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

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Charge symmetry and the nucleon form factors

- To find the flavor separated form-factors
- Charge symmetry is assumed for the form factors,
- Measuring $G^{p,n}_{E,M}$ to find $G^{u,d}_{E,M}$
- But this can break if we have non-zero strange form factors
  - which breaks the 2 equations to get 2 unknowns

Charge Symmetry

$$G^p_E = \frac{2}{3}G^{u,p}_E - \frac{1}{3}G^{d,p}_E$$

$$G^n_E = \frac{2}{3}G^{u,n}_E - \frac{1}{3}G^{d,n}_E$$

$$G^p_E = \frac{2}{3}G^{u,p}_E - \frac{1}{3}G^{d,p}_E - \frac{1}{3}G^s_E$$

$$G^n_E = \frac{2}{3}G^{u,n}_E - \frac{1}{3}G^{d,n}_E - \frac{1}{3}G^s_E$$

Charge symmetry and the nucleon form factors

- A strange quark form factor would be indistinguishable from a broken charge symmetry in u,d flavors
- We propose to measure strange form factors that will test the assumption of charge symmetry
- A measurement crucial to the flavor decomposition of the form factors
- The weak form factor provides a third linear combination:

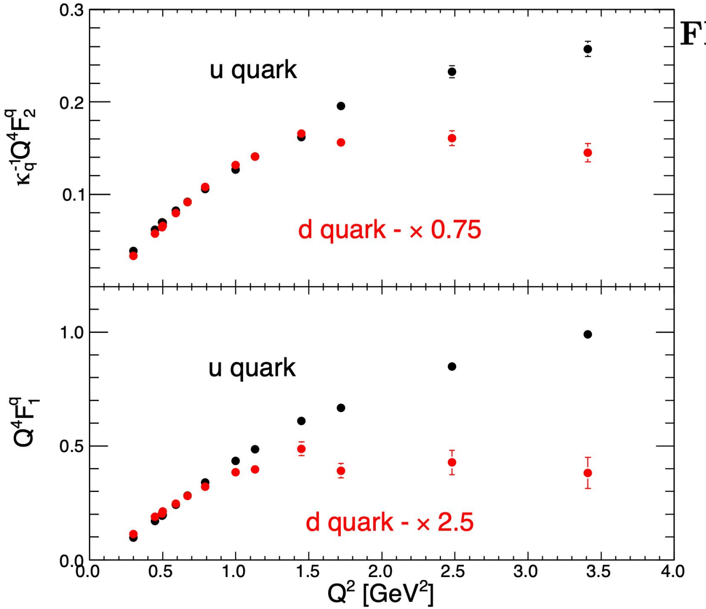
$$\delta G_E^u \equiv G_E^{u,p} - G_E^{d,n}$$

$$\delta G_E^d \equiv G_E^{d,p} - G_E^{u,n}$$

$$G_E^{p,Z} = \left(1 - \frac{8}{3}\sin^2\theta_W\right) G_E^{u,p} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right) G_E^{d,p} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right) G_E^s$$

