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SPIN PHYSICS RESULTS FROM JEFFERSON LAB HALL B AND HALL C

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The spin physics program in Jefferson Lab's Hall B and Hall C concentrates on precision studies of the nucleon spin structure functions that can be extracted with inclusive and exclusive polarized scattering experiments in and above the resonance region at low to moderate Q^2. Results on proton and deuteron spin asymmetries, $A_1(W, Q^2)$ and $A_2(W, Q^2)$ from the Resonances' Spin Structure - *RSS* experiment in Hall C and the spin structure function $g_1(x, Q^2)$ and its first moment $\Gamma_1(Q^2)$ from the *CLAS EG1* program in Hall B are presented.

1 Introduction

Studies of the nucleon spin structure functions (SSF's) have been of great interest for more than two decades. Nucleon SSF's have been measured extensively in deep inelastic scattering (DIS) experiments over a wide kinematic range in Bjorken x and four-momentum transfer squared Q^2. In recent times, studies of the SSF's 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 $A_1(W, Q^2)$ and $A_2(W, Q^2)$ throughout the resonances region (1.08 GeV $\leq W \leq$ 2 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 $g_1(x, Q^2)$ over a large range in Q^2 can uncover more information about the transition between quark-parton degrees of freedom in the scaling regime ($Q^2 > 1$ 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 and F_1 for the proton, is a topic of high current interest.

The first moment of g_1, $\Gamma_1(Q^2)$, which is directly related to the fraction of the nucleon spin carried by the quark helicities at large Q^2, is particularly interesting to study. Scaling violations, higher twist contributions, and the dominance of nucleon resonances at moderate Q^2, lead to a rapid change of Γ_1 towards the photon point, $Q^2 = 0$, where it is constrained by the Gerasimov-Drell-Hearn (GDH) sum rule.

At Jefferson Lab in Newport News, Virginia, an extensive investigation of the SFF's at low to moderate Q^2 is underway in all three experimental halls. Preliminary results from the *RSS* experiment in Hall C and the *EG1* program in Hall B are presented here.

2 *Resonances' Spin Structure (RSS)* in Hall C

This experiment (JLAB E-01-006) was the first to measure the proton and deuteron SSF's in the region of the nucleon resonances. It was designed to make high precision and high resolution measurements of the nucleon SSF's in the range of final state invariant mass $W \leq 2$ GeV at $Q^2 \sim 1.3$ GeV^2. The physics goals were to explore fundamental properties of the nucleon and QCD in this kinematic region, with adequate precision to obtain conclusive information, and to test local duality for the polarized structure functions. The neutron spin asymmetries will be extracted from the measured proton and deuteron asymmetries.

In unpolarized lepton-nucleon scattering, DIS and the resonances' region are connected by the remarkable relation known as Bloom-Gilman or local duality [1]. Unpolarized local duality has been confirmed at JLab [2] for the proton and the deuteron. The earliest mention of local duality in the SSF's can be found in the original proposal of the *RSS* experiment [3]. If local duality is a reflection of some fundamental nucleon properties and not just the result of some fortuitous coincidences, it should also be present for the neutron and for the polarized structure functions [4]. Although existing spin structure data [5,6,7,8] hint at duality in the SSF's, a quantitative confirmation of local spin duality has yet to be done.

The spin asymmetries $A_1(\nu, Q^2)$ and $A_2(\nu, Q^2)$ extend the DIS description of the nucleon spin structure to the region of the resonances (ν is the lepton energy loss). In this region the nucleon spin structure can be described in terms of either the non-scaling SSF's $G_1(\nu, Q^2)$ and $G_2(\nu, Q^2)$ or in terms of the spin asymmetries A_1 and A_2. The latter are related to virtual photon absorption cross sections $\sigma^T_{1/2}$, $\sigma^T_{3/2}$, and $\sigma^{TL}_{1/2}$ for photon helicities +1, -1, 0, respectively:

