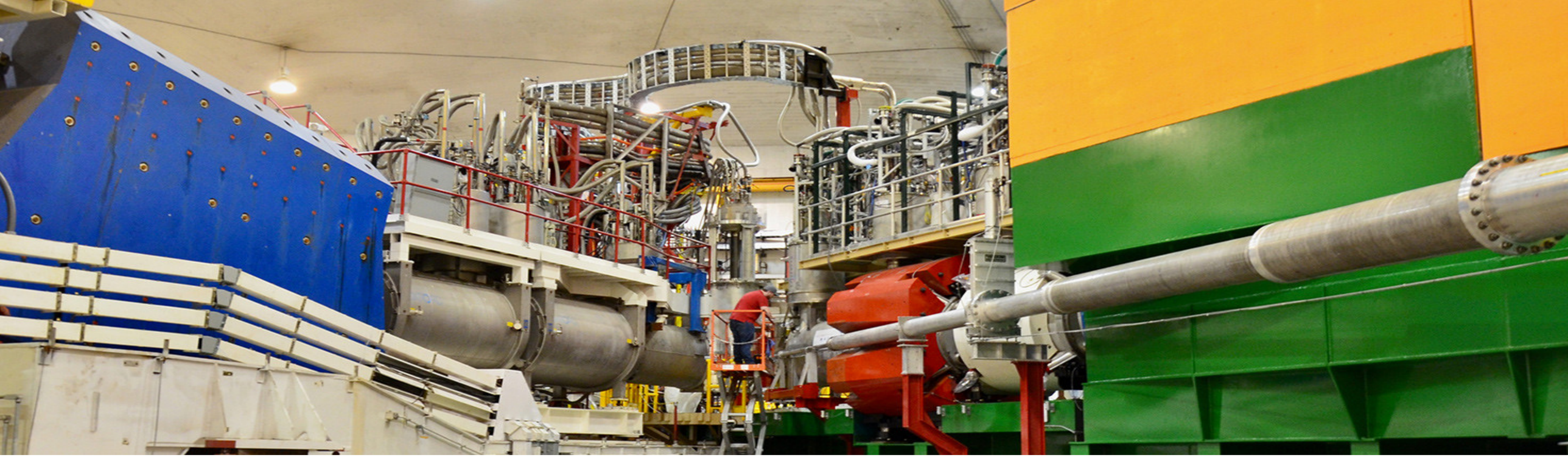


# x > 1 and EMC EFFECT MEASUREMENTS in Hall C


Burcu Duran

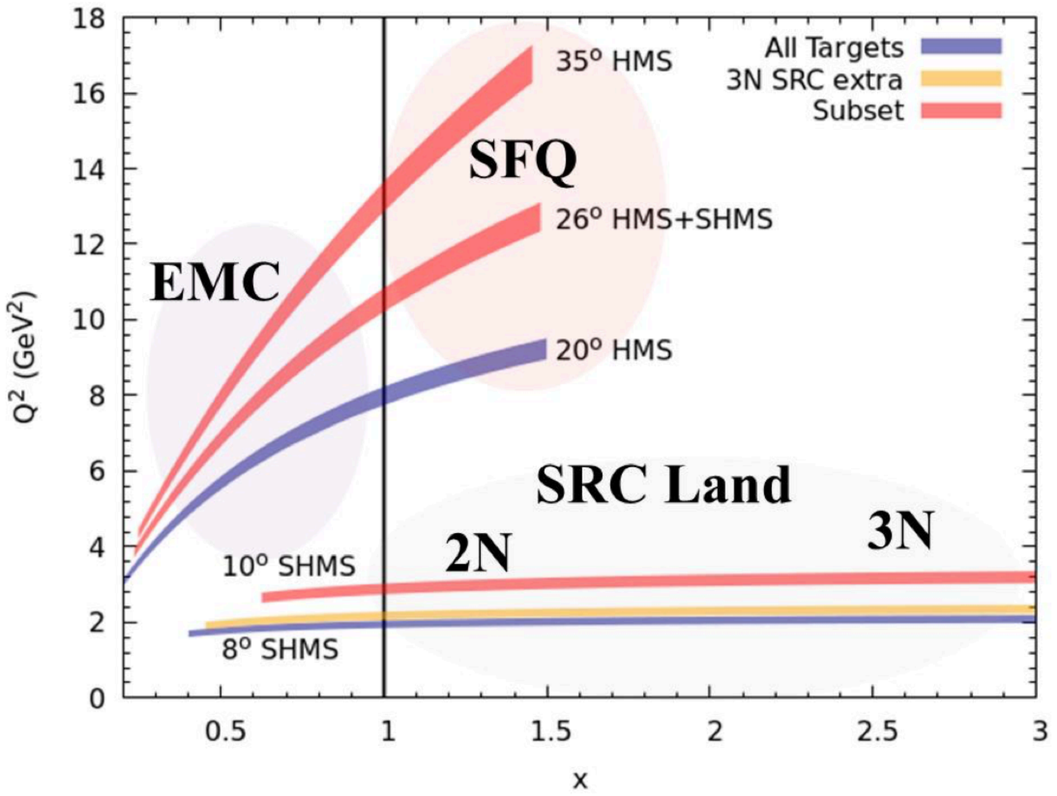
*On behalf of the XEM2 Collaboration*


**JLUO ANNUAL MEETING**

**26 June 2023**

**Newport News, VA**

# RECENTLY IN HALL C




**E12-10-008**: J. Arrington, A. Daniel, N. Fomin, D. Gaskell
Detailed Studies of the nuclear dependence of $F_2$ in light nuclei

**E12-06-105**: J. Arrington, D. Day, N. Fomin, P. Solvignon
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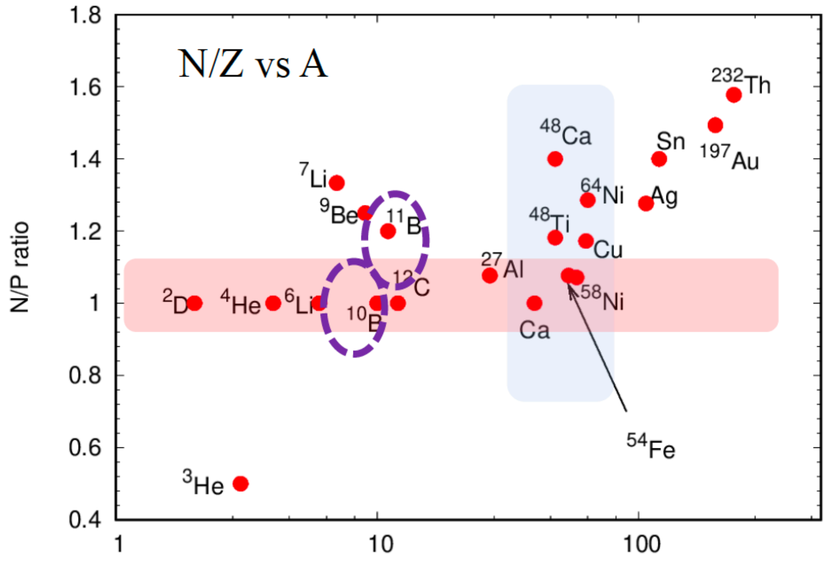
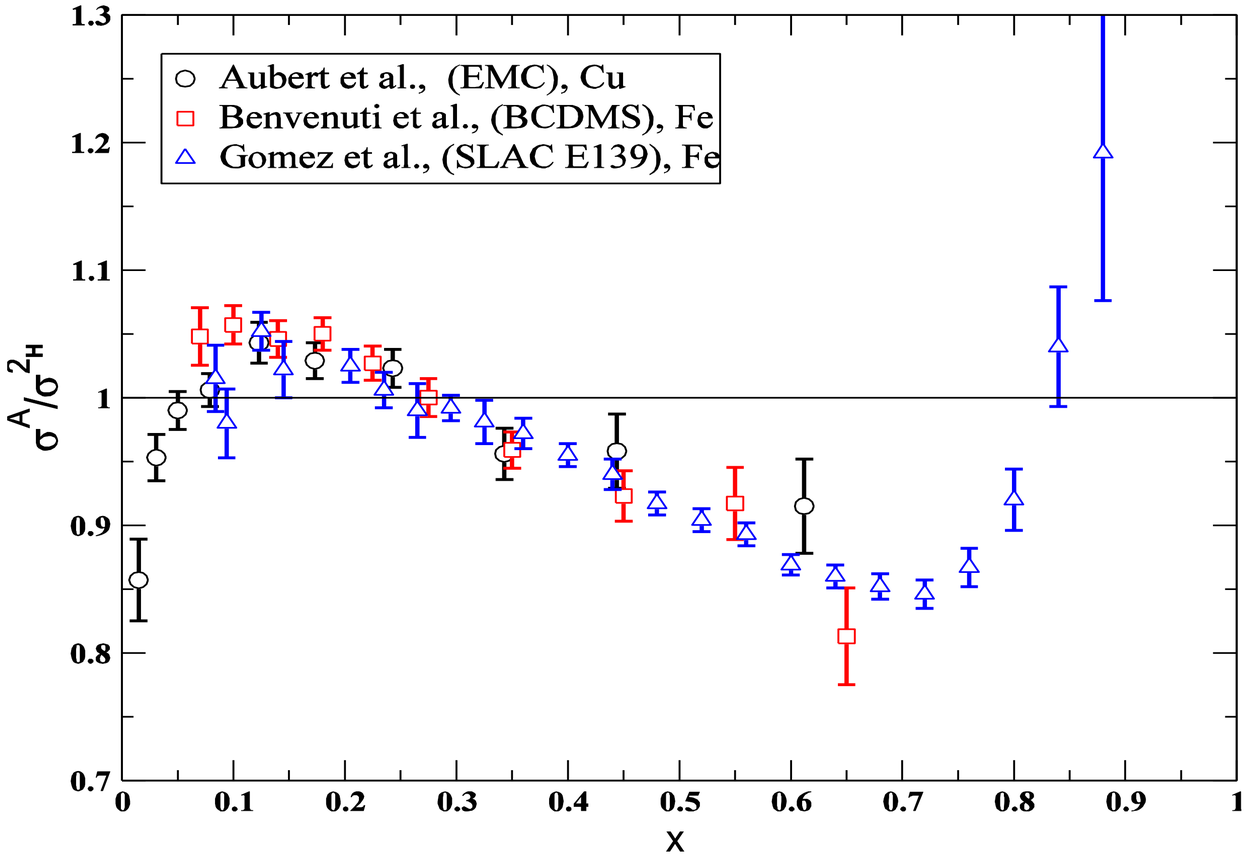


# NON-TRIVIAL STRUCTURE OF THE NUCLEUS

## THE EMC EFFECT

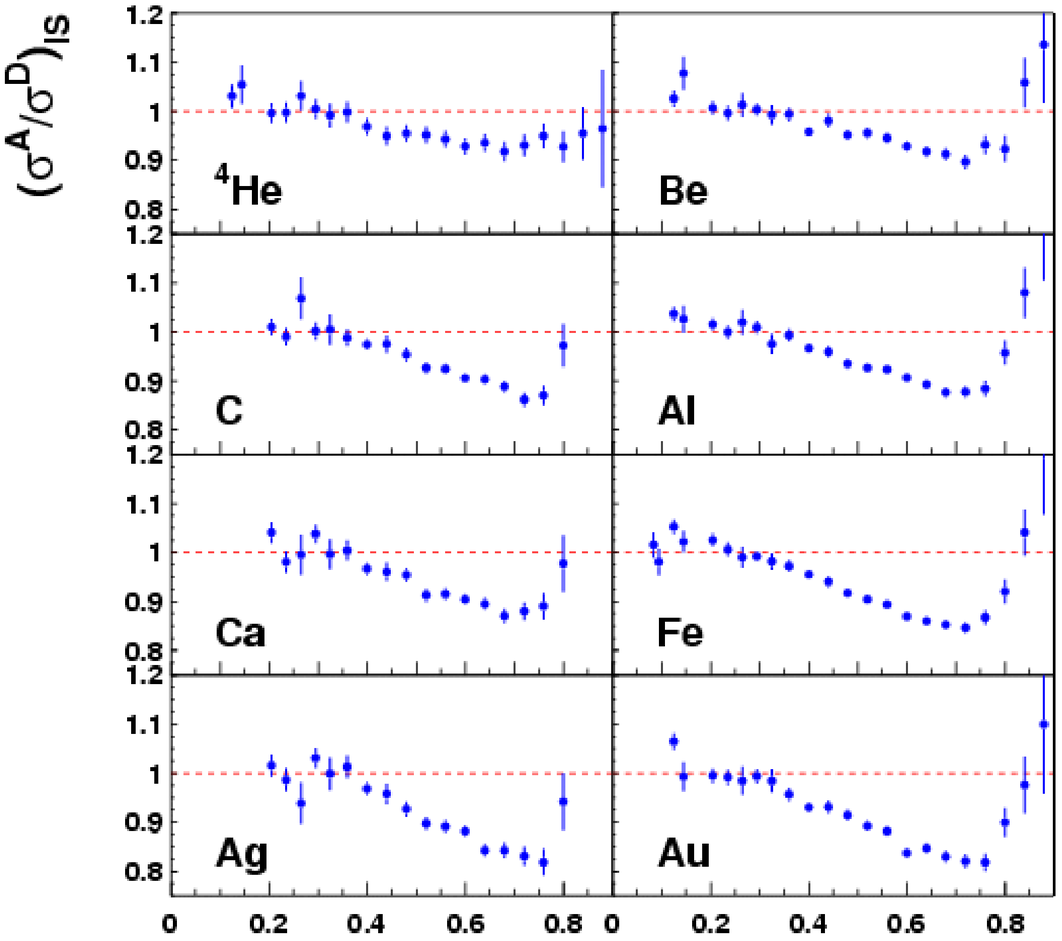



- Initial observation: per-nucleon DIS structure function for Iron significantly different than that of for deuterium. Confirmed for the several other nuclei.
- Suppression of the high momentum quarks for 0.3<x<0.7 in nuclei relative to the deuterium.
- After 40 years, no definitive explanation for the origin of the EMC effect.

