A New Measurement of the EMC Ratios in Lighter Nuclei

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Joint Hall A/C

Summer Collaboration

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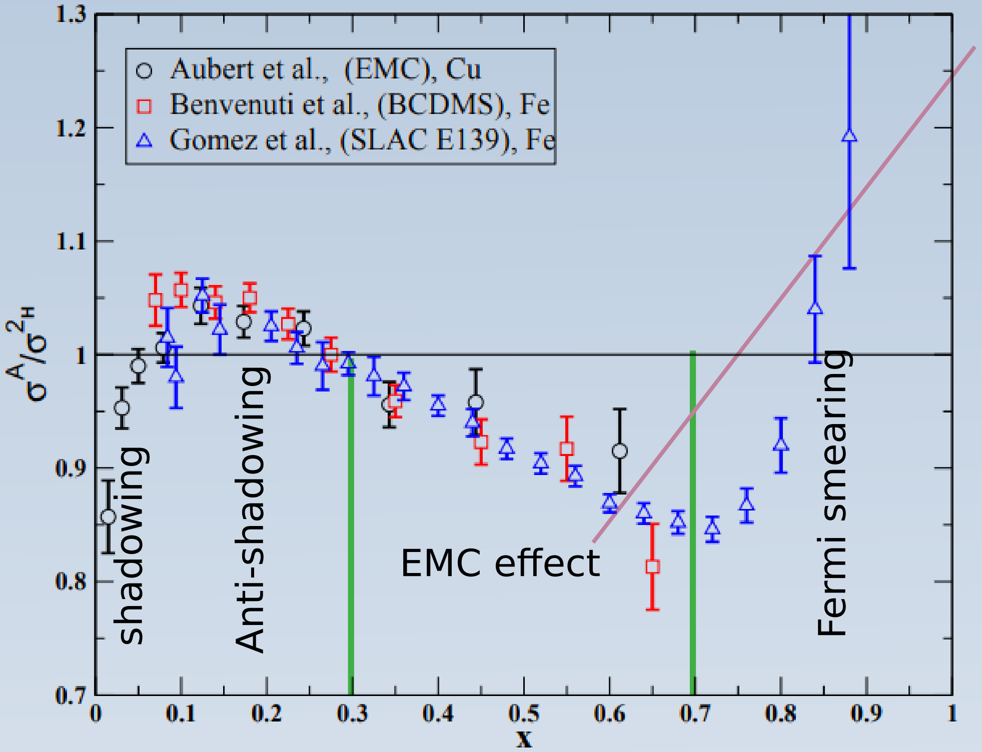
* This research is supported by U.S. DOE grant Number :DE-FGO2ER41528

Outline

- The EMC Effect
- Experiment Overview of E12-10-008
- Preliminary Result
- Summary

The EMC Effect



Quark distribution in nuclei are modified

- A program of dedicated measurements conducted at EMC(1983), BCDMS(1987), SLAC(1994), NMC(1995)
- 40 years, still no consensus

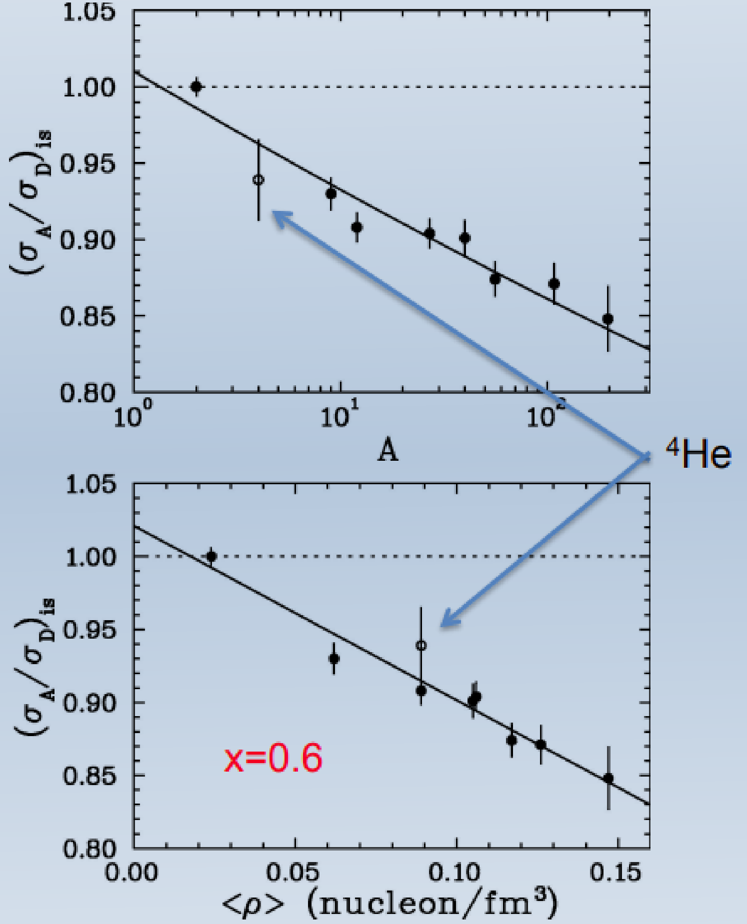
Origins of the EMC Effect

- The EMC effect cannot be described by calculations that include only “conventional” nuclear effects like fermi motion or binding (only when introducing off-shell effects)
- Early calculations using more interesting sources, like multi-quark clusters or dynamical re-scaling often treated the nucleus in a very simple manner (Fermi gas)
- More recent calculations describe the nucleus including QCD from the outset (Quark-meson coupling)
- The ideal model would include best description of the nucleus, and then incorporate “extra” effects as needed

The EMC Effect: Existing data at large x

SLAC E139 studied the *Nuclear dependence of the EMC effect at fixed x

- **SLAC E139**
  - Most precise large x-data
  - Nuclei from A = 4 to 197
- **Conclusions from SLAC E139**
  - Q^2-independent
  - Universal x-dependence for all A
  - A-dependent magnitude
    - Scales with log(A)
    - Scales with average density



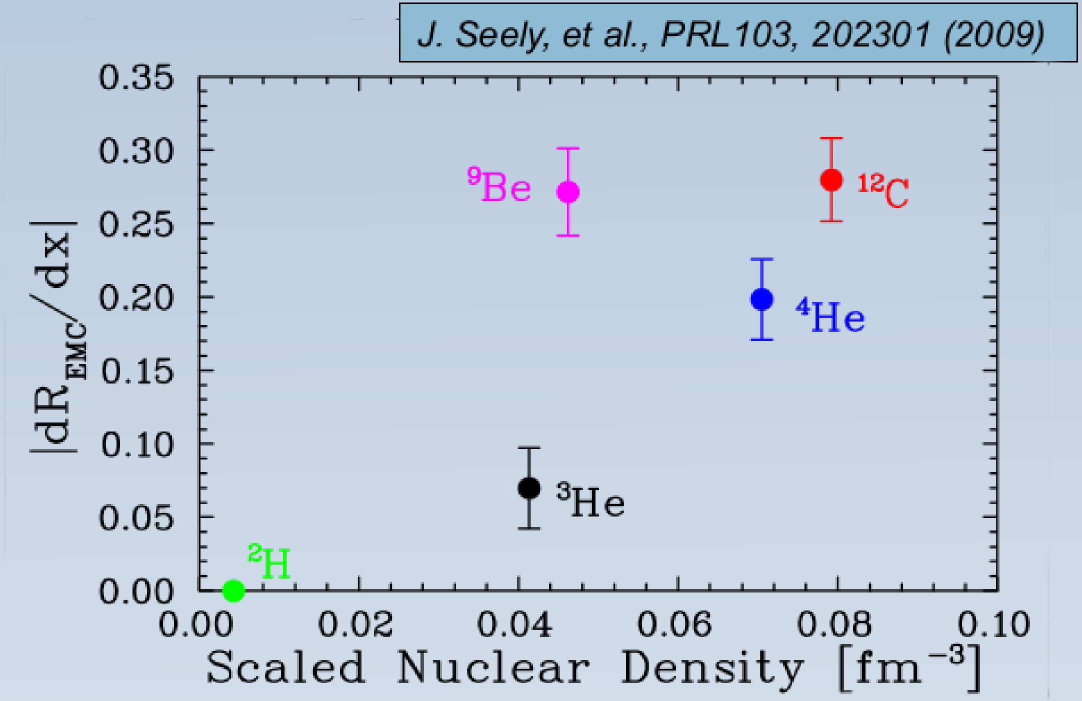
Gomez et al, PRD 49, 4348 (1994)

