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Silicon Photomultiplier Performance Results and Characterization

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1. Individual Photoelectron Detection and Noise
2. Bias Voltage Measurement
3. Saturation
4. Energy Spectra
5. Timing
6. Detection of Cosmic Ray Cherenkov Images

U.S. Department of Energy

UChicago Argonne LLC

Office of Science
U.S. DEPARTMENT OF ENERGY

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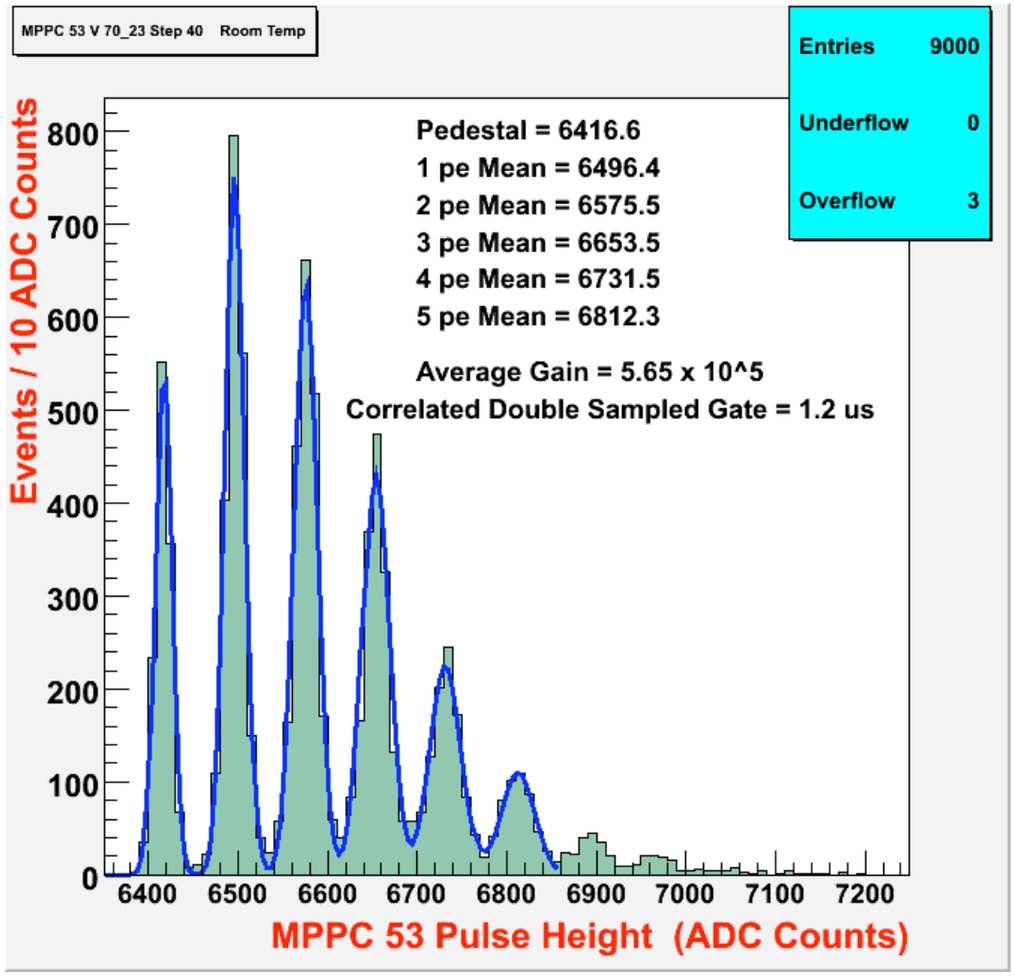
Individual Photoelectron Detection and Inferred Noise

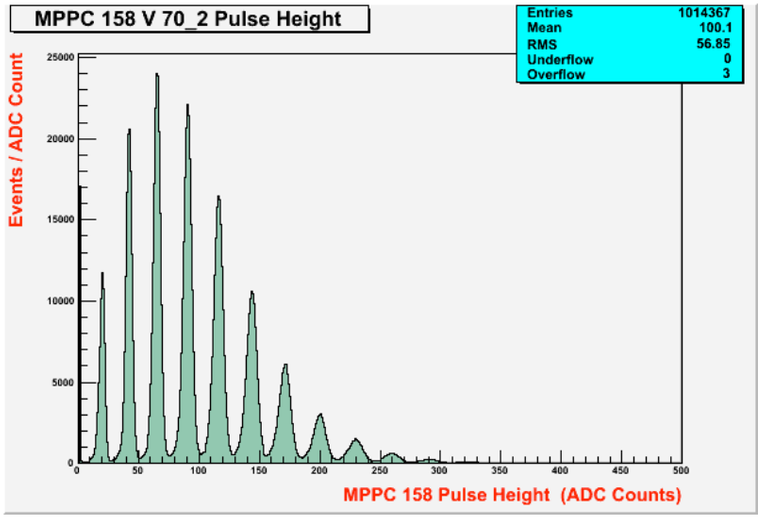
Hamamatsu 50µm Pixel MPPC



Readout via RABBIT
- Correlated double sampling system
- 1.2 µs effective gate
- 1.14 fC / ADC count

Noise is quite low as evidenced by fit of distribution to sum of 6 Gaussians w/o background contribution

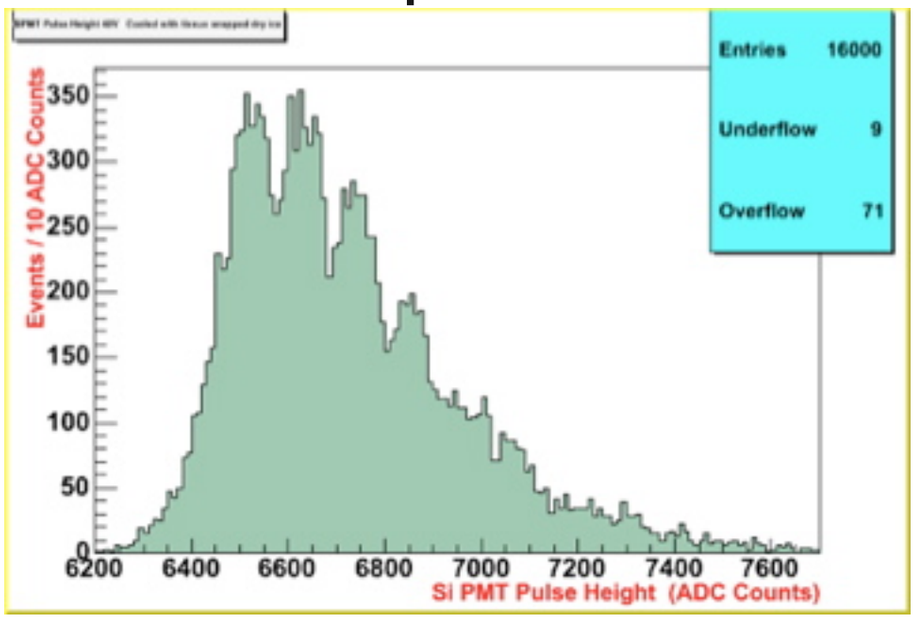
Hamamatsu 100µm Pixel MPPC



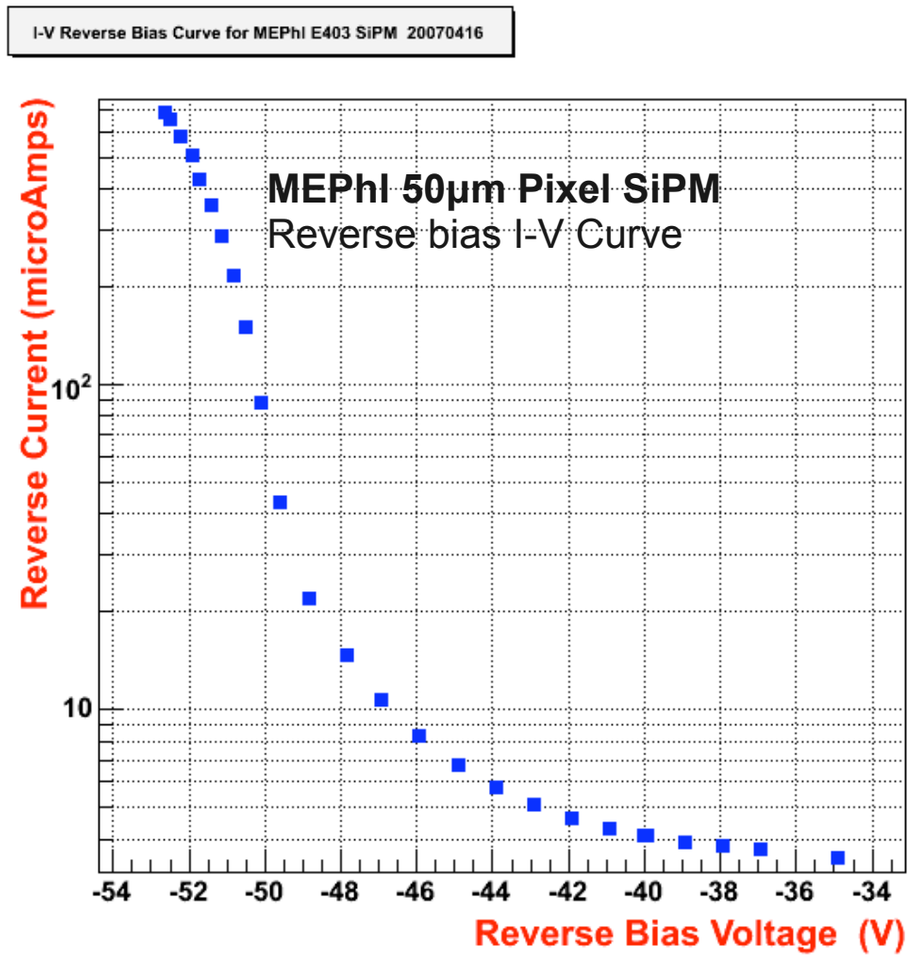
Readout via LeCroy 2229A ADC
- Raw Signal amplified by ~ x150 via Ortec 9327 amp-timing disc. → Ortec 9306 x 100 pre-amp → LeCroy 2249A
- ~15ns gate

