Study of Neutron Spin Structure Functions at Low Q^2 with Polarized ^{3}He

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Abstract. The recently completed experiment E94-010 at Jefferson Lab studies the neutron spin structure functions at low momentum transfer (Q^2) values. Using a polarized ^{3}He target and polarized electron beam, we have measured the asymmetries and cross sections for $^3\vec{\mathrm{He}}(e,e')$ from the elastic to the deep inelastic region. The covered Q^2 ranges from 0.03 to 0.1 GeV^2. From the data, the Q^2 evolution of the spin structure functions for ^{3}He and neutron, and of the Gerasimov-Drell-Hearn (GDH) sum rule has been studied, and the preliminary results are presented.

INTRODUCTION

The study of the spin structure of the nucleon has been of central interest in the last decade. Since the nucleon shows different features depending on the length scale at which it is observed, it is crucial to explore the spin structure over a wide range of the length scale. At a very small length scale, or high Q^2, the Bjorken sum rule holds [1]. On the other hand, at $Q^2 = 0$, the GDH sum rule [2,3] is valid which relates the spin dependent total cross section for hadron photoproduction to the anomalous magnetic moment of the nucleon. In the intermediate Q^2 region, it is possible to generalize the GDH sum rule for the absorption of the virtual photons, giving a Q^2 dependence. Recently, it has been shown by Ji and Osborne that this generalized GDH sum rule is closely connected to the Bjorken sum rule at high Q^2 limit [4]. Thus, the GDH sum rule is a crucial test of our understanding of the spin structure of the nucleon at all the values of Q^2.

GENERALIZED GDH SUM RULE

Originally, the GDH sum rule was derived for real photons:

$$\int_{\mathrm{thr}}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{\nu} d\nu = -\frac{2\pi^2\alpha}{M^2}\kappa^2, \qquad (1)$$

[1] *For the Jefferson Lab E94-010 Collaboration*

where $\sigma_{1/2}$ and $\sigma_{3/2}$ are the spin dependent cross sections for the absorption of real photons, and κ is the anomalous magnetic moment of the nucleon.

The integral on the left side of Eq. 1 can be easily generalized for the virtual photon case[2]:

$$I_{\rm GDH} \equiv 8\pi^2\alpha \int G_1(\nu, Q^2)\frac{d\nu}{\nu}, \tag{2}$$

where α is the electromagnetic coupling constant and $G_1(\nu, Q^2)[= g_1(x, Q^2)/M\nu]$ is the spin structure function. Then, this integral can be related to the forward virtual Compton scattering amplitude, $S_1(Q^2)$, through

$$I_{\rm GDH} = 2\pi^2\alpha S_1(Q^2), \tag{3}$$

yielding a generalized GDH sum rule valid for any values of Q^2.

At small Q^2, $S_1(Q^2)$ can be calculated using Chiral Perturbation Theory and the results of this experiment will be a valuable test of that theory. At large Q^2, it can also be calculated with a higher order QCD expansion (twist expansion). For the intermediate Q^2 regions, more theoretical efforts (such as lattice QCD calculation) are necessary.

EXPERIMENT

We have measured the inclusive cross section for the scattering of polarized electrons from a polarized ^{3}He target in Hall A of the Jefferson Lab. An electron beam with average polarization of 70% and current up to 15μA was scattered off a high density (10 atm in a 40 cm long glass cell) polarized ^{3}He target with 30 to 40% polarization. The scattered electrons were detected by the two essentially identical spectrometers sitting at 15.5° on both sides of the beam.

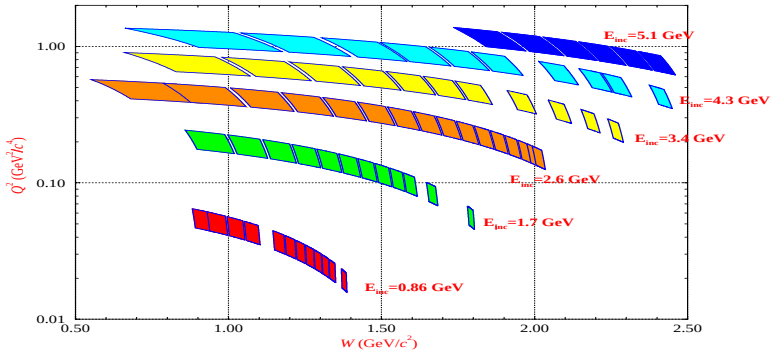

FIGURE 1. Kinematic coverage of JLab E94-010 experiment.

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[2] Actually, there are several different generalizations, all of which agrees for the real photon case at $Q^2 = 0$. We followed Ji and Osborne's definition.

