SLAC–PUB–5641
August 1991
(E)

MEASUREMENT OF THE NEUTRON SPIN STRUCTURE FUNCTION—TEST OF THE BJORKEN SUM RULE [*]

Gerassimos G. Petratos[**]
Stanford Linear Accelerator Center
Stanford University, Stanford, CA 94309

An experiment to measure the neutron spin-dependent structure function $g_1^n(x)$ over a range in x from 0.04 to 0.7 and with $Q^2 > 1$ $(\mathrm{GeV/c})^2$ is presented. The experiment consists of scattering a longitudinally polarized electron beam from the Stanford Linear Accelerator off a polarized ^{3}He target and detecting scattered electrons in two magnetic spectrometers. The experiment will provide a critical test of the Bjorken sum rule and valuable information in understanding the nucleon spin structure and the violation of the Ellis-Jaffe sum rule.

A few years ago the EMC group measured [1] the proton spin-dependent structure function $g_1^p(x)$ in a range over the Bjorken scaling variable x wide enough to calculate reliably $\int_0^1 g_1^p(x)dx$. The experimental result was found to disagree with the Ellis-Jaffe sum rule [2] based on quark current algebra and isospin symmetry, that assumed that the net polarization of the strange quark sea is zero. Assuming the validity of the Bjorken sum rule [3] and exact flavor SU(3) symmetry in the decays of the members of the baryon octet, the EMC data lead to two surprising conclusions: (1) that the quarks carry only a small fraction of the proton spin, consistent with zero within the experimental uncertainties and (2) that a rather large and negative contribution to the proton spin should be attributed to the strange quark sea. The Bjorken sum rule:

$$\int_0^1 \left[g_1^p(x) - g_1^n(x)\right]dx = \frac{1}{6}\left|\frac{g_A}{g_V}\right| \left[1 - \frac{\alpha_s(Q^2)}{\pi}\right], \tag{1}$$

where α_s is the QCD coupling constant, relates the nucleon spin structure functions to the ratio $|g_A/g_V|$ of the axial to vector weak coupling constants of the nucleon beta decay. It is regarded as a fundamental QCD sum rule based only on quark current algebra with the standard quark charge assignments and on isospin symmetry.

---

[*] Work supported by the US Department of Energy contract DE-AC03-76SF00515.

[**] To be presented on behalf of the SLAC E142 collaboration at the 13th European Conference on Few-Body Problems in Physics, Isola d' Elba, Italy, September 9–14, 1991.

The unexpected EMC result has lead to extensive discussions about the structure of the proton spin and possible explanations. Some of the questions raised include the validity of the extrapolation of $g_1^p(x)$ for $x \to 0$ and the validity of the Bjorken sum rule and perturbative QCD. The principal explanations proposed are: (a) that the nucleon spin is due to orbital angular momentum contributions from the quarks, a notion explained within the Skyrme model of the nucleon and (b) that the gluons contribute substantially to the nucleon spin. Recent reviews of many old and new theoretical developments on the subject are given in Ref. [4]. On the experimental front, the EMC result has generated a series of recently proposed or planned high precision measurements in the U.S. [5,6] and in Europe [7-9] on the neutron and proton spin-dependent structure functions using a variety of polarized targets (gas ^{3}He, NH_3, ND_3, butanol, deuterated butanol, gas hydrogen and gas deuterium).

This paper describes an approved experiment at SLAC [5] to extract the neutron spin-dependent structure function $g_1^n(x)$ by measuring the cross section asymmetries:

$$A_{\parallel} = \frac{\sigma(\uparrow\Uparrow) - \sigma(\uparrow\Downarrow)}{\sigma(\uparrow\Uparrow) + \sigma(\uparrow\Downarrow)} = \frac{1-\epsilon}{(1+\epsilon R)W_1} \left[(E + E'\cos\theta)MG_1 - Q^2 G_2\right] \qquad (2)$$

