

Extracting a free neutron structure function from proton and deuteron deep inelastic scattering data

O. Hen^{*}, E. Piassetzky^{*}, R. Shneur^{*}, L. B. Weinstein[†] and D. W. Higinbotham^{**}

^{*}*Tel Aviv University, Tel Aviv 69978, Israel*

[†]*Old Dominion University, Norfolk, Virginia 23529, USA*

^{**}*Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA*

Abstract. Due to the lack of a free neutron target the structure function of the neutron cannot be measured directly and is therefore extracted from deuteron and proton DIS data. Because the deuteron is a bound nuclear system, in order to extract the neutron structure function, one needs to apply model dependent theoretical corrections which dominate the uncertainty at the large x_B region. We present here a correlation between the magnitude of the EMC effect and the amount of two nucleon Short Range Correlation (2N-SRC) pairs in nuclei. Using this correlation we propose a phenomenological procedure to extract the free neutron structure function in the x_B range of 0.3 to 0.7.

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Knowledge of the parton (*i.e.*, quark and gluon) distribution functions of nucleons is of fundamental importance to study the structure of nucleons, in the search for new physics in collider experiments, and in analysis of neutrino oscillation experiments [1]. The F_2 structure function of the proton and the u Parton Distribution Function (uPDF) are relatively well constrained from proton Deep Inelastic Scattering (DIS) over the full Bjorken x_B range of 0 to 1. As was discussed by several speakers in this conference [2,3] the lack of a free neutron target makes the knowledge of the neutron structure function and the d distribution (dPDF) much less certain. This is especially clear in the valence quark dominant (large x_B) range.

The classic way to extract the neutron structure function and the d quark distribution is by performing DIS measurements on deuterium. The free neutron structure function is then obtained by subtracting the known proton structure function from the deuteron structure function. The dPDF can be extracted from the free proton and neutron structure functions, assuming isospin symmetry of the structure functions. These extractions are done under the assumption that the deuteron is loosely bound and can therefore be approximated to a free np (neutron proton) pair. The problem in this procedure is that the deuteron, even if only loosely bound, is not a free np system. To extract information on the free neutron from the deuteron one needs to make nuclear corrections that include both “standard” effects such as Fermi motion and binding as well as relativistic and

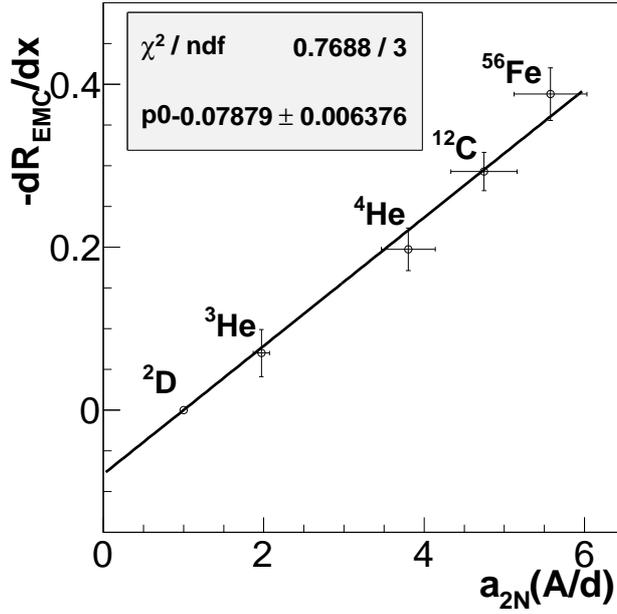


FIGURE 1. The EMC slopes versus the SRC scale factors. The fit parameter is the intercept of the line. For more details see [5].

off shell corrections, which depend on the virtuality of the nucleons. These nuclear corrections and their uncertainty propagate through the analysis procedure described above and yield a large uncertainty on the extracted neutron structure function and dPDF, especially at large x_B [4].

We propose here an alternative phenomenological procedure that allow to extract the free neutron structure function and the dPDF from DIS off the proton and deuteron without any theoretical calculations. The procedure is based on a recent report [5] that showed that the magnitude of the EMC effect, measured in electron DIS, is linearly related to the Short Range Correlation (SRC) scaling factor, obtained from electron inclusive scattering at $x_B > 1$.

Figure 1, taken from [5], shows the strength of the EMC effect (defined by its slope, dR_{EMC}/dx_B [6]) versus the SRC scale factors $a_{2N}(A/d)$ measured for different nuclei [7,8]. As can be seen clearly in the figure, the EMC strength and the SRC scaling factors are linearly correlated. Under the assumption that the value $a_{2N}(A/d) = 0$ is the limit of a free np pair with no SRC, one can use this striking correlation to extrapolate to $a_{2N}(A/d) = 0$ and obtain a phenomenological value to the deuteron to a free np pair DIS cross section ratio as a function of x_B in the range of $0.3 \leq x_B \leq 0.7$. Extrapolating the best fit line in Fig. 1 to $a_{2N}(A/d)=0$ gives an intercept of $|dR_{EMC}/dx_B| = 0.079 \pm 0.006$. The difference between this value and the deuteron EMC slope of 0 is a measure of the difference between the deuteron and a free np pair. Because the EMC effect is linear for $0.3 < x_B < 0.7$, we can parametrize the cross section ratio for the deuteron relative to a

