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Study of Nuclear Effects in the Deuteron and Extraction of Neutron to Proton Structure Function Ratio*

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Abstract

We performed a combined analysis of electron, muon, neutrino, and anti-neutrino deep inelastic scattering structure functions of hydrogen and deuterium, within the framework of quark-parton model. The neutron to proton structure function ratio was obtained using three different techniques: 1) electron and muon scattering experiments on deuterium and hydrogen by using traditional Fermi motion corrections, 2) extrapolation of the EMC effect on heavy targets to deuterium and free nucleons, and 3) using Be and C data. At high x there is a disagreement between these data.

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Introduction

The proton and neutron structure functions, $F_2^p(x, Q^2)$ and $F_2^n(x, Q^2)$, have been previously extracted from deep inelastic electron and muon scattering experiments on Hydrogen and Deuterium targets[1-3]. Some important QCD based calculations, using quark distributions extracted from these data, are sensitive to the neutron to proton structure function ratio (F_2^n/F_2^p). Extraction of neutron structure function from deuterium structure function requires separation of nuclear effects in the deuteron. Various Fermi motion effect models[4] have been used in the past to extract neutron structure function. An alternative method of extracting F_2^n/F_2^p ratio using EMC effect measured in heavy targets has been proposed by Frankfurt and Strikman[5]. In this paper we compare F_2^n/F_2^p data obtained using these techniques.

Electron and Muon Scattering Data

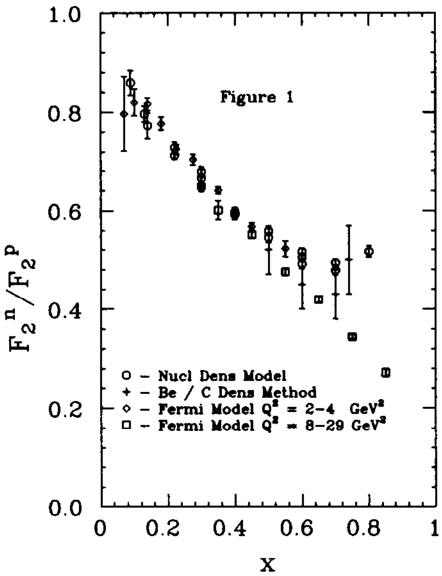
Published measurements of F_2^p and F_2^D in electron and muon scattering experiments agree very well when normalization errors and systematic effects are taken into account properly. The F_2^n/F_2^p ratio has been extracted from these experiments using traditional Fermi motion method[4] using various wave function models for the deuteron. The discrepancies of the F_2^n/F_2^p ratio in earlier analysis are now understood, and are attributed to Q^2 dependence. This Q^2 dependence can be explained by the slightly different evolution of F_2^n and F_2^p with Q^2 due to their different dependencies on x. The F_2^n/F_2^p values obtained using SLAC data are plotted versus x in the Figure 1. The ratio F_2^n/F_2^p approaches unity at small x as expected but falls very close to the theoretical limit of 0.25 as $x \to 1$. The uncertainty on the ratio F_2^n/F_2^p attributed to the choice of wave function used in Fermi motion calculations is substantial, and has prompted us to study it in more detail.

Frankfurt and Strikman[5] have proposed a model for the nuclear dependence of the EMC effect. This model expresses the nuclear effects in the deuteron, in terms of the EMC effect of heavier nuclei and their densities, as given below:

$$\frac{F_2^D}{F_2^p + F_2^n} = 1 + \frac{\rho_D}{\rho_A - \rho_D}\left[\frac{F_2^A}{F_2^D} - 1\right]. \qquad 1$$

The $F_2^D/(F_2^p + F_2^n)$ values calculated using the data from SLAC experiment E139[6] for various targets (eg. He, C, Al, Ca and Fe) are in good agreement with each other indicating that this density model is valid. We have used F_2^D and F_2^p from the combined fit to SLAC-EMC-BCDMS data, and SLAC-E139 values of $F_2^D/(F_2^p + F_2^n)$ averaged over all targets, to obtain results for F_2^n/F_2^p. These values are also plotted in Figure 1. It is clearly seen that these data, at large x, disagree with traditionally obtained values significantly.

We have further extrapolated the nuclear density model[5] and tried to extract F_2^n/F_2^p directly from E139 Be and C data, without the use of Deuterium data at all. The results obtained from this analysis, also plotted in Figure 1,



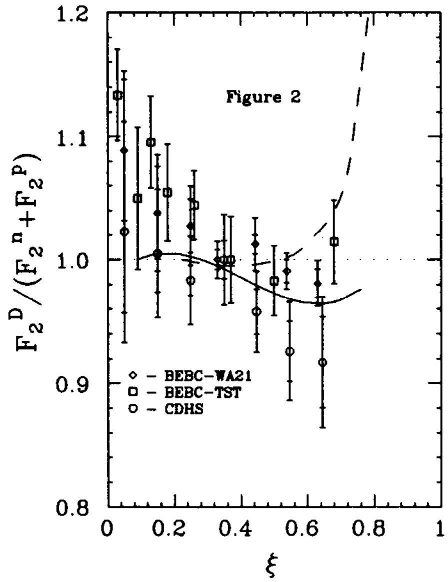


Figure 1. Electron and muon experiment data for F_2^n/F_2^p, extracted using various techniques, is plotted versus x.
Figure 2. Neutrino data for $F_2^D/(F_2^p + F_2^n)$ is plotted verus ξ. The smooth curve is a fit to data obtained using nuclear density method. The dash curve is the estimate using Fermi motion method.

have rather large errors. SLAC experiment E140-X will obtain more data for Be and C targets at large x to understand F_2^n/F_2^p better.

Neutrino Scattering Data

Neutrino and anti-neutrino scattering data from Hydrogen enables one to obtain F_2^n/F_2^p directly. Data from the experiments BEBC-WA21[7], BEBC-TST[8] and CDHS[9] experiments at CERN are available as quark distribution ratio d/u, which is directly related to F_2^n/F_2^p. However, these data have large statistical and normalization errors. These data, some preliminary at that time, have previously been used in conjunction with electron scattering data to conclude that the EMC effect in deuteron $(F_2^D/(F_2^p + F_2^n))$ is small[10]. We have repeated this analysis, again in the Nachtman variable ξ to take into effect slightly different values of Q^2 of the data. Since we expect $F_2^D/(F_2^p+F_2^n)$ to be unity at $\xi \sim 0.35$, we have also moved the data from these experiments such that the data is normalized to unity at $\xi = 0.35$. This normalization is well within the overall errors quoted by these experiments. The F_2^n/F_2^p data from Figure 1 has been used to obtain the curves for both the models. We have plotted a smooth fit to the data for clarity. We conclude from this analysis that the quality of the neutrino data is not good enough to discriminate between the Fermi motion model and the nuclear density model. Note that normalizing the data at smaller ξ would lead us to conclude that these neutrino data favor the nuclear density model.

Conclusion

We conclude that there is indeed a discrepancy in F_2^n/F_2^p data, at large $x(x \geq 0.6)$, obtained by using Fermi motion model and nuclear density model of EMC effect. The neutrino and anti-neutrino scattering data from Hydrogen is not good enough to select between the models.

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