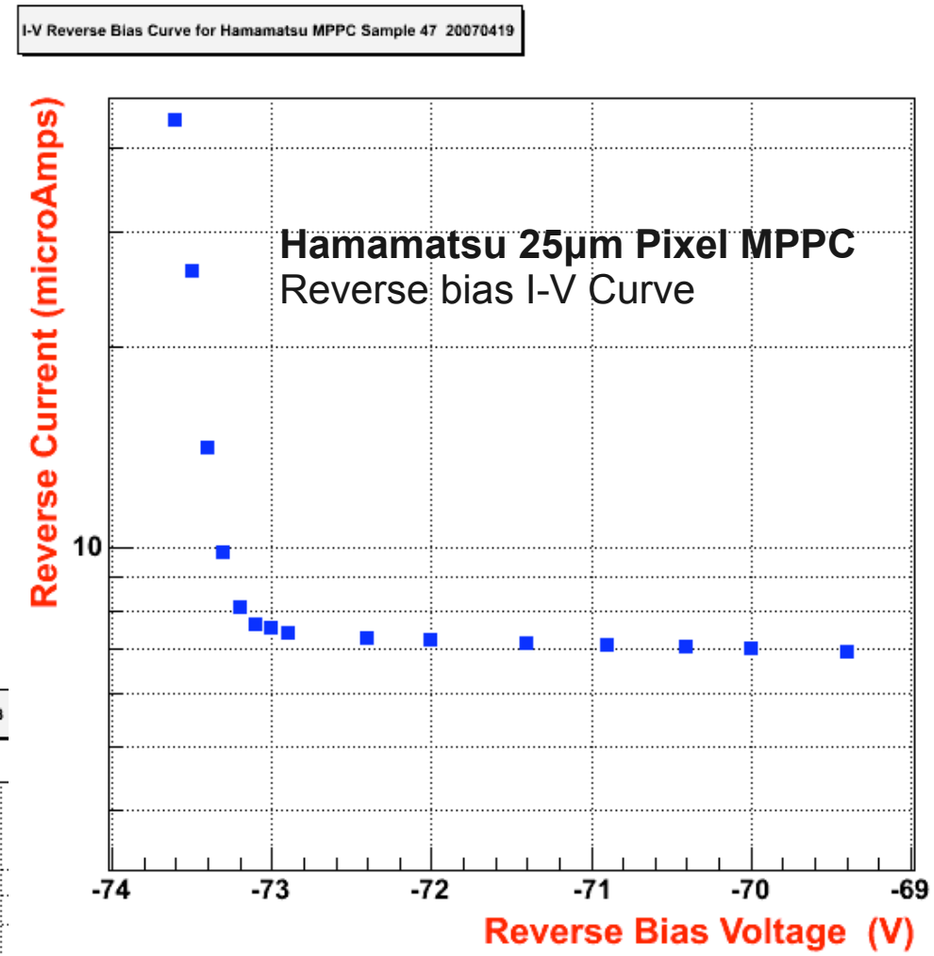
MEPhI 50µm Pixel SiPM

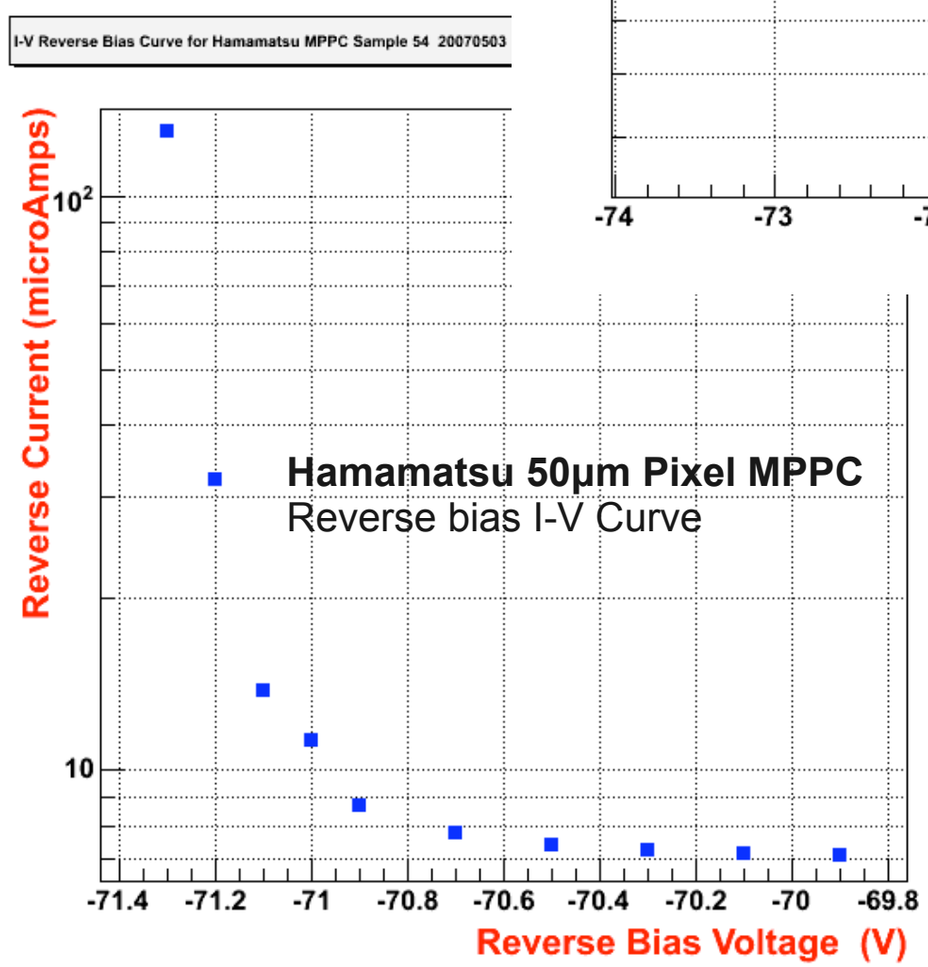
Original observation of single pe peaks with MEPhI E404 SiPM from Russia. SiPM cooled crudely with dry ice. Noise is an obvious problem



