The g_2^p Experiment

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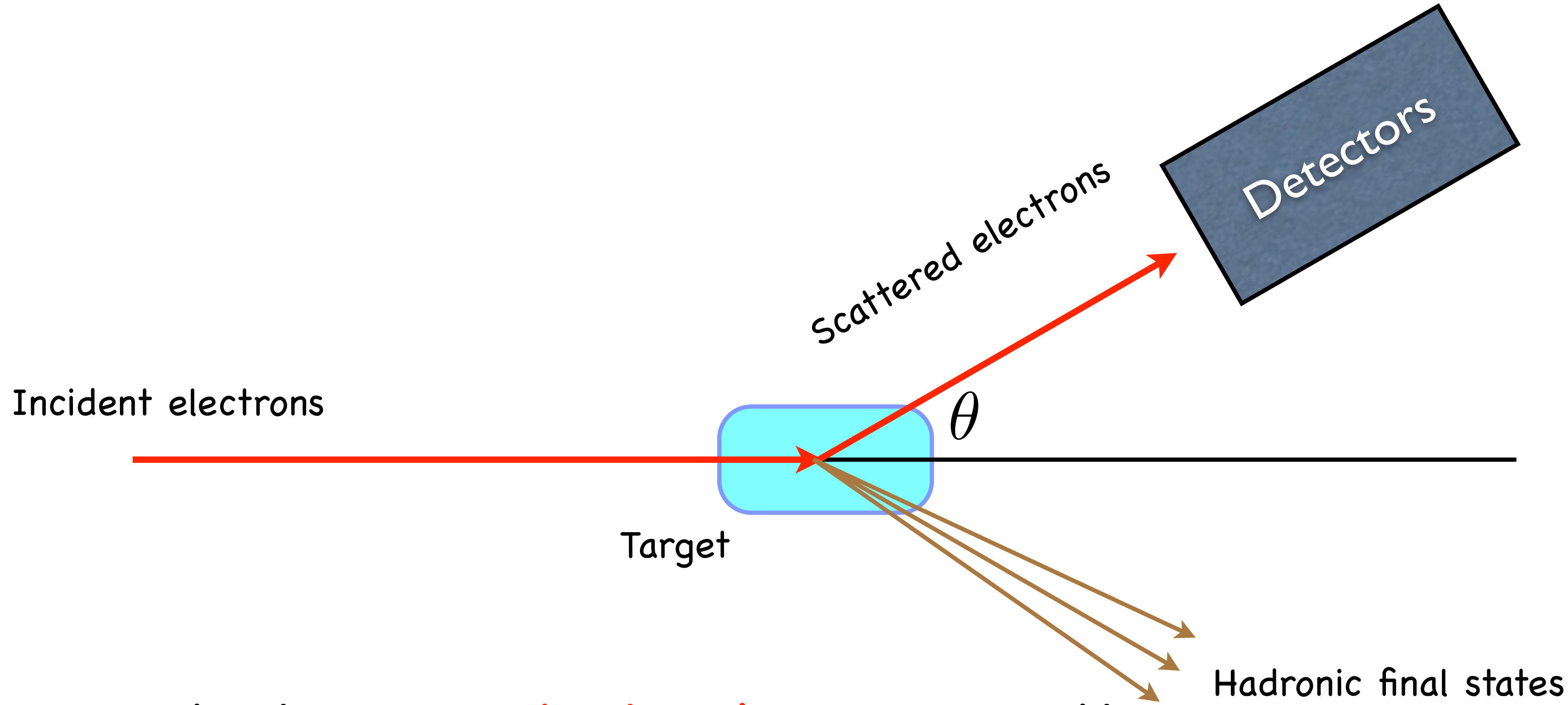
Chiral Dynamics Workshop, Aug 2012

Outline

- Review of physics motivation
- Brief review of experiment setup
- Status of experiment run

Inelastic scattering

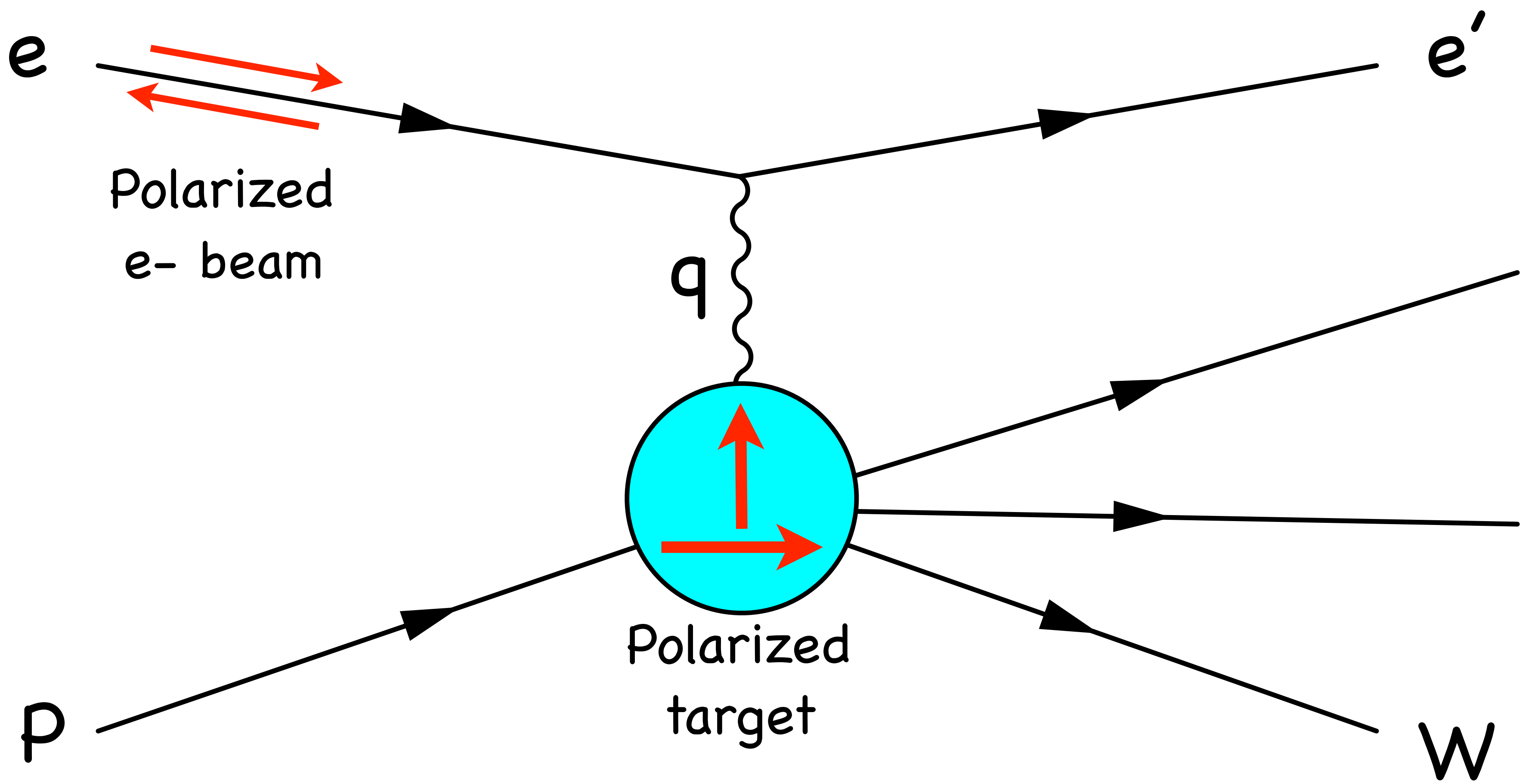


- Inclusive unpolarized cross section:

