Jefferson Lab

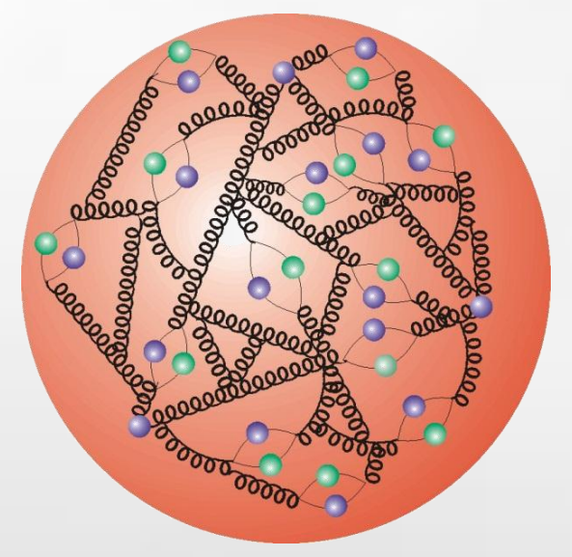
Measurement of Nucleon Form Factors at High Q^2

(HAPPEX III Collaboration, Spokesperson : Kent Paschke)

Rupesh Silwal

University of Virginia, Dept. of Physics, Charlottesville, VA

Introduction



The bare valence quarks of the nucleon carry only ~1% of the nucleon mass, the rest is in the sea of gluons, quarks and anti-quarks, which is dominated by the up, down and strange quarks.

The strange quark is a natural place to start looking for sea quark effects because any strangeness is a pure sea quark effect.

Do the strange quarks affect the static properties of the nucleon?

Recent experimental results of G0[1,2] is suggestive of a non-zero strangeness contribution to the nucleon form factors, but is not conclusive due to large uncertainty in the data at higher Q^2.

Measurement of the weak form factor through parity-violating electron scattering allows the extraction of the contribution of the strange quarks to the nucleon form factors.

Strange Form Factors

The cross-section asymmetry of longitudinally polarized electrons scattered from unpolarized protons violates parity.

$$A_{PV} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right]\frac{A_V + A_s + A_A}{\sigma_p} = A_{VA} + \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right]\frac{A_s}{\sigma_p}$$

$$A_V = [(1 - 4\sin^2\theta)\sigma_p - \epsilon G^p{}_E G^n{}_E + \tau G^p{}_M G^n{}_M]$$

$$A_s = \epsilon G^p{}_E\left(G^s{}_E + \frac{\tau G^p{}_M}{\epsilon G^p{}_E} G^s{}_M\right) = \epsilon G^p{}_E(G^s{}_E + \eta G^s{}_M)$$

$$A_A = A_0(1 - 4\sin^2\theta)\epsilon' G^p{}_M \tilde{G}^p{}_A;\ \sigma_p = \epsilon(G^p{}_E)^2 + \tau(G^p{}_M)^2$$

The Axial Form Factors, $\tilde{G}_A$

$$\tilde{G}_A = -(1 + R^{T1}{}_A)G^3{}_A + \sqrt{3}R^{T0}{}_A G^8{}_A + (1 + R^0{}_A)G^s{}_A$$

Anapole Moment Correction ($R^{T1}{}_A$ & $R^{T0}{}_A$)[3]:

- Anapole moment is due to purely multiquark weak interactions.
- The correction values are model dependent with large uncertainty.
- Anapole moment correction uncertainty dominates axial term.

