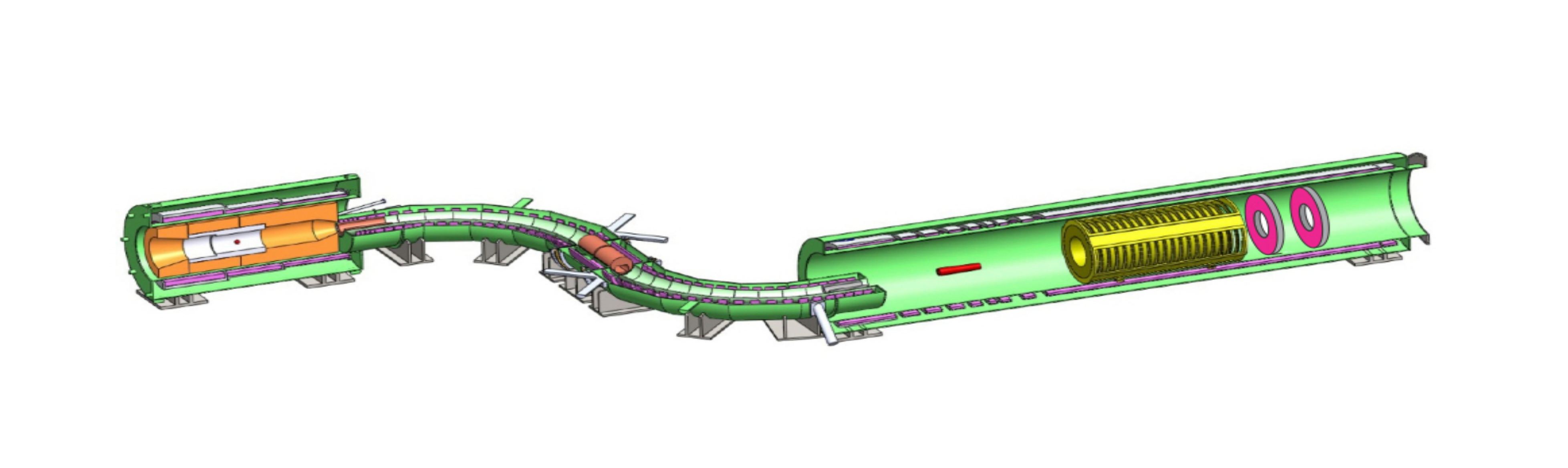
Matthias Jamison-Koenig - Brooks College Prep, CPS

# Summer 2015 @FNAL

# Mu2E Overview



- Production Solenoid - Protons strike production target to get pions
  - Pions decay into muons
- Transport Solenoid - selects high momentum muons
  - Uses magnetic fields and collimators
- Detector Solenoid – Muons hit a target and we look for signal

# Beam Delivery

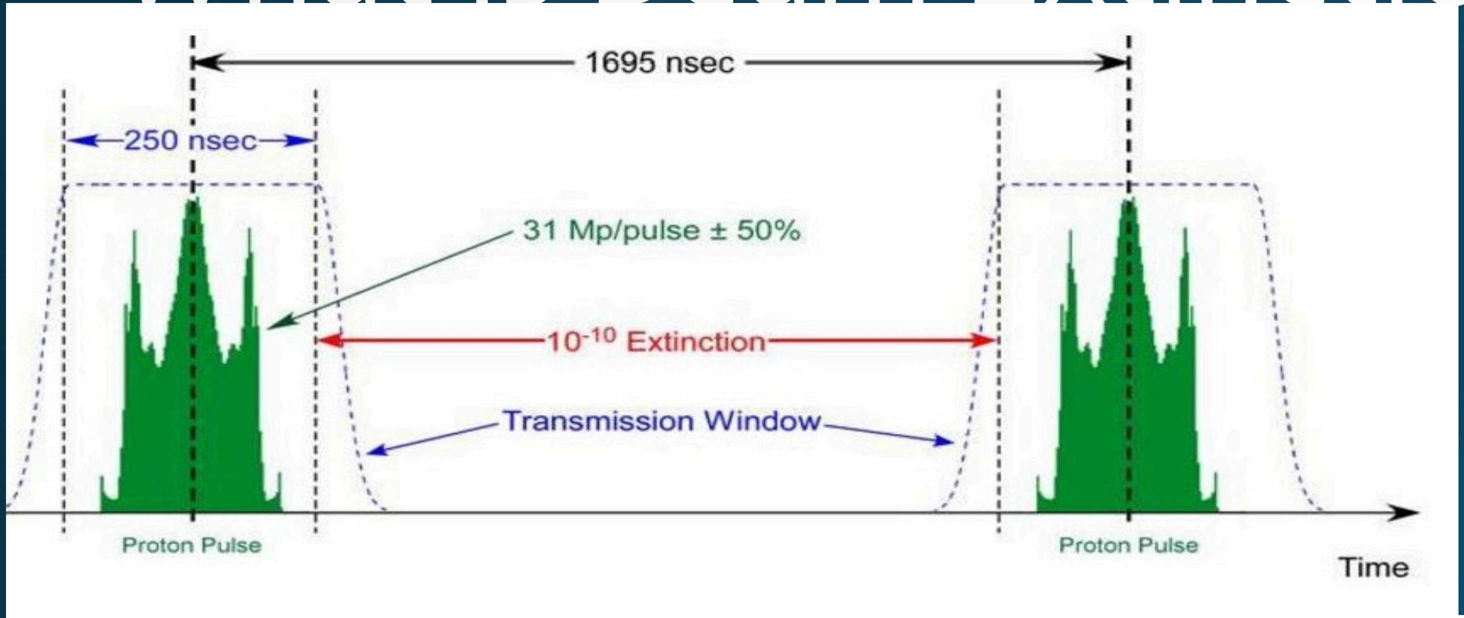

- The proton "beam" is really packets of protons, with each packet containing about $4\text{x}10^{12}$ protons.
  - These are accelerated to 8GeV in the Booster Ring (yellow) and are sent to the recycler (red).
- In the recycler, a 2.5MHz RF system splits each batch into 4 equal "bunches."
  - These are sent to the delivery ring (blue), where they are extracted to Mu2E (green)
- Each bunch should be separated by 1.7μs, with (ideally) $10^{-10}$ beam extinction at the Production Solenoid.

