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DETERMINATION OF THE NEUTRON SPIN-STRUCTURE FUNCTION*

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ABSTRACT

The neutron spin-structure function g_1^n has been determined by measuring the asymmetry in deep inelastic scattering of polarized electrons off a polarized ^{3}He target. The results are interpreted in the quark-parton model and used, in conjuction with earlier proton results, to test the Bjorken sum rule.

A measurement of the neutron spin-structure function g_1^n at SLAC by deep inelastic scattering of a polarized electron beam off a polarized ^{3}He target is reported. A similar measurement [1] on the proton g_1^p performed by the EMC Collaboration at CERN led to two surprising conclusions: i) that the amount of the proton spin carried by the valence quarks is consistent with zero, and ii) that the strange quark sea is highly polarized.

The goal of the new measurement[2] was to obtain complimentary data to the CERN experiment and to test the Bjorken sum rule[3] that relates the nucleon spin-structure functions to the ratio $\mid g_A/g_V \mid$ of the nucleon β-decay weak coupling constants,

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

where α_s is the QCD coupling constant, $x = Q^2/(2M\nu)$ is the Bjorken scaling variable, Q^2 and ν are the four momentum and energy transfers in the scattering process and M is the nucleon mass. The Bjorken sum rule is a fundamental QCD sum rule based only on quark-current algebra and isospin symmetry.

The spin-structure function $g_1 = \sum z_i^2 \left[q_i^{\uparrow}(x) - q_i^{\downarrow}(x)\right]/2$ where $q_i^{\uparrow}(x)\left(q_i^{\downarrow}(x)\right)$ is the quark distribution function of flavor i and charge z_i whose helicity is parallel (anti-parallel) to that of the nucleon, and the physics asymmetry A_1, which is a measure of the probability that the quark spins are aligned with the nucleon spin, were extracted by measuring the cross section asymmetries:
$A_{\|} = \left[\sigma(\uparrow\Uparrow) - \sigma(\uparrow\Downarrow)\right]/\left[\sigma(\uparrow\Uparrow) + \sigma(\uparrow\Downarrow)\right], A_{\perp} = \left[\sigma(\uparrow\Rightarrow) - \sigma(\uparrow\Leftarrow)\right]/\left[\sigma(\uparrow\Rightarrow) + \sigma(\uparrow\Leftarrow)\right].$
Here, $\uparrow, \downarrow$ denotes the longitudinal spin of the incoming electron (along or opposite to the direction of its motion) and $\Uparrow, \Downarrow$ or $\Rightarrow, \Leftarrow$ denotes the longitudinal or transverse spin of the target nucleon. Details on the relevant formalism are given in Ref. 2.

Polarized electrons with energy of 19 to 26 GeV were created by photo-emission from an AlGaAs photocathode illuminated by photons from a flash-lamp pumped dye laser.[4] The incident electron helicity was randomly reversed on a pulse-to-pulse basis. Polarization was measured by Møller scattering: a spectrometer consisting of a dipole magnet and a set of proportional tubes detected electrons scattered elastically off polarized electrons in a magnetized ferromagnetic foil. Polarization was found to be stable over the duration of the experiment, with an average value of about 39%.

