Preliminary Triangular Quad-Counter Data Analysis from the Fermilab Test Beam

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Objectives

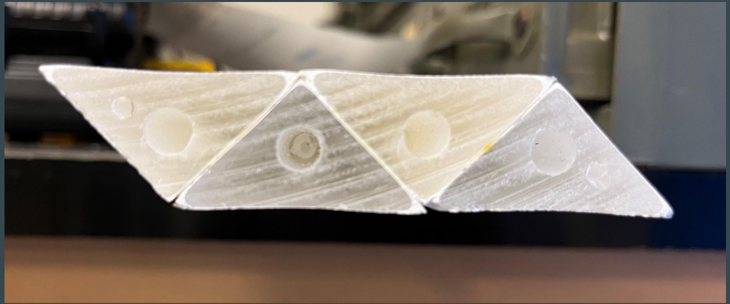
Analyze Fermilab Test Beam Data from March/April 2022

- Single waveforms
- Waveform peak fit & calibration
- PE distribution across neighboring counters
- PE count per 3 mm bins scanning across full quad-counter
    - Contour
    - Profile
- Efficiency per channel across quad-counter
- Beam intensity across run duration
- Resolution

Procedure

Four Quad-counters

- 1 unfilled quad-counter (1 m)
- 2 unfilled quad-counters (3.35 m)
- 1 Solaris-filled quad-counter (3.35 m)
    - Counter was damaged; presented histograms created for this quad-counter can be ignored



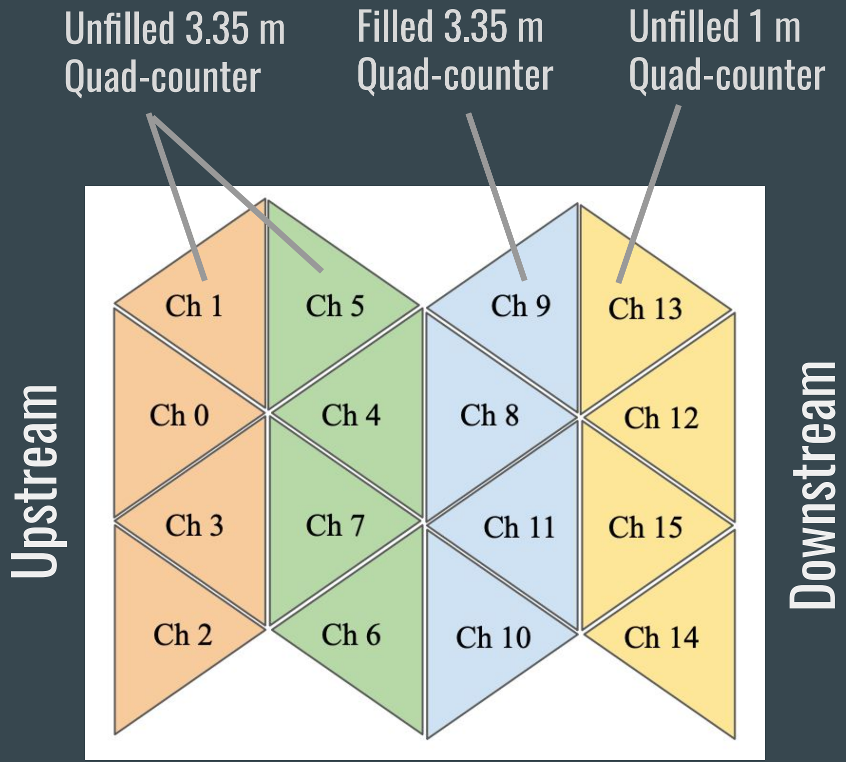
Data from runs 4729 - 4754 used

- 0 degree angle
- DAC gain 0x680

Precision measurements conducted at 80 cm from readout end

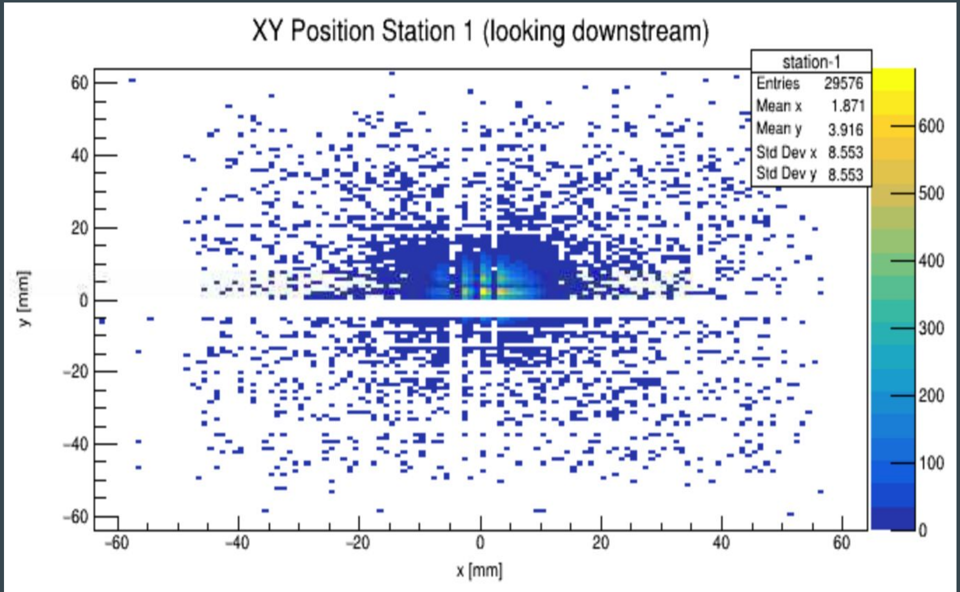
- 3 mm increments
- Range: 15 - 84 mm

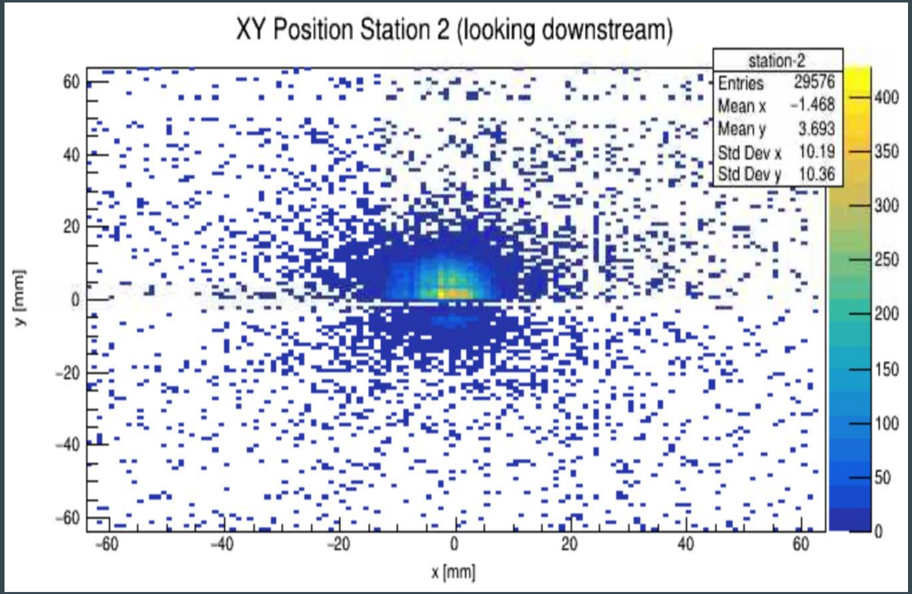
Fermilab Test Beam Setup



Fermilab test beam (left) and quad-counter configuration (right) with proton beam going from left to right. Wire chambers are located to the left (Station 1 & Station 2) of pictured quad-counters.

