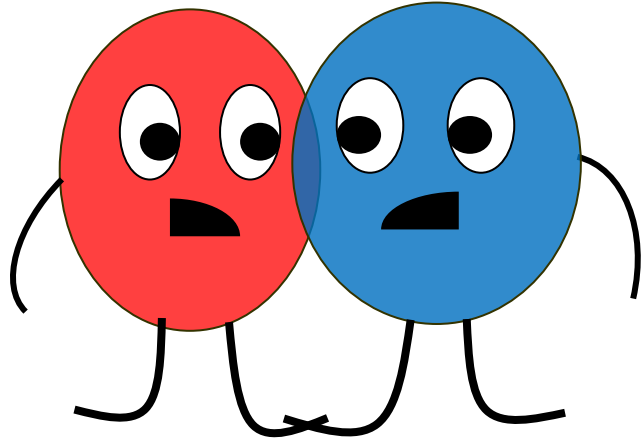


Large Tracts of Data:



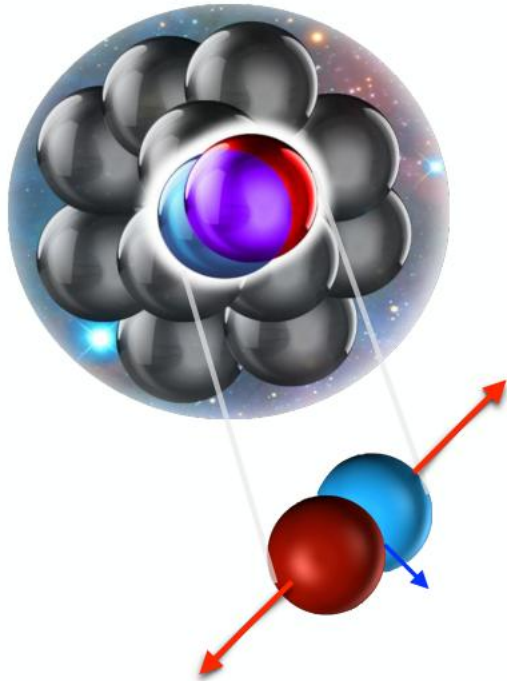
Need Theory Help for
Interpretation of Inclusive results

Nadia Fomin
(work mostly by Ramon Ogaz)

June 8, 2026

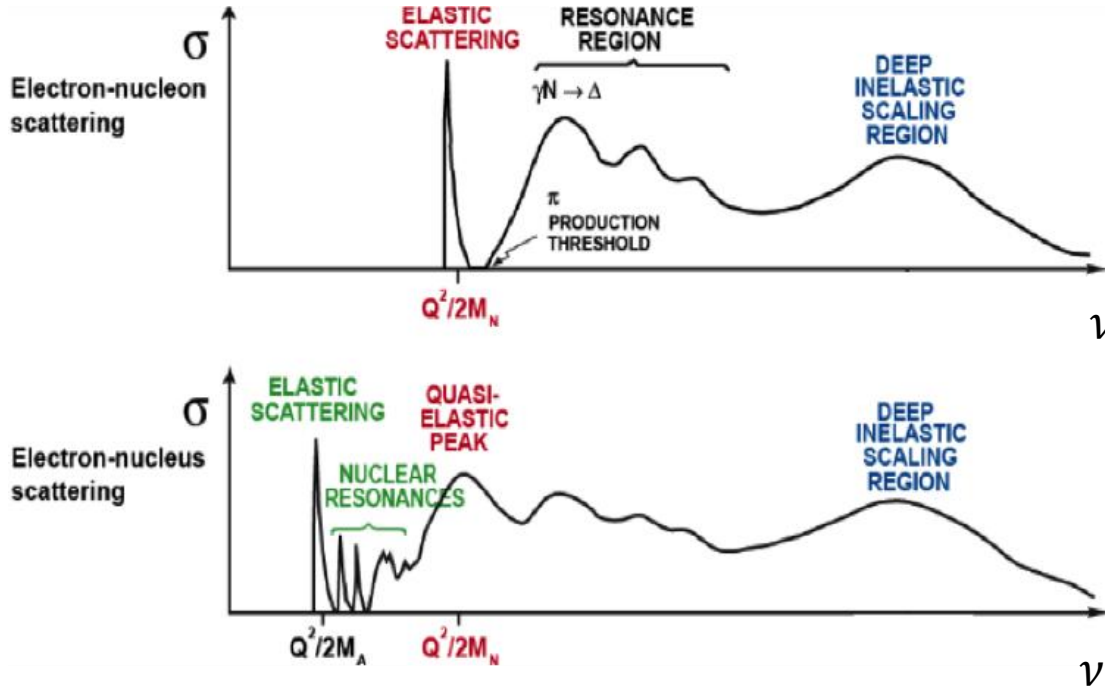


2N SRCs – we've learned so much!

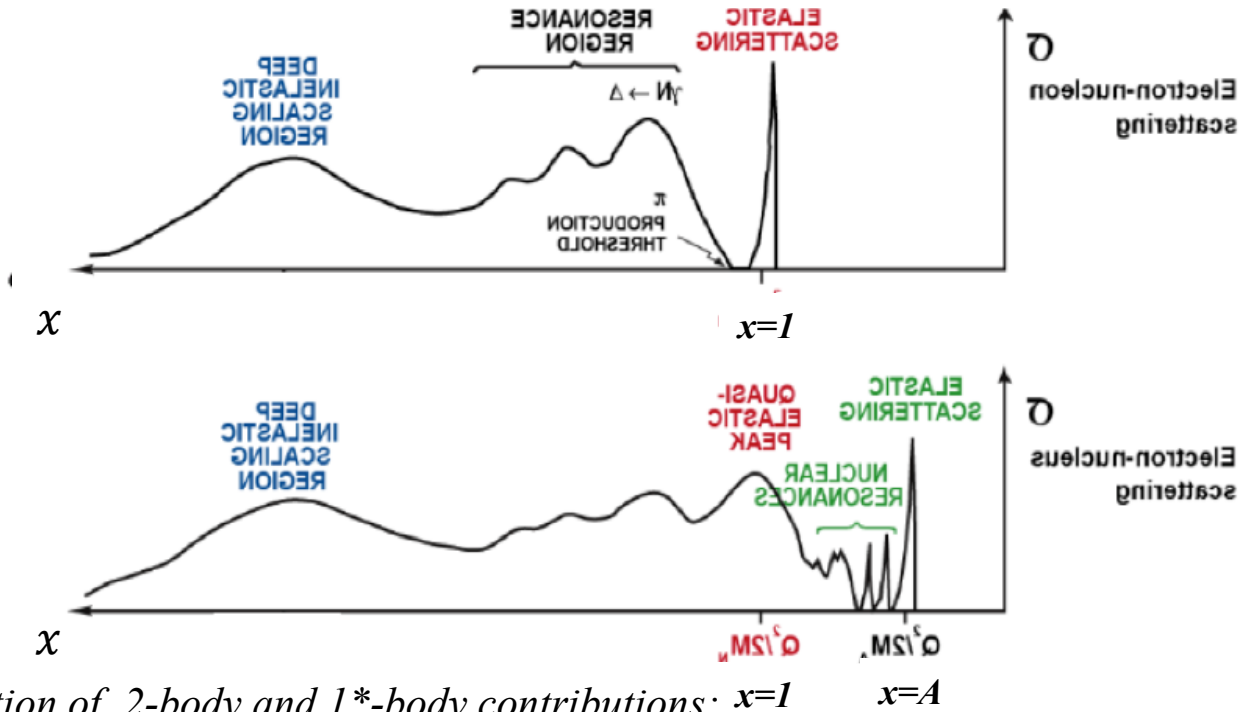


- Inclusive $A(e, e')$
 - Shows SRC dominance at $k > k_{fermi}$
 - Observed scaling of A/D cross sections at $x > 1.5$, $Q^2 > 1.5 \text{ GeV}^2/c^2$
 - a_2 across many nuclei
 - Direct comparison to theory for light nuclei
- Single Nucleon Knockout $A(e, e'p/n)$
 - Proportional to abundance of high-momentum of protons and neutron
 - Which nucleons pair (pairing mechanisms)
 - Narrow transition region (mean field \rightarrow SRC)
 - Direct comparison to theory for light nuclei
- Two-nucleon knock out $A(e, e'NN)$
 - pn pair dominance
 - All* high momentum nucleons belong in SRC pairs
 - pp/pn ratio increases with missing momentum
 - Tensor \rightarrow scalar transitions

Choosing an Appropriate Microscope



Choosing an Appropriate Microscope



$1 < x < 2$ is combination of 2-body and 1*-body contributions; $x=1$ $x=A$
 3+ body effect assumed to be small (*=Fermi-smeared)

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

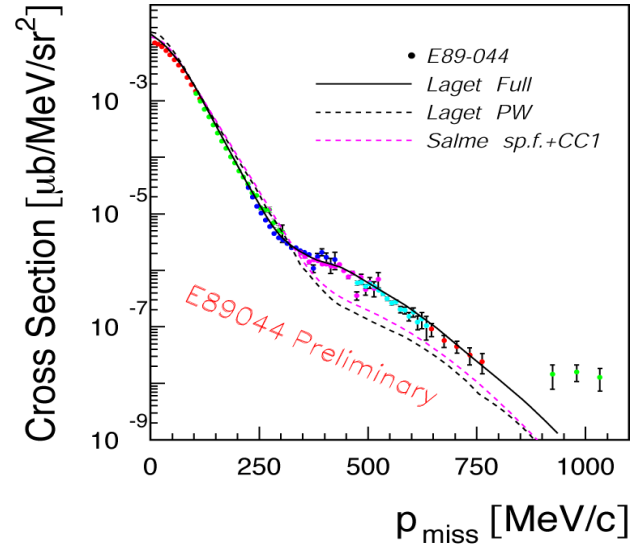
- E89-004: Measure of ${}^3\text{He}(e,e'p)d$
- Measured far into high momentum tail:
Cross section is $\sim 5\text{-}10\times$ expectation

Difficulty

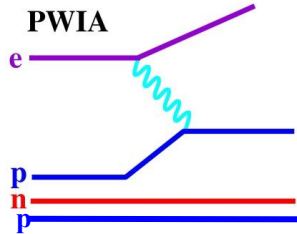
- High momentum pair can come from SRC (initial state)

OR

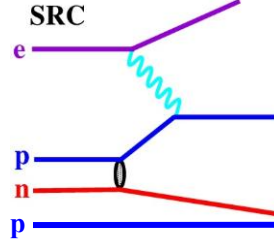
- Final State Interactions (FSI) and Meson Exchange Contributions (MEC)



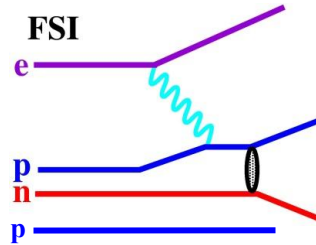
“slow”
nucleons



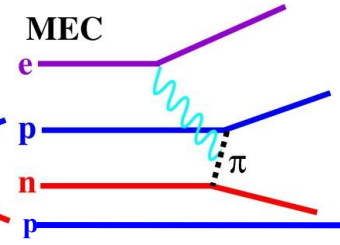
“fast” nucleons



FSI



MEC



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 $A > 2$

High momentum nucleons - Short Range Correlations

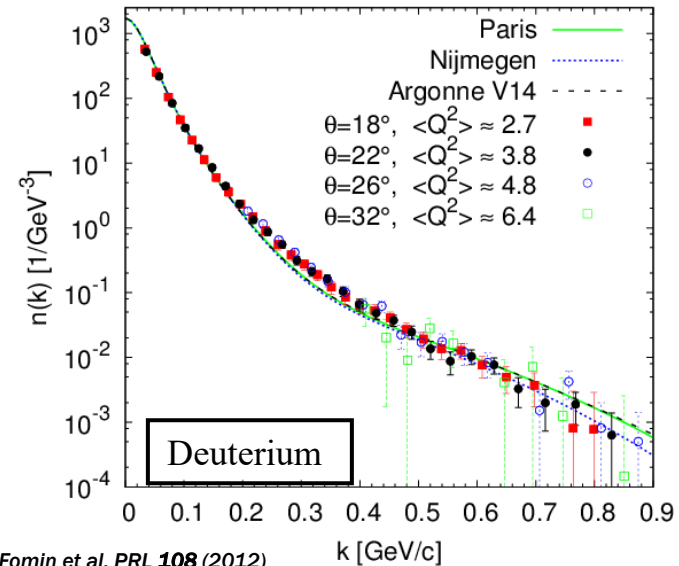
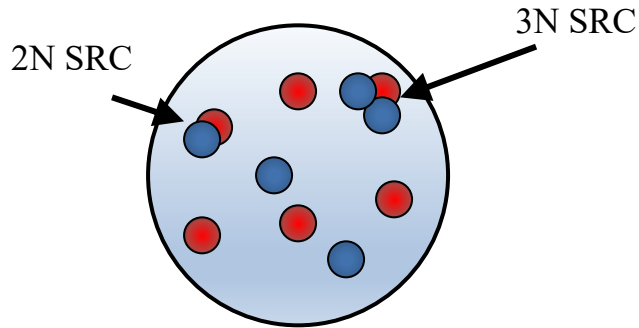
$$\frac{d\sigma^{QE}}{d\Omega dE'} \propto \int d\vec{k} \int dE \sigma_{ei} S_i(k, E) \delta(Arg)$$

