The Generalized GDH Sum Rule: Measuring the Neutron and ^{3}He Spin Structure at Low Q^2

Chao Peng (Duke University)

For the JLab Hall A and E97-110 Collaborations

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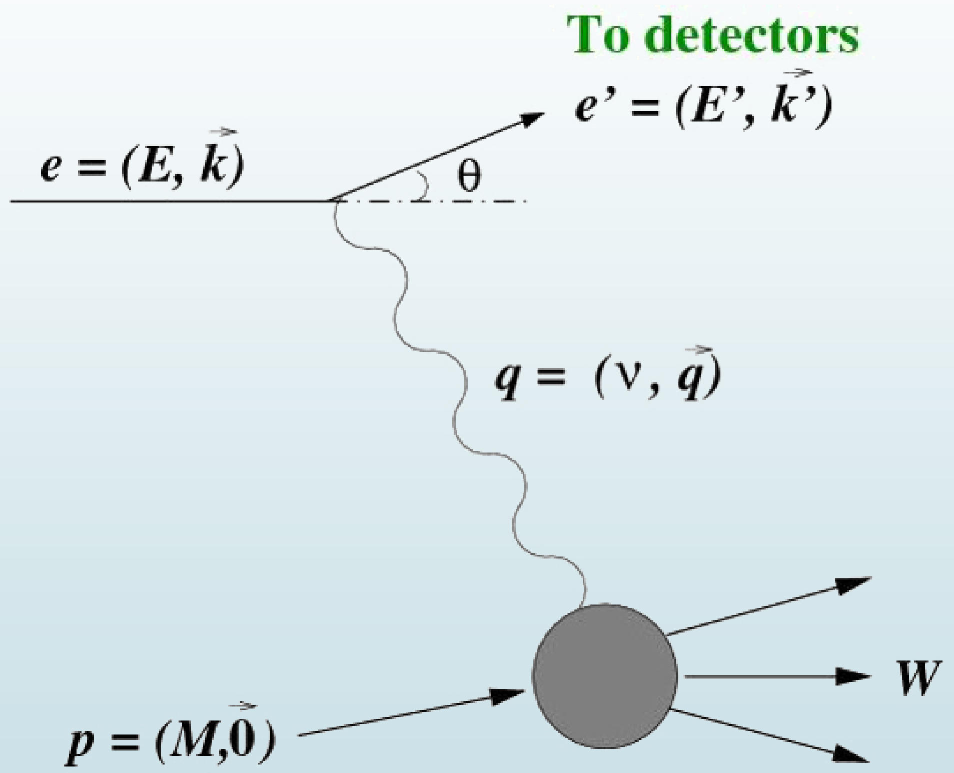
Outline

- Polarized Inclusive Scattering on Nucleon targets
- Generalized GDH Sum Rule
- Experimental Progress at low Q^2 (0.02 GeV^2)
- Preliminary Results from JLab E97-110

Polarized Inclusive Scattering



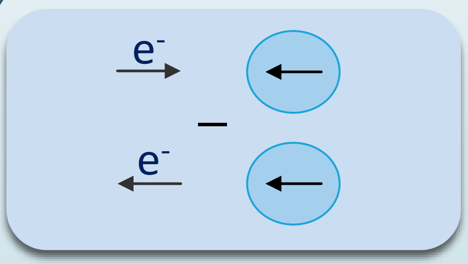
Cross Sections

$$\sigma_0 = \sigma_{\mathrm{Mott}} \left[\alpha F_1(x,Q^2) + \beta F_2(x,Q^2) + \gamma g_1(x,Q^2) + \delta g_2(x,Q^2)\right]$$

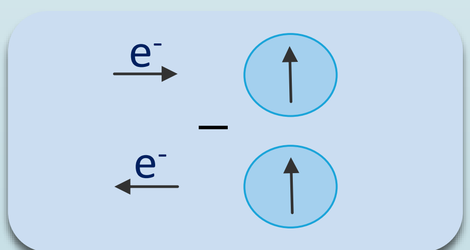
- σ_0: probability of an interaction between incident electron and nucleon target
- σ_{Mott}: structure-less (point like particles) cross section
- Structure functions:
  - Spin averaged F_1 and F_2
  - Spin dependent g_1 and g_2

Spin-dependent Structure functions

- Measuring spin-dependent structure functions
  - Asymmetry measurement
  - Electron and target spins are parallel (anti-parallel) and perpendicular



$$\Delta\sigma^{\parallel} = \frac{4\alpha^2}{M\nu Q^2}\frac{E'}{E}\left[(E + E'cos\theta)g_1 - 2Mxg_2\right]$$



$$\Delta\sigma^{\perp} = \frac{4\alpha^2}{M\nu Q^2}\frac{E'^2}{E}sin\theta\left[g_1 + \frac{2E}{\nu}g_2\right]$$

