Low Q^2 Measurements of the Neutron and ^{3}He Spin Structure

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For the Jefferson Lab Hall A Collaboration

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Inclusive Electron Scattering

Energy transfer:

$$\nu = E - E^{'}$$

4-momentum transfer squared:

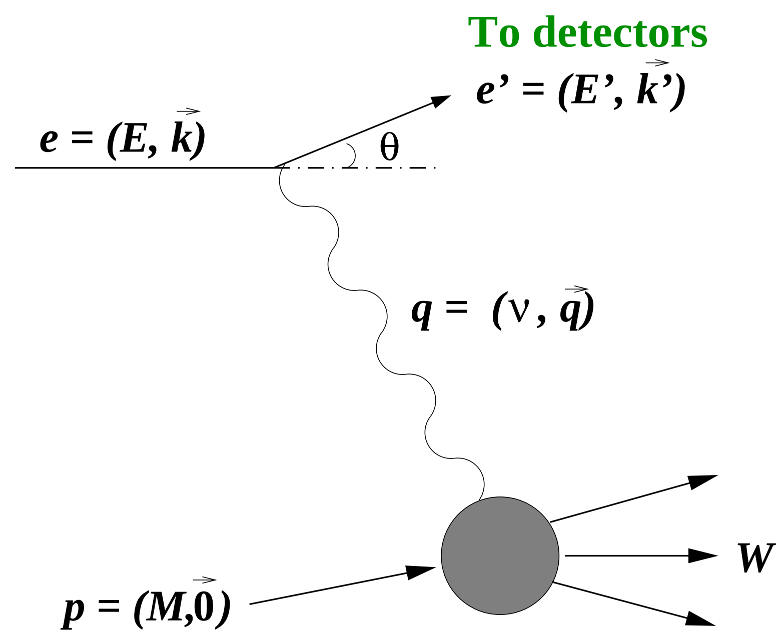
$$\vec{q} = \vec{k} - \vec{k'}$$

$$Q^2 = -q^2 = 4EE^{'}\sin^2\frac{\theta}{2}$$

Invariant Mass:

$$W^2 \equiv (P+q)^2$$

$$W^2 = M^2 + 2M\nu - Q^2$$



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

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

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

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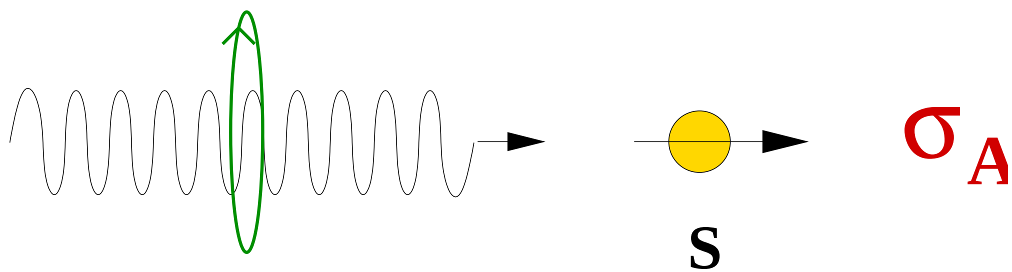
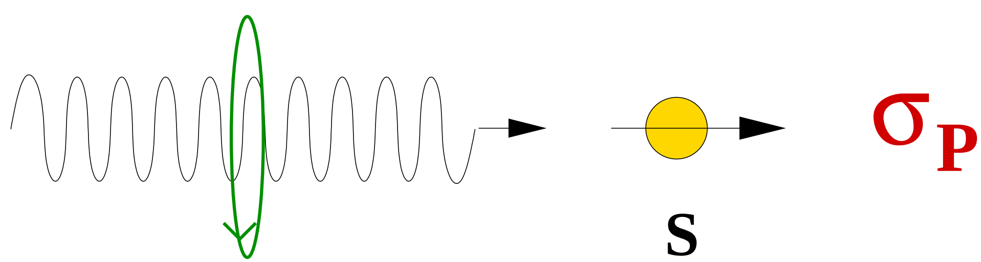
- $\sigma_{\frac{1}{2}}$ ($\sigma_{\frac{3}{2}}$) photoabsorption cross section with photon spin parallel (anti-parallel) to the target spin.





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$$I^{\rm n}_{\rm GDH} = -233.2\mu b$$

- Circularly polarized photon incident on a longitudinally polarized spin-$\frac{1}{2}$ target.
- $\sigma_{\frac{1}{2}}$ ($\sigma_{\frac{3}{2}}$) photoabsorption cross section with photon spin 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 target.

Generalized Integral ($Q^2 > 0$)