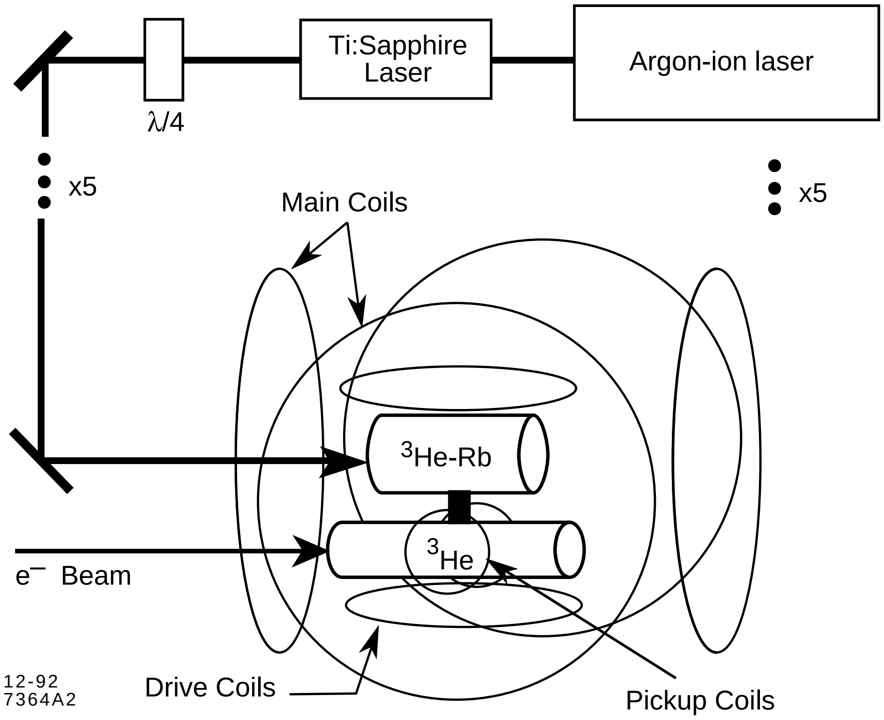

Fig. 1) The polarized ^{3}He target.

The polarized target (see Fig. 1) consisted of a double-chambered glass cell filled with ^{3}He gas. The upper cell contained a small amount of rubidium vapor. Near-infrared light from a set of high-power lasers was directed to the upper cell and polarized the rubidium valence electrons. ^{3}He was polarized in spin-exchange collisions with the rubidium vapor. The spin orientation (parallel or transverse to the beam) was achieved by an external magnetic field provided by two sets of Helmholtz coils. Drive and pick up coils were used to measure the ^{3}He polarization by NMR techniques. The average polarization of ^{3}He was approximately 35%.

Scattered electrons with energy of 7 to 20 GeV were detected in two similar magnetic spectrometers (see Fig. 2) based on an S-bend design.[5] Each spectrometer was equipped with a pair of gas-threshold Čerenkov counters for electron identification, and a scintillator hodoscope and a lead glass calorimeter for measuring the scattered electron angle and energy.

The asymmetry A_1^n and the spin-structure function g_1^n were extracted assuming a polarization of 87% (-3%) for the neutron (each proton) in ^{3}He. The results[2] are plotted as a function of x in Fig. 3. The integral of g_1^n over the measured x range is $\int_{0.03}^{0.6} g_1^n(x)dx = -0.019 \pm 0.007$ (stat.) ± 0.006 (syst.) at an average Q^2 of 2 (GeV/c)^2. The same result occurs when the integral is evaluated at a constant Q^2 of 2 (GeV/c)^2, assuming that the asymmetry A_1^n is independent of Q^2.

Corrections to the integral for the unmeasured $x < 0.03$ and $x > 0.6$ regions were made, assuming that A_1^n: a) at low x follows a simple Regge theory parameterization ($A_1^n \sim x^{1.2}$); and, b) at high x approaches 1 as suggested by perturbative QCD and quark models. The extrapolation at low x amounted to

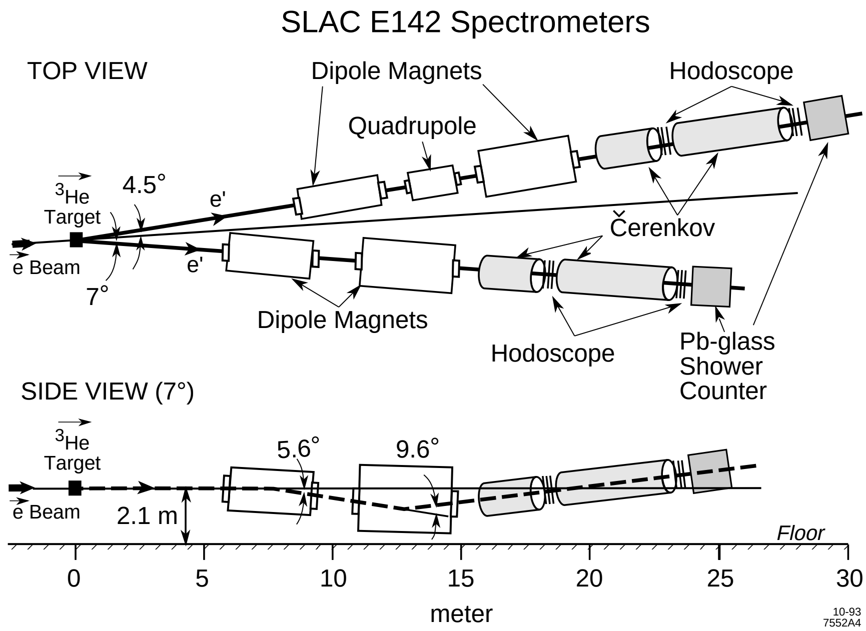

Fig. 2) The magnetic spectrometer systems.