$$
\begin{aligned}
A_1 &= \frac{\sigma^T_{1/2} - \sigma^T_{3/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}} = \frac{M\nu G_1(\nu, Q^2) - Q^2 G_2(\nu, Q^2)}{W_1(\nu, Q^2)} \\
A_2 &= \frac{\sigma^{TL}}{2\sigma^T} = \frac{\sqrt{Q^2}\big(MG_1(\nu, Q^2) + \nu G_2(\nu, Q^2)\big)}{W_1(\nu, Q^2)},
\end{aligned}
\tag{1}
$$

where $2\sigma^T = \sigma^T_{3/2} + \sigma^T_{1/2}$, M is the nucleon mass and $W_1(\nu, Q^2)$ is the transverse unpolarized structure function. In the scaling limit of DIS, the structure functions depend (up to logarithmic corrections) only on the scaling variable $x = Q^2/(2M\nu)$.

A_1 and A_2 are related to the measured asymmetries $A_\parallel$ and $A_\perp$ for the longitudinal and transverse configurations of the beam and target spins by

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

where C, c', d, d' and D are functions of kinematic variables only (D has an additional mild dependence on the unpolarized structure function $R(\nu, Q^2) = \sigma_L/\sigma_T$). Obtaining A_1 and A_2 directly in a model-independent way is a requisite for understanding the polarized local duality.

3 ***RSS*** Experimental summary

Polarized 5.755 GeV electron beam from CEBAF was scattered from ammonia and deuterated ammonia targets (^{15}NH$_3$ and ^{15}ND$_3$) polarized by Dynamic Nuclear Polarization (DNP). The Hall C High Momentum Spectrometer (HMS) was set at 13° to detect the scattered electrons. The effective kinematic coverage for W was 0.8 GeV $\leq W \leq$ 2.0 GeV at an average $< Q^2 >\sim$ 1.3 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 data were taken with a typical luminosity of 10^{35} cm^{-2}s^{-1} and beam polarization of $\sim 70\%$. The target polarization ranged from $65 - 70\%$ for ^{15}NH$_3$ and $15 - 20\%$ for ^{15}ND$_3$. The experiment completed data taking during January-March, 2002, and 160 million proton triggers and 350 million deuteron triggers were recorded.

4 ***RSS*** Preliminary Results

The measured asymmetries are extracted from the counts asymmetries $\epsilon = (L - R)/(L + R)$, where L, 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

$$A_{\parallel,\perp} = \frac{1}{C_N f_{RC}}\Big(\frac{\epsilon}{f P_b P_t} - C_D\Big) + A_{RC}. \tag{3}$$

where f is the target dilution factor, C_N, C_D are corrections for the small contribution of the polarized proton in ^{15}N, f_{RC}, A_{RC} are the multiplicative and additive radiation corrections, and P_b, P_t are the beam and target polarizations, respectively.

Preliminary uncorrected asymmetries $A_{\perp,\parallel}$ as a function of Bjorken x are shown in Fig. 1. The asymmetries are shown only for the restricted kinematic region 1.1 GeV $\leq W \leq$ 1.9 GeV. Data below and above these limits are still being analyzed. Corrections for the actual packing fractions, electromagnetic radiative effects and nitrogen polarization are not included. The $A_\perp$ results are the first and only ones of their kind in the world. A clear difference between the proton and deuteron asymmetries can be seen, in particular for $A_\parallel$. A clean extraction of the neutron asymmetry is expected on this basis.

5 ***SANE: Spin Asymmetries of the Nucleon Experiment*** in Hall C

The unpolarized and polarized structure functions of the nucleon have been studied extensively in DIS for $x \leq 0.6$. The region $0.6 \leq x \leq 1$ is hard to reach experimentally and has until recently remained largely unexplored. An experiment to measure the proton SSF's in the range $0.3 \leq x \leq 0.8$ for 2.5 GeV$^2 \leq Q^2 \leq$ 6.5 GeV^2 has recently been approved by JLab's Physics Advisory Committee (PAC), as E-03-109. This new *"Spin Asymmetries on the Nucleon Experiment" (SANE)* [9] will cover a significant part of the experimentally hard to reach region $0.6 \leq x \leq 1$.

