Probing Nuclear Structure through Electron Scattering from Tensor Polarized Targets

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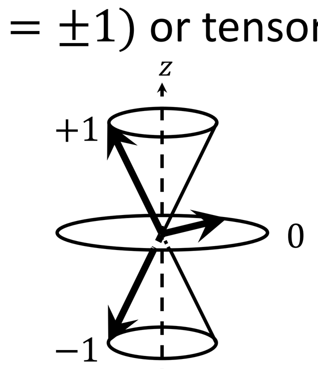
Abstract

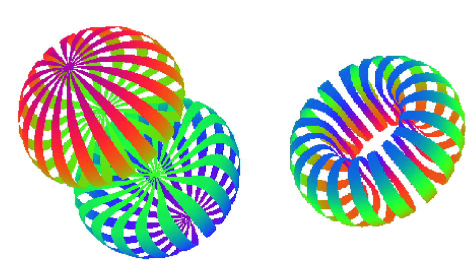
The leading twist tensor structure function of spin-1 hadrons, b_1 provides a unique tool to study partonic effects, while also being sensitive to coherent nuclear properties in the simplest nuclear system. The first measurement of b_1 taken at HERMES revealed a crossover to an anomalously large negative value in the $0.2 < x < 0.5$ region, albeit with relative large uncertainty, where all conventional models predicted a vanishing b_1. There is no known conventional nuclear mechanism that can explain the large negative value of b_1 found at large x by HERMES. However, a recent calculation by G. Miller demonstrates that this data might be understood in terms of hidden color due to a small six-quark configuration contribution to the nuclear wave function.

Jefferson Lab has approved an experiment to measure b_1 with greatly improved uncertainty using a tensor-polarized solid ND_3 target. Such a target would also provide access to tensor observables at higher x that can probe the short range repulsive core of the nucleon-nucleon potential and the ratio of the S- and D-states through a measurement of the tensor asymmetry A_{zz}.

Background

The deuteron is the simplest composite nuclear system, which makes understanding it imperative for understanding bound systems in QCD. Being a spin-1 particle, it can be vector ($m_J = \pm 1$) or tensor ($m_J = 0$) polarized[1].





$m_J = \pm 1$ $\quad$ $m_J = 0$

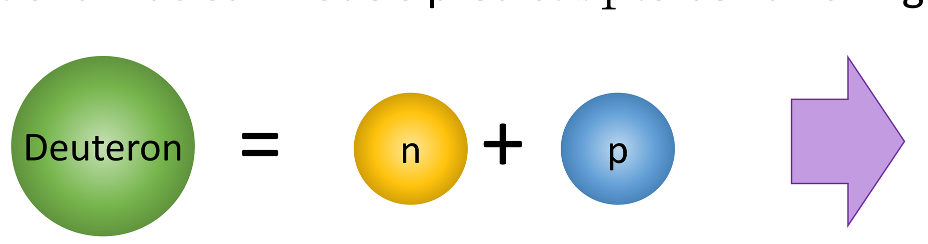
The hadronic tensor of electron scattering from the deuteron reveals four structure functions (b_1, b_2, b_3, and b_4) that cannot be accessed using a vector polarized target[2].

$$\begin{aligned} W_{\mu\nu} = & -F_1 g_{\mu\nu} + F_2 \frac{P_\mu P_\nu}{\nu} \\ & - b_1 r_{\mu\nu} + \frac{1}{6} b_2 (s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) \\ & + \frac{1}{2} b_3 (s_{\mu\nu} - u_{\mu\nu}) + \frac{1}{2} b_4 (s_{\mu\nu} - t_{\mu\nu}) \\ & + i \frac{g_1}{\nu} \epsilon_{\mu\nu\lambda\sigma} q^\lambda s^\sigma + i \frac{g_2}{\nu^2} \epsilon_{\mu\nu\lambda\sigma} q^\lambda (p \cdot q s^\sigma - s \cdot q p^\sigma) \end{aligned}$$

