Jefferson Lab's results on the Q^2-evolution of moments of spin structure functions

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Abstract. We present the recent JLab measurements on moments of spin structure functions at intermediate and low Q^2. The Bjorken sum and Burkhardt-Cottingham sum on the neutron are presented. The later appears to hold. Higher moments (generalized spin polarizabilities and d_2^n) are shown and compared to chiral perturbation theory and lattice QCD respectively.

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MOMENTS OF SPIN STRUCTURE FUNCTIONS

Polarized DIS has provided a testing ground for the study of the strong force. Moments of spin structure functions (SSF), among them the Bjorken sum, has played an important rôle in this study. The n-th (Cornwall-Norton) moment of SSF is the integral of the $x^n g_{1,2}(x,Q^2)$ SSF over x. Moments are specially useful because sum rules relate them to other quantities. Such sum rules for Γ_1, the first moment of g_1, are the Ellis-Jaffe [1] and the Bjorken sum rules [2], derived at large Q^2, and the related Gerasimov-Drell-Hearn (GDH) sum rule [3] at $Q^2=0$. The first moment of g_2, Γ_2, is given by the Burkhardt-Cottingham (BC) sum rule [4]. Rules can be also derived for higher moments, e.g., spin polarizability or d_2 sum rules.
These relations are useful in many ways: checks the theory on which the rule is based (e.g. QCD and the Bjorken sum rule); checks hypotheses used in the sum rule derivation (e.g. the Ellis-Jaffe sum rules); or checks calculations such as chiral perturbation theory (χpt), lattice QCD or Operator Product Expansion (OPE). If a sum rule rests on solid grounds or is well tested, it can be used to extract quantities otherwise hard to measure (e.g. generalized spin polarizabilities). Because $\Gamma_{1,2}$ are calculable at any Q^2 using either χpt, lattice QCD or OPE, they are particularly suited to study the transition between the hadronic to partonic descriptions of the strong force. Measurements in the transition region (intermediate Q^2) have recently been made at Jefferson Lab (JLab).

MEASUREMENTS AT JEFFERSON LAB

At moderate Q^2, resonances saturate moments. JLab's accelerator delivers CW electron beam with a maximum energy up to 6 GeV. This makes JLab the suited place to measure moments up to Q^2 of a few GeV^2. The beam current can reach 200 μA with a polarization now reaching 85% although at the time of the experiments reported here, it was typically 70%. The beam is sent simultaneously to three halls (A, B and C), all of them equipped with polarized targets. In this talk, we report on results from halls A and B.
Hall A [5] contains a polarized ^{3}He gaseous target and two high resolution spectrometers

(HRS) with 6 mSr acceptance. The target can be polarized longitudinally or transversally at typically 40% polarization with 10-15 μA of beam. The target's $\sim$ 10 atm. of ^{3}He gives a luminosity greater than 10^{36}cm^{-2}s^{-1}. Hall B [6] luminosity is typically 5×10^{33}cm^{-2}s^{-1} but is compensated by the large acceptance (about 2.5π) of the CLAS spectrometer. Cryogenic polarized targets (NH_3 and ND_3) are well suited for the low beam currents ($\sim$nA) utilized in Hall B. The target is longitudinally polarized with average 75% (NH_3) and 40% (ND_3) polarizations. Both halls can cover the large region of Q^2 and x needed to extract moments at various Q^2, either because of the large CLAS acceptance (Hall B) or because of large luminosity allowing to quickly gather data at various beam energies and HRS settings (Hall A).