The spin asymmetry A_1 and the spin structure g_2 for the proton will be obtained in a model independent way from inclusive inelastic scattering of polarized electrons on polarized protons in a solid ammonia (NH$_3$) target. A novel type of large solid

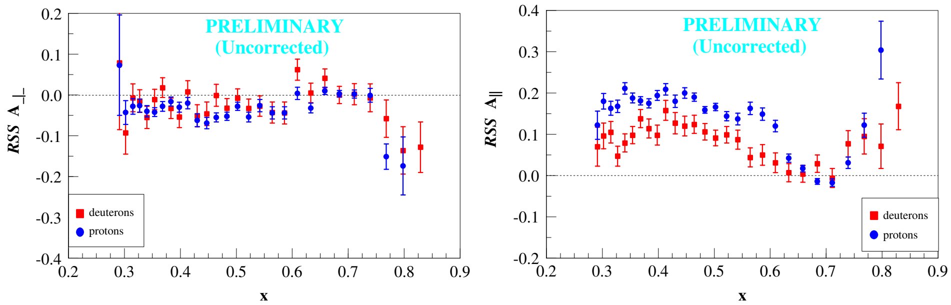

Figure 1. Preliminary measured asymmetry for the perpendicular and parallel configurations for protons (blue circles) and deuterons (red squares), without corrections (see text for details).

angle non-magnetic detector, the *Big Electron Telescope Array* (BETA) (see E-03-109 proposal for details) will be used to detect the scattered electrons. The moments of g_1 and g_2 will be measured with adequate precision to reduce the error on the twist-3 quark matrix element $d_2 = \int_0^1 x^2(2g_1 + 3g_2)dx$ to one half its current value. The error in the extrapolation of A_1 to $x = 1$ will be reduced by 60% relative to its current value, in combination with data from the *EG1* experiment in Hall B.

6 *CLAS EG1* Experimental Program in Hall B

The *EG1* program in Hall B includes measurements of the double polarization spin asymmetries in electron scattering for both inclusive and exclusive processes on the proton and the deuteron. Longitudinally polarized electrons were scattered from longitudinally polarized ammonia targets ($^{15}NH_3$ and $^{15}ND_3$) and the reaction products were detected in the CEBAF Large Acceptance Spectrometer (CLAS) up to scattering angles of 50°. The kinematic regime covered a wide range in Q^2 ($0.05\ \mathrm{GeV}^2 \leq Q^2 \leq 5\ \mathrm{GeV}^2$) and final state invariant mass W (from the elastic peak $W = m_N$ to the DIS region, $W \approx 3$ GeV). The data were taken with a typical luminosity of $10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and beam polarization of $\sim 70\%$. The target polarization ranged from $70-90\%$ for $^{15}NH_3$ and $10-35\%$ for $^{15}ND_3$. Data were collected during two running periods: *EG1a* in the fall of 1998 recorded 3 billion triggers with beam energies of 2.5 snd 4.2 GeV and for seven months in 2000-01, *EG1b* took an additional 23 billion triggers at beam energies of 1.6, 2.5, 4.2, and 5.7 GeV.

7 *EG1* Preliminary Results

Selected preliminary results from the second running period (*EG1b*) at beam energies of 1.6 and 5.7 GeV are presented here. The measured double spin asymmetries for inclusive electron scattering from the proton and the deuteron were converted to the spin structure function g_1 using a model, which has been adjusted slightly to accommodate the current *EG1* data, which includes a parameterization of the world data on A_2 and the unpolarized structure function F_1:

$$g_1(x,Q^2) = \frac{1}{1+Q^2/\nu^2}\Big(A_1(x,Q^2) + \frac{Q}{\nu}A_2(x,Q^2)\Big)F_1(x,Q^2). \qquad (4)$$

Figs. 2 and 3 show g_1 as a function of the Nachtmann variable $\xi = \frac{2x}{1+\sqrt{1+4M^2x^2/Q^2}}$ for the proton and the deuteron, respectively, for several Q^2 bins. The resonant structure is clearly evident, including the negative contribution from the $\Delta(1232)$ resonance at lower Q^2 which becomes positive with increasing Q^2. The solid curves are global fit to world data at $Q^2 = 10$ GeV^2. The Δ resonance causes g_1 to deviate strongly from DIS scaling curves. Duality for the polarized structure function g_1 seems to be valid for both proton and deuteron at Q^2 as low as ~ 1.5 GeV^2 (excluding the Δ region).

