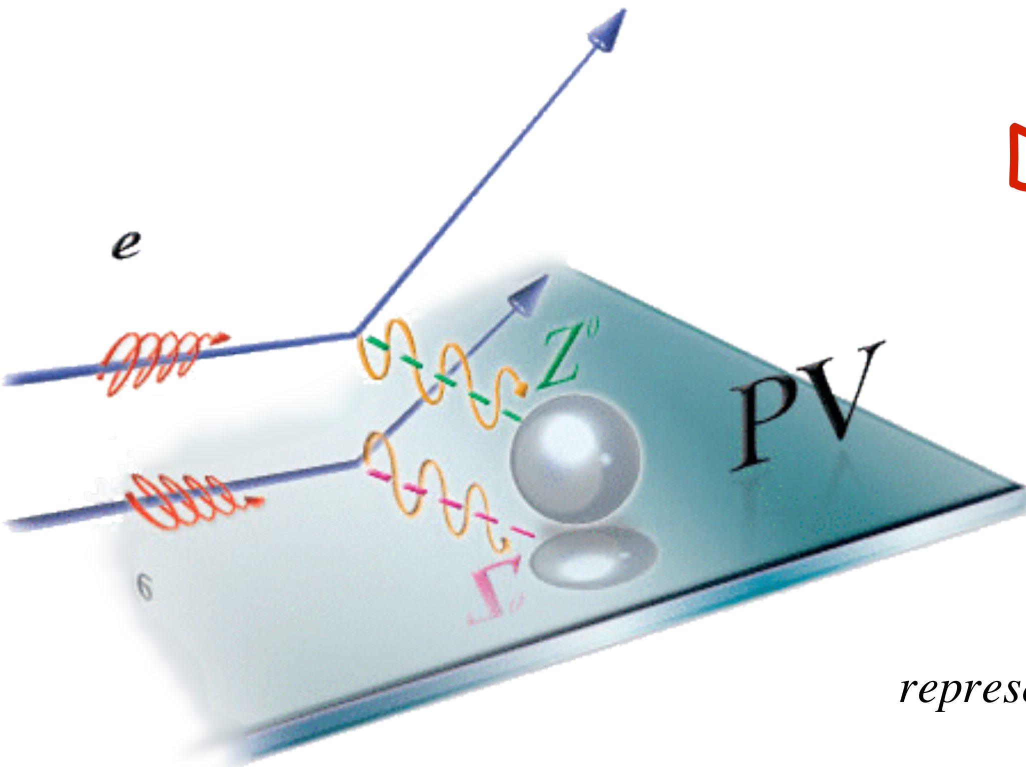
New Results from the HAPPEx Experiments at $Q^2 = 0.1\ \mathrm{GeV}/c^2$



David S. Armstrong

College of William & Mary

representing the **HAPPEX Collaboration**

From Parity Violation to Hadronic Structure… (PAVI 2006)   Milos, Greece   May 16 2006

The College of WILLIAM & MARY

Jefferson Lab

Outline

- Parity-violation in electron scattering
- Elastic Vector Strange Form Factors: G^s_E and G^s_M
- Q^2 = 0.1 $(GeV/c)^2$ as of early 2005

- Latest results from HAPPEx-II:
  - HAPPEx-hydrogen and HAPPEx-Helium

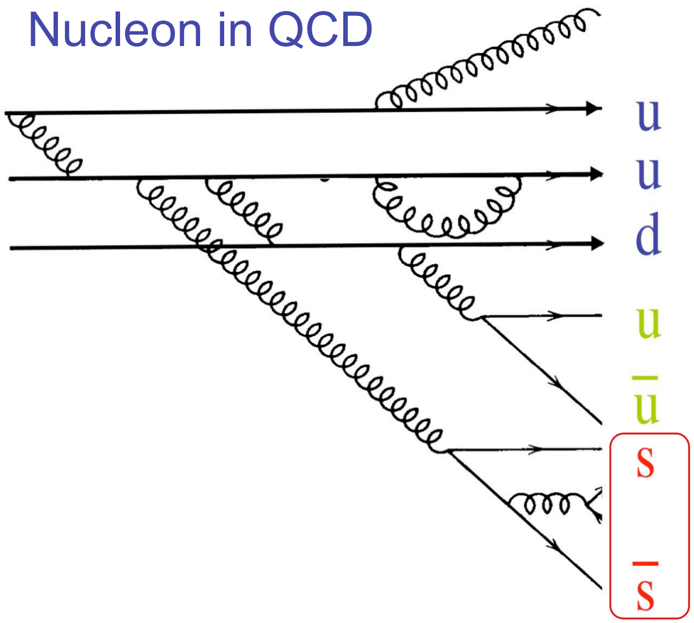
- The present situation at Q^2 = 0.1 $(GeV/c)^2$
- Implications and Conclusions

"*There is no excellent beauty that hath not some strangeness in the proportion*"

Francis Bacon 1561-1626

Strangeness in the nucleon

Nucleon in QCD



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

- s quark: cleanest candidate to study the sea

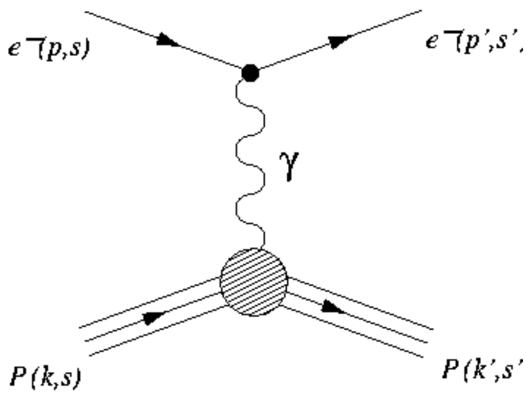
-)How much do virtual $s\bar{s}$ pairs contribute
  to the structure of the nucleon ?
  Momentum : 4 % (DIS)
  Spin : 0 to -10% (polarized DIS)
  Mass : 0 to 30 % (πN -sigma term)
  (large uncertainties on these contributions)

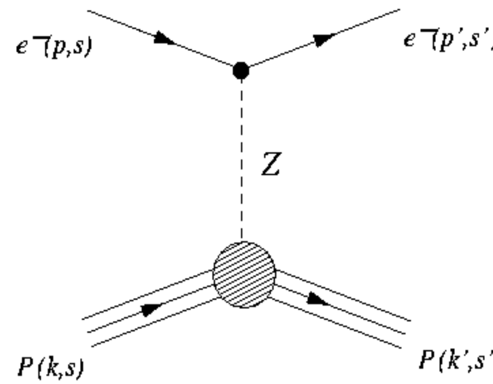
Goal: Determine the contributions of the strange quark sea ($s\bar{s}$) to the charge and current/spin distributions in the nucleon :

"strange form factors" G^s_E and G^s_M

Parity Violating Electron Scattering

⇒ Weak NC Amplitudes





$$M^{EM} = \frac{4\pi\alpha}{Q^2} Q_l \, \ell^{\mu} J_{\mu}^{EM} \qquad M_{PV}^{NC} = \frac{G_F}{2\sqrt{2}}\left[g_A \ell^{\mu 5} J_{\mu}^{NC} + g_V \ell^{\mu} J_{\mu 5}^{NC}\right]$$

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

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

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

Tiny (~10^{-6}) cross section asymmetry isolates weak interaction

Form Factors

$$J_\mu^{EM} = \sum_q Q_q \langle \overline{N} | \overline{u}_q \gamma_\mu u_q | N \rangle = \overline{N} \left[\gamma_\mu F_1^\gamma + \frac{i\sigma_{\mu\nu} q^\nu}{2M_N} F_2^\gamma \right] N$$

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

(Roughly: Fourier transforms of charge and magnetization)

NC probes 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 new benchmark for testing non-perturbative QCD structure of the nucleon

Charge Symmetry

One expects the neutron to be an isospin rotation of the proton*:

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

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

$G^{\gamma p}_{E,M}$ $G^{\gamma n}_{E,M}$ $G^{Z,p}_{E,M}$	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 → $G^{p}_{E,M}$, $G^{n}_{E,M}$

$\langle N| s\gamma s |N\rangle$ → $G^{s}_{E,M}$

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

* See B.Kubis & R. Lewis nucl-th/0605006 & Randy Lewis' talk at this meeting

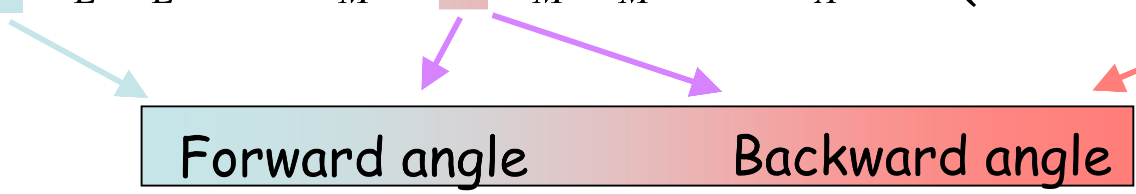
Isolating the form factors:
vary the *kinematics* or *target*

For a proton:

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

~ few parts per million

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



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

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

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 deuterium:

enhanced G_A^e sensitivity

Theoretical Approaches to Strange Form Factors

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, …

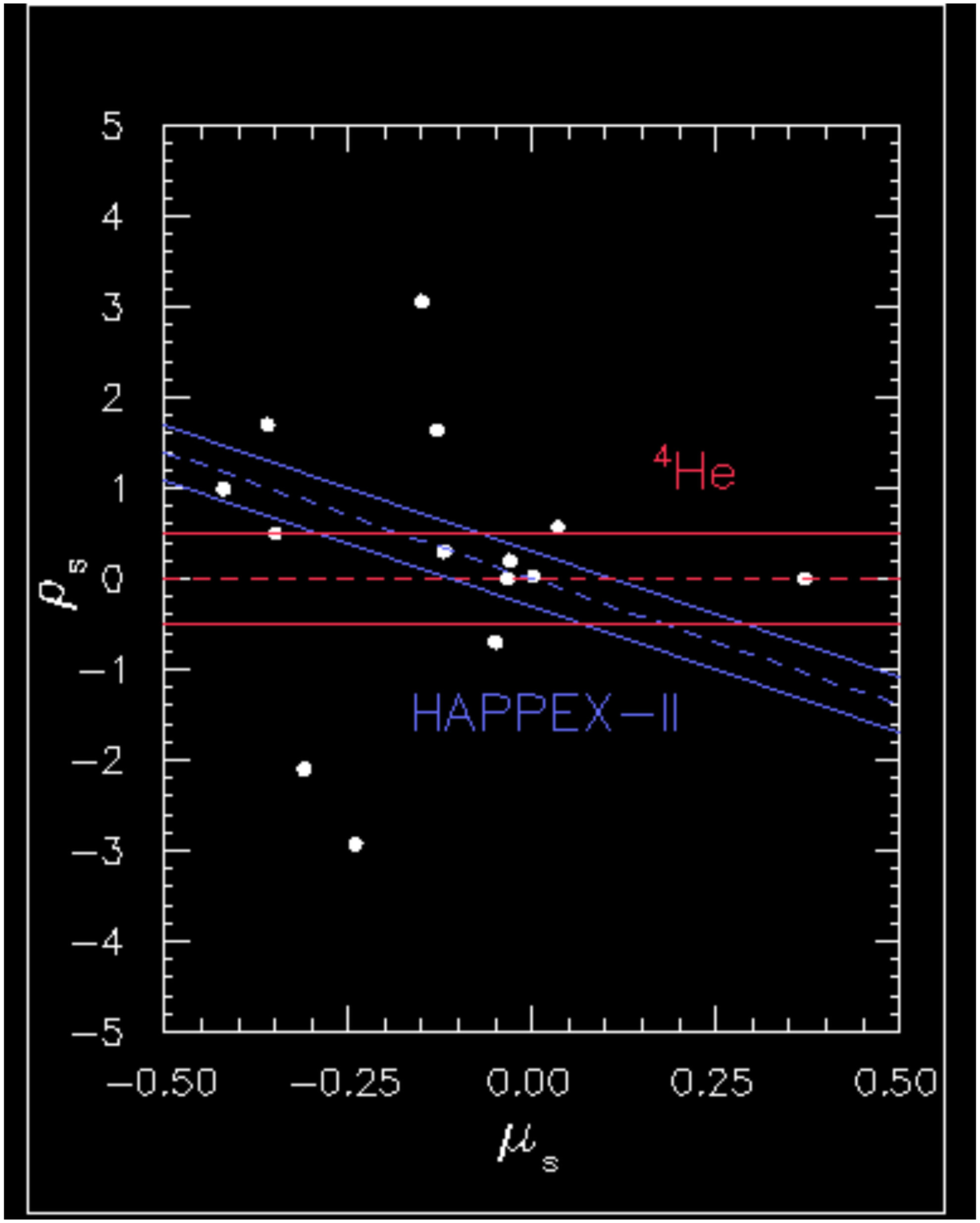
- no consensus on magnitudes or even *signs* of $G^s{}_E$ and $G^s{}_M$!

