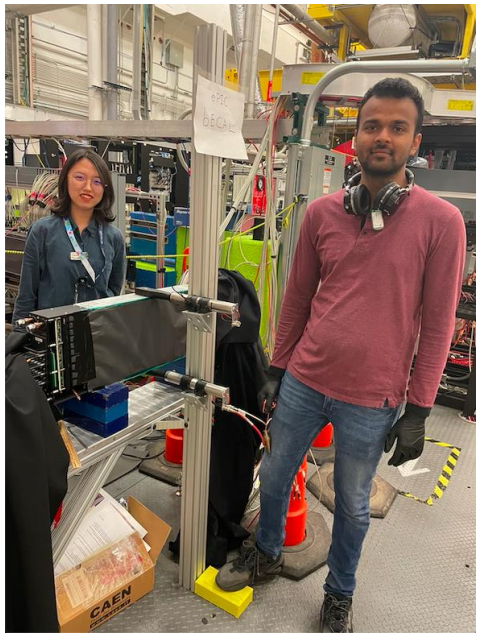
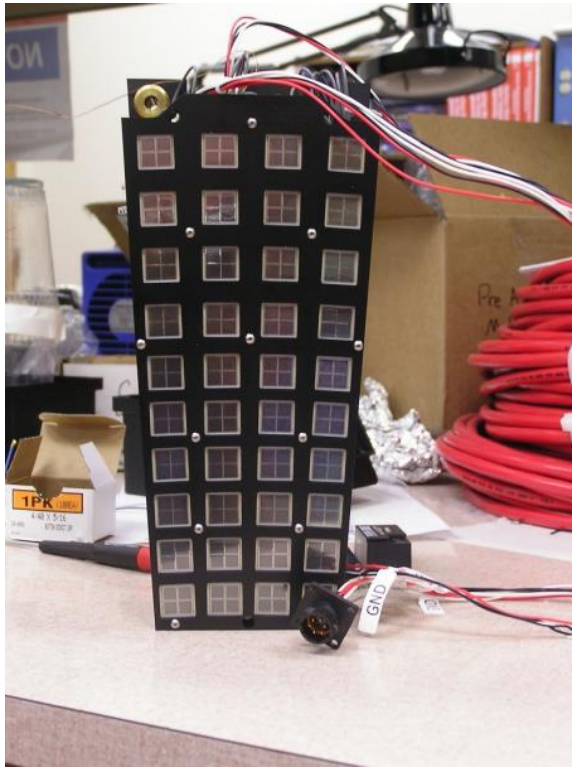


# “Baby ” BCAL Progress Report

Jon Zarling

3/6/24



# Primary Goals

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

- Resolution ($\sigma_E/E$)
- 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

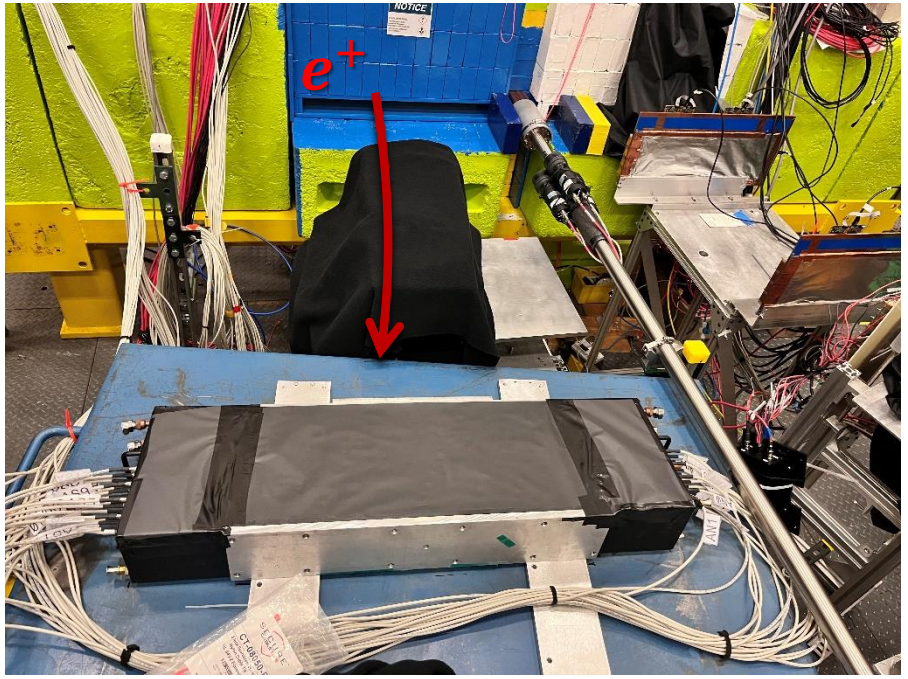
Good source of EM showers with known energy

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

Hall D pair spectrometer setup:

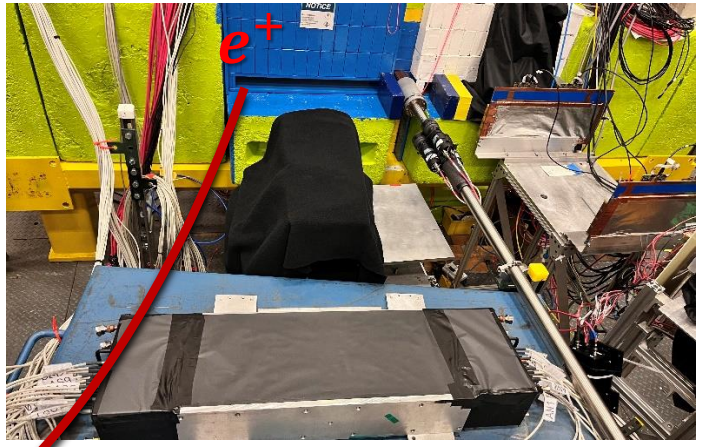
- $e^+$ tagged upstream roughly 3-6 GeV
- Unfortunately, SciGlass blocks portions
- About 1 kHz event rate BBCAL
- About 12 days (on and off) running

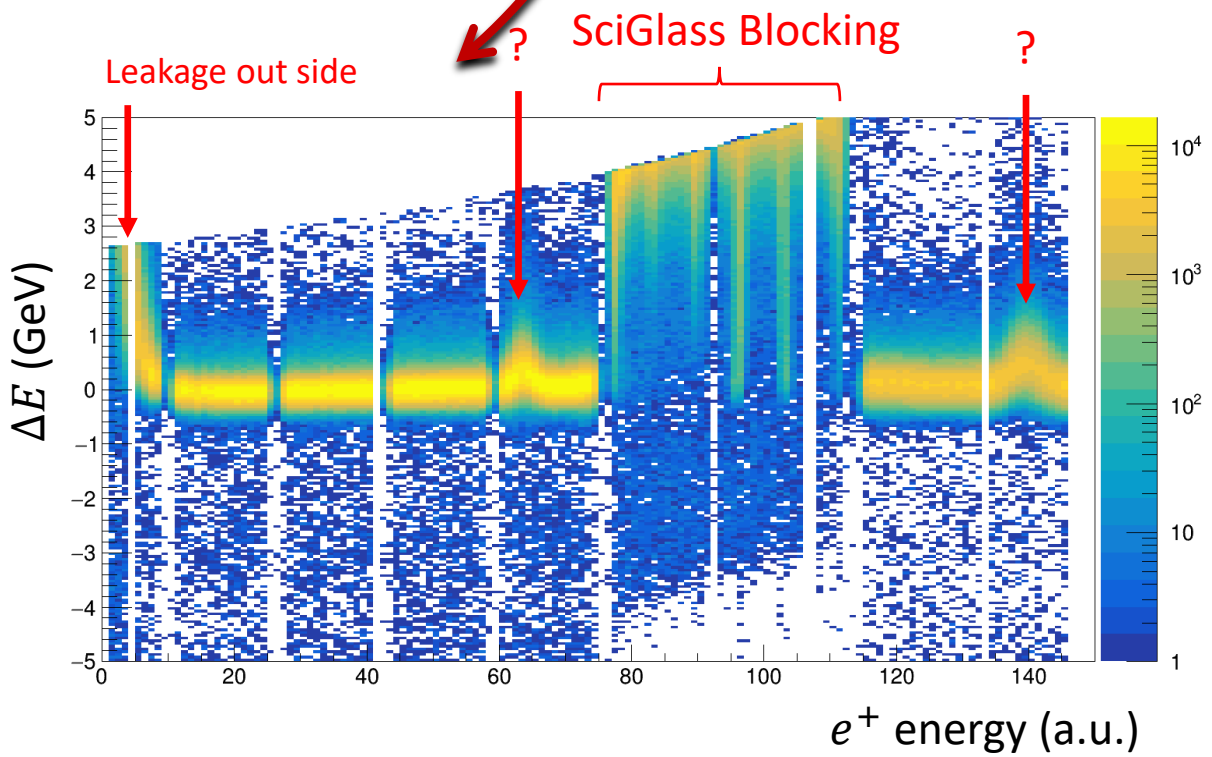
View from above



# 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.

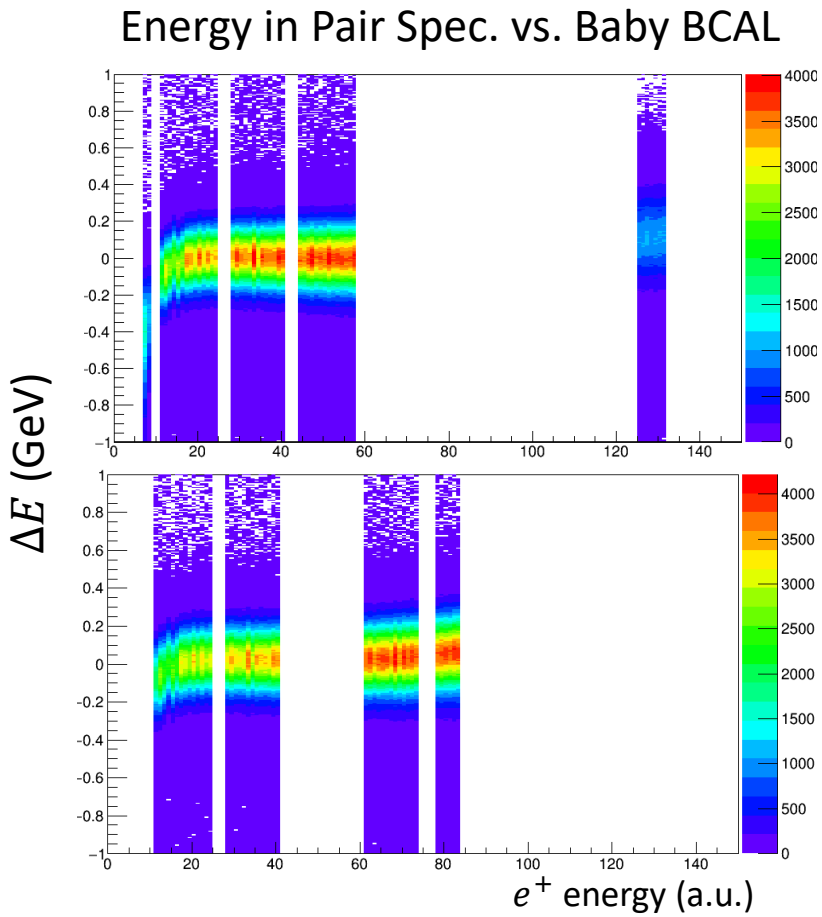
Can solve for (linear-only) gain factors $c_k$

- 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



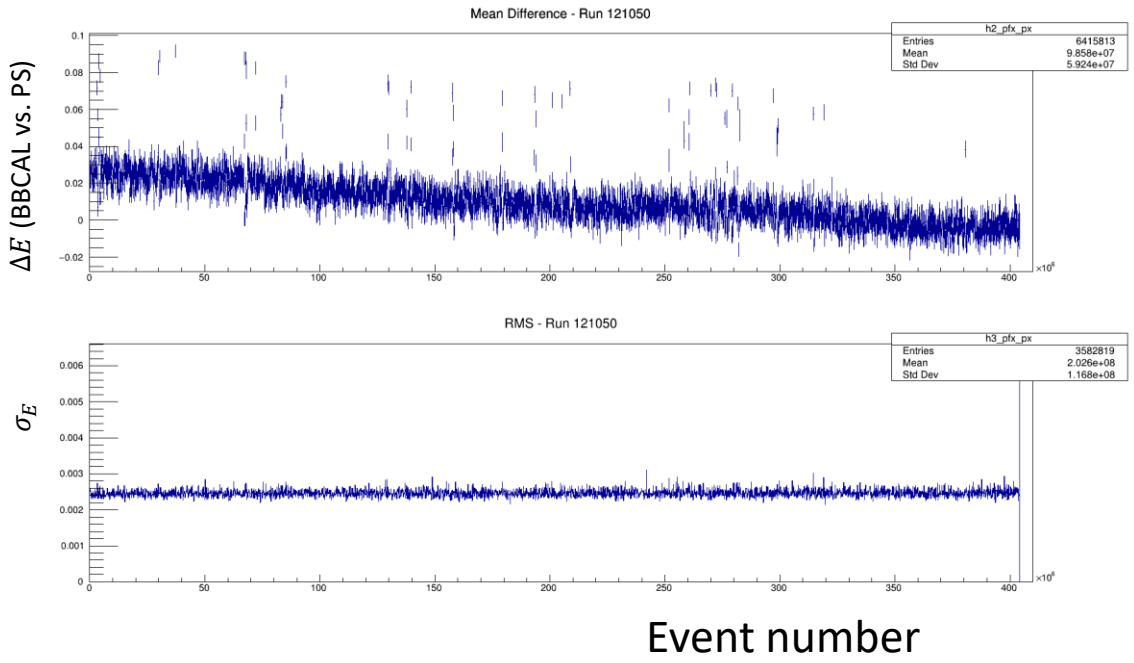
# Quality Checks

Within run (one run ~ 2 hours)

