E97-110: Small Angle GDH Experimental Status Report

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Massachusetts Institute of Technology

Hall A Collaboration Meeting

December 15th, 2009

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and the Jefferson Lab Hall A Collaboration

Introduction

- Experiment E97-110:
  - Precise measurement of moments of spin structure functions at low Q^2, 0.02 to 0.3 GeV^2 for the neutron and ^{3}He.

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  - Data from experiment E94-010 covered the transition region (0.1 to 0.9 GeV^2) from non-perturbative to perturbative QCD.
  - Preliminary results are now available and final results are expected soon.

Inclusive Cross Sections

- Unpolarized cross sections

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

- Polarized cross sections

$$\Delta\sigma_{\parallel} = \frac{d^2\sigma^{\downarrow\Uparrow}}{dE'd\Omega} - \frac{d^2\sigma^{\uparrow\Uparrow}}{dE'd\Omega} = K\left[(E + E'\cos\theta)\,g_1(x,Q^2) - \left(\frac{Q^2}{\nu}\right)g_2(x,Q^2)\right]$$

$$\Delta\sigma_{\perp} = \frac{d^2\sigma^{\downarrow\Rightarrow}}{dE'd\Omega} - \frac{d^2\sigma^{\uparrow\Rightarrow}}{dE'd\Omega} = KE'\sin\theta\left[g_1(x,Q^2) + \frac{2E}{\nu}g_2(x,Q^2)\right]$$

$$K = \frac{4\alpha^2}{M\nu Q^2}\frac{E'}{E}$$

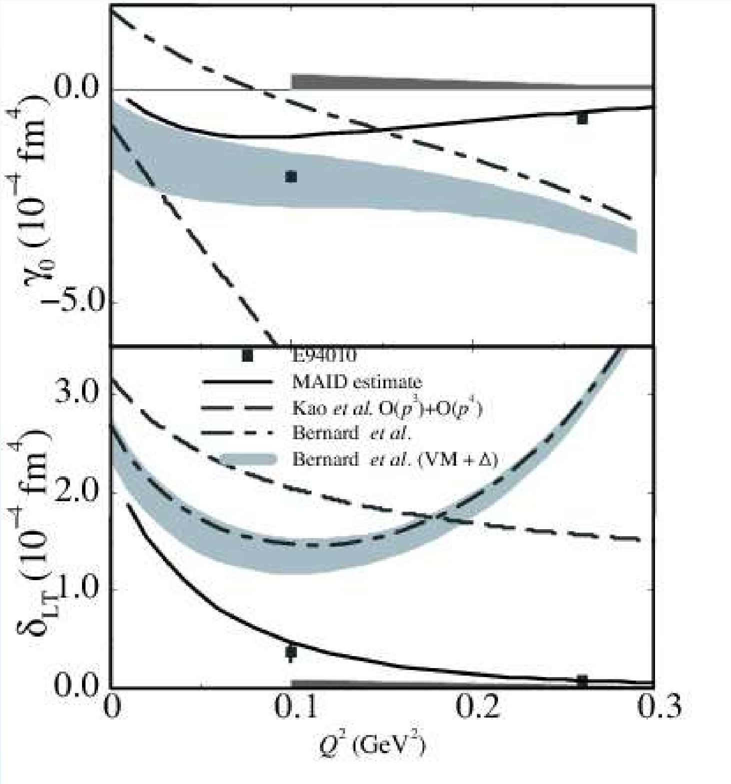
$\downarrow\uparrow$ are for electron spin, $\Uparrow\Rightarrow$ are for target spin direction

structure functions: F_1, F_2, g_1, g_2

Forward Spin Polarizabilities

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

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



M. Amarian *et al.* , PRL **93**, 152301 (2004)

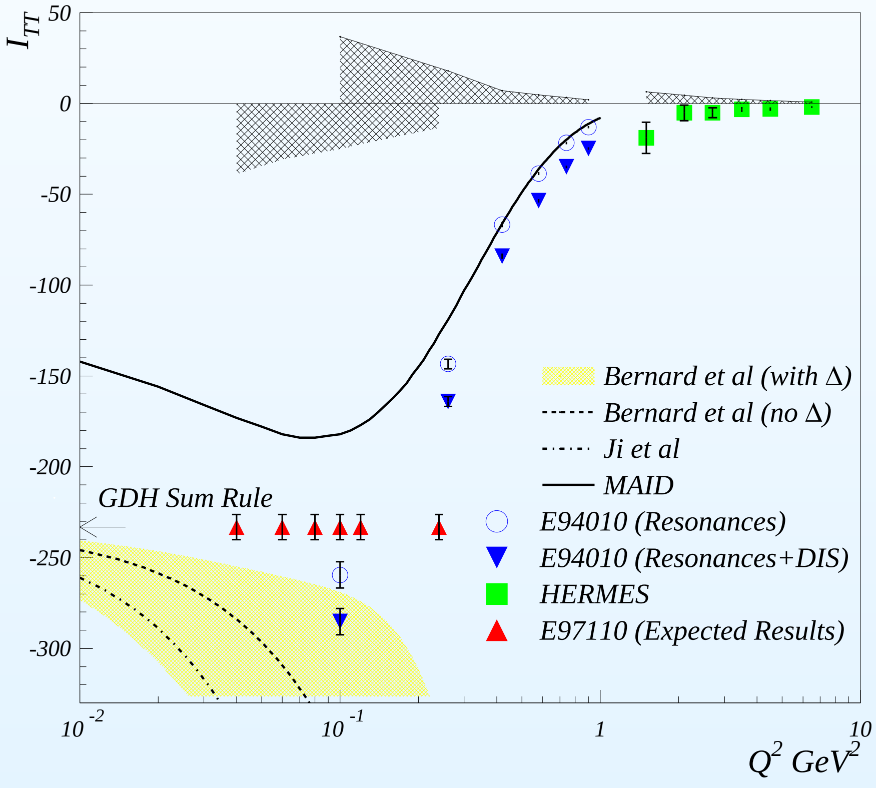
Experiment E97-110

Precise measurement of generalized GDH integral at low Q^2, 0.02 to 0.3 GeV^2

- Ran in spring and summer 2003
- Inclusive experiment: $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}},\mathrm{e}')\mathrm{X}$
  - $\Rightarrow$ Scattering angles of 6° and 9°
  - $\Rightarrow$ Polarized electron beam:

    $\langle P_{\mathrm{beam}} \rangle$ = 75%
  - $\Rightarrow$ Pol. ^{3}He target (para & perp):

    $\langle P_{\mathrm{targ}} \rangle$ = 40%
- Measured polarized cross-section differences



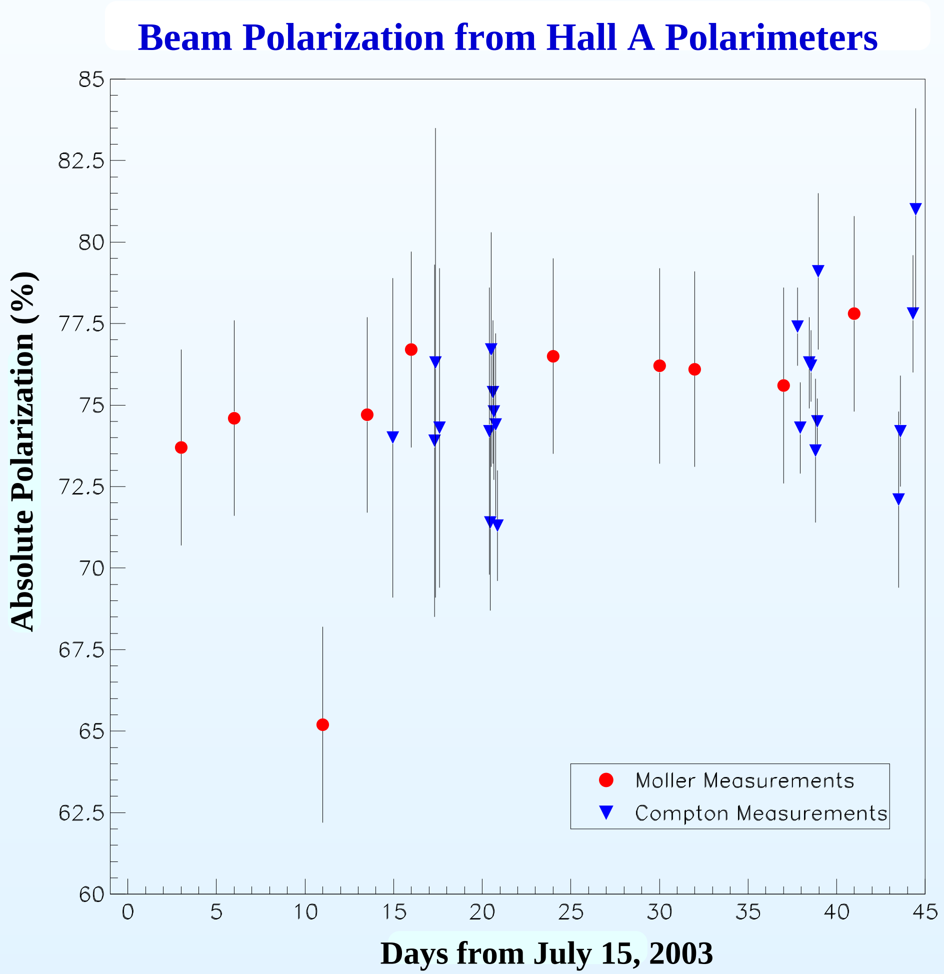
M. Amarian *et al.*, PRL **89**, 242301 (2002)

