SPIN STRUCTURE FUNCTIONS AT LOW Q^2 FROM JLAB DATA

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Spin structure functions of the nucleon in the region of large x and small to moderate Q^2 continue to be of high current interest. Among the topics one can study in this kinematic regime are the Q^2 evolution of the first moment of g_1 and the behavior of the virtual photon asymmetry A_1 at large x. A large experimental program to measure these observables for the proton and deuteron has been concluded at Jefferson Lab Hall B. We will present the results of the 1.6 and 5.7 GeV data.

1. The first moment of g_1

The first moment of the spin structure function g_1, $\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2)dx$, goes through a rapid transition from the photon point ($Q^2 = 0$), where it is constrained by the Gerasimov-Drell-Hearn sum rule[1], to the deep inelastic limit where it is sensitive to the nucleon spin fraction carried by quarks. A theoretical tool to extend the sum rules at the extreme kinematic points to finite Q^2 has been suggested by Ji and Osborne[2]. In the hadron description, the integral can be calculated in chiral perturbation theory and in the parton description it can be formalized in the OPE. Further, in the region where the transition from the parton to hadron degrees of freedom occurs the integral can be calculated in lattice QCD.

A highly polarized electron beam, dynamically polarized $^{15}NH_3$ and $^{15}ND_3$ targets and the CEBAF Large Acceptance Spectrometer (CLAS)

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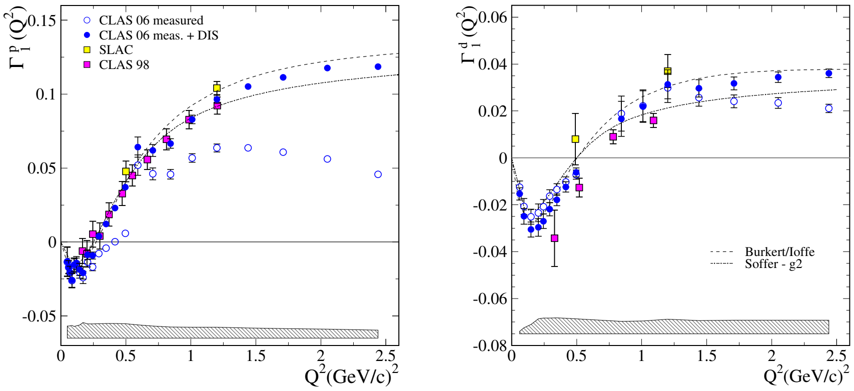

Figure 1. Results for the integral Γ_1 (Q^2) for the proton (left) and deuteron (right). The open and filled circles correspond to the measured points (CLAS 06 measured) and the full integral (CLAS 06 measured + DIS) respectively. The error bars show statistical uncertainties. The shaded region at the bottom of the plot indicate the systematic uncertainties for the full integral.

in Hall B were used to accumulate over 23 billion triggers with 4 different beam energies of 1.6, 2.5, 4.2 and 5.7 GeV spanning a range in Q^2 from 0.05 to 4.5 GeV^2. Here we present the results of the 1.6 and 5.7 GeV data[5].

To calculate the full integral of g_1 over x from 0 to x $(W = 1.07$ GeV), knowledge of the entire x region for each Q^2 bin is necessary. However our measurements do not cover the full x region, therefore g_1 in the unmeasured region was calculated using a model (a parameterization of the world data). Fig. 1 compares data to models by Burkert and Ioffe[3], and Soffer and Teryaev[4]. Only the data for Q^2 bins in which the contribution from the model is less than 50% of the full integral are shown in the plots. The data show a very strong Q^2 dependence below the $Q^2 \approx 2$ GeV^2 region. The integral is negative below $Q^2 \approx 0.4$ GeV^2, which is due to the dominance of the $A_{3/2}$ amplitude at lower Q^2 values. At larger Q^2 $A_{1/2}$ becomes the dominant amplitude and the integral becomes positive as the negative contribution due to the $\Delta(1232)$ resonance starts to diminish. The data show a trend towards the GDH slope at low Q^2.

2. Nucleon helicity structure at large x

One of the most fundamental properties of the nucleon is the structure of its valence quark distributions. The region $x \to 1$ is a relatively clean region to study the valence structure of the nucleon since this region is dominated by valence quarks while the small x region is dominated by gluon and sea densities. Several models make specific predictions for the large x behavior of quark distributions. One of the simplest models for the virtual photon asymmetry A_1 is the SU(6) quark model, which predicts; $A_1^p = 5/9$; $A_1^n = 0$; $d/u = 1/2$; $\Delta u/u = 2/3$; $\Delta d/d = -1/3$. In the hyperfine-perturbed quark model[6] SU(6) symmetry is explicitly broken by introducing hyperfine interactions between each pair of quarks. This will lead to predictions, $A_1^{p,n} \to 1$; $d/u \to 0$; $\Delta u/u \to 1$; $\Delta d/d = -1/3$. In another model[7], different SU(6) breaking scenarios are examined in the context of quark hadron duality, where certain families of resonances are required to die out at large Q^2 in order to maintain duality. An alternative argument based on pQCD[8] suggests that at large Q^2 large x the minimal number of gluon exchanges (transverse) required to transfer the momentum of the spectator pair to the struck quark can occur only if the spectator pair have opposite helicities. Consequently the struck quark must carry the same helicity as the nucleon (assume hadron helicity conservation). In this approach, as $x \to 1$, $S_z = 1$ di-quark components are suppressed relative to the $S_z = 0$ di-quark components. Therefore in the limit $x \to 1$ one has, $A_1^{p,n} \to 1$; $d/u \to 1/5$; $\Delta u/u \to 1$; $\Delta d/d = 1$. Brodsky, Burkard and Schmidt[9] also obtain a similar result by using counting rules.

