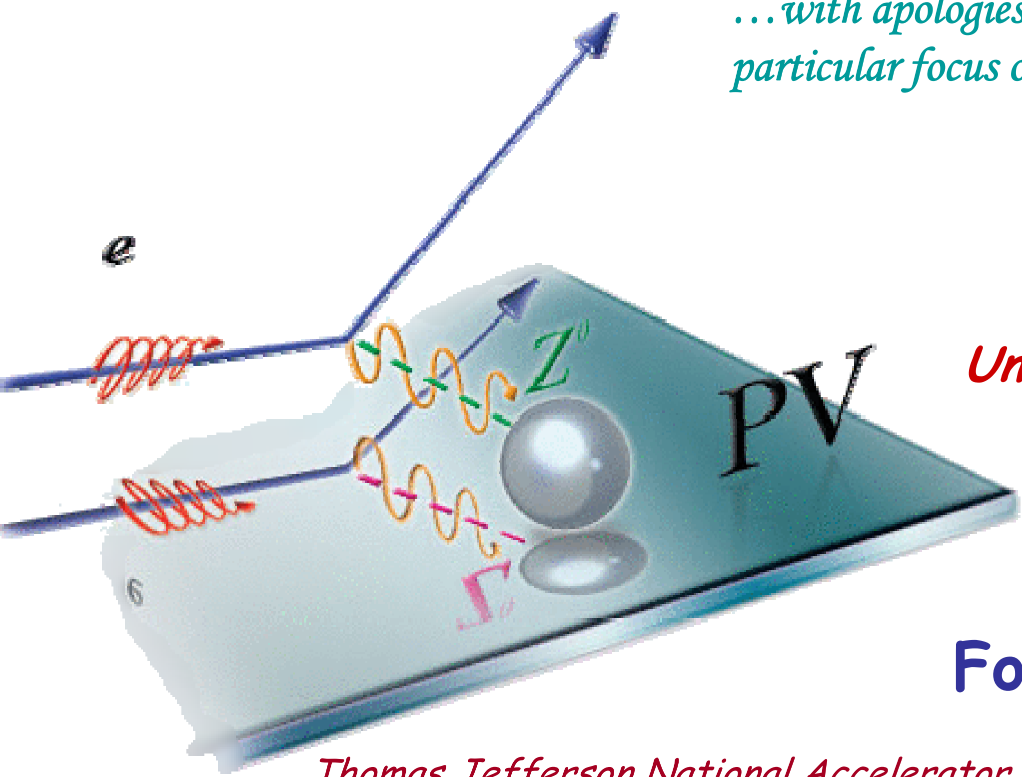
Parity-violating Electron Scattering and Strangeness in the Nucleon: Results from HAPPEX-II

…with apologies: this is a repeat of my Physics seminar, without particular focus on accelerator issues



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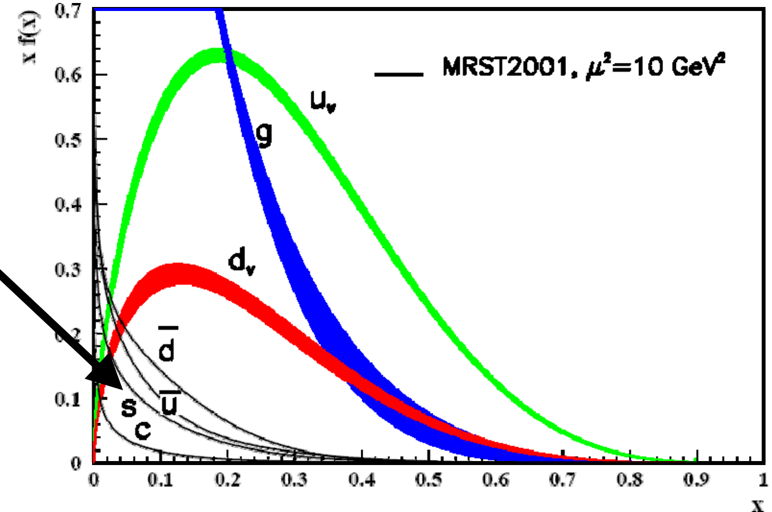
For the HAPPEX Collaboration

Thomas Jefferson National Accelerator Facility – Argonne National Laboratory – CSU, Los Angeles -William and Mary – Duke – DSM/DAPNIA/SPhN CEA Saclay - FIU – Harvard - INFN, Rome - INFN, Bari – IAE, Beijing – IPT Kharkov - Jozef Stefan Institute – Kent State - MIT – NPIRAS, St. Petersburg – ODU – Rutgers - Smith College – Syracuse – Temple – U. Blaise Pascal – U. of Illinois Urbana-Champaign – UMass, Amherst – U. of Kentucky – U. of Virginia – UST, Heifei

Strange Quarks in the Nucleon

Strange Sea

measured in νN scattering



Strange sea is well-known, but contributions to nucleon matrix elements are somewhat unsettled

Spin

polarized DIS

$$\langle N | \bar{s}\gamma^{\mu}\gamma^{5}s | N \rangle$$

Inclusive: Δs = -0.10 ± 0.06

uncertainties from SU(3), extrapolation

Semi-inclusive: Δs = 0.03 ± 0.03

fragmentation function

Strange mass

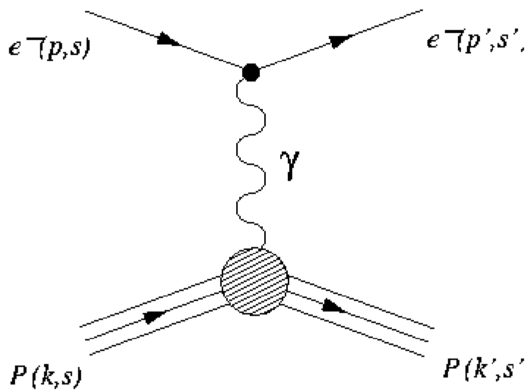
$$\langle N | \bar{s}s | N \rangle$$

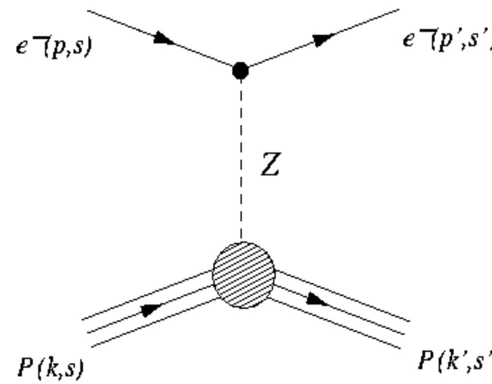
πN scattering: 0-30%

Strange vector FF

$$\langle N | \bar{s}\gamma^{\mu}s | N \rangle$$

PV Electron Scattering to Measure Weak NC Amplitudes

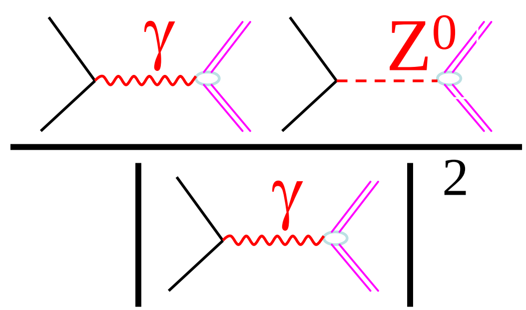




$$M^{EM} = \frac{4\pi\alpha}{Q^2} Q_\ell \lambda^\mu J_\mu^{EM} \qquad M_{PV}^{NC} = \frac{G_F}{2\sqrt{2}} \left[g_A \lambda^{\mu 5} J_\mu^{NC} + g_V \lambda^\mu J_{\mu 5}^{NC} \right]$$

Interference with EM amplitude makes NC amplitude accessible

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim$$



$$\sim \frac{\left|M_{PV}^{NC}\right|}{\left|M^{EM}\right|} \sim \frac{Q^2}{(M_Z)^2}$$

Flavor Separation of Nucleon Form Factors

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

$$G \sim \left\langle N \left| \sum_i e_i \bar{q}_i \Gamma_\mu q_i \right| N \right\rangle$$

(assumes heavy quarks are negligible)

Measuring $G^{\gamma,p}$, $G^{\gamma,n}$ cannot separate all three flavors

Adding in a measurement of $G^{Z,p}$

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

and assuming charge symmetry

$$\begin{cases} G^{u,p} = G^{d,n} \\ G^{d,p} = G^{u,n} \\ G^{s,p} = G^{s,n} \end{cases}$$

then we can write

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

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

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

Parity-violating electron scattering

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

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

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

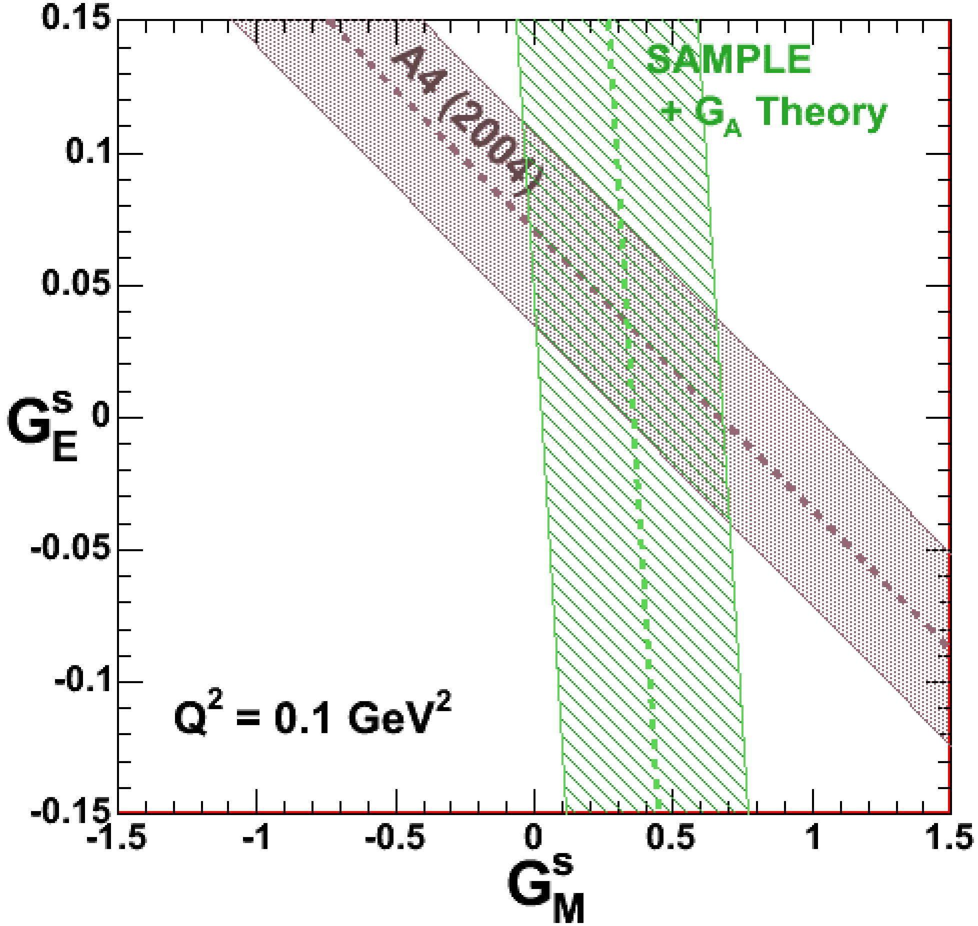
For ^{4}He: G_E^s alone (but only available at low Q^2)

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

For deuterium:

enhanced G_A^e sensitivity

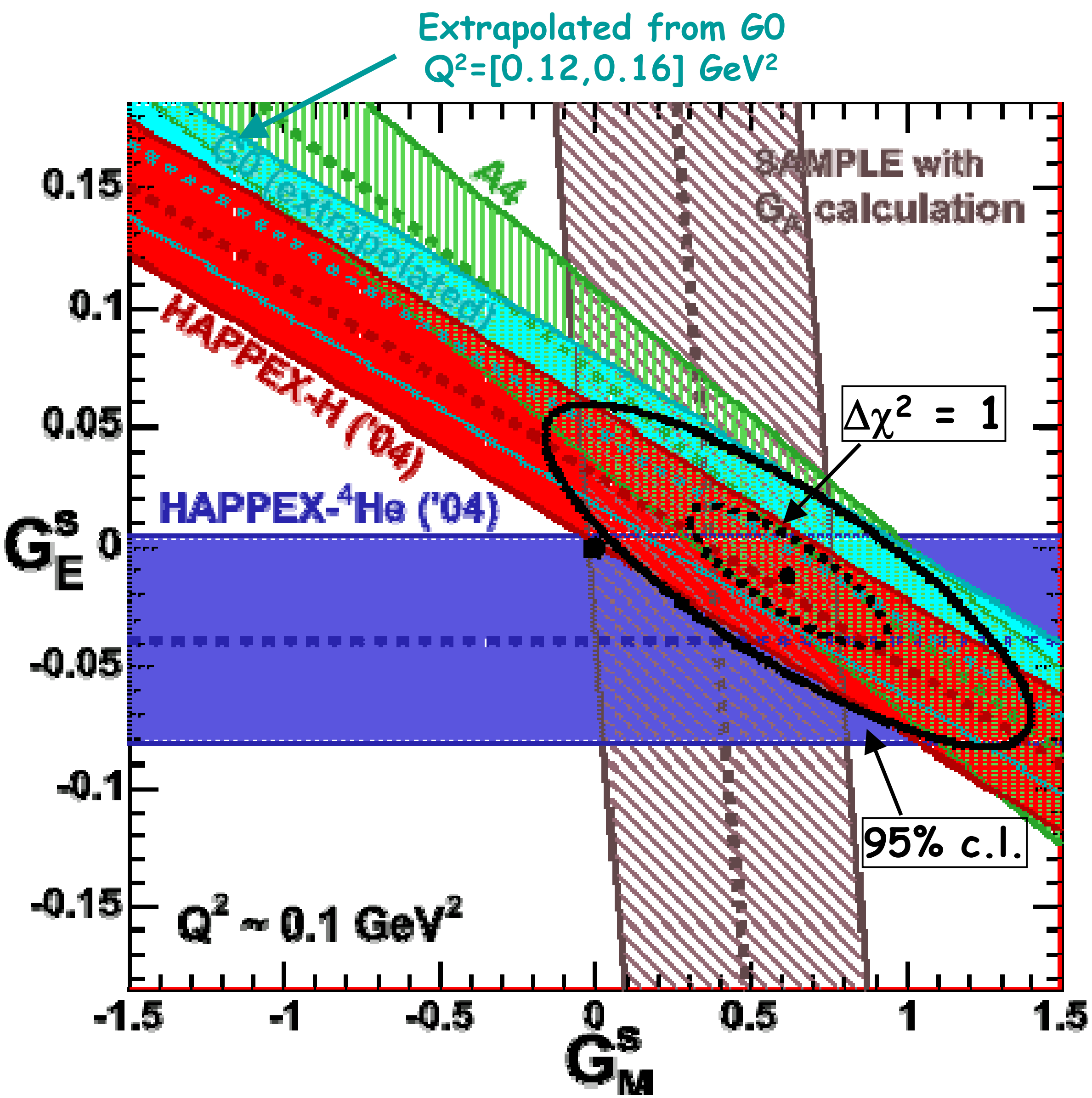
March 25, 2005: 2004 HAPPEX-II Results



$$G^s_E = -0.039 \pm 0.041_{(stat)} \pm 0.010_{(syst)} \pm 0.004_{(FF)}$$

$$G^s_E + 0.08\, G^s_M = 0.032 \pm 0.026_{(stat)} \pm 0.007_{(syst)} \pm 0.011_{(FF)}$$

