Strange Form Factors of the Proton

Mark Pitt* Virginia Tech

MENU2010: 12th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon
Williamsburg, VA May 31 – June 4, 2010

How important is the strange quark sea ($s\bar{s}$ pairs) in determining the electromagnetic (G^p_E , G^p_M) properties of the nucleon?

After 22 years of this line of inquiry, what is the status?

* Work partially supported by the National Science Foundation

Seminal Papers/Proposals for Vector Strange Form Factors

May 1988: Kaplan/Manohar, NPB310 (1988) 527: motivated by EMC strange spin content and πN sigma term – suggested elastic neutral current scattering experiments as probe of "strangeness" of the proton

STRANGE MATRIX ELEMENTS IN THE PROTON FROM NEUTRAL-CURRENT EXPERIMENTS

David B. KAPLAN[1]

Department of Physics, Harvard University, Cambridge, MA 02138, USA

Aneesh MANOHAR[2]

Center for Theoretical Physics, Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Received 19 May 1988

Recent results from EMC suggest a nonzero value for $\langle p|\bar{s}\gamma_\mu\gamma_5 s|p\rangle$; measurements of the pion–nucleon sigma term suggest a large value for $\langle p|\bar{s}s|p\rangle$. In this paper we discuss how elastic neutral-current scattering experiments may be used to extract more information about the "strangeness" of the proton. In particular, one can measure the form factor F_2 for $\langle p|\bar{s}\gamma_\mu s|p\rangle$, as well as the G_1 form factor for $\langle p|\bar{s}\gamma_\mu\gamma_5 s|p\rangle$. We also show how nonzero strange matrix elements in the proton can be reconciled with the successes of the nonrelativistic quark model.

Volume 219, number 2,3 PHYSICS LETTERS B 16 March 1989

SENSITIVITY OF POLARIZED ELASTIC ELECTRON–PROTON SCATTERING TO THE ANOMALOUS BARYON NUMBER MAGNETIC MOMENT

R.D. McKEOWN

W.K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, CA 91125, USA

Received 20 August 1988

The anomalous baryon number magnetic moment may be a useful quantity in constraining various models of nucleon structure. It is shown that this quantity can be determined quite precisely in the elastic scattering of polarized electrons by unpolarize protons at low momentum transfer.

PHYSICAL REVIEW D VOLUME 39, NUMBER 11 1 JUNE 1989

Strange-quark vector currents and parity-violating electron scattering from the nucleon and from nuclei

D. H. Beck

W.K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California 91125

(Received 3 January 1989)

Measurements of the processes $p(\pi,\pi)$, $p(\nu,\nu)/p(\bar{\nu},\bar{\nu})$, and deep-inelastic $\vec{p}(\vec{\mu},\mu')$ can be interpreted in a manner which requires a significant strange-quark contribution to proton matrix elements. In this paper some implications of strange-quark contributions to proton vector currents and their manifestation in parity-violating electron-scattering experiments are examined. It is found that strange-quark currents of plausible magnitude significantly affect the parity-violating elastic electron scattering from the nucleon in certain kinematic regimes. It is also shown that, while the effects in on-going parity-violating experiments on ^{9}Be and ^{12}C are small, significant strange-quark contributions might be expected in experiments with nuclear targets at higher-momentum transfer.

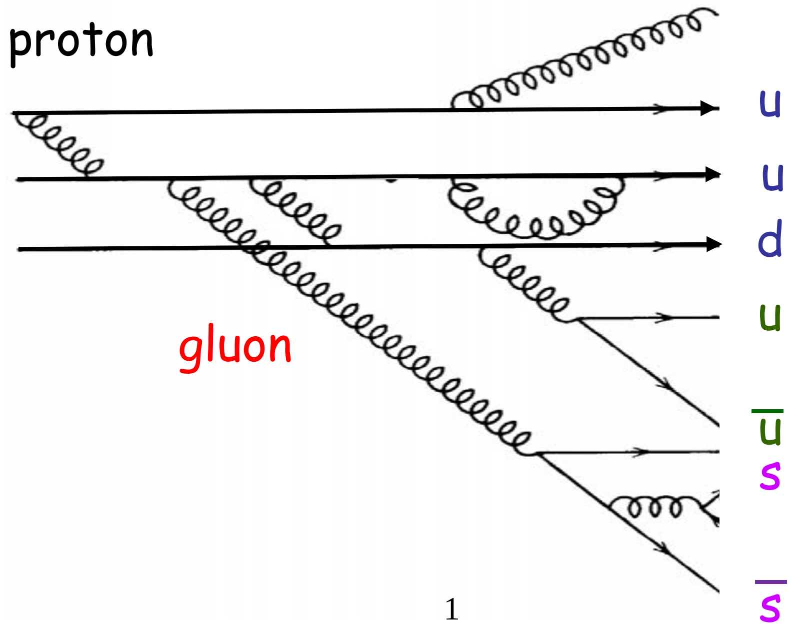
1989: McKeown and Beck point out that parity-violating electron scattering from the proton can be used to measure strange quark vector currents – "the strange form factors"

1990: SAMPLE experiment proposed at MIT-Bates

1991: G0 and HAPPEx experiments proposed at Jefferson Lab

~1995: A4 experiment launched at MAMI

What role do strange quarks play in nucleon properties?



valence quarks

"non-strange" sea ($u, \bar{u}, d, \bar{d}$) quarks

"strange" sea ($s, \bar{s}$) quarks

Momentum: $\int_0^1 x(s+\bar{s})dx \sim 4\%$ (DIS)

Spin (axial-vector): $< N|\bar{s}\gamma^5 s|N > \equiv \Delta s$ (polarized DIS)

1988: $\Delta s \sim -10\%$

2008: $\Delta s \sim -10.3\% \pm 1.7\%$ (inclusive polarized DIS; HERMES: PRD 75(2007) 012007)

$\Delta s \sim -3.7\% \pm 3.3\%$ (semi-inclusive polarized DIS; HERMES: PLB 666 (2008) 446)

Mass (scalar): $< N|\bar{s}s|N >$ (πN σ-term)

1988: $\sim 36 \pm 14\%$

2010: $\sim 2 - 7\%$ (R. Young, arXiv:1004.5163 and refs. therein)

Charge and current: $< N|\bar{s}\gamma^\mu s|N > = ?? \rightarrow G_E^s \; G_M^s$

Strange Vector Form Factors - G_E^s and G_M^s

$$< N | \bar{s} \; \gamma^\mu \; s | N > \;\; \rightarrow \;\; G_E^s \quad G_M^s$$

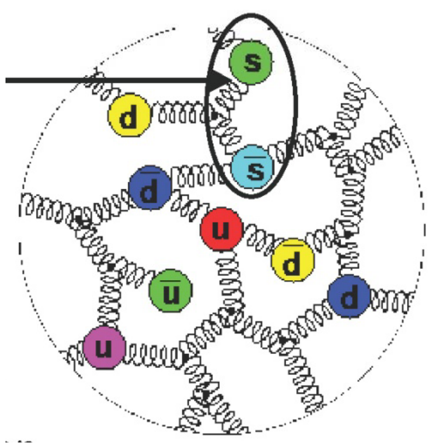
The strange vector form factors measure the contribution of the strange quark sea to the electromagnetic properties of the nucleon.

$G_E^s(Q^2)$ Strange electric form factor: measures the contribution of the strange quark sea to the nucleon's spatial charge distribution.

$G_M^s(Q^2)$ Strange magnetic form factor: measures the contribution of the strange quark sea to the nucleon's spatial magnetization distribution.

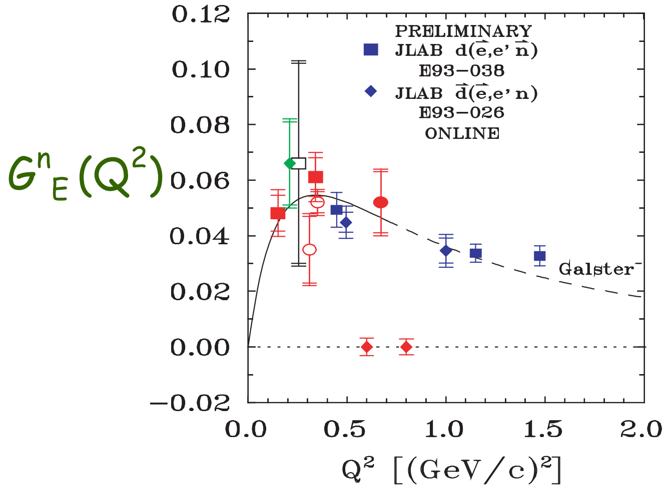
$$G_{E,M}^{\gamma,p} = \frac{2}{3} G_{E,M}^{u,p} - \frac{1}{3} G_{E,M}^{d,p} - \frac{1}{3} G_{E,M}^{s,p}$$

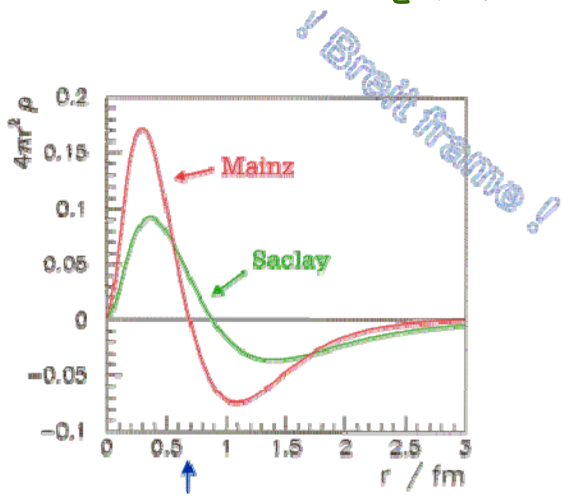
$$G_{E,M}^{\gamma,n} = \frac{2}{3} G_{E,M}^{u,n} - \frac{1}{3} G_{E,M}^{d,n} - \frac{1}{3} G_{E,M}^{s,n}$$

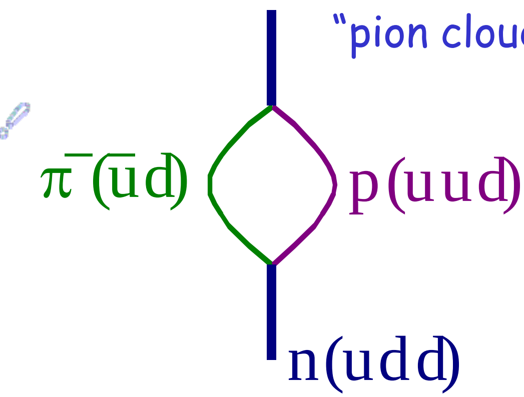


How could non-zero strange form factors come about? – a simple example

Compare to neutron electric form factor: $G^n_E(Q^2=0) = 0$

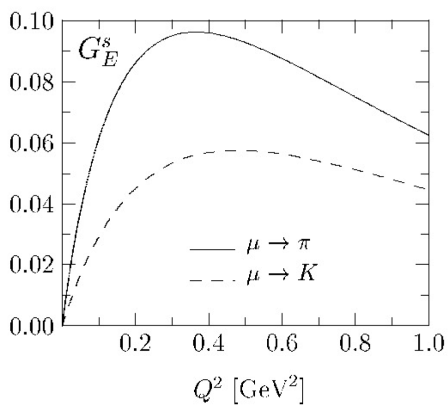


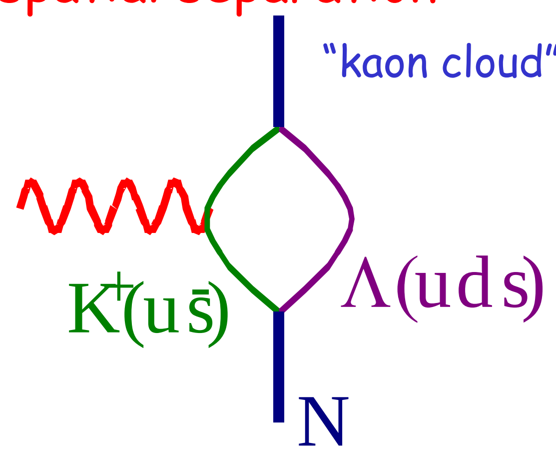




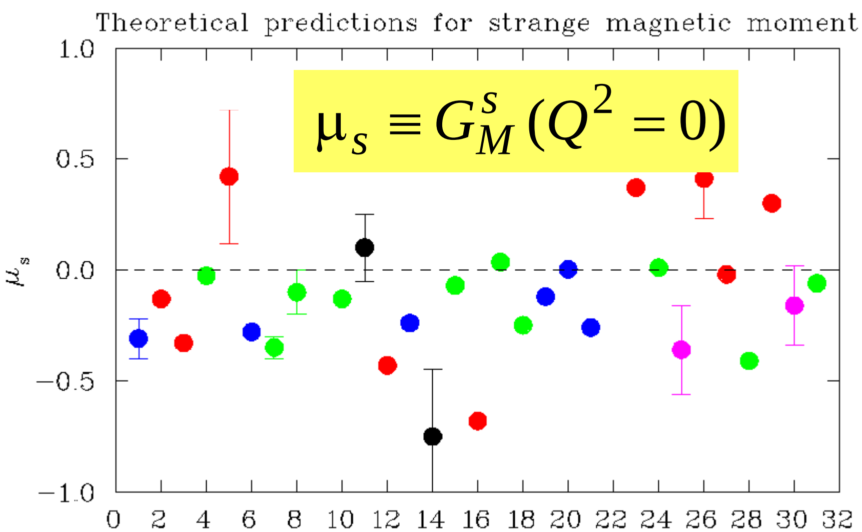
Consider strange electric form factor: $G^s_E(Q^2=0)$ =0 since no net strangeness

