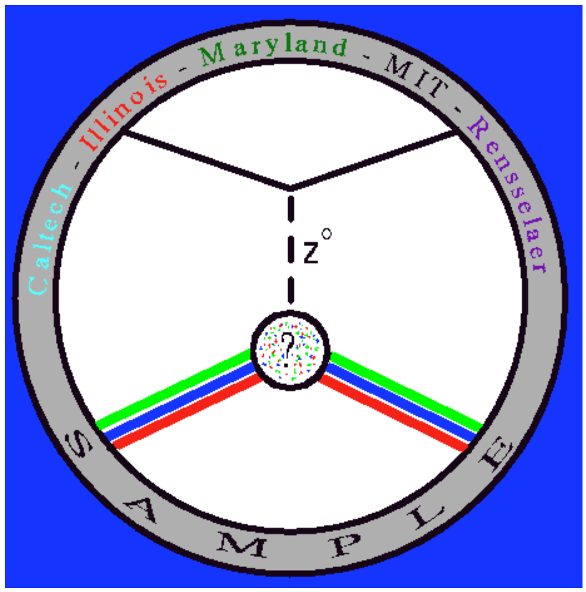
SAMPLE: Parity Violating Electron Scattering from Hydrogen and Deuterium



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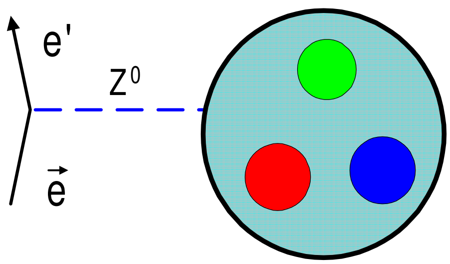
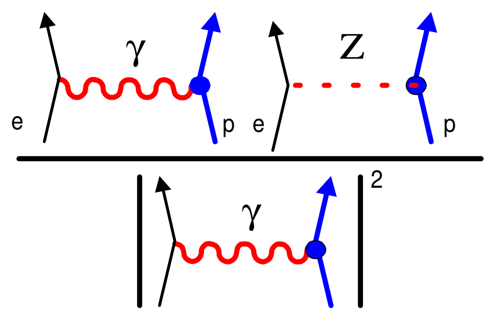
Nuclear Physics Lab, Univ. of Illinois, Urbana, IL
MIT-Bates Linear Accelerator Center, Middleton, MA
Univ. of Maryland, College Park, MD
Virginia Polytechnic Institute, Blacksburg, VA
Louisiana Tech, Ralston, LA
University of Kentucky, Lexington, KY
Rensselear Polytechnic Institute, Troy, NY
College of William and Mary, Williamsburg, VA
Argonne National Laboratory, Argonne, IL