GDH Sum Rule

- Gerasimov-Drell-Hearn (GDH) Sum Rule

$$I_{\text{GDH}} = \int_{\nu_{\text{th}}}^{\infty} \frac{\sigma_{\frac{1}{2}}(\nu) - \sigma_{\frac{3}{2}}(\nu)}{\nu} d\nu = -2\pi^2 \alpha \left(\frac{\kappa}{M}\right)^2$$

- Circularly polarized photons on a longitudinally polarized target with 1/2 spin
- Relate the photo-absorption cross sections to the anomalous magnetic moment
- Derived from general principles

GDH Measurements

	M [GeV]	Spin	κ	I_{GDH} [μ b]
Proton	0.938	$\frac{1}{2}$	1.79	–204.8
Neutron	0.940	$\frac{1}{2}$	-1.91	–233.2
Deuteron	1.876	1	-0.14	–0.65
Helium-3	2.809	$\frac{1}{2}$	-8.38	–498.0

- Proton, verified: Mainz, Bonn, LEGS
- Neutron, in progress: Mainz, Bonn, LEGS, HIGS
- Measurements on Deuteron and ^{3}He

Generalized GDH Integral

- Generalized for virtual photon

$$I_{GDH}(Q^2 \neq 0) = \frac{16\pi^2\alpha}{Q^2}\int_0^{x_{th}} g_1(x, Q^2)dx = \frac{16\pi^2\alpha}{Q^2}\Gamma_1 = 2\pi^2\alpha S_1(0, Q^2)$$

Ji and Osborne, J. Phys. G27, 127 (2001)

- Expressed as the integral of $g_1(x, Q^2)$
- Related to the forward spin-dependent Compton amplitude $S_1(0, Q^2)$
- $Q^2 = 0$, GDH sum rule
- $Q^2 \to \infty$, Bjorken sum rule

First Moment of g_1

- First Moment of g_1

$$\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2)dx$$

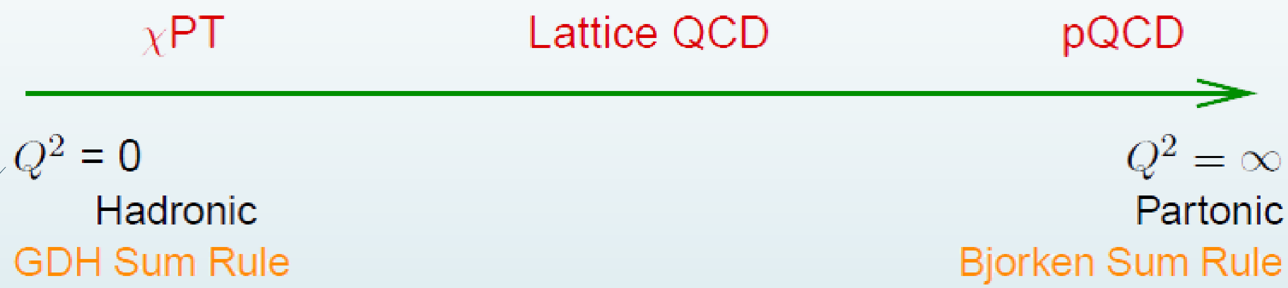
  - Connects to the total spin carried by the quarks
  - Relates to the GDH sum rule as $Q^2 \to 0$

- Bjorken Sum Rule

$$\Gamma_1^P(Q^2) - \Gamma_1^N(Q^2) = \frac{g_A}{6} + O\big(\alpha_s(Q^2)\big) + O(\frac{1}{Q^2})$$

  - g_A, nucleon axial charge
  - Consistent with experimental result in 10%

Importance of Generalized GDH Sum Rule



- Constrained at the two ends
- Calculable at any Q^2, can be tested by experiments over the measurable range
- Study the transition region from non-perturbative to perturbative QCD

