STUDY OF DUALITY IN THE TRANSITION REGION AT JLAB

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FOR THE CLAS COLLABORATION

Inclusive double spin asymmetries obtained by scattering polarized electrons off polarized protons and deuterons have been analyzed to address the issue of quark-hadron duality in the polarized spin structure functions g_1^p and g_1^d. A polarized electron beam, solid polarized NH_3 and ND_3 targets and the CEBAF Large Acceptance Spectrometer (CLAS) in Hall B were used to collect the data. The resulting g_1^p and g_1^d were averaged over the nucleon resonance energy region ($M < W < 2.00$ Gev), and three lowest lying resonances individually for tests of global and local duality.

1. Duality in spin structure function g_1

An observation that the hadronic and partonic degrees of freedom can sometimes both be successfully used to describe the structure of hadrons is called quark-hadron duality. This phenomena was discovered experimentally by Bloom and Gilman[1], who observed that the spin averaged structure function $F_2(\nu, Q^2)$ measured in the resonance region was on average equivalent to the deep inelastic one, if averaged over the variable $w' = (2M\nu+M^2)/Q^2$. Quark-hadron duality can be quantified by considering partial moments of the resonance structure functions at fixed Q^2:

$$\int_{\xi_{min}}^{\xi_{max}} F_2(\xi, Q^2)d\xi, \quad \xi = \frac{2x}{(1+(1+4M^2x^2/Q^2))^{-0.5}} \tag{1}$$

These moments are compared to the integrals of the 'scaling' structure functions in the same region of ξ at the same Q^2. The polarized parton distribution (PDF) based fits and the phenomenological fits to the DIS scattering data at high Q^2 with the ξ values corresponding to those of the resonant data are used as the 'scaling' functions. The equivalence of 'resonant' and 'scaling' moments is referred to as 'global' duality, if the integration is taken over the classical resonance region ($0.94 < W < 2.00$ GeV). If the average is taken over individual resonance regions, the 'local' duality is invoked. The duality is tested by forming a ratio of integrals of $g_1^{p,d}$ over the resonance region, or a particular resonance, to the integral of the deep-inelastic $g_1^{p,d}$ over an equivalent region in ξ:

$$I = \frac{\int_{\xi_{min}}^{\xi_{max}} g_1^{p,d}(data)(Q^2,\xi)d\xi}{\int_{\xi_{min}}^{\xi_{max}} g_1^{p,d}(fit_{DIS})(Q^2,\xi)d\xi} \tag{2}$$

Duality is realized when this ratio is consistent with unity.

2. Measurements and Analysis

g_1 was extracted from measurements of the double spin asymmetry $A_\parallel$ in inclusive ep scattering:

$$g_1 = \frac{F_1}{1+\gamma^2}[A_\parallel/D + (\gamma-\eta)A_2], \tag{3}$$

where F_1 is the unpolarized structure function, A_2 is the virtual photon asymmetry, and γ, D and η are kinematic factors. F_1 and A_2 are calculated using a parametrization of the world data, and $A_\parallel$ is measured. The spin asymmetry for ep scattering is given by:

$$A_\parallel = \frac{N_- - N_+}{N_- + N_+}\frac{C_N}{fP_bP_tf_{RC}} + A_{RC}, \tag{4}$$

where $N_-(N_+)$ is the number of scattered electrons normalized to the incident charge with negative (positive) beam helicity, f is the dilution factor needed to correct for the electrons scattering off the unpolarized background, f_{RC} and A_{RC} correct for radiative effects, and C_N is the correction factor associated with polarized ^{15}N nuclei in the target. $A_\parallel$ was measured by scattering polarized electrons off polarized nucleons using a cryogenic solid polarized target and CLAS in Hall B.

The longitudinally polarized electrons were produced by a strained $GaAs$ electron source with a typical beam polarization of $\sim 70\%$. Two solid polarized targets were used: $^{15}ND_3$ for polarized deuterons and $^{15}NH_3$ for polarized protons. The targets were polarized using the method of Dynamic Nuclear Polarization, with the typical polarization of $70-90\%$ for protons, and $10-35\%$ for deuterons. Besides the polarized targets, three unpolarized targets (^{12}C, ^{15}N, liquid ^{4}He) were used for background measurements. The scattered electrons were identified using the CLAS package[7], consisting of drift chambers, Cherenkov detector, time-of-flight counters and electromagnetic calorimeters. Data were taken with beam energies of 1.6, 2.4, 4.2 and 5.7 GeV, covering a kinematic range of of $0.05 < Q^2 < 4.5$ GeV^2 and $0.8 < W < 3.0$ GeV.

