THE ^{3}HE AND NEUTRON SPIN STRUCTURE FUNCTIONS IN THE RESONANCE REGION.

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We report on the experiment E94-010 recently completed at Jefferson Lab. The experiment studies the spin structure of the neutron. To this end we have measured polarized $\overrightarrow{^3He}(\overrightarrow{e},e')X$ inclusive cross sections and asymmetries. In this talk I give an overview of the experiment and how we control our systematic uncertainty. Preliminary results on the $g_1^{^3He}$ and $g_2^{^3He}$ spin structure functions are given.

1 Introduction.

The nucleon has been extensively studied, both in the low (Q^2,ν) region where the hadron description of the strong interaction stands and in the high (Q^2,ν) region, the Deep Inelastic Scattering (DIS) region, where the parton description of QCD holds. These two regions can be linked by using the connection between the extension of the GDH integral at finite Q^2 and the Björken sum rule, as pointed out in 1989 by Anselmino et al[1]. This work was completed in 1999 with the rigorous extension of the GDH sum rule achieved by Ji and Osborn[2]. Between the first paper of Anselmino et al and the recent paper of Ji and Osborn, a lot of theoretical results on the extended GDH have been produced, all pointing out the interest of the transition region at intermediate Q^2, domain of the resonances. The experiment E94-010, which ran in the Hall A of Jefferson Lab, is one of the experimental efforts associated with this topic. Its goal is to study the spin structure of the neutron, mainly in the resonance region, using the polarized ^3He nucleus as an effective polarized neutron. From our data we can study the Q^2 evolution of the GDH integral[3], the transverse and longitudinal asymmetries $A_1(Q^2,\nu)$ and $A_2(Q^2,\nu)$ and the spin structure functions g_1 and g_2.

The experiment and the apparatus needed to carry out such a measurement will be described. As an independent check of our understanding and control of our instrumentation some results on ^{12}C and ^3He elastic data will also be presented. We will show our preliminary results on $g_1^{^3He}$ and $g_2^{^3He}$

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and we will discuss the present difficulties to extract g_1^n and g_2^n from the ^3He data.

2 The Jefferson Lab E94-010 Experiment.

2.1 Kinematics.

The largest amount of our data are in the resonance region from $Q^2 = 0.03$ GeV^2 to $Q^2 = 1$ GeV^2, see figure 1. Data in the DIS region were also taken from $Q^2 = 0.5$ GeV^2 to $Q^2 = 1$ GeV^2 as a link to the DIS experiments E143[7] and HERMES[8]. We covered also the quasi-elastic region for ^3He nuclear studies and the elastic kinematics to study our systematics.

2.2 Overview of the Experimental Setup.

An electron beam, polarized longitudinally at about 70% is scattered off a ^3He gaseous target polarized either longitudinal or transverse to the beam direction. The target polarization was about 35% under running conditions. The scattered electrons from the inclusive $\overrightarrow{^3He}(\overrightarrow{e}, e')X$ reaction are detected by two independent, nearly identical, High Resolution Spectrometers set at $\pm 15.5^o$ from the beam direction. I should emphasize that we took only inclusive data and we used two spectrometers in order to double the solid angle and to cross check our systematics.

2.3 The Electron Beam.

The polarized electron beam is generated by a strained GaAs source. The electrons can be accelerated up to about 5 GeV by two linacs linked by recirculation arcs. The experiment used six beam energies: 0.86 GeV, 1.72 GeV, 2.58 GeV, 3.38 GeV, 4.24 GeV and 5.07 GeV. The energy is measured at a few 10^{-4} level by two independent devices. The first one measures the bending of the electron beam under a surveyed magnetic field and the second one measures in coincidence the angles of the electron and proton from the p(e,e'p) elastic reaction. The polarization of the beam is measured by a Møller polarimeter with an accuracy of about 3%.

The beam is rastered at about 20 kHz with a few mm radius in order to spread the heat load on the target. Beam Position Monitors along with the raster information and the spectrometer tracking allow us to reconstruct the reaction vertex at better than 1 mm.

