JEFFERSON LAB 12 GEV SPIN PROGRAM

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Spin structure functions provide basic information about the spin of the quark distributions inside the nucleon. Experimental understanding of the nucleon spin in the kinematic region where the three basic ("valence") quarks dominate the nucleon wave function is still rather poor. Jefferson lab, with its high quality, high polarization continuous electron beam and state of the art polarized nucleon targets in each of its three experimental halls is ideally suited for spin structure measurements in the valence region. An experimental program is underway at Jefferson Lab to measure the spin structure of the nucleon in the valence region with unprecedented precision. The planed upgrade of Jefferson lab CEBAF accelerator to 12 GeV will significantly increase the accessible kinematic range and the precision of these measurements.

One of the most fundamental properties of the nucleon is the structure of its valence quark distributions. At small values of the scaling variable x_{Bj}, sea quarks (quark-antiquark pairs), shadow the effects of valence quarks. As x_{Bj} increases beyond $\sim 0.2 - 0.3$, the sea quark contributions to the nucleon wave function becomes negligible. This allows for a direct, clean probe of the valence quark distributions at large values of x_{Bj} ($x_{Bj} > 0.4$) [1]. Unfortunately due to limitations at high energy laboratories, the quality of valence region data in many experimental fronts is rather poor. Jefferson Lab, with its high-quality, high polarization continuous electron beam, and the proposed upgrade to 12 GeV, is ideally suited for obtaining high precision data in the valence quark region.

The lack of precision experimental data in the valence region is most apparent in the case of spin observables for the neutrons. The high-luminosity polarized ^{3}He target in experimental Hall A at Jefferson Lab, combined with the 12 GeV beam, provides the best opportunity to gather precision spin observable data for the neutron in the valence region. To take the full use of the 12 GeV beam, a new spectrometer, MAD (Medium Acceptance

Device), is proposed for Hall A. This spectrometer will have a relatively large solid angle acceptance of 30 msr while providing low background conditions so that the full available beam-target luminosity can be used. The combination of MAD spectrometer and the polarized ^{3}He target in Hall A allows for a high precision measurement of neutron spin observables up to very large values of x_{Bj}. Furthermore, the relatively large acceptance of MAD combined with a polarized NH_3 target will also make it possible to significantly improve the proton spin observables in the valence region.

Improvements planed in Experimental Hall B, in conjunction with the 12 GeV program, include upgrading the CLAS spectrometer to handle luminosities of the order 10^{35} and modifying the polarized target setup to include transverse polarization. The large acceptance of CLAS allows access to a broad range in x_{Bj} and Q^2. Combined with these improvements, polarized NH_3 and ND_3 targets in Hall B create the opportunity for comprehensive high-precision spin structure function measurements of proton and deuteron.

In this paper we give a brief overview of only the inclusive spin structure function measurements that will be possible in Halls A and B. Jefferson Lab 12 GeV beam creates many other exciting opportunities to study the nucleon spin structure in inclusive, semi-inclusive and exclusive reactions in halls A, B and C. A detailed discussion of the proposed Jefferson Lab 12 GeV physics program can be found in the Jefferson Lab 12 GeV White-Paper [2].

Virtual photon asymmetry A_1, is an important observable in the study of dynamics of spin-flavor symmetry breaking. Early quark-parton models of the nucleon that preserve exact SU(6) symmetry require that $A_1^n = 0$ and $A_1^p = 5/9$. However, in nature the spin-flavor SU(6) symmetry is broken. Modern quark models with broken SU(6) symmetry predict that both $A_1^p \to 1$ and $A_1^n \to 1$ as $x \to 1$ [3,4,1]. A recent approach [5] that uses instantons as an important degree of freedom predicts that A_1^n remains negative or close to zero. Perturbative-QCD calculations [6,7] at the $x \to 1$ limit show that $A_1^p \to 1$ and $A_1^n \to 1$ as $x \to 1$.

Given the fundamental information that can be extracted from the spin observables at high x_{Bj}, it is unfortunate that there has been virtually no experimental data for A_1^n for $x_{Bj} \geq 0.4$. Figure 1 shows most of the published world data for A_1^n. While rigorous QCD predictions exist for A_1^n as $x \to 1$ and $Q^2 \to \infty$, the existing measurements at high x_{Bj} lack the precision to even distinguish any of the predictions from the naive SU(6) result.

