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 quantities such as the 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 neutron structure function F_2^n.

Keywords: neutron, structure functions, model-independent extraction, electroproduction, fixed target, high Bjorken x
PACS: 20,13.40.-f,13.60.-r,13.85.Hd,14.20.Dh

INTRODUCTION

The deep inelastic scattering (DIS) structure functions F_2^n and F_2^p provide invaluable details of the internal composition of neutron and proton, respectively. The F_2^n/F_2^p ratio at high Bjorken x can be related to the ratio of down (d) to up (u) quark parton distribution functions (PDFs):

$$\frac{d}{u} \approx \frac{4F_2^n/F_2^p - 1}{4 - F_2^n/F_2^p}, \qquad (1)$$

which lets us access the valence quark structure. But our current knowledge of the DIS structure functions at high x is unsatisfactory for the neutron where no direct measurements exist. Due to the necessity of using nuclear targets to study the neutron, the data analysis is model-dependent (see, *e.g.*, [1]). These uncertainties propagate into the d/u ratio, which is currently constrained very poorly (to values between 0 and ≈ 0.5 as $x \to 1$ [2]). A model-independent approach to extracting neutron structure functions would greatly increase our knowledge of neutron structure.

SPECTATOR TAGGING

The spectator tagging technique is based on scattering an electron off a forward moving, nearly on-shell neutron in the deuteron. The slow spectator proton, which scatters backwards, is detected and used to correct the neutron scattering (see kinematically corrected W^* and x^* below). The extracted, "tagged", structure functions essentially eliminate nuclear dependence in the ratio of neutron to proton structure functions at high x.

Such measurements were performed using a CEBAF electron beam incident on a deuterium target (situated in JLab Hall B), with the scattered electron being detected in the CLAS detector and protons being detected in a dedicated, newly constructed radial time projection chamber (RTPC), built specially for detecting low-momentum protons [3]. The RTPC was capable of resolving proton momenta between 70 and 150 MeV/c. The region in which the spectator picture is expected to be valid is below ≈100 MeV/c. At 100 MeV/c the struck neutron is only about 12 MeV off its mass shell.

The measurements performed on bound nucleons yield "effective" structure functions that are not necessarily equal to the 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 the extraction of the F_2^n structure function with minimal model uncertainties. The choice of backward kinematics combined with slow momentum spectator protons minimizes final state interactions, off-shell effects, deuteron wavefunction ambiguity, and target fragmentation [7], [8], [9], [10].

