GEn-II Analysis & Thesis Update

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17.07.23

GEN-II: Neutron Electric Form Factor at High Q^2

What?

Double polarized semi-exclusive 3He(e,e'n)pp quasi-elastic scattering

Why?

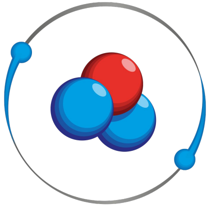
Extract Sachs Form Factor GEn with precise high Q2 GMn data.

How?

Measure transverse asymmetry $A_{\perp}$ of cross section

Where?

Hall A - Thomas Jefferson National Accelerator Facility

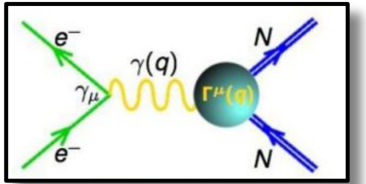


R. Hofstadter et al. (1950s)

$$\sigma(\theta_e) = \sigma_M \left| \int \rho(r) e^{iq\cdot r} d^3 r \right|^2 = \sigma_M \left| F(q) \right|^2$$

$$F_{1p}(0) = 1 \qquad \kappa_p = \mu_p - 1$$
$$F_{2p}(0) = \kappa_p$$
$$F_{1n}(0) = 0 \qquad \kappa_n = \mu_n$$
$$F_{2n}(0) = \kappa_n$$

Born Term



$$\Gamma_\mu(p,p') = \gamma_\mu F_1(Q^2) + \frac{i\sigma_{\nu\mu}}{2M} F_2(Q^2)$$

F_1: helicity non-conserving, Pauli FF

F_2: helicity conserving, Dirac FF

F.J. Ernst et al (1960s)

$$G_E = F_1 - \frac{Q^2}{M^2} F_2$$
$$G_M = F_1 + F_2$$

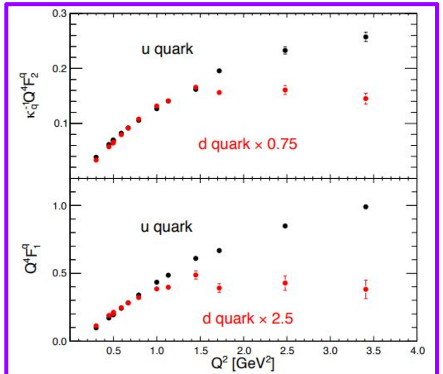
Electric form-factor

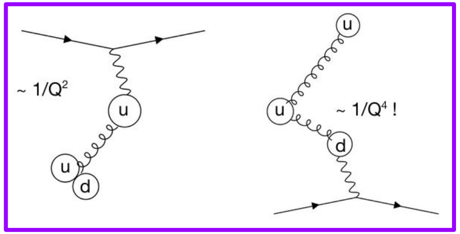
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E^2 \sin^4 \theta/2} \frac{E}{E'} \left[\frac{G_E^2 + \tau G_M^2}{1+\tau} \cos^2 \theta/2 + 2\tau G_M^2 \sin^2 \theta/2 \right]$$

