Spin Structure at JLab

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Conference on the Intersections of Particle and Nuclear Physics, Vail, CO

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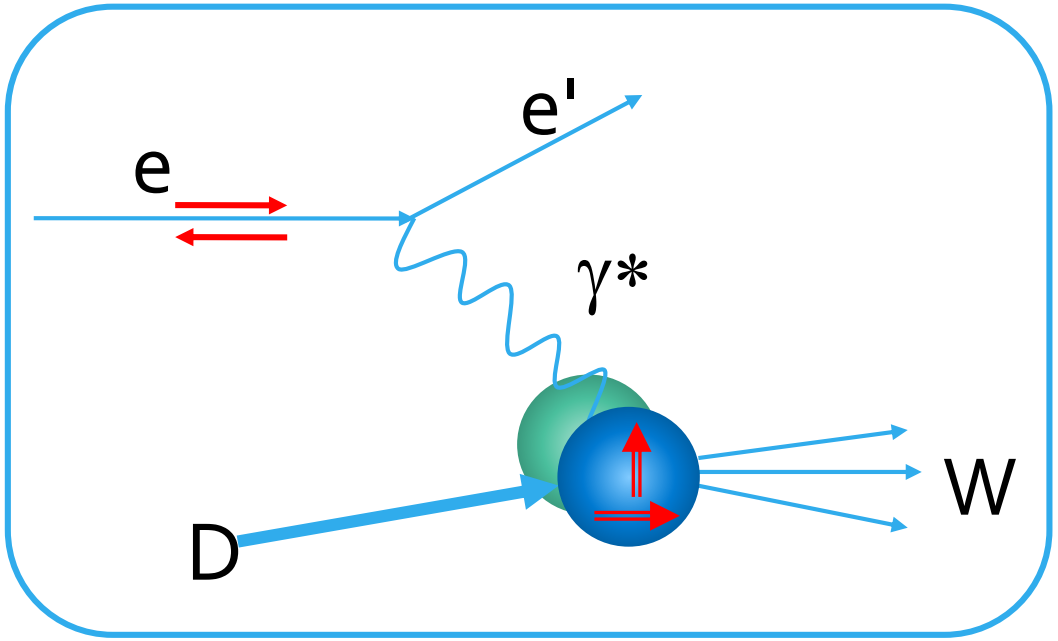
University of New Hampshire

Today's Discussion

- Brief Review
  - Inclusive scattering & Structure Functions
  - Spin Polarizabilities
- JLab Data at Low Q^2
  - Hall A: g2p
  - Hall B: EG4
- Tensor Structure
  - Hall C: b1
  - Hall C: Azz

Inclusive Scattering

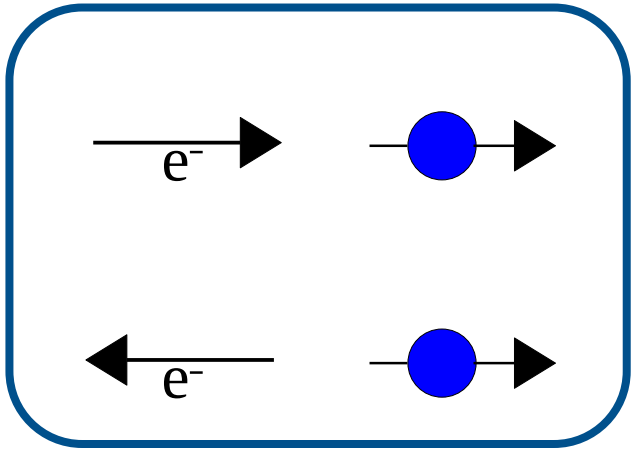


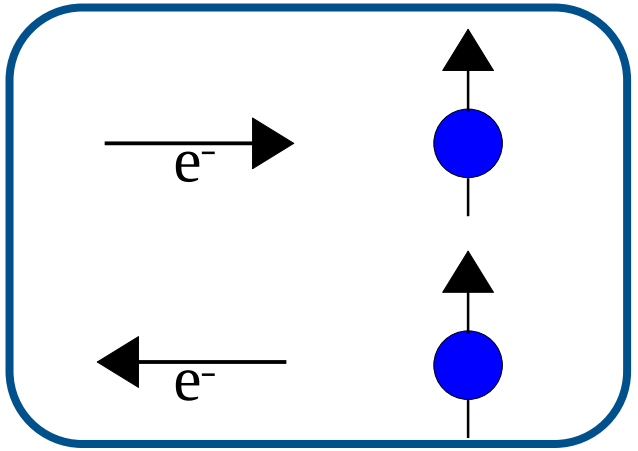
By adding spin degrees of freedom to the target and beam, we uncover new structure functions

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott}\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)\tan^2\frac{\theta}{2}\right]$$

$$+\gamma g_1(x,Q^2) + \delta g_2(x,Q^2)$$

Experimental Technique





$$\frac{d^2\sigma^{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Uparrow}}{d\Omega dE'} = \frac{4\alpha^2}{\nu Q^2}\frac{E'}{E}\left[(E + E'\cos\theta)\, g_1 - 2Mx g_2\right]$$

$$\frac{d^2\sigma^{\uparrow\Rightarrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Rightarrow}}{d\Omega dE'} = \frac{4\alpha^2}{\nu Q^2}\frac{E'}{E}\sin\theta\left[g_1 + \frac{2ME}{\nu} g_2\right]$$

Moments

$$g_{TT} = g_1 - (4M_N^2 x^2/Q^2) g_2$$

Spin Polarizabilities

$$\gamma_0(Q^2) = \frac{16\alpha M_N^2}{Q^6} \int_0^{x_0} \mathrm{d}x\, x^2 g_{TT}(x, Q^2),$$

$$\delta_{LT}(Q^2) = \frac{16\alpha M_N^2}{Q^6} \int_0^{x_0} \mathrm{d}x\, x^2 \Big[g_1(x, Q^2) + g_2(x, Q^2) \Big],$$

Color Polarizability

$$\bar{d}_2(Q^2) = \int_0^{x_0} \mathrm{d}x\, x^2 \Big[2g_1(x, Q^2) + 3g_2(x, Q^2) \Big],$$

Generalized GDH

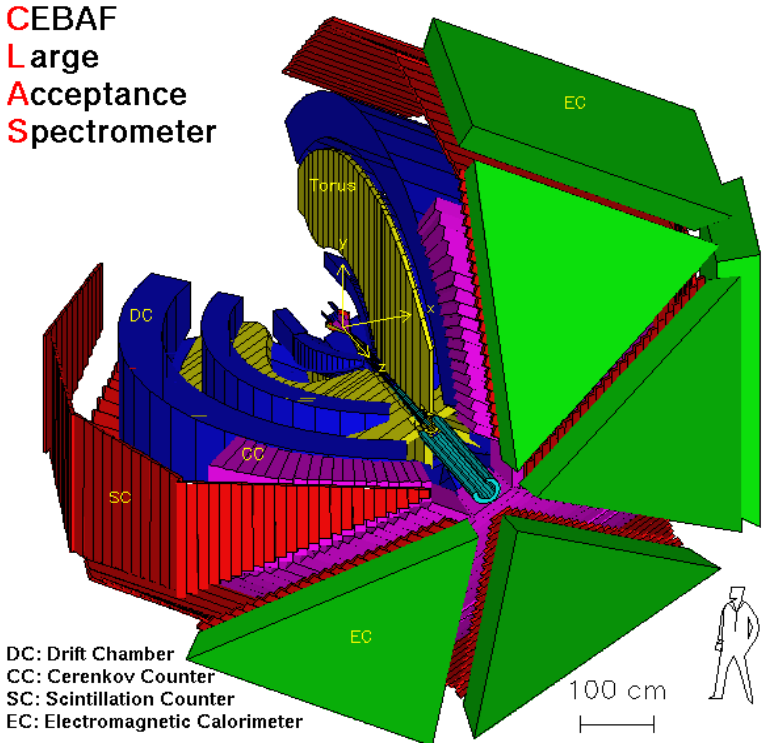
$$I_A(Q^2) = \frac{2M_N^2}{Q^2} \int_0^{x_0} \mathrm{d}x\, g_{TT}(x, Q^2),$$

$$\Gamma_1(Q^2) = \int_0^{x_0} \mathrm{d}x\, g_1(x, Q^2),$$

Burkhardt-Cottingham

$$\Gamma_2(Q^2) = \int_0^{x_0} dx\; g_2(x, Q^2)$$

EG4



Measurement of g_1 at low Q^2

Test of Chiral Perturbation Theory as $Q^2 \to 0$

Measured absolute cross sections

Goal: Extend GDH Sum Rule for Proton and Deuteron

Spokespersons:

NH_3: M. Battaglieri, A. Deur, R. De Vita, M. Ripani (Contact)

