Few-Body Systems Suppl. 0, 1–6 (1999)

Few-Body Systems

Measurements of Q^2 Evolution of the GDH Sum Rule and the Spin Structure of the ^{3}He and the Neutron

J. P. Chen*

Jefferson Lab, Newport News, VA 23606, USA

Abstract.
We have recently completed experiment E94-010 at Jefferson Lab. The experiment used a polarized ^{3}He target and polarized electron beam to measure asymmetries and cross sections for $^3\boldsymbol{He}(\boldsymbol{e}, e')$ from threshold to deep inelastic region, covering the quasielastic and the resonance region.The Q^2 range covered is from 0.03 to 1 GeV^2. From these data, the ^{3}He and the neutron spin structure and the Q^2 evolution of the Gerasimov-Drell-Hearn (GDH) sum rule will be studied This is the first measurement of the Q^2 evolution of the GDH sum rule. Preliminary results are presented. Plan for future study on this subject at Jefferson Lab is discussed.

1 Introduction

The nucleon spin has been of central interest ever since the EMC experiment found that at small distances the quarks carry only a fraction of the nucleon spin. Going from shorter to larger distances the quarks are dressed with gluons and $q\bar{q}$ pairs and acquire more and more of the nucleon spin. How is this process evolving with the distance scale? At the two extreme kinematic regions we have two fundamental sum rules: the Bjorken sum rule (Bj-SR)[1] which holds for the proton-neutron difference in the asymptotic limit, and the Gerasimov-Drell-Hearn sum rule (GDH-SR)[2, 3] at $Q^2 = 0$. What is the connection between the Bj-SR and the GDH-SR? Study the evolution of the GDH-SR at low Q^2 is crucial to answer these questions.

2 Bjorken and GDH Sum Rules and the Connection

2.1 Bjorken Sum Rule

From the 20 years of spin structure experiments in the deep inelastic region, one of the most important outcomes is the experimental test of the Bjorken Sum

* *For the Jefferson Lab E94-010 Collaboration*

Rule to about 10% level. The Bj-SR relates the spin structure over the entire energy range to a static property of the nucleon, the axial coupling constant g_A:

$$\int_0^1 (g_1^p - g_1^n)dx = \frac{1}{6}g_A \tag{1}$$

The Bj-SR is based on very general principle (QCD) and is valid at the Bjorken limit: $Q^2 \to \infty, \ \ \nu \to \infty$ while $x = Q^2/2m\nu$ is finite. For finite Q^2, there is a QCD correction factor.

2.2 GDH Sum Rule

Another fundamental sum rule, the Gerasimov Drell-Hearn sum rule (GDH-SR) [2, 3], holds at the other extreme of the kinematics, $Q^2 = 0$:

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

here again the sum rule relates the helicity (doubly polarized) cross section difference over the whole energy range to a static property of the nucleon, the anomalous magnetic moment of the nucleon, κ.

The GDH-SR is derived using the dispersion relation (without subtraction) on the forward Compton scattering amplitude, combined with the Optical and the Low Energy Theorems. The input assumptions are very general. The only asummption could be open to "reasonable" questions is the no-subtraction condition in the dispersion relation. Partial wave analysis based on unpolarized and singly polarized data, gave an estimate of the double polarization cross sections and therefore the indirect 'experimental' sum, showed a discrepancy from the GDH-SR. The direct experimental test becomes possible only now with the availability of the high luminosity polarized beam and polarized targets and the modern advanced detection technology.

2.3 GDH Sum Rule for ^{3}He

The GDH-SR is also valid for any nucleus:

$$\int_{thr}^{\infty} (\frac{\sigma_P - \sigma_A}{\nu})d\nu = \frac{4\pi^2\mu_A^2}{J} \tag{3}$$

where the subscription P (A) stand for the target polarization parallel (anti-parallel) to the beam polarization. J and μ_A are the angular momentum and the magnetic moment of the target nucleus.

In the case of polarized ^{3}He target, since it is approximately a polarized neutron target, it can be used to study both the GDH-SR for ^{3}He and for the neutron. $GDH(^3He) = 496\mu b$ and $GDH(n) = 233\mu b$. The difference of the two sum rules gives us an elegant method to study the 'nuclear' contribution to the GDH-SR for ^{3}He. The difference is $263\mu b$ and should be approximately equal to the GDH sum (^{3}He) from break-up threshold to the π threshold. One can learn how good a polarized ^{3}He target is a polarized neutron target by experimentally checking the GDH(^{3}He) sum below the π threshold.

