Proton Spin Structure in the Resonance Region

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The RSS collaboration has measured the spin structure functions of the proton at Jefferson Lab using the lab's polarized electron beam, the Hall C HMS spectrometer and a polarized solid target. The asymmetries $A_{\parallel}$ and $A_{\perp}$ were measured in the region of the nucleon resonances ($0.82\ GeV < W < 1.98\ GeV$) at an average four momentum transfer of $Q^2 = 1.3\ GeV^2$. The extracted spin structure functions and their kinematic dependence make a significant contribution in the study of higher-twist effects and polarized duality tests.

PACS numbers: list PACS here

Spin structure functions of the nucleon have been measured since the late 1970s, for example at SLAC [1], CERN [2], and DESY [3]. Most of the experimental studies have concentrated on the high Q^2 DIS region, where perturbative QCD works well with electrons scattering from an essentially free constituent quark [8]. More recently, the non-perturbative lower Q^2 ranges have become a focus of study, large due to the interest in duality and the GDH sum rule [9]. Just as in the earlier days of DIS investigations, the focus so far been on longitudinal polarization as the dominant, and technically more readily accessible, component.

Experiment E01-006 at the Thomas Jefferson National Accelerator Facility (TJNAF) has conducted a study of the proton spin structure using both longitudinal and transverse polarizations. Utilizing established procedures and equipment, we have measured the asymmetries $A_{\parallel}$ and $A_{\perp}$ at $Q^2 \approx 1.3\,GeV^2$ from proton (presented here) and deuteron targets. The lab's intermediate energy range (up to 6 GeV) polarized electron beam provided us the opportunity to study the nucleon spin structure in the lower energy resonance regime where quarks are not asymptotically free and pQCD does not apply.

The results presented here represent a significant increase in our knowledge of the spin properties of the proton, particularly since our measurement with perpendicular spin arrangement is the first at these kinematics. This high precision measurement of both $A_{\parallel}$ and $A_{\perp}$ allows us to extract the virtual photon asymmetries $A_1(\nu, Q^2)$ and $A_2(\nu, Q^2)$ without using any asymmetry models, providing a clean description of the quark contribution to the nucleon spin.

These data provide enhanced, or even first, information on the nucleon spin structure in the resonance region as well as the connection to the measurements at DIS kinematics. Polarized duality is readily observable and localized means also match DIS extrapolations. The perpendicular measurements in particular provide important information on higher twist contributions and thus quark–gluon interactions.

Following the procedure used in the DIS measurements, our effort was based in the determination of helicity based asymmetries in the cross section of polarized electrons scattering off a polarized proton target. The asymmetry is defined as the dimensioless, relative difference between the cross sections with (anti)parallel or (anti)perpendicular alignment, respectively, of the proton and the electron spins:

$$A_{||} = \frac{d\sigma^{\downarrow\uparrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\downarrow\uparrow} + d\sigma^{\uparrow\uparrow}} \qquad A_{\perp} = \frac{d\sigma^{\downarrow\rightarrow} - d\sigma^{\uparrow\rightarrow}}{d\sigma^{\downarrow\rightarrow} + d\sigma^{\uparrow\rightarrow}} \tag{1}$$

This method is well estabished and known for its insensitivity to systematic influences, allowing accurate determination of small changes to the scattering amplitude.

EXPERIMENTAL SETUP

The experiment was conducted over two months at Jefferson Lab in Hall C using the facility's continuous, polarized electron beam with energy of 5.7 GeV and a current of about 100 nA. The beam polarization was measured by a Moller polarimeter installed upstream of the target; the average beam polarization was about 70%. The beam helicity was flipped at 30 Hz on a pseudo-random basis. To minimize any false asymmetry or bias, we determined the beam charge asymmetry over five minutes intervals and the measured value was fed back to the helicity control device at the injector. The total charge corresponding to the data presented here was $42mC$ with a residual beam charge asymmetry of $< 0.1\%$ (absolute), which the data have been corrected for.

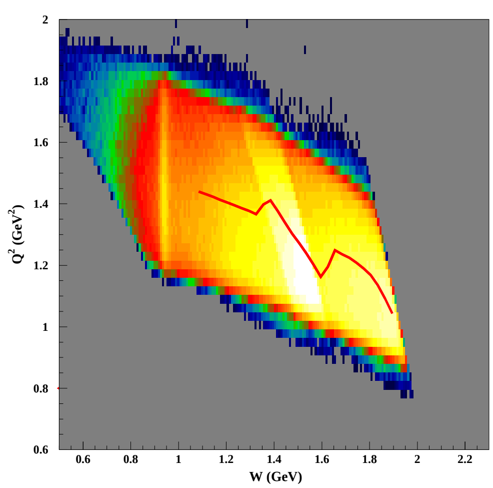

FIG. 1: Statistical and Kinematic Coverage of RSS Experiment. Notable are the elastic peak and the overlap between the two kinematic settings. The statistical average value is indicated. **change plot ranges**

