

Jefferson Lab Spin Structure Measurements at Low Q^2



Diffraction 2014

Primošten, Croatia

9/13/2014

Karl Slifer

University of New Hampshire

This Talk

Brief Review

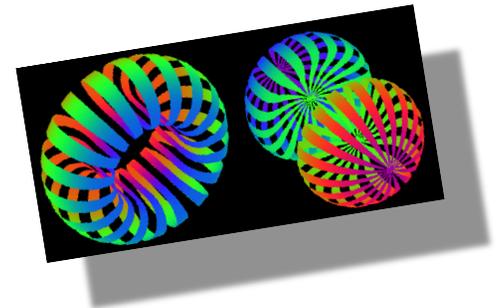
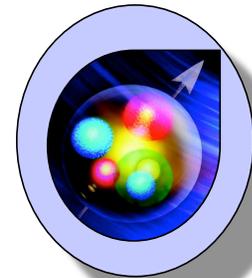
Inclusive Scattering & Structure Functions
Spin Polarizabilities and the δ_{LT} Puzzle
Applications to bound state Q.E.D.

JLab Data at Low Q^2

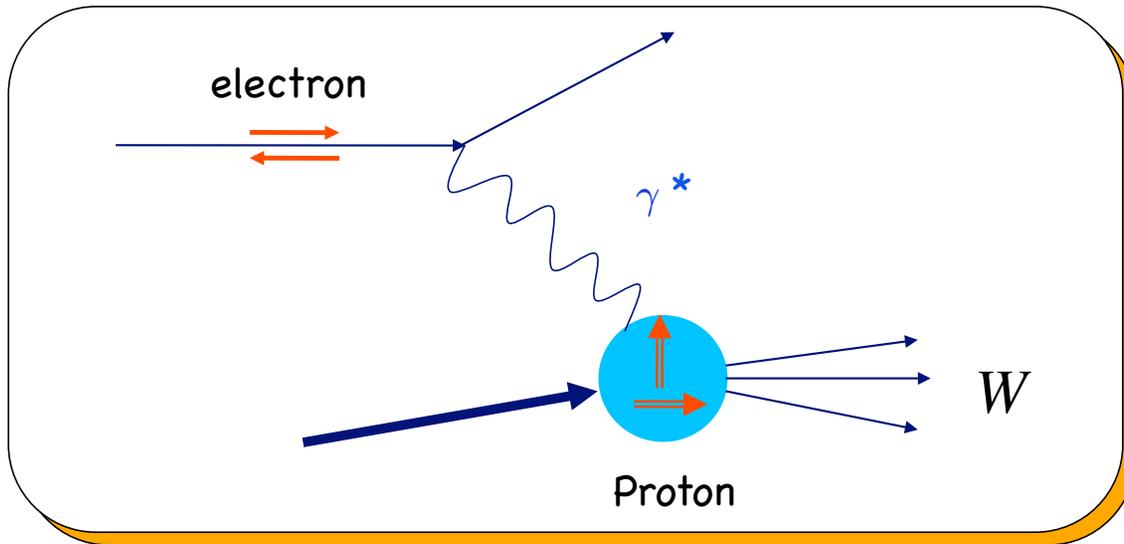
Hall A : g2p, d2n
Hall B : EG4, Eg1-DVCS

JLab Tensor Structure Measurements

E12-13-011: "The b_1 experiment"
LOI-12-14-002: " A_{zz} for $x > 1$ "
LOI-12-14-001: "NuGlu"



Inclusive Scattering

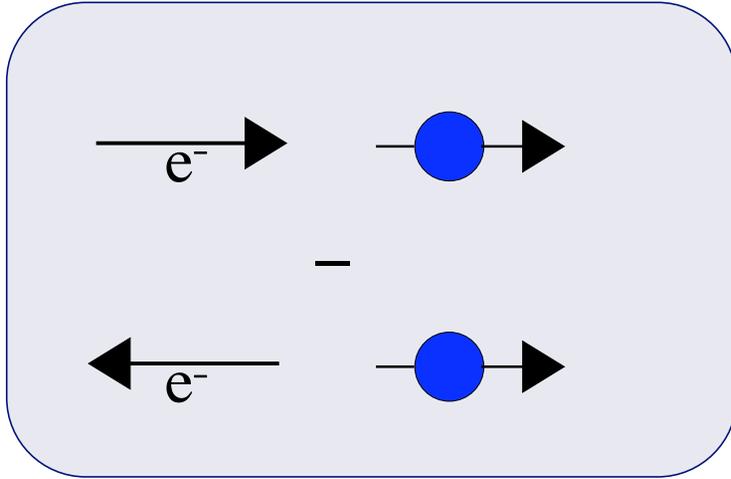


When we add spin degrees of freedom to the target and beam, 2 Additional SF needed.

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott} \left[\frac{1}{\nu} F_2(x, Q^2) + \frac{2}{M} F_1(x, Q^2) \tan^2 \frac{\theta}{2} \right] + \gamma g_1(x, Q^2) + \delta g_2(x, Q^2)$$

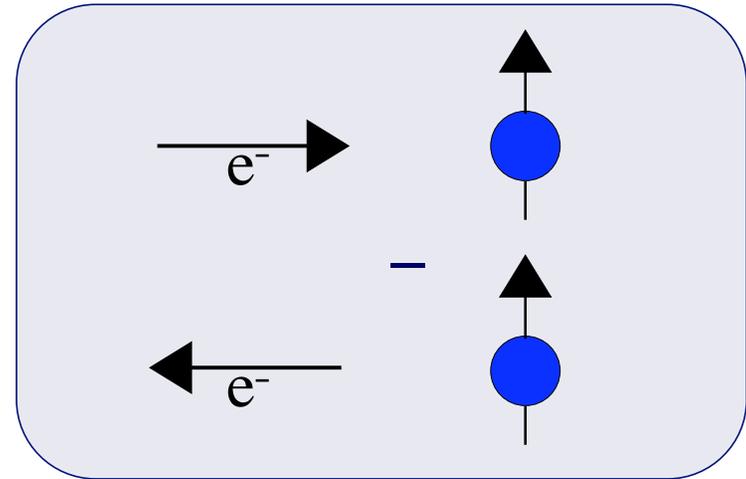
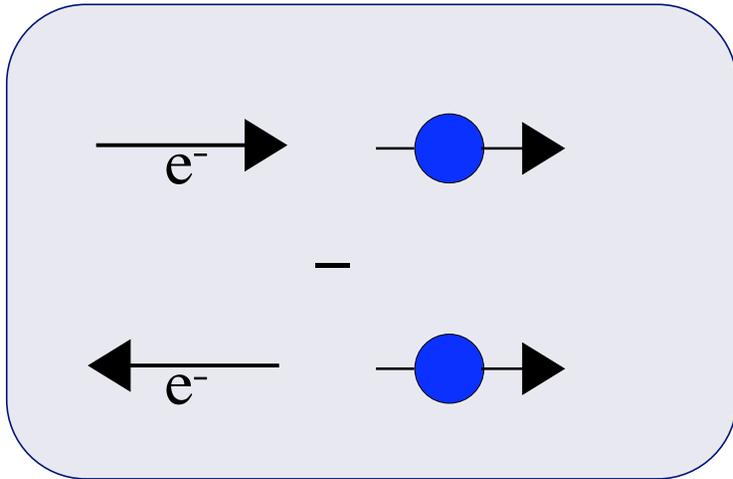
Inclusive Polarized
Cross Section

Cross section differences



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

Cross section differences



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

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

Moments

Spin
polarizabilities

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

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

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

Moments

Spin
polarizabilities

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

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

color
polarizability

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

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

Moments

Spin
polarizabilities

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

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

color
polarizability

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

Generalized
GDH

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

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

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

Moments

Spin
polarizabilities

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

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

color
polarizability

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

Generalized
GDH

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

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

Burkhardt
Cottingham

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

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

Generalized Forward Spin Polarizabilities

Drechsel, Pasquini and Vanderhaegen, Phys. Rep. 378, 99 (2003).

$$g_{TT}(\nu, Q^2) = \frac{\nu}{2\pi^2} \mathcal{P} \int_{\nu_0}^{\infty} \frac{d\nu' K}{\nu'^2 - \nu^2} \sigma_{TT}(\nu', Q^2) \quad g_{LT}(\nu, Q^2) = \frac{1}{2\pi^2} \mathcal{P} \int_{\nu_0}^{\infty} \frac{d\nu' \nu' K}{\nu'^2 - \nu^2} \sigma_{LT}(\nu', Q^2)$$

LEX of g_{TT} and g_{LT} lead to the Generalized Forward Spin Polarizabilities

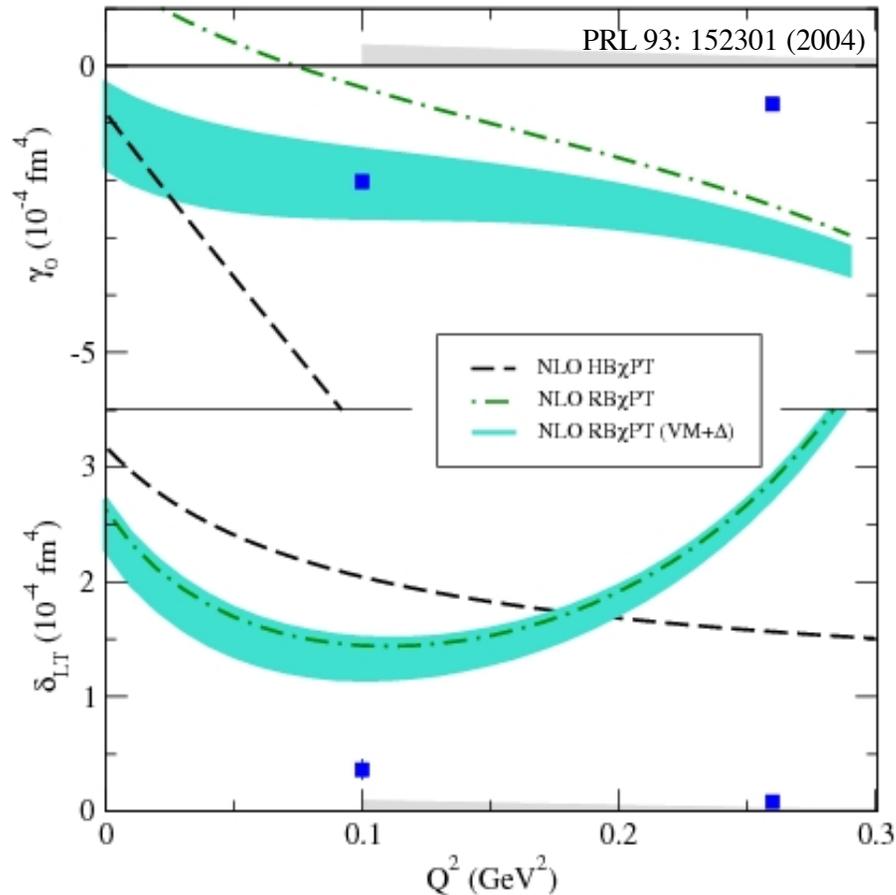
$$\begin{aligned} \gamma_0(Q^2) &= \left(\frac{1}{2\pi^2}\right) \int_{\nu_0}^{\infty} \frac{K(\nu, Q^2)}{\nu} \frac{\sigma_{TT}(\nu, Q^2)}{\nu^3} d\nu \\ &= \frac{16\alpha M^2}{Q^6} \int_0^{x_0} x^2 \left[g_1(x, Q^2) - \frac{4M^2}{Q^2} x^2 g_2(x, Q^2) \right] \end{aligned}$$

x^2 weighting
dominated by RR

$$\begin{aligned} \delta_{LT}(Q^2) &= \left(\frac{1}{2\pi^2}\right) \int_{\nu_0}^{\infty} \frac{K(\nu, Q^2)}{\nu} \frac{\sigma_{LT}(\nu, Q^2)}{Q\nu^2} d\nu \\ &= \frac{16\alpha M^2}{Q^6} \int_0^{x_0} x^2 [g_1(x, Q^2) + g_2(x, Q^2)] \end{aligned}$$

δ_{LT} Puzzle

Neutron



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

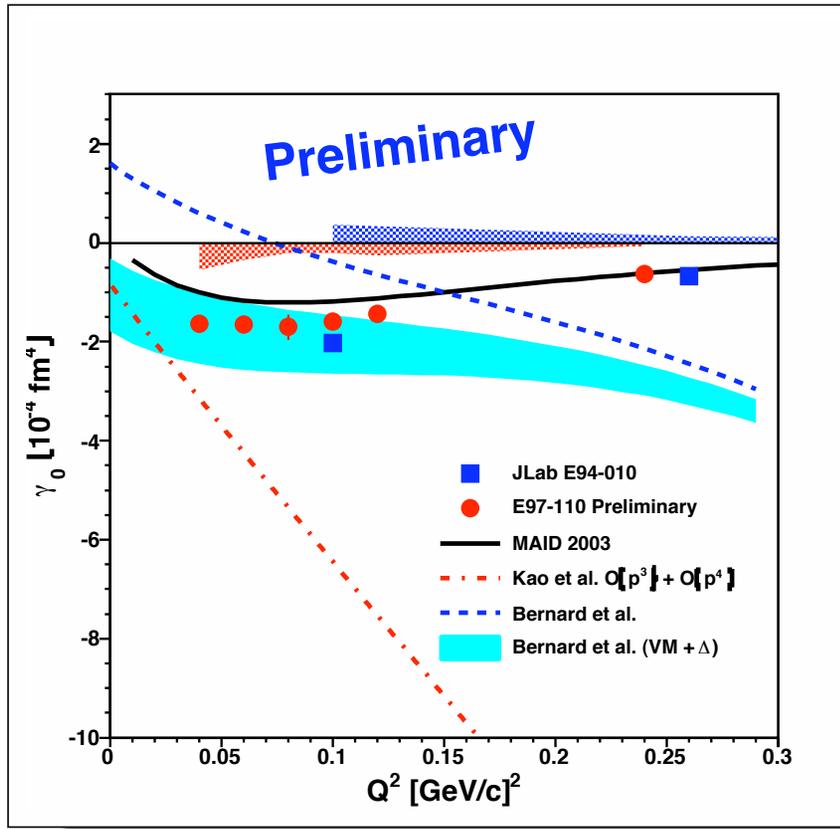
$$\delta_{LT} = \frac{16\alpha M^2}{Q^6} \int_0^{x_0} x^2 [g_1 + g_2]$$

Dramatic Discrepancy
with χ PT

--- Heavy Baryon χ PT Calculation
Kao, Spitzenberg, Vanderhaeghen
PRD 67:016001(2003)

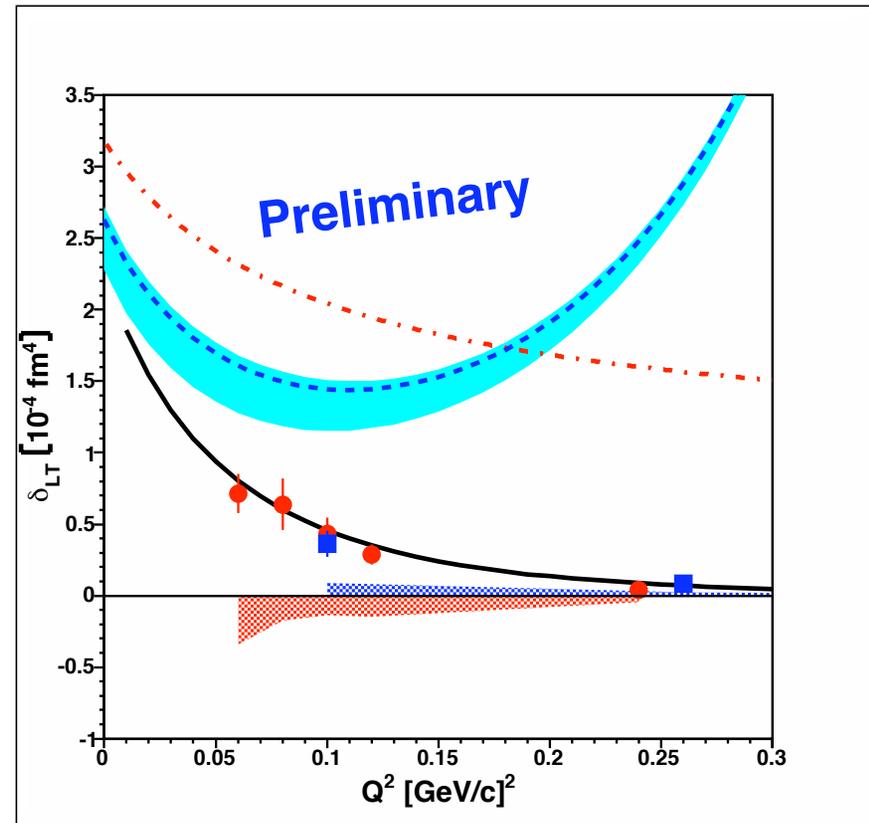
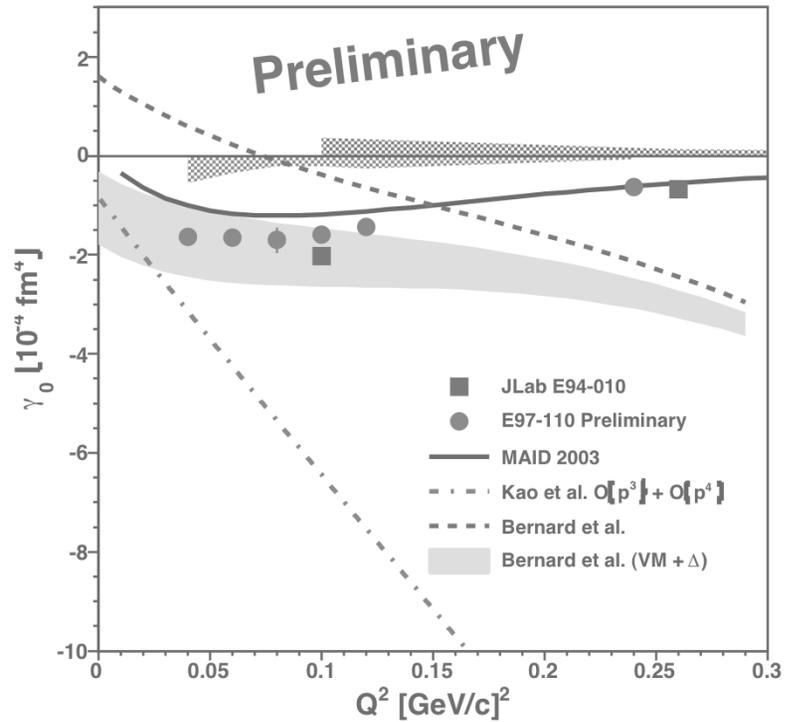
— Relativistic Baryon χ PT
Bernard, Hemmert, Meissner
PRD 67:076008(2003)

More Recent Data on the Neutron Polarizabilities



Plots courtesy of V. Sulkosky

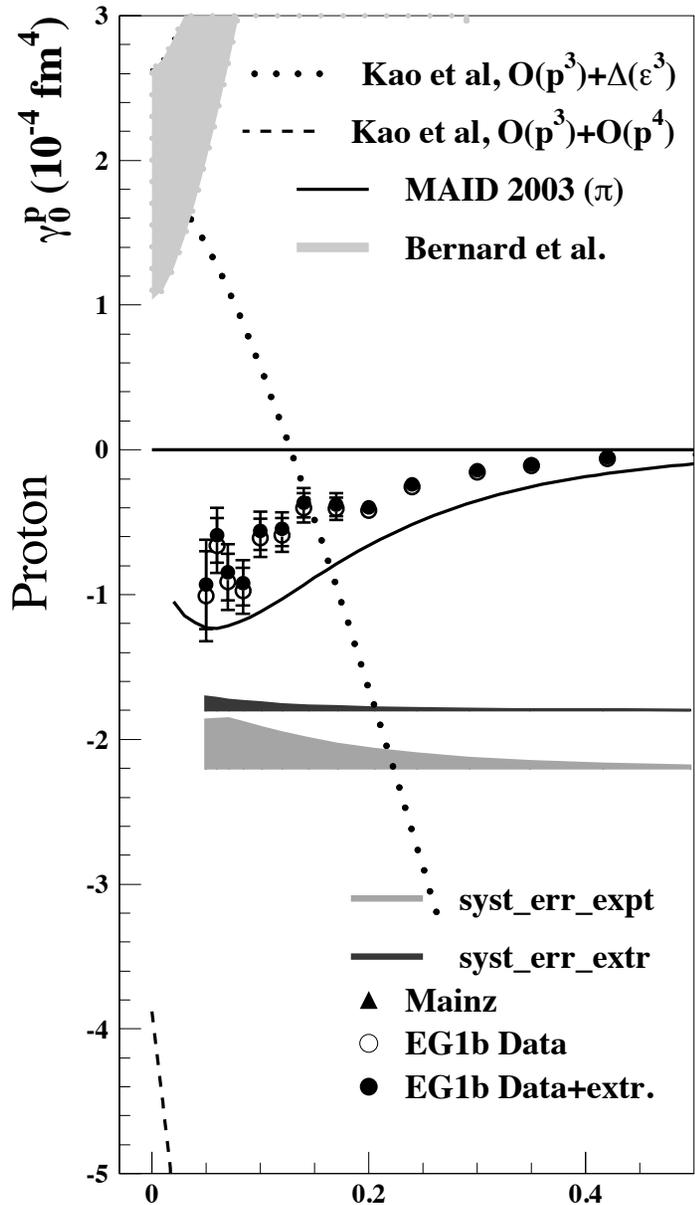
More Recent Data on the Neutron Polarizabilities