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

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

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

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 Integral

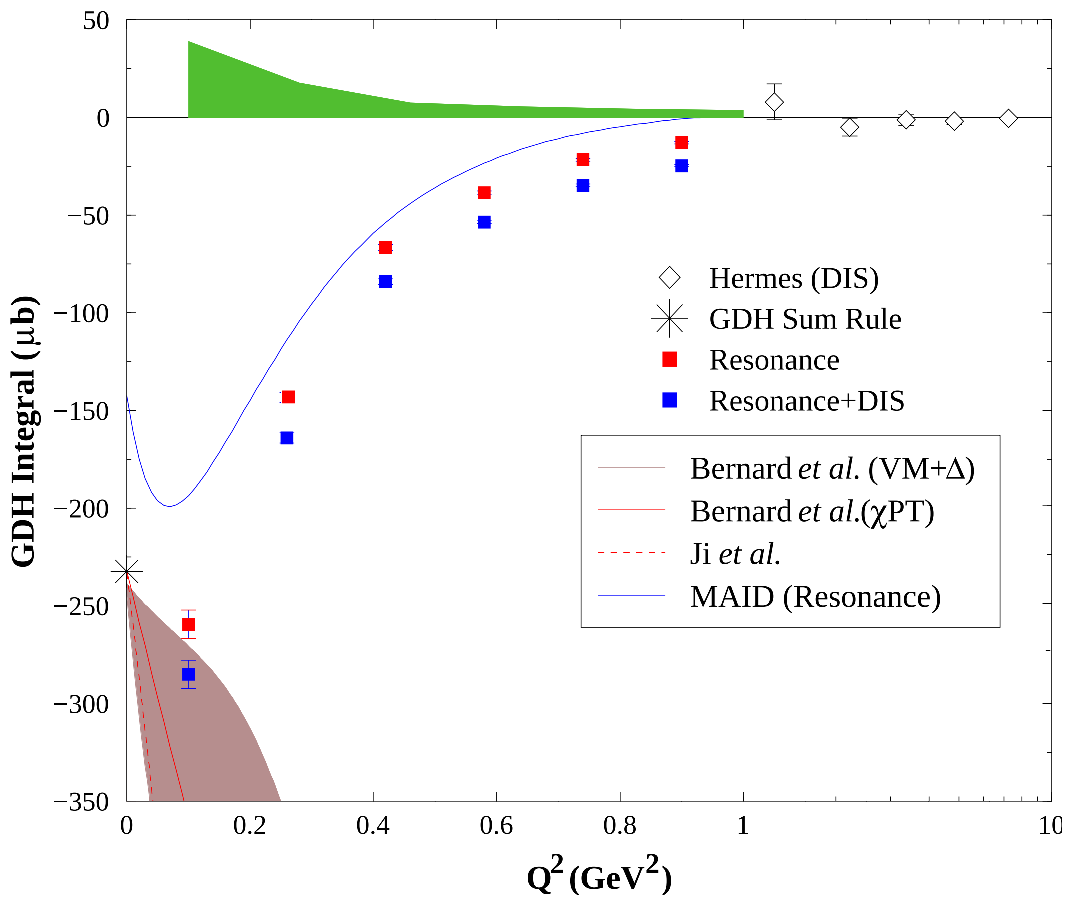
χPT Lattice QCD pQCD

Q^2 = 0 $Q^2 = \infty$

Hadronic Partonic

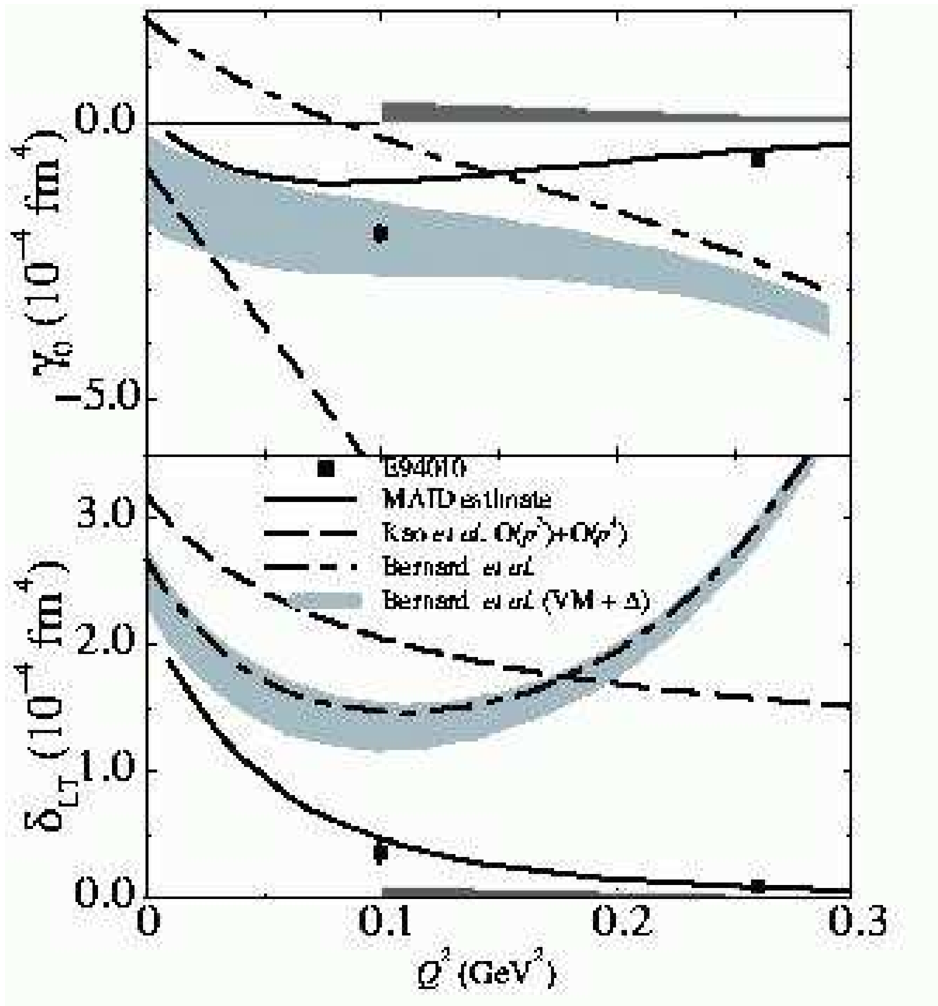
- Constrained at the two ends of the Q^2 spectrum by known sum rules.
- S_1 can be calculated at any Q^2.
- Compare theoretical predictions to experimental measurements over the entire Q^2 range.
- Provides a bridge from the non-perturbative region to the perturbative region of QCD.

