Spin Physics Results from Jefferson Lab Hall B and Hall C

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(for the CLAS Collaboration in Hall B
and the RSS Collaboration in Hall C)

XII International Workshop on
Deep Inelastic Scattering
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14–18 April, 2004

JLab E-01-006
"Resonances Spin Structure"
(RSS)

"Precision Measurement of Nucleon Spin Structure Functions in the Region of Nucleon Resonances"

Spokesmen: **Oscar A. Rondon** (U of Virginia)
Mark K. Jones (Jefferson Lab)

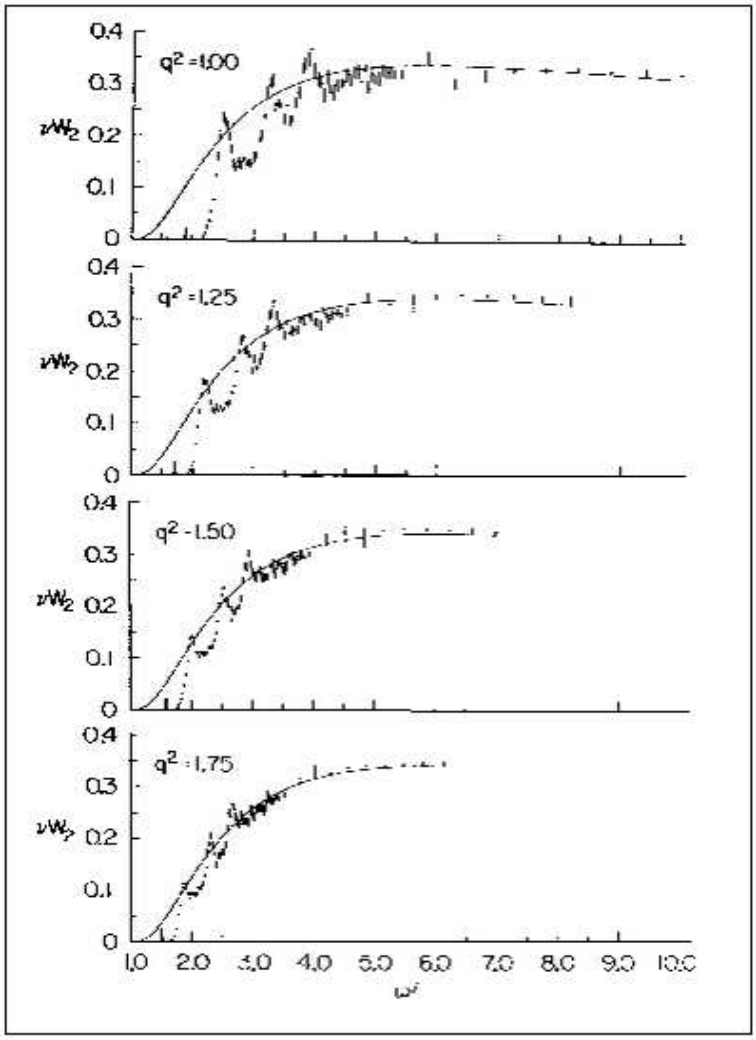
- Measure *proton* and *deuteron* spin *asymmetries*:
  - $A_1(W, Q^2)$ and $A_2(W, Q^2)$
  - at $Q^2 \approx 1.3$ GeV^2 and $0.8 \leq W \leq 2$ GeV
  - nucleon *resonances* region
- Study:
  - *W dependence*
  - onset of *polarized local duality*
  - *twist-3* effects
  - extended *GDH* sum rule
- Obtain *asymmetries* from inclusive *polarized electron* scattering on *polarized nuclei*

Local Duality (Bloom-Gilman 1971) Unpol. DIS–Resonances Connection

- Integral of *proton* $W_2(\nu, Q^2)$ structure function at fixed Q^2 over a limited range of ν (in the region of final state masses $1.071 \leq W \leq 2$ GeV) equals the integral of the *scaling function* $F_2(\omega') = \nu W_2(\omega')$ over corresponding range of ω'.

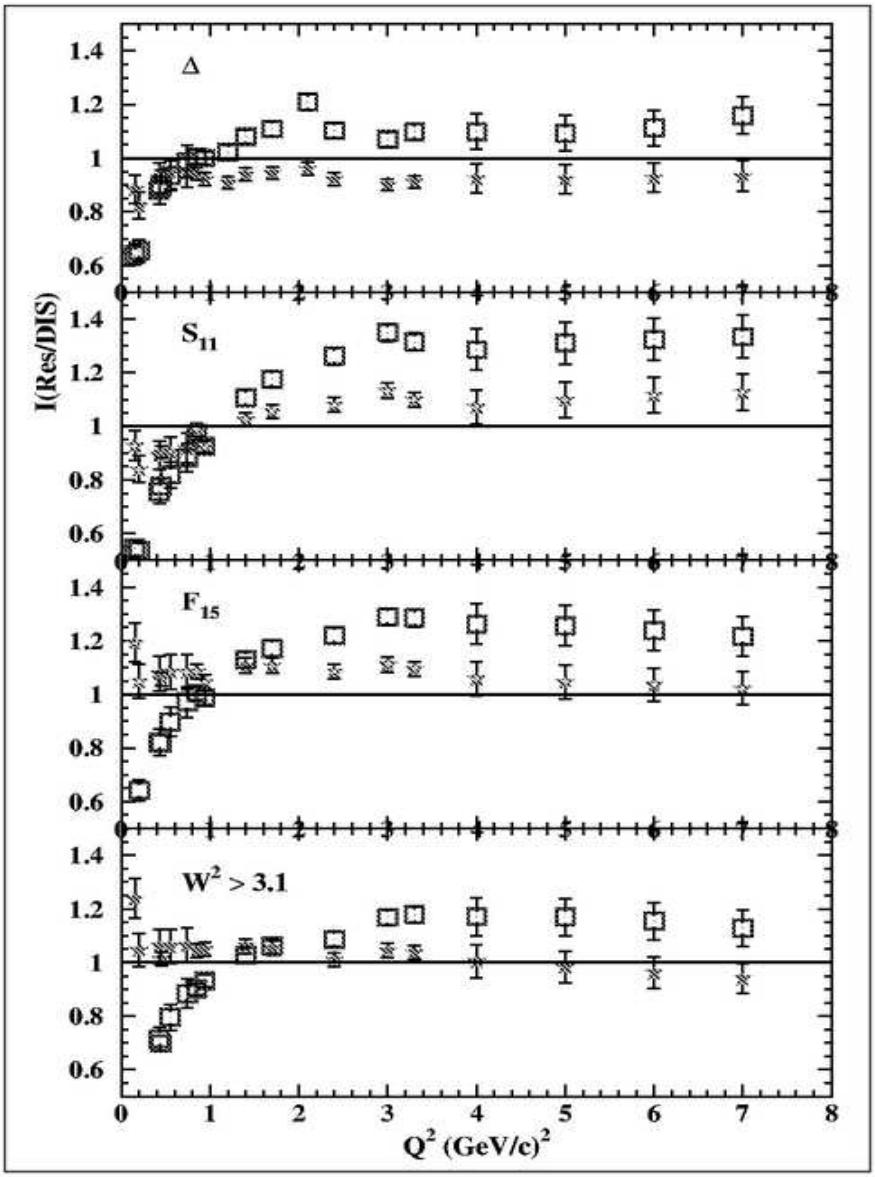
$$2\frac{M}{Q^2}\int_{\nu_a}^{\nu_b} \nu W_2(\nu, Q^2)\, d\nu = \int_{\omega'_a}^{\omega'_b} F_2(\omega')\, d\omega'$$

$$\nu_{a,b} = \frac{W_{a,b}^2 - M^2 + Q^2}{2M} \qquad \omega'_{a,b} = 1 + \frac{W_{a,b}^2}{Q^2}$$



B-G Scaling: Q^2 Dependence

- Ratio of *integrals* of νW_2 to F_2:
  - ratio ~ 1 for all mass ranges
  - ratio *independent of* Q^2 above a low ("precocious") value of $Q^2 \sim 1$ GeV^2
- Data:
  - JLab Hall C resonances data
  - NMC F_2 and Hall C fit to resonances



Duality for Other Structure Functions?

- ***Duality*** **seen for** F_2 **:**
  - **How about** F_1**?**
  - R **? Indications seen in recent Hall C measurement.**

- ***Duality*** **for** ***spin structure functions*** **?**
  (first asked in original 1995 RSS proposal)
  - $g_1 \Rightarrow$ ***polarized*** **counterpart of** F_1
  - **No unpolarized** g_2 **analog**
  - **How about** ***"composite"*** **functions like** A_1 **and** A_2**?**

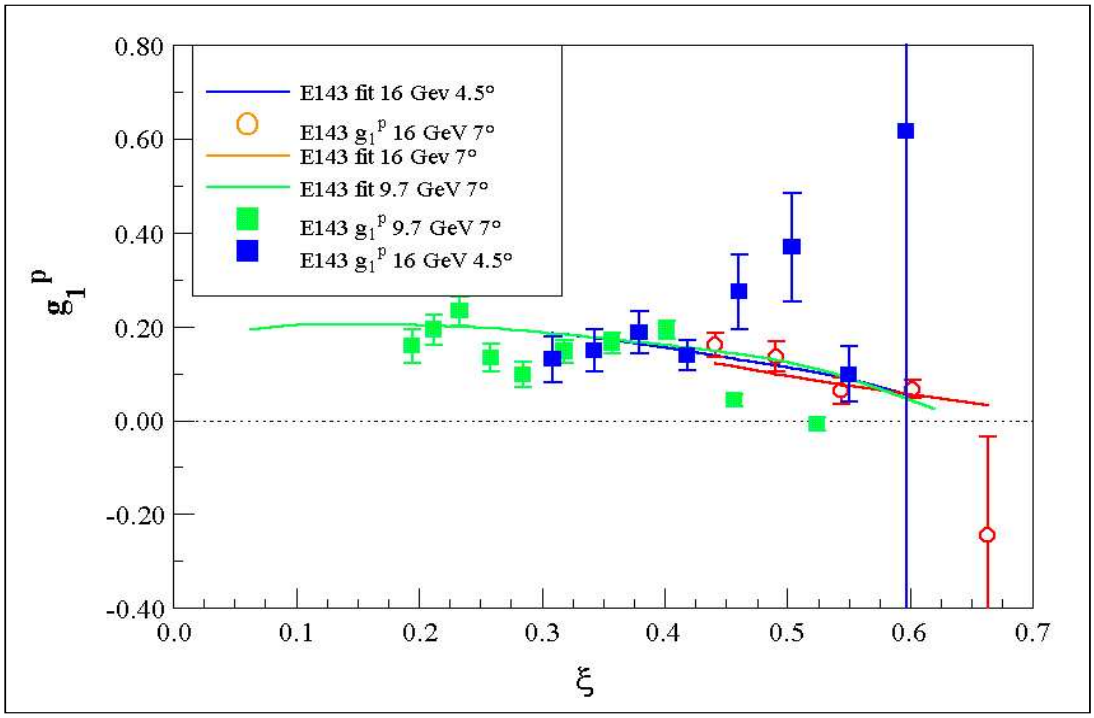
- ***Duality*** **for** ***neutron*** **structure functions:**
  - **how to** ***extract*** **them?**
  - ***free*** **vs.** ***bound*** **nucleons**

- ***Local Duality*** **can be a** ***powerful tool*** **to probe hard to reach kinematic regions**

Polarized Duality for g_1?

- **SLAC E143: g_1 from $A_{\parallel}$ assuming $A_2 = 0 = g_2$**
- **Resolution ΔW *too wide* for local duality test**
- ***Global duality* ratio of integrals:**

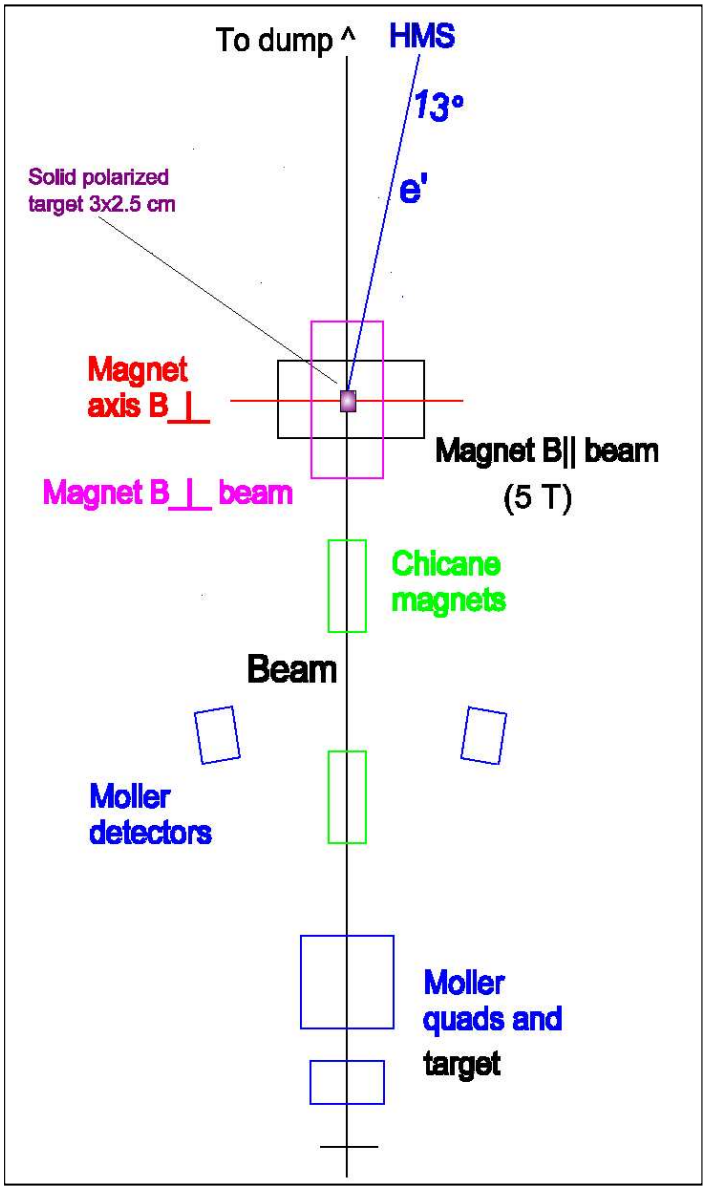
9.7 GeV	7.0°	0.67 ± 0.12
16.2 GeV	4.5°	1.40 ± 0.44
16.2 GeV	7.0°	1.14 ± 0.34



