EEEMCal HGCROC readout experience at the DESY test beam

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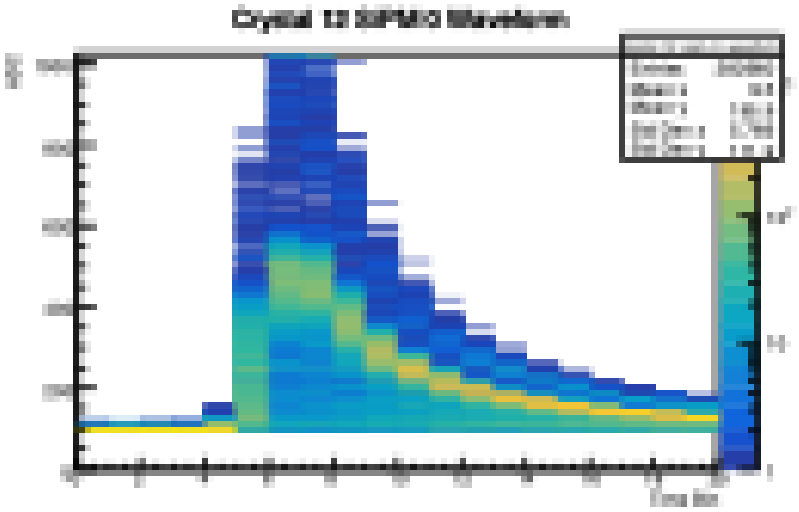
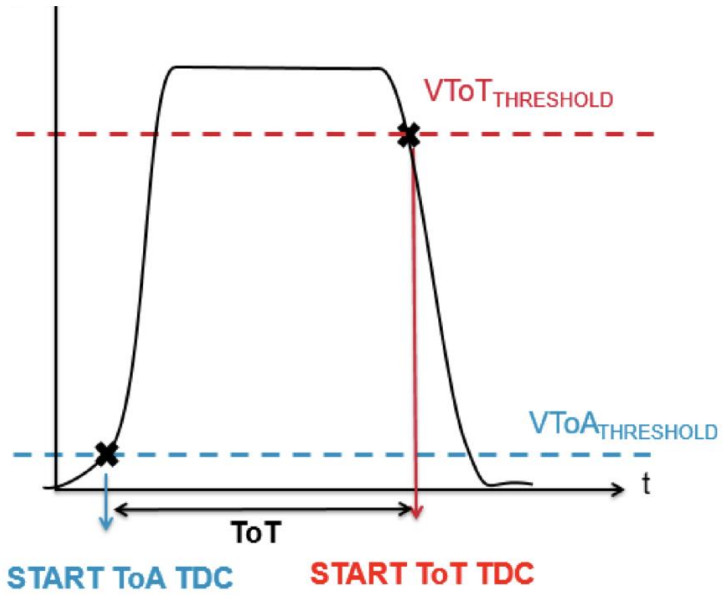
Data collection

- Test beam period Dec. 8th through 22nd, 2025
  - EEEMCal + HGCROC installed 13th through 20th
- Rate limited to ~50 Hz by introducing a 10 ms veto period after each trigger with NIM logic
- 1045 runs total, I am focusing on ~50 of them
  - 25 1.0 GeV runs centered on each crystal
  - An energy scan of runs with 0.2 GeV increments between 1.0 and 5.4 GeV
- 9x9mm upstream collimator, 10x10 downstream collimator installed

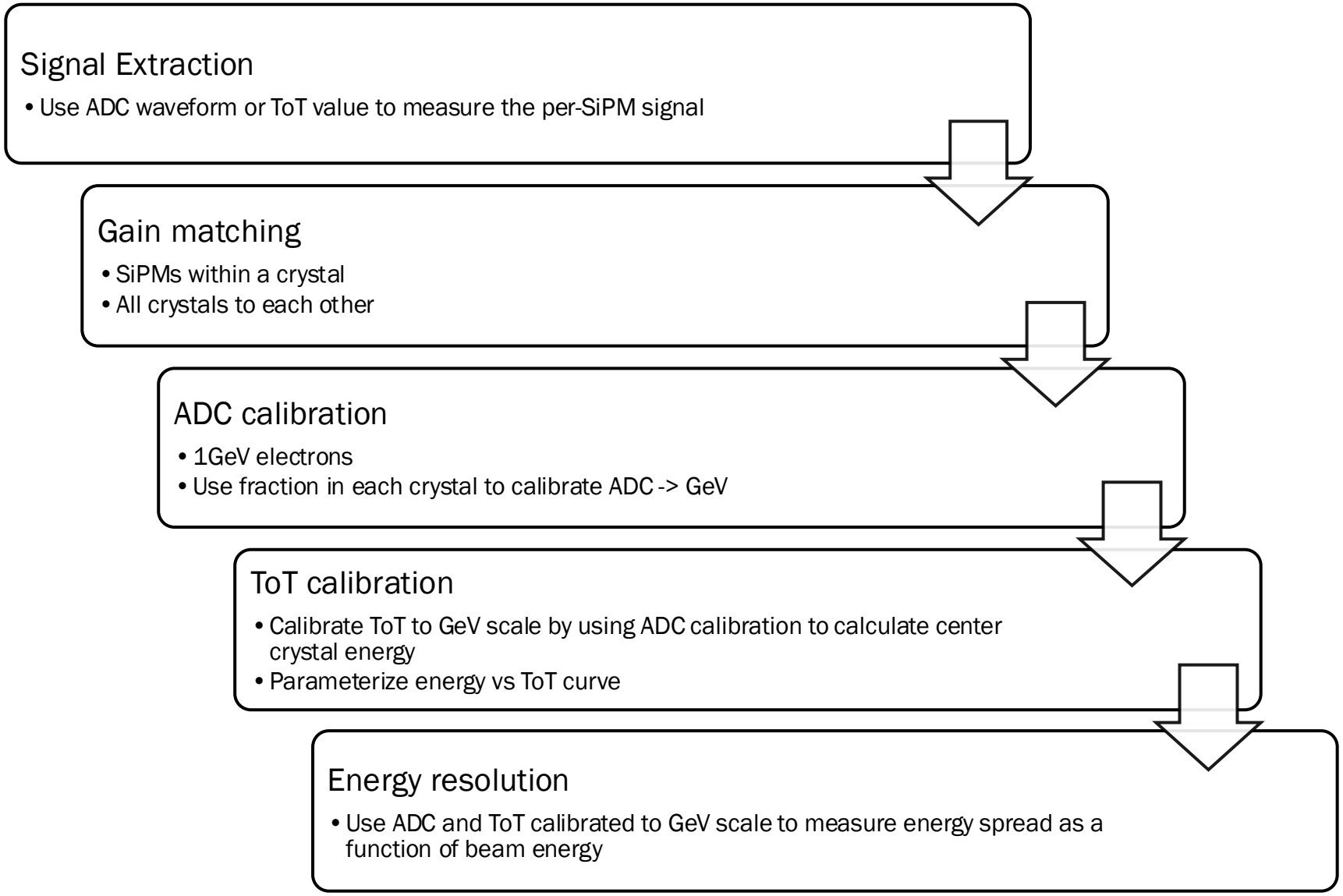
HGCROC readout

- Used as 40 MHz sampling readout
- 72 channels per ASIC
- ADC for high gain readout
- Time over threshold measurement for low gain readout
- 2 ASICs connected to each FPGA, data sent via UDP to DAQ PC
- Synchronization based on event counters and time stamp deltas
  - High (>95%) reconstruction efficiency!





