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JLAB EXPERIMENT 01-006: RESONANCES' SPIN STRUCTURE

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Experiment 01-006[1] (Resonances' Spin Structure) was carried out at Jefferson Lab's Hall C to measure the nucleon spin structure functions in the region of the nucleon resonances. Longitudinally polarized electrons of 5.76 GeV beam energy were incident on solid polarized ammonia and deuterated ammonia ($^{15}NH_3$, $^{15}N^2H_3$) targets. The scattered electrons were detected in the High Momentum Spectrometer parked at a 13.15° angle relative to the beam. The polarized target field was used to align the nucleon spins parallel and perpendicular to the beam helicity to measure the corresponding asymmetries $A_\parallel$ and $A_\perp$. The measured asymmetries are used to extract in a model-free way the nucleon spin asymmetries $A_1(W, Q^2)$ and $A_2(W, Q^2)$, which are functions of the invariant mass of the final system, W, and of the four-momentum transfer, Q^2. The measurements extend over 0.8 GeV $\leq W \leq$ 1.95 GeV and are at an average $Q^2 = 1.3$ [GeV/c]^2. Preliminary results are shown, including the world's first set of data on the perpendicular asymmetry of the proton and the deuteron for this kinematic region.

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1. Introduction

This experiment was designed to make high precision and high resolution measurements of the spin structure of the proton and deuteron in the region of the nucleon resonances, at the four-momentum transfer $Q^2 \sim 1.3$ [GeV/c]^2. The physics

[1]Representing the RSS Collaboration (TJNAF E-01-006): U. Basel, Florida International U., Hampton U., U. Massachusetts, U. Maryland, Mississippi S. U., North Carolina A&T U., U. of N. C. at Wilmington, Norfolk State U., Old Dominion U., S. U. New Orleans, U. of Tel-Aviv, TJNAF, U. of Virginia, Virginia P. I. & S. U., Yerevan Physics I.; Spokesmen: O. A. Rondon-Aramayo, UVA and M. Jones, JLab.

goal was to explore fundamental properties of the nucleon and QCD with adequate precision to obtain conclusive information. The neutron spin asymmetries will be extracted from the measured proton and deuteron asymmetries.

The spin asymmetries $A_1(\nu, Q^2)$ and $A_2(\nu, Q^2)$ extend the deep inelastic scattering (DIS) description of the nucleon spin structure to the region of the resonances. $\nu = E - E'$ is the lepton energy loss, E and E' are the beam and final energies. In this region the nucleon spin structure can be described in terms of either the $G_1(\nu, Q^2)$ and $G_2(\nu, Q^2)$ spin structure functions (SSF's) or A_1 and A_2. The latter are constructed starting from the virtual photon absorption cross sections $\sigma^{\mathrm{T}}_{1/2}$, $\sigma^{\mathrm{T}}_{3/2}$, and $\sigma^{\mathrm{TL}}_{1/2}$ for photon helicities +1, -1, 0, respectively:

$$A_1 = \frac{\sigma^{\mathrm{T}}_{1/2} - \sigma^{\mathrm{T}}_{3/2}}{\sigma^{\mathrm{T}}_{1/2} + \sigma^{\mathrm{T}}_{3/2}} = \frac{M\nu G_1(\nu, Q^2) - Q^2 G_2(\nu, Q^2)}{W_1(\nu, Q^2)}\,, \tag{1}$$

$$A_2 = \frac{\sigma^{\mathrm{TL}}}{2\sigma^{\mathrm{T}}} = \frac{\sqrt{Q^2}\big(MG_1(\nu, Q^2) + \nu G_2(\nu, Q^2)\big)}{W_1(\nu, Q^2)}\,,$$

where $2\sigma^{\mathrm{T}} = \sigma^{\mathrm{T}}_{3/2} + \sigma^{\mathrm{T}}_{1/2}$, M is the nucleon mass and $W_1(\nu, Q^2)$ is transverse unpolarized structure function.

