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

R. Beminiwattha, C. Palatchi,
K. Paschke, and B. Wojtsekhowski

Collaboration

R.Beminiwattha, S.P.Wells, N.Simicevic, C.Palatchi, K.Paschke, S.Ali, X.Bai, G.Cates, R.Lindgren, N.Liyanage, V.Nelyubin, X.Zheng, B.Wojtsekhowski, S.Barcus, A.Camsonne, R.Carlini, S.Covrig Dusa, P.Degtiarenko, D.Gaskell, O.Hansen, D.Higinbotham, D.Flay, D.Jones, M.Jones, C.Keppel, D.Meekins, R.Michaels, B.Reydo, G.Smith, H.Szumila-Vance, A.S.Tadepalli, T.Horn, E.Cisbani, E.King, J.Napolitano, P.M.King, P.A.Souder, D.Hamilton, O.Jevons, R.Montgomery, P.Markowitz, E.Brash, P.Monaghan, T.Hobbs, G.Miller, J.Lichtenstadt, T.Kolar, E.Piasetzky, G.Ron, D.Armstrong, T.Averett, S.Mayilyan, H.Mkrtchyan, A.Mkrtchyan, A.Shahinyan, V.Tadevosyan, H.Voskanyan, W.Tireman, P.Datta, E.Fuchey, A.J.R.Puckett, S.Seeds, C.Munoz-Camacho

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PR12-22-005

PAC50 report

Scientific Rating: N/A

Recommendation: Deferred

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

Spokespersons: R. Beminiwattha, C. Palatchi, K. Paschke, B. Wojtsekhowski (contact)

Motivation: The experiment aims at measuring the strange quark contribution to the proton electromagnetic form factors. This is crucial for their flavour decomposition. This compelling physics case is motivated by recent progress in lattice QCD calculations and by phenomenological models highlighting the potential of a measurement at large Q^2.

Measurement and Feasibility: The experiment proposes to measure the parity violation asymmetry in electron-proton scattering at $Q^2 = 2.5$ $(GeV/c)^2$. For this purpose, modules of the existing HCAL and NPS need to be rebuilt in a very different detector arrangement, and a new scintillator-based hodoscope (a 45700 channel scintillator array read out by fibers and pixel PMTs) needs to be built. Although the setup is very simple from the kinematic point of view and the measurement is largely limited by statistical uncertainty, the PAC is concerned by the lack of several important experimental details in the proposal.

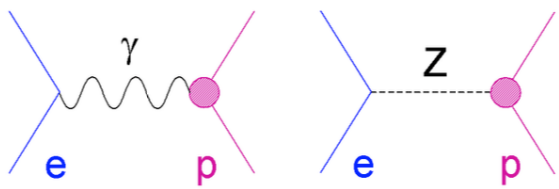
Issues: The PAC would like to see the results of a detailed Geant4 simulation of the experiment confirming the claim of low background in the experiment, as the independent TAC report recommended. In addition, a detailed design of the experimental setup (including electronics and DAQ) should be presented to assess the viability of the measurement.

Summary: The presented physics case is timely and extremely compelling. However, the PAC has identified a number of critical items especially in the experimental method, which should be addressed to make sure that no hidden technical problems will jeopardize a successful experimental campaign. The PAC strongly encourages the collaboration to address these items in the future.

Strangeness form factors

Method from R.McKeown and D.Beck, 1989

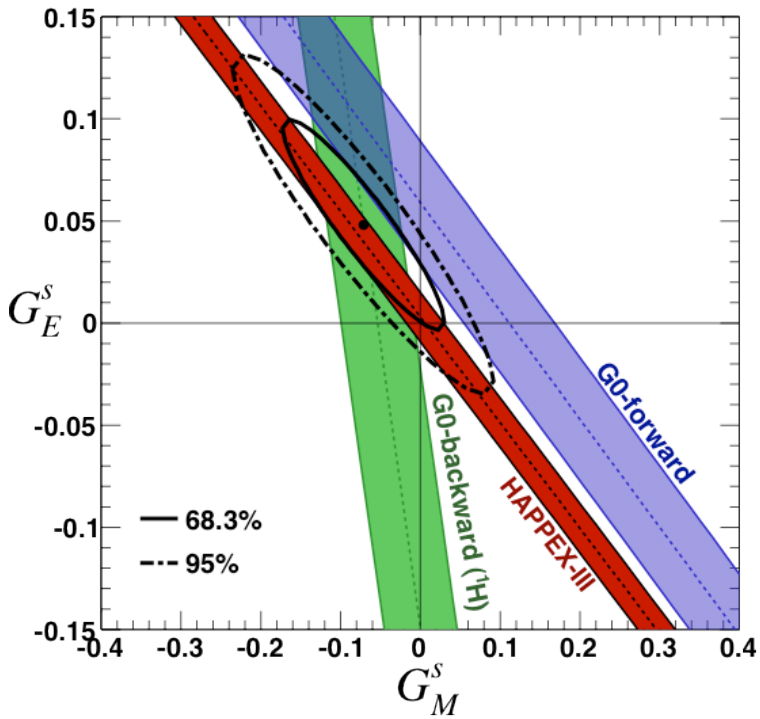
Polarized electron beam elastic e-p scattering

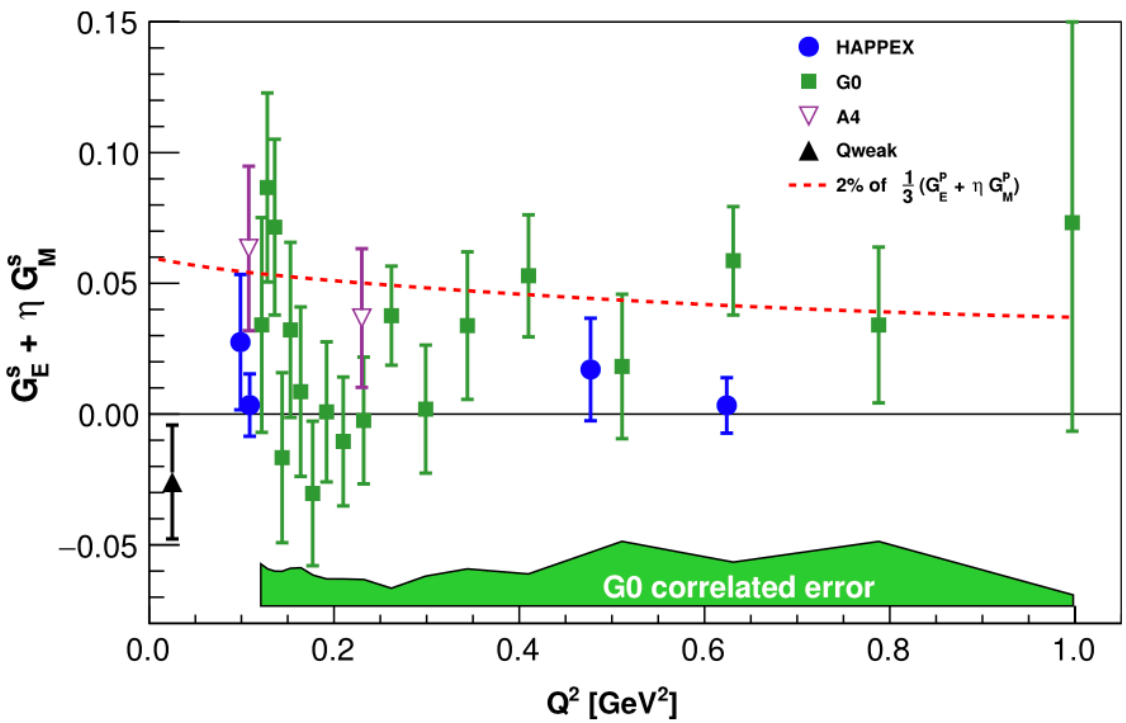


$$A_{PV} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \cdot [(1-4\sin^2\theta_W) - \frac{\epsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2} - \frac{\epsilon G_E^p G_E^s + \tau G_M^p G_M^s}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}$$
$$+ \epsilon'(1-4\sin^2\theta_W)\frac{G_M^p G_A^{Zp}}{\epsilon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