Analysis Progress

- Preliminary structure functions and moments have been extracted at constant Q^2.
- Collimator background: polarized or unpolarized?
  - Mostly from polarized ^{3}He.
  - Need to estimate size of leakage into physics asymmetry.
- Beam polarization: check bleedthrough correction with Compton. Checks still needed for the first period.
- Issues and analysis still in progress:
  - Acceptance: some issues need to be resolved.
  - Finalize radiative corrections.
  - Target polarization: $\sim$ 15% relative difference between NMR and EPR calibrations.
  - Elastic analysis as a cross check of systematics (V. Laine).

Compton Versus Møller

Work by T. Holmstrom.



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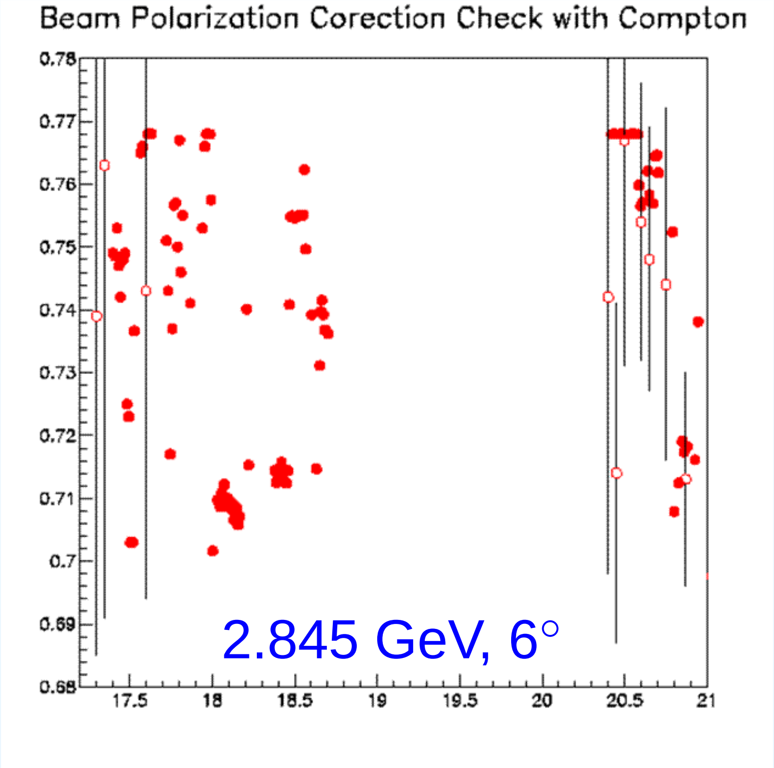