In the scaling limit of DIS, the structure functions depend (up to logarithmic corrections) only on the scaling variable $x = Q^2/(2M\nu)$:

$$\begin{aligned} \lim_{Q^2,\nu\to\infty} M^2\nu G_1(\nu, Q^2) &= g_1(x)\,, \\ \lim_{Q^2,\nu\to\infty} M\nu^2 G_2(\nu, Q^2) &= g_2(x)\,, \\ \lim_{Q^2,\nu\to\infty} MW_1(\nu, Q^2) &= F_1(x). \end{aligned} \tag{2}$$

There is a connection between the DIS and resonance's regions of lepton-nucleon scattering, known as Bloom-Gilman (B-G) or local duality [1]. B-G duality can be summarized as the averaging out of the magnitude of the unpolarized structure function $\nu W_2(\nu, Q^2)$ in the region of the resonances to the extrapolation of its DIS counterpart $F_2(\omega')$. The local character of duality is reflected in the fact that the averaging applies to individual resonances, not just to the region as a whole. Quantitatively, local duality can be expressed in terms of the equality of two integrals:

$$\frac{2M}{Q^2}\int_{\nu_a}^{\nu_b} \mathrm{d}\nu\, \nu W_2(\nu, Q^2) = \int_{\omega'_a}^{\omega'_b} \mathrm{d}\omega' F_2(\omega')\,, \tag{3}$$

$$\text{where} \quad \nu_{a,b} = \frac{W^2_{a,b} - M^2 + Q^2}{2M}, \quad \text{and} \quad \omega'_{a,b} = 1 + \frac{W^2_{a,b}}{Q^2}\,.$$

The integrand on the left is the structure function in the resonances, the one on the right is its DIS counterpart, extrapolated to the same region of final state mass $W_b - W_a$. For the unpolarized structure function $F_2^p(W, Q^2)$, the equality above is within $\pm \sim 0.1$ or better, for each of the major resonance regions starting at $Q^2 \geq \ \sim 1$ [GeV/c]^2.

The earliest mention of local duality in the spin structure functions can be found in the original proposal of this experiment [2]. Unpolarized local duality has been confirmed at JLab [3] for the proton and deuteron. 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 – 8] hint at duality in the SSF's, a quantitative confirmation of local spin duality has yet to be done.

In addition to testing the polarized local duality, the precise measurement of A_1 and A_2 in RSS will improve our understanding of the quarks' contribution to the nucleon spin and explore the effects of quark-gluon interactions which can be represented by twist-3 matrix elements calculable in Lattice QCD.

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

$$A_1 = \frac{C}{D}\Big(A_\parallel - dA_\perp\Big) \tag{4}$$

$$\text{and} \qquad A_2 = \frac{C}{D}\Big(c'A_\parallel + d'A_\perp\Big),$$

where C, c', d, d' and D are functions of kinematic variables only (D has an additional mild dependence on the unpolarized structure function $R(\nu, Q^2)$).

Extracting both A_1 and A_2 without assumptions, which can be done thanks to our technique of measuring both $A_\parallel$ and $A_\perp$, is a requisite for understanding the polarized local duality.

2. *Experimental details*

Polarized electrons of 5.755 GeV beam energy produced by CEBAF were used. The Hall C High Momentum Spectrometer (HMS), parked at 13.15°, was used to detect the scattered electrons. Two central momentum settings were used, 4.7 GeV/c and 4.09 GeV/c. The deflection of the beam downstream of the target in the configuration to measure $A_\perp$ required a special beam pipe and helium bag. The deflection for the upstream beam line was corrected by the Hall C's two-magnet chicane.

The resulting effective kinematics for this energy and HMS angle are shown in Fig. 1, which displays Q^2 plotted against the final-state mass W. The overlap of the ranges of Q^2 and W covered in each of the two HMS central momentum settings is visible. The band at constant $W = 0.94$ GeV corresponding to ep elastic scattering