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



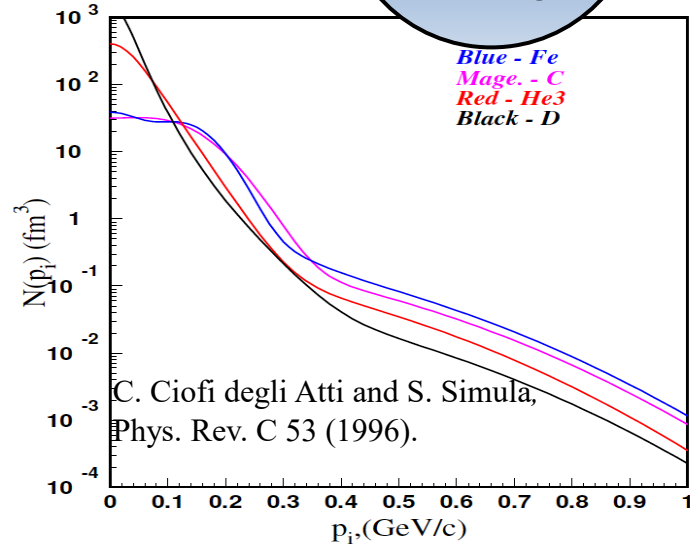
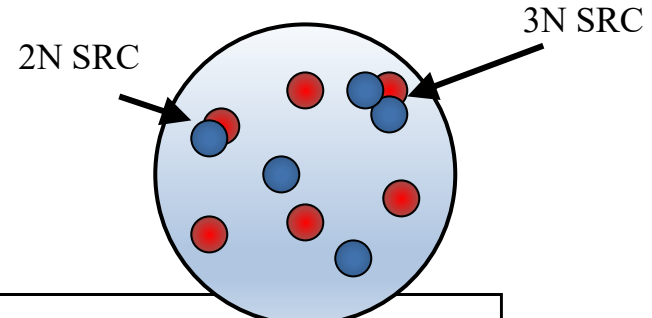
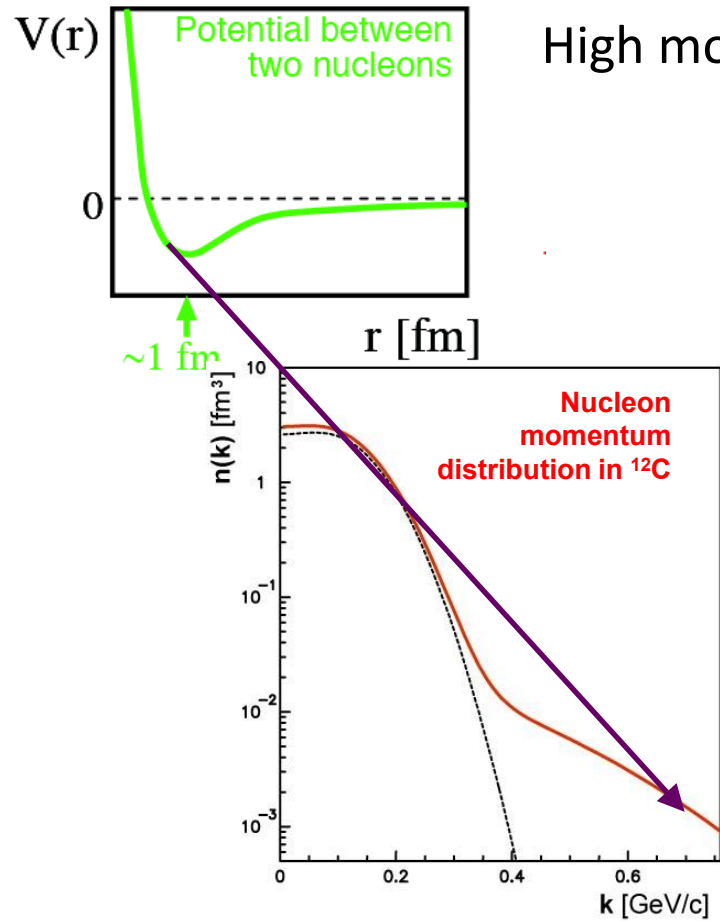
$$F(y, \mathbf{q}) = \frac{d^2\sigma}{d\Omega d\nu} \frac{1}{(Z\sigma_p + N\sigma_n)} \frac{\mathbf{q}}{\sqrt{M^2 + (y+q)^2}}$$

$$= 2\pi \int_0^\infty n(k) k dk$$

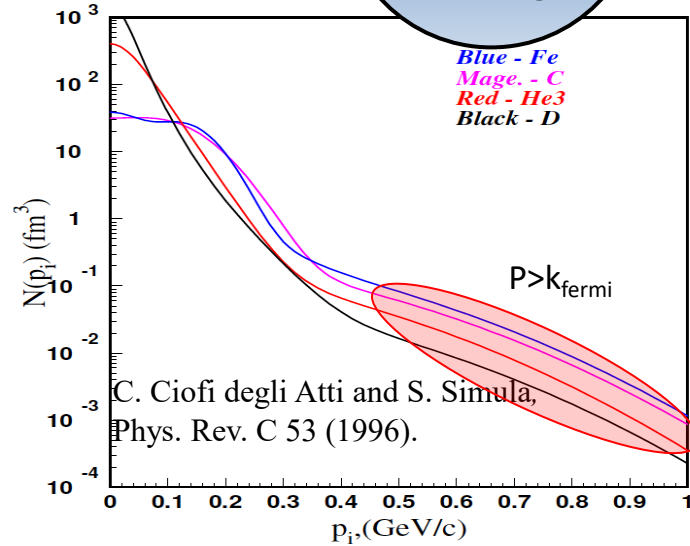
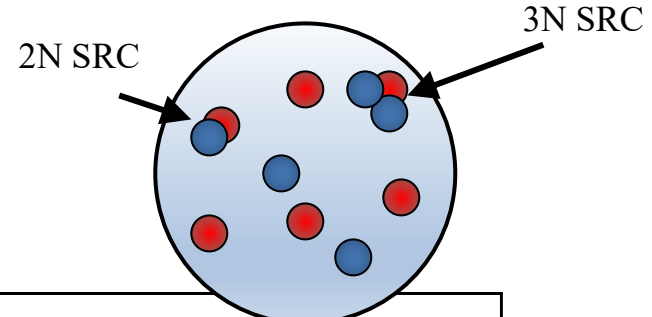
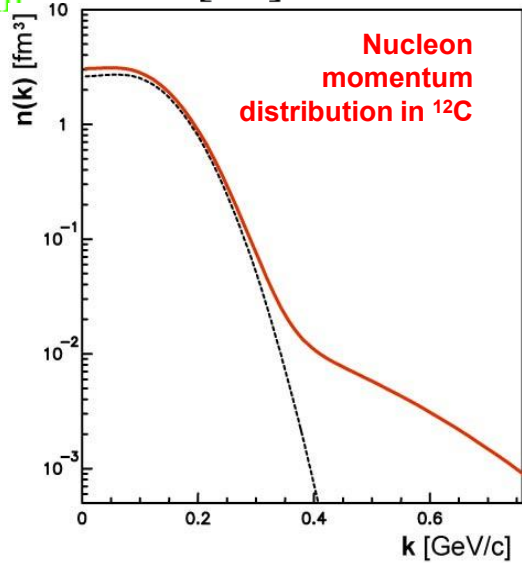
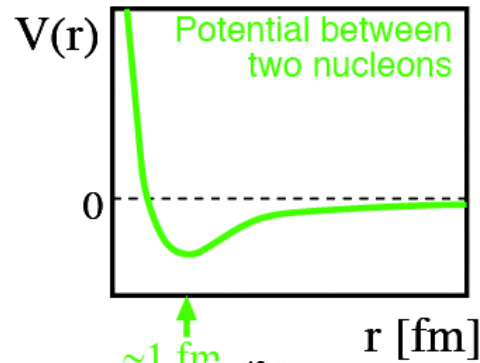


Fomin et al, PRL **108** (2012)

High momentum nucleons - Short Range Correlations



High momentum nucleons - Short Range Correlations

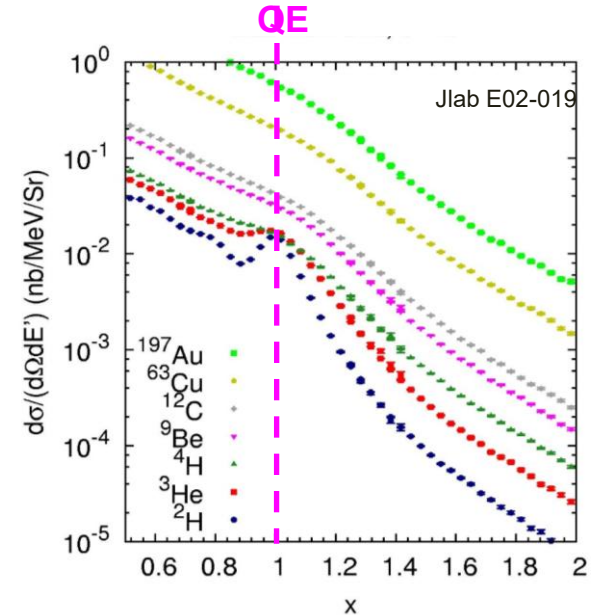


Short Range Correlations

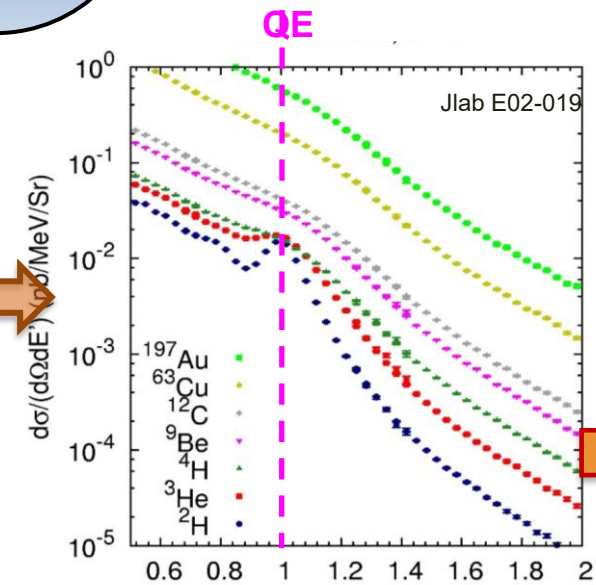
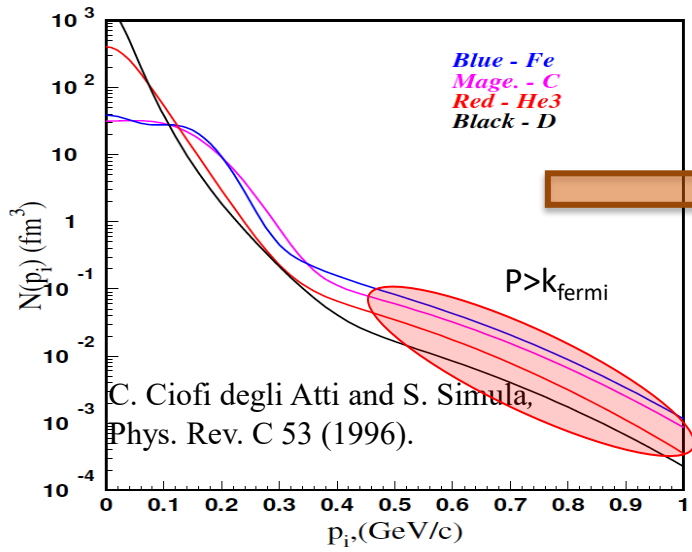
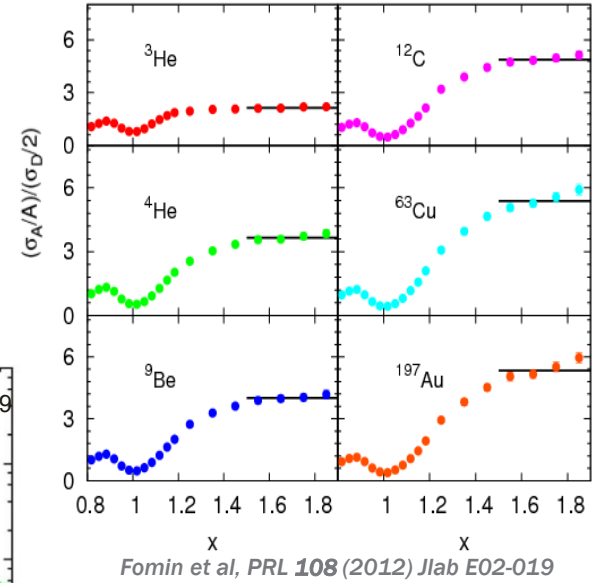
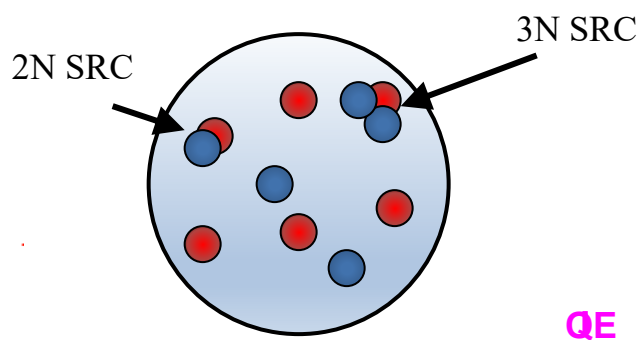
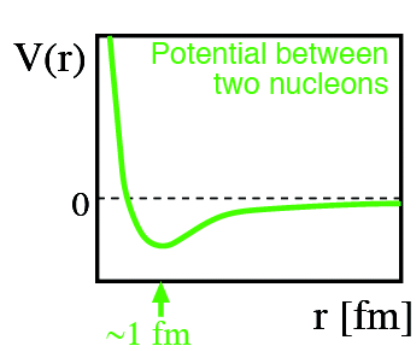
- To experimentally probe SRCs, must be in the high-momentum region ($x > 1$)
- To measure the relative probability of finding a correlation, ratios of heavy to light nuclei are taken
- In the high momentum region, FSIs are thought to be confined to the SRCs and therefore, cancel in the cross section ratios

$$\begin{aligned}\sigma(x, Q^2) &= \sum_{j=1}^A A \frac{1}{j} a_j(A) \sigma_j(x, Q^2) \\ &= \frac{A}{2} a_2(A) \sigma_2(x, Q^2) + \\ &\quad \frac{A}{3} a_3(A) \sigma_3(x, Q^2) + \dots\end{aligned}$$

