The Generalized GDH Sum Rule:

Measuring the Spin Structure of ^{3}He and the Neutron using Nearly Real Photons

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For the Jefferson Lab Hall A Collaboration

GDH2004

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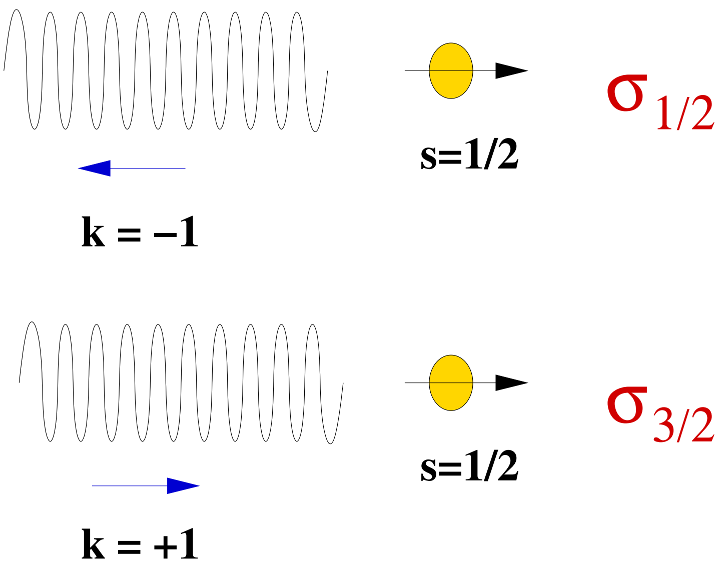
GDH Sum Rule

GDH Sum Rule ($Q^2 = 0$)

- Scattering of circularly polarized photon beam on longitudinally polarized spin-$\frac{1}{2}$ target

$$
\begin{aligned}
I_{GDH} = \int_{\nu_0}^{\infty} (\sigma_{1/2} - \sigma_{3/2}) \frac{d\nu}{\nu} &= -\left(\frac{2\pi^2\alpha}{M_N^2}\right)\kappa_N^2 \\
&= -496\mu b \\
&\quad (^3He) \\
&= -233.2\mu b \\
&\quad (neutron)
\end{aligned}
$$



GDH at Finite Q^2

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

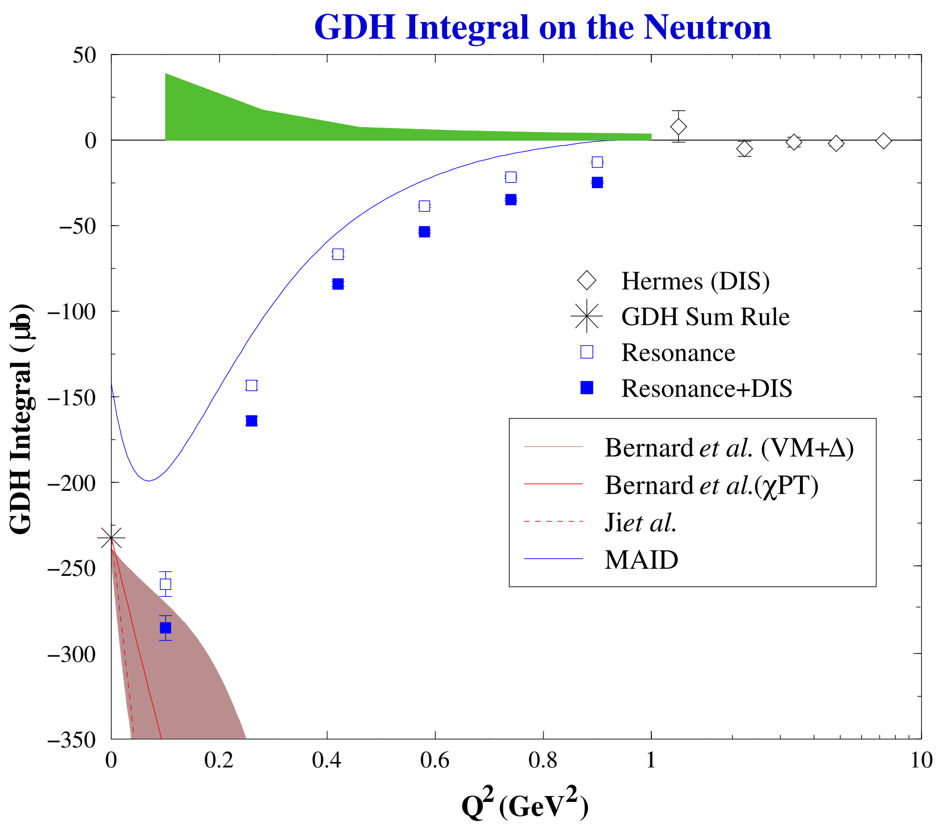
$$I(Q^2) \;=\; \int_{\nu_0}^{\infty}[\sigma_{1/2}(\nu,Q^2)-\sigma_{3/2}(\nu,Q^2)]\frac{d\nu}{\nu}$$

$$\int_{\nu_0}^{\infty} G_{1(2)}\frac{d\nu}{\nu} = \overline{S_{1(2)}}$$

- Related to the forward Compton scattering amplitude ($S_{1(2)}$)
- Provides a bridge from the the non-perturbative region to the perturbative region of QCD
- Compares an experimentally measured quantity to theoretical predictions over the whole Q^2 range

JLab Experiment E94-010

- Extended GDH integral on the Neutron at intermediate Q^2 (0.1 to 0.9 GeV^2)
- M. Amarian et al. (Hall A E94-010 Collaboration), PRL **89**, 242301 (2002)
- Second paper on the moments of g_1^n and g_2^n published (PRL **92**, 022301 (2004)).



