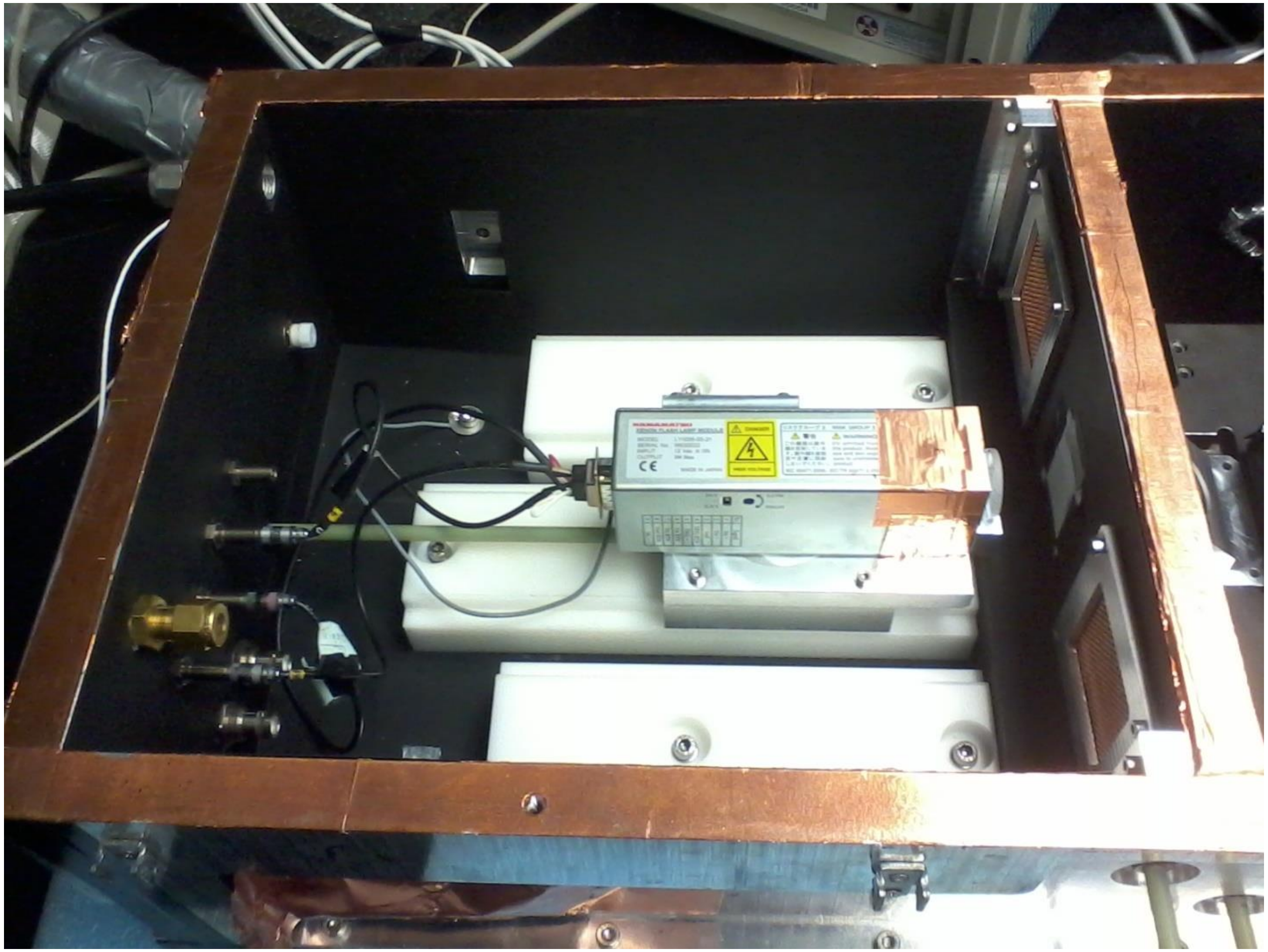
nEXO Photomultiplier Test Setup

June 25, 2015

Setup – Box

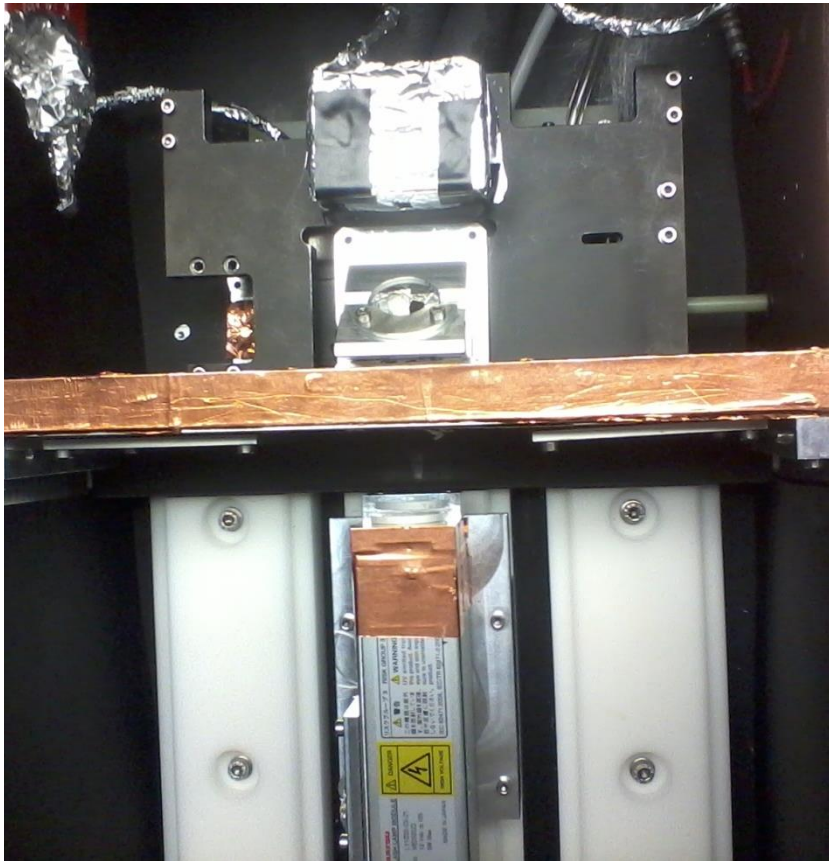
- Made of aluminum
- Two sections – lamp and detector
- Aluminum lid latches onto box

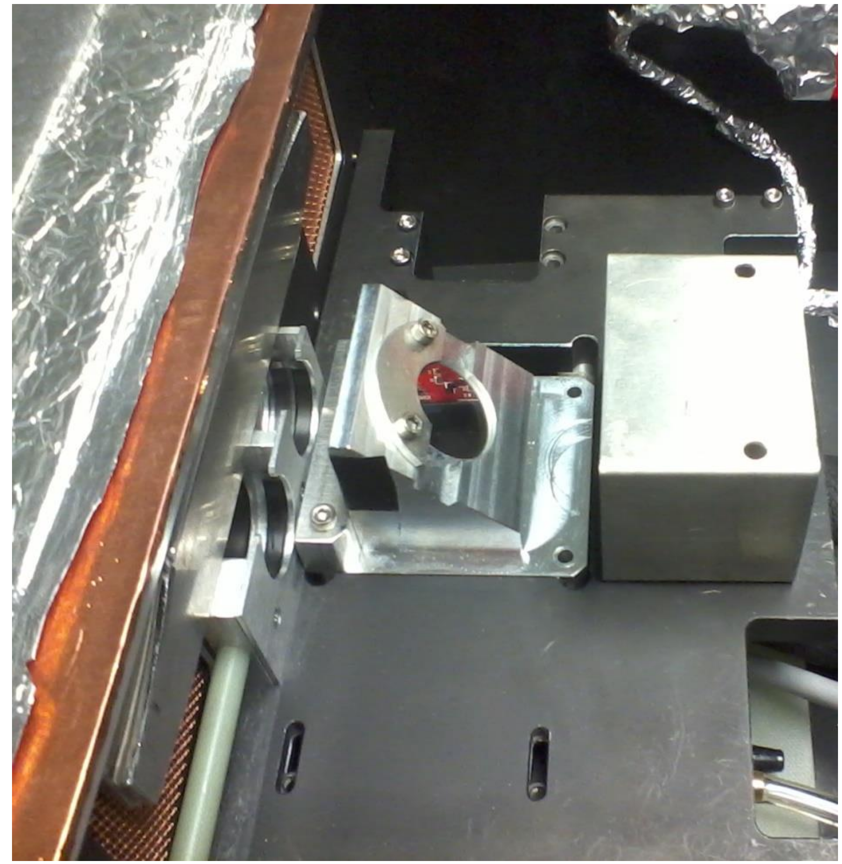
Setup – Lamp and Trigger



- Xe Flash Lamp
- Triggers externally - 10μs pulse every 10ms
- Most photons in first μs

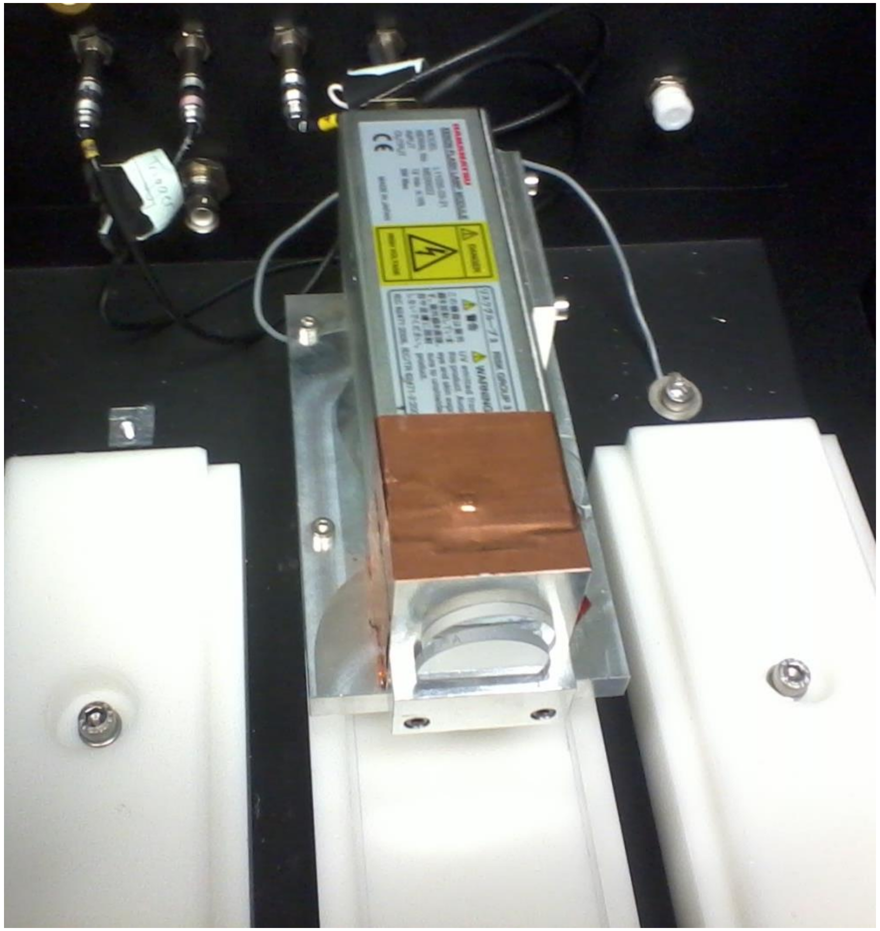
Setup – Beam Splitter





- Lamp light split into two beams (50/50)
- Beam to top and bottom detectors

Setup – Filtering

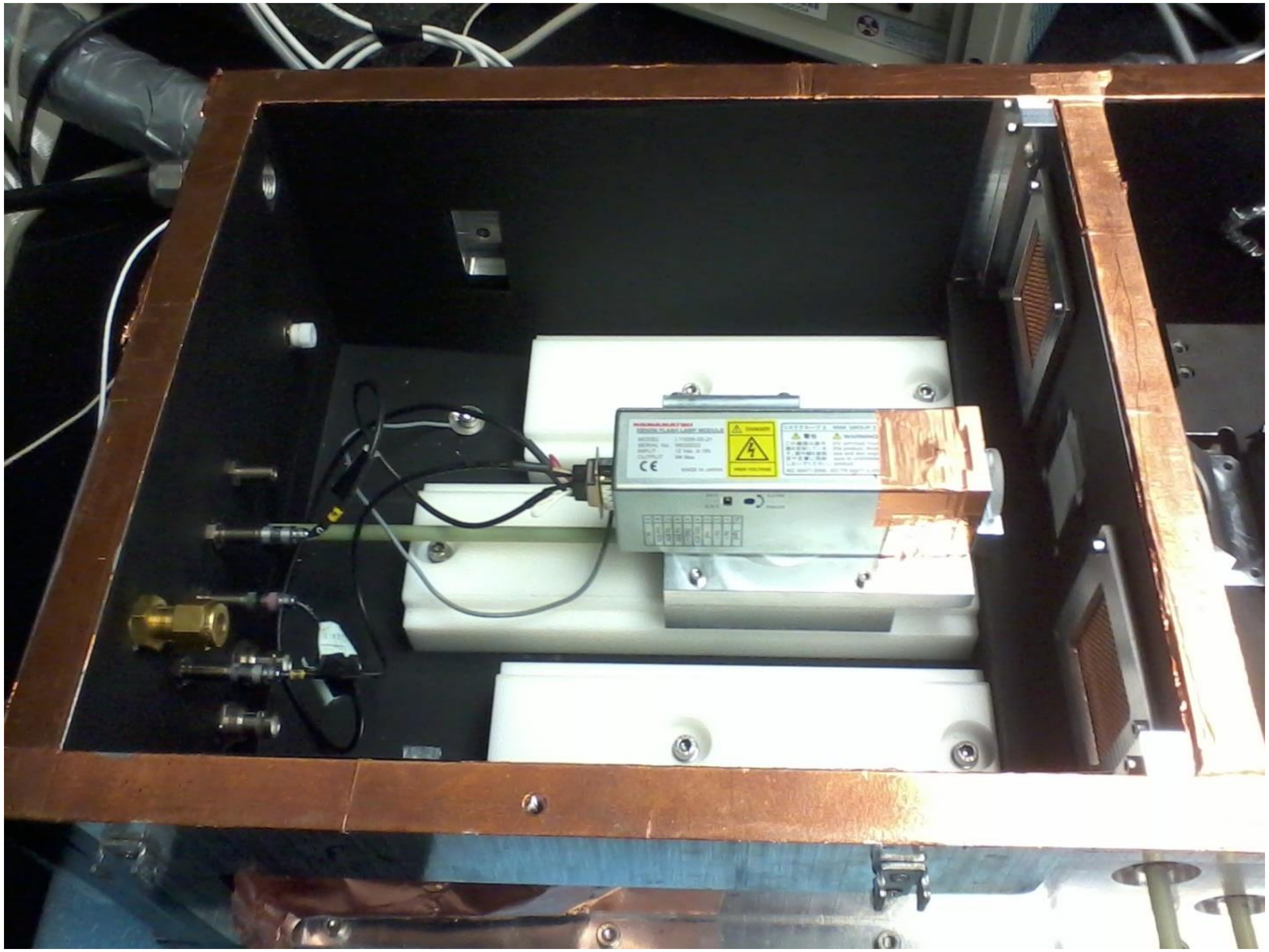


- Three 175nm UV filters
- Two on lamp; one after hole in box divider

Setup – Filtering – Testing for UV

- Need to eliminate non 175nm light for atteuation
- Visible light tested for with glass slides
- Significant light with three filters
- Slides blocked all light with three filters in place
- Not the case with two filters