$$A_{\perp} = \frac{\sigma(\uparrow\Rightarrow) - \sigma(\uparrow\Leftarrow)}{\sigma(\uparrow\Rightarrow) + \sigma(\uparrow\Leftarrow)} = \frac{(1-\epsilon)E'}{(1+\epsilon R)W_1} \left[(MG_1 + 2EG_2)\sin\theta\right] \qquad (3)$$

in deep inelastic scattering of polarized electrons from polarized neutrons, where $\uparrow, \downarrow$ denotes the longitudinal spin of the incoming electron (along or opposite its direction of motion) and $\Uparrow, \Downarrow$ or $\Leftarrow, \Rightarrow$ denotes the longitudinal or transverse spin of the target nucleon. The asymmetries are functions of kinematics (E and E' are the incident and scattered electron energies, θ is the scattering angle, $\epsilon = [1 + 2(1 + \nu^2/Q^2)\tan^2(\theta/2)]^{-1}$), of the unpolarized structure functions W_1 and W_2 connected via $R = (1+\nu^2/Q^2)W_2/W_1 - 1$ and of the polarized structure functions G_1 and G_2, which in the Bjorken scaling limit of large momentum $Q^2 = 4EE'\sin^2(\theta/2)$ and energy $\nu = E - E'$ transfers, become functions only of $x = Q^2/2M\nu$: $M^2\nu G_1(x, Q^2) \to g_1(x)$, $M\nu^2 G_2(x, Q^2) \to g_2(x)$.

Polarized electrons of 22.7 GeV energy and 5μA intensity will be produced by a laser optically pumped GaAs source presently being built for the Stanford Linear Collider. This type of source, used successfully in the electron-deuteron scattering parity violation experiment [10], is capable of providing high intensity beams (in excess of 5×10^{11} electrons per 1.6 μs long pulse at 120 Hz) with an average polarization near 40%. The helicity of the beam can be reversed randomly on a pulse-to-pulse basis by reversing the circular polarization of the excitation photons. The beam polarization will be monitored during the experiment by performing Møller scattering from magnetized Permendur foils and measuring the outgoing electrons at 90° in the CM frame in a magnetic spectrometer consisting of a dipole magnet and a calorimeter.

The experiment will use a polarized ^{3}He target. The nucleon spin structure of a polarized ^{3}He target is the same as a polarized free neutron target to the extend that the ^{3}He nucleus is in its space-symmetric S state. In this state, the two proton spins are aligned antiparallel due to the Pauli exclusion principle, implying that scattering from a polarized ^{3}He nucleus represents scattering from a polarized neutron. The presence of some D state admixture in the ^{3}He ground state complicates the above picture by introducing a polarized proton component in the total polarization of the nucleus. Theoretical calculations [11] have shown that this component has a small effect in the cross section asymmetry measurements and that the theoretical uncertainty in extracting the spin structure function $g_1^n(x)$ is small.

