Search for a Nonzero Strange Form Factor of the Proton at 2.5 $(GeV/c)^2$

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Hall A/C Meeting 6/17/22

University of Virginia

Jefferson Lab

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Collaborators

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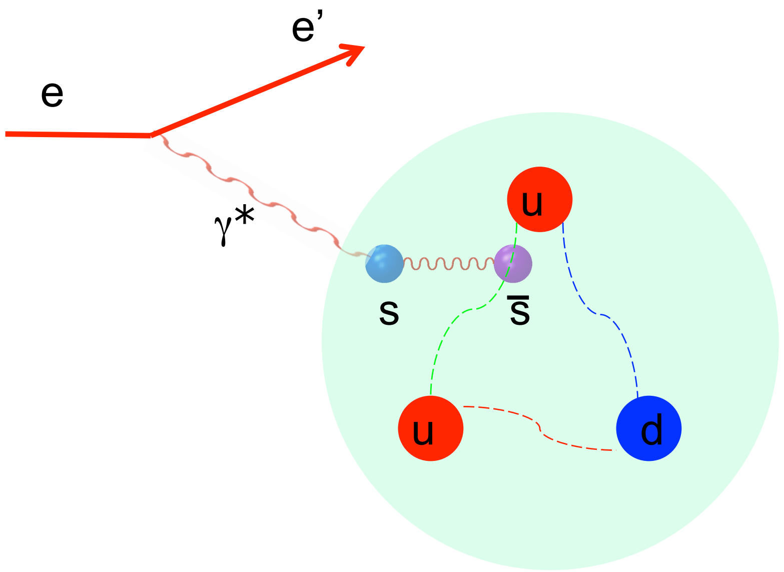


Extracting Strange Quark

Charge Symmetry

$$G_E^p = \frac{2}{3} G_E^{u,p} - \frac{1}{3} G_E^{d,p}$$

$$G_E^n = \frac{2}{3} G_E^{u,n} - \frac{1}{3} G_E^{d,n}$$

$$G_E^p = \frac{2}{3} G_E^{u,p} - \frac{1}{3} G_E^{d,p} - \frac{1}{3} G_E^s$$

$$G_E^n = \frac{2}{3} G_E^{u,n} - \frac{1}{3} G_E^{d,n} - \frac{1}{3} G_E^s$$

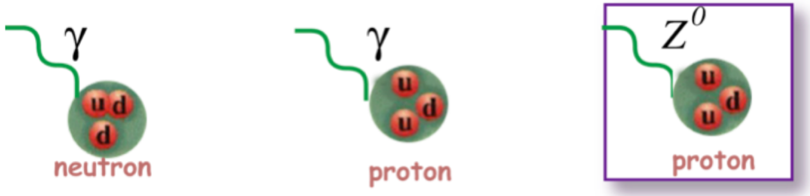
Need Charge Symmetry for Flavor decomposition of FF

Charge symmetry, swap p↔n, u↔d

Measure $G_{E,M}^{p,n}$ to determine $G_{E,M}^{u,d}$

Flavor decomposition of FF has sensitivity to strange FF

Non-zero strangeness form-factors break charge symmetry and confuse the flavor separation of nucleon form-factors



The weak form factor, accessible via parity violation, provides a third linear combination, testing charge symmetry

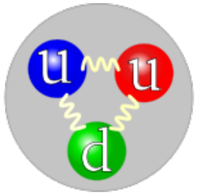
$$A = \left[\frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\right] \frac{A_E + A_M + A_A}{\sigma_p}$$

-150ppm @ 2.5GeV^2

$$A_E = \epsilon\, G_E^p G_E^Z \qquad A_M = \tau\, G_M^p G_M^Z \qquad A_A = (1 - 4\sin^2\theta_W)\epsilon'\, G_M^p \tilde{G}_A$$

