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NEUTRON SPIN STRUCTURE EXPERIMENTS AT JEFFERSON LAB*

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Two experiments at Jefferson Lab have recently measured the neutron asymmetry A_1^n at $0.3 \leqslant x_{\mathrm{Bj}} \leqslant 0.6$ and the neutron spin structure function g_2^n at $x_{\mathrm{Bj}} \simeq 0.2$ ($0.6\ \mathrm{GeV}^2 \leqslant Q^2 \leqslant 1.4\ \mathrm{GeV}^2$) in the deep inelastic region. A brief description of both experiments is given and preliminary results for the A_1^n are presented.

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1. Introduction

Polarized deep inelastic scattering provides an important insight into the internal structure of nucleons. In a typical polarized DIS experiment, a longitudinally polarized electron beam collides with a longitudinally or transversely polarized nucleon target. The experimental quantities measured are the asymmetries, $A_{||}$ and $A_{\perp}$, in the cross section:

$$A_{||} \equiv \frac{\sigma(\uparrow\Downarrow) - \sigma(\uparrow\Uparrow)}{\sigma(\uparrow\Downarrow) + \sigma(\uparrow\Uparrow)}\,, \qquad A_{\perp} \equiv \frac{\sigma(\uparrow\Leftarrow) - \sigma(\uparrow\Rightarrow)}{\sigma(\uparrow\Leftarrow) + \sigma(\uparrow\Rightarrow)}\,, \tag{1}$$

where the thin arrow stands for beam and the double arrow for target polarization.

The virtual photon asymmetry A_1 has recently gained considerable interest. It is defined as:

$$A_1 \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}\,, \tag{2}$$

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where $\sigma_{1/2}$ ($\sigma_{3/2}$) denote cross section with virtual photon spin anti-parallel (parallel) to the target spin. The A_1 asymmetry can be expressed via the experimental $A_{\|}$ and $A_{\perp}$ asymmetries:

$$A_1 = \frac{1}{D(1+\eta\xi)} A_{\|} - \frac{\eta}{d(1+\eta\xi)} A_{\perp}\,, \tag{3}$$

where D, d, η and ξ are kinematical factors (see *e.g.* [1]).

The valence quark contribution to A_1 is presumed to dominate for high x_{Bj}. Thus, the constituent quark models should work fairly well in this region. At the same time, for deep inelastic scattering at high x_{Bj}, it is possible to perform perturbative QCD (pQCD) calculations. The neutron data at high x_{Bj} suffers from high error bars, however, making comparison with the theory very hard (see Fig. 2).

2. The E99-117 experiment

The experiment was carried out in Hall-A [2] at the Jefferson Lab (see Fig. 1) in the Summer of 2001. The goal was to measure A_1^n in the deep inelastic region for $0.33 \leqslant x \leqslant 0.61$, see Table I.

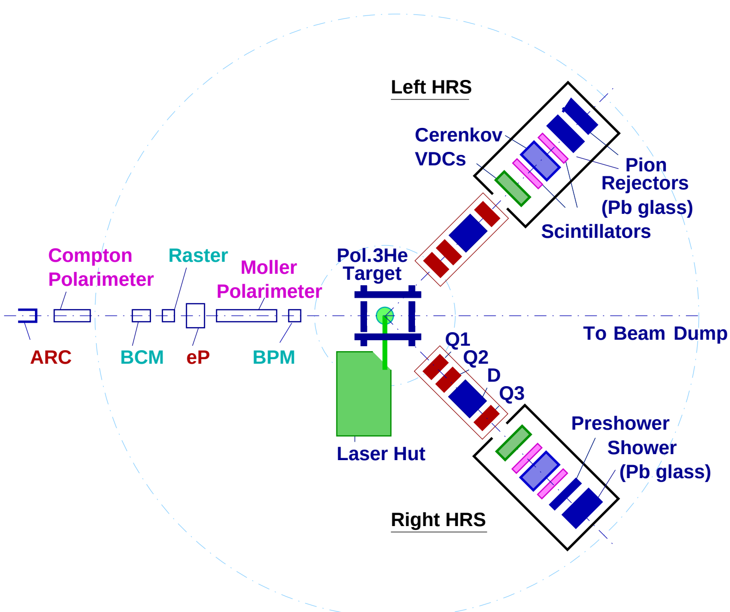

Fig. 1. Hall-A at the Jefferson Lab.

