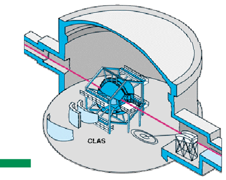

Spin Structure Functions at CLAS

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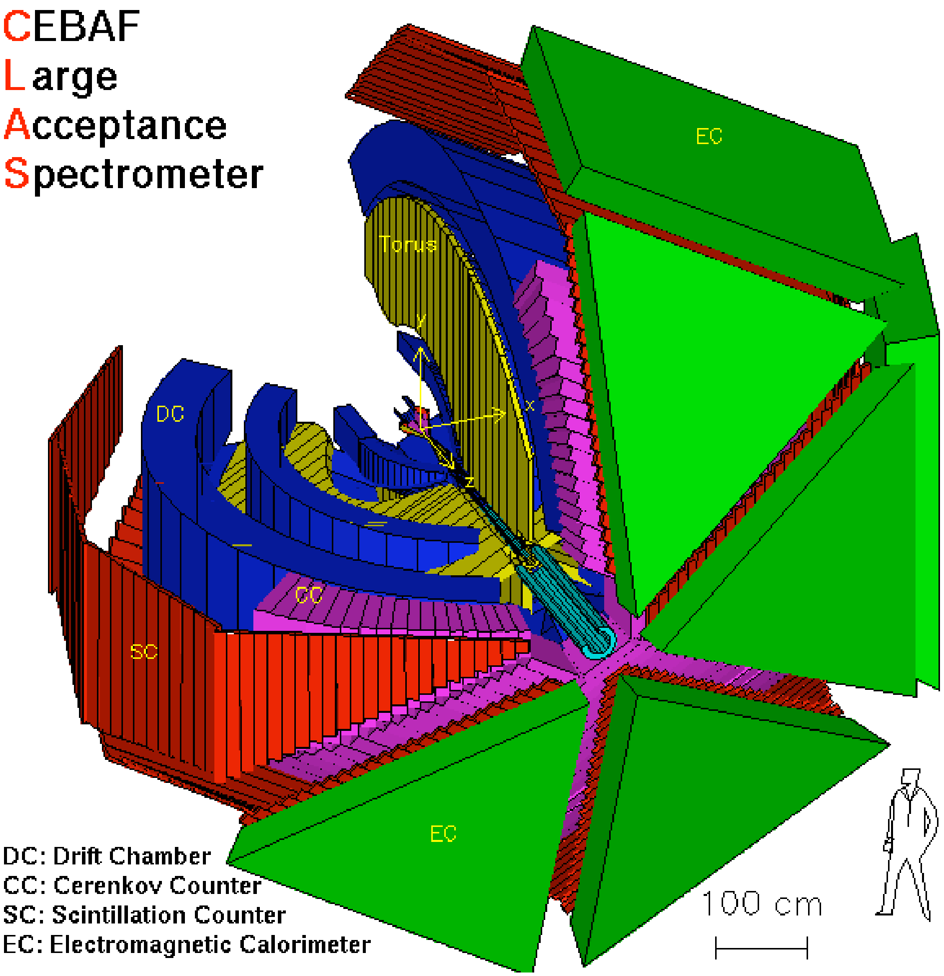
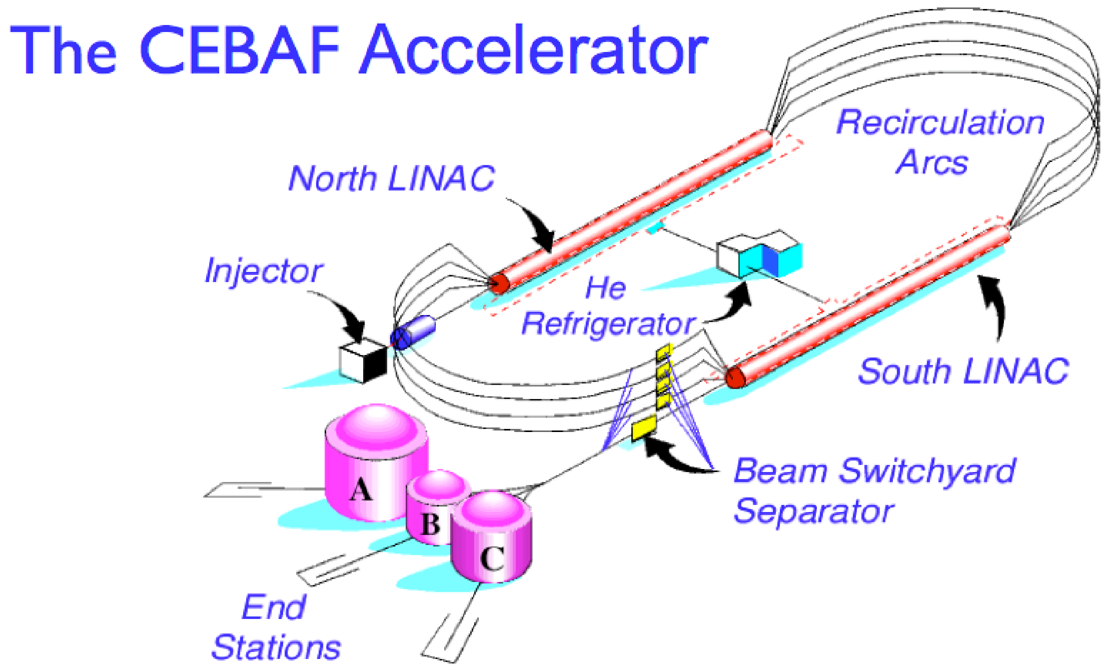
Presented by J. Pierce
University of Virginia

Spin Structure with CLAS

- Long-standing program in Hall-B at JLab to measure longitudinal double spin asymmetries $A_{||}$ on $^{15}NH_3$ and $^{15}ND_3$
- EG1: $0.05<Q^2<3.5$ GeV^2
  - data (2001); anal (2007)
- EG4: $0.01<Q^2<1$ GeV^2
  - data (2006); anal (2008)
- EG12: $0.5<Q^2<7$ GeV^2
  - data (2012?); anal (2014)

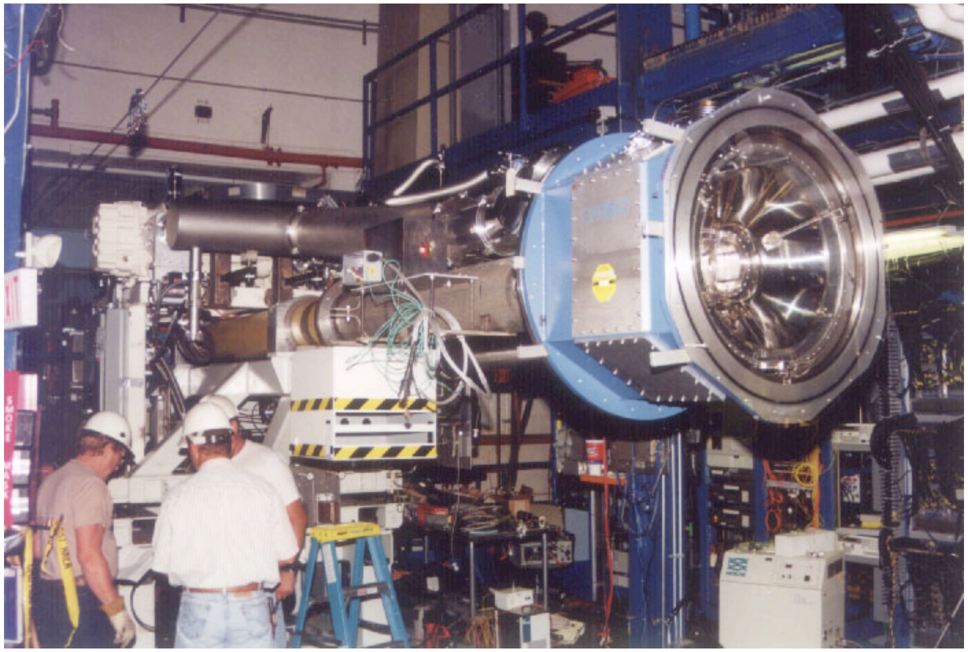


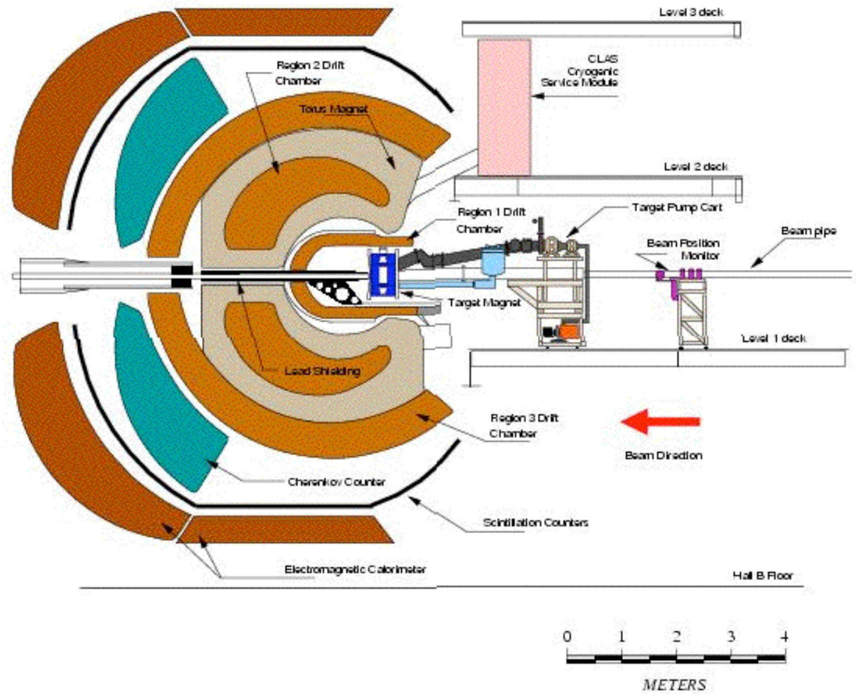
CEBAF Accelerator



- Electron beams up to 5.7 GeV with >80% longitudinal polarization
- Beam currents of 1-50 nA in Hall B