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 *and* hep-lat/0601025

Strangeness Models (as/of 2000)

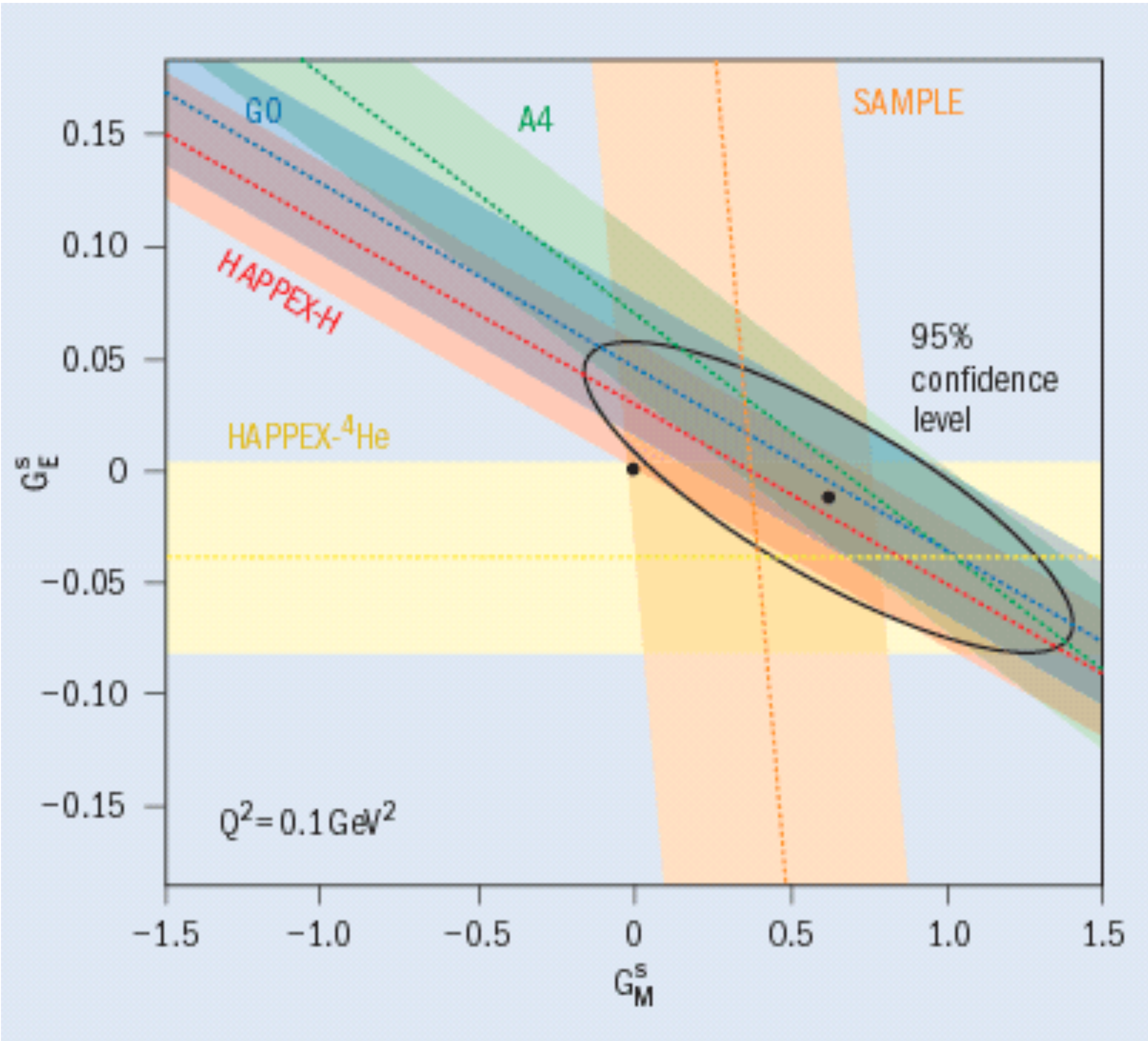


Leading moments of form factors:

$\mu_s = G_M^s(Q^2=0)$

$\rho_s = \partial G_E^s/\partial\tau\,(Q^2=0)$

World Data (early 2005) at $Q^2 \sim 0.1$ GeV^2



$G_E^s = -0.12 \pm 0.29$

$G_M^s = 0.62 \pm 0.32$

Would imply that 5-10% of nucleon magnetic moment is *Strange*

Caution: the combined fit is approximate. Correlated errors and assumptions not taken into account

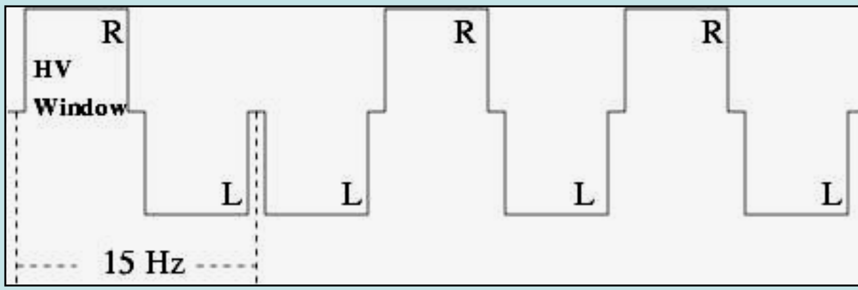
Measurement of P-V Asymmetries

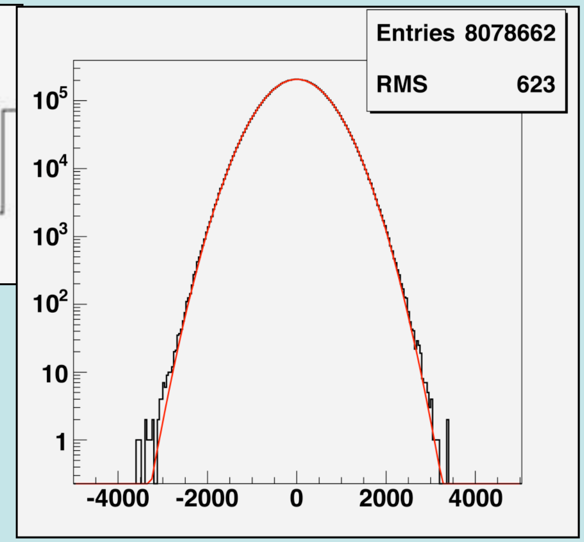
$$A_{LR} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \approx 10^{-6}$$

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)
- Polarized source uses optical pumping of strained photocathode: high polarization and rapid flip

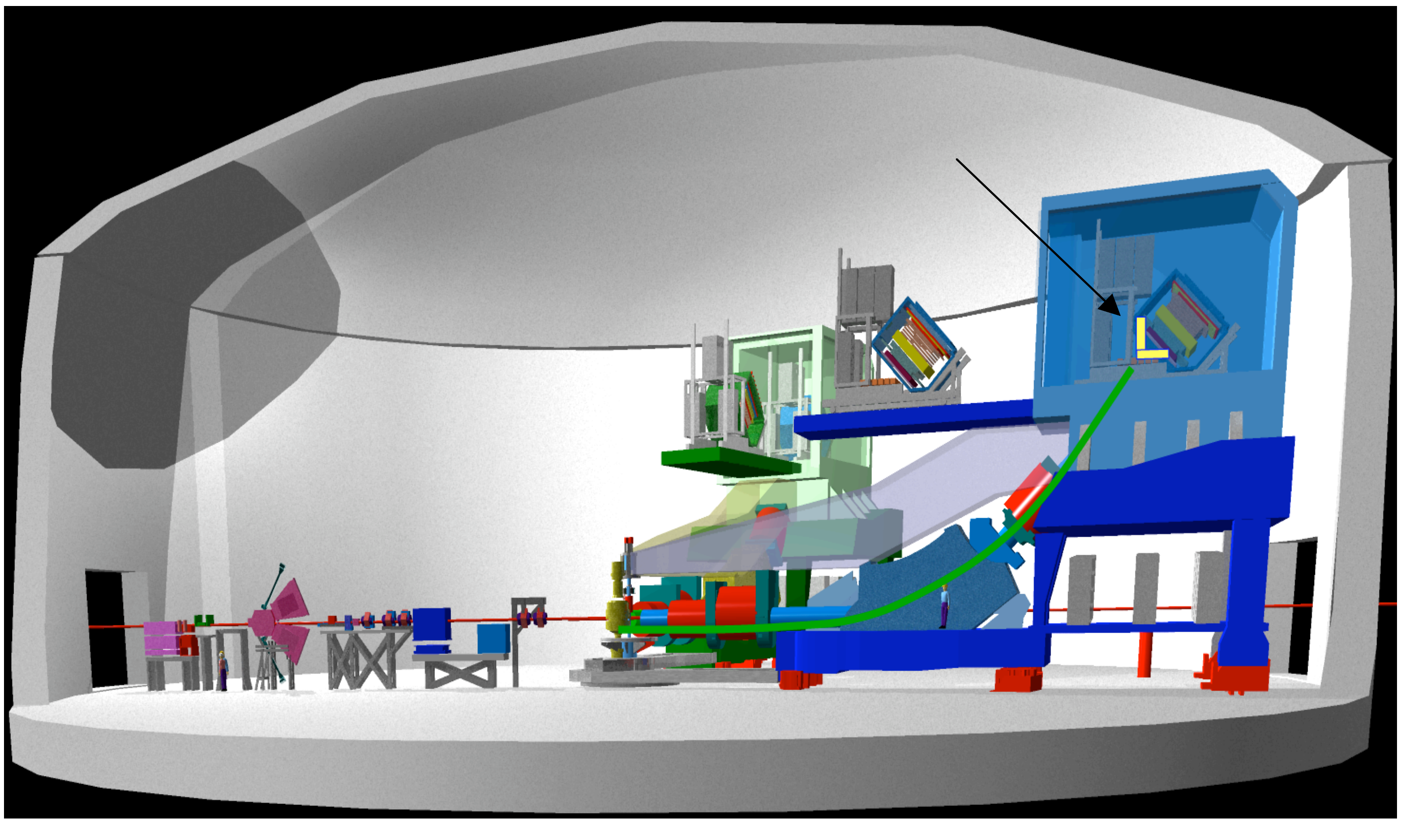
Statistics: high rate, low noise
Systematics: beam asymmetries, backgrounds, Helicity correlated DAQ
Normalization: Polarization, Linearity, Background

HAPPEX (second generation)