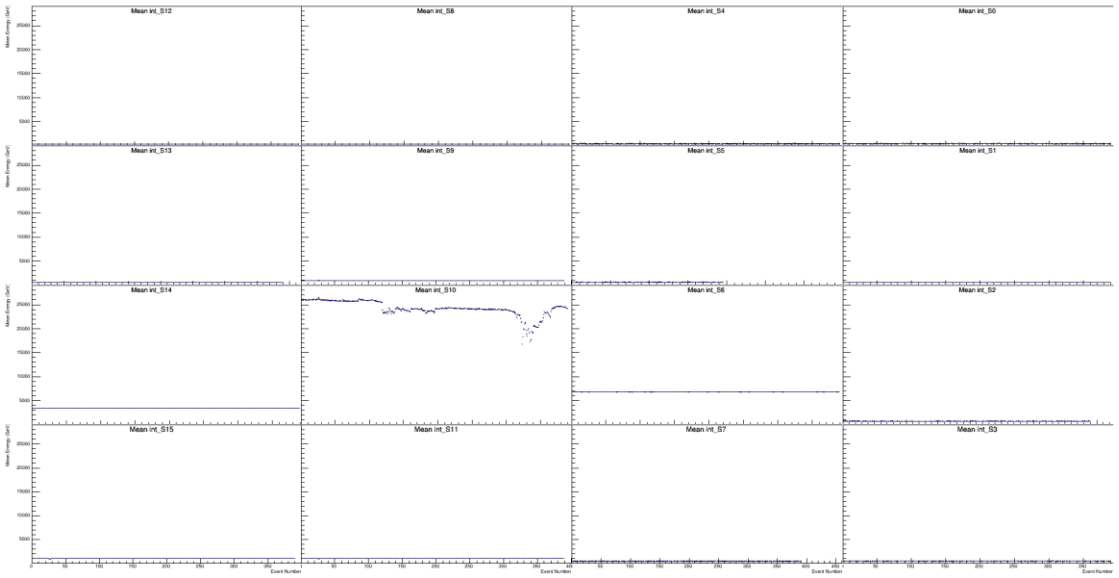
- Check individual channel stability
- Check overall energy stability

**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?

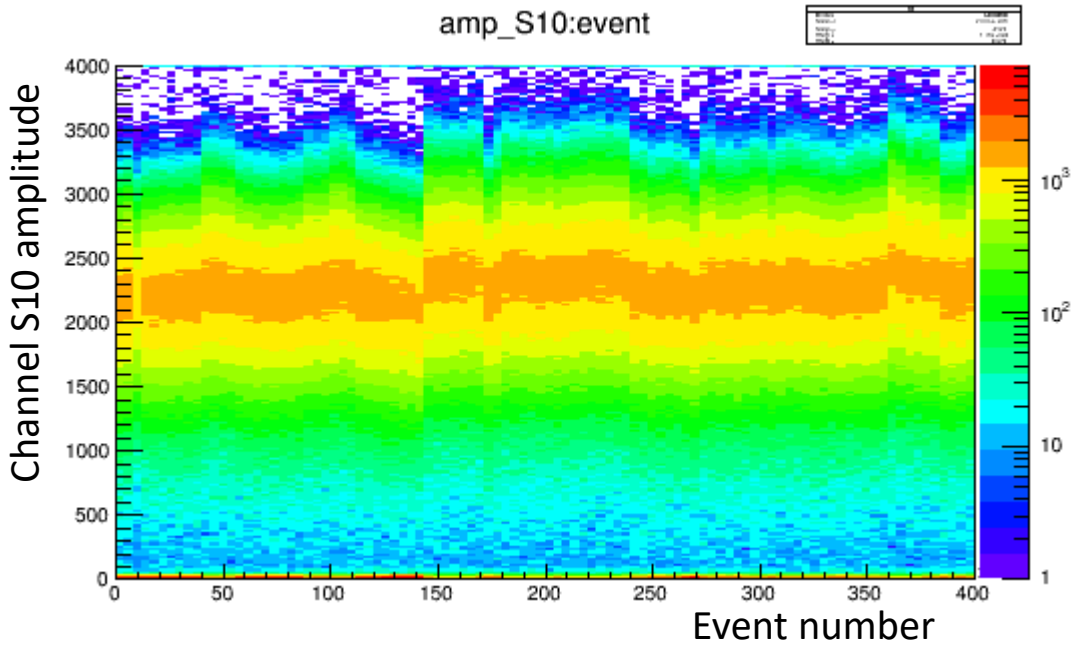



Individual Channels

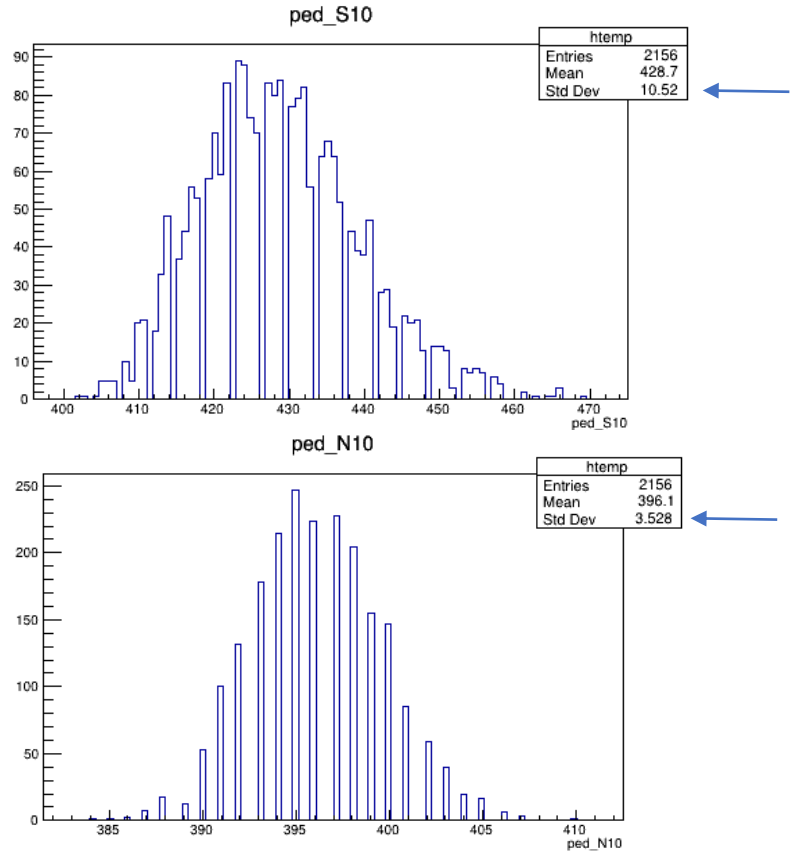


# Quality Checks, cont.

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

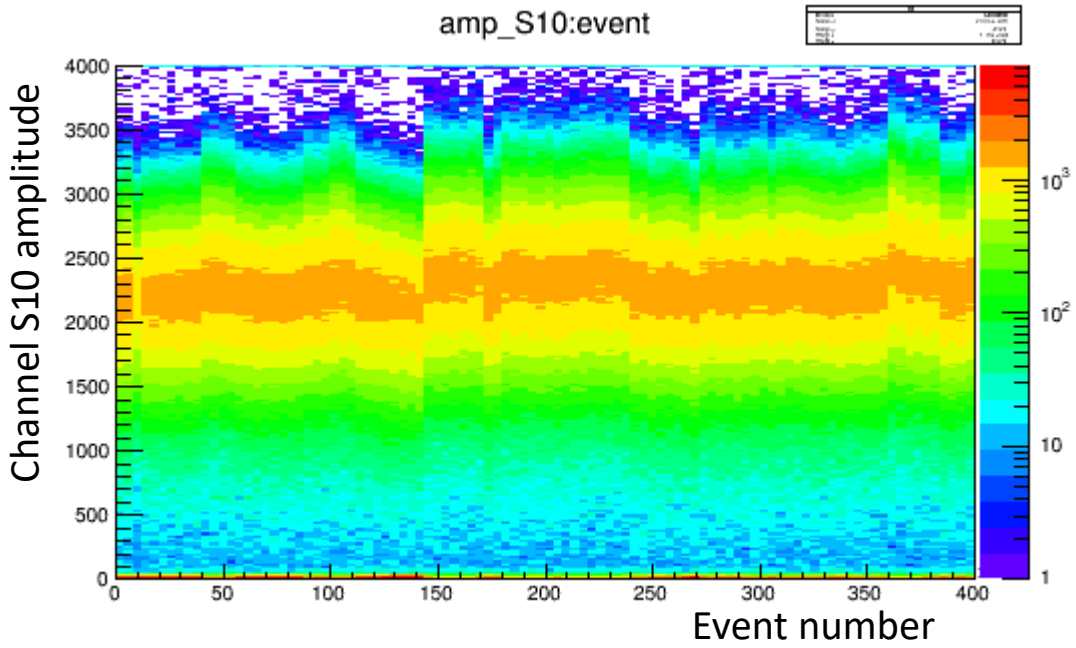



Measured Pedestal
(4 sample sum)

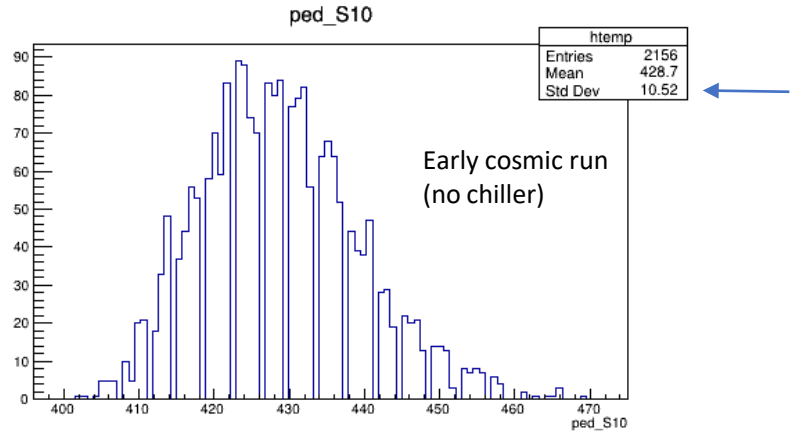


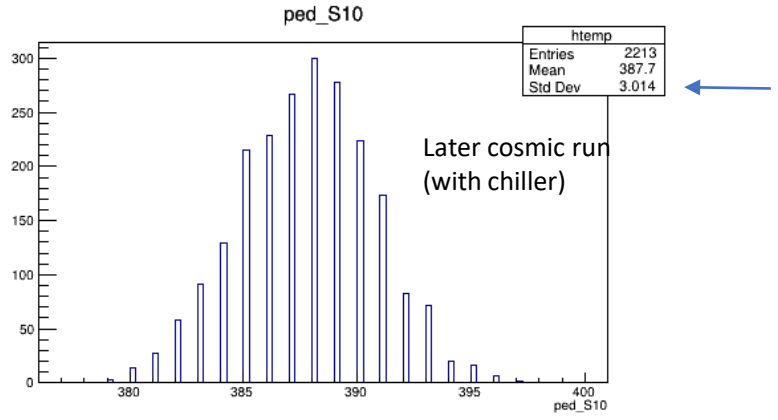
# Quality Checks, cont.