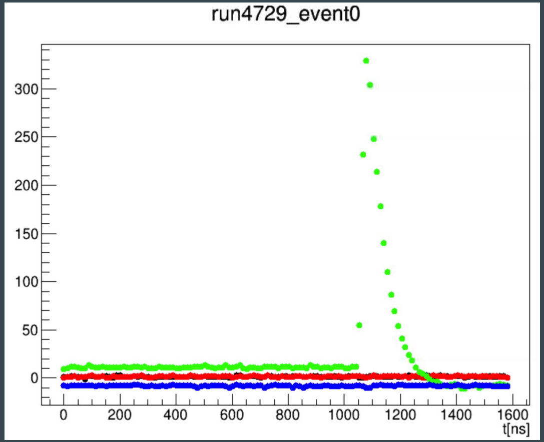
Wire Chambers at 30% Track Reconstruction Capability

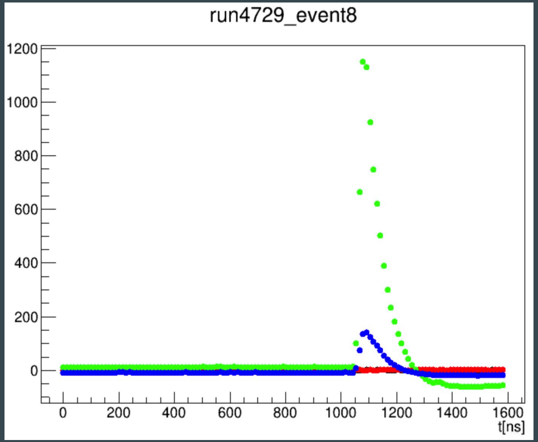


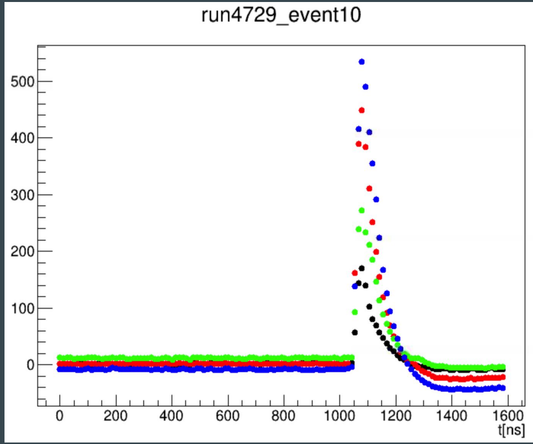


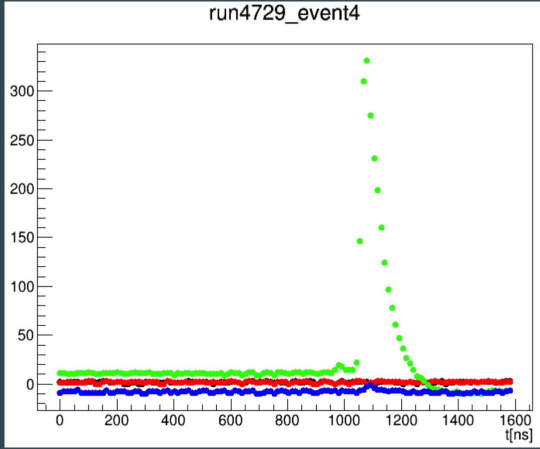
- 2 wire chambers
- Sizable amount of dead wires

Event Waveforms from 4 Quad-counter Channels







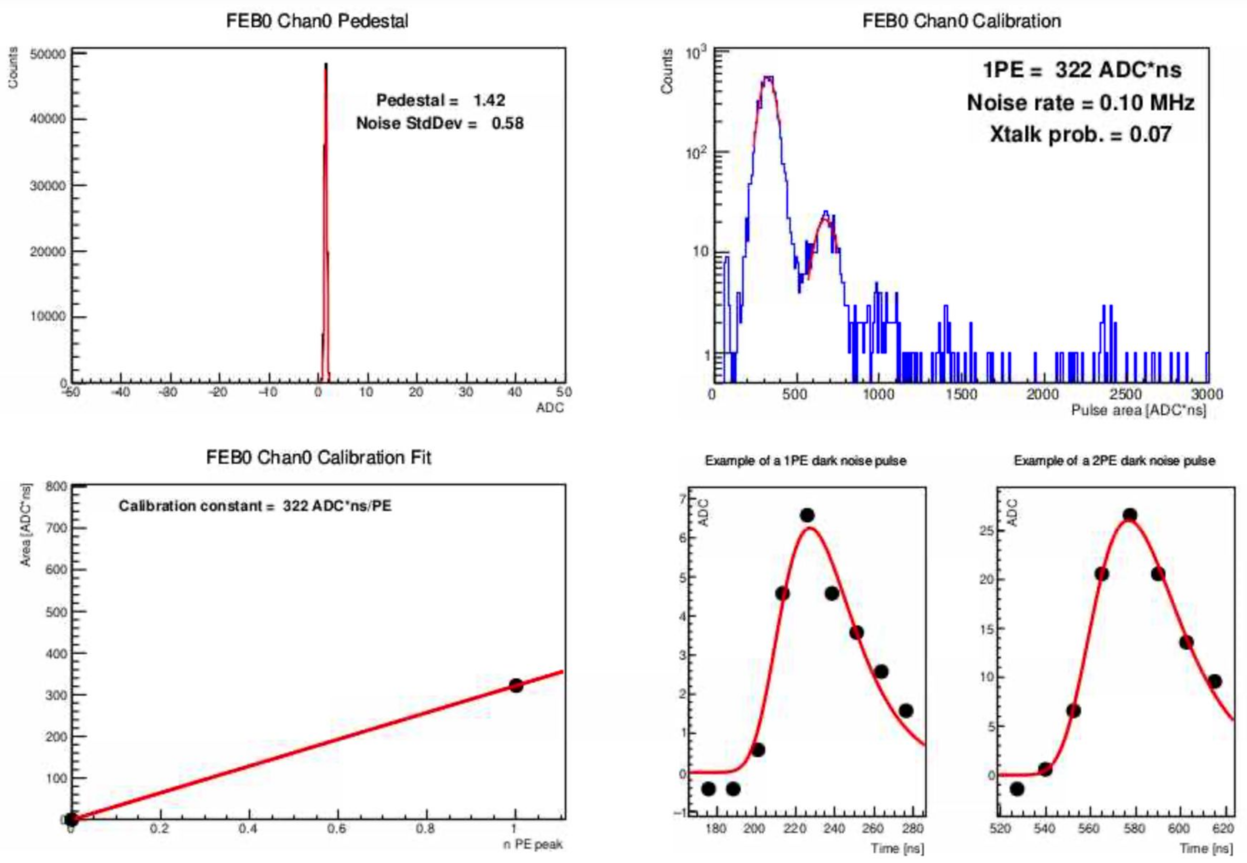


Multiple scenarios can occur:

- Event passes only through one quad-counter
- Event passes diagonally through two quad-counters
- Event passes through multiple or all quad-counters

SiPM crosstalk produces pre-signal discharges used for calibration from ADC to PEs

Event Reconstruction with Pulse Fit & Calibration



- Find pedestal
- Calibrate waveform with SiPM discharge in pre-signal region
    - Pulse area & PEs
- Pulse area histogram contains all SiPM crosstalk pulses
    - Mark 1 & 2 PE curves
- Linearly fit ADC values to find PE relationship