# THE EMC EFFECT: DATA STATUS

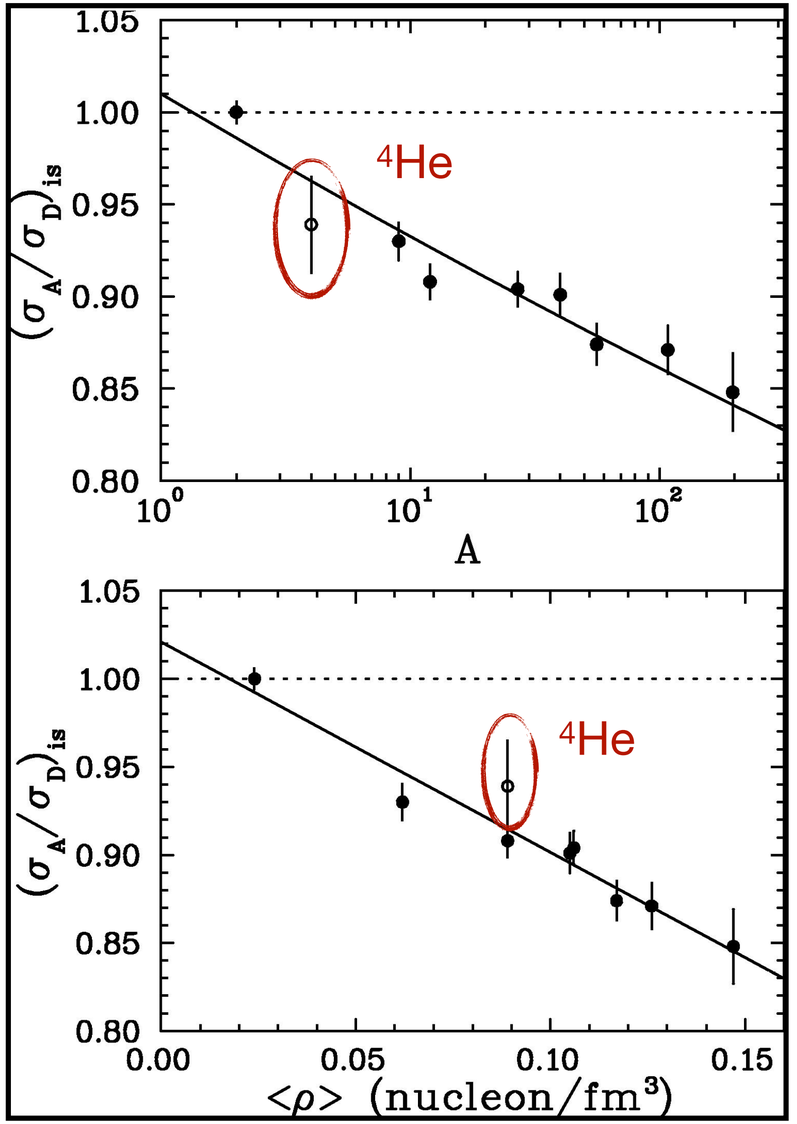
- SLAC E139:

*"Nuclear Dependence of the EMC Effect at Fixed x"*



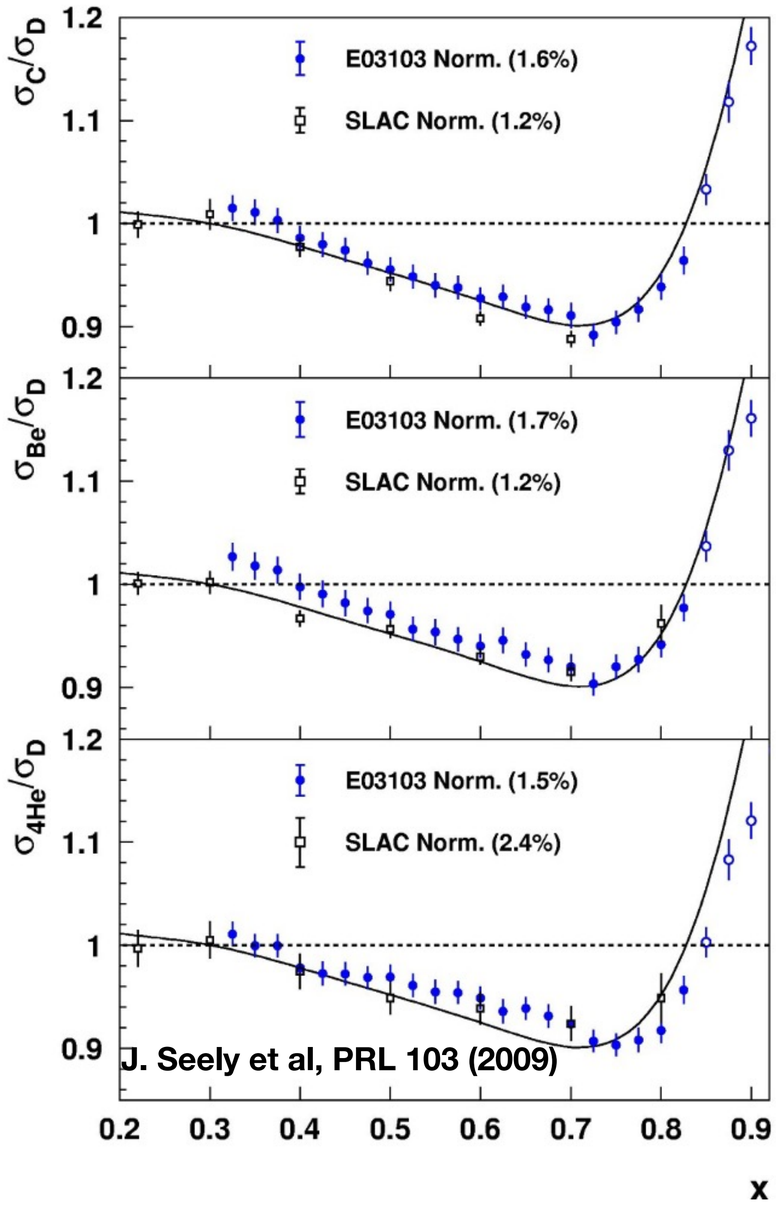

- Universal x-dependence for all the nuclei measured

x=0.6




- Modification scales with log(A) and average density

# THE EMC EFFECT: JLab E03-103 RESULTS



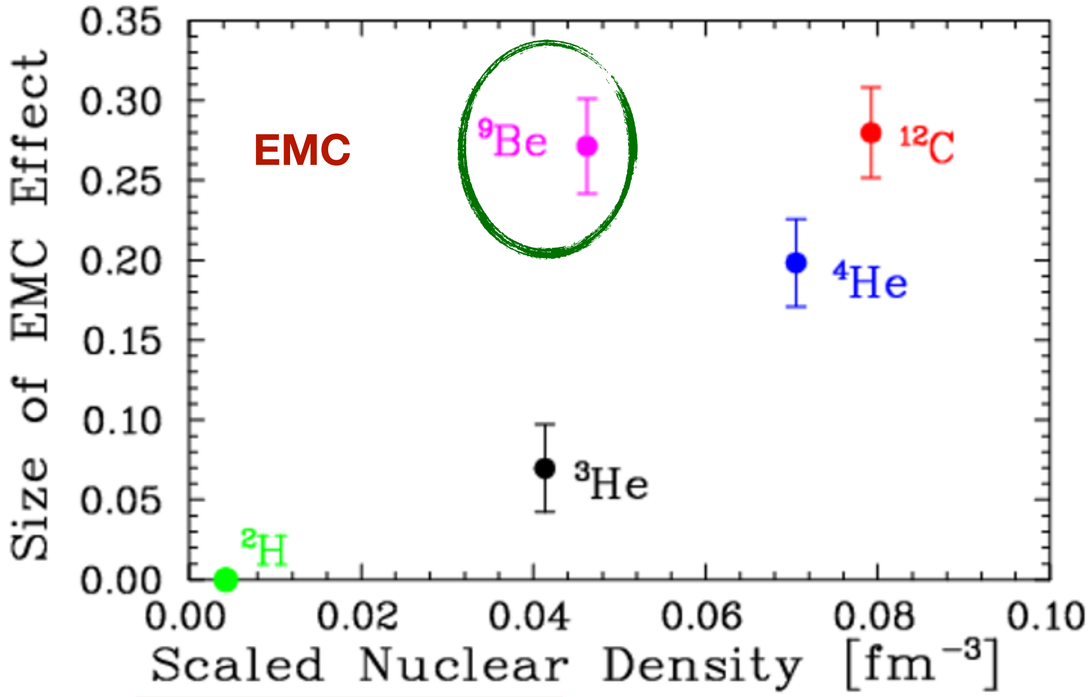

***Hall C E03-103: Precision Results on Light Nuclei***

- Emphasis on light nuclei (4He, 9Be, 12C)
- Confirms the SLAC results
- Much better precision at high x
- Improved $^4$He statistics
- Additional light nuclei measurement with $^3$He

# THE EMC EFFECT: JLab E03-103 RESULTS

## $^9$Be does not fit the trend!

J. Seely et al, PRL 103



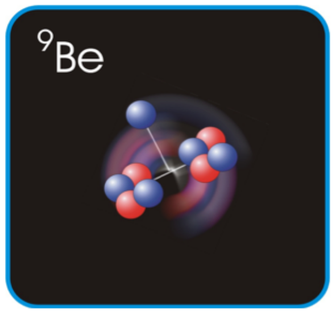

Density determined from *ab initio* few-body calculation
*S.C. Pieper and R.B. Wiringa, Ann. Rev. Nucl. Part. Sci 51, 53 (2001)*

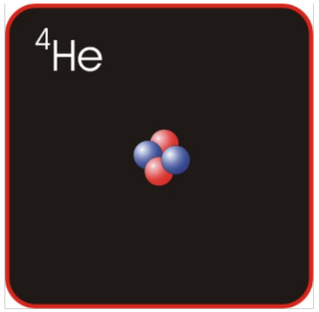
**average nuclear density was scaled by a factor of (A-1)/A to remove the struck nucleon's contribution to the average nuclear density*

## *Hall C E03-103: Precision Results on Light Nuclei*

$^9$Be → **strong alpha clustering**

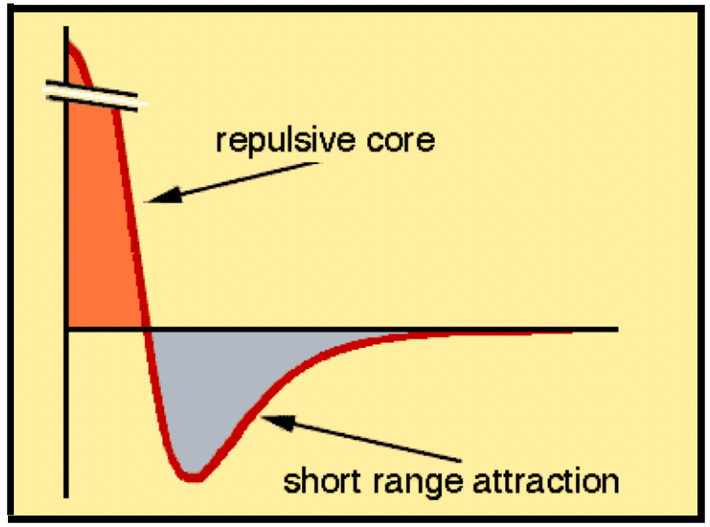
**3 body system** of **2 alpha clusters** and **a neutron**