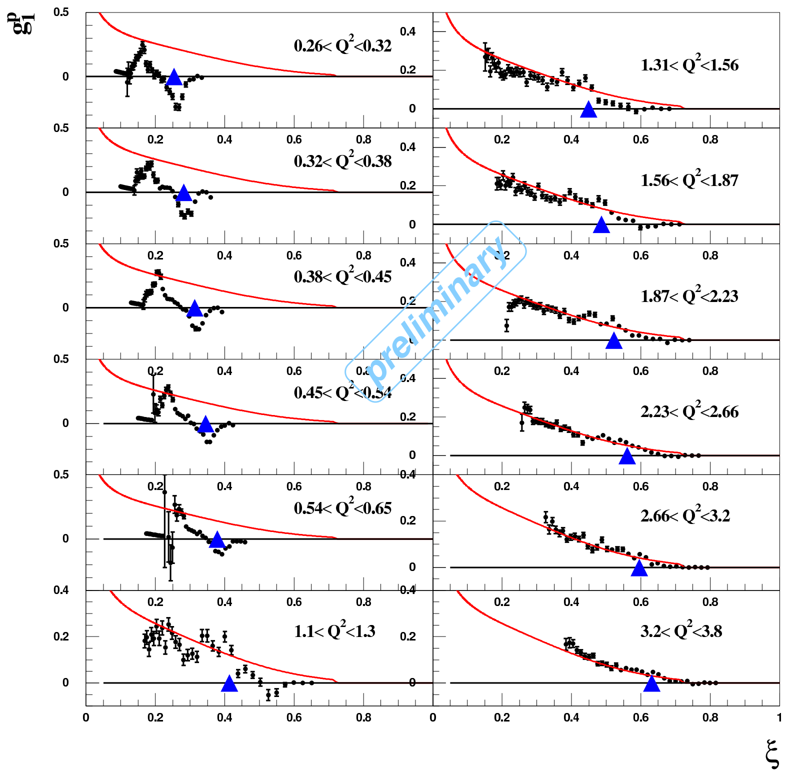

Figure 2. g_1 for the proton plotted *vs* ξ and the parameterization of the DIS world data at $Q^2 = 10$ GeV^2 (red curves). The $\Delta(1232)$ is indicated by the triangles (blue).

The $g_1(x,Q^2)$ results over the measured range in x were integrated to determine its first moment, $\Gamma_1(Q^2) = \int_0^1 g_1(x,Q^2)\,dx$. A parameterization of the world data on SSF's was added to extrapolate the obtained results to the full integral over all x. The data agree well with the phenomenological model of Burkert and Ioffe [10]