The results for $A_1(x)$, averaged over $Q^2 > 1$ GeV^2 and $W > 2$ GeV, are shown in Fig. 2 for the proton. The hyperfine perturbed quark model is closest to the data. Of the different mechanisms for SU(6) symmetry breaking considered, the model with suppression of the symmetric quark wave function deviates least from the data. In general, our results are in better agreement with models in which the ratio of down to up quarks goes to zero and the polarization of down quarks tends to stay negative for rather large values of x. Our estimate (assumes LO and no contribution from strange quarks) of $\Delta d/d$ shows no indication of a sign change to positive values. At the same time, our data for $\Delta u/u$ are the statistically most precise available at this time and show a trend towards one. While the absolute value of $\Delta u/u$ and $\Delta d/d$ might be somewhat different from more sophisticated NLO DGLAP analyses, the error bars in Fig. 2 give an indication of the possible improvement in precision when our data are included in such fits. It is important to point out that these results are expected to improve the uncertainty in the polarized gluon distributions at large x once they are included in NLO analyses. Future measurements, in particular with the energy-upgraded Jefferson Lab accelerator, will be able to extend these data with improved precision upto $x \approx 0.8$, allowing

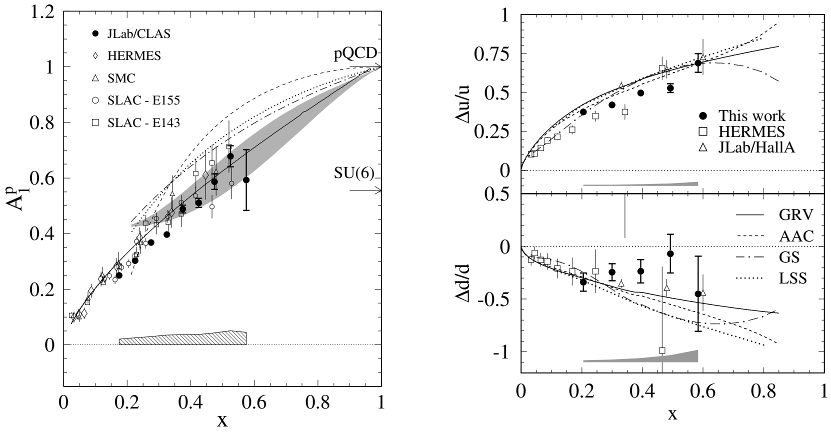

Figure 2. Results for the asymmetry $A_1(x)$ on the proton (left) and quark polarizations $\Delta u/u$ and $\Delta d/d$ extracted from our data (right). The solid line shows our parameterization of the world data at a fixed $Q^2 = 10$ GeV^2. The shaded band covers a range of calculations by Isgure (hyperfine perturbed quark model). The remaining three curves correspond to different scenarios of SU(6) symmetry predictions; helicity-1/2 dominance (dashed), spin-1/2 dominance (dotted) and symmetric wave function suppression (dash-dotted). Also shown are LO predictions by different groups (GRV, AAC, GS and LSS).

definitive tests of the properties of the valence structure of the nucleon at large x.

References

1. S. B. Gerasimov, Sov. J. Nucl. Phys. **2**, 430 (1966); S. D. Drell and A. C. Hearn, Phys. Rev. Lett. **16**, 908 (1966).
2. X. Ji and J. Osborne, J. Phys. G **27**, 127 (2001).
3. V. D. Burkert and B. L. Ioffe, Phys. Lett. B **296**, (1992).
4. J. Soffer and O. Teryaev, Phys. Rev. Lett. **70**, 3373 (1993); J. Soffer and O. Teryaev, Phys. Rev. D **51**, 25 (1995); J. Soffer and O. Teryaev, Phys. Rev. D **56**, 7458 (1997).
5. K. V. Dharmawardane, S. E. Kuhn, P. Bosted and Y. Prok [the CLAS Collaboration], arXiv:nucl-ex/0605028.
6. N. Isgur, Phys. Rev. D **59**, 34013 (1999).
7. F. E. Close and W. Melnitchouk, Phys. Rev. C **68**, 035210 (2003).
8. G. R. Farrar and D. R. Jackson, Phys. Rev. Lett. **35**, 1416 (1975); G. R. Farrar, Phys. Lett. B **70**, 346 (1977).
9. S. J. Brodsky, M. Burkardt and I. Schmidt, Nucl. Phys. B **441**, 197 (1995) [arXiv:hep-ph/9401328].