Strangeness in the Proportion:
Nucleon Structure probed using Parity Violation

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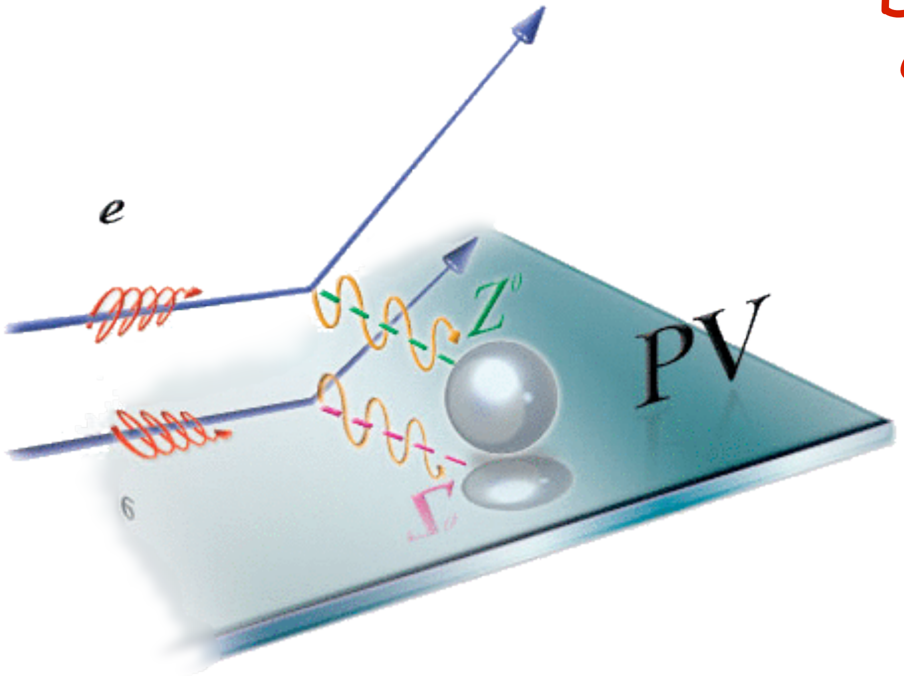
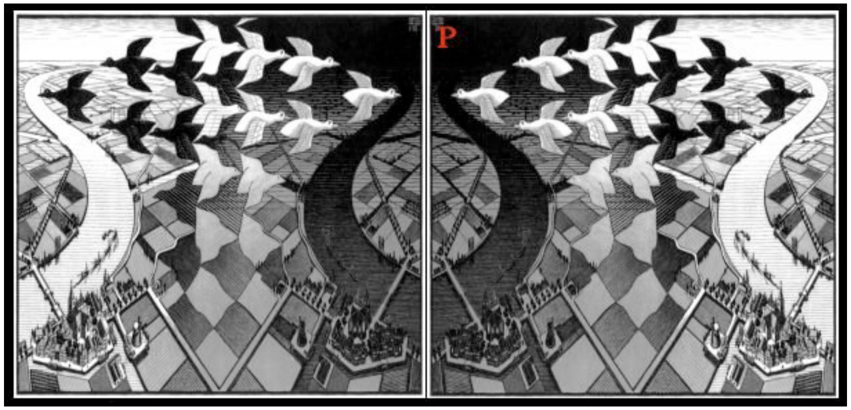
College of William & Mary
G0 and HAPPEx Collaborations





CNS Nuclear Physics Seminar
George Washington U.
October 19 2010

The College of WILLIAM & MARY

Jefferson Lab

Outline

- Parity violation in electron scattering
- Vector Strange Form Factors: $\boxed{G_E^s \text{ and } G_M^s}$
- World Experimental Effort

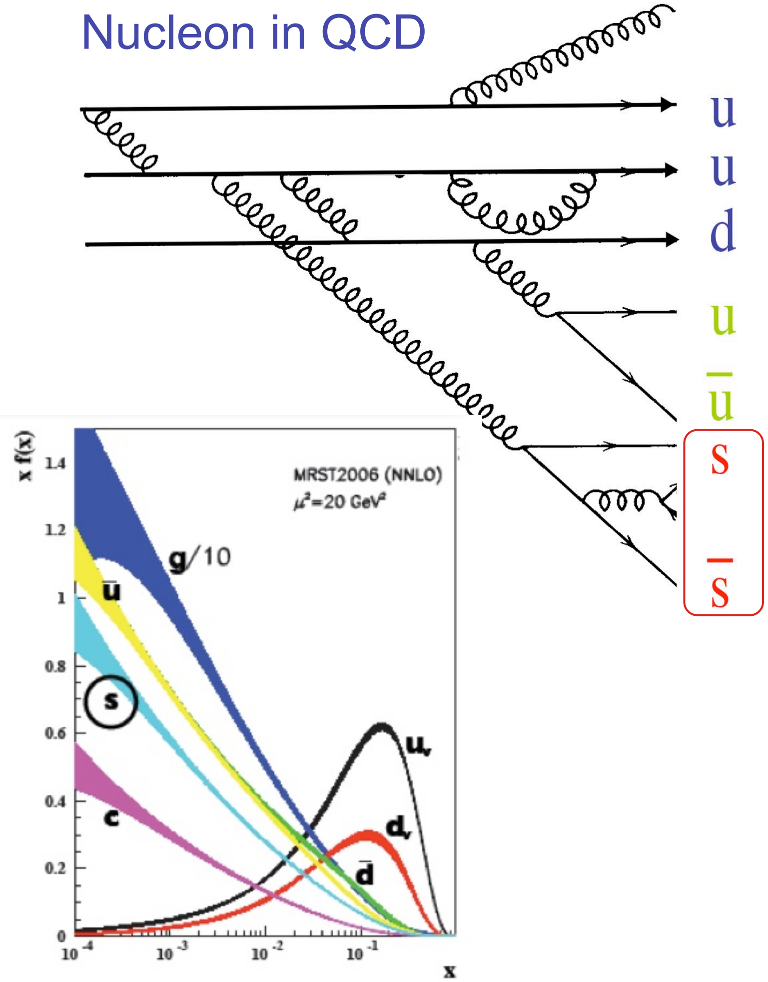
- Recent Results from PV-A4, G0 at backward angles:
  - Separated form factors at $Q^2 = 0.23, 0.63$ (GeV/c)^2

- Implications for Standard Model Tests
- Conclusions

" There is no excellent beauty that hath not some
strangeness in the proportion "
Francis Bacon 1561-1626

Strangeness in the nucleon

Nucleon in QCD



- $P = uud + \underbrace{u\bar{u} + d\bar{d} + s\bar{s} + g \; + ...}_{\text{« sea »}}$

- s quark: clean candidate to study the sea

- How much do virtual $s\bar{s}$ pairs contribute to the structure of the nucleon ?

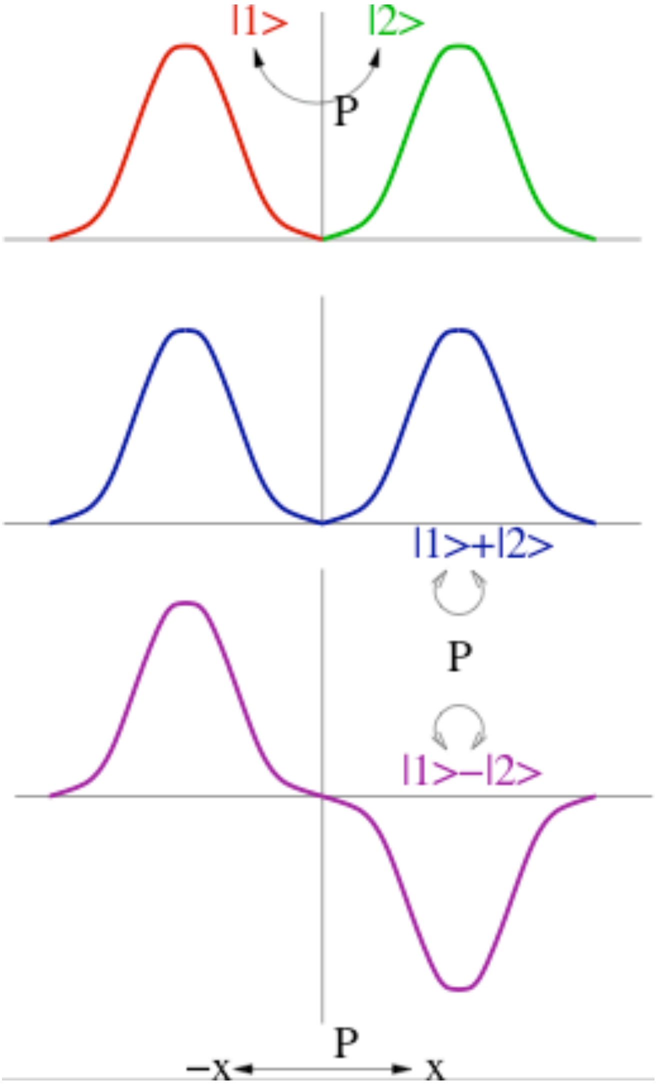
  Momentum : 4% (DIS)
  Spin : 0 to -10% (polarized DIS)
  Mass : 0 to 30% (πN-sigma term)
  (the latter two are far from settled)

also: OZI violations in $p\bar{p} \rightarrow \dfrac{\phi\gamma}{\omega\gamma}$

Goal: Determine the contributions of the strange quark sea ($s\bar{s}$) to the charge and magnetization distributions in the nucleon :

Vector “strange form factors”: G^s_E and G^s_M

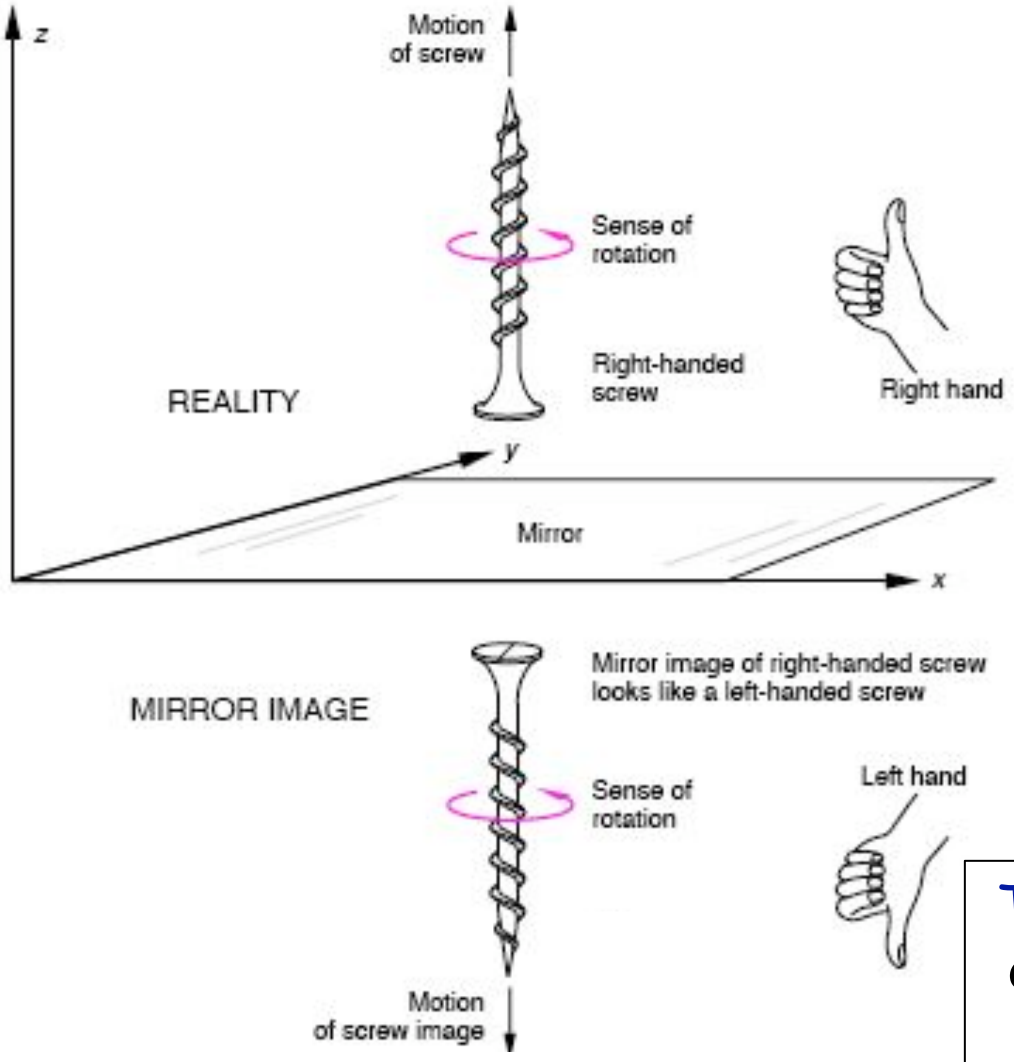
Parity



$$P : \begin{pmatrix} x \\ y \\ z \end{pmatrix} \mapsto \begin{pmatrix} -x \\ -y \\ -z \end{pmatrix}$$

Parity operation inverts sign of all spatial coordinates

Parity and the Mirror World



Since: $\mathbf{L} = \mathbf{r} \times \mathbf{p}$

r, **p** change sign under parity
(vectors)

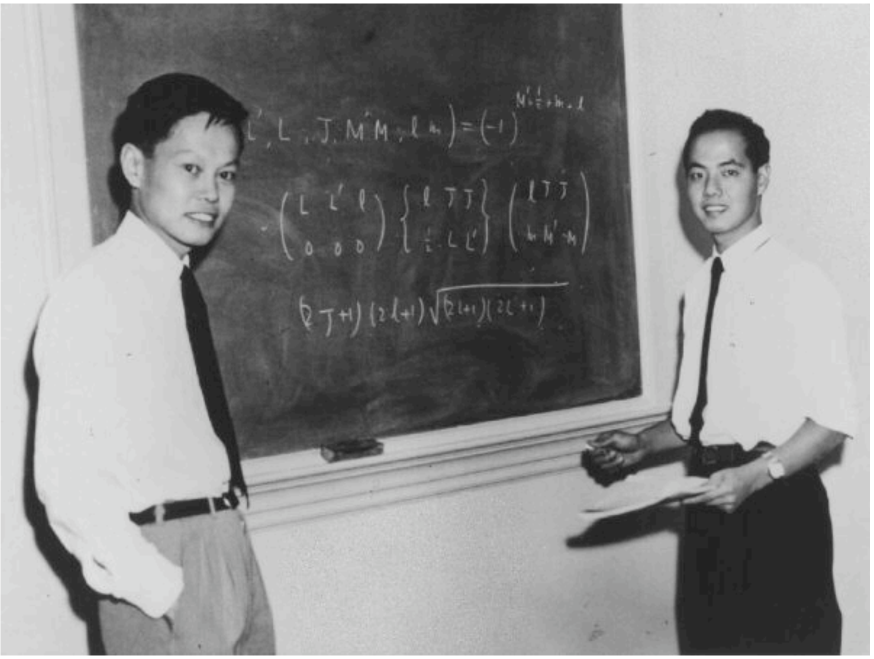
L does not
(axial vector)