Hall A Neutron Results



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

Neutron Spin Polarizabilities

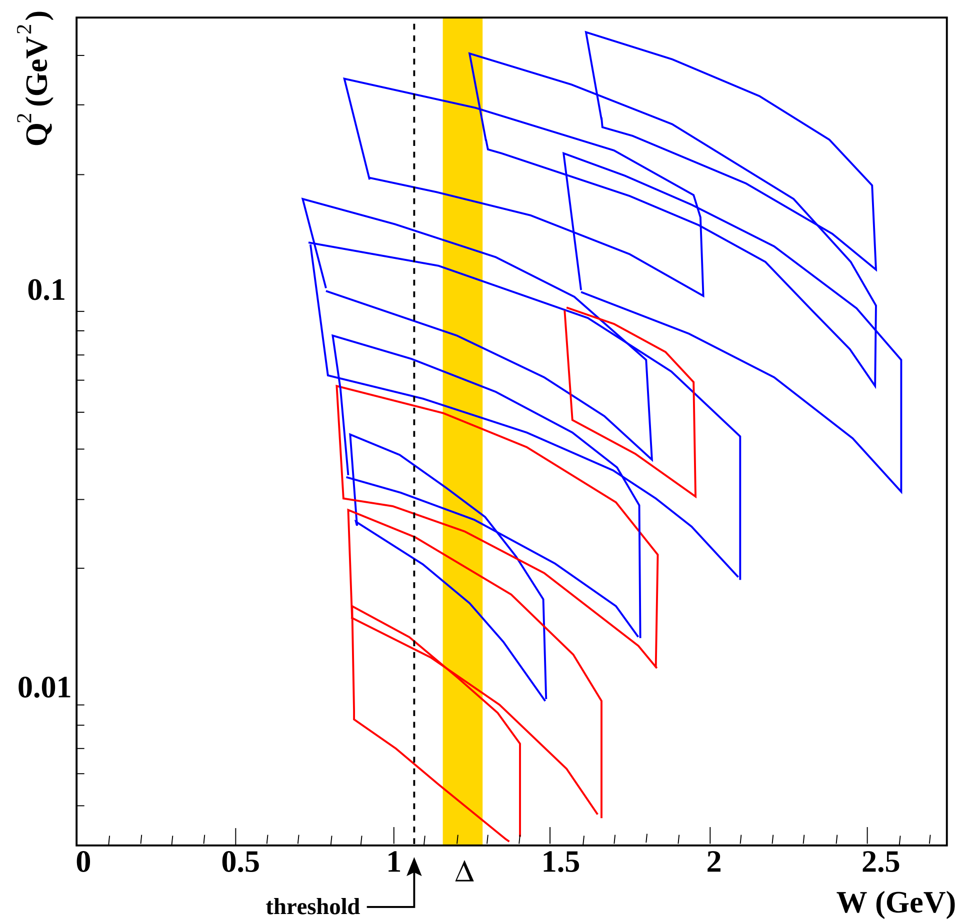


M. Amarian *et al.* , PRL **93**, 152301 (2004)

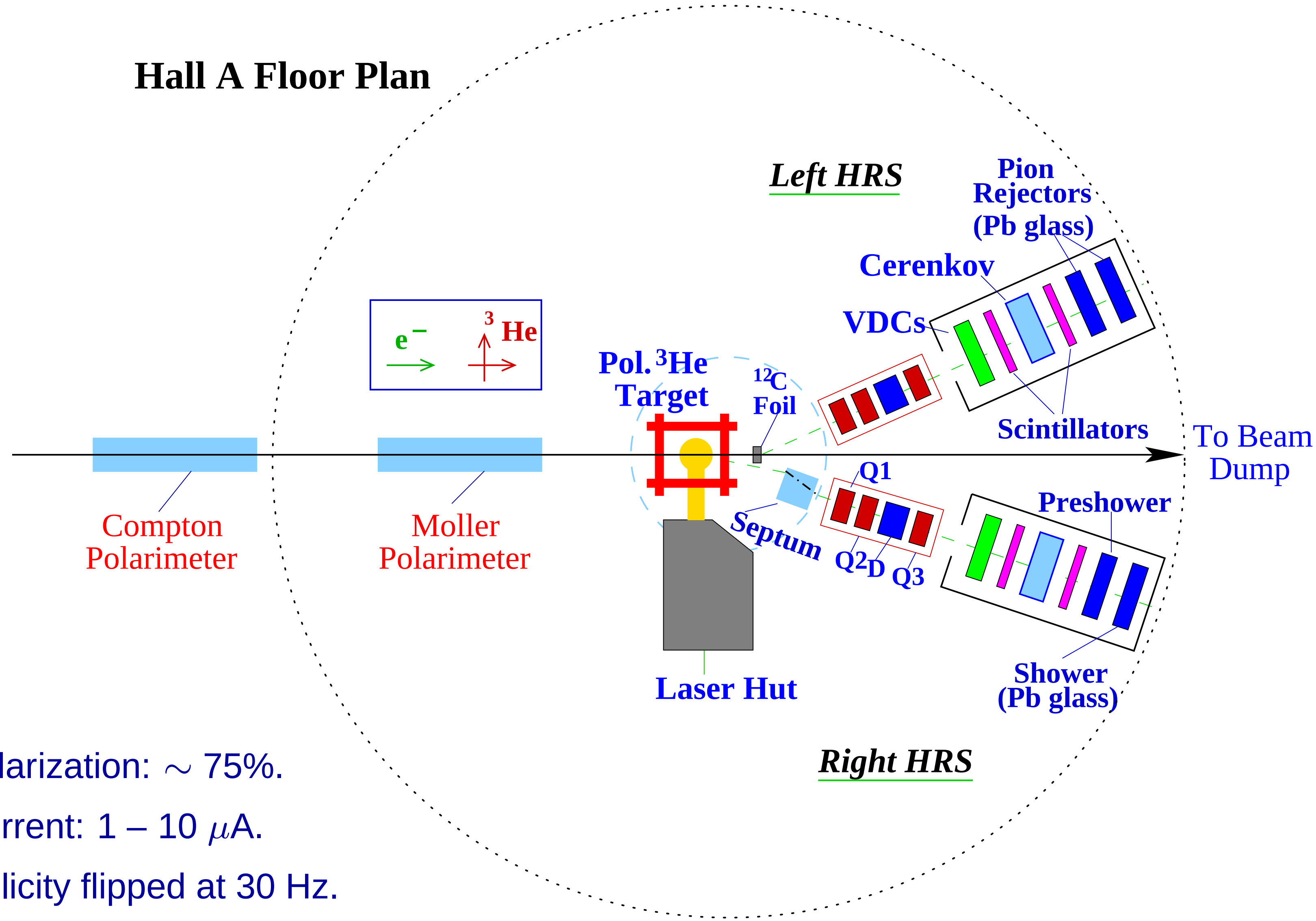
Experiment E97-110

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: $^3\overrightarrow{\mathrm{He}}(\vec{e},e')X$
- Measured polarized cross section differences
- Seven different beam energies from 1.1 GeV to 4.4 GeV were used and two angles.
- The spectrometer momentum was varied from 0.5 GeV/c to 3.1 GeV/c.



Experimental Setup



Beam Polarization: $\sim$ 75%.

Beam Current: 1 – 10 μA.