I-V Curve Measurements



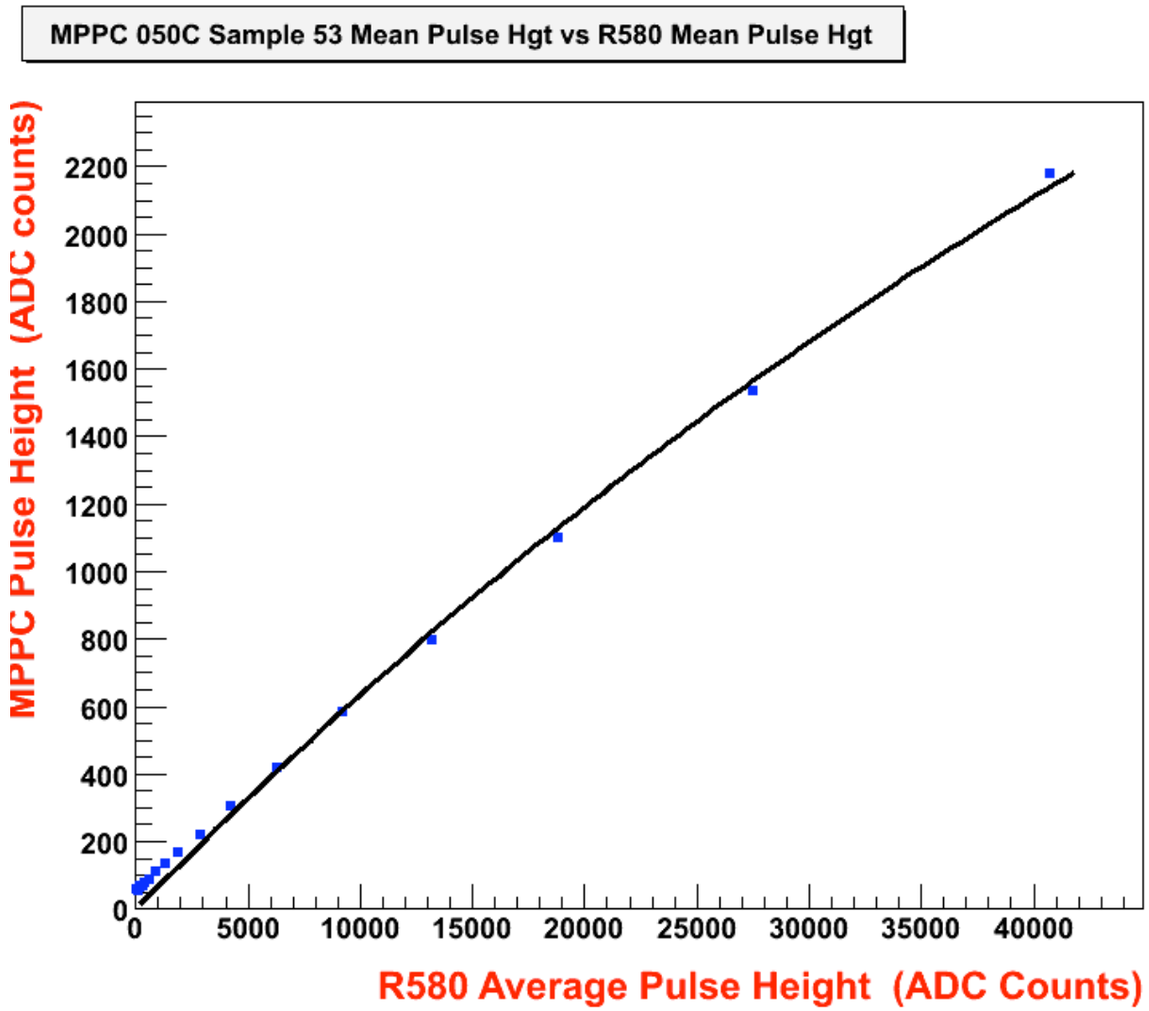


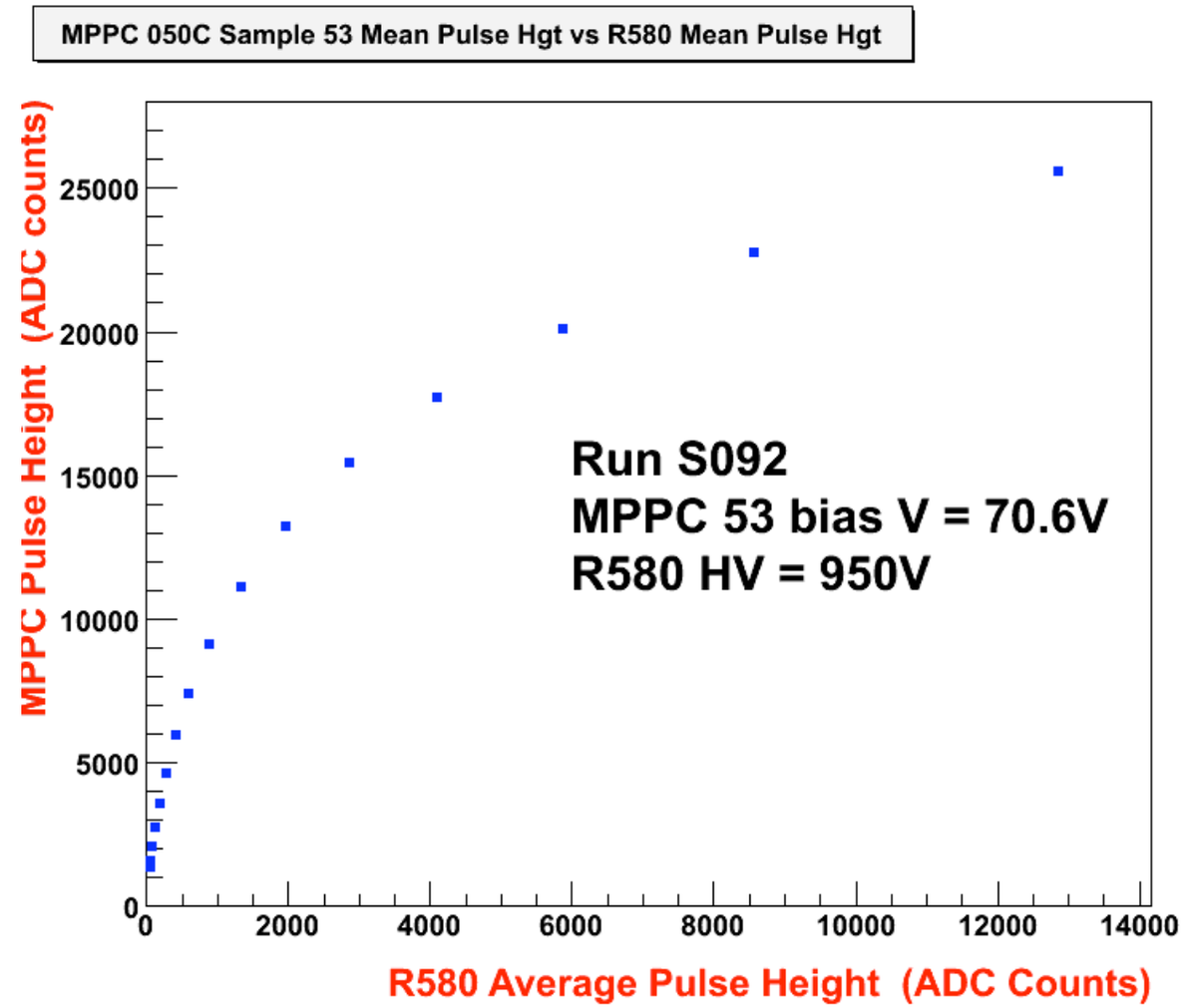


Hamamatsu MPPC have much sharper turn on than MEPhI SiPMs

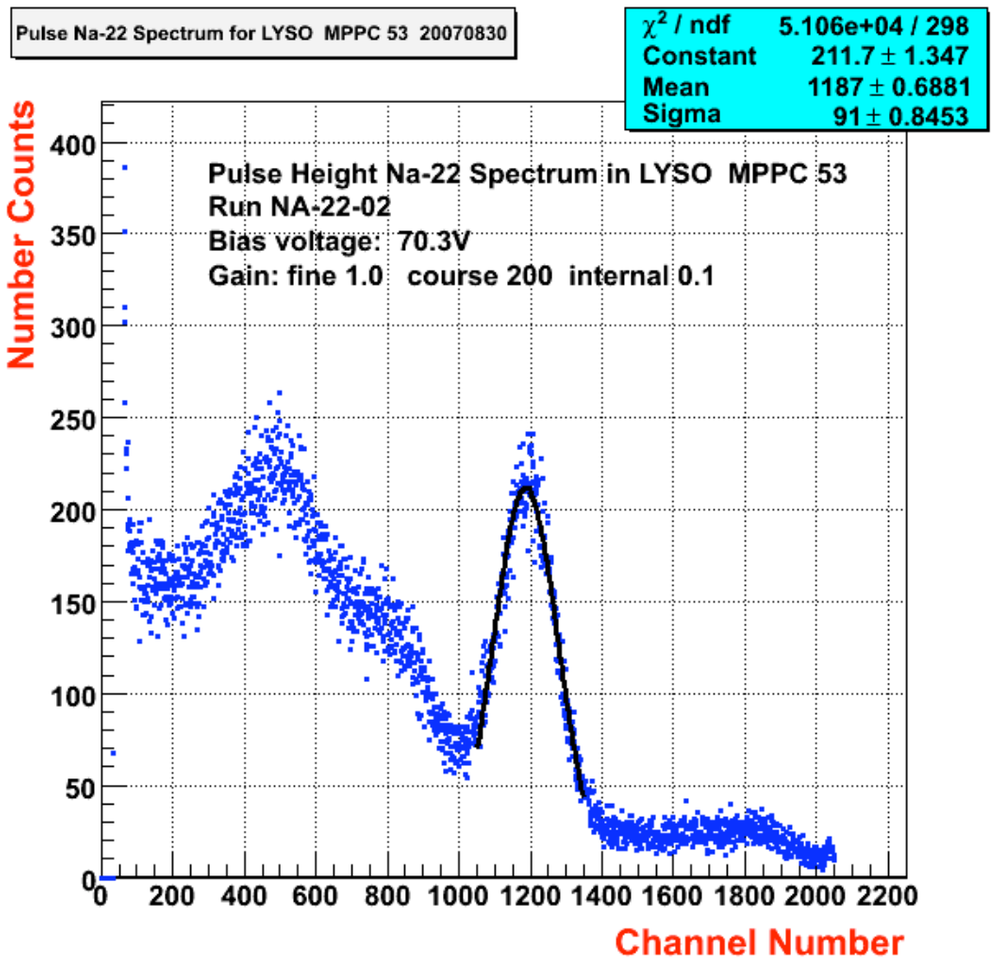
n.b. baseline current may offset due to instrument effects