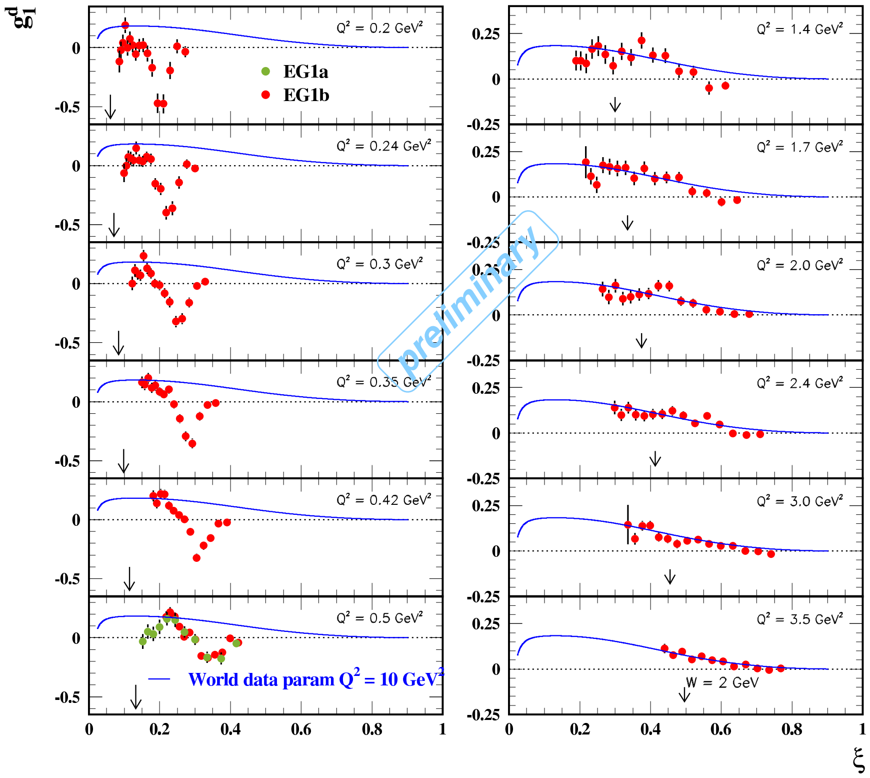

Figure 3. Same as Fig. 2 but for the deuteron. The arrow indicates the $W = 2$ GeV point.

that connects the DIS results with the slope predicted by the GDH sum rule. Fig. 4 shows $\Gamma_1(Q^2)$ for the proton and deuteron compared to various model calculations. The deuteron data are the first precise results for Γ_1^d at $Q^2 < 0.5$ GeV^2. The low Q^2 region is of particular interest where there are predictions from chiral perturbation theory below $Q^2 = 0.1$ GeV^2 [11].

8 Conclusion

An extensive program of spin physics with 6 GeV beam energy has started in all three experimental halls at Jefferson Lab. In addition to the completed and currently in preparation inclusive experiments, a semi-inclusive experiment has been proposed. There is also a preliminary program for the 12 GeV upgrade of CEBAF, which includes doing a full test of polarized local duality on protons and deuterons and extending the semi-inclusive measurements.

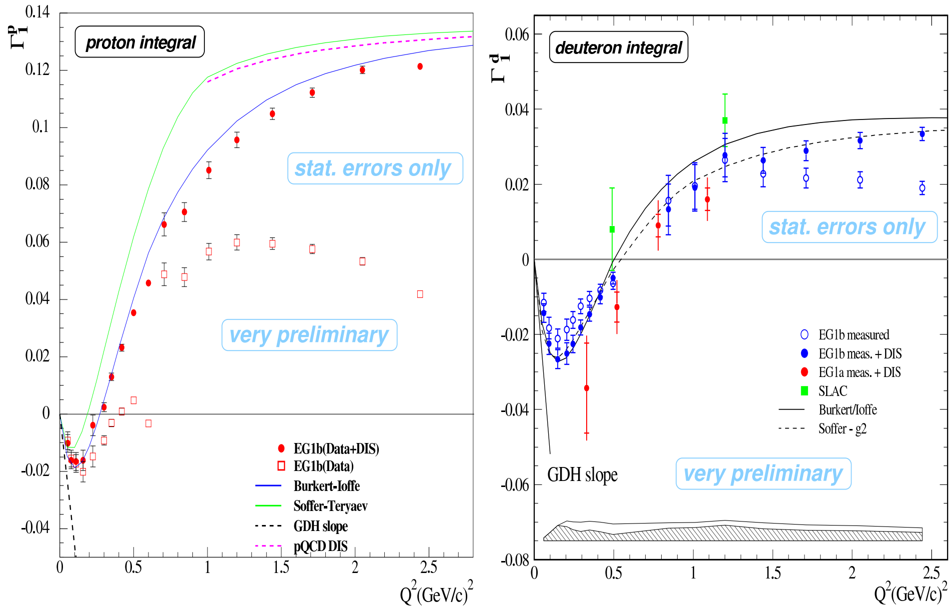

Figure 4. $\Gamma_1(Q^2)$ for the proton (left panel) and the deuteron (right panel) integrated over the measured range in x (open symbols) and including an extrapolation to $x = 0$ (solid symbols). The systematic uncertainties on the measured integral are shown by the hatched region and the line above it shows the additional contribution from the extrapolation. Model calculations are from Burkert and Ioffe [10] and Soffer and Teryaev [12].

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