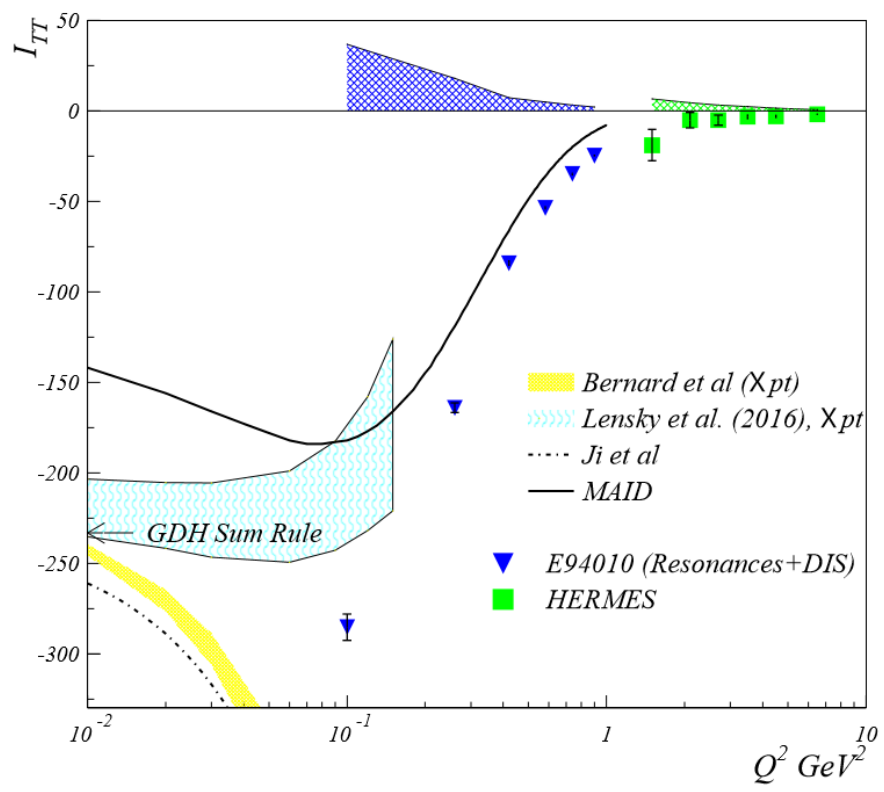
Experimental progress

Observable	H target	D target	^{3}He target
g_1, g_2, Γ_1 & Γ_2 at high Q^2	SLAC JLAB SANE	SLAC	SLAC JLAB E97-117 JLAB E01-012 JLAB E06-014
g_1 & Γ_1 at high Q^2	SMC HERMES JLAB EG1	SMC HERMES JLAB EG1	HERMES
Γ_1 & Γ_2 at low Q^2	JLab RSS	JLab RSS	JLab E94-010 JLab E97-103
Γ_1 at low Q^2	SLAC HERMES JLAB EG1	SLAC HERMES JLAB EG1	HERMES
$\Gamma_1, Q^2 << 1$ GeV^2	JLab EG4	JLab EG4	JLab E97-110
$\Gamma_2, Q^2 << 1$ GeV^2	JLab E08-027		JLab E97-110

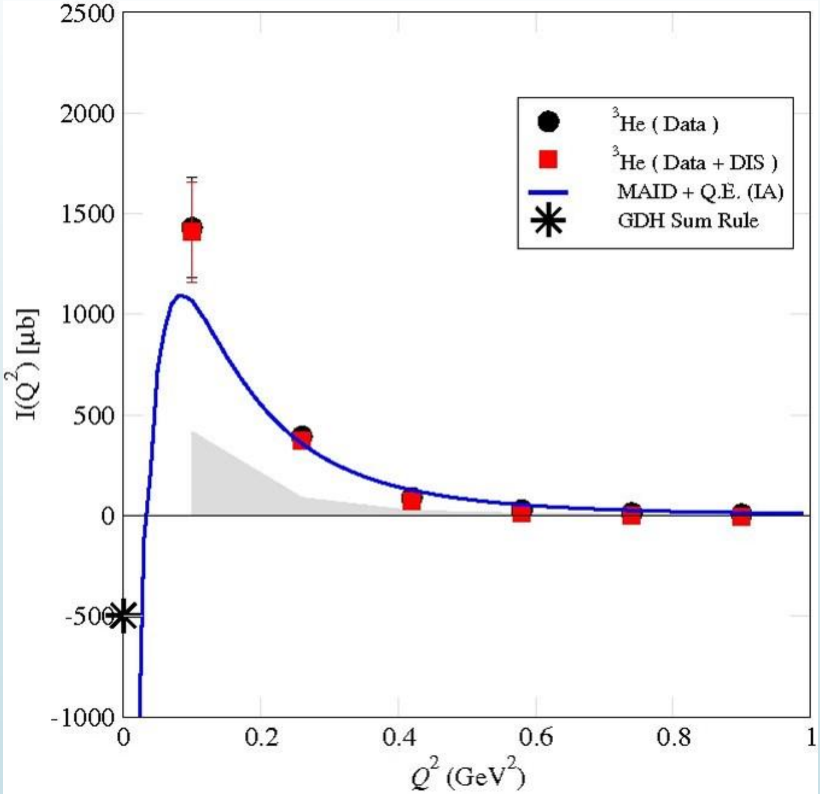
Other related JLab experiments are covered in the talks from V. Burkert, A. Deur, K. Slifer and etc.