OUTLINE



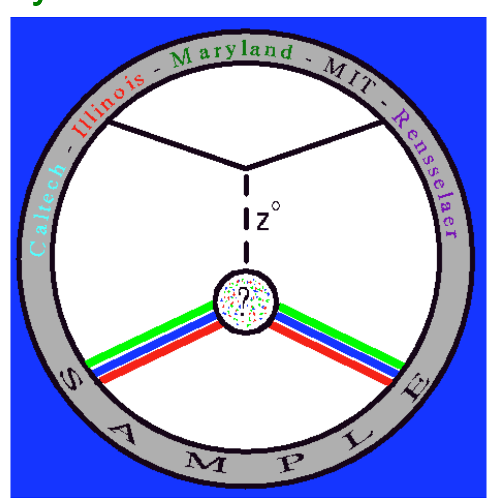


Overview of Neutral Weak current and observables

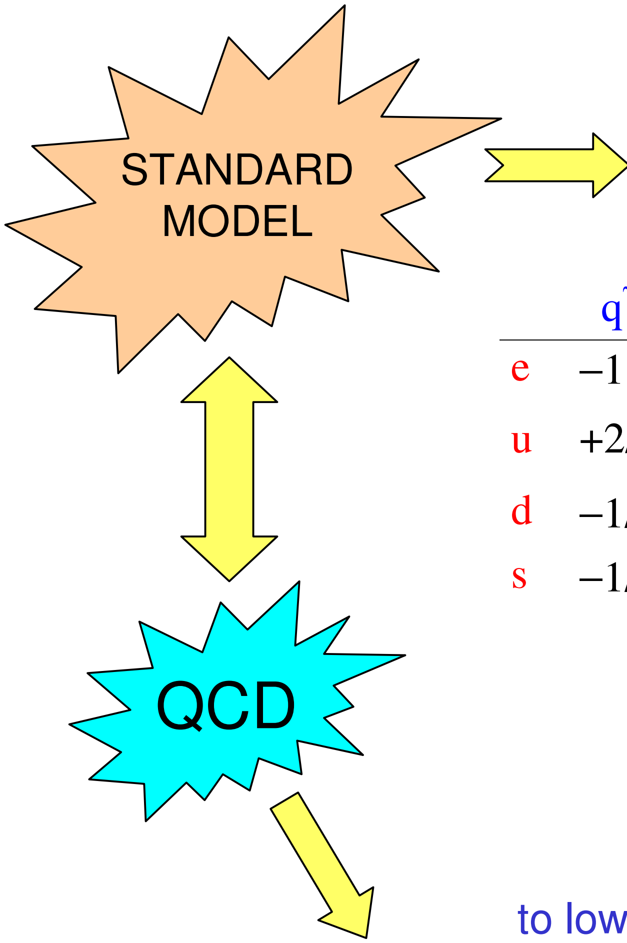
- s-quarks: $G_M^s(0) \quad = \mu_s$
  $G_E^s(Q^2) \;\rightarrow\; r^2{}_s$ = *slope at* $Q^2=0.$
  Q^2 *dependence*
- e-N axial form factor G_A^e
  nucleon anapole moment

SAMPLE measurements

- 1998 H_2 data (thesis: D.Spayde, Univ Maryland)
- 1999 D_2 data (thesis: R. Hasty, Univ Illinois)
- transverse polarization asymmetry
- *plans for SAMPLE 2000*



The Standard Model and Hadron Structure



$$J_\gamma^\mu = q^\gamma \gamma^\mu$$

$$J_Z^\mu = q^Z \gamma^\mu + a^Z \gamma^\mu \gamma^5$$

	q^γ	q^Z	a^Z
e	-1	$-1 + 4\sin^2\theta_W$	$+1$
u	$+2/3$	$1 - 8/3 \sin^2\theta_W$	-1
d	$-1/3$	$-1 + 4/3 \sin^2\theta_W$	$+1$
s	$-1/3$	$-1 + 4/3 \sin^2\theta_W$	$+1$

$$\sin^2\theta_W = 0.2315 \pm 0.0004$$

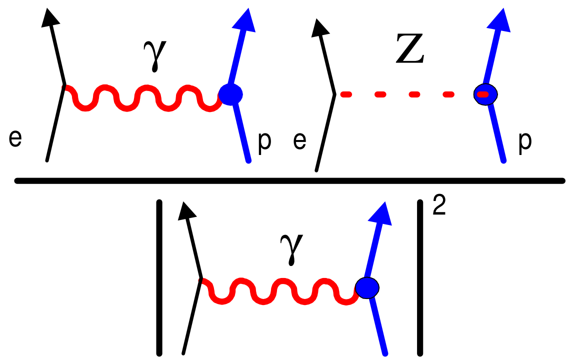
to lowest order...

	q^γ	μ^γ	q^Z	μ^Z	a^Z
e	-1	-1	-0.074	-0.074	1
p	$+1$	$+2.79$	$0.074 + G_E^s$	$+2.08 - \mu_s$	$-1.26 + \Delta s$
n	0	-1.91	$-1 + G_E^s$	$-2.92 - \mu_s$	$+1.26 + \Delta s$

$$\left(\mu_p^\gamma, \mu_n^\gamma, \mu^Z\right) \Leftrightarrow \left(\mu_u, \mu_d, \mu_s\right)$$

Parity Violating Electron Scattering

polarized electrons
unpolarized target



$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

for a proton:

$$\boxed{= \left[\frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\right] \frac{\varepsilon G_E^\gamma G_E^Z + \tau G_M^\gamma G_M^Z - (1 - 4\sin^2\theta_W)\varepsilon' G_M^\gamma G_A^e}{\varepsilon (G_E^\gamma)^2 + \tau (G_M^\gamma)^2}}$$

forward angles

backward angles

$$\tau = \frac{Q^2}{4M^2}$$
$$\varepsilon = \left[1 + 2(1+\tau)\tan^2\left(\tfrac{\theta}{2}\right)\right]^{-1}$$
$$\varepsilon' = \sqrt{(1-\varepsilon^2)\tau(1+\tau)}$$

