New Measurement of the EMC effect for Light Nuclei and Global Study of the A-Dependence

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Outline

- JLab E03-103 preliminary results:
  - $Q^2$-dependence study with Carbon
  - $^3\text{He}$ and $^4\text{He}$
  - Heavy nuclei and Coulomb distortion

- Nuclear dependence of the EMC effect
  - World data re-analysis
  - New extrapolation to nuclear matter

- Resonance data and target mass corrections
The EMC ratio

Ratio of cross sections per nucleon:

\[ R_{EMC} = \frac{\sigma^A_2 / A}{\sigma^D_2 / 2} \cdot \left( \frac{1 + F^n_2 / F^p_2}{Z + NF^n_2 / F^p_2} \right) \]

Isoscalar correction
Existing EMC Data

- SLAC E139 most complete and precise data set for $x > 0.2$

- $\sigma_A/\sigma_D$ for $A=4$ to 197
  - $^4\text{He}$, $^9\text{Be}$, $^{12}\text{C}$, $^{27}\text{Al}$, $^{40}\text{Ca}$, $^{56}\text{Fe}$, $^{108}\text{Ag}$, and $^{197}\text{Au}$
  - Size at fixed $x$ varies with $A$, but shape is nearly constant
**Existing EMC Data**

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- E03-103 will improve with
  - Higher precision data for $^4\text{He}$
  - Addition of $^3\text{He}$ data
  - Precision data at large $x$ and on heavy nuclei
  
  $\Rightarrow$ Lowering $Q^2$ to reach high $x$ region

![Graph showing the ratio $(\sigma_A/\sigma_D)_s$ for various nuclei.](image)
JLab Experiment E03-103

A(e,e’) at 5.0 and 5.8 GeV in Hall C

- Targets: H, ²H, ³He, ⁴He, Be, C, Al, Cu, Au
- 10 angles to measure $Q^2$-dependence

Spokespersons: D. Gaskell and J. Arrington
Post-doc: P. Solvignon
Graduate students: J. Seely and A. Daniel
Small angle, low $Q^2 \Rightarrow$ clear scaling violations for $x>0.7$,
but surprisingly good agreement at lower $x$
At larger angles ➔ indication of scaling to very large $x$
More detailed look at scaling

C/D ratios at fixed $x$ are $Q^2$ independent for:

$W > 1.4 \text{ GeV}^2$

and

$Q^2 > 3 \text{ GeV}^2$

limits E03-103 coverage to $x = 0.85$

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Note: Ratios at larger $x$ will be shown, but should be taken cautiously
At larger angles $\Rightarrow$ indication of scaling to very large $x$

The combined two highest $Q^2$ are used in the rest of the talk
E03-103: Carbon EMC ratio

- $W > 2.0$ GeV
- $W > 1.4$ GeV
- $1.1 < W < 1.4$ GeV

Preliminary
E03-103: $^4$He

JLab results consistent with SLAC E139
→ Improved statistics and systematic errors
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Large $x$ shape more clearly consistent with heavier nuclei
E03-103: $^4$He

JLab results consistent with SLAC E139

→ Improved statistics and systematic errors

Large $x$ shape more clearly consistent with heavier nuclei

Models shown do a reasonable job describing the data
E03-103: comparison carbon and $^4$He

Magnitude of the EMC Effect for C and $^4$He very similar

$^4$He more consistent with SLAC A=12 fit than A=4
E03-103: comparison carbon and $^4\text{He}$

Magnitude of the EMC Effect for C and $^4\text{He}$ very similar

$^4\text{He}$ more consistent with SLAC $A=12$ fit than $A=4$

→ $^4\text{He}$ acts like a “real nucleus”

→ Some hint of difference in shape, but hard to tell with existing errors
**E03-103: Preliminary $^3$He EMC ratio**

Large proton excess correction
Good agreement with HERMES in overlap region
E03-103: Preliminary $^3\text{He}$ EMC ratio
E03-103: Preliminary $^3$He EMC ratio

All calculations shown use convolution formalism at some level

\[
\frac{F_2^{^3He}}{(F_2^D + F_2^p)} \quad \frac{F_2^{^3He}}{(2F_2^p + F_2^n)}
\]

Melnitchouk = Afnan et.al. PRC68 035201 (2003)
Benhar = private communication (Hannover SF, Paris potential)
Coulomb distortions on heavy nuclei

Initial (scattered) electrons are accelerated (decelerated) in Coulomb field of nucleus with $Z$ protons

- Not accounted for in typical radiative corrections
- Usually, not a large effect at high energy machines – *not true at JLab (6 GeV!)*

E03-103 uses modified Effective Momentum Approximation (EMA)


\[
E \rightarrow E + \Delta \\
E' \rightarrow E' + \Delta
\]

*with* $\Delta = -\frac{3}{4} V_0$

\[
V_0 = 3\alpha(Z-1)/(2r_c)
\]

\[
\sigma_{\text{born}}/\sigma_{\text{cc}}
\]

$x$

0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

1 1.05 1.1 1.15 1.2

197 Au, 50° 197 Au, 40° 56 Fe, 50° 56 Fe, 40°
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$E \rightarrow E'$

$E' \rightarrow E' + \Delta$

$$\Delta = -\frac{3}{4} V_0, \quad V_0 = \frac{3\alpha(Z-1)}{2r_c}$$

EMA tested against DWBA calculation for QE scattering

→ application to inelastic scattering?
Effect of the coulomb distortion on E03-103 data