For the HAPPEX-III kinematics, the expected asymmetry in the case of **zero strange quark** contribution is

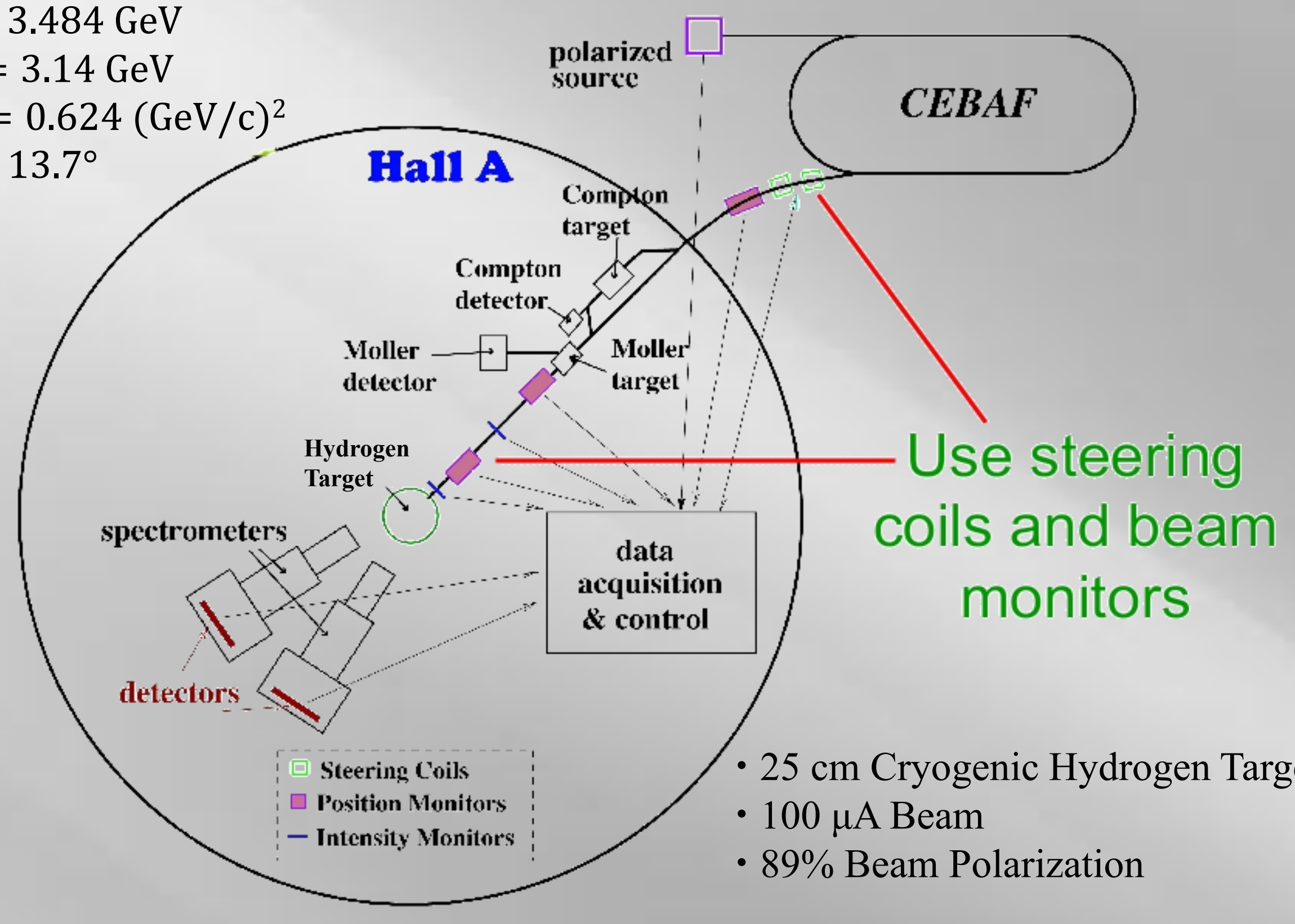
$$\boxed{A_{VA} = -24.060 \pm 0.734(FF)\ ppm}$$

The uncertainty is due to the precision of knowledge of the electromagnetic form-factors, and uncertainties in the axial radiative corrections.

Experimental Setup

Jefferson Lab is an ideal place for parity-violating experiments due to small experimental systematics, and extremely good beam quality.