point-like target

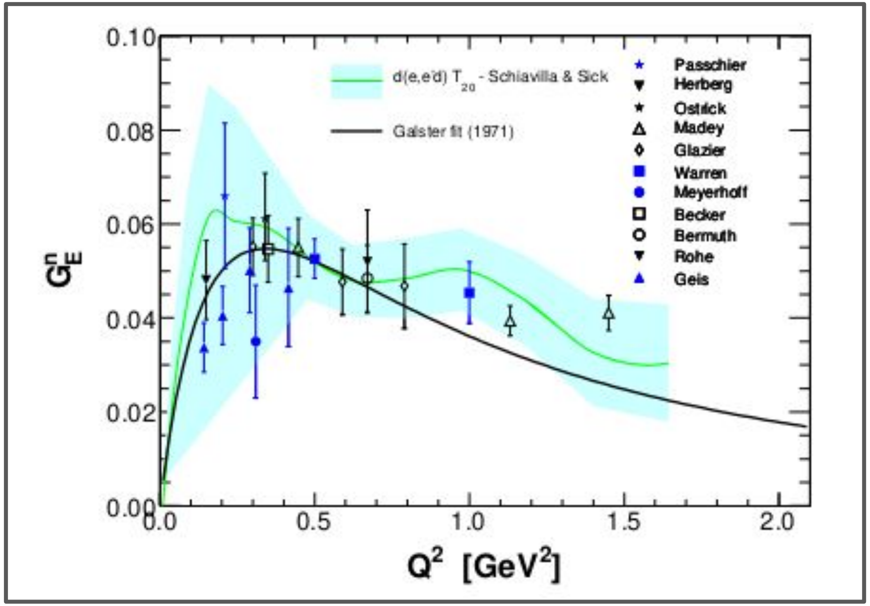
Magnetic form-factor

$$\tau \equiv \frac{Q^2}{4M^2}$$

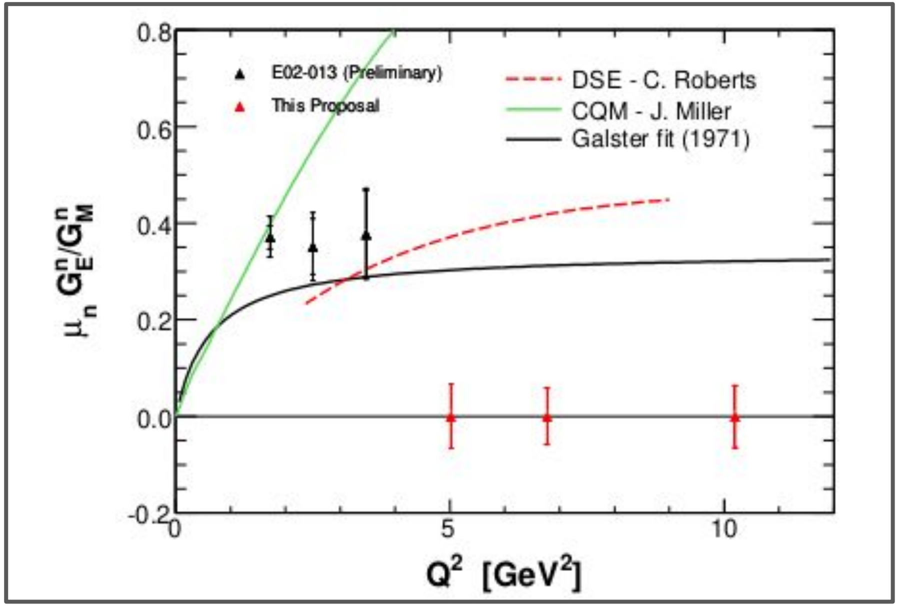




Different u & d behaviour may indicate diquark correlations!



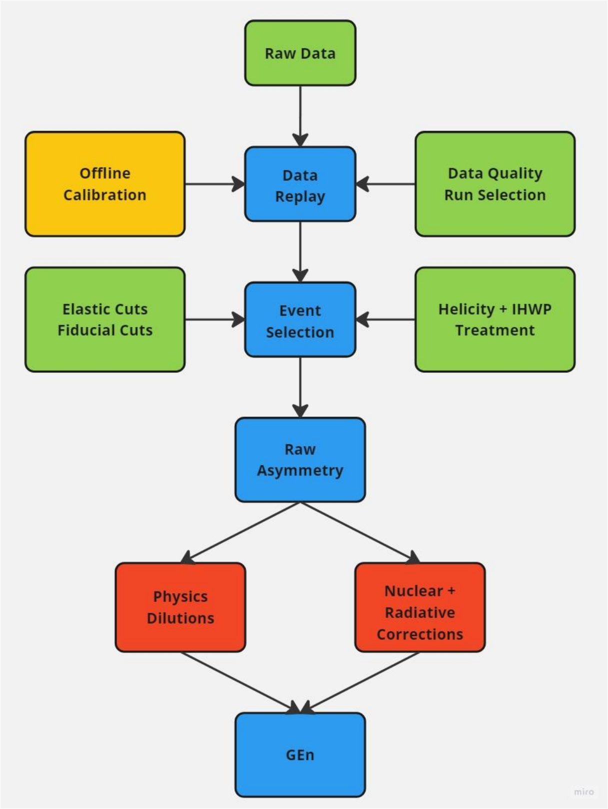
World data for GEn from polarized measurements and deuteron quadrupole measurement (Green), with Galster fit.



Projected points for GEn-II experiment, with (OLD PRELIMINARY) results from GEn-I shown.

Q^2	E_e	θ_e	p_e	θ_n	p_n
2.9	4.288	29.5	2.69	34.7	2.37
6.6	6.3	35.9	2.77	22.1	4.38
9.7	8.400	35.0	3.21	18.0	6.07

Analysis Workflow



A_{phys} Dilutions

P_{beam}: Polarisation of beam. Typically about 80-85%

P_{He3}: Polarisation of Helium-3 target. Varies run to run based on spin-up and cell. 20-50%

P_n: Fraction of polarisation of Neutron in He^3. Known to be about 84%.

D_{N2}: Dilution due to Nitrogen in the target cell

D_{π}: Pion background dilution

D_{FSI}: Final state interaction influences.

