Measurements of the Spin Structure Function g_2 from SLAC E155x.

Peter Bosted, for the E155x Collaboration [a] *

[a] Physics Department, University of Massachusetts, Amherst, MA USA

We have measured the spin structure functions g_2^p and g_2^d over the kinematic range $0.02 \leq x \leq 0.8$ and $0.6 \leq Q^2 \leq 20$ $(\mathrm{GeV/c})^2$ by scattering 29.1 and 32.3 GeV longitudinally polarized electrons from transversely polarized NH_3 and ^6LiD targets. The statistical errors are approximately three times smaller than previous measurements. Preliminary results are compared with several calculations. The twist-3 matrix element d_2 is found to be close to zero for both the proton and neutron.

1. INTRODUCTION

The deep inelastic spin structure functions of the nucleons, g_1 and g_2, depend on the spin distribution of the partons and their correlations. The transverse structure function $g_T = g_1 + g_2$ has a simple parton interpretation in terms of the transverse polarization of the quark spins, which is proportional to quark masses. However, g_2 is also sensitive to higher twist effects such as quark-gluon correlations [1] and is not easily interpreted in pQCD where such effects are not included. By interpreting g_2 using the operator product expansion (OPE) [1,2], it is possible to study contributions to the nucleon spin structure beyond the simple quark parton model.

The structure function g_2 can be written:

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \overline{g_2}(x,Q^2) \tag{1}$$

where

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

$$\overline{g_2}(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left(\frac{m}{M} h_T(y,Q^2) + \xi(y,Q^2)\right)\frac{dy}{y} \tag{3}$$

where x is the Bjorken scaling variable and Q^2 is the absolute value of the virtual photon four-momentum squared. The twist-2 term g_2^{WW} was derived by Wandzura and Wilczek [3] and depends only on the well-measured g_1 structure function. The

*Work supported by the National Science Foundation and the Department of Energy contract DE–AC03–76SF00515.

function $h_T(x, Q^2)$ is an additional twist-2 contribution [4] that depends on the transverse polarization density in the nucleon, but is suppressed by the quark-to-nucleon mass ratio. The twist-3 part, ξ, comes from quark-gluon correlations and is the main focus of our study.

2. EXPERIMENT

The recent SLAC experiment E155x made new measurements of g_2 for the proton and deuteron from February to May of last year (1999). The statistical errors are approximately three times smaller than previous measurements [5–7]. We used the 120 Hz SLAC electron beam with a longitudinal polarization of $(83 \pm 3)\%$ at energies of 29.1 and 32.3 GeV and a typical current of 25 nA. The beam helicity direction was randomly chosen pulse-by-pulse. We used transversely polarized NH_3 and ^6LiD targets as sources of polarized protons (average polarization 75%) and deuterons (average polarization 20%). The targets were made from small pellets immersed in liquid helium at 1 K, in a 5 T magnetic field to allow dynamic nuclear polarization. The magnetic field, and hence the nuclear spin direction, was at an angle $\alpha = 92.4°$ to the beam direction. Scattered electrons were detected in three independent spectrometers centered at 2.75°, 5.5°, and 10.5°. Electrons in each spectrometer were separated from pions using gas Cherenkov counters and segmented electromagnetic calorimeters. Tracking was done with scintillator hodoscopes. The 10.5° spectrometer had some new detectors for this experiment, but otherwise the setup was identical to that of E155 [7].

The asymmetry $A(E, x, Q^2)$ for each kinematic bin was formed using

$$A(E, x, Q^2) = \frac{C_1}{f P_t f_{RC}} \left(\left(\frac{N_L - N_R}{N_L + N_R} \right) \frac{1}{P_b} + A_{EW} \right) + A_{RC}$$

where N_L and N_R are the measured counting rates from the two beam helicities, including small corrections for pion and charge symmetric backgrounds, P_b is the beam polarization, P_t is the target polarization, f is the target dilution factor, C_1 includes a small correction for polarized ^{15}N, and A_{EW} corrects for the electroweak asymmetry ($\approx 8 \times 10^{-5} Q^2$) The factors f_{RC} and A_{RC} correct for radiative tails, which can be large at low x. Preliminary radiative correction calculations were made using the g_2^{WW} model and the E155 fit to g_1. The calculations will be improved by iterating on a model fit to g_2, and by a more careful treatment of the radiative dilution factor f_{RC}, which only includes elastic tails in this analysis.