Last Summer, Jefferson lab experiment 99-117 used the Hall A polarized ^{3}He target to measure A_1^n with unprecedented precision up to $x \sim 0.61$ [10] The availability of 12 GeV beam and the MAD spectrometer in Hall A will allow the A_1^n measurement to be extended to $x_{Bj} \sim 0.8$ with high precision. The anticipated data are shown in Fig. 1. While an invariant mass cut of $W > 2$ GeV, would allow the deep inelastic continuum to be cleanly accessed, one may extend the measurements of A_1^n to even larger x_{Bj} by using quark-hadron duality in the resonance region. We discuss this in more detail later in this presentation.

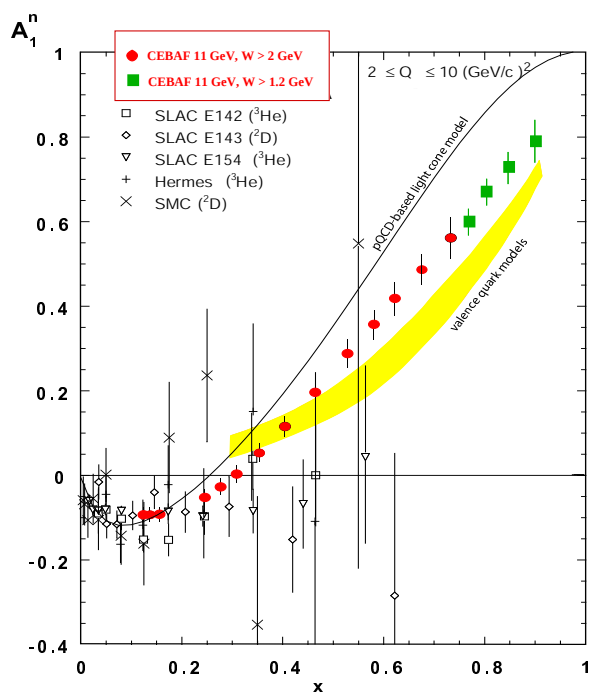

Figure 1. Projected data for a measurement of A_1^n in the large Bjørken-x region, The red filled circles are for the data in the DIS region ($W > 2$ GeV), while the filled squares show the possibility of extending the measurement to higher x_{Bj} by relaxing the invariant mass cut.

The high precision spin structure function measurements in both deep inelastic and resonance regions will allow for a stringent test of parton-hadron duality for spin structure functions. Parton-hadron duality refers to

the observation, first made by Bloom and Gilman [11], that the scaling curve seen at high momentum transfer is an accurate average over the resonance bumps at lower momentum transfer but at the same value of x_{Bj}. While the origins of duality still remains a mystery, the new precision data on F_2 structure function from Jefferson Lab [12] have stimulated a considerable amount of theoretical activity on Bloom-Gilman duality [14,15,16,17,18,19]. It is vital for our understanding of duality and its practical exploitation that the spin and flavor dependence of duality be established empirically.

The best overlap between DIS and resonance regions is over the moderate to high x_{Bj} range between 0.1 and 0.75. As described in the previous section, the DIS spin structure function measurements of neutron and proton possible with the 12 GeV beam at Jefferson lab will provide the most precise DIS spin data over this x_{Bj} range. With the availability of 12 GeV beam, the spin structure measurements of proton, neutron and deuteron in Halls A, B and C can be extended up to $Q^2 < 10.0\,(\mathrm{GeV/c})^2$ and $x_{Bj} < 0.95$ in the resonance region. These data, combined with the precision high x_{Bj} spin structure function data in the DIS region can be used for a stringent test of parton-hadron duality for spin structure functions. If duality is observed to hold, averaging over small regions of invariant mass will enable the dominant scaling component to be measured out to $x_{Bj} \sim 0.95$.

While the g_1 structure function has a simple interpretation in the quark-parton model in terms of quark helicity distributions and has been the focus of extensive experimental programs over the last decade, there have been few dedicated experimental studies of the g_2 structure function. The g_2 structure function is related to the transverse polarization of the nucleon, and although it does not have a simple quark-parton model interpretation, it contains important information about quark-gluon correlations within the nucleon.