Breakdown of u/d scaling at larger Q^2

Why is there a breakdown of u/d scaling at > 1 GeV^2



Flavor decomposition of the elastic nucleon electromagnetic form factors

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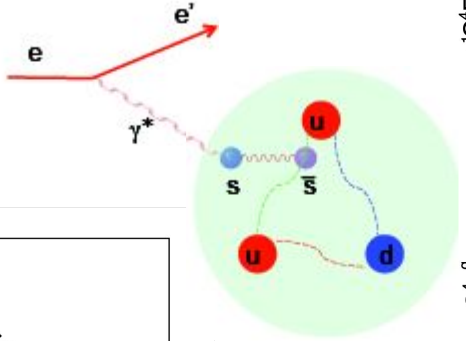
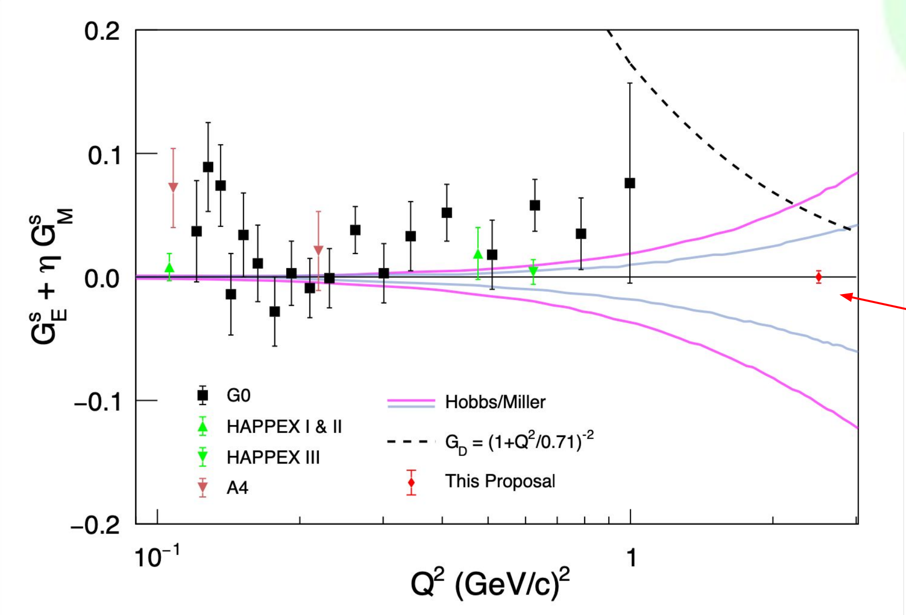
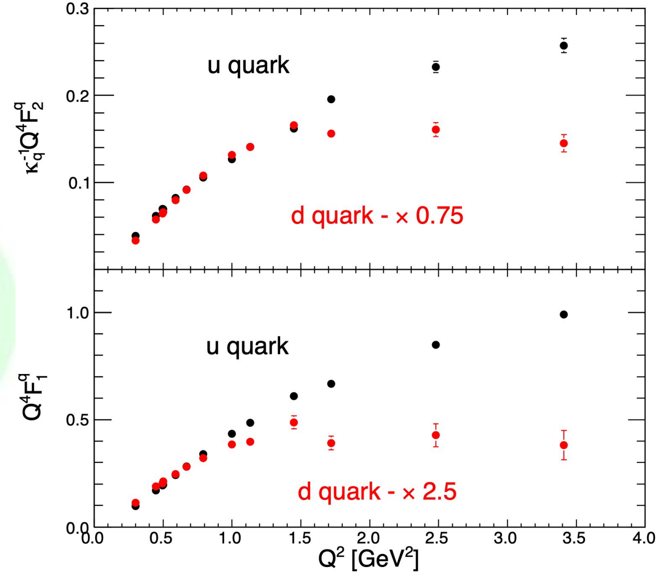
The u- and d-quark contributions to the elastic nucleon electromagnetic form factors have been determined using experimental data on G_E^n, G_M^n, G_E^p, and G_M^p. Such a flavor separation of the form factors became possible up to 3.4 GeV^2 with recent data on G_E^n from Hall A at JLab. At a negative 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.

Strange FF zero at high Q2?

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







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

Strangeness form factors

Using Polarized electron beam elastic e-p scattering we can measure the parity violating asymmetry,

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

$$+ \epsilon'(1-4\sin^2\theta_W)\frac{G_M^p G_A^{Zp}}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}]$$

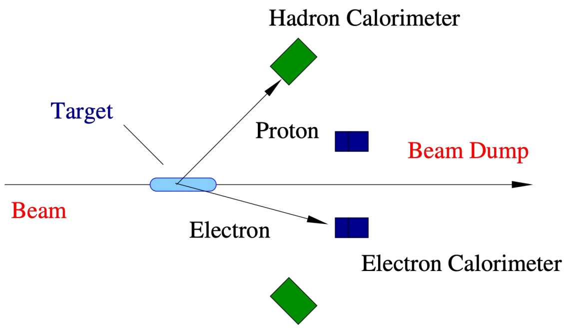
A_{PV} = (-226 ppm) *[0.075 + 0.542 – 6.43*($G_M^s + 0.32\, G_E^s$) + 0.038]

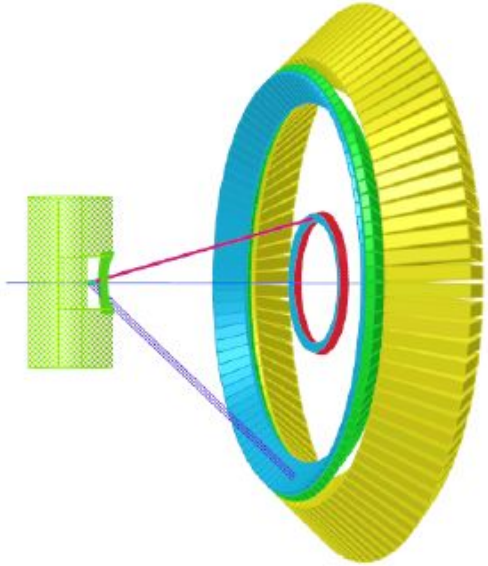
Q_w EMFF strange form-factors axial

A_{PV} = 150 ppm at θ = 15.5°, Q^2 = 2.5 GeV^2 (for sFF = 0)

