The BigBite Calorimeter (BBCAL)

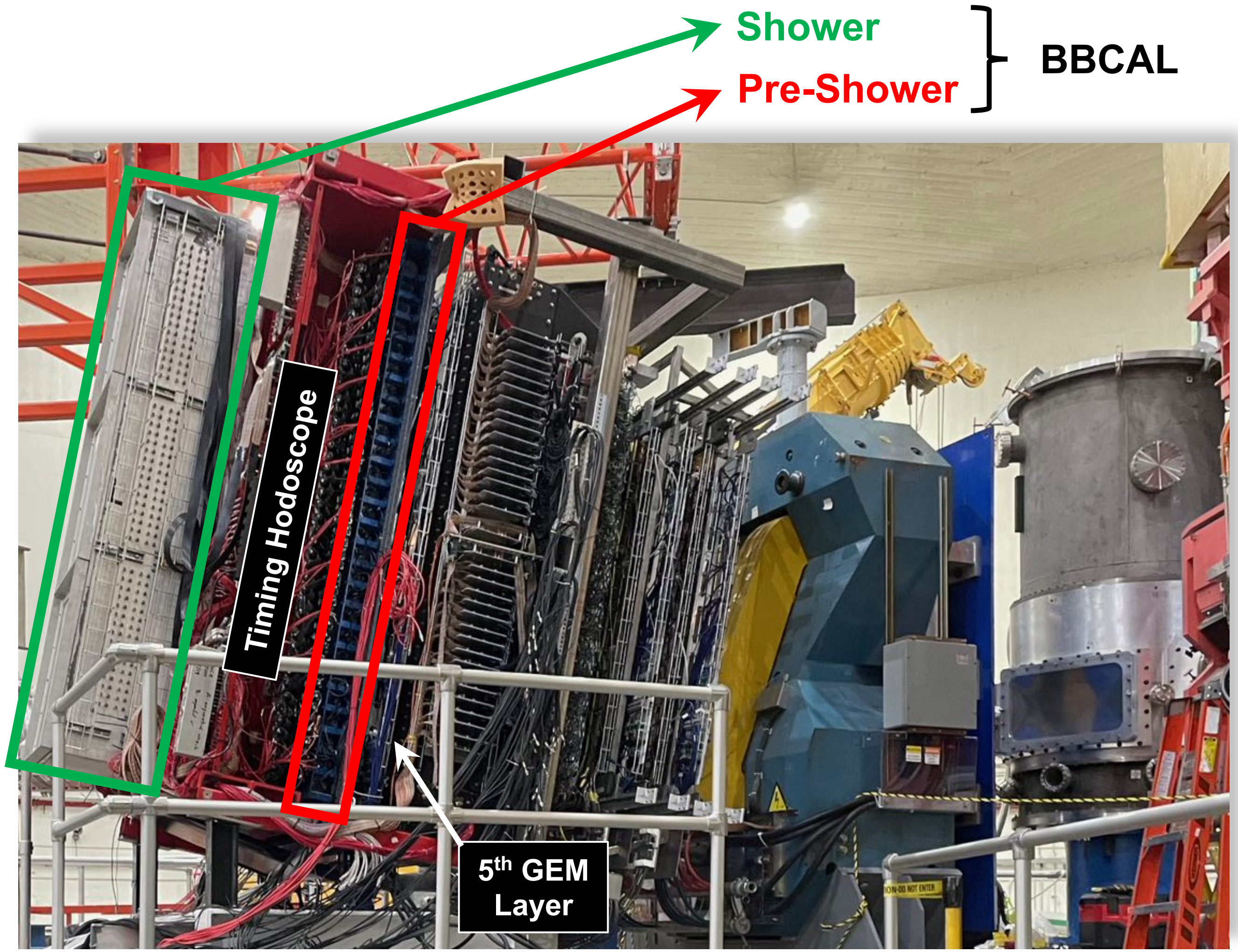
- Design, Purpose, & Performance

Provakar Datta

(On behalf of the SBS Collaboration)

Introduction

- For the next couple of years (at least) **Hall A's future** is **SBS**.
- **The BigBite Spectrometer** is being used to detect and fully characterize the kinematics of the **scattered e^-s** for almost all the SBS collaboration experiments.
- **The BigBite Calorimeter** A.K.A. **BBCAL** is an integral part of it. BBCAL has two parts:
  - Pre-Shower (PS) Calorimeter
  - Shower (SH) Calorimeter



The BigBite Spectrometer in Hall A (Side View)

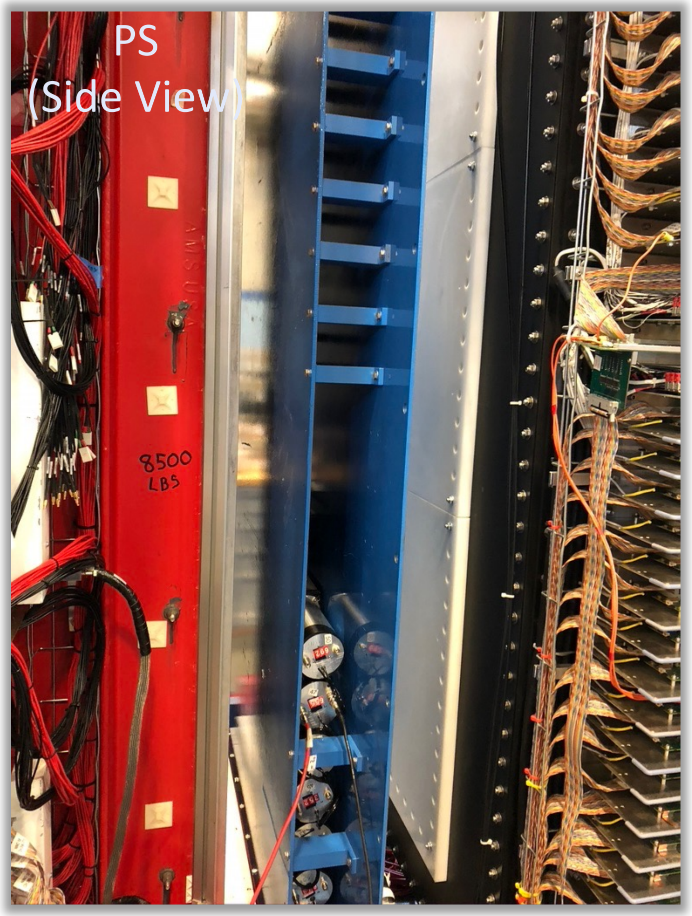
Design: Pre-Shower (PS)

+y, away from beamline

+z ,towards particle motion

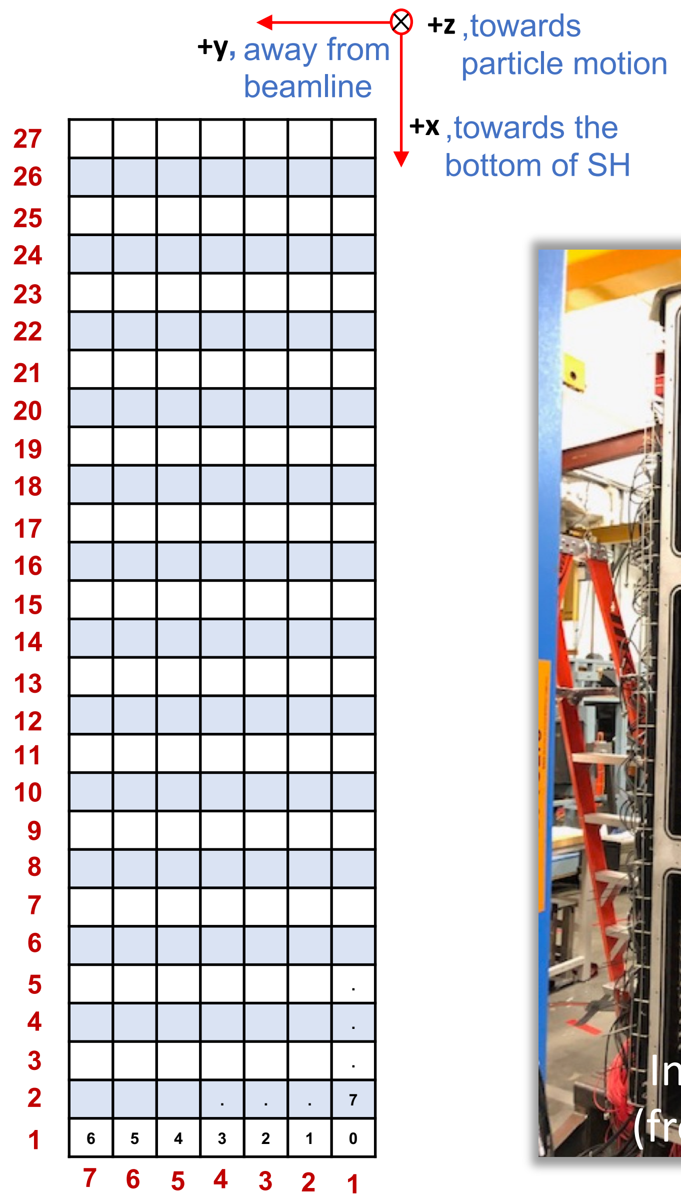
+x ,towards the bottom of PS

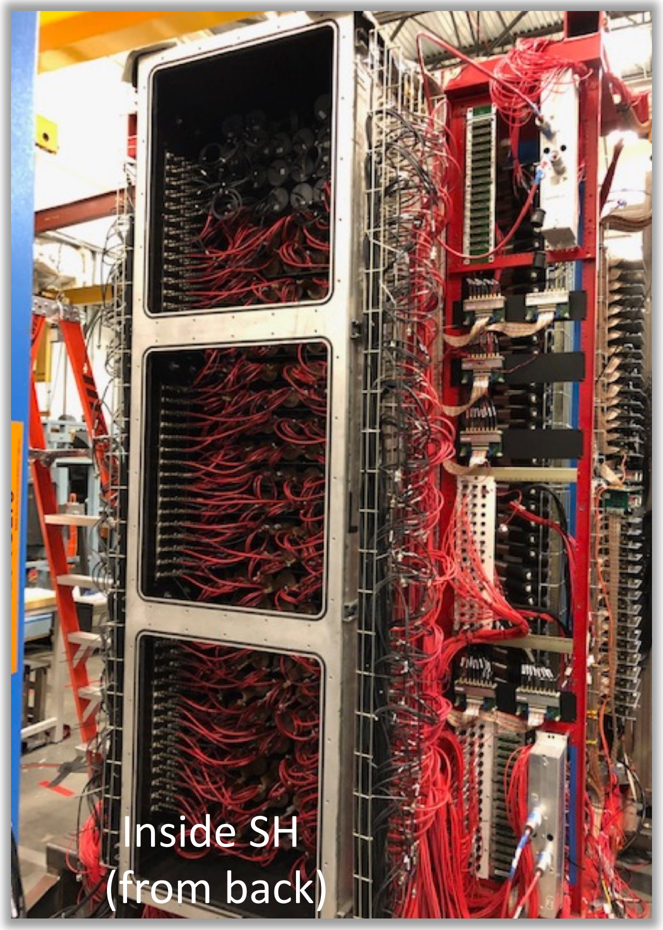
26	51	50
25	49	48
24	47	46
23	45	44
22	43	42
21	41	40
20	39	38
19	37	36
18	35	34
17	33	32
16	31	30
15	29	28
14	27	26
13	25	24
12	23	22
11	21	20
10	19	18
9	17	16
8	15	14
7	13	12
6	11	10
5	9	8
4	7	6
3	5	4
2	3	2
1	1	0
	2	1



- PS is made of 52 rad-hard lead-glass blocks.
- Signals generated in each block are readout by a PMT.
- Block dimension: 9 x 9 x 29.5 cm^3
- Blocks are stacked in 26 rows of 2 columns facing each other.
- mu-metal shielding around each block.

Design: Shower (SH)




Inside SH (from back)

- BB Shower is made of 189 lead-glass blocks.
- Signals generated in each block are readout by a PMT.
- Block dimension: 8.5 x 8.5 x 34 cm^3
- Blocks are stacked in 27 rows of 7 columns facing the spectrometer axis.
- mu-metal shielding outside & between rows.


