

A new study of the EMC Effect using the F_2^n neutron structure function

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Abstract

The persistently mysterious deviations from unity of the ratio of nuclear target structure functions to those of deuterium as measured in deep inelastic scattering (often termed the “EMC Effect”) have become the canonical observable for studies of nuclear medium modifications to free nucleon structure in the valence regime. The structure function of the free proton is well known from numerous experiments spanning decades. The free neutron structure function, however, has remained difficult to access. Recently it has been extracted in a systematic study of the global data within a parton distribution function extraction framework and is available from the CTEQ-Jefferson Lab (CJ) Collaboration. Here, we leverage the latter to introduce a new method to study the EMC Effect in nuclei by re-examining existing data in light of the the magnitude of the medium modifications to the free neutron and proton structure functions independently. From the extraction of the free neutron from world data, it is possible to examine the nuclear effects in deuterium and their contribution to our interpretation of the EMC Effect. In this study, we observe that the ratio of the deuteron to the sum of the free neutron and proton structure functions has some x_B and Q^2 dependencies that impact the magnitude of the EMC Effect as typically observed. Specifically, different EMC slopes are obtained when data from different x_B and Q^2 values are utilized. While a linear correlation persists between the EMC and short range correlation effects, the slope is modified when deuteron nuclear effects are removed.

1 Introduction

Deep inelastic scattering (DIS) has produced a wealth of information on the partonic structure of nuclei spanning several decades of experiments. The EMC Effect, or the observed modification to the bound nucleon partonic structure as compared to that of the free nucleon, is a direct observation from these experiments. The EMC Effect is observed in the regime where x_B is from 0.3–0.7, and the magnitude may be measured as the slope of the ratio of the F_2^A/F_2^d nucleon structure function ratio where A indicates the target nucleus and d is deuterium. It was previously anticipated that this slope should be flat, but the surprising results indicated there is an A -dependent negative slope with increasing x_B . The interpretation of this modification has been the subject of many experiments and sustained theoretical efforts for several decades.

From DIS, a great deal of information is known about the proton, but the neutron’s partonic structure is less understood. A recent effort by the CTEQ-Jefferson Lab Collaboration has reviewed the world DIS data and extracted free neutron structure functions for all kinematics [1] [2]. Knowledge of the neutron structure function is critical, for instance, to constraining the (down quark) $d(x, Q^2)$ parton distribution function (PDF) and reducing uncertainties on other PDFs thereby via the momentum sum rule.

Using the newly obtained free neutron structure function from CJ15, the EMC Effect can be examined in a different way. Rather than studying measured nuclear structure function ratios to

deuterium, the effect on single nucleons investigated here was derived from measured nuclear and proton cross sections. The original SLAC E139 experiment [3] is the only experiment to have published the measured cross sections in addition to the measured F_2^A/F_2^d ratios. By extracting the F_2^A structure function data starting from the cross sections of the SLAC E139 experiment, the EMC Effect can be understood in terms of the free proton and free neutron independently of the nuclear effects in deuterium. Fig. 1 shows the kinematics and targets of the E139 experiment in terms of the Bjorken scaling variable x_B and the four-momentum transfer Q^2 in the inelastic scattering process.

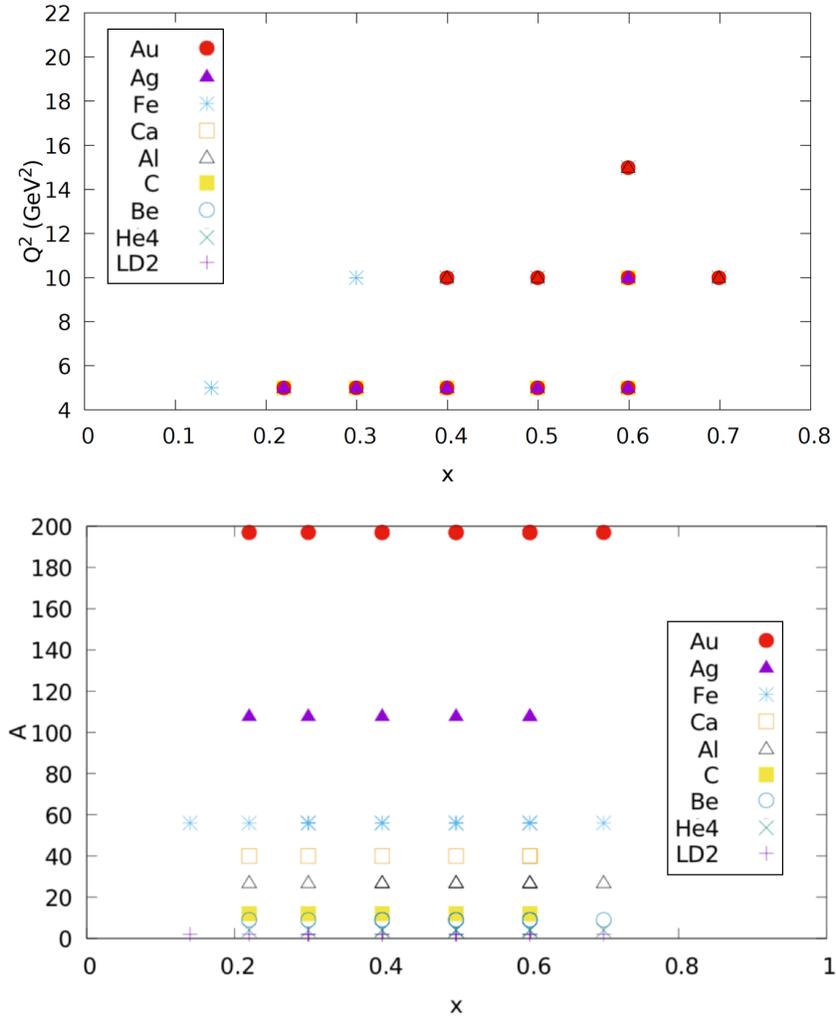


Figure 1: Top: The kinematics of the SLAC E139 experiment are shown as they span x_B and Q^2 for various target nuclei. Bottom: x_B is shown per nuclei in the SLAC E139 experiment.

The kinematics of the E139 experiment span the range of x_B from approximately 0.1–0.7 and Q^2 from 2–15 GeV²/c², depending on the target nucleus. The target nuclei include ²H, ⁴He, ⁹Be, ¹²C, ²⁷Al, ⁴⁰Ca, ⁵⁶Fe, ¹⁰⁸Ag, and ¹⁹⁷Au. It is important to note that here, as with all of the fixed target lepton scattering EMC study data sets, x_B and Q^2 are correlated variables.

2 Theory predictions using nuclear matter

Recent theoretical extractions of the F_2^d structure function per nucleon are shown in Fig. 2 from CJ15 [4]. These results indicate that, for x_B relevant to the EMC Effect (0.3–0.7), theoretical models show a nuclear modification of nearly -2% at $x_B < 0.5$, increasing and changing sign up to $+4\%$ at $x_B \approx 0.75$. While this may not seem large, we note that the EMC Effect at its largest is about a 15% effect in total. Therefore, the deuteron nuclear effects alone may account for up to about 30% of the observed nuclear medium modifications. This general shape is common with other extractions, all predicting a steep rise in deuteron nuclear effects at the largest x_B , although the CJ rise shows an onset at somewhat lower x_B than some. Importantly, the nuclear effects in deuterium do not exhibit a linear behavior in the $0.3 < x_B < 0.7$ region typically studied for the EMC Effect using F_2^d in the denominator. Another common feature to deuteron nuclear effect theory is a predicted Q^2 dependence (a feature also shared, for instance, with predictions by Kulagin-Petti [5] albeit at somewhat different magnitudes). We note here again that, for most of the EMC-type data sets, x_B and Q^2 are correlated variables.