TABLE I

E99-117 kinematics.

$x_{\rm Bj}$	0.33	0.47	0.61
$Q^2({\rm GeV}/c)^2$	2.74	3.57	4.89
$W^2({\rm GeV}/c)^2$	6.43	4.85	4.02

The E99–117 experiment employed a longitudinally polarized beam of 5.7 GeV electrons that was scattered off a ^{3}He target. The target was polarized either in longitudinal or transverse direction with respect to the incoming electron momentum. The beam polarization, $P_{\rm b} = 82\%$, was continuously monitored by a Compton polarimeter and measured by a Møller polarimeter to a precision of better than 3%. The beam helicity was flipped with a frequency of 30 Hz. A set of two cavities and an Unser monitor provided the beam current measurement at the percent level. The current was limited to average 12 μA in order to protect the target from radiation damage and to minimize the depolarization. The Hall-A polarized ^{3}He target is an improved version of the E142 target [3]. In running conditions, the target polarization $P_{\rm t}$ ranged from 35 to 45%. Two independent methods were used to determine and monitor the target polarization with the accuracy better than 3%: NMR with adiabatic fast passage and EPR (Electron Paramagnetic Resonance). In order to minimize the systematic errors the target polarization and the sign of the beam helicity were regularly reversed.

The scattered electrons were detected in two high resolution magnetic spectrometers ($\Delta p/p \simeq 10^{-4}$) located symmetrically at either side of the beam line. Detector packages consisted of a set of wire chambers for tracking, two planes of scintillators for triggering, and a set of pre-shower, shower and Čerenkov detector for particle identification (π rejection factor was found to be better than 10^4).

The experimental raw asymmetries were determined from the number of scattered electrons $N^{\pm}$ per incident live-time corrected beam charge $Q^{\pm}_{\rm LT}$:

$$A_{\rm raw} = \frac{N^+/Q^+_{\rm LT} - N^-/Q^-_{\rm LT}}{N^+/Q^+_{\rm LT} + N^-/Q^-_{\rm LT}}\,, \tag{4}$$

where + or − signs denote the beam helicity. The raw asymmetries were then corrected for the target polarization $P_{\rm t}$, beam polarization $P_{\rm b}$ and the dilution factor f ($\sim$ 0.92–0.94) to obtain physics asymmetries, $A_\perp$ and $A_\|$: $A_{\rm phys} = A_{\rm raw}/(fP_{\rm b}P_{\rm t})$. Radiative corrections were applied to the $A_\perp^{^3{\rm He}}$ and $A_\|^{^3{\rm He}}$ asymmetries using POLRAD prescription [4]. Finally, the $A_1^{^3{\rm He}}$ asymmetries were computed from Eq. (3).

The sign of the physics asymmetries was checked by measuring the well-known elastic ^{3}He and $\Delta(1232)$ asymmetries. False asymmetries were measured by polarized e^- scattering off unpolarized carbon foils and were found to be negligible when compared to physics asymmetries.

In its ground state, the ^{3}He nucleus is primarily S-wave and that is what makes it such an excellent polarized neutron target. Small admixtures of S- and D-wave components cause that the two protons contribute to the total ^{3}He spin. In our analysis we used a model of Bissey *et al.* [5] to extract the A_1^n from $A_1^{^3\mathrm{He}}$.