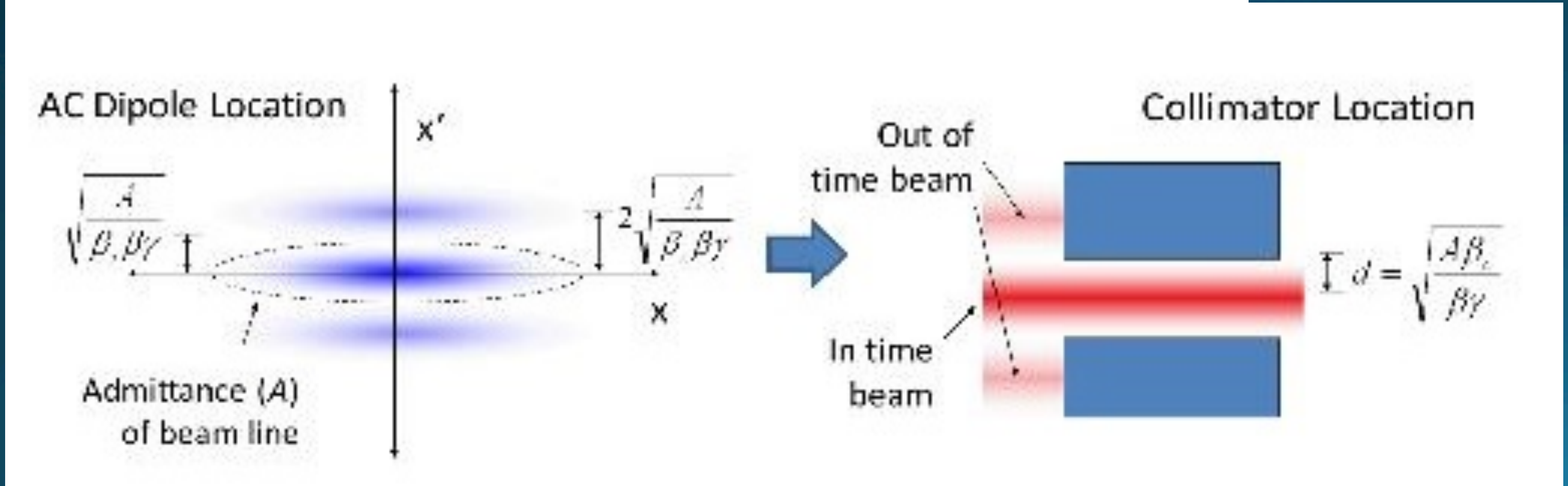
# What Is Beam Extinction?

- In between each packet, there could be extra protons that leaked out from the packets.
  - This could be caused by a number of things…basically anything that would cause a proton to lose momentum.
  - The out-of-time beam will be dealt with using collimators and deflection magnets, timed to only allow in-time protons through the system.

- Since the search window for the experiment is between the bunches, any out-of-time beam would cause HUGE background issues. We need to keep it as low as possible.

# What Is Beam Extinction?



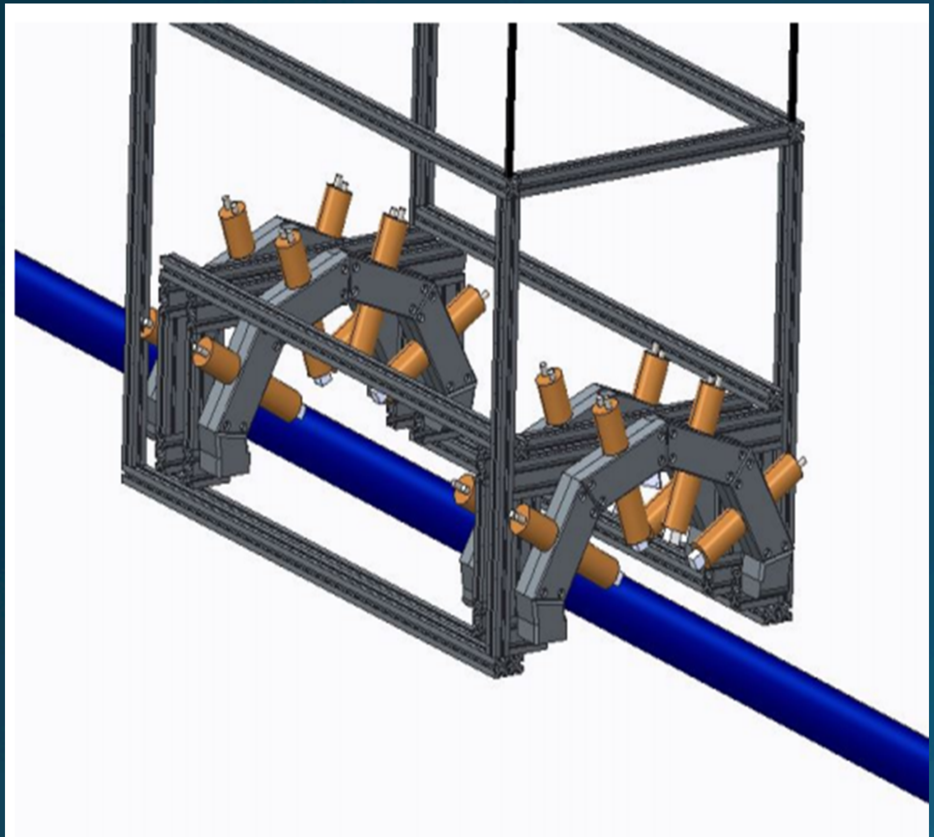
# What are acceptable levels?

- Within the experiment, we want $10^{-10}$, which corresponds to one out-of-time proton for every 300 bunches, in the Detector Solenoid.
  - This is hard to monitor live…

- Simulations indicated that if the beam had an extinction of $10^{-5}$ while it's in the Recycler, we could achieve the extinction goals in the experiment. This corresponds to no more than $10^{7}$ protons between each bunch.
  - This is much easier to monitor live!

- Current estimates indicate we might have $10^{-7}$ extinction right now, but the current system will only measure down to $10^{-3}$.

# Our Plan



- An array of detectors will look for out-of-time beam as it enters the Delivery Ring. These consist of PMTs attached to quartz “radiators.”
- By looking for coincident hits in multiple detectors, we can re-create “tracks” scattered by scrapers in the Recycler.
- Detectors will only look for tracks between each bunch using a trigger clock. This gives us a statistical measure of beam extinction.

# The Quartz Radiator

- The quartz radiator relies on Cherenkov radiation produced by a high energy charged particle passing through the quartz. The attached PMT detects the light and creates a measurable signal.
- Since they rely on Cherenkov radiation, they are blind to any low-momentum particles (soft radiation) and neutrons, meaning their background will be very low.
- They also have a very fast response time (femtoseconds!) and produce a very clean signal for the PMTs.