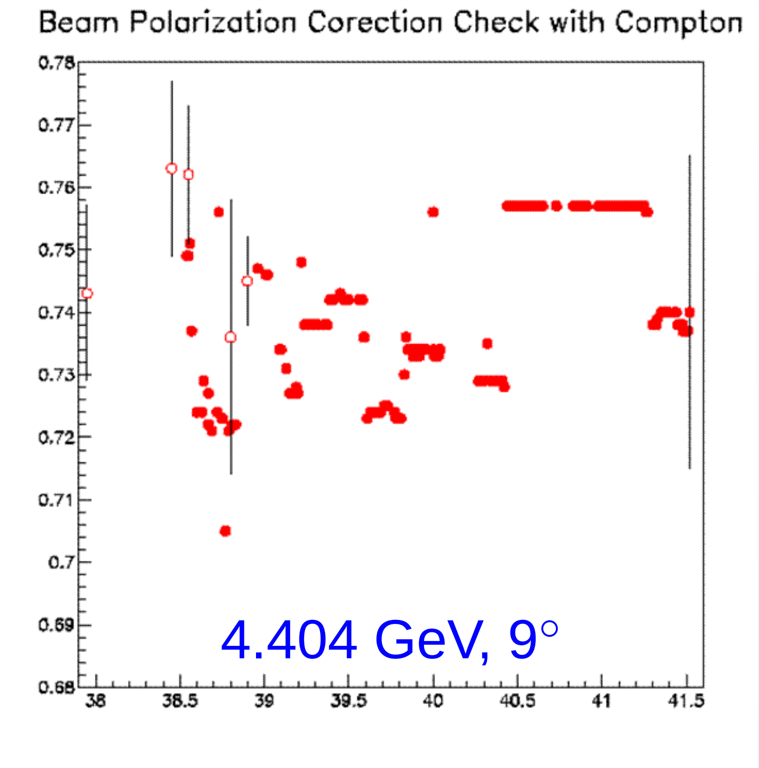

Open circles: Compton

Solid circles: Corrected Møller

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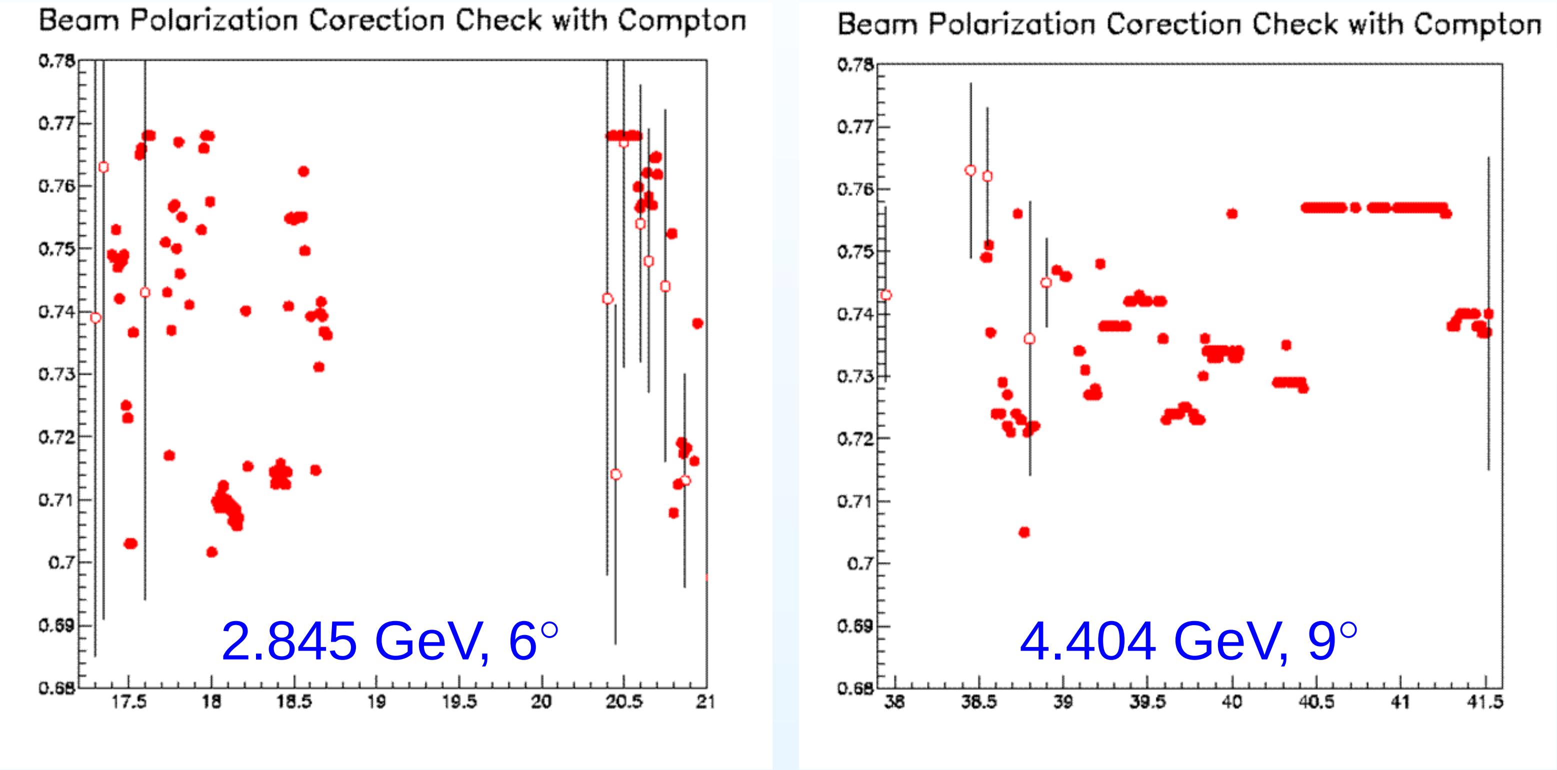
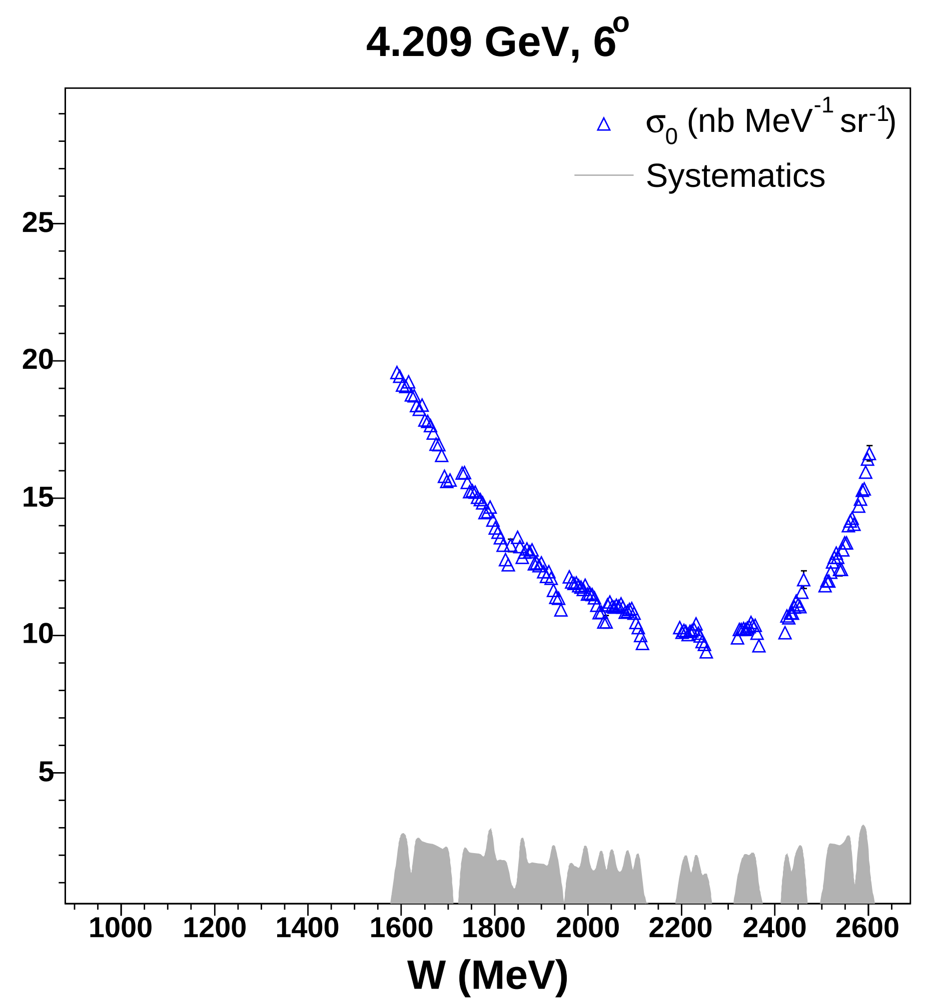


Open circles: Compton

Solid circles: Corrected Møller

- Compton does not refute Møller bleedthrough correction.
- Hall C bleedthrough was only measured once in the first period.
- No Compton measurements during the first period.