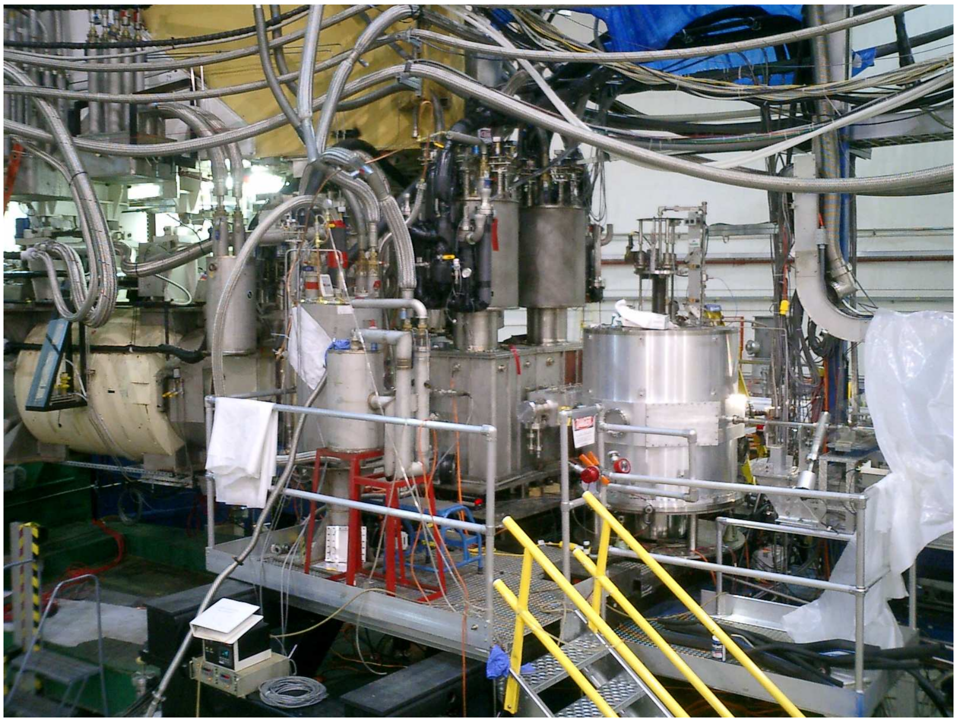
JLab Experiment E97-110

Goals of the experiment:

- Precise measurement of generalized GDH integral at low Q^2 (0.02 to 0.3 $(\text{GeV})^2$)
  - Determine the slope of the generalized GDH integral and test dynamics of $\chi\mathrm{PT}$ at low Q^2
  - Extrapolate to the real photon point
  - Learn more about the structure of ^{3}He and the resonance structure of the neutron
- The moments of the spin structure functions and the forward spin polarizabilities will also be extracted
- Overlap with previous Hall A GDH experiment E94-010

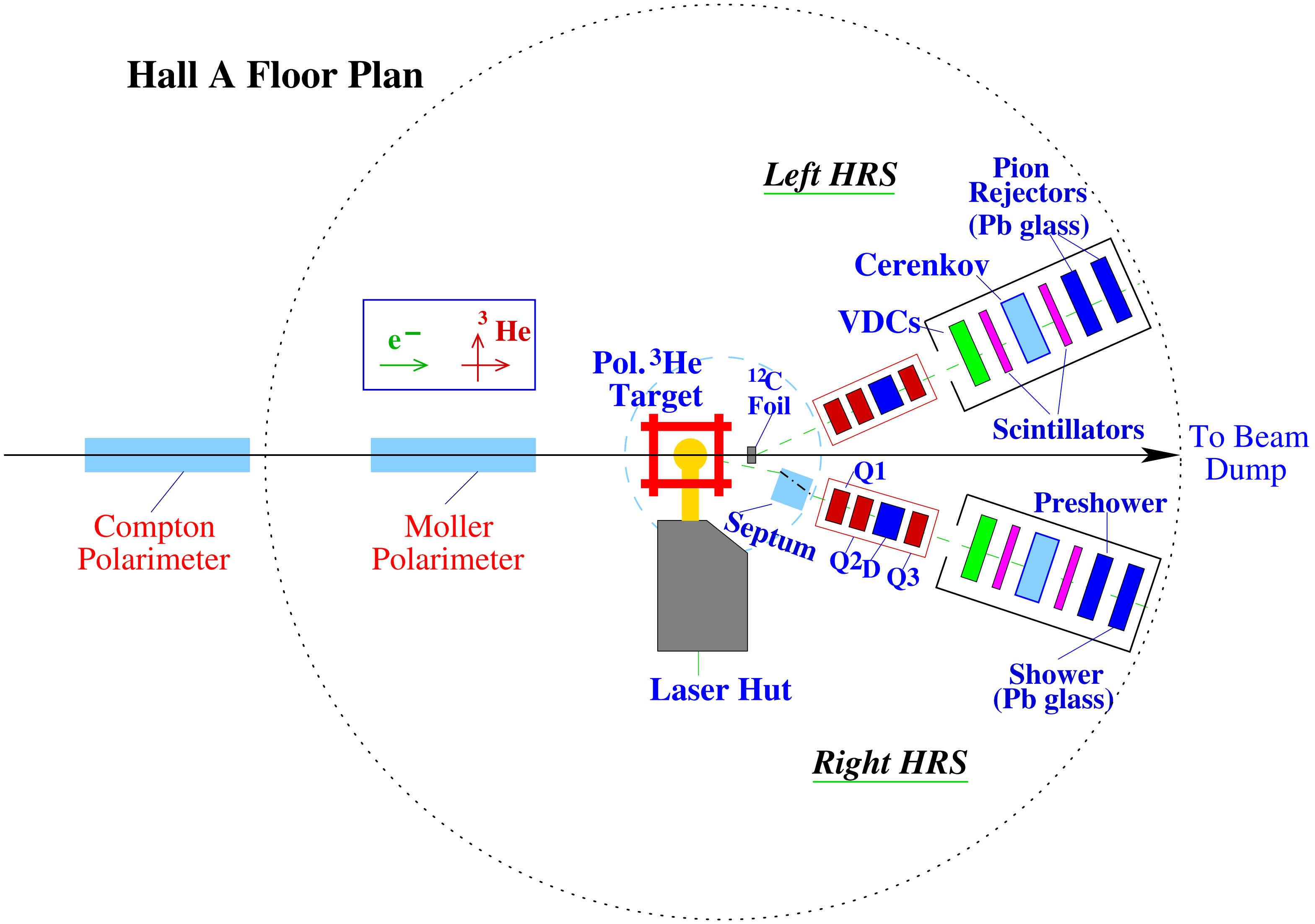
Aspects of the experiment:

- The experiment ran in Hall A during Spring and Summer 2003
- Polarized cross sections and asymmetries were measured.
- Right septum magnet was commissioned at scattering angles of 6° and 9°
- Compensating coils and magnetic field clamps were used to reduce field gradients from the septum.



