Probing Nuclear Structure through Electron Scattering from Tensor Polarized Targets

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E. Long, on behalf of the b_1 collaboration

Abstract

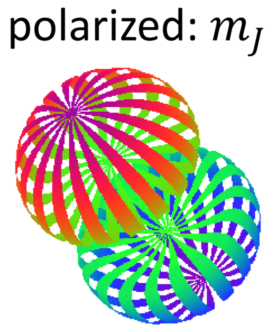
The leading twist tensor structure function of spin-1 hadrons, b_1 provides a unique tool to study partonic effects, while also being sensitive to coherent nuclear properties in the simplest nuclear system. The first measurement of b_1 taken at HERMES revealed a crossover to an anomalously large negative 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.

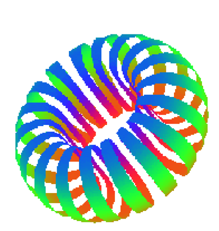
Jefferson Lab has approved an experiment to measure b_1 with greatly improved uncertainty using a tensor-polarized solid ND_3 target. Such a target would also provide access to tensor observables at higher x that can probe the short range repulsive core of the nucleon-nucleon potential and the ratio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

Background

The deuteron is the simplest composite nuclear system

- Understanding deuteron necessary for understanding QCD bound systems
- Spin-1 nucleus can be vector or tensor polarized[1]
  - Vector polarized: $m_J = \pm 1$
  - Tensor polarized: $m_J = 0$





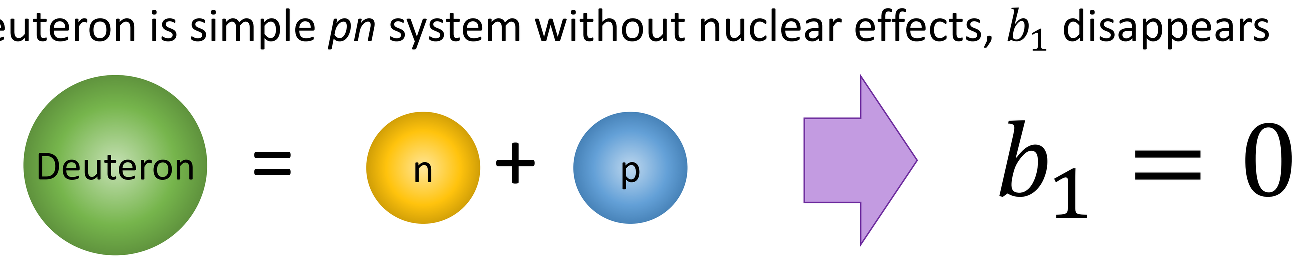
Tensor-polarized D(e,e') hadronic tensor reveals four structure functions[2]

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

- b_1, b_2, b_3, and b_4 not accessible from unpolarized or vector polarized D(e,e')
  - b_2 has Callan-Gross relation to b_1, such that $b_2 = x b_1$
  - b_3 is higher-twist
  - b_4 leading twist, but kinematically suppressed with longitudinal polarized target
- Leading twist b_1
  - Probes momentum fraction of quarks while nucleus is in $m_J = \pm 1$ or 0 states

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

  - Accesses gross nuclear effects at the partonic level
  - If deuteron is simple pn system without nuclear effects, b_1 disappears