Analysis Workflow: GEn Extraction

$$A = \frac{N^+ - N^-}{N} = PA^{true}$$

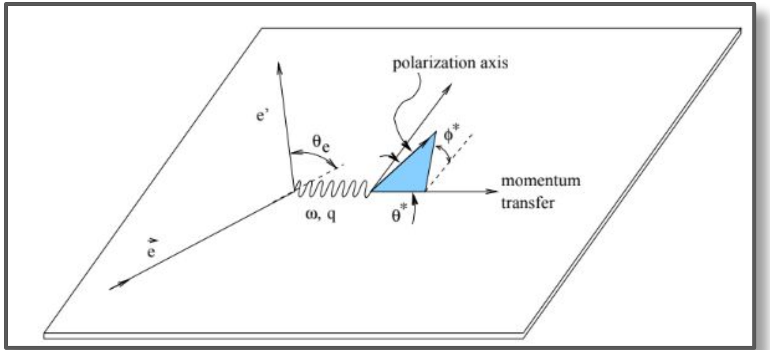
$$A_{phys} = \frac{A_{exp}}{P_{beam} P_{He^3} P_n D_{N^2} D_\pi D_{FSI}}$$

$$A_{phys} = \frac{A_{true}}{P_n D_{N^2} D_\pi D_{FSI}}$$

Systematics / Dilutions

$$A_{phys} = -\frac{2\sqrt{\tau(\tau+1)}\tan(\theta/2) G_E^n G_M^n \sin\theta^* \cos\phi^*}{(G_E^n)^2 + (G_M^n)^2(\tau + 2\tau(1+\tau)\tan^2(\theta/2))} - \frac{2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2(\theta/2)}\tan(\theta/2)(G_M^n)^2\cos\theta^*}{(G_E^n)^2 + (G_M^n)^2(\tau+2\tau(1+\tau)\tan^2(\theta/2))}.$$

$$A_\perp = -\frac{G_E^n}{G_M^n}\frac{2\sqrt{\tau(\tau+1)}\tan(\theta/2)}{(G_E^n/G_M^n)^2 + (\tau+2\tau(1+\tau)\tan^2(\theta/2))}.$$



Magnetic field set such that polarization perpendicular to q vector

GEn small → (GEn/GMn)^2 negligible

Extract ratio from asymmetry

Scope of Thesis

Primarily an analysis of GEN2 kinematic. (possibly with some focus specifically on hodoscope)

- Chapter 1: Introduction
- Chapter 2: Theory & Motivations
- Chapter 3: Experimental Setup
- Chapter 4: Data Analysis
- Chapter 5: Results and Discussion
- Chapter 6: Conclusion
- Appendices

Submission deadline June 2024

Measurement of the Neutron Electric Form Factor at $Q^2 = 2.9$ GeV^2.

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Presented as a Thesis for the degree of
Doctor of Philosophy

School of Physics and Astronomy
College of Science and Engineering
University of Glasgow

Analysis Progress Since Starting Ph.D

<u>January 2021 - Now:</u>

- Preliminary GMn Analysis
  - LH2, LD2 elastic/Quasielastic rates for all kinematics.
- GEn Simulation Framework
  - Sims for all kinematics + generators prior to running
- Full GEn Analysis Framework
  - Progressed from GMn analysis elastics script
  - Raw Asymmetry with background subtraction
- Final result calculation framework

Analysis Status

Cuts

Global: fabs(tr_vz) < 0.27, hcal_nclus > 0,

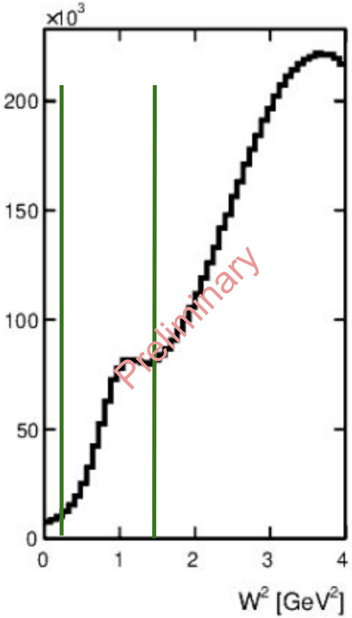
tr_n > 0, gem_nlayers > 3

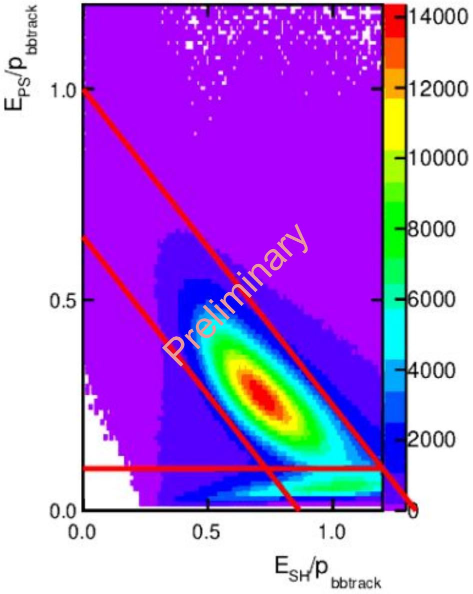
$PS_E > 0.1$ GeV (π^- rejection)