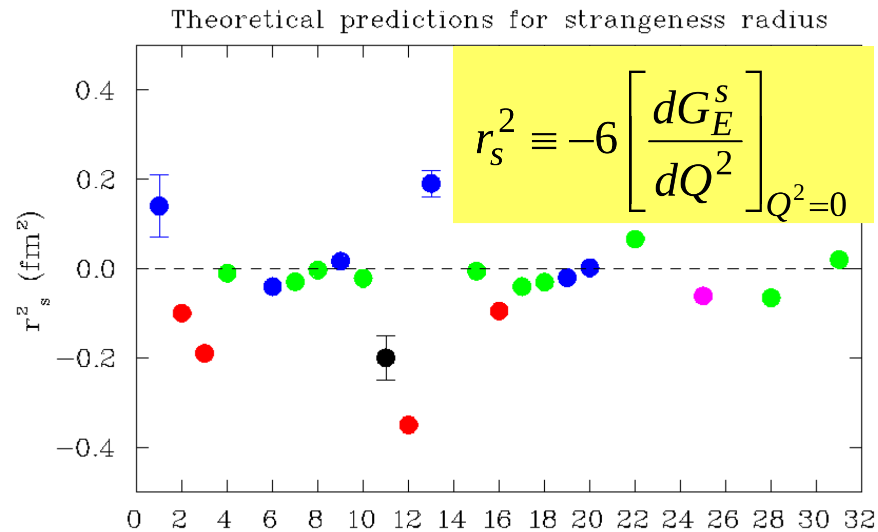
Non-zero value of G^s_E requires a process to cause spatial separation of s and $\bar{s}$





Theoretical Approaches to Strange Form Factors





Much theoretical effort has gone into strange form factors in past 22 years.

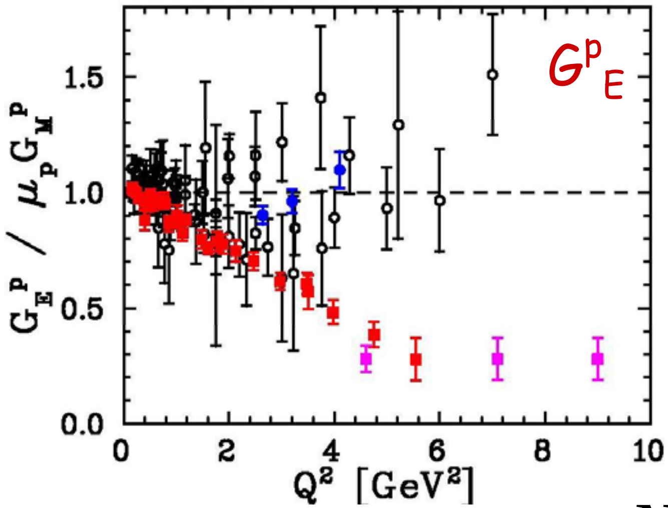
Models - a non-exhaustive list:

kaon loops, vector dominance, Skyrme model, chiral quark model, dispersion relations, NJL model, quark-meson coupling model, chiral bag model, HBChPT, chiral hyperbag, QCD equalities, …

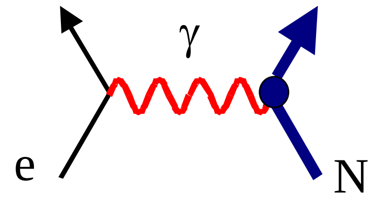
QCD Lattice calculations -

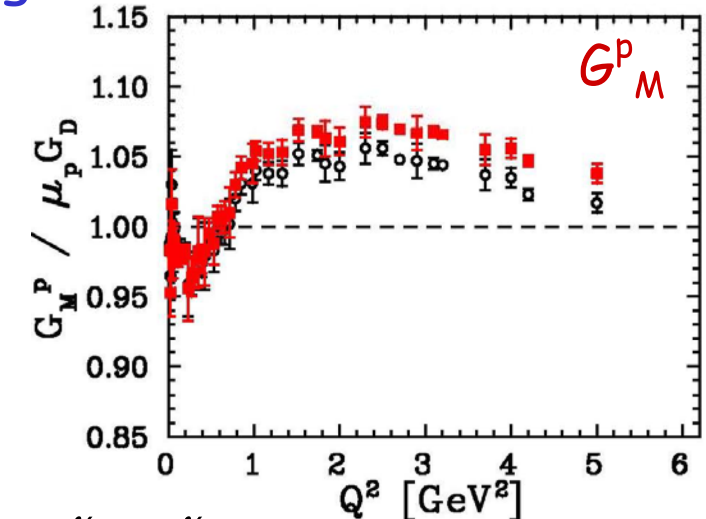
- Dong, Liu, Williams PRD **58**(1998)074504
- Lewis, Wilcox, Woloshyn PRD **67**(2003)013003
- Leinweber, Thomas, Young *et al.* PRL **94**(2005) 212001; PRL **97** (2006) 022001
- Wang, Leinweber, Thomas, Young PRC **79**(2009) 065202
- Doi, Liu *et al.* , PRD **80**(2009)094503

Nucleon elastic form factors – electromagnetic and neutral weak



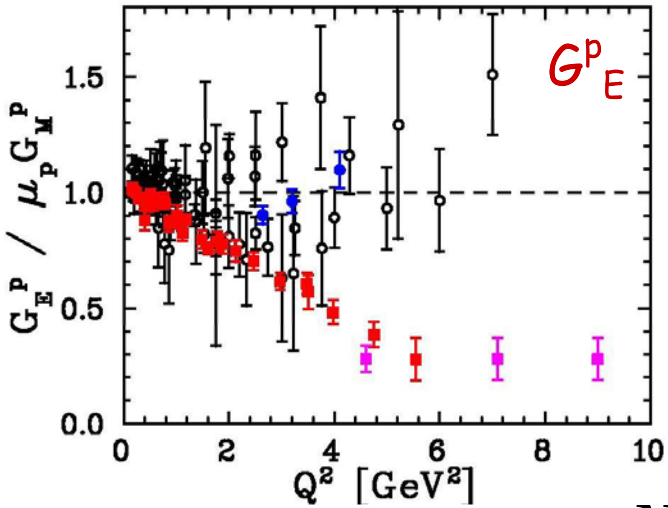
electromagnetic form factors



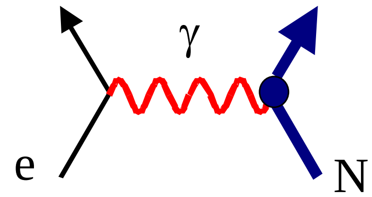


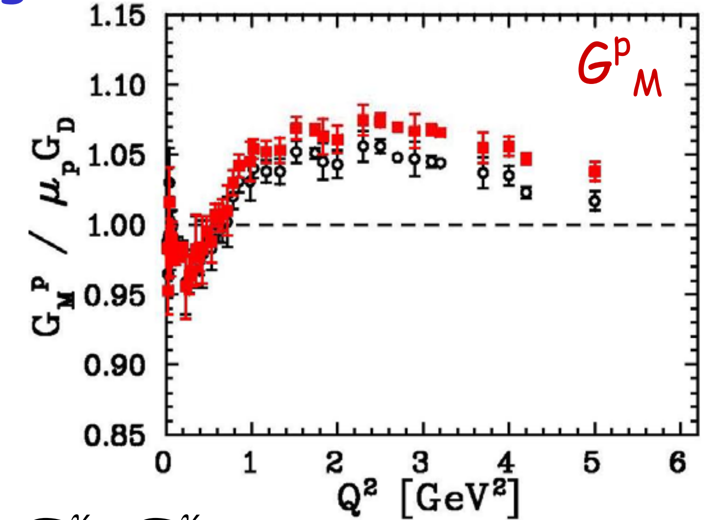
$$< N \,|\, J_\mu^\gamma \,|\, N > \quad \rightarrow \quad G_E^\gamma, G_M^\gamma$$

Nucleon elastic form factors – electromagnetic and neutral weak



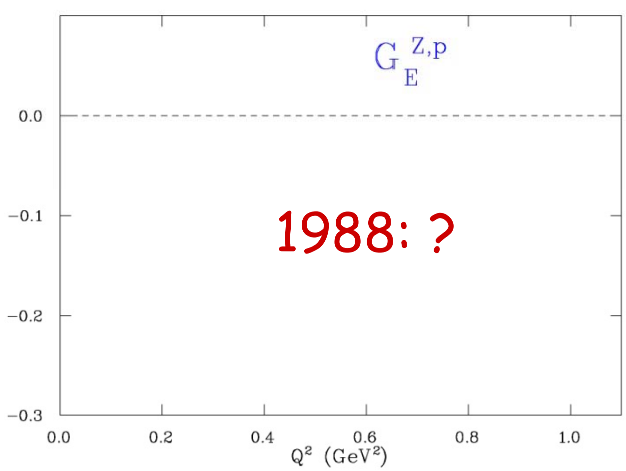
electromagnetic form factors

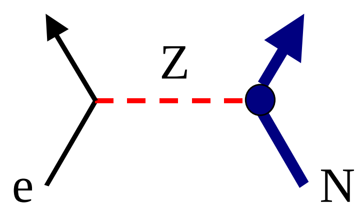


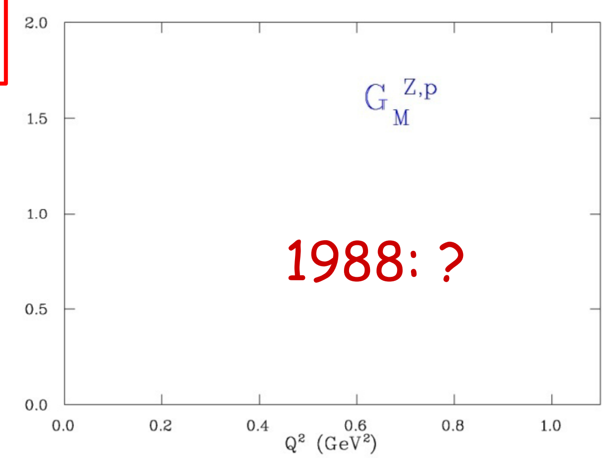


$$< N \,|\, J_\mu^\gamma \,|\, N > \quad \rightarrow \quad G_E^\gamma, G_M^\gamma$$

neutral weak form factors

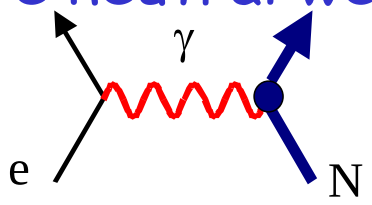




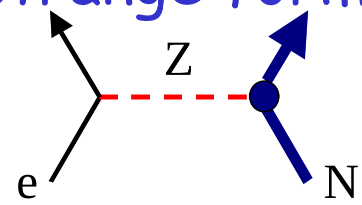


$$< N \,|\, J_\mu^Z \,|\, N > \quad \rightarrow \quad G_E^Z, G_M^Z$$

Measure neutral weak form factors → strange form factors



$< N | J_\mu^\gamma | N > \quad \rightarrow \quad G_E^\gamma, G_M^\gamma$



$< N | J_\mu^Z | N > \quad \rightarrow \quad G_E^Z, G_M^Z$

Use SM couplings:

	Q^γ	Q^Z
u	+2/3	$1 - 8/3 \sin^2\theta_W$
d	−1/3	$-1 + 4/3 \sin^2\theta_W$
s	−1/3	$-1 + 4/3 \sin^2\theta_W$

Electroweak currents:

$$J_\mu^\gamma = \sum_i Q_i^\gamma \, \bar{q}_i \gamma_\mu q_i \qquad J_\mu^Z = \sum_i Q_i^Z \, \bar{q}_i \gamma_\mu q_i$$

Flavor decomposition of nucleon E/M form factors:

$$< p | J_\mu^\gamma | p >: \quad G_{E,M}^{\gamma,p} = \frac{2}{3} G_{E,M}^{u,p} - \frac{1}{3} G_{E,M}^{d,p} - \frac{1}{3} G_{E,M}^{s,p}$$

$$< n | J_\mu^\gamma | n >: \quad G_{E,M}^{\gamma,n} = \frac{2}{3} G_{E,M}^{u,n} - \frac{1}{3} G_{E,M}^{d,n} - \frac{1}{3} G_{E,M}^{s,n}$$

$$< p | J_\mu^Z | p >: \quad G_{E,M}^{Z,p} = \left(1 - \frac{8}{3}\sin^2\theta_W\right) G_{E,M}^{u,p} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right) G_{E,M}^{d,p} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right) G_{E,M}^{s,p}$$

Invoke proton/neutron charge symmetry

(recent work; Kubis, Lewis PRC **74** (2006) 015204)

$$u \leftrightarrow d$$

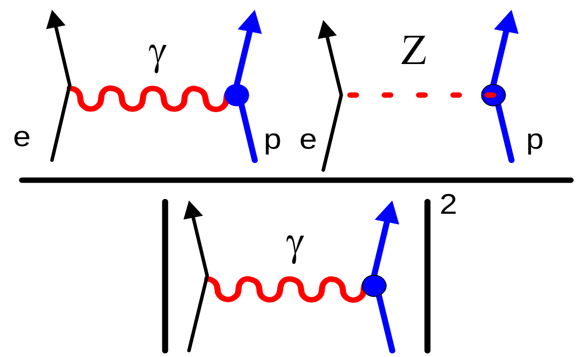
$$G_{E,M}^{u,p} = G_{E,M}^{d,n} \qquad G_{E,M}^{d,p} = G_{E,M}^{u,n} \qquad G_{E,M}^{s,p} = G_{E,M}^{s,n}$$

→ 3 equations, 3 unknowns

$$\left(G_{E,M}^{\gamma,p}, G_{E,M}^{\gamma,n}, G_{E,M}^{Z,p}\right) \Leftrightarrow \left(G_{E,M}^{u}, G_{E,M}^{d}, G_{E,M}^{s}\right)$$

Parity Violating Elastic e-N Scattering - Probe of Neutral Weak Form Factors

polarized electrons, unpolarized target



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

$$A_E = \varepsilon(\theta) G_E^Z(Q^2) G_E^\gamma(Q^2)$$
$$A_M = \tau(Q^2) G_M^Z(Q^2) G_M^\gamma(Q^2)$$
$$A_A = -(1 - 4\sin^2\theta_W)\varepsilon' G_A^e(Q^2) G_M^\gamma(Q^2)$$

$\rightarrow G_E^s$
$\rightarrow G_M^s$
$\rightarrow G_A^e$

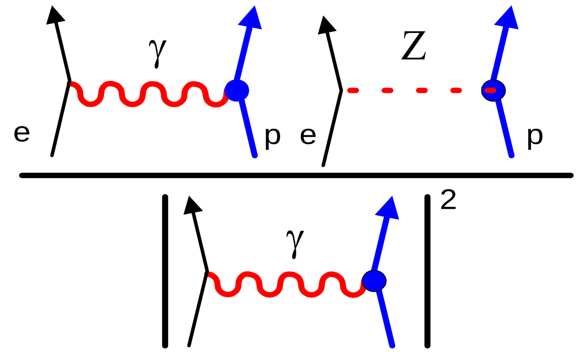
Strange electric and magnetic form factors,
+ axial form factor

At a given Q^2 decomposition of G^s_E, G^s_M, G^e_A requires 3 measurements:

Forward angle $\vec{e}$ + p (elastic)
Backward angle $\vec{e}$ + p (elastic)
Backward angle $\vec{e}$ + d (quasi-elastic)

Parity Violating Elastic e-N Scattering - Probe of Neutral Weak Form Factors

polarized electrons, unpolarized target



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$\rightarrow G_E^s$
$\rightarrow G_M^s$
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Strange electric and magnetic form factors,
+ axial form factor

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Parity Violating Elastic e-N Scattering - Probe of Neutral Weak Form Factors

polarized electrons, unpolarized target

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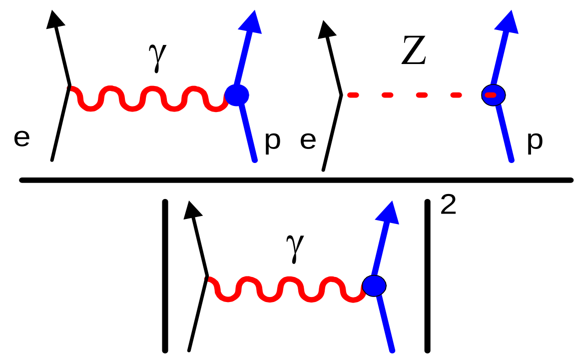

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$$\rightarrow G_E^s$$
$$\rightarrow G_M^s$$
$$\rightarrow G_A^e$$

Strange electric and magnetic form factors, + axial form factor

At a given Q² decomposition of G^s_E, G^s_M, G^e_A requires 3 measurements:

Forward angle $\vec{e}$ + p (elastic)
Backward angle $\vec{e}$ + p (elastic)
Backward angle $\vec{e}$ + d (quasi-elastic)

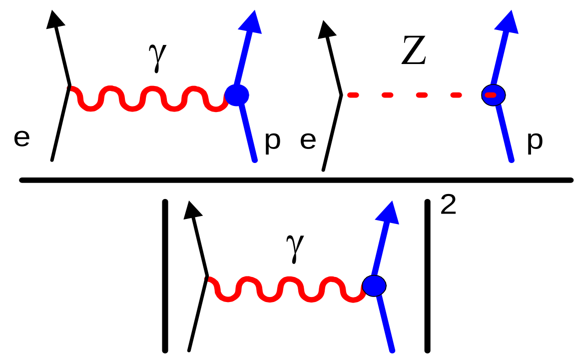
For ^{4}He (elastic): G_E^s alone

$$A_{PV} = \frac{G_F Q^2}{\pi\alpha\sqrt{2}}\left[\sin^2\theta_W + \frac{G_E^s}{2(G_E^p + G_E^n)}\right]$$

Parity Violating Elastic e-N Scattering - Probe of Neutral Weak Form Factors

polarized electrons, unpolarized target

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



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$\rightarrow G_E^s$
$\rightarrow G_M^s$
$\rightarrow G_A^e$

Strange electric and magnetic form factors, + axial form factor

At a given Q^2 decomposition of G^s_E, G^s_M, G^e_A requires 3 measurements:

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$$A_{PV} = \frac{G_F Q^2}{\pi\alpha\sqrt{2}}\left[\sin^2\theta_W + \frac{G_E^s}{2(G_E^p + G_E^n)}\right]$$

In full analysis need to include electroweak radiative corrections:
(see Blunden,Kao talks in session 5C)

$$G^Z_{E,M} = (1 - 4\sin^2\theta_W)(1 + R_V^p)G^p_{E,M} - (1_3 + R_V^n)G^n_{E,M} - G^s_{E,M}$$

$$G_A^e = -\tau_3(1 + R_A^{T=1})G_A + \sqrt{3}R_A^{T=0}G_A^8 + \Delta s$$

General Experimental Requirements

Want to measure A_{PV} ~ -2 to -40 ppm with precision $\delta A_{PV} / A_{PV}$ ~ 5%
AND separate G_E^s and G_M^s

Statistics (need 10^{13} - 10^{14} events):

- Reliable high polarization, high current polarized electron source
- Large acceptance detector
- High count rate capability detectors/electronics (either run in integrating mode or have highly segmented detector)

Systematics (need to reduce false asymmetries, accurately measure dilution factors):

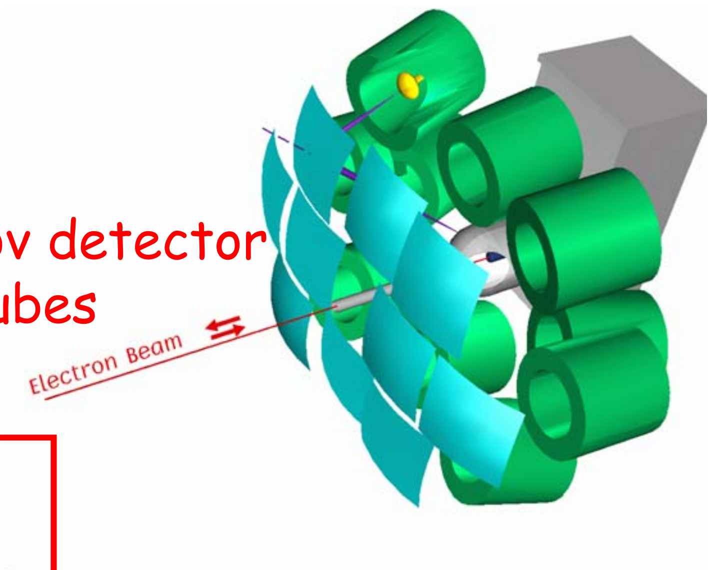
- Small helicity-correlated beam properties
- Capability to isolate elastic scattering from other processes

Parity-Violating Electron Scattering Program

Expt/Lab	Target/ Angle	Q^2 (GeV^2)	A_{phys} (ppm)	Sensitivity	Status
SAMPLE/Bates					
SAMPLE I	LH_2/145	0.1	-6	$\mu_s + 0.4G_A$	2000
SAMPLE II	LD_2/145	0.1	-8	$\mu_s + 2G_A$	2004
SAMPLE III	LD_2/145	0.04	-4	$\mu_s + 3G_A$	2004
HAPPEx/JLab					
HAPPEx	LH_2/12.5	0.47	-15	$G_E + 0.39G_M$	2001
HAPPEx II, III	LH_2/6	0.11	-1.6	$G_E + 0.1G_M$	2006, 2007
HAPPEx He	^4He/6	0.11	+6	G_E	2006, 2007
HAPPEx	LH_2/14	0.63	-24	$G_E + 0.5G_M$	(2009)
A4/Mainz					
	LH_2/35	0.23	-5	$G_E + 0.2G_M$	2004
	LH_2/35	0.11	-1.4	$G_E + 0.1G_M$	2005
	LH_2/145	0.23	-17	$G_E + \eta G_M + \eta' G_A$	2009
	LH_2/35	0.63	-28	$G_E + 0.64G_M$	(2009)
G0/JLab					
Forward	LH_2/35	0.1 to 1	-1 to -40	$G_E + \eta G_M$	2005
Backward	LH_2/LD_2/110	0.23, 0.63	-12 to -45	$G_E + \eta G_M + \eta' G_A$	2009

