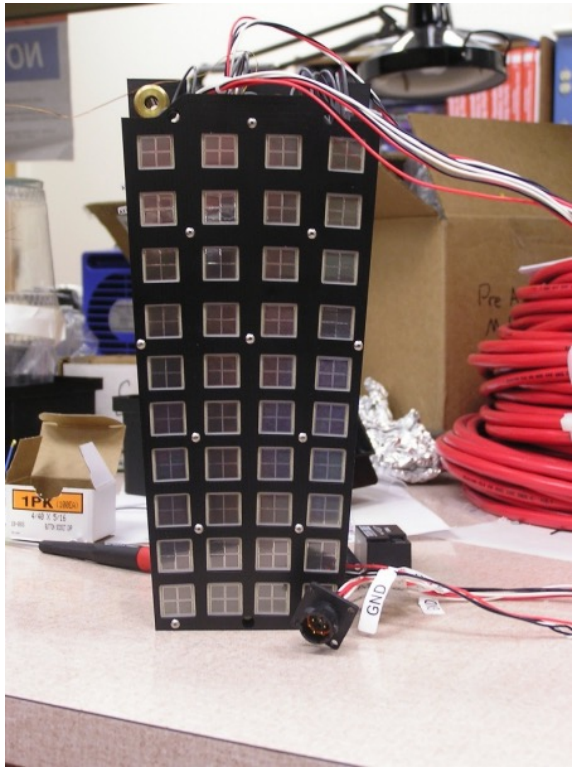
“Baby ” BCAL Progress Report

Jon Zarling

5/14/24



Primary Goals

Using 58 cm “baby” BCAL sector, improve determination of:

- Resolution (σ_E/E)
- Number of photoelectrons per GeV ($N_{p.e.}$)

GlueX BCAL: coverage up to 2 GeV

Pair Spectrometer in Hall D: **3-6 GeV**

e^+ Beam Setup

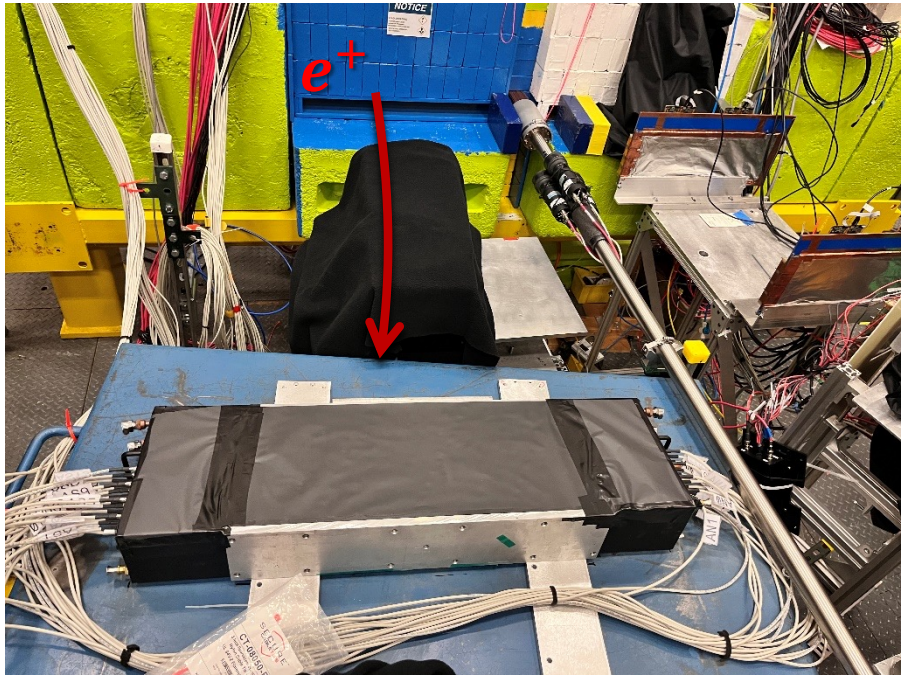
Good source of EM showers with known energy

Essentially identical to GlueX lead SciFi wedge, except 58 cm in length rather than 390 cm

Hall D pair spectrometer setup:

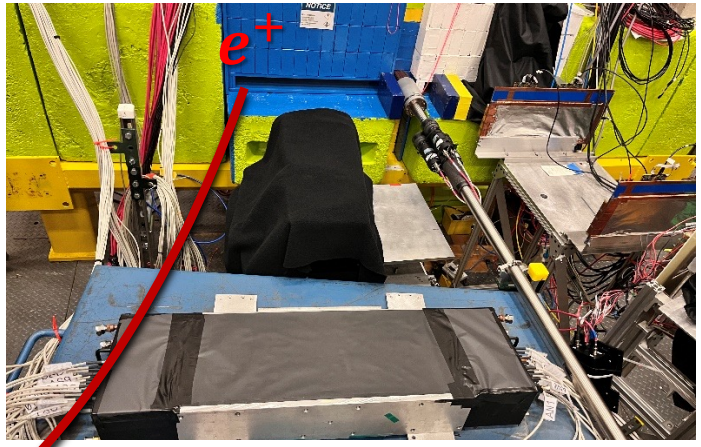
- e^+ tagged upstream roughly 3-6 GeV
- Unfortunately, SciGlass blocks portions
- About 1 kHz event rate BBCAL
- About 12 days (on and off) running

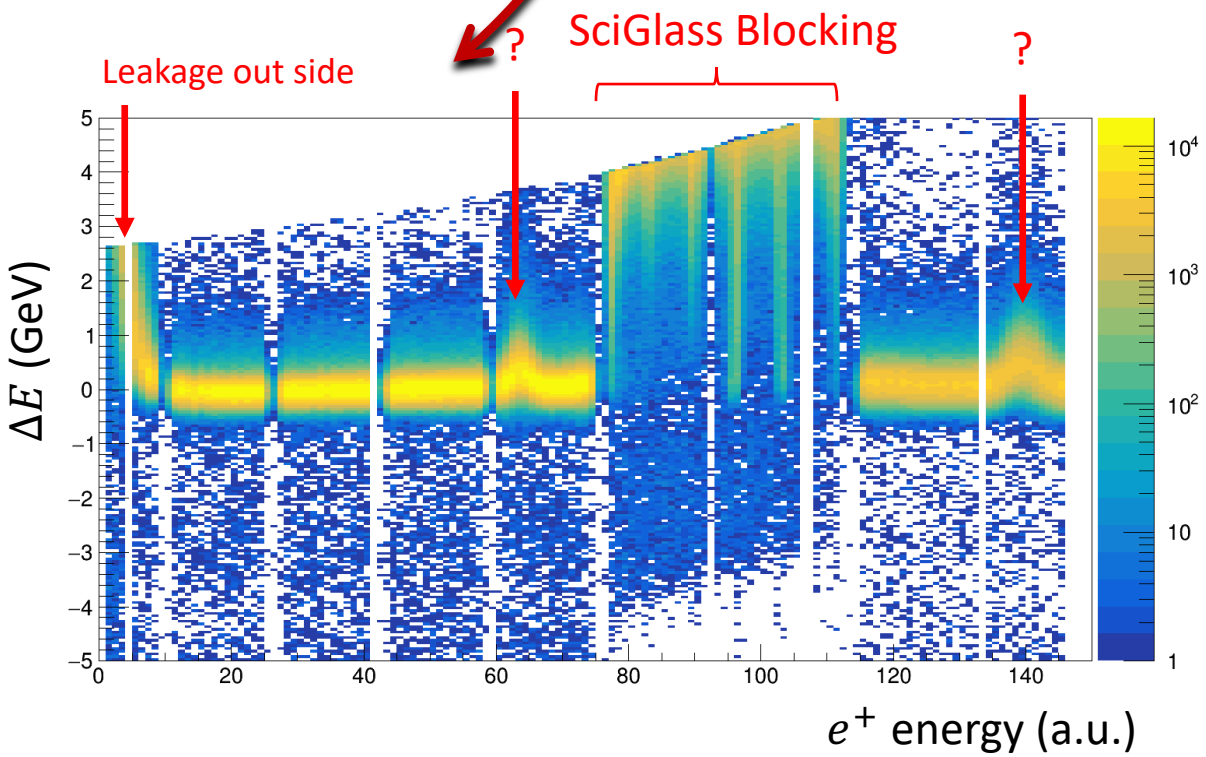
View from above



Pair Spectrometer Setup

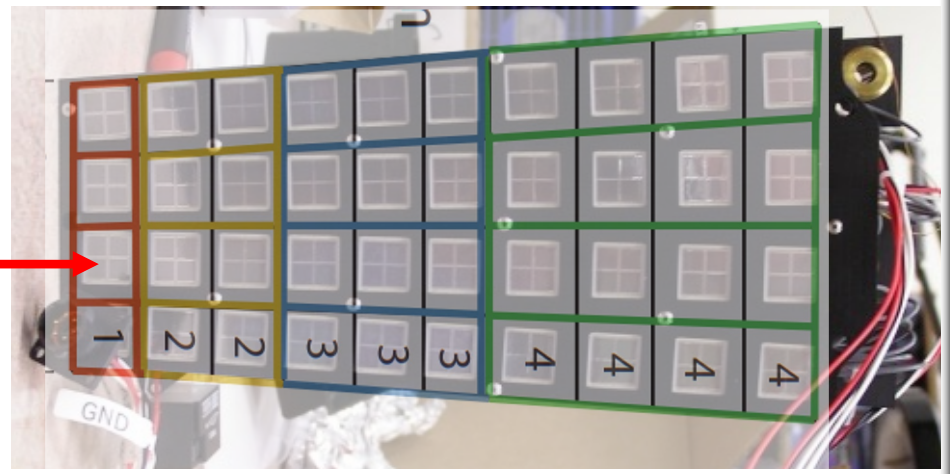
View from above





View from side

e^+



(summation for bottom channels 1, 2, 3, 4)

Energy Calibration

Not calibrated prior! Fortunately e^+ energy is known.

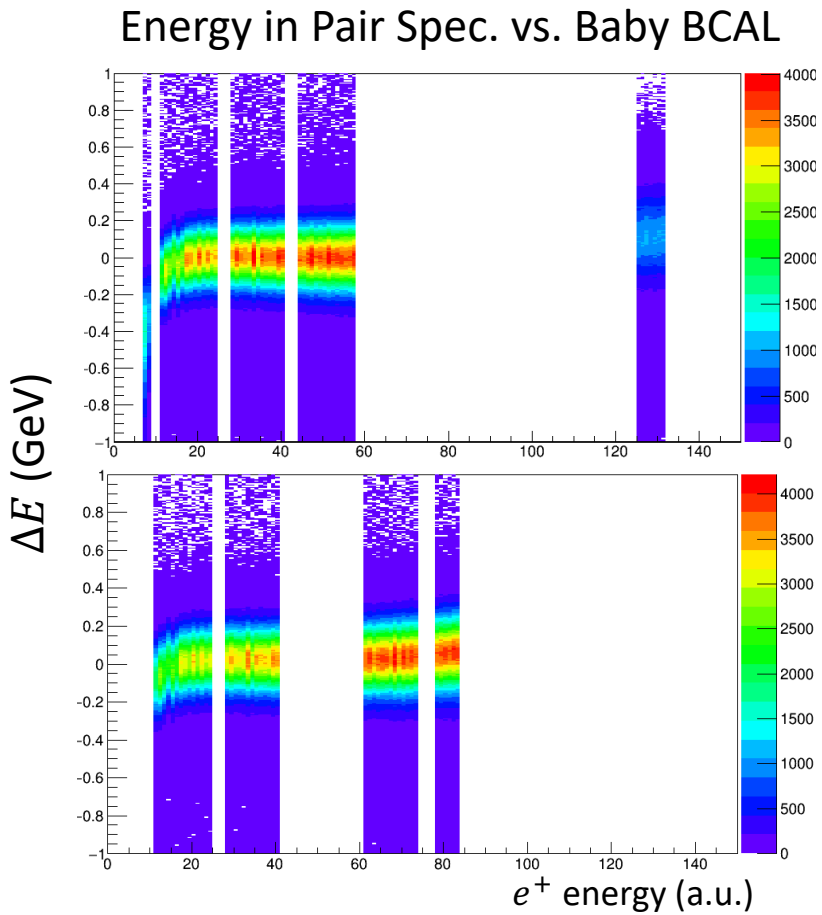
Can solve for (linear-only) gain factors c_k

- Minimize $F = \sum_i^{events} \left(E_i^{BCAL} - E^{PS}\right)^2$

  E^{BCAL} is sum of north and south readouts

  $E^{BCAL} = \sum_j^{16} c_j \left(A_j^N + A_j^S\right) = \sum_j^{16} c_j \, A_j^{sum}$

- Calculate c_k with $\frac{\partial F}{\partial c_k} = 0$
- Math in backup slides



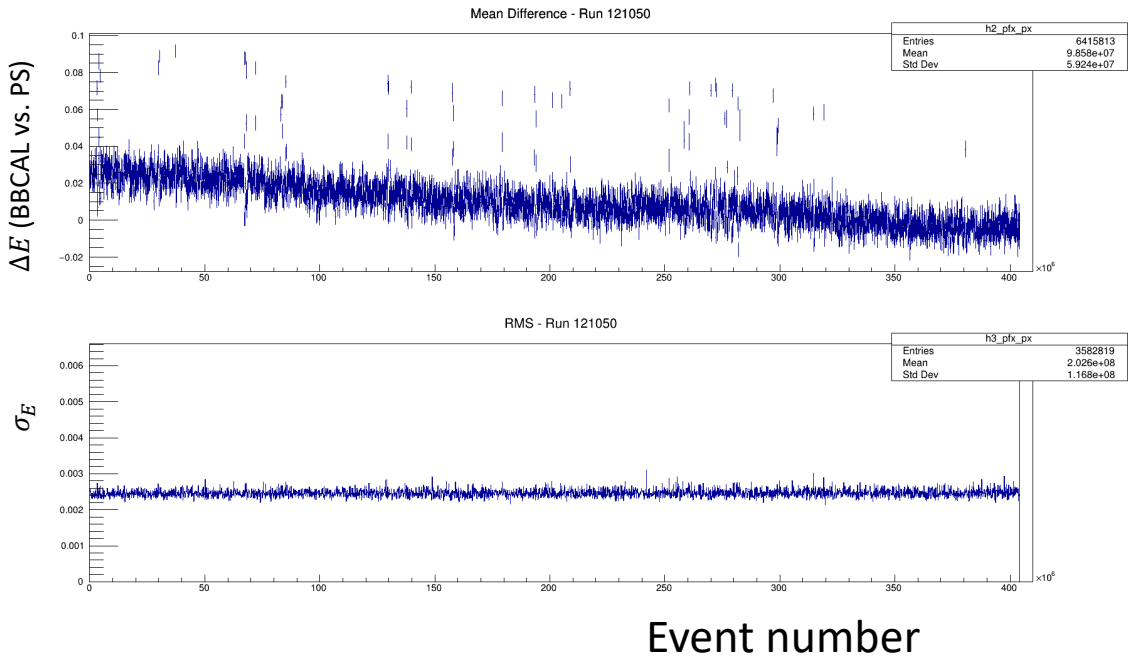
Quality Checks

Within run (one run ~ 2 hours)