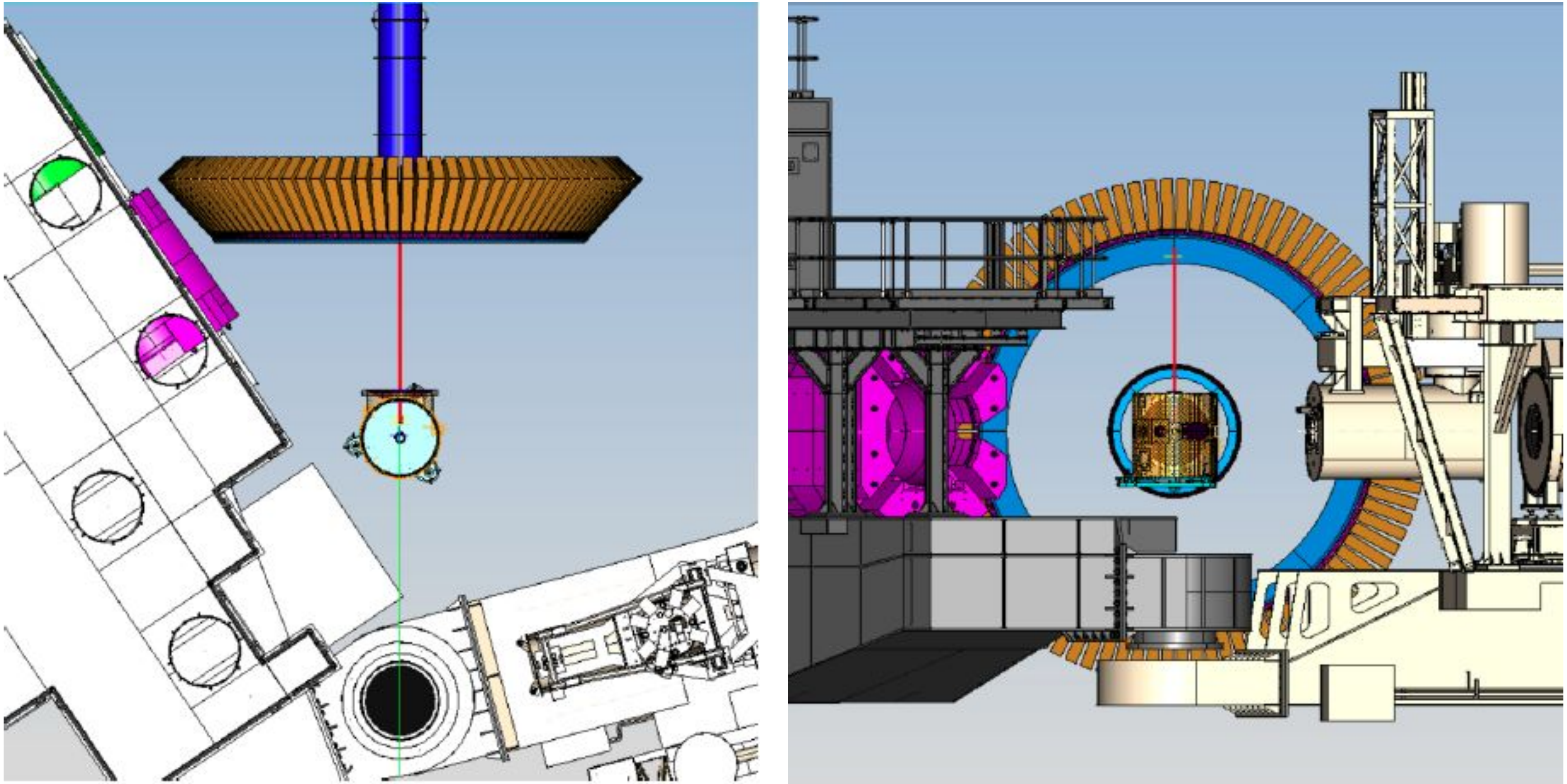
Experiment Setup

- 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)
- Recoil protons are detected in the outer ring (highly segmented hadron calorimeter+Hodoscope)
- Apparatus will re-use two calorimeters from the GEp/SBS experiments
- Electrons acceptance: 15.5 ± 1^{o} , Proton acceptance: 42.5 ± 2^{o}
- Coincidence Elastic Rate 26 kHz (before radiative losses)
    - Total Rate estimates are 153 kHz (electron arm), 19 MHz (proton arm)





