The Neutron and ^3He Spin Structure Functions at Low Q^2

Vincent A. Sulkosky

12000 Jefferson Avenue, Suite #4, Newport News, VA 23606

Abstract. Experiment E97-110 was performed at the Thomas Jefferson National Accelerator Facility in Hall A to provide a precise measurement of the moments of the neutron and ^3He spin structure functions. A longitudinally-polarized electron beam was scattered from a longitudinally or transversely polarized ^3He target. The extended Gerasimov-Drell-Hearn integral and other moments of the neutron and ^3He spin structure functions were extracted at very low momentum transfers ($0.02 < Q^2 < 0.3 \text{ [GeV}/c]^2$). These data allow us to make a benchmark check of Chiral Perturbation Theory calculations in a region where they are expected to be valid. In these proceedings, the experimental details are discussed and preliminary results on the moments of the spin structure functions are presented.

Keywords: neutron, spin structure, chiral perturbation theory

PACS: 14.20.Dh

INTRODUCTION

Over the past few decades, the study of nucleon spin structure has been an active field, both experimentally and theoretically [1, 2]. Spin-dependent sum rules such as the Gerasimov-Drell-Hearn (GDH) [3] sum rule are important tools available to study nucleon spin structure. The GDH sum rule was originally derived for real photon absorption but was extended to virtual photon absorption [4]. The extension by Ji and Osborne [5] forms a Q^2 -dependent sum rule. The relationship between the forward Compton scattering amplitudes and the spin-dependent structure functions $g_1(x, Q^2)$ and $g_2(x, Q^2)$ serves as a natural extension of the sum rule to virtual-photon scattering. This unique relation, valid at any four-momentum transfer (Q^2), can be used to make comparisons between theoretical calculations and experimental data, where they are available. This comparison allows an examination of the transition between the non-perturbative region and the perturbative region of Quantum Chromodynamics. In particular, low-energy effective field theories such as Chiral Perturbation Theory provide calculations for sum rules in the non-perturbative regime of QCD.

THE EXPERIMENT

Experiment E97-110 [6] acquired data at Jefferson Lab in Hall A [7]. The data were collected using seven incident electron beam energies and two angles to obtain the necessary kinematic coverage to extract the moments at constant Q^2 . The experiment covered an invariant mass range including the elastic, quasi-elastic and resonance regions up to

an invariant mass $W = 2.5$ GeV. The scattered electrons were detected by one of the Hall A High Resolution Spectrometers [7] with the addition of a horizontally-bending dipole magnet [8] to achieve scattering angles of 6° and 9° ; without this magnet the minimum spectrometer angle is 12.5° . For this experiment, we used a polarized ^3He target as an effective polarized neutron target.

A longitudinally polarized electron beam was scattered from a longitudinally or transversely (in-plane) polarized ^3He target [7] to measure the inclusive reaction $^3\text{He}(\vec{e}, e')$. The electron beam was used with a current of up to $10 \mu\text{A}$ and had an average polarization of $\sim 75\%$. The ^3He nuclei were polarized by spin-exchange optical pumping with rubidium atoms and were oriented in either the longitudinal or transverse direction (with respect to the beam direction) with the aid of two sets of Helmholtz coils. Two independent polarimetries [7] were used to monitor the polarization: NMR and EPR. The average target polarization was $\sim 40\%$.

By measuring both target polarization orientations, the spin structure functions $g_1(x, Q^2)$ and $g_2(x, Q^2)$ were extracted from the measured polarized cross-section differences without the need for models. The first moments of the ^3He polarized structure functions were then formed. The first moment of the g_1 structure function is given by

$$\bar{\Gamma}_1(Q^2) = \int_0^{x_0} g_1(x, Q^2) dx, \quad (1)$$

where x_0 is the inelastic threshold. This integral is related to the GDH sum rule as $Q^2 \rightarrow 0$ [9]. The Burkhardt-Cottingham (BC) sum rule [10], which is uniquely zero for any Q^2 , is related to the first moment of g_2 :

$$\Gamma_2(Q^2) = \int_0^1 g_2(x, Q^2) dx = 0. \quad (2)$$

The neutron moments were extracted from the measured ^3He quantities by using the prescription described in [12]. At $Q^2 \leq 0.1$ $[\text{GeV}/c]^2$, the systematic uncertainty due to this extraction was estimated to be 10%. In addition, we have used the parameterization in [11] to account for the unmeasured DIS contribution.

PRELIMINARY RESULTS

The left-hand side of Fig. 1 shows the preliminary results for the integral of $g_1(x, Q^2)$ compared to theoretical calculations and previous data [13, 14, 15, 16]. The solid triangles represent the new data, and the inverted triangles show the results from a previous neutron experiment [16] in Hall A for $0.1 \leq Q^2 \leq 0.9$ $[\text{GeV}/c]^2$. The error bars on the points include both systematic and statistical uncertainties. For the final results, we expect to significantly improve the (largely dominant) systematic uncertainties. The preliminary results agree well with the higher Q^2 data and also with the two model calculations [17, 18]. As $Q^2 \rightarrow 0$, the results indicate a smooth transition toward zero. Near $Q^2 = 0$, two calculations from Chiral Perturbation Theory are available [19, 20]. One of the calculations includes an estimate of the Δ -resonance contribution and is

FIGURE 1. Preliminary neutron Γ_1 (left) and Γ_2 (right) results (see text for details)

represented by the band at low Q^2 . The band is the result of the uncertainties on the parameterization of the Δ resonance. The data agree with the relativistic baryon calculation [19] within the experimental uncertainties, and the three lowest- Q^2 points agree well with the heavy baryon calculation [20].

