New Results from the G0 Experiment

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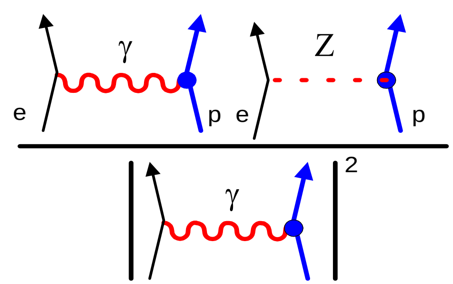
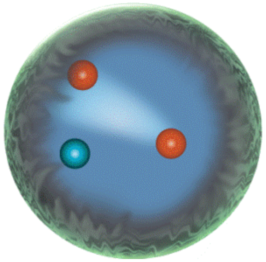
- Parity-violating electron scattering from the nucleon
  - Hydrogen and deuterium targets
  - <u>Strange quark contributions to electromagnetic form factors</u>
  - Axial-vector N-Δ transition
  - Weak interaction contribution to pion photoproduction
  - Transverse beam spin asymmetries



Spatial distribution of s-quarks in the nucleon



courtesy of JLab

Access via form factors: contribution to nucleon charge and magnetism

Electromagnetic:

$$G \rightarrow \langle N | \sum e_q \bar{q} \Gamma_\mu q | N \rangle$$

$$G^{\gamma,p} = \frac{2}{3} G^{u,p} - \frac{1}{3}\left(G^{d,p} + G^{s,p}\right)$$

and use

$$\left.\begin{aligned} G^{u,p} &= G^{d,n} \\ G^{d,p} &= G^{u,n} \\ G^{s,p} &= G^{s,n} \end{aligned}\right\} \text{charge symmetry}$$

	EM charge	Weak charge
e	–1	$-1 + 4\sin^2\theta_W$
u	+2/3	$1 - 8/3\sin^2\theta_W$
d	–1/3	$-1 + 4/3\sin^2\theta_W$
s	–1/3	$-1 + 4/3\sin^2\theta_W$

$$G^{u,p}_{E,M} = \left(3 - 4\sin^2\theta_W\right) G^{\gamma,p}_{E,M} - G^{Z,p}_{E,M}$$

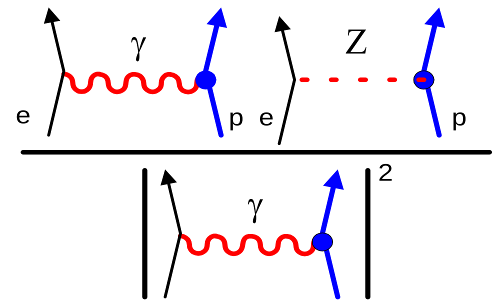
$$G^{d,p}_{E,M} = \left(2 - 4\sin^2\theta_W\right) G^{\gamma,p}_{E,M} - G^{\gamma,n}_{E,M} - G^{Z,p}_{E,M}$$

$$G^{s,p}_{E,M} = \left(1 - 4\sin^2\theta_W\right) G^{\gamma,p}_{E,M} - G^{\gamma,n}_{E,M} - G^{Z,p}_{E,M}$$

$\sin^2\theta_W = 0.2312$

Parity Violating elastic e-N scattering

polarized electrons, unpolarized target



$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \left[\frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\right] \frac{A_E + A_M + A_A}{2\sigma_{unpol}}$$

forward, H

back, H

back, D

$$\begin{pmatrix} A_F \\ A_B \\ A_d \end{pmatrix} = \begin{pmatrix} a_{1F} & a_{2F} & a_{3F} \\ a_{1B} & a_{2B} & a_{3B} \\ a_{1d} & a_{2d} & a_{3d} \end{pmatrix} \begin{pmatrix} G_E^s \\ G_M^s \\ G_A^e \end{pmatrix} + \begin{pmatrix} a_{0F} \\ a_{0B} \\ a_{0d} \end{pmatrix}$$

e.g.: G0 at 687 MeV (Q^2~ 0.6 GeV^2)

	a_0 (ppm)	a_1 (ppm)	a_2 (ppm)	a_3 (ppm)
A_F	-24	**80**	43	3
A_B	-39	22	**63**	12
A_d	-50	19	13	**14**

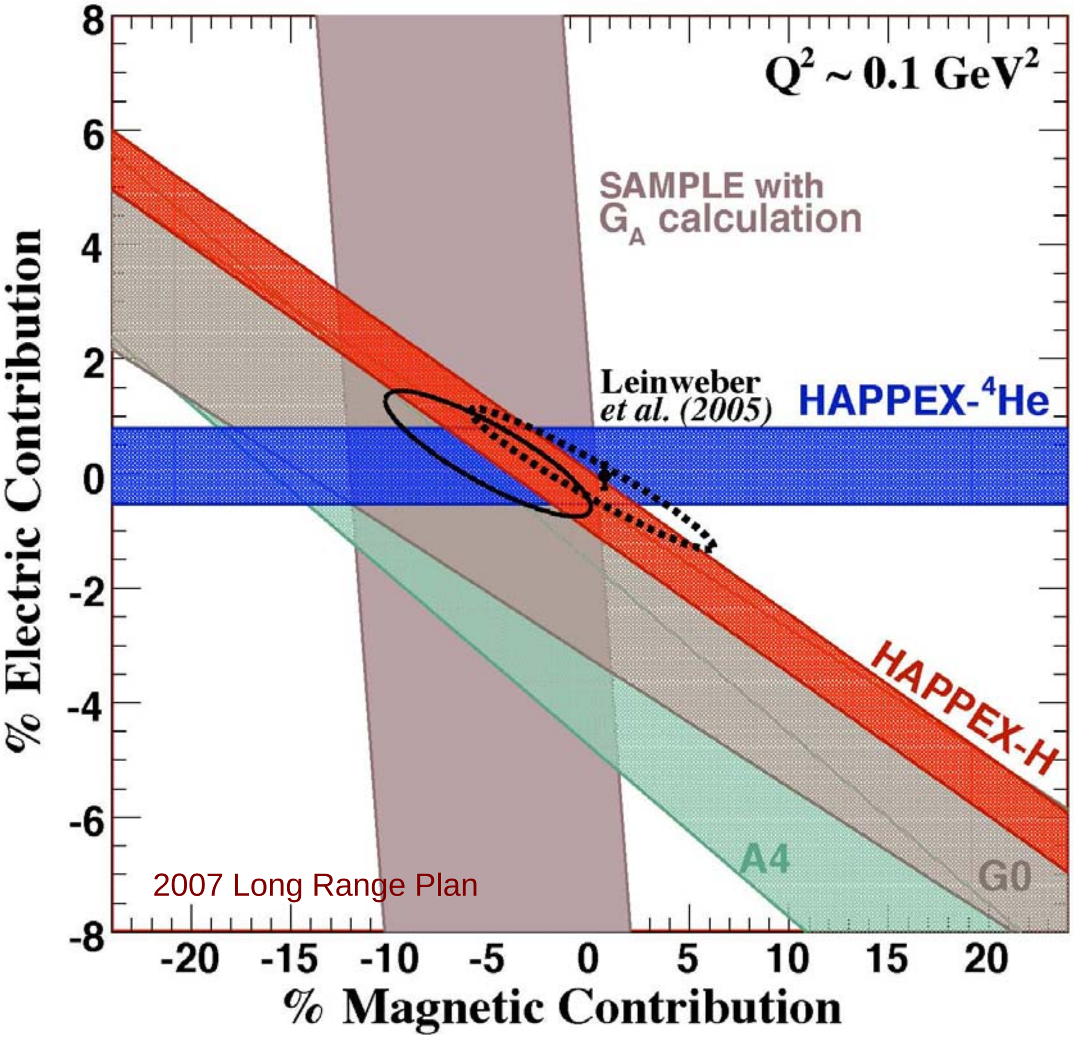
Summary of data at $Q^2 = 0.1$ GeV^2

Solid ellipse:
K. Pashke, private comm,
[same as J. Liu, et al
PRC 76, 025202 (2007)],
uses theoretical constraints
on the axial form factor

Dashed ellipse:
R. Young ,et al.
PRL 97 (2006) 102002,
does not constrain G_A with
theory

note: Placement of SAMPLE band on the graph depends on choice for G_A

$$\% \text{ contrib} = \frac{G^s_{E,M}}{G^p_{E,M}} \times \left(-\frac{1}{3}\right) \times 100$$



(thanks to K. Pashke, R. Young)