Frozen $^{15}NH_3$ was used as the proton target in the UVa target apparatus [10]. A ^3He evaporation refrigerator coupled with a $5T$ polarizing magnet created a stable polarization environment. The actual polarization population enhancement was achieved via a Dynamic Nuclear Polarization technique [11] and measured by an NMR system using pickup coils embedded in the target material. For the $A_{\perp}$ measurement, the entire target apparatus was rotated by 90° from its parallel position. *SEM?*

Scattered electrons were detected using the High Momentum Spectrometer (HMS), positioned at a scattering angle of 13.15°. Two different HMS momentum setting were used to cover wider kinematic range, as shown in figure 1, resulting in an average Q^2 of $\approx 1.3\ GeV^2$. A detector package consisting of hodoscope planes, wire chambers, a Cerenkov counter and a lead glass calorimeter allowed for particle identification and measurement of the event kinematics. *raster?*

DATA ANALYSIS

Approximately 160 million scattering events were recorded on the proton target, resulting in highly precise determinations of the parallel and perpendicular asymmetries. These are determined from observed raw event counting asymmetries which are scaled to 100% polarization and corrected for contamination from alternative (radiative) and additional (dilution) processes:

$$A = \frac{1}{fC_N P_b P_t f_{RC}} \times \frac{N^- - N^+}{N^- + N^+} + A_{RC} \tag{2}$$

Here, $N^{\pm}$ is the charge corrected observed count rate for the parallel (perpendicular) and anti-parallel (anti-perpendicular) spin alignment, respectively. P_b and P_t are the beam and target polarizations, f is the dilution factor, C_N is the ^{15}N nuclear correction, and f_{RC} and A_{RC} are the radiative corrections. The fully corrected asymmetries $A_{||}$ and $A_{\perp}$ are shown in figure 2, together with dilution and radiative corrections. The average proton polarization was around 69%, and the beam polarization was 71% (66%) during the parallel (perpendicular) running.

The other two significant corrections, dilution and radiative, were determined with the use of various model calculations. The dilution factor was calculated from the ratio of cross section models (figure 3) which had been normalized to calibration data acquired specifically for this purpose. This correction is unique for each individual target cell and varies with kinematics; it ranges between 0 and 50% of the observed asymmetry. Since *refs!!* the reference data were taken with the same experimental setup, acceptances and other detector specific corrections are automatically accounted for.

The radiative corrections, accounting for polarized and

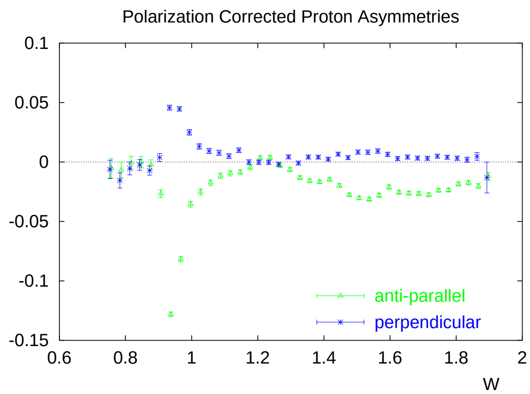

FIG. 2: Experimental NH_3 count asymmetries, with beam–target polarization parallel and perpendicular. The experiment's anti-parallel alignment of target polarization and beam direction results in the negative sign for $A_{||}$. **add dilution and RC for comparison**

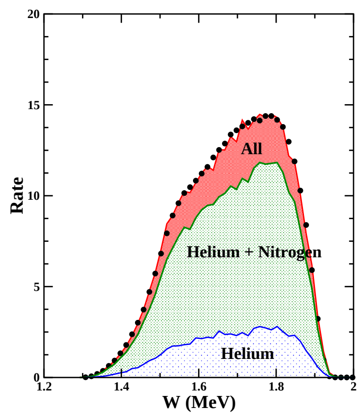

FIG. 3: Dilution Factor Break-Down. Shown are data rates and the different components from the Monte Carlo simulation. The dilution factor corresponds to the ratio between *All* and *Helium+Nitrogen*. **change from sums to components, change ranges**

unpolarized influences in the observed asymmetry, were
more!! determined using the POLRAD software.