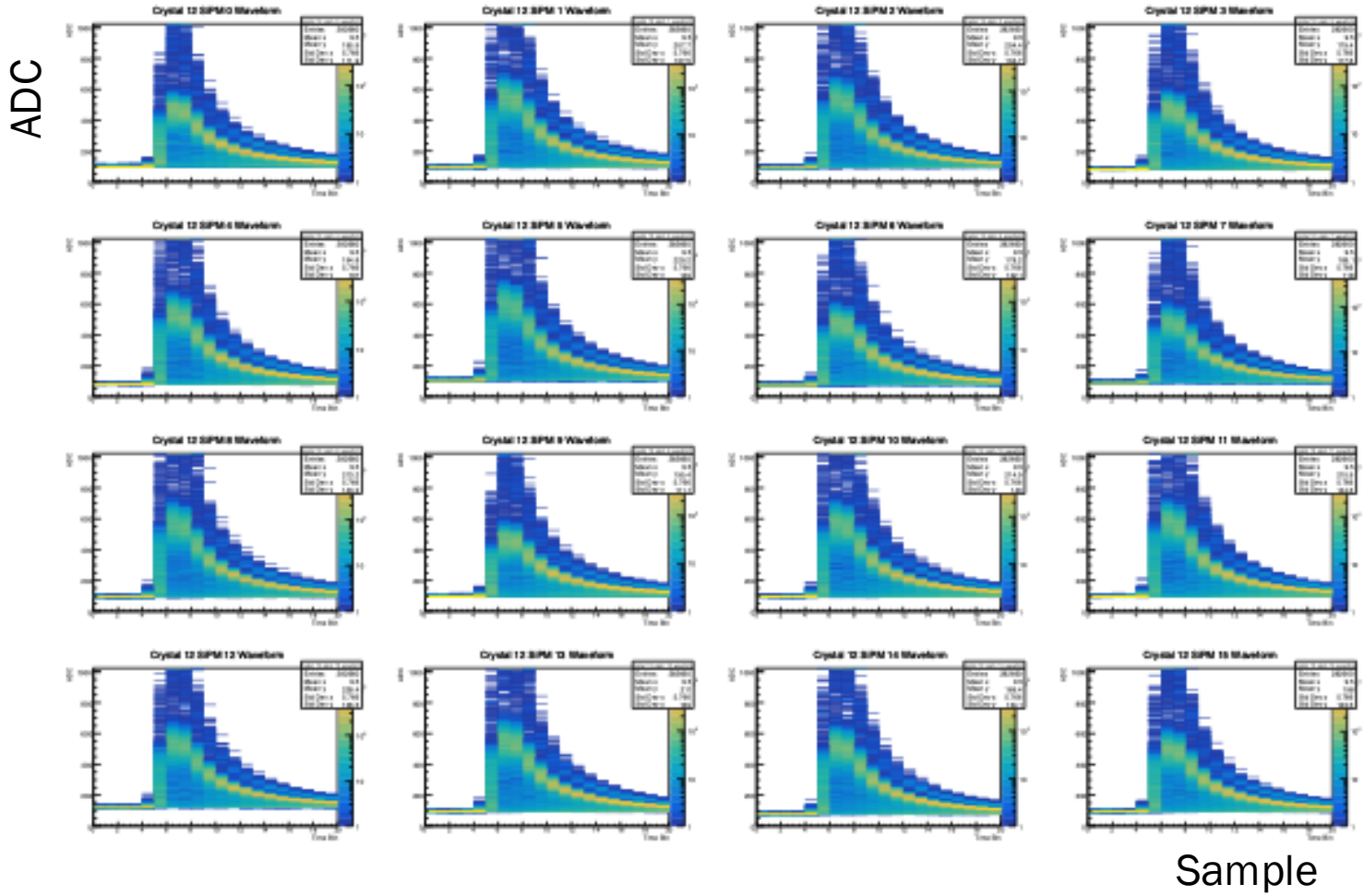
Outline


Signal Extraction
• Use ADC waveform or ToT value to measure the per-SiPM signal
Gain matching
• SiPMs within a crystal
• All crystals to each other
ADC calibration
• 1GeV electrons
• Use fraction in each crystal to calibrate ADC -> GeV
ToT calibration
• Calibrate ToT to GeV scale by using ADC calibration to calculate center crystal energy
• Parameterize energy vs ToT curve
Energy resolution
• Use ADC and ToT calibrated to GeV scale to measure energy spread as a function of beam energy

Signal extraction

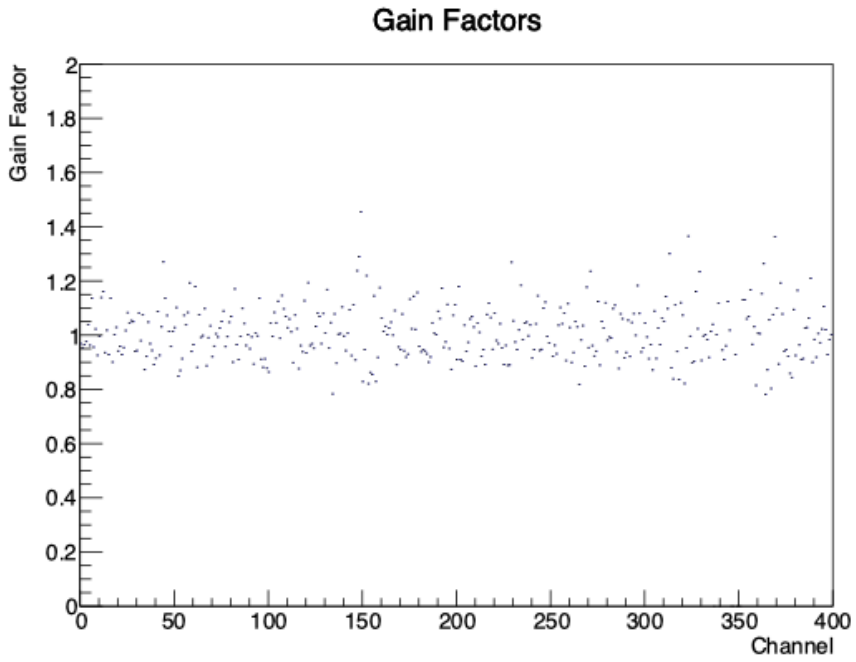
- 20 samples per trigger, taken 25 ns apart
- ADC signal
  - Define the per-event pedestal: $p = \frac{1}{3}(s_0 + s_1 + s_2)$
  - Let i be the index of the largest ADC value
  - The signal E is then $E = s_{i-1} + s_i + s_{i+1} + s_{i+2} - 4p$
- Several other methods are under investigation