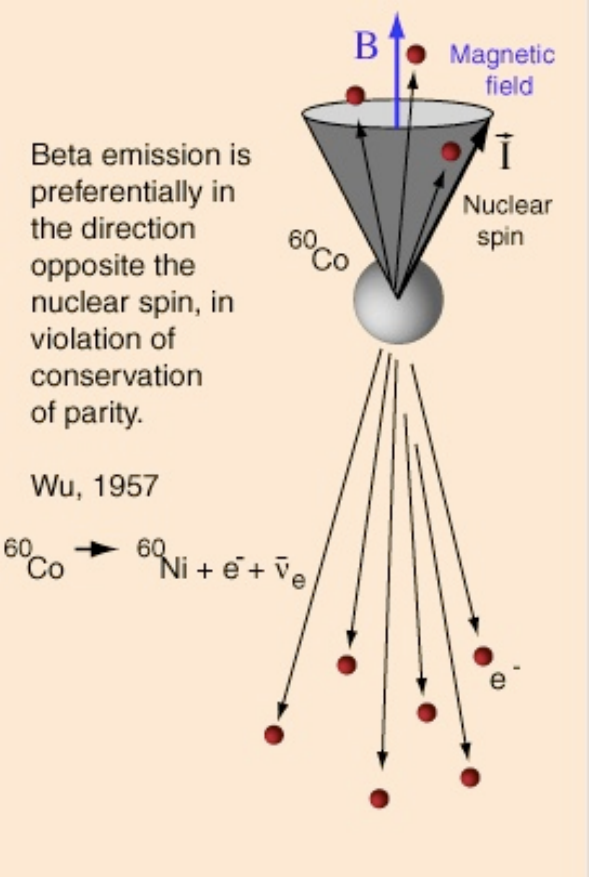
(x ➔ -x and y ➔ -y is same as a 180° rotation around z axis)

Thus: *if* parity symmetry is obeyed, reaction rate can't depend on $\sigma \bullet \mathbf{p}$
Right and left handed electrons should scatter the same

Parity Violation in the Weak Interaction

T.D. Lee and C.N. Yang suggested parity violation in the weak interaction (1956)





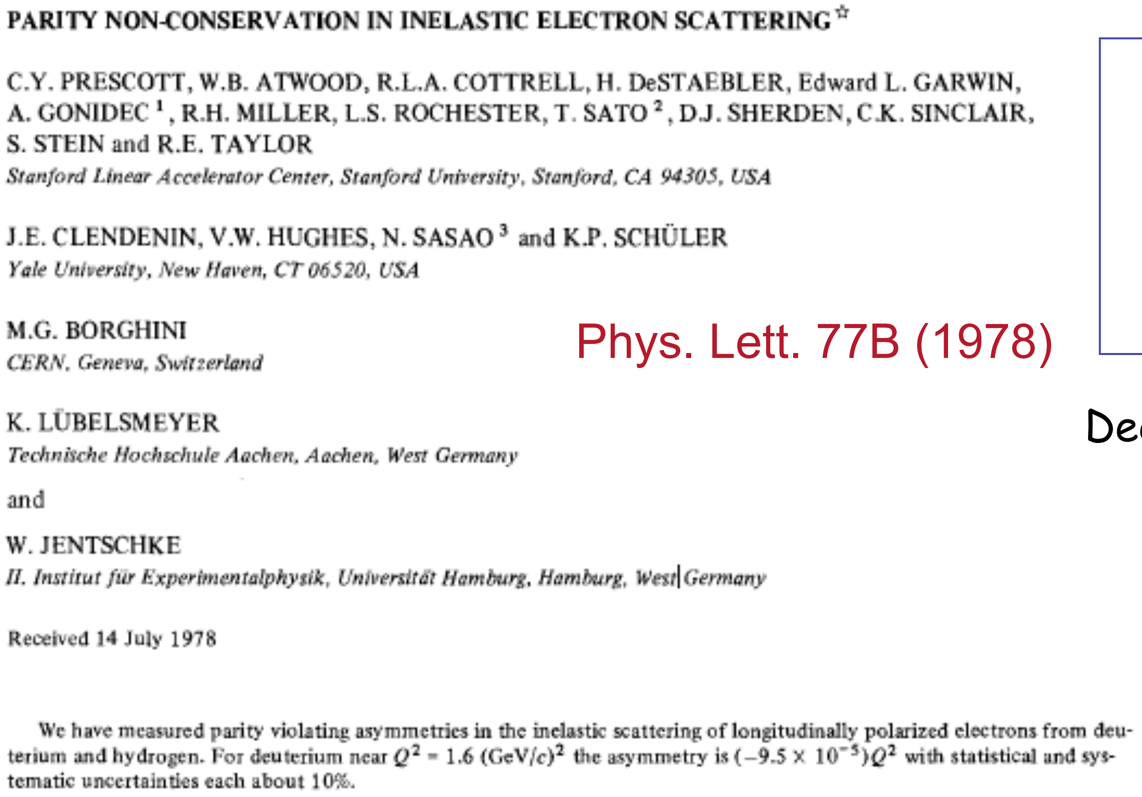
Beta emission is preferentially in the direction opposite the nuclear spin, in violation of conservation of parity.

Wu, 1957

$^{60}\mathrm{Co} \rightarrow {}^{60}\mathrm{Ni} + e^- + \bar{\nu}_e$

C.S. Wu and collaborators observed effect in nuclear beta decay later that year

Hmmm....



PARITY NON-CONSERVATION IN INELASTIC ELECTRON SCATTERING ☆

C.Y. PRESCOTT, W.B. ATWOOD, R.L.A. COTTRELL, H. DeSTAEBLER, Edward L. GARWIN,
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Received 14 July 1978

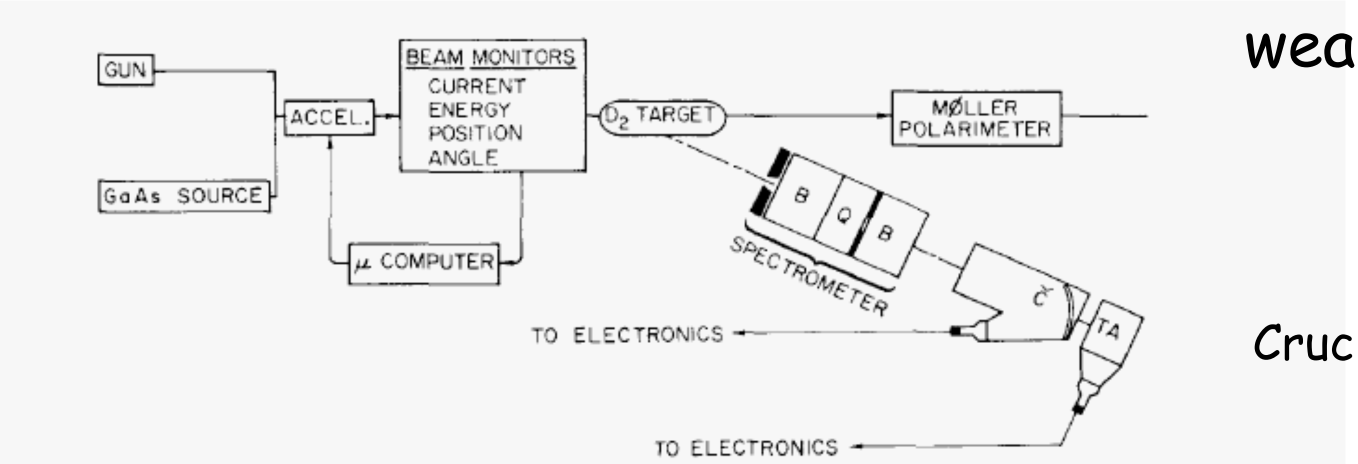
We have measured parity violating asymmetries in the inelastic scattering of longitudinally polarized electrons from deuterium and hydrogen. For deuterium near $Q^2 = 1.6$ (GeV/c)^2 the asymmetry is $(-9.5 \times 10^{-5})Q^2$ with statistical and systematic uncertainties each about 10%.

Phys. Lett. 77B (1978)

Pioneering Experiment

SLAC E122

Deep-inelastic electron scattering from isoscalar target

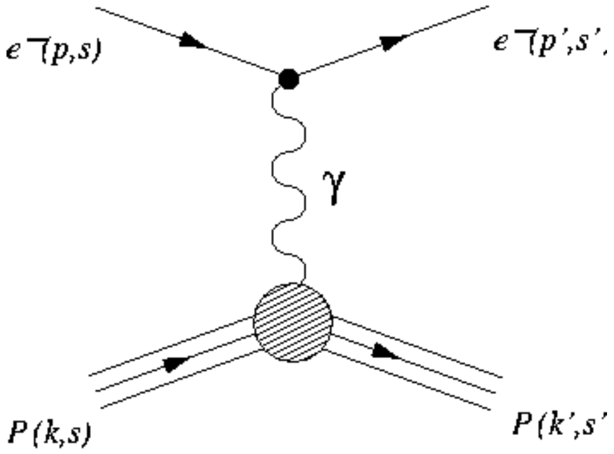


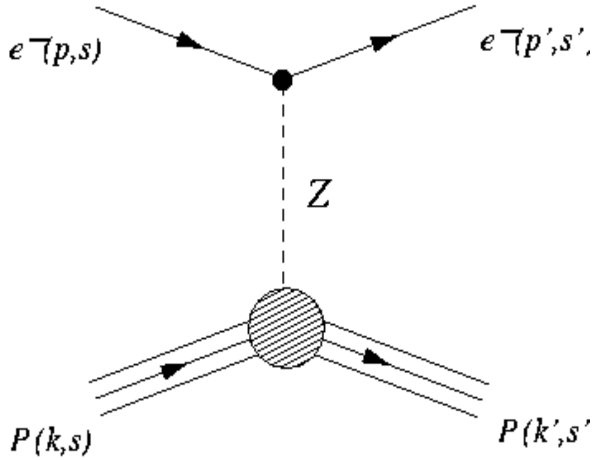
Observation of parity-violation in electron scattering: weak neutral current (Z^0) in weak interaction

Crucial test of electroweak Standard Model

Textbook Physics: *High Energy Physics* (D.H. Perkins)

Parity-Violating Electron Scattering
⇨ Weak NC Amplitudes





scatter electrons of opposite helicities from unpolarized target

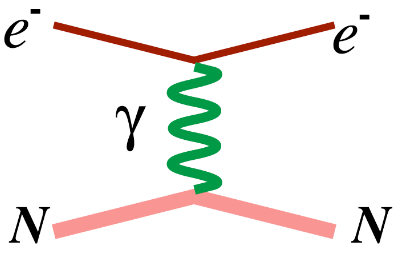
Interference: $\sigma \sim |M^{EM}|^2 + |M^{NC}|^2 + 2Re(M^{EM*})M^{NC}$

Interference with EM amplitude makes Neutral Current (NC) amplitude accessible ⇨

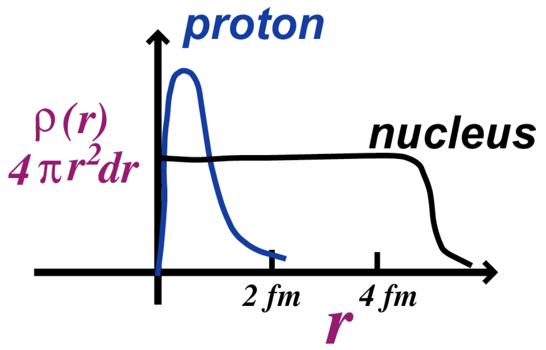
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim \frac{|M^{NC}_{PV}|}{|M^{EM}|} \sim \frac{Q^2}{(M_Z)^2}$$

Small ($\sim 10^{-6}$) cross section asymmetry isolates weak interaction

Nucleon Form Factors



Neglecting recoil and spin:
Obtain Fourier transform of
charge distribution



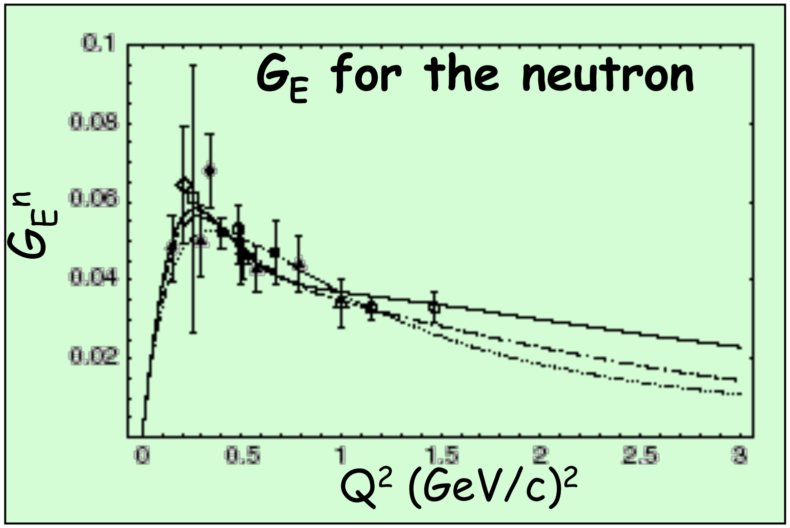
Nucleon charge and magnetization distributions:

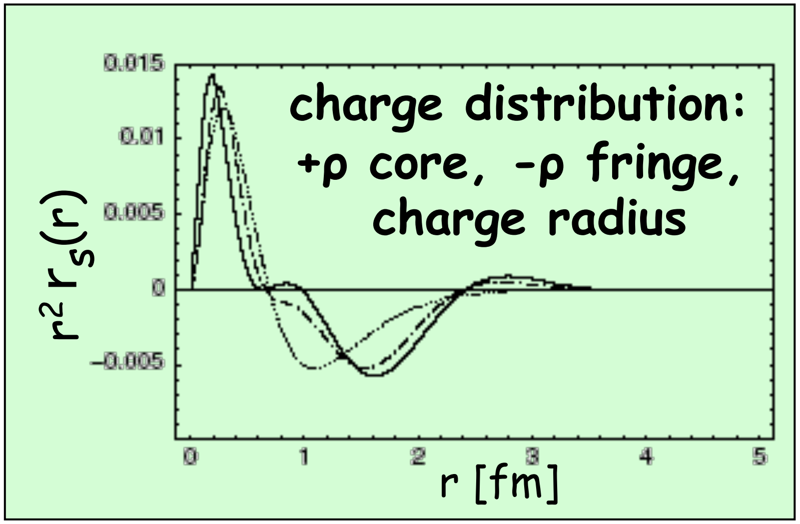
$G_E(Q^2)$, $G_M(Q^2)$

electric and magnetic form factors

$G_E^p(0) = 1$ $\qquad$ $G_M^p(0) = +2.79\ \mu_N$

$G_E^n(0) = 0$ $\qquad$ $G_M^n(0) = -1.91\ \mu_N$





Nucleon Form Factors

Adopt Sachs FF: $G_E^\gamma = F_1^\gamma + \tau F_2^\gamma$ $G_M^\gamma = F_1^\gamma + F_2^\gamma$

Roughly: Fourier transforms of charge and magnetization

NC and EM probe same hadronic flavor structure, with different couplings:

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

$$G_{E/M}^Z = \left(1 - \frac{8}{3}\sin^2\theta_W\right) G_{E/M}^u - \left(1 - \frac{4}{3}\sin^2\theta_W\right) G_{E/M}^d - \left(1 - \frac{4}{3}\sin^2\theta_W\right) G_{E/M}^s$$

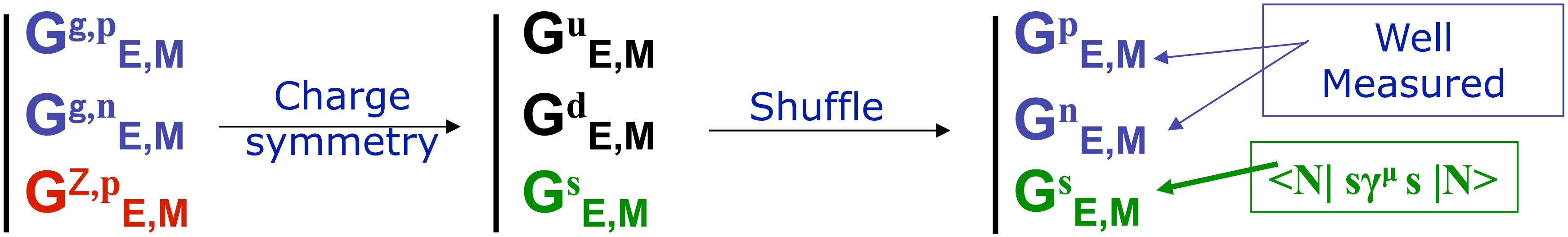
$G^Z_{E/M}$ provide an important benchmark for testing non-perturbative QCD structure of the nucleon