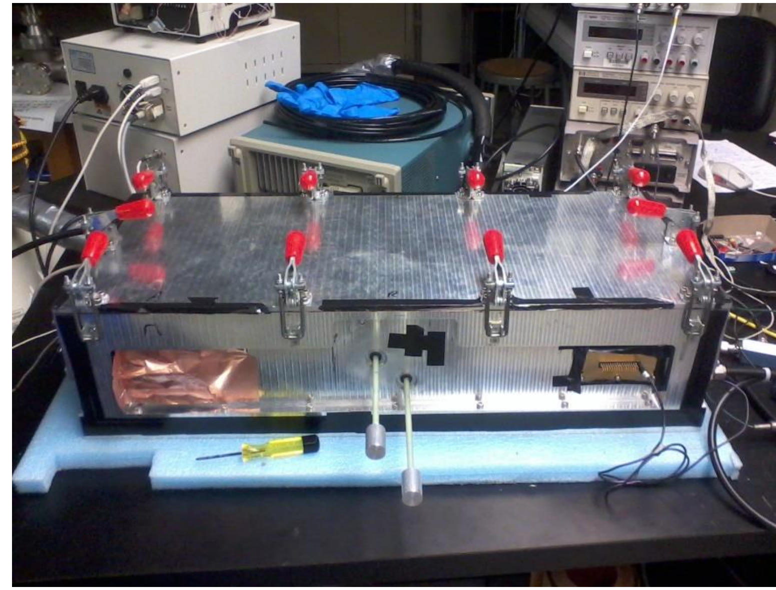
Setup – Attenuation

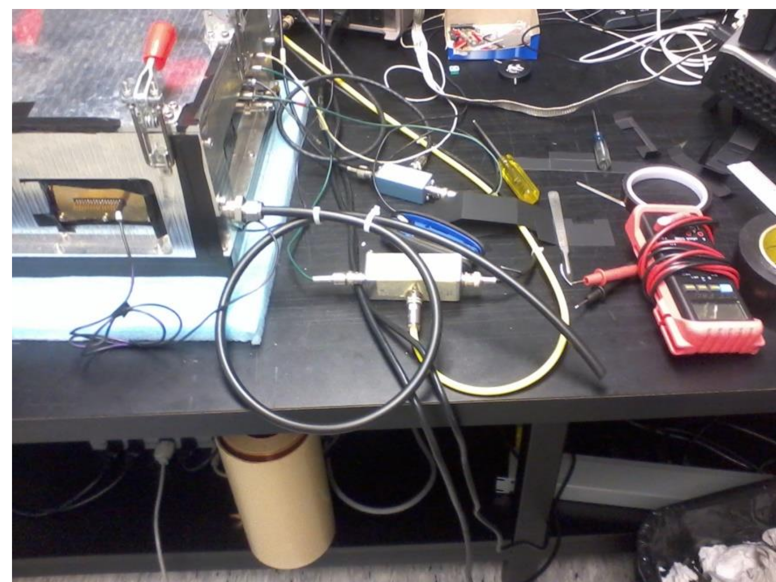


- Lamp light attenuated to individual photon level
- Since mostly 175nm light, specialized means not required
- Attenuated using three layers of Kimwipes over hole

Setup – N_2

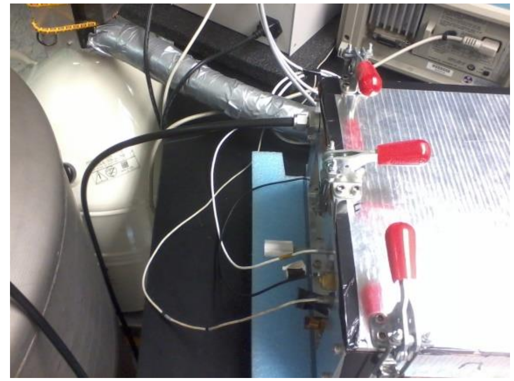
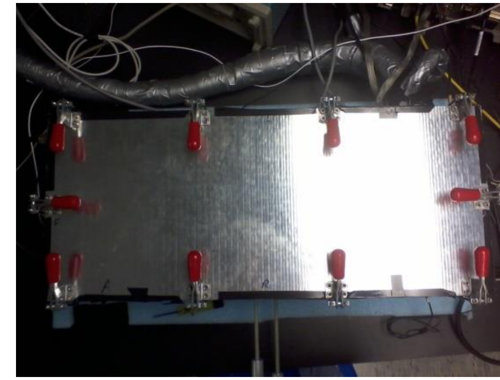
- N_2 transparent to UV
- O_2 and H_2O are not
- N_2 also prevents condensation and frost while cooling
- Nitrogen gas vented into box from dewer of LN_2
- N_2 enters lamp side and exits detector side

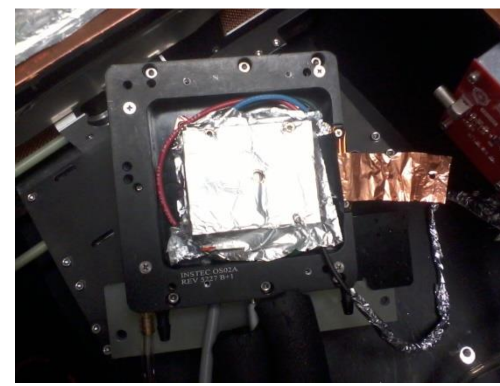




Setup – Cooling

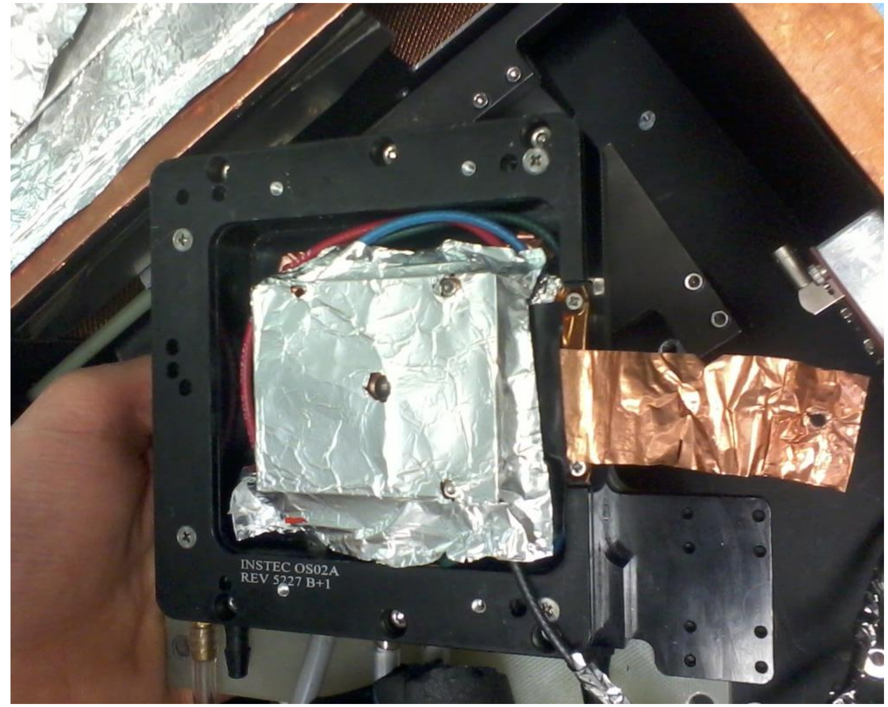


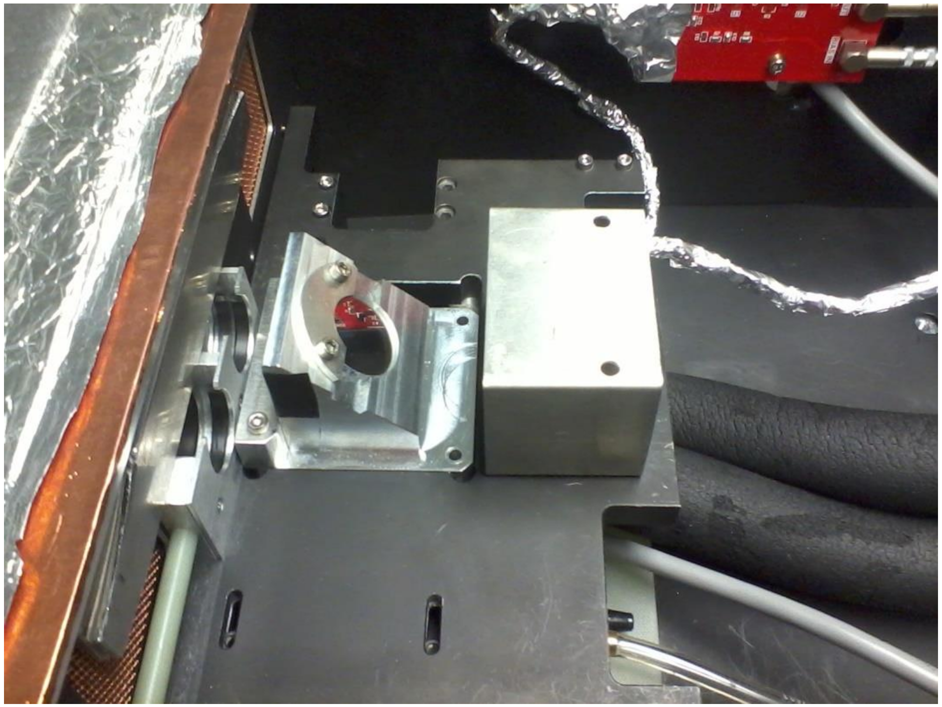
- LN_2 pumped into platform under detector
- Platform then cools detector
- Only lower detector can be cooled
- N_2 vented into box to prevent condensation

Setup – Detector Holders



- Two detectors – reference and test
- Reference on top
- Test on bottom (cooled)

Setup – Detectors Holders - Reference



- VUV2 serves as reference
- Low dark count of 580 kcps at 25°C
- Not cooled

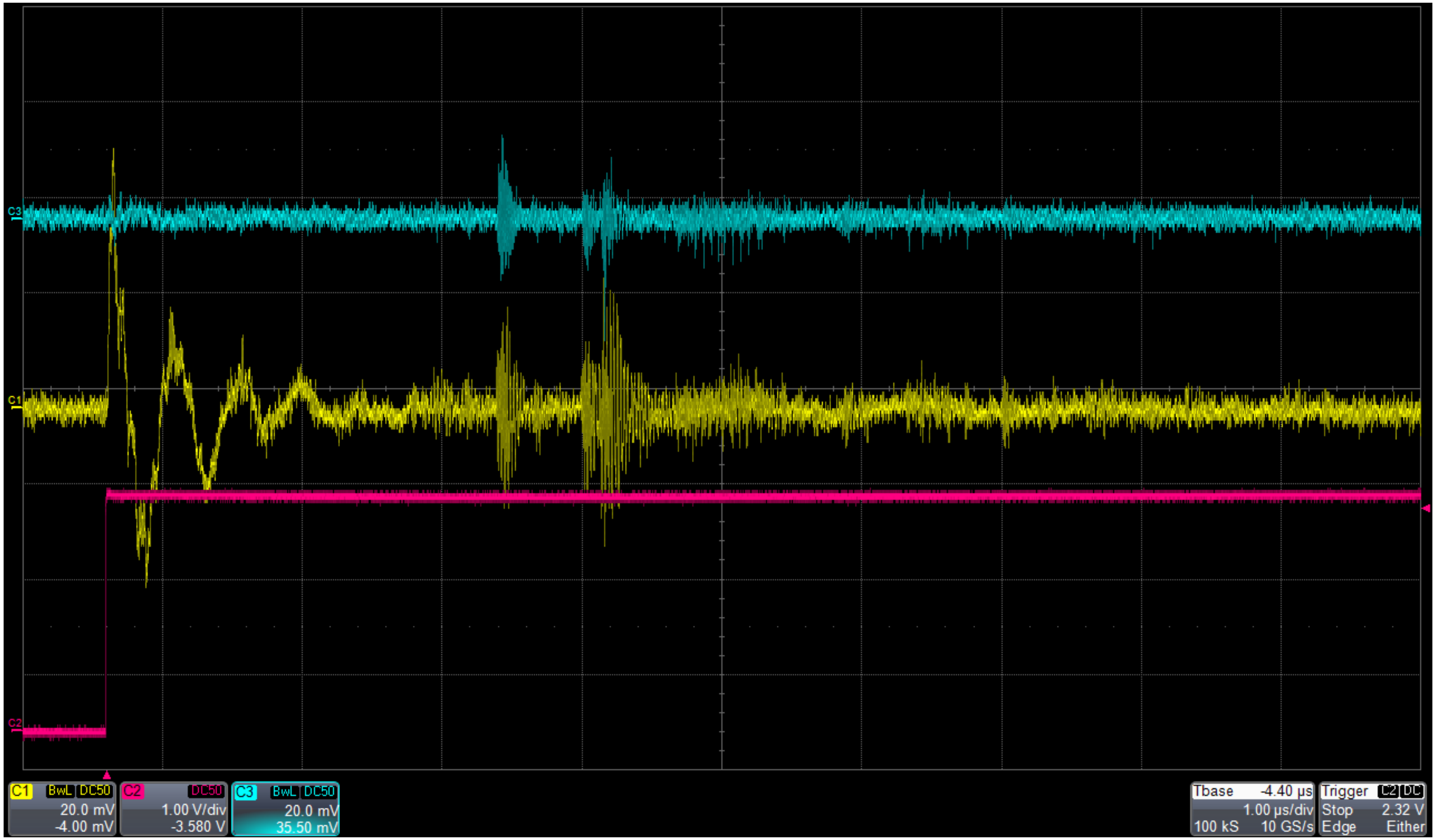
Setup – Amplifiers

- Two custom amplifiers
- Amplifier for test detector is attenuated to allow high OV tests of VUV3

