THE GENERALIZED GDH SUM RULE: MEASURING THE SPIN STRUCTURE OF ^{3}HE AND THE NEUTRON USING NEARLY REAL PHOTONS

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The Gerasimov–Drell–Hearn sum rule was originally derived for real photon absorption and has been generalized to finite Q^2. Jefferson Lab experiment E97-110 has performed a precise measurement of the generalized GDH integral for both ^{3}He and neutron and the neutron spin structure function moments in order to study their Q^2 dependence between 0.02 and 0.3 GeV^2. This range will allow us to test the dynamics of Chiral Perturbation Theory. The status and prospects of the data analysis will be discussed.

1. The GDH Sum Rule and generalization to finite Q^2

The spin structure of the nucleon has been of great interest over the past few decades. The Gerasimov–Drell–Hearn (GDH) sum rule [1] is one method used to study the nucleon spin structure. The GDH sum rule relates the helicity dependent photoproduction cross sections for scattering a circularly polarized photon beam off a longitudinally polarized target. For spin 1/2 targets

$$\int_{\nu_0}^{\infty} [\sigma_{\frac{1}{2}}(\nu) - \sigma_{\frac{3}{2}}(\nu)] \frac{\mathrm{d}\nu}{\nu} = -\frac{2\pi^2 \alpha \kappa_{\mathrm{N}}^2}{\mathrm{M}_{\mathrm{N}}^2} \quad (1)$$

where κ_{N}, M_{N} are the anomalous magnetic moment and mass of the target, ν_0 the pion photoproduction threshold, ν the photon energy, and $\frac{1}{2}$ ($\frac{3}{2}$) corresponds to the case of the photon helicity being anti-parallel (parallel) to the target spin.

Recently the GDH integral was generalized to finite Q^2. One method is to replace the photoproduction cross sections with the electroproduction cross sections [2] (see eq. 2).

$$I(Q^2) = \int_{\nu_0}^{\infty} [\sigma_{\frac{1}{2}}(\nu, Q^2) - \sigma_{\frac{3}{2}}(\nu, Q^2)] \frac{d\nu}{\nu} \tag{2}$$

Other definitions exist that add a kinematical factor that depends on the convention chosen for the photon flux.[3,4] All these generalizations reduce to the original GDH sum rule at $Q^2 = 0$.

Due to its connection with the Bjorken sum rule,[5] the extension of the integral to finite Q^2 provides a bridge from the non-perturbative region to the perturbative region of QCD. This bridge allows a comparison of the measured quantity to theoretical predictions over the entire Q^2 range.

2. Experiment E97-110

Experiment E97-110 [6] made a precise measurement of the spin dependent $^3\vec{He}(\vec{e}, e')$ inclusive cross sections and asymmetries to evaluate the generalized GDH integral at low Q^2 from 0.02 to 0.3 GeV^2. The experiment was conducted at the Thomas Jefferson National Accelerator Facility (JLab). The goals of the experiment are to determine the slope of the generalized GDH integral, which tests the dynamics of χPT, extrapolate to the real photon point, and learn more about the spin structure of ^{3}He and the neutron.

The spin structure function moments and forward spin polarizabilities will also be extracted. Furthermore, the kinematic region of the data overlaps with the previous Hall A GDH experiment E94-010.[7]

The JLab longitudinally polarized electron beam was employed at several incident energies from 1.15 to 4.4 GeV. During the experiment, we used one of the Hall A high resolution spectrometers [8] along with a septum magnet[6] to detect the electrons at scattering angles of 6° and 9°. The septum magnet was necessary to reach the small angles, since the minimum spectrometer angle is 12.5°. The magnet was commissioned during E97-110. See Fig. 1 for a diagram of the Hall A floor layout.

A polarized ^{3}He target [6,7] with 40% average polarization in beam and 10^{36} $(cm^2{\cdot}s)^{-1}$ luminosity was used as an effective polarized neutron target. Data were acquired with both longitudinal and transverse target polarization configurations. The target polarization was measured by two methods of polarimetry: NMR and EPR.[9,10] Since the magnet's close proximity and large fields would adversely affect the target polarization, magnetic field clamps and compensating coils were used to reduce the field gradients from the septum magnet in the target region.

Up to 10 μA of beam was used, and the beam helicity was pseudo-randomly flipped at 30 Hz. The beam polarization was measured with both Møller and Compton polarimeters.[8] Typically a Møller measurement was taken at each beam energy, whereas Compton was used to continuously monitor the polarization. The average polarization from both Møller and Compton was $\sim 75\%$.