ND_3: A. Deur (Contact), G. Dodge, K. Slifer

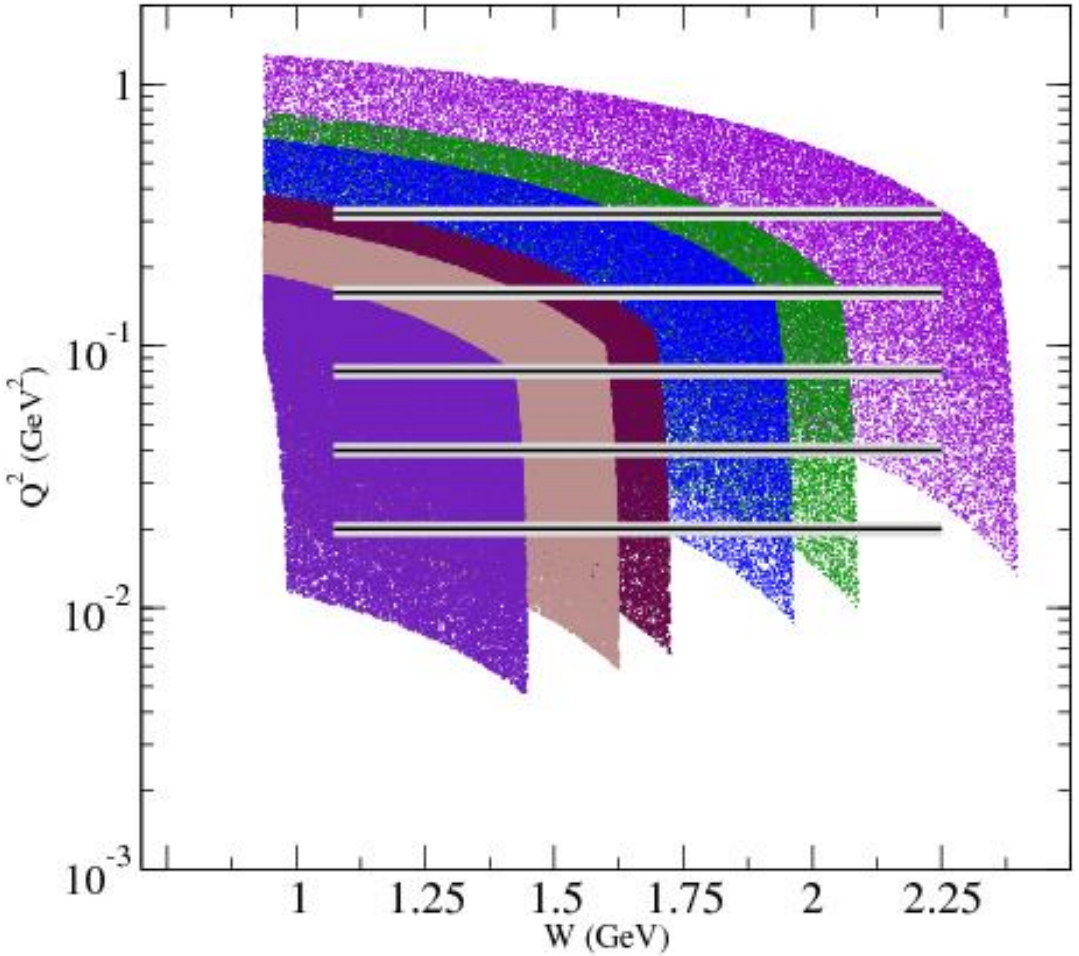
Graduate Students:

K. Adhikari, H. Kang, K. Kovacs

EG4 – Kinematic Coverage

EG4: g1 Proton and Deuteron

$0.02 < Q^2 < 0.5\ \mathrm{GeV}^2$



Thanks to
Hyekoo Kang (Seoul)
and
Krishna Adhikari (ODU)

EG4 – Preliminary g1p ($0.02 < Q^2 < 0.07\ \mathrm{GeV}^2$)

H. Kang, Ph.D. Thesis

Preliminary

EG4 – Preliminary g1p ($0.08 < Q^2 < 0.24\ \mathrm{GeV}^2$)

H. Kang, Ph.D. Thesis

Preliminary

EG4 – Preliminary g1p ($0.29 < Q^2 < 0.50\ \mathrm{GeV}^2$)

H. Kang, Ph.D. Thesis

Preliminary

EG4 – Preliminary Proton Moments

H. Kang, Ph.D. Thesis

Preliminary

EG4 – Preliminary Deuteron g1 $(0.02 < Q^2 < 0.05\ \mathrm{GeV}^2)$

K Adhikari, Ph.D. Thesis

Preliminary

EG4 – Preliminary Deuteron g1 $(0.06 < Q^2 < 0.14\ \mathrm{GeV}^2)$

K Adhikari, Ph.D. Thesis

Preliminary

EG4 – Preliminary Deuteron g1 $(0.17 < Q^2 < 0.71\ \mathrm{GeV}^2)$

K Adhikari, Ph.D. Thesis

Preliminary

EG4 – Preliminary Deuteron Moments

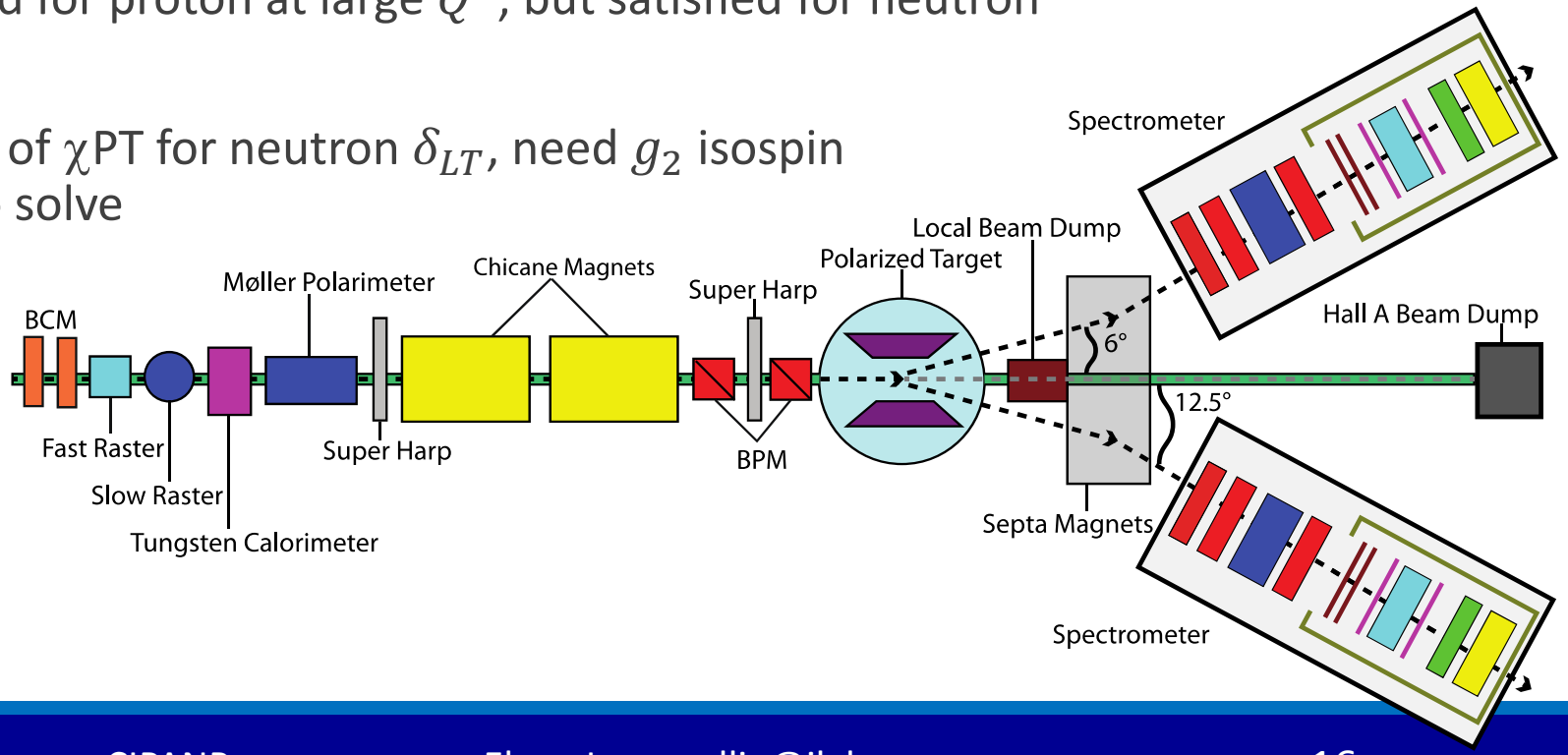
Preliminary

Hall A - g2p

Fundamental spin structure function has never been measured at low or moderate Q^2

BC Sum Rule: Violation suggested for proton at large Q^2, but satisfied for neutron and ^{3}He

Spin Polarizability: Major failure of χPT for neutron δ_{LT}, need g_2 isospin separation to solve



Spokespersons:

A. Camsonne, D. Crabb, J.P. Chen, K. Slifer

Graduate Students:

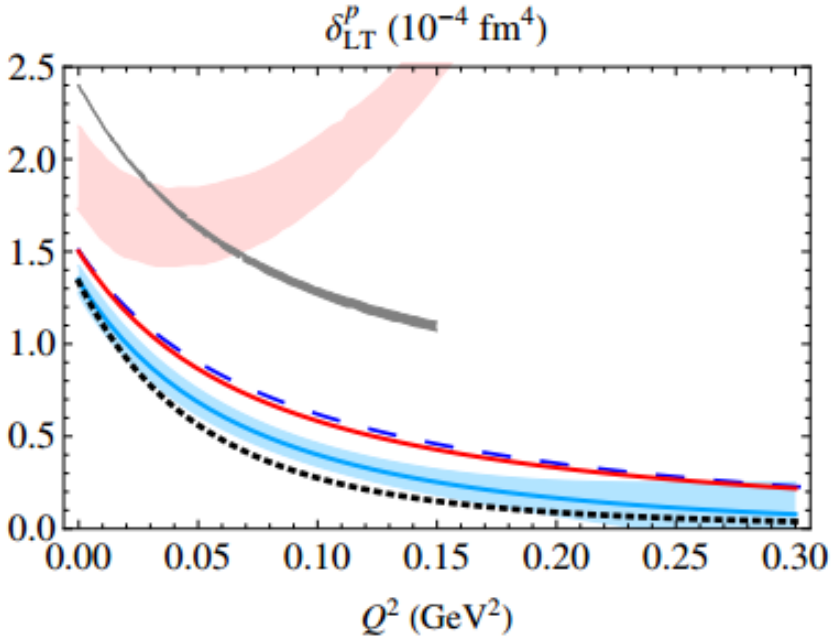
T. Badman, M. Cummings, C. Gu, M. Huang, J. Liu, P. Zhu, R. Zielinski