Proton strangeness Form Factors via parity non-conserving elastic electron scattering

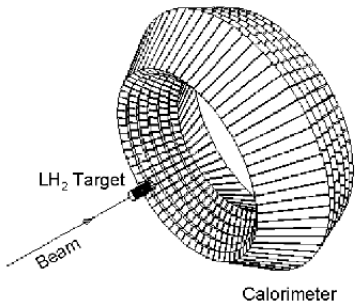
$\eta = \tau G_M^p / \epsilon G_E^p$

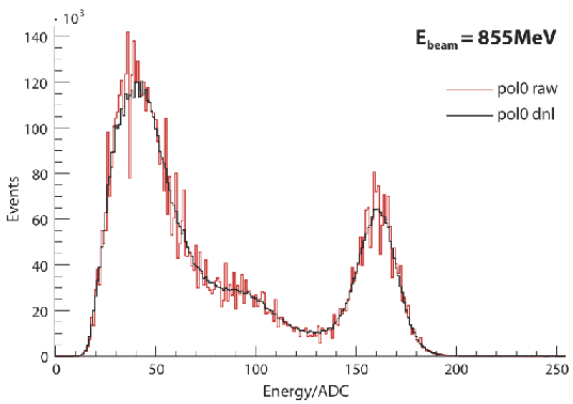




PVES "counting" experiments

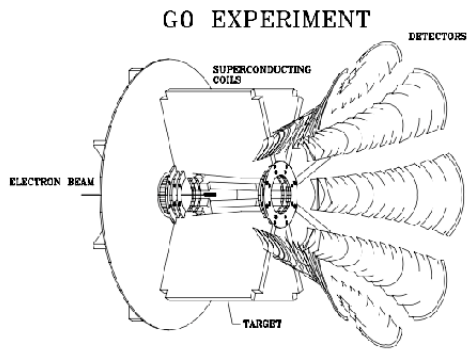
Mainz A4

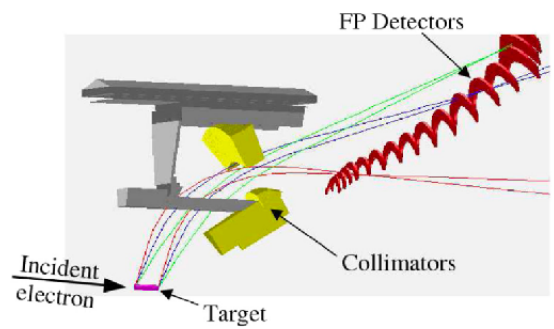




Total energy of electron

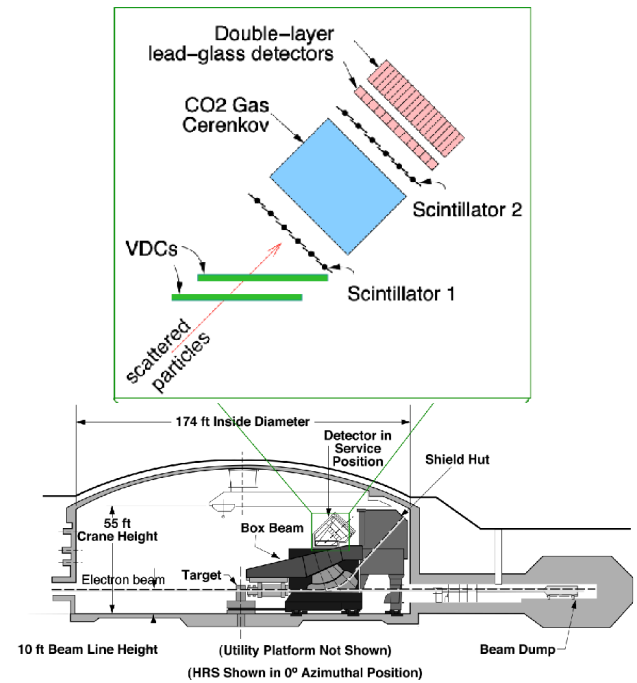
G0





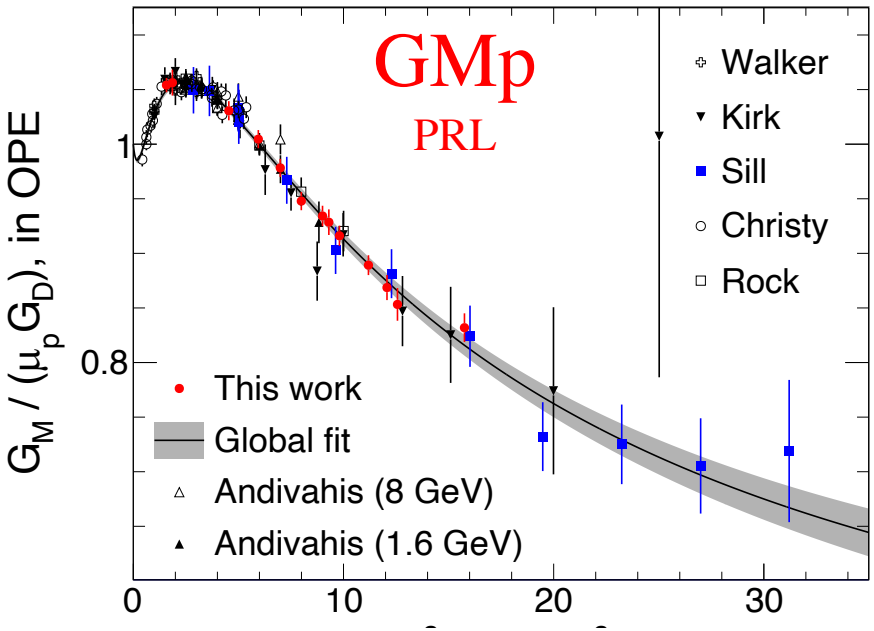
