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.

Keywords: nucleon spin, structure functions, polarized scattering


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 $\alpha_S$, 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.

JLAB E01-006 - RESONANCES SPIN STRUCTURE (RSS)

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 ($^{15}$NH$_3$ and $^{15}$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 $13.15^\circ$. 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 UV A-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 $\varepsilon$ by

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

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 $^{15,14}$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

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

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 $0.083 \pm 0.017$ was used for $A_2^d$.

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

$$
g_1 = \frac{F_1}{1 + \gamma^2} (A_1 + \gamma A_2), \quad g_2 = \frac{F_1}{1 + \gamma^2} (\frac{A_2}{\gamma} - A_1),$$

where $\gamma = \frac{2xM}{\sqrt{Q^2}}$.

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.

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

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 RSSproton data smeared using the convention for unpolarized structure functions.

FIGURE 3. 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 RSSproton data smeared using the convention for unpolarized structure functions.
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 requires additional terms, called higher twists, representing multiparton interactions. The $g_2$ SSF is composed of leading twist, $g_{2WW}$, and twist-3 contributions. The difference between the measured $g_2$ and $g_{2WW}$ 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 $g_{2WW}$ calculated from $g_1$ measured in RSS. The difference between the data and $g_{2WW}$ 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 $g_2$ for $x > 0.4$.

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REFERENCES