- 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

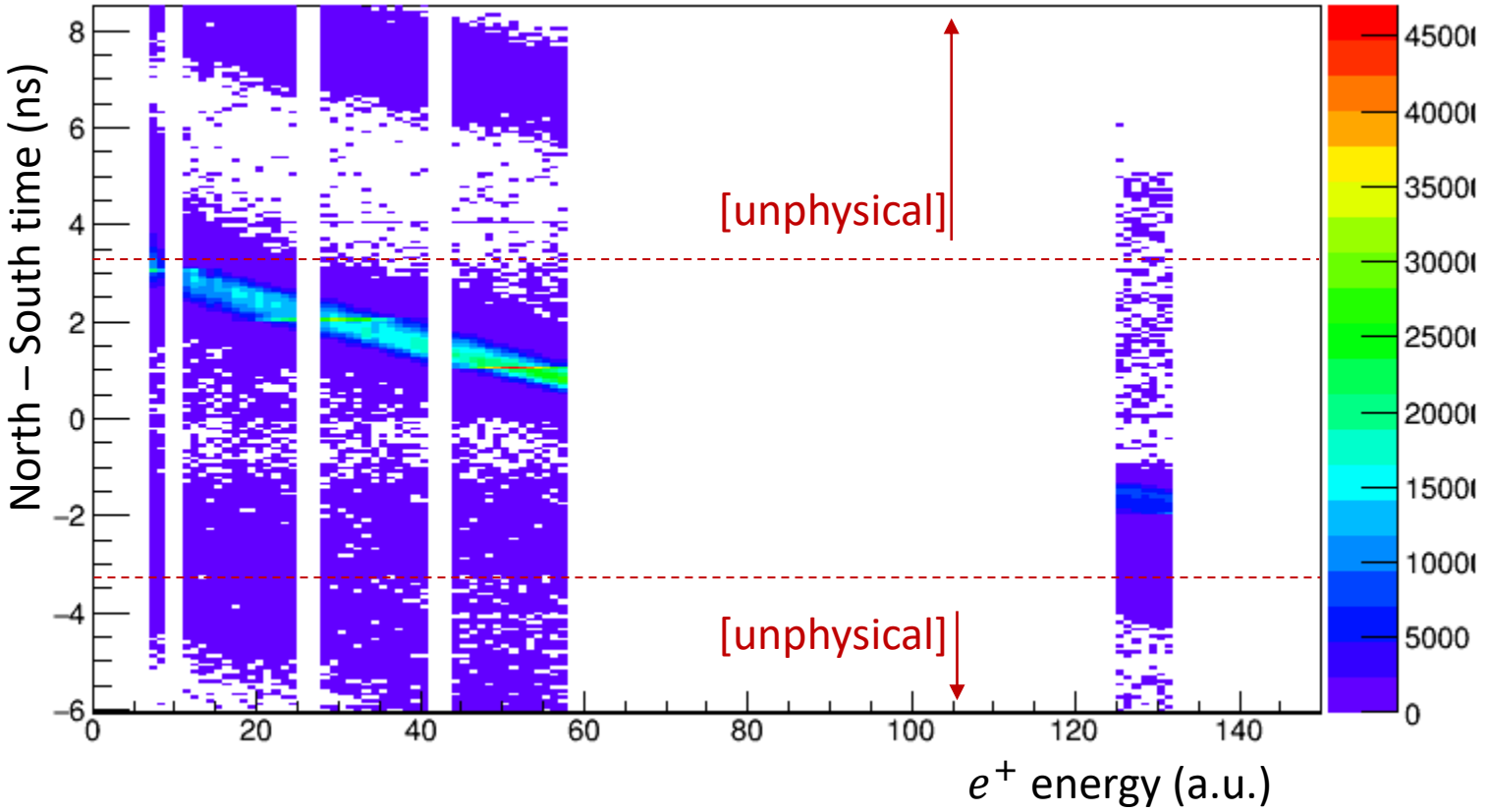
- S10: noisy, time-dependent, bad dark rate
  - Good: earliest runs in March
    + final cosmic runs (after chiller added)
  - Bad: everything in between
- S2 & S3: no signal in some cosmic runs
- Recommended checks:
  - Check ratio of N/S sides for each channel
  - Check pedestal RMS for dark rate

[run tracking spreadsheet]

# Energy Leakage

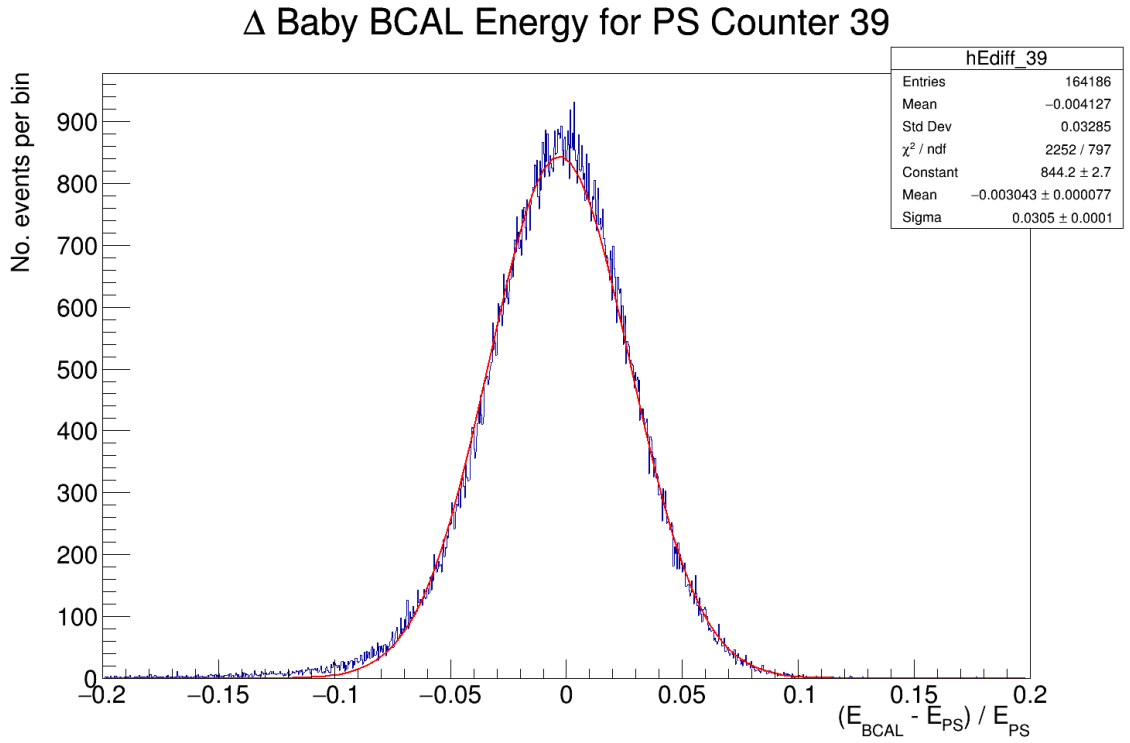
Timing difference confirms lowest energy $e^+$ hits at edge of baby BCAL

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



# Energy Resolution Extraction

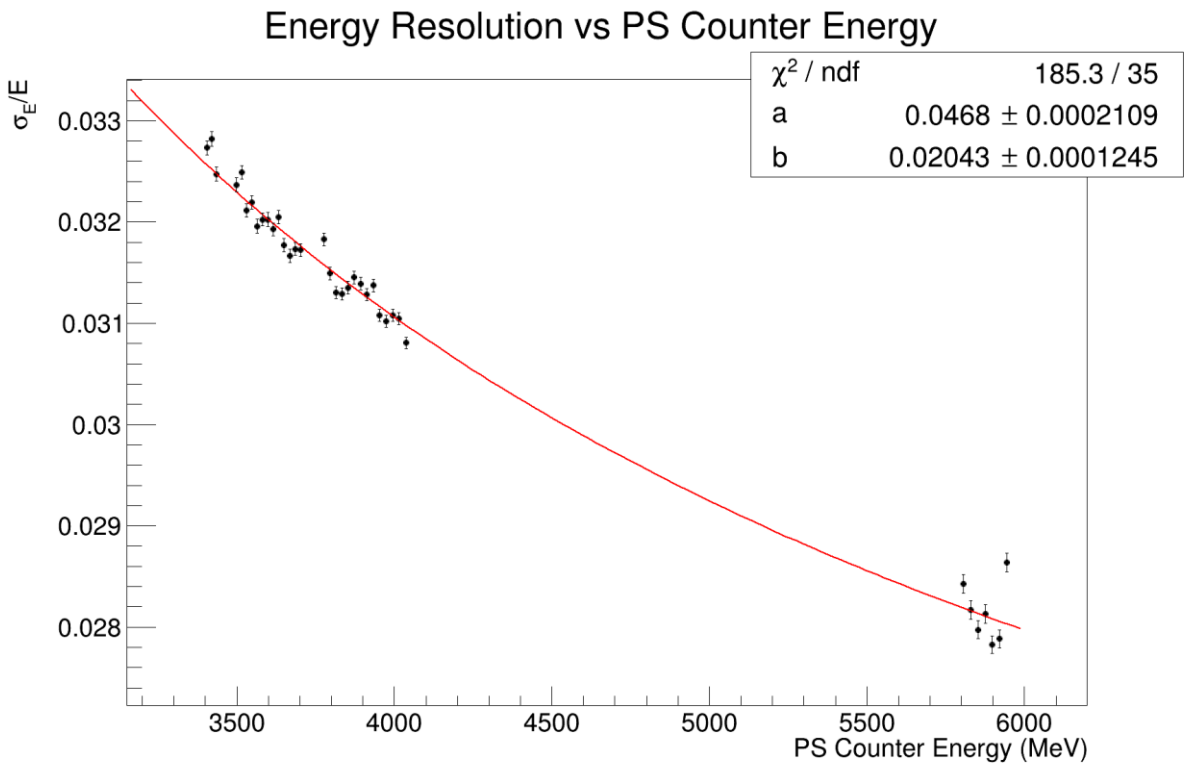
- Fit for single PS counter
  (positrons energy $\pm 10$ MeV at most)
- Fit to get $\sigma_E / E$
- Repeat for all good PS counters



# Energy Resolution

Fit function

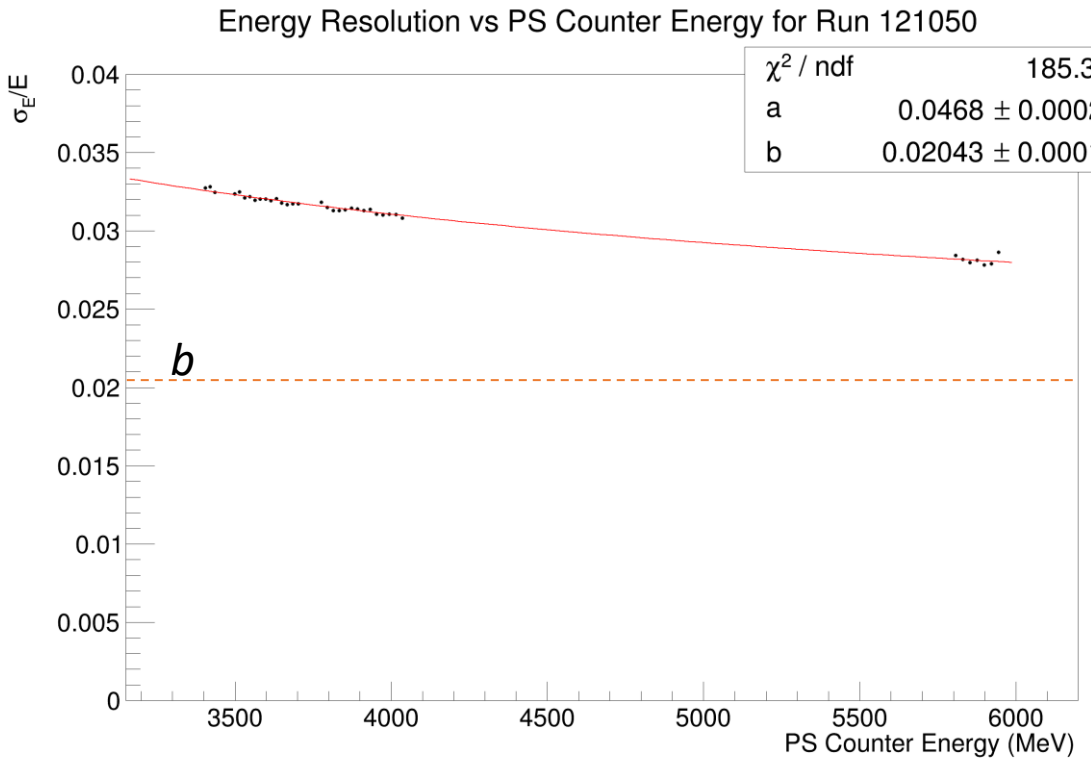
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}\,(\mathrm{GeV})} \oplus b$$