- **Preliminary results from Hall A E94-010 and Hall B EG1 show *indications* of *Polarized Duality***
  - ***Quantitative analysis* needed to establish *Local Duality***
- **Recent work by Liuti, Bianchi, and Fantoni [hep-ph/0308057]**

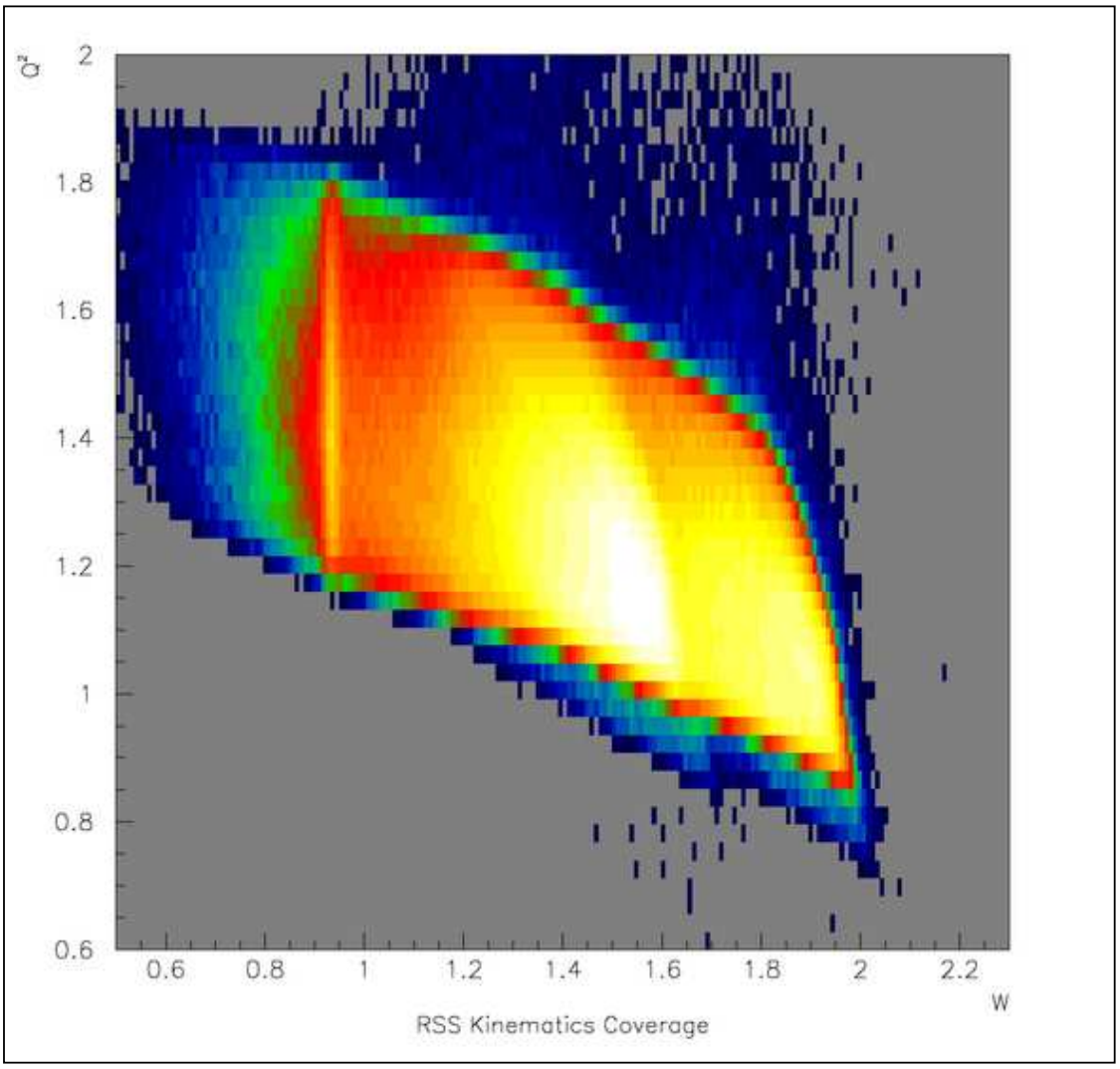
RSS Technique

- Measure *count asymmetries* $A_{\parallel}$, $A_{\perp}$ on *protons*, *deuterons*
- CEBAF *polarized electron* beam in Hall C
- *Polarized* NH_3 and ND_3 targets: Luminosity $\sim 10^{35}$ Hz cm^{-2}
- High Momentum Spectrometer HMS
- Data run period – Jan 21 to Mar 3, 2002
  - 160 M *proton* and 350 M *deuteron* triggers



RSS Kinematics

- **Beam** *energy* $E_0 = 5.755$ GeV
- **HMS** *angle* $\theta_{HMS} = 13^\circ$
- **HMS** *central momenta* 4.71 GeV/c **and** 4.08 GeV/c
- **Final state** *mass range* $0.8 \leq W \leq 2.0$ GeV
- $< Q^2 > = 1.3\,(\mathrm{GeV}/c)^2$



Measured Asymmetries $A_{\parallel}, A_{\perp}$

- Measure inclusive ***asymmetries*** of ***polarized electrons*** scattered off ***polarized target***

- Target polarization $\parallel$ and $\perp$ to the beam, $A_{\parallel}, A_{\perp}$

$$A_{\parallel,\perp} = \frac{1}{C_N f_{RC}} \left(\frac{\epsilon}{f P_b P_t} - C_D \right) + A_{RC}$$

$$\epsilon = \frac{L - R}{L + R}$$

- L, R = charge norm., dead time and pion corr. nos. of *counts* for *opposite beam helicities*
- f = *dilution factor* – ratio of rates from polarized nucleons/all nucleons
- P_b, P_t = beam, target *polarizations*
- C_N, C_D = *corrections* for N in *ammonia*
- f_{RC}, A_{RC} = *radiative corrections*

How to get A_1, A_2?

- From $A_{\parallel}$ and $A_{\perp}$, can determine A_1 and A_2:

$$\boxed{A_1 = \frac{C}{D}\left(A_{\parallel} - dA_{\perp}\right)}$$

$$\boxed{A_2 = \frac{C}{D}\left(c'A_{\parallel} + d'A_{\perp}\right)}$$

- C, c', d, d', D are *kinematic variables*, albeit D depends on $(R = \sigma_L/\sigma_T)$

- Compatible systematic effects for both $A_{\parallel}$, $A_{\perp}$ are important

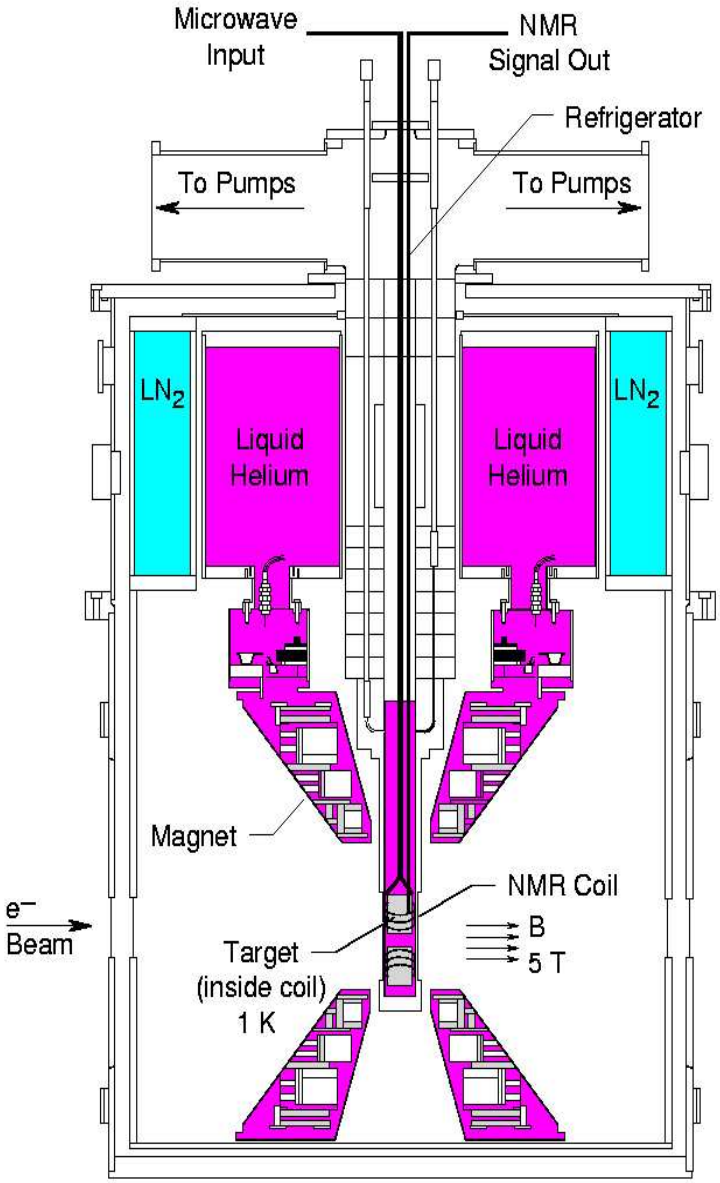
- g_1 and g_2 can be extracted from:
  - $A_{\parallel}$ and $A_{\perp}$
  - A_1 and A_2

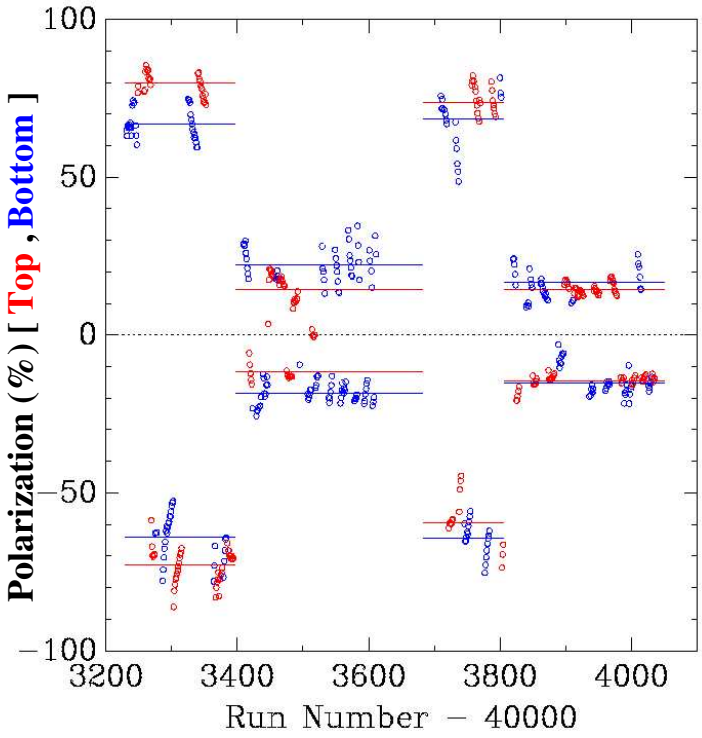
  } requires F_2 and R

  - directly from *cross section difference*; without F_2 and R

Polarized Target

- ***Dynamic Nuclear Polarized*** **(DNP) ammonia (NH_3) and deuterated ammonia (ND_3)**
- **^{12}C disks and ^4He for *normalization***