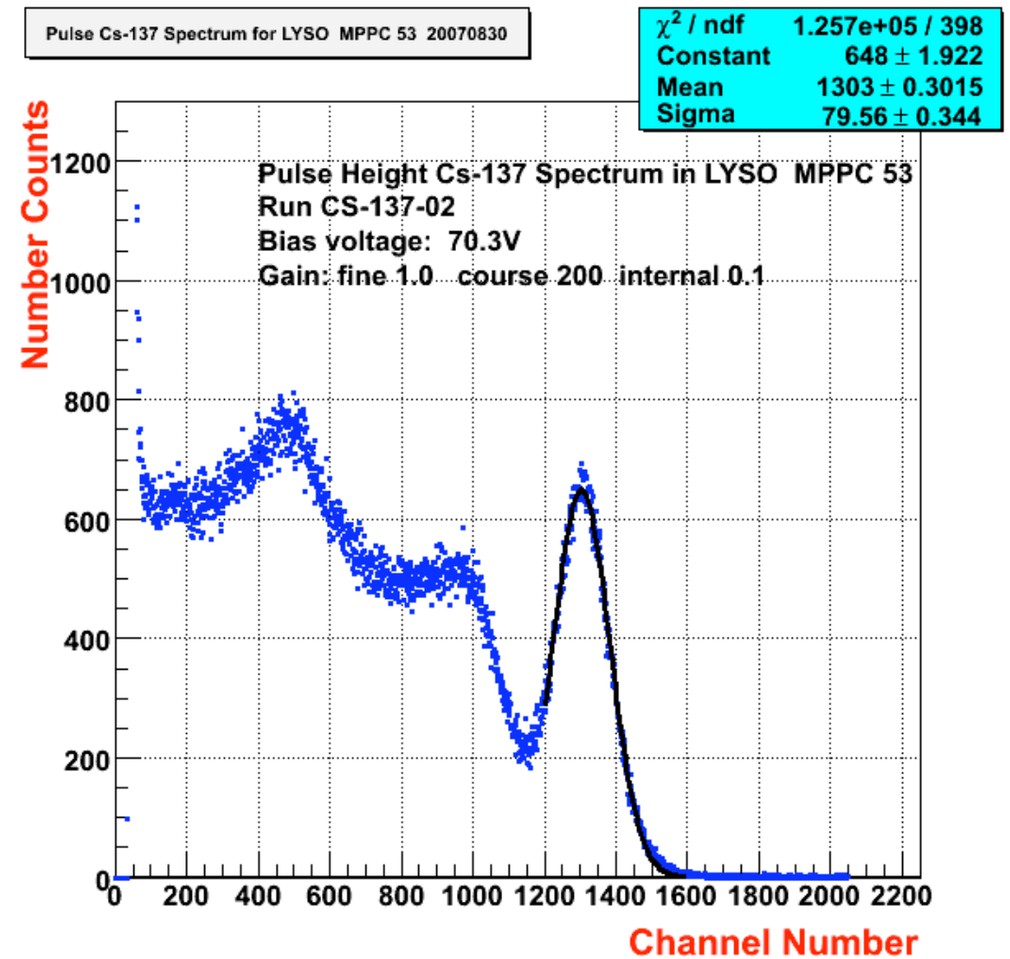
Linearity and Saturation Measurements





Energy Spectra Measurements with ^{22}Na and ^{137}Cs Sources





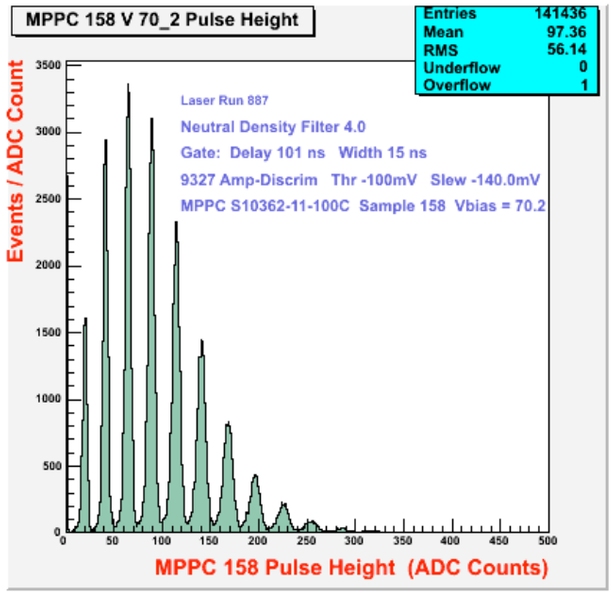
Energy Resolution FWHM 18%

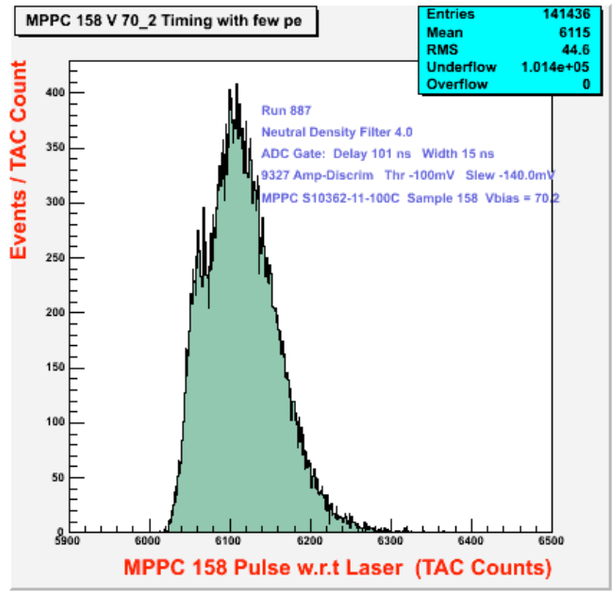
Energy Resolution FWHM 14%

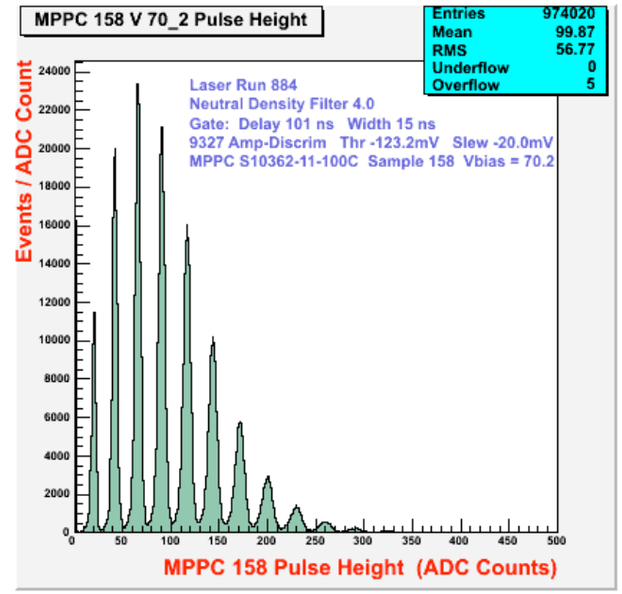
Measured with LYSO crystal 1x1x10mm^3
Source and MPPC positioned at opposite ends of 1x1mm^2 cross section

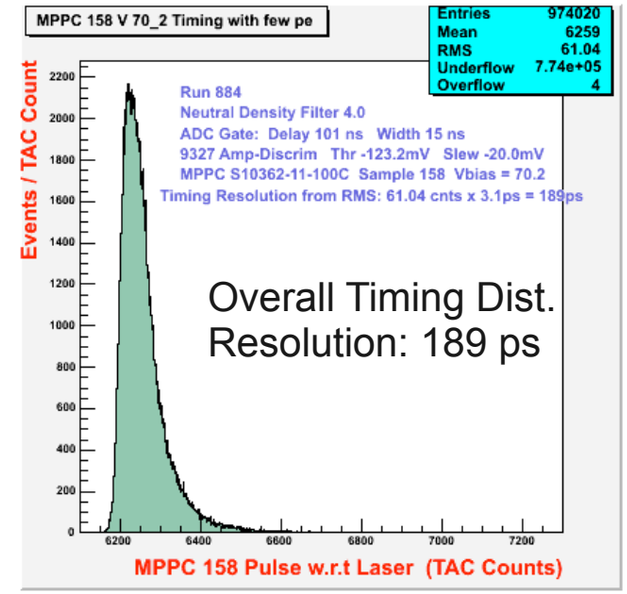
Timing Resolution Measurements

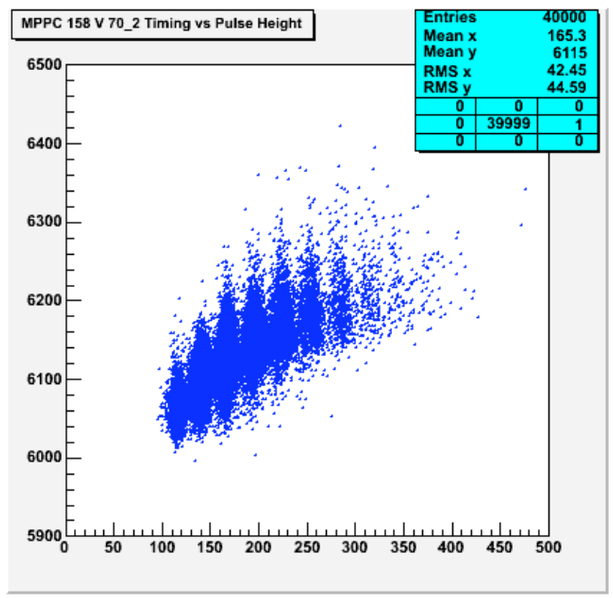
408nm 75ps Pulsed Laser Diode
Attenuated with 4.0 ND filter
Centered by eye on MPPC