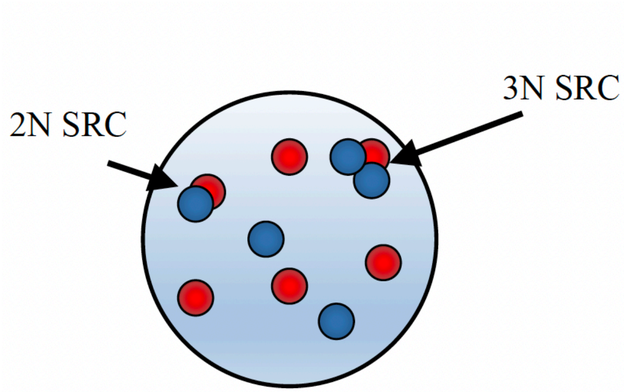



**EMC effect seems to follow local density rather than average density!**

# LOCAL DENSITY → SHORT RANGE CORRELATIONS



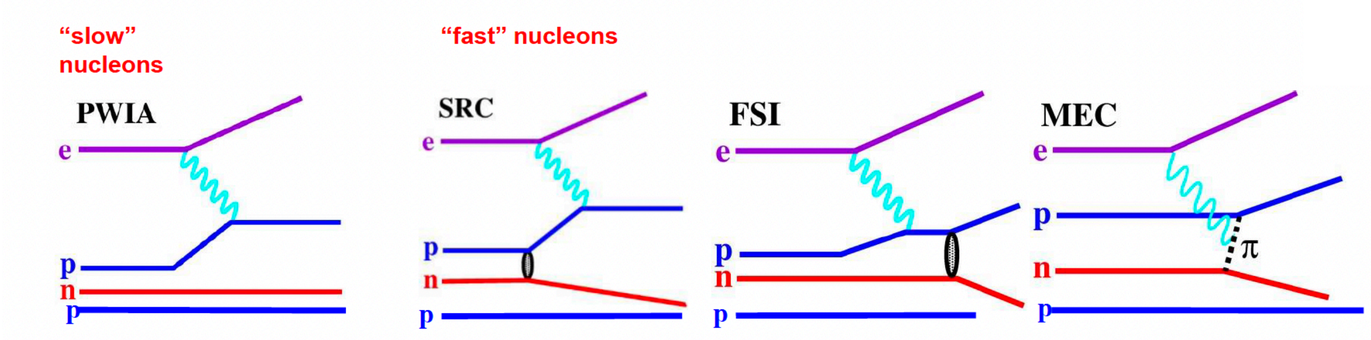

***What drives high local density in the nucleus?***

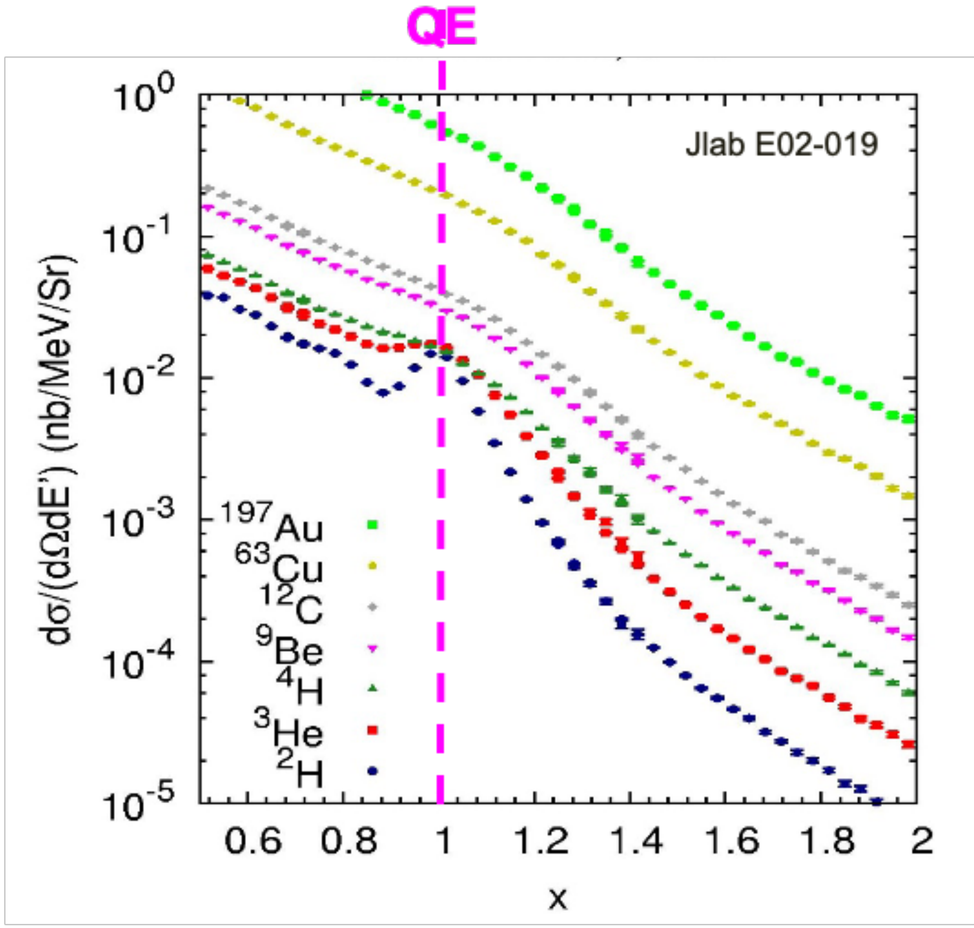
**The short-distance part of the nucleon-nucleon interaction:**

- **A hard short-range repulsive core + strong intermediate-range tensor attraction**
- These strong interactions between nucleons at short distance yield **high-momentum components in the nucleon momentum distributions in nuclei**
- **Pairs of nucleons with high back to back momenta: short range correlations**

# MEASURING THE SHORT RANGE CORRELATIONS

- To measure the relative probability of finding a correlation, ratios of heavy to light nuclei are taken
- To experimentally probe SRCs, must be in the high-momentum region (x>1): QE scattering
- If the high momentum nucleons in nuclei come from correlated pairs, ratio of A/D should show a plateau.
- FSIs are thought to be confined to the SRCs so cancel in the cross section ratios

