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SLAC MEASUREMENT OF THE NEUTRON SPIN STRUCTURE FUNCTION

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ABSTRACT

A measurement of the nucleon spin asymmetries from deep inelastic scattering of polarized electrons by polarized ^{3}He has been performed. The neutron spin structure function g_1^n is extracted and used to test the Bjorken sum rule. The neutron integral assuming a simple Regge theory extrapolation at low x is $\int_0^1 g_1^n(x)dx = -0.022 \pm 0.011$. Combined with the EMC proton results, the Bjorken sum rule predicts a neutron integral of $\int_0^1 g_1^n(x)dx = -0.065 \pm 0.018$.

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In 1988 the European Muon Collaboration (EMC) at CERN reported on the measurement of the proton spin structure function [1] which violated a Quark Parton Model (QPM) sum rule derived by Ellis and Jaffe [2]. The first responses attributed the violation as evidence that the proton strange sea is highly polarized. However, hundreds of theoretical papers followed with explanations ranging from large gluon and angular momentum contributions to the breakdown of QCD itself. The 'proton spin crisis' was born.

The natural follow up to understanding the proton spin problem is to measure the neutron spin structure function. The neutron measurement has a special significance in that not only does it give complementary information for interpreting the internal nucleon spin structure, but the combined proton and neutron results allow for a test of a "foundation" QCD sum rule derived from Bjorken [3]. First presentations of the neutron spin structure function extracted from scattering polarized leptons off polarized deuterium (CERN) and polarized ^{3}He (SLAC) were given at this conference. This paper describes the SLAC experiment and results.

SLAC experiment E142 involved scattering 19 to 26 GeV longitudinally polarized electrons off a longitudinally polarized ^{3}He gas target. Polarized ^{3}He was used to extract the neutron information, since the two proton spins in the ^{3}He nucleus largely align themselves anti-parallel to one another due to the Pauli exclusion principle. Electrons scattered from the target were detected in two single arm spectrometers at scattering angles of 4.5° and 7° (Fig. 1). The two chosen scattering angles yield a measurement of the neutron spin structure function $g_1^n(x, Q^2)$ over a large range of x ($0.03 < x < 0.6$) at reasonably high Q^2 ($Q^2 > 1\ GeV^2$). The low forward scattering angles yield a high counting rate for the experiment.

The experiment collected data for a total of five weeks and produced approximately 350 hours of data to tape. The electron beam current was high with a typical value of 2 μA, and the beam polarization remained stable at 40%. The polarized ^{3}He target was large (30 cm long), had thin glass windows (each 0.1 mm thick) and a large ^{3}He density (9 atmospheres). The target was polarized using the method of spin exchange collisions with optically pumped rubidium vapor [4]. This was the first polarized ^{3}He target with such a large size and was designed specifically for this experiment. Among the major accomplishments was the operation of the

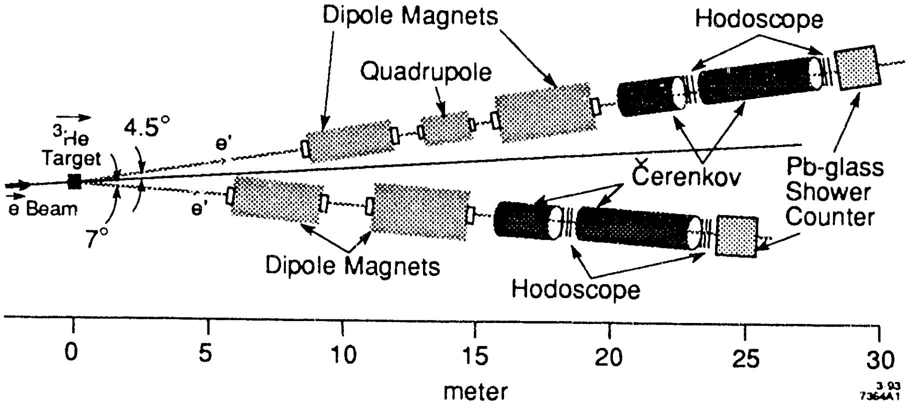

Figure 1. Experimental set up of the two single arm spectrometers.

target in a vacuum to reduce background from unpolarized scattering and the operation of five sets of Argon ion pumped Ti:sapphire laser systems for maintaining the target polarization. The target's polarization in the presence of the electron beam was between 30% and 40%.

The primary goal of the analysis of the experiment was to extract the polarized virtual photon-nucleon asymmetries:

$$A_1(x,Q^2) = \frac{\sigma^{1/2}(x,Q^2) - \sigma^{3/2}(x,Q^2)}{\sigma^{1/2}(x,Q^2) + \sigma^{3/2}(x,Q^2)}$$

where $\sigma^{1/2(3/2)}$ is the cross-section for scattering a virtual photon with spin parallel (anti-parallel) to the target nucleon spin. The quantities x and Q^2 are the Bjorken scaling variables. From the measurement of $A_1^n(x,Q^2)$, the neutron spin structure function is determined (ignoring small corrections):

$$g_1^n(x,Q^2) \sim \frac{A_1^n(x,Q^2)F_2^n(x,Q^2)}{2x(1+R(x,Q^2))}$$

where F_2^n is the unpolarized neutron structure function and R is the ratio of longitudinal to transverse neutron structure functions.