SH Modules

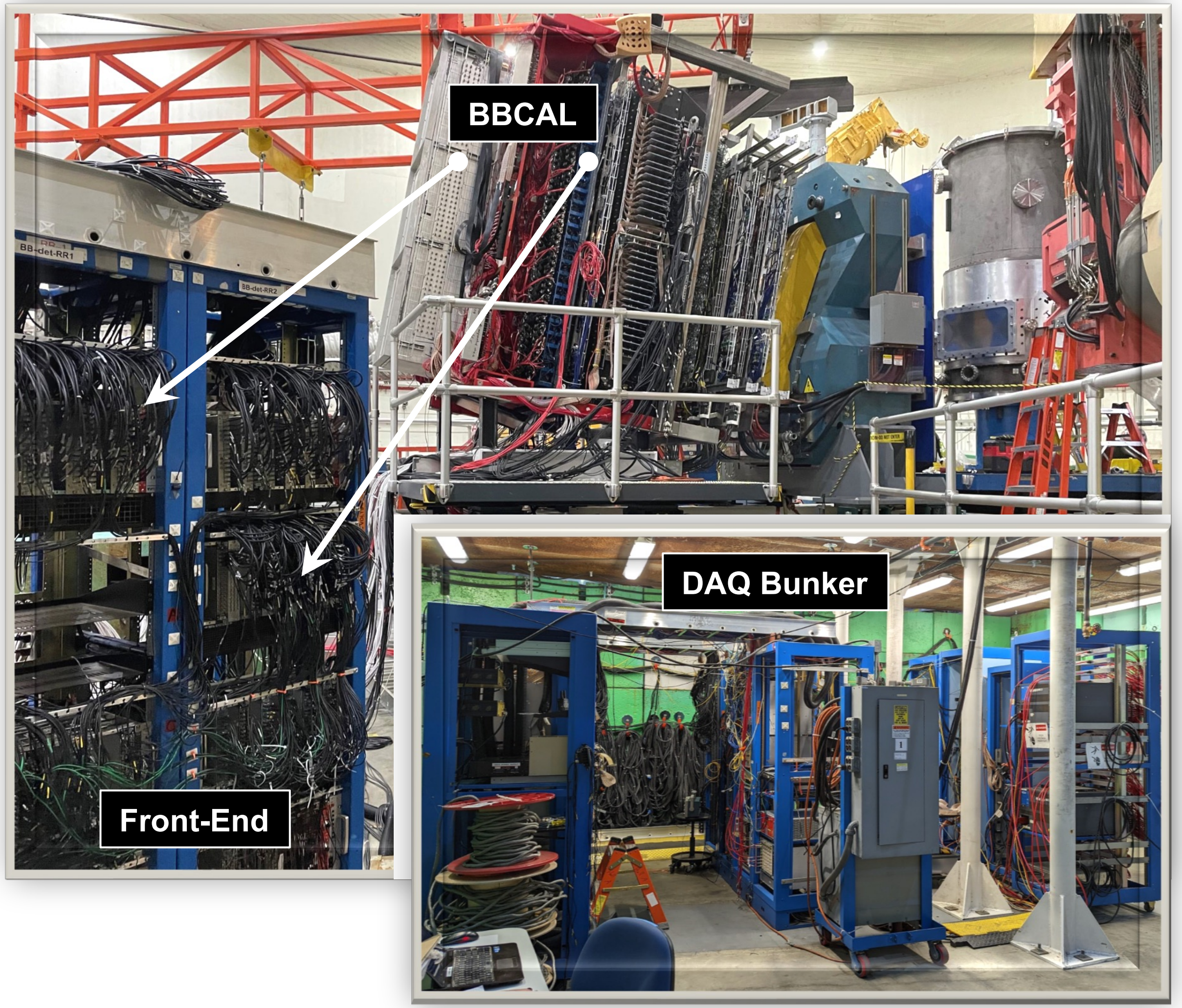
Basic Working & Purpose

- High energy e^{-}s lose energy in lead-glass by the formation of **electromagnetic shower**.
  - PS thickness is not enough to stop them. So, e^{-}s deposit only a fraction of their energy in it.
  - SH, on the other hand, define the 'End of the road' for incoming e^{-}s by containing them fully.

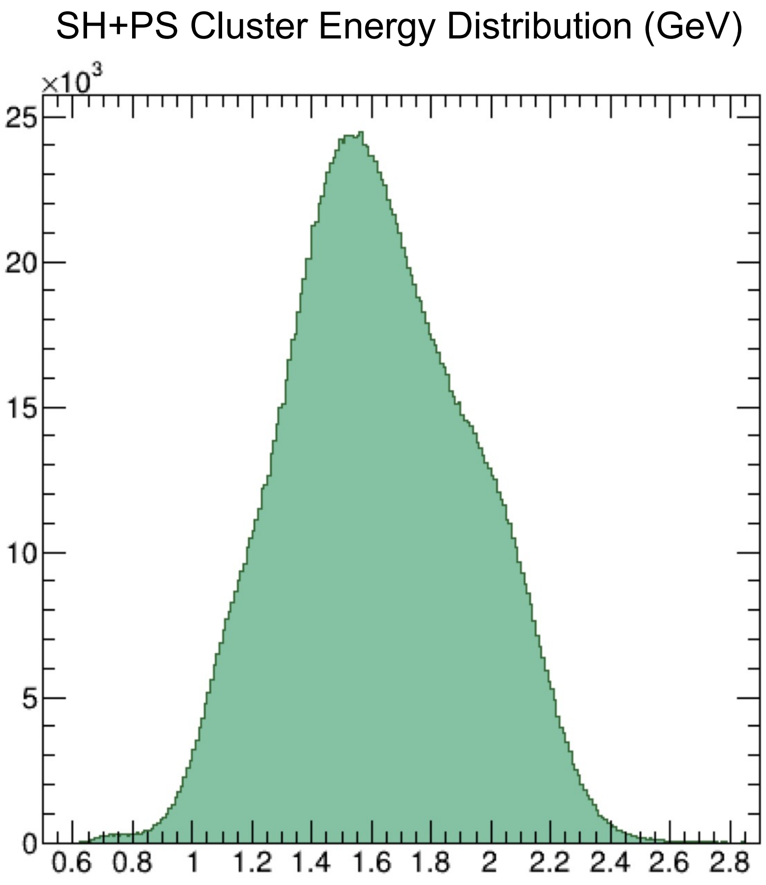
- Primary uses of BBCAL:
  1. Measures the scattered e^{-} energy and crudely determines the track position.
  2. Provides handle for pion background rejection (PS energy deposit is used for this purpose).
  3. Provides trigger for the BigBite spectrometer.
  4. Gives constraint for the track search region.

1. Energy Measurement

- **Detect**, **Digitize**, & **Convert** (from mV to GeV) the signal produced by EM shower in PS and SH modules.

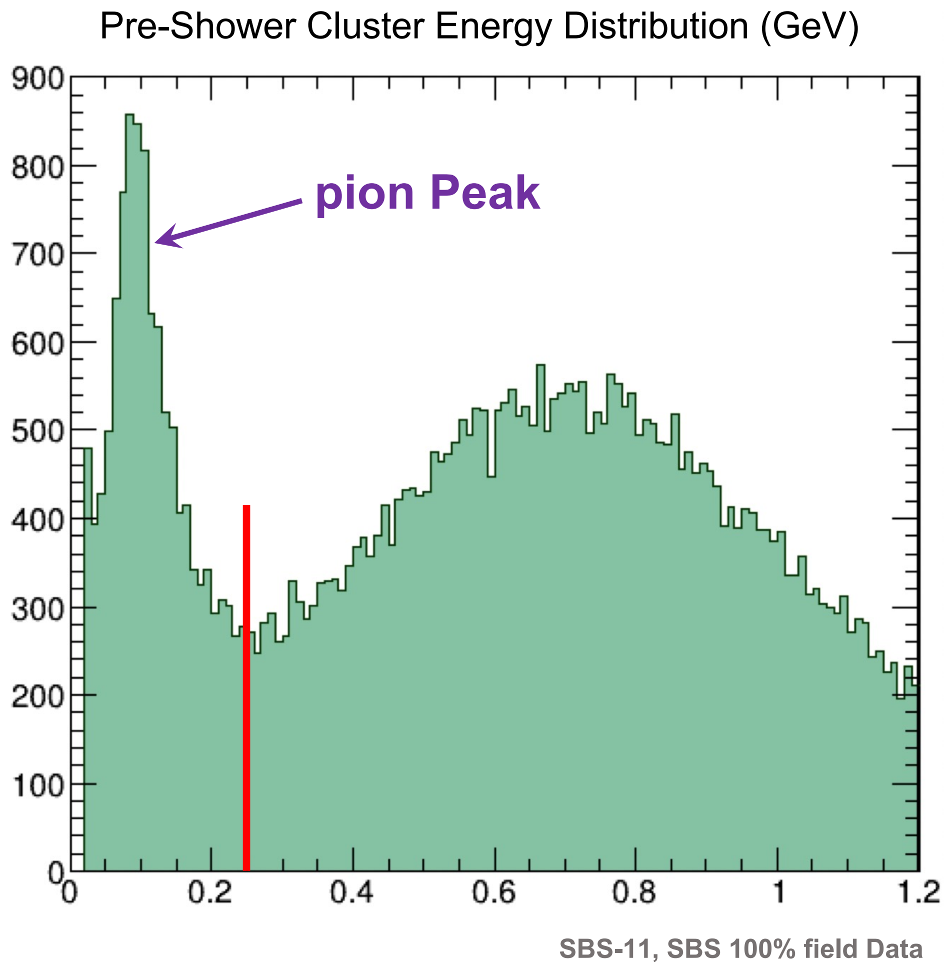


PMT
↓ mV
Amplifier at Front-End
↓ mV
FADC
↓ RAU
Replay
↓ GeV
Cluster Energy

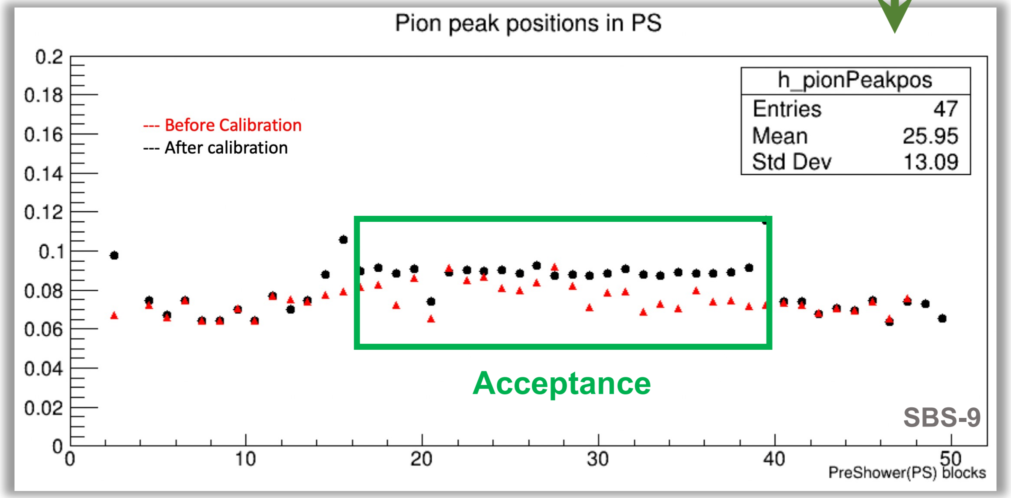


SBS-4, SBS 30% field Data

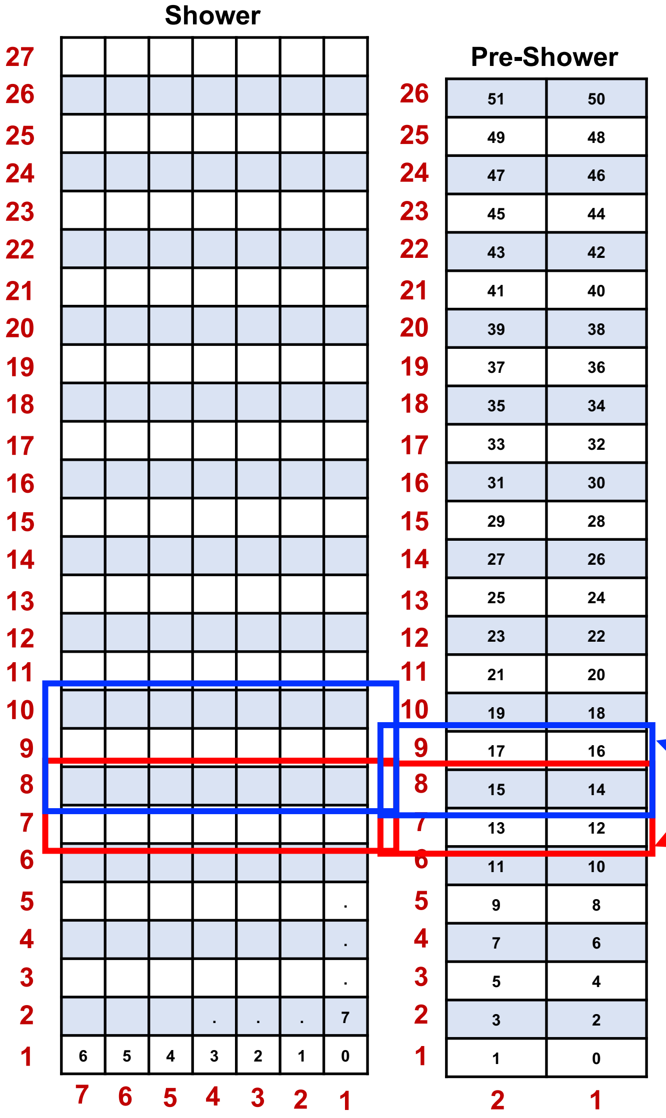
2. pion Background Rejection



- pions produce MIP like signal in PS modules in the momentum range of interest.
- Peak due to pions is **easily distinguishable** from the e^- peak.
- Hence, **a simple cut** on the PS energy can reject significant number of pions.
- One can also use pion peak positions to check the quality of PS calibration.

