The BigBite Calorimeter (BBCal) for GMn, GEn-II, and GEn-RP

Kate Evans

SBS Collaboration Meeting

March 4th, 2026

BBCal Paper Submitted to NIM!

The BigBite Calorimeter for the Super Bigbite Spectrometer Program at Jefferson Lab

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Paper has been submitted for publication.

2 reviewers have accepted – waiting for comments.

Draft of paper is up on arXiv and JLab STI publications portal.

First SBS subsystem paper to be written!

Thank you to everyone in the collaboration who provided support and feedback!

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NIM Status

Peer review status

The BigBite Calorimeter for the Super Bigbite Spectrometer Program at Jefferson Lab

- Reviews completed: 0
- Review invitations accepted: 2
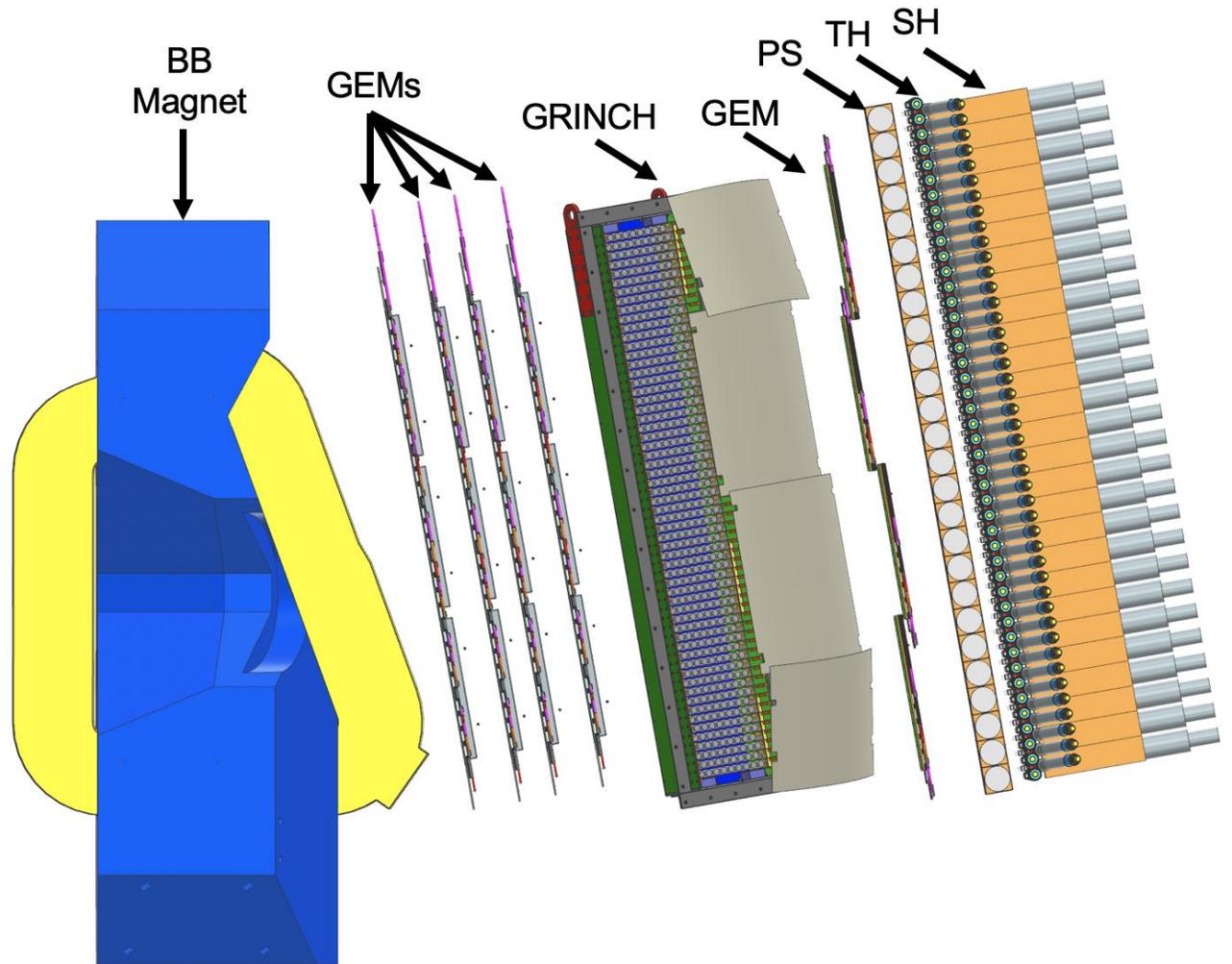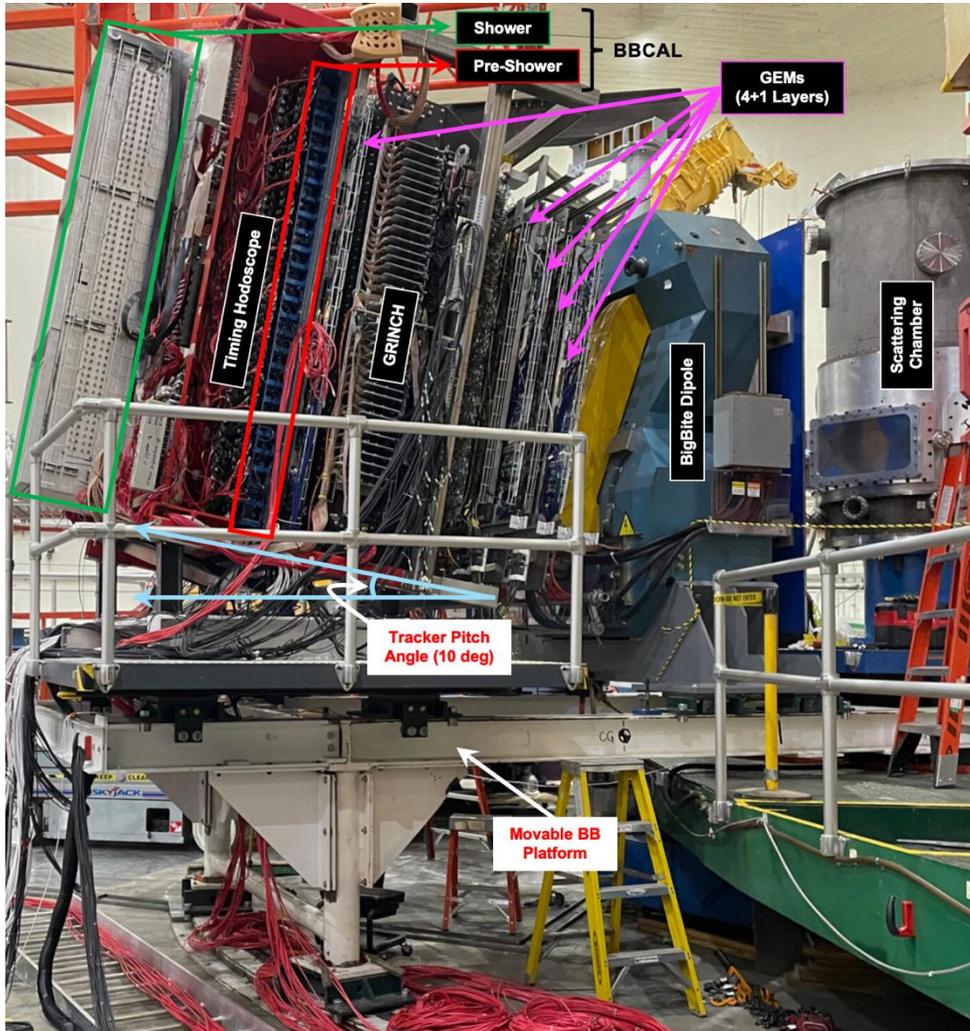- Review invitations sent: 2+

