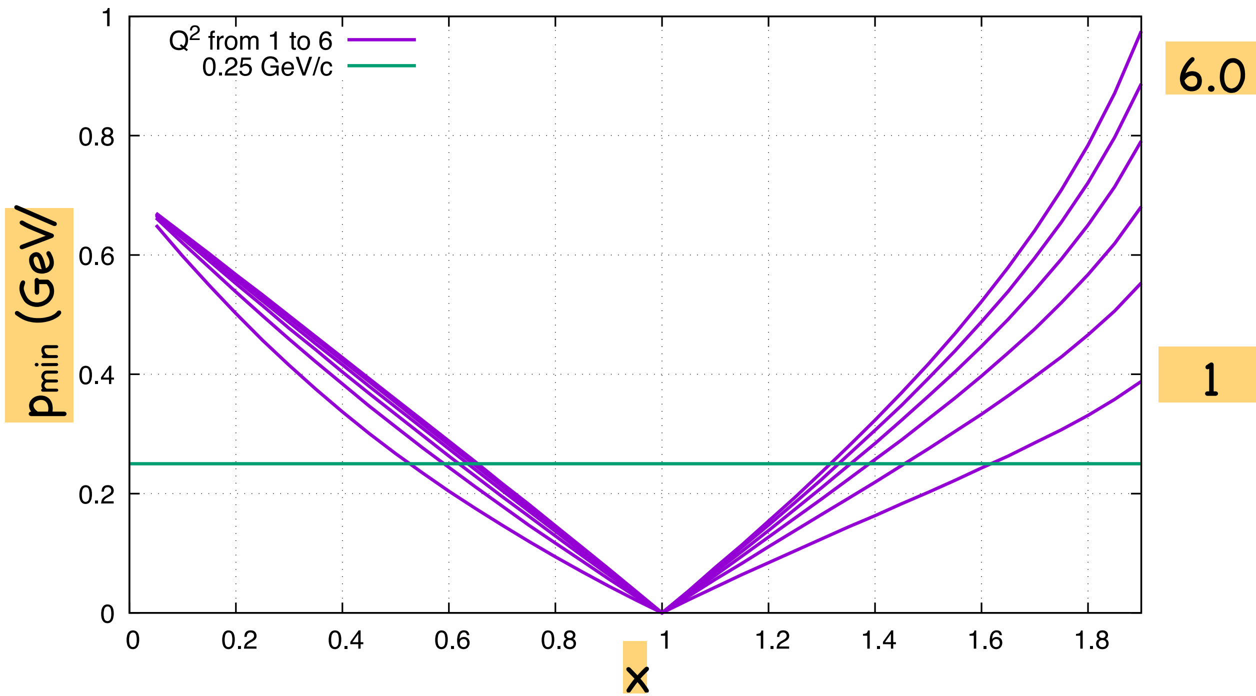
Accounts for Q^2 dependence

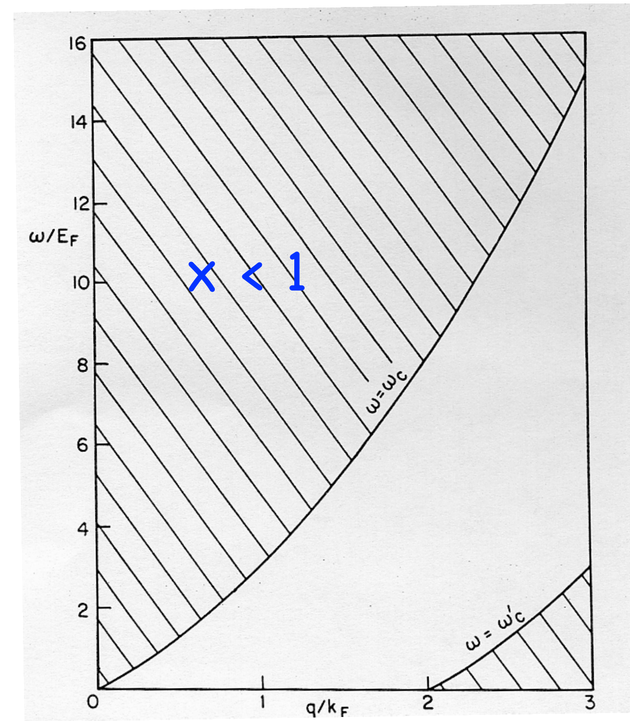




FSDS, Phys.Rev.C48:2451-2461,1993

2N SRCs: Where to look in inclusive A(e,e′)





x > 1, low ω side of qep

Look in kinematics that are forbidden to the stationary nucleon AND minimize DIS, MEC, and nucleon excitations:

- $Q^2 \gtrsim 1.5$ and $1.4 < x < 1.9$ (Q^2 dependent)
- This insures that the struck nucleon momentum is greater than the mean-field k_f.
- As A increases we have to higher x or Q^2 to be confident scattering is not from mean-field nucleon

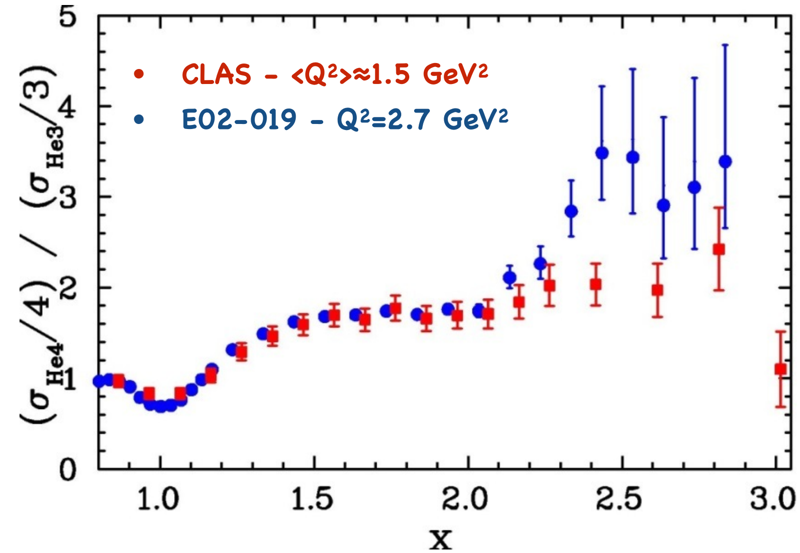
Inelastic electron scattering from fluctuations in the nuclear charge distribution

Wieslaw Czyż and Kurt Gottfried

Annals of Physics 21, 47 (1963)

SRC Ratios at Jlab

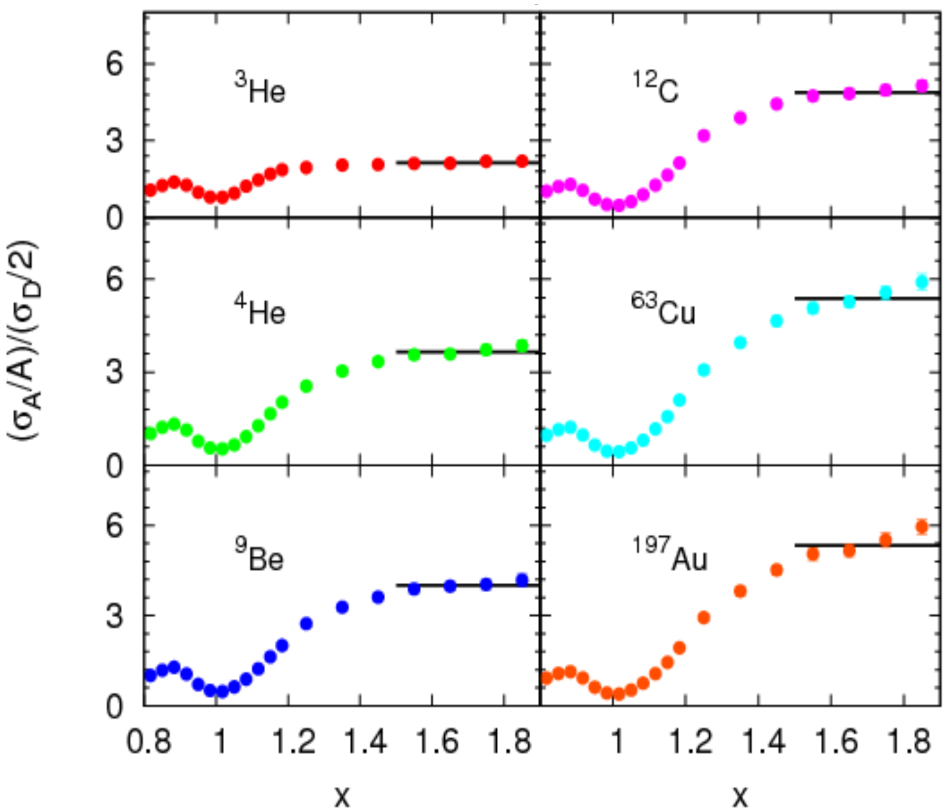
K. Egiyan et al, PRL96, 082501 (2006)



Simple SRC Model:

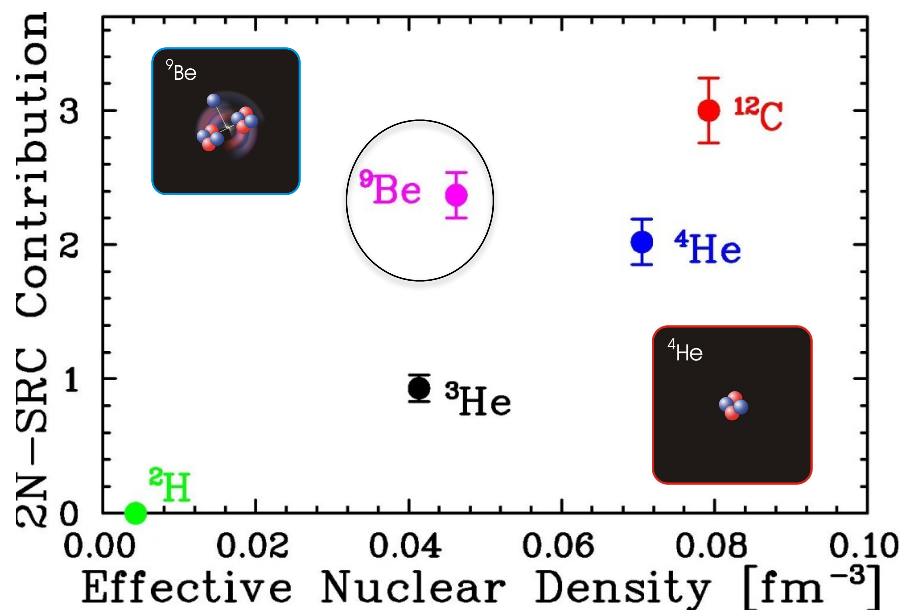
- 1N, 2N, 3N dominate at $x \leq 1, 2, 3$
- 2N, 3N configurations "at rest"
- Isospin independent
- Depends on Average Density

N. Fomin, et al., PRL 108 (2012) 092052

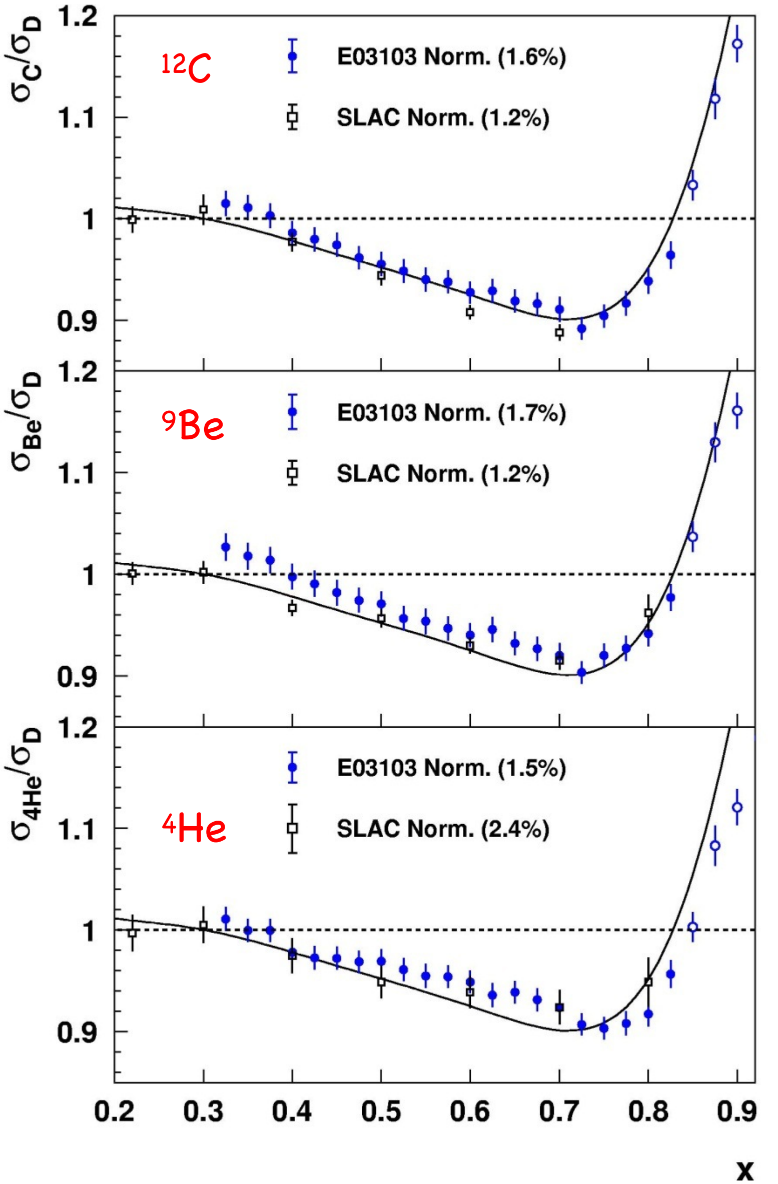


Experimental observations:

- Clear evidence for 2N-SRC at x>1.5
- Suggestion of 3N-SRC plateau(?)
- Isospin dependence ?
- Local Density dependence



JLab E03-103: Light nuclei



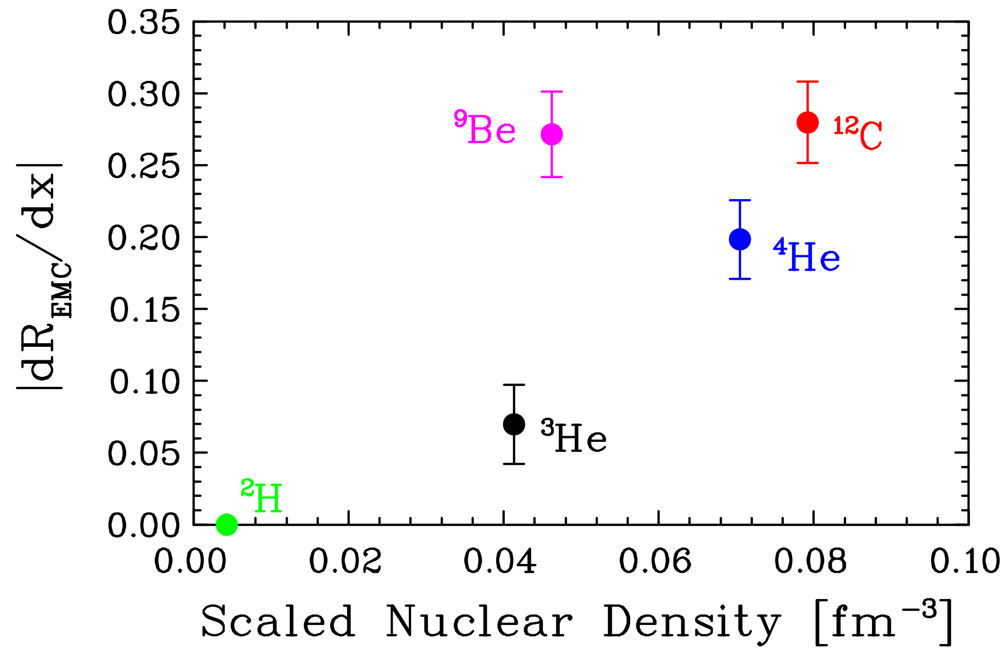
J. Seely, et al., PRL103, 202301 (2009)

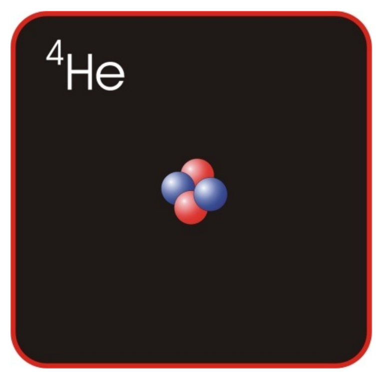
Consistent shape for all nuclei (curves show shape from SLAC fit)

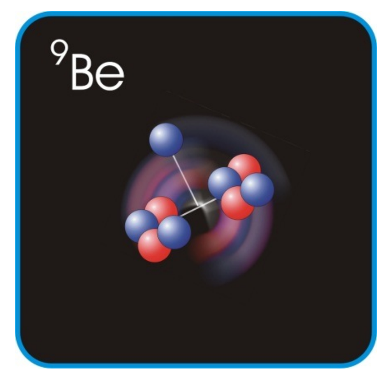
If shape (x-dependence) is same for all nuclei:

Then the slope (0.35<x<0.7) can be used to study dependence on A

EMC Effect and Local Nuclear Density

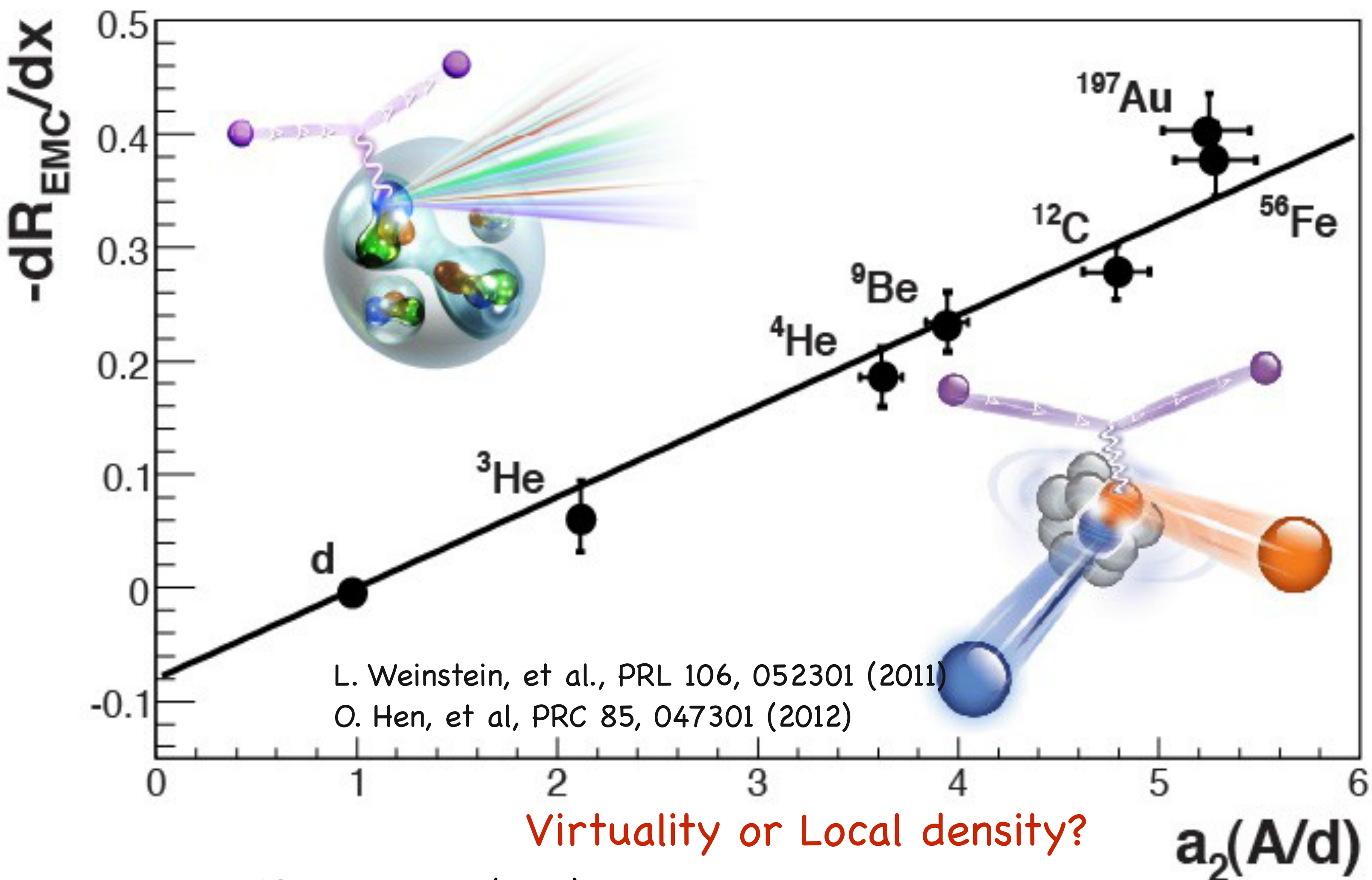






Credit: P. Mueller, via John Arrington

Connection between SRCs and EMC effect: Importance of two-body correlations?



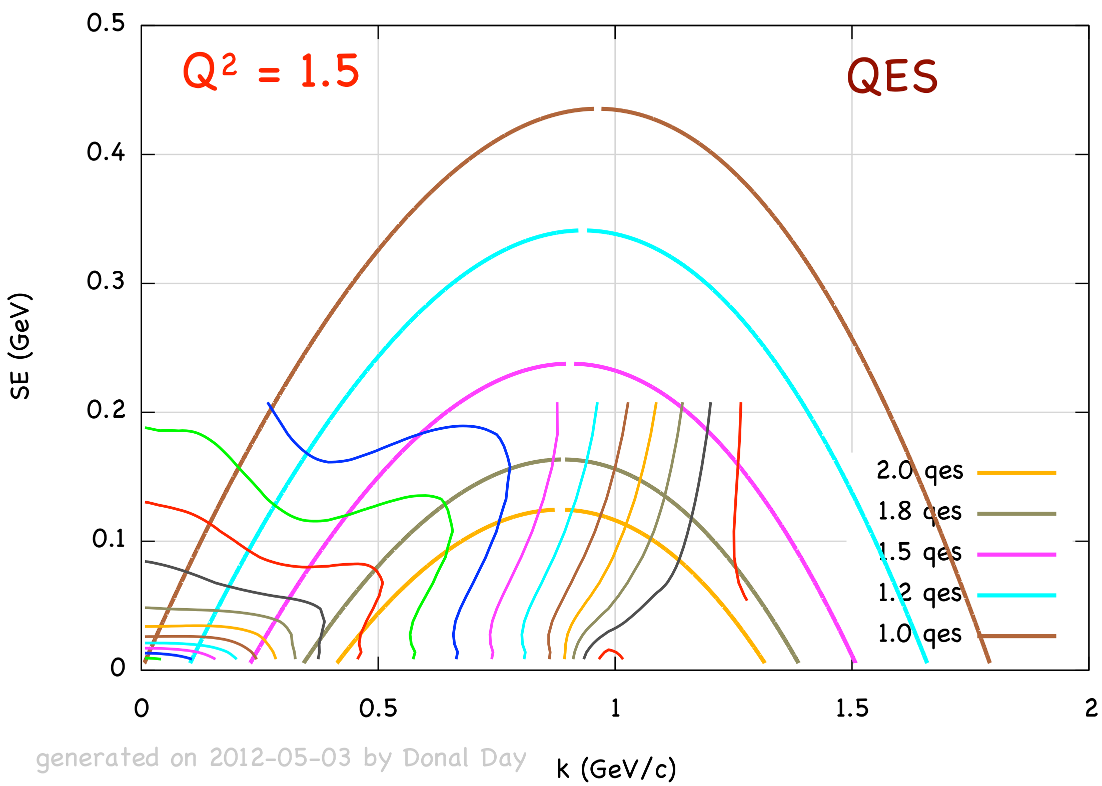
Virtuality or Local density?

J. Seely, et al., PRL103, 202301 (2009)
N. Fomin, et al., PRL 108, 092052 (2012)
J. Arrington, A. Daniel, D. Day, N. Fomin, D. Gaskell, P. Solvignon, PRC 86 (2012) 065204

Many body calculations connecting SRC and EMC are lacking

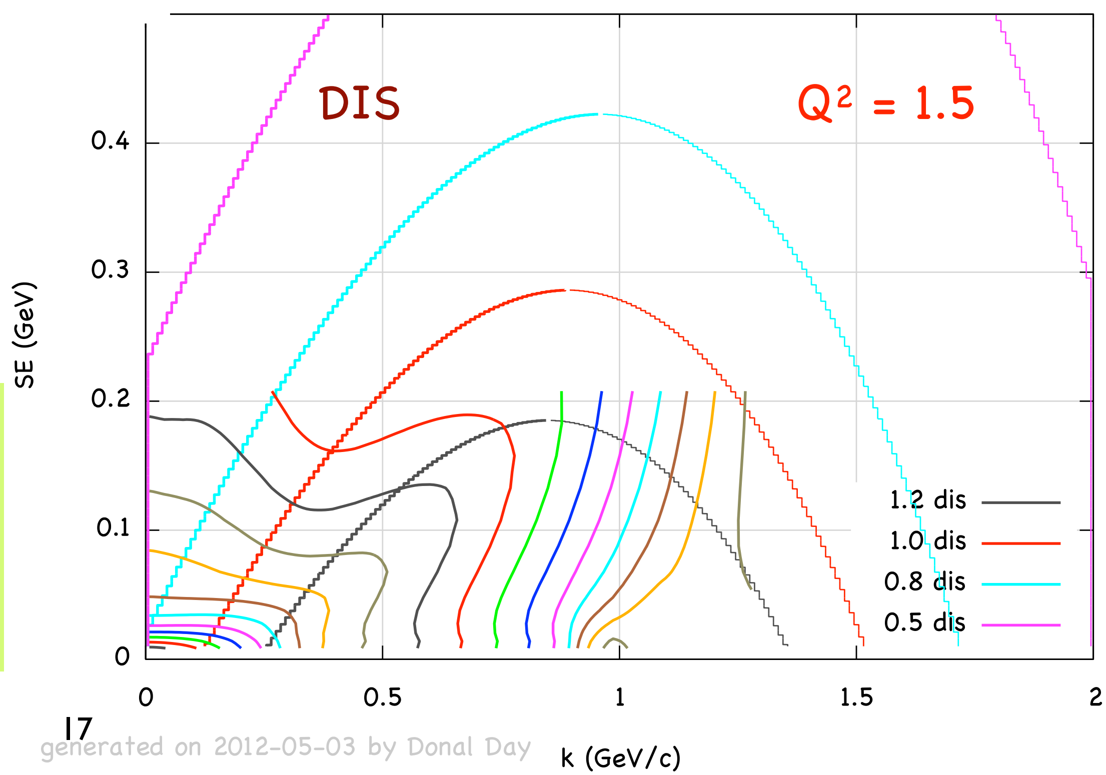
Integration limits over spectral function

The limits on the integrals are determined by the kinematics. Specific (x, Q^2) select specific pieces of the spectral function.