***Nuclear dependence** is interesting as it helps to provide more information to test models

Motivation: Jlab E03-103

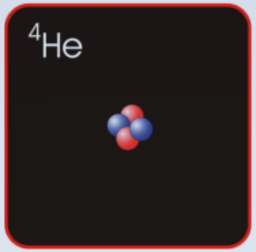
Measured σ_A/σ_D for ^{3}He, ^{4}He, Be, C

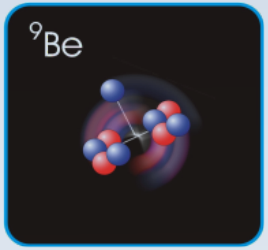
- ^{3}He, ^{4}He, C EMC effect scales well with density
- **^{9}Be** does not fit the trend



Conclusion:

- Both A and ρ dependent fits fail to describe these light nuclei
- Suggest that the EMC Effect does not scale with average nuclear density
- Hints that the effect may be driven by local environment

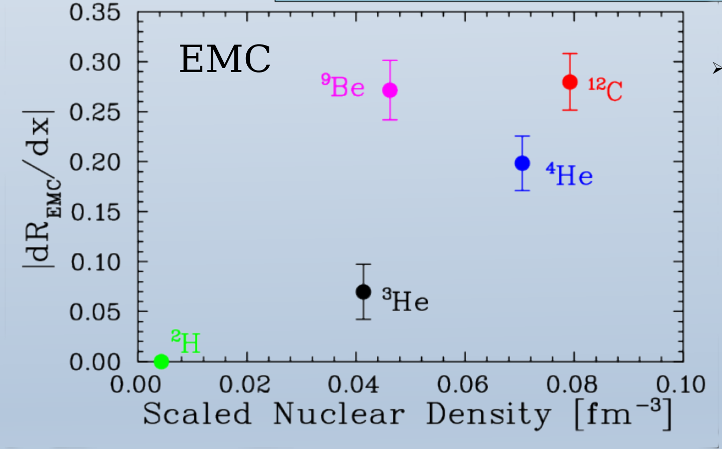




^{9}Be structure : 2α + n

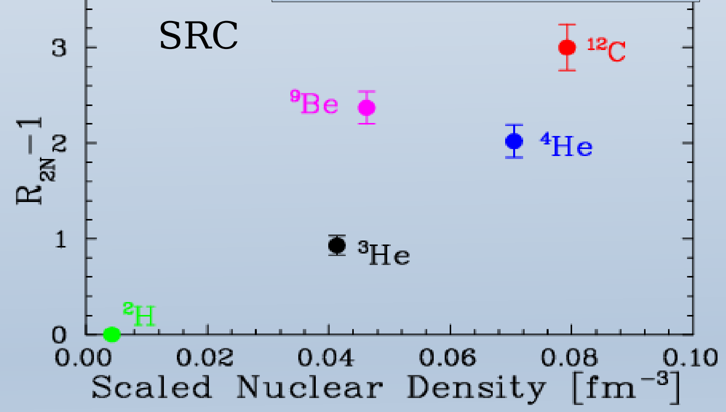
Motivation: SRC & EMC correlation

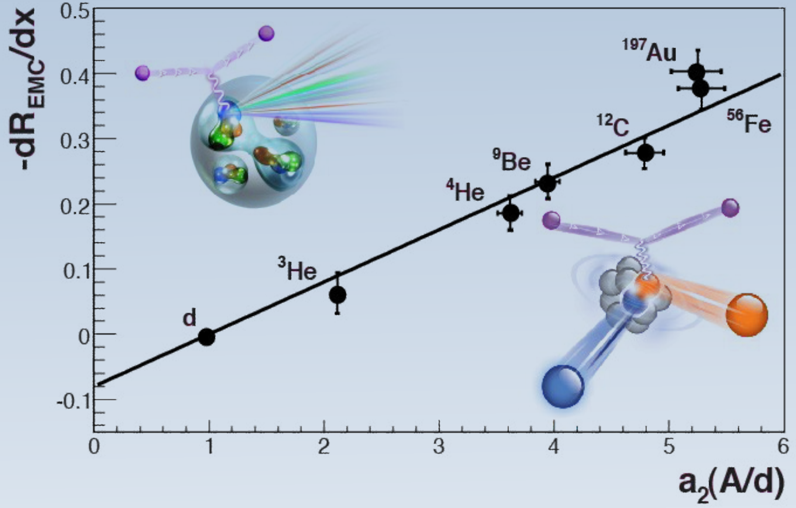
J. Seely, et al., PRL103, 202301 (2009)



- EMC-SRC connection became more intriguing with the addition of Be SRC data from JLab

N. Fomin et al, PRL 108 (2012)





N. Fomin, et al, PRL 108, 092052 (2012)
J. Arrington, A. Daniel, D. Day, N. Formin, D. Gaskell, Solvignon, PRC 86, 065204 (2012)
O. Hen, et al, PRC 84, 047301 (2012)
L. Weinstein, et al, PRL, 106, 052301 (2011)

Motivation: SRC & EMC correlation

Broadly two classes of hypotheses:

- Local density (LD) – EMC effect driven by the presence of nucleons in close proximity
- High Virtuality (HV) – EMC effect being driven by highly virtual (very off-shell) nucleon

A recent work : model modification of the nuclear S.F (F_2^A) as entirely due to modification of np-SRC pairs (n_{SRC}^A)

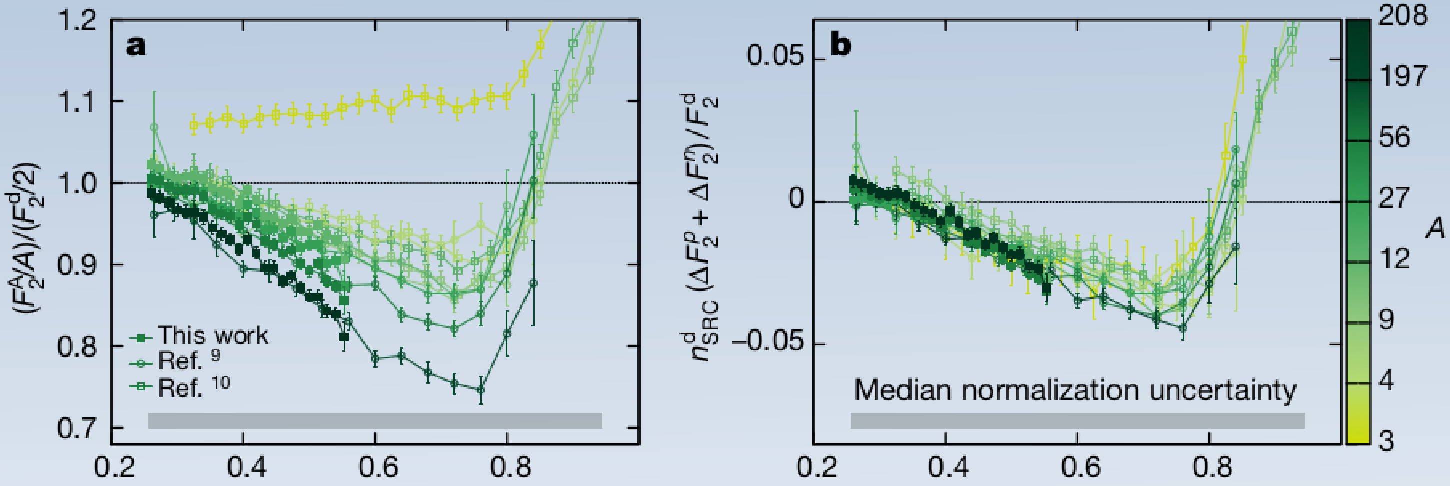
$$F_2^A = (Z - n_{SRC}^A) F_2^p + (N - n_{SRC}^A) F_2^n + n_{SRC}^A (F_2^{p*} + F_2^{n*}) = Z F_2^p + N F_2^n + n_{SRC}^A (\Delta F_2^p + \Delta F_2^n) \; ; \; \Delta F_2^n = F_2^{n*} - F_2^n$$