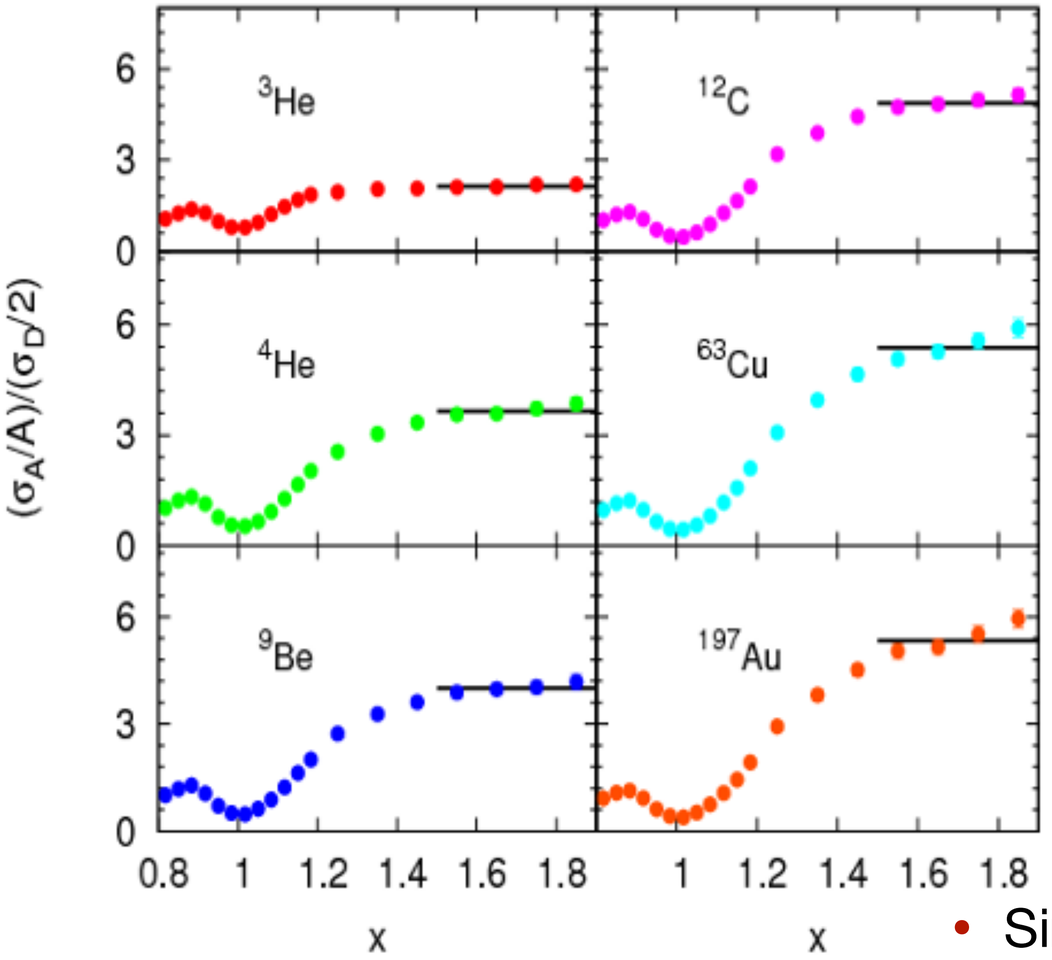


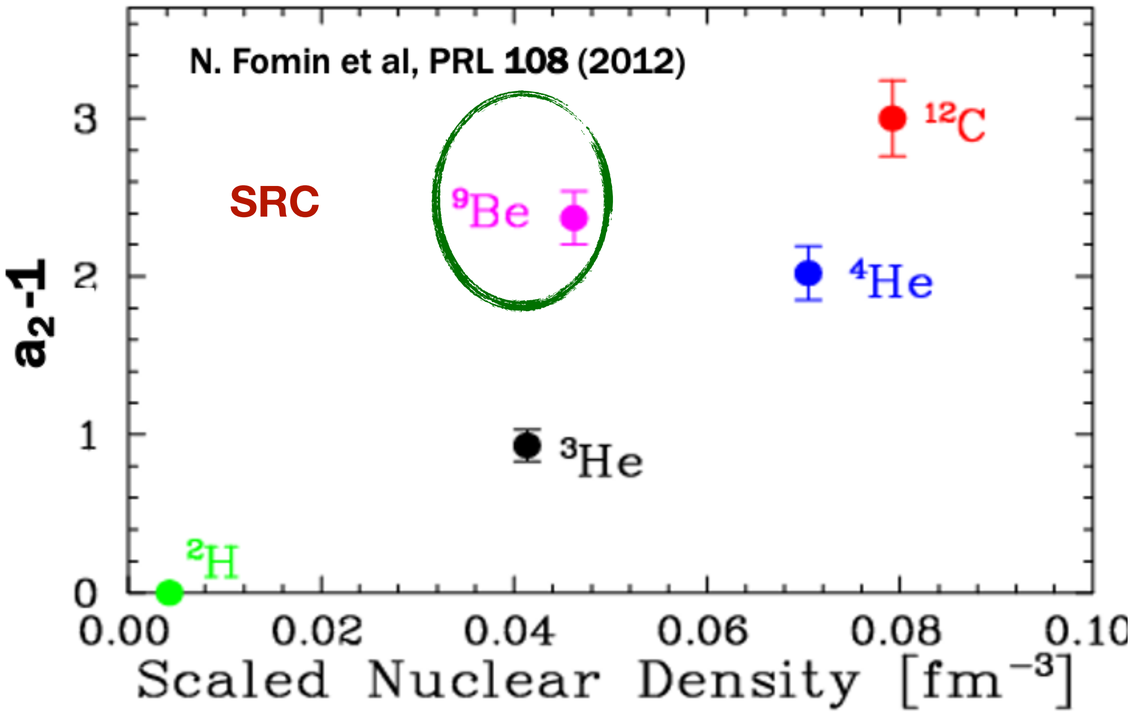




$$\frac{2}{A}\frac{\sigma_A}{\sigma_D} = a_2(A)$$

# JLab HALL C 6 GeV 2N SRC RESULTS

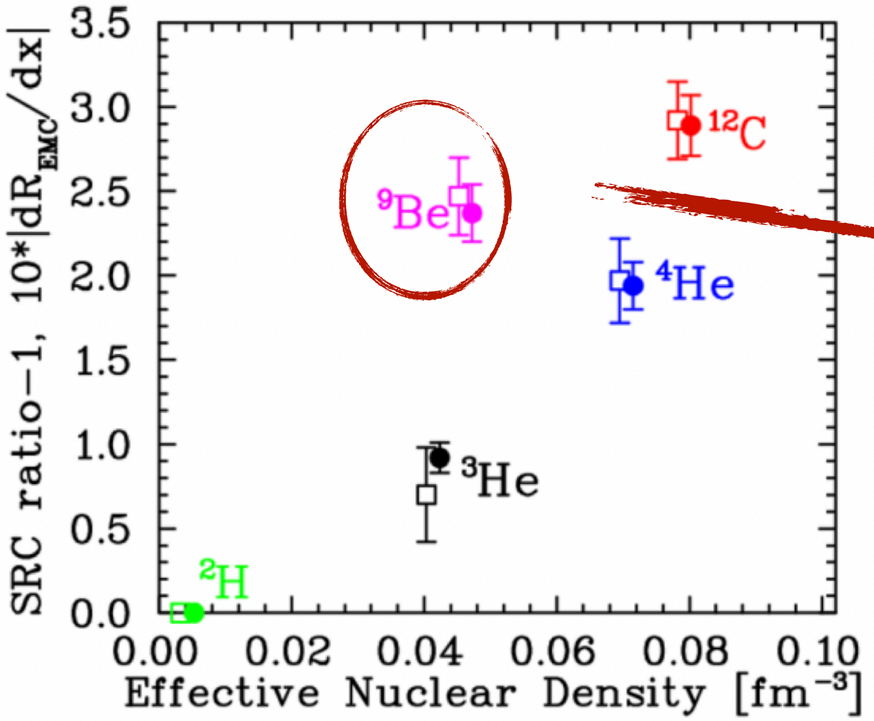
***Hall C E02-019: Precision Results on Light Nuclei***




- Similar pattern with the SRC measurements in light nuclei
- Suggesting a possible connection between the EMC and SRC?

# EMC-SRC CORRELATION



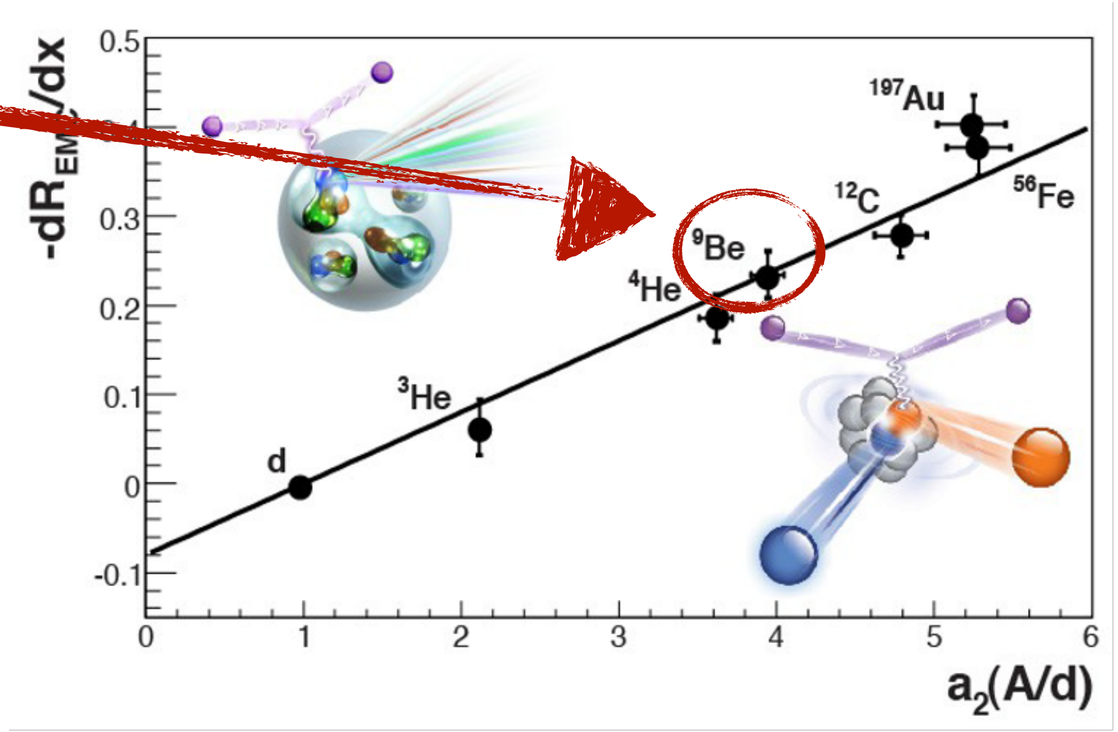

J. Seely, et al., PRL103, 202301 (2009)

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

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

**9Be strengthens the case!**

**Linear correlation between the size of the EMC effect and SRC plateau**

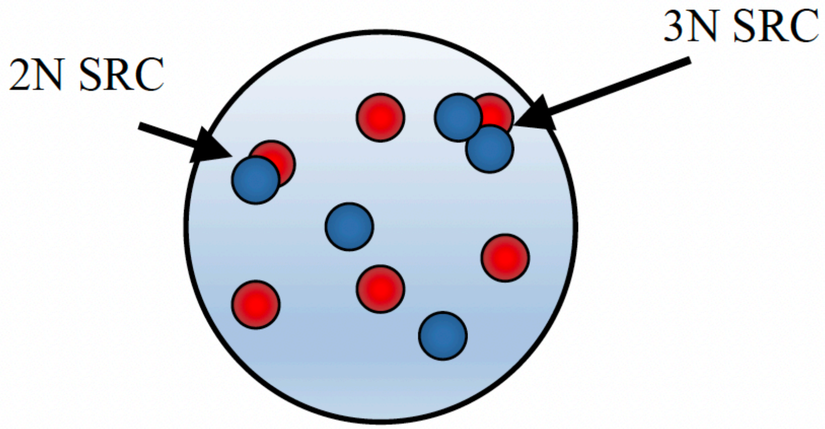



O. Hen, et al, PRC 85, 047301 (2012)

L. Weinstein, et al., PRL 106, 052301 (2011)

**Quantitative test of level of correlation between two effects**

# 3N SHORT RANGE CORRELATIONS




$1.4 < x < 2$ => 2 nucleon correlation

$2.4 < x < 3$ => 3 nucleon correlation

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

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

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

**Well established 2N SRC presence in 1.4<x<2**

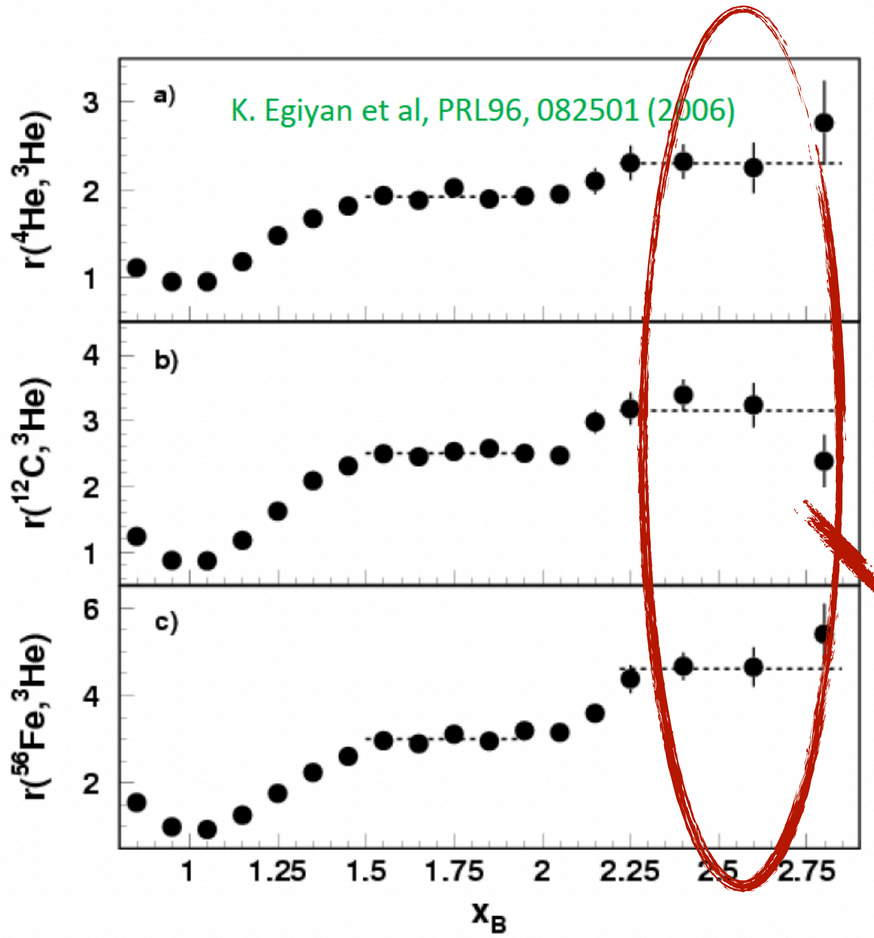
**3N SRCs: leading to a second plateau (A/3He) at x>2 ???**

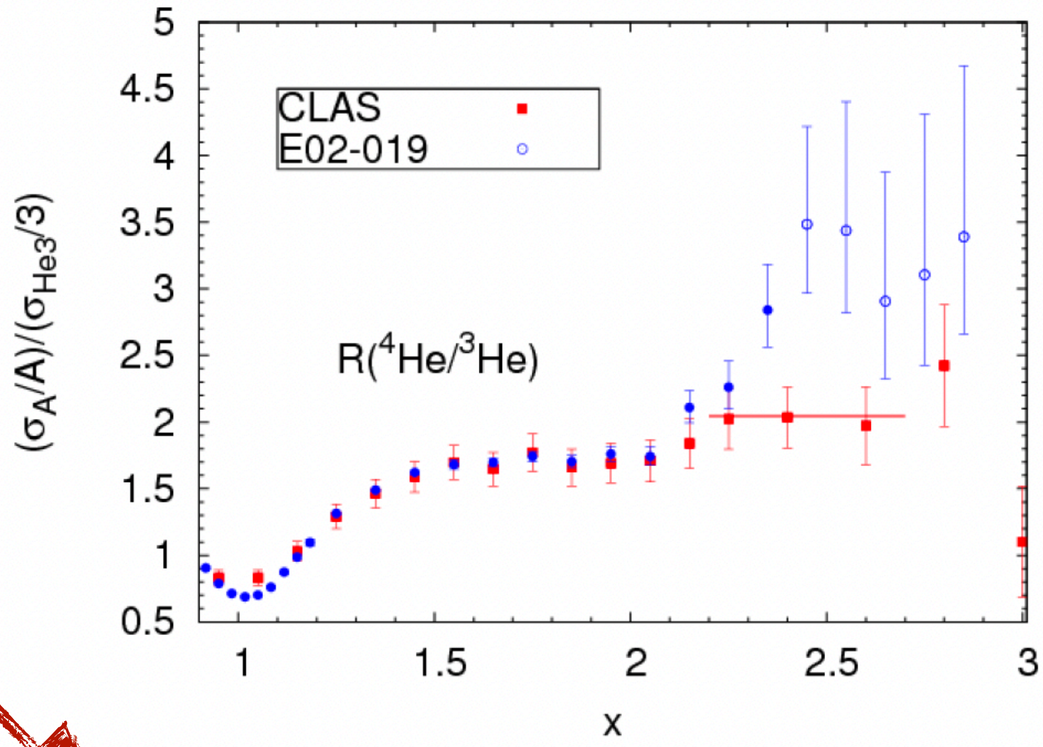
**3N-SRCs: theoretically possible but never observed experimentally**