Because the measured asymmetries are very small (few tenths of a percent), we used two methods to cancel out possible false asymmetries. The first was to change the orientation of the target polarization, to point either to the right or the left of the beam line. The second method was to change the beam energy by 3.3 GeV, corresponding to a 180 degree rotation of the polarization in the 24 degree bend of the transport line from the SLAC linac to the experimental hall. The data indicate no significant sources of false asymmetries.

3. RESULTS FOR g_2

We used our measured $A(E, x, Q^2)$ values together with a fit to g_1 to obtain values for g_2 using [8]

$$g_2 = \frac{\nu}{2EE'[\cos(\Theta) - \cos(\alpha)]}\left[\frac{\nu(1+\epsilon R)(1+\gamma^2)F_2 A}{2x(1-\epsilon)(1+R)} - g_1[E\cos(\alpha) + E'\cos(\Theta)]\right]$$

where E and E' are the incident and scattered electron energies, $\nu = E - E'$, $\gamma^2 = Q^2/\nu^2$, $\epsilon^{-1} = 1+2[1+\gamma^{-2}]\tan^2(\theta/2)$, θ is the electron scattering angle, $\cos(\Theta) = \sin(\theta)\sin(\alpha)\cos(\phi) + \cos(\alpha)\cos(\theta)$, and ϕ is the angle between electron-nucleon spin plane and the electron scattering plane (close to 1 for the 5.5° spectrometer, and close to -1 for the other two spectrometers). The NMC fit to $F_2(x, Q^2)$ [9] and the new SLAC fit to $R(x, Q^2) = \sigma_L/\sigma_T$ [10] were used.

Preliminary results for xg_2 for each of three spectrometers are shown for both the proton and deuteron targets in Fig. 1. Results with the two beam energies (29 and 32 GeV) have been averaged. The average Q^2 values are approximately 1, 4, and 10 GeV^2 at 2.75, 5.5, and 10.5 degrees, respectively. Overall, the results show little difference from the g_2^{WW} model, shown at the same kinematics as the data as the solid curve on each plot, changing from positive values at low x to significantly negative values at high x, especially for the proton target. The zero-crossing point is quite sensitive to radiative corrections, and may change when these are finalized. Since the results are not inconsistent with the Q^2 dependence of the g_2^{WW} model, they were averaged together using this assumption to produce the averaged values shown in Fig. 2. This was done to facilitate comparison to previous data and a selection of models calculated at fixed values of Q^2.

The proton results for g_2 are clearly different than zero, and exhibit an x-dependence similar to that of the g_2^{WW} model, although there appears to be a small difference from this model at high x, possibly indicating non-zero twist-3 contributions are important. The data are in qualitative agreement with the bag model calculation of Stratmann [11] and the chiral soliton calculation of Weigel [12], but are considerably more negative than the model of Song [4]. The deuteron data have larger errors than the proton data, but also indicate significantly negative values at high x, and are in qualitative agreements with g_2^{WW}, Stratmann [11], and Weigel [12].

The g_2 structure function is of particular interest because quark-gluon correlations can introduce relatively large twist-3 contributions, which can be evaluated in a variety of models. We fit a smooth function to world data (dominated by E155x) for $\overline{g_2}(x, Q^2) = g_2(x, Q^2) - g_2^{WW}(x, Q^2)$, then evaluated the twist-3 matrix element d_2, defined as

$$d_2 = \int_0^1 x^2 \overline{g_2}(x)dx \tag{4}$$

assuming that $\overline{g_2}(x)$ is independent of Q^2 in the measured region. This is not unreasonable since d$_n$ is supposed to depend logarithmically on Q^2[1]. Because of the x^2 weighting factor, the contribution from the unmeasured region $x < 0.02$ is negligible.