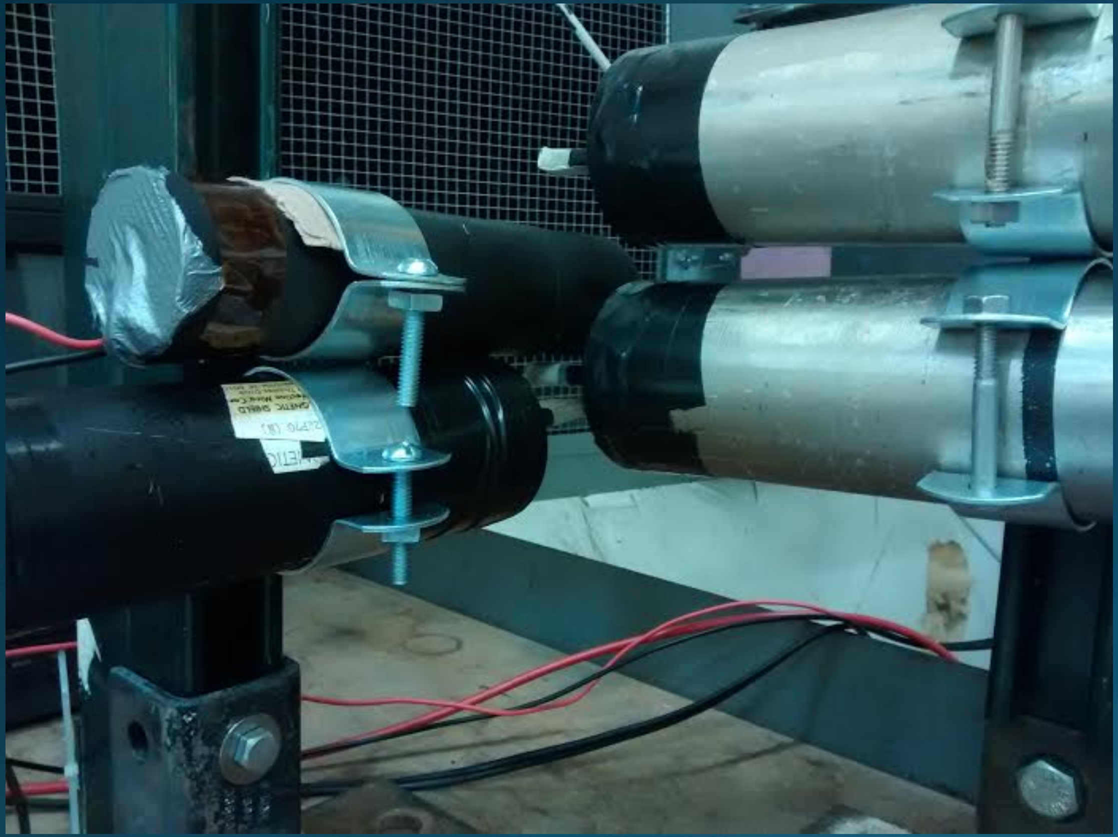
# Our Short-term Objective

- We want to make sure the quartz radiator will work as expected, with proper soft particle exclusion and no after-pulsing. We also need to evaluate it's efficiency.

- We will do that using high-energy cosmic rays. By placing the radiator in a cosmic ray telescope and using it as a trigger, we can look at the signals produced by high-energy charged particles.

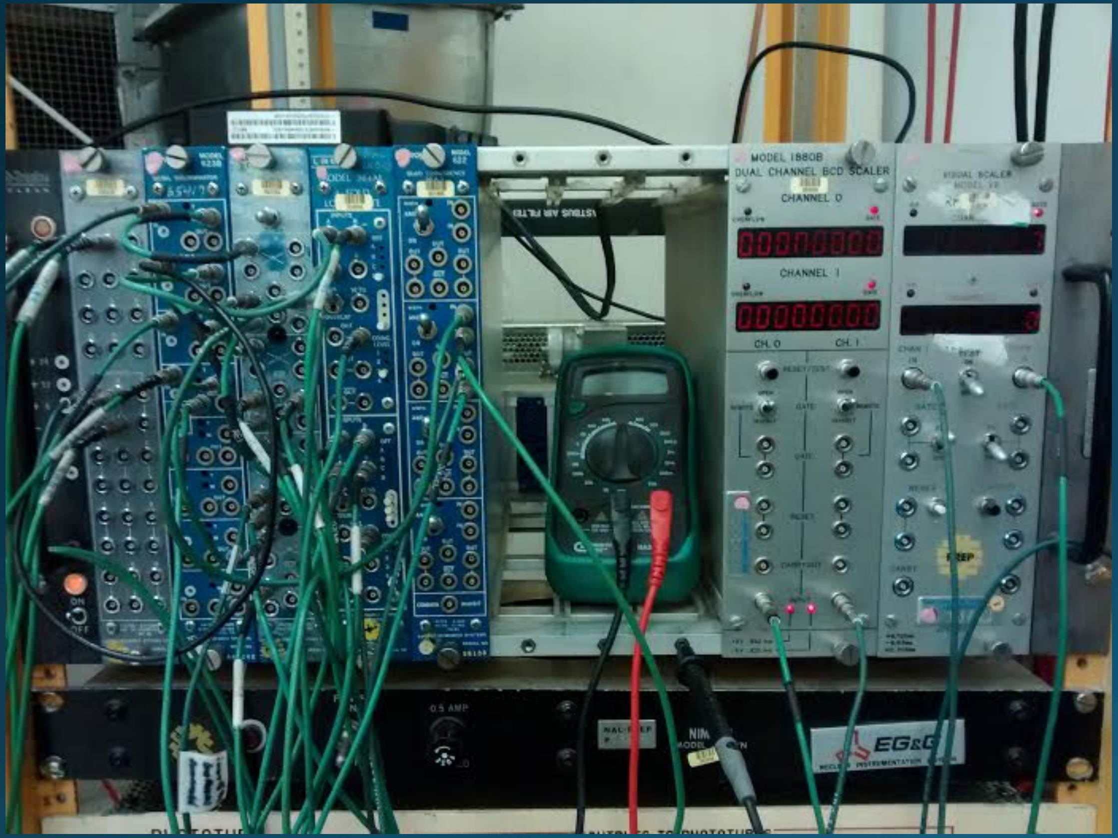
- Unfortunately, particles hot enough only enter our home-made telescope twice or so an hour. Long data runs…

# The Setup



- Three PMT’s with plastic scintillators aligned to detect cosmic rays
- Quartz radiator attached to PMT
- Setup is collinear (we think…) and about 8cm thick.