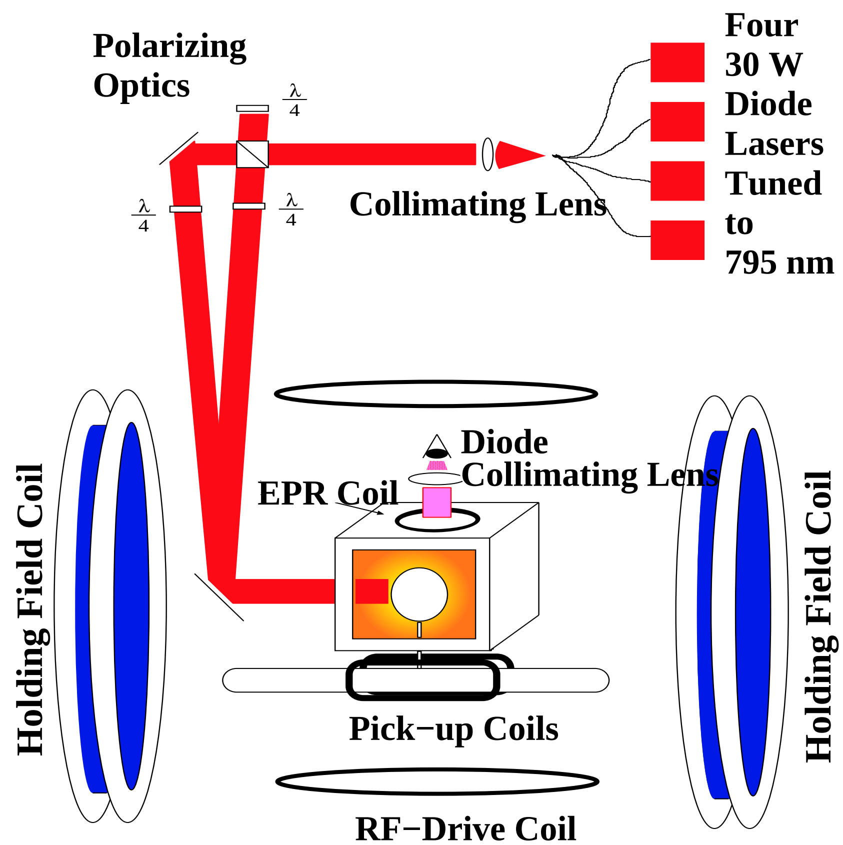
Beam Helicity flipped at 30 Hz.

The Septum Magnet

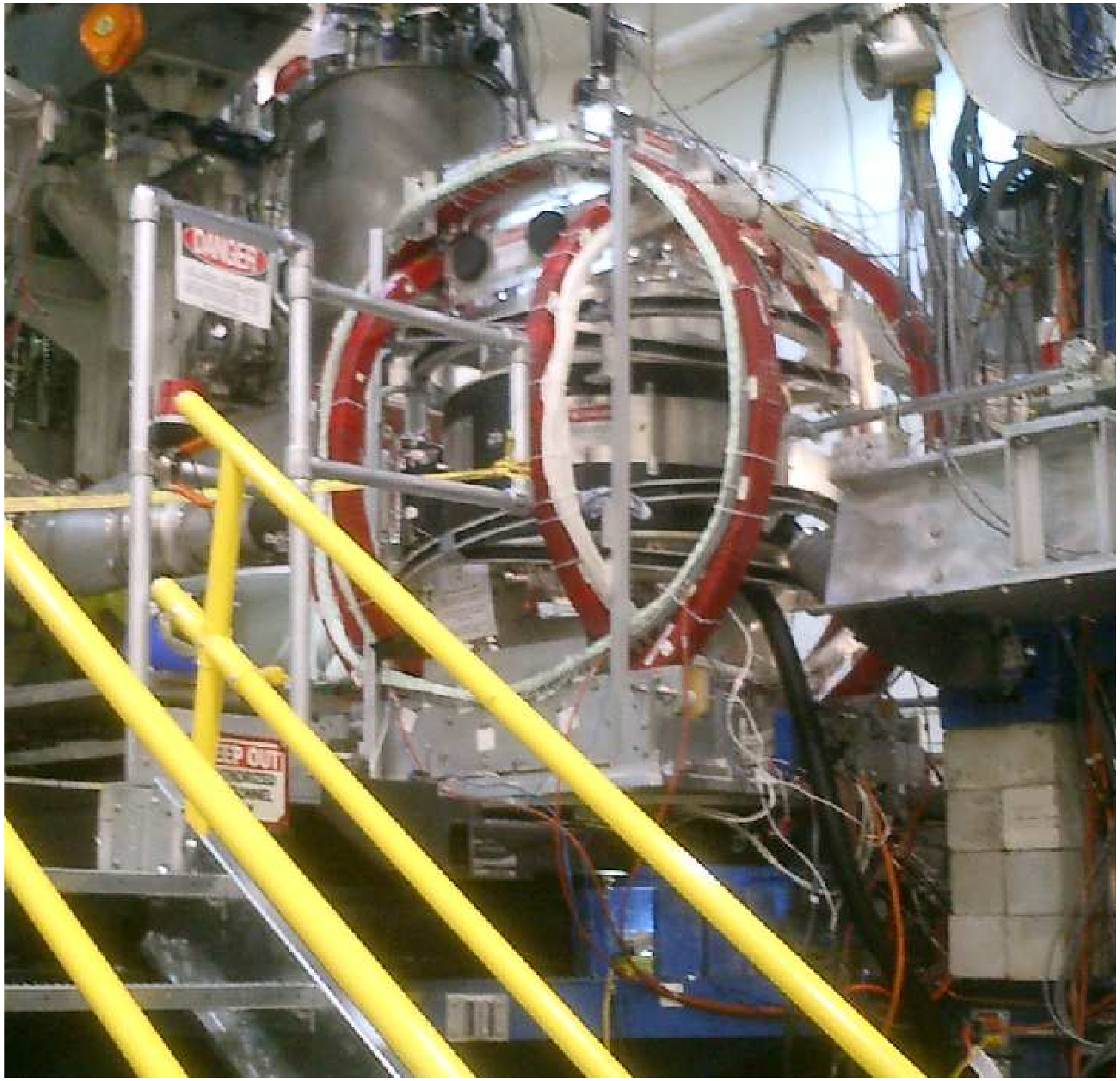
- Low Q^2 requires forward angles.
- Minimum spectrometer angle is 12.5°.
- The septum magnet allows detection of electrons with scattering angles of 6° and 9°.
- Designed for the spectrometers to retain their resolution and acceptance.