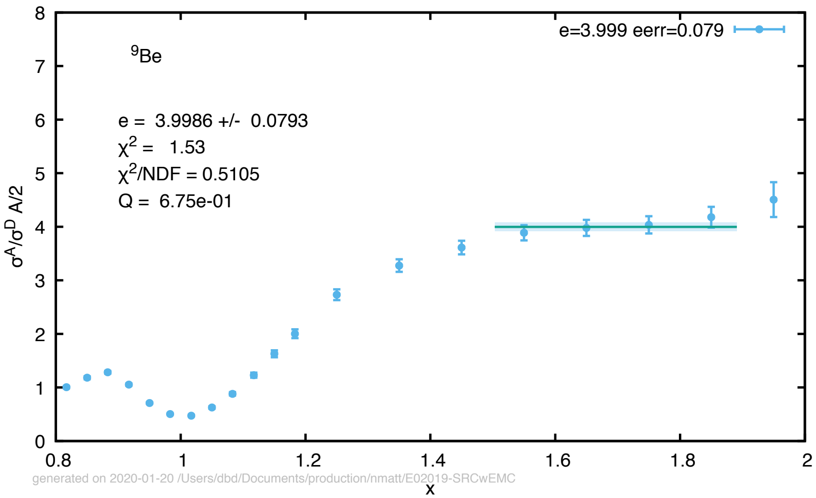
$$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE \sigma_{ei} \underbrace{S_i(k,E)}_{\text{Spectral function}} \delta()$$

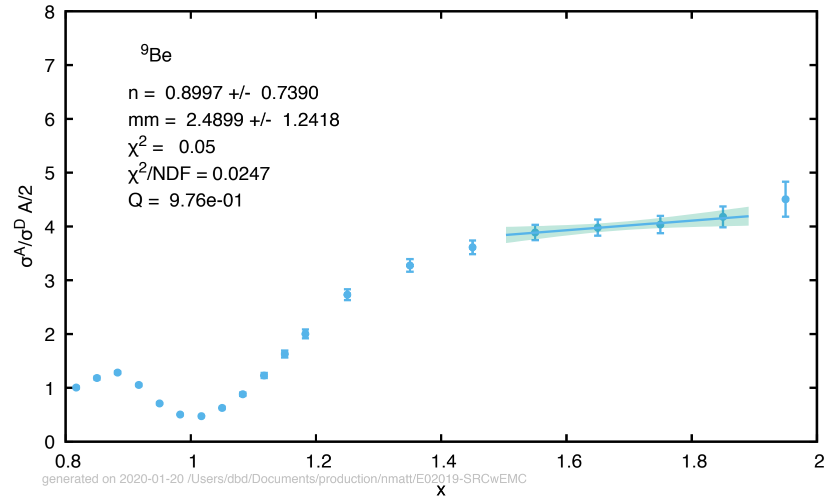
$$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE \, W_{1,2}^{(p,n)} \underbrace{S_i(k,E)}_{\text{Spectral function}}$$

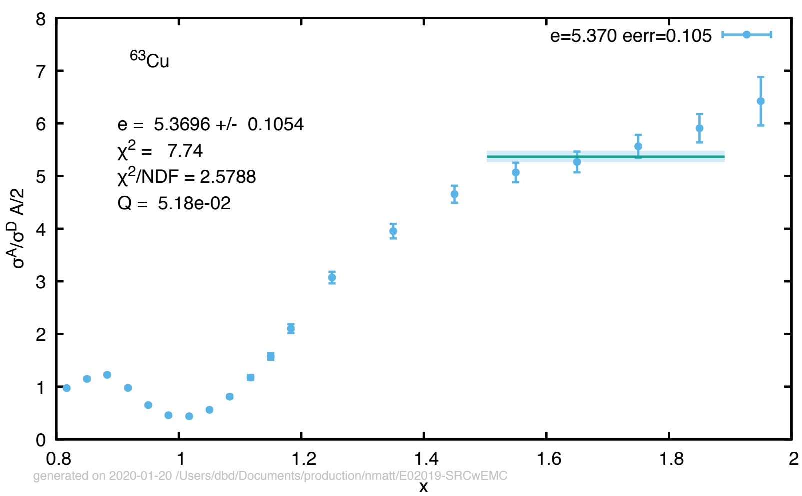


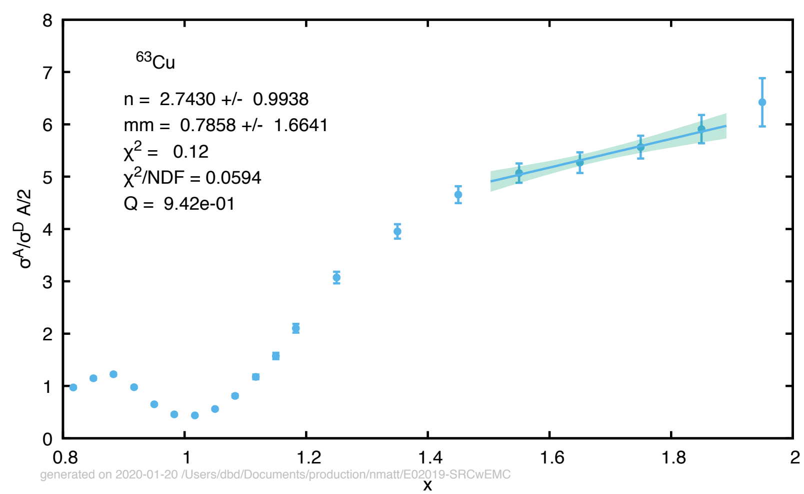
Given the fact that EMC and SRC integrate over very different parts of the spectral function needs close examination

2NSRC plateaus



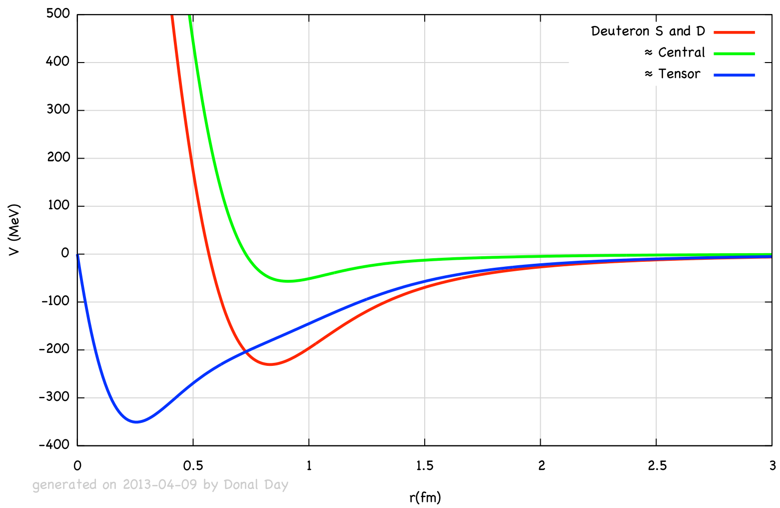


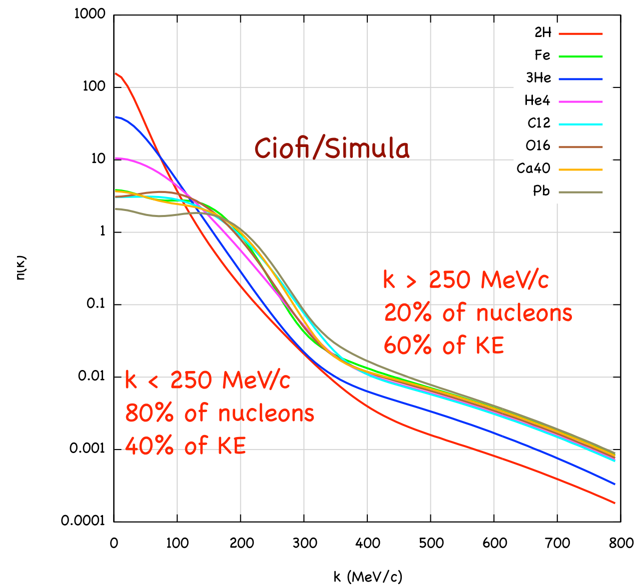




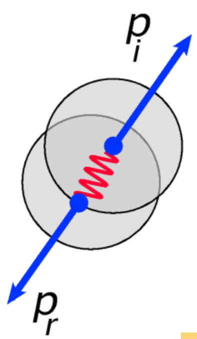
In every case, straight-line fit best represents the data

Theory, Dynamics Precipitate 2N-SRC plateaus

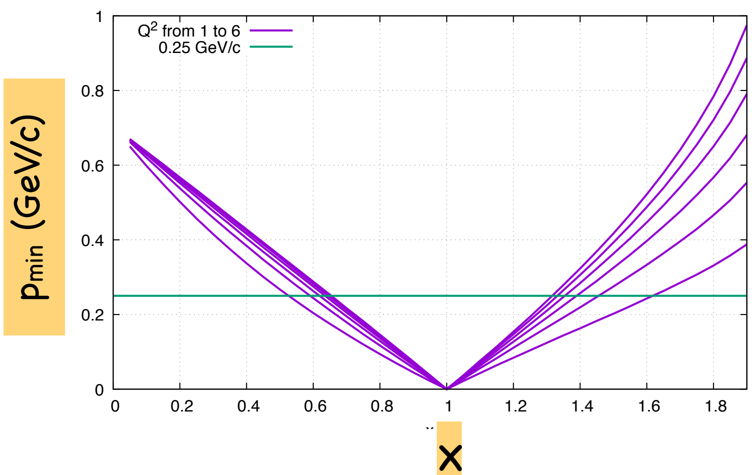


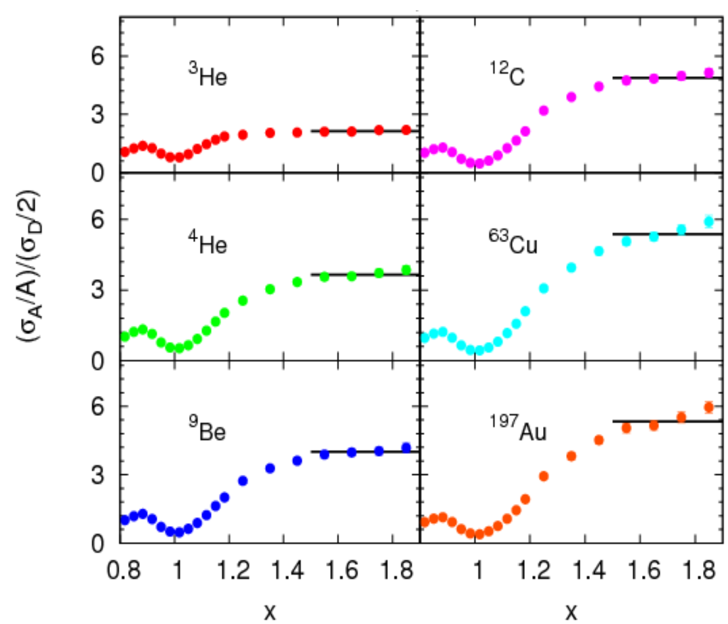


Common shape of n(k) tail reveals the shared NN potential of all nuclei – the source of these dynamical correlations. And suggests an isospin dependence of the deuteron