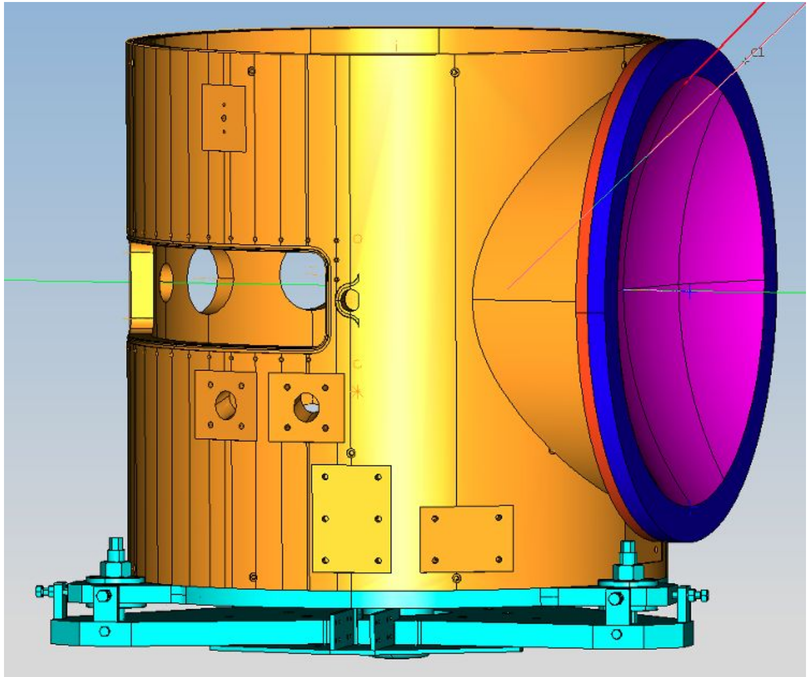
Experiment Setup



The geometry of the experiment in Hall C. The top view is shown on the left part of the figure, and the view from the beam dump is shown on the right part of the figure

Liquid Hydrogen Target

- The liquid hydrogen target with a 10-cm-long target cell
- Almost 360° azimuthal aperture for detection of the particles in the forward direction from 14 to 47°.
- The target will be shifted downstream by 25 cm from the center of the scattering chamber
- The cylindrical part of the chamber will be a new one with a 60-cm diameter window



Detector System

Hadron calorimeter

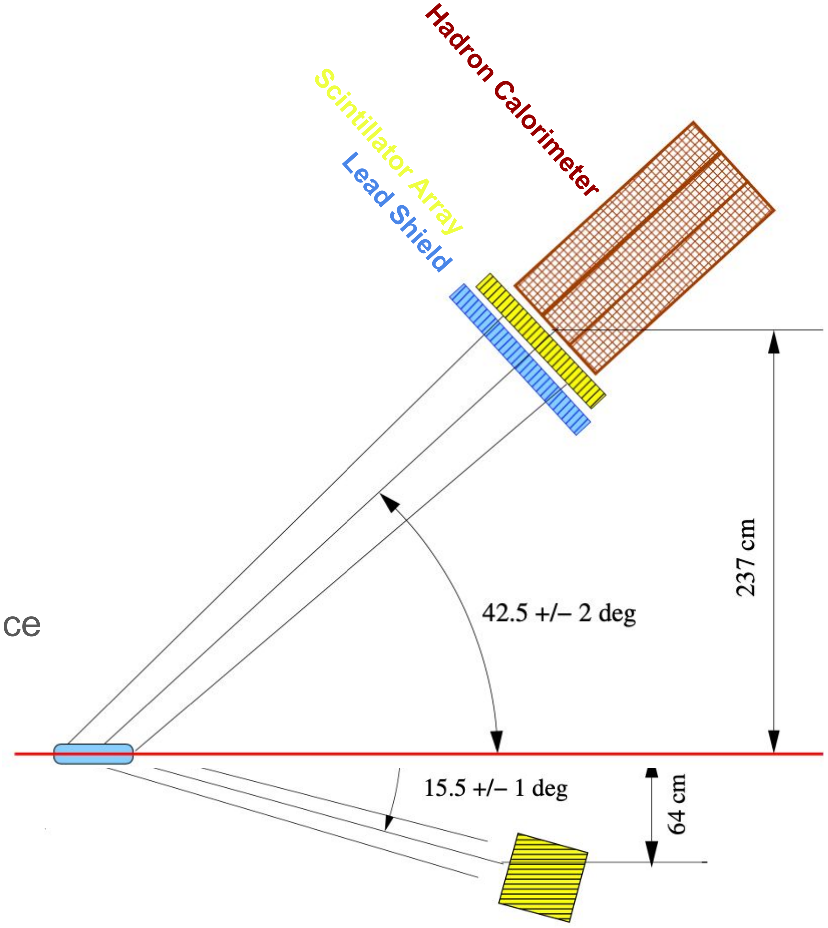
- Reassembled from detector elements from the SBS HCAL
- 288 blocks, each 15.5 x 15.5 x 100 cm^3
- iron/scintillator sandwich with wavelength shifting fiber readout

