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Precision Spin Structure Functions for the Proton and Deuteron with CLAS

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Abstract. An extensive experimental program to measure the spin structure of the nucleon has been carried out in Hall B at Jefferson Lab with the CEBAF Large Acceptance Spectrometer (CLAS). Using a longitudinally polarized beam scattering off longitudinally polarized NH_3 and ND_3 targets, the double spin asymmetry $A_{||}$ was measured over a large range in Q^2 and W , providing data of impressive high precision that will give a better understanding of the structure of the nucleon in the Deep Inelastic Scattering and the valence quarks regions. Using a world data parameterization of A_2 and F_1 , the virtual photon asymmetry A_1 and the structure function g_1 were extracted in a Q^2 range from 0.05 to 5 GeV^2 and a W range from 1.08 to 3.0 GeV. As a result of the extended kinematical range, first moments of structure functions were measured over a large range in Q^2 and duality was tested. Finally, using the large kinematical overlap of different beam energies, A_2 was extracted.

Keywords: Spin structure, Nucleon Spin

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INTRODUCTION

After the "spin crisis" in 1980, large experimental programs have been devoted to unraveling the spin structure of nucleon. Inclusive inelastic scattering of polarized electrons off polarized nucleons is a powerful tool to study the polarized structure functions and their moments. For a longitudinally polarized beam and target the measured asymmetry is $A_{||} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$ where σ^+ and σ^- are the cross sections for beam and target polarization oriented antiparallel and parallel, respectively. $A_{||}$ is related to the virtual photon asymmetries A_1 and A_2 by

$$\frac{A_{||}}{D} = A_1 + \eta A_2 \quad (1)$$

where $\eta = \epsilon Q / (E - E' \epsilon)$, $D = (1 - E' \epsilon / E) / (1 + \epsilon R)$ is the photon depolarization factor, $R = \sigma_L / \sigma_T$ is the ratio of longitudinal and transverse virtual photon-absorption cross sections, Q^2 is the squared 4-momentum transfer, and $\epsilon = (1 + 2 \frac{\vec{q}^2}{Q^2} \tan^2 \frac{\theta_e}{2})^{-1}$ is the degree of transverse polarization. The asymmetry A_1 is related to the difference of virtual photo-absorption cross sections for total helicity between photon and nucleon of 1/2 and 3/2. A_2 is related to the interference term between the transverse and longitudinal photon-nucleon amplitudes.

Given the virtual photon asymmetries, one can extract the spin structure function g_1 using:

$$g_1(x, Q^2) = \frac{\tau}{1 + \tau} (A_1 + \frac{1}{\sqrt{\tau}} A_2) F_1(x, Q^2) \quad (2)$$

where $\tau = v^2/Q^2$, v is the energy transfer of the virtual photon, and F_1 is the unpolarized structure function.

A quantity of particular interest is Γ_1 , the first moment of g_1

$$\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2) dx. \quad (3)$$

At high Q^2 this quantity is related to spin carried by the quarks and it is constrained by the Bjorken sum rule. For $Q^2 \rightarrow 0$ this quantity becomes $\frac{Q^2}{2M^2} I_{GDH}$, where I_{GDH} is the Gerasimov-Drell-Hearn sum rule and is equal to $-1/4k^2$, where k is the nucleon anomalous magnetic moment.

THE EXPERIMENTS EG1 AND EG4 WITH CLAS

The two key experiments devoted to the measurement of spin structure functions in Hall-B at Jefferson Laboratory are the EG1 experiment, run in two separate periods in 1998 and 2000 and the EG4 experiment, run in 2006. The Continuous Electron Beam Accelerator Facility (CEBAF) delivered a longitudinally polarized electron beam with energies of 1.6, 2.5, 4.2, and 5.75 GeV for EG1 and 1.1, 1.3, 1.5, 2.2, and 3.0 GeV for EG4. Hall-B hosts the CEBAF Large Acceptance Spectrometer (CLAS), which allows multiple-particle identification with a nearly 2π acceptance. The beam was scattered off longitudinally polarized solid, 1-cm-long, ammonia targets, $^{15}\text{NH}_3$ and $^{15}\text{ND}_3$, polarized up to 70% and 40% respectively via Dynamic Nuclear Polarization [1]. Additional ^{12}C , ^{15}N , and the empty target cells were used for background studies. The hardware trigger was set to be a coincidence of the Cerenkov Counter and Electromagnetic Calorimeter signal that allows the identification of electrons. The EG1 experiment achieved a kinematic coverage from 0.05 up to 5 GeV^2 in Q^2 and from 1.08 to 3 GeV in W . The EG4 experiment utilized an additional Cherenkov counter in one sector to detect electrons with angles as low as 6° and therefore to extend the Q^2 range down to 0.015 GeV^2 .