$E = 3.484$ GeV
$E' = 3.14$ GeV
$Q^2 = 0.624\ (\mathrm{GeV/c})^2$
$\theta = 13.7°$



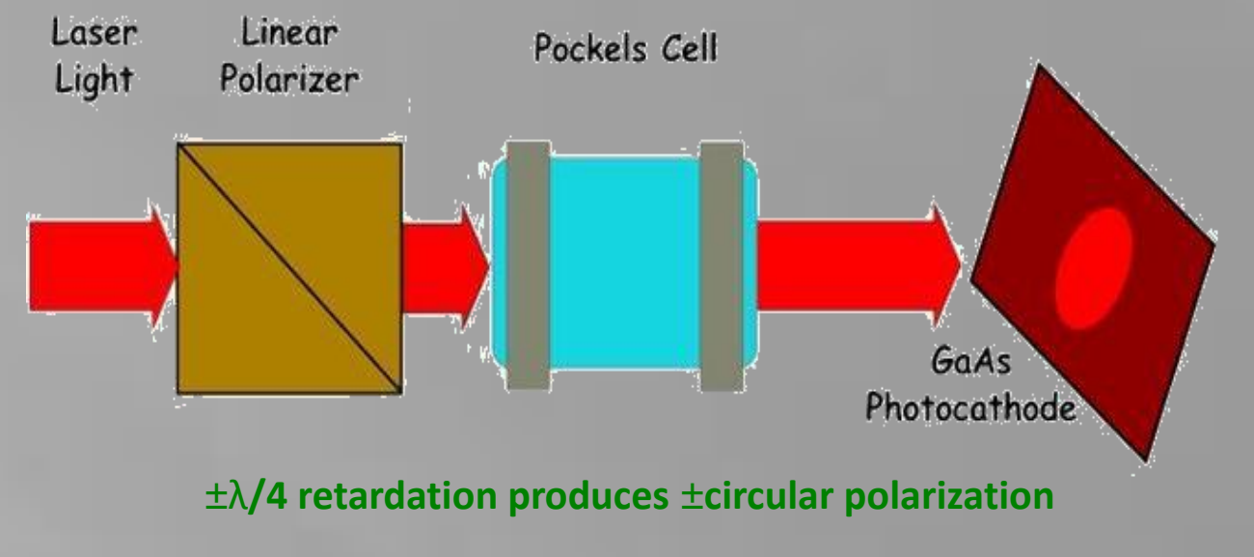
Use steering coils and beam monitors

- 25 cm Cryogenic Hydrogen Target
- 100 μA Beam
- 89% Beam Polarization

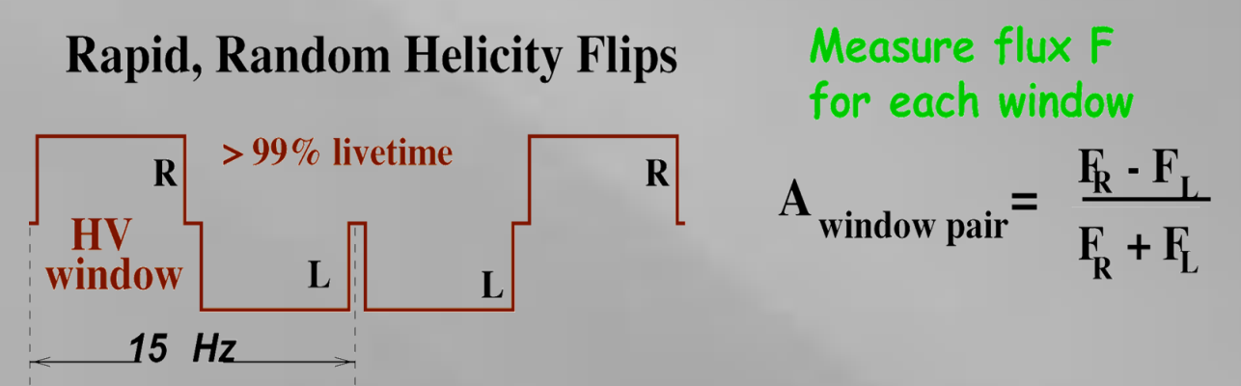
- Compton and Moller provide beam polarization to within ~1%.
- The two high resolution spectrometers (HRS) provide independent measurement, doubling the solid angle and acceptance.
- The precision HRS focus only elastic events onto the detector, with all inelastic events swept out of the acceptance, and allow for clean suppression of backgrounds.