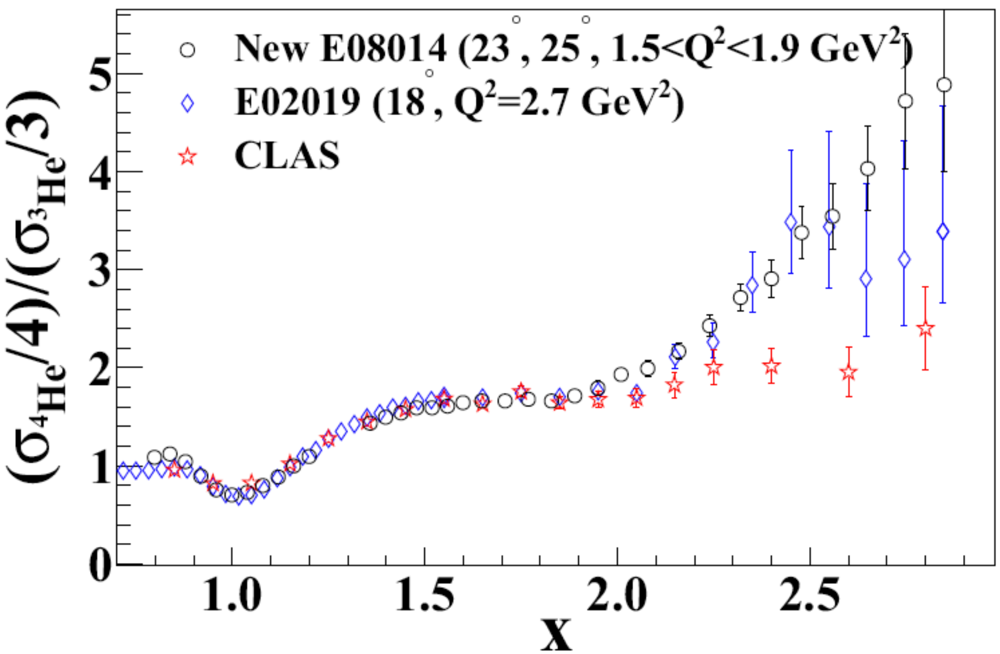


A one page review



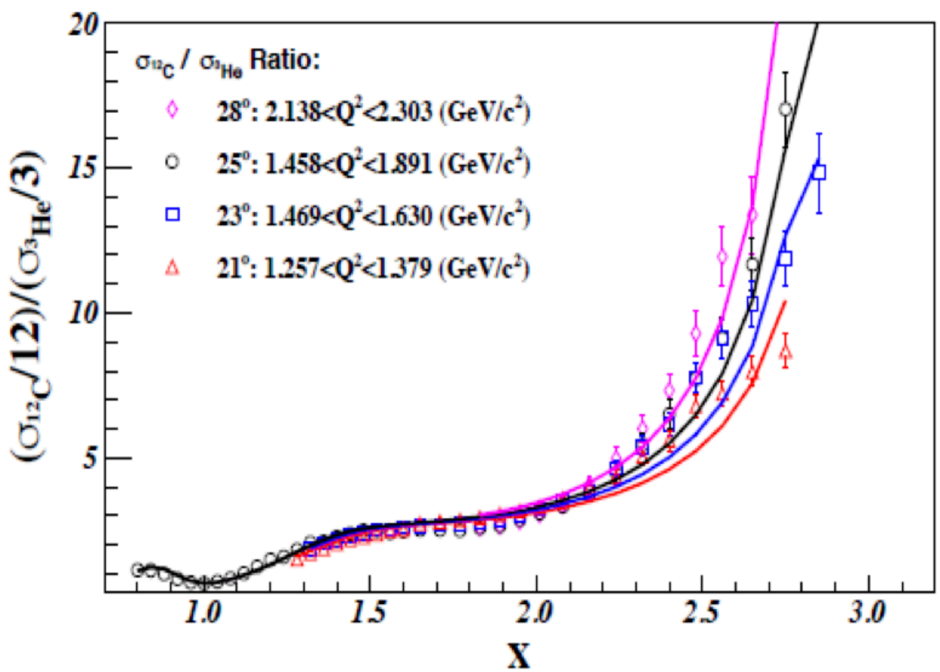


Search for 3N SRCs in Hall A - E08014



Z. Ye, Phys. Rev. C 97, 065204 (2018)

- Better precision than Hall-B, similar to Hall C
- Small Q^2 values (close to Hall-B)
- Data from ^{2}H, ^{3}He, ^{4}He, ^{12}C, ^{40}Ca, ^{48}Ca
- No any indication of 3N-SRC at x>2 in either ^{4}He/^{3}He and ^{12}C/^{3}He ratios
- Also shows a Q^2 dependence at x>2



3NSRC - Where to look

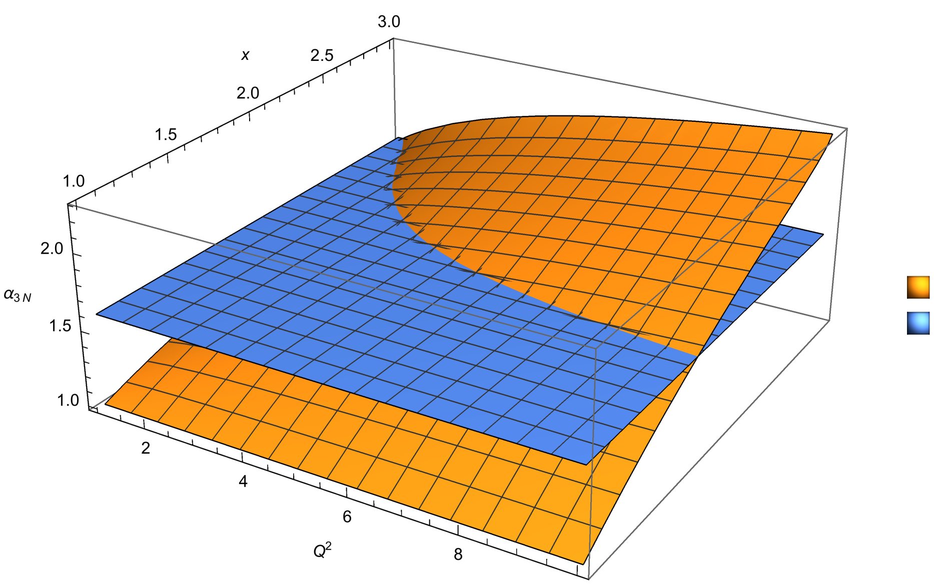
Day, Frankfurt, Sargsian, Strikman. arXiv:1803.07629 [nucl-th]
Sargsian, Day, Frankfurt, Strikman, PRC 100, 044320 (2019)

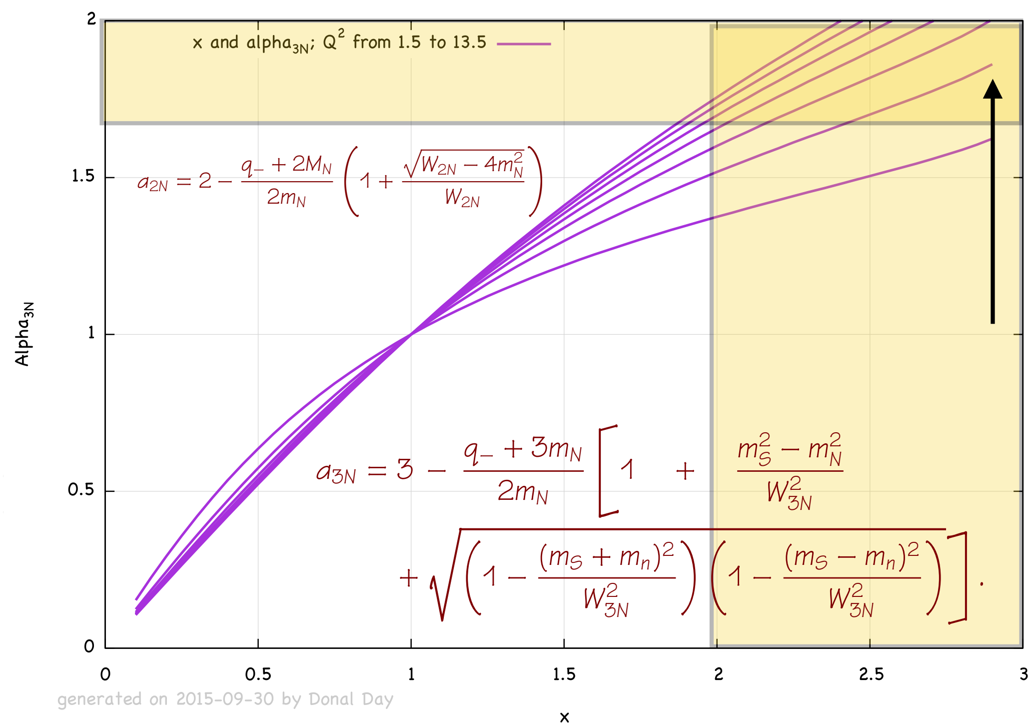
To evaluate the LC momentum fraction, (α_{3N}) of the interacting nucleon in the 3N-SRC, consider the kinematics of quasielastic scattering from a 3N system: $q+3m_N = p_f + p_S$, where q, p_f and p_S are the four momenta of the virtual photon, final struck nucleon and recoil two-nucleon system respectively. One defines the LC momentum fraction of the interacting nucleon, $\alpha_{3N} = 3 - \alpha_S$, where $\alpha_S \equiv 3\frac{E_S - p_S^z}{E_{3N} - p_{3N}^z}$ is the light-cone fraction of the two spectator nucleons in the center of mass of the $\gamma^*(3N)$ system with $z||q$. Using the boost invariance of the light-cone momentum fractions one arrives at the following lab-frame expression

$$a_{3N} = 3 - \frac{q_- + 3m_N}{2m_N}\left[1 + \frac{m_S^2 - m_N^2}{W_{3N}^2} + \sqrt{\left(1 - \frac{(m_S+m_n)^2}{W_{3N}^2}\right)\left(1 - \frac{(m_S-m_n)^2}{W_{3N}^2}\right)}\,\right].$$

invariant mass $W_{3N}^2 = (q + 3m_N)^2 = Q^2\frac{3-x}{x} + 9m_N^2.$ $\quad q_- = q_o - |\vec{q}\,|$

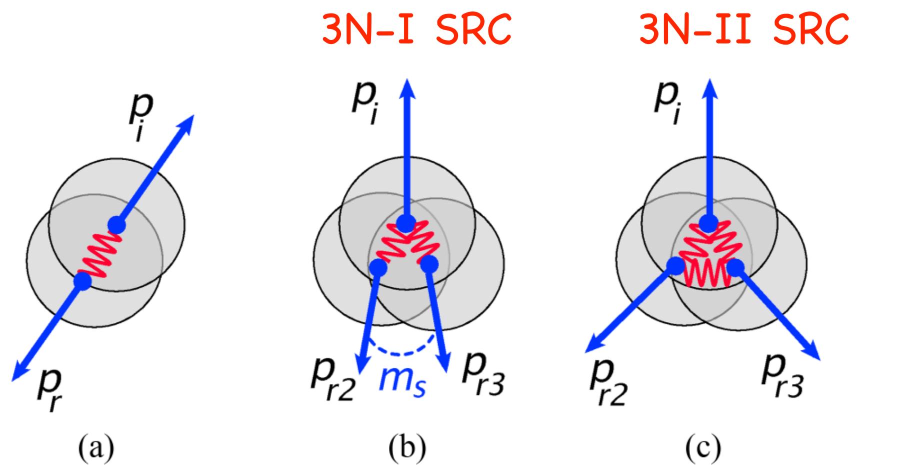
Where to look: The surface above the horizontal plane, α_{3N} = 1.6, below or top right corner in right figure: $p_{min} \geqq$ 600/700 MeV/c, $Q^2 \geq$ 3 or more





3NSRC - not so simple

M. M. Sargsian, T. V. Abrahamyan, M. I. Strikman, L. L. Frankfurt, Phys. Rev. C 71, 044614 (2005) and Phys. Rev. C 71, 044615 (2005)



struck nucleon balanced by 2 recoils w/momenta ≅ $p_m/2$

all 3 nucleons have comparable momenta with θ ≅ 120^0

2N-SRCs is simple [two fast nucleons nearly balancing each other]. Two extreme cases are possible for 3N-SRC configurations.

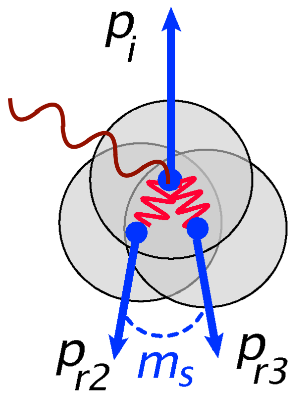
"Star Formation"

In the case of 3N SRCs the geometry of balancing three fast nucleons is not unique, ranging from configurations in which two almost parallel spectator nucleons with momenta, ≈ $p_i/2$ balance the third nucleon with momentum p_i to the configurations in which all three nucleons have momenta p_i with relative angles ≈ 120

The first (b) is referred as type 3N-I SRC, corresponds to the situation in which the probed fast nucleon is balanced by two fast spectator nucleons p_{r2}, p_{r3} ~ $p_m/2$ which have small relative angle between them, thus small invariant mass, m_S ~ $2m_N$. The second case c), type 3N-II SRC corresponds to the symmetric situation in which all three nucleons have comparable momenta with relative angles θ ~ 120^o.

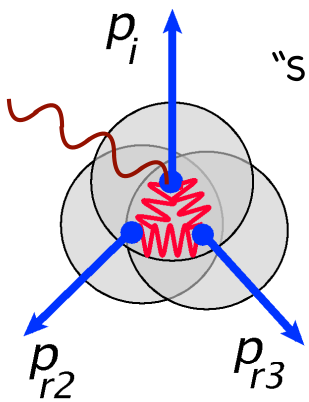
Day, Frankfurt, Sargsian, Strikman. arXiv:1803.07629 [nucl-th]
Sargsian, Day, Frankfurt, Strikman, PRC 100, 044320 (2019)

3NSRC - not so simple



3N-I SRC

struck nucleon balanced by 2 recoils w/momenta ≅ $p_m/2$

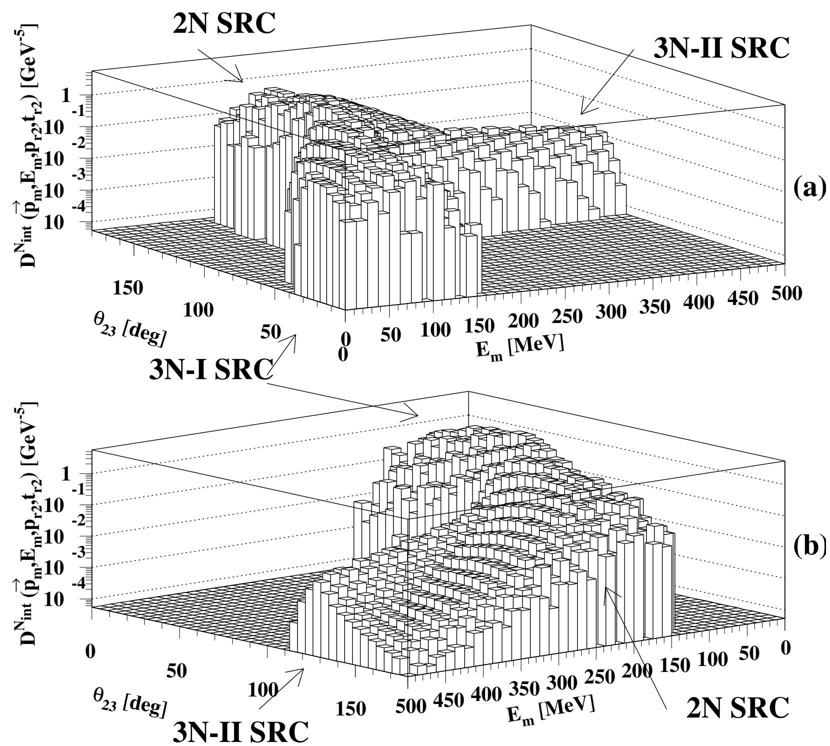


"Star Formation"

3N-II SRC

all 3 nucleons have comparable momenta with θ ≅ 120^0

Decay function: the joint probability to find a nucleon in the nucleus with momentum $\mathbf{p}_m$ (>= 700 MeV/c), missing energy E_m, and the recoil nucleon with momentum $\mathbf{p}_{r2}$ ($\mathbf{p}_{r1}$, $\mathbf{p}_{r2}$ > k_f) in the decay product of the residual A – 1 nucleus.