The leading twist tensor structure functions are expected to have a Callan-Gross relation, where $b_2 = x b_1$. The b_1 probes the momentum fraction of quarks while the whole nucleus is in the $m_J = \pm 1$ or $m_J = 0$ states,

$$b_1(x) = \frac{q^0(x) - q^{\pm 1}(x)}{2}.$$

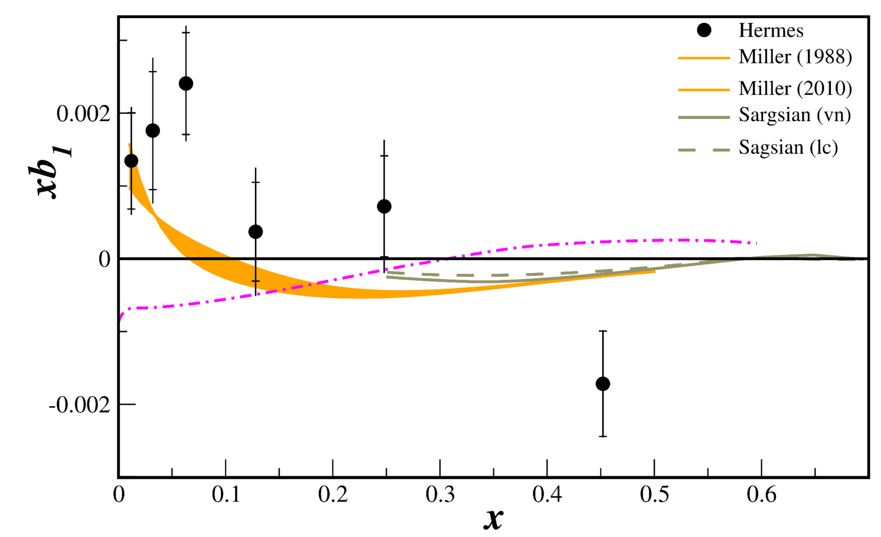
Probing the tensor structure of the deuteron through inclusive DIS electron scattering D(e,e') accesses gross nuclear effects at the partonic level. If the deuteron is described without nuclear effects, b_1 disappears. Even including D-state admixture, all conventional nuclear models predict b_1 to be vanishingly small.