BONUS RESULTS

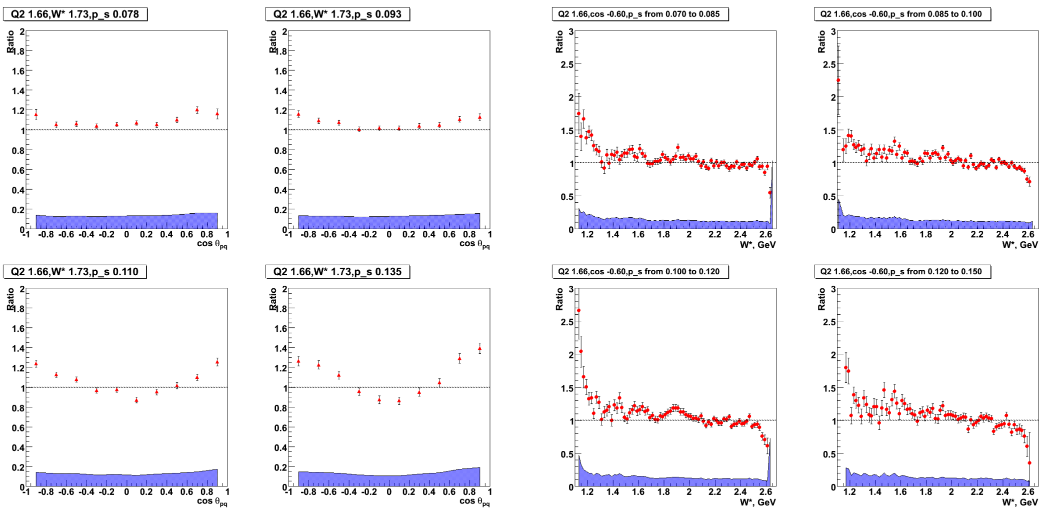

FIGURE 1. Left panel: ratio of experimental data with subtracted accidental background and elastic tail to the full simulation in the PWIA spectator picture is shown as a function of $\cos\theta_{pq}$. W^* from 1.60 to 1.85 GeV. Right panel: ratio of experimental data with subtracted accidental background 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 uncertainties are shown as a band (blue online). The line at $Ratio$=1 is drawn to guide the eye. 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. See text for the definition of variables.

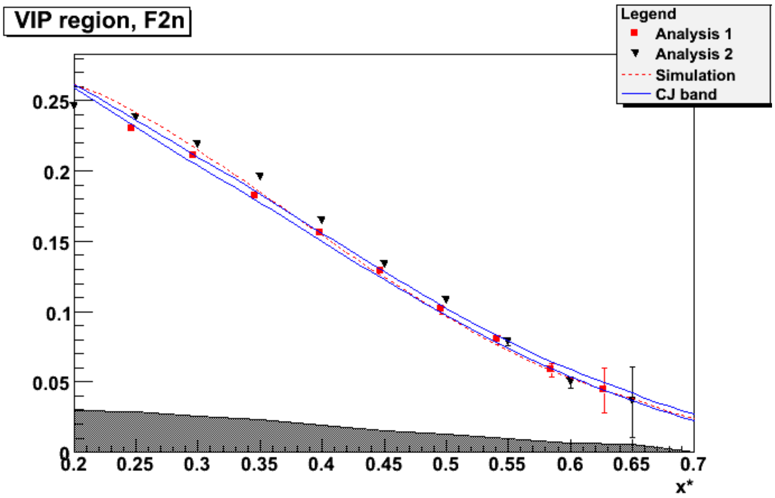

FIGURE 2. Neutron structure function F_2^n as a function of x^* for the "VIP" region (W^*>1.8 GeV, $\cos\theta_{pq}$<-0.2, and p_s<100 MeV/c). Results of 2 independent analyses are shown (black triangle and red square), as well as the simulation in PWIA spectator picture (dashed line, red online), and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

The objective of the BONUS analysis was twofold: to confirm the benefits of using backward kinematics and slow protons, and to extract the F_2^n structure function.

Deviations from unity of the ratio of the data to the simulation using the plane wave impulse approximation (PWIA) spectator model described in the previous section were investigated as a function of of spectator momentum, p_s, the angle between the spectator proton and the virtual photon, θ_{pq}, and the kinematically corrected (using the tagged proton information) invariant mass of the struck neutron, W^*, or, equivalently, the kinematically corrected Bjorken x, x^*. Figure 1(a) (left panel) shows that deviations from PWIA are below 10 % for $p_s < 100$ MeV/c, with possible θ_{pq} dependence for higher momenta. Figure 1(b) (right panel) shows that the agreement with the PWIA model is reasonably good. The lowest W^* region is contaminated by the radiative elastic tail and should be ignored. There are visible bumps in the resonance region indicating that resonance contributions may be underestimated in our input model.

We can conclude 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 for two different analyses of BONUS data. These very different methods, one using the Monte-Carlo simulation of the detector with PWIA spectator model used as an input and the other using the ratio of tagged to untagged (*i.e.* inclusive deuteron scattering) events are consistent within systematic uncertainties, and in good agreement with the CJ parameterization of world DIS data [2].

Our analysis demonstrated the success of the spectator tagging technique as well as the plausibility of the spectator model. The measurements will be extended to higher x after Jefferson Lab energy upgrade.

ACKNOWLEDGMENTS

I want to thank the whole BONUS collaboration, and in particular S. Kuhn, K. Griffoen, N. Baillie, and J. Zhang for their help and support.

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