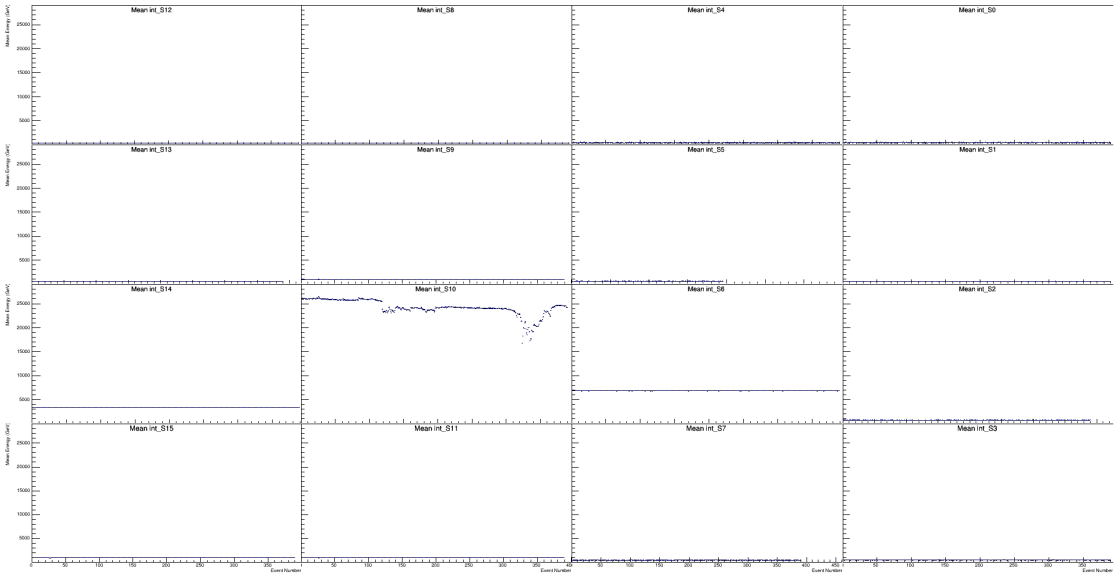
- Check individual channel stability
- Check overall energy stability

Broad features:

- Channel S10 stopped working early in March 23 data
- Resolution fairly stable over ~ few hours
- Some slow drift in overall energy, maybe temperature related?

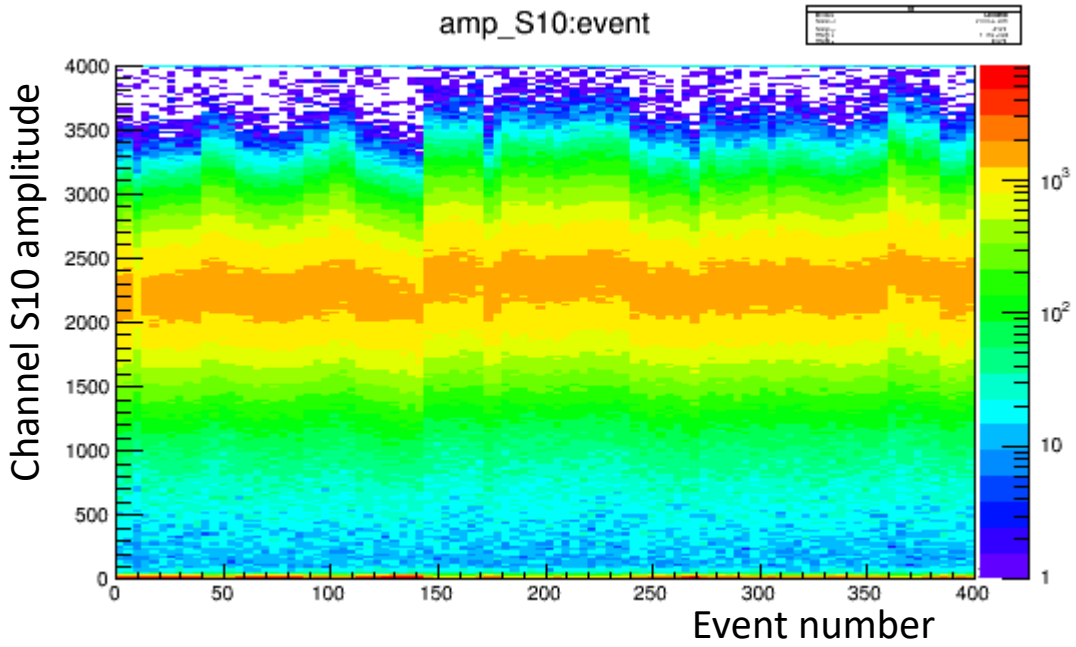


Individual Channels

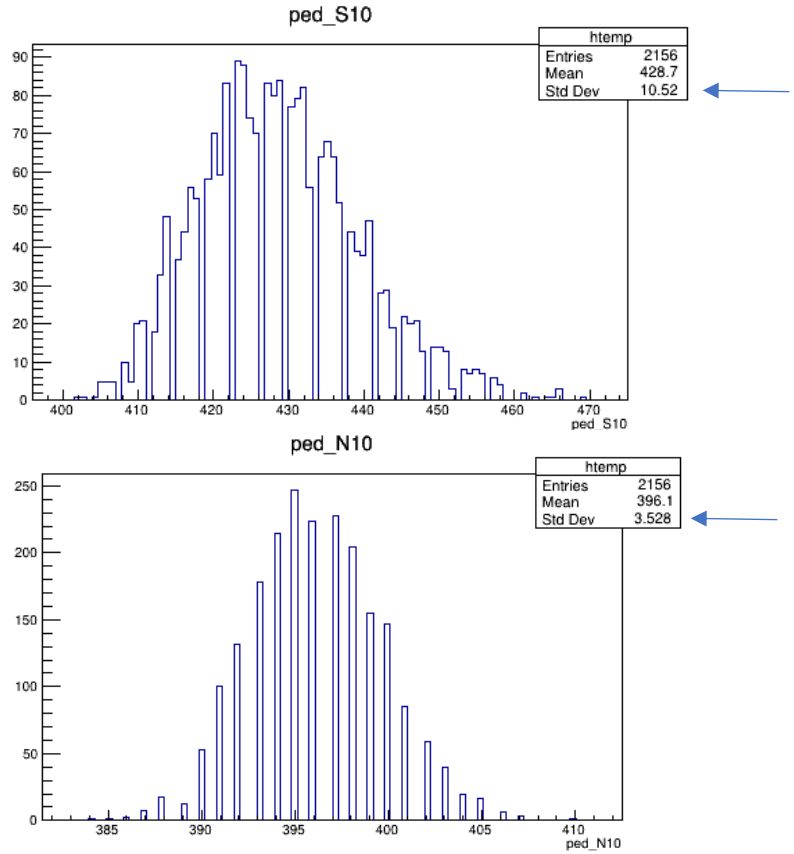


Quality Checks, cont.

- Channel S10 demonstrates time-instability
- Also higher dark rate (pedestal RMS)

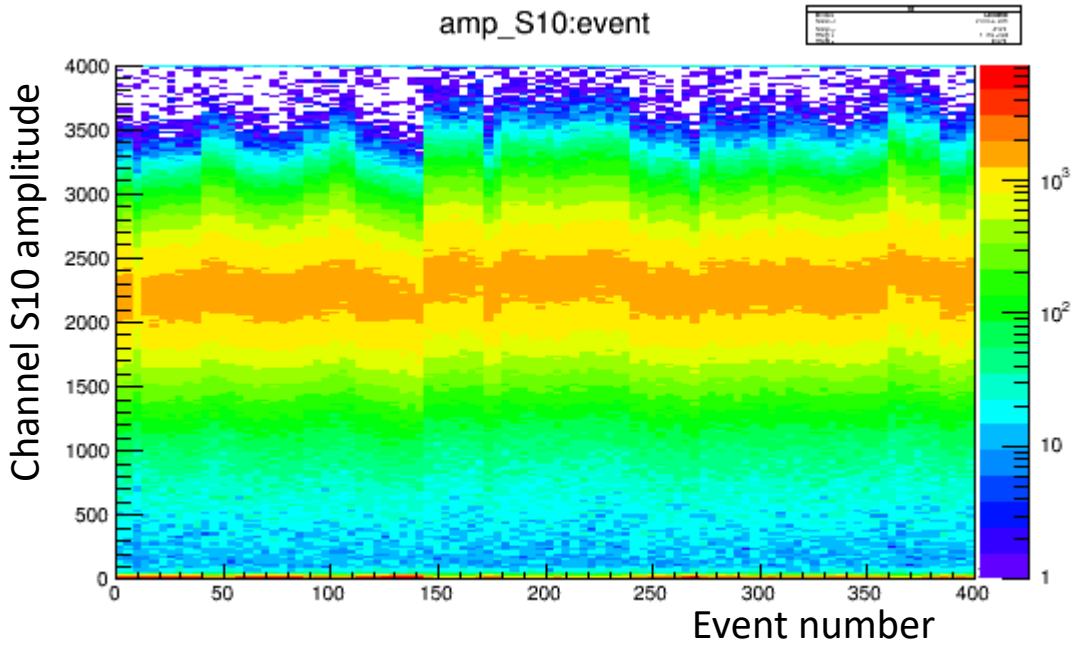


Measured Pedestal
(4 sample sum)

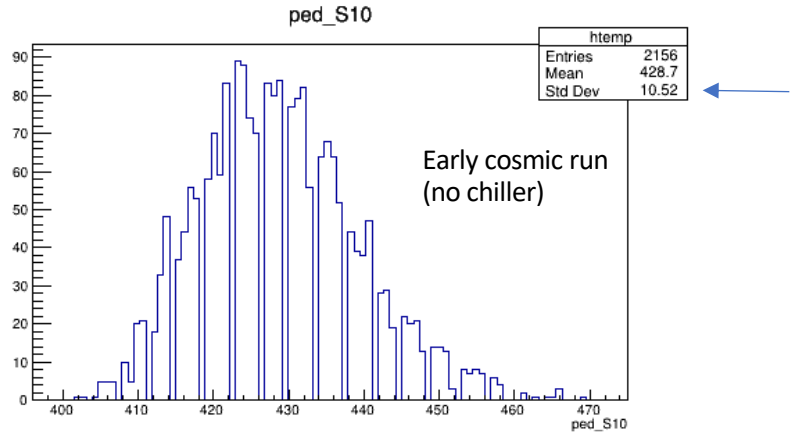


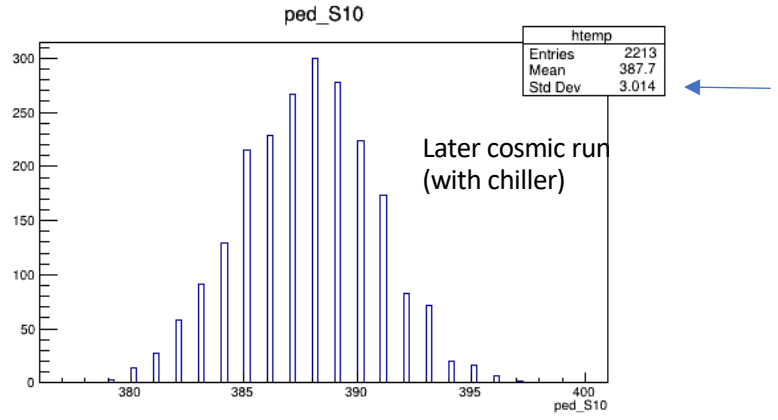
Quality Checks, cont.