New Results from PVA4

S. Baunack et al., PRL 102 (2009) 151803

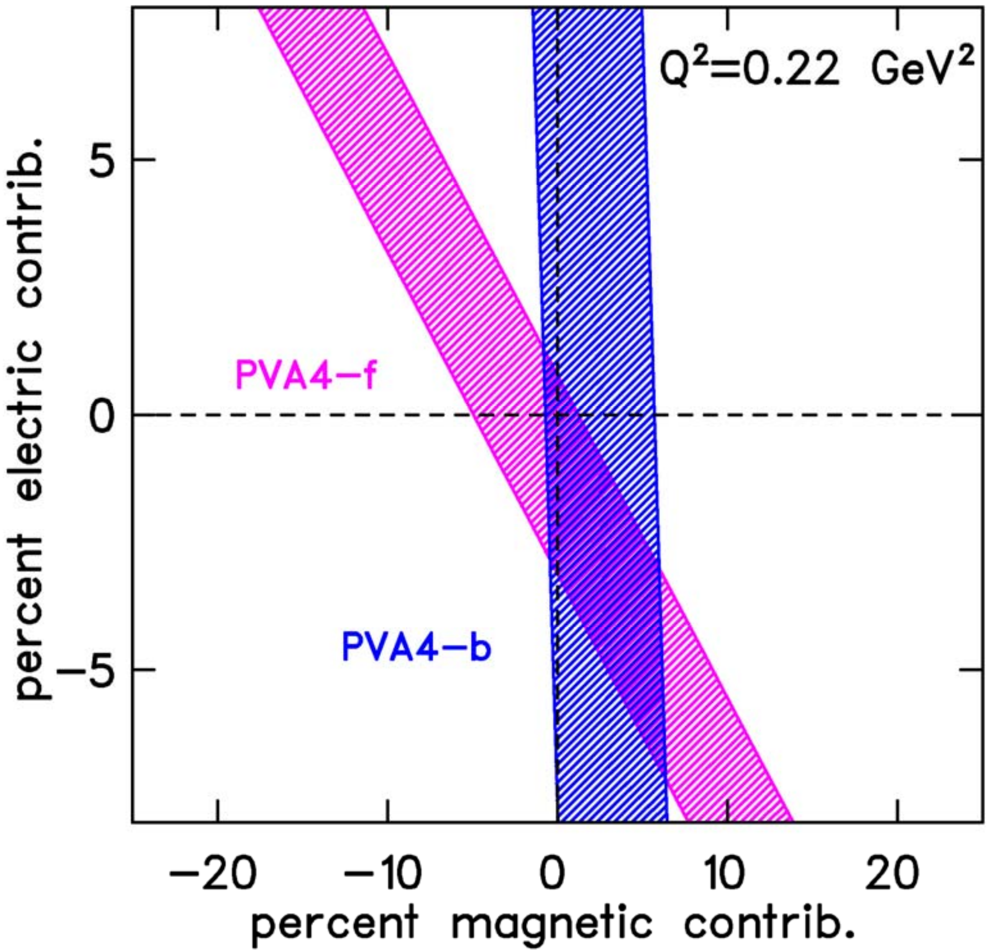
Q^2 = 0.22 GeV^2, θ = 145°
A_{meas} = –17.23 ± 0.82 ± 0.89 ppm

A_{nvs} = –15.87 ± 1.22 ppm
(uses theoretical constraint of Zhu et al., for the axial FF)

$$G_E^s = 0.050 \pm 0.038 \pm 0.019$$

$$G_M^s = -0.14 \pm 0.11 \pm 0.11$$

% contribution to proton:
electric: –3.0 ± 2.5 %
magnetic: +2.9 ± 3.2 %



Quasielastic PV (ee') in Deuterium

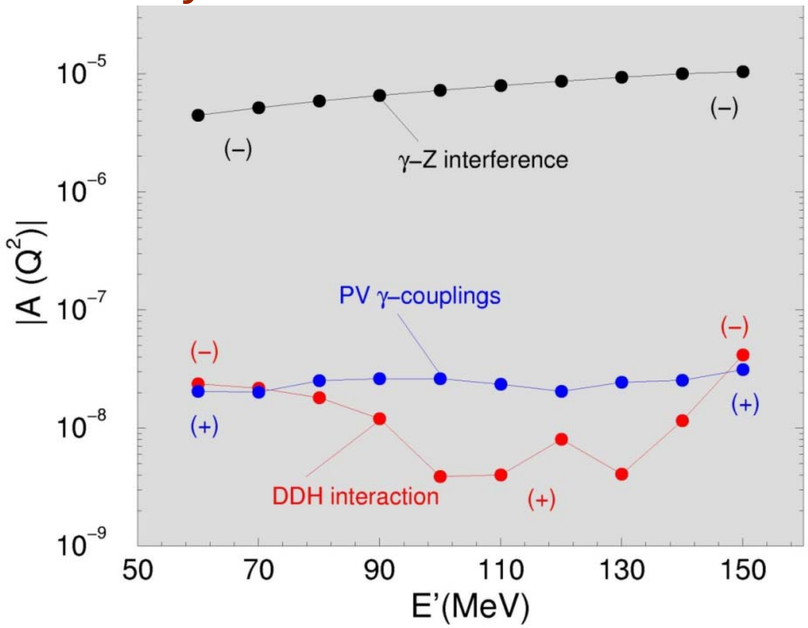
Use Quasielastic scattering from deuterium as lever arm for $G_A^e(Q^2)$

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

Parity conserving nuclear corrections to the asymmetry are generally small, 1-3% at backward angles. Calculation provided to us by R. Schiavilla includes final state interactions and 2-body effects.

Diaconescu, Schiavilla + van Kolck,
PRC 63 (2001) 044007
Schiavilla, Carlson + Paris,
PRC 67 (2003) 032501

See also
Hadjimichael, Poulis + Donnelly, PRC45 (1992) 2666
Schramm + Horowitz, PRC 49 (1994) 2777
Kuster + Arenhovel, NPA 626 (1997) 911
Liu, Prezeau, + Ramsey-Musolf,
PRC 67 (2003) 035501