The beam current and charge asymmetry are monitored by the combination of an UNSER monitor sandwiched between two cavities. The accuracy

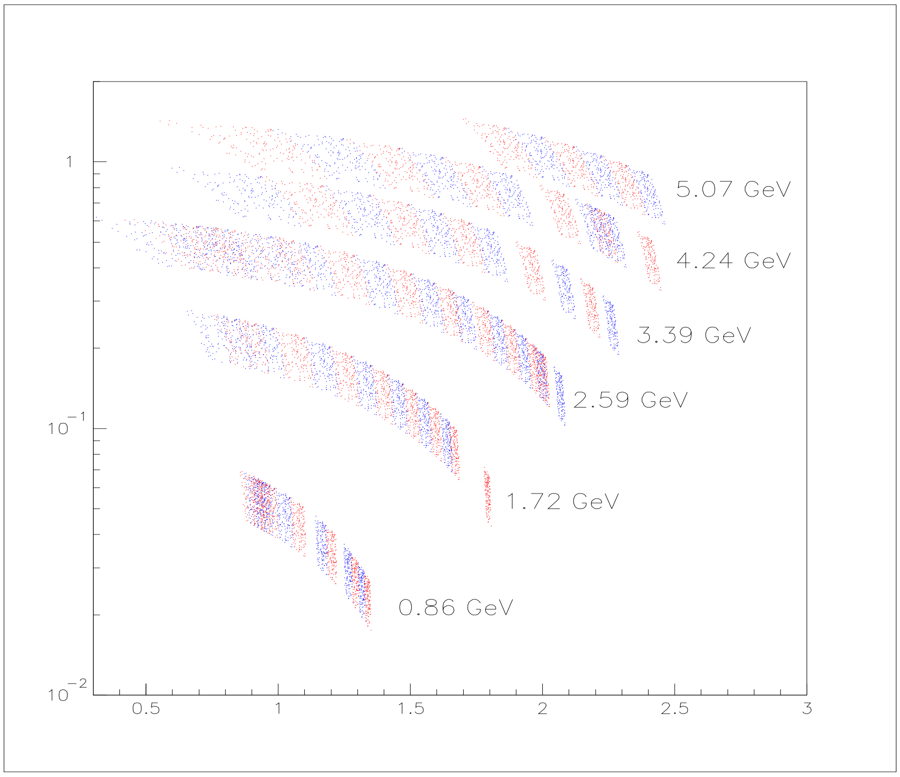

Figure 1. The experiment kinematics in the Q^2 (vertical scale) vs W (horizontal scale) plane. Each strip corresponds to a beam energy.

on the beam current is better than 1%. The current ranged from 3 to 15 μA. Nevertheless the source could have delivered up to 100 μA. We chose not to exceed 15 μA in order to avoid too much radiation damage to the cell and to minimize the target depolarization.

2.4 The Polarized Target.

The target consists of a 40 cm glass cylinder of gaseous ^3He at about 12 atm (in running conditions). The target length and the high density allow to keep a reasonable counting rate (typically of the kHz) in spite of the gaseous nature of the target. This cylinder is connected to a spherical chamber where polarized ^3He gas is produced. The target polarization is achieved in three steps:

- Atoms of Rubidium are optically pumped with a set of lasers.
- The Rb polarization is transmitted to the ^3He by spin exchange collisions.
- The polarized ^3He goes in the cylinder by diffusion and convection.

The target can be pumped in either transverse or longitudinal direction with two sets of 90 W lasers. This feature allows us to measure g_1 and A_1 (essentially longitudinal quantities) and g_2 and A_2 (essentially transverse quantities).

The polarization is measured by Nuclear Magnetic Resonance calibrated using two independent techniques: The known proton thermal polarization (water calibration) and the Electron Paramagnetic Resonance of Rb. Both calibrations are consistent. We control the target polarization at 4%. Note that in the particular case of the extraction of g_1 and g_2 we use the product of the target polarization with the density. This product is known to better than 3

Details about the target can be found in[4].

2.5 The High Resolution Spectrometers (HRS).

The two Hall A HRS are independently used to measure the momentum of the scattered electrons. The resolution achieved is of the order of $\Delta E/E \simeq 10^{-4}$. A set of detectors sits after the magnetic elements of the HRS. It consists of two scintillator planes for trigger, two pairs of drift chambers for tracking (vertex reconstruction and momentum measurement) and two independent detectors for particle identification (a Cerenkov counter and a shower counter). The pion rejection efficiency achieved is close to 10^{-4} which is largely sufficient in our case: The pion/electron ratio was never worse than 5.