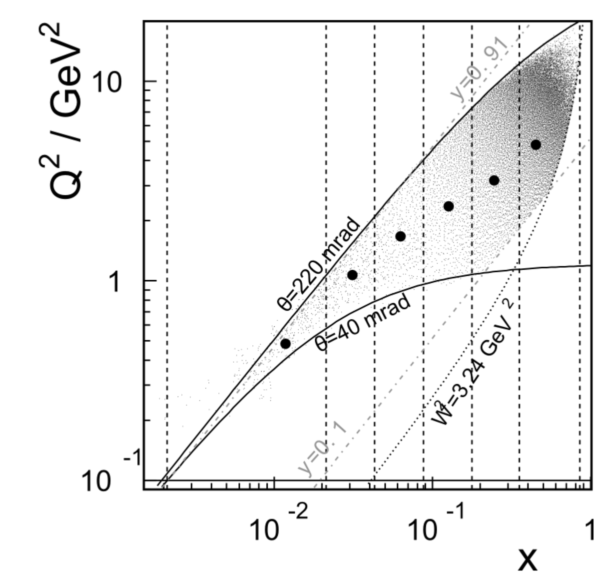


$$b_1 = 0$$

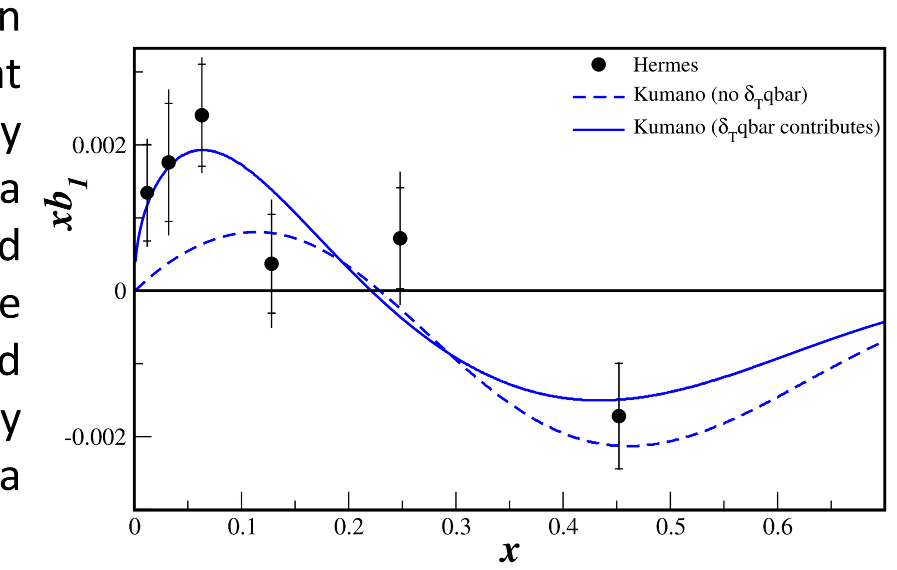
Motivation

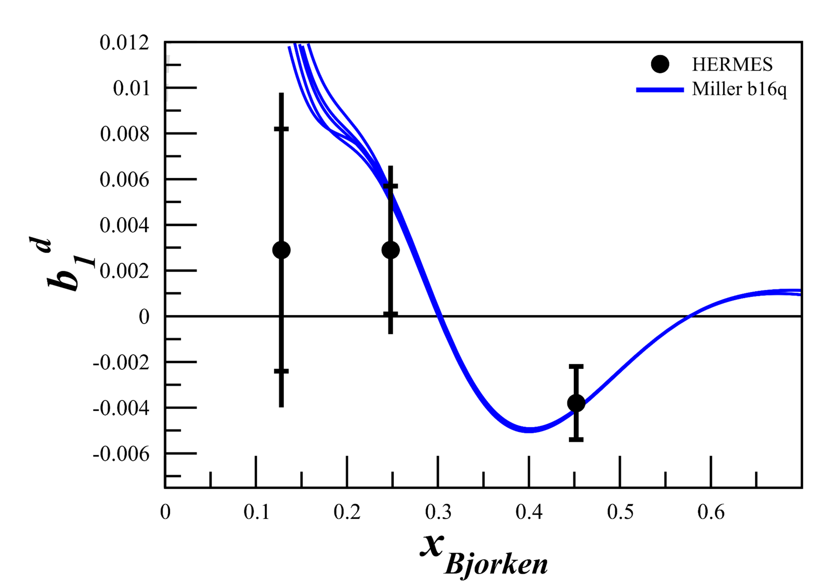
Conventional models are plotted below, as well as the first measurement of b_1 from HERMES[3] alongside their kinematic coverage.





The HERMES measurement found an unexpected large negative value of b_1 at $x = 0.46$ that cannot be explained by conventional models. S. Kumano built a fit of the HERMES data that modeled the quark-antiquark distributions in the deuteron and found that he could better recreate the HERMES data by including tensor polarization of the sea quarks[4].