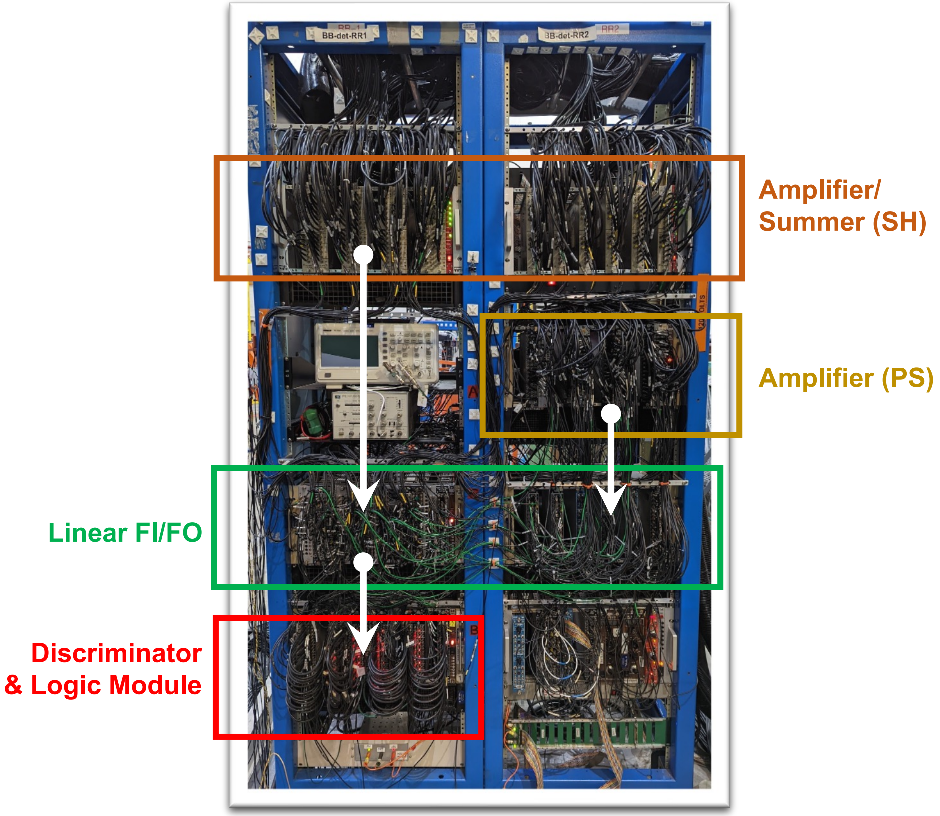


3. BigBite Trigger: Logic & Implementation

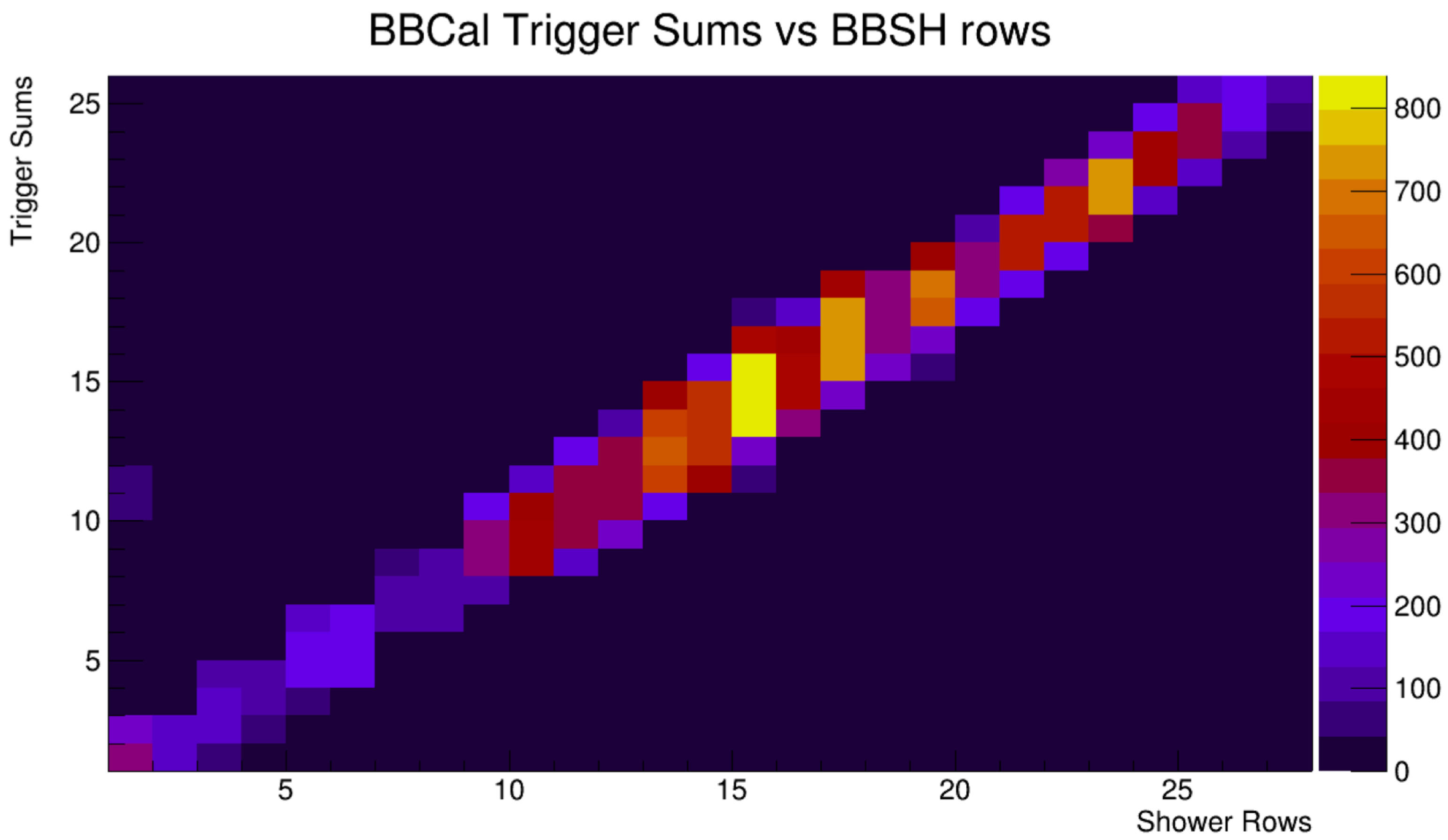


Trigger Sums	Associated SH and PS rows
SC 25-26	SH 26 + SH 27 + PS 25 + PS 26
SC 24-25	SH 25 + SH 26 + PS 24 + PS 25
SC 23-24	SH 24 + SH 25 + PS 23 + PS 24
SC 22-23	SH 23 + SH 24 + PS 22 + PS 23
SC 21-22	SH 22 + SH 23 + PS 21 + PS 22
SC 20-21	SH 21 + SH 22 + PS 20 + PS 21
SC 19-20	SH 20 + SH 21 + PS 19 + PS 20
SC 18-19	SH 18 + SH 19 + SH 20 + PS 18 + PS 19
SC 17-18	SH 17 + SH 18 + SH 19 + PS 17 + PS 18
SC 16-17	SH 16 + SH 17 + SH 18 + PS 16 + PS 17
SC 15-16	SH 15 + SH 16 + SH 17 + PS 15 + PS 16
SC 14-15	SH 14 + SH 15 + SH 16 + PS 14 + PS 15
SC 13-14	SH 13 + SH 14 + SH 15 + PS 13 + PS 14
SC 12-13	SH 12 + SH 13 + SH 14 + PS 12 + PS 13
SC 11-12	SH 11 + SH 12 + SH 13 + PS 11 + PS 12
SC 10-11	SH 10 + SH 11 + SH 12 + PS 10 + PS 11
SC 9-10	SH 9 + SH 10 + SH 11 + PS 9 + PS 10
SC 8-9	SH 8 + SH 9 + SH 10 + PS 8 + PS 9
SC 7-8	SH 7 + SH 8 + PS 7 + PS 8
SC 6-7	SH 6 + SH 7 + PS 6 + PS 7
SC 5-6	SH 5 + SH 6 + PS 5 + PS 6
SC 4-5	SH 4 + SH 5 + PS 4 + PS 5
SC 3-4	SH 3 + SH 4 + PS 3 + PS 4
SC 2-3	SH 2 + SH 3 + PS 2 + PS 3
SC 1-2	SH 1 + SH 2 + PS 1 + PS 2

- Overlapping SH and PS row sums constitute the trigger logic.
- Logical OR of all the discriminated sums make the final trigger.



BBCAL Front-End



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SC 22-23	SH 23 + SH 24 + PS 22 + PS 23
SC 21-22	SH 22 + SH 23 + PS 21 + PS 22
SC 20-21	SH 21 + SH 22 + PS 20 + PS 21
SC 19-20	SH 20 + SH 21 + PS 19 + PS 20
SC 18-19	SH 18 + SH 19 + SH 20 + PS 18 + PS 19
SC 17-18	SH 17 + SH 18 + SH 19 + PS 17 + PS 18
SC 16-17	SH 16 + SH 17 + SH 18 + PS 16 + PS 17
SC 15-16	SH 15 + SH 16 + SH 17 + PS 15 + PS 16
SC 14-15	SH 14 + SH 15 + SH 16 + PS 14 + PS 15
SC 13-14	SH 13 + SH 14 + SH 15 + PS 13 + PS 14
SC 12-13	SH 12 + SH 13 + SH 14 + PS 12 + PS 13
SC 11-12	SH 11 + SH 12 + SH 13 + PS 11 + PS 12
SC 10-11	SH 10 + SH 11 + SH 12 + PS 10 + PS 11
SC 9-10	SH 9 + SH 10 + SH 11 + PS 9 + PS 10
SC 8-9	SH 8 + SH 9 + SH 10 + PS 8 + PS 9
SC 7-8	SH 7 + SH 8 + PS 7 + PS 8
SC 6-7	SH 6 + SH 7 + PS 6 + PS 7
SC 5-6	SH 5 + SH 6 + PS 5 + PS 6
SC 4-5	SH 4 + SH 5 + PS 4 + PS 5
SC 3-4	SH 3 + SH 4 + PS 3 + PS 4
SC 2-3	SH 2 + SH 3 + PS 2 + PS 3
SC 1-2	SH 1 + SH 2 + PS 1 + PS 2

2 SH Rows

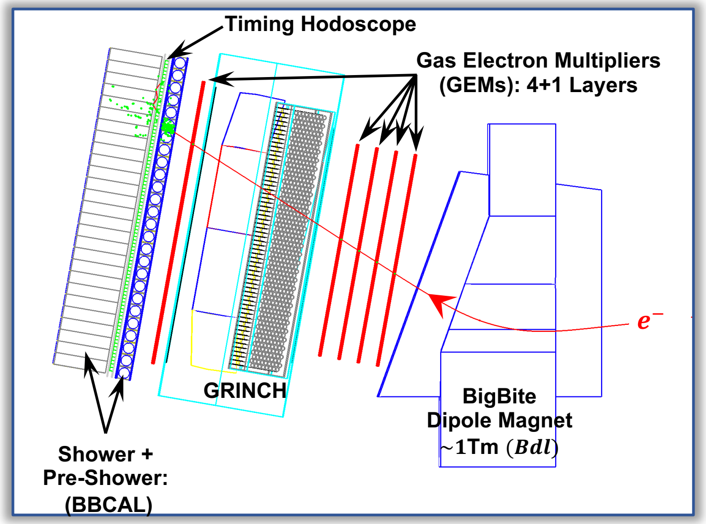
3 SH Rows

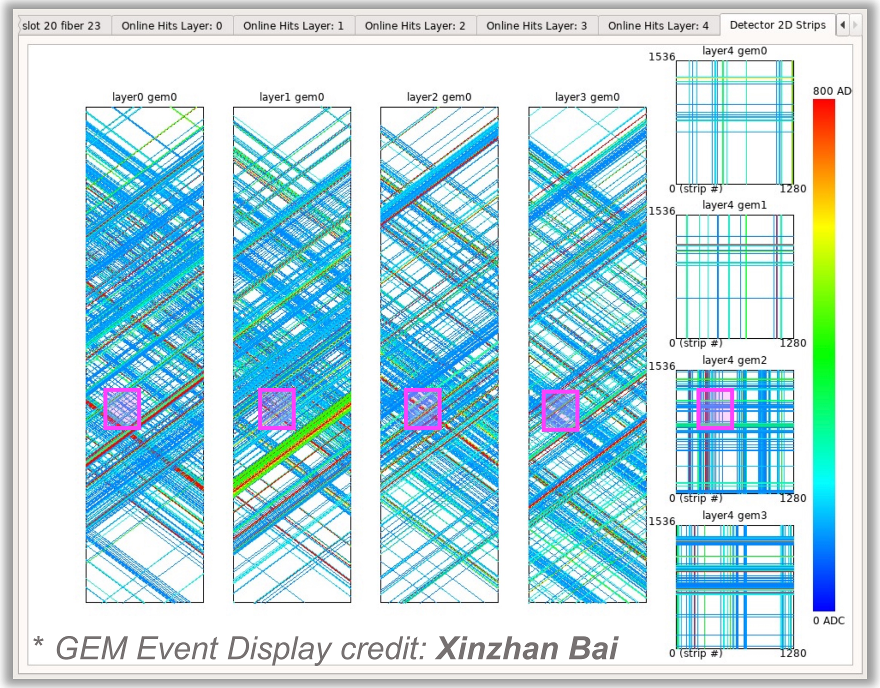
2 SH Rows

- All the trigger sums associated to same SH row, fire uniformly.