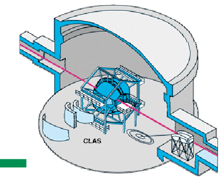
Polarized Target





- Dynamic nuclear polarization of NH_3 and ND_3
- Polarizations of 70-80% for p and 20-30% for d
- Luminosity 10^{35} $cm^{-2}s^{-1}$

Formalism



$$A_{\parallel} = \frac{\sigma^{\downarrow\uparrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\downarrow\uparrow} + \sigma^{\uparrow\uparrow}}$$

$$A_{\parallel} = D(A_1 + \eta A_2)$$

$$A_1 = \frac{\sigma^T_{1/2} - \sigma^T_{3/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}}$$

$$= \frac{g_1(x,Q^2) - \gamma^2 g_2(x,Q^2)}{F_1(x,Q^2)}$$

We can extract A_1 using a model for A_2 (small), or g_1 using a model for g_2 (small)

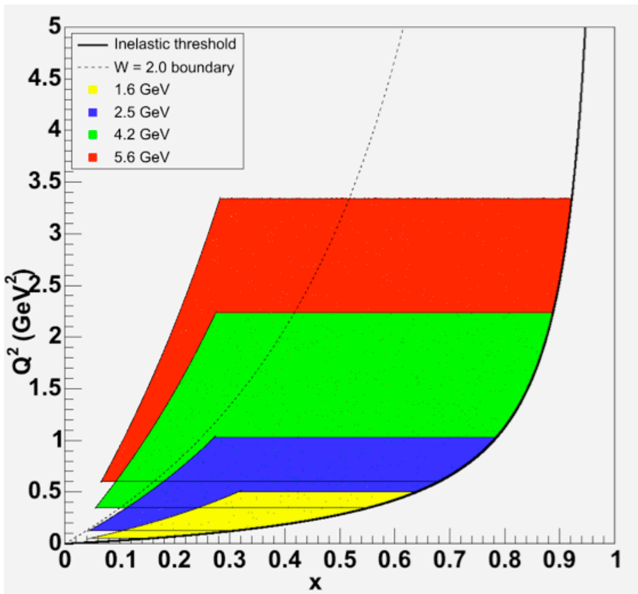
$$A_2 = \frac{2\sigma_{LT}}{\sigma^T_{1/2} + \sigma^T_{3/2}}$$

$$= \frac{\gamma[g_1(x,Q^2) + g_2(x,Q^2)]}{F_1(x,Q^2)}$$

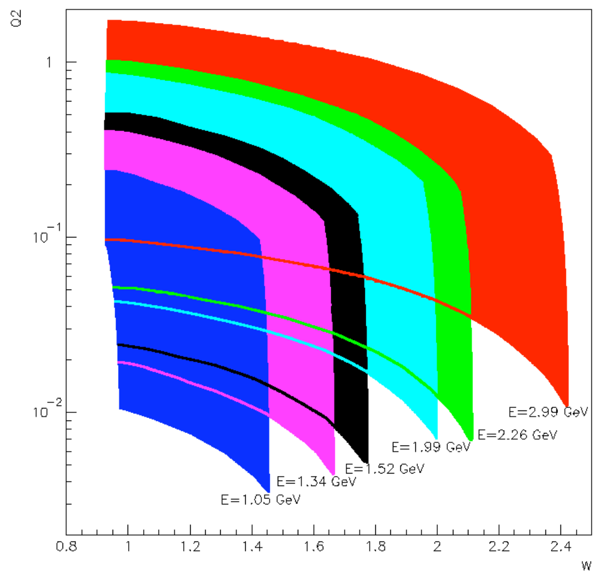
We can extract A_1 and A_2 from $A_{\parallel}$ at multiple values of $\eta(E_{beam})$

Kinematics

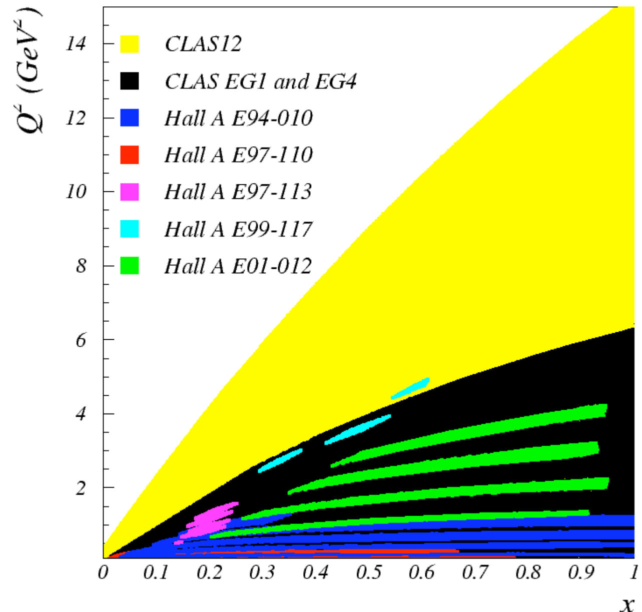
EG1



EG4

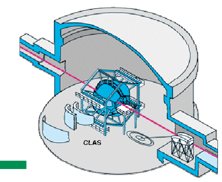


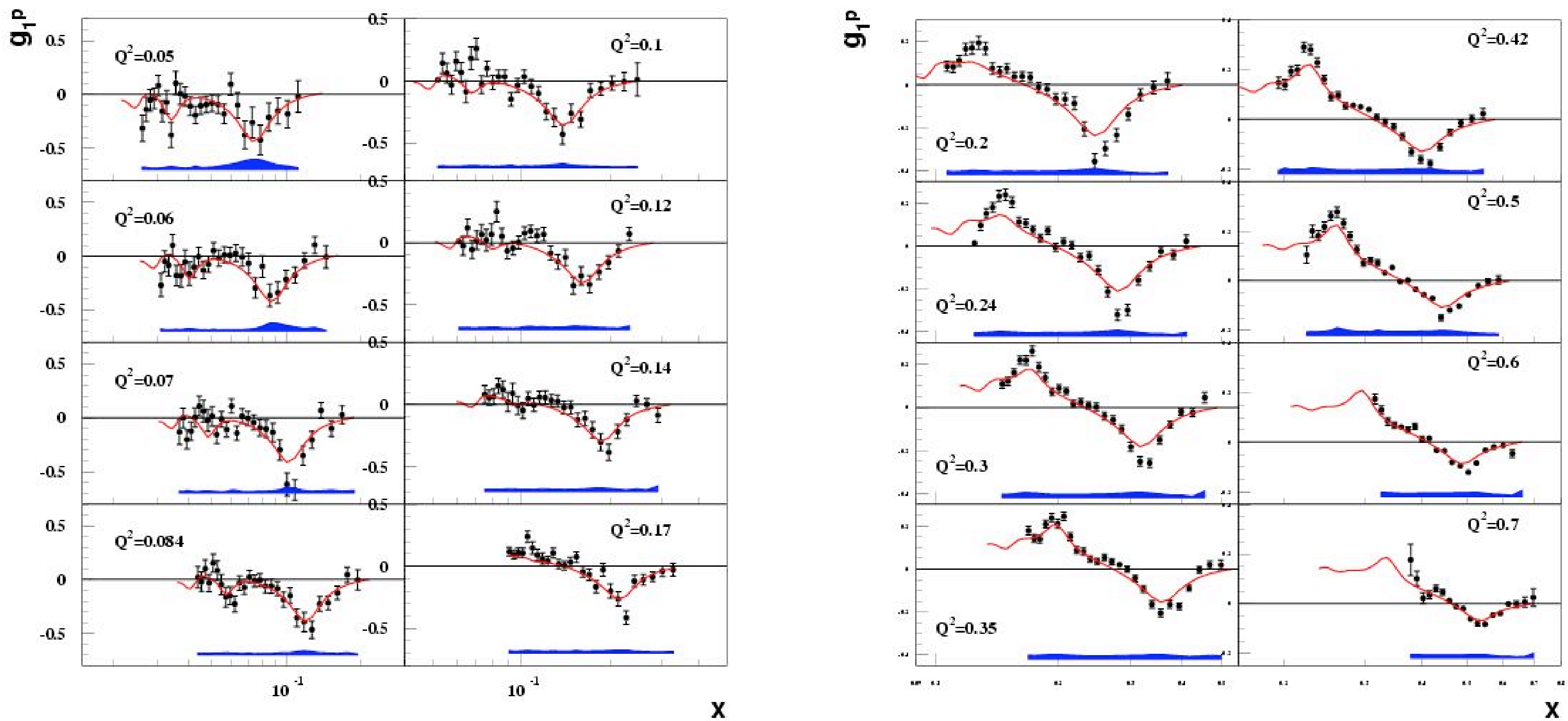
EG12



- Overlapping colors correspond to different beam energies
- CLAS measures a large range in x at each fixed Q^2
- Different E_{beam} for fixed (x,Q^2) allows separation of A_1 & A_2

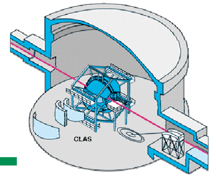
EG1 g_1^p (Q^2<0.7)