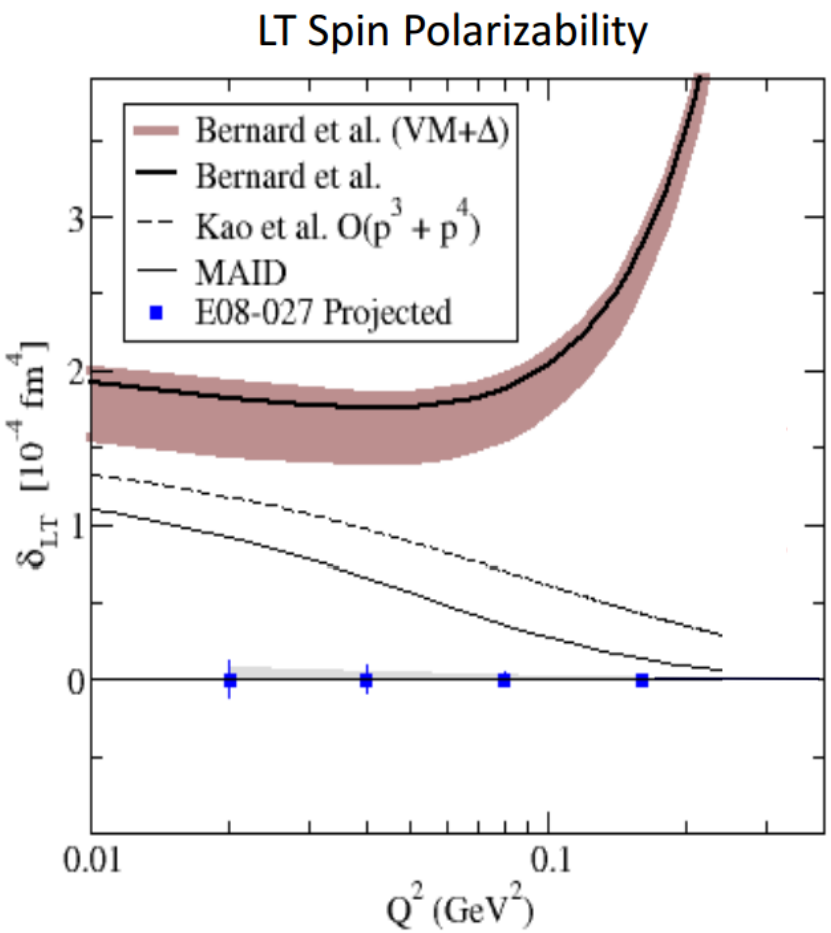
Need Proton Spin Polarizability Data!

χPT calculations don't describe neutron δ_{LT}^{n}

No current data for proton δ_{LT}^{p}

(See V. Pascalutsa's talk from Wed. evening)





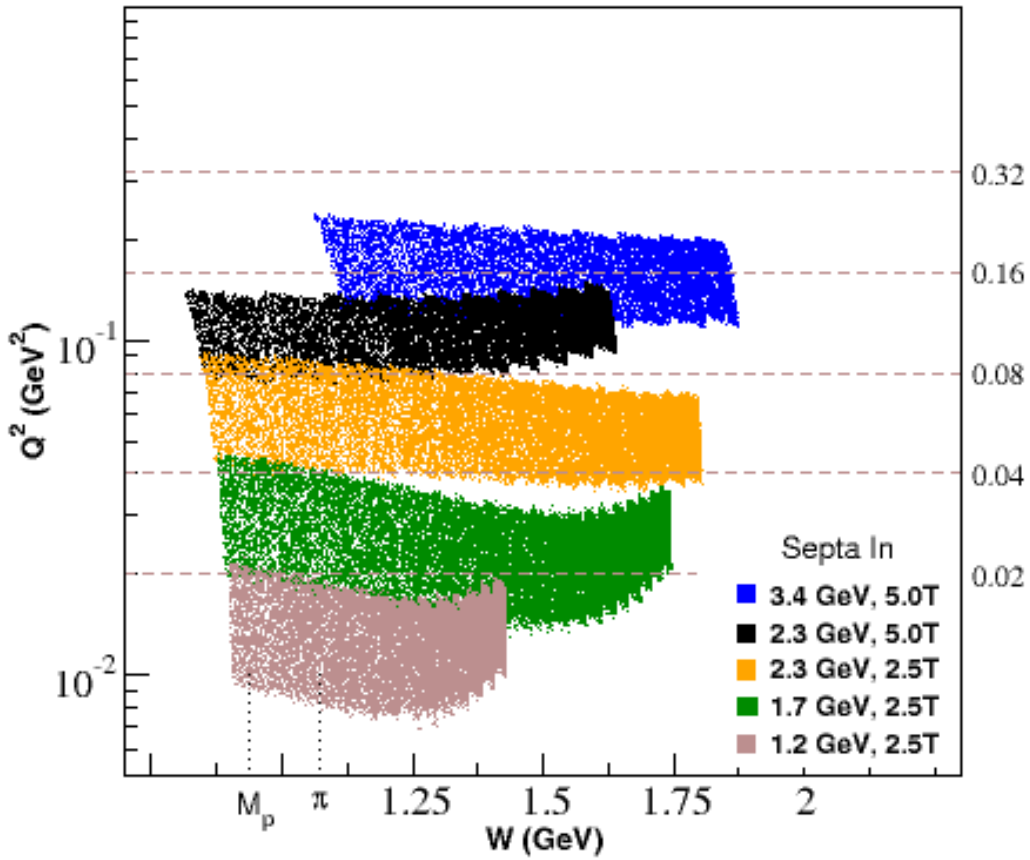
DeltaLT puzzle — none of chiral PT cal

aLT.

Vladimir Pascalutsa — ChPT in Puzzles — CIP

3

g2p Kinematics



Dashed lines show planned extrapolation to constant Q^2

$0.02 < Q^2 < 0.16$

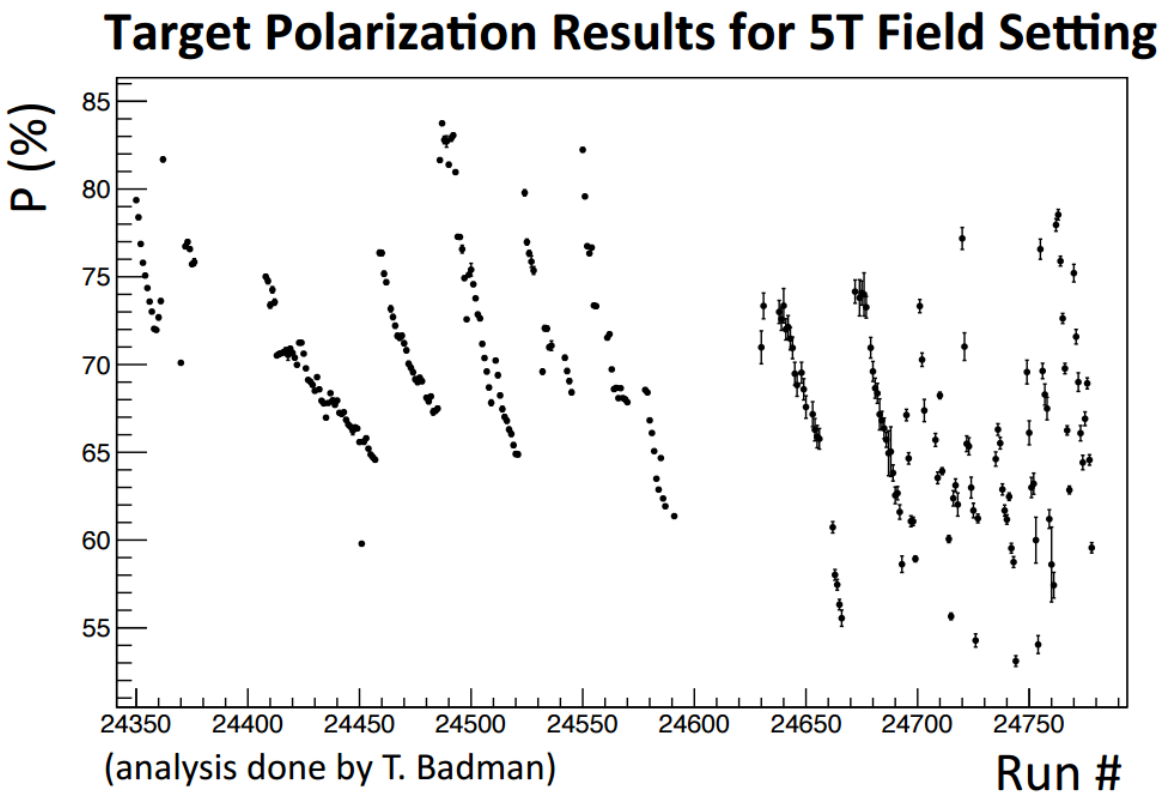
g2p Status

Completed:

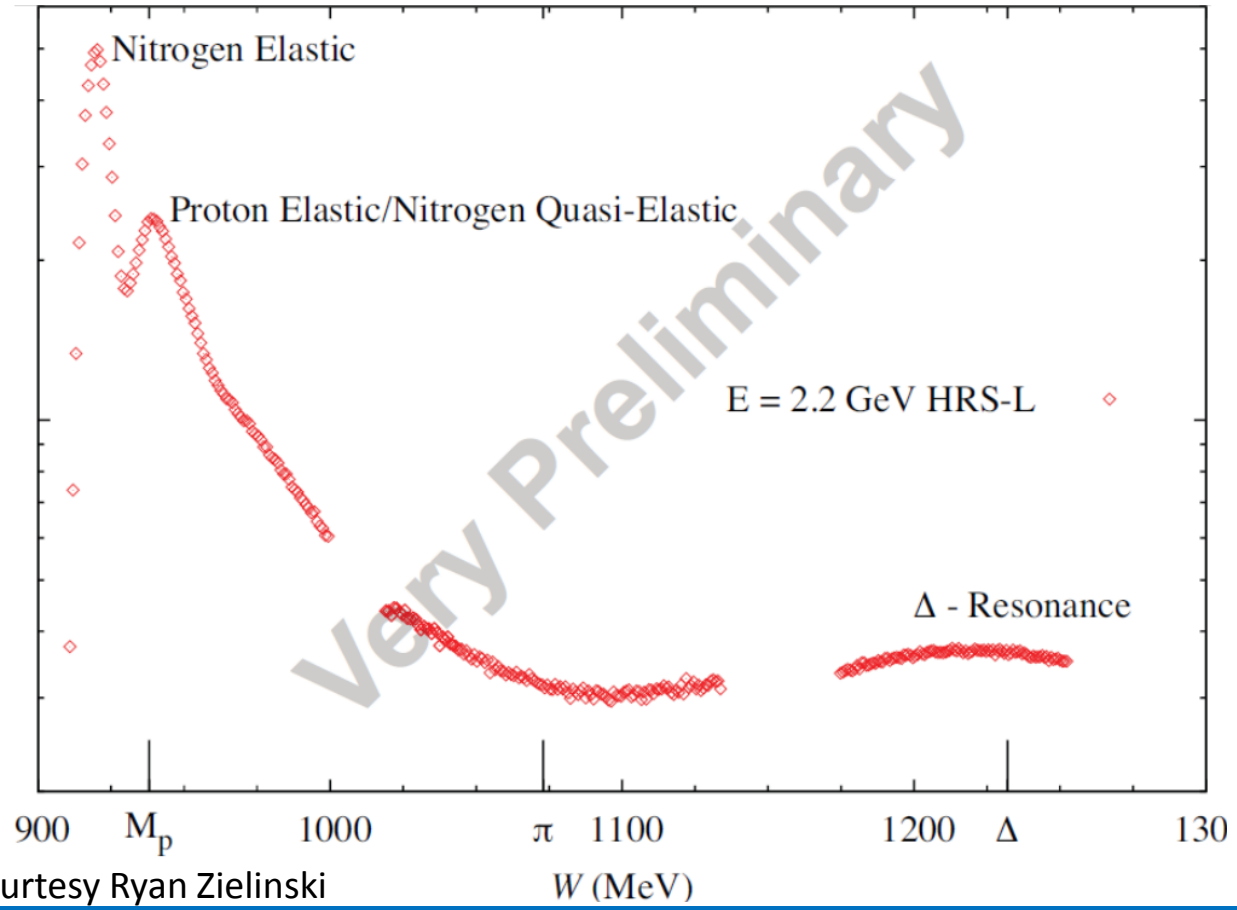
- Run Database
- HRS Optics
- Detector Calibrations and Efficiencies
- Scalers
- Target Polarization
- BPM Calibrations

In Progress:

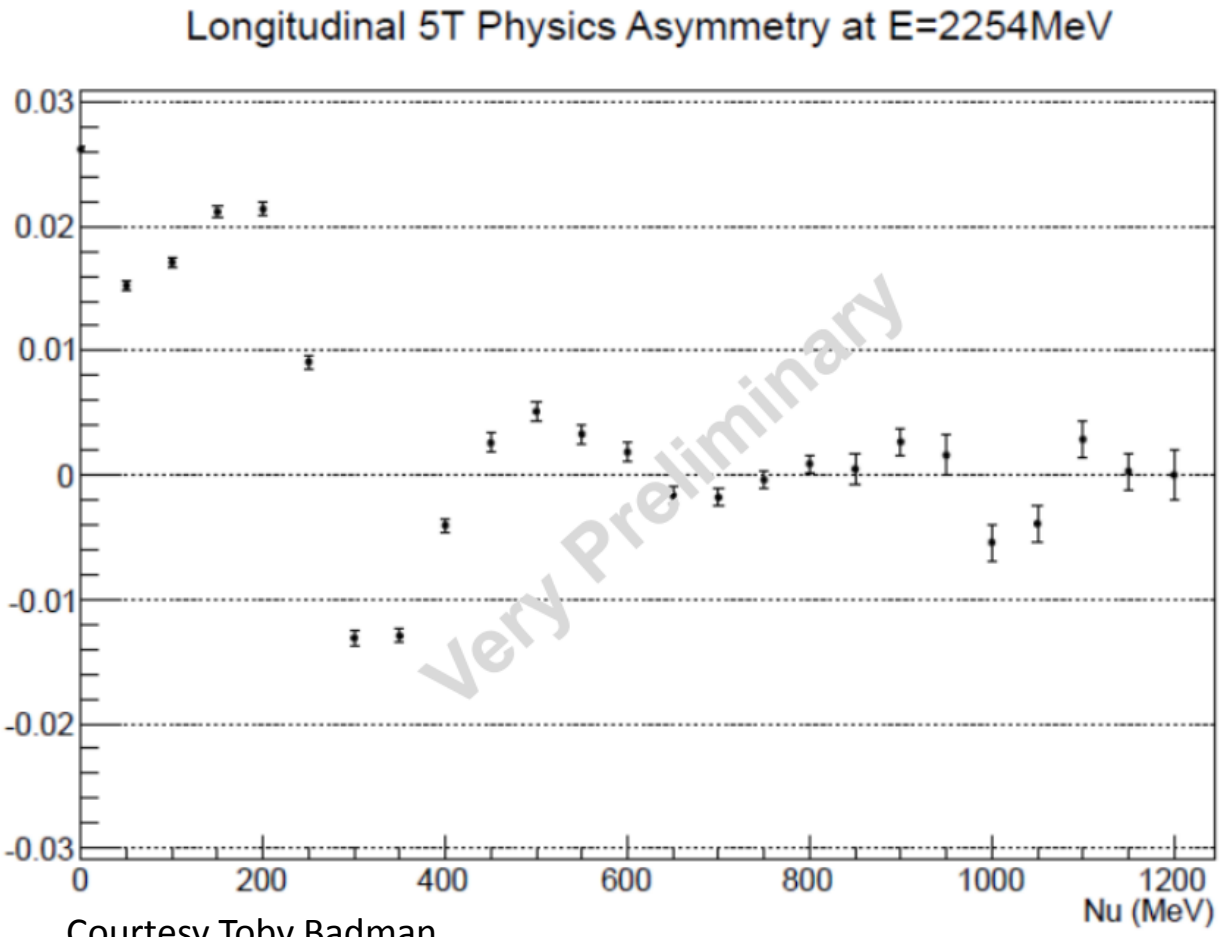
- Packing Fraction
- Dilution Analysis
- Radiative Corrections
- Elastic Analysis
- Yields
- Raster Calibration



g2p – Preliminary Yields and Asymmetries

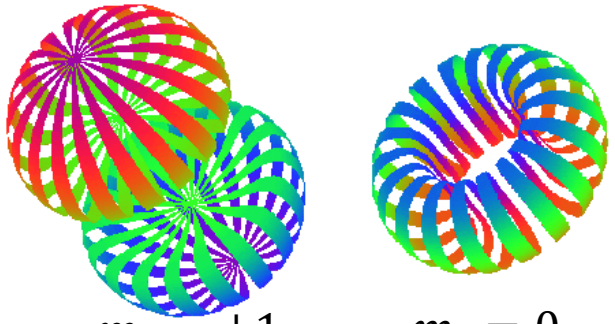


Courtesy Ryan Zielinski



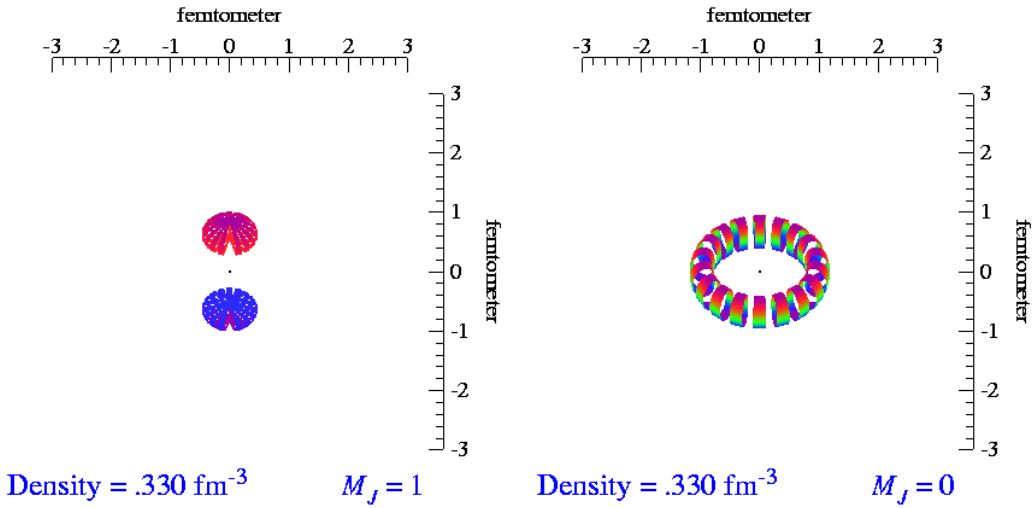
Courtesy Toby Badman

Tensor Polarization



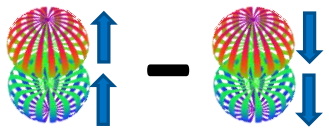
$m_J = \pm 1$ $m_J = 0$

For tensor polarization, need spin-1 particles

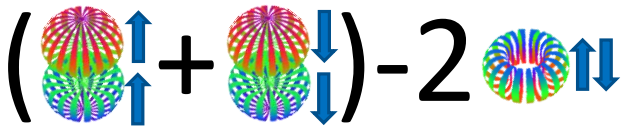


Development of a high luminosity, high tensor polarized target has promise as a novel probe of nuclear physics

Vector $P_z = p_+ - p_-$



Tensor $P_{zz} = (p_+ + p_-) - 2p_0$



Animations by SC Pieper, *et al*, http://www.phy.anl.gov/theory/movie-run.html

J Forest, *et al*, PRC **54** 646 (1996)