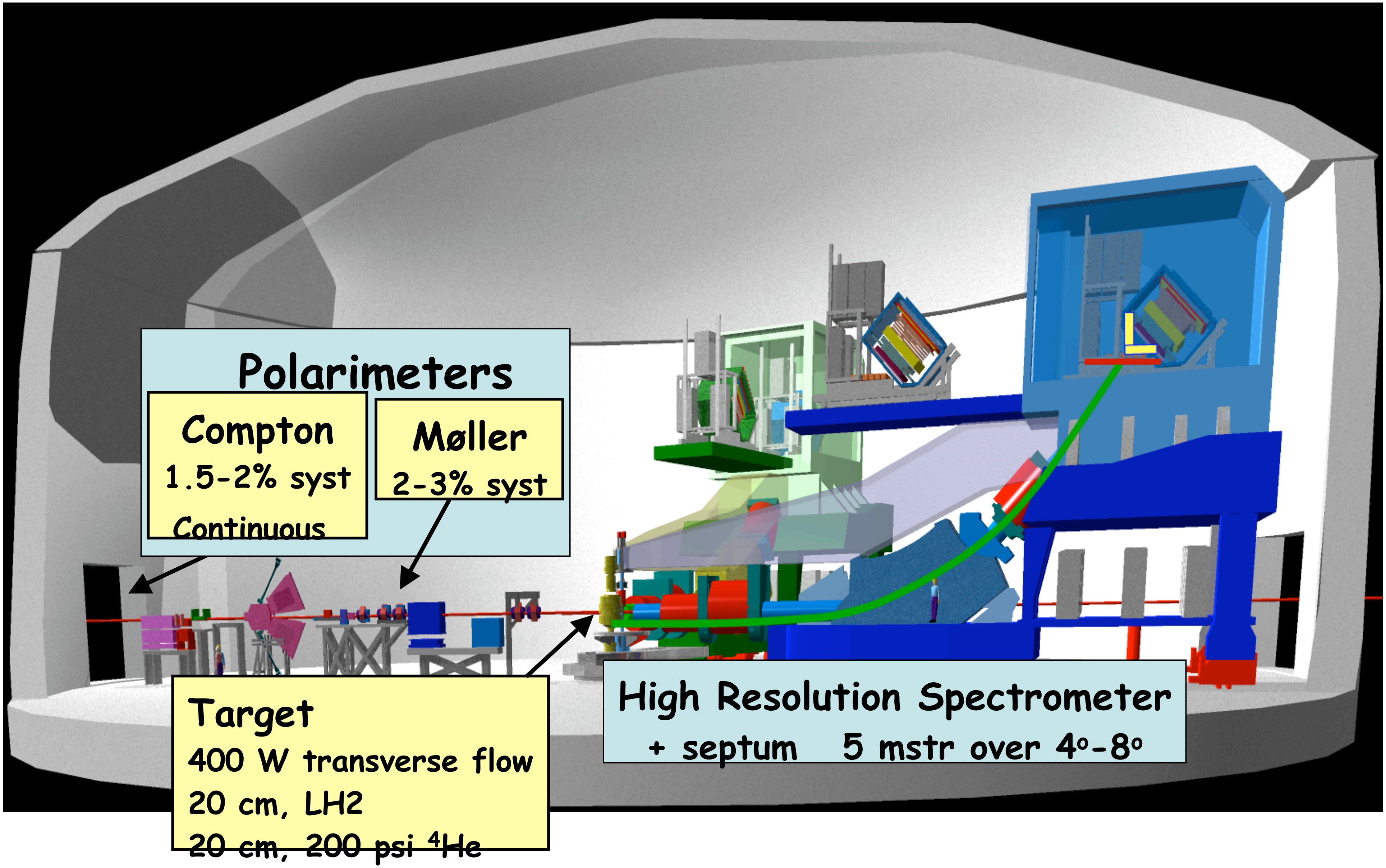
E=3 GeV θ=6° Q^2= 0.1 $(GeV/c)^2$

New results: just released *(P. Souder at Dallas APS meeting)*

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



Hall A

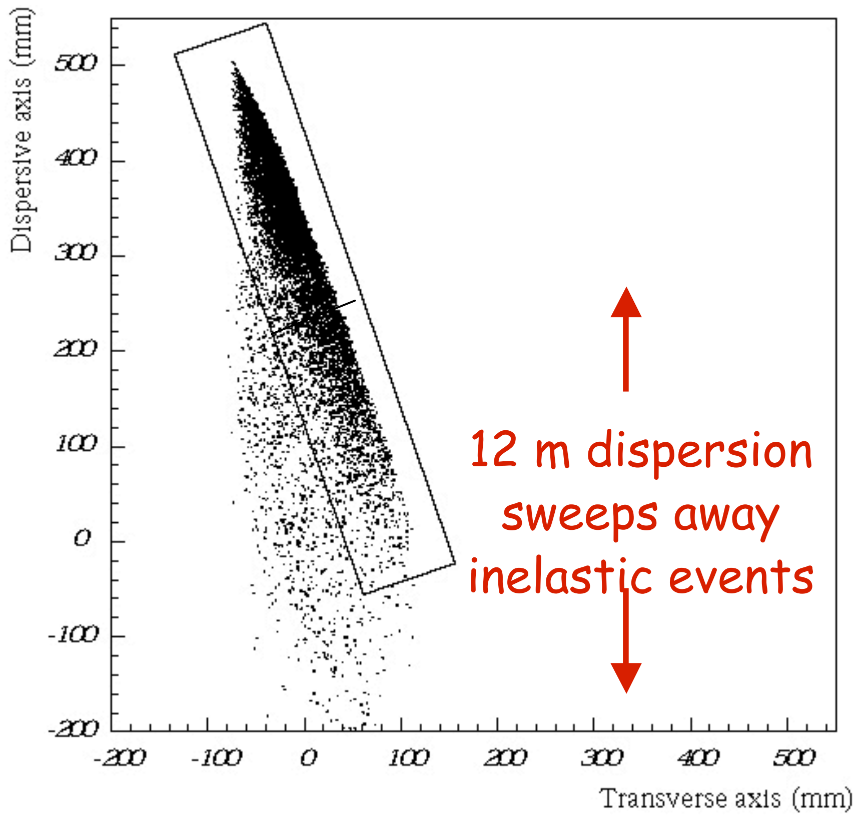

Polarimeters
Compton
1.5-2% syst
Continuous
Møller
2-3% syst
Target
400 W transverse flow
20 cm, LH2
20 cm, 200 psi 4He
High Resolution Spectrometer
+ septum 5 mstr over 4°-8°

Summary of Data Runs: HAPPEX-II

June 2004	HAPPEX-He • about 3M pairs at 1300 ppm => □A_{stat} ~ 0.74 ppm
June – July 2004	HAPPEX-H • about 9M pairs at 620 ppm => □A_{stat} ~ 0.2 ppm
July-Sept 2005	HAPPEX-He • about 35M pairs at 1130 ppm => □A_{stat} ~ 0.19 ppm
Oct – Nov 2005	HAPPEX-H • about 25M pairs at 540 ppm => □A_{stat} ~ 0.105 ppm

High Resolution Spectrometers

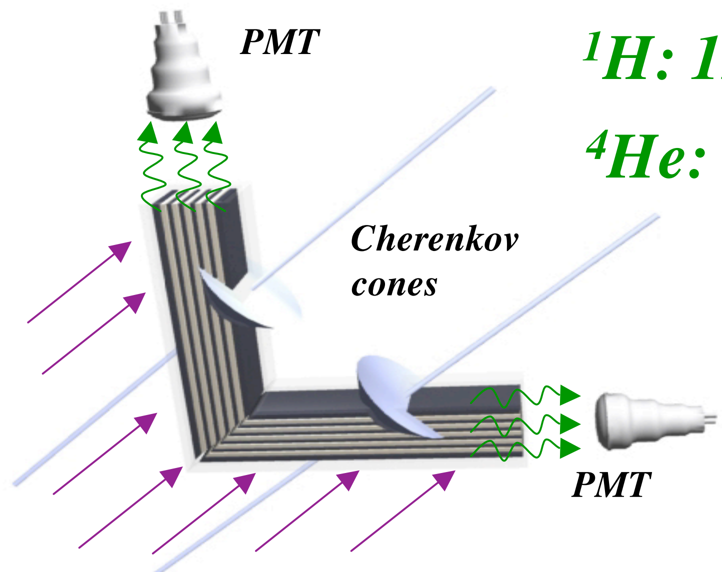
Clean separation of elastic events by HRS optics → Locate detector over elastic line and integrate the flux



Elastic Rate:

^{1}H: 120 MHz

^{4}He: 12 MHz



Brass-Quartz Integrating Cerenkov Shower Calorimeter

Large dispersion & heavy shielding reduce backgrounds at focal plane

Correcting Beam Asymmetries

$$A_{raw} = A_{det} - A_Q + \Sigma_{i=1,5} \alpha_i \Delta x_i$$

Slopes from

- **natural beam jitter (regression)**
- **beam modulation (dithering)**

Independent methods provide a cross-check.
Each is subject to different systematic errors.

Regression:

- Natural beam motion, measure $dA/d\Delta x_i$
- Simultaneous fit establishes independent sensitivities
- By definition, removes correlation of asymmetry to beam *monitors*
- Sensitive to highly correlated beam motion and electronics noise

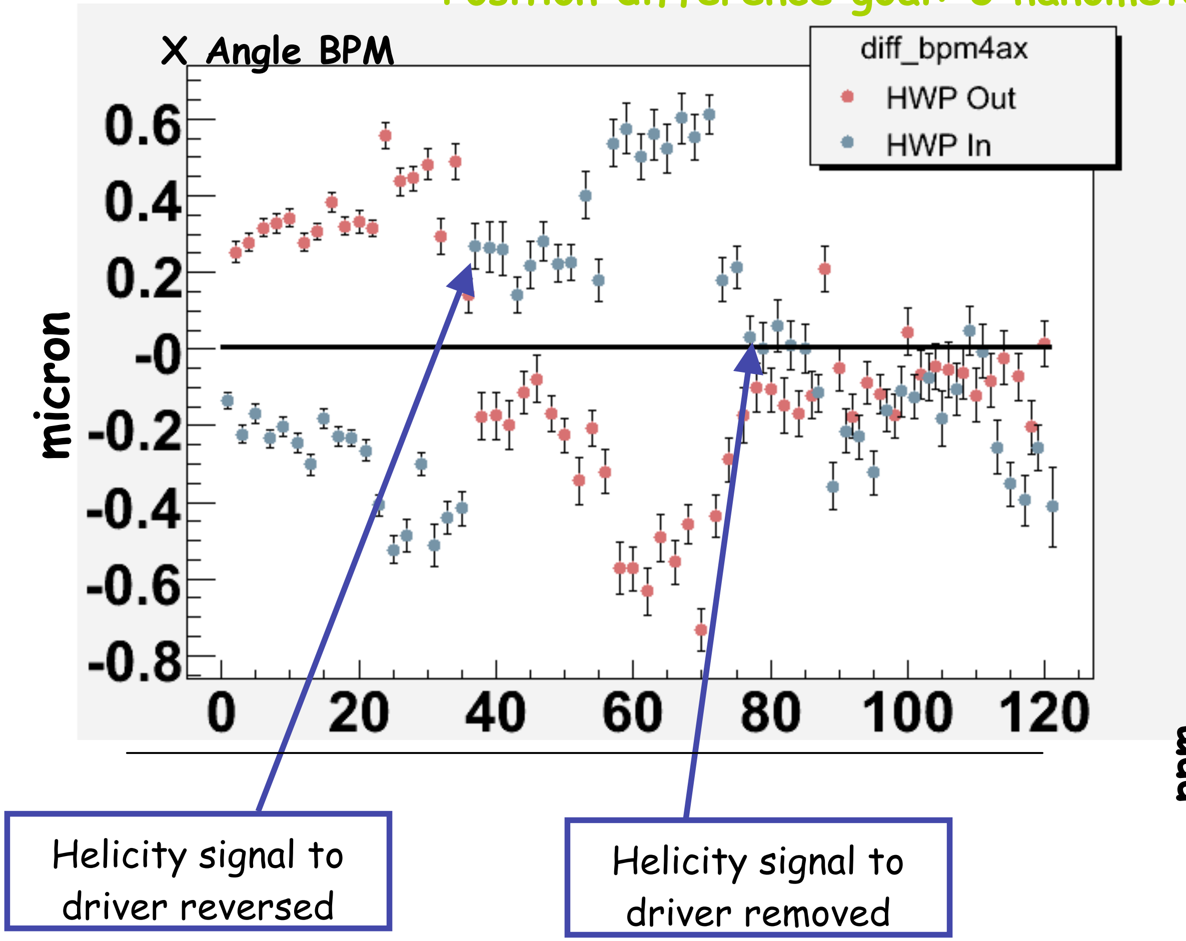
"Dithering":

- Induce non-HC beam motion with coils, measure dS/dC_i, dx_i/dC_i
- Relate slopes to dS/dx_i
- Not compromised by correlated beam motion
- Robust, clear signals for failures
- Sensitive to non-linearities

⇨ See Kent Paschke's talk

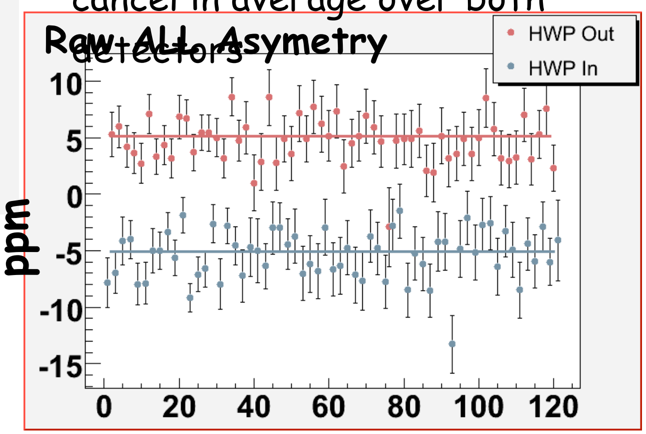
Beam Position Differences, Helium

Position difference goal: 3 nanometers!



All's well that ends well

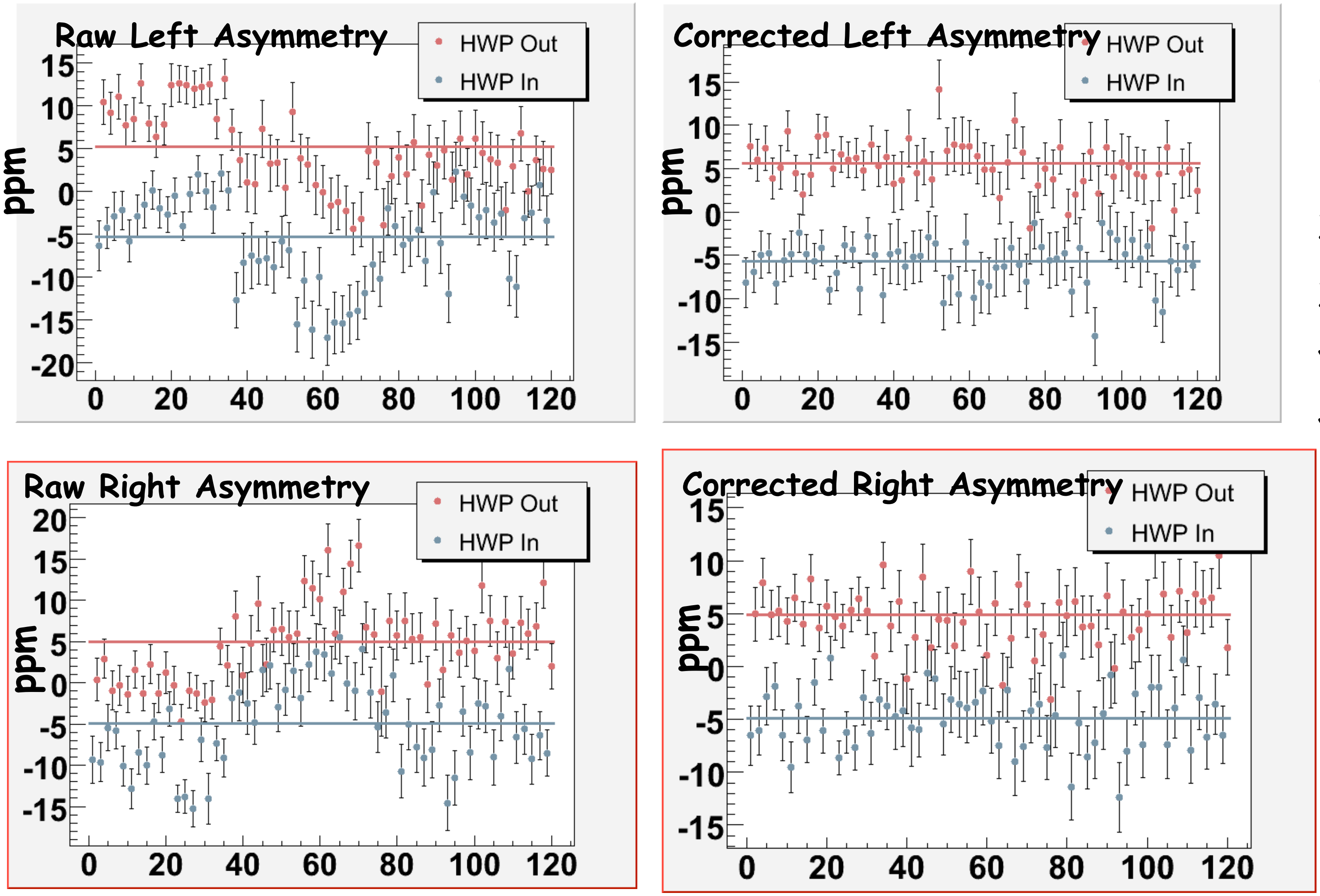
- Problem clearly identified as beam steering from electronic cross-talk
- No helicity-correlated electronics noise in Hall DAQ at < ppb level
- Large position differences → cancel in average over both detectors