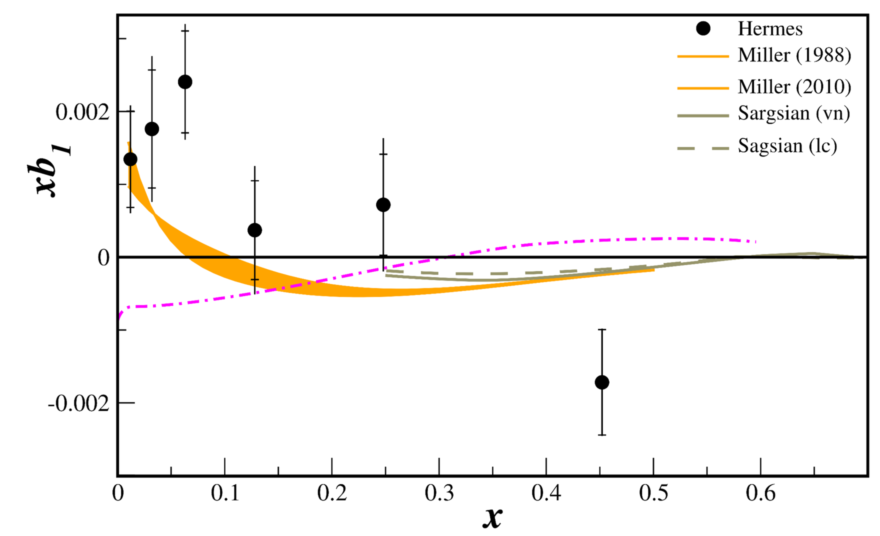


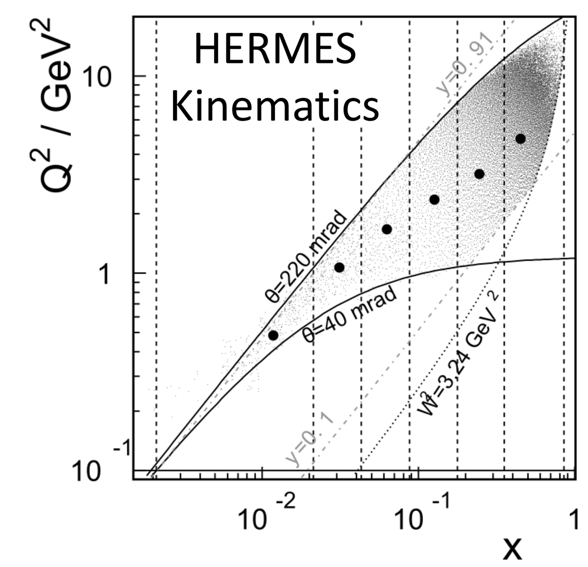
  - Even with D-state, all conventional models predict b_1 to be vanishingly small

Motivation

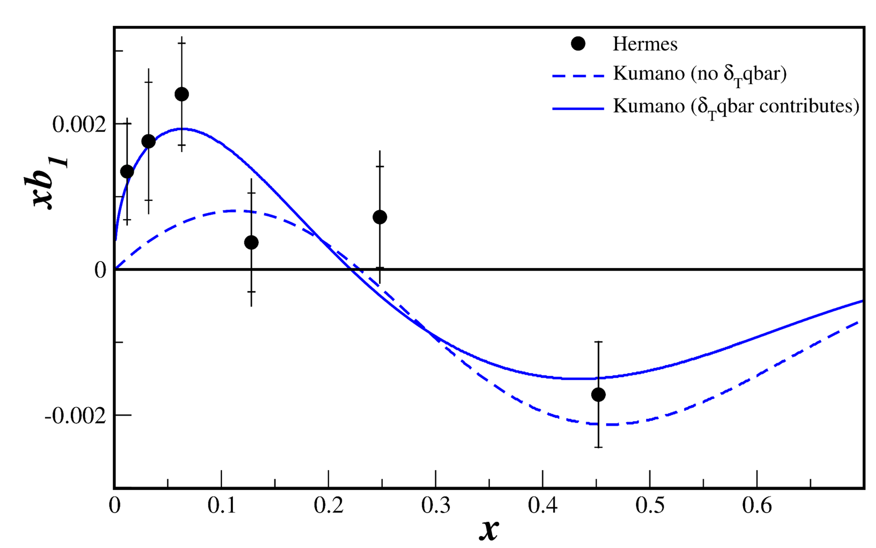
Conventional b_1 models can not reproduce the first measurement by HERMES[3]

