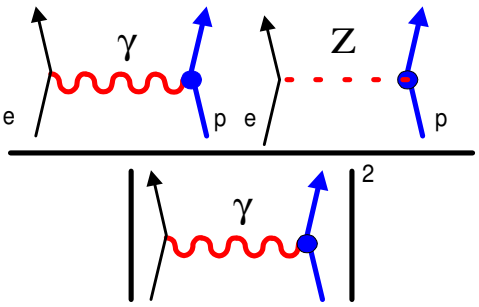
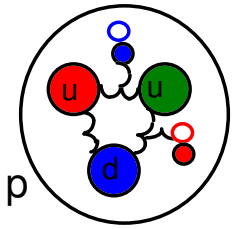
# PARITY VIOLATION

now ...




... and again

- Weak Interaction and Hadronic Structure
- recent experimental progress

SAMPLE

and

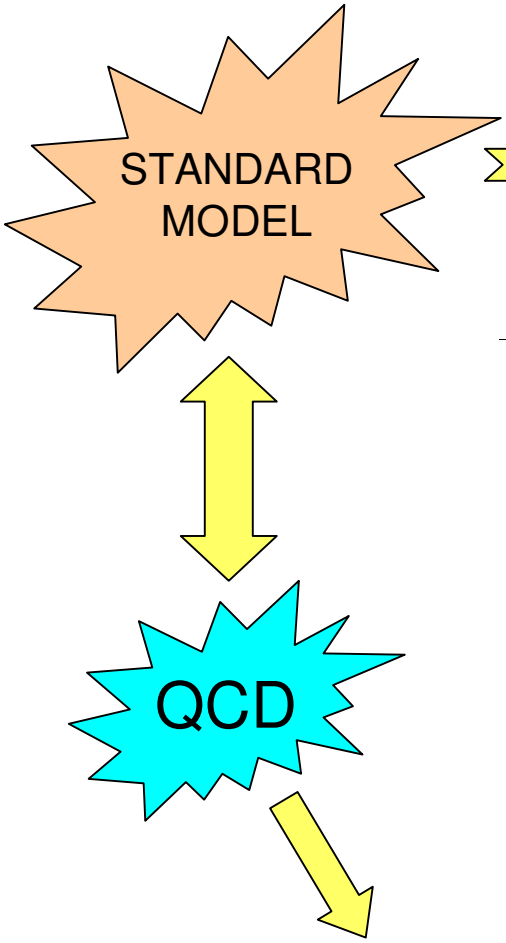
HAPPEX

Mainz

G0

E. Beise
U Maryland

# The Standard Model and Hadron Structure




$$J^{\mu}_{\gamma} = q^{\gamma}\gamma^{\mu}$$

$$J^{\mu}_{Z} = q^{Z}\gamma^{\mu} + a^{Z}\gamma^{\mu}\gamma^{5}$$

| | $q^{\gamma}$ | $q^{Z}$ | $a^{Z}$ |
|---|---|---|---|
| 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 | $-1/3$ | $-1 + 4/3\sin^2\theta_W$ | $+1$ |

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

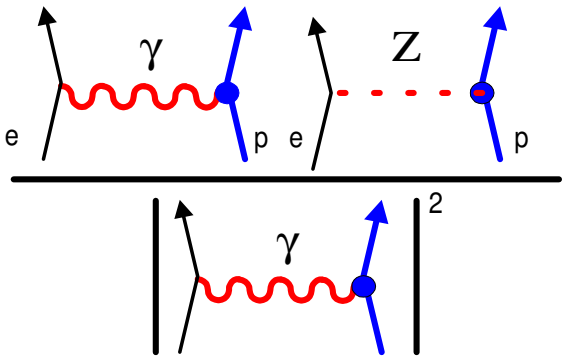
to lowest order...

| | $q^{\gamma}$ | $\mu^{\gamma}$ | $q^{Z}$ | $\mu^{Z}$ | $a^{Z}$ |
|---|---|---|---|---|---|
| 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:

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

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...