Problem: Helicity signal deflecting the beam through electronics "pickup"

Large beam deflections even when Pockels cell is off

Beam Position Corrections, Helium



Beam Asymmetries

Energy: -3ppb

X Target: -5 nm

X Angle: -28 nm

Y Target :-21 nm

Y Angle: 1 nm

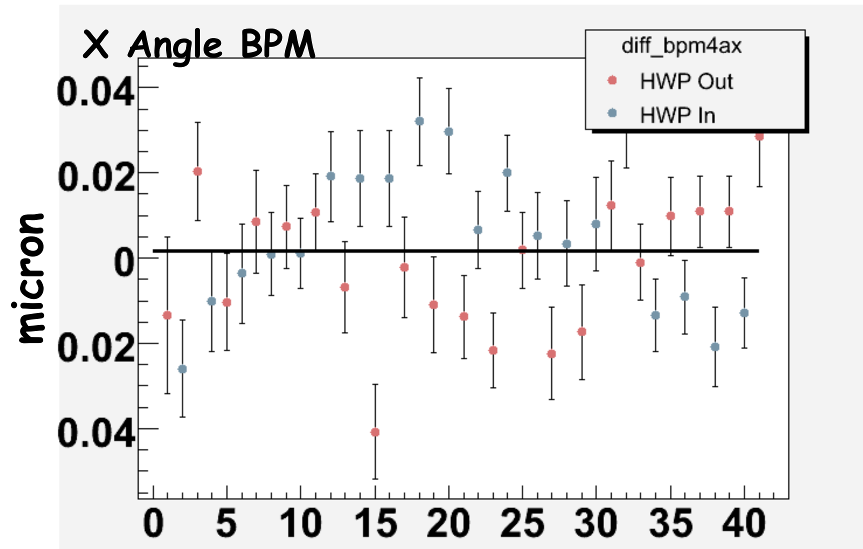
Total Corrections:

Left: -370 ppb

Right: 80 ppb

All: 120 ppb

Beam Position Corrections, Hydrogen



Surpassed Beam Asymmetry Goals for Hydrogen Run

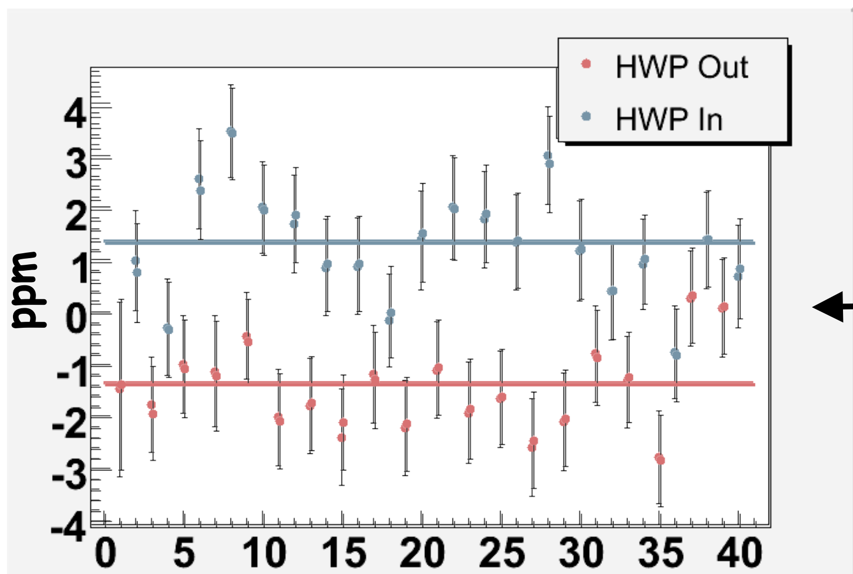
Energy: -0.25 ppb

X Target: 1 nm

X Angle: 2 nm

Y Target : 1 nm

Y Angle: <1 nm



Corrected and Raw, Left arm alone,

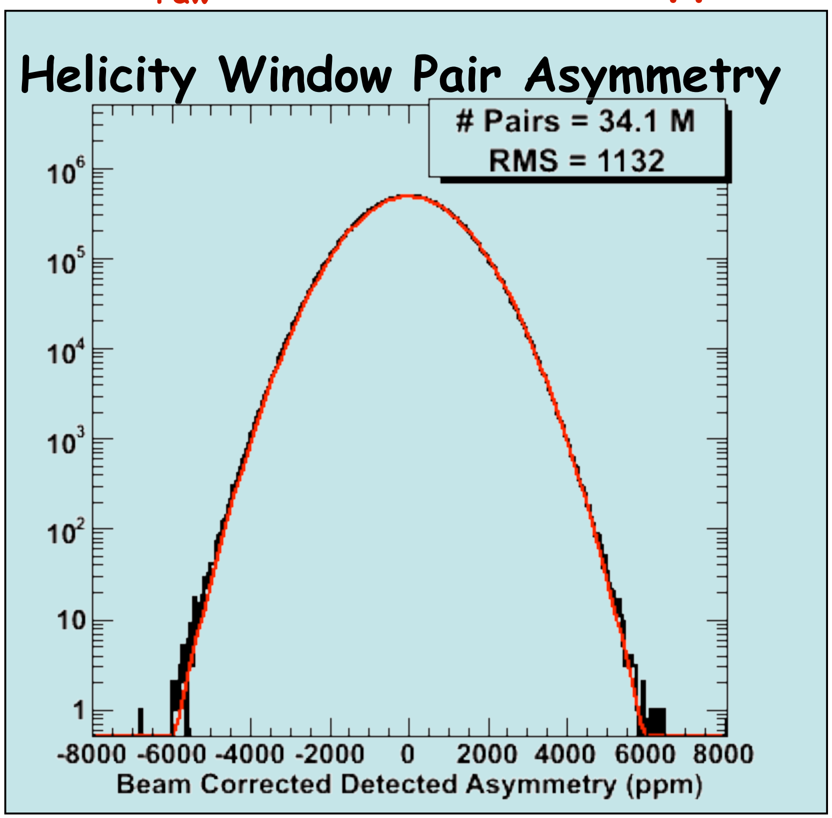
Superimposed!

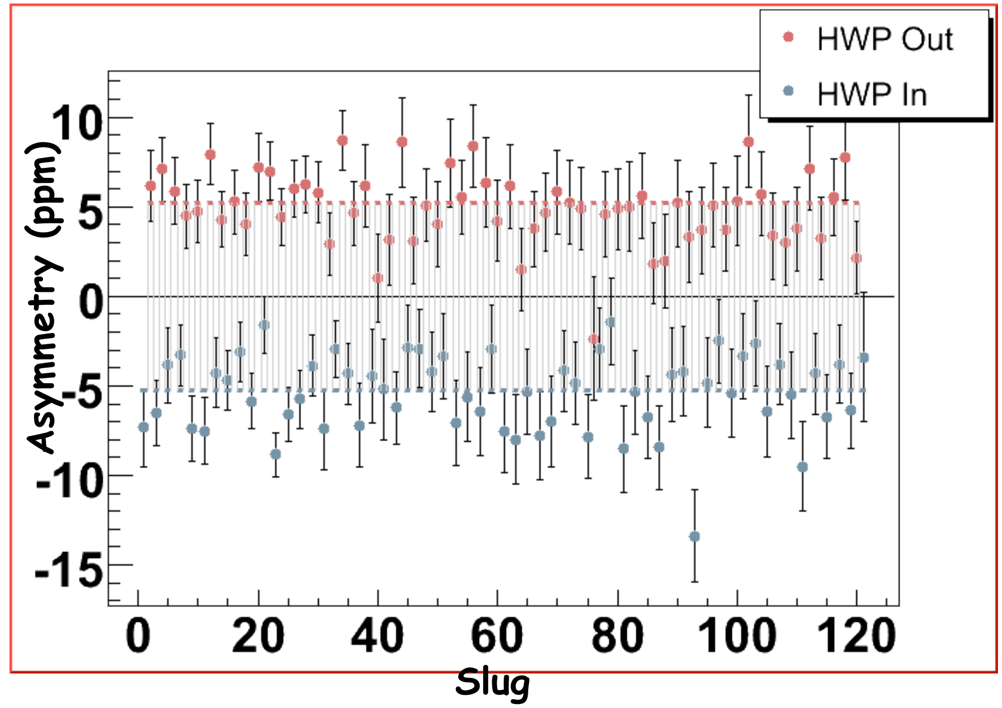
Total correction for beam position asymmetry on Left, Right, or ALL detector: 10 ppb

^{4}He Preliminary Results

Raw Parity Violating Asymmetry

A_{raw} correction ~ 0.12 ppm





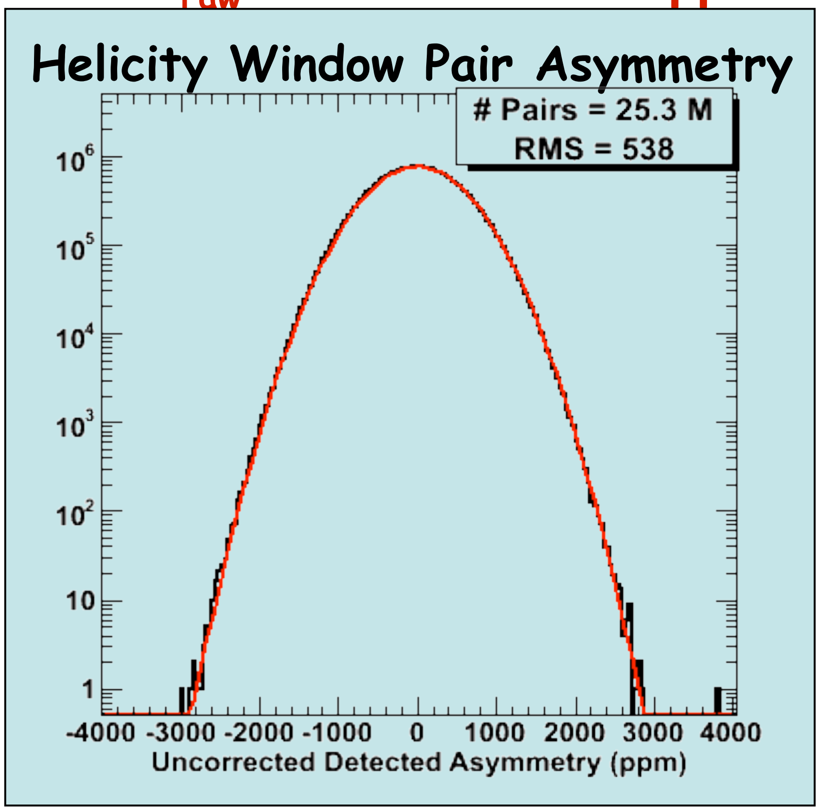
Q^2 = 0.07725 ± 0.0007 GeV^2

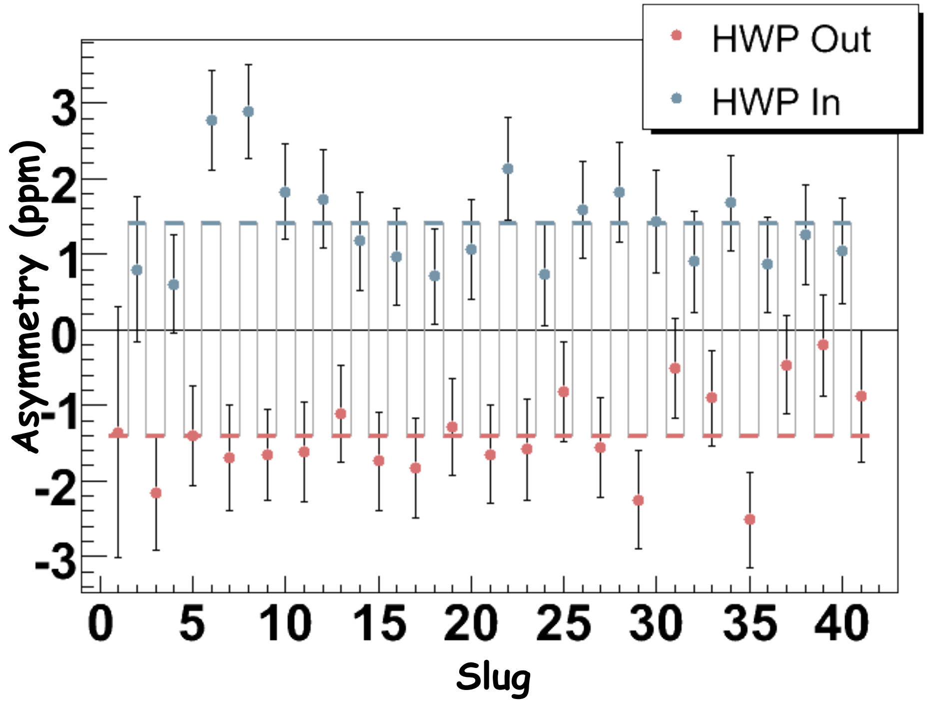
A_{raw} = 5.253 ppm ± 0.191 ppm (stat)