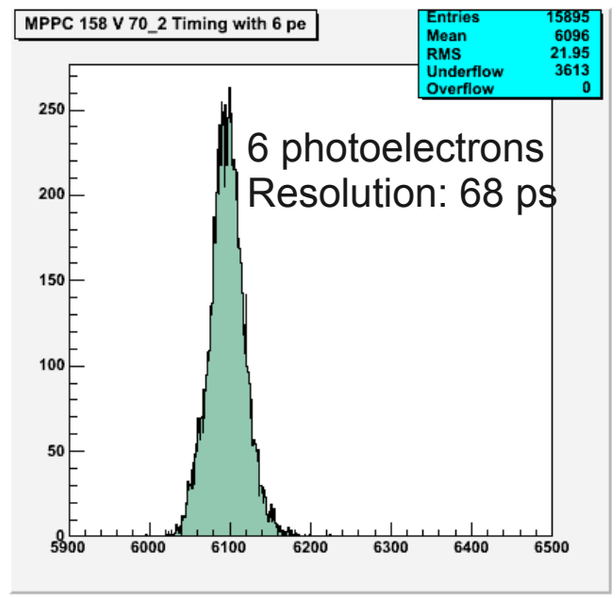


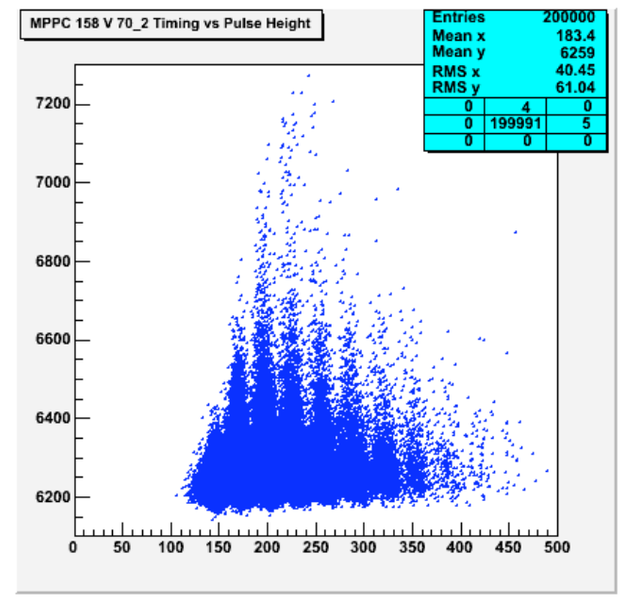


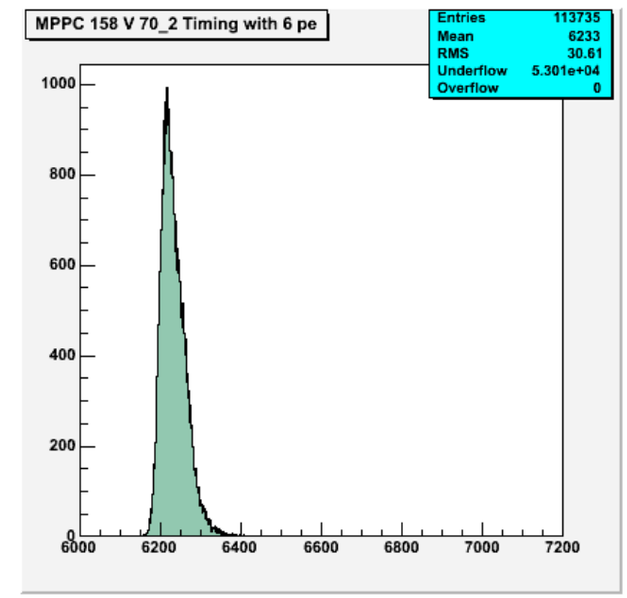






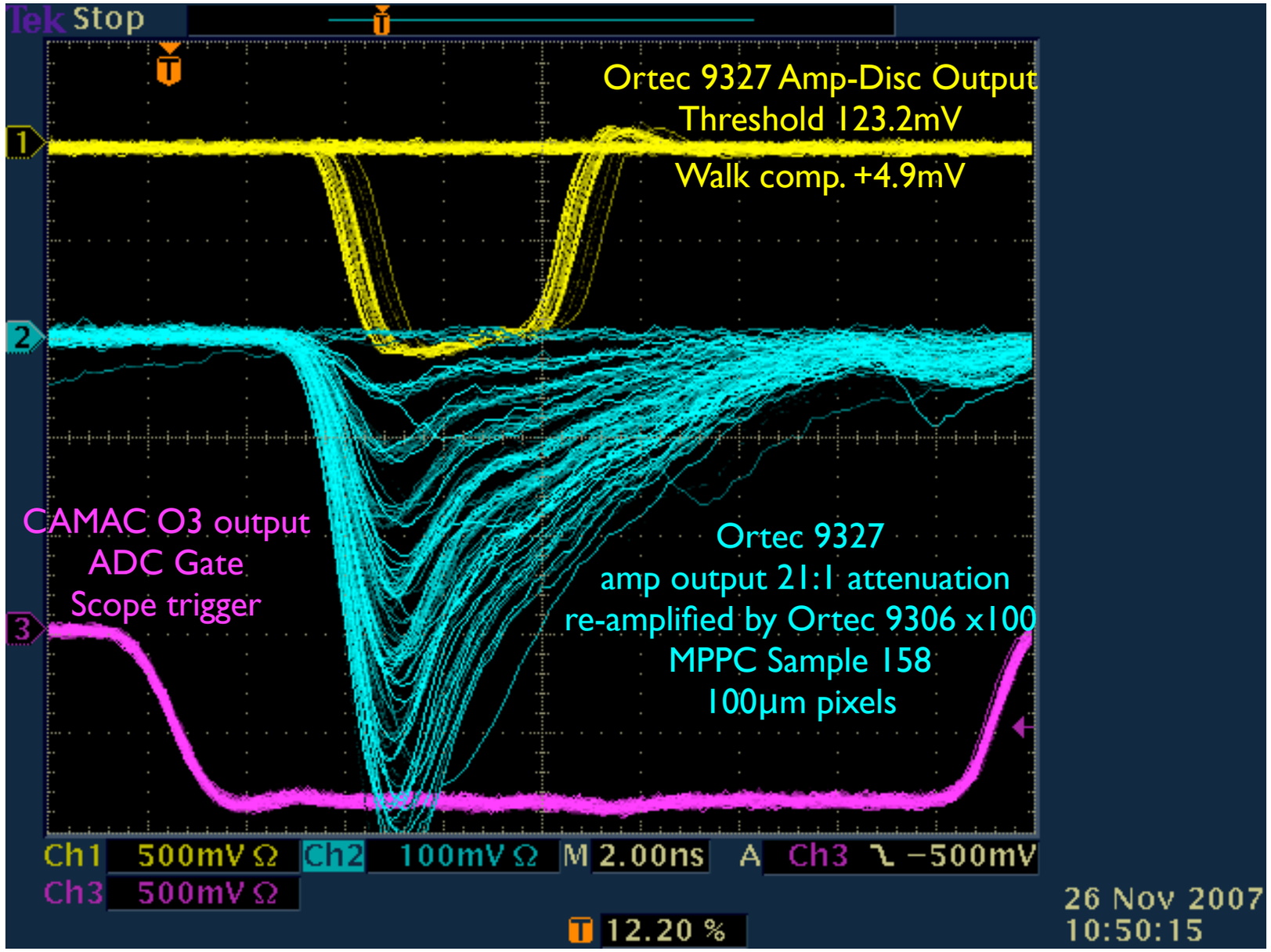




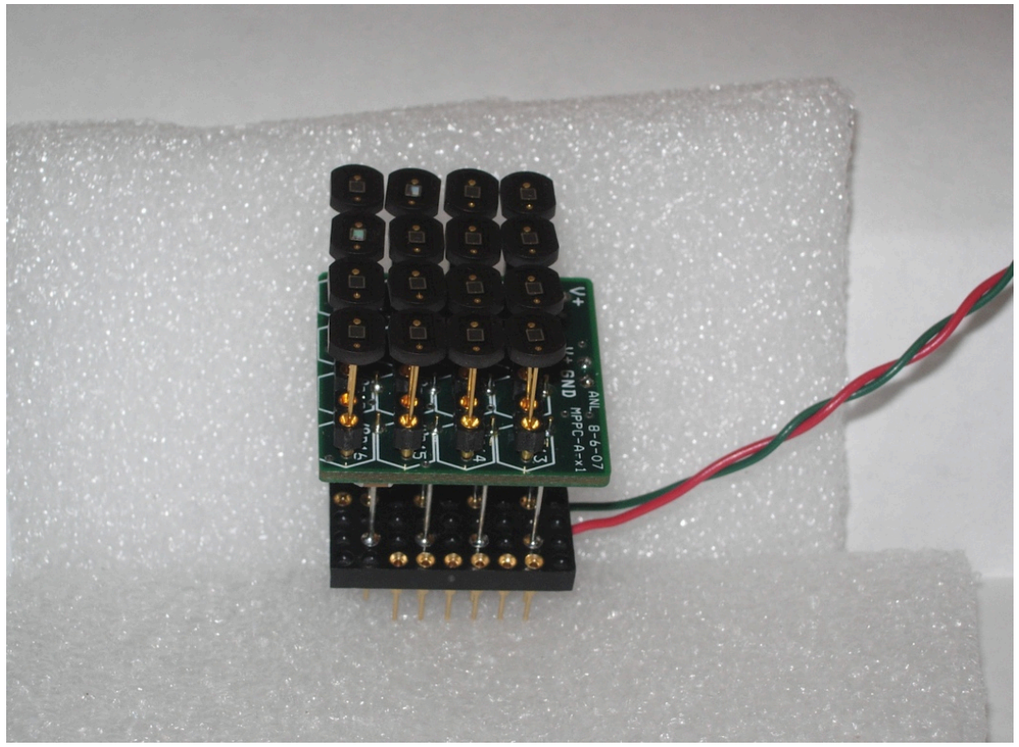


Timing measurement with Ortec 9327 1GHz amp/timing discriminator
→ Ortec 566 TAC (3.1ps/count) → Ortec AD144 16k ADC
(left) Best time resolution for individual pe Thr: -100mV Slew: -140mV
(right) Flat mean timing Thr: -123mV Slew: -20mV

Timing Resolution (2)

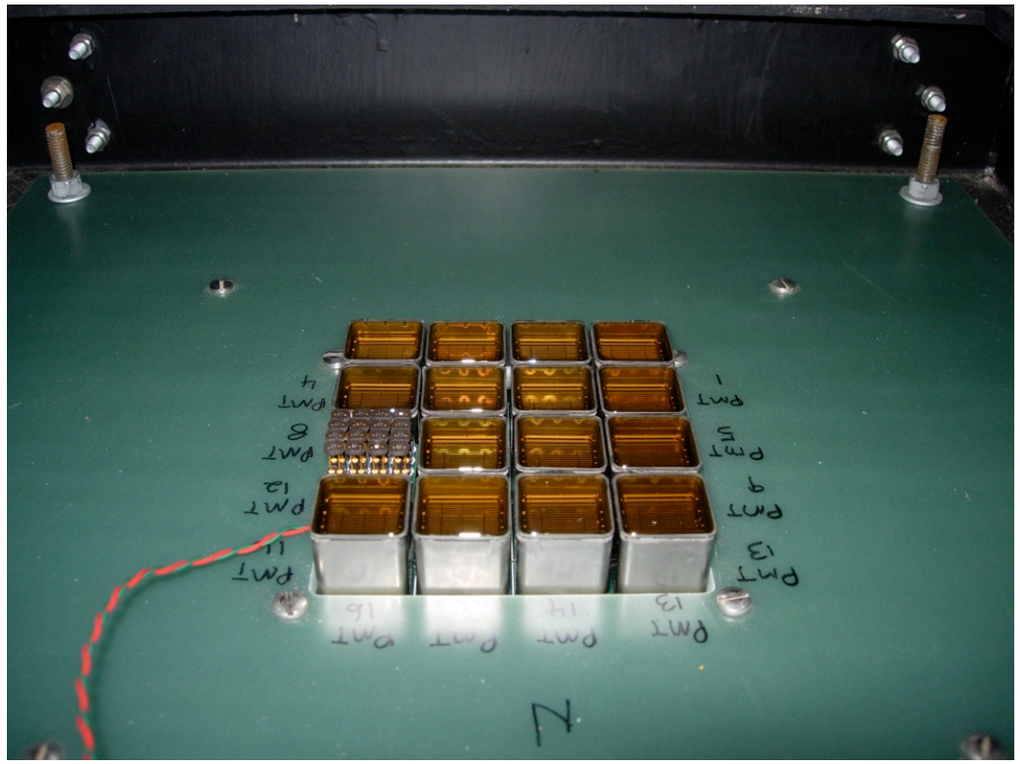


Observation of Cosmic Ray Shower Images with MPPC Array in TrICE



MPPC Drop-in replacement for R8900 tube.