June 4^{th}, 2004

Hall A Floor Plan

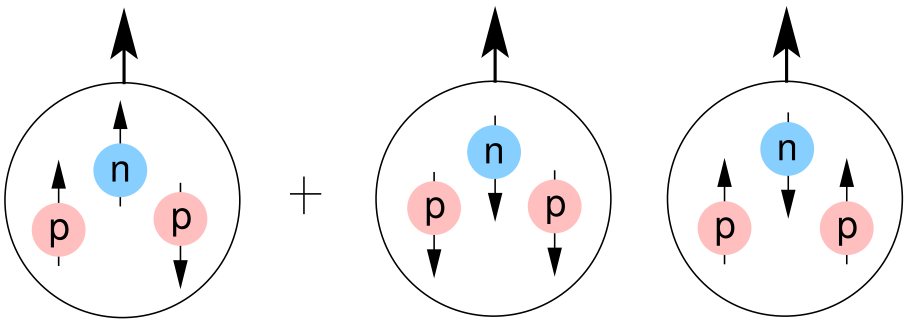


Vincent Sulkosky

From ^{3}He to the Neutron

- ^{3}He ground state wavefunction mainly consists of three states: S, D, S'.
- The dominant S state leads to an effective neutron polarization of 86%. (J. Friar et al.).

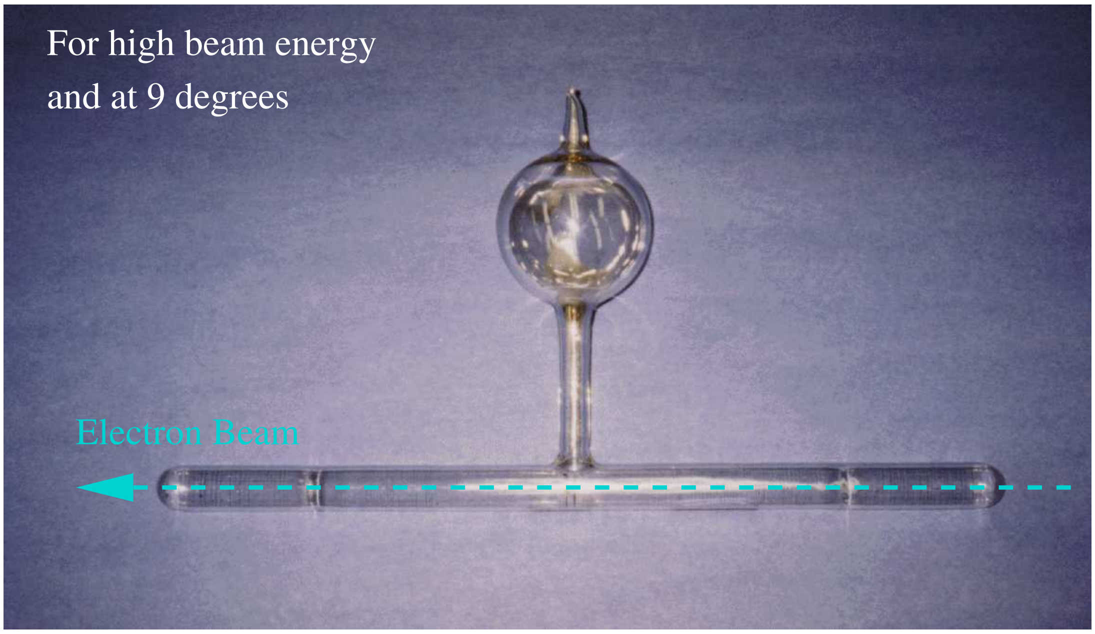
$$\mathrm{I}^{^3\mathrm{He}}(\mathrm{Q}^2) = 2\mathrm{P_p}\mathrm{I^p}(\mathrm{Q}^2) + \mathrm{P_n}\mathrm{I^n}(\mathrm{Q}^2)$$

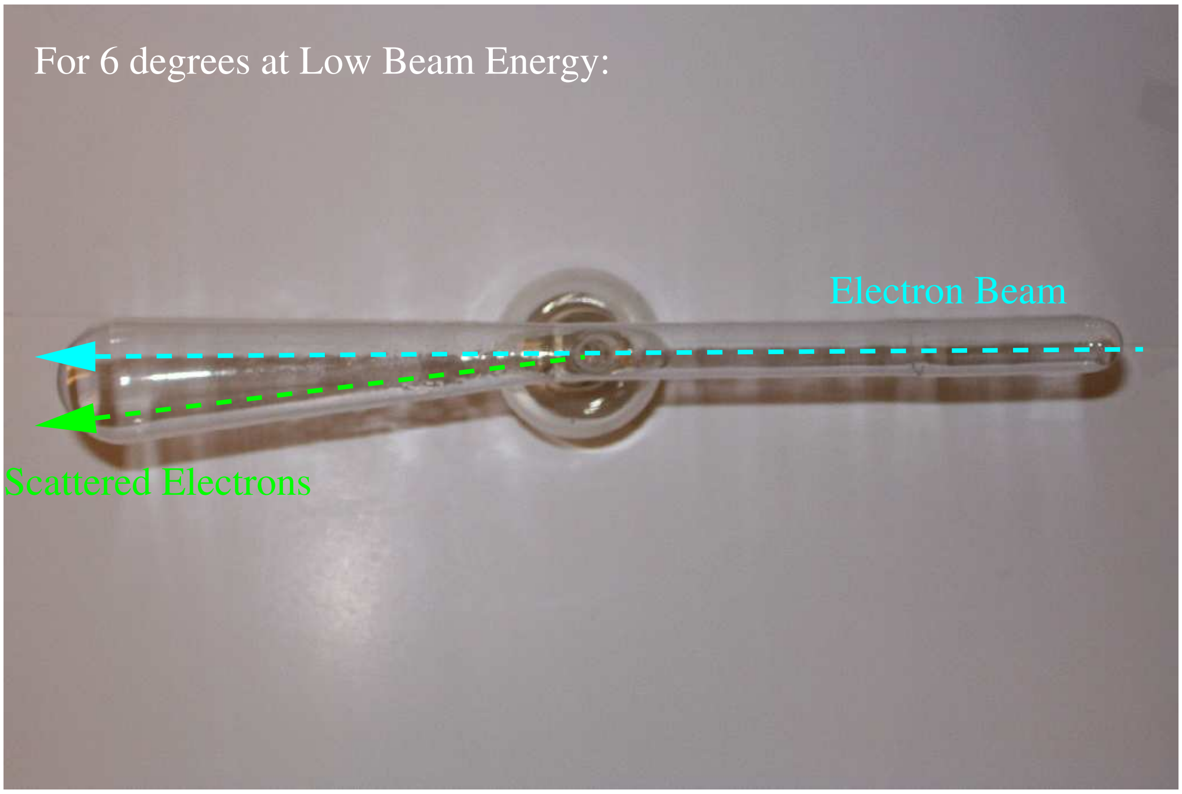


S state ($\sim$88.2%) D state ($\sim$9.8%) S' state ($\sim$1.4%)