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

$$G_A^Z = -(1+R_A^1)G_A + R_A^0 + \Delta s$$

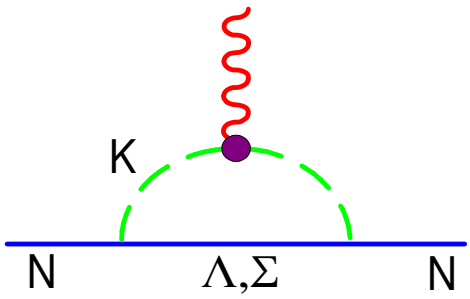
# Strange Form Factors & Kaon Loops

- Koepf, Henley + Pollock (92)

  $\mu_s \sim -0.026\ \mu_N$

- Musolf + Burkardt (94)

  $\mu_s \sim -0.31\ \mu_N$




## *Quark-K Loops*

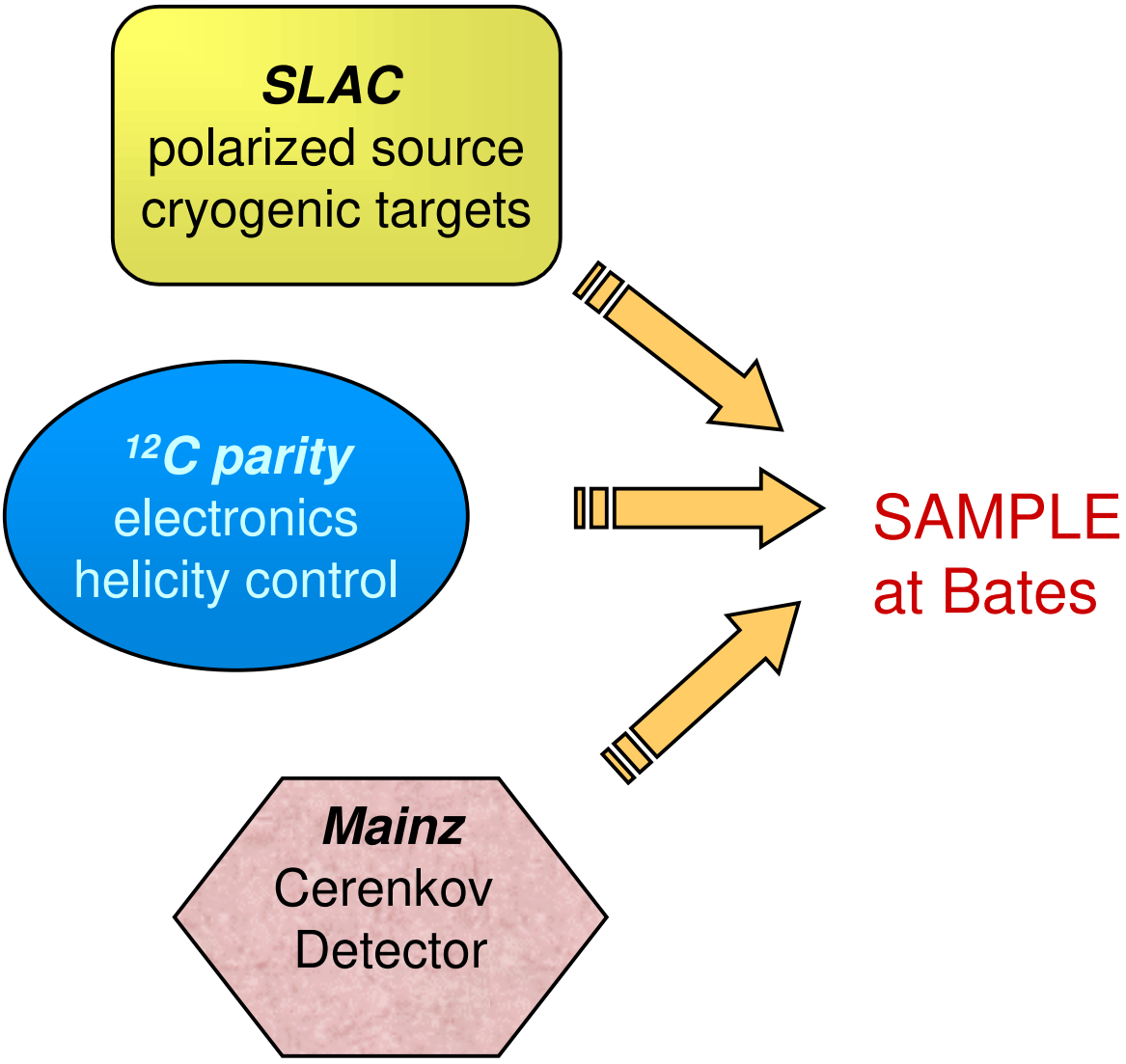
- Geiger + Isgur (97) K* loops important $\mu_s \rightarrow 0.035\ \mu_N$
- Riska (99) K* loops not important $\mu_s \rightarrow -0.05\ \mu_N$