In order to reproduce the HRS acceptance and to study the spectrometer magnetic transport, dedicated data were taken with a sieve slit and a target made of thin carbon foils.

2.6 Measurement of the Systematic Errors.

The elastic carbon data allow us to check our level of control of some factors coming into the cross section calculation: The HRS solid angles, the detector efficiencies, the beam current and the acquisition deadtime. A simulation reproducing our experiment and using the ^{12}C form factors world data (known

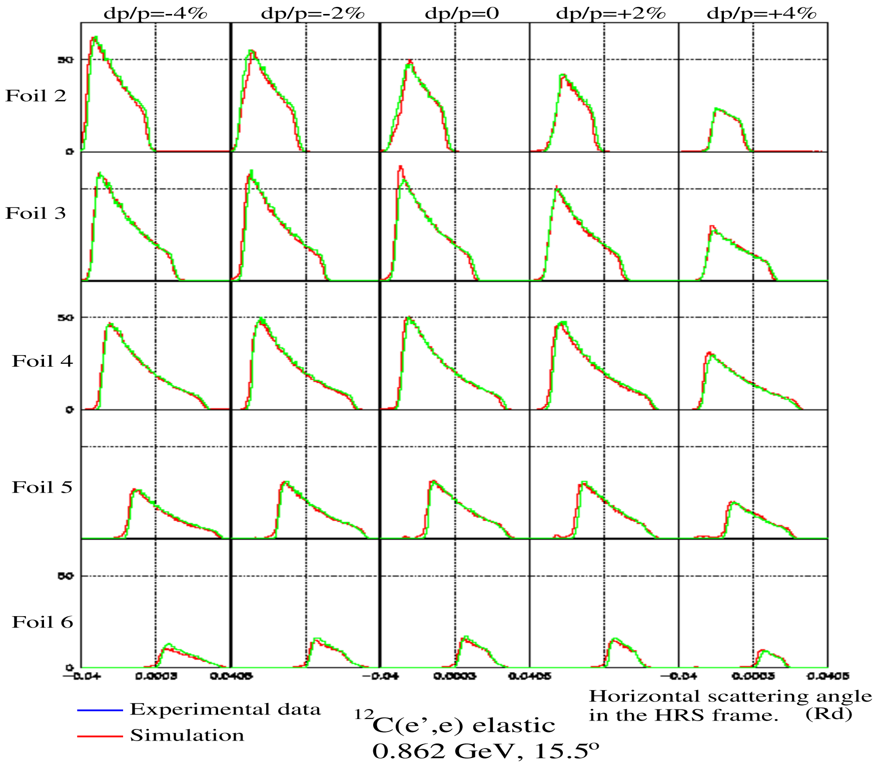

Figure 2. comparison between the simulated and the measured ^{12}C data.

at about 1%) is in agreement to better than 4 % with our experimental data (see figure 2).

The elastic ^3He polarized data allow another, more global, check of our systematics. It is indeed a measurement giving an estimate of our systematics. In addition to the previous factors, we check the ^3He target density, the target and beam polarimetries, the HRS acceptances with an extended target, the charge asymmetry and the control of the helicity correlated quantities. Our experimental data agree with the simulation (see figures 3 and 4). The systematic uncertainty on the experimental ^3He cross section is typically 6%. It is 5% on the simulated one. The systematic uncertainty on the asymmetry is 6%. For both elastic and inelastic cases, the statistical error is negligible with respect to the systematic error. The analysis is still under way and