World Data at $Q^2 \sim 0.1$ GeV^2



Note: excellent agreement of world data set

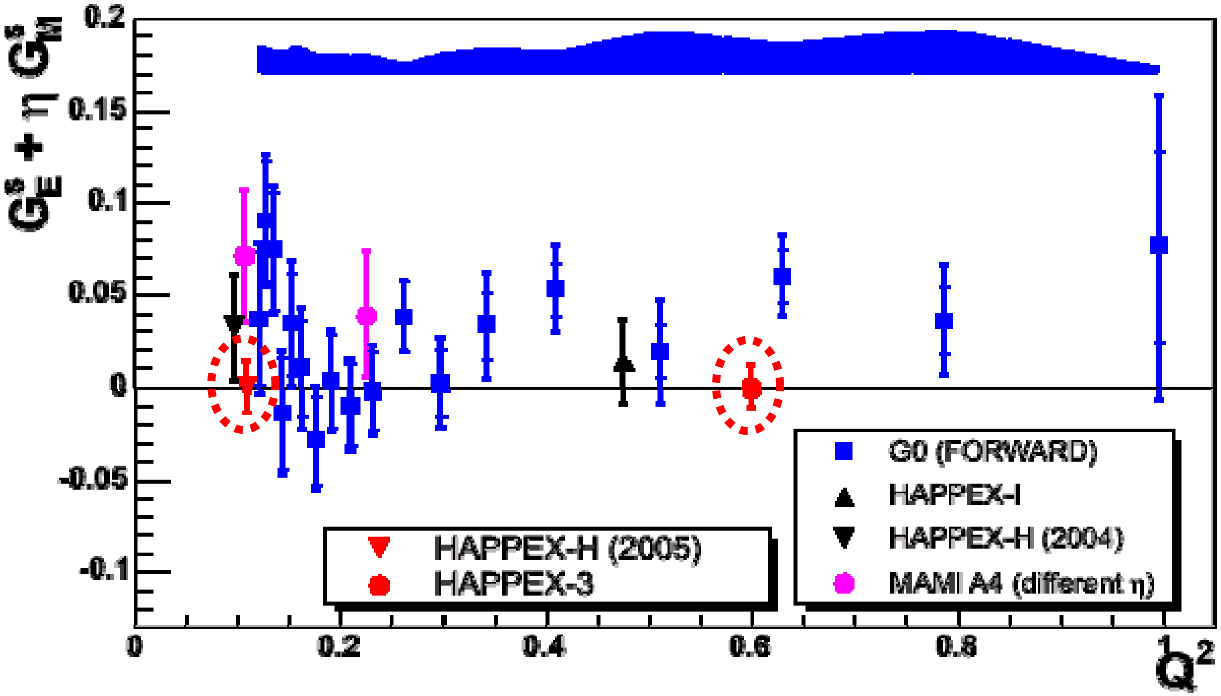
$G_E^s = -0.12 \pm 0.29$

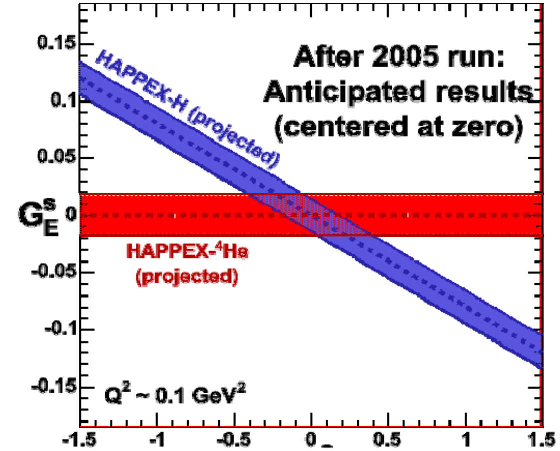
$G_M^s = 0.62 \pm 0.32$

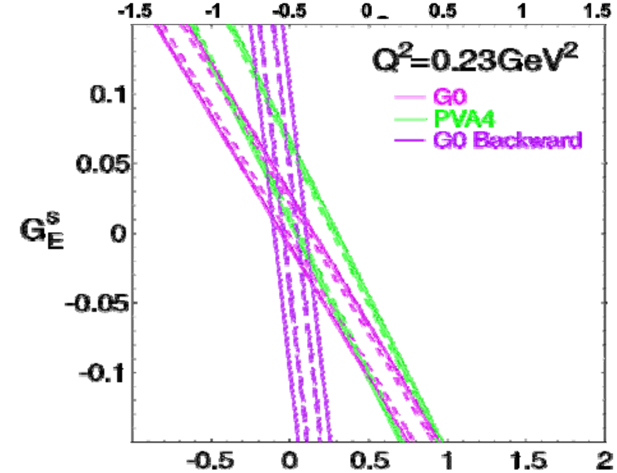
Would imply that 7% of nucleon magnetic moment is *Strange*

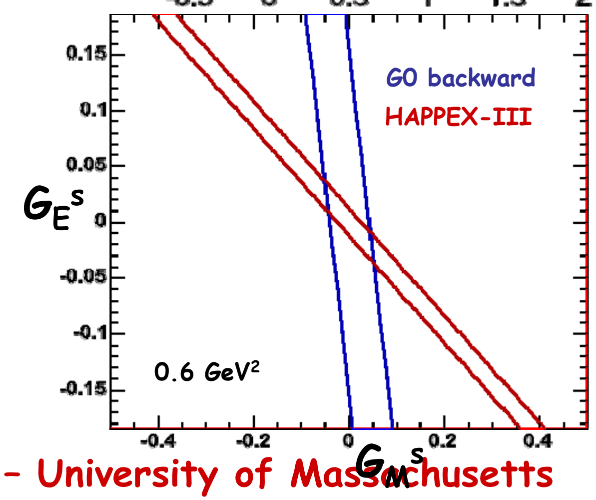
Caution: the combined fit is approximate. Correlated errors and assumptions not taken into account

Summary (Sept 2005)









- Suggested large values at Q^2~0.1 GeV^2
  - HAPPEX-II, H and He running now!
- Large possible cancellation at Q^2~0.2 GeV^2
  - G^0 backangle, conditionally approved for Summer '06
  - A4 backangle?
- Possible large values at Q^2>0.4 GeV^2
  - G^0 backangle, approved for Spring '06
  - HAPPEX-III, conditionally approved - 2007?
  - A4 backangle?

HAPPEX (second generation)

E=3 GeV θ=6 deg Q^2=0.1 $(GeV/c)^2$

- **Hydrogen** : $G^s_E + \alpha\, G^s_M$
- ^{4}**He**: Pure G^s_E :

$$A^{PV} = -\frac{A_0}{2}\left(2\sin^2\theta_W + \frac{G_E^s}{G_E^{p\gamma} + G_E^{n\gamma}}\right)$$

target	A_{PV} $G^s = 0$ (ppm)	Stat. Error (ppm)	Syst. Error (ppm)	sensitivity
^1H	-1.4	0.08 (5.7%)	0.04 (2.9%)	$\delta\,(G^s_E + 0.08 G^s_M) = 0.010$
^4He	+7.8	0.18 (2.2%)	0.18 (2.1%)	$\delta\,(G^s_E) = 0.015$

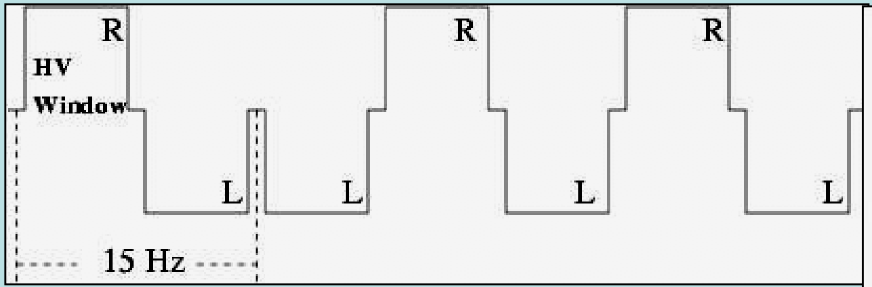
Measurement of P-V Asymmetries

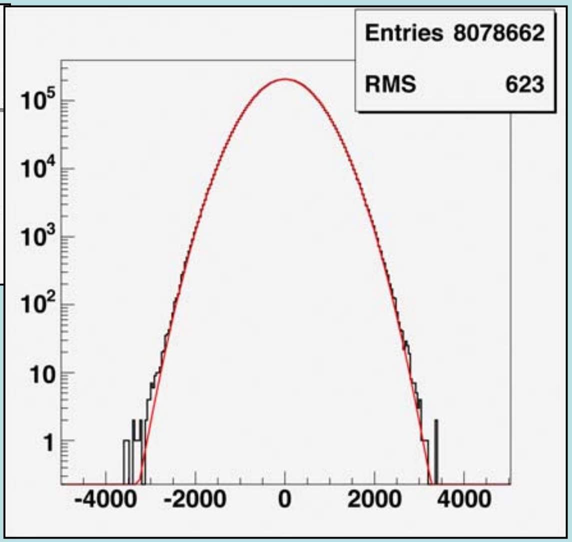
$$A_{LR} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \approx 10^{-6}$$

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

Rapid Helicity Flip: Measure the asymmetry at few 10^{-4} level, 30 million times

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





- Analog integration of rates ~100 MHz
- 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

Apparatus Upgrade

HAPPEX-I precision:
~ 1 ppm, 15%

HAPPEX-H accuracy ~ 50 ppb
HAPPEX-He accuracy ~ 2%

- **High Luminosity** => High I and P_e (superlattice), thick new targets, rad-hard integrating det., improved DAQ.
- **Small forward angle** => new Septum magnets
- **Accurate Normalization** => improved polarimetry, new focal plane profile scanner
- **High systematic accuracy** => improved polarized source, close attention to beam optics, luminosity monitor.

HAPPEX-II

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

2004 Results

Parity-Violating Asymmetry

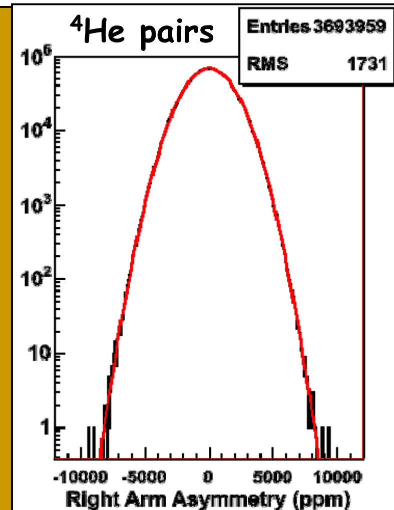
^{4}He

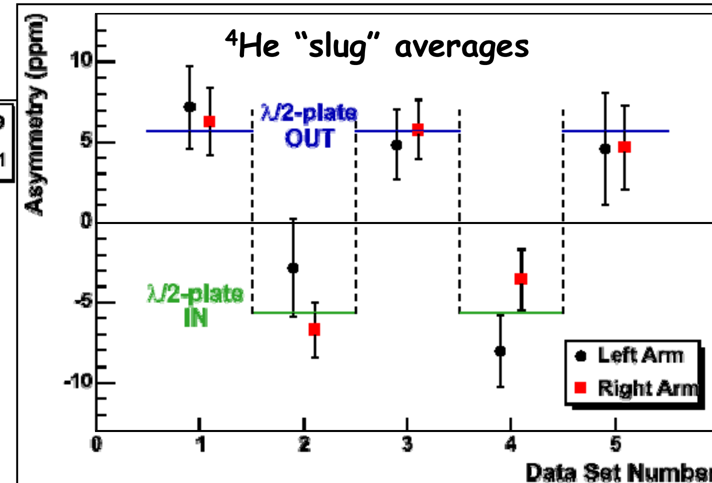
3.3 M pairs,
total width ~1300 ppm

A_{raw} correction < 0.2 ppm

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

$A(G^s=0) = +7.51$ ppm $\pm$ 0.08 ppm





A_{PV} = 6.72 ppm $\pm$ 0.84$_{(stat)}$ ppm $\pm$ 0.21$_{(syst)}$ ppm

"blinded" analysis used to eliminate human bias

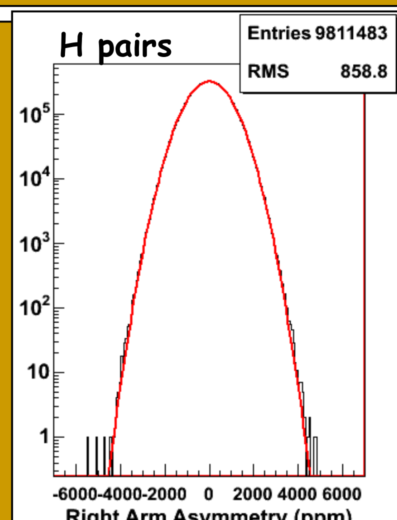
^{1}H

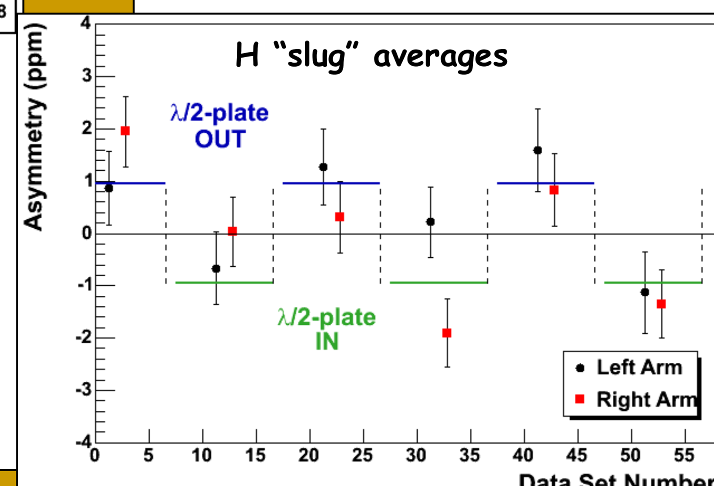
9.5 M pairs,
total width ~620 ppm

A_{raw} correction < 0.06 ppm

K.A.Aniol et al., Phys. Lett. B 635 (2006) 275.

