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Spin Physics Experiments at SLAC

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Abstract

Recent results from E155 and E155x on the g_1 and g_2 spin structure functions of the proton and neutron are presented. Plans for future experiments using polarized photon beams are discussed.

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1 Introduction

A brief summary of recent SLAC results for the g_1 and g_2 spin structure functions and related sum rules is presented. In line with the title of this conference, special attention is paid to the nuclear corrections needed to extract proton and neutron structure functions from NH_3 and LiD targets.

Three future experiments are planned at SLAC, all involving polarized photon beams. The physics prospects from these approved experiments is reviewed.

2 Results on g_1

The final results from SLAC E155 have now been published[1]. The structure functions g_1^p and g_1^n were measured in a single experimental setup over the large kinematic range $0.014 < x < 0.9$ and $1 < Q^2 < 40$ GeV^2 using deep-inelastic scattering of 48 GeV longitudinally polarized electrons from polarized protons and deuterons. The higher beam energy of E155 allowed a significant extension of the kinematic range of the earlier E143 experiment. The data indicate that the Q^2 dependence of g_1^p (g_1^n) at fixed x is very similar to that of the spin-averaged structure function F_1^p (F_1^n). Simple empirical fits to the data are given by

$$\frac{g_1^p}{F_1^p} = x^{0.700}(0.817 + 1.014x - 1.489x^2)(1 - \frac{0.04}{Q^2}) \tag{1}$$

$$\frac{g_1^n}{F_1^n} = x^{-0.335}(-0.013 - 0.330x + 0.761x^2)(1 + \frac{0.13}{Q^2}). \tag{2}$$

From an NLO QCD fit to all available data, E155 finds that the difference of first moments $\Gamma_1^p - \Gamma_1^n = 0.176 \pm 0.003 \pm 0.007$ at $Q^2 = 5$ GeV^2, in agreement with the Bjorken sum rule prediction of 0.182 ± 0.005. Using the same NLO pQCD fit, the quark singlet contribution in the $\bar{M}S$ scheme is $\Delta\Sigma = 0.23 \pm 0.04$(stat)$\pm 0.06$(syst) at $Q^2 = 5$ GeV^2, confirming earlier indications that quarks carry only a small fraction of the spin of the nucleon.

3 The g_2 structure function

3.1 The experiment

The recent (1999) experiment SLAC E155x made the best measurements of g_2 for the proton and deuteron to date. The final results have recently been submitted for be publication [2]. 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. We used transversely polarized NH_3 and ^{6}LiD targets as sources of polarized protons (average polarization 75%) and deuterons (average polarization 20%). 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.

3.2 Nuclear Corrections

The physics asymmetry $A(x, Q^2)$ was determined according to

$$A(x, Q^2) = \frac{R^{\uparrow\downarrow} - R^{\uparrow\uparrow}}{R^{\uparrow\downarrow} + R^{\uparrow\uparrow}} \frac{1}{C_1 P_B P_T f} + C_2 A_p(x, Q^2) \frac{\sigma_p}{\sigma_d} \tag{3}$$

where $P_B P_T f$ accounts for beam polarization, target polarization, and dilution factor. [Radiative corrections are also made]. The nuclear corrections are contained in the C_1 and C_2 terms, which depend only slightly on x and Q^2, and take into account scattering from nuclei other than free proton or deuterons in the solid polarized targets. For NH_3, $C_2 = 0$ by definition, and C_1 accounts for polarized ^{15}N, which is polarized opposite to free protons because it acts like single proton "hole" [3]. Numerically, $C_1 \approx 1 - 0.11 * P_N/P_p$ ranges from 1.01 to 1.04, where P_N (P_p) is the nitrogen (proton) polarization. The ratio P_N/P_p was measured as a function of P_p with a special NMR setup, and a fit was used to determine the C_1 correction for the varying values of P_p during the main E155x data taking. For LiD $C_1 \approx 1.86$ because the nuclear wave function of ^{6}Li is similar to 0.86 of a free polarized deuteron, plus a spectator unpolarized α particle [3]. The LiD material used in E155x contained 4% of the ^{7}Li isotope, which has an unpaired proton, and gives a non-negligible C_2 correction, which multiplies the measured proton asymmetry at the same (x, Q^2) at which the deuteron asymmetry is obtained. Typically, C_2 was -0.042 for E155x.