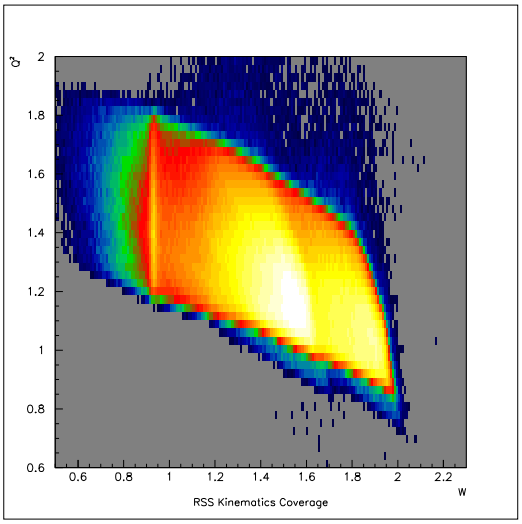

Fig. 1. Kinematics of E-01-006.

can also be seen. The kinematic region covered by the data connects very well with other polarized DIS experiments, for direct comparison of the DIS data with data measured in the resonances to study local duality. This choice of kinematics has the additional advantage that the spin structure function $g_1(W, Q^2)$ measured in our experiment can be used to test the extended Gerasimov-Drell-Hearn [9, 10] sum rules with a minimum of interpolations or use of fits to the world data.

The Hall C Møller polarimeter was used to measure the beam polarization. A total of 64 measurements were done during the run. A summary of the average effective beam polarizations for the four configurations of asymmetry measurement and target material is shown in Table 1.

TABLE. 1. Average beam current, and beam and target polarizations.

Configuration	Target	Beam I [nA]	Beam polarization	Target polarization
$A_\perp$	NH_3	100	65.6%	69.1%
	ND_3	115	65.6%	18.3%
$A_\parallel$	NH_3	91	71.0%	66.9%
	ND_3	112	71.0%	15.1%

The Hall C beam raster system, as modified for E93-026 (GEn01) was used. to distribute the beam uniformly over the target cell face. To verify the actual relative positions of the beam and the target cells, an optics cell with tungsten wire cross-hairs was installed as part of the target insert.

Data were taken on 3 cm long ammonia and deuterated ammonia targets ($^{15}NH_3$ and $^{15}N^2H_3$). The ammonia was polarized by dynamic nuclear polarization (DNP)

in a 5 T magnetic field cooled to $\sim$ 1 K by a ^{4}He evaporation refrigerator. The polarization was measured by NMR. Table 1 lists the average polarizations for each species during the corresponding measurement periods.

3. *Analysis and preliminary results*

In addition to the asymmetry data, calibration data were taken for optics studies of the HMS and for background correction. For the latter, data on a C disk target and on a cell alternately empty or filled only with LHe were taken. The polarized target contains ^{15}N, ^{4}He and other materials besides the polarized hydrogen or deuterium. The dilution factor f is defined as the fraction of counts coming from the hydrogen or deuterium in the target. The C and empty target data are used to calculate the packing fraction of ammonia material in the cells by comparing the measured C and He rates to model rates. A model of the ammonia target is adjusted to match the data. The same model is used to calculate the dilution factor.

Sample spectra for the ammonia, carbon and helium targets as functions of W together with the current Monte-Carlo (MC) simulation[2], and the ratios of MC to data rates, are shown in Fig. 2. The data correspond to a special high HMS mo-

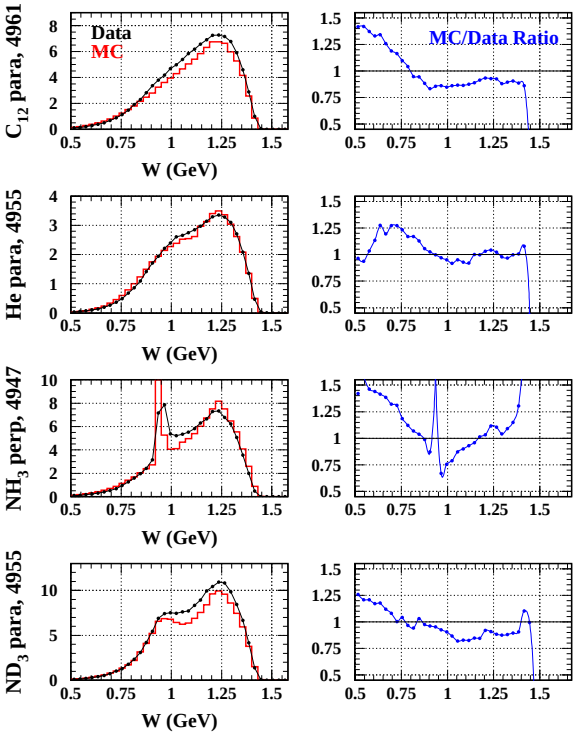

Fig. 2. Carbon, helium and ammonia spectra for the HMS high momentum setting (black circles) and Monte-Carlo (MC) simulation (red histograms) versus final state mass. The MC represents absolute rates calculated with a single normalization factor for C *and* He*. The ammonia MC rates are calculated for a nominal 50% packing fraction. The ratio MC to data rates is shown in blue.*