## *N-K Loops*

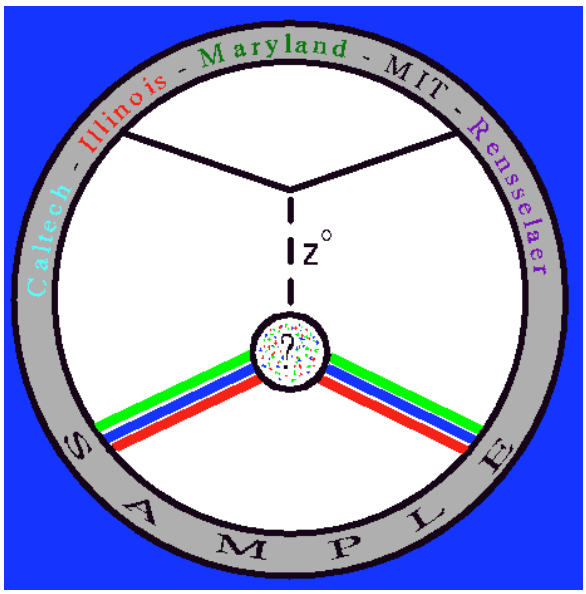
- Barz, Forkel, Hammer (98): need B and K*, large uncertainty
- Hammer + Ramsey-Musolf (99) :
  - K K continuum contributes significantly to $\mu_s$ and $G_E^s$ through $\phi$ resonance.
  - $G_M^s$ and $G_E^s$ have opposite sign.

$$\mu_s = -0.42 \text{ n.m.}$$

$$\left| G_E^s + 0.39 G_M^s \right|_{K\bar{K}} = 0.053 \ (Q^2 = 0.48 \text{ GeV}^2)$$


SLAC
polarized source
cryogenic targets
12C parity
electronics
helicity control
Mainz
Cerenkov
Detector
SAMPLE
at Bates

# SAMPLE: Parity Violating Electron Scattering from Hydrogen and Deuterium




*Kellogg Radiation Lab, Caltech Pasadena, CA*
*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*

# SAMPLE 1998 $H_2$ Results

- *beam helicity correlations*

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

$$-1.14 \pm 0.14 = (-1.08 \pm 0.14) - (0.06 \pm 0.06)\ ppm$$

- $A_{corr} \rightarrow A_p$

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

$$R = 1.08$$

$$P_B = 0.363 \pm 0.014$$

$$f_{light} = 0.844$$

$$f_{el} = 0.822 \pm 0.033$$

$$A_p = -4.92 \pm 0.61 \pm 0.73\ \ ppm$$

- *in terms of form factors:*

$$A_p = -5.61 + 3.49\, G_M^s + 1.55\, G_A^Z \quad ppm$$

$$\downarrow$$

$$G_M^s = -0.445\, G_A^Z + 0.197 \pm 0.17(stat) \pm 0.21(sys)$$

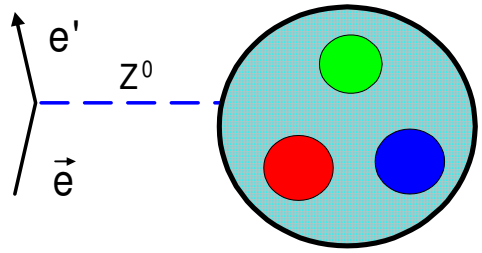
$$G_A^Z = -G_A + \Delta s + (R_A^0 - R_A^1 G_A)$$

$G_A(0) = 1.267$ $\quad = -0.12$ $\quad ?$

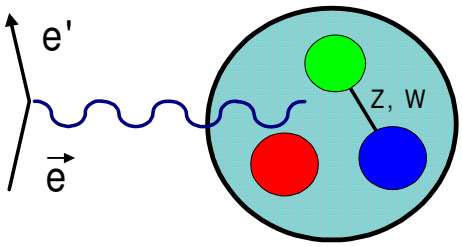
HOUSE
OF
CORRECTION
NEXT LEFT

# Contributions to $G_A^Z$

$A_{PV}$ measures




But $A_{PV}$ can also have contributions from




→ *Nucleon "anapole moment" (inside* $G_A^Z$*)*

- cannot experimentally separate from $Z^0$-exchange
- also has contributions from $Z^0$-$\gamma$ box diagrams