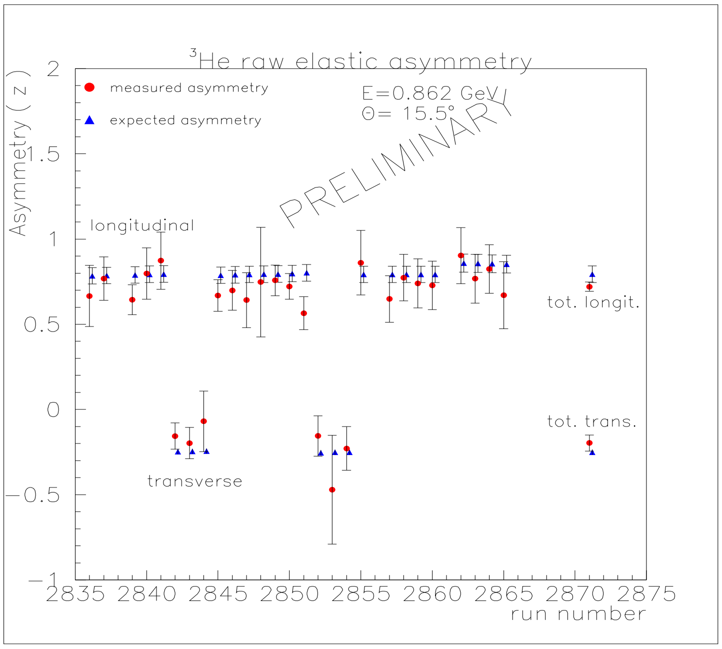

Figure 3. Experimental and expected raw elastic asymmetries for 0.862 GeV and 15.5^o. The negative asymmetries correspond to a transverse target polarization

these systematics will improve. To conclude, the final results on inelastic data should have an uncertainty of the order of 5 % for a negligible statistic uncertainty.

Note that this estimate of the size of our systematics using the elastic data is expected to be larger than the size of our systematic uncertainty in the inelastic data because of the fast variation of the elastic cross section within the HRS acceptance.

3 The Spin Structure Functions.

The preliminary results on $g_1^{^3He}$ and $g_2^{^3He}$ are given in the figure 5. They are directly extracted from our measurement of polarized cross sections: The helicity plus and helicity minus cross section difference yields the two equations[9]:

$$\frac{d^2\sigma^{\downarrow\Uparrow}}{dE'd\Omega} - \frac{d^2\sigma^{\uparrow\Uparrow}}{dE'd\Omega} = \frac{4\alpha^2}{M^3Q^2}\frac{E'}{E}[\frac{g_1(Q^2,\nu)}{\nu}M^2(E+E'cos\theta) - Q^2M^2\frac{g_2(Q^2,\nu)}{\nu^2}]$$

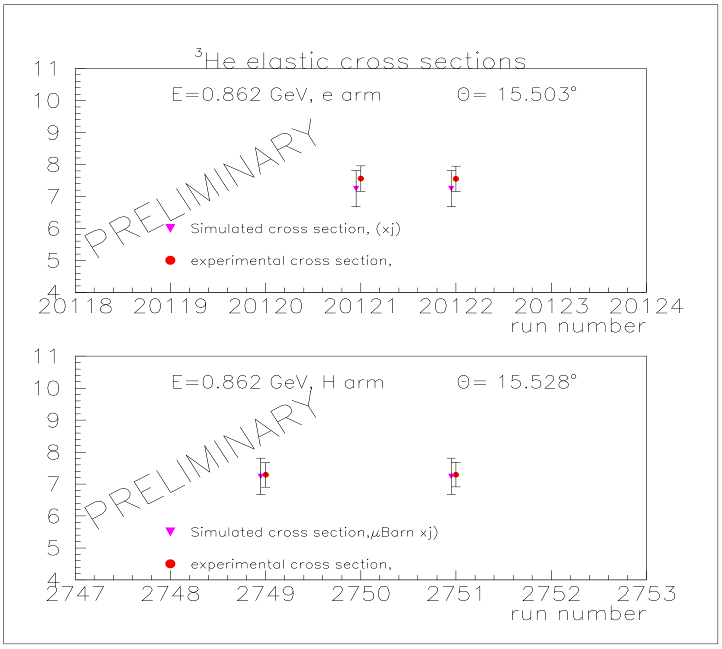

Figure 4. Experimental and expected elastic cross sections for 0.862 GeV and 15.5^o. Radiative and acceptance effects are folded in both results

$$\frac{d^2\sigma^{\uparrow\Rightarrow}}{dE'd\Omega} - \frac{d^2\sigma^{\uparrow\Leftarrow}}{dE'd\Omega} = \frac{4\alpha^2}{M^3Q^2}\frac{E'^2}{E} sin\theta[M^2\frac{g_1(Q^2,\nu)}{\nu} + 2EM^2\frac{g_2(Q^2,\nu)}{\nu^2}]$$

from where we extract the spin structure functions. Both structure functions are large in the resonance domain. As expected, in the DIS domain g_1 is still relatively large while g_2 is dying out. A striking feature of our data is the fact that g_1 and g_2 are mirror images. This can be interpreted by writing the Wilczeck-Wandzura relation[10]:

$$g_2^{ww}(x,Q^2) = \int_x^1 g_1(x',Q^2)\frac{dx'}{x'} - g_1(x,Q^2)$$

where g_2^{ww} contains only twist 2 elements. We see that at large x (in the resonance region) we expect $g_2^{ww} \simeq -g_1$. However it seems from our data that we have $g_2 \simeq -g_1$.