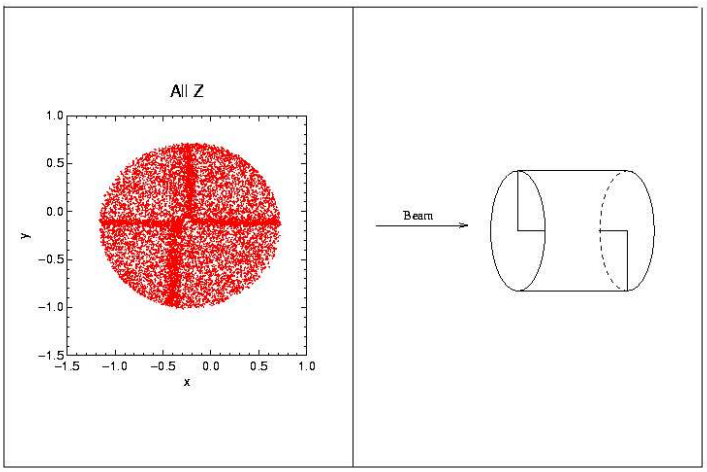




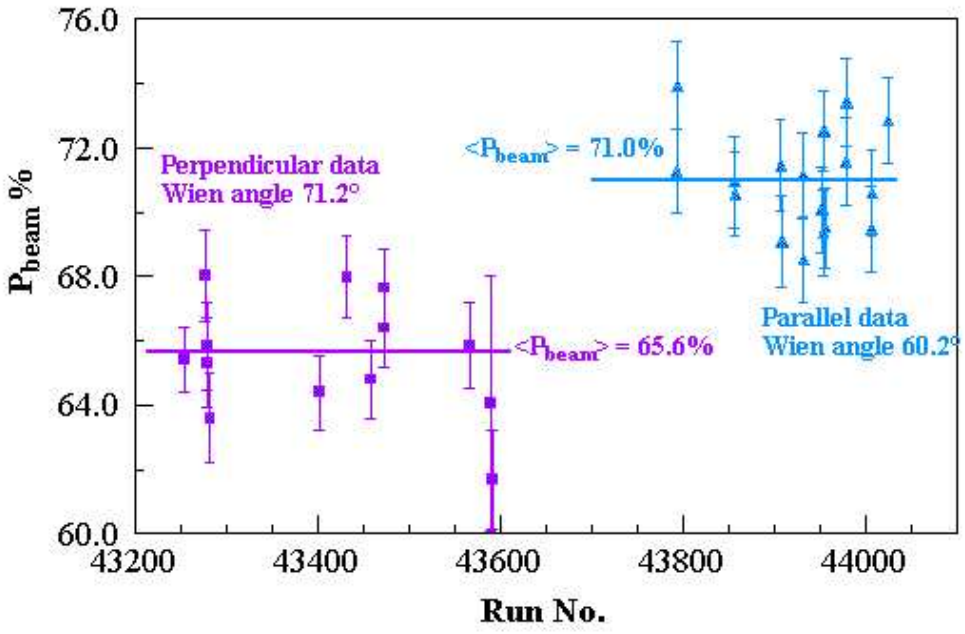
Beam

- Beam *current*:
  - 150 – 200 nA for ND_3, ^{12}C, ^4He
  - 85 – 100 nA for NH_3

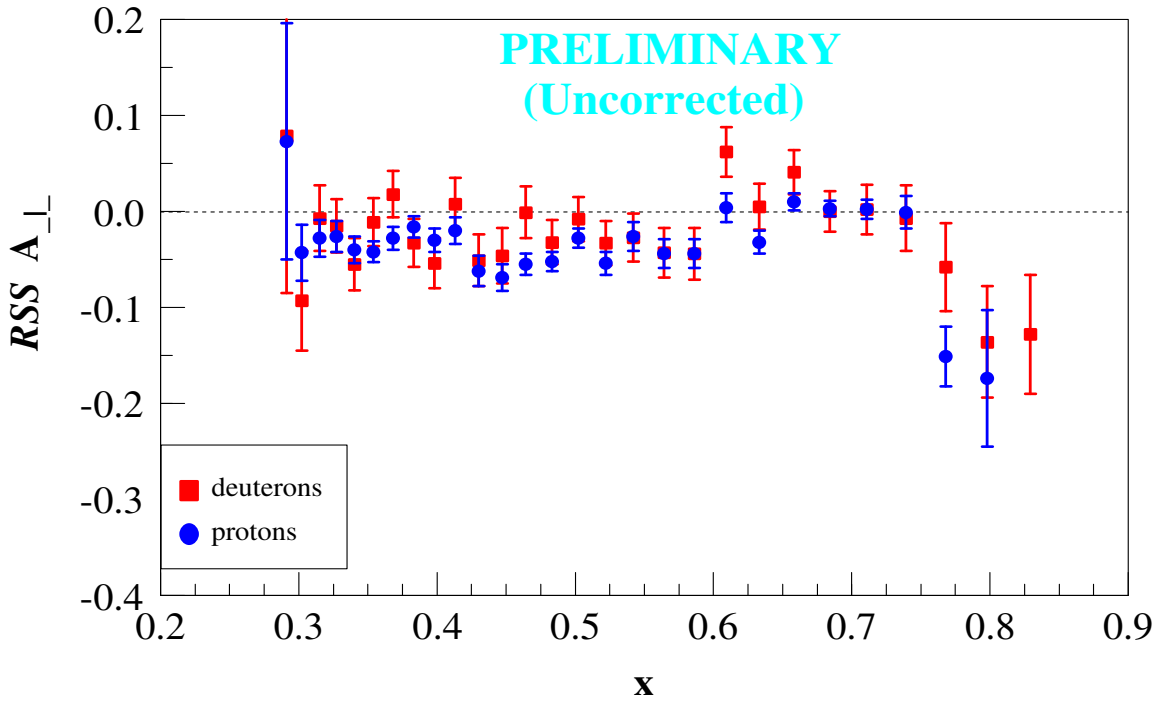
- Beam *position* on target monitored w/ tungsten cross hairs

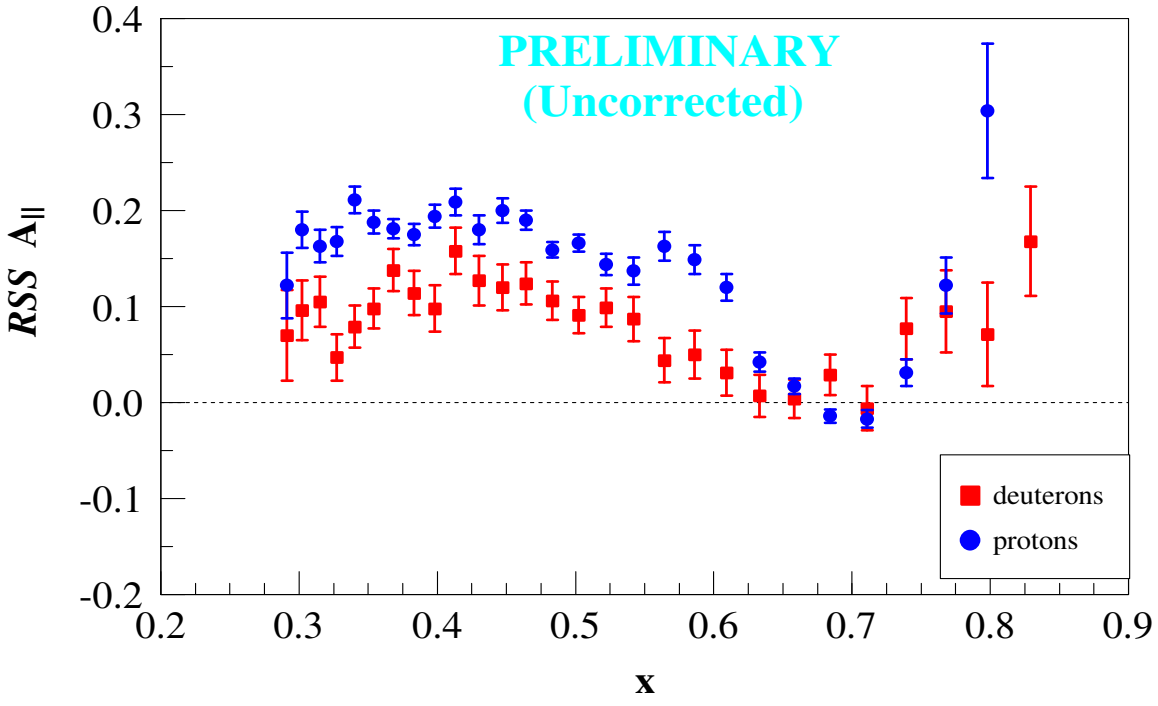


- Beam *polarization* measured with Moller polarimeter in Hall



RSS Preliminary Asymmetries





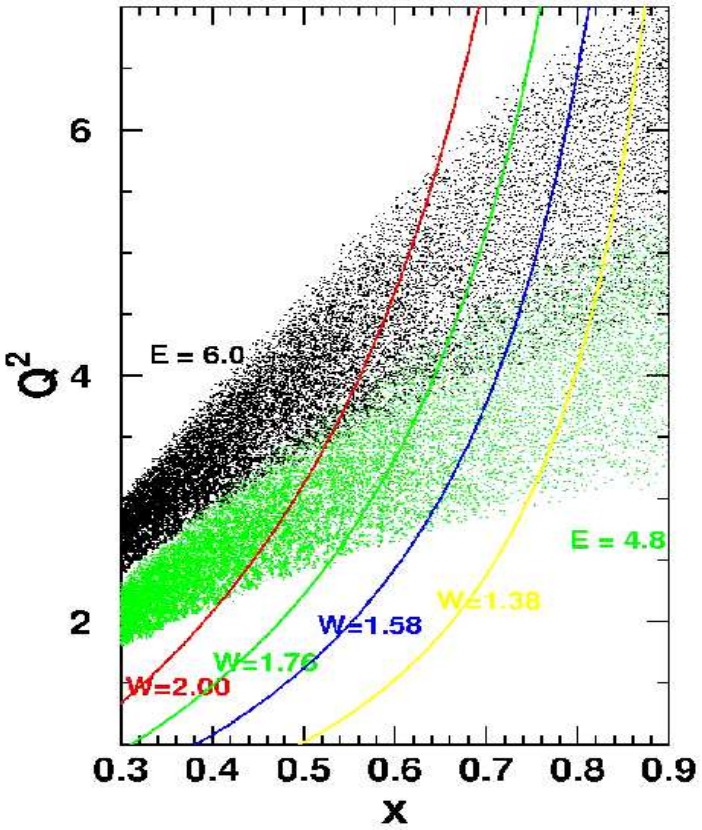
- Preliminary *dilution factor* (same packing fraction for all targets) applied in restricted range: $1.0 < W < 1.9$ GeV
- *Radiative corrections*, individual *packing fractions*, *N asymmetry* – to be done

JLab E-03-109
"Spin Asymmetries of Nucleon Expt."
(SANE)

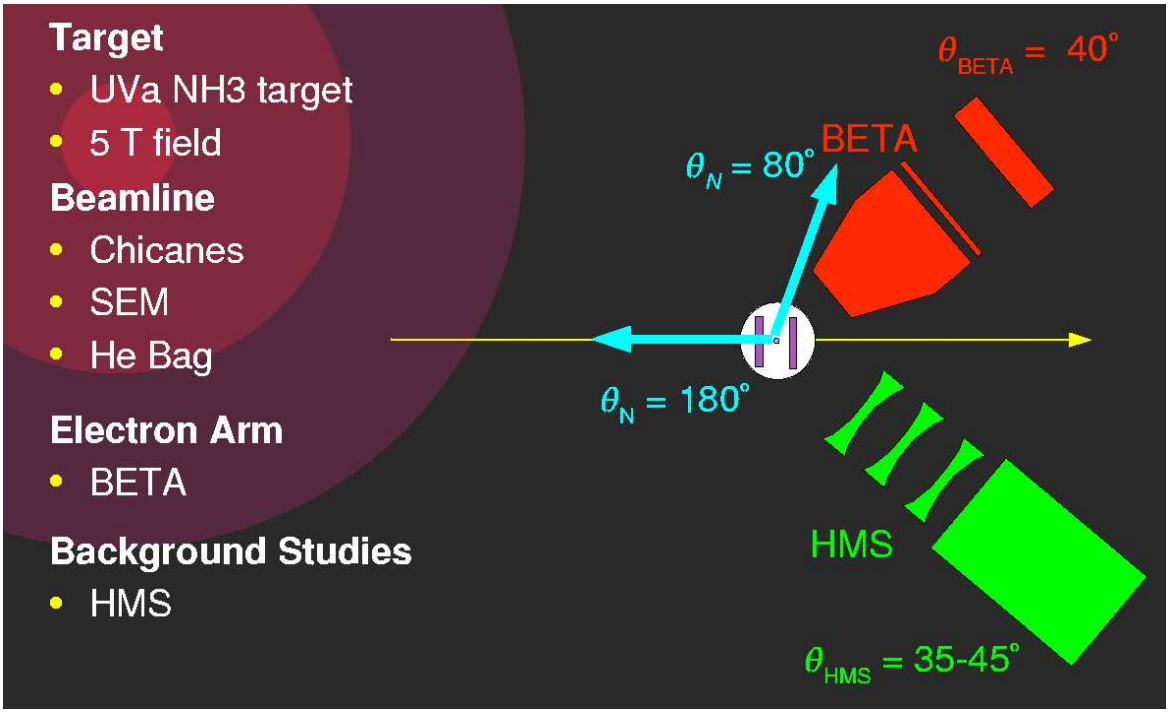
Spokesmen:	**Glen Warren**	**(Jefferson Lab)**
	Oscar A. Rondon	**(U of Virginia)**
	Zein-Eddine Meziani	**(Temple Univ.)**
	Seonho Choi	**(Temple Univ.)**

- **Measure *proton* spin structure function $g_2(x, Q^2)$ and spin asymmetry $A_1(x, Q^2)$**
  - **at $2.5 \leq Q^2 \leq 6.5$ GeV^2 and $0.3 \leq x \leq 0.8$**
- **Study:**
  - **x and Q^2 *dependence***
  - ***twist-3* effects**
  - **moments of g_2 and g_1**
  - **comparison with *Lattice* QCD predictions**
  - **test *polarized local duality* for $W > 1.4$ GeV**
- **Detect electrons with:**
  - **large solid angle electron telescope BETA**