2.4 Generalized GDH Sum Rule: Connecting GDH and Bjorken Sum Rules

Phenomenological models have been proposed to extend the GDH-SR integral for the proton and neutron to finite Q^2 and connect it to the Bj-SR in deep inelastic regime [4, 5]. Recently Ji and Osborne[6] made a rigorous extension of the GDH-SR to the entire region of Q^2. With the same assumptions as the GDH-SR, Ji and Osborne derived the generalized GDH-SR:

$$4\int_{el}^{\infty} \frac{G_1(\nu, Q^2)}{\nu} d\nu = S_1(Q^2)$$

where $S_1(Q^2)$ is the forward virtual Compton Scattering amplitude. The GDH-SR and Bj-SR are the two limiting cases ($Q^2 = 0$ and $Q^2 = \infty$) of the generalized GDH-SR. Other than the two limiting cases, the $S_1(Q^2)$ can also be calculated at small Q^2, where hadrons are the relevant degree of freedom, with Chiral Perturbation theory and at large Q^2, where quarks and gluons(partons) are the relevant degree of freedom, with higher order QCD expansion (twist expansion). At small Q^2, it was calculated to the leading order[6] using the Chiral Perturbation theory with the Heavy Baryon approximation. At large Q^2, twist-2 and twist-4 terms have been calculated. Efforts are underway to calculate to higher orders for both small and large Q^2.

A crucial question in this connection is how low in Q^2 the Bj-SR can be evolved using the high twist expansion? Recent estimates [6] suggest a Q^2 value as low as 0.5 GeV^2. Also at the other end, chiral perturbation theory is applicable at small Q^2, and may allow evolution of the GDH-SR to $Q^2 = 0.02$ GeV^2 or higher. Theoretical efforts (such as lattice calculations) are needed to bridge the remaining gap.

The importance of such efforts cannot be overemphasized as it would mark the first time that hadronic structure is described by a fundamental theory in the entire kinematics regime, from short to large distances.

3 JLab E94-010 experiment

Experiment JLab E94-010[7], has recently been completed with a polarized ^{3}He targets to study the Q^2 evolution of the GDH integral for ^{3}He and the neutron. The experiment covers a range of $Q^2 = 0.03 - 1.1\ GeV^2$ and from the elastic to the deep inelastic regime, covering the quasielastic and the resonance region. Figure 1 shows the kinematic coverage of the experiment.

3.1 The Experimental Setup

The experiment was carried out in Hall A of the Jefferson Lab. Highly polarized (70%) electron beam with current up to 15 μA scattered off a high density

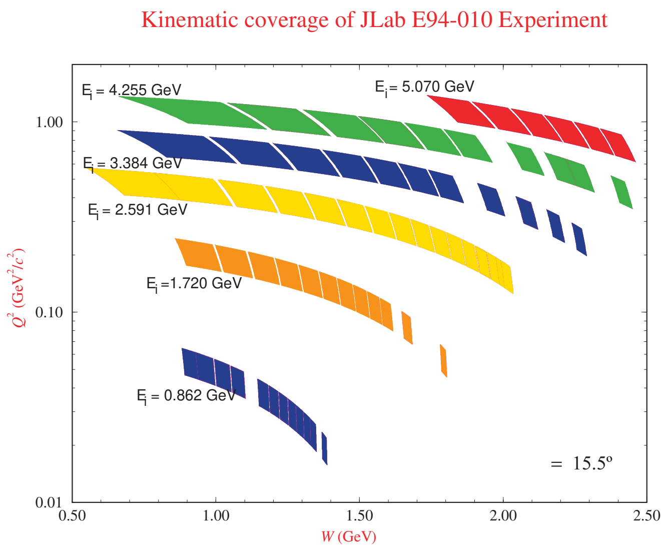

Figure 1. E94-010 Kinematics

(10 atm gaseous in a 40 cm long glass cell) polarized ^{3}He target (30-40% polarization in-beam). The recently built polarized ^{3}He target was based on the spin exchange principle. Rubidium atoms were polarized by optical pumping, and the polarization was transfered to ^{3}He nuclei via spin exchange collisions. The target was polarized either parallel or perpendicular to the beam direction and the polarization was measured with two independent methods: NMR with Adiabatic Fast Passage, and EPR (Electron Paramagnetic Resonance).

Two nearly identical spectrometers, setting at same scattering angle of 15.5°, were used to detect the scattered electrons. Both spectrometers were equipped with standard electron detector packages. The comparison of the data from the two spectrometers gives us a check of the data quality and minimizes some systematic uncertainties.

3.2 Preliminary Results

The data analysis is still underway. The raw ^{3}He elastic asymmetries were checked against the world elastic data weighted by the beam and target polarizations. Figure 2 shows the spectra of the raw parallel and perpendicular asymmetries for four energies. The data are still preliminary since radiative corrections, acceptance corrections, dilution corrections and some other correction factors have not been applied. The error bars are statistical only. Final results on the ^{3}He asymmetries are expected to be available in the next a few months and the results on the generalized ^{3}He GDH sum will follow afterwards.