Setup – Power Supplies

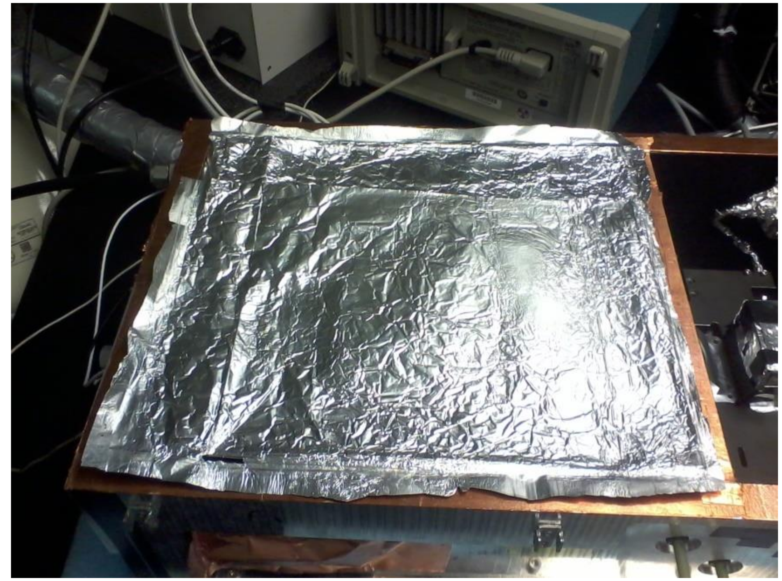
- Two power supplies for the two detectors
- One power supply for the amplifiers
- One power supply for the lamp

Setup – Shielding



- Lamp emits radio waves
- Faraday cages are used throughout the setup to block/absorb them

Setup – Shielding – Lamp Section



- Chunk of steel, sheet of aluminum, aluminum foil, and another sheet of aluminum used as faraday cage over lamp
- Chunk of steel dissipates the radio waves
- Foil blocks it from escaping around the steel
- Sheets help make proper contact for ground

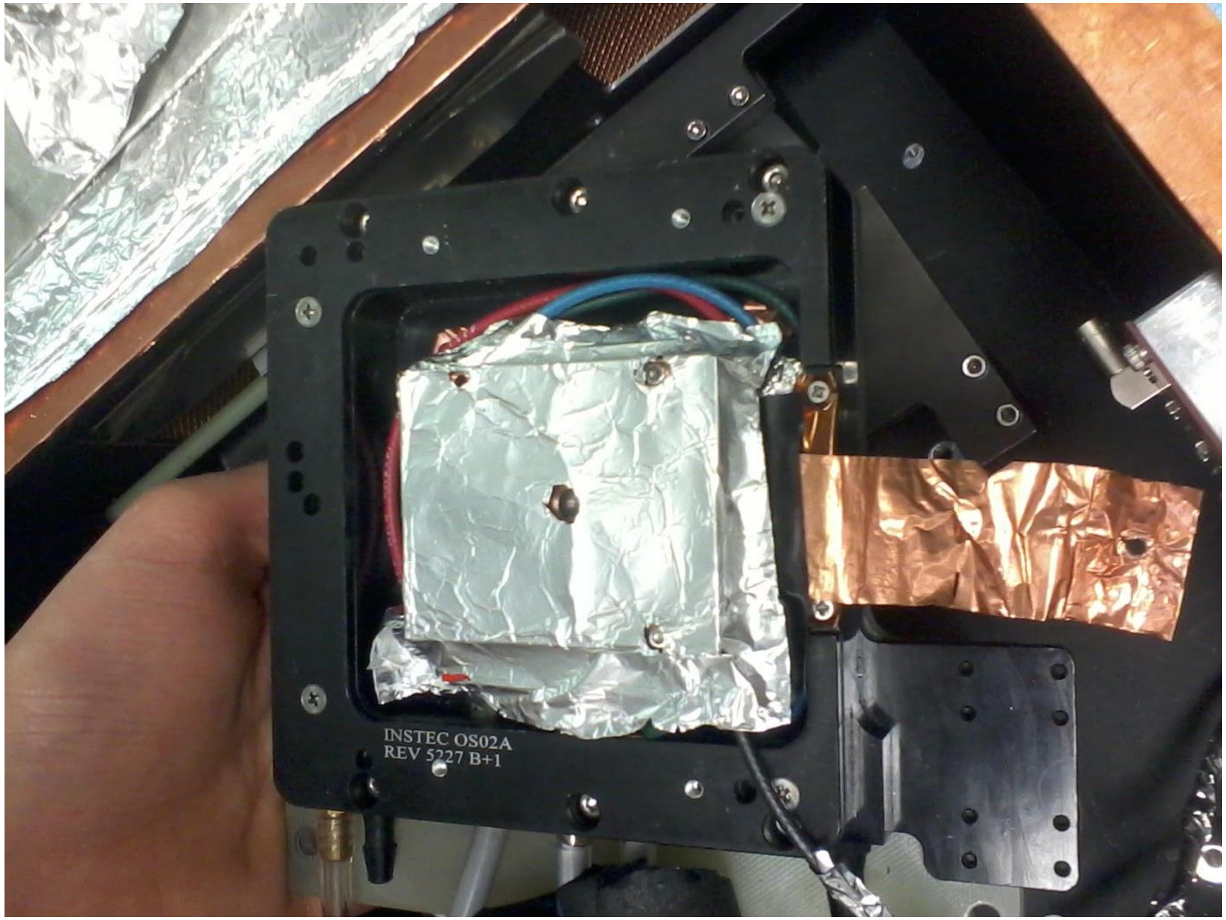
Setup – Shielding – Air Vents

- Air vents between section divider are covered with a copper mesh to block radio waves

Setup – Shielding – Copper Tape

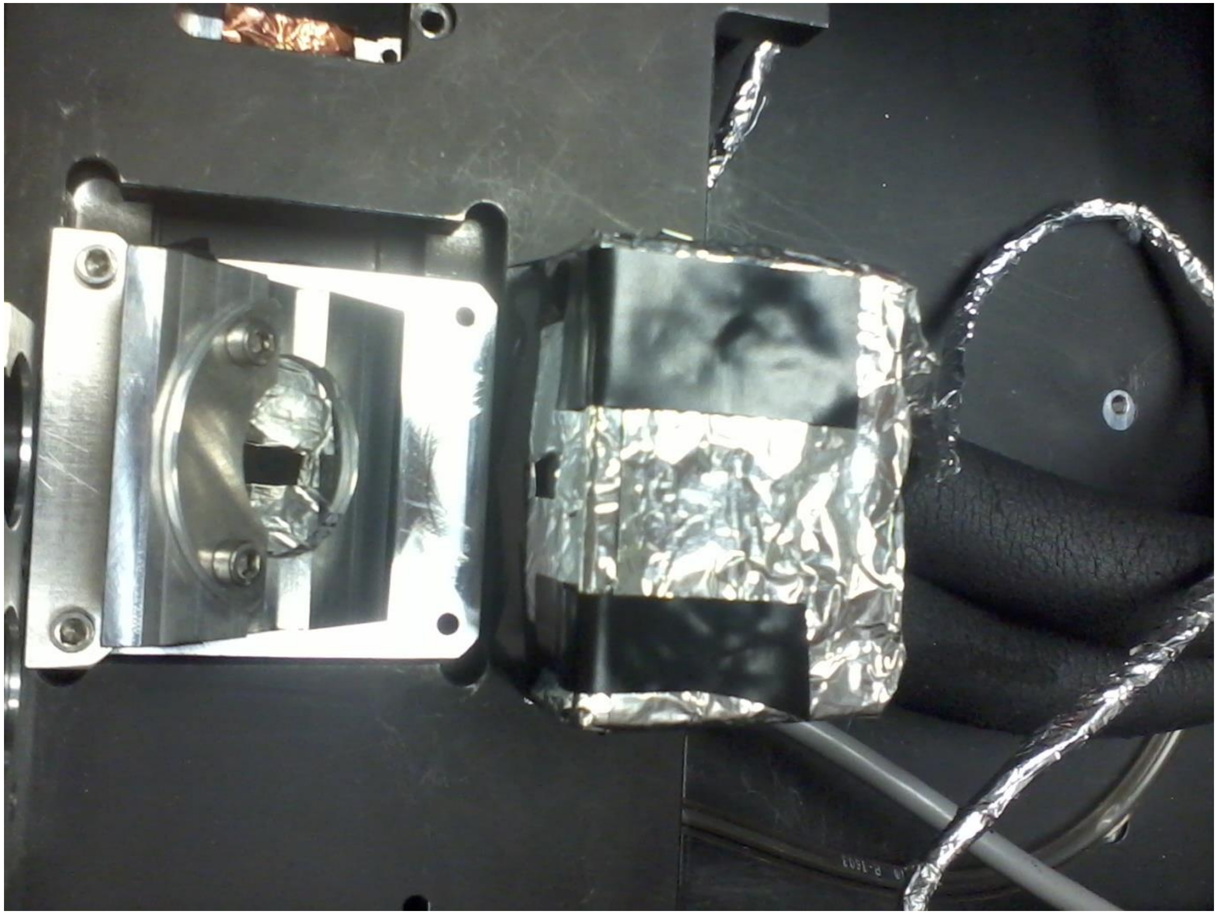
- Perimeter of box and lid covered in copper tape
- Beneath copper tape on lid is insulating tape to prevent leakage of radio waves into lid
- If radio waves leak into lid, lid will transmit them to amplifier

Setup – Shielding – Bottom Detector



- Copper plate sits over bottom detector
- Aluminum foil covers areas not covered by plate

Setup – Shielding – Top Detector



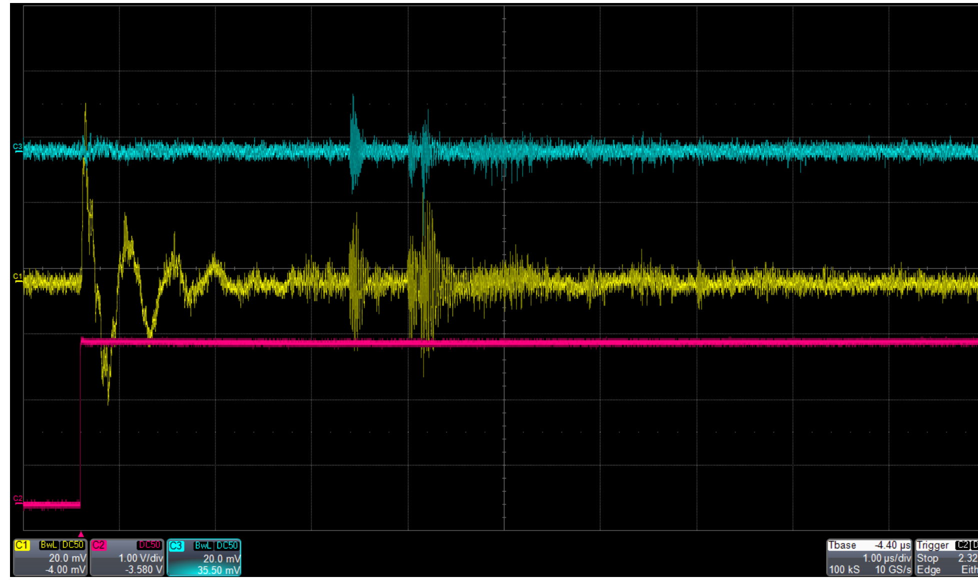
- Reference detector sits behind collimator
- Faraday cage of foil around stand