Beyond 1st order...

$$G_{E,M}^Z = (1 - 4\sin^2\theta_W)(1 + R_V^p)G_{E,M}^p - (1 + R_V^n)G_{E,M}^n - G_{E,M}^s$$

$$G_A^e = -G_A + \Delta s + \eta F_A + R^e$$

electroweak radiative corrections

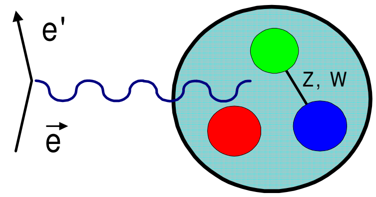
Z exchange

anapole

$$\eta = \frac{8\pi\alpha\sqrt{2}}{1 - 4\sin^2\theta_W} = 3.45$$

NUCLEON ANAPOLE MOMENT

Musolf+Holstein, PRD43 (1991) 2956



- General form of EM coupling

  (assumes Lorentz invariance, current conservation)

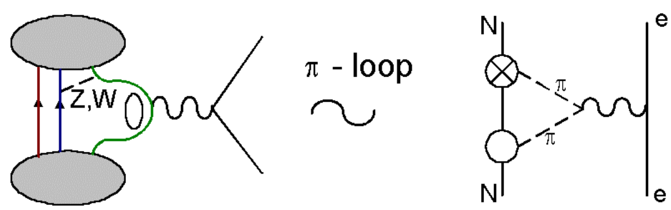
$$\boxed{\begin{aligned}\langle p'|J^{\mu}_{EM}|p\rangle &= \bar{u}(p')\Big[F_1(q^2)\gamma_\mu - \tfrac{i}{2M}F_2(q^2)\sigma_{\mu\nu}q^\nu \\ &+ \tfrac{1}{M^2}F_A(q^2)(q^2\gamma_\mu - \not{q}q_\mu)\gamma_5 - \tfrac{i}{2M}F_E(q^2)\sigma_{\mu\nu}q^\nu\gamma_5\Big]u(p)\end{aligned}}$$

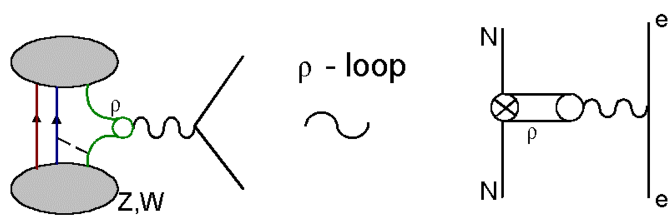
Anapole
(TRI , PV)

Electric dipole
(TRV, PV)

