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PRECISION MEASUREMENTS OF THE NEUTRON SPIN-STRUCTURE FUNCTIONS USING POLARIZED ^{3}HE AT JEFFERSON LAB

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In the summer of 2001, the Jefferson Lab Hall A Polarized ^{3}He collaboration performed two experiments whose purpose was the precision measurement of neutron spin-structure functions. The first was a measurement of the virtual photon asymmetry for the neutron, A_1^n, at large x kinematics. The increased precision of A_1^n in this kinematic region allows clear differentiation between SU(6), broken SU(6), perturbative QCD, constituent quark and chiral solition models. The second experiment measures g_2^n at $x \approx 0.2$ and from a Q^2 range of 0.54 GeV^2 to 1.36 GeV^2. Comparisons of these precision points with g_2^n calculated using the Wandzura-Wilczek relation allows a clean measurement of the magnitude of higher-twist effects in this kinematic region. Results from both experiments are presented and compared to previous data and predictions.

1 A_1^n at high x

For electron scattering on a polarized target, the virtual photon asymmetry A_1 is defined as

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \tag{1}$$

where $\sigma_{1/2}$ and $\sigma_{3/2}$ are the total virtual photoabsorption cross-section for the nucleon with a of total spin of 1/2 and 3/2, respectively, along the momentum direction of the photon. A_1 can be expressed as a ratio of the polarized structure functions g_1, g_2 and the spin-independent structure function F_1 as

$$A_1 = \frac{g_1(x,Q^2) - \gamma^2 g_2(x,Q^2)}{F_1(x,Q^2)} \tag{2}$$

where $\gamma^2 = 4M^2x^2/Q^2$ is a kinematic factor, M is the nucleon mass, x is the Bjorken scaling variable and Q^2 the four-momentum transfer squared.

To first approximation, the constituent quarks in the nucleon are descibed by the SU(6) wavefunctions

$$\begin{aligned} |n\uparrow\rangle = \tfrac{1}{2}|d\uparrow(ud)_{S=0}\rangle + \tfrac{1}{\sqrt{18}}|d\uparrow(ud)_{S=1}\rangle - \tfrac{1}{3}|d\downarrow(ud)_{S=1}\rangle \\ -\tfrac{1}{3}|u^{\uparrow}(dd)_{S=1}\rangle - \tfrac{\sqrt{2}}{3}|u\downarrow(dd)_{S=1}\rangle \end{aligned} \tag{3}$$

where the subscript S denotes the total spin of the diquark state. In this limit, where SU(6) is an exact symmetry, both diquark spin states $S=1$ and $S=0$ contribute equally to the virtual photon asymmetry leading to predictions of $A_1^p = 5/9$ and $A_1^n = 0$.

However, SU(6) symmetry is known to be broken. Constituent quark models attribute the broken symmetry to a hyperfine interaction amongst the quarks [1]. Models based on perturbative QCD use a property known as hadron helicity conservation, where only the diquark spin projection is suppressed as $x \to 1$ rather than the entire diquark spin, to explain the broken symmetry [2]. Both of these models predict $A_1^n \to 1$ as $x \to 1$. In addition to these two types of models, there are a few other models which can predict values for A_1^n at large x, including a statistical model [3], a local duality model [4], an instaton model [5] and a chiral soliton model [6]. Previous to these experiment the world data set has only points with very poor statistics above $x > 0.4$ and even the sign of A_1^n cannot be determined at high x.

2 Experiment E99-117

The Hall A Polarized ^{3}He Collaboration at Jefferson Lab performed experiment E99-117 in the summer of 2001. The experiment consisted of longitudinally polarized electrons with an energy of 5.7 GeV and average polarization of 81% from the Jefferson Lab accelerator scattering off a polarized ^{3}He gas target. The target is centered around a double-chambered glass cell and uses spin-exchange with optically polarized rubidium vapor to polarize the ^{3}He nuclei. The scattered electrons were detected in two high-resolution spectrometers that were configured symmetrically to double the counting rate. A CO_2 gas Cherenkov detector and a double-layered lead-glass shower counter provided particle identification with the pion rejection factor found to be better than 1 in to 10^4 for both spectrometers and a electron identification efficiency of 99%.