Central crystal ADC vs sample, 1 GeV

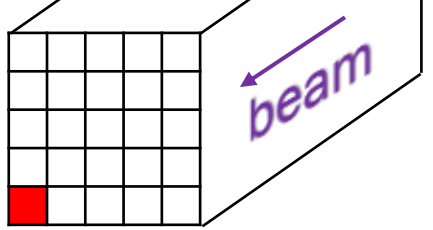


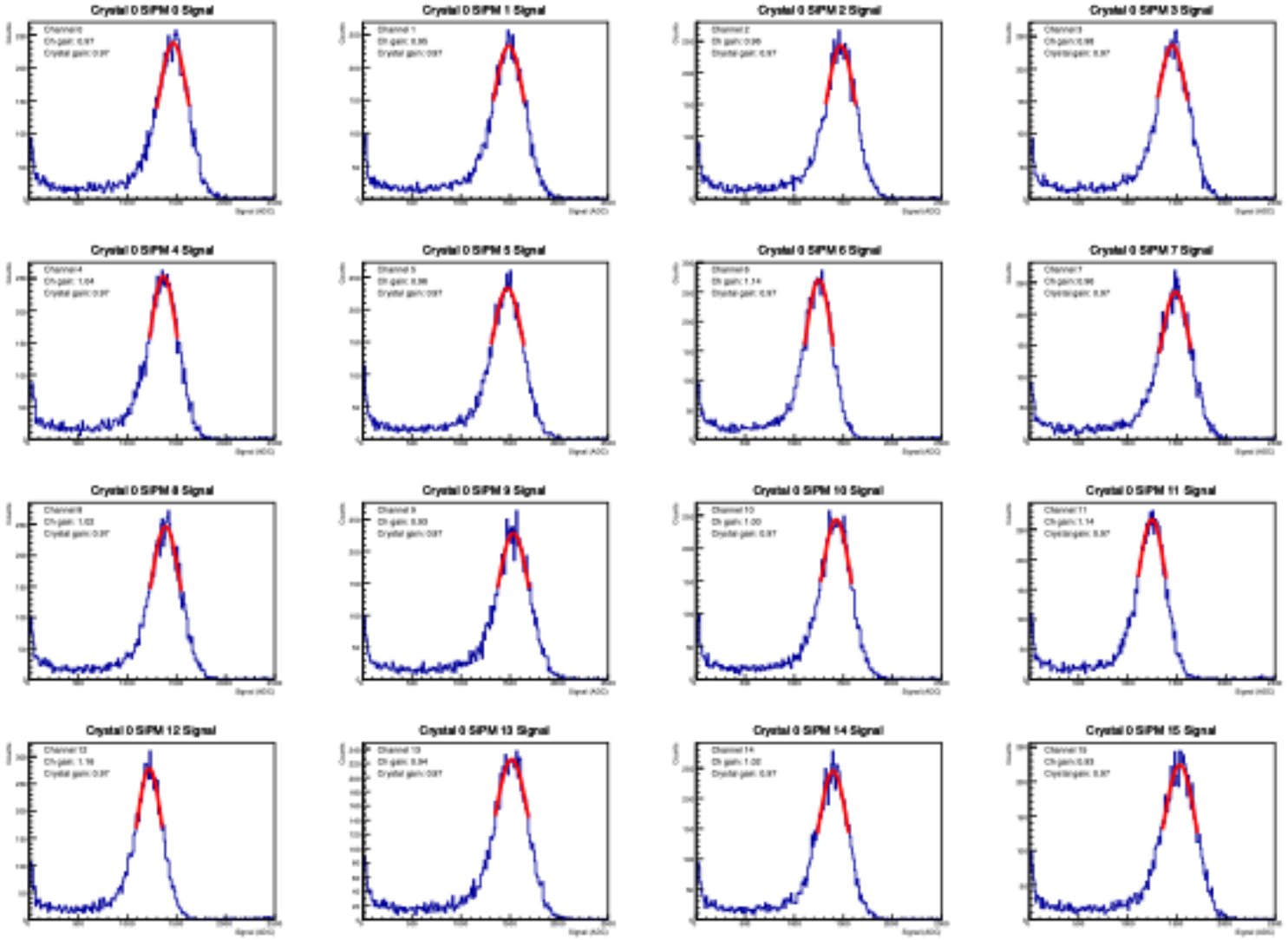
Gain Matching, SiPMs

- Locate the signal peak for each of the 16 SiPMs on a crystal
- Calculate then mean signal peak per crystal, and define a gain factor such that all SiPMs peak there
- Most values between 0.85 and 1.15



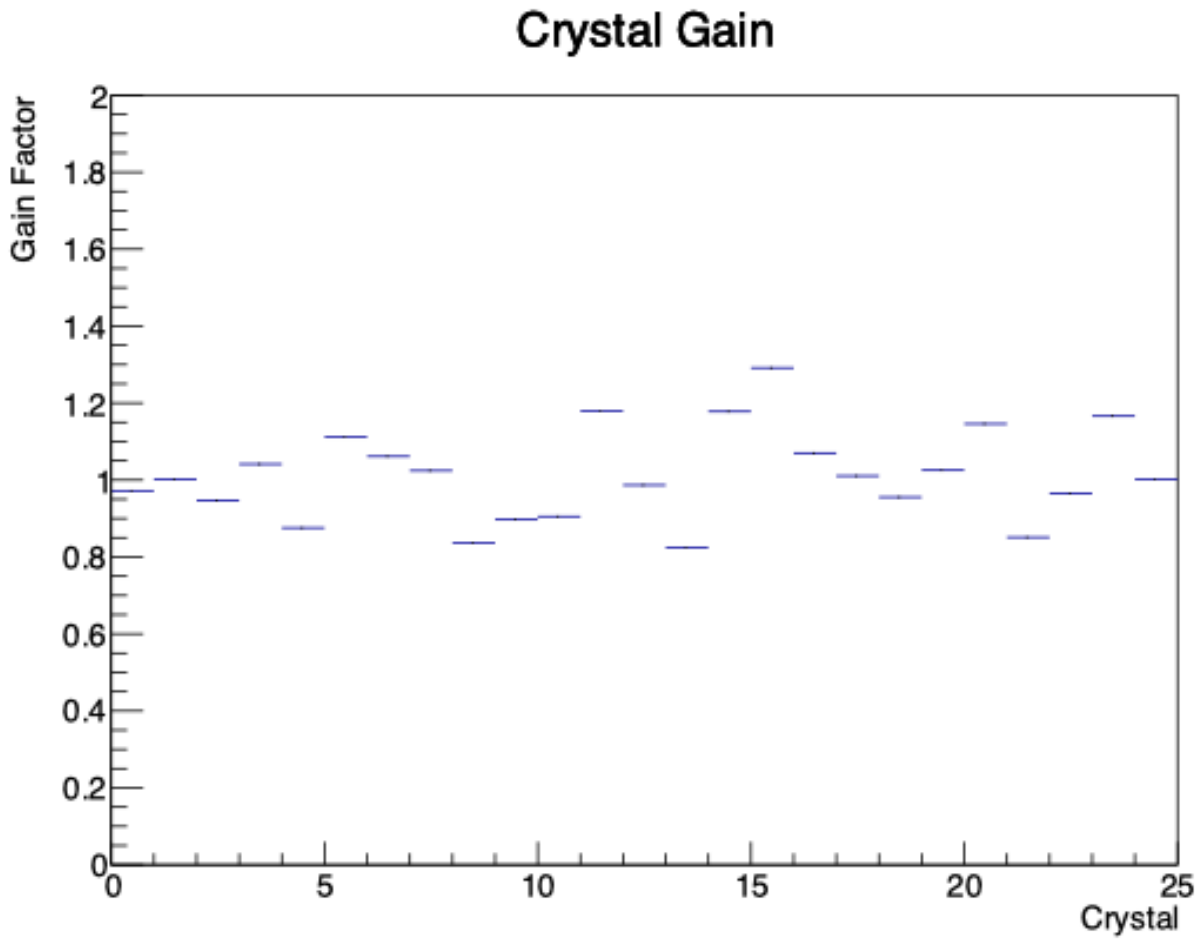
1 GeV electrons, centered on crystal 0





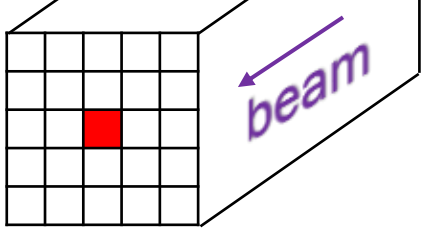
Gain matching, crystals

- Using per-SiPM gain factors, calculate the crystal signal as the sum of all 16 SiPM signals
- Calculate a per-crystal gain factor such that all 25 have the same mean value
- $\mathrm{ADC}_{\mathrm{tot}} = \sum g_i * (\sum g_j s_{ij})$
  - g_i - crystal gain
  - g_{ij} - SiPM gain
  - s_{ij} - signal from crystal i SiPM j
- Will check for consistency with single step gain matching