Polarized ^{3}He System

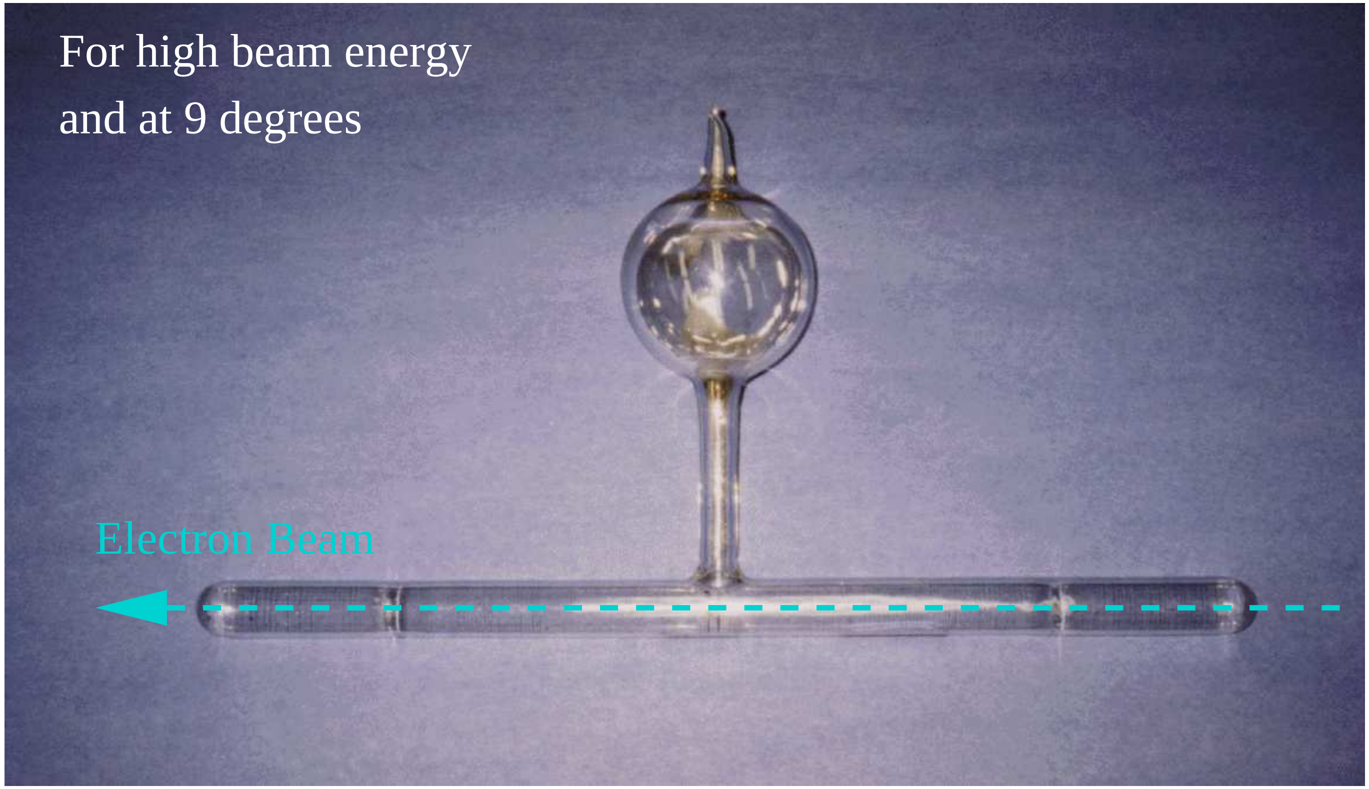
- Spin Exchange with optically pumped Rb atoms.
- Both longitudinal and transverse configurations.
- Two independent polarimetries: NMR and EPR
- Average polarization $\sim$ 40%.