Charge Symmetry

One expects the neutron is ≈ an isospin rotation of the proton*:

$$G^{p,u}_{E/M} = G^{n,d}_{E/M}, \qquad G^{p,d}_{E/M} = G^{n,u}_{E/M}, \qquad G^{p,s}_{E/M} = G^{n,s}_{E/M}$$

$$G^{\gamma,p}_{E/M} = \frac{2}{3}G^{u}_{E/M} - \frac{1}{3}G^{d}_{E/M} - \frac{1}{3}G^{s}_{E/M} \longrightarrow G^{\gamma,n}_{E/M} = \frac{2}{3}G^{d}_{E/M} - \frac{1}{3}G^{u}_{E/M} - \frac{1}{3}G^{s}_{E/M}$$



$G^{g,p}_{E,M}$

$G^{g,n}_{E,M}$

$G^{Z,p}_{E,M}$

Charge symmetry

$G^{u}_{E,M}$

$G^{d}_{E,M}$

$G^{s}_{E,M}$

Shuffle

$G^{p}_{E,M}$

$G^{n}_{E,M}$

$G^{s}_{E,M}$

Well Measured

<N| sγ$^\mu$ s |N>

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \propto \frac{M_Z M_\gamma}{\left|M_\gamma\right|^2} = -\frac{G_F Q^2}{\sqrt{2}\pi\alpha} \mathrm{F}\left(G^{p}_{E/M}, G^{n}_{E/M}, G^{s}_{E/M}, G_A\right)$$

* Effect of charge symmetry violations: B. Kubis & R. Lewis Phys. Rev. C **74** (2006) 015204

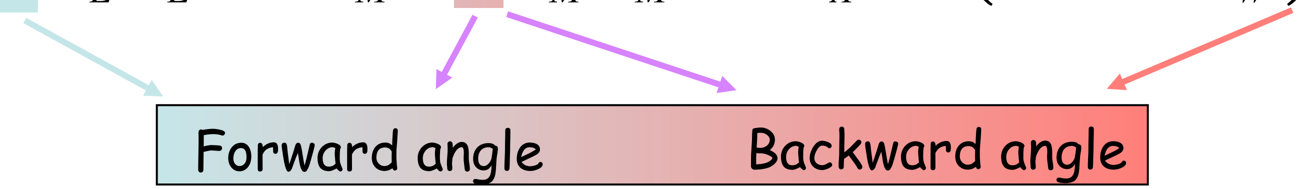
Isolating individual form factors:
vary *kinematics* or *target*

For a proton:

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

~ few parts per million

$$A_E = \varepsilon\, G_E^p G_E^Z, \qquad A_M = \tau\, G_M^p G_M^Z, \qquad A_A = -\left(1 - 4\sin^2\theta_W\right)\varepsilon' G_M^p G_A^e$$



Forward angle

Backward angle

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

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

For ^{4}He: G_E^s alone

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

For deuteron:

enhanced G_A^e sensitivity

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

Theoretical Approaches to Strange Form Factors

Models - a non-exhaustive list:

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

- no consensus on magnitudes or even *signs* of G_E^s and G_M^s !

Only model-independent statement: $\boxed{G_E^s(Q^2=0)=0}$

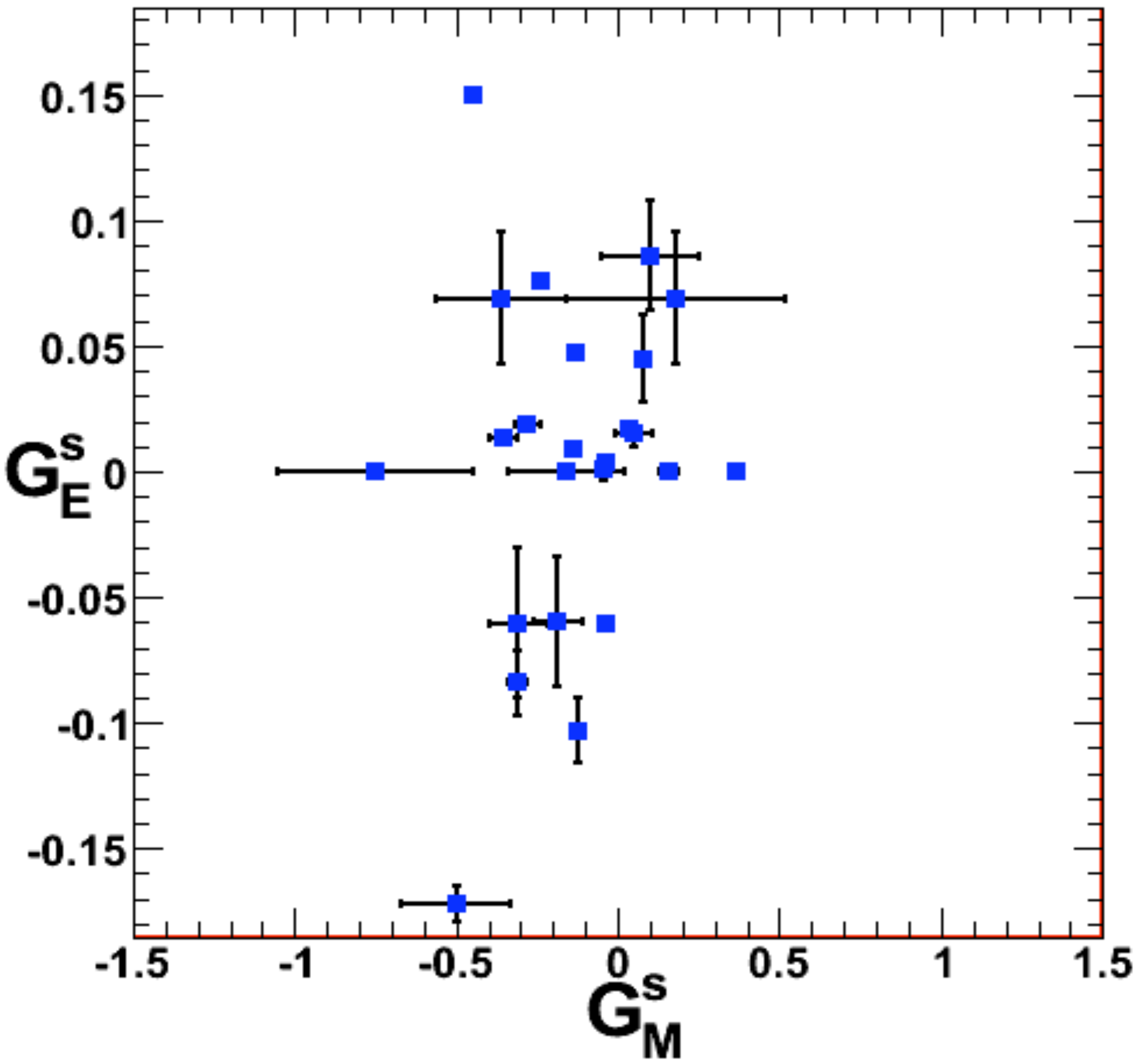
a challenging problem in non-perturbative QCD

What about QCD on the lattice?

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

Disconnected insertions – technically challenging

Strangeness Models



(as/of circa 2005)

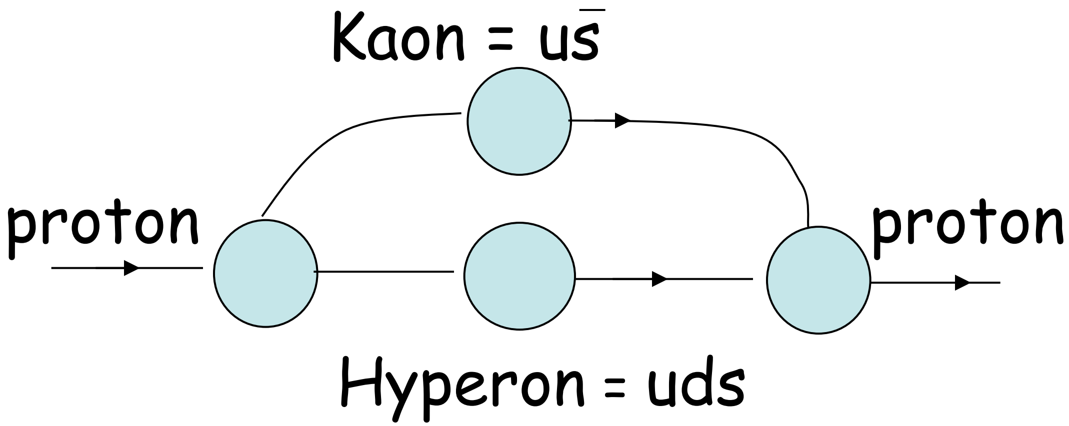
note: caveats...

What would non-zero G^s_E and G^s_M imply?

$G^s_E \neq 0 \Longrightarrow$ s and $\bar{s}$ have different spatial distributions in proton

$G^s_M \neq 0 \Longrightarrow$ s and $\bar{s}$ have different magnetization distributions in proton

-> contribute to magnetic moment, etc.



(naive model for illustration)

The Axial Current Contribution

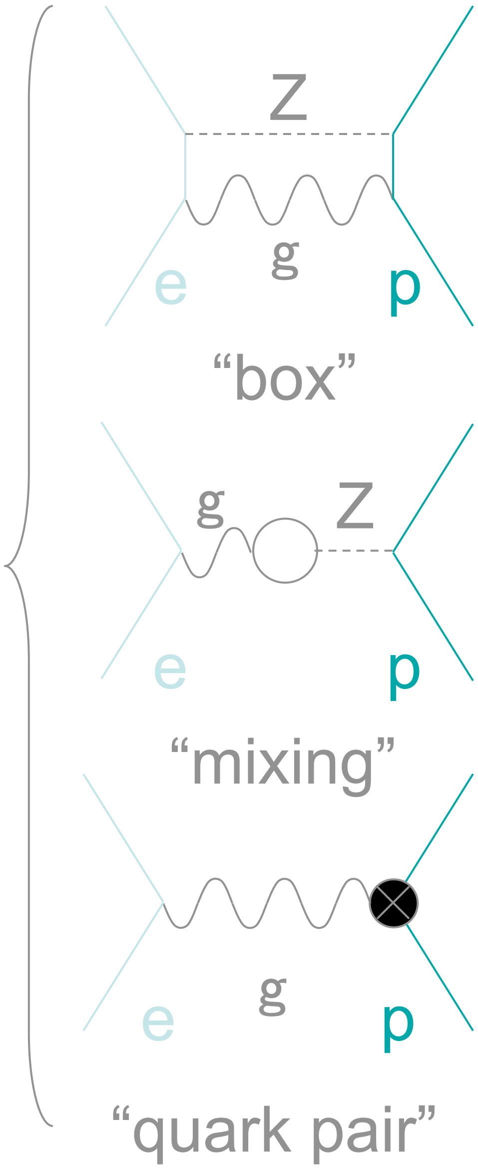
- **Recall:** $A^{PV} \propto \frac{A_E + A_M + A_A}{2\sigma_{unp}}$

$$A_E = \varepsilon(\theta) G_E^\gamma G_E^Z, \quad A_M = \tau G_M^\gamma G_M^Z$$

$$A_A = -\left(1 - 4\sin^2\theta_W\right) \varepsilon'(\theta)\, G_M^\gamma G_A^e$$

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

  - Effective axial form factor: $G_A^e(Q^2)$
  - related to form factor measured in ν scattering
  - also contains "*anapole*" form factor
  - determine isovector piece by combining proton and neutron (deuteron) measurements



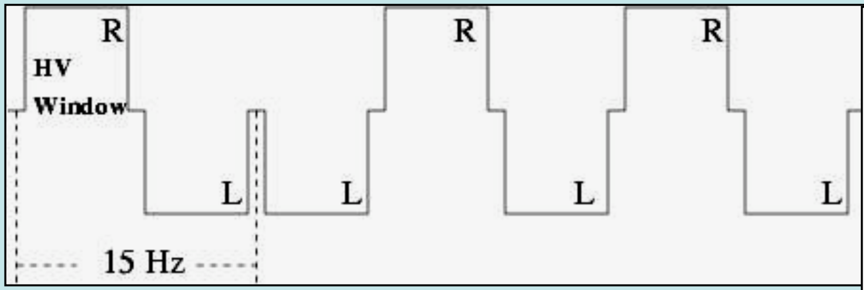
Measurement of P-V Asymmetries

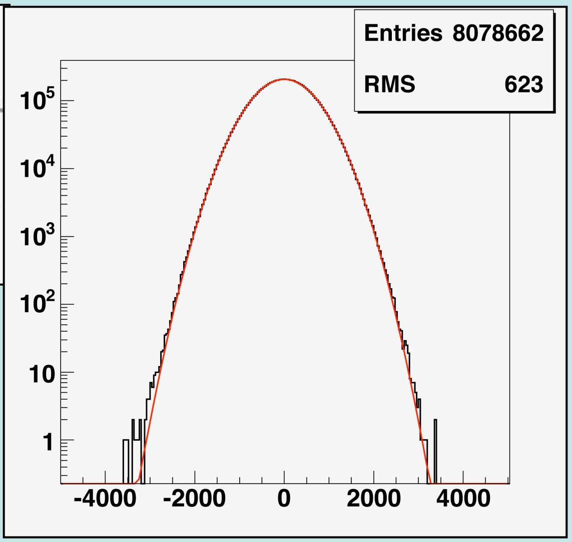
$$A_{LR} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \approx 10^{-6}$$

e.g. 5% Statistical Precision on 1 ppm
-> requires 4×10^{14} counts

Rapid Helicity Flip: Measure the asymmetry at 10^{-4} level, 10 million times

$$A_{LR} = \frac{N_R - N_L}{N_R + N_L}$$



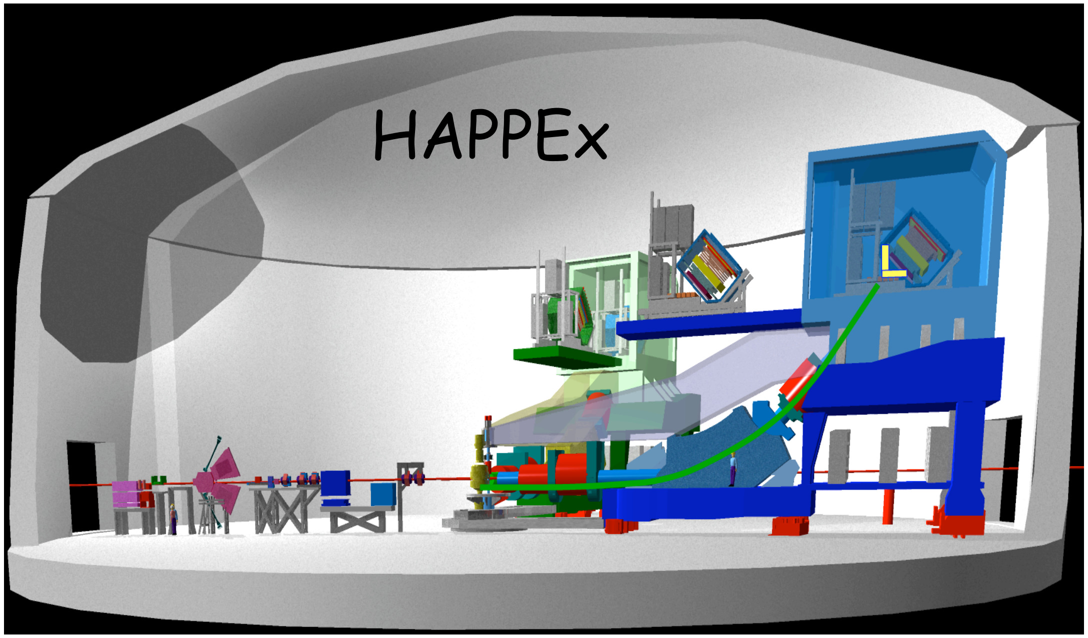


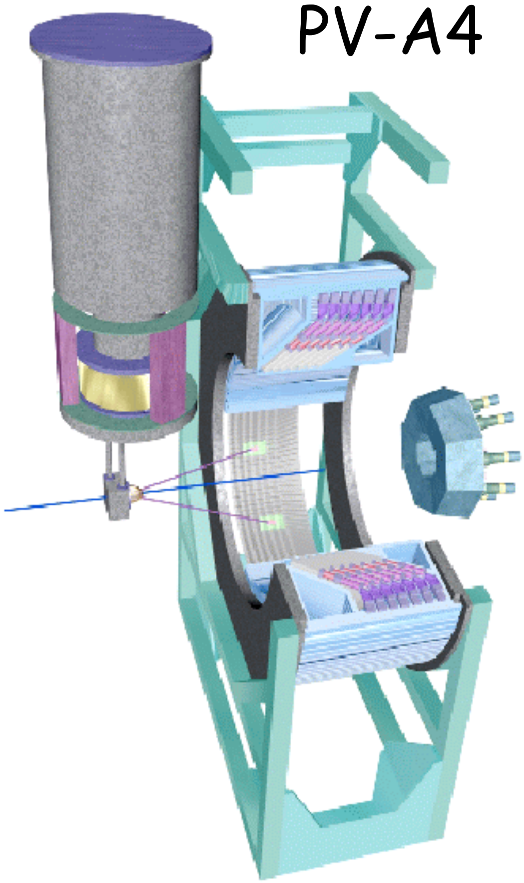
- High luminosity: thick targets, high beam current
- Control noise (target, electronics)
- High beam polarization and rapid flip