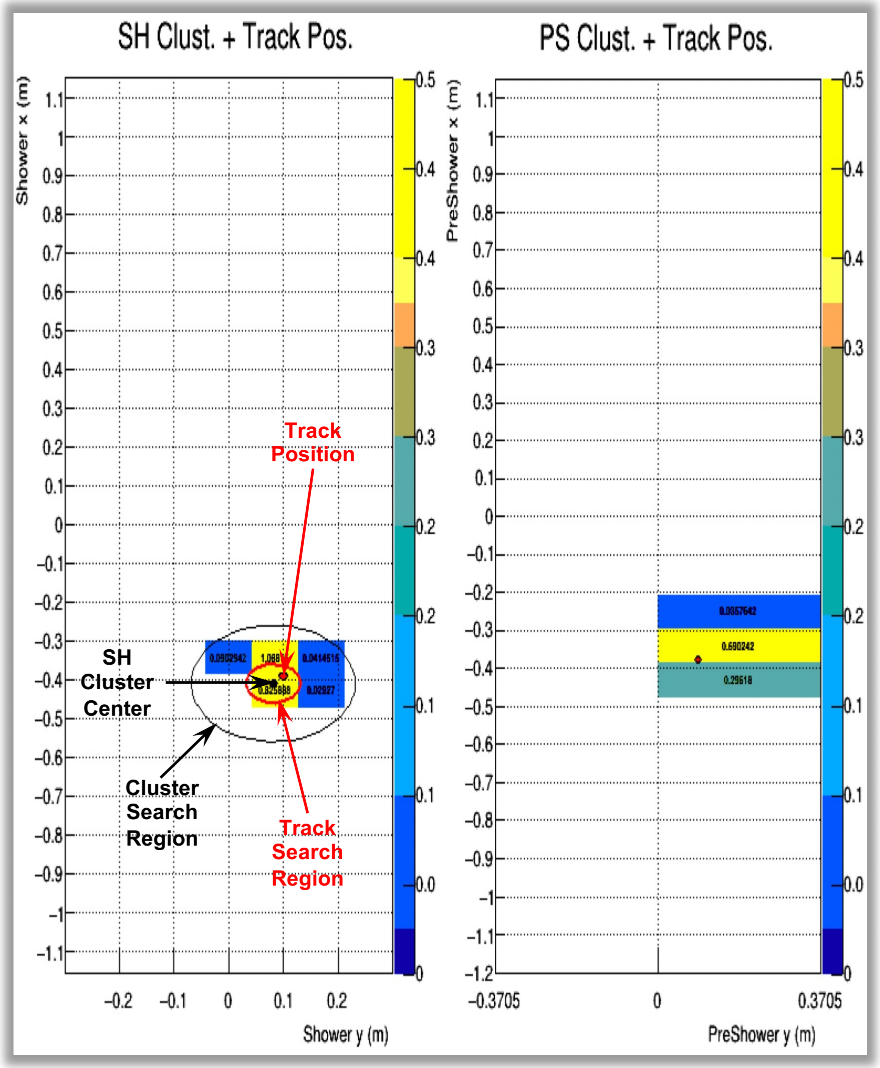
* *https://logbooks.jlab.org/entry/3927778*

4. Constraint for Track Search Region





* GEM Event Display credit: ***Xinzhan Bai***



- We reconstruct scattered e^- tracks in BigBite backwards.
- First, we define a search region around SH cluster position.
- Then propagate that region to all the GEM layers and search for tracks within.
- SH cluster position also gives starting vertical position and vertical angle for track search.

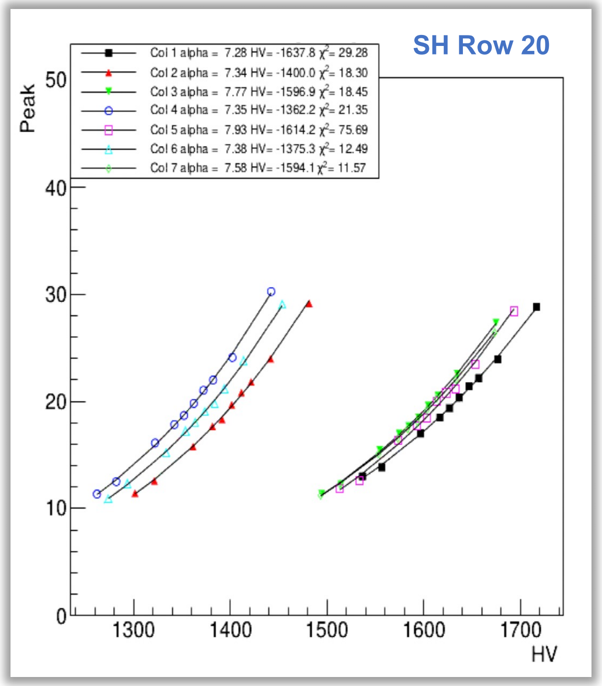
❖ This utility of BBCAL makes replay possible for SBS experiments!

- The constraint reduces the search region to **2-3%** of the entire GEM active area.
- Good BBCAL energy calibration is necessary to use this feature.

❖ Better calibration lets us optimize the search region which in turn improves the reconstruction efficiency significantly.

Cosmic Calibration

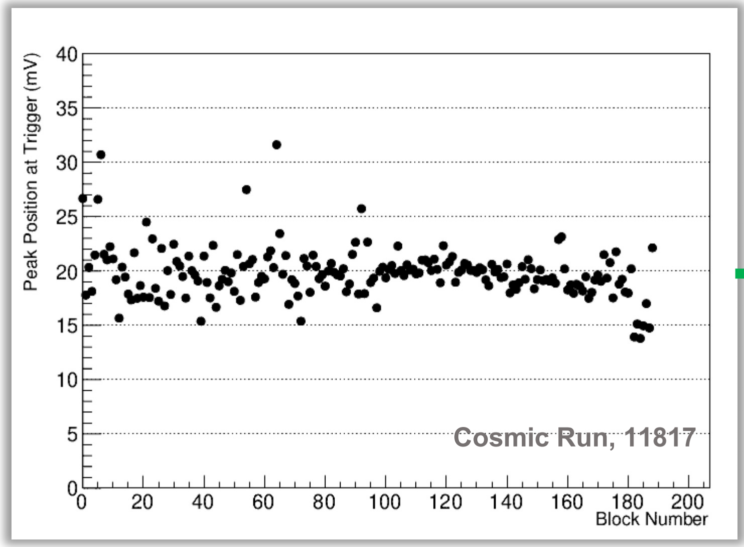
- Two primary methos of calibration – 1. Cosmic Calibration & 2. Beam Calibration (using LH_2)

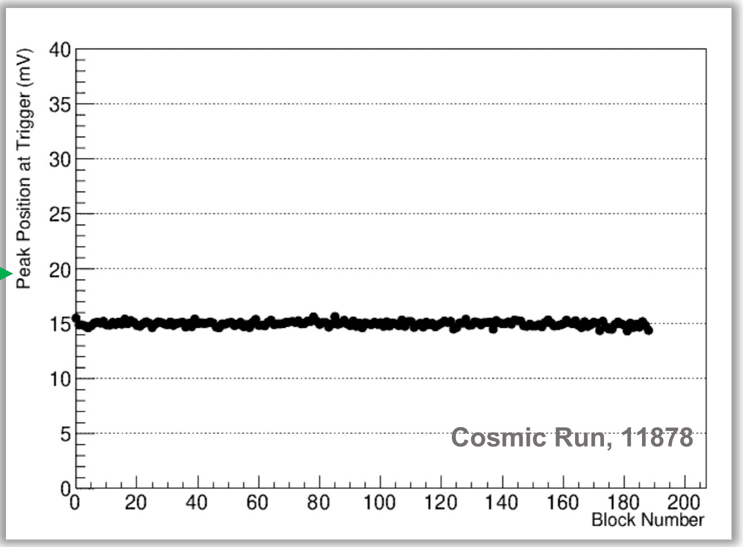


- Perform HV scan over a broad range.
- Get α by fitting Peak Position vs. HV plot, using: $\text{Peak Pos.} = \text{const} \times \text{HV}^{\alpha}$

❖ Only need to do this once since α value for a PMT should be stable.

- We then follow **2 simple steps** to perform cosmic calibration:





1

- Take a cosmic run with enough events.
- Fit the ADC amplitude distributions and extract peak positions for individual SH and PS blocks.

2

- Generate new HV settings that align Peak positions at the trigger to target ADC amplitude, using:

$$\text{HV}_{\text{new}} = \text{HV}_{\text{old}} \left[\frac{\text{Target ADC Amp.}}{\text{Current ADC Amp.}} \right]^{\frac{1}{\alpha}}$$

Beam Calibration: Procedure

- **Method**:
  - χ^2 minimization:

$$\chi^2 = \sum_{i=1}^{N}\left(E_e^i - \sum_{k=0}^{M} C_k A_k^i\right)^2 ,$$
$$= \sum_{i=1}^{N}\left(\left(E_e^i\right)^2 + \left(\sum_{k=0}^{M} C_k A_k^i\right)^2 - 2E_e^i \sum_{k=0}^{M} C_k A_k^i\right)$$

- Minimizing χ^2 with respect to the coefficients:

$$\frac{\partial \chi^2}{\partial C_j} = 0 \Rightarrow \sum_{i=0}^{N}\sum_{k,l=0}^{P}\left(\underset{B}{A_l^i} - \underset{C}{C_k^i}\underbrace{\frac{A_k^i A_l^i}{E_e^i}}_{M}\right) = 0$$

- Solving M linear equations to get the C_js:

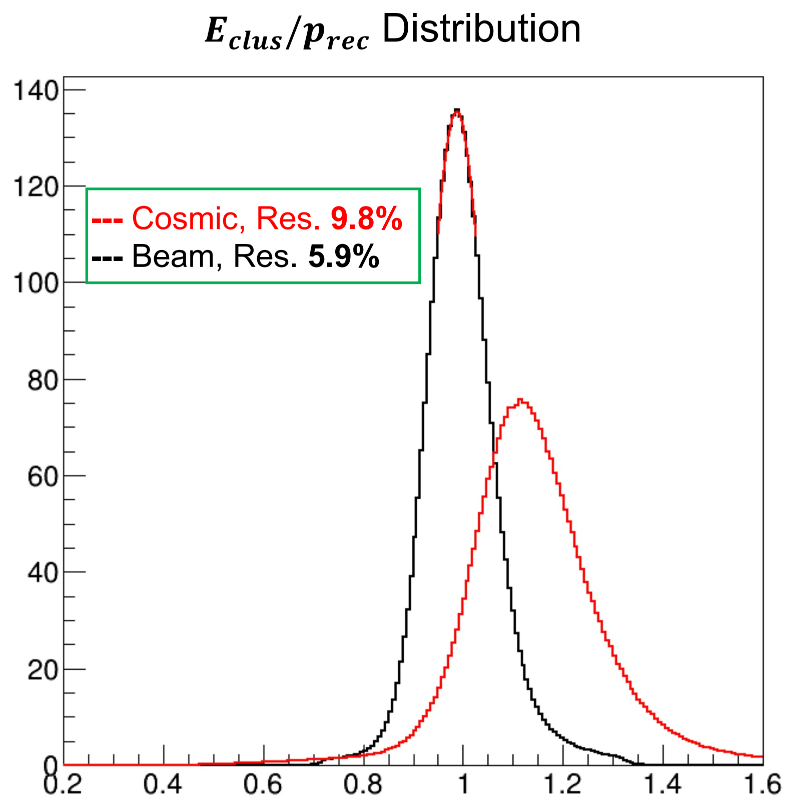
$$\boxed{C = M^{-1}B}$$

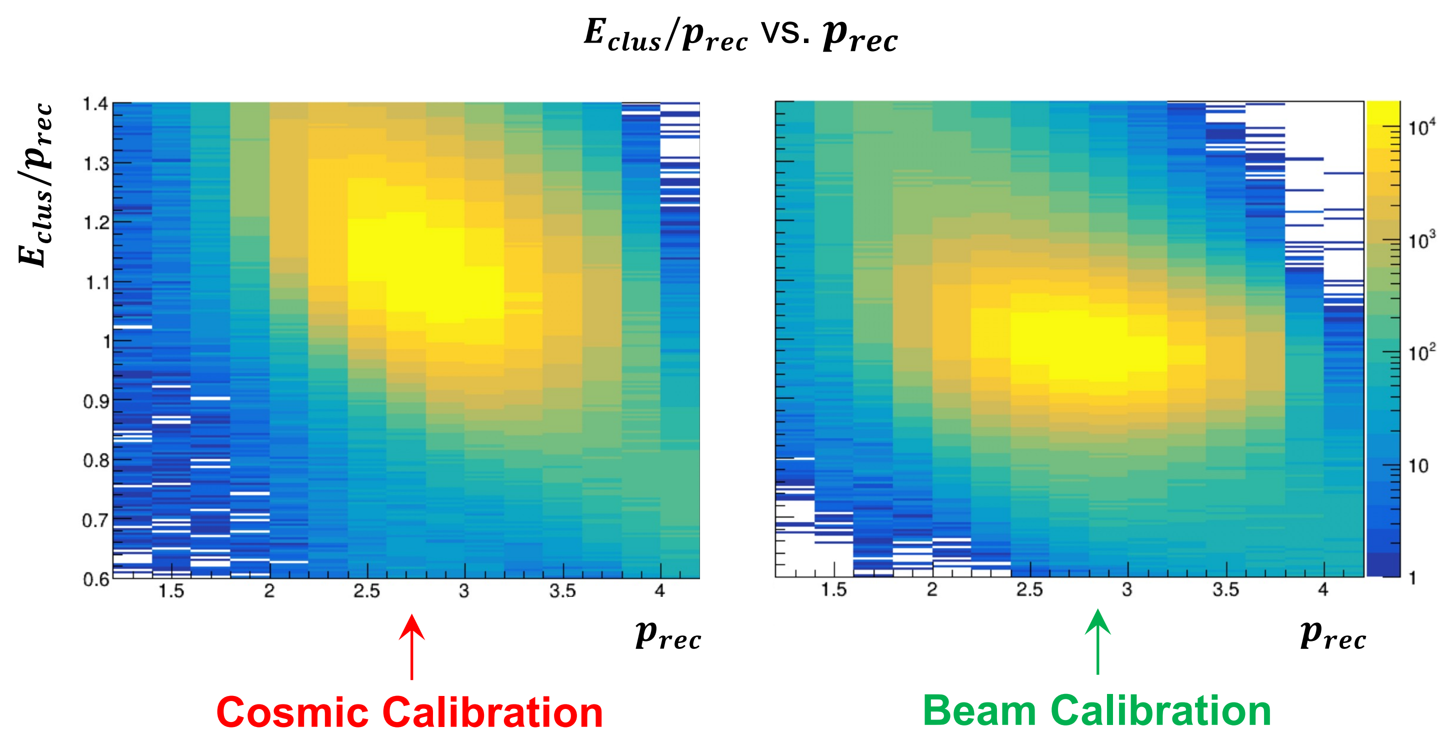
- E_e^i: Track momentum at i^{th} event.
- A_k^i: Energy deposited in k^{th} block at i^{th} event.
- C_k: Gain coefficient of the k^{th} block.
- N: Total # events being analyzed.
- P: Total # BBCAL (189 SH + 52 PS) blocks.

Primary Cuts

1. No. of tracks per event = 1
2. No. of GEM planes that had hit > 3
3. $|(\text{vertex})_z| < 0.08$ m
4. HCAL cluster energy > 0.025 GeV
5. PS cluster energy > 0.2 GeV
6. SH + PS cluster energy > 1.9 GeV
7. $|E/p - 1| < 0.3$
8. $2.1 < p_{rec} < 3.0$ (GeV)

Beam Calibration: Preliminary Results





- Initially we see a strong negative correlation between E_{clus}/p_{rec} and p_{rec} which almost disappears with just 1st round of calibration with beam.
- Energy resolution improves drastically with beam calibration.

SBS-8, SBS 70% field Data

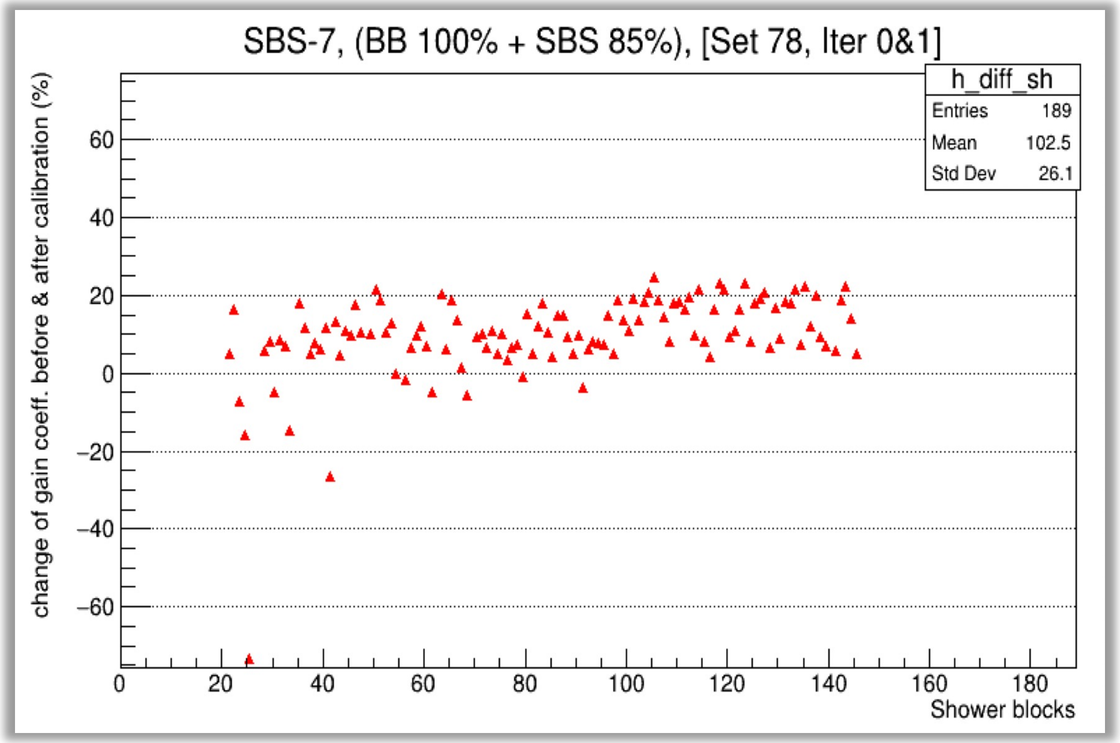
Beam Calibration: Preliminary Results contd.

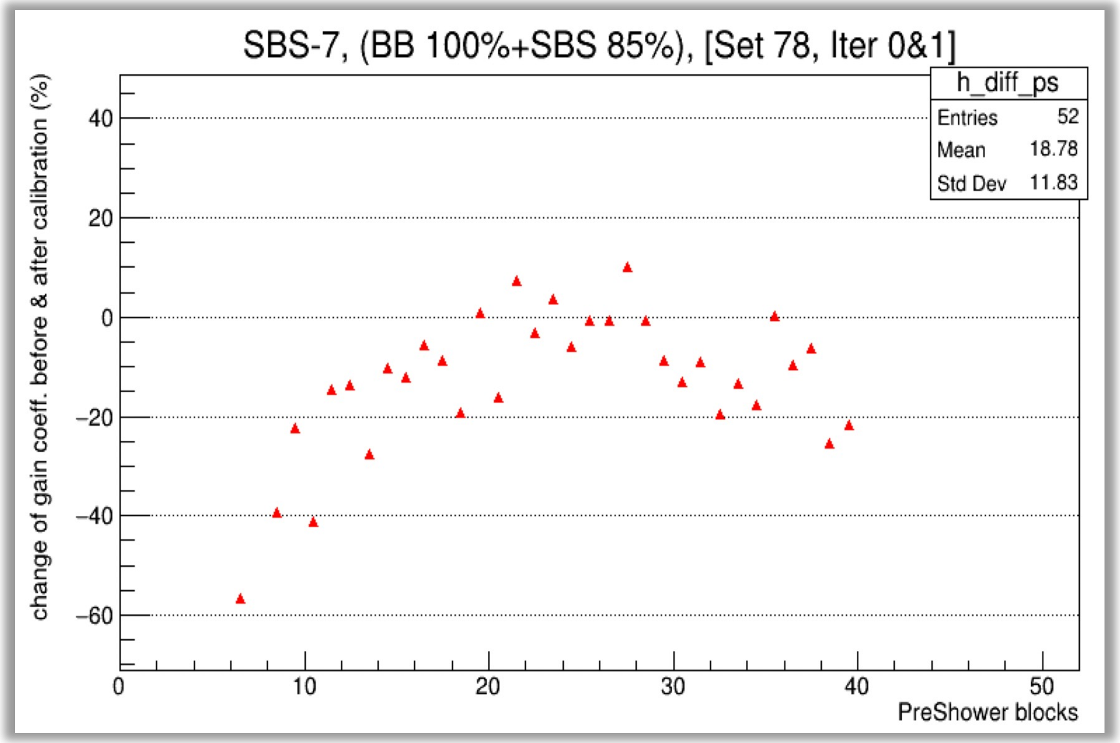
Table I: **BBCAL energy resolution before and after calibration for all SBS configurations.**

Configuration	E_{beam} (GeV)	$E_{e'}$ (GeV)	Magnet Current (A)		BBCAL Resolution (%)	
			BB	SBS	Before Calib.	After Calib.
SBS-4	3.728	2.11	750	0	8.9	**6.5**
			750	630	8.6	**6.6**
			750	1050	9.5	**6.6**
SBS-7	7.906	2.67	750	1785	9.4	**6.8**
SBS-11	9.91	2.67	750	0	12.3	**7.8**
			750	2100	12.2	**7.9**
SBS-14	5.965	2.00	750	0	10.5	**7.8**
			750	1470	10.7	**7.3**
SBS-8	5.965	3.59	750	0	9.8	**6.0**
			750	1050	9.8	**5.8**
			750	1470	9.8	**5.9**
			750	2100	9.8	**5.9**
SBS-9	4.015	1.63	750	1470	9.7	**7.8**

- Completed **initial** calibration of all 13 different settings across 6 SBS configurations.
- Achieved **5.9% energy resolution at 3.6 GeV** scattered e^- energy.
- Work in progress for the most challenging setting (SBS-11).

How Good is Cosmic Calibration?