Avg modified S.F

Universal modification function: $F_{univ}^{HV} = \dfrac{(\sigma_A/\sigma_D) - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}$

(iso-spin dependent)

B. Schmookler et al. Nature (2019)

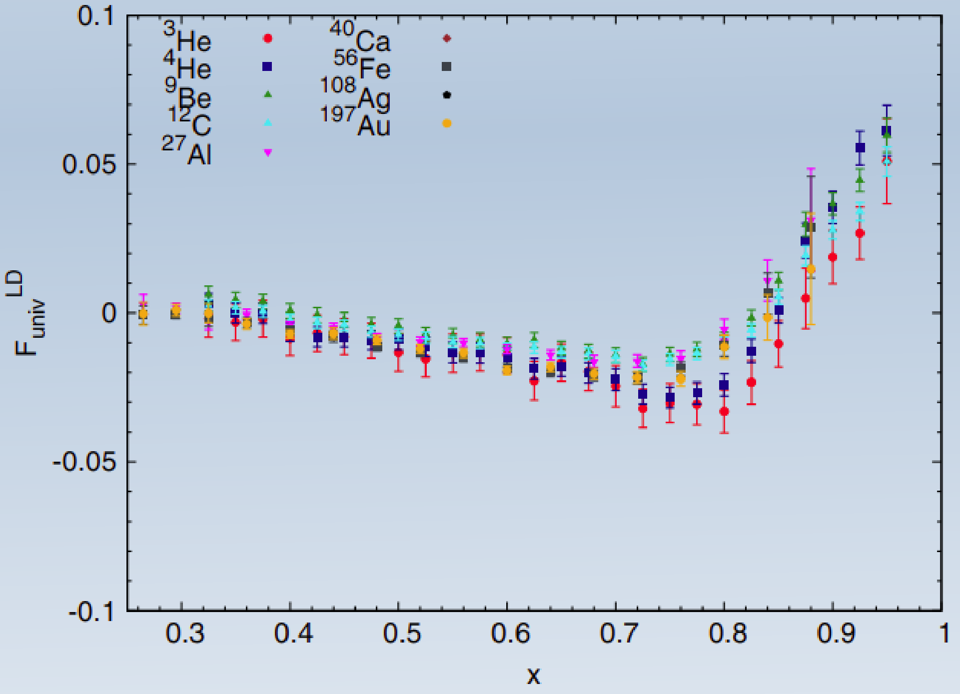


Motivation: SRC & EMC correlation

Broadly two classes of hypotheses:

- Local density (LD) – EMC effect driven by the presence of nucleons in close proximity
- High Virtuality (HV) – EMC effect being driven by highly virtual (very off-shell) nucleon

LD-based description also works well (Arrington and Fomin, PRL 123 (2019) 4, 042501)

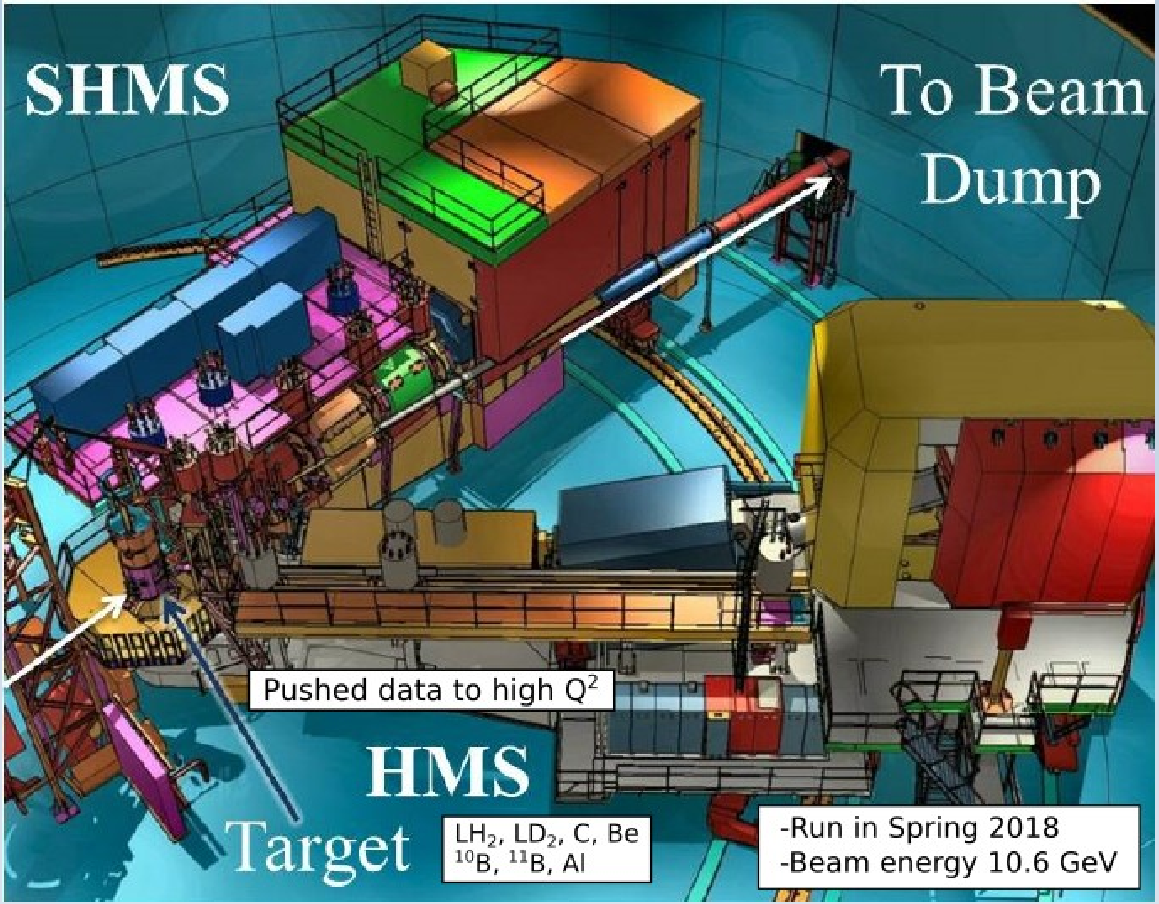


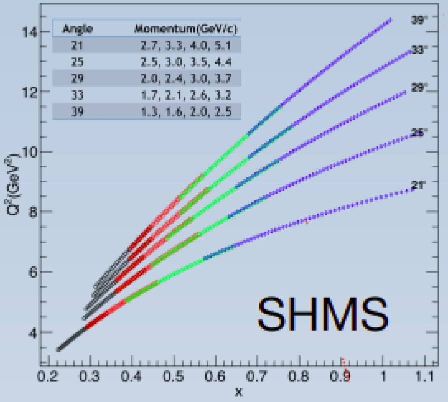
Motivation to E12-10-008

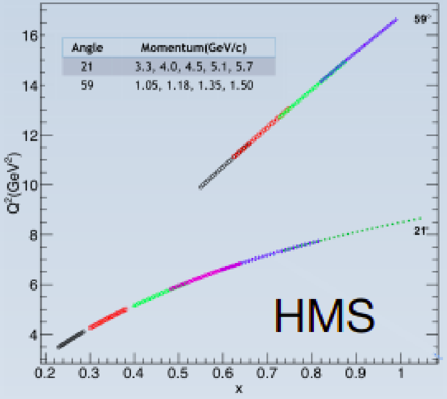
- Pushed to higher Q^2, expand range in x (both high and low)
- Investigate the influence of local environment on the observed nuclear dependence with additional light nuclei.
- To map out the SRC/EMC connection for the additional light nuclei.