Acceptance Issues



Acceptance Issues

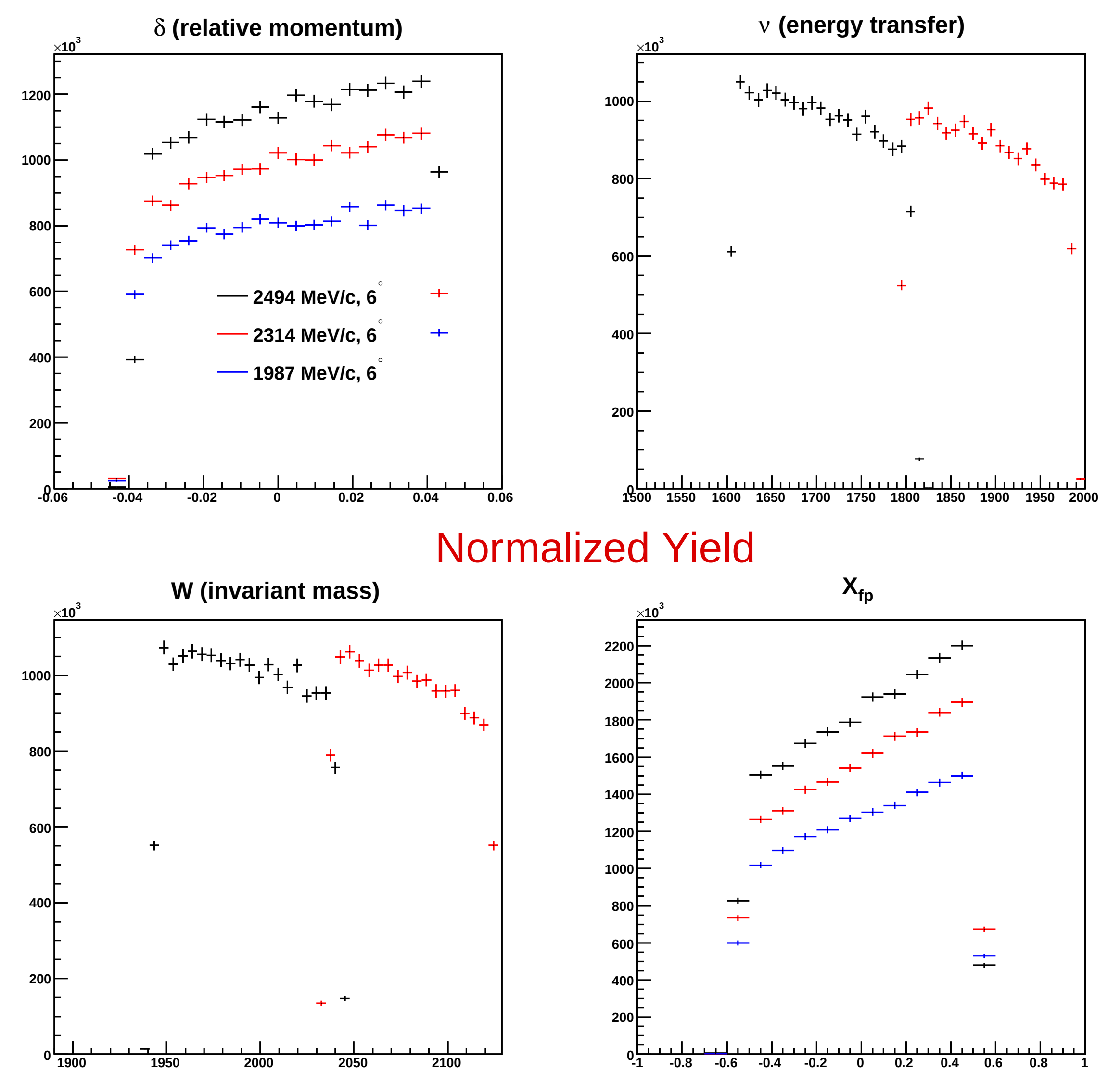
$|\delta| < 4.5\%$

$|\phi_{\mathrm{tg}}| < 5$ mrad

$|\theta_{\mathrm{tg}}| < 15$ mrad

$|y_{\mathrm{tg}}| < 0.75$ cm

$z_{\mathrm{react}} < 6.0$ cm



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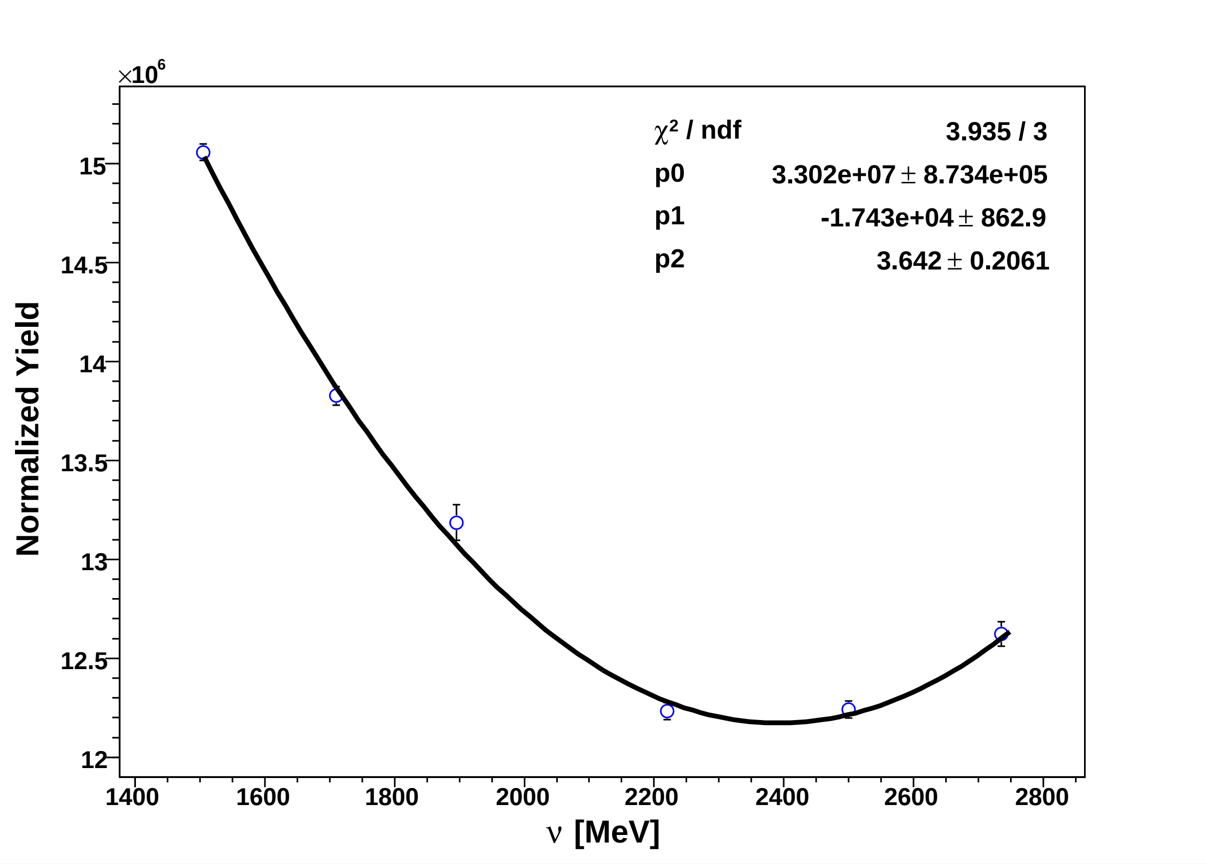


$|\delta| <$ 4.5%

$|\phi_{\rm tg}| <$ 25 mrad

$|\theta_{\rm tg}| <$ 50 mrad

$|y_{\rm tg}| <$ 1.5 cm

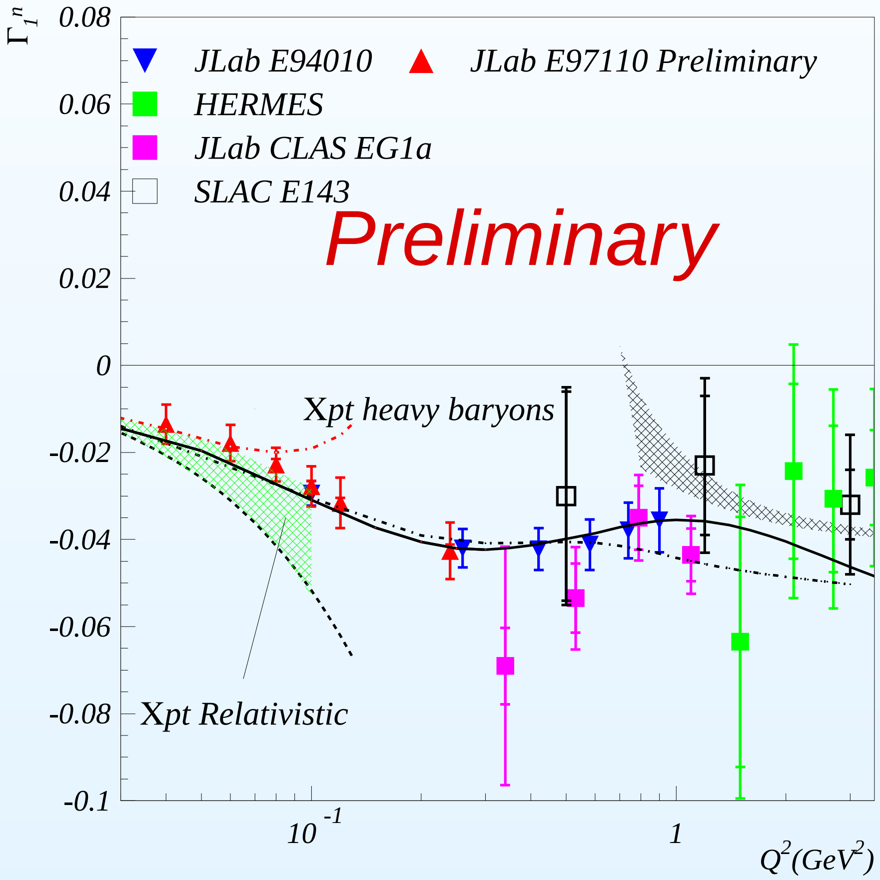
$z_{\rm react} <$ 6.0 cm

$x_{\rm fp} <$ 10.0 cm

- Unfold the cross section from the data.
- Extract the acceptance function and correct each momentum setting to obtain acceptance corrected yields.