Before coulomb corrections

Gold

E03-103

\[(\sigma_A/\sigma_D)_S\]

\(x\)

0 0.2 0.4 0.6 0.8 1

0.7 0.8 0.9 1.0 1.1

\(40^\circ\)

\(50^\circ\)
Effect of the coulomb distortion on E03-103 data

After coulomb corrections

Gold

E03-103
E03-013 heavy target results and world data

Before coulomb corrections

![Graphs showing E03-013 heavy target results and world data](image)
E03-013 heavy target results and world data

After coulomb corrections on all data
E03-103: EMC effect in heavy nuclei
E03-103: EMC effect in heavy nuclei

E03-103 data corrected for coulomb distortion

Cross overs independent of A
Nuclear dependence of the EMC effect

Main difference due to E139 data sets used:
- Sick & Day used E139 $Q^2$-avg tables
- we used E139 constant $Q^2$ to be able to apply CC
Nuclear dependence of the EMC effect

After coulomb corrections
Nuclear dependence of the EMC effect

- Good agreement between E03-103 and SLAC E139 data after Coulomb corrections.
- Preliminary E03-103 results confirm A-dependence of the EMC effect.

Note: n/p correction is also A-dependent!
Nuclear matter

\[ \frac{\sigma_{NN}}{\sigma_d} \]

- □ Sick & Day, PLB274 (1992)
- ○ All world data (cc)
Nuclear matter

\[
\frac{\sigma_{NM}}{\sigma_d}\) vs \(x\)
\]

- Sick & Day, PLB274 (1992)
- All world data (cc)
- including E03-103 prel. (cc)
Target Mass Correction on the EMC ratio

\[ F_2(x, Q^2) = F_2(x, Q^2; M = 0) + \frac{M^2}{Q^2} F_2^{(1)TMC}(x, Q^2) + \frac{h(x, Q^2)}{Q^2} + O(1/Q^4) \]

- Purely kinematic effects: finite value of \( 4M^2x^2/Q^2 \)
- Need to be applied before calculating higher twist effects
- TMCs are expressed by higher moments of \( F_2(x, Q^2; M=0) \)
Target Mass Correction on the EMC ratio

\[ F_2(x, Q^2) = \frac{x^2}{r^3} F(\xi) + 6 \frac{M^2}{Q^2} \frac{x^3}{r^4} \int_\xi^1 d\xi' F(\xi') \]

\[ + 12 \frac{M^4}{Q^4} \frac{x^4}{r^5} \int_\xi^1 d\xi' \int_\xi^1 d\xi'' F(\xi'') \]

\[ \xi = \frac{2x}{1 + r} \]

\[ r = \sqrt{1 + 4x^2 \frac{M^2}{Q^2}} \]
Target Mass Correction on the EMC ratio

\[ F_2(x, Q^2) = \frac{x^2}{r^3} F(\xi) + 6 \frac{M^2}{Q^2} \frac{x^3}{r^4} \int_{\xi}^{1} d\xi' F(\xi') \]

\[ + 12 \frac{M^4}{Q^4} \frac{x^4}{r^5} \int_{\xi}^{1} d\xi' \int_{\xi'}^{1} d\xi'' F(\xi'') \]

A-independent \Rightarrow mostly cancel in the ratio

At first order, the TM correction on the EMC ratio is equivalent to express them versus \( \xi \) and plot versus \( x \).
E03-103 data on Carbon
E03-103 data on Carbon with TMC
$A$-dependence

$(\sigma_A/\sigma_d)_S$

$A^{-1/3}$

$x = 0.6$

preliminary

- **Sick & Day, PLB274 (1992)**
- **World data re-analysis (cc)**
- **E03-103 prel. (cc)**

NM
A-dependence with TMC

\[
\left( \frac{\sigma_A}{\sigma_d} \right)_S
\]

\[x = 0.6\]

\[A^{-1/3}\]

- NM
- Sick & Day, PLB274 (1992)
- World data re-analysis (cc)
- E03-103 prel. (cc)

preliminary
Nuclear matter and TMC

\[ \frac{\sigma_{NM}}{\sigma_d} \] vs. \( x \)

- Sick & Day, PLB274 (1992)
- All world data (cc)
- Including E03-103 prel. (cc)

Preliminary
Summary

- JLab E03-103 provides:
  - Precision nuclear structure ratios for light nuclei
  - Access to large $x$ EMC region for $^3$He $\rightarrow$ $^{197}$Au

- Preliminary observations:
  - Scaling of the structure function ratios for $W<2$GeV down to low $Q^2$
  - Carbon and $^4$He have the same EMC effect
  - Large EMC effect in $^3$He
  - Similar large $x$ shape of the structure function ratios for $A>3$

- In progress:
  - Absolute cross sections for $^1$H, $^2$H, $^3$He and $^4$He: test models of $\sigma_n/\sigma_p$ and nuclear effects in few-body nuclei
  - Quantitative studies of the $Q^2$-dependence in structure functions and their ratios
  - Coulomb distortion
  - Nuclear density calculations
  - Target mass correction