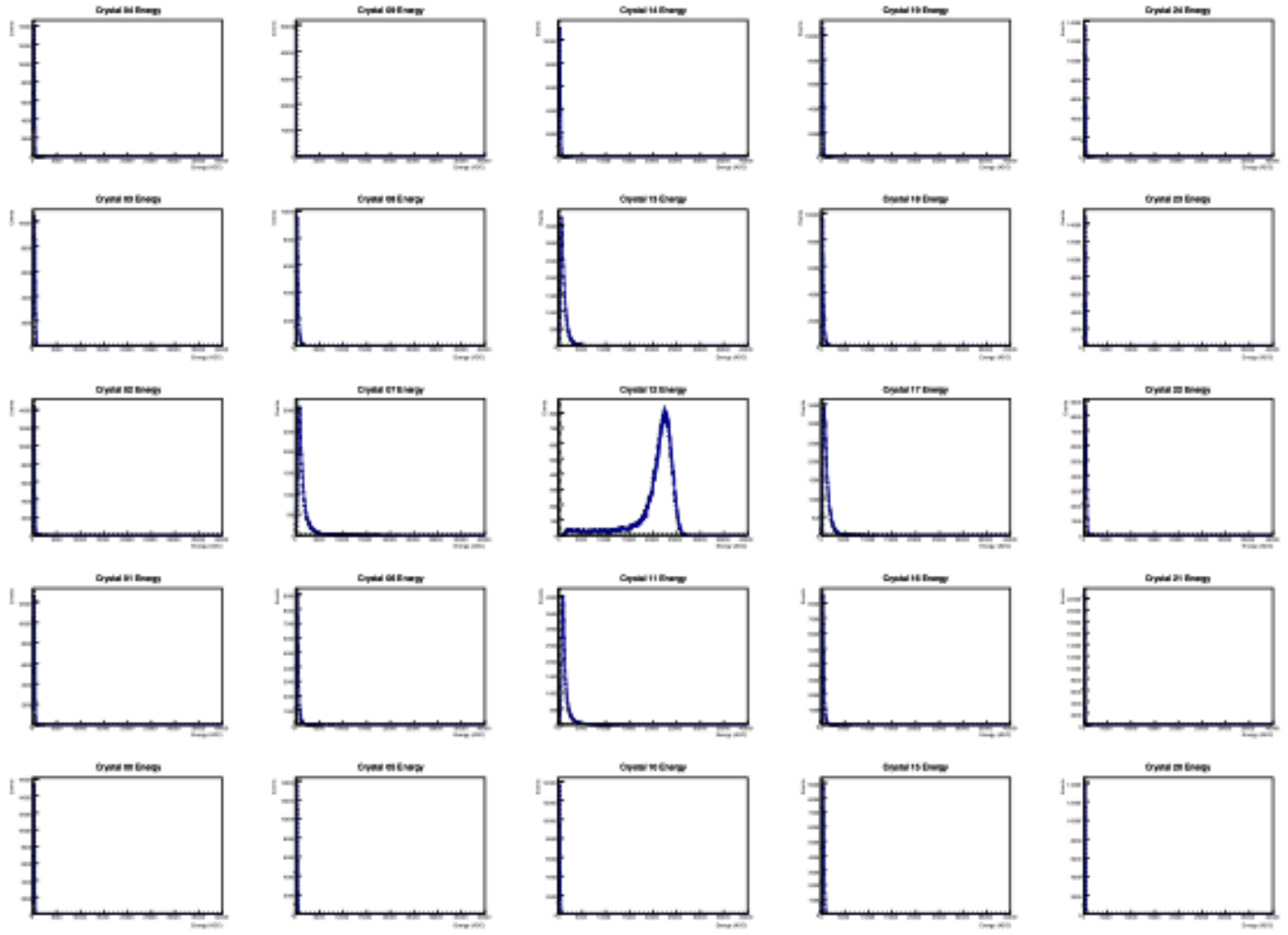


ADC calibration

- At 1 GeV, the ADC does not saturate and the ToT does not fire
- Most the signal is in the center crystal, small fractions spill out into neigbors

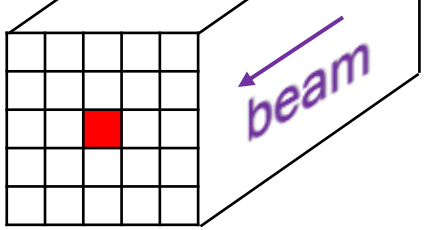


ADC signal, 1 GeV

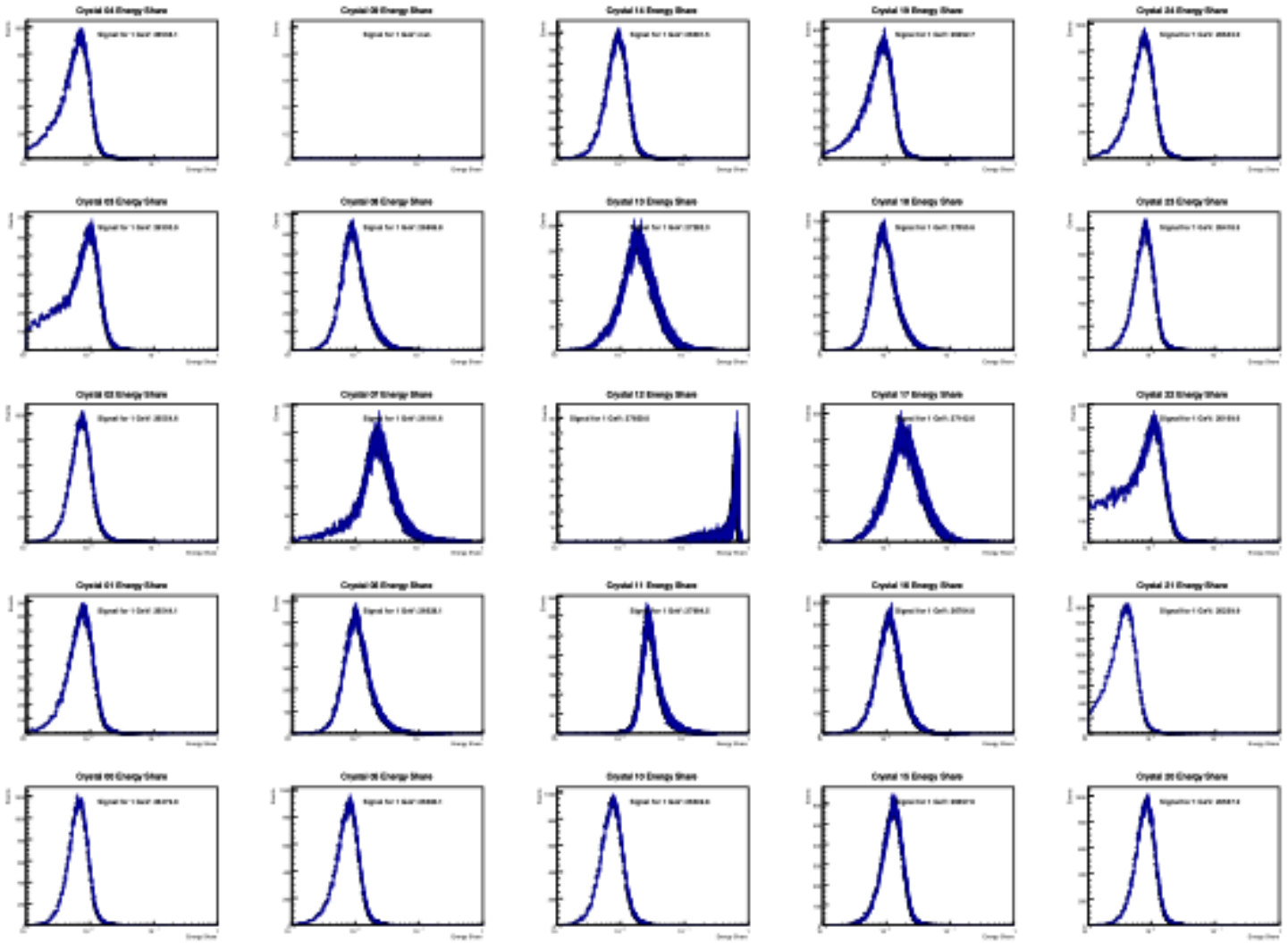


ADC calibration

- ~65% in central crystal
- ~15% in above/below
- ~5% in diagonals
- Remaining 15% in outer 16 crystals
- Assume all energy is captured: Calculate factor to convert signal to energy in GeV for each crystal
- Mean of 26,704.4 signal = 1 GeV