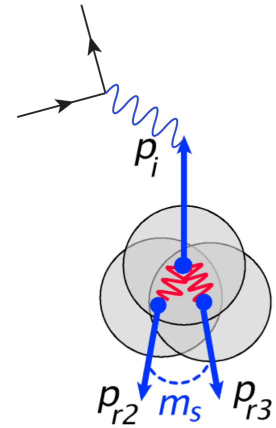
Configurations with the smallest $m_s \simeq 2m_N$ dominate the 3N nuclear spectral (decay) function at lower excitation energies,

The inclusive cross section is the result of the integration of the decay function - it is dominated by small E_m and hence 3N-I SRC reactions prevail.

M. M. Sargsian, T. V. Abrahamyan, M. I. Strikman, L. L. Frankfurt, Phys. Rev. C 71, 044614 (2005) and Phys. Rev. C 71, 044615 (2005)

Day, Frankfurt, Sargsian, Strikman. arXiv:1803.07629 [nucl-th]
Sargsian, Day, Frankfurt, Strikman, PRC 100, 044320 (2019)

3N Correlations



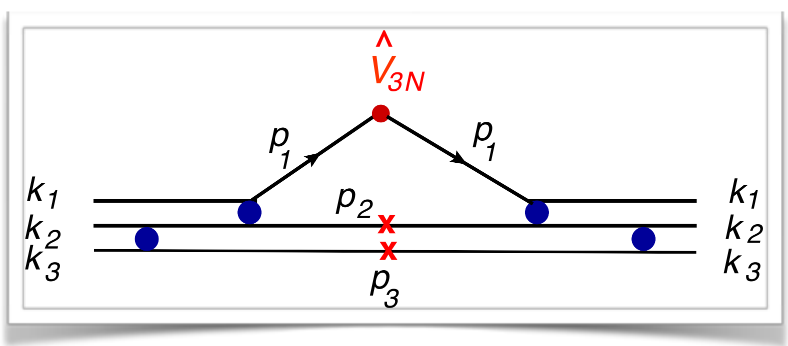
3N-SRCs produced by a sequence of 2 SR interactions with the virtual photon interacting with the nucleon with the largest momentum

The pn dominance of SR interactions leads us to expect 3N-SRCs are due to successive pn short range interactions (blue circles in figure) and m_s small ~ $2m_N$. These 2 SR interactions give rise to the nucleon with the largest momentum, p_1.

For this reason, the threshold for three-nucleon SRCs to appear is that the relative light cone momenta of the pairs should each satisfy the threshold condition for which short range two-nucleon interactions occur, namely they should both be above the Fermi momentum k_F.

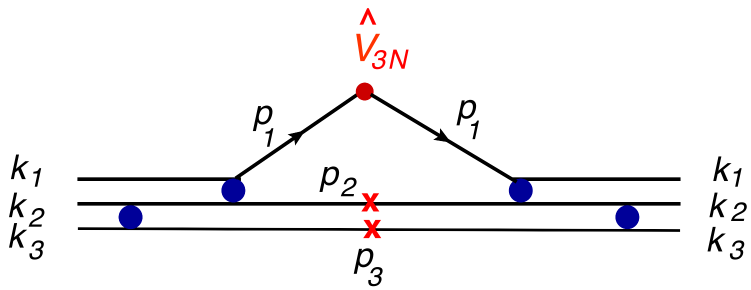
In addition we expect that 3N-SRCs dominated by pnp or npn configurations; ppp and nnn configurations are strongly suppressed

Freese, Sargsian, Strikman, Eur. Phys. J. C (2015) 75:534
Artiles, Sargsian, Phys.Rev. C94 (2016) no.6, 064318



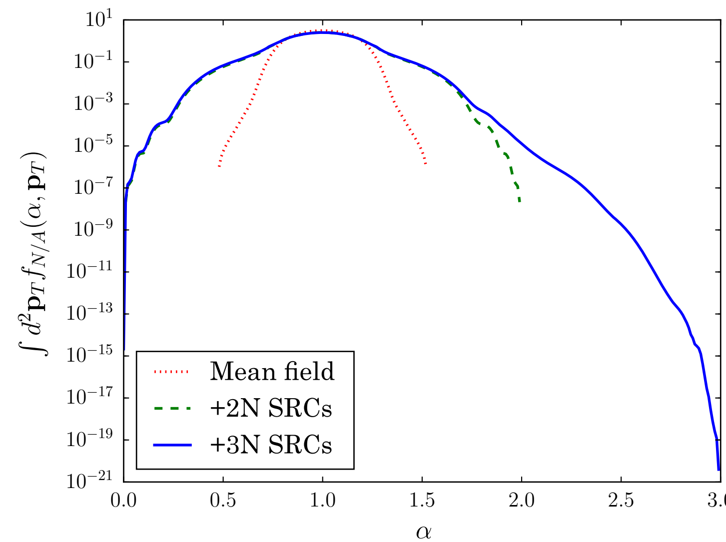
3N Correlations

3N SRCs due to successive pn short range interactions



Freese, Sargsian, Strikman, Eur. Phys. J. C (2015) 75:534

The α distribution of the light-front density matrix.

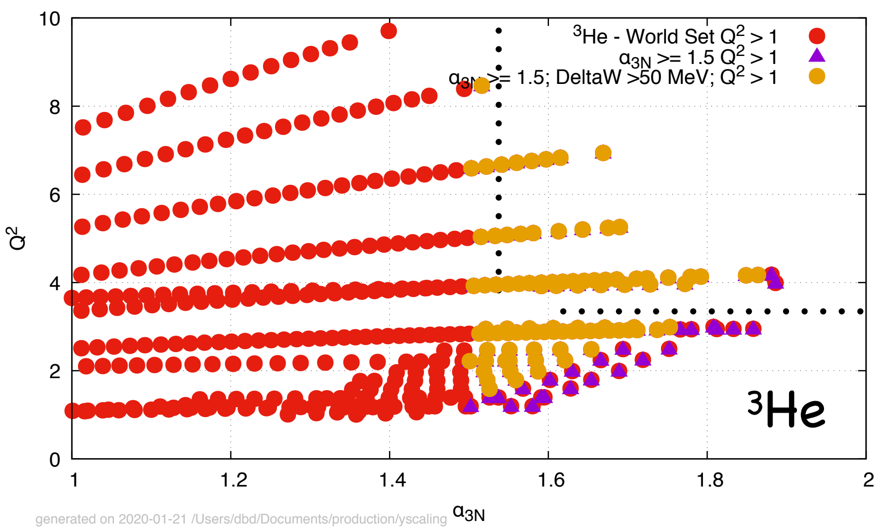


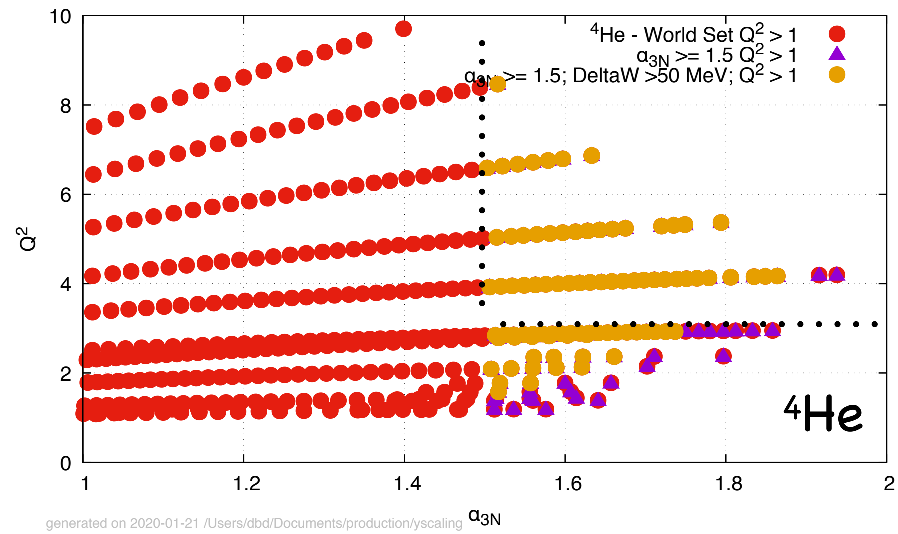
$$\rho_{3N}(\alpha_1) = \int \frac{1}{4}\left[\frac{3-\alpha_3}{(2-\alpha_3)^3}\rho_{pn}(\alpha_3, p_{3\perp})\,\rho_{pn}\left(\frac{2\alpha_2}{3-\alpha_3}p_{2\perp} + \frac{\alpha_1}{3-\alpha_3}p_{3\perp}\right) + \frac{3-\alpha_2}{(2-\alpha_2)^3}\rho_{pn}(\alpha_2, p_{2\perp})\,\rho_{pn}\left(\frac{2\alpha_3}{3-\alpha_2}p_{3\perp} + \frac{\alpha_1}{3-\alpha_2}p_{2\perp}\right)\right]\delta\left(\sum_{i=1}^{3}\alpha_i - 3\right) d\alpha_2 d^2p_{2\perp} d\alpha_3 d^2p_{3\perp}$$

$$a_{3N}(A) \sim [a_{2N}(A)]^2$$

Freese, Sargsian, Strikman, Eur. Phys. J. C (2015) 75:534
Artiles, Sargsian, Phys.Rev. C94 (2016) no.6, 064318

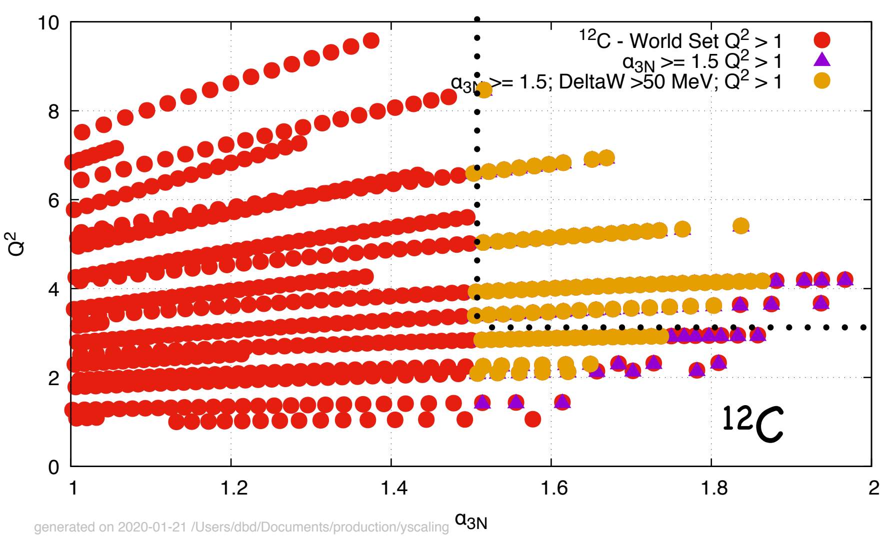
World data set at large Q^2 and α_{3N} is limited