$$F_A(0) \approx M^2 G_F \approx 10^{-5}$$

Modeled by Musolf+Holstein
(1990) using DDH parameters



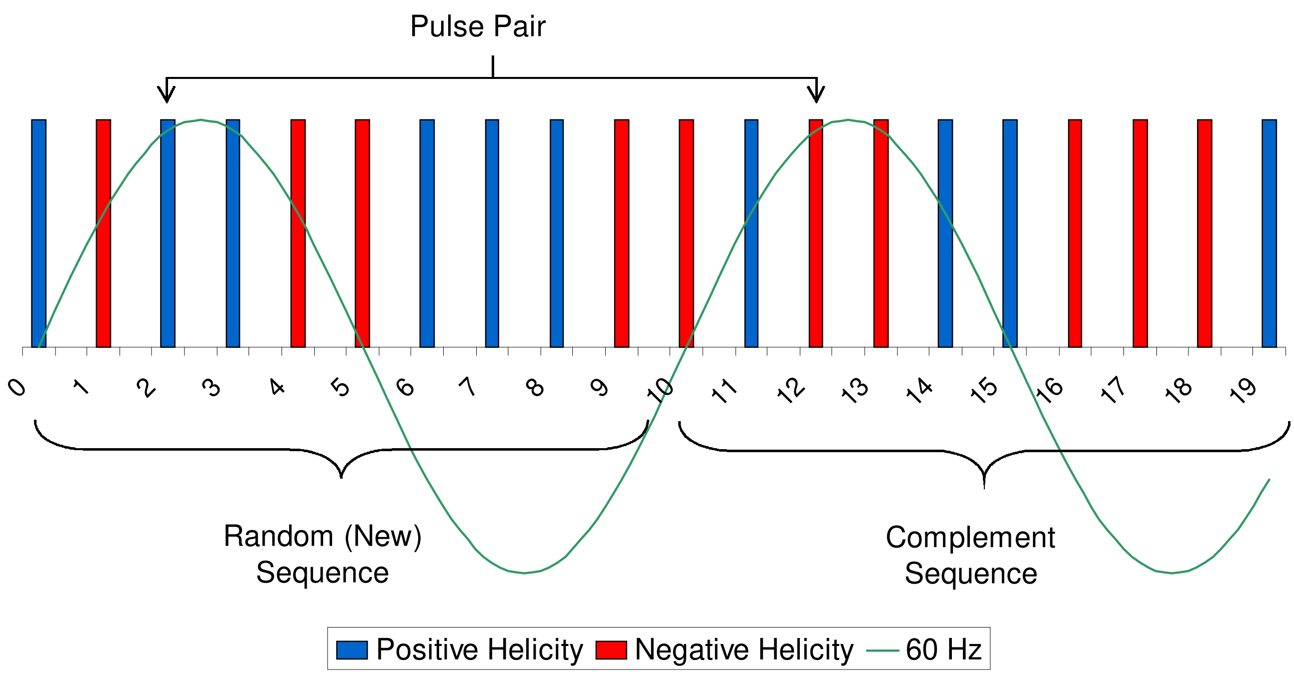


Recent updates:

- Zhu, Puglia, Holstein, Musolf, hep-ph/0002252
- Maekawa and van Kolck, KRL preprint MAP-265
- D. Riska, hep-ph 0003132

Forming the Asymmetry, $A^{Measured}$

$$A^{Measured} = \frac{Y^{Positive} - Y^{Negative}}{Y^{Positive} + Y^{Negative}}$$



- Asymmetry between pulses separated by 1/60 s → remove effects due to 60 Hz
- Rapid helicity reversal → reduce effects of long-term drifts
- Slow helicity reversal → remove helicity-correlated electronics effects

Corrections Procedure

- Removes helicity-correlated beam parameter effects from the measured asymmetry.

$$A_{Corrected} = A_{Measured} - \frac{1}{2\langle Y \rangle} \sum_{i=x,\theta,y,\phi,E,I} \frac{\partial Y}{\partial P_i} \Delta P_i$$

$$A_{Measured} = \frac{Y^{+}_{Measured} - Y^{-}_{Measured}}{Y^{+}_{Measured} + Y^{-}_{Measured}}$$

$$\Delta P_i = P_i^{+} - P_i^{-}$$

Calculated

- The slopes are extracted from the measured correlations between yield and beam parameters.

Measured

$$\langle \delta Y \delta P_i \rangle = \sum_{j=x,\theta,y,\phi,E,I} \langle \delta P_i \delta P_j \rangle \frac{\partial Y}{\partial P_j}, \quad i = x, \theta, y, \phi, E, I$$

$$\langle \delta Y \delta P_i \rangle = \frac{1}{N} \sum_{k=1}^{N} \left(Y^k - \langle Y \rangle \right)\left(P_i^k - \langle P_i \rangle \right), \quad N = \text{\# of beam pulses}$$

$$\langle \delta P_i \delta P_j \rangle = \frac{1}{N} \sum_{k=1}^{N} \left(P_i^k - \langle P_i \rangle \right)\left(P_j^k - \langle P_j \rangle \right), \quad N = \text{\# of beam pulses}$$