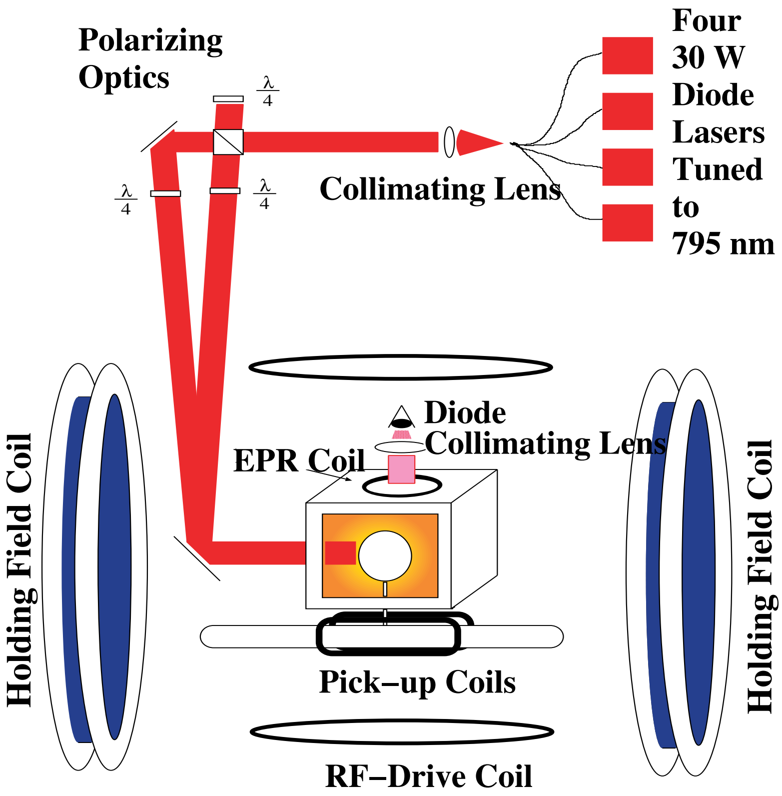
- Convolution model takes into account Fermi motion and binding effects. (C. Ciofi degli Atti, S. Scopetta et al.).