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

Breakdown of U/D scaling at larger Q^2



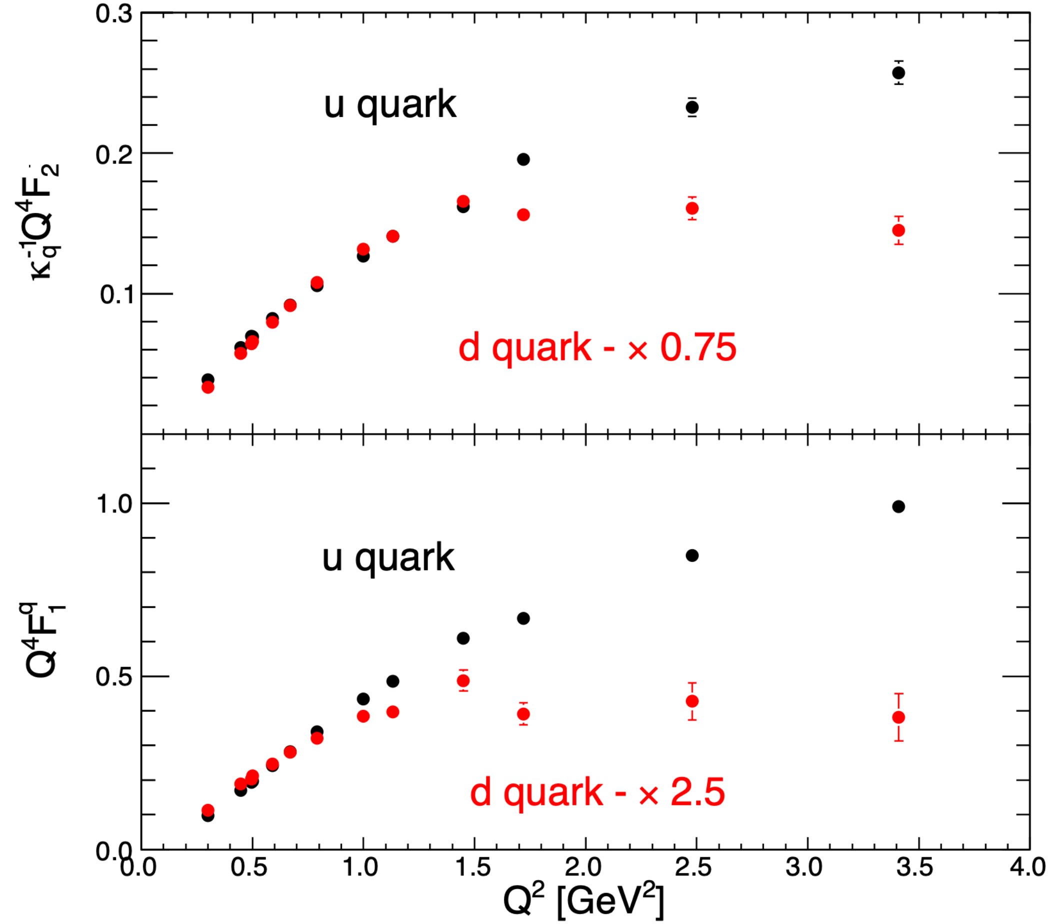


FIG. 3: The Q^2-dependence for the u- and d-contributions to the proton form factors (multiplied by Q^4). The data points are explained in the text.

Flavor decomposition of the elastic nucleon electromagnetic form factors

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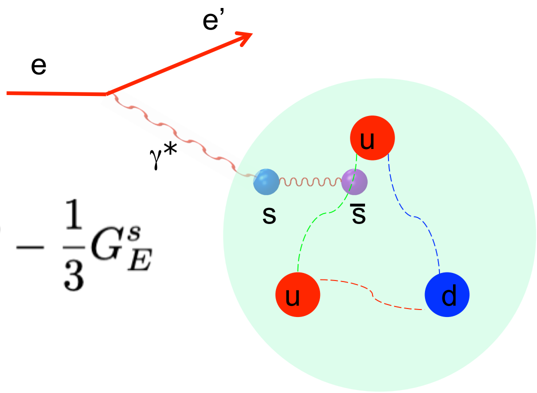
(Dated: March 6, 2011)