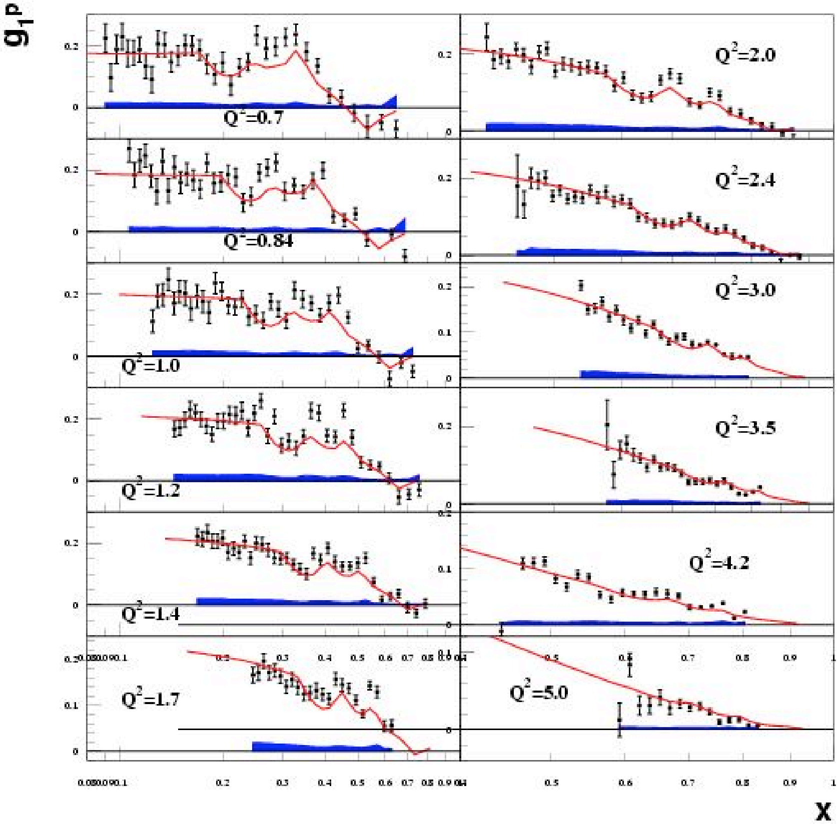


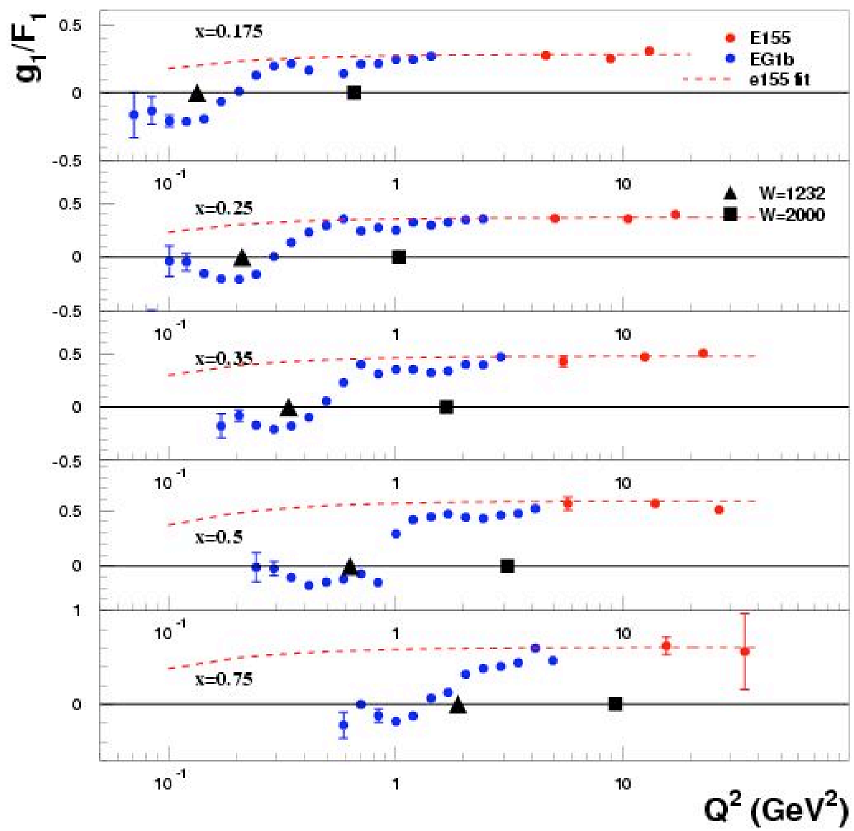


- At low Q^2 the Δ resonance drives g_1 negative
- Extensive x-range at fixed Q^2 allows integration over x
- Red curve is the EG1 model used for radiative corrections

EG1 g_1^p (Q^2>0.7) & g_1/F_1

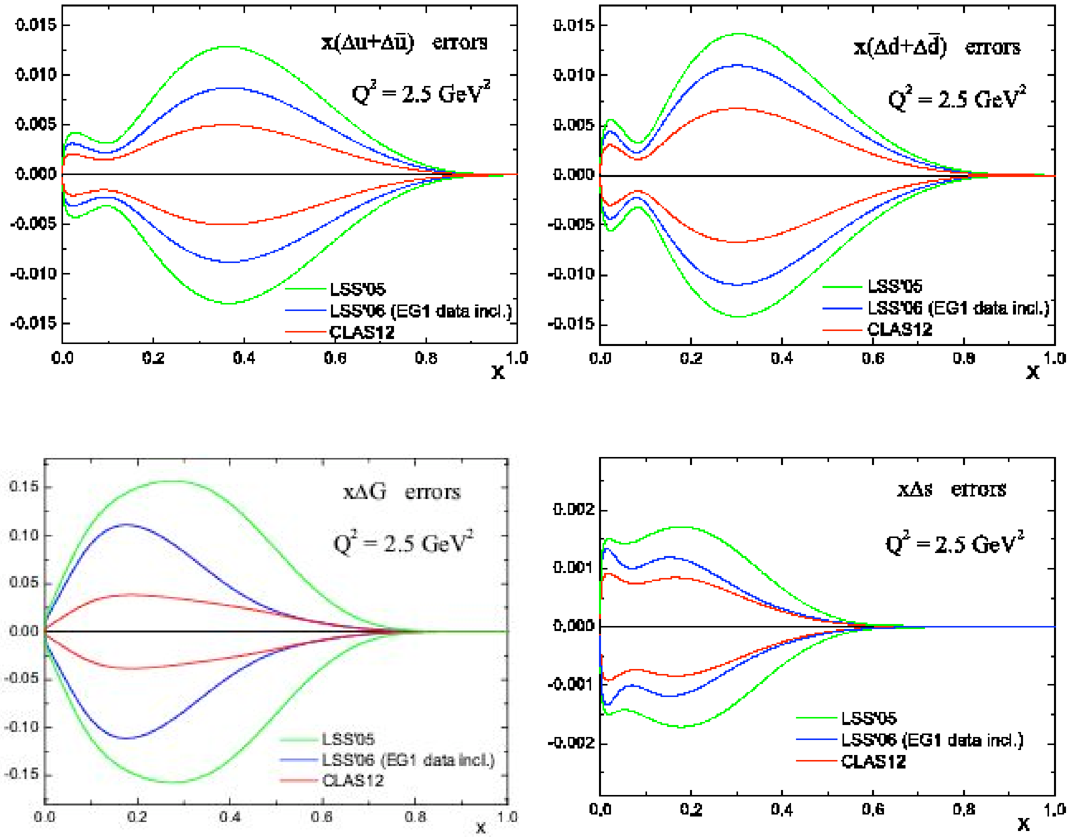






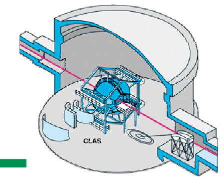
- At higher Q^2, g_1 becomes positive everywhere
- g_1/F_1 falls far below the DIS extrapolation at low Q^2
- Red curve is the EG1 model (dashed: DIS extrapolation)

PDFs and CLAS



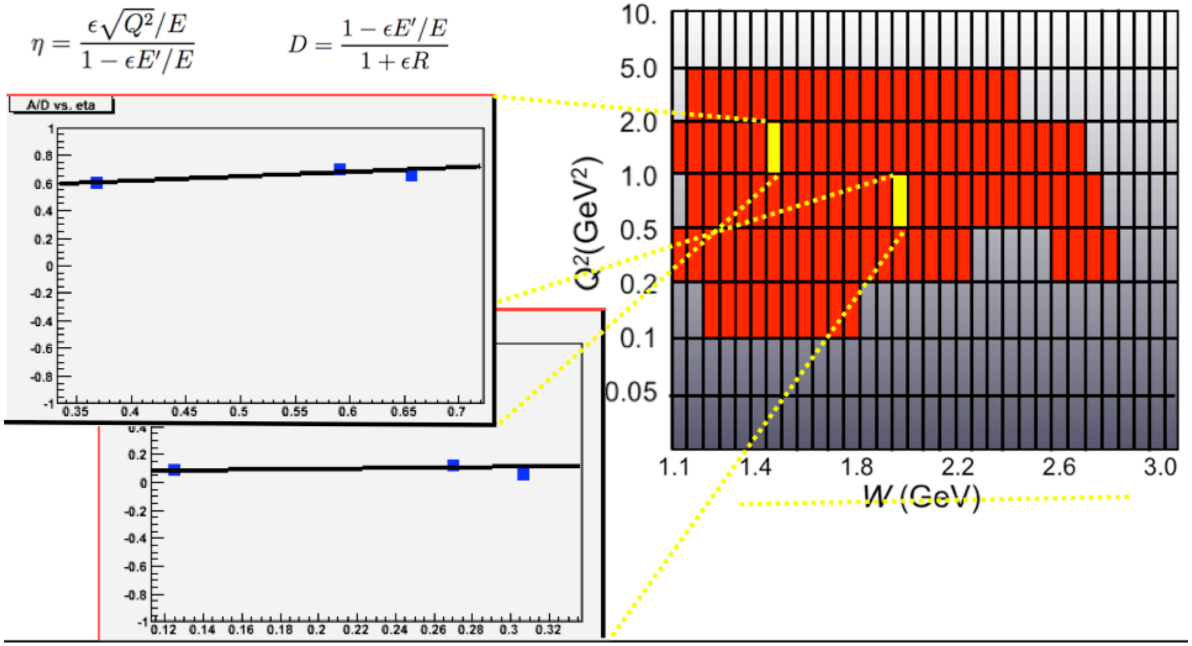
- Error envelopes for PDFs from LSS05 global analysis (green)
- CLAS EG1 data significantly improve errors on Δu, Δd, Δx and ΔG (blue)
- CLAS EG12 (12 GeV upgrade) will especially improve ΔG (red)