Under Review

Last review activity: 16th February 2026 ⓘ

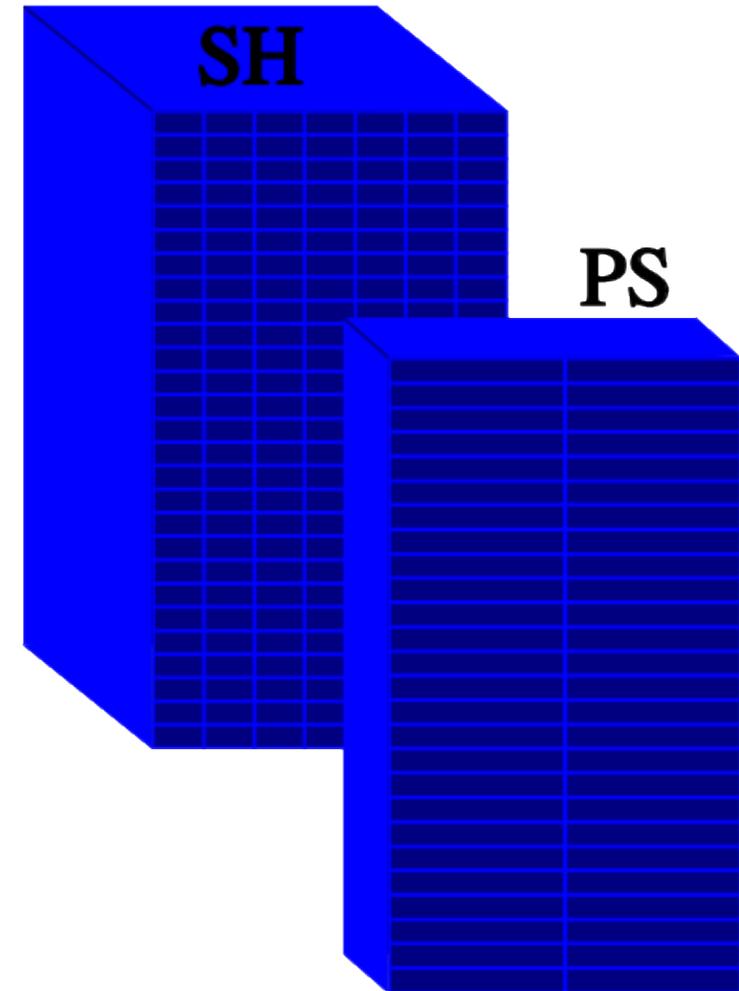Watch to learn what we're doing behind the scenes ↗

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Detector Overview

# BigBite Spectrometer Stack

BBCal Basics

- Lead-glass electromagnetic calorimeter
  - High energy electrons shower through the lead-glass, producing light that is measured by PMTs
- Composed of two layers: **preshower** (PS) and **shower** (SH)
- Main purposes:
  1. Act as main experiment trigger (need good time resolution)
  2. Measure total scattered electron energy
  3. Differentiate incoming pions and electrons
  4. Define region-of-interest for GEM tracking algorithm

Preshower Layer
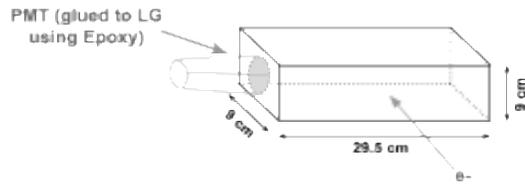
Mean = 89.0 (1) MeV, σ = 21.0 (1) MeV

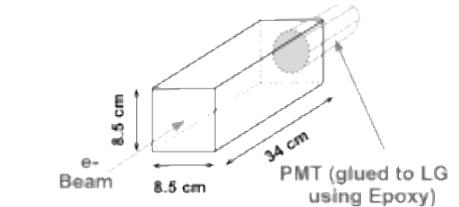Legend: MIP peak / Fit / $E_{PS} > 0.20$ GeV

E_{PS} (GeV)
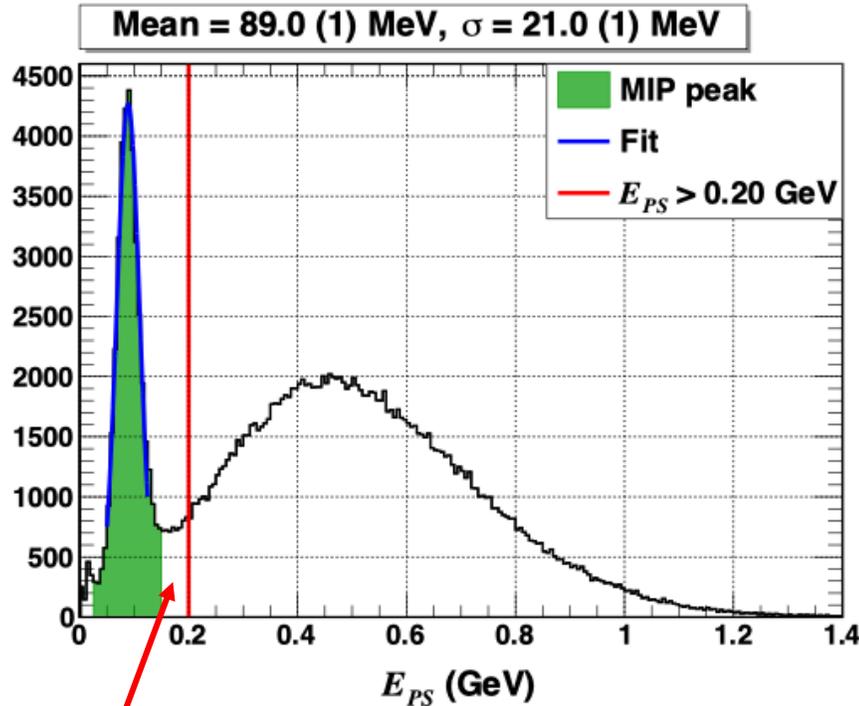
Simple cut on PS energy allows for easy background reduction in analysis.

- 26 rows, 2 columns
- Particles traverse $3\chi_0$
  - Initiate electron shower
  - Increase electron signal above MIP signal
  - Low probability for charged pions to create large signal
- Pion signature is readily identifiable in energy distribution

Shower Layer

- 27 rows, 7 columns
- Particles traverse $14\chi_0$
  - Combined with the PS, the scattered electrons fully deposit their energy within BBCal
- PS and SH both have mu-metal sheets between rows to shield against stray magnetic fields

$$PS + SH = 17\chi_0$$

Lead-glass blocks are attached to PMTs

PMTs read out to FE electronics

BBCal on the Floor

BBCal Front End Electronics

PS signals sent to a 10x amplifier, then:

1. One signal copy sent to fADC250

2. Other signal copy sent to a splitter, then 5x amplifier, then a LFI/O module to create the trigger sums

SH signals sent to a summer/amplifier module, then:

1. One signal copy was 5x amplified then sent to fADC250

2. Other signal copy sent to a 3.5x amplifier then sent to the trigger sums
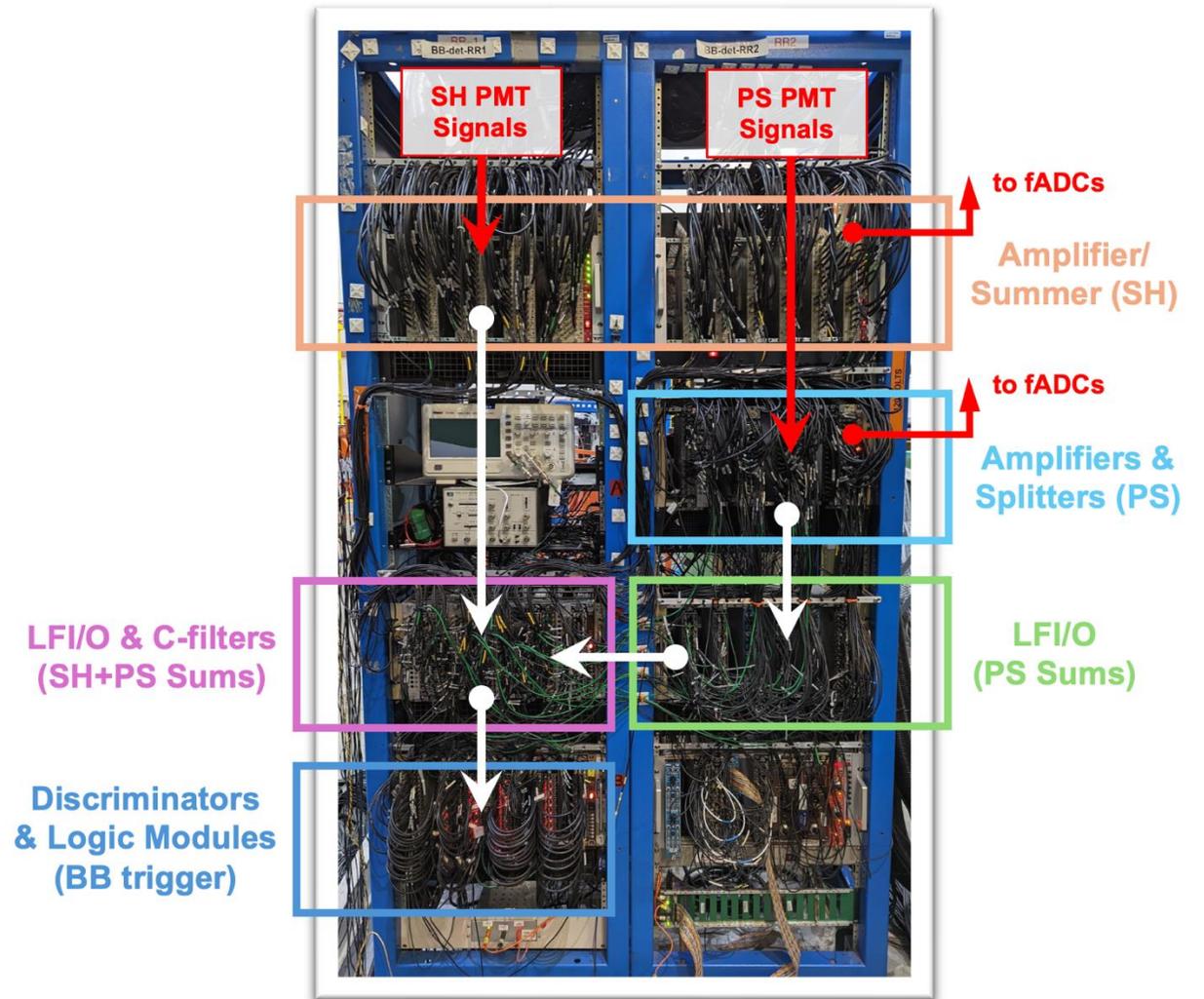
Trigger Sums

Trigger Sums	Associated SH & PS Rows
SC 1-2	SH-1 + SH-2 + PS-1 + PS-2
SC 2-3	SH-2 + SH-3 + PS-2 + PS-3
SC 3-4	SH-3 + SH-4 + PS-3 + PS-4
SC 4-5	SH-4 + SH-5 + PS-4 + PS-5
SC 5-6	SH-5 + SH-6 + PS-5 + PS-6
SC 6-7	SH-6 + SH-7 + PS-6 + PS-7
SC 7-8	SH-7 + SH-8 + PS-7 + PS-8
SC 8-9	SH-8 + SH-9 + SH-10 + PS-8 + PS-9
SC 9-10	SH-9 + SH-10 + SH-11 + PS-9 + PS-10
SC 10-11	SH-10 + SH-11 + SH-12 + PS-10 + PS-11
SC 11-12	SH-11 + SH-12 + SH-13 + PS-11 + PS-12
SC 12-13	SH-12 + SH-13 + SH-14 + PS-12 + PS-13
SC 13-14	SH-13 + SH-14 + SH-15 + PS-13 + PS-14
SC 14-15	SH-14 + SH-15 + SH-16 + PS-14 + PS-15
SC 15-16	SH-15 + SH-16 + SH-17 + PS-15 + PS-16
SC 16-17	SH-16 + SH-17 + SH-18 + PS-16 + PS-17
SC 17-18	SH-17 + SH-18 + SH-19 + PS-17 + PS-18
SC 18-19	SH-18 + SH-19 + SH-20 + PS-18 + PS-19
SC 19-20	SH-20 + SH-21 + PS-19 + PS-20
SC 20-21	SH-21 + SH-22 + PS-20 + PS-21
SC 21-22	SH-22 + SH-23 + PS-21 + PS-22
SC 22-23	SH-23 + SH-24 + PS-22 + PS-23
SC 23-24	SH-24 + SH-25 + PS-23 + PS-24
SC 24-25	SH-25 + SH-26 + PS-24 + PS-25
SC 25-26	SH-26 + SH-27 + PS-25 + PS-26
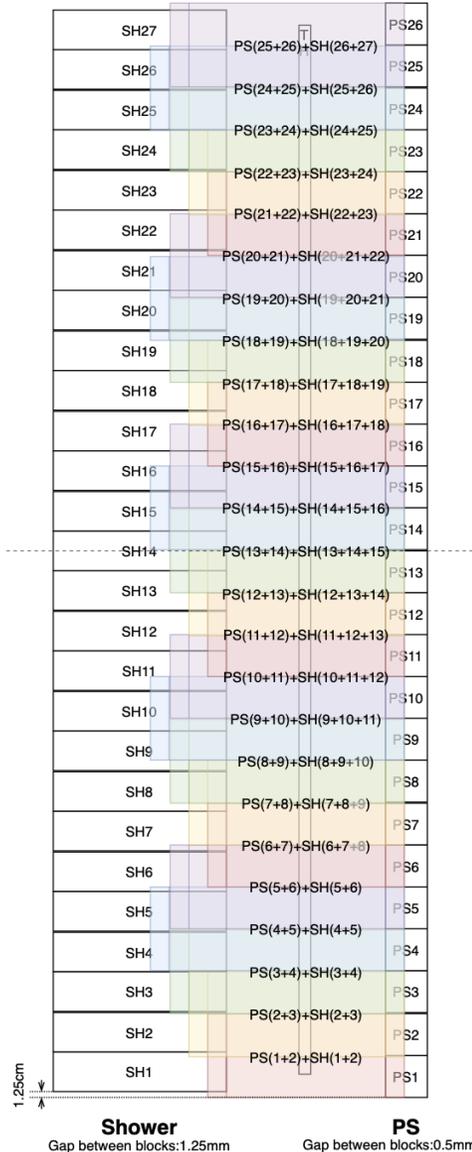
- PS and SH signals combined into 25 trigger sums within the LFI/O modules
- Trigger sums are used to create the experiment trigger
- Organized to focus on main region of acceptance and account for different number of rows in PS and SH

Threshold Determination

Threshold value was set to record scattered electrons above a certain energy -- helps keep DAQ rate reasonable.

Must convert energy in MeV to threshold setting in mV using:

$$Th_{CF} = C \times A_{Trig}$$

- Th_{CF} is the threshold conversion factor in units of mV/MeV
- C is a constant in units of MeV^{-1}
- A_{Trig} is the signal amplitude at trigger level in units of mV after cosmic calibrations

An upper bound on A_{Trig} was established during calibrations based on our electronics.

Central E_e' (GeV)	Minimum E_e' (GeV)	Maximum E_e' (GeV)	Q^2 (GeV/c)^2	E_{beam} (GeV)	Th_{CF} (mV/MeV)
1.6	1.43	1.86	4.5	4.0	0.44
2.0	1.75	2.31	7.4	6.0	0.35
2.1	1.88	2.39	3.0	3.7	0.35
2.7	2.27	3.15	9.9	7.9	0.26
2.7	2.29	3.25	13.6	9.9	0.26
3.6	3.09	4.14	4.5	6.0	0.18