# Electronics



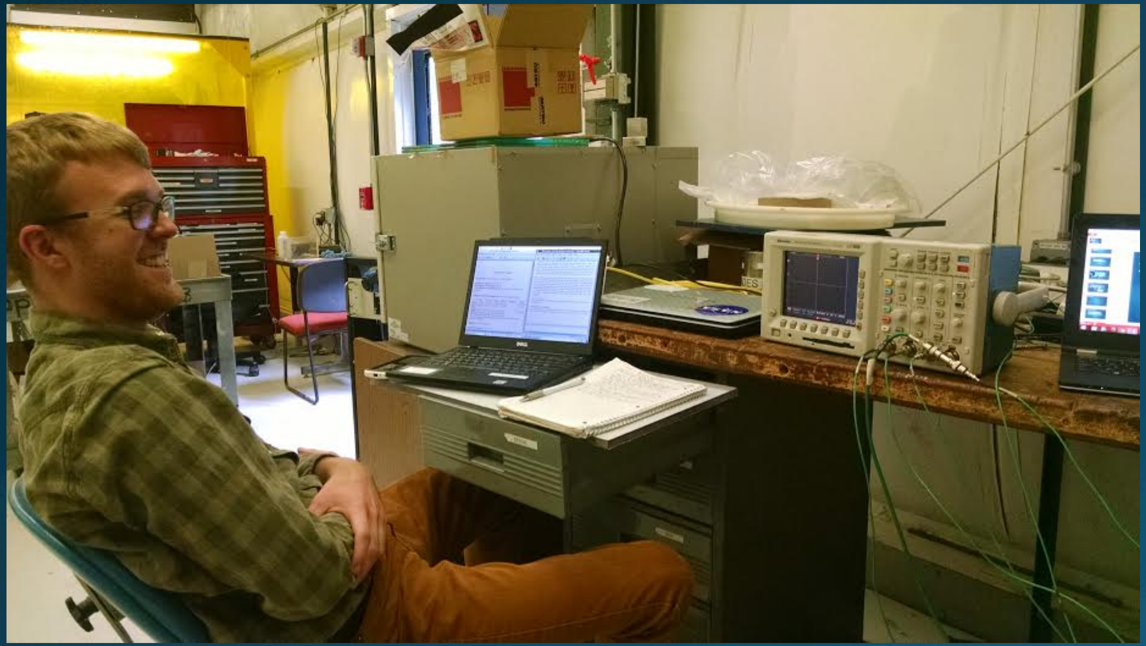

- Counters looking for simultaneous hits in:
  - all 3 scintillators,
  - 3+radiator,
  - the two scintillators nearest the radiator
  - 2+radiator.

# Notes on Setup

- The two PMTs nearest the radiator are being amplified 10x in order to get a clear signal. That signal is fed into the discriminator. The 3rd PMT and the quartz radiator's PMT are producing a strong enough signal that amplification doesn't appear to be necessary.

- The thresholds of the plastic scintillator PMT's are currently fairly low (50-30mV), and they each see about 70 hits per second. The quartz is set to 223mV and sees ~1200 hits per second.

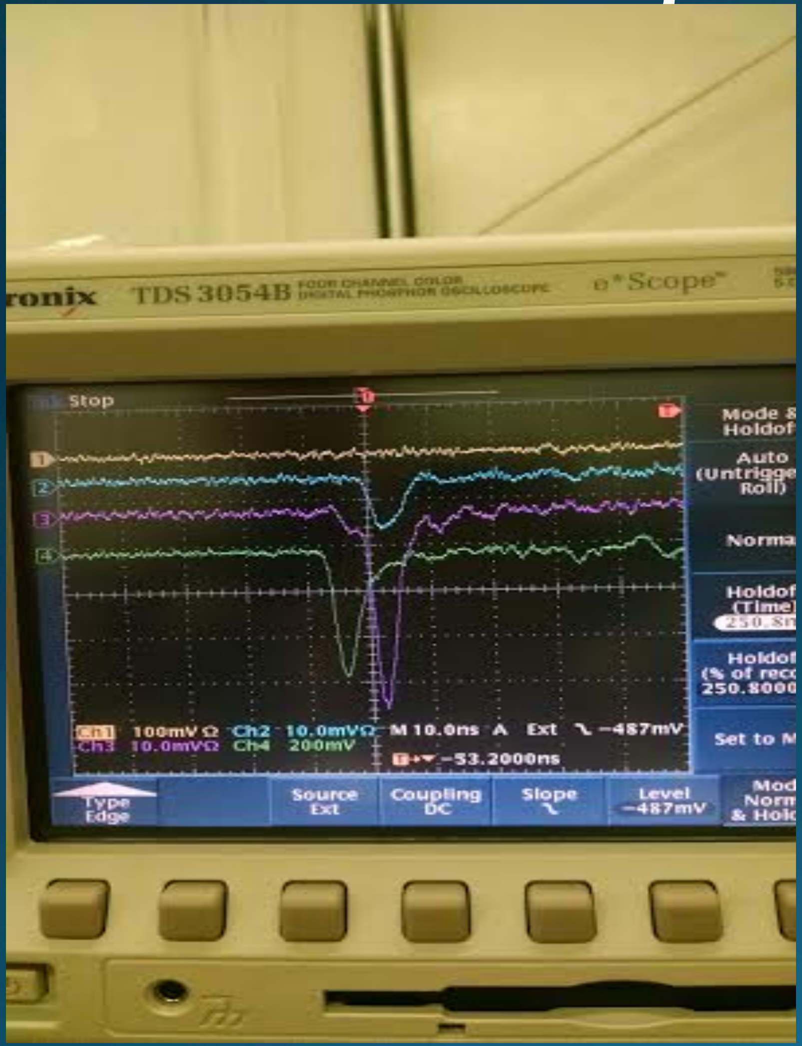
# Data Capture



- A scope triggers on a coincidence in all three plastic scintillators

- Meet my minion…err…I mean coworker, Logan (a Lee Teng intern). He took care of a lot of the software related to data acquisition from the scope.

# An interesting event…




- Is this signal?
  - 1=lowest pmt
  - 2=high pmt
  - 3=pmt just below radiator
  - 4=radiator

