Measurement of the structure functions g_1^p and g_1^n with the CLAS at Jefferson Lab

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Abstract. Inelastic scattering using polarized nucleon targets and polarized charged lepton beams allows the extraction of the structure functions g_1 and g_2 which provide information on the spin structure of the nucleon. A program designed to study such processes has been underway in Jefferson Lab since 1998. A polarized electron beam, solid polarized NH_3 and ND_3 targets and the CEBAF Large Acceptance Spectrometer (CLAS) in Hall B were used to collect the desired data. 3 billion events were accumulated during the first run, and over 23 billion events were accumulated during the second run. The measurements cover the resonance region with unprecedented detail and add significantly to the DIS data set at low to moderate Q^2 and moderate to high x .

MOTIVATION

Spin structure function g_1

Spin structure functions g_1 and g_2 have been measured extensively since the polarized nucleon targets and polarized lepton beams became available several decades ago. In particular, the structure function $g_1(x, Q^2)$, its first moment $\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2) dx$ and their Q^2 dependence have been subjects of great interest. At high Q^2 , g_1 provides information on how the nucleon spin is composed of the spin of its constituent quarks. From the deep inelastic scattering experiments, the value of $\Gamma_1(Q^2)$ at high Q^2 is known to be positive and slow varying. On the other end of the kinematic region, as Q^2 decreases, the nucleon resonances become important, and they cause $\Gamma_1(Q^2)$ to decrease rapidly in size. At $Q^2 = 0$, $\Gamma_1(Q^2)$ is bounded by the Gerasimov-Drell-Hearn sum rule, which relates the spin-dependent photo-nucleon cross sections to the anomalous magnetic moment κ of the target nucleon[1][2]:

$$\int_{\nu_{th}}^{\infty} \frac{d\nu}{\nu} (\sigma^{3/2} - \sigma^{1/2}) = \frac{2\pi^2 \alpha_{em} \kappa^2}{M^2}. \quad (1)$$

Assuming a smooth connection between the real and virtual photo-nucleon cross sections, the GDH sum rule could be generalized for the case of the virtual photon scattering, which results in a prediction for the Q^2 -evolution of $\Gamma_1(Q^2)$ at low Q^2 . For the

proton, the generalized GDH sum rule predicts as $Q^2 \rightarrow 0$:

$$\Gamma_1^p(Q^2) = \frac{Q^2}{16\pi^2\alpha_{em}} \int_{v_{th}}^{\infty} (\sigma_p^{1/2} - \sigma_p^{3/2}) \frac{dv}{v} \rightarrow -\frac{Q^2}{8M_p^2} \kappa_p^2. \quad (2)$$

According to the GDH sum rule, $\Gamma_1(Q^2)$ approaches zero with a negative slope, and since $\Gamma_1(Q^2)$ is positive at high Q^2 , it must change sign at some low Q^2 . The low Q^2 region is dominated by nucleon resonances, and contains a transition from the hadronic to partonic degrees of freedom. Most of the existing data lies in the deep inelastic region ($Q^2 > 1 \text{ GeV}^2$), but very few data exists in the resonance region. This region remained largely unexplored until the recent experiments at Jefferson Lab.

MEASUREMENTS

g_1 can be extracted from the measurement of the double spin asymmetry $A_{||}$ in the inclusive ep scattering:

$$g_1 = \frac{F_1}{1 + \gamma^2} [A_{||}/D + (\gamma - \eta)A_2], \quad (3)$$

where F_1 is the unpolarized structure function, A_2 is the virtual photon asymmetry, and γ , D and η are kinematic factors. F_1 and A_2 are calculated from the parametrization of the world data, and $A_{||}$ is measured. The spin asymmetry for ep scattering is given by:

$$A_{||} = \frac{\sigma_- - \sigma_+}{\sigma_+ + \sigma_- - bckg} \frac{1}{P_b P_t} + \Delta_{RC}, \quad (4)$$

where σ_+ and σ_- are the cross sections for the electron and proton spin, polarized parallel and anti-parallel respectively, $P_b P_t$ is the product of the beam and target polarizations, and $bckg$ is the background which accounts for the unpolarized material in the target. First measurements of g_1 of the proton and the deuteron were taken in Hall B of Jefferson Lab in the fall and winter of 1998, and were significantly enhanced during the second run which was completed in spring of 2001. $A_{||}$ was measured by scattering polarized electrons off polarized nucleons using a cryogenic solid polarized target and the CEBAF Large Acceptance Spectrometer (CLAS) in Hall B. The CLAS is a magnetic toroidal multi-gap spectrometer, with the magnetic field generated by six superconducting coils arranged around the beam line. The detector package consists of drift chambers for track reconstruction, gas Cerenkov counters for electron identification, scintillation counters for measurement of the time of flight, and an electromagnetic calorimeter to identify showering particles. The longitudinally polarized electrons were produced by a strained *GaAs* electron source with a typical beam polarization of $\sim 70\%$. The solid polarized target consisted of ammonia beads placed in a $5T$ magnetic field and cooled down to $\sim 1K$ by a liquid helium evaporation refrigerator. The target material had a high concentration

FIGURE 1. The first moment $\Gamma_1^P(Q^2)$ vs Q^2 for the proton. The closed circles represent g_1 integrated over the measurements. The opened circles are obtained by extending the integration into the DIS region with $x = 0$. The error bars indicate statistical uncertainty.

of polarizable nucleons, and also contained paramagnetic centers which provided unpaired electron spins. The unpaired electrons were highly polarized in the 5T magnetic field, and their polarization was transferred to the nucleons using microwaves to drive the hyperfine transitions between the polarized electrons and polarized nucleons. The target material used was ND_3 for polarized deuterons and NH_3 for polarized protons. The typical polarization was 50 – 70% for protons in the NH_3 target, and 20 – 30% for deuterons in the ND_3 target. Besides the the polarized targets, two unpolarized targets were used for the background measurements. These targets were solid ^{12}C , frozen ^{15}N , and an empty target filled with liquid ^4He .

Several steps are needed in order to extract g_1 and Γ_1 from the scattering data. Raw count asymmetries need to be formed and corrected for the scatters from the unpolarized background material in the target. The background consists mostly of ^{15}N in the ammonia target, and we obtain its contribution by using the scattering data on ^{12}C target, and correcting it, taking into account differences between ^{12}C and ^{15}N . The product of target and beam polarizations $P_b P_t$ needs to be extracted from the elastic part of the data. The asymmetries must be corrected for radiative effects and contamination from positrons and pions. Also, systematic effects need to be estimated and corrected

FIGURE 2. Experimental electron asymmetry $A_{\parallel} = \frac{\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow}}{\sigma_{\uparrow\uparrow} + \sigma_{\uparrow\downarrow}}$

for. The analysis of the first data set is nearly complete, and preliminary results of Γ_1 obtained with the beam energies of 2.6 GeV and 4.3 GeV, are shown in figure 1, along with the already existing data from SLAC[5] and predicted values for Γ_1 from two phenomenological models. The Burkert-Ioffe model[3] uses the parametrization of pion production amplitudes to calculate the contribution of the nucleon resonances to Γ_1 . The Soffer-Teryaev model[4] uses the known information about the longitudinal-transverse interference cross-section which is related to the first moment of g_T , where $g_T = g_1 + g_2$.

The analysis of the second data set has been in progress since the fall of 2001, and we expect to have our first results on Γ_1 to be ready in the next few months. A plot of the raw count asymmetry from the data taken at a beam energy of 5.6 GeV is displayed in Figure 2. The displayed data represents approximately 10% of the complete data set obtained at this energy.

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