Neutron and ^{3}He Results

Neutron

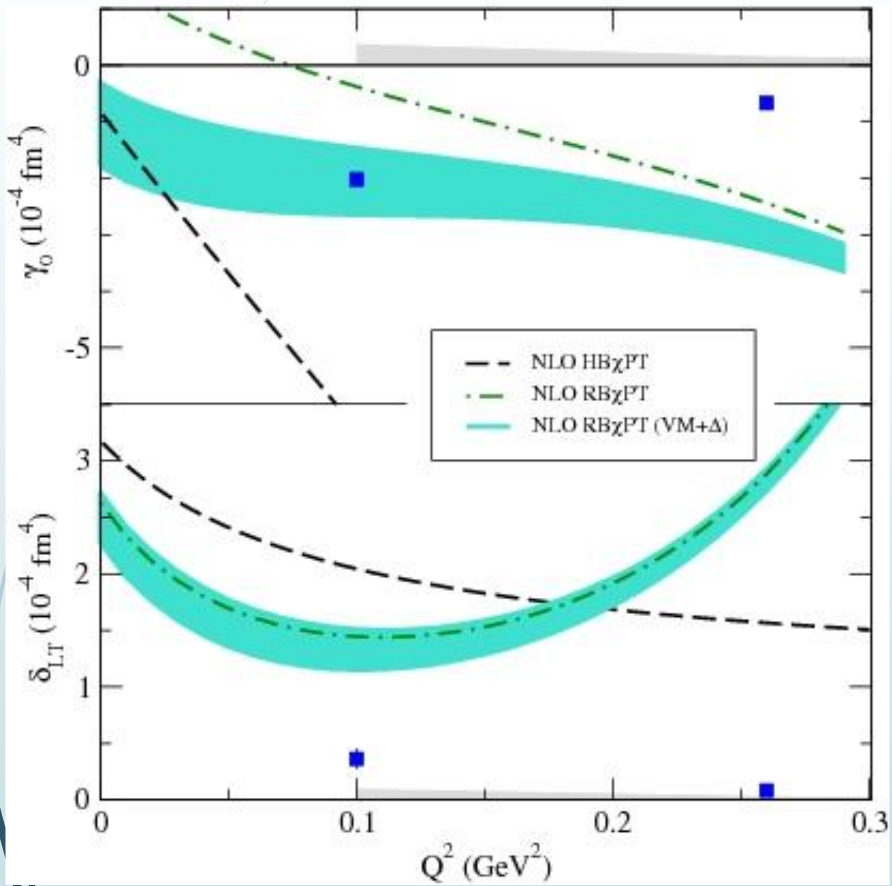


Helium-3



MAID: phenomenological model with only resonance contributions

Neutron Spin Polarizabilities



$$\gamma_0 = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2\left[g_1 - \frac{4M^2}{Q^2}x^2 g_2\right]$$

$$\delta_{LT} = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2\,[g_1 + g_2]$$

Failure of χPT calculations?

