

## Spin Duality on the Neutron ( $^3\text{He}$ )

Patricia Solvignon<sup>1</sup>  
For the Jefferson Lab Hall A Collaboration

<sup>1,a</sup> Temple University,  
19122 Philadelphia, USA

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**Abstract.** Thomas Jefferson National Accelerator Facility experiment E01-012 measured the  $^3\text{He}$  spin structure functions and virtual photon asymmetries in the resonance region in the momentum transfer range  $1.0 < Q^2 < 4.0$  ( $\text{GeV}/c$ )<sup>2</sup>. 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  $^3\text{He}$  and the neutron. Preliminary results for  $A_1^{^3\text{He}}$  are presented, as well as some details about the experiment.

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### 1. Motivation

One of the biggest challenges in the study of the nucleon structure is the understanding of the transition from hadronic to partonic degrees of freedom. In 1970, Bloom and Gilman[1] noticed that structure function data taken at the Stanford Linear Accelerator Center (SLAC) in the resonance region average to the scaling curve of deep inelastic scattering (DIS). 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 ( $Q^2$ ) as low as 0.5 and 1.6 ( $\text{GeV}/c$ )<sup>2</sup> 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, for  $x \rightarrow 1$ , 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  $(1-x)^3$  when  $x \rightarrow 1$ .  $A_1$  is expected[5] to tend to 1 as  $x \rightarrow 1$  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  $A_1^{n,p} \rightarrow 1$  as  $x \rightarrow 1$ .

Because of the different resonance behavior, it is expected, in certain theoretical models, that the onset of duality for the neutron will happen at lower momentum transfer than for the proton. Now that precise neutron spin structure data[7] in the DIS region are available at large  $x$ , data in the resonance region are needed in order to test quark-hadron duality on the neutron spin structure functions. The goal of experiment E01-012 was to provide such data on the neutron ( $^3\text{He}$ ) 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  $^3\text{He}$  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:

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

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

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  $\sigma_0$  the unpolarized cross section, and  $\eta$ ,  $\xi$ ,  $D$  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.

The polarized  $^3\text{He}$  target is based on spin exchange between optically pumped rubidium and  $^3\text{He}$ . A small amount of nitrogen is added as buffering gas. With

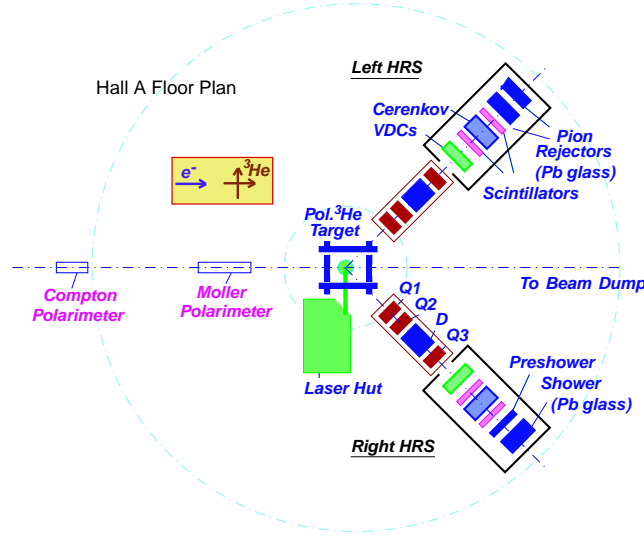


Fig. 1. Hall A floor plan. The electron beam is coming from the left.

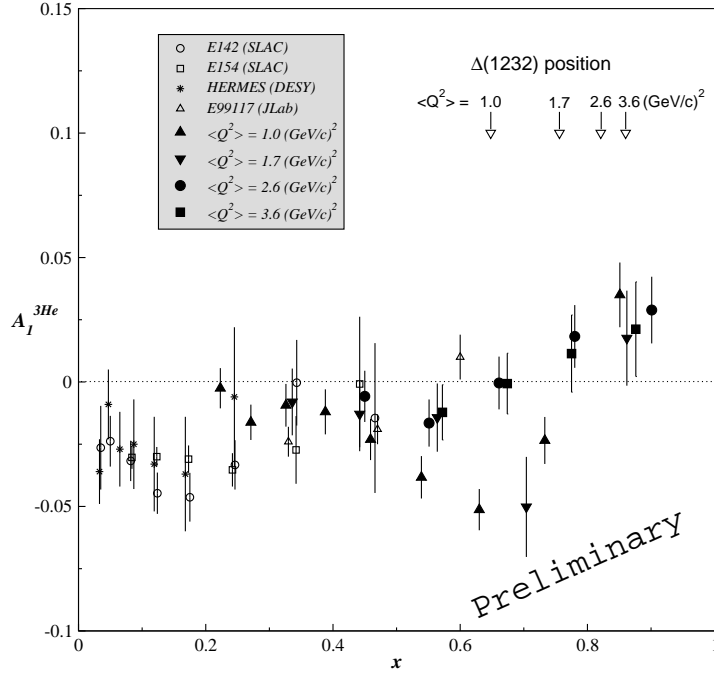
two sets of Helmholtz coils and two sets of laser optics, longitudinal and transverse polarizations can both be achieved. The polarization of the target was monitored approximately every 4 hours by two independent polarimetries[8]: NMR and EPR. From the preliminary analysis, the average target polarization 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

$A_1^{^3\text{He}}$  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  $^3\text{He}$  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  $A_1^{^3\text{He}}$  at four different  $Q^2$  values. The position of the  $\Delta(1232)$  resonance is indicated for each subset of data. The most noticeable feature is the negative contribution of the  $\Delta(1232)$  resonance at low  $Q^2$ . It has been argued[4][6] that quark-hadron duality should not work in the  $\Delta$  region at low  $Q^2$ . However, at  $Q^2$  above  $2.0$   $(\text{GeV}/c)^2$ , the dominant negative bump at the location of  $\Delta(1232)$

seems to vanish. Furthermore the results from these higher  $Q^2$  settings show that  $A_1^{3\text{He}}$  become positive with increasing  $x$ , following the same trend as the DIS world data[7][10].  $A_1^{3\text{He}}$  from the two highest  $Q^2$  settings agree well with each other showing no strong  $Q^2$ -dependence.



**Fig. 2.** Preliminary result of  $A_1^{3\text{He}}$ . The error bars are statistical only.

Preliminary results of the spin asymmetry  $A_2$  and the spin structure functions  $g_1$  and  $g_2$  for  $^3\text{He}$  were also presented at this symposium.

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

#### 4. Summary

Experiment E01-012 provides spin structure data in the resonance region for the neutron ( $^3\text{He}$ ) for  $1.0 < Q^2 < 4.0 \text{ (GeV/c)}^2$  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  $^3\text{He}$  spin structure functions. Preliminary results show that  $A_1^{3\text{He}}$  in the

resonance region follows a similar behavior as  $A_1^{^3\text{He}}$  measured in the DIS region. The confirmation of quark-hadron duality for the neutron structure functions will provide a better understanding of the mechanism of quark-gluon and quark-quark interactions. Combined with already existing proton resonance data, a study of spin and flavor dependence of duality can be performed. These data will also be used to extract moments 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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## Notes

- a.* Permanent address: Temple University  
Department of Physics  
1900 N. 13th street  
Philadelphia, PA 19122 , USA;  
E-mail: solvigno@jlab.org

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