# 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)

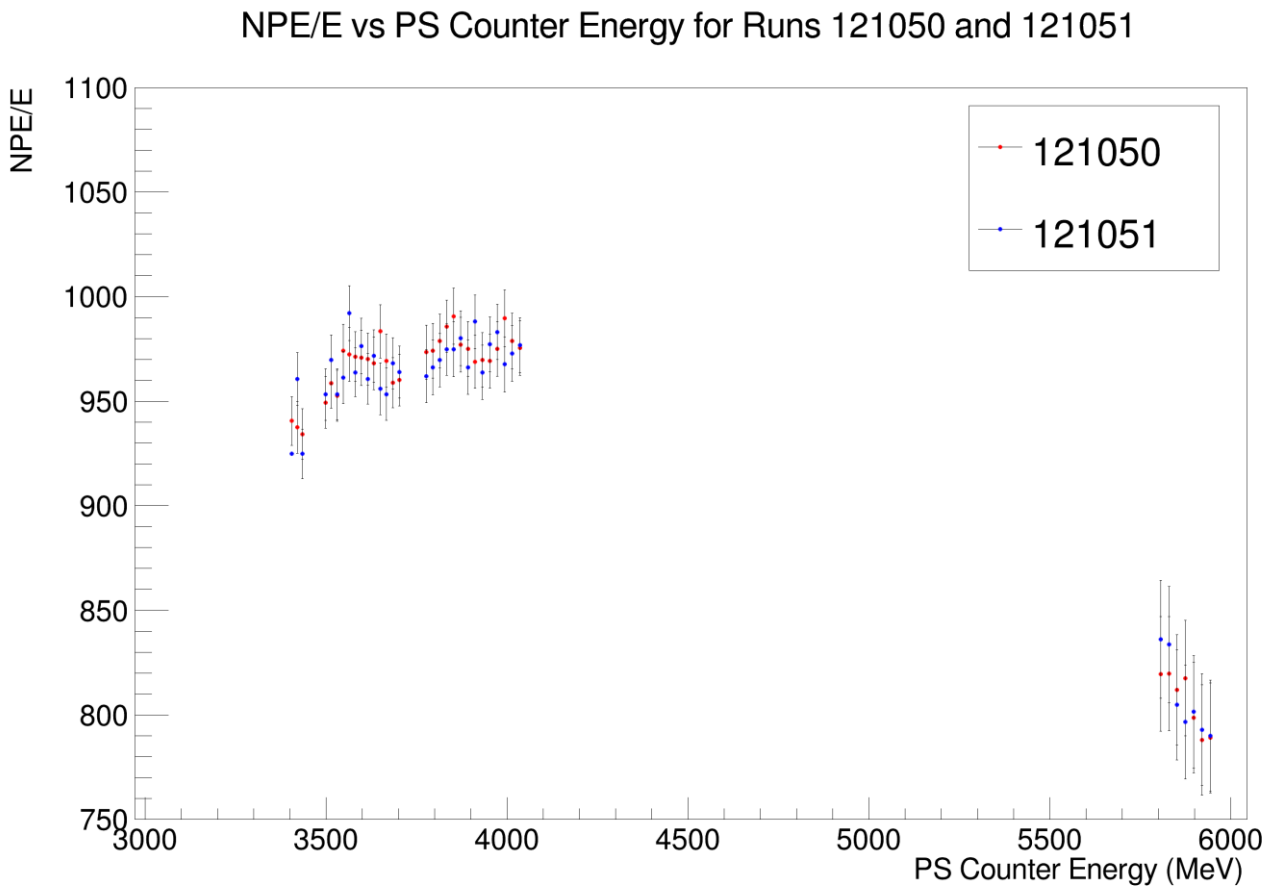
- Form the ratio of energy measured on north/south sides
  - Reduces uncertainty due to sampling fraction
  - Poisson-type statistical process on each end
  - $N_{PE}$ extracted from fit

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

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

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

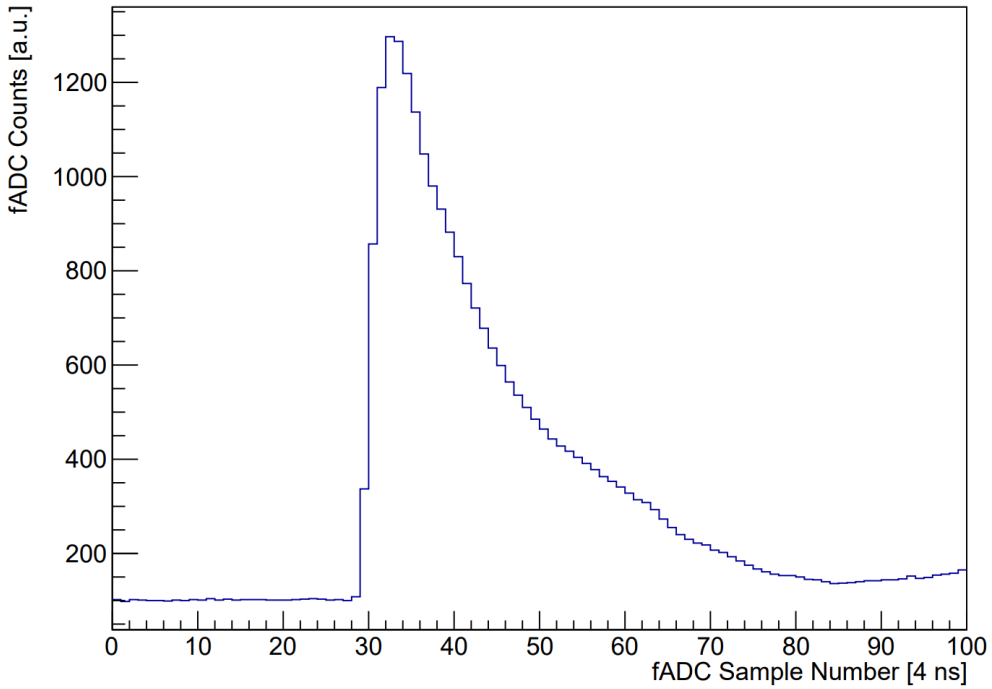
# $N_{PE}$ Over Positron Energy




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

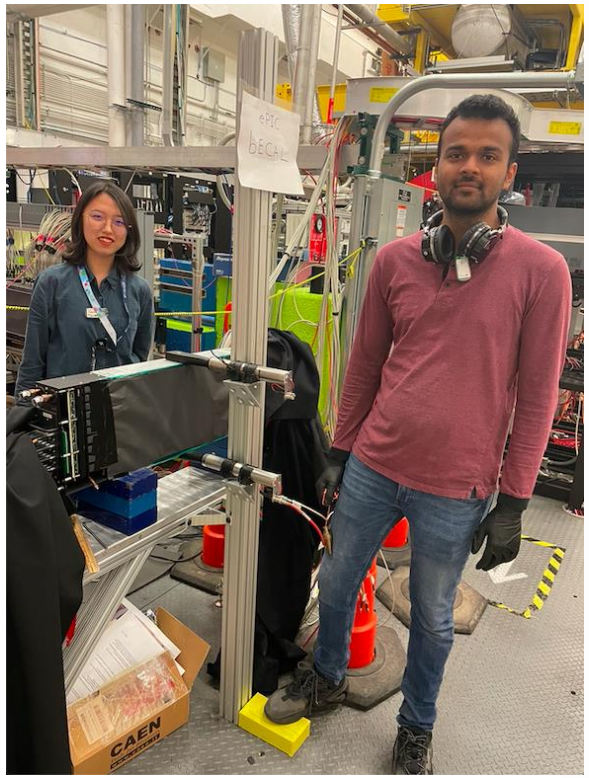
# Raw Waveforms

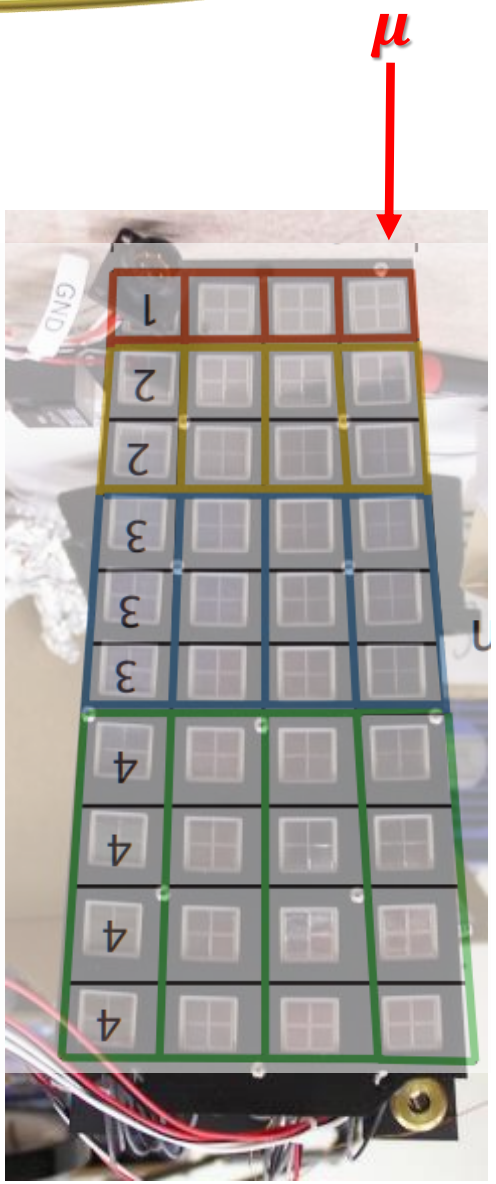
- A number of runs with full waveforms
- Could look for double pulses?
  - Might be rare, analysis challenge to isolate
  - May have enough data though



# Cosmic Runs

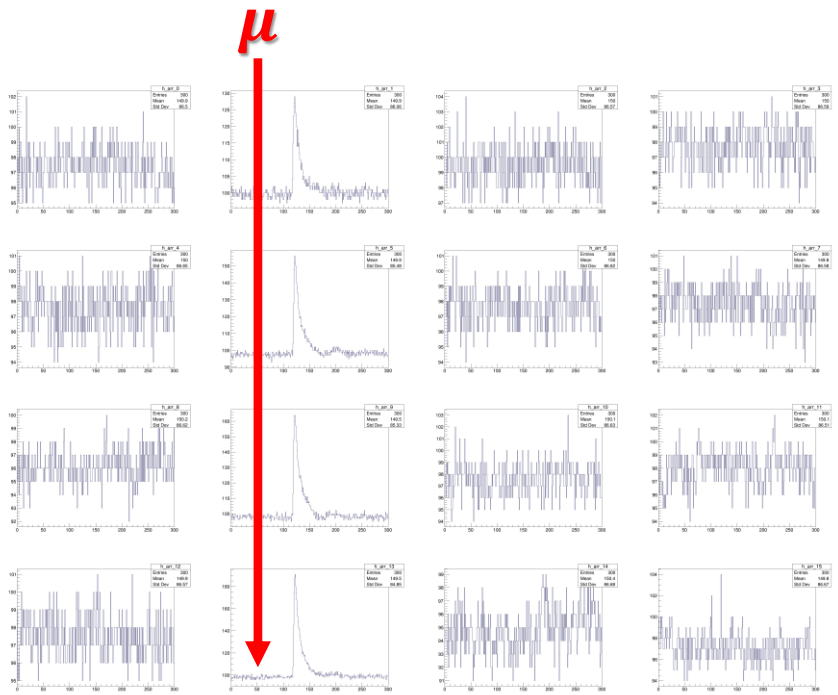
- Unfortunately, $e^+$ always struck the same spot on the baby BCAL
- 99.5% of energy deposited in 12 channels
  - Easy gain determination
- Other 4 channels had very little energy deposition
  - Cosmics for gain determination?



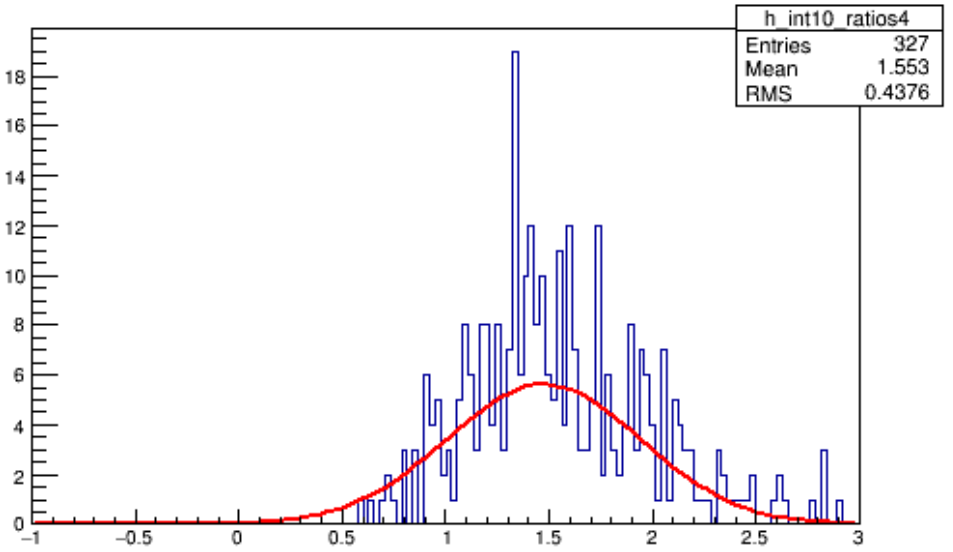



# Cosmic Runs, cont.

- 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?

