GEn-II Analysis Status

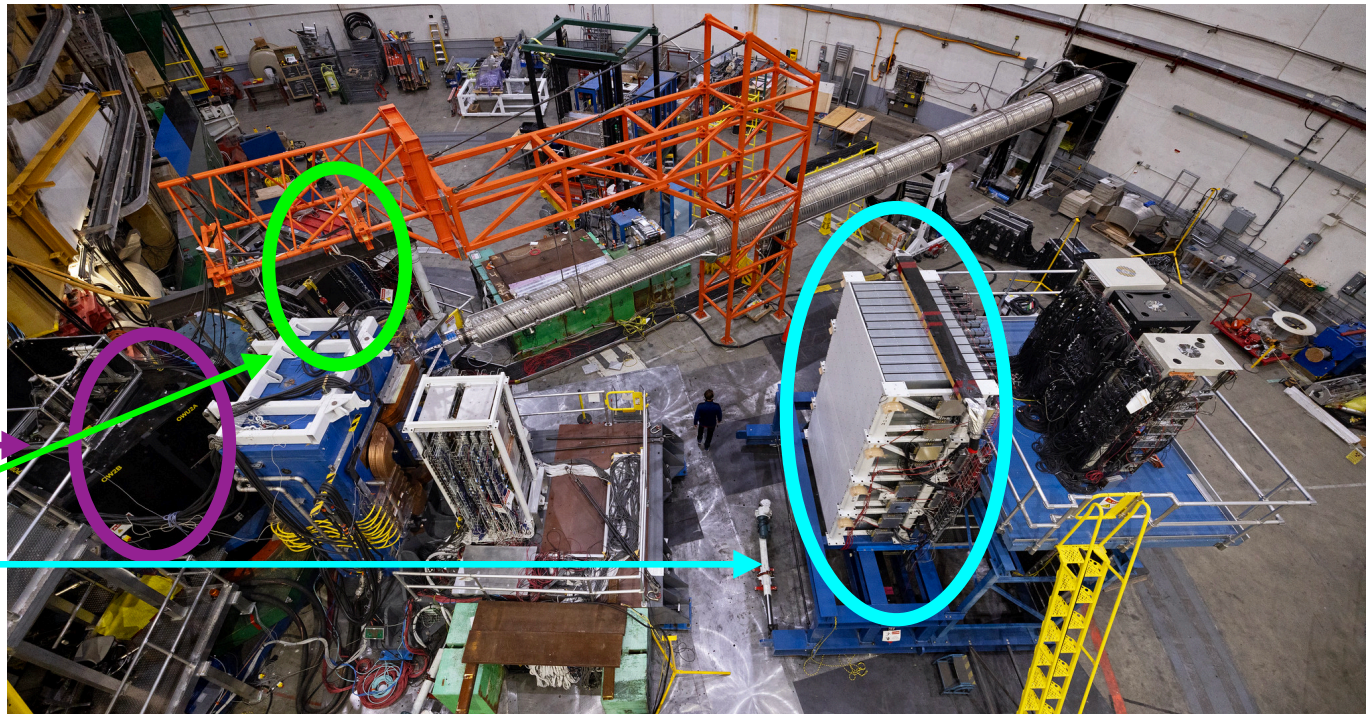
Jack Jackson

On Behalf of the SBS Collaboration
January 22, 2026

The SBS Program

- The Super BigBite (SBS) Program began running in October 2021, running through August 2025 in Hall A
  - GMn
  - GEn-II
  - GEn-RP
  - GEp-V

- Target Enclosure
- BigBite Detector Stack
  - HCal



GEn-II floor setup courtesy of JLab Hall A poster

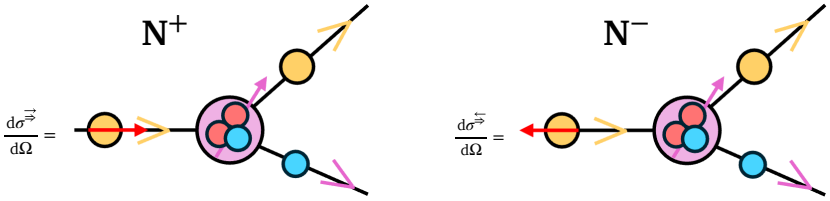
GEn-II: Electromagnetic Form Factor Ratio G_E^n/G_M^n

GEn-II used the double polarization method for neutron electromagnetic form factor extraction

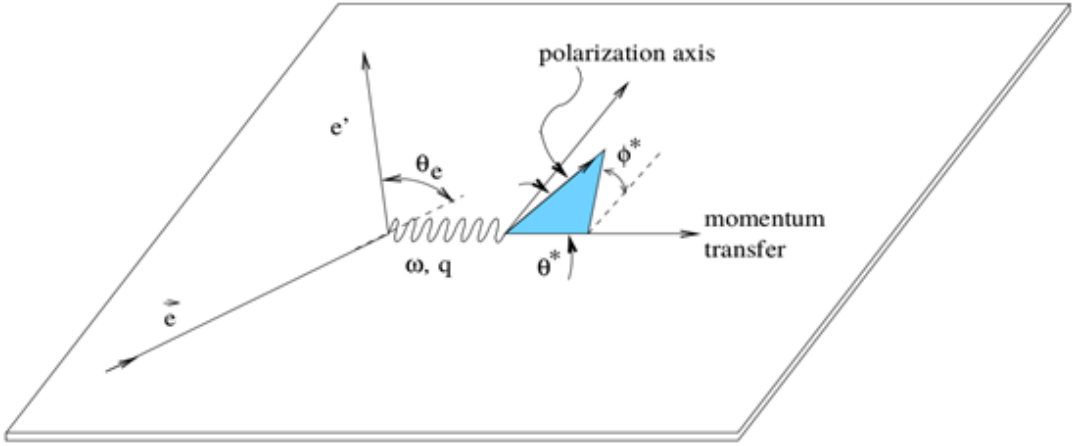
The helicity dependent elastic scattering cross-section for single photon exchange approximation

$$\frac{d\sigma^{\vec{\Rightarrow},\overleftarrow{\Rightarrow}}}{d\Omega} = \Sigma \pm \Delta$$

$\rightarrow, \leftarrow$ represent +1,-1 helicity states of the electron and $\Rightarrow$ represents the fixed target's longitudinal spin



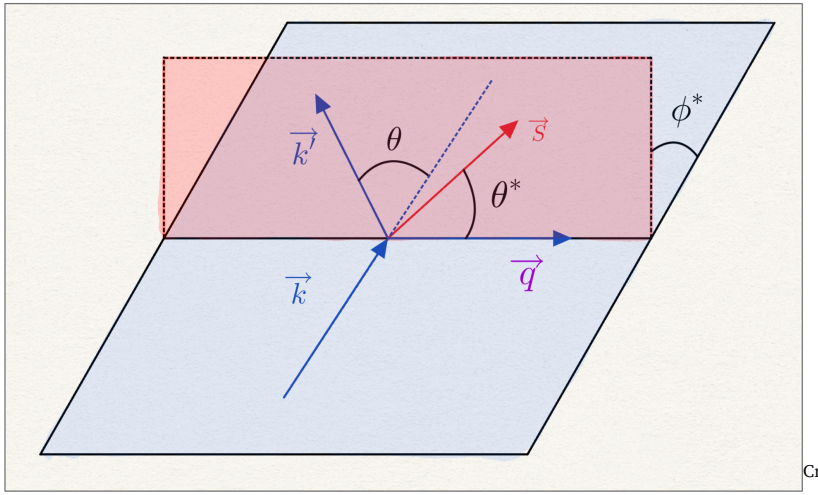
Credit: J. Koenemann



GEn-II: Electromagnetic Form Factor Ratio G_E^n/G_M^n

$$A_{raw} = \frac{N^+ - N^-}{N^+ + N^-} \rightarrow A_{phys} = \frac{A_{raw} - \Sigma_{x \neq n} f_x A_x}{P_{beam} P_{^3He} P_n f_n}$$

$$A_{phys} = -\frac{1}{1 + \frac{\epsilon}{\tau}\left(\frac{G_E^n}{G_M^n}\right)^2}\left[\left(\frac{G_E^n}{G_M^n}\right)\sqrt{\frac{2\epsilon(1-\epsilon)}{\tau}}P_x + \sqrt{1-\epsilon^2}P_z\right]$$



Credit: H. Presley

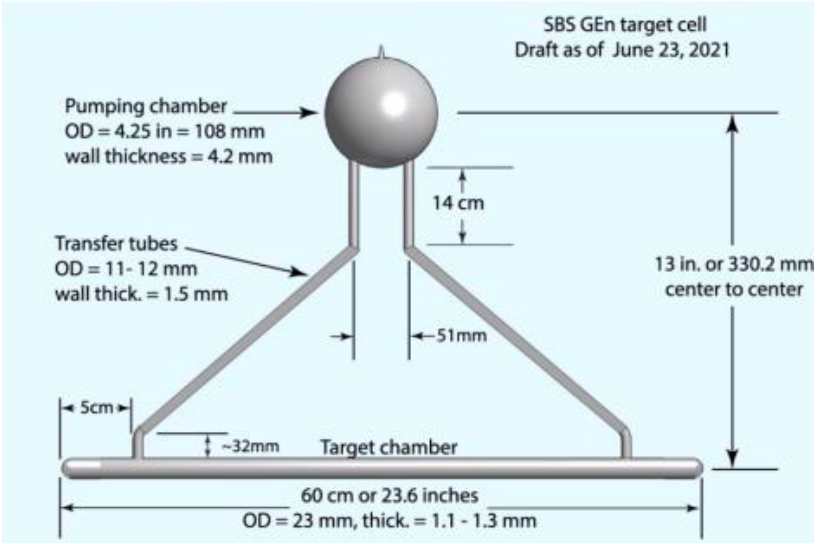
$\epsilon \rightarrow \left(1 + 2(1+\tau)\tan^2(\theta/2)\right)^{-1}$

$\tau \rightarrow \frac{Q^2}{4M_N^2}$

$P_x \rightarrow$ target spin component $\perp$ to $\vec{q} \Rightarrow \sin\theta^* \cos\phi^*$

$P_z \rightarrow$ target spin component $\parallel$ to $\vec{q} \Rightarrow \cos\theta^*$