The integral Γ_2^n is shown in the right-hand side of Fig. 1 for the measured region (solid squares). The open diamonds represent the integral after inclusion of the elastic contribution. The solid triangles represent the full integral with an estimate of the DIS contribution assuming $g_2 = g_2^{WW}$, where g_2^{WW} is the twist-2 part of g_2 derived by Wandzura and Wilczek [21]. The preliminary data agree well with the earlier neutron results [16], and the resonance data follow the MAID model [22]. The band centered near -0.015 represents the systematic errors. The darker band shows the total systematic uncertainty, while the lighter band shows the error for the unmeasured low- x part. The results, including the elastic and DIS contributions, are consistent with the BC sum rule over the measured Q^2 region. Also on the plot is a high- Q^2 point from the SLAC E155x collaboration [23], which is also consistent with zero but with a large uncertainty.

SUMMARY

Experiment E97-110 was conducted to provide precise spin structure data for the neutron and ^3He at low Q^2 between 0.02 and 0.3 $[\text{GeV}/c]^2$. From the measured structure functions, the generalized GDH integral and other moments of the spin structure functions are extracted. At low Q^2 , these quantities provide an important benchmark check of Chiral Perturbation Theory calculations. Here, the preliminary results on the integrals of $g_1(x, Q^2)$ and $g_2(x, Q^2)$ have been presented. The $\bar{\Gamma}_1(Q^2)$ integral shows good agree-

ment with published data at higher Q^2 and the relativistic baryon calculation, whereas only the three lowest- Q^2 points agree with the heavy baryon calculation. The integral Γ_2^n is consistent with the BC sum rule prediction. Systematic checks are ongoing, and final neutron results are expected soon. In the near future, the other moments of the spin structure functions, including the generalized forward spin polarizabilities [24] will also be extracted.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy contract DE-AC05-84ER40150, Modification No. M175, under which the Southeastern Universities Research Association operates the Thomas Jefferson National Accelerator Facility.

REFERENCES

1. B. W. Filippone and X. Ji, *Adv. Nucl. Phys.* **26** 1 (2001).
2. S. E. Kuhn, J.-P. Chen and E. Leader, arXiv:08123535 (2008).
3. S. B. Gerasimov, *Sov. J. Nucl. Phys.* **2** 430 (1966);
S. D. Drell and A. C. Hearn, *Phys. Rev. Lett.* **16** 908 (1966).
4. M. Anselmino, B. L. Ioffe and E. Leader, *Sov. J. Nucl. Phys.* **49** 136 (1989).
5. X. Ji and J. Osborne, *J. Phys. G* **27** 127 (2001).
6. For details see V. Sulkosky's thesis at <http://halloweb.jlab.org/experiment/E97-110/thesis.html>.
7. J. Alcorn *et al.*, *Nucl. Instrum. Meth. A* **522** 294 (2004).
8. P. Brindza *et al.*, *IEEE Transactions on Applied Superconductivity* **11** 1594 (2001).
9. D. Drechsel and L. Tiator, *Annu. Rev. Nucl. Part. Sci.* **54** 69 (2004).
10. H. Burkhardt and W. N. Cottingham, *Ann. Phys.* **56** 453 (1970).
11. N. Bianchi and E. Thomas, *Nucl. Phys. B (Proc. Suppl.)* **82** 256 (2000).
12. C. Ciofi degli Atti and S. Scopetta, *Nucl. Phys. B* **404** 223 (1997).
13. P. L. Anthony *et al.*, *Phys. Rev. D* **54** 6620 (1996);
K. Abe *et al.*, *Phys. Rev. D* **58** 112003 (1998);
K. Abe *et al.*, *Phys. Rev. Lett.* **79** 26 (1997).
14. A. Airapetian *et al.*, *Eur. Phys. J. C* **26** 527 (2003).
15. J. Yun *et al.*, *Phys. Rev. C* **67** 055204 (2003).
16. M. Amarian *et al.*, *Phys. Rev. Lett.* **89** 242301 (2002);
M. Amarian *et al.*, *Phys. Rev. Lett.* **92** 022301 (2004);
M. Amarian *et al.*, *Phys. Rev. Lett.* **93** 152301 (2004).
17. V. D. Burkert and B. L. Ioffe, *Phys. Lett. B* **296** 223 (1992).
18. J. Soffer and O. V. Teryaev, *Phys. Rev. D* **70** 116004 (2004).
19. V. Bernard, T. R. Hemmert and U.-G. Meissner, *Phys. Lett. B* **545** 105 (2002);
V. Bernard, T. R. Hemmert and U.-G. Meissner, *Phys. Rev. D* **67** 076008 (2003).
20. X. Ji, C. Kao and J. Osborne, *Phys. Lett. B* **472** 1 (2000).
21. S. Wandzura and F. Wilczek, *Phys. Lett. B* **72**, 195 (1977).
22. D. Drechsel, S. S. Kamalov and L. Tiator, *Phys. Rev. D* **63** 114010 (2001).
23. P. L. Anthony *et al.*, *Phys. Lett. B* **553** 18 (2003).
24. J.-P. Chen, A. Deur and Z.-E. Meziani, *Mod. Phys. Lett. A* **20** 2745 (2005).