SAMPLE

- MIT-Bates Linear Accelerator Center
- $\theta \sim 130 - 170^{\circ}$
- Detected electrons in large solid angle Cerenkov detector
- Operated in "integrating" mode with 10 phototubes



Published results:

$$Q^2 = 0.10\,\text{GeV}^2 \quad A(\vec{e}p) = -5.61 \pm .67 \pm .88\ \text{ppm}$$

$$Q^2 = 0.10\,\text{GeV}^2 \quad A(\vec{e}d;QE) = -7.77 \pm .73 \pm .72\ \text{ppm}$$

$$Q^2 = 0.038\,\text{GeV}^2 \quad A(\vec{e}d;QE) = -3.51 \pm .57 \pm .58\ \text{ppm}$$

Refs: T. Ito, et al., PRL 92 (2004) 102003
D.T. Spayde, et al., PLB 583 (2004) 79

Combined D_2/H_2 at 200 MeV

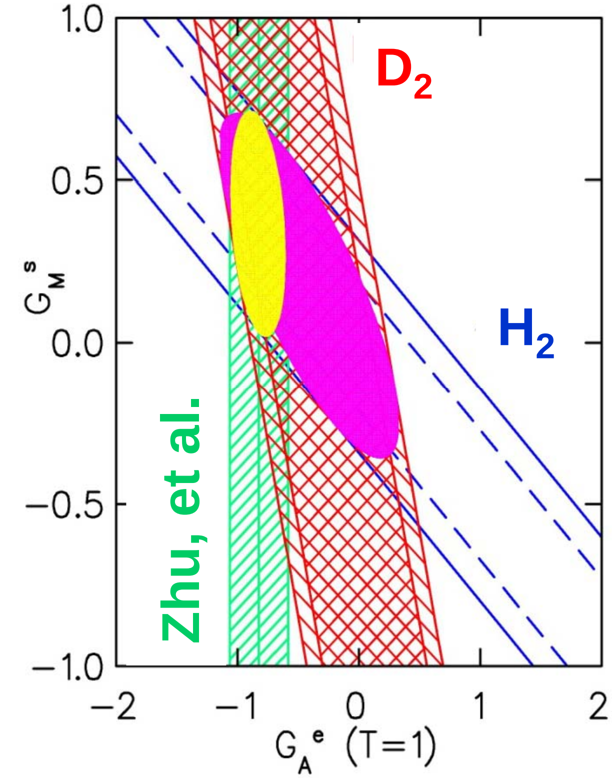
$$G_M^s = 0.23 \pm 0.36 \pm 0.40$$

$$G_A^e(T=1) = -0.53 \pm 0.57 \pm 0.50$$

Using Zhu et al. for $G_A^e(T=1)$

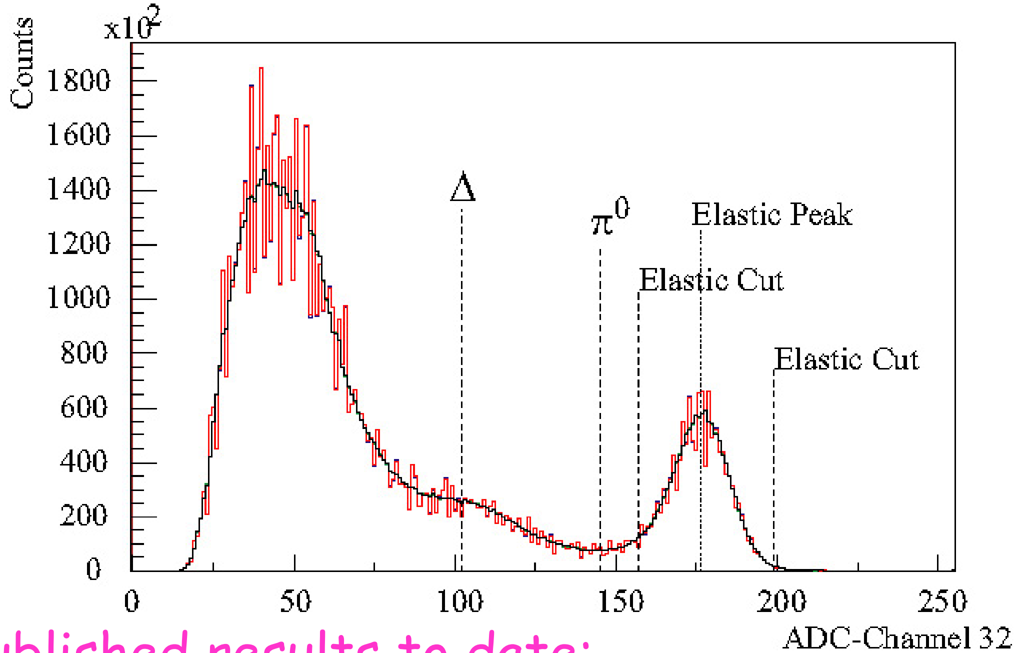
$$G_M^s = 0.37 \pm 0.20 \pm 0.26 \pm 0.07$$

$Q^2 = 0.1\,\text{GeV}^2$



Mainz PV-A4

- Mainz MAMI microtron
- θ = 35° , 145°; detects electrons
- Array of PbF_2 crystals for calorimetry
- Custom electronics for high rate histogramming



Published results to date:

$$35^o : Q^2 = 0.23\,\mathrm{GeV}^2 \quad A(\vec{e}p) = -5.44 \pm .54 \pm .26\ \mathrm{ppm} \quad G_E^s + 0.225\,G_M^s = 0.039 \pm 0.034$$

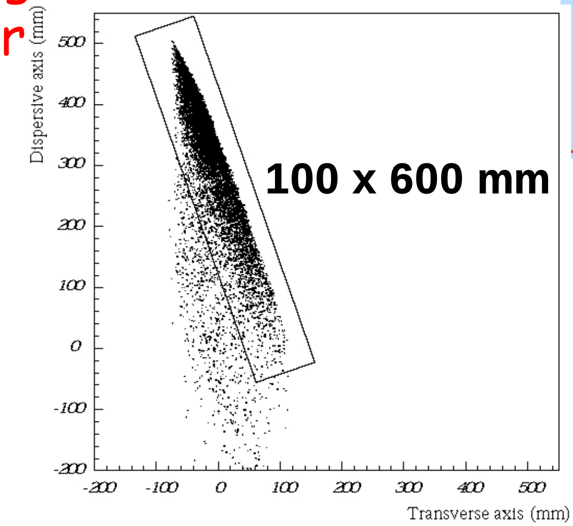
$$35^o : Q^2 = 0.11\,\mathrm{GeV}^2 \quad A(\vec{e}p) = -1.36 \pm .29 \pm .13\ \mathrm{ppm} \quad G_E^s + 0.106\,G_M^s = 0.071 \pm 0.036$$

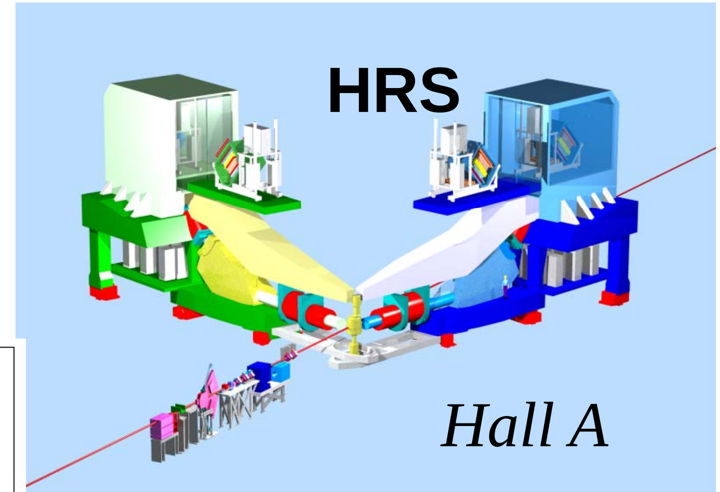
$$145^o : Q^2 = 0.22\,\mathrm{GeV}^2 \quad A(\vec{e}p) = -17.23 \pm .82 \pm .89\ \mathrm{ppm} \quad 0.26 G_E^s + G_M^s = -0.12 \pm 0.16$$

Refs: F. Maas, etal, PRL **93** (2004) 022002, F. Maas, et al. PRL **94** (2005) 152001
S. Baunack, etal, PRL **102** (2009) 151803

HAPPEx

- Hall A at Jefferson Lab
- θ = 6 and 12.5°
- Uses the pair of HRS spectrometers in Hall A
- Detects electrons in integration mode in focal plane calorimeter





Published results to date:

$$Q^2 = 0.48\,\mathrm{GeV}^2 \quad A(\vec{e}p) = -15.05 \pm .98 \pm .56\ \mathrm{ppm} \quad G_E^s + 0.392\,G_M^s = 0.014 \pm 0.020 \pm 0.010$$

$$Q^2 = 0.109\,\mathrm{GeV}^2 \quad A(\vec{e}p) = -1.58 \pm .12 \pm .04\ \mathrm{ppm} \quad G_E^s + 0.090\,G_M^s = 0.007 \pm 0.011 \pm .006$$

$$Q^2 = 0.077\,\mathrm{GeV}^2 \quad A(\vec{e}\,{}^4He) = 6.40 \pm .23 \pm .12\ \mathrm{ppm} \quad G_E^s = 0.002 \pm 0.014 \pm .007$$

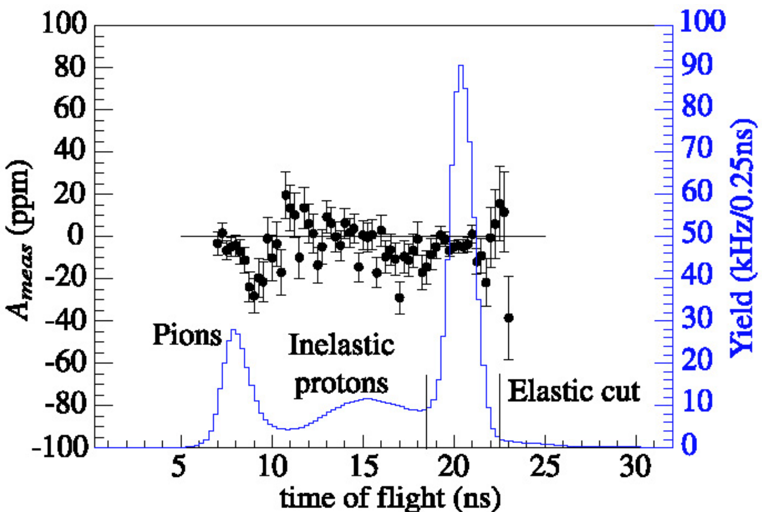
Refs: K.A. Aniol, *et al.*, Phys. Rev. C **69**, 065501 (2004)

K.A. Aniol, *et al.*, Phys. Rev. Lett **96**, 022003 (2006), PLB 635, 275 (2006)

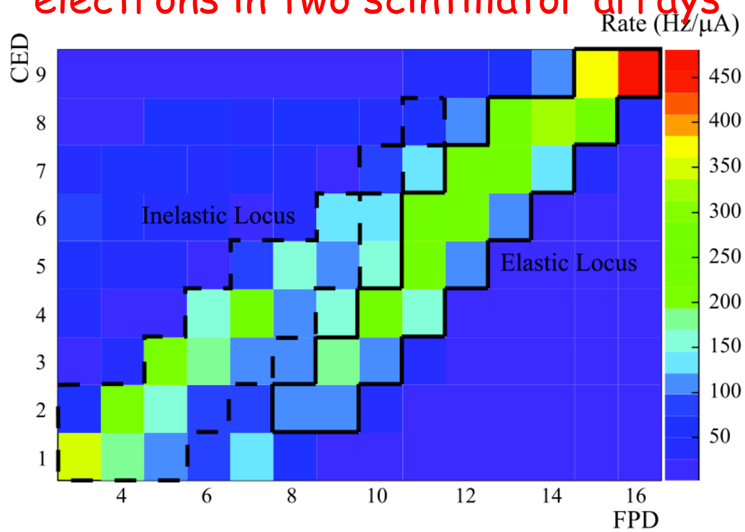
A. Acha, *et al.*, Phys. Rev. Lett **98**, 032301 (2007)