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

Structure Function
which indicates the
parton distribution

Inelastic scattering



- Inclusive polarized cross section:

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

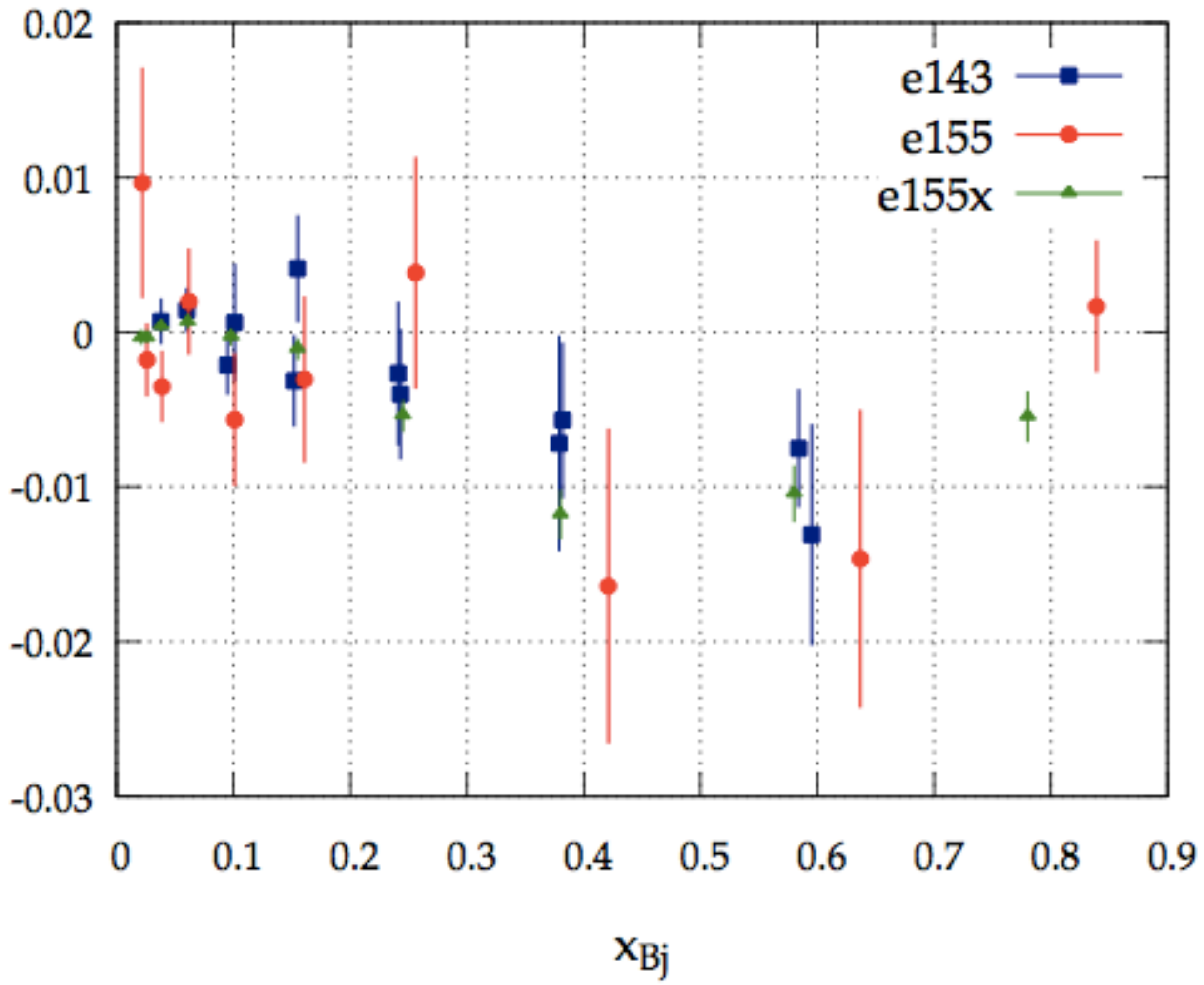
2 addition Structure Function which related to the spin distribution

Motivation

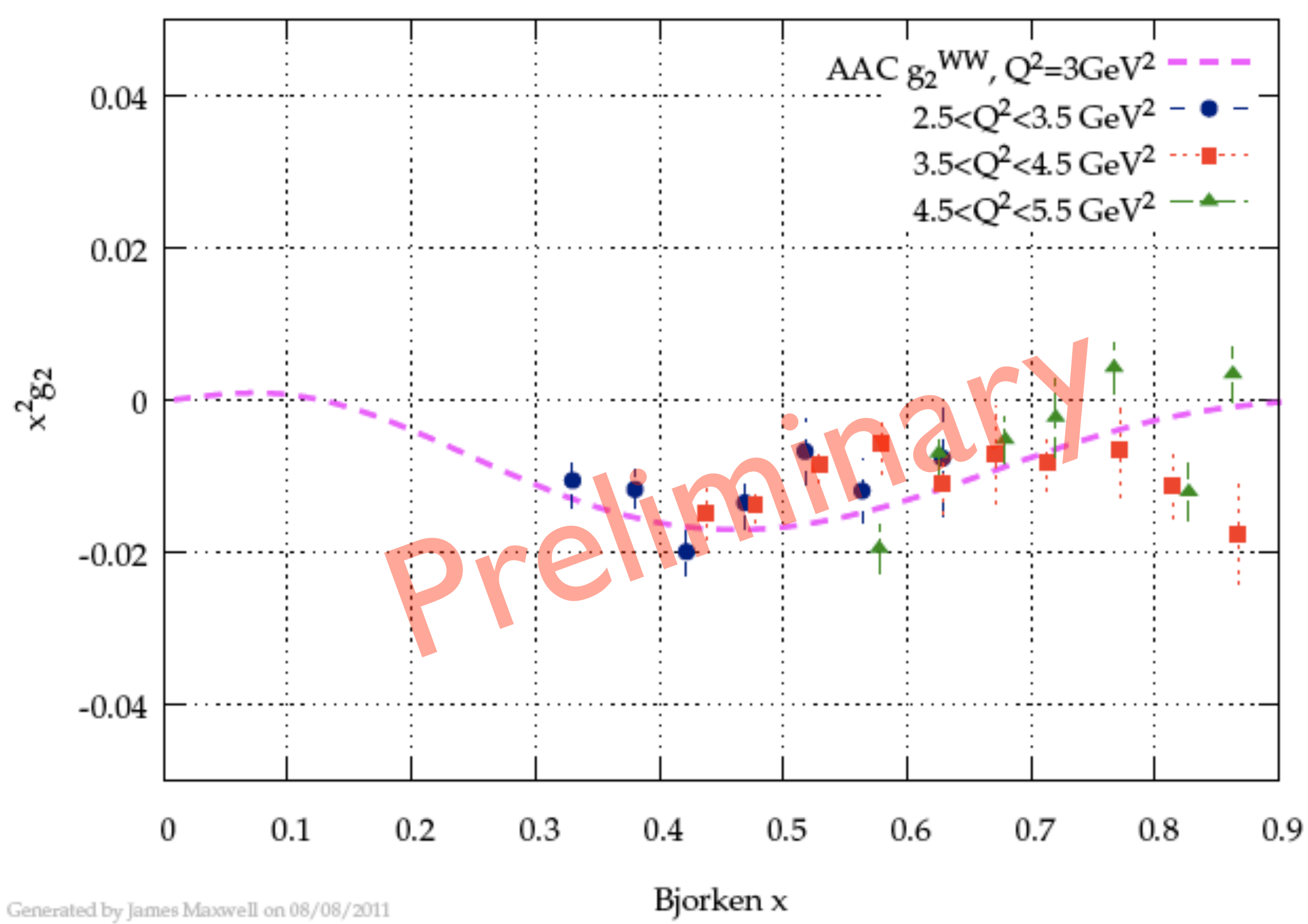
- Measure proton g_2 structure function at low Q^2 region (0.02-0.2GeV^2) for the first time
- Will help to clarify several puzzles:
    - Test the Burkhardt-Cottingham (BC) Sum Rule at low Q^2
    - Extract the generalized longitudinal-transverse spin polarizability δ_{LT} to give a test for Chiral Perturbation Theory (χPT)
    - Improve the calculation of Proton Hyperfine Splitting
    - Proton charge radius from uP lamb shift disagrees with eP scattering result