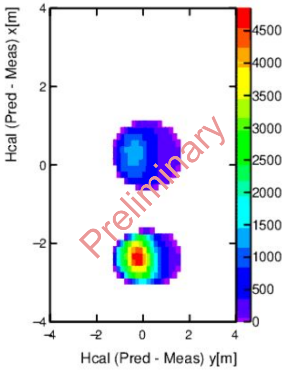
$0.65 < PS_E/p + 0.75 * SH_E/p < 1.0$

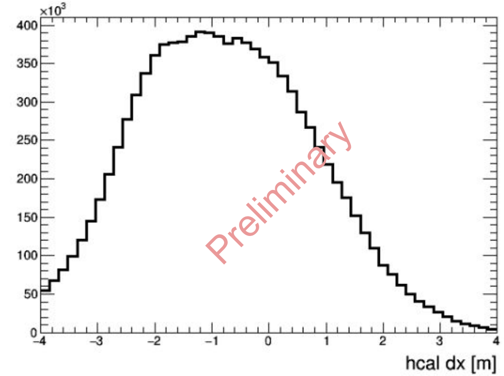
3σ cut around W2 ($0.25 < W^2 < 1.5$ GeV^2)

3σ Neutron spot cut (plot on right is 1m radial)



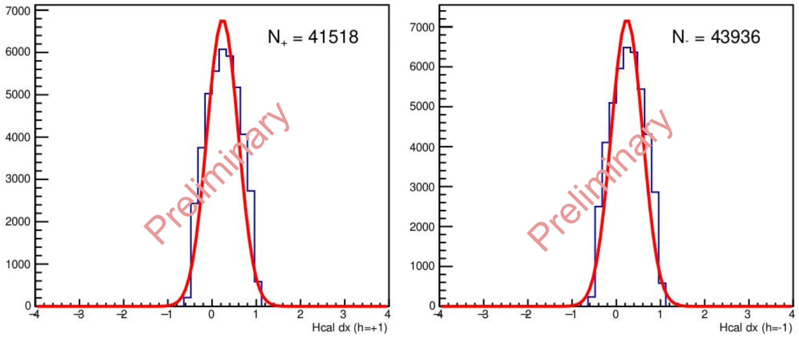






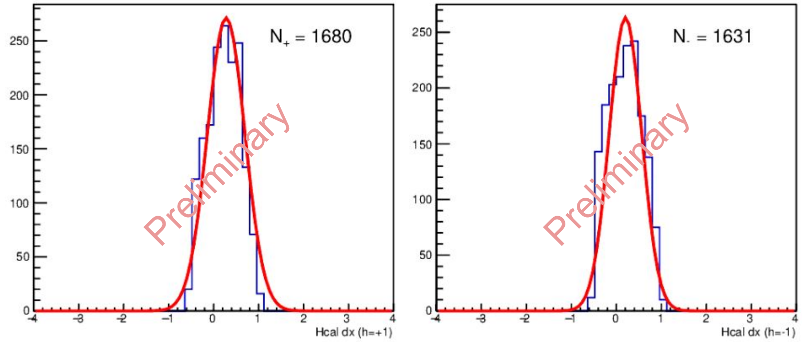
Analysis Status: Preliminary Raw Asymmetry