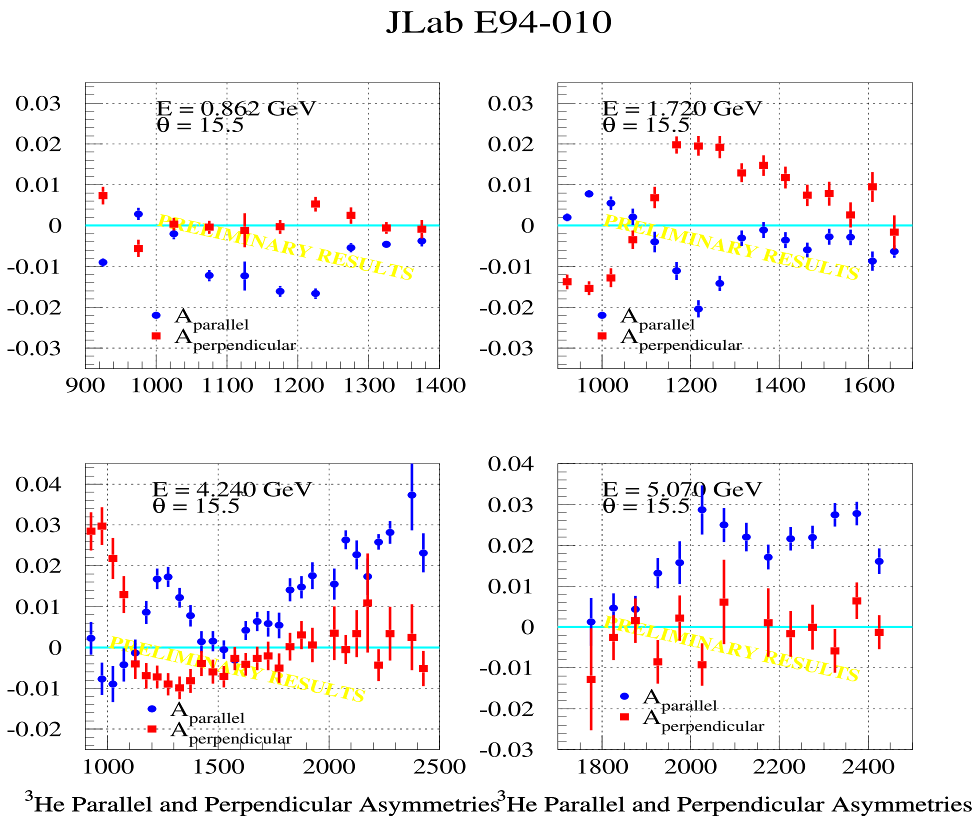

Figure 2. Preliminary Raw ^{3}He Asymmetries

4 Extraction of the Neutron Results

Due to the small components of S' and D waves in the ^{3}He ground state, the polarized ^{3}He target is only approximately a polarized neutron target. J. Friar et al. [8] calculated the effective polarization of the neutron and proton in a polarized ^{3}He target. The results are that the effective neutron polarization is about 87% and the effective proton polarization is about -3%. Recently, C. degli Atti and S. Scopetta[9] studied the extraction of the neutron asymmetries and the generalized GDH sum from a polarized ^{3}He target. Although at the resonance region at low Q^2, the extracted neutron spin structure function g_1

could differ significantly from g_1 of the free neutron, the extracted neutron GDH sum does not differ much from the free neutron GDH sum. The reason is that the Fermi motion, being the main effect, does not affect the integrated results. Other theory groups[10] will also study this problem in the future.

5 Outlook and Summary

The spin structure and the GDH sum rule study are one of the major efforts at Jefferson Lab. Experiments on the proton[11] and the deuteron[12] have been partially completed. An extension of the ^{3}He experiment to very low Q^2[13] and higher energy (6 GeV) is planned. It will enable us to extrapolate to the real photon point and also study the convergence of the sum rule. JLab is planning to upgrade the accelerator to 12 GeV. In the future, extension to 12 GeV can test the Regge behavior of the GDH sum rule.

In summary, the spin structure and the generalized GDH sum rule of the nucleon and few-body nuclei are one important area of research at Jefferson Lab. JLab E94-010 is the first completed experiment measuring the spin structure and the generalized GDH sum rule for ^{3}He and the neutron at low Q^2 region. Preliminary results were shown. Future extension to nearly real photon kinematics and higher energies are planned. Experiments on the proton and deuteron are also being carried out at JLab. Fruitful results from the GDH sum rule and spin structure study are expected in the next few years.

References

1. J. D. Bjorken, Phys. Rev. 148, 1467 (1966)
2. S. B. Gerasimov, Sov. J. Nucl. Phys. 2, 430 (1966)
3. S. D. Drell and A. C. Hearn, Phys. Rev. Lett. 16, 908 (1966)
4. M. Anselmino, B. Ioffe and E. Leader, Sov. J. Nucl. Phys. 49, 136 (1989)
5. V. Burkert and B. Ioffe, JETP, Vol. 105, 1153 (1994)
6. X. Ji and J. Osborne, hep-ph/9905010 (1999)
7. JLab E94-010, Spokespersons, Z. E. Meziani, G. Cates and J. P. Chen
8. J. Friar et. al., Phys. Rev. C42, 2310 (1990)
9. C. degli Atti and S. Scopetta, Phys. Lett. B44, 223, (1997)
10. R. Schiavilla, W. Glockle, private communication
11. JLab E91-023, Spokespersons, V. Burkert, D. Crabb and R. Minehart
12. JLab E93-009, Spokespersons, S. Kuhn and M. Taiuti
13. JLab E97-110, Spokespersons, J. P. Chen, G. Cates and F. Garibaldi