Existing Data

SLAC



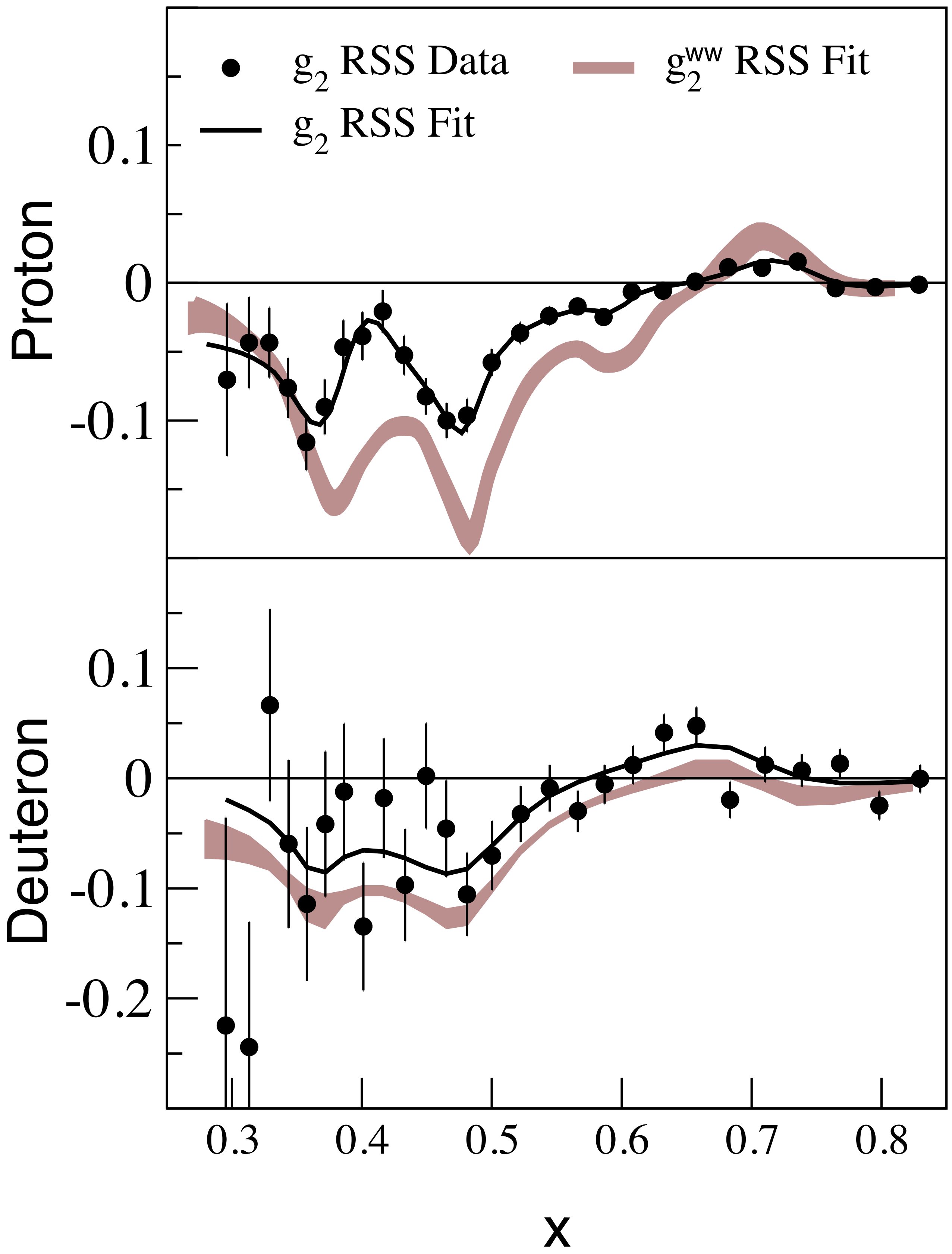
JLab SANE



SLAC: Q^2 ~5GeV^2

JLab SANE: Q^2 3~6GeV^2

Existing Data



JLab RSS: Q^2 ~1.3GeV^2

K. Slifer et al, arXiv:0812.0031

BC Sum Rule

- BC Sum Rule:

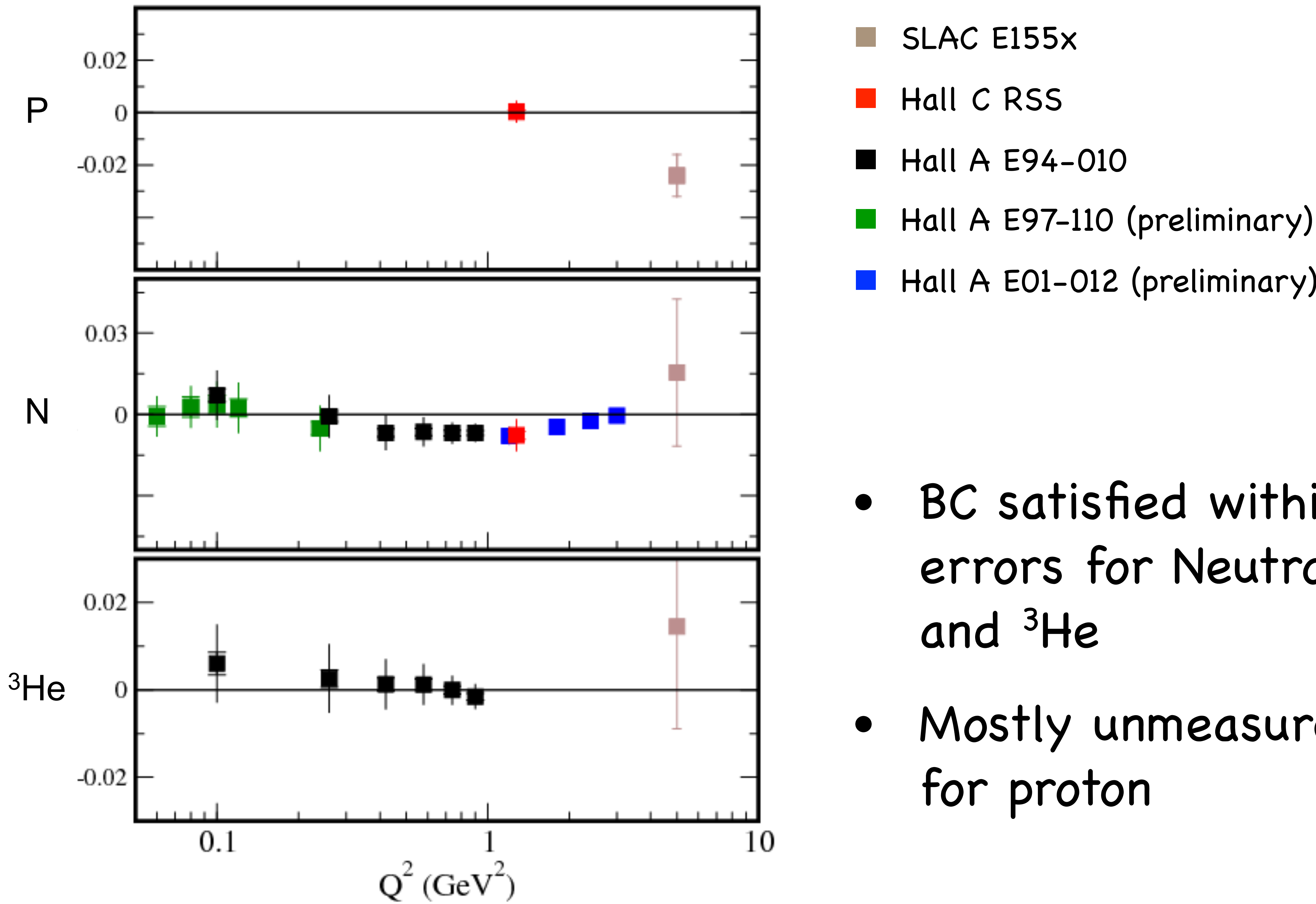
$$\int_0^1 g_2(x, Q^2)\mathrm{d}x = 0$$

H. Burkhardt and W. N. Cottingham, Annals. Phys., 56(1970)453

- BC Sum Rule will fail if g2:
  - exhibits non-Regge behavior at low x
  - exhibits a delta function singularity at x=0

R. L. Jaffe and X.-D. Ji, Phys. Rev. D, 43(1991)724

BC Sum Rule



- BC satisfied within errors for Neutron and ^{3}He
- Mostly unmeasured for proton

Generalized Longitudinal-Transverse Polarizability

- Start from forward spin-flip doubly-virtual Compton scattering (VVCS) amplitude g_{TT} and g_{LT}

$$\mathrm{Re}[g_{TT}^{\text{non-pole}}(\nu, Q^2)] = \frac{\nu}{2\pi^2}\mathcal{P}\int_{\nu_\pi}^{\infty} \frac{\mathrm{d}\nu' K}{\nu'^2 - \nu^2}\sigma_{TT}(\nu', Q^2)$$

$$\mathrm{Re}[g_{LT}^{\text{non-pole}}(\nu, Q^2)] = \frac{1}{2\pi^2}\mathcal{P}\int_{\nu_\pi}^{\infty} \frac{\mathrm{d}\nu' \nu' K}{\nu'^2 - \nu^2}\sigma_{LT}(\nu', Q^2)$$

- g_{TT} and g_{LT} can be expanded in power series of ν

$O(\nu^3)$ term of g_{TT} leads to the generalized forward spin polarizability γ_0

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

$O(\nu^2)$ term of g_{LT} leads to the generalized longitudinal-transverse polarizability δ_{LT}

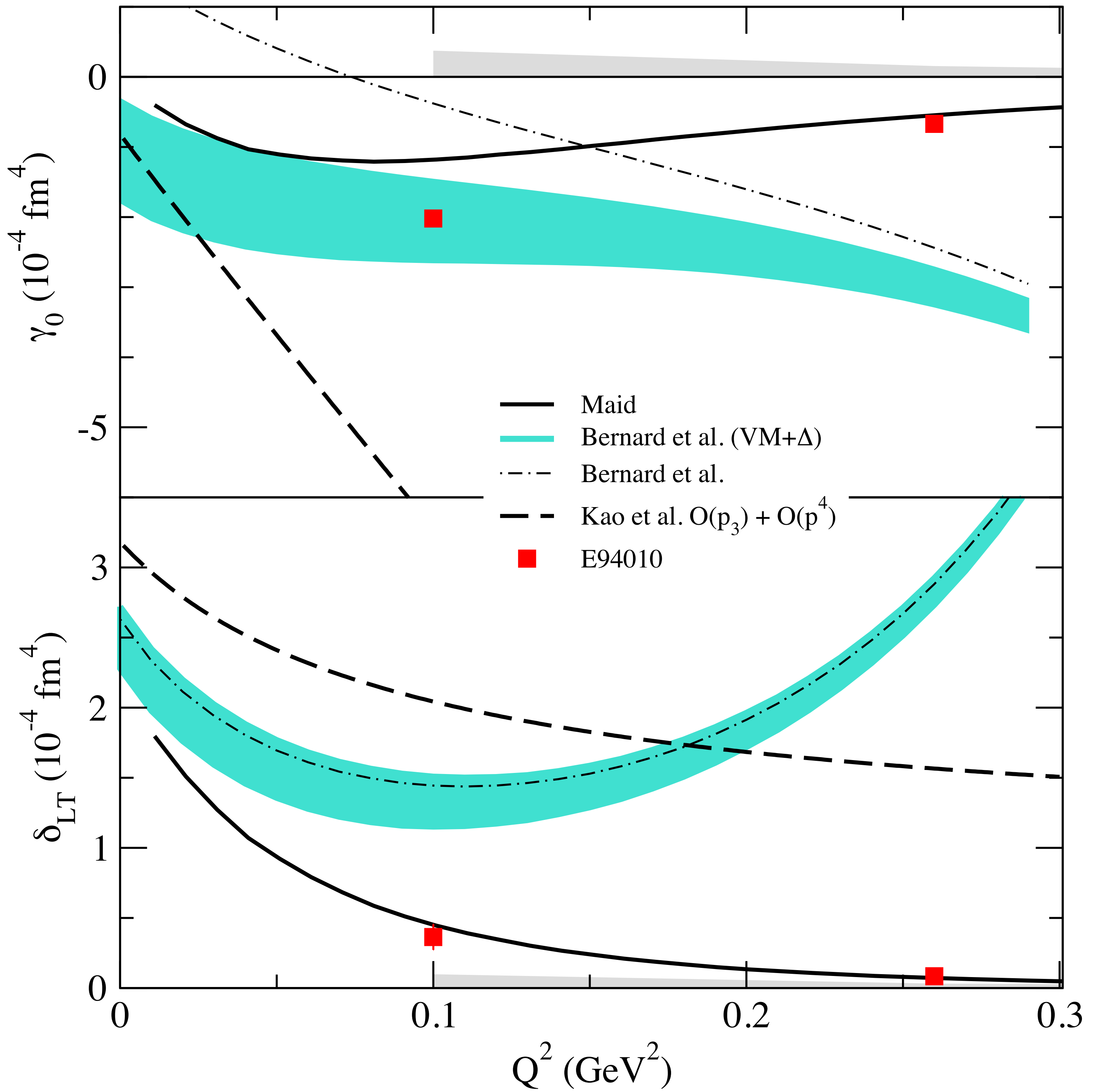
$$\delta_{LT}(Q^2) = \frac{1}{2\pi^2}\int_{\nu_\pi}^{\infty} \frac{K(\nu, Q^2)}{\nu}\frac{\sigma_{LT}(\nu, Q^2)}{Q\nu^2}\mathrm{d}\nu$$
$$= \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2[g_1 + g_2]\mathrm{d}x$$

