Light Yield & Uniformity Measurements of different Scintillator Tiles and Studies of 4th Generation Hamamatsu MPPCs

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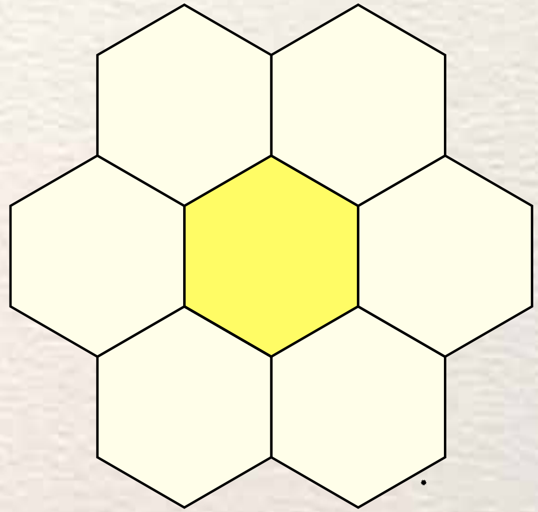
Outline

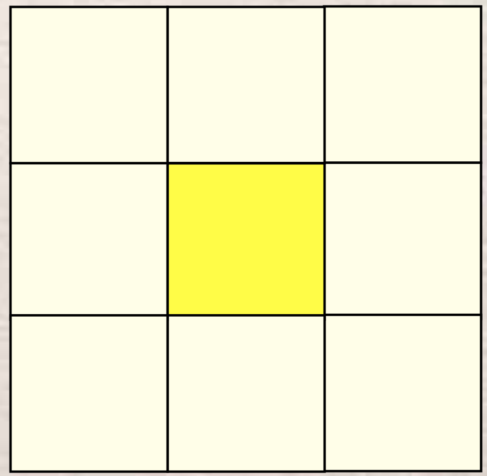
- Introduction
- Measurement setup
- Test of hexagonal and square tiles with different readout sites
- Gain and dark current measurements of new S14160 MPPCs
- Read out of ATLAS tiles with MPPCs
- Conclusions and outlook

Introduction

- The SiD ECAL uses hexagonal silicon pixels motivated by higher pixel yields from a wafer
- A hexagon is a better approximation to a circle than a square,
  - As for squares larger arrays can be constructed with hexagons without gaps
  - But at the module edges, we have to deal with half hexagons



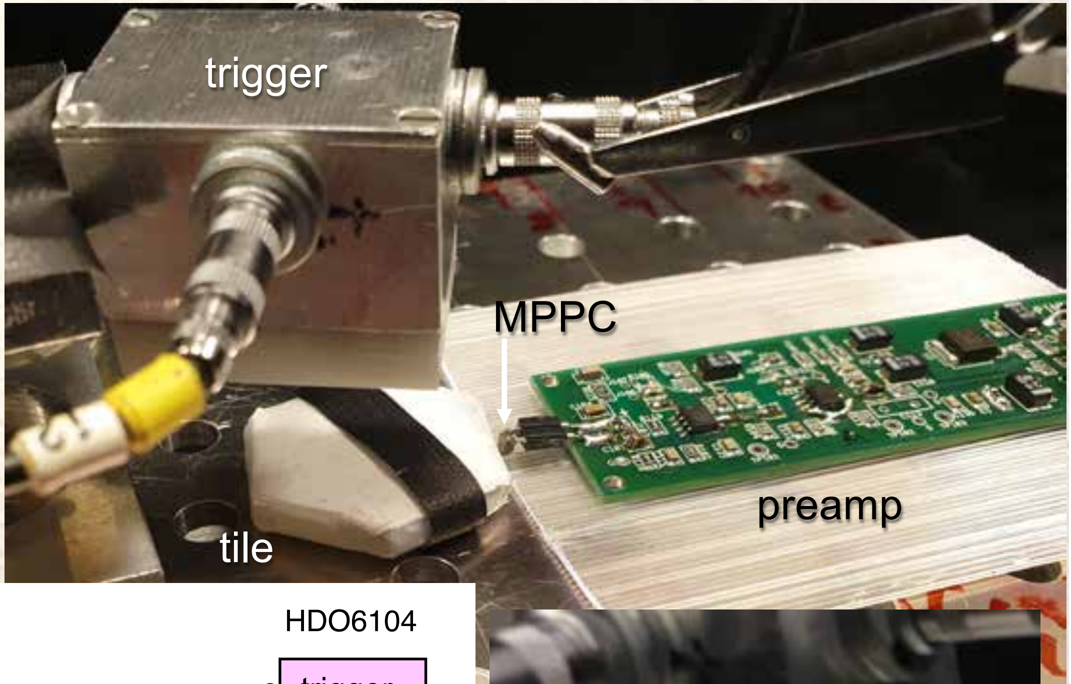
- For EM showers, we expect a better performance for hexagonal cells than for square cells since the first ring around a center tile consists of 6 not 8 tiles and the second ring consists of 12 rather than 16 tiles
  - Better S/N since the energy of less cells is summed

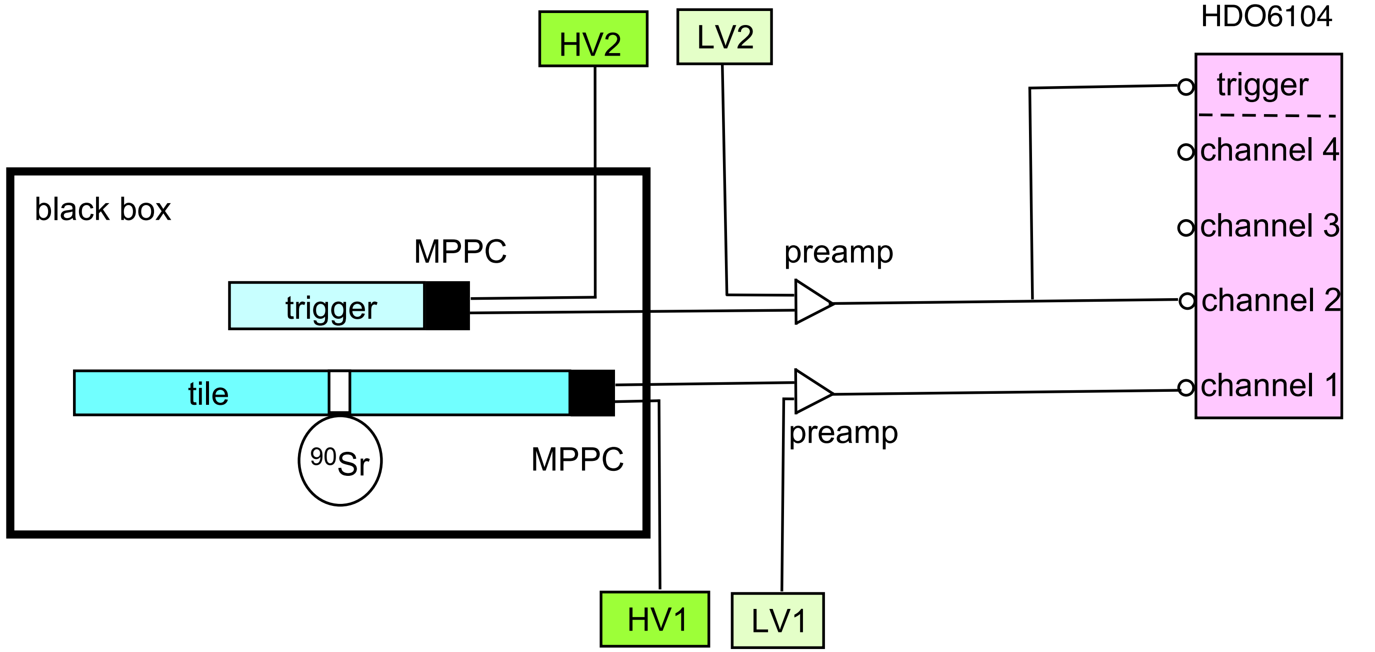


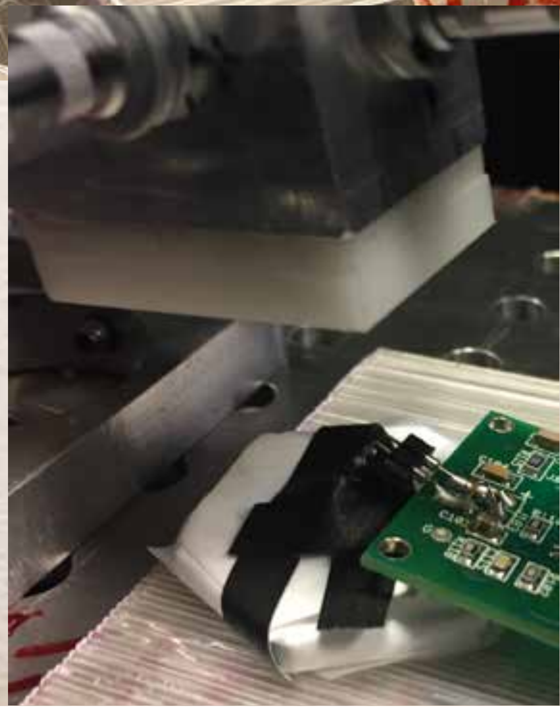
- We started to test the performance of hexagonal tiles with 3 different readout schemes wrt to that of square tiles
- We started to test the 4th generation MPPCs from Hamamatsu, which should have lower noise and afterpulsing
- We started to check upon the performance of ATLAS TileCal tiles with SiPM readout ➔ interesting for future hadron collider hadron calorimeters

Measurement Setup

- Work in black box
- Use MIP of electrons from ^{90}Sr source
- MPPC is loosely coupled to tile
- Trigger on second tile
- Record 50k waveforms

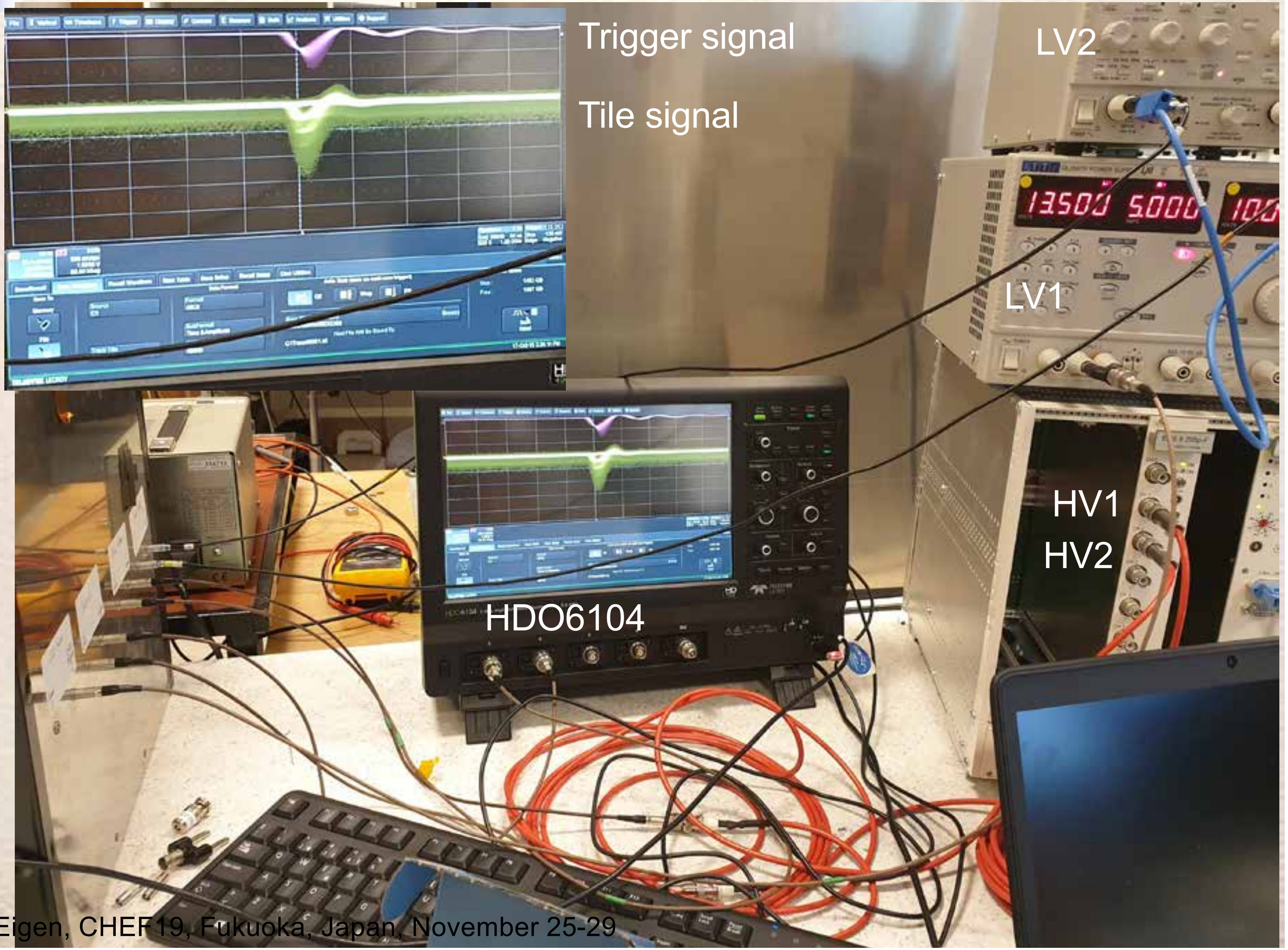






Signal Recording

- Take 50k wave-forms in a run
-



Tile Layouts

- Our machine shop produced 9 hexagonal-shaped tiles (a=1.86 cm) and 9 square-shape tiles (3 cm × 3 cm), which have the same area, thickness 3 mm
- Scintillator material is from St Gobain (Bicron) BC404
- We use 3 different readout schemes
  - Via Y11 fiber inserted into a groove located in the middle of the tile
  - Via a dimple in the center
  - Via coupling to a corner/side