Large discrepancy with δ_{LT} remains

Plots courtesy of V. Sulkosky

Proton γ_0



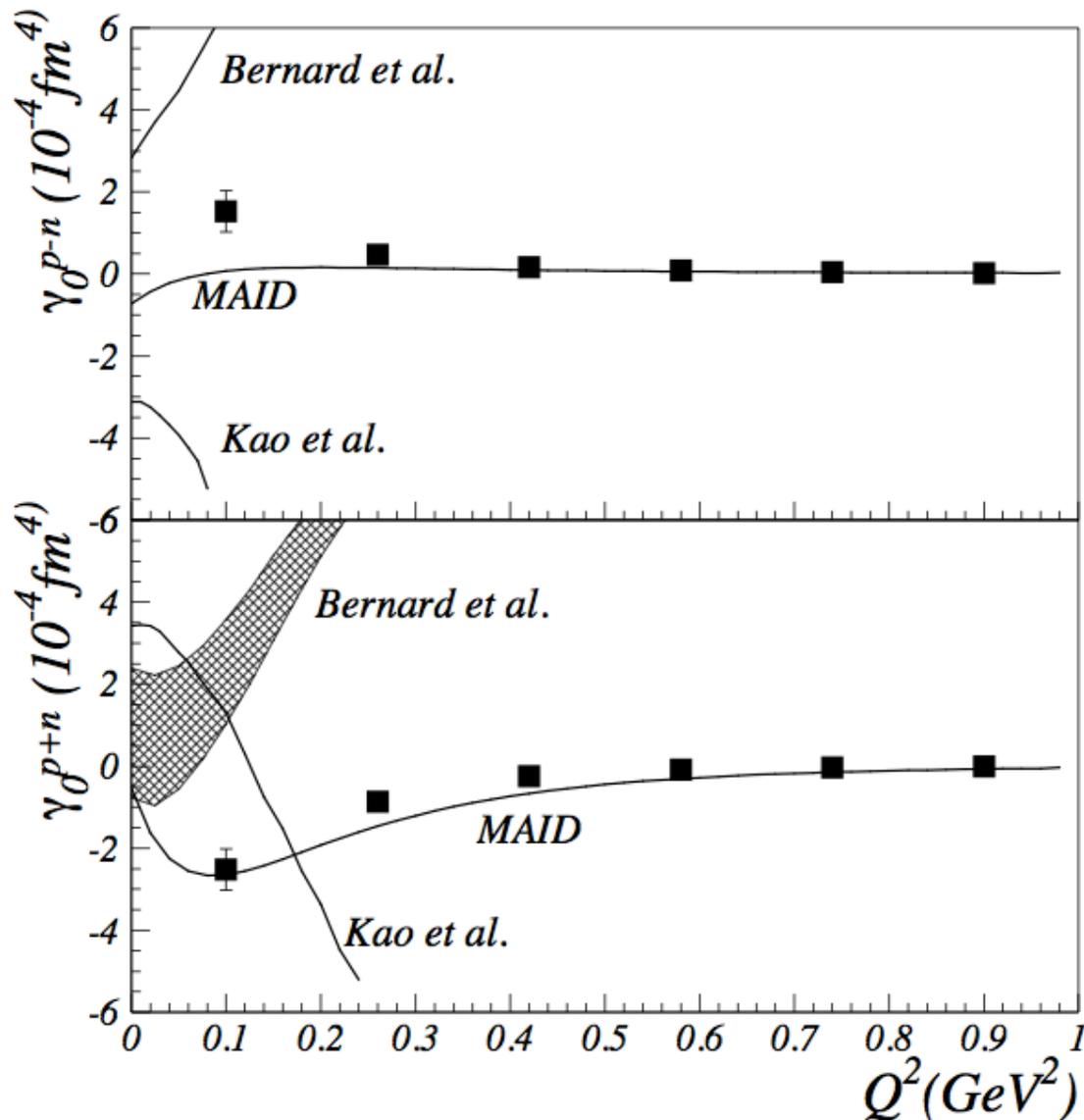
$$\gamma_0 = \frac{16\alpha M^2}{Q^6} \int_0^{x_0} x^2 \left[g_1 - \frac{4M^2}{Q^2} x^2 g_2 \right]$$

Older Calcs failed for proton γ_0

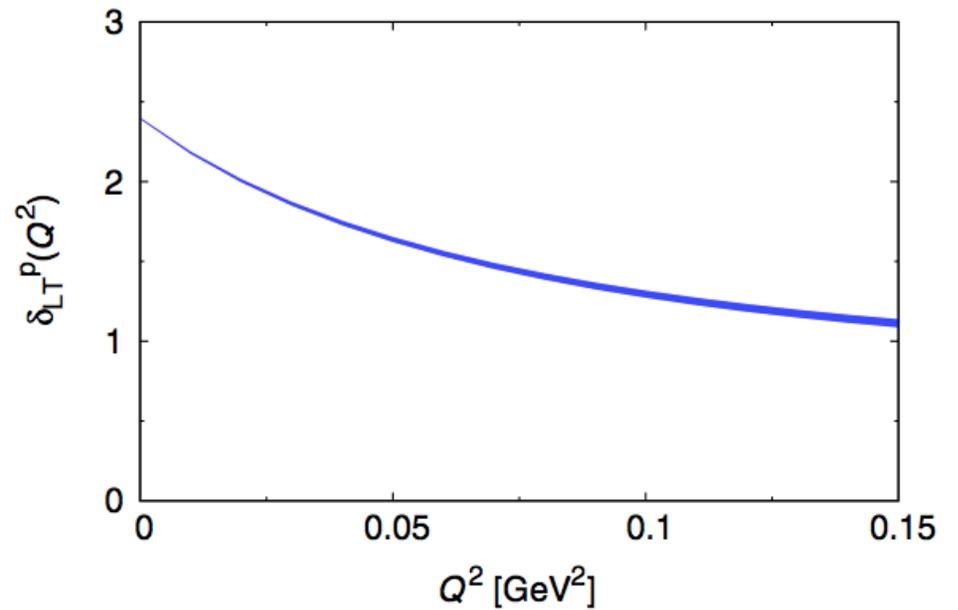
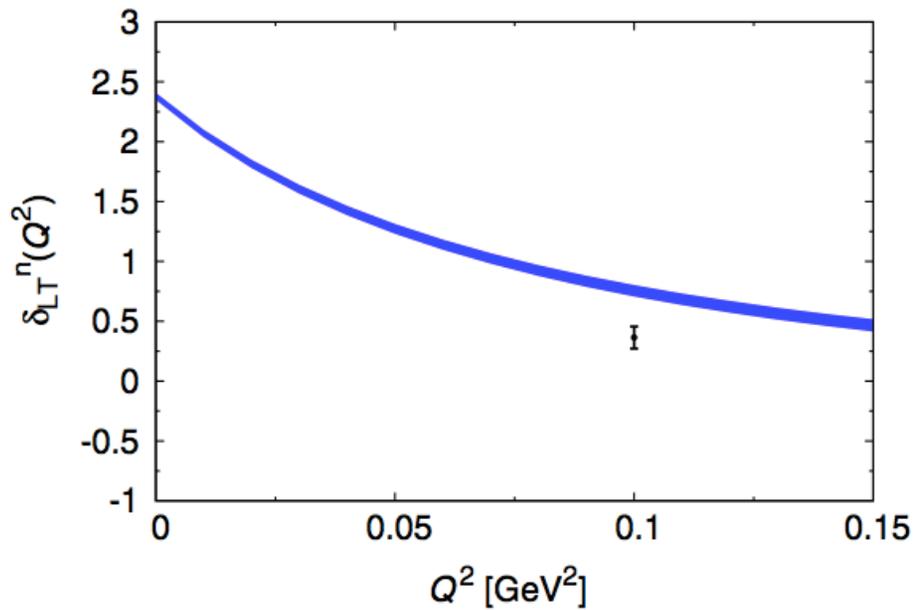
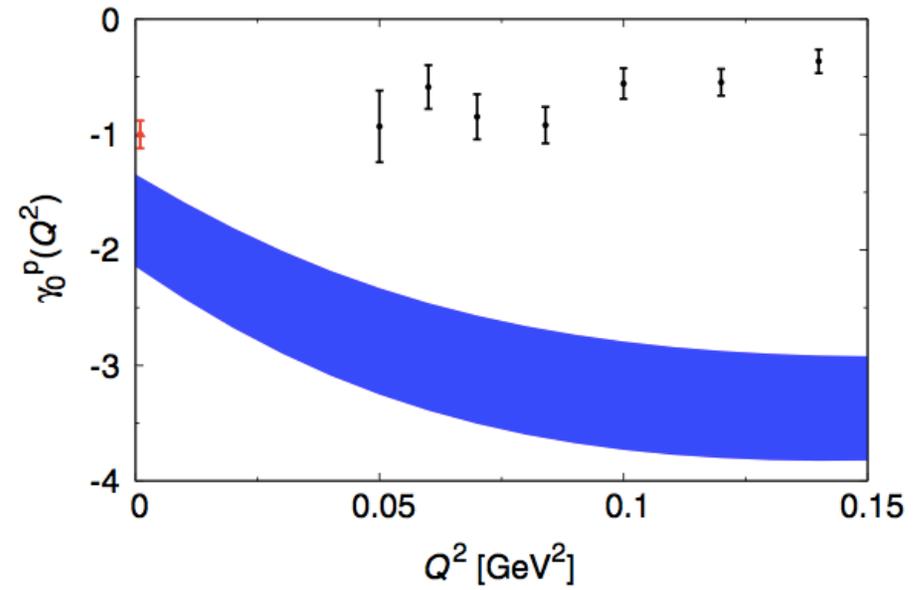
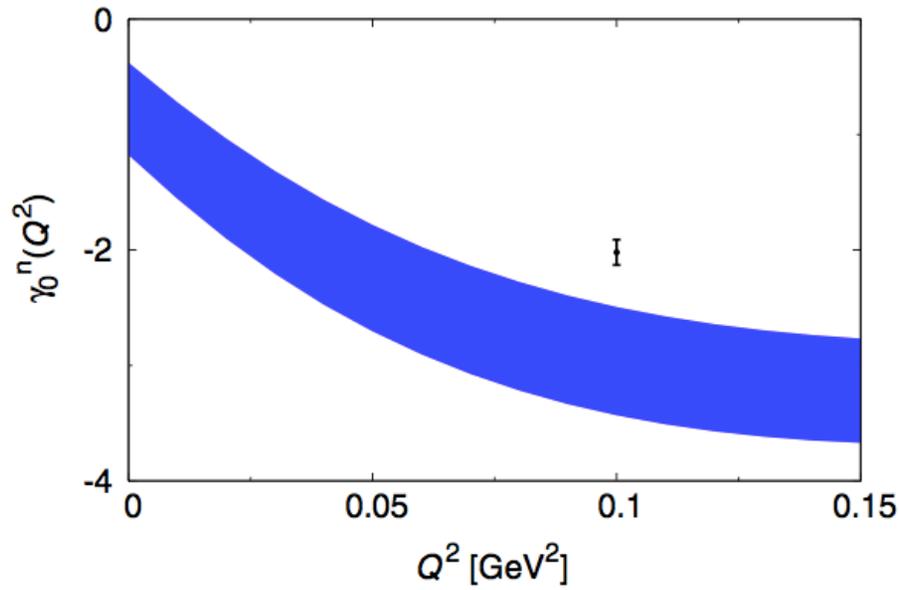
PLB 672 12, 2009

published data goes down to about 0.06 GeV^2

P-N and P+N



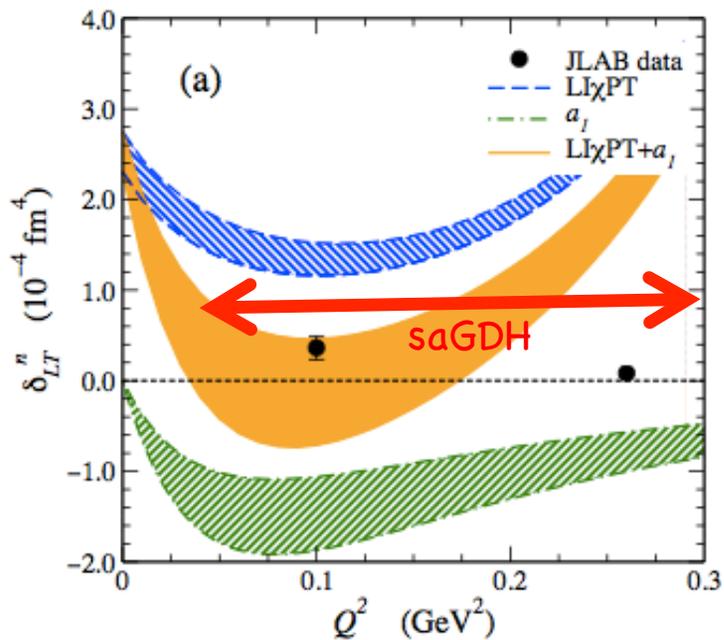
Deur et al., Phys.Rev. D78 (2008) 032001



LT Spin Polarizability

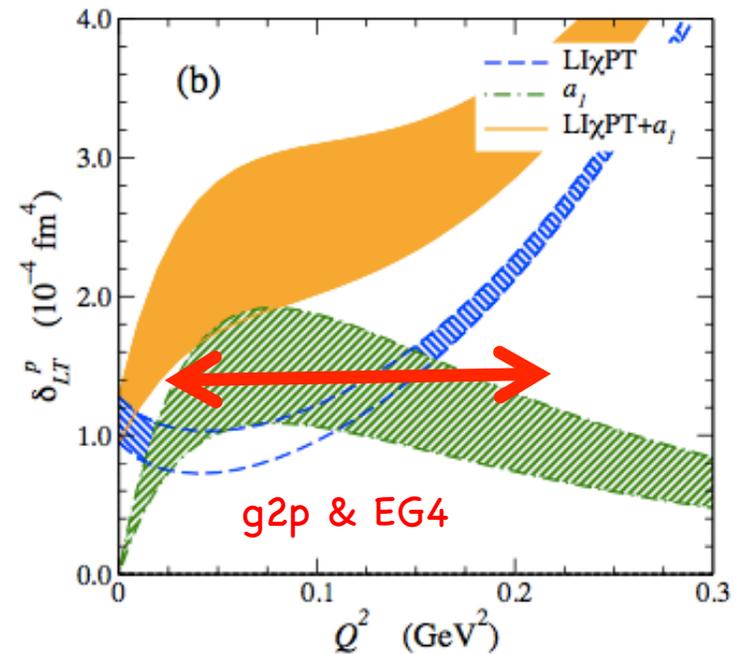
Kochelev & Oh. Phys.Rev. D85 (2012) 016012
Improves agreement with neutron,

Neutron

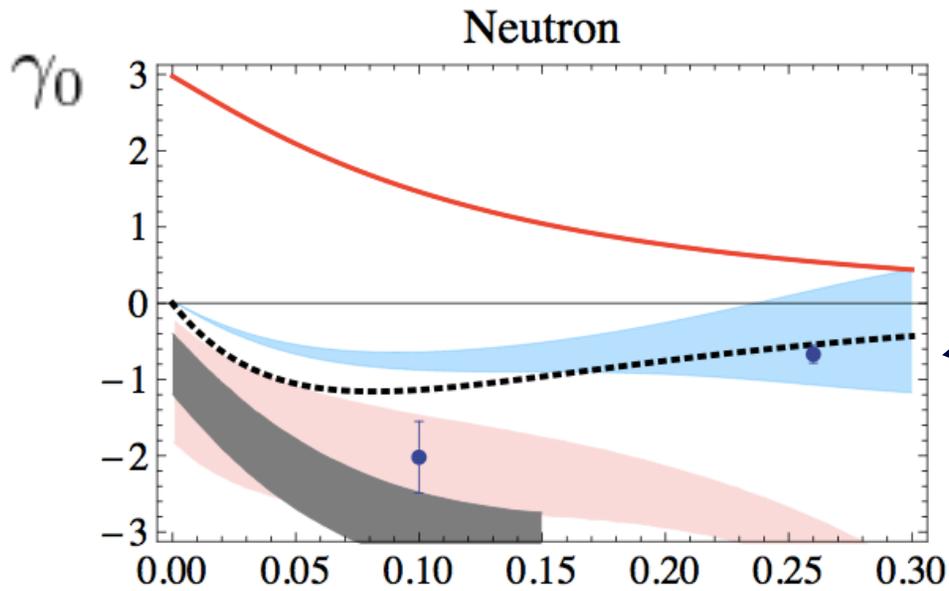


New Data available soon

Proton



Progress....

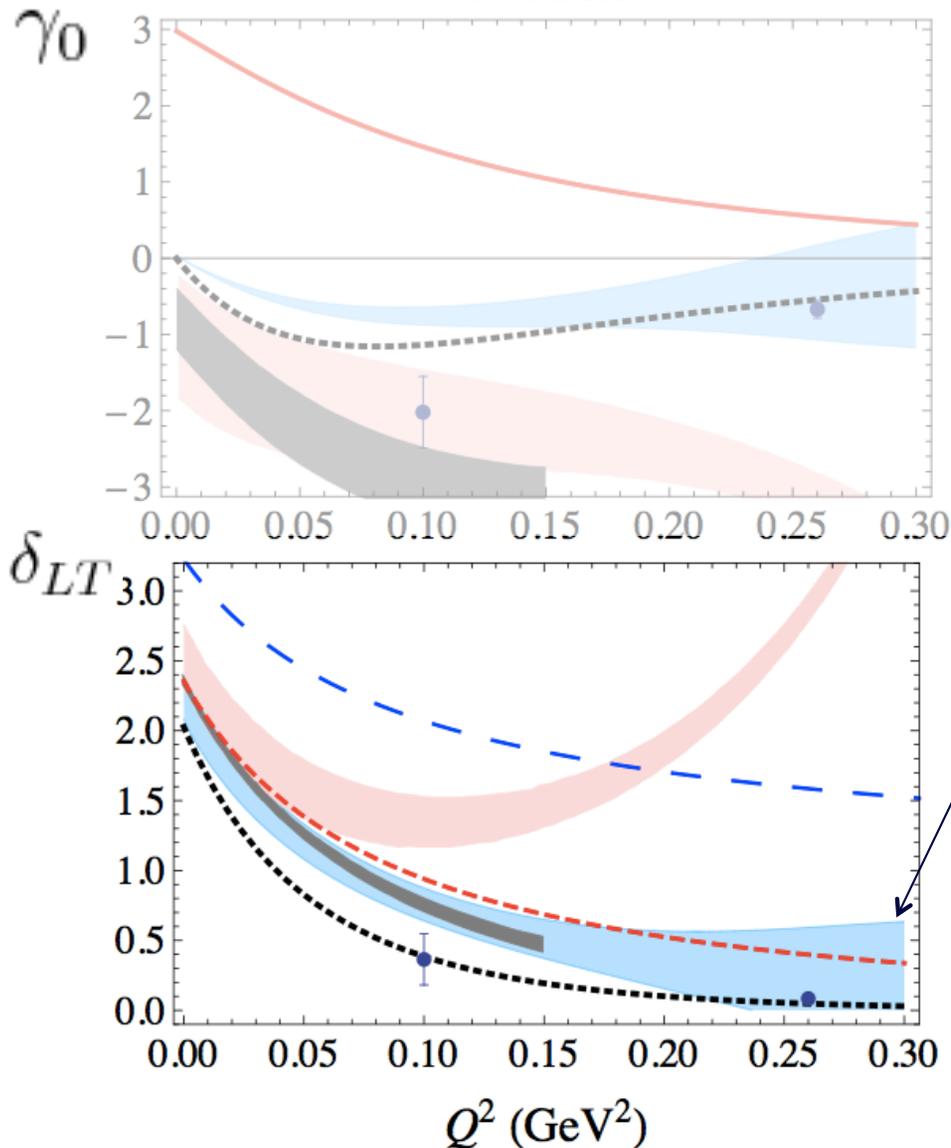


Lensky, Alarcon, Pascalutsa.
arxiv:1407.2574 (2014)

NLO: Blue Band

Progress...

Neutron

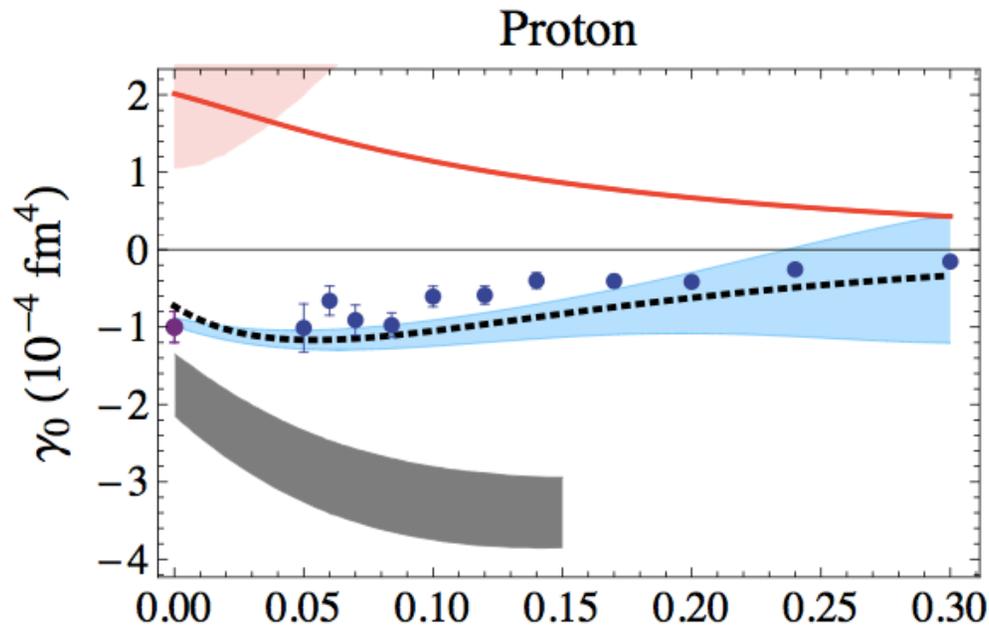


Lensky, Alarcon, Pascalutsa.
arxiv:1407.2574 (2014)

NLO: Blue Band

$B\chi$ PT approach seems to give
reasonable results for the
neutron

Progress...