Overview of the Experiment

- Hall C Comissioning experiment
- Electrons detected in both SHMS & HMS
- Detector package
  - Drift Chamber
  - Hodoscopes
  - Cherenkovs
  - Calorimeter







First measurement of EMC ratio in ^{10}B, ^{11}B

Cross-section extraction

Yield is converted to x-sec via the Monte-Carlo ratio method:

Experimental Yield

Simulated Yield
evaluated at
Born Level

$$\left(\frac{d\sigma}{d\Omega dE'}\right)_{\text{exp}} = \frac{Y_{\text{exp}}}{Y_{\text{sim}}}\left(\frac{d\sigma}{d\Omega dE'}\right)_{\text{model}}$$

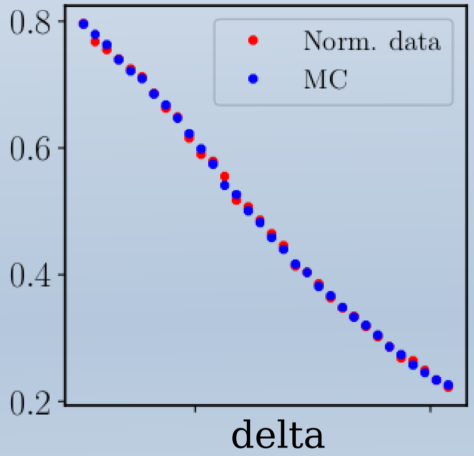
Monte-Carlo yield

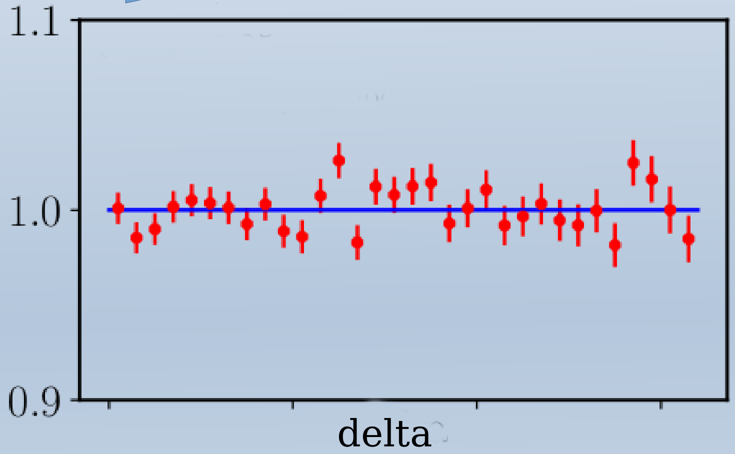
Cross-section extraction

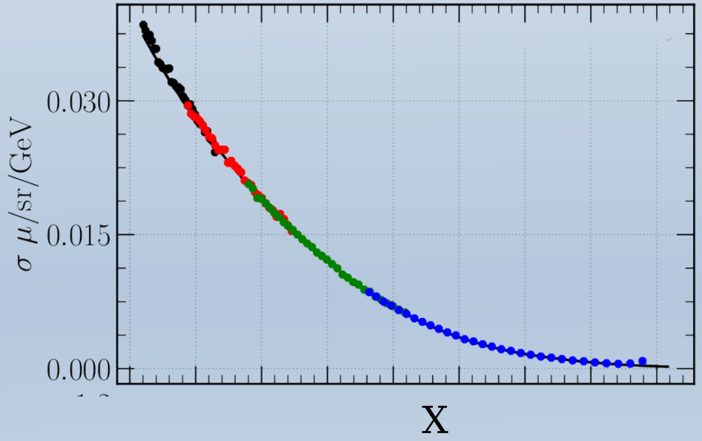
$$\left(\frac{d\sigma}{d\Omega dE'}\right)_{\mathrm{exp}} = \frac{Y_{\mathrm{exp}}}{Y_{\mathrm{sim}}}\left(\frac{d\sigma}{d\Omega dE'}\right)_{\mathrm{model}}$$

Ratio data/MC

Multiply each bin by σ_{model}







1) MC (weighted with radiative x-sec) and corrected data yields are binned in delta (1% delta)

2) Take ratio of data and MC

3) Multiply each bin by model to get x-section

Nuclear Model :

sig_born_total = sig_born_inel + sig_born_qe

x< 0.78 = nuclear x-sec is INEFT fit to deuterium times emc_fit

x>0.78 = smearing (single iteration to improve agreement of inelastic model with data)

QE = Peter's F1F2QE09 based on super scaling fit

Result & Discussion

Systematic uncertainties :

- Point to point (independent of target & x bins)
- x-correlated (vary in size with x, impact all points simultaneously)
- Normalization (contribute to all point collectively, affecting over all scale)

