Model independent extraction of neutron structure functions from deuterium data.

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Abstract.
We know much less about the neutron than the proton due to the absence of free neutron targets. Neutron information has to be extracted from data on nuclear targets like deuterium. This requires model-dependent corrections for off-shell and binding effects. As a consequence, the same data can be interpreted in different ways, leading to different conclusions about important questions such as d/u quark ratio at large momentum fraction x.

The Barely Off-shell NUcleon Structure (BONUS) experiment at Jefferson Lab addressed this problem by tagging spectator protons in coincidence with inelastic electrons scattering from deuterium. We collected data in the kinematic region where off-shell, binding, target fragmentation, and final state interaction effects are minimized.

Data were taken at beam energies of 2, 4 and 5 GeV. I present experimental evidence for the validity of the spectator picture as well as results on the extracted structure function F_2^n of the neutron.

Keywords: neutron, structure functions, model-independent extraction, electroproduction, fixed target, high Bjorken x
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INTRODUCTION

The Deep Inelastic Scattering (DIS) cross-section can be written as

$$\frac{d\sigma}{d\Omega} = \frac{4\alpha^2 E'^2}{Q^4}\left(\frac{F_2(x)}{\nu}\cos^2\frac{\theta_e}{2} + 2\frac{F_1(x)}{M}\sin^2\frac{\theta_e}{2}\right), \tag{1}$$

where α is the electromagnetic running constant, E' is the scattered electron energy, ν is the energy transfer from the electron to the target, M is the mass of the target nucleon, θ_e is the scattering angle of the electron, x is Bjorken $x = \frac{Q^2}{2M\nu}$ (in the lab frame), and $F_1(x)$ and $F_2(x)$ are DIS structure functions.

The structure functions contain information on the composite nature of the nucleon, they can be related to parton distribution functions $f_i(x)$[1] as:

$$F_1(x) = \frac{1}{2}\sum_i e_i^2 f_i(x), \tag{2a}$$

$$F_2(x) = \sum_i e_i^2 x f_i(x), \tag{2b}$$

e_i being parton charge. Thus, DIS structure functions do not only contain information allowing us to extract the cross-section, and consequently physical quantities associated with the scattering, but also invaluable details of the internal composition of nucleons. The ratio of neutron to proton F_2 structure functions can be related to the ratio of down to up quark PDF's:

$$\frac{d}{u} \approx \frac{4F_2^n/F_2^p - 1}{4 - F_2^n/F_2^p}, \tag{3}$$

thus enabling us to access PDF's once we have F_2 structure functions measured. But our current knowledge of DIS structure functions is unsatisfactory, especially in the case of the neutron. Due to the necessity of emulating neutron targets with nuclear one and model dependence of the data analysis, completely different theories can be supported using the same experimental data set (see, *e.g.* [1]). The situation is alarming and requires finding some model-independent approach to extracting neutron structure functions.

SPECTATOR TAGGING

The measurement of structure functions in semi-inclusive deep inelastic scattering with slow recoil proton detected in the backward hemisphere can help us resolve the ambiguities introduced by nuclear model dependence and extract the ratio of neutron to proton structure functions at high-x region, hence accessing the long-sought d/u distribution ratio. Kinematics can be chosen such that the slow proton is a spectator of the reaction, "tagged" by the aforementioned proton.

The measurements performed on bound nucleons yield "effective" structure functions that are not guaranteed to be very close to free nucleon structure functions. Nevertheless, by selecting only the slowest recoil protons and backward scattering angles we are able to measure them in the region where the target nucleon is almost on-shell, thus enabling ourselves to extract the F_2^n structure function with minimal model uncertainties. It has been shown that the choice of backward kinematic combined with using slow momentum spectator protons minimize these effects, such as final state interactions, on-shell extrapolation, deuteron wavefunction ambiguity, and target fragmentation [5], [6], [7], [8].

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[1] The probability that a struck parton of king i and charge e_i carries nucleon momentum fraction x. I will use $d \equiv f_d$ for down quark PDF, and $u \equiv f_u$ for up quark PDF.