Kinematic 2:
$Q^2 = 2.9\ GeV^2$



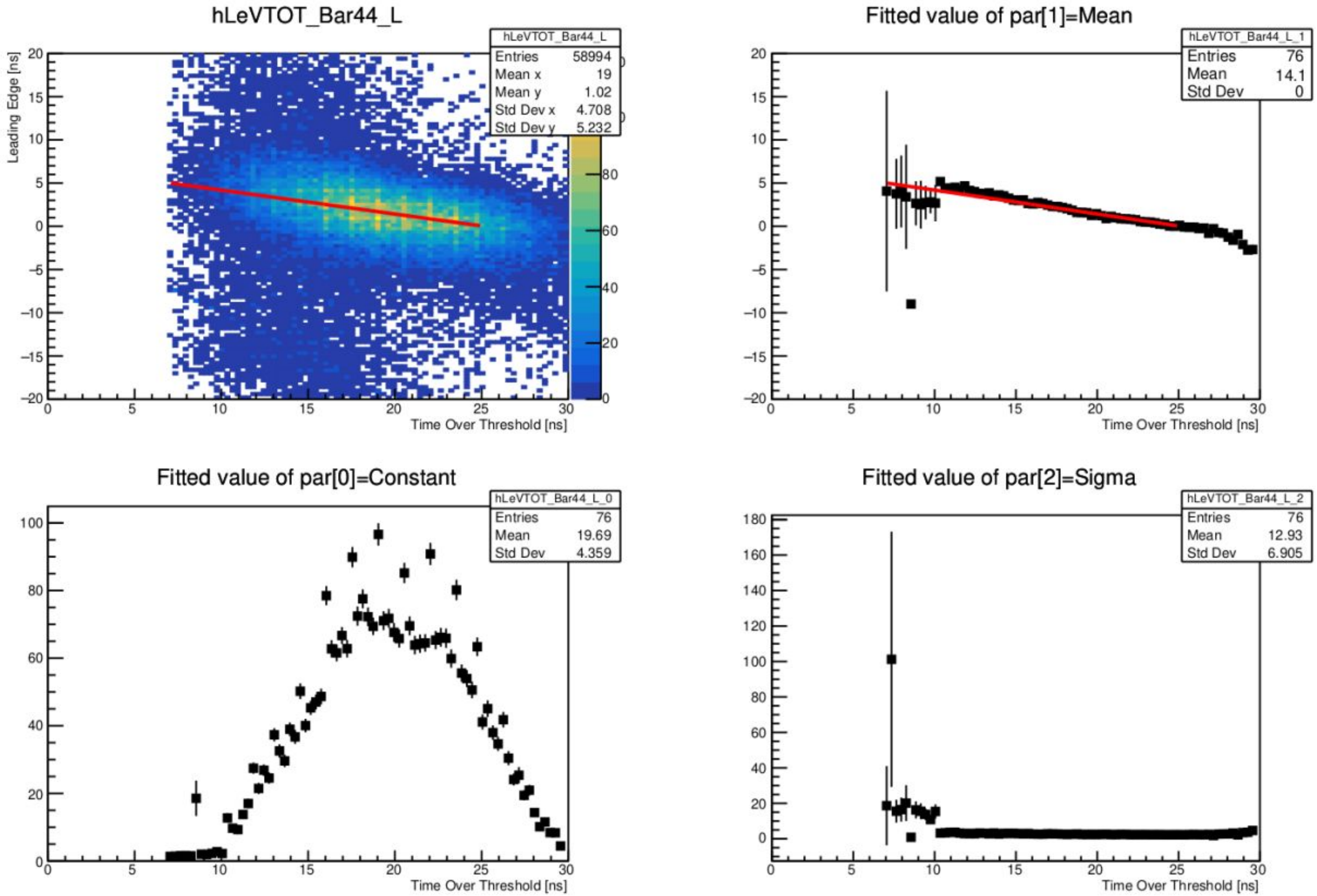
$A_{raw} = 0.02830 \pm 0.00342$
$A_{true} = 0.12909 \pm 0.01560$
~ 40M / 169M total stats