**3N-SRCs: Where to look at?**

- Rapid fall off of the mean field contributions, makes it easy to determine the kinematic onset of the 2N-SRCs!
- Kinematics needed to isolate 3N-SRCs is much less clear 2N-SRCs fall more slowly than mean field contributions
- Kinematic onset of the 3N-SRCs is very sensitive to the size and nature of the 3N-SRCs (model-dependent)
- Searches for 3N-SRCs had to take A/3He cross sections at whatever Q2 values were accessible and look for a clear plateau in x for x well above 2, to suppress the 2N-SRCs

# SEARCHING FOR 3N SRCs



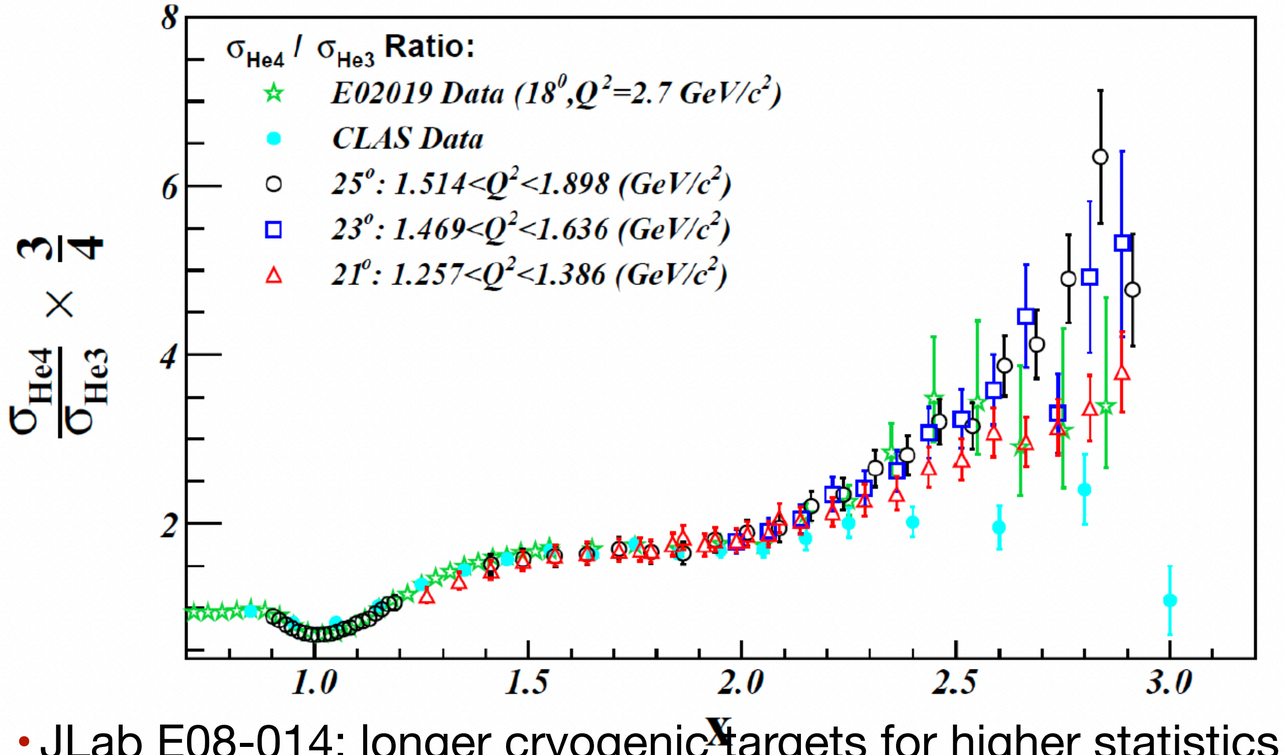

<$Q^2$> ($GeV^2$): *CLAS: 1.6* *E02-019: 2.7*

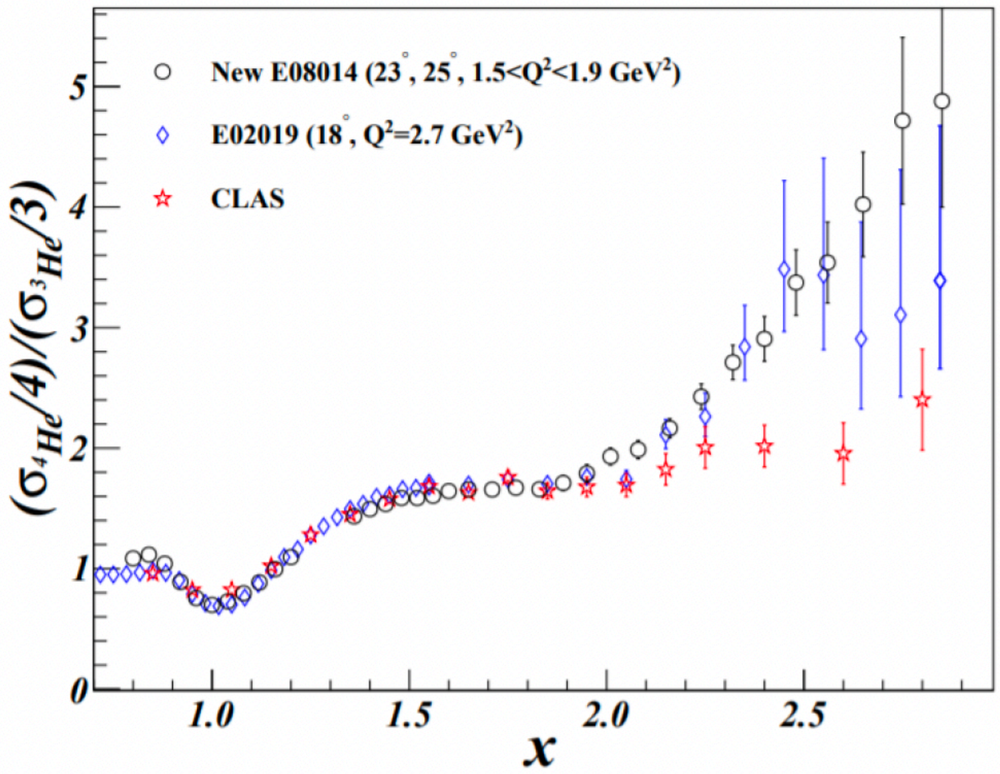
Comment on "Measurement of Two- and Three-Nucleon Short-Range Correlation Probabilities in Nuclei"

Douglas W. Higinbotham and Or Hen
Phys. Rev. Lett. **114**, 169201 – Published 24 April 2015

**Artifact of bin migration associated with 1% momentum resolution in CLAS detector**

# SEARCHING FOR 3N SRCs

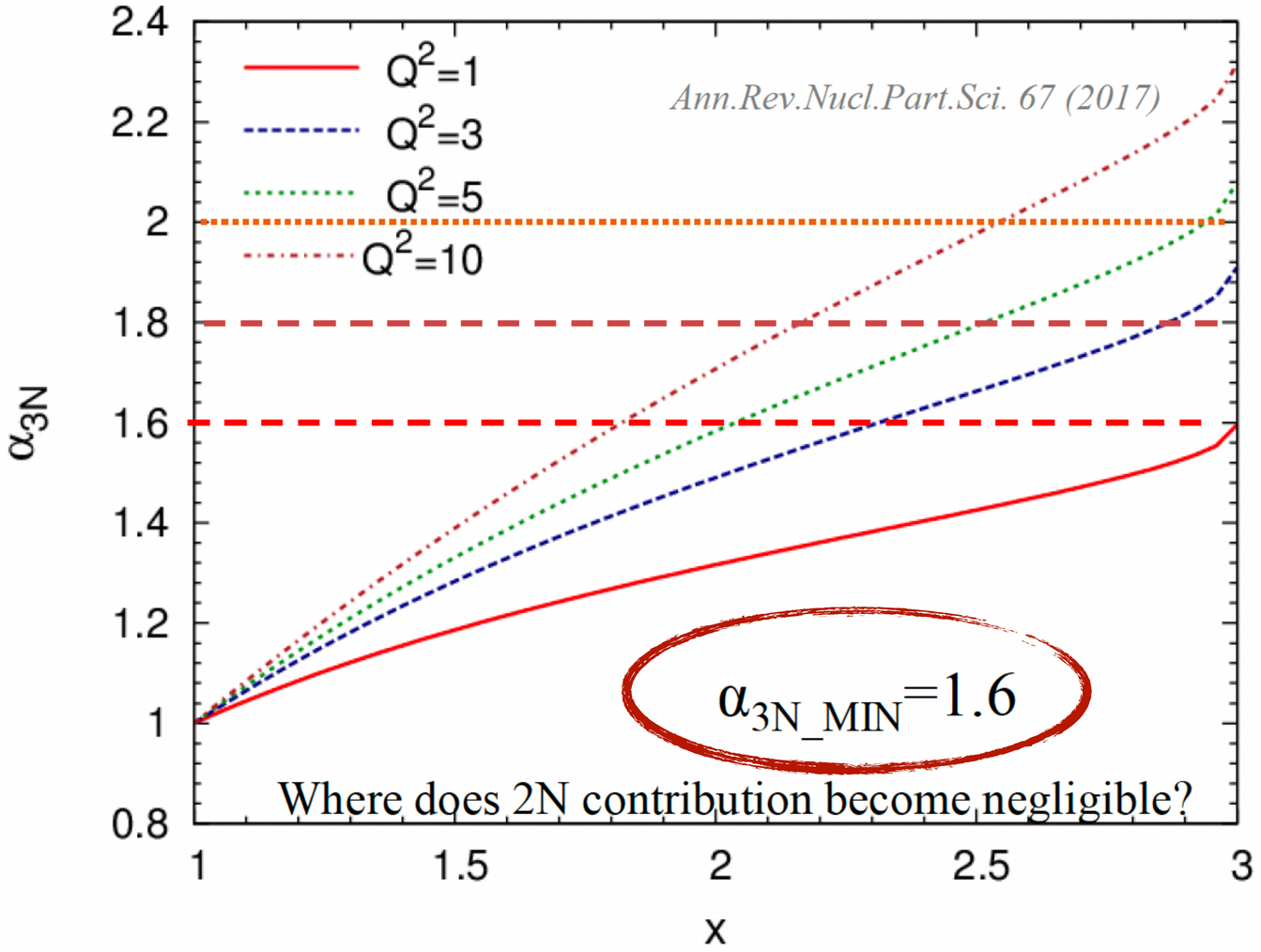



- JLab E08-014: longer cryogenic targets for higher statistics
- Overlapped kinematics with CLAS
- Results consistent with Hall C data, disagreed with CLAS results
- No second plateau observed

*Z. Ye et al, PRC 97 (2018) 6*

# SEARCHING FOR 3N SRCs

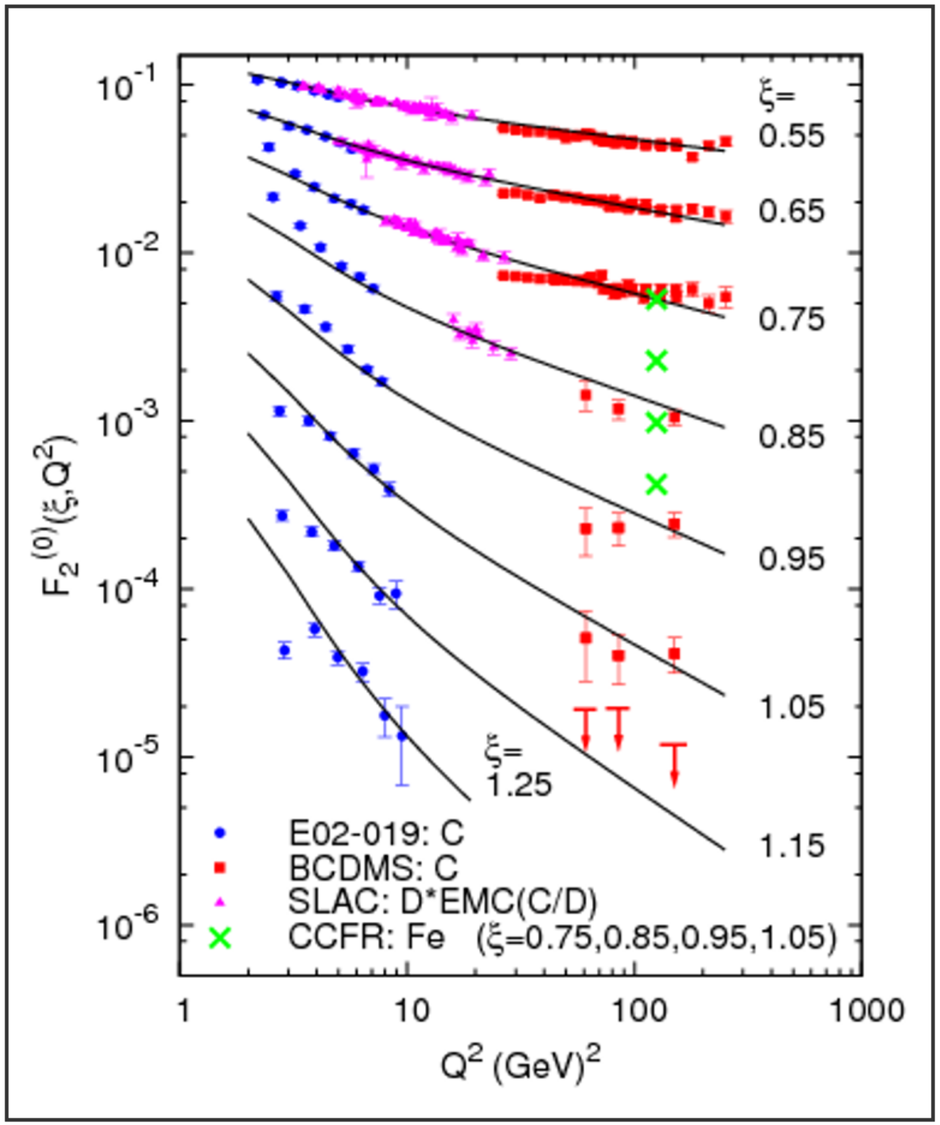



12 GeV Hall C x>1 measurement aimed to reach the highest Q2 in the minimal amount of time.

$\alpha i$ represents the light-cone momentum fraction of 3N SRCs carried by the correlated nucleon $i$