Novel ^{3}He Target

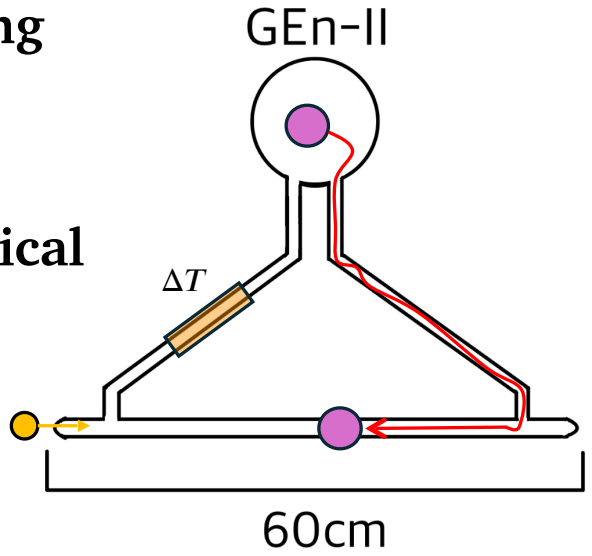


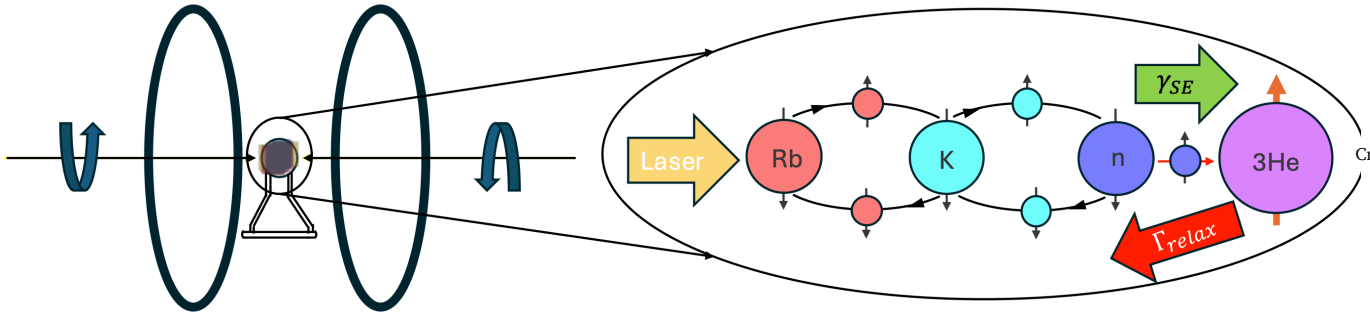
Credit: G. Cates

Increased Length & Pumping Chamber

Convection Replacement

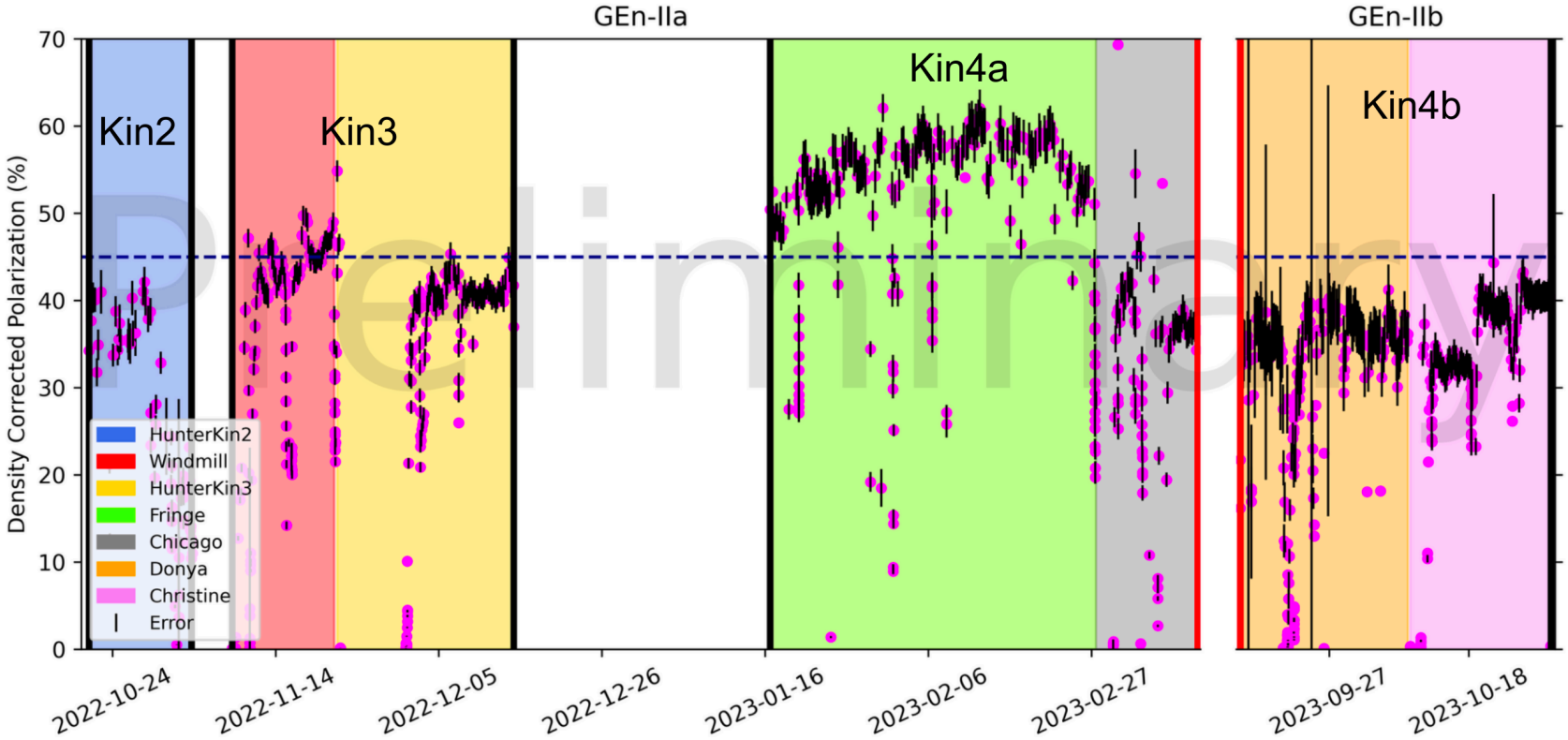
2-Sided Spin Exchange Optical Pumping (SEOP)





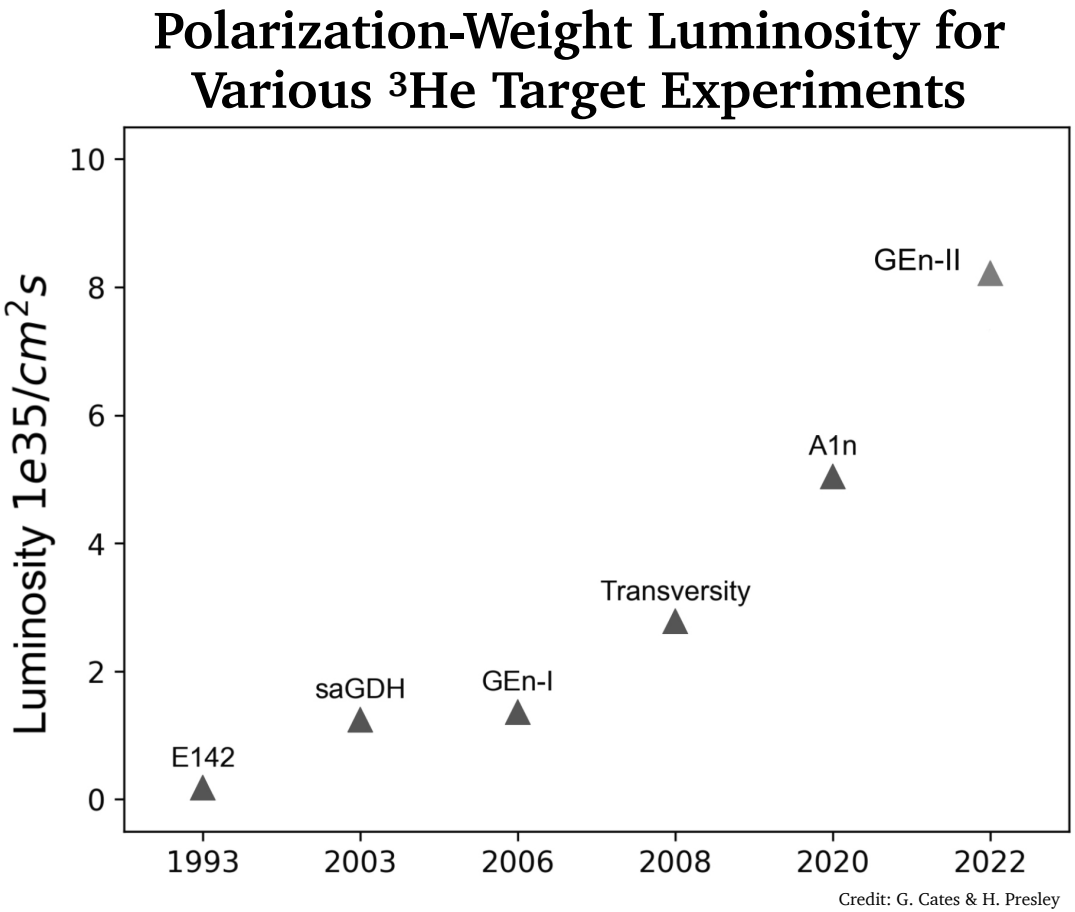
Credit: J. Koenemann

Novel ^{3}He Target: Polarization Performance

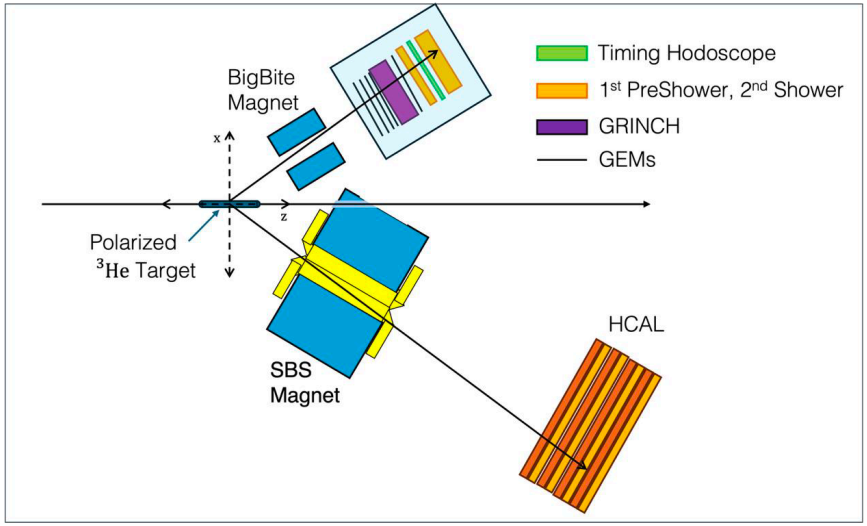


* credit: H. Presley thesis

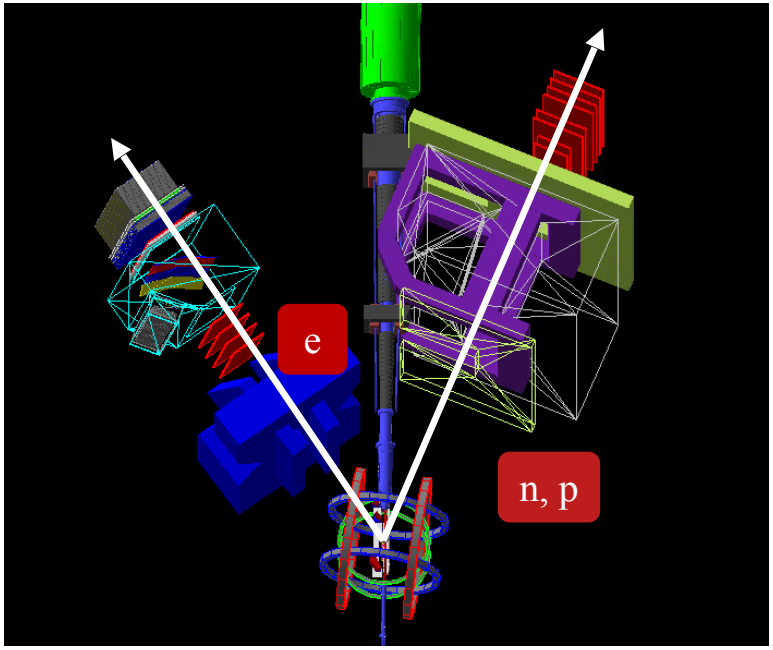
Target Performance



Experiment Parameters



Credit: J. Koenemann



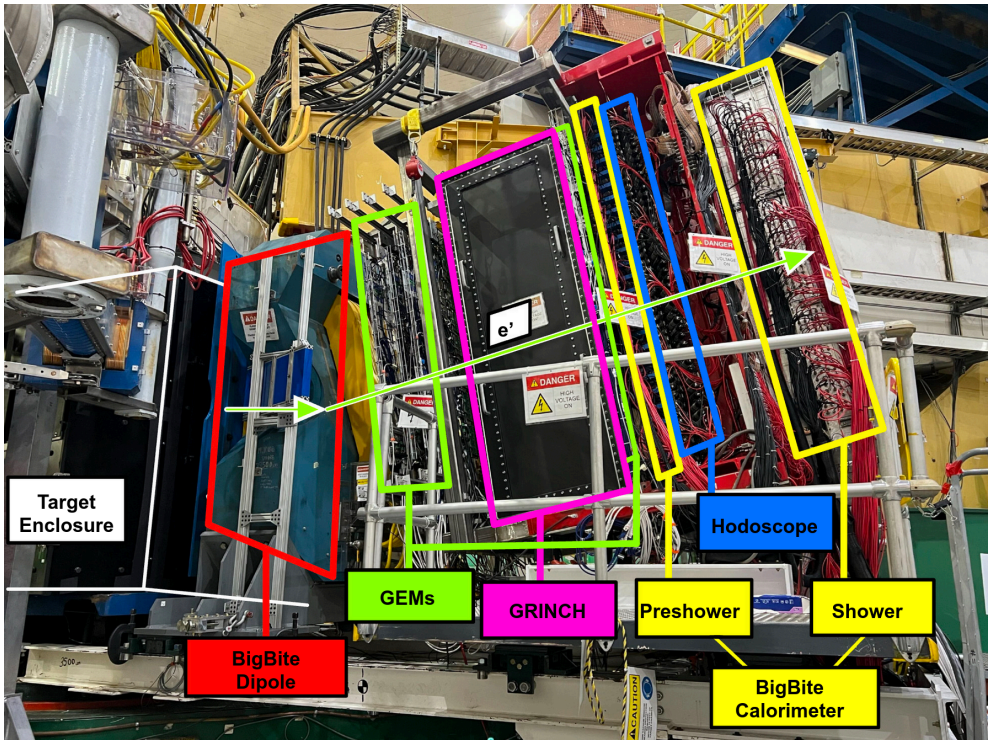
Credit: K Evans

	Q^2 (GeV^2)	E_{beam} (GeV)	I_{beam} (μA)	θ_e(deg)
Kin2	2.93	4.29	45.0	29.5
Kin3	6.79	6.37	45.0	36.5
Kin4	9.78	8.45	45.0	35.0