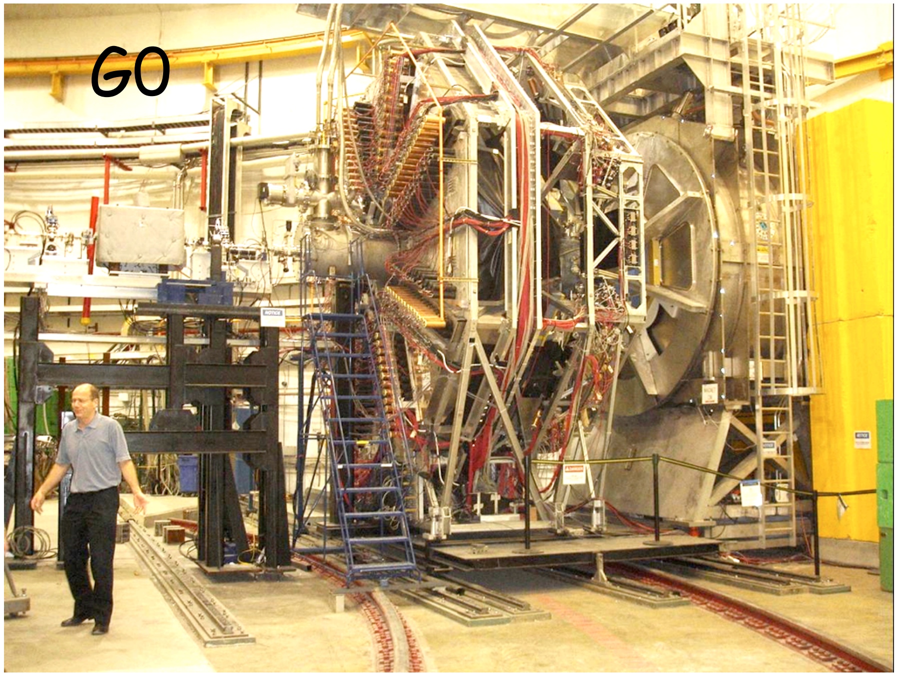
Statistics: high rate, low noise
Systematics: beam asymmetries, backgrounds, helicity-correlated pickup
Normalization: Polarization, linearity, dilution

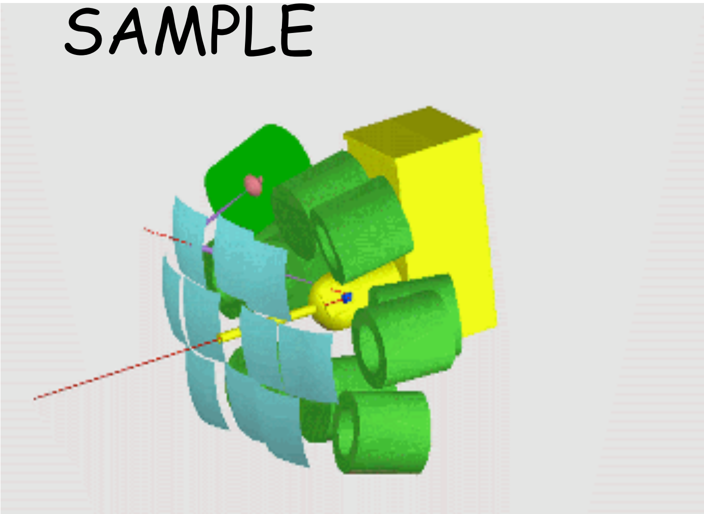
Parity-Violating Electron Scattering Program

Expt/Lab	Target/Angle	Q^2 (GeV^2)	A_{pv} (ppm)	Sensitivity	Status
SAMPLE/Bates					
SAMPLE I	LH_2/145	0.1	-6	$G_M + 0.4G_A$	2000
SAMPLE II	LD_2/145	0.1	-8	$G_M + 2G_A$	2004
SAMPLE III	LD_2/145	0.04	-4	$G_M + 3G_A$	2004
HAPPEx/JLab					
HAPPEx	LH_2/12.5	0.47	-15	$G_E + 0.39G_M$	1999
HAPPEx II	LH_2/6	0.11	-1.6	$G_E + 0.1G_M$	2006, 2007
HAPPEx He	^{4}He/6	0.11	+6	G_E	2006, 2007
HAPPEx III	LH_2/14	0.63	-24	$G_E + 0.5G_M$	(2009)
PV-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


HAPPEx

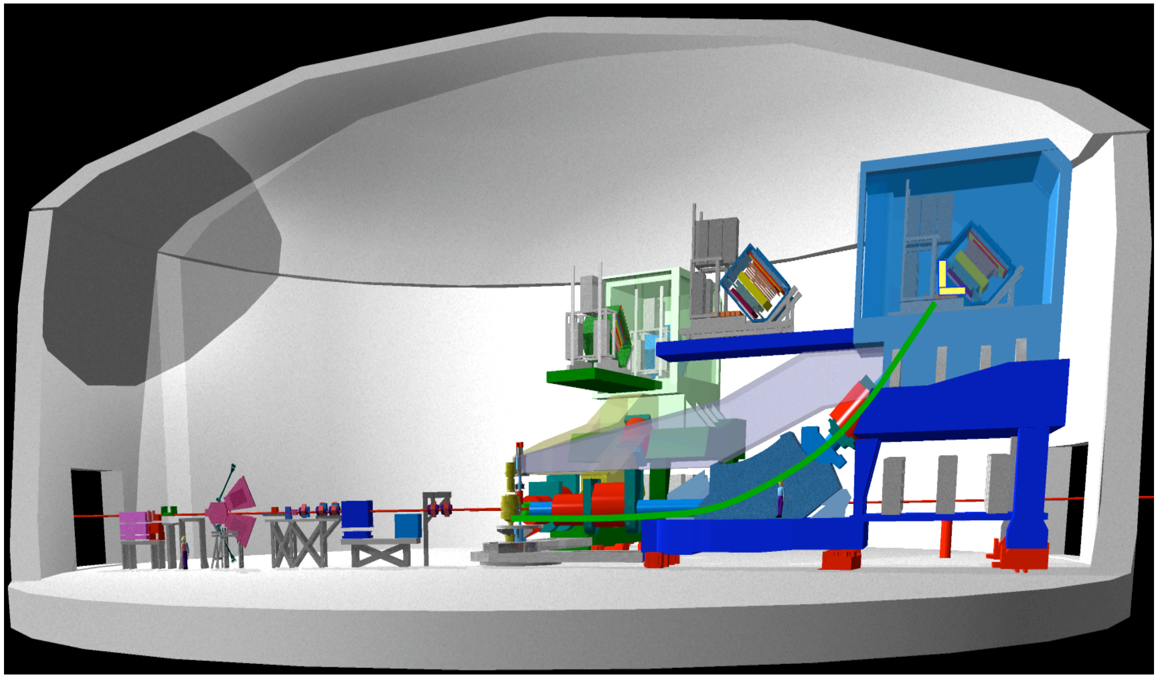

PV-A4

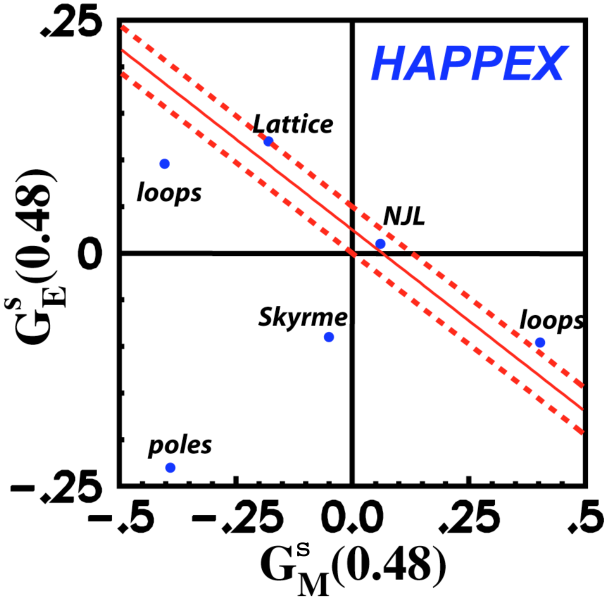

GO


SAMPLE

HAPPEX-I Jlab/Hall-A

Hydrogen Target: E= 3.3 GeV θ=12.5° Q^2=0.48 (GeV/c)^2





A^{PV} = -14.92 ppm ± 0.98 (stat) ppm ± 0.56 (syst) ppm

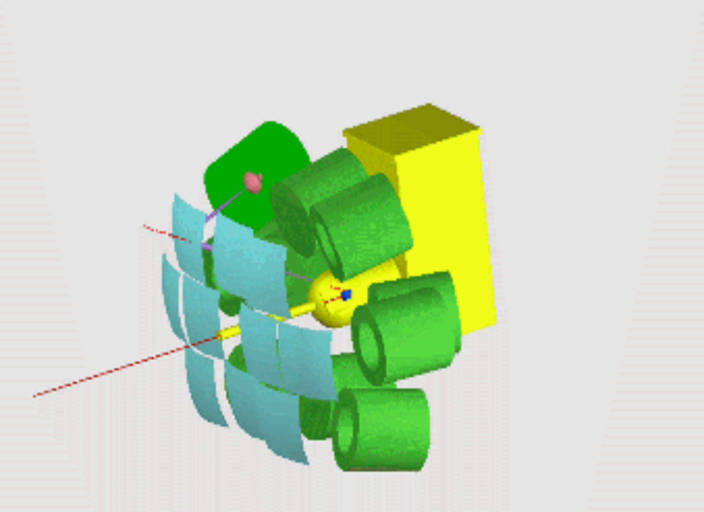
$$\boxed{G^s_E + 0.39 G^s_M = 0.014 \pm 0.020\ (exp) \pm 0.010\ (FF)}$$

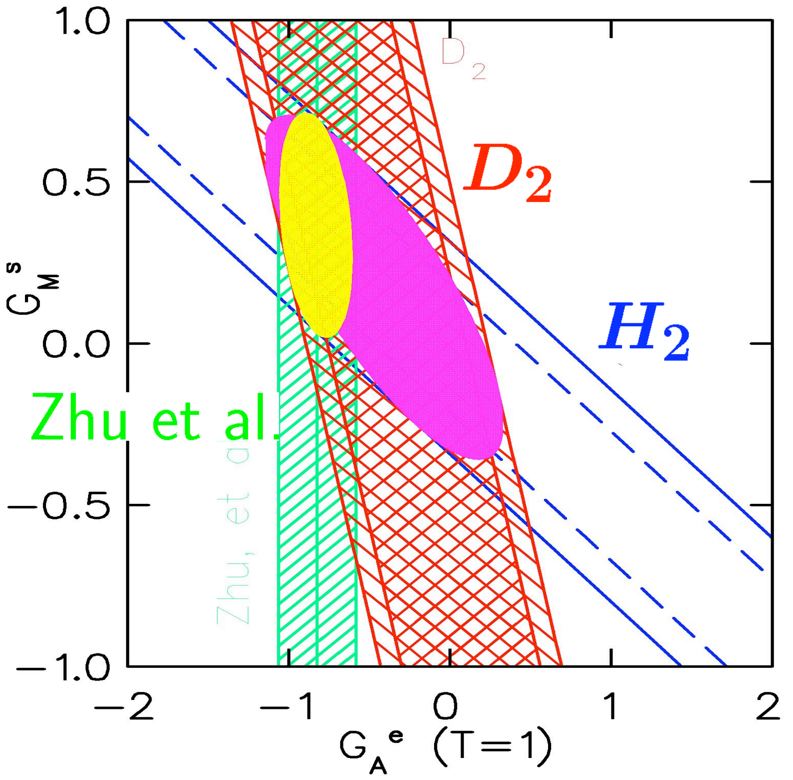
Phys. Rev. Lett. 82,1096 (1999);
Phys. Lett. B509, 211 (2001);
Phys. Rev. C 69, 065501 (2004)

SAMPLE (MIT/Bates)

Backward angle (θ=150°), integrating

$Q^2(\text{GeV}^2)$	A_{PV} (ppm)	$A_0 + \alpha G^s_M + \beta G^e_A(T=1)$
$0.1, LH_2$	$-5.61 \pm 0.67 \pm 0.88$	$-5.56 + 3.37G^s_M + 1.54G^e_A$
$0.1, LD_2$	$-7.06 \pm 0.73 \pm 0.72$	$-7.06 + 0.72G^s_M + 1.66G^e_A$
$0.03, LD_2$	$-3.51 \pm 0.57 \pm 0.58$	$-2.14 + 0.27G^s_M + 0.76G^e_A$





G_M^s = 0.23 ± 0.36 ± 0.40

$G^e_A{}^{(T=1)}$ = -0.53 ± 0.57 ± 0.50

E.J. Beise *et al.*, Prog Nuc Part Phys 54 (2005)

Results of Zhu *et al.* commonly used to constrain G^S_M result:

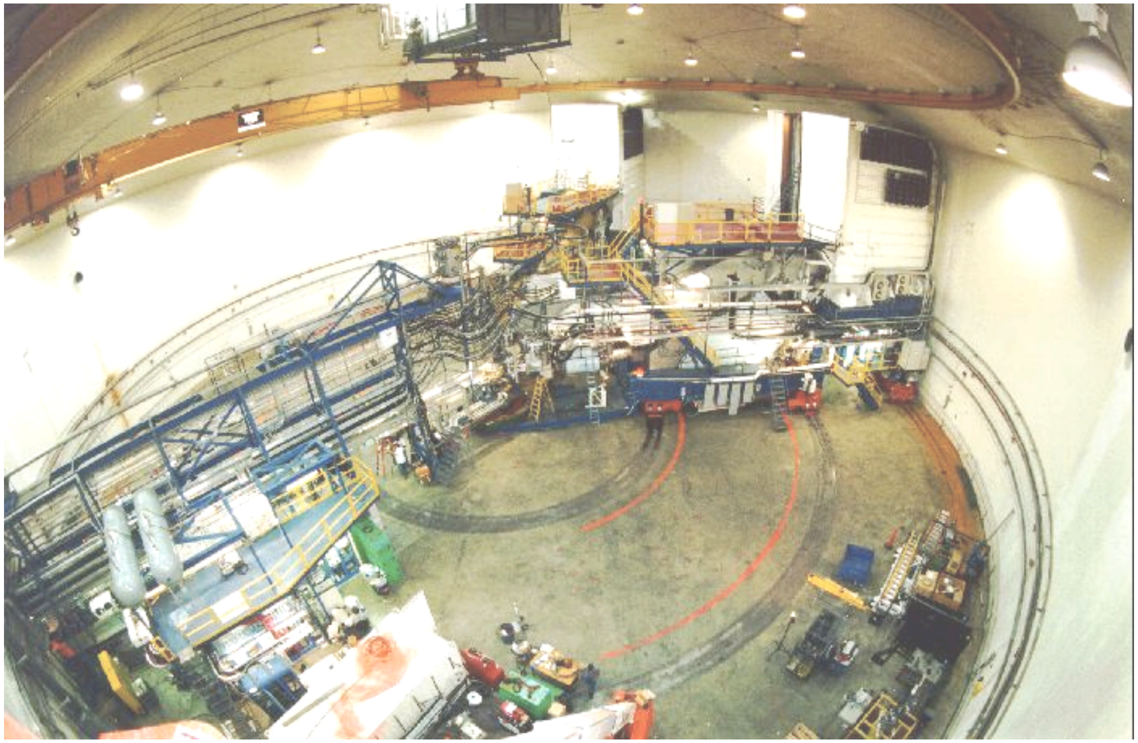
$G^s_M = 0.37 \pm 0.20_{Stat} \pm 0.36_{Syst} \pm 0.07_{FF}$

HAPPEX-II

E=3 GeV θ=6° Q^2= 0.1 (GeV/c)^2

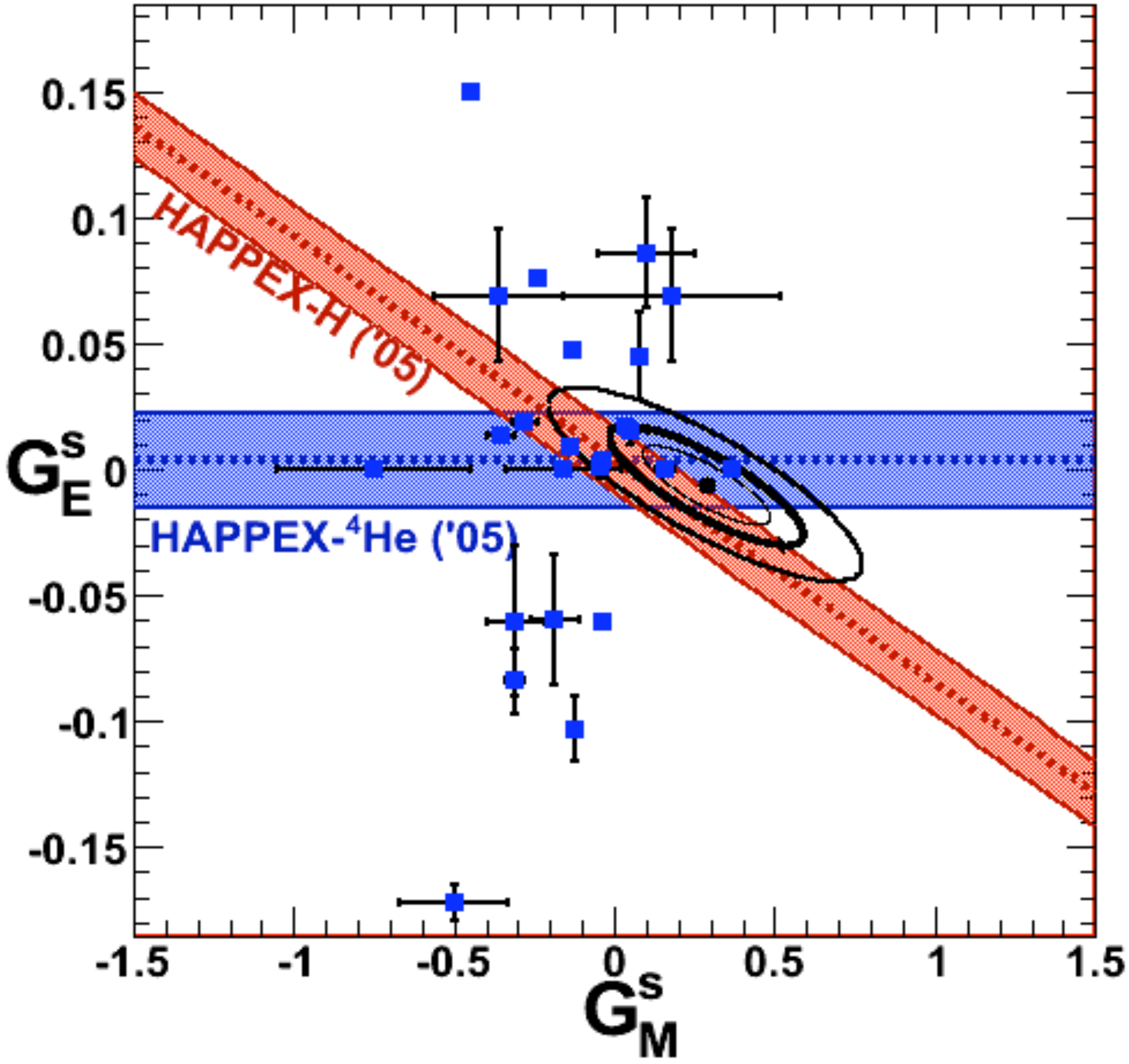
- **Hydrogen** : $G_E^s + \eta G_M^s$
- **^{4}He**: Pure G_E^s : $A^{PV} = -\frac{A_0}{2}\left(2\sin^2\theta_W + \frac{G_E^s}{G_E^{p\gamma} + G_E^{n\gamma}}\right)$

2 runs: 2004 & 2005



A. Acha, et al. PRL 98(2007)032301

HAPPEx data at Q^2 ~0.1 GeV^2



$$G_M^s = 0.28 \pm 0.20$$

↓

21% of $\mu_N^{T=0}$

$$\left\langle r^2 \right\rangle_E^p = 0.766 \pm 0.012\, fm^2$$

$$\left\langle r^2 \right\rangle_E^s = 0.002 \pm 0.015\, fm^2$$

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

Solid ellipse:

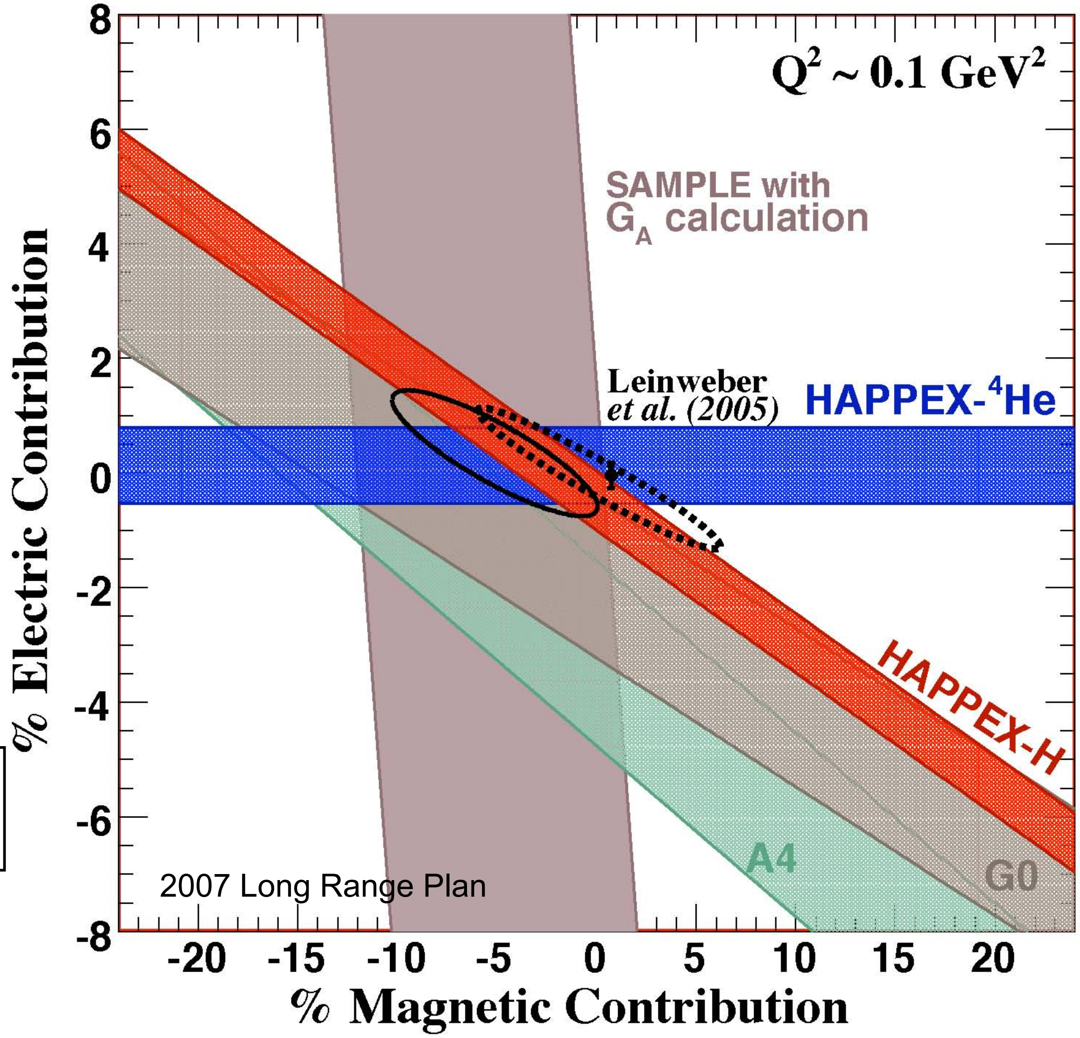
K. Paschke, priv. comm.
[≈ J. Liu et al.
PRC 76, 025202 (2007)]
uses theoretical constraints
on the axial form factor

Dashed ellipse:

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

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

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



(figure: thanks to K. Paschke, R. Young)

Theoretical Refinements

1. Two Boson exchange: H.Q. Zhou, C.W. Kao and S.N. Yang
   Phys.Rev.Lett.99:262001 (2007); Phys.Rev.C **79**:062501 (2009)

   γZ box dominates the two boson effects at HAPPex, PVA4 kinematics

   $\longrightarrow$ reduces extracted $G^s_E + \eta\, G^s_M$

   (not yet put into global fits)

2. Charge-symmetry breaking effects:

   Hydrogen: B. Kubis & R. Lewis Phys. Rev. C **74**:015204 (2006)
   ^{4}He: Viviani, Schiavilla, Kubis, Lewis, et al.
   Phys.Rev.Lett. **99**:112002 (2007)

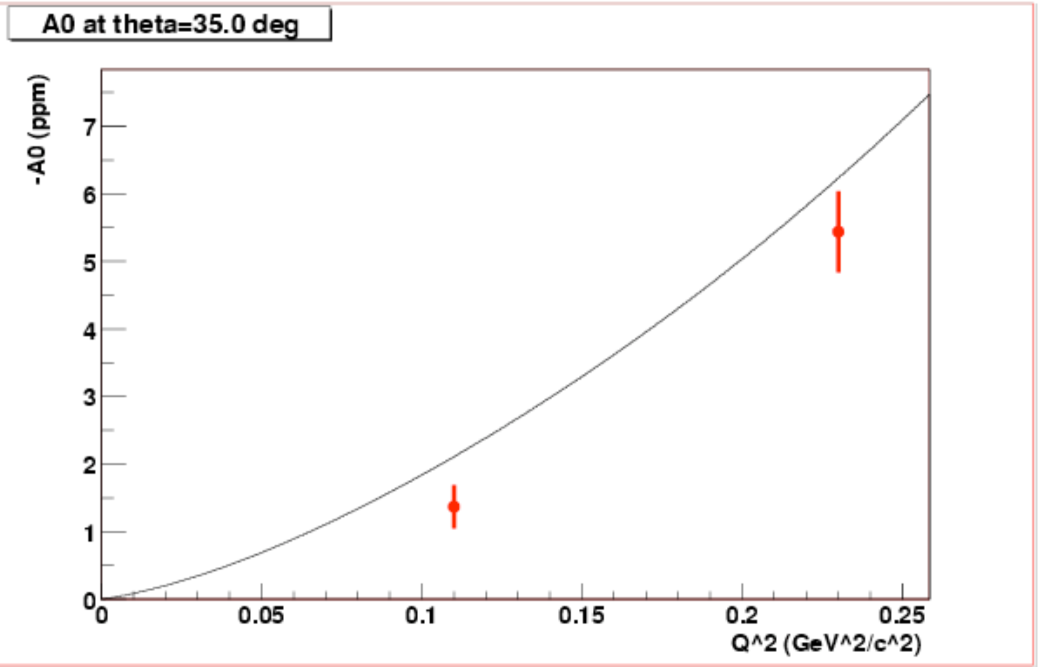
still only a (modest) fraction of smallest experimental statistical errors.

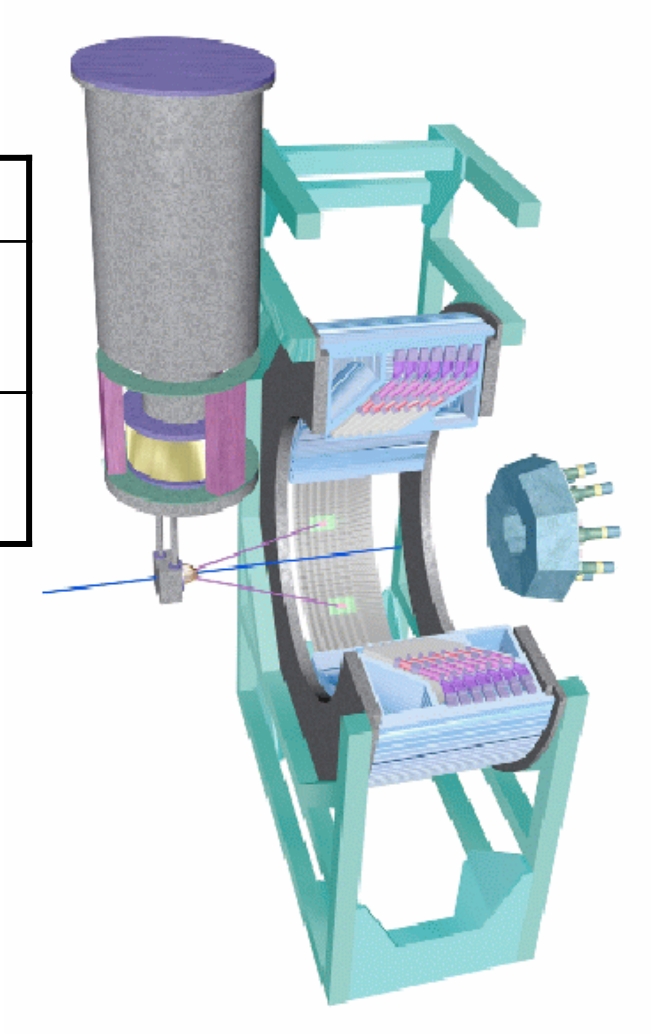
(not yet put into global fits)

PV-A4 (MAMI/Mainz)

Q^2 (GeV^2)	$A_{PV} \pm$ stat $\pm$ syst (ppm)	$G_E^s + \eta G_M^s$
0.230	$-5.44 \pm 0.54 \pm 0.26$	$G_E^s + 0.225\, G_M^s$ $= 0.039 \pm 0.034$
0.110	$-1.36 \pm 0.29 \pm 0.13$	$G_E^s + 0.106\, G_M^s$ $= 0.071 \pm 0.036$