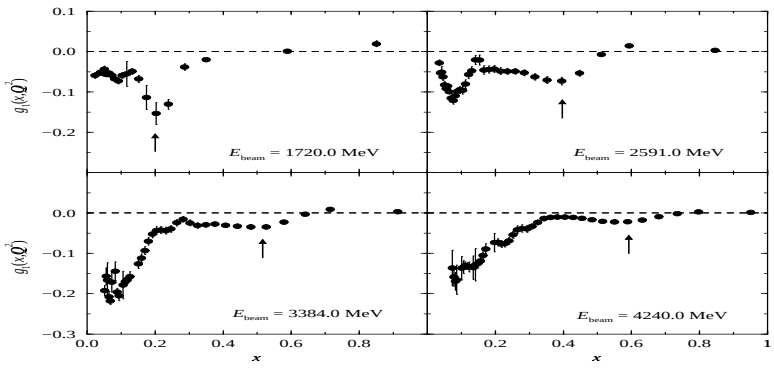

FIGURE 2. Preliminary results on the spin dependent structure function $g_1^{^3He}(x, Q^2)$.

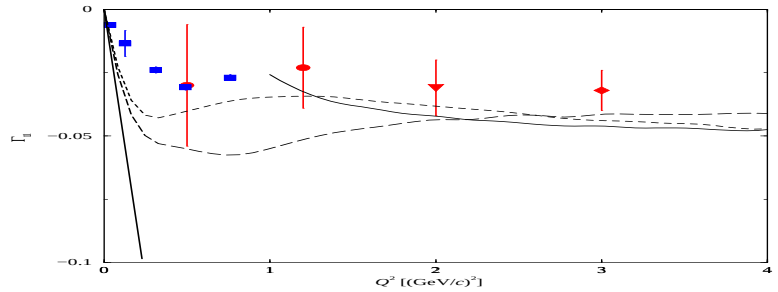

FIGURE 3. Integral of $g_1(x, Q^2)$ for the neutron. The present data (squares) are plotted together with data from SLAC E142 (inverted triangle) and E143(circle). The curves correspond to the evolution[7] of the deep-inelastic results due to changing α_s (solid), the predictions of Burkert and Ioffe[8] (dotted), the model of Soffer[9] (long dash), and the GDH approach to $Q^2 = 0$ (solid).

The ^{3}He target was polarized using spin exchange principle. Rb atoms were polarized by optical pumping and the polarization was transferred to ^{3}He via spin exchange collisions. The target has been polarized either parallel or perpendicular to the beam direction. The magnitude of the polarization was monitored with three independent methods: NMR with adiabatic fast passage, Electron Paramagnetic Resonance (EPR), and measurement of the elastic asymmetry.

The experiment covers a range of Q^2 from 0.03 to 1.1 GeV^2, and from the elastic to the deep inelastic regime, including the quasi-elastic and the resonance regions. Figure 1 shows the kinematic coverage of this experiment in Q^2 and invariant mass W.

PRELIMINARY RESULTS

The differential cross sections for each combination of electron and ^{3}He spin directions have been deduced from the experimental data. Overall consistency has

been checked comparing ^{3}He elastic cross sections and asymmetries with the world data.

From the polarized beam asymmetries with the target polarization either parallel or perpendicular to the beam direction, the structure functions $g_1^{^3He}(x,Q^2)$ and $g_2^{^3He}(x,Q^2)$ have been calculated. Figure 2 shows the structure function $g_1^{^3He}(x,Q^2)$ for four beam energies. We can observe that $g_1^{^3He}(x,Q^2)$ for Δ resonance (arrow mark) is negative and decreases in magnitude as the beam energy (or Q^2) increases.

In Fig. 3, the integral of $g_1(x,Q^2)$, $\Gamma_1 = \int_0^1 g_1(x,Q^2)dx$ has been compared with the existing data from SLAC E142 [5] and E143 [6], and a few calculations. The preliminary results are compatible with the existing data but with much more improved statistical precision[3].

SUMMARY AND FUTURE

We have measured spin dependent cross sections and asymmetries for $^3\vec{\mathrm{He}}(e,e')$. The preliminary results are compatible with the existing data and have significantly improved statistical precision. Detailed analysis of the systematic errors is in progress, and final results will be available in a few months. An extension to even smaller Q^2 ranges and higher energies is planned in the future at Jefferson Lab. A more detailed study of the GDH sum rule and the spin structure of the nucleon will enrich our understanding of the internal structure of the nucleon.

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[3] Due to the small components of S' and D waves in the ground state of the ^{3}He, there are corrections to be made to get g_1^{neutron} from $g_1^{^3He}$ [10]. These corrections have been ignored in this comparison. For our results, the integral has been performed with $g_1^{^3He}(x,Q^2)$ at constant beam energy within the measured region of x, and the results are plotted versus average Q^2 value.