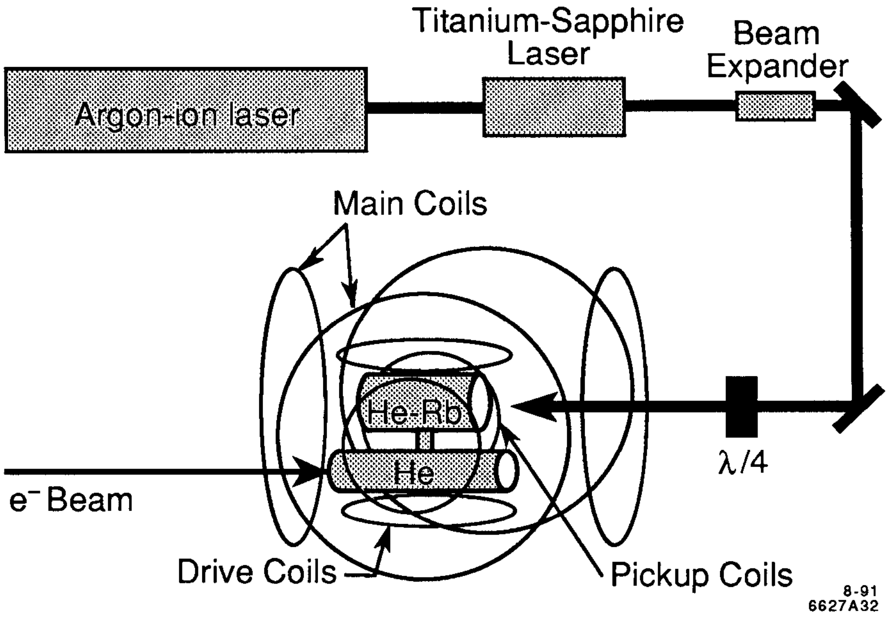

Fig. 1: The polarized ^{3}He target system.

The target is based on the technique of ^{3}He polarization by spin exchange with Rb vapor [12]. The Rb atoms are polarized via laser optical pumping by absorbing circularly polarized photons at a wavelength of 795 nm. The spin exchange from Rb to ^{3}He occurs due to the hyperfine interaction between the polarized valence electron of Rb and the ^{3}He nucleus. The ^{3}He nuclear polarization is measured by means of NMR adiabatic fast passage [12] and by observing the frequency shift caused in the electron-paramagnetic-resonance line of the Rb by the polarized ^{3}He [13].

The major elements of the target system are shown in Fig. 1. To avoid Rb depolarization by the beam, the optical pumping region is separated from the bombardment region by using a dual target cell. The main cell is a 30 cm glass tube, containing a ^{3}He density of 3×10^{20} cm^{-3} at 10 atm and a density of $\sim3\times10^{18}$ cm^{-3} of N_2. The N_2

is necessary for non-radiatively quenching the Rb excited state populated by the absorption of the laser light. The pumping cell contains several milligrams of Rb metal and is heated to ~180°C to obtain the desired density of Rb vapor. The axis of quantization for polarization is established by the magnetic field produced by the two main Helmholtz coil sets. The drive and pickup coils are used for the ^{3}He polarization measurements. The lasers for optical pumping are four solid state titanium-sapphire lasers, each pumped by an argon-ion laser and producing greater than 20 watts of power.