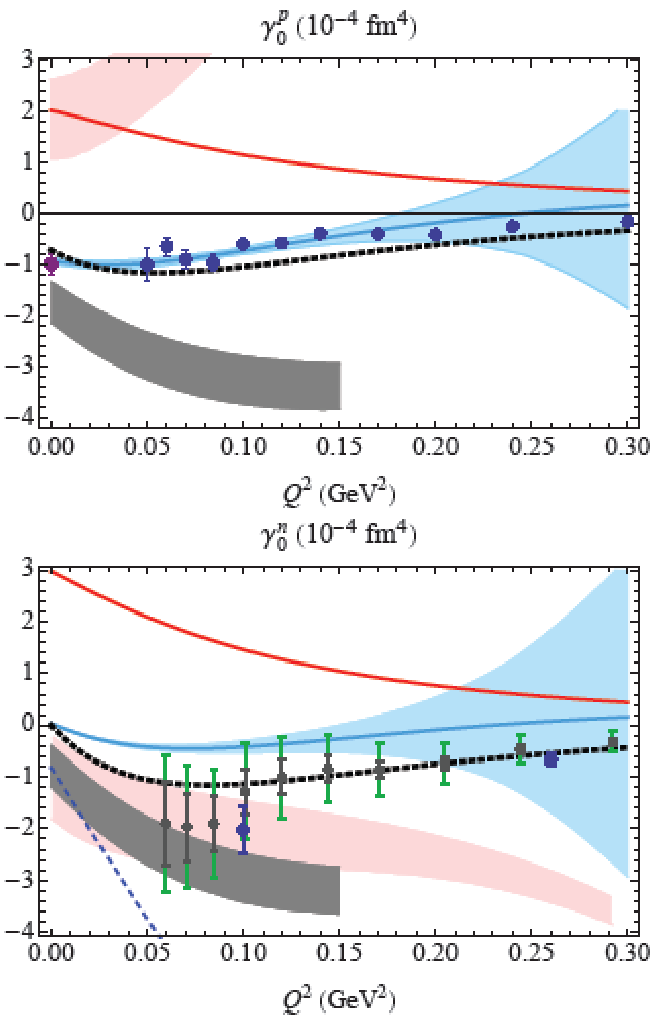
<u>Heavy Baryon χPT Calculation</u>

Kao, Spitzenberg, Vanderhaeghen
PRD 67:016001(2003)

<u>Relativistic Baryon χPT</u>

Bernard, Hemmert, Meissner
PRD 67:076008(2003)

Theoretical Developments



Curves:

- MAID (empir.)
- LO-HBChPT
- NLO-HBChPT
- NLO- IRBChPT [Bernard et al (2006)]
- LO-BChPT
- NLO-BChPT [Lensky, Alarcon & V.P, PRC (2014)]
- NLO-BChPT [Bernard et al (2013)]

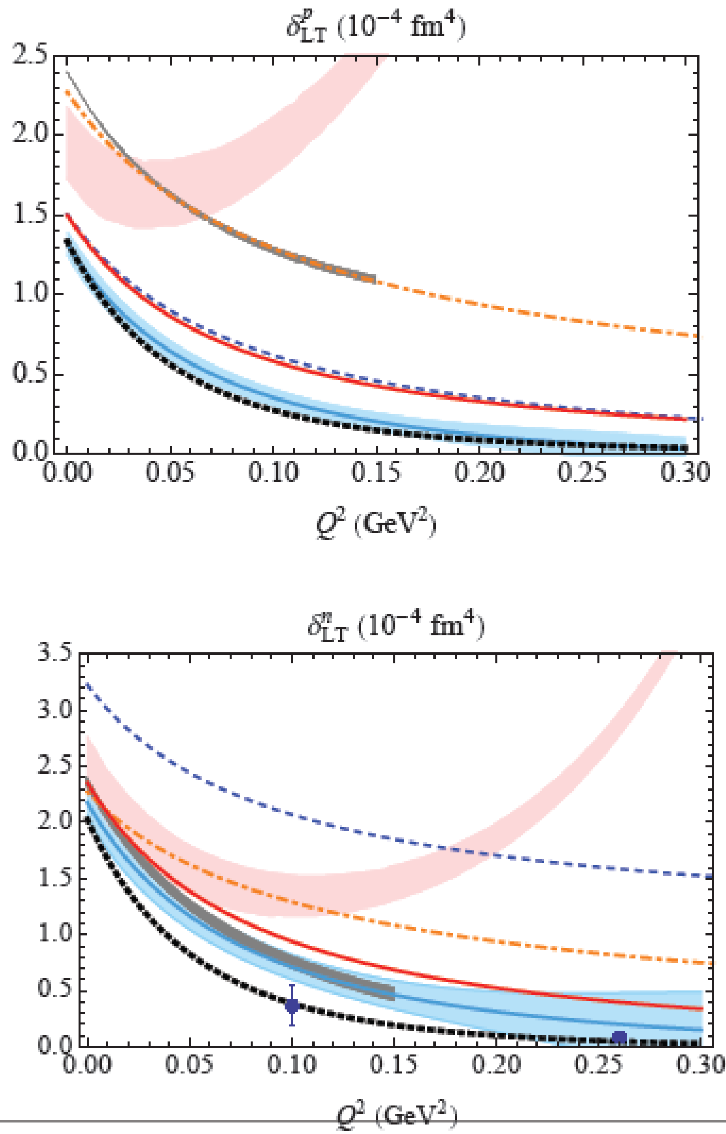
see talk by H. Krebs

Data points:

K. Slifer, J.-P. Chen, S. Kuhn, et al

[Jefferson Lab spin program]