$$\frac{2}{A} \frac{\sigma_A}{\sigma_D} = a_2(A)$$

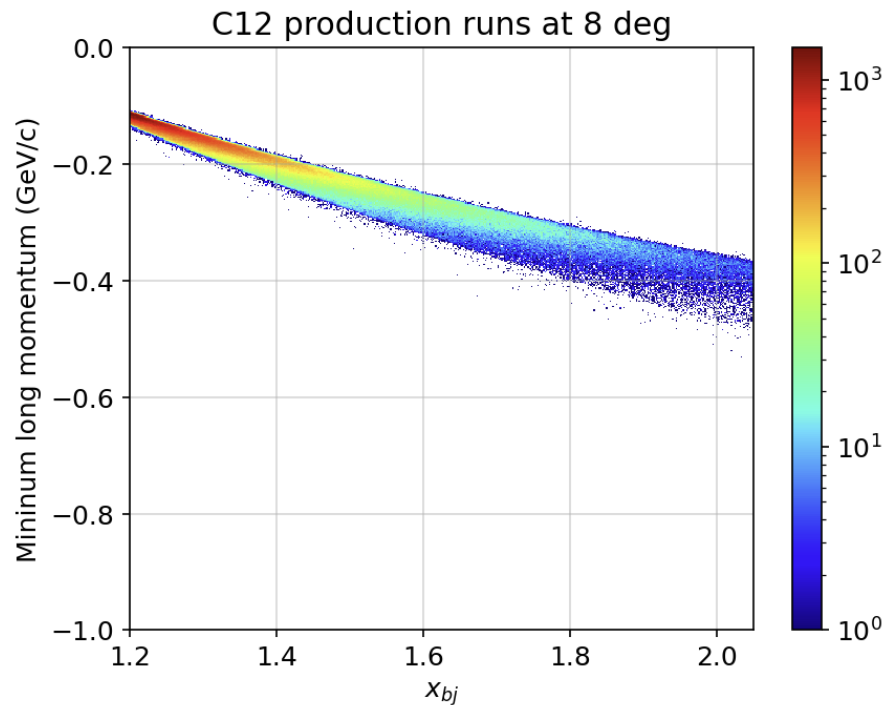
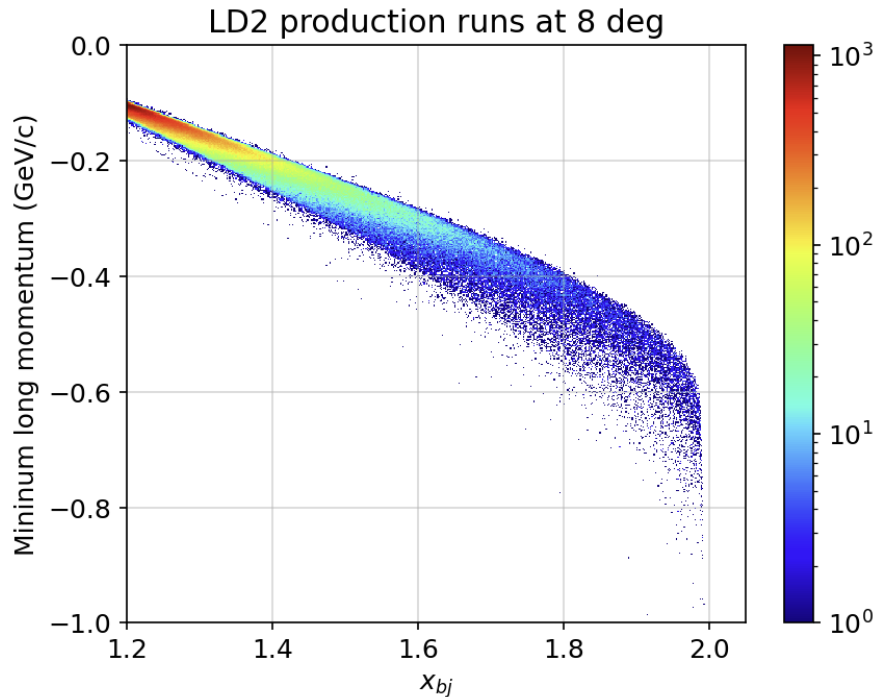


1.4 < x < 2 => 2 nucleon correlation



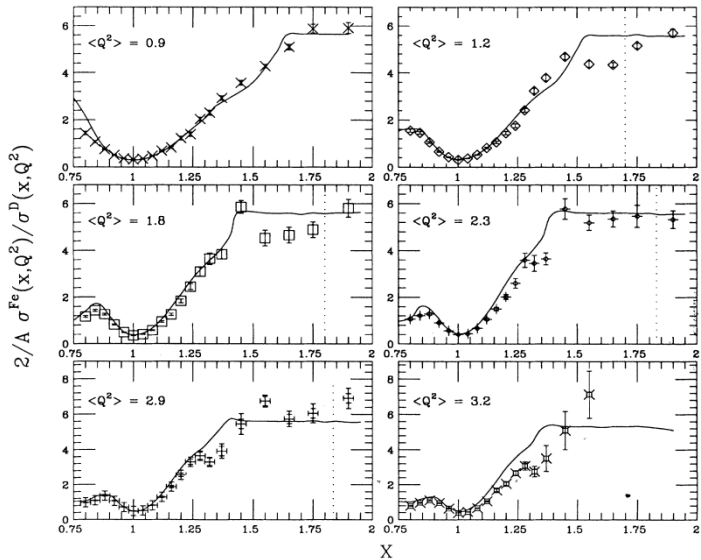
$1.4 < x < 2 \Rightarrow$ 2 nucleon correlation

Not quite same momentum tails – does it matter?

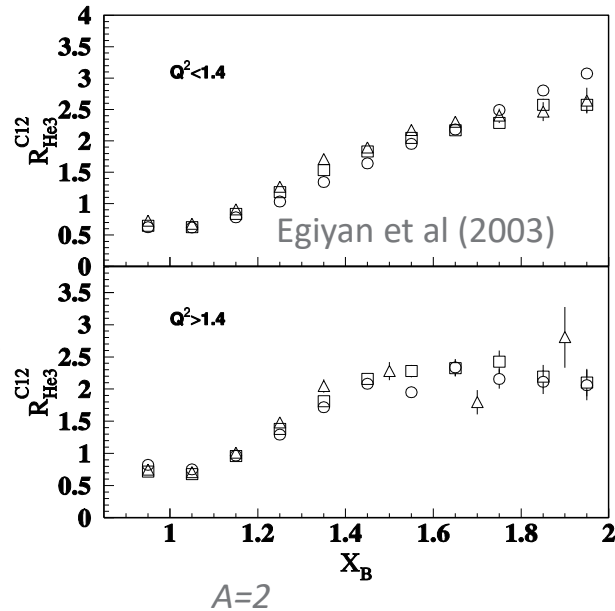


Plot by J. O’Kronley

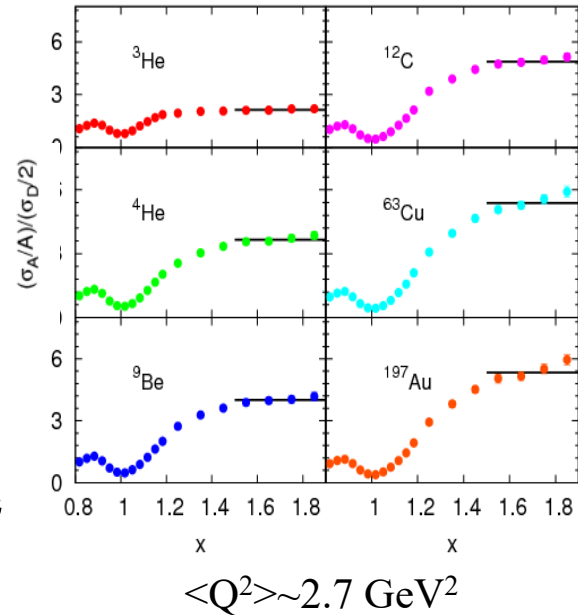
Q^2 threshold for 2N SRC Observation



Day et al 1993, PRC

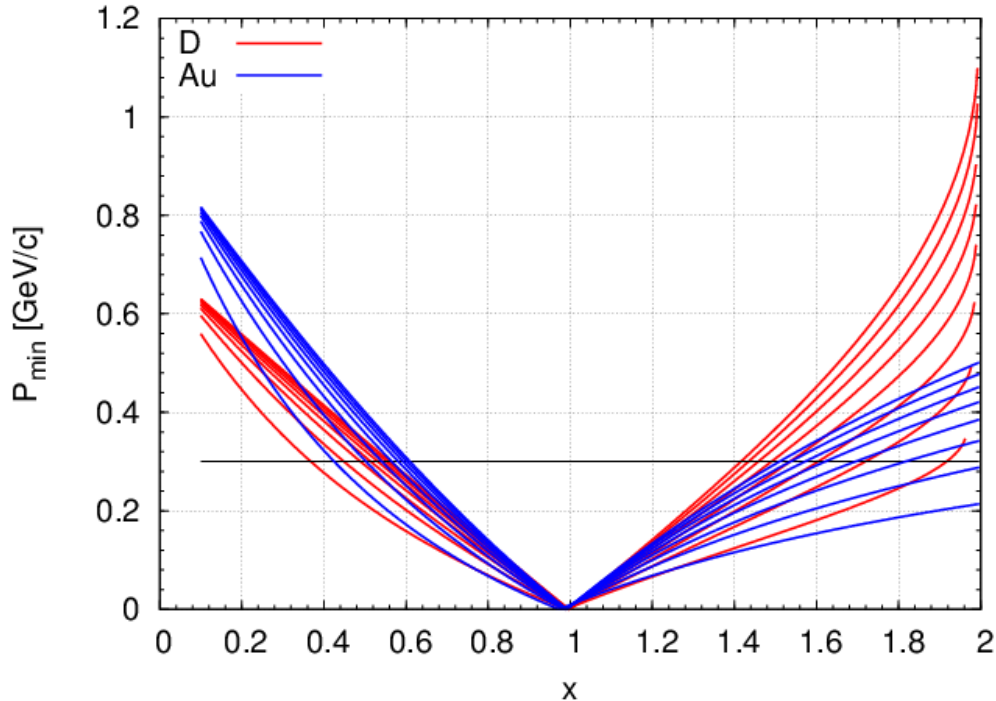


Egiyan et al (2003)



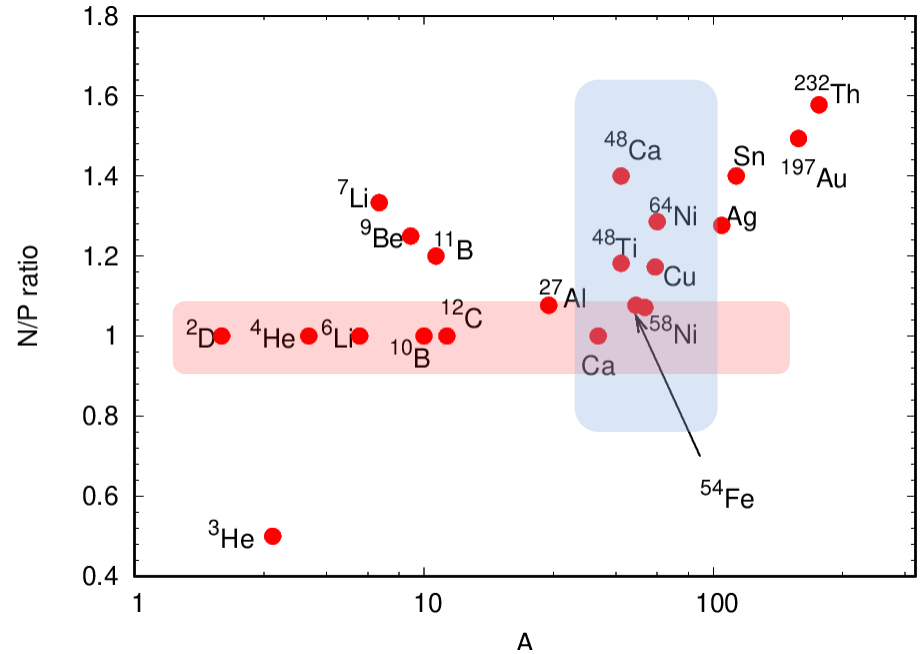
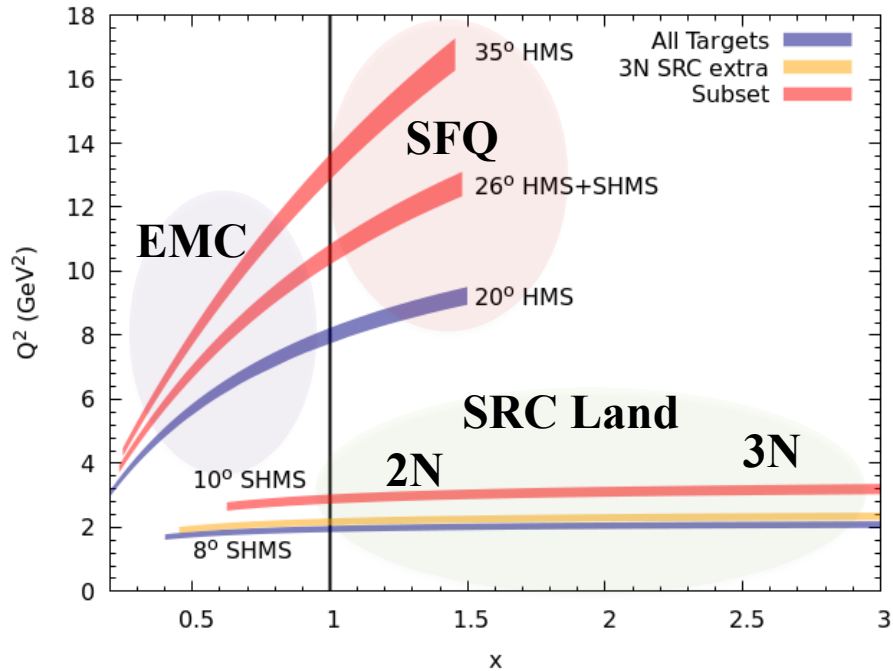
Fomin et al, PRL 108 (2012) Jlab E02-019