PE Distribution Across Quad-counters

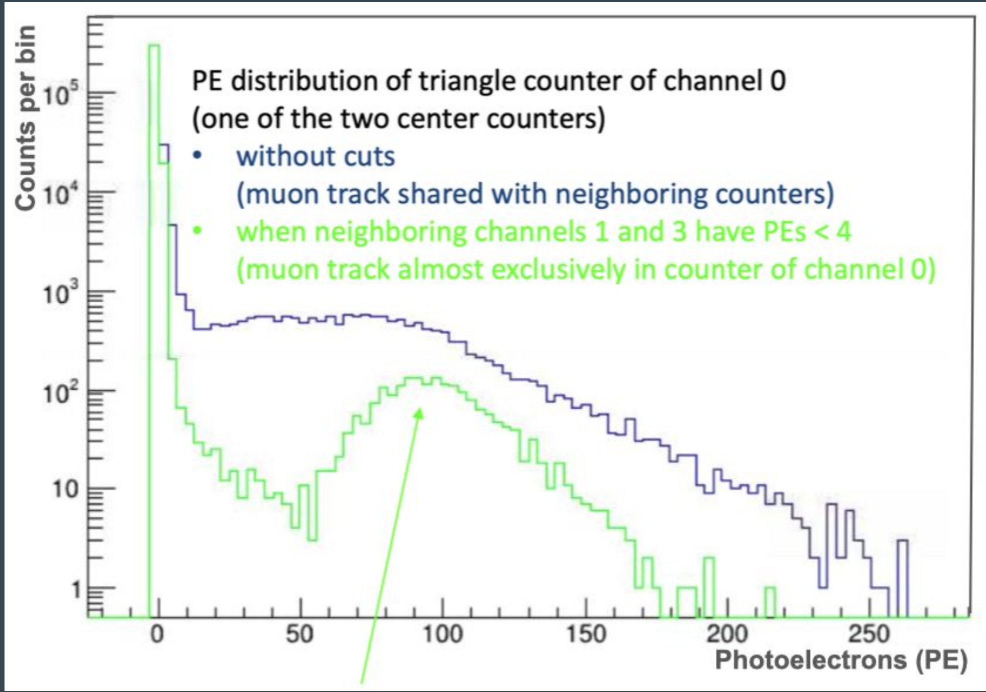
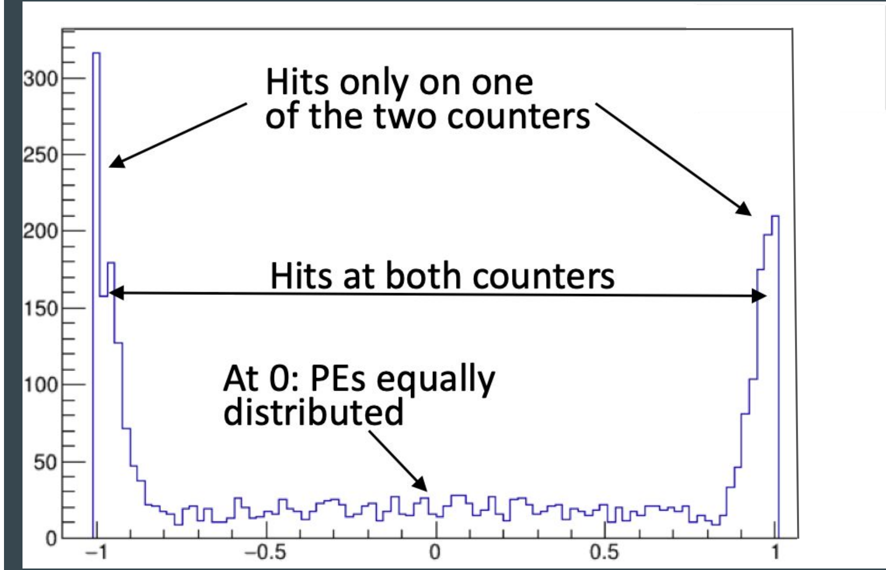


Photo electron (PE) yield

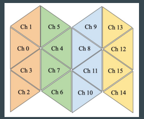
- Each proton event causes **~ 100 PEs**



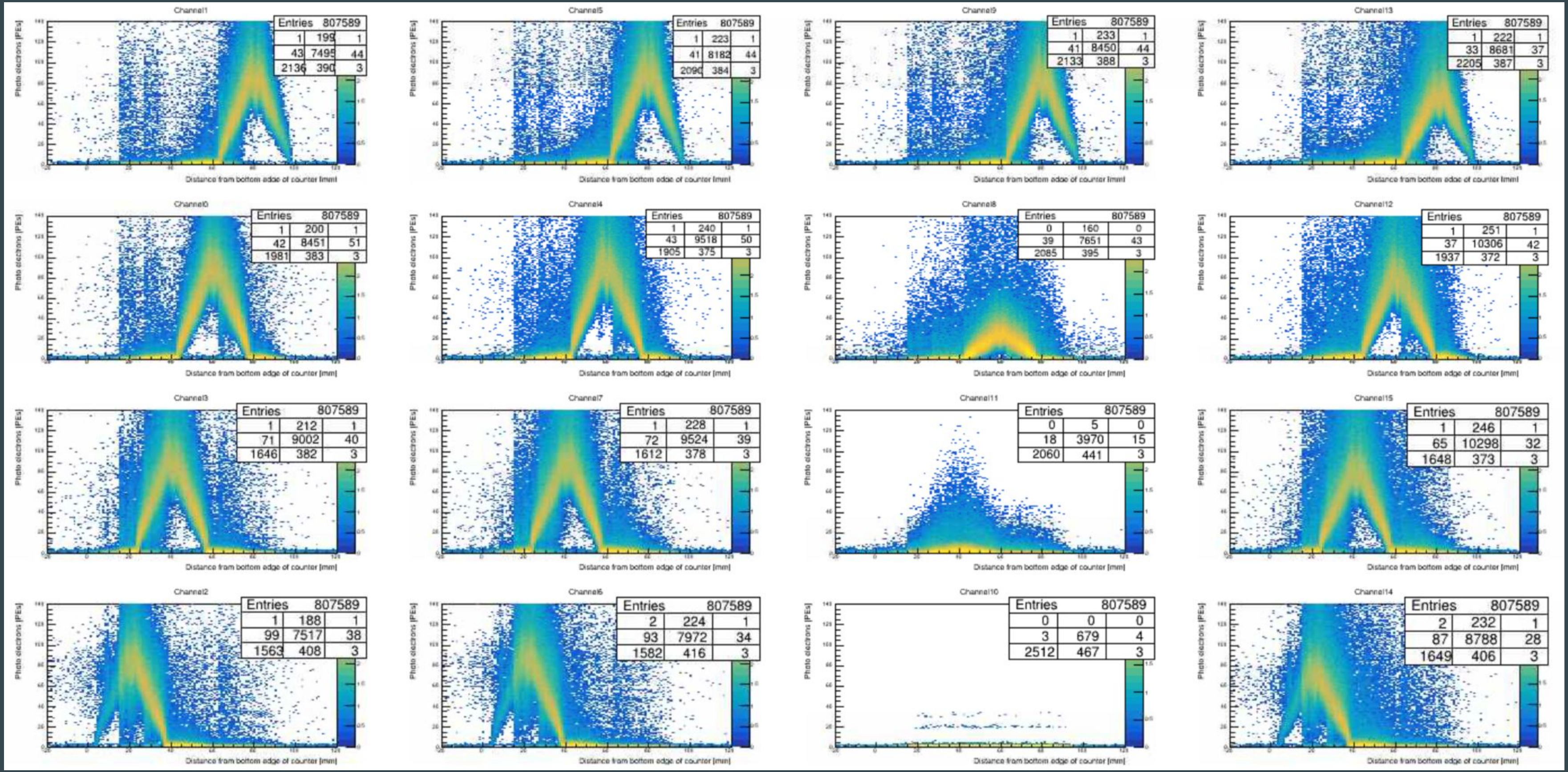
Fraction of events hitting one or both neighboring counters.