First Moment of g_1

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



Xpt - Chiral Perturbation Theory

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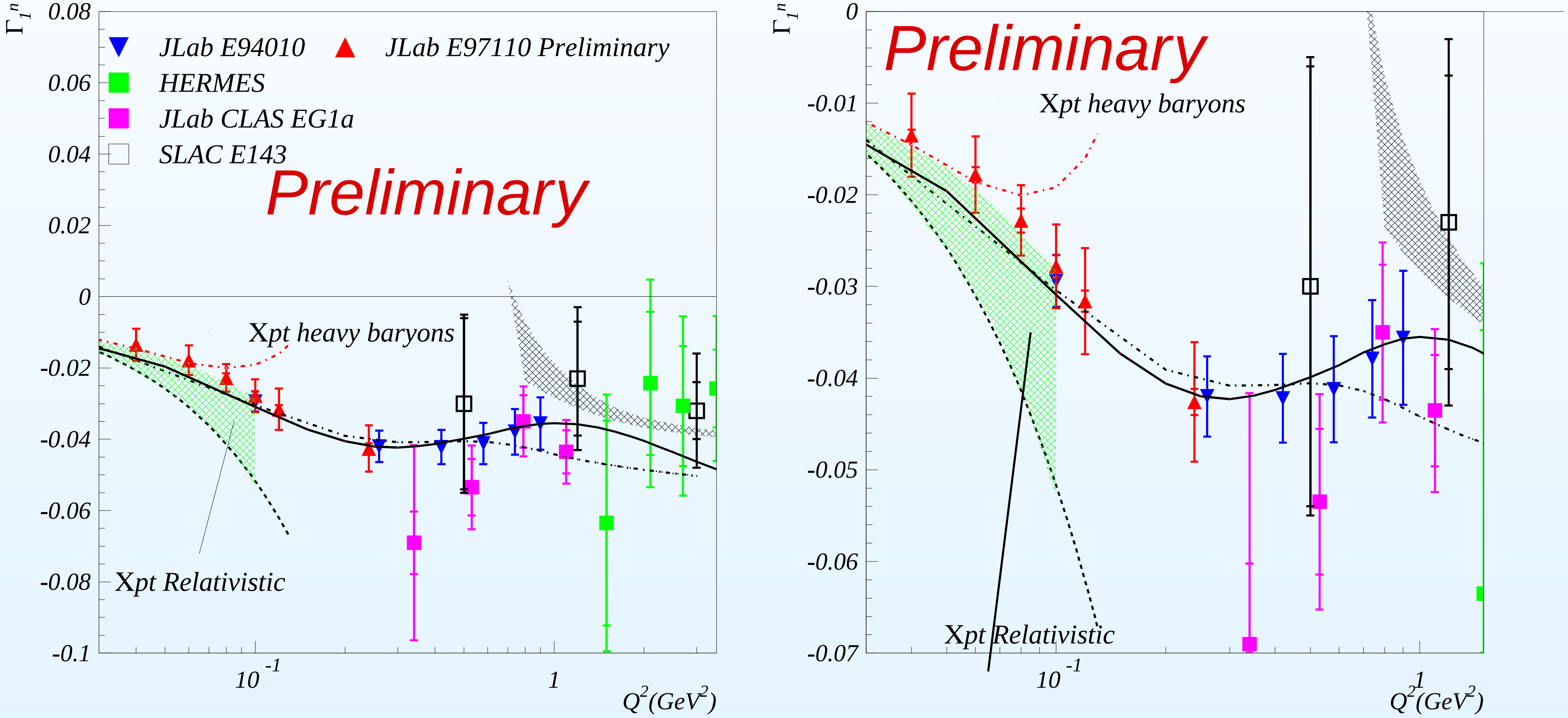
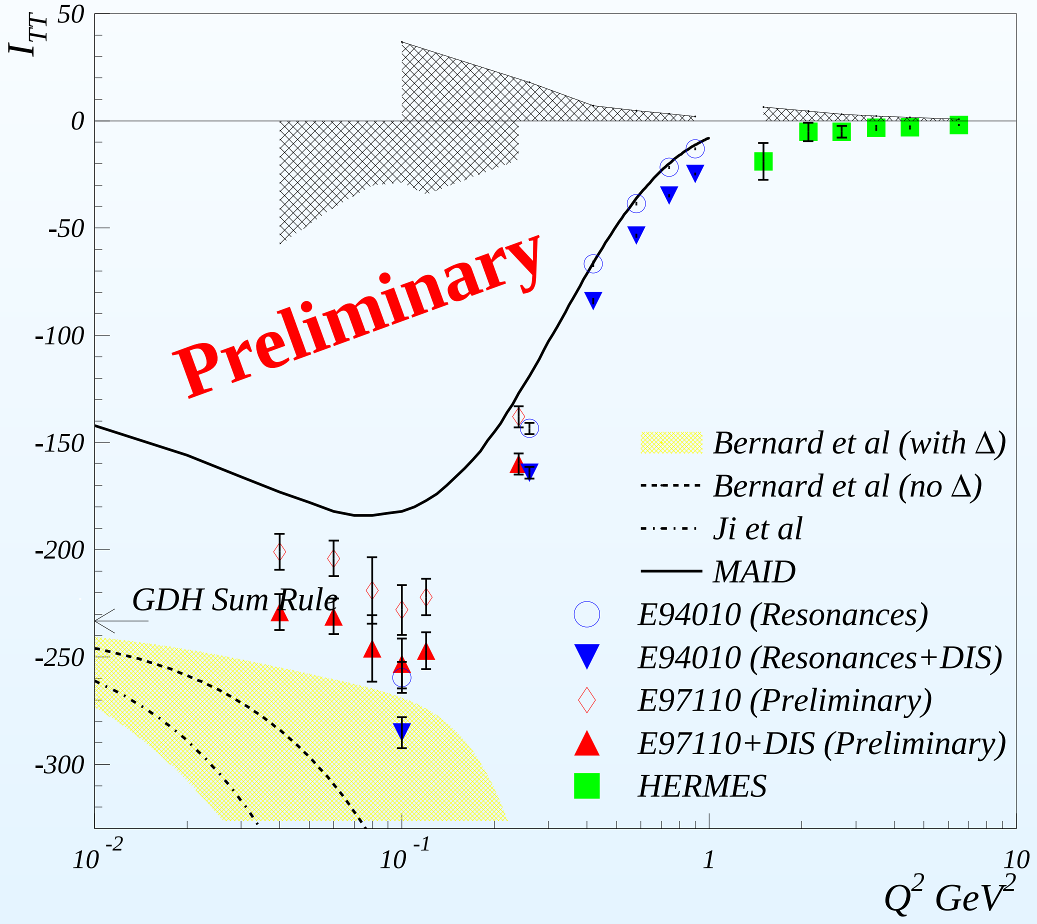


Xpt - Chiral Perturbation Theory

Neutron I_{GDH}



What Needs to be Done

Current Work

- Finalize acceptance for cross sections (V. Sulkosky).
- Elastic ^{3}He analysis (V. Laine).
- Radiative corrections (J. Singh)?
- Finalize target polarization: claim is that EPR is correct (J. Singh)?
- Remove QE contribution (V. Sulkosky).

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First Period Progress and Work

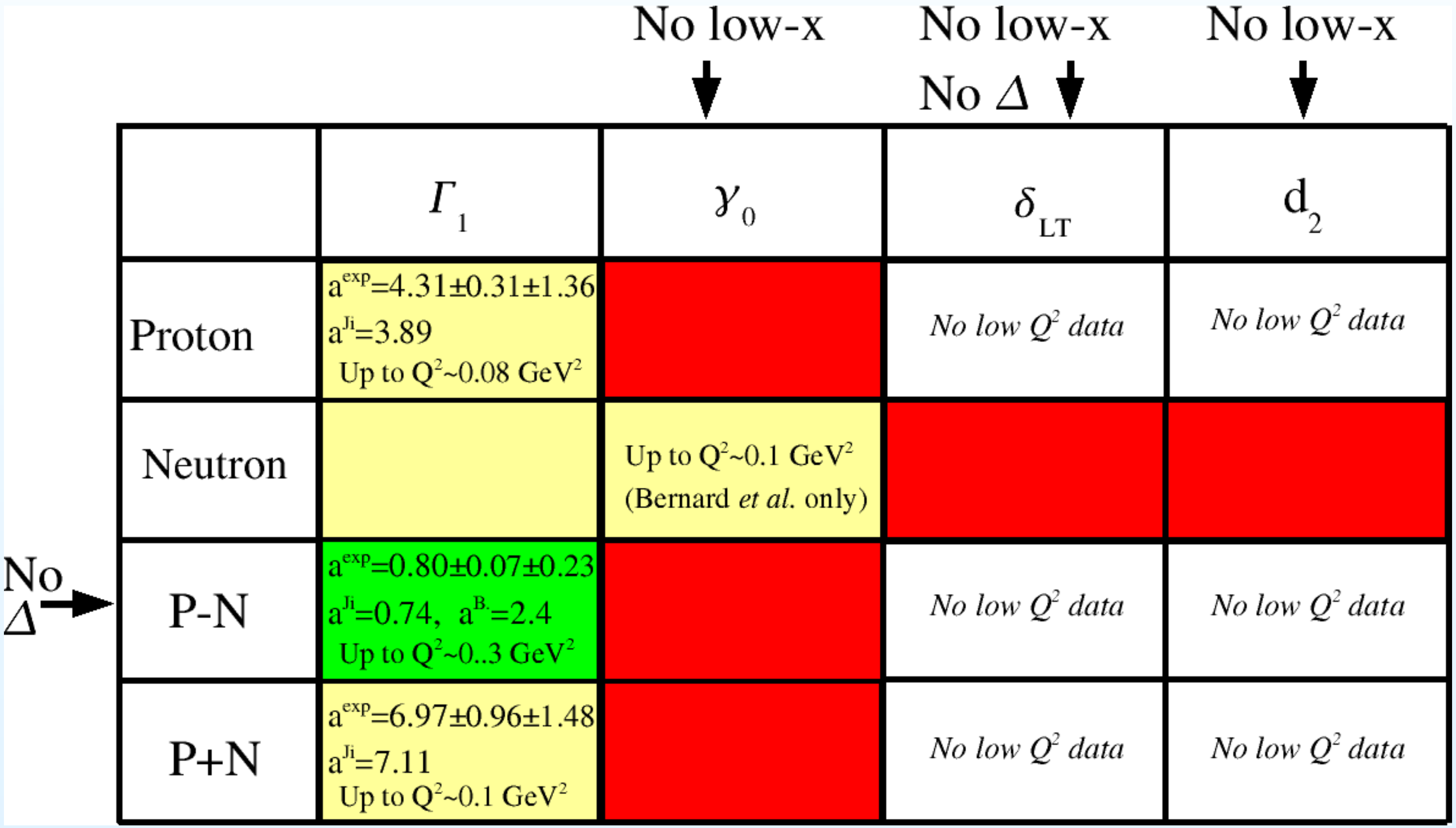
- Nilanga created a forward optics matrix for 'skewed' septum data.
- Hai-jiang Lu (USTC) was at JLab this summer to work on first period cross section and asymmetry analysis.
- Target analysis is a major task that needs to be completed.