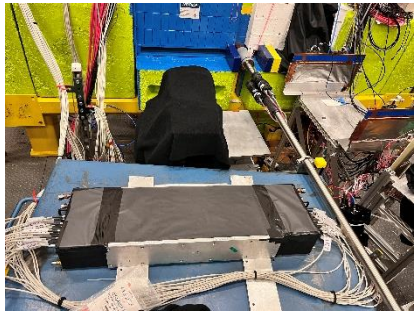
<u>Hope to have publication draft this summer</u>

# 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

# Backup: $e^+$ Beam in Hall D

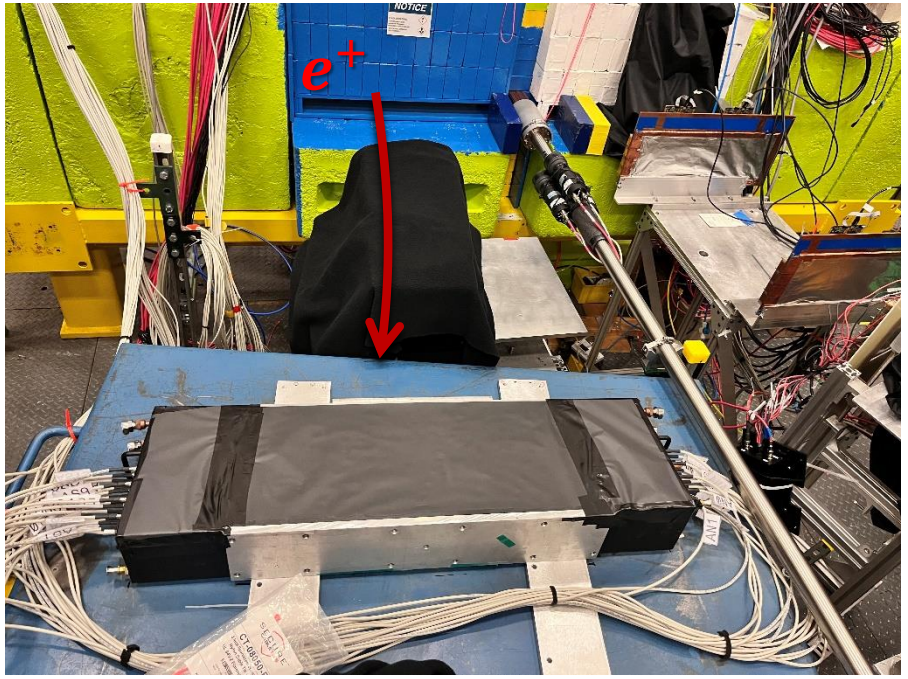
Good source of EM showers with known energy

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

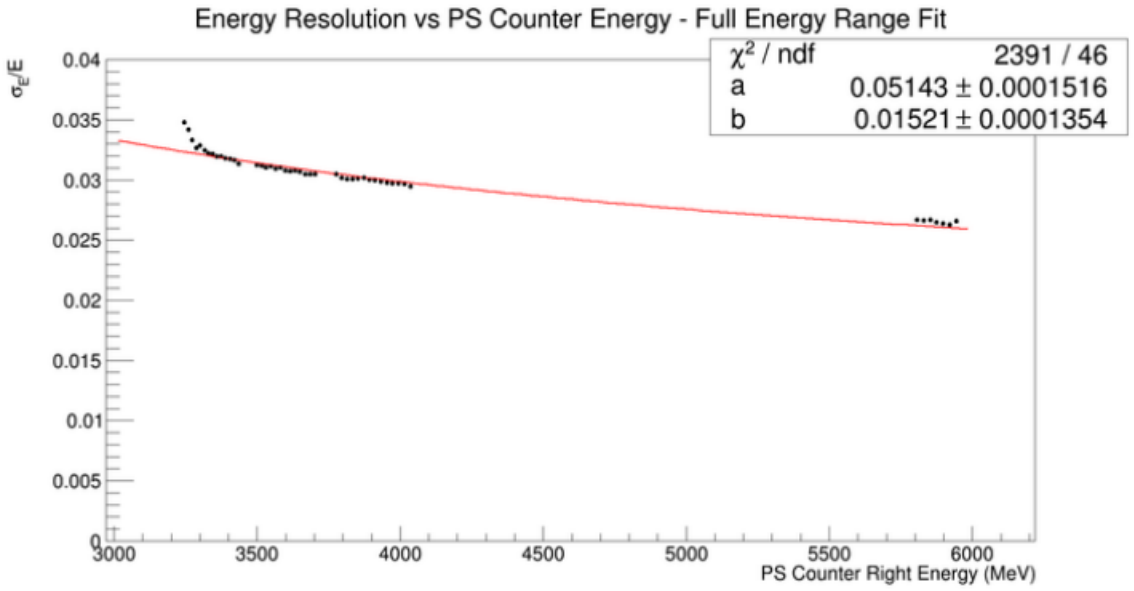
Hall D pair spectrometer:

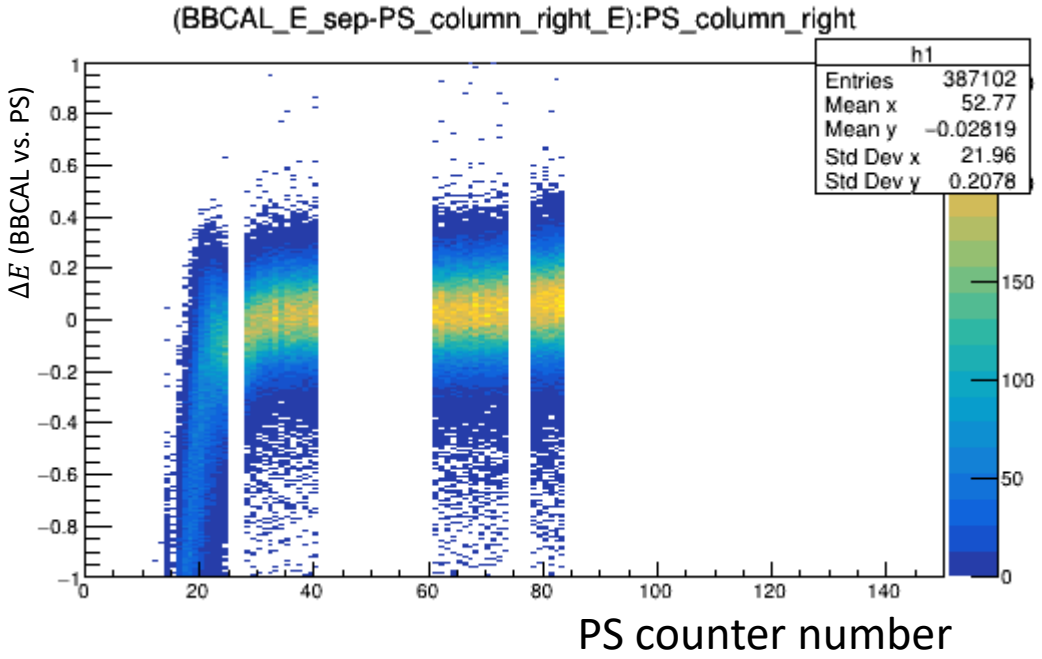
- $e^+$ energy roughly 3-6 GeV
- Unfortunately, SciGlass blocks portions
- About 1 kHz event rate BBCAL
- About 12 days (on and off) running

View from above



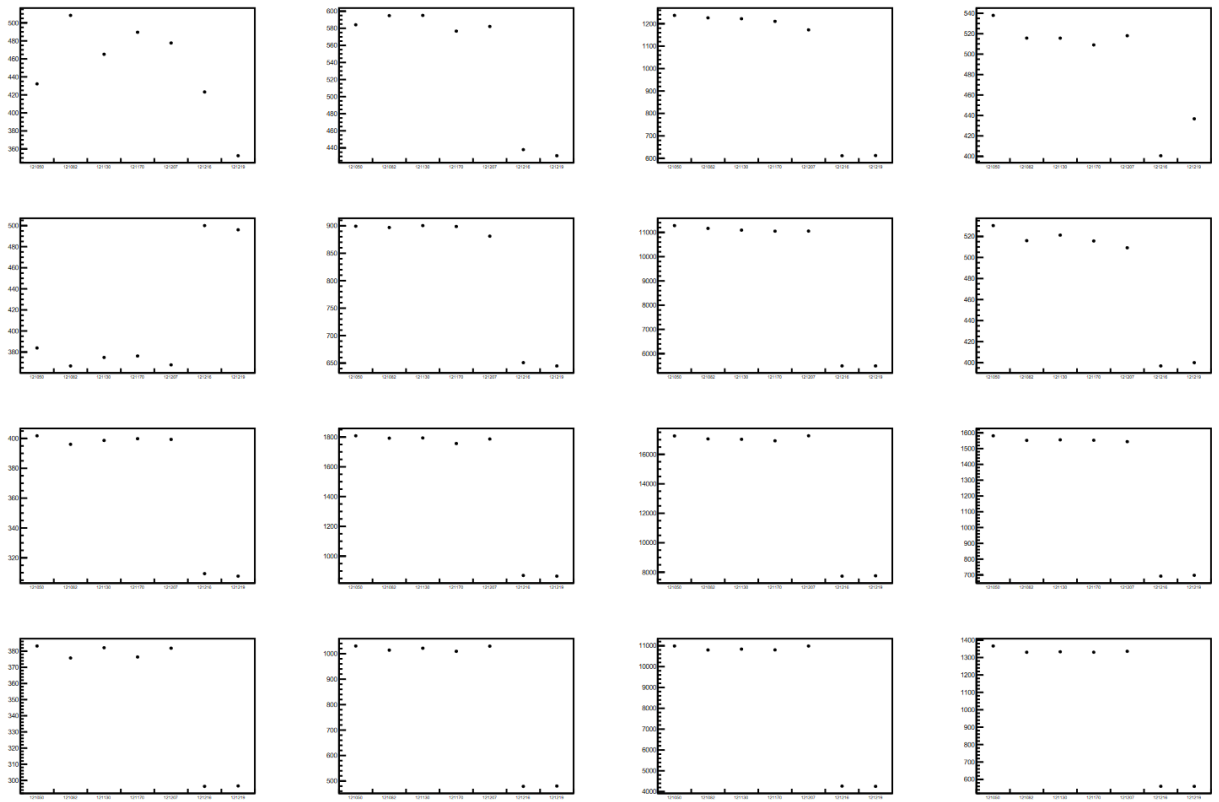
# Backup: More Energy Leakage Plots



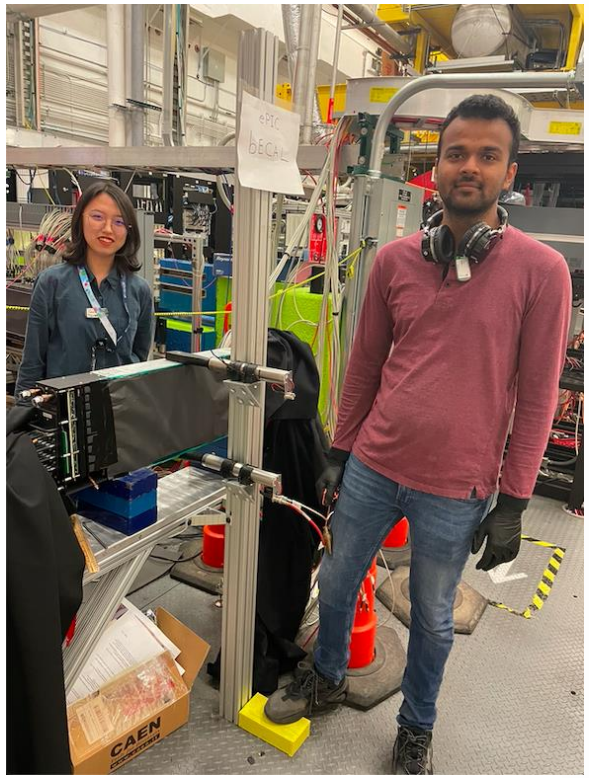
# Backup: Longer Term Stability

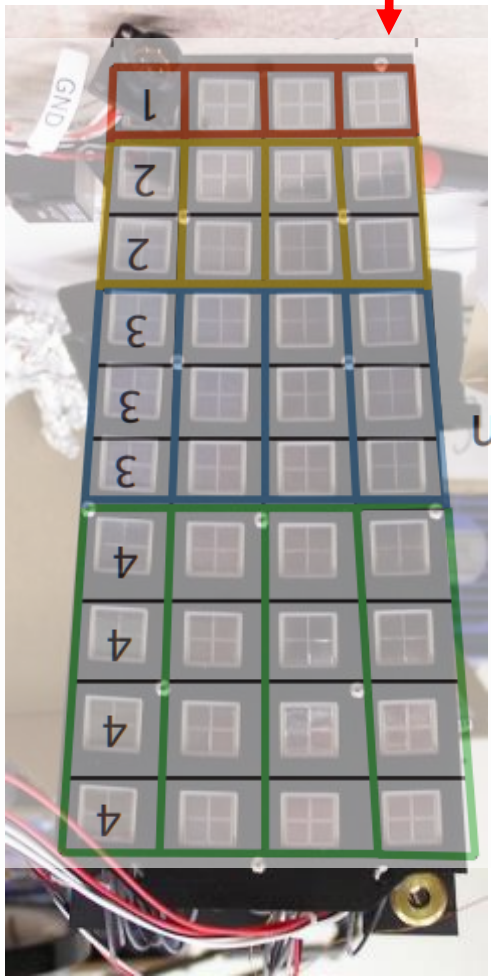
- Check individual channels over 12 day period
- Mostly checking for rad. damage
- Average fADC integral in un-shadowed region
- SiPM bias voltage change for last two points, jump expected



# Backup: Cosmic Setup Details

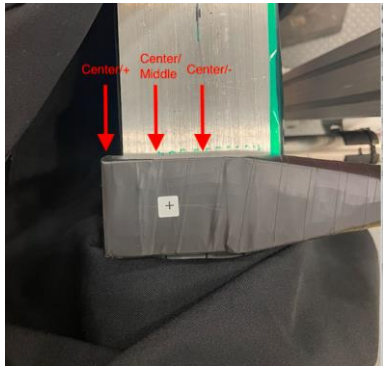
- Unfortunately, $e^+$ always struck the same spot on the baby BCAL
- Very low occupancy in some channels
- Use MIPs to calibrate?
- Cosmic setup ran from August – October collecting data
  - Close to 30,000 muons collected