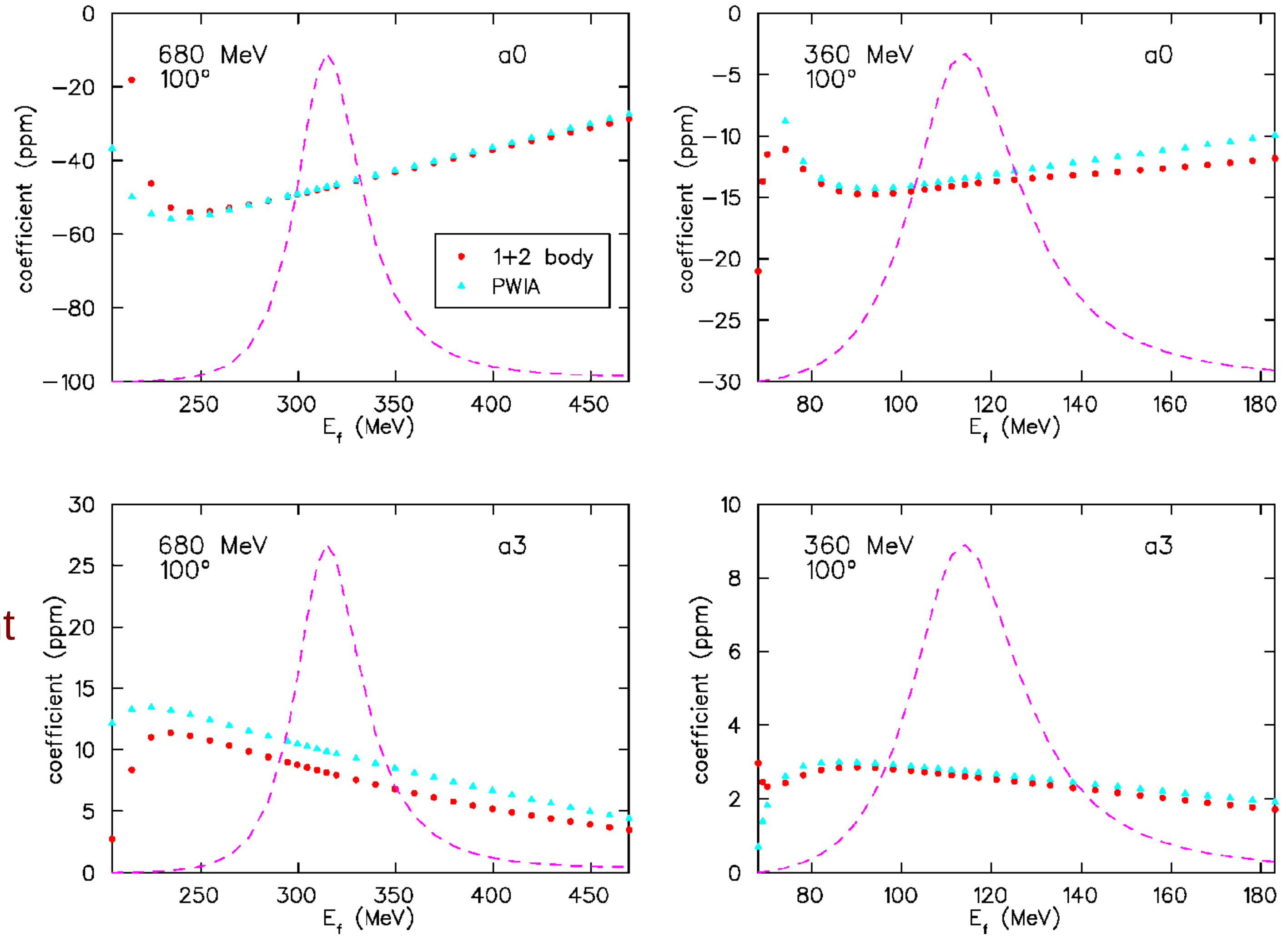


2-body effects in the D asymmetry

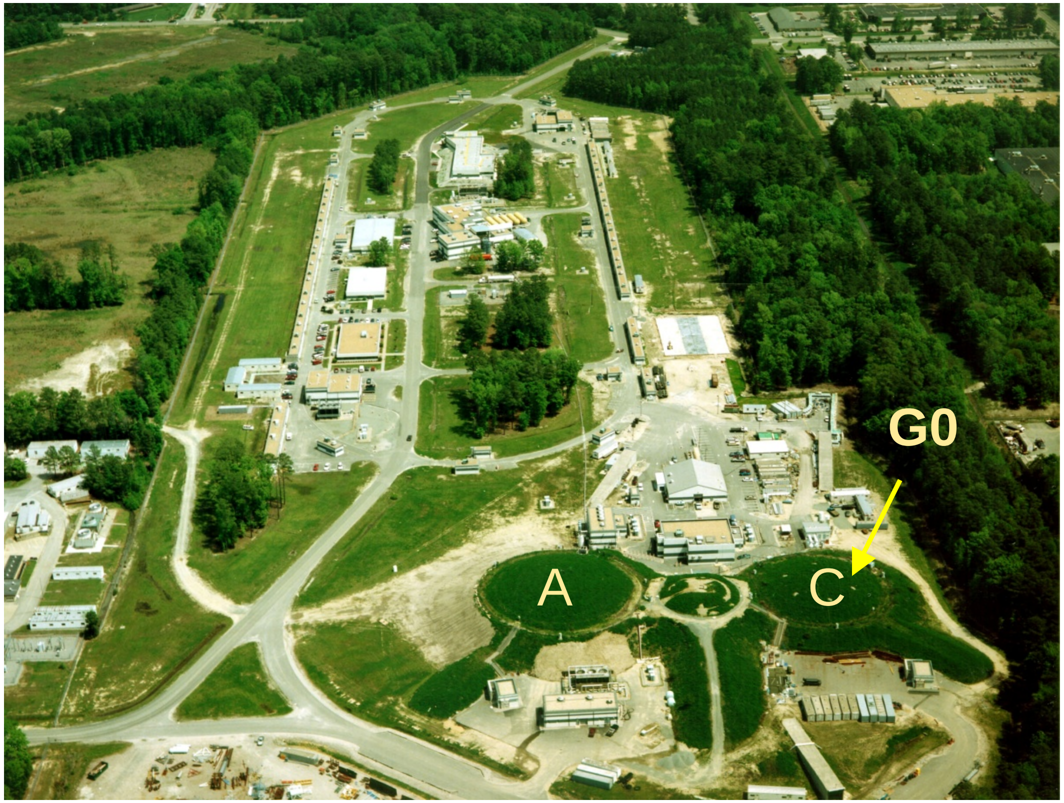
calculations from R. Schiavilla, see also R.S., J. Carlson, and M. Paris, PRC70, 044007 (2004).