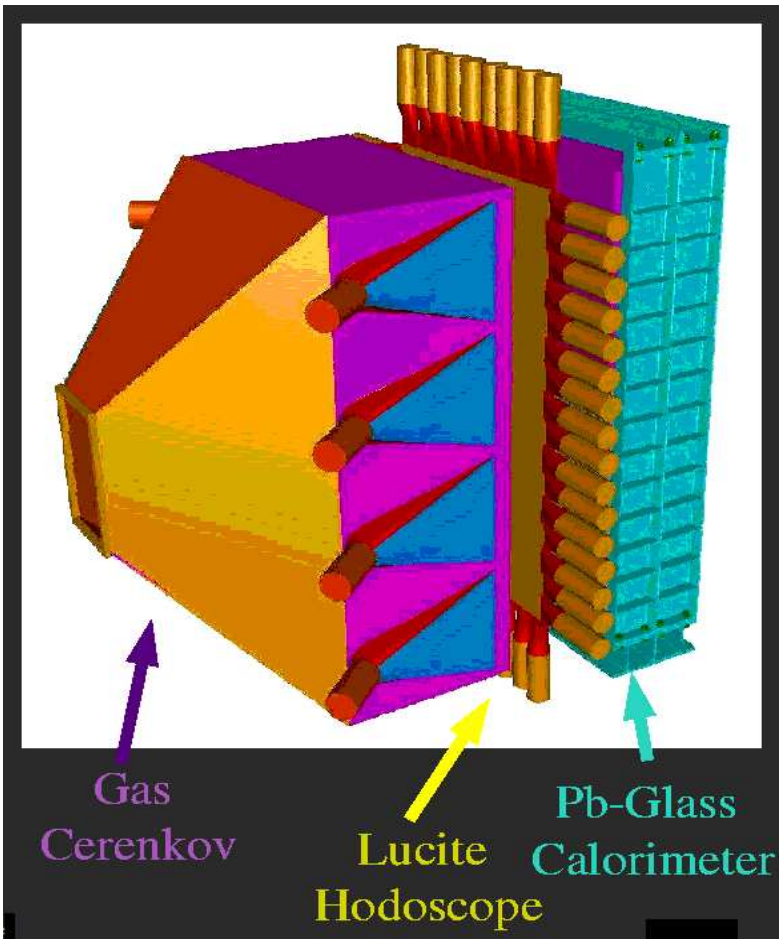
SANE Kinematics and Layout



- **Two beam *energies* – *4.8* GeV and *6.0* GeV**



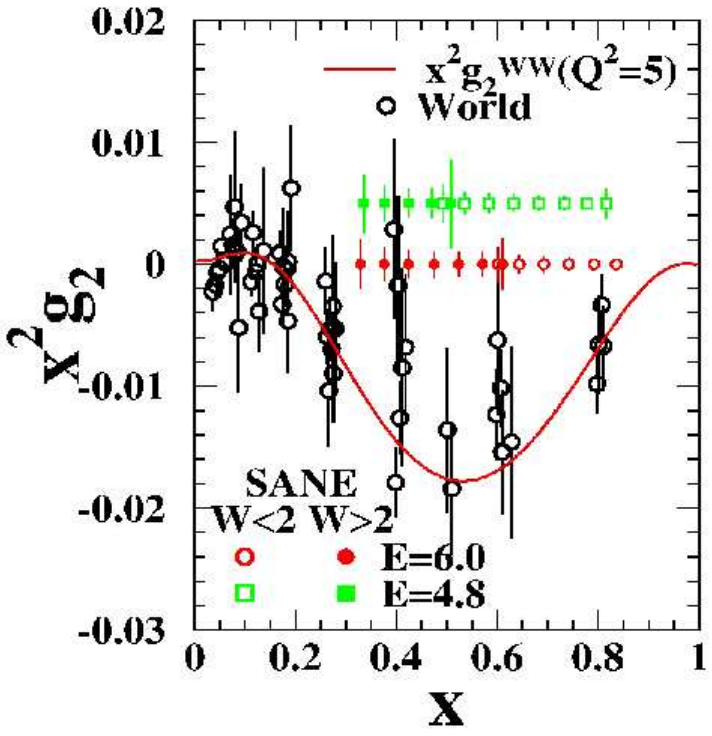
Big Electron Telescope Array - BETA

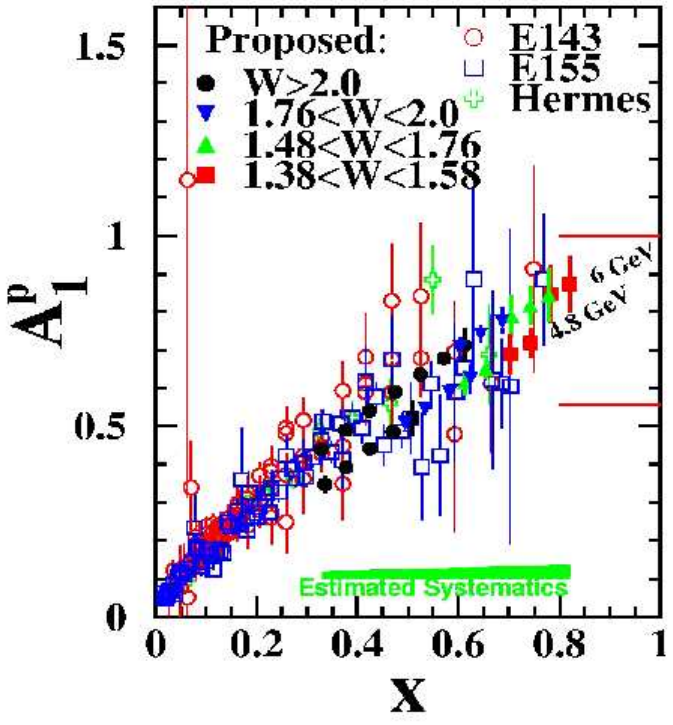


- ***Three subsystems*:**
  - ***Lead glass calorimeter*** – main detector
  - ***Gas Cherenkov (N)*** – additional pion rejection
  - ***Lucite hodoscope*** – tracking
- ***Characteristics*:**
  - ***Effective solid angle*** (with cuts) = ***0.194*** sr
  - ***Energy resolution*** $5\%/\sqrt{E}$
  - ***Angular resolution*** 2°
  - ***1000:1 pion rejection***

SANE Expected Results - I

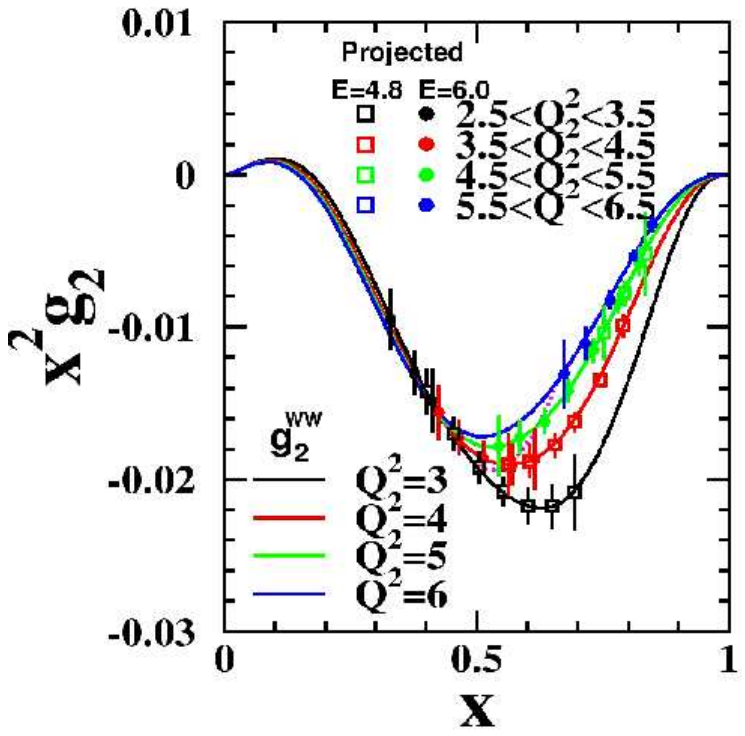
- DIS data for x up to 0.6
- Resonance data measured down to $W = 1.38$ GeV

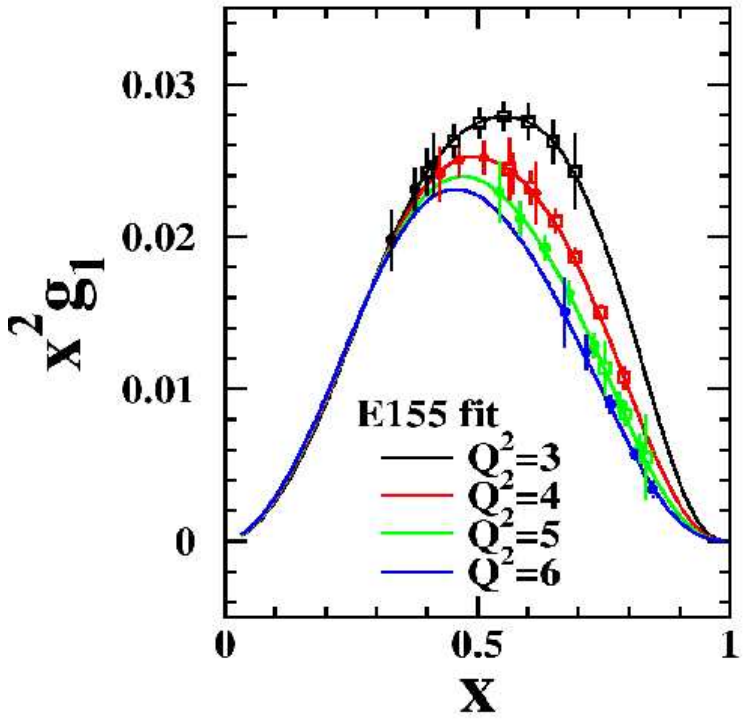




SANE Expected Results - II

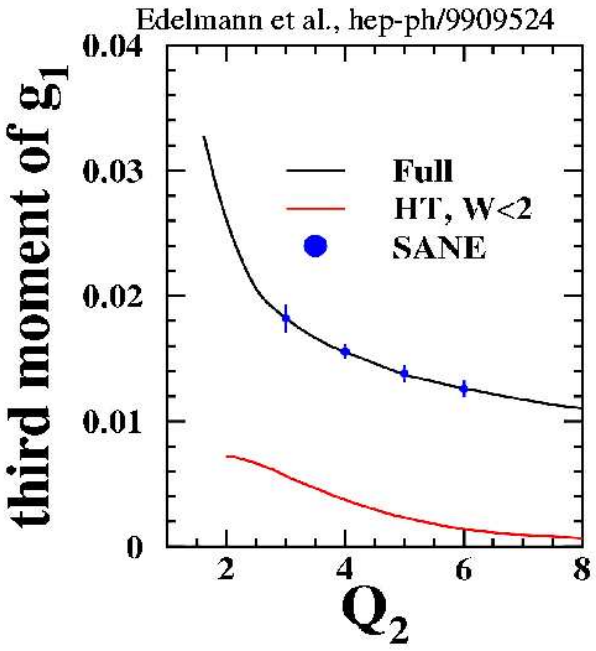
- x dependence at *constant* Q^2 and Q^2 dependence at *fixed* x

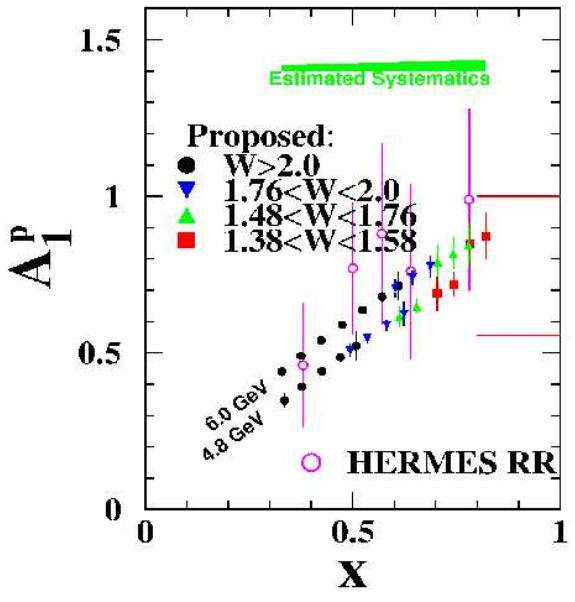




SANE Expected Results - III

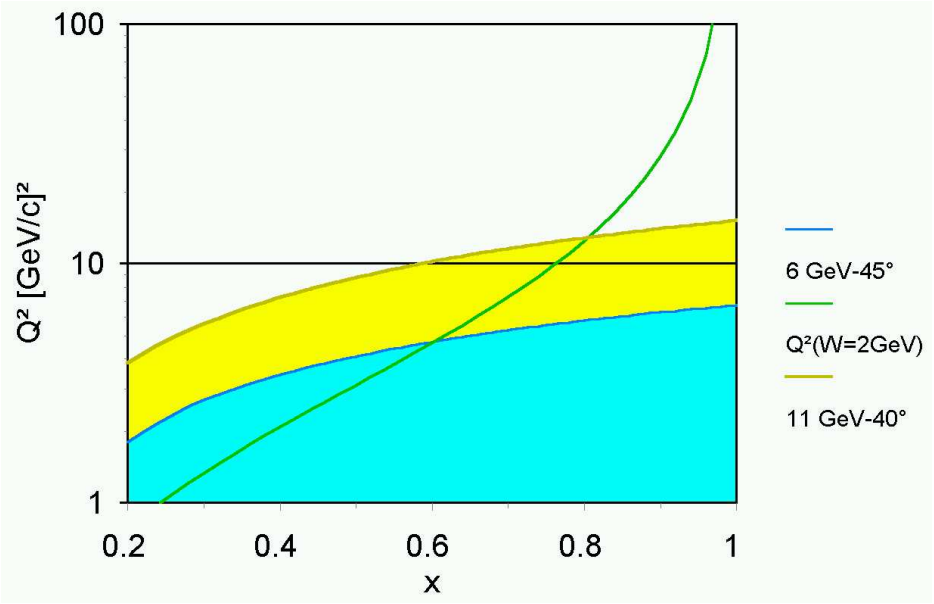
- ***Twist-3*** matrix element $d_2 = \int_0^1 x^2\,(2g_1 + 3g_2)\,dx$ calc. in lattice QCD
- Expected ***error*** on d_2 ($Q^2 = 2.5$ to 6.5 GeV^2) = **0.0009** (*1/2* the error of the current world data)
- Test ***polarized local duality*** w/ ΔW resolution $\leq$ 130 MeV, constant Q^2