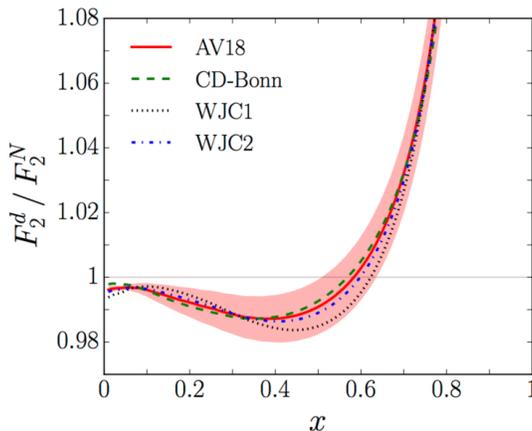


Figure 2: The theoretical extraction of the ratio of F_2^d / F_2^N where N indicates per nucleon. The deuteron exhibits some x_B -dependence such that the ratio is modified by as much as 6% in the regime of x_B between 0.3–0.7 of interest to the EMC Effect [6].

Beginning with quark models and choosing $Q^2 = 5 \text{ GeV}^2/c^2$, theoretically-derived F_2 deuterium ratios with respect to the free neutron and free proton from Cloet are shown in Fig. 3 [7].

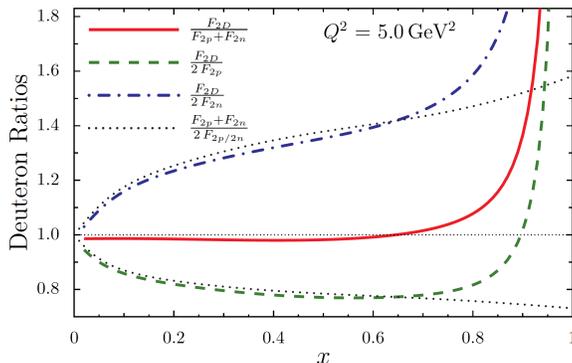


Figure 3: Theoretically-derived deuteron F_2 ratios with respect to the free neutron and proton. These results are shown for fixed $Q^2 = 5 \text{ GeV}^2/c^2$.

Here, the F_2 deuterium ratio with respect to the sum of the free neutron and free proton contributions is shown in red dipping just below unity in the EMC Effect regime and rising at large x_B , as CJ qualitatively describes. By taking the ratio of $F_2^d/2F_2^p$ (shown in green) where p indicates the proton structure function, the slope dips well below unity and is far greater in magnitude than the F_2 deuterium ratio shown in red. Taking $F_2^d/2F_2^n$, where n indicates the neutron structure function, shows conversely a positive slope that is of greater magnitude still than $F_2^d/2F_2^p$. The proton dominance is expected, given that the $d(x_B)/u(x_B)$ (quark) PDF is predicted to decline substantially at large x_B and so similarly F_2^n/F_2^p . It is nonetheless interesting that the size of the nuclear effects is predicted to be roughly equal to the conventional F_2^A/F_2^d EMC Effect alone for the proton, but twice this EMC Effect magnitude for the neutron.

3 F_2^n extraction and the CJ15 fit

The CTEQ-Jefferson Lab (CJ) Collaboration recently reviewed the world DIS data on the proton and deuteron structure functions, including all inclusive data from the Jefferson Lab 6 GeV program and performed an extraction of the free neutron structure function from proton and deuteron data over the full available kinematics. The extraction utilized the CJ15 simultaneous QCD fit of PDFs and deuteron nuclear corrections [8] to calculate the $d/(p+n)$ ratio and convert experimental data on the deuteron and proton obtained at matching kinematics to neutron data [1]. In this paper, we utilize this extracted free neutron structure function data to examine the EMC Effect in a new way.

One should note that a QCD fit similar in spirit to the CJ15 fit was performed in 2017 by Alekhin, Kulagin and Petti [5], but resulted in a markedly different fitted offshell correction function. The reasons for this are not clear but are being actively investigated by both collaborations [5, 9]. The resulting F_2^n structure function is, roughly speaking, about 10% different than its CJ15 counterpart, crossing at $x \sim 0.4$ and displaying a steeper slope [9]. However, information was not available for an extraction of the F_2^n structure function data, and so we cannot quantify the differences this would induce on the results we present here. We do expect the general observations to be similar.

In Fig. 4, general comparisons of the newly extracted F_2^n are made with respect to F_2^p obtained from an NMC fit. [10] On the left of Fig. 4, the F_2^n and F_2^p for the same x_B and Q^2 kinematics is shown. The F_2^n in blue is extracted from the world data, and the F_2^p is the corresponding value (for the same kinematics) from the NMC fit [10]. The overall x_B dependence is somewhat different for the neutron and proton; the neutron structure function flattens earlier at larger x_B while the

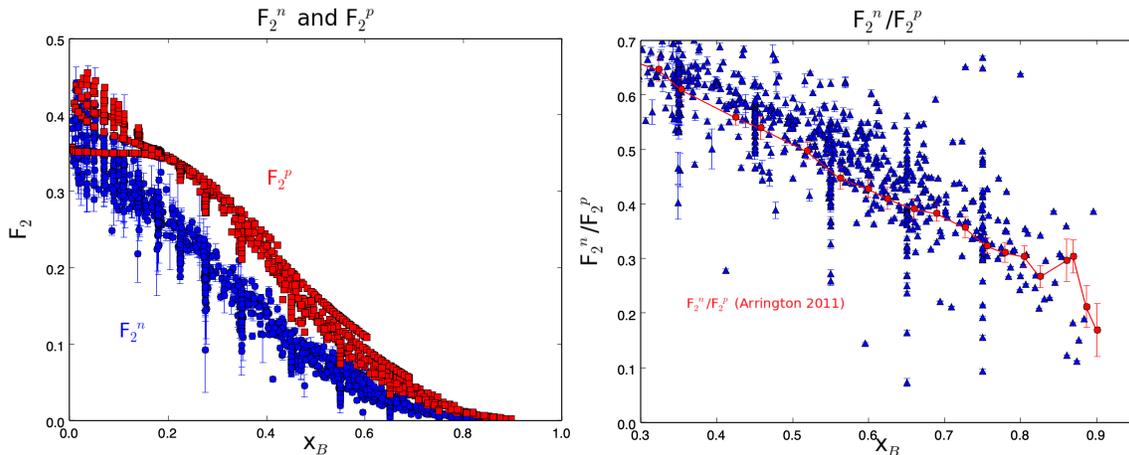


Figure 4: Left: The extracted CJ F_2^n DIS data are shown in blue, and the F_2^p from the NMC global fit is shown in red for the same corresponding x_B and Q^2 [10]. Right: The ratio F_2^n/F_2^p from the left is shown as a function of x_B . A comparison to a previous extraction of the F_2^n/F_2^p ratio from [11] is shown in red.

proton structure function drops off more sharply. The ratio of these quantities is shown on the right in Fig. 4 and agrees with previously extracted results [11]. The bands and striping reflect Q^2 differences at fixed x_B .

3.1. Q^2 dependence

A significant observation in the CJ15 extracted structure functions is the Q^2 dependence. The proton structure function is shown on the left in Fig. 5 for various Q^2 from the CJ15 global PDF fit. The middle plot shows the same Q^2 dependence for the neutron structure function from CJ, and the corresponding deuteron structure function is shown on the right in Fig. 5. Here, no uncertainties are shown as we focus on the Q^2 dependence. The SLAC E139 experiment took measurements at Q^2 in the range of 5–15 GeV^2/c^2 . The nucleon and deuteron structure functions from CJ show a clear Q^2 dependence for fixed values of x_B in this range of Q^2 . This can translate into a Q^2 dependence in the EMC Effect ratio F_2^A/F_2^d if the deuteron Q^2 dependence is different from the heavier nuclei and ultimately contributes to understanding medium modifications to the free nucleon taking into account proton and neutron individual differences.

The nuclear effects of the proton and neutron in the deuteron can be directly characterized by dividing the deuteron structure function by the sum of the free proton and free neutron structure functions. The result is shown on the left in Fig. 6. Over most of the typical range of x_B that is relevant to the EMC Effect, the Q^2 dependence is minimal. At approximately $x_B = 0.6$ and greater, however, the ratio diverges greatly with Q^2 dependence.