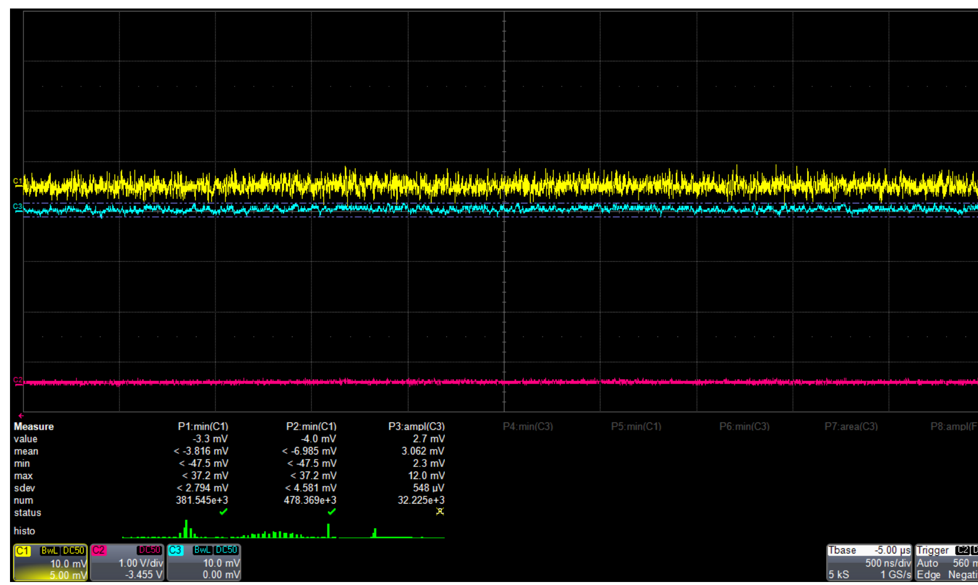
Setup – Shielding – Cables

- Internal shielding of cables seems insufficient
- Shielding supplemented with foil around cables
- Significant reduction in noise with this shielding

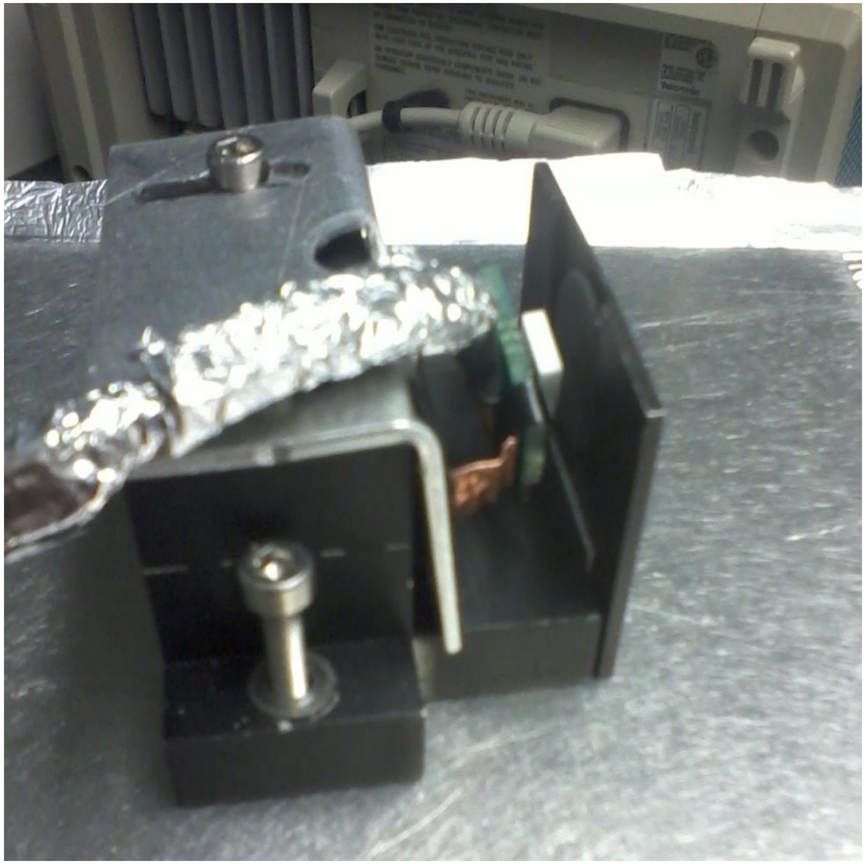
Setup – Grounding

- Oscillations attributed to lack of ground
- Solved by grounding detectors
- Faraday cages also require grounding





Setup – Grounding – Detectors



- Copper tape provides proper grounding for bottom detector
- Copper tape provides additional grounding for top detector

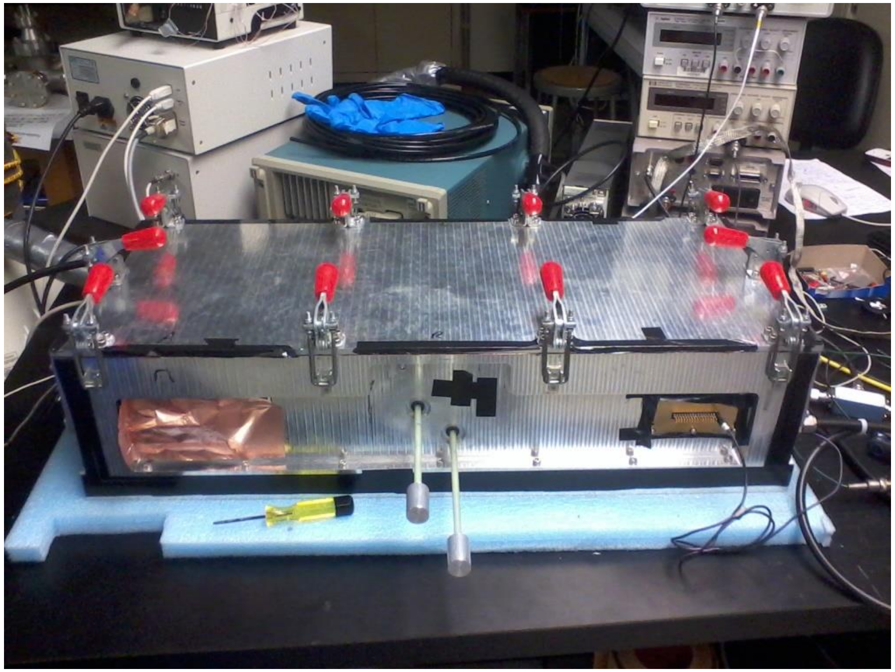
DAQ – Lamp

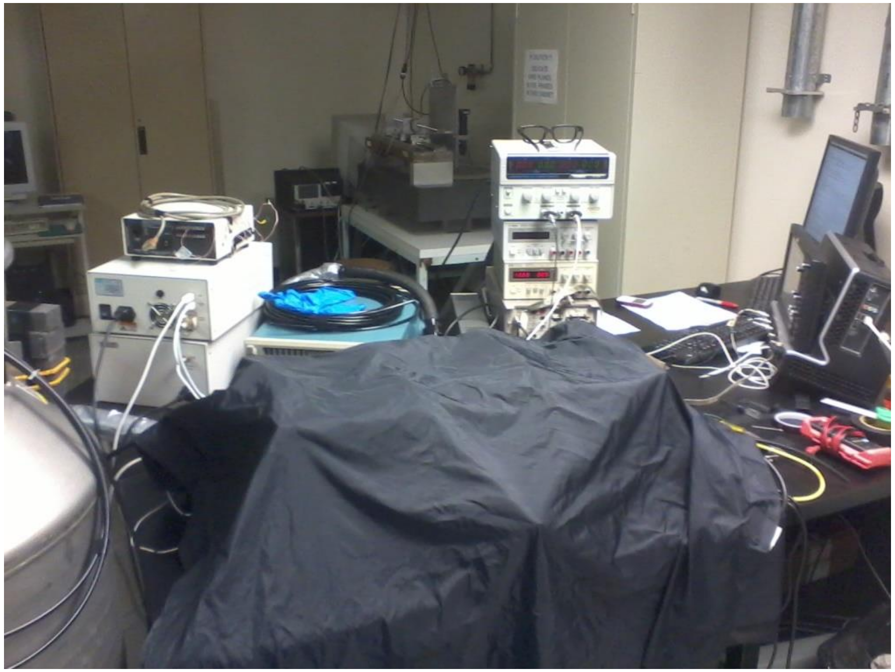
- Lamp position is set at a fixed distance
- Position marked with felt pen
- Voltage remains unchanged at 2.8V
- Lamp triggers externally
- 10μs pulse every 10ms

DAQ – Alignment

- Reference detector placed in front of collimator
- Alignment of reference ensured through use of small flashlight
- Reference detector not moved after initial alignment
- Bottom detector aligned if centred relative to hole in copper plate

DAQ – After Alignment



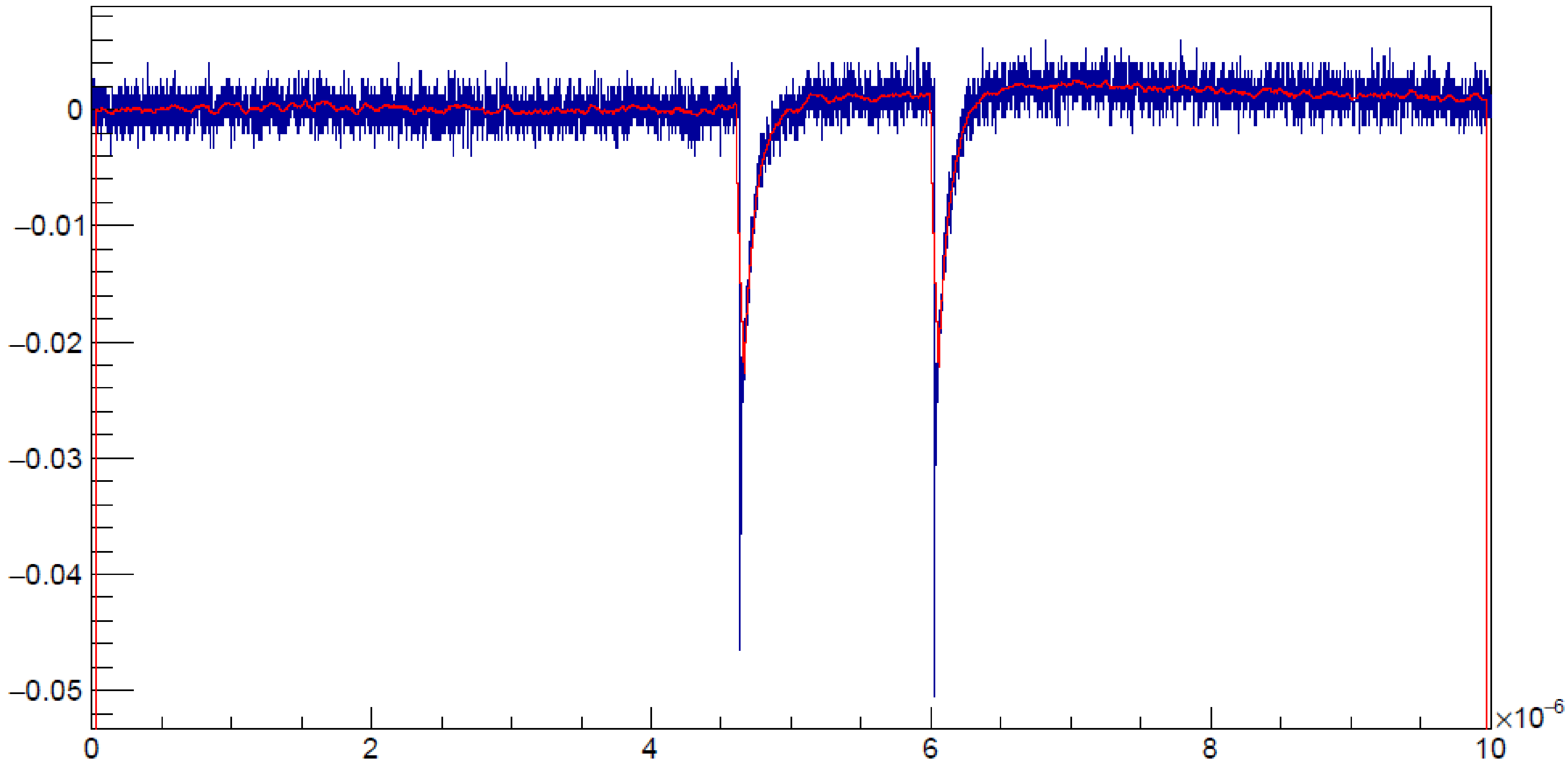


- Lid placed on box and latched
- Black cloth used to block any light leaks
- Nitrogen vented into box
- Cooling system started
- Lamp turned on