To extract g^n the ^3He nuclear effects have to be taken into account. The procedure[5,6] works will in most of the DIS region. It works reasonably well too in both the DIS and the resonance region for integrated quantities (such as the extended GDH sum rules). However it is not giving satisfactory results, up to now, on non-integrated quantities (such as the spin structure functions or the asymmetries) in the resonance region. We need a more reliable model in order to extract the neutron data from the ^3He data in the resonance region. The experimental physics community working on ^3He as a means to study the neutron structure will greatly benefit from any theoretical help on this matter.

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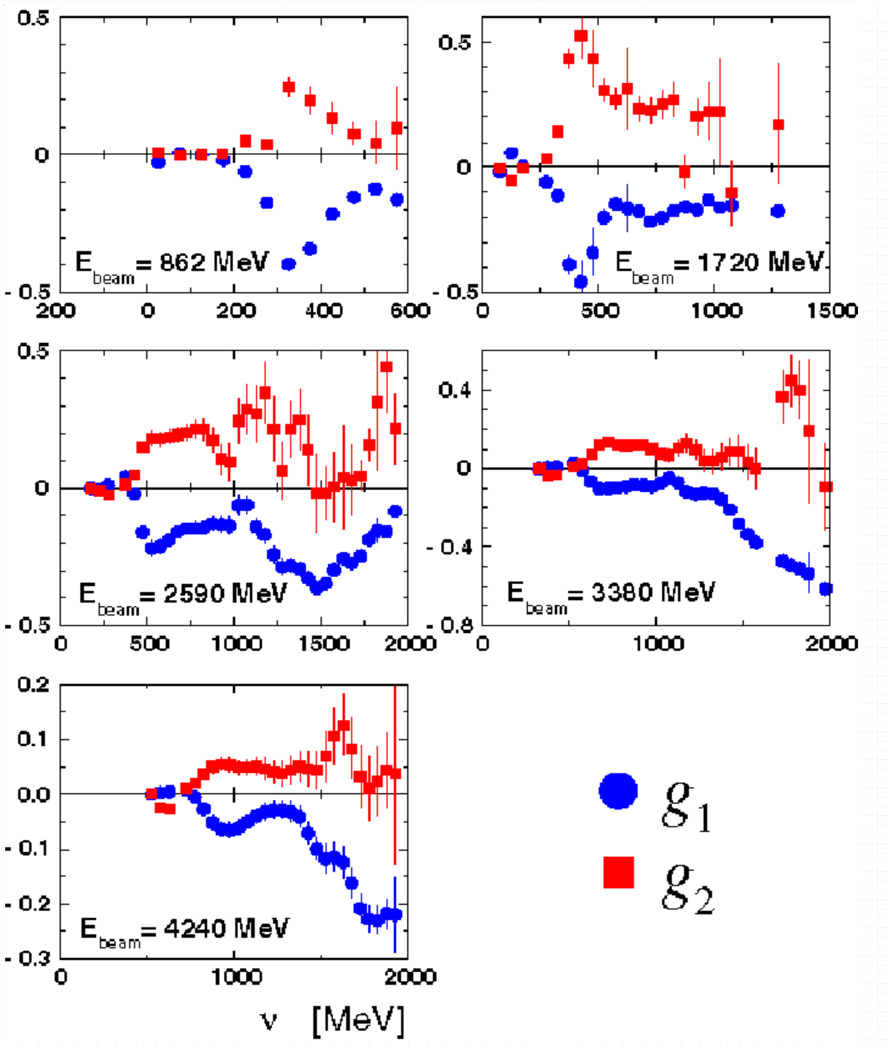

Figure 5. $g_1^{^3He}$ and $g_2^{^3He}$ for the first five energies. The horizontal scale is the virtual photon energy.