^{1}H Preliminary Results

Raw Parity Violating Asymmetry

A_{raw} correction ~11 ppb

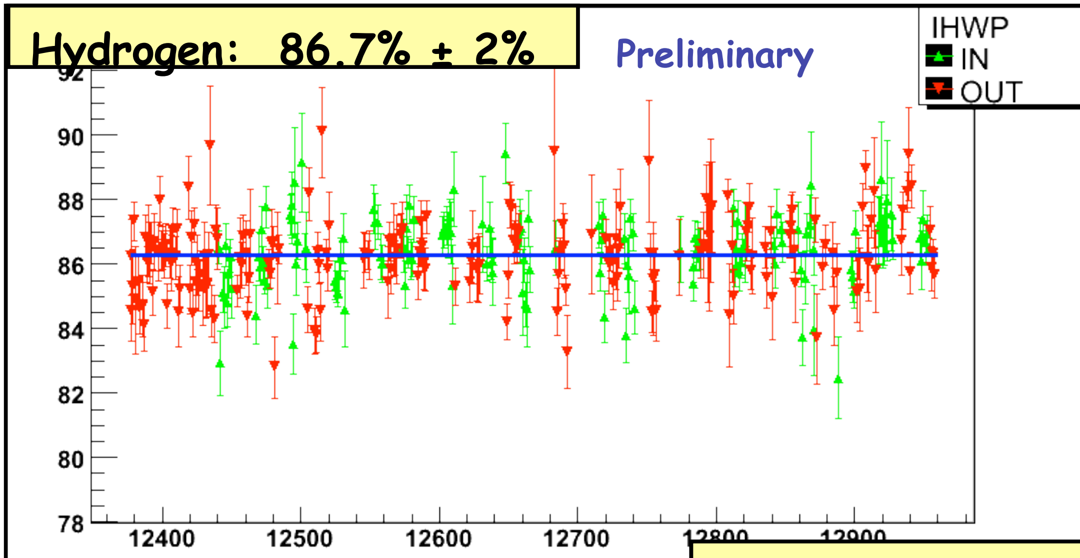




$Q^2 = 0.1089 \pm 0.0011 GeV^2$

$A_{raw} = -1.418$ ppm $\pm$ 0.105 ppm (stat)

Compton Polarimetry

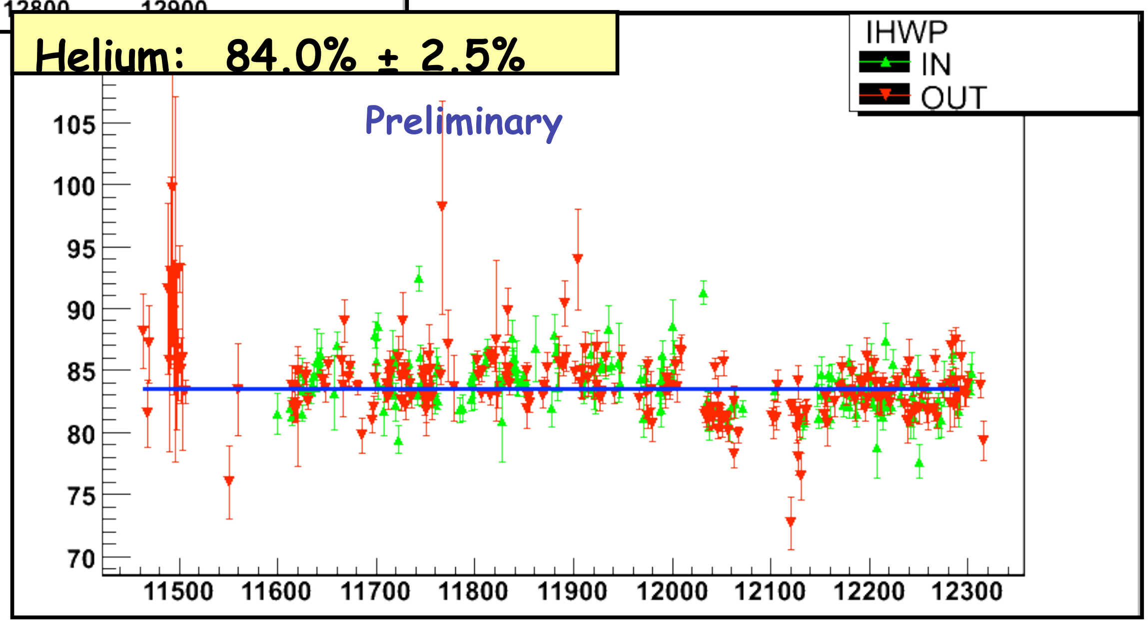


Continuous, non-invasive

Here : Electron Detector analysis

Cross-checked with Møller, Mott polarimeters

also: independent electron analysis



Helium ran with lower beam energy, making the analysis significantly more challenging.

New developments in both photon and electron analyses in preparation: anticipate <2% systematic uncertainty

Miscellany

- Backgrounds: ⇨ Bryan Moffit's talk

Dilutions:	2.2% (^4He)	0.8% (^1H)
Systematic	60 ppb (^4He)	16 ppb (^1H)

- Q^2 & effective kinematics: □Q^2 < 1.0% ⇨ Bryan Moffit's talk

- Two-photon exchange corrections:

  small ⇨ Marc Vanderhaeghan's talk (no explicit correction made)

- Transverse asymmetry:

  measured directly in dedicated runs, □cancels in left-right sum;

  Systematic: 4 ppb (^1H) 8 ppb (^4He) ⇨ Lisa Kaufmann's talk

- Electromagnetic Form Factors: use Friedrich & Walcher parameterization, Eur. Phys. J. A, **17**, 607 (2003), and BLAST data for G_E^n
- Axial Form Factor: highly suppressed for ^1H (not present for ^4He)
- Vector Electroweak Radiative Corrections: Particle Data Group

- Blinded Analysis

4He: Nuclear Effects

- Any one body operator:

HAPPEx

Error Budget-Helium

2005

False Asymmetries	48 ppb
Polarization	192 ppb
Linearity	58 ppb
Radiative Corrections	6 ppb
Q^2 Uncertainty	58 ppb
Al background	32 ppb
Helium quasi-elastic background	24 ppb
Total	216 ppb

2004

False Asymmetries	103 ppb
Polarization	115 ppb
Linearity	78 ppb
Radiative Corrections	7 ppb
Q^2 Uncertainty	66 ppb
Al background	14 ppb
Helium quasi-elastic background	86 ppb
Total	205 ppb

Error Budget-Hydrogen

2005

False Asymmetries	17 ppb
Polarization	37 ppb
Linearity	15 ppb
Radiative Corrections	3 ppb
Q^2 Uncertainty	16 ppb
Al background	15 ppb
Rescattering Background	4 ppb
Total	49 ppb

2004

False Asymmetries	43 ppb
Polarization	23 ppb
Linearity	15 ppb
Radiative Corrections	7 ppb
Q^2 Uncertainty	12 ppb
Al background	16 ppb
Rescattering Background	32 ppb
Total	63 ppb

HAPPEX-II 2005 Preliminary Results

HAPPEX-^{4}He:

$Q^2 = 0.0772 \pm 0.0007\ (GeV/c)^2$

$A_{PV} = +6.43 \pm 0.23\ (stat) \pm 0.22\ (syst)\ ppm$

$A(G^s=0) = +6.37\ ppm$

$G^s_E = 0.004 \pm 0.014_{(stat)} \pm 0.013_{(syst)}$

HAPPEX-H:

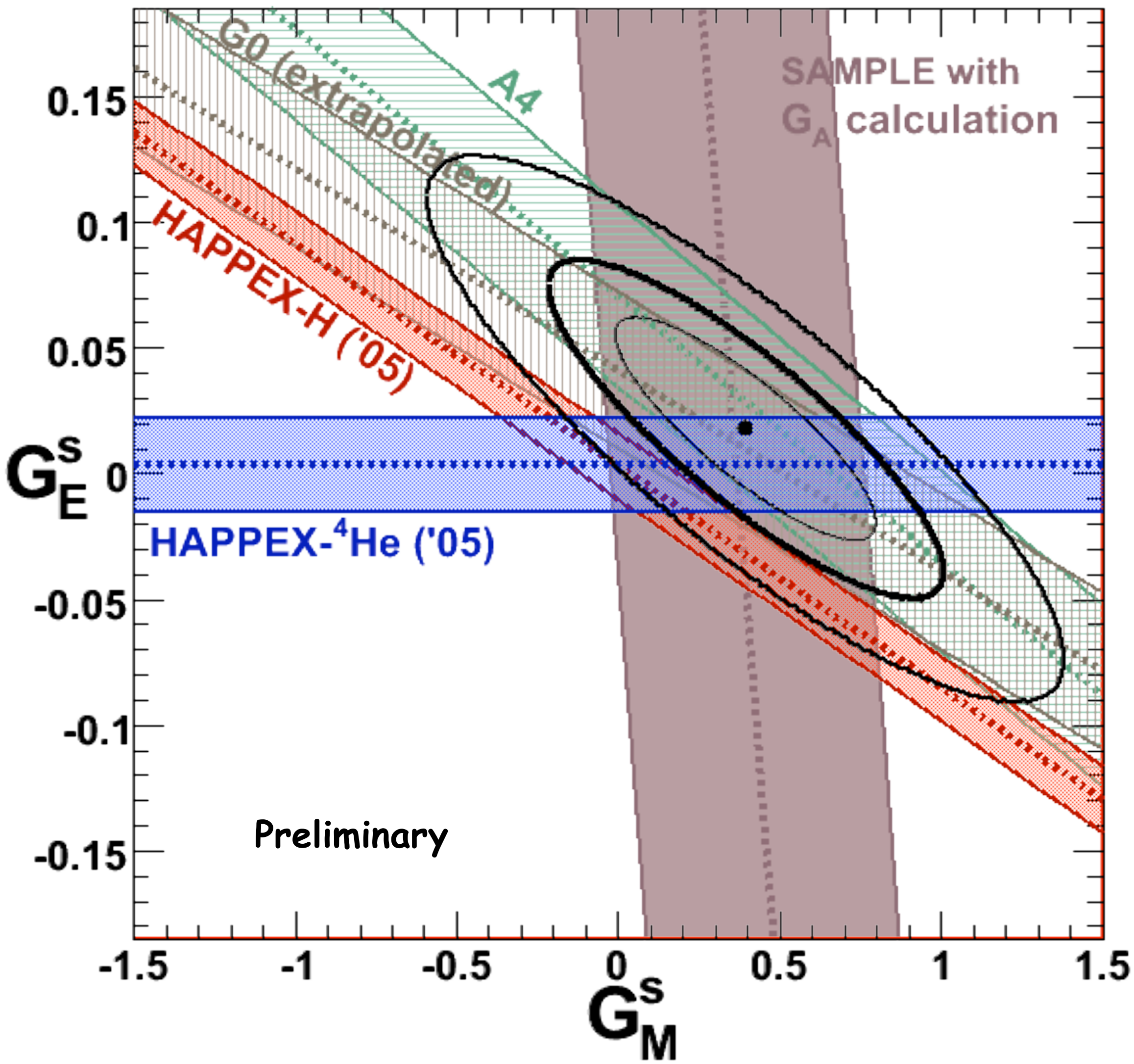
$Q^2 = 0.1089 \pm 0.0011\ (GeV/c)^2$

$A_{PV} = -1.60 \pm 0.12\ (stat) \pm 0.05\ (syst)\ ppm$

$A(G^s=0) = -1.640\ ppm \pm 0.041\ ppm$

$G^s_E + 0.088\ G^s_M = 0.004 \pm 0.011_{(stat)} \pm 0.005_{(syst)} \pm 0.004_{(FF)}$

HAPPEX-II 2005 Preliminary Results

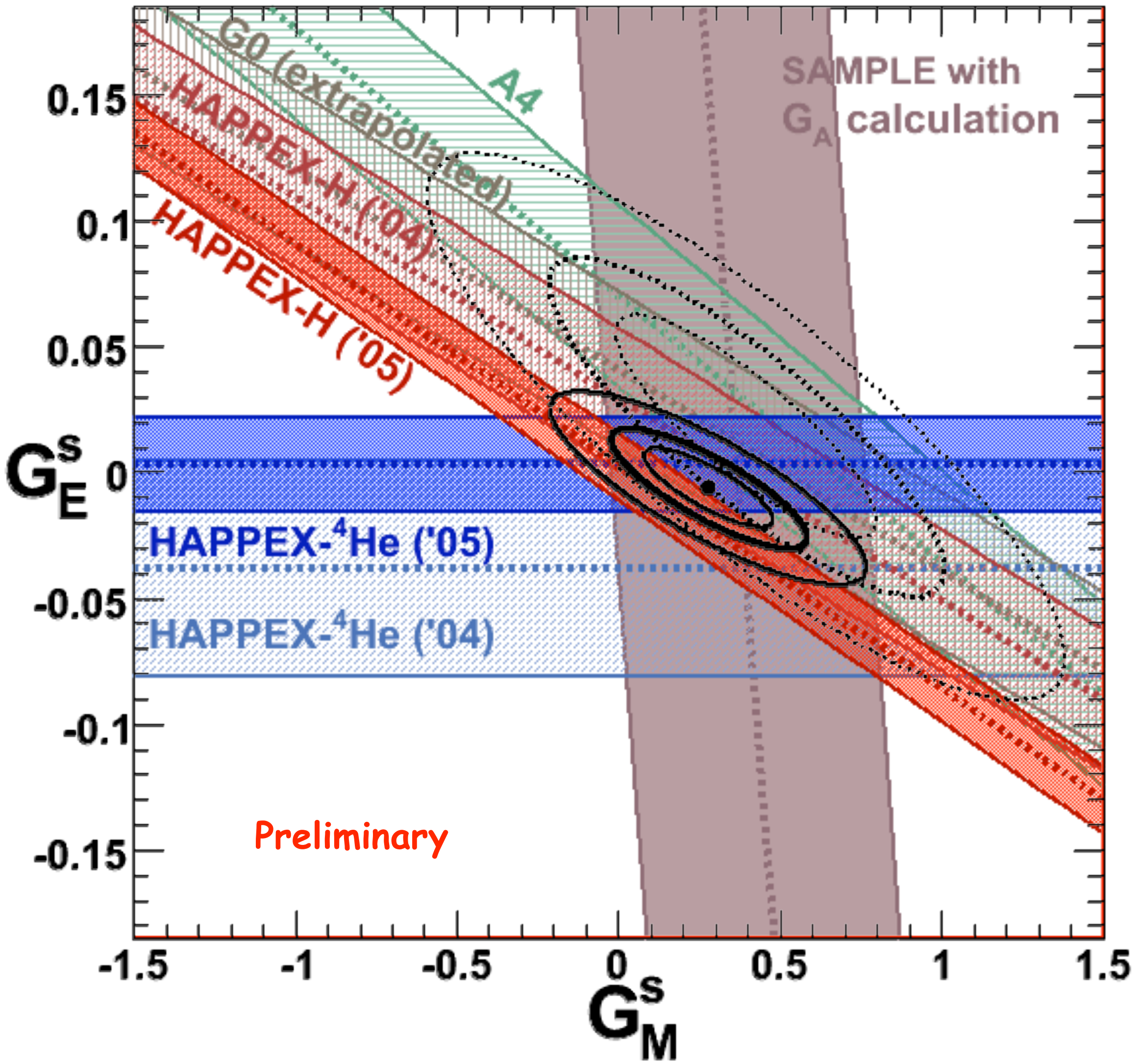


Three bands:

1. Inner: Project to axis for 1-D error bar
2. Middle: 68% probability contour
3. Outer: 95% probability contour

Caution: the combined fit is approximate. Correlated errors and assumptions not taken into account

World Data near Q^2 ~0.1 GeV^2



G_M^s = 0.28 +/- 0.20

G_E^s = -0.006 +/- 0.016

~3% +/- 2.3% of proton magnetic moment

~0.2 +/- 0.5% of electric distribution

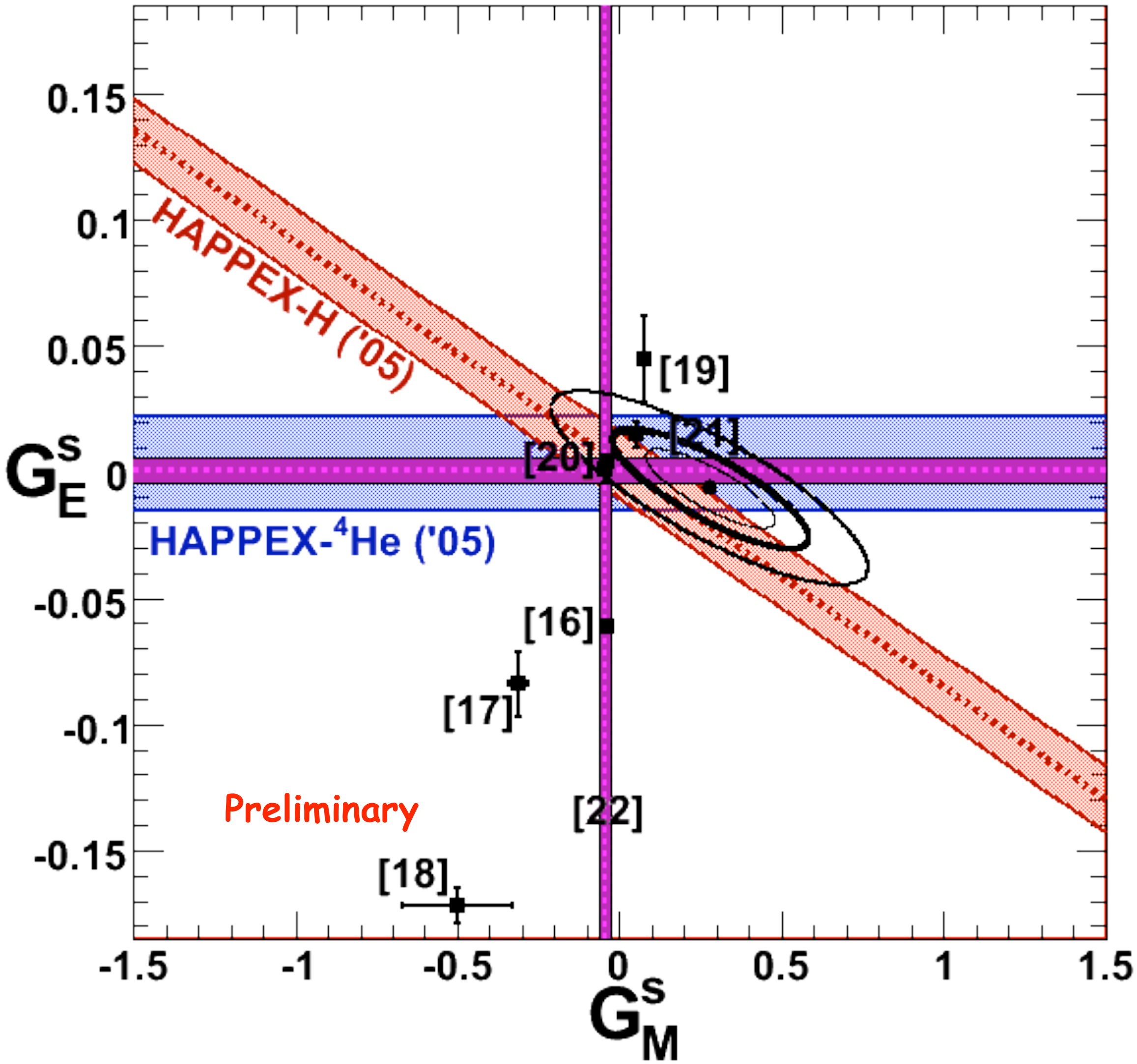
HAPPEX-only fit suggests something even smaller:

G_M^s = 0.12 +/- 0.24

G_E^s = -0.002 +/- 0.017

Caution: the combined fit is approximate. Correlated errors and assumptions not taken into account

World data consistent with state of the art theoretical predictions



16. **Skyrme Model** - N.W. Park and H. Weigel, Nucl. Phys. A **451**, 453 (1992).
17. **Dispersion Relation** - H.W. Hammer, U.G. Meissner, D. Drechsel, Phys. Lett. B **367**, 323 (1996).
18. **Dispersion Relation** - H.-W. Hammer and Ramsey-Musolf, Phys. Rev. C **60**, 045204 (1999).
19. **Chiral Quark Soliton Model** - A. Sliva *et al.*, Phys. Rev. D **65**, 014015 (2001).
20. **Perturbative Chiral Quark Model** - V. Lyubovitskij *et al.*, Phys. Rev. C **66**, 055204 (2002).
21. **Lattice** - R. Lewis *et al.*, Phys. Rev. D **67**, 013003 (2003).
22. **Lattice + charge symmetry** - Leinweber et al., Phys. Rev. Lett. **94**, 212001 (2005) & hep-lat/0601025

See Ross Young's talk

A Global Fit: R.D. Young, et al. nucl-ex/0604010

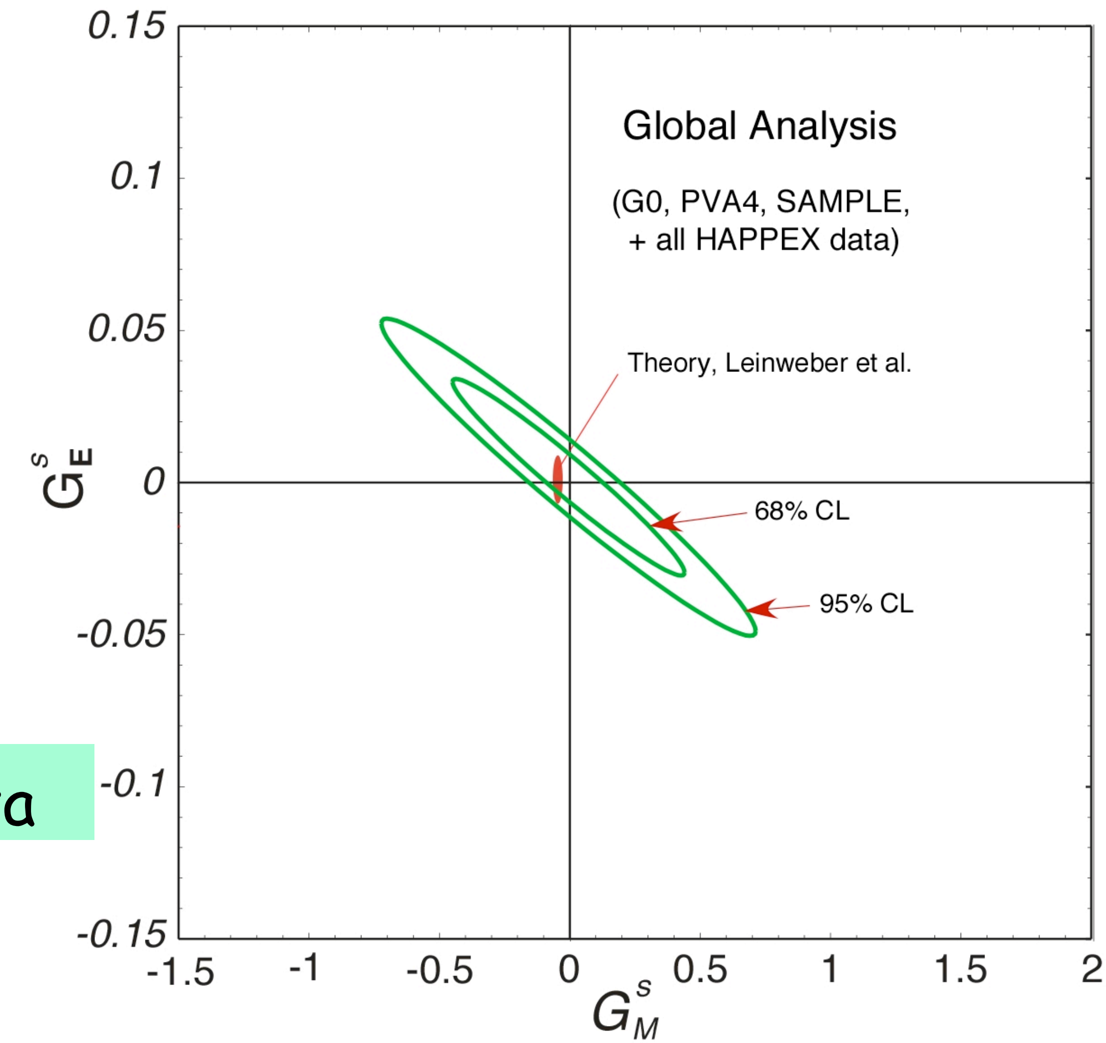
- all data $Q^2 < 0.3$, leading moments of G_E^s , G_M^s

- Kelly's EMF

- Float G_A^e separately for neutron and proton

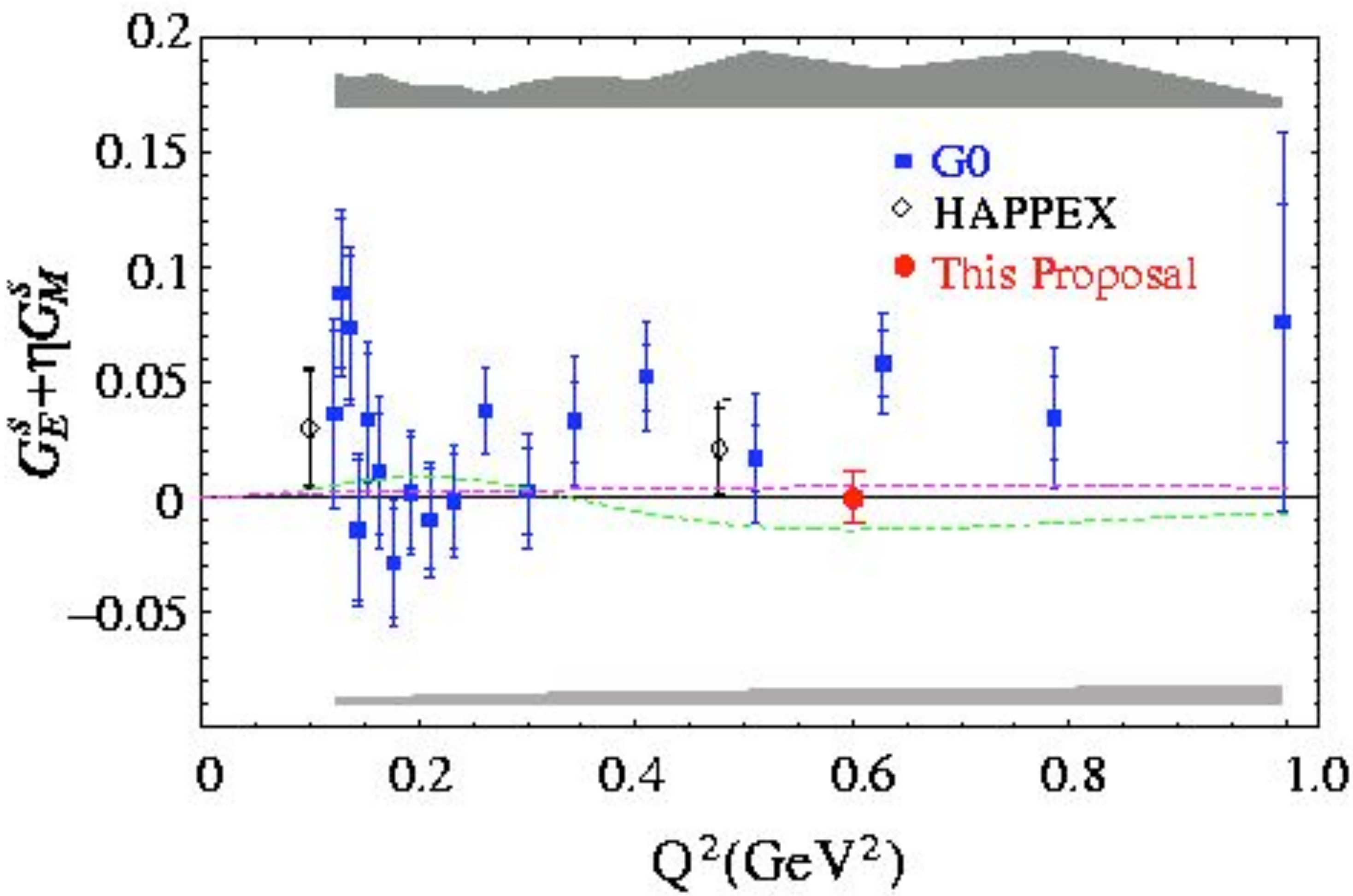
With HAPPEx-2005 data

data



Figures: courtesy of R. Carlini, R. Young

Future: HAPPEX-III (2008)



Paschke & Souder, E05-109

Conclusions

- *Marvelous* consistency of data, *esp.* at Q^2=0.1 GeV^2.
- Q^2 = 0.1 GeV^2 data: G^s_M and G^s_E consistent with zero;
  constraining axial FF to Zhu *et al.* theory favors positive G^s_M
- Still room (& hints?) for non-zero values at higher Q^2

Future of Strangeness form factors:

- G0 Backward: will allow G^s_M and G^s_E separation at two Q^2
- Mainz: PV-A4 backward-angle program well underway
- HAPPEx-III: high precision forward-angle @ Q^2 = 0.6 GeV^2

Backup Slides

Two Photon Exchange

1. Beyond single boson exchange in electroweak interference:
   - γγ and γZ box and crossing diagrams.
   - effects appear small at large ε and small Q^2
   - not a concern at present experimental precision.

