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 ^{3}He spin structure functions and virtual photon asymmetries in the resonance region in the range $1.0<Q^2<4.0(\mathrm{GeV/c})^2$. Our data combined with existing deep inelastic data can be used to test quark-hadron duality on g_1 and A_1 for ^{3}He 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 $A_1^{^3He}$ will be presented as well as an overview of the experiment and theoretical developments.

1. Introduction

In the 70's, Bloom and Gilman[1] 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 deuteron[2] and for the virtual photon asymmetry A_1 of the proton[3].

Substantial efforts are ongoing in investigating quark-hadron duality in polarized structure functions both experimentally and theoretically. Carlson and Mukhopadhyay[4] 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:

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

where g_+ is a constant and $1/Q^2 \approx \frac{1-x}{m_R^2 - M_N^2}$ for $X \to 1$ 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:

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

Finally they predicted A_1 tends to 1 as $x \to 1$ 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 Melnitchouk[5] 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 $A_1^{n,p} \to 1$ as $x \to 1$.

Now that precise spin structure data in the deep inelastic region[6] 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 $4.0(\mathrm{GeV/c})^2$ 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 ^{3}He target[7]. 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 $Q^2 = 4(\mathrm{GeV/c})^2$:

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

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

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 ± 0.03)%. The polarization of the target was determined by two independents polarimetries[7]: NMR and EPR. From the preliminary analysis, the target polarization was 37(1 ± 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%.

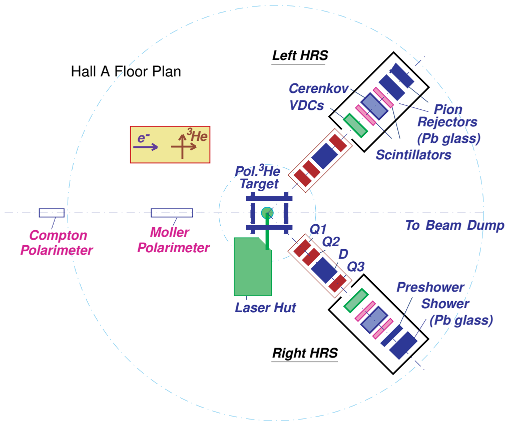

Figure 1. Hall A floor plan. The electron beam is coming from the left.

3. Preliminary results

For our first pass analysis, $A_1^{^3He}$ 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 $A_1^{^3He}$ at four different Q^2 values in function of the Nachtmann scaling variable $\xi = 2x/(1+\sqrt{1+\frac{4M^2x^2}{Q^2}})$. The position of the $\Delta(1232)$ resonance is indicated in each plot.

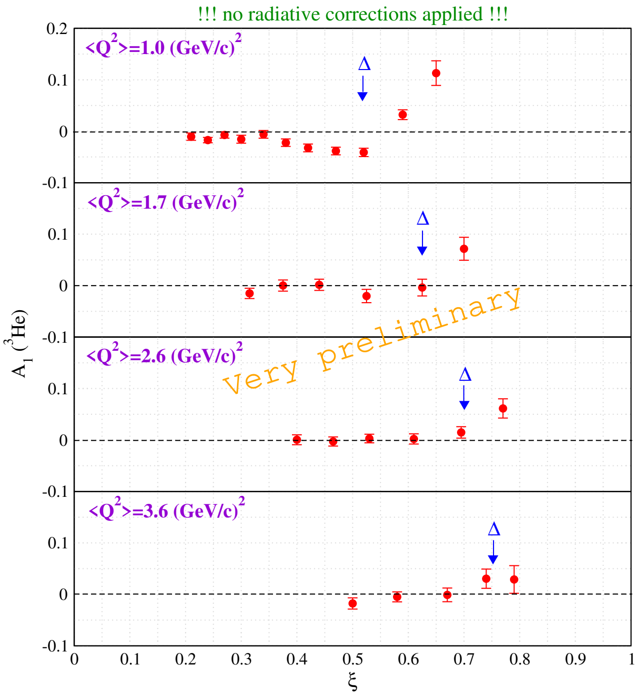

Figure 2. Preliminary result of $A_1^{^3He}$. See text for discussions.

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, $A_1^{^3He}$ 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 data[8] 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. Morever, if duality is confirmed, E01-012 will provide the first precise measure-

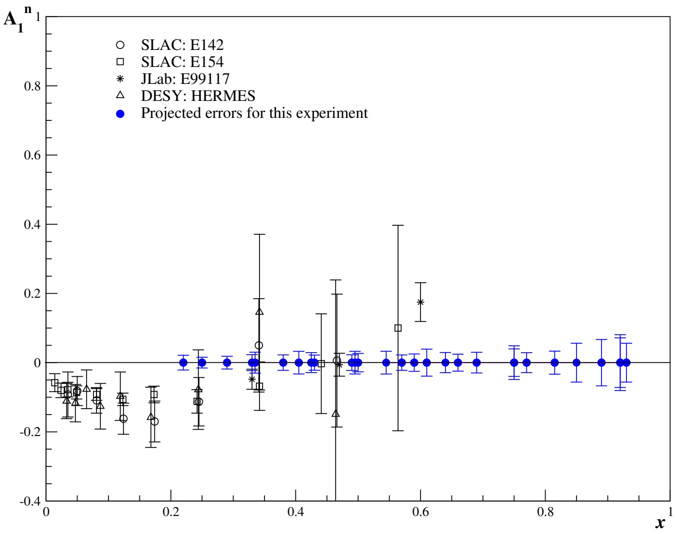

Figure 3. A_1^n results measured in the deep inelastic region using polarized ^{3}He targets and E01-012 projected statistical errors are shown.

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.

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