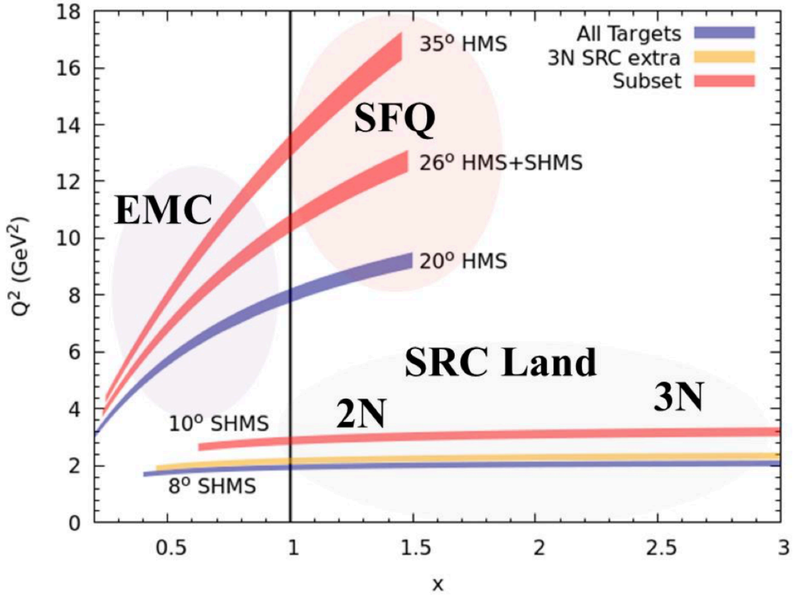
# SUPERFAST QUARKS

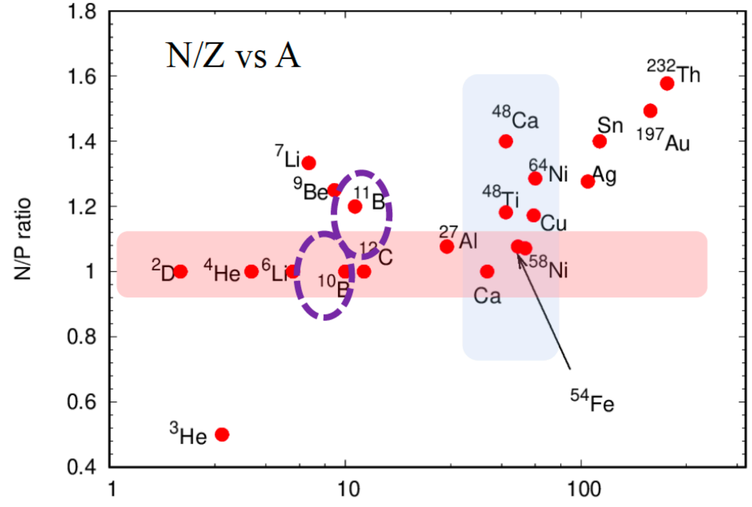
- The quark distributions in nuclei at large x are poorly understood
- An additional way to look for the effect of short range correlations
- High sensitivity to non-hadronic components of nuclear structure in these high density, short range configurations within nuclei
- Higher Q2 reach:
  - small QE scattering contribution to the total cross section
  - much smaller scaling violations



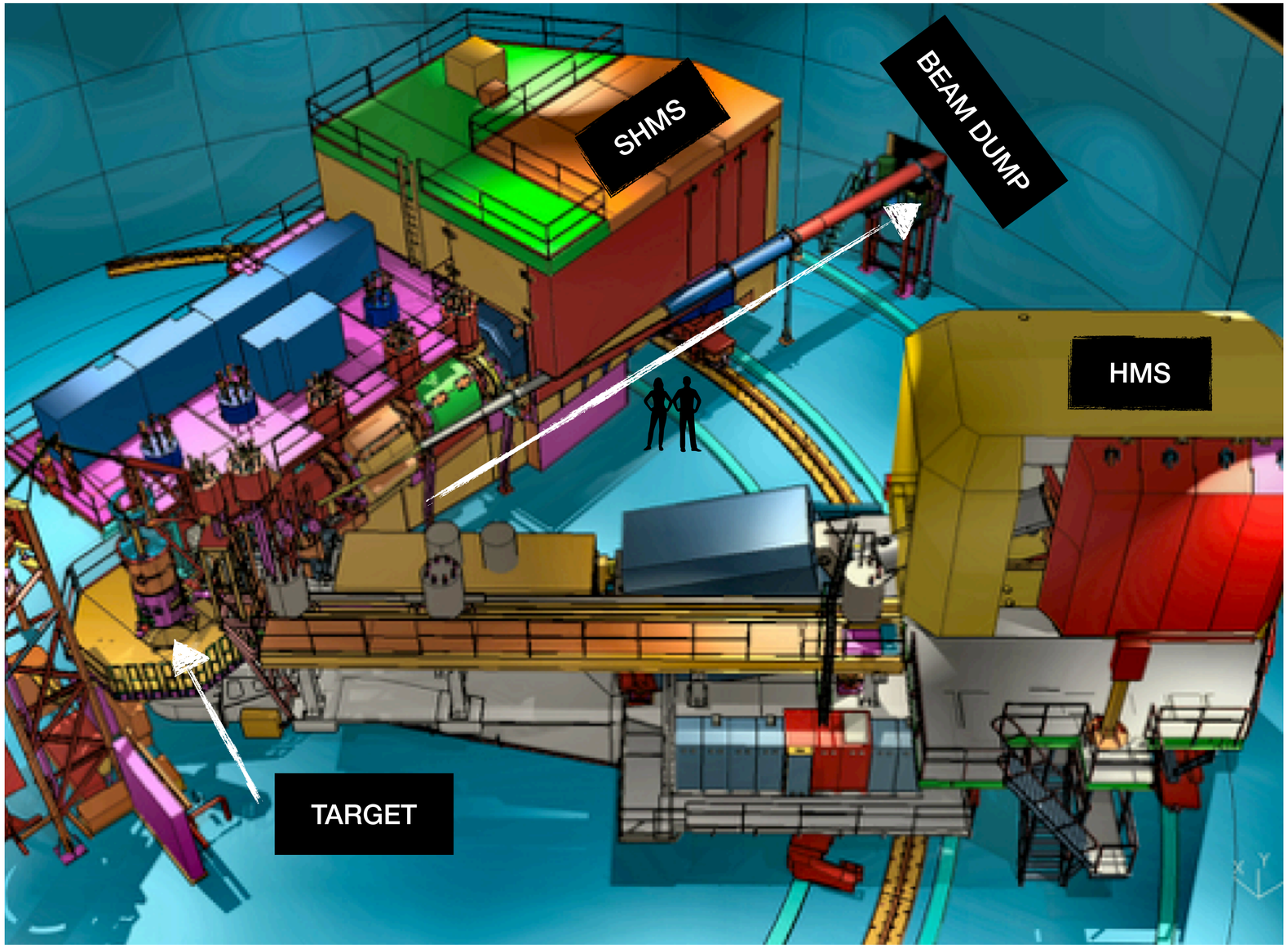
# x>1 and EMC EFFECT EXPERIMENTS in 12 GeV Hall C

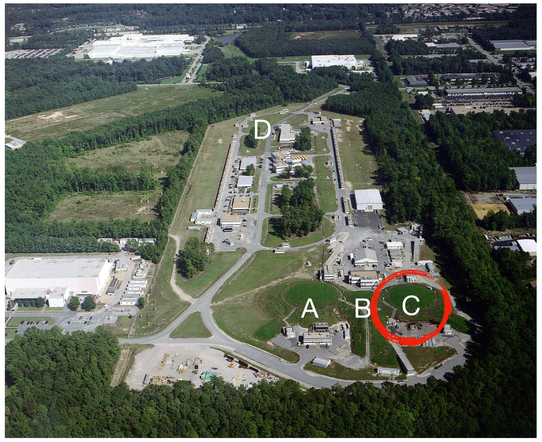
- Covered x and Q2 range allows measurement of nuclear dependence of EMC effect, 2N- and 3N- SRCs, and SFQ.
  - If observed, 3N-SRC would be its first experimental observation ever!
- More measurements on well understood light nuclei but also heavy nuclei
- First measurement on the Boron isotopes - crucial for the clustering effects
- Heavy nuclei including 40Ca, 48Ca and Cu and additional heavy nuclei of particular interest for EMC-SRC correlation studies
- Explore N/Z dependence at fixed A and A dependence at fixed N/Z
- Q2 dependence studies at larger angles



# XEM2 EXPERIMENTAL SETUP in HALL C




## Experimental Setup

- 10.5 GeV electron beam
- Several cryogenic and solid targets
- Each spectrometer equipped with: hodoscopes, drift chambers, cherenkovs, electromagnetic calorimeters.
- **SHMS:** x>1 measurement
- **HMS:** EMC and SFQ measurement

# SMALL SUBSET OF THE DATA TAKEN IN 2018/19

## Overview of the experiment( E12-10-008) Phase - I

- Ran during spring 2018 concurrently with E12-10-002 ($F_2$) as a part of commissioning experiment in HallC
- Measurement of inclusive electron scattering cross section from lighter Nuclei
  - Cryo tragets: H, $^{2}H$
  - Solid targets: Be, C, Al, $^{10,11}B$ (Al for cell wall subtraction)
- Single-arm measurement
- Unpolarized electron beam energy 10.6 GeV
- Data were taken at a single ( $Q^2$) /angle ($21^0$)
  - Additional data on C were taken at larger angle to investigate detailed Q2-dependence of the EMC ratios