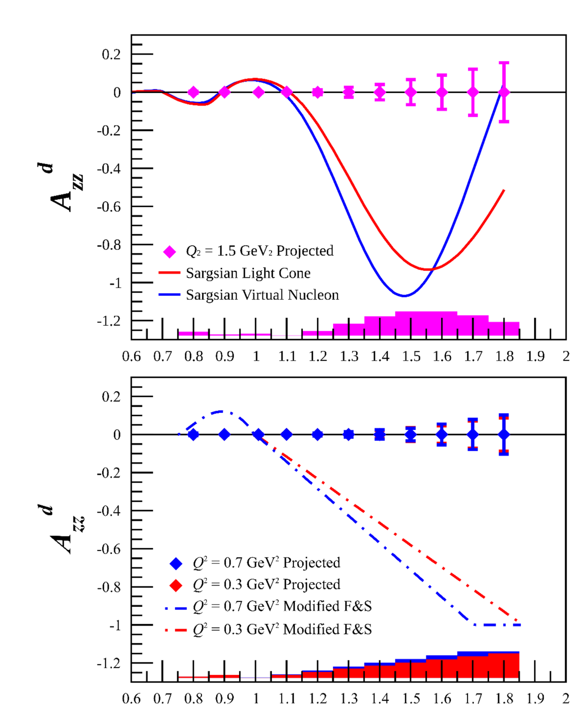




G. Miller[5] looked at the anomalous HERMES point through a hidden-color model. Conventional pionic contributions dominate in the $x < 0.3$ range. Around $x \sim 0.1$, pionic effects are negligible, but the addition of hidden-color six-quark states causes b_1 to cross zero and creates a negative dip on the order of the HERMES data. In addition, the negative structure of six-quark, hidden color effects are able to compensate for the entirely positive pion effects such that the Close-Kumano sum rule ($\int dx b_1(x) = 0$) can be valid.

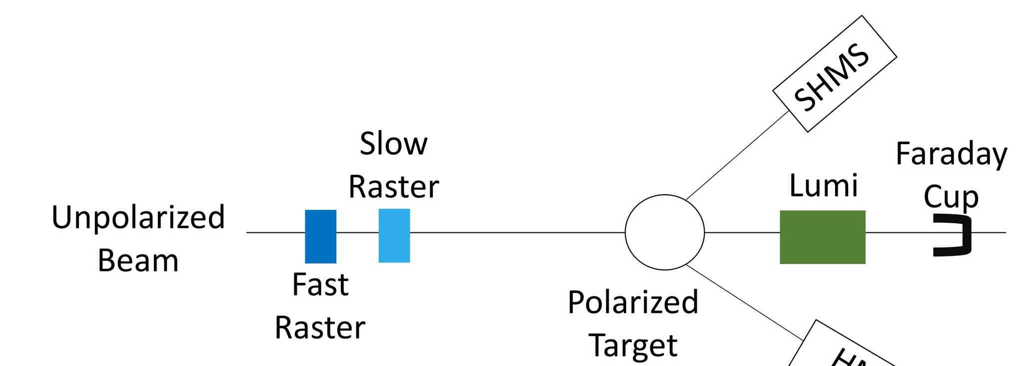
As discussed, the $x = 0.46$ HERMES result is intriguing in that it can only be explained with nonconventional models, but it is unfortunately only 2σ from 0. Thus, there is ample room for improvement. Such a measurement (E12-13-011) was conditionally approved by the JLab PAC40.

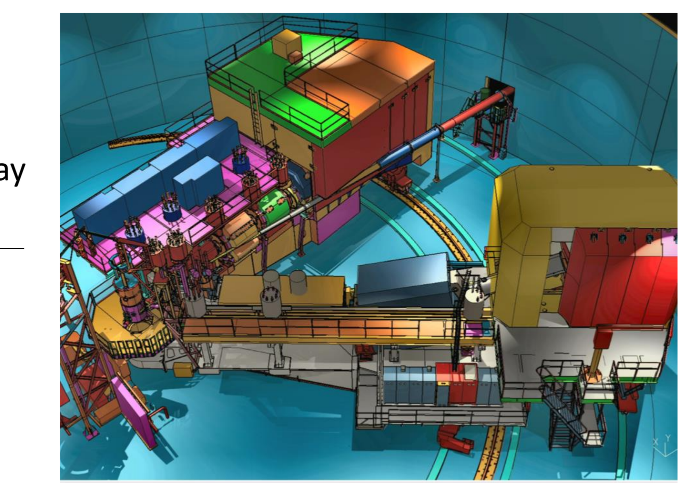
In addition, each of the b_1 measurements are extracted from the observable $A_{zz} = \frac{2}{f P_{zz}} \left(\frac{N_{Pol}}{N_{Unpol}} - 1 \right)$. In the quasi-elastic $x > 1$ region, it is sensitive to light cone and virtual nucleon calculations[6], making it an important quantity to determine for understanding tensor effects such as the dominance of pn correlations in nuclei. The recent JLAB letter of intent LOI12-14-002 explores the potential to measure A_{zz} in the $x > 1$ region from $0.3 < Q^2 < 1.5$ GeV² utilizing identical equipment to the E12-13-011 b_1 measurement.