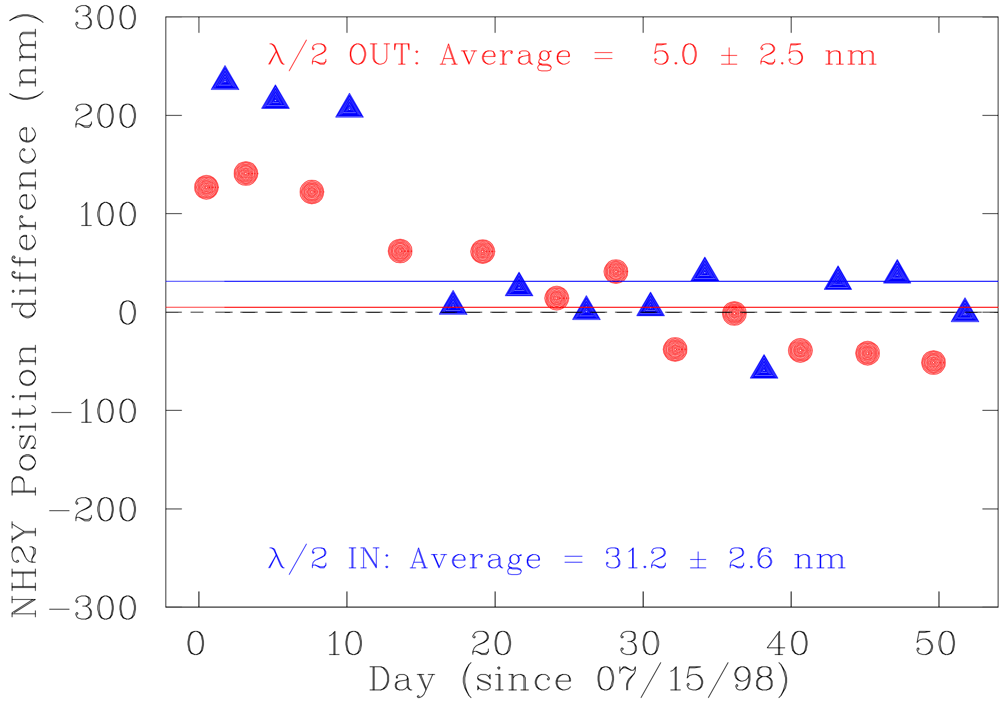
- Procedure is applied to individual mirrors and luminosity monitors.

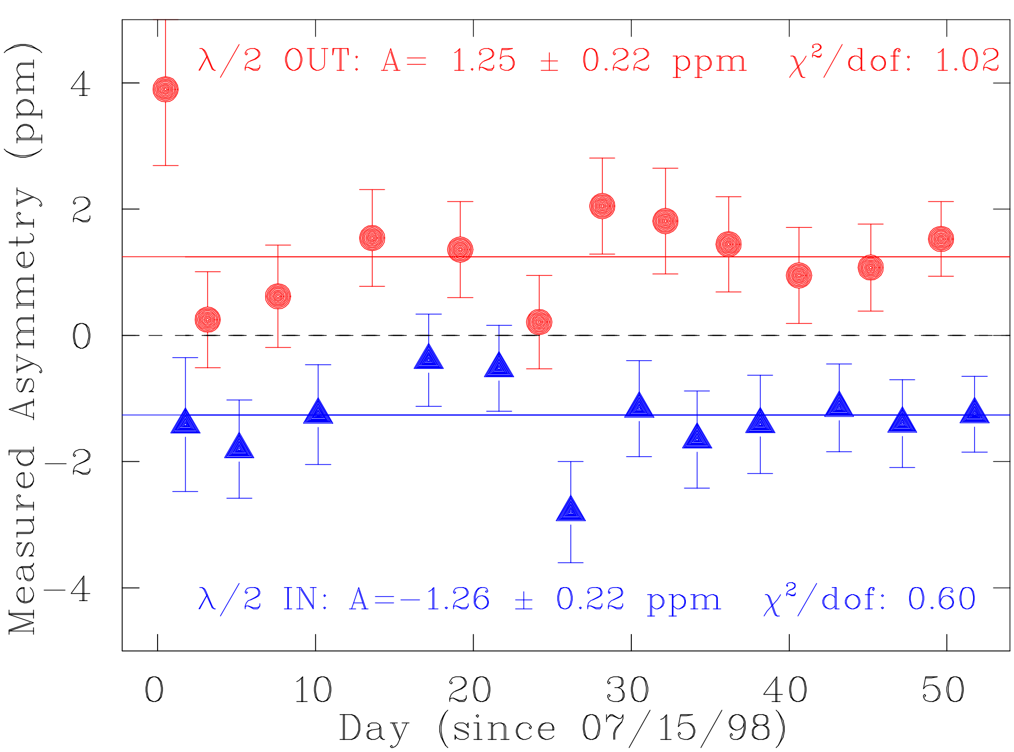
SAMPLE 1998 Hydrogen Data

136 Coulombs of beam delivered

1st use of piezo feedback after 10 days running

T. Averett, et al., NIM A438 (1999)246.





SAMPLE 1998 H_2 Results

- *beam helicity correlations*

$$\begin{array}{ccccc} A_{corr} & = & A_{meas} & - & \frac{1}{2\langle Y\rangle}\sum_{x,\theta,y,\phi,E,I}\frac{\partial Y}{\partial P_i}\Delta P_i \\ -1.14\pm0.14 & = & (-1.08\pm0.14) & - & (0.06\pm0.06)\ ppm \end{array}$$