The first step of the data analysis consisted of extracting $A_{\text{raw}} = (N^+/Q^+ - N^-/Q^-)/(N^+/Q^+ + N^-/Q^-)$, where N^+ , and N^- are the counts for beam and target polarization antiparallel and parallel, respectively, and Q^+ and Q^- are live time gated beam charge for the two polarizations. Secondly, $A_{||} = C_{\text{back}} \cdot A_{\text{raw}} / (P_e P_t \cdot DF)$ was extracted by correcting for the polarization values ($P_e P_t$), the dilution factor (DF) and background contamination stemming from pair symmetric processes and pions (C_{back}). Finally A_1 and consequently g_1 were extracted using world data parameterization for the virtual photon asymmetry A_2 , the unpolarized structure function F_1 and R .

RESULTS AND OUTLOOK

Preliminary results are shown in Figure 1 for the virtual photon asymmetry A_1 for the proton (left) and deuterium (right) averaged in the deep inelastic region $Q^2 > 1 \text{ GeV}^2$ and $W > 2 \text{ GeV}$. The new preliminary results confirm the trend of A_1 to exceed the SU(6) limit at $x=1$. Data are consistent with the hyperfine perturbed quark model [2] at higher x , where the valence quarks are expected to dominate.

FIGURE 1. A_1 vs. x for proton (left) and deuteron (right)

FIGURE 2. g_1 vs x for several Q^2 bins from 0.06 to 2.23 GeV^2 .

Figure 2 shows g_1 for several Q^2 bins. As can be seen at low Q^2 the $\Delta(1232)$ resonance drives the structure function towards negative values, due to the 3/2 amplitude dominance. At higher Q^2 , g_1 becomes positive everywhere.

Finally Figure 3 shows the first moment of the structure function g_1 (see Eq. 3). The world data parameterization was used to include the unmeasured part to the integral down to $x=0.001$. The low Q^2 data points are consistent with the I_{GDH} limit, and are in fairly good agreement with the phenomenological model by Burkert and Ioffe [3] that

FIGURE 3. Γ_1^p vs Q^2 . The left plot shows the full range in Q^2 while the right plot shows the lower Q^2 region. The Figure shows the new preliminary data from E11 (squares) and the previous E11 (diamonds), HERMES (crosses) and SLAC E143 (stars) results. Phenomenological predictions (Burkert-Ioffe, Soffer-Teryaev, ChPT) and the GDH slope are also shown.

parameterizes the transition between the real photon point and the DIS regime using measured pion electro- and photo-production resonance amplitudes. The comparison of data at low Q^2 with the ChPT calculation of Ji (dashed curve) [4] shows a disagreement; however this calculation is an expansion up to Q^4 and a fit of the data up to Q^8 shows agreement with Ji's Q^4 coefficient and a non negligible Q^6 term even at $Q^2 < 0.1$ GeV².

The analyses of the full data set of the E11 run for both the proton and deuteron target give unprecedented measurements of the spin structure function A_1 , g_1 , Γ_1 and related quantities. While results from the analysis of the 1.6 and 5.7 GeV data set have been published [5, 6], these new results reduce the errors significantly and extend the kinematic coverage. The analysis of the E14 data, currently in progress, will extend the measurement of Γ_1 down to 0.015 GeV² allowing a better test of the ChPT calculations. Thanks to the kinematic overlap of different beam energies, the E11 data set also allows an extraction of the A_2 virtual photon asymmetry over a large kinematic range.

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