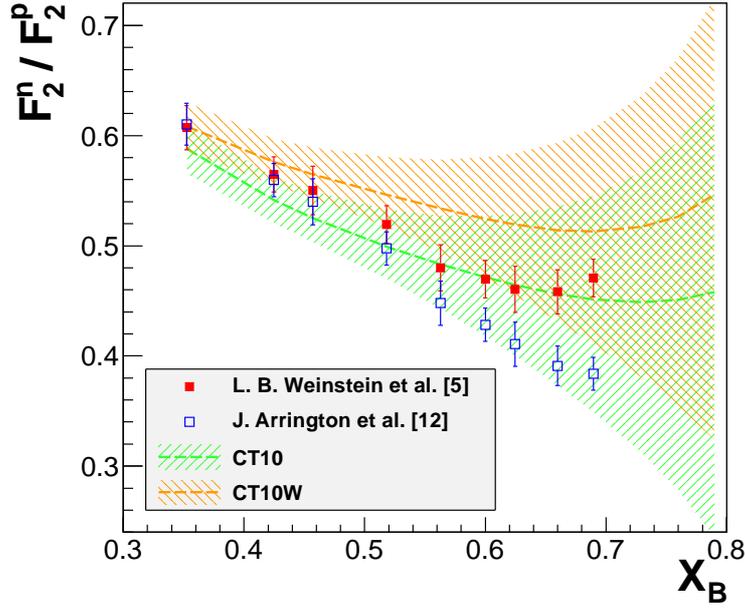


FIGURE 2. The structure function ratio of the proton and neutron as extracted from DIS off the deuteron and proton. The open squares (blue online) are from [12] corrected for the nucleon motion only. The full squares (red online) include the phenomenological correction for nuclear effects as discussed here and in [5]. The shaded areas show the structure function ratios calculated using CT10 (green online) and CT10W (orange online) PDFs [11]. The width of these areas correspond to one standard deviation.

free np pair by:

$$\frac{\sigma_d}{\sigma_n + \sigma_p} = 1 - a(x_B - b) \quad (1)$$

where σ_d , σ_p , and σ_n are the DIS scattering cross sections for scattering off deuterium, the free proton and the free neutron, respectively. $a = 0.079 \pm 0.006$ as extracted from Fig. 1 and $b = 0.31 \pm 0.04$ is the average value of x_B where the EMC ratio is unity as determined from Refs. [6,9], taking into account the quoted normalization uncertainties.

If the structure function F_2 is proportional to the DIS cross section (*i.e.*, the ratio of the longitudinal to transverse cross sections is the same for the proton, neutron and deuterium, see discussion in [10]), then the free neutron structure function can be extracted from the measured deuteron and proton structure functions:

$$F_2^n(x_B, Q^2) = \frac{2F_2^d(x_B, Q^2)}{1 - a(x_B - b)} - F_2^p(x_B, Q^2) \quad (2)$$

which leads to:

$$\frac{F_2^n(x_B, Q^2)}{F_2^p(x_B, Q^2)} = \frac{2 \frac{F_2^d(x_B, Q^2)}{F_2^p(x_B, Q^2)}}{1 - a(x_B - b)} - 1 \quad (3)$$

Figure 2 shows different extractions of $F_2^n(x_B, Q^2)/F_2^p(x_B, Q^2)$ including our extraction using Eq. 2 and the world data for the ratio of the deuteron and proton structure

functions, an extraction using the same world data, corrected for the Fermi motion of nucleons in deuterium alone [12], and two different PDF analyses of the CTEQ group [11].

The data with the phenomenological correction agrees better with the CT10W fit which includes W asymmetry and W -lepton asymmetry data [13]. The phenomenological correction which also takes into account possible modification of the bound nucleon structure functions reduces the x_B dependence of the neutron to proton structure function ratio at large x_B . In collaboration with the CTEQ group, we plan to continue and examine the effect of the extracted neutron structure function on the uncertainty in the d/u ratio at large x_B .

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REFERENCES

1. S. Kuhlmann et al., Phys. Lett. B 476, 291 (2000).
2. S. Tkachenko, "Model independent extraction of neutron structure functions from deuterium data", a talk given at the Structure functions and Parton Densities session of DIS2011.
3. J. Owens, "Uncertainties in determining the d quark PDF at large values of x", a talk given at the Structure functions and Parton Densities session of DIS2011.
4. A. Accardi et al., Phys. Rev. D 84, 014008 (2011).
5. L. B. Weinstein et al., Phys. Rev. Lett. 106, 052301 (2011).
6. J. Seely et al., Phys. Rev. Lett. 103, 202301 (2009).
7. K. Egiyan et al., Phys. Rev. C 68, 014313 (2003).
8. K. Egiyan et al., Phys. Rev. Lett. 96, 082501 (2006).
9. J. Gomez et al., Phys. Rev. D 49, 4348 (1994).
10. D. Geesaman, K. Saito, and A. Thomas, Ann. Rev. Nucl. and Part. Sci. 45, 337 (1995).
11. H. I. Lai et al., Phys. Rev. D 82, 074024 (2010) and Private Communications.
12. J. Arrington, F. Coester, R. Holt, and T.-S. H. Lee, J. Phys. G 36, 025005 (2009)
13. H. Schellman, "W charge asymmetry at D0", a talk given at the Structure functions and Parton Densities session of DIS2011.