Kinematic cutoff is A-dependent

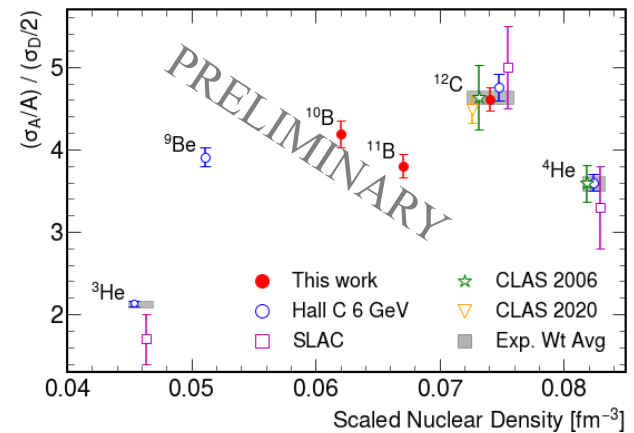
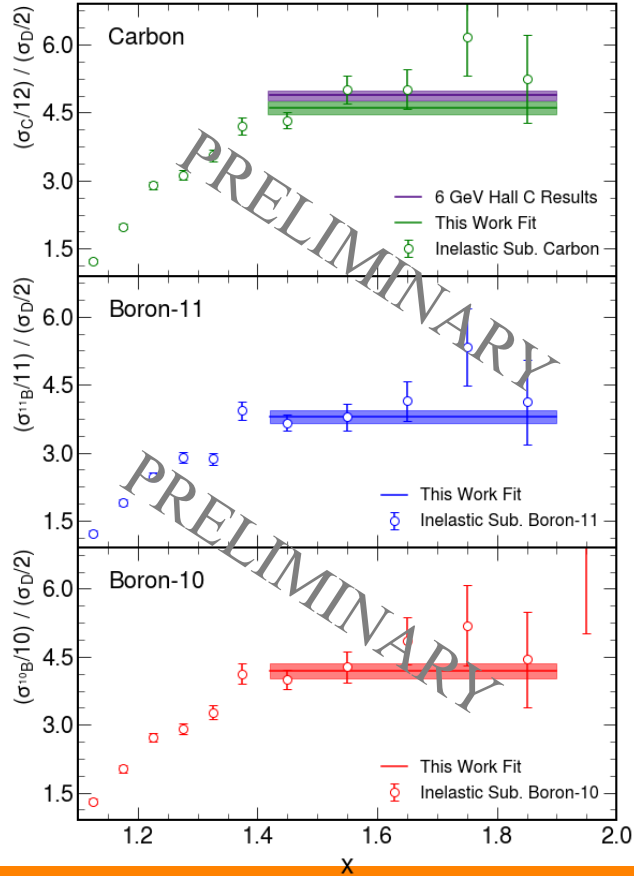


- For heavy nuclei, the minimum momentum changes \rightarrow heavier recoil system requires less kinetic energy to balance the momentum of the struck nucleon
- Larger fermi momenta for $A > 2 \rightarrow$ MF contribution persists for longer
- Imperfect plateau, but the picture still holds

JLab E12-06-105 (XEM2): So Much Data



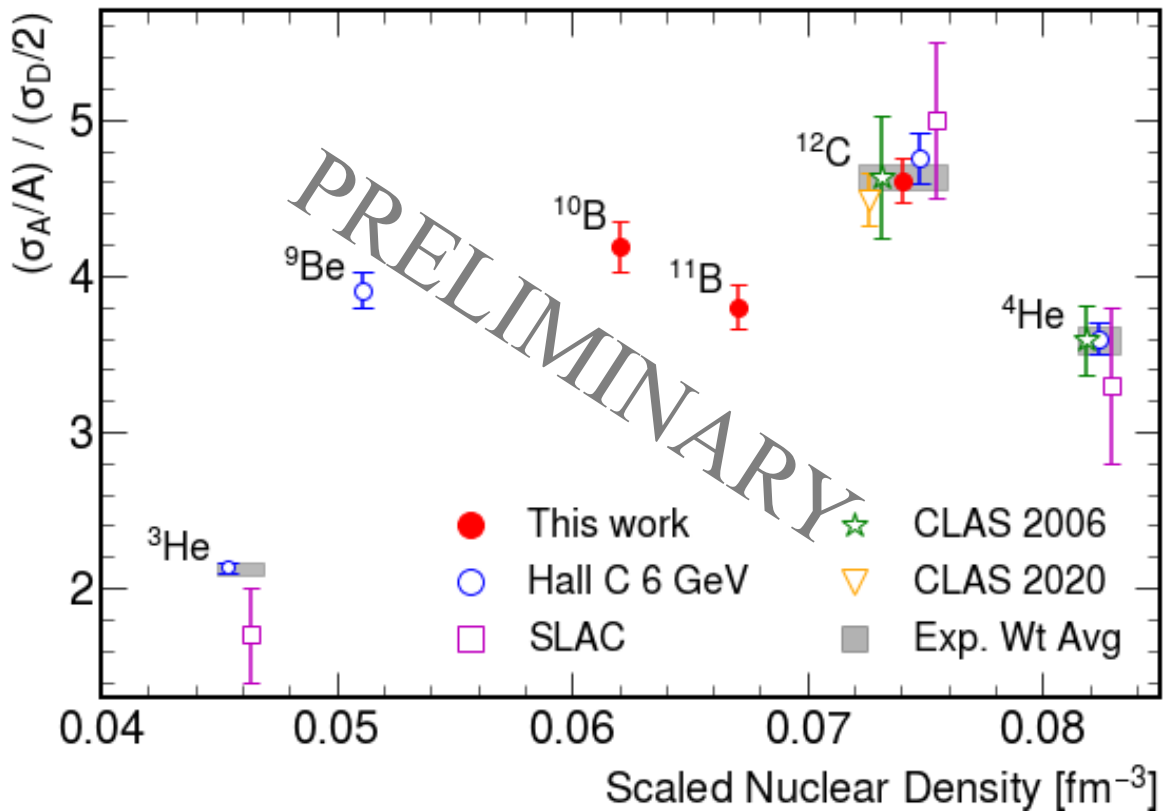
Commissioning data from 2019 – almost published



First Measurement of Short-Range Correlations in ^{10}B and ^{11}B

C. Morean,¹ A. Karki,² D. Biswas,³ F. A. Gonzalez,⁴ W. Henry,⁵ A. Nadeeshani,³ A. Sun,⁶ D. Abrams,⁷ Z. Ahmed,⁸ B. Aljawrneh,⁹ S. Alsalmi,¹⁰ R. Ambrose,⁸ D. Andrico,¹¹ W. Armstrong,¹² J. Arrington,¹³ A. Asaturyan,¹⁴ K. Assumin-Gyimah,² C. Ayerbe Gayoso,^{15,2} A. Bandari,¹⁵ S. Basnet,⁸ V. Berdnikov,¹⁶ H. Bhatt,² D. Bhetuwal,² W. U. Boeglin,¹⁷ P. Bosted,¹⁵ E. Brash,¹⁸ M. H. S. Bukhari,¹⁹ H. Chen,⁷ J. P. Chen,⁵ M. Chen,⁷ M. E. Christy,³ S. Covrig,⁵ K. Craycraft,¹ S. Danagoulian,⁹ D. Day,⁷ M. Diefenthaler,⁵ M. Dlamini,²⁰ D. Dutta,² J. Dunne,² B. Duran,^{1,12} R. Ent,⁵ R. Evans,⁸ H. Fenker,⁵ N. Fomin,¹ E. Fuchey,²¹ D. Gaskell,⁵ T. N. Gautam,³ J. O. Hansen,⁵ F. Hauenstein,²² A. V. Hernandez,¹⁶ T. Horn,¹⁶ G. M. Huber,⁸ M. K. Jones,⁵ S. Joosten,²³ M. L. Kabir,² C. Keppel,⁵ A. Khanal,¹⁷ P. M. King,²⁰ E. Kinney,²⁴ H. S. Ko,²⁵ M. Kohl,³ N. Lashley-Colthirst,³ S. Li,²⁶ W. B. Li,¹⁵ A. H. Liyanage,³ D. Mack,⁵ S. Malace,⁵ P. Markowitz,¹⁷ J. Matter,⁷ D. Meekins,⁵ R. Michaels,⁵ A. Mkrtchyan,¹⁴ H. Mkrtchyan,¹⁴ S.J. Nazeer,³ S. Nanda,² G. Niculescu,²⁷ I. Niculescu,²⁷ D. Nguyen,⁷ Nuruzzaman,²⁸ B. Pandey,³ S. Park,⁴ E. Poeser,⁵ A. Puckett,²¹ M. Rehfuss,¹² J. Reinhold,¹⁷ N. Santiesteban,²⁶ B. Sawatzky,⁵ G. R. Smith,⁵ H. Szumila-Vance,⁵ A. Tadepalli,²⁸ V. Tadevosyan,¹⁴ R. Trotta,¹⁶ S. A. Wood,⁵ C. Yero,¹⁷ and J. Zhang⁴

Commissioning data from 2019 – almost published



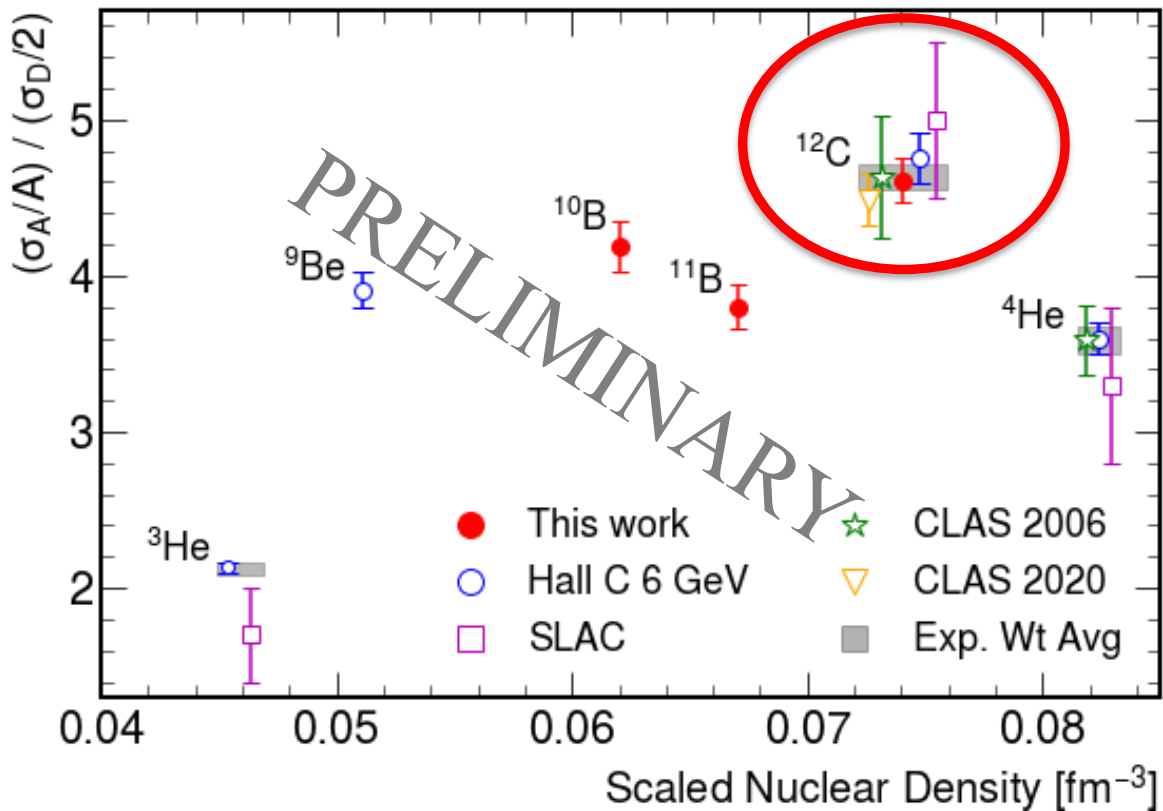
Note: Boron a2 values

SRG Calculation by
Tropiano:

B10 a2 = 3.70328

B11 a2 = 3.63394

Commissioning data from 2019 – almost published



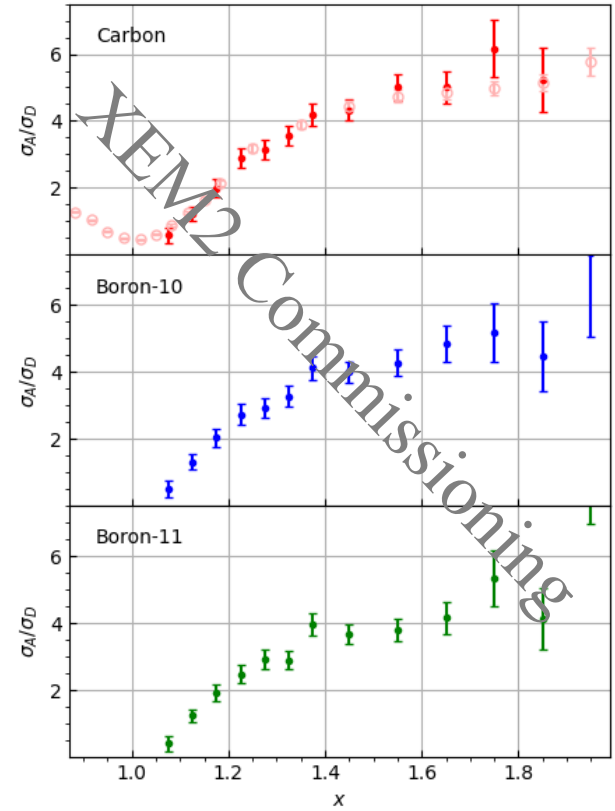
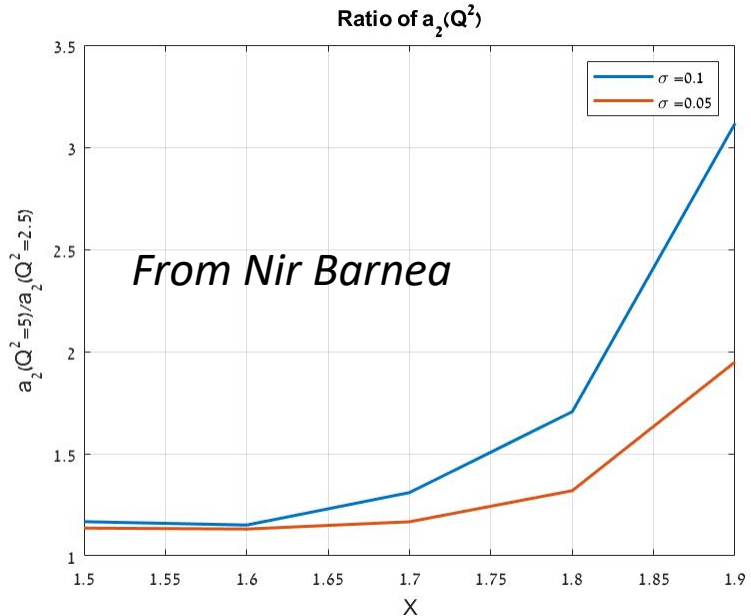
Note: Boron a2 values