[2]Hall C's SIMC modified to include polarized target magnetic field and large beam raster. The Born cross sections are modifications of the QFS program [11]

mentum setting dedicated to dilution-factor modeling. The ammonia model rates are calculated for a a nominal 50% packing fraction. Preliminary dilution factors for protons and deuterons are shown in Fig. 3. Work to improve the MC/data agreement even further is ongoing. At the moment, MC and data agree to about 10% (better for the parallel configuration than for the perpendicular one).

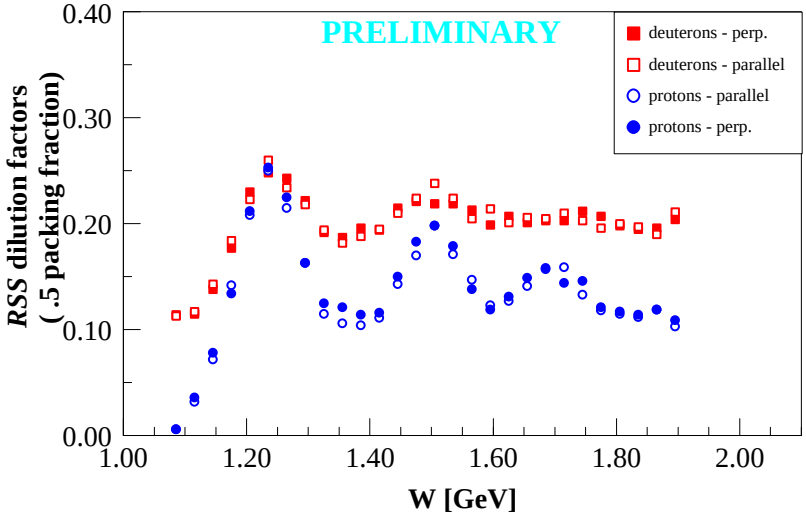

Fig. 3. Preliminary dilution factors for protons (blue circles) and deuterons (red squares), for the parallel (solid symbols) and perpendicular (open) configurations. The dilution factors are calculated for a nominal 50% packing fraction.

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 the dead time and pion contamination. $A_\parallel$ and $A_\perp$ are related to ϵ by

$$A_{\parallel,\perp} = \frac{1}{C_{\mathrm{N}} f_{\mathrm{RC}}} \left(\frac{\epsilon}{f P_{\mathrm{b}} P_{\mathrm{t}}} - C_{\mathrm{D}} \right) + A_{\mathrm{RC}} \,, \tag{5}$$

where $C_{\mathrm{N}}, C_{\mathrm{D}}$ are corrections for the small contribution of the polarized proton in ^{15}N, $f_{\mathrm{RC}}, A_{\mathrm{RC}}$ are the multiplicative and additive radiation corrections, and $P_{\mathrm{b}}, P_{\mathrm{t}}$ are the beam and target polarizations, respectively.

Preliminary uncorrected asymmetries $A_{\perp,\parallel}$ are shown in Figs. 4 and 5. 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.