leading term of the asymmetry

axial form factor coefficient has ~15% correction from 2-body effects



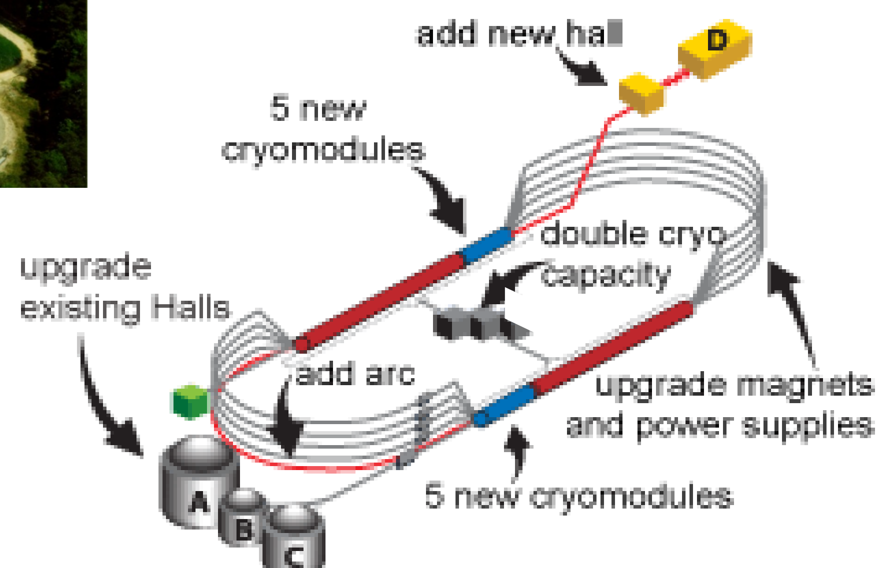
Jefferson Laboratory



upgrade to 12 GeV now underway

E ~ 6 GeV
Continuous Polarized Electron Beam

> 100 μA
up to 85% polarization
concurrent to 3 Halls

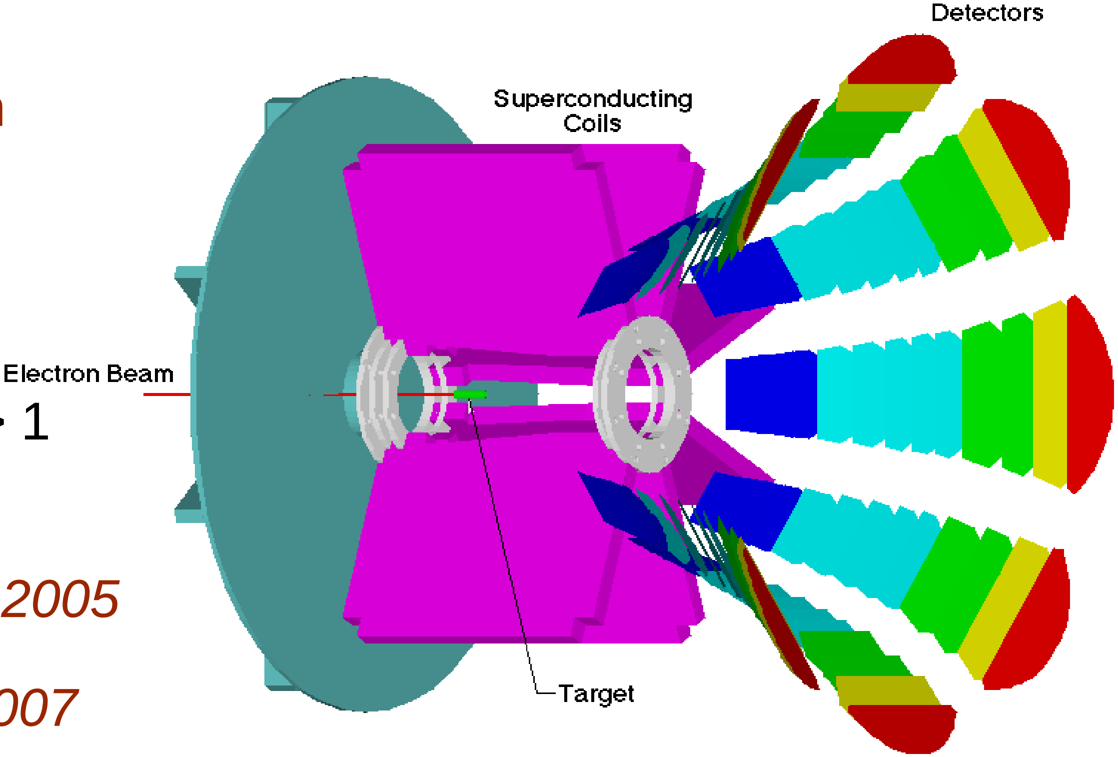


The G0 experiment at JLAB

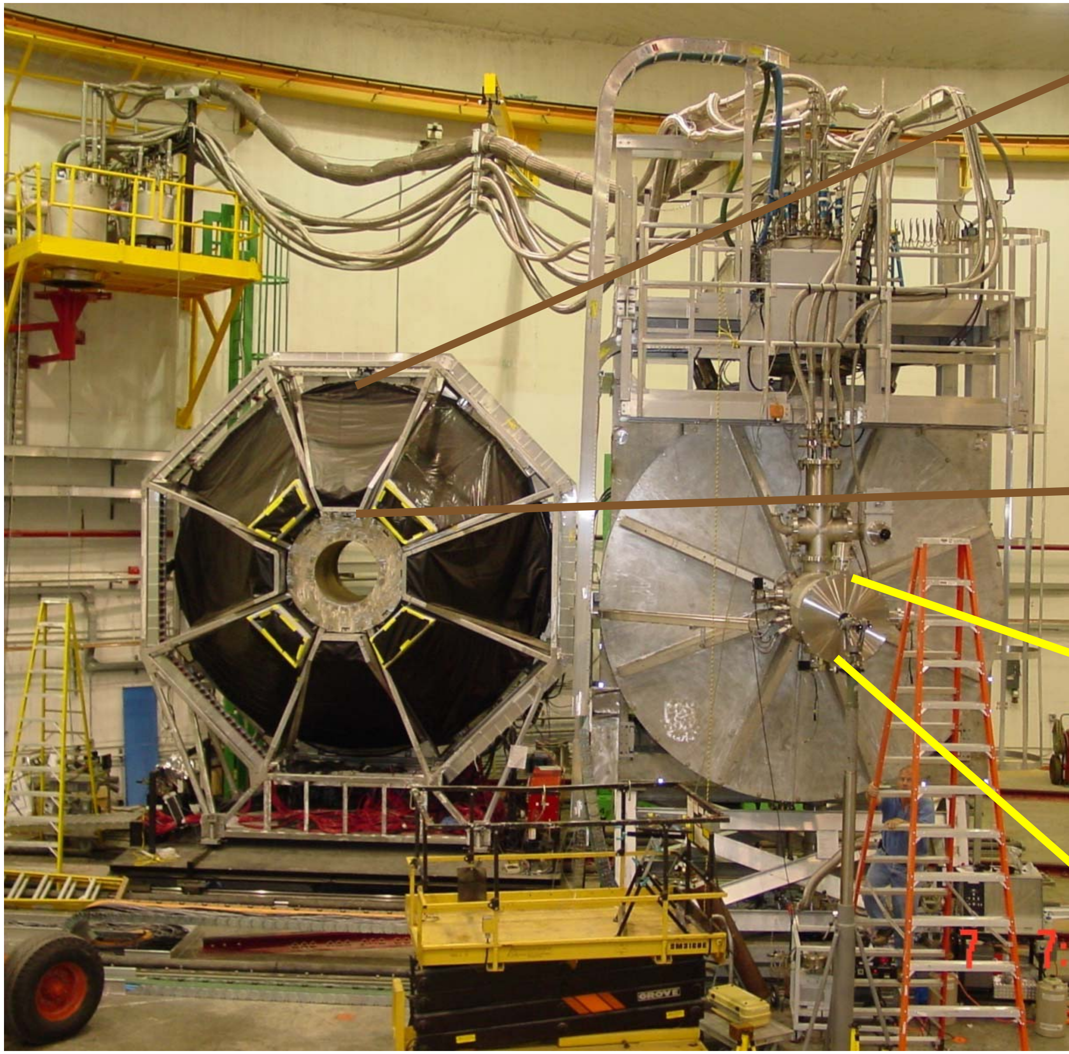
- Forward and backward angle PV e-p elastic and e-d (quasielastic) in JLab Hall C

G_E^s, G_M^s and G_A^e separated over range $Q^2 \sim 0.1 - 1.0\ (\mathrm{GeV/c})^2$

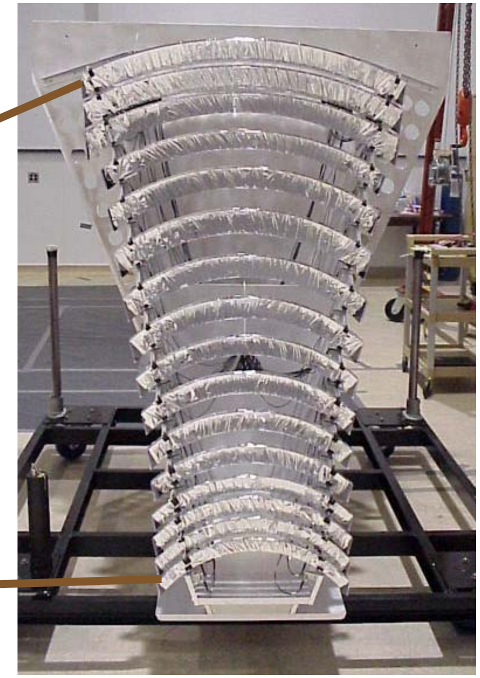
- superconducting toroidal magnet
  - scattered particles detected in segmented scintillator arrays in spectrometer focal plane
  - custom electronics count and process scattered particles at > 1 MHz
  - *forward angle data published 2005*
  - *backward angle data: 2006-2007*



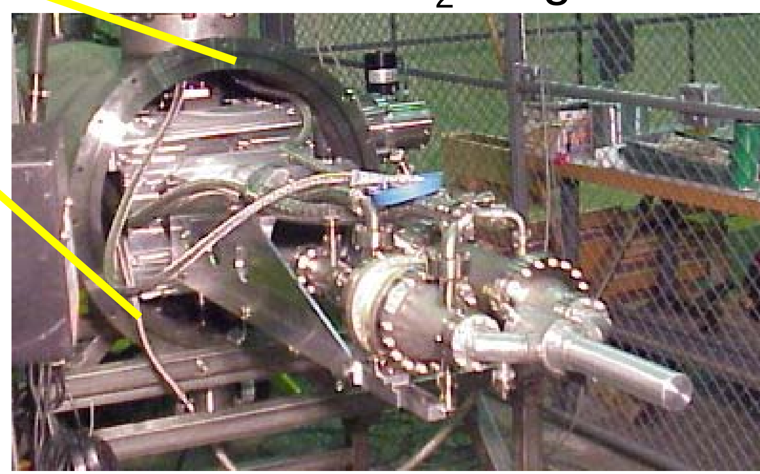
G0 Apparatus



One octant's scintillator array



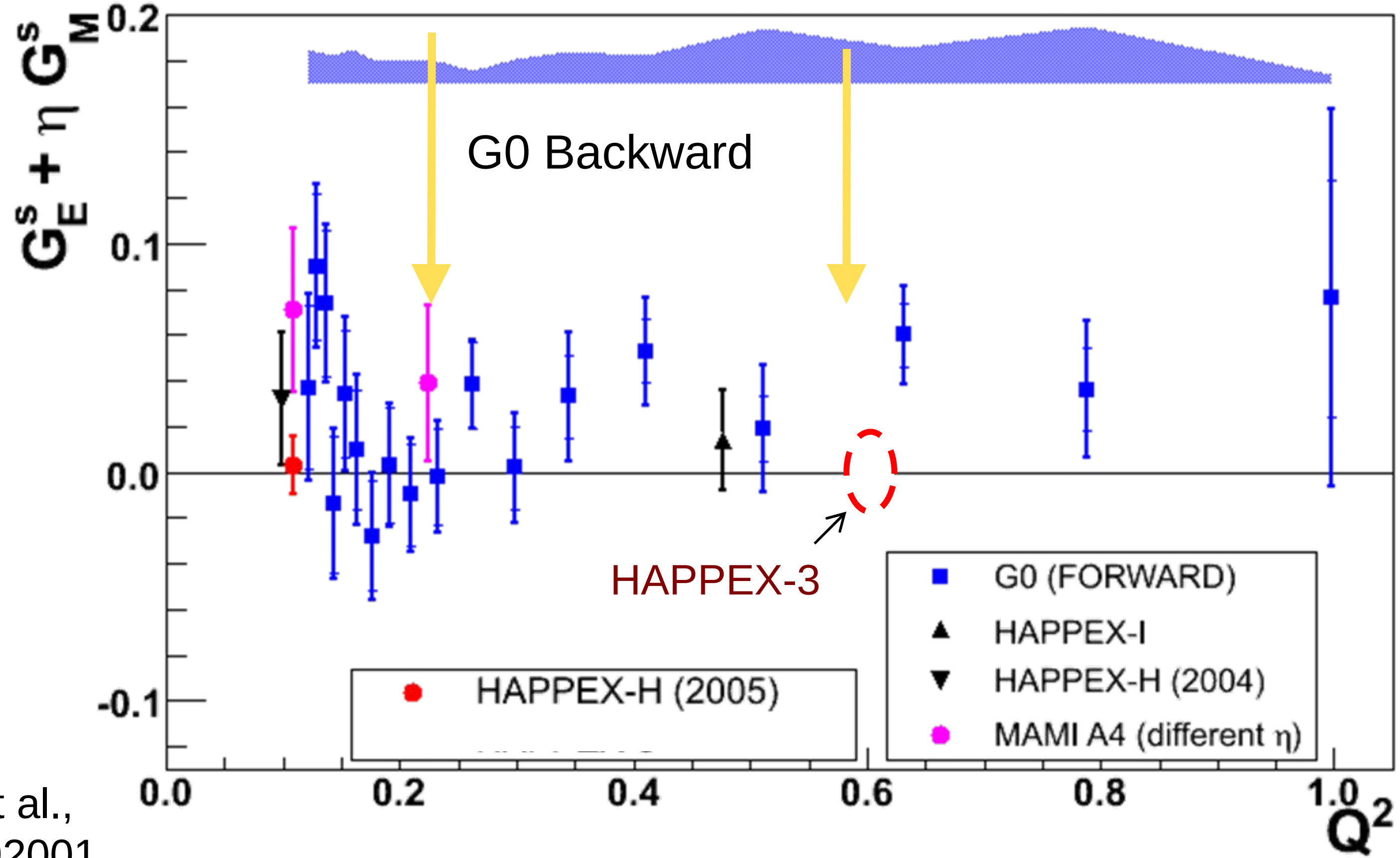
20 cm LH_2 Target



G0 Forward angle Results

$$G_E^s + \eta G_M^s = \frac{4\pi\alpha\sqrt{2}}{G_F Q^2} \frac{\varepsilon G_E^{p\,2} + \tau G_M^{p\,2}}{\varepsilon G_E^p \left(1 + R_V^{(0)}\right)} \left(A_{phys} - A_{NVS}\right)$$

EM form factors:
J.J.Kelly, PRC **70,** 068202 (2004)