Jefferson Lab

BigBite Arm & SBS Arm

BigBite Detector Stack



Credit: H. Presley

GEMs - Tracking (on SBS arm as well)

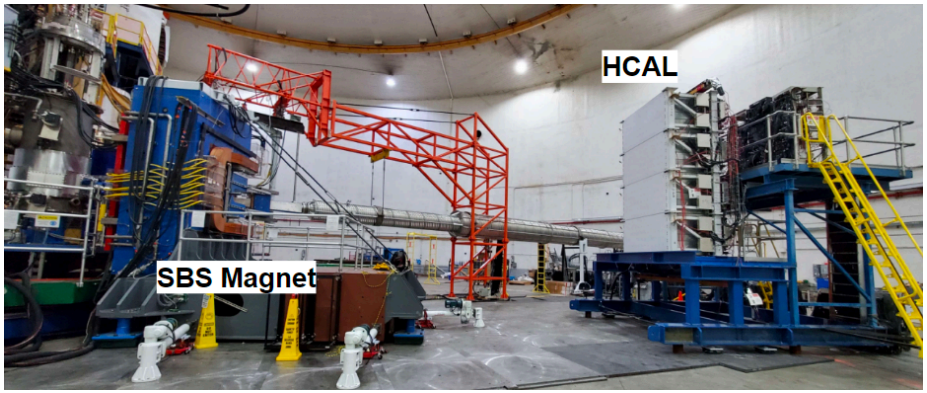
Gas RINg Cherenkov - Particle I.D.

PreShower - PID & Cluster Positioning

Hodoscope - Precise Timing Reference

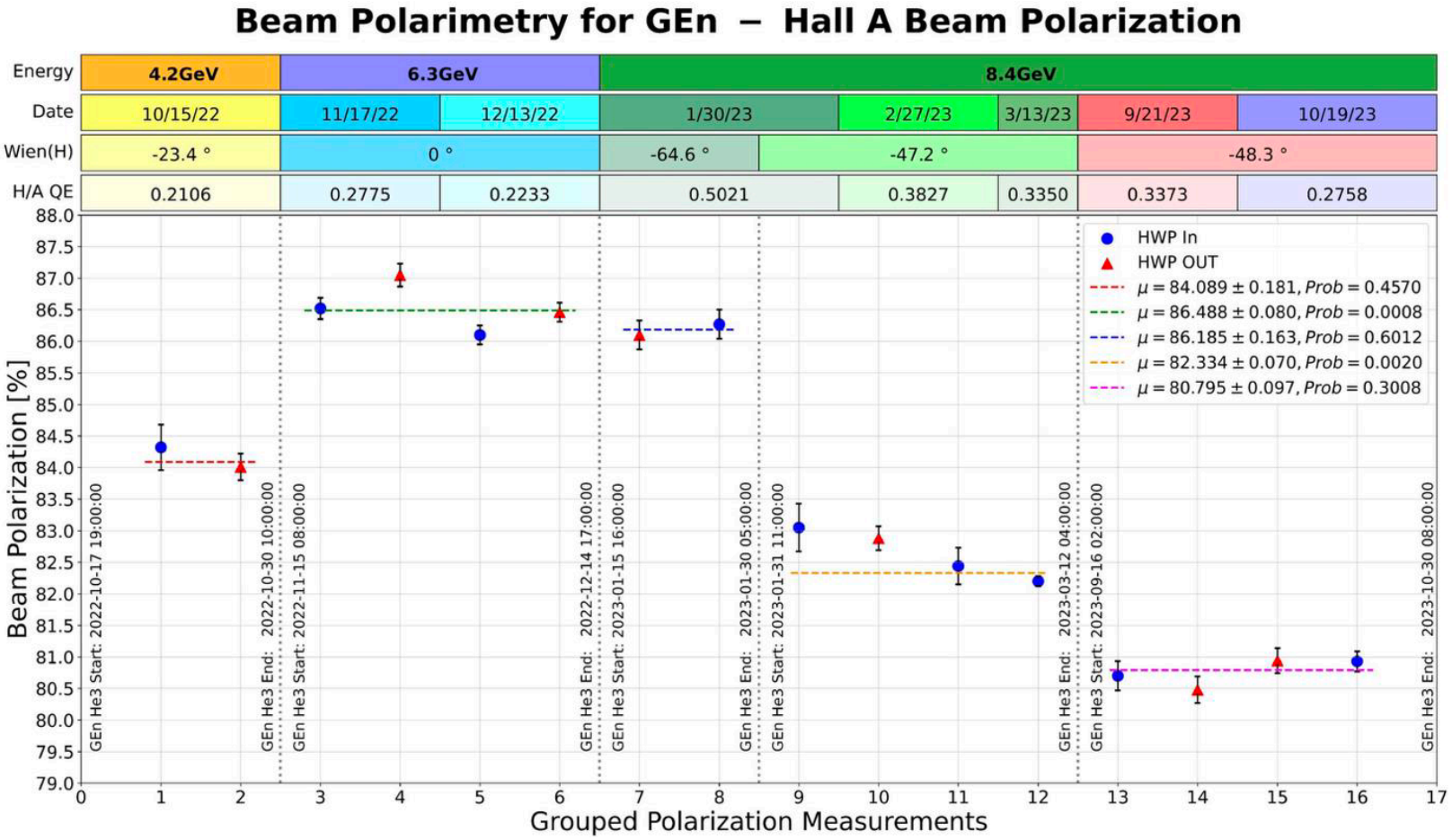
Shower - E_{elec} & Timing of Electron Arm

SBS Magnet & HCal



Credit: H. Presley

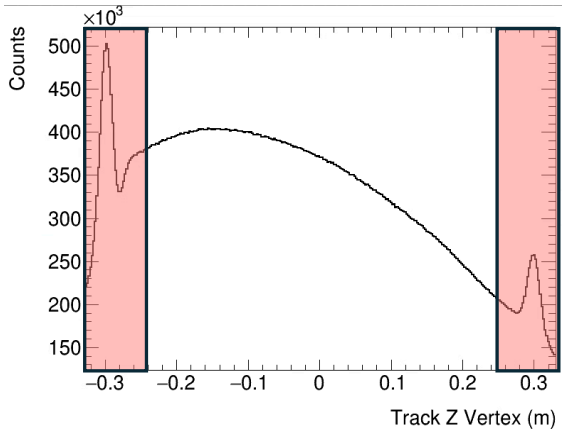
Beam Polarization

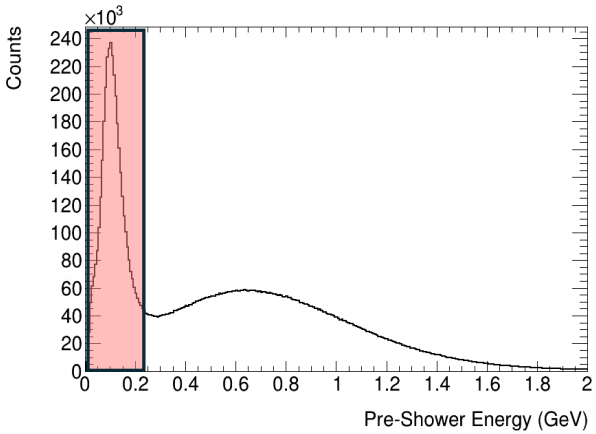


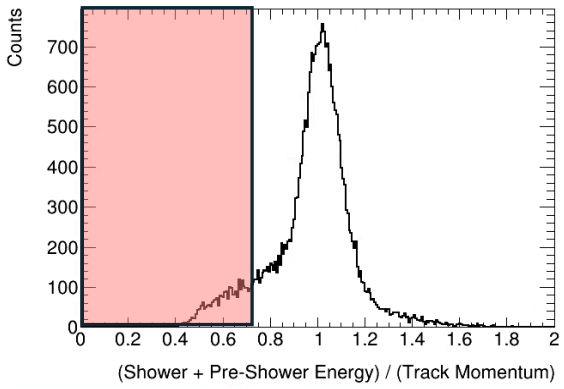
Beam polarization: nearly finalized and incorporated into analysis

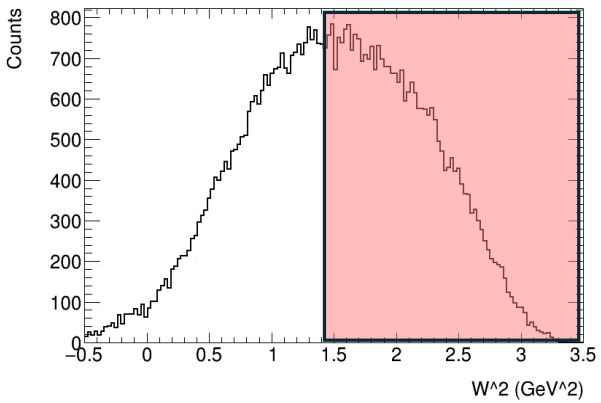
Analysis: Quasi-Elastic Event Selection

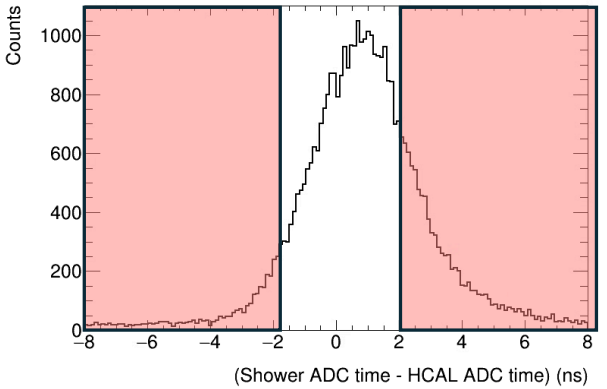
- Track Cuts for target only events
- PSe > 0.2 GeV maximizing pion rejection / electron selection
- E/p cut for Quasi-Elastic (Q.E.) events
- Invariant mass (W^2 cut for Q.E.)
- Coincidence time for removal of accidentals
- HCal Energy (not shown) for background removal











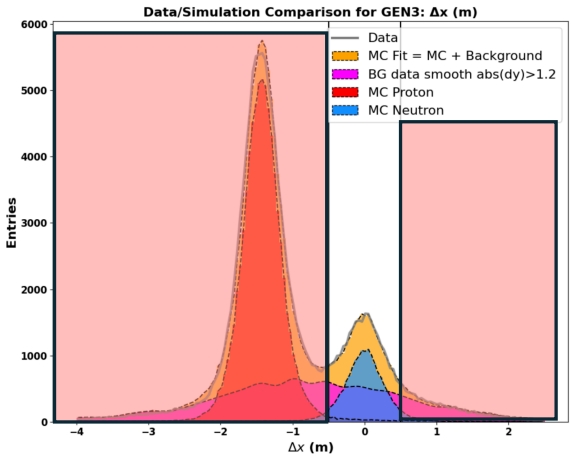
Credit: J. Koenemann (all)

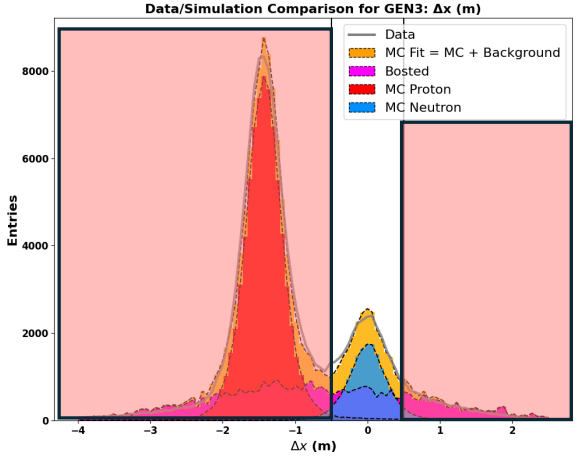
Analysis: Estimating Background

We are still working on estimating neutron yields vs. background.

