HIGHER TWIST EFFECTS IN POLARIZED EXPERIMENTS

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Higher twist effects in nucleon spin structure functions provide an opportunity to understand quark-quark and quark-gluon correlations in the nucleon. A series of experiments in Jefferson Lab Hall A has enabled the extraction of higher twist effects in the neutron with unprecedented precision

A series of recent polarized electron scattering experiments performed at Jefferson Lab has provided an extensive data set for spin structure functions g_1 , g_2 and virtual photon asymmetries A_1 and A_2 at low and moderate momentum transfers. These data allow for a precision study of the higher twist effects in polarized structure functions.

The higher-twist effects in structure functions can be best understood within the formalism of the Operator Product Expansion (OPE). In this framework g_2 can be separated into a twist-2 and a higher-twist term:

$$g_2(x, Q^2) = g_2^{WW}(x, Q^2) + g_2^{H.T.}(x, Q^2) , \quad (1)$$

where the leading-twist (twist-2) term, $g_2^{WW}(x, Q^2)$, can be determined using g_1 as⁴

$$g_2^{WW}(x, Q^2) = -g_1(x, Q^2) + \int_x^1 \frac{g_1(y, Q^2)}{y} dy . \quad (2)$$

The higher-twist term arises from the quark-gluon correlations. Thus g_2 provides a clean way to study higher-twist effects. Furthermore, at high Q^2 , the twist-3 matrix element d_2 is derived from the x^2 -weighted moment of the twist-3 part of g_2 :

$$d_2 = \int_0^1 x^2 [g_2(x) - g_2^{WW}(x)] dx . \quad (3)$$

The d_2 matrix element is related to the color polarizabilities⁵ of the nucleon. Predictions for d_2 exist from various models and lattice QCD.

In this paper we present results for g_2^n , A_2^n and d_2^n from a series of experiments carried out in Jefferson lab Hall A over the last few years. These experiments used the Hall A polarized ^3He target as an effective neutron target. The design of this target allows for easy transition into the transverse target polarization mode from the longitudinal polarization mode. Parallel and perpendicular asymmetries were extracted for ^3He in this series of experiments. The combination of parallel and perpendicular asymmetries allows for a clean separation of structure functions g_1 and g_2 (and asymmetries A_1 and A_2)⁶. Both Hall A High Resolution spectrometers (HRS) were used in a symmetric configuration in electron detection mode to measure the inclusive $^3\tilde{\text{H}}e(e, e')X$ reaction.

The measured parallel and perpendicular asymmetries were combined with the beam and target polarization measurements and the dilution factor to extract structure functions, and in some cases, virtual photon asymmetries for ^3He . The most recent models⁷ were used to apply nuclear corrections to the data in the DIS region to obtain the corresponding quantities for the neutron. In the case of low Q^2 resonance region data, the nuclear correction were applied to extract moments of the neutron spin structure functions.

Jefferson lab Hall A experiment E97-103⁸ made a precision measurement of g_2^n in the DIS region at $x \approx 0.2$ covering five Q^2 values from 0.58 to 1.36 GeV^2 . Results for g_2^n and g_1^n from this experiment are given in Fig. 1. The light-shaded areas in the two plots give the leading-twist contribution to these two quantities. The dark-shaded areas (next to the horizontal axes) show the systematic errors.

Figure 1. Results for g_1^n (left) and g_2^n (right) from E97103.

The precision reached in this experiment is more than an order of magnitude improvement over that of previous world data. The deviation of g_2 from the leading twist part (g_2^{WW}) calculations⁴ is a measure of higher twist effects arising from quark-gluon correlations. The g_2^{WW} values were

obtained from a fit⁹ to the high Q^2 world data on g_1^n . This fit was then evolved down to the Q^2 values of this experiment. The measured g_2^n values are consistently higher than g_2^{WW} . For the first time, there is a clear indication of higher-twist effects at the level of precision of these data. The new g_1^n data agree with the leading-twist calculations within the uncertainties.

In 2001, Hall A experiment E99-117¹⁰ made a precision measurement of A_1^n in the high x region from $x = 0.33$ to $x = 0.61$ (Q^2 from 2.7 to 4.8 GeV²). This data also allowed the extraction of A_2^n . The precision of the A_2^n thus extracted is comparable to that of the best existing world data¹¹ at high x . Combining these results with the world data, d_2^n was extracted at an average Q^2 of 5 GeV²:

$$d_2^n = 0.0062 \pm 0.0028. \quad (4)$$

Compared to the previously published result¹¹, the uncertainty on d_2^n has been improved by about a factor of 2.

The d_2^n measurements also provide the means to study the transition of nucleon spin structure from high Q^2 to low Q^2 . At low Q^2 , $\bar{d}_2$ is defined to be the inelastic part of $d_2(Q^2)$. At high Q^2 , $\bar{d}_2$ becomes d_2 since the elastic contribution is negligible.

Hall A experiment E94-010¹² measured $\bar{d}_2$ (among several other results) at six values of Q^2 from 0.1 to 0.9 GeV². In Fig. 2, $\bar{d}_2(Q^2)$ measured in E94-010 and E99-117 are shown along with SLAC results from Experiment E155¹¹ (solid circles). The grey band represents the systematic uncertainty. The solid line is the MAID¹³ calculation containing only the resonance contribution. At low Q^2 a Heavy Baryon χ PT calculation¹⁴ (dashed line) is shown. The Lattice QCD prediction¹⁵ at $Q^2 = 5$ GeV² is negative but close to zero. At moderate Q^2 , our data show that $\bar{d}_2^n$ is positive and decreases with Q^2 .

The spin structure data from Jefferson Lab Experimental Halls A and B have been used to calculate twist-4 and twist-6 coefficients of the OPE series of Γ_1 , the first moment of g_1 , for the proton and the neutron. These coefficients have then been used to extract the twist-4 matrix element f_2 . Due to lack of space, the details of this higher twist extraction is not given here and the reader is referred to ^{20,21,22} and ²³. The results for extracted f_2 for the proton, neutron and $p - n$ are compared to theoretical calculations in Fig. 2 (right).

In summary, polarized experiments in Jefferson Lab Halls A and B have provided precision spin structure data that has enabled an extraction of higher twist effects in the nucleon with unprecedented accuracy. These

Figure 2. The left panel shows the Hall A results of $\bar{d}_2$ for the neutron along with SLAC data at high Q^2 compared to Lattice QCD, MAID model and HB χ PT calculations. The right plot compares f_2 with calculations of Stein *et al.*¹⁶, MIT bag model¹⁷, QCD sum rules¹⁸ and an instanton model¹⁹.

new results are essential for understanding quark-gluon correlations.

The work presented was supported in part by the U. S. Department of Energy (DOE) contract DE-AC05-84ER40150 Modification NO. M175, under which the Southeastern Universities Research Association operates the Thomas Jefferson National Accelerator Facility.

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