$A(G^s=0) = -1.44$ ppm $\pm$ 0.11 ppm

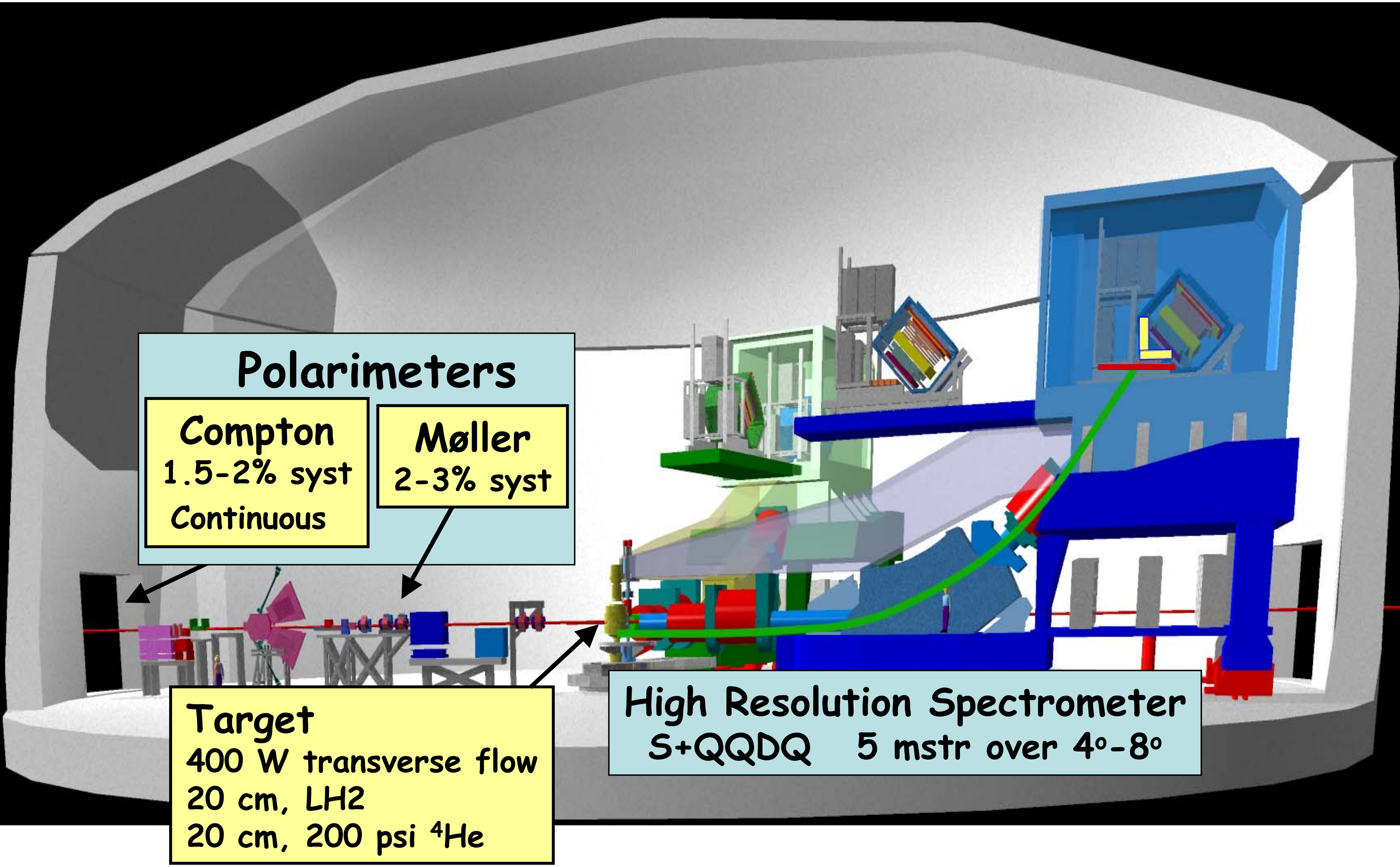




A_{PV} = -1.14 ppm $\pm$ 0.24$_{(stat)}$ ppm $\pm$ 0.06$_{(stat)}$ ppm

– University of Massachusetts

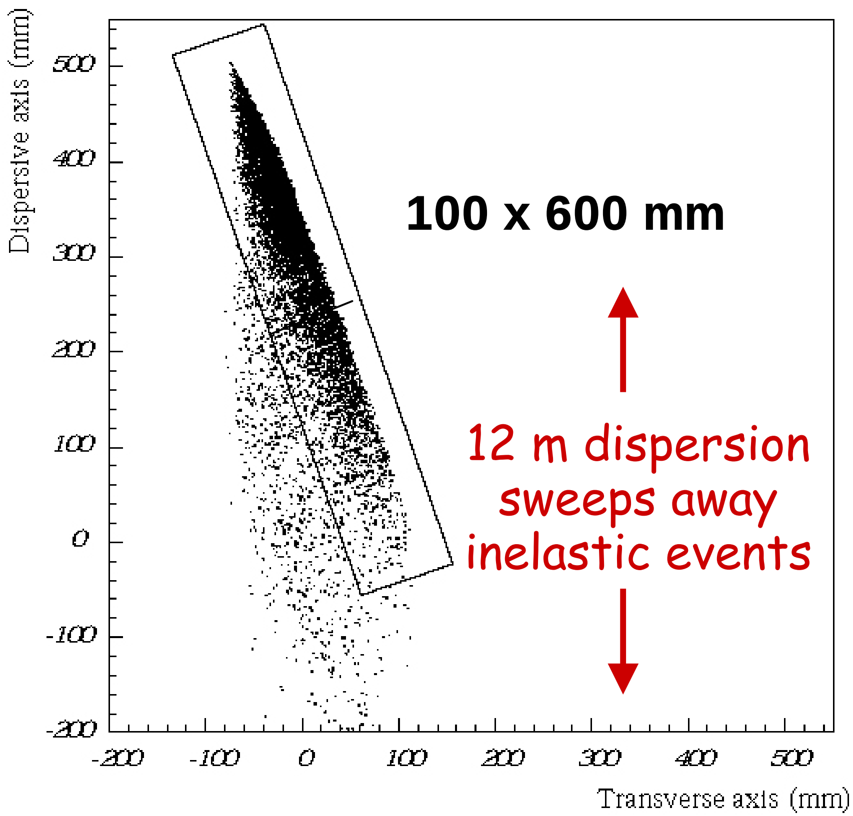
Hall A

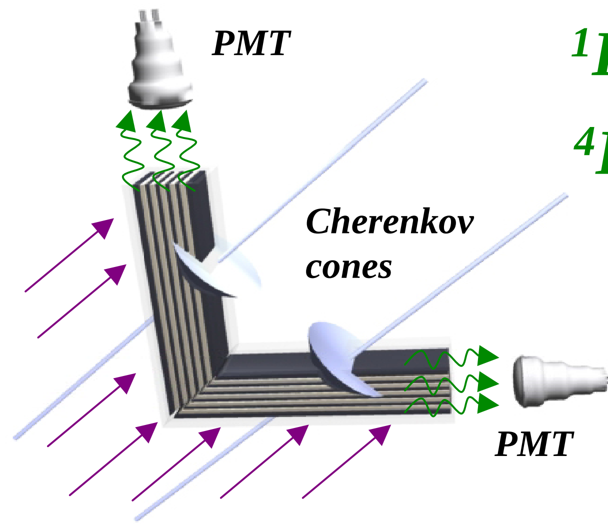


Polarimeters
Compton
1.5-2% syst
Continuous
Møller
2-3% syst
Target
400 W transverse flow
20 cm, LH2
20 cm, 200 psi ^{4}He
High Resolution Spectrometer
S+QQDQ 5 mstr over 4°-8°

High Resolution Spectrometers

Very clean separation of elastic events by HRS optics → Overlap the elastic line above the focal plane and integrate the flux





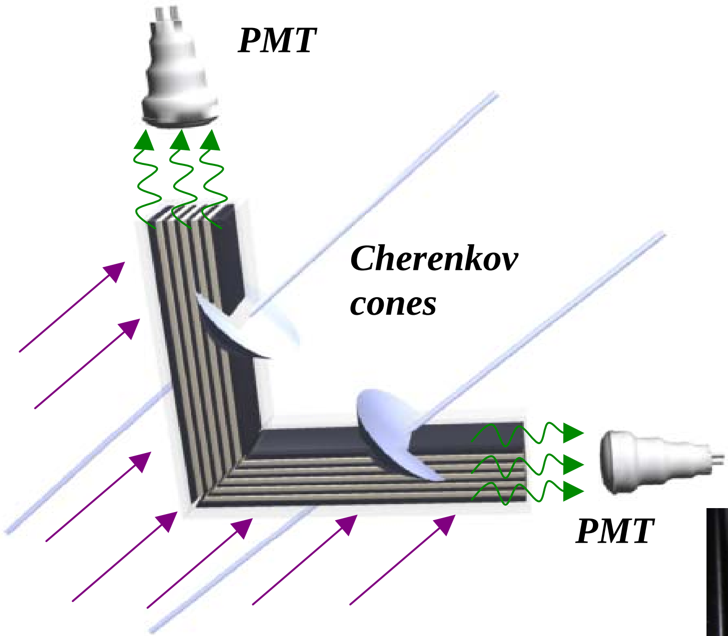
Elastic Rate:

^{1}H: 120 MHz

^{4}He: 12 MHz

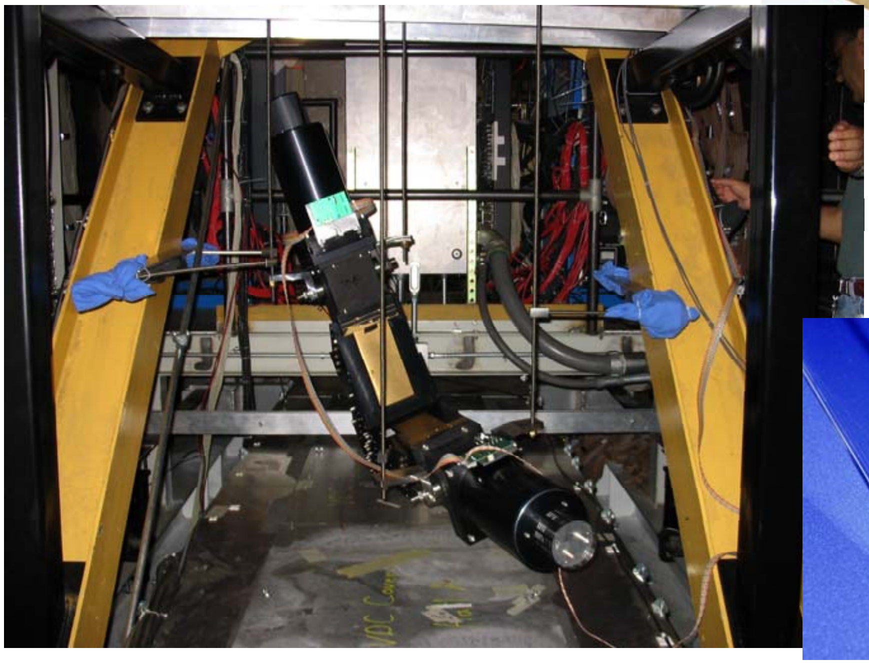
Large dispersion and heavy shielding reduce backgrounds at the focal plane

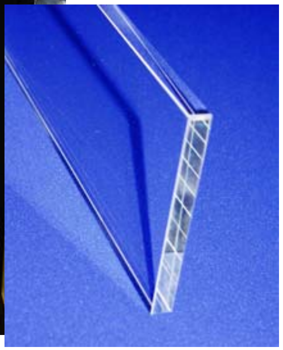
Focal Plane Detectors



Brass-Quartz Integrating Cerenkov Shower Calorimeter

- Insensitive to background
- Directional sensitivity
- High-resolution
- Rad hard



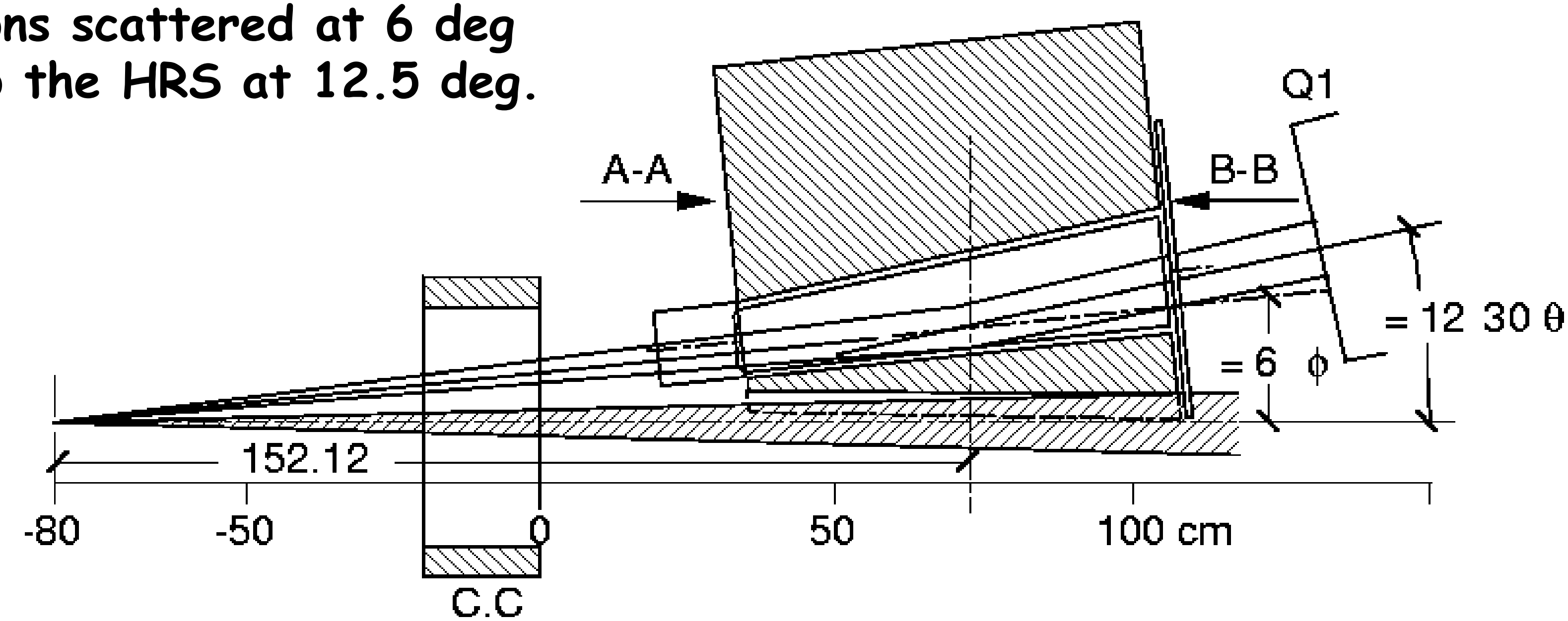


Two segment "L"-shape covers hydrogen elastic peak

Smaller ^{4}He elastic peak requires only $\frac{1}{2}$ single-segment detector

Septum Magnets

Electrons scattered at 6 deg
sent to the HRS at 12.5 deg.

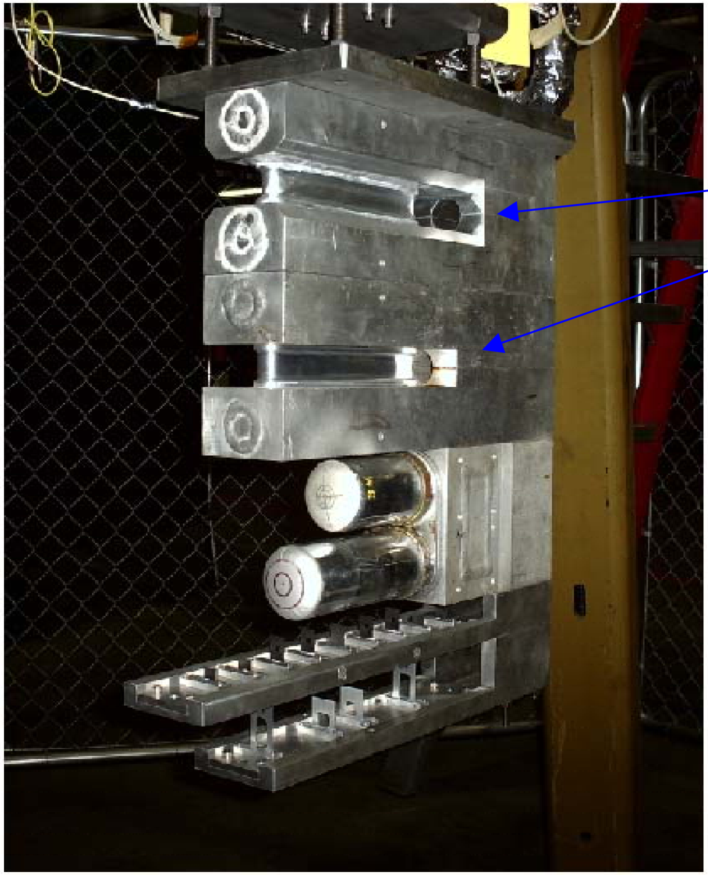


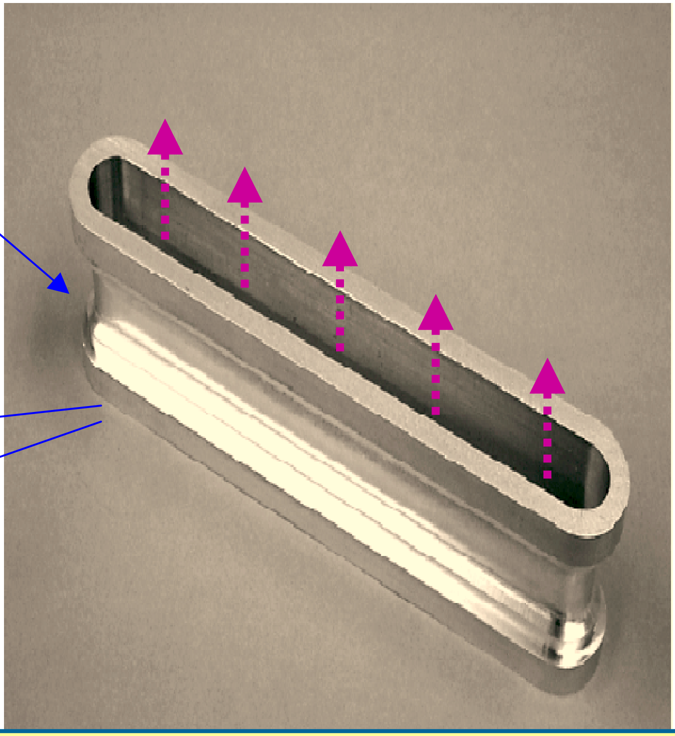
•Superconducting magnets with low cooling power: sensitive to scattered flux from the target!