- $A_{corr} \rightarrow A_p$

$$A_p = \frac{R}{P_B f_{light} f_{el}} A_{corr}$$

$$\begin{aligned} R &= 1.08 \\ P_B &= 0.363\pm0.014 \\ f_{light} &= 0.844 \\ f_{el} &= 0.822\pm0.033 \end{aligned}$$

$$\boxed{A_p = -4.92 \pm 0.61 \pm 0.73\ \ ppm}$$

- *in terms of form factors:*

$$\boxed{A_p = -5.61 + 3.49\, G_M^s + 1.55\, G_A^e \quad ppm}$$

$$G_A^e = G_A^e(T=1) + G_A^e(T=0)$$

$$= R_A^0 + \Delta s$$
$$= -0.07 \pm 0.11$$

?

$$G_A^e(T=1) = -0.83 \pm 0.26$$

Zhu et al., hep-ph/0002252

→ 5% from anapole

PV QUASIELASTIC (e,e') from DEUTERIUM

"static" approximation:

$$\boxed{A_d = \frac{\sigma_p A_p + \sigma_n A_n}{\sigma_d}}$$

$$A_d = \left[\frac{.049}{\sigma_d}\right]\left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right]\left[1 - 0.22 G_A^e(T=1) - 0.10 G_M^s\right]$$

$$A_p = \left[\frac{.026}{\sigma_p}\right]\left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right]\left[1 - 0.24 G_A^e(T=1) - 0.61 G_M^s\right]$$

Combined proton and deuteron allows for separate determination of G_M^s and $G_A^e(T=1)$

- nuclear model uncertainties: ~ few %
  (Hadjimichael, Poulis + Donnelly, PR C45 (1992) 2666.)
- SAMPLE has contributions from threshold breakup and elastic e-D scattering: ~ few %

$$A = \frac{\sigma_{QE} A_{QE} + \sigma_{EL} A_{EL} + \sigma_{TED} A_{TED}}{\sigma_{QE} + \sigma_{EL} + \sigma_{TED}}$$

Pollock, PR D42 (1990) 3010.
Musolf + Donnelly, NP A546 (1992) 509.
Simon et al., NP A324 (1979) 277.

Mott Asymmetry in p($\vec{e}$,e')

S. Wells, et al., nucl-ex/0002010

- transverse beam pol'n + full ϕ-coverage of detector gives access to possible spin dependent terms in elastic cross section.

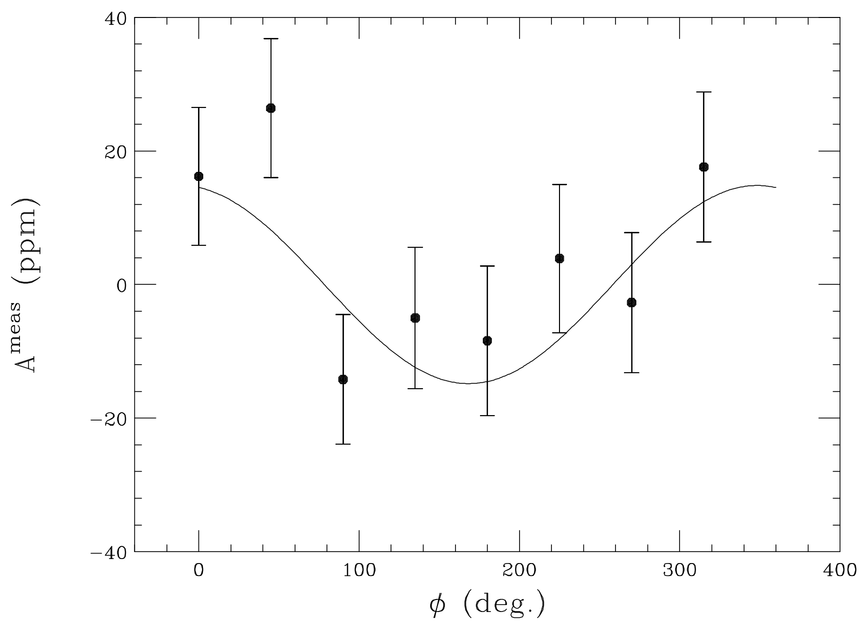
$$\varepsilon(\theta) = \frac{\sigma_\uparrow(\theta) - \sigma_\downarrow(\theta)}{\sigma_\uparrow(\theta) + \sigma_\downarrow(\theta)} = A(\theta)\langle P \rangle$$

