Recent Results from Jefferson Lab *RSS* Spin Physics Program

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Abstract. The spin physics program in Jefferson Lab's Hall C concentrates on high precision and high resolution studies of the nucleon spin structure that can be extracted from inclusive polarized scattering experiments. The Resonances Spin Structure - *RSS* experiment has measured nucleon spin structure functions in the resonances region at an intermediate four-momentum transfer $Q^2 \simeq 1.3 \text{ GeV}^2$. The polarized target in Hall C could be polarized longitudinally and transversely, allowing extraction of both spin-dependent structure functions g_1 and g_2 . Results on proton and deuteron spin asymmetries A_1 and A_2 , and spin structure functions g_1 and g_2 , are presented here.

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INTRODUCTION

Nucleon spin structure functions (SSFs) have been measured extensively for more than two decades in deep inelastic scattering (DIS) experiments over a wide kinematic range in Bjorken x and four-momentum transfer Q^2 . In recent times, studies of the SSFs in the region of low to moderate Q^2 have become a very active and exciting field of study. Measurement of the virtual photon-nucleon asymmetries A_1 and A_2 throughout the resonances region ($1.08 \text{ GeV} \leq W \leq 2 \text{ GeV}$) can reveal information about the spin-isospin structure of the resonance transition matrix elements and their interference with the non-resonant background. Studies of the spin-dependent structure function g_1 over a large range in Q^2 can uncover more information about the transition between quark-parton degrees of freedom in the scaling regime ($Q^2 > 1 \text{ GeV}^2$) and hadronic degrees of freedom in the region where α_s , the strong coupling constant, is not small. The question whether g_1 exhibits a similar “duality” between the DIS and the resonance regions, as has been observed for the unpolarized structure functions F_2 for the proton, is a topic of high current interest.

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The *RSS* experiment [1] was the first to measure both the proton and the deuteron resonances' g_1 and g_2 SSFs; others had measured only g_1^p (Hall B, SLAC) and g_1^n (Hall A) before. *RSS* was designed to make high precision and high resolution measurements of the nucleon SSFs in the range of final state invariant mass $W \leq 2 \text{ GeV}$ at $Q^2 \sim 1.3 \text{ GeV}^2$.

The physics goals were to study the dependence of the SSFs on the final state mass W , to search for the onset of polarized local duality, and to explore the contribution of twist-3 processes to the g_2 structure function.

Polarized 5.76 GeV electron beam with a polarization of $\sim 70\%$ from the CEBAF accelerator was scattered from ammonia and deuterated ammonia targets ($^{15}\text{NH}_3$ and $^{15}\text{ND}_3$) polarized by Dynamic Nuclear Polarization (DNP). The scattered electrons were detected by the Hall C High Momentum Spectrometer (HMS) which was set at 13.15° . The central momentum of the HMS was set for two settings, 4.73 and 4.09 GeV/ c . The effective kinematic coverage for W was $0.8 \text{ GeV} \leq W \leq 2.0 \text{ GeV}$ at an average $\langle Q^2 \rangle \sim 1.3 \text{ GeV}^2$. This region connects very well with other polarized DIS experiments, for direct comparison of data in the DIS and resonances regions to study local duality.

The UVA-JLab solid polarized target used in Hall C is a unique device which is capable of operating at proton and deuteron luminosities of $10^{35} \text{ cm}^{-2}\text{s}^{-1}$. The average in-beam target polarization ranged from 65 – 70% for proton and 20 – 30% for deuteron. The uniqueness of the polarized target is due to its open geometry that allows a wide range of polarization alignments relative to the beam direction. Asymmetries with the nucleon spin parallel, $A_{\parallel}$, and perpendicular, $A_{\perp}$, to the beam helicity can be measured to obtain the physics asymmetries in a model-independent way. The experiment completed data taking during January-March, 2002.

The measured asymmetries are extracted from the raw counts asymmetries $\varepsilon = (N_L - N_R)/(N_L + N_R)$, where N_L, N_R are charge normalized numbers of counts for opposite beam helicities, corrected for dead time and pion contamination. $A_{\parallel}$ and $A_{\perp}$ are related to ε by

$$A_{\parallel,\perp} = \frac{1}{f_{RC}} \left(\frac{\varepsilon}{C_N f P_b P_t} + C_D \right) + A_{RC}, \quad (1)$$

where P_b, P_t are the beam and target polarizations, respectively, f is the target dilution factor (ratio of rates from polarized nucleons over all nucleons), C_N, C_D are corrections for the small contribution of the polarized nucleons in $^{15,14}\text{N}$, f_{RC}, A_{RC} are the multiplicative and additive radiation corrections.