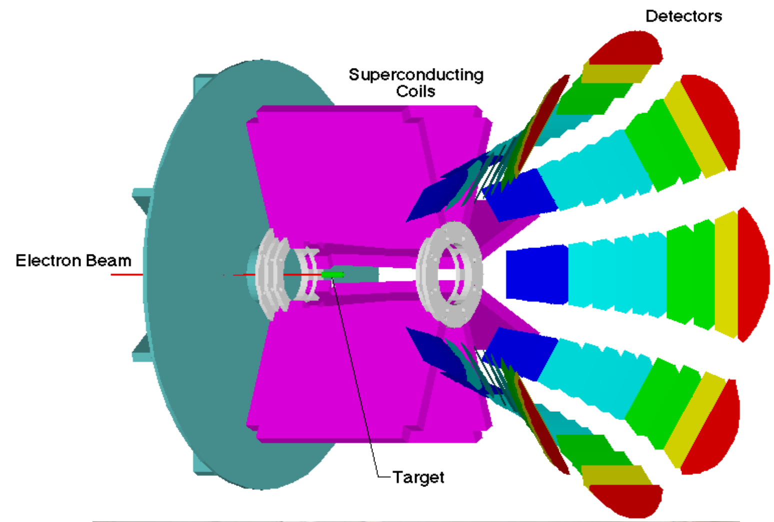
G^0

- Hall C at Jefferson Lab
- dedicated superconducting toroidal magnet
- θ_e = 5° - 15° (forward angle mode); detects recoil protons in scintillator array; time-of-flight



- θ_e ~ 108° (backward angle mode); detects electrons in two scintillator arrays





Published results to date:

- forward on proton at 0.12 < Q^2 < 1.0 GeV^2

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

- backward on proton and deuteron at Q^2 = 0.22 and 0.63 1.0 GeV^2

D. Androic, *et al.*, PRL **104**, 012001 (2010)

2006: Results of Strange Form Factor Measurements – Q^2 = 0.1 GeV^2

In 2006, five experiments had been completed at $Q^2 \sim 0.1$ GeV^2

→ separate extractions of G^s_E and G^s_M

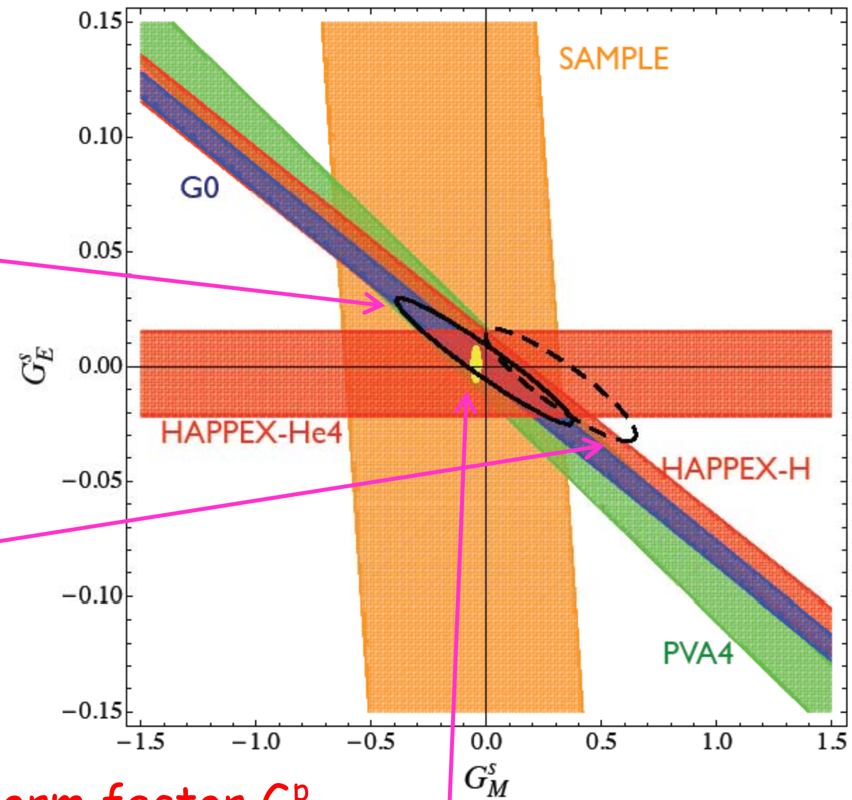
→ two global analyses done, with slightly slightly different results depending on assumptions made about the axial form factor G^e_A

R.D. Young, *et al.*, PRL 97, 10200 (2006):

$$G^s_E(Q^2 = 0.1\,\mathrm{GeV}^2) = 0.002 \pm 0.018$$
$$G^s_M(Q^2 = 0.1\,\mathrm{GeV}^2) = -0.01 \pm 0.25$$

J. Liu, *et al.*, PRC 76, 025202 (2007):

$$G^s_E(Q^2 = 0.1\,\mathrm{GeV}^2) = -0.008 \pm 0.016$$
$$G^s_M(Q^2 = 0.1\,\mathrm{GeV}^2) = +0.29 \pm 0.21$$



Both results imply that at Q^2 = 0.1 GeV^2:

G^s_E contributes < 1% to protons' electric form factor G^p_E

G^s_M contributes < 6% to proton's magnetic form factor G^p_M

QCD lattice predictions at Q^2 = 0.1 GeV^2:

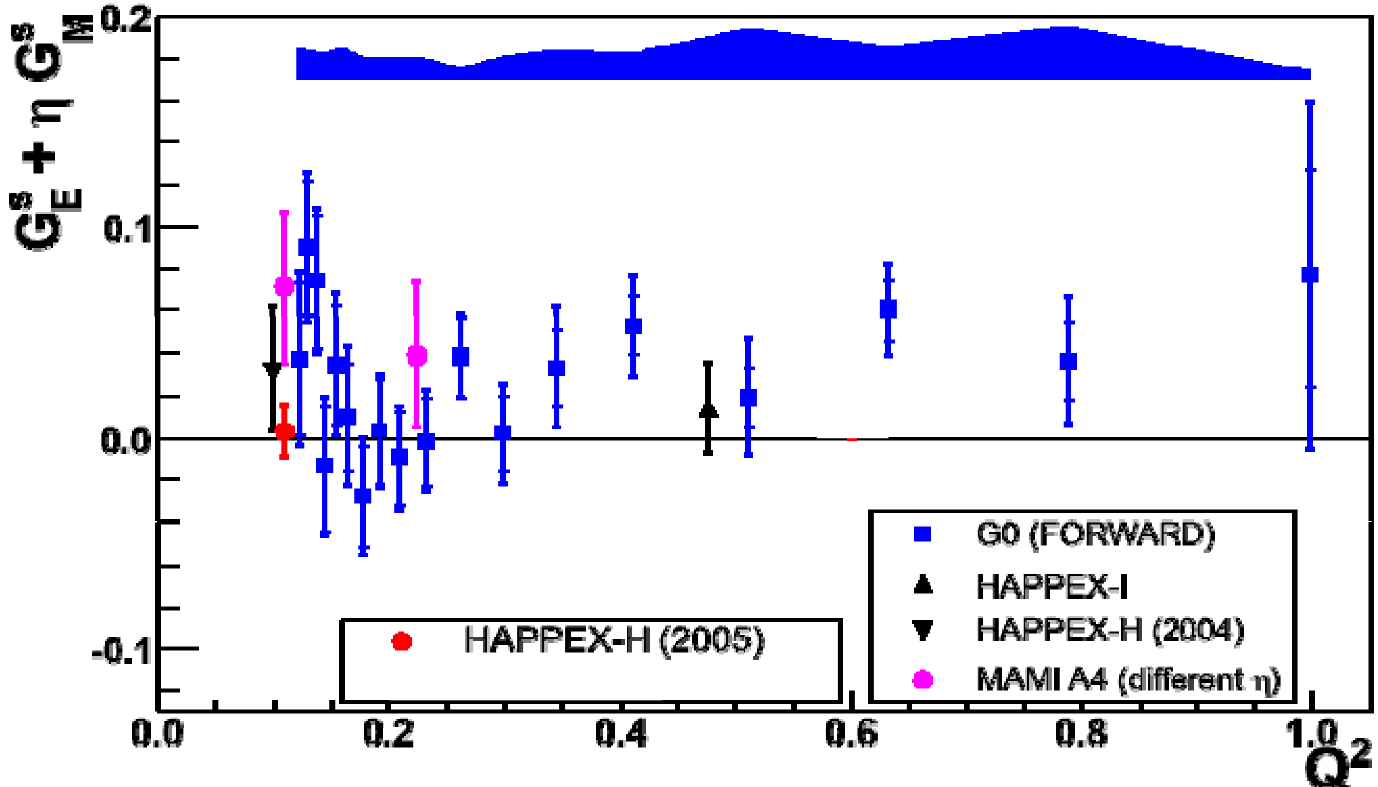
$G^s_M = -0.046 \pm 0.019$ D. Leinweber *et al.*, PRL **94**(2005) 212001

$G^s_E = 0.001 \pm 0.006$ D. Leinweber *et al.*, PRL **97**(2006) 022001

2006: Results of Strange Form Factor Measurements – higher Q^2

In 2006, at higher Q^2, only forward angle data existed

→ only linear combinations of G^s_E and G^s_M could be extracted



Note: Considering G^0 data alone the $G^s_E = G^s_M = 0$ hypothesis is ruled out at 89% CL

To obtain separated values of G^s_E and G^s_M at higher Q^2, backward angle data is needed

2009: Separated form factors at higher Q^2

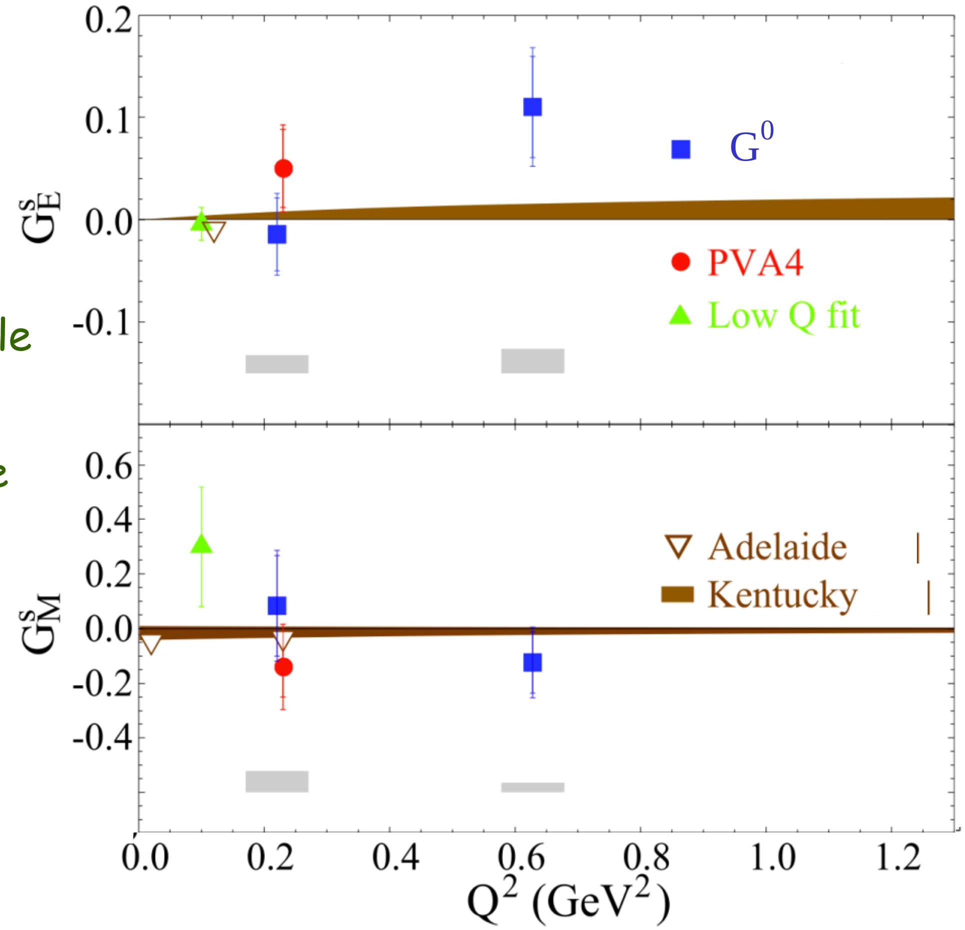
New backward angle data in 2009 allows for separated form factors at higher Q^2