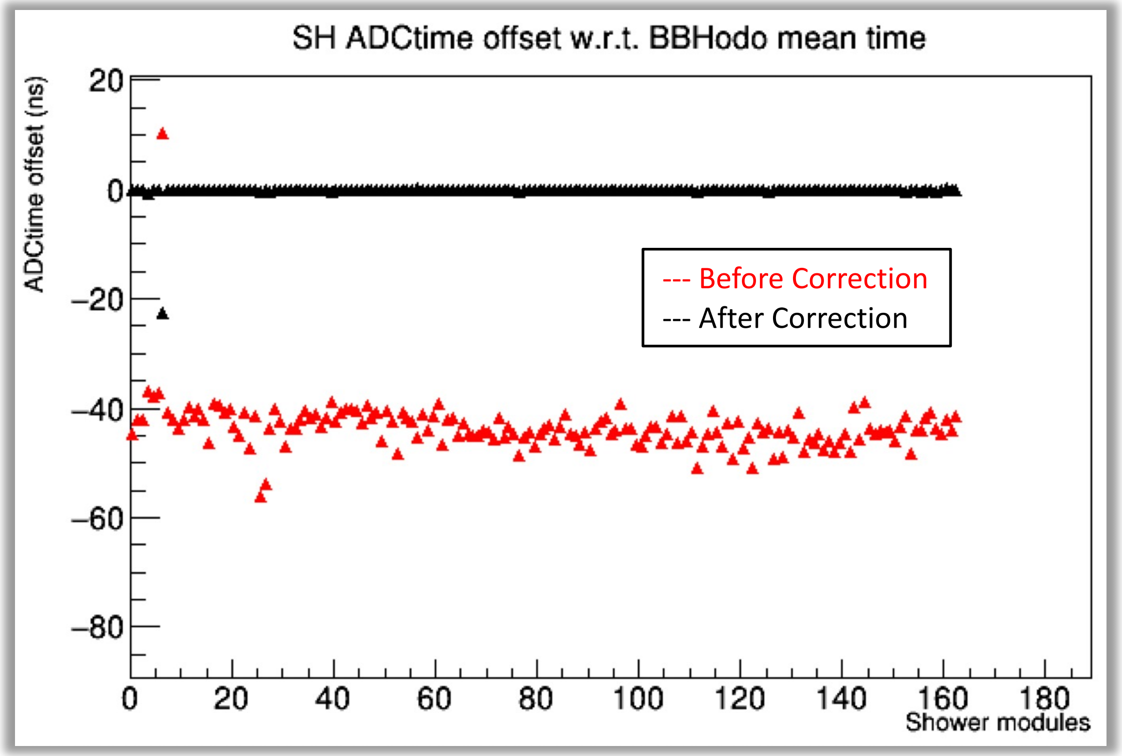


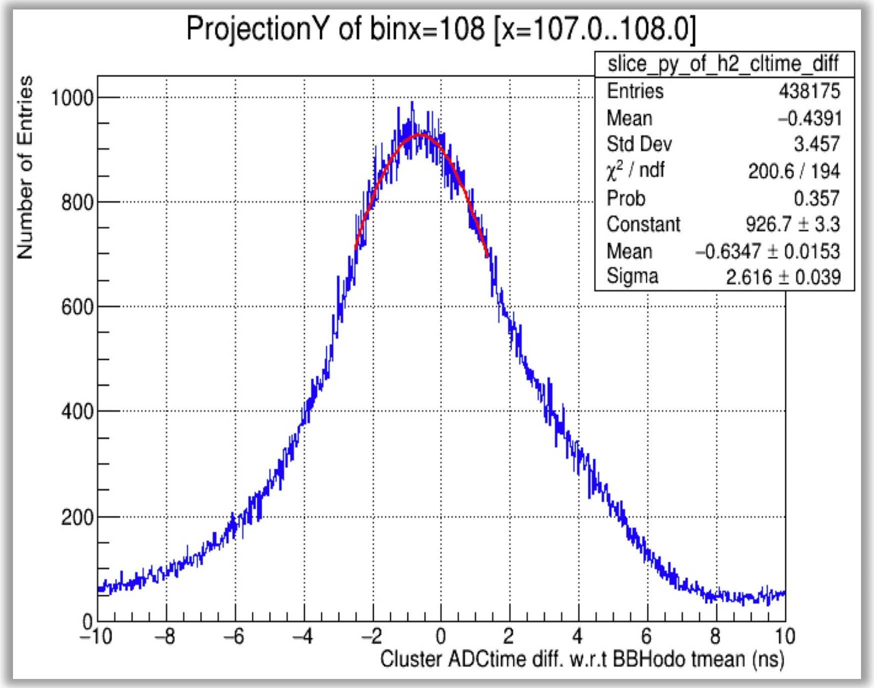
- Y-axis represents:

$$\left(\frac{ADC\ gain\ coeff.\ after\ calibration\ with\ LH_2\ data}{ADC\ gain\ coeff.\ estimated\ using\ cosmic} - 1\right)\times 100\%$$

- For SH, the differences are mostly concentrated within $\pm 10\%$ but for PS the range is more like $\pm 20\%$. Not bad at all!

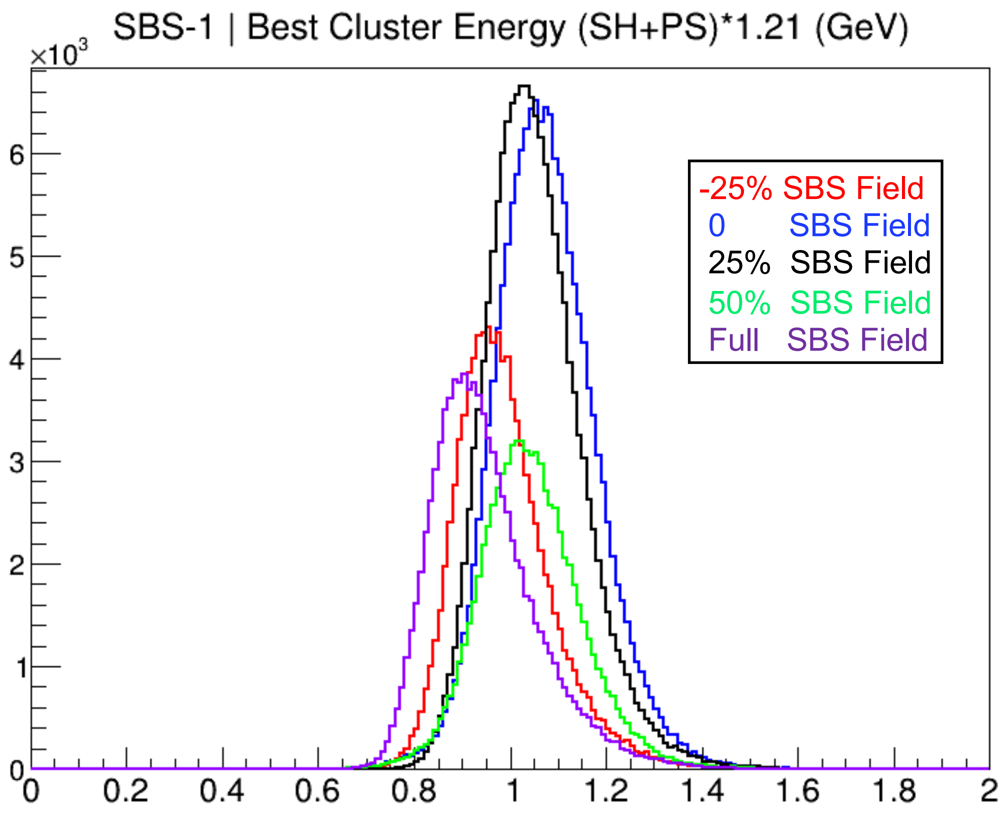
ADC Time Offset Correction





- **Left Plot:** Shows results of ADC time offset correction for individual shower blocks w.r.t BBHodo cluster mean time. Similar results were achieved for Pre-Shower modules as well.
- **Right Plot:** Shows the distribution of the difference between BBHodo cluster mean time and ADC time of all blocks of the corresponding SH cluster. Resolution achieved: **2.62 ns** (Preliminary).
- Time walk corrections are yet to be implemented.

Biggest Challenge During G_M^n Run! – The Issue



SBS Field (%)	Mean (GeV)	Sigma (GeV)	Change w.r.t. 0 field (%)
-25	0.9606	0.0831	9.5
0	1.0612	0.0954	0
25	1.0323	0.0894	2.7
50	1.0295	0.0948	3.0
100	0.9091	0.0834	14.3

- Configuration: SBS-1
- Target: LH_2
- Events selected: Elastic (Tight cut on W)

- Above plots show the distribution of total BBCAL cluster energy at different SBS field settings.
- Analysis of SBS 0 field data shows that the energy calibration of BBCAL with cosmics was 21% off. In order to compensate for that discrepancy, we have multiplied the total cluster energy with a constant factor of 1.21.
- Preliminary results show, **SBS fringe field** has non-negligible effect on BBCAL PMT gain.

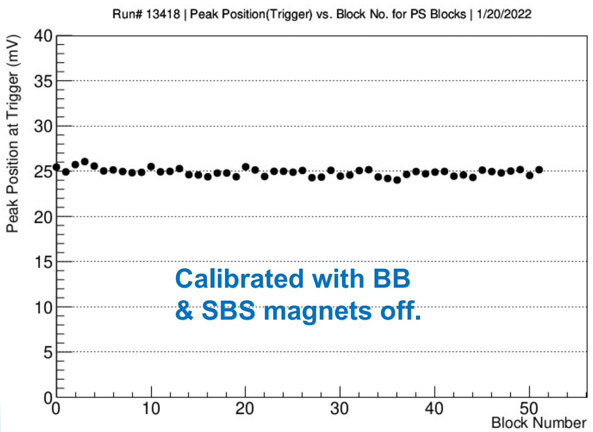
* *https://logbooks.jlab.org/entry/3932475*

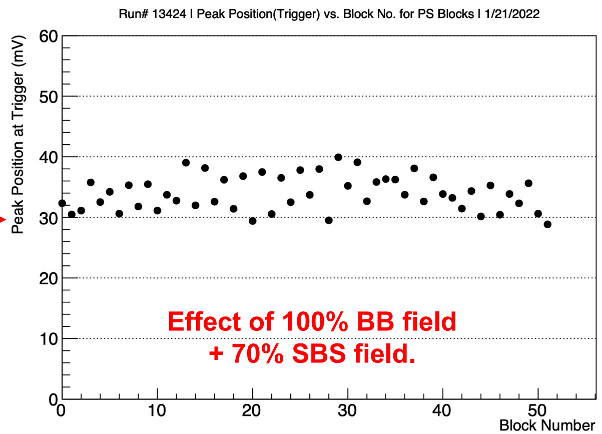
Biggest Challenge During G_M^n Run! – The Solution

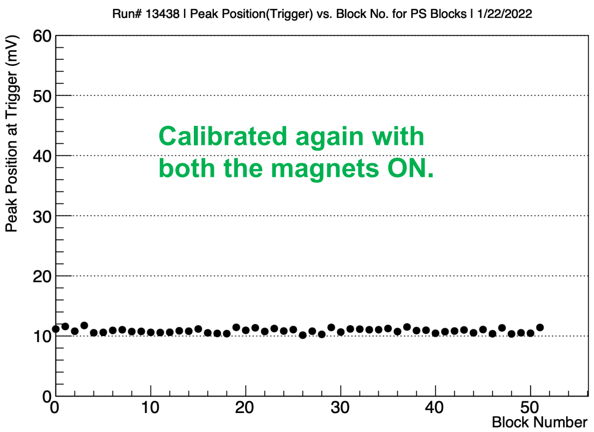
3 Step Solution:

1. Start off with a calibrated HV setting for both magnets OFF .
2. Turn the magnets ON and then take a quick cosmic run (~30 mins).
3. Recalibrate and generate a new set of HVs.

Fringe Field Effect on **PS** Peak Positions

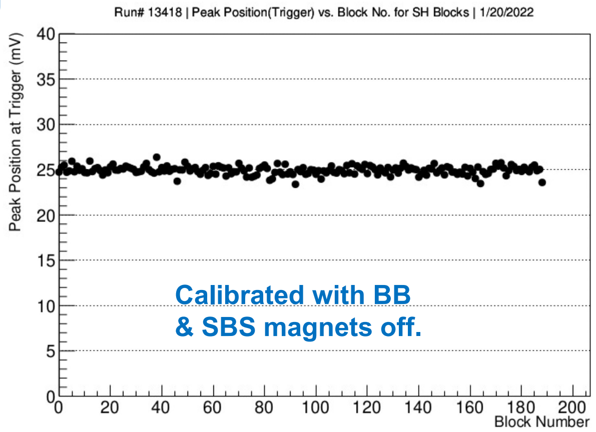


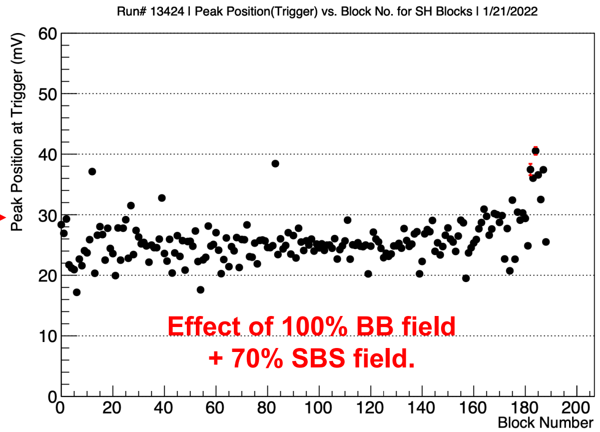


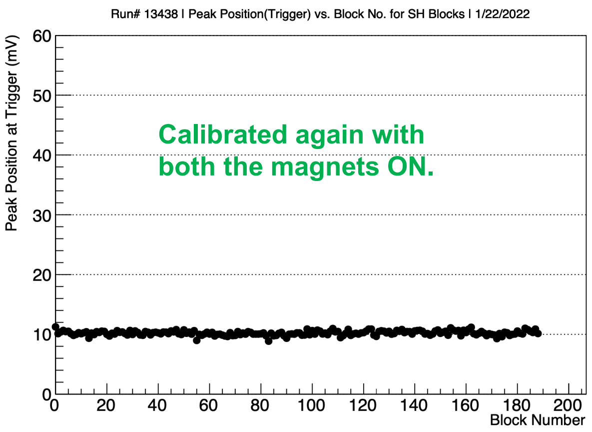


X-axis: Block Number (PS/SH)
Y-axis: Peak Position (at Trigger)

Fringe Field Effect on **SH** Peak Positions







- We tried this solution for all the later SBS configurations, and it worked beautifully.

Summary & Future Work

- We came across a lot of different challenges during SBS-G_M^n run.
- But we could overcome all of those by working as a team and kept notes of all the lessons learned.
- **BBCAL trigger during SBS-G_M^n was very stable.** It allowed us to set the threshold very high to keep DAQ rate manageable without loosing elastic events.
- Performance of BBCAL look promising even with very preliminary calibrations.
- This is very encouraging since all the upcoming SBS experiments, except for G_E^p 5, will use BBCAL for trigger as well as for energy measurements.
- No hardware upgrade or major changes is required, so **BBCAL is pretty much ready for the SBS-G_E^n experiment** which is scheduled to run later this fall.