δ_{LT} puzzle

- At low Q^2, the generalized polarizabilities have been evaluated with NLO χPT calculations:
  - Relativistic Baryon χPT (V. Bernard, T. Hemmert and Ulf-G. Meissner, Phys. Rev. D, 67(2003)076008)
  - Heavy Baryon χPT (C.W. Kao, T. Spitzenberg and M. Vanderhaeghen, Phys. Rev. D, 67(2003)016001)
- One issue in the calculation is how to properly include the nucleon resonance contributions, especially the Δ resonance
  - γ_0 is sensitive to resonances
  - δ_{LT} is insensitive to the Δ resonance
- δ_{LT} should be more suitable than γ_0 to serve as a testing ground for the chiral dynamics of QCD

δ_{LT} puzzle

- Neutron Data shows a large deviation from the χPT calculations
- No proton data yet
- This experiment will provide a test with proton data

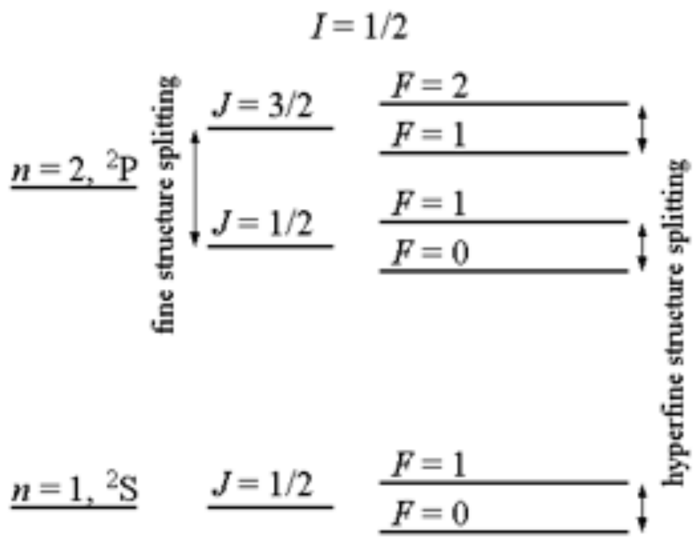


Neutron Data for γ_0 and δ_{LT}

M. Amarian et al, arXiv:0406005

Hydrogen Hyperfine Structure

- Hydrogen hyperfine splitting in the ground state has been measured to a relative high accuracy of 10^{-13}



$$\Delta E = 1420.4057517667(9)\mathrm{MHz}$$
$$= (1+\delta)E_F$$
$$\delta = (\delta_{\mathrm{QED}} + \delta_R + \delta_{\mathrm{small}}) + \Delta_S$$

- Δ_S is the proton structure correction and has the largest uncertainty

$$\Delta_S = \Delta_Z + \Delta_{\mathrm{pol}}$$

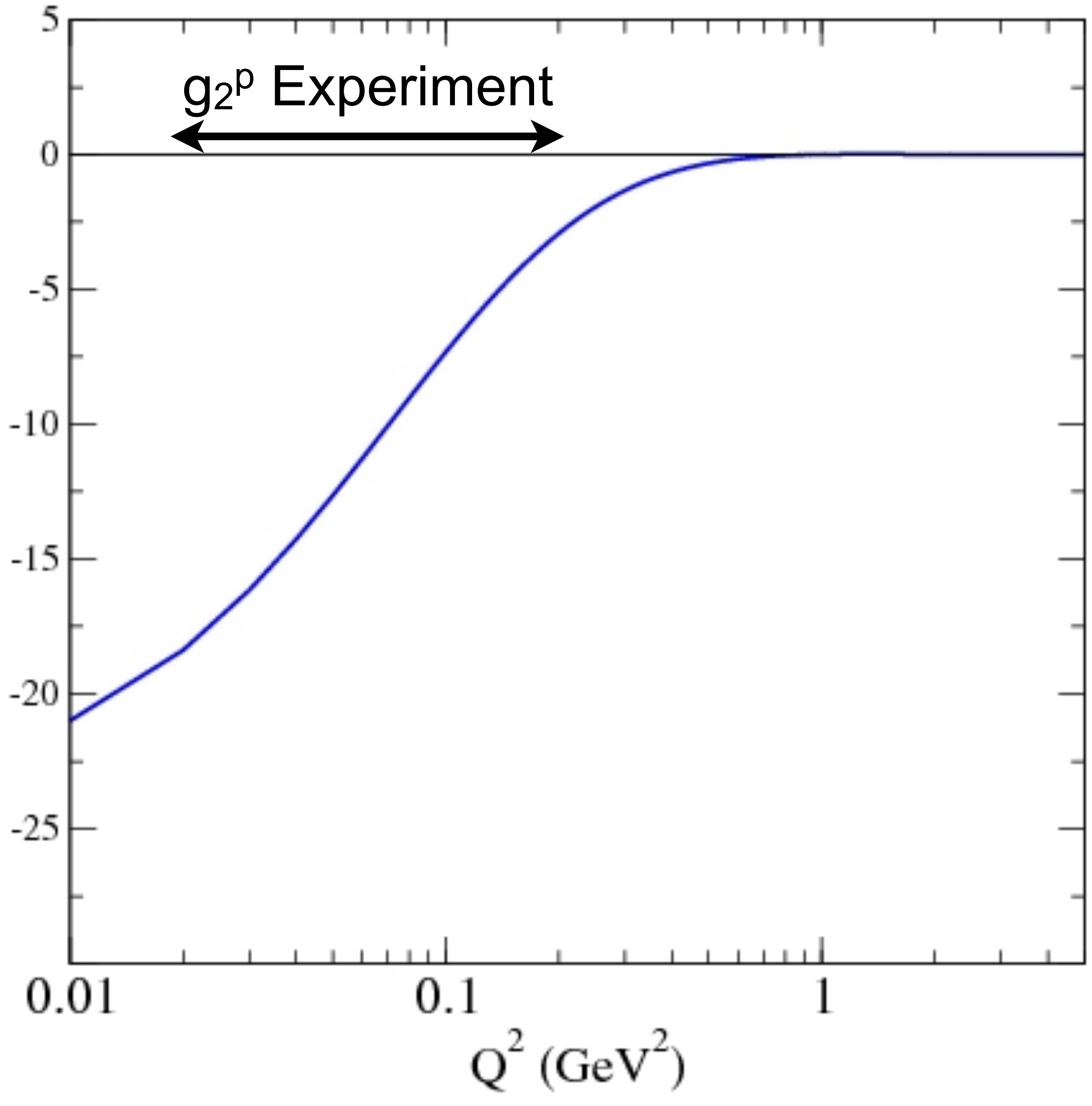
- Δ_Z can be determined from elastic scattering, which is $-41.0 \pm 0.5 \times 10^{-6}$