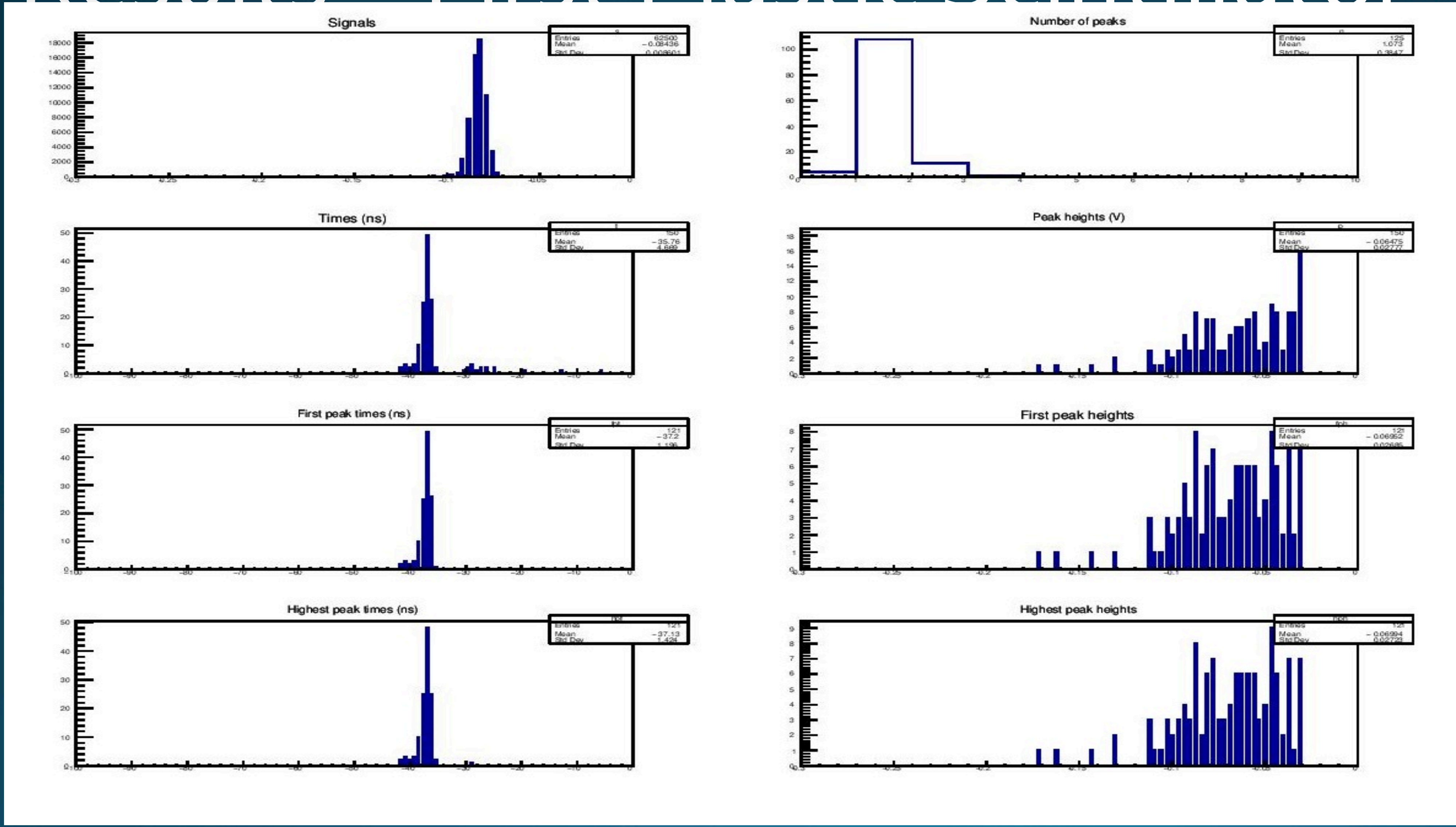
# The Analysis

- Using a ROOT script, the data from the scope is read out, analyzed, and filled into histogram outputs. This included a peak finding algorithm that identified signal events in the scope readout.
  - “SIGNALS” and “Peaks Per Event” are bug checks, mostly…
  - The second row contains times and energies of all peaks.
  - The third row contains times and energies of the first peak in the event.
  - The fourth row contains times and energies of the largest peak in the event.

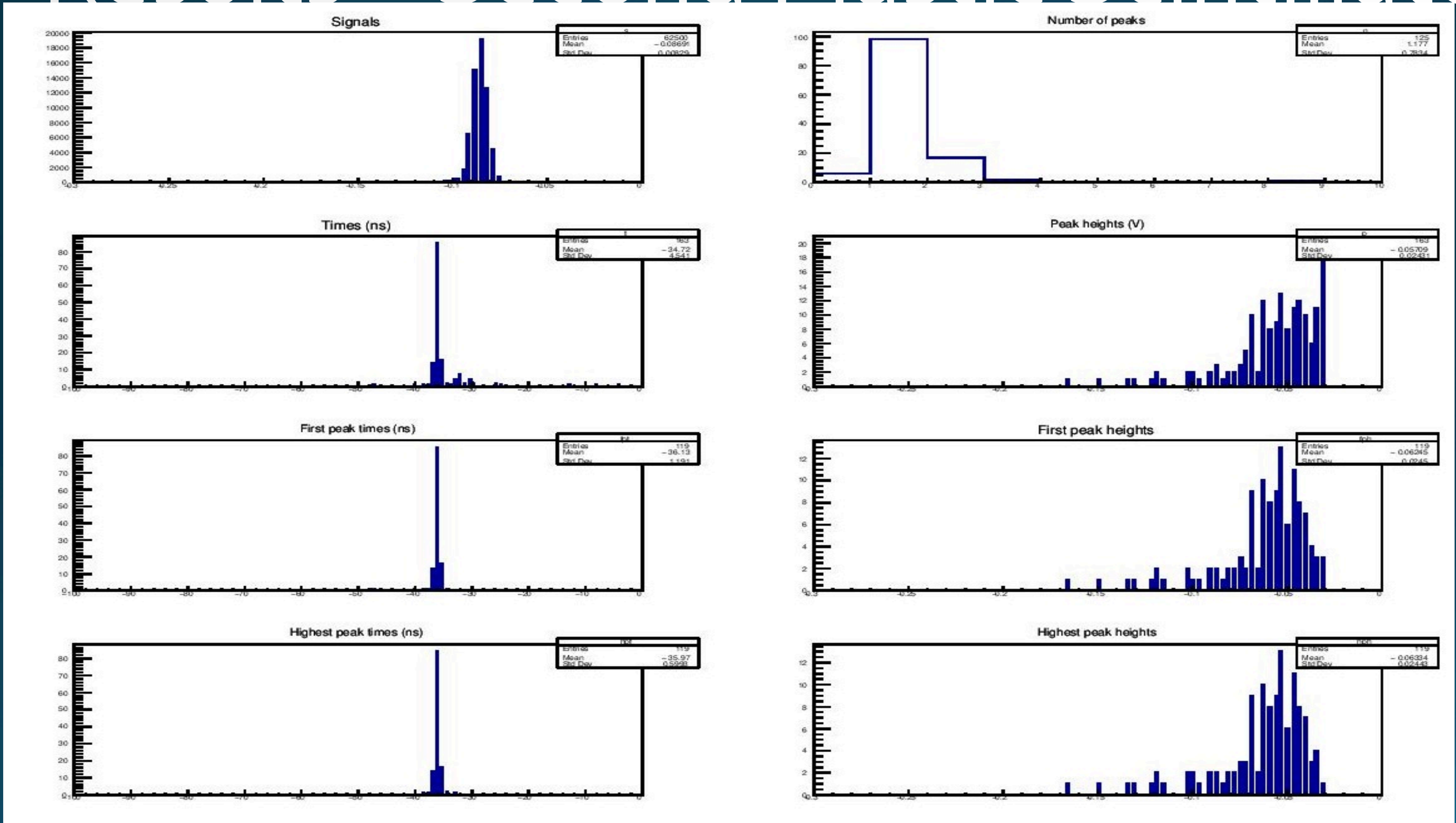
# Notes on This Data Set (Run 11)

- The quartz was oriented exposing a thin cross-section.
- The flat cross-section run had a little malfunction.  It is currently running again.  Results coming soon.
- We thought we had major problems earlier.  Turns out my boss made a math mistake.  This is our first “clean” run that went as predicted.