Time of flight of recoil proton

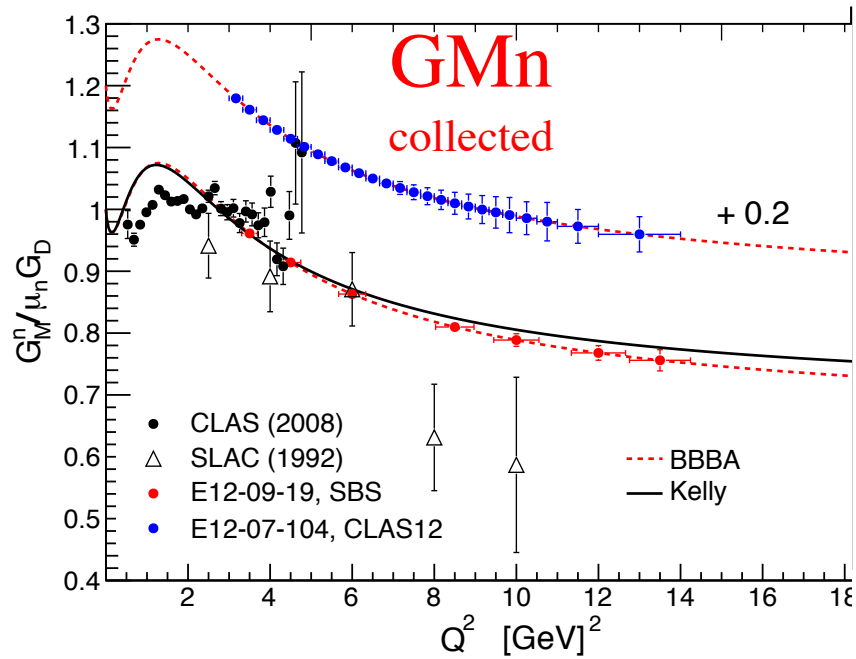
PVDIS-6

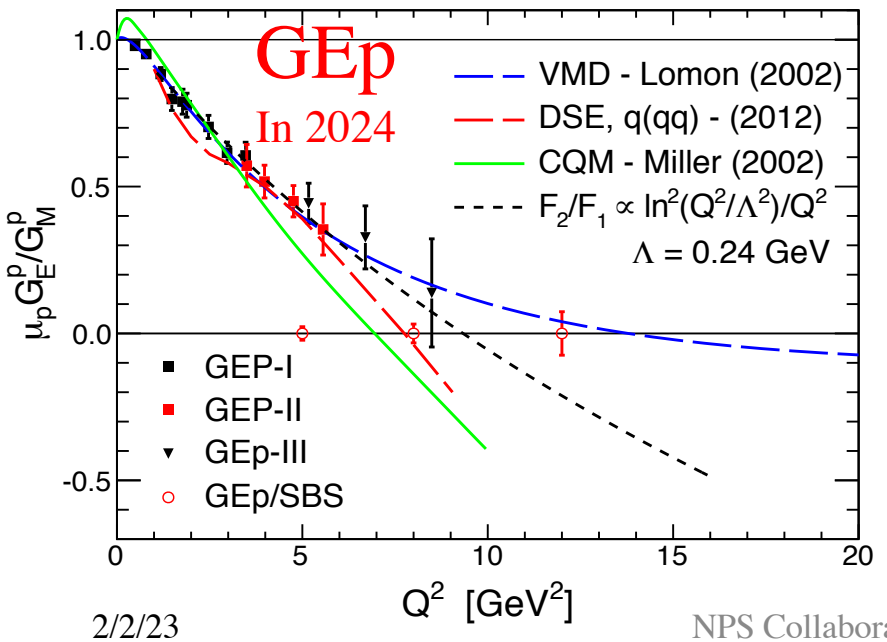


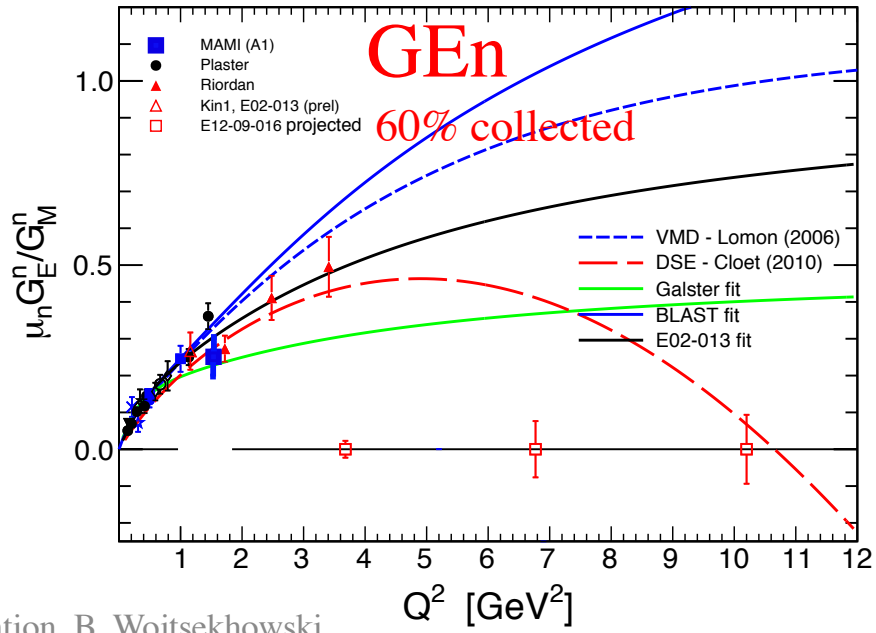
Calorimetry + Cerenkov PID

The nucleon electromagnetic form factors









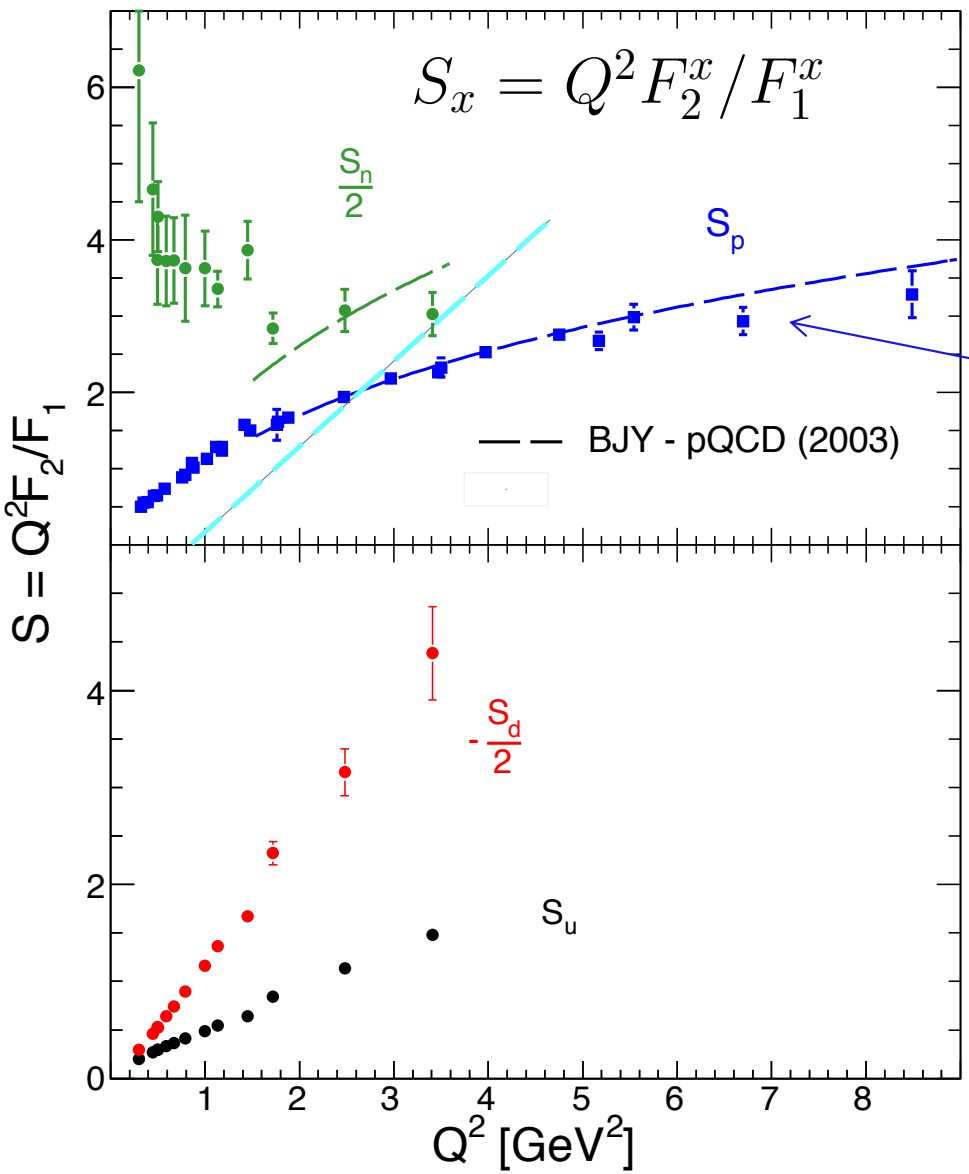
Electromagnetic form factors

$$F_i^p = e_u F_i^u + e_d F_i^d + e_s F_i^s \,,$$
$$F_i^n = e_u F_i^d + e_d F_i^u + e_s F_i^s \,,$$