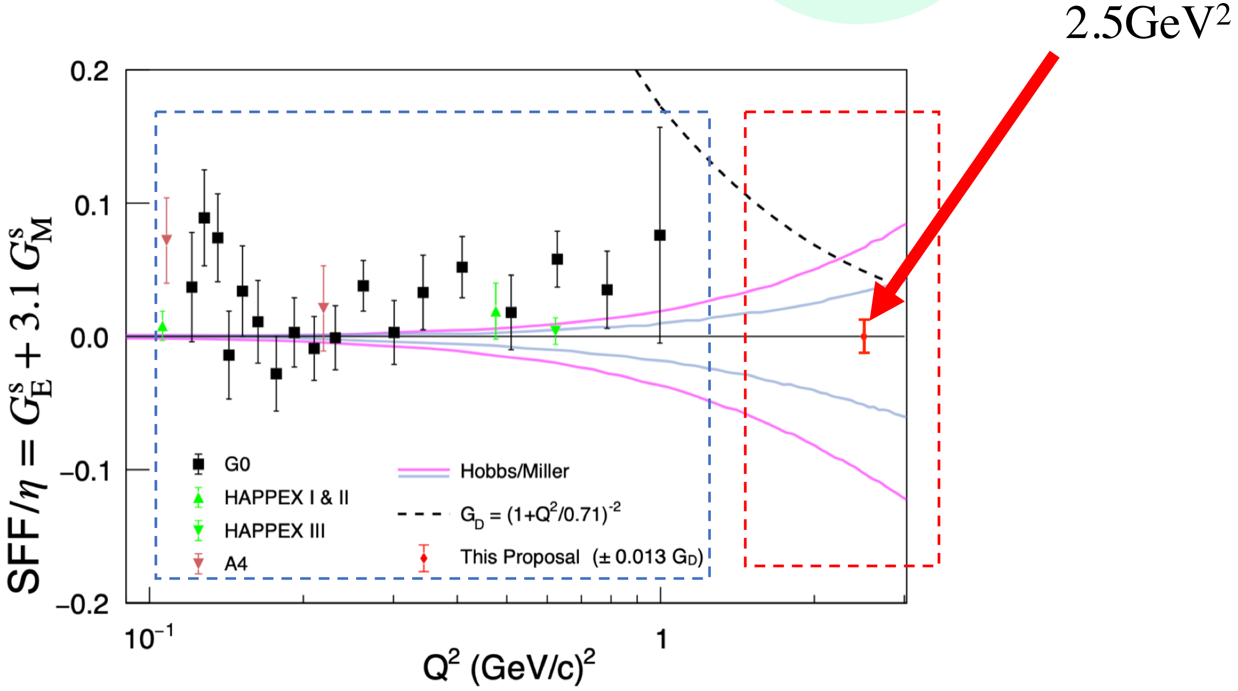
The u- and d-quark contributions to the elastic nucleon electromagnetic form factors have been determined using experimental data on G_E^n, G_M^n, G_E^p, and G_M^p. Such a flavor separation of the form factors became possible up to 3.4 GeV^2 with recent data on G_E^n from Hall A at JLab. At a negative four-momentum transfer squared Q^2 above 1 GeV^2, for both the u- and d-quark components, the ratio of the Pauli form factor to the Dirac form factor, F_2/F_1, was found to be almost constant, and for each of F_2 and F_1 individually, the d-quark component drops continuously with increasing Q^2.

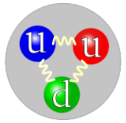
- Why is there a breakdown of U/D scaling at > 1 GeV^2
- Diquark?
  - "In the framework of Dyson-Schwinger equation calculations, the reduction of the ratios F_1^d/F_1^u and F_2^d/F_2^u at high Q^2 is related to diquark degrees of freedom"
- Unless there's something strange going on….