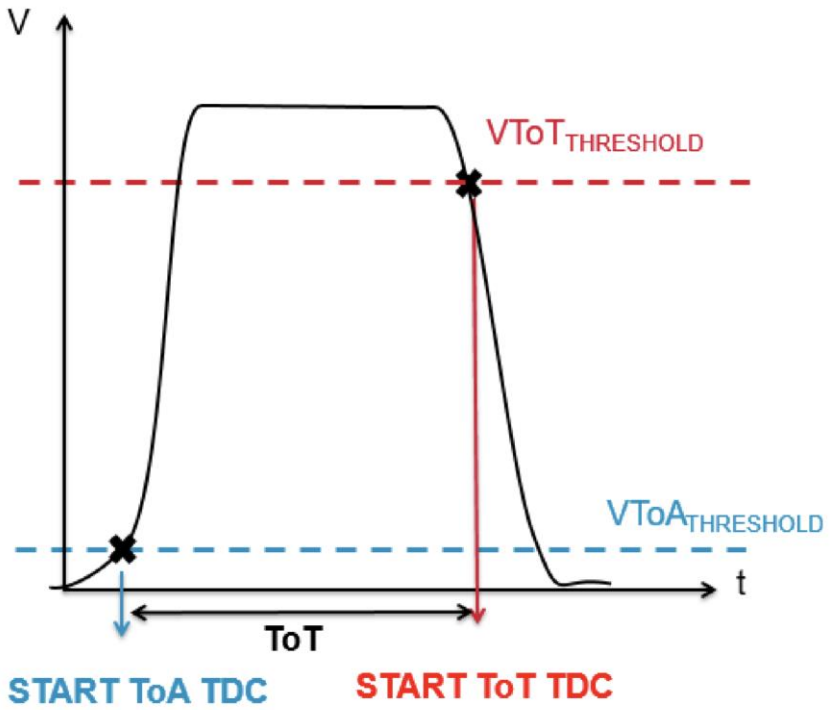


Signal fraction, 1 GeV



Using ToA to correct for the phase

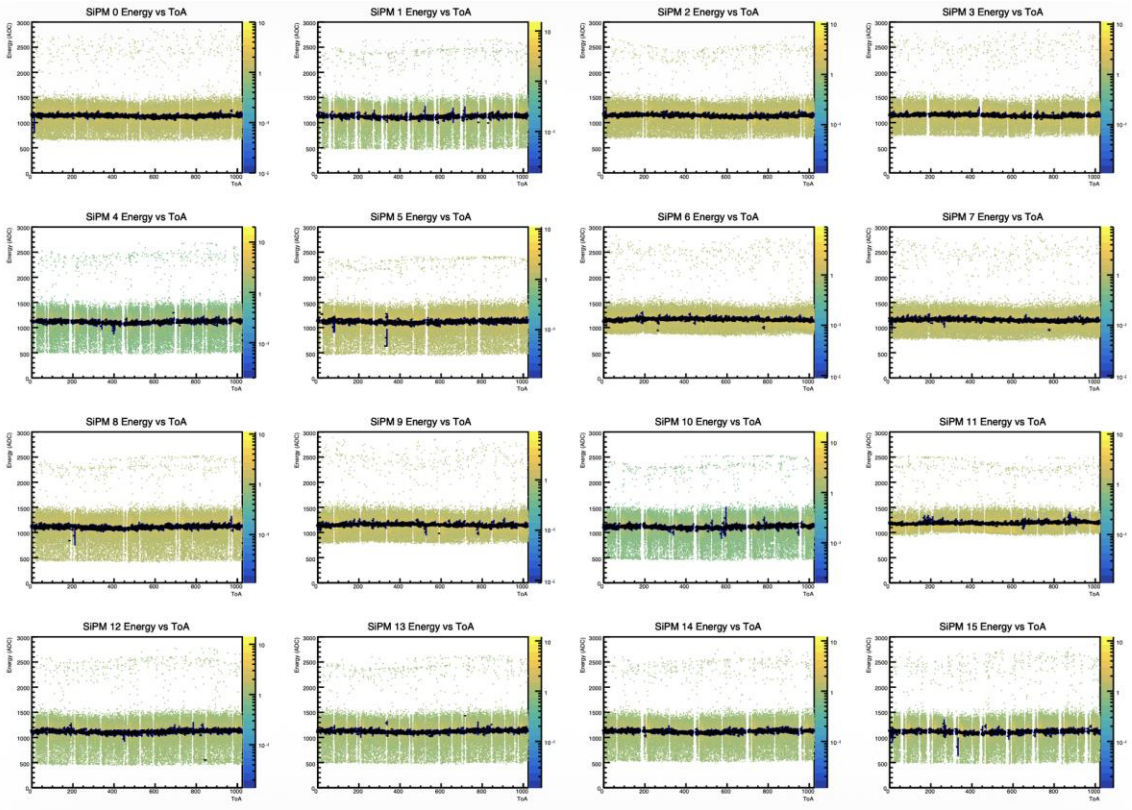
- Since we are not synchronous to beam arrival, the phase w.r.t the HGCROC clock is not timed to anything
- The ToA could help correct for this
- 20 ps resolution clock telling us when the signal goes above a threshold
- Either
  - Fit the waveform and use the ToA to determine the phase
  - Make a selection on the ToA to only analyze events with a certain phase
- If there is a dependence, we would expect to see the ADC signal of an event depend on the ToA value



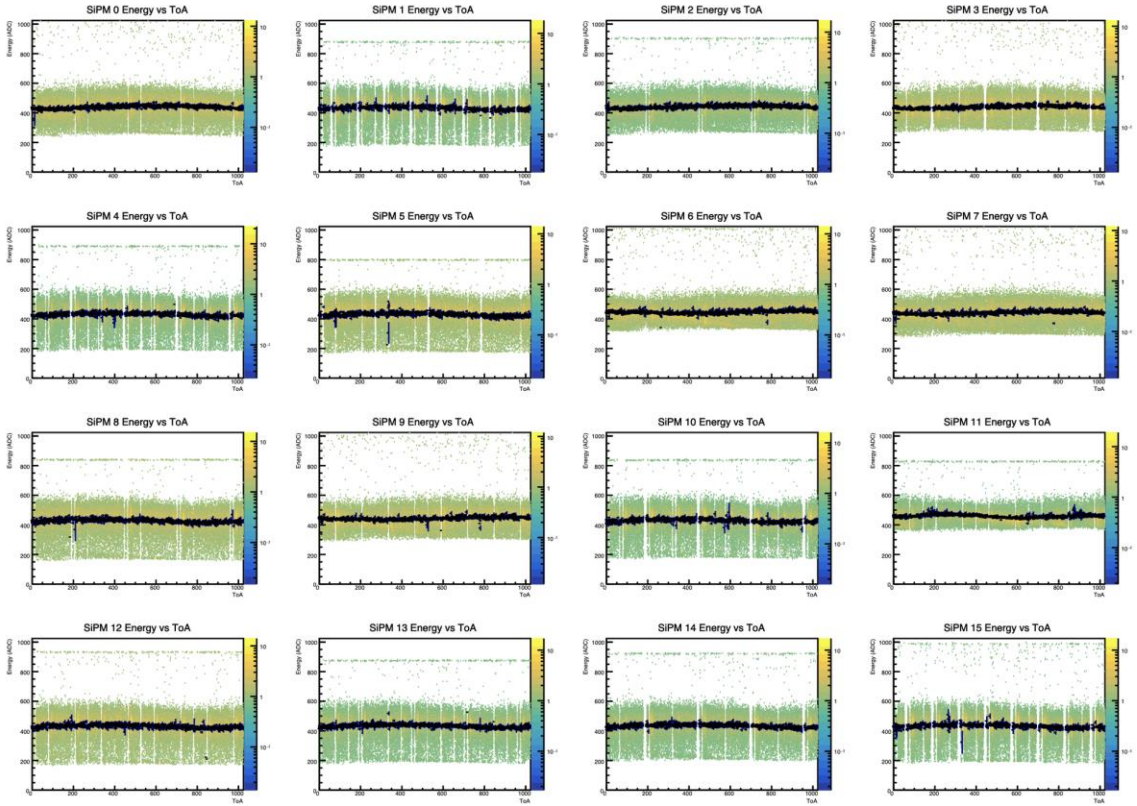
Energy vs ToA

- With three samples, there is basically no dependence
- A very weak dependence is seen only using the largest sample
- Likely because of the long shaping time and larger capacitance of the SiPMs used