	BC-400	BC-404	BC-408	BC-412	BC-416
Light Output, % Anthracene	65	68	64	60	38
Rise Time, ns	0.9	0.7	0.9	1	-
Decay Time, ns	2.4	1.8	2.1	3.3	4
Pulse Width, FWHM, ns	2.7	2.2	~2.5	4.2	5.3
Light Attenuation Length, cm*	160	140	210	210	210
Wavelength of Max. Emission, nm	423	408	425	434	434
No. of H Atoms per cm^3, ($x10^{22}$)	5.23	5.21	5.23	5.23	5.25
No. of C Atoms per cm^3, ($x10^{22}$)	4.74	4.74	4.74	4.74	4.73
Ratio H:C Atoms	1.103	1.1	1.104	1.104	1.11
No. of Electrons per cm^3, ($x10^{23}$)	3.37	3.37	3.37	3.37	3.37
Principal uses/applications	General purpose	Fast counting	TOF counters, large area	Large area	Large area, economy

Tile Wrapping and Readout

- Tiles on top and bottom are wrapped with 2 layers of Tyvec paper
- Use 2 layers of Teflon tape on sides
- Readout hole in Tyvec is 1 mm
- Green fiber is Y11 from Kuraray
- For readout we use the Hamamatsu MPPC S13360-3025 as well as 4th generation MPPCs: S14160-1315 , S14160-1310, S14160-3015 and S14160-3010

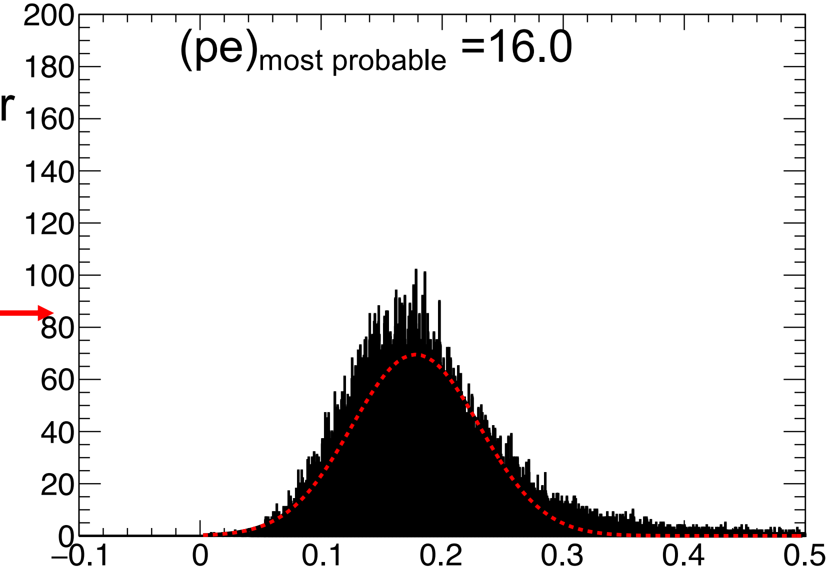
S14160-1315

S13360-3025

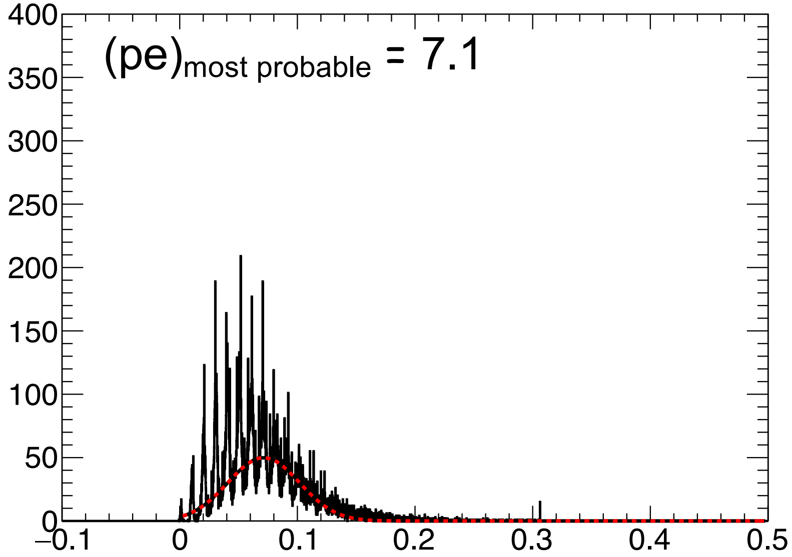
Comparison of the 3 Readout Schemes

- Hexagonal tiles read out with 3x3mm^2 MPPC
- For side and center readout, use 1 mm hole, fiber is at a corner also 1 mm
- Measure center position of tile
  - For readout with fiber
  - For readout on the tile center
  - For read on the tile side
- Measure high light yields

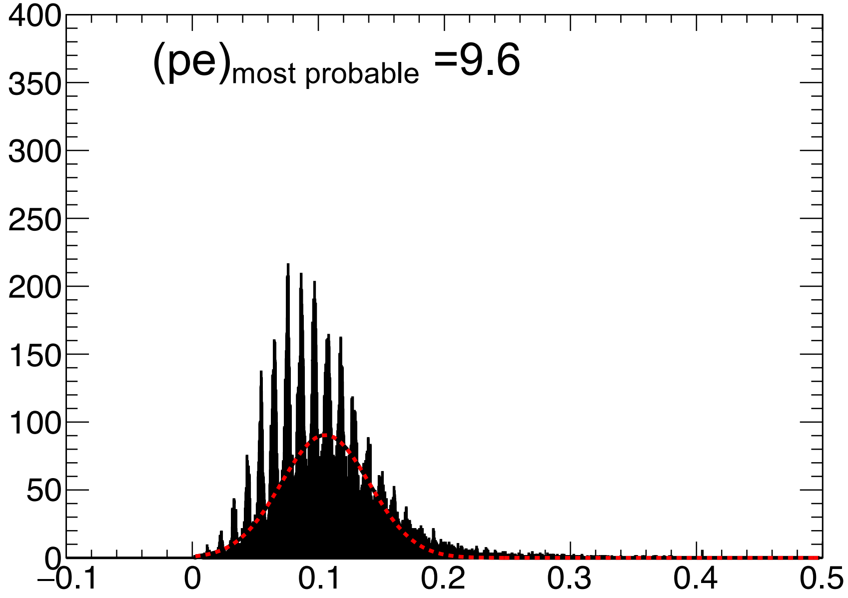
SiPM read out with fiber



SiPM's mounted in the center

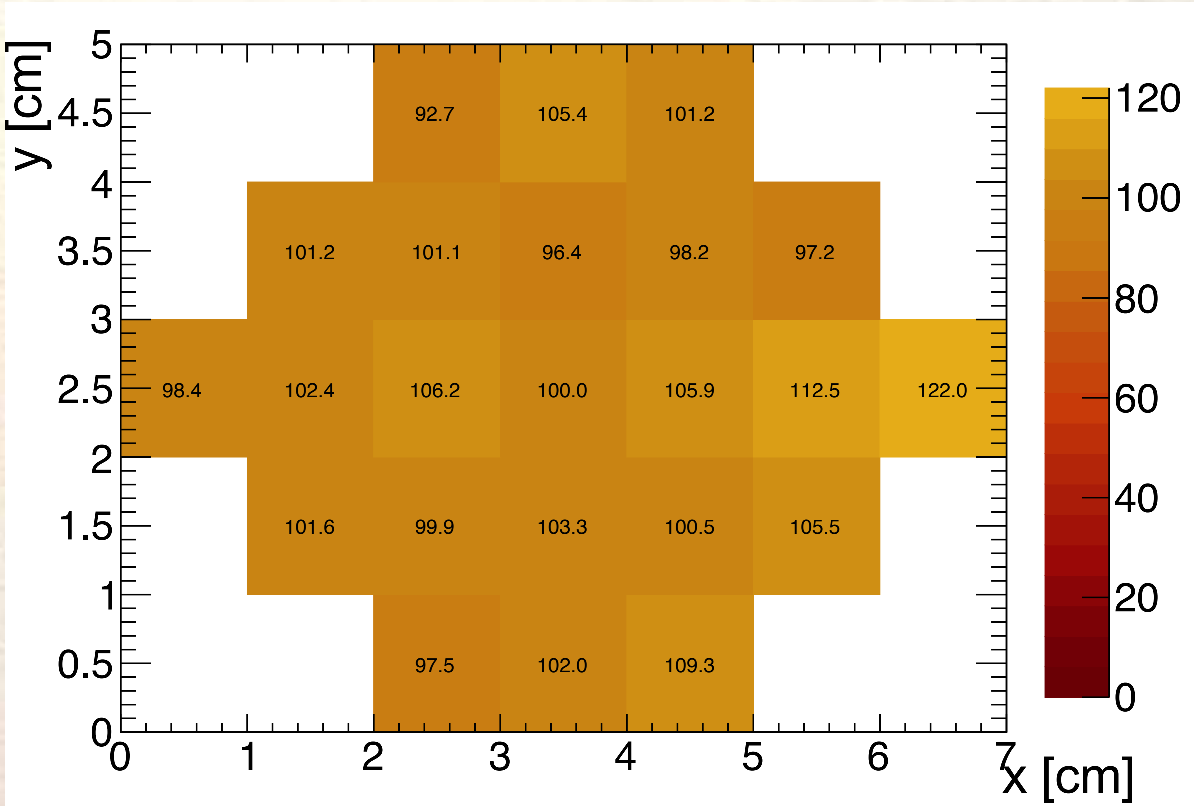


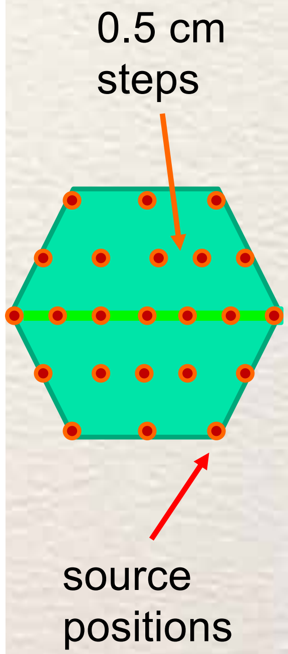
SiPM's mounted on the side

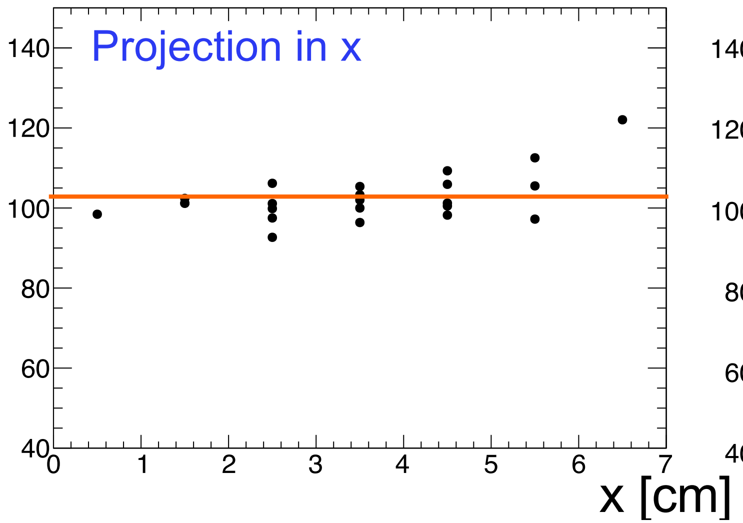


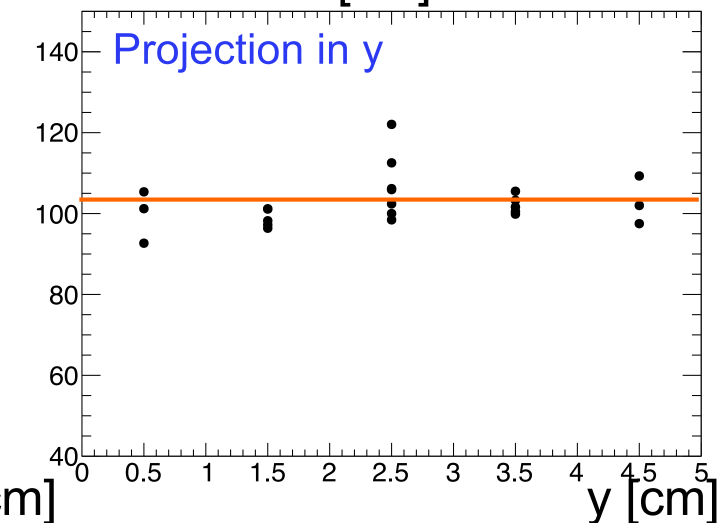
Uniformity Measurement of Fiber Readout

- Rewrap tile due to rather non-uniform behavior
- Center point is used for normalization
- Except for light yield at fiber end all other point have a mean light yield of (101.7 ±1.0)% wrt center LY
- Uniformity within ~ ±10% except for value value at the fiber end (~20% higher)