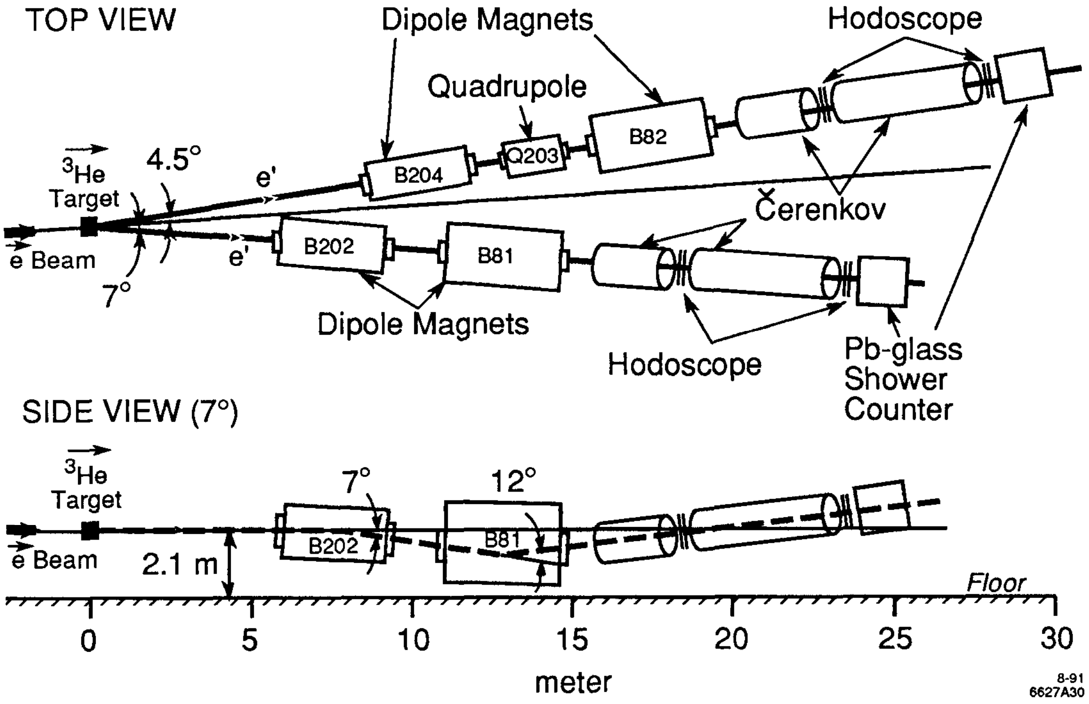

Fig. 2: The magnetic spectrometer system.

Scattered electrons of 7 to 18 GeV in energy will be detected in two magnetic spectrometers centered at 4.5° and 7° respectively, as shown in Fig. 2. Each spectrometer is based on two large aperture dipole magnets bending in opposite directions. This 'reverse' deflection design doubles the solid angle, integrated over the 7-18 GeV/c range, of the conventional design of same direction bending, used in previous polarized electron scattering experiments at SLAC [14]. The solid angle of the 4.5° arm is 0.2 msr and of the 7° arm is 0.7 msr. Proper choice of the deflection angles and the distance between the two magnets in each spectrometer allow background photons from radiative processes to reach the detectors only after having bounced twice on the spectrometer vacuum walls, resulting in an expected tolerable background. Each spectrometer is equipped with a pair of Čerenkov detectors, a pair of scintillator hodoscopes and a lead-glass shower calorimeter providing electron and pion identification with ~ ±2% momentum resolution, sufficient for the asymmetry measurements.

The experiment is expected to be limited by systematic uncertainties. Their percentage contributions on $\int g_1^n(x)dx$ have been estimated assuming that it has the value -0.07 as predicted by the Bjorken sum rule in conjunction with the EMC result on $\int g_1^p(x)dx$. The beam polarization measurement is inherently limited to ~ ±5% by a background subtraction of the signal and an uncertainty in the amount of the Møller target foil spin magnetism. The ^{3}He target polarization measurement is limited to ~ ±5% by the uncertainty in the density of ^{3}He in the cell and in the absolute calibration as compared to a water sample. The uncertainty in the dilution factor (the ratio of the polarizable to the total number of nucleons) is dominated by the uncertainty in the thickness of the glass cell walls and in the ^{3}He density and is ~ ±5%. The experimental uncertainties in the measurement of the unpolarized W_2^n structure function (~ ±5%) and of the ratio R (~ ±2%) in the kinematic regime of this experiment are directly translated as uncertainties in the $g_1^n(x)$ measurement. Radiative corrections uncertainties (~ ±2%) are not expected to contribute in a sizable way to the asymmetry measurements.

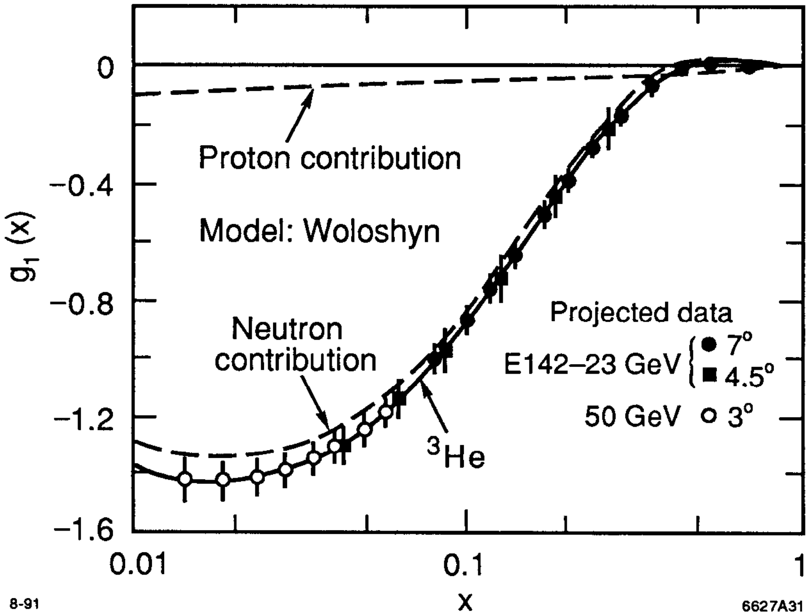

Fig. 3: Projected data for the neutron spin structure function $g_1^n(x)$.