I report here on the Hall A E94010 [7] and Hall B EG1 experiments. EG1 was split in two runs: EG1a (1998) which results are published [8], and EG1b (2000) that is still being analyzed. SSF are extracted differently in halls A and B. In Hall A, *absolute* cross sections asymmetries $\Delta\sigma^{\parallel(\perp)}$ were measured for longitudinal (transverse) target spin orientations. g_1 and g_2 are linear combinations of these $\Delta\sigma$ and are extracted without external input. Furthermore, unpolarized contributions, e.g. target cell windows or the (mostly) unpolarized protons in the ^{3}He nucleus, cancel out. The *relative* longitudinal asymmetry $A_{\parallel}$ is measured in Hall B. Models for F_1, g_2 and $R=\sigma_L/\sigma_T$ are then used to extract g_1. F_1 and R are constrained at low Q^2 by recent Hall C data [9]. g_2 is estimated using models (resonance region) or its leading twist part g_2^{ww} (DIS domain). The unmeasured low-x part of the moment is estimated using a parametrization developed by the EG1 collaboration, while the E94010 group used a Regge-type fit of DIS data [10]. Results on Γ_1^p, Γ_1^n and Γ_1^d are shown in Fig. 1, together with χpt calculations [16, 17] models [12, 15] and leading twist OPE prediction. HERMES [13] and SLAC [14] results are also shown. The halls A and B data, reanalyzed at matched Q^2 points and with a consistent low-x estimate [10] were used to form the Bjorken sum Γ_1^{p-n} [11]. Preliminary Γ_1^{p-n} from EG1b is also shown. Γ_1^{p-n} is a unique quantity to study parton-hadron transition because its non-singlet structure makes it an easier quantity to handle for χpt, lattice QCD and OPE. These data form, for both nucleons, an accurate mapping at intermediate Q^2 that connects to SLAC, HERMES and CERN DIS data. At low Q^2, χpt disagrees with the data above $Q^2=0.2$ GeV^2, while models based on different physics reproduce equally well the data. Twist 2 description also works well down to low Q^2, indicating an overall suppressed higher twist rôle. Indeed, in OPE analysis results [11, 18, 19], twist 4 and 6 coefficients are either small or canceling each others at Q^2=1 GeV^2.

The availability of transverse data in Hall A allows us to form Γ_2^n and thereby check the BC sum rule ($\Gamma_2=0$) on the neutron (fig. 2). The sum rule is based on dispersion relations and is Q^2-invariant. A striking feature is the almost perfect cancellation between elastic and resonance contributions leading to the verification of the sum rule. Other sum rules link SSF moments to the generalized spin polarizabilities γ_0 and δ_{LT}:

$$\gamma_0=\frac{4e^2M^2}{\pi Q^6}\int_0^{1^-}x^2(g_1-\frac{4M^2}{Q^2}x^2g_2)dx\ ;\ \delta_{LT}=\frac{4e^2M^2}{\pi Q^6}\int_0^{1^-}x^2(g_1+g_2)dx$$

Results from Hall A can be seen in fig. 2 [20]. δ_{LT} is interesting because the Δ_{1232} rôle is suppressed. Hence δ_{LT} is easier to access by χpt. However, calculations and data disagree for both γ_0 and δ_{LT}. The MAID model [21], however, well reproduces the data.

