NEUTRON SPIN STRUCTURE IN THE RESONANCE REGION AND QUARK-HADRON DUALITY

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The Thomas Jefferson National Accelerator Facility experiment E01-012 measured the ^3He spin structure functions and virtual photon asymmetries in the resonance region in the range $1.0 < Q^2 < 4.0 (\text{GeV}/c)^2$. Our data combined with existing deep inelastic data can be used to test quark-hadron duality on g_1 and A_1 for ^3He and the neutron. The demonstration of duality for spin structure functions will enable the use of resonance data to study nucleon spin structure in the very high x_{bj} region. Preliminary results of $A_1^{^3\text{He}}$ will be presented as well as an overview of the experiment and theoretical developments.

1. Introduction

In the 70's, Bloom and Gilman¹ observed that the nucleon resonances average on the high Q^2 scaling curve when an appropriate scaling variable is used. Since then Bloom-Gilman duality has been experimentally demonstrated for the spin independent structure function F_2 of the proton and the deuteron² and for the virtual photon asymmetry A_1 of the proton³.

Substantial efforts are ongoing in investigating quark-hadron duality in polarized structure functions both experimentally and theoretically. Carlson and Mukhopadhyay⁴ showed using perturbative QCD that the structure functions in the resonance region fall with increasing Q^2 at the same rate as in the deep inelastic region. The behavior of g_1 in the resonance region at high Q^2 is proportional to the helicity amplitude $G_+ = g_+/Q^3$ and can be written as follow:

$$g_1 = \frac{m_N^2}{\pi m_R \Sigma_R} G_+^2 = \frac{m_N^2}{\pi m_R \Sigma_R} \frac{g_+^2}{(m_R^2 - M_N^2)^3} (1-x)^3 \quad (1)$$

where g_+ is a constant and $1/Q^2 \approx \frac{1-x}{m_R^2 - M_N^2}$ for $X \rightarrow 1$ and $W \approx M_R$. In the deep inelastic region, the photon is more likely to interact with the quark having the same helicity as the nucleon. This implies that g_1 and F_1 behave the same way as x approaches 1 and:

$$g_1(x) \propto (1-x)^3 \text{ as } x \rightarrow 1 \quad (2)$$

Finally they predicted A_1 tends to 1 as $x \rightarrow 1$ in the scaling region and the same is true for A_1 in the resonance region at high enough Q^2 considering resonant and non-resonant background.

Recently, Close and Melnitchouk⁵ studied three different conditions of SU(6) breaking applied in the resonance region under which predictions of the structure functions at large x lead to the same result as the parton model. They examined the cases where certain resonances are removed from the summation, (that is, suppression of spin- $\frac{3}{2}$, suppression of helicity- $\frac{3}{2}$ and suppression of symmetric wave function), and found that each scenario predicts $A_1^{n,p} \rightarrow 1$ as $x \rightarrow 1$.

Now that precise spin structure data in the deep inelastic region⁶ are available, data in the resonance region is needed (especially for the neutron) in order to test duality in the polarized case. Thus the goal of the experiment E01-012 was to produce such data in the moderate Q^2 region of 1.0 to 4.0(GeV/c)² where duality is expected to hold.

2. The E01-012 experiment

E01-012 ran successfully in January-February 2003 at Jefferson Lab in Hall A (see fig. 1). It was an inclusive experiment of longitudinally polarized electrons scattering on a longitudinally or transversely polarized ³He target⁷. Asymmetries and cross section differences are formed in order to extract the spin structure function g_1 and the virtual photon asymmetry A_1 in the resonance region up to $Q^2 = 4(\text{GeV}/c)^2$:

$$g_1 = \frac{MQ^2\nu}{4\alpha_e^2} \frac{E}{E'} \frac{1}{E+E'} \left[\Delta\sigma_{\parallel} + \tan\left(\frac{\theta}{2}\right)\Delta\sigma_{\perp} \right] \quad (3)$$

$$A_1 = \frac{A_{\parallel}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)} \quad (4)$$

where $A_{\parallel}$ ($A_{\perp}$) is the parallel (perpendicular) asymmetry corrected for data

acquisition deadtime, beam charge asymmetry, target and beam polarizations and nitrogen dilution. $\Delta\sigma_{\parallel(\perp)} = 2A_{\parallel(\perp)}\sigma_0$ with σ_0 the unpolarized cross section, and η , ξ , D and d are kinematic factors (see for example ⁶). To determine D and d , world data for $R(x, Q^2)$ will be used. However our data allows a direct extraction of g_1 and g_2 without the need of external input.

The beam polarization measured using a Moller polarimeter was on average $77(1 \pm 0.03)\%$. The polarization of the target was determined by two independent polarimetries⁷: NMR and EPR. From the preliminary analysis, the target polarization was $37(1 \pm 0.04)\%$ on average. Two almost identical spectrometers were used in a symmetric configuration in order to double our statistics and check our systematics. In order to select good scattered electrons, a gas cerenkov counter along with a two-layer electromagnetic calorimeter was used in the analysis. These allowed us to reduce the pion contamination by a factor better than 10^4 while keeping the electron efficiency above 99%.

Figure 1. Hall A floor plan. The electron beam is coming from the left.

3. Preliminary results

For our first pass analysis, $A_1^{3\text{He}}$ was extracted from the asymmetries. $R(x, Q^2)$ was assumed constant with a value of 0.18. No radiative corrections are applied and the error bars are statistical only. Figure 2 shows $A_1^{3\text{He}}$ at four different Q^2 values in function of the Nachtmann scaling vari-

able $\xi = 2x/(1 + \sqrt{1 + \frac{4M^2 x^2}{Q^2}})$. The position of the $\Delta(1232)$ resonance is indicated in each plot.

Figure 2. Preliminary result of $A_1^{^3\text{He}}$. See text for discussions.

The most important feature is the negative contribution of the $\Delta(1232)$ resonance at low Q^2 . It is reported ^{4,5} that quark-hadron duality is not expected to apply in the Δ region at this low Q^2 . However at higher Q^2 , $A_1^{^3\text{He}}$ in the $\Delta(1232)$ increases due to the fall off of the resonance and the rising background. At large ξ , our data tend to follow the same pattern as the DIS world data⁸ and indicate the validity of duality.

4. Summary

E01-012 resonance data cover the region of $0.2 < x < 0.90$ (see fig. 3). At $x < 0.60$ where DIS data are available, we will provide a precision test of quark-hadron duality predictions for neutron spin structure functions. Moreover, if duality is confirmed, E01-012 will provide the first precise measure-

Figure 3. A_1^n results measured in the deep inelastic region using polarized ^3He targets and E01-012 projected statistical errors are shown.

ment of g_1^n and A_1^n in the range $0.60 < x < 0.90$.

Our data will also be used to extract moments of the structure functions, for example: the extended GDH sum, d_2 matrix element and the Burkhardt-Cottingham sum rule.

Acknowledgments

This work was supported by DOE contract DE-AC05-84ER40150 under which the Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility.

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