$$A(\theta) = -A(-\theta)$$

$$A_{fit} = A_\theta P \sin(\phi + \delta)$$

- lowest order is 2-γ exchange

mir #	θ	ϕ
1	146	135
2	154	90
3	146	45
4	138	180
5	161	180
6	161	0
7	138	0
8	146	225
9	154	270
10	146	315

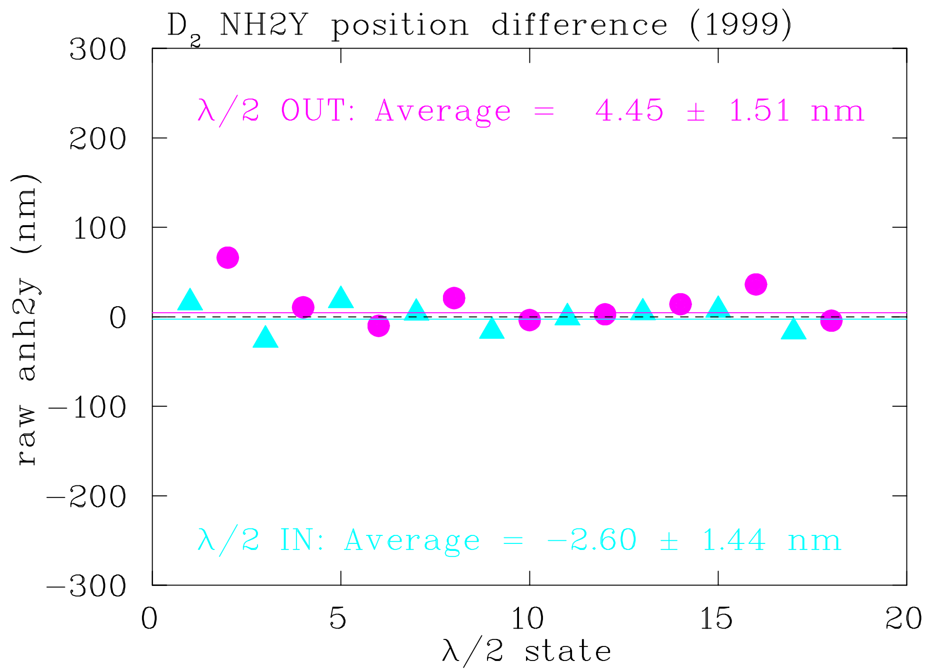


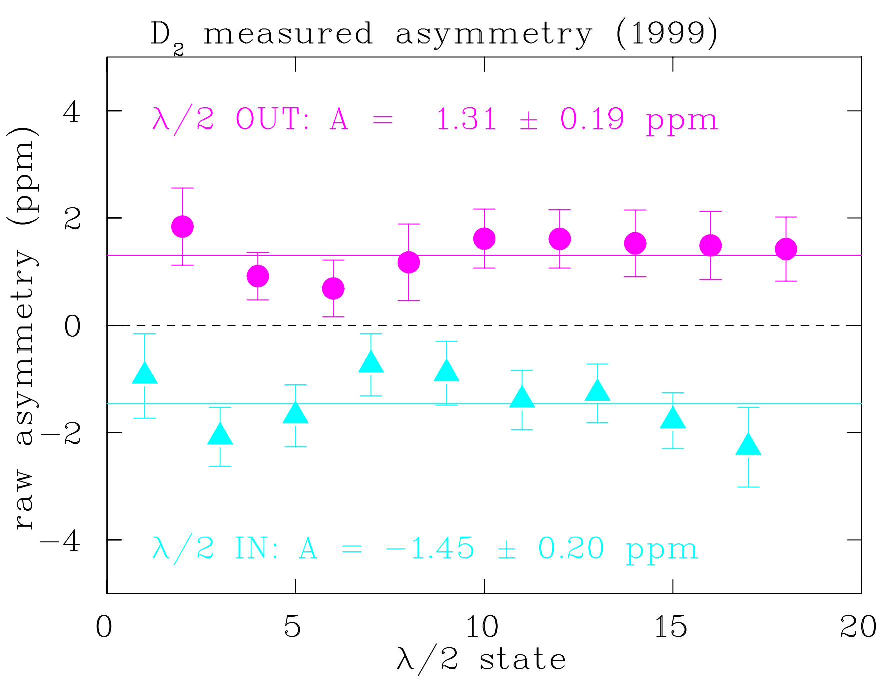
- *1st measurement at "high" energy*
- *no calculations exist for spin-1/2 target*

