E97-110: Small Angle GDH Experimental Status Report

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on the behalf of the Spokespersons: J.P. Chen, A. Deur and F. Garibaldi

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Hall A Collaboration Meeting

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Jefferson Lab

Introduction

- Experiment E97-110:
  - Precise measurement of generalized GDH integral at low Q^2, 0.02 to 0.3 GeV^2.
  - Cover an unmeasured region of kinematics to test rigorous theoretical predictions (Chiral Perturbation Theory).

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  - Data from experiment E94-010 covered the transition region (0.1 to 0.9 GeV^2) from non-perturbative (mesons and baryons) to perturbative QCD (quarks and gluons).
  - Preliminary results are now available and should be finalized in a few months.

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

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

- Circularly polarized photons incident on a longitudinally polarized spin-$\frac{1}{2}$ target.

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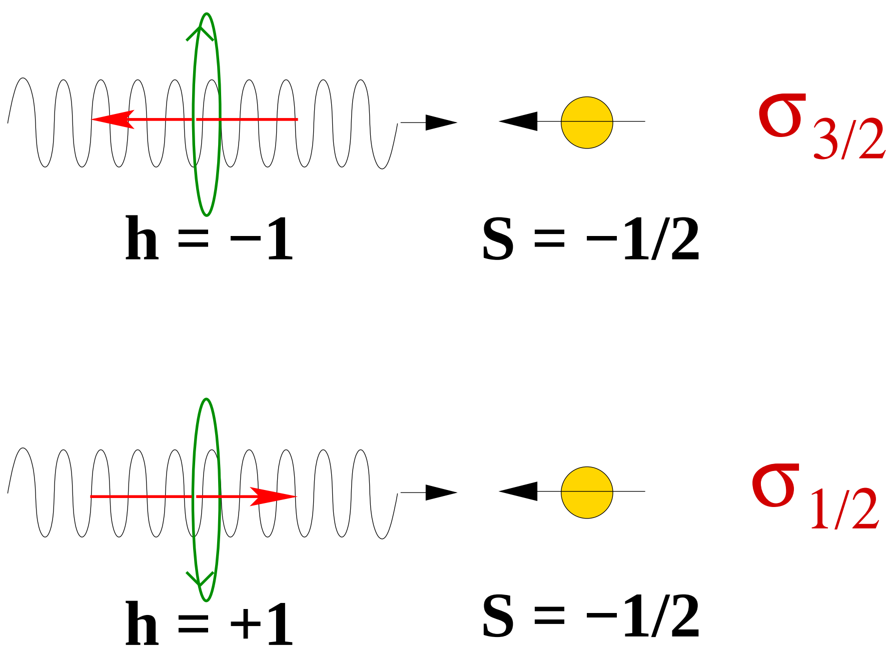
- $\sigma_{\frac{1}{2}}$ ($\sigma_{\frac{3}{2}}$) photoabsorption cross section with photon helicity parallel (anti-parallel) to the target spin.



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- 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.
- The sum rule is valid for any spin-S target.

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 Generalized GDH Sum Rule

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 predictions to experimental measurements over the entire Q^2 range.
- Tool to study non-perturbative QCD, while starting on known theoretical grounds (pQCD).

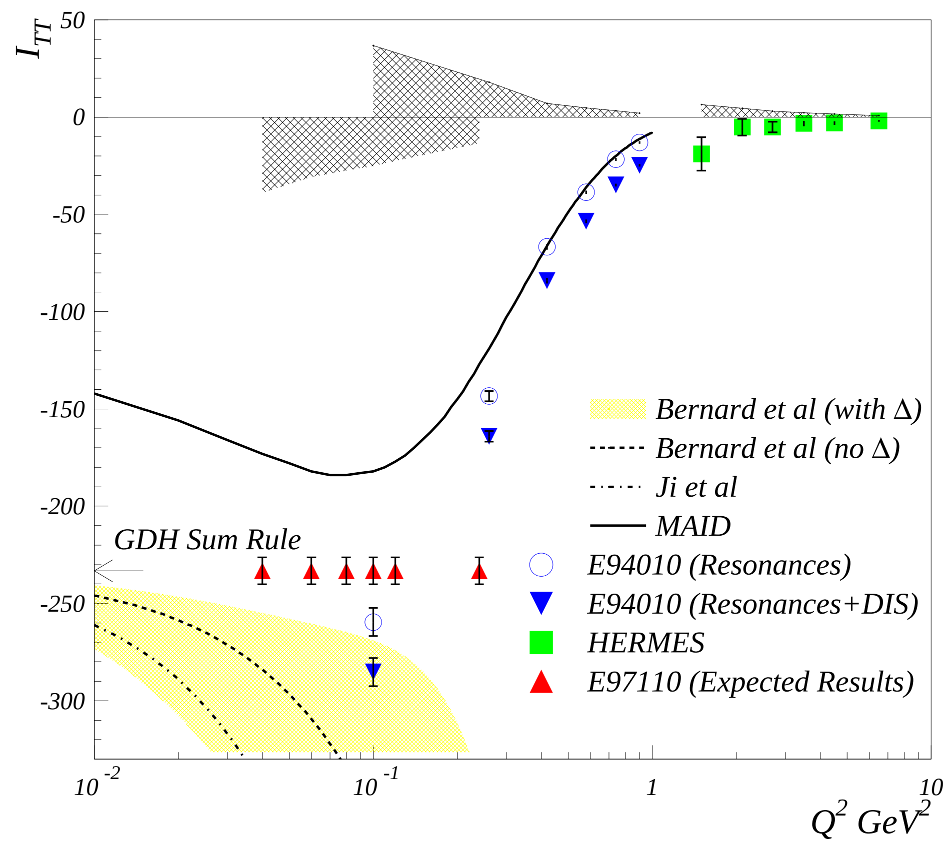
Experiment E97-110

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: $^3\overrightarrow{\mathrm{He}}(\vec{e},e')X$
  - ⇒ Scattering angles of 6° and 9°
  - ⇒ Polarized electron beam:

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

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



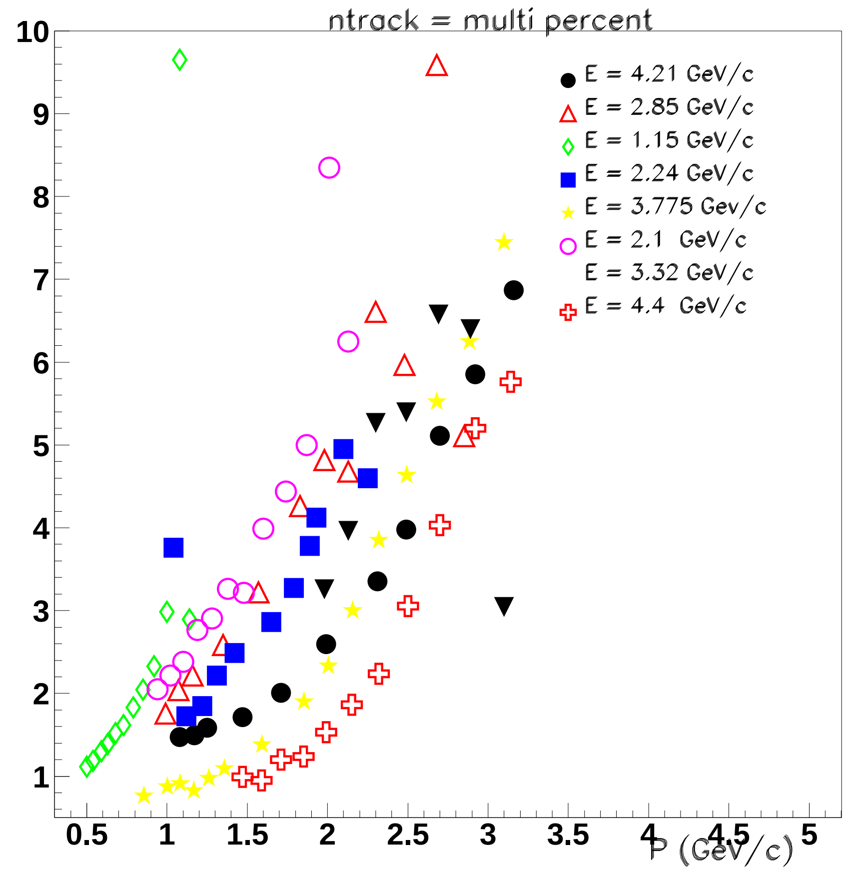
Analysis Progress

- Preliminary structure functions and moments have been extracted at constant Q^2.
- Issues that still need to be addressed:
  - Beam polarization: check bleedthrough correction with Compton where available.
  - Target polarization: track down 15% relative difference between NMR and EPR calibrations.
  - Acceptance: some issues need to be resolved.
  - Collimator background: polarized or unpolarized?
  - Elastic analysis as a cross check of systematics.

Systematic Uncertainties

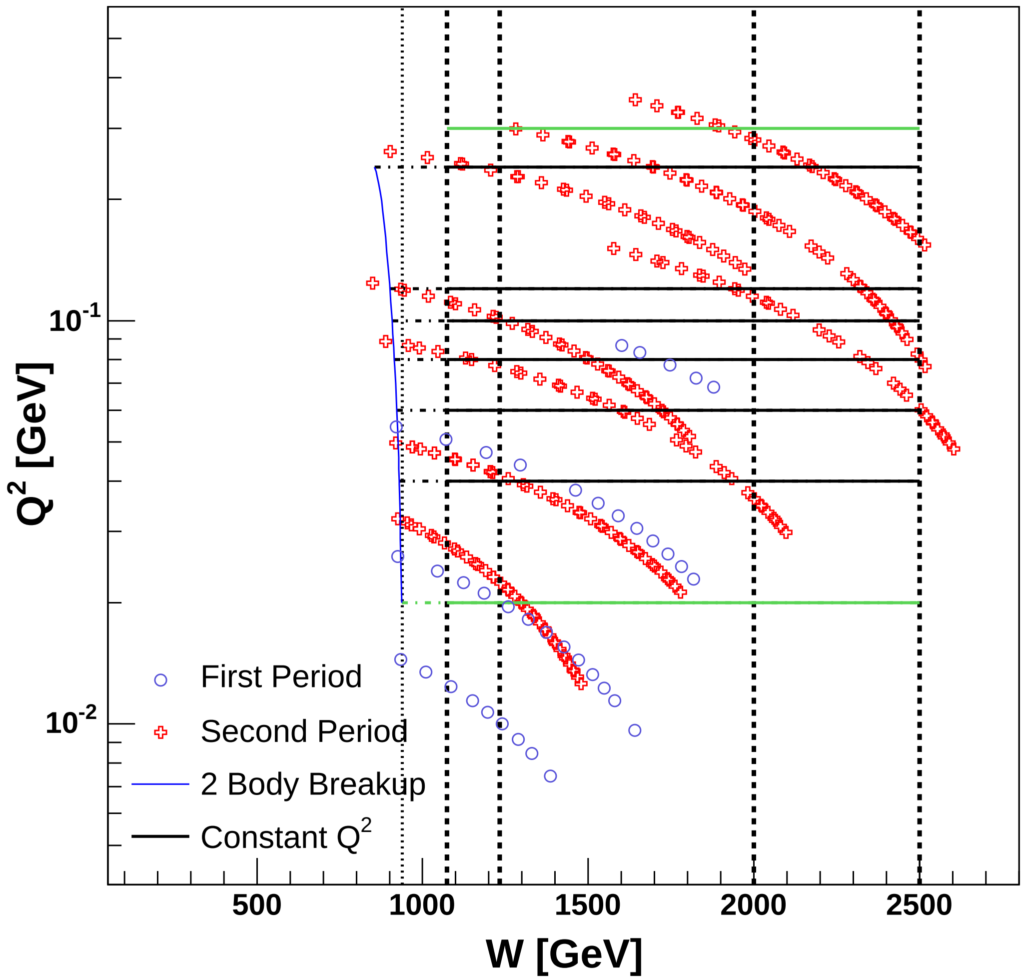
Source	Systematic Uncertainty		
Angle	6°	9°	3.775 GeV, 9°
Target density		2.0%	
Acceptance/Effects	5.0%	5.0%	15.0%
VDC efficiency	3.0%	2.5%	2.5%
Charge		1.0%	
PID Detector and Cut effs.		$<$ 1.0%	
$\delta\sigma_{\mathrm{raw}}$	6.4%	6.2%	15.5%
Nitrogen dilution		0.2–0.5%	
$\delta\sigma_{\mathrm{exp}}$	6.5%	6.3%	15.5%
Beam Polarization		3.5%	
Target Polarization		7.5%	
Radiative Corrections		5–10% in Δ region	
Total on $\Delta\sigma$	11.6–14.5%	11.5–14.4%	18.3–20.2%