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Signal Amplitude Mapping

- There was a discrepancy between signals at the trigger level and at fADCs

- A mapping was made for each channel to account for variation in the summer/amplifiers
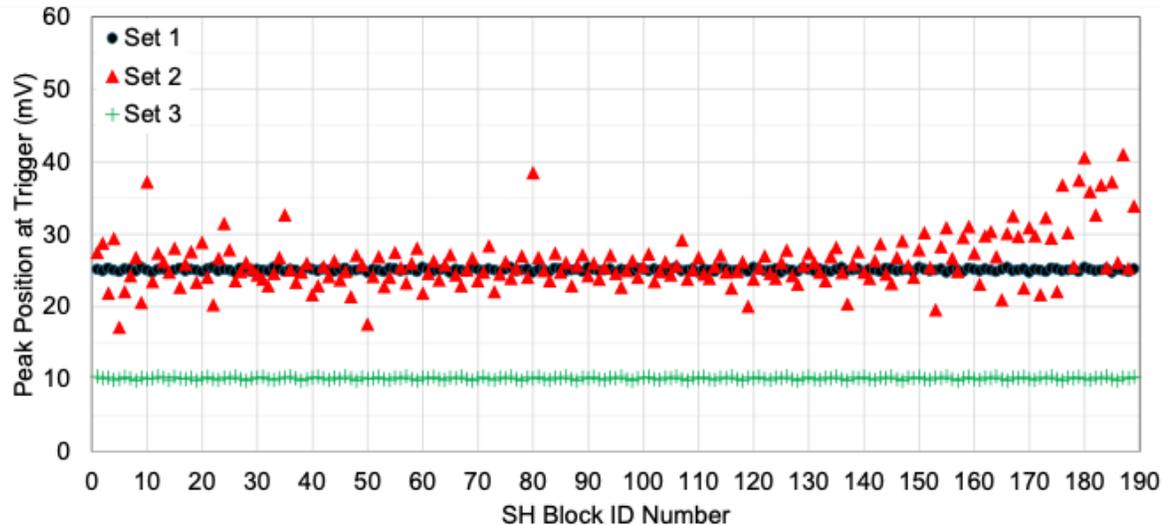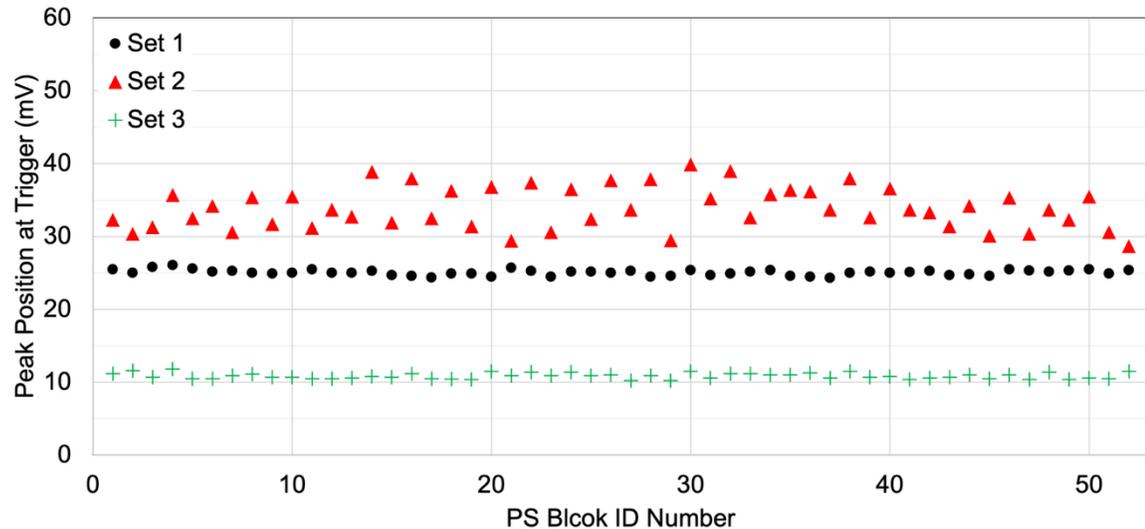
- Match signal amplitudes at trigger level
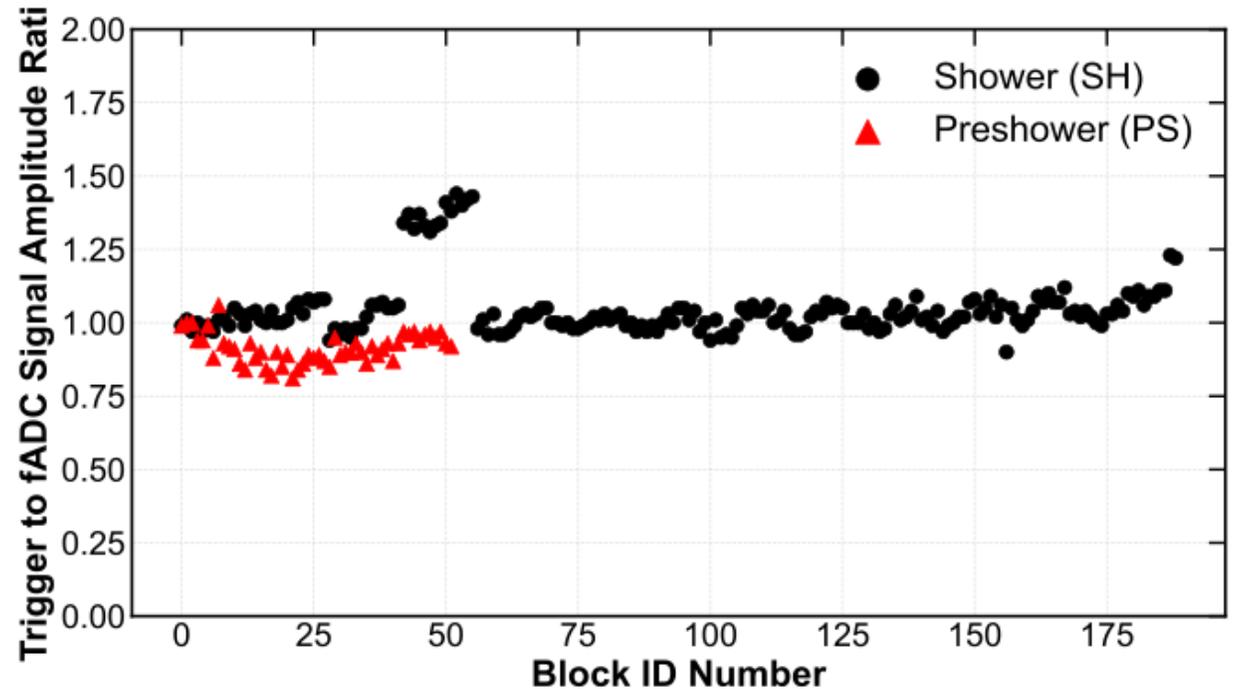
Cosmic Ray Calibrations
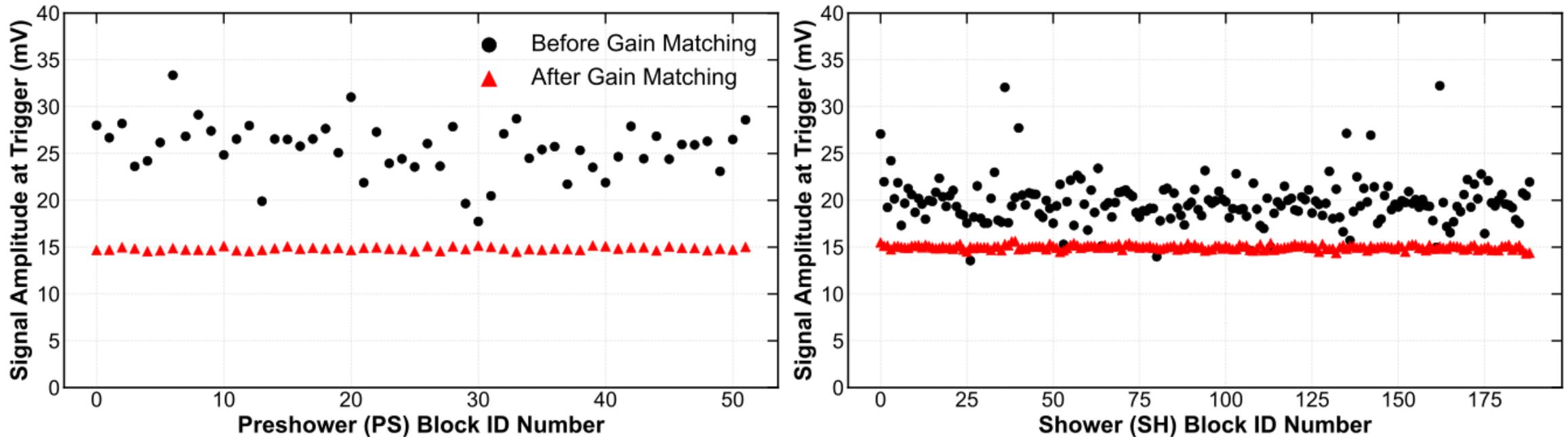
- Initial energy calibrations done using cosmic rays

- Select events using a verticality cut (reject events with horizontal tracks)

- Signal amplitude peaks were fitted and then aligned by adjusting the PMT HV

Magnetic Field Mitigation

- BB and SBS magnets produced fringe field of ~50G at the PS and SH positions
- This caused shifts in PMT gains
- Set 1: gain-matched cosmic ray data with both magnets OFF
- Set 2: same gain-matching with both magnets ON
- Set 3: gain-matched with magnets on during cosmic calibrations

Clustering and Calibrations

BBCal Event Formation

Raw Data:
25 4-ns fADC waveform samples

Estimate Pedestal:
Average four voltage samples from beginning and end of waveform

Subtract pedestal from each waveform

Locate Threshold Crossing:
Reconstruct pulse amplitude, charge integral, and leading-edge time

Convert Charge Integral:
Use calibrations to extract an energy deposition value

"Good" events are sent to the clustering algorithm!