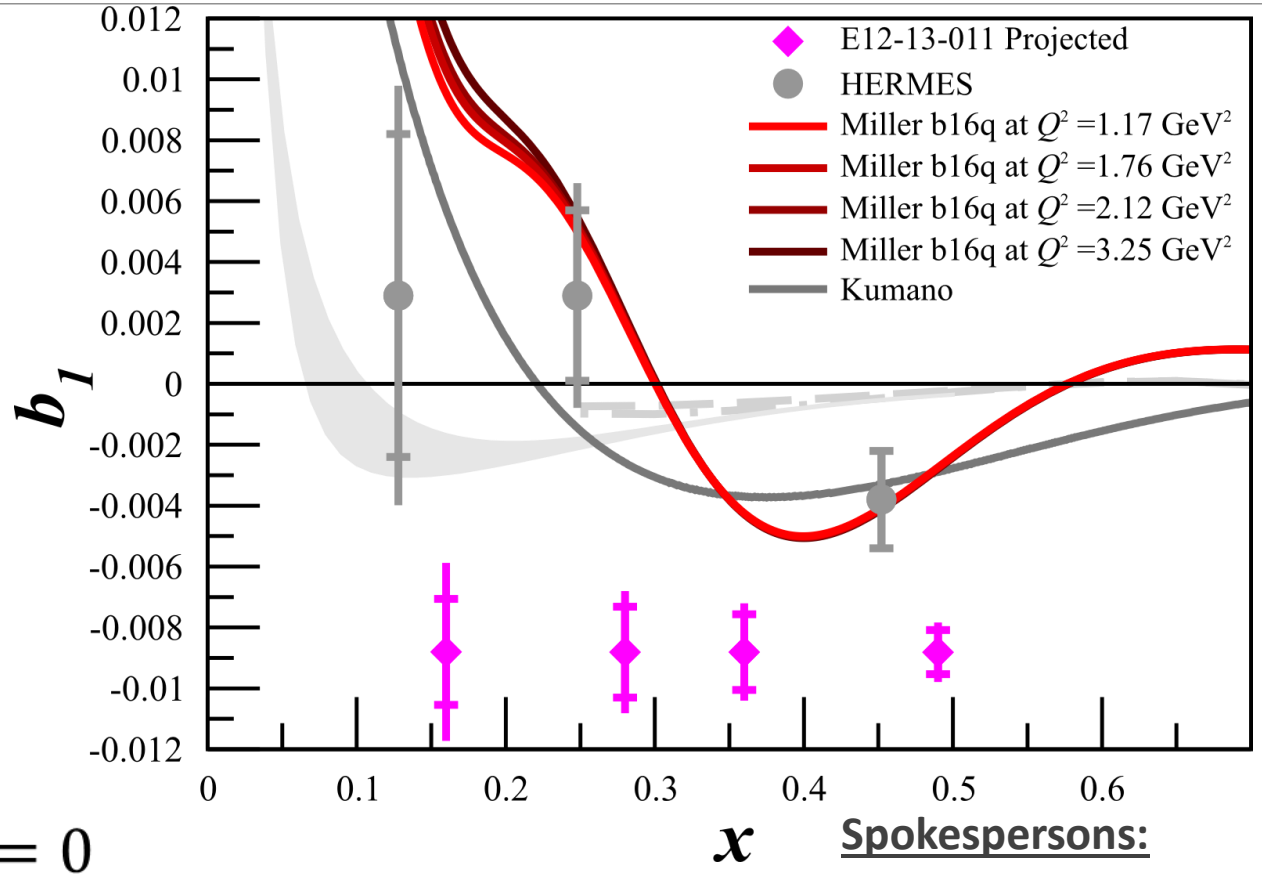
[1] P Hoodbhoy *et al*, Nucl. Phys. **B312,** 571 (1989)
[2] FE Close, S Kumano, Phys. Rev. **D42,** 2377 (1990)
[3] G Miller, Phys. Rev. **C89,** 045203 (2014)
[4] SK Taneja *et al*, Phys. Rev. **D86,** 036008 (2012)
[5] S Kumano, Phys. Rev. **D82,** 017501 (2010)

Tensor Structure Function - b_1

New tensor structure functions[1]

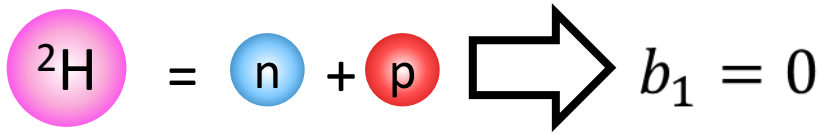
$$W_{\mu\nu} = -\alpha F_1 + \beta F_2 + i\gamma g_1 + i\delta g_2 - \varepsilon b_1 + \zeta b_2 + \eta b_3 + \kappa b_4$$

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



JLab E12-13-011, A- Rating, C1 Approved Tensor Structure Function b_1

Close-Kumano sum rule[2]
6-quark, hidden color[3]
OAM and spin crisis[4]
Pionic effects[3,5]
Polarized sea quarks[5]



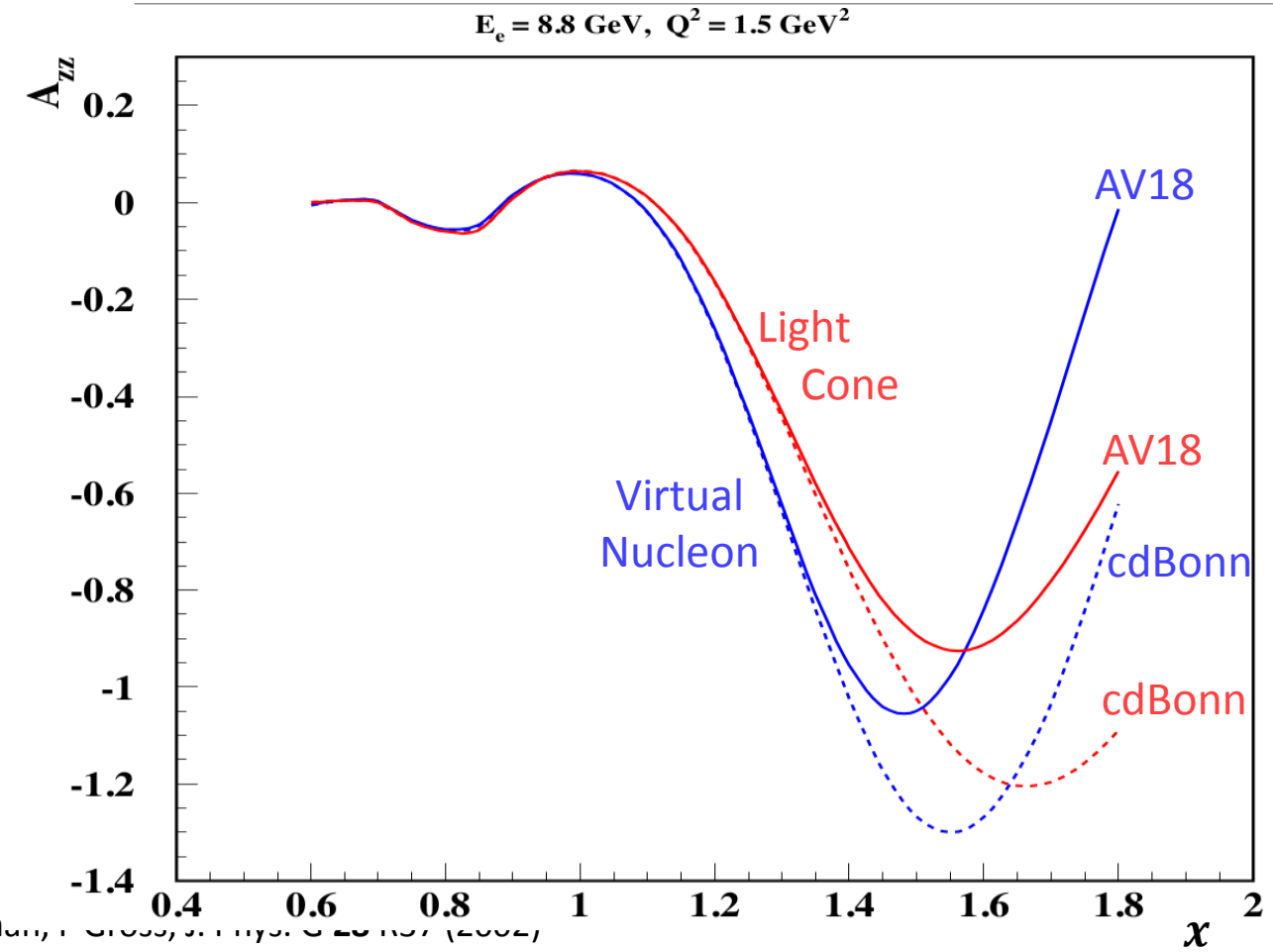
$b_1 = 0$

Spokespersons:

K. Slifer, E. Long, J.P. Chen, P. Solvignon, O. Rondon, D. Keller, N. Kalantarians

Tensor Asymmetry A_{zz}

- DIS → $b_1 \propto F_1 A_{zz}$
- QE → A_{zz}
- Elastic → $T_{20} \propto A_{zz}$



R Gilman, F Gross, J. Phys. G **28** R37 (2002)