Theoretical Developments



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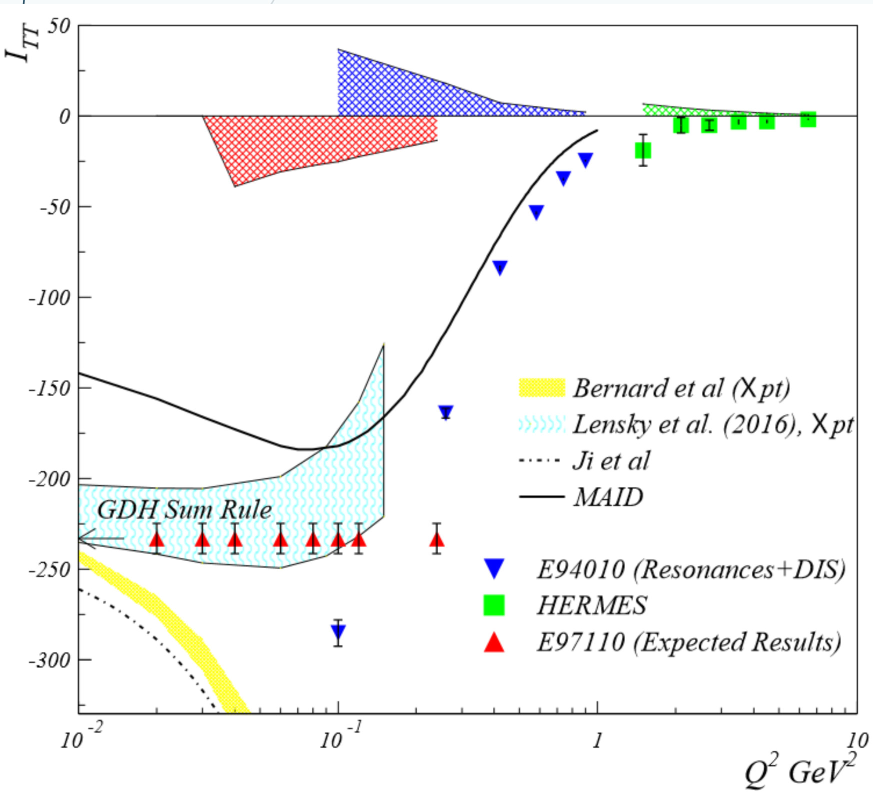
E97-110 at Jefferson Lab

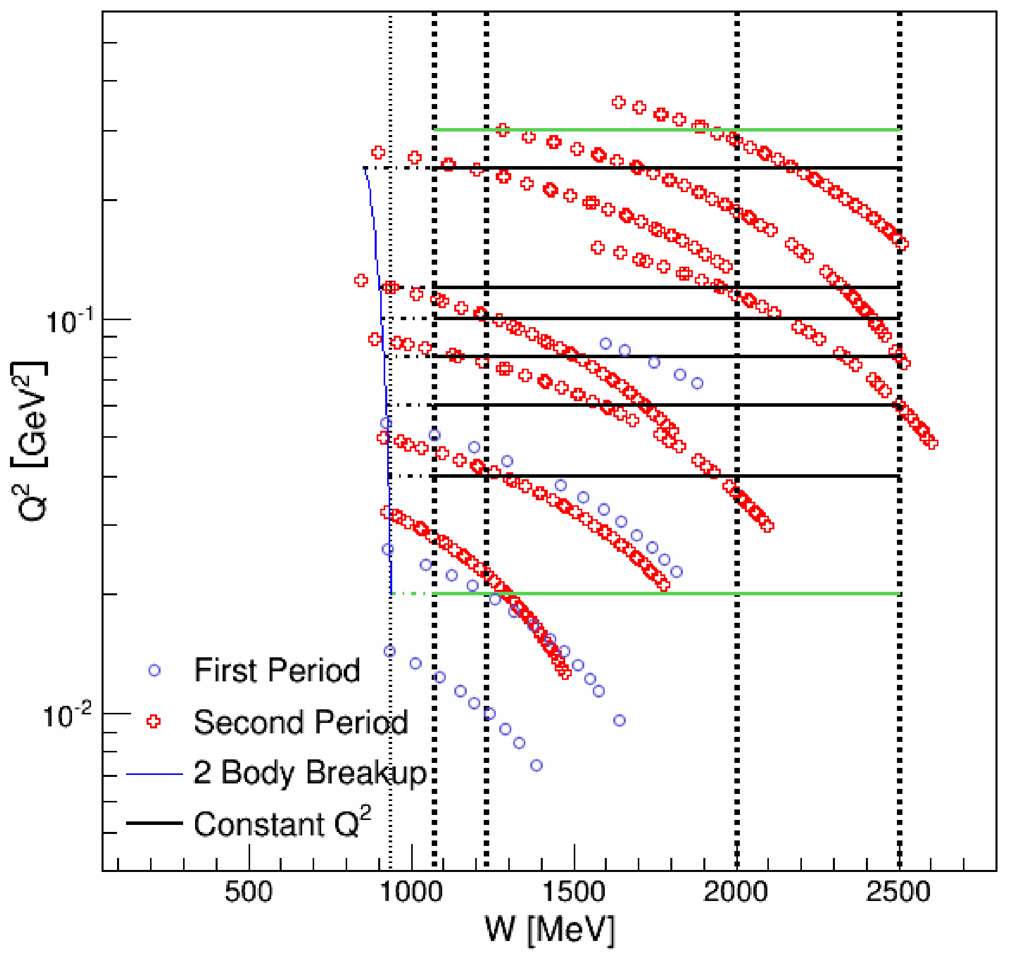


- Inclusive measurement, $^3\vec{\mathrm{He}}(\vec{e},e')X$
  - Scattering angles: 6º and 9º
  - Polarized electron beam, P_{beam} = 75%
  - Polarized ^{3}He target, P_{target} = 40%
- Measured the differences of polarized cross sections
  - Parallel (anti-parallel)
  - Perpendicular

