Measurement of the Q^2dependence of the Deuteron Spin Structure Function g_1 and its Moments at Low Q^2 with CLAS

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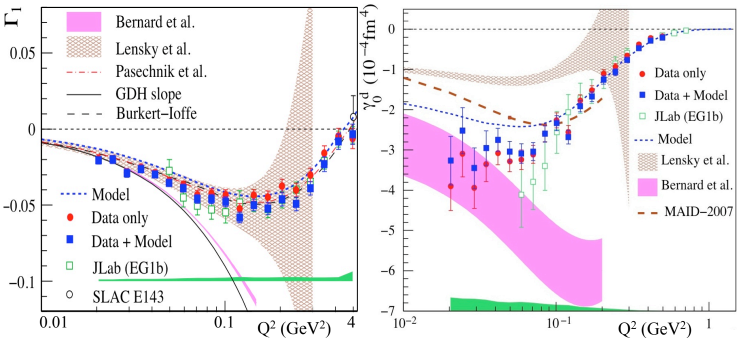
Quantum chromodynamics (QCD) is the fundamental theory of the strong interaction, the force that binds quarks into nucleons and nucleons into nuclei. It also rules the most violent collisions between quarks in the early universe. While the equations of QCD can be solved with high precision at short distances (much shorter than the size of a nucleon), at longer distances calculations become difficult and require either immense computer power (within the framework of lattice QCD) or "effective theories" that capture the main essence of QCD in that regime, without the complicated details. One such effective theory is Chiral Perturbation Theory (χPT) which has had some impressive successes describing the properties and interactions of bound quark states at large distances.

One way to experimentally test χPT is to use the property of "spin" that most elementary particles possess, and that is akin to a rotation around a particle's axis. History has shown that spin can test models and theories like χPT with scalpel-like precision, often much more stringently than other experiments. A particular useful tool is the evaluation of spin sum rules. These relate an integral over a spin-polarized cross section (where a target with its spins aligned in a specific direction is probed) to a fundamental property of that target (e.g., its magnetic dipole moment). Examples are the famous Gerasimov-Drell-Hearn (GDH) and Bjorken Sum Rules that have been evaluated by dozens of experiments world-wide.

Our article reports the first precise experimental study at very long distance of such sum rules, namely the generalized Gerasimov-Drell-Hearn (GDH) and the spin polarizability γ_0 sum rules. Their earlier measurements has challenged χPT. Those were, however, of limited precision and barely probed distances long enough for χPT to safely apply. Our new results, from the Jefferson Lab (JLab) EG4 experiment, evaluated the two sum rules at significantly larger distances (beyond 1 fm) than the previous ones and thus provide a better test of χPT. The data reported here were taken on the deuteron.

The EG4 experiment took place in Hall B using its CLAS spectrometer. It detected electrons resulting from scattering a high energy polarized electron beam off protons or deuterons that were spin-polarized along the beam direction For the deuteron run, two beam energies were used, 1.3 and 2.0 GeV. To probe long distances (corresponding to small momentum transfers, Q^2), electrons needed to be detected at scattering angles of about 6°, smaller than usually accessible with CLAS. To this end, a new Cherenkov detector covering forward angles was constructed. Furthermore, the target position was moved 1 m upstream of the nominal CLAS center and the magnetic field of CLAS was set to bent electrons outward.

We studied the GDH sum rule by integrating the spin-dependent deuteron structure function $g_1^D(x, Q^2)$ over the quark relative momentum x to form the moment called $\Gamma_1(Q^2)$. The result is shown on the left graph of the figure. Since Q^2 is inverse to the distance scale probed, larger distances correspond to the left part of the graph. The measured part of the integral (solid red circles) is complemented by a model in the unmeasured x region to form the full value of Γ_1 (solid blue squares). This is a small correction. The new data agree with previous measurements where they overlap, with significantly higher precision, and reach a 3 times smaller Q^2. The most recent χPT calculation (Lensky *et al.*) compares well with the data on $\Gamma_1(Q^2)$, while another recent one (Bernard *et al.*) using a different method, only agrees with a few data points at the lowest Q^2. Two available phenomenological models (Pasechnik *et al.* and Burkert-Ioffe) describe the data well for all Q^2.



EG4 data on Γ_1 (left) and γ_0 (right) compared to the χPT calculations (Lensky *et al.* and Bernard *et al.*) and models (Pasechnik *et al.*, Burkert-Ioffe, and MAID).

Our result for the spin polarizability γ_0 is shown on the right graph. This quantity emphasizes different aspects of nucleon structure and therefore can be used as independent test of χPT. Our data agree with the Bernard *et al.* calculation over the same small Q^2 range as for Γ_1. However the Lensky *et al.* calculation and the MAID parametrization disagree with the data over all Q^2 probed.

Thus, the first precise measurement of Γ_1 and γ_0 at distance scales large enough for the χPT approximation to unambiguously apply shows that no single method successfully describes both observables, except at the smallest Q^2. Hence, while χPT calculations are reaching higher precision, a satisfactory description of spin observables remains challenging. The program of providing benchmark spin observables for χPT will be completed when the proton EG4 data become available, as well as data on the neutron (^{3}He) and proton from JLab's Hall A.