SPIN DUALITY ON THE NEUTRON (^{3}HE)

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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 $1.0<Q^2<4.0$ (GeV/c)^2. Our data, when compared with existing deep inelastic scattering data, can be used to test quark-hadron duality in g_1 and A_1 for ^{3}He and the neutron. Preliminary results for $A_1^{^3He}$ are presented, as well as an overview of the experimental and theoretical developments.

1. Motivation

Quark-Hadron Duality was first observed in 1970 by Bloom and Gilman[1] for the spin independent structure function F_2. The authors noticed that the nucleon resonances average on the F_2 scaling curve. Recent data[2,3] on the proton unpolarized and polarized structure functions measured in the resonance region indicate the onset of duality at momentum transfers as low as 0.5 and 1.6 (GeV/c)^2 respectively.

Substantial efforts are ongoing to investigate quark-hadron duality in polarized structure functions both experimentally and theoretically. Carlson and Mukhopadhyay[4] showed within perturbative QCD that structure functions in the resonance region fall with increasing Q^2 at the same rate as in the deep inelastic scattering (DIS) region. In the high x region, the photon is more likely to interact with the quark having the same helicity as the nucleon. This implies that both g_1 and F_1 behave as x approaches 1 and $(1-x)^3$ as $x \to 1$. A_1 is expected[5] to tend to 1 as $x \to 1$ in the scaling region. Carlson and Mukhopadhyay, considering resonant contributions and non-resonant background, predict the same behavior in the resonance region at large enough momentum transfer.

Recently, Close and Melnitchouk[6] studied three different conditions of

SU(6) symmetry breaking 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 conditions in which certain resonances are removed from the summation (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 $x \to 1$.

Many more theorists are working on this exciting phenomenon (see, for example, the proceeding of A. Fantoni for this symposium).

Now that precise spin structure data[7] in the DIS region are available at large x, data in the resonance region are needed in order to test polarized duality. The goal of experiment E01-012 was to provide such data on the neutron (^{3}He) in the moderate Q^2 region up to $Q^2 = 4.0$ (GeV/c)^2 where duality is expected to hold.

2. The experiment

E01-012 ran successfully in January-February 2003 at Jefferson Lab in Hall A. It was an inclusive measurement of longitudinally polarized electrons scattering off a longitudinally or transversely polarized ^{3}He target[8]. Asymmetries and cross section differences were measured in order to extract the spin structure function g_1 and the virtual photon asymmetry A_1 in the resonance region:

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

$$A_1 = \frac{A_\parallel}{D(1+\eta\xi)} - \frac{\eta A_\perp}{d(1+\eta\xi)} \qquad (2)$$

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 [7]). D and d depend on $R(x,Q^2)$ for which we will use recent data[9] from Jefferson Lab experiment E94-110. However our data allows a direct extraction of g_1 (and g_2) without the need of external input.

The incident electron beam was produced by a strained GaAs cathode illuminated with a polarized diode laser. The helicity of the longitudinally polarized electrons is inverted at 30Hz when passing through a pockell cell. The beam polarization was measured with a Möller polarimeter to be between 70 and 85% depending on the incident energy.

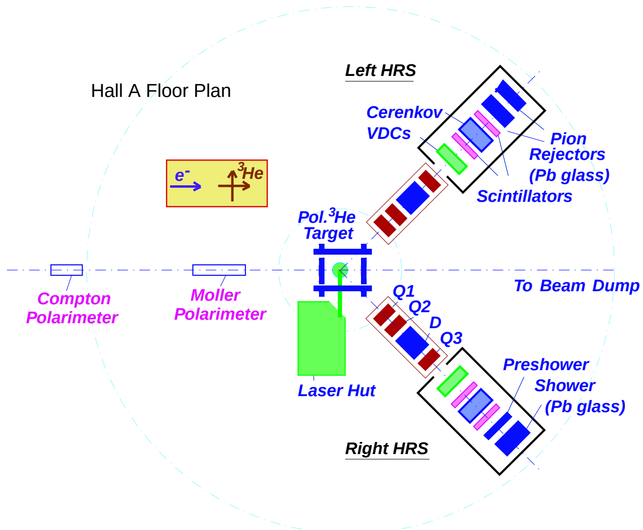

Figure 1. Hall A floor plan. The electron beam is coming from the left.

The polarized ^{3}He target is based on spin exchange between optically pumped rubidium and ^{3}He. A small amount of nitrogen is added as buffering gas. With two sets of Helmhotz coils and two sets of laser optics, longitudinal and transverse polarizations can both be achieved. The polarization of the target was monitored approximately every 4 hours by two independent polarimetries[8]: NMR and EPR. From the preliminary analysis, the average target polarization was $(37.0 \pm 1.5)\%$.