Experimental Method

- The polarized electrons are generated by photoemission from a GaAs photocathode using Right(R)/Left(L) circularly polarized laser beam.
- The laser light polarization is prepared using an electro-optic Pockels cell with R/L Quarter-wave phase differences generated from ± voltages.



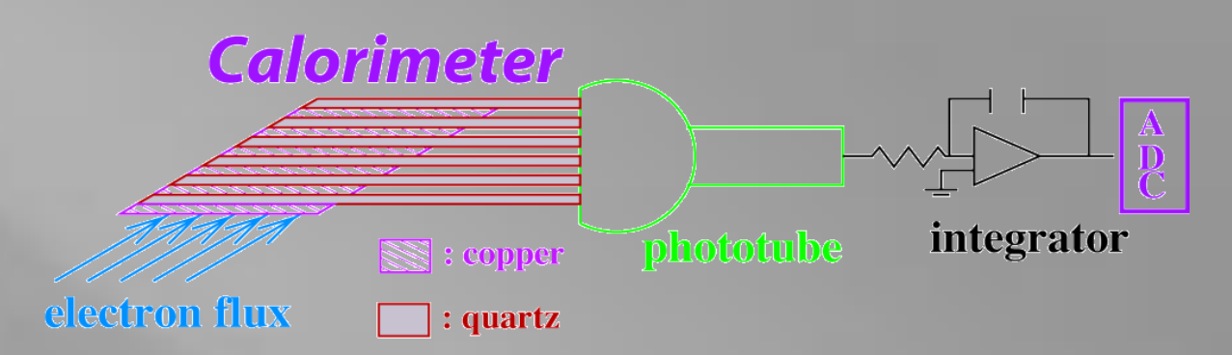
±λ/4 retardation produces ±circular polarization



$$A_{\text{window pair}} = \frac{F_R - F_L}{F_R + F_L}$$

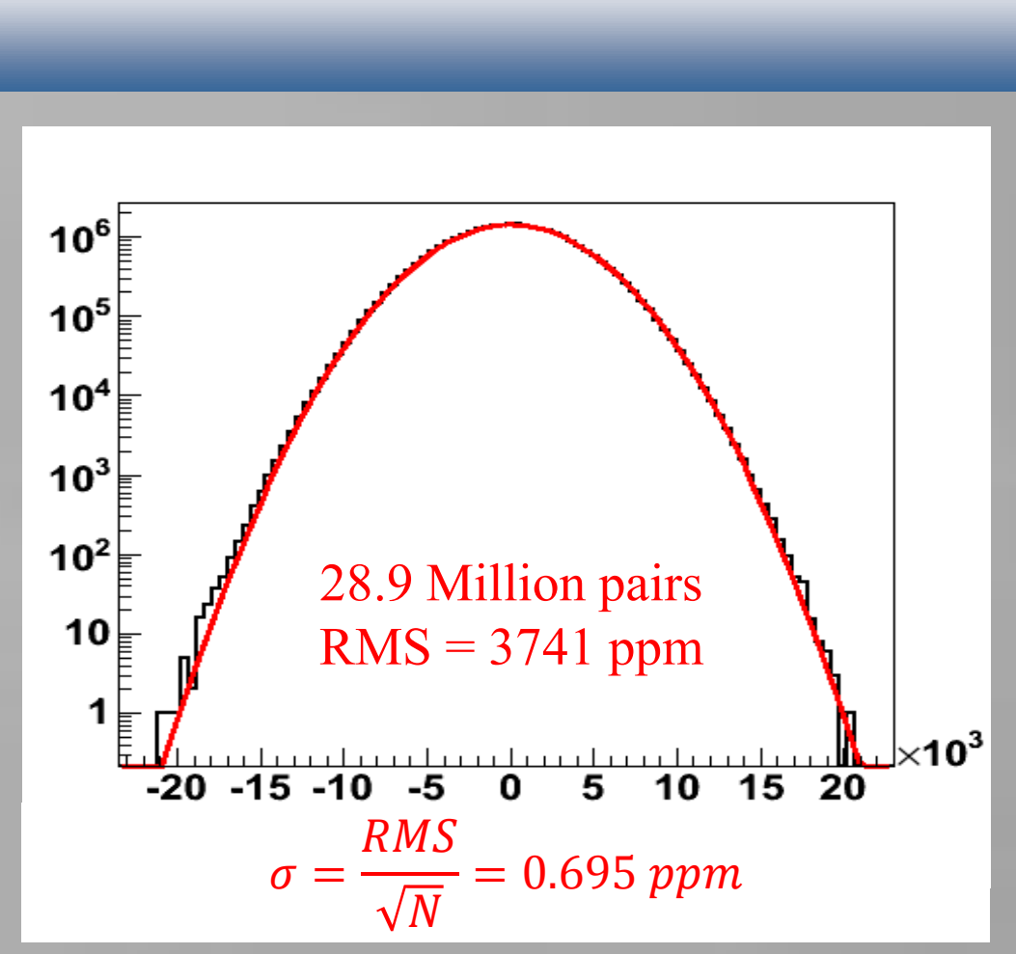
The helicity is reversed rapidly to decrease sensitivity to slow drifts such as temperature changes.