- Δ_{pol} involves contributions of the inelastic part (exciting state), and can be extracted to 2 terms corresponding to 2 different spin-dependent structure function of proton

Hydrogen Hyperfine Structure

$$\Delta_{\rm pol} = \frac{\alpha m_e}{\pi g_p m_p}(\Delta_1 + \Delta_2)$$

Integrand of Δ_2



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

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

$$\beta_2(\tau) = 1 + 2\tau - 2\sqrt{\tau(\tau+1)}$$

- B_2 is dominated by low Q2 part
- g_2^p is unknown in this region, so there may be huge error when calculating Δ_2
- This experiment will provide a constraint

Nazaryan, Carlson, Griffieon, PRL, 96(2006)163001

Size of the Proton

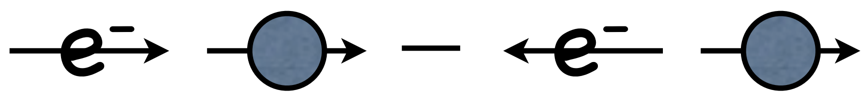
- 2 ways to measure:
  - energy splitting of the $2S_{1/2}$–$2P_{1/2}$ level (Lamb shift)
  - scattering experiment
- The result do not match when using muonic hydrogen
  - $\langle R_p \rangle = 0.84184 \pm 0.00067$fm by Lamb shift in muonic hydrogen
  - $\langle R_p \rangle = 0.87680 \pm 0.0069$fm CODATA world average
- The main uncertainties originates from the proton polarizability and different values of the Zemach radius
  - This experiment will reduce the uncertainty of proton polarizability

R. Pohl et al, Nature, 466(2010)213

Primary Motivation

Measure proton g_2 structure function at $0.02 < Q^2 < 0.2$ GeV^2 region with an uncertainty of 5-7%

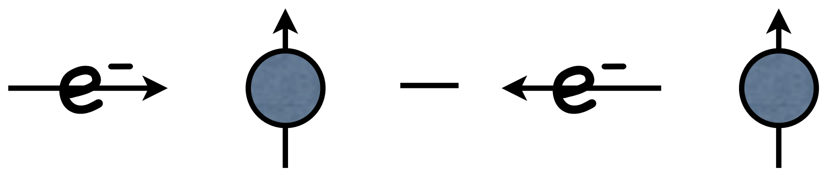
How to get g_2

$\Delta\sigma_{\parallel} =$ 

$$= \frac{d^2\sigma^{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Uparrow}}{d\Omega dE'}$$

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

JLab Hall B experiment EG4 measured this quantity and extracted g_1^p at low Q^2

$\Delta\sigma_{\perp} =$ 

$$= \frac{d^2\sigma^{\uparrow\Rightarrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Rightarrow}}{d\Omega dE'}$$

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

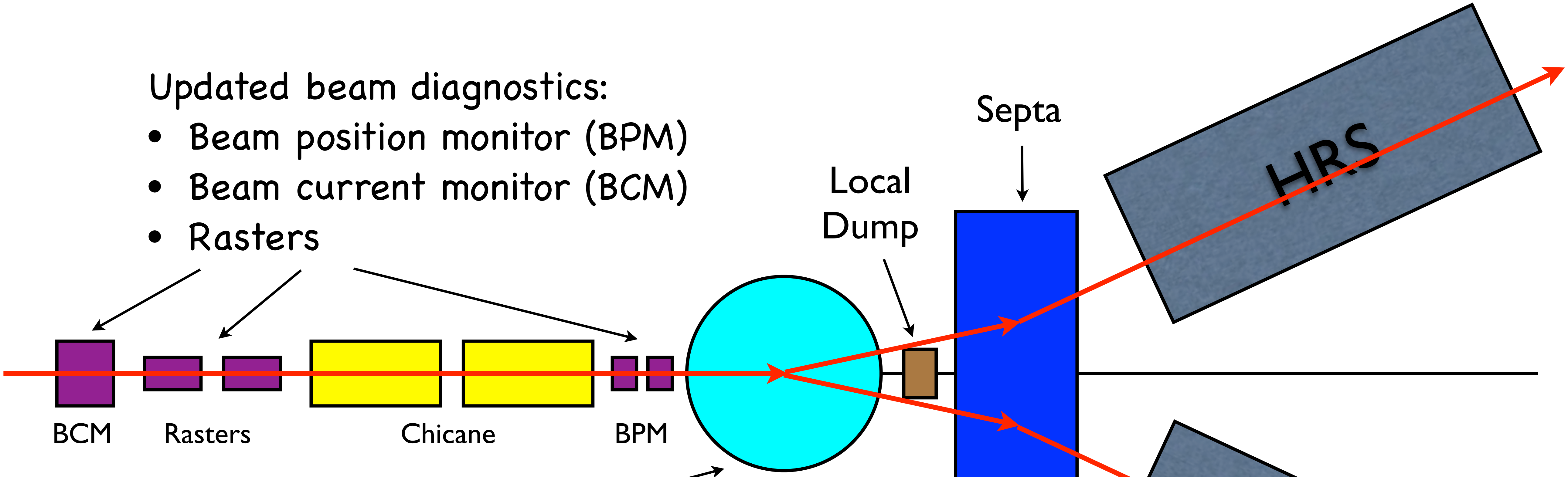
g2p experiment will measure this, combing the EG4 g_1^p data to get g_2^p at low Q^2