SRG Calculation by Tropiano:

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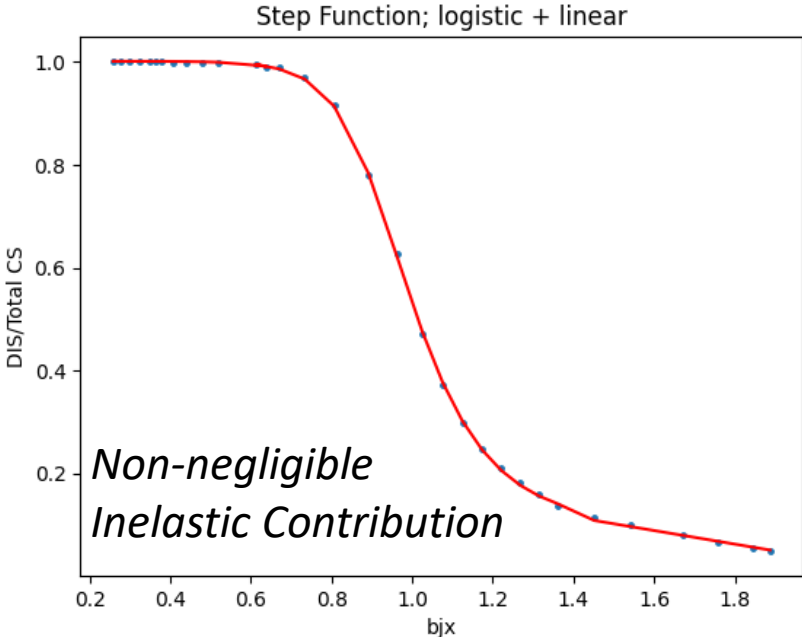
B11 a2 = 3.63394

Is the a_2 scaling Q^2 independent?

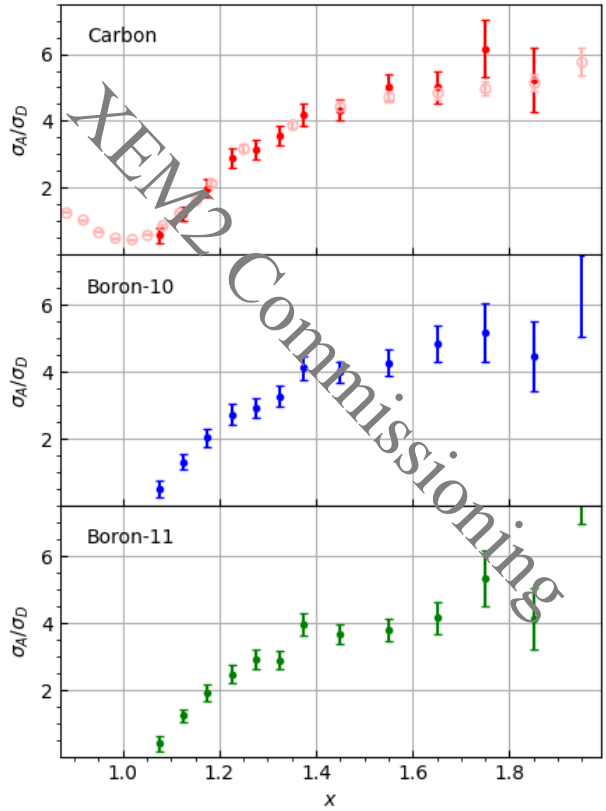


Hall C 6 GeV – 2.7 GeV²
XEM2 2019 – 5.0 GeV²

Is the a_2 scaling Q^2 independent?



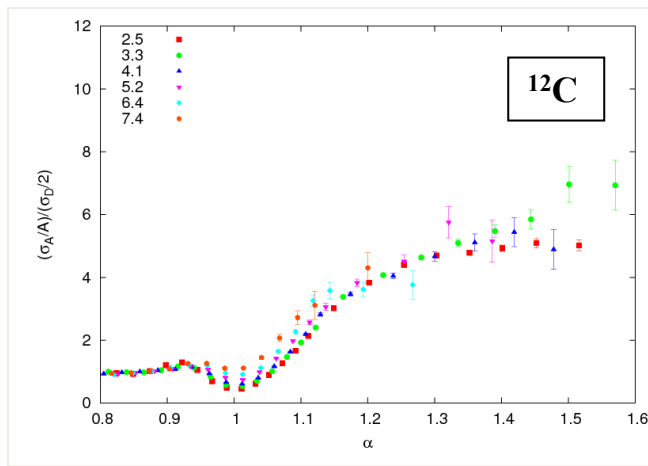
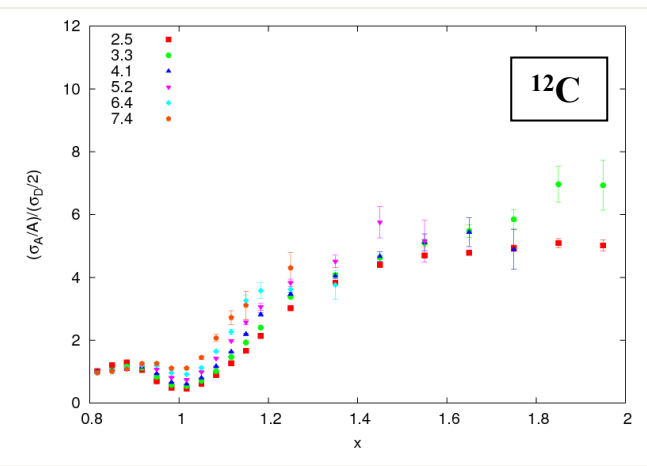
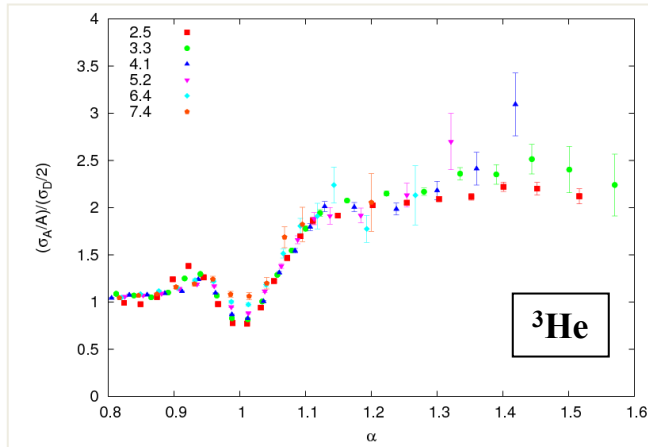
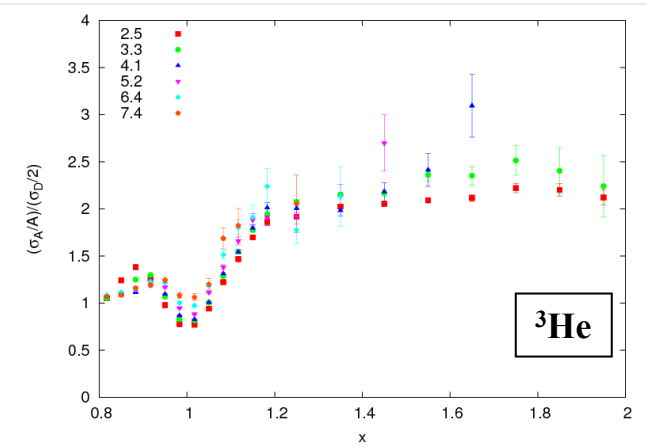
Hall C 6 GeV – 2.7 GeV²
 XEM2 2019 – 5.0 GeV²



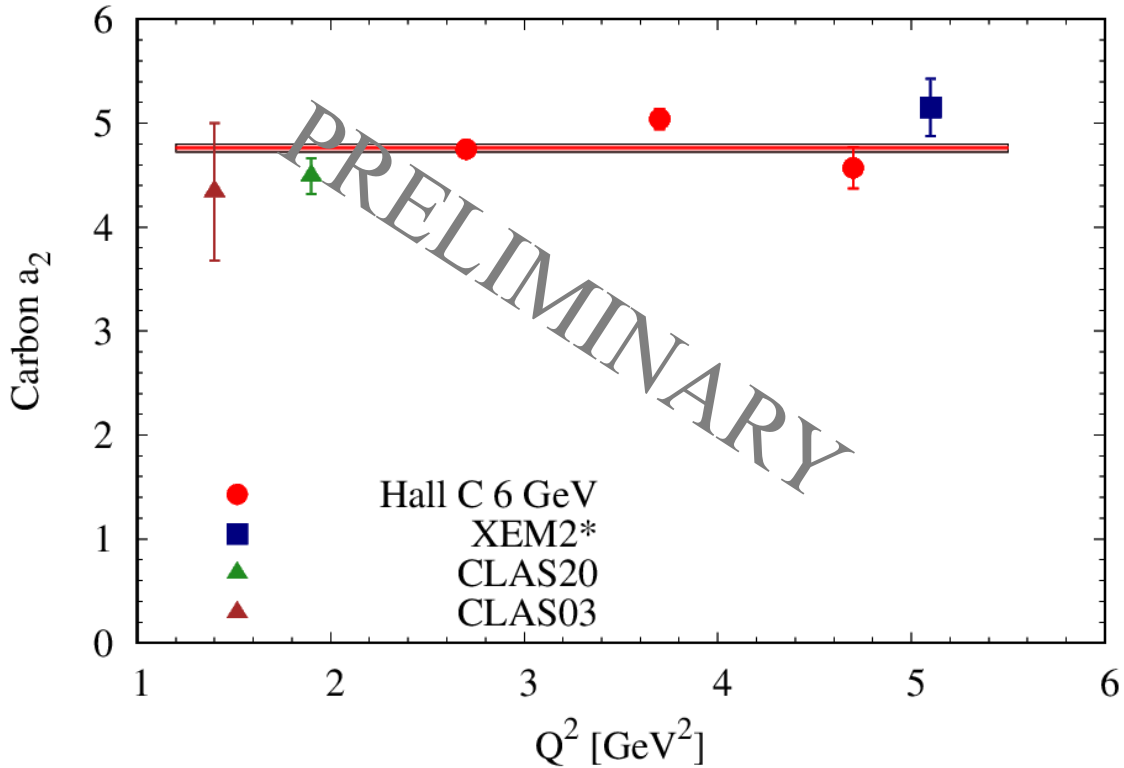
Test scaling in x and Q^2

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

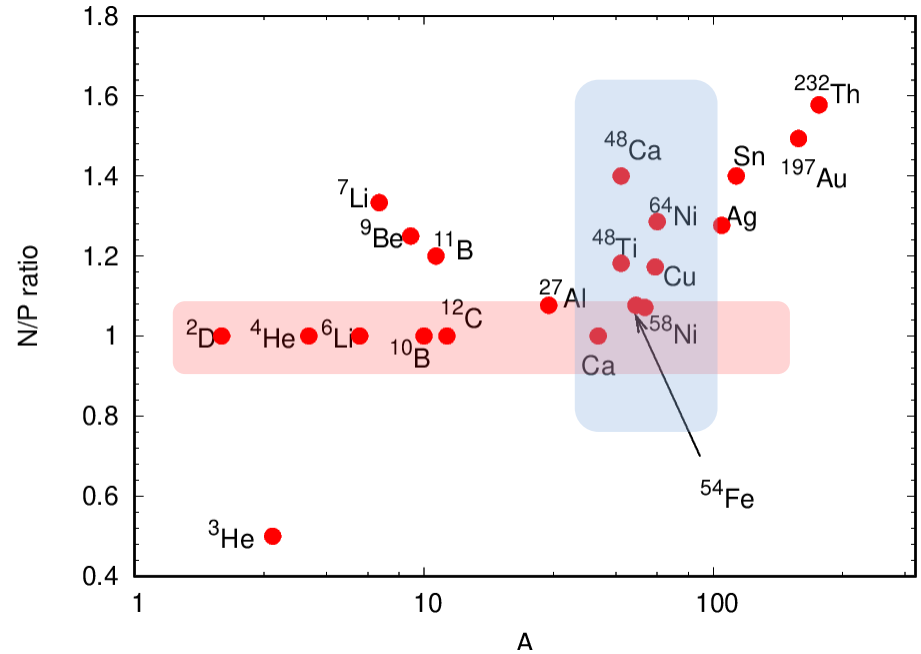
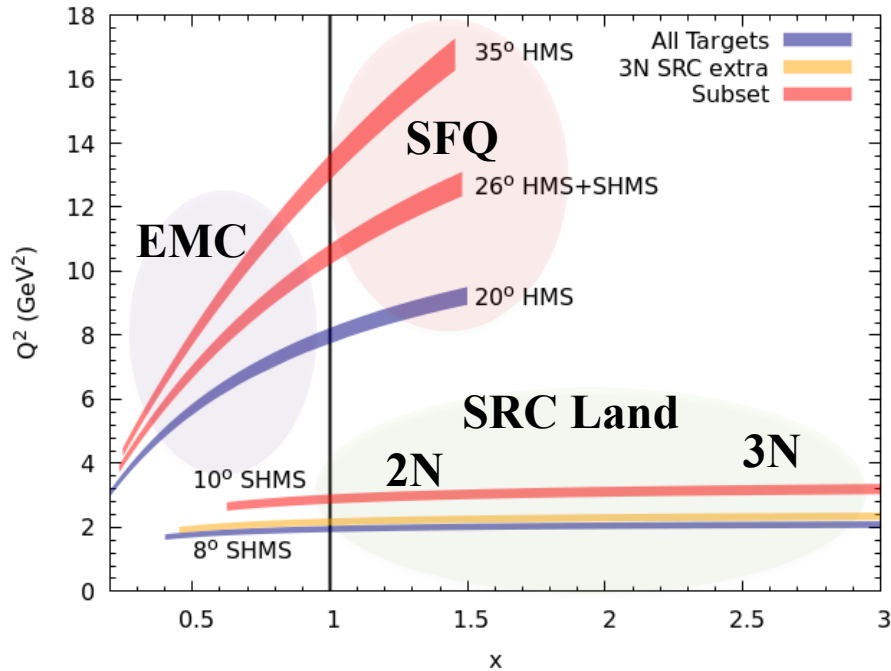
Phys. Rev. C **48**, 2451(1993)