Hall A Polarized ^{3}He Target



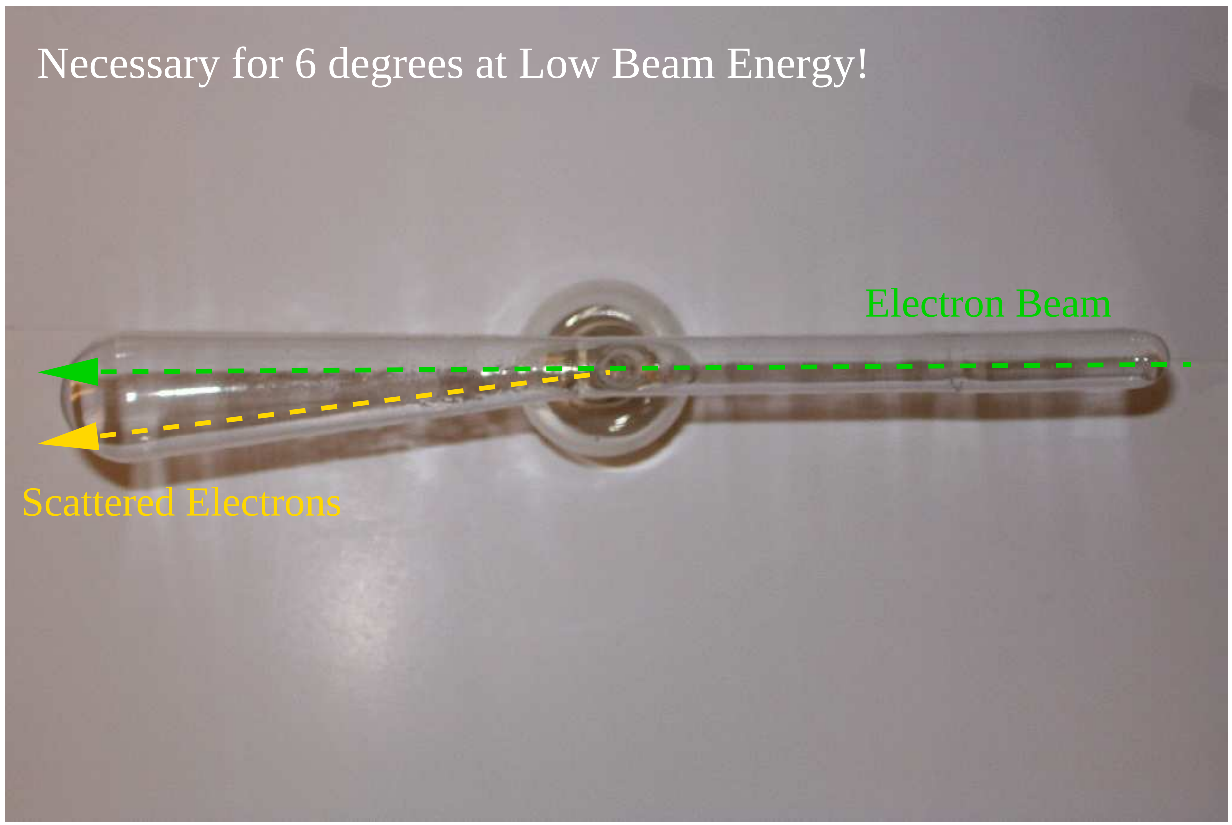
Polarized ^{3}He Target: Standard cell



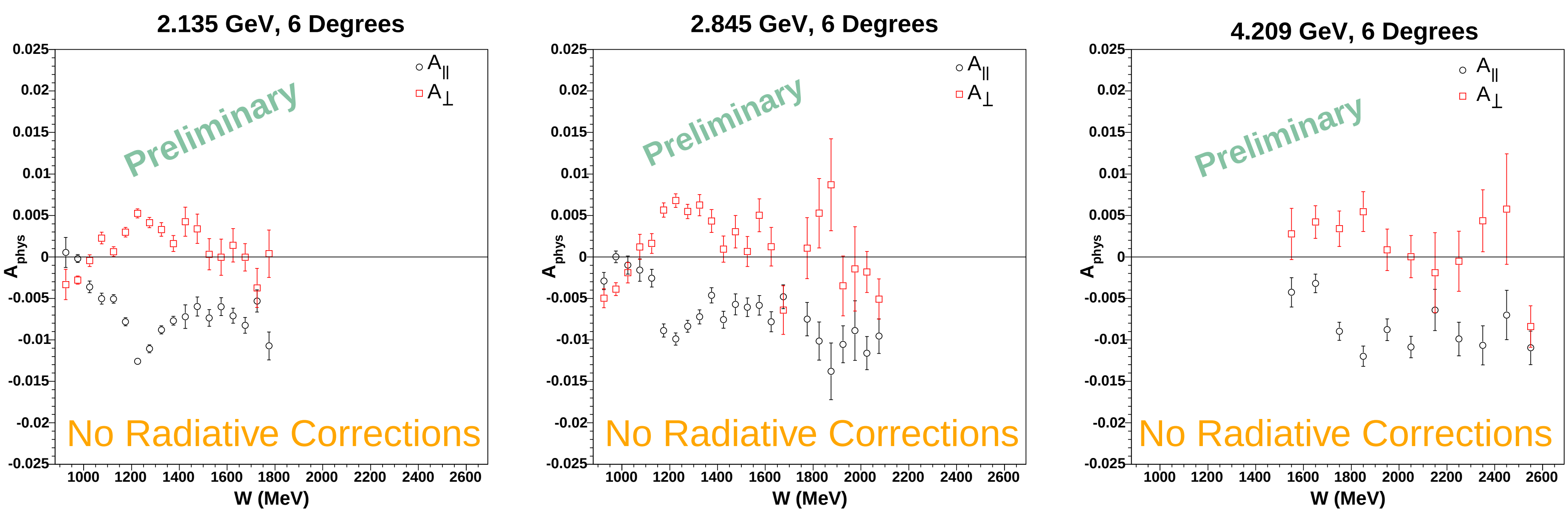
- Two chamber cell
- Pressure $\sim$ 12–14 atm under running conditions
- Length $\sim$ 40 cm

Polarized ^{3}He Target: "Ice Cone" cell

- Used to reduce scattered electron energy loss.
- The design, production, and testing took about 1 year.
- Length $\sim$ 34 cm with comparable target polarization.