DAQ – After Cooling

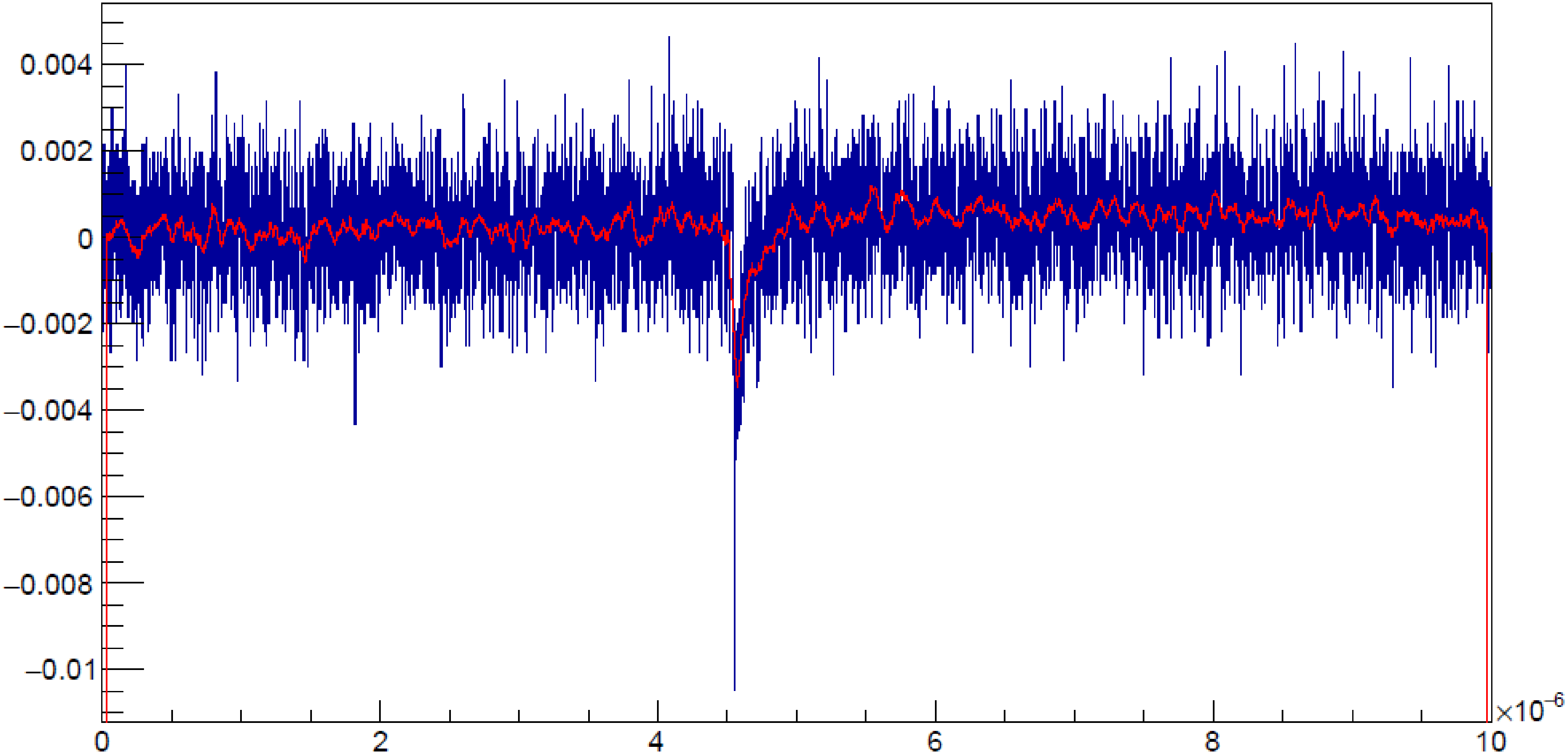
- SiPM and amplifier power supplies turned on
- Lecroy oscilloscope reads output from amplifiers and lamp trigger
- Python program fetch.exe records the two amplifier waveforms in HDF5 format
- Bias voltage changed, and data taken again

Data – Waveforms



- Blue = raw waveform
- Red = smoothed waveform

Data – Waveforms – Smoothing



- Smoothing simplifies detection of small pulses
- Boxcar method averages 30ns before and after each point

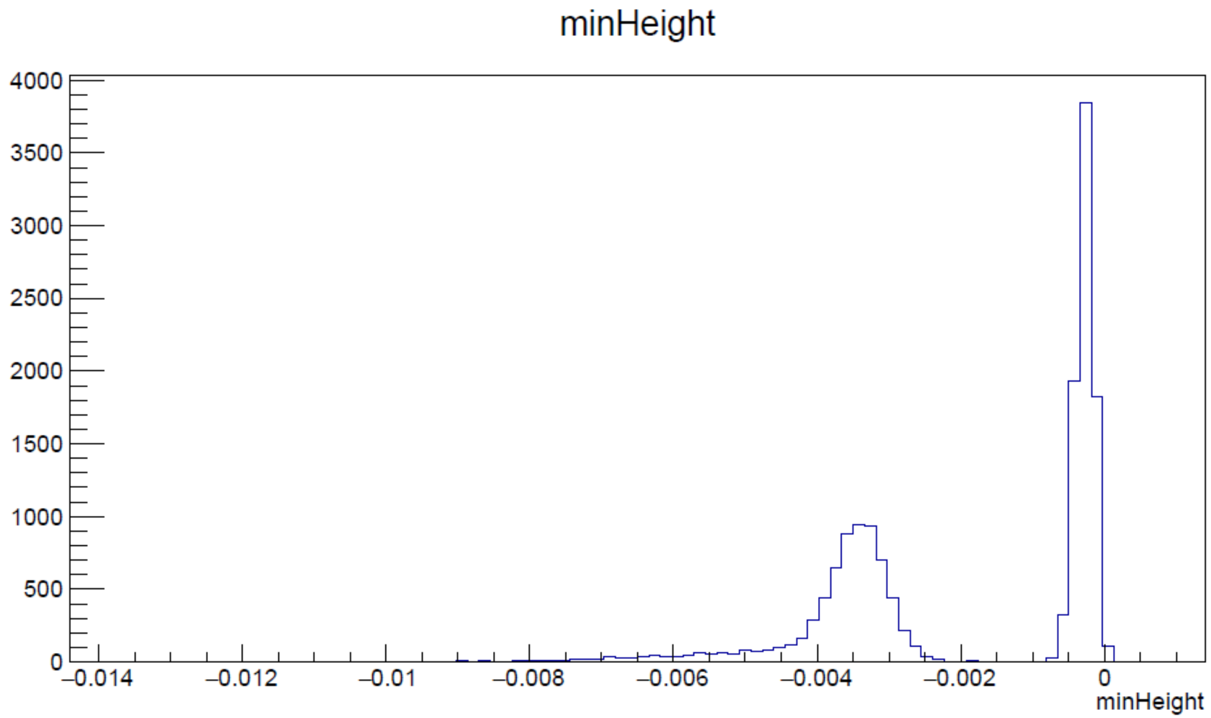
Data – WaveformProcessor

- HDF5 to ROOT interface and processor already written
- Peak finder requires great deal of tuning each time
- Problem when analyzing large variety of data
- Peak finder re-written to require less tuning

Data – WaveformProcessor – Pulse Finder

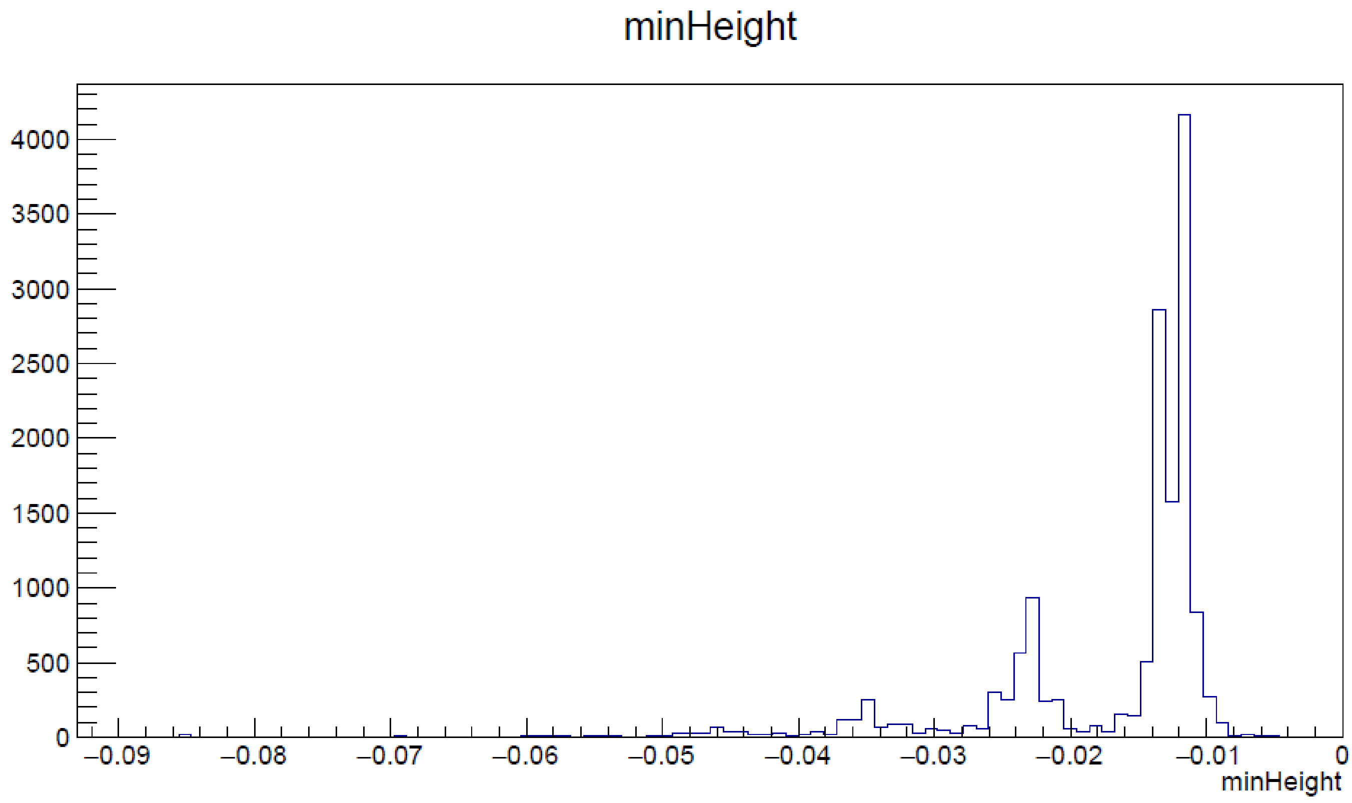
- Calculate baseline mean and std. dev.
- Use multiple of std. dev. to find pulses
- Record pulse height, charge, and width
- Can use this to remove false detections
- One version of pulse finder skips 120ns ahead of each peak before looking for next peak

Data – efficiency.exe



- Front end for processing runs
- Contains many switches for easy runtime configuration
- Waveform divided into “light” and “dark” regions
- Finds minimum (for negative pulses) in each region to find number of zeros
- Also runs peak finder

Data – fillNtp.exe

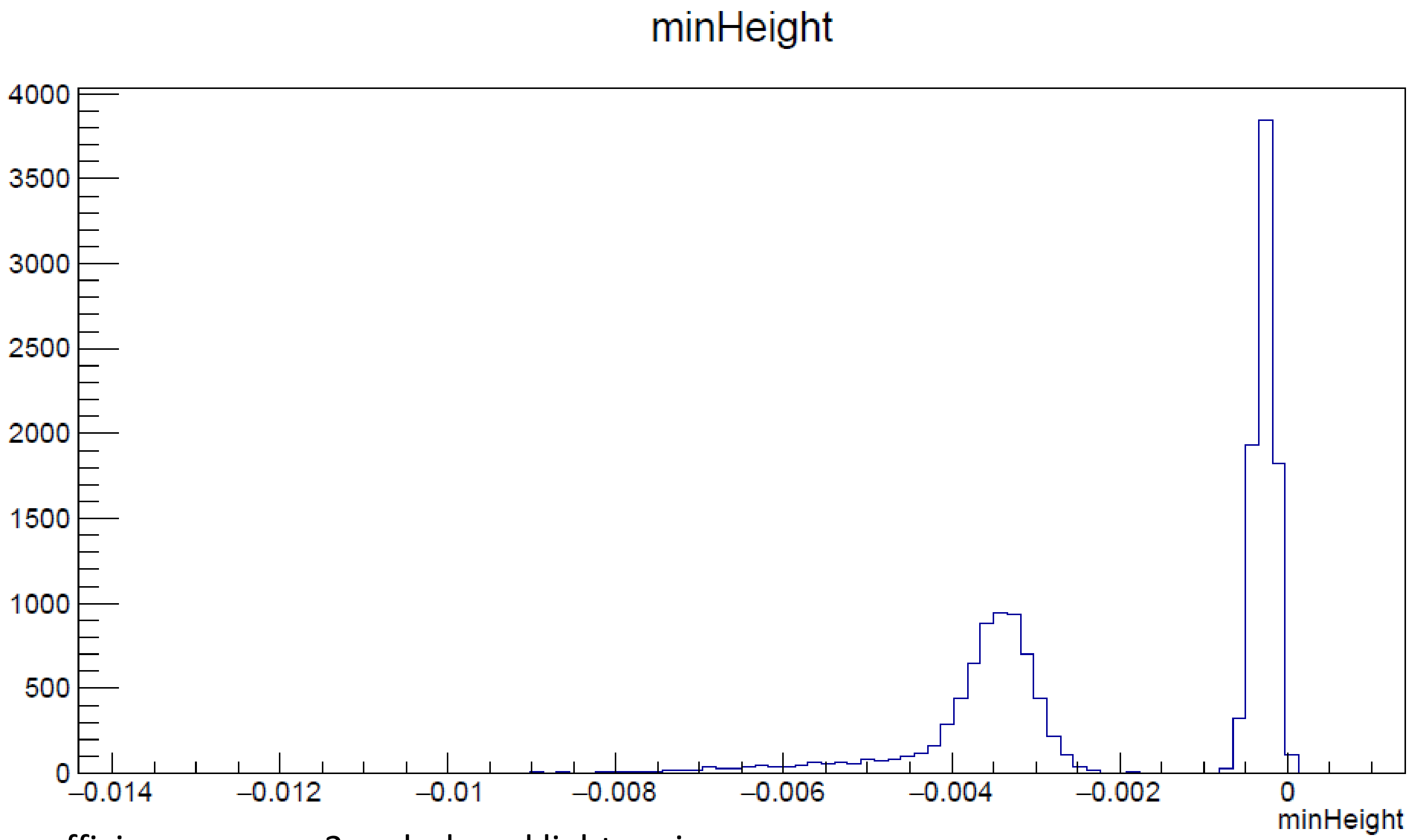


- Scans specific region of waveform for peaks
- Does not separate waveform into sections
- Records minimum of region and runs peak finder