- Channel S10 demonstrates time-instability
- Also higher dark rate (pedestal RMS)
- Somehow, recovered when chiller was put in (late cosmic runs)



Measured Pedestal
(4 sample sum)





Suspicious Channel Summary

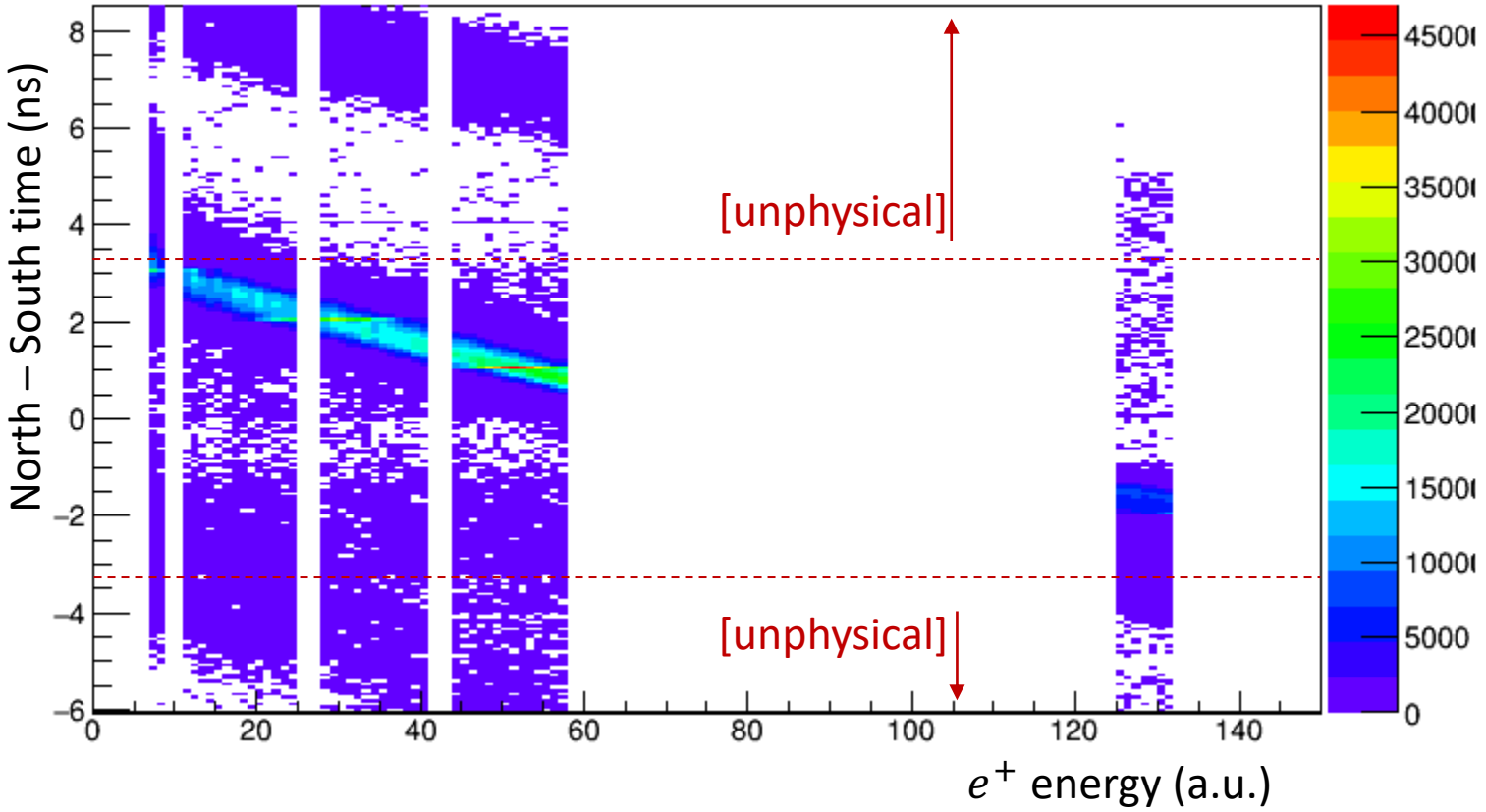
- S10: noisy, time-dependent, bad dark rate
  - Good: earliest runs in March
    + final cosmic runs (after chiller added)
  - Bad: everything in between
- S2 & S3: no signal in some cosmic runs
- Recommended checks:
  - Check ratio of N/S sides for each channel
  - Check pedestal RMS for dark rate

[run tracking spreadsheet]

Energy Leakage

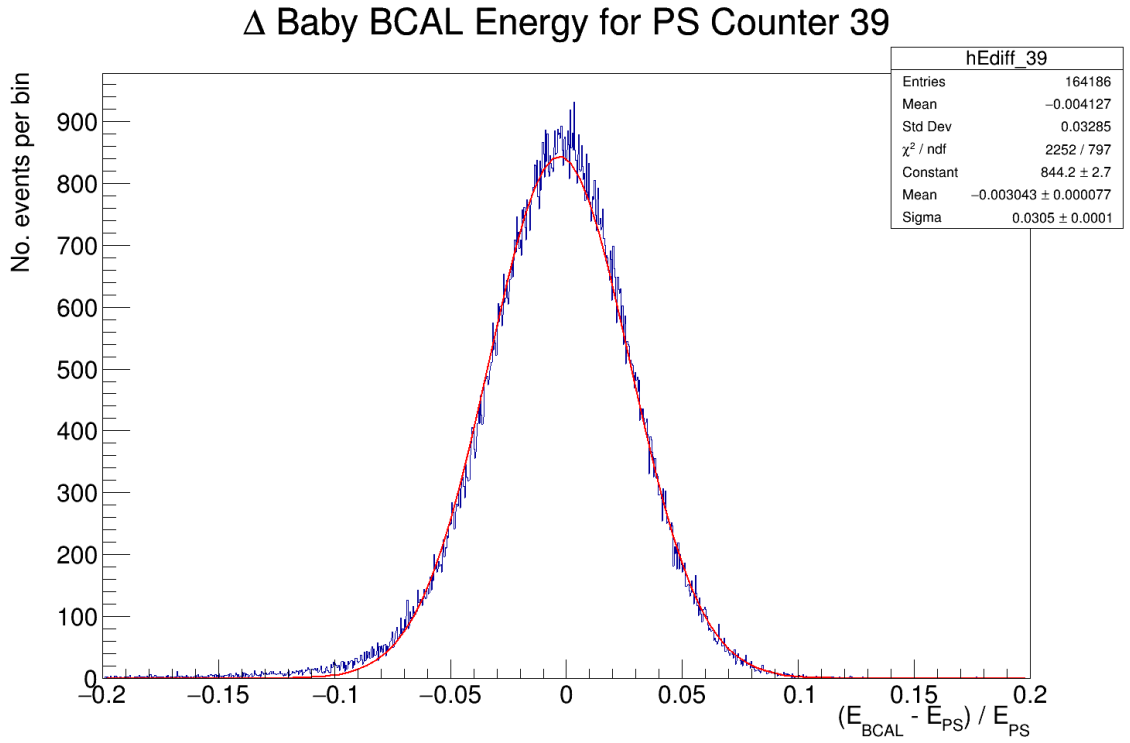
Timing difference confirms lowest energy e^+ hits at edge of baby BCAL

Dashed lines: time for signal to travel full length (58 cm)



Energy Resolution Extraction

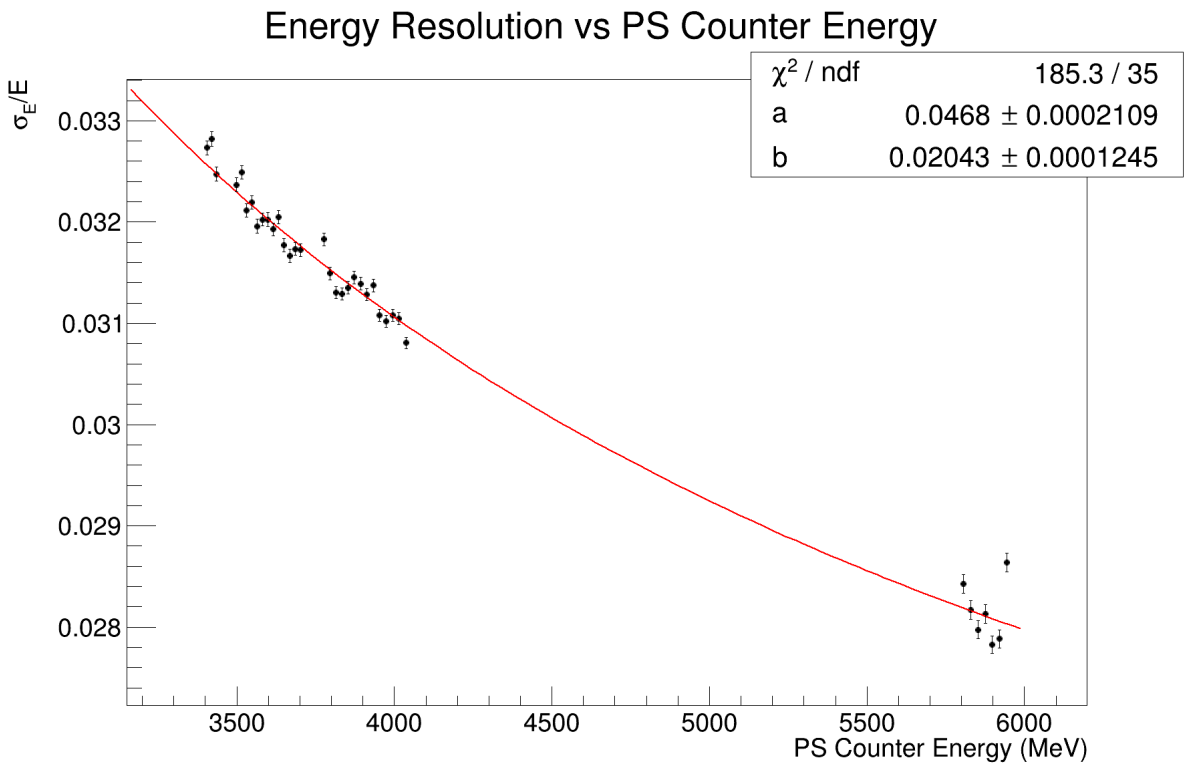
- Fit for single PS counter
  (positrons energy ± 10 MeV at most)
- Fit to get σ_E / E
- Repeat for all good PS counters



Energy Resolution

Fit function

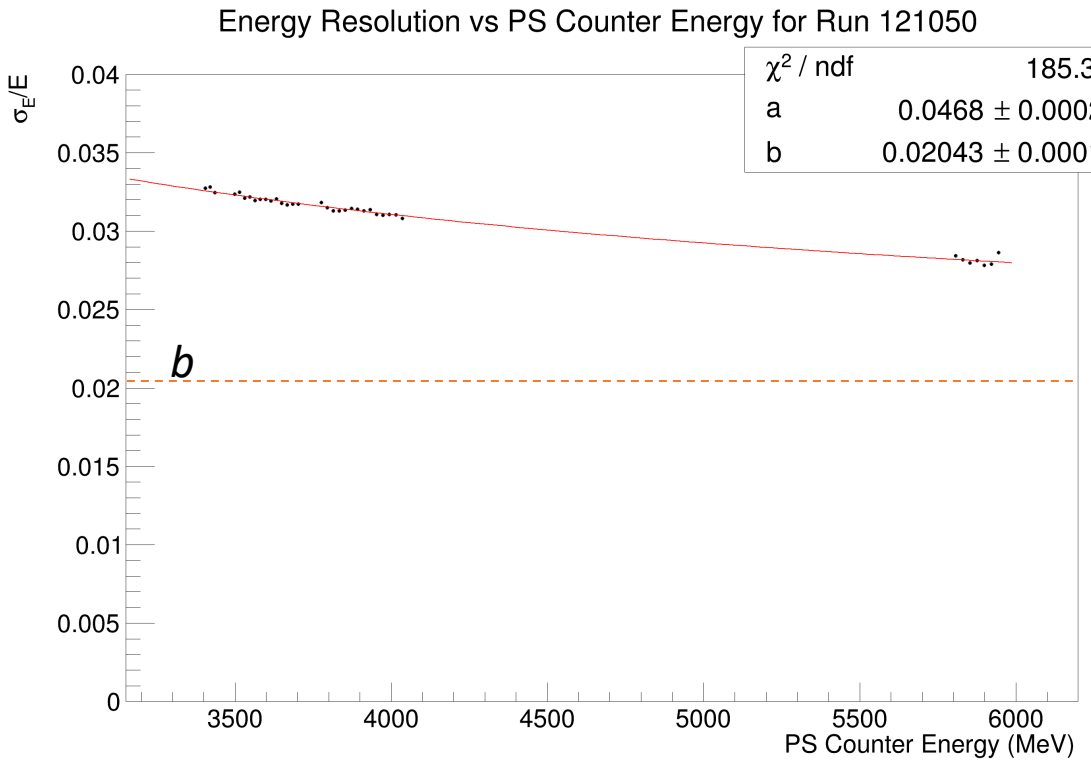
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}\,(\mathrm{GeV})} \oplus b$$



Energy Resolution (zoomed out)

Fit function

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}\,(\mathrm{GeV})} \oplus b$$



BCAL NIM (2018):

a: 0.052

b: 0.036

(measured via symmetric etas in $\gamma p \to \eta\pi^+\pi^-$p)

Energy Resolution

Run Number	a (stochastic term, $\sqrt{GeV}$)	b (flat term, unitless)
121050	0.047	0.020
121051	0.047	0.020
121128	0.047	0.023
121129	0.047	0.024
121185	0.047	0.23
121186	0.047	0.024
121197	0.046	0.021
121199	0.047	0.021
121200	0.047	0.021
121201	0.047	0.021
121204	0.046	0.021
121206	0.047	0.021

Reasonably consistent across runs

Number of Photoelectrons (per GeV)