3 Samples

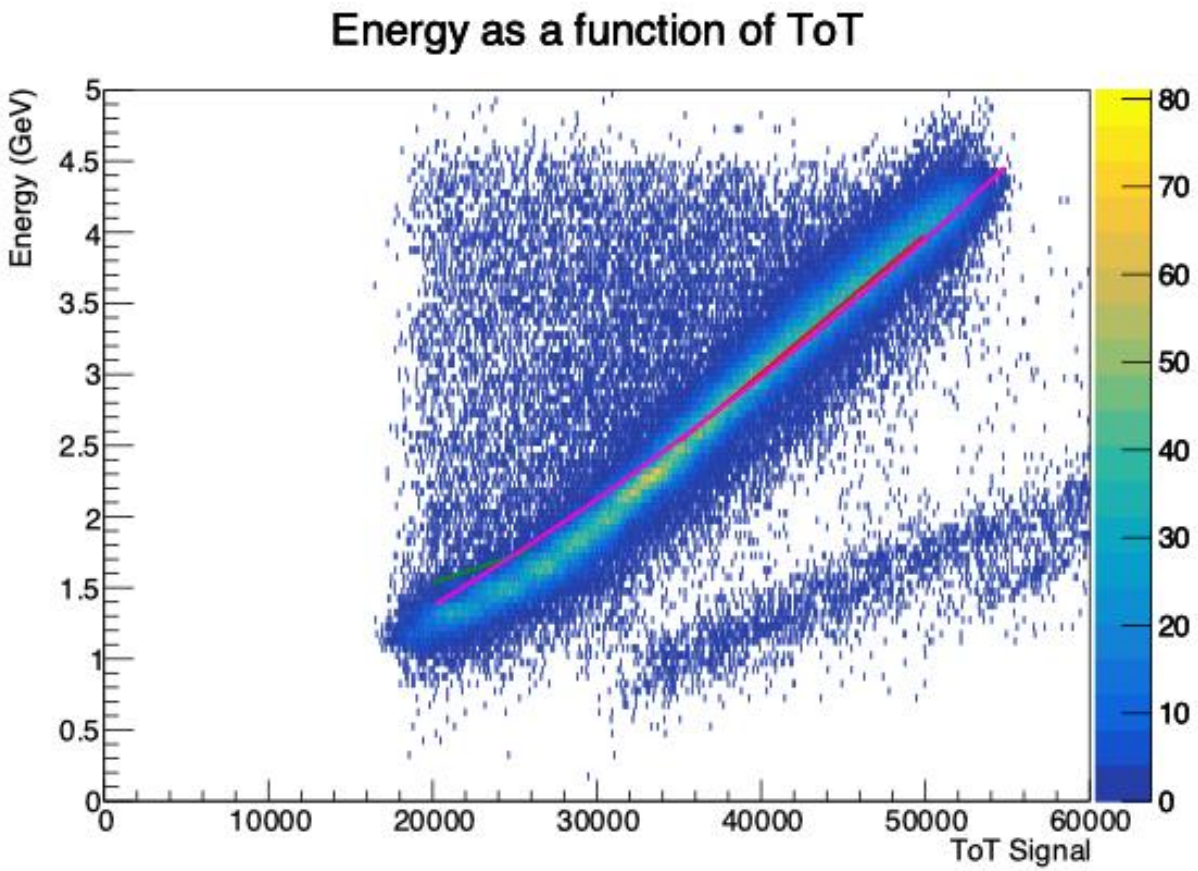


1 Sample



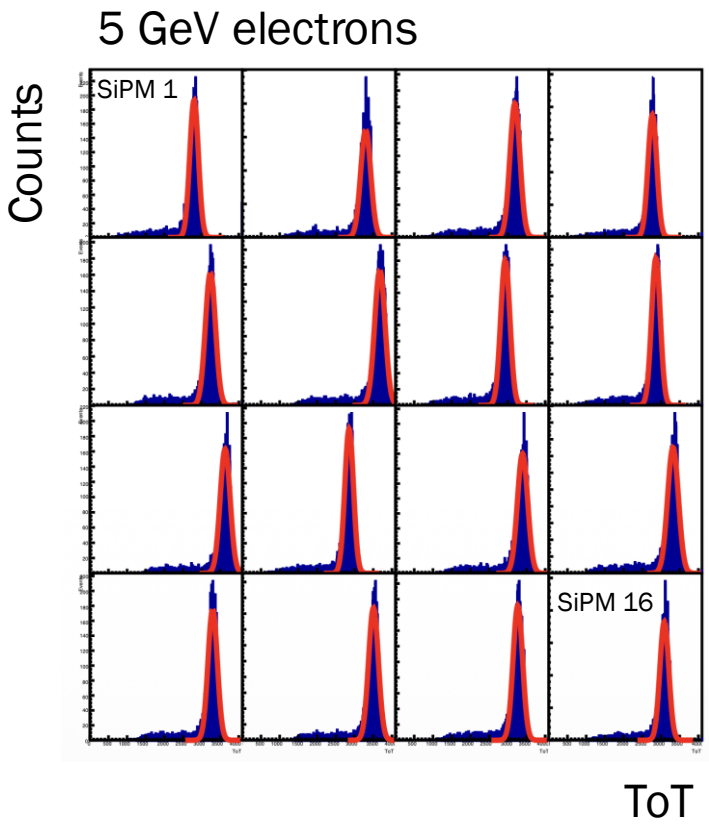
ToT calibration

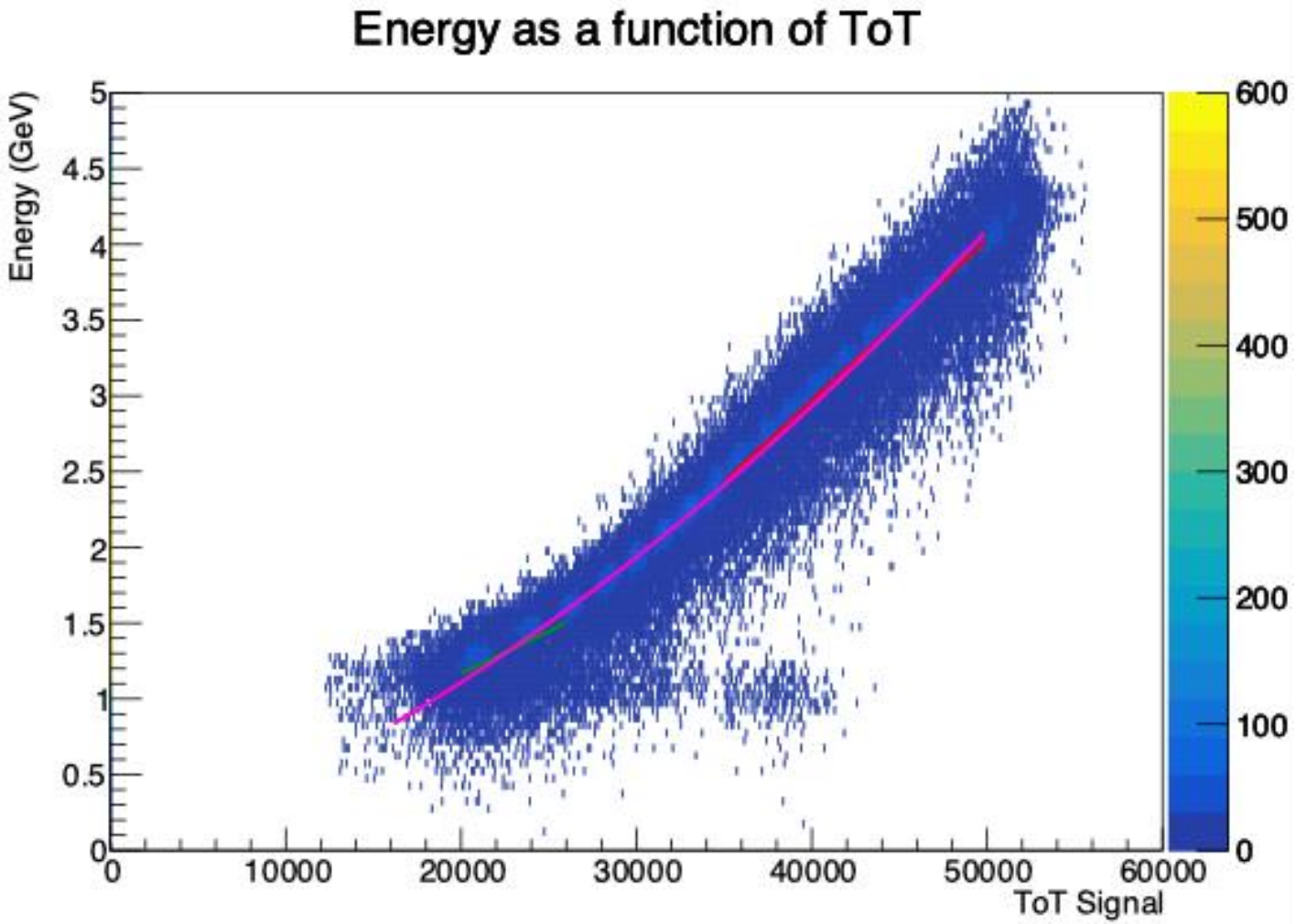
- In the range 1.2 through 5.4 GeV, the center crystal is in the ToT range and the other 24 are in the ADC range
- Use the ADC calibration to determine the remaining energy in the center crystal event-by-event
- Only events where all 16 SiPMs have a ToT value are used
- Lots of noise to cut away, still trying to understand the source of it



ToT calibration

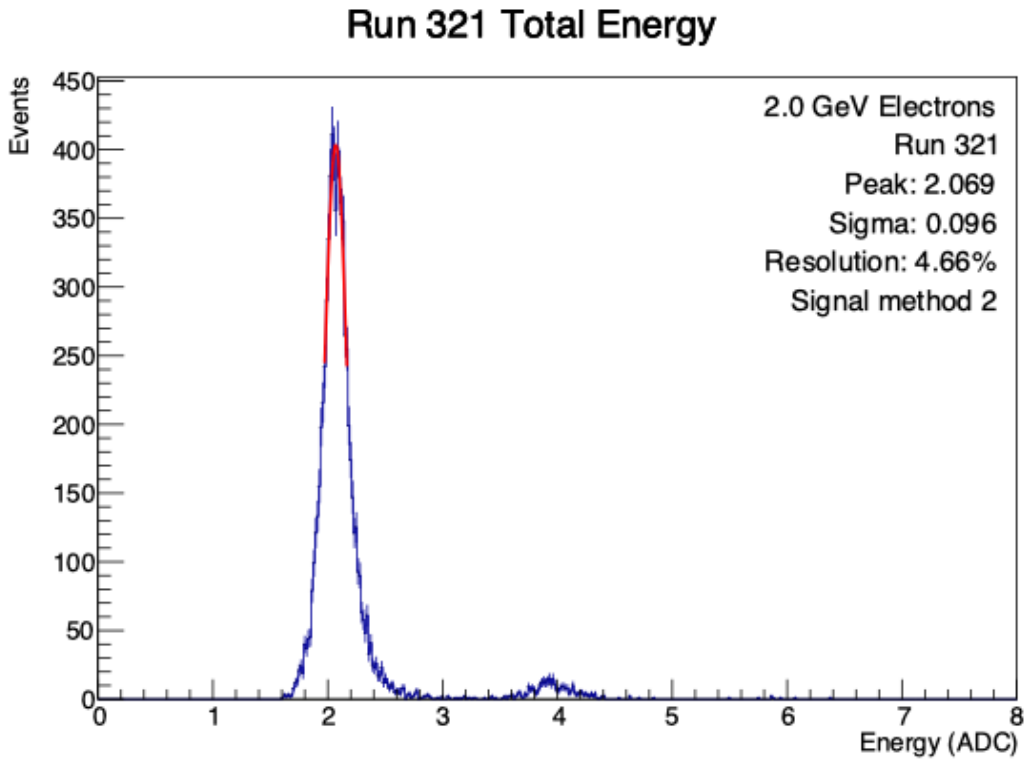
- To clean up the signal, the peak is fit and only ToT within $\pm 1.5\sigma$ are kept
- Fit with a 2nd order polynomial seems reasonable