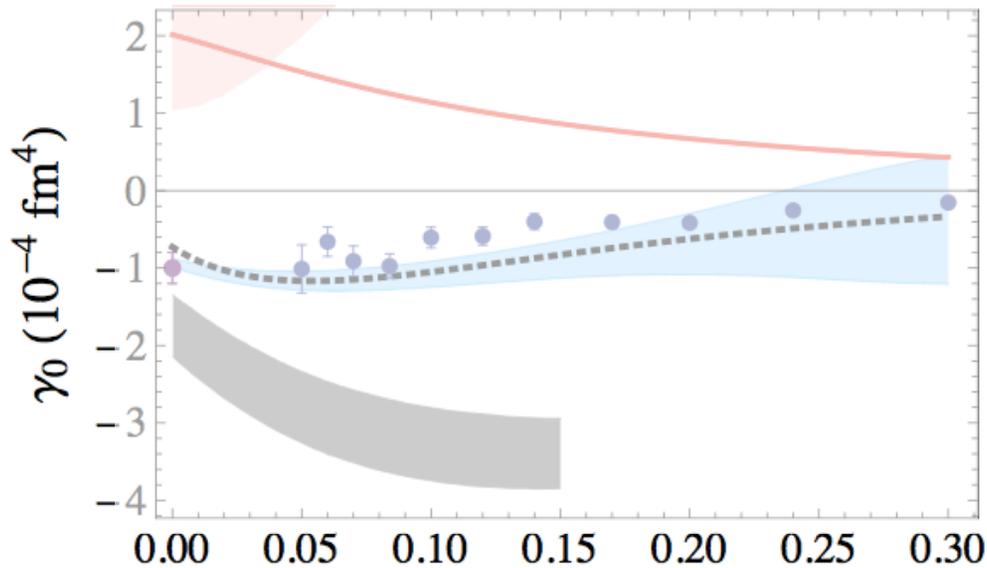
Lensky, Alarcon, Pascalutsa.
arxiv:1407.2574 (2014)

NLO: Blue Band

$B\chi_{\text{PT}}$: good agreement with the
proton γ_0

Progress...

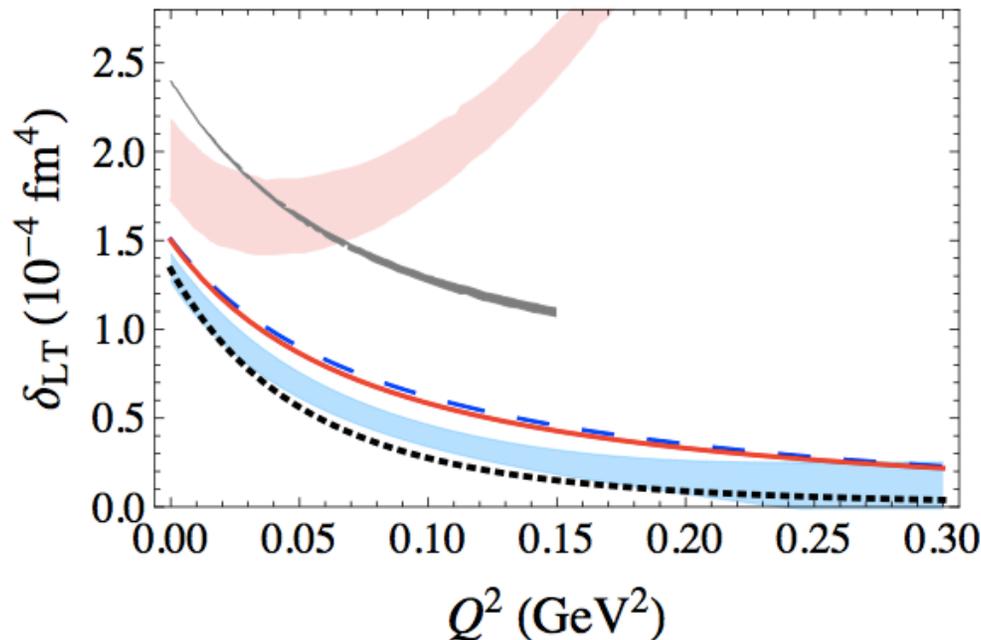
Proton



Lensky, Alarcon, Pascalutsa.
arxiv:1407.2574 (2014)

NLO: Blue Band

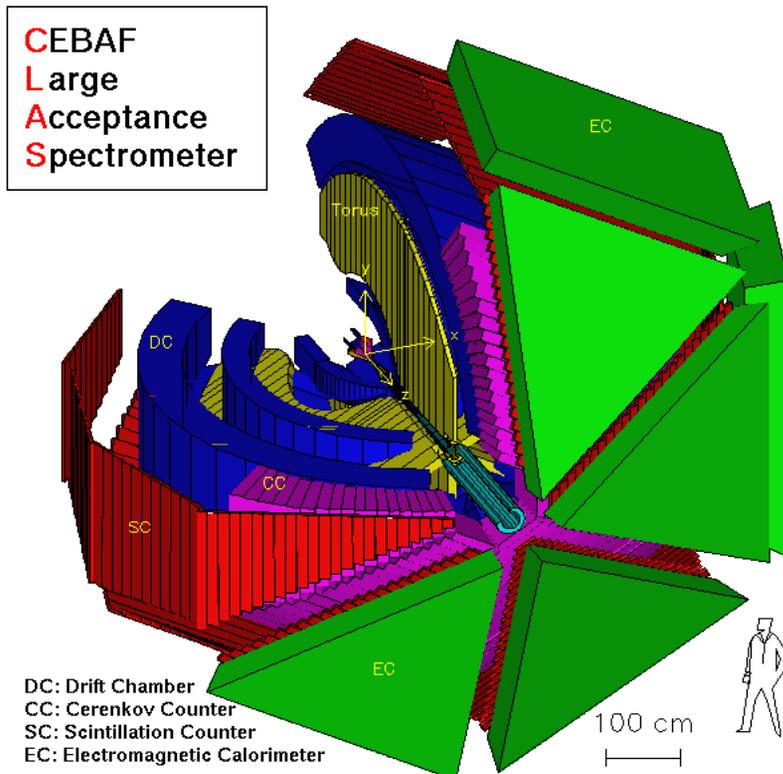
$B\chi_{\text{PT}}$: good agreement with the
proton γ_0



$B\chi_{\text{PT}}$: reasonable agreement with
MAID model for δ_{LT}

δ_{LT} puzzle Solved? Need data to confirm
data anticipated from EG4+g2p experiments

The EG4 Experiment



Measurement of g_1 at low Q^2

Test of ChPT as $Q^2 \rightarrow 0$

Measured Absolute XS differences

Goal : Extended GDH Sum Rule

Proton

Deuteron

Spokespersons

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

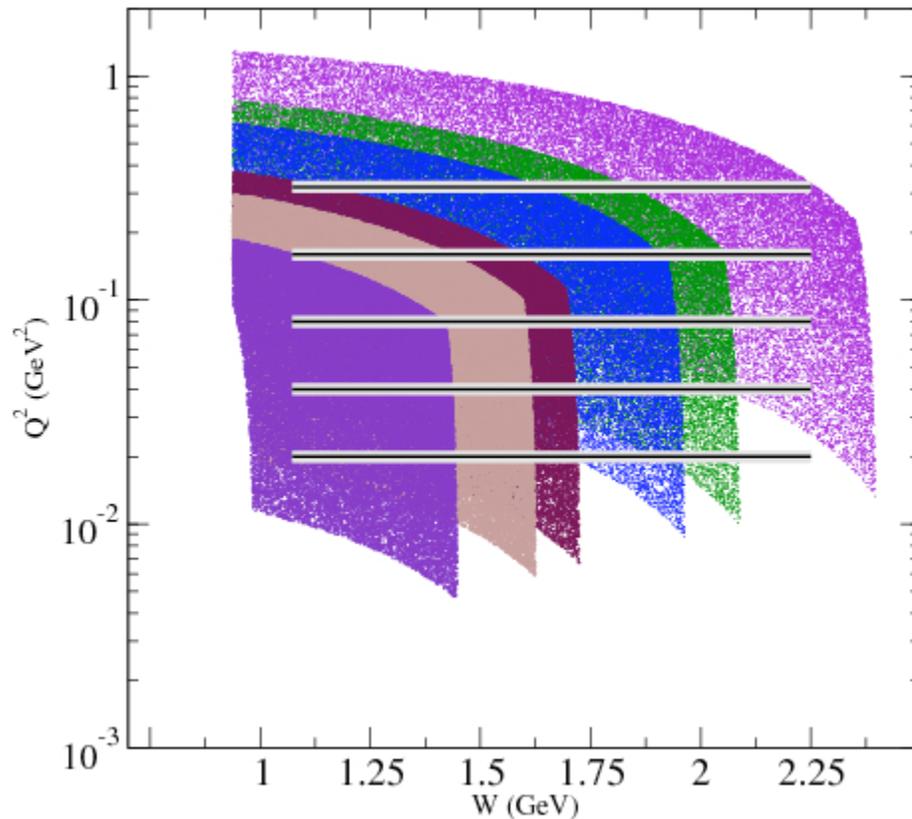
ND_3 : A. Deur(Contact), G. Dodge, K. Slifer

PhD. Students

K. Adhikari, H. Kang, K. Kovacs

Kinematic Coverage

EG4: g_1 (Proton and Deuteron)



Incident Energies

Proton Target
1.0, 1.3, 2.0, 2.3 and 3.0 GeV.

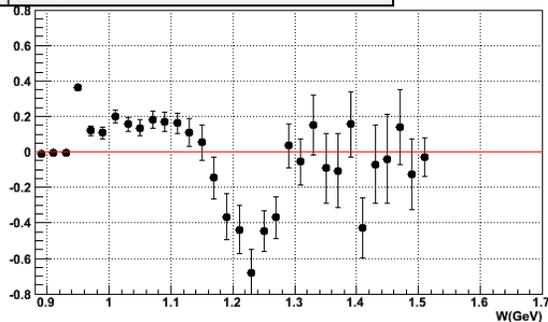
Deuteron Target
1.3 and 2.0 GeV

$0.02 < Q^2 < 0.5 \text{ GeV}^2$
Resonance Region

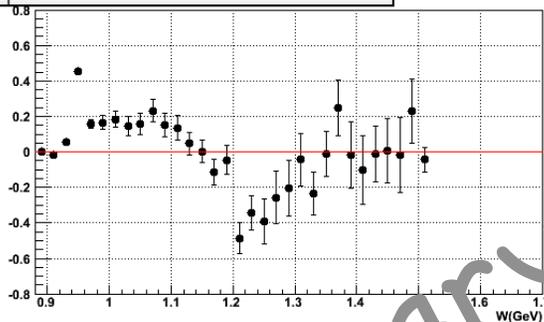
thanks to
Hyekoo Kang (Seoul)
And
Krishna Adhikari (ODU)

Preliminary EG4 Proton g_1

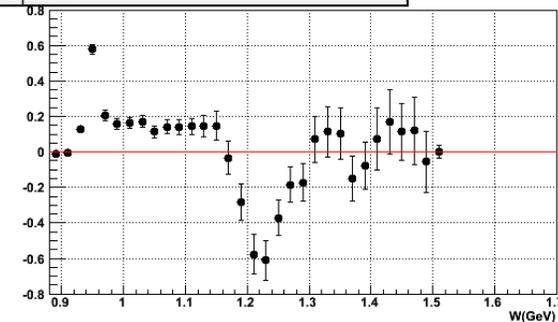
$g_1(W, Q^2)$, SCc, $\langle Q^2 \rangle = 0.0244$ (#6), $E = 1.054$ GeV 0.02



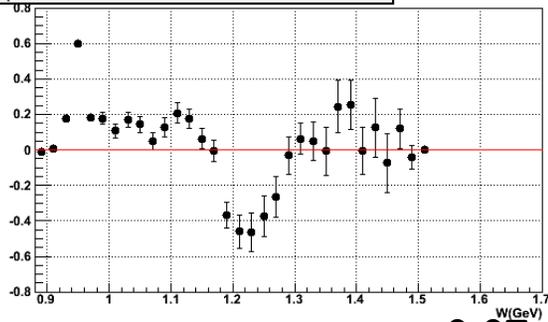
$g_1(W, Q^2)$, SCc, $\langle Q^2 \rangle = 0.0292$ (#7), $E = 1.054$ GeV 0.03



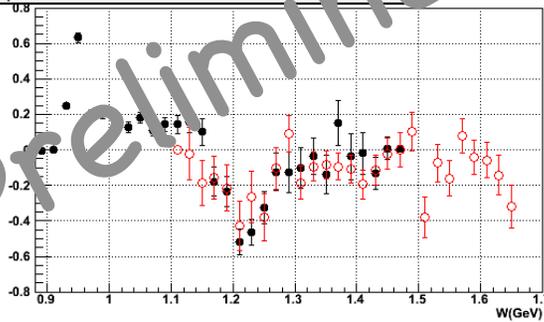
$g_1(W, Q^2)$, SCc, $\langle Q^2 \rangle = 0.0348$ (#8), $E = 1.054$ GeV 0.035



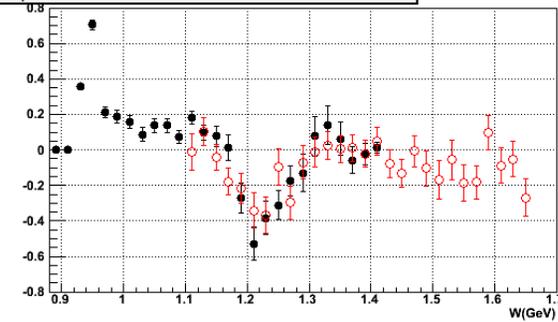
$g_1(W, Q^2)$, SCc, $\langle Q^2 \rangle = 0.0416$ (#9), $E = 1.054$ GeV 0.04



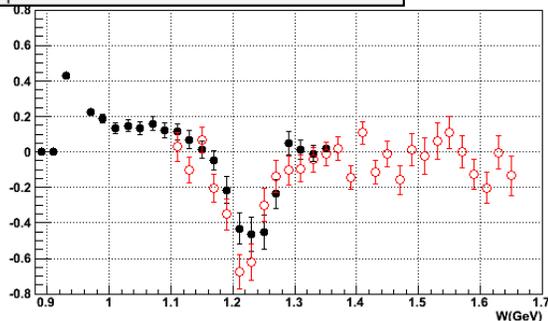
$g_1(W, Q^2)$, SCc, $\langle Q^2 \rangle = 0.0496$ (#10), $E = 1.054$ GeV 0.05



$g_1(W, Q^2)$, SCc, $\langle Q^2 \rangle = 0.0592$ (#11), $E = 1.054$ GeV 0.06

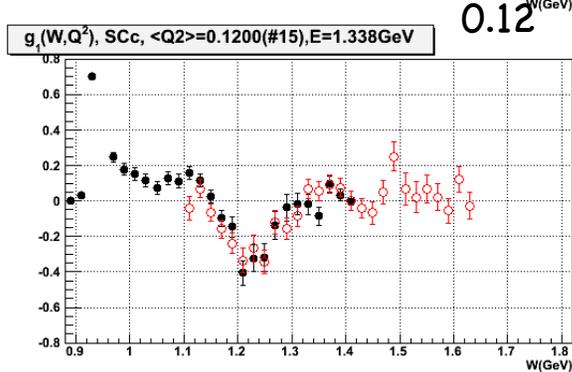
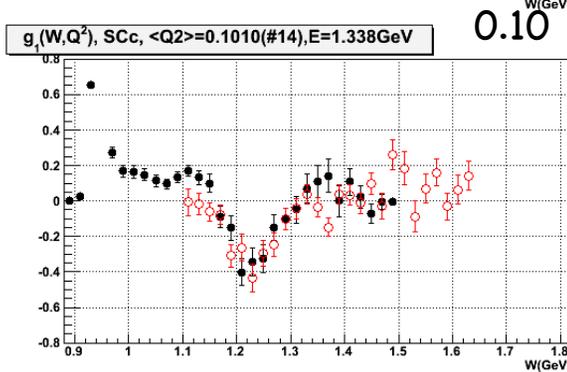
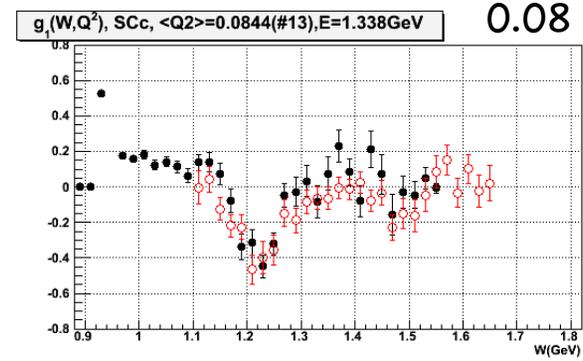
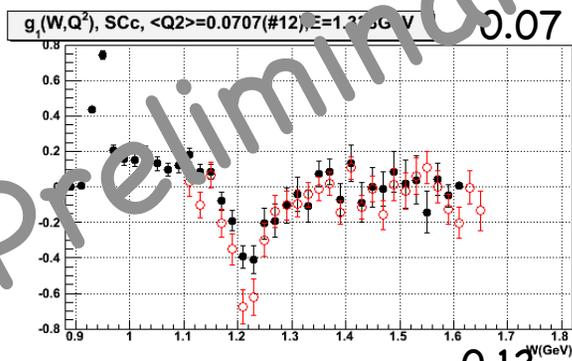
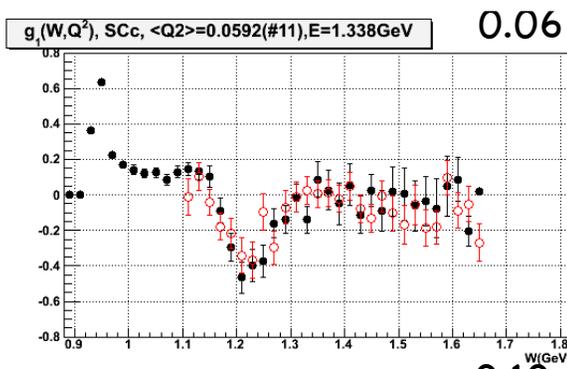
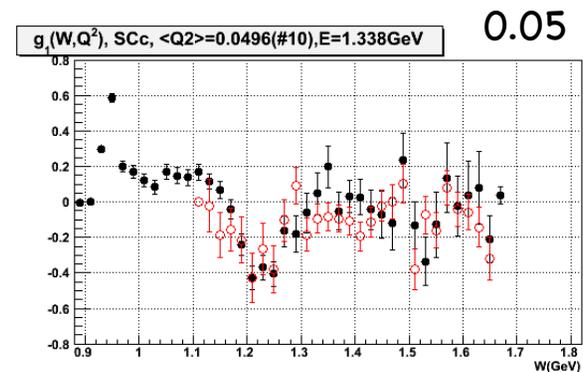
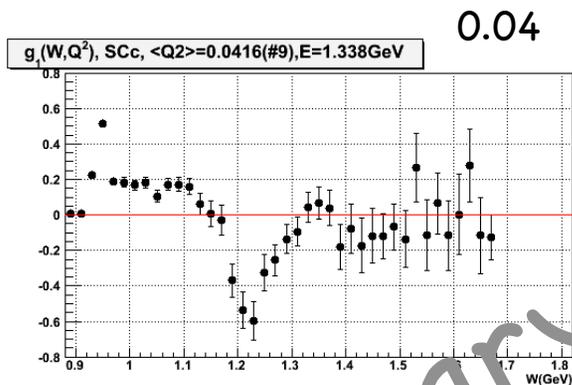