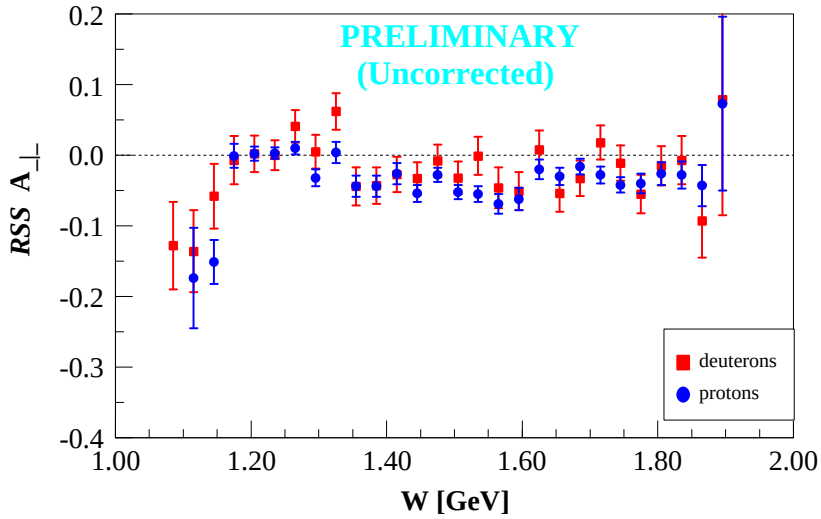

Fig. 4. Preliminary measured asymmetry for the perpendicular configuration for protons (blue circles) and deuterons (red squares), without corrections (see text for details).

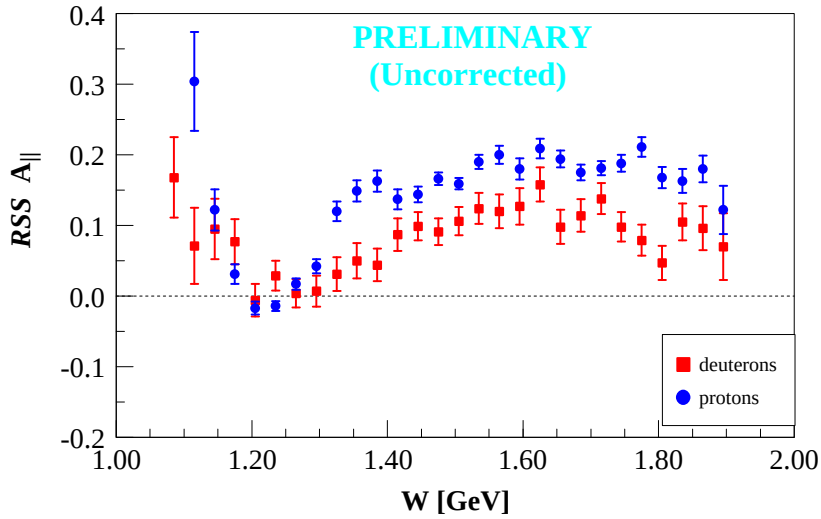

Fig. 5. Preliminary measured asymmetry for the parallel configuration for protons (blue circles) and deuterons (red squares), without corrections (see text for details).

The analysis of this experiment is the dedicated work of senior physicists and UVA and JLab research associates, including the spokesmen. Final results are expected by the end of 2004.

Acknowledgements

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MJERENJE 01-006 U JLABU: SPINSKA STRUKTURA REZONANCIJA

Mjerenje 01-006 (Spinska struktura rezonancija) izveli smo u Hali C Jeffersonovog Laba radi određivanja nuklearnih spinskih funkcija u području nukleonskih rezonancija. Uzdužno polariziranim elektronima energije 5.76 GeV ozračivali smo čvrste mete polariziranog amonijaka i deuteriranog amonijaka ($^{15}NH_3$, $^{15}N^2H_3$). Raspršene elektrone detektirali smo u spektrometru za velike impulse, postavljenom na 13.15° u odnosu na snop. Polje polariziranih meta se usmjeravalo usporedno i okomito na helicitet snopa, radi određivanja odgovarajućih asimetrija $A_\parallel$ i $A_\perp$. Te su asimetrije poslužile da se, neovisno o modelima, izvedu nukleonske spinske asimetrije $A_1(W, Q^2)$ i $A_2(W, Q^2)$, koje su funkcije invarijantne mase konačnog stanja, W, i prijenosa četiri-impulsa, Q^2. Područje mjerenja je 0.8 GeV $\leq W \leq$ 1.95 GeV sa srednjom vrijednošću $Q^2 = 1.3$ [GeV/c]^2. Daju se prethodni ishodi mjerenja, uključujući prvi skup podataka o poprečnoj asimetriji protona i deuterona u ovom kinematskom području.