VDC Multi-track Analysis



- Using typical shower cut ($0.8 < \frac{E}{P} < 1.1$) on two-track events, nearly 70% of these events are good events (J. Yuan).

Kinematic Coverage and Interpolation



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

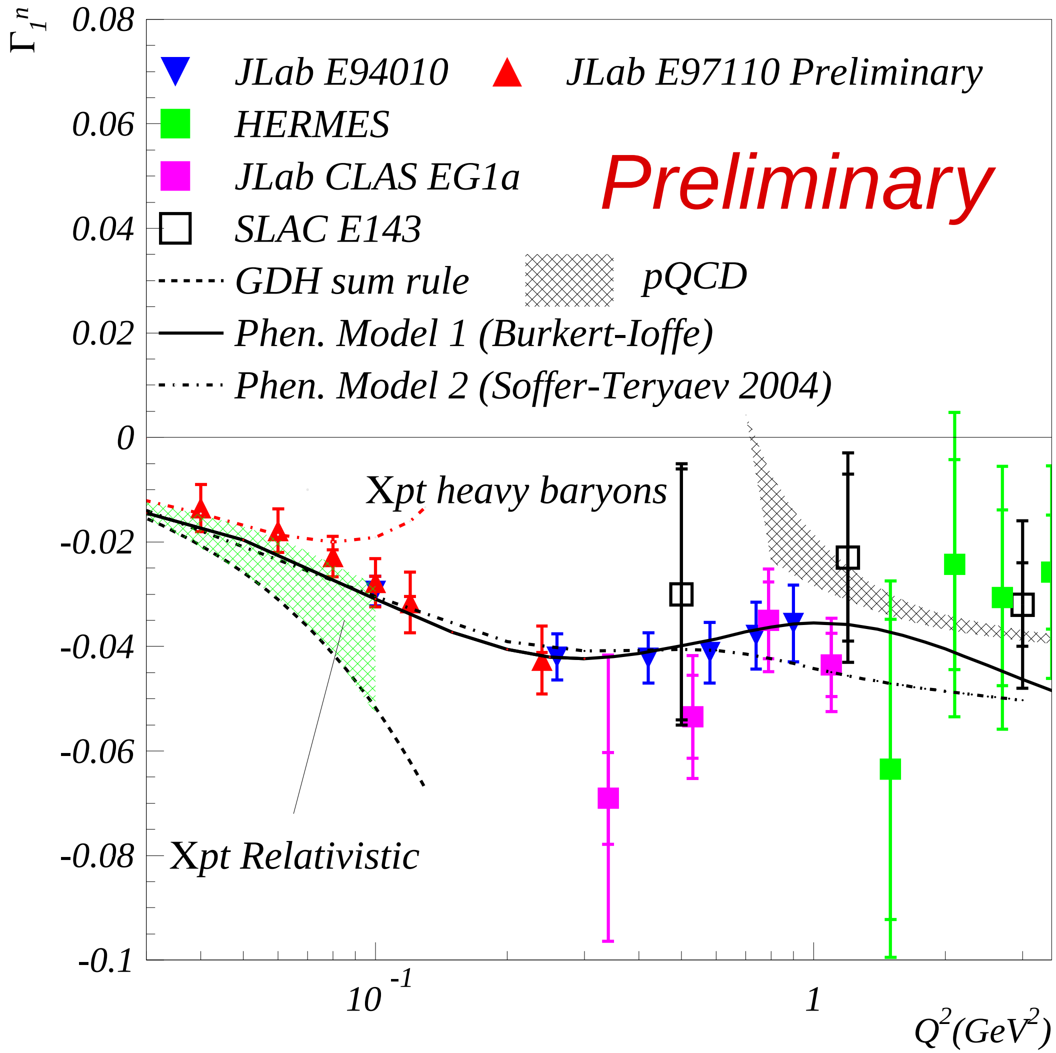
Constant Q^2 Interpolation and Integral Extraction

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%).

