EMC effect in few-body nuclei

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(for the JLab E03-103 collaboration)

Overview

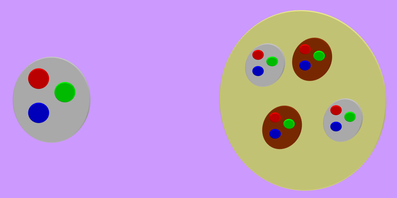
Understanding of the structure of matter is one of the most important quests of modern physics. Matter in the universe is made from three particles; the proton, the neutron, and the electron. The protons and neutrons are bound together to form the nuclei. Nuclei are held together by a strong, long-range force of traditional nuclear physics.

Looking deeper, we find that Quantum ChromoDynamics (QCD) is the underlying theory that explains the existence of protons and neutrons. It describes the interactions that bind the fundamental constituents of matter, called quarks and gluons, into protons and neutrons, and binds these into nuclei. Understanding matter in terms of it's fundamental quark and gluon degrees of freedom remains the greatest unsolved problems. The challenge arises in part from the fact that quarks and gluons cannot be examined in isolation. However, detailed studies of protons and neutrons can provide a wealth of information on the nature of QCD.

Deep inelastic scattering (DIS) has long proved to be one of the most powerful tools in nuclear and particle physics. Starting in the late 1960s, experiments have provided evidence in support of the existence of constituents of the nucleon by exploiting the high resolution of virtual photons probing nucleon structure in DIS. The point-like probe and well-understood electromagnetic interaction mean that the structure of the target can be deduced from the measured scattering cross-section.

The EMC effect

Since nuclei consist of protons and neutrons, the naïve expectation was the cross-section for lepton scattering on nuclei would be the sum of the cross-sections from the nucleon constituents of the target. However, in 1982, this expectation was found to be incorrect by the European Muon Collaboration (EMC) at CERN. They found that the quarks are influenced by the surrounding nuclear medium. Thus the nuclear EMC effect shows that the quark distributions are different in nuclear systems.



In other words, the behavior of quarks in a free nucleon (left side) is not the same as in a bound nucleon (right side). Dedicated experiments are needed to understand the precise nature of these "medium modifications". One way to improve our understanding of this phenomena is extend measurements to the lightest nuclei.

E03-103 experiment @ Hall C of Jefferson Lab

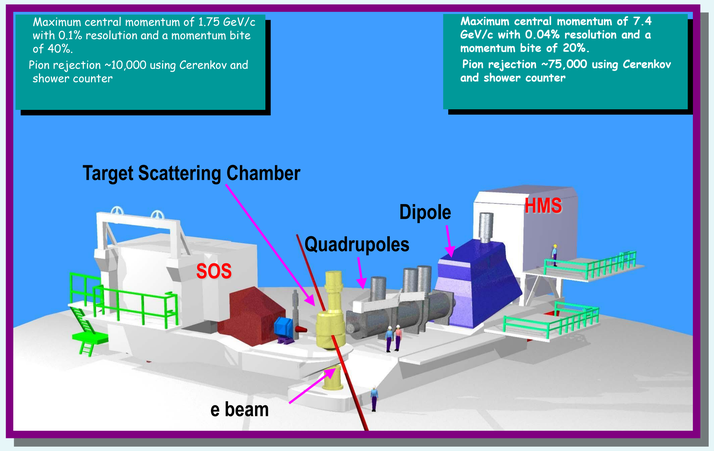


Figure showing the experimental layout in Hall C

Details of the experiment

- Ran summer and fall of 2004 in HALL C of JLAB with a 5.77 GeV electron beam
- Scattered electron detected with **HMS** and **SOS**
- Cryo targets **H,^{2}H,^{3}He,^{4}He**
- Solid targets **^{9}Be,^{12}C,^{27}Al,^{63}Cu,^{197}Au**

Main goals of the experiment

- Increase the precision of ^{4}He ratios.
- First measurement of EMC effect on ^{3}He for x > 0.4
- Precision data at large x (largest x in the resonance region).
- Test models of the EMC effect in "exact" few-body calculations.
- Information on the neutron structure function.

Results from E03-103

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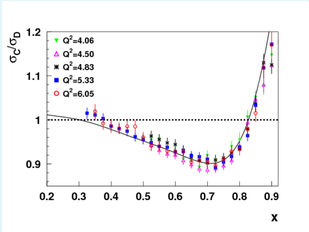
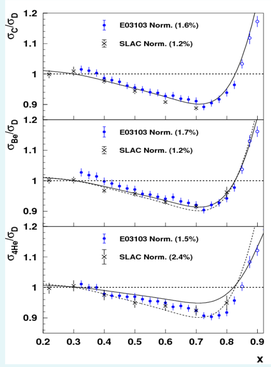
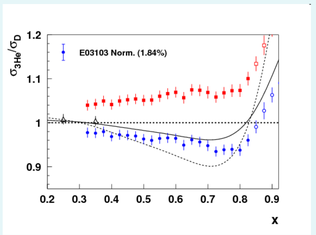
Shown below are the EMC ratios for carbon as a function of x for the five highest Q^2 settings. The solid curve is the SLAC fit to the Carbon EMC ratio. The data show no Q^2 dependence.



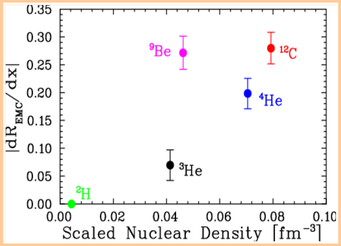


EMC ratios for ^{12}C, ^{9}Be, and ^{4}He, compared to SLAC results. The solid curve is the A-dependent fit to the SLAC data, while the dashed curve is the fit to ^{12}C

Shown below is the EMC ratio for ^{3}He. The upper squares are the raw ^{3}He/^{2}H ratios, while the bottom circles show the isoscalar EMC ratio. The triangles are the HERMES results. The solid (dashed) curves are the SLAC A-dependent fits to ^{3}He and Carbon.

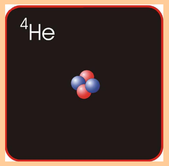


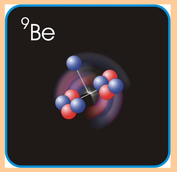
Conclusions



Shown above are the slopes of the isoscalar EMC ratios for 0.35<x<0.7 as a function of average nuclear density, calculated from *ab initio* Greens Function Monte Carlo Calculation of spatial distributions. The EMC effect in ^{3}He is roughly one third of the effect in ^{4}He, in contrast to the mass dependence that explains heavy nuclei. On the other hand, the large EMC effect in ^{9}Be contradicts the alternative density-dependent picture. The size of the EMC effect in ^{9}Be is similar to that carbon, which is twice as dense.

The behavior ^{9}Be could be due to its unusual structure. Most of the time, berylliums configuration consists of two orbiting clusters that look like ^{4}He nuclei, and an additional neutron orbiting around. The orbiting clusters yield a large radius and anomalously low *average* density even though most of the nucleons are contained within the high *local* densities of the alpha (^{4}He) clusters.





Thus the results for the light nuclei suggests that the modifications of quark distributions in nuclei might be due to the microscopic structure of the nucleus under consideration. An approved experiment (E12-10-008) at HALL C with 11 GeV beam energy will further investigate the influence of local environment on the observed nuclear dependence with a more complete set of light nuclei.

Acknowledgements

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For further information about the experiment visit XEM website at
https://hallcweb.jlab.org/experiments/E03103/