BONUS RESULTS

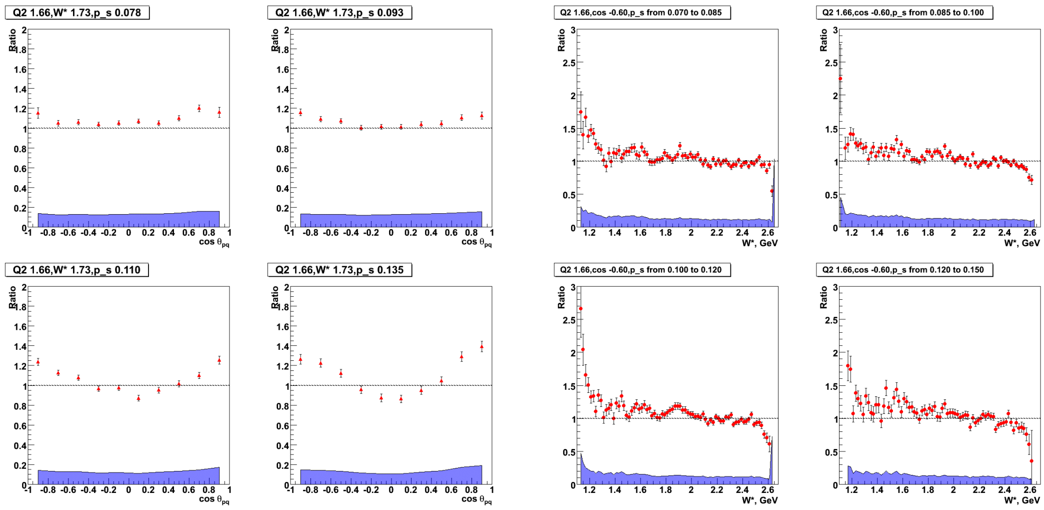

FIGURE 1. Left panel: ratio of experimental data with subtracted accidental background and elastic tail to the full simulation in the PWIA spectator picture is shown as a function of $\cos\theta_{pq}$. W^* from 1.60 to 1.85 GeV. Right panel: ratio of experimental data with subtracted accidental background and elastic tail to the full simulation in the PWIA spectator picture is shown as a function of W^*. $\cos\theta_{pq}$ from -1.0 to -0.2. Both panels: data are for Q^2 from 1.10 to 2.23 (GeV/c)^2, the beam energy is 5.254 GeV. Error bars are statistical only. Systematic errors are shown as a blue band. Spectator momentum bins are from 70 to 85 and 85 to 100 MeV/c in upper rows, and 100 to 120 and 120 to 150 MeV/c in lower rows.

The objective of BONUS analysis was thus twofold: we needed to confirm the aforementioned assumption about benefits of using backward kinematics[2] and slow protons, and, once that is confirmed, use this kinematics for extracting the neutron structure functions F_2^n.

The deviation of the ratio of the data to the simulation using plane wave impulse approximation spectator model was investigated. It was plotted for different spectator momenta:

- As a function of the angle between the spectator proton and the virtual photon. As can be seen from an example shown in figure 1(a), there are no significant deviations from PWIA for low spectator momenta ($p_s < 100$ MeV/c), with possible θ dependence for higher momenta.
- As a function of the invariant mass of the reaction or, equivalently, Bjorken x[3]. For backwards angles shown in figure 1(b), the agreement with the model is reasonably good. The artefacts of elastic tail subtraction can be seen at low W^*. There are visible bumps in the resonance region indicating that resonance contributions may

[2] Angle between the virtual photon and spectator proton, θ_{pq} was used for defining kinematics.
[3] Both variables were modified to account for the motion of the target nucleon, and were denoted W^* and x^* respectively.

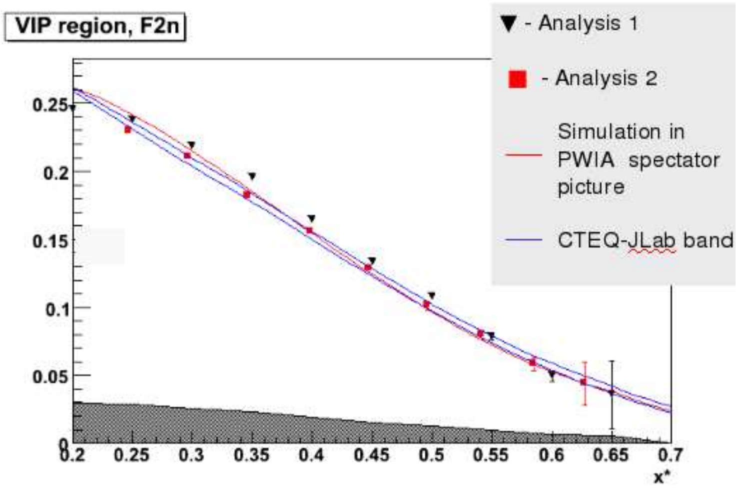

FIGURE 2. Neutron structure function F_2^n as a function of x^* for the "VIP" region (W^*>1.8 GeV, $\cos\theta_{pq}$<-0.2, and p_s<100 MeV/c). Results of 2 independent analyses are shown (black triangle and red square), as well as the simulation in PWIA spectator picture (red line), and CTEQ-JLab band (blue lines) [9]. Systematic errors are shown for the analysis plotted with black triangles.

be underestimated in our model.

Thus, we can draw a conclusion that the spectator model describes the data well for backwards going slow protons, and we can use this region to extract the neutron structure function F_2^n in a model-independent way. Figure 2 shows our results that are consistent between two different analyses of BONUS data, and in good agreement with CTEQ-JLab parameterization [9].

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