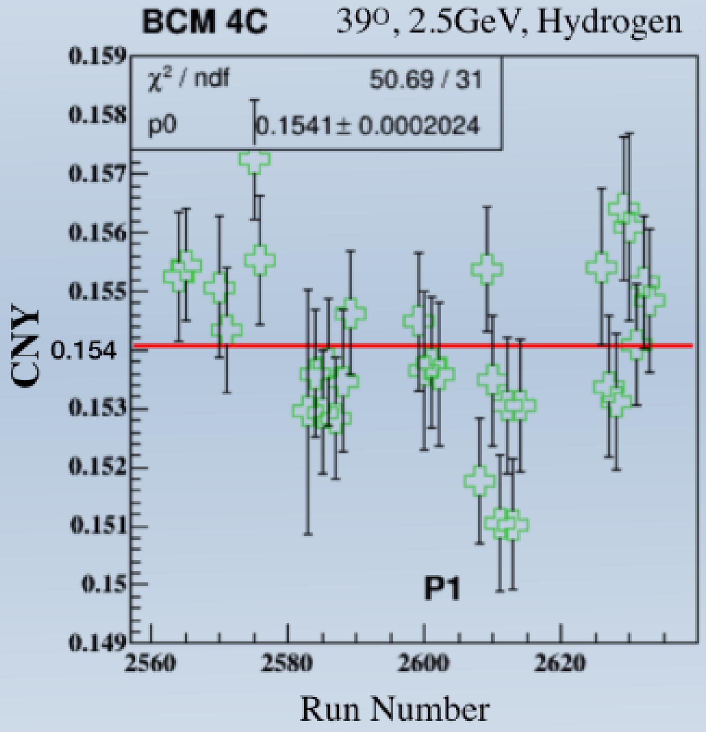
Result & Discussion

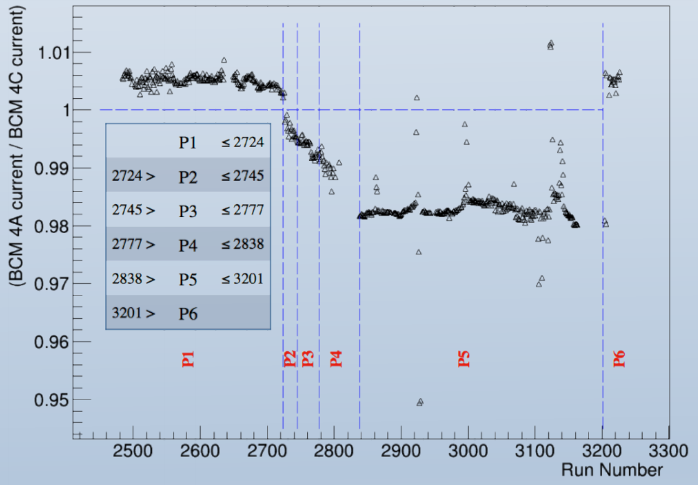
Source	Absolute Uncertainty	Relative Uncertainty	$\delta\sigma/\sigma(\%)$	$\delta R/R(\%)$ point-to-point	$\delta R/R(\%)$ scale	$\delta R/R(\%)$ correlated
SHMS Momentum	0.1 %	0.01 %	0.1 - 2.5 %	-	-	0.1 - 1.0 %
Beam Energy	0.1 %	0.005 %	0.5 %	-	-	0.0 - 0.5 %
θ	0.5 mr	0.2 mr	0.5 - 3.0 %	-	-	0.01 - 0.5 %
charge	0.44 %	0.35 %	0.56 %	0.35 %	-	-
Target Boiling	0.31 %	0.031-0.063 %	0.31 %	0.031-0.063 %	0.31 %	-
Tracking Efficiency	1.0 %	0.2 %	1.0 %	-	-	-
Trigger Efficiency	-	0.02 %	0.02 %	-	-	-
Electronic Dead Time	0.1 %	(0.02 - 0.04)/ (0.11 - 0.18) %	0.1 %	0.15 %	0.14 %	-
Computer Dead Time	-	-	-	-	-	-
CSB	-	0.1/ 0.075 %	0.1/0.075 %	0.13 %	-	-
Pion Contamination	-	0.1 %	-	-	-	-
Radiative Correction	1.0 %	0.5 %	1.1 %	0.55 %	0.5 %	-
Acceptance	1.0 %	0.1 %	0.1 %	-	0.1 %	-
τ_D	0.6 %	-	0.6 %	-	0.6 %	-
τ_C	0.5 %	-	0.5 %	-	0.5 %	-
$\tau_{B^{10}}$	0.66 %	-	0.66 %	-	0.66 %	-
$\tau_{B^{11}}$	0.65 %	-	0.65 %	-	0.65 %	-
Acceptance point/extended target	-	-	-	0.5 %	-	-
Endcap Subtraction	0.5 %	-	0.5 %	-	0.5 %	-
Detector Efficiency	0.1 %	0.07/0.09 %	0.07/0.09 %	0.11 %	-	-
HMS Comparison	-	-	-	-	0.5 %	-
Normalization Uncertainty	-	-	-	-	1.0%	-
Total				0.87 %	1.56 %	

Table 1.1: Systematic Uncertainties.

Result & Discussion

Uncertainty on charge





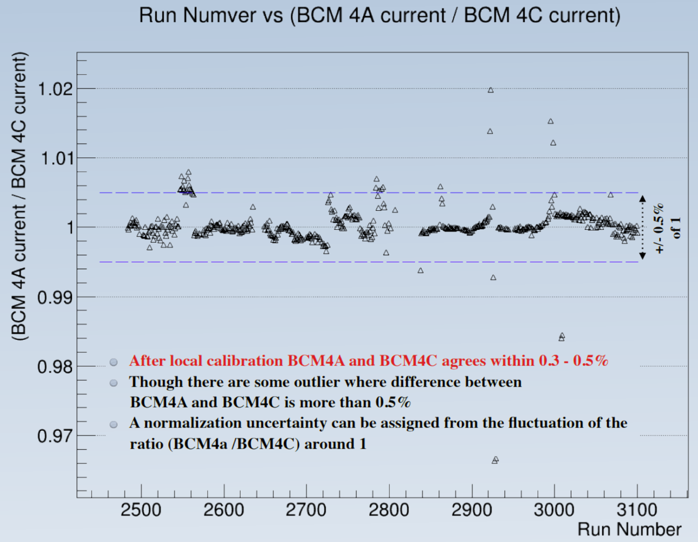


Fig credit : Deb Biswas

Result & Discussion

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Endcap Subtraction	0.5 %	-	0.5 %	-	0.5 %	-
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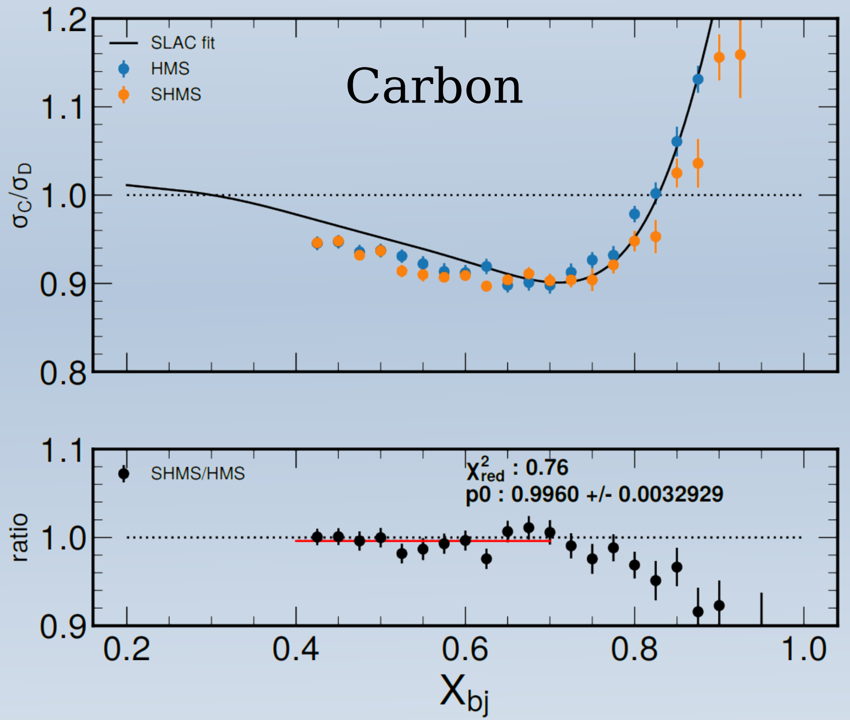
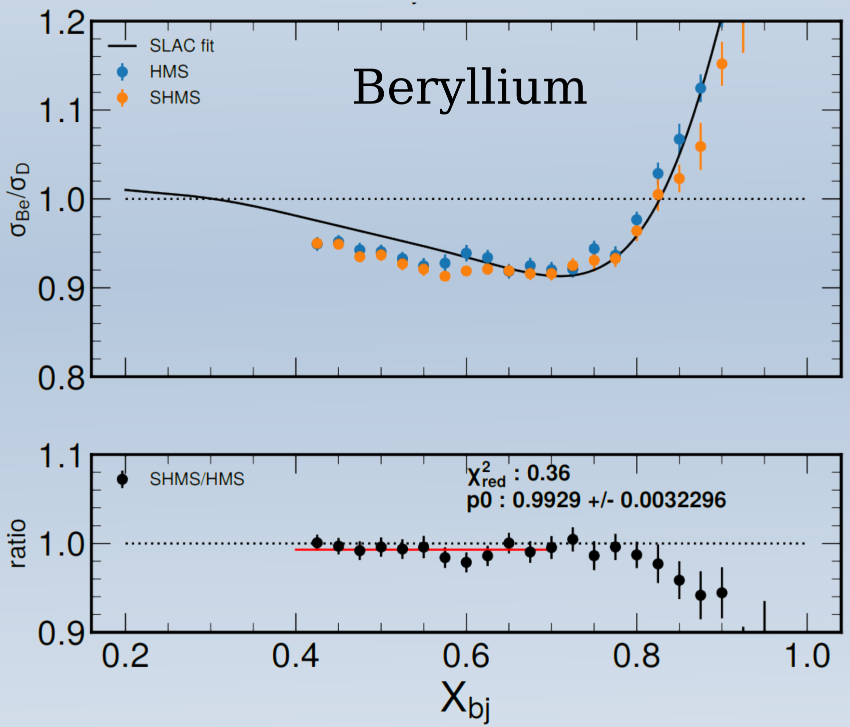
Table 1.1: Systematic Uncertainties.