^{3}He Asymmetries



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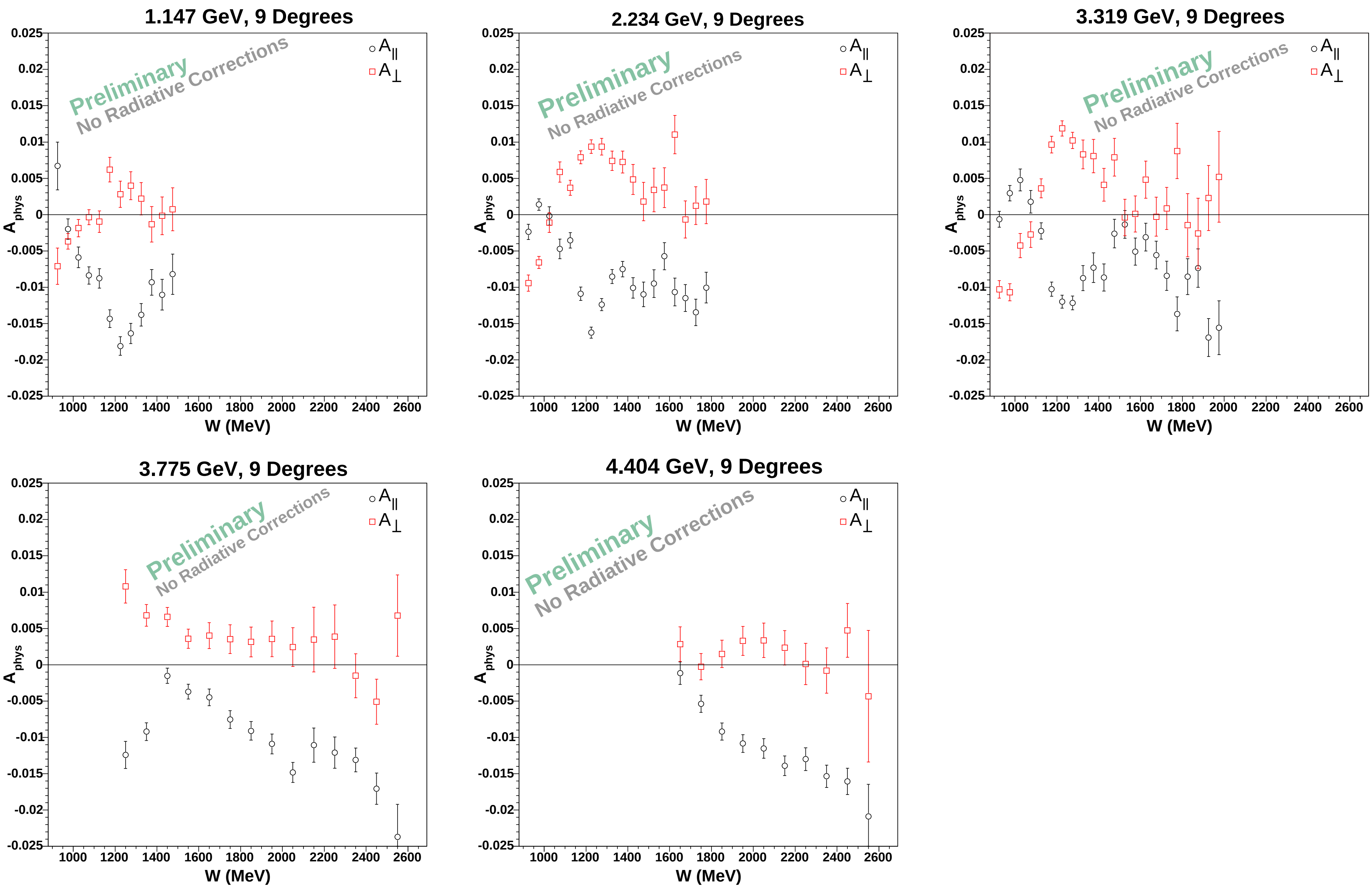
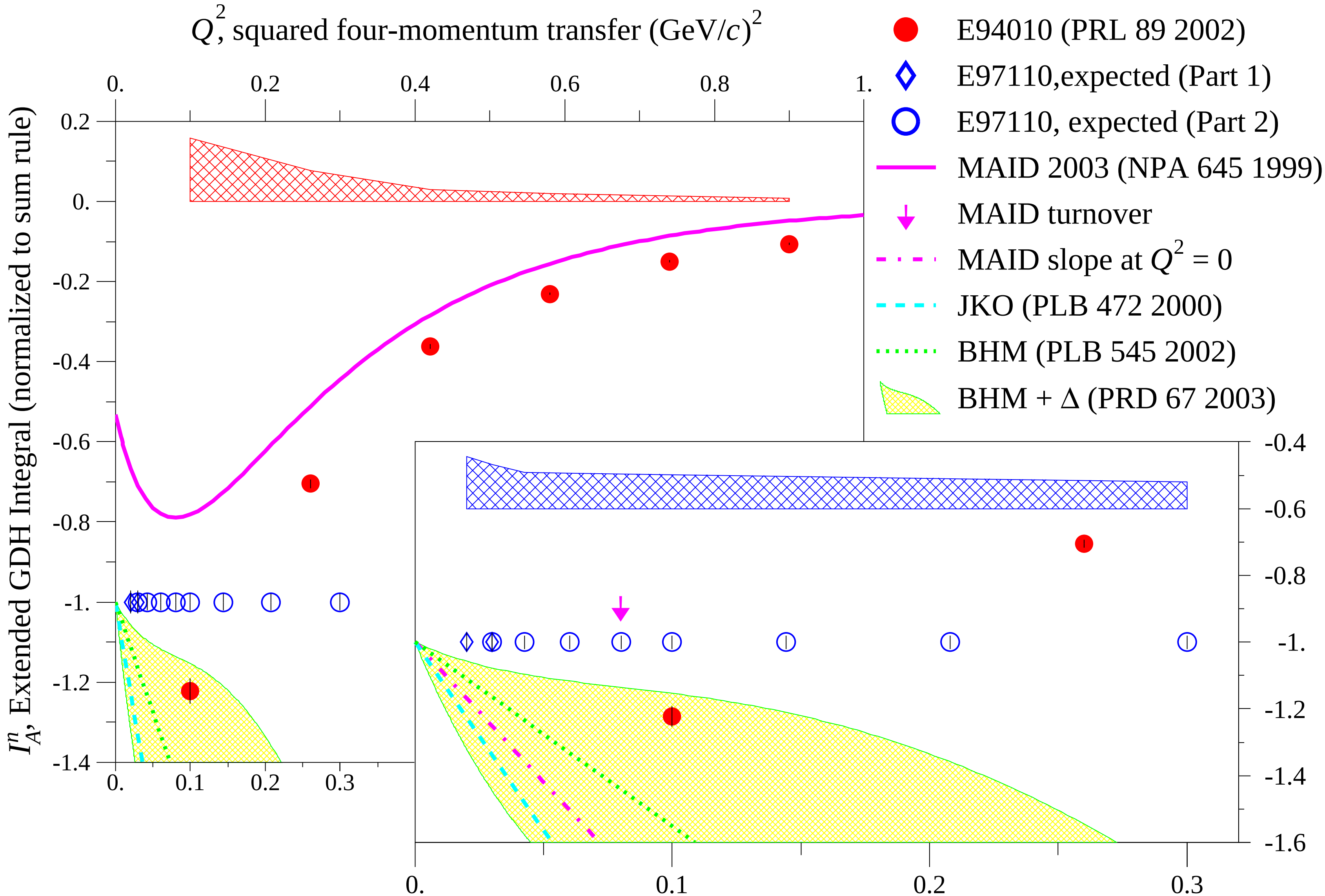


Expected Neutron Results



Summary

- The Generalized GDH Integral is an important tool used to study the nucleon over the full Q^2 range.
- E97-110 provides precision data for the generalized GDH integral at low Q^2, 0.02 to 0.3 GeV^2
- This data set will allow us to check χPT at low Q^2.
- Preliminary asymmetries look reasonable.
- Cross section results will be available soon.
- The moments of the spin structure functions and the forward spin polarizabilities will also be extracted.