3.3 Results

Since the results for g_2 in the three spectrometers and two beam energies are reasonably consistent with the Q^2 dependence of the twist-two g_2^{WW} model, they are averaged together using this assumption to produce the averaged values shown in Fig. 1.

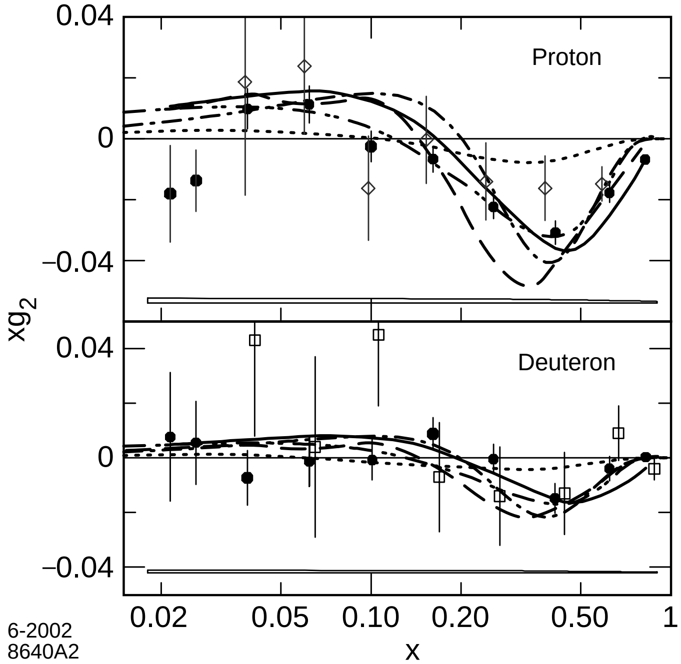

Figure 1: The structure function xg_2 averaged over the three spectrometers for E155x (solid circles), and data from E143 [4] (diamonds) and E155 [5] (squares). The errors are statistical; the systematic errors are shown at the bottom of each panel. Also shown is g_2^{WW} at the average Q^2 of this experiment at each value of x (solid curves) and the calculations of Stratmann [6] (dash-dot-dot), Gamberg and Weigel [7] (dash-dot), Song [8] (dot), and Wakamatsu[9] (dash).

The proton results are clearly different than zero, and exhibit an x-dependence similar to that of the g_2^{WW} model. There appear to be statistically significant differences from the g_2^{WW} model, possibly indicating non-zero twist-3 contributions. The data are in qualitative agreement with the bag model calculation of Stratmann [6] and the chiral soliton calculation of Gamberg and Weigel [7], but are considerably more negative than the model of Song [8]. 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 [6], and Gamberg and Weigel [7].

4 Future: $\Delta\sigma^{\gamma N}(k)$ and the High Energy Contribution to the GDH Sum Rule

An experiment (E159[12]) has recently been approved at SLAC to measure $\Delta\sigma^{\gamma N}(k)$, the helicity-dependent total photo-absorption cross section, for photon energies $5 < k < 40$ GeV, on both proton and deuteron targets. Our first goal is to complement our extensive set of measurements of g_1 at $Q^2 > 0$ with the anchor points at $Q^2 = 0$, useful for global fitting[11, 14] and understanding the low-x behavior. Our second goal is to test the convergence of the GDH sum rule [13],

$$\int_{k_\pi}^{\infty} \frac{dk}{k} \Delta\sigma^{\gamma N}(k) = \frac{2\pi^2\alpha\kappa^2}{M^2} \tag{4}$$

where M and κ are the nucleon mass and anomalous magnetic moment, and k_π is the threshold energy needed to produce at least one pion. Early indications from measurements in the resonance region are that the sum rule may already be over-saturated, requiring a sign change to $\Delta\sigma^{\gamma N}(k)$ for convergence.