Result & Discussion

Cross check with HMS – limited x range





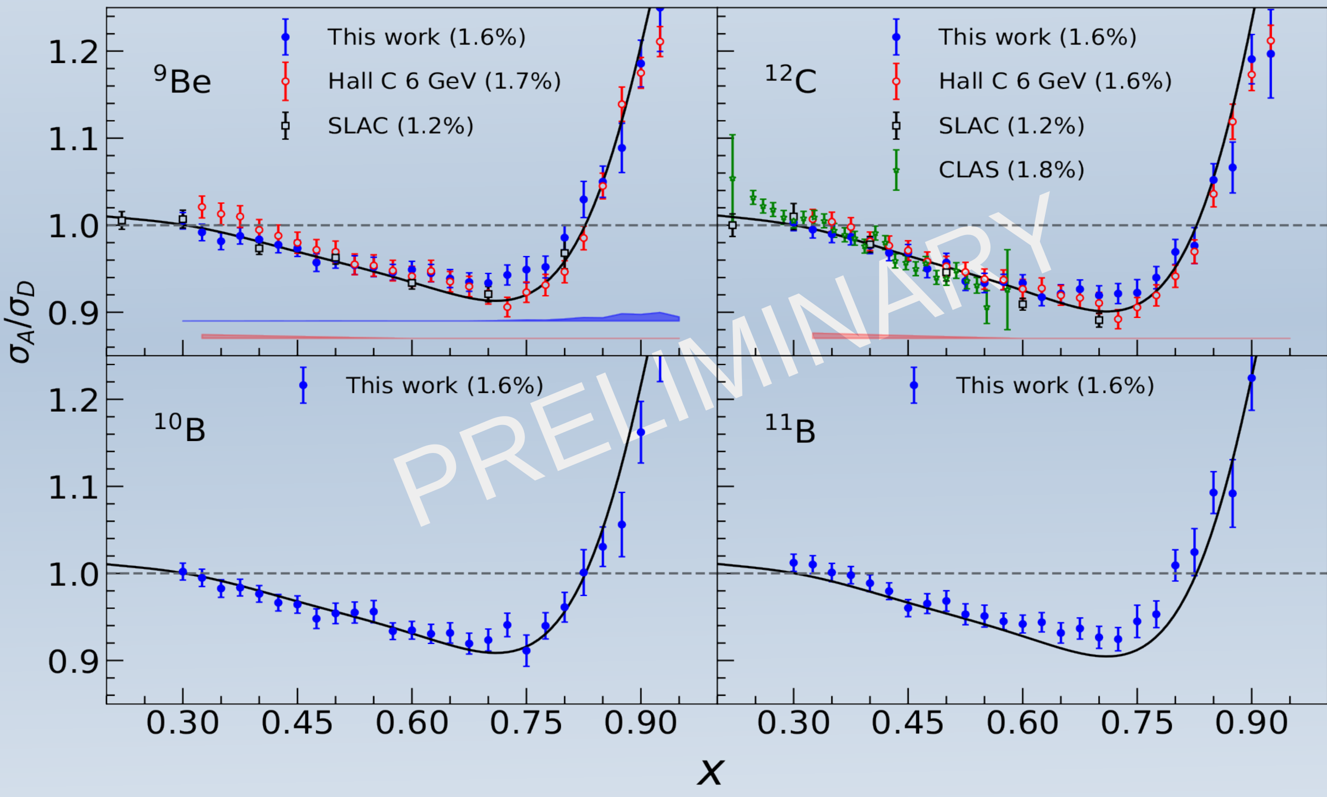
Result & Discussion

Normalization Uncertainty:

- EMC ratio systematically off by 2% than previous measurement
- Exists for all solid targets
- Possibly due to unknown effect with respect to the deuterium (thickness, density)
- From previous data, empirical observation, EMC ratio is 1 at $x = 0.3$, independent of target
- Used the extracted normalization factor
- Limitation on precision of previous world data at $x = 0.3$, 1% uncertainty is added
- Slope has very small sensitivity to overall normalization of the EMC ratios.

Result & Discussion

- Ratio of x-sec per nucleon vs *x*
- Error bars include statistics combined with point-to-point systematic errors.
- The normalization error for each experiment is noted in the label
- The red and blue band denotes x-correlated error the Jlab Hall C 6 GeV and for this experiment.
- The solid black curve is the A-dependent fit of the EMC effect from SLAC 139.



N.B Paper is in collaboration review

Result & Discussion

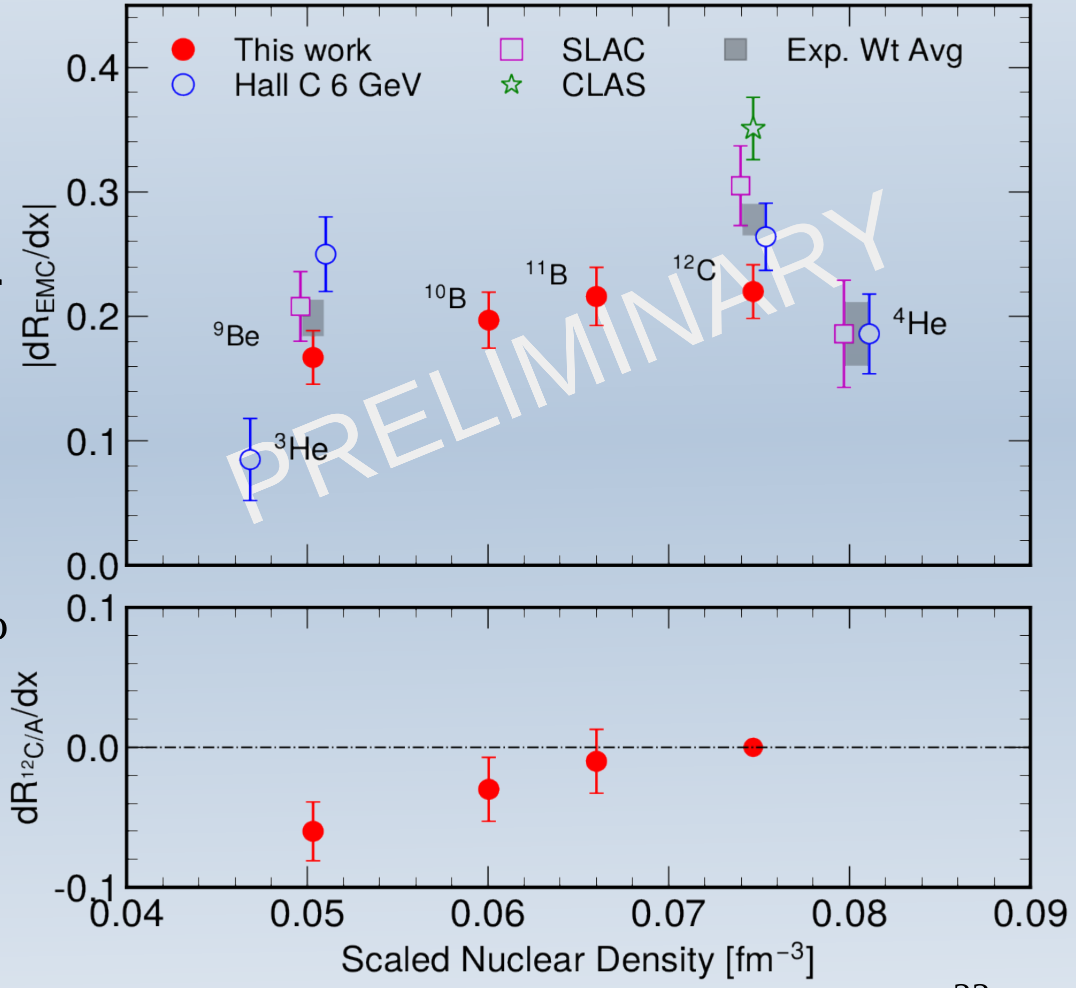
Top:

- * Size of the EMC effect vs scaled Nuclear density.
- Some points have been offset horizontally for visibility.
- Grey band denotes weighted average for all experiments shown for a given target

Bottom:

- Slope extracted from x-section ratios of ^{12}C to ^{9}Be, $^{10,11}B$ from this experiment.

* Size of the EMC effect: slope from x-sec ratio 0.3 < x < 0.7
scaled Nuclear density = ρ(A-1)/A



Summary

- The First measurements of the EMC effect in ^{10}B and ^{11}B
- New information on the nuclear dependence of the EMC effect
- Strengthen the hypothesis that the EMC effect driven by local density

Acknowledgment

- Dipangkar Dutta (Advisor)
- Dave Gaskell (Spokesperson + Advisor)
- John Arrington (Spokesperson)
- Nadia Fomin (Spokesperson)
- The funding Agency
- The accelerator group

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M. Jones, D. J. Mack, D. G. Meekins, G. Smith, P. Solvignon, S. A. Wood
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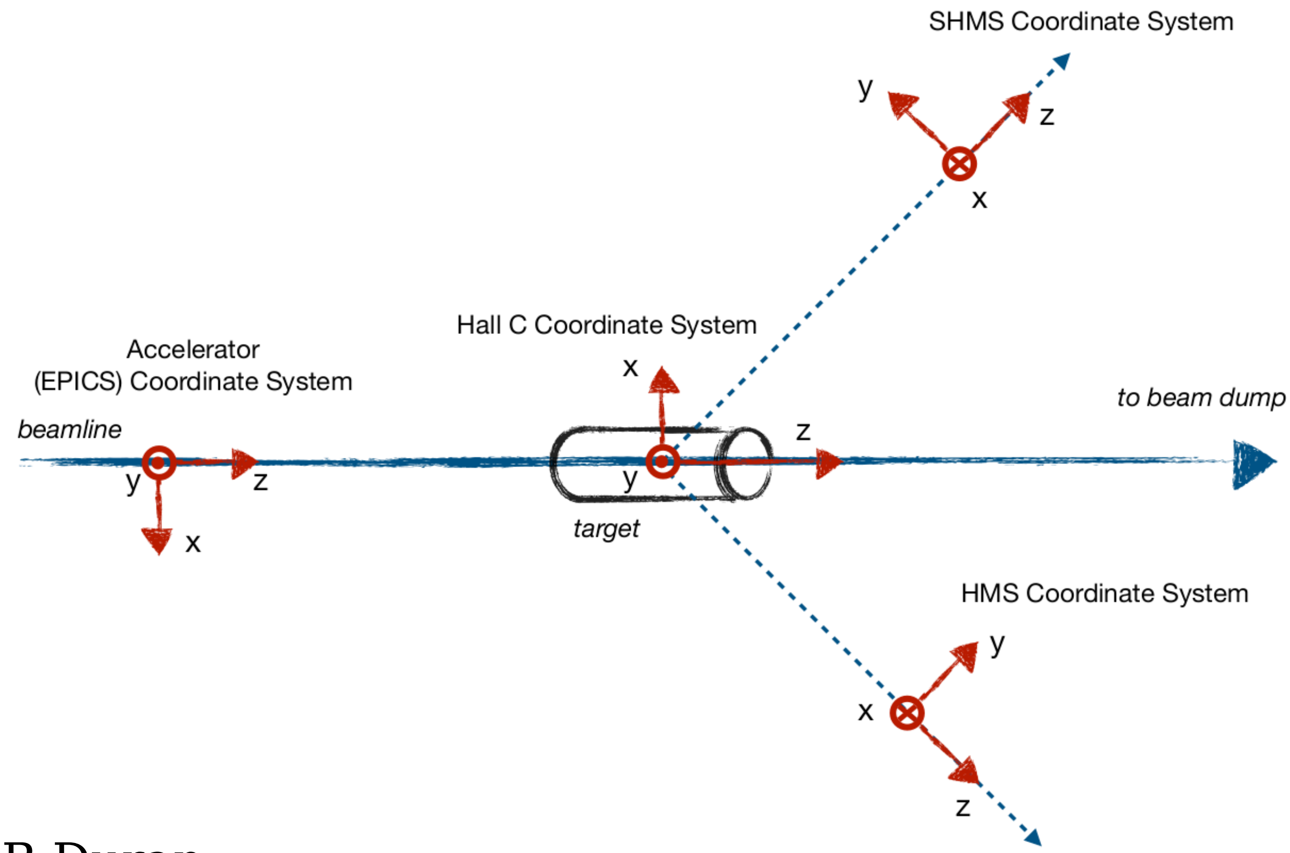
BackUp



Courtesy plot :B Duran

Analysis Status: Isoscalar correction

- Proton and neutron have different x-sections, x-sections for nuclei with z ≠A/2 will significantly differ from that of nuclei with z =A/2 (Isoscalar)

- Needs to correct for excess of neutrons or protons. The multiplicative correction factor is,

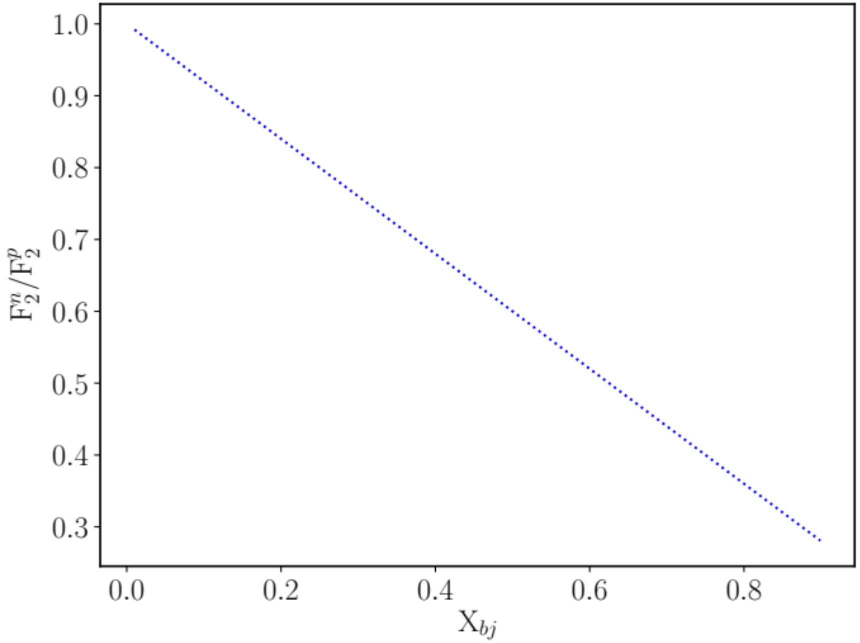
$$f^A_{iso} = \frac{\frac{1}{2}\left(1 + F^n_2/F^p_2\right)}{\frac{1}{A}\left(Z + (A-Z)F^n_2/F^p_2\right)}$$