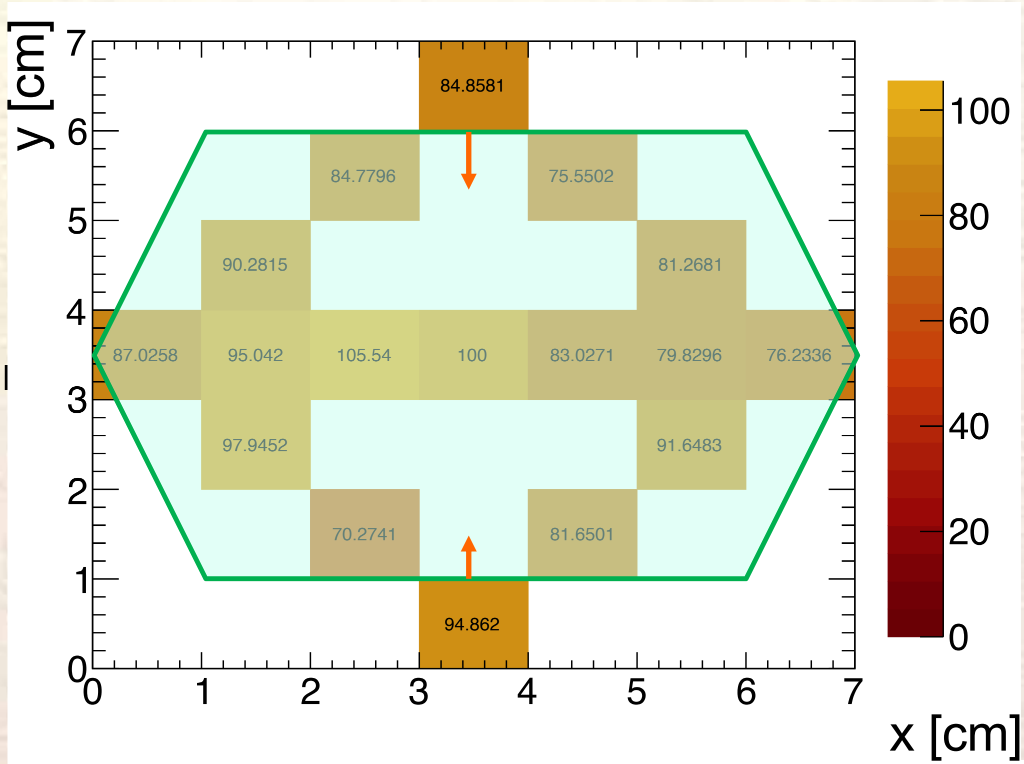


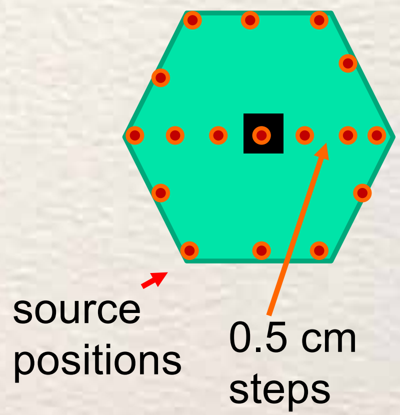


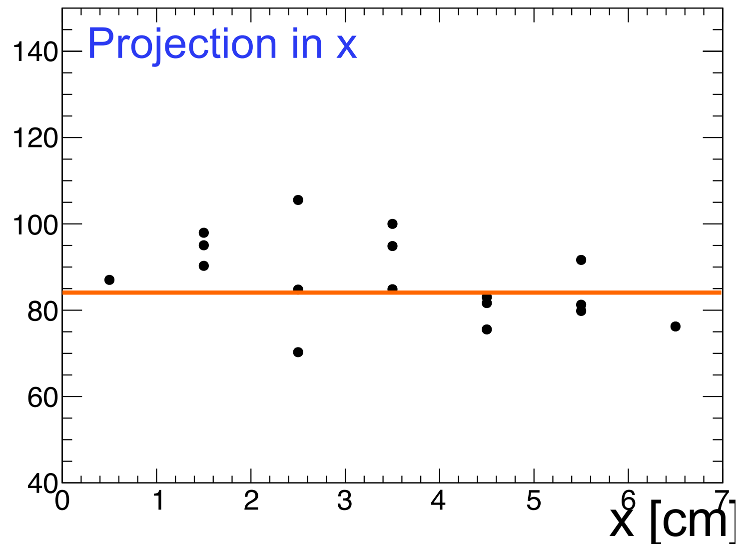


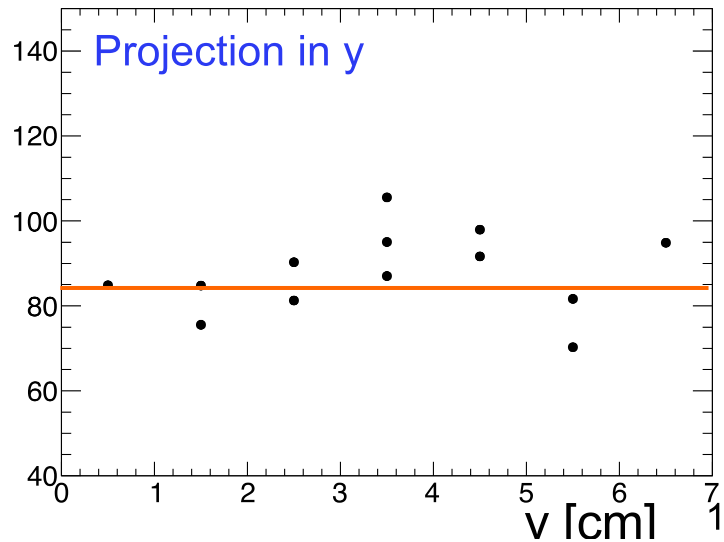
Uniformity Measurement of Center-mount MPPC

- Center point sees ~1.2 times more light wrt average
- Excluding light yield at tile center, center, tile center, all other mean light yield is (86.2 ±2.4)% wrt center LY
- Uniformity within ±6% except for value at the center
- Need to enlarge dimple!



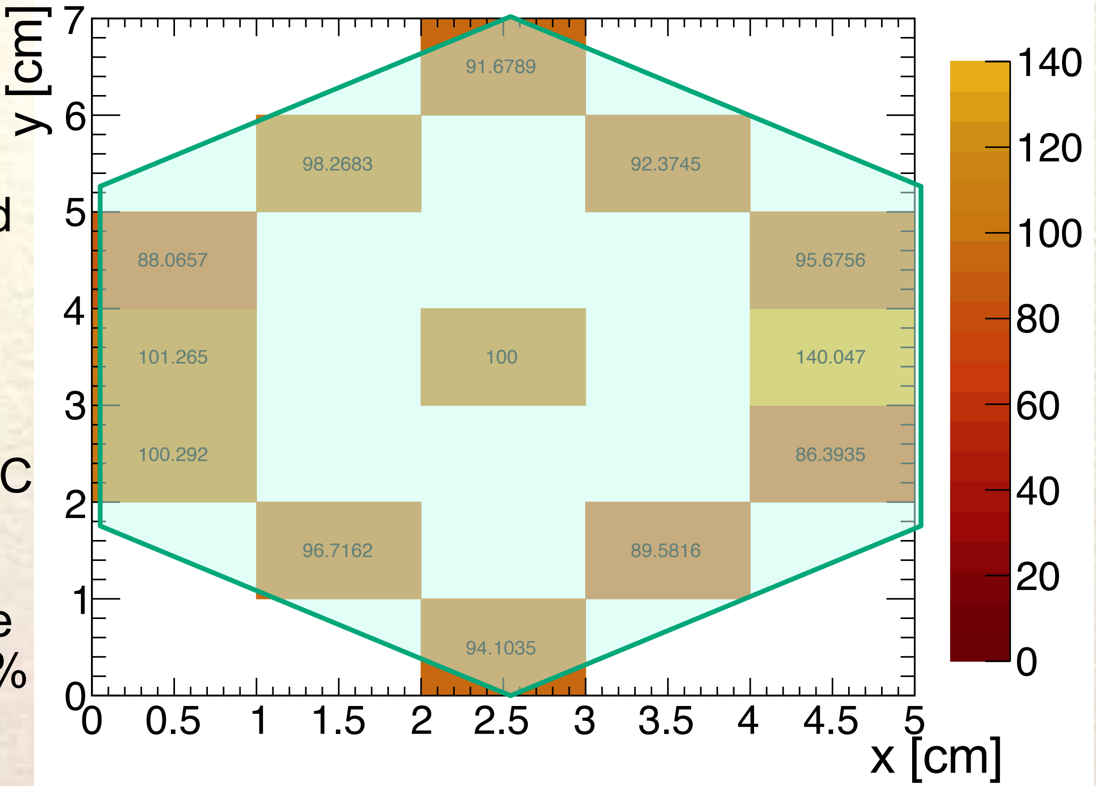


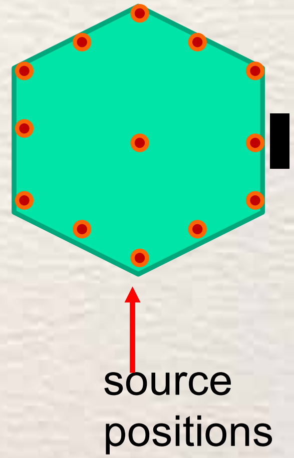




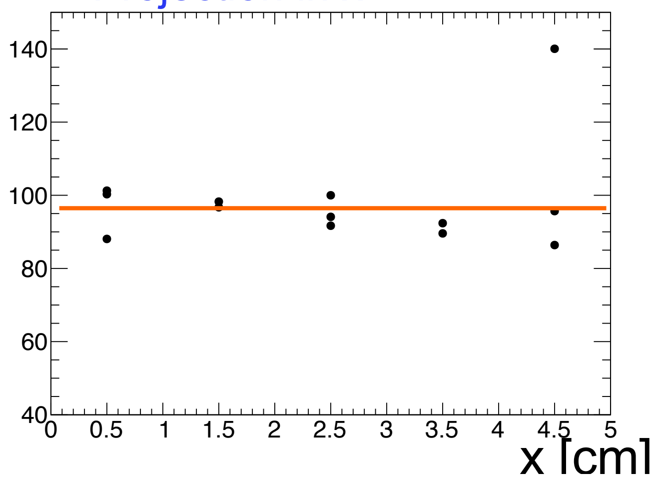
Uniformity Measurement of Side-mount MPPC

- Mean value of fitted Gaussian for each position is divided by the light yield measured at center position
  - Note the increase in the number of PE's in the right most bin near MPPC
- Excluding point near MPPC, average relative light yield is (94.6±1.5)%
- Uniformity within ~ ±7% except for value at the readout side
- Position at readout position is enhanced by 1.48 wrt average value