- HERMES found unexpected large and negative b_1 at $x = 0.46$

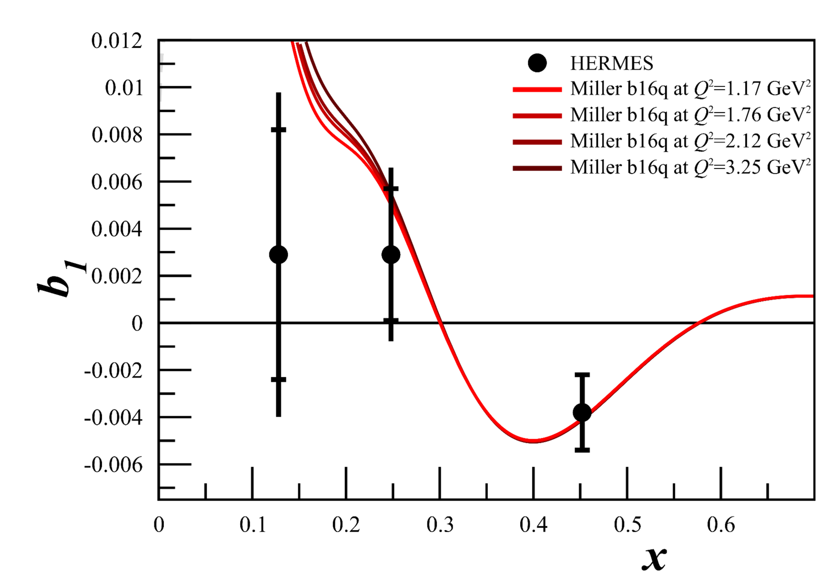




- S. Kumano fit the HERMES data using quark-antiquark distributions[4]
- HERMES data recreated by including tensor polarization of sea quarks



- G. Miller's six quark, hidden-color model reproduces HERMES data[5]
- Pion contributions dominate in $x < 0.3$
  - Can't account for HERMES result
- Hidden color states cause zero-crossing
  - 6q $b_1 < 0$ balances positive π effects
  - Allows valid Close-Kumano sum rule
    - $\int dx b_1(x) = 0$

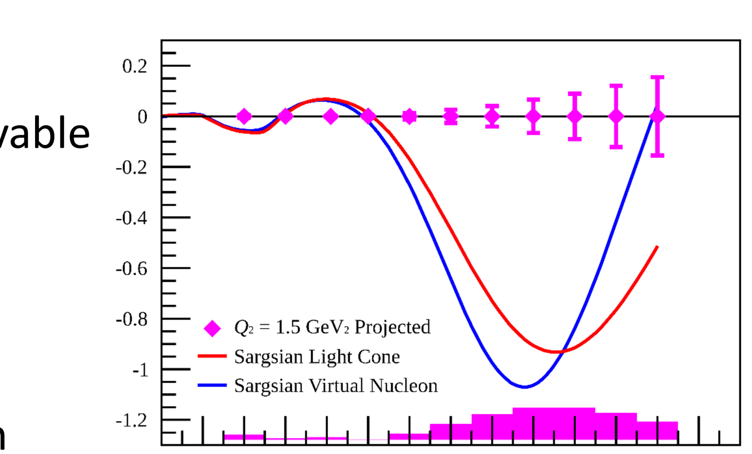


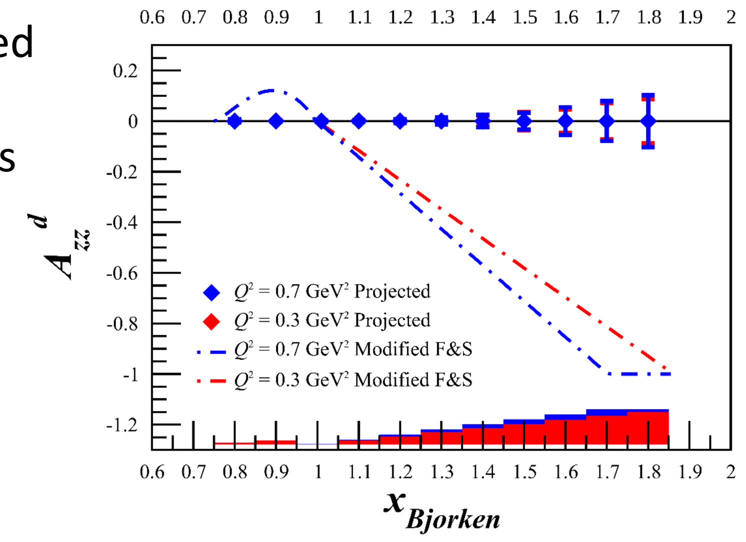
- Anomalous $x = 0.46$ HERMES result can only be explained with nonconventional models
  - Unfortunately it is only 2σ from 0
  - Ample room for improvement
- C1 approved JLab E12-13-011 measurement will verify HERMES results with greatly reduced uncertainty

