Update on the New Measurement of the EMC Ratio in Lighter Nuclei

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Outline

- The EMC Effect
- Experiment E12-10-008 at Hall C (Upcoming run Plans)
- Current Analysis Status
- Summary
The EMC Effect

- DIS from atomic Nuclei is not simple sum of scattering from it’s constituent nucleons
  \[ i.e \ F_2^A(x) \neq ZF_2^p(x) + NF_2^n(x) \]
- EMC Effect : Quarks distributions are modified inside nuclei
- Different kinematic regions understood in terms of different process
- Conventional nuclear physics models
  - Fermi smearing
  - Binding energy
  - Nuclear pions
- Exotic models
  - Multi-quarks clusters (6q, 9q) bags
  - Dynamical rescaling
  - Modification of nucleon structure

More than 36+ years yet no generally accepted explanation of the EMC effect
The EMC Effect: Representative data

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 A ($\sim A^{1/3}$)
    • Scales with average density

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

**Jlab E03-103**

Measured $\sigma_A/\sigma_D$ for $^3$He, $^4$He, Be, C

- $^3$He, $^4$He, C EMC effect scales well with density
- **Be** does not fit the trend
- **$^4$He** matches better with C data and SLAC parameterizations
  - Avg nuclear density of $^4$He and C are similar
  - Also, $^9$Be data matches better with C data. However avg nuclear density of Be<<C

![Graph showing $dR_{EMC}/dx$ vs. Scaled Nuclear Density](image)

- Plot shows slope of ratio $\sigma_A/\sigma_D$ at EMC region

**Both A- and $\rho$-dependent fits fail to describe these light nuclei**
Motivation

**Jlab E03-103:**
- Suggest that EMC Effect does not scale with average nuclear density
- Hints that the effect may be driven by local environment

One could explain if one considers that the nuclear structure of $^{9}\text{Be}$ to be that of cluster of two alpha particles with an extra neutron.

Nucleons are in high local densities of alpha cluster

$^{9}\text{Be}: \text{large components of structure is } 2\alpha+n$
Motivation: SRC & EMC correlation

If the EMC effect is a local density effect, then it seems reasonable to look for connections to other local density effects

- EMC-SRC connection became more intriguing with the addition of Be SRC data from Jlab
  - Both display similar Nuclear dependence on nuclear density

Quantitative test of level of correlation between the two effects

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 targets: H, $^2$H  
  - Solid targets: Be, C, *Al, $^{10,11}$B (*Al for cell wall subtraction)  
- Single-arm measurement  
- Un-polarized electron beam energy 10.6 GeV  
- Data were taken at a single ($Q^2$) /angle (21°)  
  - Additional data on C were taken at larger angle to investigate Q2-dependence of the EMC ratios

First Measurement of EMC effect in $^{10,11}$B
Kinematic Coverage: Phase - I

Main EMC ratios extraction is done using data at angle 21° using both spectrometer.

Data at large angle will provide $Q^2$ dependence study.

We took data in HMS and SHMS at same kinematics to cross-check the SHMS results as well as for the final results we will add data from HMS.
Future Measurement: E12-10-008  Phase - II
Kinematic Overview

- Runs concurrently with E12-06-105 (x>1)
- Covers a range of angles (20 - 55) degree
- HMS: 20° - 55°, 1.4 - 6.4 GeV/c
- SHMS: 8° - 33°, 1.4 - 10.6 GeV/c
- Beam Energy ≈ 11 GeV
- HMS and SHMS run in parallel
- 23 PAC days for Phase I and Phase II
  - 2 days completed spring 2018 (Phase I)

- 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
Outcome: E12-10-008 Phase I

Plot courtesy from D. Gaskell
Analysis Status

- Detector calibration complete.
- Extraction of experimental efficiencies mostly complete
  - Still working on dead time (See Casey Talk)
- Understanding the SHMS Acceptance is ongoing
  - Currently, fixing the x-beam offset and z-target offset
- Detailed Data/Monte-Carlo comparison is ongoing
- Extraction of EMC ratios are in progress
Analysis Status: x-section extraction by MC Ratio

We simulate Monte – Carlo (MC) data using a cross-section model to obtain:

\[ Y_{MC}(E',\theta) = L \times \sigma_{\text{model}} \times (\Delta E, \Delta \Omega) \times A_{MC}(E',\theta) \]

Taking ratio to data and assuming that \( A_{MC} = A \), yields

\[ \frac{d\sigma}{d\Omega dE'} = \sigma_{\text{model}} \times \left[ \frac{Y(E',\theta)}{Y_{MC}(E',\theta)} \right] \]

\begin{align*}
Y_{MC} &= \text{Monte-Carlo Yield} \\
Y &= \text{Data Yield} \\
L &= \text{Luminosity} \\
\sigma &= \text{Model x-section} \\
A &= \text{Acceptance}
\end{align*}
Analysis Status: Data to MC

- 10.6 GeV beam energy
- $^{12}$C at 2.7 GeV, $21^0$
- Delta, ytar, yptar, xptar
- Integral difference ~ 6%
- Data Ytar resolution not so well
Analysis Status: x-beam offset & z-target offset