$$A_{Mott} = -15.4 \pm 5.4\ ppm \qquad \left(\theta = 146.1^\circ,\ Q^2 = 0.1(GeV/c)^2\right)$$

SAMPLE 1999 Deuterium Run

174 Coulombs delivered





P_B ~ 35.5%
f_{light} ~ 0.67
$f_{elastic}$ ~ 0.91

SAMPLE 1999 D_2 **PRELIMINARY** Results

- correct for helicity-correlated beam properties

$$A_{corr} = A_{meas} - \frac{1}{2\langle Y \rangle} \sum_{x,\theta,y,\phi,E,I} \frac{\partial Y}{\partial P_i} \Delta P_i$$

$$-1.33 \pm 0.14 = (-1.39 \pm 0.14) + (0.06 \pm 0.06)\ \text{ppm}$$

- $A_{corr} \rightarrow A_d$

$$A_d = \frac{R}{P_B\, f_{light}\, f_{el}} A_{corr}$$

$$R \sim 1.09$$

$$P_B \sim 0.36$$

$$f_{light} = 0.66$$

$$f_{el} = 0.91$$

$$A_d = -6.79 \pm 0.64\,(\text{stat}) \pm 0.51\,(\text{syst}^*)\ \text{ppm}$$

* Systematic error is projected based on the H_2 experience

other analysis issues (underway)

- π production/decay: ~ 2-3 % correction
- neutron background asymmetry: negligible
- breakup and elastic: < 2% correction
- nuclear structure model dependence: 1-2 %
  (assume static approximation)

SAMPLE 2000: D(e,e') at 120 MeV

spokesperson: T. Ito, Caltech

- $Q^2 = 0.04\ (GeV/c)^2$

$$A_d = \left[\frac{.028}{\sigma_d}\right]\left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right]\left[1 - 0.31 G_A^e(T=1) - 0.09 G_M^s\right]$$

- different systematic effects

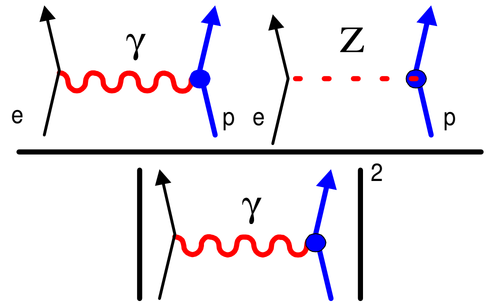
$$A_{120} = 0.3\ A_{200}$$
$$\sigma_{120} = 1.9\ \sigma_{200}$$

- background similar, so S/B improved
- similar sensitivity to $G_A^e(T=1)$
- other systematic errors comparable
- in 2 month run, expect

$$\delta\, G_A^e(T=1) = \pm 0.45(stat) \pm 0.25(sys)$$

- *approved by Bates PAC, March 2000*

Summary

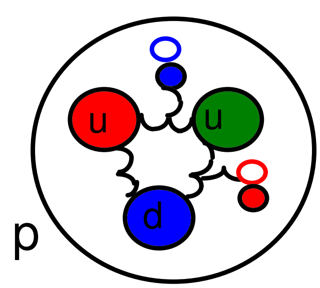


SAMPLE H_2 data (published) and **preliminary** D_2 data indicate

- Slightly positive G_M^s, but consistent with 0
- e-N axial form factor G_A^e is significantly different from theoretical predictions

? nucleon anapole moment
electroweak radiative corrections
new physics?

New measurement of D(ee') at 120 MeV should help confirm 200 MeV results and further constrain G_A^e.



- *Q^2 dependence: need JLAB experiments*