Spokespersons: J.-P. Chen, A. Deur, F. Garibaldi

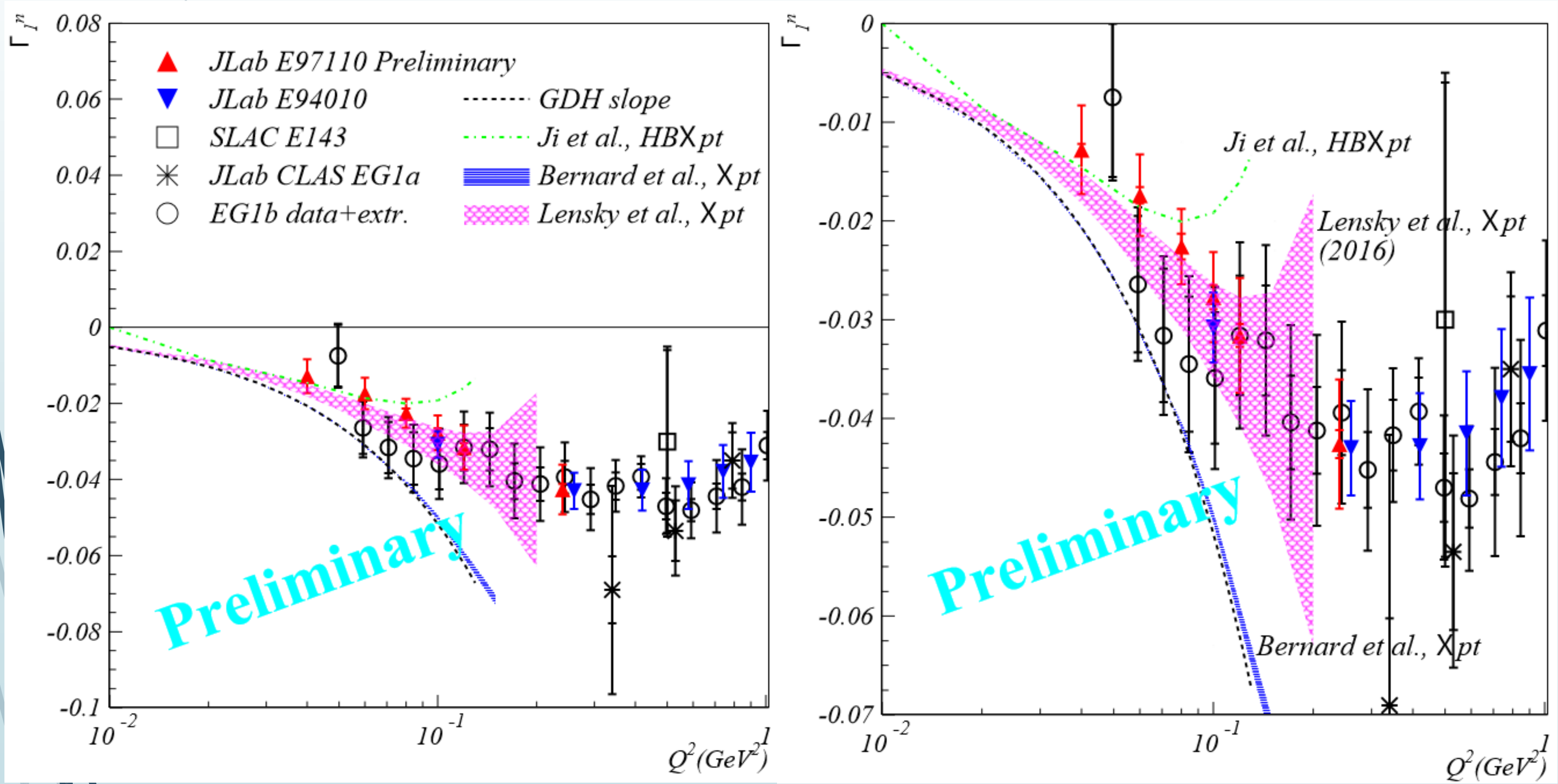
Graduate students: J. Singh, V. Sulkosky, J. Yuan, C. Peng, N. Ton