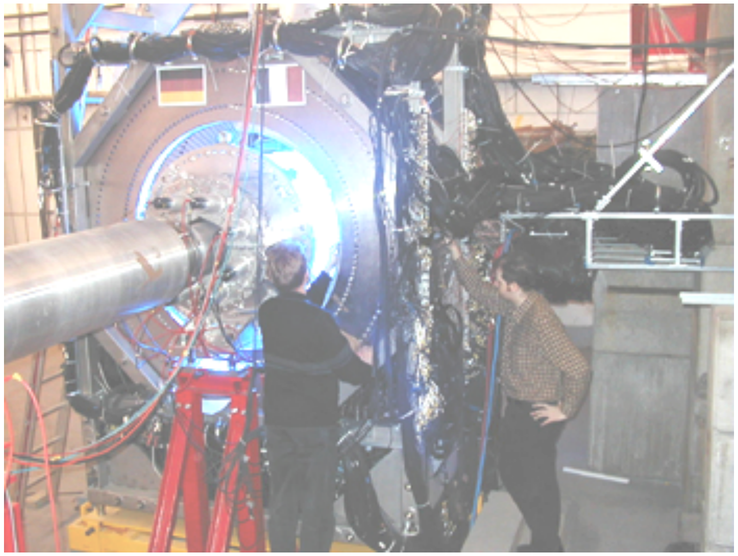
Counting – fast energy histograms





"Evidence for Strange Quark Contributions to the Nucleon's Form Factors at $Q^2 = 0.1$ GeV^2"
F. Maas et al. PRL 94, 152001 (2006)

New results from PV-A4

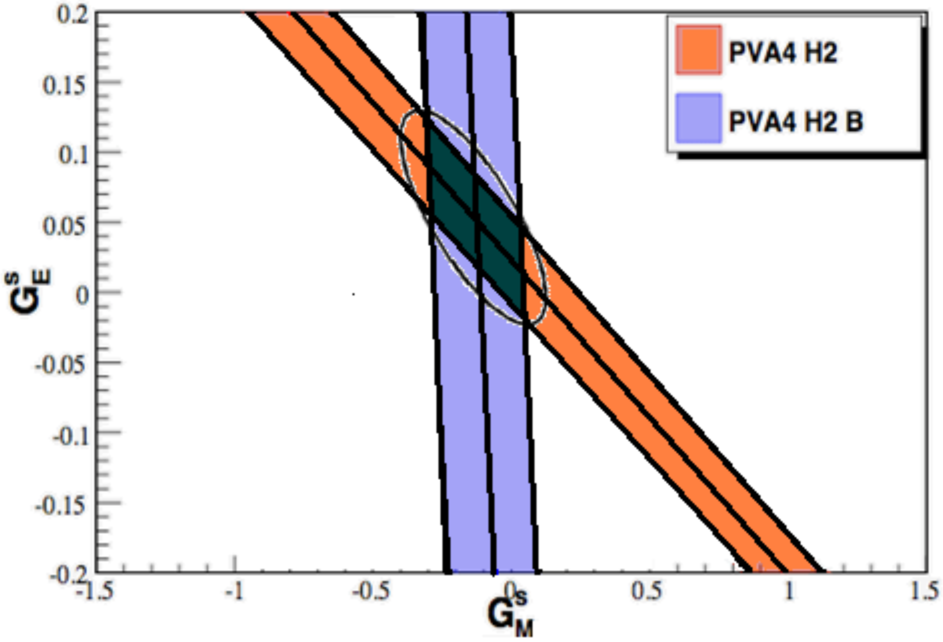


$\theta = 145°$ $\quad Q^2 = 0.22\ (\mathrm{GeV}/c)^2$

$A_{\mathrm{meas}} = -17.23 \pm 0.82 \pm 0.89$ ppm

$G^s_E = 0.050 \pm 0.038 \pm 0.019$
$G^s_M = -0.14 \pm 0.11 \pm 0.11$

(use theoretical constraint of Zhu et al., for the axial FF)



% contribution to proton:

electric: *3.0 ± 2.5 %*

magnetic: *2.9 ± 3.2 %*

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

Deuterium results at same Q2 – still being analyzed….

G^0 (JLab – Hall C)

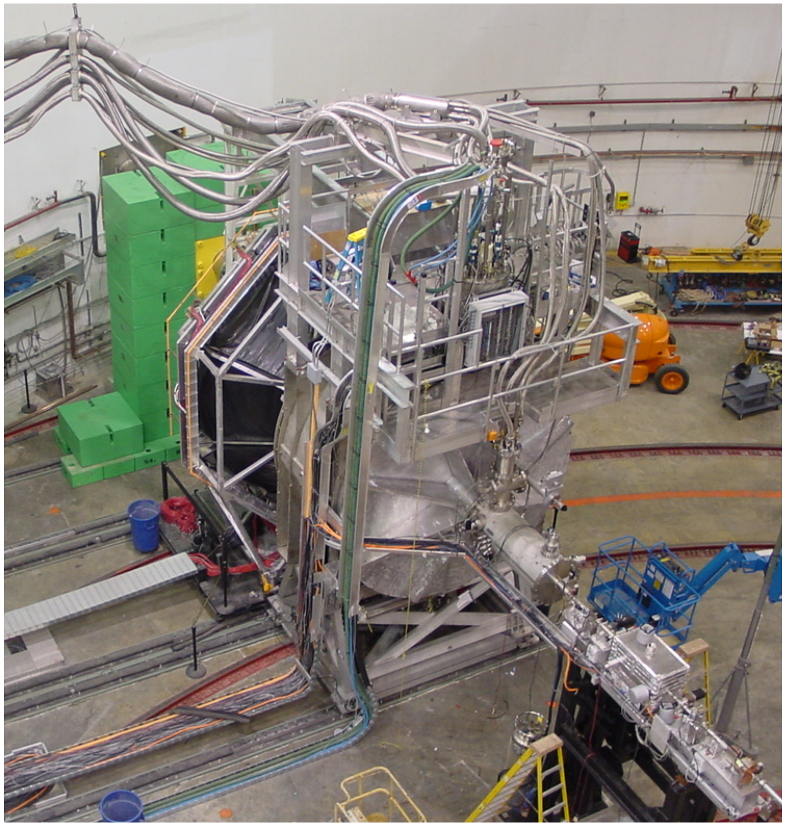
- Superconducting toroidal magnetic spectrometer

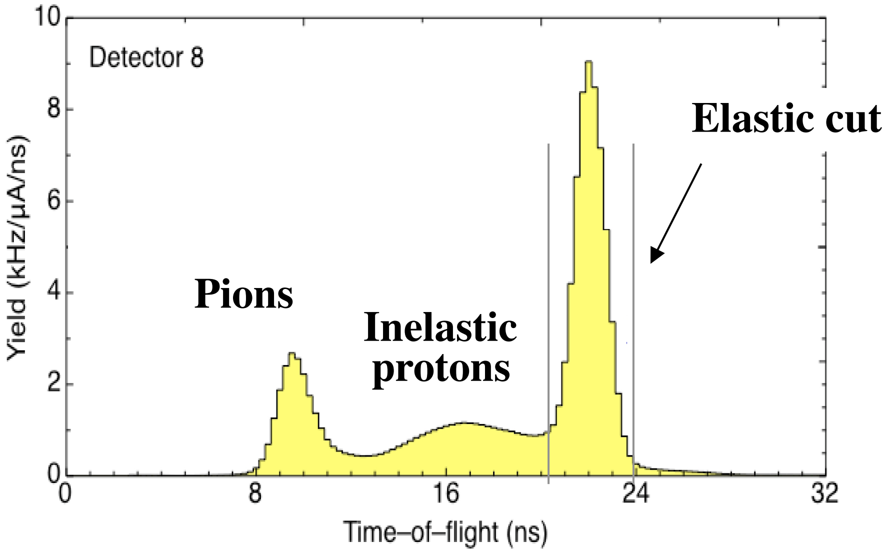
Forward angle mode

- LH_2: $E_e = 3.0$ GeV

  Recoil proton detection

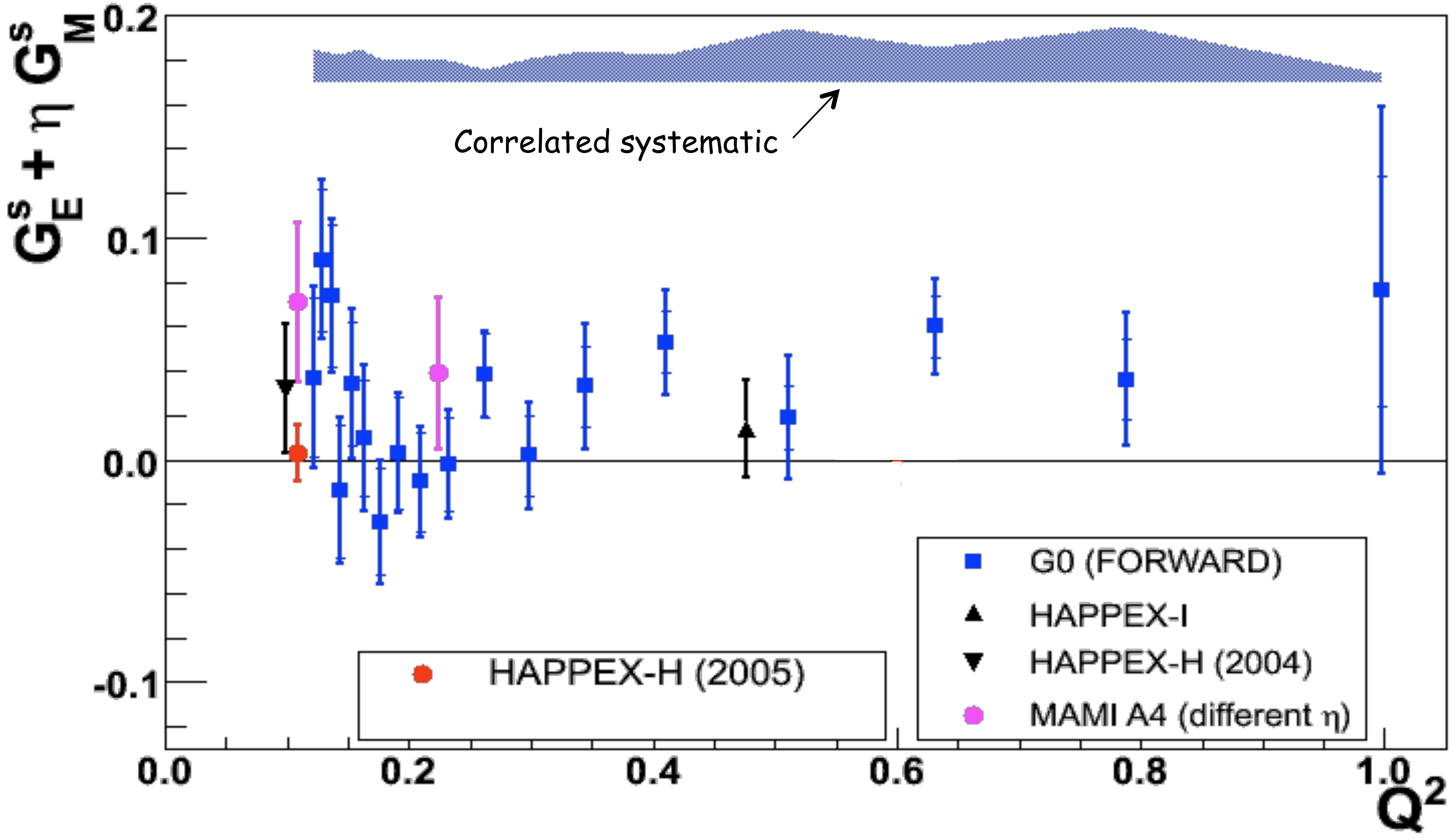
  ➩ $0.12 \leq Q^2 \leq 1.0$ $(GeV/c)^2$
- Counting experiment – separate backgrounds via time-of-flight





G0: Forward-angle results

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



$G_E^s = G_M^s = 0$ Hypothesis excluded at 89% C.L.

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

G0 Back Angle Apparatus: schematic

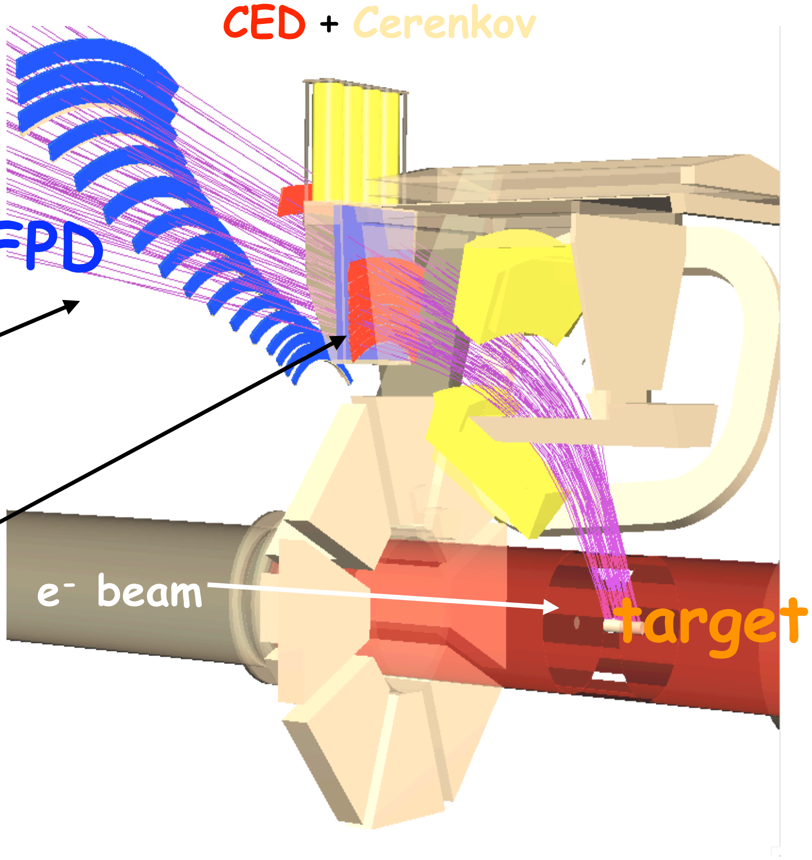
Single Octant Schematic

🟫
🟨 Shielding

FPD: Focal Plane Detector

CED: Cryostat Exit Detector

Kinematic separation of elastic, inelastic



- Polarized electron beam at 362, 687 MeV
- Target: 20 cm LH_2, LD_2
- (quasi)elastic, inelastic scattering at ~108°
- e/π separation using aerogel Cerenkov