•Sweeper Magnet, located inside the scattering chamber, used in 2005 to reduce the flux of low energy Moller electrons

High-Power Cryogenic Target

New "race track" design – 20 cm
(transverse cryogen flow)

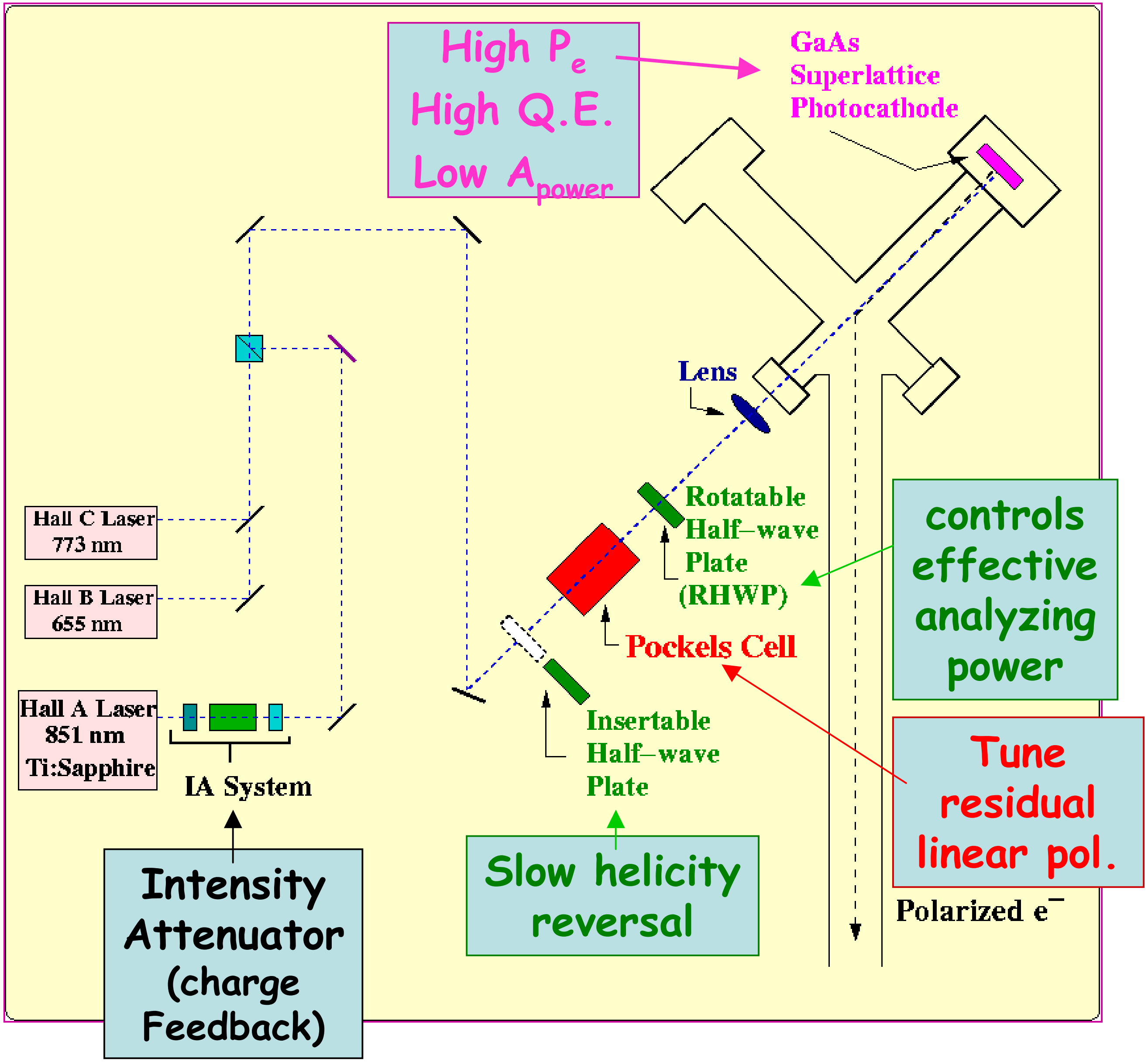




20 cm 1.8% R.L. LH_2
20 cm 2.2% R.L. ^{4}He gas cell
- Cold (6.6K), dense (230 psi)

Al wall thickness
- 4 mils (H)
- 10 mils (He)

Polarized Source

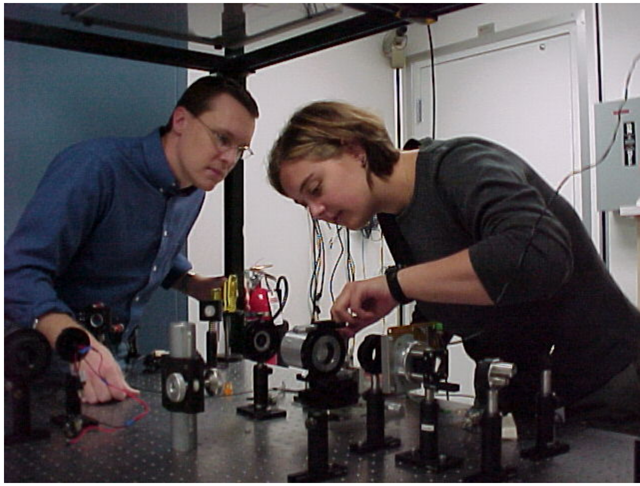


- Optical pumping of solid-state photocathode
- High Polarization
- Pockels cell allows rapid helicity flip
- Careful configuration to reduce beam asymmetries.
- Slow helicity reversal to further cancel beam asymmetries

Controlling Position Differences

Identify and control sources of position differences

- Intrinsic birefringence gradient in the Pockels cell
- Steering from distortions due to piezo-electric deformation of the Pockels cell
- Analyzing power gradients
- Plus: vacuum window, QE hole, transmission, upstream gradients, beam loading, current limit… *and electronic pickup…*



T.B. Humensky *et. al.*, NIM A 521, 261 (2004)

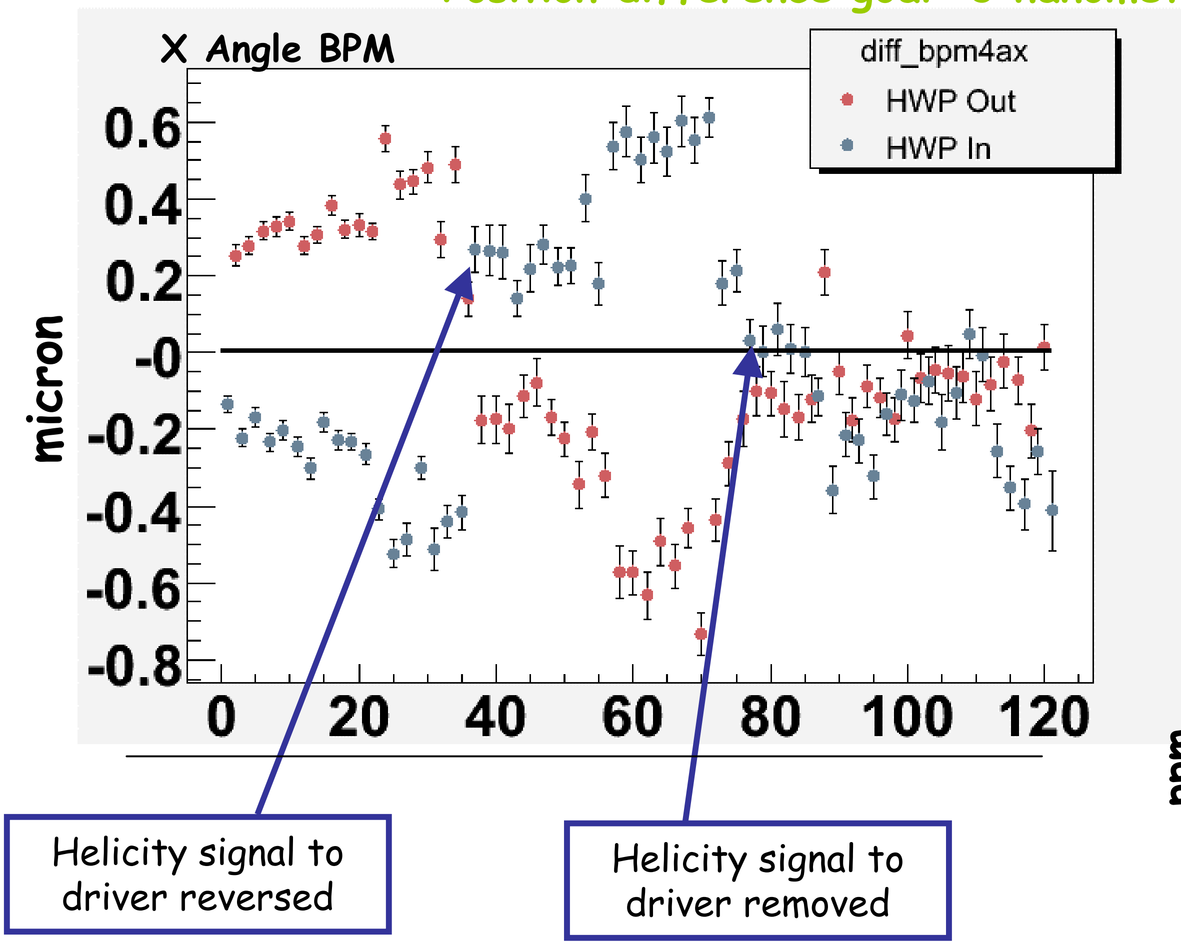
G.D. Cates, Proceedings from PAVI '04

Close Collaboration with the Electron Gun Group in analyzing causes and developing solutions

Laser Test Stand studies and Electron Beam studies have been crucial for developing an understanding of these effects.

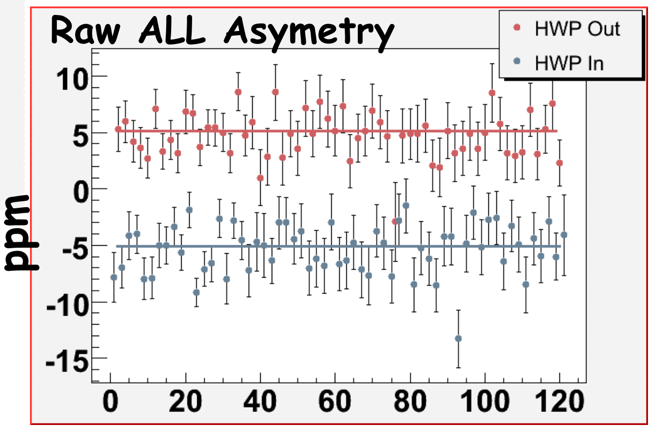
Beam Position Differences, Helium 2005

Position difference goal: 3 nanometers!



All's well that ends well

- Problem clearly identified as beam steering from electronic cross-talk
- Tests verify no helicity-correlated electronics noise in Hall DAQ at sub-ppb level
- Large position differences mostly cancel in average over both detectors



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

Large beam deflections even when Pockels cell is off

Correcting Beam Asymmetries

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

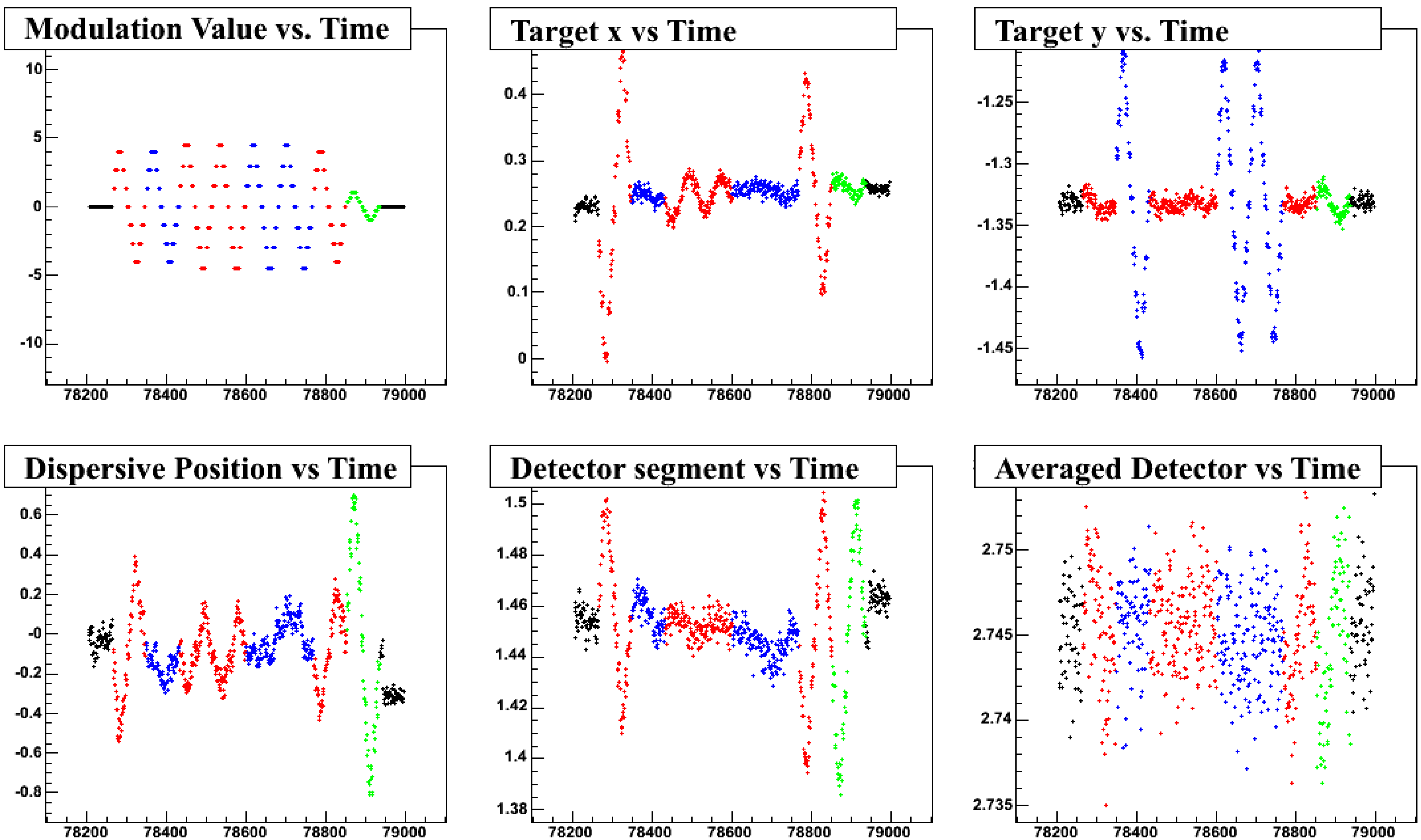
Slopes from
- **natural beam jitter (regression)**
- **beam modulation (dithering)**

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

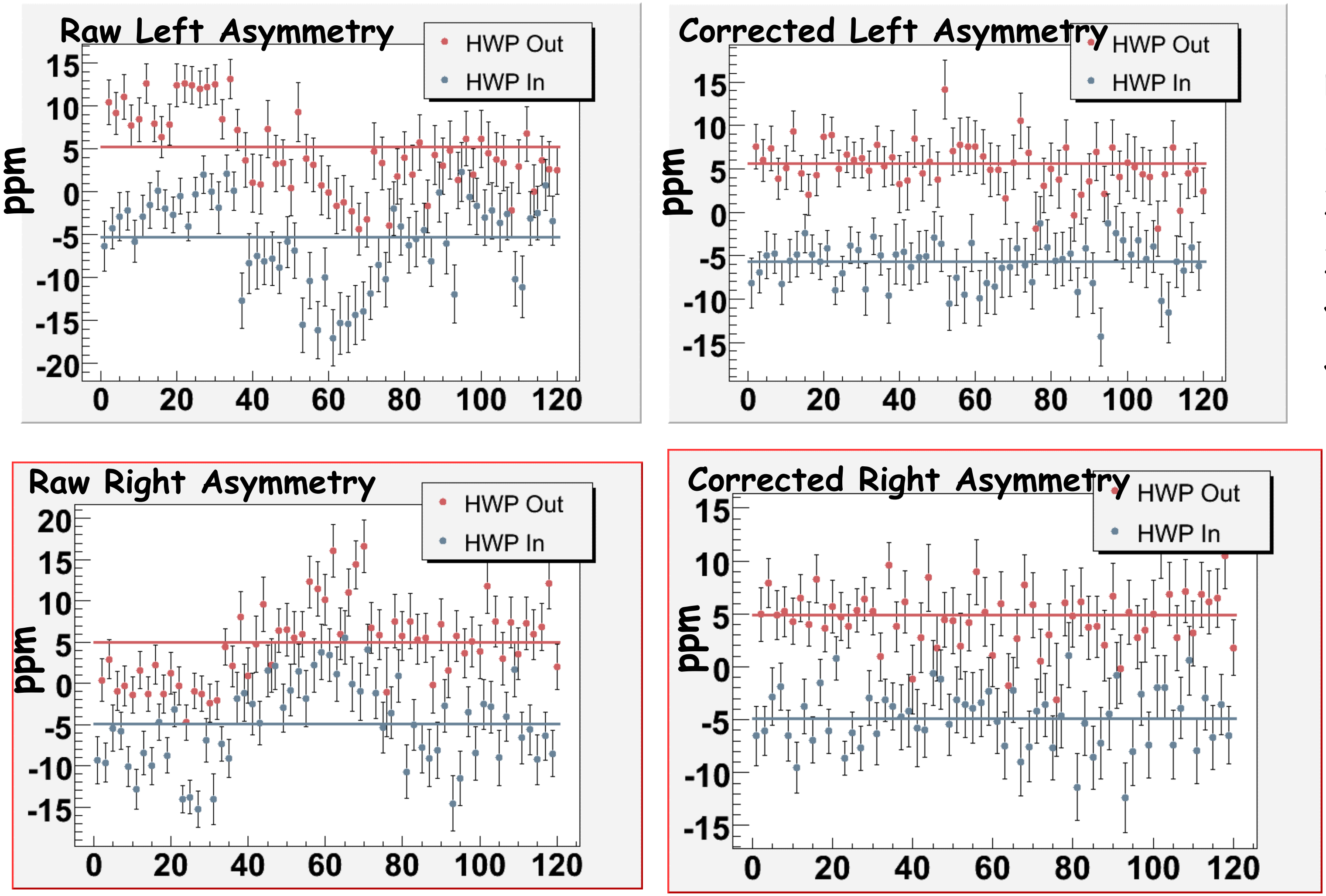
Regression:
- Natural beam motion, measure $dA/d\Delta x_i$
- Simultaneous fit establishes independent sensitivities
- By definition, removes correlation of asymmetry to beam *monitors*
- Sensitive to highly correlated beam motion and electronics noise