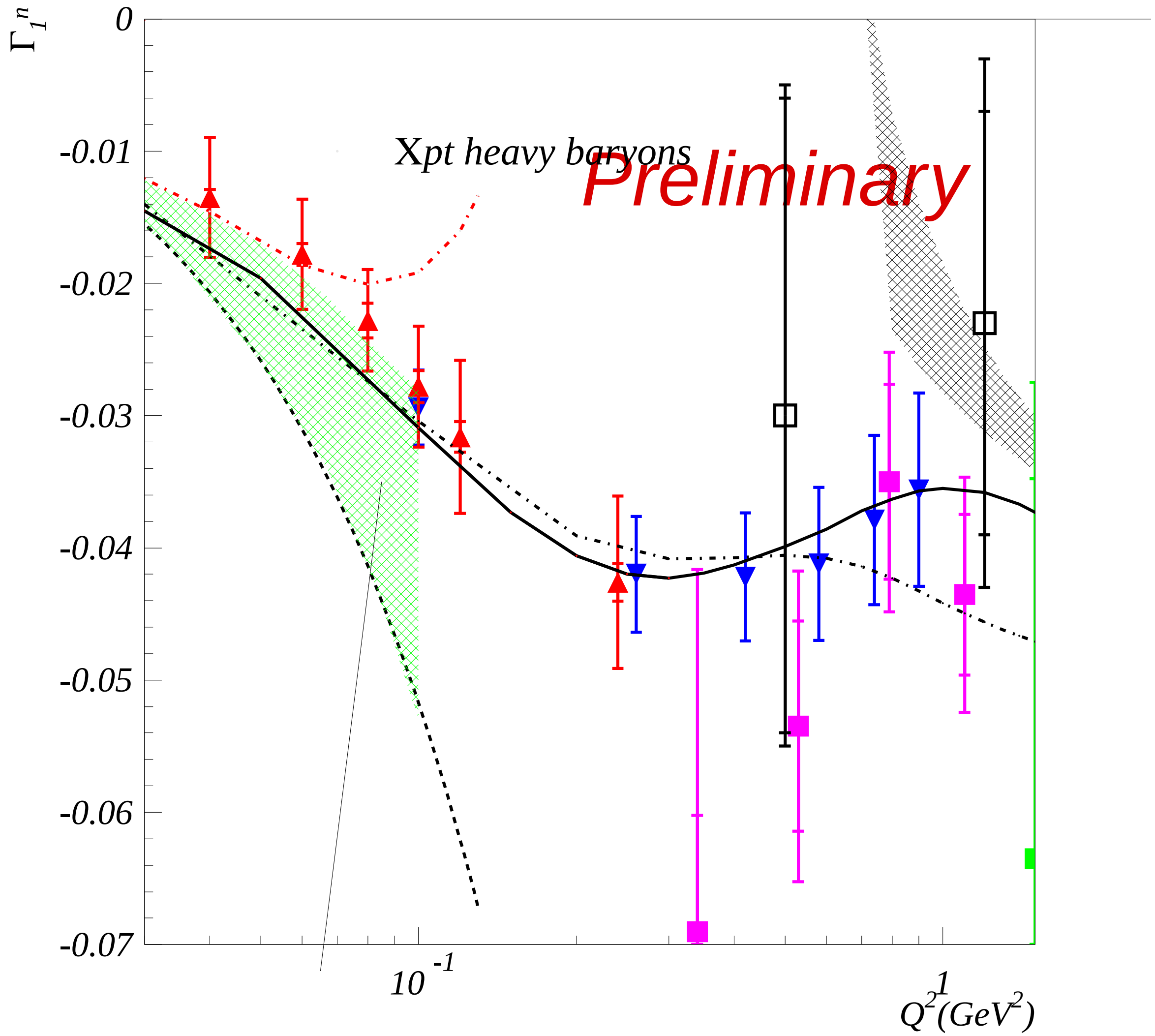
Γ_1^n: First Moment of g_1

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



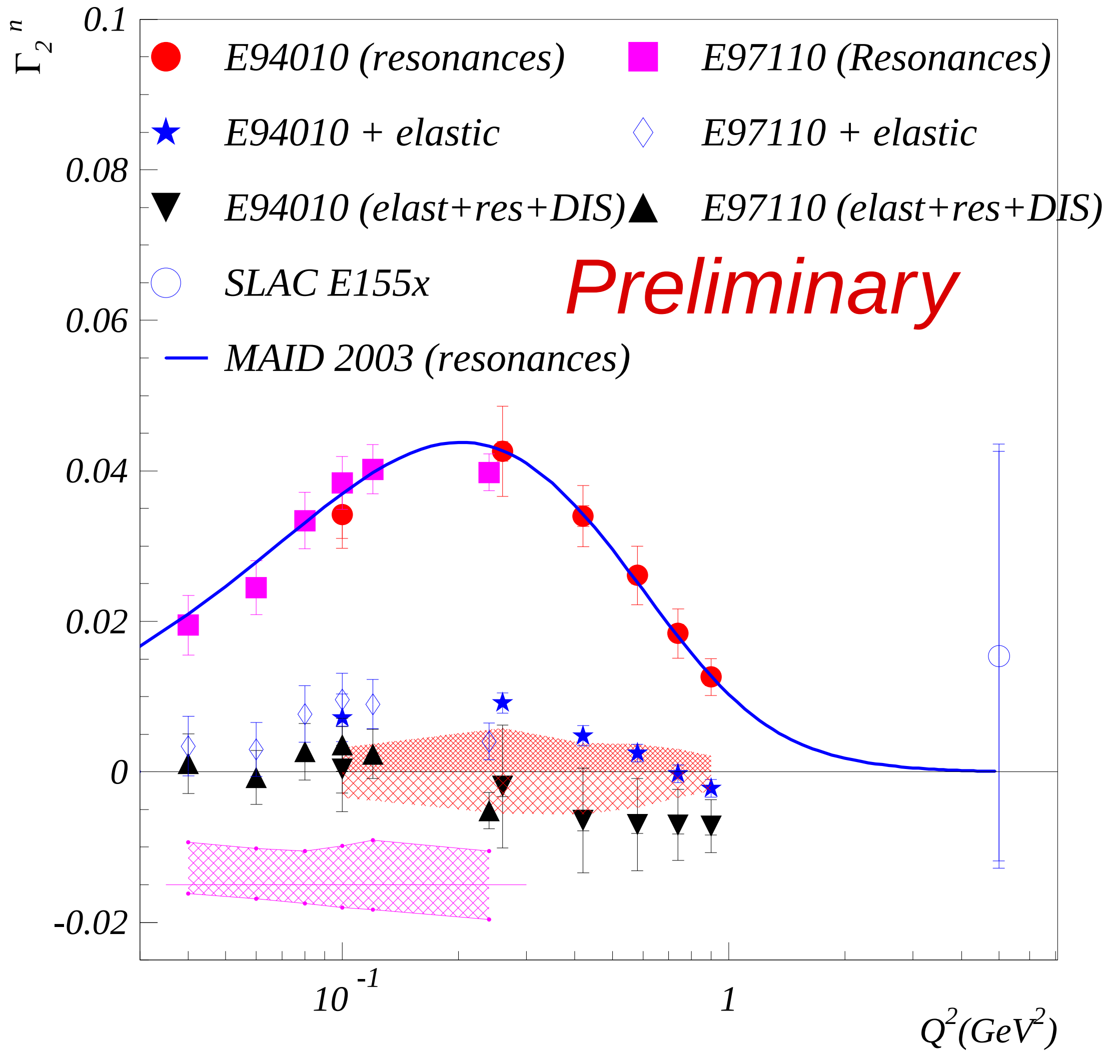
Γ_1^n: First Moment of g_1

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



Γ_2^n: First Moment of g_2

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



What Needs to be Done

- Check and refine constant Q^2 interpolation and integral extraction (Mostly Completed).
- VDC multi-track study (Completed by J. Yuan).
- Radiative corrections (J. Singh).
- Finalize target polarization (J. Singh).
- Collimator background (R. Pandolfi).
- Finalize acceptance for cross sections (V. Sulkosky).
- Model and subtract QE contribution (V. Sulkosky).
- Elastic ^{3}He analysis.