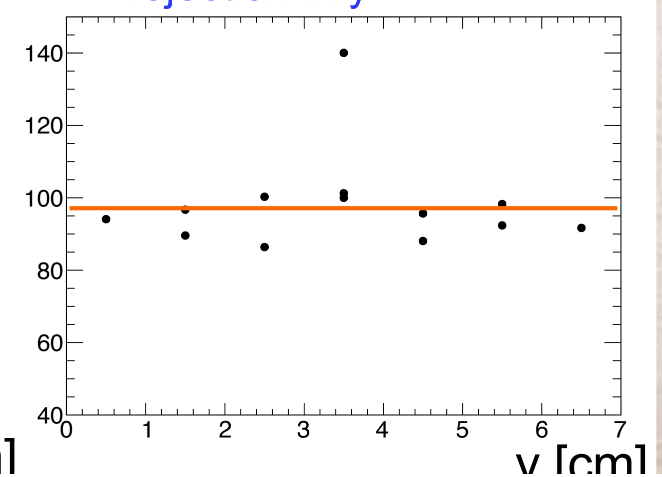




Projection in x

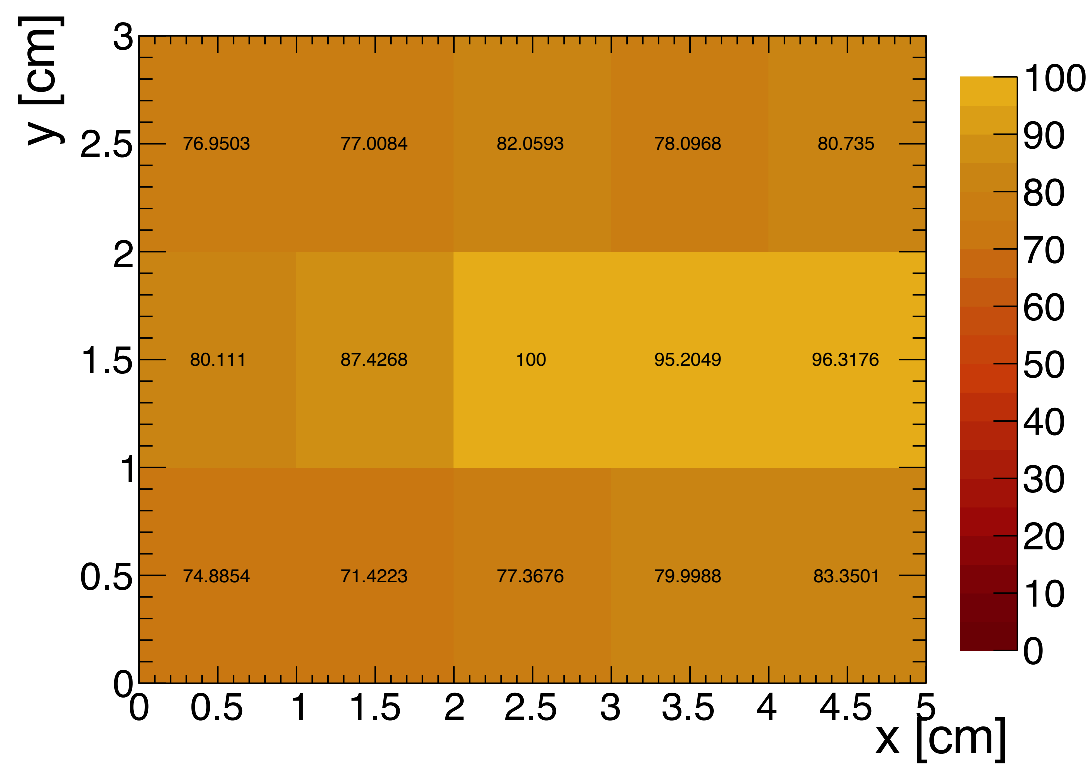


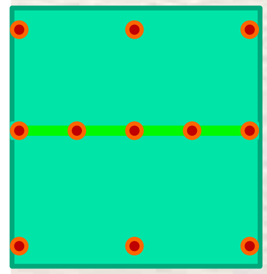
Projection in y

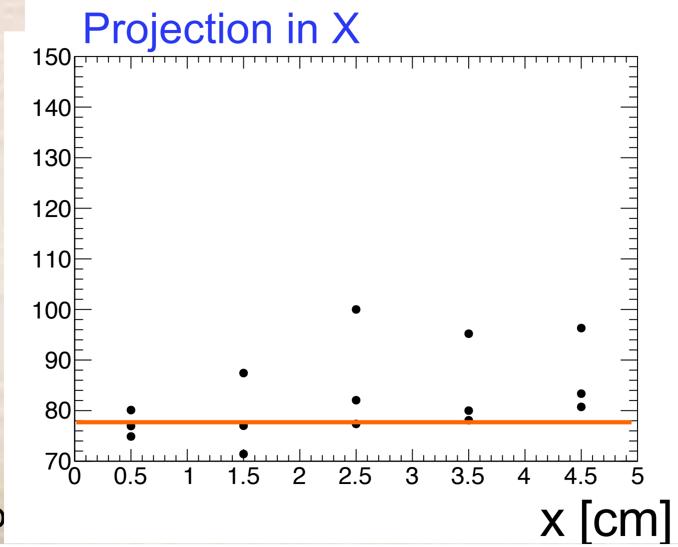


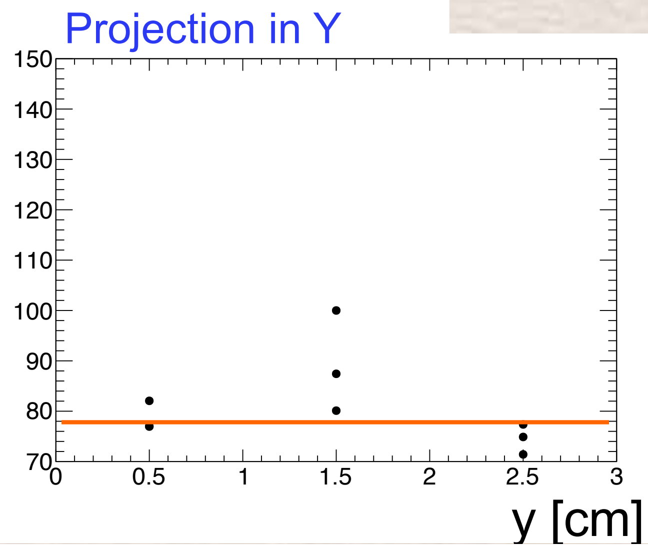
Uniformity of Square Tile with Fiber Readout

- Mean value of fitted Gaussian for each position is divided by the light yield measured at the center position
- Most probable light yield at the center position $(pe)_{most\ probable}$ =19.4 pe
- Average relative light yield is (78.2±1.2)% determined from upper and lower row
- Uniformity is within ±7%
- Right-hand side of middle row is ~15-20% higher



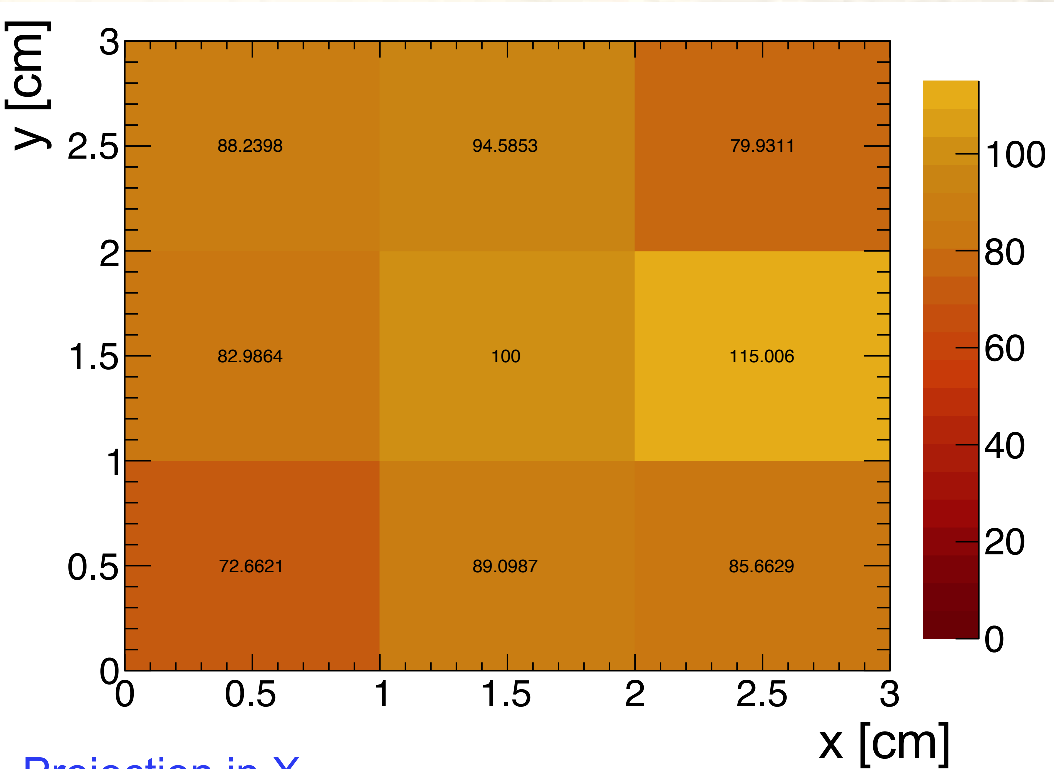


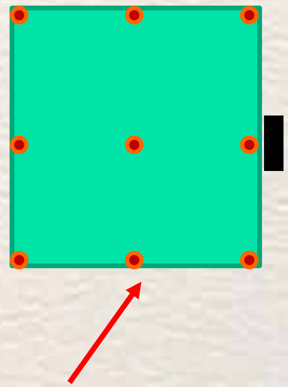


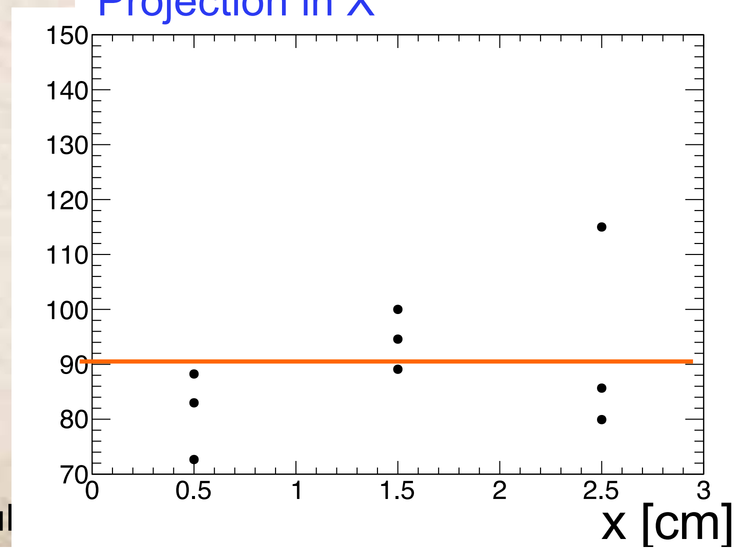


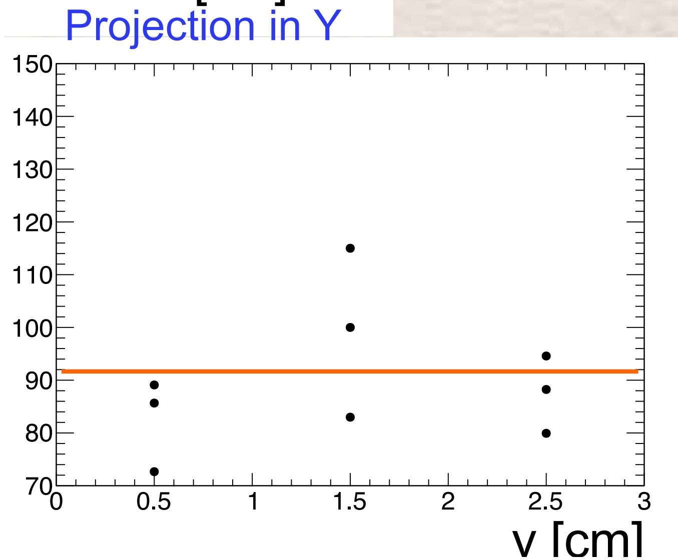
Uniformity of Square Tile with MPPC on Side

- Mean value of fitted Gaussian for each position is divided by the light yield measured at the center position
- Most probable light yield at the center position $(pe)_{most\ probable}$ =7.91 pe
- Average relative light yield is (86.7±3.2)%
- Tile is uniform within ±13% (cause is probably non homogeneous wrapping)







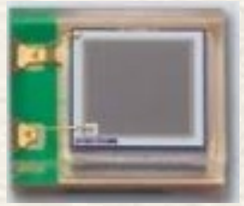


Properties of 4th Generation MPPCs S14160

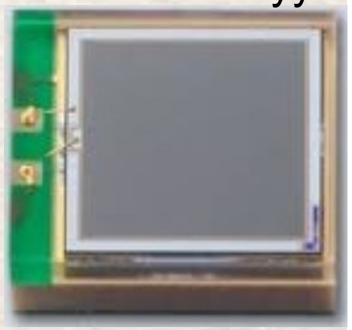
- We received 8 MPPCs from Hamamatsu (2 of each type)