"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

Beam Modulation



Beam Position Corrections, Helium 2005



Beam Asymmetries

Energy: -3ppb

X Target: -5 nm

X Angle: -28 nm

Y Target :-21 nm

Y Angle: 1 nm

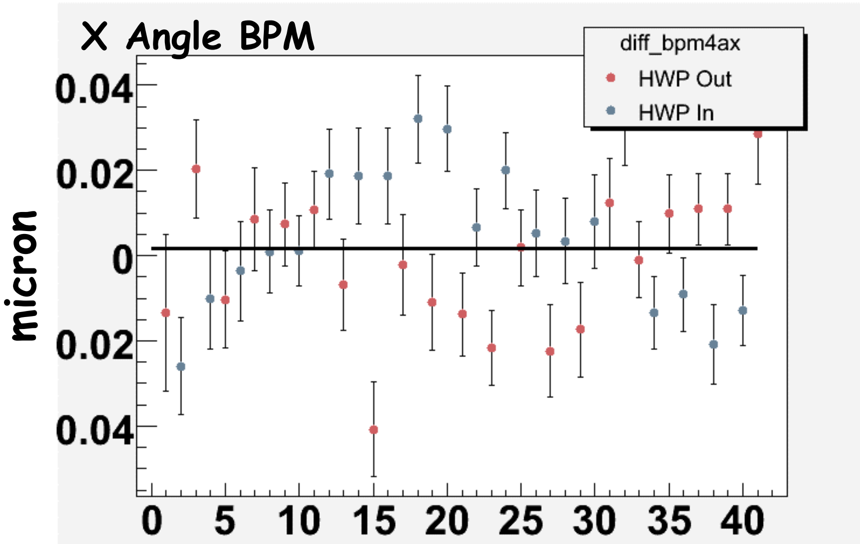
Total Corrections:

Left: -370 ppb

Right: 80 ppb

All: 120 ppb

Beam Position Corrections, Hydrogen 2005



Surpassed Beam Asymmetry Goals for Hydrogen Run

Energy: -0.25 ppb

X Target: 1 nm

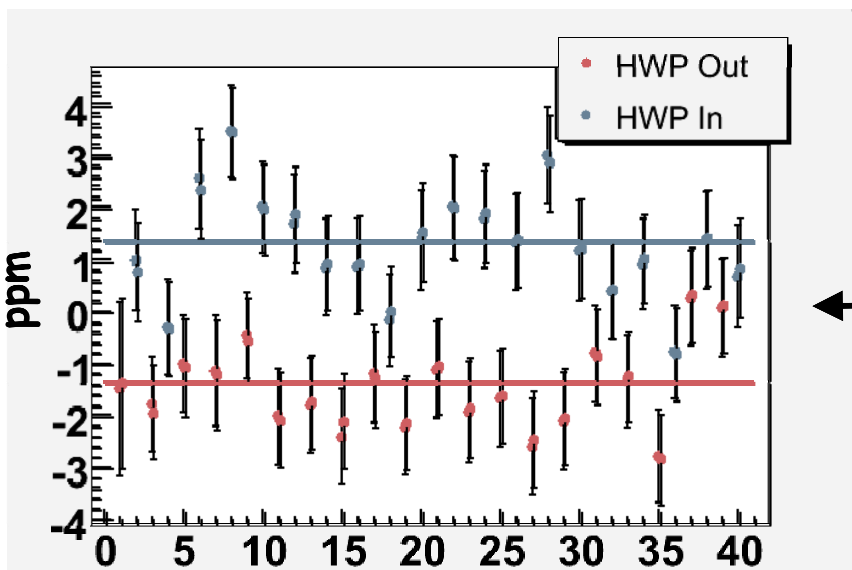
X Angle: 2 nm

Y Target : 1 nm

Y Angle: <1 nm

Good enough for QWeak & PREx

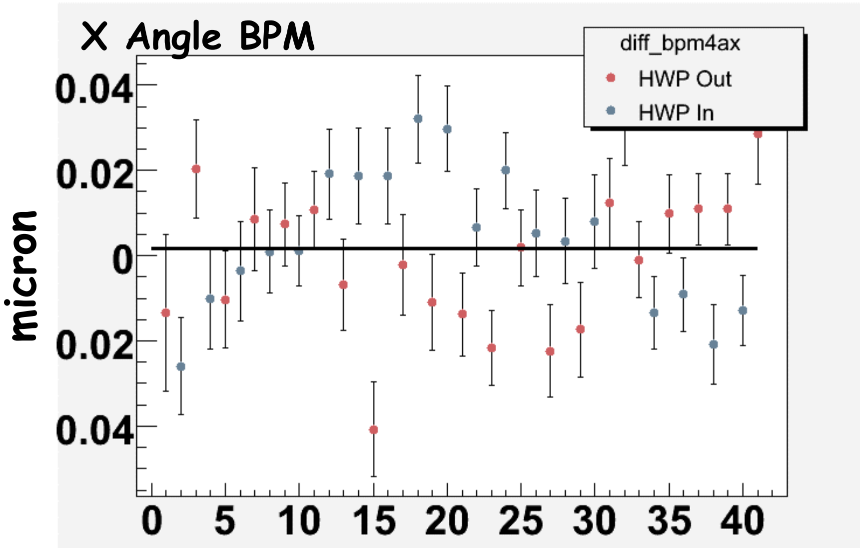
(Next battle: higher order effects!)



Corrected and Raw, Left arm alone, Superimposed!

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

Adiabatic Damping



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Energy: -0.25 ppb

X Target: 1 nm

X Angle: 2 nm

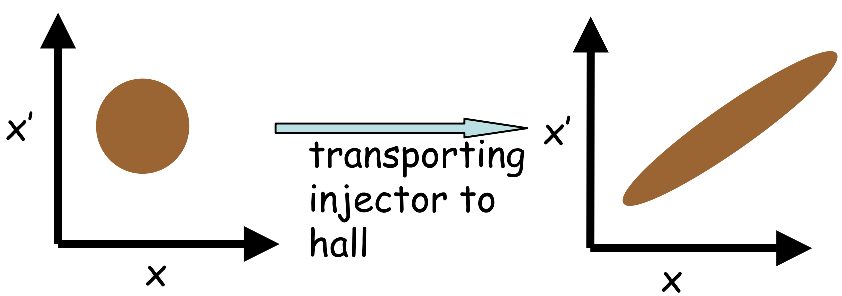
Y Target : 1 nm

Y Angle: <1 nm

Good enough for QWeak & PREx

(Next battle: higher order effects!)

The extremely small position differences observed in HAPPEX-H were, in large part, due to the improvements in "matching"



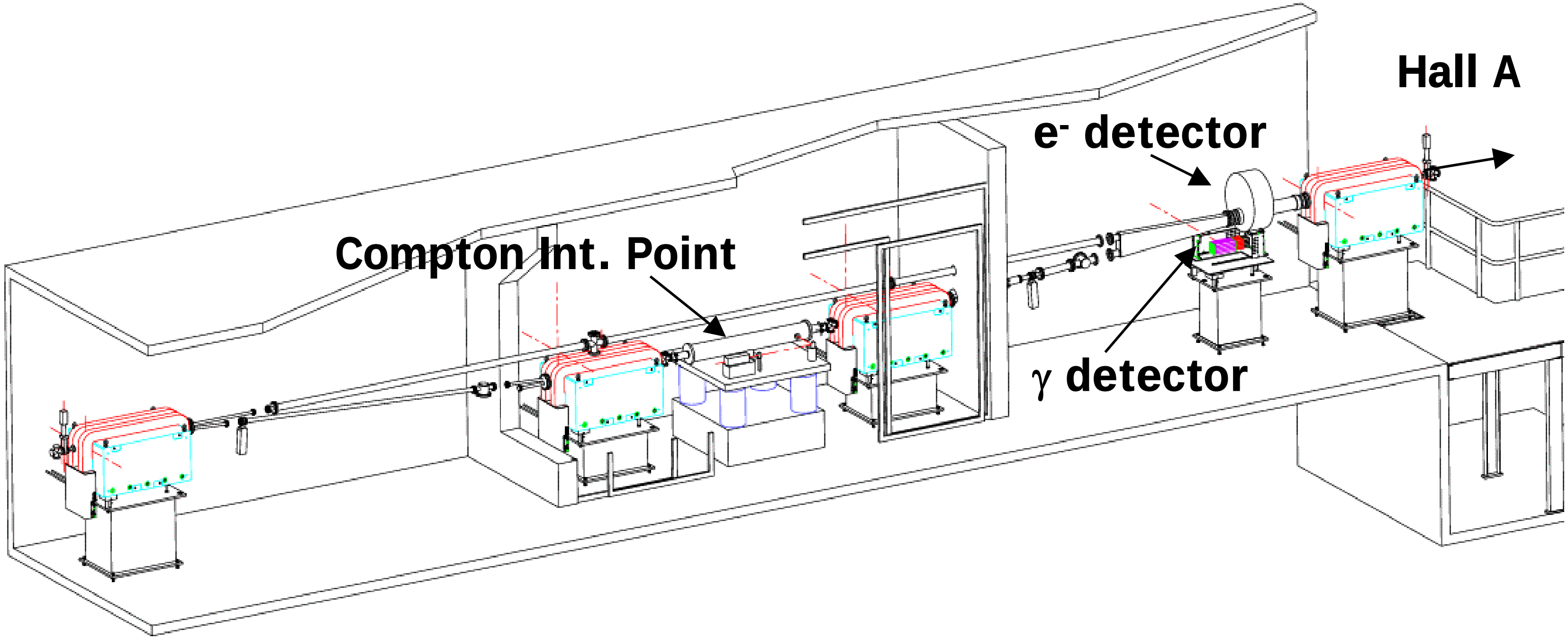
Area preserved, but phase space allows much larger Δx projection

Developments for Helium run were not left in (time pressures + complications)

Hydrogen improved damping factors from "few" to ">10, maybe >>10"

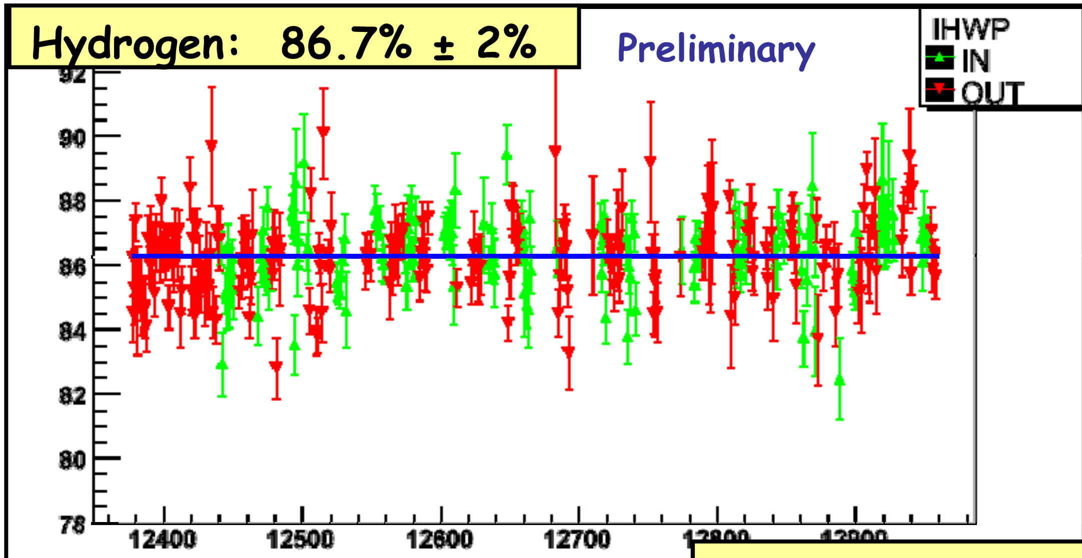
A HUGE SUCCESS FOR THIS HIGH PRECISION FACILITY!

COMPTON POLARIMETRY



- Non-invasive, continuous polarimetry
- 2% systematic error at 3 GeV MUCH HARDER AT 2.7 GeV
- Independent photon and electron analyses
- Cross-checked with Hall A Møller, 5 MeV Mott
- Requires ~10^{-10} halo, 5mm from primary beam

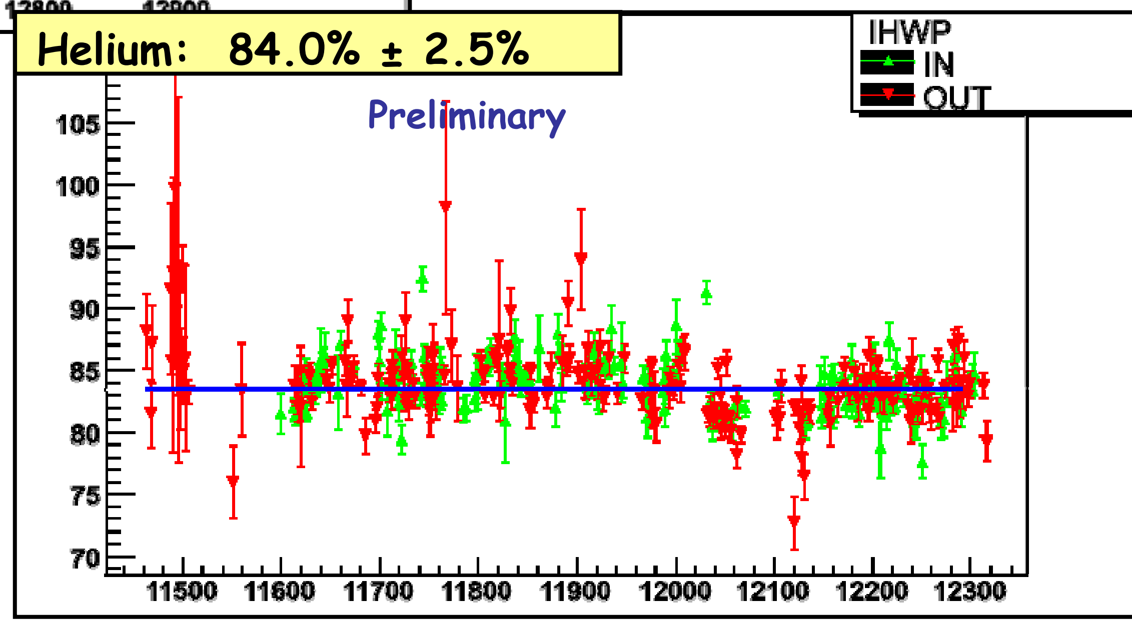
Compton Polarimetry



Electron Detector analysis

Cross-checked with Møller

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



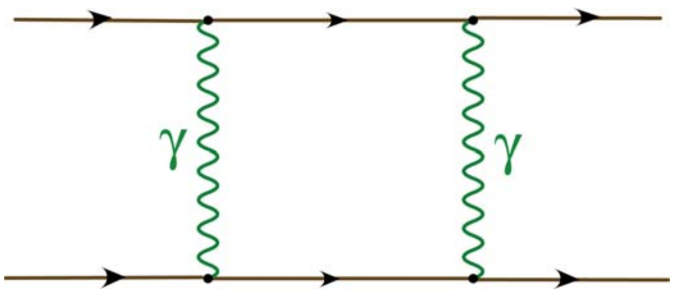
New developments in both photon and electron analyses in preparation: anticipate <2% systematic uncertainty

Transverse Asymmetries

Beam-Normal Asymmetry in elastic electron scattering

Electron beam polarized transverse to beam direction

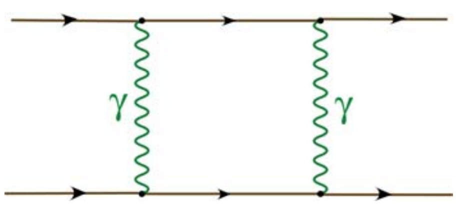
$$A_T \equiv \frac{2\pi}{\sigma^{\uparrow} + \sigma^{\downarrow}} \frac{d(\sigma^{\uparrow} - \sigma^{\downarrow})}{d\phi} \propto \vec{S}_e \bullet (\vec{k}_e \times \vec{k'}_e)$$



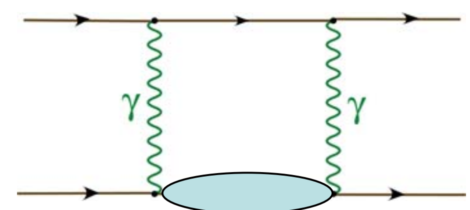
Interference between one- and two-photon exchange

$$A_T \propto \frac{\alpha m_e}{\sqrt{s}}$$

Effect suppressed by
- **α**
- **Lorentz boost**



"elastic"