3 Results from E99-117

The data points collected during E99-117 are displayed in Figure 1. The datum at $x = 0.33$ is consistent with the world data and the two higher x points show a clear trend towards a positive value of A_1^n as $x \to 1$. Two models which use the world data as input - the LSS parameterization and Soffer's statistical model - can be refined if the data from this experiment are included. The consituent quark models follow the trend towards positive values even though they don't follow the data as closely as the previous two models. These results have been published in reference [7].

4 Higher twists in g_2^n

The operator product expansion allows one to expand structure functions in terms of coeffecients and operators. The leading term in the expansion dominates the structure functions in the deep inelastic scattering regime and represents a virtual photon scattering off an asymptotically free quark. Any other interaction that might influence a virtual photon-nucleon scattering is known as a higher-twist effect.

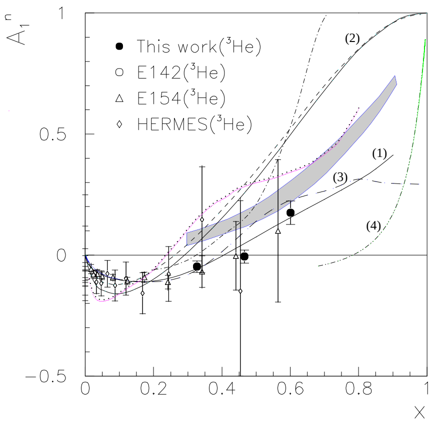

Figure 1. World data set for A_1^n including data from E99-117. These points are compared to the following models: curve (1) is a prediction of g_1/F_1 from pQCD based model using LSS 2001 parameterization at $Q^2 = 5$ GeV^2, the light shaded band is A_1^n from constiuent quark models, line (2) is a pQCD model using BBS parameterization, curve (3) is a statistical model at $Q^2 = 4$GeV^2 and curve (4) is a calculation based on local duality.

The ability to study higher twist effects in g_2^n comes from the Wandzura-Wilczek relation [8] which states

$$g_2^{\rm WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 \frac{dx'}{x'} g_1(x',Q^2) \qquad (4)$$

where $g_2^{\rm WW}$ is the leading twist part of $g_2(x,Q^2)$. This means that if there is sufficient data set for g_1 and a precise measurement of g_2, the leading twist term can be subtracted and the remainding value represents higher-twist contribution to the structure functions.

5 Experiment E97-103

The Hall A Polarized ^{3}He Collaboration performed experiment E97-103 directly after E99-117. The experiment required three beam energies with a longitudinal beam polarization from 69.3% to 81.6%. This experiment was also performed with a polarized ^{3}He gas target. The Hall A high-resolution spectrometers were used in a symmetric configuration with the same particle identification package used in E99-117.

6 Results of E97-103

The results from experiment E97-103 are shown in Figure 2. The data is compared to a g_2^{WW} calculated from a Blümlein and Böttcher parameterization of the parton distrubution functions [9] evolved to the relevant kinematics. There is statisically significant deviation of 2-3 σ from g_2^{WW} in the three lower Q^2 points. Since it is a small data set, it is difficult to make an estimation to the Q^2 evolution of this deviation.

There are two sources of systematic uncertainty which contribute almost equally to the results of the experiment : the unpolarized cross-section for ^{3}He and polarized radiative corrections. Other smaller sources of uncertainty which contribute significantly to the systematic error are from potential false asymmetries and extracting neutron contribution from polarized ^{3}He. These results are still being finalized with hopes to publish in summer 2004.

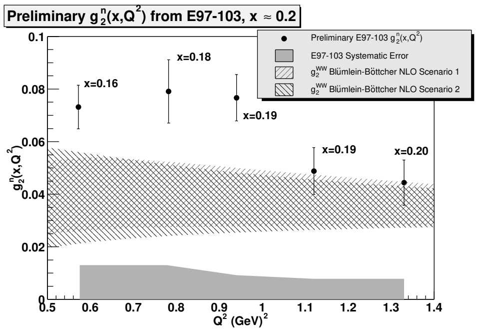

Figure 2. Results from E97-103. The data is compared to two NLO scenarios from Blümlein and Böttcher

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