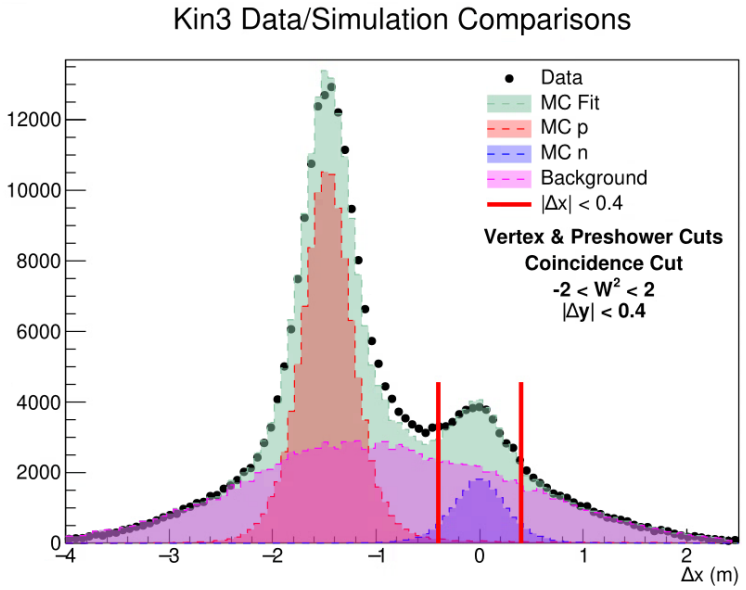
Background Pass 1 - sideband (anti-dy)

Background Pass 2 - looked at inelastic SIM and sideband



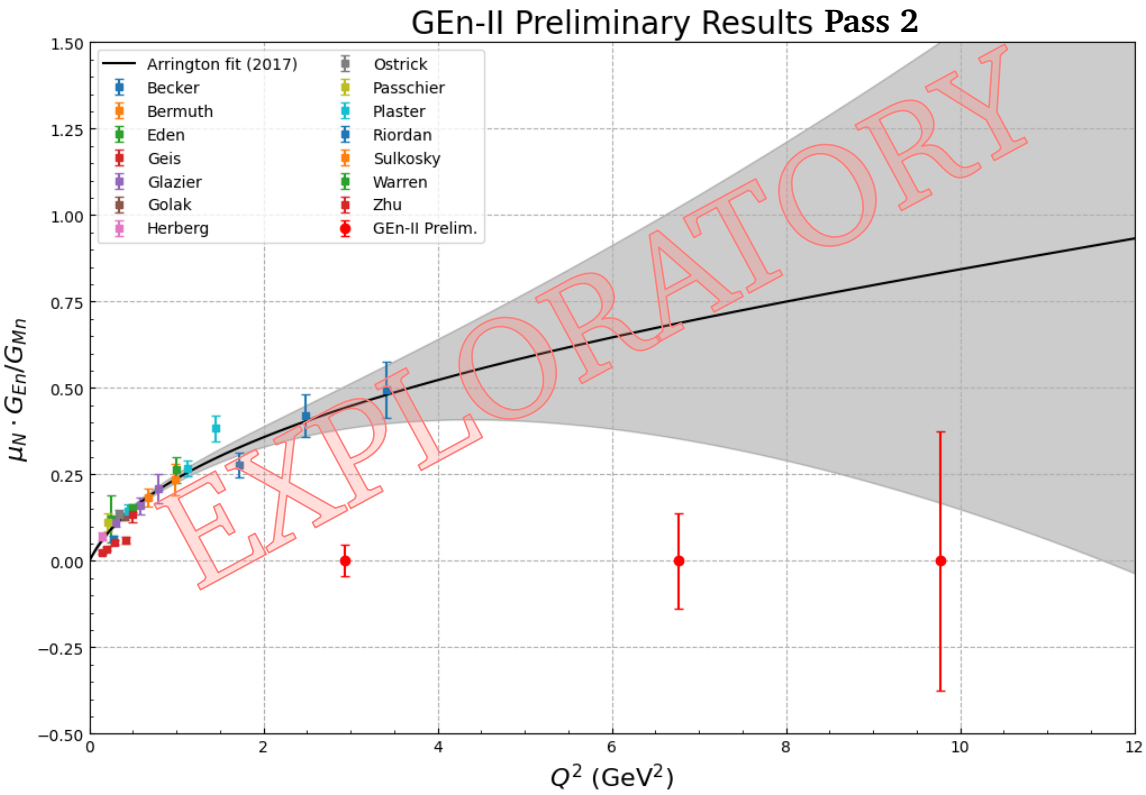


Credit: H. Presley



Credit: S. Jeffas

Exploratory Pass 2 Results



Improvements in Pass 2

- Better coincidence timing
- Improved energy calibrations
  - BB arm & HCAL arm
- Reconstruction efficiency significantly lower for Kin4 (~16.3%)

	Kin2	Kin3	Kin4
Q^2	2.9311	6.7613	9.7784
$\delta\mu_n G_E^n/G_M^n$	±0.0330(stat) ±0.0309(sys)	±0.1321(stat) ±0.0374(sys)	±0.3675(stat) ±0.0692(sys)

Credit: H. Presley's Thesis

Pass 3 Improvements

Nearly implemented:

- BBCAL Energy fine-tuned calibrations
- Coincidence timing improvements

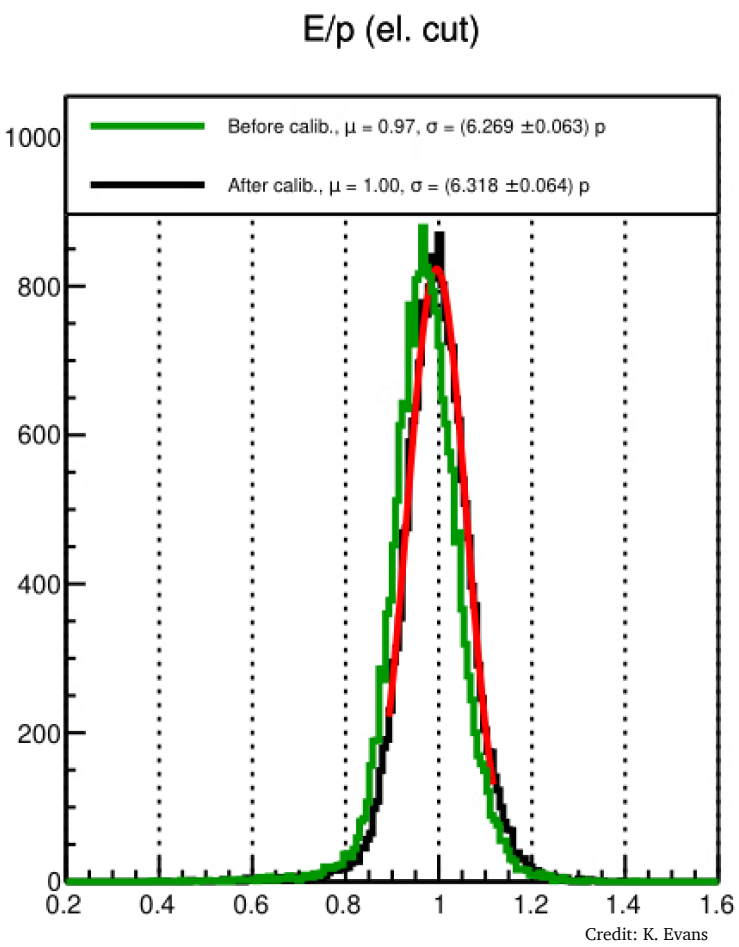
Next up:

- HCAL Energy further calibrations

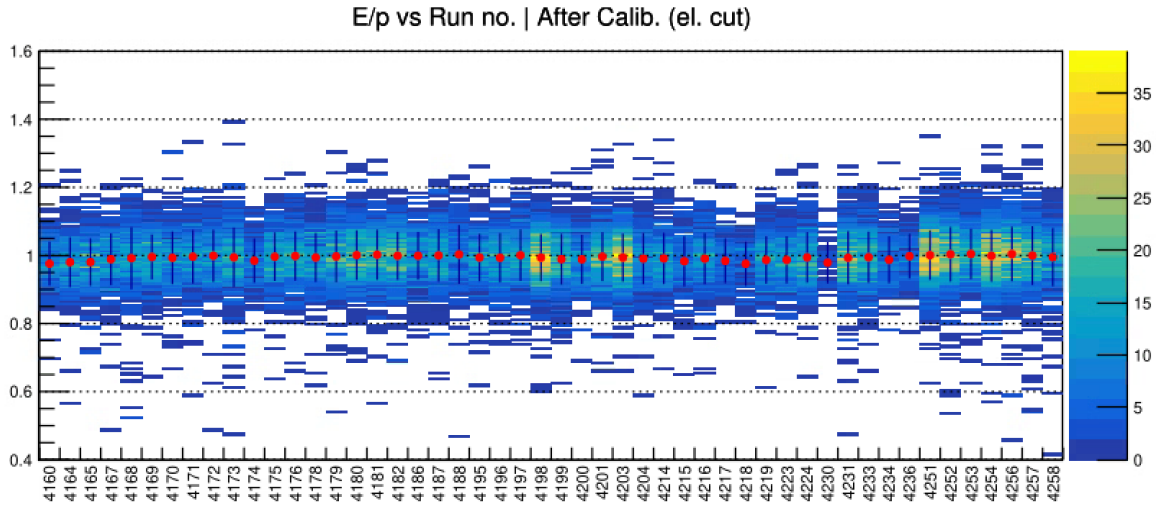
Not critical but ongoing:

- GRINCH timing improvements
- Waveforms in HCal
- Background (Simulation / Estimation)

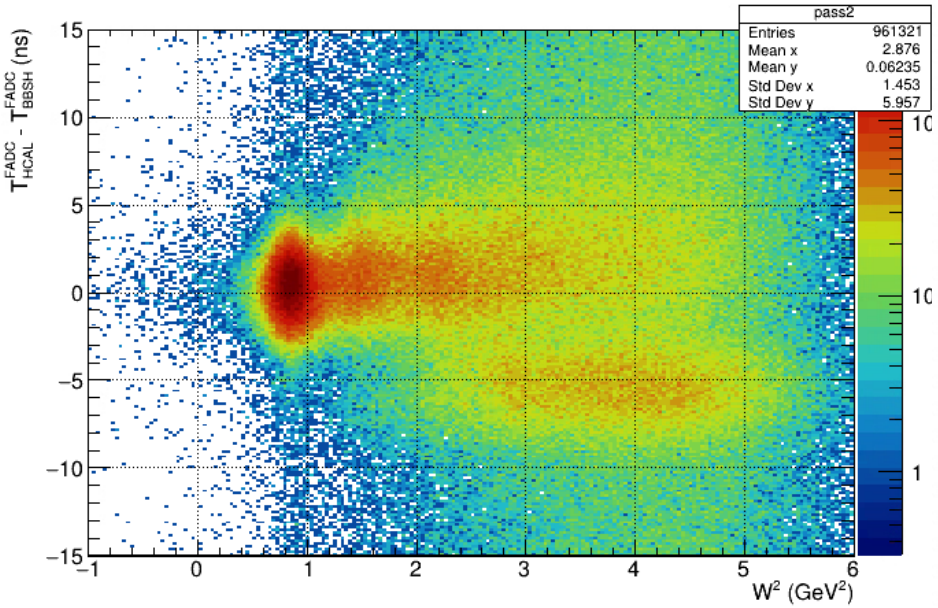
Kin4a Energy Calibrations (Fine Tuning)