MPPC	S14160-1310	S14160-3010	S14160-1315	S14160-3015
Sens. area	1.3 x 1.3 mm^2	3 x 3 mm^2	1.3 x 1.3 mm^2	3 x 3 mm^2
Pixel size	10 μ	10 μ	15 μ	15 μ
# pixels	16675	90000	7296	40000
V_b	~43.4	43.1	41.6	42.5
Dark rate	120 kHz	700 kHz	120 kHz	700 kHz
gain	1.8×10^5	1.8×10^5	3.6×10^5	3.6×10^5
C at Vop	100 pF	530 pF	100 pF	530 pF

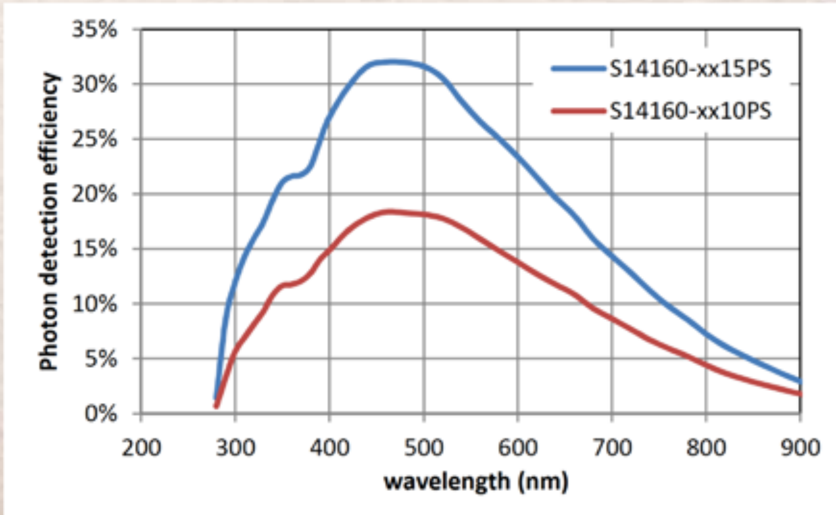
S14160-13yy



S14160-30yy

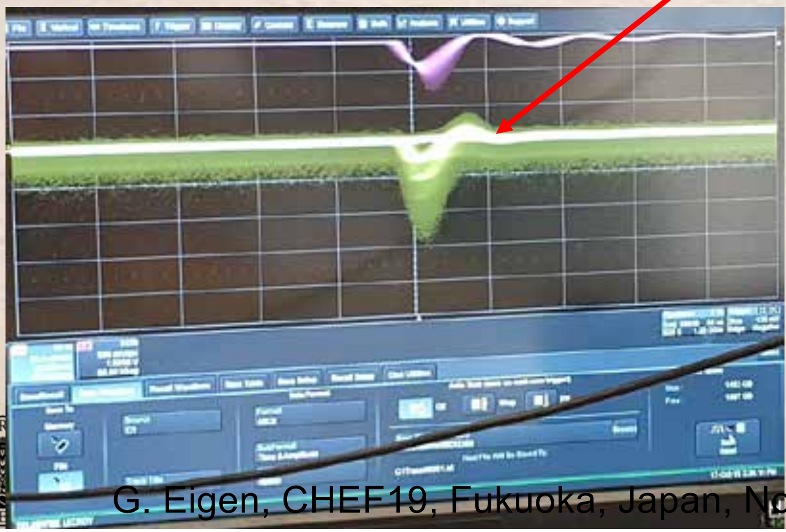


- Photodetection efficiency is highest for green light from Y11 fiber
- BC404 has maximum wavelength at 408 nm
- Photon detection efficiency of 10 μm pixel is about half of that of the 15 μm pixel sensors

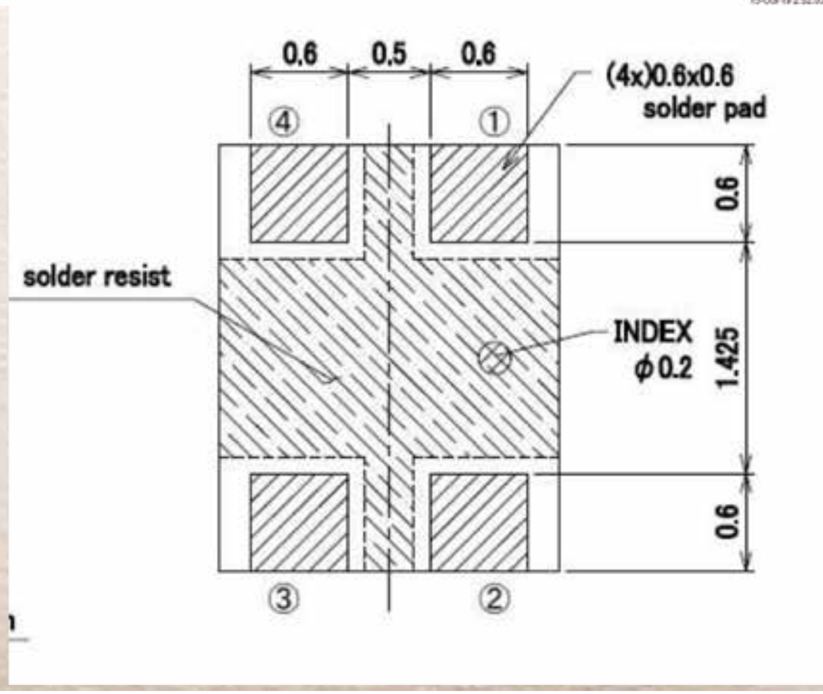


Experience with S14160 MPPCs

- Waveform of S14160-1315 sensor at V_b=43.33 V and T=25^{o}C
- Clearly see individual photoelectrons
- Solder joints are rather touchy in 3 S14160-13 sensors, solder pads detached from sensor
- Our electronics engineer could fix two S14160-1310 sensors
- Waveform looks similar as that of the unbroken sensor s14160-1315

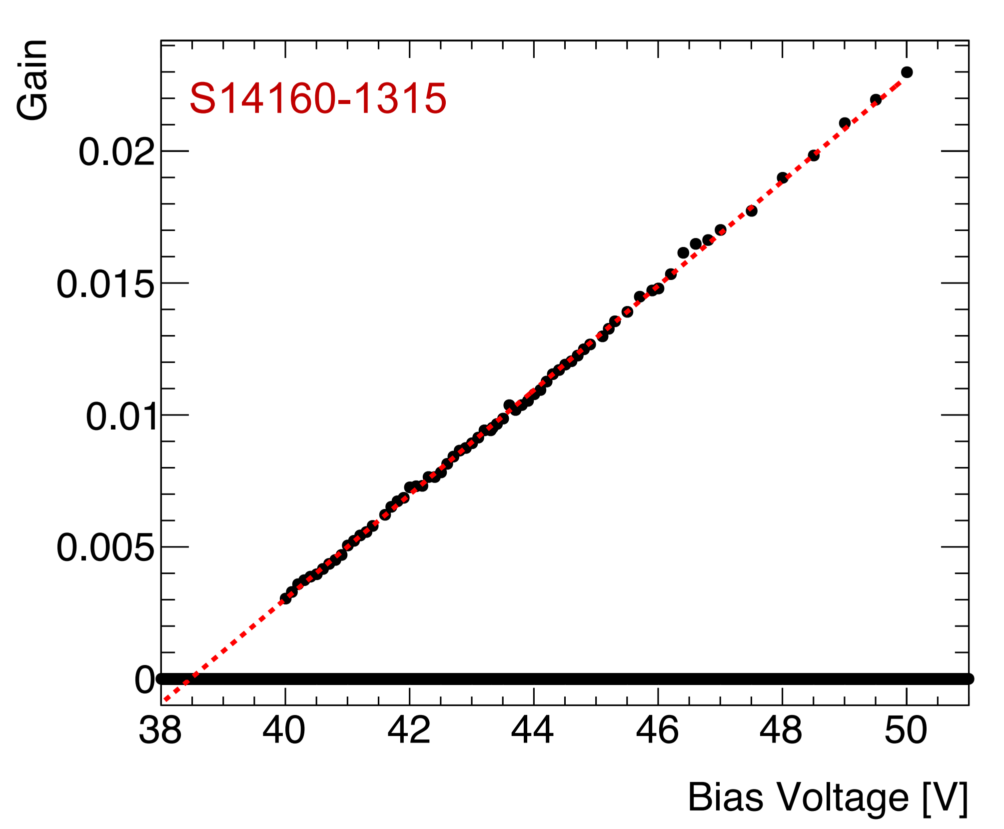


S14160-1315



Gain versus Reverse Bias Voltage

- Use ^{90}Sr source on hexagonal tile read out with fiber and an S14160 sensor
- Determine peak of photoelectron distribution
- Determine gain from the distance between two adjacent photoelectron peaks
- Gain can be fitted with linear dependence, slope = 0.002/V
- Deviations from line may come from small temperature fluctuations



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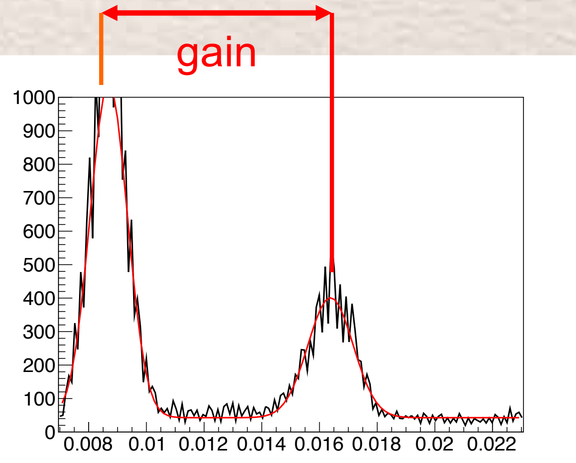
- Slope corresponds to 0.002/V
- At nominal V_b=43.4 V: G=1.8x10^5
- Breakdown voltage V_{break} =38.5 V