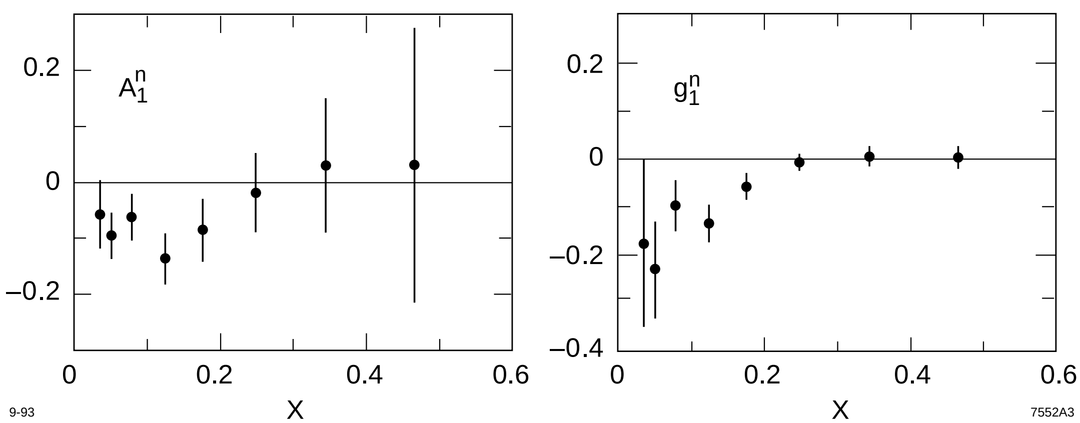

Fig. 3) The structure function g_1^n and the asymmetry A_1^n.

-0.006 ± 0.006, and at high x amounted to $+0.003 \pm 0.003$, resulting in the final result: $\int_0^1 g_1^n(x)dx = -0.022 \pm 0.011$. This result is in agreement with an updated value of -0.021 ± 0.018 of the Ellis-Jaffe neutron sum rule[6] which assumes that the strange sea polarization is zero. It is also consistent with a measurement[7] by the SMC CERN Collaboration $\int_0^1 g_1^n(x)dx = -0.08 \pm 0.06$.

In the quark-parton model, the integral $\int_0^1 g_1^n(x)dx$ is related to the individual integrals of quark distributions $\Delta q \equiv \int_0^1 [q^{\uparrow}(x) - q^{\downarrow}(x)]dx$, where the arrows represent spins parallel and antiparallel to the nucleon spin, by

$$\int_0^1 g_1^n(x)dx = \frac{1}{2}\left[\frac{4}{9}\Delta u + \frac{1}{9}\Delta d + \frac{1}{9}\Delta s\right]\left(1 - \frac{\alpha_s(Q^2)}{\pi}\right) .$$

This relation, in conjunction with the SU(3) flavor symmetry relationship $\Delta d - \Delta s = F - D$, and the neutron beta decay relationship $\Delta u - \Delta d = F + D$, can be used to separate the three quark distributions. Using $F = 0.47 \pm 0.04$ and $D = 0.81 \pm 0.03$ from Ref. 8, we obtain $\Delta u = 0.93 \pm 0.06$, $\Delta d = -0.35 \pm 0.04$, and $\Delta s = -0.01 \pm 0.06$, implying that the quarks contribute approximately one half of the nucleon spin ($\Delta u + \Delta d + \Delta s = 0.57 \pm 0.11$), and that the strange sea contribution is consistent with zero. Orbital angular momentum[9] and the spin of the gluons[10] may account for the other half.

Combining the neutron $g_1^n(x)$ integral with the proton $g_1^p(x)$ integral from the EMC experiment corrected to $Q^2 = 2$ (GeV/c)^2 gives

$$\int_0^1 \left[g_1^p(x) - g_1^n(x)\right]dx = 0.146 \pm 0.021 ,$$

in an apparent two standard deviation discrepancy with a Bjorken sum rule prediction of 0.183 ± 0.007 at the same Q^2 value. Higher-order QCD corrections[11] and higher-twist effects[12] may account for the discrepancy that has been the subject of recent intense theoretical investigations.[13]

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