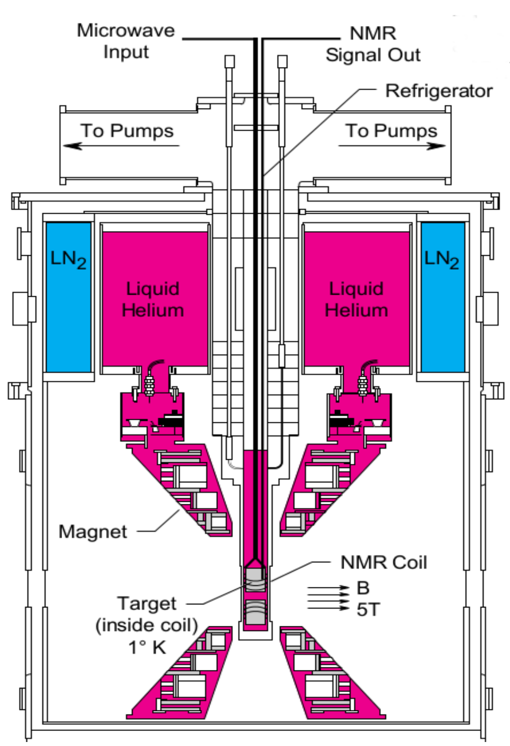
Experiment Setup

Jefferson Lab Hall A

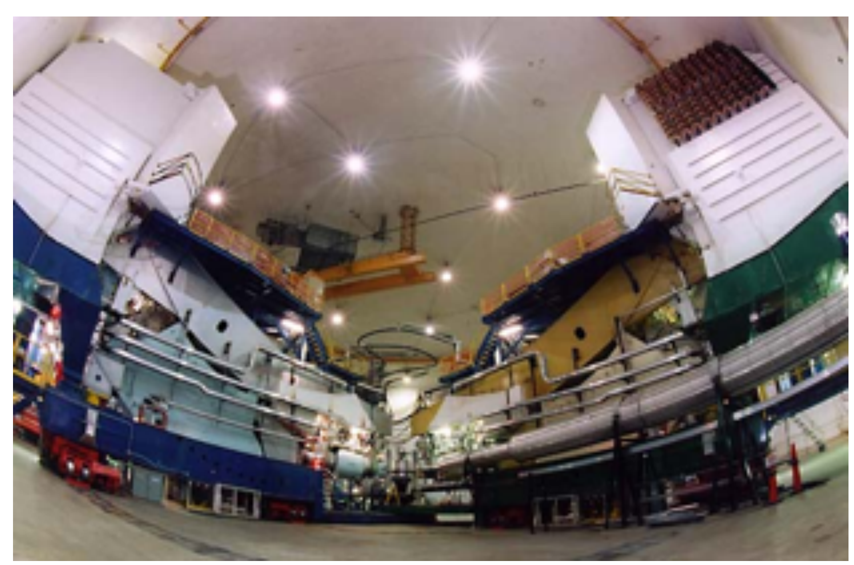
Updated beam diagnostics:

- Beam position monitor (BPM)
- Beam current monitor (BCM)
- Rasters





Polarized NH_3 Target

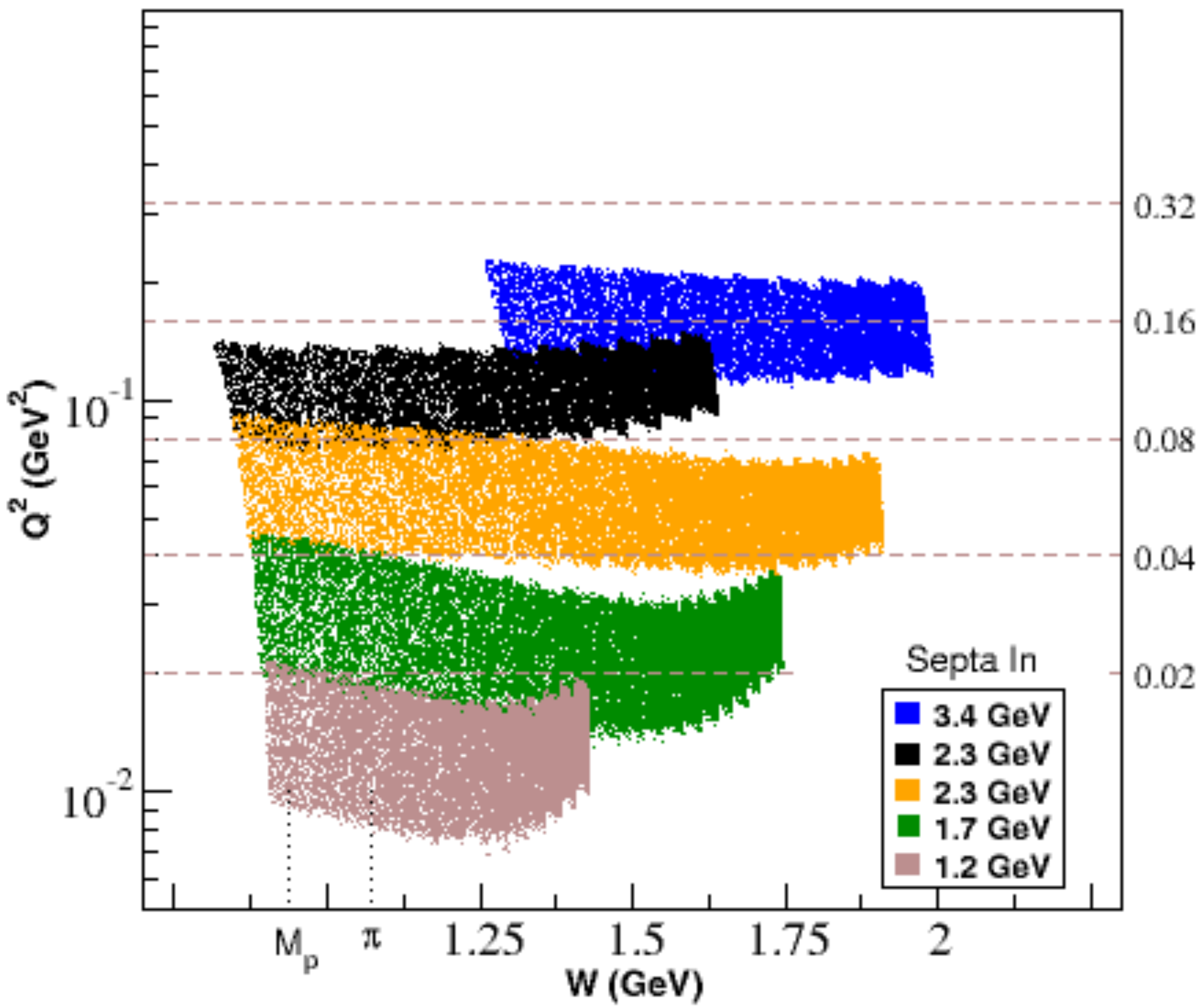


Hall A High Resolution Spectrometer (HRS)

Experiment Setup

- Challenge: lowest possible Q^2
  - Small scattering angle (~6°)
    - Use septa magnet to detect forward scattering
- Polarized NH_3 target: 2.5T~5T magnetic field
    - Use Chicane to provide an incident angle
    - Outgoing beam is not straight: use local dump
- Low current polarized beam
    - Upgrades to existing Beam Diagnostics to work at 50 nA