Scintillator array in front of HCAL

- Used for improved position resolution in front of HCAL
  - But not used to form trigger
- 7200 blocks, each 3 x 3 x 10 cm^3
- Lead shield in front (thickness to be optimized) to reduce photon load

Electron calorimeter

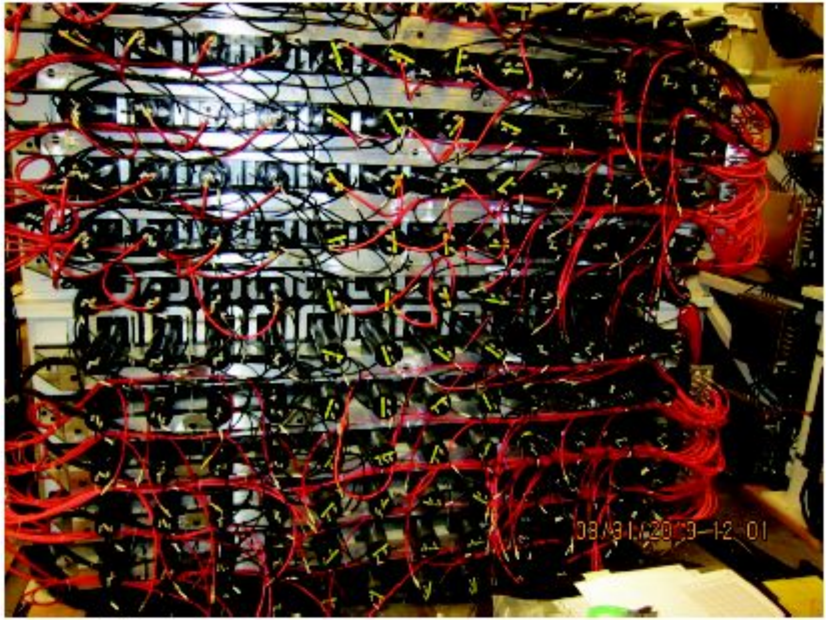
- Reassembled from detector elements from the NPS calorimeter
- 1000 blocks, each 2 x 2 x 20 cm^3
- $PbWO_4$ scintillator