We will use an untagged coherent bremsstrahlung beam to create a high flux of circularly polarized photons. With coherent bremsstrahlung, a set of high intensity spikes is generated by proper orientation of a diamond crystal radiator. With longitudinally polarized electrons, the incoherent bremsstrahlung photons are circularly polarized, with the polarization maximal at the endpoint. The coherent photons are elliptically polarized: the circular component is almost identical to that for incoherent photons. The coherent peak polarization also has a linear component which will cancel in the measurement of $\Delta\sigma^{\gamma N}(k)$, but will allow for the measurement of possibly interesting azimuthal asymmetries.

For targets, we will use polarized NH_3 and ND_3 as sources of polarized protons and neutrons. Polarized deuterons to first order allow measurements of the isovector combination $(n+p)/2$, with small corrections for the deuteron D-state, shadowing, and nuclear coherent hadron production. An extension to this proposal could use a polarized ^{3}He target to verify the consistency of $\Delta\sigma^{\gamma n}(k)$ for the neutron as extracted from either deuterium or ^{3}He. The detector is a simple calorimeter optimized to measure $> 98\%$ of all hadronic interactions, and to reject electromagnetic backgrounds.

The expected errors are shown in Fig. 2 for both the proton and neutron, and for two data taking modes, one involving counting each hadronic interaction individually, and one where only the total flux of hadrons for each helicity state is measured. Even with the larger counting mode statistical errors, a very good determination can be made of both the magnitude and energy dependence of $\Delta\sigma^{\gamma N}(k)$ for $5 < k < 40$ GeV. By measuring with both proton and deuteron targets, the high energy contributions to both the isovector and isoscalar GDH sum rules can be determined. This will allow tests of Regge-inspired models, which predict very different behavior for the isovector and isoscalar contributions, and will provide a baseline for studies of the polarized spin-structure functions measured with virtual photons.

5 Future: Polarized Charm Photoproduction and the Gluon Spin

Another approved SLAC experiment using the circularly polarized photon facility mentioned above is E161[15], designed to study the gluon spin structure of nucleons using open charm photoproduction. The measurements will utilize a ^{6}LiD polarized target to measure the asymmetry A_{cc} in open charm photoproduction. This process is dominated by the photon-gluon fusion mechanism. The open charm signal will be measured by detecting the muons from charm decay at large p_T. This experiment will measure the asymmetry A_{cc} over a range of energies and p_T sensitive to x from 0.1 to 0.3 with statistical precision of about 0.01. This is to be compared with the range of

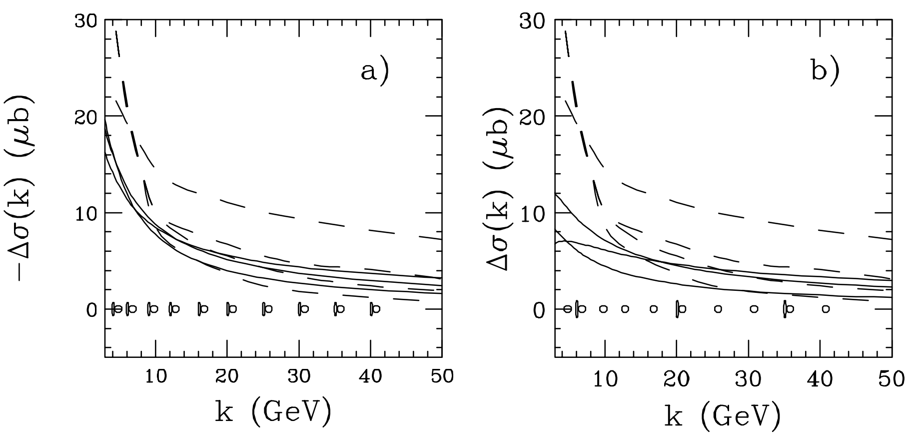

Figure 2: a) Projected proton error bars for $\Delta\sigma^{\gamma p}(k)$ for E159 as a function of photon energy for the counting mode (rectangles) and flux integration mode (circles). The dashed curves are representative models from Ref. [14], the solid curves are from Ref. [11]; b) same but for the neutron as measured with ND_3.

current theoretical models in which the values of A_{cc} differ by more than 0.1 and $x\Delta g(x)$ differ by up to 0.3 in this x range.