- 4×4 array of 1mm^2 active area MPPCs on PC board with anode pins to plug into TrICE camera board base
- MPPCs are 50μm pixel size with 400 total pixels
- MPPCs selected from sample of 200 for similar V_{oper}
  - 70.19 - 70.28V
  - Gain: 7.5×10^5
- V bias set to 70.33V for data acquisition
  - Operating Gain: ~8×10^5
  - Compare to R8900 gain: 1-2×10^5



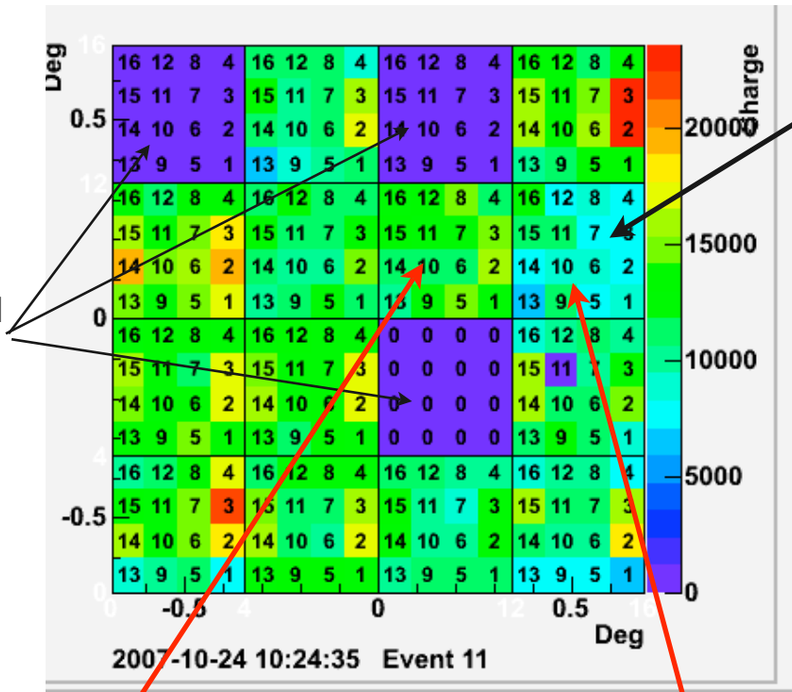
MPPC Array in TrICE camera

R8900 MAPMT & MPPC Array Response to Blue LED

- Blue LED flashed at 50 Hz in light drum with white mylar skin
  - Used to flat field camera response

TrICE Readout

- Prototype charge integration boards (MINDERs) for MINOS neutrino oscillation experiment
- Digitize every 19ns (Fermilab 53 MHz clock)
- Trigger on summed last dynodes of 4 central R8900s. Demand 2 of 4 coinc.
- Readout eight 19ns time slices.



MPPC Array replaces PMT12

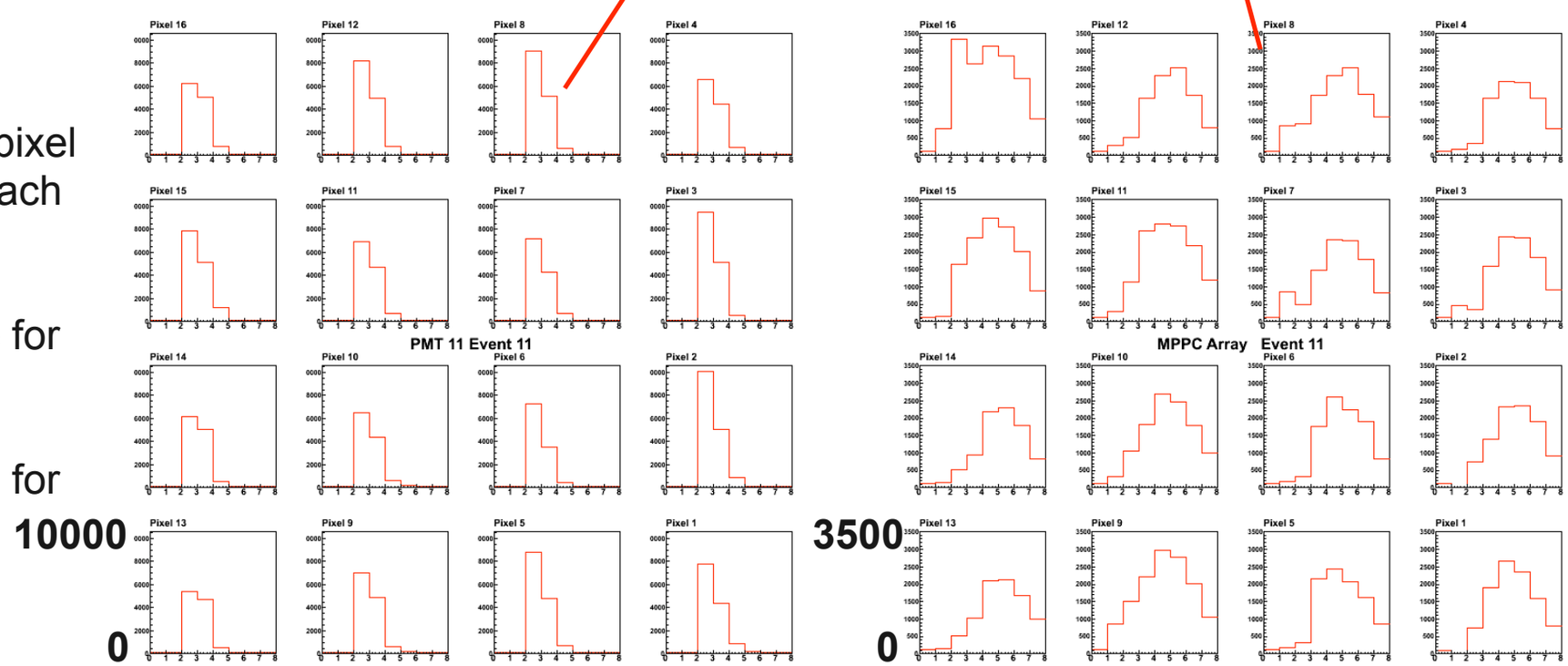
MINDER Board problems

Pulse height display of LED response summed over time <u>slices 2-6</u>

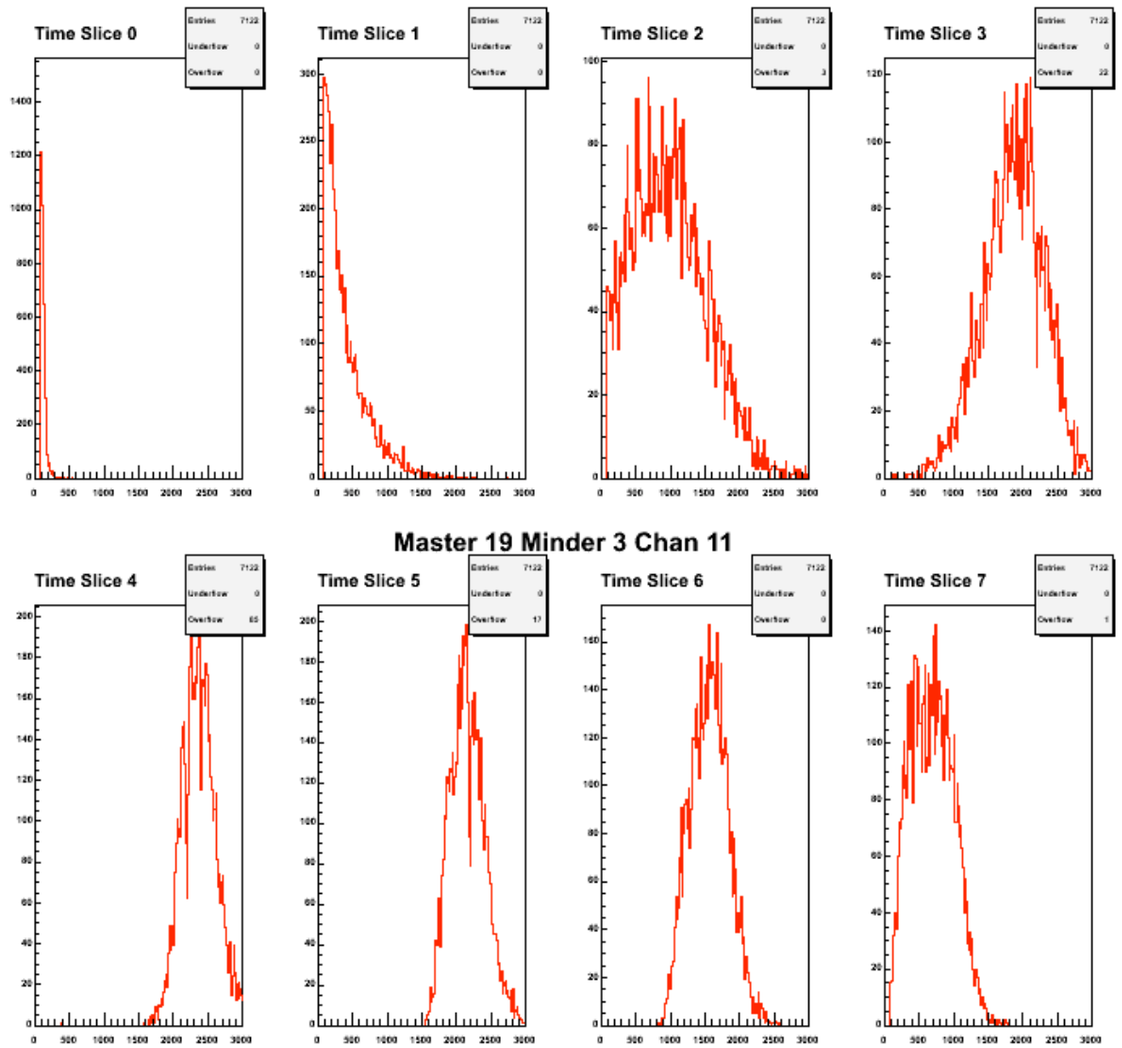
Time slice displays for each R8900 pixel or MPPC. Pulse height shown for each time slice 0-7.