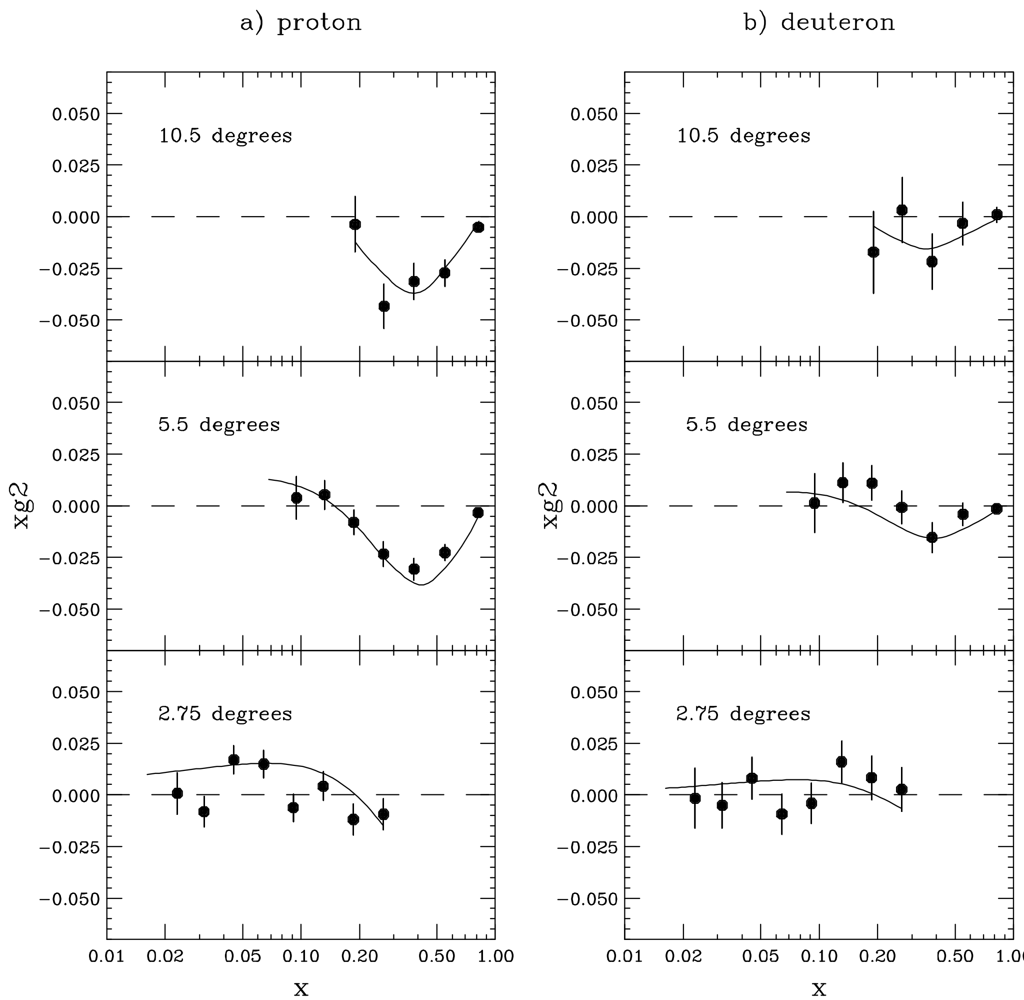

Figure 1. Preliminary results from E155x for xg_2 in the 2.75°, 5.5° and 10.5° spectrometers for a) proton and b) deuteron targets. The results using 29 and 32 GeV beam energies have been combined. The errors are statistical; the systematic errors are negligible in comparison. The solid curves are g_2^{WW} at the kinematics corresponding to the data.