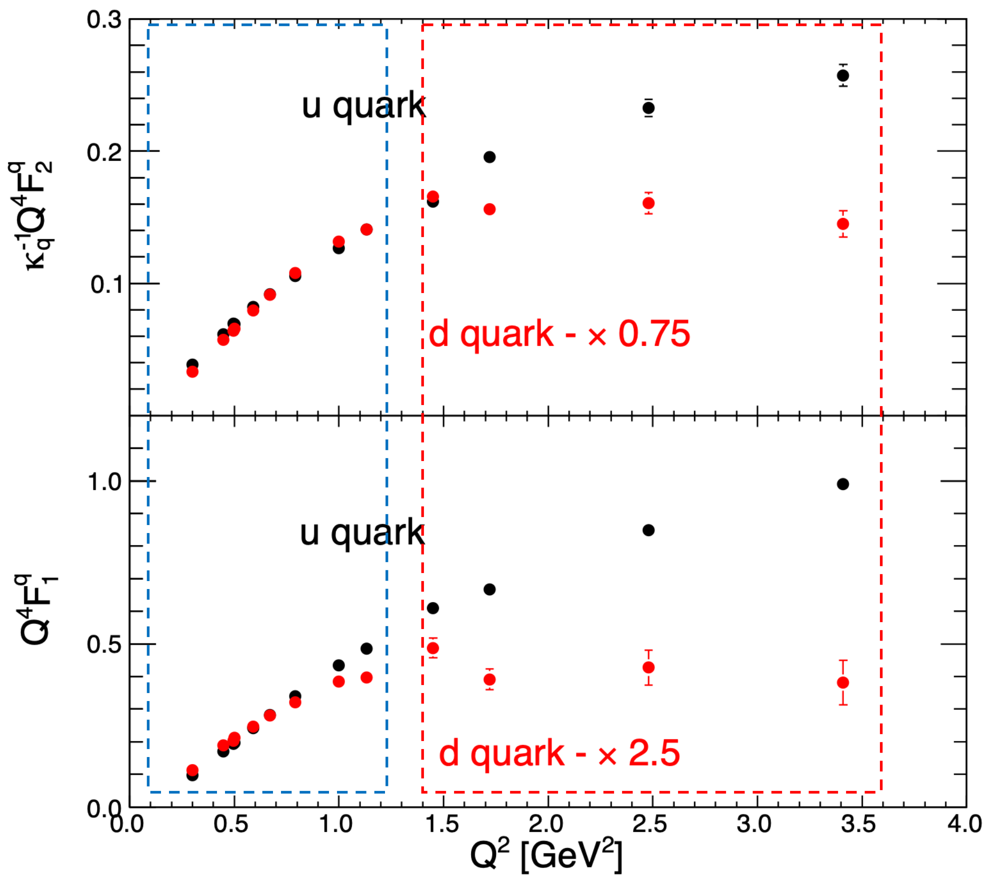
Strange FF zero at high Q^2?

$$G_E^p = \frac{2}{3}G_E^{u,p} - \frac{1}{3}G_E^{d,p} - \frac{1}{3}G_E^s$$





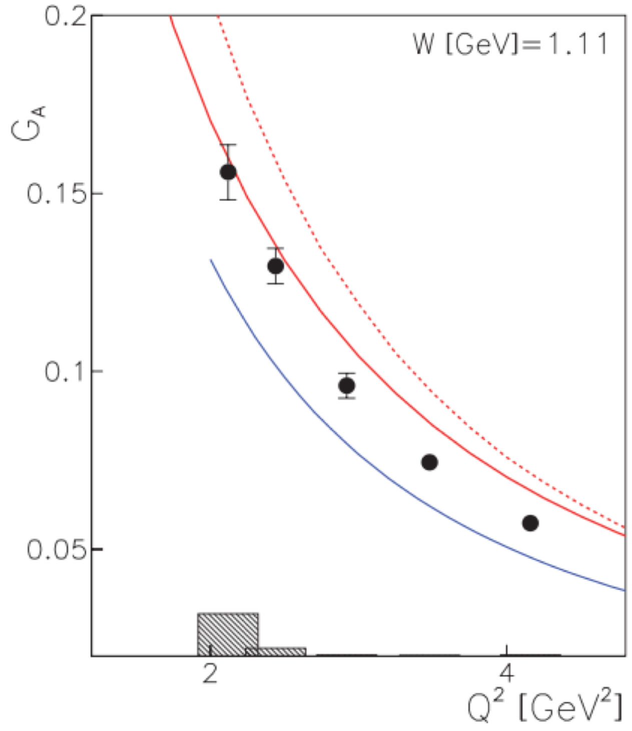




- How will SFF impact flavor decomposition of the nucleon FF at higher Q^2?

Axial FF Contributions

$$A_A = (1 - 4\sin^2\theta_W)\epsilon' G_M^p \tilde{G}_A$$



K. Park *et al*. [CLAS Collaboration], Phys. Rev. C **85**, 035208 (2012).

- Axial form factor parameterization $G_A{}^p = 0.15$ at $Q^2 = 2.5$ GeV^2

  C. Chen, C. S. Fischer, C. D. Roberts, and J. Segovia, Form factors of the nucleon axial current, Physics Letters B 815, 136150 (2021)