Electromagnetic Form Factors used to extract strange form factors:

- which form factors to use?

Transverse Asymmetry/Beam normal asymmetry/Vector analyzing power:

- ☹ "background" to PV measurements, if electron beam not 100% longitudinal and detectors not perfectly symmetric.

Validity of charge symmetry assumption

$$u \leftrightarrow d$$

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

Size of charge symmetry breaking effects in some n,p observables:

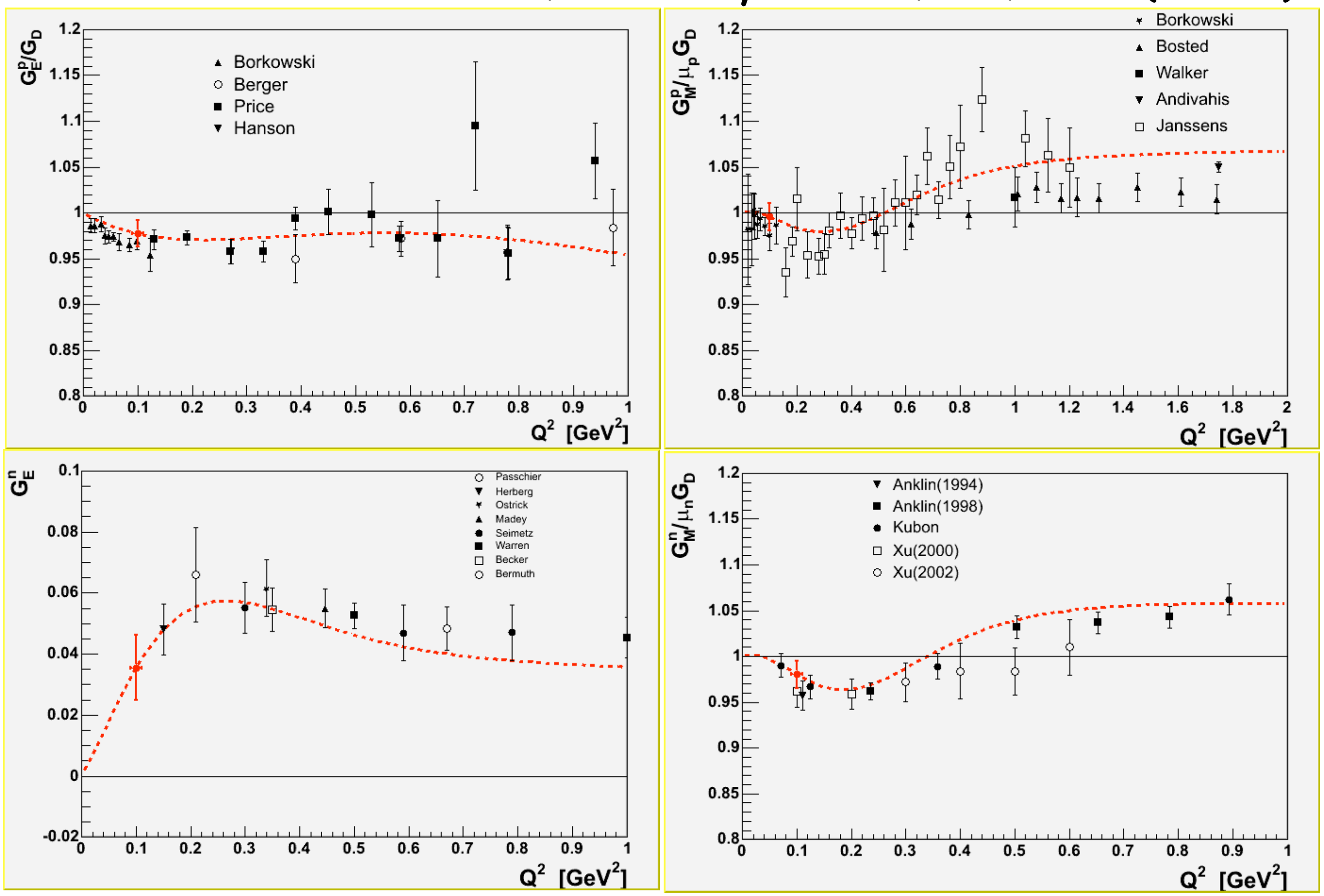
- n - p mass difference ⇒ $(m_n - m_p)/m_n \sim 0.14\%$
- polarized elastic scattering $\vec{n}$ + p, $\vec{p}$+n $\Delta A = A_n - A_p = (33 \pm 6) \times 10^{-4}$
  Vigdor et al, PRC 46, 410 (1992)
- Forward backward asymmetry n + p → d + π^0 $A_{fb} \sim (17 \pm 10) \times 10^{-4}$
  Opper et al, nucl-ex 0306027 (2003)

⇒ For vector FF: theoretical CSB estimates indicate < 1% violations -
Miller PRC **57**, 1492 (1998) Lewis & Mobed, PRD **59**, 073002(1999)

Very recent : effects could be large as statistical error on our data!
Kubis & Lewis nucl-th/0605006 and Randy Lewis' talk at this meeting

EM Form Factors

Electromagnetic form factors parameterized as by:
Friedrich and Walcher, Eur. Phys. J. A, **17**, 607 (2003)



GEn from BLAST:

Claimed uncertainty at 7-8%

FF	Error
G_E^p	2.5%
G_M^p	1.5%
G_E^n	10%
G_M^n	1.5%
$G_A^{(3)}$	-
$G_A^{(8)}$	-

HAPPEX (first generation)

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

$$A^{PV} = \left[\frac{-G_F M_p^2 \tau}{\pi\alpha\sqrt{2}}\right]\Big\{(1-4\sin^2\theta_W) - \frac{[\varepsilon G_E^{p\gamma}(G_E^{n\gamma} + \boxed{G_E^s}) + \tau G_M^{p\gamma}(G_M^{n\gamma} + \boxed{G_M^s})]}{\varepsilon(G_E^{p\gamma})^2 + \tau(G_M^{p\gamma})^2}\Big\} - A_A$$

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

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

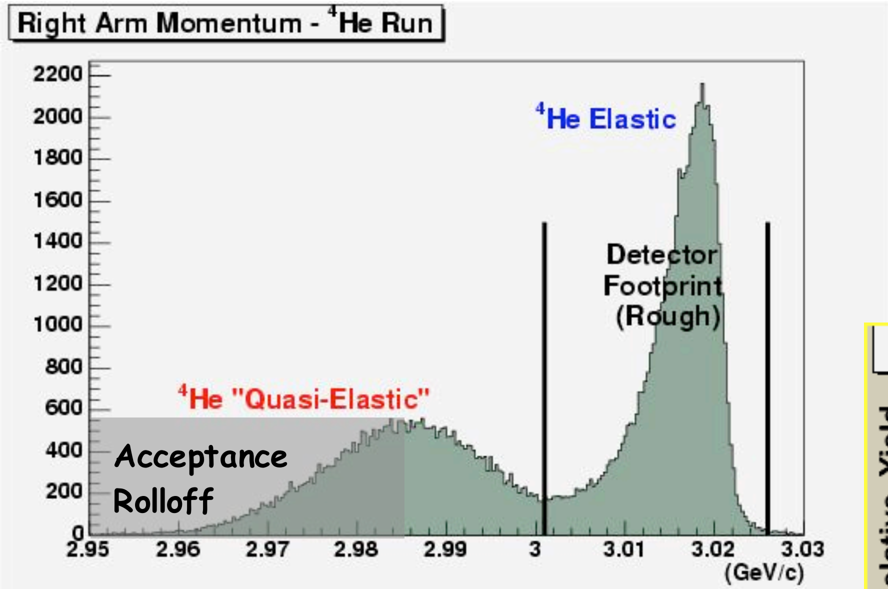
"Parity Quality" Beam @ JLab

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

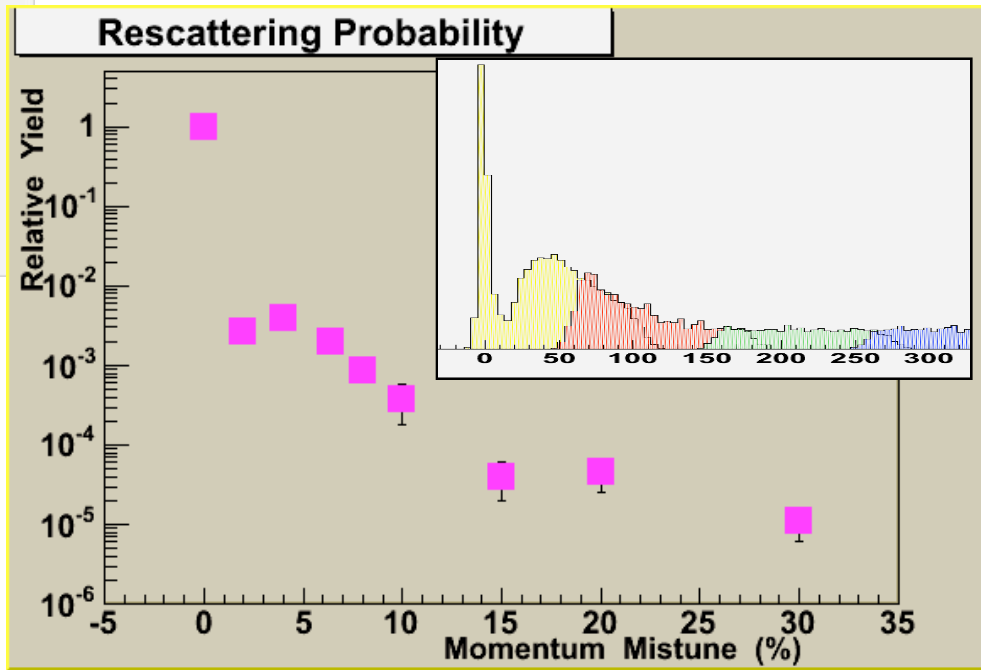
A_A suppressed by $\varepsilon'(1 - 4\sin^2\theta_W)$ where $\varepsilon' = [\tau(1+\tau)(1-\varepsilon^2)]^{\frac{1}{2}}$ $\approx$ (0.08)(0.08) here.

Background

Dedicated runs at very low current using track reconstruction of the HRS



Dipole field scan to measure the probability of rescattering inside the spectrometer



Helium

Helium QE in detector: 0.15 +/- 0.15%

Helium QE rescatter: 0.25 +/- 0.15%

Al fraction: 1.8 +/- 0.2%

Hydrogen:

Al fraction 0.75 +/- 25 %

Hydrogen Tail + Delta rescatter: <0.1%

Total systematic uncertainty contribution ~40 ppb (Helium), ~15ppb (Hydrogen)

Determining Q^2

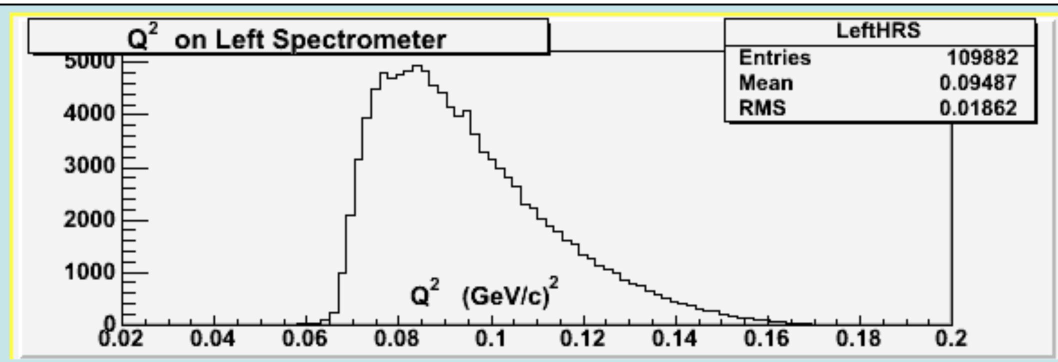
Asymmetry explicitly depends on Q^2:

$$A_{PV} = \frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\left[\left(1-4\sin^2\theta_W\right) - \frac{\varepsilon G_E^p(G_E^n+G_E^s)+\tau G_M^p(G_M^n+G_M^s)}{\varepsilon(G_E^p)^2+\tau(G_M^p)^2}\right]$$

$$Q^2 = 2EE'\left(1-\cos\theta\right)$$

Goal: $\delta_{Q^2} < 1\%$

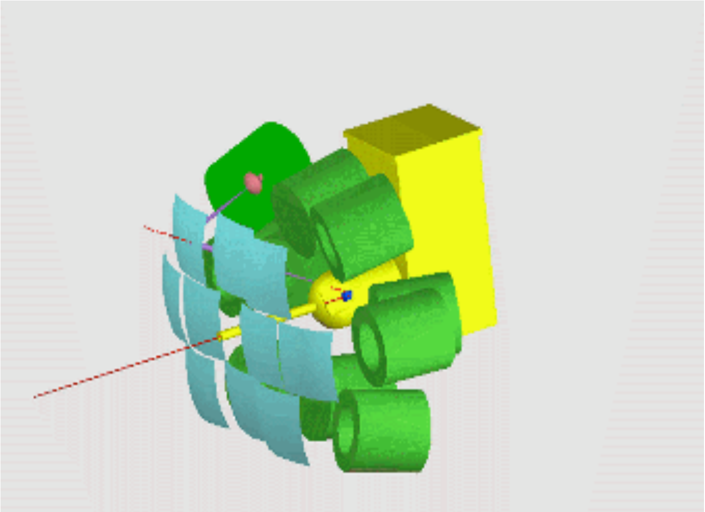
Q^2 measured using standard HRS tracking package, with reduced beam current