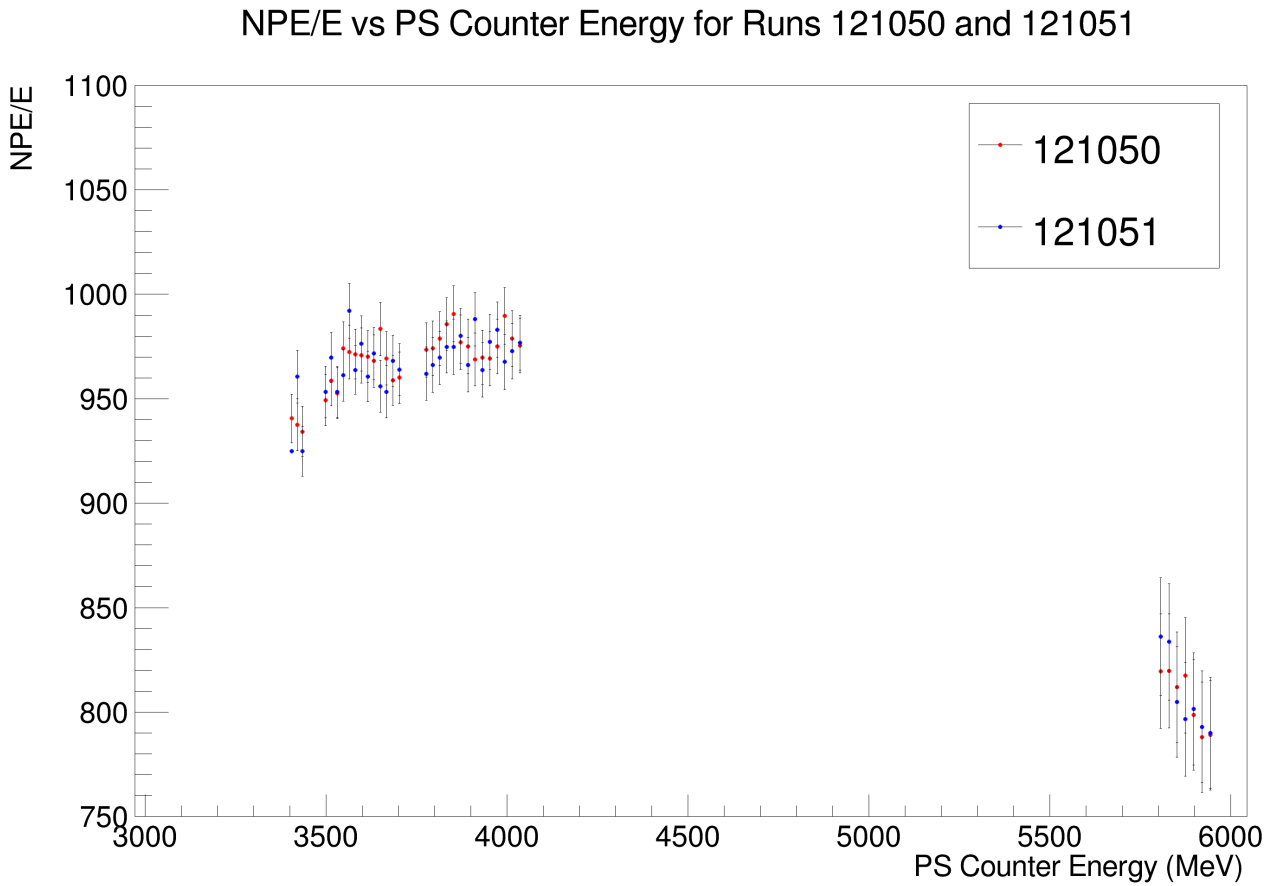
- Form the ratio of energy measured on north/south sides
  - Reduces uncertainty due to sampling fraction
  - Poisson-type statistical process on each end
  - N_{PE} extracted from fit

$$f(r) \sim \int P(x, N_{\mathrm{pe}} \cdot \sqrt{R}) \cdot \frac{1}{r} P\left(\frac{x}{r}, \frac{N_{\mathrm{pe}}}{\sqrt{R}}\right) \left[\frac{x}{r}\, \mathrm{d}x\right]$$

$$P(x, N) = \frac{\mathrm{e}^{-N} N^{x}}{\Gamma(x+1)}$$

BCAL prototype NIM: NIM **A596** (2008) 327-337

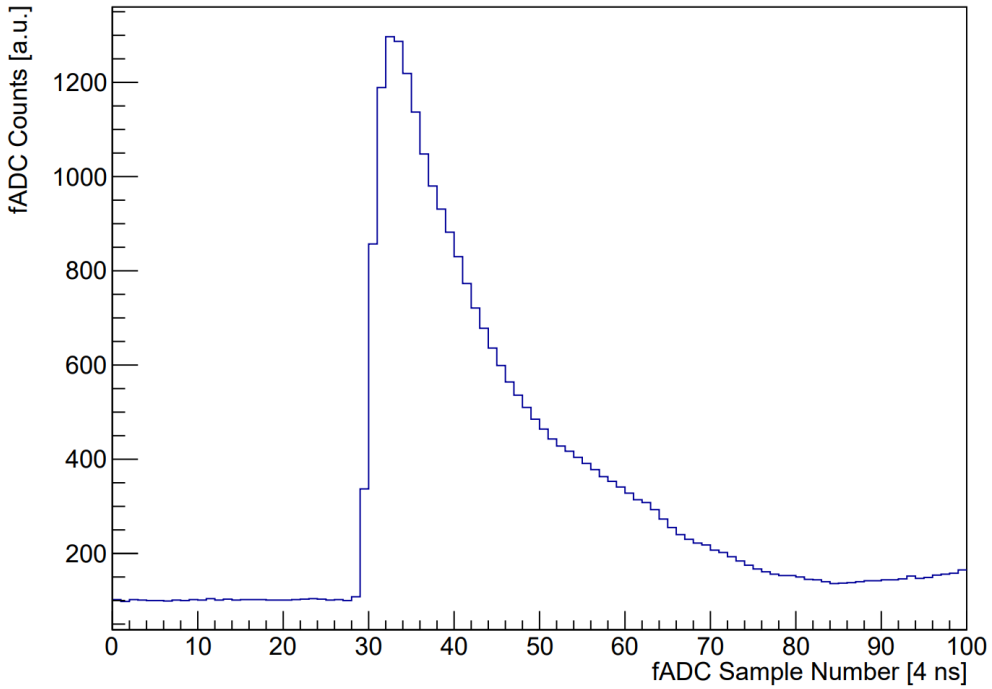
N_{PE} Over Positron Energy



[S10 channel prevents us from easily extracting in later runs]

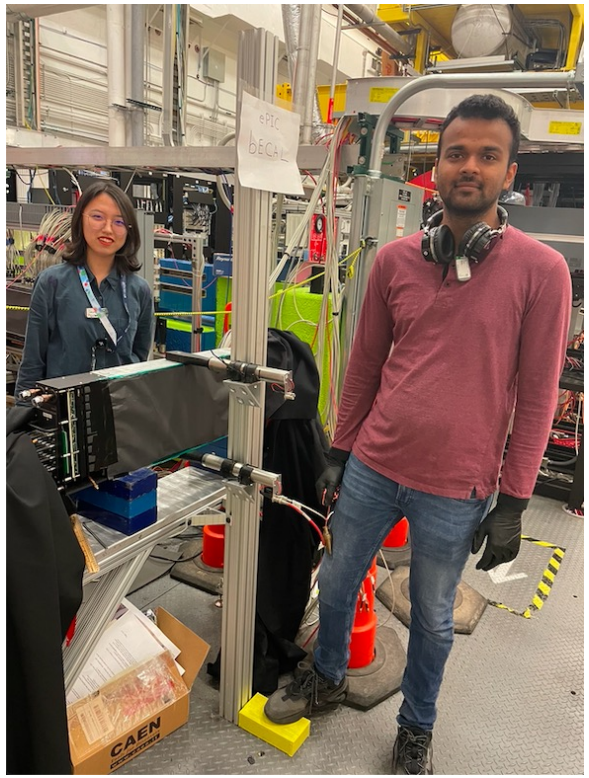
Raw Waveforms

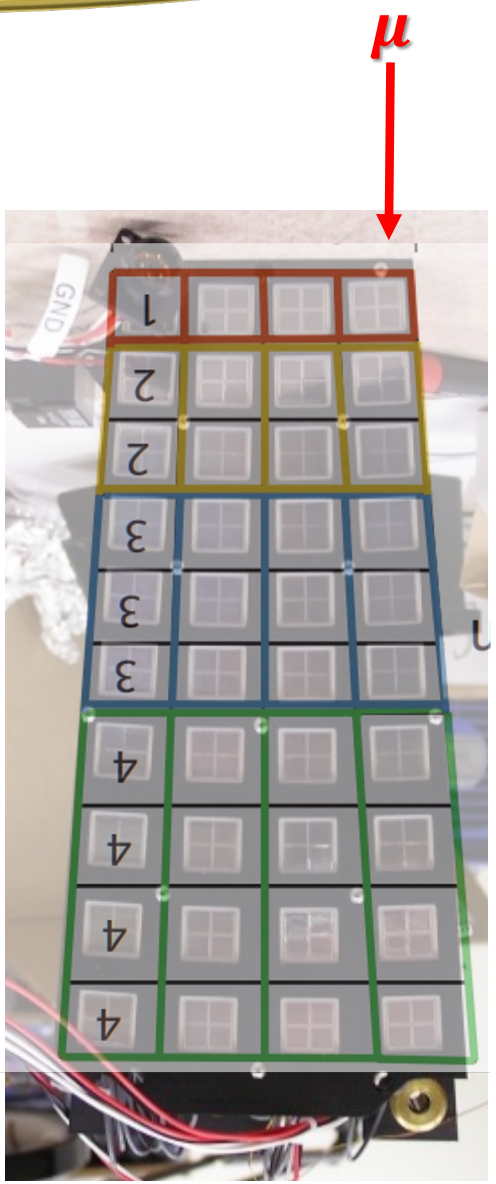
- A number of runs with full waveforms
- Could look for double pulses?
  - Might be rare, analysis challenge to isolate
  - May have enough data though



Cosmic Runs

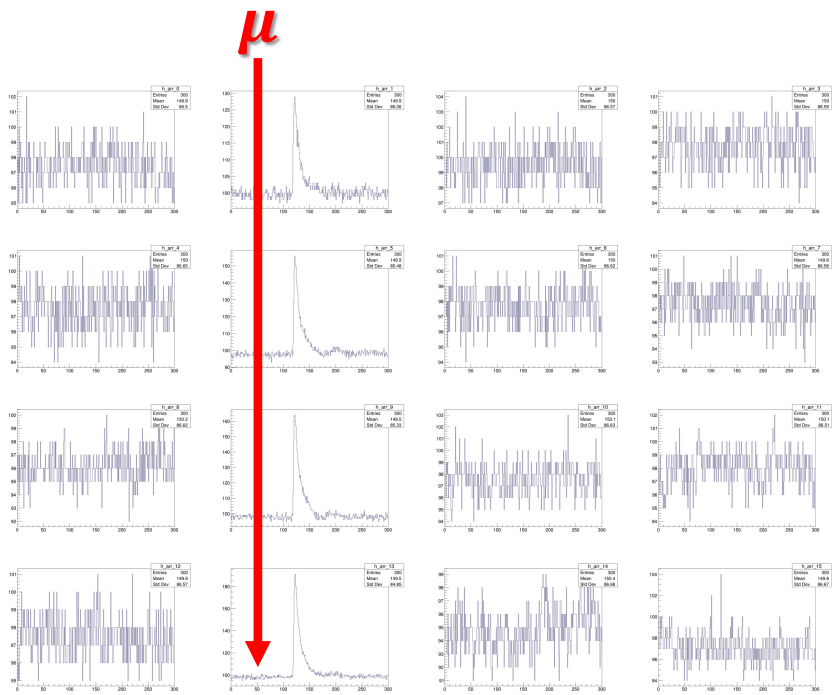
- Unfortunately, e^+ always struck the same spot on the baby BCAL
- 99.5% of energy deposited in 12 channels
  - Easy gain determination
- Other 4 channels had very little energy deposition
  - Cosmics for gain determination?



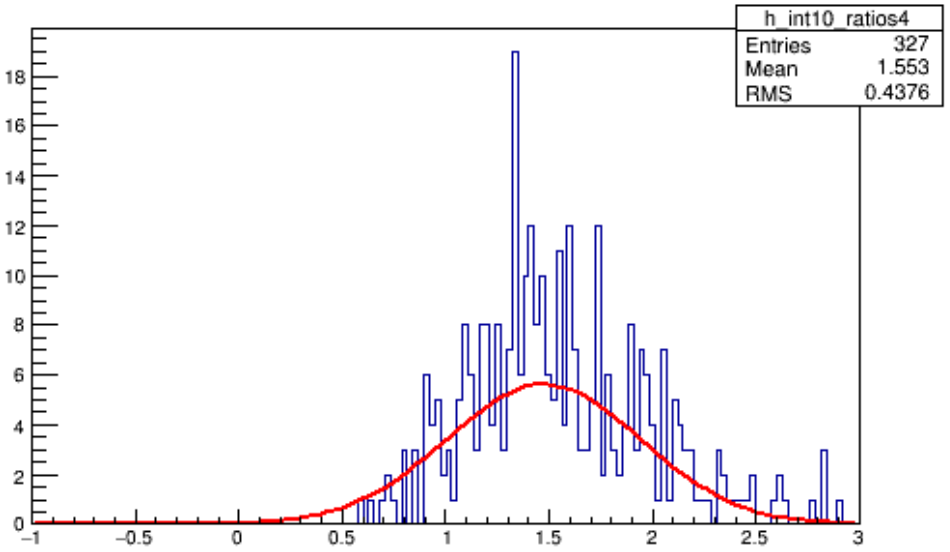


Cosmic Runs, cont.

- Match voltage settings during March running
- Good cosmic events, but rate is extremely low
- Unclear if relative gains would be useful



South 6 / South 14
Cosmics: **1.47**
March: **1.55**



Ratio (length corrected)

Publication Plans

- $\frac{\sigma_E}{E}$ essentially ready
- $N_{p.e.}$ a few additional checks to perform, consistency looks good
- Anything else high priority?