In QCD the quark-gluon correlations are associated with so-called higher twist operators (where "twist" is defined as the difference between dimension and spin of an operator), which are suppressed by additional factors of $1/Q$ relative to the leading twist contribution (which is associated with free quark scattering). At large values of Q^2, QCD allows one to relate moments of spin structure functions to the matrix elements of operators of given twist. The simplest twist-3 matrix element that contains information on quark-gluon correlations is given by:

$$d_2(Q^2) = \int_0^1 dx_{Bj}\; x_{Bj}^2 \left[2g_1(x_{Bj}, Q^2) + 3g_2(x_{Bj}, Q^2)\right] \qquad (1)$$

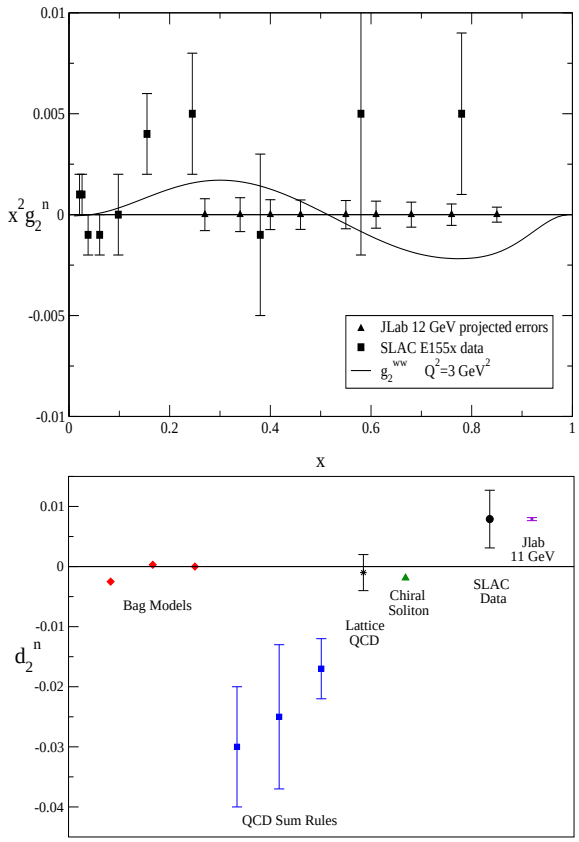

Figure 2. The upper panel show measured values for $x_{Bj}^2 g_2^n$ from experiment E155x at SLAC and projected errors for a 12 GeV measurement at Jefferson Lab. Also shown is the twist-2 projection, g_2^{WW}. The lower panel shows various theoretical models for the neutron twist-3 matrix element d_2^n along with the measured value from SLAC and the expected value from a 12 GeV Jefferson Lab measurement

Note that because of the x_{Bj}^2 weighting in Eq.(1), d_2 is dominated by the large-x_{Bj} behavior of g_1 and g_2. The physical significance of d_2 is that it reflects the response of a quark to the polarization of the gluon color field in the nucleon, $d_2 = (2\chi_B + \chi_E)/3$, with χ_B (χ_E) the gluon-field polarizability in response to a color magnetic (electric) field $\vec{B}$ ($\vec{E}$).

A 12 GeV JLab experiment will make a factor of 10 statistical improvement in the error on d_2^n, by taking advantage of the high luminosity beam and the large acceptance MAD spectrometer. Precision data for g_2 will be

obtained in the range $0.15 \leq x_{Bj} \leq 0.8$, $W > 2$ GeV, for example at $Q^2 = 5$ (GeV/c)^2, with special focus on the high x_{Bj} region which dominates d_2.

Hall B 12 GeV spin program The large acceptance coverage of CLAS with the planed luminosity upgrade to 10^{35} combined with 12 GeV beam will allow access to a large range of x_{Bj} and Q^2. For the spin structure function measurements with the 12 GeV beam, the Hall B collaboration plans to build a dedicated polarized target similar to the existing EG1 target. This target will contain dynamically polarized solid Ammonia ($^{15}NH_3$ and $^{15}ND_3$) foils. While initially this target will only have longitudinal polarization (like the present EG1 target), studies are underway to check the possibility of installing a transversely polarized target in the future. This will allow for the mapping of g_2^p structure function in x_{Bj} and Q^2 and for the determination of g_1^p and A_1^p in a model independent manner.

The precision that can be achieved for proton asymmetry A_1^p and A_1^D are shown in Fig 3. The high precision data projected here for both proton and deuteron over several bins in Q^2 will allow for the determination of logarithmic and $1/Q^2$ scaling violations of spin structure functions, determine their higher moments and study duality for spin structure functions in detail.

Finally, if the attempts to install a transversely polarized target in CLAS++ are successful, g_2^p structure function measured using that target will significantly improve on the existing data with smaller error bars and finer bins in x_{Bj} and Q^2. This will allow for the study of evolution of this structure function and for the determination of the twist-3 matrix element d_2 for the proton with high precision.