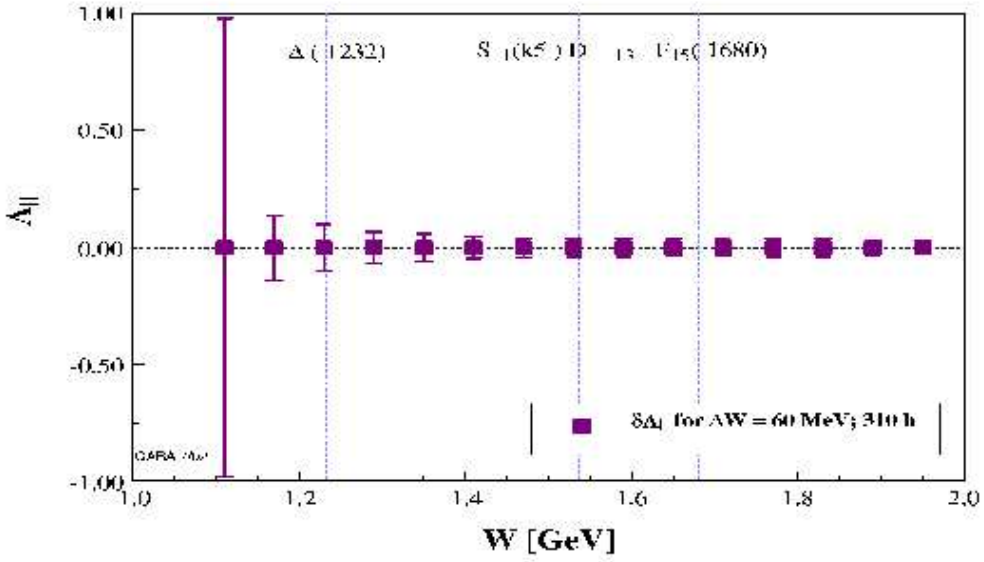




Local Duality at 12 GeV

- **CEBAF *12* GeV upgrade extends Q^2 range, improves count rates**
- ***Precision tests* of local *polarized* and *unpolarized* duality possible**
- **Positive results would establish *local duality as tool for other physics***





CLAS "EG1" Experimental Program

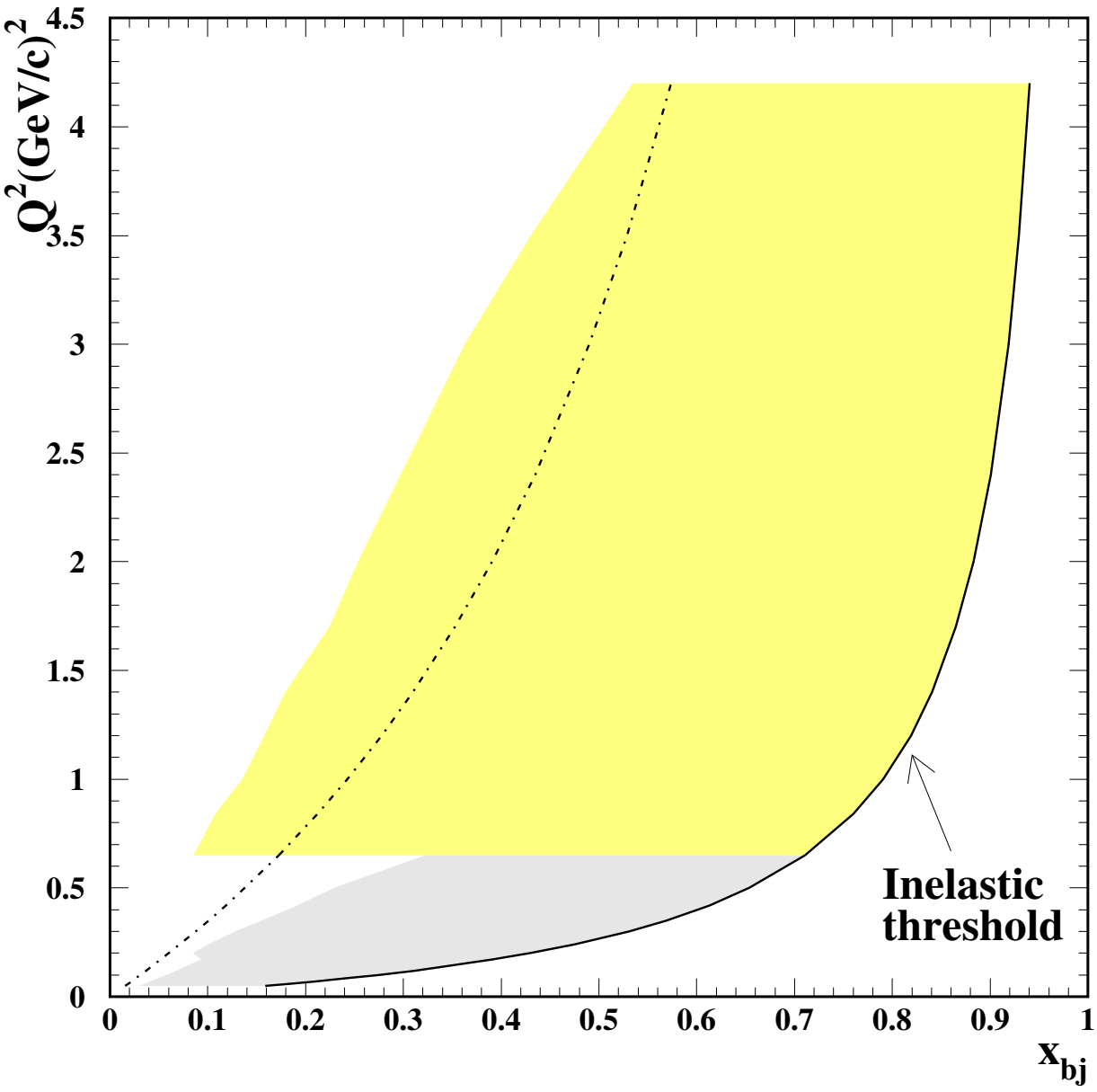
"Proton and Deuteron Spin Structure Function Measurements at CLAS"

Reporting on the work of *three graduate students*

▶ Vipuli Dharmawardane	(Old Dominion University)
▶ Yelena Prok	(University of Virginia)
▶ Shifeng Chen	(Florida State University)

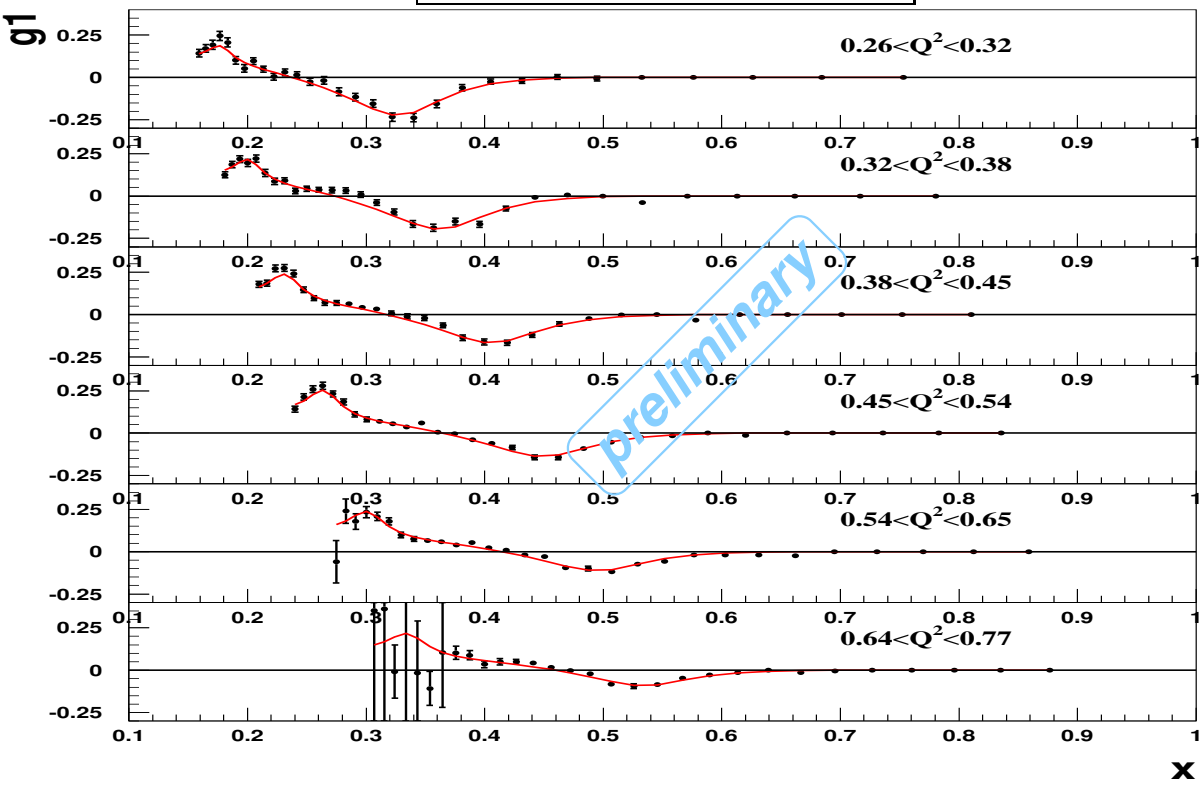
- Longitudinally *polarized electrons* from CEBAF
  - beam *polarization* $\sim$ *70%*
  - beam *energies* – *1.6, 2.5, 4.2, 5.6* GeV
- CEBAF Large Acceptance Spectrometer (CLAS) in Hall B
  - multi-particle final states
  - measure large range in Q^2 and W
- *Polarized* solid ammonia *targets*
  - NH_3 polarization: *70-90%*
  - ND_3 polarization: *10-35%*
  - ^{12}C, ^{15}N, ^{4}He targets for background subtraction
- *Two* running periods
  - *EG1a* - 1998 for 2 months; 3×10^9 triggers
  - *EG1b* - 2000-01 for 7 months; 23×10^9 triggers
- Only *1.6* GeV and *5.6* GeV data analyzed so far
- *Spin Asymmetries*, A_1, and *Structure Functions*, g_1 from $A_{\|}$
- Generalized *GDH Integrals*, Γ_1, at low Q^2