- b_1 measurements extracted from A_{zz} observable

$$A_{zz} = \frac{2}{f P_{zz}}\left(\frac{N_{Pol}}{N_{Unpol}} - 1\right)$$

- f = dilution factor, P_{zz} = tensor polarization
- In $x > 1$ region, A_{zz} has never been measured
  - Sensitive to NN interactions
  - Important for understanding tensor effects
  - Dominance of pn correlations in nuclei
  - Structure of short-range repulsive core
- Light cone & VN models[6] differ up to 2x
- JLab letter of intent LOI12-14-002
  - Measure A_{zz} in the $x > 1$ region
  - Uses same equipment as E12-13-011

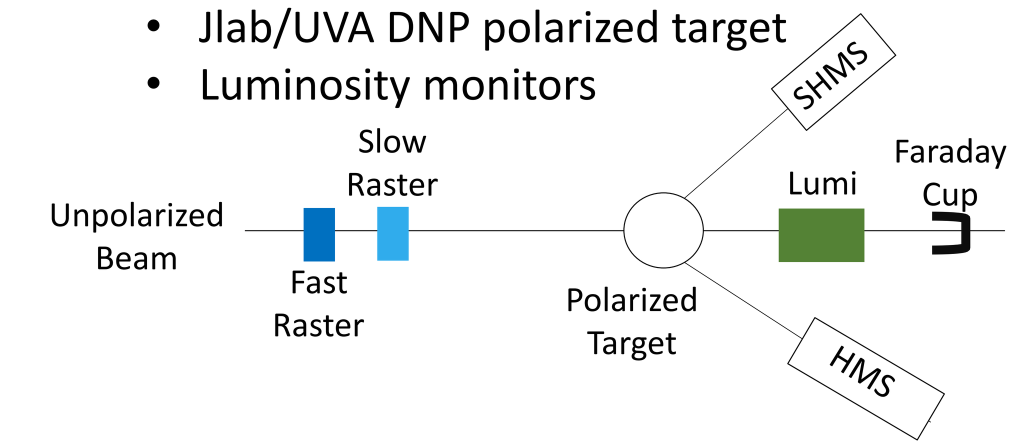