Summary and Conclusion

- Experiment E97-110 provides precision data for moments of the spin structure functions at low Q^2: 0.02 to 0.3 [GeV/c]^2
- Preliminary results of the the neutron moments are available and work is in progress to finalize the systematic effects.
- These data provide a precise-benchmark test of Chiral Perturbation Theory calculations at a Q^2 where they are expected to be valid.
- Expect final neutron results soon and a draft of the first publication early next year.

Summary of Data Comparison with χPT

Courtesy A. Deur



			No low-x	No low-x No Δ	No low-x
		Γ_1	γ_0	δ_{LT}	d_2
	Proton	$a^{exp}=4.31\pm0.31\pm1.36$ $a^{Ji}=3.89$ Up to Q^2~0.08 GeV^2	🟥	*No low Q^2 data*	*No low Q^2 data*
	Neutron	🟨	Up to Q^2~0.1 GeV^2 (Bernard *et al.* only)	🟥	🟥
No Δ →	P-N	$a^{exp}=0.80\pm0.07\pm0.23$ $a^{Ji}=0.74$, $a^{B.}=2.4$ Up to Q^2~0..3 GeV^2	🟥	*No low Q^2 data*	*No low Q^2 data*
	P+N	$a^{exp}=6.97\pm0.96\pm1.48$ $a^{Ji}=7.11$ Up to Q^2~0.1 GeV^2	🟥	*No low Q^2 data*	*No low Q^2 data*

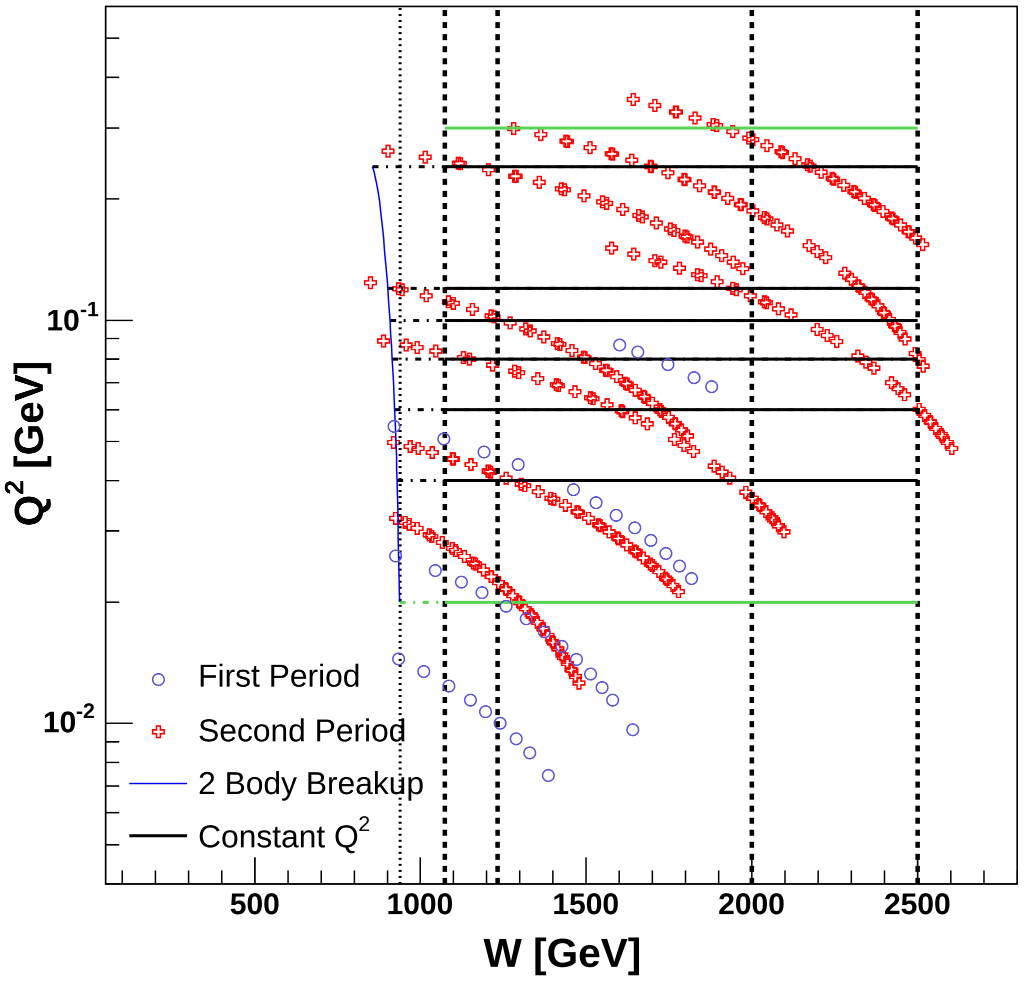
Extra Slides

Systematic Uncertainties

Source	Systematic Uncertainty		
Angle	6°	9°	3.775 GeV, 9°
Target density	2.0%		
Acceptance	5.0%	5.0%	15.0%
VDC efficiency	3.0%	2.5%	2.5%
Charge	1.0%		
PID efficiency	$<$ 1.0%		
$\delta\sigma_{\mathrm{raw}}$	6.4%	6.2%	15.5%
Nitrogen dilution	0.2–0.5%		
$\delta\sigma_{\mathrm{exp}}$	6.5%	6.3%	15.5%
Beam Polarization	3.5%		
Target Polarization	7.5%		
Radiative Corrections*	20% (40% for $Q^2 \leq$ 0.08)		
Total on $\Delta\sigma$	12.1%	12.0%	18.6%

$*$ Radiative correction uncertainty $\approx$ 6% in delta region

Kinematic Coverage and Interpolation



Six constant Q^2 points: 0.04, 0.06, 0.08, 0.1, 0.12 and 0.24 GeV^2.

Constant Q^2 Interpolation and Integral Extraction

Procedure:

- First interpolate to constant W for each energy.
- Second interpolation with respect to Q^2.
- Integrals formed from W = 1073 GeV to 2000 GeV.
- We could use our own data above W = 2000 GeV.
- DIS contribution included up to W = $\sqrt{1000}$ using Thomas and Bianchi parameterization.
- Neutron extraction performed using calculation from Scopetta and Ciofi degli Atti for $Q^2 >=$ 0.1 GeV^2.
- $Q^2 <$ 0.1 GeV^2 use effective polarization technique (difference $\sim$ 5–10%).

First moments of g_1 and g_2

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

$$\Gamma_2 = \int_0^1 g_2(x, Q^2)dx$$

Bjorken Sum Rule ($Q^2 \rightarrow \infty$)

$$\Gamma_1^{\mathrm{p}} - \Gamma_1^{\mathrm{n}} = \frac{g_{\mathrm{A}}}{6}$$

J.D. Bjorken, Phys. Rev. **148**, 1467 (1966)

- g_{A} is the nucleon axial charge.
- The sum rule has been confirmed to 10%.

Gerasimov-Drell-Hearn (GDH) Sum Rule (Q^2 = 0)

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

- Circularly polarized photons incident on a longitudinally polarized spin-$\frac{1}{2}$ target.
- $\sigma_{\frac{1}{2}}$ ($\sigma_{\frac{3}{2}}$) photoabsorption cross section with photon helicity parallel (anti-parallel) to the target spin.
- The sum rule is related to the target's mass M and anomalous part of the magnetic moment κ.
- Solid theoretical predictions based on general principles.
- Sum rule valid for any target with definite spin-S.