**First Measurement of EMC effect in $^{10,11}B$**

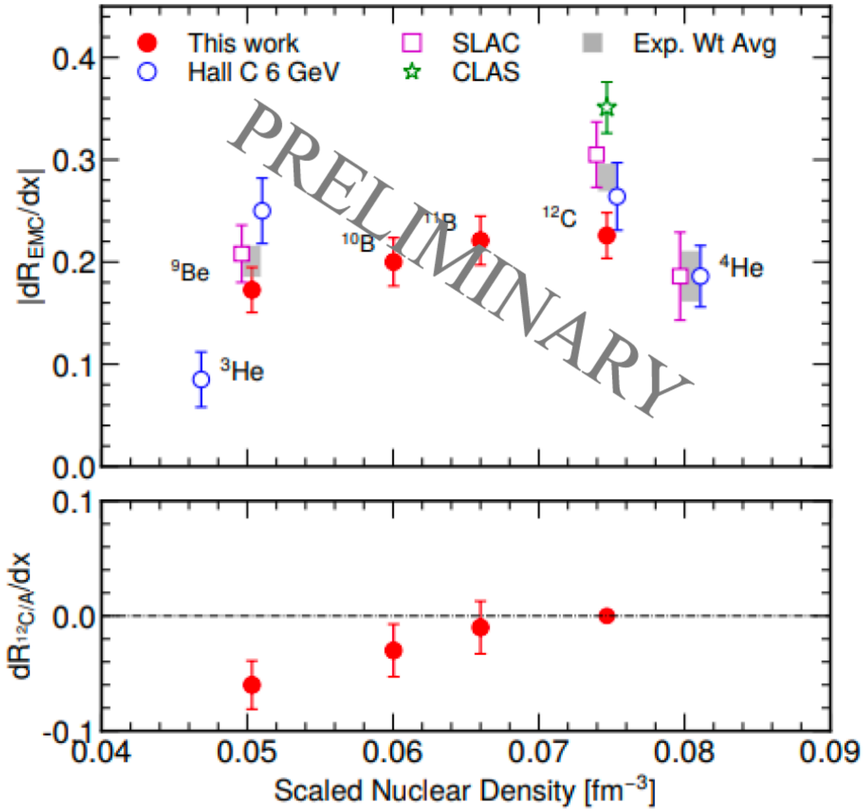
***Slide Credit: Abishek Karki***

# FIRST PUBLICATION FROM COMMISSIONING DATA SUBMITTED TO PRL

**First Measurement of the EMC Effect in $^{10}$B and $^{11}$B**

A. Karki,[1] D. Biswas,[2,*] F. A. Gonzalez,[3] W. Henry,[4] C. Morean,[5] A. Nadeeshani,[2] A. Sun,[6] D. Abrams,[7] Z. Ahmed,[8] B. Aljawrneh,[9,†] S. Alsalmi,[10] R. Ambrose,[8] D. Androic,[11] W. Armstrong,[12] J. Arrington,[13] A. Asaturyan,[14] K. Assumin-Gyimah,[1] C. Ayerbe Gayoso,[15,1] A. Bandari,[15] J. Bane,[5] J. Barrow,[5] S. Basnet,[8] V. Berdnikov,[16] H. Bhatt,[1] D. Bhetuwal,[1] W. U. Boeglin,[17] P. Bosted,[15] E. Brash,[18] M. H. S. Bukhari,[19] H. Chen,[7] J. P. Chen,[4] M. Chen,[7] M. E. Christy,[2] S. Covrig,[4] K. Craycraft,[5] S. Danagoulian,[9] D. Day,[7] M. Diefenthaler,[4] M. Dlamini,[20] J. Dunne,[1] B. Duran,[21] D. Dutta,[1] C. Elliott,[5] R. Ent,[4] H. Fenker,[4] N. Fomin,[5] E. Fuchey,[22] D. Gaskell,[4] T. N. Gautam,[2] J. O. Hansen,[4] F. Hauenstein,[23] A. V. Hernandez,[16] T. Horn,[16] G. M. Huber,[8] M. K. Jones,[4] S. Joosten,[12] M. L. Kabir,[1] N. Kalantarians,[24] C. Keppel,[4] A. Khanal,[17] P. M. King,[20] E. Kinney,[25] H. S. Ko,[26] M. Kohl,[2] N. Lashley-Colthirst,[2] S. Li,[27] W. B. Li,[15] A. H. Liyanage,[2] D. Mack,[4] S. Malace,[4] P. Markowitz,[17] J. Matter,[7] D. Meekins,[4] R. Michaels,[4] A. Mkrtchyan,[14] H. Mkrtchyan,[14] S. Nanda,[1] D. Nguyen,[7] G. Niculescu,[28] I. Niculescu,[28] Nuruzzaman,[29] B. Pandey,[2] S. Park,[3] E. Pooser,[4] A. J. R. Puckett,[22] M. Rehfuss,[21] J. Reinhold,[17] N. Santiesteban,[27] B. Sawatzky,[4] G. R. Smith,[4] H. Szumila-Vance,[4] A. S. Tadepalli,[29] V. Tadevosyan,[14] R. Trotta,[16] S. A. Wood,[4] C. Yero,[17] and J. Zhang[3,‡]

(for the Hall C Collaboration)




***Analysis by Abishek Karki (MSU)***

# SMALL SUBSET OF THE DATA TAKEN IN 2018/19

**E12-06-105 PHASE I**

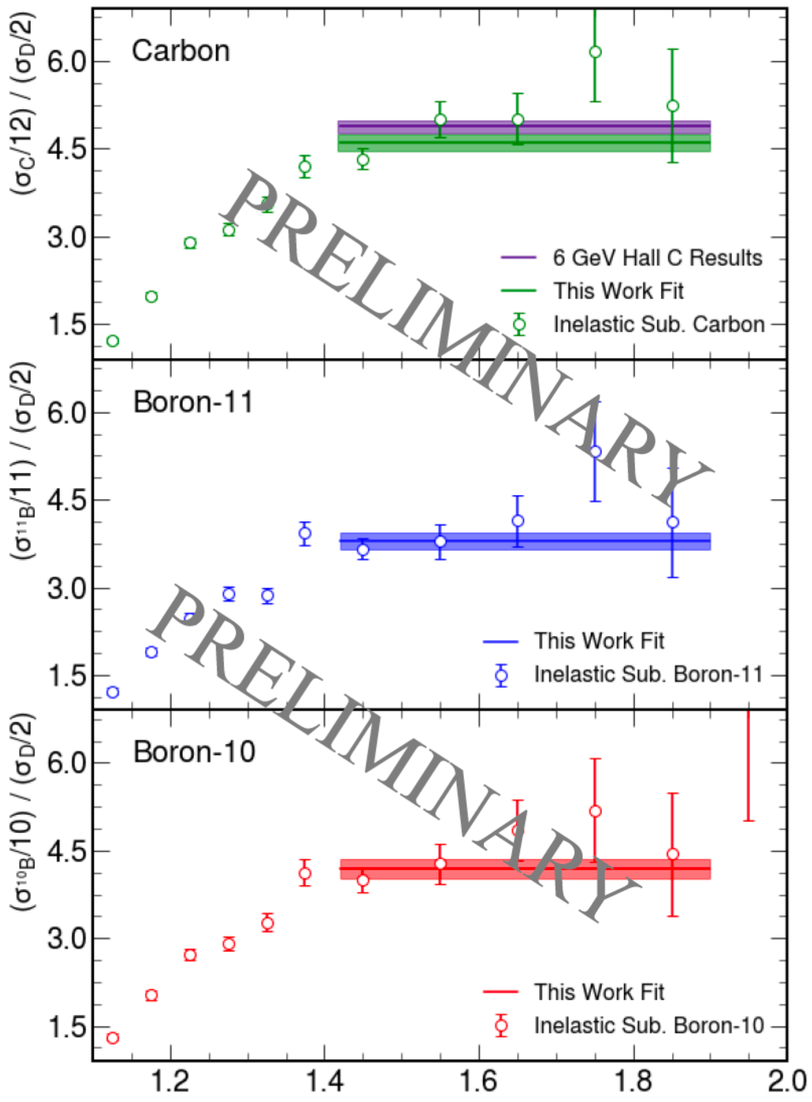
| 2018 | |
|---|---|
| Central Momentum | 9.8 GeV |
| $Q^2$ | 2.08 |
| Angles | 8.02 |
| Elements | H, D, C, Al, $^{9}$Be,$^{10}$**B**,$^{11}$**B** |

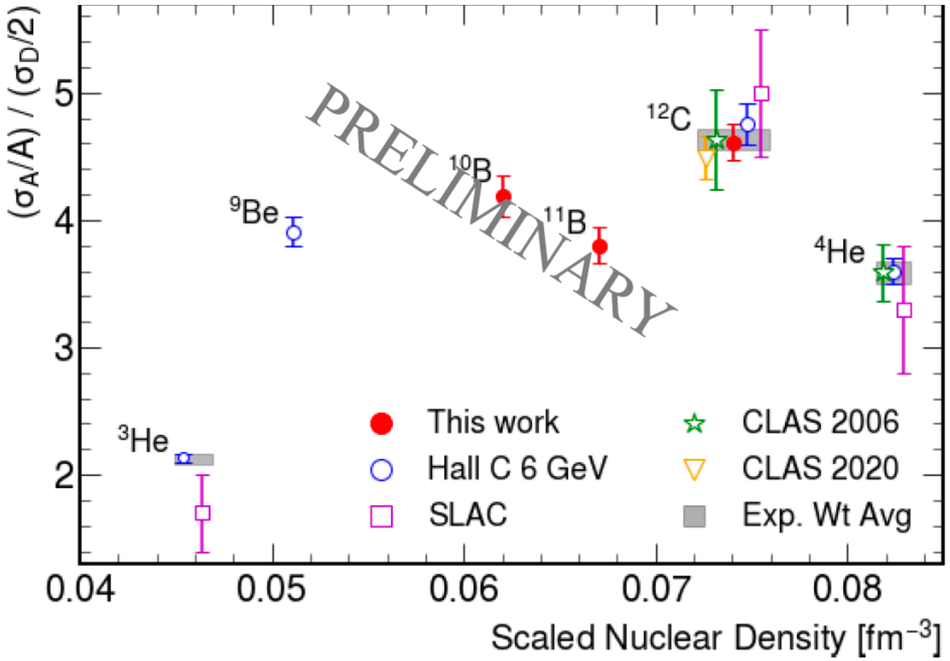
| 2019 | |
|---|---|
| Central Momentum | 9.8 GeV |
| $Q^2$ | 4.46 |
| Angle | 13.10 |
| Elements | H, D, C, Al, $^{10}$**B**,$^{11}$**B** |

*Boron targets are boron carbide $B_4C$

***Slide Credit: Casey Morean***

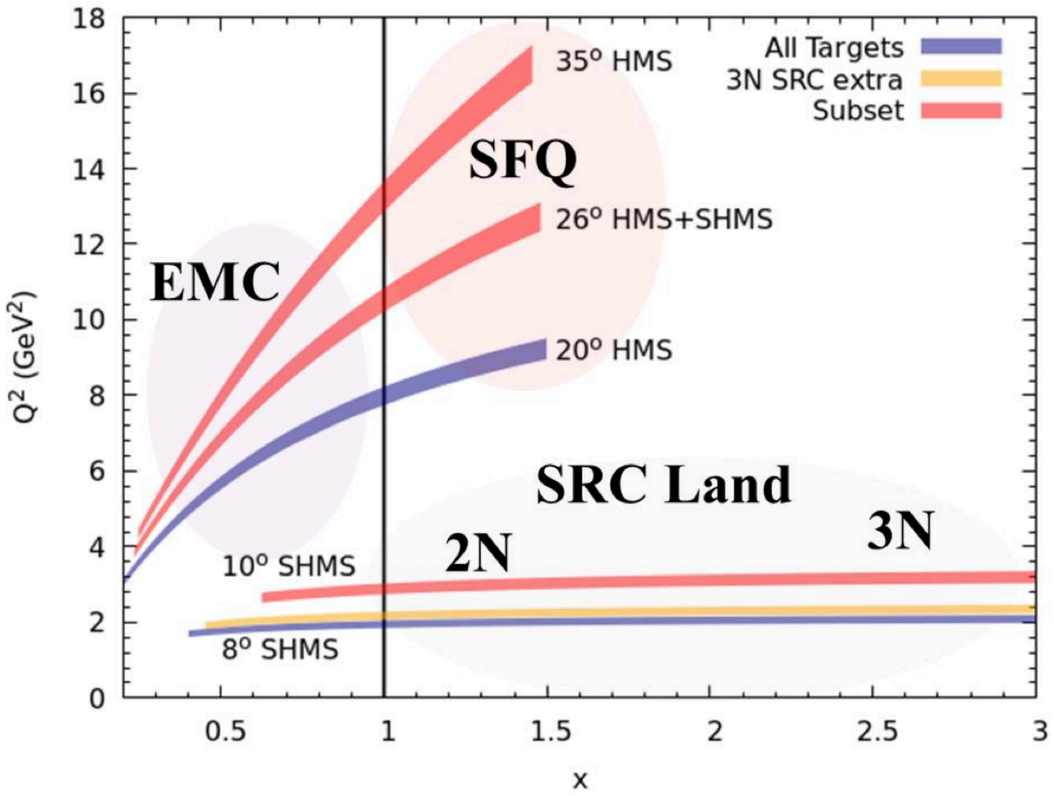
# PRELIMINARY RESULTS on B10 and B11 (2019)




***Analysis by Casey Morean (UTK)***

# XEM2 September 2022 - February 2023

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Detailed Studies of the nuclear dependence of $F_2$ in light nuclei