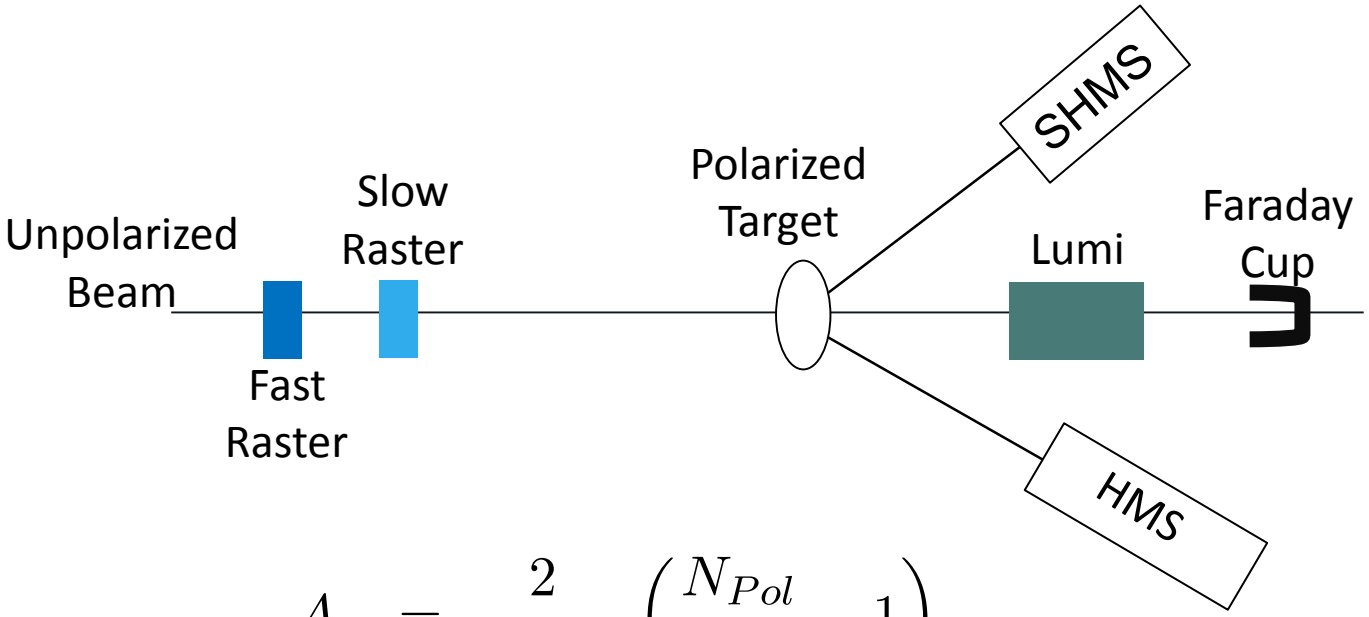
- Tensor polarization enhances D-state
- $x > 1$ region probes short distances
- Using both amplifies short-range effects
  - Sensitivity to hard/soft NN potentials
  - Sensitivity to relativistic models
- Probes tensor effects important to understanding deuteron wave function, SRCs, neutron star equations of state

$$A_{zz} \propto \frac{\frac{1}{2}w^2 - uw\sqrt{2}}{u^2 + w^2}$$

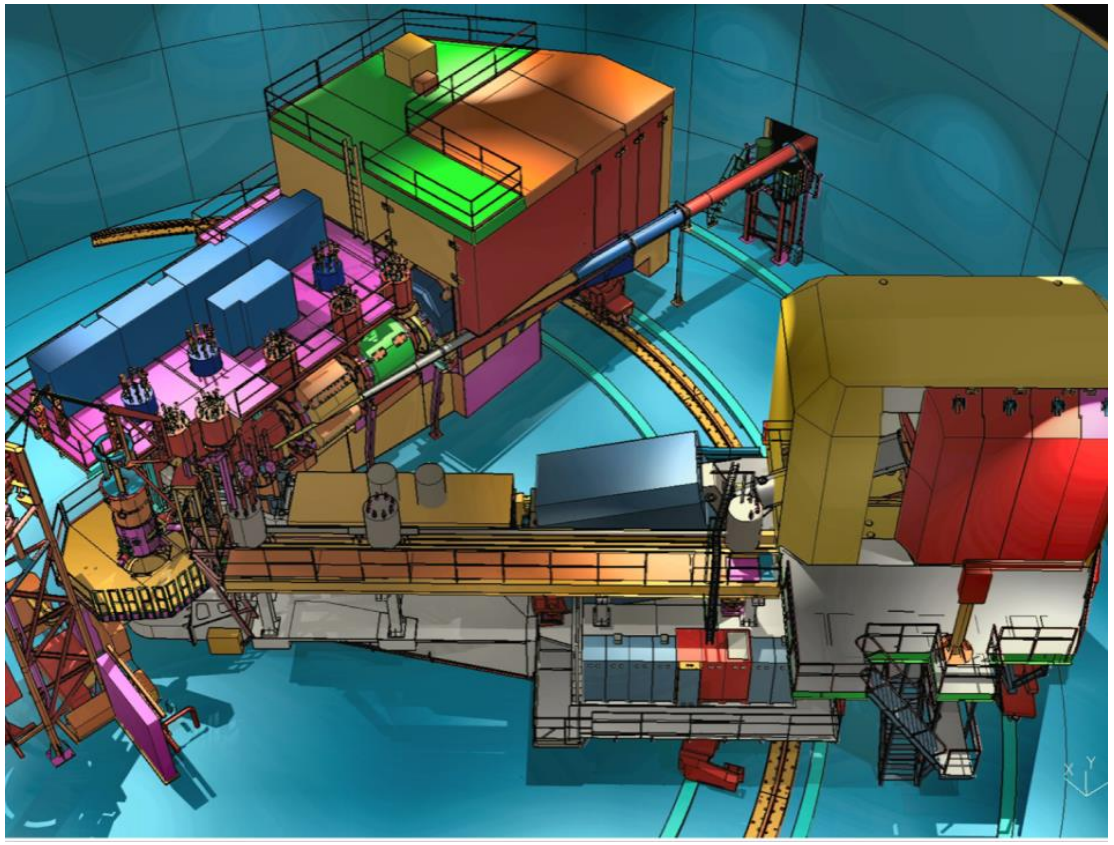
M Sargsian, M Strikman, J. Phys.: Conf. Ser. **543**, 012099 (2014)
L. Frankfurt, M. Strikman, Phys. Rept. **160** 235 (1988)

A_{zz} Experimental Set-Up

- Hall C
- Identical equipment as b_1 (E12-13-011)



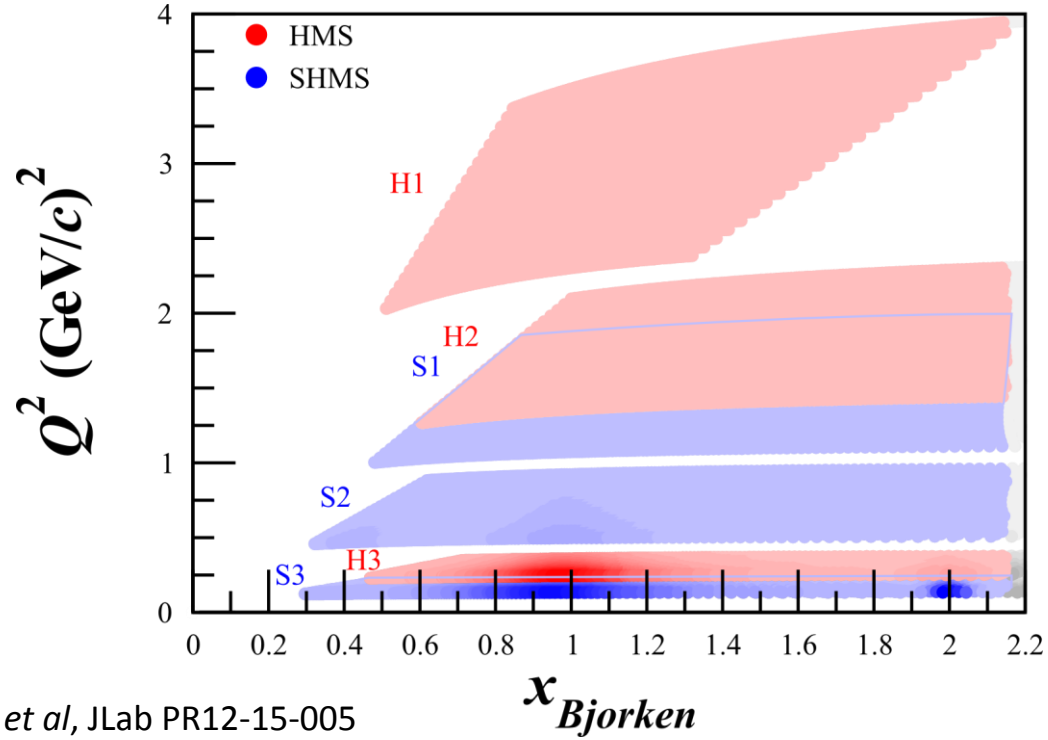
$$A_{zz} = \frac{2}{f \cdot P_{zz}} \left(\frac{N_{Pol}}{N_u} - 1 \right)$$

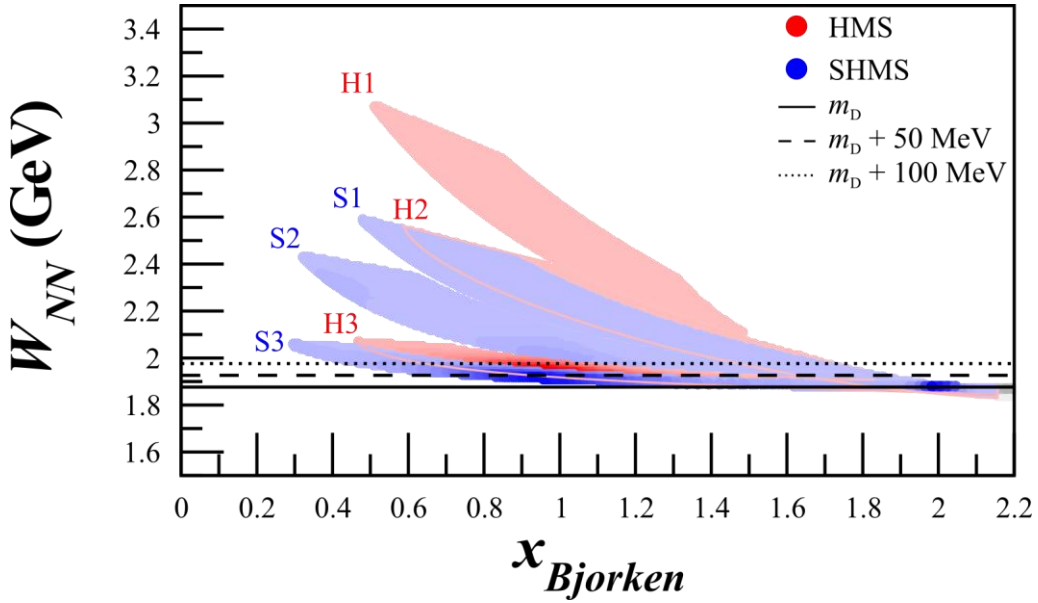


Kinematics

$I = 80$ nA
$\mathcal{L}_D = 1.2 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