$g_1(W, Q^2)$, SCc, $\langle Q^2 \rangle = 0.0707$ (#12), $E = 1.054$ GeV 0.07



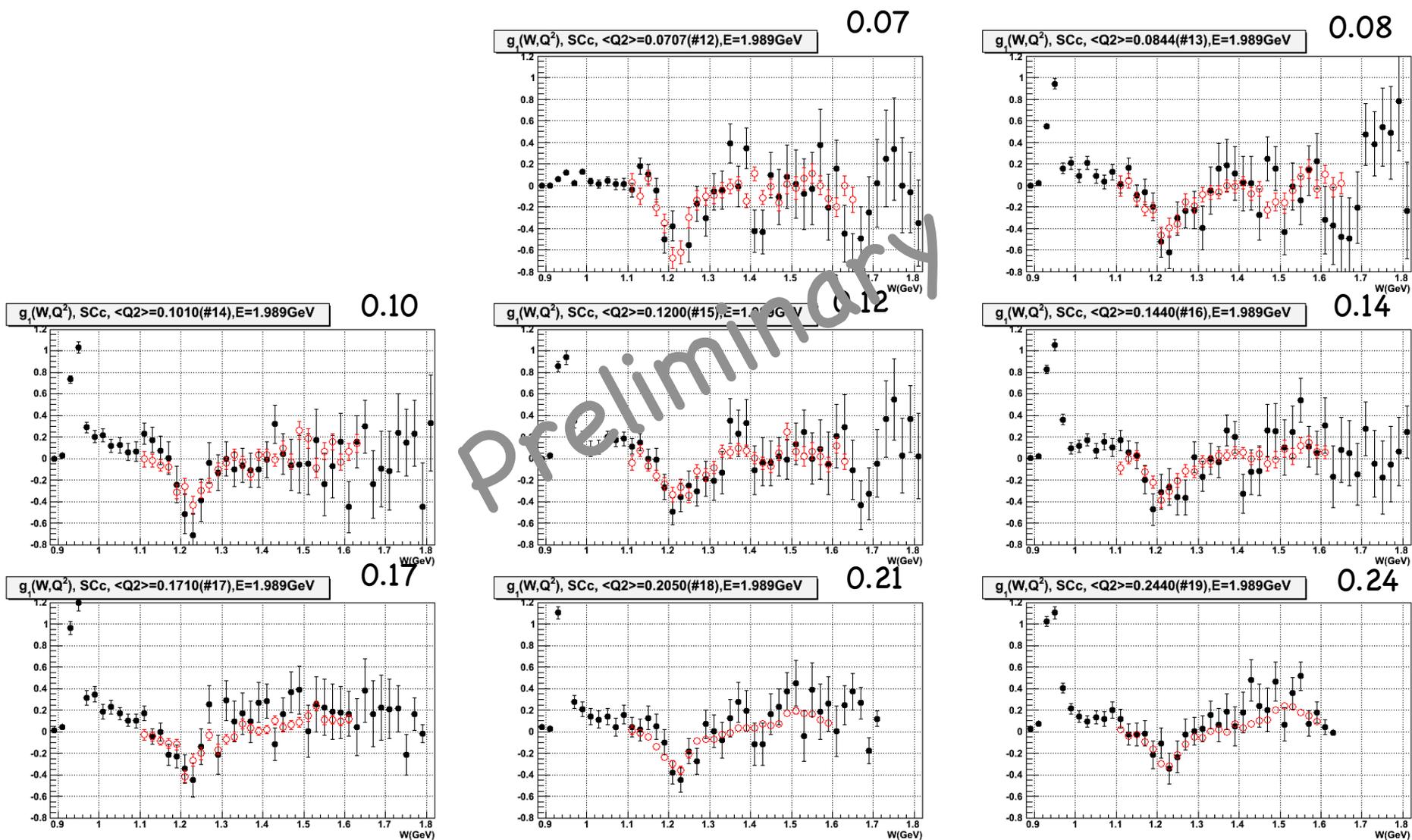
Black: 1.0 GeV
Red: EG1b

Preliminary EG4 Proton g_1



Black: 1.3 GeV
Red: EG1b

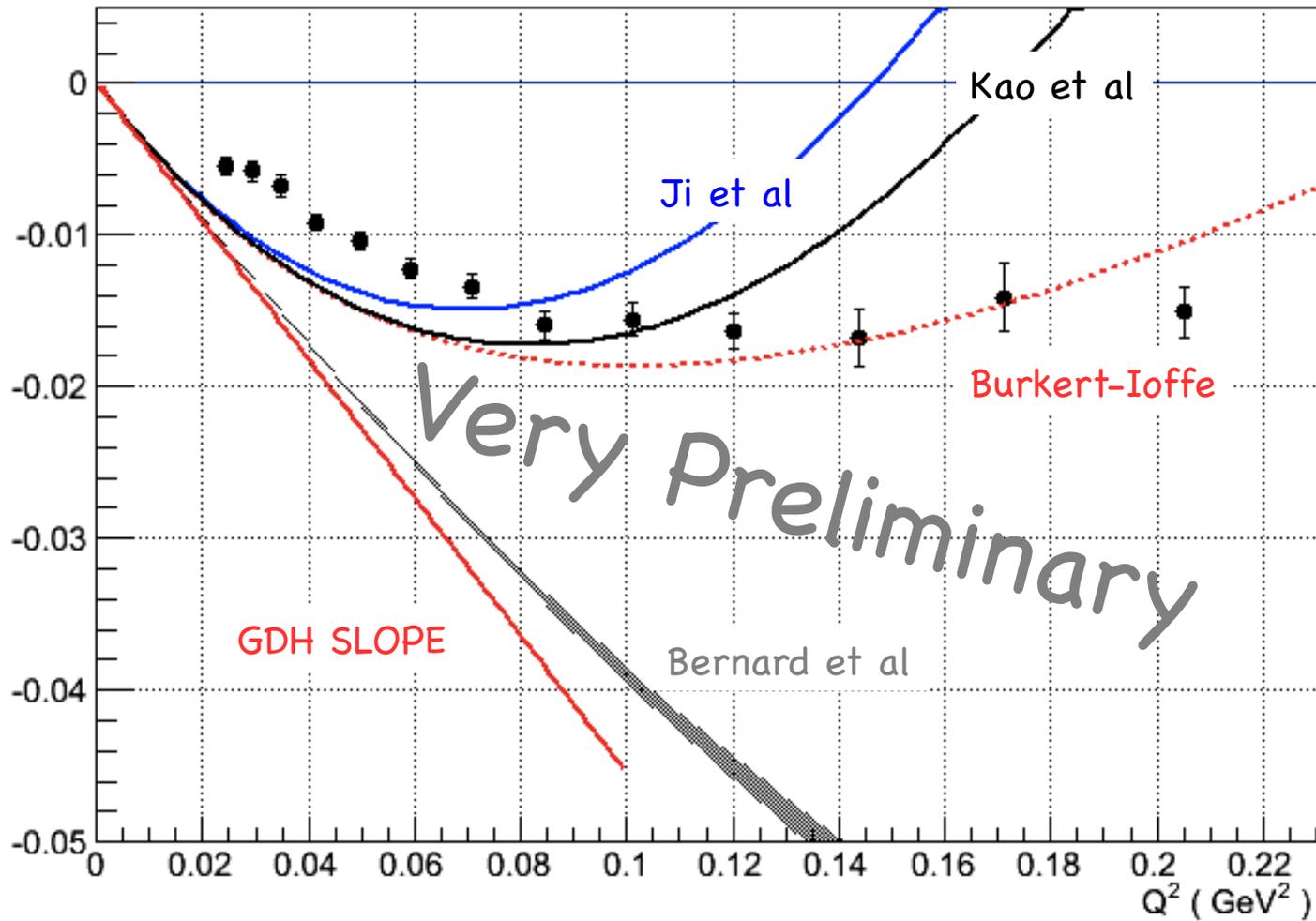
Preliminary EG4 Proton g_1



Black: 2.0 GeV
Red: EG1b

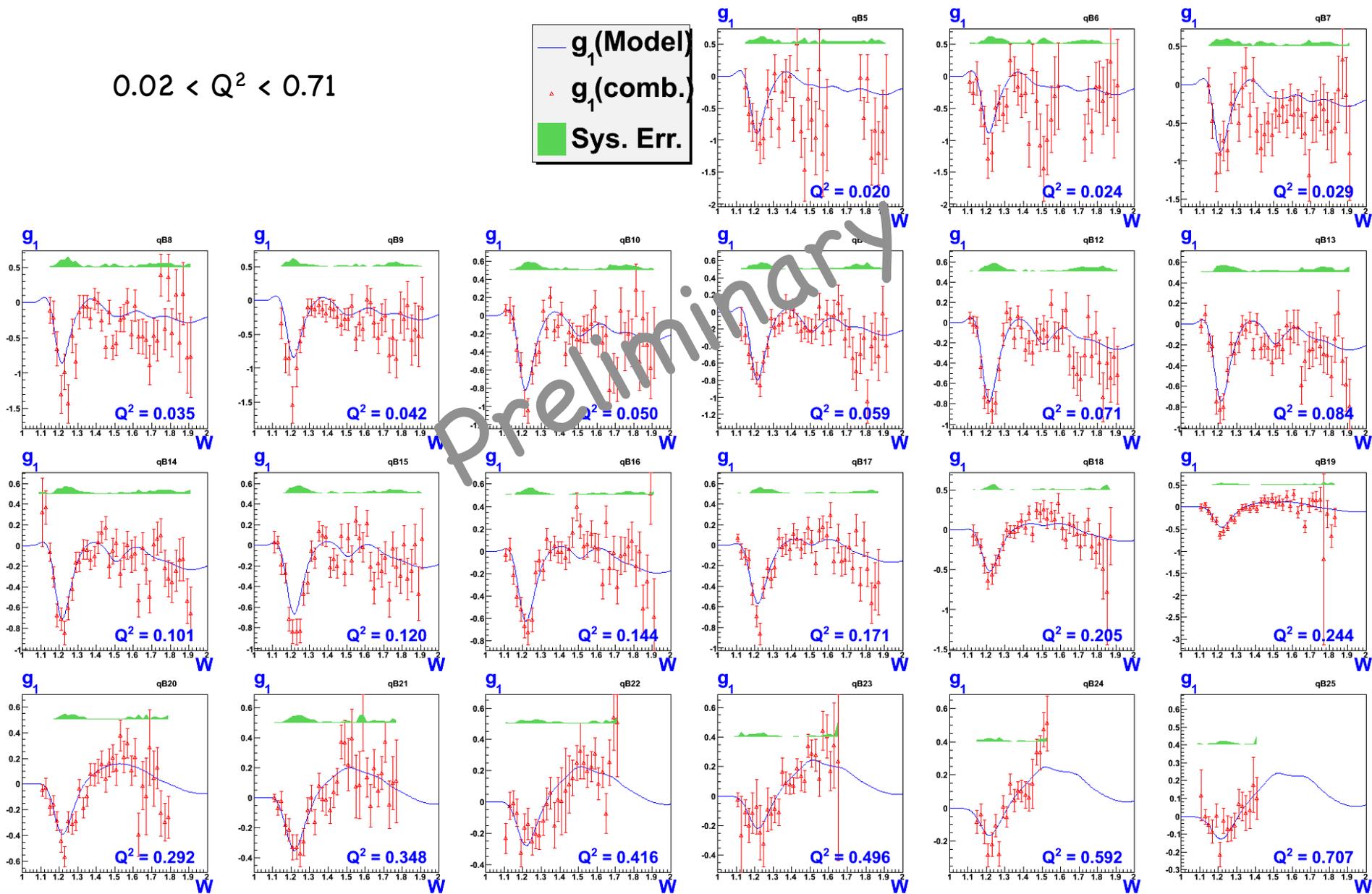
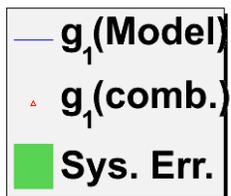
Preliminary EG4 Proton Γ_1

Stat error only

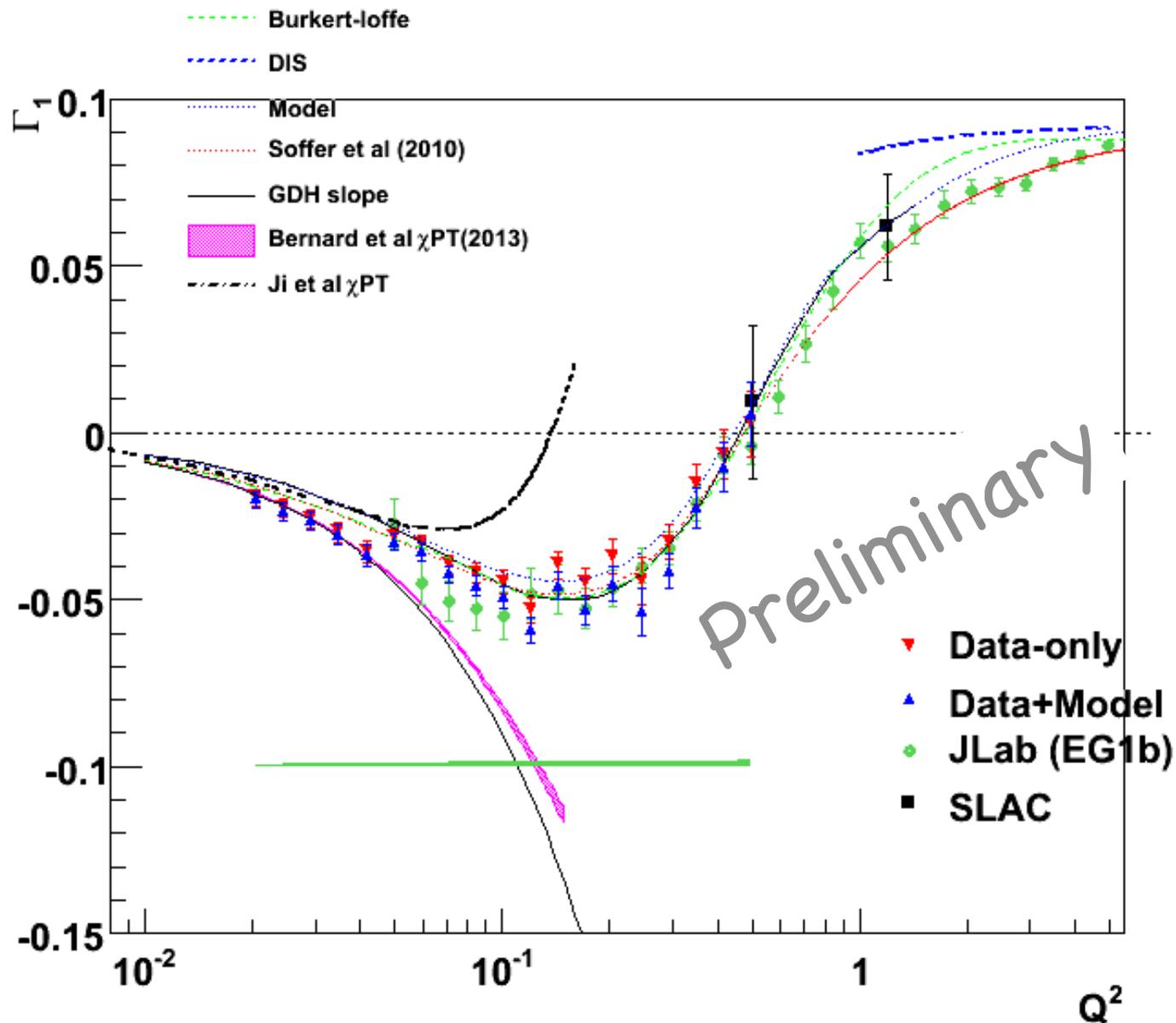


Preliminary EG4 Deuteron g_1

$0.02 < Q^2 < 0.71$



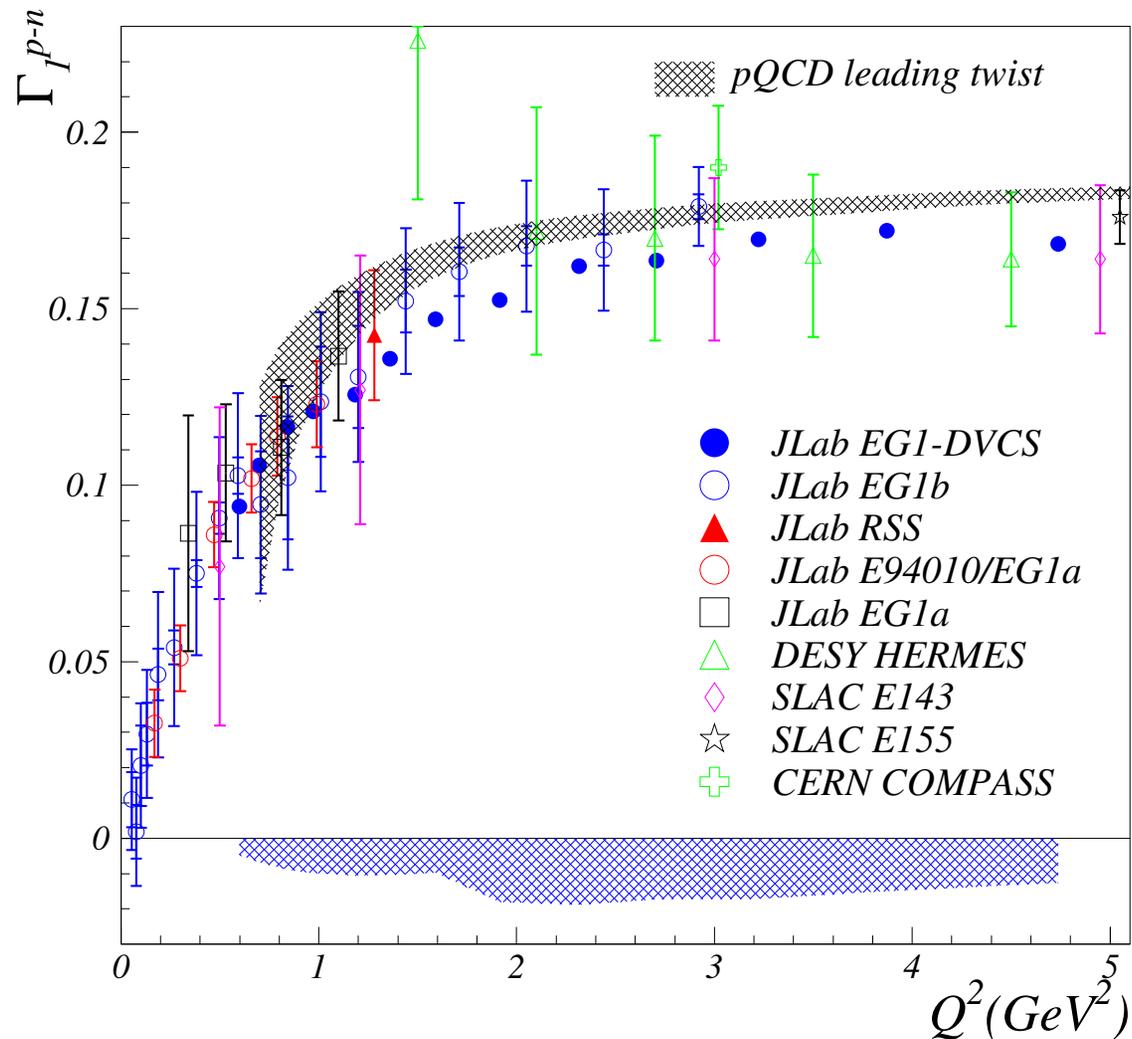
Preliminary EG4 Deuteron Γ_1



EG1-DVCS Experiment : Bjorken Sum

$$\Gamma_1^{p-n} \equiv \Gamma_1^p - \Gamma_1^n \equiv \int_0^1 dx (g_1^p(x) - g_1^n(x)) = \frac{g_A}{6}$$

PRD 90, 012009 (2014)

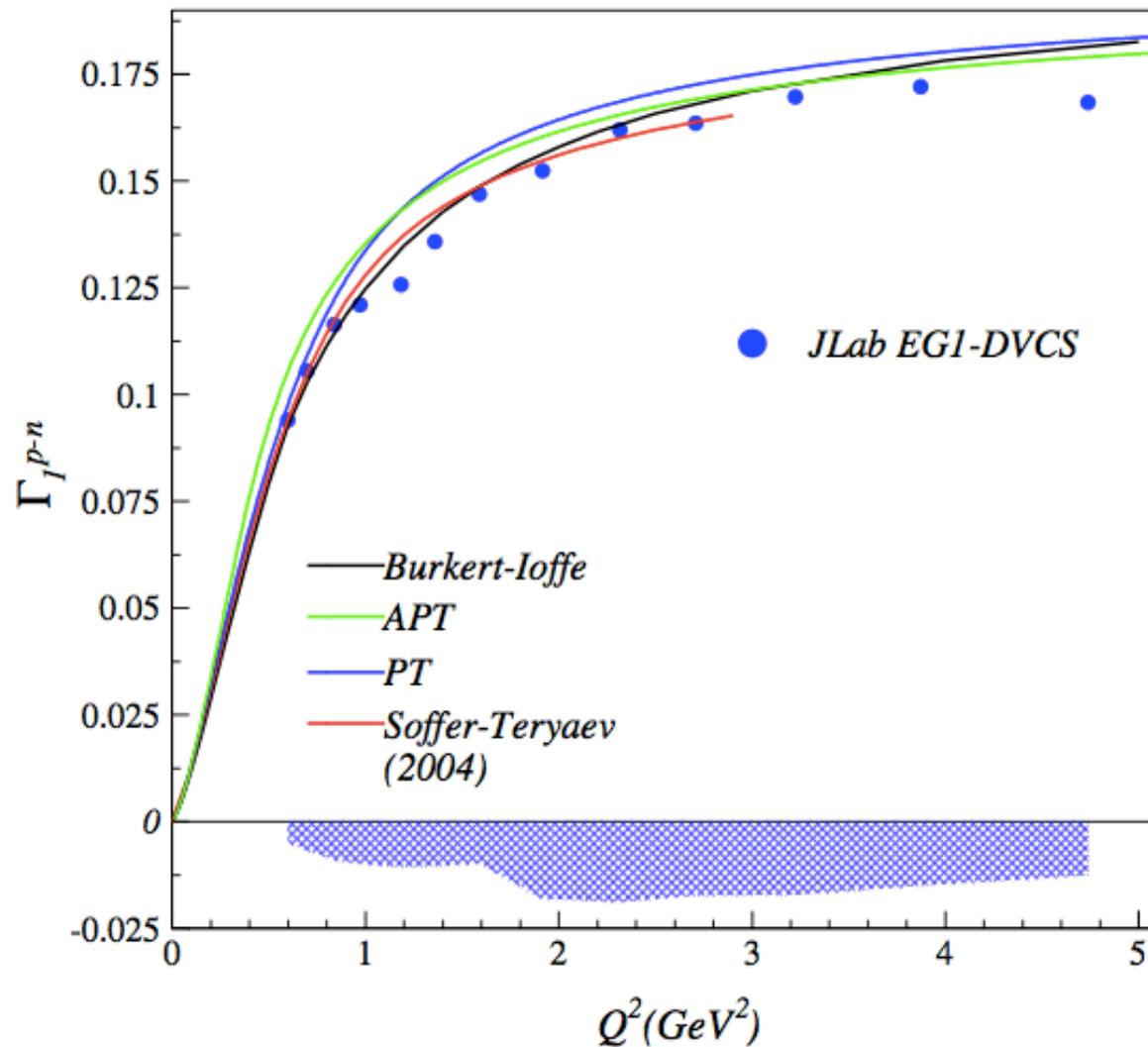


EG1-DVCS Experiment : Bjorken Sum

$$\Gamma_1^{p-n} \equiv \Gamma_1^p - \Gamma_1^n \equiv \int_0^1 dx (g_1^p(x) - g_1^n(x)) = \frac{g_A}{6}$$

PHYSICAL REVIEW D **90**, 012009 (2014)

PRD **90**, 012009 (2014)



E08-027 : Proton g_2 Structure Function

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

Spokesmen: A. Camsonne, D. Crabb, J.Chen, & K.S.