The same ratio of deuteron to the sum of free nucleons is shown on the right in Fig. 6 using SLAC deuterium data [13]. The same general trend is observed as that observed in CJ15 fits where Q^2 has a more significant effect on the ratio at large values of x_B . The separate F_2^d/F_2^p and F_2^d/F_2^n ratios from the CJ15 fit are shown in Fig. 7. Here, it is useful to note that F_2^d/F_2^p , which is independent of theoretical bias, shows large x_B and Q^2 dependence.

In Fig. 7, the deuterium ratio to the neutron structure function appears to have a general divergence that increases with increasing x_B while the ratio to the proton has a more consistent offset throughout the range of $x_B < 0.7$ relevant to EMC studies. It is important to note the

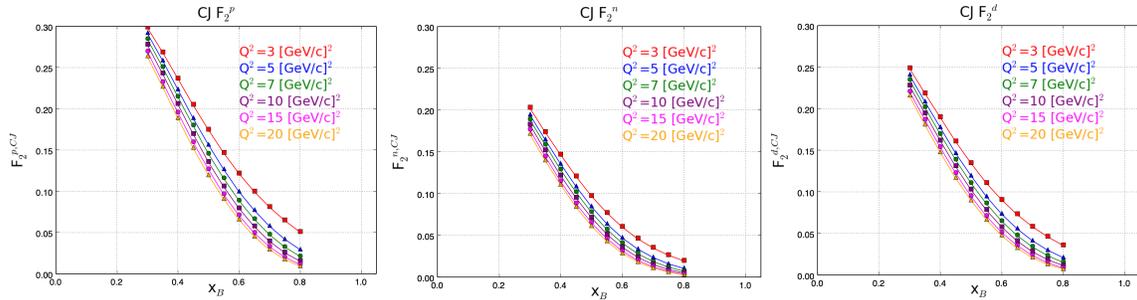


Figure 5: Left: The proton structure function from CJ15 is shown as a function of x_B for various fixed Q^2 (as indicated). Middle: The neutron structure function from CJ15 is shown as a function of x_B for various fixed Q^2 . Right: The deuteron structure function from CJ15 is shown as a function of x_B for various fixed Q^2 . All are shown without uncertainty to better reflect the Q^2 dependence of each.

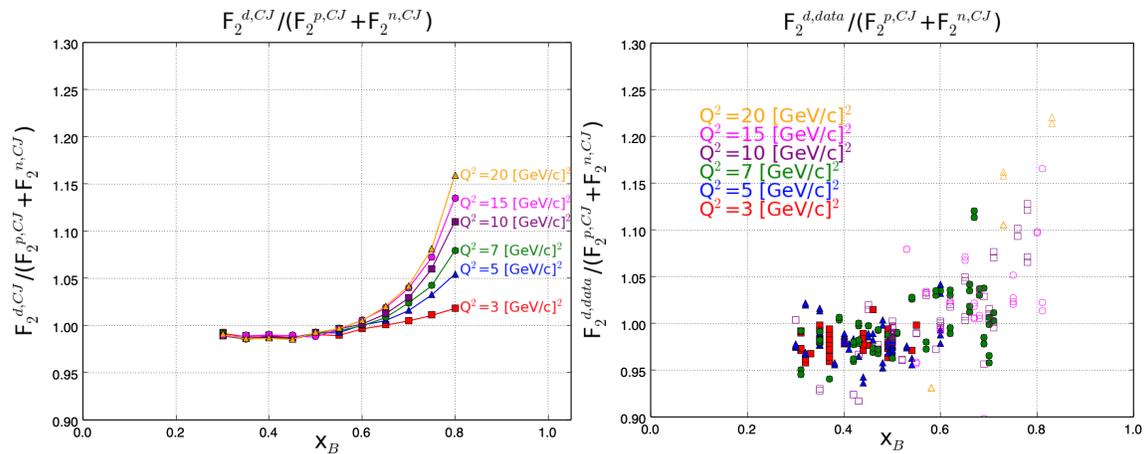


Figure 6: Left: The deuteron structure function divided by the sum of the free proton and free neutron structure functions from the CJ15 fit is shown for various Q^2 . This ratio reflects the magnitude of the nuclear effects in the deuteron. The Q^2 dependence shows significant spread above $x_B = 0.6$ where the ratio begins to increase. Right: The Whitlow deuterium data from SLAC [12] is shown divided by the sum of the free proton and free neutron structure functions from the CJ15 fit. In both cases, uncertainties are not shown in order to emphasize the general kinematic dependence.

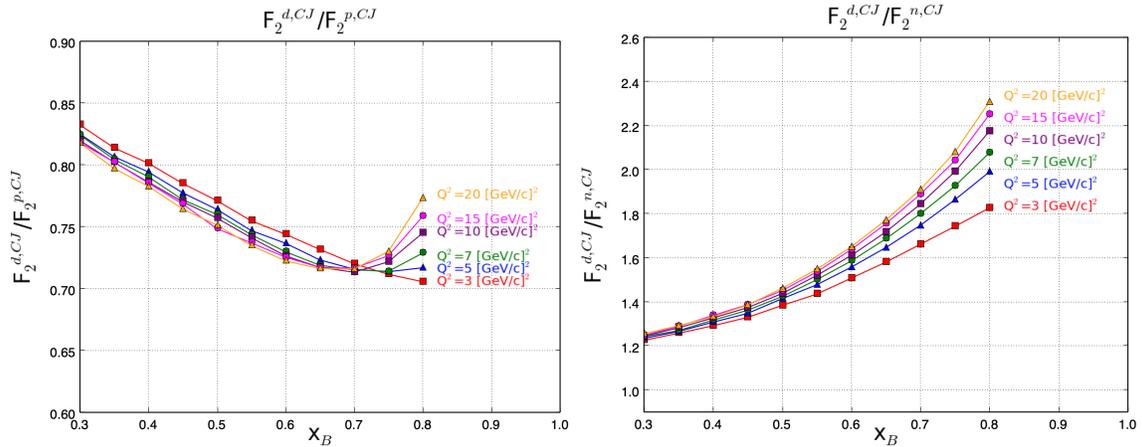


Figure 7: Left: The deuteron structure function from the CJ15 fit is shown as a ratio to the proton structure function from CJ15 for various Q^2 . Right: The deuteron structure function from the CJ15 fit is shown as a ratio to the neutron structure function from CJ15 for various Q^2 . Uncertainties are not shown to emphasize the kinematic dependence of the structure functions.

magnitude of this spread in ratios at large x_B values as many experiments, SLAC E139 included, averaged Q^2 to achieve statistical precision for each point in x_B [3].

Additionally, the EMC Effect has more recently been characterized by a linear fit in the range of x_B from 0.3–0.7 where deuteron in fact exhibits non-linear nuclear modification effects. These two observations (i.e. the x_B and Q^2 dependence of the deuteron nuclear effects) should be taken into account in the interpretation and extraction of the EMC Effect.