References

1. N. Isgur, Phys. Rev. D **59**, 034013 (1999).
2. The Science Driving the 12 GeV Upgrade of CEBAF, Available at http://www.jlab.org/div_dept/physics_division/GeV/WhitePaper_V11.pdf
3. F. Close, Phys. Lett. **B 43**, 422 (1973), Nucl. Phys. **B 80**, 269 (1974); and *An Introduction to Quarks and Partons*, Academic Press, N.Y., p. 197 (1976)
4. R. Carlitz, Phys. Lett. **B58**, 345 (1975)
5. N. Kochelev, Phys. Rev. **D 57** 5539 (1998); N. Kochelev and A. De Roeck, hep-ph/9803330
6. S. J. Brodsky and G. R. Farrar, Phys. Rev. Lett. **31**, 1153 (1973); Phys. Rev. **D 11**, 1309 (1975).
7. G. R. Farrar and D. R. Jackson, Phys. Rev. Lett. **35**, 1416 (1975).
8. S. Brodsky, M. Burkhardt and I Schmidt, Nucl. Phys. **B 441** 197 (1995)

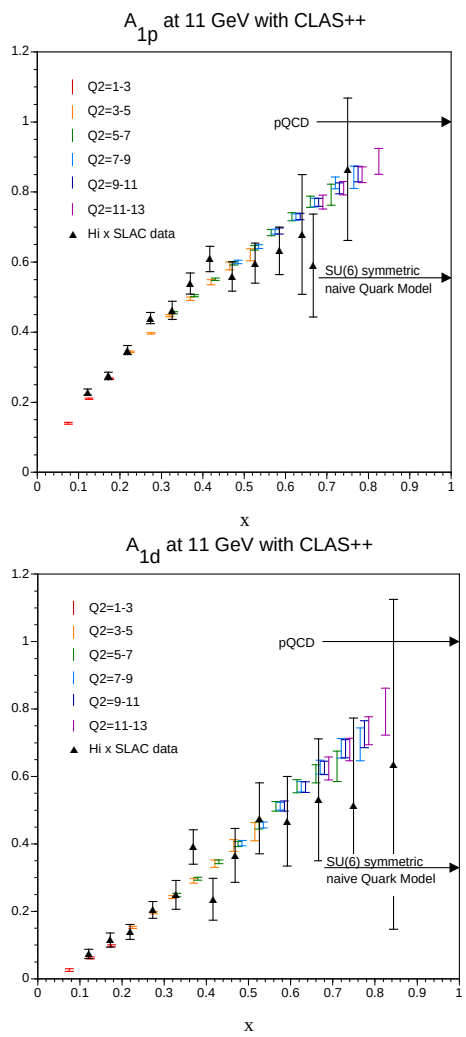

Figure 3. The projected statistical error for A_1^p (top) and A_1^D (bottom) from CLAS with 12 GeV beam at Jefferson Lab compared to existing SLAC data (E130, E143, E155). The errors are for 40 days of running. As indicated, the large acceptance of CLAS allows to gather data from several bins in Q^2 at each value of x_{Bj}.

9. E. Leader, A. V. Sidorov, and D. B. Stamenov, Int. J. Mod. Phys. **A 13** 5573 (1998).
10. See the presentation by X. Zheng at this workshop.

11. E. D. Bloom and F. J. Gilman, Phys. Rev. Lett. **25**, 1140 (1970); Phys. Rev. **D 4**, 2901 (1971).
12. I. Niculescu *et al.*, Phys. Rev. Lett. **85**, 1186 (2000); I. Niculescu *et al.*, Phys. Rev. Lett. **85**, 1182 (2000).
13. De Rujula, H Georgi, and H. D. Politzer, Ann. Phys. (N.Y.) **103** 315(1977).
14. C. E. Carlson and N. C. Mukhopadhyay, Phys. Rev. **D 41**, R2343 (1990); Phys. Rev. **D 47**, R1737 (1993); Phys. Rev. Lett. **74**, 1228 (1995).
15. X. Ji and P. Unrau, Phys. Rev. **D 52**, 72 (1995).
16. X. Ji and Melnitchouk, Phys. Rev. **D 56**, 1 (1997).
17. C. E. Carlson and N. C. Mukhopadhyay, Phys. Rev. **D 58**, 094029 (1998).
18. F. E. Close and N. Isgur, Phys.Lett. B **509**, 81 (2001).
19. N. Isgur, S. Jeschonnek, W. Melnitchouk, and J. W. Van Orden, Phys.Rev. D **64** 054005 (2001).