Target Cell Designs



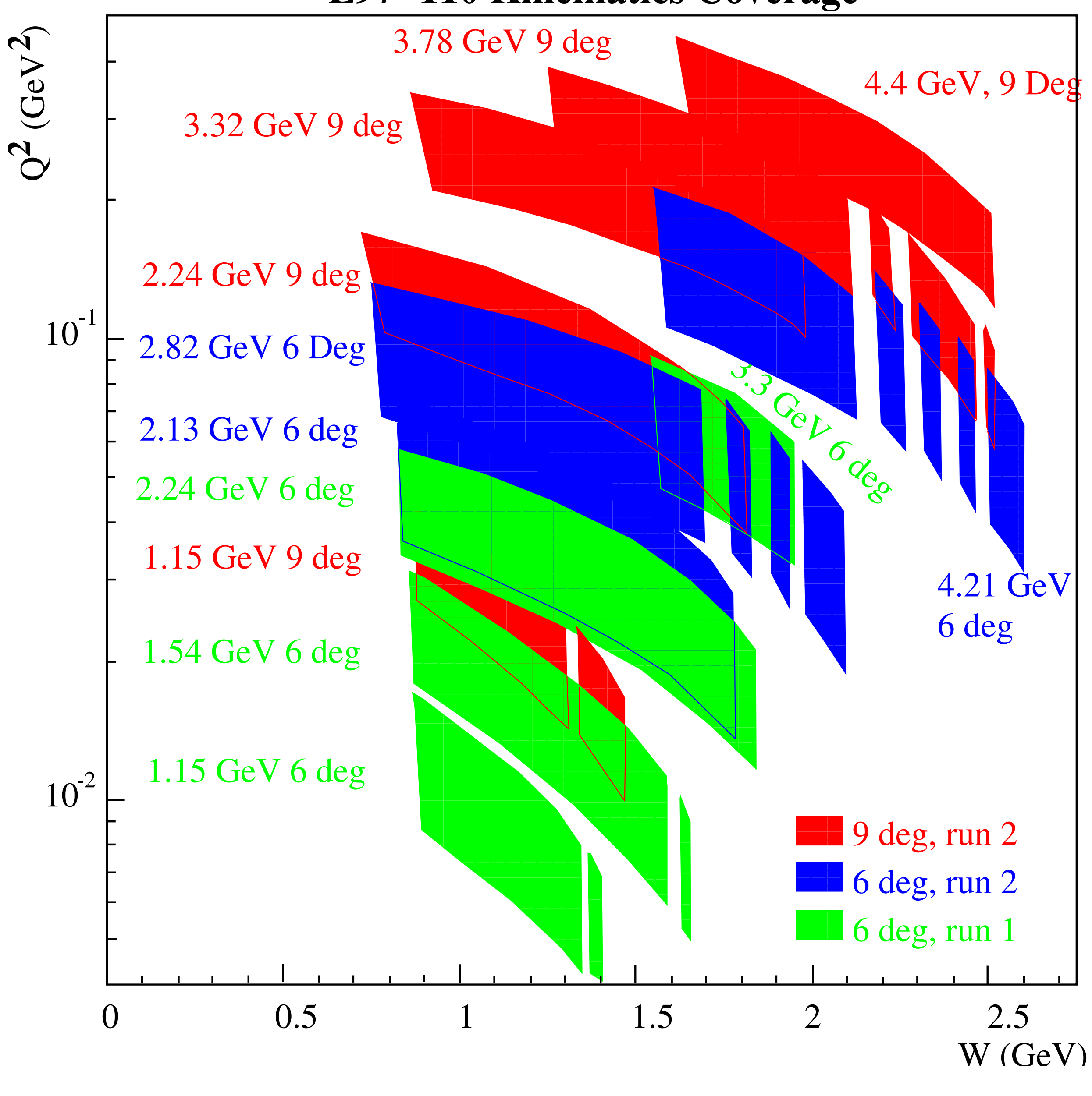


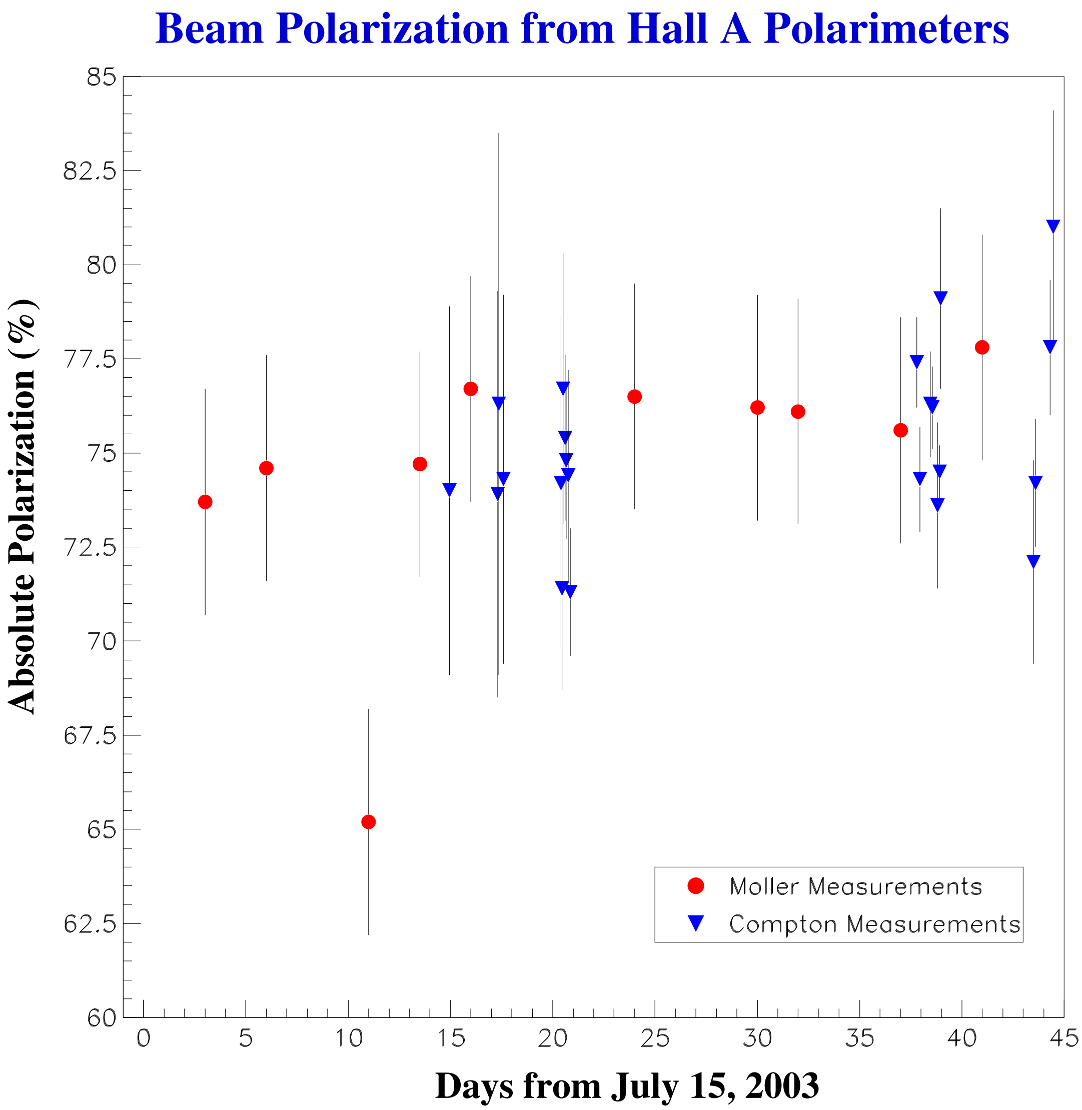
Polarized ^{3}He target



- ^{3}He is polarized through spin exchange with optically pumped Rb atoms.
- Longitudinal and transverse polarization configurations were used.
- Two methods of polarimetry: NMR and EPR
- Target polarization in beam $\sim$ 40%