$$\int_0^1 \mathrm{d}x \big[s(x) - \bar{s}(x) \big] = 0$$

$$F_1^s(0) = 0 \qquad F_2^s(0) = \mu_s$$

Q^2 dependence of F2/F1



pQCD prediction for large Q^2:
$S \rightarrow Q^2 F_2/F_1$

pQCD updated prediction:
$S \rightarrow \left[Q^2/\ln^2(Q^2/\Lambda^2)\right] F_2/F_1$

Flavor separated contributions:
The log scaling for the proton
Form Factor ratio at few GeV^2
is likely "accidental".

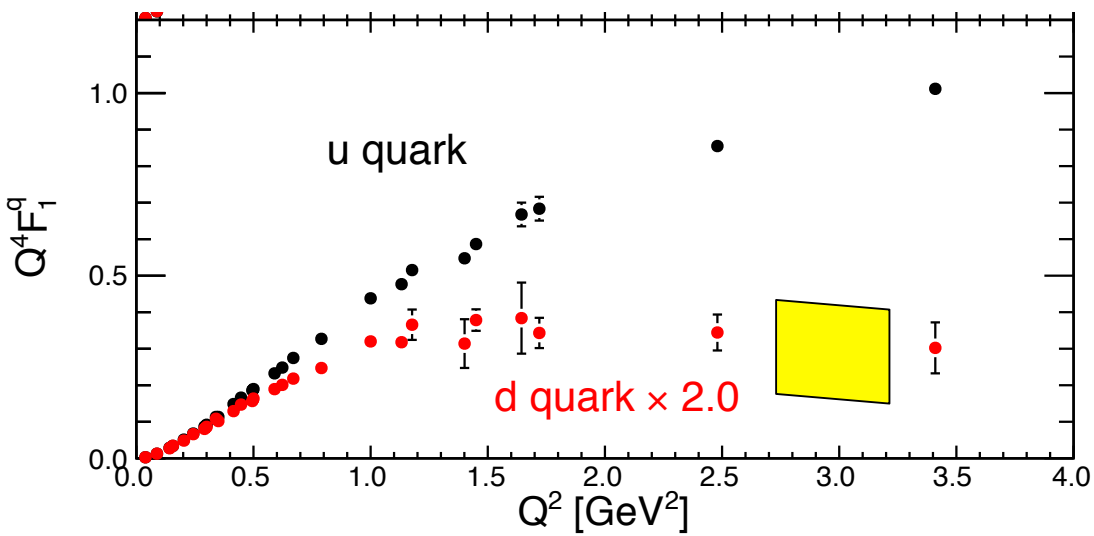
The lines for individual flavor
are straight!

Q^2 dependence of Q^4F1

$$F_{1p} = e_u\, F_1^u \;+\; e_d\, F_1^d \;+\; e_s\, F_1^s$$

$$F_{1n} = e_u\, F_1^d \;+\; e_d\, F_1^u \;+\; e_s\, F_1^s$$

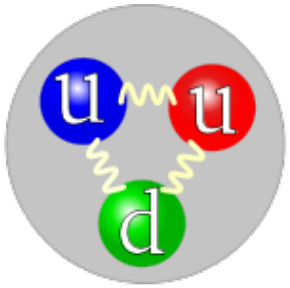
$$F_1^u = 2\, F_{1p} \;+\; F_{1n} - \tfrac{1}{3} F_1^s, \quad F_1^d = 2\, F_{1n} \;+\; F_{1p} - \tfrac{1}{3} F_1^s$$

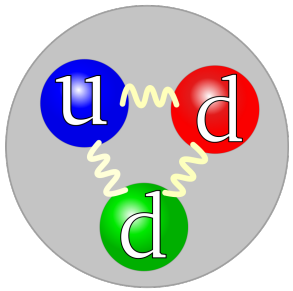


Yellow box demonstrates importance of sFF for EMFF decomposition (approximate current uncertainty)