Clustering Algorithm – SH Clusters

Island clustering:

- "Good" hits are ordered by descending energy
- First block in the "good" hit list is used as the "seed" for the cluster
  - When blocks are added to a cluster, they are removed from the "good" hit list to avoid double counting
- "Good" hits are iterated through and compared to each previously added block in the cluster:

$$r_{ij}^2 \equiv (x_i - x_j)^2 + (y_i - y_j)^2 \qquad t_j \equiv |t_0 - t_j|$$

$$r_{ij}^2 \leq r_{max}^2 \qquad t_j \leq t_{max}$$

$$r_{max} = 15cm$$
$$t_{max} = 10ns$$

The ith block is one already added to the cluster

The 0th block is the seed block

The jth block is an "unused" block in the "good" hit list

(x,y) is the central position of a given block

t is the ADC time

Each cluster must pass a final total energy threshold before being considered

Clustering Algorithm – PS Clusters

- PS blocks are similarly ordered in descending energy

- Central block position is compared to energy-weighted centroid of the SH cluster, projected back to the PS
  - Each PS block must be within 15cm vertically and 20cm horizontally of the energy-weighted centroid of the SH

- Compare ADC time to SH cluster ADC time and accept within 10ns

- "Best" cluster = highest PS+SH energy
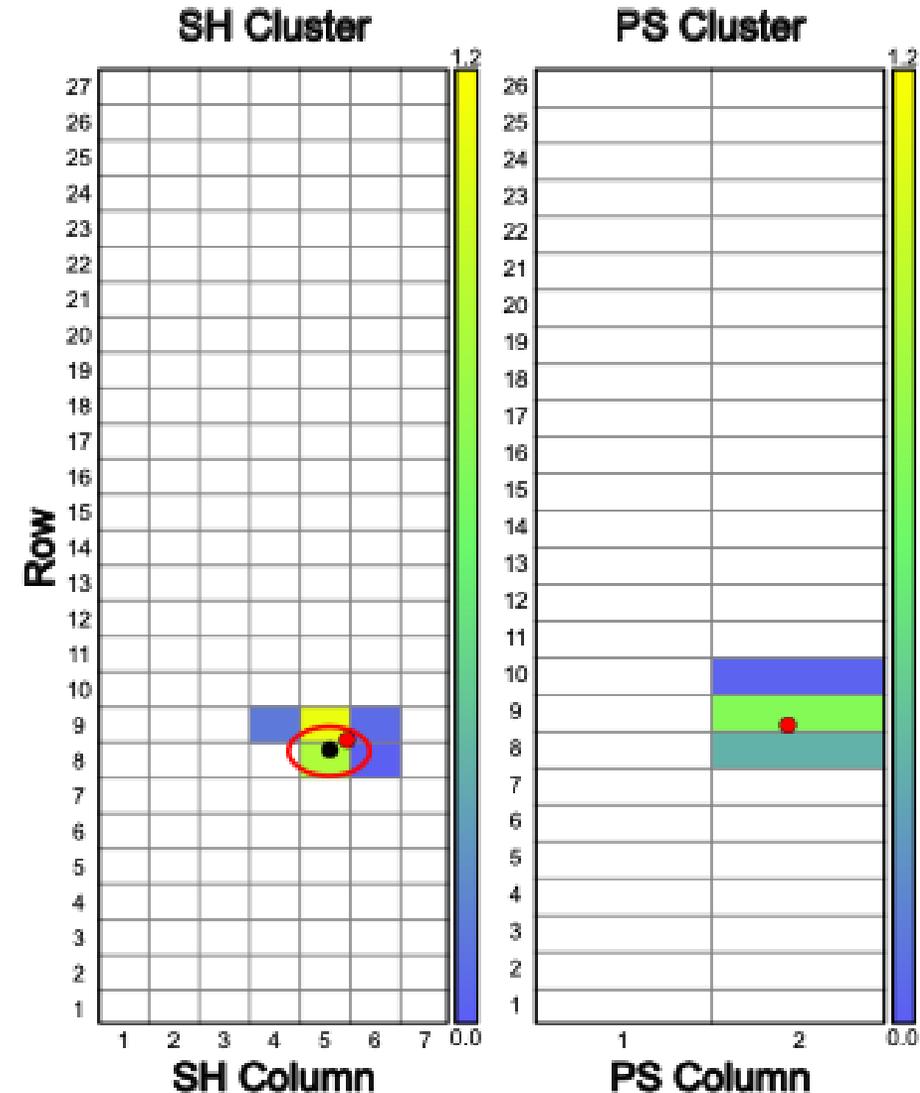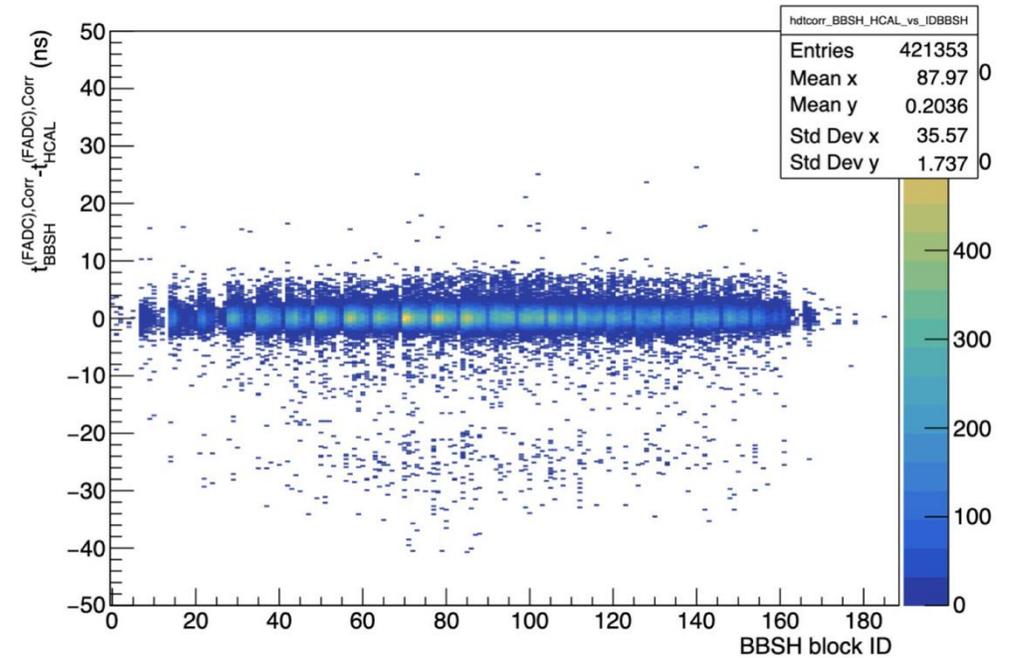
Timing Calibration