EG1 Kinematics

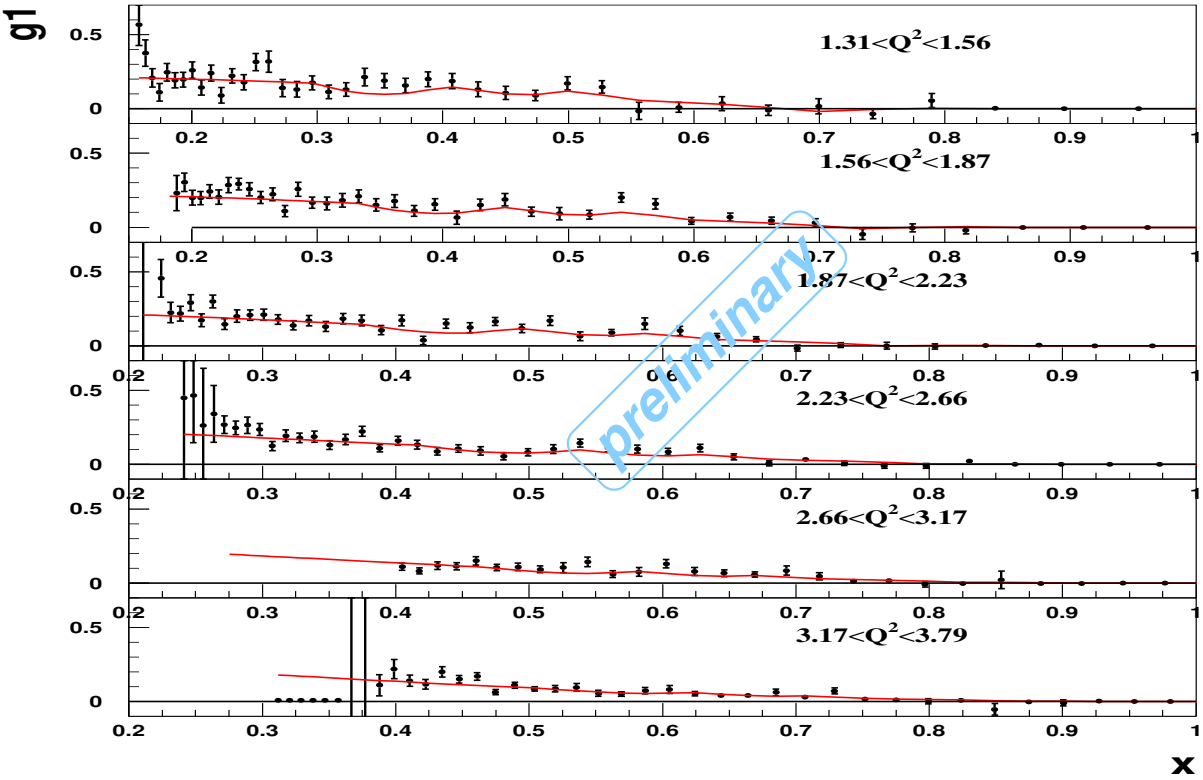


$g_1(x)$ for the Proton

$g_1^p(x)$ for $E=1.6$ GeV

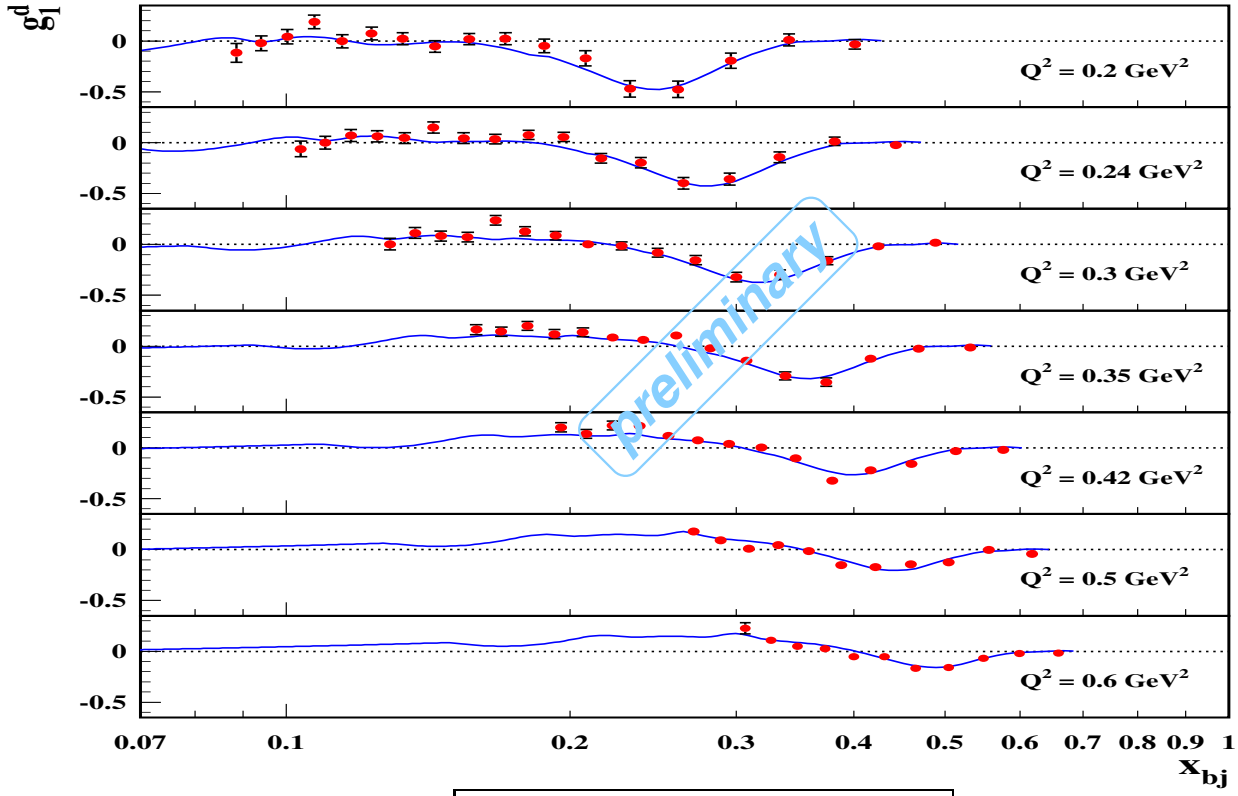


$g_1^p(x)$ for $E=5.6$ GeV

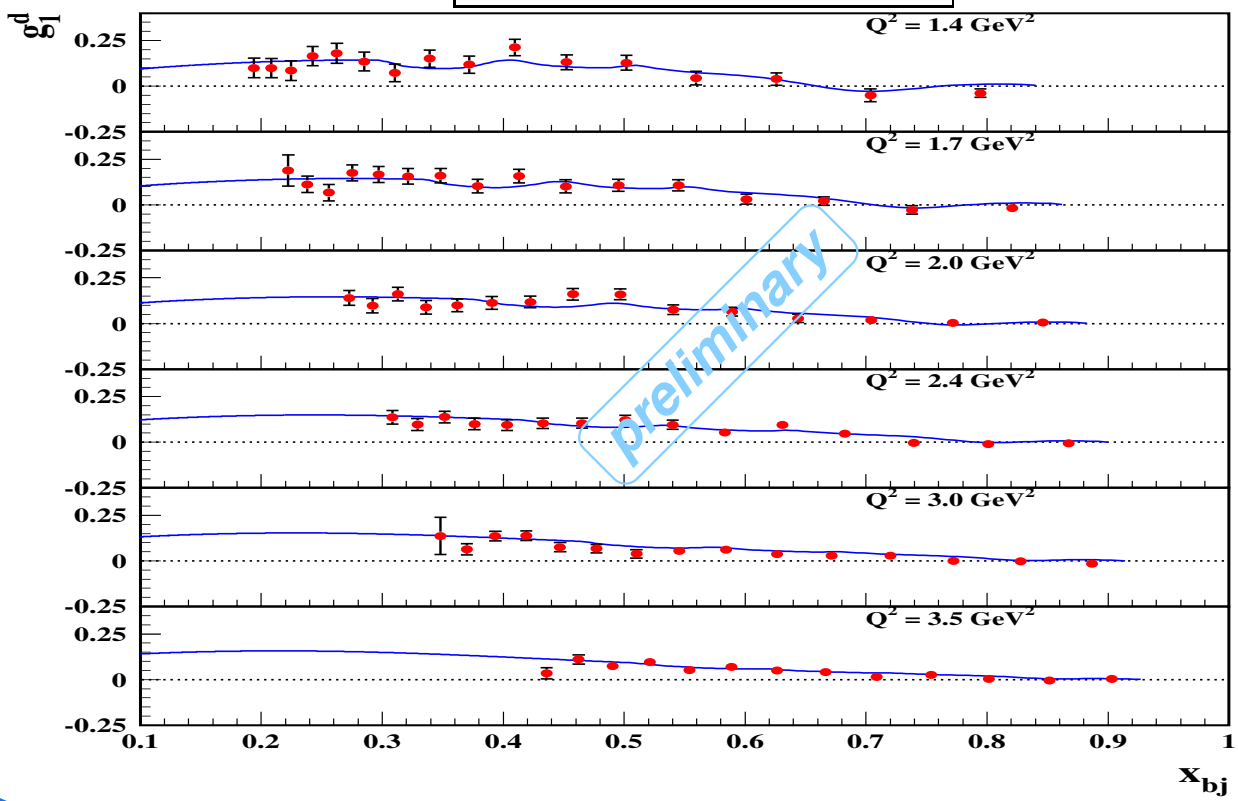


$g_1(x)$ for the Deuteron

$g_1^d(x)$ for $E=1.6$ GeV



$g_1^d(x)$ for $E=5.6$ GeV

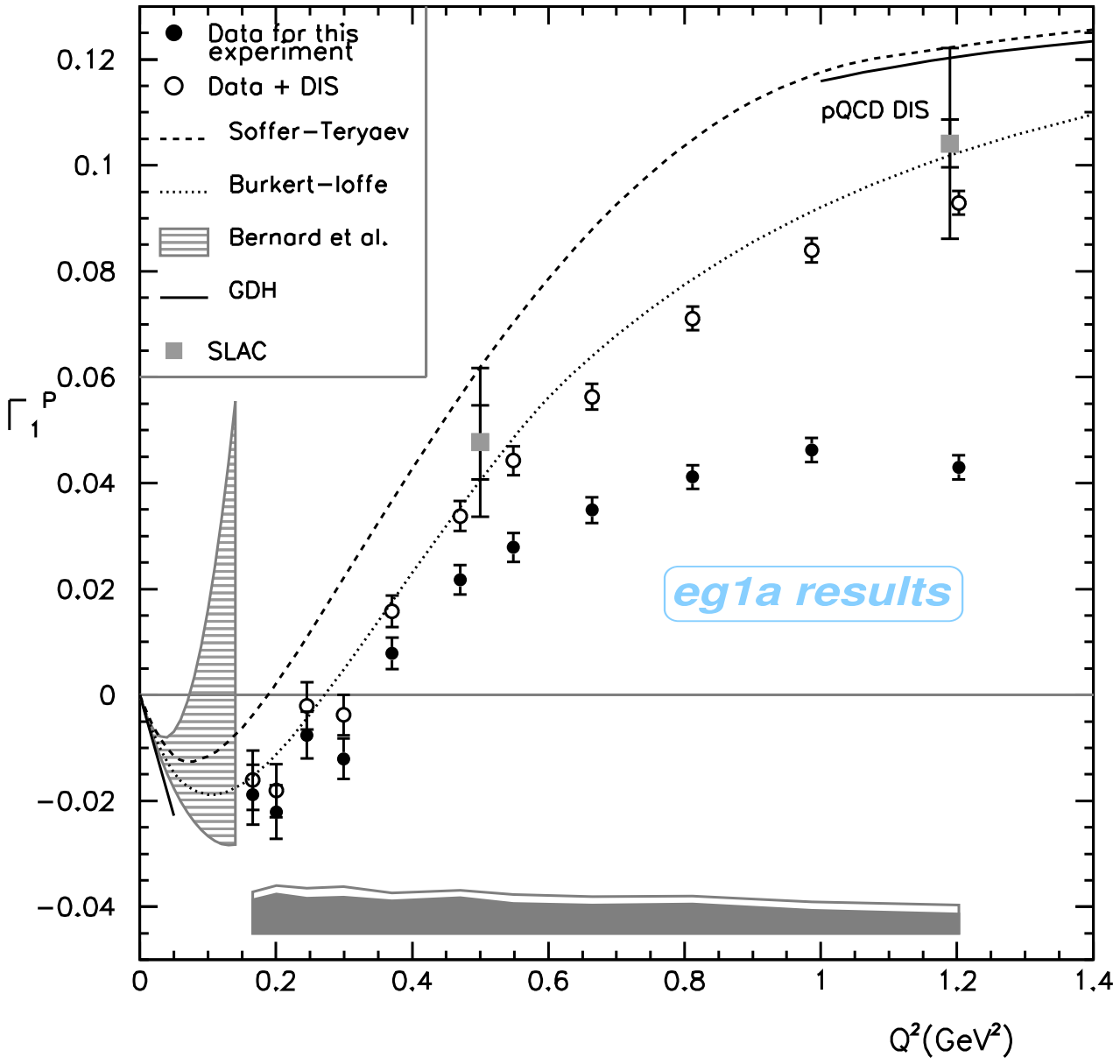


$g_1(x)$ for Proton and Deuteron

- $g_1(x)$ from $A_{||}$ only, ηA_2 small from model estimate
- Δ drives $g_1^p(x)$ and $g_1^d(x)$ *negative* at low Q^2 and moderate x
- $g_1^p(x)$ and $g_1^d(x)$ *positive* for higher lying resonances
- Curves are *EG1 Models*
  - fit to data
  - resonance calculations using AO and MAID with helicity amplitudes modified to fit data
  - include fit to data for R and F_2

Integral $\Gamma_1(Q^2)$ for the Proton - I

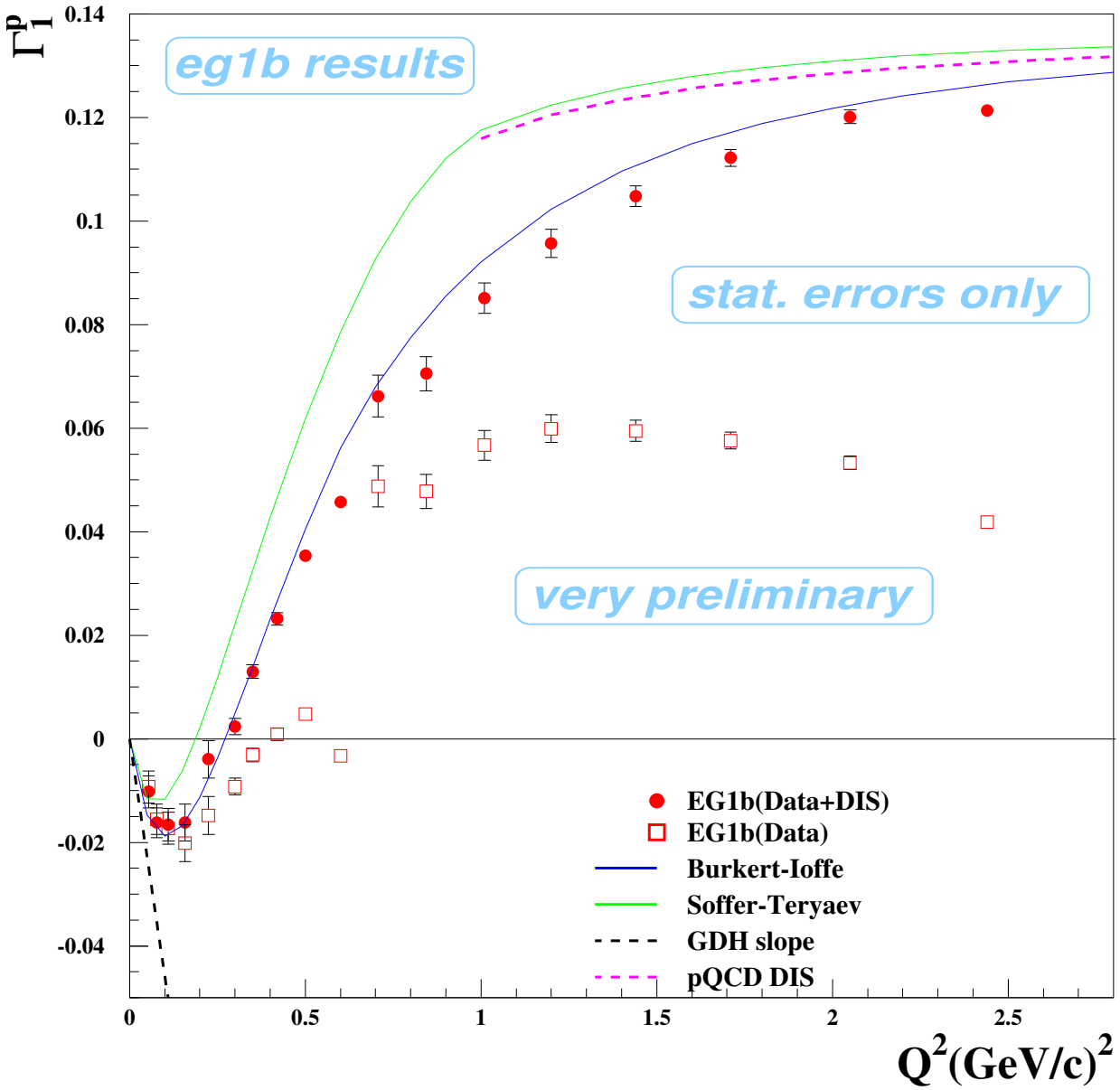
$$\Gamma_1^p(Q^2) = \int_o^1 g_1^p(x, Q^2)\, dx$$ *(elastic excluded)*