Uncertainty of F_1^d due to G_s

sFF data and projections



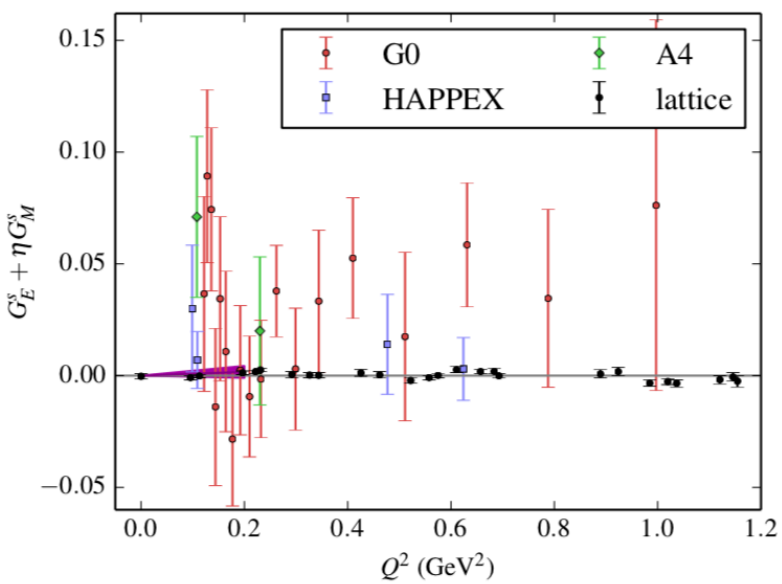


Expectations for
the strangeness FF

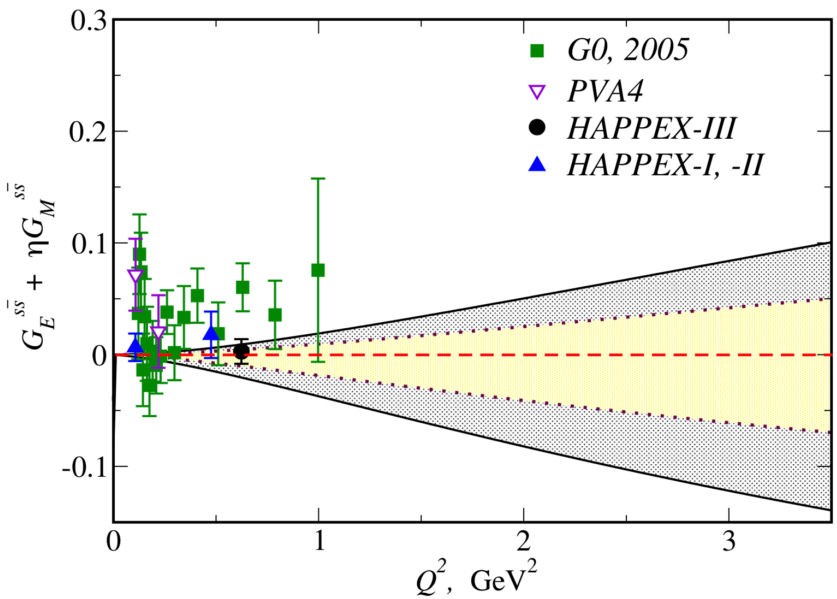
G_D at 3 GeV^2 is 0.037

$G_s/G_D \sim 1$ is not excluded

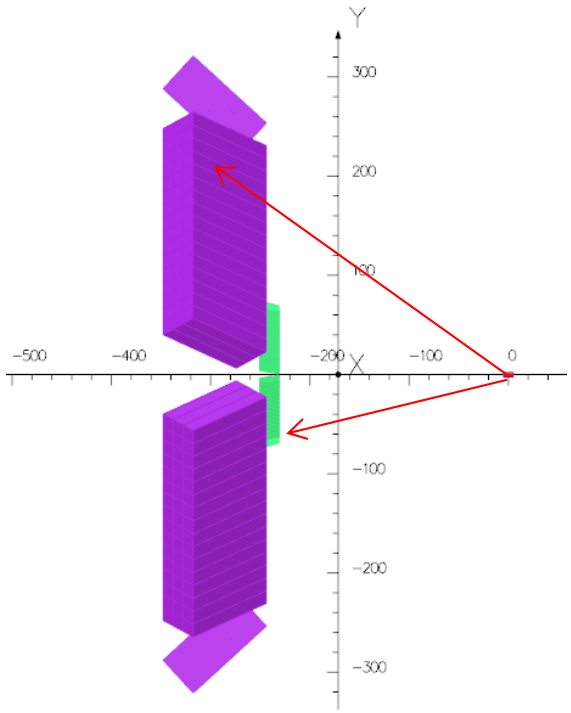
J.Green etal, 2015

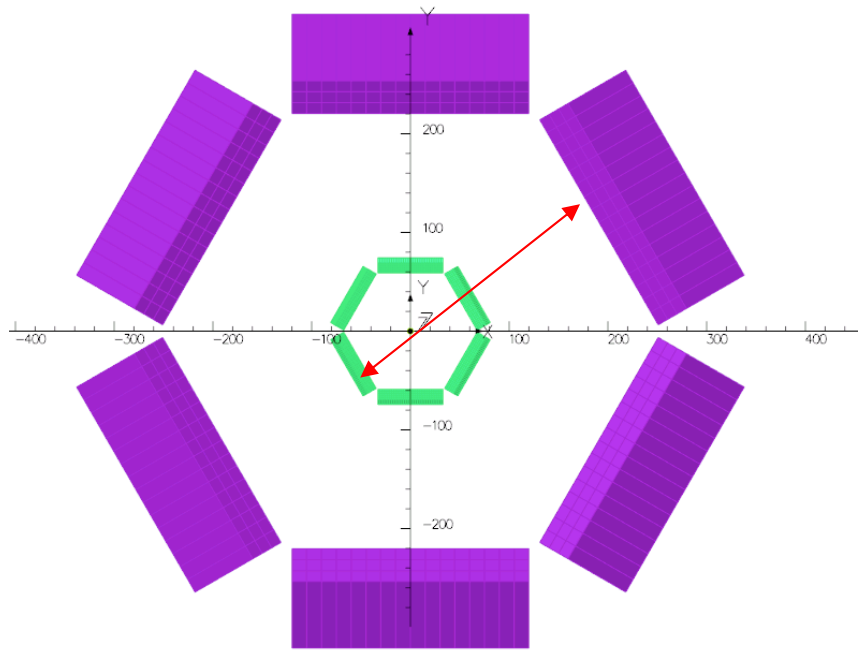


T.Hobbs & J.Miller, 2018



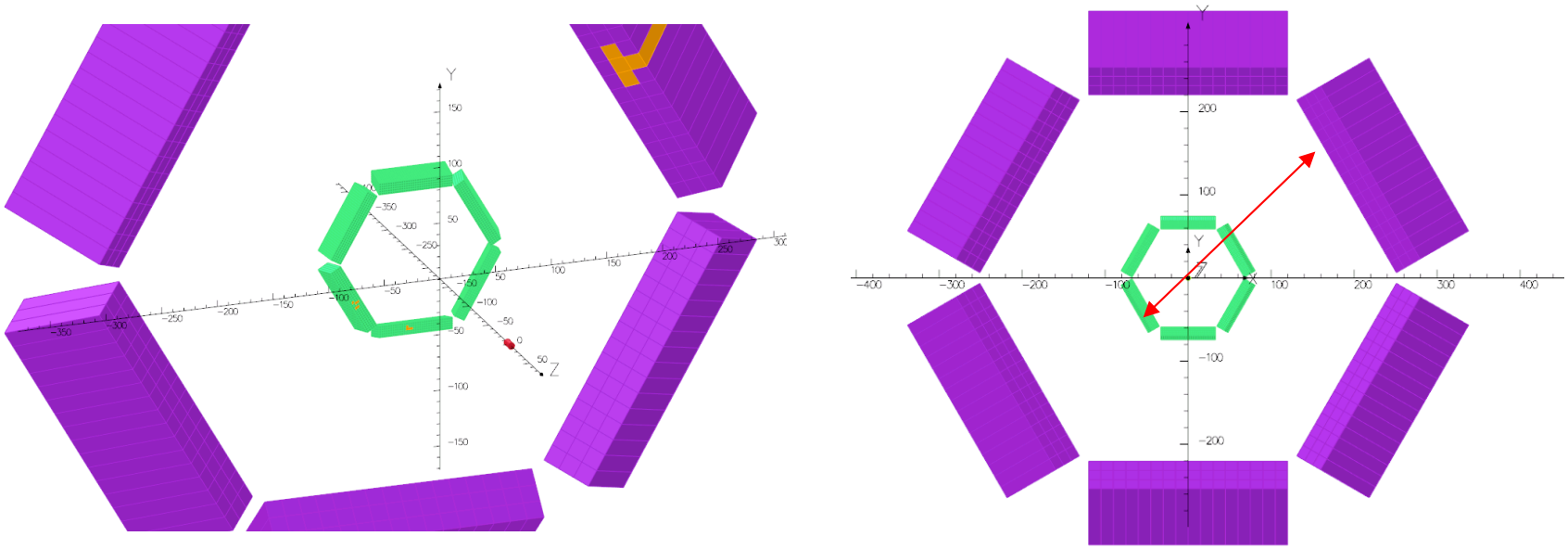
Coincidence parity experiment





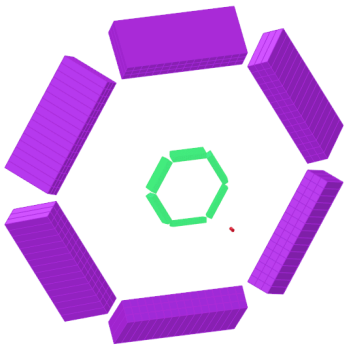
Beam of 6.6 GeV with scattered electron to 15.5 degrees.
High resolution in large solid angle ~ 42 msr => 8x of HRS
The apparatus reuses components of two calorimeters from the SBS and NPS

Coincidence parity experiment



The projected rate of good elastic e-p events is 14 kHz
Statistical raw accuracy is ~ 5 ppm in a 30 day run.
Projected PV asymmetry estimated to be -150 ppm