→ *can measure* $G_A^Z$ *with* $LD_2$ *target*

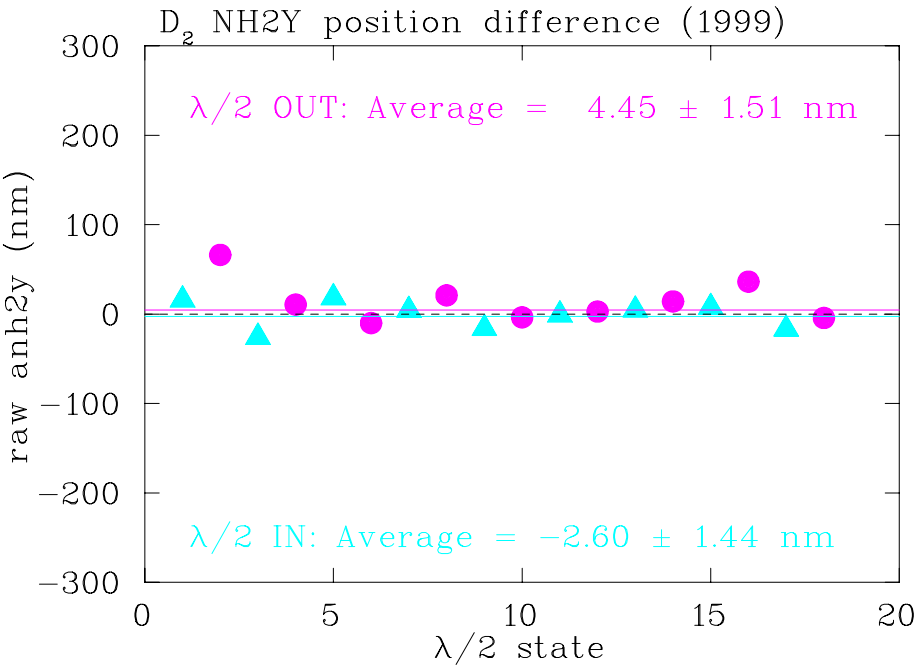
$$G_{E,M}^Z = (1-4\sin^2\theta_W)(1+R_V^p)G_{E,M}^p - (1+R_V^n)G_{E,M}^n - G_{E,M}^s$$

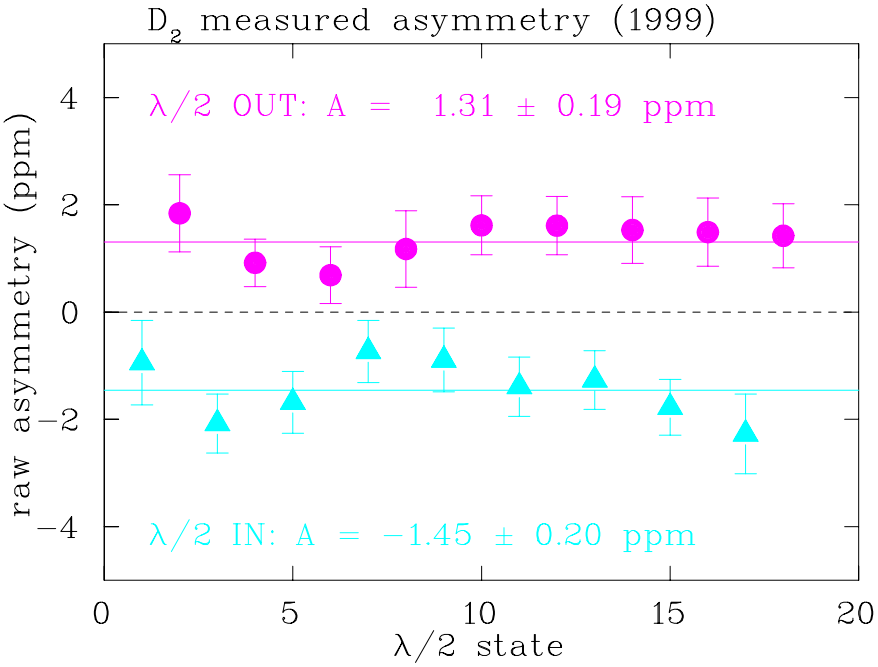
$$G_A^Z = -G_A + \Delta s + \left(R_A^0 - R_A^1 G_A\right)$$