- The flux over each helicity window is integrated.
- Integration allows very high flux detection with minimal rate dependent corrections.



HAPPEX III flux: 550 KHz

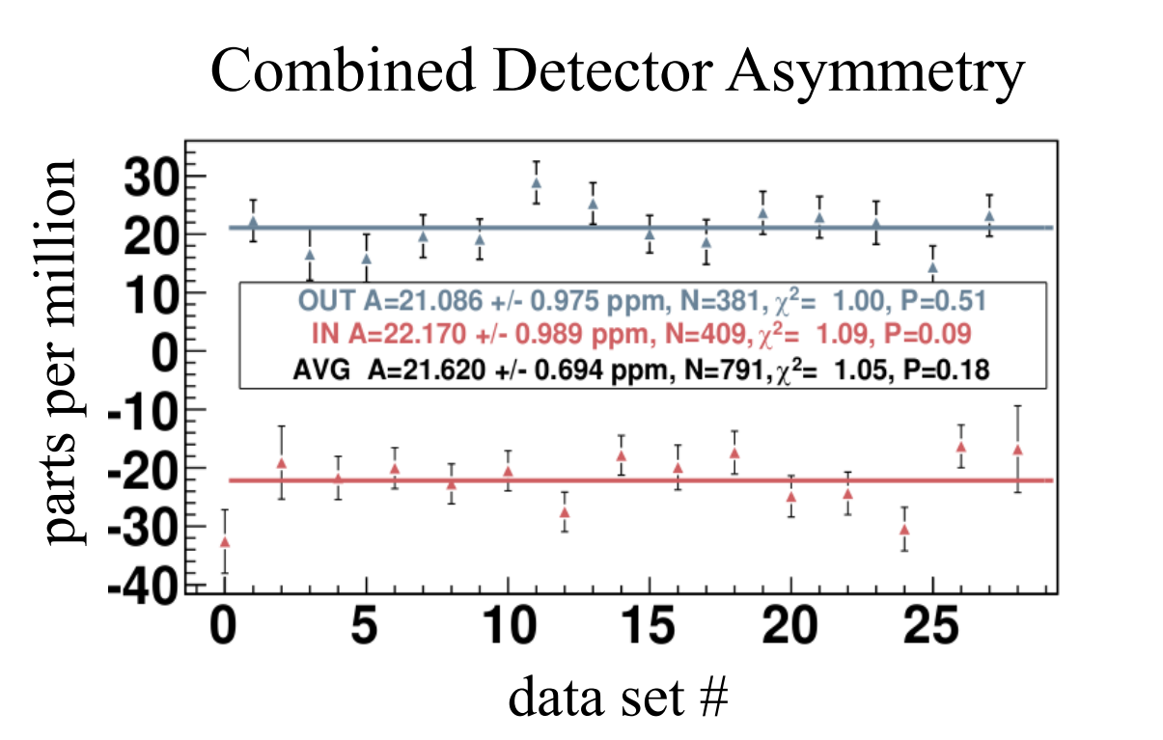
Results



$$\sigma = \frac{RMS}{\sqrt{N}} = 0.695\ ppm$$

- The detector measurement is counting statistics dominated, indicating negligible instrumentation and window-to-window noise.
- Statistical precision of 0.00007 %.