The two almost identical Hall A High Resolution Spectrometers[8] were used in a symmetric configuration (see fig. 1) in order to double the statistics and provide a systematic cross check. The detector package contains two double planes of vertical drift chambers (VDC) for particle tracking, two planes of scintillators used to trigger the data acquisition, and a gas Čerenkov counter plus two layer electromagnetic calorimeter for particle identification. The PID detectors allowed us to reduce the pion contamination by a factor better than 10^4 while keeping the electron efficiency above 99%.

3. Preliminary results

$A_1^{^3He}$ was extracted from our data. For this analysis, a constant value of $R(x,Q^2)$=0.18 was used. A complete analysis will be done later in order to evaluate R(x,Q^2) for ^{3}He at our kinematics. The nitrogen dilution was determined from data taken with an identical cell filled with nitrogen. Radiative corrections have been applied. Figure 2 shows $A_1^{^3He}$ at four different Q^2 values. The position of the Δ(1232) resonance is indicated for each subset of data. The most noticeable feature is the negative contribution of the Δ(1232) resonance at low Q^2. It has been argued[4,6] that quark-hadron duality should not work in the Δ region at low Q^2. However, at Q^2 above 2.0 $(GeV/c)^2$, the dominant negative bump at the location of Δ(1232) seems to vanish. Furthermore the results from these higher Q^2 settings show that $A_1^{^3He}$ become positive with increasing x, following the same trend as the DIS world data[7,10]. $A_1^{^3He}$ from the two highest Q^2 settings agree well with each other showing no strong Q^2-dependence.

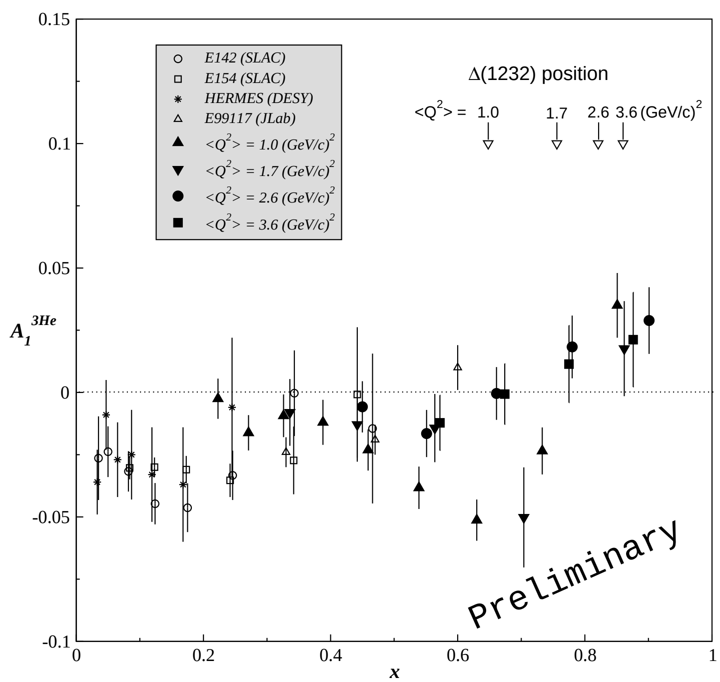

Figure 2. Preliminary result of $A_1^{^3He}$. The error bars are statistical only.

Results of the spin asymmetry A_2 and the spin structure functions g_1 and g_2 for ^{3}He were also presented at this workshop.

The polarized ^{3}He target was used in this experiment as an effective neutron target. Because of the dominant S-state of ^{3}He where the two protons have their spins anti-aligned, we can expect neutron spin structure functions to show similar behavior as observed for ^{3}He structure functions here. Work is ongoing to extract the neutron results from the ^{3}He results.

4. Summary

Experiment E01-012 provides spin structure data in the resonance region for the neutron (^{3}He) for $1.0<Q^2<4.0$ $(\mathrm{GeV}/c)^2$ and $0.2<x<0.90$. At $x<0.60$, where DIS data are available, these data will allow a test of quark-hadron duality for neutron and ^{3}He spin structure functions. Preliminary results show that $A_1^{^3He}$ in the resonance region follows the same behavior as $A_1^{^3He}$ measured in the DIS region. These data will also be used to extract moments[11] of the structure functions, for example: the extended GDH sum, the d_2 matrix element and the Burkhardt-Cottingham sum rule.

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11. For more details, see Z.-E. Meziani's proceeding.