Acknowledgements

- **Core Group:** Bogdan W., Mark Jones, Arun Tadepalli*, Provakar Datta, Eric Fuchey.
- **Software/Analysis Support:** Andrew Puckett, William Tireman, Gary Penman.
- **DAQ:** Alexandre Camsonne, Bryan Moffit, Ben Raydo.
- **Slow Control:** Steve Wood.
- **Installation:** Jessie & his team, Robin & her team, Jack, Ellen, Sebastian Seeds, Bhesha Devkota, Hem Bhatt, Zeke Wertz, Abishek Karki.
- **Hardware Support:** JLab Electronics group, Chuck Long, Detector Support Group.
- **Useful Suggestions:** Brad Sawatzky.
- A lot of other people whose name I cannot recall at the moment. **Thank you all!**

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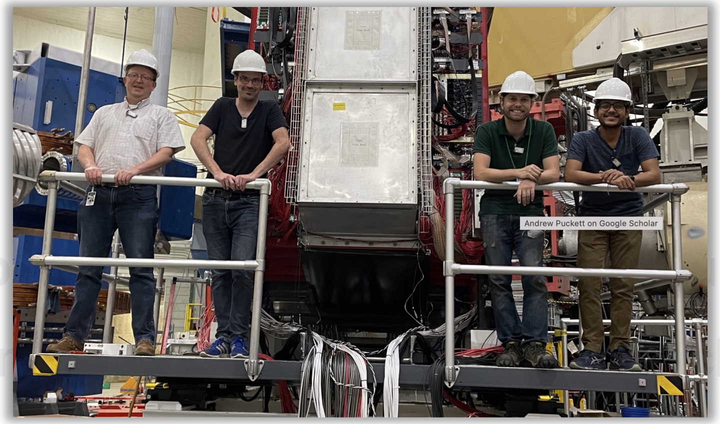

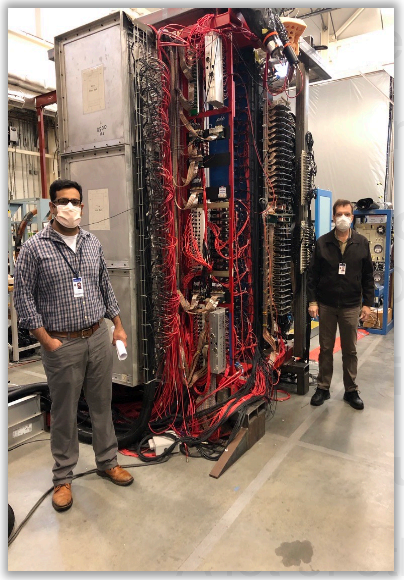

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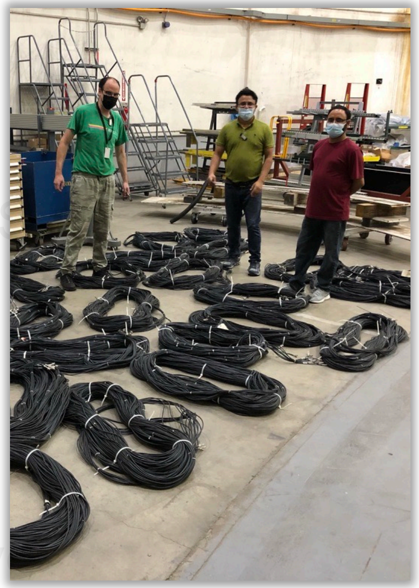
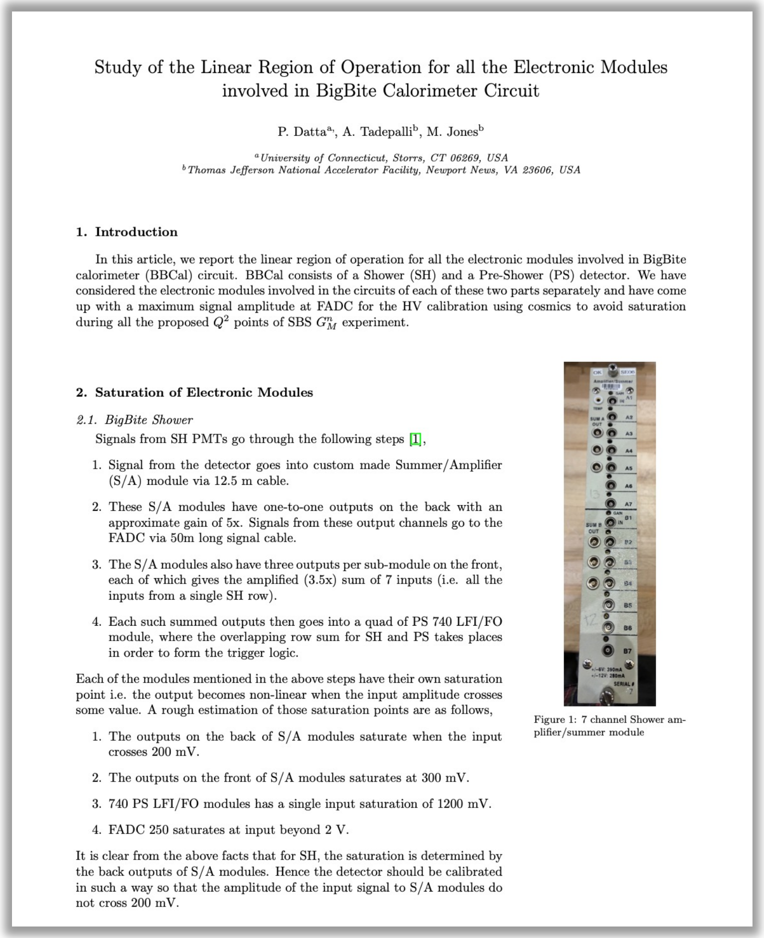


- Core Group ... n T ... a, Eric Fuchey.
- Software/A ... kett ... Penman.
- ... x Camsonne, Bryan Moffit, Ben Raydo.
- ... ntrol: Steve Woods.
- ... on: Jessi ... his team, Robin ... her team, Jack, Ellen, Sebastia ...
- ... Devkot ...
- ... ics & Hardware Support: JLab Electronics group, Chuck Long.
- ... uggestions: Brad Sawatzky.
- ... her people whose name I cannot recall at the moment. Thank y ...

❖ This work is supp ... nt o ... e, Office of Nuclear Physics, ...

Backup Slides

Resources



Study of the Linear Region of Operation for all the Electronic Modules involved in BigBite Calorimeter Circuit

P. Datta[a], A. Tadepalli[b], M. Jones[b]

[a] University of Connecticut, Storrs, CT 06269, USA
[b] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

1. Introduction

In this article, we report the linear region of operation for all the electronic modules involved in BigBite calorimeter (BBCal) circuit. BBCal consists of a Shower (SH) and a Pre-Shower (PS) detector. We have considered the electronic modules involved in the circuits of each of these two parts separately and have come up with a maximum signal amplitude at FADC for the HV calibration using cosmics to avoid saturation during all the proposed Q^2 points of SBS G_M^n experiment.

2. Saturation of Electronic Modules

2.1. BigBite Shower

Signals from SH PMTs go through the following steps [1],

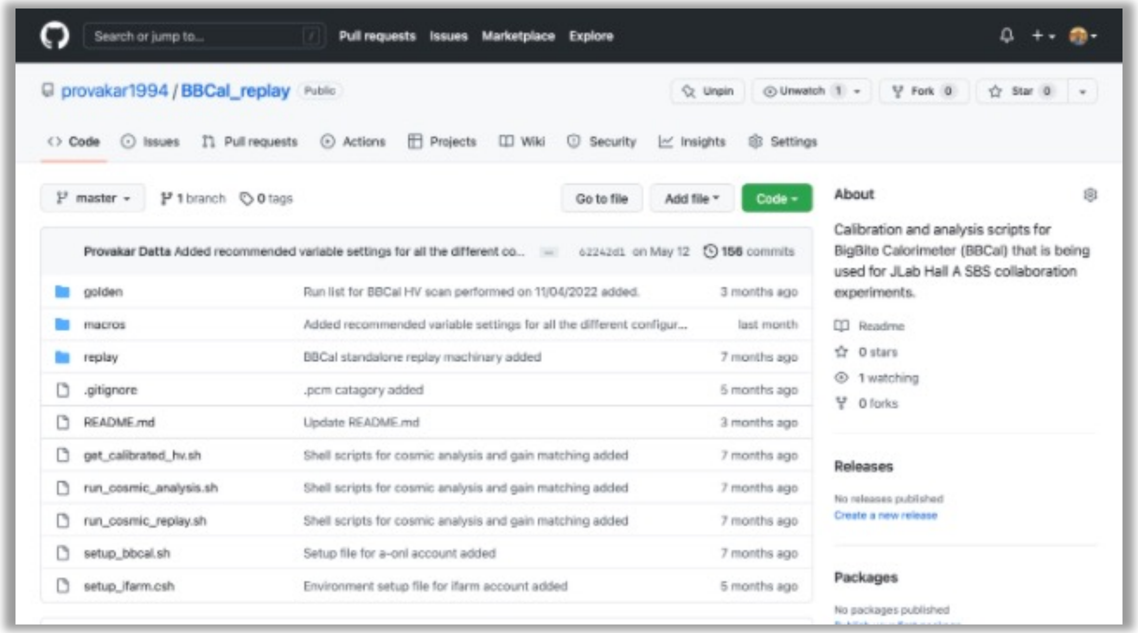
1. Signal from the detector goes into custom made Summer/Amplifier (S/A) module via 12.5 m cable.
2. These S/A modules have one-to-one outputs on the back with an approximate gain of 5x. Signals from these output channels go to the FADC via 50m long signal cable.
3. The S/A modules also have three outputs per sub-module on the front, each of which gives the amplified (3.5x) sum of 7 inputs (i.e. all the inputs from a single SH row).
4. Each such summed outputs then goes into a quad of PS 740 LFI/FO module, where the overlapping row sum for SH and PS takes places in order to form the trigger logic.

Each of the modules mentioned in the above steps have their own saturation point i.e. the output becomes non-linear when the input amplitude crosses some value. A rough estimation of those saturation points are as follows,

1. The outputs on the back of S/A modules saturate when the input crosses 200 mV.
2. The outputs on the front of S/A modules saturates at 300 mV.
3. 740 PS LFI/FO modules has a single input saturation of 1200 mV.
4. FADC 250 saturates at input beyond 2 V.

It is clear from the above facts that for SH, the saturation is determined by the back outputs of S/A modules. Hence the detector should be calibrated in such a way so that the amplitude of the input signal to S/A modules do not cross 200 mV.

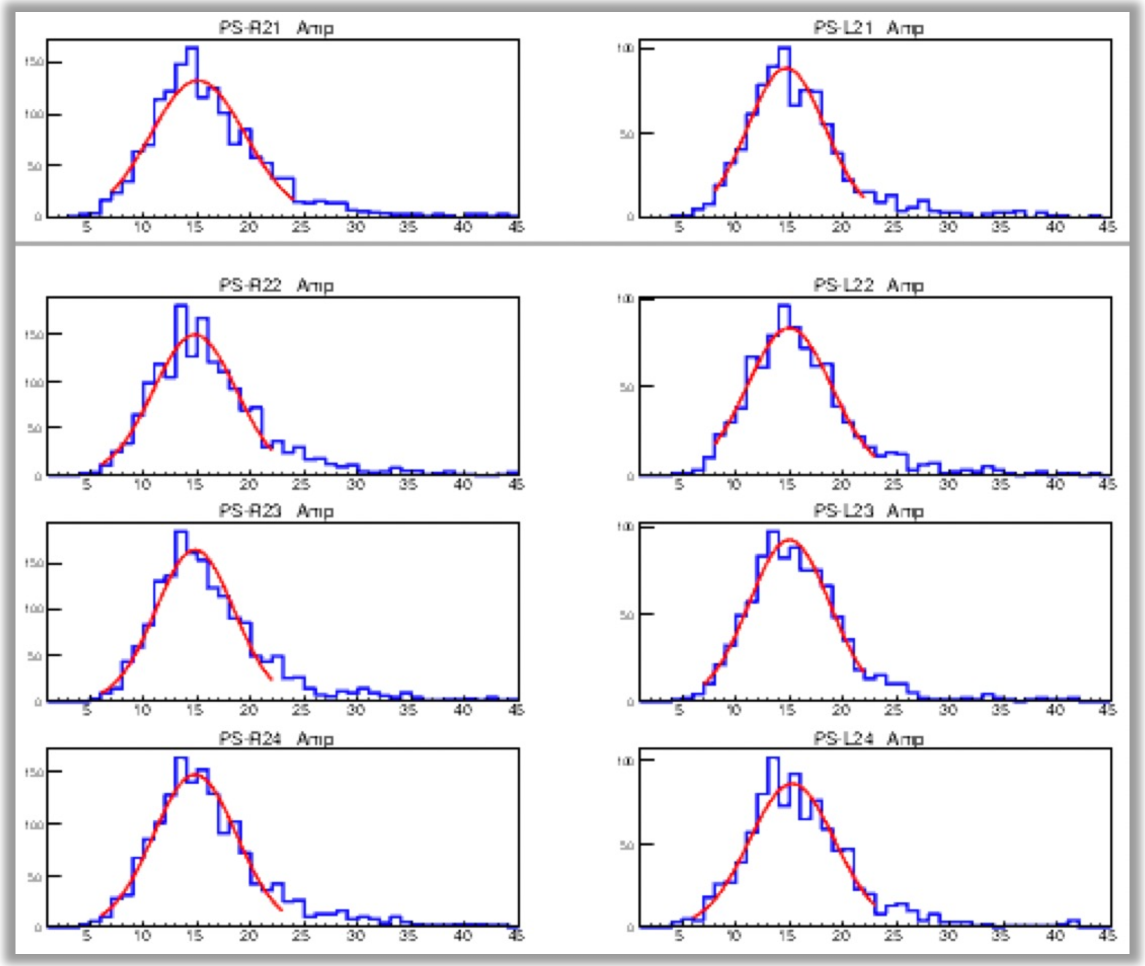
Figure 1: 7 channel Shower amplifier/summer module