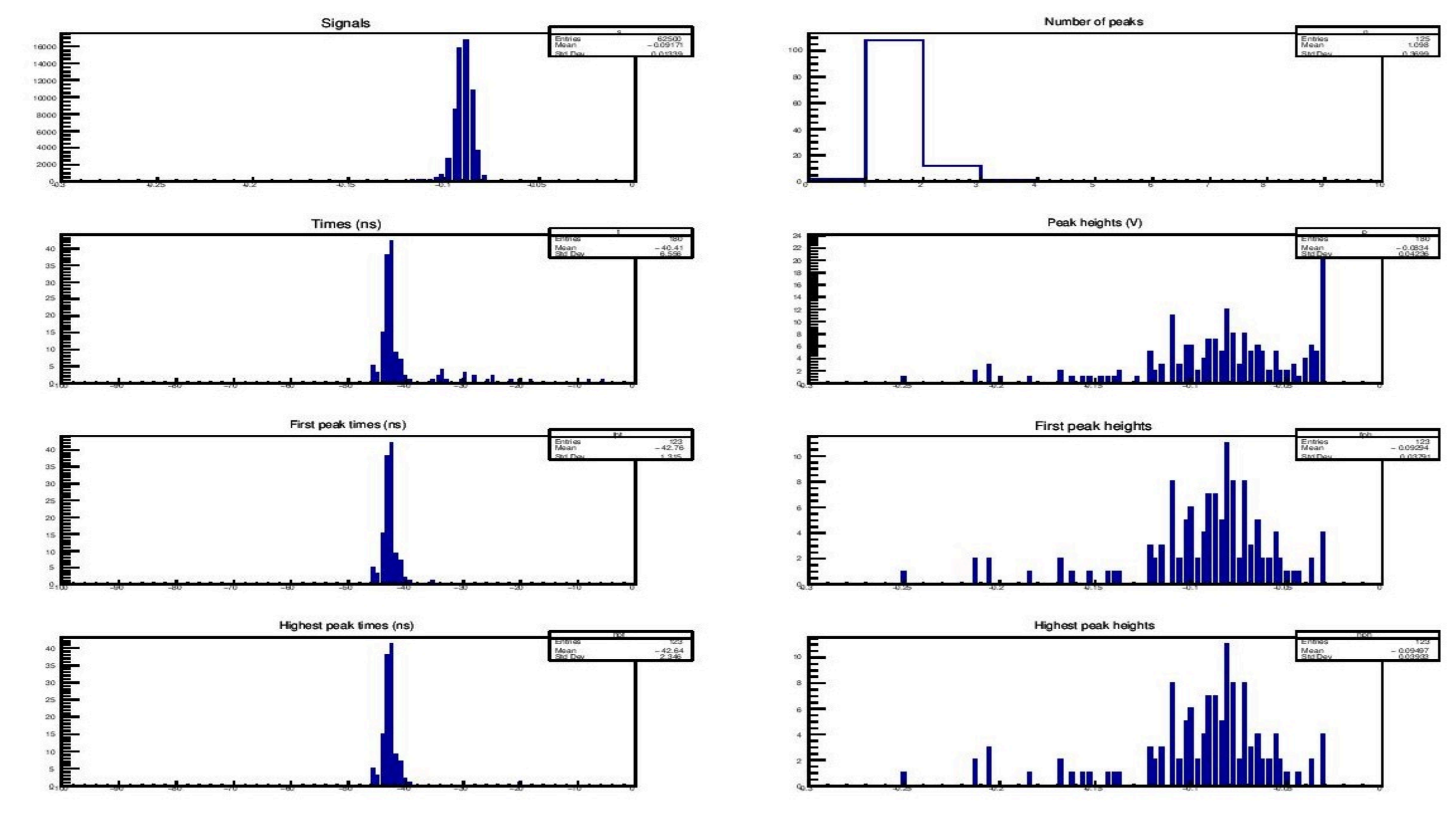
# Results – First Plastic Scintillator



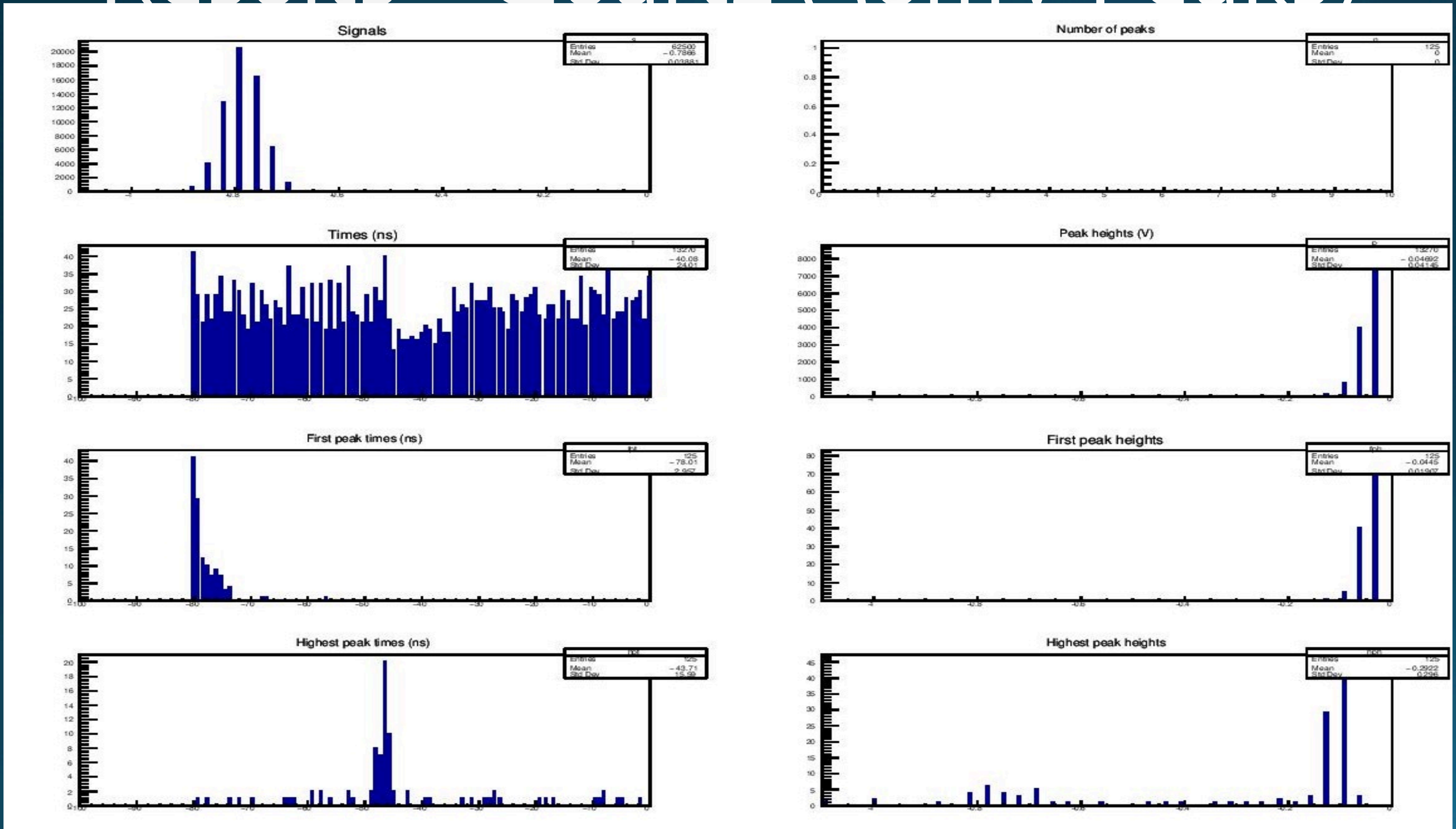
# Results – Second Plastic Scintillator