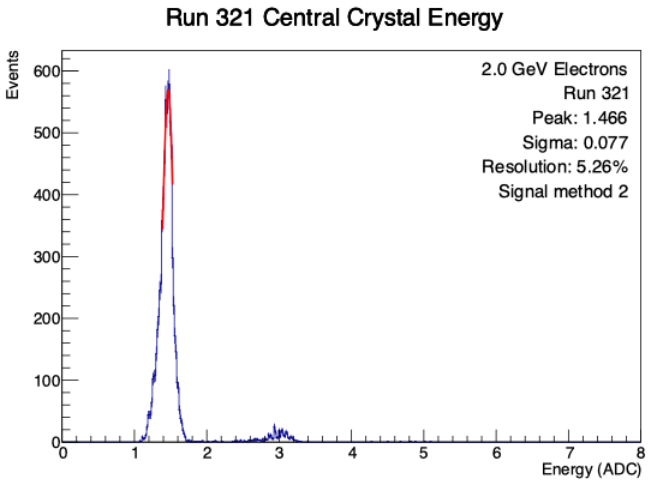


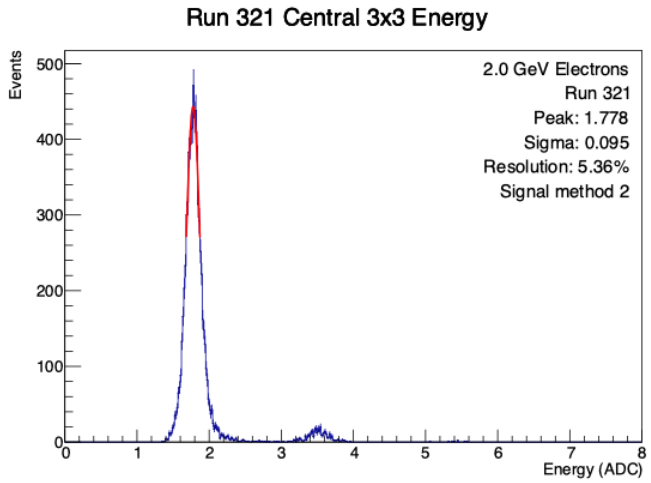


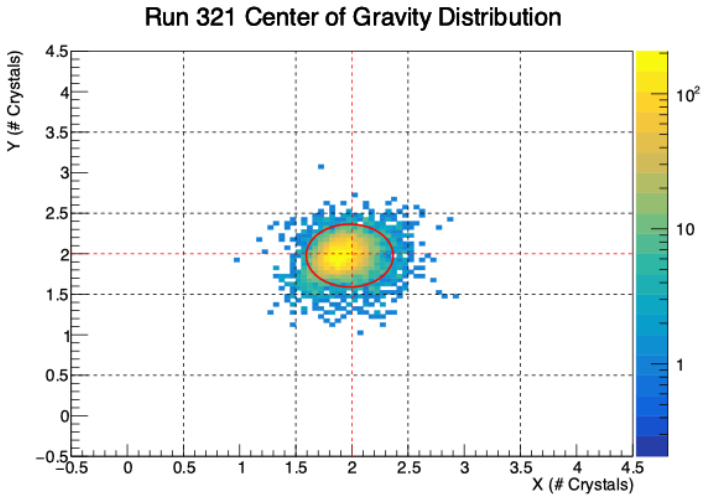
Energy resolution

- Using all 25 crystals, the total energy measured by the calorimeter can be summed
  - Pile-up peak visible at 2x energy!
- Cuts on the CoG of the cluster
- σ/E extracted from the width over the mean
- Repeated for all energies and different crystal combinations
  - Center only, 3x3, 5x5