- Align BBCal ADC time to Hodoscope ADC time
- PS and SH are aligned separately
- A BBCal cluster ADC time is the ADC time of the cluster seed block
  - For the PS, its cluster ADC time is the ADC time of the highest energy block in the cluster
- See student talks for more details on SBS timing calibration updates
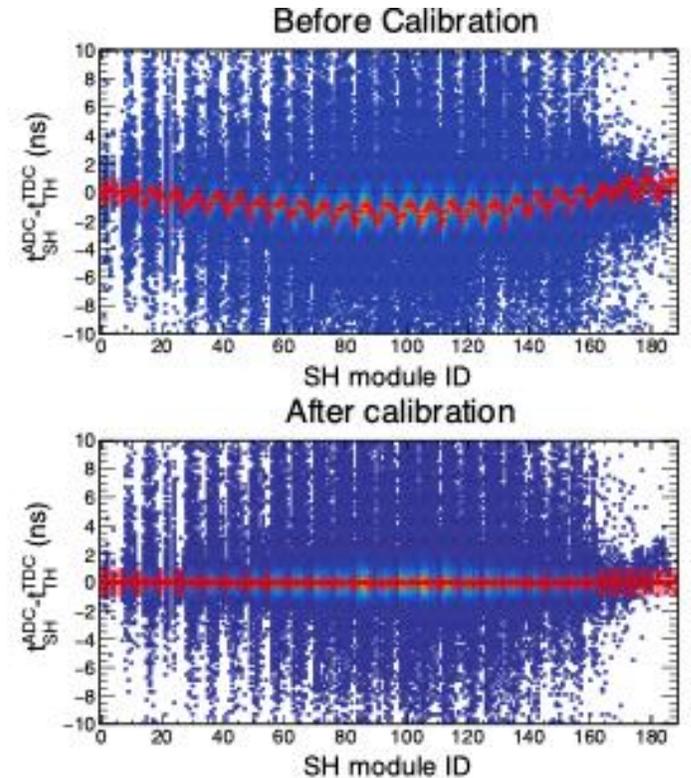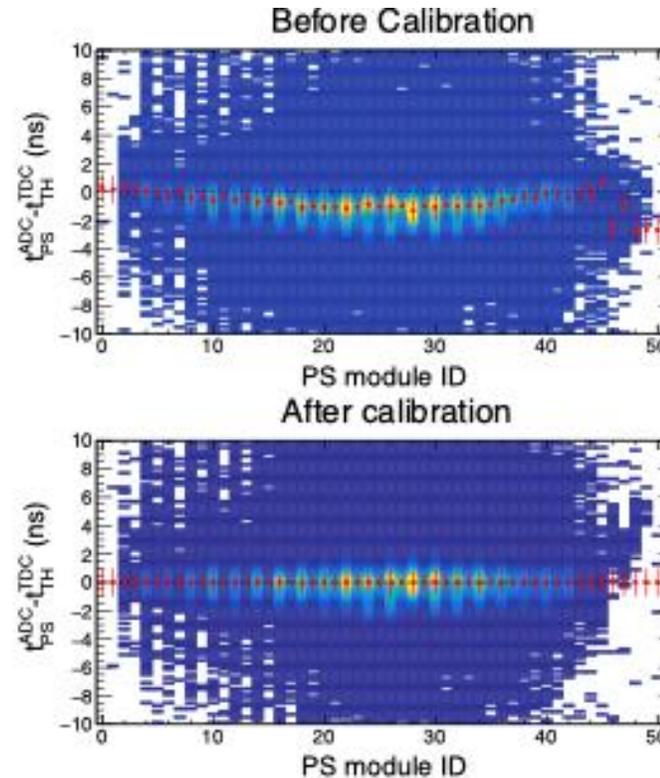
Timing Calibration – Example Results
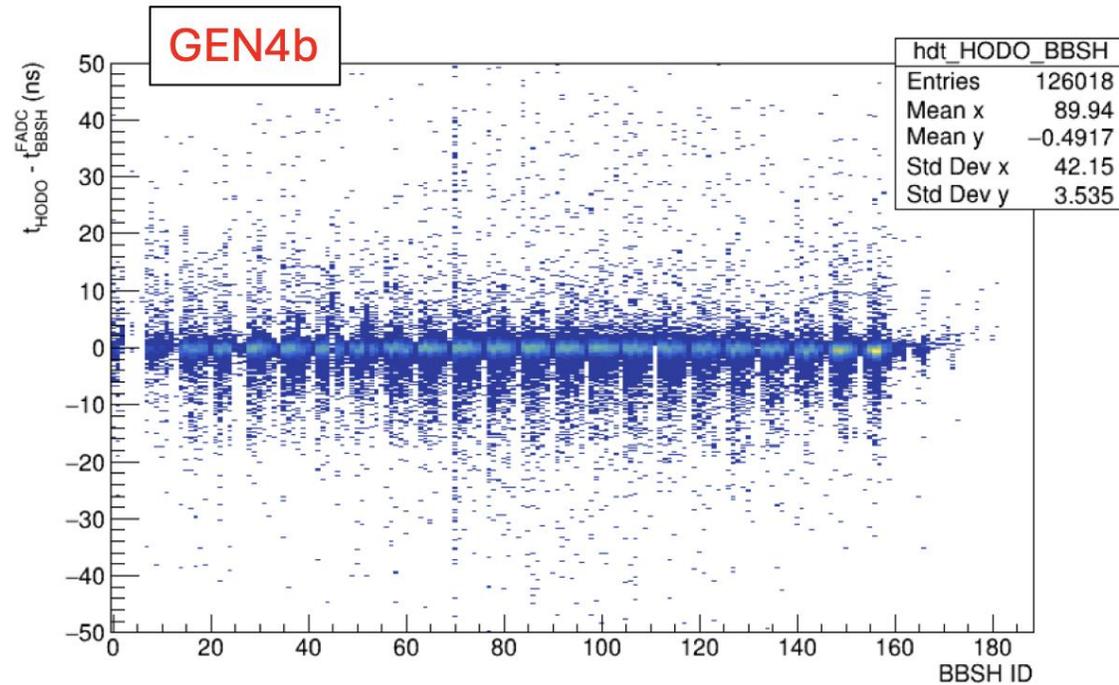
GEn-II

GEn-RP

*Calibrations done by Jacob Koenemann and Bhasitha Dharmasena Purijjala respectively
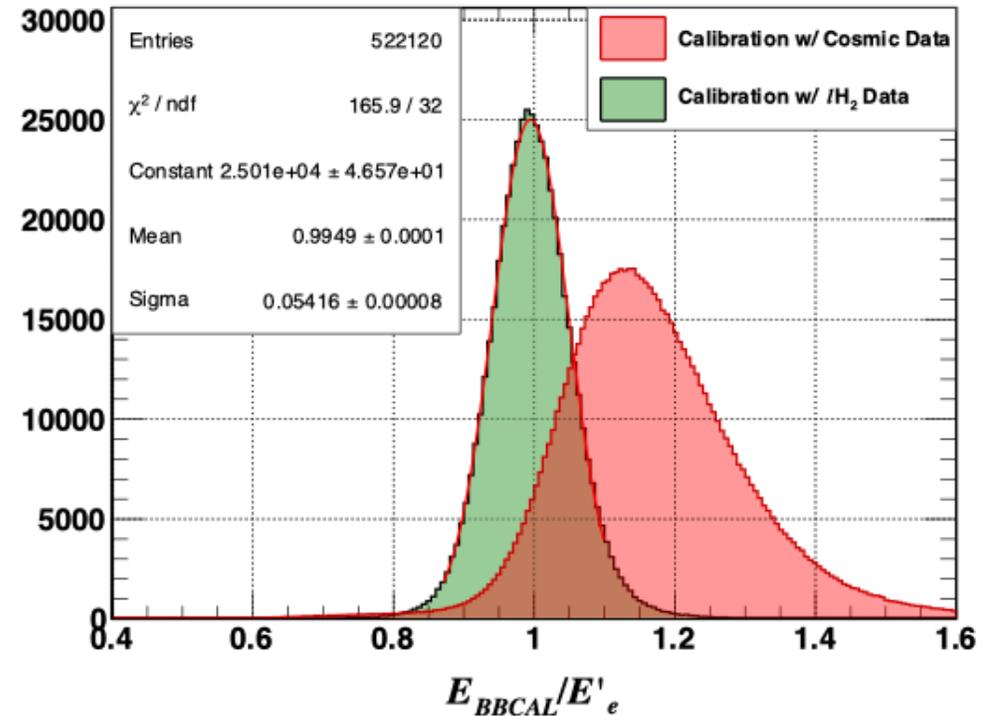
Energy Calibrations

- Use beam on (ideally) H2
  - Used beam on 3He data for some of GEn-II when H2 data were unavailable