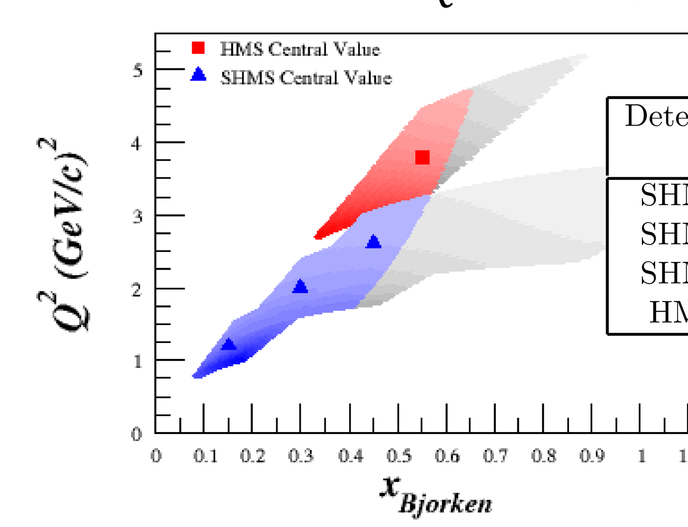
E12-13-011 Experiment

The C1-approved Jefferson Lab E12-13-011 experiment will measure the deuteron tensor structure function b_1 from DIS D(e,e') scattering in the $0.1 < x < 0.6$ range. It will take place in Hall C and utilize the HMS and SHMS spectrometers, luminosity monitors, and the Jlab/UVA solid DNP polarized target.





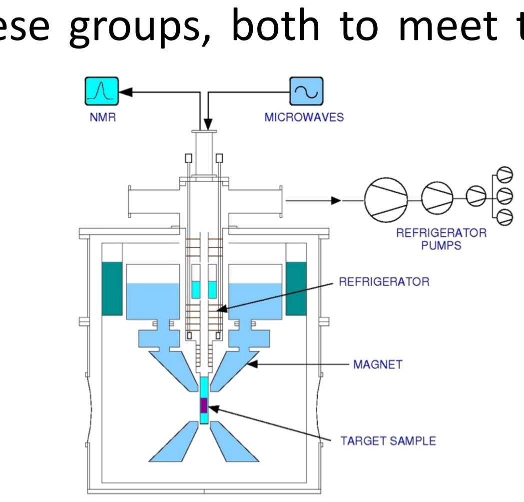
Utilizing a 115nA unpolarized beam, the kinematic range of the experiment will extend from $0.5 < Q^2 < 5.0$ GeV².



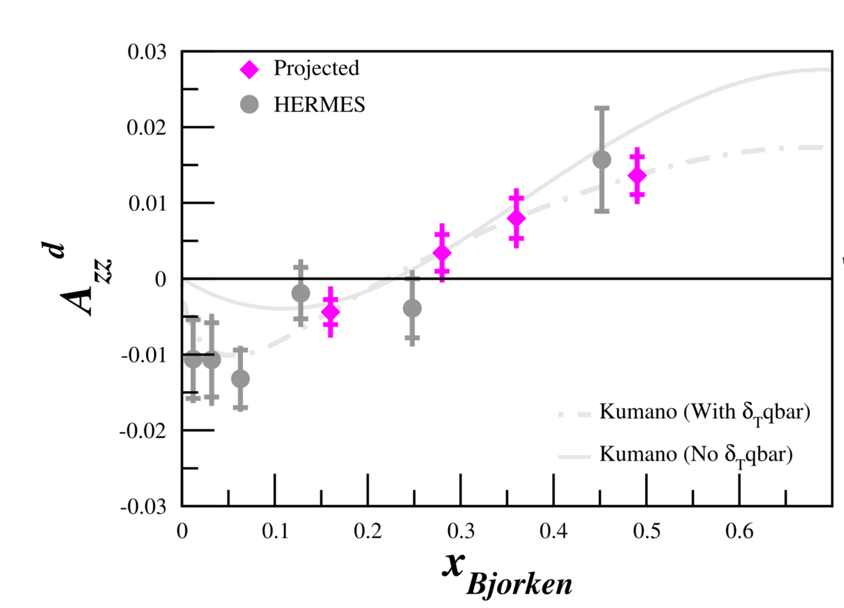
Detector	x	Q^2 (GeV^2)	W (GeV)	$E_{e'}$ (GeV)	$\theta_{e'}$ (deg.)	θ_q (deg.)	Rates (kHz)	Time (Days)
SHMS	0.15	1.21	2.78	6.70	7.35	11.13	1.66	6
SHMS	0.30	2.00	2.36	7.45	8.96	17.66	0.79	9
SHMS	0.45	2.58	2.00	7.96	9.85	23.31	0.38	15
HMS	0.55	3.81	2.00	7.31	12.50	22.26	0.11	30