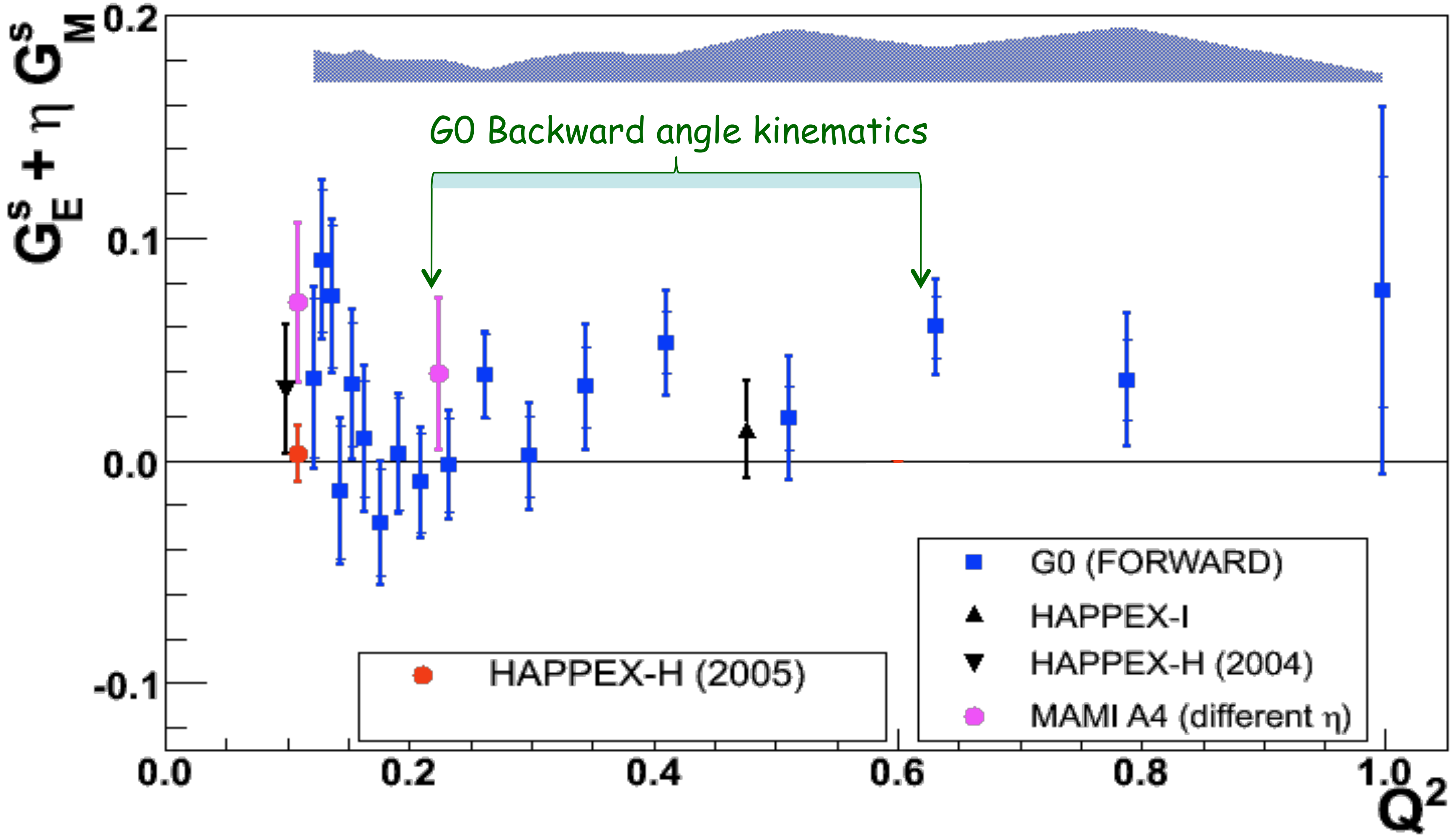
G0 Asymmetries

(backward angle measurements)

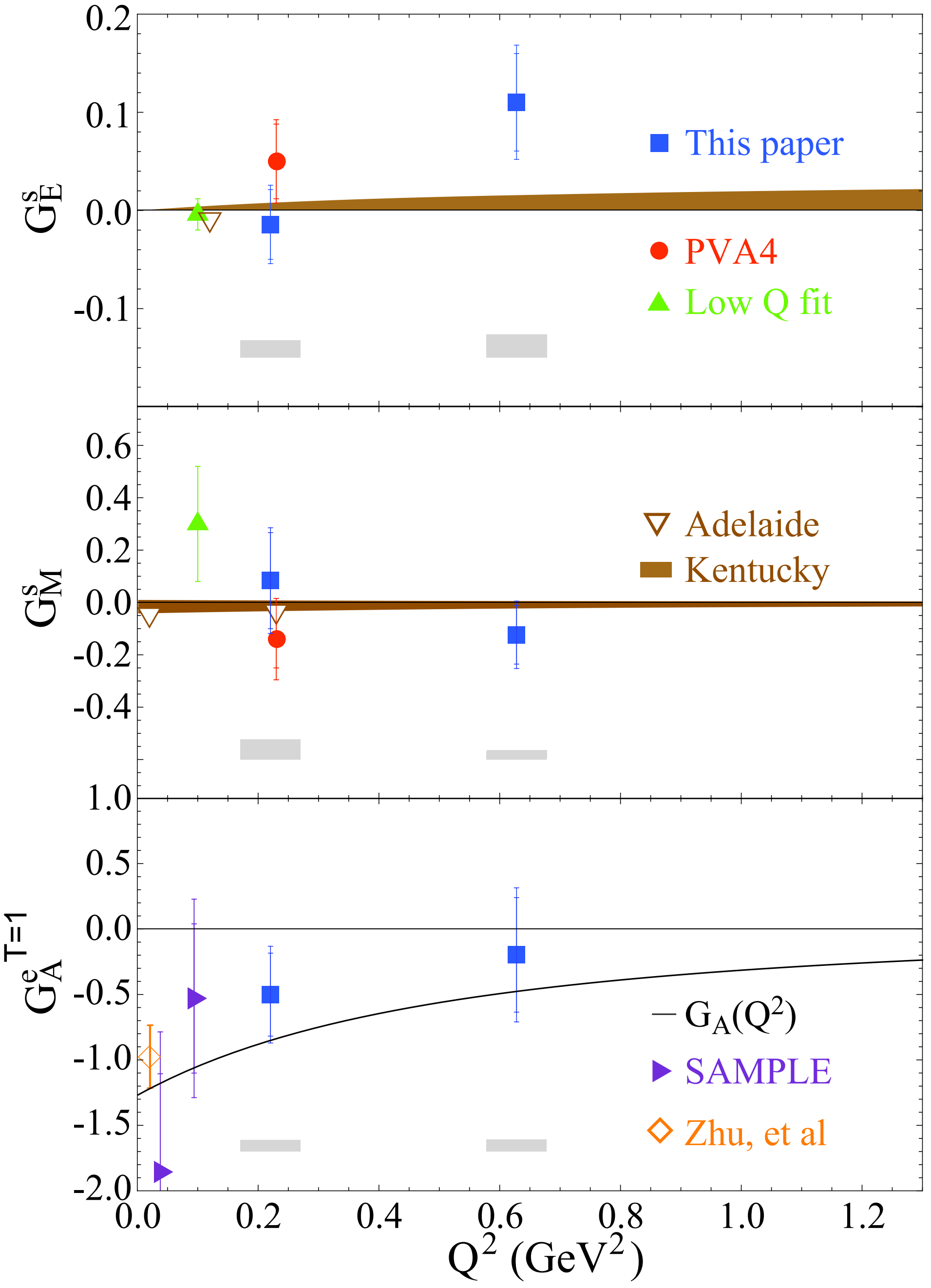
Set	Asymmetries *(ppm)*	Stat *(ppm)*	Sys pt *(ppm)*	Sys Global *(ppm)*	Total *(ppm)*
H 362	-11.416	0.872	0.268	0.385	0.990
D 362	-17.018	0.813	0.411	0.197	0.932
H 687	-46.14	2.43	0.84	0.75	2.68
D 687	-55.87	3.34	1.98	0.64	3.92

$Q^2 = 0.22$ GeV^2 and $Q^2 = 0.63$ GeV^2

Forward Angle Results - reminder



G0 Backward Angle Results



Combined with interpolation of
G0 forward measurements

assumes:

$$G_{A,NS}^{T=0}\left(Q^2\right) = R_A^{T=0}\,\frac{3F-D}{2}\,G_A^{dipole}\left(Q^2\right)$$

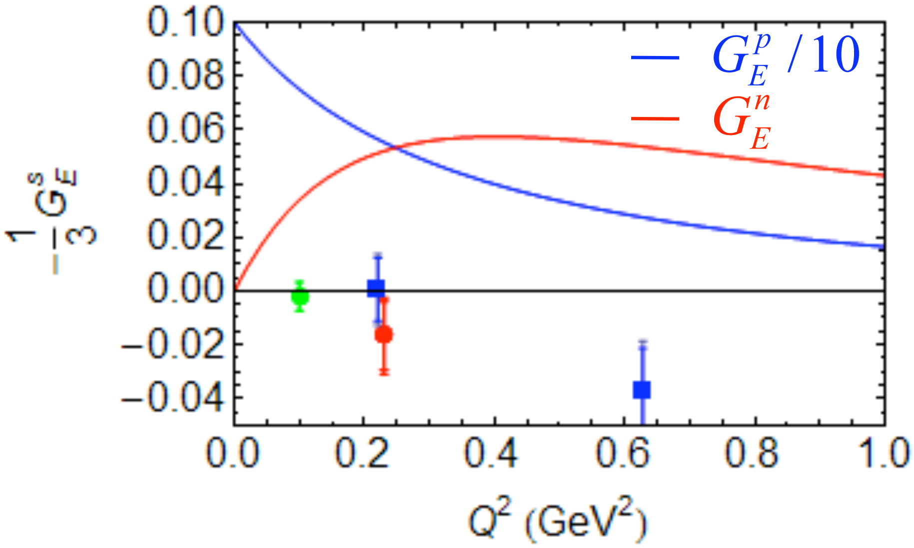
$$G_{A,NS}^{T=0}\left(Q^2=0\right) = 0.070$$

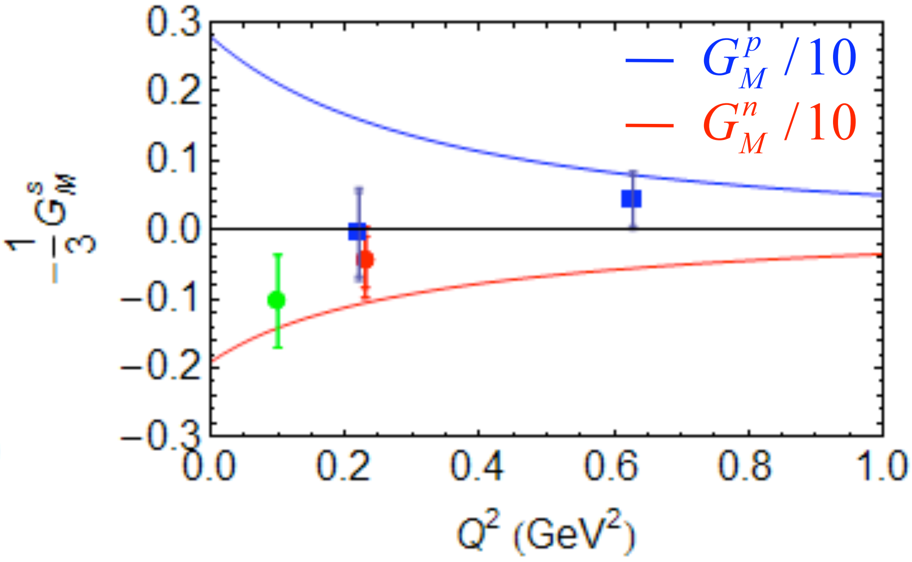
▨ = Global systematic

Also assumes: no CSV

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

Contributions to Overall Form Factors

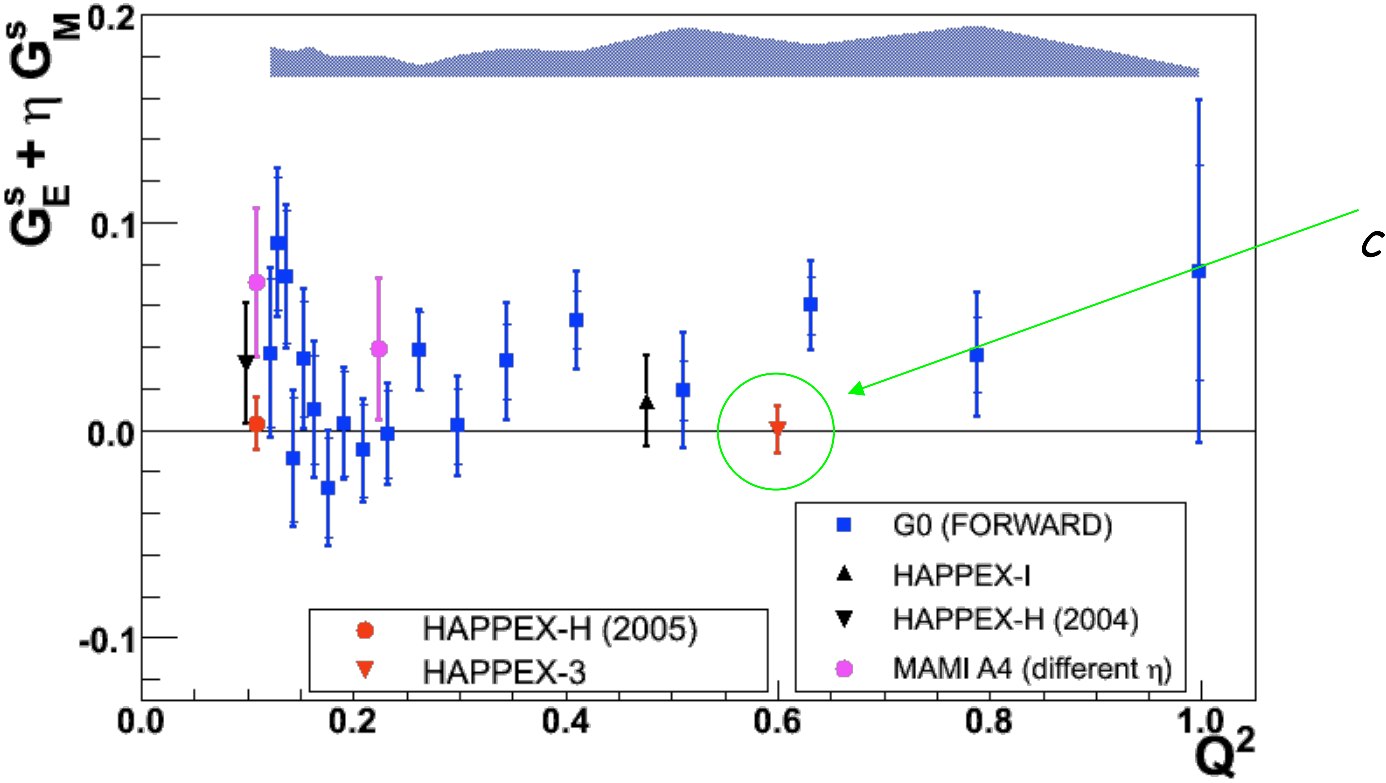




Advertisement: other physics from G0

- First measurement of neutral current N→Δ transition   ($Q^2 \approx 0.3$ GeV^2)
  (analysis: Carissa Capuano, William & Mary)
- First measurement of PV asymmetry in inclusive π^- production at low Q^2
  (analysis: Alexandre Coppens, U. Manitoba)
- Two-photon exchange seen via beam-normal single spin asymmetries
  (analysis: Juliette Mammei, Virginia Tech)

HAPPEX-III Spokepersons: K. Paschke & P. Souder



Data-taking completed Oct 2009

Result soon…

A higher precision repeat of HAPPEx-I, at slightly higher Q^2

(0.63 GeV^2 – matches higher G0 backward data point)