- Confirmed with pion photoproduction measurements

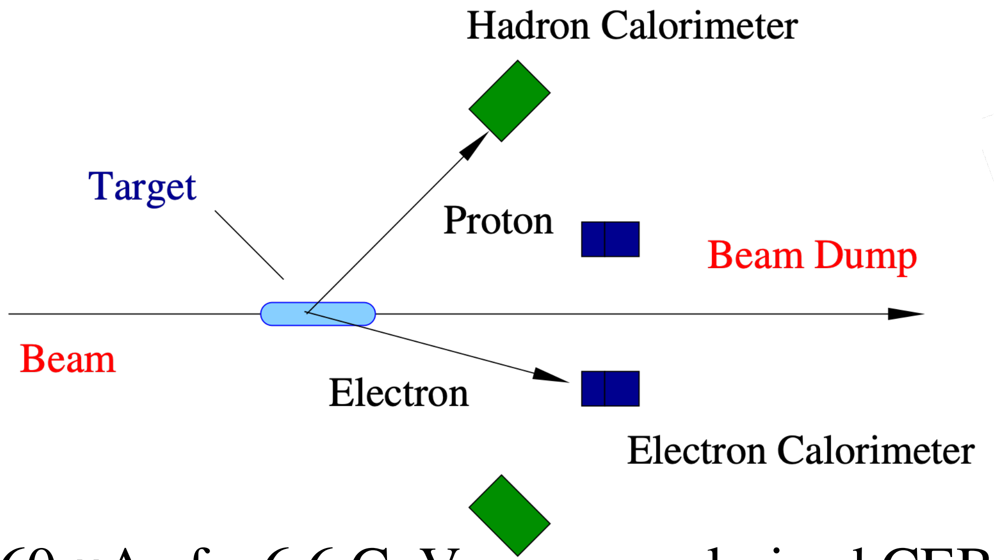
  K. Park *et al*. [CLAS Collaboration], Phys. Rev. C **85**, 035208 (2012).

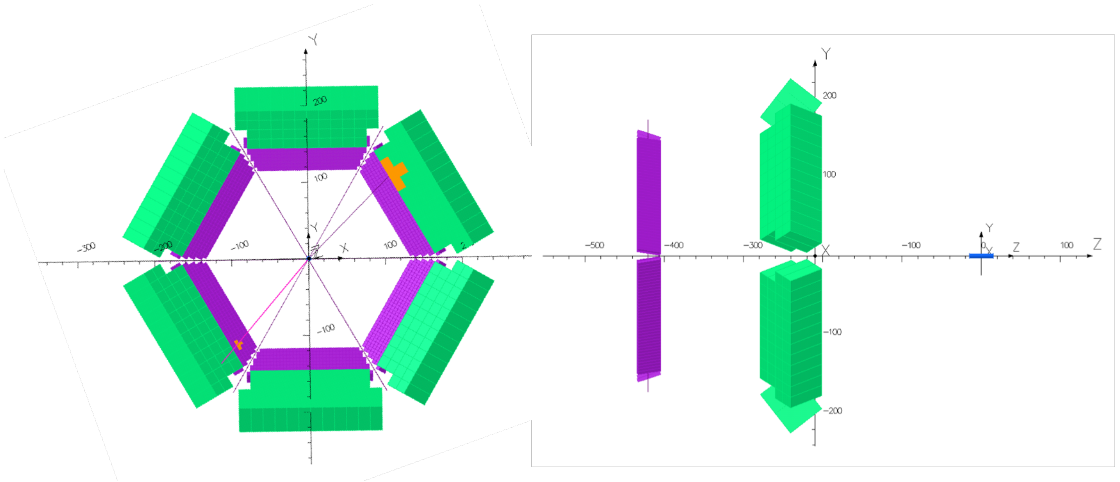
  - (~15% interpretation uncertainty)

  I.V. Anikin, V.M. Braun, and N. Offen, Phys.Rev.D 94 (2016) 3, 034011.

- How uncertain is this measurement because of it?
  - Axial term ~6% of APV
  - ~15% uncertainty, so estimate 1% relative uncertainty on the 4% statistical measurement