- Left/Right detectors are combined to extract a cumulative asymmetry.
- Passive beam polarization reversal is used to cancel out some of the beam systematic effects.



	δA_{PV} (ppm)	$\delta A_{PV} / A_{PV}$
Polarization	0.202	0.85%
Q^2 Measurement	0.160	0.67%
Backgrounds	0.194	0.82%
Linearity	0.129	0.54%
Finite Acceptance	0.048	0.20%
False Asymmetries	0.041	0.17%
Total Systematic	0.353	1.49%
Statistics	0.776	3.27%
Total Experimental	0.853	3.59%

- The beam systematic errors, false asymmetries, are well suppressed, which left unchecked can be the dominant source of systematic error.
- The systematic error due to non-linearity is primarily from the detectors, which is bound via *in situ* and bench studies.
- The beam polarization measurement and backgrounds are the dominant source of systematic errors.

Net raw asymmetry:

$$\boxed{A_{raw} = -21.591 \pm 0.688(stat)ppm}$$

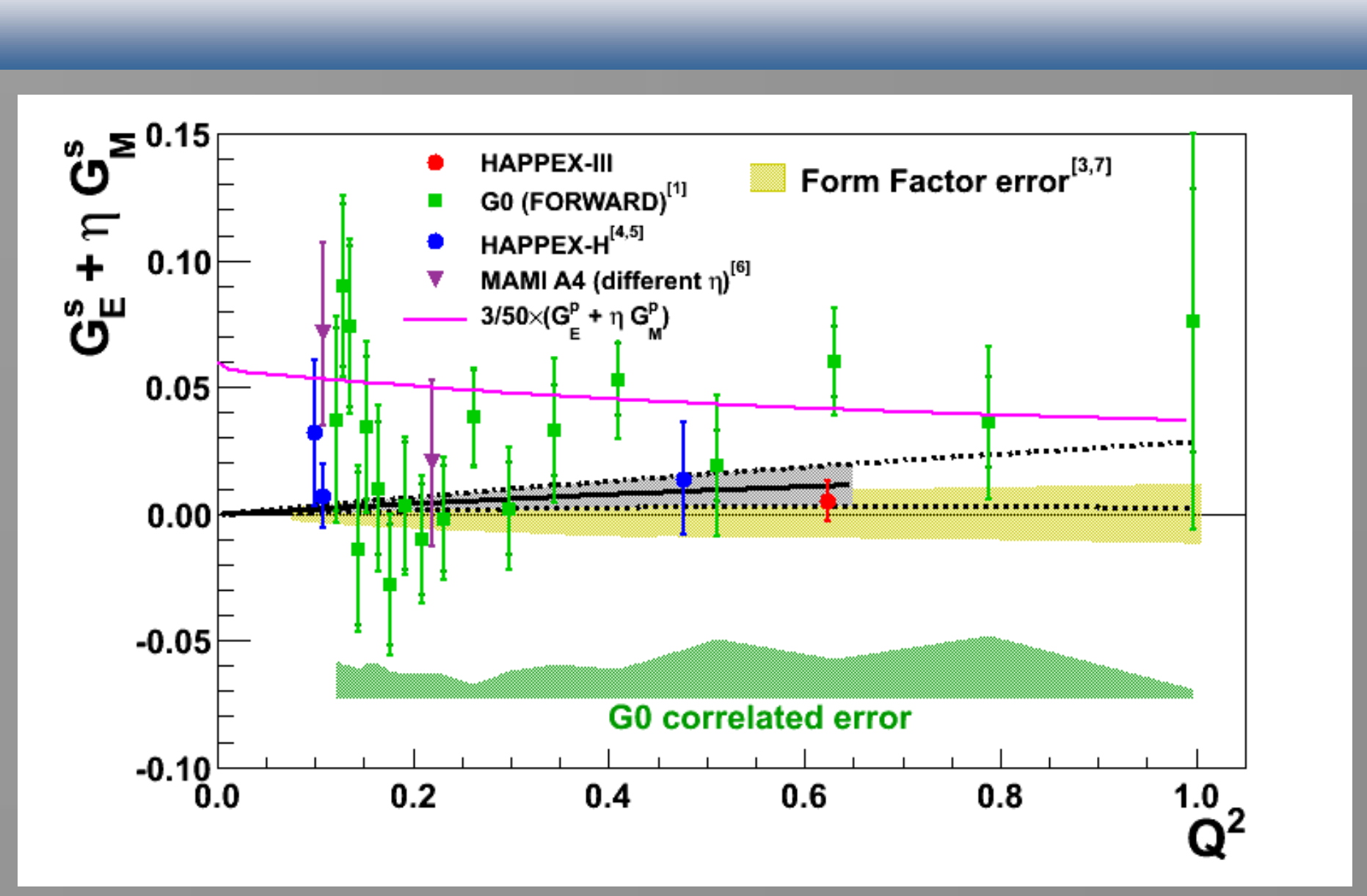
Physics asymmetry:

$$\boxed{A_{PV} = -23.742 \pm 0.776(stat) \pm 0.353(syst)\ ppm}$$

$$@\ \boxed{Q^2 = 0.6241 \pm 0.0028\ (\mathrm{GeV/c})^2}$$

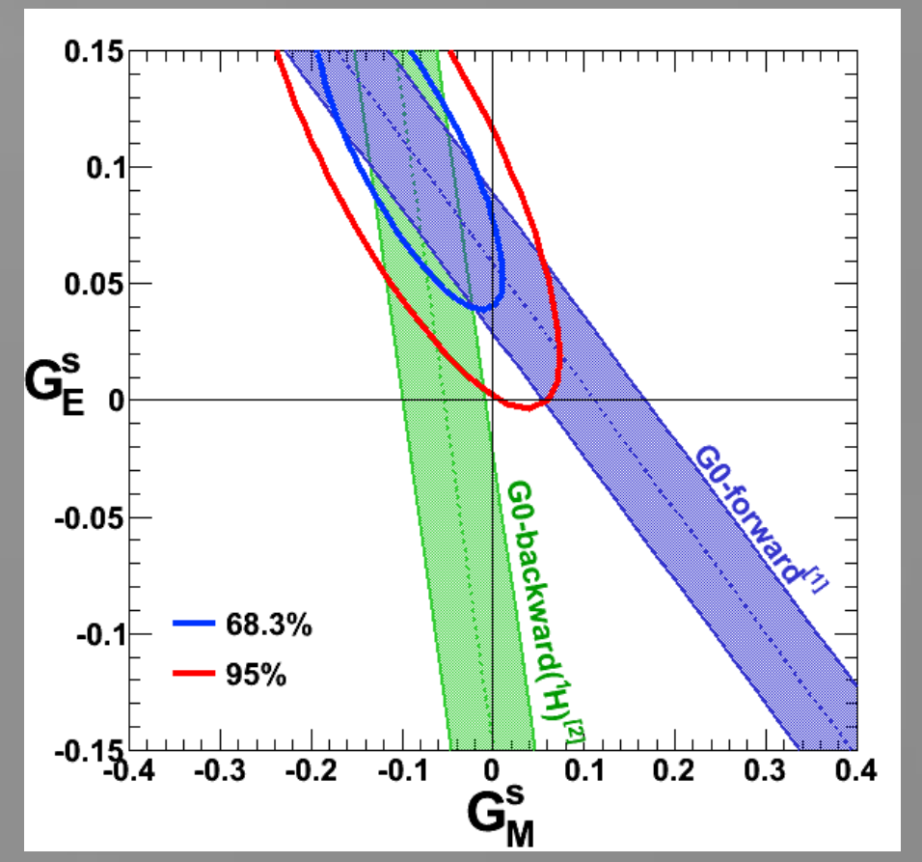
$$\boxed{\boldsymbol{G^s{}_E + 0.517 G^s{}_M = 0.004 \pm 0.010(stat) \pm 0.004(syst) \pm 0.009(FF)}}$$