Putting all the Carbon data together

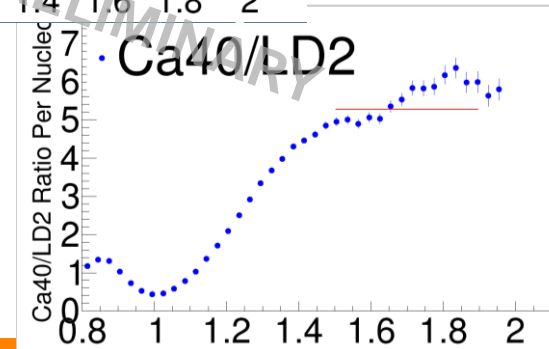
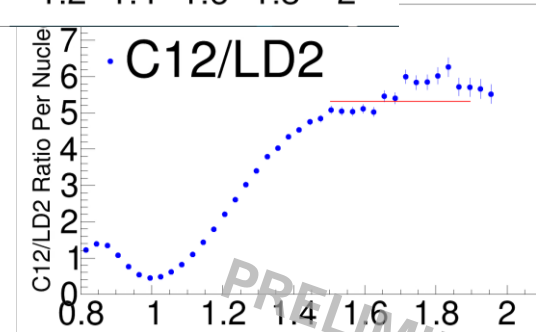
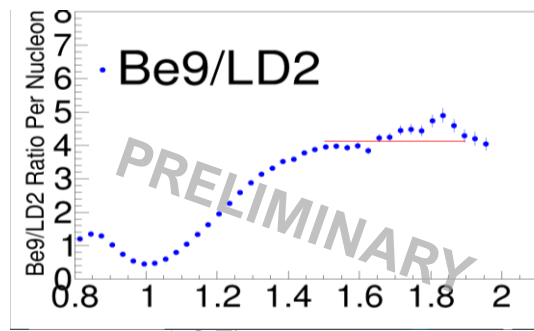
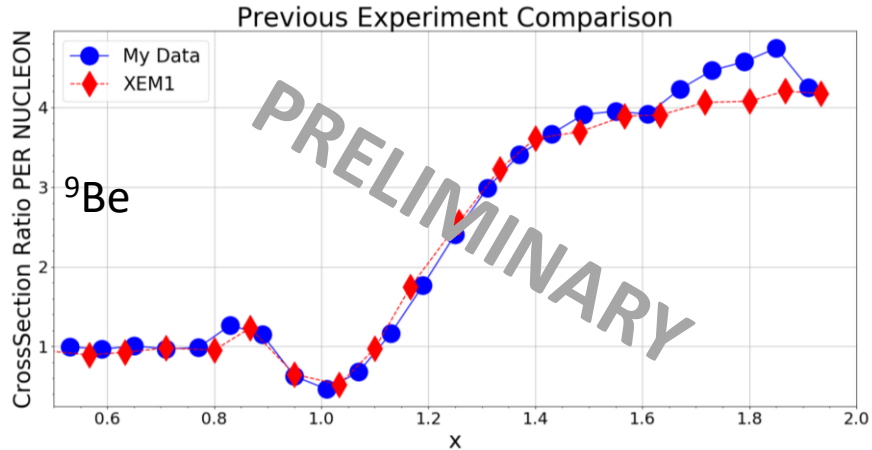


JLab E12-06-105 (XEM2): Now ALL the data



JLab E12-06-105 (XEM2)

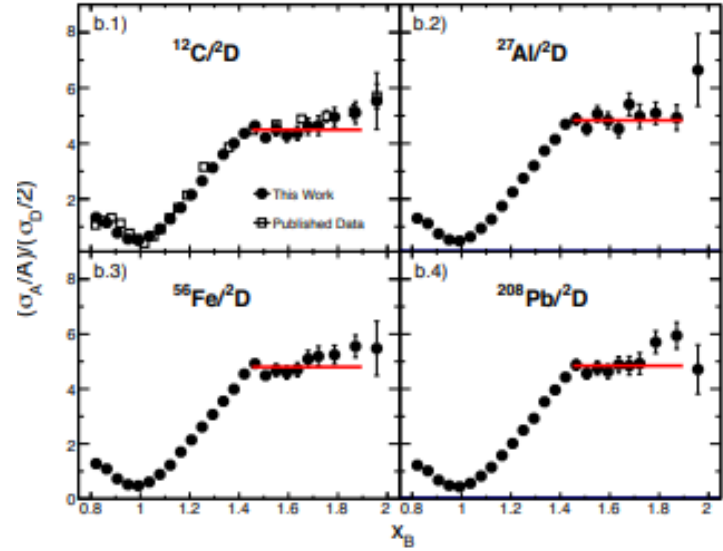
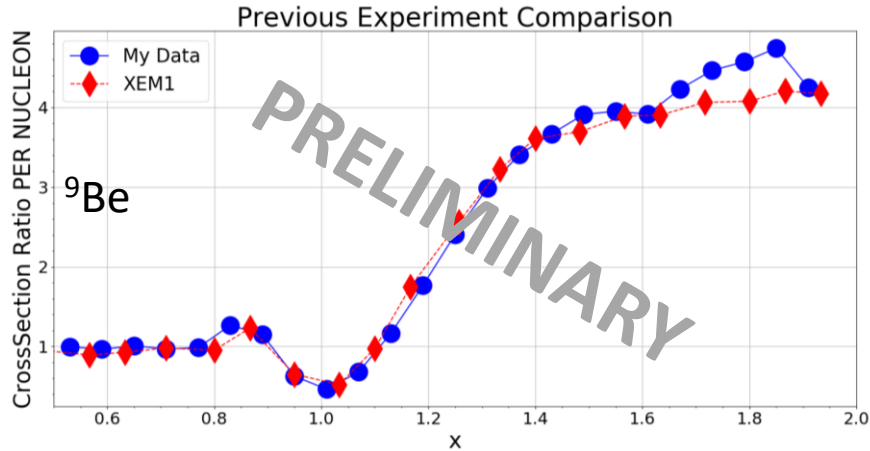
Selected Results*



PhD Student Ramon Ogaz (UT)
All corrections applied

JLab E12-06-105 (XEM2)

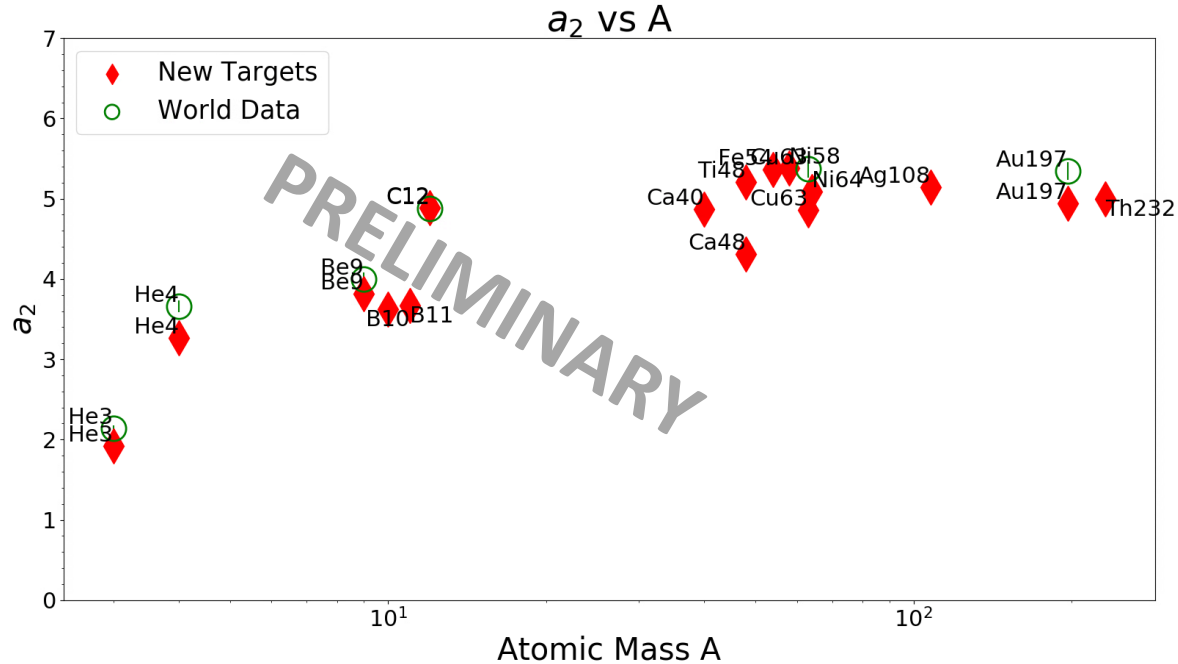
Selected Results*



B. Schmookler, Nature, 2019

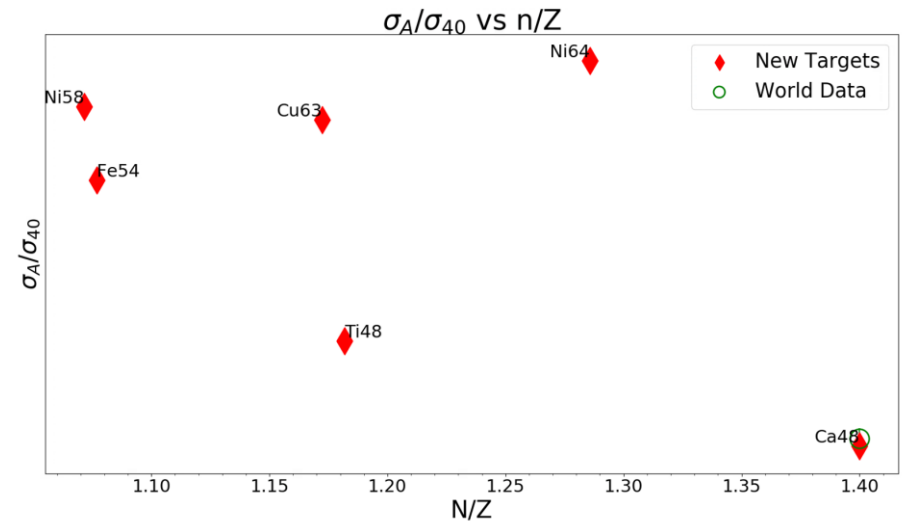
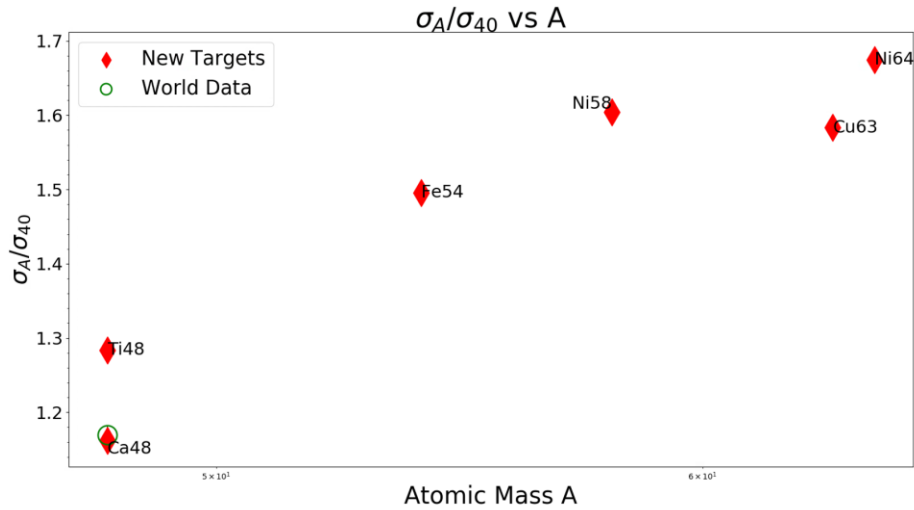
PhD Student Ramon Ogaz (UT)
All corrections applied