Calorimeters Reusing Components

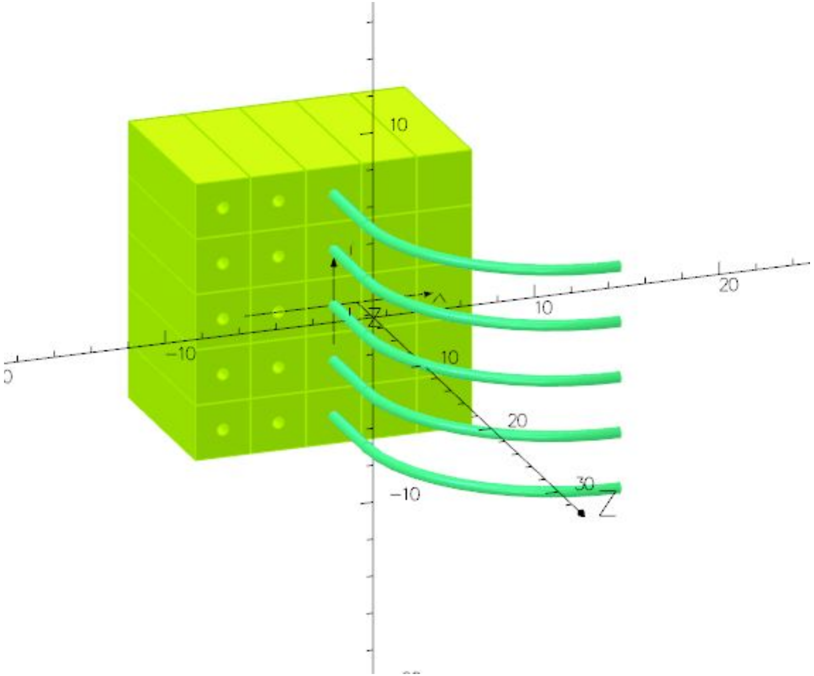
From NPS electromagnetic calorimeter: 1080 $PBWO_4$ scintillators, PMTs + bases

SBS hadronic calorimeter: 288 iron/scintillator detectors, PMTs + bases



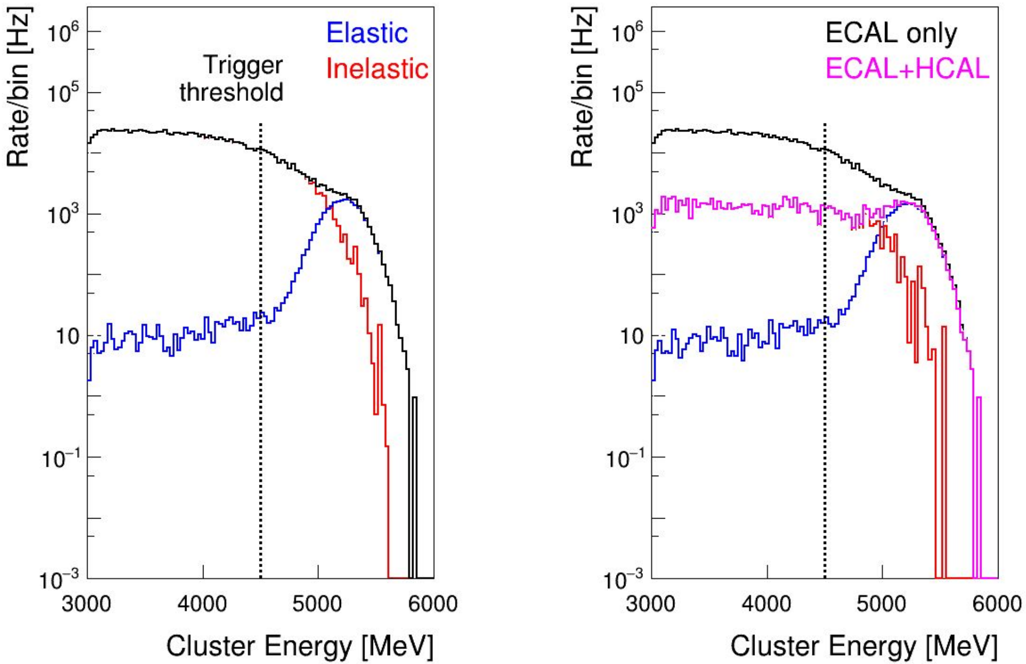
Scintillator array

- New detector, must be built for this experiment
- Extruded plastic scintillator block
- Readout with wavelength-shifting fiber
- Each fiber read by pixel on multi-anode PMT
- 3x3 cm^2 provides sufficient resolution
- 7200 blocks, each 3 x 3 x 10 cm^3



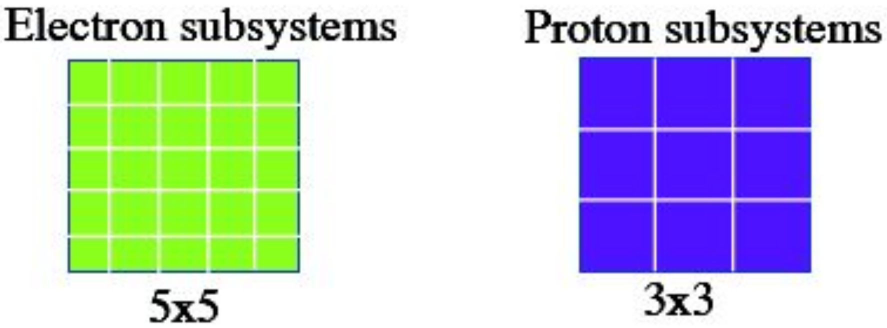
MC Simulation Calorimeter Rates

- The inelastic + elastic rate is estimated to be around 153 kHz for the full electron arm (1200 counters)
  - The elastic rate is 26 kHz
- Electron arm rate with and without requiring a coincident hit in the corresponding HCAL grouping. The coincident elastic rate is estimated to be 18.3 kHz, which is around 70% of the single electron arm elastic rate



Simulated rate in the 5x5 crystals subsystem of the electron arm as a function of cluster energy.