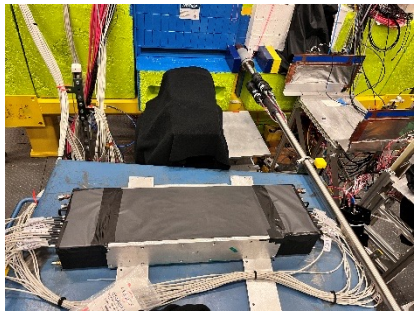
<u>Hope to have publication draft this summer</u>

Backup: Two Setups in JLab Hall D

March e^+ Beam

- GlueX fADCs and DAQ
- e^+ energy 3-6 GeV

- Goal: resolution studies & $N_{p.e.}$ extraction
- Upstream hodoscope to measure e^+ energy and trigger
- Largely uncalibrated prior



Fall Cosmics

- GlueX fADCs and DAQ
- Trigger on cosmics

- Goal: better gain determination for low occupancy channels
- Scintillator paddles above/below provide trigger
- Better geometric coverage for calibrations

- GlueX fADCs and DAQ
- e^+ energy 3-6 GeV

- Goal: resolution studies & $N_{p.e.}$ extraction
- Upstream hodoscope to measure e^+ energy and trigger
- Largely uncalibrated prior

Backup: e^+ Beam in Hall D

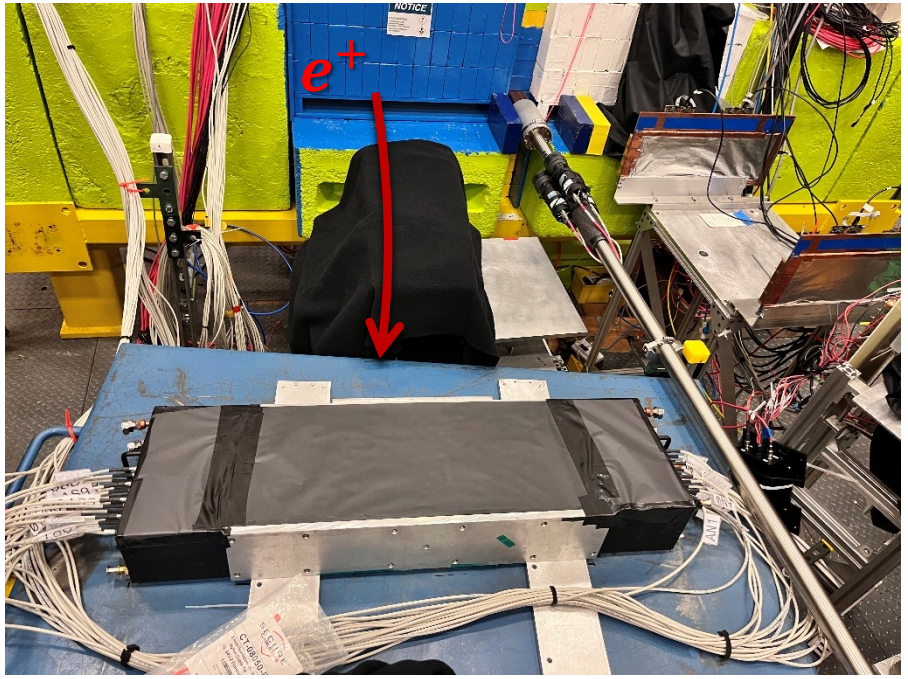
Good source of EM showers with known energy

Essentially identical to GlueX lead SciFi wedge, except 58 cm in length rather than 390 cm

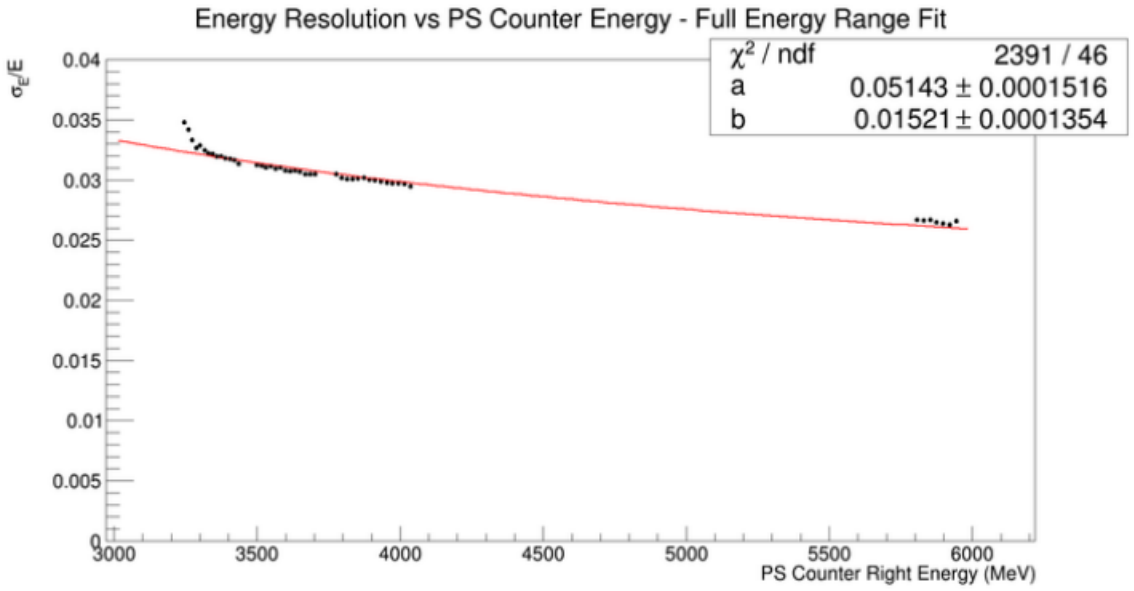
Hall D pair spectrometer:

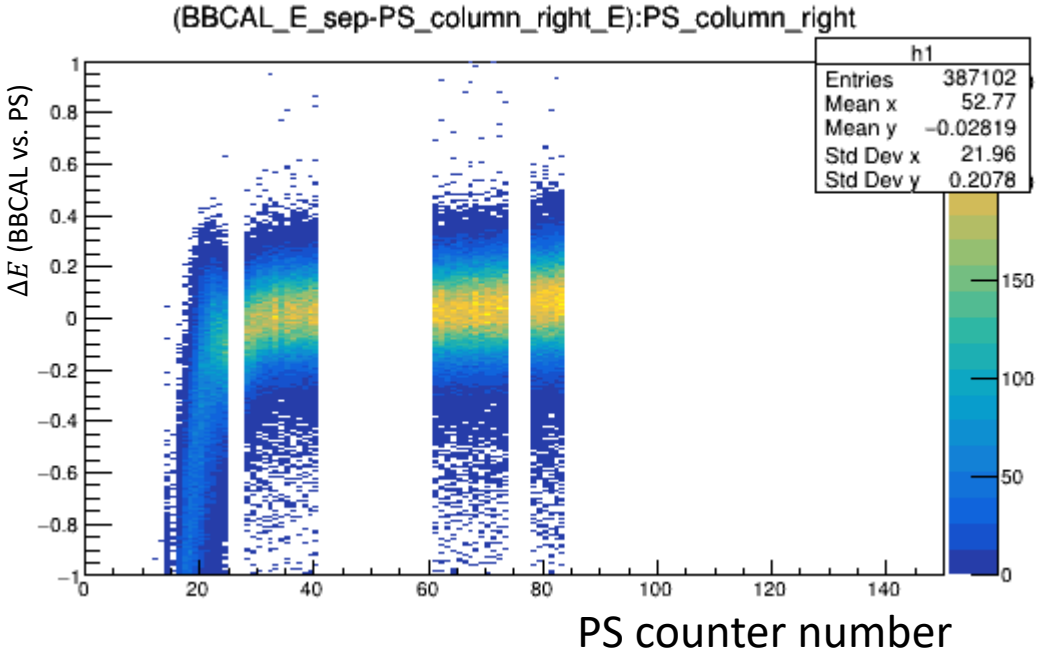
- e^+ energy roughly 3-6 GeV
- Unfortunately, SciGlass blocks portions
- About 1 kHz event rate BBCAL
- About 12 days (on and off) running

View from above



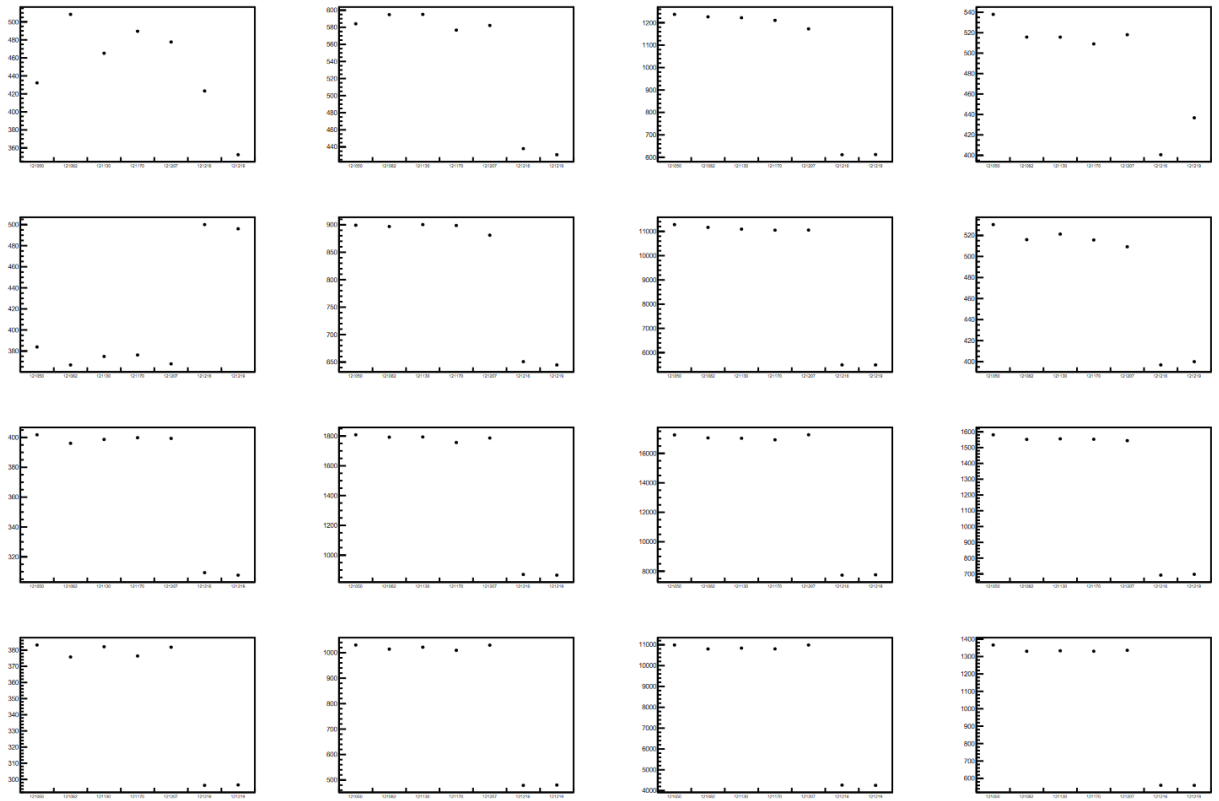
Backup: More Energy Leakage Plots





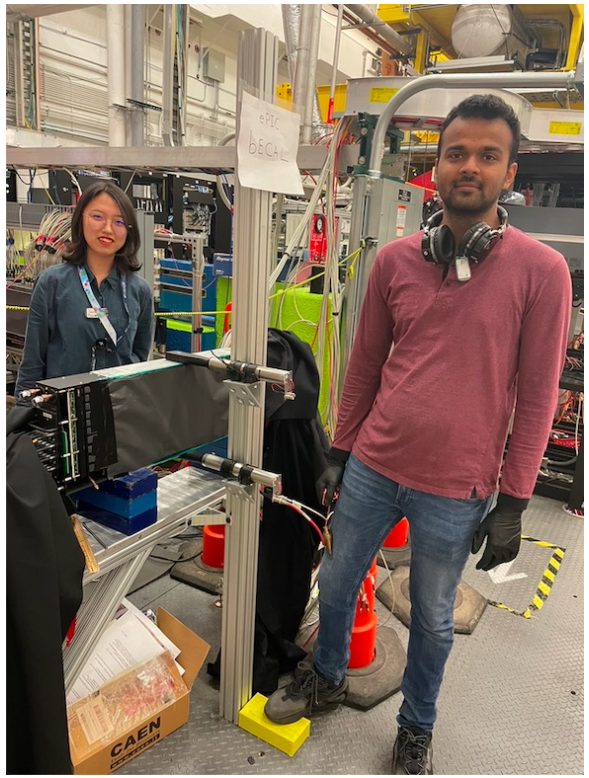
Backup: Longer Term Stability

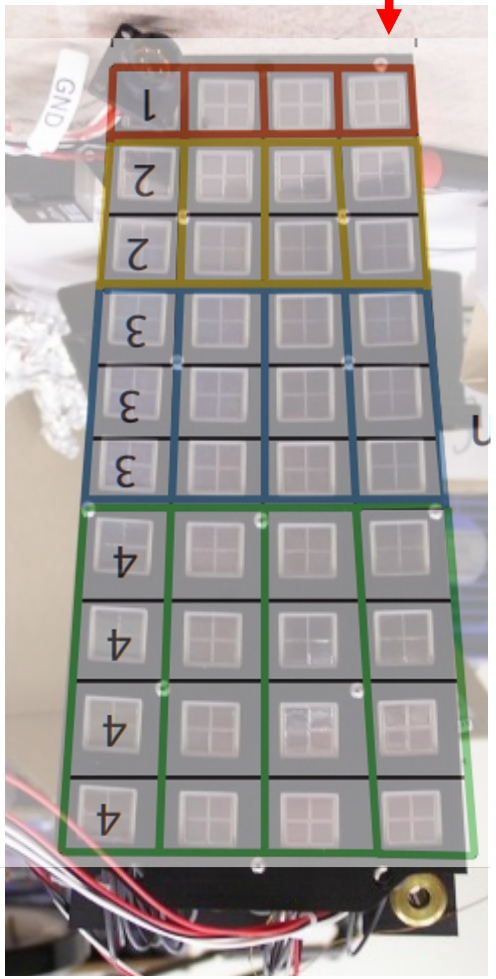
- Check individual channels over 12 day period
- Mostly checking for rad. damage
- Average fADC integral in un-shadowed region
- SiPM bias voltage change for last two points, jump expected



Backup: Cosmic Setup Details

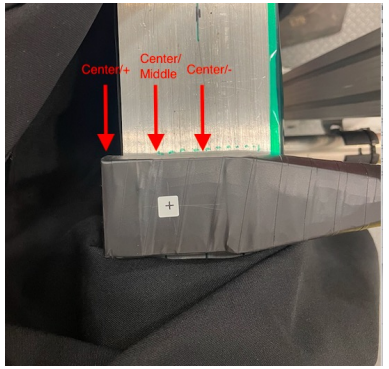
- Unfortunately, e^+ always struck the same spot on the baby BCAL
- Very low occupancy in some channels
- Use MIPs to calibrate?
- Cosmic setup ran from August – October collecting data
  - Close to 30,000 muons collected