Preliminary results for A_1^n are presented in Fig. 2. The error bars are statistical only. A detailed study has shown that the statistical errors dominate the total uncertainty. The E99–117 data are compared with the world data from HERMES and SLAC and with some of the theoretical predictions. A closer inspection of Fig. 2 reveals that our lowest $x = 0.33$ data point is in a good agreement with the existing data. Our high precision data show clearly that A_1^n becomes positive at large x.

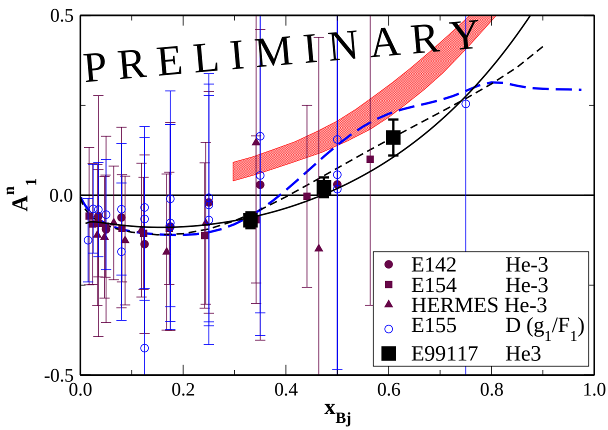

Fig. 2. Preliminary results for A_1^n compared with the world data and theoretical predictions: CQM [6] (shaded region) and statistical model [7] (long dashed line) calculations for A_1^n, g_1/F_1 LSS 2001 parameterization [8] (short dashed line) and a A_1^n calculation of from E155 [9] g_1/F_1 fit at $Q^2 = 4$ (GeV$/c)^2$ (solid line).

3. The E97–103 experiment

Over 20 years ago Wandzura and Wilczek [10] proposed a decomposition of the polarized structure functions $g_2(x, Q^2)$ into two parts:

$$g_2(x,Q^2) = g_2^{\mathrm{WW}}(x,Q^2) + g_2^{\mathrm{HT}}(x,Q^2)\,. \tag{5}$$

The g^{WW} is purely leading twist (twist-2) and can be expressed in terms of $g_1(x,Q^2)$ as follows:

$$g_2^{\mathrm{WW}}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 \frac{d\xi}{\xi} g_1(\xi,Q^2)\,. \tag{6}$$

The second term, g^{HT}, contains higher twist contributions (twist-3 or higher) and is sensitive to quark–gluon correlations in nuclei. Because of the $1/Q$ dependence of the higher twist effects, typical DIS measurements of g_2 at $Q^2 \sim 5$ GeV^2 have limited sensitivity to g^{HT}.

The experiment E97-103 measured the g_2^n and g_1^n structure functions in low Q^2 region at a nearly constant x_{Bj}, see Table II.

TABLE II

E97–103 kinematics coverage.

E [GeV]	3.47	4.60	4.60	5.73	5.73
x	0.17	0.20	0.18	0.20	0.21
Q^2 [GeV^2]	0.58	0.96	0.80	1.14	1.36

The experiment ran immediately after E99–117 and the experimental techniques were the same for both experiments. The data for bot g_2^n and g_1^n will soon be available. And with the improved precision, roughly an order of magnitude better than the previous experiments, the E97–103 measurement is more sensitive to the higher twist effects.

4. Summary and outlook

The experiment E99–117 provides first precise data on neutron spin asymmetry A_1^n for $0.3 \leqslant x \leqslant 0.6$. Data on the structure functions g_1^n, g_2^n and A_1^n are also available. The results of this experiment provide a valuable insight to the valence quark structure of the neutron. The data allow to critically test and improve various theoretical calculations. The measurements of A_1^n are also an important part of the JLab 12 GeV upgrade [11], which will allow to measure A_1^n up to $x = 0.8$ over a broader, $2\,\mathrm{GeV}^2 < Q^2 < 10\,\mathrm{GeV}^2$, Q^2 range.

The experiment E97–103 will provide first precise data on g_2^n structure function and possible higher twist effects in the low Q^2 region of the DIS.

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