- Published ***EG1a*** data at *2.6* and *4.3* GeV
  R. Fatemi *et al.*, [PRL 91, 222002 (2003)]
- Low Q^2 region is interesting
  - χPT prediction below $Q^2 = 0.1$ GeV^2

Integral $\Gamma_1(Q^2)$ for the Proton - II

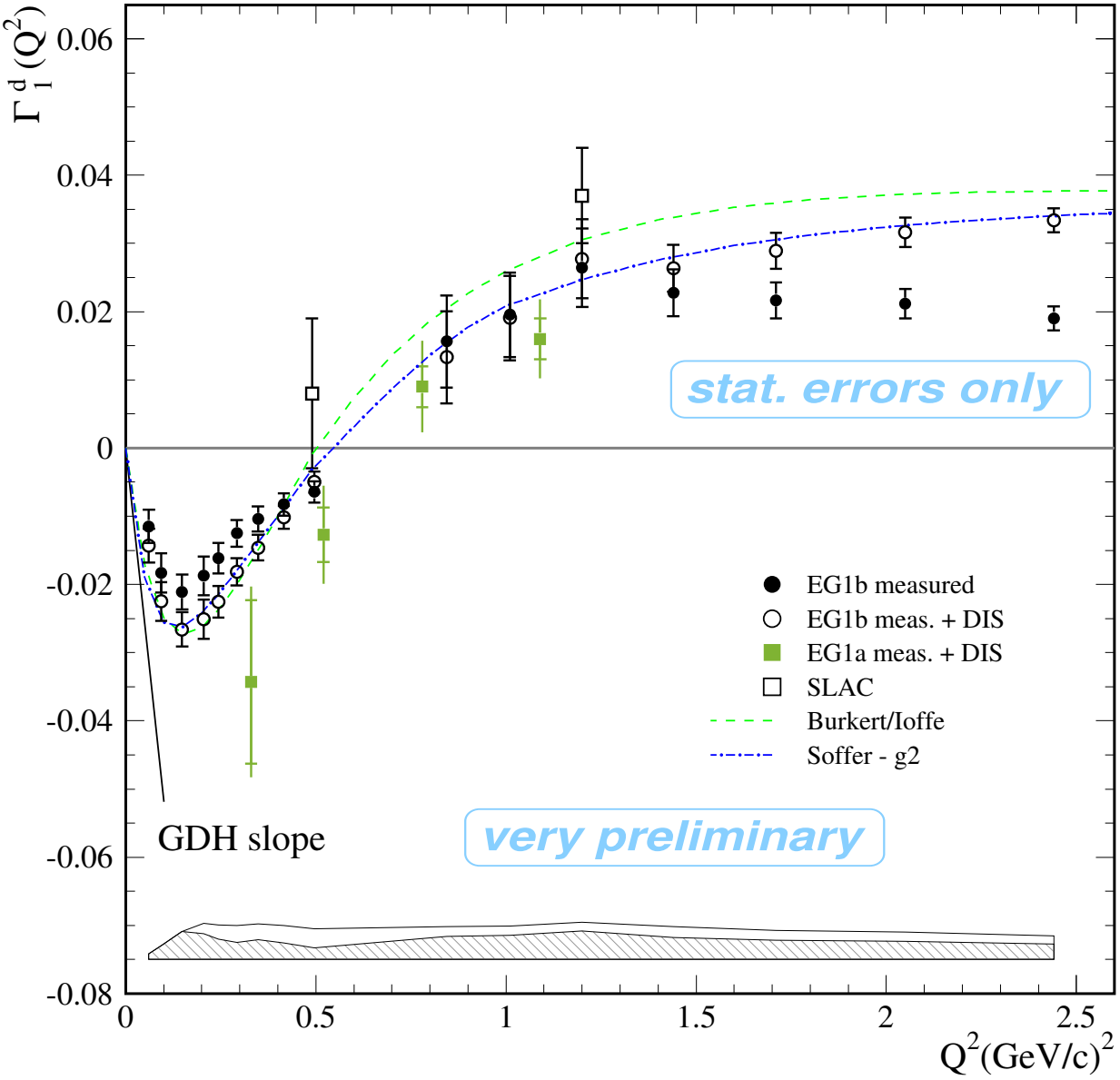
$$\Gamma_1^p(Q^2) = \int_o^1 g_1^p(x, Q^2)\, dx$$ *(elastic excluded)*



- High statistics data for $Q^2 < 0.5$ GeV^2
- With new *2.5* GeV and *4.2* GeV data
  - gap in Q^2 will be filled-in with better precision

Integral $\Gamma_1(Q^2)$ for the Deuteron - I

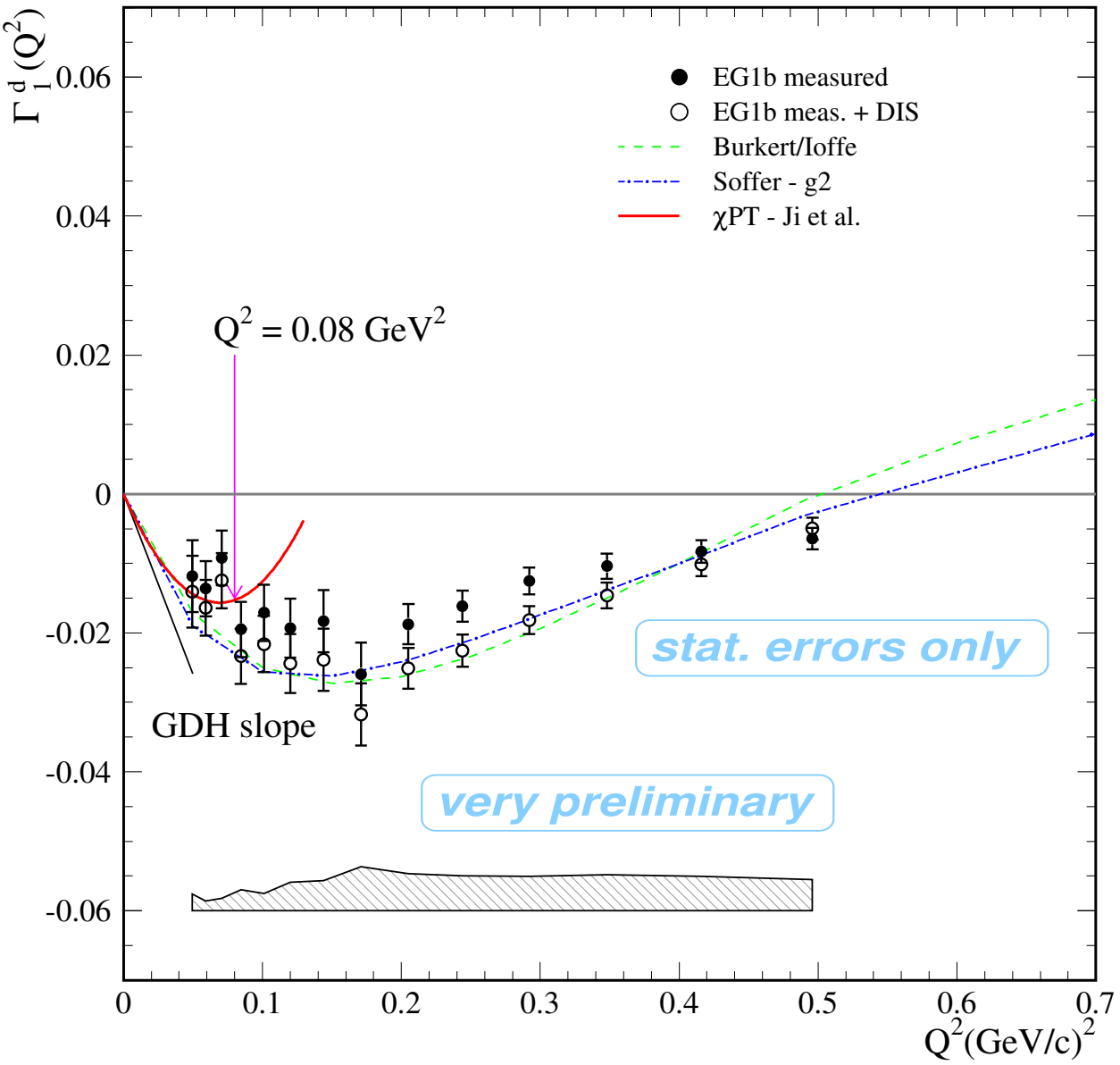
$$\Gamma_1^d(Q^2) = \int_o^1 g_1^d(x, Q^2)\, dx$$