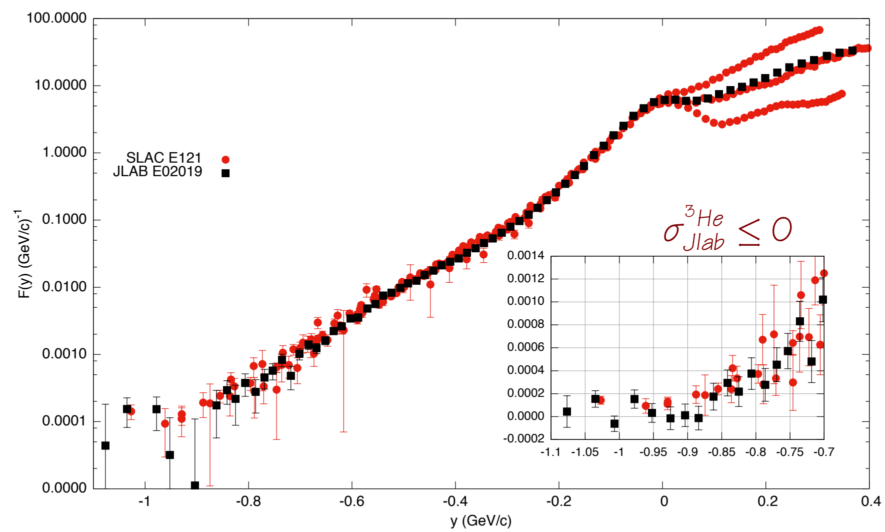




$$\Delta W = M_{^3He} - W_{3N}$$

ΔW > 50 MeV: stay away from elastic peak and FSI

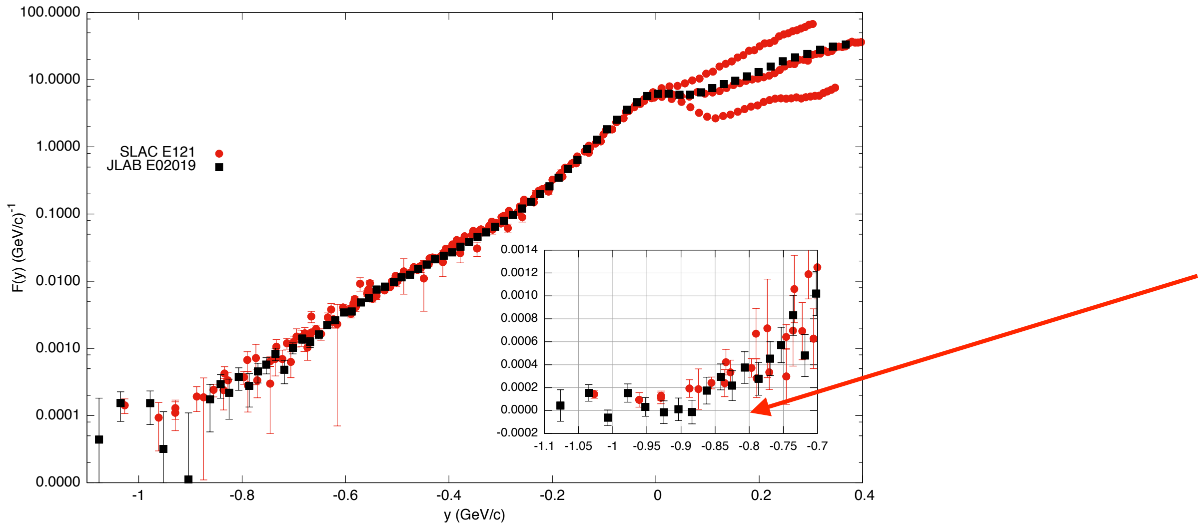




W^2_{3N} approaches $(3M)^2$

What was done

JLAB ^{3}He data at x>> of poor quality - very difficult to separate target walls from ^{3}He events due to target cell design - a diameter of 4 cm. Resulted in points with negative cross sections/negative going error bars. Also seen in ^{4}He at extreme values of x



In originating publication, PRL 108, 092502 (2012), the ratio was treated, not the problematic ^{3}He data. First, the ratio ^{3}He/^{4}He was formed and then rebinned, combining three bins into one for x > 1.15. Subsequently, the bins in that ratio with error bars falling below zero were moved along a truncated Gaussian, such that the lower edge of the error bar was at zero. The ratio was then inverted to give ^{4}He/^{3}He shown in a previous figure. The use of a truncated Gaussian gave rise to the asymmetric error bars.

The main problem with this approach is that it would have to be repeated for each of the other ratios, ^{9}Be/^{3}He, ^{12}C/^{3}He, etc, separately with the result that the both the numerator and the denominator were modified in way that would be unique for each set.

What was done

To avoid this problem it seemed more reasonable to treat the main problem - the ^{3}He data and leave the other cross sections alone

1. Replace JLAB original set (fine bins) in the range $1.6 < \alpha_{3N} < 1.8$ with σ's generated with scaling function F(y) fit to
   a) SLAC data alone
   b) SLAC and JLAB data together
   c) JLAB data alone
   d) JLAB data alone w/o negative points
2. Absolute error bar preserved as in JLAB data
3. The 3N-SRC parameter $R_3^{exp}(A)$ was obtained by a weighted average of points for $1.6 < \alpha_{3N} < 1.8$
   a) All 4 weighted average from the different fits were constant within error bars.
4. The lower limit on the weighted average was varied from just less than $\alpha_{3N} = 1.6$ to a maximum of 1.7 and the central value was found to be consistent within the growing error bars

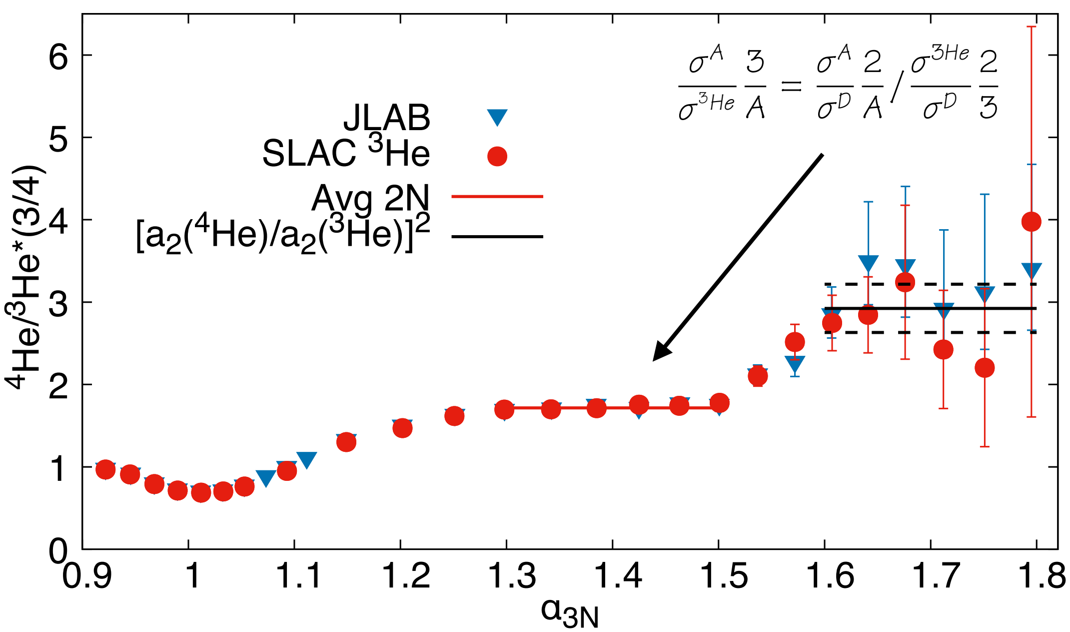
3N-SRC prediction

$$R_2 = \frac{3\sigma_{eA}(A)}{A\sigma_{eA}(^3He)} \qquad 1.3 \leq \alpha_{3N} \leq 1.5 \qquad R_3(A,Z) \approx R_2(A,Z)^2$$

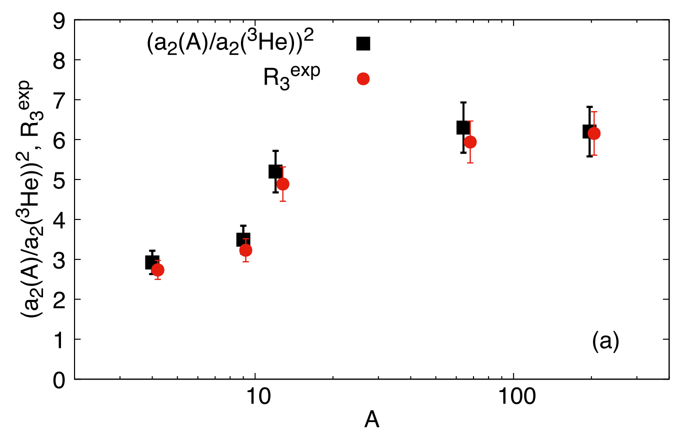
$$R_3 = \frac{3\sigma_{eA}(A)}{A\sigma_{eA}(^3He))} \qquad 1.6 \leq \alpha_{3N} \leq 1.8 \qquad R_3(A,Z) \approx \left(\frac{a_2(A,Z)}{a_2(^3He)}\right)^2$$

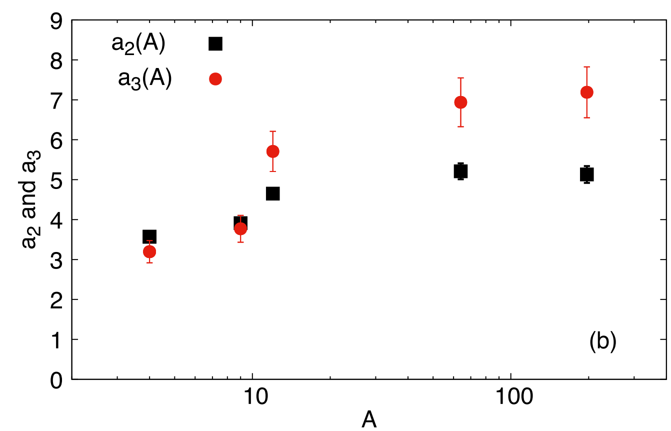
a_3 is the probability of finding 3N SRCs in the nuclear ground state.

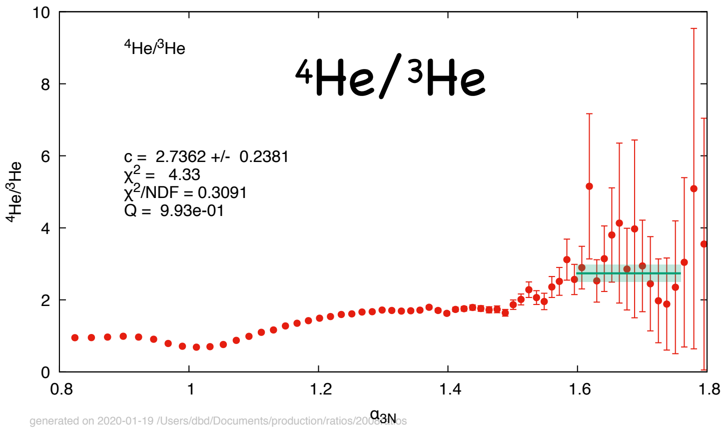
$$a_3(A,Z) = R_3(A,Z)\frac{(2\sigma_{ep}+\sigma_{en})/3}{(\sigma_{ep}+\sigma_{en})/2}$$

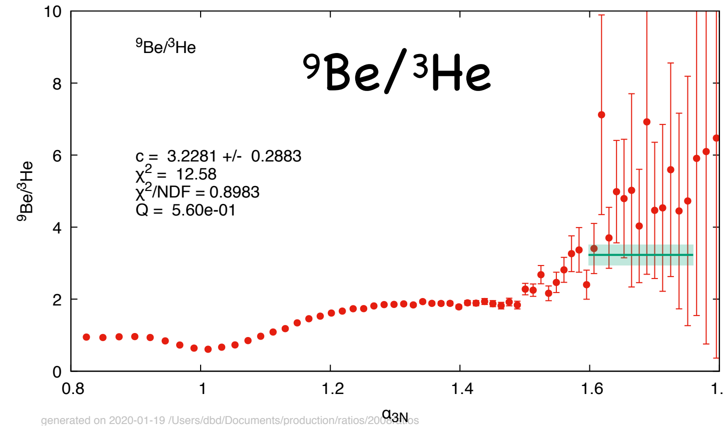


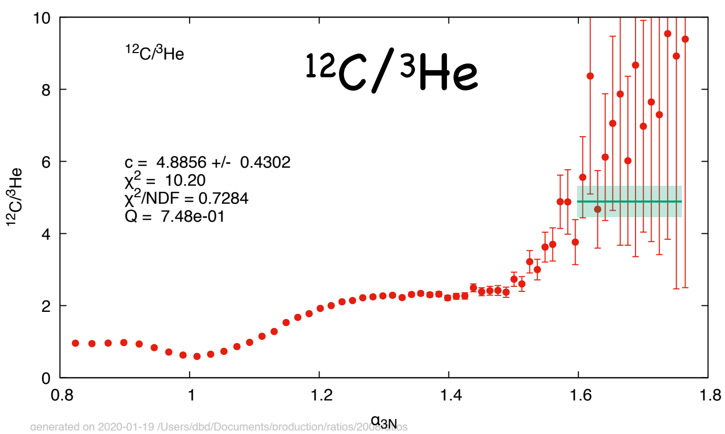
$a_2(A)$ from Fomin et. al. : PRL 108, 092502 (2012)