E97−110 Kinematics Coverage

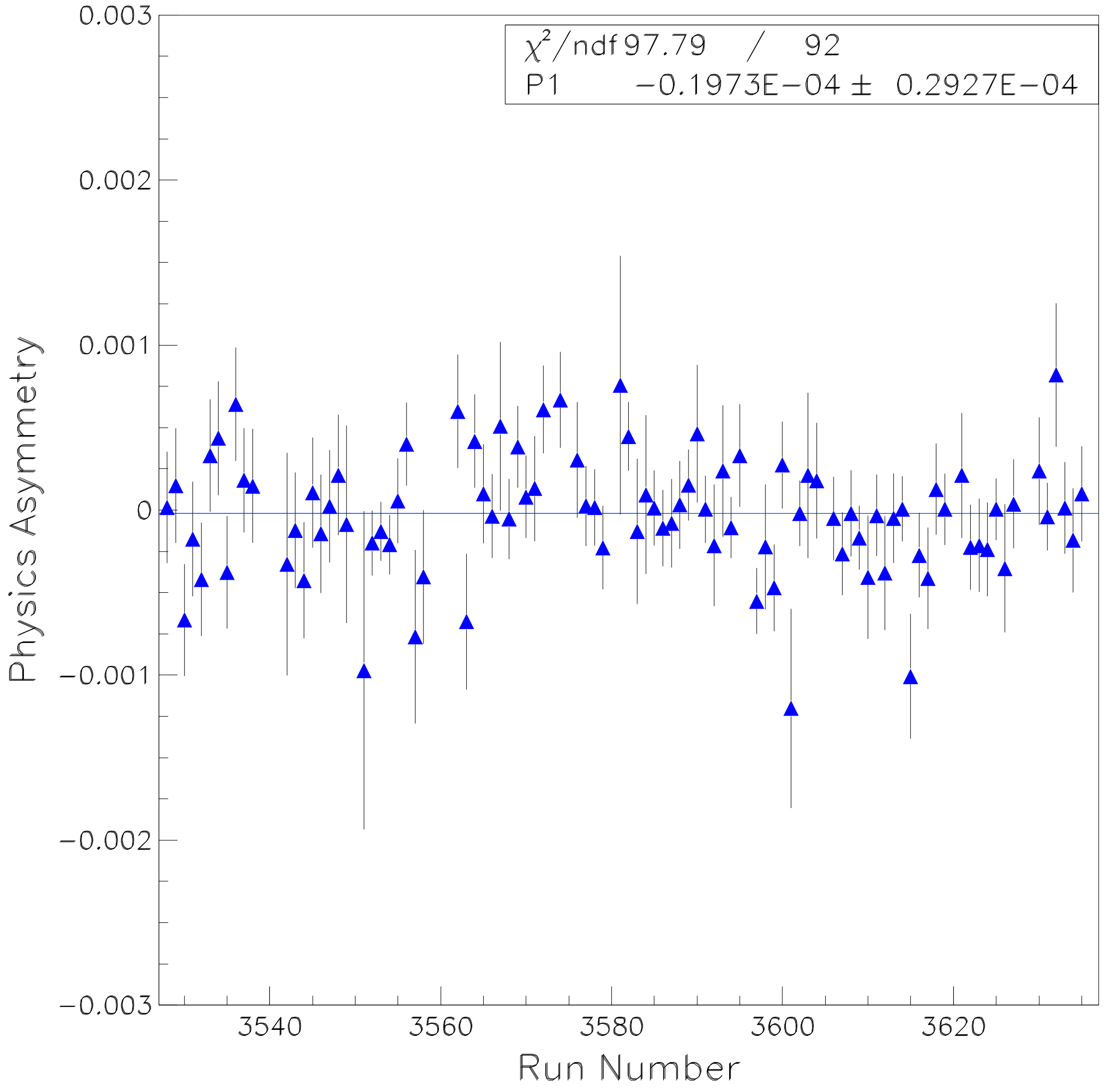




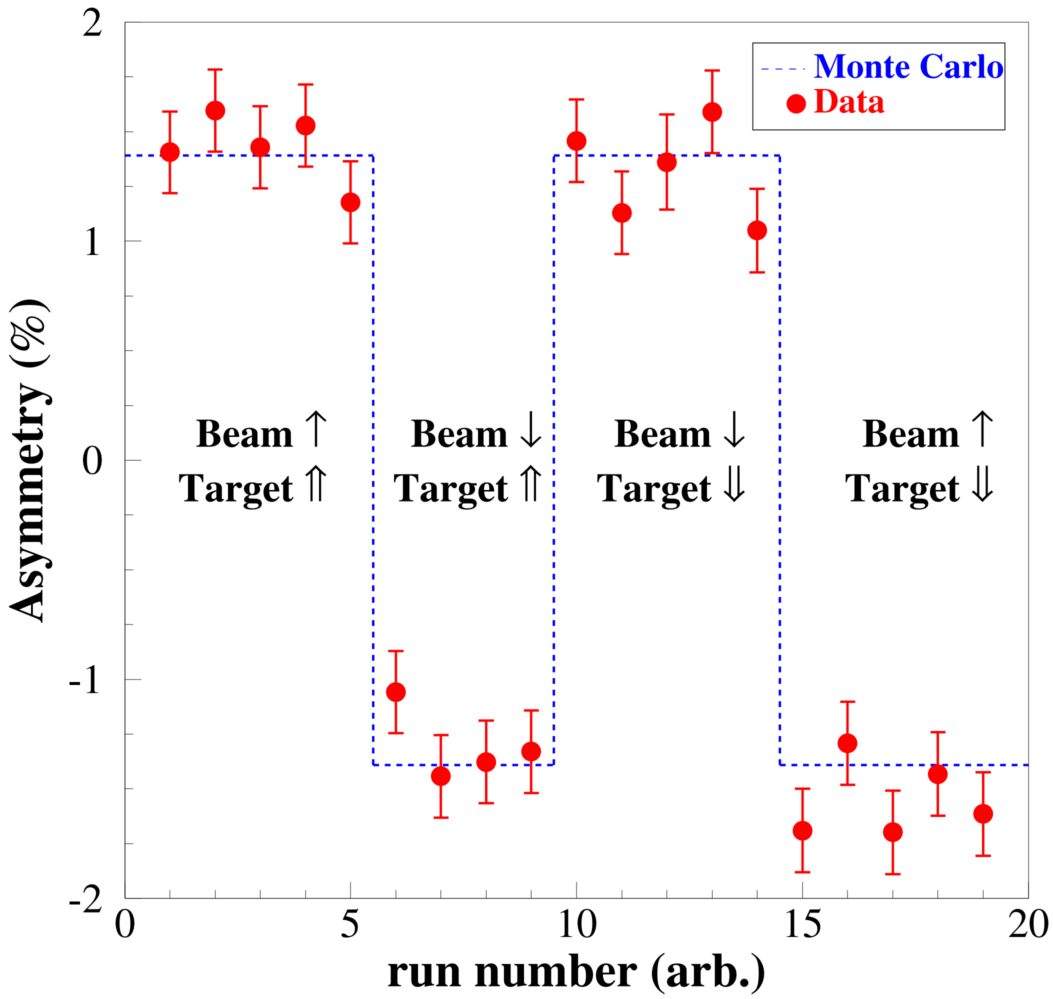
- Average beam polarization was 74.7% from Møller and 74.9% from Compton