The spectrometer detector package contains drift chambers for tracking, scintillators for triggering, and preshower, shower and Cherenkov detectors for particle identification. Using these detectors, the pion contamination was reduced by a factor of 10^4.

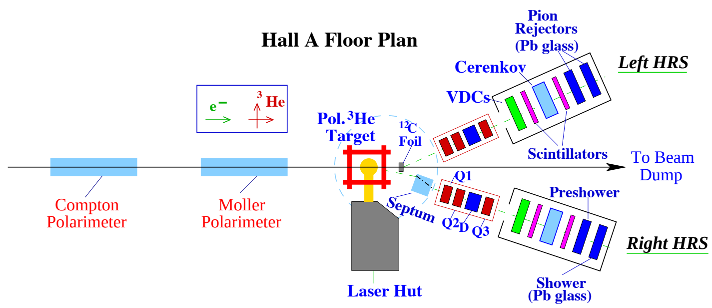

Figure 1. E97-110 experimental setup.

3. From ^{3}He to the Neutron

The ^{3}He ground state wavefunction mainly consists of three states: S, D, and S'. Approximately 88% of the ^{3}He wavefunction is in the S state, where the two proton spins anti-align due to the Pauli exclusion principle. In this picture, their contribution to the nuclear spin cancels, and the ^{3}He nucleus is an effective neutron target. To extract the neutron integral, the small contribution due to the net proton polarization still needs to be taken into account. This can be done by using the so called effective polarizations of the neutron and proton in the ^{3}He nucleus.[11] This method works for integrated quantities or in the DIS region. To account for Fermi motion and binding energy a convolution model is used.[12]

4. Preliminary Results

The analysis from the past year has concentrated on calibrations and systematic checks. These include the particle identification detectors, analysis of the false asymmetry data, elastic asymmetry analysis, and the spectrometer optics. The left spectrometer was used for monitoring various systematics for the experiment such as false asymmetries. The false asymmetries from an unpolarized carbon target were found to be consistent with zero. The preliminary analysis of the ^{3}He elastic asymmetry also shows good agreement with the world data.

The septum magnet is a new optical component to the spectrometer system that requires careful study of the reconstruction of the target coordinates.[13] Elastic data were acquired for several beam energies to optimize and test the target reconstruction. For most of the beam energies, the spectrometer optics calibration is completed, and the addition of the septum magnet to the spectrometer system is understood.

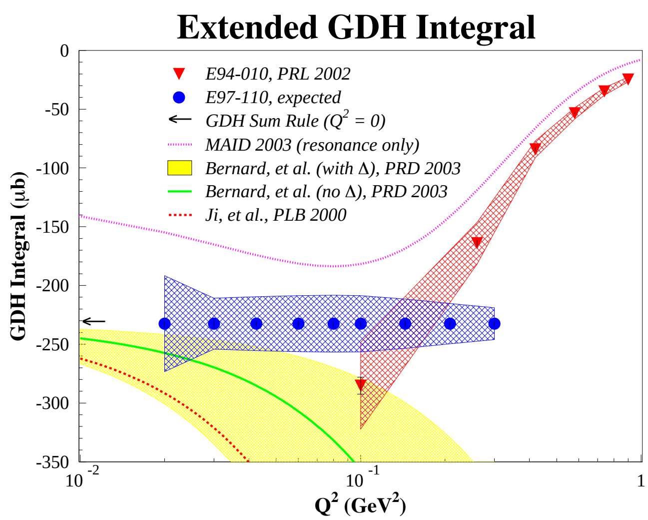

Figure 2. E97-110 expected results.

Fig. 2 shows the expected quality of the results for the neutron extended GDH integral. The triangles are the data from the previous experiment, E94-010.[7] The circles show the Q^2 range, and the band indicates the total expected uncertainty that we plan to achieve for the integral. The arrow represents the real photon point for the sum rule at $Q^2 = 0$. The dotted curve shows the MAID phenomenological model,[3] and the solid and dashed curves are two Chiral Perturbation Theory calculations.[14,15]

5. Summary

The new low Q^2 measurements of the extended GDH integral will allow us to test the dynamics of Chiral Perturbation Theory and to determine if the integral turns over, which would allow an extrapolation to the real photon point. The data will complement the E94-010 data below Q^2 of 0.1 GeV^2, and the spin structure function moments and forward spin polarizabilities will be extracted. Currently the data analysis is underway: The false asymmetries are consistent with zero, preliminary elastic asymmetries are in good agreement with the world data, and understanding of the spectrometer optics is close to completion.

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