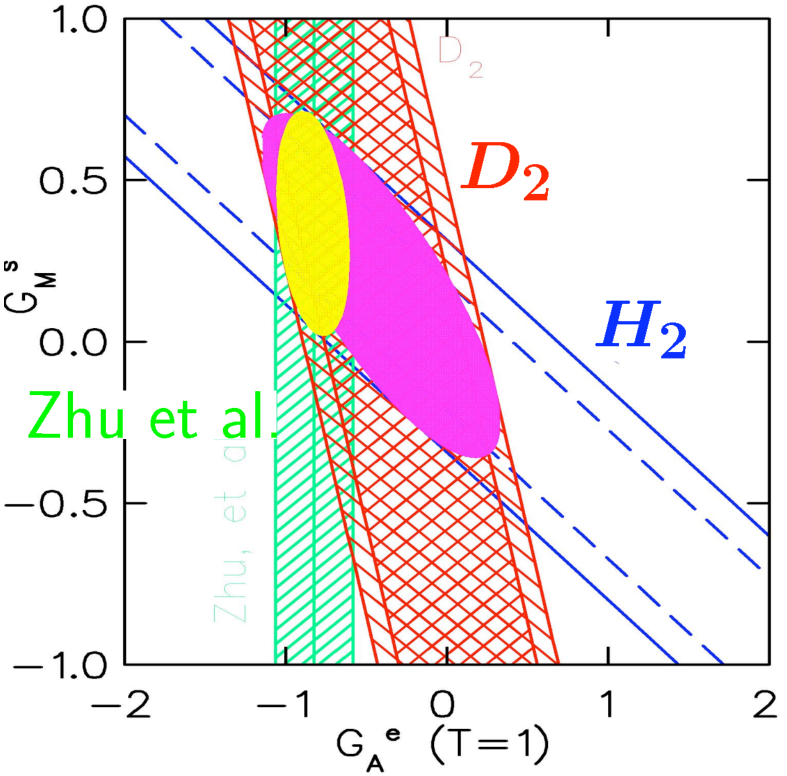


- Central scattering angle must be measured to $\delta\theta$ < 0.5%
- Asymmetry distribution must be averaged over finite acceptance

SAMPLE (MIT/Bates)

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





G_M^s = 0.23 ± 0.36 ± 0.40

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

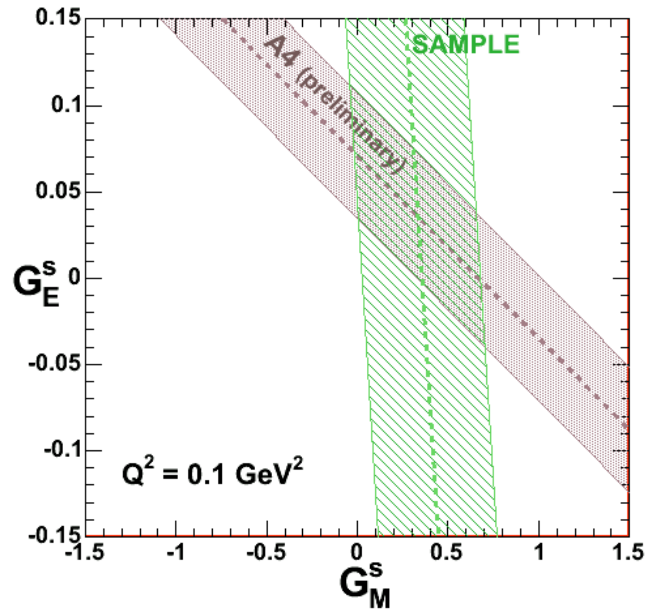
E.J. Beise *et al.*, Prog Nuc Part Phys 54 (2005)

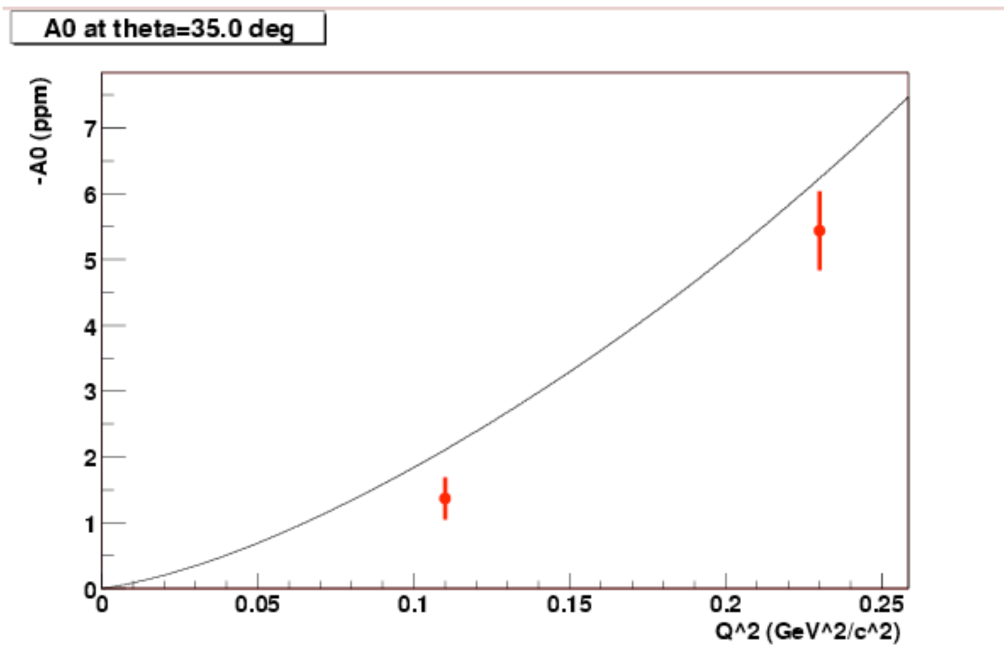
Results of Zhu *et al* commonly used to constrain G^S_M result:

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

PV-A4 (MAMI/Mainz)

Q^2 (GeV^2)	A ± stat ± syst (ppm)	G_E^s + □G_M^s
0.230	-5.44 ± 0.54 ± 0.26	G_E^s + 0.225 G_M^s = 0.039 ± 0.034
0.101	-1.36 ± 0.29 ± 0.13	G_E^s + 0.106 G_M^s = 0.071 ± 0.036





"Evidence for Strange Quark Contributions to the Nucleon's Form Factors at Q2 = 0.1 GeV^2"
PRL 94, 152001 (2006)

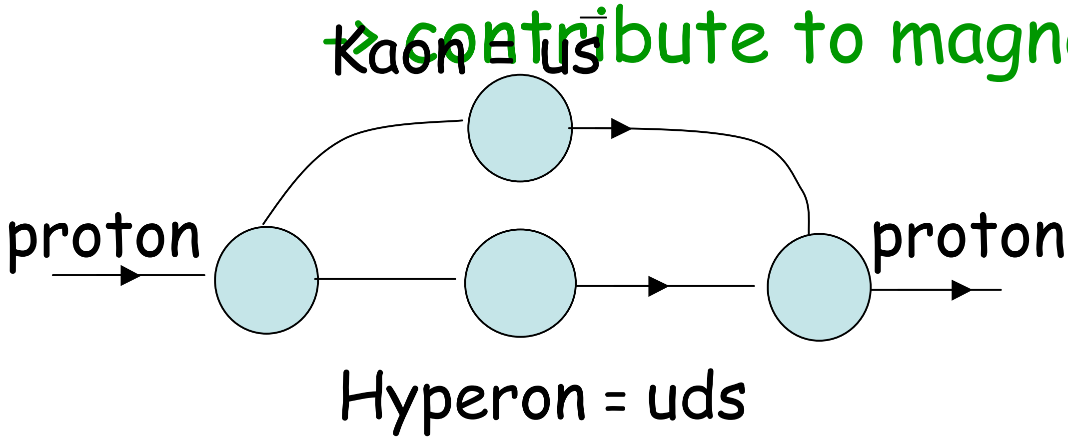
Back Angle runs underway to separate G^s_M, G_A at additional points…

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

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

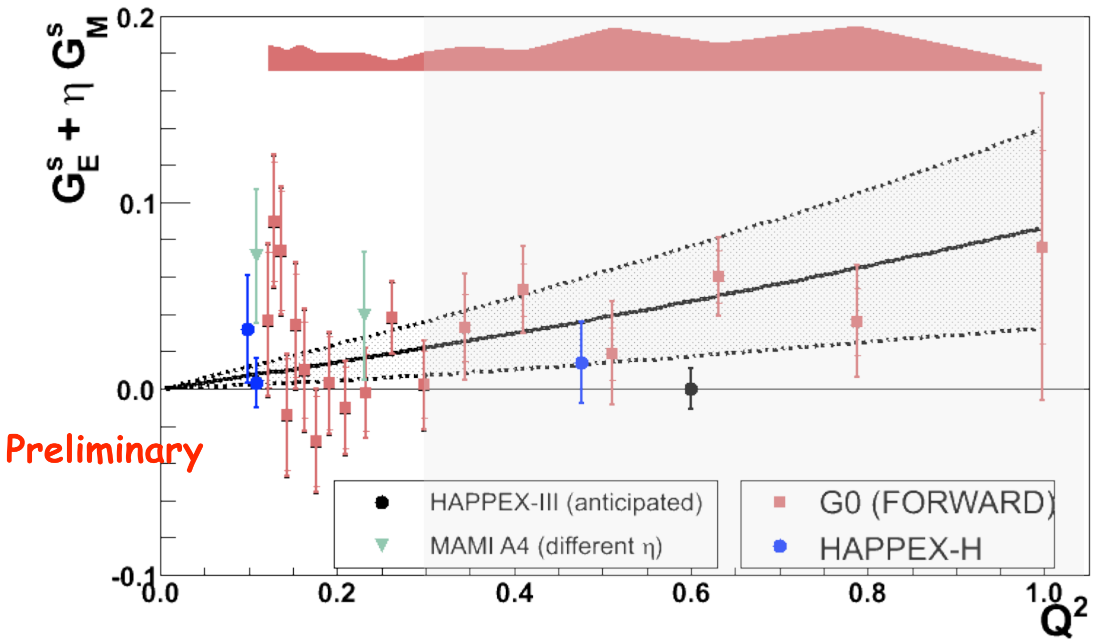
$G^s_M \neq 0$ ⇒ s and $\bar{s}$ have different magnetization distributions in proton

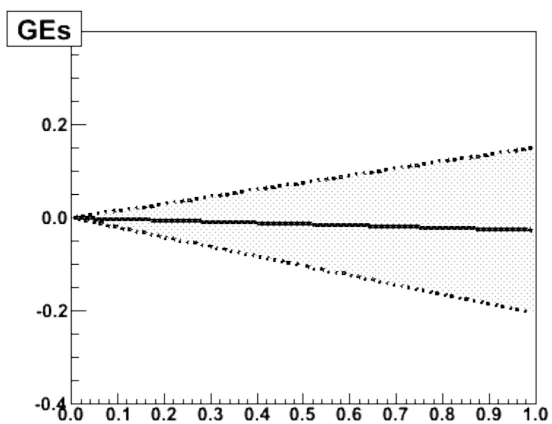
-> contribute to magnetic moment, etc.

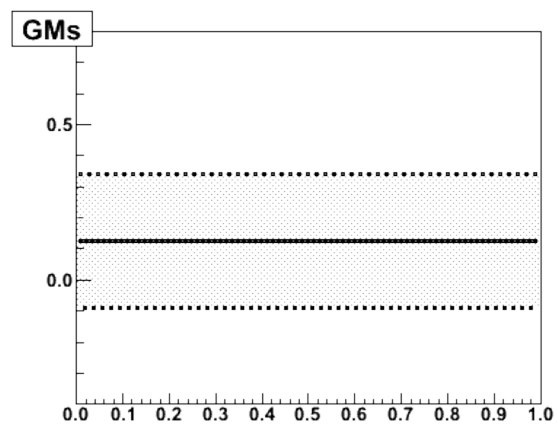


(naive model for illustration)

A Simple Fit (for a simple point)







Simple fit:

GEs = r_s*□

GMs = mu_s

Includes only data $Q^2 < 0.3$ GeV^2

Includes SAMPLE constrainted with G_A theory and HAPPEX-He 2004, 2005

G0 Global error allowed to float with unit constraint

Nothing intelligent done with form factors, correlated errors, etc.

Quantitative values should NOT be taken very seriously, but some clear, basic points:

- **The world data are consistent.**
- **Rapid Q^2 dependence of strange form-factors is not required.**
- **Sizeable contributions at higher Q2 are not definitively ruled out. (To be tested by HAPPEX-III, G0 and A4 backangle.)**