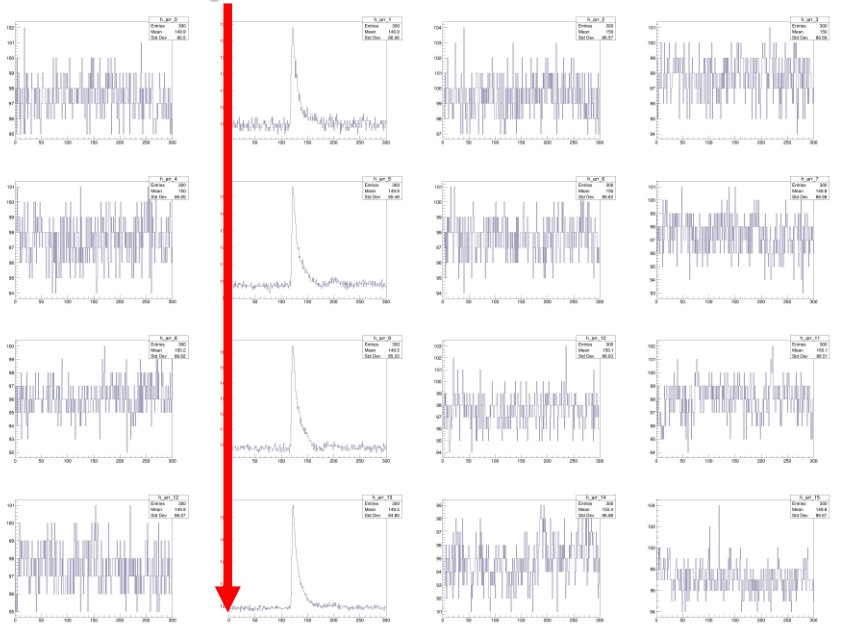



# Backup: Cosmic Analysis and Event Selection

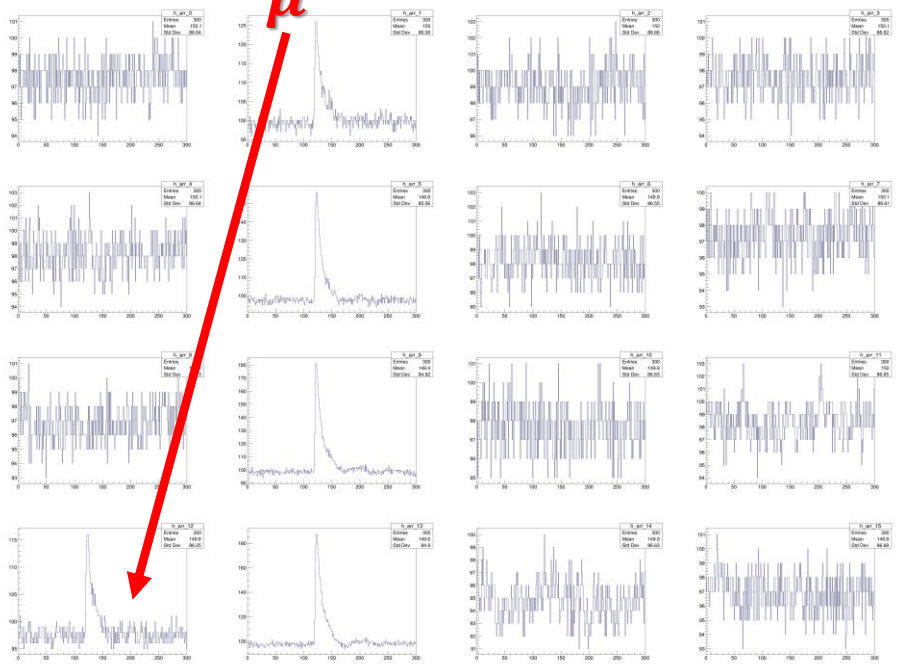
- Match voltage settings during March running
- Paddles ensure that tracks are fairly vertical
- Can still improve with some event selection




$\mu$ [want to accept]

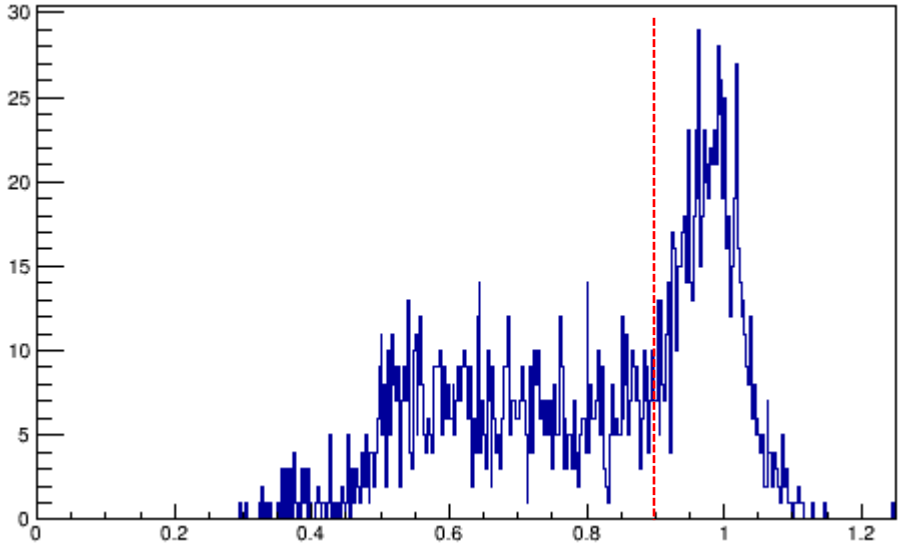


[want to reject] $\mu$

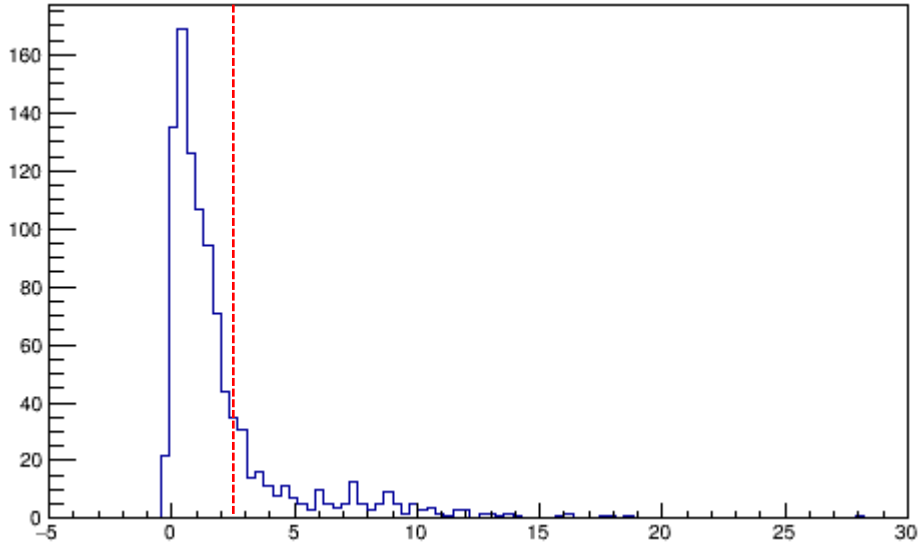


# Backup: Cosmic Event Selection, cont.

- 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

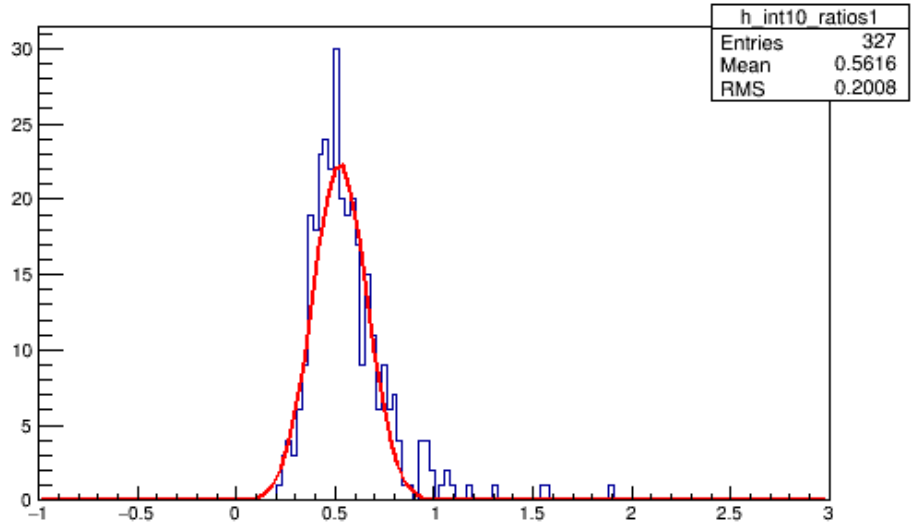



Largest top/bottom neighbor (a.u.)