- Analysis of the ^{12}C False asymmetry using left arm scalers

1.15 GeV at 9°



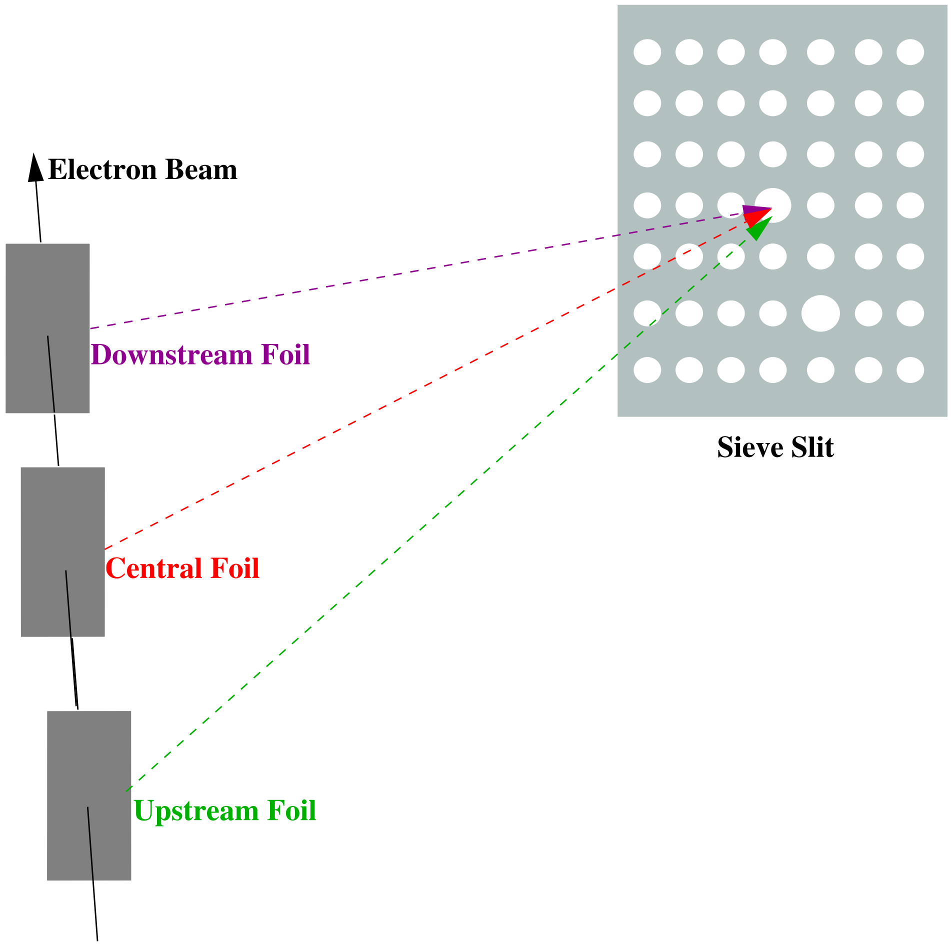
^{3}He Elastic Asymmetry

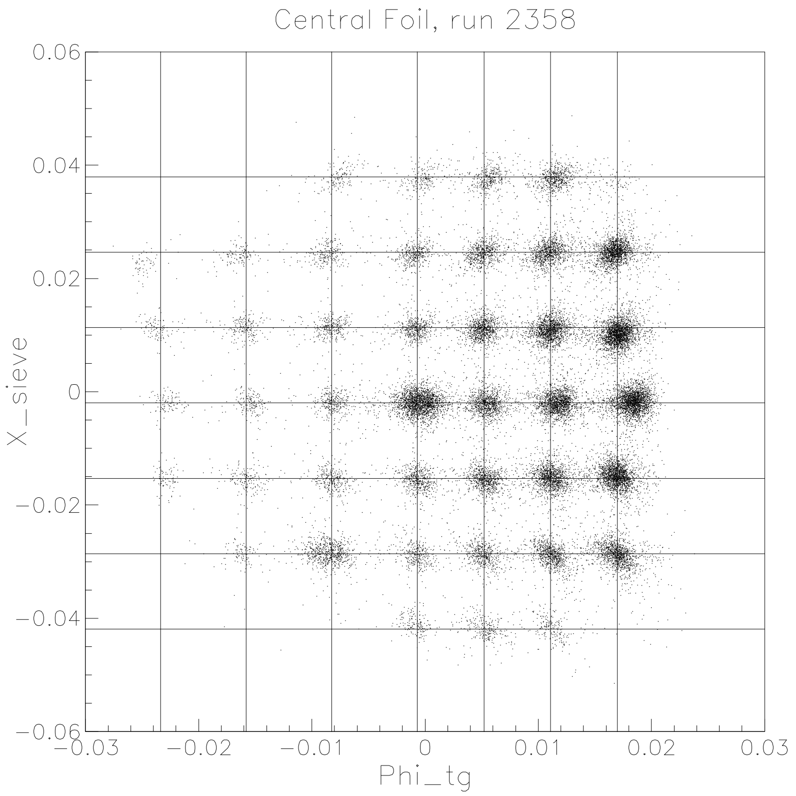


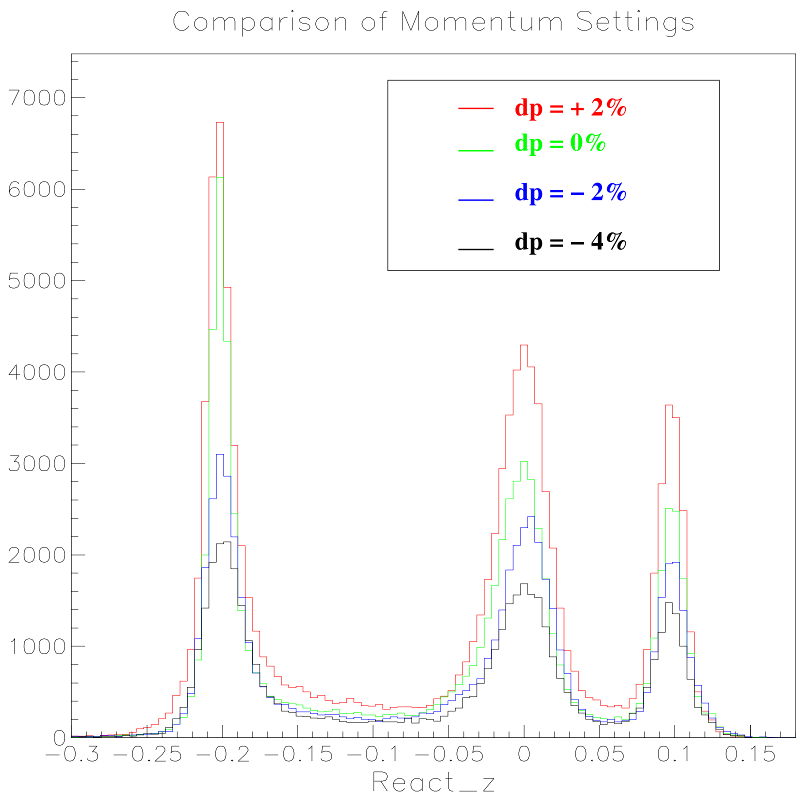
- Preliminary analysis agrees with Monte Carlo predictions. Monte Carlo = 1.390%, $< \mathrm{Data} >$ = (1.403 $\pm$ 0.044)% with $\chi^2/\mathrm{N_{dof}}$ = 1.08.
- Four target and beam configurations