From the measured asymmetries, small corrections due to the polarization of the neutron in ^{3}He ($\sim$ 87%) and the polarization of the two protons ($\sim -2.7\%$ each) were applied [5,6]. Table 1 gives a breakdown of the primary systematic uncertainties effecting the neutron integral. The average Q^2 of the experiment is 3 GeV^2 whereas the Q^2 of the average non-zero contribution to the neutron integral is $\sim$ 2 GeV^2. No other nuclear corrections were applied. Figure 2 presents A_1^n and g_1^n as a function of x. A clear negative neutron spin structure function is evident at moderately low x. Over the measured range of x, we find $\int_{0.03}^{0.6} g_1^n(x)dx = -0.019 \pm 0.007$ (*stat*) ± 0.006 (*syst*). Extrapolating the integral over the entire range of x from 0 to 1 gives an additive contribution of -0.006 ± 0.006 at low x and 0.003 ± 0.003 at high x. This yields the result $\int_0^1 g_1^n(x)dx = -0.022 \pm 0.011$. We have taken a simple Regge theory extrapolation ($A_1^n \sim x^{1.2}$) [7] to extract the integral from x of 0.03 to zero. Extrapolations of the results at low x outside the quoted error are possible, but imply a significantly different functional dependence in the extrapolation [8].

Table 1. Values of significant systematic errors which contribute to the uncertainty in the value of $\int g_1^n(x)dx$.

Systematic Uncertainties	
Uncertainty	$\Delta \int g_1^n(x)dx$
Beam polarization	0.001
Target thickness	0.003
R	0.001
Deadtime	0.001
Target polarization	0.002
F_2^n	0.002
Radiative corrections	0.002
A_2^n	0.003
TOTAL	0.006

Interpretation of the E142 result in the Quark Parton Model assuming SU(3) flavor symmetry gives a spin contribution of the up, down and strange quarks of $\Delta u = 0.93 \pm 0.06$, $\Delta d = -0.35 \pm 0.04$, $\Delta s = -0.01 \pm 0.06$, and a total quark contribution of $\Delta q = 0.57 \pm 0.11$. Therefore, approximately half the nucleon spin is carried by the quarks and the strange sea polarization is small. In order to derive these values, we have used the updated values for the hyperon decay constants of F = 0.47 ± 0.04 and D = 0.81 ± 0.03 [9]. These results are

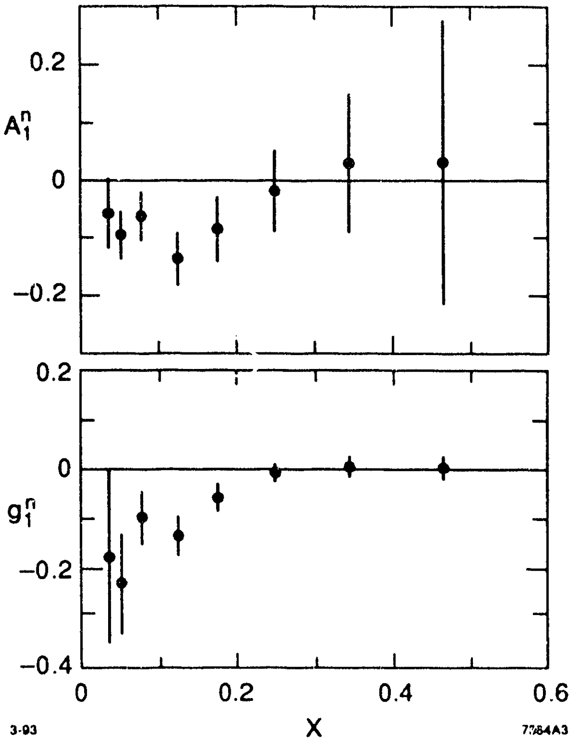

Figure 2. Results for neutron asymmetries, A_1^n and the neutron spin structure function, g_1^n, as a function of x averaged over Q^2. Statistical and systematic error bars are added in quadruture.

in contradiction to the EMC and SMC results which predict a large strange quark polarization (~ −20%) and essentially no total quark contribution to the proton spin. Part of the discrepancy (~ 1σ) is due to the change in the values of the F and D constants [9].

Taken verbatim, the E142 result in conjunction with the EMC result on the proton differs by about two standard deviations from the Bjorken sum rule prediction when only leading order QCD corrections are applied. From the experiments $\int_0^1 g_1^p(x)dx - \int_0^1 g_1^n(x)dx = 0.148 \pm 0.022$ as compared to the Bjorken sum rule prediction that $\int_0^1 g_1^p(x)dx - \int_0^1 g_1^n(x)dx = 0.187 \pm 0.004$, where the last uncertainty comes from the difference in Q^2 range of the E142 and EMC experiments. Application of QCD corrections to the Bjorken sum rule up to third order in α_s [10] appears to bring the discrepancy down to ~ 1.5 standard deviations.

It is still unclear whether experimental results or theoretical issues (low x extrapolation, PQCD corrections, higher twist effects) are the cause of the remaining small discrepancy. The motivation to remeasure the proton with higher precision is, however, evident.

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