Generalized GDH Integral ($Q^2 > 0$)

$$I(Q^2) \;=\; \int_{\nu_{\rm th}}^{\infty} \left[\sigma_{\frac{1}{2}}(\nu,Q^2) - \sigma_{\frac{3}{2}}(\nu,Q^2)\right] \frac{d\nu}{\nu}$$

$$\sigma_{1/2} - \sigma_{3/2} = \frac{8\pi^2\alpha}{MK}\left[g_1(\nu,Q^2) - \left(\frac{Q^2}{\nu^2}\right) g_2(\nu,Q^2)\right]$$

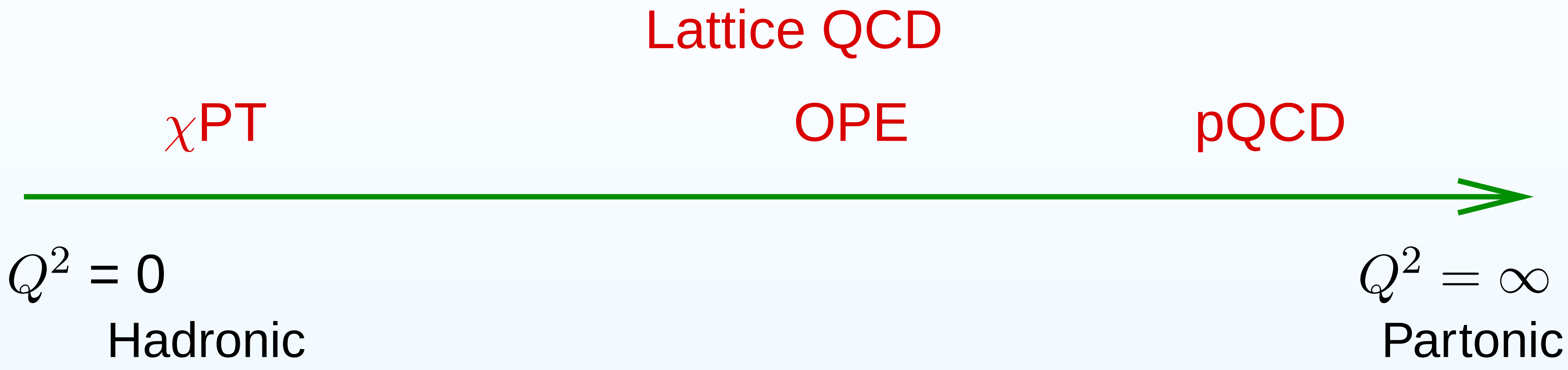
- Replace photoproduction cross sections with the corresponding electroproduction cross sections.
- The integral is related to the Compton scattering amplitudes: $S_1(Q^2)$ and $S_2(Q^2)$.

$$S_1(Q^2) = \frac{8}{Q^2}\int_0^1 g_1(x,Q^2)dx = \frac{8}{Q^2}\Gamma_1(Q^2)$$

X.-D. Ji and J. Osborne, J. Phys. **G27**, 127 (2001)

At Q^2 = 0, the GDH sum rule is recovered.

Importance of the Spin Structure Moments



Lattice QCD

χPT

OPE

pQCD

Q^2 = 0

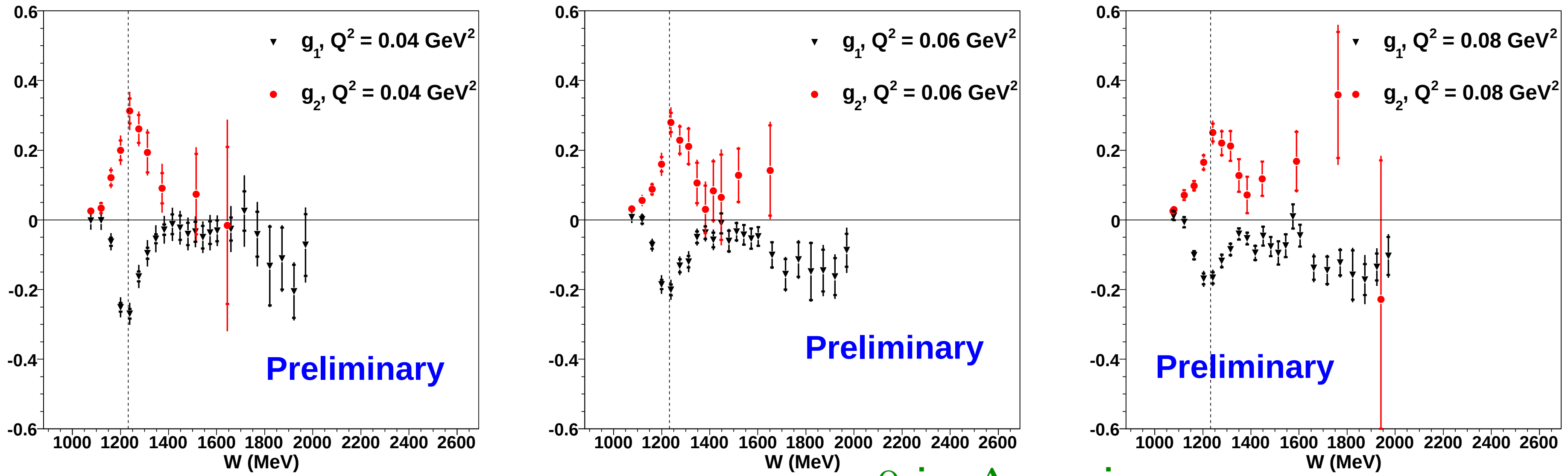
Hadronic

$Q^2 = \infty$

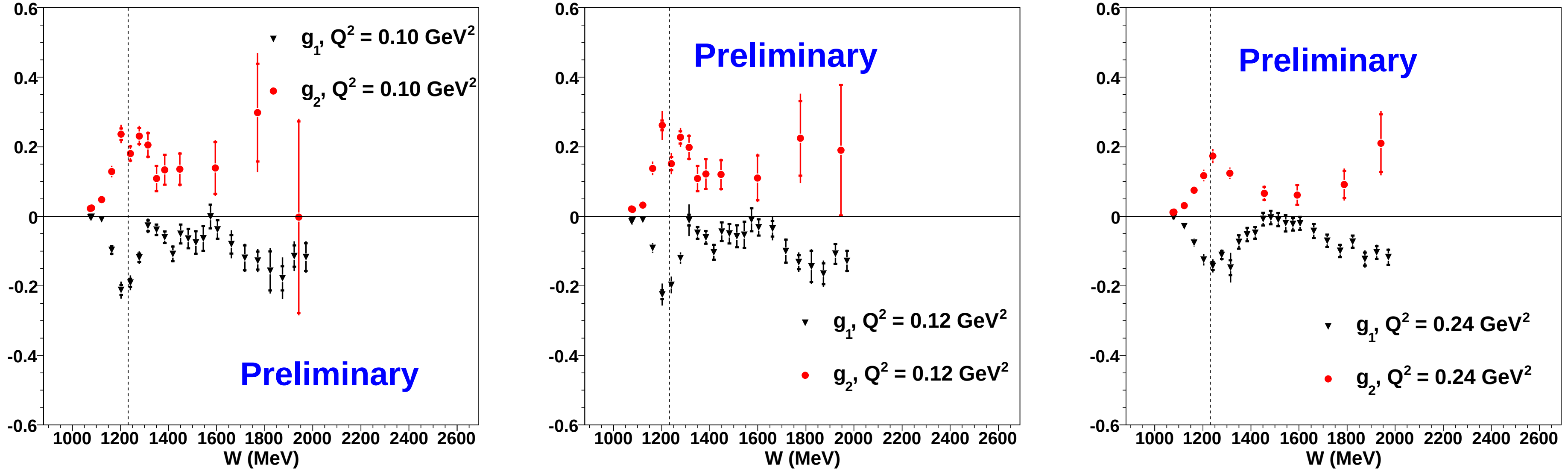
Partonic

- Constrained at the two ends of the Q^2 spectrum by known sum rules: GDH (Q^2 = 0) and Bjorken ($Q^2 \to \infty$).
- Generalized GDH Integral is calculable at any Q^2.
- Compare theoretical calculations to experimental measurements over the measurable Q^2 range.
- Tool to study non-perturbative QCD, while starting on known theoretical grounds (pQCD).