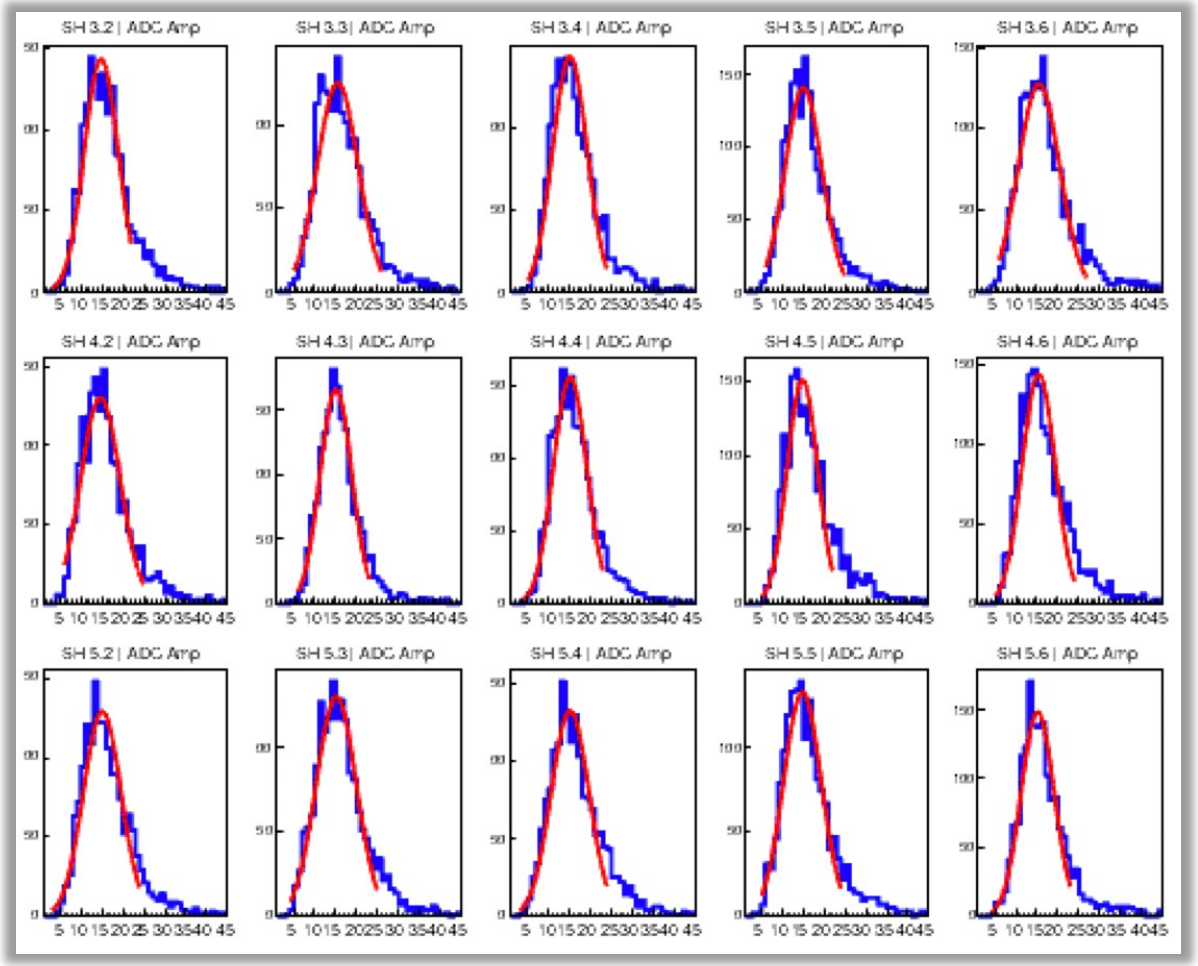


https://sbs.jlab.org/DocDB/0001/000118/001/BBCal_sig_circuit_saturation.pdf

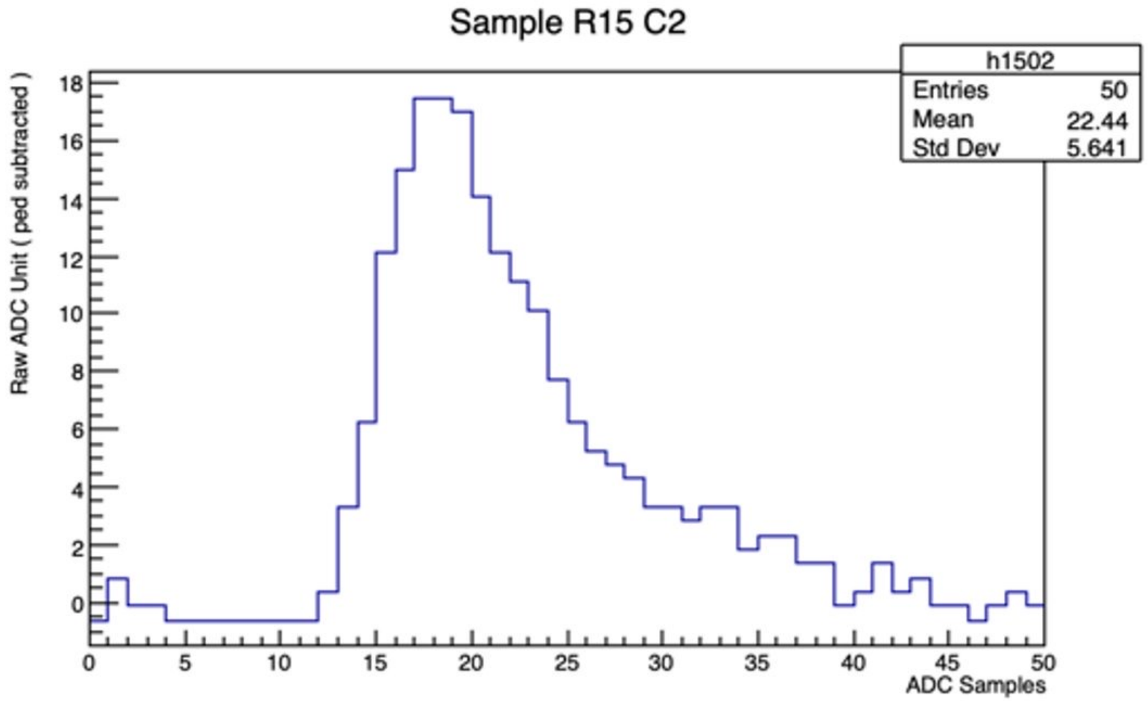
https://github.com/provakar1994/BBCal_replay

Cosmic Peaks – PS and SH





ADC time calculation

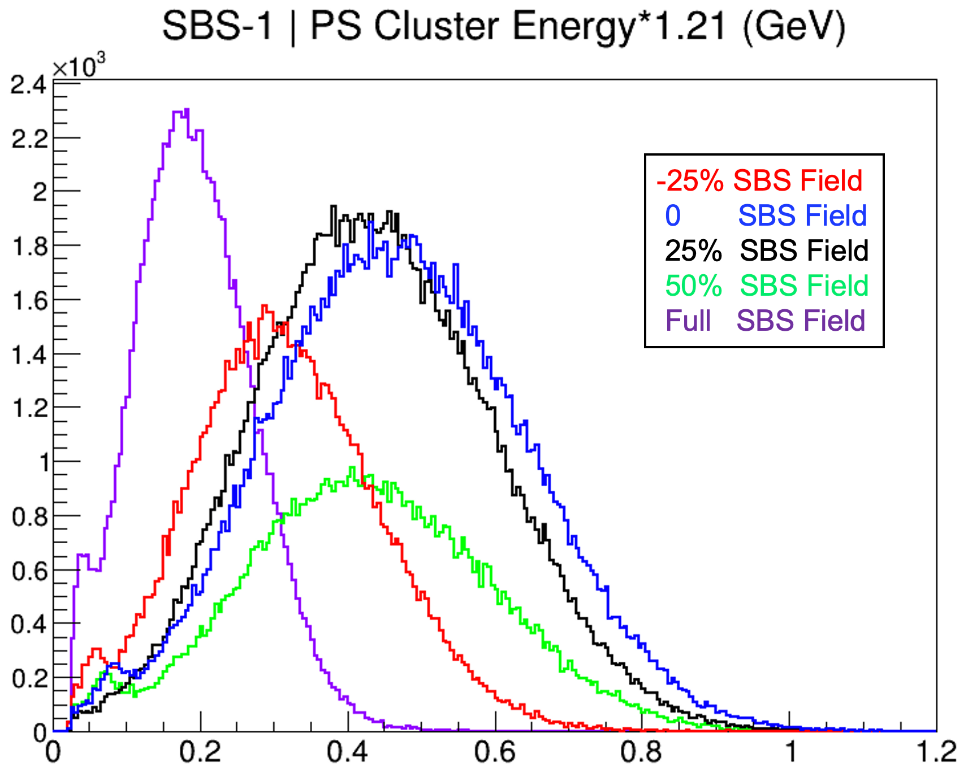


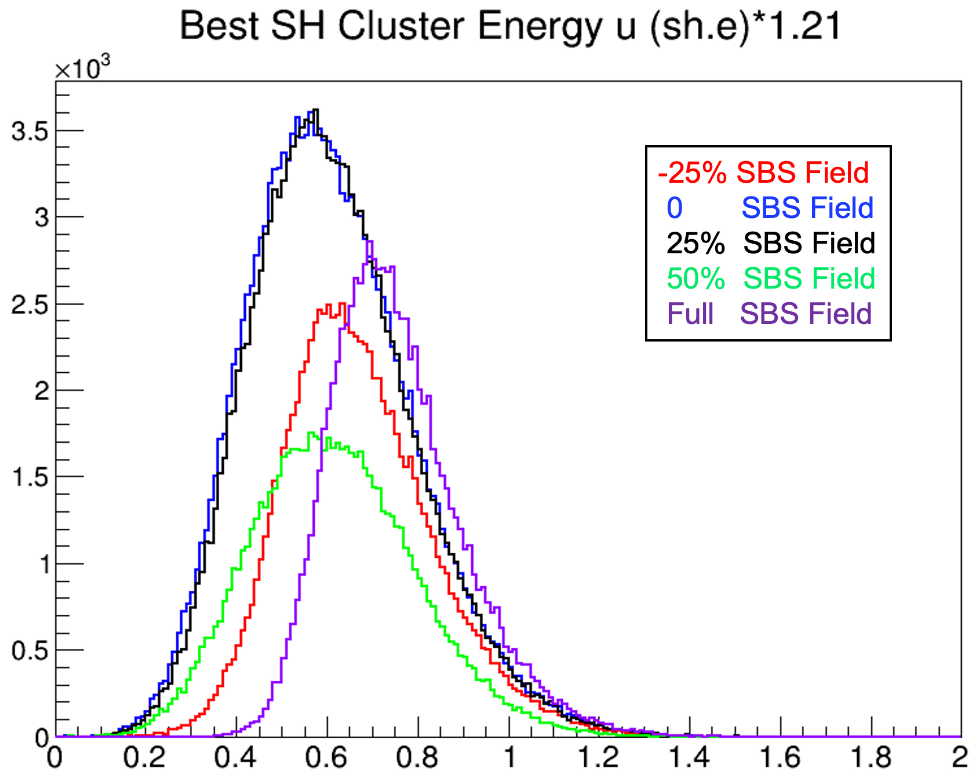
$$FADC_{time} = 4ns * [i + \frac{V_{Mid} - V_i}{V_{i+1} - V_i}]$$

here, $$V_{Mid} = \frac{(V_{peak} + pedestal)}{2}$$

- "*i*" is the sample which has value greater than V_{Mid} and the next sample, "*i+1*", is less than V_{Mid}.

SBS Fringe Field Effect – PS and SH





Example HV Configuration – PS and SH