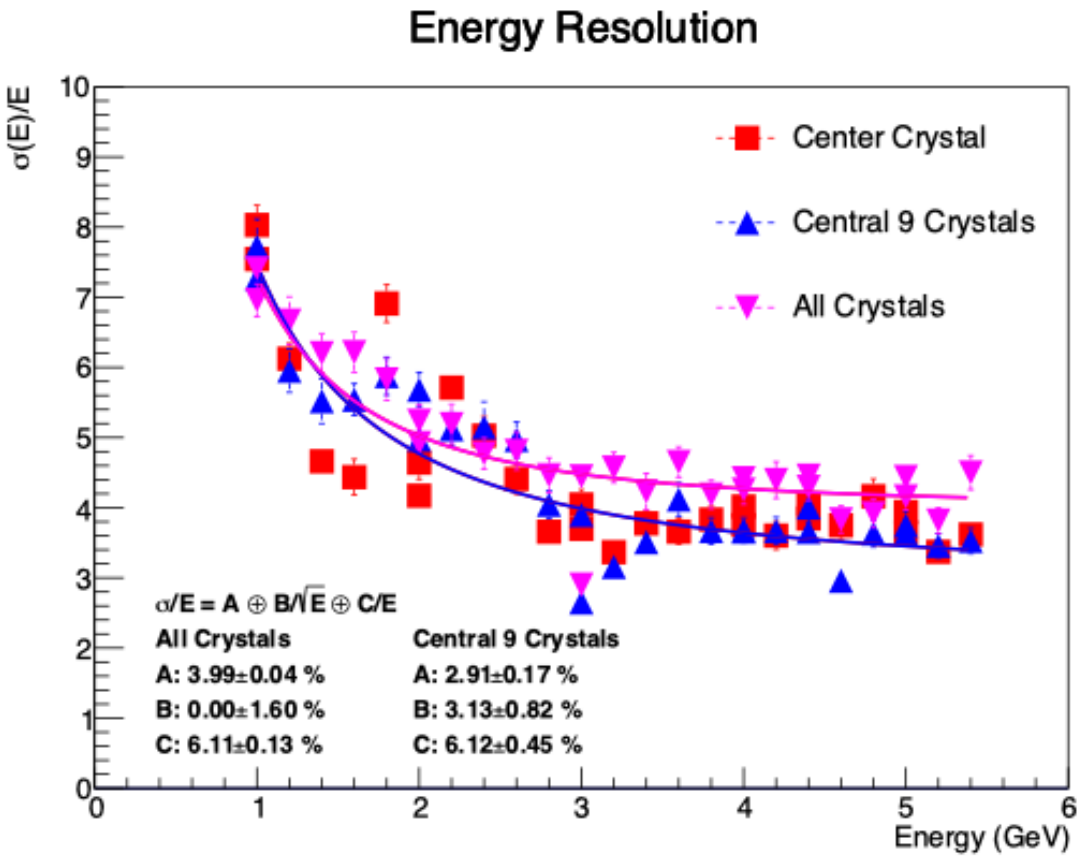


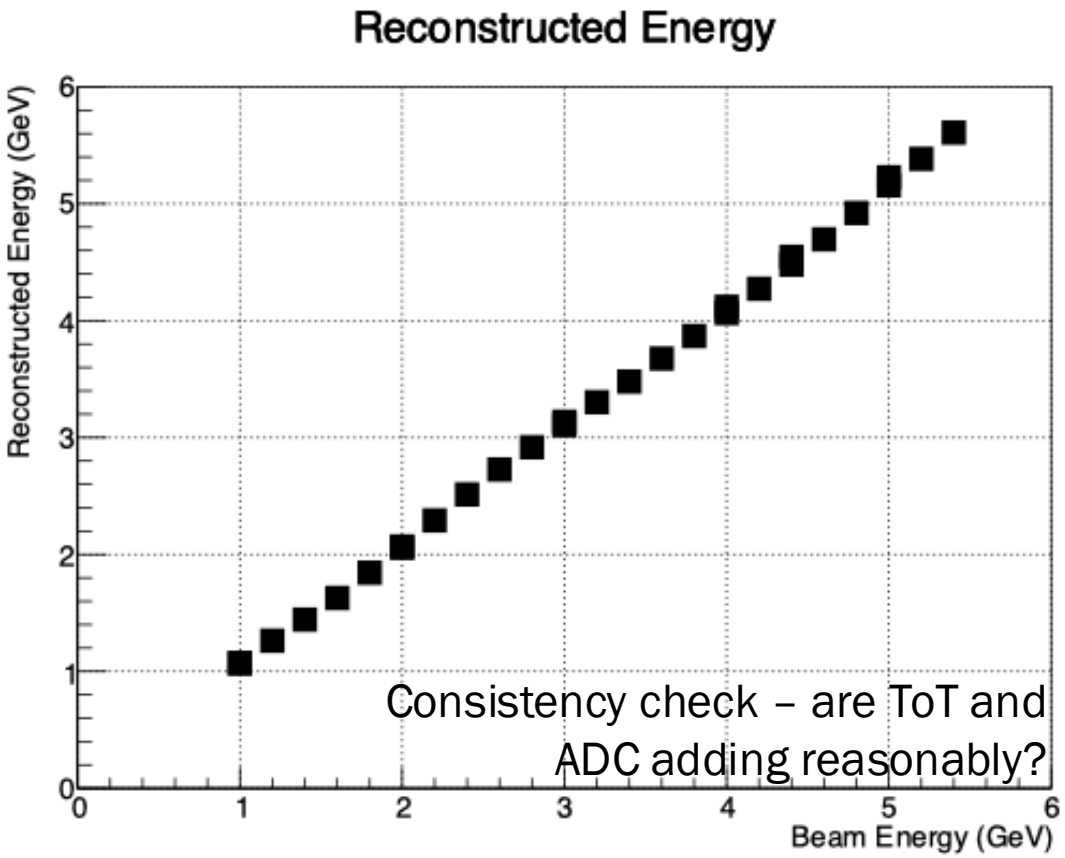




2σ cut around center

Energy resolution





- A: Constant term
- B: Stochastic term
- C: Noise term
- Still plenty of work to go integrating all 25 crystals
- Hard to constrain fit well over such a small energy range

Outlook

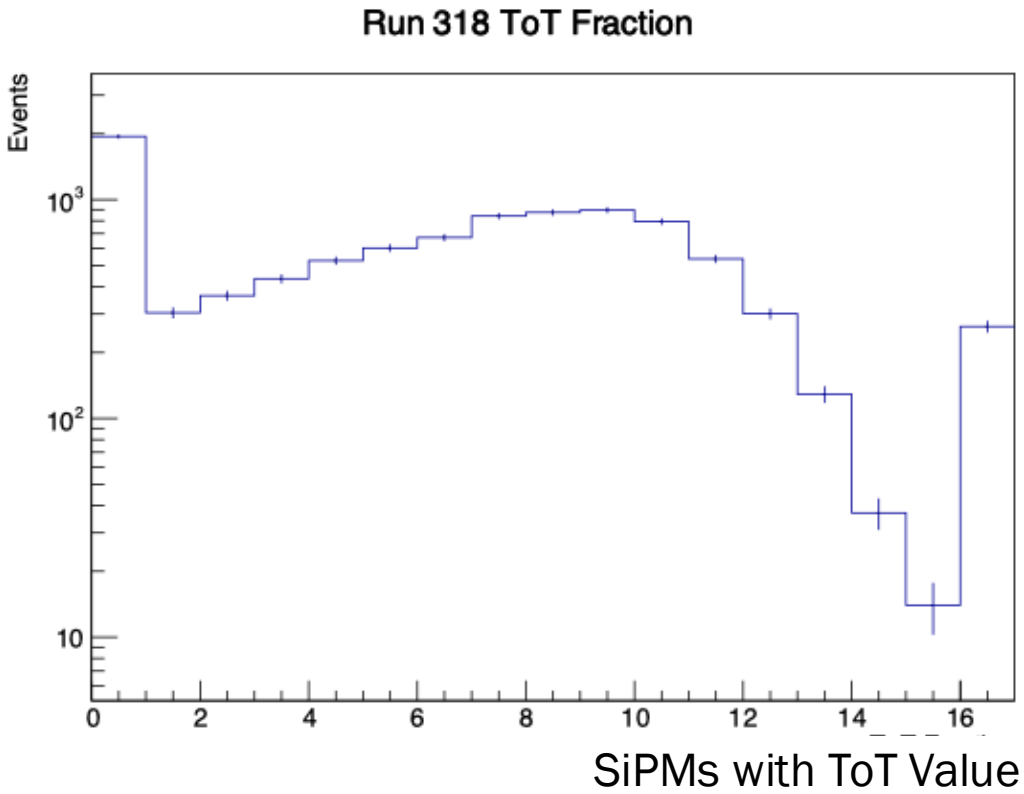
- ToA characterization
  - Phase correction, width characterization
- Improve ADC signal processing
  - Waveform fitting with information from ToA to set phase?
  - Select a narrow ToA bin
  - Studying pedestals – correlated or uncorrelated noise?
- Crystal 11 issues
  - The crystal below the center is showing strange behavior – no explanation yet
- ToT normalization – apply same gains as found for the ADC
  - Also interest in the widths of the ToT distributions
- Understanding why the resolution worsens with all 25 crystals over central 9

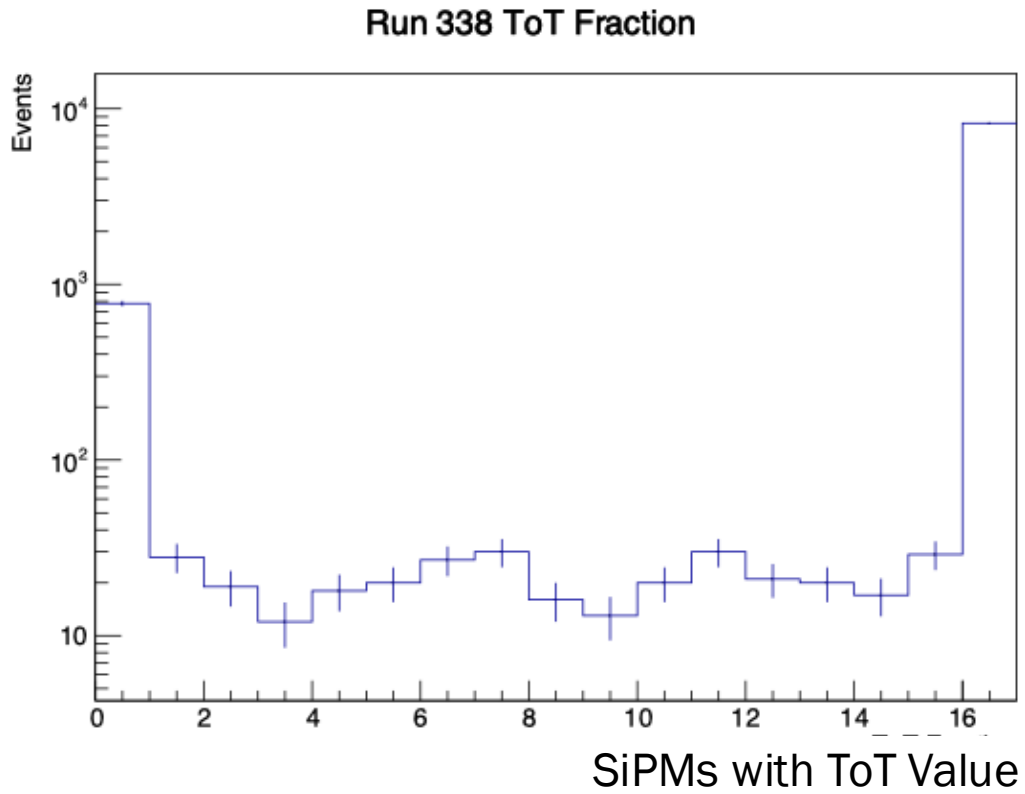
All code at https://github.com/tlprotzman/eeemcal_desy_dec2025

Backup

ToT oddities

- In transition energy region (~1.6 GeV), we see a mix of SiPMs on the center crystal with and without ToT values
- At top energy, we still see events (~1%) where not all SiPMs have a ToT value





ToT oddities

- Both events are from a 5 GeV run where a ToT was found in exactly 8 channels
- The left may be from the low energy tail
- In the right event, all ADC saturate but still not ToT in 8 channels
  - Still under investigation