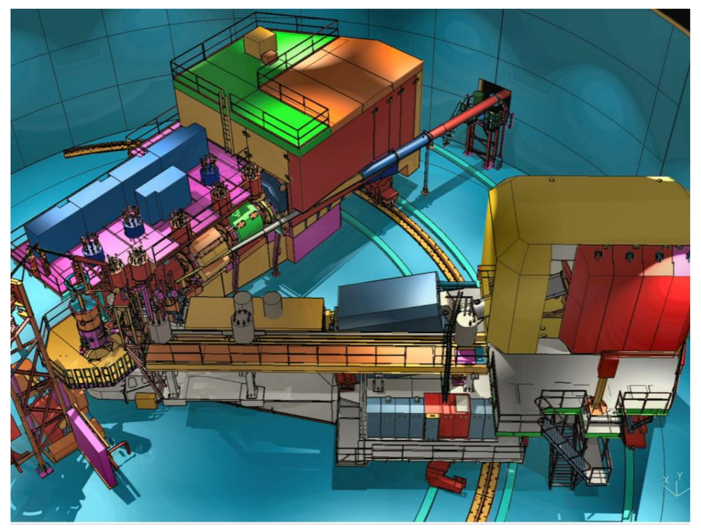


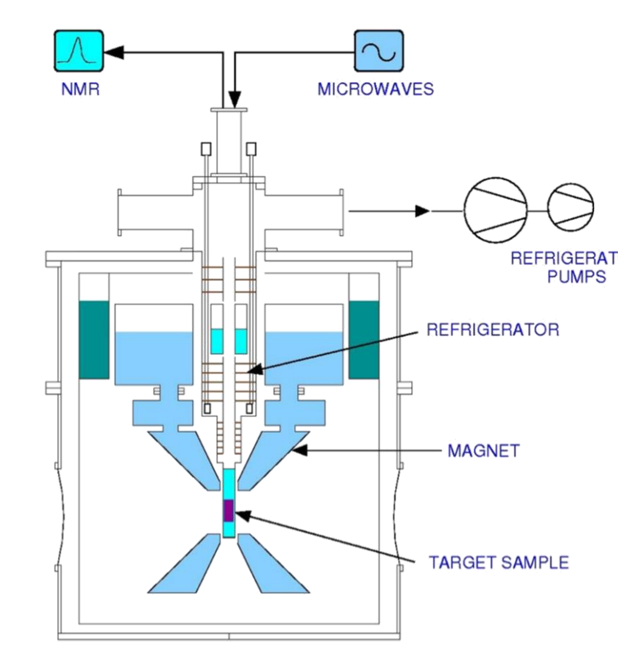
E12-13-011 Experiment

C1-approved Jefferson Lab experiment

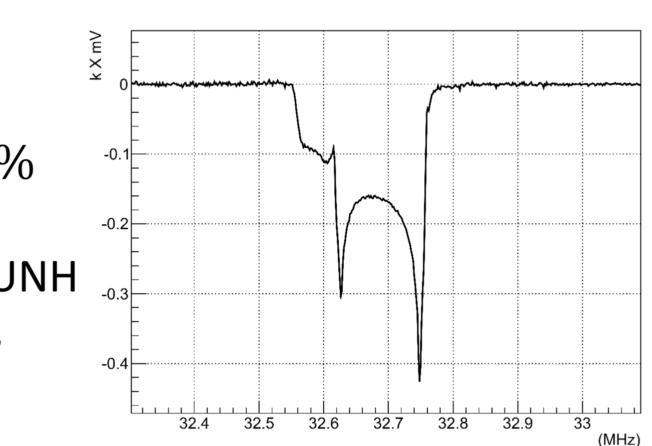
- Measure ²D tensor structure function b_1 from DIS D(e,e') in $0.1 < x < 0.6$
- To take place using Hall C equipment
  - 115nA unpolarized beam
  - HMS and SHMS spectrometers
  - Jlab/UVA DNP polarized target
  - Luminosity monitors



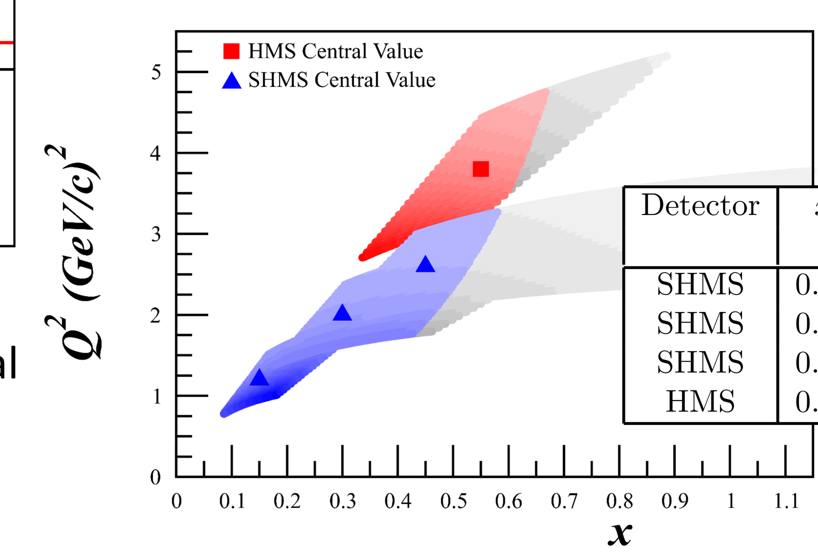




- PAC C1 condition:
  - In-beam tensor polarization $\geq 30\%$
- Target development underway at UVA & UNH
- Leading systematic is tensor polarimetry