Kinematic 3:
$Q^2 = 6.6\ GeV^2$

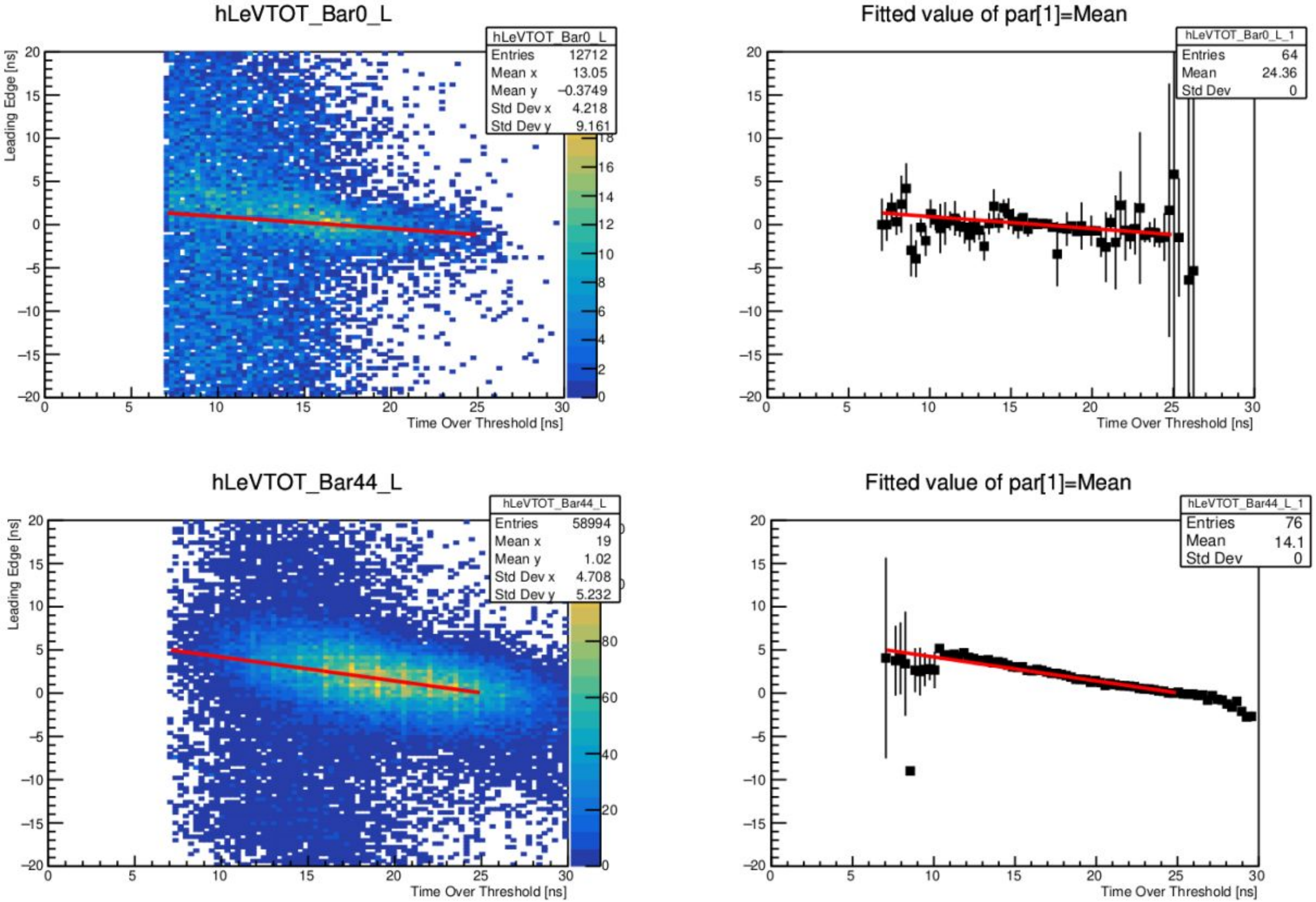


$A_{raw} = 0.01480 \pm 0.01738$
$A_{true} = 0.40783 \pm 0.47886$
~70M / 500M total stats

Hodoscope Calibration



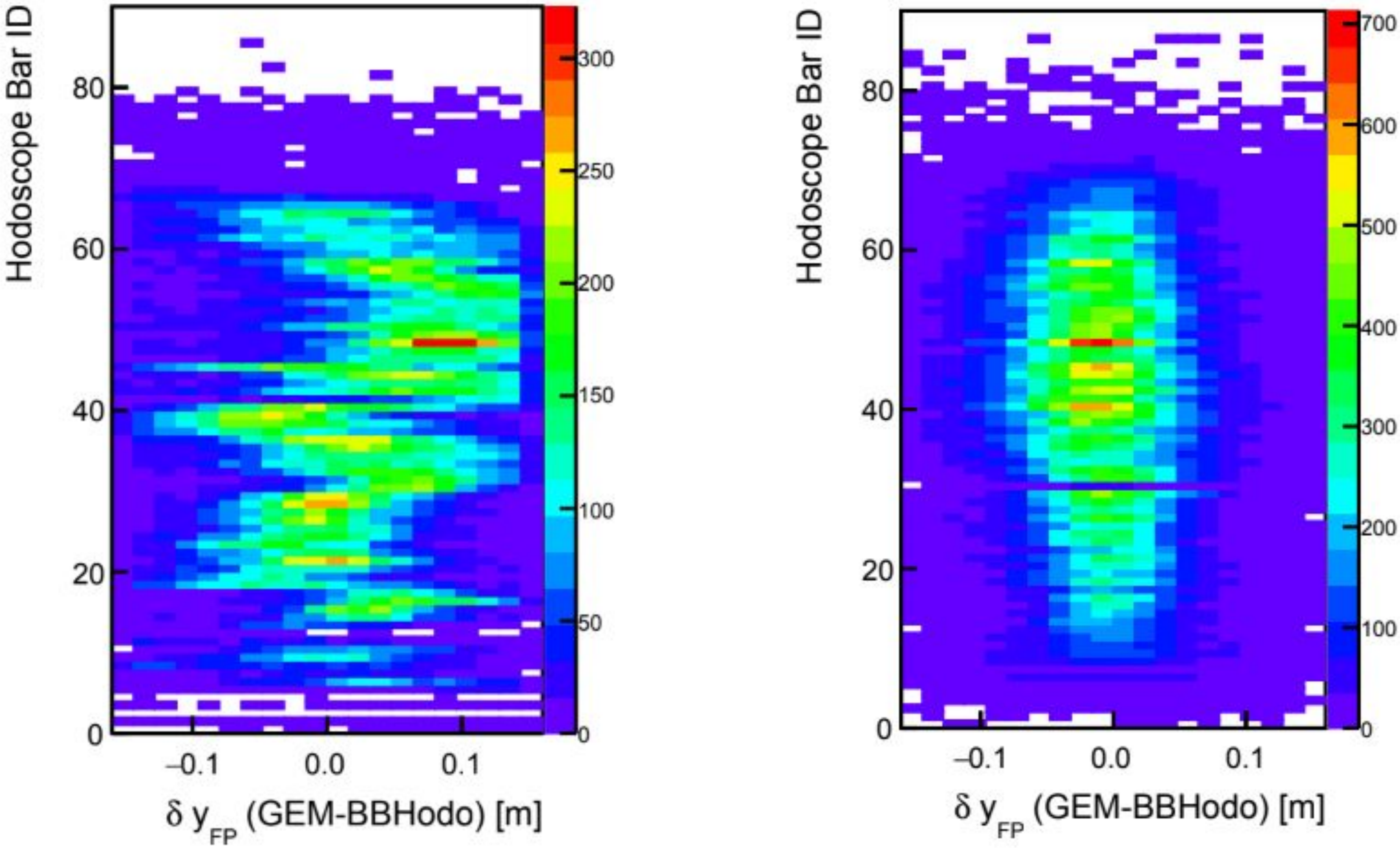
hLeVTOT_Bar44_L
hLeVTOT_Bar44_L
Entries 58994
Mean x 19
Mean y 1.02
Std Dev x 4.708
Std Dev y 5.232
Leading Edge [ns]
Time Over Threshold [ns]
Fitted value of par[1]=Mean
hLeVTOT_Bar44_L_1
Entries 76
Mean 14.1
Std Dev 0
Time Over Threshold [ns]
Fitted value of par[0]=Constant
hLeVTOT_Bar44_L_0
Entries 76
Mean 19.69
Std Dev 4.359
Time Over Threshold [ns]
Fitted value of par[2]=Sigma
hLeVTOT_Bar44_L_2
Entries 76
Mean 12.93
Std Dev 6.905
Time Over Threshold [ns]