$$\frac{PE_2 - PE_3}{PE_2 + PE_3}$$

Photo Electrons Detected Scanning from Bottom to Top of Quad-counters

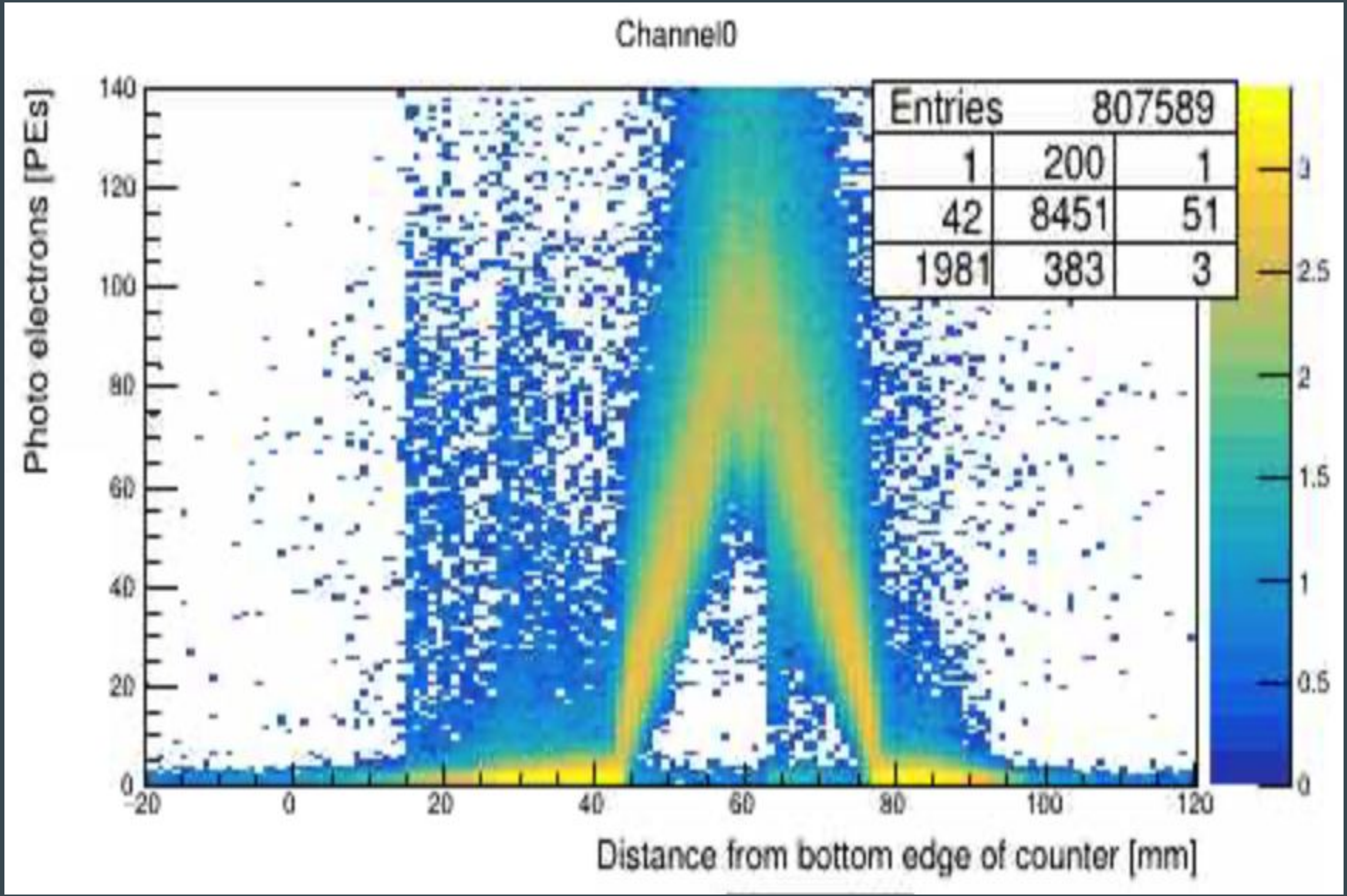


Upstream



Downstream

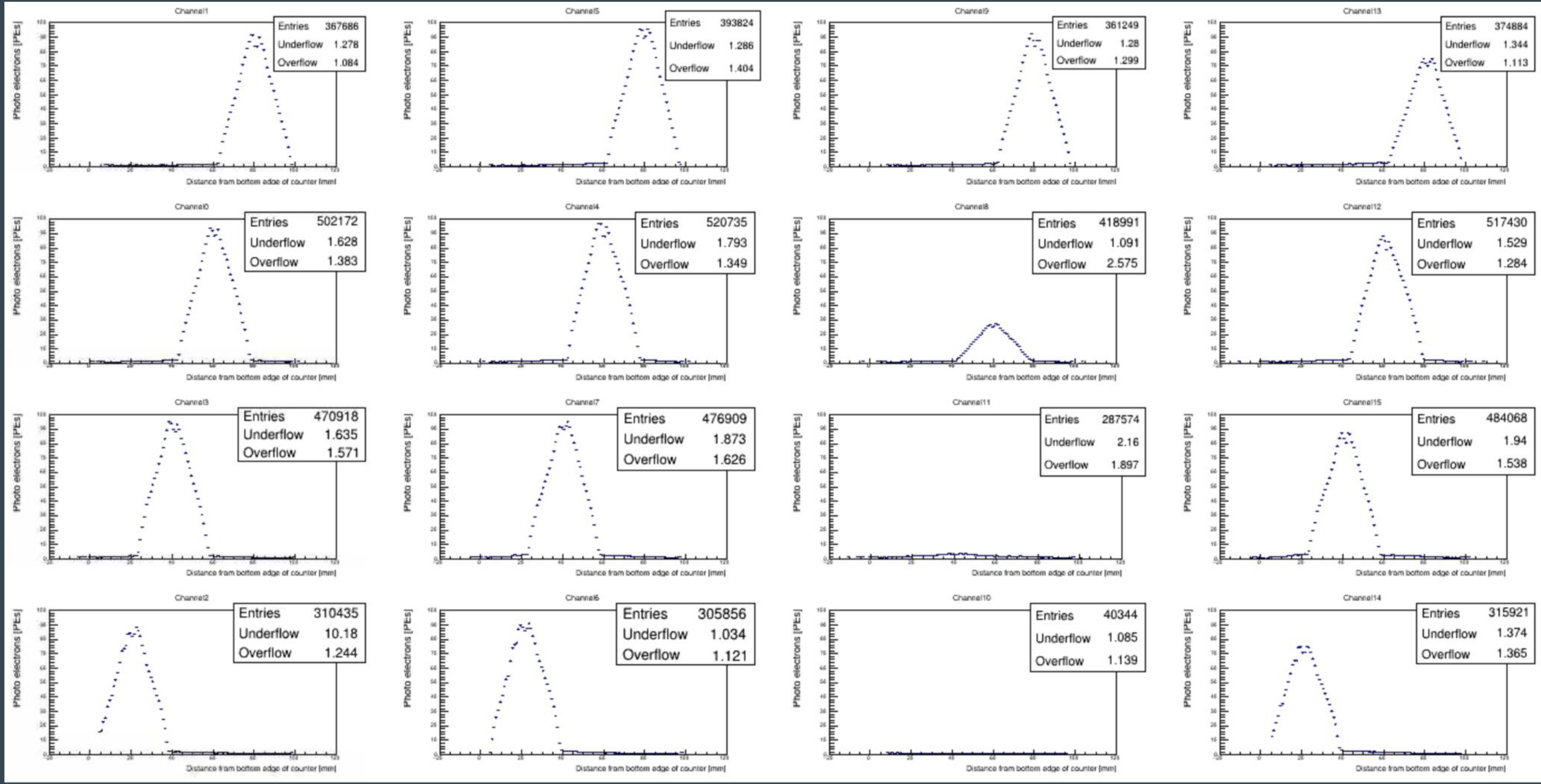
Photo Electrons Detected Scanning from Bottom to Top of Quad-counters



- Logarithmic scale
- About 100 PEs peak near counter vertex
- Slight peak dip visible

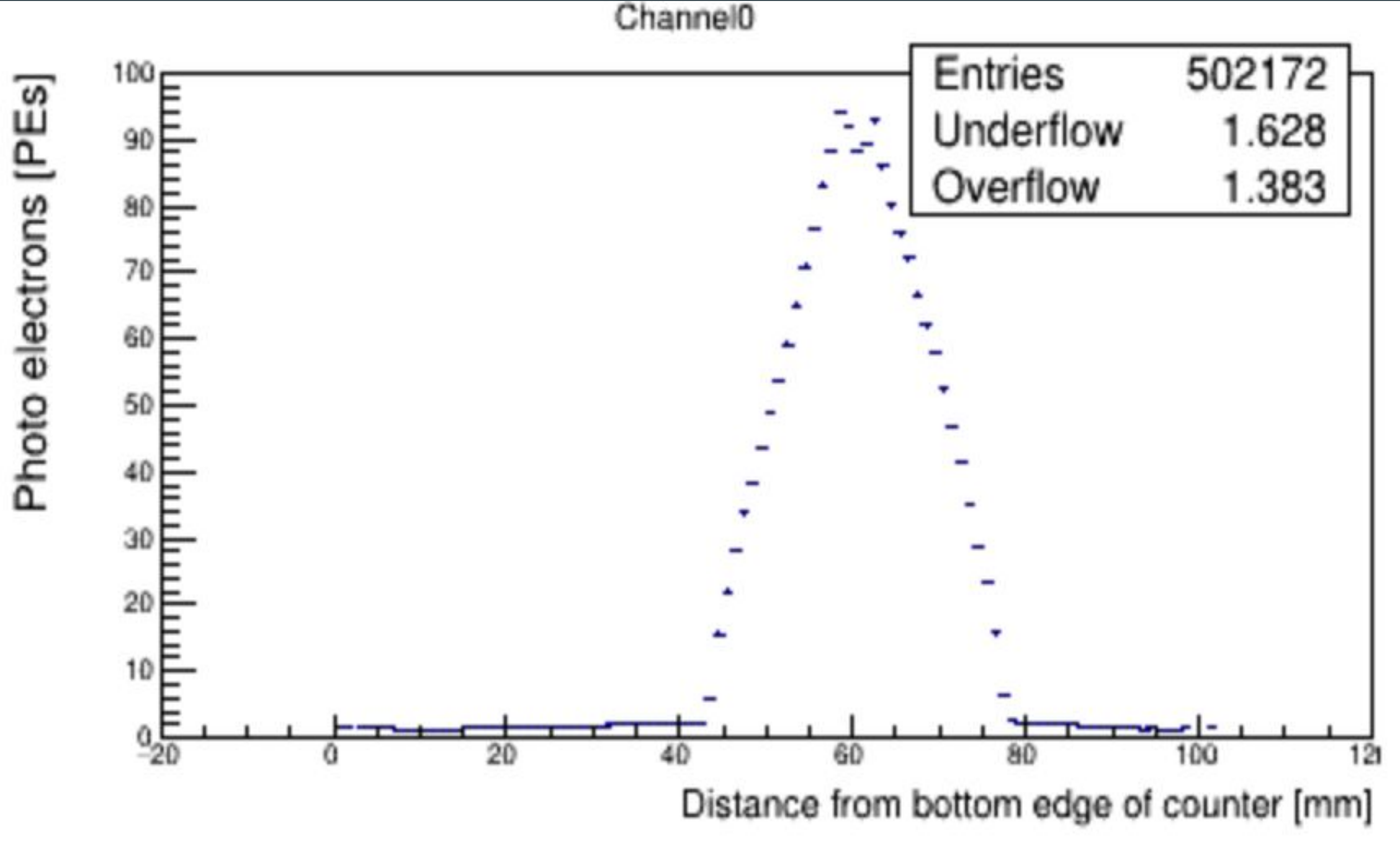
Photo Electrons Detected Scanning from Bottom to Top of Quad-counters