Experiment Setup

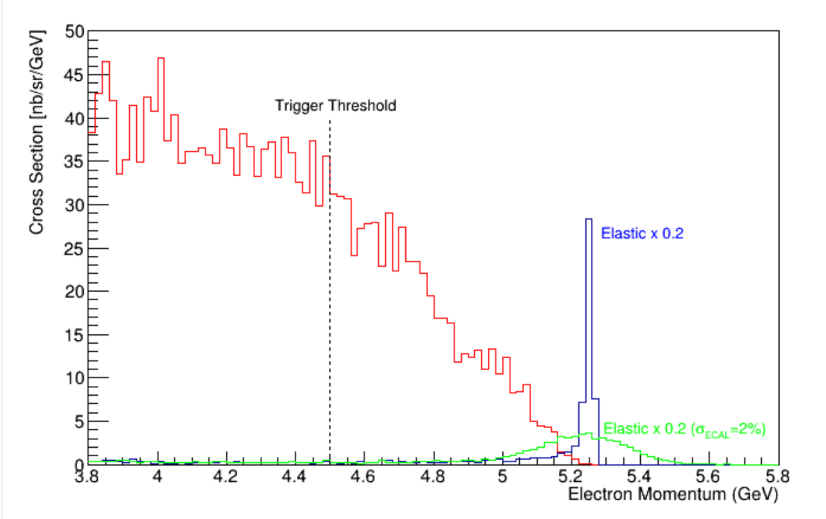




- 60 μA of a 6.6 GeV energy polarized CEBAF electron beam
- The target is a liquid hydrogen 10-cm-long cylinder
- Scattered electrons are detected in the inner ring (highly segmented electromagnetic calorimeter) and recoil protons are detected in the outer ring (highly segmented hadron calorimeter)
- Apparatus will re-use two calorimeters from the GEp/SBS experiment
- Electrons acceptance: 15.5 ± 1^{o} , Proton acceptance: 42.5 ± 2^{o}
- Coincidence Rate 37kHz
  - Vs Total Rate estimates are 155kHz (electron arm), 1.2MHz (proton arm)

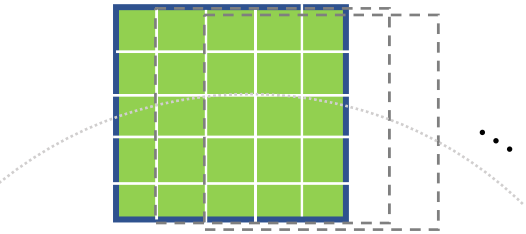
Coincidence Measurement

- Coincidence between the scattered electrons and recoil protons detected in the shower counters help isolate the elastic process(signal) from the inelastic processes (background)
- The time coincidence between the scattered electrons and recoil protons detected in the shower counters will be used for the identification of the elastic process.
- The e-p angular and energy correlations will be measured for suppression of the inelastic processes
- **Subsystem coincidence:** high efficiency / resolution & Clean e-p coincidence