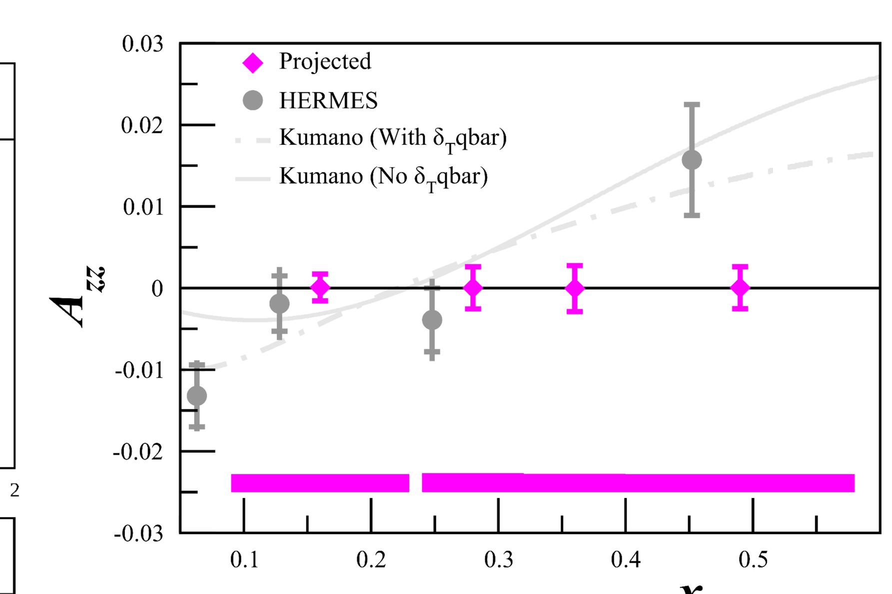
Source	Relative Uncertainty
Polarimetry	8.0%
Dilution/Packing Fraction	4.0%
Radiative Corrections	1.5%
Charge Determination	1.0%
Detector Resolution and Efficiency	1.0%
Total	9.2%

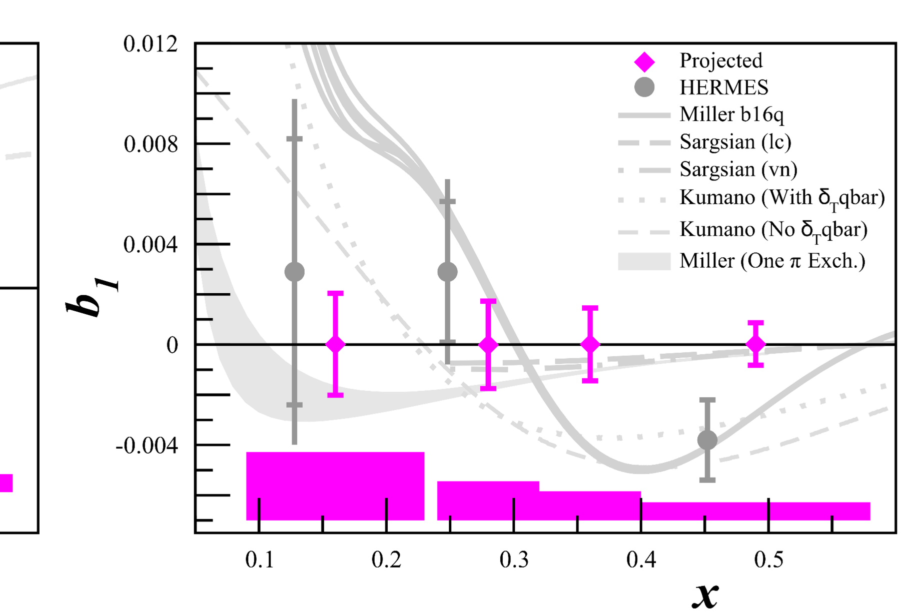


- Kinematic range from $0.5 < Q^2 < 5.0$ GeV²

Detector	x	Q^2 (GeV²)	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

- b_1 is extracted from A_{zz} by $b_1 = -\frac{3}{2} F_1 A_{zz}$
- Predicted experimental uncertainties shown below





References

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