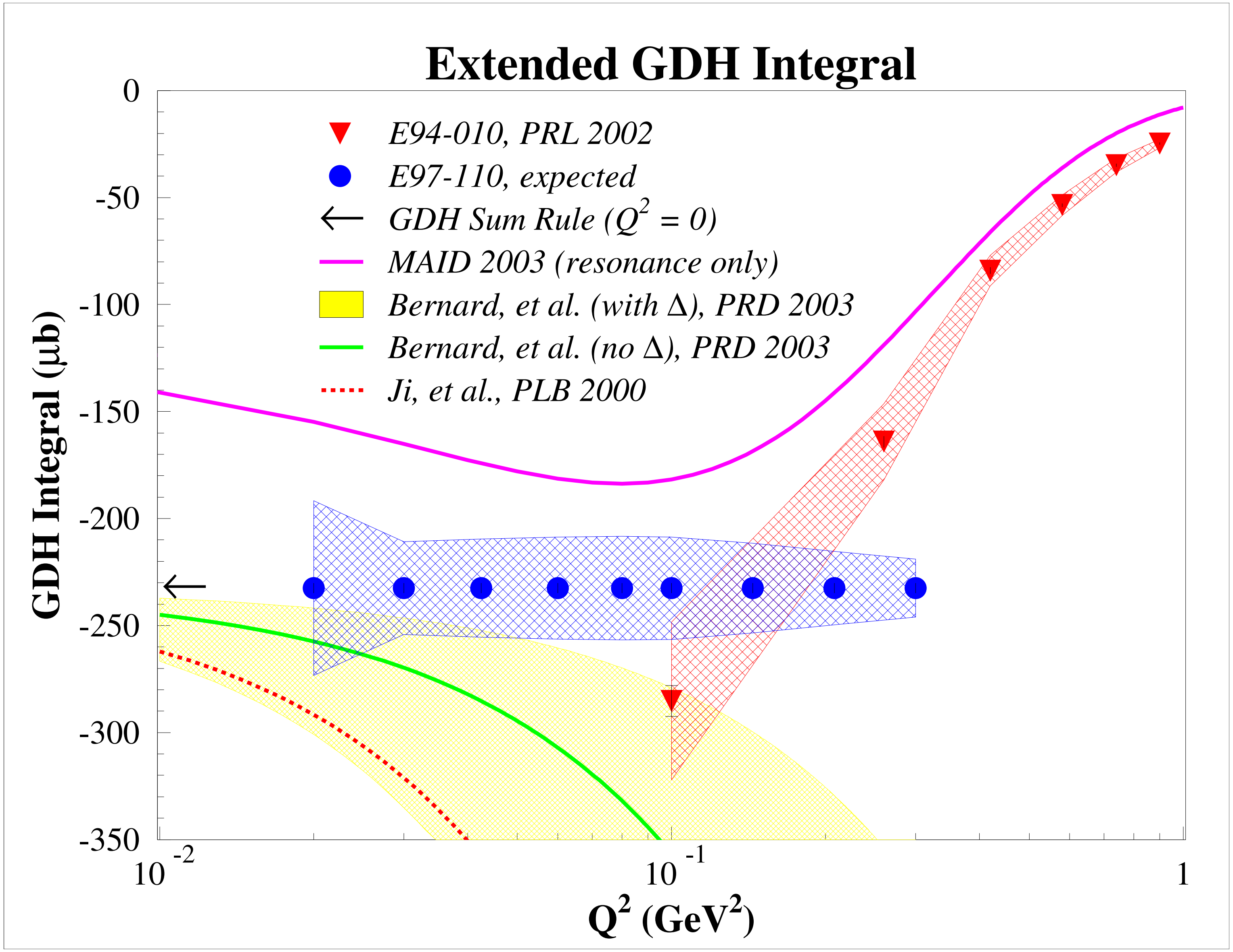
Spectrometer Optics Calibration

- The septum magnet is a new optics component to the standard Hall A HRS system.
- Optics data acquired for several energies for the right septum with the HRS.
- Optimization completed at 6° for 2.134 GeV beam energy.




Central Foil, run 2358
X_sieve
Phi_tg
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.03
−0.02
−0.01
0
0.01
0.02
0.03


Comparison of Momentum Settings
dp = + 2%
dp = 0%
dp = − 2%
dp = − 4%
React_z
7000
6000
5000
4000
3000
2000
1000
0
−0.3
−0.25
−0.2
−0.15
−0.1
−0.05
0
0.05
0.1
0.15



Extended GDH Integral
E94-010, PRL 2002
E97-110, expected
GDH Sum Rule (Q^2 = 0)
MAID 2003 (resonance only)
Bernard, et al. (with Δ), PRD 2003
Bernard, et al. (no Δ), PRD 2003
Ji, et al., PLB 2000
GDH Integral (μb)
0
-50
-100
-150
-200
-250
-300
-350
10^{-2}
10^{-1}
1
Q^2 (GeV^2)

Summary

- Summary:
  - New low Q^2 measurements of the extended GDH integral will:
    - test the dynamics of Chiral Perturbation Theory
    - determine where or if the slope turns over
    - allow an extrapolation to the real photon point
  - Data complements E94010 data set above Q^2 of 0.10 with improved precision
  - The moments of the spin structure functions and the forward spin polarizabilities will be extracted
- Analysis is underway:
  - ^{12}C False asymmetries small and consistent with zero
  - Preliminary elastic asymmetry analysis looks good.
  - Understanding of the septum optics is close to completion for the second run, but more work remains.