Summary and Conclusion

- The GDH integral is an important tool that can be used to study nucleon spin structure over the full Q^2 range.
- E97-110 provides precision data for the generalized GDH integral and moments of spin structure functions at low Q^2, 0.02 to 0.3 GeV^2.
- Preliminary results of the the neutron moments are available and work is in progress to finalize the systematic effects.
- These data provide a precision test of Chiral Perturbation Theory predictions at a Q^2 where they are expected to be valid.
- Expect final neutron results in a few months.

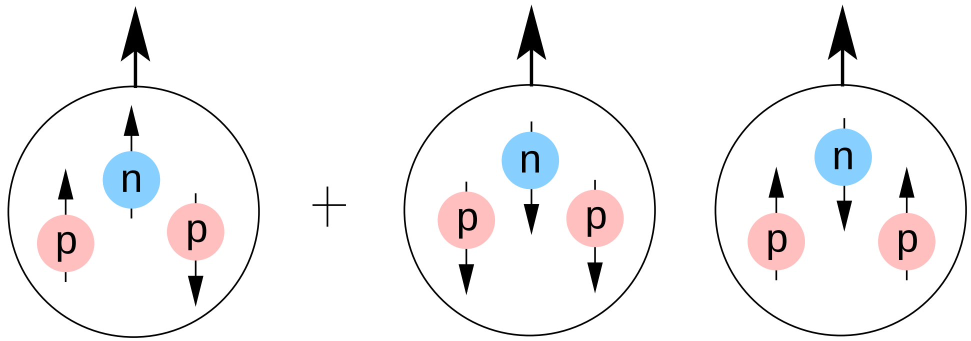
The E97-110 Collaboration

S. Abrahamyan, K. Aniol, D. Armstrong, T. Averett, S. Bailey, P. Bertin, W. Boeglin, F. Butaru, A. Camsonne, G.D. Cates, G. Chang, **J.P. Chen**, Seonho Choi, E. Chudakov, L. Coman, J. Cornejo, B. Craver, F. Cusanno, R. De Leo, C.W. de Jager, **A. Deur**, K.E. Ellen, R. Feuerbach, M. Finn, S. Frullani, K. Fuoti, H. Gao, **F. Garibaldi**, O. Gayou, R. Gilman, A. Glamazdin, C. Glashausser, J. Gomez, O. Hansen, D. Hayes, B. Hersman, D. W. Higinbotham, T. Holmstrom, T.B. Humensky, C. Hyde-Wright, H. Ibrahim, M. Iodice, X. Jiang, L. Kaufman, A. Kelleher, W. Kim, A. Kolarkar, N. Kolb, W. Korsch, K. Kramer, G. Kumbartzki, L. Lagamba, G. Laveissiere, J. LeRose, D. Lhuillier, R. Lindgren, N. Liyanage, B. Ma, D. Margaziotis, P. Markowitz, K. McCormick, Z.E. Meziani, R. Michaels, B. Moffit, P. Monaghan, S. Nanda, J. Niedziela, M. Niskin, K. Paschke, M. Potokar, A. Puckett, V. Punjabi, Y. Qiang, R. Ransome, B. Reitz, R. Roche, A. Saha, A. Shabetai, **J. Singh**, S. Sirca, K. Slifer, R. Snyder, P. Solvignon, R. Stringer, R. Subedi, **V. Sulkosky**, W.A. Tobias, P. Ulmer, G. Urciuoli, A. Vacheret, E. Voutier, K. Wang, L. Wan, B. Wojtsekhowski, S. Woo, H. Yao, **J. Yuan**, X. Zheng, L. Zhu

and the Jefferson Lab Hall A Collaboration

Extra Slides

^{3}He as an Effective Polarized Neutron Target



S state ($\sim$88.2%) D state ($\sim$9.8%) S' state ($\sim$1.4%)