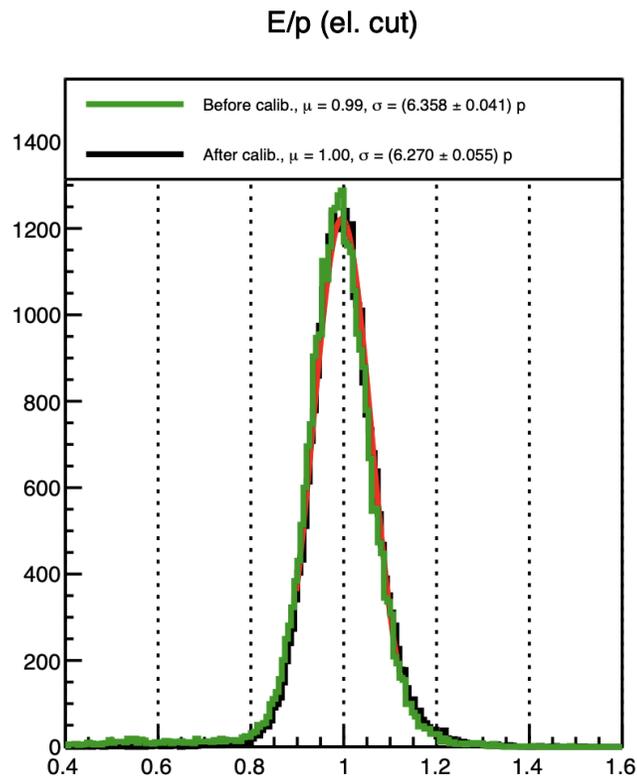- Minimize the following:

$$\chi^2 = \sum_{i=1}^{N} (p^i - E^i)^2$$

p^i is the reconstructed track momentum

E^i is the total cluster energy of the best cluster and contains a dependence on each block's ADC pulse integral and gain coefficient
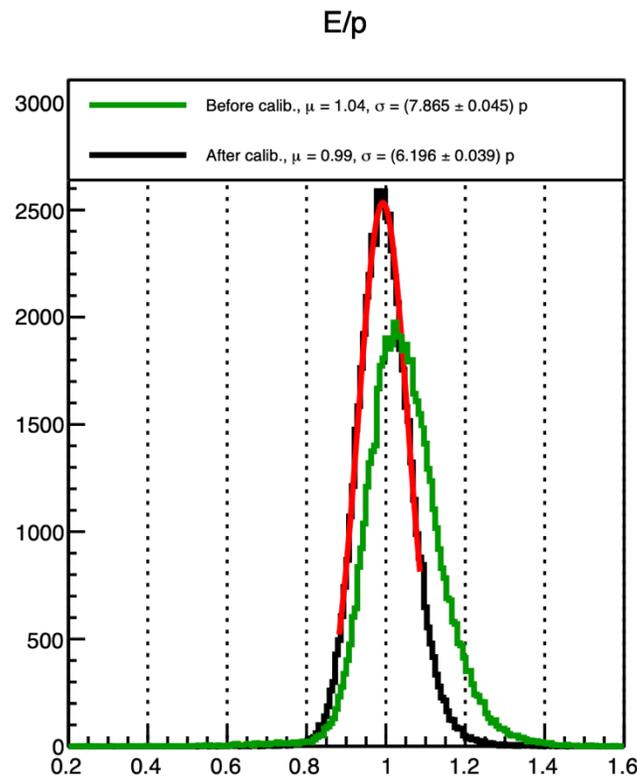
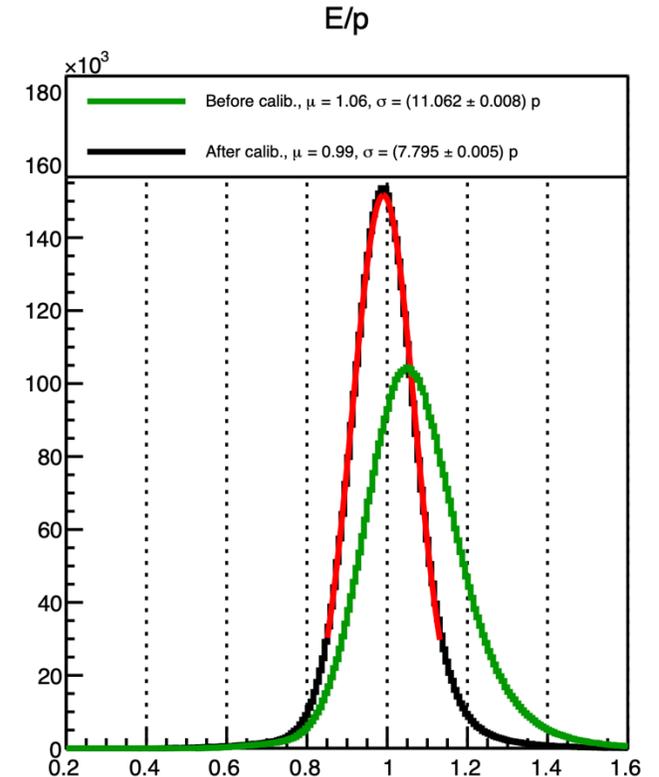N is the total number of events