BC Sum Rule : violation suggested for proton at large Q^2 , but found satisfied for the neutron & ^3He .

Spin Polarizability : Major failure ($>8\sigma$) of χPT for neutron δ_{LT} . Need g_2 isospin separation to solve.

Hydrogen HyperFine Splitting : Lack of knowledge of g_2 at low Q^2 is one of the leading uncertainties.

Experiment Overview

Polarized proton target

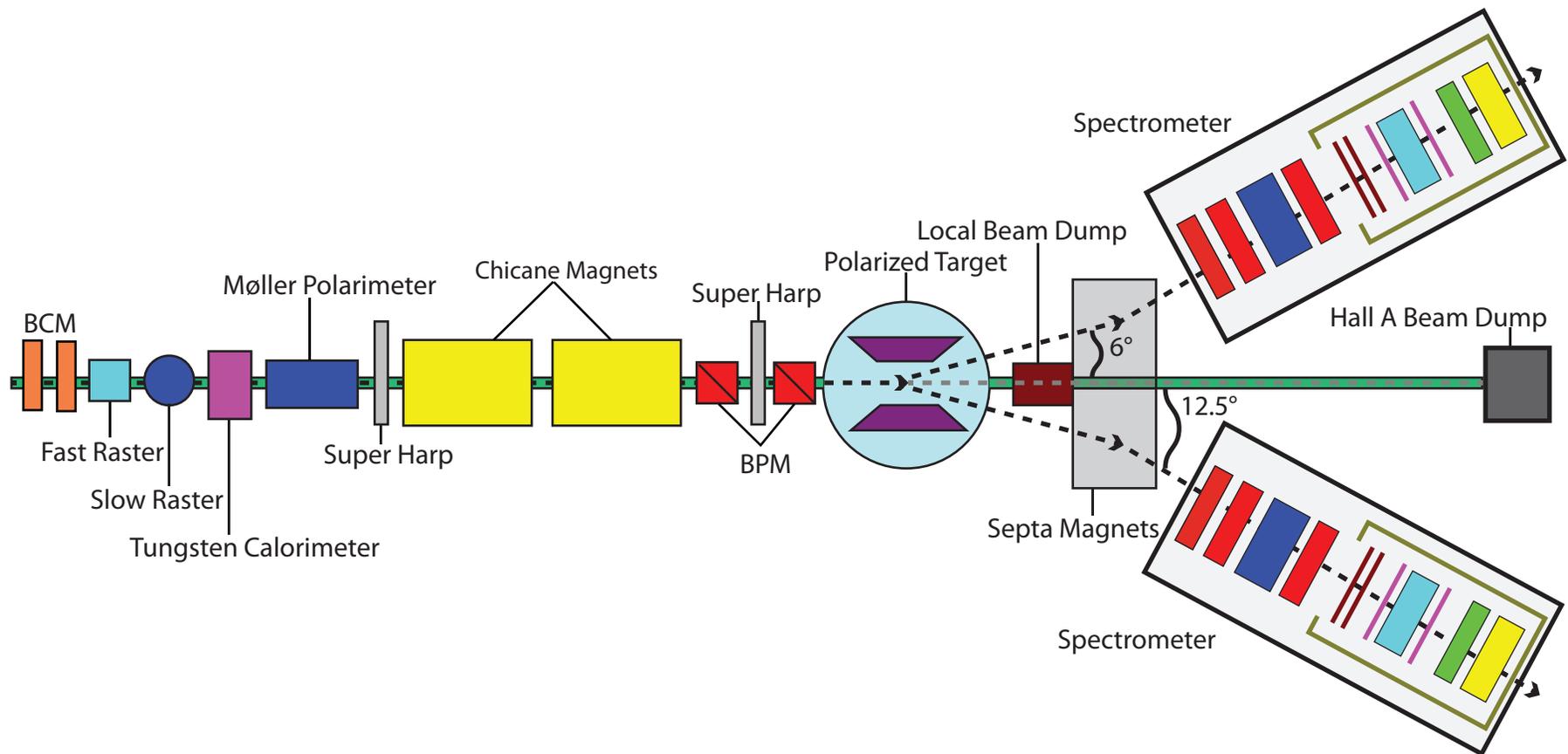
- upstream chicane
- downstream local dump

Low current polarized beam

Upgrades to existing Beam Diagnostics to work at 85 nA

Lowest possible Q^2 in the resonance region

Septa Magnets to detect forward scattering



Largest Installation in Hall A History

Polarized proton target

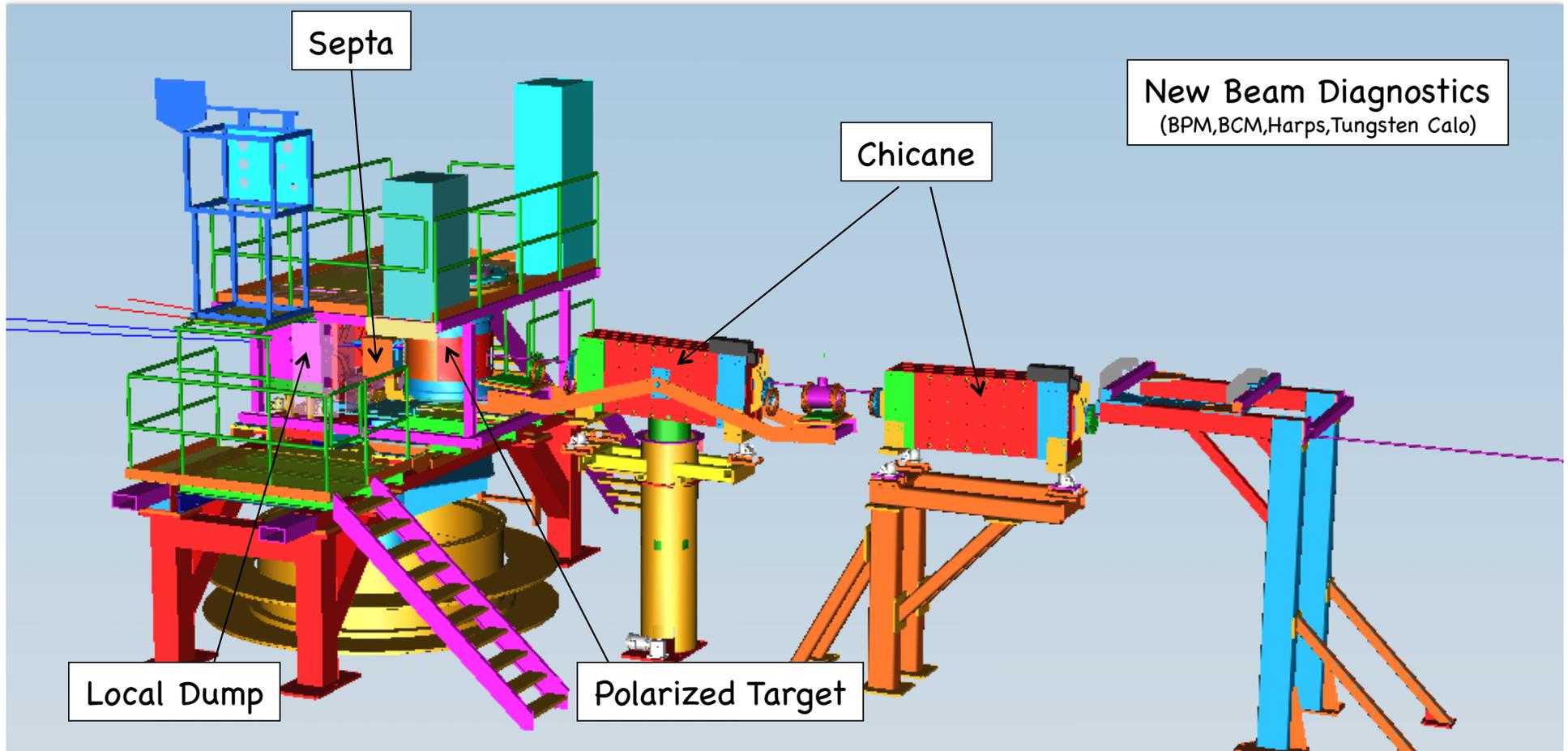
upstream chicane
downstream local dump

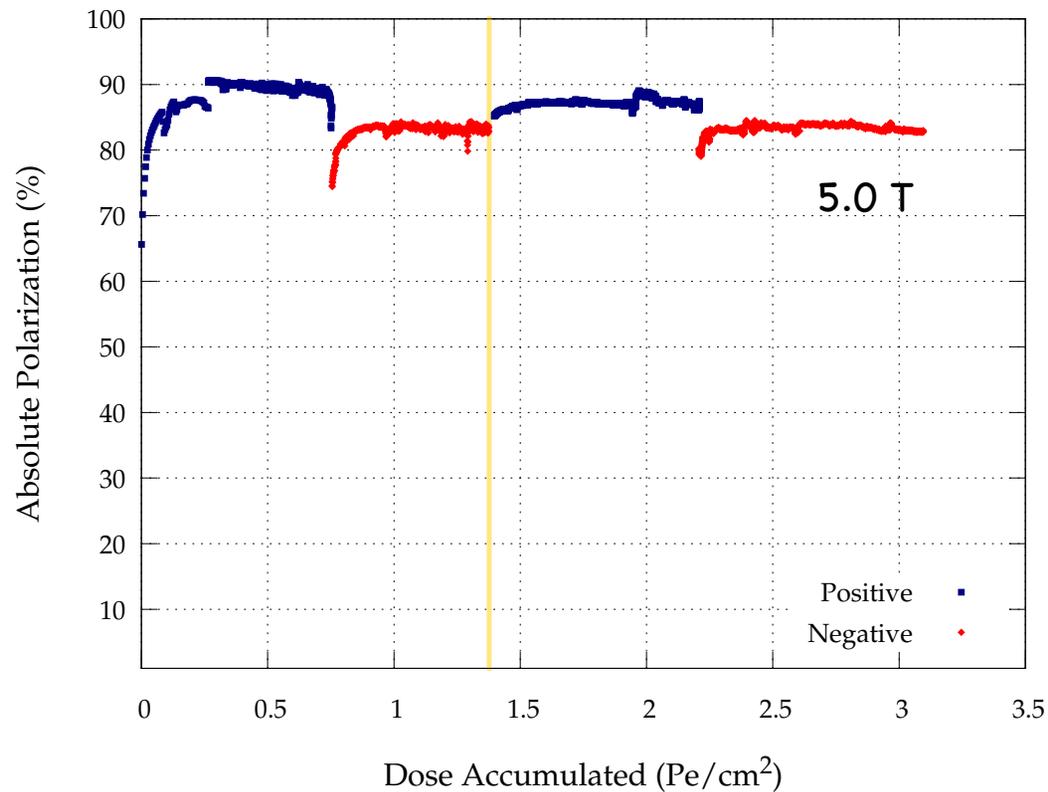
Low current polarized beam

Upgrades to existing Beam Diagnostics to work at 85 nA

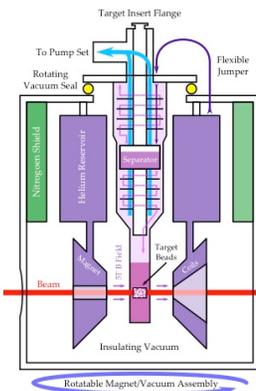
Lowest possible Q^2 in the resonance region

Septa Magnets to detect forward scattering





Target Polarization Analysis
is mostly complete
(Finalizing Systematics)



Dynamically polarized target for the g_2^p and G_E^p experiments at Jefferson Lab

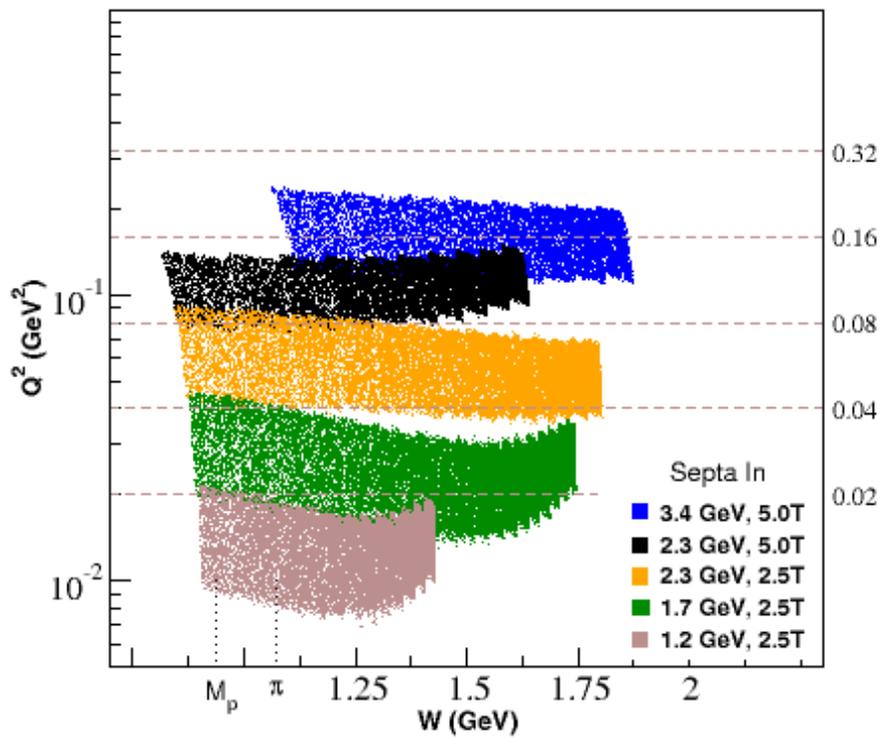
J. Pierce^{a,*}, J. Maxwell^{b,1}, T. Badman^b, J. Brock^a, C. Carlin^a, D. G. Crabb^c, D. Day^c, N. Kvaltine^c, D.G. Meekins^a, J. Mulholland^{c,2}, J. Shields^c, K. Slifer^b, C.D. Keith^a

^aThomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

^bDept. of Physics, University of New Hampshire, Durham, NH 03824, USA

^cDept. of Physics, University of Virginia, Charlottesville, VA 22904, USA

Kinematic Coverage



Dashed lines show
planned extrapolation
to constant Q^2

$$0.02 < Q^2 < 0.16$$

E08-027 Highlights & Prelim Results

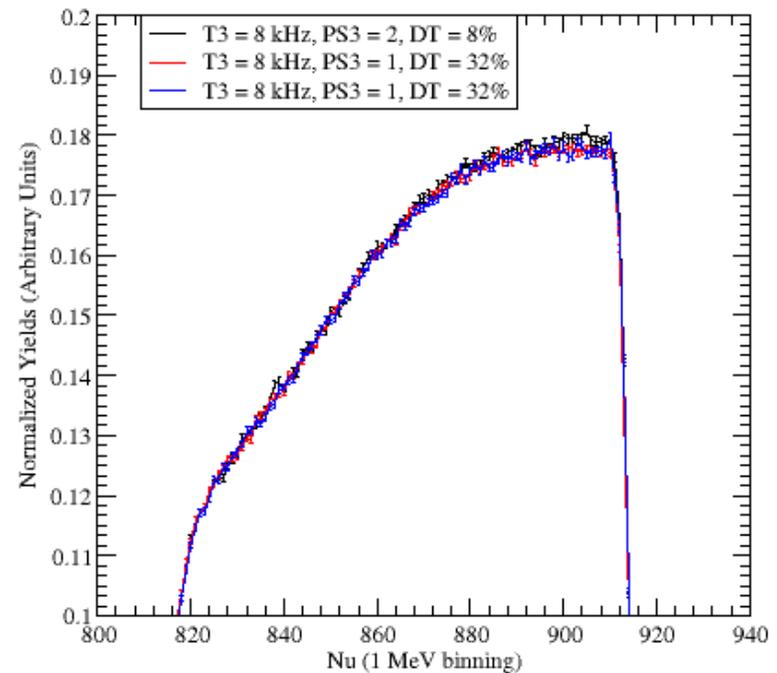
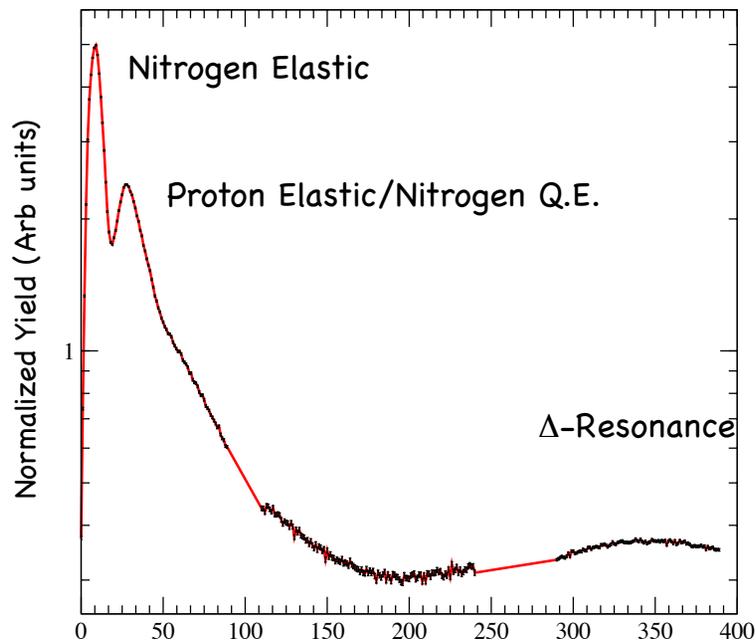
Will be the definitive measurement of g_{2p} for $0.02 < Q^2 < 0.2 \text{ GeV}^2$

Largest Installation in Hall A History

Entire new suite of beamline diagnostics for operation at 50nA

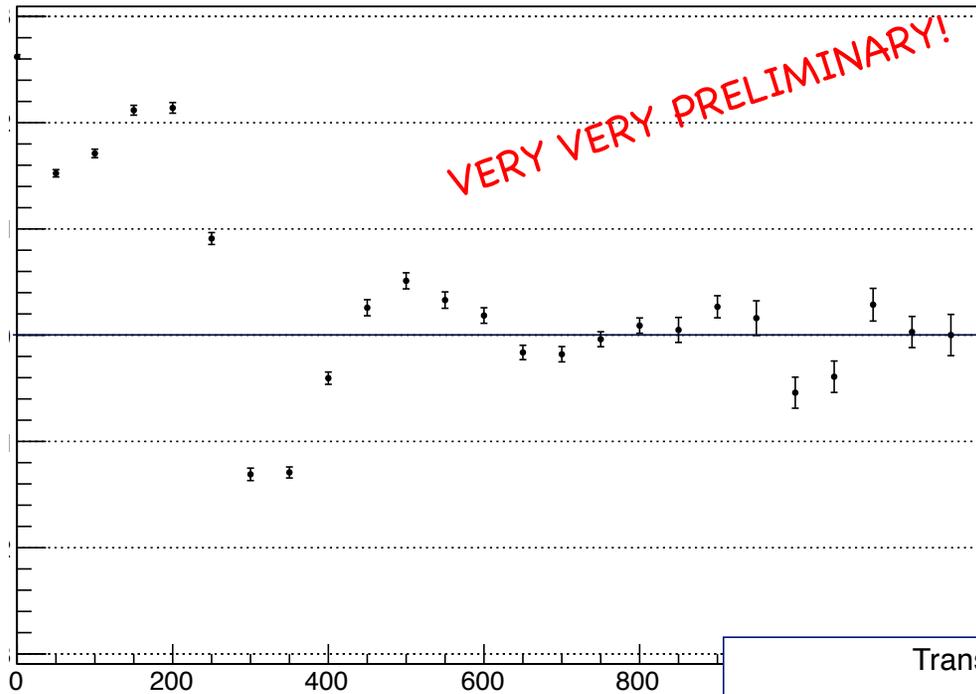
DAQ rate was Hall A record : 6.5 kHz/HRS with $<25\%$ downtime