$P_{\rm n}$ = 86% and $P_{\rm p}$ = -2.8%

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

Extraction of Neutron Results

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

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

Inclusive Cross Sections

- Unpolarized cross sections

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

- Polarized cross sections

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

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

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

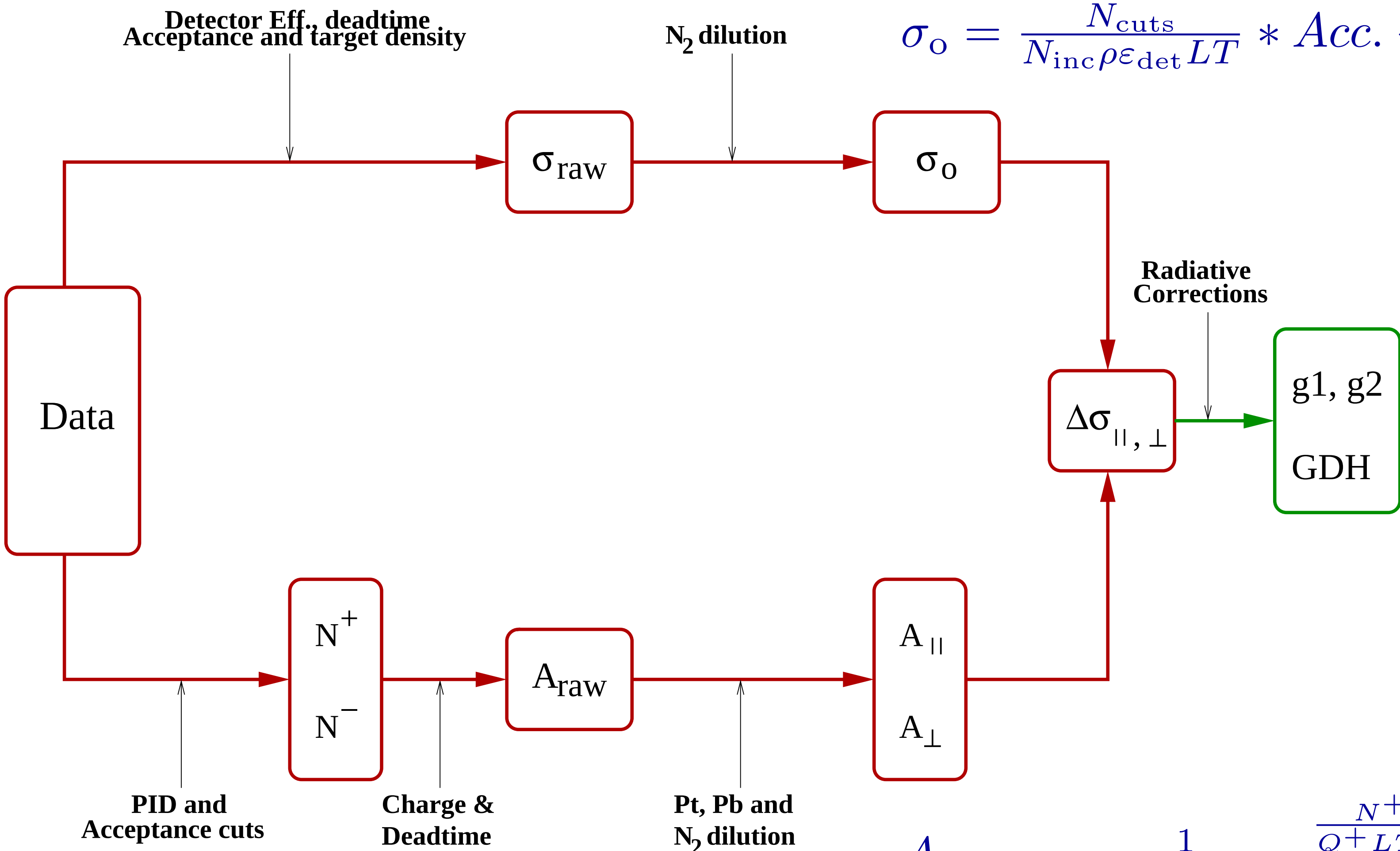
$\downarrow$, $\uparrow$ are for electron spin

$\Uparrow$, $\Rightarrow$ are for target spin direction

F_1, F_2, g_1, g_2: structure functions

Analysis Procedure

$$\sigma_o = \frac{N_{\rm cuts}}{N_{\rm inc}\rho\varepsilon_{\rm det}LT} * Acc. - \frac{2\rho_{\rm N_2}}{\rho + \rho_{\rm N_2}}\sigma_{\rm N_2}$$



$$A_{\parallel,\perp} = \frac{1}{f_{\rm N_2}P_{\rm tg}P_{\rm beam}}\frac{\frac{N^+}{Q^+LT^+}-\frac{N^-}{Q^-LT^-}}{\frac{N^+}{Q^+LT^+}+\frac{N^-}{Q^-LT^-}}$$

Chiral Symmetry

$$\mathcal{L}_{\rm QCD} = -\frac{1}{4g^2} G^{\alpha}_{\mu\nu} G^{\mu\nu}_{\alpha} + \bar{q} i \gamma^{\mu} D_{\mu} q - \bar{q} \mathcal{M} q$$
$$\mathcal{L}_{\rm QCD} = \mathcal{L}_0 + \mathcal{L}_{sb}$$

- Consider the limit where the light quark masses vanish.
- For massless fermions, chirality (handedness) is identical to a particle's helicity.
- Extra symmetry to the Lagrangian and obtain left and right handed quark fields.

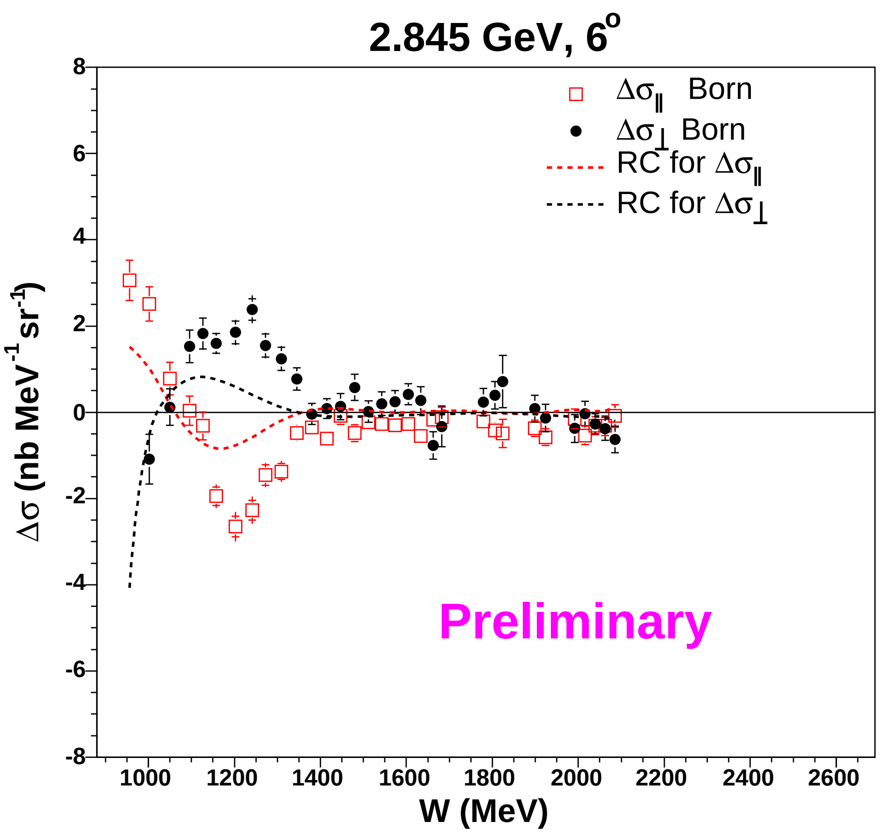
$$q_{L,R} = \frac{1}{2}(1 \mp \gamma_5) q \,,$$