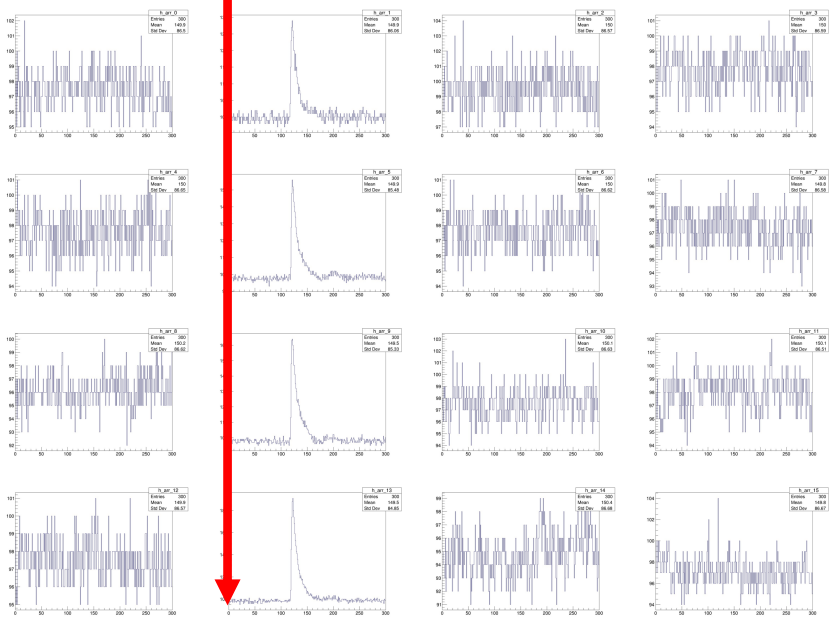


Backup: Cosmic Analysis and Event Selection

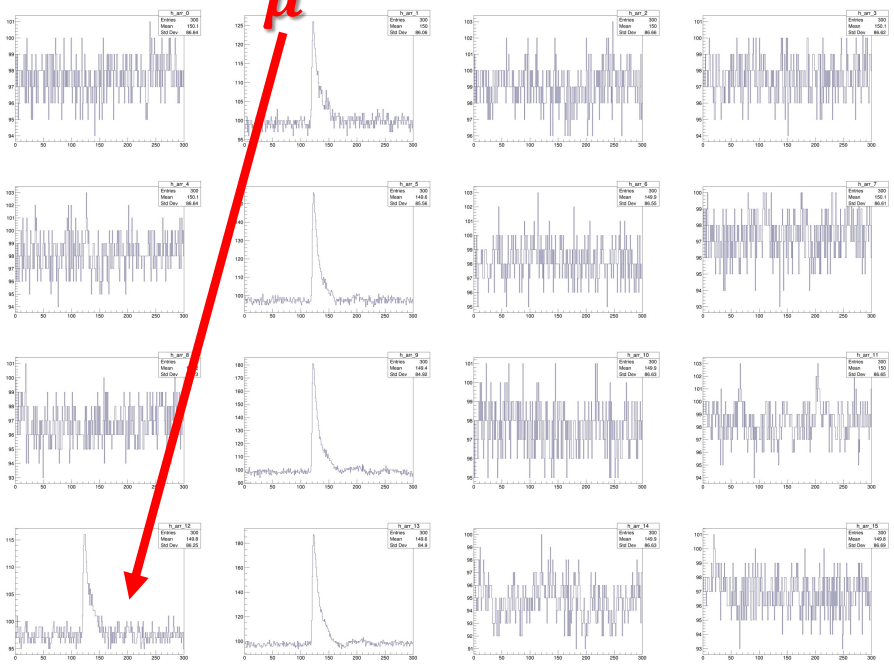
- Match voltage settings during March running
- Paddles ensure that tracks are fairly vertical
- Can still improve with some event selection



μ [want to accept]

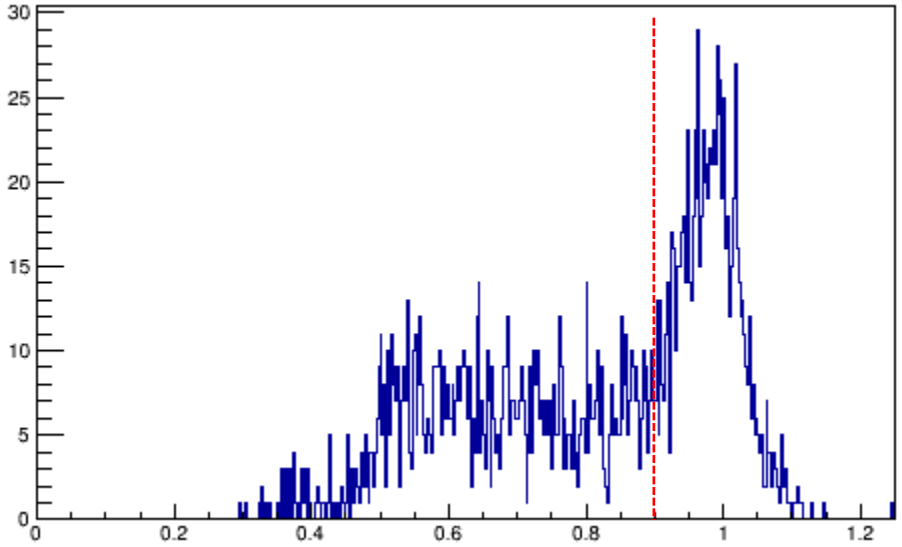


[want to reject] μ

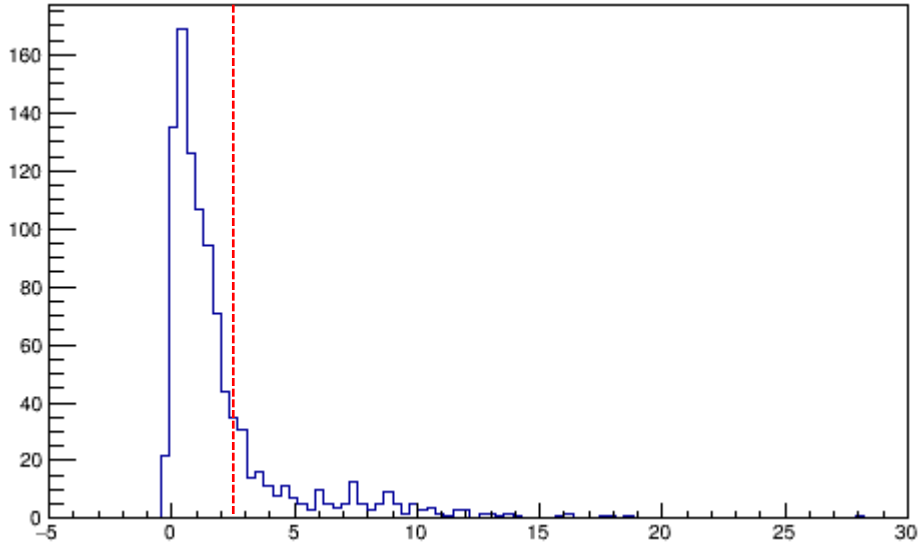


Backup: Cosmic Event Selection, cont.

- Find column with most deposition
  - Require > 90%
- Find largest neighboring top/bottom cell
  - Require this to be very small (< 2.5 ADC units)
- Afterwards: less than $\pm$1.5% length traversed



Fraction of ADC integral sum

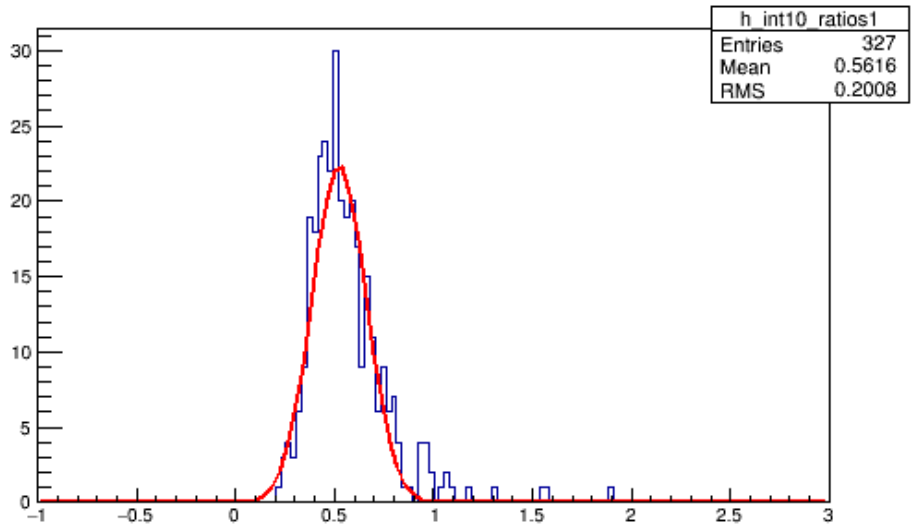


Largest top/bottom neighbor (a.u.)

Backup: Cosmic Initial Checks

- Check channels that were well determined in March run

North 6 / North 14
Cosmics: **0.524**
March: **0.733**



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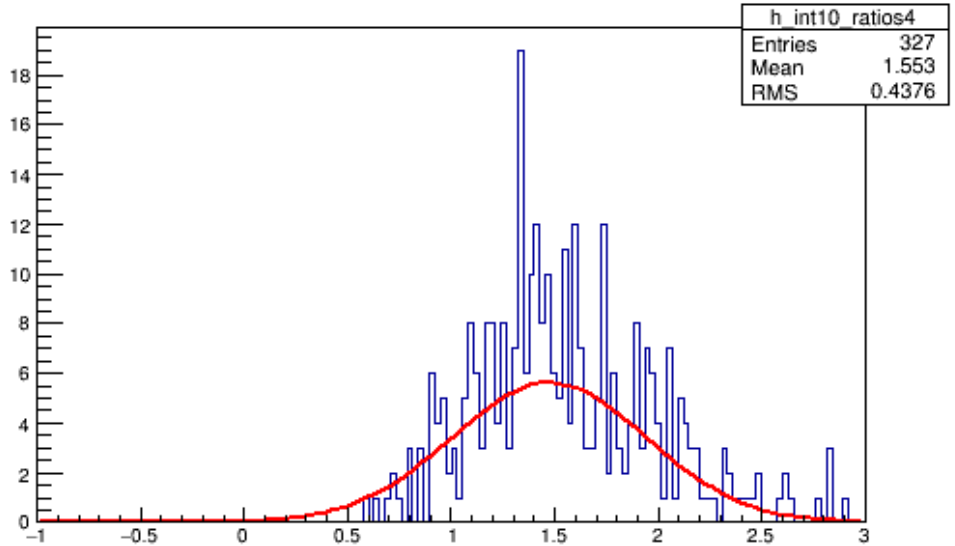
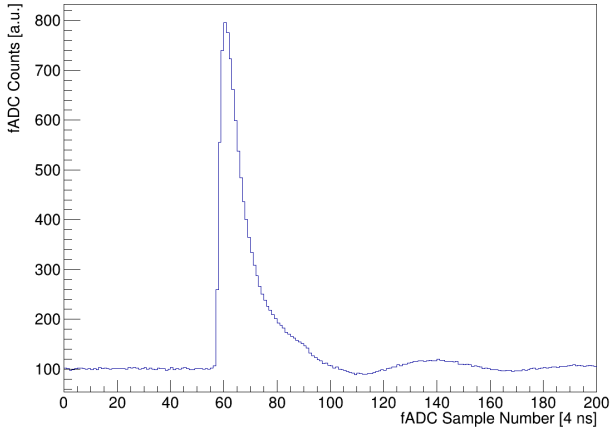


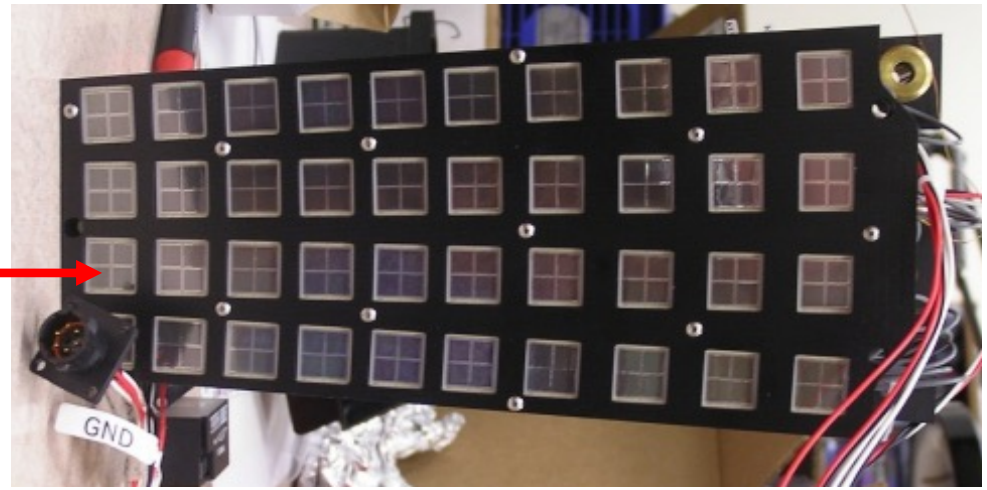
Backup: Segmentation and Readout

Flash ADC readout

- 250 MHz readout frequency (or every 4 ns)
- Up to 200 samples, if storing full waveform
- Some ~ 25 sample integral used otherwise



View from side



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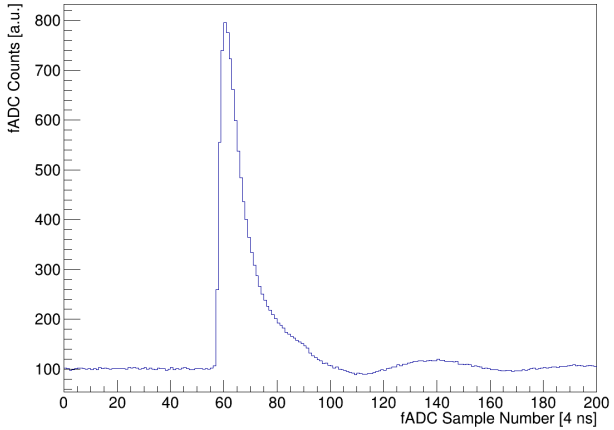
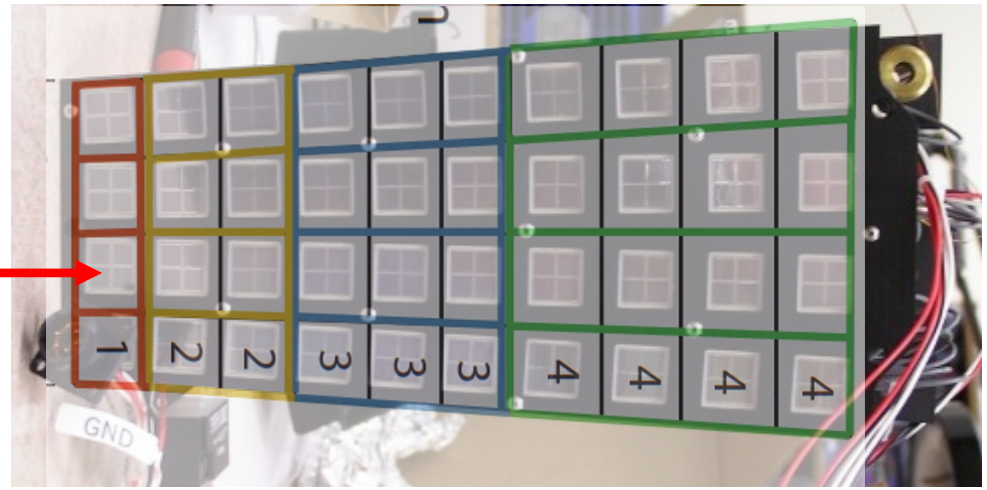