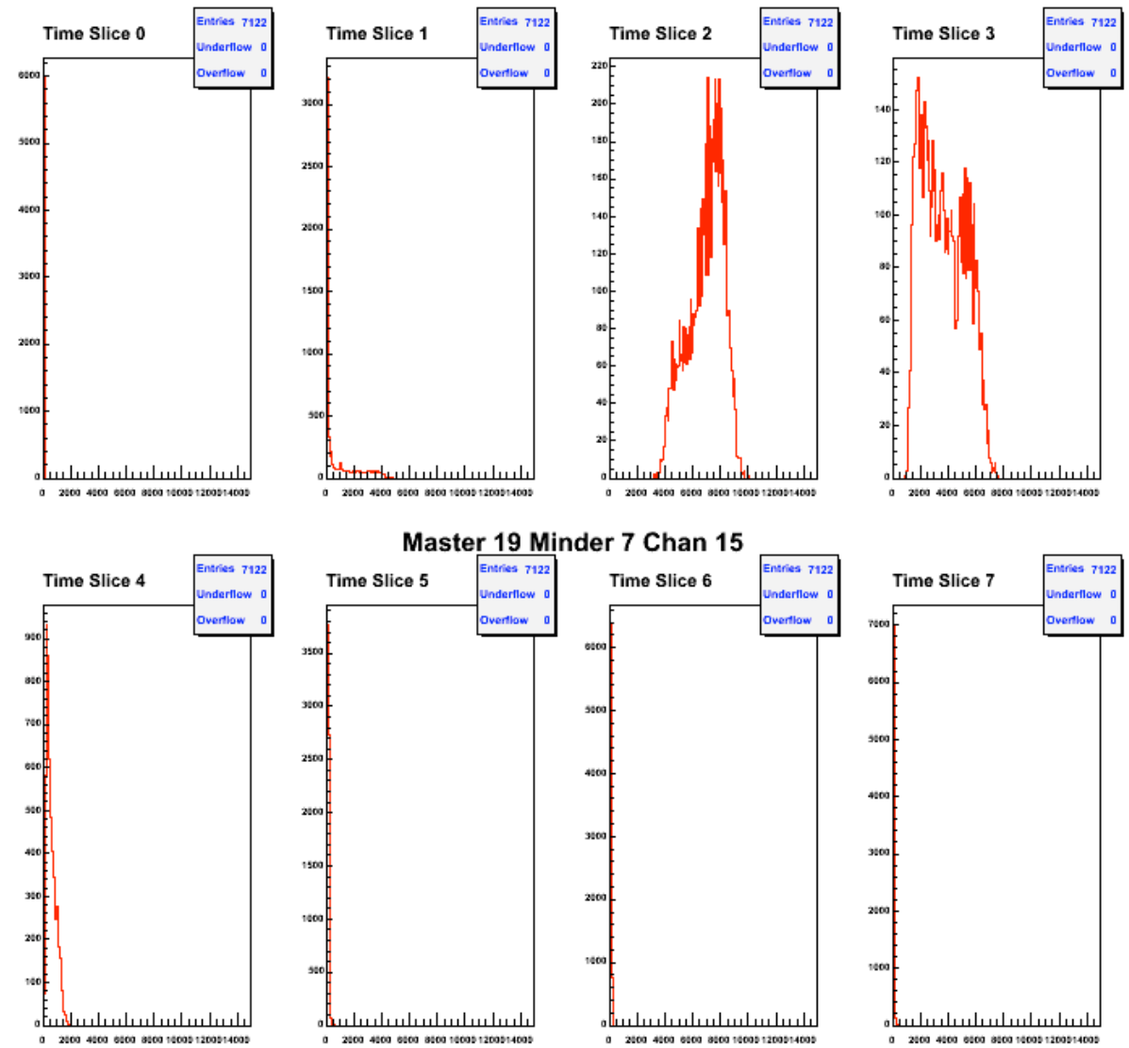
LED signal appears in time slice 2-3 for R8900s.

LED signal appears in time slice 2-7 for MPPC array



LED Pulse Height Distribution by Time Slice





MPPC Array Pixel 12
Pulse height distribution over LED run by time slice
LED response in time slices 1-7

PMT 16 Pixel 16
Pulse height distribution over LED run by time slice
LED response in time slices 2-3

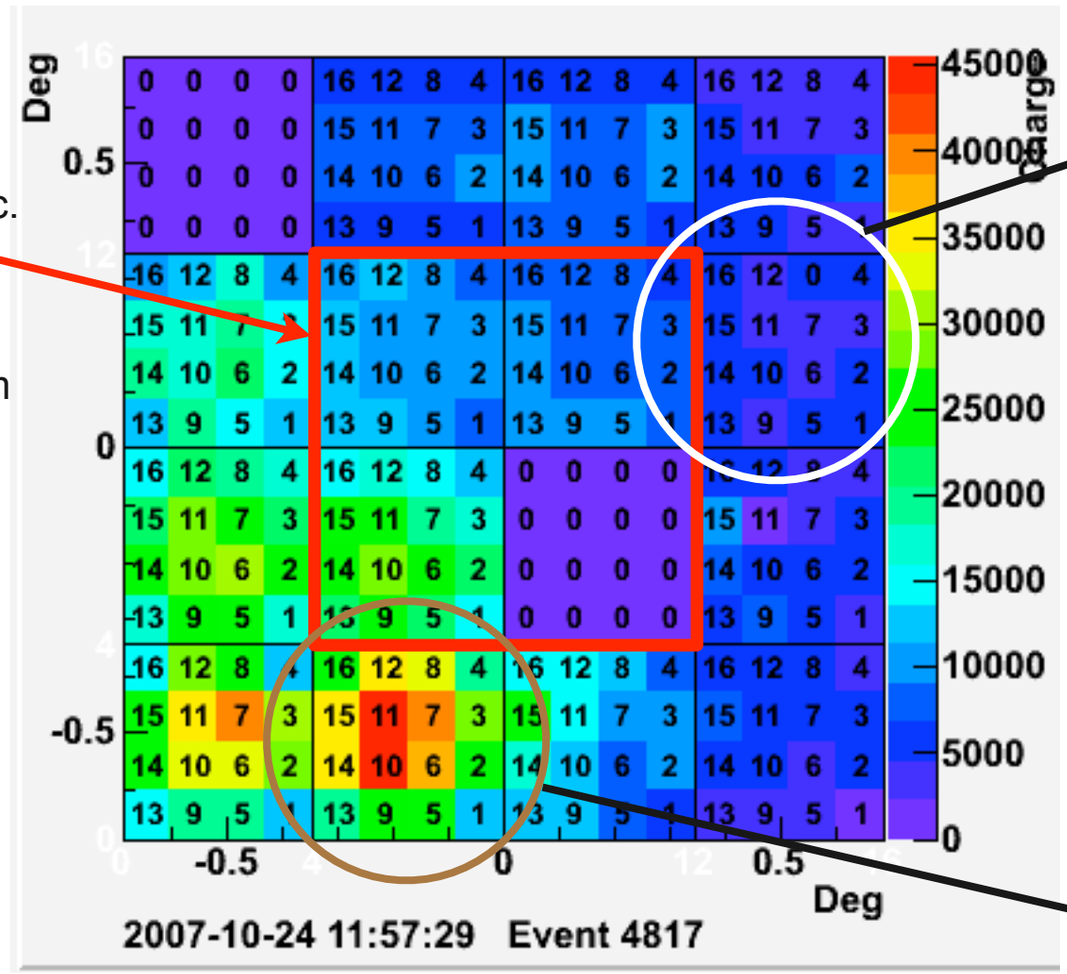
Probably need to adjust RC time in MPPC bias circuit

Observation of Cosmic Ray Cherenkov Image with a Multi-Pixel Photon Counter Array

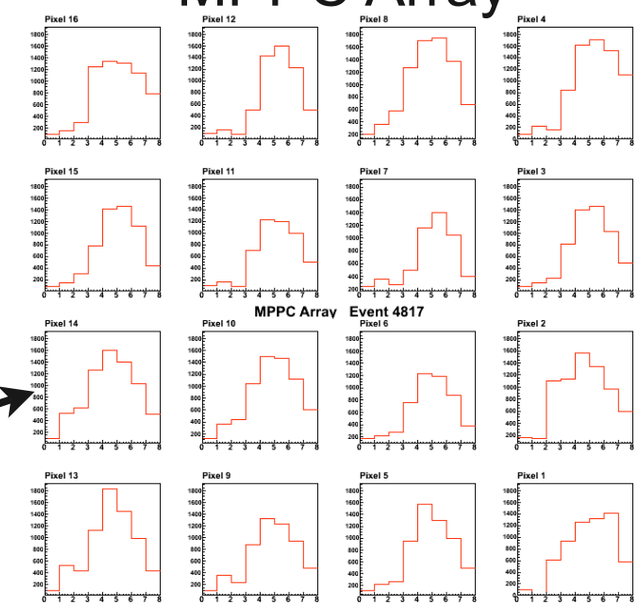
Very Large Pulse Height Event

Camera readout triggered by 2-fold coinc. of summed last dynode from 4 central R8900 MAPMTs
(of course, one of readout boards of central tubes (purple) developed problem during LED calibration before data taking).