The relationship between the target z position which is the position of the target relative to pivot, beam x position and the reconstructed target quantities Y-tar, 

$$\Delta Y = \Delta x \cos \theta - \Delta z \sin \theta$$

Here,

$$\theta = \text{spectrometer angle}$$

$$\Delta Y = \text{in plane offset of the target relative to the spectrometer}$$

$$\Delta x = \text{in plane beam position offset relative to pivot}$$

$$\Delta Y / \cos \theta = \Delta x - \Delta z \tan \theta$$
Analysis Status: x-beam offset & z-target offset

SHMS

\[ \Delta Y = \Delta x \cos \theta - \Delta z \sin \theta \]

- Corr-Ytar is reconstructed Ytar obtained from carbon target from both spectrometer after correcting for mispointing and bpm's.
- Mispointing was determined by survey at various spectrometer angles.
Analysis Status: x-beam offset & z-target offset

SHMS

C12, 2.7 GeV, 21.0 deg (With Offset)

C12, 2.7 GeV, 21.0 deg (No Offset)
Analysis Status: x-beam offset & z-target offset

SHMS
Analysis Status: Background Correction
Charge Symmetric Background (CSB)

- \# of e^-_{\text{detected}} = \# of e^-_{\text{primary}} + \# of e^-_{\text{background}}
- Equal \# of e^+ and e^- are produced
- Allows to estimate the no of secondary background e- by running the spectrometer with +ve polarity
- Data were taken at the kinematics setting where CSB was large.
- Positron data are subjected to the same cuts as electron data
- JMU group extracted positron x-section for H, D (See Bill’s Talk)

• Plot shows CSB as a function of x for 21^0
Analysis Status: Charge symmetric background (CSB)

Since we also need nuclear target we can use radiation length dependence and JMU Model for other angles where we didn’t take carbon data.
Analysis Status: Background Correction Pion Contamination

- Shows a nice drop in pion contamination as momentum increase
- Pion contamination is very small
- Increased in pion contamination after 4.5 GeV is due to fact pion threshold for Cherenkov is 4.4 GeV
- Abel (F2) also looked into this and our result matches to great extend (see Bill’s talk)

- Plot shows pions to the sum of pions and electrons as a function of SHMS momentum for 21°
We used Arie Bodek’s fit to proton and deuterium inelastic structure functions, and then a separate fit to the EMC effect in nuclei.

For radiative correction, we use QE model (F1F209 from Peter Bosted and Vahe Mamyan). In the x-region of interest, this model agrees pretty well with F1F220 (Eric Christy).

For Final analysis we will use generalized model that uses F1F220 for inelastic and an improved y-scaling (See Casey Talk).
x-sec from Boron Target

Note:
- B4C targets were used while taking data
- Need to subtract the carbon contribution
  So little more involved
- Also, 10B and 11B are not 100% isotopically pure they are listed to be “at least 95%” pure), So there will be small extra uncertainty
Analysis Status: x-section extracted from Solid Target

SHMS

![Graphs showing cross-section data for Boron10 and Boron11](image)

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Analysis Status: x-section extracted from Cryo Target

SHMS

Deuterium

Hydrogen
Analysis Status: EMC Ratio at 21°

\[ \frac{2}{A} \times \frac{\sigma_A}{\sigma_D} \] is plotted vs xbj

- Preliminary EMC ratio
- Shape is roughly as expected
- Some normalization issue is under investigation (~ 3%)
- No Pion contamination correction
Analysis Status: EMC Ratio at 21°
Analysis Status: Isoscalar correction

- Proton and neutron have different x-sections, x-sections for nuclei with $z \neq A/2$ 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,

$$f_{iso}^A = \frac{\frac{1}{2} (1 + F_{2n}^n / F_{2p}^p)}{\frac{1}{A} (Z + (A - Z) F_{2n}^n / F_{2p}^p)}$$

- Since there is no free neutron target, extraction of $F_{2n}^n / F_{2p}^p$ is always model-dependent

- Currently using SLAC Parameterization:

$$F_{2n}^n / F_{2p}^p = 1 - 0.8 \times X_{bj}$$
Analysis Status: EMC Ratio at 21°

Beryllium

Preliminary Analysis Status: EMC Ratio at 21°

Boron 11

Preliminary
To do:

- At low momentum, dead time and BCM needs to be looked out
- Acceptance corrections need to be worked out
- Study the z-target offset for other solid and cryo-targets
- Need to implement the pion contamination corrections
- Need to include Coloumb corrections
- Extract Carbon EMC ratio at larger angle.
- Cross check with some existing Analysis
Summary

- Experiment E12-10-008 (EMC) and E12-06-105 (x>1) will provide new data on several nuclei to map out the SRC/EMC connections.
- First EMC measurements on $^{10}$B and $^{11}$B.
- Preliminary EMC ratios for Solid target were shown.
- Preliminary ratios extraction showed some global normalization issue.
- Ratios extraction from HMS is ongoing.
- Final results are coming soon.

Thank you