The E97-110 Collaboration

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and the Jefferson Lab Hall A Collaboration

Extra Slides

Inclusive Polarized Cross Sections

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

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

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

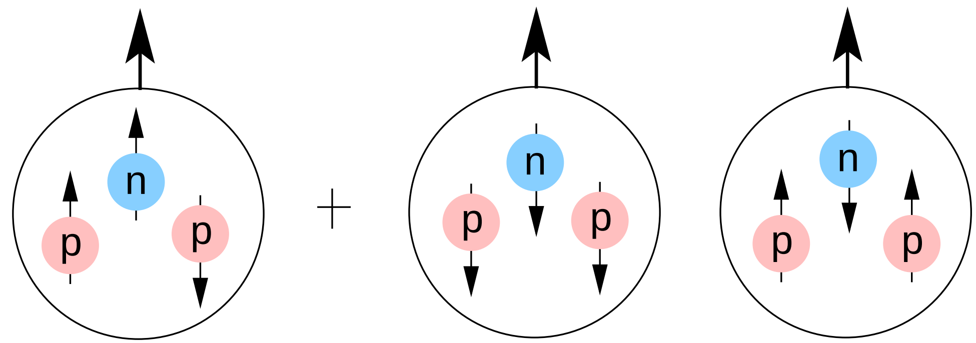
$\downarrow\uparrow$ is for electron spin

$\Uparrow\Rightarrow$ is for target spin direction

g_1, g_2: spin dependent structure functions

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

^{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**, 2310 (1990)

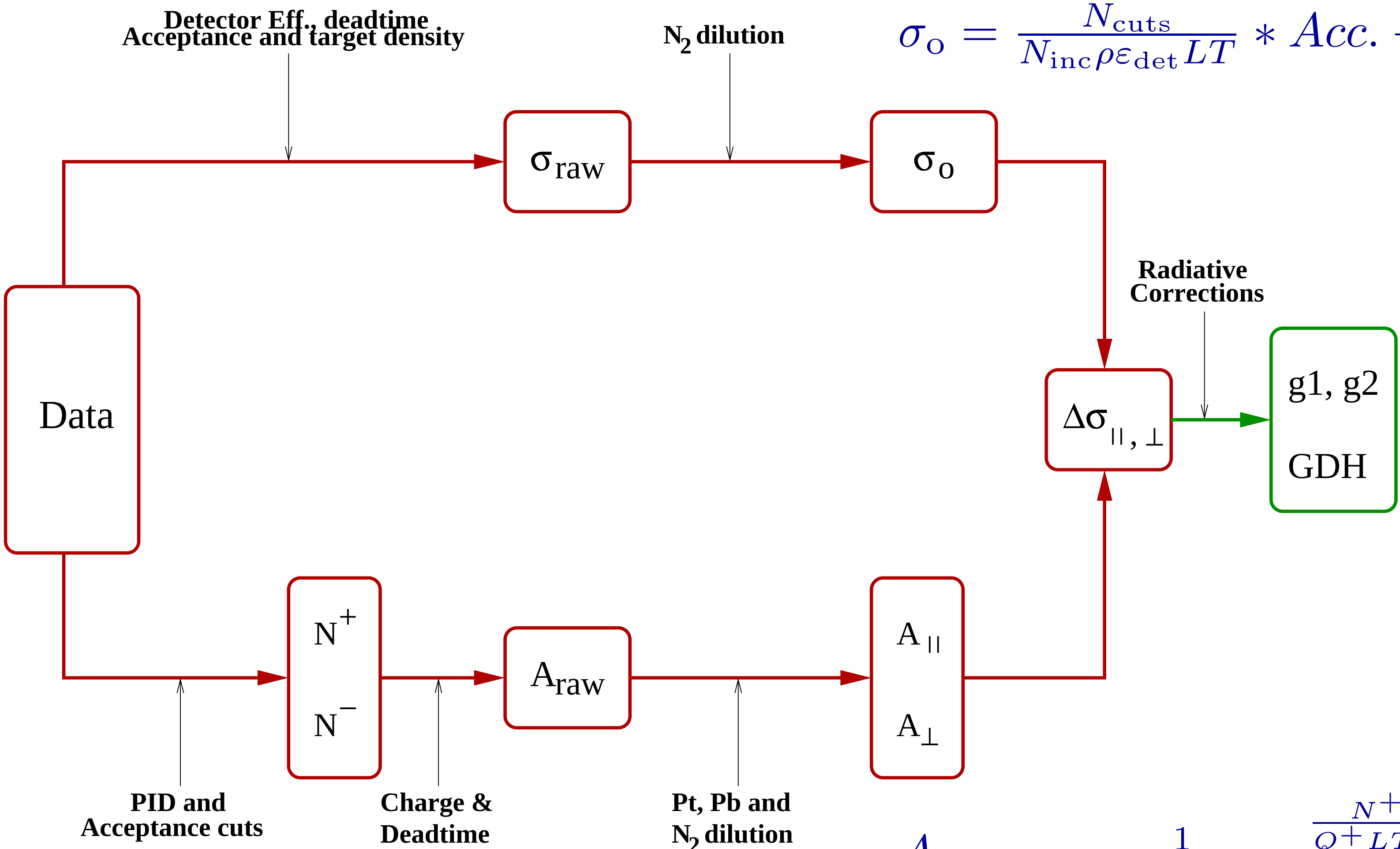
Extraction of Neutron Results

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

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

Analysis Procedure

$$\sigma_0 = \frac{N_{cuts}}{N_{inc}\rho\varepsilon_{det}LT} * Acc. - \frac{2\rho_{N_2}}{\rho + \rho_{N_2}}\sigma_{N_2}$$



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

Future Perspectives

- E03-006, proton GDH: 0.015 GeV$^2 < Q^2 <$ 0.5 GeV^2 (Ran Spring 2006).
- E06-017, Deuteron GDH: 0.015 GeV$^2 < Q^2 <$ 0.3 GeV^2 (Ran Spring 2006).
- E06-017 will provide a check of the neutron extraction from E97-110.