RESULTS & CONCLUSIONS

From the fully corrected physics asymmetries $A_{||}$ and $A_{\perp}$ we can extract the virtual photon asymmetries A_1 and A_2 (figure 4), and the spin structure functions g_1 and g_2, shown in figure 5. The extraction of these physics quantities from the measured count asymmetries utilized F_2 and R from recent fits to other Hall C data [7].

A comparison of the A_1 data to the DIS extrapolation [12] strongly suggest polarized duality, over the entire measured range. A_2 tracks A_1 and is clearly nonzero and significant. The current MAID model calculation [13] replicates the general trend of the data but does

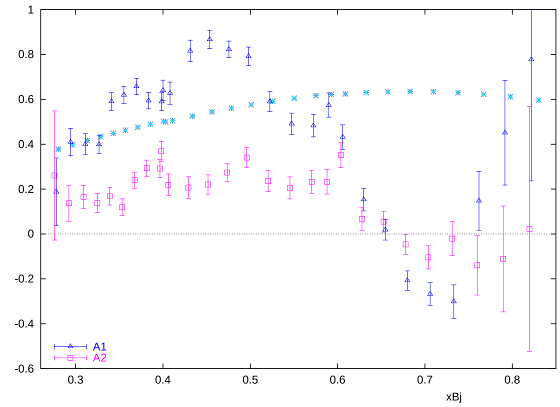

FIG. 4: Virtual Photon Asymmetries A_1^p and A_2^p. Also shown is the E155 fit to DIS data, evaluated at our (x, Q^2). **show plot with A1 A2 E155 DIS MAID**

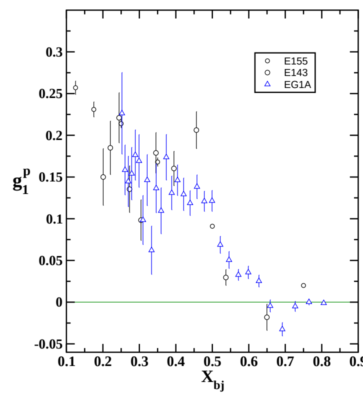

FIG. 5: Spin Structure Function g_1. See text for identification of the model curves. **add PDFs to plot**

not quite match our results. The difference between our data and the DIS measurements [14] highlights the Q^2 dependence outside the scaling regime.

The extracted values for the spin structure functions g_1 and g_2 highlight the dire neccessity of a measure-

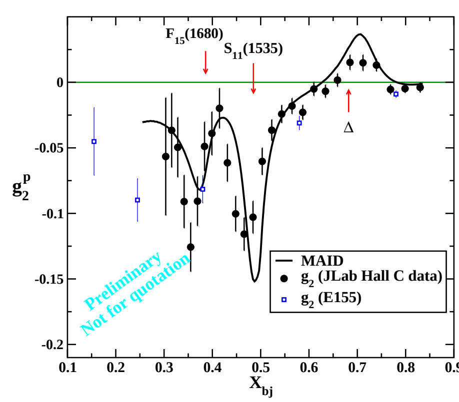

FIG. 6: Spin Structure Function g_2. See text for identification of the model curves. **add g2ww and loose MAID**

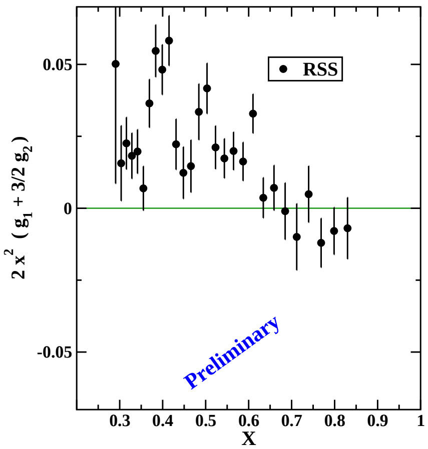

FIG. 7: Measured Integrand d_2. **change plot ranges, drop label**

ment such as ours: none of the parton distribution function models available reflect more than the most general trend. The significant contributions to g_2 from terms other than the leading g_2^{WW} are clear evidence of higher twist terms' significance.

GDH?

Since our data correlate g_1 and g_2, we can investigate the twist-2 contribution via the matrix element d_2:

$$d_2 \;=\; 3\int_0^1 x^2(g_2 - g_2^{\mathrm{WW}})\,dx \;=\; 2\int_0^1 x^2(g_1 + \frac{3}{2}g_2)\,dx \quad (3)$$

Our measured values of the integrand d_2 are shown in figure 7; over the measured range ($0.29 < x_{bj} < 0.84$), the integral evaluates to $d_2 = 0.0106 \pm 0.0012$ (stat). The overall systematic error is 6%. Along with other programs at Jefferson Lab [4] [5] [6], this measurement contributes significantly to the world data on the spin structure functions.

how syst?

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