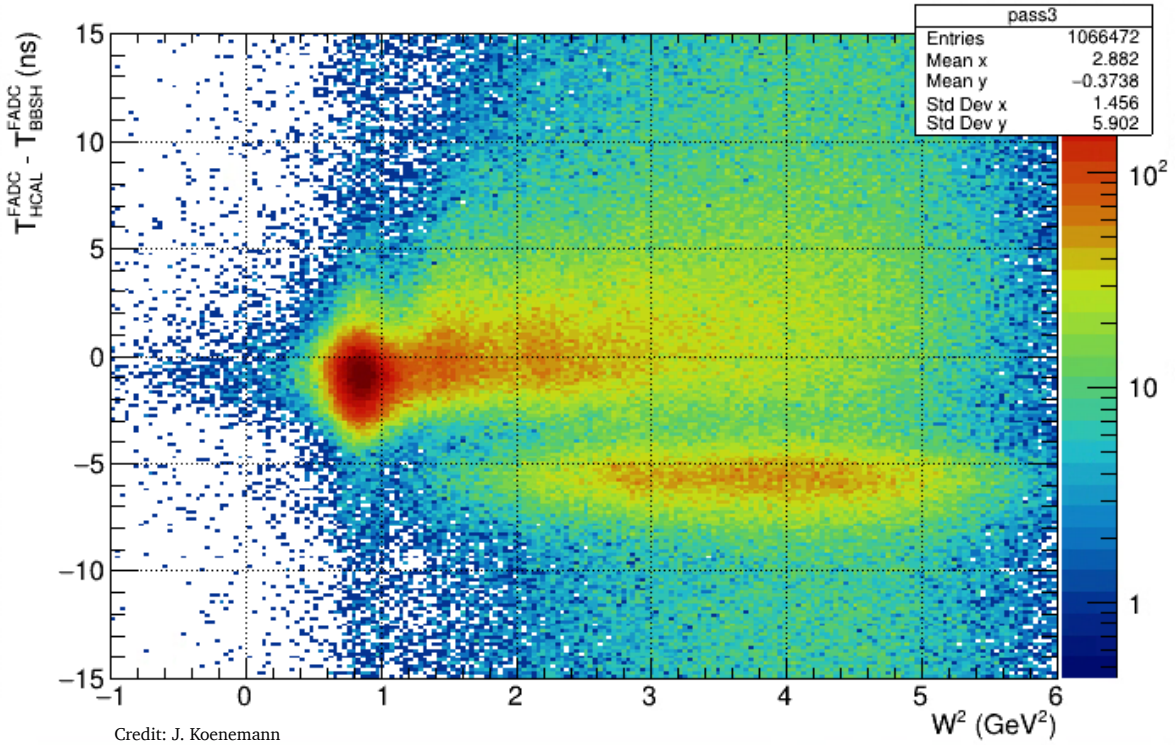
Credit: K. Evans



Coincidence Improvements: W^2 vs. Coincidence Time

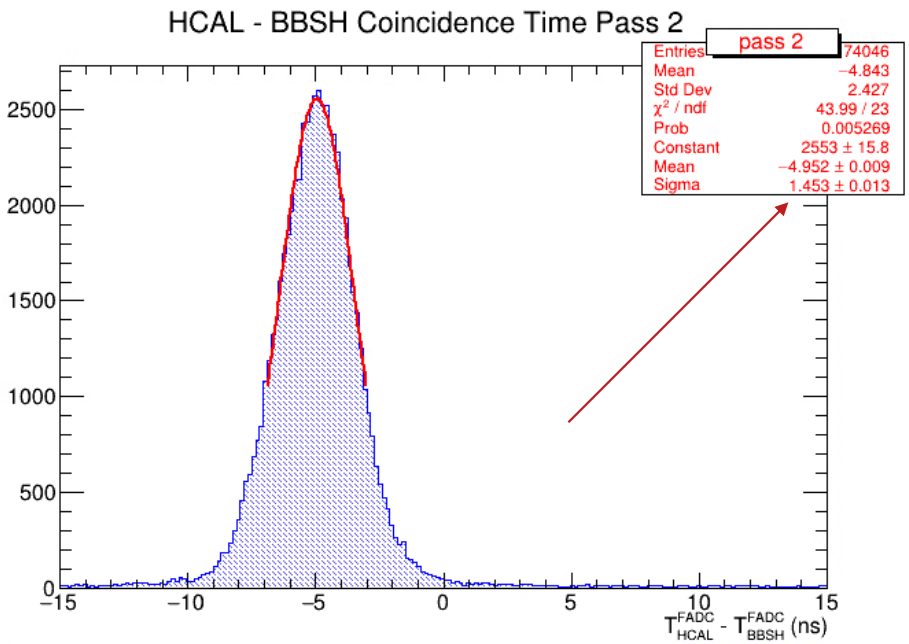


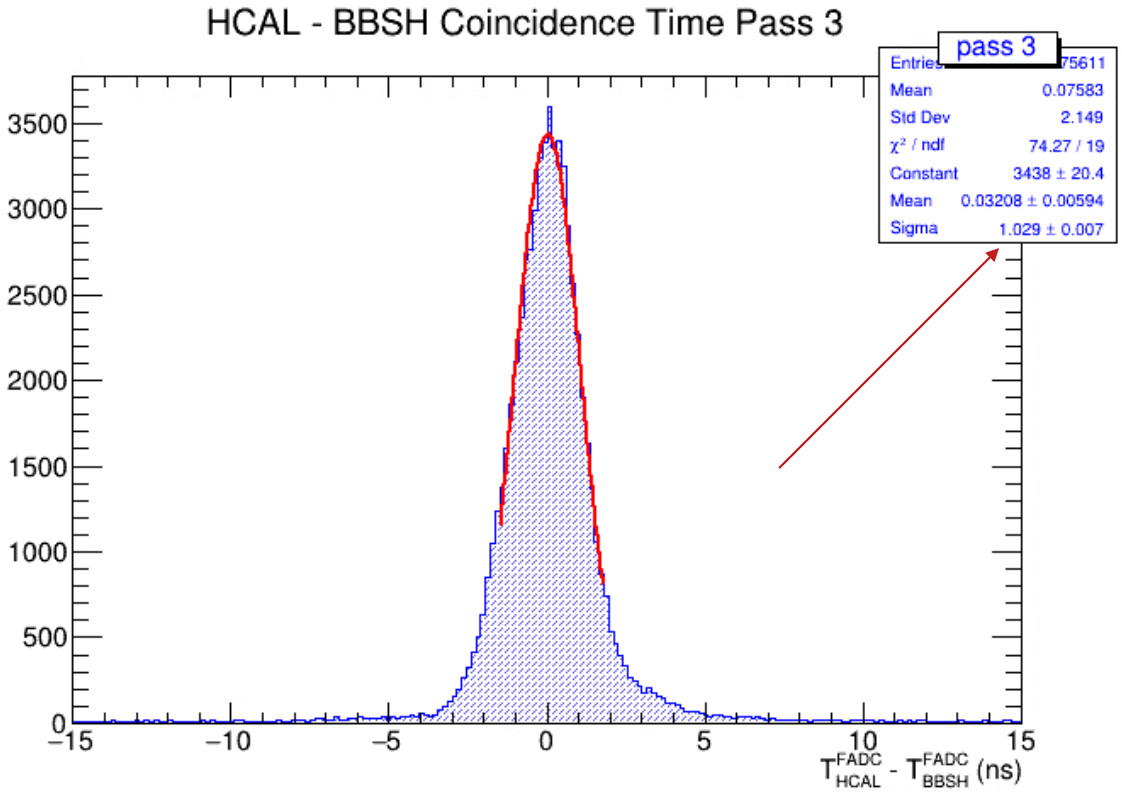
Kin2 (2.93 GeV) ^{2}H data



Credit: J. Koenemann

Coincidence Improvements



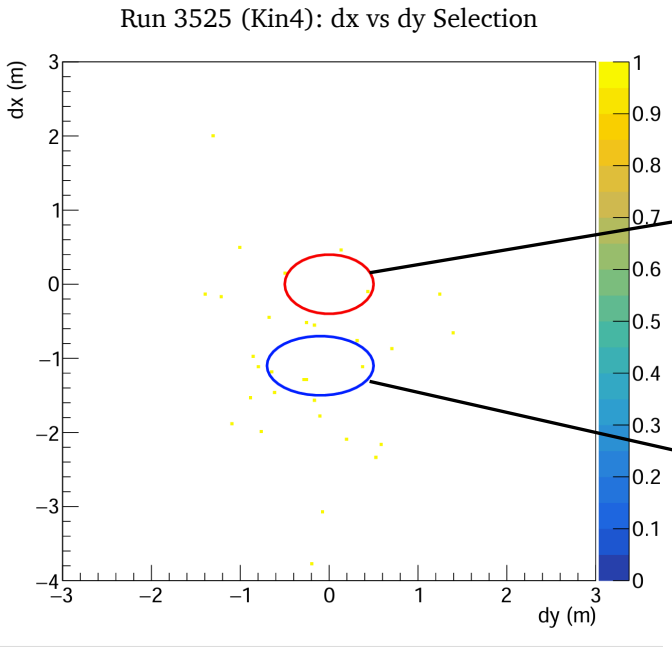


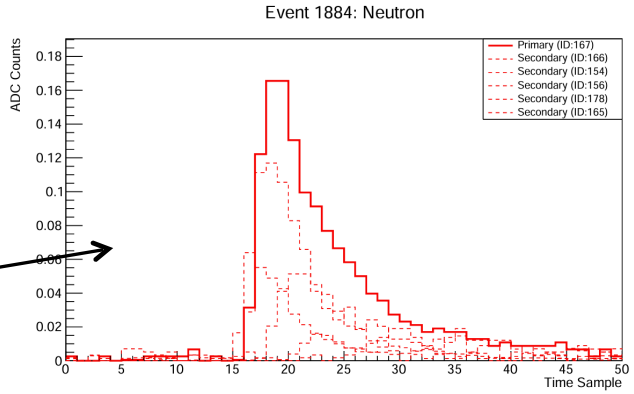
Credit: J. Koenemann

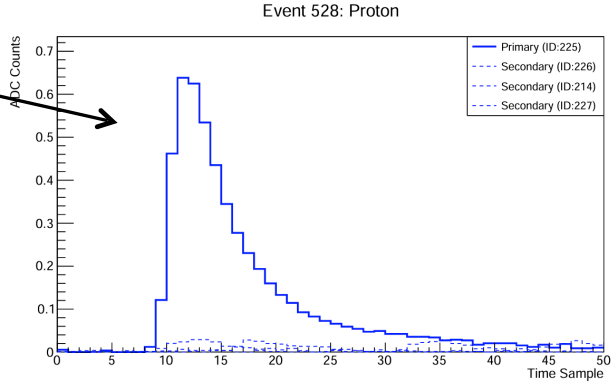
Kin2 (2.93 GeV) ^{2}H data

σ down from 1.453ns to 1.029ns

Waveforms: A Look Ahead







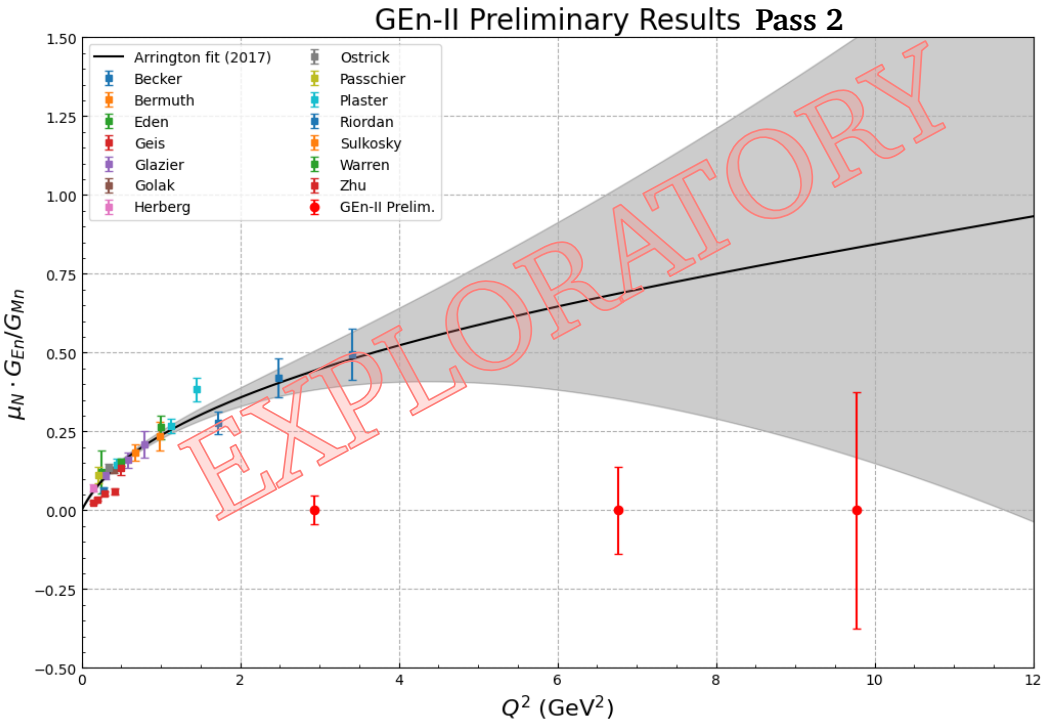
Currently, we are looking at waveforms of events in HCal that have a high probability of being Q.E. neutrons or protons.

This may be another way to boost reconstruction efficiency.

Summary

Nearing Data Replay Pass 3

- Fine-tuned energy calibrations
- Further improved coincidence timing
- Current work on timing of all subsystems
- Raising reconstruction efficiency
- Continue work on Background reduction



Thank You to:

Jack Jackson

cmjackson@wm.edu

Spokespeople:

- Todd Averett
- Gordon Cates
- Bogdan Wojteskhowski

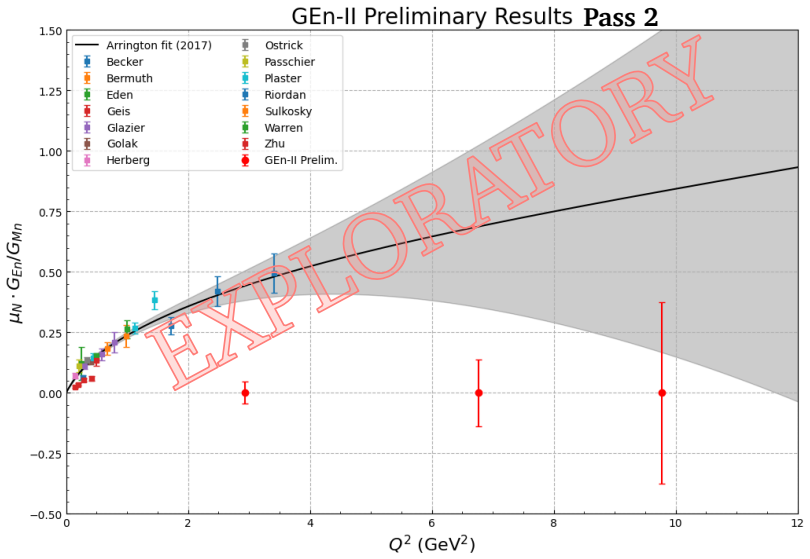
Analysis Leadership:

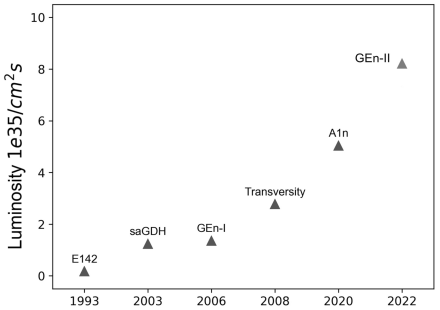
- Andrew Puckett
- Arun Tadepalli

Students:

- Faraz Chahili
- Kate Evans
- Vimukthi Gamage
- Jacob Koenemann
- Braian Mederos
- Sean Jeffas
- Gary Penman
- Hunter Presley

and all others who are involved with analysis





Backup Slides

Backup GEn-II: Electromagnetic Form Factor Ratio G_E^n/G_M^n

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

$$A_{phys} = -\frac{1}{1+\frac{\epsilon}{\tau}\left(\frac{G_E^n}{G_M^n}\right)^2}\left[\left(\frac{G_E^n}{G_M^n}\right)\sqrt{\frac{2\epsilon(1-\epsilon)}{\tau}}P_x + \sqrt{1-\epsilon^2}P_z\right]$$