Two-ended readout:

- 4 SiPM readouts up/down
- 10 SiPMs left/right, some summed pre-readout
- **16 fADC readouts per side** (32 in total)

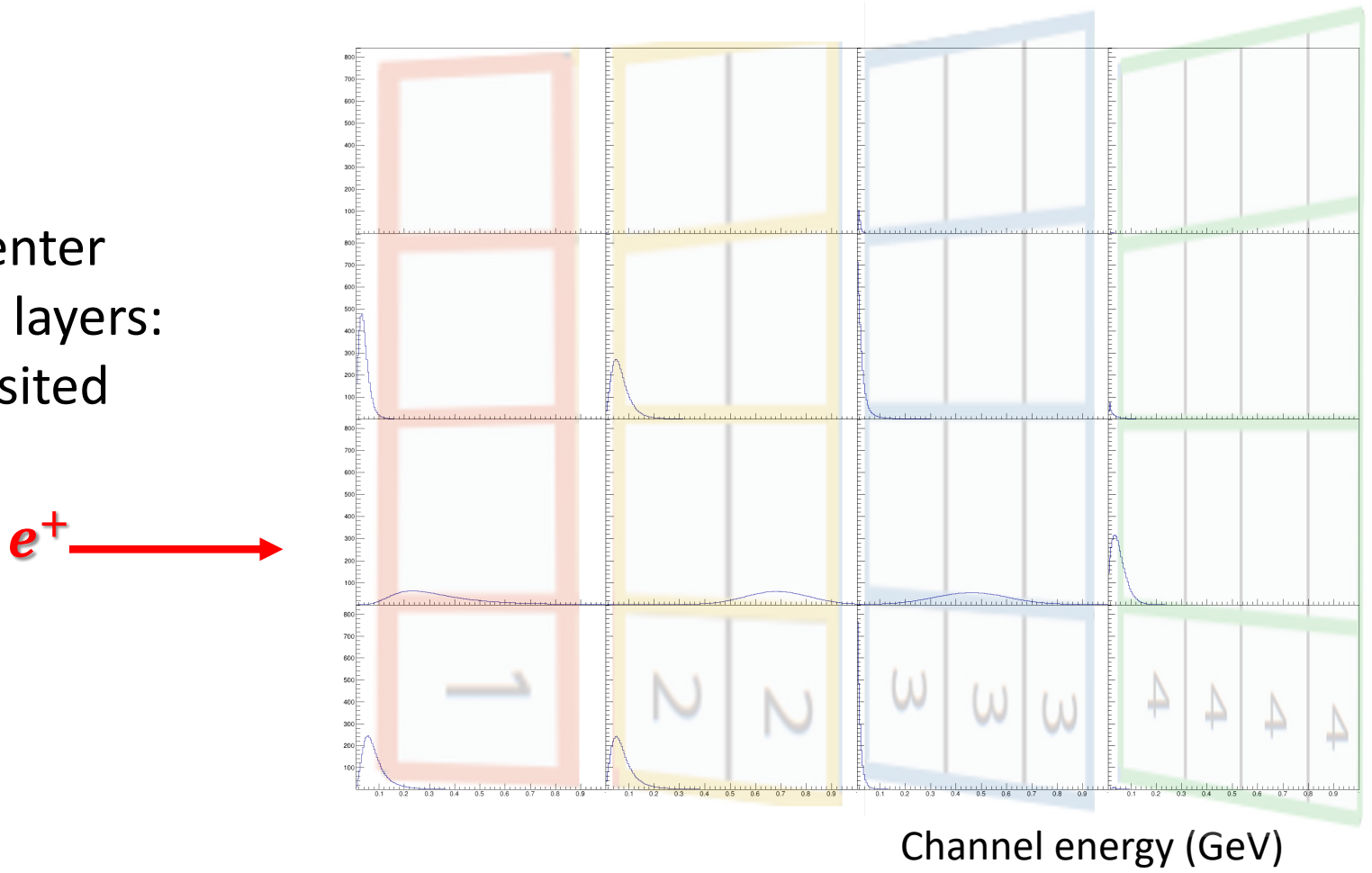
View from side



(summation for bottom channels 1, 2, 3, 4)

Backup: Showers in Baby BCAL

- Strikes a little low of center
- Upper left & rightmost layers: very little energy deposited



Backup: Baby BCAL Gains

- Minimize $F = \sum_i^{events} \left(\sum_j^{16} c_j \, A_{ij}^{sum} - E^{PS} \right)^2$
- $\frac{\partial F}{\partial c_k} = 0 = 2 \sum_i^{events} A_{ik}^{sum} \left(\sum_j^{16} c_j \, A_{ij}^{sum} - E^{PS} \right)$
- $\Rightarrow \sum_i^{events} A_{ij}^{sum} E^{PS} = \sum_i^{events} A_{ij}^{sum} \left(\sum_j^{16} c_j \, A_{ij}^{sum} - E^{PS} \right)$

Backup: Baby BCAL Gains

- $\sum_i^{events} A_{ik}^{sum} E^{PS} = \sum_i^{events} A_{ik}^{sum} \left(\sum_j^{16} c_j \, A_{ij}^{sum} \right)$
  - Define vectors $\mathbf{A_i} = \begin{bmatrix} A_{i0}^{sum} \\ \dots \\ A_{i15}^{sum} \end{bmatrix}$ and $\boldsymbol{C} = \begin{bmatrix} c_0 \\ \dots \\ c_{15} \end{bmatrix}$
- Then in matrix form $\sum_i E_i^{PS} \, \mathbf{A_i} = \left(\sum_i \boldsymbol{A_i} \boldsymbol{A_i^T} \right) \boldsymbol{C}$
  - Now define $\boldsymbol{W} = \sum_i E_i^{PS} \, \mathbf{A_i}$, and $\boldsymbol{Z} = \left(\sum_i \boldsymbol{A_i} \boldsymbol{A_i^T} \right)$
- $\Rightarrow \boldsymbol{W} = \mathbf{Z} \, \mathbf{C}$
- Solving for gain constants $\boldsymbol{C}$:
  - $\boldsymbol{C} = \boldsymbol{Z}^{-1} \, \boldsymbol{W}$

Backup: Baby BCAL Gains

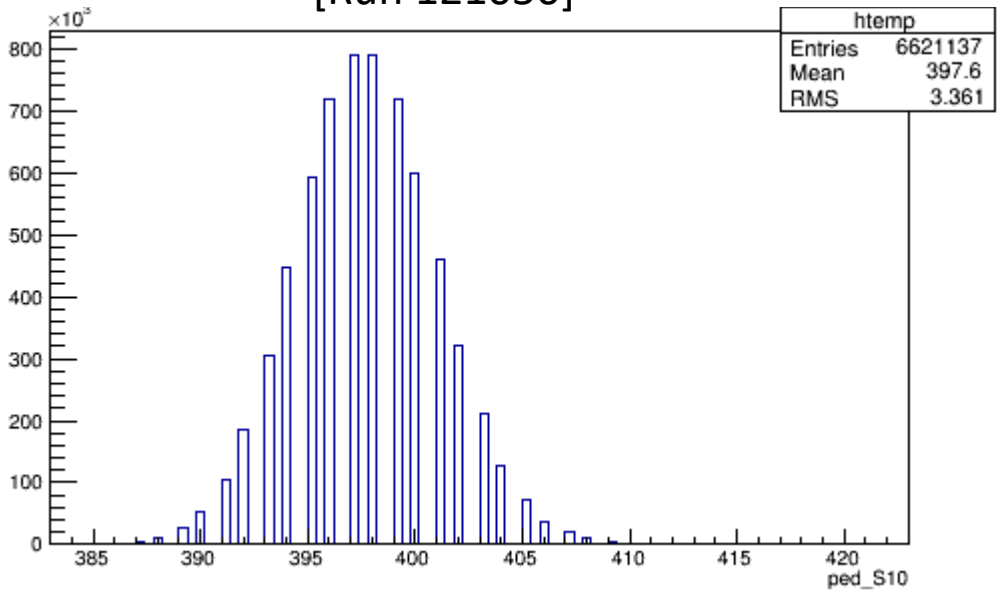
- Determine separate north/south
- Let $f_j = \frac{\sum_i A_j^N}{\sum_i \left(A_j^N + A_j^S\right)} \Rightarrow \left(1 - f_j\right) = \frac{\sum_i A_j^S}{\sum_i \left(A_j^N + A_j^S\right)}$

- Final gain factors: $\boldsymbol{c_j^N = \frac{c_j}{2f_j}}$ and $\boldsymbol{c_j^S = \frac{c_j}{2\left(1-f_j\right)}}$

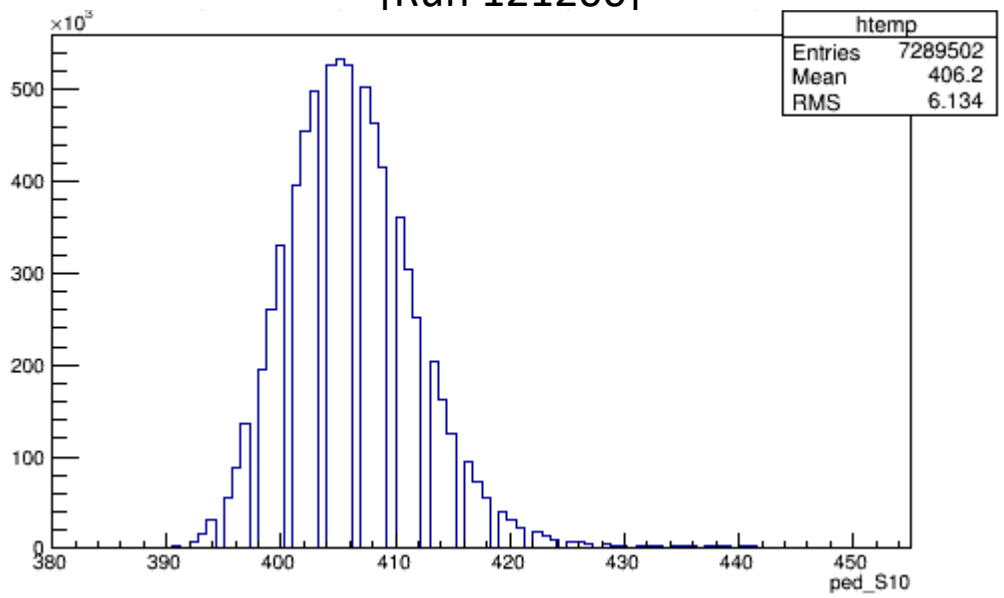
Backup: Channel S10 Degrading over March Runs

Measured Pedestal
(4 sample sum)

[Run 121050]



[Run 121200]

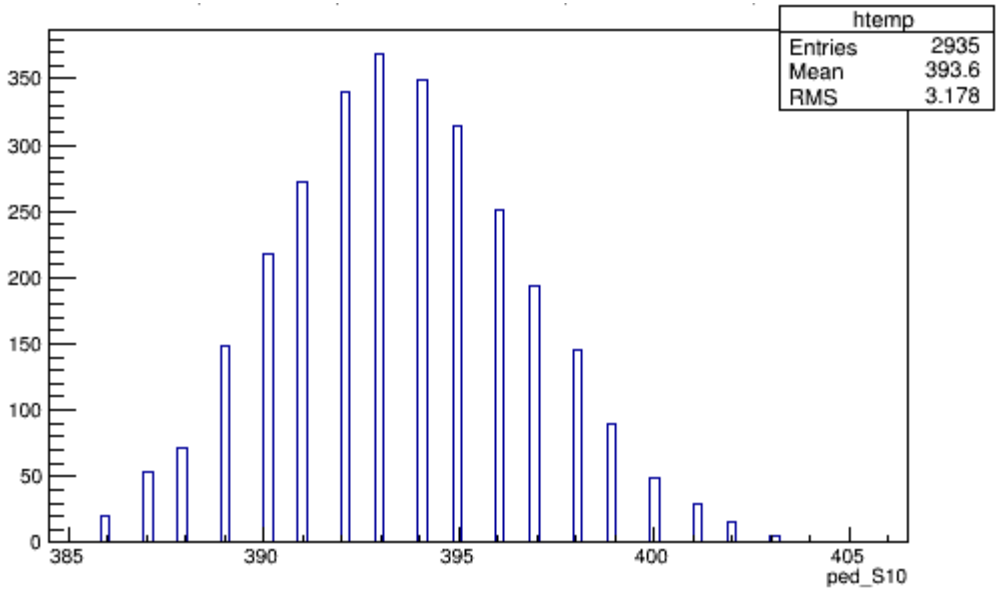


Backup: Channel S10 in Cosmic Data

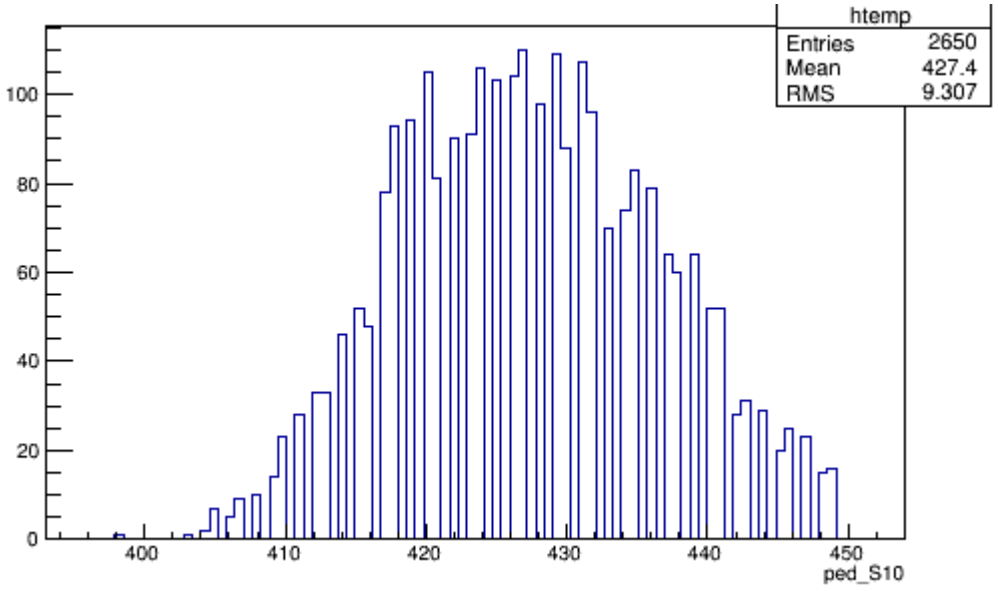
Before chillers

Measured Pedestal
(4 sample sum)