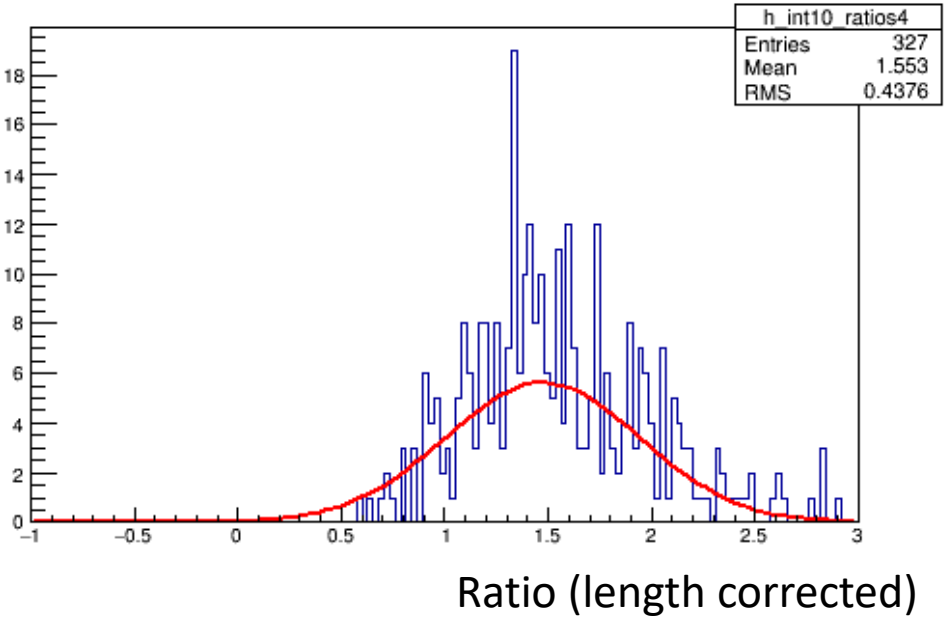
# Backup: Cosmic Initial Checks

- Check channels that were well determined in March run

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



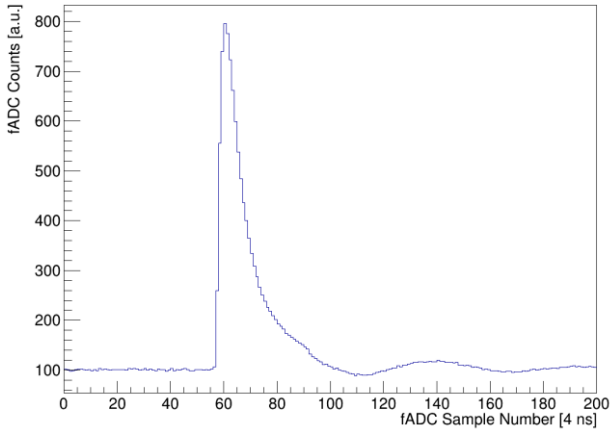

South 6 / South 14
Cosmics: **1.47**
March: **1.55**



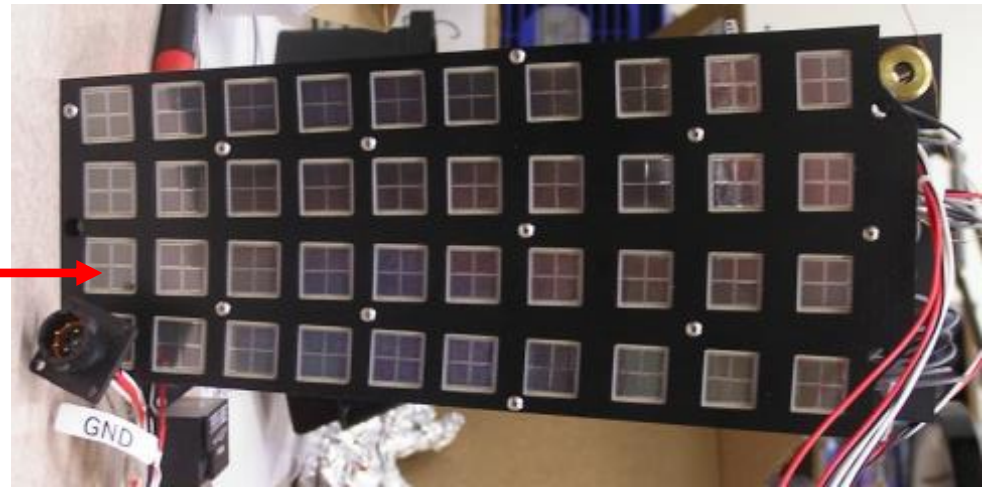
# Backup: Segmentation and Readout

## 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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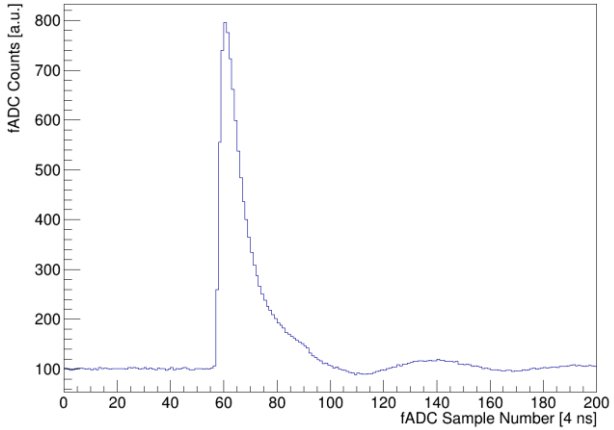
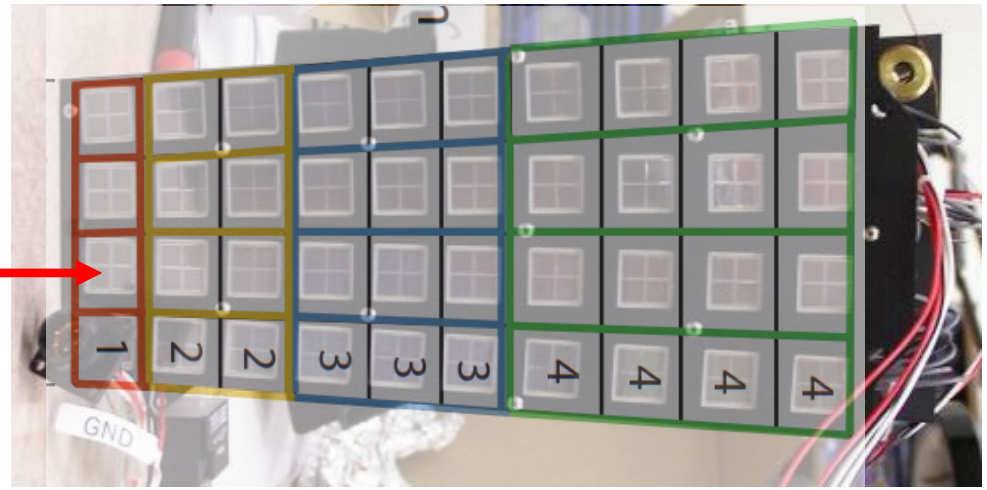



## Two-ended readout:

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

View from side

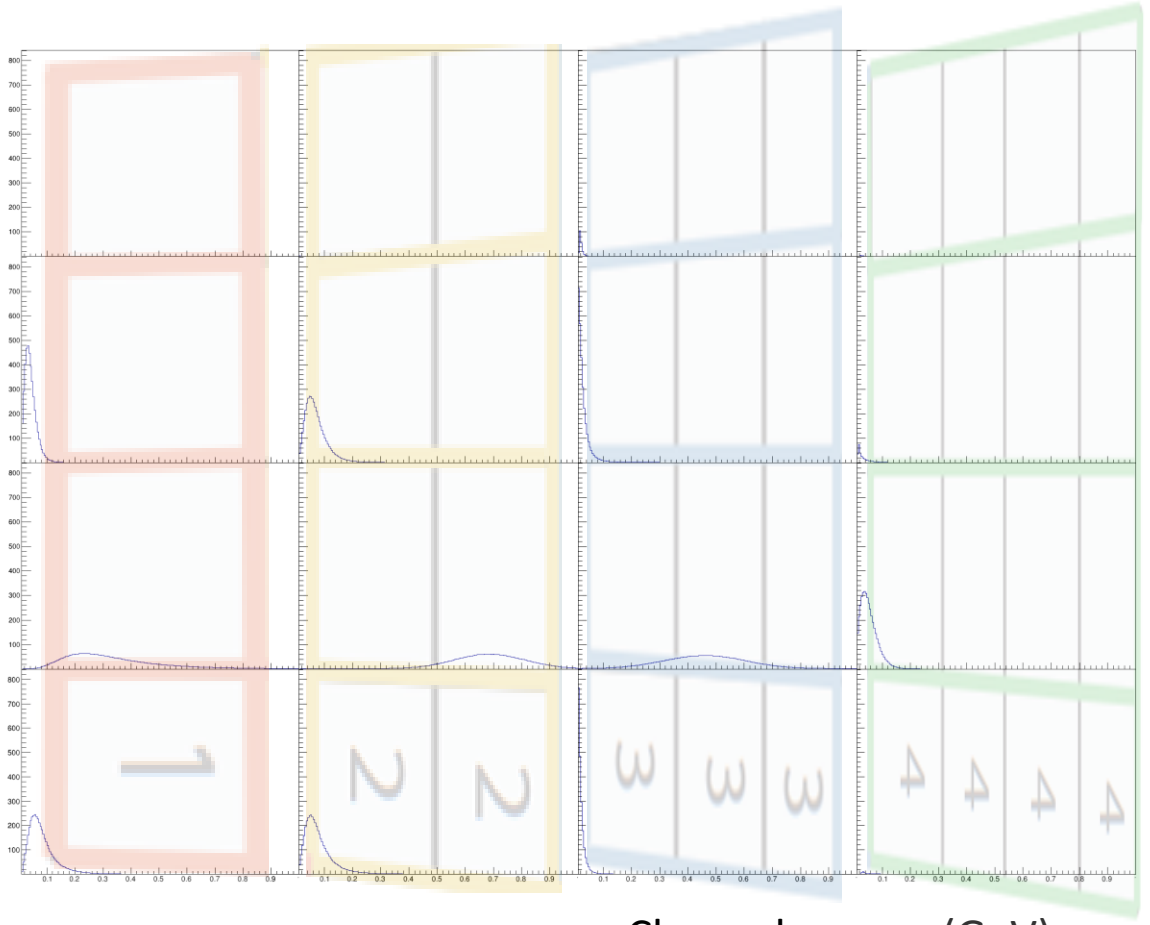



(summation for bottom channels 1, 2, 3, 4)

# Backup: Showers in Baby BCAL

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

$e^+$




Channel energy (GeV)

# 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

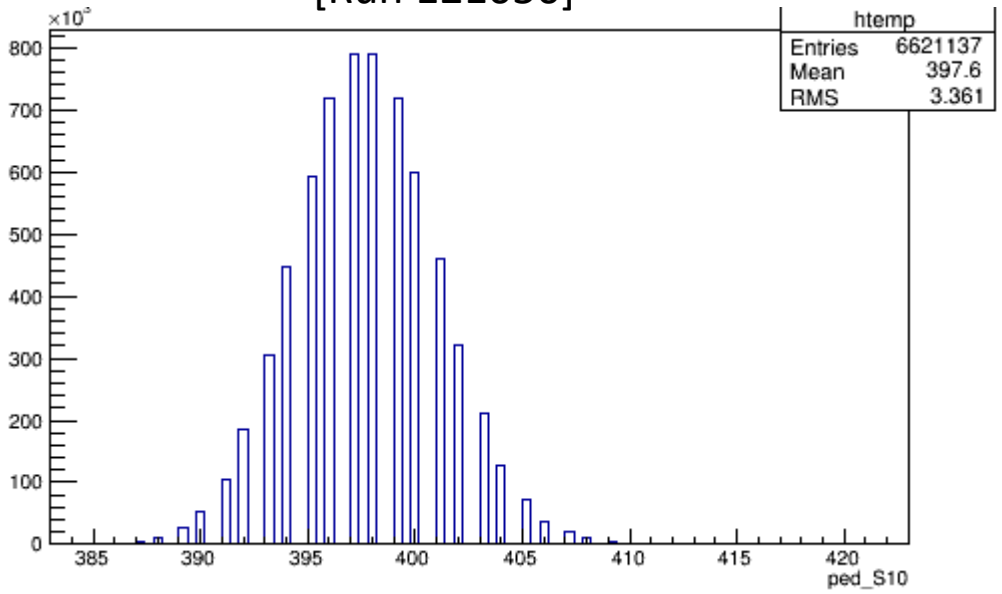
- Determine separate north/south
- Let $f_j = \frac{\sum_i A_j^N}{\sum_i \left(A_j^N + A_j^S\right)} \Rightarrow \left(1 - f_j\right) = \frac{\sum_i A_j^S}{\sum_i \left(A_j^N + A_j^S\right)}$

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

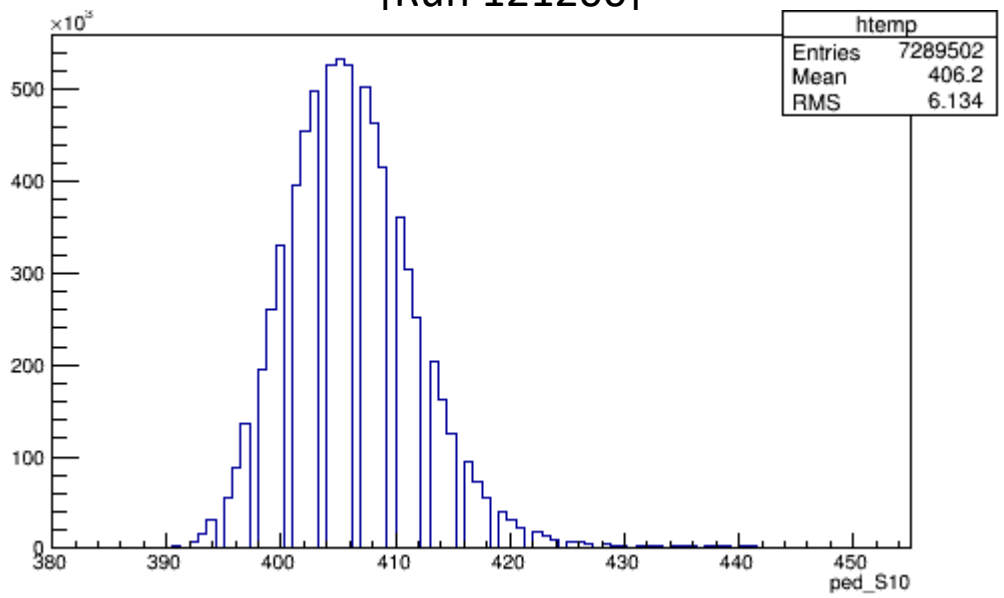
# Backup: Channel S10 Degrading over March Runs

**Measured Pedestal**
**(4 sample sum)**

[Run 121050]




[Run 121200]

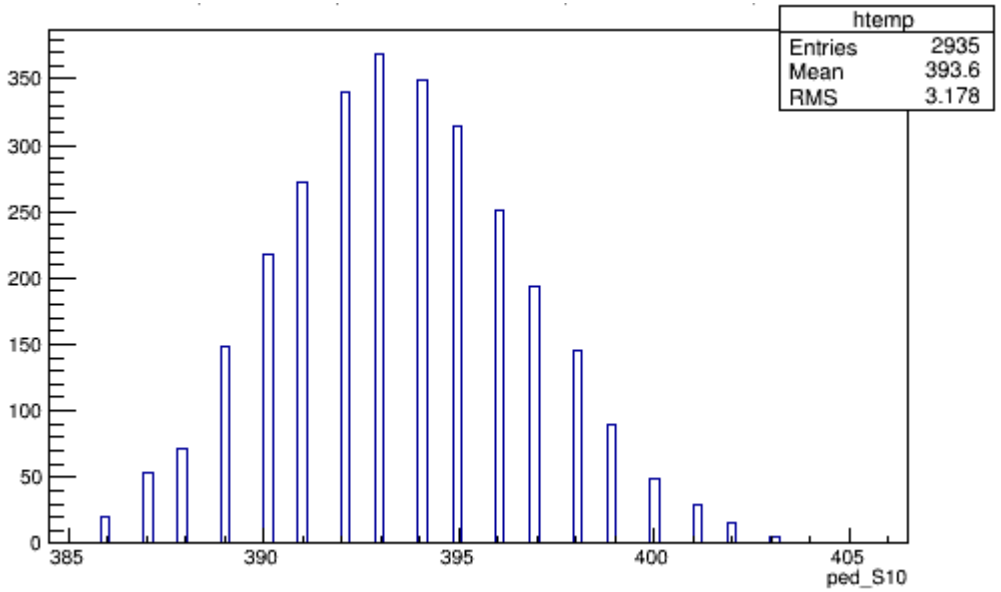


# Backup: Channel S10 in Cosmic Data

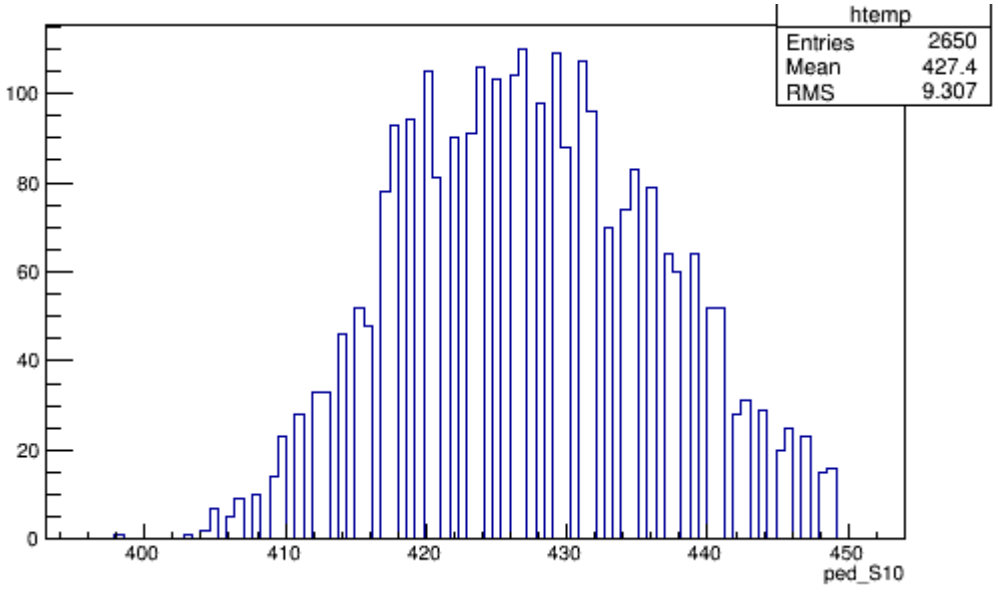
## Before chillers

**Measured Pedestal**
**(4 sample sum)**

[Run 121303]



