Neutron Spin Structure In the Valence Quark Region

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Received on 29 October, 2003

I present in this talk the latest results of the neutron spin physics program at Jefferson Laboratory in Hall A using the highly polarized electron beam and a high pressure polarized 3He target. This program includes among others experiment E99-117 in which the neutron spin asymmetry $A^B_n$ was measured in the deep inelastic region with high precision. This asymmetry is observed, for the first time, to change sign from negative to positive values between $0.3 < x < 0.6$. Furthermore we perform a flavor decomposition of the spin-dependent to spin-independent quark distributions ratios in the nucleon and find that relativistic quark models are in better agreement than pQCD fits using the hadron helicity conservation constraint as $x \to 1$.

1 Introduction

After 25 years of spin structure measurements at the high energy physics laboratories (i.e. CERN, SLAC and DESY) leading to the determination of the quark spin content of the nucleon [1, 2] and culminating with the test of the Bjorken sum rule [3], the spin structure of the neutron in the deep inelastic large $x$ region at $Q^2$ (above 1 GeV$^2$) is still poorly measured. This region does not contribute much to the first moment of spin structure functions, but it is crucial for evaluating higher moments of these functions. These moments offer a testing ground of QCD because they are connected with specific matrix elements [4, 5] that are directly calculable in lattice QCD [6]. The spin structure function in this valence quark region can also be tested through quark model calculations.

The scattered electrons were detected using two high resolution spectrometers (HRS) which sat symmetrically on each side of the electron beam line to double the count rate. The spectrometers were equipped with standard detector packages which consists of two vertical drift chambers for momentum and scattering angle determination, a CO$_2$ gas Cherenkov counter and a double-layered lead-glass shower counter for particle identification [9]. The electron identification efficiency was 99% and the $\pi^-$ rejection factor was found to be better than $10^4$ for both spectrometers which was sufficient for all experiments. The momentum of each spectrometer was stepped through the relevant excitation spectrum at each incident energy of a given experiment. In many cases the comparison of the data between the two identical spectrometers at symmetric angles allowed us to minimize many of the systematic uncertainties.

2 Experimental method and setup

Here we present results of a precision measurement (JLab E99-117) of the neutron asymmetry $A^B_n$ in the valence region (large $x > 0.3$ and $Q^2 > 2$GeV$^2$). The above experiment was carried out at Jefferson Lab in Hall A using a highly polarized electron beam (70-80%) with an average current up to 15µA and a high pressure polarized (on average between 30% and 40% in-beam) 3He target with the highest polarized luminosity in the world. Details on these experiments can be found at[7]. The target is based on the spin exchange principle where rubidium atoms are polarized by optical pumping and their polarization is transferred to the 3He atoms via spin exchange collisions [8]. The target was polarized either parallel or perpendicular to the direction of the electron beam and its polarization measured by three independent methods: Nuclear Magnetic Resonance (NMR) through the Adiabatic Fast Passage (AFP) technique, Electron Paramagnetic Resonance technique (EPR) and elastic scattering off 3He. In each case the results of the three methods agreed within systematic errors.

3 Spin and flavor decomposition in the valence quark region

The virtual photon-nucleon asymmetry $A^B_n$ and spin structure function $g_2^n$ are the most poorly known in the valence quark region ($x > 0.3$). This shortcoming is due to the small scattering cross sections at large $x$ and $Q^2$ combined with a lack of high polarized luminosity facilities. This region, however, is clean and unambiguous since it is not polluted by sea quarks and gluons offering thus a unique opportunity to test predictions that are difficult if not impossible at low $x$. The set of predictions of $A^B_n$ in the valence quark region fall into two categories, those of relativistic constituent quark models (RCQM) which break SU(6) symmetry in the ground state wave function by hyperfine interaction [10, 11], and those of perturbative quantum chromodynamics (pQCD) with a hadron helicity conservation (HHC) constraint [12, 13] as $x \to 1$ which break SU(6) symmetry dynamically.

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The difference between these approaches is dramatic when the constituents flavor-spin decomposition is performed. For a proton and in the case of pQCD with HHC, we have $\Delta u(x)/u(x) \to 1$ and $\Delta d(x)/d(x) \to 1$, while for the case of RCQM's $\Delta u/u \to 1, \Delta d/d \to -2/3$. We notice that in leading order pQCD with HHC $\Delta d/d$ changes sign from negative at low $x$ to positive at large $x$.

In Figure 1 we show preliminary results of $A_1^n$. The first data point at $x = 0.33$ is in good agreement with previous measurements. The data points show a clear change of sign of $A_1^n$ as $x$ increases and are compared with theoretical predictions. The total error in each point is dominated by the statistical error. The solid line is a prediction using HHC based on LSS(BBS) parameterization of $g_1^p/E_1^p$ [14], the long-dashed line is a prediction of $g_1^n/E_1^n$ from LSS 2001 parametrization at $Q^2 = 5$ GeV$^2$ without HHC constraints [15]. The shaded area is a range of predictions of $A_1^n$ from the constituent quark model [11] while the dashed line is a calculation of the statistical model at $Q^2 = 4$ GeV$^2$ by Bourrely et al. [16]. The short-dashed line is the chiral soliton model prediction at $Q^2 = 3$ GeV$^2$ by Weigel, Gamborg and Reinhardt [17]. Finally, the dot-dashed line is a bag model calculation but without meson cloud by Boros and Thomas [18]. Data from Hermes and SLAC are original values without being re-analyzed for the $\Delta$ contribution of the nuclear corrections.

We used the quark parton model interpretation of $g_1$ and $F_1$ to perform a flavor decomposition of the spin dependent quark distributions assuming a negligible strange quark contribution above $x = 0.3$. The up-quark and down-quark distributions obtained in E99-117 (filled circles) along with preliminary results of the HERMES semi-inclusive measurements (open circles) [19] are also shown in Fig. 2. The solid line is a pQCD fit to the world data using the HHC constraint as $x \to 1$. The dashed line correspond to an RCQM prediction. It is clear that up to $x = 0.6$ the data favor the RCQM rather than the HHC pQCD based calculations. In the latter no orbital angular momentum (OAM) is considered while in the RCQM some OAM is included through the small components of the nucleon wavefunction. These results, perhaps point to the importance of considering the orbital momentum of quarks in the nucleon wave function. The dotted curve is a calculation by Wakamatsu [20] within the SU(2) chiral soliton model. The agreement of the latter with the data is quite encouraging. In the meantime, one has to wait for more measurements at larger values of $x$ and a more complete QCD calculation.

4 Conclusion

In summary, we took advantage of the highly polarized beam and high pressure polarized $^3$He target at Jefferson Lab Hall A to investigate the internal spin structure of the neutron in the perturbative and the strong regimes of QCD. In E99-117 we have determined the world most precise down-quark helicity distribution in the valence region. The results agree with the relativistic constituent quark model and chiral soliton model rather than the HHC constrained pQCD prediction. This perhaps points to the importance of the quark OAM in this region.
Acknowledgments

I thank Roberto Ribas and the local organizers for a very well organized and productive meeting. The work presented here was supported in part with funds provided to the Nuclear and Particle Group at Temple University by the U.S. Department of Energy (DOE) under contract number DE-FG-02-94ER40844. The Southeastern Universities Research Association operates the Thomas Jefferson Accelerator Facility for the DOE under contract DE-AC05-84ER40150.

References

[7] Details of experiments at www.jlab.org/e99117/ and www.jlab.org/e94010/.