Bar 0L and 44L as examples

Top 10 bars (not shown) are difficult to fit due to low statistics.

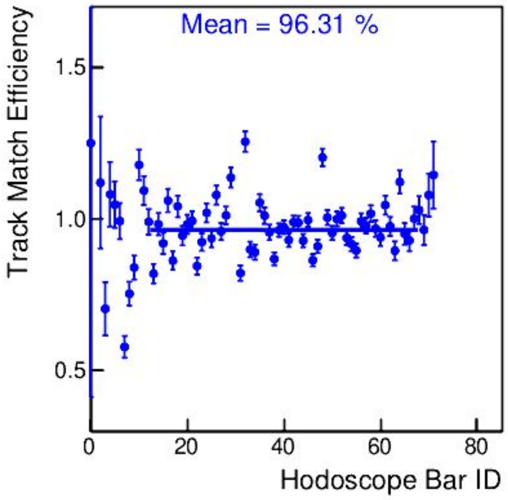
This is unavoidable as these are very much out of elastic acceptance.

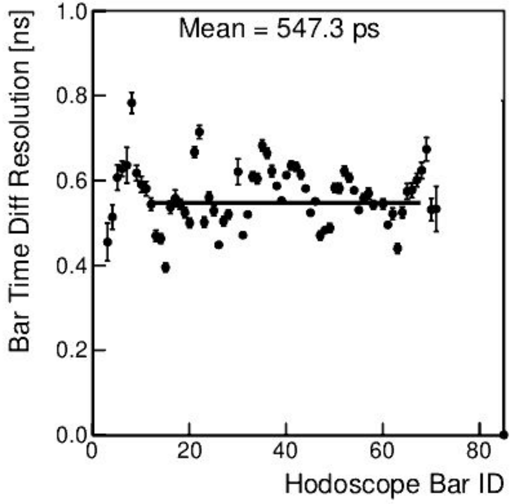


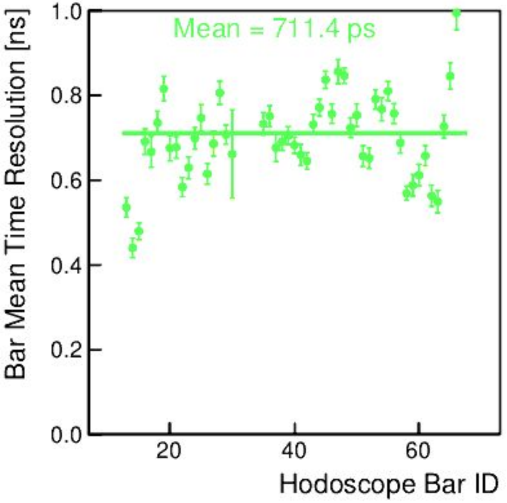
Hodoscope Bar ID
0
20
40
60
80
−0.1
0.0
0.1
δ y_FP (GEM-BBHodo) [m]
0
50
100
150
200
250
300
Hodoscope Bar ID
0
20
40
60
80
−0.1
0.0
0.1
δ y_FP (GEM-BBHodo) [m]
0
100
200
300
400
500
600
700