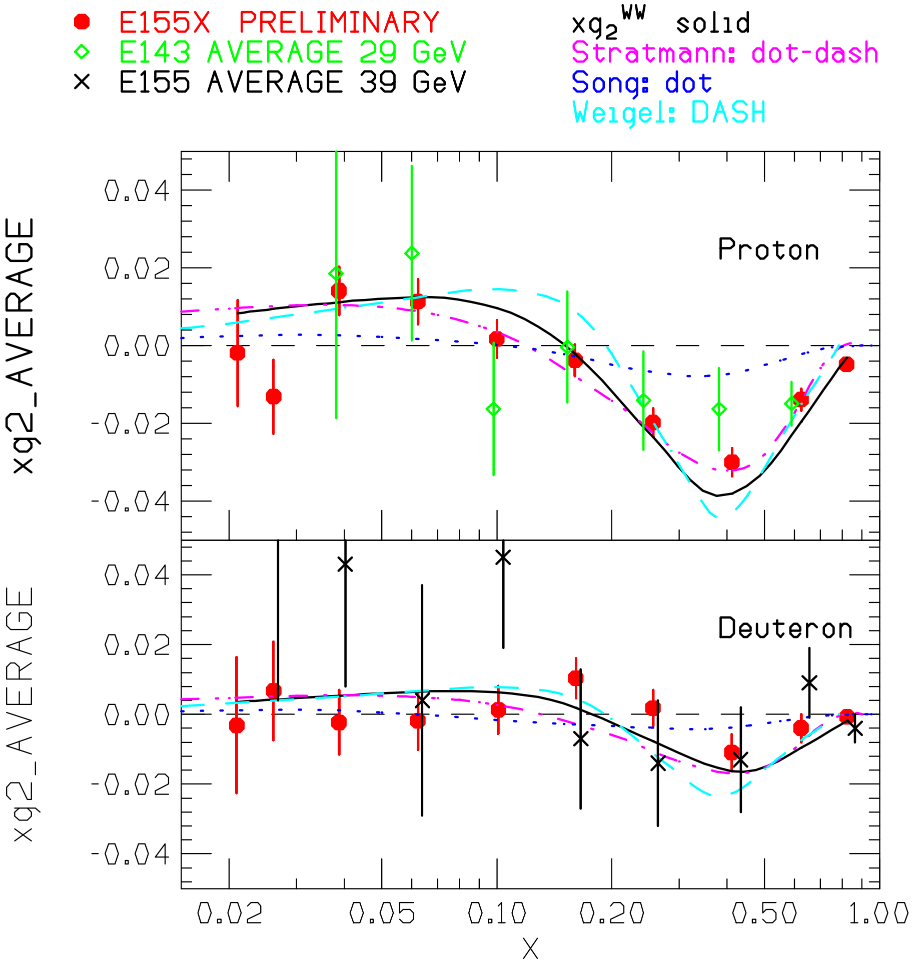

Figure 2. The structure function xg_2 averaged over the three spectrometers for E155x (solid circles, preliminary), and data from E143 [5] (diamonds) and E155 [7] (stars). The errors are statistical; the systematic errors are negligible. Also shown is g_2^{WW} at the average Q^2 of this experiment at each value of x (solid curves) and the calculations of Stratmann [11] (dot-dash curves), Weigel [12] (dashed curves), and Song [4] (dotted curves).