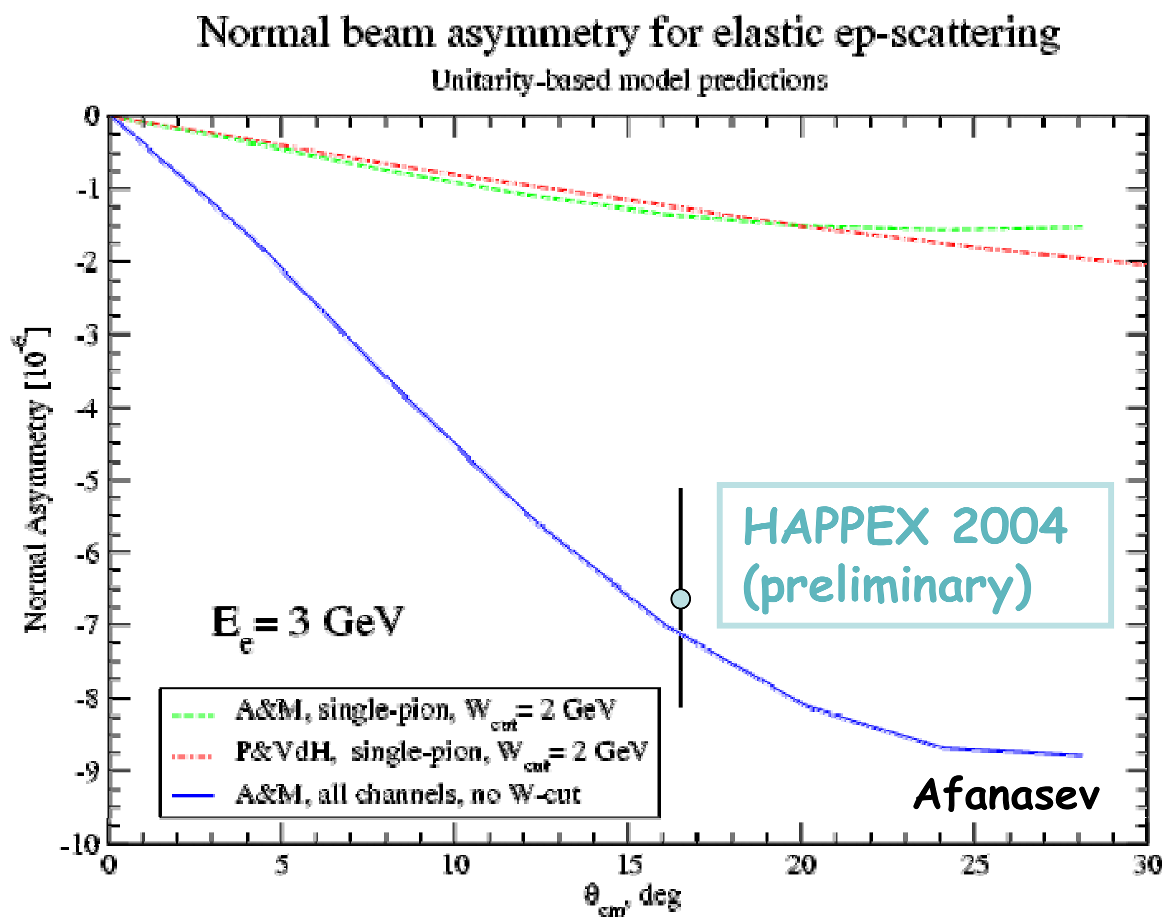
"inelastic"

A_T for Hydrogen: HAPPEX 2004

Residual transverse beam polarization can produce a Left vs. Right asymmetry

Which COULD create a systematic false asymmetry through imperfect Left/Right symmetry in the detector

Hydrogen:
A_T = -6.58 ppm
± 1.47 ppm (stat)
± 0.24 ppm (syst)

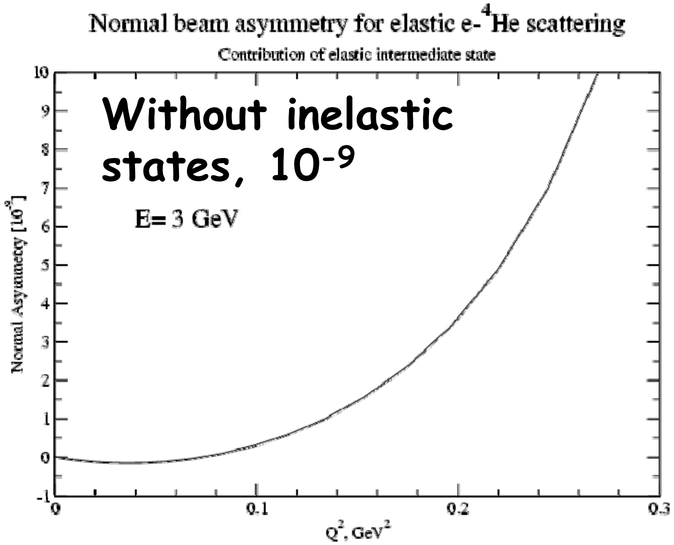


Vertical polarization created for this measurement using solenoids in 100 keV injector.

For parity-violating (longitudinal) measurement, P_V should be nulled (using these solenoids).

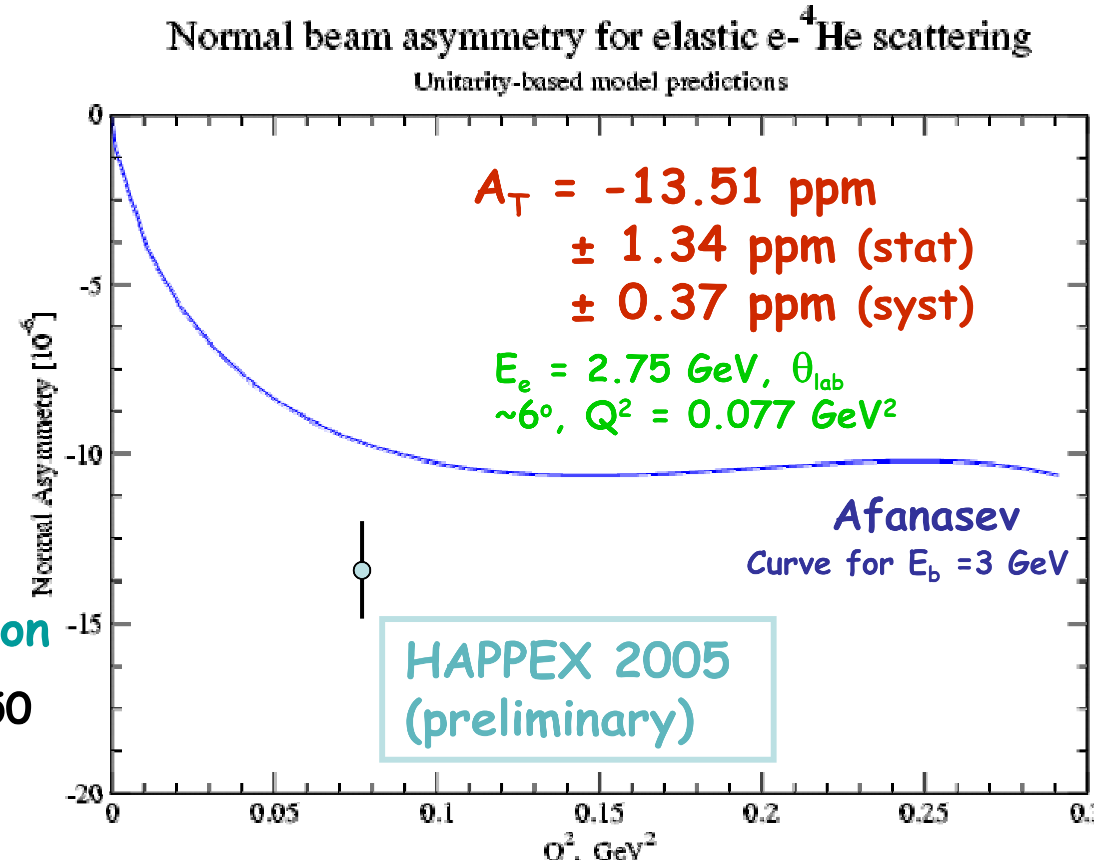
A_T from Helium: HAPPEX 2005

In HAPPEX-He 2005: A(left) – A(right) > 1 ppm!



Vertical polarization P_V = 3.6%

-> Explains L/R difference



Error bar as good as HAPPEX-I, but in 1 day!!!!

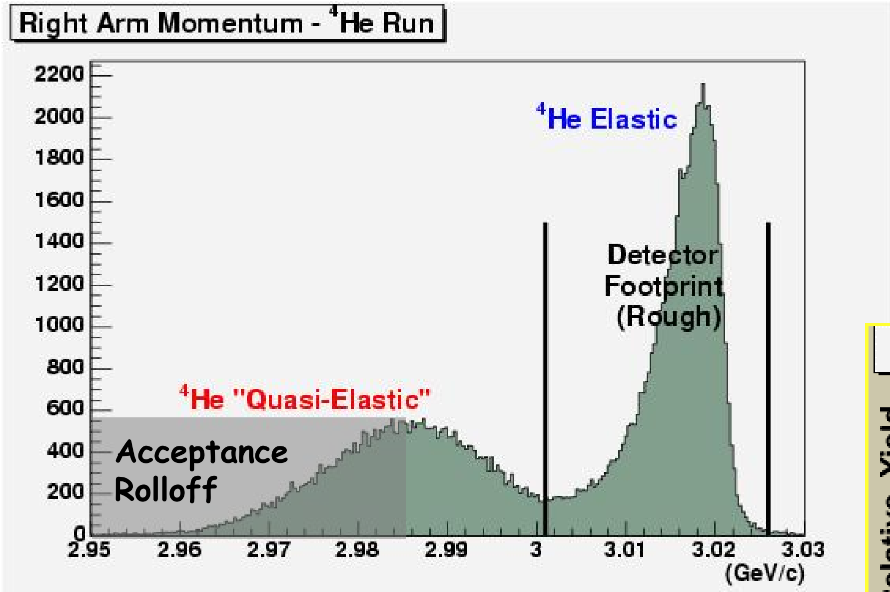
Ultimately, a very small systematic uncertainty contribution

- Good L/R acceptance symmetry: 1/50
- Reversed P_V for 1/3 of run: 1/50
- Contributed Systematic ~ 8 ppb

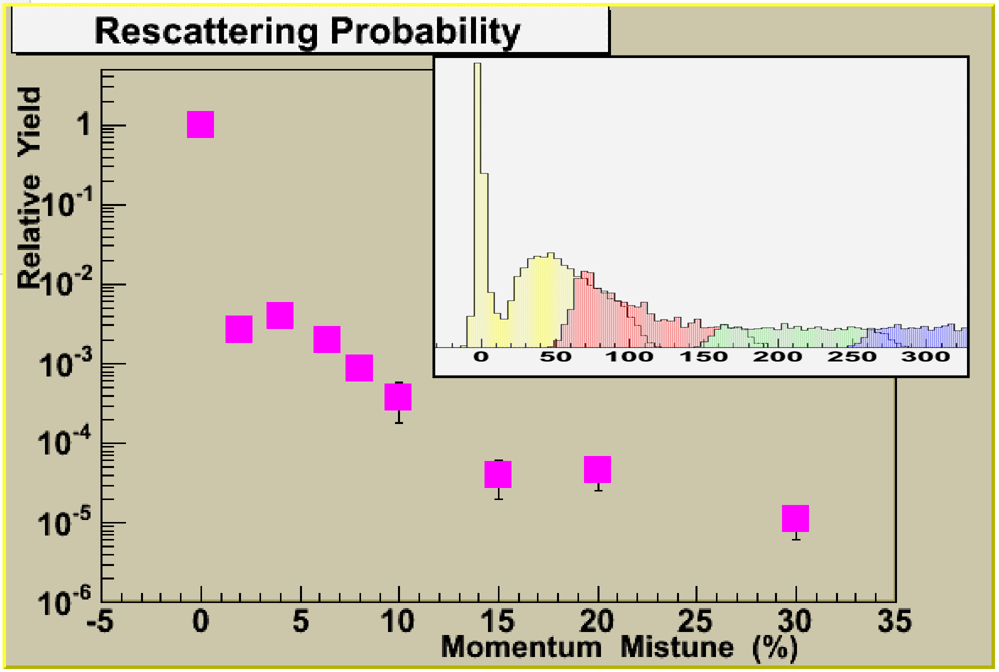
Kent Paschke – University of Massachusetts

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%

(For reference: G0 typically f = 5-20%)

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

Determining Q^2

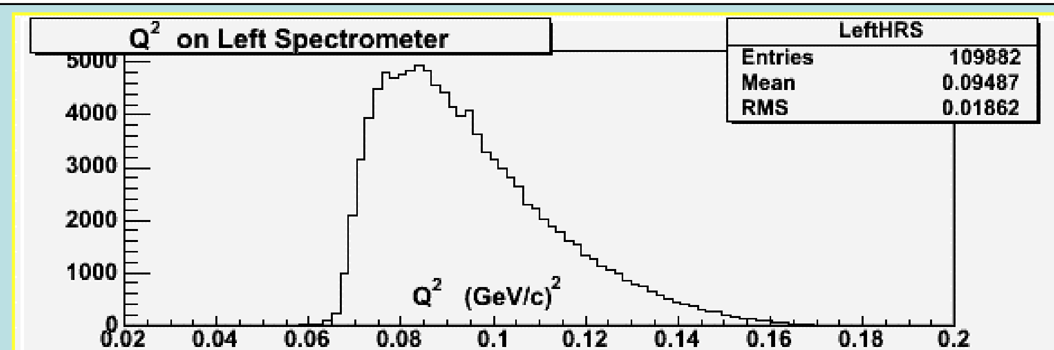
Asymmetry explicitly depends on Q^2:

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

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

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

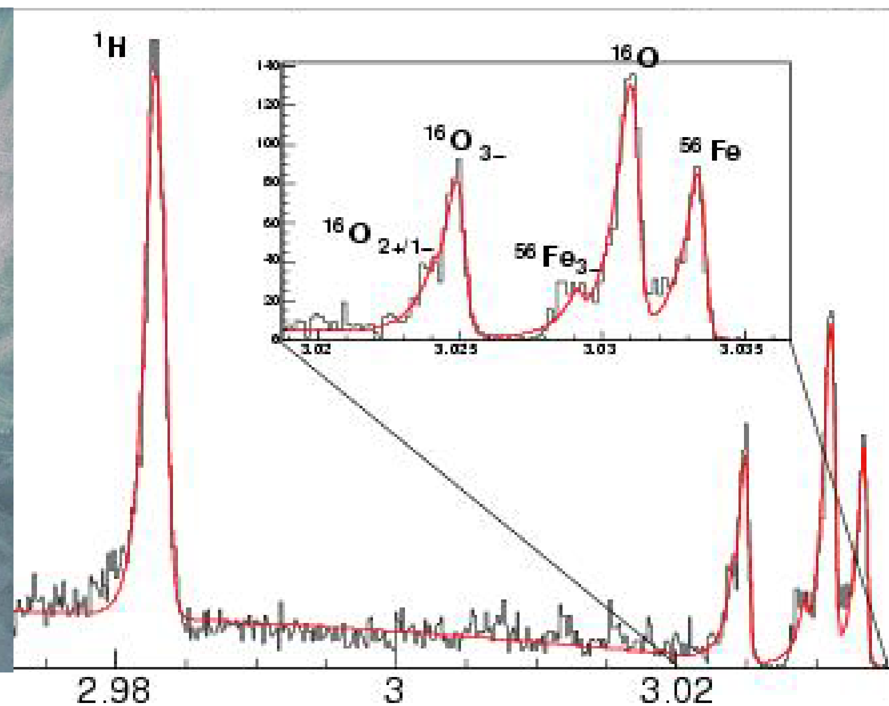
Measuring Central Angle

Novel Water Cell optics target developed

δp between elastic and excited state peaks reduced systematic error from spectrometer calibration

$\delta\theta \sim 0.3\%$ -> $\delta Q^2 \sim 0.7\%$

$$E' = \frac{E_0 - \frac{1}{2m}\left(m^{*2} - m^2\right)}{1 + \frac{E_0}{m\left(1 - \cos\theta\right)}}$$