3. Results

Fig. 1 shows g_1^p plotted vs ξ in Q^2 bins, compared with the next-to-leading order twist-2 PDF predictions[2],[3] and the DIS SLAC fit[4]. Each version of the pQCD calculation has been corrected for the target mass effects[5], taking into account the fact that the measurements were taken at a low Q^2. Both PDF curves agree well on average with the data points, with exception of the resonance regions. The data points in the second and third resonances tend to lie above the fits, and the region of the $\Delta(W = 1232)$ resonance is 'below' the fits at $Q^2 < 3.0$ GeV^2. The DIS fit is consistent with the PDF predictions, beginning to deviate at low values of ξ.

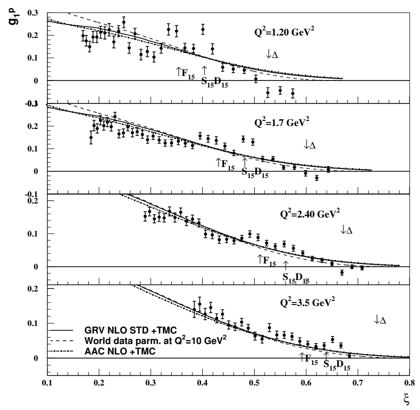

Figure 1. g_1^p plotted vs ξ in Q^2 bins, compared with the 2 PDF models and the DIS fit at Q^2=10 GeV^2. The PDF models are corrected for the target mass effects as described in the text.

In order to test the global and local duality for $g_1^{p,d}$, the ratio in equation 2 was evaluated for the whole resonance region ($1.07 < W < 2$ GeV), and three low-mass resonance regions: $1.12 < W < 1.38$ GeV ($\Delta P_{33}(1232)$), $1.38 < W < 1.58$ GeV ($D_{13}(1520), S_{11}(1535)$), and $1.58 < W < 1.8$ GeV ($F_{15}(1680)$ and others). The numerator of the above equation is displayed as data points, weighted by Q^2, with the curves showing the Q^2 weighted denominator, evaluated by integrating over the structure function g_1^p predicted by the PDFs and the DIS data fit at Q^2=10 GeV^2. An effect of adding the elastic contribution to the numerator was also tested, with the elastic contribution evaluated from the elastic form factors[6].

Results of this study are shown in Fig. 2. Without the inclusion of the

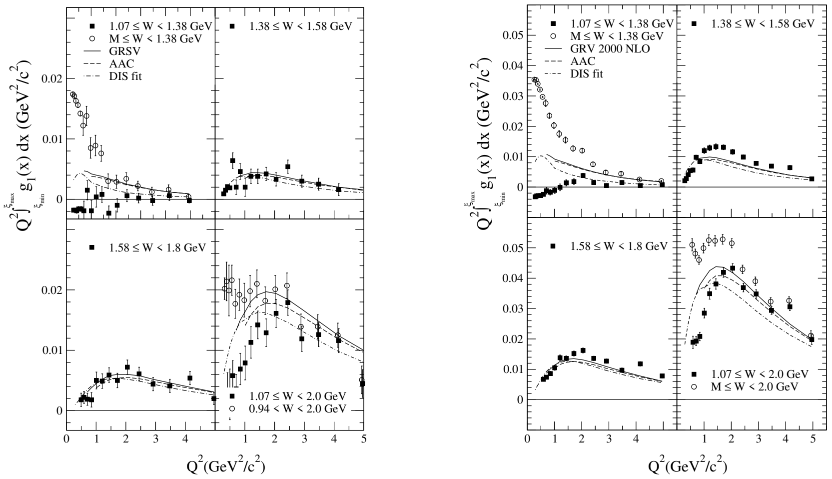

Figure 2. Right: The Q^2 evolution of the numerator of I (Eq. 2), weighted by Q^2, in the entire resonance region, and 3 individual regions, for the proton. Left: Same for the deuteron. Empty circles correspond to the inclusion of the elastic contribution. The deviations from unity smaller than 10% are not considered significant in this study, as there is systematic uncertainty in the data on the order of 6-7 %, and a similar uncertainty in the DIS fit.

elastic constribution, the onset of global ($1.07 < W < 2.00$ GeV) duality for the proton and deuteron is observed when Q^2 values exceed 1.2 GeV^2, while including the elastic constribution delays it until the higher values of Q^2. The local duality does not appear to hold for the proton in the first and second resonance regions, with the first region showing negative asymmetry due to the $\Delta(1232)$ constribution, and the second region having a large positive asymmetry due to the negative parity resonances S_{11} and D_{13}. In case of a deuteron, the local duality appears to hold in the second and third resonance regions.

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