EG1 Extraction of A_2

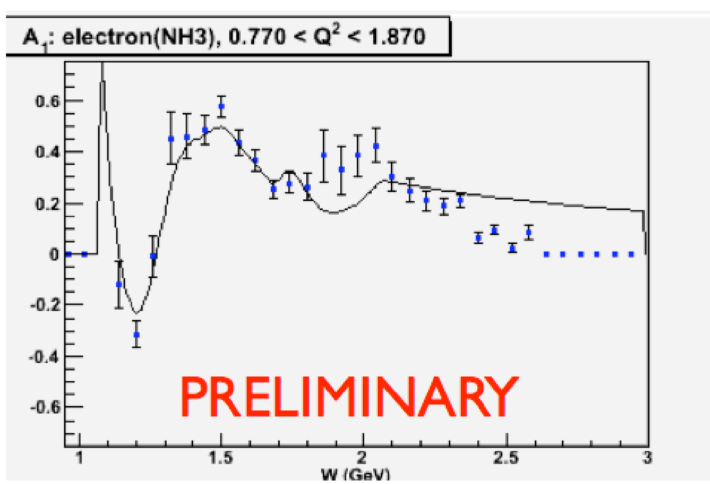


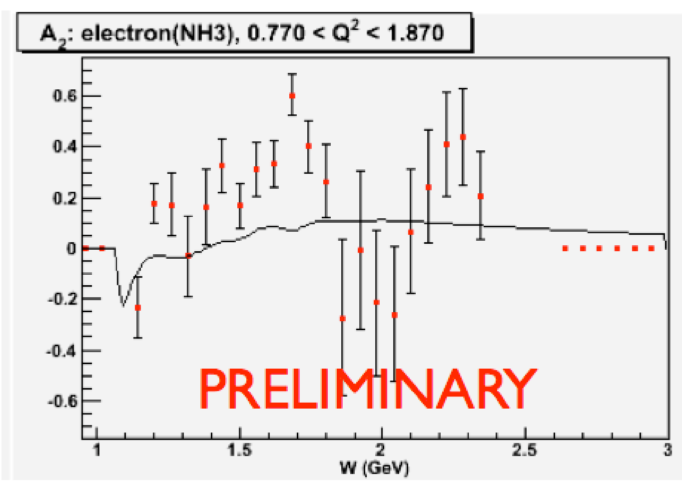
$$A_{\|} = D(A_1 + \eta A_2)$$

$$\eta = \frac{\epsilon\sqrt{Q^2}/E}{1-\epsilon E'/E} \qquad D = \frac{1-\epsilon E'/E}{1+\epsilon R}$$



- Analysis is in progress to obtain both A_1 and A_2 from the EG1 data
- Intercept gives A_1
- Slope gives A_2
- A_2 is larger than EG1 model (MAID, AO) as is Hall C RSS experiment



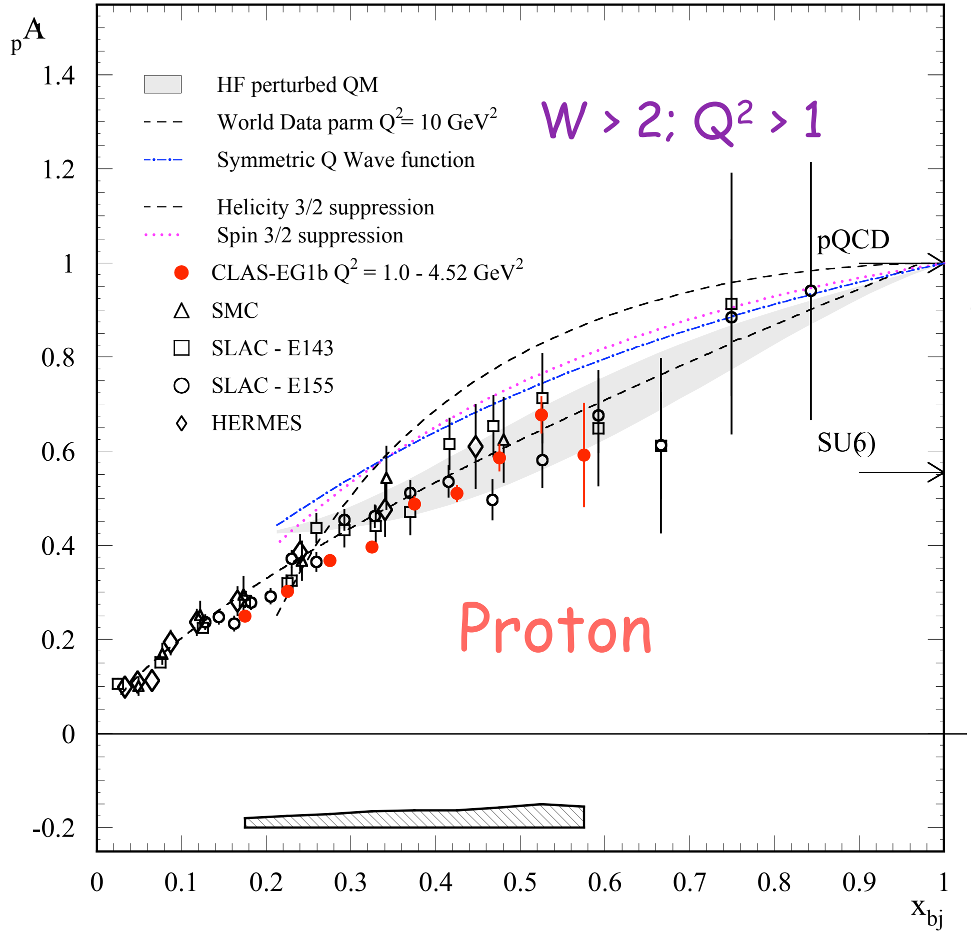


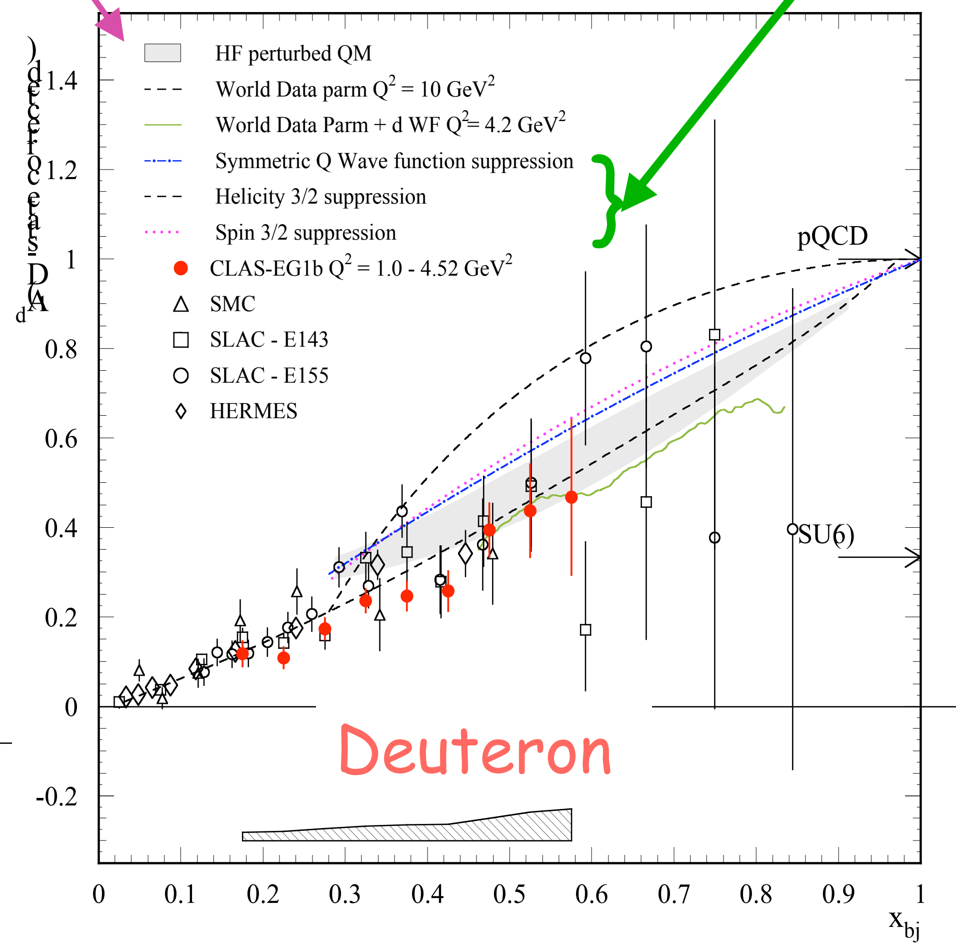
A_1 Data from EG1

The College of WILLIAM & MARY

Isgur, PRD **59**, 034013 (2003)