JLab E12-06-105 (XEM2) - Selected Results*

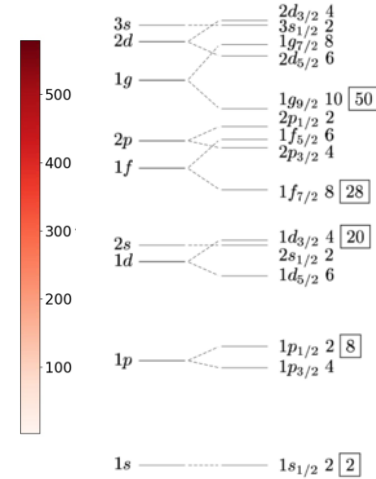
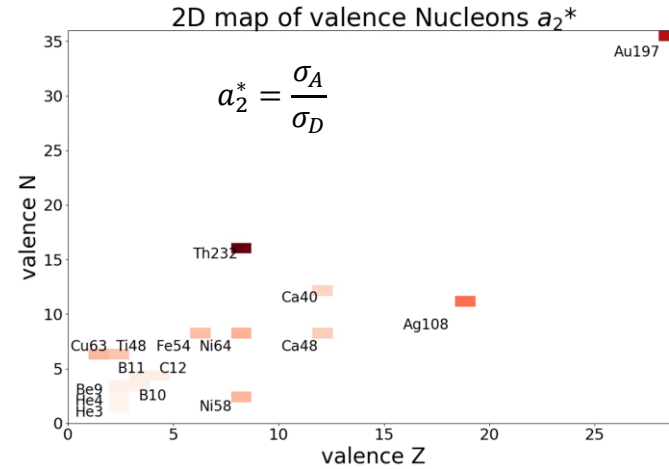
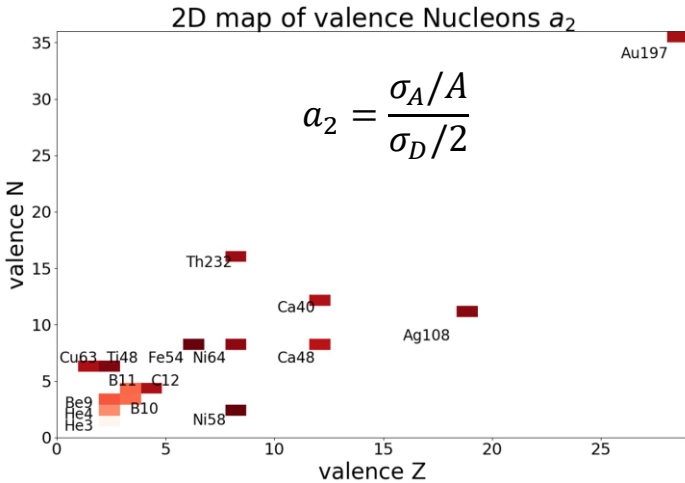


PhD Student Ramon Ogaz (UT)
All corrections applied

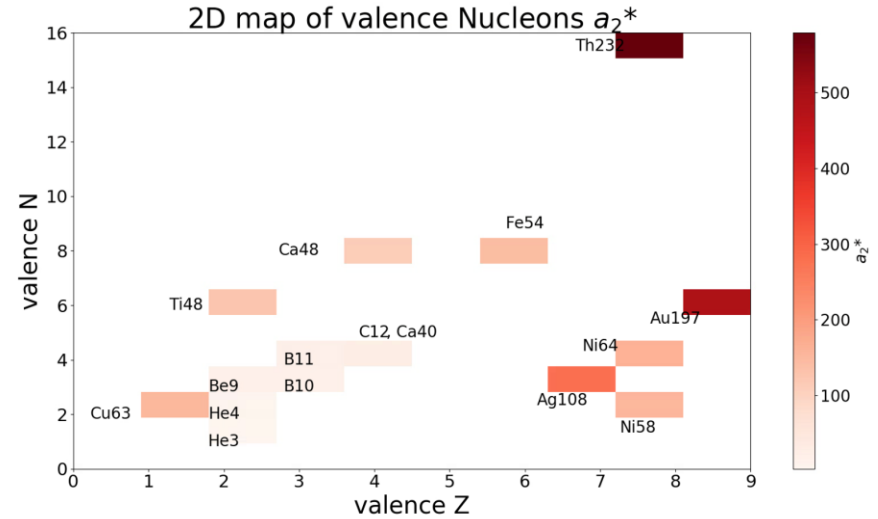
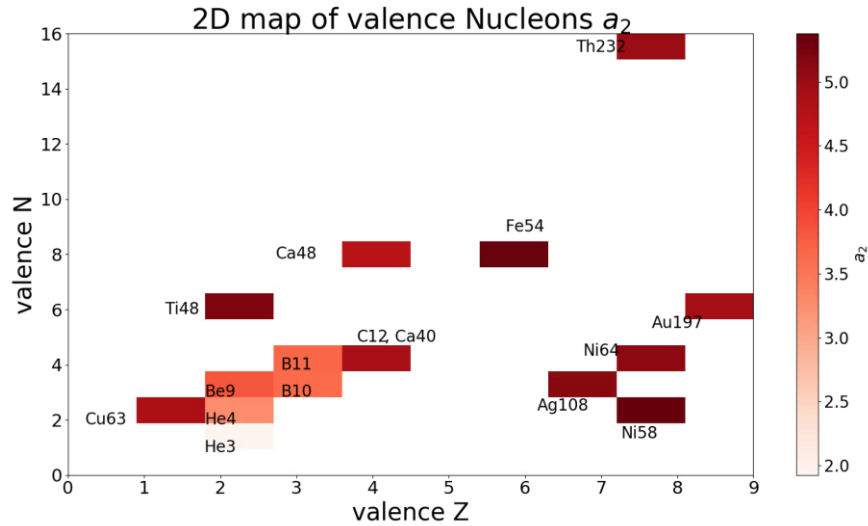
Looking at medium-A nuclei



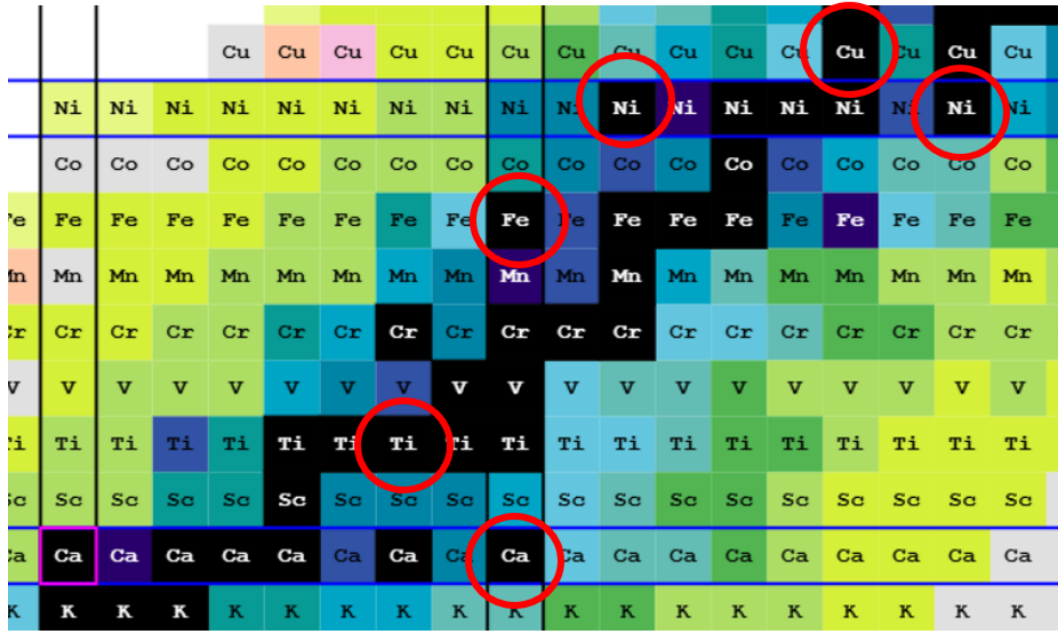
Let's look at it in a confusing way – nuclear shells



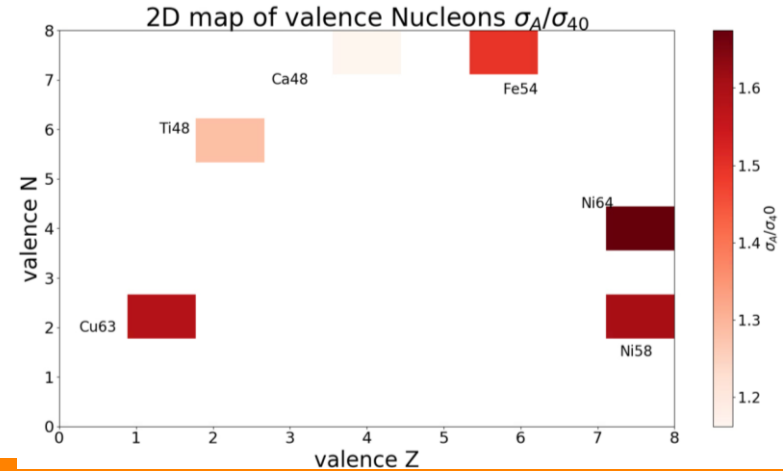
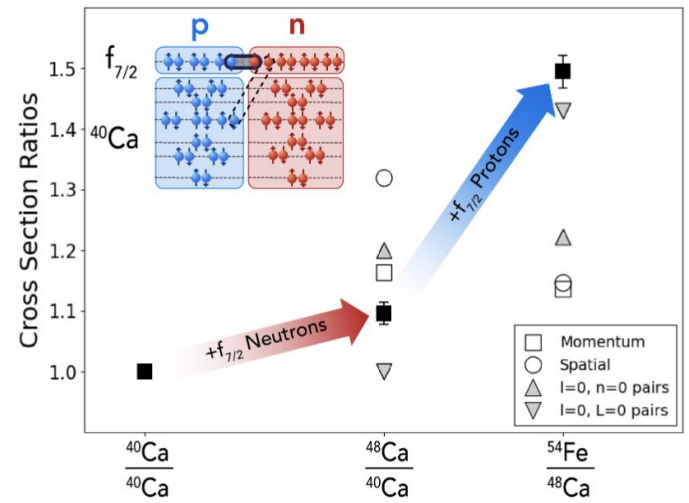
Let's look at it in a different confusing way - orbitals



Comparing with CaFe



Takeaway: Ni64 has highest ratio



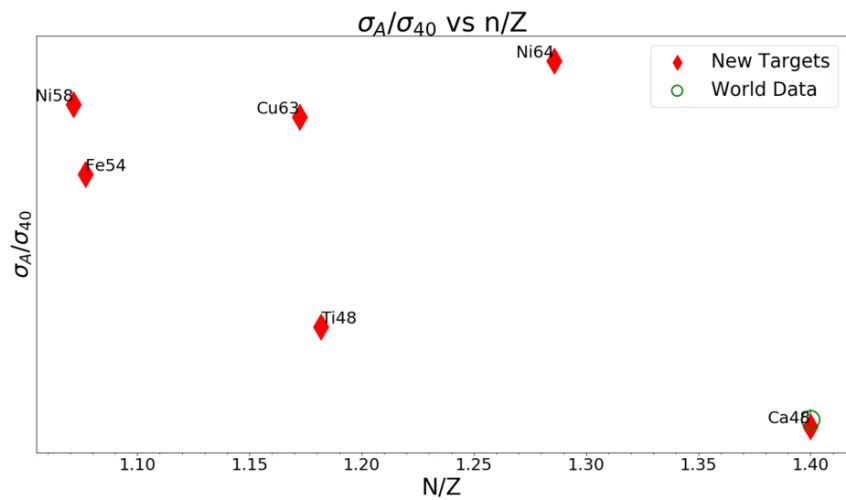
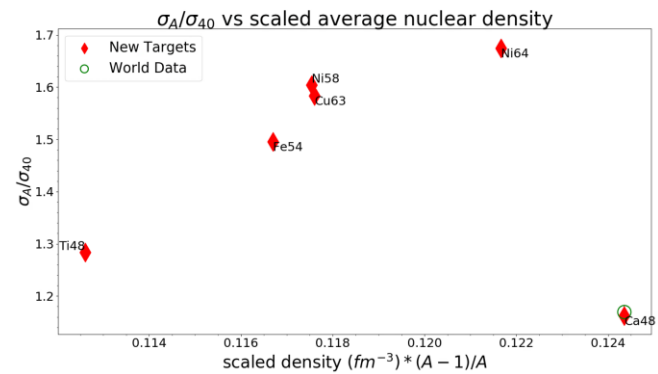
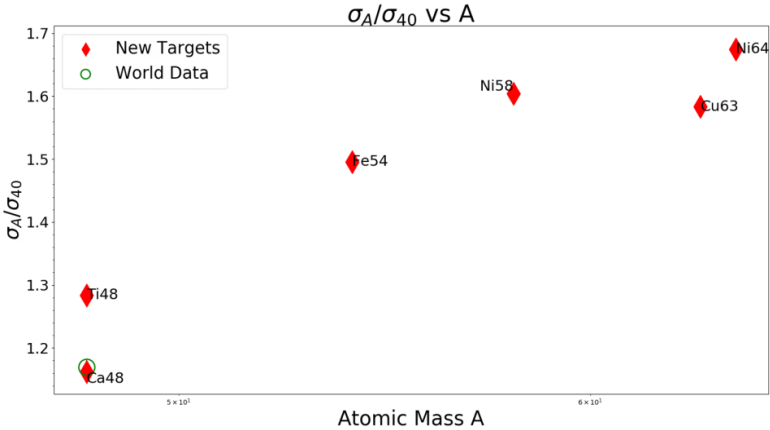
Too much data – make it make sense

- In discussion with Augusto M – welcome additional insight
- More inclusive a_2 data is not useful if we don't extract all possible info from this data set
- Working on results for ${}^6\text{Li}$, ${}^7\text{Li}$ – would love some calculations for comparison