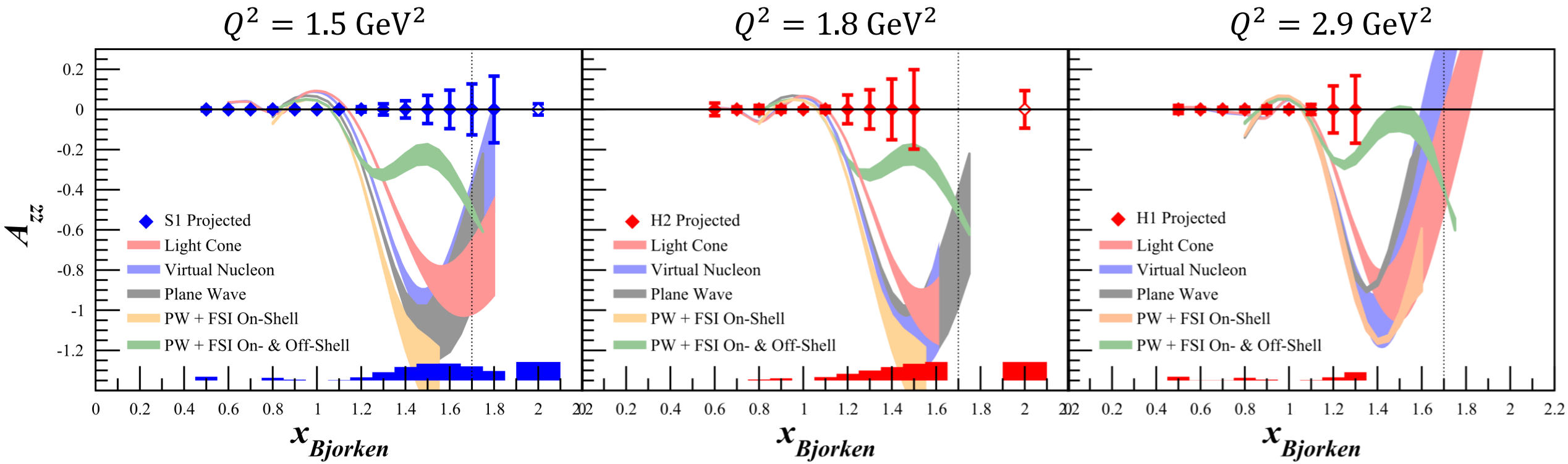
		E_0 (GeV)	Q^2 (GeV^2)	E' (GeV)	$\theta_{e'}$ (°)	Rates (kHz)	PAC Time (Days)
SHMS	(S1)	8.8	1.5	8.36	8.2	0.38	25
HMS	(H1)	8.8	2.9	7.26	12.2	0.04	25
SHMS	(S2)	6.6	0.7	6.35	7.5	3.57	8
HMS	(H2)	6.6	1.8	5.96	12.3	0.09	8
SHMS	(S3)	2.2	0.2	2.15	10.9	10.5	1
HMS	(H3)	2.2	0.3	2.11	14.9	3.23	1