D.S. Armstrong et al., PRL 95 (2005) 092001

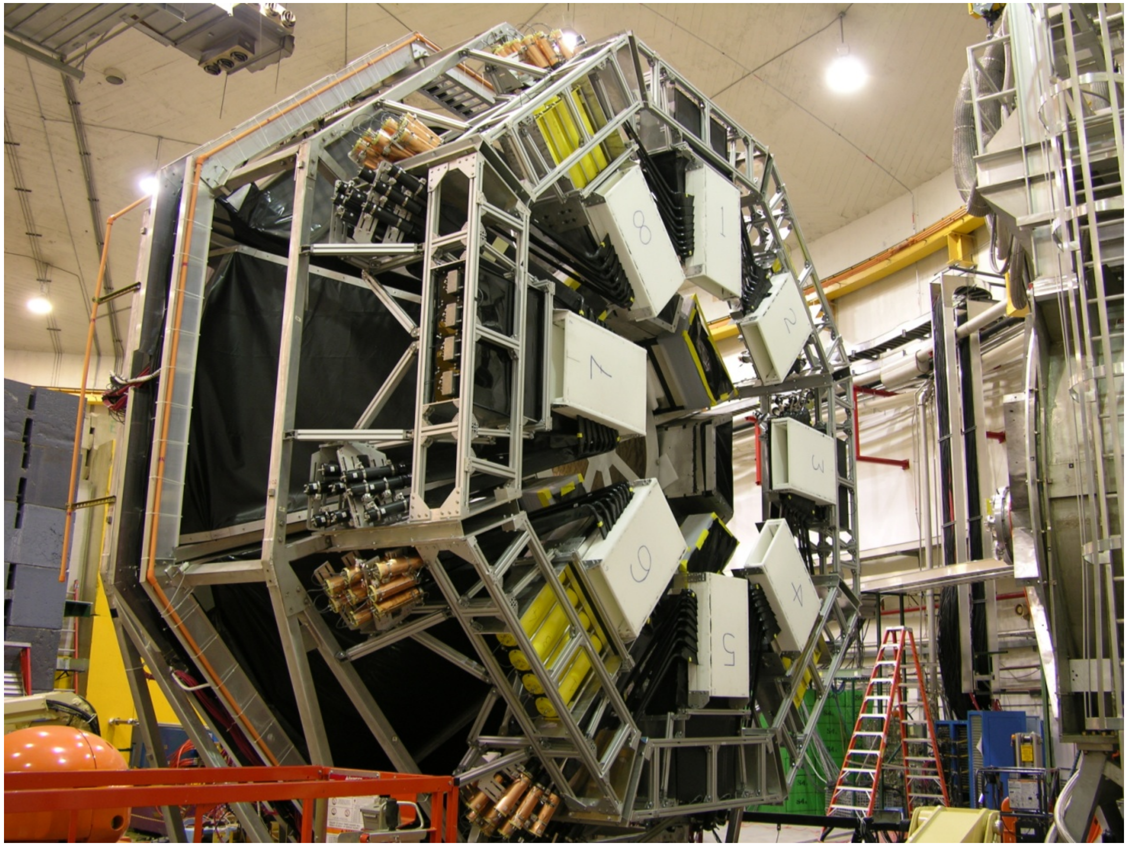
G0 Backward Angle

Electron detection: θ = 108°, H and D targets
Add Cryostat Exit Detectors (CED) to define electron trajectory
Aerogel Cerenkov detector for π/e separation (p_π < 380 MeV/c)
1 scaler per channel FPD/CED pair (w/ and wo/ CER)

E_e (MeV)	Q^2 (GeV^2)
362	0.23
687	0.62

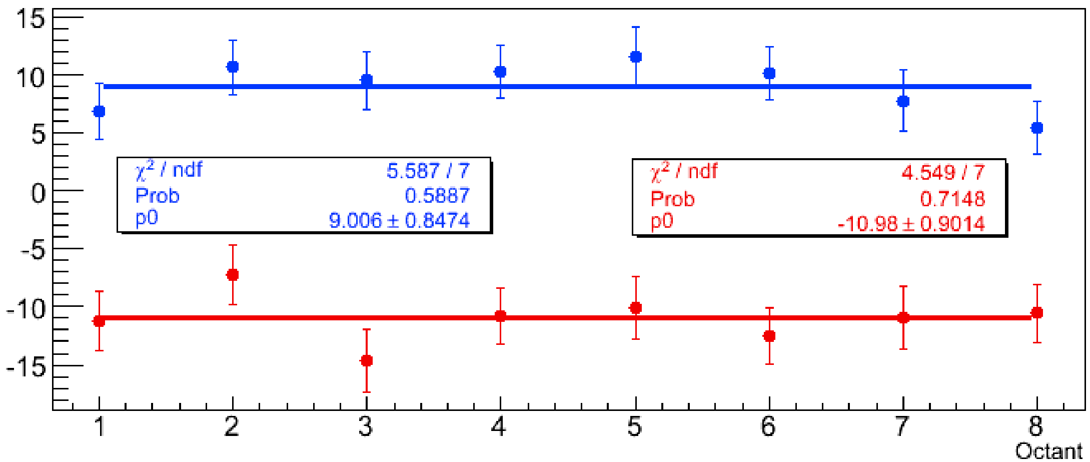
Both H and D
at each kinematic setting

Common Q^2 with
HAPPEX-III and PVA4

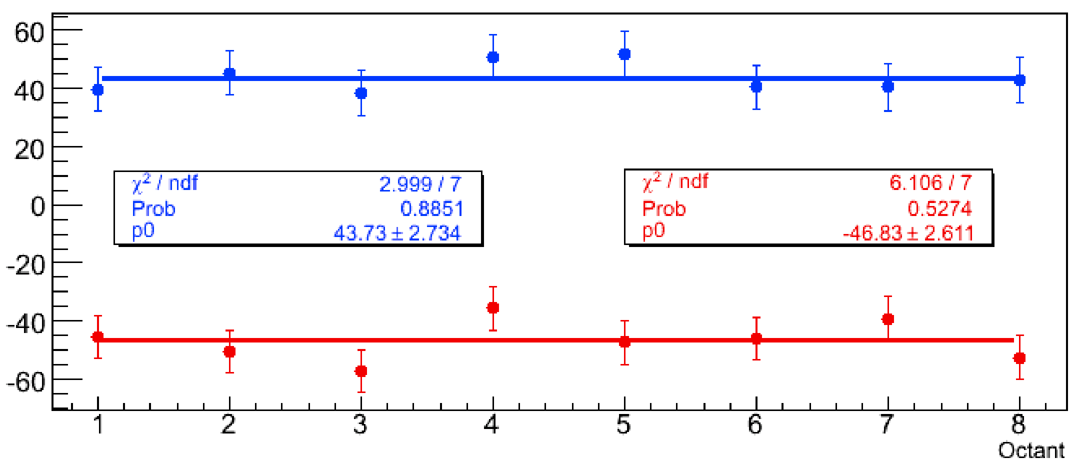


Hydrogen raw electron data

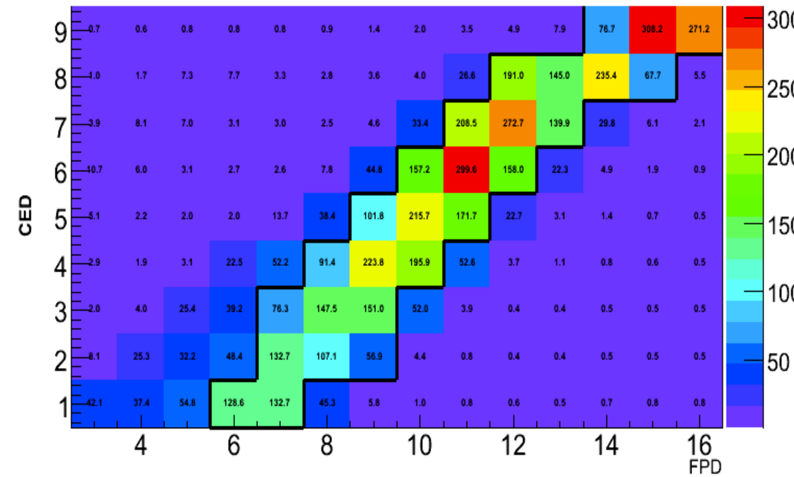
blinded raw asymmetries (ppm)