Upstream



Downstream

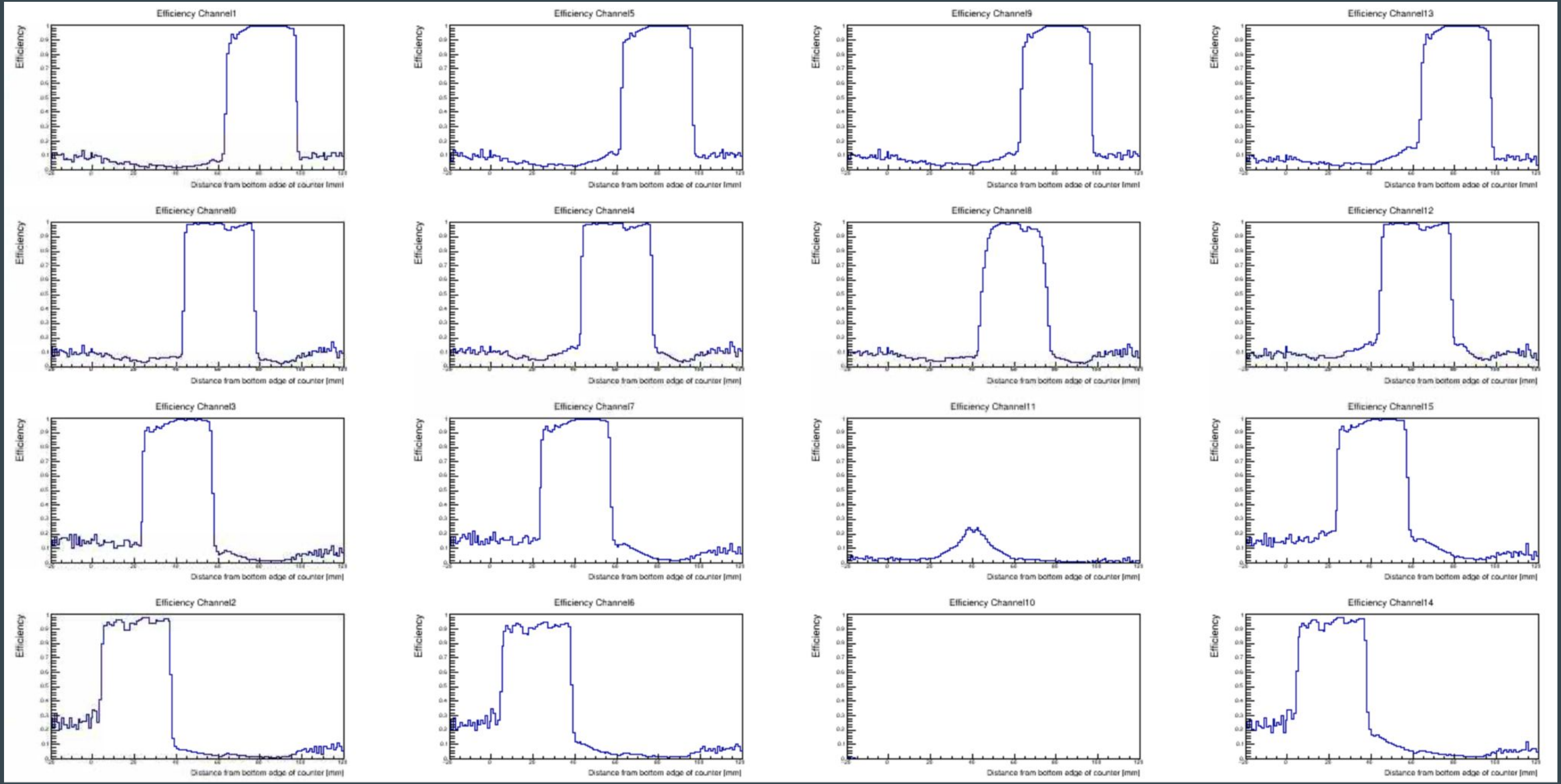
Photo Electrons Detected Scanning from Bottom to Top of Quad-counters



Slight peak dip visible (caused by ~2 mm fiber hole at center of counter)

Efficiency Per Channel Across Quad-counters

Upstream



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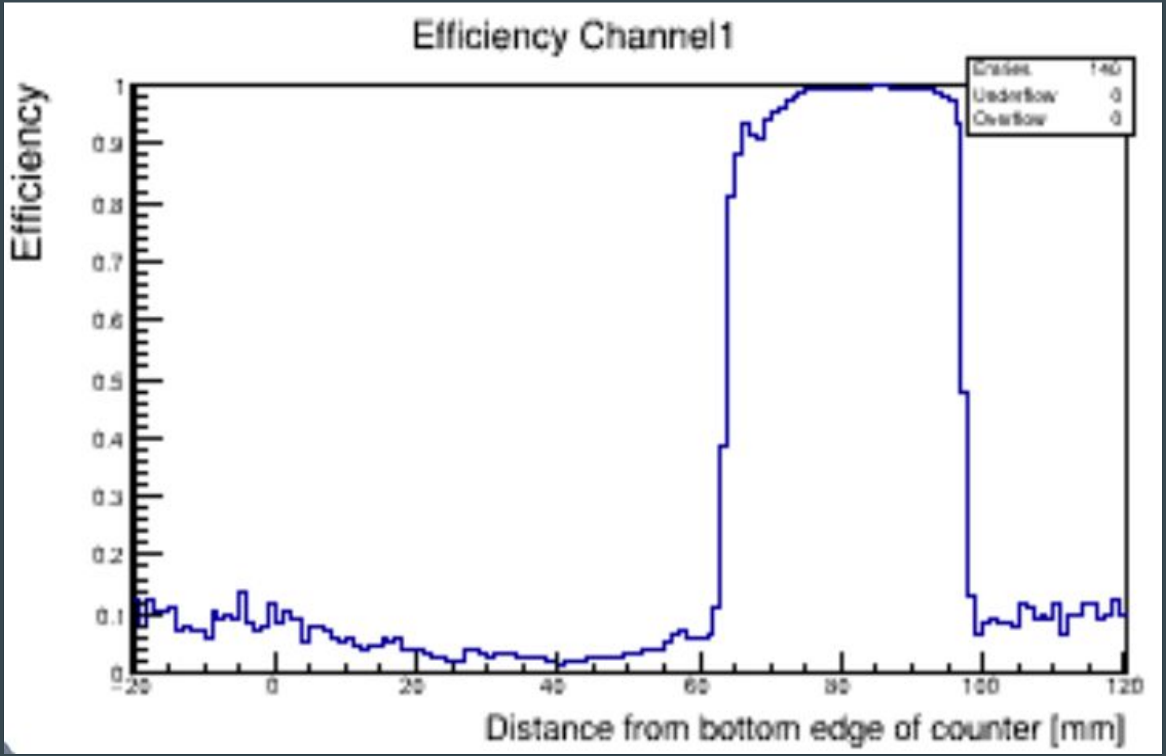
Efficiency Per Channel Across Quad-counters