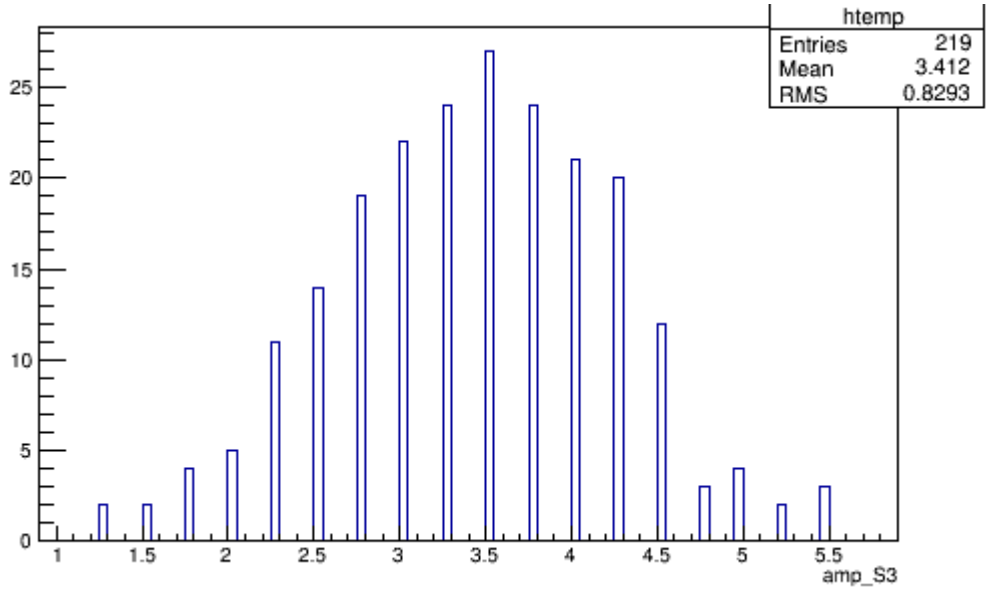

[Run 121304]

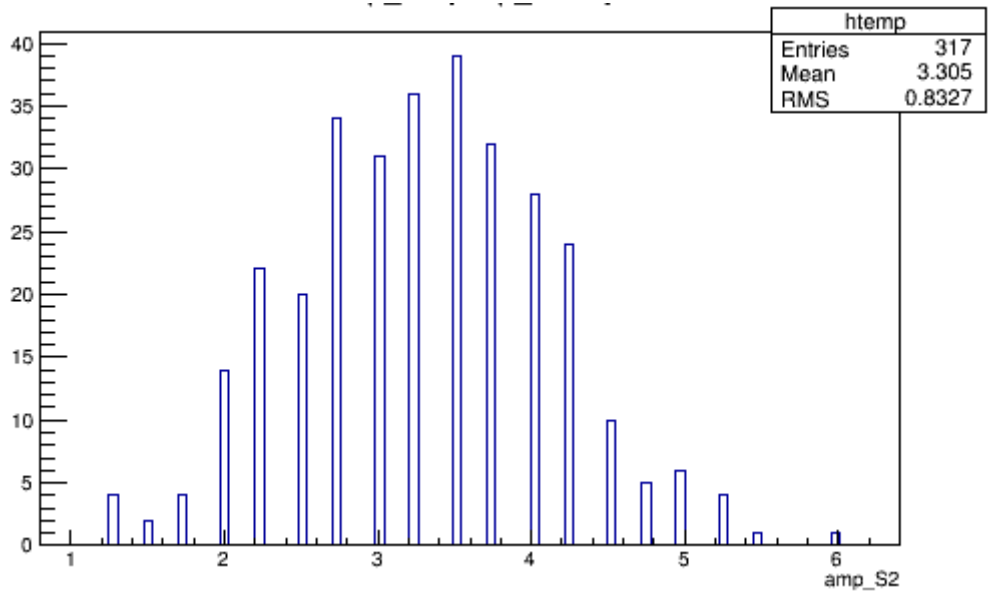


# Backup: Also curious

## 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

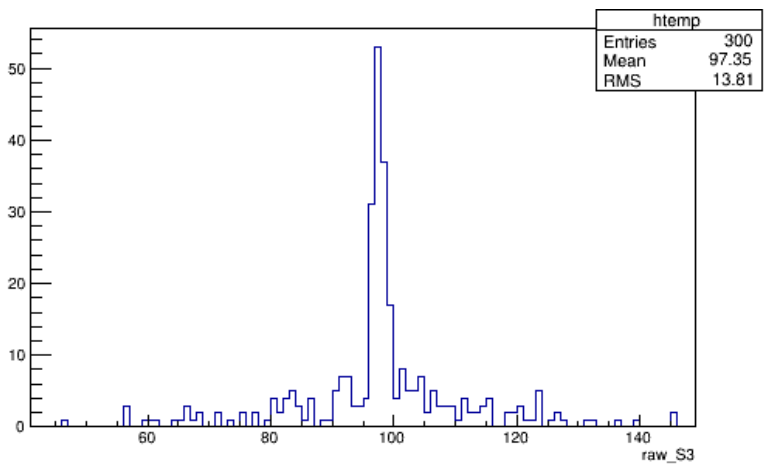


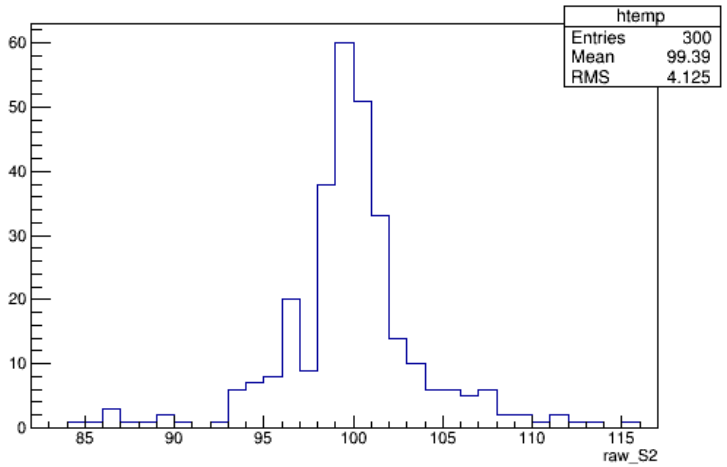
# Backup: Exactly Two Events

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

**[Run 121316]**




**[Run 121318]**

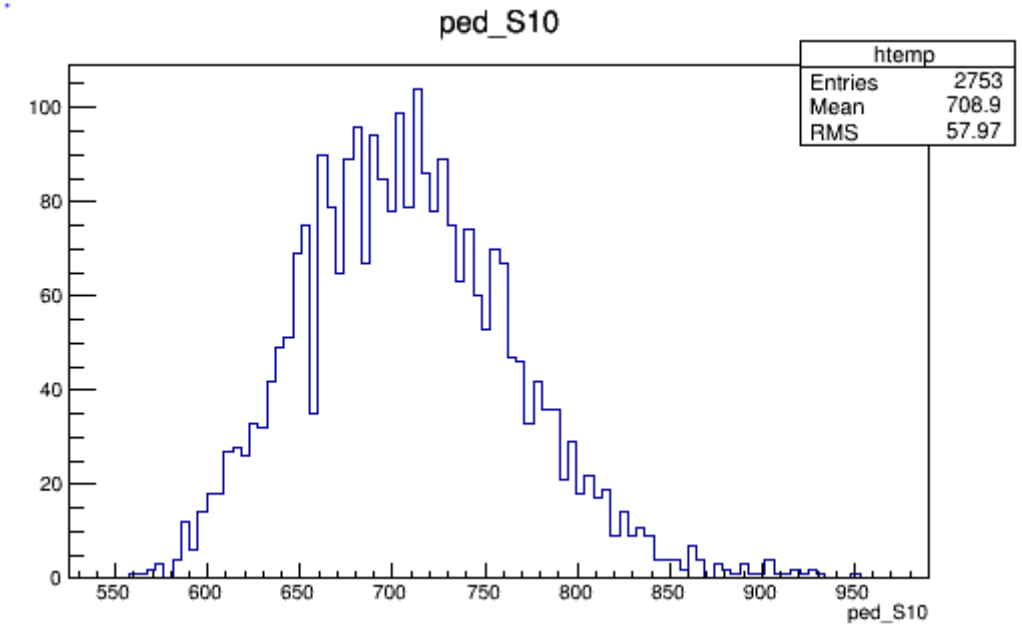



Points to some combination of voltage setting, connectors, or power distribution?

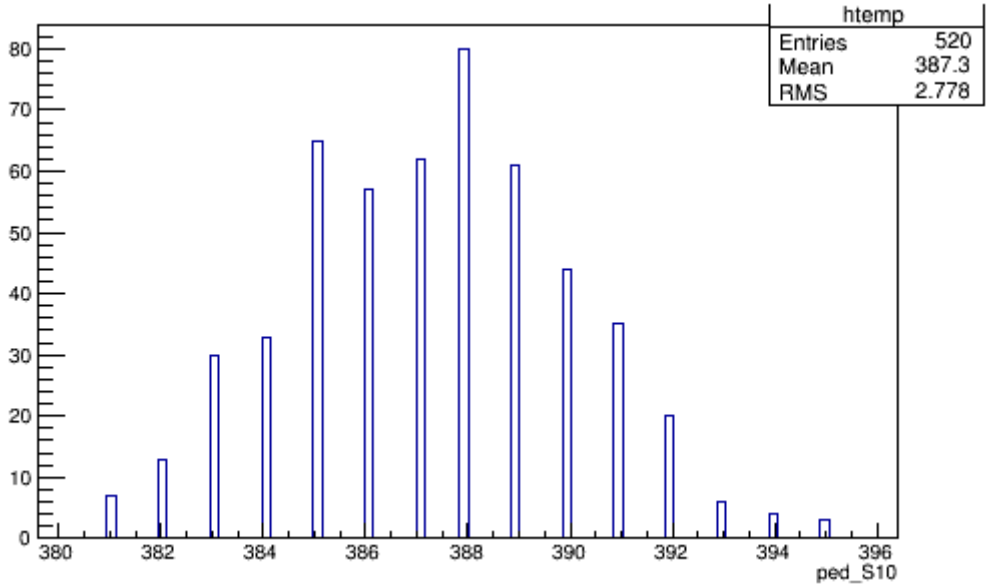
# Backup: Channel S10 in Cosmic Data

- 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]**



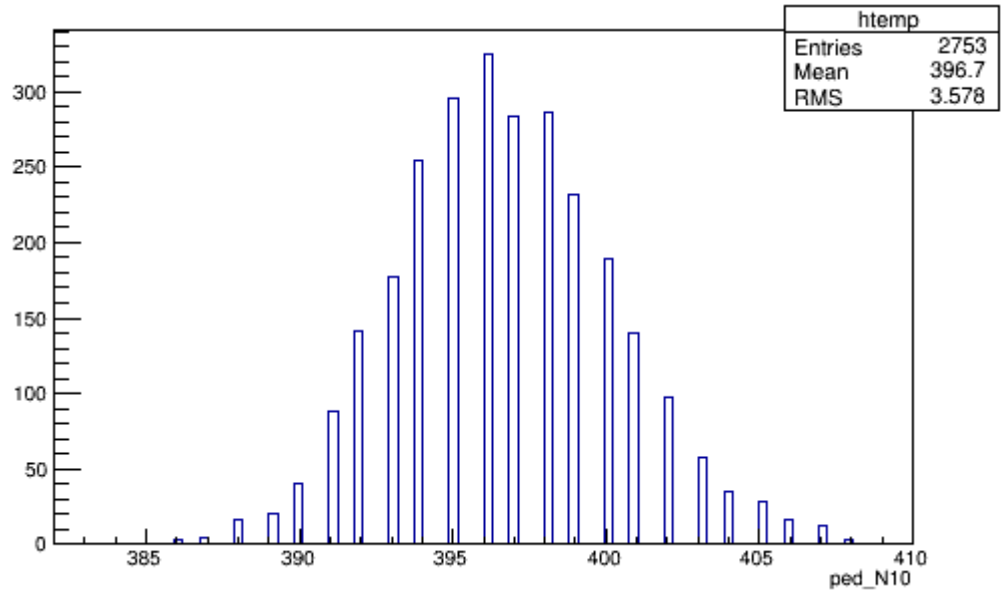

**[Run 121312]**



# 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]**