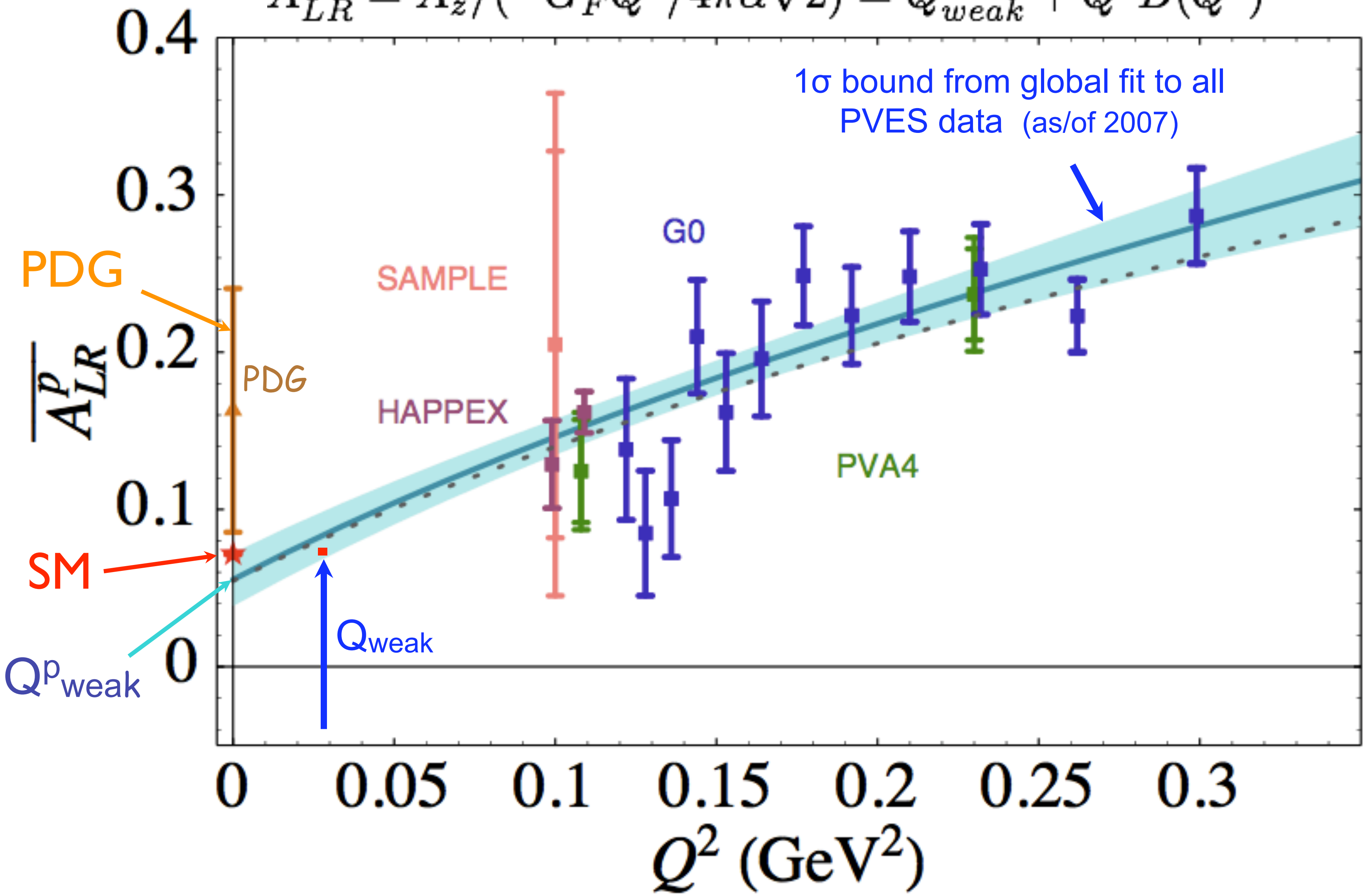
- 100 μA beam current, 89% polarization (c.f. 35 μA at 70% polarization for HAPPEx-I)
- If central value from G0 holds, could see ≈ 5σ non-zero strange quark signal.

PV-A4 also has taken data at ≈ same Q^2

Parity-Violating Asymmetry Extrapolated to $Q^2 = 0$

(R.D. Young et al. PRL 99, 122003 (2007))

$$\overline{A^p_{LR}} = A_z/(-G_F Q^2/4\pi\alpha\sqrt{2}) = Q^p_{weak} + Q^2 B(Q^2)$$



1σ bound from global fit to all PVES data (as/of 2007)

PDG

SM

Q^p_{weak}

Qweak

Beyond Strangeness:
Parity-Violating Electron Scattering as a Standard Model Test

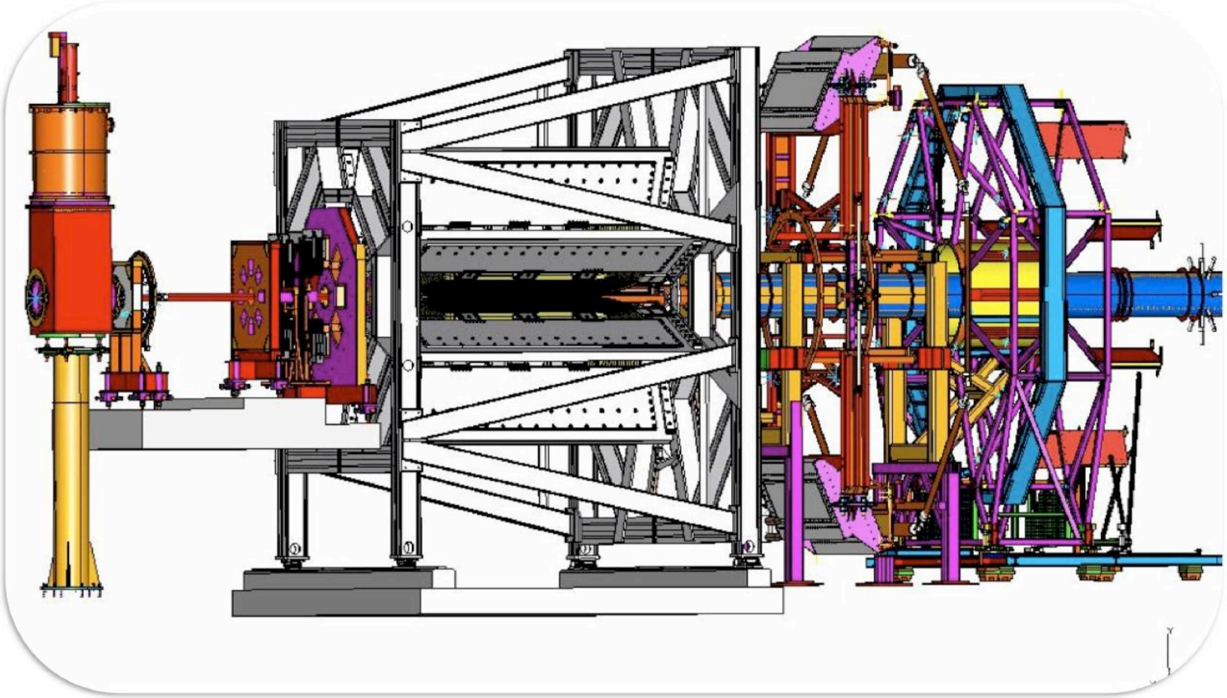
Recall: Prescott et al. (first PV electron scattering experiment) – crucial test of electroweak Standard Model

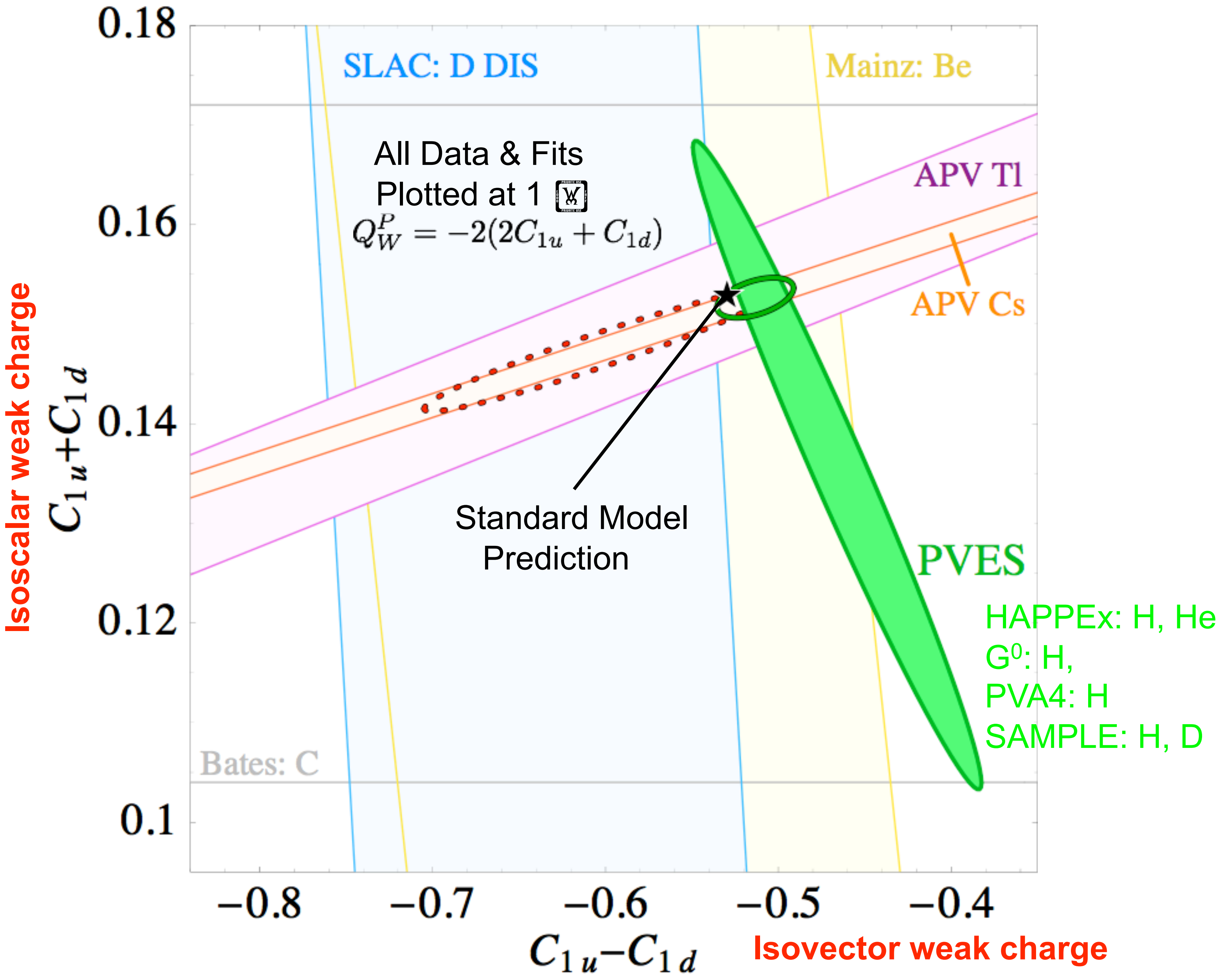
At low Q^2 & forward angles: $A_{PV} \propto Q_w^p = (1 - 4\sin^2\theta_W)$

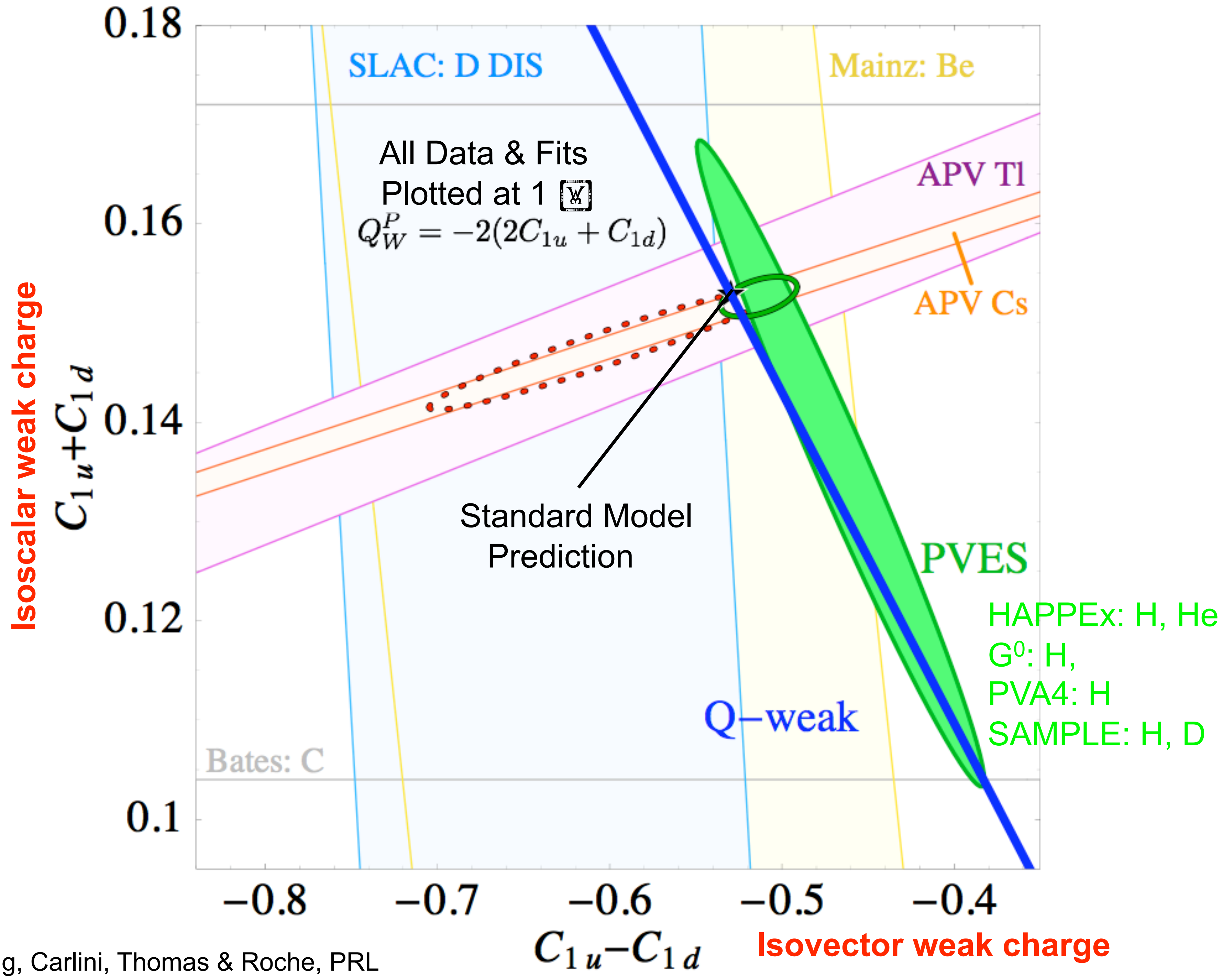
Q_w^p : Weak charge of the proton – precise Standard Model prediction, poorly tested experimentally

Experiment underway at JLab – complete data-taking May 2012

***GWU collaborators*:**
A.K. Opper
A. Micherdzinska
B. Stokes (former postdoc)
R. Subedi (present postdoc)
K. Myers (PhD student)
D. Jones (undergrad)




SLAC: D DIS
Mainz: Be
All Data & Fits
Plotted at 1
$Q_W^P = -2(2C_{1u} + C_{1d})$
APV Tl
APV Cs
Standard Model
Prediction
PVES
HAPPEx: H, He
G^0: H,
PVA4: H
SAMPLE: H, D
Bates: C
0.18
0.16
0.14
0.12
0.1
−0.8
−0.7
−0.6
−0.5
−0.4
$C_{1u}+C_{1d}$
Isoscalar weak charge
$C_{1u}-C_{1d}$
Isovector weak charge



Young, Carlini, Thomas & Roche, PRL

Summary

- Comparison of electromagnetic and weak neutral elastic form factors allows determination of strange quark contribution
  - large distance scale dynamics of the sea
- Separated form factors at three Q^2
- Small positive G_E^s at highest Q^2, G_M^s consistent with zero, small quenching of G_A^e, consistent with theory

- Next steps:
  - newer data very soon at $Q^2 = 0.63$ (HAPPEx-III, PV-A4)
  - global fits to all 36 asymmetries, including 2-boson & CSV effects, consistent electromagnetic form factors
  - no plans on pushing experimental effort further… lattice?

> *"Do not infest your mind with beating on the strangeness of this business" - W. Shakespeare (The Tempest)*