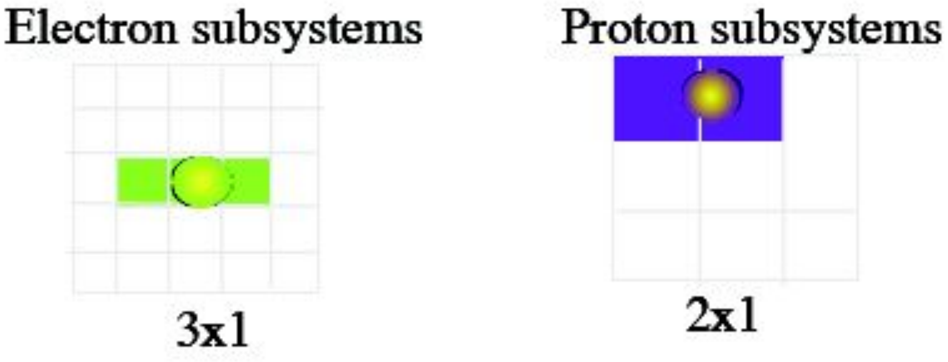
Realtime Trigger



Coincidance elastic rate is 18.3 kHz in full detector using 5x5 ECAL blocks and 3x3 HCAL blocks,

- 153 kHz total rate DIS in e-arm
- 19 MHz total rate in proton arm
- Temporal coincidence cut 40 ns

Offline Trigger



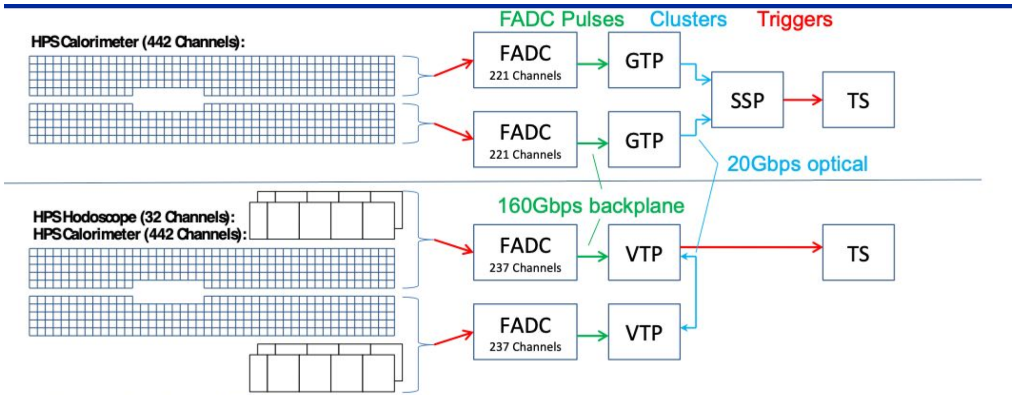
Coincidance elastic rate of 13.3 kHz in full detector using 3x1 (ECAL), and 2x1 (HCAL) subsystem counters,

- 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 2 ns

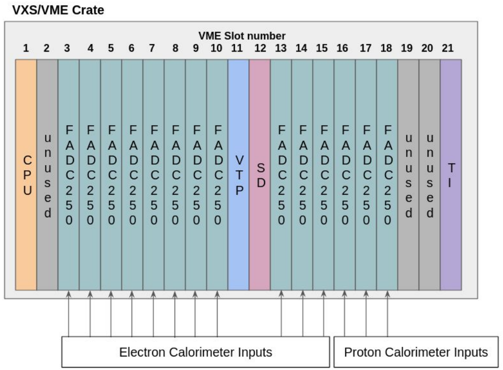
This is the estimated production rate for FOM calculations