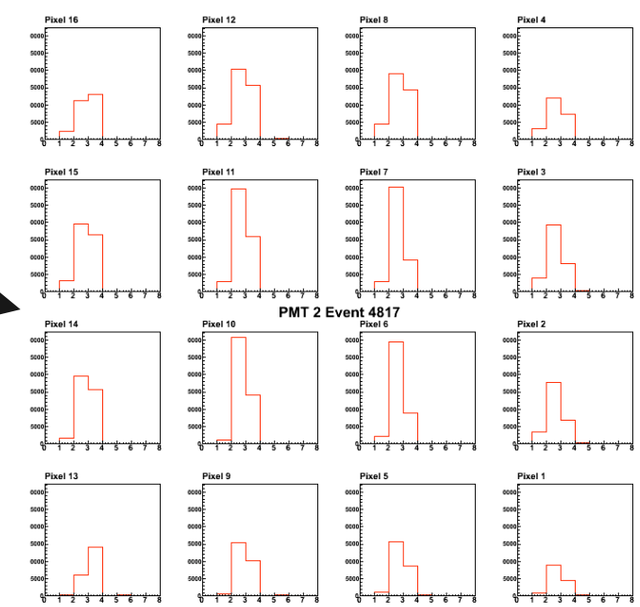
Sum of time slices 2-6



MPPC Array



✳Pulse height distribution by 19 ns time slice for each pixel in R8900 MAPMT or MPPC Array



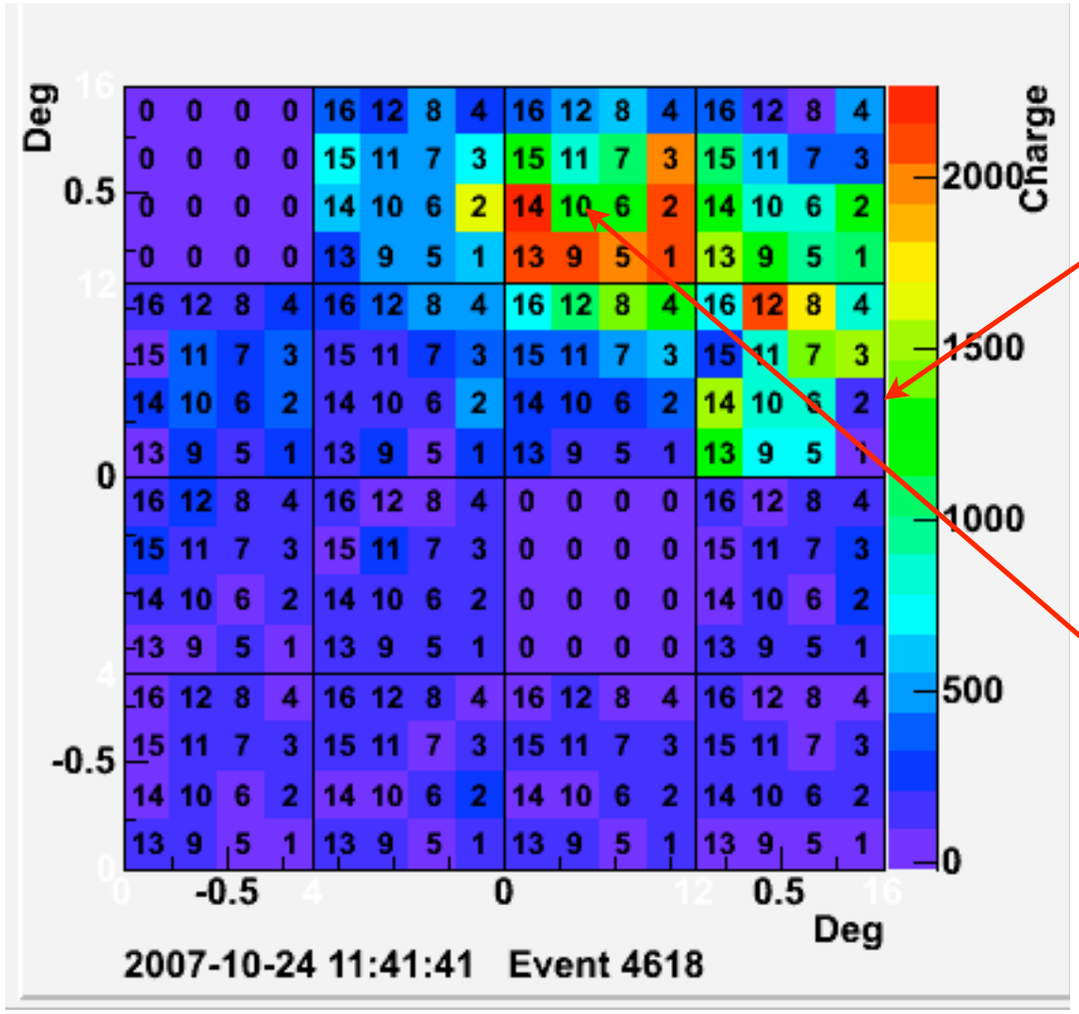
PMT 2

Cosmic Ray Shower imaged on TrICE Telescope camera

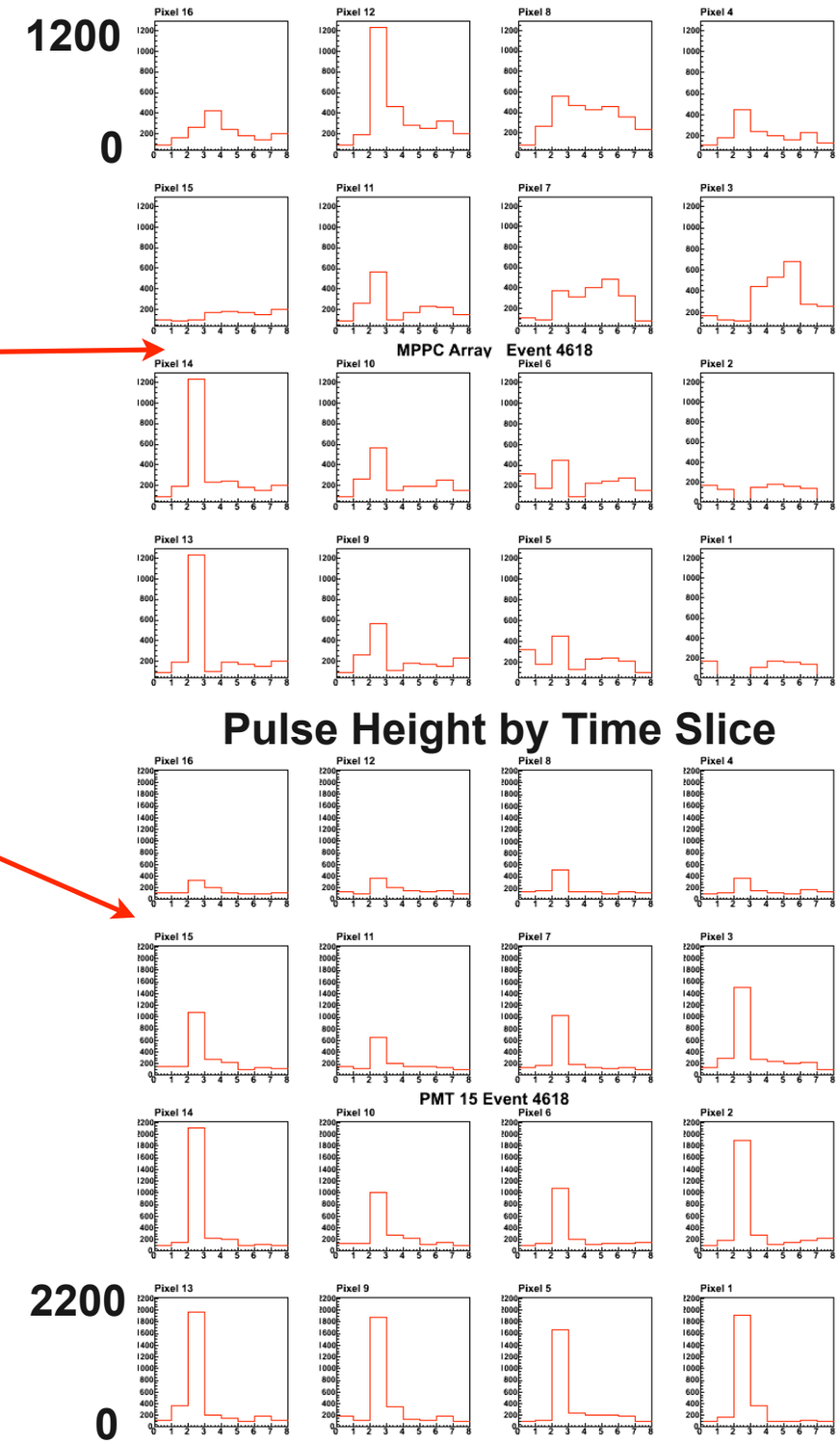
- Camera is 4×4 array of Hamamatsu R8900 MAPMT
  - 6×6mm^2 pixels
  - Operated at 600V with Gain ~1-2×10^5
- Replace one R8900 with 4×4 array of MPPCs

Smaller Pulse Height Cosmic Ray Image with MAPMT & MPPC

Sum of time slices 2-6



Raw image w/o correction for relative gain

MPPC Array

PMT 15