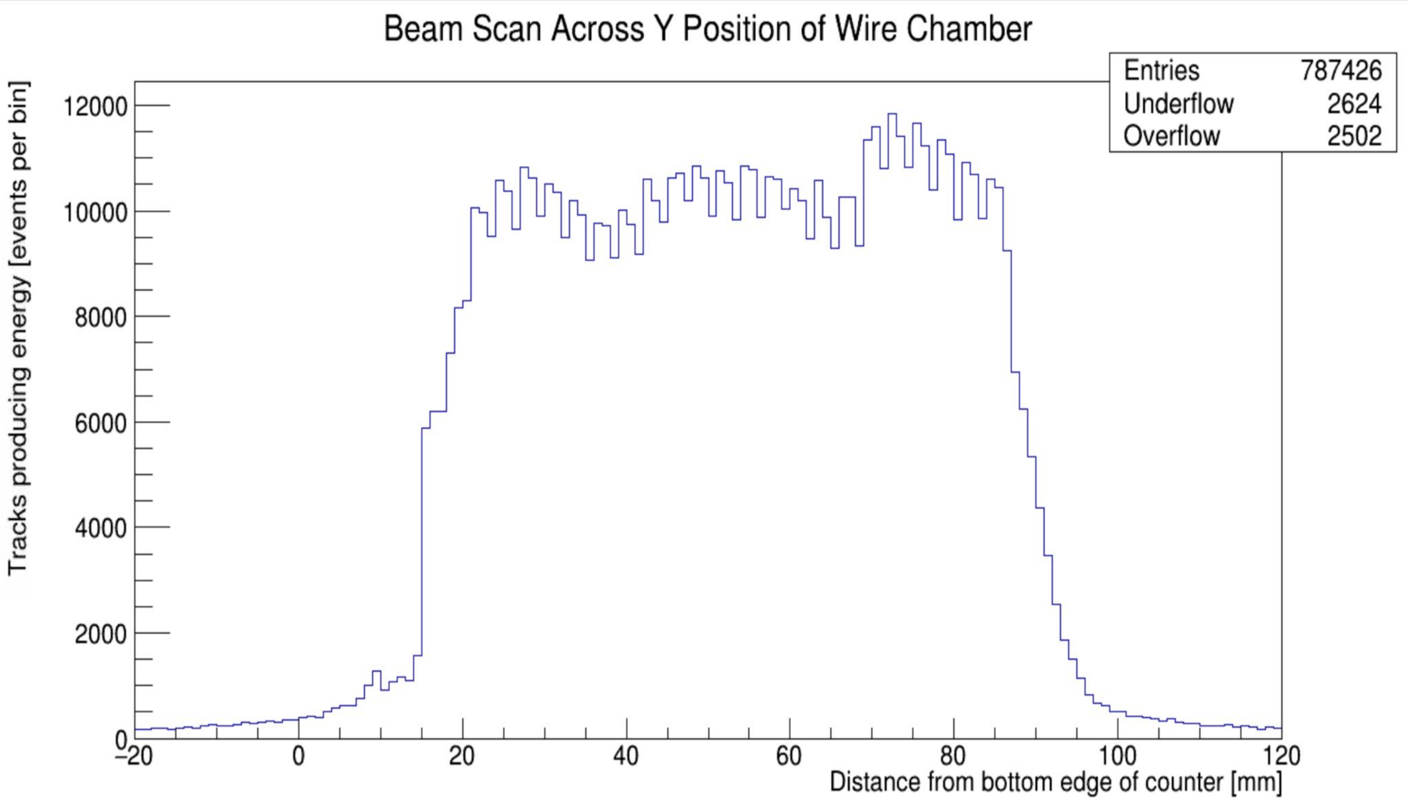
Possible reasons for efficiencies outside of quad-counter range

- Repetition of events
- Track misconstruction
- Secondaries

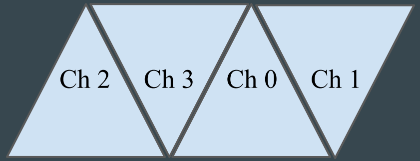
Zero redundancy method underway

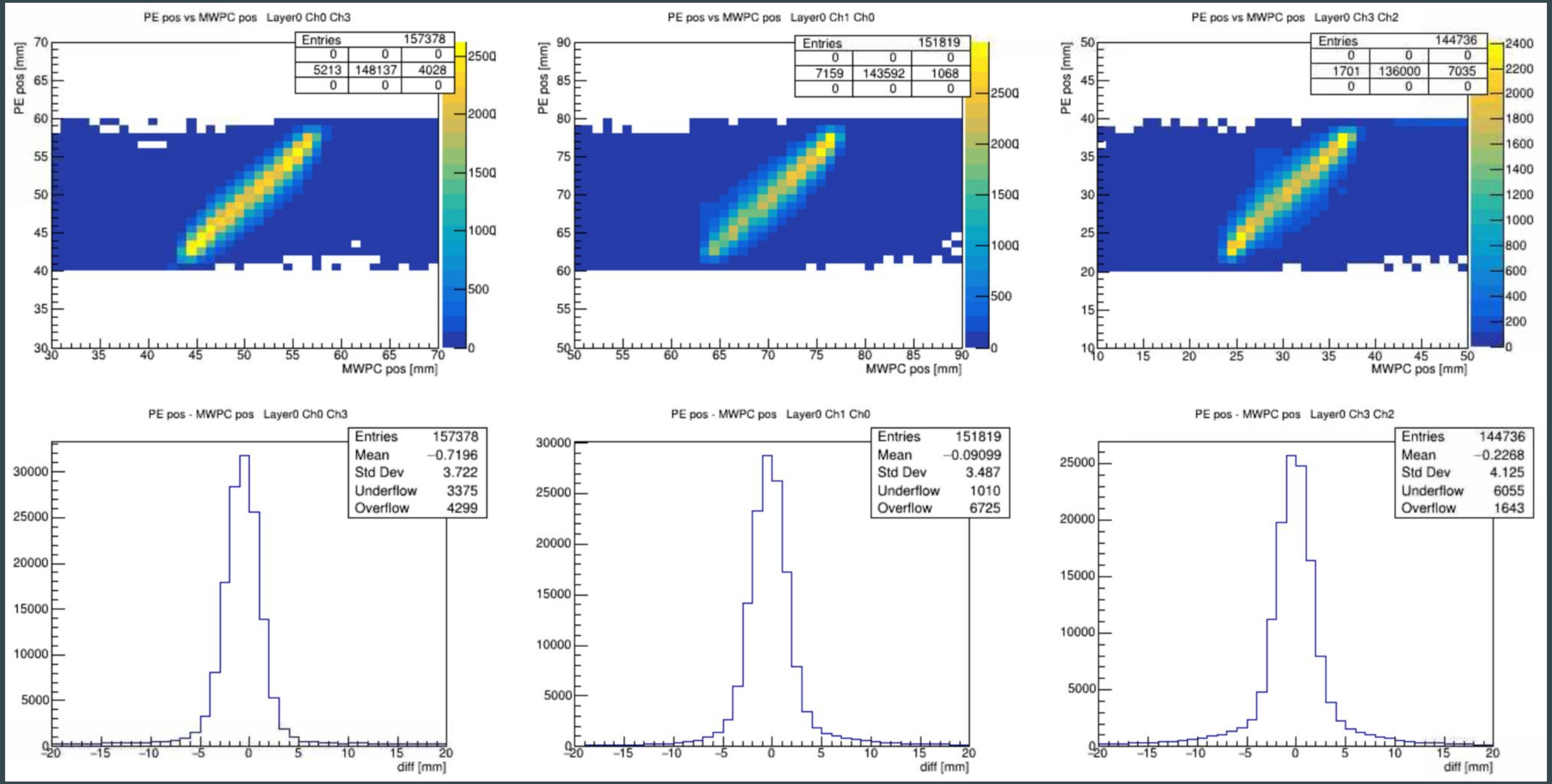
Beam Scan Variance over Quad-counters' 100 mm Length Displays Total Events for All Runs