Polarized target performed very reliably



Prelim data from Ryan Zielinski

Longitudinal 5T Physics Asymmetry at E=2254MeV

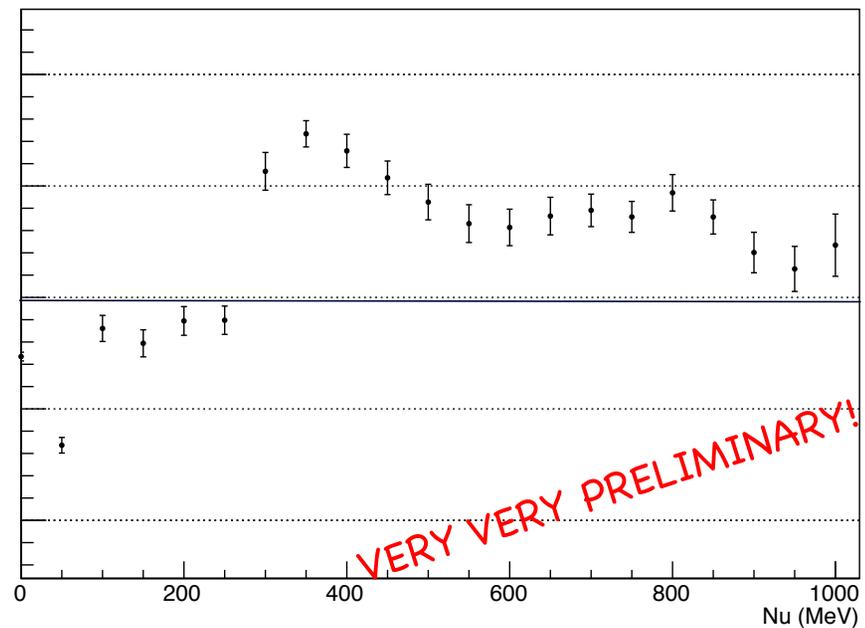


Caveat Emptor

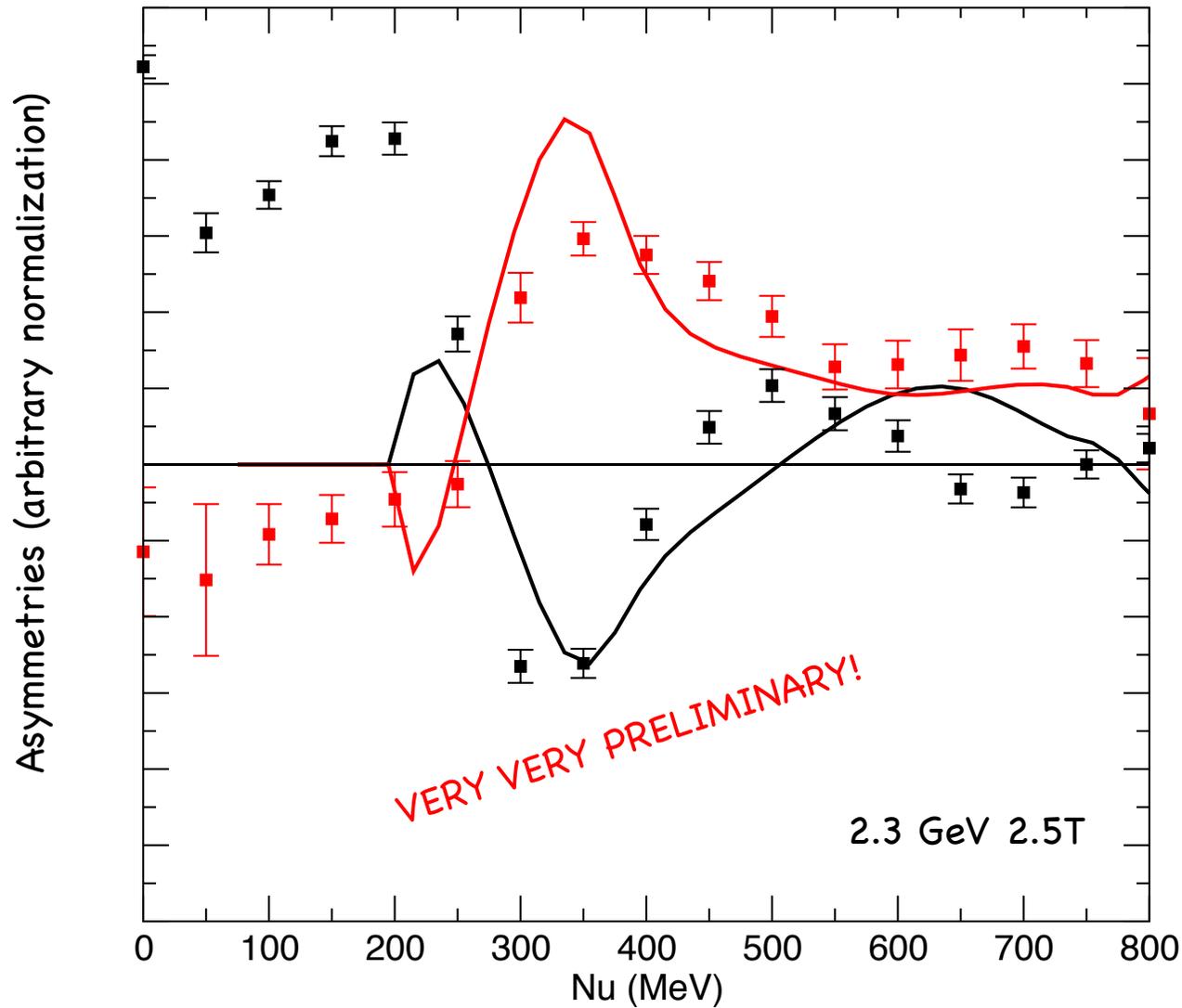
No Radiative Corrections
Crude Diluton Factor
Online Polarization

$$\langle Q^2 \rangle \approx 0.1 \text{ GeV}^2$$

Transverse 5T Physics Asymmetry at E=2254MeV



$$\langle Q^2 \rangle \approx 0.06 \text{ GeV}^2$$



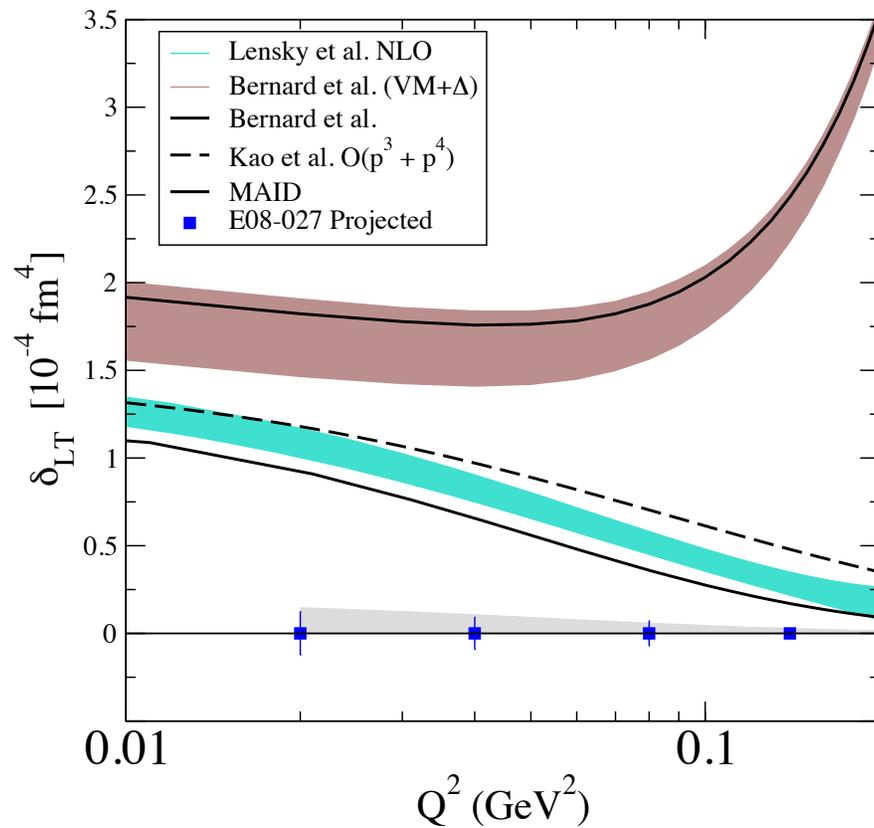
Caveat Emptor

No Radiative Corrections
Crude Diluton Factor
Online Polarization

VERY VERY PRELIMINARY!

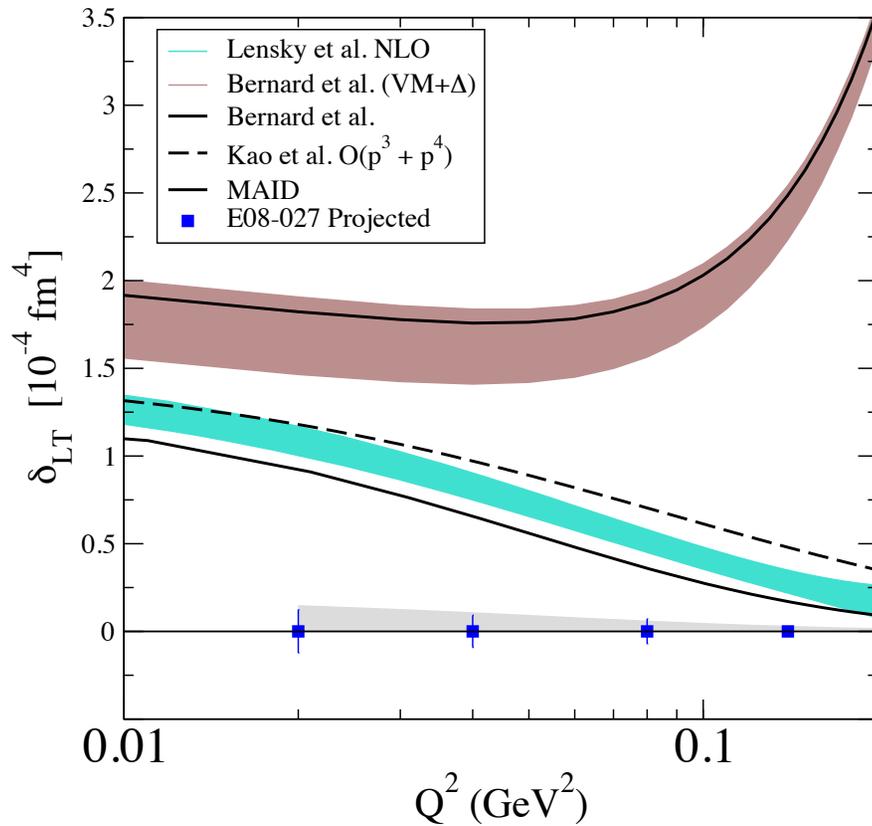
Projections

LT Spin Polarizability

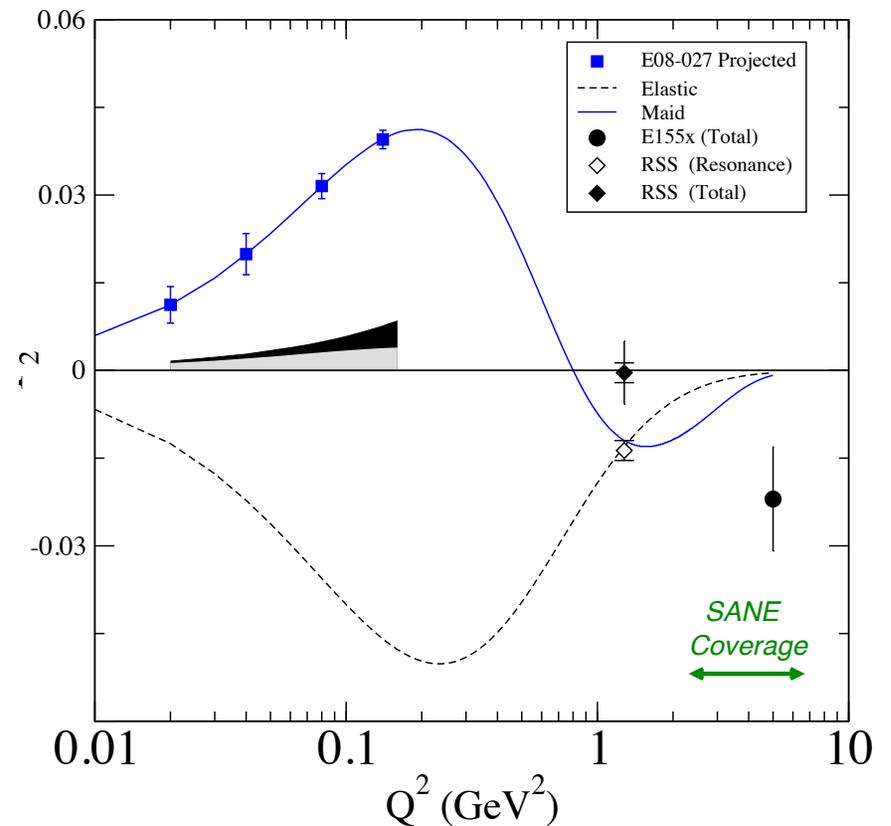


Projections

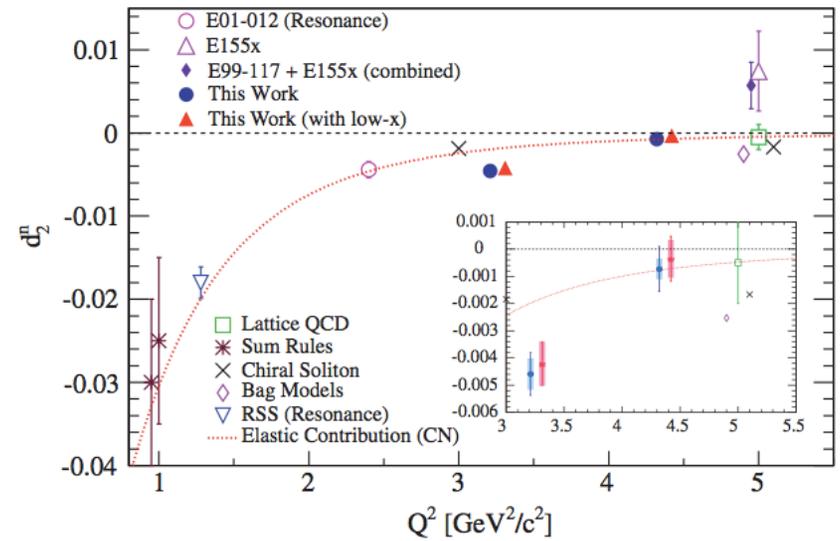
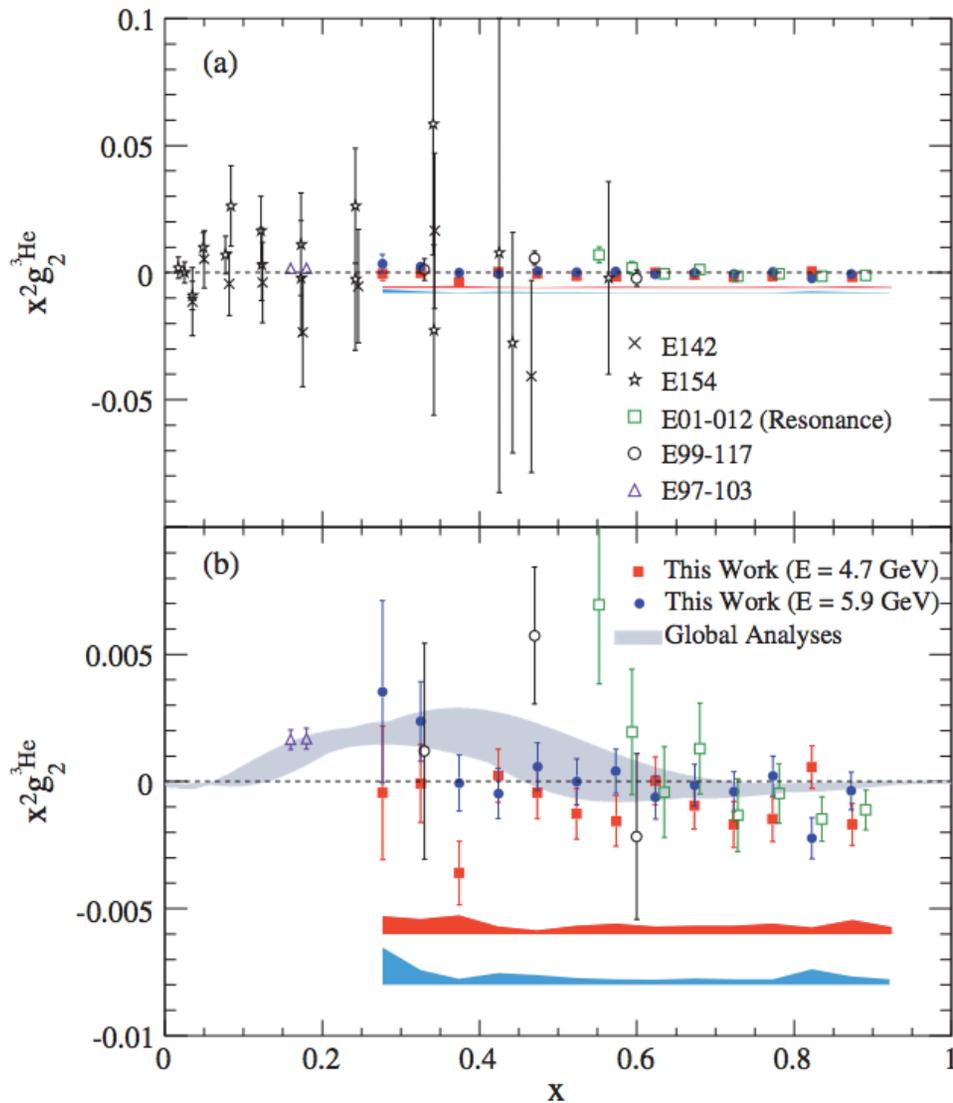
LT Spin Polarizability



BC Sum Integral Γ_2

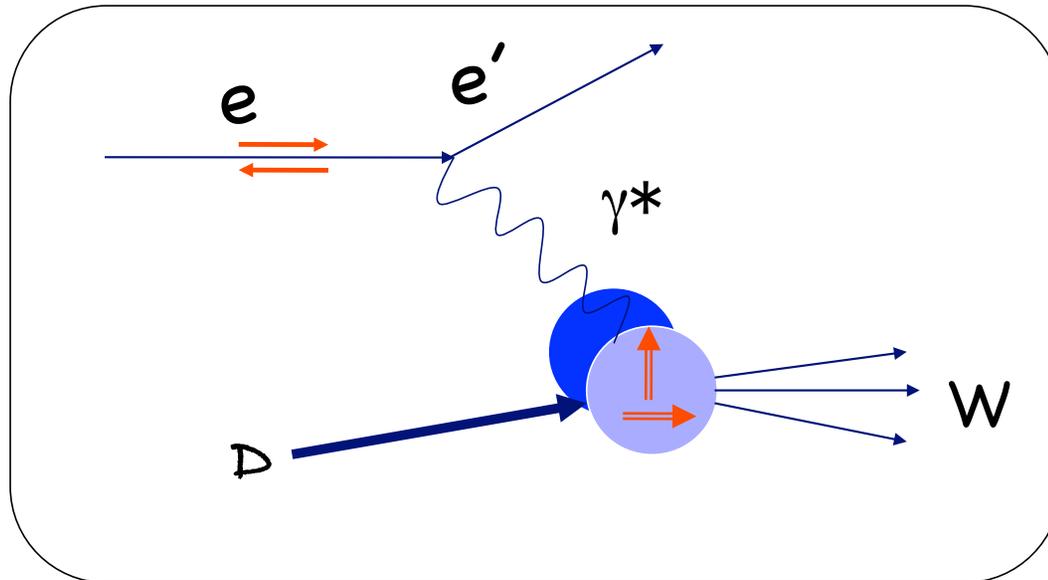


E06-014 (d2n experiment)



Posik et al, PRL 113, 022002 (2014)

Inclusive Scattering



Construct the most general
Tensor W consistent with
Lorentz and gauge invariance

Frankfurt & Strikman (1983)

Hoodbhoy, Jaffe, Manohar (1989)

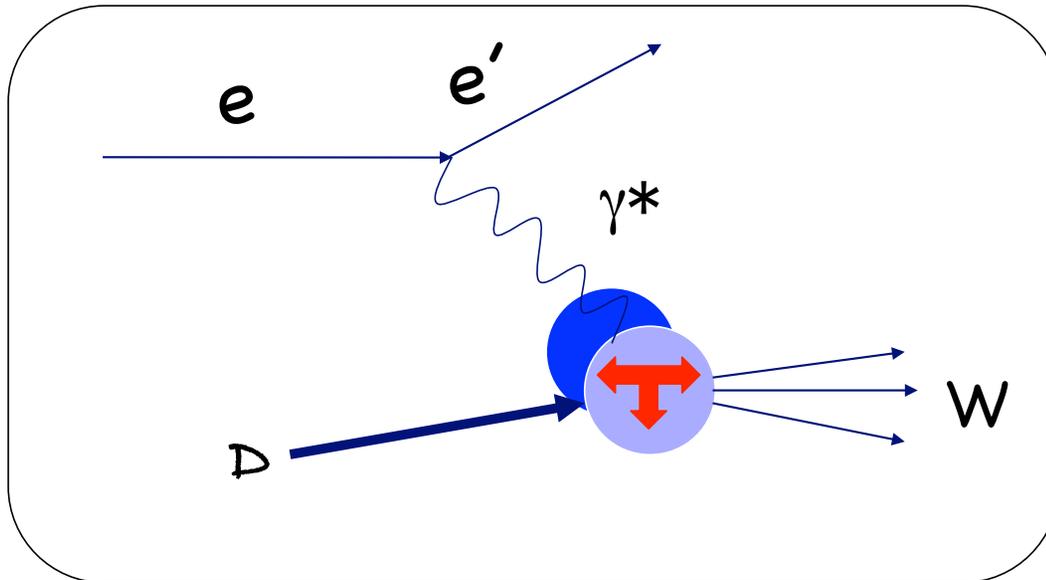
$$W_{\mu\nu} = -F_1 g_{\mu\nu} + F_2 \frac{P_\mu P_\nu}{\nu}$$

Unpolarized Scattering

$$+ i \frac{g_1}{\nu} \epsilon_{\mu\nu\lambda\sigma} q^\lambda s^\sigma + i \frac{g_2}{\nu^2} \epsilon_{\mu\nu\lambda\sigma} q^\lambda (p \cdot q s^\sigma - s \cdot q p^\sigma)$$

Vector Polarization

Tensor Structure Functions



Construct the most general
Tensor W consistent with
Lorentz and gauge invariance

Frankfurt & Strikman (1983)

Hoodbhoy, Jaffe, Manohar (1989)

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

Tensor Structure Functions

	Nucleon	Deuteron
F_1	$\frac{1}{2} \sum_q e_q^2 [q_{\uparrow}^{1/2} + q_{\downarrow}^{-1/2}]$	$\frac{1}{3} \sum_q e_q^2 [q_{\uparrow}^1 + q_{\uparrow}^{-1} + q_{\uparrow}^0]$
g_1	$\frac{1}{2} \sum_q e_q^2 [q_{\uparrow}^{1/2} - q_{\downarrow}^{-1/2}]$	$\frac{1}{2} \sum_q e_q^2 [q_{\uparrow}^1 - q_{\downarrow}^1]$
b_1	\dots	$\frac{1}{2} \sum_q e_q^2 [q^0 - q^1]$

Leading Twist

F_1 : quark distributions averaged over target spin states

g_1 : difference of distributions of quarks aligned/anti-aligned with hadron

b_1 : difference of helicity-0/helicity non-zero states of *the deuteron*

Tensor Structure Functions

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F_1	$\frac{1}{2} \sum_q e_q^2 [q_{\uparrow}^{1/2} + q_{\downarrow}^{-1/2}]$	$\frac{1}{3} \sum_q e_q^2 [q_{\uparrow}^1 + q_{\uparrow}^{-1} + q_{\uparrow}^0]$
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b_1	\dots	$\frac{1}{2} \sum_q e_q^2 [q^0 - q^1]$

Leading Twist

F_1 : quark distributions averaged over target spin states

g_1 : difference of distributions of quarks aligned/anti-aligned with hadron

b_1 : difference of helicity-0/helicity non-zero states of *the deuteron*

b_2 : related to b_1 by A Callan-Gross relation

b_4 : Also Leading Twist, but kinematically suppressed for a longitudinally polarized target.