Kinematics Coverage



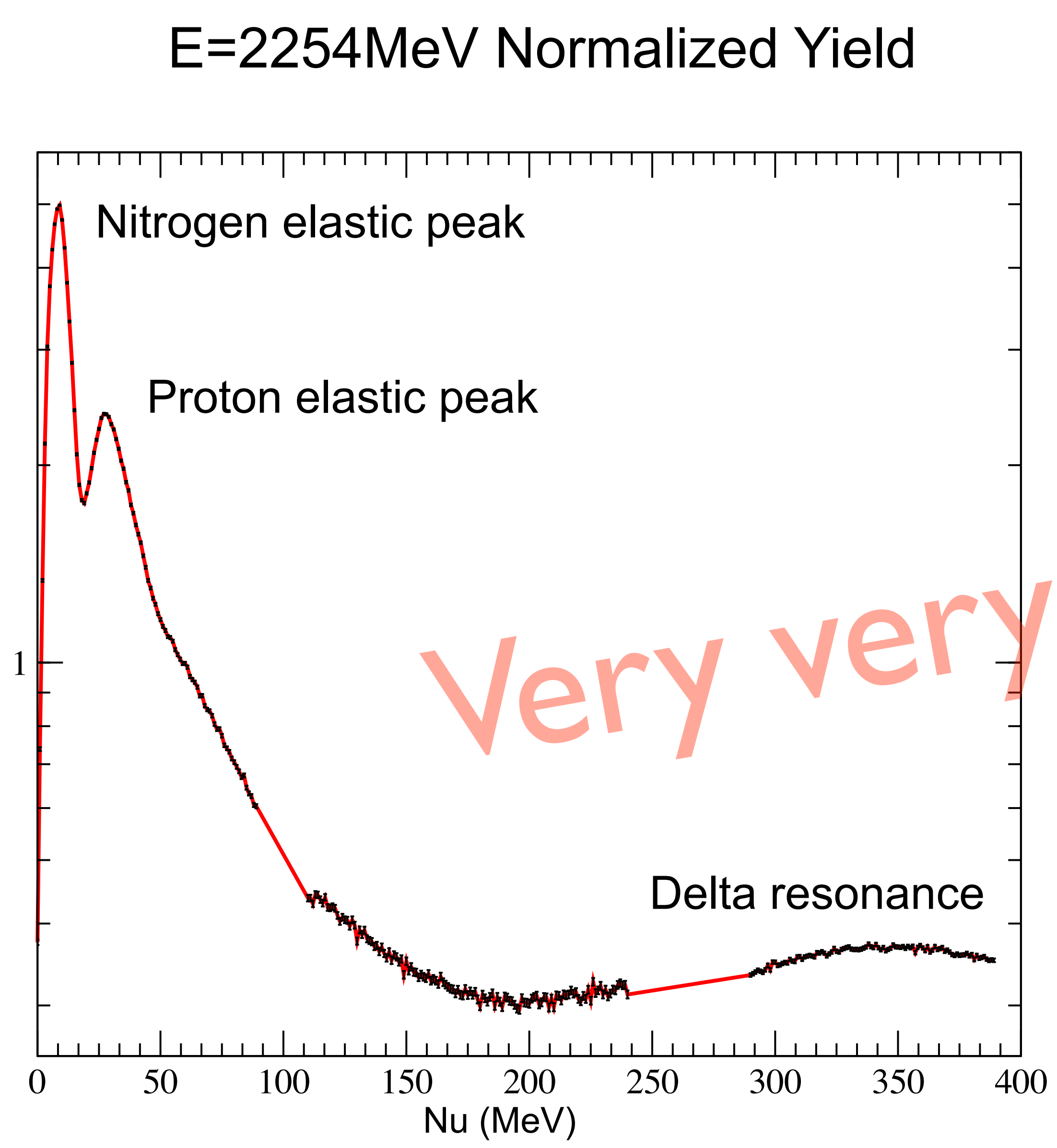
$M_p < W < 2$ GeV

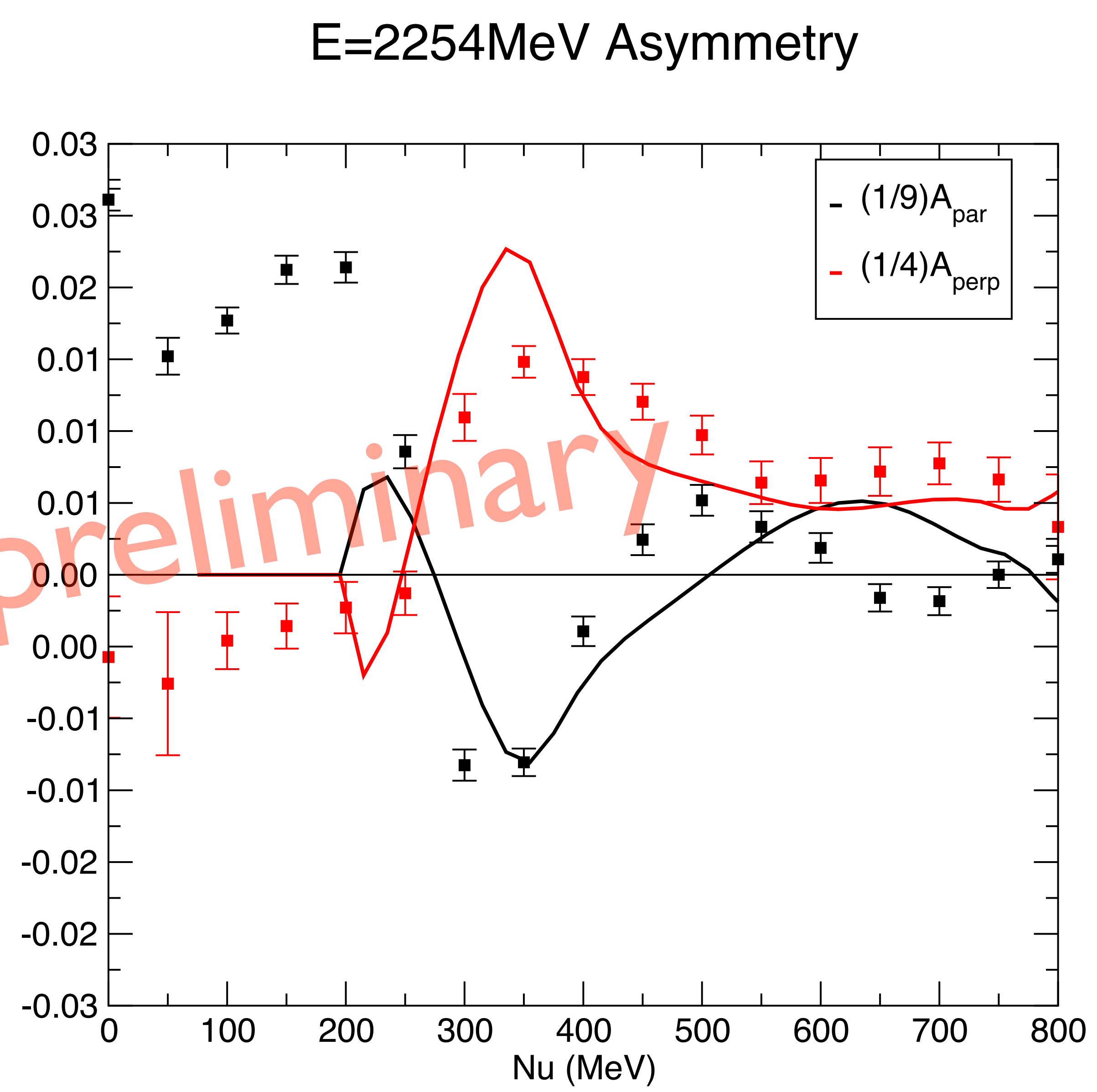
$0.02 < Q^2 < 0.2$ GeV^2

- The Experiment was conducted at JLab Hall A successfully from 3/2/2012 to 5/18/2012
- Statistics:

Beam Energy / GeV	Target Field /T	Recorded trigger
2.254	2.5	3.80E+09
1.706	2.5	3.20E+09
1.158	2.5	4.00E+09
2.254	5.0	7.00E+08
3.352	5.0	4.00E+08

Online results





$$\Delta\sigma_{\perp} = \sigma_{\text{total}} \cdot A_{\perp}$$

Conclusion

- We managed to accomplish most of our physics goals
- New instruments are demonstrated working well during the experiment
- Will provide the an accurate measurement of g_2 in low Q^2 region
- Will also extract the fundamental quantities δ_{LT} to provide a test of χPT calculations

Thanks