4 Structure function extraction from the E139 cross sections

For this analysis, experimental cross sections (as opposed to published ratios) were desirable for the flexibility to construct and study ratios of nuclei to free nucleon quantities. The SLAC E139 experiment published the experimental cross sections for the following nuclei: ^2H , ^4He , ^9Be , ^{12}C , ^{27}Al , ^{40}Ca , ^{56}Fe , ^{108}Ag , and ^{197}Au . The cross sections include published statistical and systematic errors. The F_2 structure function for each nucleus is extracted from the cross section using the relationship shown in Equation (1):

$$F_2(x_B, Q^2) = \frac{d^2\sigma}{d\Omega dE'} \frac{1+R}{1+\epsilon R} \frac{K\nu}{4\pi^2\alpha\Gamma(1+\nu^2/Q^2)} \quad (1)$$

In Equation (1), ϵ , K , and Γ are defined by the electron-nucleon deep inelastic scattering kinematics in Equation (4). These quantities include the measured scattering angle θ , the momentum transfer Q^2 , the energy transfer ν , the scattered electron energy E' , the mass of the proton M , and the squared invariant mass W^2 . R in this analysis was determined from the R1990 fit [14] to world data and is here assumed to be A -independent.

$$\epsilon = \left(1 + 2 \frac{\nu^2 + Q^2}{Q^2} \tan^2 \frac{\theta}{2}\right)^{-1} \quad (2)$$

$$K = \frac{W^2 - M^2}{2M} \quad (3)$$

$$\Gamma = \frac{\alpha K E'}{2\pi^2 Q^2 E (1 - \epsilon)} \quad (4)$$

For most published cross section ratios, corrections are applied to account for the excess of neutrons in asymmetric nuclei for comparison to deuterium. This correction is referred to as the ‘‘isoscalar correction’’ and is defined in Equation (5). While this correction is not applied in this paper for the F_2 ratio results per free proton and free neutron, it is relevant for accurately reconstructing the published F_2^A/F_2^d ratios in most analyses.

For analysis in this paper, an additional requirement for $W^2 > 4 \text{ GeV}^2/c^2$ was applied in order to ensure that the results obtained are above the resonance region. As noted above, no nuclear dependence of R is assumed. This may not be the case and will be further studied [15] [16].

$$f_{iso}^A = \frac{\frac{1}{2}(1 + F_2^n/F_2^p)}{\frac{1}{A}(Z + (A - Z)F_2^n/F_2^p)} \quad (5)$$

For this reason, fits and models characterizing the EMC Effect (for instance, [17]) often do not include any Q^2 dependence.

5 EMC studies per nucleon

The standard EMC structure function ratio of nucleus to deuterium (F_2^A/F_2^d) is compared with ratios of the structure function of each nucleus to that of the free proton and free neutron, separately. The F_2^A/F_2^d ratios for the carbon and gold nuclei are shown in Fig. 8 using the collective world data as published in Ref. [17]. The gold nucleus (heavier than carbon) exhibits a steeper slope, a standard observation of the EMC Effect. The F_2^A/AF_2^p ratio is the per nucleon ratio to the proton structure function and is also shown on the left in Fig. 8. These ratios are consistent with theory predictions and exhibit a similar trend to the ratio of the nuclear structure functions to deuterium in that the slope steepens for heavier nuclei. The vertical spread in the ratios of the various nuclei softens when an iso-scalar correction is applied. The F_2^p structure function is obtained from the CJ15 fit. The F_2^A/AF_2^n , shown on the left of Fig. 8, is the per nucleon ratio with respect to the free neutron. Here, we observe a positive slope such that the heavier nuclei exhibit shallower slopes than the lighter nuclei.

The F_2^A/AF_2^n ratio is the per nucleon to the free neutron. The free neutron F_2^n is from the CJ15 extraction from the world data. As shown in Fig. 8, the F_2^A/AF_2^n ratios for the SLAC E139 nuclei exhibit a larger vertical spread when compared to the vertical spread of the F_2^A/AF_2^p ratios for various nuclei. The F_2^A/AF_2^n ratios also exhibit a positive slope in contrast to the ratios constructed using the free proton. These observations are further magnified on the right in Fig. 8 where the ratios for each nuclei are shown as per proton (F_2^A/ZF_2^p) and per neutron (F_2^A/NF_2^n). The per proton ratios taken with respect to the free proton yield ratios that are nearly indistinguishable when compared to the large spread of the per neutron ratios taken with respect to the free neutron. Again, the per neutron slopes on the right of Fig. 8 indicate a shallower slope (always positive) for the heavier nuclei.

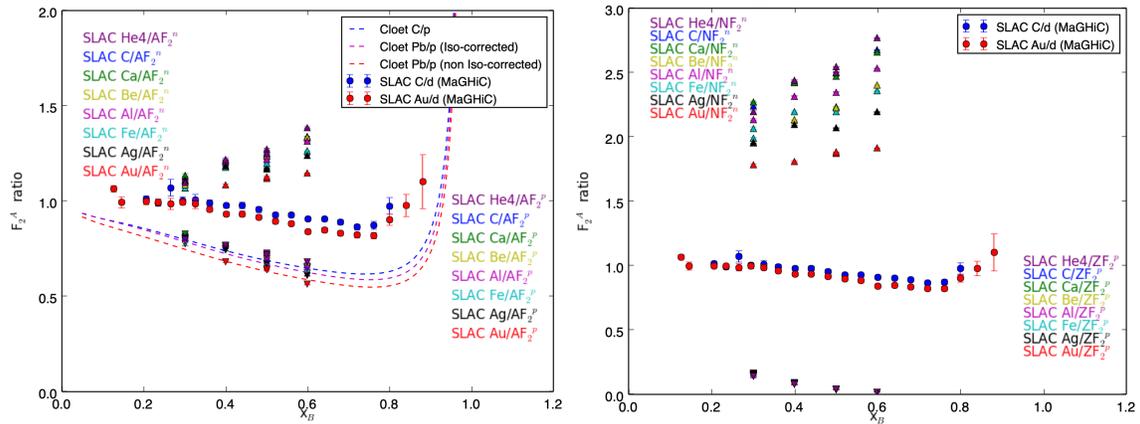


Figure 8: Left: F_2^A calculated from the published SLAC E139 cross sections is taken as a ratio per nucleon to F_2^n and F_2^p , separately. The published ratios for carbon and gold [17] are shown for reference as F_2^A / F_2^d per nucleon. Theory predictions for the F_2^A structure function per nucleon as a ratio to F_2^p are also shown [7]. The nuclei from the SLAC E139 experiment are shown as ratios per nucleon relative to F_2^p (bottom) and F_2^n (top). Right: F_2^A calculated from the published SLAC E139 cross sections is taken as a ratio per neutron or proton and F_2^n and F_2^p , separately. The published EMC ratios for carbon and gold [17] are shown for reference. Different from the plot on the left, the nuclei from the SLAC E139 experiment are shown as ratios per proton relative to F_2^p (bottom) and per neutron F_2^n (top). A larger spread in the nuclei is observed per neutron than per proton for x_B .

6 Deuterium nuclear effects and kinematic dependence

6.1. Deuterium

The nuclear effects in deuterium are non-negligible for values of x_B from 0.3–0.7 in the region of interest to the EMC Effect. The nuclear effects in deuterium can be quantified somewhat as the difference between the sum of the free proton and free neutron to that of the measured deuterium structure function. In Fig. 9, the F_2^A ratio is defined in two ways: the standard F_2^A / F_2^d (shown in blue) and the ratio to the sum of the free neutron and free proton $F_2^A / (ZF_2^p + (A - Z)F_2^n)$ (shown in red). The SLAC E139 data was taken for Q^2 of 5, 10, and 15 GeV^2/c^2 .

In Fig. 9, the deuterium to nucleon ratios from the SLAC E139 deuterium data are shown using the CJ15 structure function constructs in the F_2 nucleon denominators. The different Q^2 data are shown using different shapes in each plot, and fits to the ratios are taken separately with and without the highest x_B point at 0.7. There is a small systematic offset from unity for deuterium taken as a ratio to itself, but the ratio is relatively flat across x_B . There exists a clear difference between the ratio taken relative to the deuteron structure function (blue) and the ratio taken relative to sum of the free neutron and free proton structure functions (red), a measure of the nuclear effects in the deuteron. This difference also exhibits a small spread in Q^2 . We note the important changes when different x_B , Q^2 cuts are made to the data; reflecting the kinematic dependence in both x_B and Q^2 of deuteron nuclear effects.