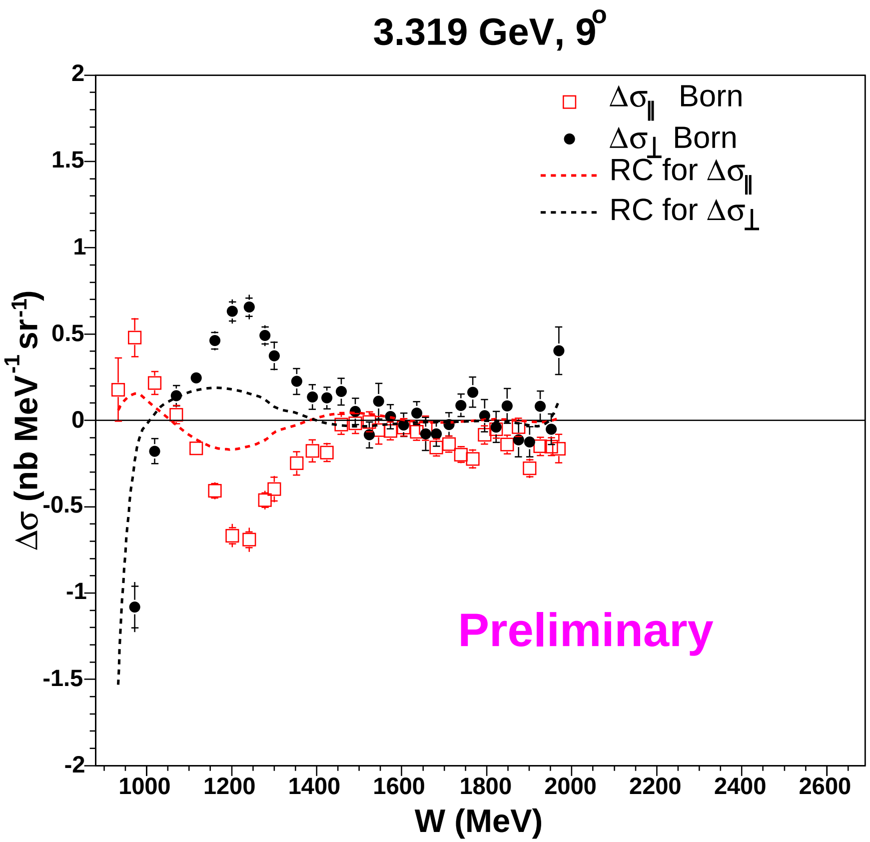
GDH Derivation

Based on fundamental physical arguments

- Lorentz and gauge invariance: low energy theorem, Phys. Rev. **96**, 1428 (1954).
- Unitarity of the S-matrix: optical theorem.
- Causality: dispersion relations for forward compton scattering.