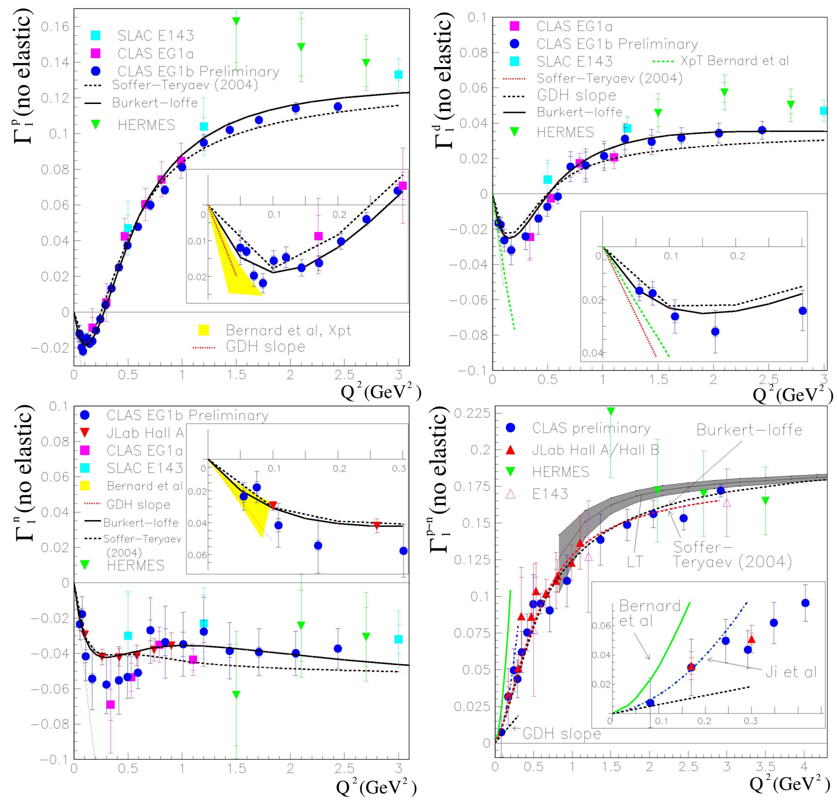

FIGURE 1. First moments Γ_1^p, Γ_1^n, Γ_1^d and the Bjorken sum Γ_1^{p-n}. The elastic contribution is excluded.

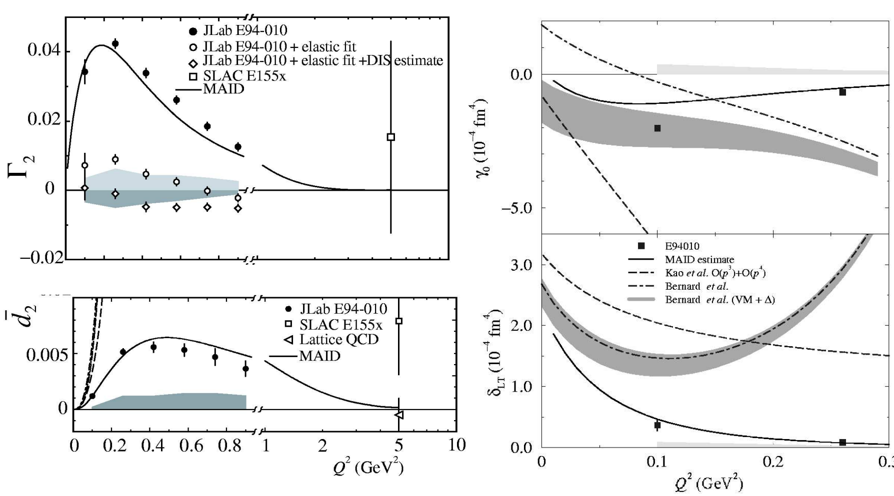

FIGURE 2. Moments Γ_2^n and $\overline{d}_2^n$ (left), and generalized spin polarizabilities γ_0 and δ_{LT} (right)

Another higher moment that can be formed is d_2^n, the integral of $x^2(g_2 - g_2^{ww})$ where g_2^{ww} is the leading twist part of g_2. Thus d_2 is sensitive to twist 3 and higher. The measured $\overline{d}_2^n$ (the bar indicates the exclusion of $x = 1$) trends toward the lattice QCD results, although larger Q^2 data are necessary to establish a possible agreement.

SUMMARY AND PERSPECTIVES

The hadron-parton transition region is covered by data of the SSF moments from JLab. These can be calculated at any Q^2, thus providing a ground for studying the link between hadronic and partonic descriptions of the strong force. An OPE analysis reveals that in this domain, high twist effects are small. The BC sum rule was shown on the neutron and found to be valid. Data and sum rules were used to extract neutron generalized spin polarizabilities. Those disagree with the present χpt calculations. Further data from Hall A E01-012 [22], Hall B EG1b, and Hall C RSS [23] will be available shortly in the resonance region. New data at very low Q^2 have been taken on the neutron in Hall A [24] and will be gathered early 2006 for the proton in Hall B [25]. The 12 GeV upgrade of JLab will allow us to access both larger-x and lower-x. This will allow for more precise measurements of the moments, in particular by addressing the low$x$ issue.

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