- MAMI PVA4 backward angle data at $Q^2 = 0.22$ GeV^2
- G^0 backward angle data at $Q^2 = 0.22$ and 0.63 GeV^2

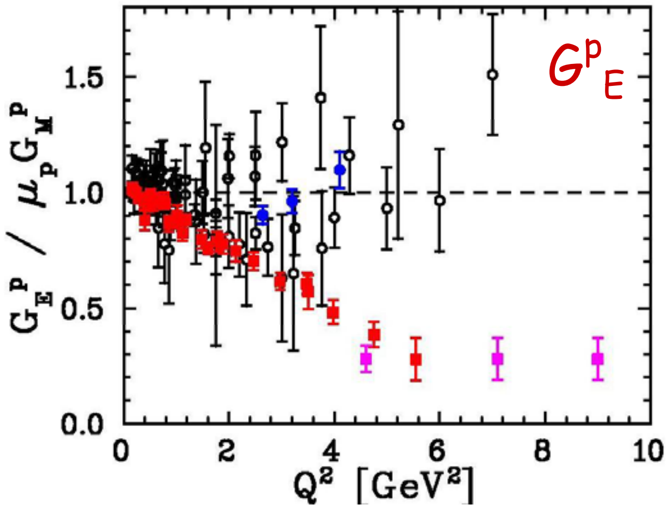
Conclusions:

- PVA4 and G data agree at the point of overlap $Q^2 = 0.22$ GeV^2
- Values are consistent with zero with possible exception of G^s_E at $Q^2 \sim 0.63$ GeV^2
- Experimental values are consistent with the lattice QCD predictions:

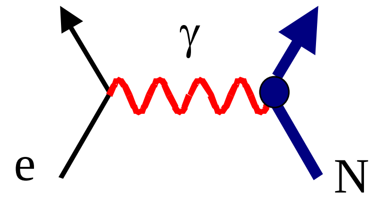
Adelaide: Leinweber *et al.*, PRL **94**(2005) 212001
Leinweber *et al.*, PRL **97**(2006) 022001
Wang *et al.*, PRC **79**(2009) 065202
Kentucky: Doi *et al.*, PRD **80** (2009) 094503

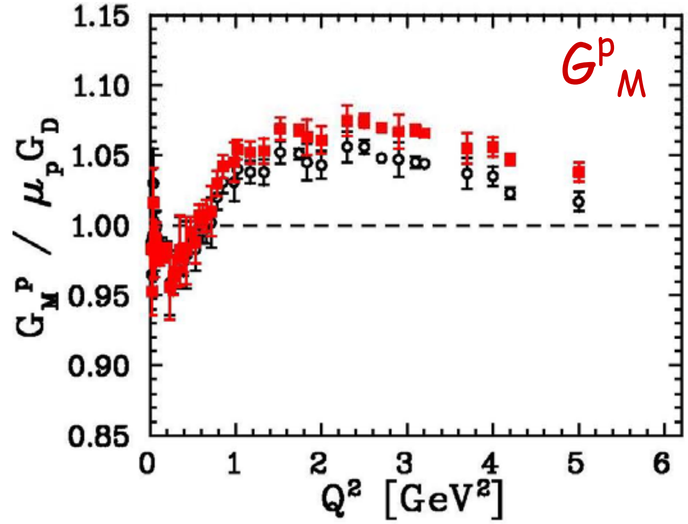


Neutral weak form factors -status in 2010



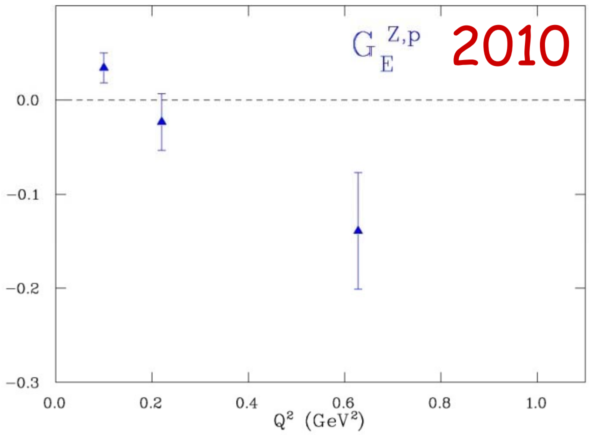
electromagnetic form factors

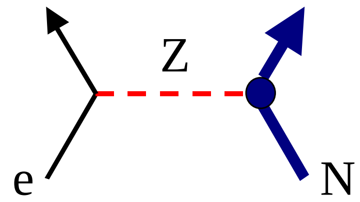


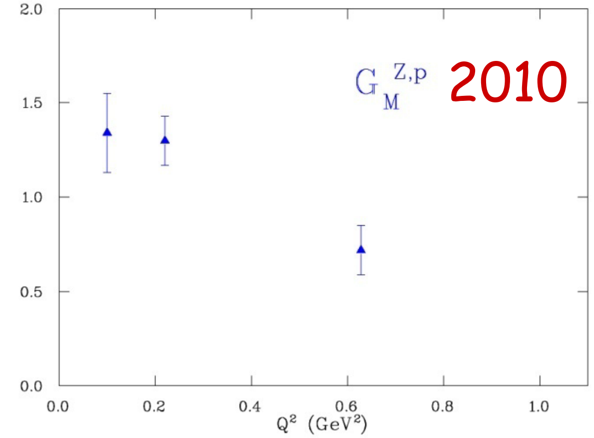


Neutral weak form factors -status in 2010

neutral weak form factors

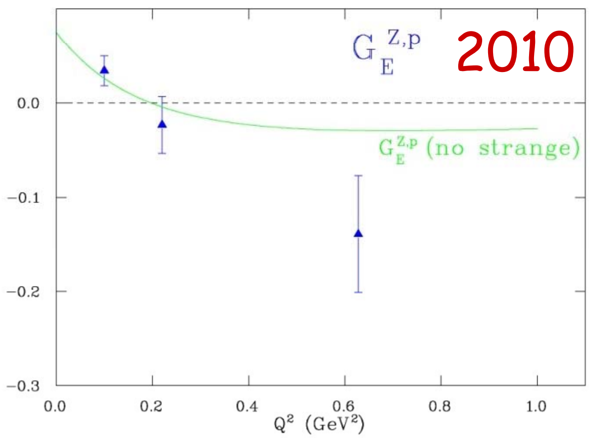


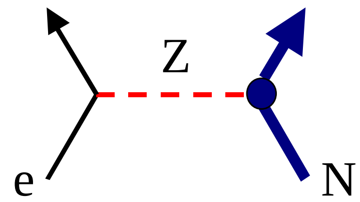


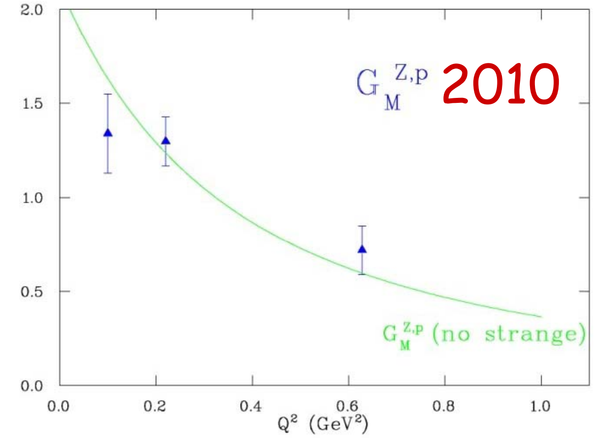


Neutral weak form factors -status in 2010

neutral weak
form factors

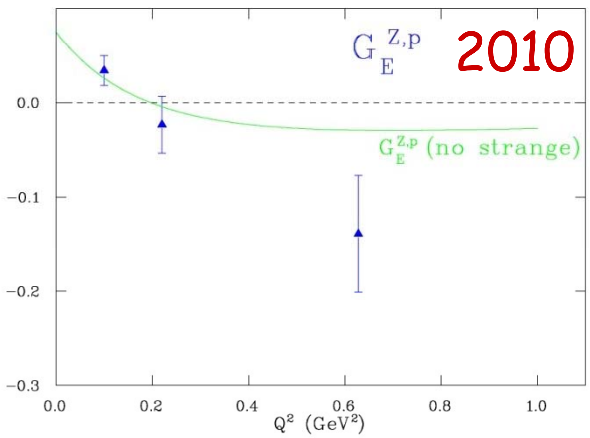


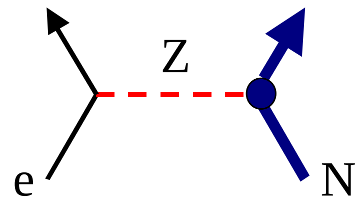


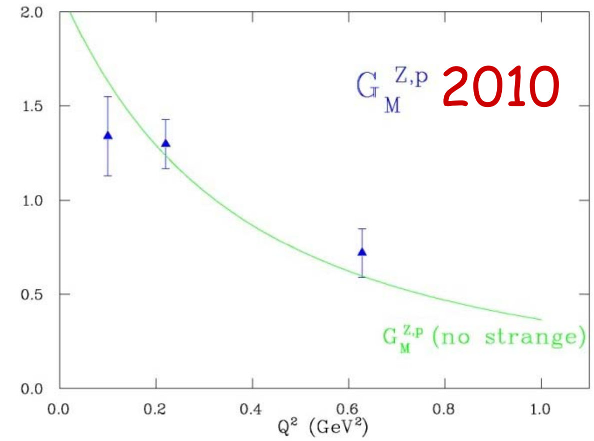


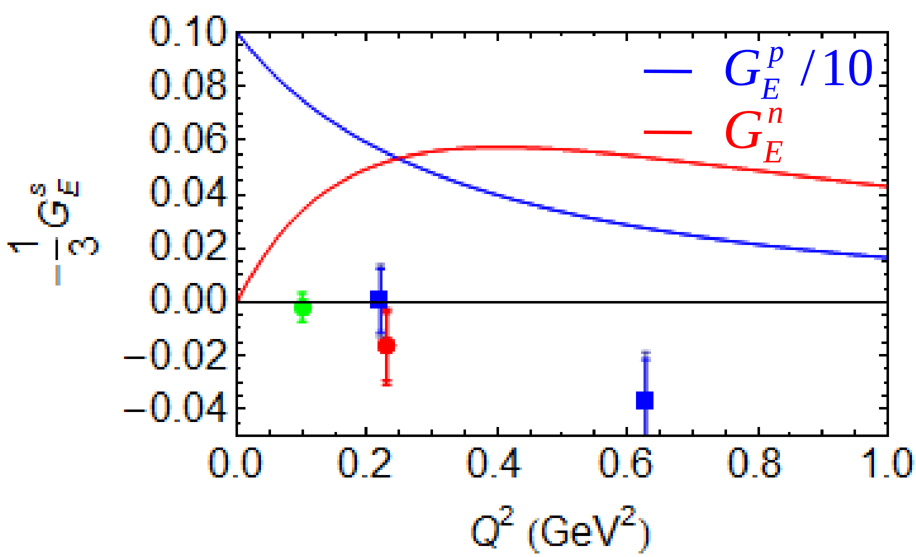
Neutral weak form factors -status in 2010