SAMPLE 1999: quasielastic PV-ee in deuterium

# SAMPLE 1999 Deuterium Run

## 174 Coulombs delivered




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

# SAMPLE $D_2$ PRELIMINARY Results

$$A_d = -6.79 \pm 0.64 \pm 0.86 \; ppm$$

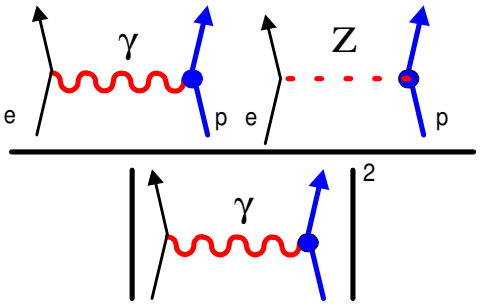
*When combined with proton asymmetry...*

$$\left(A_p, A_d\right) \quad \Leftrightarrow \quad \left(G_M^s, G_A^Z\right)$$

$D_2$ Analysis issues:

- nuclear structure
- contributions from $\pi$ production/decay
- neutron background
- radiative corrections
- sensitivity to cuts
- $G_A{}^Z$ *in proton =* $G_A{}^Z(p)$ *in deuteron?*

# Summary

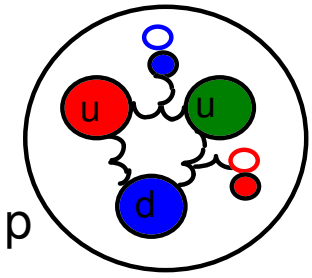



- first results now becoming available on s–quark contributions to nucleon electroweak structure

- $(G_M^s\ ,\ G_E^s\ )$ : small ?

- $G_A^Z$: anapole moment ...

  → *theoretical support needed!*




- $Q^2$ *dependence still to come ....*

# Electroweak Properties of Nucleons

$$J^{\mu}_{\gamma} = q^{\gamma}\gamma^{\mu}$$
$$J^{\mu}_{Z} = q^{Z}\gamma^{\mu} + a^{Z}\gamma^{\mu}\gamma^{5}$$

| | $q^{\gamma}$ | $\mu^{\gamma}$ | $q^{Z}$ | $\mu^{Z}$ | $a^{Z}$ |
|---|---|---|---|---|---|
| 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 | $-1 + G_E^s$ | $-2.92 - \mu_s$ | $+1.26 + \Delta s$ |

$\sin^2\theta_W = 0.2315$

• EM and neutral weak observables allow us to decompose flavor structure of the proton into contributions from its fundamental constituents.

$$\mu_u = (3 - 4\sin^2\theta_W)\mu_p - \mu_Z$$
$$\mu_d = (2 - 4\sin^2\theta_W)\mu_p + \mu_n - \mu_Z$$
$$\mu_s = (1 - 4\sin^2\theta_W)\mu_p - \mu_n - \mu_Z$$

# NEUTRAL WEAK FORM FACTORS

- EM interaction:

$$\langle p \rangle^{\gamma} = \bar{u}_p \left[ F_1(q^2)\gamma^{\mu} + \frac{i}{2M_N} F_2(q^2)\sigma^{\mu\nu} q_{\nu} \right] u_p$$

Sachs notation:

$$G_E^p = F_1 - \tau F_2 \qquad \text{charge}$$

$$G_M^p = F_1 + F_2 \qquad \text{magnetic moment}$$

- Z-exchange:

$$\langle p \rangle^{Z} \Rightarrow G_E^Z(Q^2), G_M^Z(Q^2) \qquad \text{vector}$$

$$G_A^Z(Q^2) \qquad \text{axial vector}$$

- strange quark observables

$$\mu_s = \tfrac{1}{2}\left[ \int d^3 r \langle p | \vec{r} \times \bar{s}\vec{\gamma} s | p \rangle \right]_{z-comp} = G_M^s(0)$$

$$r_s^2 = \tfrac{1}{2} \int d^3 r \langle p | \vec{r}^{\,2}\, \bar{s}\vec{\gamma}_0 s | p \rangle = -6 \frac{dG_E^s}{dQ^2}\bigg|_{Q^2=0}$$

- *$Q^2$ dependence ?*