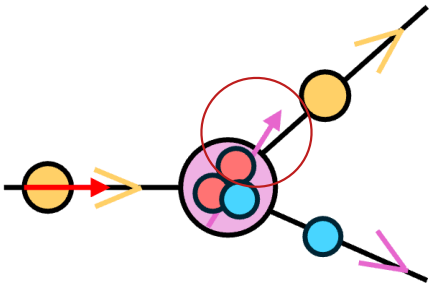
$\epsilon \rightarrow \left(1+2(1+\tau)\tan^2(\theta/2)\right)^{-1}$

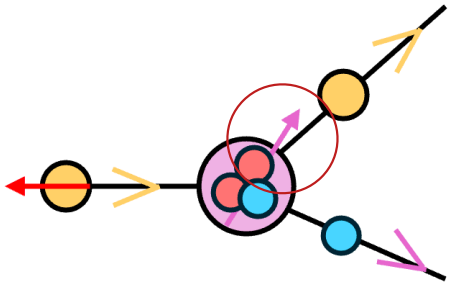
$\tau \rightarrow \frac{Q^2}{4M_N^2}$

$P_x \rightarrow$ target spin component $\perp$ to $\vec{q} \Rightarrow \sin\theta^*\cos\phi^*$

$P_z \rightarrow$ target spin component $\parallel$ to $\vec{q} \Rightarrow \cos\theta^*$

- P_z is more sensitive to the FF ratio, so target polarization is aligned to this direction

$N^+ =$ 

$N^- =$ 

Backup Slide leftover from target slides

Components of the Polarized ^{3}He Target System

- ^{3}He Target Cell
- Oven
- Helmholtz Coils
- Soft Iron Shielding
- RF Coils for NMR & EPR
- Target Ladder
- Optics Foils
- Reference Cell
- Cooling Jets
- Laser System & Optics

Backup Target Avg. Pol & Lum.

- Finished

	Cell Name	Max Polarization	Average Polarization	Average Luminosity 1e35/cm^2s	Duration Installed
Kinematic 2	Hunter	42.22%	35.54%	**4.97**	20 days
Kinematic 3	Windmill	48.61%	43.74%	**8.34**	14 days
	Hunter	44.16%	39.32	**5.82**	24 days
Kinematic 4	Fringe	61.59%	55.14%	**10.26**	60 days
	Chicago	41.18%	38.92%	**4.72**	12 days
	Donya	45.56%	35.21%	**4.21**	31 days
	Christin	51.20%	36.70%	**5.40**	20 days

Backup: BB Pass 2 to Pass 3

BBCal energy calibration improvements:

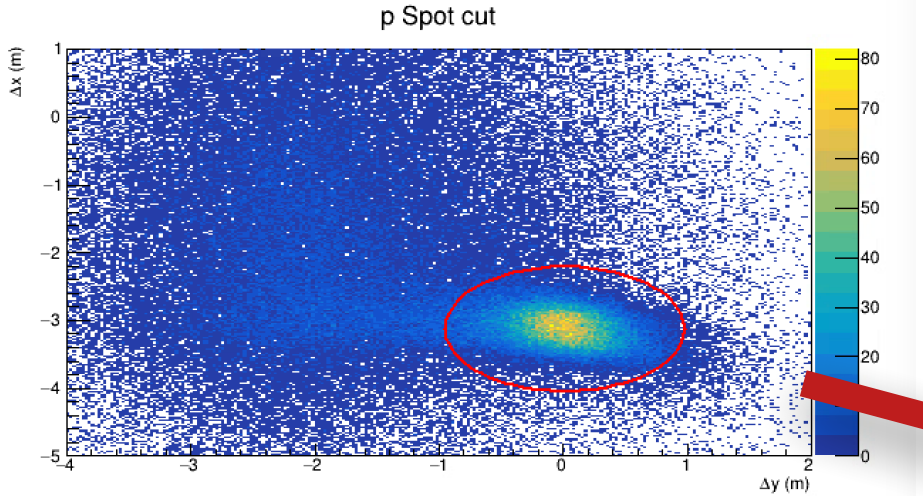
- Tighter Proton spot cuts on H2 data (Kin2 and Kin3)
- Loose Proton spot cuts on He3 data due to backgrounds (Kin4)
- More refined optics validity cuts
- DB fixes to improve Kin4

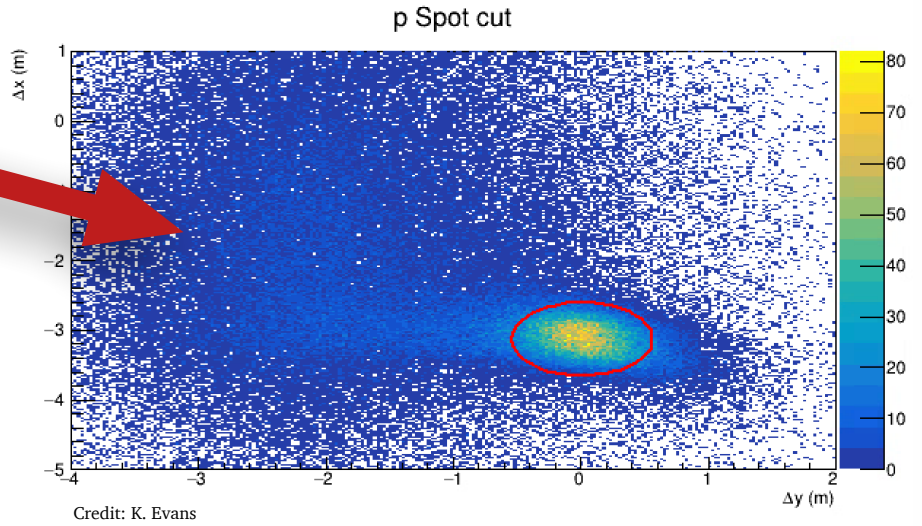
These improvements help to select “good electrons” for higher quality calibration results