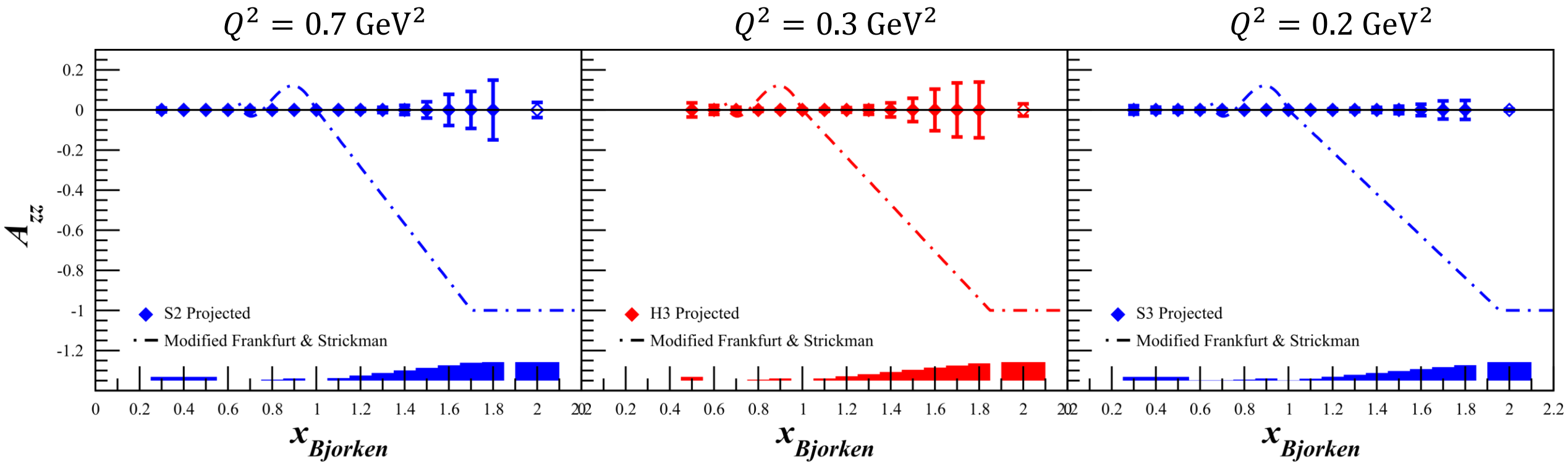
E. Long, *et al*, JLab PR12-15-005

A_{zz} for $Q^2 > 1\ \mathrm{GeV}^2$



E. Long, *et al*, JLab PR12-15-005

A_{zz} for $Q^2 < 1\ \mathrm{GeV}^2$



E. Long, *et al*, JLab PR12-15-005

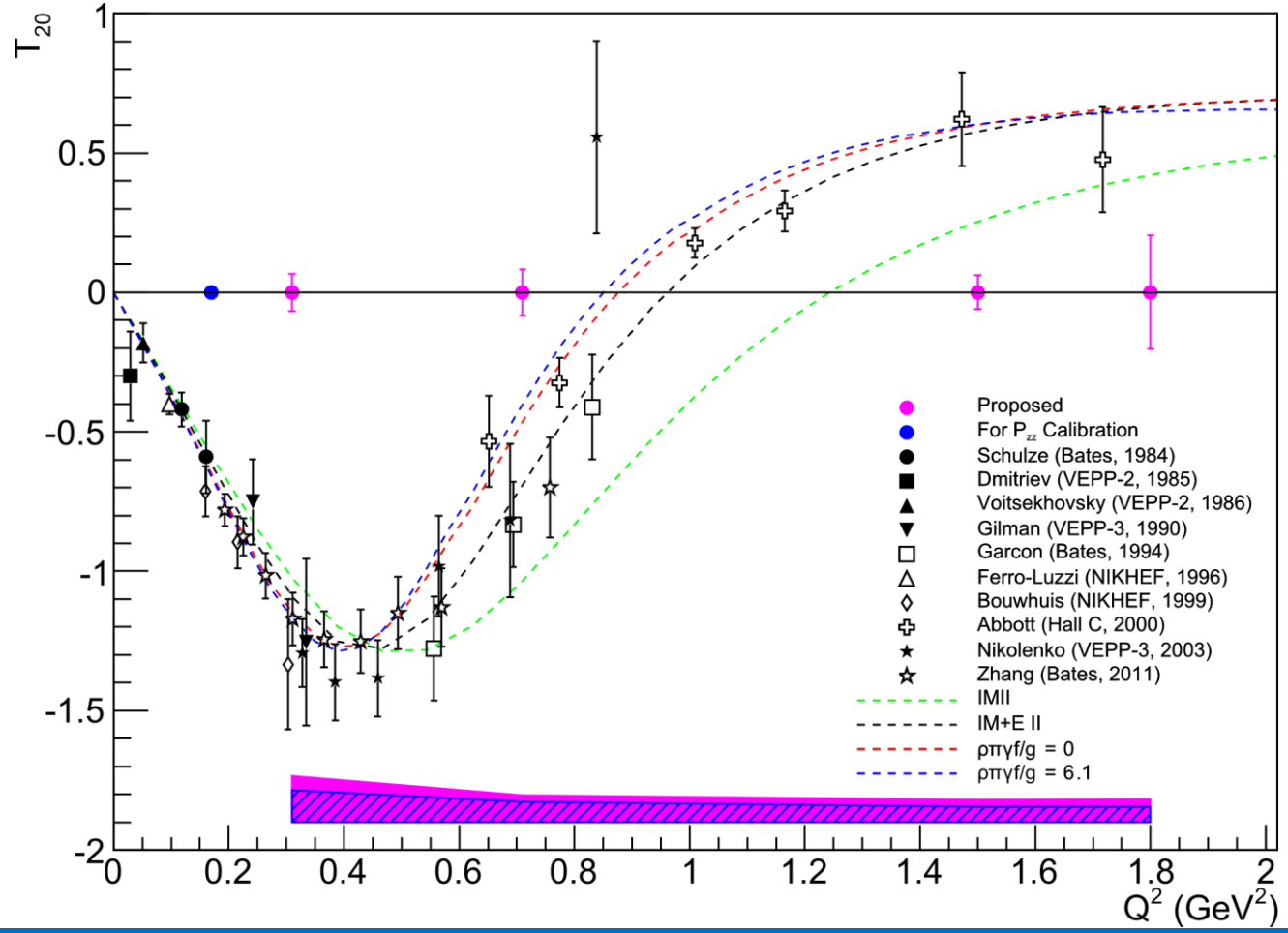
* More model predictions coming soon…

Elastic T_{20} - Simultaneous Measurement

$$A = G_C^2 + \frac{2}{3}\eta G_M^2 + \frac{8}{9}\eta^2 G_Q^2$$

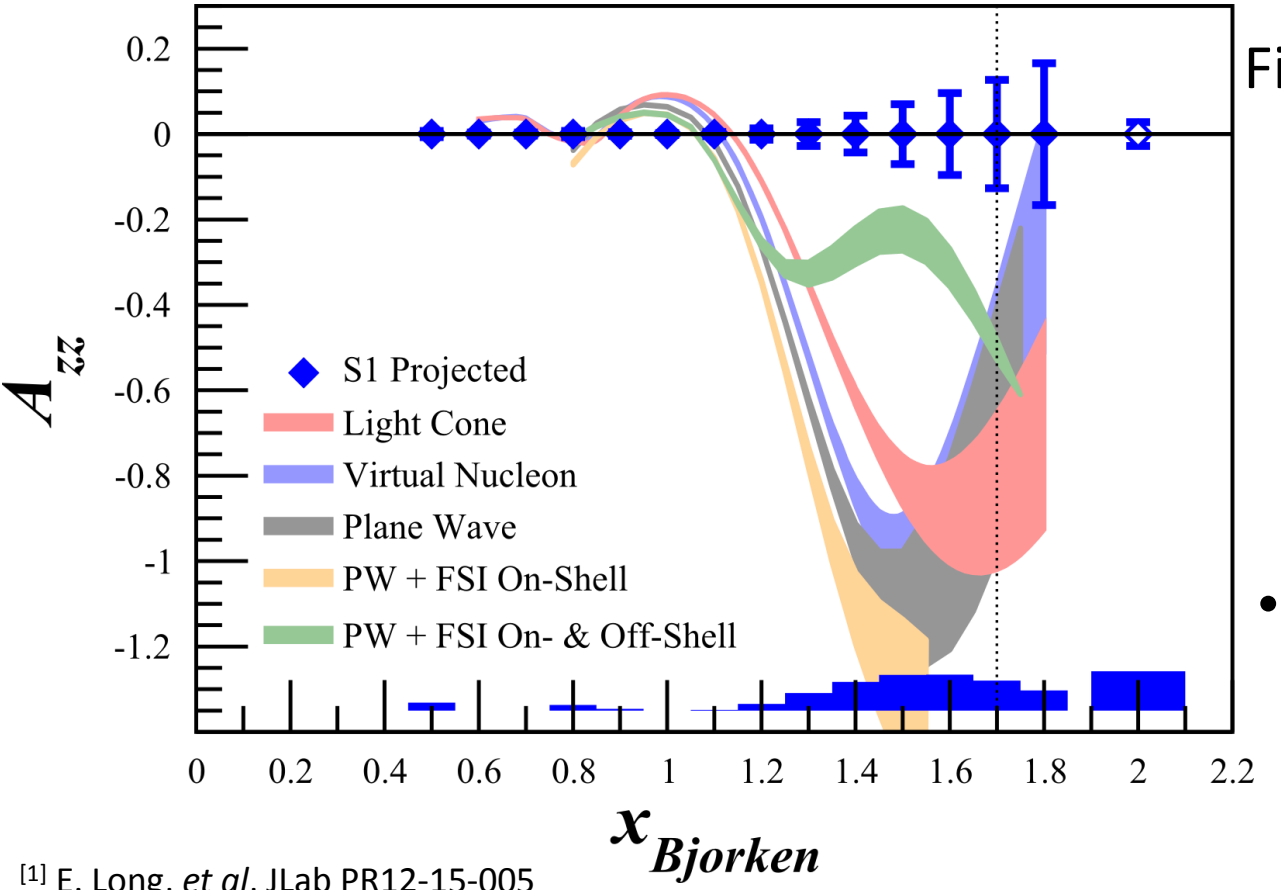
$$B = \frac{4}{3}\eta(1+\eta)G_M^2$$

$$T_{20} = -\frac{\frac{8}{9}\eta^2 G_C^2 + \frac{8}{3}\eta G_C G_Q}{\sqrt{2}\left[A + B\tan^2\left(\frac{\theta}{2}\right)\right]} + \frac{\frac{2}{3}\eta G_M^2\left[\frac{1}{2} + (1+\eta)\tan^2(\theta/2)\right]}{\sqrt{2}\left[A + B\tan^2\left(\frac{\theta}{2}\right)\right]}$$



RJ Holt, R Gilman, Rep. Prog. Phys. **75** 086301 (2012)

Tensor Asymmetry A_{zz} for $x > 1$



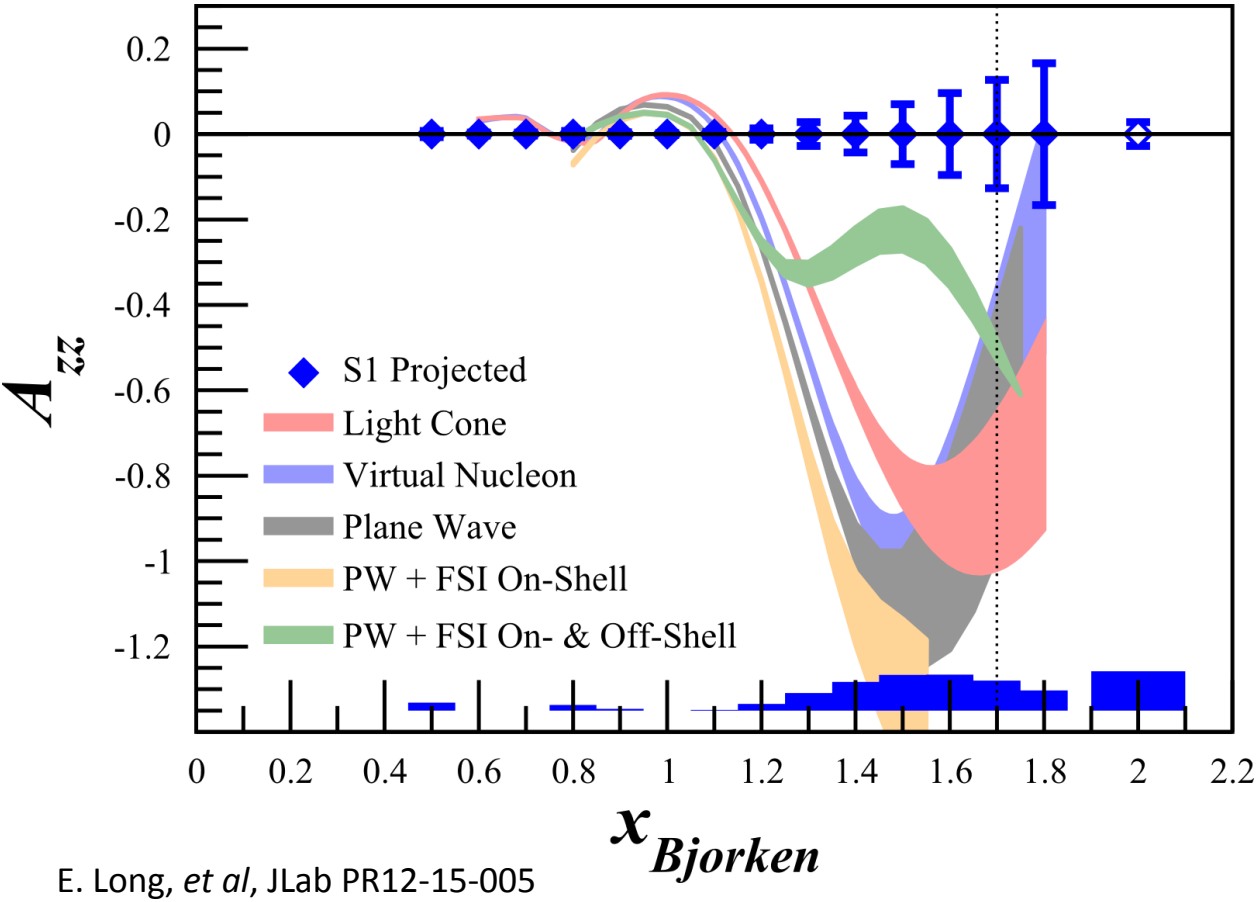
First measurement of QE A_{zz} will give insight into:

- Relativistic LC and VN models[1,2]
  - Hard or soft NN potentials[4]
    - SRCs & pn dominance[3]
  - Final state interaction models[5]

- Bonus: T_{20} for largest Q^2 range ever measured in a single experiment, region of systematic discrepancy, highest Q^2 measured

[1] E. Long, *et al*, JLab PR12-15-005
[2] Sargsian, Strikman, J. Phys.: Conf. Ser. **543**, 012099 (2014)
[3] J Arrington *et al*, Prog. Part. Nucl. Phys. **67,** 898 (2012)
[4] L Frankfurt, M Strikman, Phys. Rept. **160,** 235
[5] W Cosyn, M Sargsian, arXiv:1407.1653

Tensor A_{zz} for $x > 1$



E. Long, *et al*, JLab PR12-15-005
Sargsian, Strikman, J. Phys.: Conf. Ser. **543**, 012099 (2014)

Encouraged for full submission by PAC42

"The measurement proposed here arises from a well-developed context, presents a clear objective, and enjoys strong theory support. It would further explore the nature of short-range *pn* correlations in nuclei, the discovery of which has been one of the most important results of the JLab 6 GeV nuclear program."

-JLab PAC42 Theory Advisory Committee

Thank you