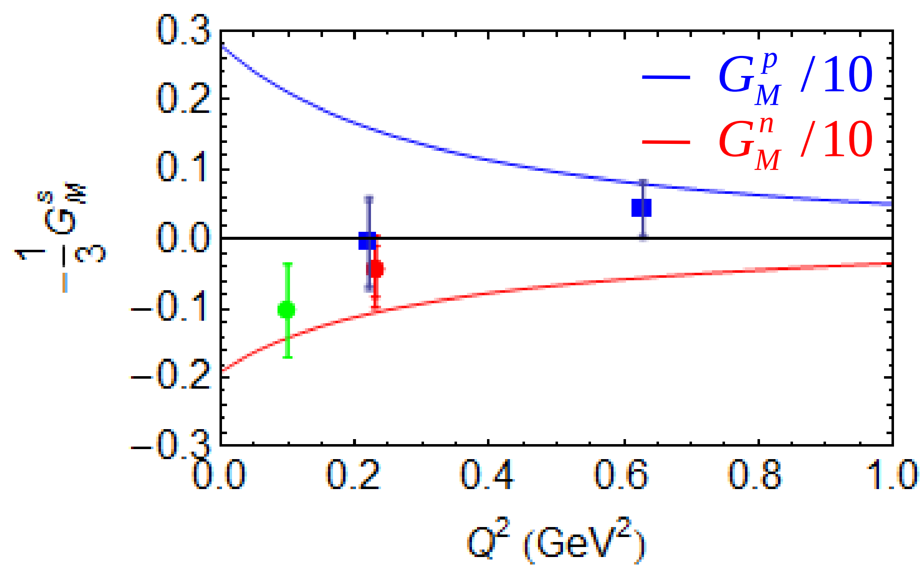
neutral weak form factors











$$G_{E,M}^{\gamma,p} = \frac{2}{3}G_{E,M}^{u,p} - \frac{1}{3}G_{E,M}^{d,p} - \frac{1}{3}G_{E,M}^{s,p} \qquad G_{E,M}^{\gamma,n} = \frac{2}{3}G_{E,M}^{u,n} - \frac{1}{3}G_{E,M}^{d,n} - \frac{1}{3}G_{E,M}^{s,n}$$

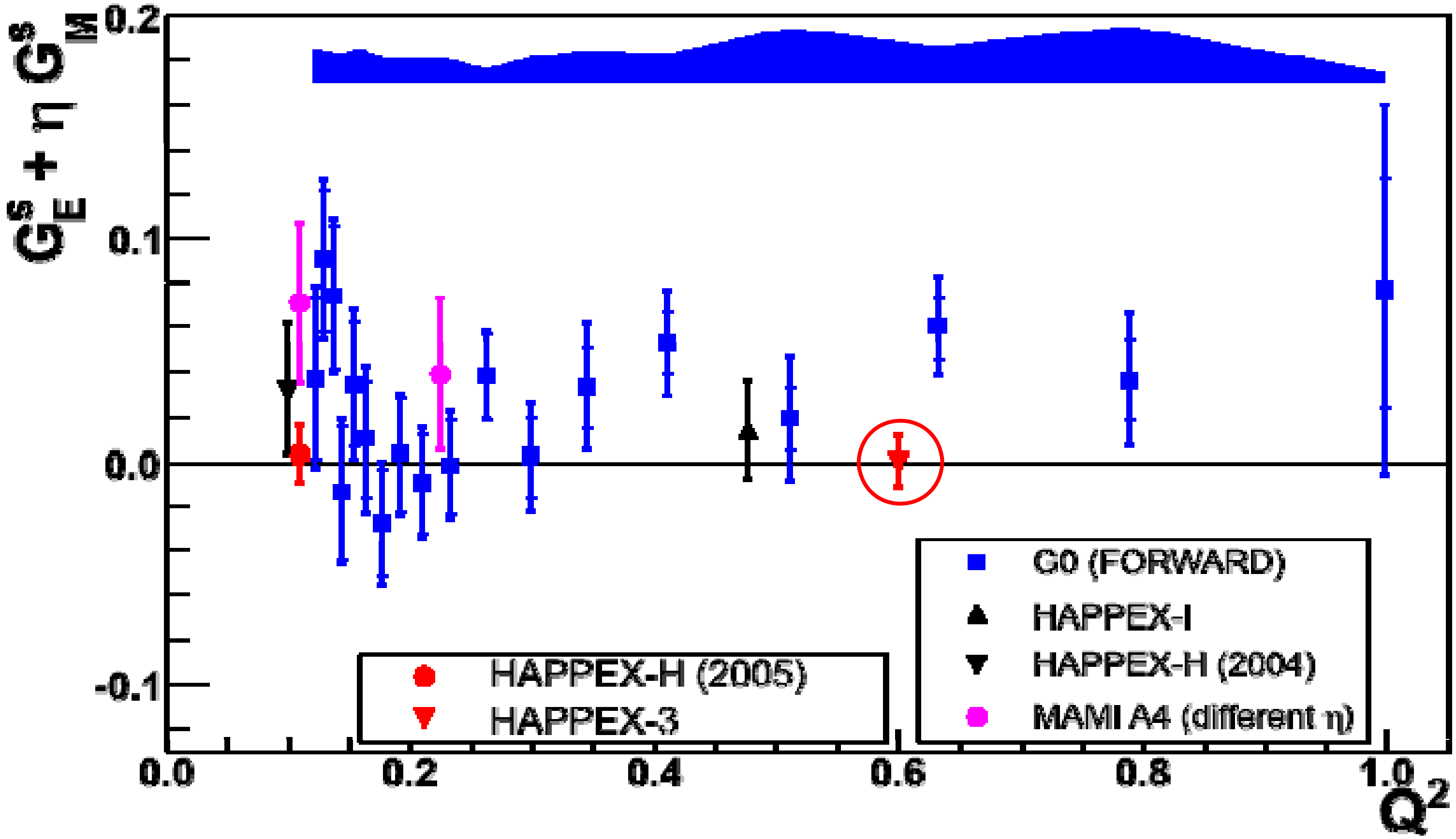
The strange quark contributions are generally < 10% of the charge and magnetic nucleon form factors at these Q^2 values.

Strange Form Factor Measurements – upcoming measurements

The suggestion of positive non-zero G^s_E at higher Q^2 is being explored by two forward angle measurements at $Q^2 \sim 0.63$ GeV^2 on the proton

HAPPEx III: data-taking complete in Fall 2009, analysis in progress
(see Kent Paschke talk in Session 6A)

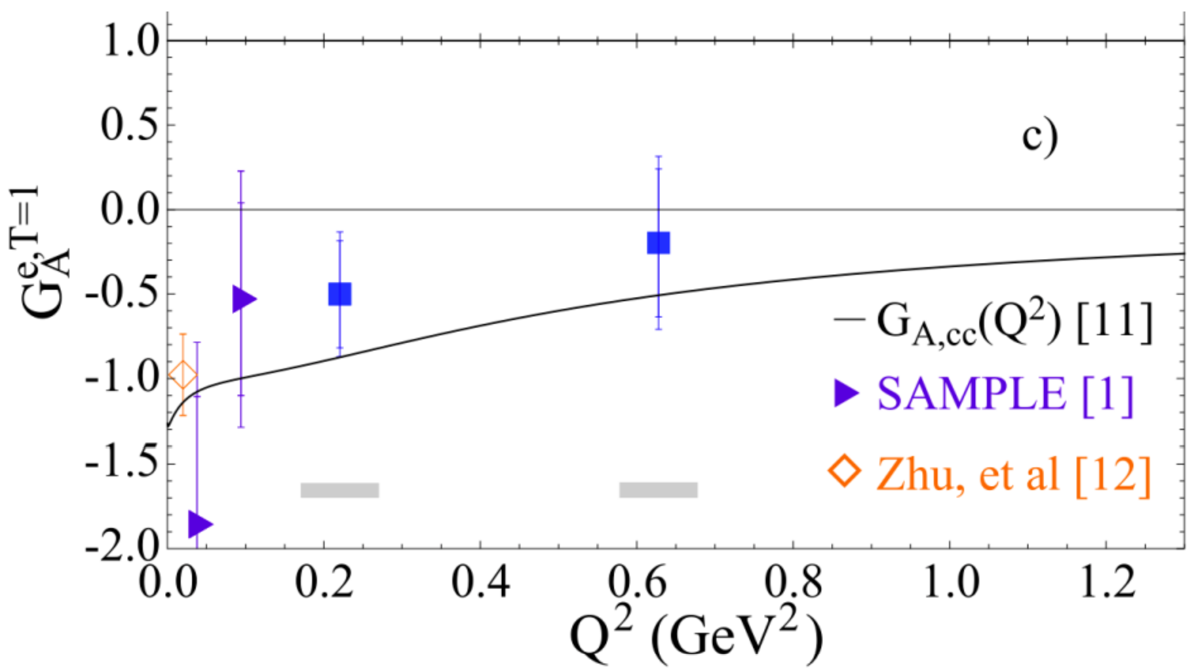
MAMI PVA4: data-taking in progress

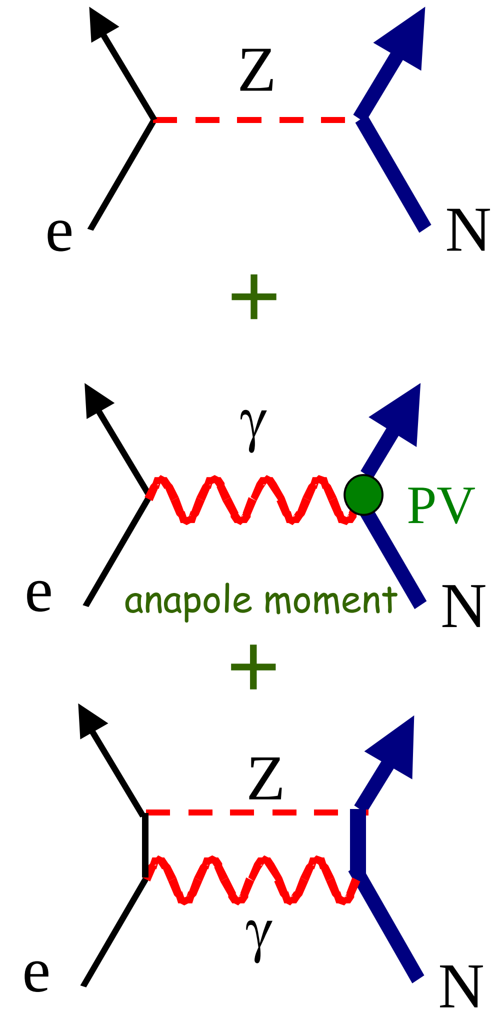


"Spin-off 1": Axial Form Factor Measurements

SAMPLE and G^0 took quasi-elastic data on deuterium at backward angles

$$G_A^{e,T=1} = (1 + R_A^{T=1}) G_A^Z$$





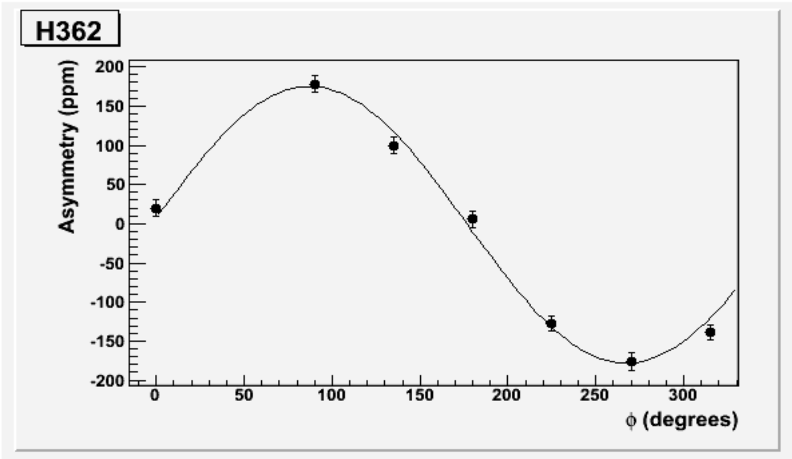
First information on Q^2 dependence of nucleon anapole moment effects