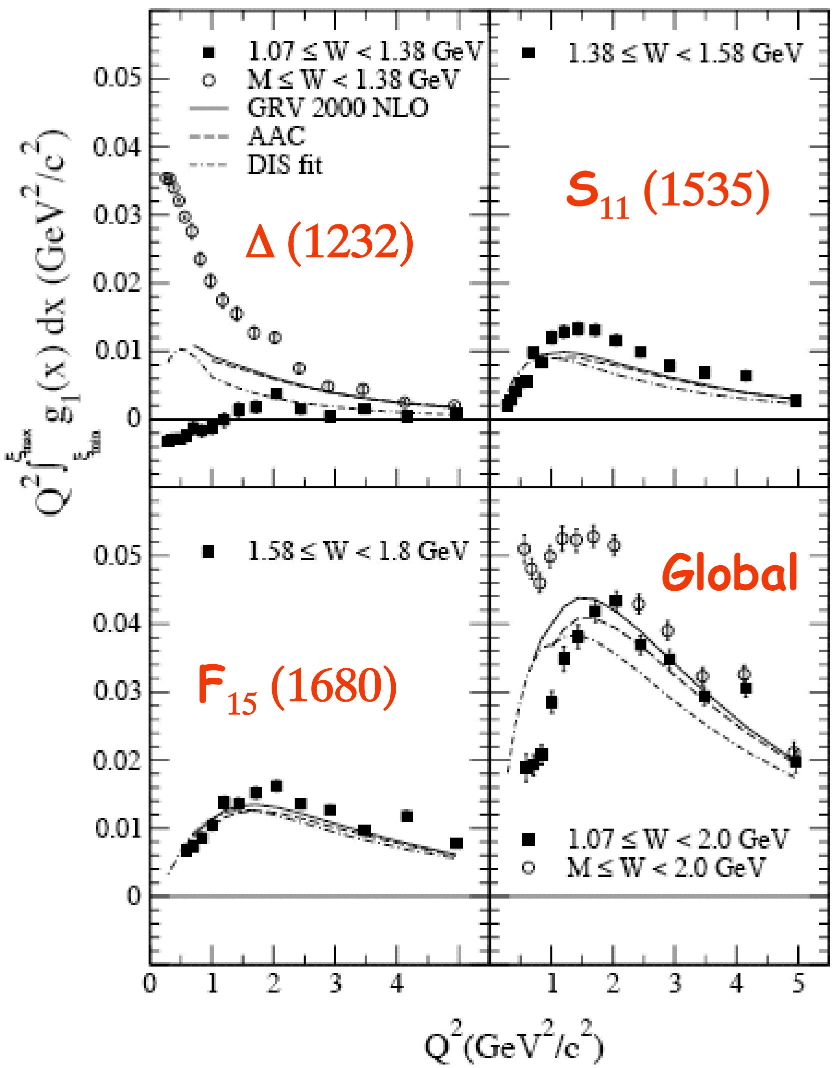
Close and Melnitchouk, PRC **68**, 035210 (2003)



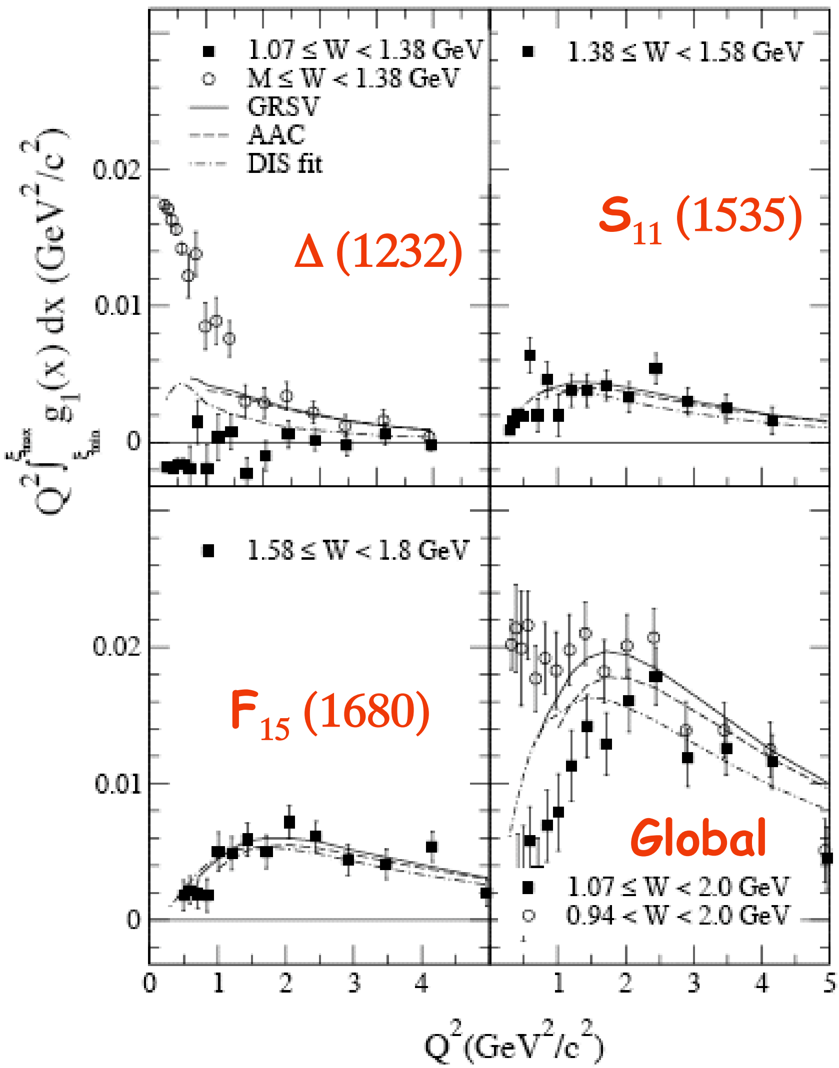


Duality

Proton

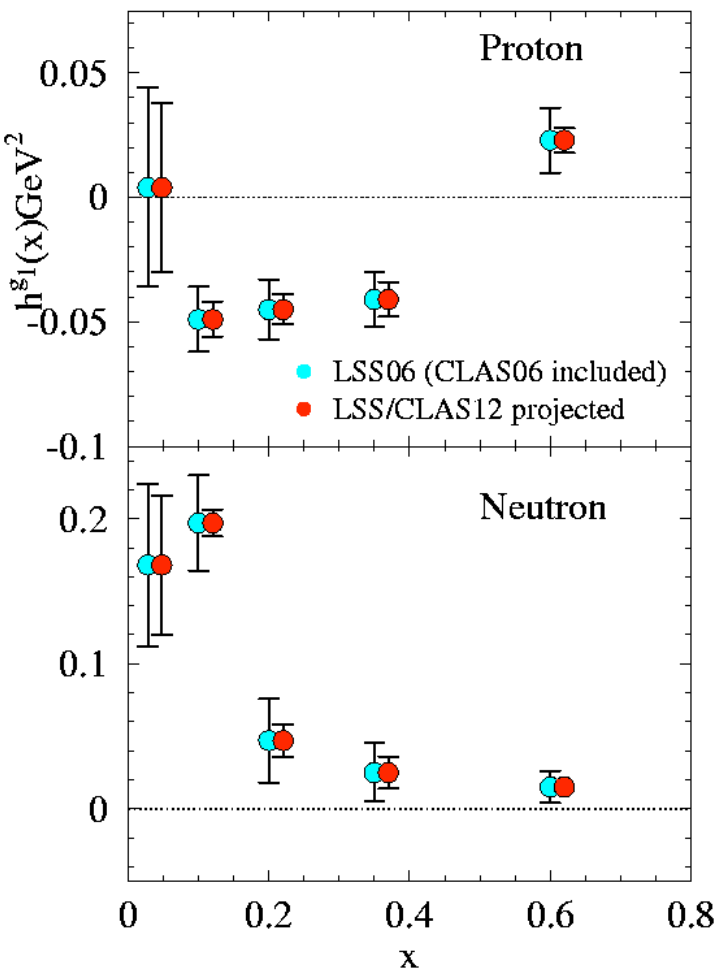


Deuteron



Higher Twist from g_1

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{\exp} F_1(x,Q^2)_{\exp} = g_1(x,Q^2)_{\exp} = g_1(x,Q^2)_{LT} + h^{g_1}(x)/Q^2$$



$$1 < Q^2 < 5\ \mathrm{GeV}^2, \quad 2 < W < 3.5\ \mathrm{GeV}$$

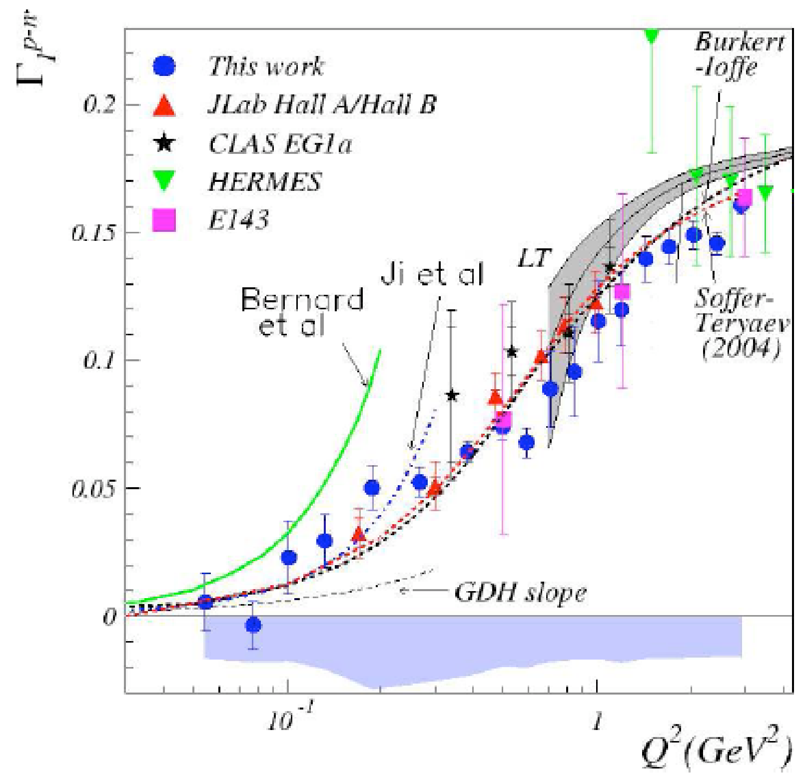
$$\int_0^1 dx h^{g_1}(x) = \frac{4}{9} M^2 (d_2 + f_2)$$

- F_1 from NMC fit to F_2 and 1998 SLAC fit to R
- g_1 (leading twist) from NLO fit at high Q^2
- h from fit to all data, especially CLAS in the pre-asymptotic region
- d_2: twist-3, f_2: twist-4