^{3}He - g_1, g_2 versus W at constant Q^2



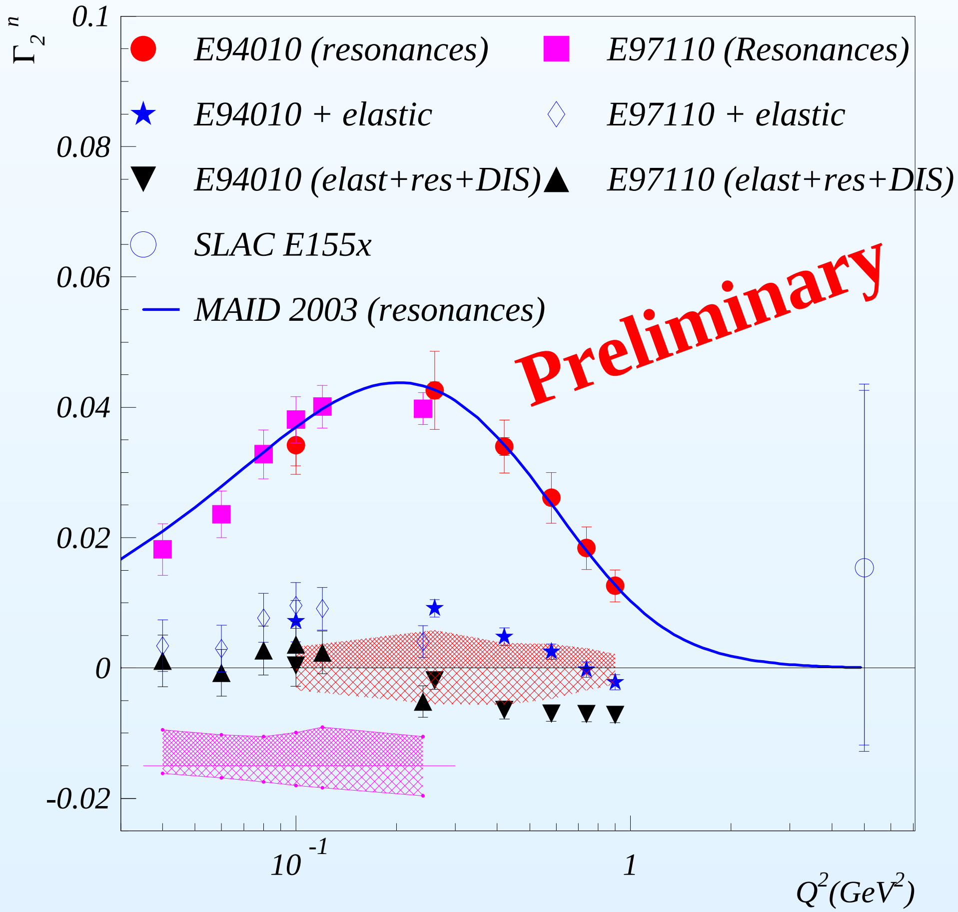
$g_2 \approx -g_1 \Rightarrow \sigma_{LT} \approx 0$ in Δ region



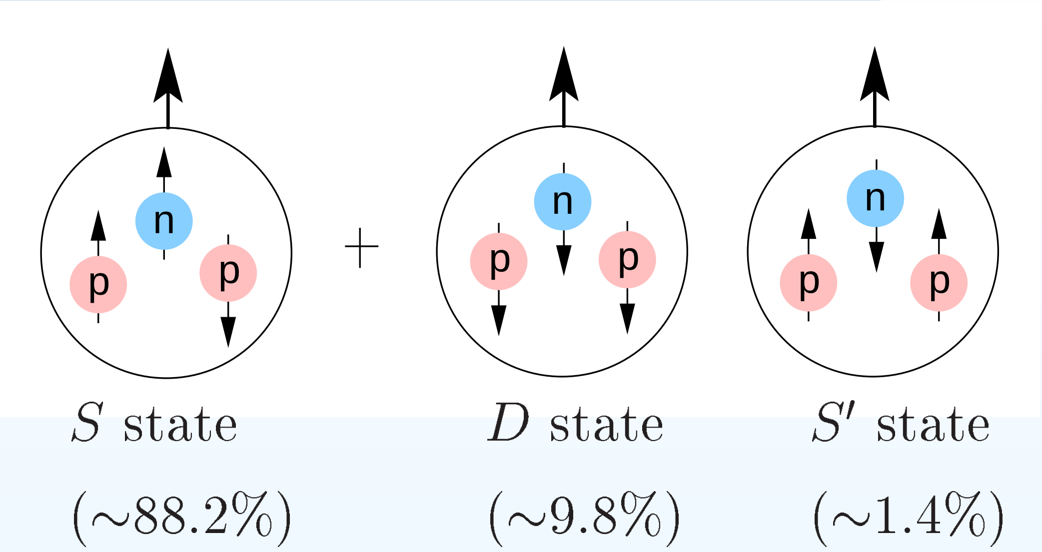
First Moment of g_2

$$\Gamma_2^n(Q^2) = \int_0^1 g_2(x,Q^2)dx = 0$$

Burkhardt-Cottingham Sum Rule



^{3}He as an Effective Polarized Neutron Target



P_{n} = 86% and P_{p} = -2.8%

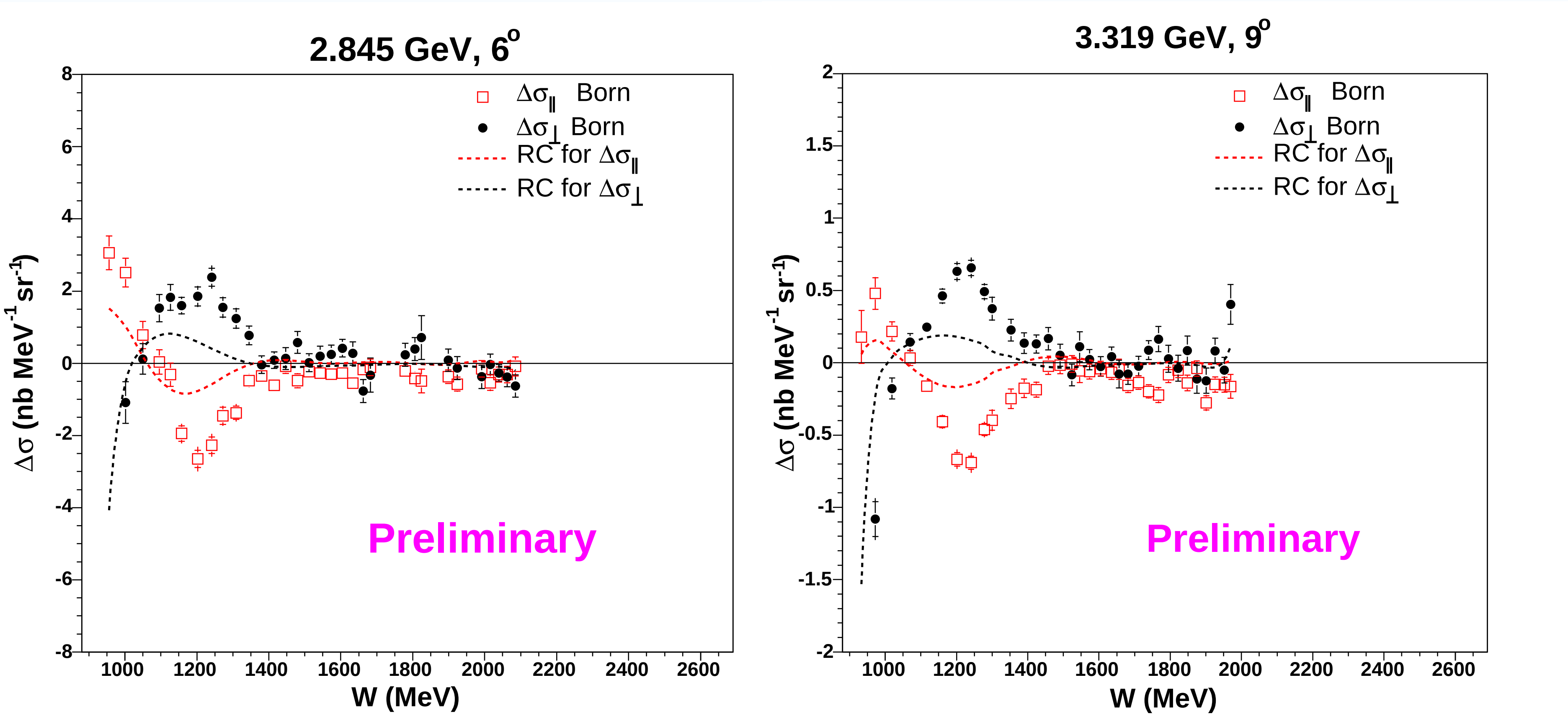
J.L. Friar *et al.*, PRC **42**, (1990) 2310

Extraction of Neutron Results

$$\Gamma_1^{\mathrm{n}}(Q^2) = \frac{1}{P_{\mathrm{n}}}\left[\Gamma_1^{^3\mathrm{He}}(Q^2) - 2P_{\mathrm{p}}\Gamma_1^{\mathrm{p}}(Q^2)\right]$$

C. Ciofi degli Atti & S. Scopetta, PLB **404**, (1997) 223

Cross Section Differences



Radiative corrections: formalism of L. Mo and Y. Tsai (unpolarized) and POLRAD (polarized), work done by J. Singh.

Preliminary Target Polarization