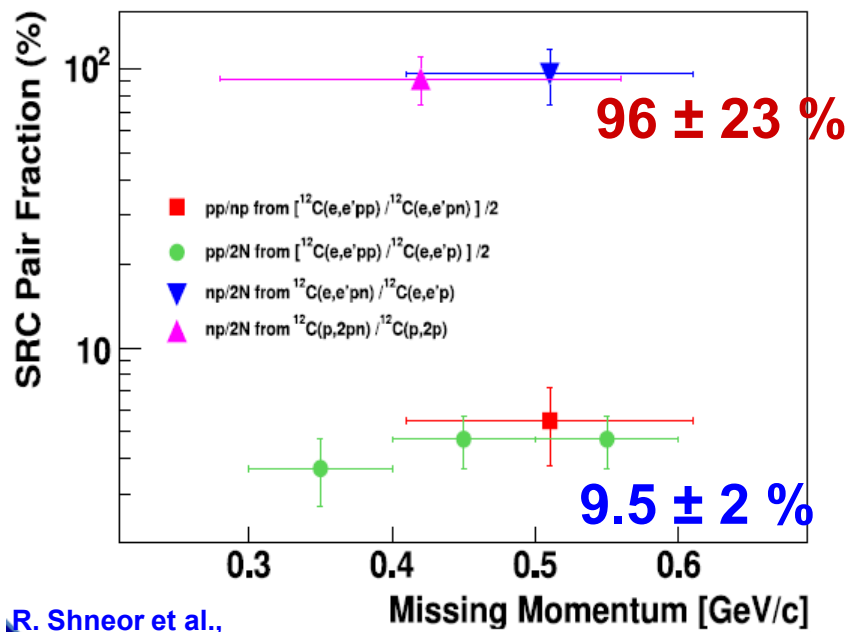


Old Stuff





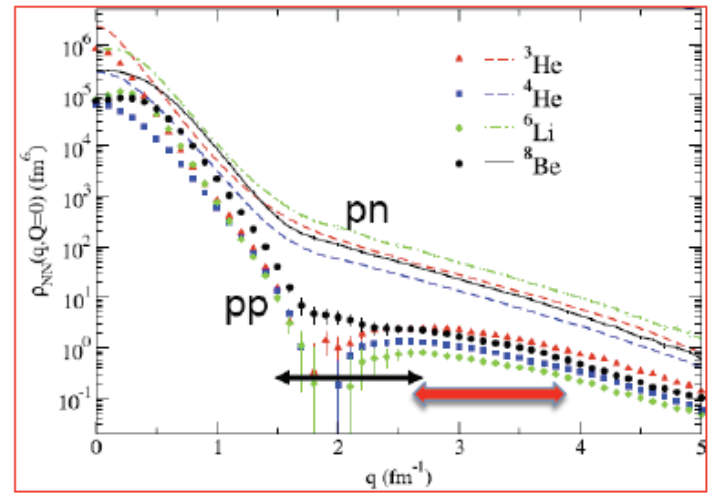
NP dominance



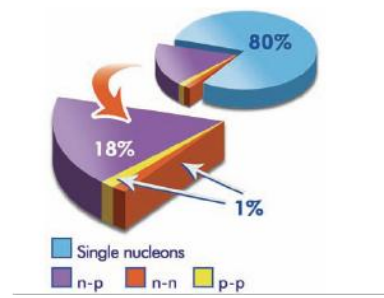
R. Shneor et al.,
 PRI 99 072501 (2007)

also

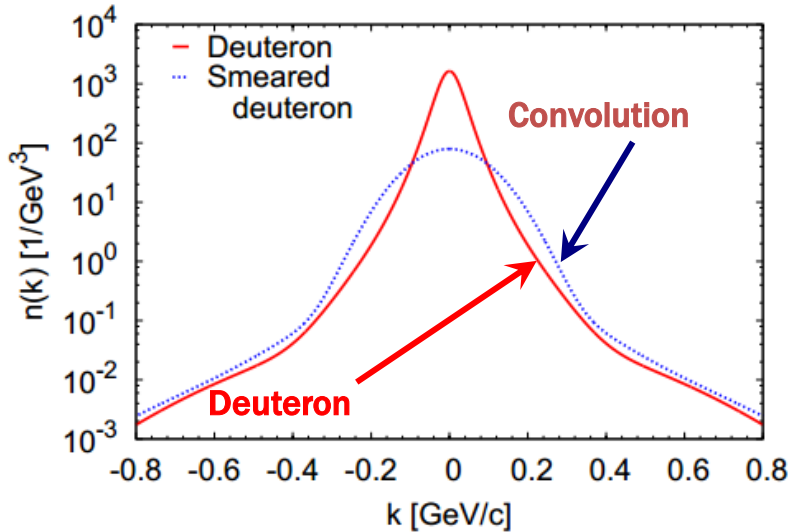
- Ciofi and Alvioli PRL 100, 162503 (2008)
- Sargsian, Abrahamyan, Strikman, Frankfurt PR C71 044615 (2005)



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



NOTE: $a_2 = \frac{\sigma_A}{\sigma_D} ! = \text{RELATIVE \#OF SRCS}$



$\underline{a_2 = \sigma_A / \sigma_D} \rightarrow$ relative measure of high momentum nucleons

$\underline{R_{2n}} \rightarrow$ relative measure of correlated pairs

$n_D^{CONV}(k)$ is the convolution of $n_D(k)$ with the CM motion of correlated pairs in iron

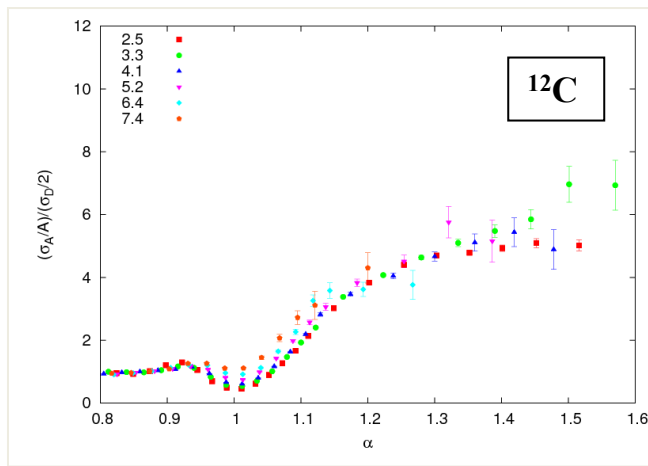
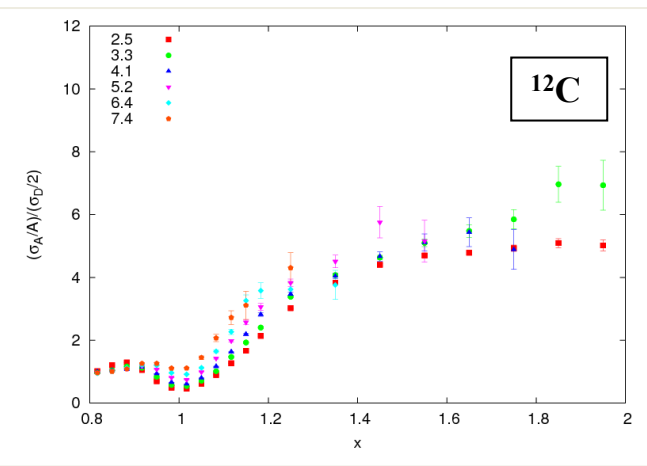
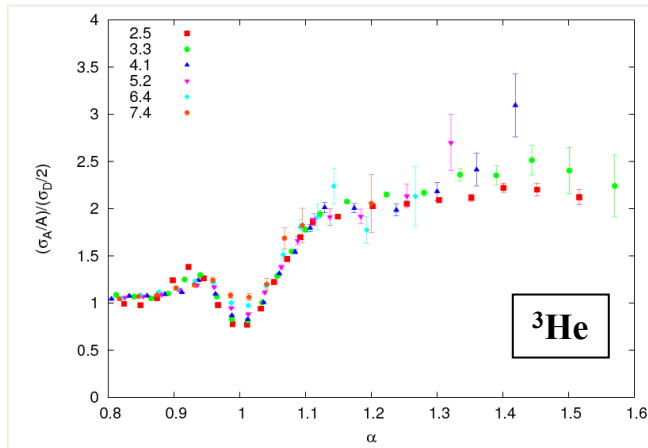
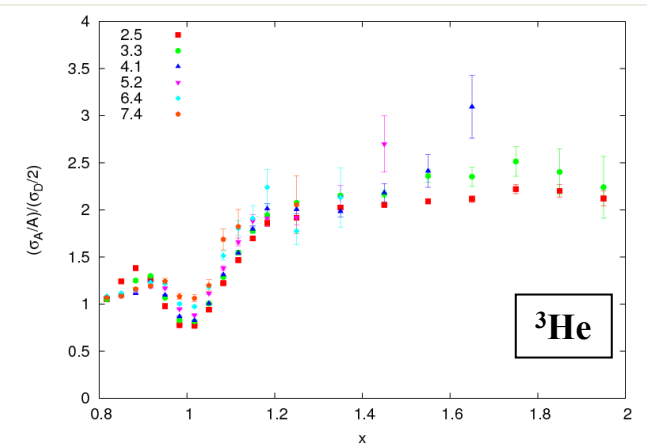
Following prescription from C. Ciofi degli Atti and S. Simula, Phys. Rev. C 53 (1996)

	E02-019	SLAC	CLAS	R_{2N-ALL}	a_2-ALL
^3He	1.93 ± 0.10	1.8 ± 0.3	–	1.92 ± 0.09	2.13 ± 0.04
^4He	3.02 ± 0.17	2.8 ± 0.4	2.80 ± 0.28	2.94 ± 0.14	3.57 ± 0.09
Be	3.37 ± 0.17	–	–	3.37 ± 0.17	3.91 ± 0.12
C	4.00 ± 0.24	4.2 ± 0.5	3.50 ± 0.35	3.89 ± 0.18	4.65 ± 0.14
Al	–	4.4 ± 0.6	–	4.40 ± 0.60	5.30 ± 0.60
Fe	–	4.3 ± 0.8	3.90 ± 0.37	3.97 ± 0.34	4.75 ± 0.29
Cu	4.33 ± 0.28	–	–	4.33 ± 0.28	5.21 ± 0.20
Au	4.26 ± 0.29	4.0 ± 0.6	–	4.21 ± 0.26	5.13 ± 0.21

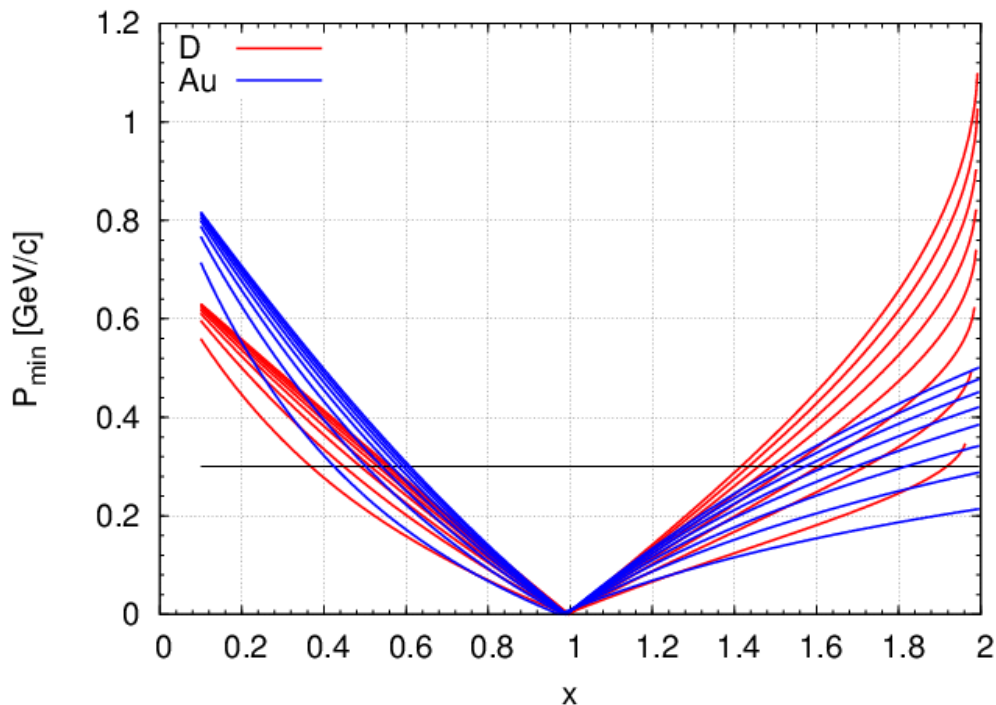
Test scaling in x and Q^2

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

Phys. Rev. C **48**, 2451(1993)

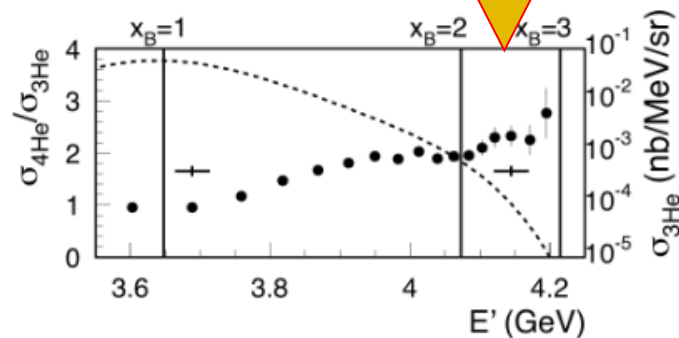
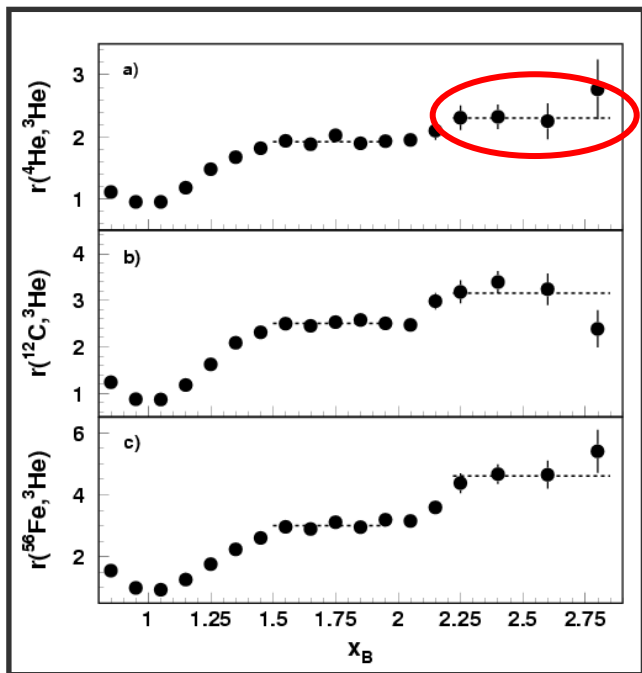


Kinematic cutoff is A -dependent



- For heavy nuclei, the minimum momentum changes \rightarrow heavier recoil system requires less kinetic energy to balance the momentum of the struck nucleon
- Larger fermi momenta for $A > 2 \rightarrow$ MF contribution persists for longer
- Imperfect plateau, but the picture still holds

Have we actually seen 3N SRC in ratios?



comment on “Measurement of 2- and 3-nucleon short range correlation probabilities in nuclei”

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