Bjorken Sum & Higher Twist

$$\Gamma_1^{(n)} = \int_0^1 x^n g_1(x,Q^2)dx = \frac{a_n}{2}, \quad n = 0,2,4,\ldots,$$

$$\Gamma_2^{(n)} = \int_0^1 x^n g_2(x,Q^2)dx = \frac{1}{2}\frac{n}{n+1}(d_n - a_n), \quad n = 2,4,\ldots,$$



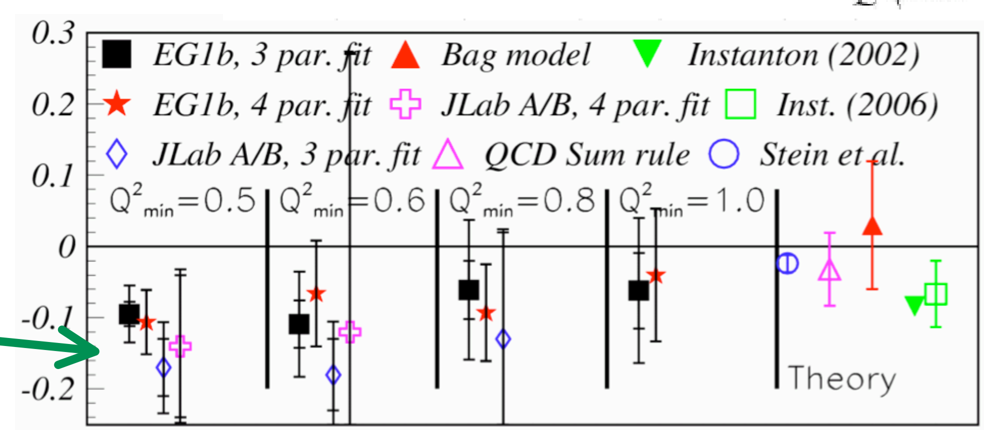
Bjorken Sum Rule:

$$\Gamma_1^{p-n} = \frac{g_A}{6}\left[1 - \frac{\alpha_s}{\pi} - 3.58\left(\frac{\alpha_s}{\pi}\right)^2 - 20.21\left(\frac{\alpha_s}{\pi}\right)^3\right] + \frac{\mu_4^{p-n}}{Q^2} + \ldots$$

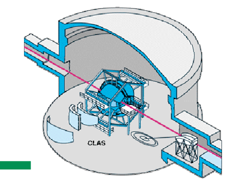
$$\mu_4^{p-n} = \frac{M^2}{9}\left(a_2^{p-n} + 4d_2^{p-n} + 4f_2^{p-n}\right)$$

$$d_2^{p-n} = \int_0^1 dx\, x^2\left(2g_1^{p-n} + 3g_2^{p-n}\right)$$

Fit Γ_1^{p-n} to powers of $1/Q^2$ and extract f_2^{p-n}



Moments $\Gamma_1^{p,d}$



$$\Gamma_1^{p,d}(Q^2) = \int_0^1 g_1^{p,d}(x,Q^2)dx \qquad \Gamma_1(Q^2) = aQ^2 + bQ^4 + cQ^6 + dQ^8$$

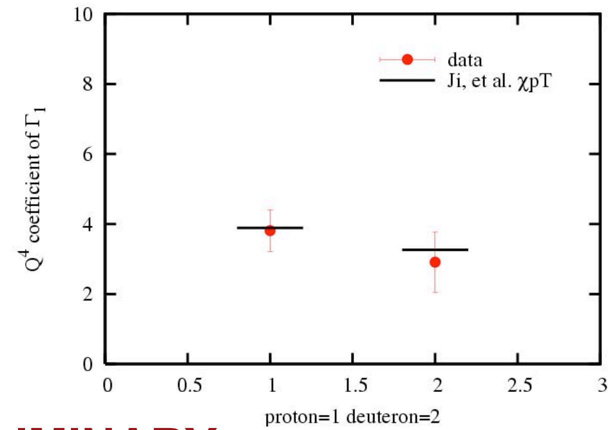
low Q^2 fit

$$\Gamma_1^d(Q^2) = (1 - 1.5\omega_D)\{\Gamma_1^p(Q^2) + \Gamma_1^n(Q^2)\}$$

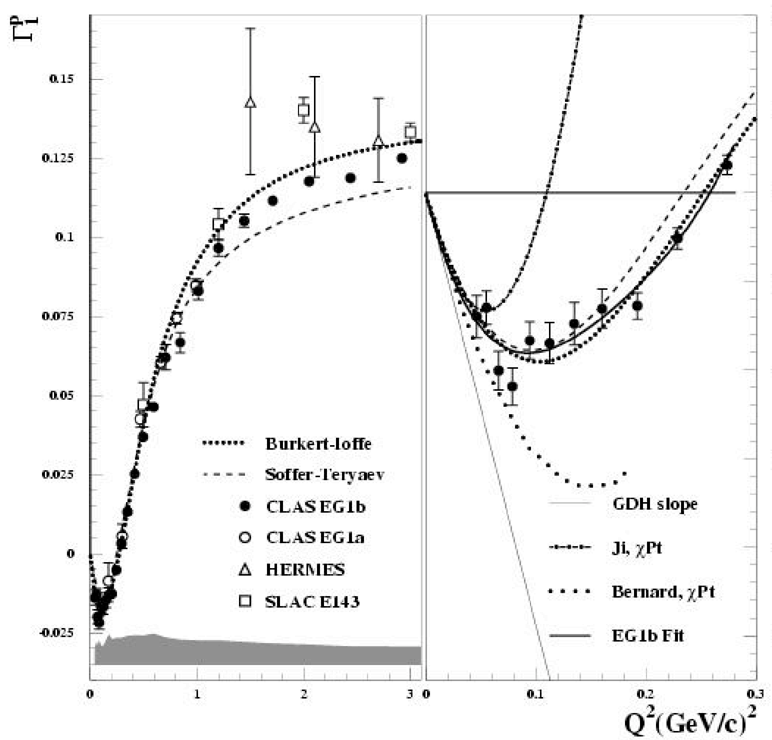
$$\Gamma_1^p(Q^2) = -\frac{\kappa_p^2}{8M^2}Q^2 + 3.89Q^4 + \ldots$$