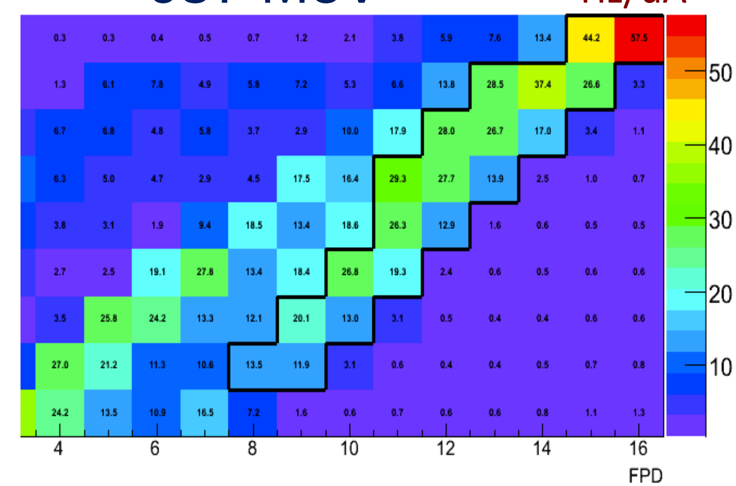
octant # (azimuthal distribution) ⟶



362 MeV Hz/uA

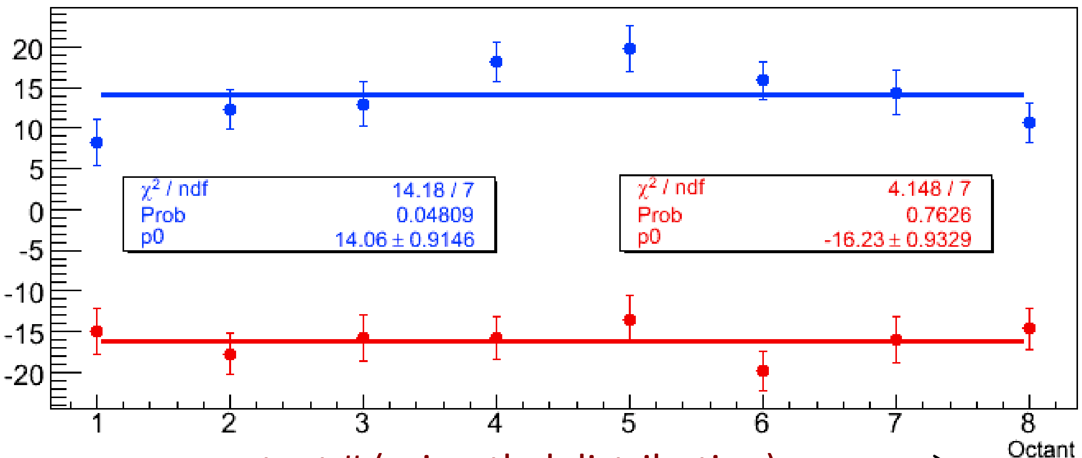


687 MeV Hz/uA

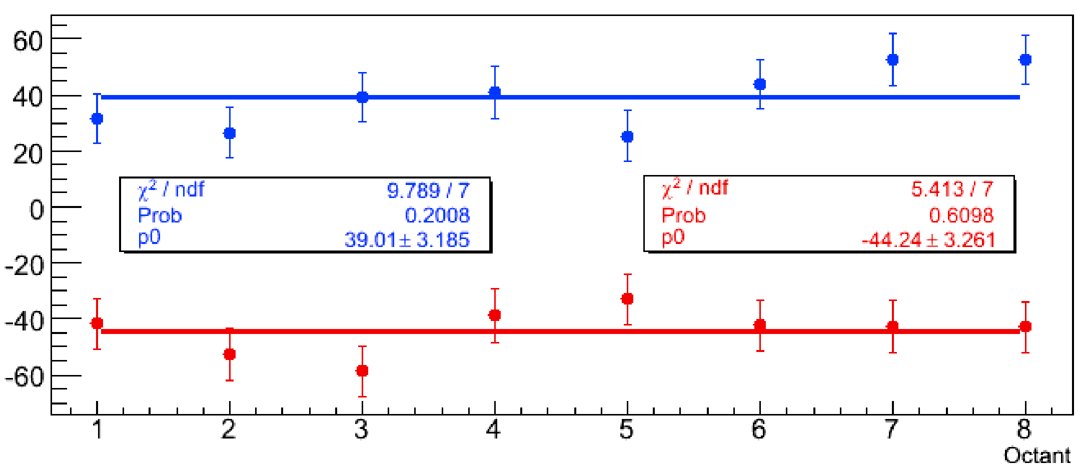


Deuterium raw electron data

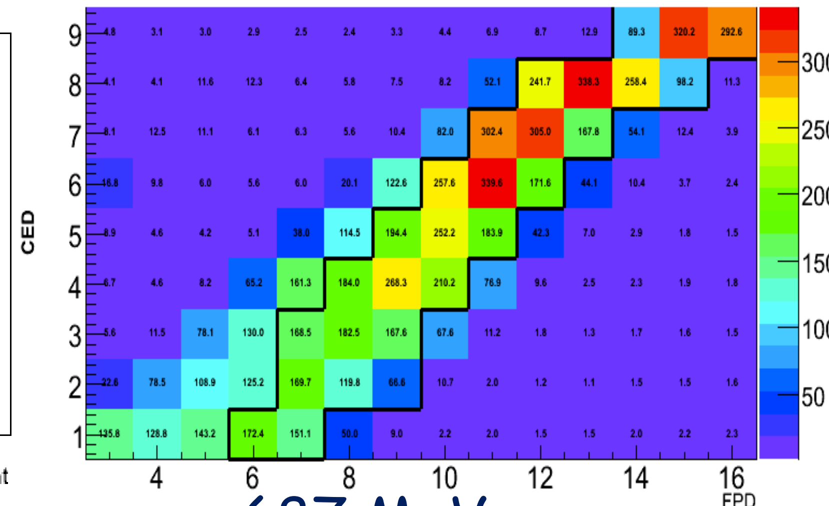
blinded raw asymmetries (ppm)



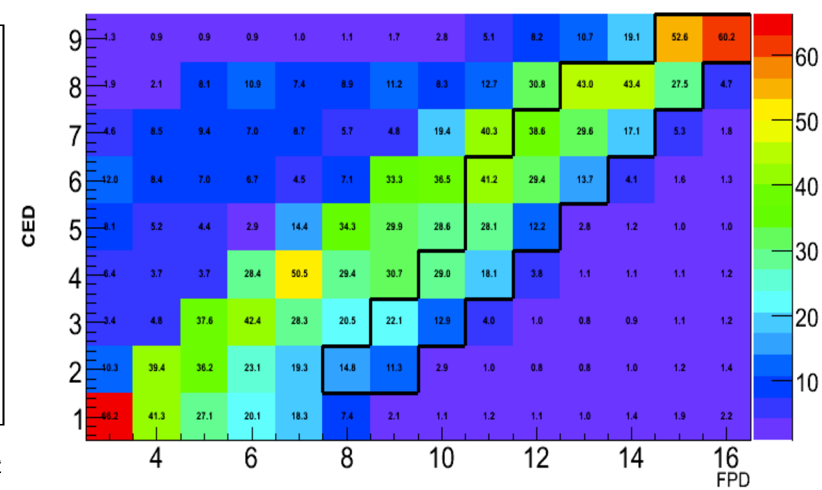
octant # (azimuthal distribution) →



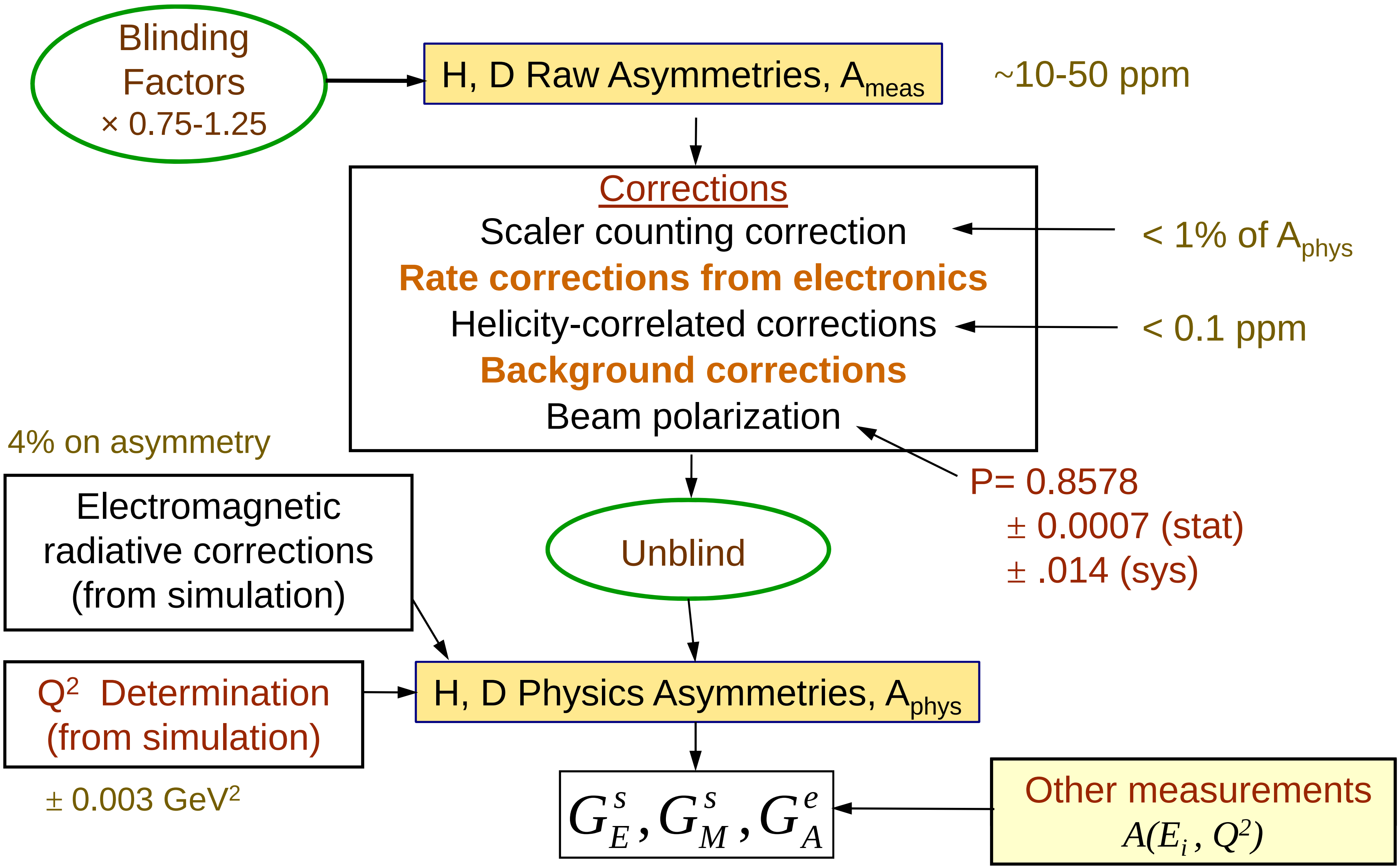
362 MeV Hz/uA



687 MeV Hz/uA



Analysis Strategy



Rate Corrections

Correct the yields for random coincidences and electronic deadtime prior to asymmetry calculation