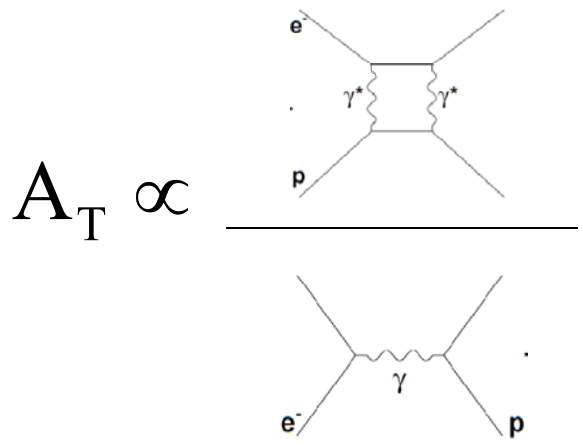
Data analysis in progress by MAMI PVA4 on QE deuterium at $Q^2 \sim 0.22$ GeV^2

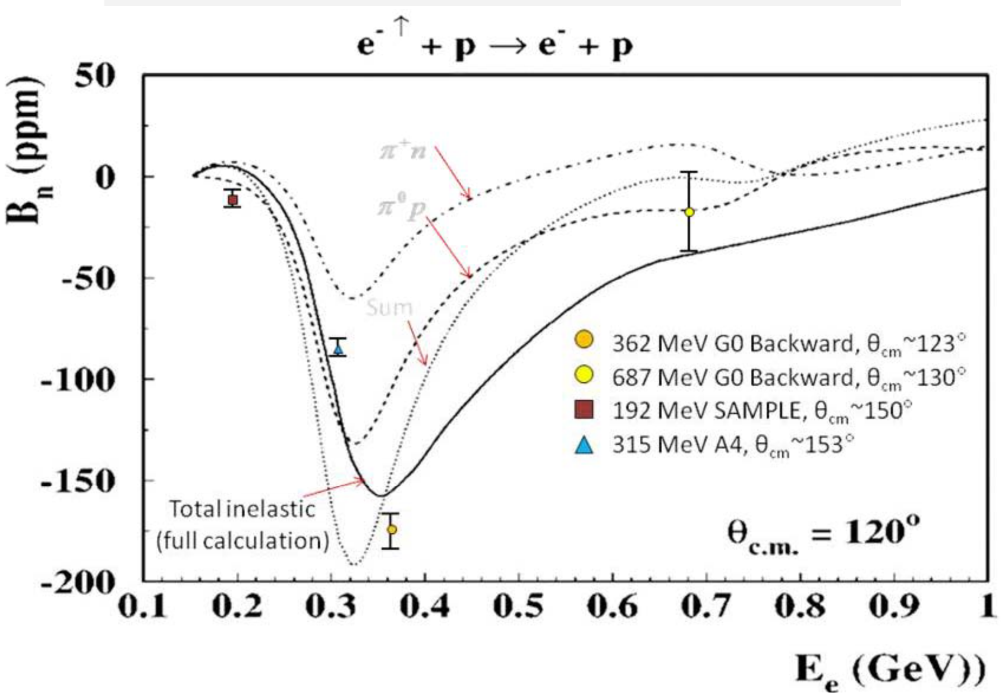
"Spin-off 2": 2-photon Exchange Effects from Transverse Asymmetries

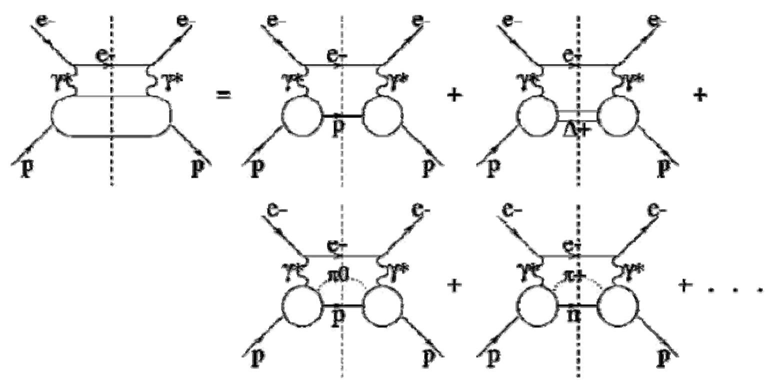
All four experimental programs have taken data at forward and backward angles on "transverse asymmetries" – parity conserving asymmetry with transversely polarized electrons scattering off unpolarized protons (and deuterons)

$\rightarrow$ sensitive to the imaginary part of the 2 photon exchange diagram







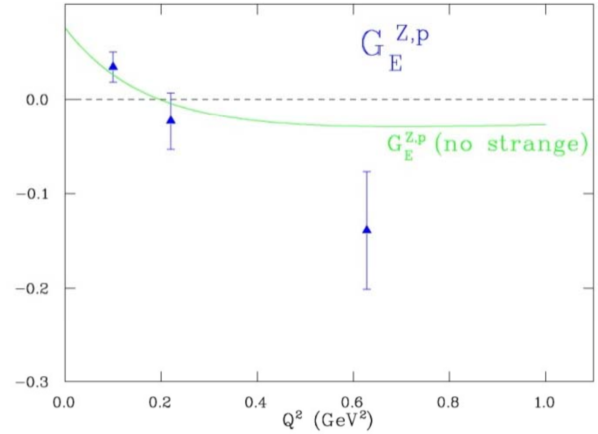


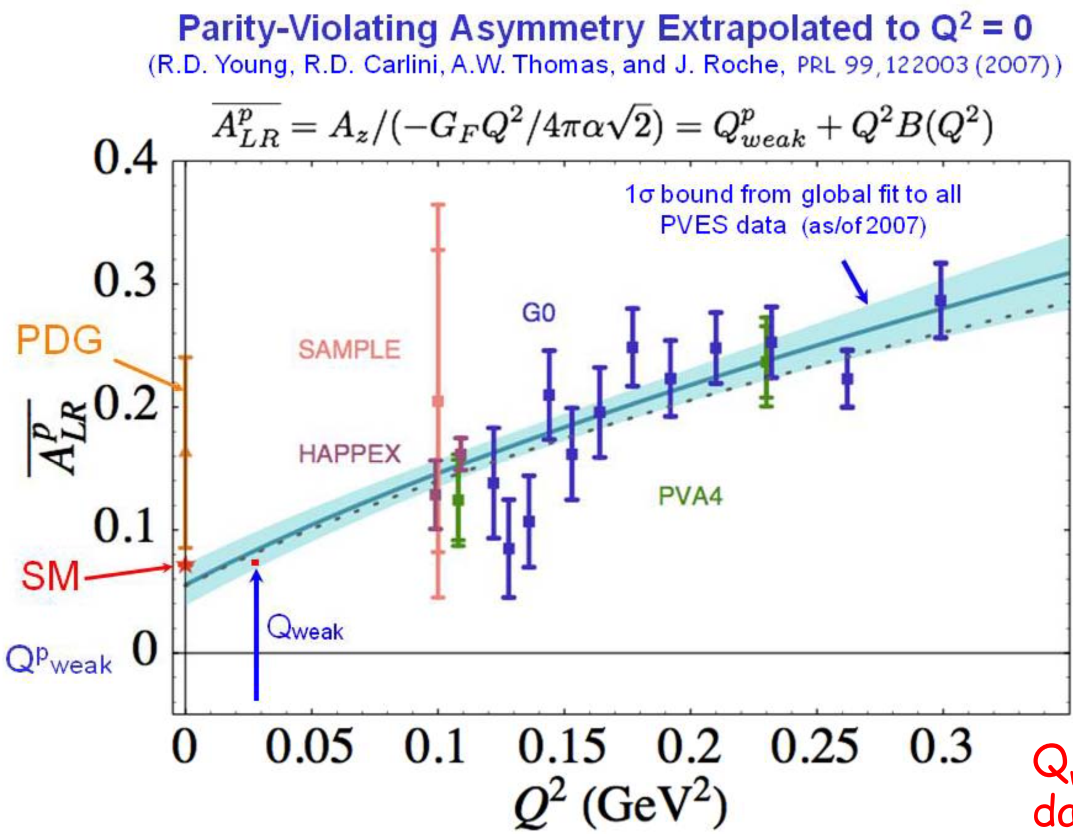
All results to date are consistent with the need to include π-N intermediate states in the calculations

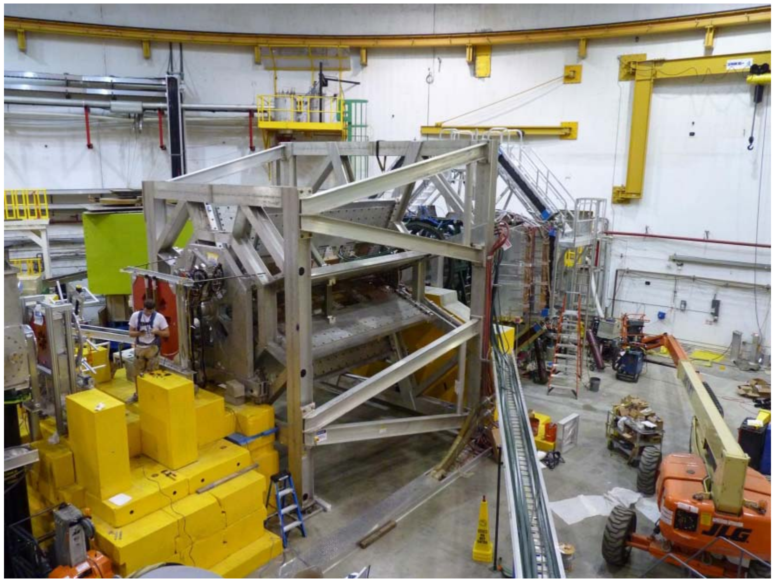
"Spin-off 3": Input to Standard Model Tests

$$Q^{p}_{weak} = G_E^{Z,p}(Q^2 = 0) = 1 - 4\sin^2\theta_W$$

The Q_{weak} experiment at Jefferson Lab will measure the PV asymmetry in e-p elastic scattering at $Q^2 = 0.03\ GeV^2$ as a test of the Standard Model.
Input from the strange form factor experiments will be used to constrain the hadronic structure contribution.







Q_{weak} is currently being installed in Hall C; data-taking to begin in June 2010

Summary

- Separated values of the vector strange form factors - G^s_E and G^s_M - have been determined at three Q^2 values – 0.1, 0.22, 0.63 GeV^2
- Results are consistent with zero except for G^s_E at high Q^2 – further results will be forthcoming there from HAPPEX-III and MAMI PVA4
- Generally, the strange quark contributions to the charge and magnetic form factors of the nucleon have been shown to be < 10% over this Q^2 range

Related talks this week:

- Session 5C: Peter Blunden "γ-Z exhange corrections in parity-violating electron scattering
- Session 5C: Chung Wen Kao "Two-boson exchange corrections in PVES"
- Session 5E: Wouter Deconinck "The Qweak experiment: a precision search for new physics at the TeV scale"
- Session 5 E: Dustin McNulty "Ultra-precise measurement of the weak mixing angle with an 11 GeV electron beam at Jefferson Lab"
- Session 6A: Takumi Doi "Nucleon Strangeness Form Factors and PDFs"
- Session 6A: Kent Paschke "Strangeness HAPPEX-III"
- Session 6A: Ramesh Subedi "Parity-violating DIS"
- Session 6A: Xiaoyan Deng: "Electron-deuteron PVDIS at Jefferson Lab 6 GeV"
- Session 6A: Diancheng Wang: "eD PVDIS at Jefferson Lab with 6 GeV"

Thanks to: John Arrington, Betsy Beise, Kent Paschke, Ross Young for slide materials