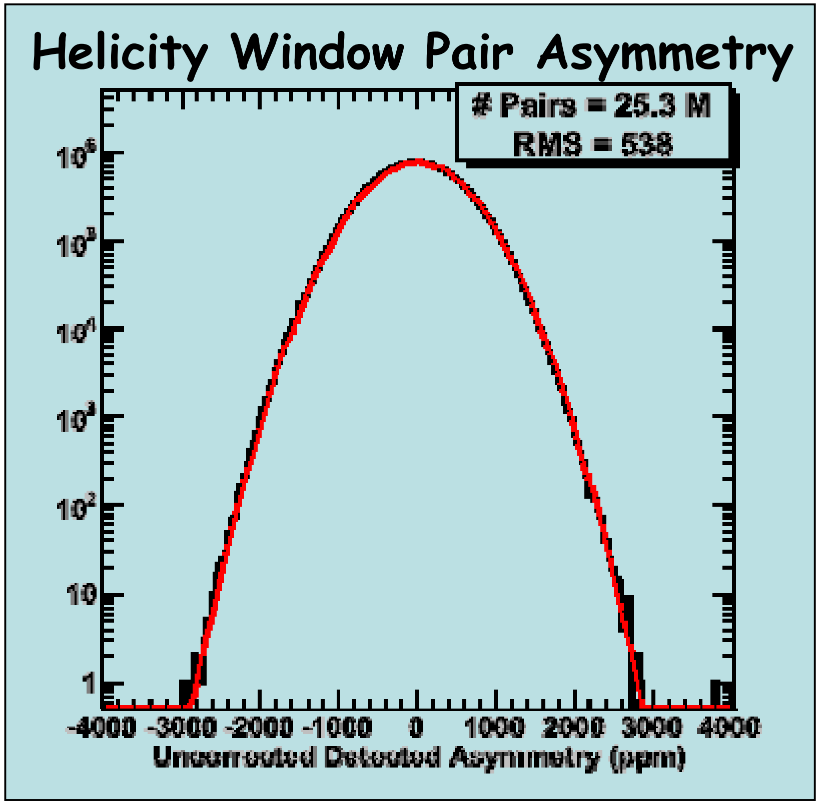


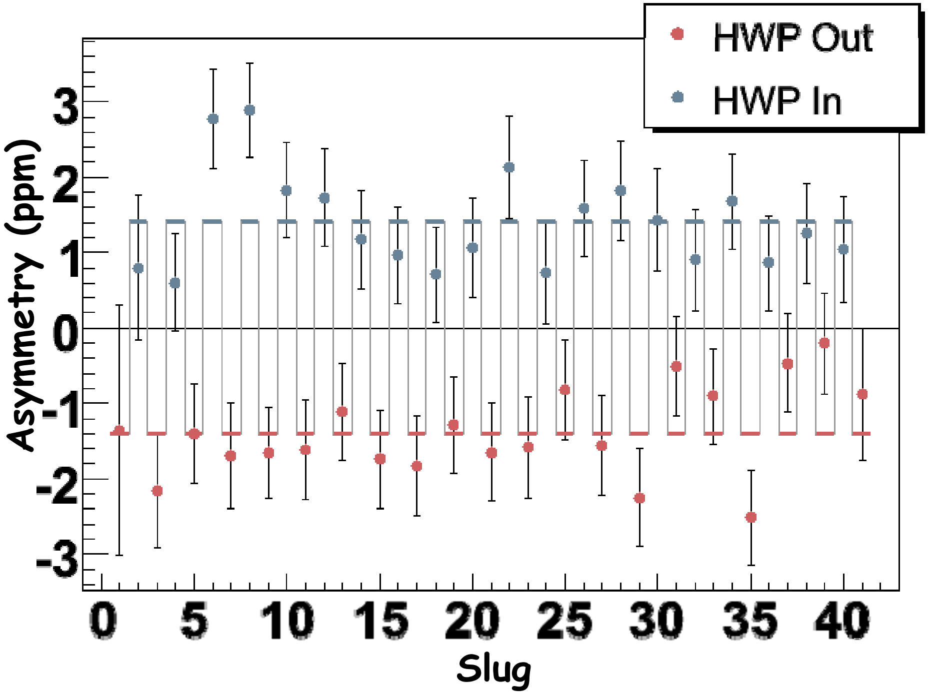
^{1}H Preliminary Results

Raw Parity Violating Asymmetry

~25 M pairs, width ~540 ppm

A_{raw} correction ~11 ppb





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

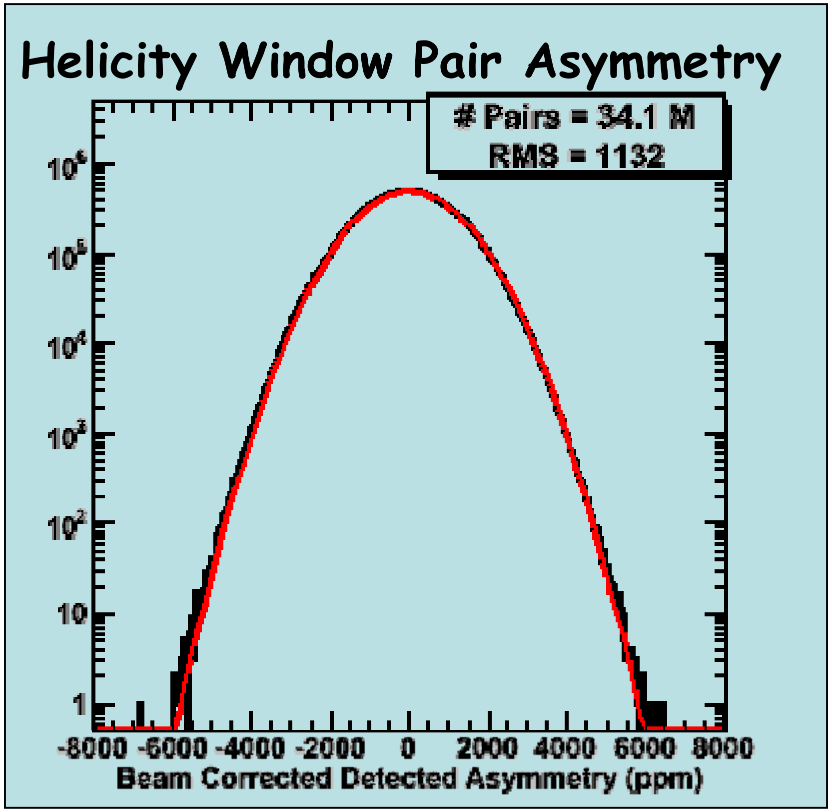
A_{raw} = -1.418 ppm ± 0.105 ppm (stat)

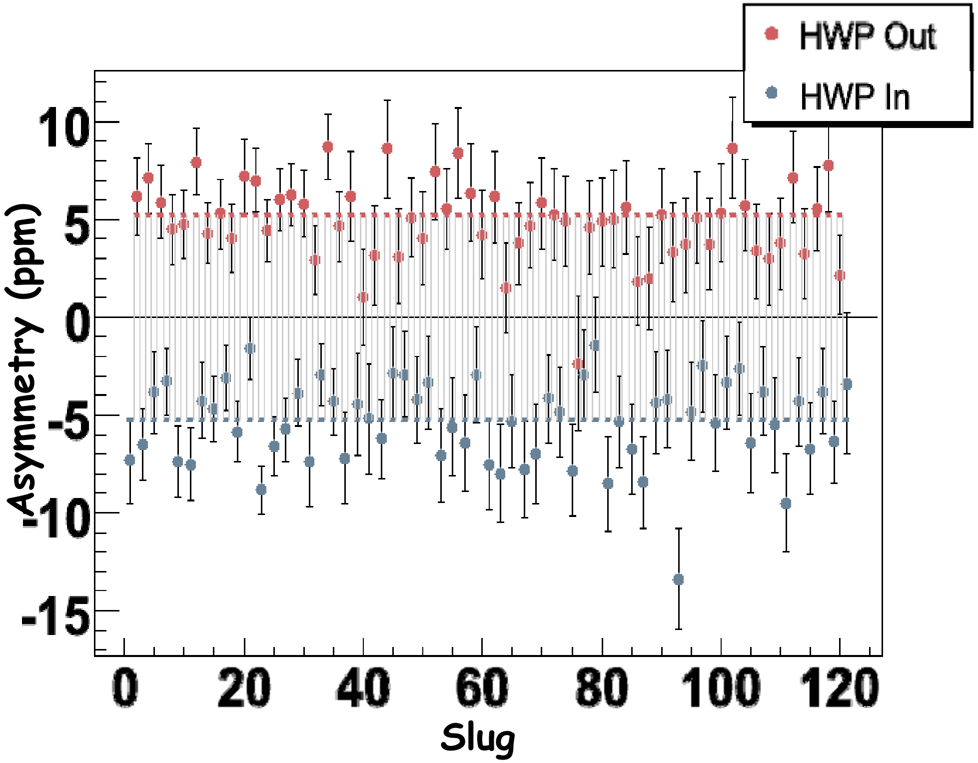
^{4}He Preliminary Results

Raw Parity Violating Asymmetry

35 M pairs, total width ~1130 ppm

A_{raw} correction ~ 0.12 ppm





$Q^2 = 0.07725 \pm 0.0007$ GeV^2

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

HAPPEX-II 2005 Preliminary Results

HAPPEX-^{4}He:

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

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

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

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

HAPPEX-H:

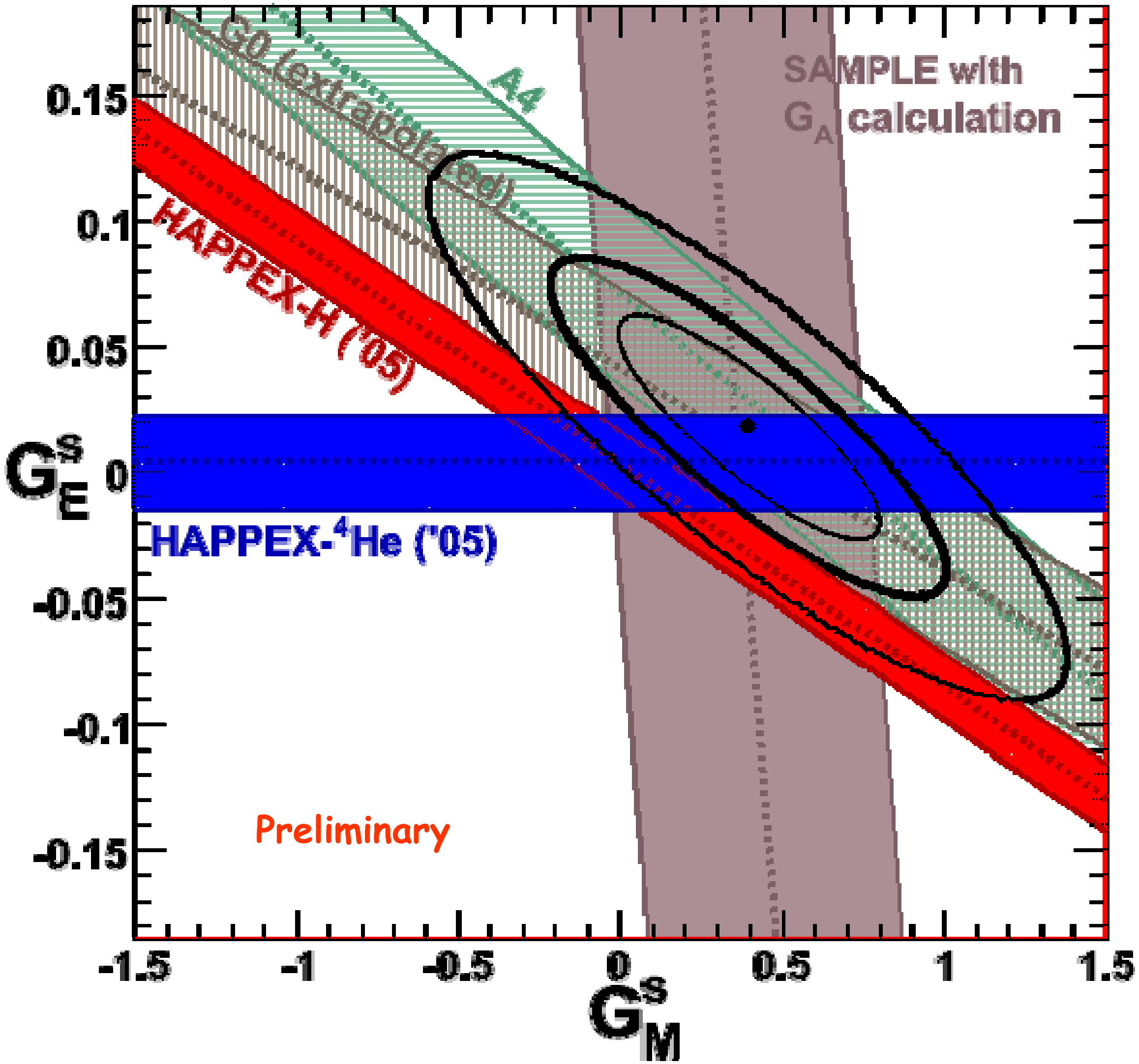
$$Q^2 = 0.1089 \pm 0.0011\ (\mathrm{GeV}/c)^2$$

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

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

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

HAPPEX-II 2005 Preliminary Results

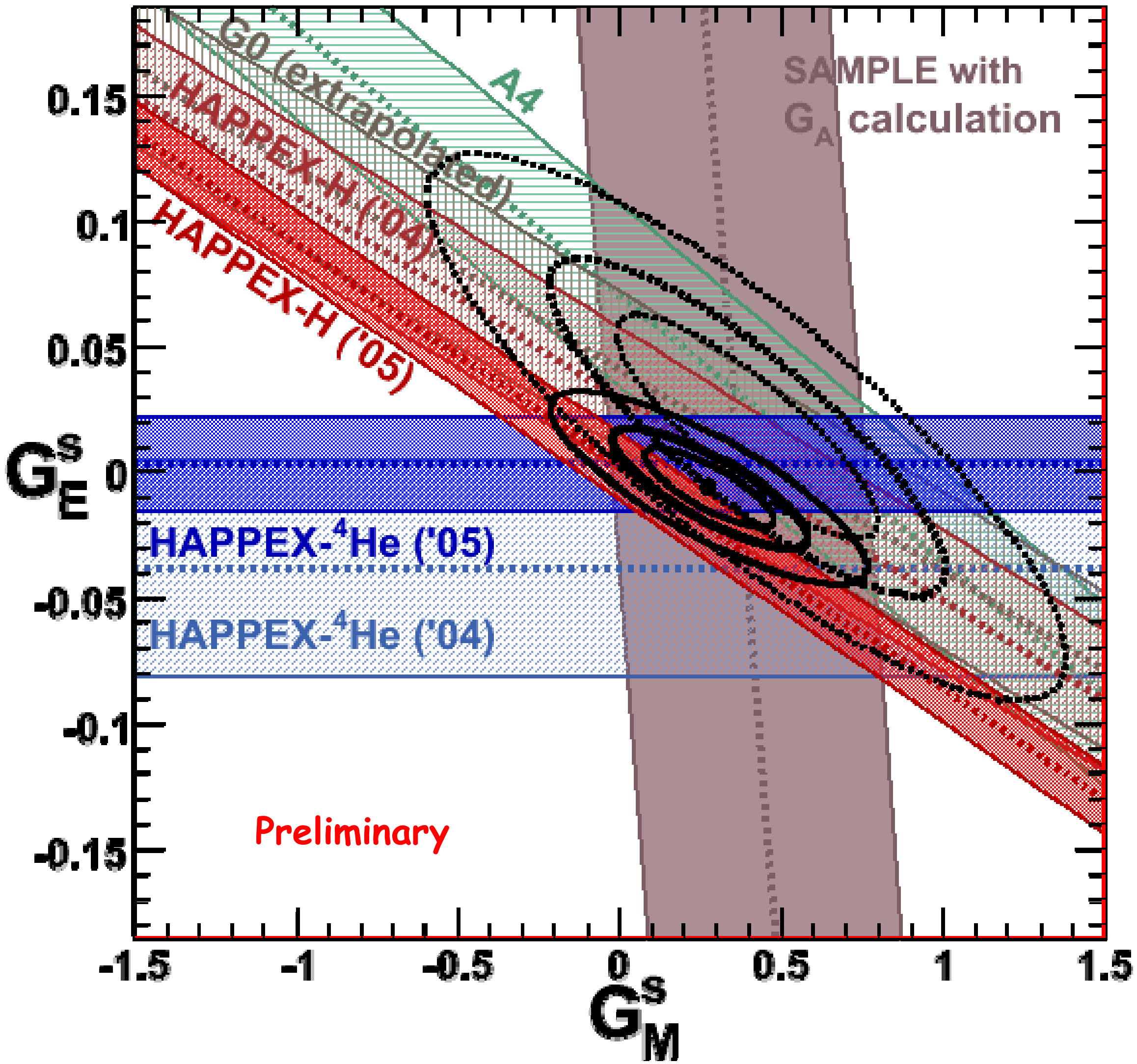


Three bands:

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

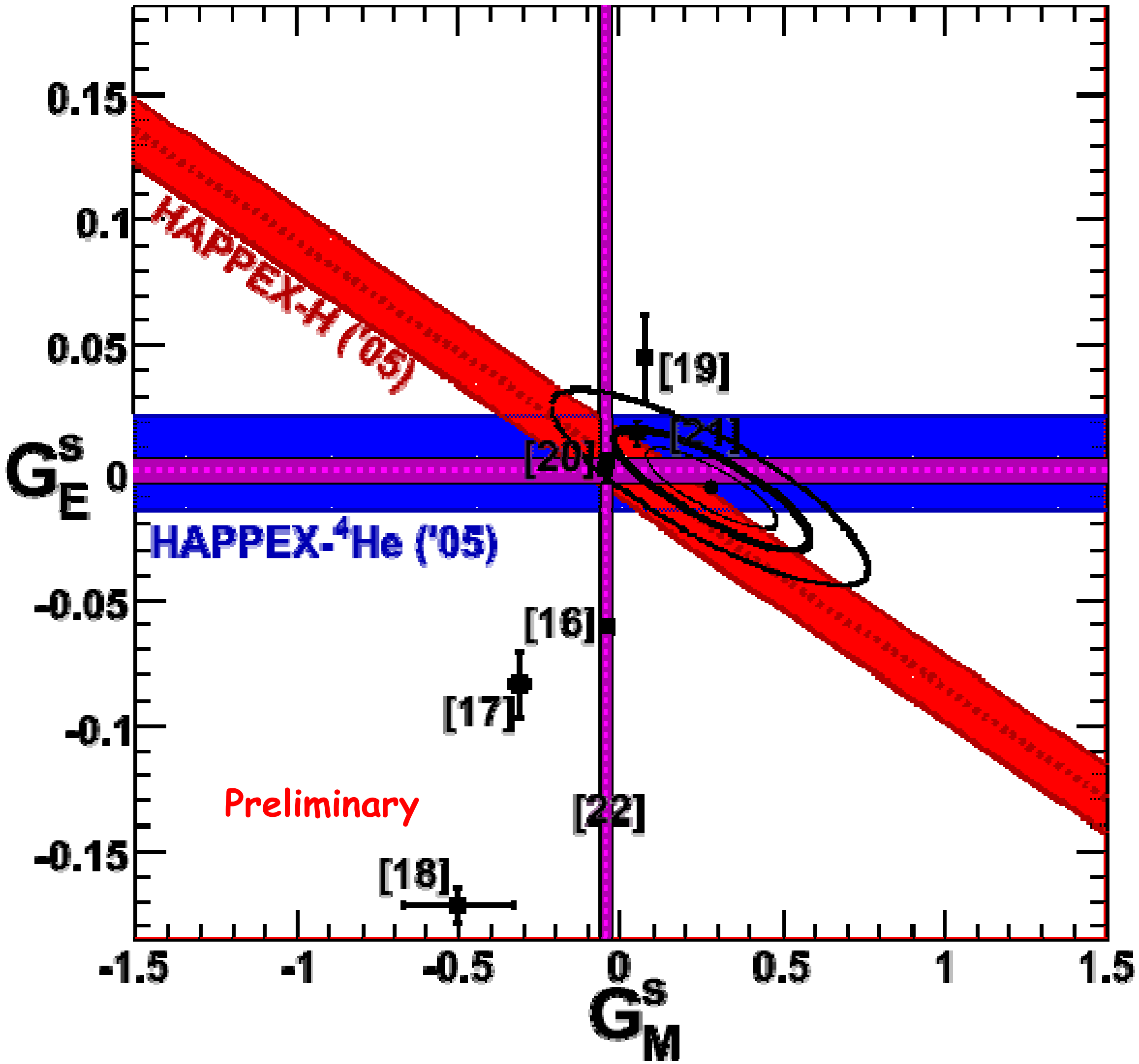
HAPPEX-only fit suggests something even smaller:

G_M^s = 0.12 +/- 0.24

G_E^s = -0.002 +/- 0.017

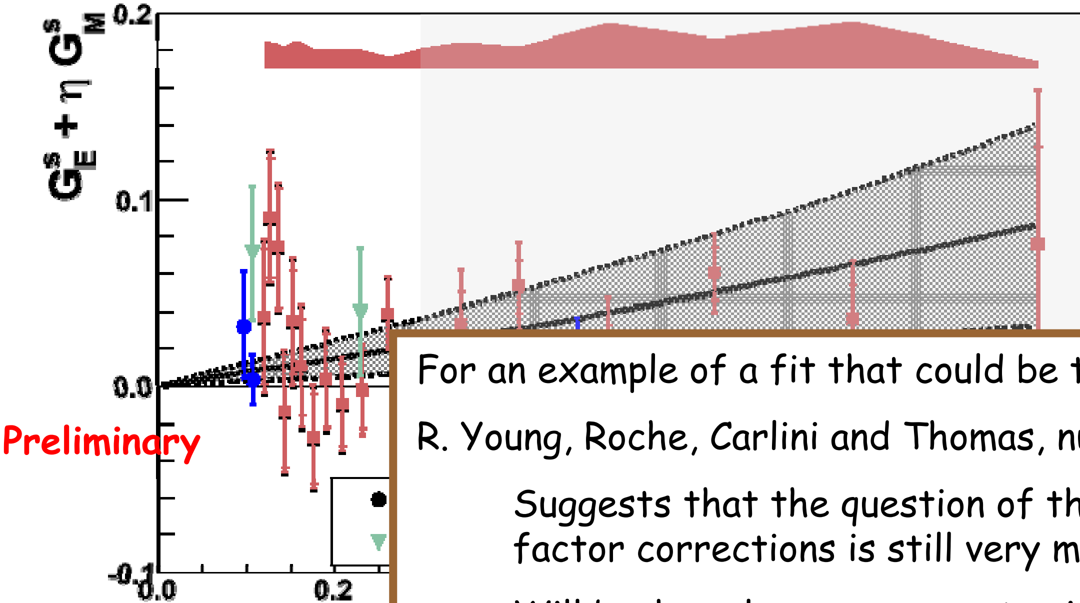
Caution: the combined fit is approximate. Correlated errors and assumptions not taken into account

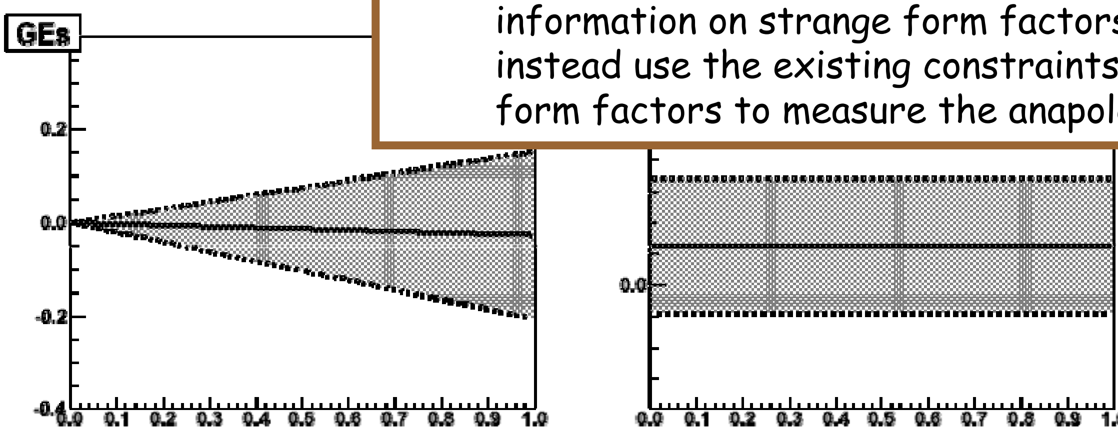
World data consistent with state of the art theoretical predictions



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

A Simple Fit (for a simple point)





For an example of a fit that could be taken seriously:

R. Young, Roche, Carlini and Thomas, nucl-ex/0604010

> Suggests that the question of the axial form factor corrections is still very much alive.
>
> Will back angle measurements give us more information on strange form factors, or will they instead use the existing constraints on strange form factors to measure the anapole term?

Simple fit:

GEs = $r_s * \tau$

GMs = μ_s

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

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

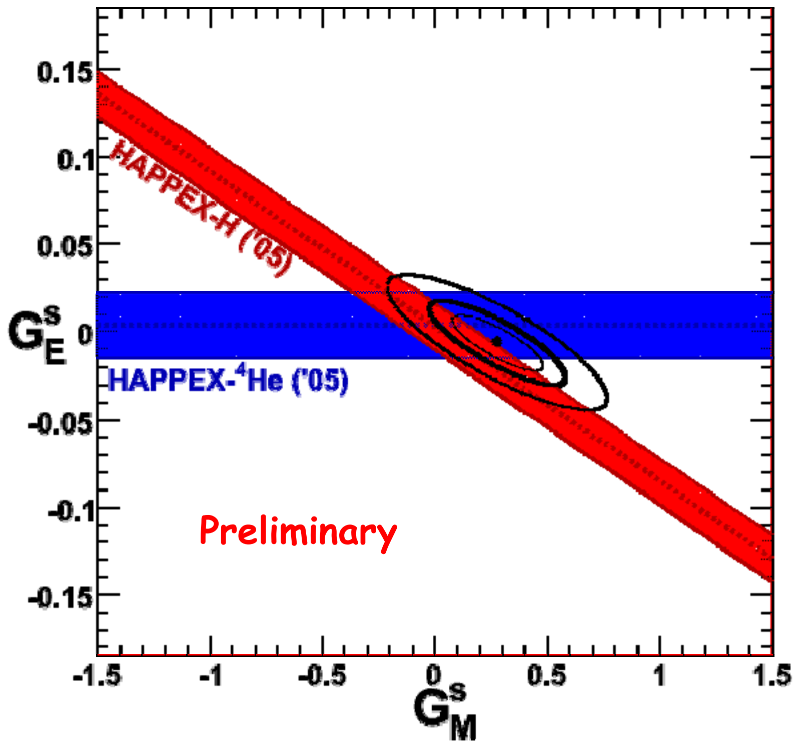
G0 Global error allowed to float with unit constraint

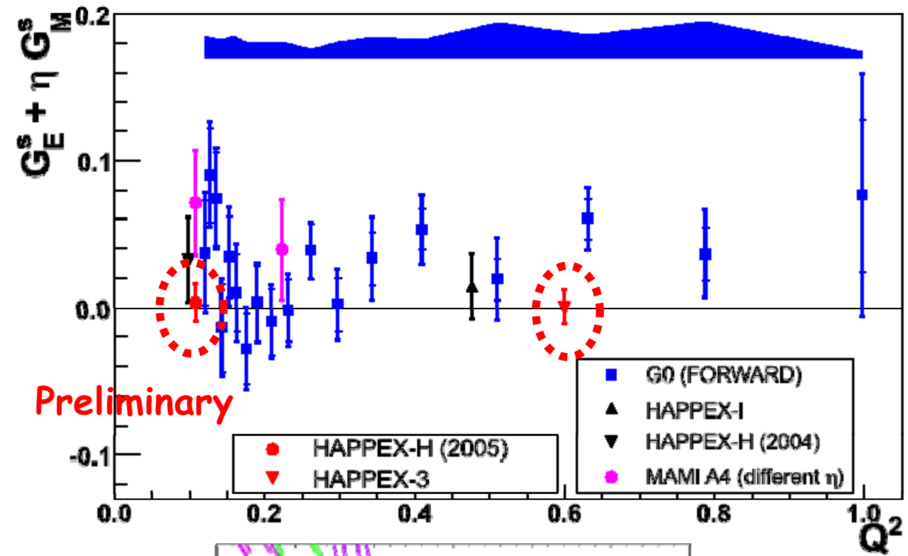
...t done with form ...elated errors, etc.

...alues should NOT ...ery seriously, but ..., basic points:

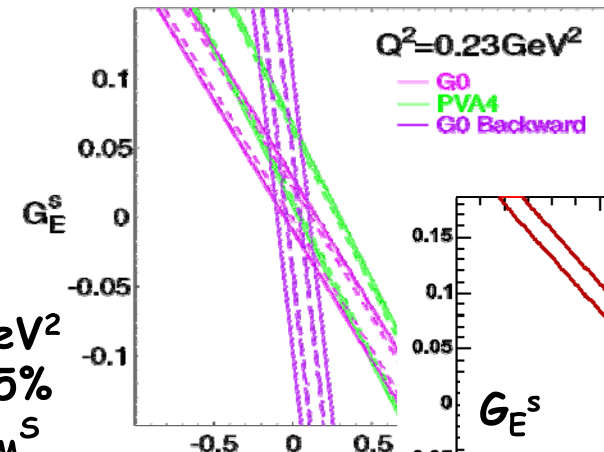
- **...data is consistent.**
- **... dependence of strange form-factors is not required.**
- **Sizeable contributions at higher Q^2 are not definitively ruled out. (To be tested by HAPPEX-III, G0 and A4 backangle.)**

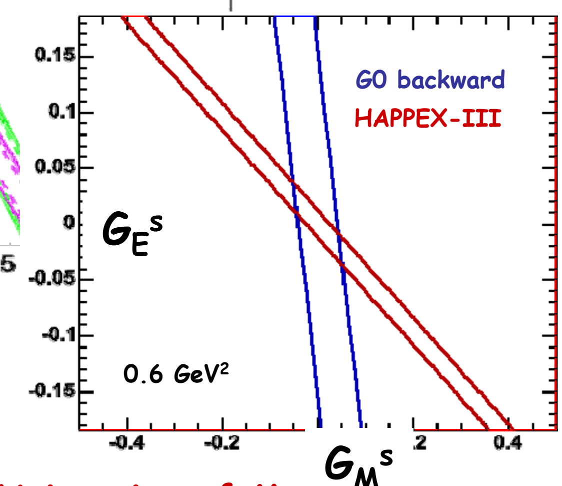
Summary





- Suggested large values at Q^2~0.1 GeV^2
  - Ruled out
- Large possible cancellation at Q^2~0.2 GeV^2
  - Very unlikely given constraint at 0.1 GeV^2
  - G0 back angle at low Q^2 (error bar~1.5% of μ_p) maintains sensitivity to discover G_M^S
- Possible large values at Q^2>0.4 GeV^2
  - G^0 backangle, Running now!
  - HAPPEX-III - 2008





Conclusion

If you haven't found something strange during the day, it hasn't been much of a day.

John A. Wheeler

Experimental:

- Helium: first ever <4% relative error on any PV electron scattering measurement (future PREx, HAPPEX-III, QWeak propose 1-2%)
- Hydrogen: spectacular "parity quality", through superior source configuration and exquisite beam transport… ~1nm, without feedback!
- Hydrogen: first <100 ppb precision measurement at JLab

Physics:

- Tight upper-bound shows that strange quarks <1% of charge density, <5% of magnetic density of the proton

There is no known fundamental QCD reason why this should be so

- Experimental upper-limits agree with state-of-the-art theoretical calculations

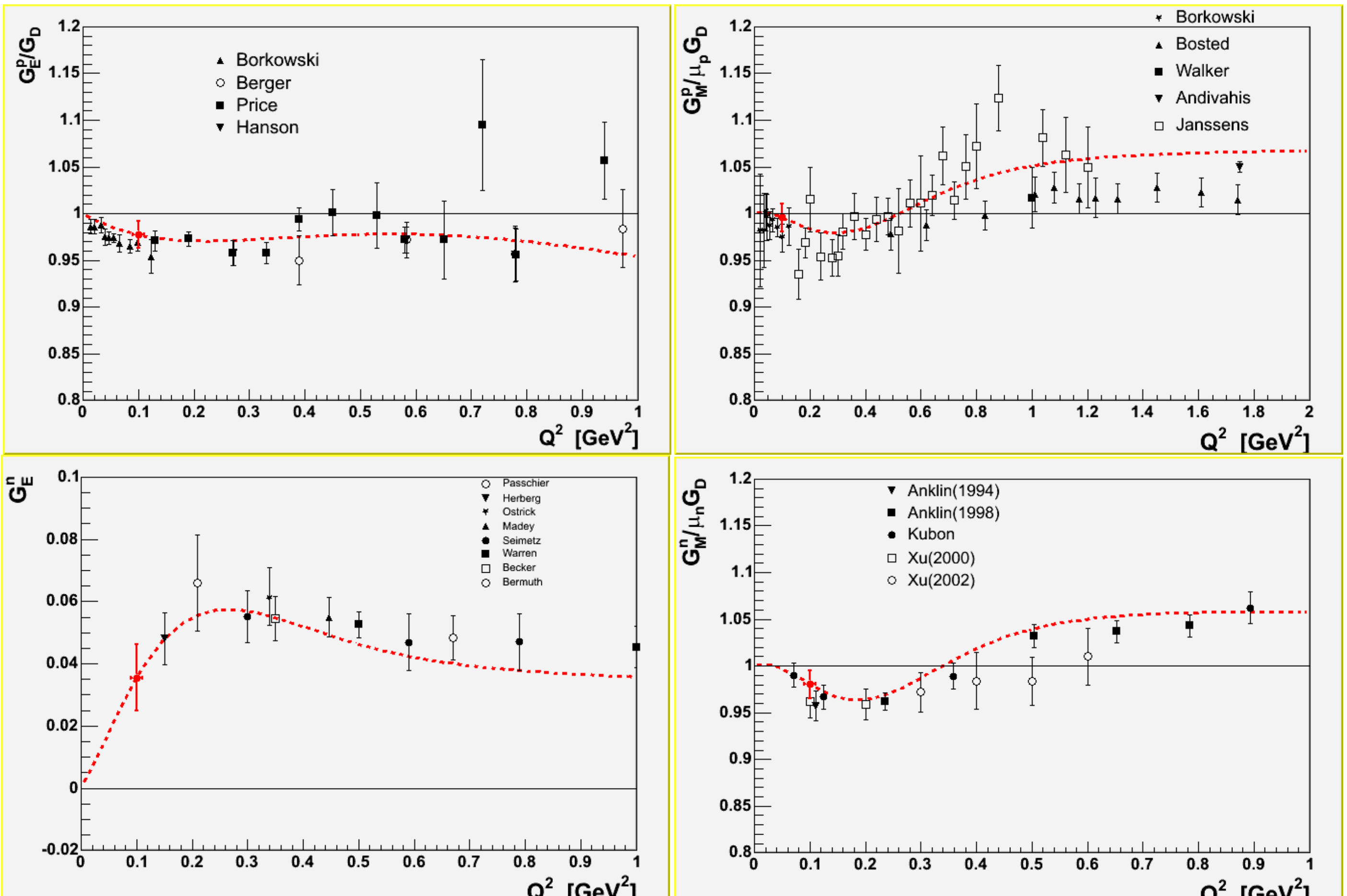
Nathan Isgur: Zero may be the MOST interesting of the possible results!

Is there an unknown symmetry of QCD that forces this contribution to such a small level?

These beautiful results on the strangely non-strange proton make this a wonderful day!

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%
$G_A^{(3)}$	-
$G_A^{(8)}$	-

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

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

Error Budget-Helium 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 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