New Results on the EMC Effect at Large $x$

For the E03-103 collaboration

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The EMC effect

Energy scale of DIS ~ GeV. Typical energy scale of nuclear processes ~ MeV.

Naïve expectation: cross section ratios (per nucleon) don't depend on nuclear target (except for the very large x region; Fermi motion)

**Not true!!!**

Measurement of nuclear dependence of $F_2$ by the European Muon Collaboration in 1983 observed systematic deviation from naïve expectation. **The EMC effect**


Re-analysis showed that ratios at $x<0.2$ was wrong, but large x trend confirmed
The EMC effect

- Extensive measurements on heavy targets (SLAC, NMC, BCDMS ...)

- Magnitude depends on $A$, but shape more or less the same.

- Limited world data for light nuclei.

- Poor precision at large $x$. $W^2 > 4$ requires very large energy.

Several models. Some only valid in certain regions. Some inconsistent with other reactions (e.g., Drell Yan)
The EMC effect: E03-103

Main goals of E03-103

- First measurement of EMC effect on $^3$He for $x > 0.4$
- Increase in the precision of $^4$He ratios.
- Precision data at large $x$ for heavy nuclei.
Overview of the experiment

• JLab E03-103 collaboration

• Spokespersons: D. Gaskell (Jlab) and J. Arrington (Argonne)

  Graduate students: J. Seely (M.I.T) and A. Daniel (Houston)

• E03-103 was a measurement of the inclusive electron-nucleus scattering cross section.

• Ran during summer and fall of 2004 in HALL C of JLAB with 5.77 GeV.

• Cryo targets: H, ²H, ³He, ⁴He

• Solid targets: Be, C, Al, Cu, Au (Al for cell wall subtraction)

• Additional data at 5 GeV on carbon and deuterium to investigate detailed Q² dependence of the EMC ratios.

• Concurrent with E02-019 (inclusive cross sections at x>1, F(y) scaling, short range correlations, ...) N. Fomin U.Va, R. Trojer Basel
Two largest angles used to extract cross section ratios

But high $x$ ($x > 0.6$) data not in the typical DIS region ($W^2 < 2$; resonance region)

Data at smaller angles will allow us to put quantitative limits on deviation from scaling in the cross sections and cross section ratios

Solid lines $5.77$ GeV and hatched lines $5.01$ GeV
Backgrounds: charge symmetric processes

Electroproduction of neutral pions in target

\[ \pi^0 \rightarrow \gamma + \gamma \]
\[ \gamma + \text{Nucleus} \rightarrow e^+ + e^- \]
\[ \pi^0 \rightarrow \gamma + e^+ + e^- \]

\(e^+\) and \(e^-\) data acquisition on HMS, hence yields are directly subtracted

Targets with large radiation length have a significant background
Radiative corrections

For heavy nuclei and low $x$, the contribution from quasi-elastic tail is significant. This contribution is the dominant uncertainty in the radiative corrections at low $x$. 
Coulomb corrections

Plane wave Born approximation not valid for heavy nuclei (high Z).

Coulomb distortion changes the vertex values (focusing, acceleration, deceleration), and the measured asymptotic values should be corrected.


\[ F_{\text{cor}} = \frac{\sigma(E,E')}{\sigma(E+\Delta E, E'+\Delta E)} \left[ \frac{E}{E + \Delta E} \right]^2 \]

For Au and near quasi elastic peak, magnitude of the correction is 18%
Isoscalar corrections

Usually EMC ratios are quoted for isoscalar ($Z=N$) nuclei.

For non-isoscalar nuclei, we need to correct for excess of neutrons or protons. The correction function is,

$$f_{iso}^A = \frac{1}{A} \left( \frac{1 + F_2^n / F_2^p}{Z + (A - Z) F_2^n / F_2^p} \right)$$

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


NMC: data mostly at low $x$. No binding correction.

SLAC: $x$ range same as ours. Also corrected for Fermi motion effects when extracting $F_2^n / F_2^p$ from $\sigma_D / \sigma_p$.

E03-103 analysed using SLAC parametrization.
Preliminary results: differential cross sections

\( ^2\text{H} \)

\( ^3\text{He} \)

\( ^4\text{He} \)

\( \text{C} \)
Preliminary results: differential cross sections

Be

Cu

Au
Preliminary results: The $F_2$ structure function
Preliminary results: scaling of $F_2^D$ structure function

Open squares: E89-008, open circles: SLAC, solid circles E03-103

Curves are fit to high $Q^2$ SLAC (DIS) data

$$\frac{d \ln(F_2)}{d \ln(Q^2)} = \text{constant}$$

Scaling breaks down sooner in $x$ than in $\zeta$

At $\zeta = 0.75$, 50 and 40 degrees are consistent with scaling, even though well below $W^2 = 4$ GeV$^2$

EMC ratios are extracted using 40 and 50 degrees with $W^2 > 1.2$ GeV$^2$
The EMC effect: World data in resonance region

Red = resonance region E89-008 data
$Q^2 \sim 4 \text{ GeV}^2$
$1.3 < W^2 < 2.8 \text{ GeV}^2$

Blue, purple, green = DIS data from SLAC, BCDMS

Medium modifications to the structure function ratios are the same in the resonance region as in the DIS.

Preliminary results: scaling of cross section ratios

36 and 46 degrees results are for 5.01 GeV data; remaining results are for 5.76 GeV.

At \( x = 0.7 \), \( Q^2 \) varies from 4 to 6 GeV\(^2\).

E03-103 results are more precise.

Ratios are \( Q^2 \) independent at large \( Q^2 \).
Results: EMC effect in carbon

The EMC effect has been well studied in carbon.

No complications from isoscalar corrections.

Our results are consistent with SLAC data, but have much higher precision at large $x$

Calculation from Cloet et al., (QMC frame-work)
Results: EMC effect in $^4$He

No complications from isoscalar corrections.

$^4$He ratio is consistent with SLAC data, but has much higher precision.

Calculations from Cloet et al. (private communication), Burov, Molochkov and Smirnov PLB 466, 1 (1999), Benhar et al., (private communication)
Results: comparison of the EMC effect in $^4$He and carbon

$^4$He matches better with the SLAC parameterization for $A = 12$ (ln($A$) dependence fit) and with carbon cross section ratios.
Results: EMC effect in $^3$He

Magnitude of isoscalar correction significant (3-15%).

HERMES used NMC parametrization for isoscalar correction.

All the calculations are done with convolution formalism and agree below $x=0.7$.

Brown band is the normalization uncertainty (2.2%)

Brown band + orange band is the sum in quadratures of the normalization and isoscalar correction uncertainties.
Results: EMC effect in Au and Cu

Heavy nuclei more complicated (6% of radiation length)

At low $x$: CSB is high and QE contribution from the radiated tail is significant.

At high $x$: Coulomb distortions are significant

The world data shown are re-analysed to correct for Coulomb distortion (P. Solvignon, ANL)

Brown band is the normalization uncertainty (1.7% for Cu and 2.4% for Au). Brown + magenta + orange band is the sum in quadratures of the normalization, Coulomb and isoscalar correction uncertainties.
Summary

- Differential cross sections and structure functions for $^2$H, $^3$He, $^4$He, C, Be, Cu and Au over a broad range in x and Q$^2$.

- First measurement of the EMC effect in $^3$He above x=0.4 and precision measurement in $^4$He.

- Our heavy target data improves the precision for x > 0.75, where Fermi motion and binding dominates.

- Analysis in the final stage; systematic uncertainties and model dependency of radiative corrections and isoscalar corrections are still under investigation.