The first goal of RSS was to determine the W dependence of the spin asymmetries (SAs) $A_1(W, Q^2)$ and $A_2(W, Q^2)$ which extend the DIS description of the nucleon spin structure to the region of the resonances. A_1 and A_2 are related to the measured asymmetries $A_{\parallel}$ and $A_{\perp}$ by

$$A_1 = \frac{C}{D} (A_{\parallel} - d A_{\perp}) \quad \text{and} \quad A_2 = \frac{C}{D} (c' A_{\parallel} + d' A_{\perp}), \quad (2)$$

where C, c', d, d' and D are functions of kinematic variables only (D has an additional mild dependence on the unpolarized structure function $R = \sigma_L/\sigma_T$). The SAs obtained by this method have a minimal dependence on quantities not measured in the experiment itself (R and the unpolarized structure function F_1 are from fits to $e-p$ and $e-d$ resonance data [2]).

The results for proton [5] and deuteron A_1 and A_2 are shown in Fig. 1. The proton asymmetries were fitted independently with four Breit-Wigner (B-W) shapes and a DIS background. The larger uncertainties of the deuteron SAs compared to the proton's limited the resolution of the fits. Only three B-W shapes and a linear background was

used to fit A_1^d , while only a non-zero constant 0.083 ± 0.017 was used for A_2^d .

FIGURE 1. A_1 and A_2 for proton (left panel) and deuteron (right panel) at $\langle Q^2 \rangle \sim 1.3 \text{ GeV}^2$ as a function of W . The bands at the bottom of the proton panel represent the systematic errors.

The spin structure functions g_1 and g_2 are related to the SAs and the unpolarized structure function (SF) F_1 by

$$g_1 = \frac{F_1}{1 + \gamma^2} (A_1 + \gamma A_2), \quad g_2 = \frac{F_1}{1 + \gamma^2} \left(\frac{A_2}{\gamma} - A_1 \right), \quad \text{where } \gamma = \frac{2xM}{\sqrt{Q^2}} \quad (3)$$

Proton and neutron g_1 results are shown in Fig. 2. The proton data are compared with g_1 computed from PDFs evolved to RSS kinematics, along with resonances data from SLAC and JLab. Preliminary neutron g_1^n data are obtained from the difference between the deuteron and smeared proton data.

FIGURE 2. Proton g_1^p (left panel) along with g_1 from PDFs evolved to RSS kinematics and world data. Preliminary neutron g_1^n (right panel) from RSS deuteron and RSS proton data smeared using the convention for unpolarized structure functions.

Search for the onset of polarized local duality in the SSFs was another goal of RSS . Unpolarized local duality, first noted by Bloom and Gilman [3], has been observed for the F_2 structure function at JLab [4]. Observation of duality in the polarized counterpart of F_2 , the g_1 SSF would imply that duality is the result of fundamental properties of the nucleon, and not simply a fortuitous coincidence. RSS result for the global version of duality for the proton (ratio of integrals of resonance g_1^p over DIS g_1^p over the entire region of the resonances) are plotted in Fig. 3, along with data from JLab Hall B. The trend of the ratio of integrals indicates that global duality may manifest above $Q^2 \sim 1.8 \text{ GeV}^2$. No polarized local duality was observed at $Q^2 \sim 1.3 \text{ GeV}^2$.

FIGURE 3. LEFT: Global duality integral ratios for g_1^p as a function of Q^2 . RIGHT: Proton and deuteron measured g_2 SSF, along with RSS fits (solid curve) and the twist-2 part of g_1 (g_2^{WW} - gray band).

Asymptotic freedom in QCD at very large momentum transfers is modified at low energies by processes that involve interactions among the partons (quarks and gluons) in a nucleon. The correct description of nucleon structure at low energies require additional terms, called higher twists, representing multiparton interactions. The g_2 SSF is composed of leading twist, g_2^{WW} , and twist-3 contributions. The difference between the measured g_2 and g_2^{WW} indicates the presence of higher twists. RSS measured $g_2^{p,d}$ is the first world data in the resonances region. The right panel of Fig. 3 shows the RSS data on g_2 for protons and deuterons [6], along with g_2^{WW} calculated from g_1 measured in RSS. The difference between the data and g_2^{WW} is almost entirely due to higher twist components in g_2 , because the ratio of the Nachtmann to Cornwall-Norton moments of g_1 is nearly unity, indicating little admixture of higher twists in g_1 . Clear evidence is seen for higher twist contribution to g_2^p for $x > 0.4$.

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