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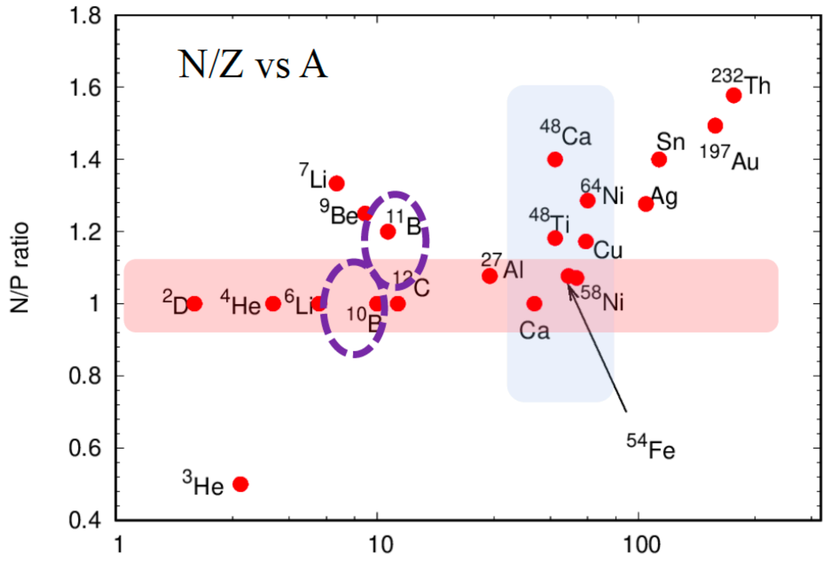
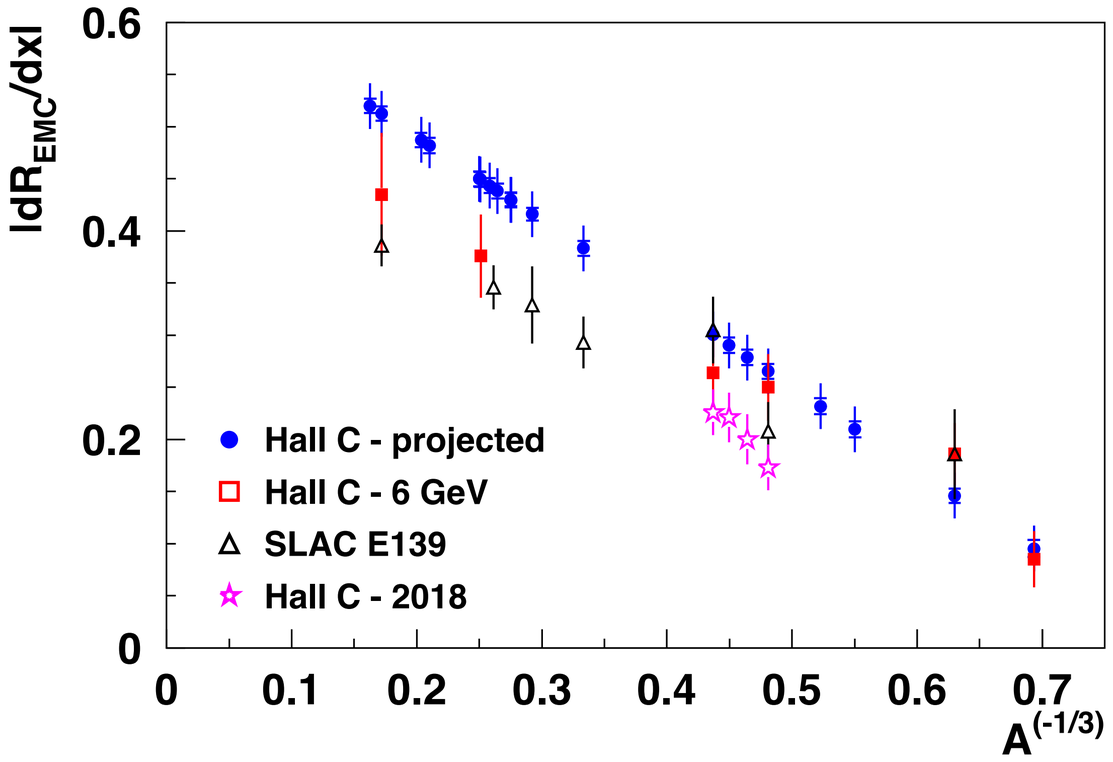
Inclusive Scattering from Nuclei at x>1 in the quasielastic and deeply inelastic regimes

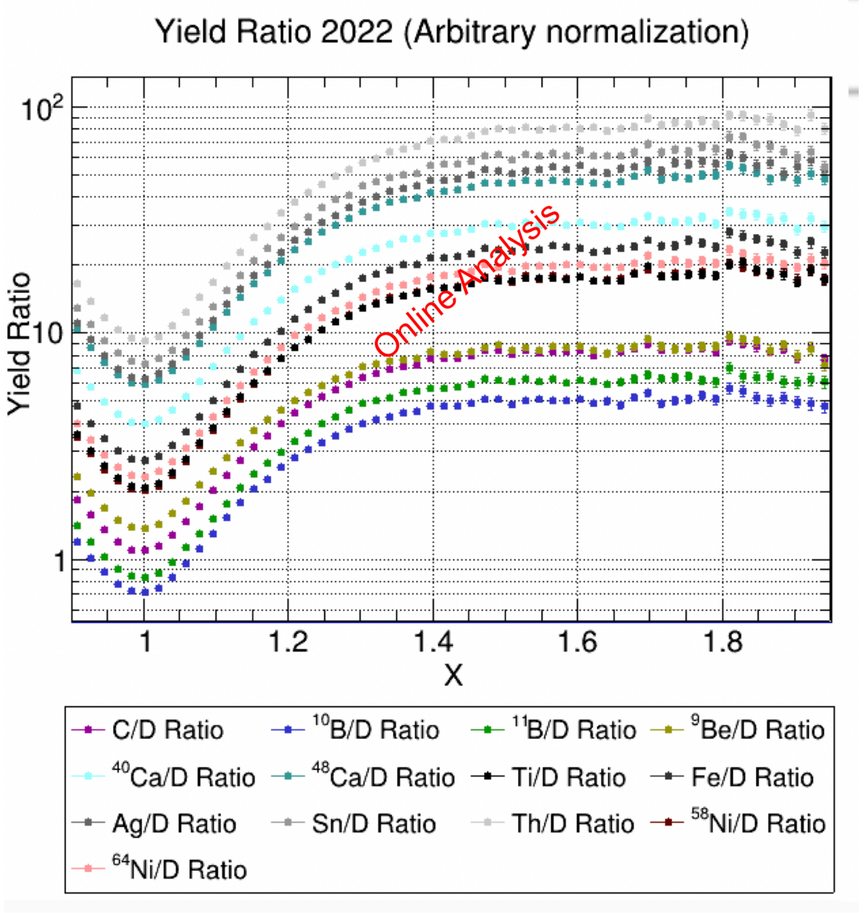


# CURRENT ANALYSIS STATUS

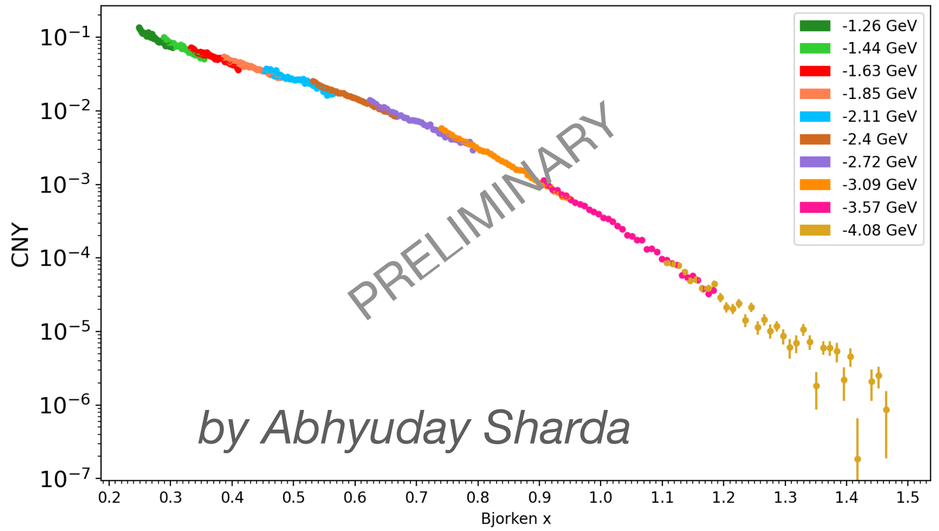
- Data quality checks
- Reference and timing window cuts determination
- Detector calibrations in progress (almost done)
- Initial look at elastic data for the spectrometer offset determination in progress
- Initial look at data to MC comparisons

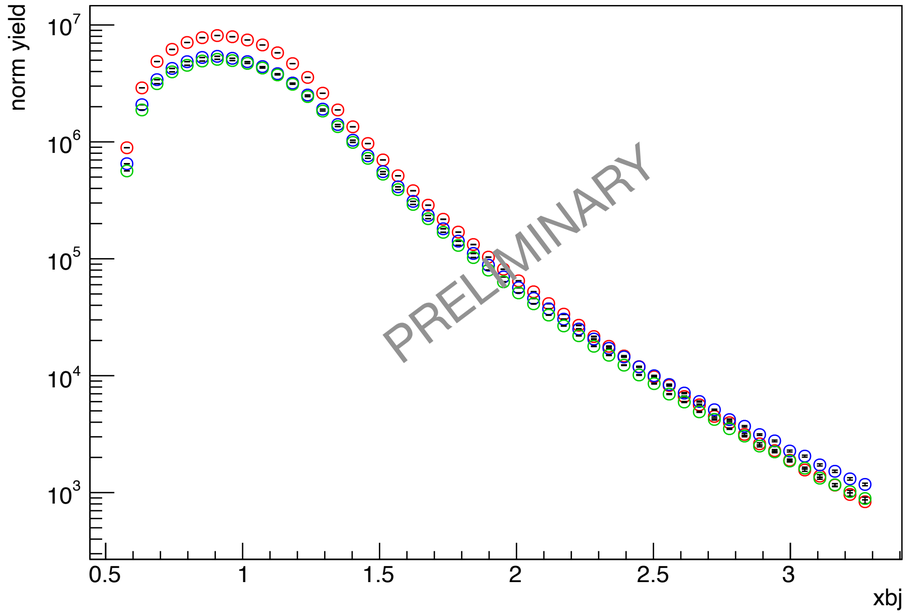


# SUMMARY




*by Casey Morean*



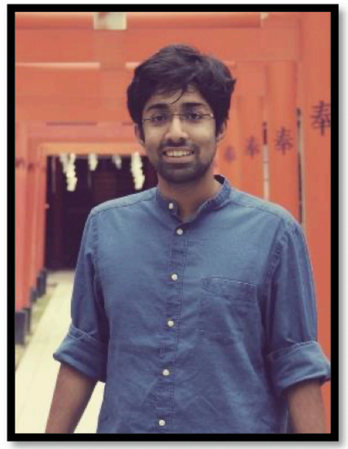



Cameron Cotton
UVA

Ryan Goodman
UTK

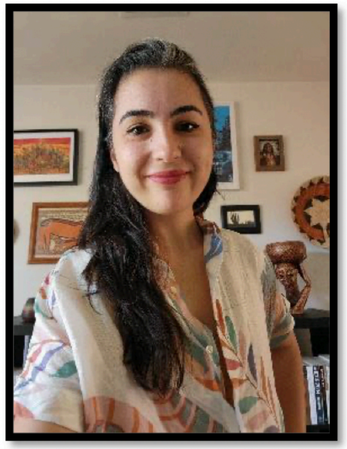
Abishek Karki
MSU

Casey Morean
UTK

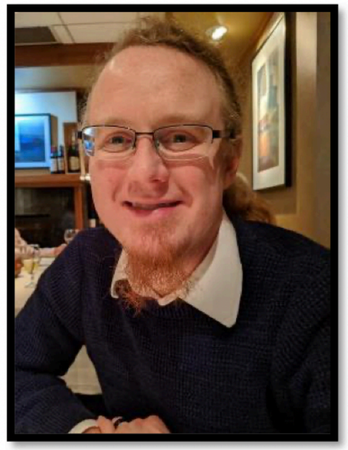


Abhyuday Sharda
UTK

Zoe Walters - UNH
Ramon Ogaz - UTK
Sebastian Vasquez - UCR



Burcu Duran
UTK



Tyler Hague
LBL

Shujie Li
LBL

<u>Spokespersons</u>
Nadia Fomin, Dave Gaskell, John Arrington, Donal Day, Aji Daniel

**THANK YOU!**

# BACK UP SLIDES