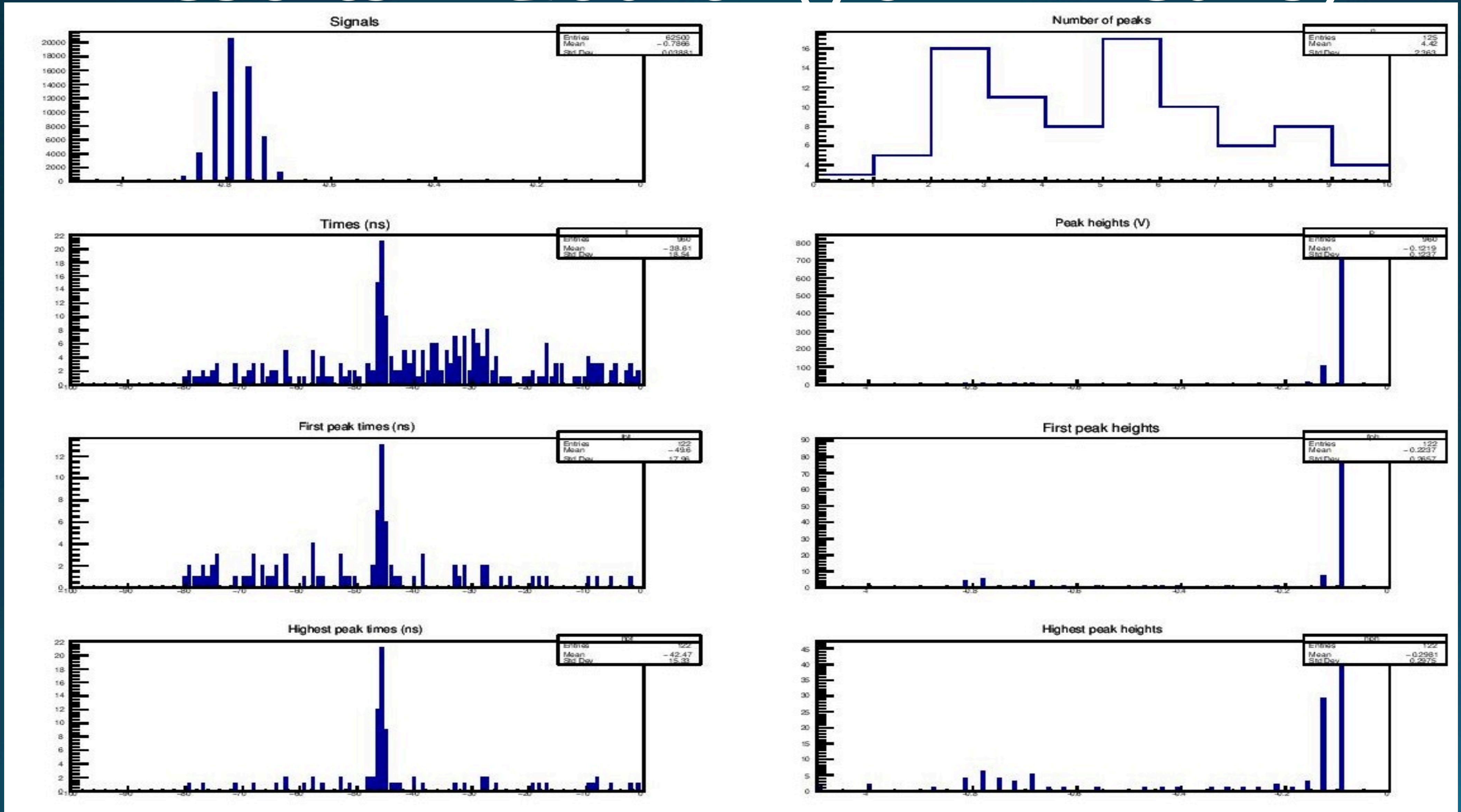
# Results – Third Plastic Scintillator



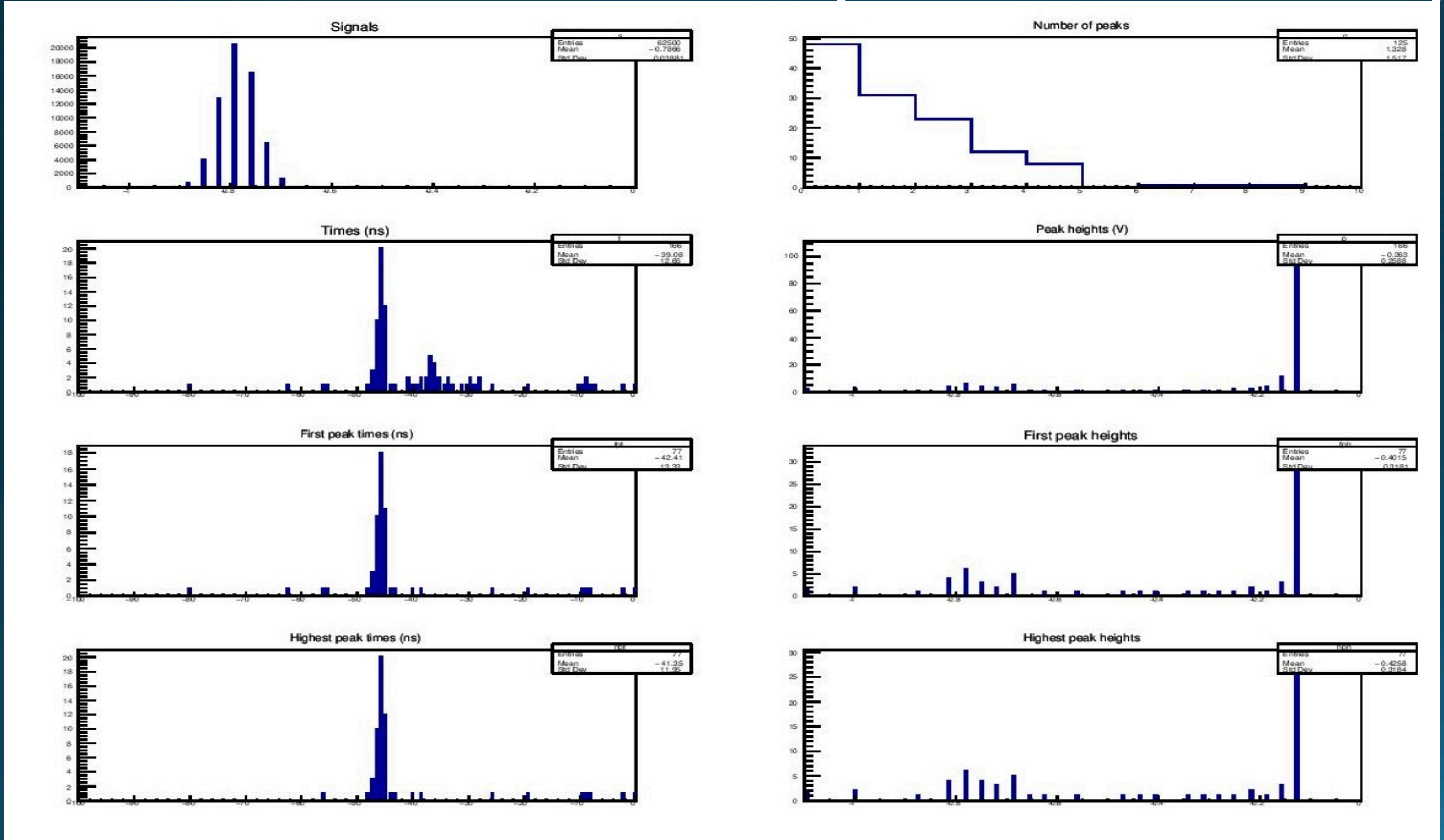
# Results – Quartz (30mV Peaks)