Data – NormGain.exe

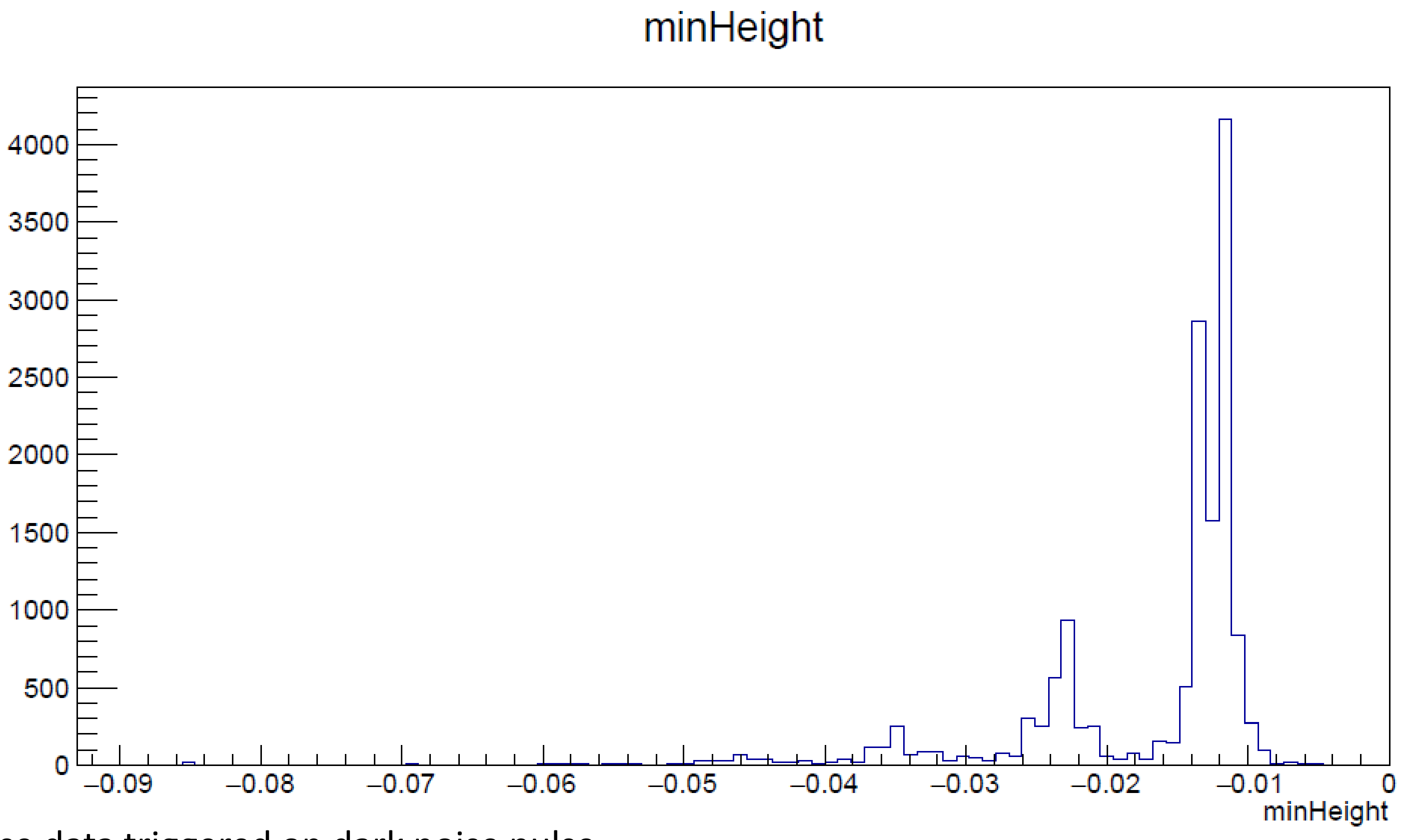
- Automatically measures the gain of the normalization detector
- Runs pulse finder over entire waveform
- Only records well separated pulses to preserve normal amplitude dist.
- Records amplitude hist.
- Fits 1PE peak and returns mean and sigma

Analysis – <PE>



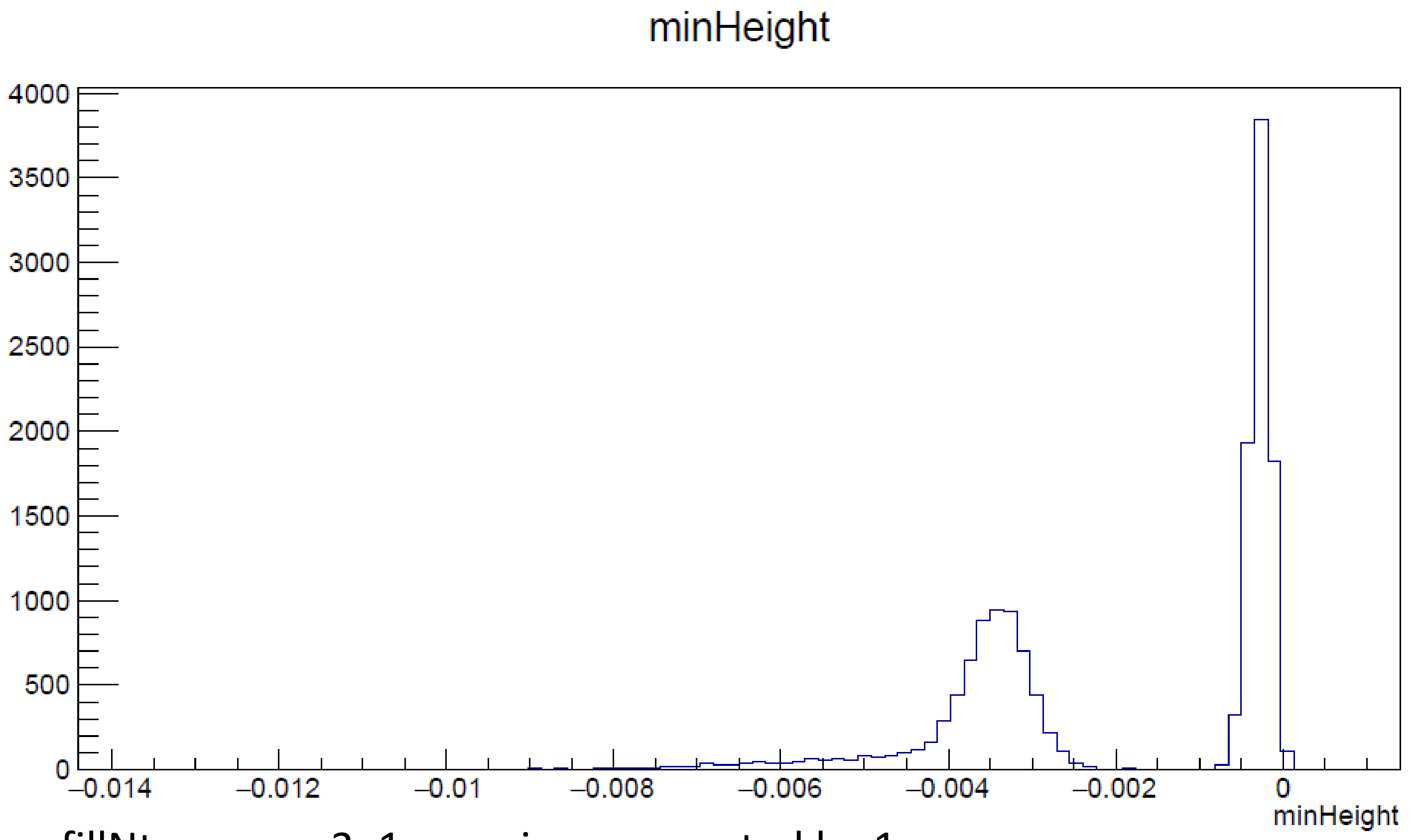
- Run efficiency.exe on 3µs dark and light regions
- Integrate 0PE peak manually for each region (15000 waveforms)
- **<PE> = LN(D0/L0) / 3**
- PD0 = D0 / 15000; PL0 = L0 / 15000
- ΔPD0 = SQRT(PD0 * (1-PD0) / 15000)
  ΔPL0 = SQRT(PL0 * (1-PL0) / 15000)
- **Δ<PE> = SQRT((ΔPD0 / PD0)^2 + (ΔPL0 / PL0)^2) / 3**

Analysis – <CT>



- Use data triggered on dark noise pulse
- Run fillNtp.exe on 200ns region in centre of waveform
- Integrate 1PE peak manually (15000 waveforms)
- **<CT> = LN(15000/PE1)**
- PPE1 = PE1 / 15000
- ΔPPE1 = SQRT(PPE1 * (1-PPE1) / 15000)
- **Δ<CT> = ΔPPE1 / PPE1**

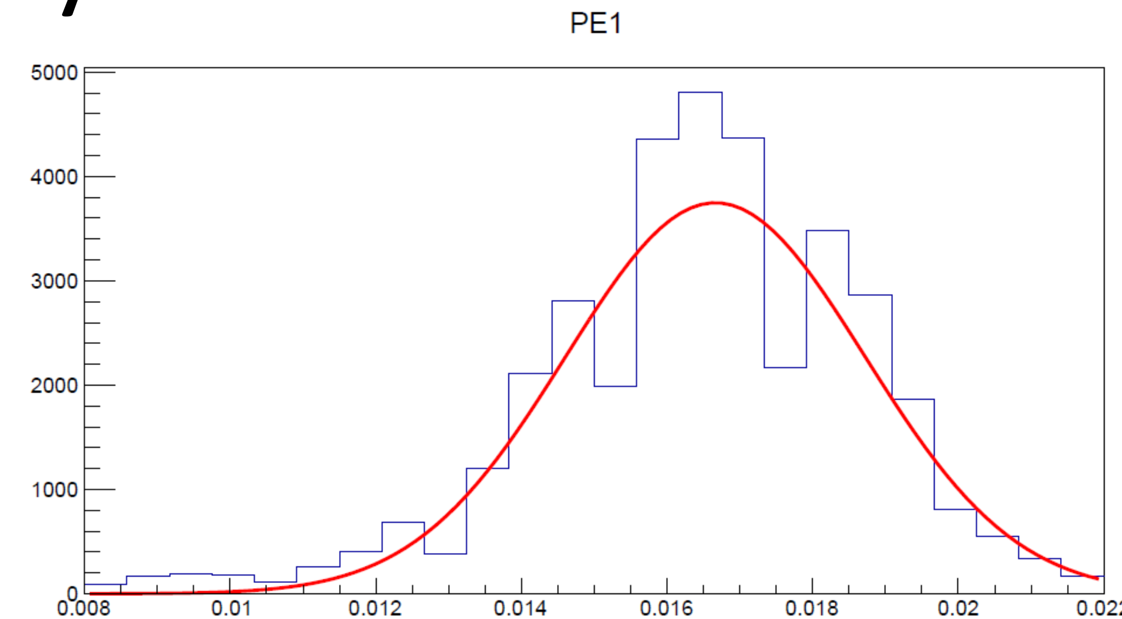
Analysis – <DN>

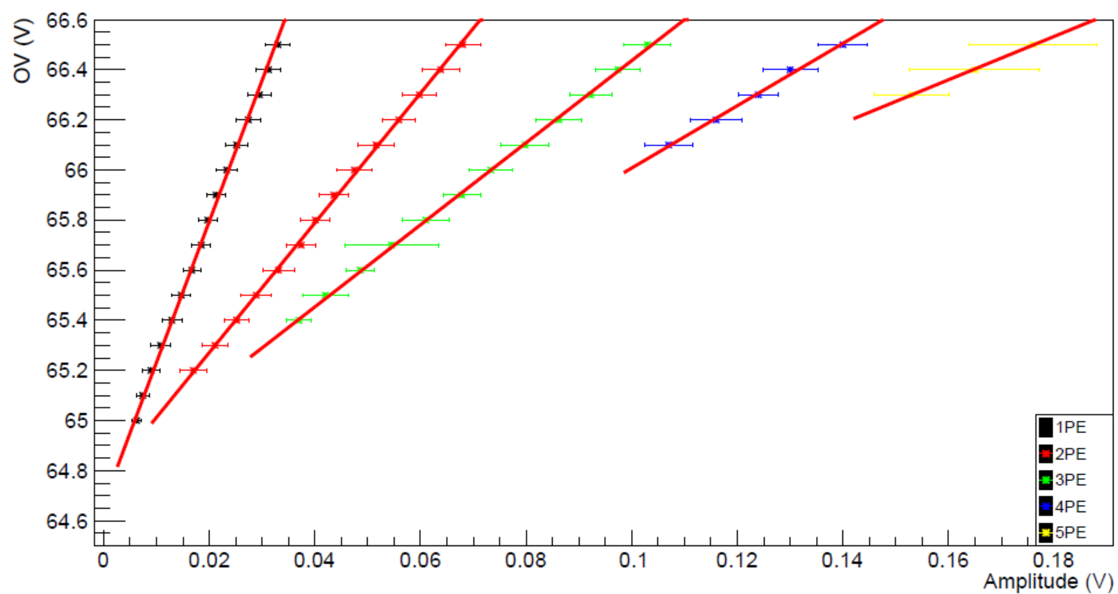


- Run fillNtp.exe on 3, 1µs regions separated by 1µs
- Integrate 0PE peak manually for each region (15000 waveforms)
- **<DN> = LN(D0 / (3 * 15000))**
- PD0 = D0 / 45000
- ΔPD0 = SQRT(PD0 * (1-PD0) / 45000)
- **Δ<DN> = ΔPD0 / PD0**