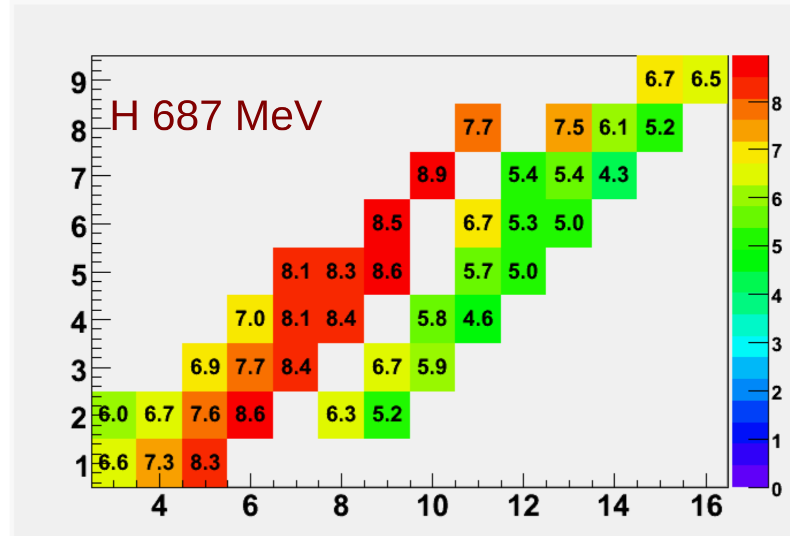
randoms small except for D-687 (due to higher pion rate)

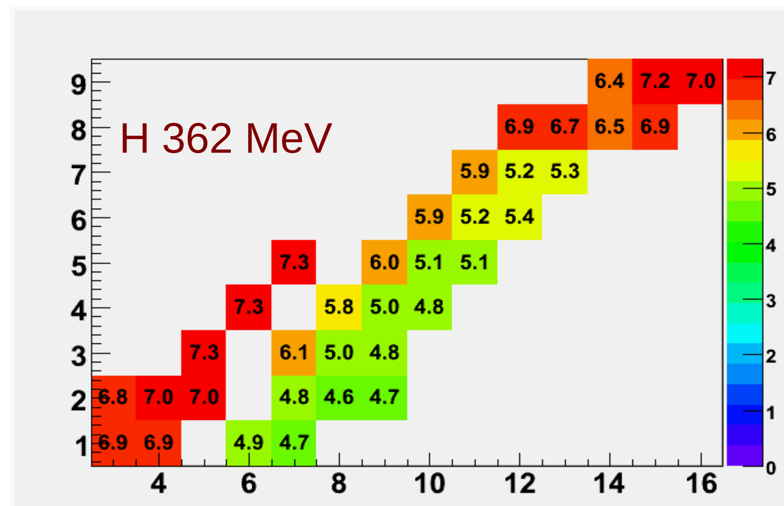
Direct (out-of-time) randoms measured

Validated with simulation of the complete electronics chain

Data set	Correction to Yield (%)	Asymmetry Correction (ppm)	systematic error (ppm)
H 362	6	0.3	0.06
H 687	7	1.4	0.17
D 362	13	0.7	0.2
D 687	9	6	1.8

Deadtimes (%)

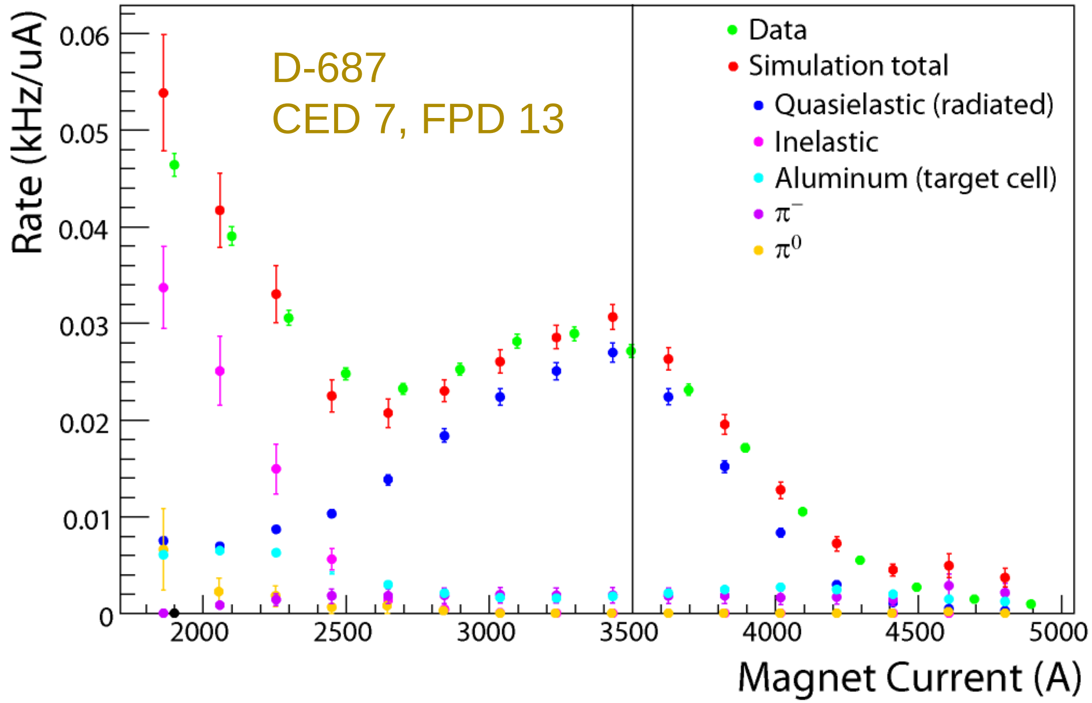




Backgrounds: Magnetic Field Scans

Use simulation *shapes* to help determine dilution factors

Main contributions are Aluminum windows (~10%), pions (for D-687 data only).



Data set	Asymmetry Correction (ppm)	systematic error (ppm)
H 362	0.50	0.37
H 687	0.13	0.78
D 362	0.06	0.02
D 687	2.03	0.37

Experimental "Physics" Asymmetries

PRELIMINARY – NOT FOR QUOTATION

all entries in ppm

Data Set	Asymmetry	Stat	Sys pt	Global
H 362	-11.01	0.84	0.26	0.37
D 362	-16.50	0.79	0.39	0.19
H 687	-44.76	2.36	0.80	0.72
D 687	-54.03	3.22	1.91	0.62

H: systematic uncertainties dominated by beam polarization
D: rate corrections also contribute to uncertainty

Asymmetries to Form Factors

$$A_{phys} = a_0 + a_E G_E^s + a_M G_M^s + a_A G_A^e$$

Electromagnetic form factors: Kelly (PRC **70** (2004))

- also used in Schiavilla calculation for D
- does not include new low Q^2 data from BLAST or JLab
- eventually use new fits (Arrington & Melnitchouk for p, Arrington & Sick for n)

differences in fits become 0.5 – 1 % in the asymmetry

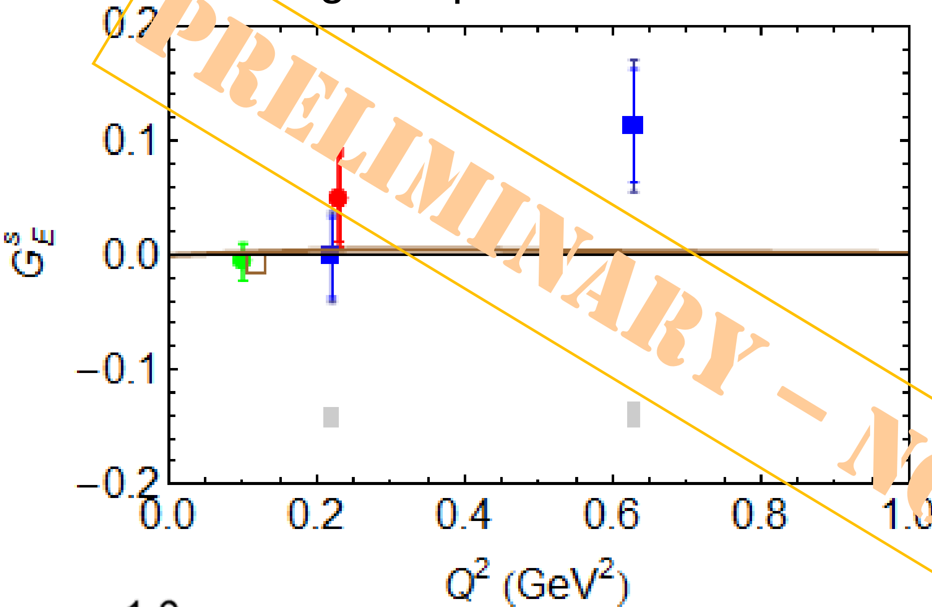
Two-boson exchange corrections to Asymmetry: 0.5 -1.2%