Backup: BB Examples of Fine Tuning BigBite

Kin2

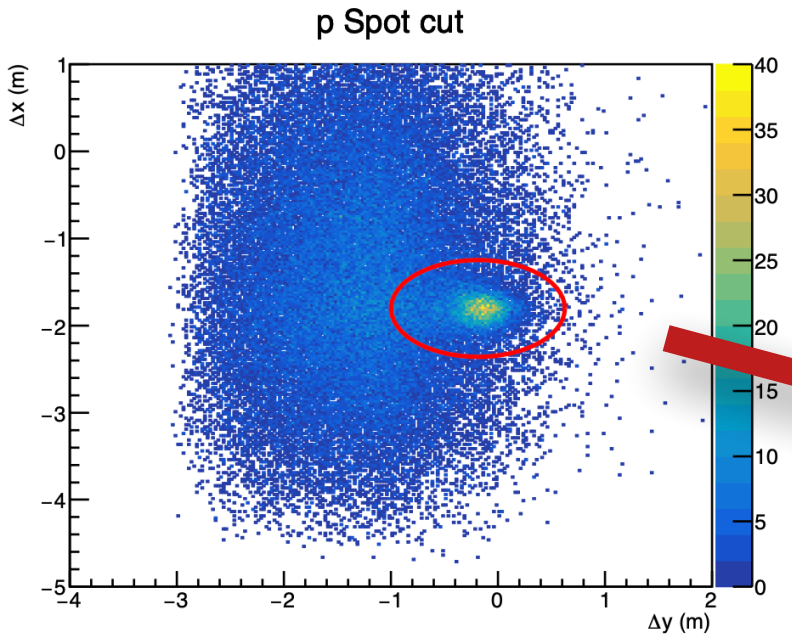
Tighter Proton spot cut





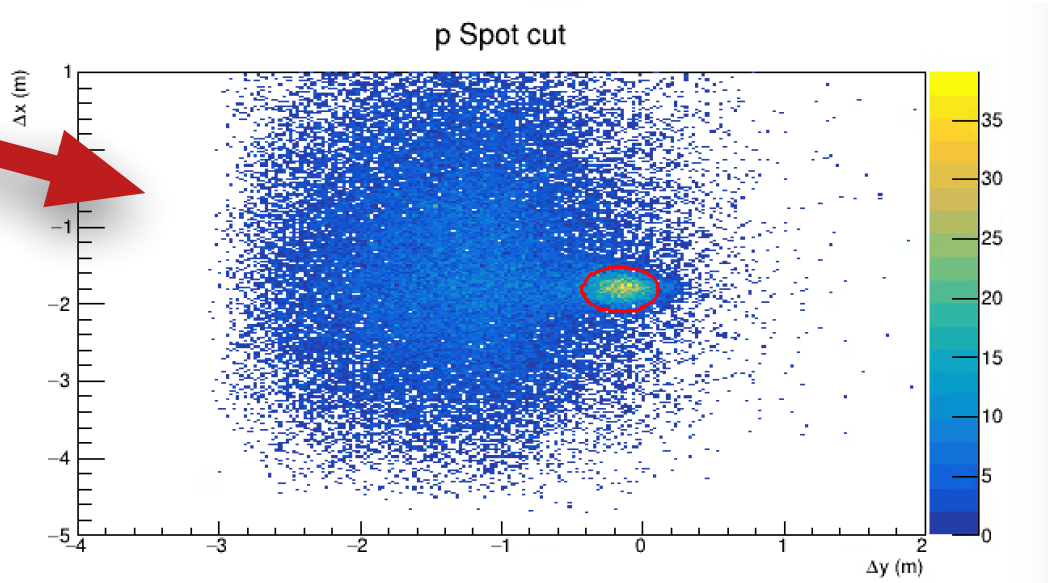
Credit: K. Evans

BB Backup Slide

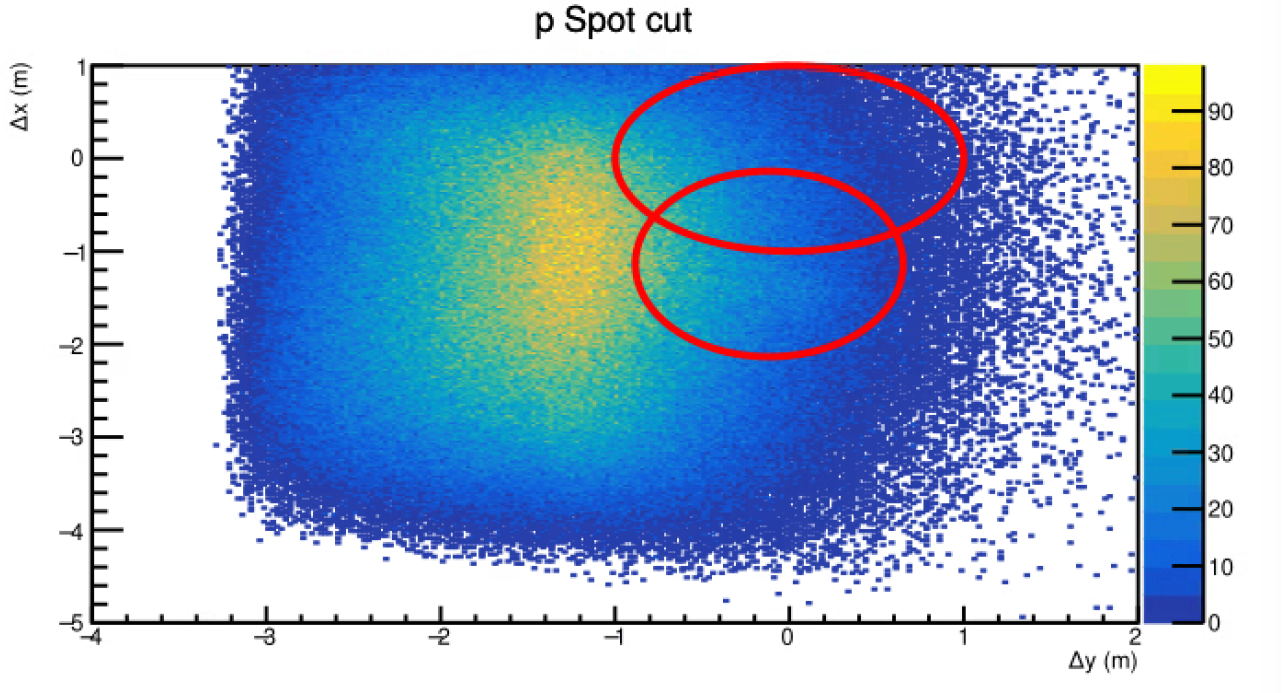


Kin3

Tighter spot cut



BB Backup Slide

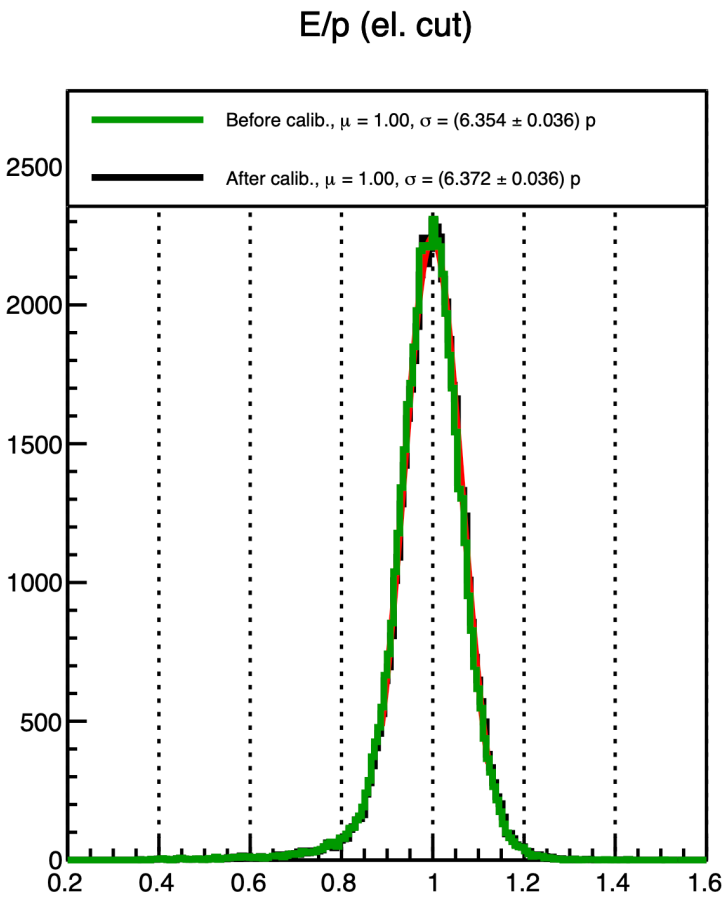


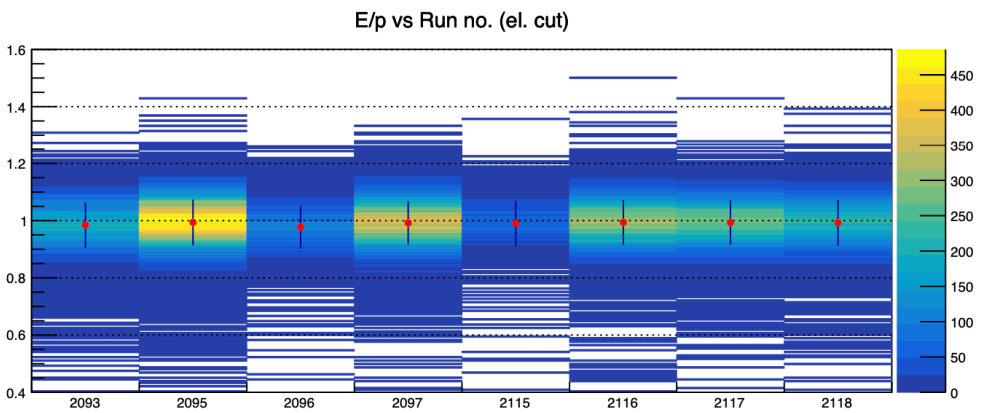
Kin4

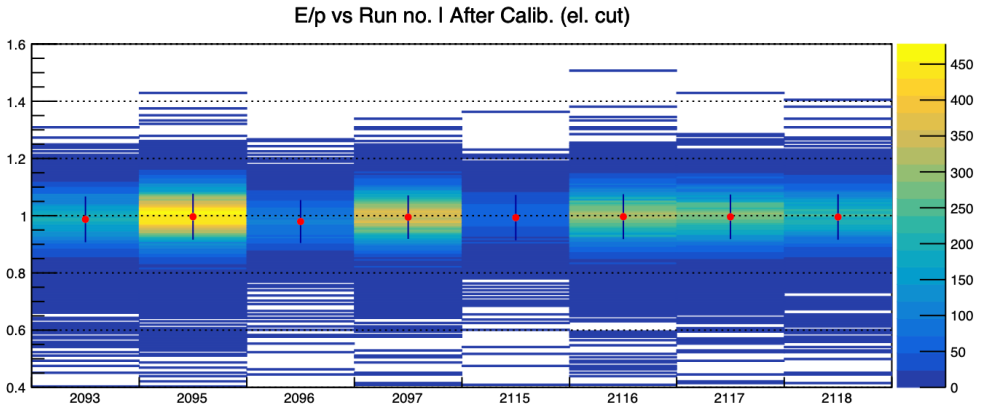
Loose spot cut

Washed in background

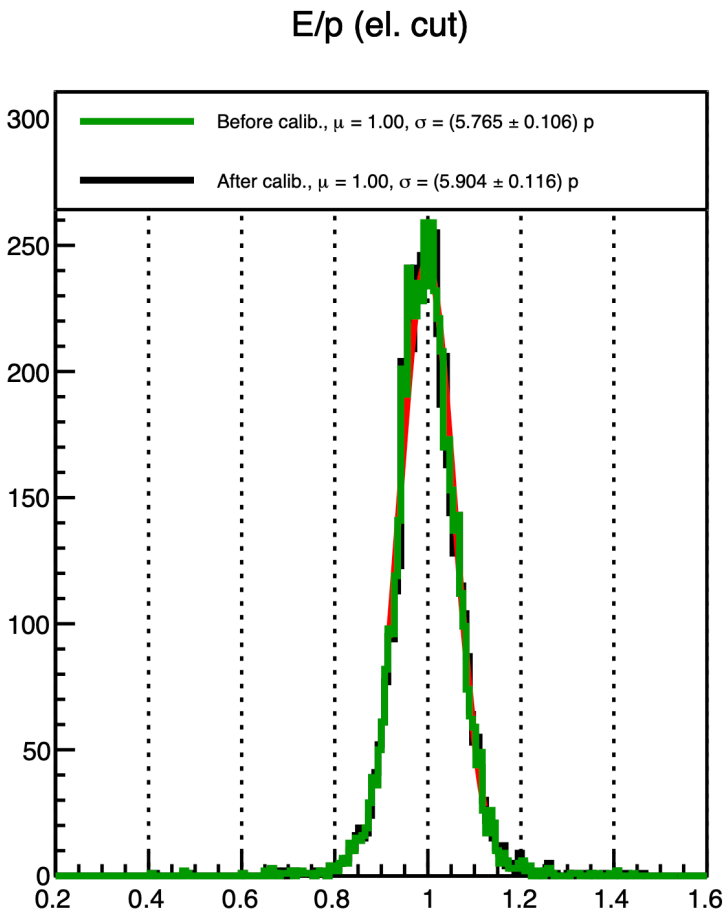
Kin2 Energy Calibrations

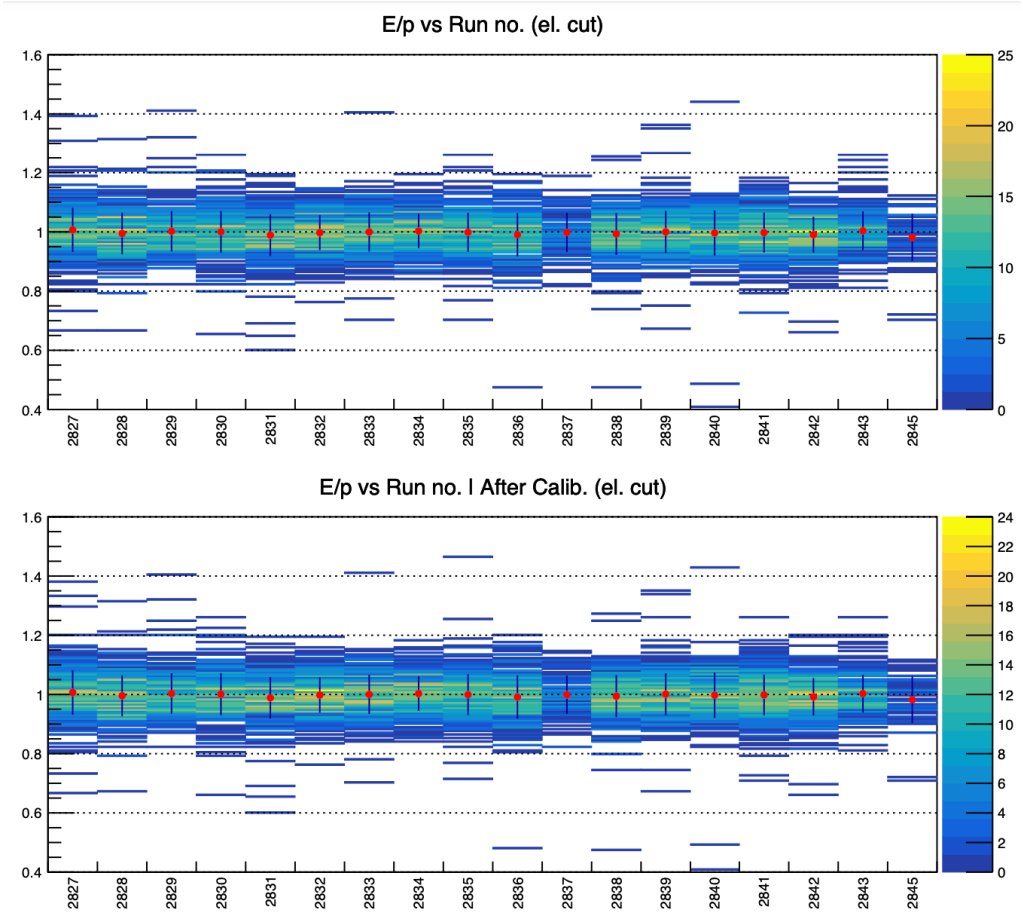




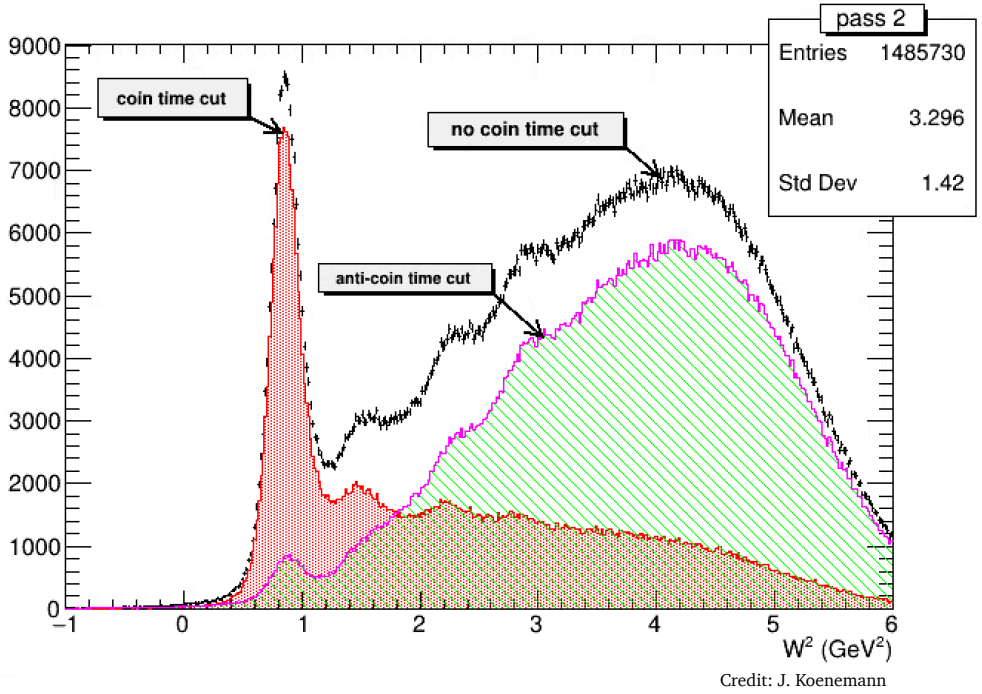


Kin3 Energy Calibrations

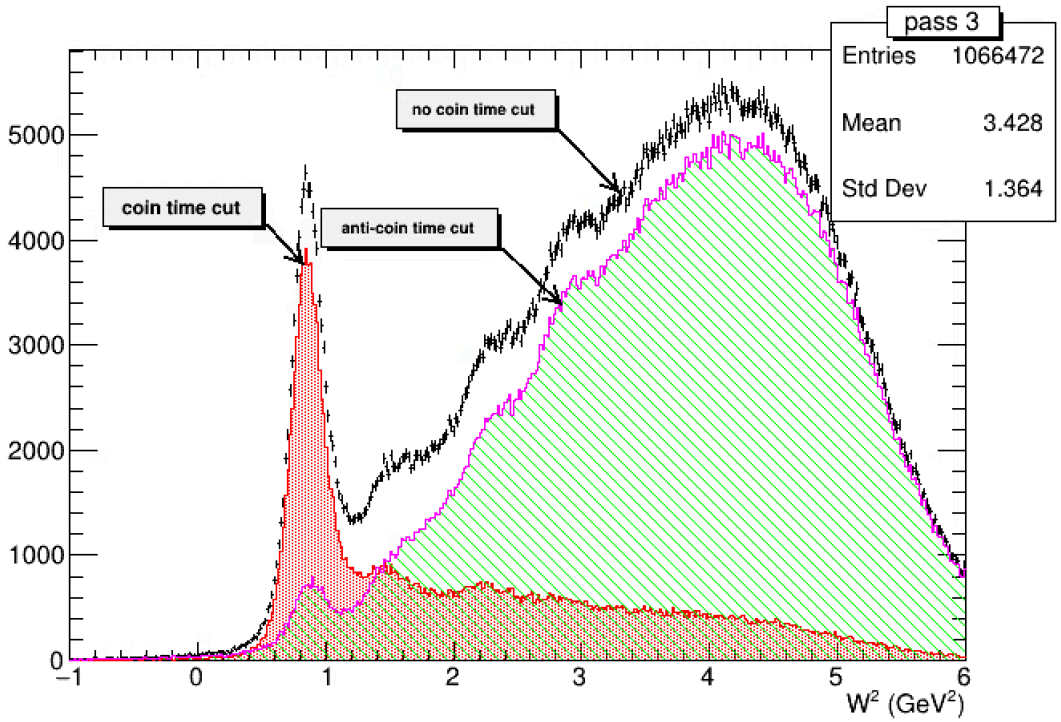




Backup: Coincidence Improvements



Credit: J. Koenemann