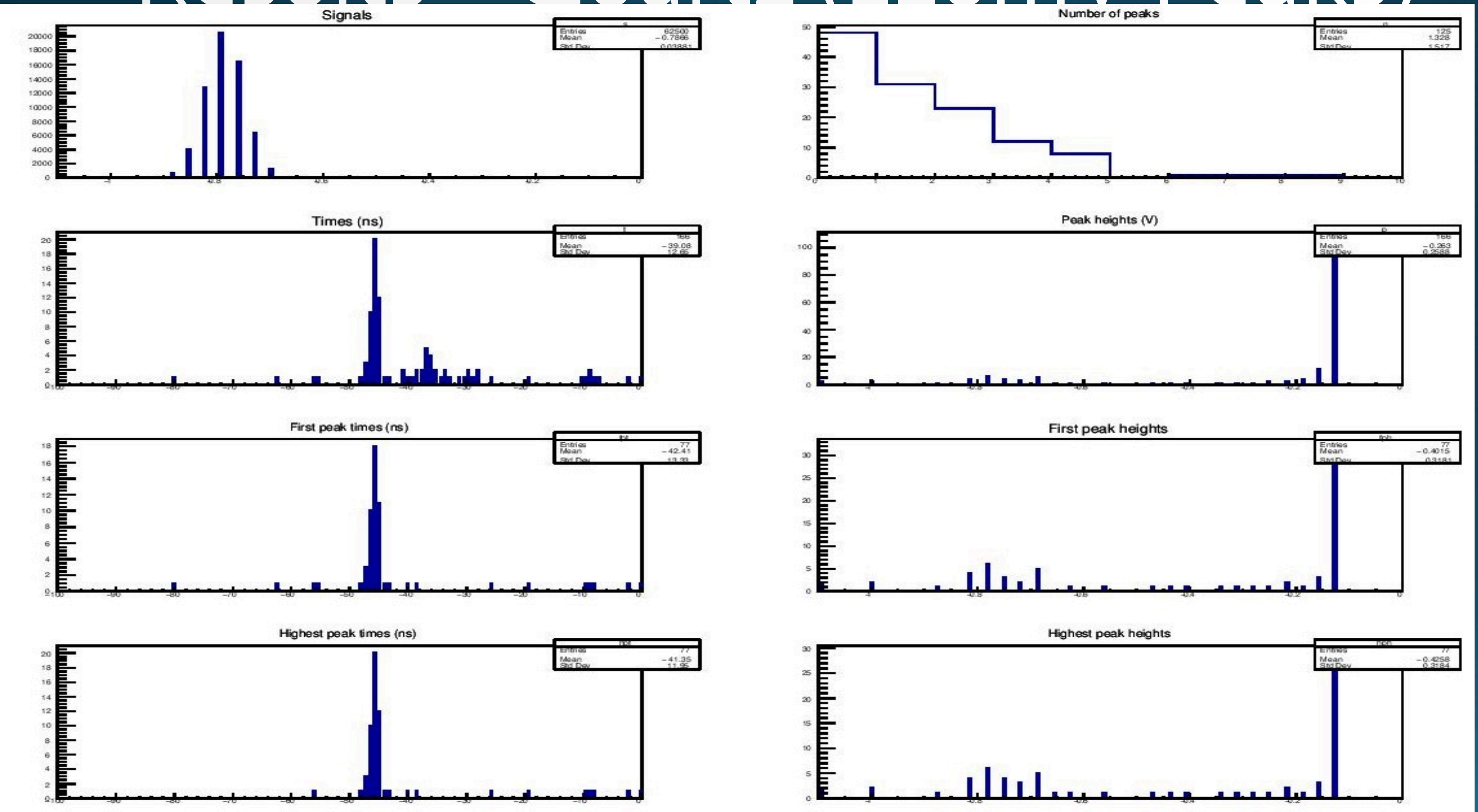
# Results – Quartz (70mV Peaks)



# Results – Quartz (100mV Peaks)



# Results – Quartz (120mV Peaks)



# What does this mean?

- Out of 120 high-energy cosmic rays, the quartz saw about 70 or 80.

- This low efficiency is likely due to two factors
  - Orientation
  - Soft particles

- We confirmed that it works. We also confirmed that real signals from the quartz tend to be pretty large, while noise has lower peaks.
  - We can use a high discriminator threshold to filter noise without eliminating any real signal. This will result in far lower "fakes" in the real data run.

# Coming Soon to a Lab Near You…

- Filter soft particles using a lead brick we found lying around.
- Apply low-pass filter to scintillator trigger system (to idiot check above approach).
- Measure after-pulsing characteristics (there should be none).
- Measure individual photon response (if I have time).

# What Am I Taking Away From All This?

- Creativity
- Rigor
- Data Analysis -> Conclusions
- Effective Collaboration
- Community

# How Will My Kids Benefit From This?

- More investigation-based activities
- Encouraging open and respectful dialogue
- Scaffolding effective collaboration
- Create peer-like collaboration between teacher and student.

# A Very Special Thanks

- Eric Prebys
- Harry Cheung
- Logan Rudd
- Marjorie Corcoran
- The TRAC posse

# How I Felt Coming Back

# How I'll Feel Leaving Y'all