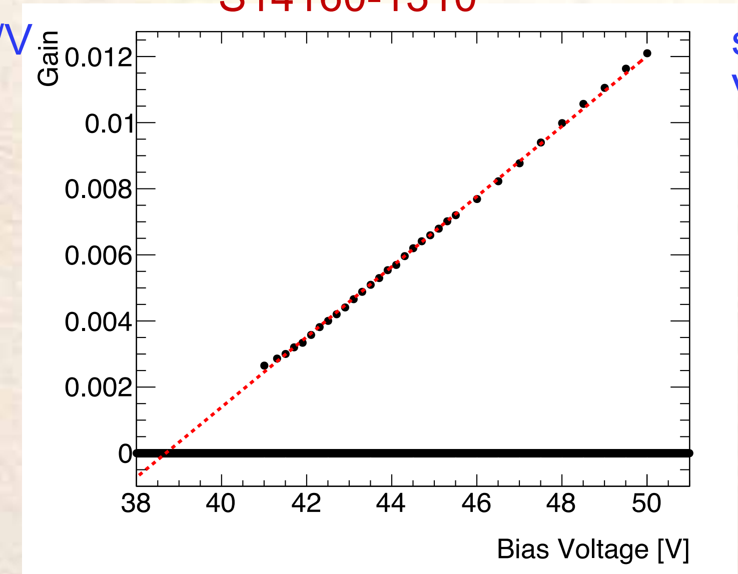


Gain versus Reverse Bias Voltage

- Four all 4 S14160 sensors the gain depends linearly on V_b on 40-50 V range

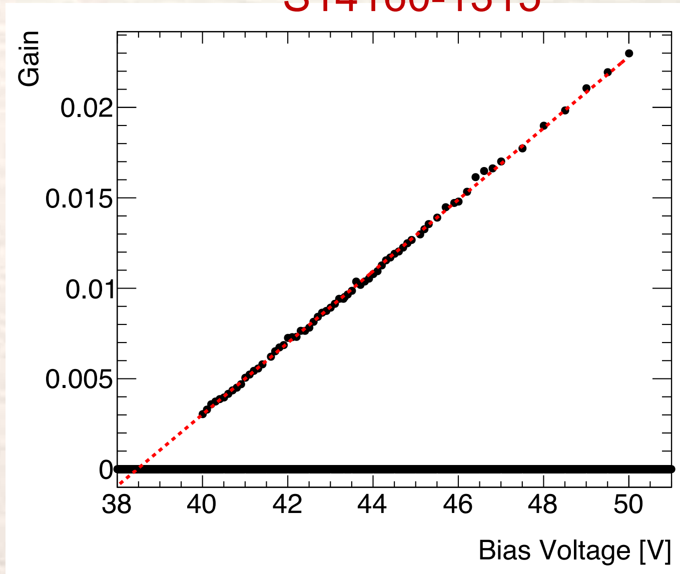
S14160-1310

slope=0.00106/V
V_b=38.5 V



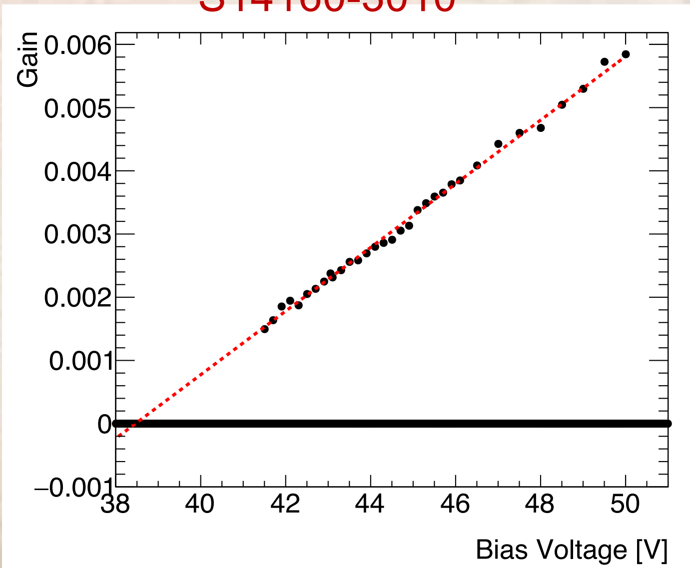
S14160-1315

slope=0.002/V
V_b=38.5 V



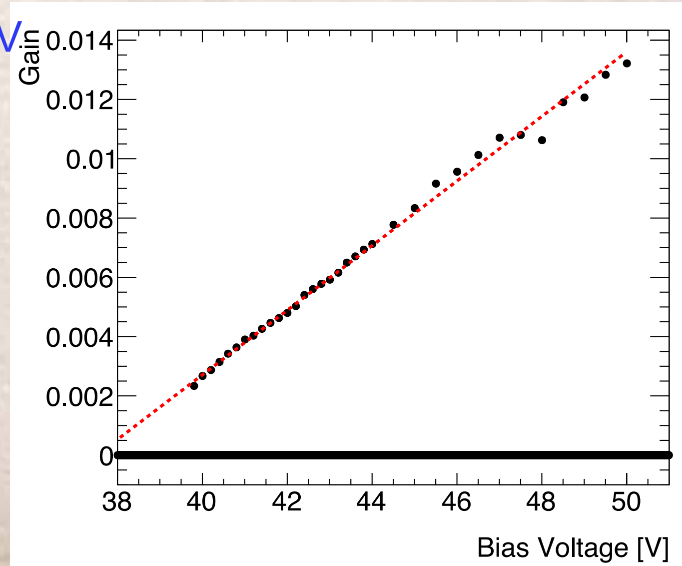
S14160-3010

slope=0.0005/V
V_b=38.5 V



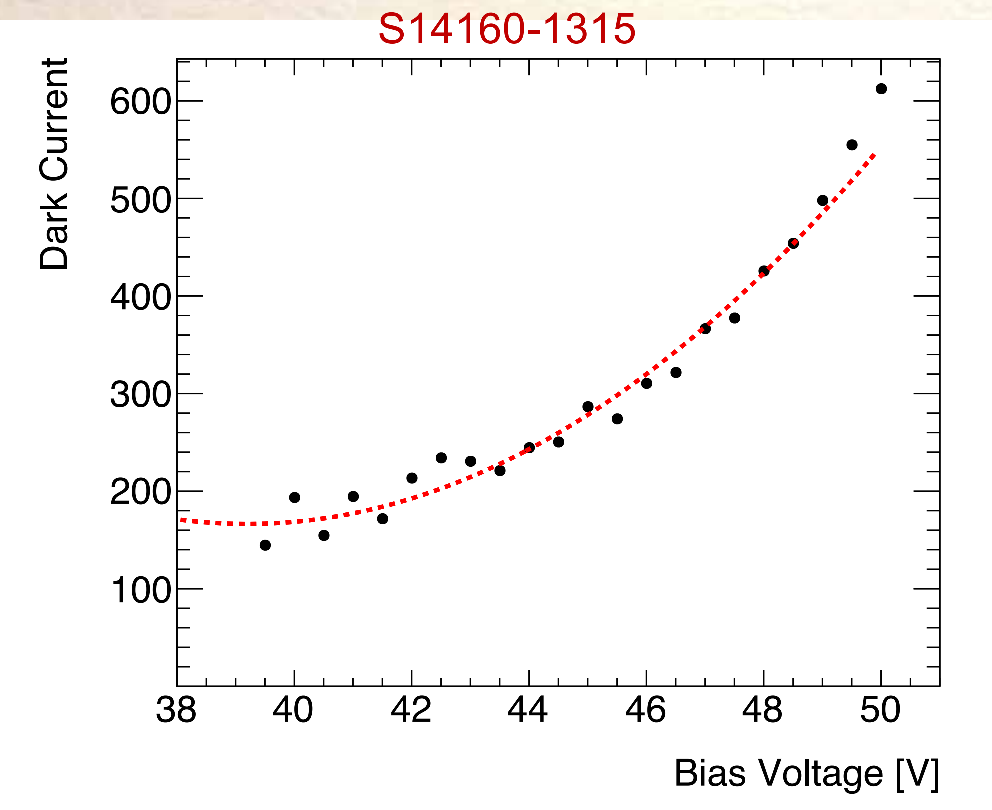
S14160-3015

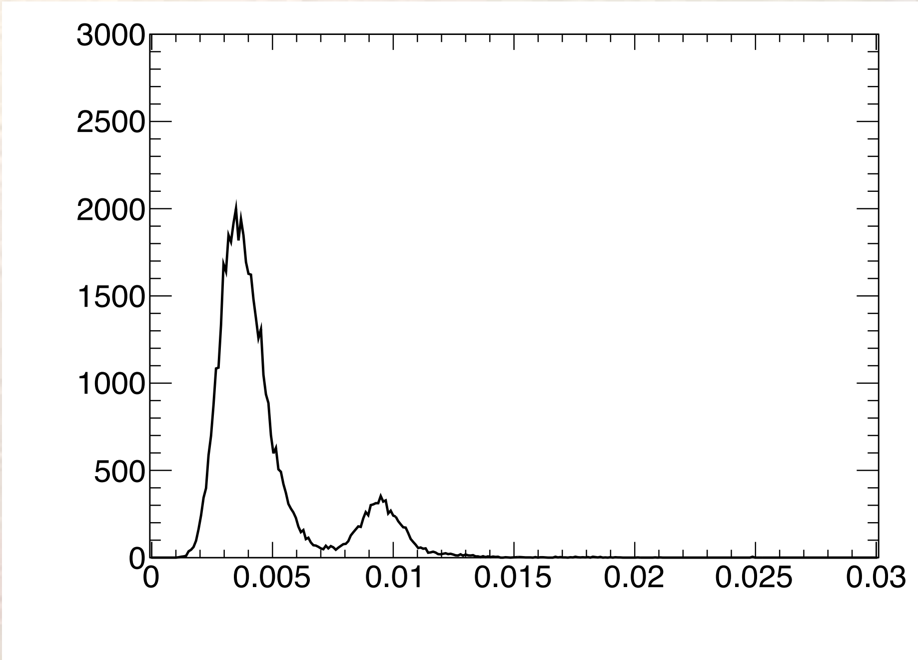
slope=0.0011/V
V_b=37.5 V



Dark Current vs Reverse Bias Voltage

- Determine dark current from minimum of the waveform without source
- Dark current increases rapidly with increased reversed bias voltage
- Fit is second-order polynomial

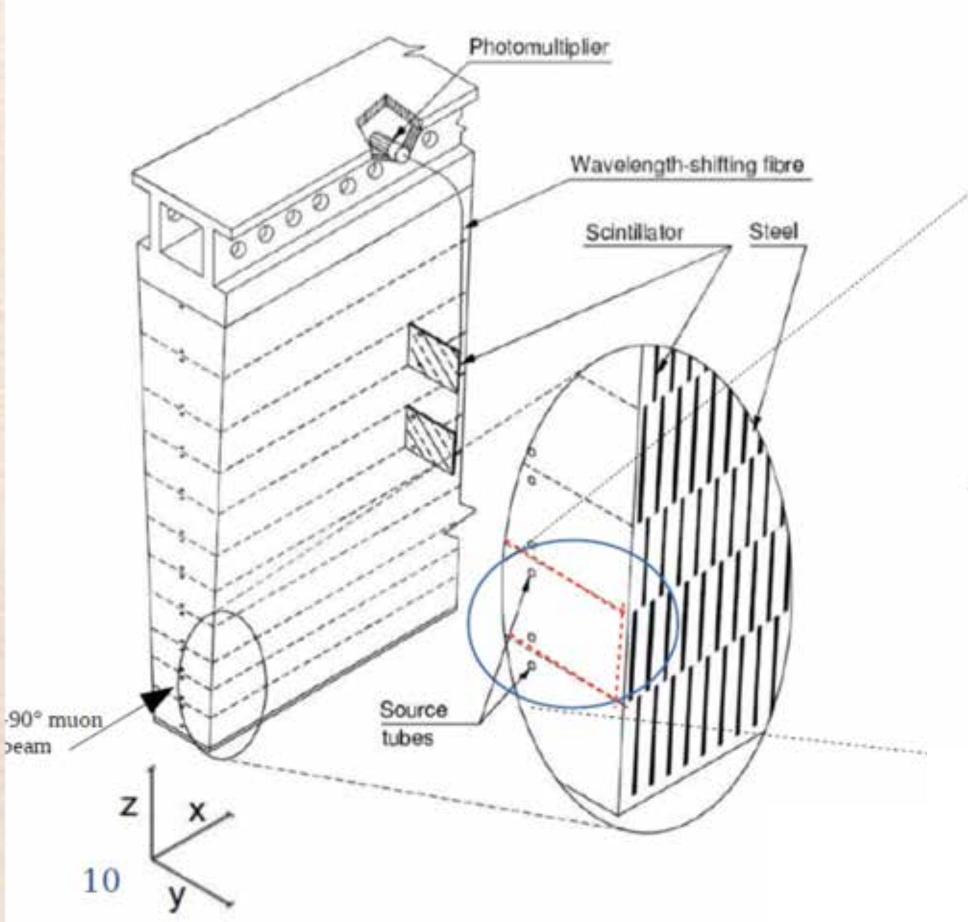


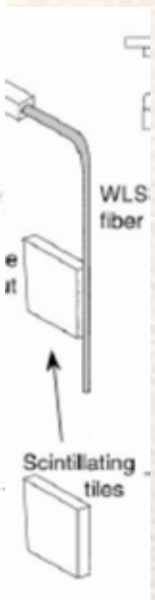


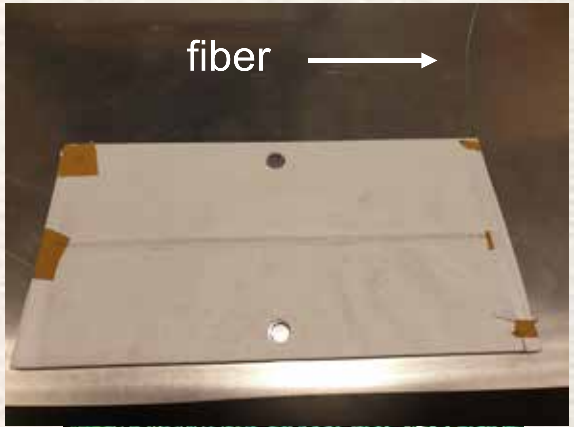
- We measured dark currents of the other S14160 sensors, but analysis is not yet finished

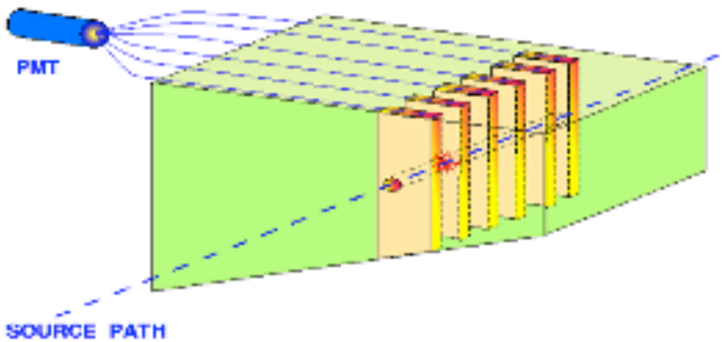
ATLAS Tile Calorimeter

- The ATLAS Tile Calorimeter is a sandwich of scintillating tiles read out by wavelength-shifting fibers and PMTs and steel absorber plates