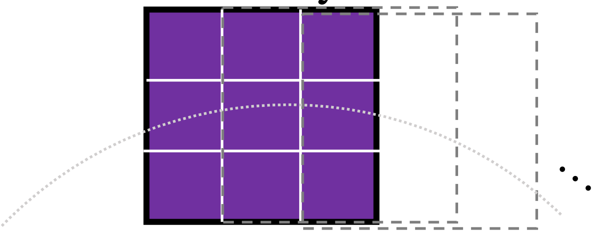
Subsystems

Electron subsystems

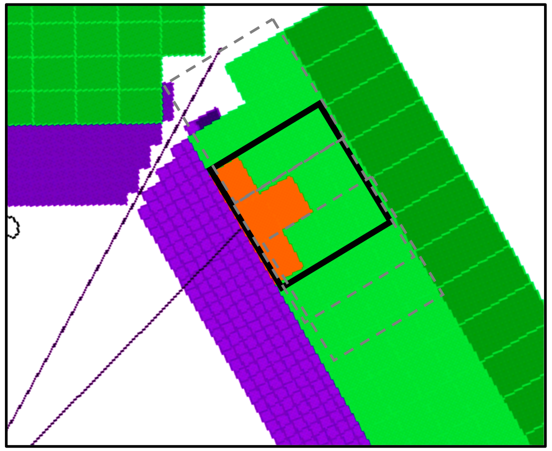


1000 PWO crystals total
5x5 subsystem counters
200 overlapping subsystems

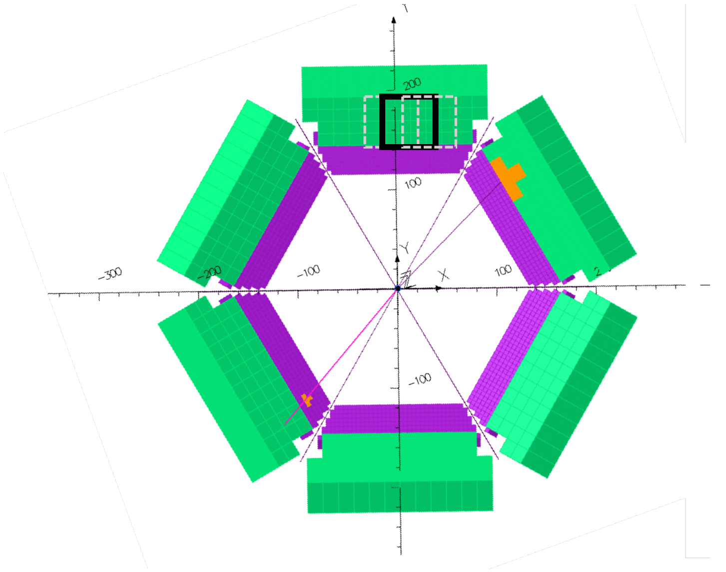
Proton subsystems



288 iron scintillators total
3x3 subsystem counters
96 overlapping subsystems
32 azimuthal positions

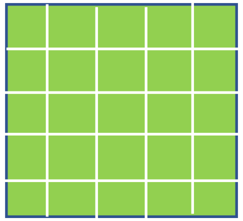


Subsystems adjacent crystals



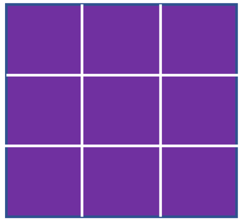
Coincidence Cuts

Electron subsystems



5x5

Proton subsystems

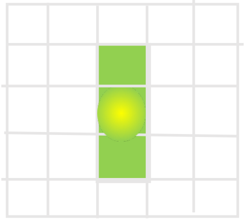


3x3

Online

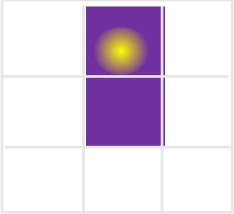
- Elastic 37 kHz signal in full detector
  - 155kHz total rate DIS in e-arm
  - 1.2MHz (proton arm)
- 5x5(electron) & 3x3(proton) subsystem counters
- Temporal coincidence cut 40ns
- Energy cut 4.5GeV
- Ratio real/accidentals: 1300

Electron subsystems



3x1

Proton subsystems



2x1

Offline

- Elastic 17.7 kHz signal
- use center of cluster to better define azimuth of each hit
  - e-arm select 3x1 subsystems hi-res area
  - p-arm 2x1 subsystems hi-res area
- reduce temporal coincident cut to 4ns
- sharpen geometric/angular cuts
- Energy cut 5.1GeV
- Ratio real/accidentals 1.6×10^5

Uncertainties

Statistical (4.1%)

- With 30 days of production running:
- Measurement of Apv expected to be -150 ppm (without Strange FF) at a precision of 4.1% or ± 6.2 ppm

Systematics (3%)

quantity	value	contributed uncertainty
Beam polarization	$85\% \pm 1.5\%$	1.8%
Beam energy	$6.6 +/- 0.003$ GeV	0.1%
Scattering angle	$15.5^\circ \pm 0.1^\circ$	1.2%
$\mathrm{GEN}/G_{\mathrm{Dipole}}$	0.41 ± 0.04	0.62%
$\mathrm{GEP}/G_{\mathrm{Dipole}}$	0.75 ± 0.02	0.5%
$\mathrm{GMN}/G_{\mathrm{Dipole}}$	1.01 ± 0.02	1.7%
$G_A^{Zp}/G_{\mathrm{Dipole}}$	-0.15 ± 0.02	0.9%
Total systematics:		3.0%

- Helicity correlated beam position and energy variation
  - Due to large angle scattering, HCBA's are much easier than HAPPEX was, which is quite manageable
  - Effect of the beam position variation to a large extent cancels out due to the 2π coverage of the electron detector
  - Even a huge 100 nm helicity related beam motion on the target is acceptable for this experiment
- Helicity correlated dead time of DAQ
  - Due to development of the flash ADC, the readout system currently could be arranged almost dead time free
- Helicity correlated accidental events
  - Signal/Accidental ratio estimated to be 1.6×10^5

Summary

Search for a Nonzero Strange Form Factor of the Proton at 2.5 (GeV/c)^2

- Measurement of A_{pv} in e-p scattering at high $Q^2 = 2.5$ GeV^2
- Coincidence-Parity measurement with highly segmented calorimeters
- Goal: Confirm whether Strange Form Factor is zero or non-zero in this kinematic region
- Result informs the breakdown of U/D scaling
- Allows for flavor decomposition at high Q^2