~ 10k events steadily passed through the 15-84 mm range

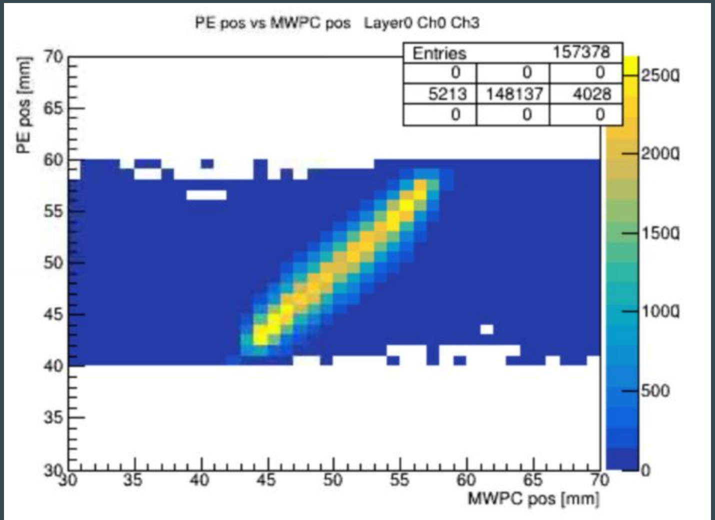


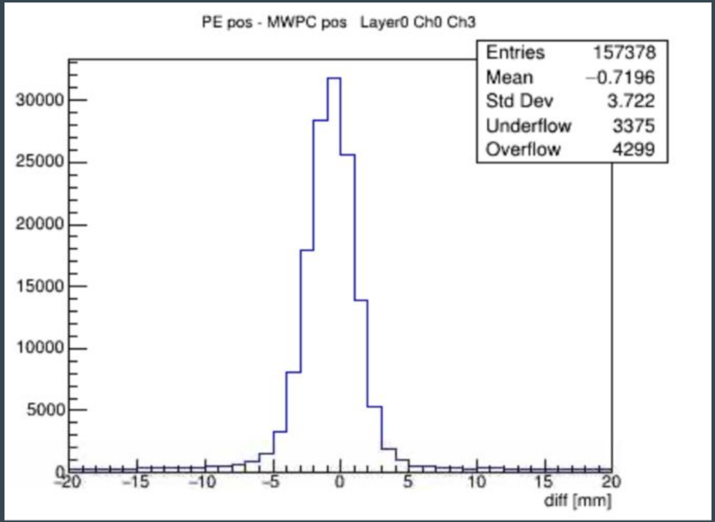
PE Yield Between Neighboring Quad-counters





Initial PE Resolution for Total Runs ~3.6 mm (Middle of First Quad-counter)





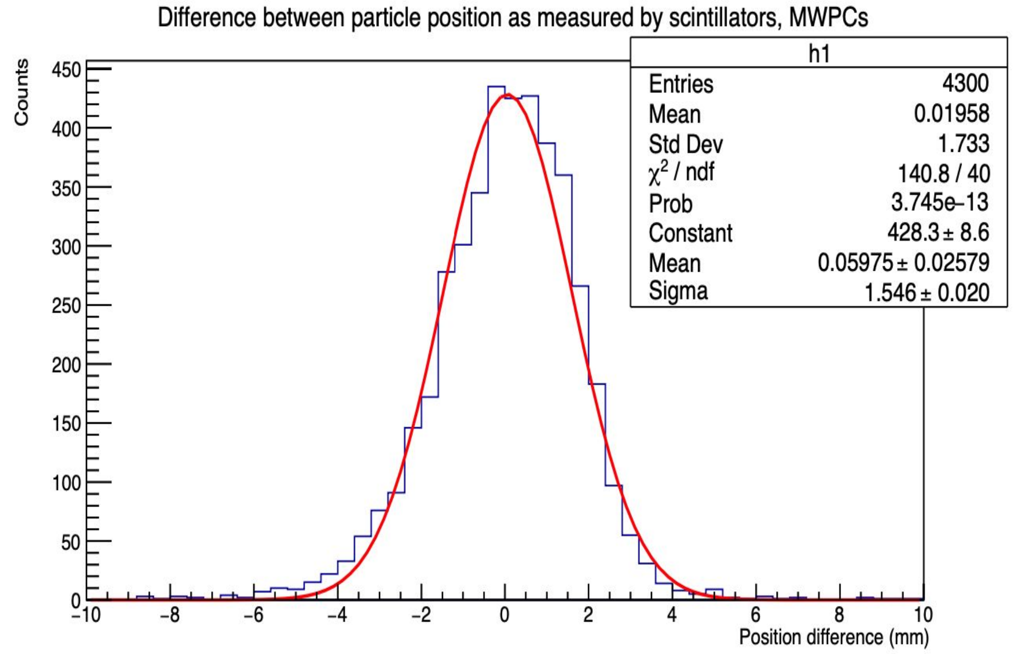
Full System Resolution Range: 3.4 - 5.2 mm

$$\sigma = \sqrt{\sigma_{MWPC}{}^2 + \sigma_{PE}{}^2}$$

$$3.722\ mm = \sqrt{(1\ mm)^2 + \sigma_{PE}{}^2}$$

$$\sigma_{PE} = 3.59\ mm$$

New PE Equation for Single Runs Yields ~1.5 mm Resolution



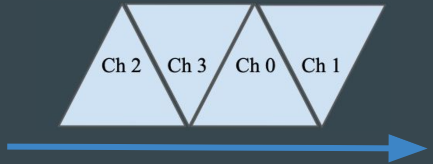
Joren Husic, "Exploring the Great Pyramid: Scintillator Test Report," May 2022.

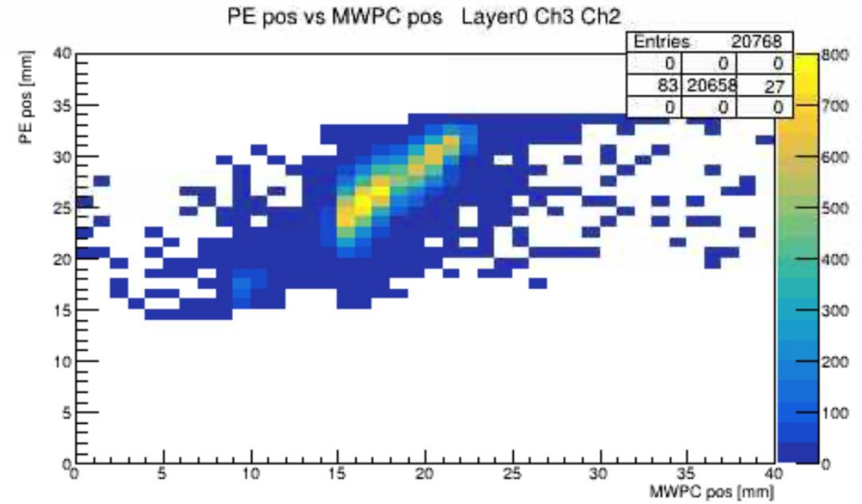
Revisiting of NAUM analysis code

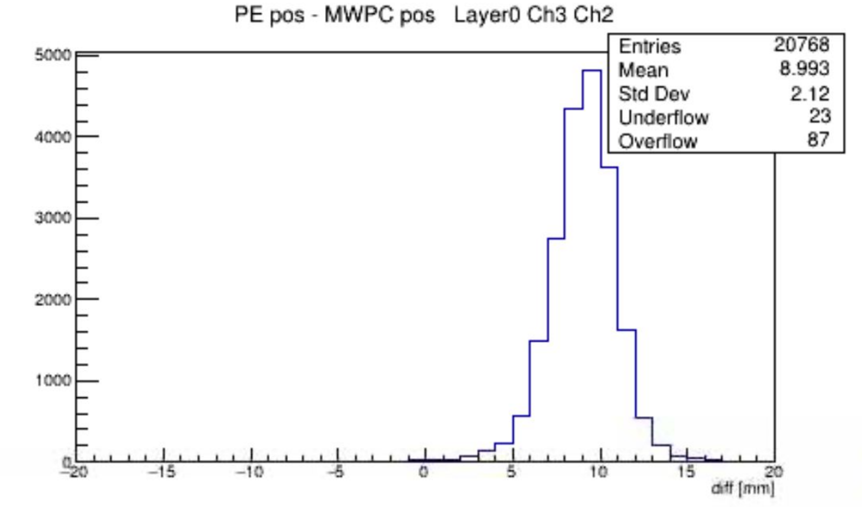
- Single runs vs all test runs
- New position-determining method

$$Z = \frac{E_1 \cdot P_1 + E_2 \cdot P_2}{E_1 + E_2}$$

for:
Z, muon hit location along quadcounter face
E_1 and E_2, energies deposited in neighboring counters 1 and 2
P_1 and P_2, Z-positions for nearest scintillator vertex