6.2. Heavier nuclei

The EMC ratios for all the target nuclei in the SLAC E139 experiment are compared for ratios where the denominator is deuterium and where the denominator is the sum of the free proton

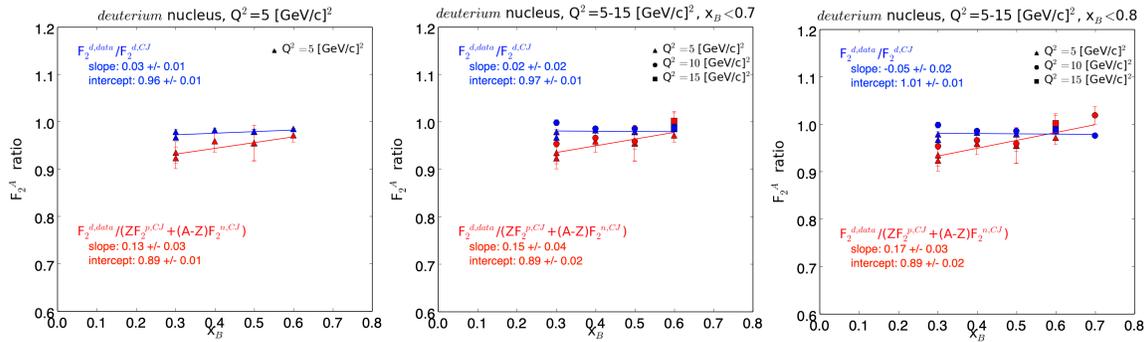


Figure 9: Linear fits to the deuterium target data with cuts on Q^2 and x_B . The blue data shows the ratio of the E139 deuterium data relative to the C15 deuterium while the red data shows the ratio of the E139 deuterium data relative to the sum of the free proton and free neutron (excludes nuclear effects of deuterium). Left: Data taken for $Q^2 = 5$ GeV $^2/c^2$. Center: Data taken for all Q^2 but excluding the data at $x_B = 0.7$. Right: All data taken through $x_B = 0.7$.

and neutron contributions. This comparison provides a measure of the contribution of deuterium nuclear corrections to the EMC Effect. Carbon is a symmetric nucleus, and the results are shown in Fig. ???. Also shown in Fig. ??? is a linear fit to the two types of ratios, over the EMC range of data at $x_B = 0.3$ and above. No data was taken in the E139 experiment for carbon at $x_B > 0.6$, where deuteron nuclear effects increase. The slope is more shallow for the ratio taken with the free neutron and proton components only. A more extreme case is seen in the heavy and asymmetric gold nucleus in Fig. 11.

For the gold nucleus, the slope of the fit to ratios obtained with respect to the free neutron and free proton is shallower than the slope with respect to deuterium (as consistent with the general trend observed in carbon and deuterium as previously discussed). When data is fitted for a range of Q^2 values, a noticeable striping at each point in x_B is apparent indicating some Q^2 dependence. Furthermore, the higher x_B data (also higher Q^2 due to the experimental kinematics in scattering angle), is barely linear with respect to the lower x_B data. In all nuclei (see Appendix), this discrepancy is most apparent for increasing values of x_B around 0.7. This observation is where one would expect to see the contributions from the deuteron nuclear effects as shown in Fig. 2.

Similar fits are made to all the nuclei (shown in the Appendix). The resultant summary of the slopes is shown in Tables 1, 2, and 3. The slopes are shown as a function of A for the nuclei in Fig. 12.

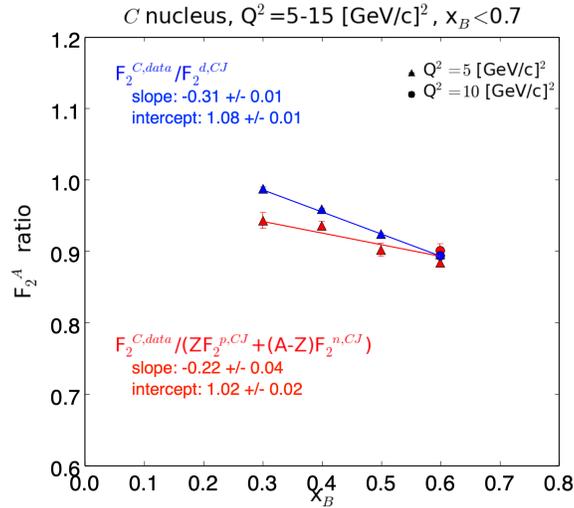


Figure 10: Linear fits to the C target data with cuts on Q^2 and x_B . The blue data shows the ratio of the nucleus relative to deuterium while the red data shows the ratio of the nucleus relative to the sum of the free proton and free neutron (excluding the nuclear effects of deuterium). The linear fit to the data is taken for all Q^2 , where $5 < Q^2 < 15$ GeV/c². No data was taken in the E139 experiment for carbon at $x_B = 0.7$.

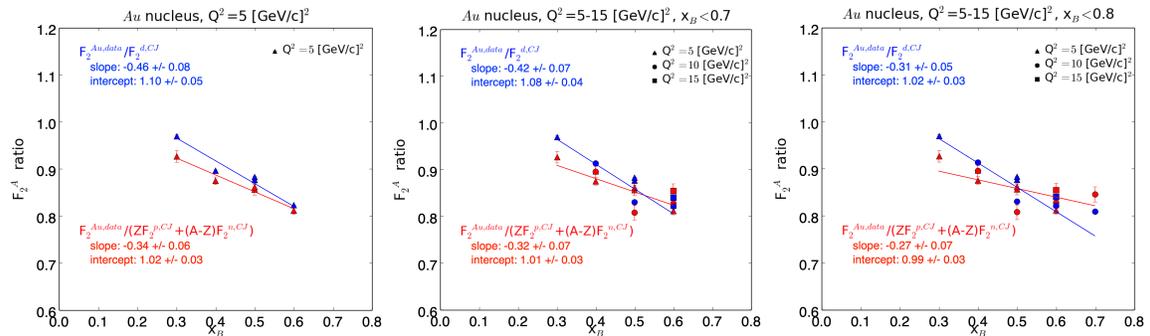


Figure 11: Linear fits to the Au target data with cuts on Q^2 and x_B . The blue data shows the ratio of the nucleus relative to deuterium while the red data shows the ratio of the nucleus relative to the sum of the free proton and free neutron (excluding nuclear effects of deuterium). Left: linear fit to the data taken for $Q^2 = 5$ GeV²/c². Center: linear fit to the data taken for all Q^2 but excluding the data at $x_B = 0.7$. Right: linear fit to all data taken through $x_B = 0.7$.

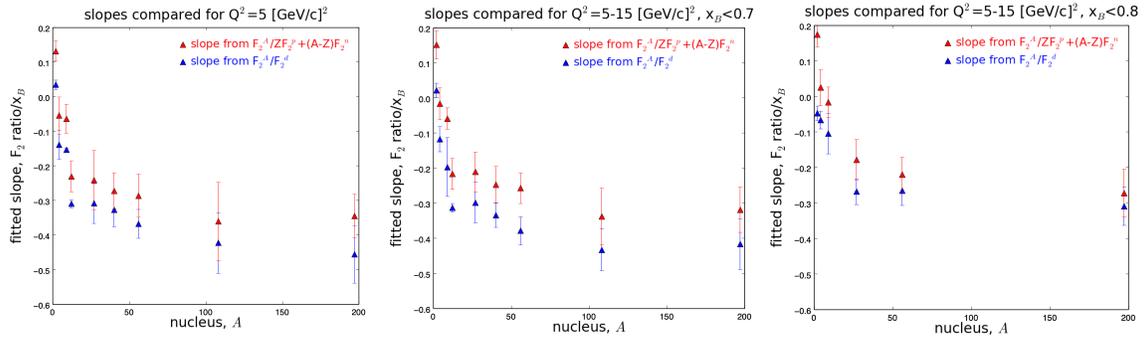


Figure 12: The slopes to the fits of the F_2 ratios versus x_B are shown for both denominators (deuterium and the sum of the free proton and free neutron) as a function of the target A . In all cases, the ratio taken with respect to the sum of the free neutron and free proton components exhibits a shallower slope than that for deuterium. Left: The slope comparisons are made using all data with $Q^2 = 5 [\text{GeV}/c]^2$. Center: The slopes are compared with no cut on Q^2 but requiring that $x_B < 0.7$. Right: The slopes are compared with no cut on Q^2 and $x_B < 0.8$.