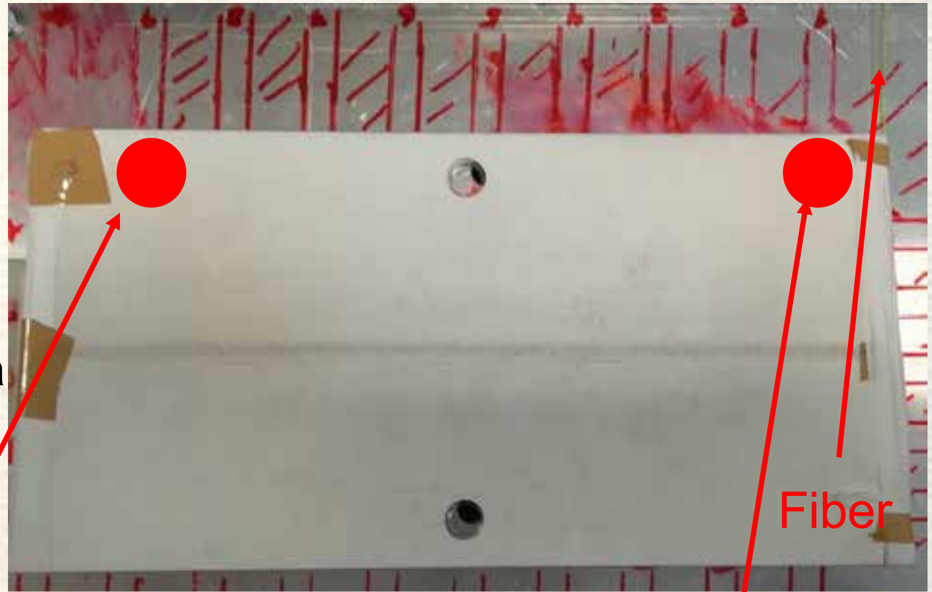
- ATLAS use 3 tile sizes
- Tiles are slightly tapered
- A Y11 fiber is coupled by air gap to the tile
- A bundle of fibers is read out by PMT
- Some tiles have a hole to shoot ^{137}Cs source through

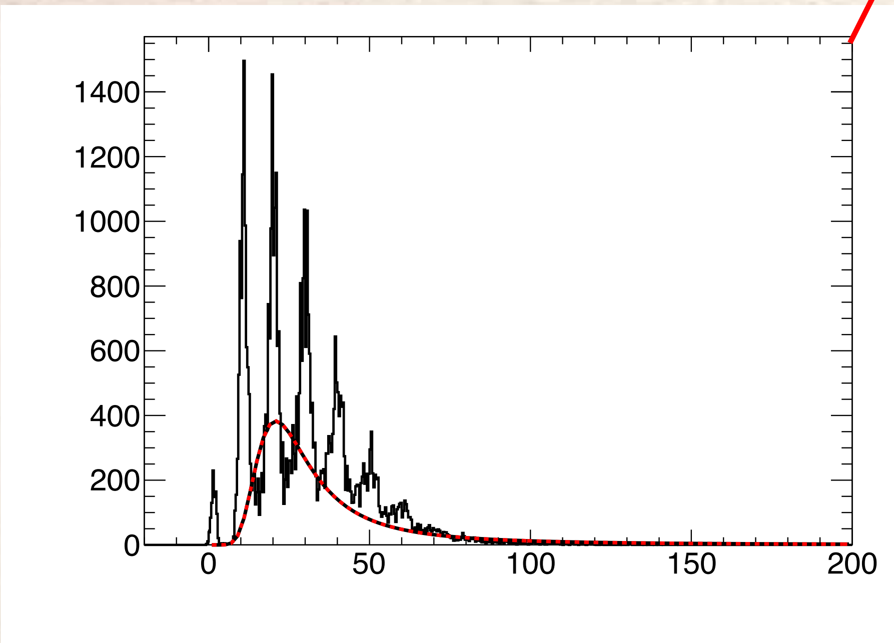
Tile	Size [cm^2]
small	12x 26
medium	14.5x30
big	18.5x35

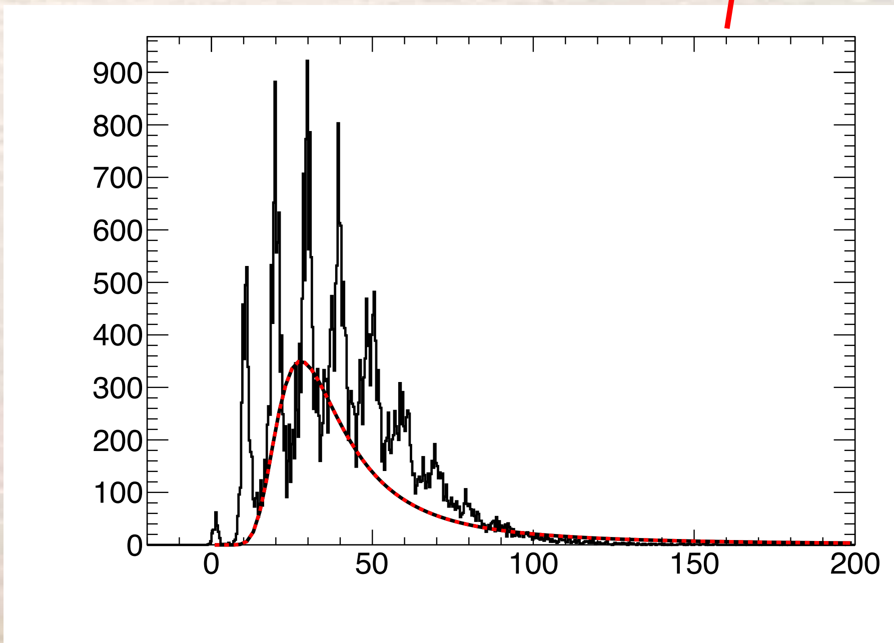
ATLAS Tile Uniformity Measurements

- Place tile a table that has arrangement of holes in a grid ➔ allows source to be held in a number of different locations on the tile

- At each location extract photoelectron (PE) spectra by taking minimum of each of 50,000 triggered waveforms and plotting spectra that are fitted to a Landau distribution after subtracting the position of the pedestal

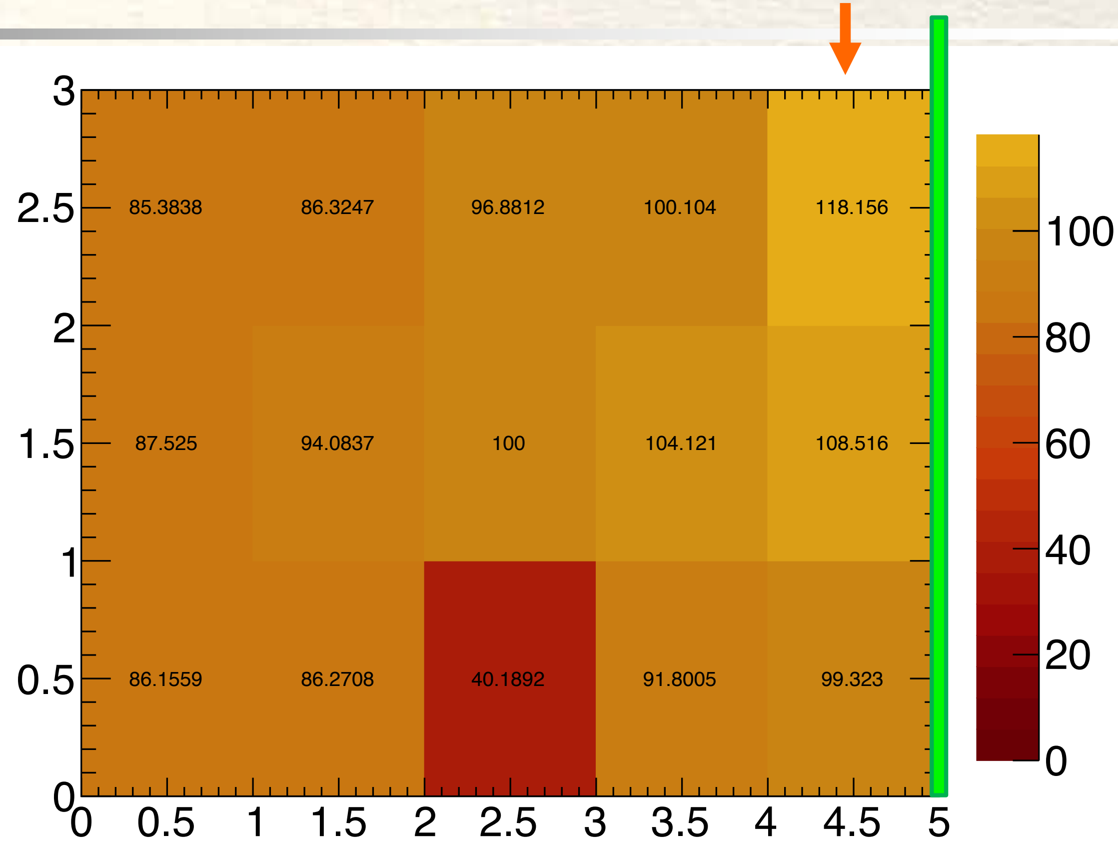


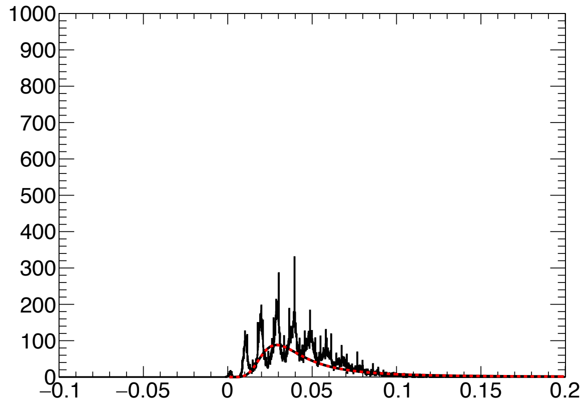




Uniformity of ATLAS Small Tiles

- Plot the most probable value of the fitted Landau distribution normalized to the value at the center position
- Note that the most probable value increases closer to where the fiber is located (i.e. see more PE peaks on average)
- MIP peak is around 3-4 photoelectrons