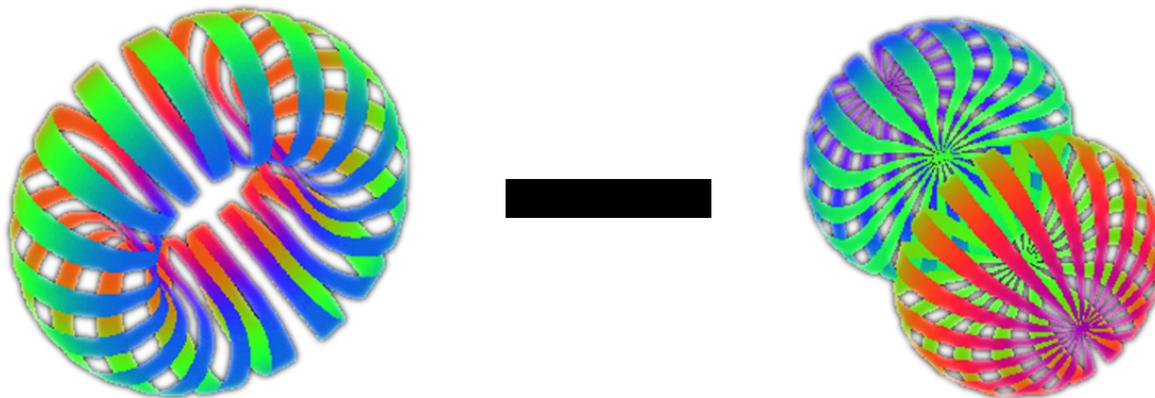
b_3 : higher twist, like g_2

b_1 Structure Function

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

q^0 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state $m=0$

q^1 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state $|m| = 1$



Nice mix of nuclear and quark physics

measured in DIS (so probing quarks), but depends solely on the deuteron spin state

Investigate nuclear effects at the level of partons!

b_1 Structure Function

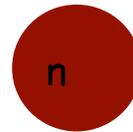
Hoodbhoy, Jaffe and Manohar (1989)

b_1 vanishes in the absence of nuclear effects

i.e. if...



=



+



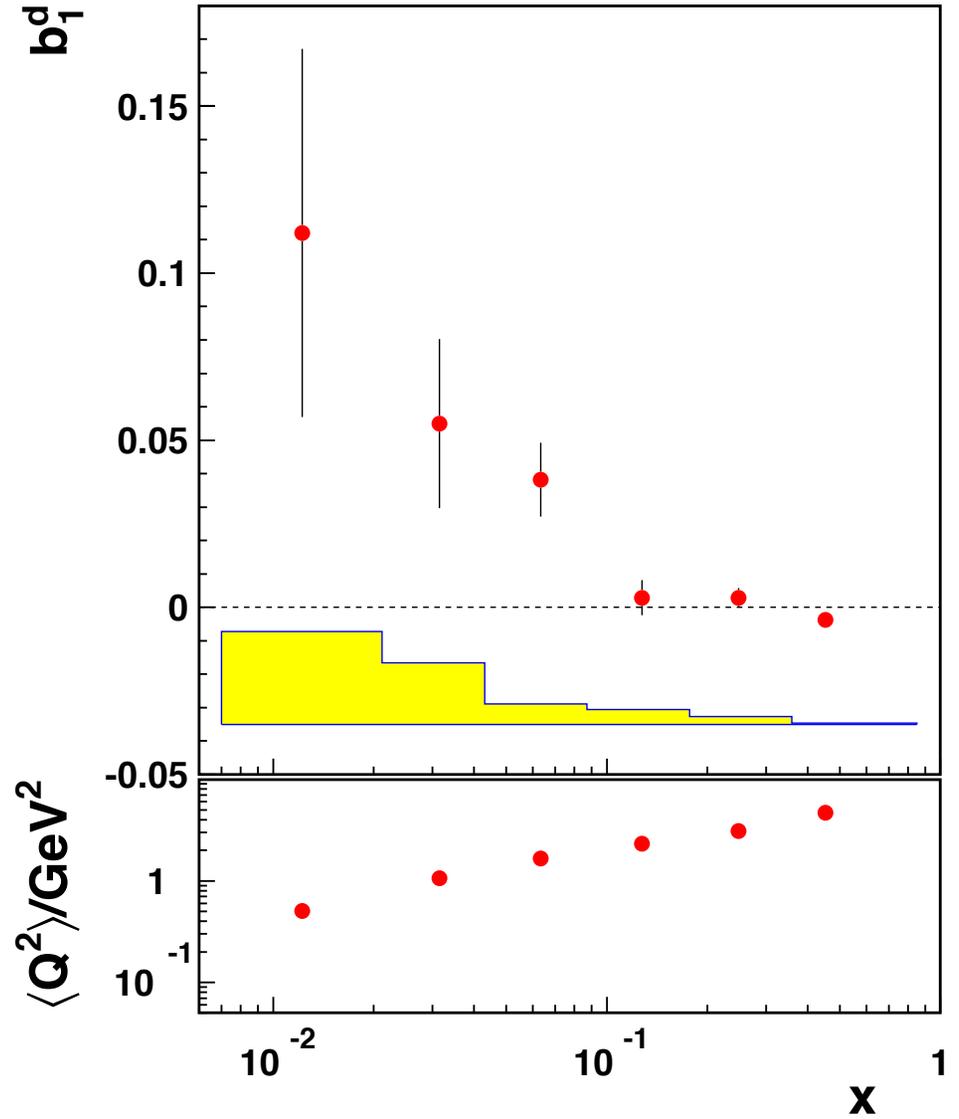
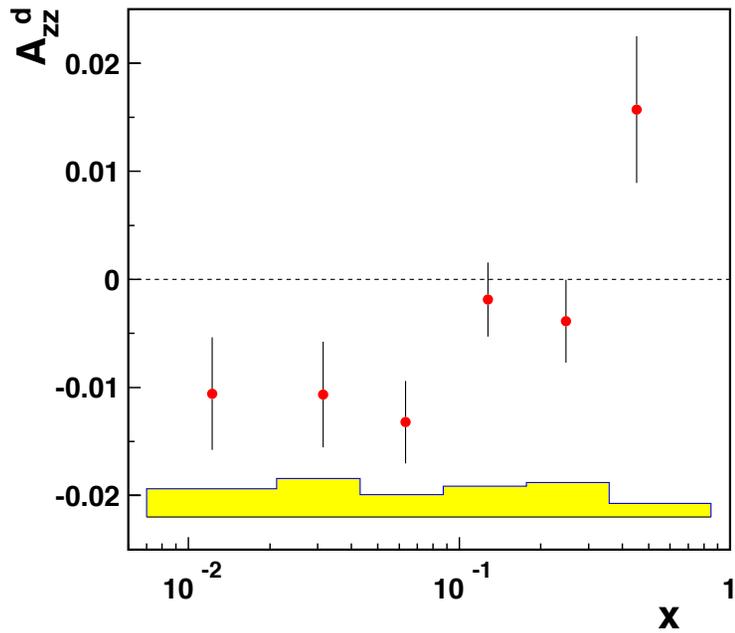
Proton Neutron in relative S-state

Even accounting for D-State admixture b_1 expected to be vanishingly small

Khan & Hoodbhoy, PRC 44 ,1219 (1991) : $b_1 \approx O(10^{-4})$
Relativistic convolution model with binding

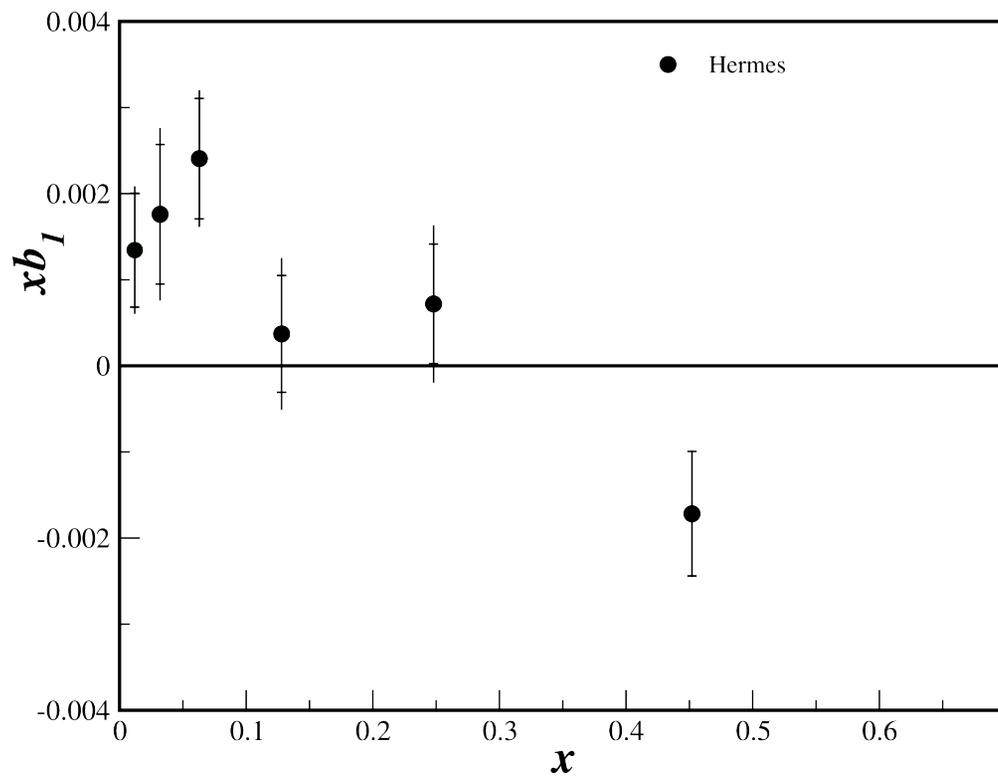
Umnikov, PLB 391, 177 (1997) : $b_1 \approx O(10^{-3})$
Relativistic convolution with Bethe-Salpeter formalism

Data from HERMES



PRL **95**, 242001 (2005)

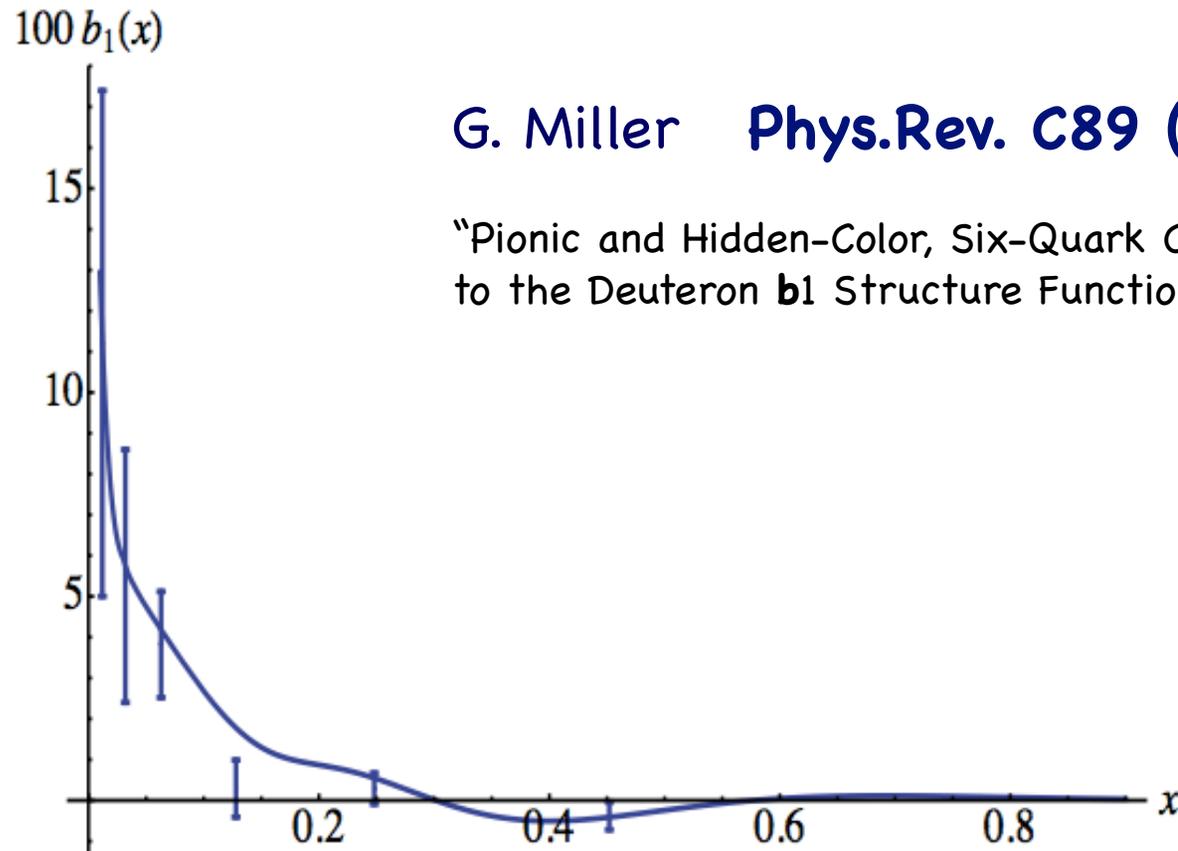
Data from HERMES



$$b_1 = -\frac{3}{2}F_1A_{zz}$$

PRL **95**, 242001 (2005)

Unique signal of Hidden Color



G. Miller **Phys.Rev. C89 (2014) 045203**

“Pionic and Hidden-Color, Six-Quark Contributions to the Deuteron b_1 Structure Function”

no conventional nuclear mechanism can reproduce the Hermes data,

but that the 6-quark probability needed to do so ($P_{6Q} = 0.0015$) is small enough that it does not violate conventional nuclear physics.

The Deuteron Polarized Tensor Structure Function b_1

JLAB E12-14-011

A⁻ rating by PAC40

(C1: conditional on target performance)

Spokespersons

KS (contact), Solvignon, Long, Chen, Rondon, Kalantarians

Experimental Method

$$A_{zz} = \frac{2}{fP_{zz}} \frac{\sigma_{\uparrow} - \sigma_0}{\sigma_0}$$

$$= \frac{2}{fP_{zz}} \left(\frac{N_{\uparrow}}{N_0} - 1 \right)$$

Observable is the Normalized XS Difference

B-Field, density, temp, etc. held same in both states

$$b_1 = -\frac{3}{2} F_1^d A_{zz}$$

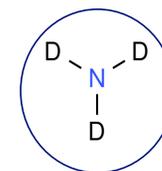
σ_{\uparrow} : Tensor Polarized cross-section

σ_0 : Unpolarized cross-section

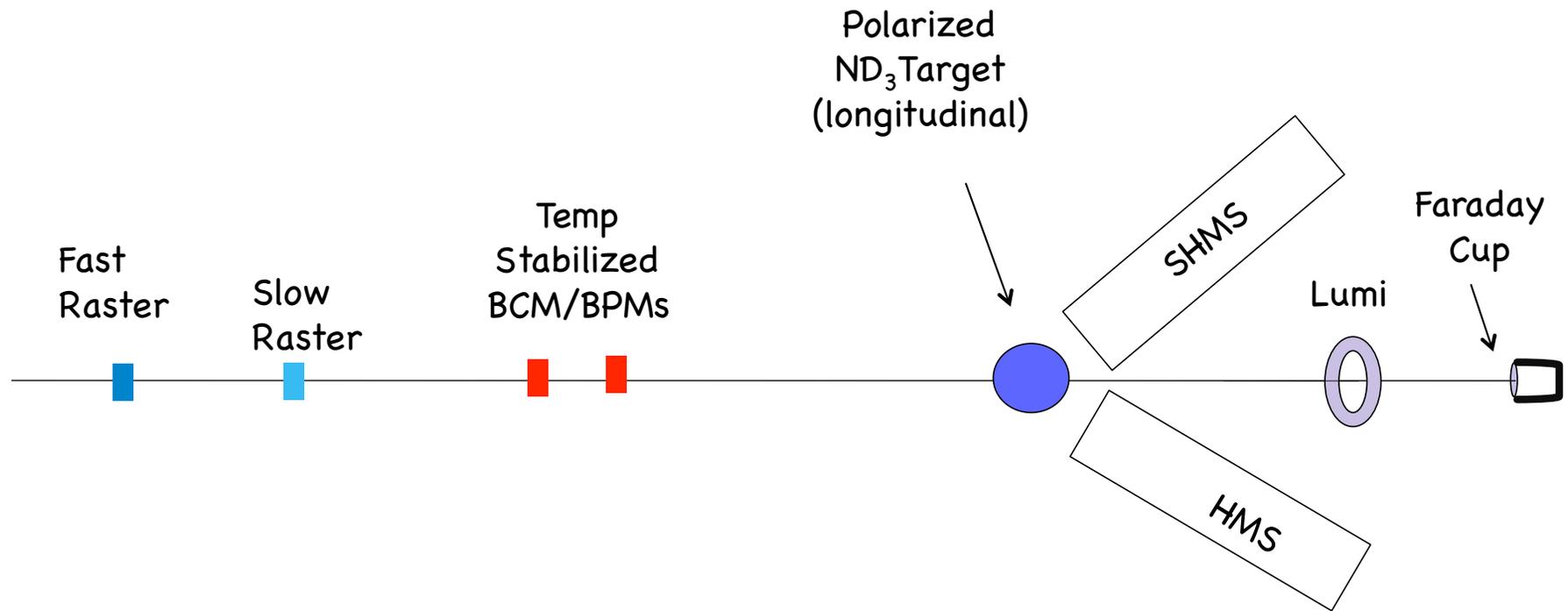
P_{zz} : Tensor Polarization

dilution factor

$$f \approx \frac{6}{20}$$



Hall C

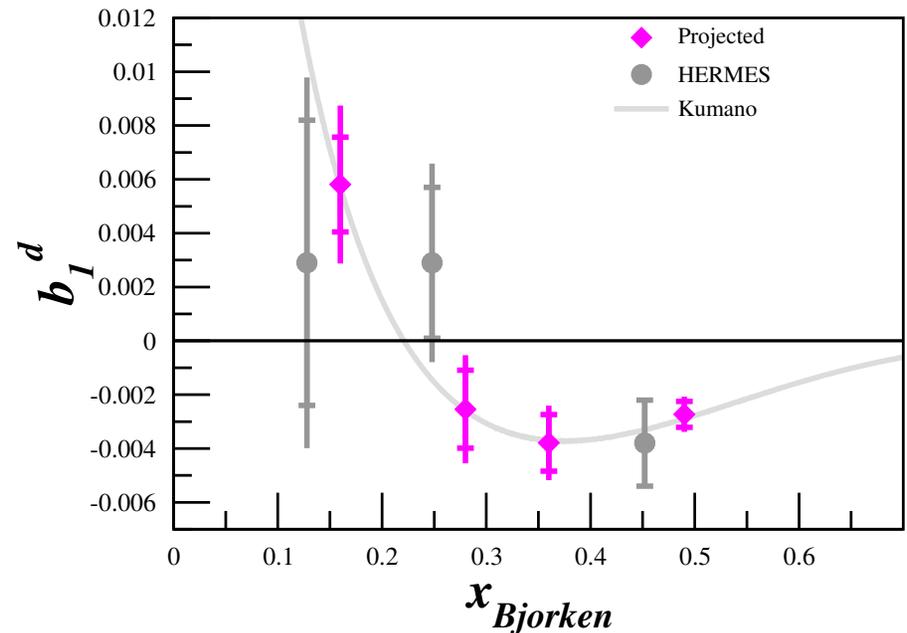
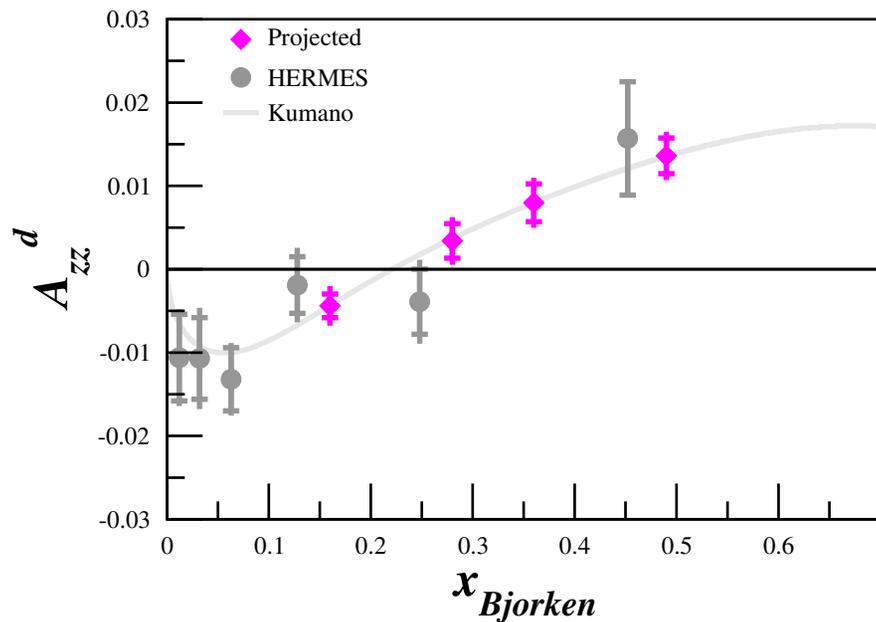


Unpolarized Beam
UVa/JLab Polarized Target

Magnetic Field Held Along Beam Line at all times

$$\mathcal{L} = 10^{35}$$

Projected Results $P_{zz} \approx 35\%$



30 Days in Jlab Hall C
 A- Physics Rating
 Conditional Approval (Target Performance)

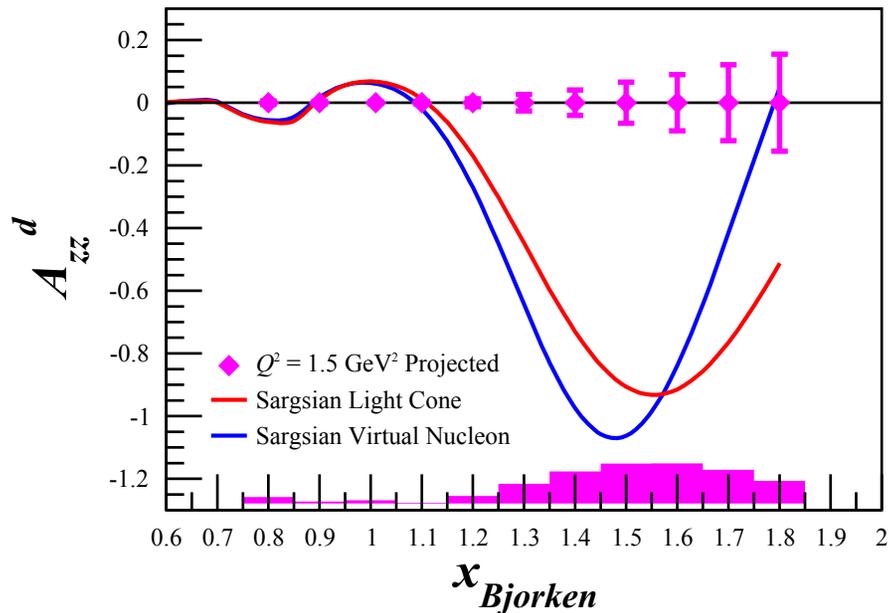
false asymmetries suppressed by $1/P_{zz}$

$$\delta A_{zz} = \pm \frac{2}{f P_{zz} \sqrt{N_{cycles}}} \delta \xi$$

JLAB LOI 12-14-002

A_{zz} in the $x > 1$ Region

Ellie Long (contact), Donal Day, Doug Higinbotham, Dustin Keller, KS, Patricia Solvignon



"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".