The projected statistical accuracy of the experiment is shown for 100/10 hours of running with longitudinal/transverse target polarization in Fig. 3, assuming that $g_1^n(x)$ follows the model of Ref. [11]. The figure also shows the small correction factor relating the neutron spin structure function $g_1^n(x)$ to that of ^{3}He. The experiment will also provide a crude (statistically limited) measurement of the $g_2^n(x)$ structure function, not shown in the figure. The different contributions to the total (±15%) projected uncertainty on the Bjorken sum rule are shown in Table 1, where a conservative theoretical error of ±20% on the extraction of $\int g_1^n(x)dx$ from that of ^{3}He has been assumed.

Table 1: Expected uncertainties on the Bjorken sum rule test.

Quantity	Type of Uncertainty	Value
$\int g_1^n(x)dx$	Statistical	±.004
$\int g_1^n(x)dx$	Systematic	±.010
$\int g_1^n(x)dx$	Total experimental	±.012
$\int g_1^n(x)dx$	Theoretical	±.016
$\int g_1^n(x)dx$	Total experimental and theoretical	±.020
$\int g_1^p(x)dx$	Experimental (EMC)	±.021
$\int [g_1^p(x) - g_1^n(x)]dx$	Combined TOTAL	±.03

Future measurements at SLAC will provide a better measurement of $g_2^n(x)$ as well as measurements at lower x values. Such projected measurements on $g_1^n(x)$ using a planned upgraded beam energy of 50 GeV [15] are also shown in Fig. 3. These measurements assume the same running conditions, for 3° scattering, using the new generation of polarized guns (> 70% beam polarization) being developed [16]. In summary, this experiment is expected to make significant new measurements on the neutron spin structure, and together with other proposed experiments, should provide precise tests of the Bjorken sum rule and of our understanding of the spin structure of the nucleons.

REFERENCES

[1] J. Ashman *et al.,* Nucl. Phys. **B 328**, 1 (1989).

[2] J. Ellis and R. L. Jaffe, Phys. Rev. **D 9**, 1444 (1974); **D 10**, 1669 (1974).

[3] J. D. Bjorken, Phys. Rev. **148**, 1467 (1966); **D 1**, 1376 (1970).

[4] G. Altarelli, CERN preprint CERN–TH–5675/90 (1990) ; G. G. Ross, Oxford University preprint OUTP–89–39P (1989).

[5] SLAC Proposal E142, E. W. Hughes *et al.,* (1989).

[6] J. S. McCarthy and C. Y. Prescott, private communication.

[7] CERN Proposal CERN/SPSC 88–47, V. W. Hughes *et al.,* (1988).

[8] DESY Proposal PRC 90/1, R. Milner, K. Rith *et al.,* (1990).

[9] CERN Letter of Intent CERN/LEPC 88–16, L. Dick *et al.,* (1988).

[10] C. Y. Prescott *et al.,* Phys. Lett. **B 77**, 347 (1978); **B 84**, 524 (1979).

[11] R. M. Woloshyn, Nucl. Phys. **A 496**, 749 (1989).

[12] T. E. Chupp *et al.,* , Phys. Rev. **C 36**, 2244 (1987).

[13] S. R. Schaefer *et al.,* Phys. Rev. **A 39**, 5613 (1989).

[14] G. Baum *et al.,* Phys. Rev. Lett. **51**, 1135 (1983).

[15] C. Y. Prescott, private communication.

[16] T. Maruyama *et al.,* Phys. Rev. Lett. **66**, 2376 (1991).