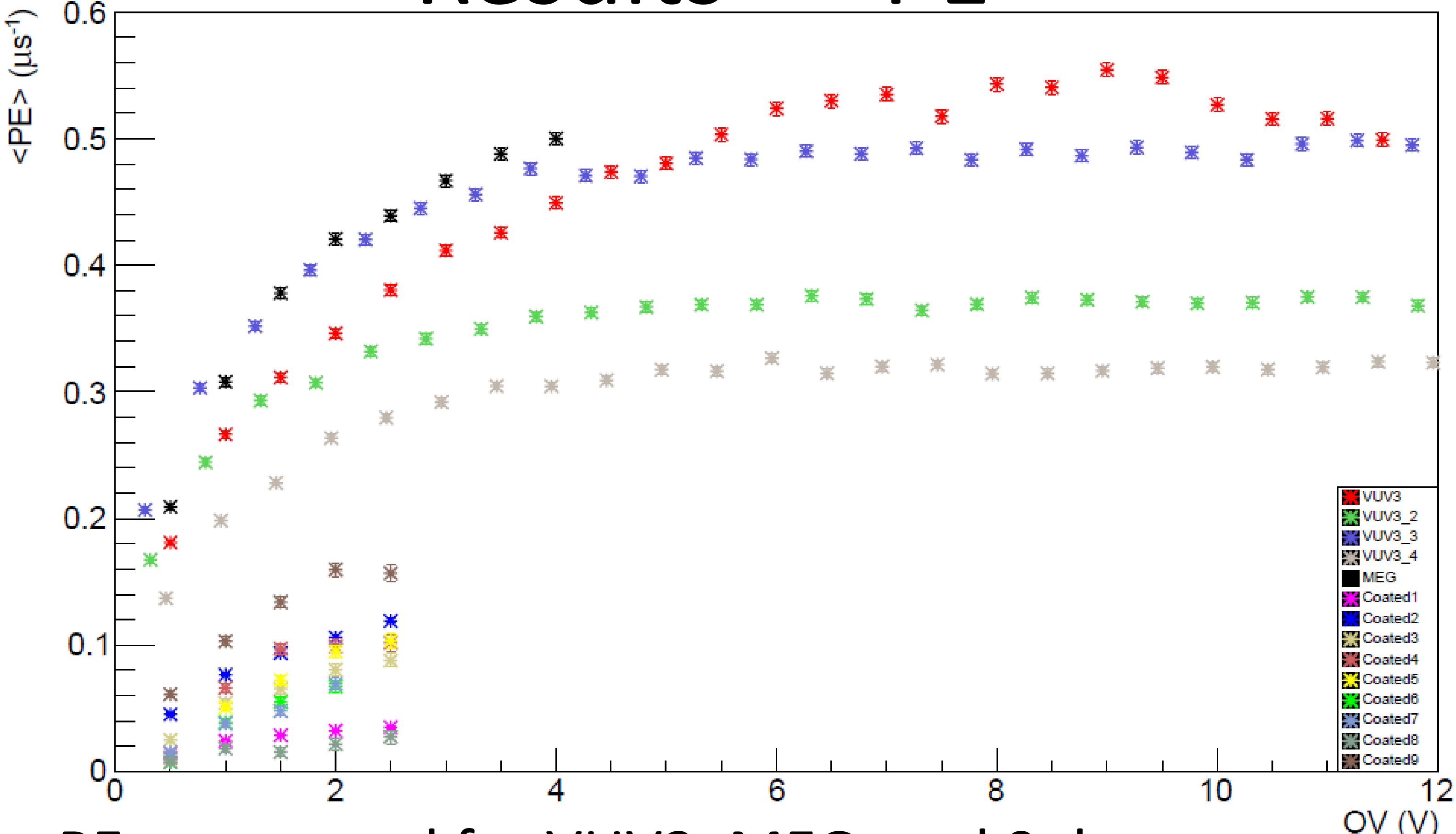
Analysis – Gain

- Run peak finder on entire waveform
- Find 1PE peak manually and fit it
- Record mean and sigma
- Repeat for each bias voltage
- Fit to get breakdown voltage
- Repeat for other PE peaks
- NormGain.exe automates this, as 1PE peak is normally the largest after 0PE
- Must use peak finder, not minHeight, to avoid bias in amplitude



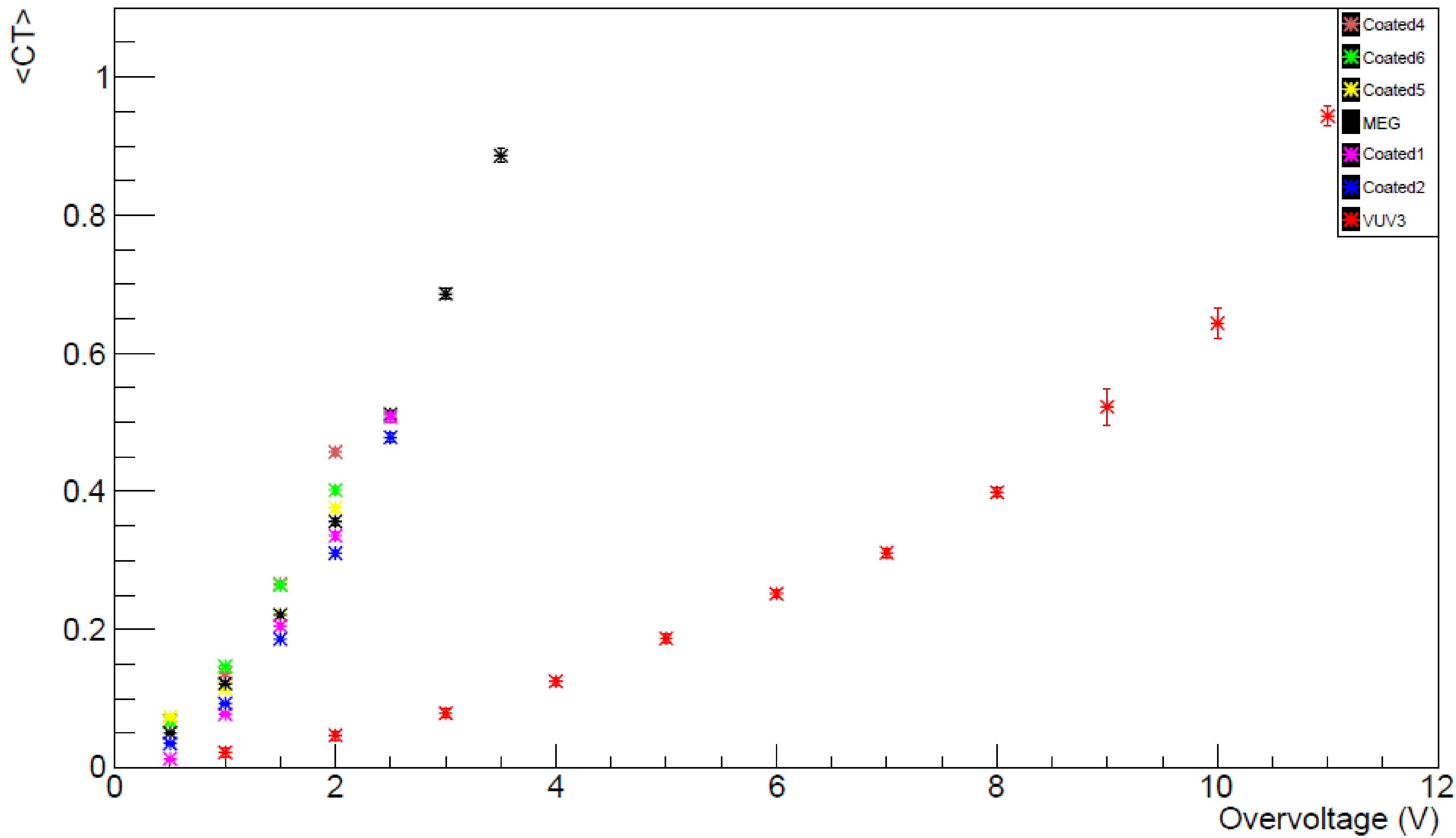


Results – <PE>



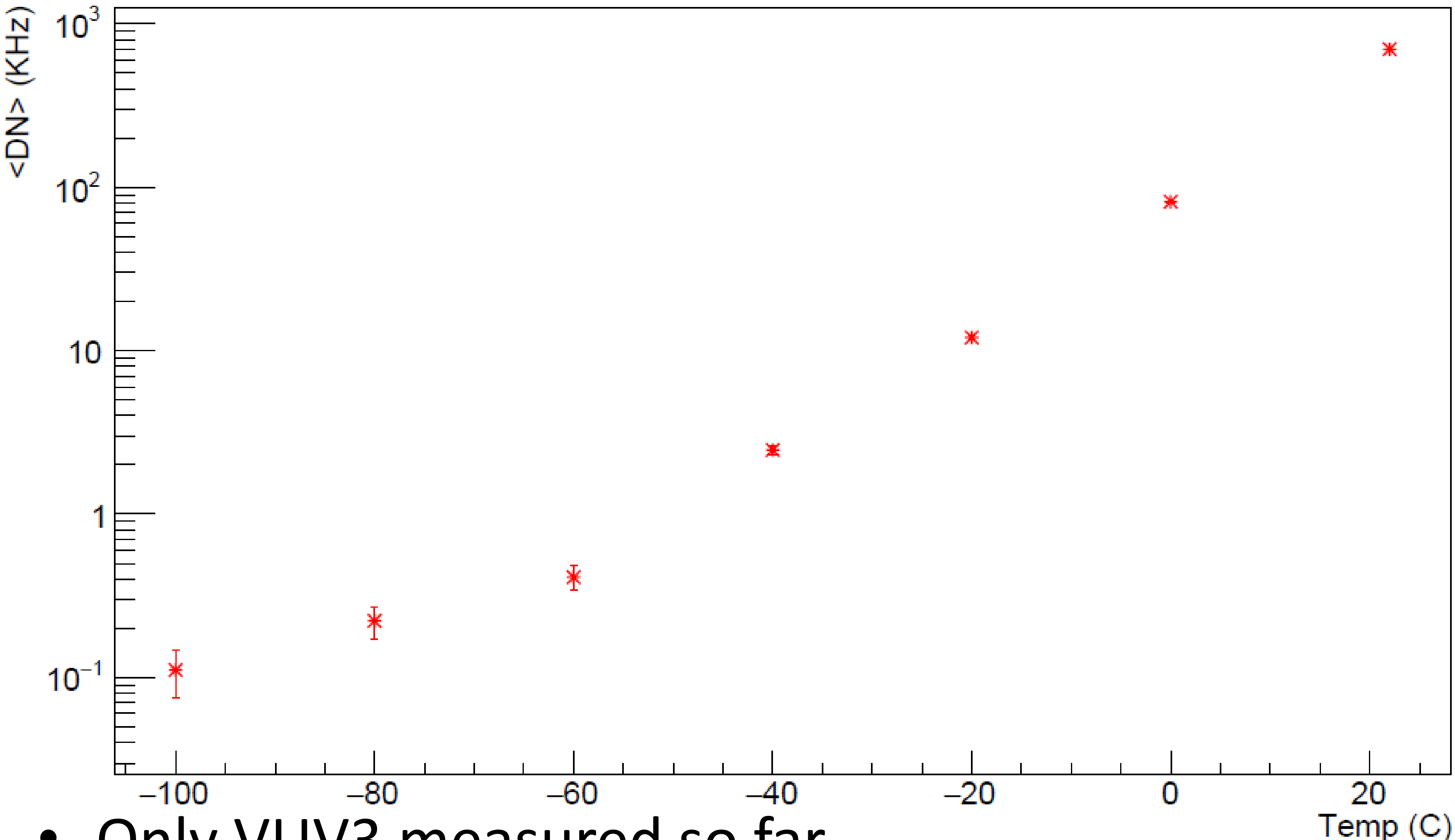
- <PE> measured for VUV3, MEG, and 9 detectors coated with wavelength shifter
- Problem with reproducibility being investigated. Dust or movement of light spot on detector are suspects.