Energy Calibrations – Example Results
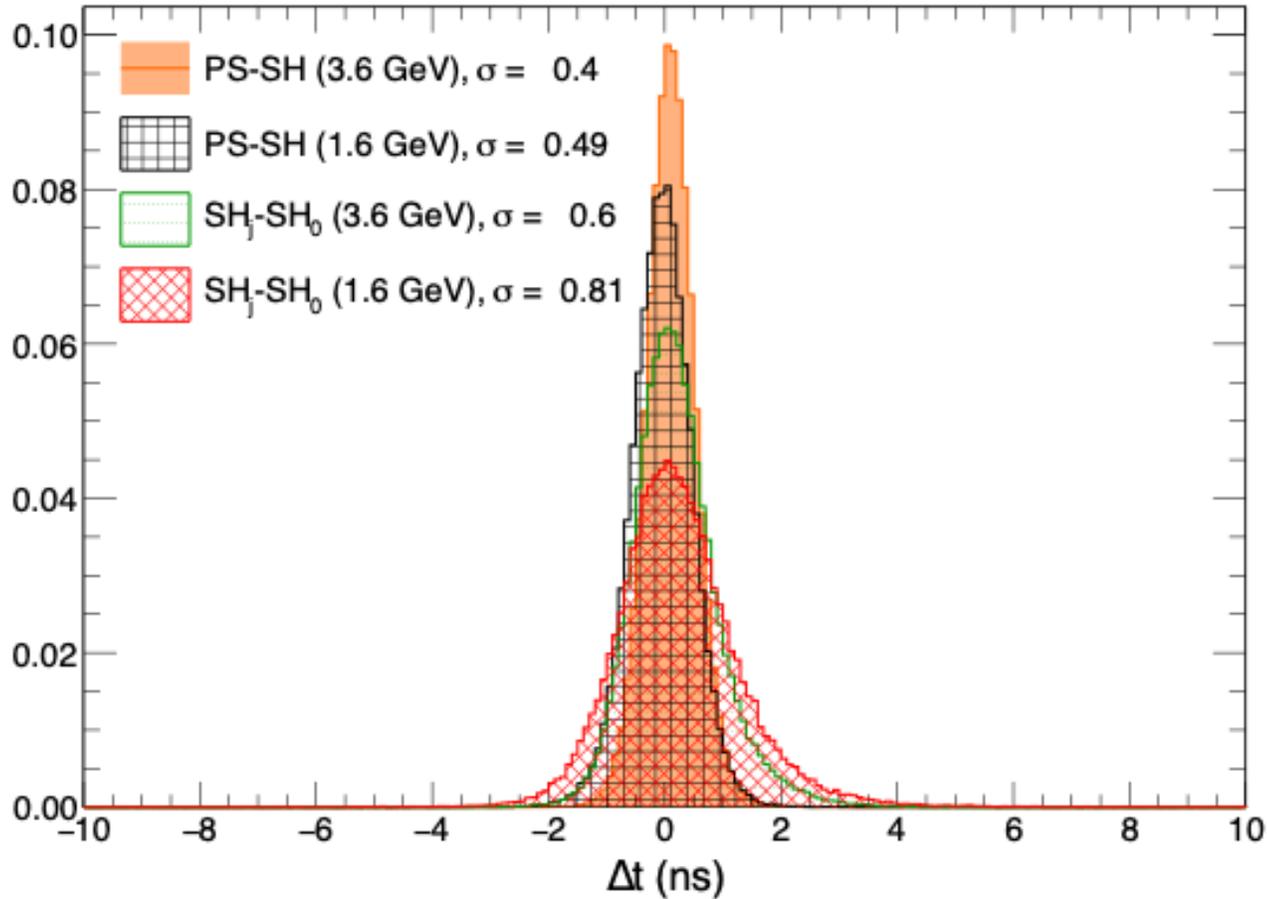

GMn – Pass2

GEn-II – Pass2

GEn-RP – Pass1

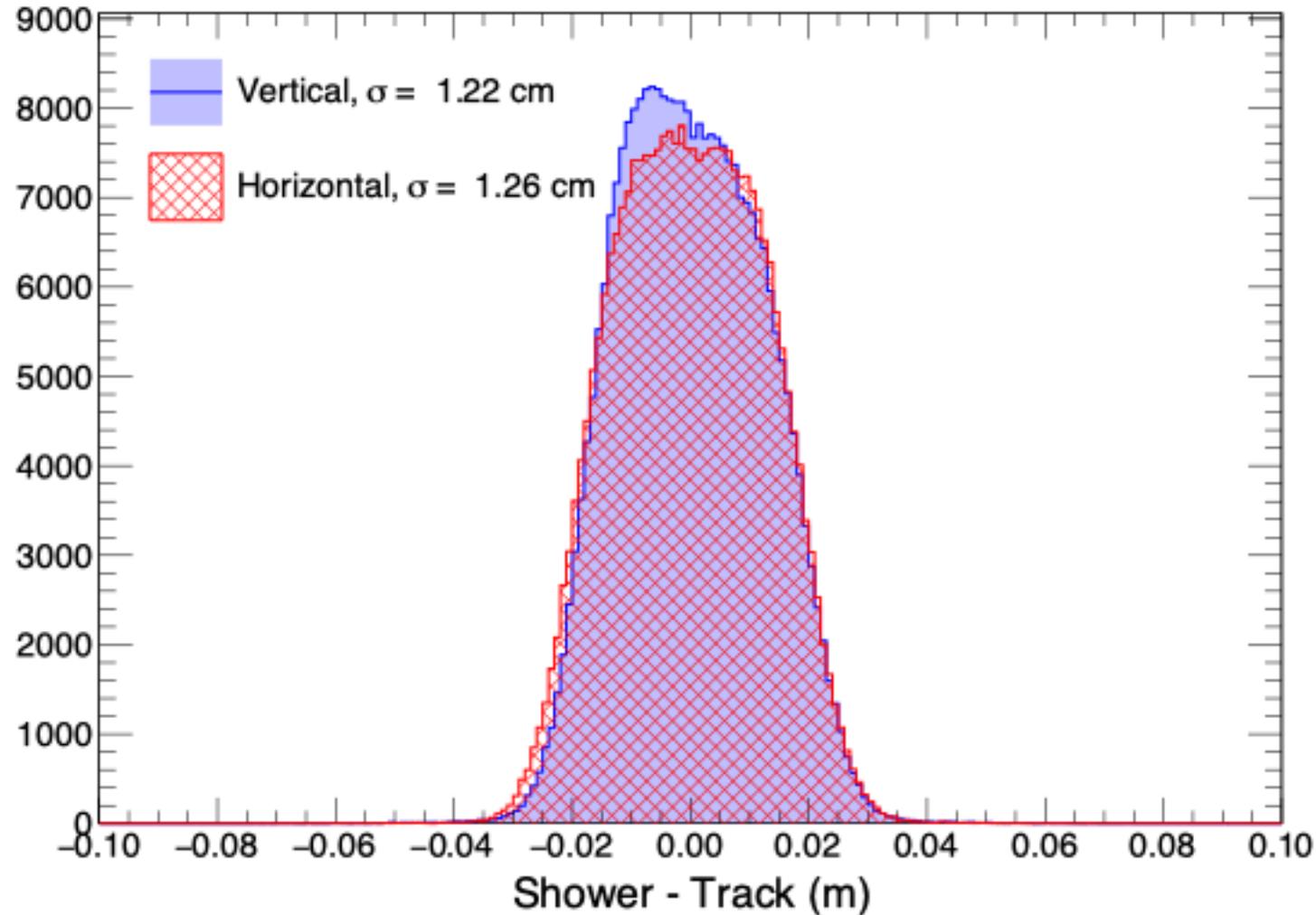*Calibrations done by Provakar Datta, Kate Evans, and Andrew Cheyne respectively

23

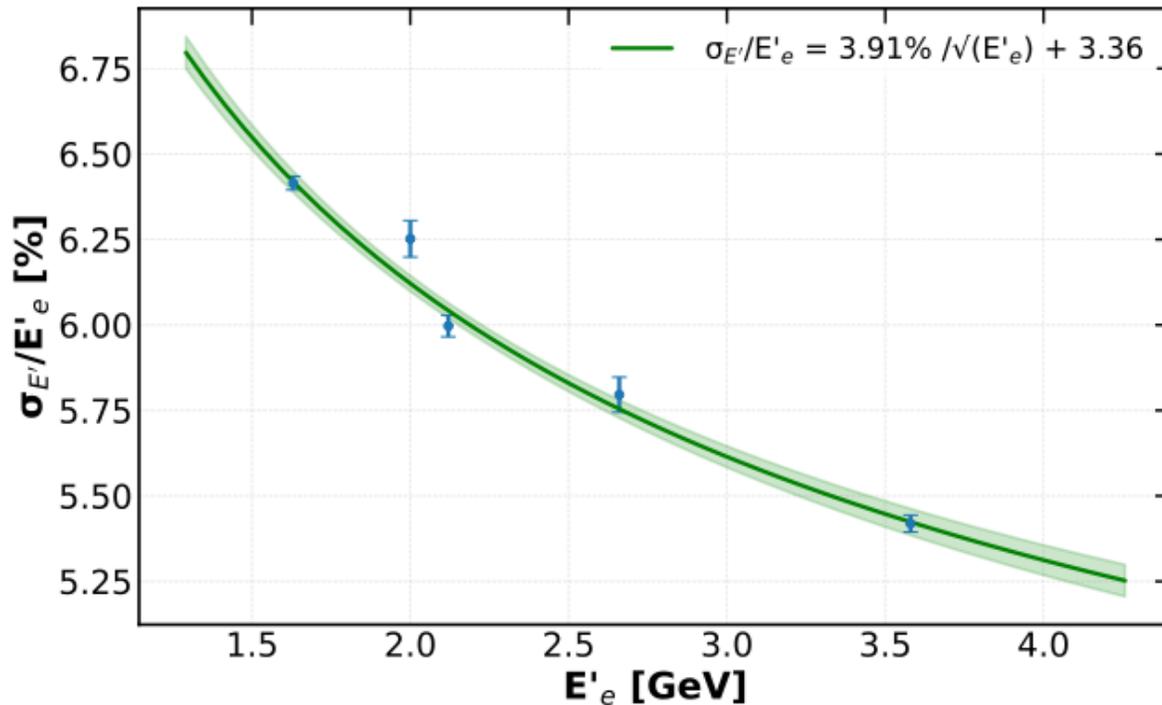# Performance

Timing Resolution

- Compare primary and secondary blocks within a cluster
- Average timing resolution is ~0.5ns

Position Resolution

- Compare the BBCal cluster energy-weighted centroid position to the track position measured by the GEMs

- BBCal position resolution is 1.2-1.4cm

Energy Resolution

$$\frac{\sigma_{E'}}{E'_e} = \frac{(3.9 \pm 0.1)}{\sqrt{E'_e}}\% + (3.4 \pm 0.2)\%$$

- The first term is a stochastic term that accounts for shower intrinsic fluctuations.
- The second term is a constant term that accounts for inhomogeneities in the detector that may arise from calibrations or geometry.
  - The random fluctuations of the "undetected" energy deposited outside of BBCal also contribute.
- The average energy resolution is ~6.2%

Questions?

Thank you to Arun and Provakar!

Mark Jones, Bogdan, Andrew Puckett

SBS Collaboration

Hall A Technicians