The slopes for each ratio for various cuts in Q^2 and x_B are compared in Fig. 13. The inclusion of higher Q^2 and x_B data in the fits generates somewhat shallower slopes due to the rise seen from the nuclear effects. The inclusion of the largest x_B , Q^2 yields a deuterium F_2^A / F_2^d ratio closest to one even though this is the region of largest deuteron nuclear correction. In all cases, the ratios to the free neutron and proton have a reduced EMC Effect (i.e. shallower slopes) than the deuteron ratios. In all cases, linear fits are sufficient to describe the data. Including the largest x_B data further reduces the slopes, underscoring the large effect of deuteron nuclear corrections, which increase with increasing x_B .

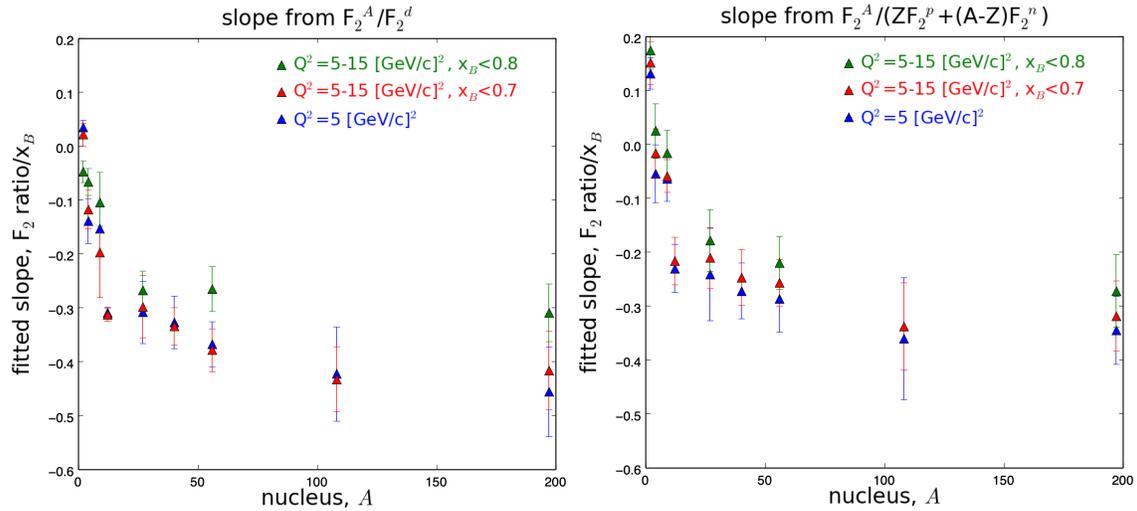


Figure 13: The slopes are compared for the different cuts in Q^2 and x_B . The inclusion of larger Q^2 and x_B points in the fit generates a somewhat shallower slope.

Table 1 shows the fitted slope and intercept values for both the F_2^A ratio for each nucleus taken with respect to deuterium and the sum of the free neutron and free proton contributions.

In Table 1, only fits to the data where $Q^2 = 5 \text{ GeV}^2/c^2$ are shown. No iso-scalar corrections are applied to the asymmetric nuclei.

Table 1: Summary of linear fits to ratios as a function of x_B where $Q^2 = 5 \text{ GeV}^2/c^2$.

Nucleus	A/d slope	A/d intercept	A/(n+p) slope	A/(n+p) intercept
^2H	0.03+/-0.01	0.96+/-0.01	0.13+/-0.03	0.89+/-0.01
^4He	-0.14+/-0.04	1.01+/-0.02	-0.05+/-0.05	0.95+/-0.03
^9Be	-0.15+/-0.00	1.021+/-0.00	-0.06+/-0.04	0.96+/-0.02
^{12}C	-0.31+/-0.01	1.08+/-0.00	-0.23+/-0.05	1.02+/-0.02
^{27}Al	-0.31+/-0.06	1.07+/-0.03	-0.24+/-0.09	1.02+/-0.04
^{40}Ca	-0.33+/-0.05	1.09+/-0.03	-0.27+/-0.05	1.04+/-0.03
^{56}Fe	-0.37+/-0.04	1.09+/-0.02	-0.29+/-0.06	1.03+/-0.03
^{108}Ag	-0.42+/-0.09	1.12+/-0.05	-0.36+/-0.11	1.07+/-0.06
^{197}Au	-0.46+/-0.08	1.10+/-0.05	-0.35+/-0.06	1.02+/-0.03

Table 2 shows the fitted slope and intercept values for both the F_2^A ratios where all E139 Q^2 data are included at $x_B < 0.7$.

Table 2: Summary of linear fits to ratios as a function of x_B where $Q^2 = 5 - 15 \text{ GeV}^2/c^2$ and $x_B < 0.7$.

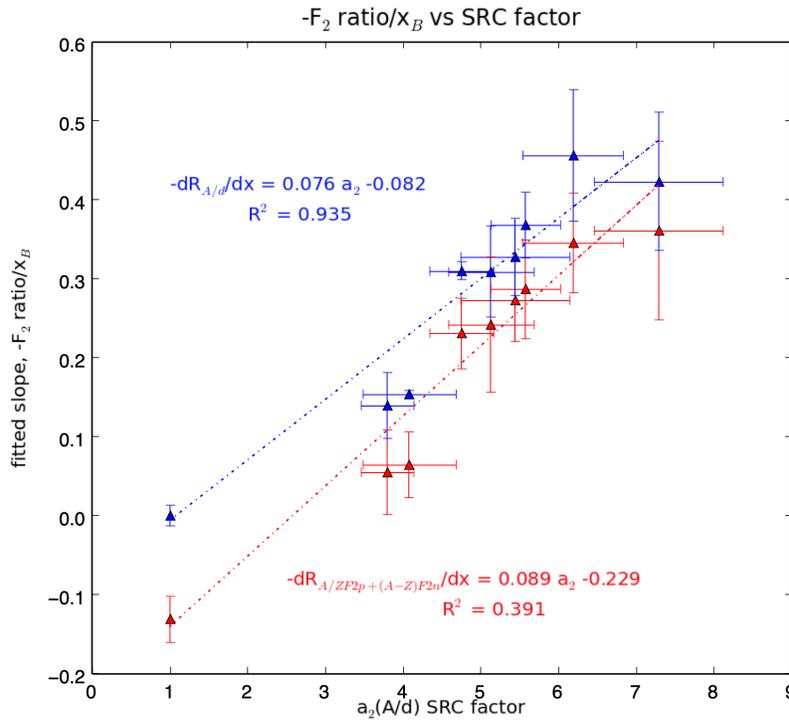
Nucleus	A/d slope	A/d intercept	A/(n+p) slope	A/(n+p) intercept
^2H	0.02+/-0.02	0.98+/-0.01	0.15+/-0.04	0.90+/-0.02
^4He	-0.12+/-0.04	1.0+/-0.02	-0.02+/-0.05	0.93+/-0.02
^9Be	-0.20+/-0.08	1.04+/-0.05	-0.06+/-0.03	0.95+/-0.02
^{12}C	-0.31+/-0.01	1.08+/-0.01	-0.22+/-0.04	1.02+/-0.02
^{27}Al	-0.30+/-0.06	1.07+/-0.03	-0.21+/-0.06	1.01+/-0.03
^{40}Ca	-0.33+/-0.03	1.09+/-0.02	-0.25+/-0.05	1.03+/-0.03
^{56}Fe	-0.38+/-0.04	1.09+/-0.02	-0.26+/-0.04	1.01+/-0.02
^{108}Ag	-0.43+/-0.06	1.12+/-0.03	-0.34+/-0.08	1.06+/-0.04
^{197}Au	-0.42+/-0.07	1.08+/-0.04	-0.32+/-0.07	1.01+/-0.03

Table 3 shows the fitted slope and intercept values for both the F_2^A ratios where all E139 Q^2 data are included with no cuts on $x_B < 0.8$. In all three tables, the fits were taken excluding data below x_B of 0.3.