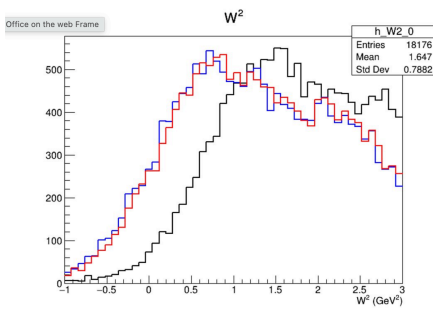
Kin2 ^{2}H data with 3σ cut

Pass 3 only includes the production settings. Pass 2 includes some calibration runs.

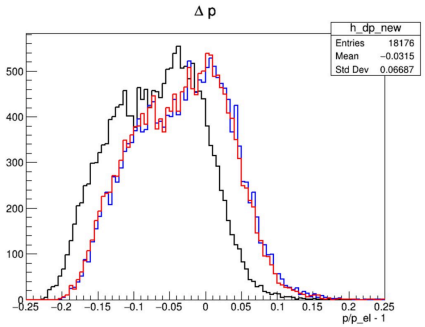
Backup Optics & Momentum Coefficients

Split in GEN4a & 4b (aka Kin4a & Kin4b) should have the same distributions but did not. Now fixed

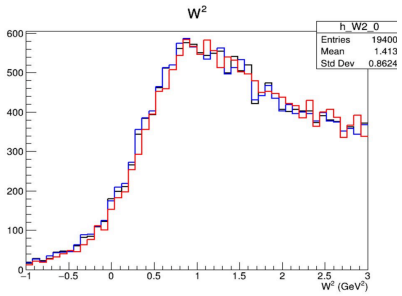
- **Blue was Pass 1**
- **Black was Pass 2**
- **Red is Pass 3**



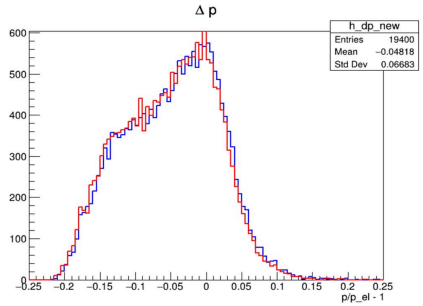
GEN4 ^{3}He W^2 distribution



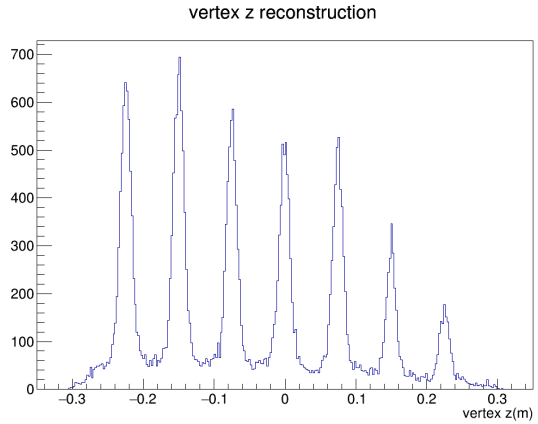
GEN4 ^{3}He delta-p distribution



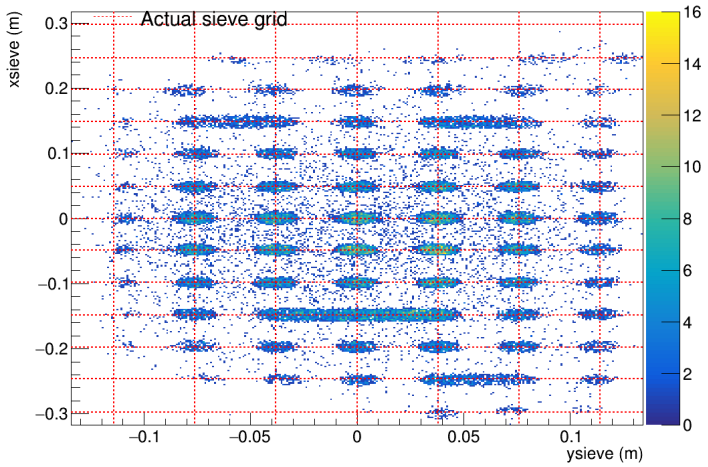
GEN4b ^{3}He W^2 distribution



GEN4b ^{3}He delta-p distribution



2D Sieve Pattern with Actual Grid



Jefferson Lab