Very Large Tensor Asymmetries predicted

Similar to t_{20} , but measured in QE region

Sensitive to the S/D-wave ratio in the deuteron wave function at large relative momenta $k > 300 \text{ MeV}$

SRCs and pn dominance
Direct probe of tensor force

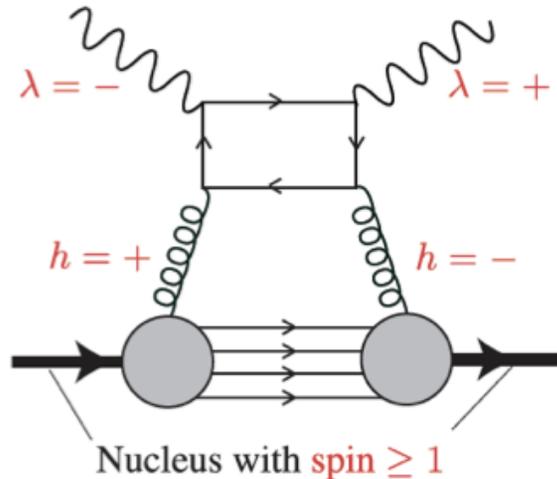
Better understanding of s/d
Final state interaction models

Encouraged for full submission by PAC42

JLAB LOI 12-14-001

b_4 Structure Function

Maxwell (contact), Milner, Jaffe



b_4 is a.k.a. $\Delta(x, Q^2)$

Deep inelastic scattering experiment:

Unpolarized electrons

Polarized $^{14}\text{NH}_3$ Target

Target spin aligned transverse to beam

“Nuclear Gluonometry”

Non-zero value would be a clear signature of exotic gluon states in the nucleus

$$\frac{2\pi \frac{d\sigma}{dx dy d\phi}}{\frac{d\sigma}{dx dy}} = 1 - \frac{1}{2} \frac{x(1-y)\Delta(x, Q^2) \cos 2\phi}{xy^2 F_1(x, Q^2) + (1-y)F_2(x, Q^2)}$$

Encouraged for full submission by PAC42

TENSOR SPIN OBSERVABLES WORKSHOP

MARCH 10-12, 2014
JEFFERSON LAB

TOPICS:

- Tensor Polarization in DIS
- Tensor Structure Functions
- Hidden Color at Large x
- Tensor Observables in $x > 1$
- Solid Tensor-Polarized Target Development
- Elastic Deuteron Form Factors
- Tensor Polarization at EIC
- Analyzing Powers in Scattering From Tensor-Polarized Targets

ORGANIZING COMMITTEE:

Karl Slifer (Chair, University of New Hampshire)
Douglas Higinbotham (Jefferson Lab)
Christopher Keith (Jefferson Lab)
Elena Long (University of New Hampshire)
Misak Sargsian (Florida International University)
Patricia Solvignon (University of New Hampshire)

www.jlab.org/conferences/tensor2014



Summary

Spin Polarizabilities

δ_{LT} puzzle and χ_{PT} calculations : theoretical progress is being made.

New proton data from E08-027 (g2p) and EG4 (g1p) being analyzed.

Future Developments

E12-11-011: Tensor Polarized Structure function b1 of the Deuteron

LOI12-14-002: Tensor Asymmetry A_{zz} for $x > 1$

LOI12-14-001: Tensor Structure Function b4

Significant challenge to develop the target to the level required for this ambitious physics program.

JLAB SSF Experiments

A	E94-010 ("GDH")	$0.1 < Q^2 < 0.9$	$g_{1n}, g_{2n}, g_{13}, g_{23}$, moments
	E99-117 ("A1n")	$2.7 < Q^2 < 4.8$	$A_{1n}, A_{2n}, g_{1n}, g_{2n}$, (and He3 also)
	E97-103 ("g2n") ($W > 2$)	$0.6 < Q^2 < 1.3$	g_{1n}, g_{2n}
	E01-012 ("Spin Duality")	$1.2 < Q^2 < 3.0$	$g_{1n}, g_{2n}, \text{He3}$, moments
	E97-110 ("Small angle GDH")	$0.04 < Q^2 < 0.15$	$g_{1n}, g_{2n}, g_{13}, g_{23}$, moments
	E08-027 ("g2p")	$0.02 < Q^2 < 0.2$	g_{2p}, g_{1p} , moments
	E06-014 ("d2n")	$\langle Q^2 \rangle = 3.0$	DIS: d_{2n}, A_1, A_2
B	EG1	$0.15 < Q^2 < 2.0$	g_{1p}, g_{1d} , moments
	EG1b	$0.1 < Q^2 < 4.0$	
	EG1-DVCS	$1.2 < Q^2 < 4.9$	DIS: g_{1p}, A_{1p}
	EG4	$0.02 < Q^2 < 0.4$	$g_{1p}, g_{1d}(n)$, moments
C	E01-006 ("RSS")	$Q^2 = 1.3$	$g_{1p}, g_{2p}, g_{1d}, g_{2d}$, moments.
	E07-003 ("SANE")	$1.2 < Q^2 < 4.9$	DIS: $A_{1p}, A_{2p}, g_{1p}, g_{2p}$, moments

12 GeV planned

Hall A&C : d_{2n}

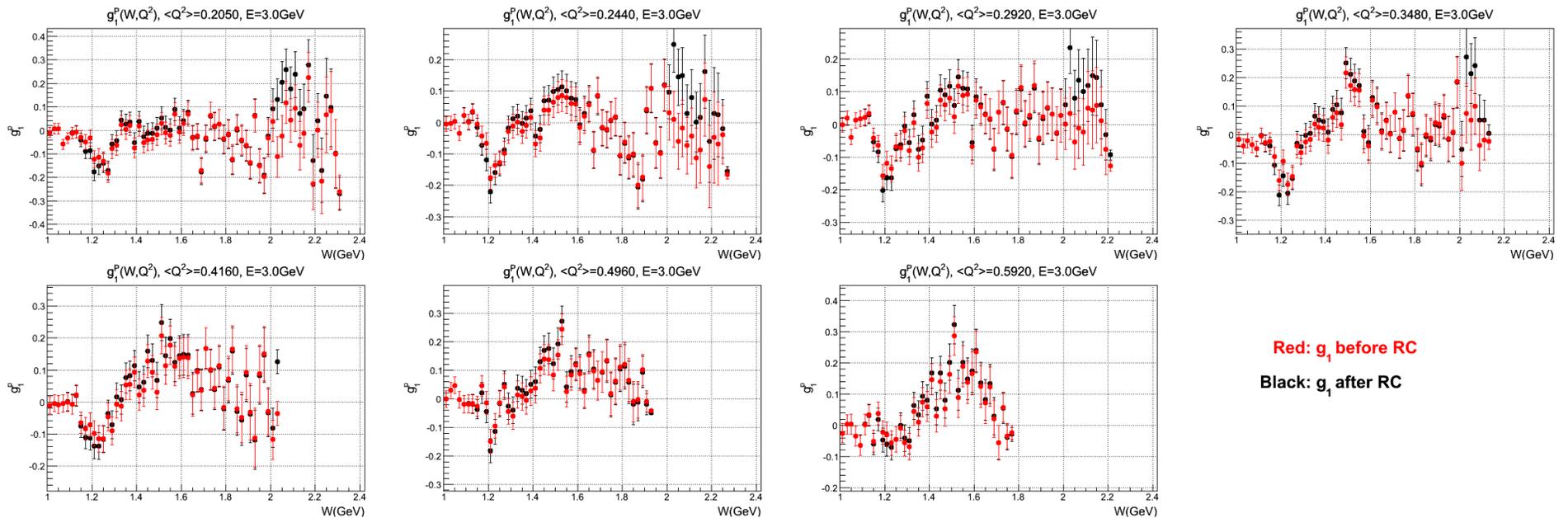
Hall B : A_{1p}

Hall C : b_{1d}, A_{zz} tensor structure

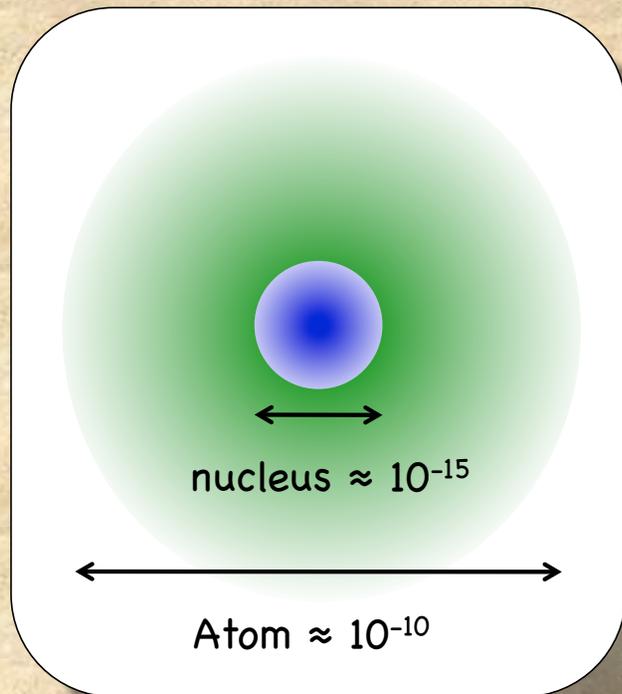
black : published

green : unpublished

Preliminary EG4 Proton g_1



Applications to Bound State Q.E.D.

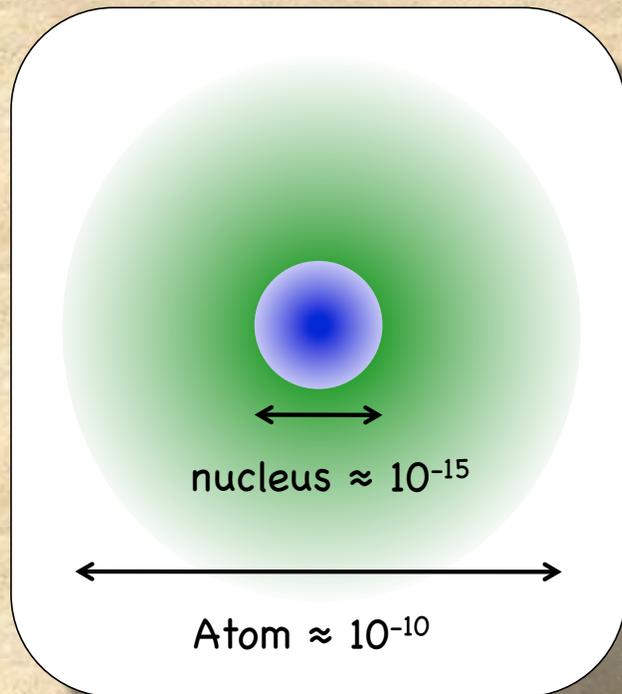


Hydrogen HF Splitting

$$\begin{aligned}\Delta E &= 1420.405\,751\,766\,7(9) \text{ MHz} \\ &= (1 + \delta)E_F\end{aligned}$$

The finite size of the nucleus plays a small but significant role in atomic energy levels.

Applications to Bound State Q.E.D.



The finite size of the nucleus plays a small but significant role in atomic energy levels.

Hydrogen HF Splitting

$$\begin{aligned}\Delta E &= 1420.405\,751\,766\,7(9) \text{ MHz} \\ &= (1 + \delta)E_F\end{aligned}$$

$$\delta = (\delta_{QED} + \delta_R + \delta_{small}) + \Delta_S$$

Friar & Sick PLB **579** 285(2003)

Structure dependence of Hydrogen HF Splitting

$$\Delta_S = \Delta_Z + \Delta_{POL}$$

Elastic Scattering

$$\Delta_Z = -41.0 \pm 0.5 \text{ ppm}$$

$$\Delta_Z = -2\alpha m_e r_Z (1 + \delta_Z^{\text{rad}})$$

$$r_Z = -\frac{4}{\pi} \int_0^\infty \frac{dQ}{Q^2} \left[G_E(Q^2) \frac{G_M(Q^2)}{1 + \kappa_p} - 1 \right]$$

Structure dependence of Hydrogen HF Splitting

$$\Delta_S = \Delta_Z + \Delta_{POL}$$

Inelastic

Nazaryan, Carlson, Griffieon
PRL 96 163001 (2006)

$$\Delta_Z = -41.0 \pm 0.5 \text{ ppm}$$

$$\Delta_{pol} \approx 1.3 \pm 0.3 \text{ ppm}$$

Elastic piece larger but with similar uncertainty

$$\Delta_{POL} = 0.2265 (\Delta_1 + \Delta_2) \text{ ppm}$$

integral of g_1 & F_1

Structure dependence of Hydrogen HF Splitting

$$\Delta_S = \Delta_Z + \Delta_{POL}$$

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Nazaryan, Carlson, Griffioen
PRL **96** 163001 (2006)

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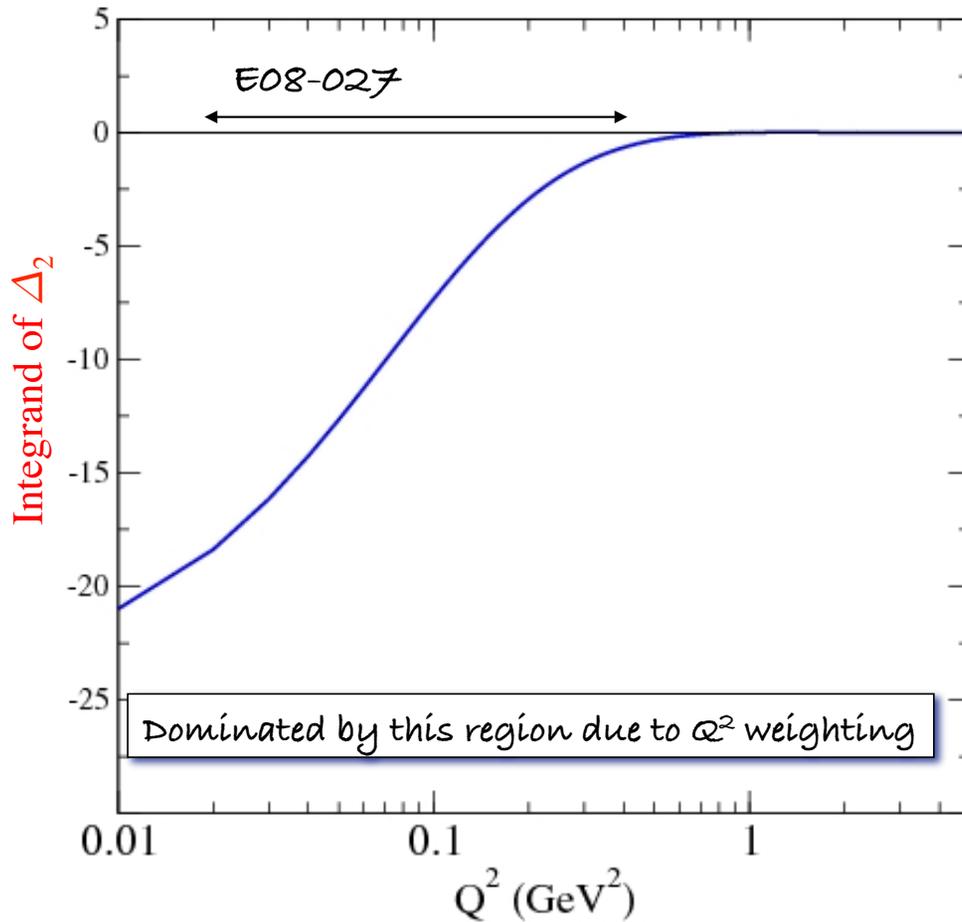
$$\Delta_{POL} = 0.2265 (\Delta_1 + \Delta_2) \text{ ppm}$$

$$\Delta_2 = -24m_p^2 \int_0^\infty \frac{dQ^2}{Q^4} B_2(Q^2)$$

$$B_2(Q^2) = \int_0^{x_{th}} dx \beta_2(\tau) g_2(x, Q^2)$$

weighted heavily to low Q^2

g2p contribution to HF Splitting

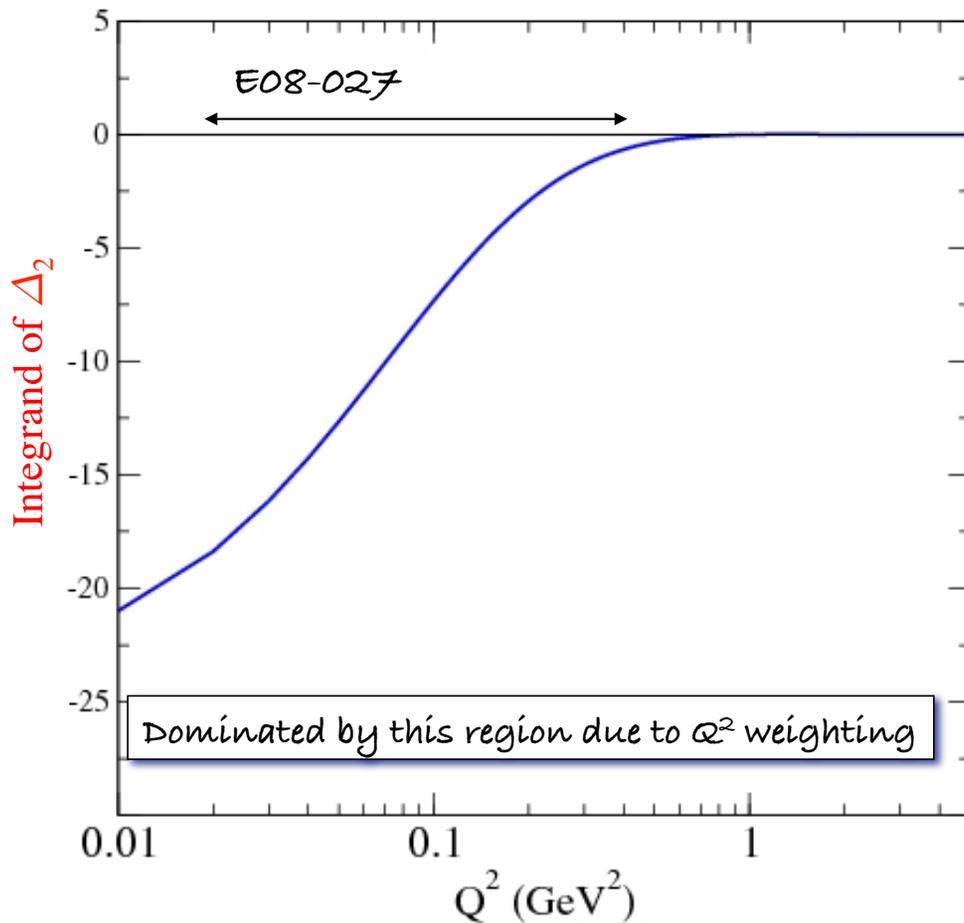


$$\Delta_2 = -24m_p^2 \int_0^\infty \frac{dQ^2}{Q^4} B_2(Q^2)$$

$$= -0.57 \pm 0.57$$

assuming CLAS model with 100% error

g2p contribution to HF Splitting



$$\Delta_2 = -24m_p^2 \int_0^\infty \frac{dQ^2}{Q^4} B_2(Q^2)$$

$$= -0.57 \pm 0.57$$

assuming CLAS model with 100% error

But, g_2^p unknown in this region:

$$\Delta_2 = -1.98 \quad \text{MAID Model}$$

$$\Delta_2 = -1.86 \quad \text{Simula Model}$$

So 100% error probably too optimistic

E08-027 will provide first real constraint on Δ_2