[Run 121303]



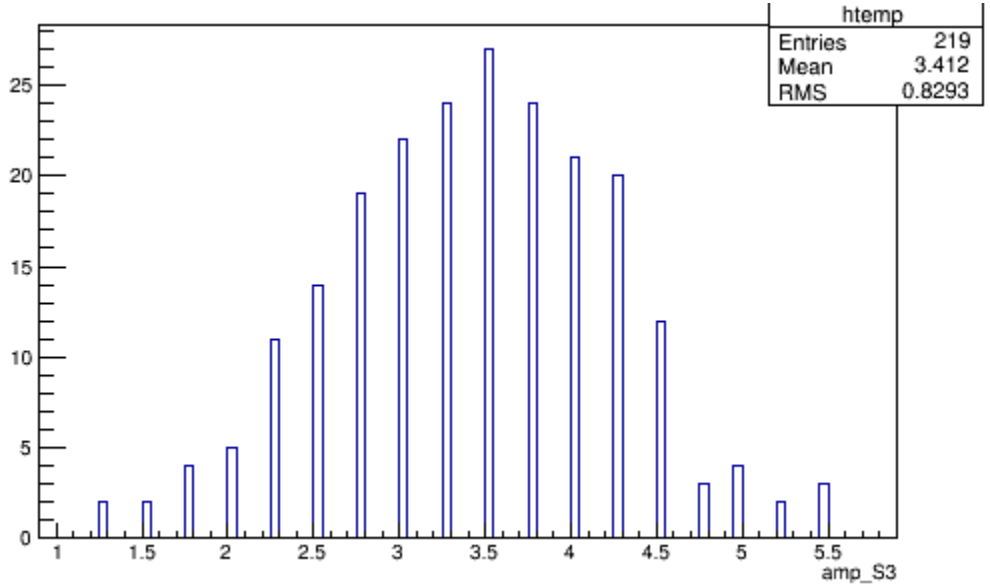
[Run 121304]

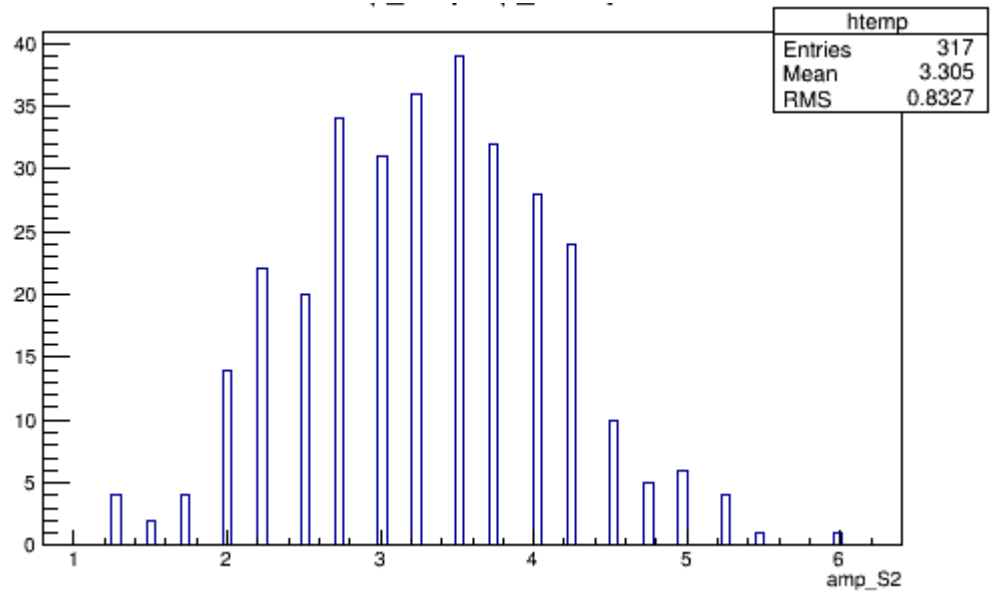


Backup: Also curious

99.9% of the time:

- Either S10 is in a bad state
  - (pedestal too large, integral too high, varies with time)
- Or S2 & S3 are BOTH in bad state
  - Looks like just fADC noise, nothing from BBCAL

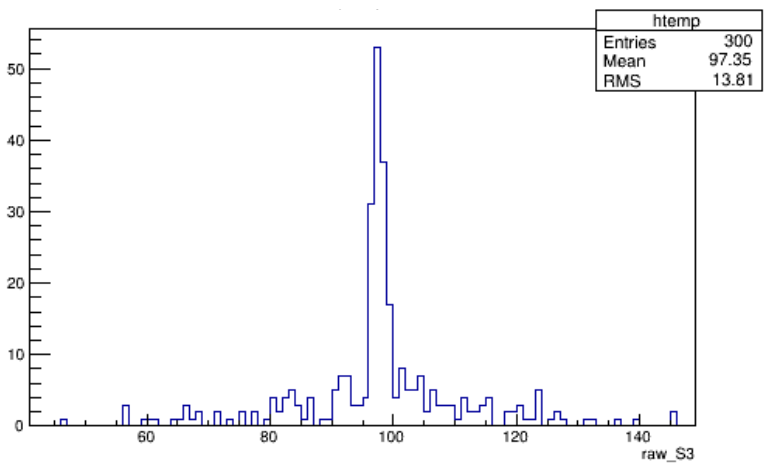




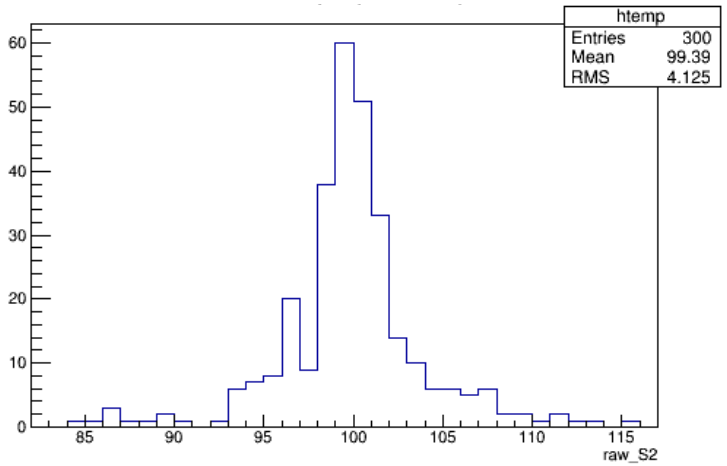
Backup: Exactly Two Events

After adding chillers, found two events where S2 and S3 seem to read out above pedestal

[Run 121316]



[Run 121318]

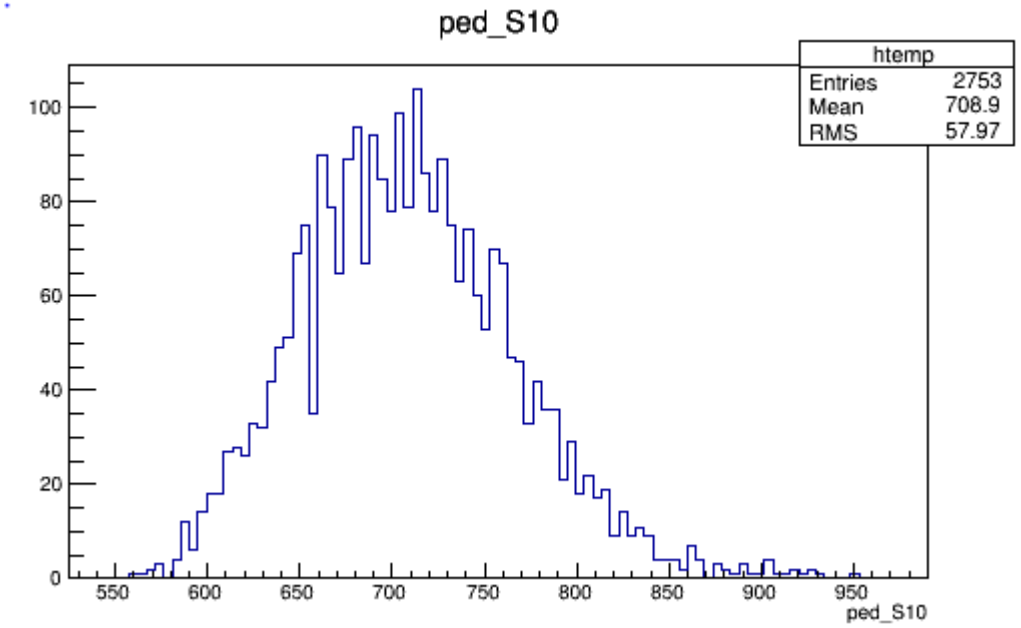


Points to some combination of voltage setting, connectors, or power distribution?

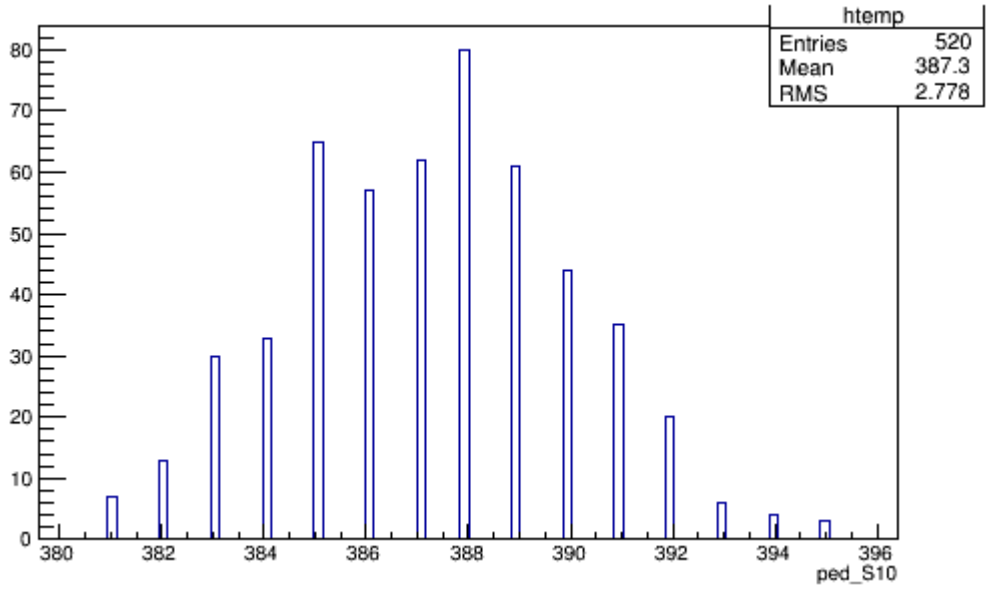
Backup: Channel S10 in Cosmic Data

- Runs 121308 and 121309: significantly worse
- Only two 75.5 / 74.0 V setting runs. Is 75.5 the south or north side?
- Better when chillers added in run 121312

[Run 121308]



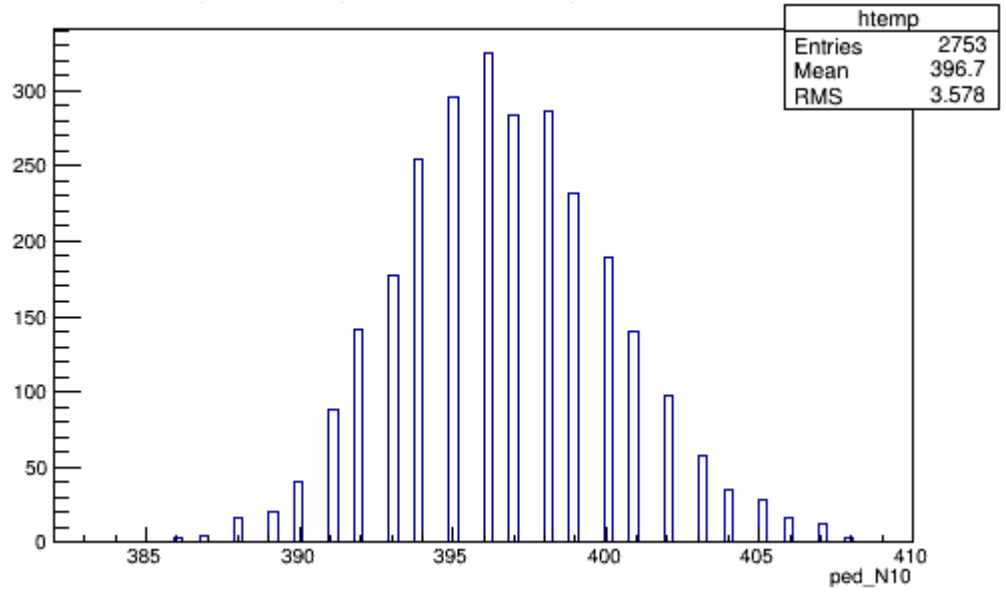
[Run 121312]



Backup: Chillers in Channel N10 in Cosmic Data

- When chillers added, good channels saw pedestal go down too
- Here: channel N10

[Run 121308]



[Run 121312]