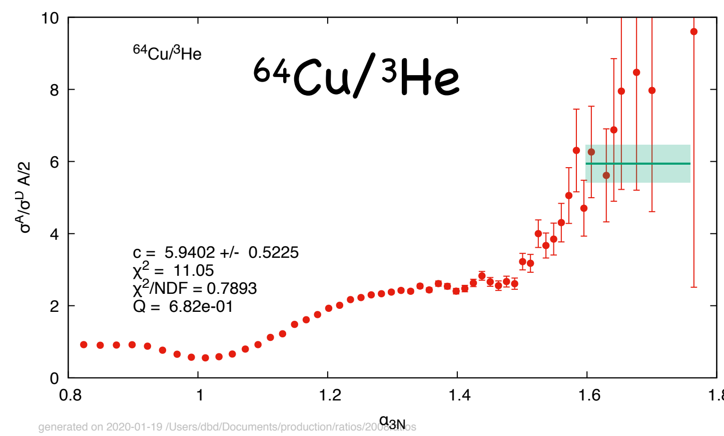


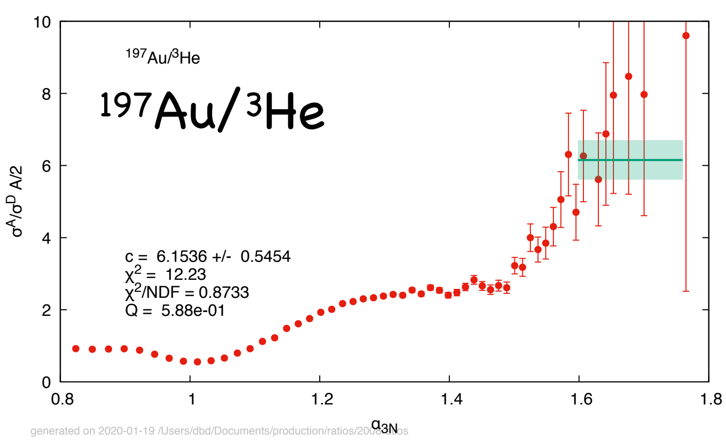


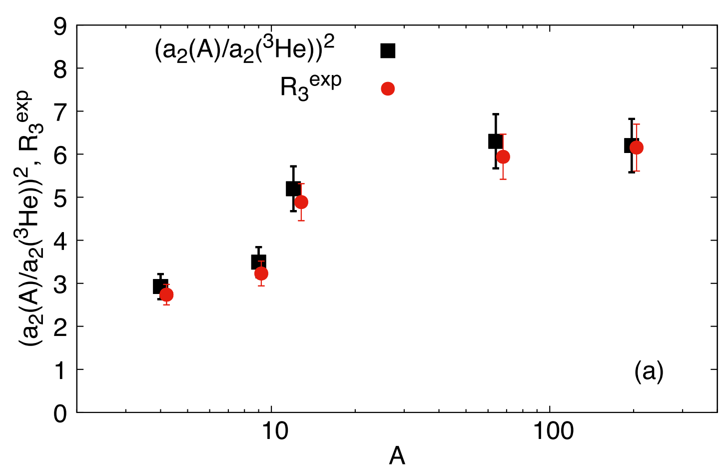

4He/3He
$^4He/^3He$
c = 2.7362 +/- 0.2381
χ^2 = 4.33
χ^2/NDF = 0.3091
Q = 9.93e-01
α_{3N}


9Be/3He
$^9Be/^3He$
c = 3.2281 +/- 0.2883
χ^2 = 12.58
χ^2/NDF = 0.8983
Q = 5.60e-01
α_{3N}


12C/3He
$^{12}C/^3He$
c = 4.8856 +/- 0.4302
χ^2 = 10.20
χ^2/NDF = 0.7284
Q = 7.48e-01
α_{3N}


64Cu/3He
$^{64}Cu/^3He$
c = 5.9402 +/- 0.5225
χ^2 = 11.05
χ^2/NDF = 0.7893
Q = 6.82e-01
σ^A/σ^D A/2
α_{3N}


197Au/3He
$^{197}Au/^3He$
c = 6.1536 +/- 0.5454
χ^2 = 12.23
χ^2/NDF = 0.8733
Q = 5.88e-01
σ^A/σ^D A/2
α_{3N}


$(a_2(A)/a_2(^3He))^2$
R_3^{exp}
$(a_2(A)/a_2(^3He))^2$, R_3^{exp}
(a)
A

Rise in 3N-SRC ratios to ^{3}He?

Naive SRC model, where 2N- and 3N-SRCs are at rest, the rise in the ratio as $x \to 3$ as coming from the difference between stationary 3N-SRC in ^{3}He and moving SRCs in heavier nuclei.

Violation of naive scaling picture, which predicts a plateau

This violation is also seen in ratios to ^{2}H 2N-SRC region - as I have shown

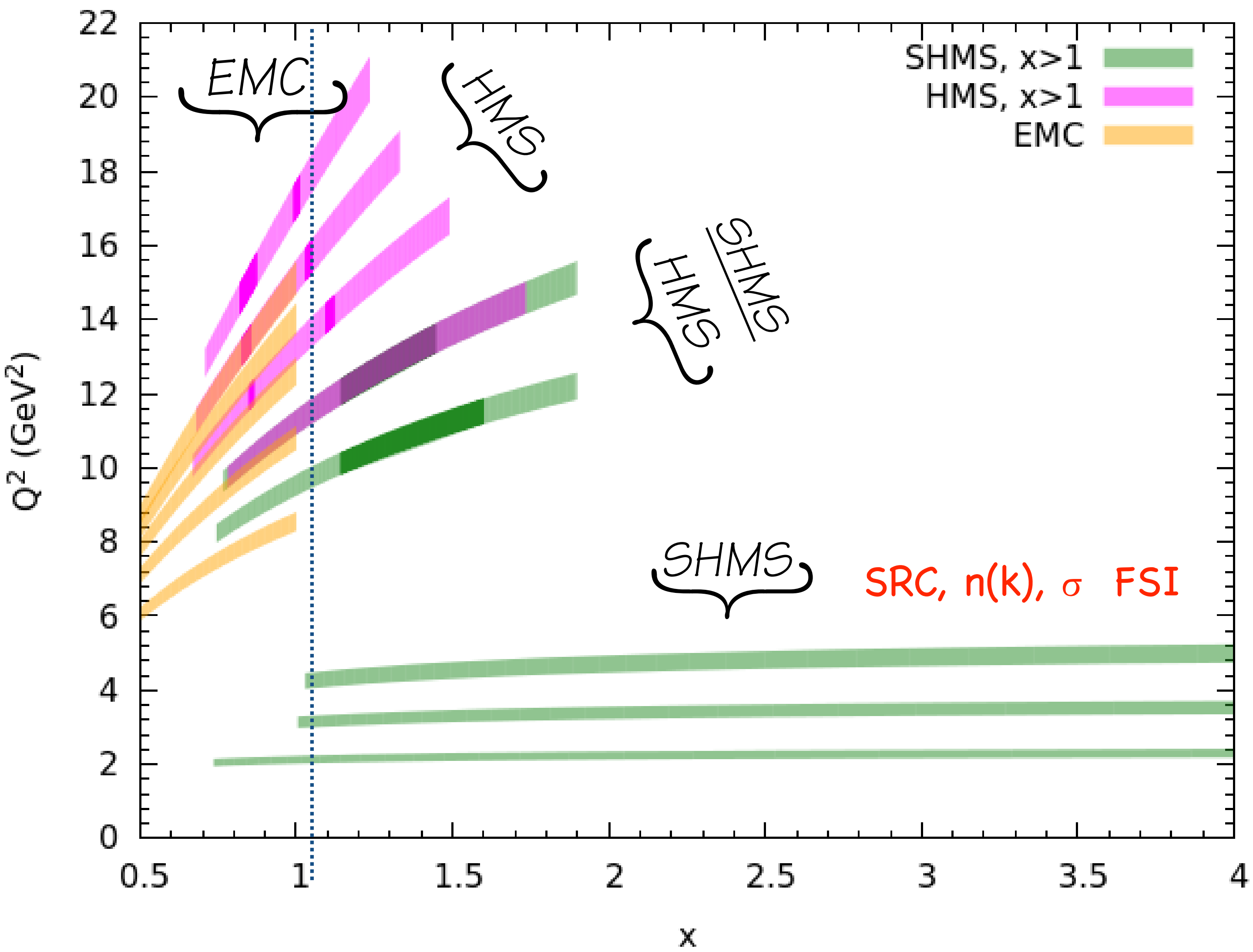
It is different as the motion of the 2N-SRC yields mainly a small enhancement of the plateau, with modest distortion until $x > 1.9$, where the deuteron cross section falls sharply with its exponential falloff with x

For 3N-SRCs, motion of the correlations would yield a sharp rise further from the kinematic limit at $x = 3$ due to the earlier onset of the rapid cross section falloff

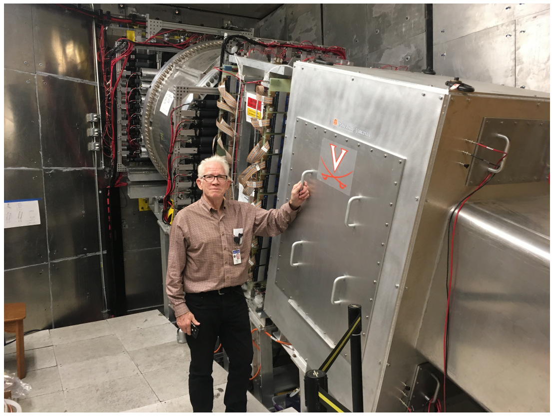
Ratios to ^{4}He in 3N-SRC region likely a better choice

E12-06-105: Inclusive Scattering from Nuclei at x > 1 in the quasielastic and deeply inelastic regimes [Hall C], Arrington, Day and Fomin

super-fast quarks, SRCs, quark distribution functions, medium modifications



E12-06-105
2021?



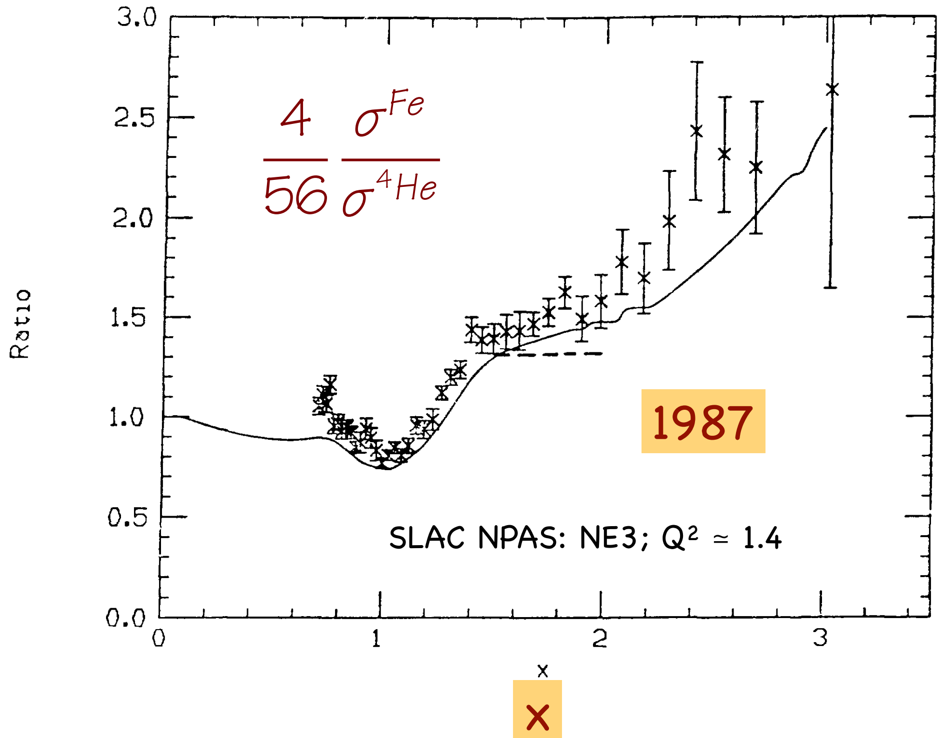
Summary

- 2N SRC and their isospin dependence (anticipated by our understanding of the NN interaction) is now firmly established in multiple observables, experiments projectiles, final states and nuclei
- Relation of SRC to EMC established - only lacking are calculations that fully exposes the underlying connection
- Refined theory and calculation are needed incorporating SRC, FSI, and off-shell behavior will advance understanding
- SRC demand high densities (momenta, virtuality) and, if these rare fluctuations can be captured, they should expose, potentially large, medium modifications
- Cross section ratios at large x (2.5 - 3) are indicative 3N SRCs
  - Higher Q^2 needed, rates <<
- Next big opportunity in inclusive scattering (in my view) is the transition from QES to DIS at $x > 1$ at very large momenta transfer: SRCs will contribute here with the same impact.