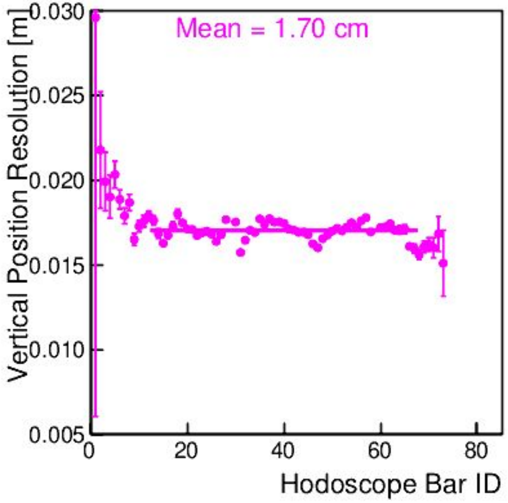
GEN-2

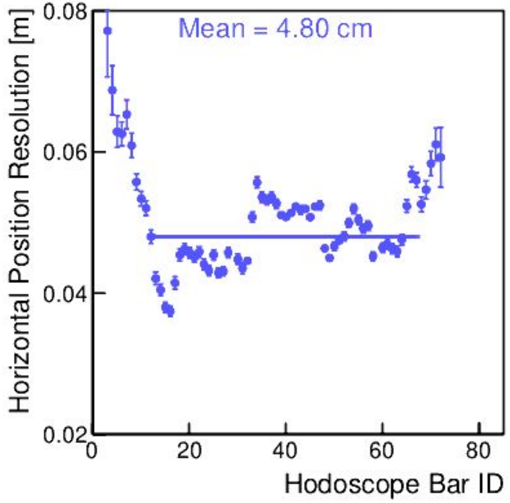
All H2 Runs











Next Steps

- Hodoscope Path Length Corrections
  - Looking at time vs (x,y,theta,phi) empirically
  - Plan to use g4sbs data too
- Full GEN2 He3 statistics A_{raw} (Code updated today)
- Finish Experimental Setup chapter of thesis
- Visit lab for shifts on run extension
- Pass 0 -> Pass 1 -> Pass 2
- Final result

Backup

Statistical Uncertainty Handling

Correlated Asymmetries

$$q = \frac{N^+}{N}$$

$$\sigma_q^2 = \frac{\sigma_{N+}^2}{N^2}$$

$$\sigma_{N+}^2 = Nq(1-q)$$

$$\sigma_A^2 = \frac{4q(1-q)}{N} = \frac{4N^+N^-}{N^3}$$

Asymmetry in Polarisation measurement

$$A = \frac{N^+ - N^-}{N} = PA^{true}$$

$$\begin{aligned}
\sigma_{A^{true}}^2 &= \frac{1}{P^2}\sigma_A^2 + \frac{A^2}{P^4}\sigma_P^2 \\
&= \frac{4N^+N^-}{N^3P^2} + \frac{(N^+ - N^-)^2}{N^2P^4}\sigma_P^2 \\
&= \frac{4q(1-q)}{NP^2} + \frac{(2q-1)^2}{P^4}\sigma_P^2
\end{aligned}$$

$$\begin{aligned}
A^{true} &= \frac{\sum A_i^{true} N_i P_i^2}{\sum N_i P_i^2} \\
&= \frac{\sum (N_i^+ - N_i^-) P_i}{\sum N_i P_i^2}
\end{aligned}$$

→

$$\sigma_{A^{true}}^2 = \frac{4q(1-q)}{\sum N_i P_i^2}$$

$$\sigma_h = \Sigma + h\Delta$$

$$A_N = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{\Delta}{\Sigma}$$

$$\Sigma = \left.\frac{d\sigma}{d\Omega}\right|_{\text{Mott}} \frac{E_f}{E_i} \left(\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2(\theta/2) \right)$$

$$\Delta = -2 \left.\frac{d\sigma}{d\Omega}\right|_{\text{Mott}} \frac{E_f}{E_i} \sqrt{\frac{\tau}{1+\tau}} \tan(\theta/2) \left[\sqrt{\tau(1+(1+\tau)\tan^2(\theta/2))} \cos\theta^* G_M^2 + \sin\theta^* \cos\phi^* G_M G_E \right]$$

$$A_{\text{phys}} = -\frac{2\sqrt{\tau(\tau+1)}\tan(\theta/2) G_E^n G_M^n \sin\theta^* \cos\phi^*}{(G_E^n)^2 + (G_M^n)^2(\tau + 2\tau(1+\tau)\tan^2(\theta/2))}$$

$$-\frac{2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2(\theta/2)}\tan(\theta/2)(G_M^n)^2 \cos\theta^*}{(G_E^n)^2 + (G_M^n)^2(\tau + 2\tau(1+\tau)\tan^2(\theta/2))}$$

$$A_\perp = -\frac{G_E^n}{G_M^n} \frac{2\sqrt{\tau(\tau+1)}\tan(\theta/2)}{(G_E^n/G_M^n)^2 + (\tau + 2\tau(1+\tau)\tan^2(\theta/2))}$$

Miscellaneous Contributions to GEN / SBS

Hodoscope Technical & Mapping Document

Target Install Work

GEN Hodoscope calibrations + documentation

35 SL+TO Shifts (More in new run)

GEN2 Data validation + good run list


FedEx



JLG LIFT
Windmill