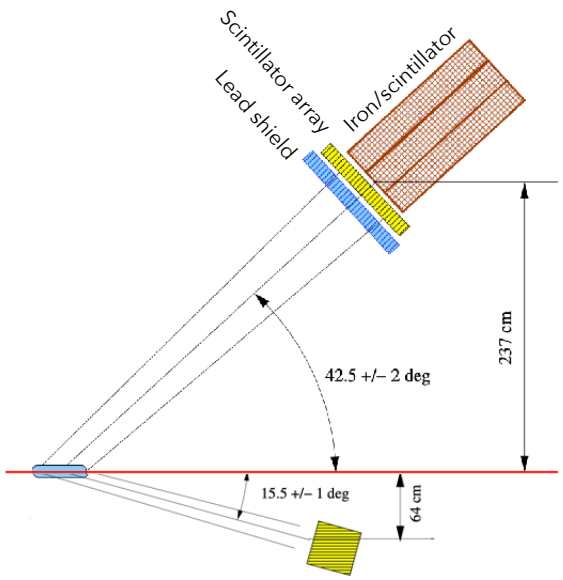
Detector System



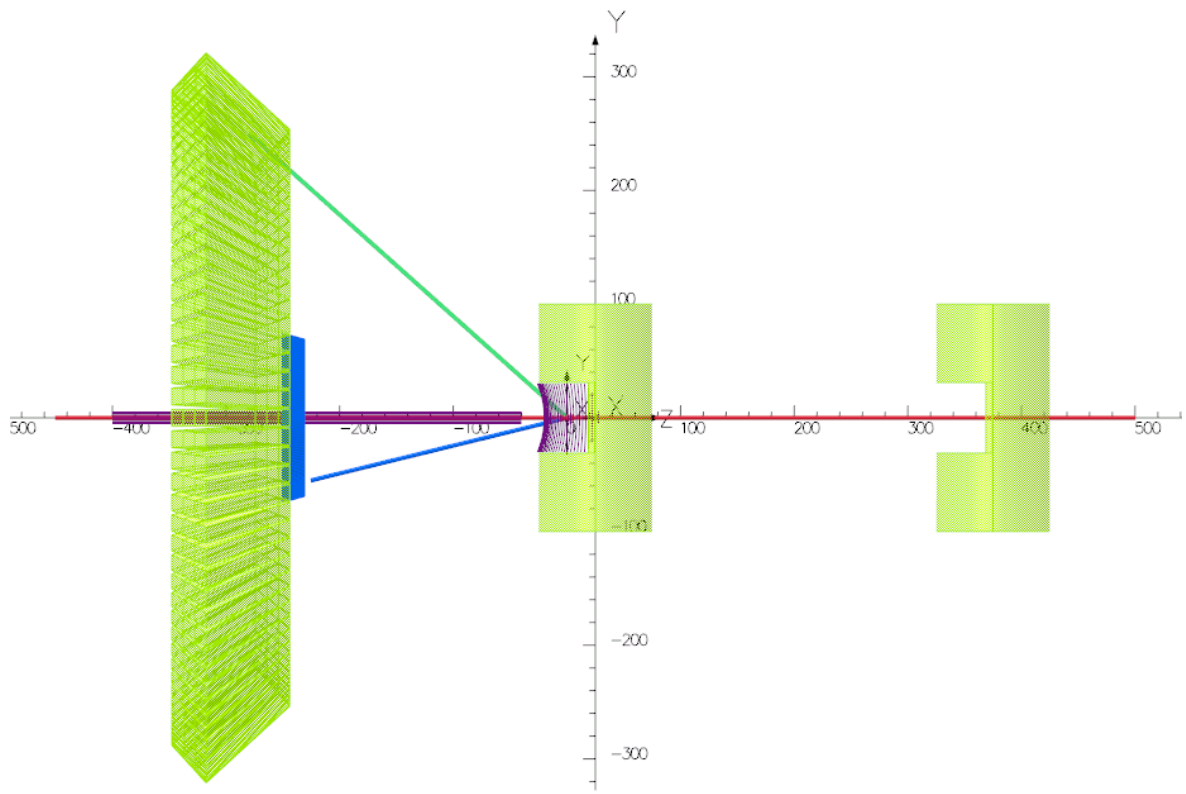
HCAL - hadron calorimeter
- Reassembled from detector elements from the SBS HCAL
- 288 blocks, each 15.5 x 15.5 x 100 cm^3
- iron/scintillator sandwich with wavelength shifting fiber readout

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

Scintillator array
- Used for improved position resolution in front of HCAL
- 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