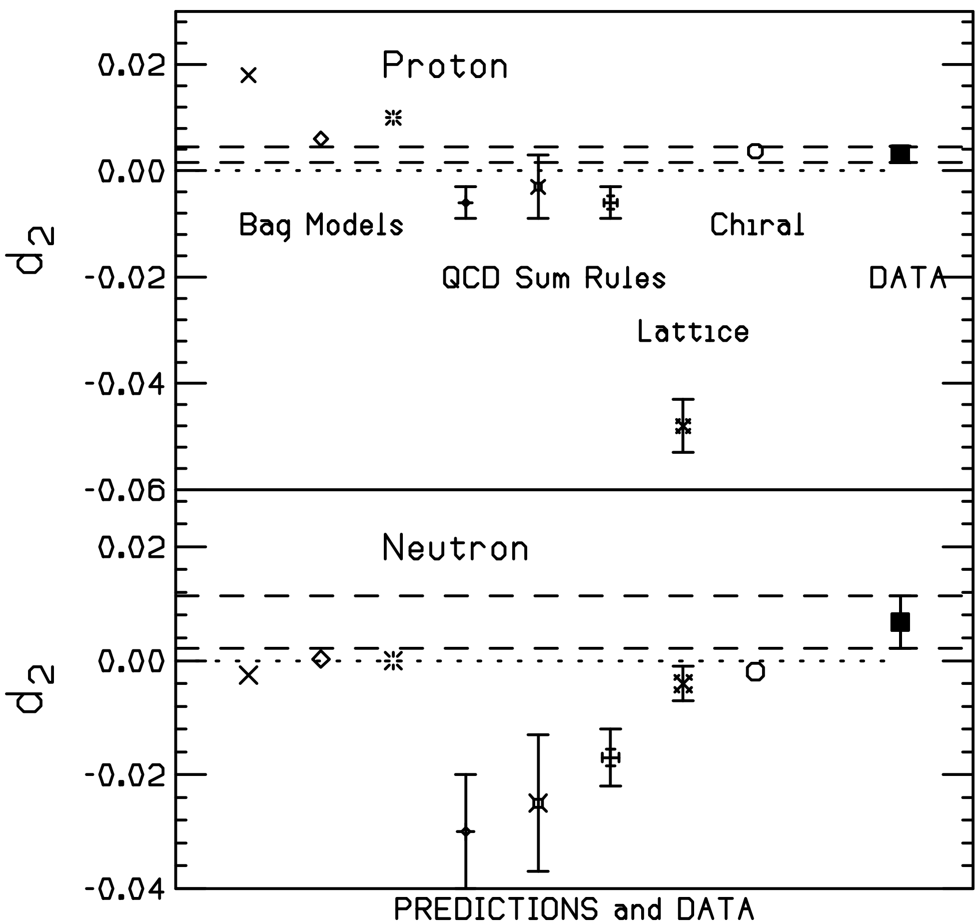

Figure 3. Preliminary results for the twist-3 matrix element d_2 from a fit to all available data (dominated by E155x) for both the proton and neutron. For comparison, the results of three bag model calculations [4,11,13], three QCD sum rule calculation [14–16], a lattice calculation [17], and a chiral soliton model [12] are also shown.

Figure 3 shows the experimental values of d_2 for proton and neutron with their error, plotted along with theoretical calculations using bag models (Song[4], Stratmann[11], and Ji[13]); QCD sum rules (Stein[14], BBK[15], Ehrnsperger[16]); chiral soliton model [12]; and lattice QCD[17]. As has already been seen, the preliminary proton result is inconsistent with the bag model of Song[4], and appears to be of opposite sign to the three QCD sum rule calculations. The lattice calculation has been re-done, but the revised results were not available at the time of this report. The E155x data has improved the error on the world data for d_2 by about a factor of three, allowing significant distinctions to be made between various models. However, caution should be used in drawing conclusions until the E155x data analysis is completed.

REFERENCES

1. E. Shuryak and A. Vainshtein, Nuc. Phys. B201 (1982) 141.
2. R. Jaffe and X. Ji, Phys. Rev. D 43 (1991) 724.
3. S. Wandzura and F. Wilczek, Phys. Lett. B 72 (1977) 195.
4. X. Song, Phys. Rev. D 54 (1996) 1955.
5. E143 collaboration: K. Abe *et al.*, Phys. Rev. Lett. 76 (1996) 587; Phys. Rev. D 58 (1998) 112003.
6. SMC collaboration: D. Adams *et al.*, Phys. Lett. B 336 (1994) 125; Phys. Lett. B 396 (1997) 338.
7. E155 collaboration: P. Anthony *et al.* Phys. Lett. B 458 (1999) 529.
8. M. Anselmino, A. Efremov, and E. Leader, Phys. Rept. 261 (1995) 1; Erratum-ibid. 281: (1997) 399.
9. NMC collaboration: M. Arneodo *et al.*, Phys. Lett. B 364, (1995) 107.
10. E143 Collaboration: K. Abe *et al.*, Phys. Lett. B 452 (1999) 194.
11. M. Stratmann, Z. Phys. C 60 (1993) 763.
12. H. Weigel, L. Gamberg, and H. Reinhart, Phys. Rev. D 55 (1997) 6910.
13. X. Ji and P. Unrau, Phys. Lett. B **333** (1994) 228.
14. E. Stein *et al.*, Phys. Lett. B **343** (1995) 369.
15. I. Balitsky, V. Braun and A. Kolesnichenko, Phys. Lett. B **242** (1990) 245; B **318** (1993) 648 (Erratum).
16. B. Ehrnsperger and A. Schafer, Phys. Rev. D52, 2709 (1995).
17. M. Göckeler *et al.*, Phys. Rev. D **53** (1996) 2317.