The slopes from Table 1 where $Q^2 = 5 \text{ GeV}^2/c^2$ only are shown plotted against the short range correlated (SRC) scale factor a_2 [18], derived as the ratio A/d in the plateau region of large x_B and can be summarized as the probability that a nucleon belongs to an SRC pair. The general fitted slope is still linear across the a_2 values for each nucleus, but there is a clear systematic offset between the intercept values of these two fits. The fits to the slopes with respect to the SRC factor are shown in Fig. 14. It should be noted that the a_2 values shown here include predicted values from [18]. While some work has been done to improve these values from later analysis, [18] provides the most complete list for the nuclei of interest and was used for consistency.

Table 3: Summary of linear fits to ratios as a function of x_B where $Q^2 = 5 - 15 \text{ GeV}^2/c^2$ and $x_B < 0.8$.

Nucleus	A/d slope	A/d intercept	A/(n+p) slope	A/(n+p) intercept
^2H	-0.05+/-0.02	1.01+/-0.01	0.17+/-0.03	0.89+/-0.02
^4He	-0.07+/-0.03	0.97+/-0.02	0.03+/-0.05	0.91+/-0.03
^9Be	-0.11+/-0.06	0.99+/-0.04	-0.02+/-0.04	0.94+/-0.02
^{12}C	—	—	—	—
^{27}Al	-0.27+/-0.04	1.06+/-0.02	-0.18+/-0.06	1.0+/-0.03
^{40}Ca	—	—	—	—
^{56}Fe	-0.27+/-0.04	1.03+/-0.03	-0.22+/-0.05	0.99+/-0.02
^{108}Ag	—	—	—	—
^{197}Au	-0.31+/-0.05	1.02+/-0.03	-0.27+/-0.07	0.99+/-0.03


Figure 14: The slopes of the fit to the data for $Q^2 = 5 \text{ GeV}^2/c^2$ are shown versus the a_2 SRC factor from [18]. The points shown in blue are the slopes from the ratios taken with respect to deuterium, and the points in red are from the slopes with respect to the free neutron and free proton denominator. The slope value for deuterium taken with respect to itself (blue) is set to 0.

The intercept value of approximately -0.08 for the ratio taken with respect to deuterium (Fig. 14) is consistent with previous studies [18] [19]. The intercept value is significantly smaller for the data where the slope ratio was taken with respect to the sum of the free proton and free neutron contributions and thus yields a smaller intercept value of approximately -0.23. While later analysis has yielded some slightly different calculations for the a_2 values, the overall differences between the slopes and intercept will remain consistent.

7 Conclusions

The CJ Collaboration has recently extracted the free neutron structure function from the world DIS data, thereby opening new windows for exploring the EMC Effect and deuteron nuclear effects. General observations show that the deuteron ratio to the sum of the free proton and free neutron structure functions has some dependence on Q^2 , most significantly at large Q^2 and large x_B . As the EMC Effect is often obtained from the slope of the nuclear to deuteron structure function ratios over a range in large x_B , there are kinematically-dependent nuclear effects in this regime from the deuteron alone. Such dependence may have been minimized in previous studies as the nuclear data were averaged in Q^2 . Additionally, the correlation of these effects in x_B and Q^2 dictate that the structure function ratios obtained using data at $x_B > 0.6$ do not follow the same linear trend of the data from lower x_B . The EMC Effect as calculated using the slope of the F_2^A/F_2^d ratio has an x_B and Q^2 dependence. Also, there appears to be a more significant spread in A in the data where the structure function of the nucleus is taken with respect to the neutron as compared to the proton. This spread arises from the drop in the ratio F_2^n/F_2^p as a function of x_B . Moreover, by removing the deuteron nuclear effects, a correlation is still observed between the resultant EMC slope and short range correlated pairs in the nucleus, but the overall slope of this correlation is modified slightly, yielding a smaller intercept. The authors of this paper would be interested to further investigate avenues for disentangling the x_B and Q^2 data at higher x_B to better understand the nuclear effects in this regime.

8 Acknowledgments

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9 Appendix

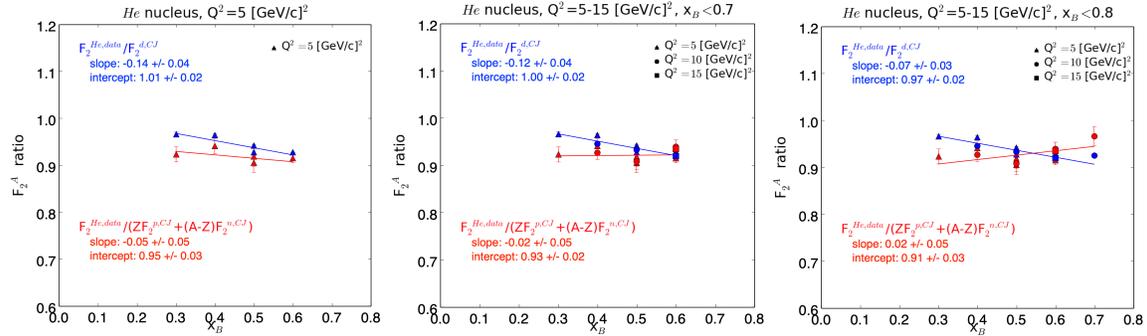


Figure 15: Linear fits to the He target data with cuts on Q^2 and x_B from the E139 experiment. Left: The ratios are constructed requiring that $Q^2 = 5 \text{ GeV}^2/c^2$. Center: The ratios include all data $5 < Q^2 < 15 \text{ GeV}^2/c^2$ where $x_B < 0.7$. Right: The ratios include all data $5 < Q^2 < 15 \text{ GeV}^2/c^2$ up to $x_B < 0.8$.

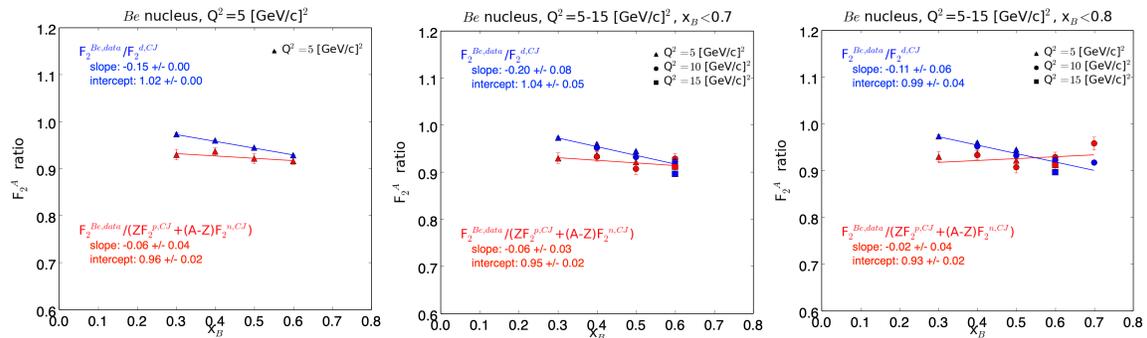


Figure 16: Linear fits to the Be target data with cuts on Q^2 and x_B from the E139 experiment. Left: The ratios are constructed requiring that $Q^2 = 5 \text{ GeV}^2/c^2$. Center: The ratios include all data $5 < Q^2 < 15 \text{ GeV}^2/c^2$ where $x_B < 0.7$. Right: The ratios include all data $5 < Q^2 < 15 \text{ GeV}^2/c^2$ up to $x_B < 0.8$.