$$\Gamma_1^n(Q^2) = -\frac{\kappa_n^2}{8M^2}Q^2 + 3.15Q^4 + \ldots.$$

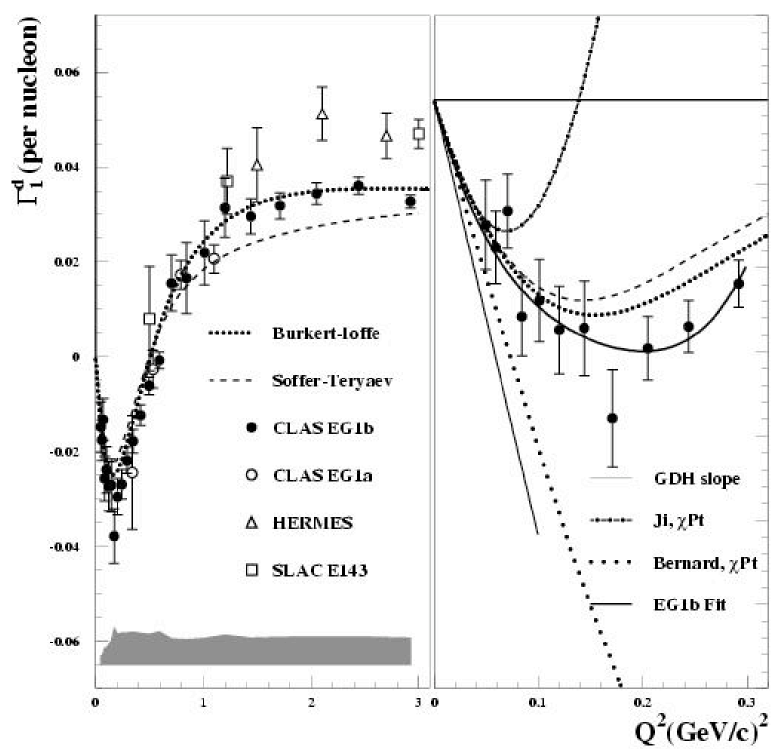
GDH + χpT



PRELIMINARY

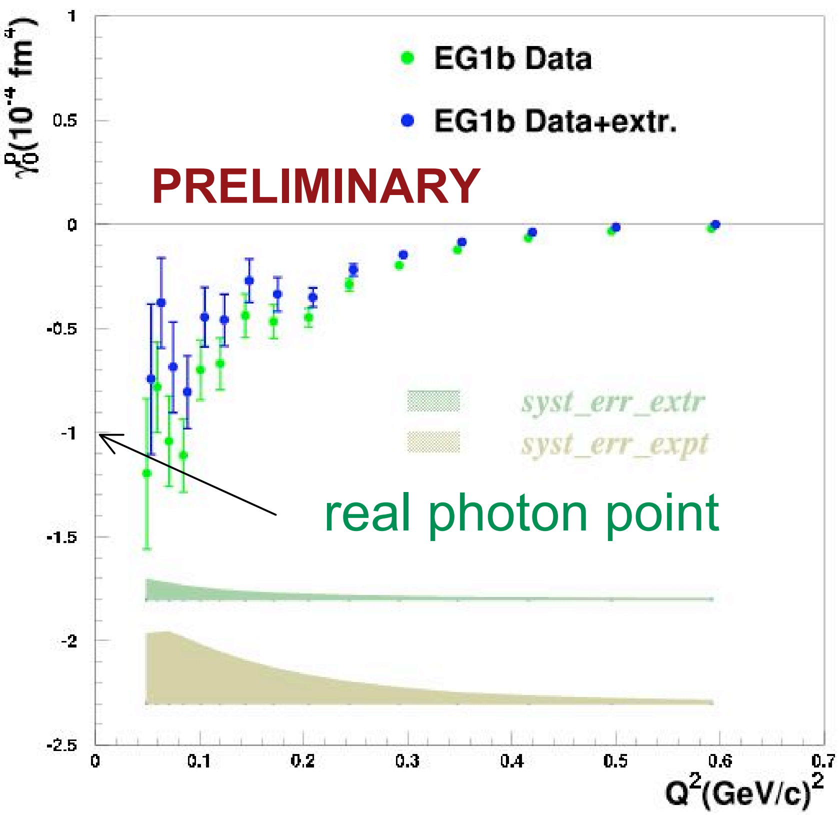


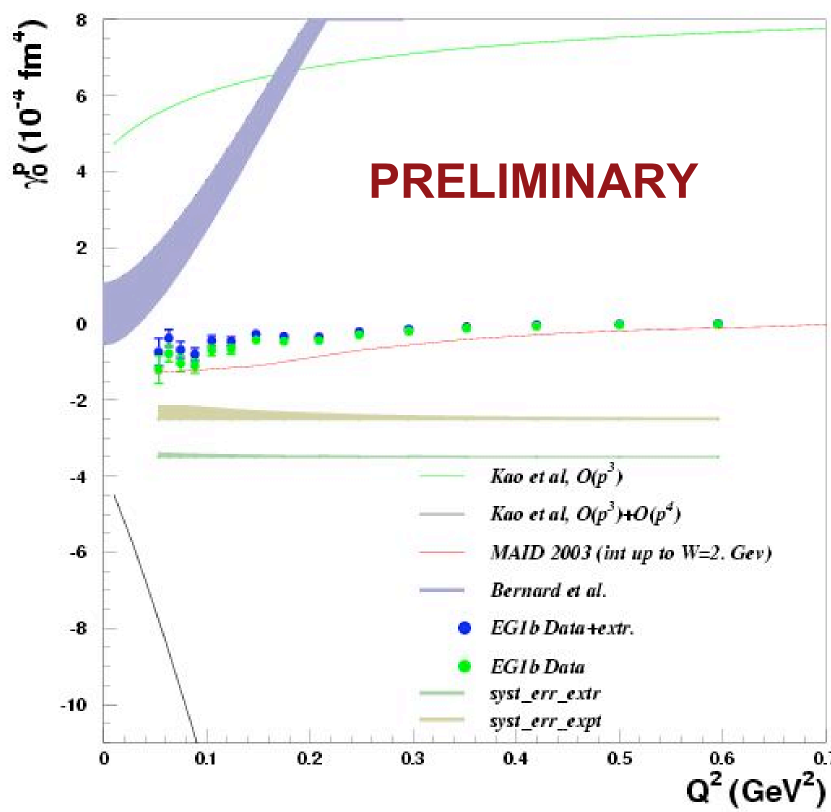
PRELIMINARY



Forward Spin Polarizability

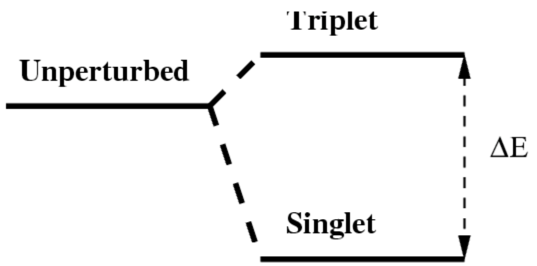
$$\gamma_0(Q^2) = \frac{4e^2M^2}{\pi Q^6}\int_0^{x_0} dx\, x^2 \left\{g_1(x,Q^2) - \gamma^2 g_2(x,Q^2)\right\}$$





Hydrogen Hyperfine Splitting

$$E_{\rm HFS}(e^- p) = 1.4204057517667(9)\,{\rm GHz} = (1+\Delta_{QED}+\Delta_R^p+\Delta_S)E_F^p$$



$$\Delta_S = \Delta_Z + \Delta_{\rm pol} \qquad \delta_Z^{\rm rad} = \frac{\alpha}{3\pi}\left[2\ln\frac{\Lambda^2}{m^2} - \frac{4111}{420}\right]$$

Zemach: $\Delta_Z = -2\alpha m_e \langle r\rangle_Z (1+\delta_Z^{\rm rad})$

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

$\Delta_S = -38.62(16)$ ppm $\Delta_Z = -41.0(5)$ ppm $\Delta_{\rm pol} = 2.38(58)$ ppm

$$\Delta_{\rm pol} = \frac{\alpha m_e}{2\pi(1+\kappa)M}(\Delta_1 + \Delta_2) = (0.2264798\ {\rm ppm})(\Delta_1 + \Delta_2)$$

$$\Delta_1 = \frac{9}{4}\int_0^\infty \frac{dQ^2}{Q^2}\left\{F_2^2(Q^2) + \frac{8m_p^2}{Q^2}B_1(Q^2)\right\}$$

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

$$\tau = \nu^2/Q^2$$

$$B_1 = \int_0^{x_{\rm th}} dx\,\beta(\tau)g_1(x,Q^2)\,,$$

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

$$\beta(\tau) = \frac{4}{9}\left(-3\tau + 2\tau^2 + 2(2-\tau)\sqrt{\tau(\tau+1)}\right)$$

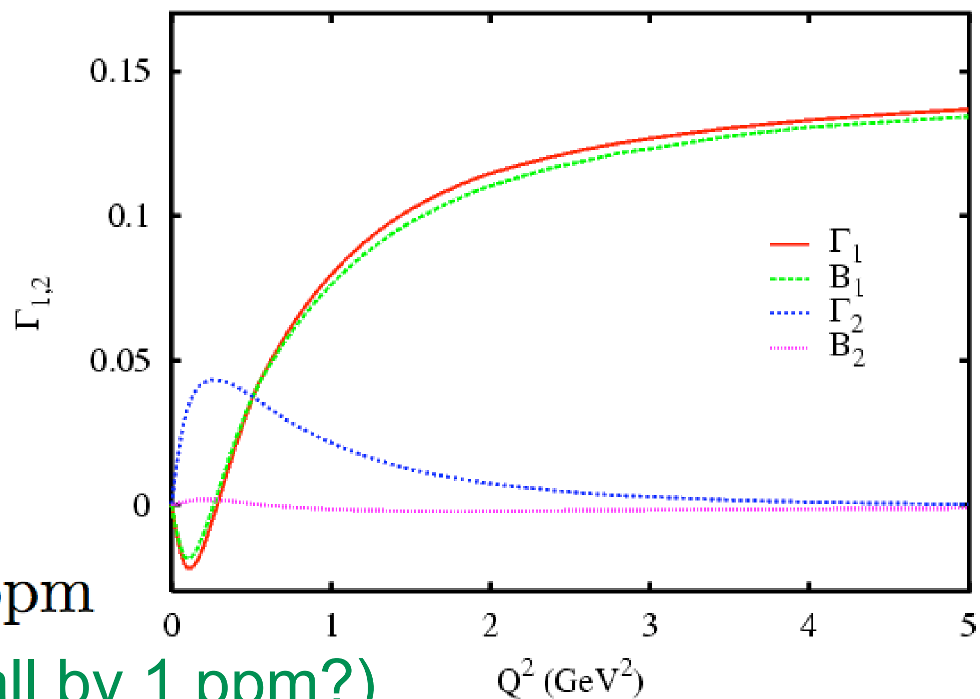
$$\beta_2(\tau) = 1 + 2\tau - 2\sqrt{\tau(\tau+1)}\,,$$

$\Delta_{1,2}$ from $g_{1,2}$

Comparisons between $\Gamma_1 = \int g_1 dx$ and $B_1 = \int \beta_1 g_1 dx$
and between $\Gamma_2 = \int g_2 dx$ and $B_2 = \int \beta_2 g_2 dx$

PRL**96**,163001

- $B_1 \approx \Gamma_1$
- $B_2 \approx 0$
- Experimentally, errors on Γ_1 are understood; we exploit this fact.
- $\Gamma_2 = \int g_2 dx \neq 0$ at low Q^2.