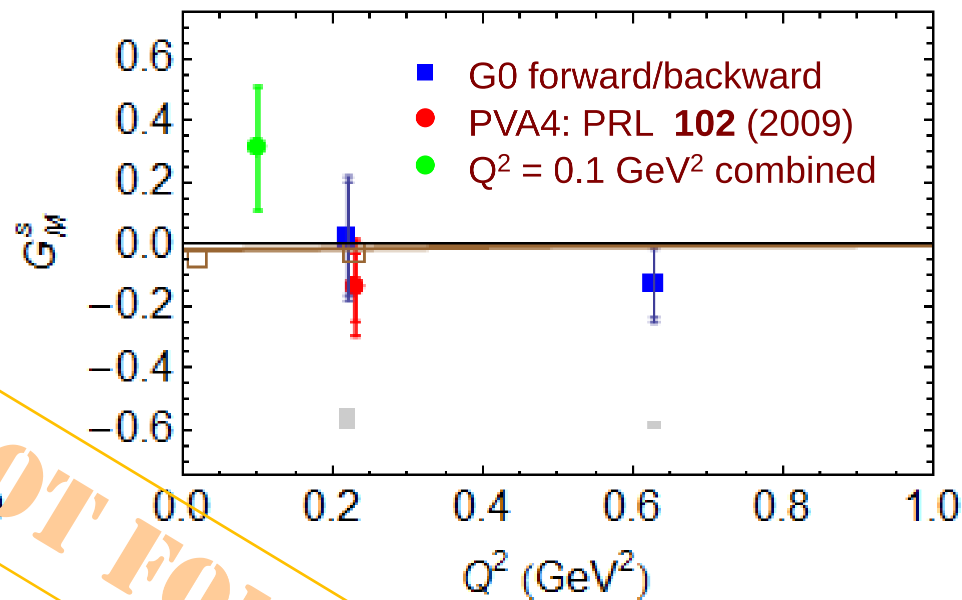
- (see Tjon, Blunden & Melnitchouk, arXiv:0903.2759v1)
- includes D contributions, calculation for n in progress

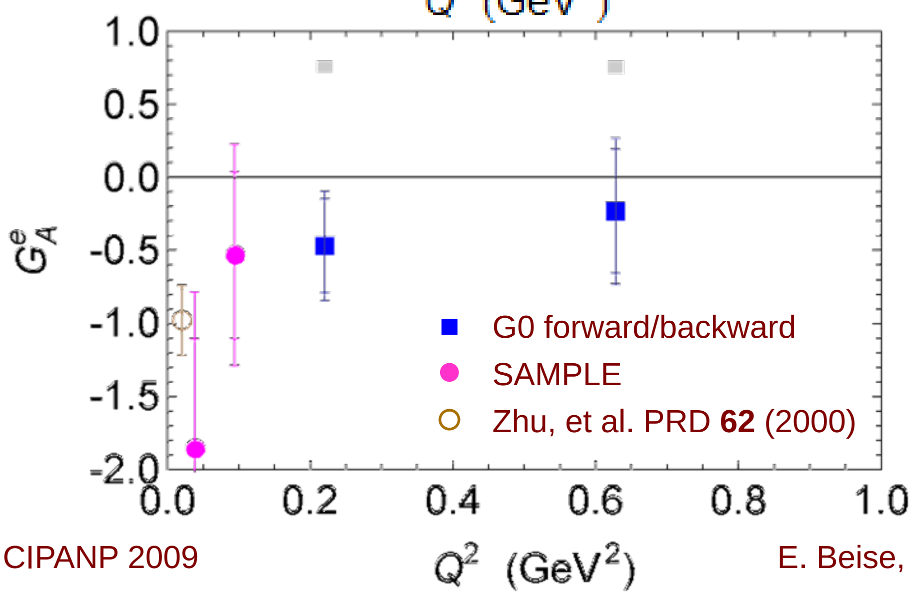
$$A_{meas} = (1+\delta) A_{Born} = \left(\frac{1+\delta_{Z(\gamma\gamma)} + \delta_{\gamma(\gamma Z)}}{1+\delta_{\gamma(\gamma\gamma)}} \right) A_{Born}$$

Form Factor Results

- Using interpolation of G0 forward measurements







Global uncertainties

Calculations:

Leinweber, et al. PRL 97 (2006) 022001
Leinweber, et al. PRL 94 (2005) 152001
Wang, et al arXiv:0807.0944 (Q^2 = 0.2 GeV^2)
Doi, et al, arXiv:0903.3232

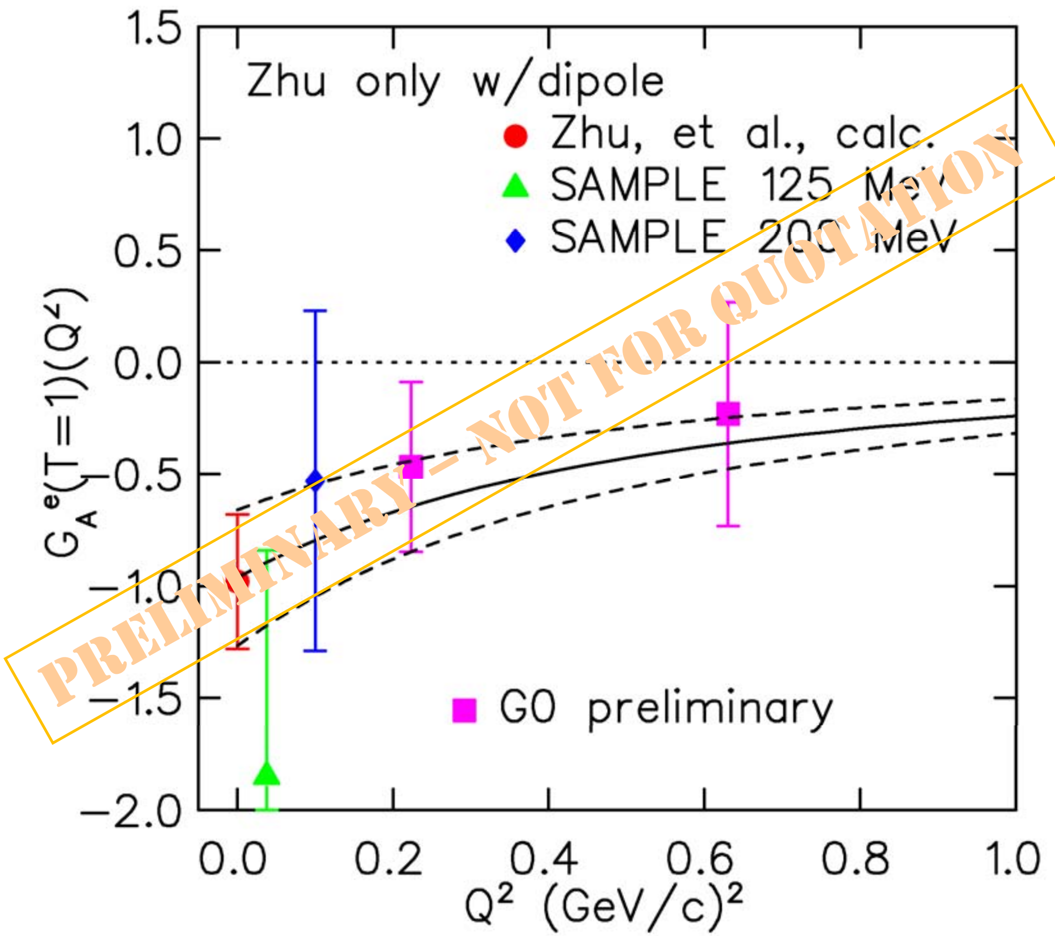
Anapole form factor $F^{\gamma}_{A}(Q^2)$

Three scenarios

1. $F_A(Q^2)$ is like $G_A(Q^2)$

2. $F_A(Q^2)$ is flat
(Riska, NPA 678 (2000) 79)

3. $F_A(Q^2) \sim 1 + Q^2$
(Maekawa, Viega, van Kolck, PLB 488 (2000) 167)
– (shown here are the most extreme set of model parameters)



Summary

• first look at Q^2 behavior of strangeness contribution to proton's charge and magnetism: continue to be small

• first results for the Q^2 behavior of the anapole contributions to the axial form factor

• other results to come soon from G0:

→ transverse beam spin asymmetries (2-γ exchange) in H and D

→ PV in the N-Δ transition: axial transition f.f.

→ PV asymmetry in inclusive π^- production

The G^0 Collaboration (backward angle run)

Caltech, Carnegie Mellon, William and Mary, Hendricks College, Orsay, Grenoble, LA Tech, NMSU, Ohio, JLab, TRIUMF, Illinois, Kentucky, Manitoba, Maryland, Winnipeg, Zagreb, Virginia Tech, Yerevan Physics Institute