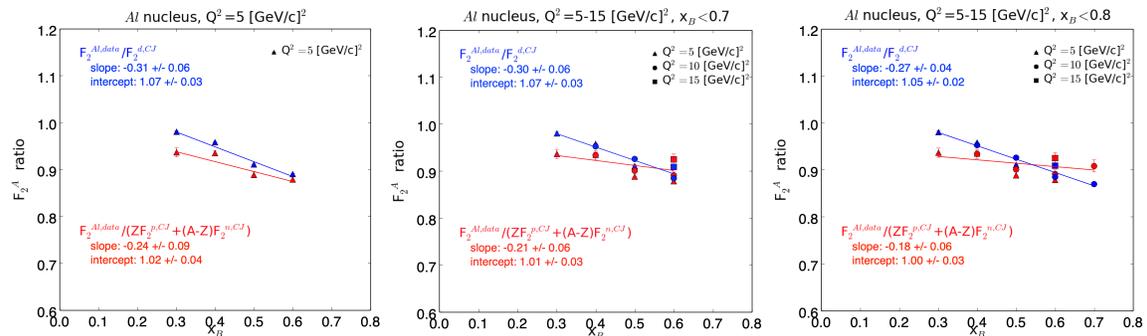


Figure 17: Linear fits to the Al target data with cuts on Q^2 and x_B from the E139 experiment. Left: The ratios are constructed requiring that $Q^2 = 5 \text{ GeV}^2/c^2$. Center: The ratios include all data $5 < Q^2 < 15 \text{ GeV}^2/c^2$ where $x_B < 0.7$. Right: The ratios include all data $5 < Q^2 < 15 \text{ GeV}^2/c^2$ up to $x_B < 0.8$.

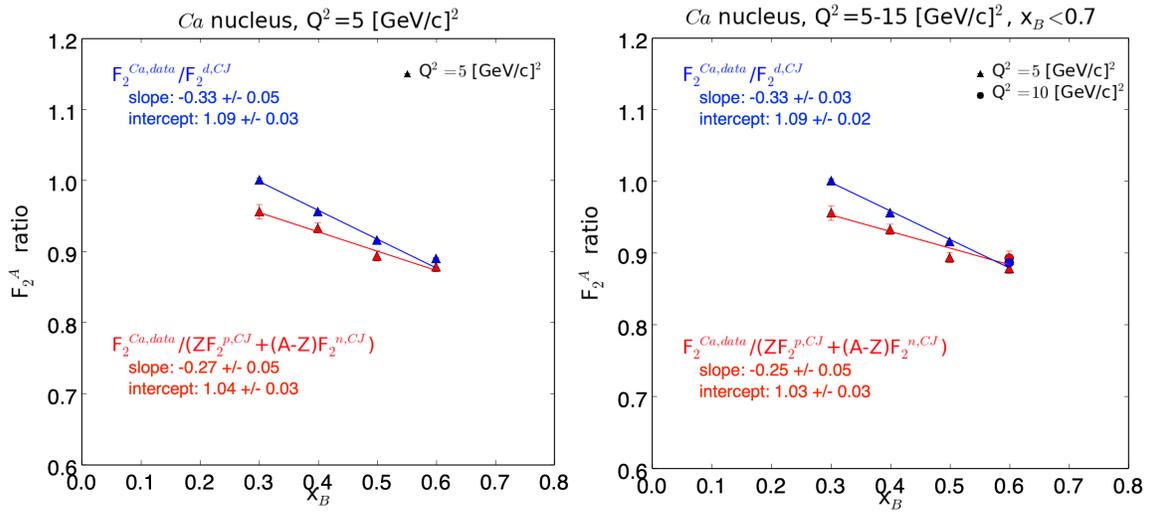


Figure 18: Linear fits to the Ca target data with cuts on Q^2 and x_B from the E139 experiment. Left: The ratios are constructed requiring that $Q^2 = 5$ GeV²/c². Right: The ratios include all data $5 < Q^2 < 15$ GeV²/c² where $x_B < 0.7$. No data was taken on Ca beyond $x_B = 0.6$.

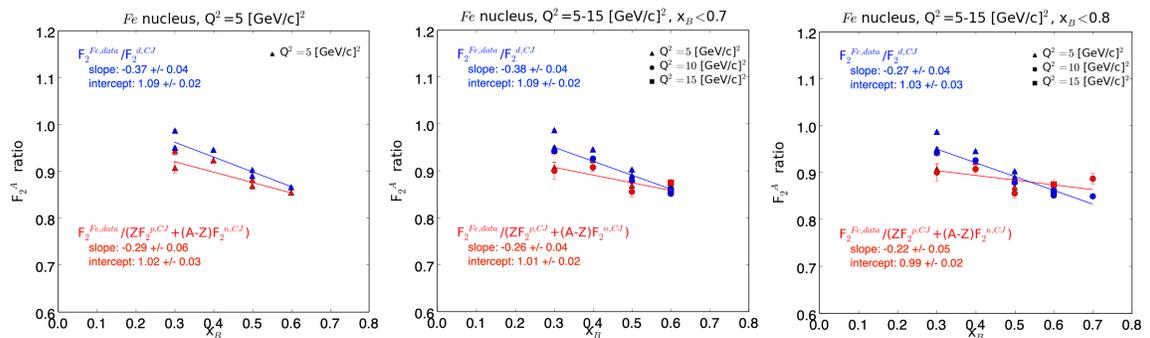


Figure 19: Linear fits to the Fe target data with cuts on Q^2 and x_B from the E139 experiment. Left: The ratios are constructed requiring that $Q^2 = 5$ GeV²/c². Center: The ratios include all data $5 < Q^2 < 15$ GeV²/c² where $x_B < 0.7$. Right: The ratios include all data $5 < Q^2 < 15$ GeV²/c² up to $x_B < 0.8$.

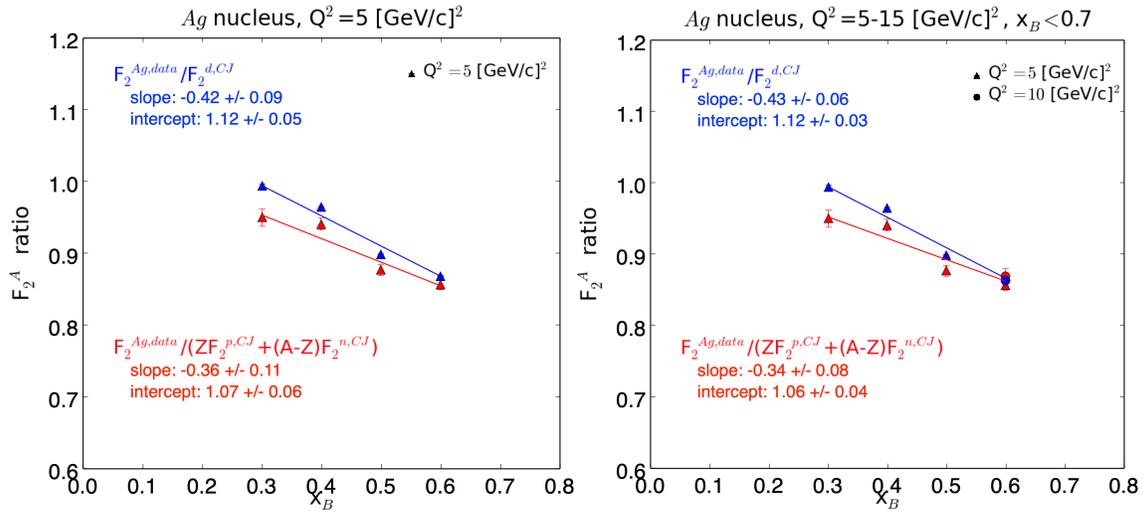


Figure 20: Linear fits to the Ag target data with cuts on Q^2 and x_B from the E139 experiment. Left: The ratios are constructed requiring that $Q^2 = 5 \text{ GeV}^2/c^2$. Right: The ratios include all data $5 < Q^2 < 15 \text{ GeV}^2/c^2$ where $x_B < 0.7$. No data was taken on Ag beyond $x_B = 0.6$.