- Since there is no free neutron target, extraction of F_2^n/F_2^p is always model-dependent

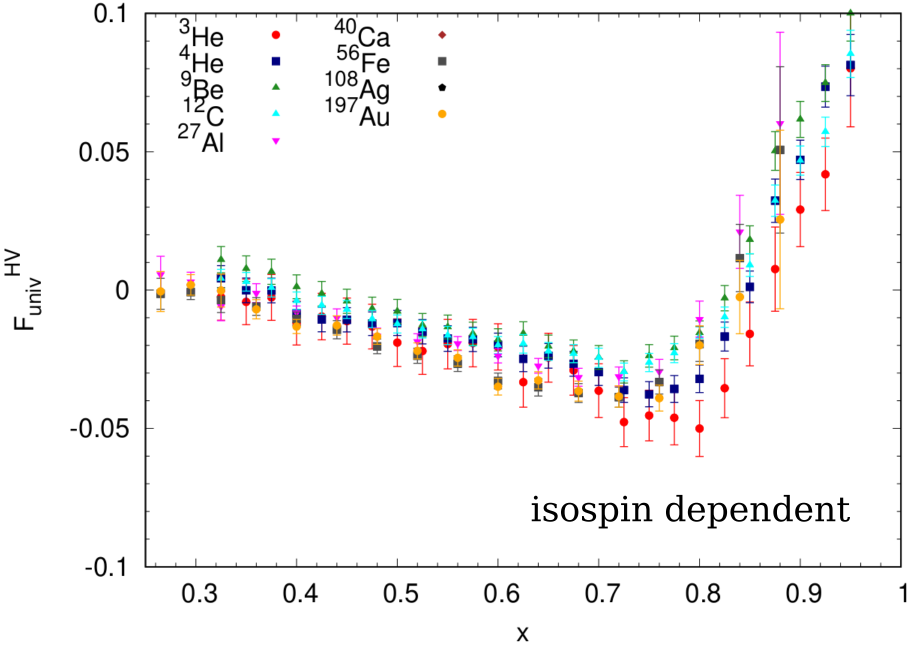
- Currently using SLAC Parameterization:

F_2^n/F_2^p = 1- 0.8 * X_{Bj}

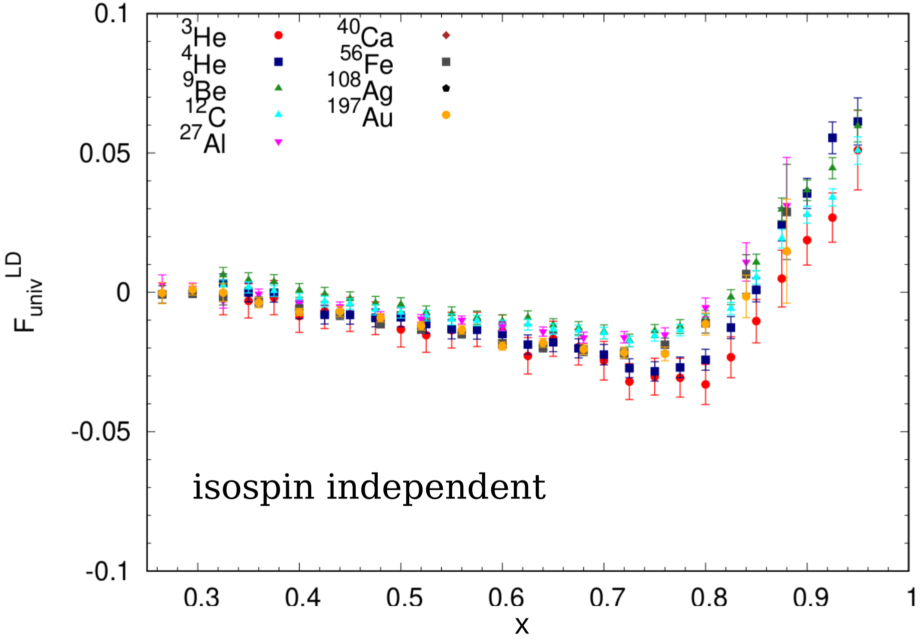
SLAC Parameterization



Motivation: SRC & EMC correlation



Arrington/Fomin PRL (2019)



Extract universal functions to test both HV and LD hypotheses

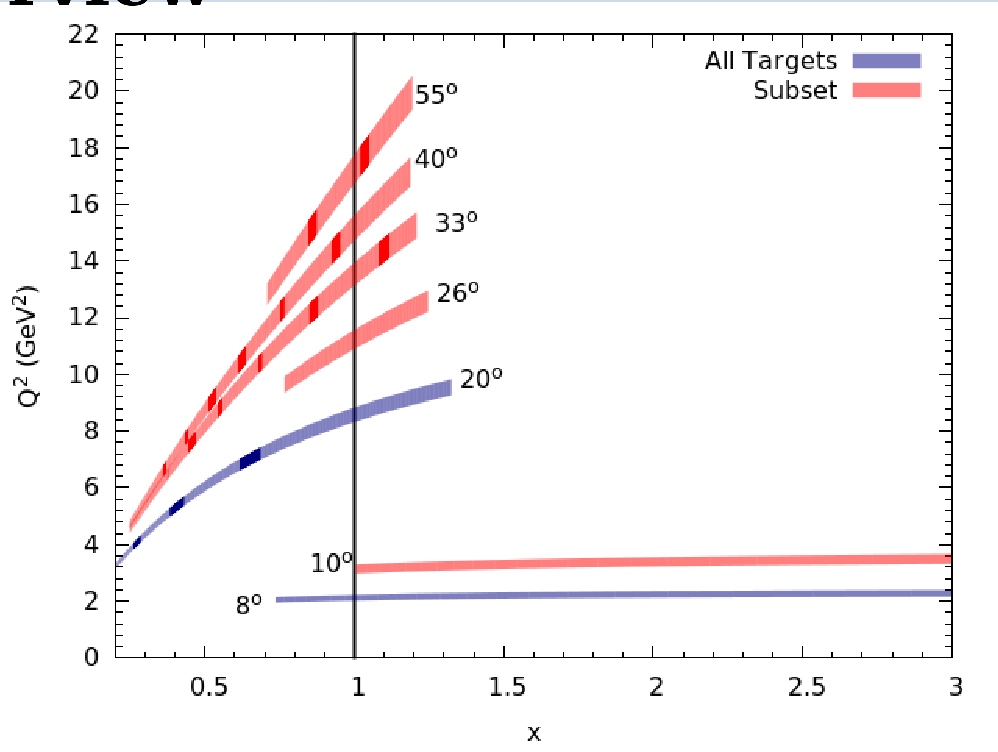
Quantitative understanding requires additional light nuclei

Future Measurement: E12-10-008 Phase – II Kinematic Overview

Spectrometer	Angle	Momentum (GeV/c)	Beam Energy (GeV)
SHMS	8 - 33	1.4 - 10.6	11
HMS	20 - 55	1.4 - 6.4	11

- Runs concurrently with E12-06-105 (x>1)
- Covers range of angles
- HMS and SHMS run in parallel
- 23 PAC days for Phase I and Phase II
    - 2 days completed spring 2018 (Phase I)

*** Running Aug 27, 2022**



- Plot shows kinematics coverage for EMC and x>1.
- The lower x represent the EMC effect data

Future Measurement: E12-10-008 Phase – II Kinematic Overview

- Target Choice motivated by physics impact
  - To study A dependence at fixed N/Z
  - To study N/Z dependence at fixed A

- Focus on target ratios
  - Light nuclei: cluster structure (Reliable calculation of nuclear structure)
  - Heavier nuclei: vary N/Z

- Large range of nuclei will test the proposed universal modification function of SRC-EMC correlation