Results – <CT>



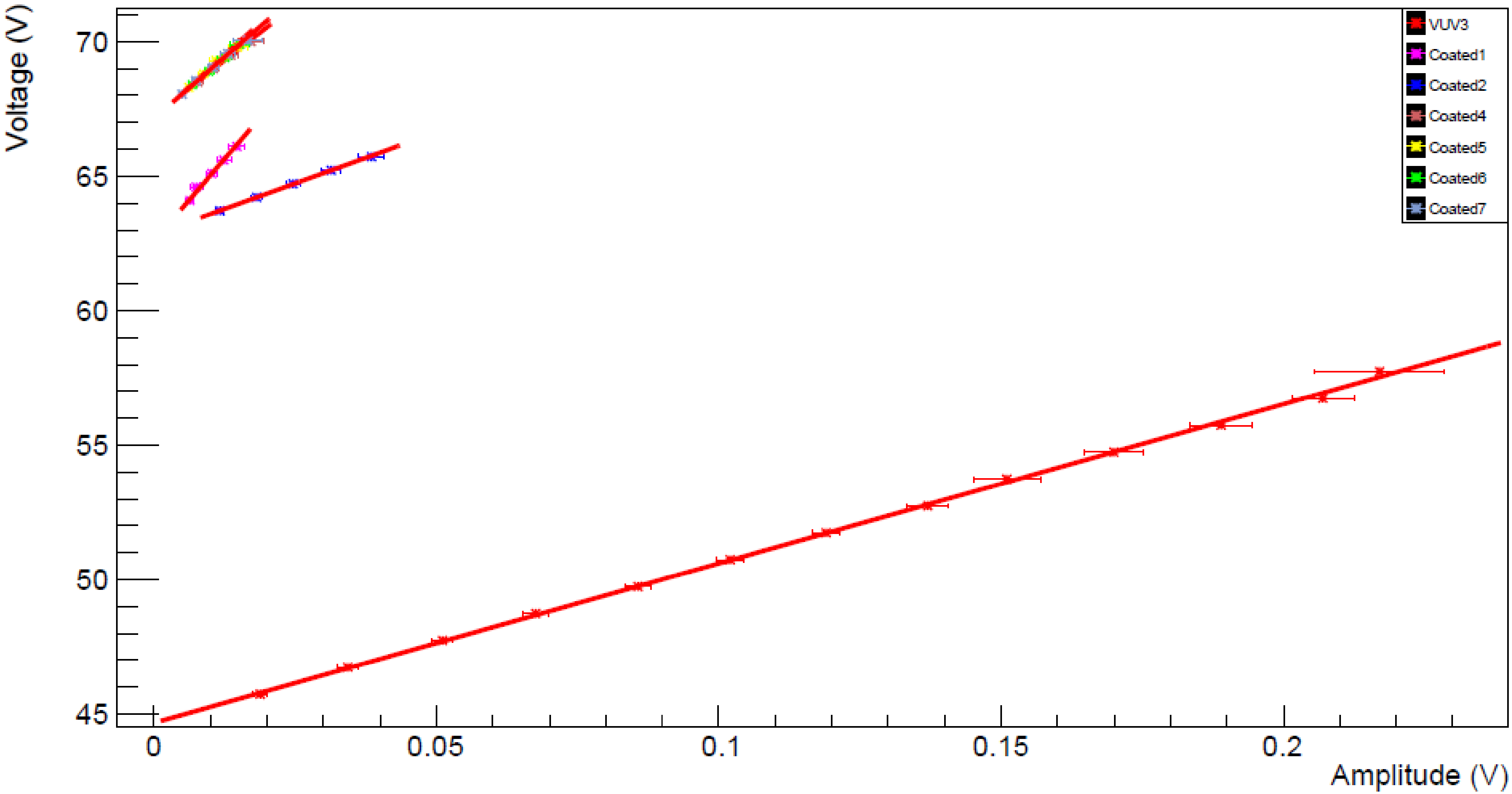
- Measured for VUV3, MEG, and 7 Coated

Results – <DN>



- Only VUV3 measured so far
- Measurement is time consuming and low priority

Results – Gain

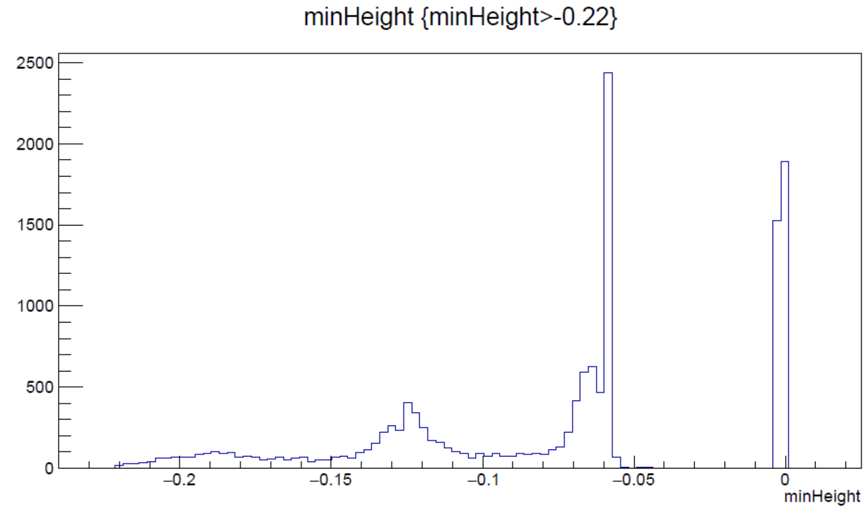


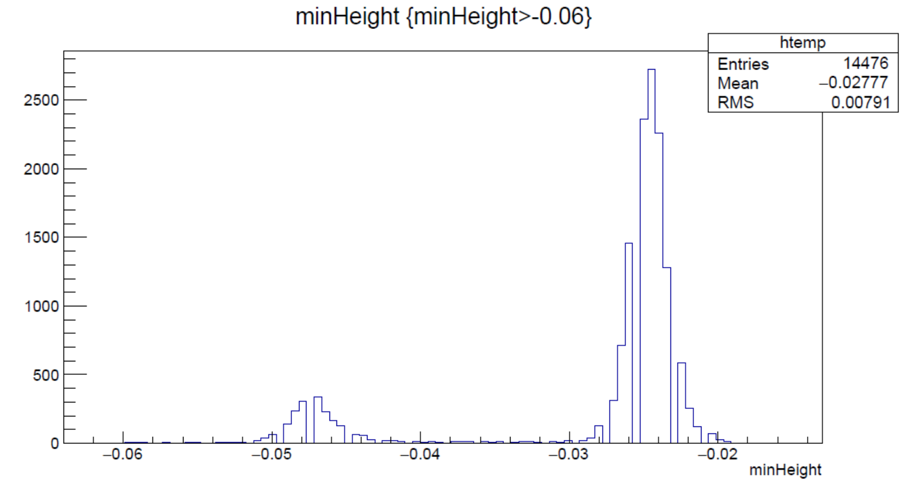
- 1PE Amplitudes at different bias voltages

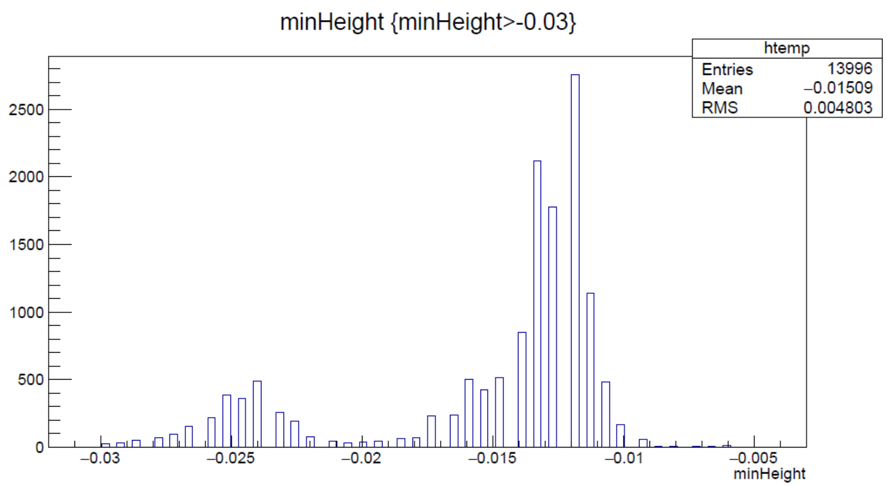
Results – Gain – Linear Fit Results

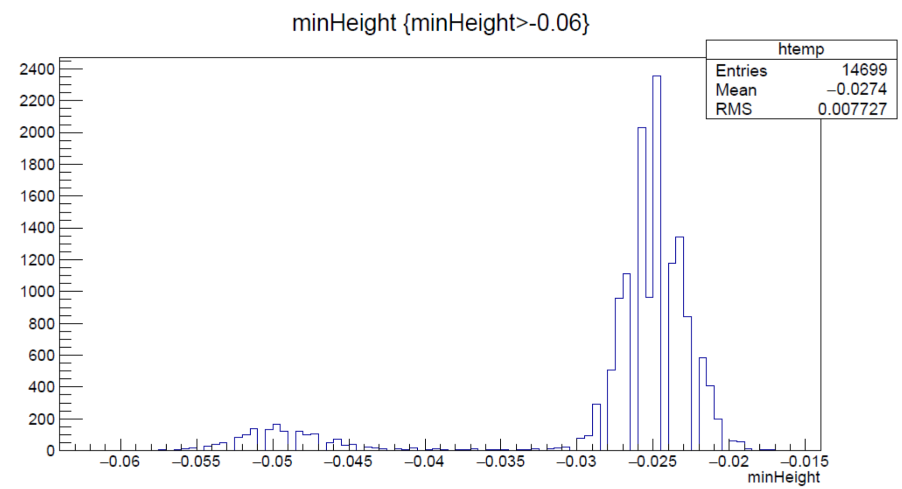
Device	Temperature (°C)	Breakdown Voltage (V)	Slope (OV/Amplitude)
VUV2	22	64.67 ± 0.05	56 ± 3
VUV3	-100	44.67 ± 0.07	59.3 ± 0.9
Coated1	-100	62.6 ± 0.3	2.4e2 ± 0.4e2
Coated2	-20	62.84 ± 0.09	76 ± 5
Coated4	-20	67.2 ± 0.4	1.7e2 ± 0.3e2
Coated5	-20	67.1 ± 0.2	1.9e2 ± 0.3e2
Coated6	-20	67.2 ± 0.3	1.7e2 ± 0.3e2
Coated7	-20	67.2 ± 0.1	1.8e2 ± 0.2e2

Results – <CT> – Afterpulse Problem



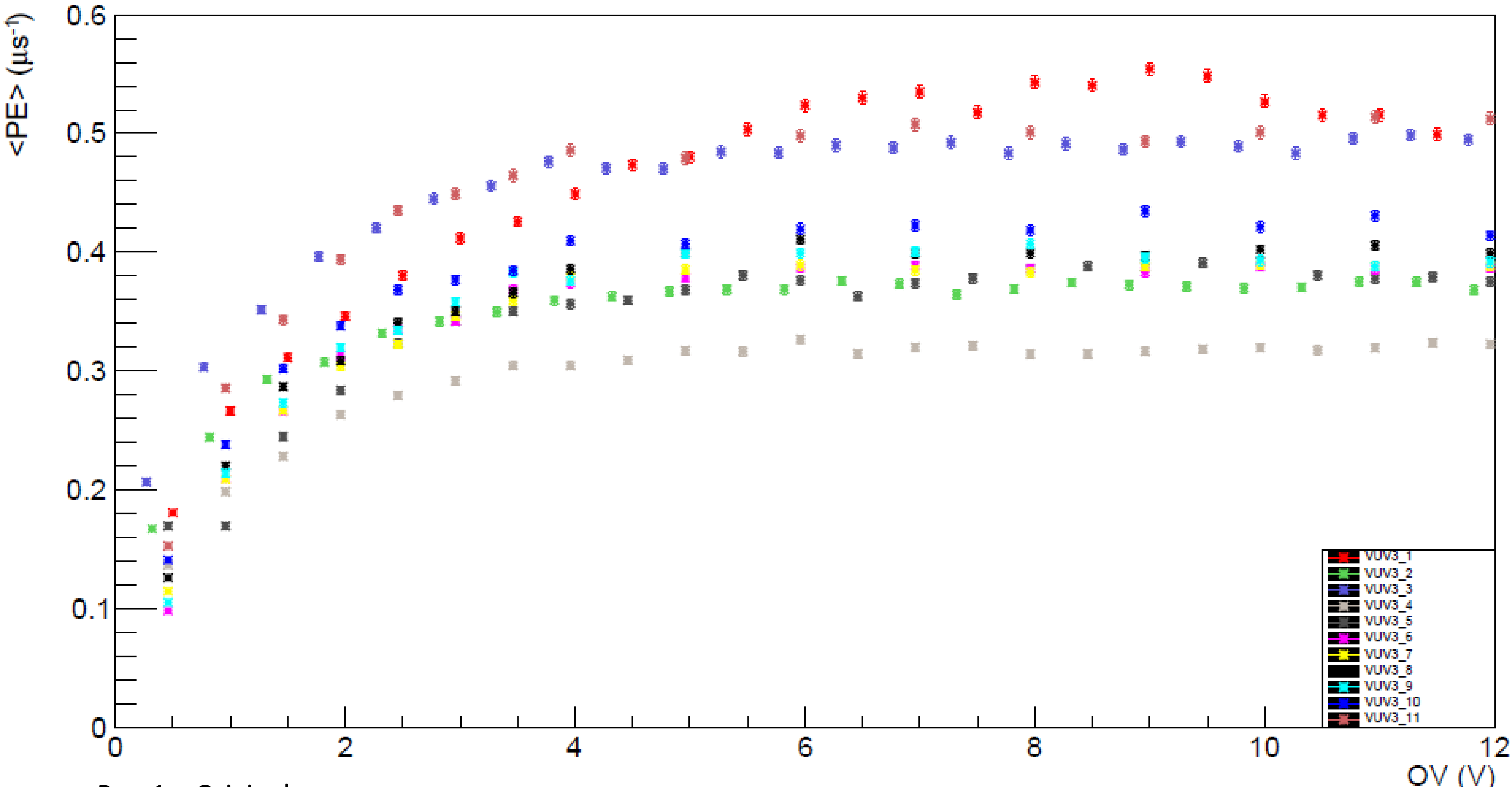






- Afterpulse a problem for some devices
- Above: VUV3, 7.3 OV, -100°C; Coated2, 1.88OV, -100°C; Coated6, 2.2OV, -20°C, VUV2, 1.33OV, room temp.
- Afterpulse interferes with proper counting of PEs

Results – <PE> – Reproducibility



- Run 1 = Original
- Run 2 = Dust on detector
- Run 3 = Dust removed
- Run 4 – 5 = Tests taken one day apart
- Run 6 – 7 = Tests done concurrently
- Run 8 – 9 = Tests done consecutively
- Run 10 = Detector blown to remove any dust
- Run 11 = Detector position changed

Summary

- Successes
  - Noise ellimination
    - Grounding
    - Shielding
  - <PE>, <CT>, <DN>, and Gain almost ready for mass testing
- Ongoing work
  - Continued improvements to code
  - Study of setup to determine cause of changes between runs
- Unresolved issues
  - <PE> fluctuates significantly between runs
    - Studying setup to solve this
  - Afterpulse
    - Will incorporate fitting into codeFuture work
  - Solve issues just described
  - Correct results
  - Take data with Ketek and FBK detectors