Scheme of the vacuum chamber

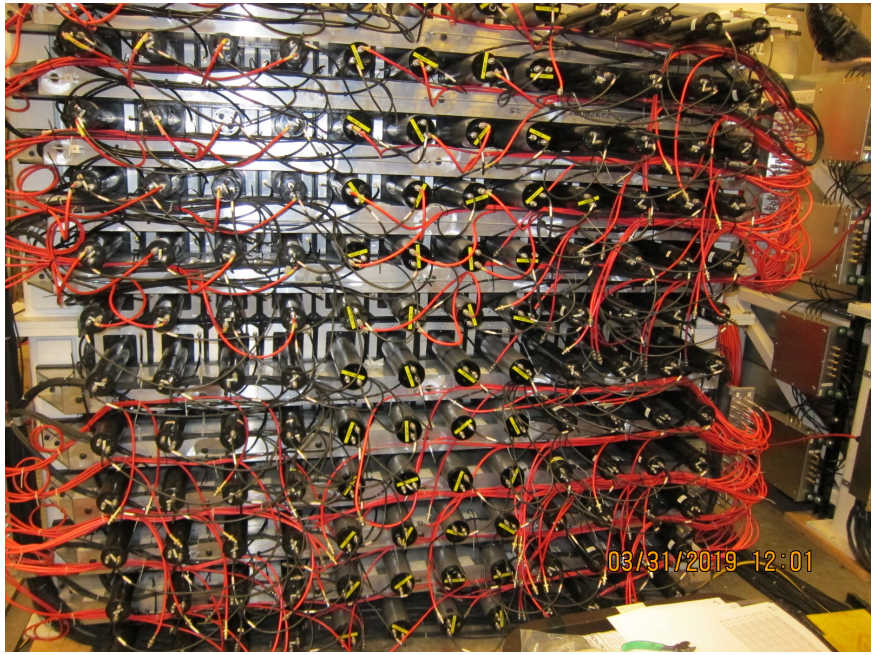


3.5 m target shift downstream is due to space limitation on the SHMS side

Detectors

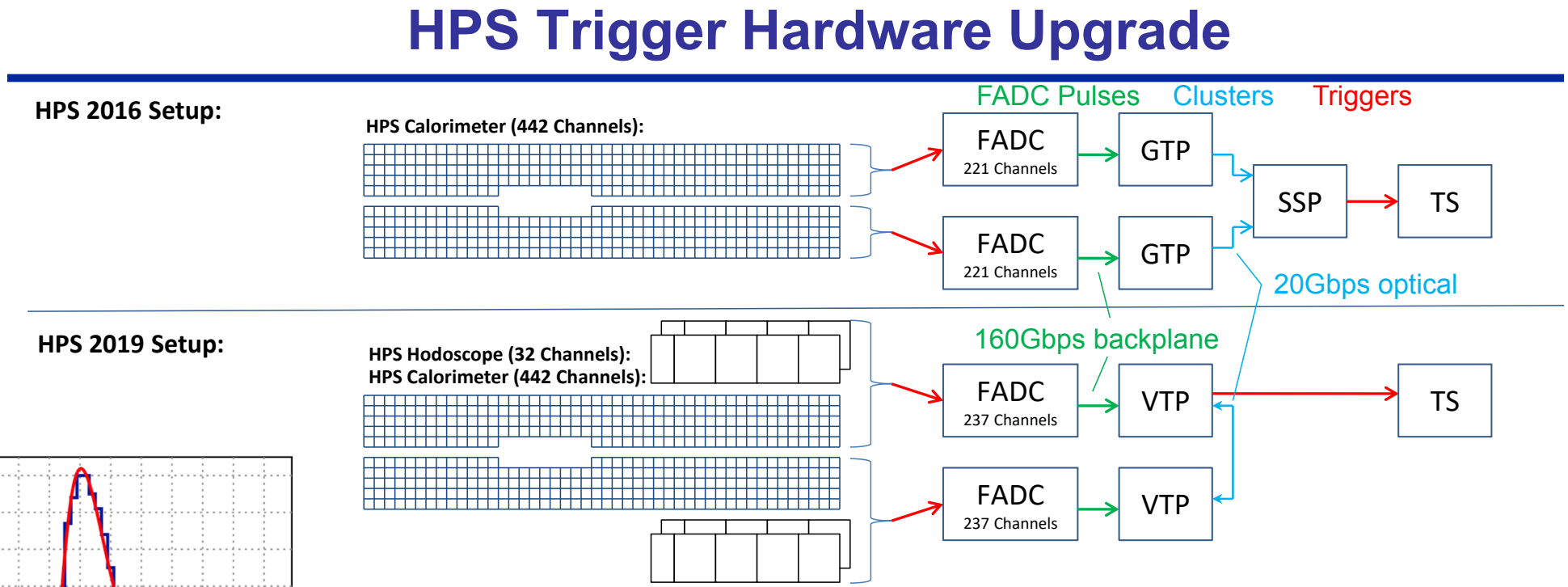
NPS, 1080 2x2x20 cm^3

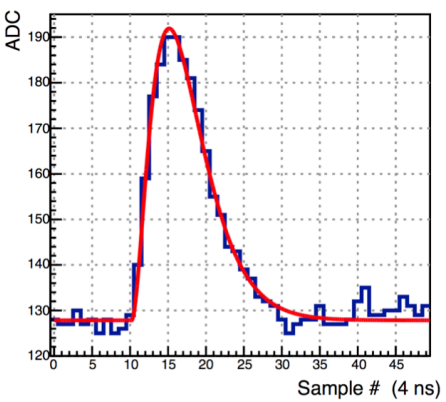
HCal, 288 15.5x15.5x100 cm^3



DAQ block diagram

Similar to operational HPS DAQ





Projected asymmetry

1. Counting statistics 5 ppm
2. Beam polarization 85%
3. EMFFs
4. Axial FF
5. High order corrections

A_{PV} = 150 ppm at 2.5 GeV^2 (for sFF = 0)

A_{PV} = prop. to (0.075 + 0.542 – 0.0 + 0.038)

axial

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

A = -226ppm * { 0.66 - (sFF/G_D) / 9.9 }

Rates and Statistical Precision

Beam and target: 60 uA on 10 cm LH2 => luminosity is 1.6 x 10^{38} cm^{-2}/s
Total: 1.2 MHz proton, 220 kHz electron arm

On-line trigger: accidental rate 1.6 kHz (40 ns), 37 kHz elastic coincidence, ~40 kHz total coincidence trigger rate; Data volume 56 MB/s

Off-line: e-p rate 14.2 kHz – production statistics! (4 ns, angular correlation cuts)

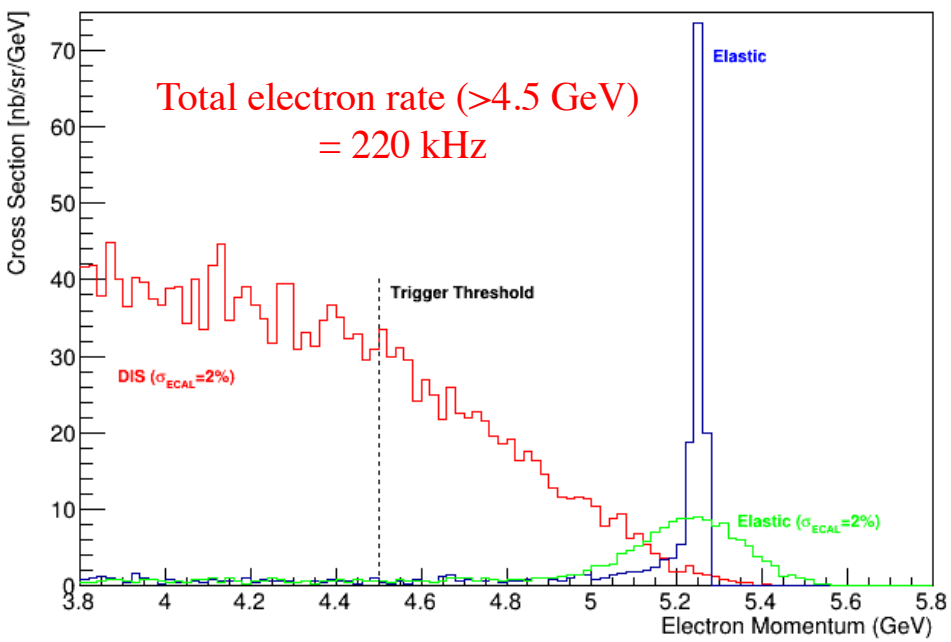
Real/Accidental ratio in final event sample is > 10^3

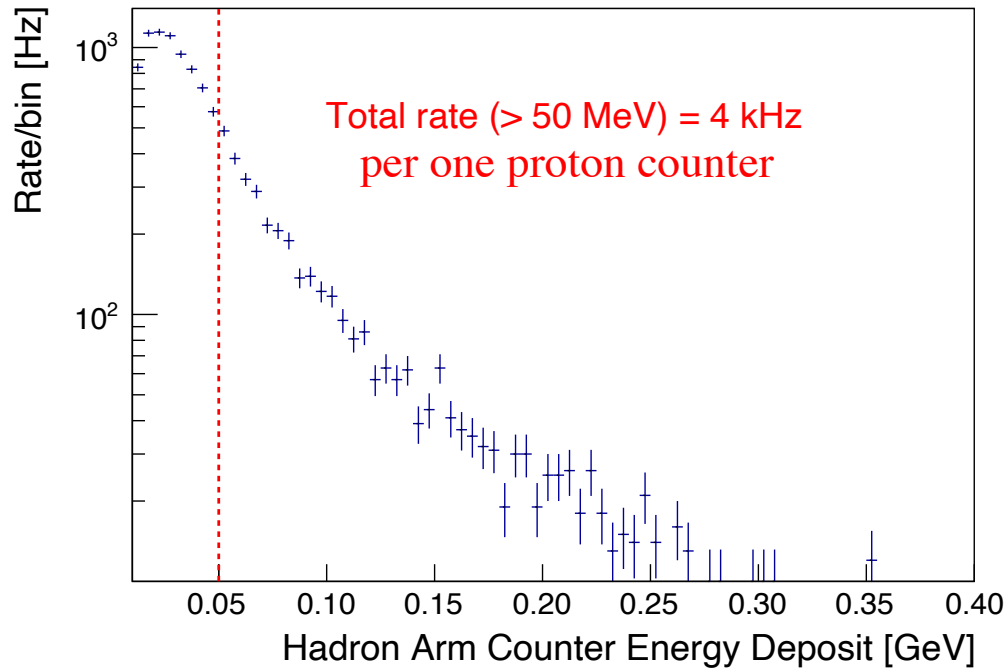
Beam polarization 85%

Counting statistics in 30 days => Raw asymmetry accuracy ~ 5 ppm

=> A_{PV} = -150 +/- 6.2 ppm

Electron and proton rates





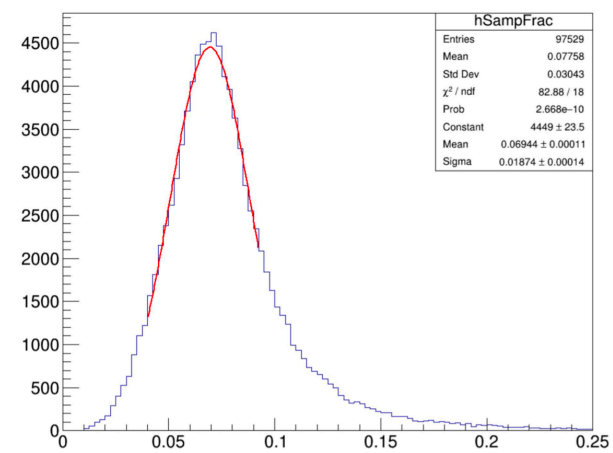
Inelastic:

E_e> 4.5 GeV rate is 220 kHz

E_e> 5.0 GeV rate is 18 kHz

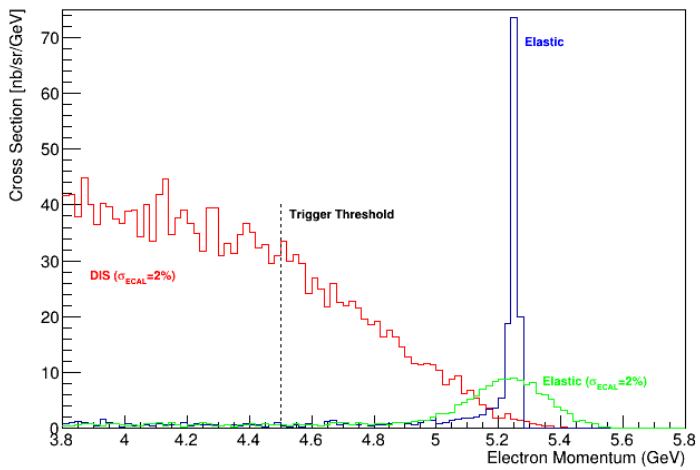
E_e> 5.2 GeV rate is 2.8 kHz

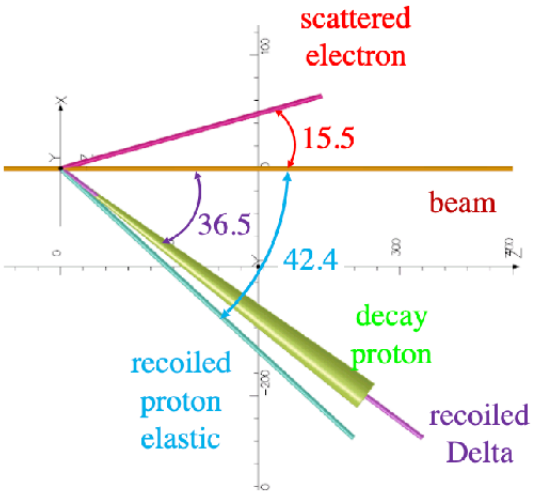
Shape of HACL amplitude for 2.4 GeV protons



Delta contribution via electro-production

Pion-production background rate calculation

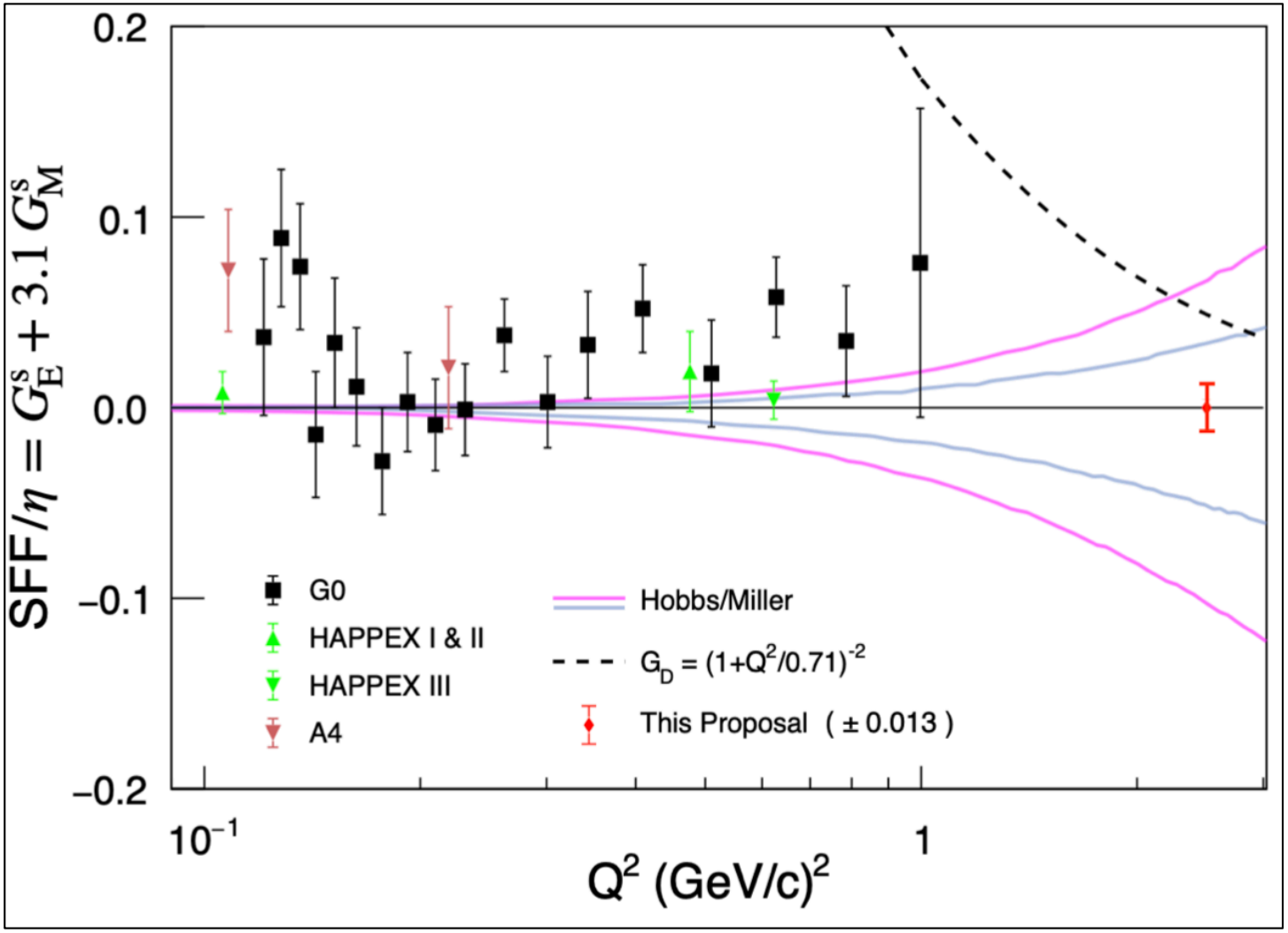




Online:
Electron arm single rate for $E_{e'}$ > 5 GeV is ~18 kHz
about 50% enters HCAL acceptance as coincidence, so ~10kHz

Offline:
electron arm single rate for E> 5.2 GeV is ~3 kHz
high angular resolution excludes >99%

Projected result accuracy



Summary (per PAC50 proposal)

- After 10+ years since last sFF searches were performed a new experiment is proposed for much higher Q^2.

- Projected accuracy 0.27 of the Dipole value allows high sensitivity search for non-zero strange form factor.

- We request PAC approval of 35 days of beam time (60 uA on 10 cm long LH2 target).