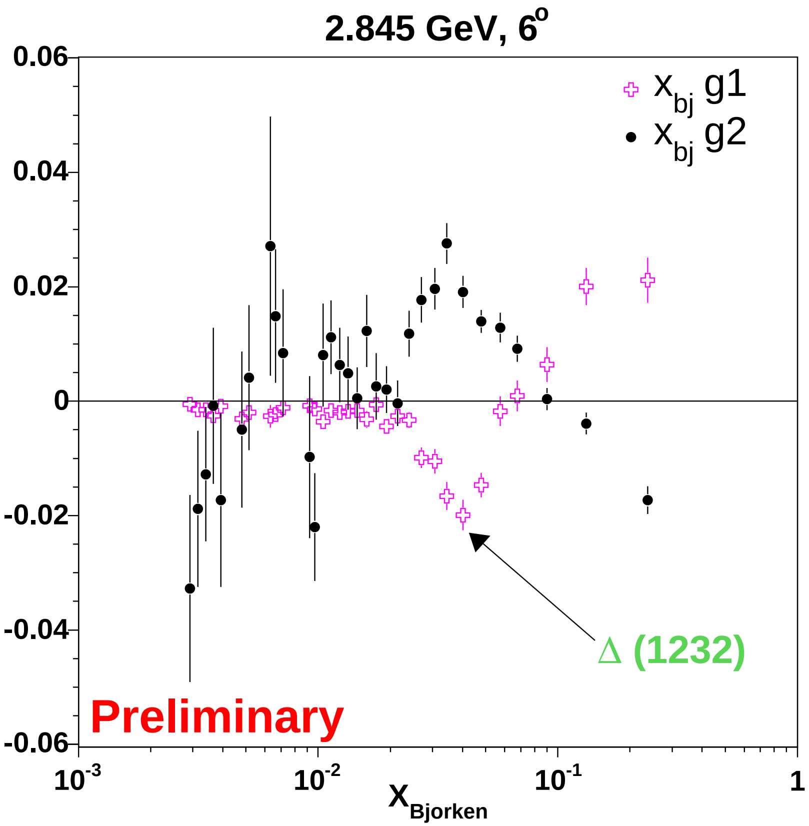
Cross Section Differences

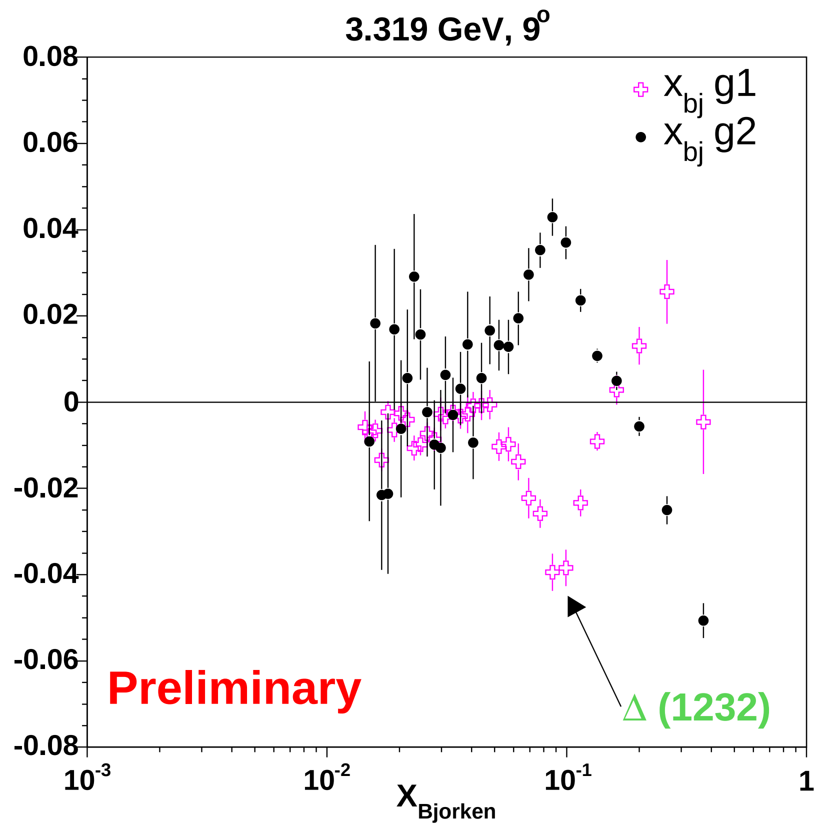




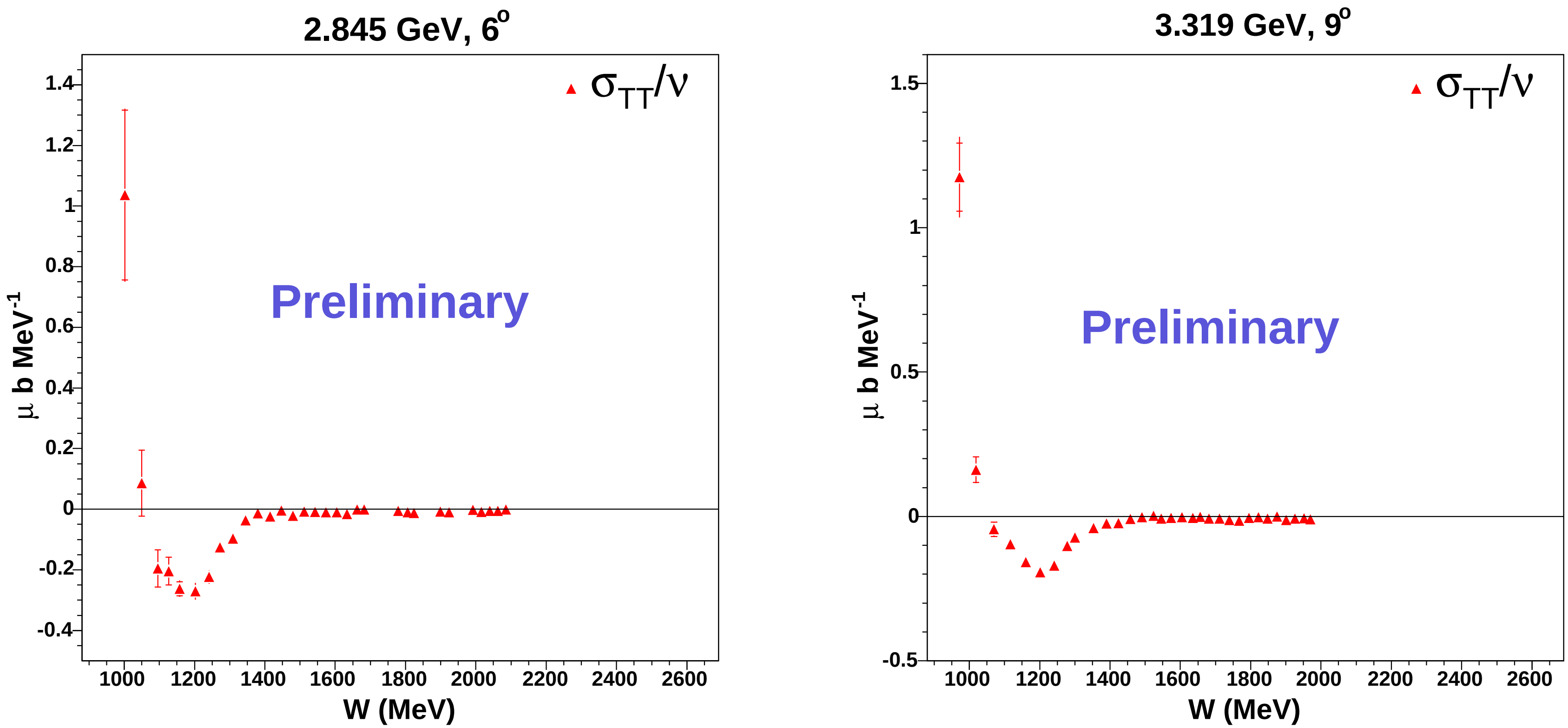
Radiative corrections: formalism of L. Mo and Y. Tsai (unpolarized) and POLRAD (polarized), work done by J. Singh.

^{3}He Spin Structure Functions





The GDH Integrand: $\sigma_{\rm TT}$



$$I(Q^2) = \int_{\nu_{\rm th}}^{\infty} \frac{2\sigma_{\rm TT}}{\nu} d\nu; \quad 2\sigma_{\rm TT} = \sigma_{1/2}(\nu, Q^2) - \sigma_{3/2}(\nu, Q^2)$$

$$\sigma_{\rm TT} = \frac{4\pi^2\alpha}{MK}\left[g_1(\nu, Q^2) - \left(\frac{Q^2}{\nu^2}\right) g_2(\nu, Q^2)\right]$$

Preliminary Target Polarization