Conclusions

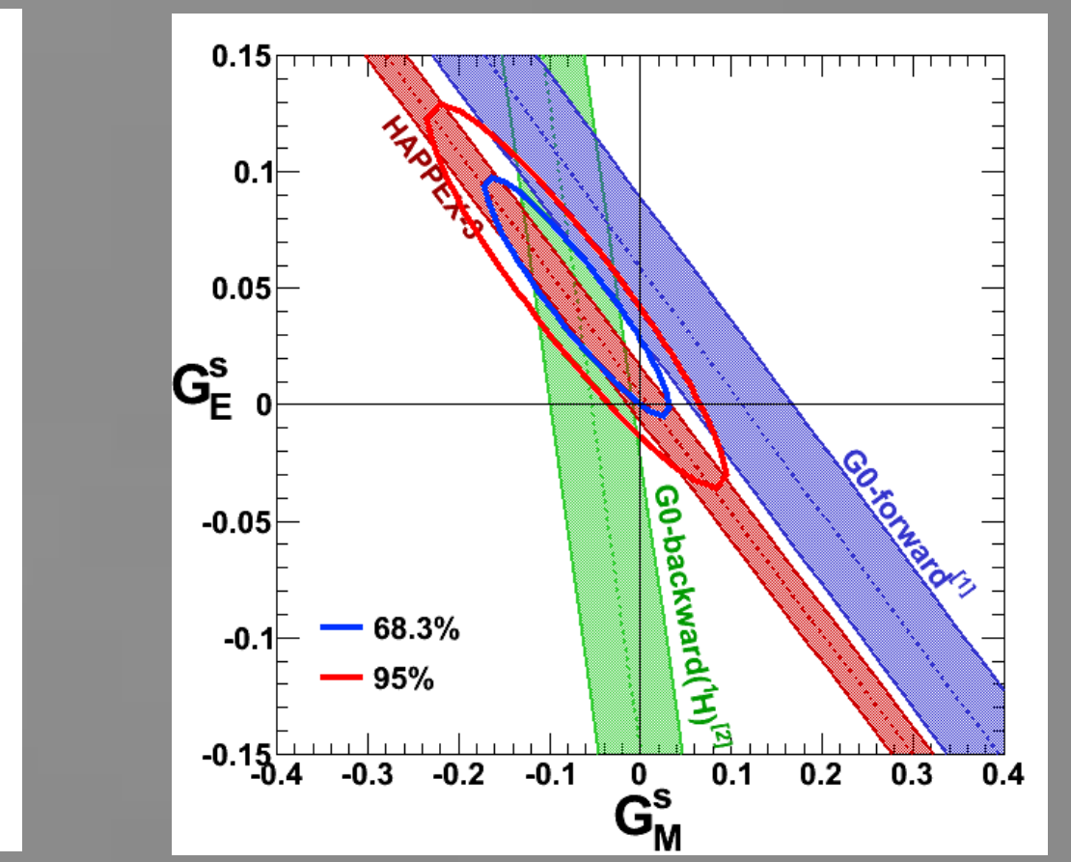


- HAPPEX III result is consistent with **zero** within the form factor uncertainties.
- Leading order fit of the world data (shaded region), anchored by the HAPPEX III point, suggests a **zero** strangeness contribution to the nucleon form-factors (pink trace is 2% of the proton form factor).

World Data @ Q^2=0.62 $(\mathrm{GeV/c})^2$:



Without HAPPEX III result



With HAPPEX III result

The HAPPEX measurements, which possess the highest precision and lowest systematic error of measurements of the strange form factor, strongly suggest that any strange contributions are small, and consistent with **zero** at the level of interpretability of these experiments.

- Recent lattice QCD results[8] suggest a non-zero strange form factor, but with values smaller than the current form factor uncertainties.

References

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