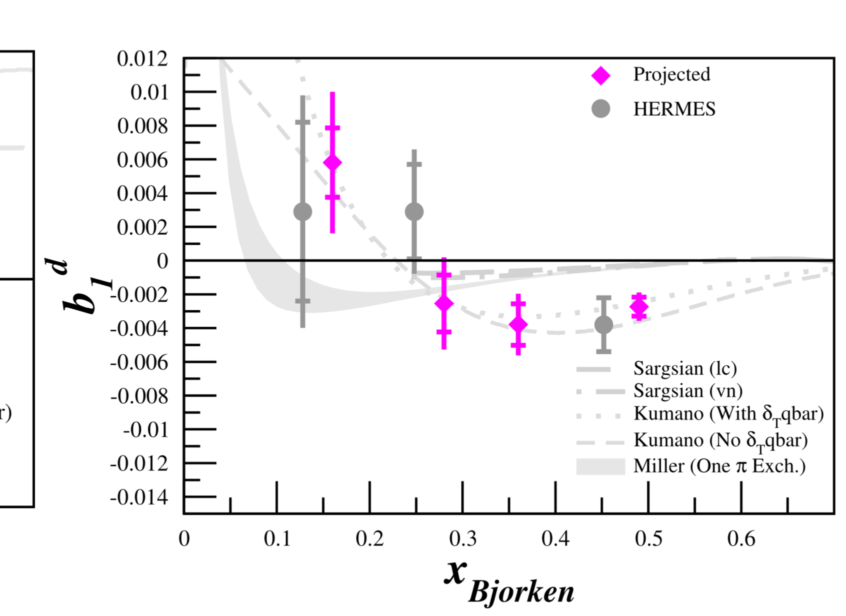
The condition given by the PAC is to obtain an in-beam tensor polarization of at least 30%. Target development is in progress at both the UVA and UNH DNP target labs. Understanding tensor polarization is a top goal of these groups, both to meet the PAC condition and because target polarimetry is the leading systematic uncertainty.

Source	Relative Uncertainty
Polarimetry	8.0%
Dilution/Packing Fraction	4.0%
Radiative Corrections	1.5%
Charge Determination	1.0%
Detector Resolution and Efficiency	1.0%
Total	9.2%



The b_1 structure function is extracted from the observable $A_{zz} = \frac{2}{f P_{zz}} \left(\frac{N_{Pol}}{N_{Unpol}} - 1 \right)$ by $b_1 = -\frac{3}{2} F_1 A_{zz}$. The predicted uncertainties for both are shown below.





References

[1] J. L. Forest et al., Phys. Rev. C **54**, 646 (1996)
[2] P. Hoodbhoy et al., Nuc. Phys. **B312**, 571 (1989)
[3] A. Airapetian et al., Phys. Rev. Lett. **95**, 242001 (2005)
[4] S. Kumano, Phys. Rev. D **82**, 017501 (2010)
[5] G. Miller, arXiv:1311.4561 (2014)
[6] M. Sargsian, Private communication