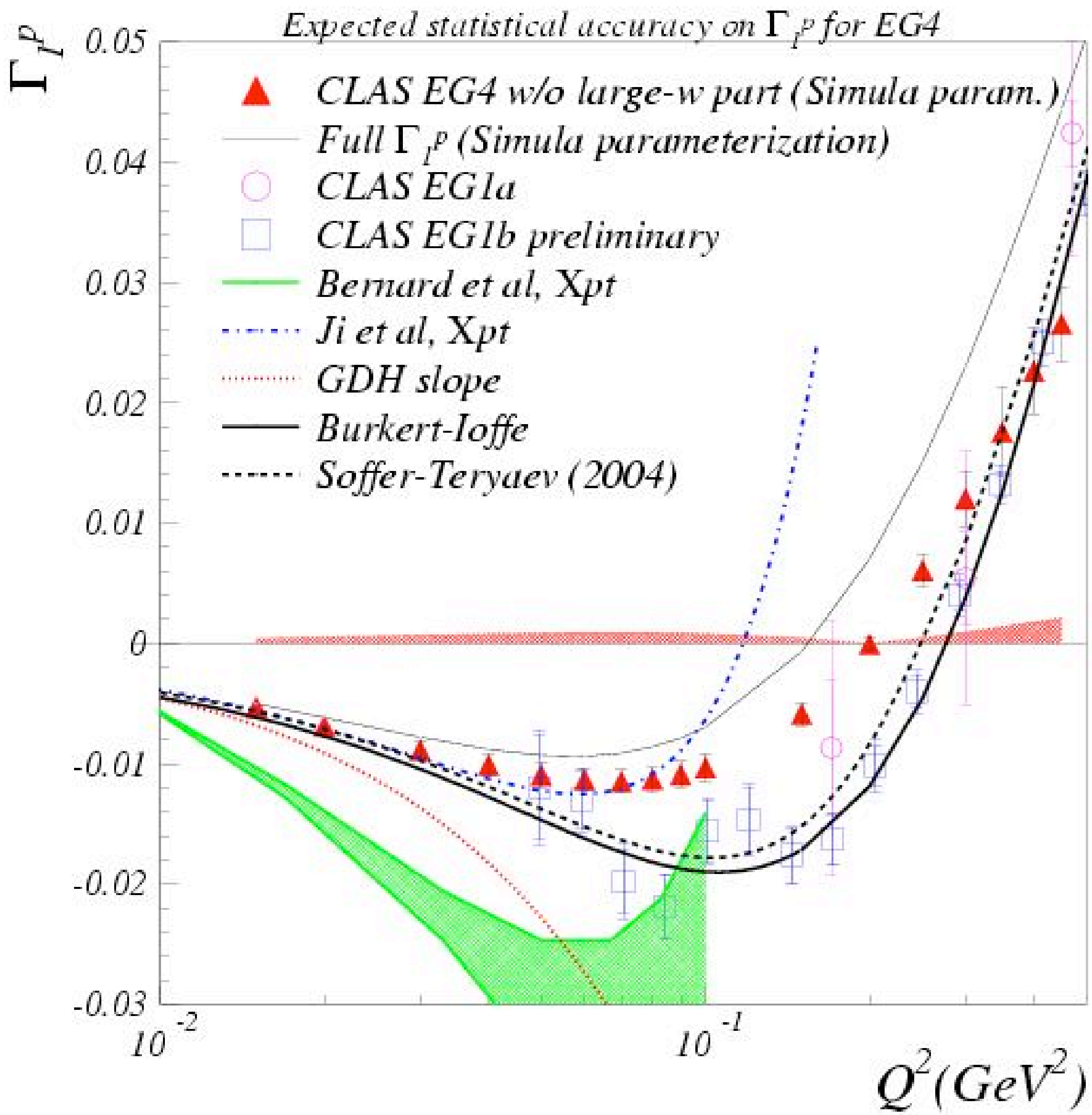


$$\Delta_{\rm pol} = (1.3 \pm 0.3)\ \rm ppm$$

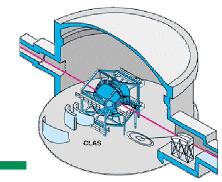
(from EG1: too small by 1 ppm?)

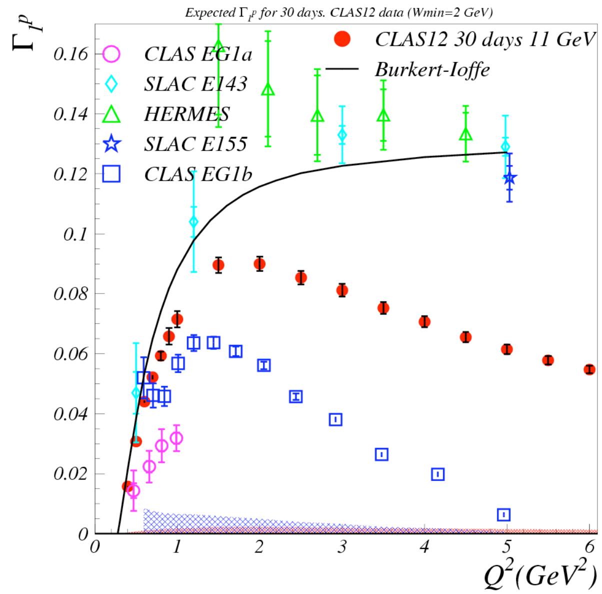
Nucleon structure is the largest uncertainty in calculating HFS.
Better g_1, g_2, G_M, G_E data at low Q^2 required to resolve discrepancy.

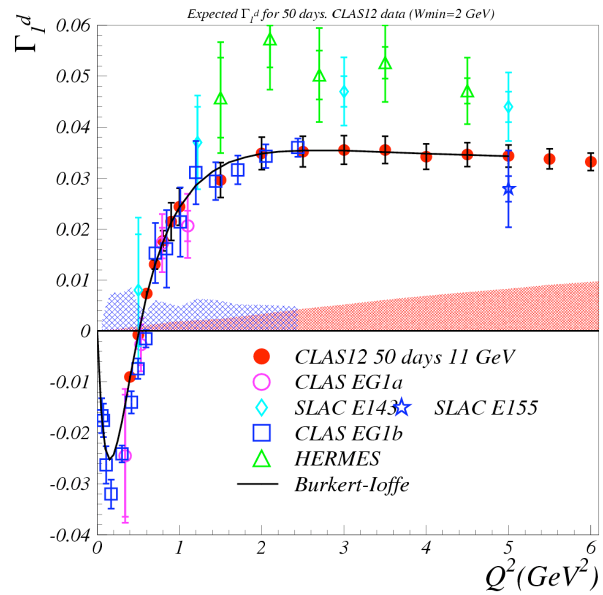
EG4 Expectations

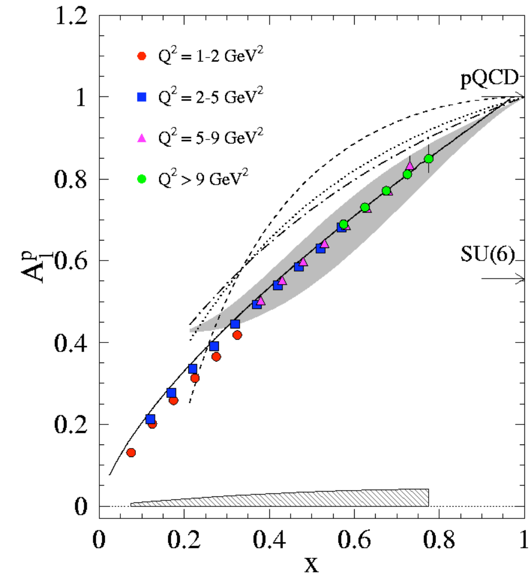


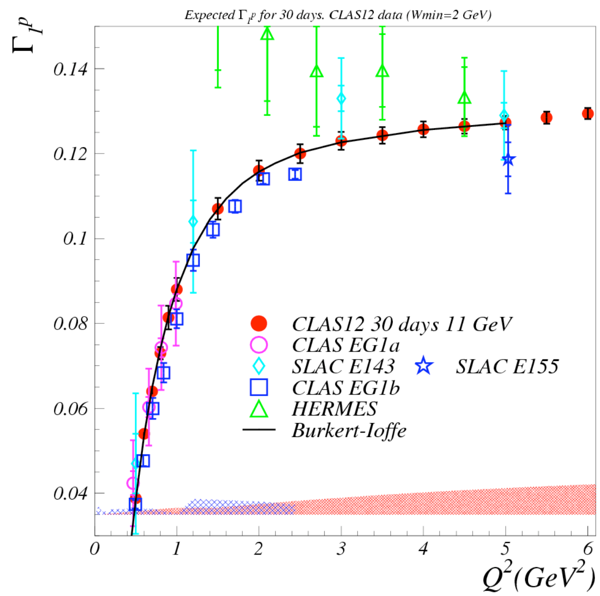
EG12 Expectations

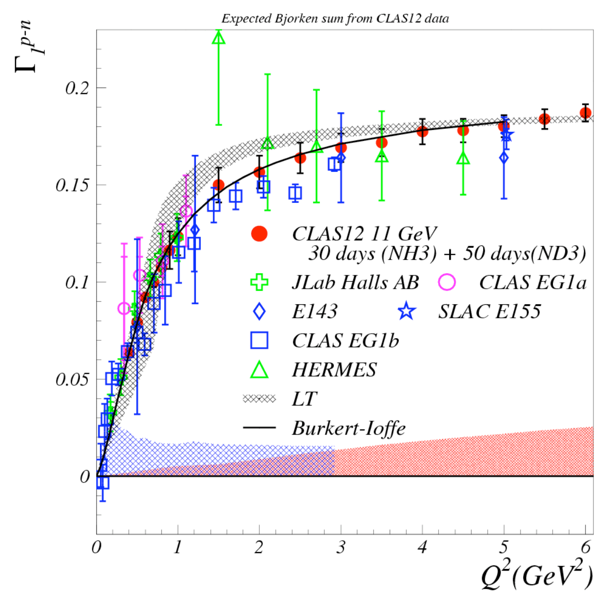


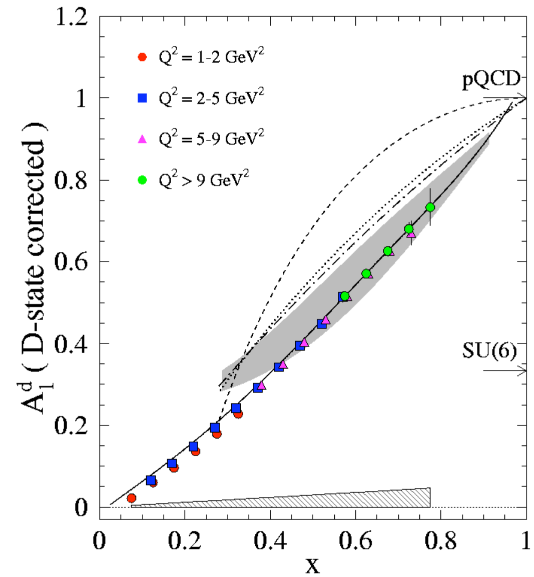




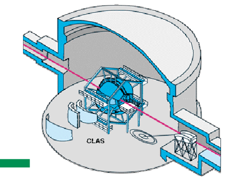








In Conclusion



CLAS, past, present and future, provides high-quality $A_{||}$ data over a large and continuous range in x and Q^2 that

- significantly improve global PDF fits to Δu, Δd, Δs and ΔG
- precisely determine higher twists
- rigorously probe duality over a wide Q^2 range
- quantitatively test χPT calculations at low Q^2
- accurately yield the polarizability correction to hydrogen hyperfine splittings

NB The scope of this talk was limited to the inclusive measurements. A number of semi-inclusive and exclusive measurements are also in progress using the same data sets (see J. Pierce's talk in this conference).