- **First precise results for Γ_1^d at $Q^2 < 0.5$ GeV^2**

Integral $\Gamma_1(Q^2)$ for the Deuteron - II

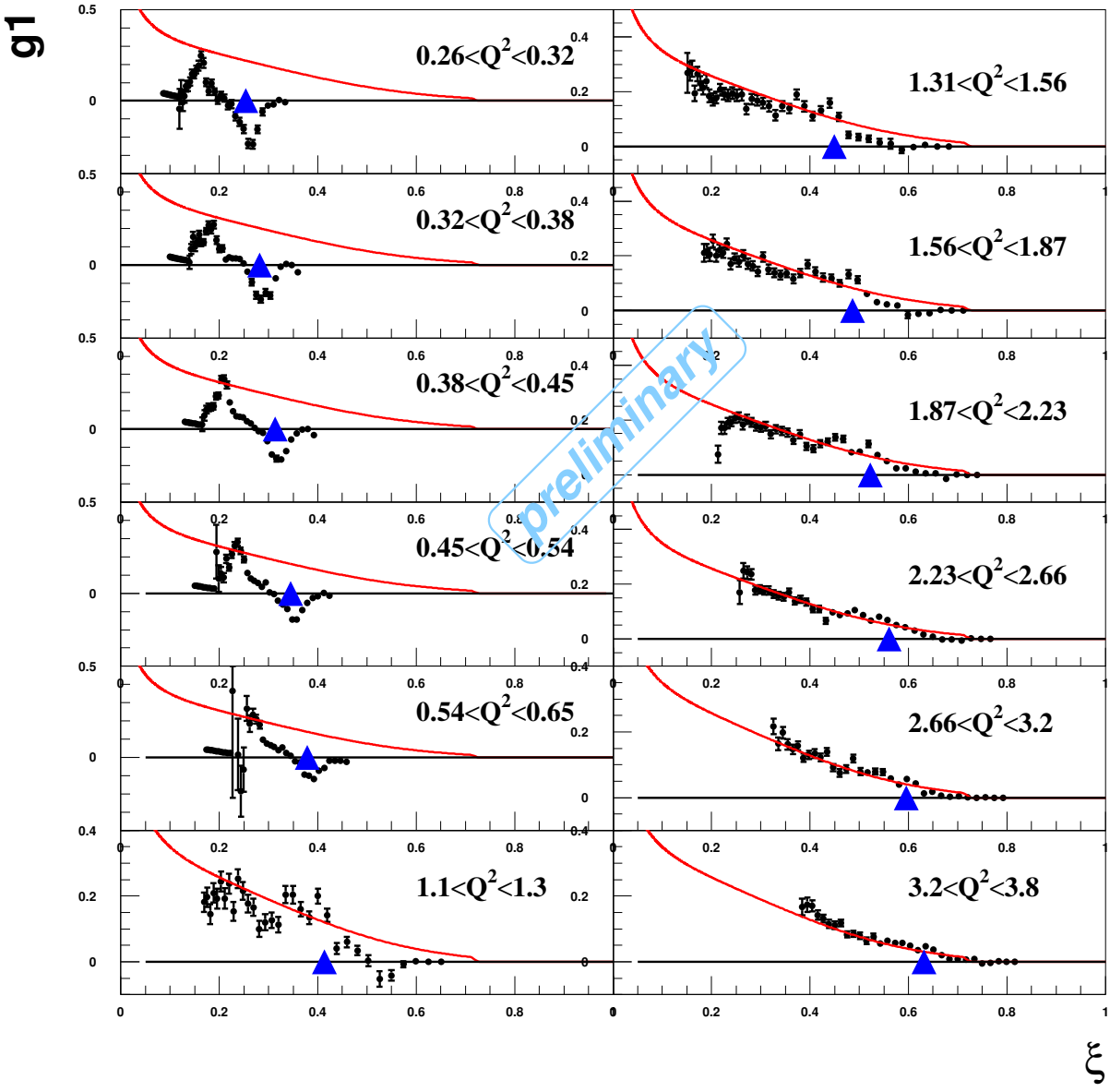
Γ_1^d for $Q^2 < 0.5$ GeV^2



- ***χPT* prediction below $Q^2 = 0.1$ GeV^2**

$g_1(\xi)$ *Duality for the Proton*

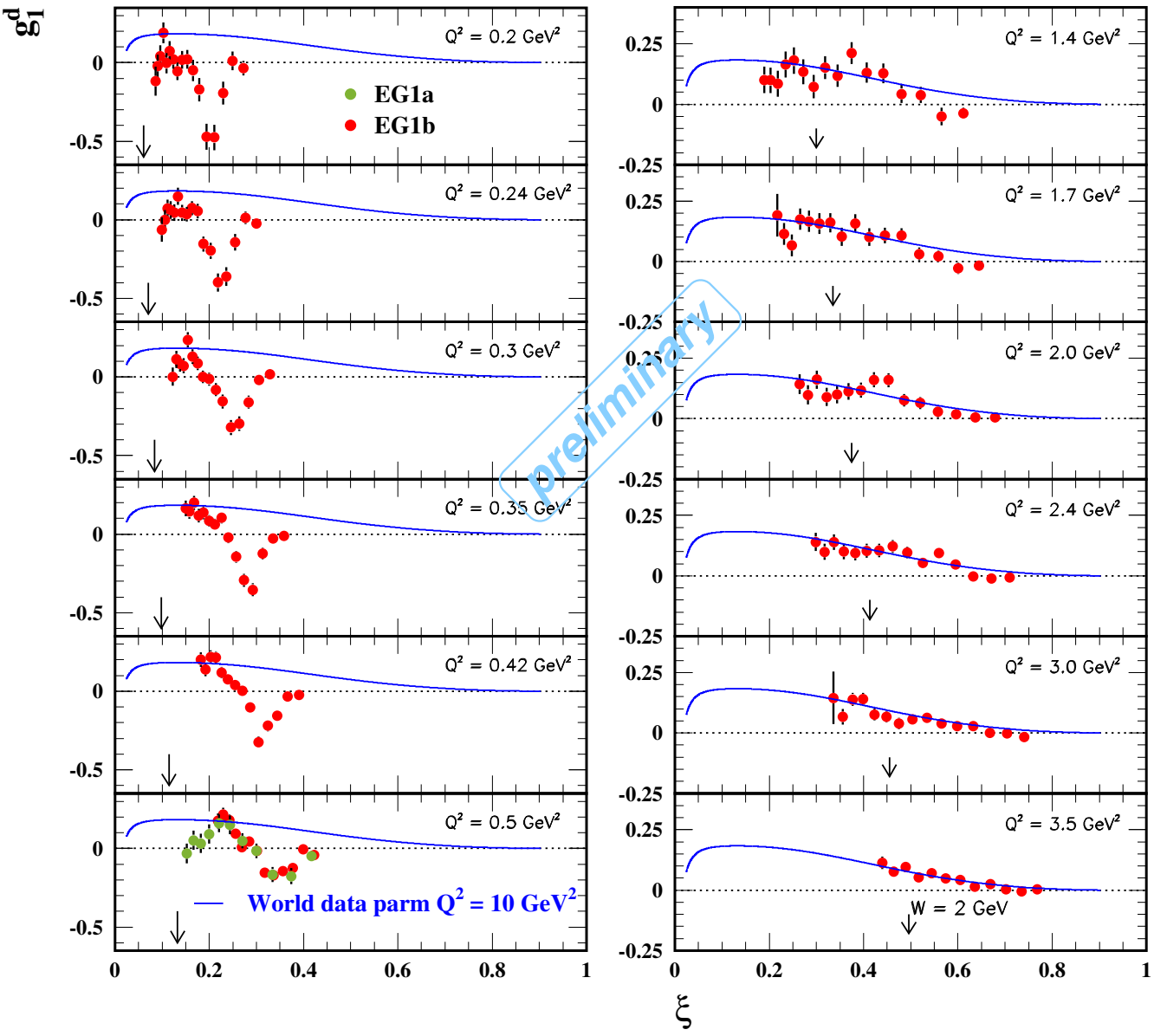
$g_1^p(\xi)$ for *E=1.6* and *E=5.6* GeV



- *Nachtmann* variable, $\xi = \frac{2x}{1+\sqrt{1+4M^2x^2/Q^2}}$
  ($\sim 0.2 < Q^2 < 3.5$ GeV^2)
- Curves are global fit to world data at $Q^2 = 10$ GeV^2
- Δ causes g_1 to deviate strongly from DIS scaling curves

$g_1(\xi)$ Duality for the Deuteron

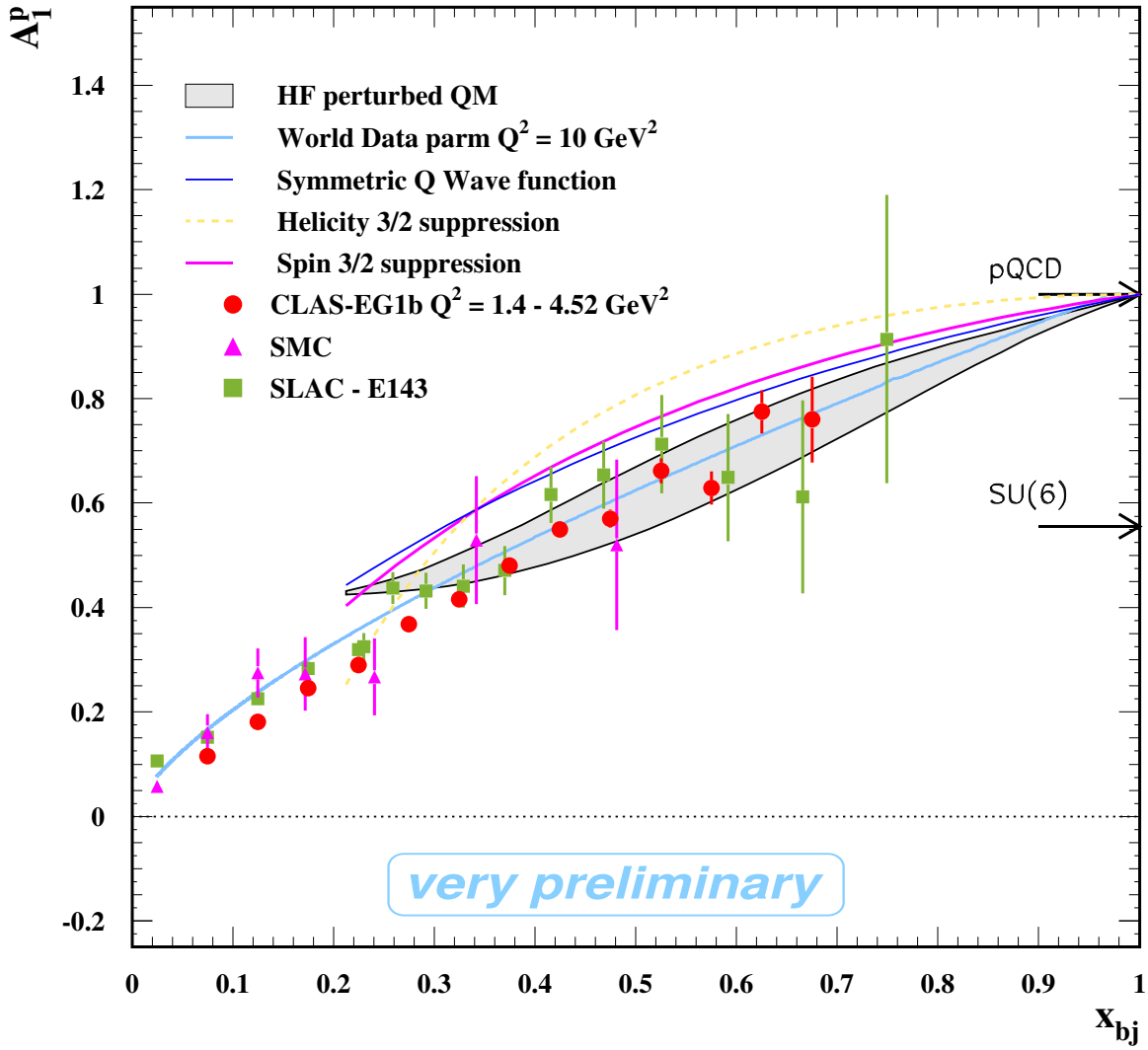
$g_1^d(\xi)$ for E=1.6 and E=5.6 GeV



- *Duality* seems to be *valid* for *proton* and *deuteron* g_1 for as low as $Q^2 \sim 1.4$ GeV^2 (excluding Δ region)

Asymmetry $A_1(x)$ for the Proton

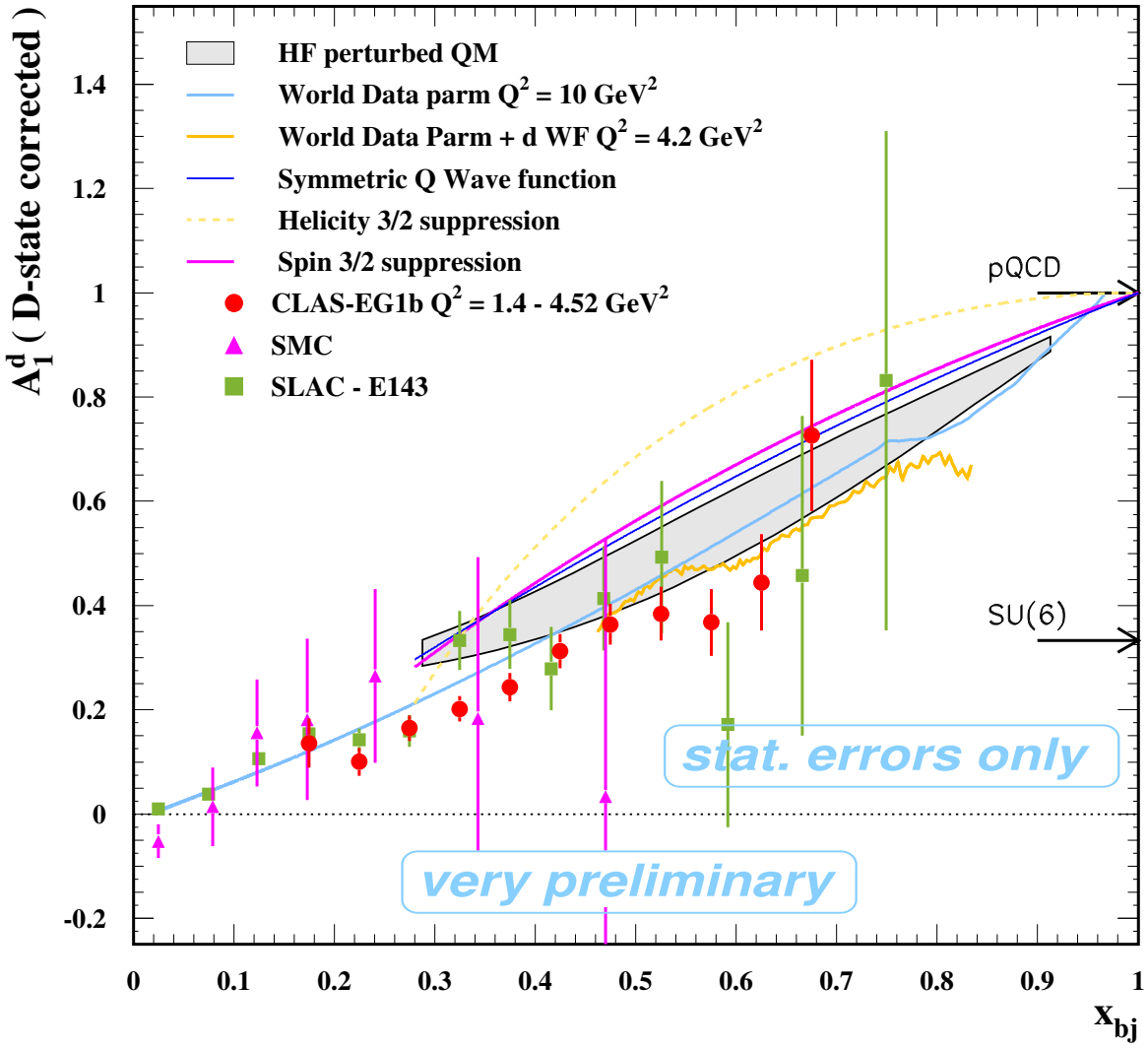
$$A_1^p = (g_1^p - \gamma^2 g_2^p)/F_1^p, \text{ where } \gamma = 2Mx/Q$$



- $A_1^p(x)$ results consistent with:
  - *Hyperfine Perturbed Quark Model* of Isgur [PRD 59, 034013 (1999)]
  - *Symmetric Quark Wave Fcn.* of Close & Melnitchouk [hep-ph/0302013]

Asymmetry $A_1(x)$ for the Deuteron

$$A_1^d = (g_1^d - \gamma^2 g_2^d)/F_1^d, \text{ where } \gamma = 2Mx/Q$$



- $A_1^d(x)$ reasonably well described by *HFQM* and *SQWF* models

Summary

- Has *Polarized Local Duality* been *established?*
- *Not quite, still some ways to go*
- Need in region $0.5 < x < 1$, $Q^2 <\sim 10$ GeV^2
  - high resolution, model free g_1 and g_2
    - approved new high-x experiment in Hall C - *SANE*
    - *local duality* at 12 GeV – extend $Q^2 >\sim 8$ GeV^2
  - better $R(x, Q^2)$, probably high-x F_2 also
  - *proton* and *neutron* structure functions
  - *theoretical* interpretation for *spin duality* (if confirmed)