Uniformity of ATLAS Small Tiles

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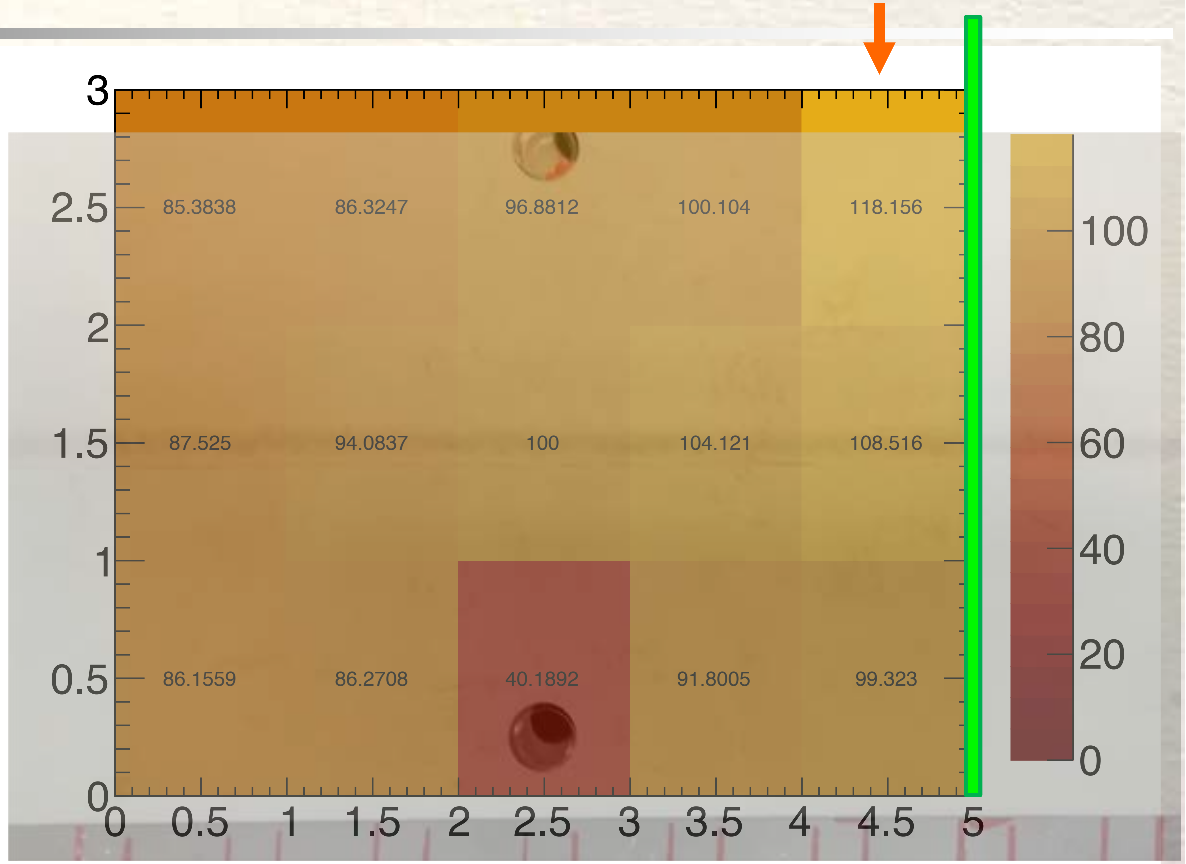
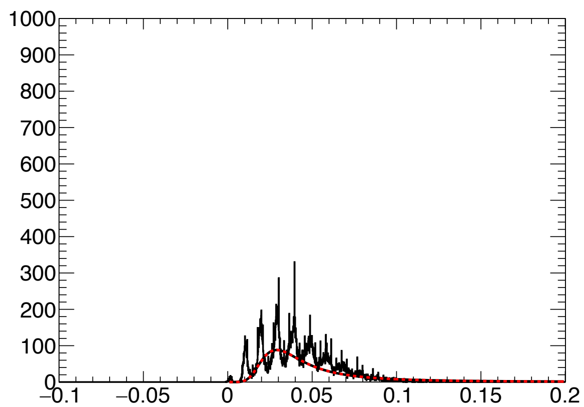
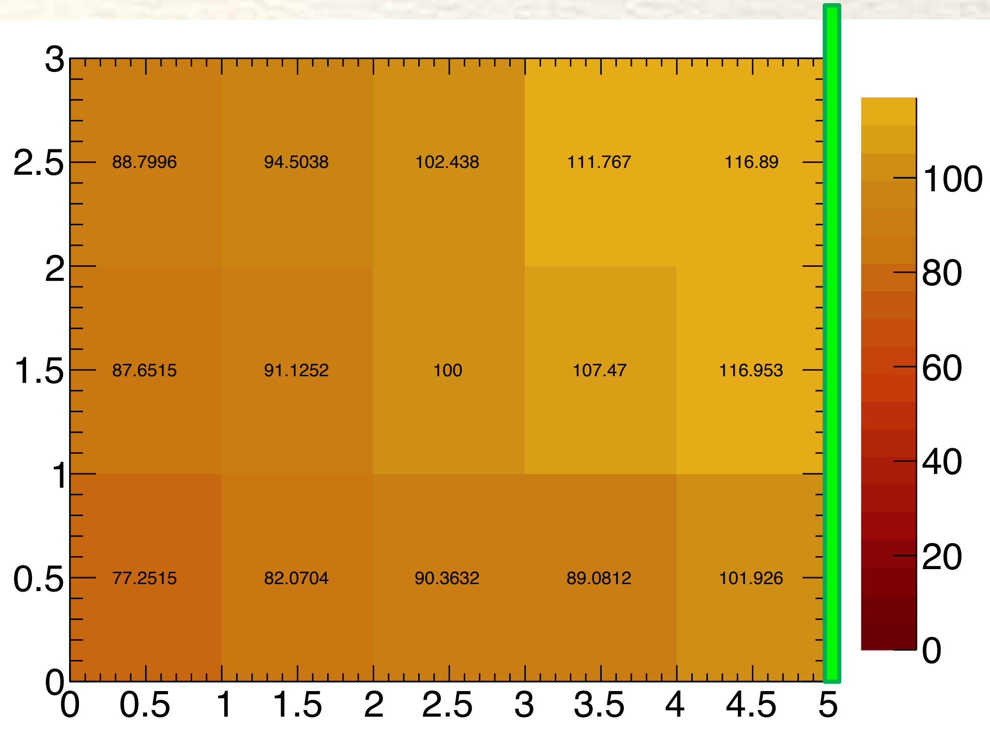
- Note that the most probable value increases closer to where the fiber is located (i.e. see more PE peaks on average)
- MIP peak is around 3-4 photoelectrons
- Note that the hole in the tile has a large affect on the light collection

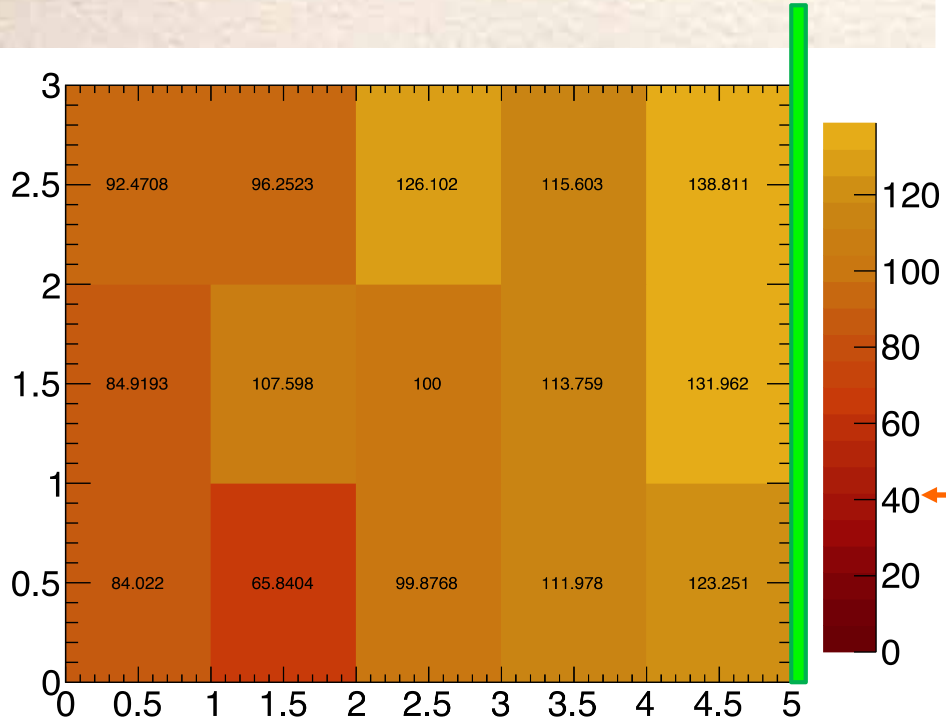


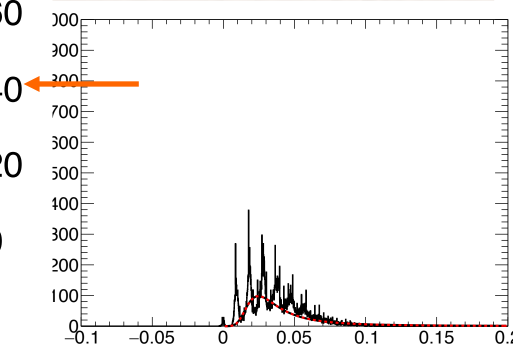


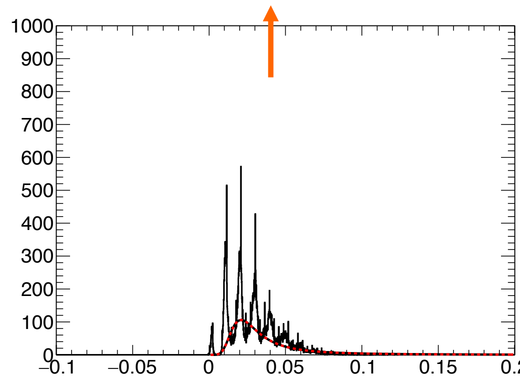
Uniformity of ATLAS Medium & Large Tiles

- Except positions with a hole, light yield is rather uniform for all tiles (~±15%)
- We measured uniformity of three tiles of each size ➔ uniformity of other tiles agrees with the results shown
- Light yield of all tiles is large enough to read out the TileCal with MPPCs









Conclusions and Outlook

- Performance of hexagonal tiles looks promising
  - Readout with fiber gives highest light yield, uniformity within 10% except near sensor
  - Tiles with center/side readout need larger dimple, uniformity within 6-7% except near sensor
- Performance of square tiles with fiber (side) readout looks fine
  - Uniformity is within ±7% (±13%) except for position close to MPPC
  - Need sufficiently large dimple for center and side readout
- First test of 4th generation MPPCs, 14160 series
  - Gain of S14160 sensors is linear with V_b between 40 and 50 V
  - Dark current increases rapidly with V_b
  - Both fixed S14160-1310 MPPCs work fine
- Different-size ATLAS tiles with present fiber couplings can be read out with MPPCs
  ➔ MIP peak produces enough photoelectrons
- Do more performance studies of hexagonal/square tiles (wrapping, RO location)
- Do further studies with new MPPCs (afterpulsing, linearity, noise, T dependence)
- Plan to read out fiber bundle of ATLAS tiles with MPCC arrays

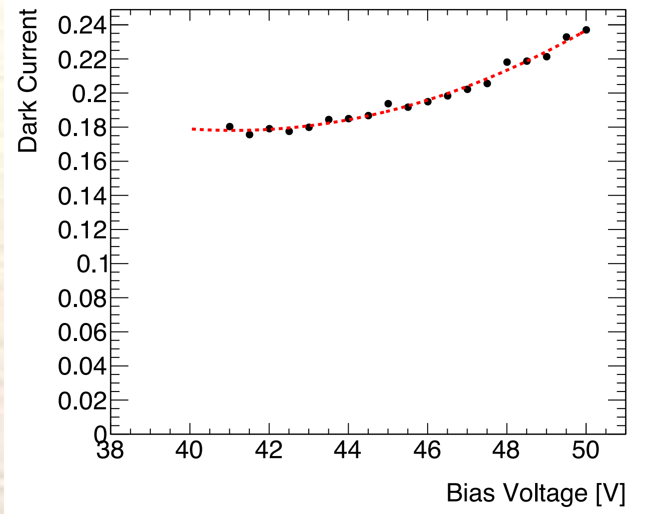
Backup

Slides

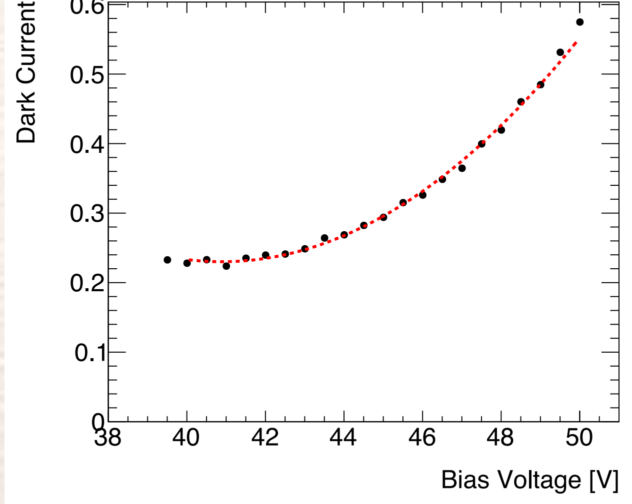
Dark Current vs Reverse Bias Voltage

- Determine dark current from integral of waveform without the source (I-V curves) and plot rms
- Fit is second-order polynomial

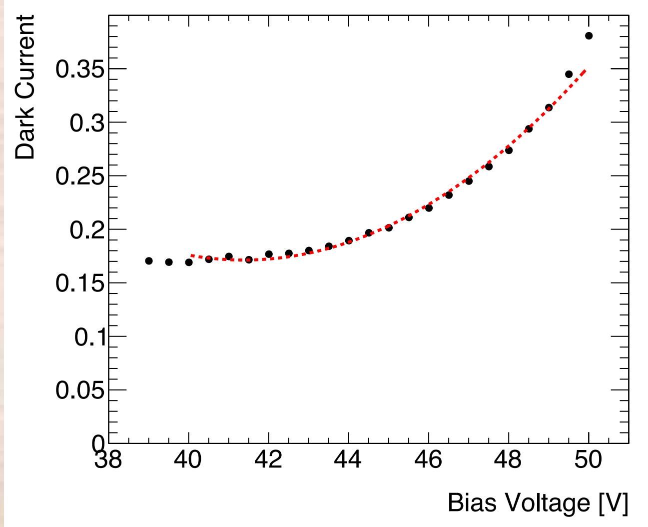
S14160-1310



S14160-1315



S14160-3010



S14160-3015