Kinematic Coverage



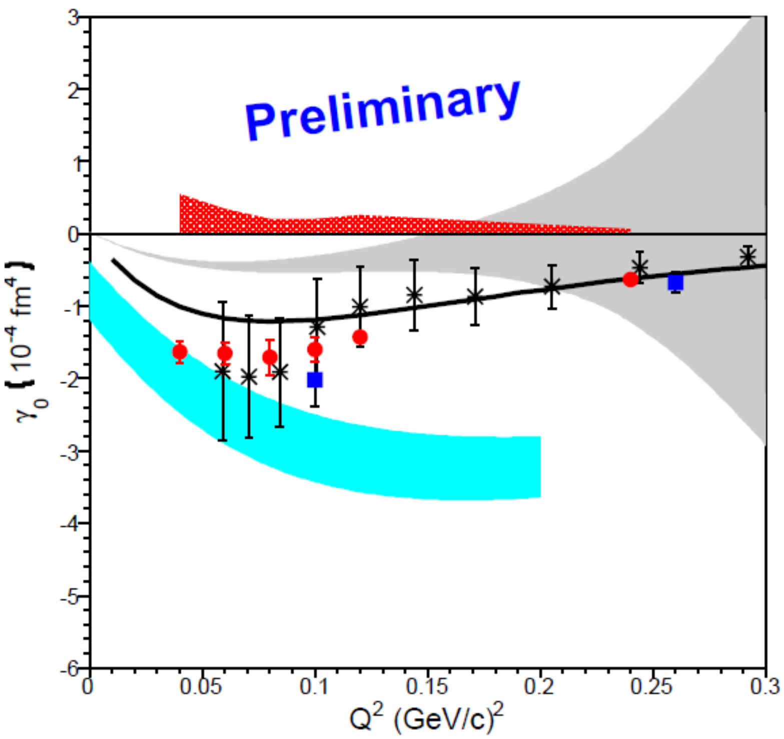
Preliminary Result

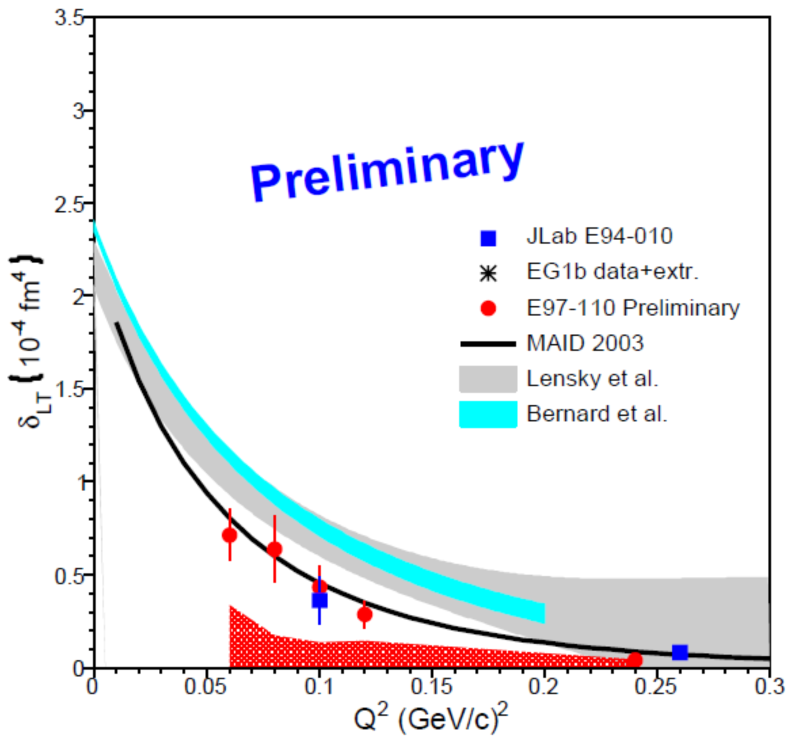
- First moment of g_1



Neutron Spin Polarizabilities

$$\gamma_0 = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2 \left[g_1 - \frac{4M^2}{Q^2}x^2 g_2\right] \qquad \delta_{LT} = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2 \left[g_1 + g_2\right]$$





Summary

- Generalized GDH sum rule is useful to study the transition region
- New high precision data at low Q^2
  - E97-110: g_1 and g_2 on neutron, soon to be published
- Preliminary result for neutron data from E97-110 still indicate a discrepancy with the theoretical calculations
- Acknowledgement
  - Thanks for Vincent Sulkosky providing the plots
  - The work is supported in part by US DOE grant DE-FG02-03ER41231

Thank you