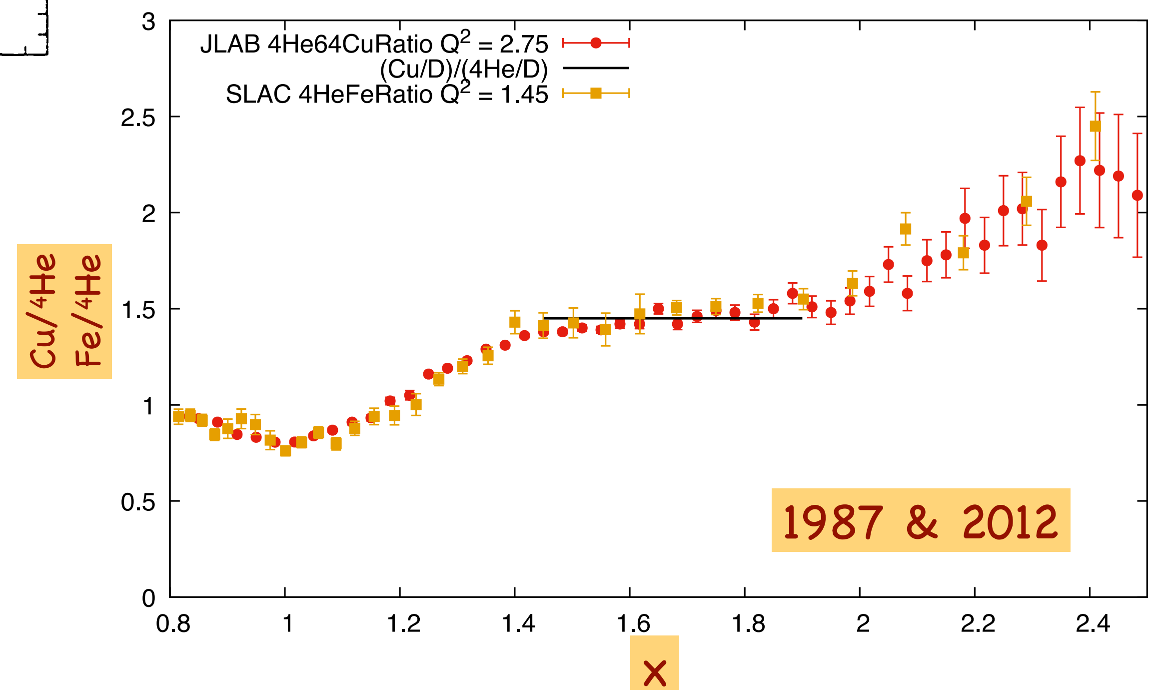
Extra

Plateau in ratios - 1987 - first observation

DD, Nuclear Physics A, V478, 29 February–7 March 1988, Pages 397-406 (1988)
1987 PANIC Proceedings



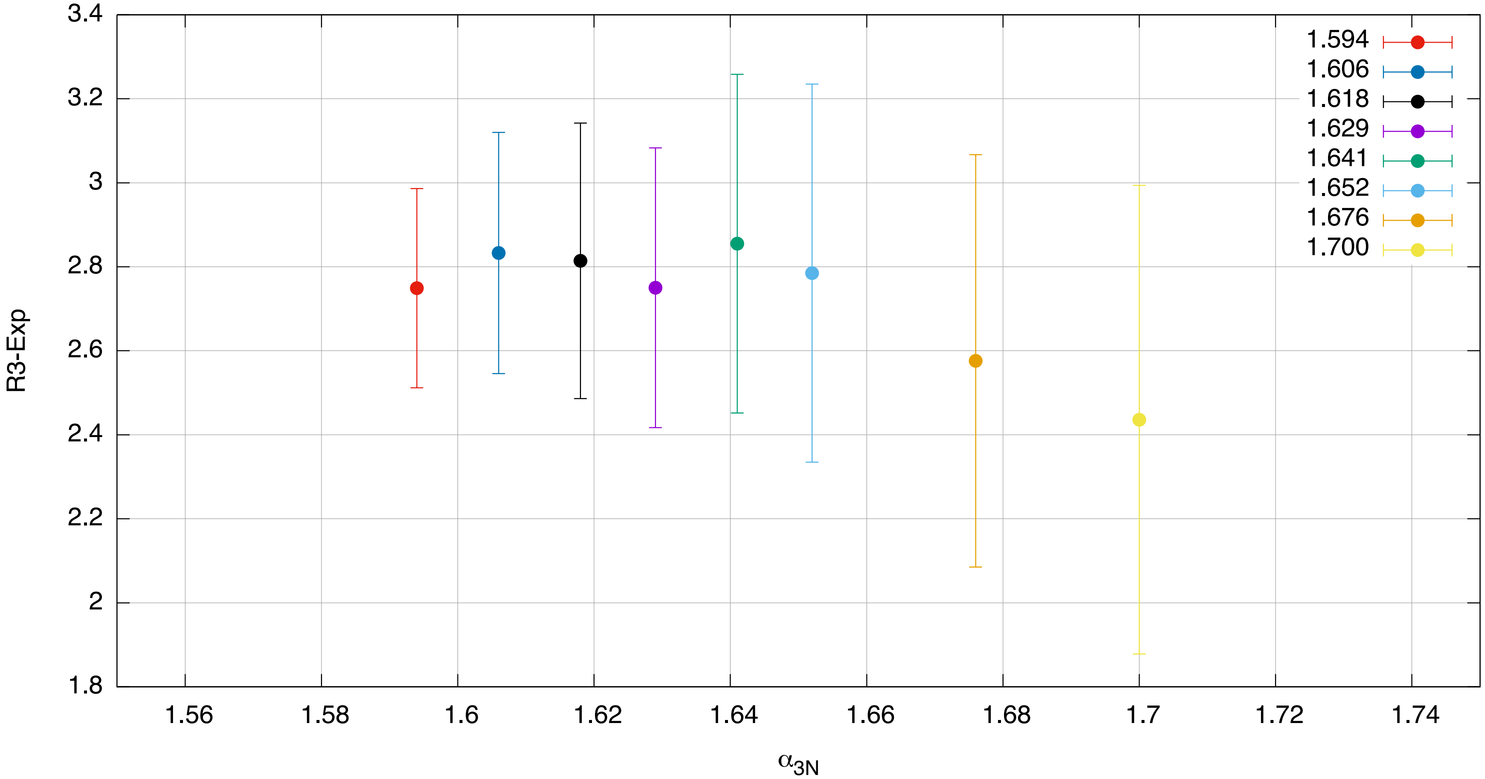
Discussed as by Vary and Pirner by a quark-cluster effect!



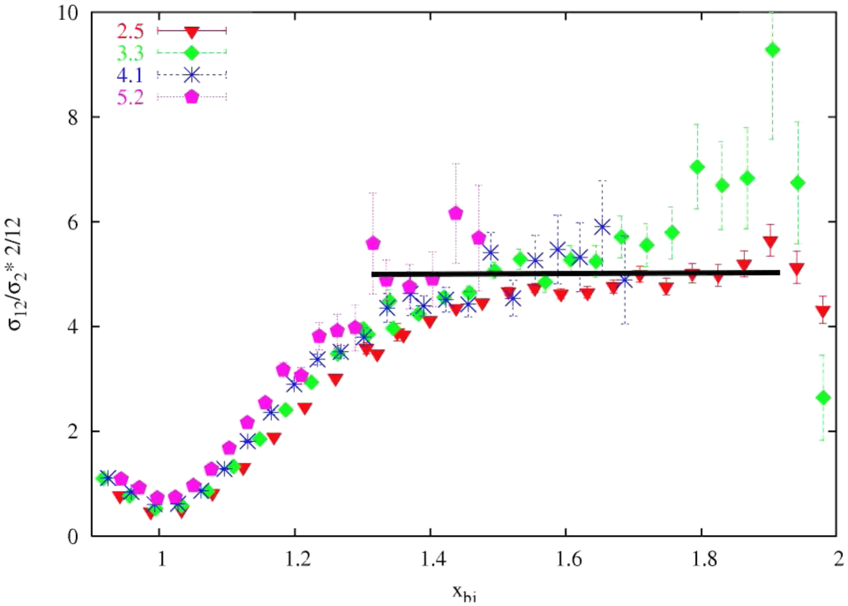
Line is $a_2(Cu/^2H)/a_2(^4He/^2H)$

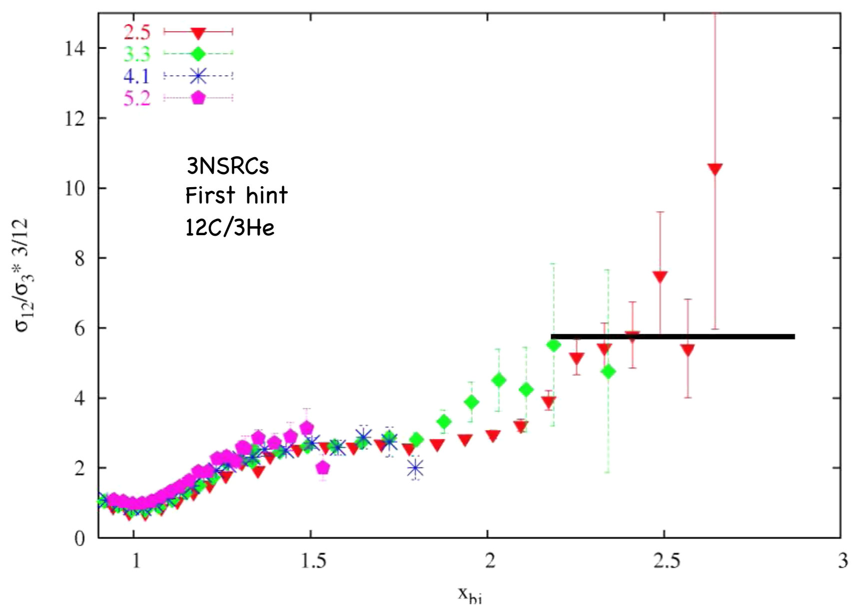
N. Fomin, et al., PRL 108 (2012) 092052

R3-exp Sensitivity on Lower Limit of Weighted Mean Average
4He/3He



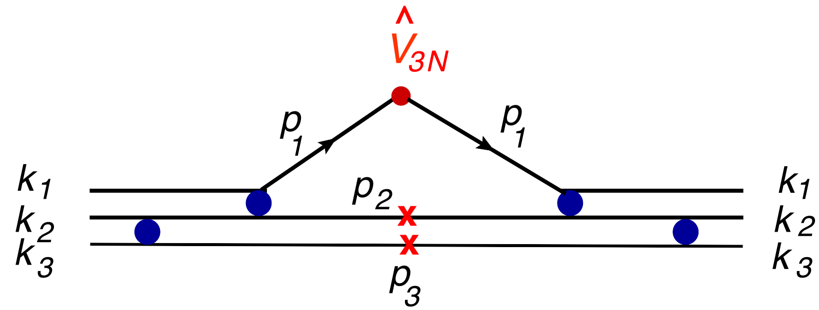
N. Fomin: AIP Conference Proceedings 947, 174 (2007); doi: 10.1063/1.2813799





A	a_2	R_2	R_2^{exp}	R_2^2	R_3^{exp}	a_3
3	2.14 ±0.04	NA	NA	NA	NA	1
4	3.66 ±0.07	1.71 ±0.026	1.722 ±0.013	2.924 ±0.29	3.034 ±0.23	4.55 ± 0.35
9	4.00 ±0.08	1.84 ±0.027	1.878 ±0.018	3.38 ±0.38	4.01 ±0.52	6.0 ± 0.78
12	4.88 ±0.10	2.28 ±0.027	2.301 ±0.021	5.2 ±0.5	5.78 ±0.71	8.7 ± 1.1
27	5.30 ±0.60	NA	NA	NA	NA	NA
56	4.75 ±0.29	NA	NA	NA	NA	NA
64	5.37 ±0.11	2.51 ±0.027	2.502 ±0.024	6.3 ±0.63	6.780 ±0.875	10.2 ± 1.3
197	5.34 ±0.11	2.46 ±0.028	2.532 ±0.026	6.05 ±0.6	7.059 ±0.970	10.6 ± 1.5

3N-SRC Dynamics



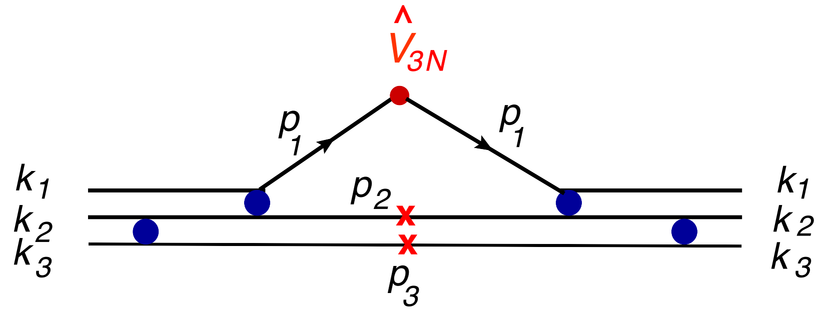
pn dominance leads, inexorably, to expect that 3N-SRCs are produced by successive pn short-range interactions, the mass of the 3N spectator be small, $m_s \sim 2m_N$.

$$R_2 = \frac{3\sigma_{eA}(a_{3N})}{A\sigma_{eA}(a_{3N})} \quad \text{in the region} \quad 1.3 \le a_{3N} \le 1.5$$

$$R_3 = \frac{3\sigma_{eA}(a_{3N})}{A\sigma_{eA}(a_{3N})} \quad \text{in the region} \quad 1.6 \le a_{3N} \le 1.8$$

$$R_3(A,Z) \approx R_2(A,Z)^2$$

3N-SRC Dynamics



pn dominance leads, inexorably, to expect that 3N-SRCs are produced by successive pn short-range interactions, the mass of the 3N spectator be small, $m_s \sim 2m_N$.

$$\rho_{pn}(a, p_\perp) \approx a_2(A)\rho_D(a, p_\perp) \qquad \rho_{3N} \sim a_2(A)a_2(A)^2$$

$$\sigma_{eA} = \sum_N \sigma_{eN}\rho_{3N}(a_{3N}) \qquad R_3(A,Z) \equiv \frac{3\sigma_A(x,Q^2)}{A\sigma_{^3He}(x,Q^2)}\Big|_{a_{3N}>a_{3N}^0}$$

$$R_3(A,Z) = \frac{9}{8}\frac{(\sigma_{ep}+\sigma_{eN})/2}{(2\sigma_{ep}+\sigma_{eN})/3}\left(\frac{a_2(A,Z)}{a_2(^3He)}\right)^2$$

$$R_3(A,Z) = \frac{9}{8}\frac{(\sigma_{ep}+\sigma_{eN})/2}{(2\sigma_{ep}+\sigma_{eN})/3}R_2^2(A,Z) \qquad R_3(A,Z) \approx \left(\frac{a_2(A,Z)}{a_2(^3He)}\right)^2$$

$$R_2(A,Z) = \frac{3}{A}\frac{\sigma_{eA}}{\sigma_{e^3He}}\Big|_{1.3<a_{3N}<1.5} = \frac{a_2(A)}{a_2(^3He)}$$