Figure 3 shows the expected statistical error on A_{cc} as as function of p_T^μ for $5 < P_\mu < 10$ GeV for three incident photon coherent peak energies. The points are arbitrarily plotted at a value of zero. Also shown are the calculated asymmetries from a sample of gluon polarization models. The systematic errors of 10% of the value of the asymmetry (typical error 0.01) will be highly correlated point-to-point. There will be additional data for higher momentum muons. Our statistical errors are projected to be significantly smaller than the similar COMPASS experiment[16] at CERN, but our lower photon energies correspond to larger values of x for the gluons.

The E161 experiment will also measure the double spin asymmetry for elastic and inelastic photoproduction of closed charm (J/ψ particles). The latter may also yield interesting information on the gluon spin, if the relative contributions from color singlet and color octet mechanisms can be reliably modeled.

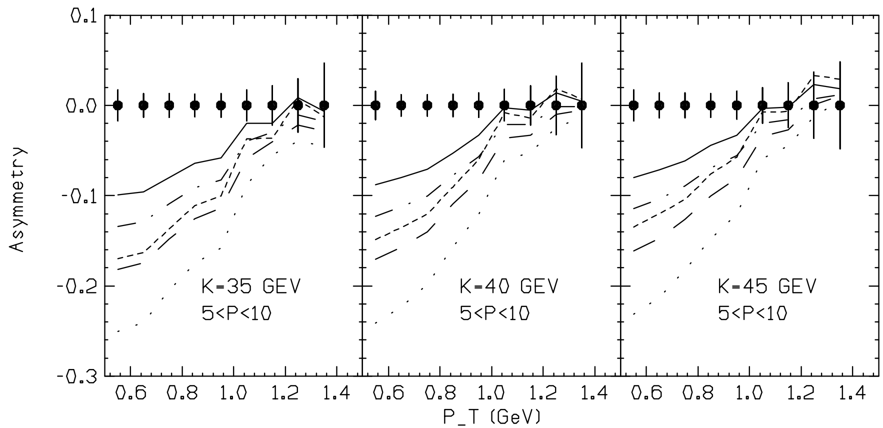

Figure 3: The E161 projected statistical errors on the asymmetry A_{cc} for open charm production as a function of p_T^μ of the detected muon for $5 < P_\mu < 10$ GeV. Also shown are asymmetries for several gluon polarization models.

6 Future: Linear Polarization Asymmetry in Charm Photoproduction

A third planned experiment at SLAC, E160[17], will use unpolarized electrons to make coherent bremsstrahlung beams at 15, 25, and 35 GeV. These photons will have a fairly high degree of linear polarization. While the main goal of the experiment is to measure the A-dependence of J/ψ and ψ' quasi-elastic photoproduction, we will also measure the linear polarization single-spin asymmetry for nuclear coherent, quasi-elastic, and inelastic J/ψ photoproduction "for free". At present, I do not know of any predictions for these asymmetries. However, there is a QCD prediction[18] for open charm photoproduction at our photon energies: the single-spin asymmetry is predicted to be large, at about 0.2, and unlike the cross section itself, is quite stable against higher order QCD corrections. We can identify open charm events in our muon spectrometer by single muons with transverse momenta near 1 GeV, where the backgrounds from π, K, and J/ψ decays are the smallest, or as two like-sign muons. Preliminary estimates are that we can measure the linear polarization asymmetry with a statistical error of about 0.02 or better, which would provide a meaningful test of the prediction. It would be very nice if calculations could be done for the closed charm case: this may be a good way to learn about the relative importance of color singlet and color octet mechanisms.

7 Summary

The recent SLAC data on g_1 and g_2 have provided significant new information of the spin structure of the nucleon. Future experiments using polarized photon beams should provide insight into the role of gluon polarization in the nucleon, and the behavior of the spin structure functions in the limit of $Q^2 = 0$.

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