Counting DAQ

- JLab FADC250 for HCAL and ECAL readout Provides the pulse information for a fast, “deadtime-less” trigger
- VTP (VXS Trigger Processor) will be used for clusters in time, sums over subsystems, finds ECAL+HCAL coincidence
- One VXS crate will handle one sixth of ECAL + HCAL, also provide external trigger for ScintArray pipeline TDC readout



Concept very similar to the HPS and NPS DAQ



Error Budget for A_{PV}

- A_{PV} will be measured to a statistical precision of ±6.2 ppm
- The expected uncertainty of the SFF is ±0.0042 (stat) ± 0.0024 (syst)

quantity	value	contributed uncertainty
Beam polarization	$85\% \pm 1\%$	1.2%
Beam energy	$6.6 +/- 0.003$ GeV	0.1%
Scattering angle	$15.5^\circ \pm 0.03^\circ$	0.4%
Beam intensity	<100 nm,<10 ppm	0.2%
Backgrounds	< 0.2 ppm	0.2%
G_E^n/G_M^n	-0.2122 ± 0.017	0.9%
G_E^p/G_M^p	0.246 ± 0.0016	0.1%
σ_n/σ_p	0.402 ± 0.012	1.2%
$G_A^{Zp}/G_{\text{Dipole}}$	-0.15 ± 0.02	0.9%
Total systematic uncertainty:		2.2%

The estimates of contributions to the relative error of A_{PV} result, to be compared to the statistical precision of $\delta(A_{PV})/A_{PV}$ = 4.1%

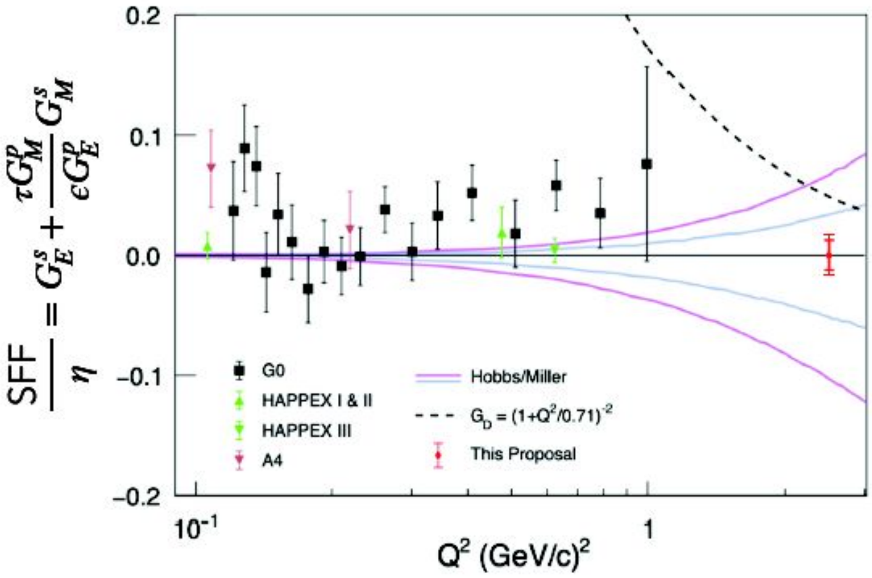
Projected SFF Results

$$\delta A_{PV} = \pm 6.2\ \text{(stat)} \pm 4.5\ \text{(syst)}$$

$$\delta\left(G_E^s + 3.1 G_M^s\right) = \pm 0.0042\ \text{(stat)} \pm 0.0024\ \text{(syst)} = \pm 0.005$$

If $G_M^s = 0$, $\delta G_E^s \sim \pm 0.005$ (about 34% of G_D)

If $G_E^s = 0$, $\delta G_M^s \sim \pm 0.0016$, (about 11% of G_D)



1. The proposed measurement is especially sensitive to G^s_M
2. The proposed error bar reaches the range of lattice predictions, and
3. The our empirically unknown range is much larger than projected proposal uncertainty

Summary

- We request 45 days of beam time for the measurement of the strange form factor of the proton at $Q^2 = 2.5\ (GeV/c)^2$ in elastic scattering of 6.6 GeV electrons at 15.5°
- We propose to measure A_{PV} to a statistical precision of ±6.2 ppm
- The projected statistical uncertainty of the form factor measurement is ±0.0042 (stat) ± 0.0024 (syst)
- Such accuracy will allow significant improvement of flavor decomposition of the nucleon form factors, will test the lattice QCD predictions, and may lead to observation of the non-zero SFF