New PE Equation for Single Runs Yields ~1.9 mm Resolution

Significant increase seen with new method

- First quad-counter layer
- Between channels 2 and 3
- Smallest observed resolution

$$\sigma = \sqrt{\sigma_{\mathrm{MWPC}}{}^2 + \sigma_{\mathrm{PE}}{}^2}$$

$$2.12 = \sqrt{(1\ mm)^2 + \sigma_{\mathrm{PE}}{}^2}$$

$$\sigma_{\mathrm{PE}} = 1.87\ mm$$

Conclusion

- Around 100 PEs created per event
- 3 of 4 triangular quad-counter PE distributions performed as expected
  - Max PE values of ~100 at counter peak vertex
  - Average >90% efficiency across tested range
- Initial detector resolution 3.59 mm
  - New resolution method yielded 1.87 mm resolution

Graphs plotted:

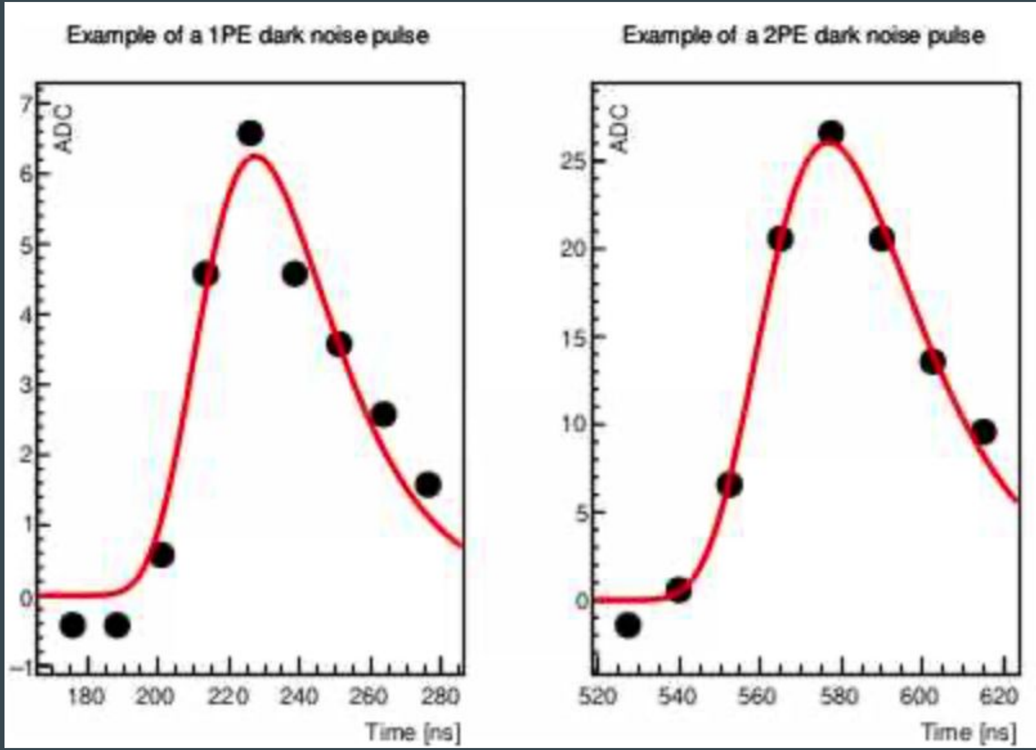
- Single waveforms
- Waveform peak fit & calibration
- PE distribution across neighboring counters
- PE count scan across full quad-counter
  - Contour
  - Profile
- Efficiency per channel across quad-counter
- Beam intensity across run duration

Backup Slides

Pulse Fit uses Modified Gumbel Distribution

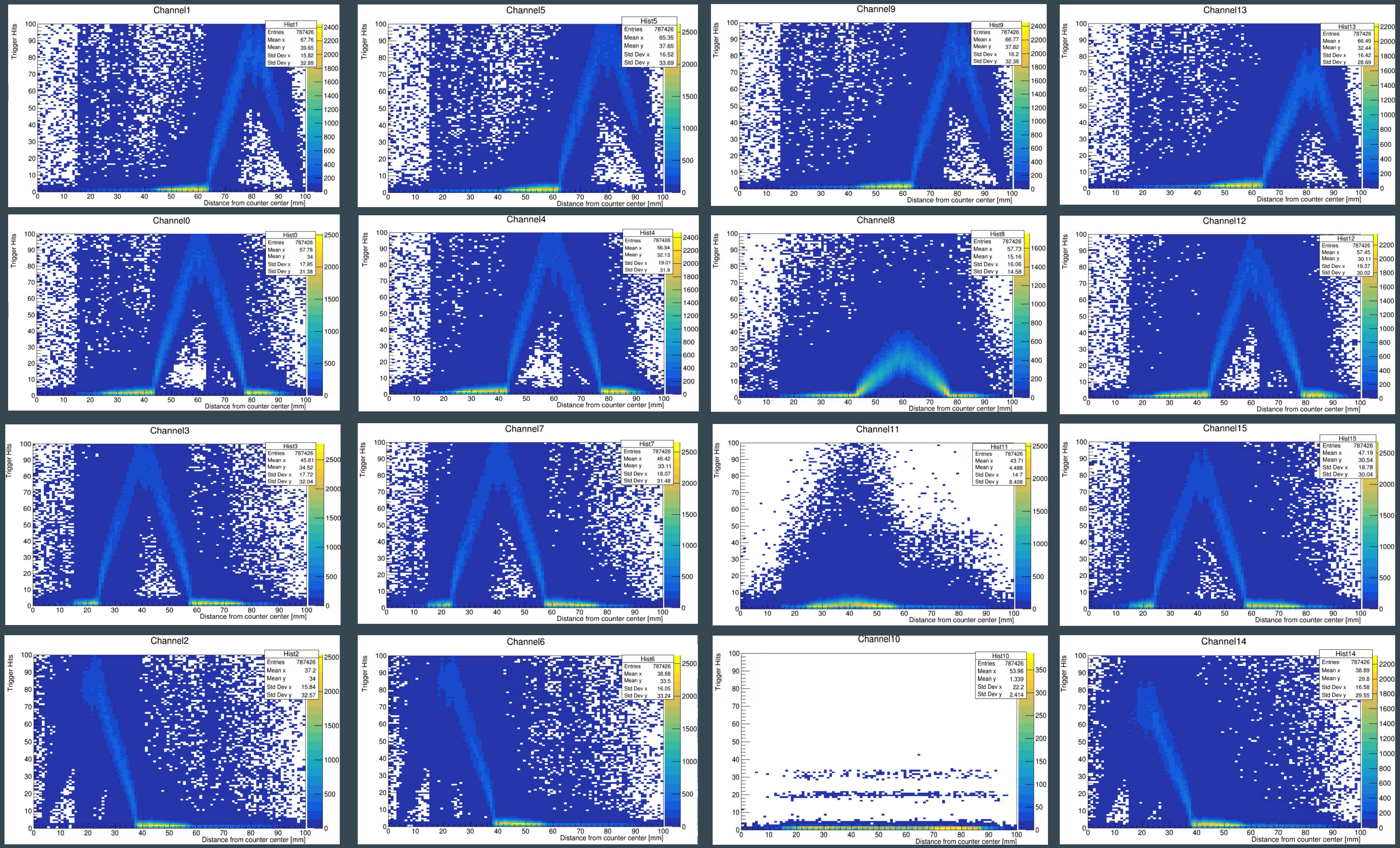
$$f(t) = A \cdot e^{-\frac{t-\mu}{\beta} - e^{-\frac{t-\mu}{\beta}}}$$

- Pulse height: A/e
- Peak time: μ
- Pulse area: $A \cdot \beta$
- Pulse width: $\beta\pi/\sqrt{6}$



https://mu2e-docdb.fnal.gov/cgi-bin/sso/RetrieveFile?docid=12239&filename=The%20Mu2e%20CRV%20Testbeam%20v6.pdf&version=4

Upstream



Downstream

Axis Labels x: Distance from bottom of counter (mm)
y: Photo electrons (PEs)