Studies of Scintillator Tiles and new MPPCs

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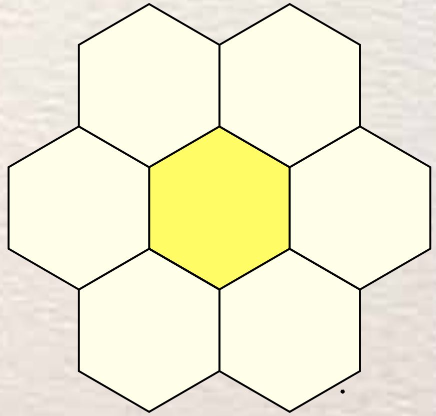
Outline

- Introduction
- Measurement setup
- Performance of 4^{th}-generation MPPCs S14160
- Uniformity measurements of hexagonal and square tiles with different readout schemes
- Plans for the ATLAS TileCal
- Conclusions and outlook

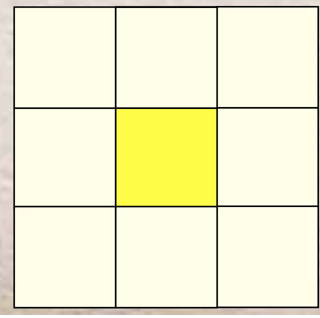
Introduction

- At the last CALICE meeting, Graham showed our uniformity measurements of ATLAS TileCal tiles with SiPM readout
  - We got interested in this because SiPM readout of TileCal tiles provides more details on hadron shower shapes than the collective readout with a PMT ➔ If successful this justifies a proposal for a TileCal upgrade and it provides a new approach for hadron calorimeters at future hadron colliders
  - Brief discussion of our plans



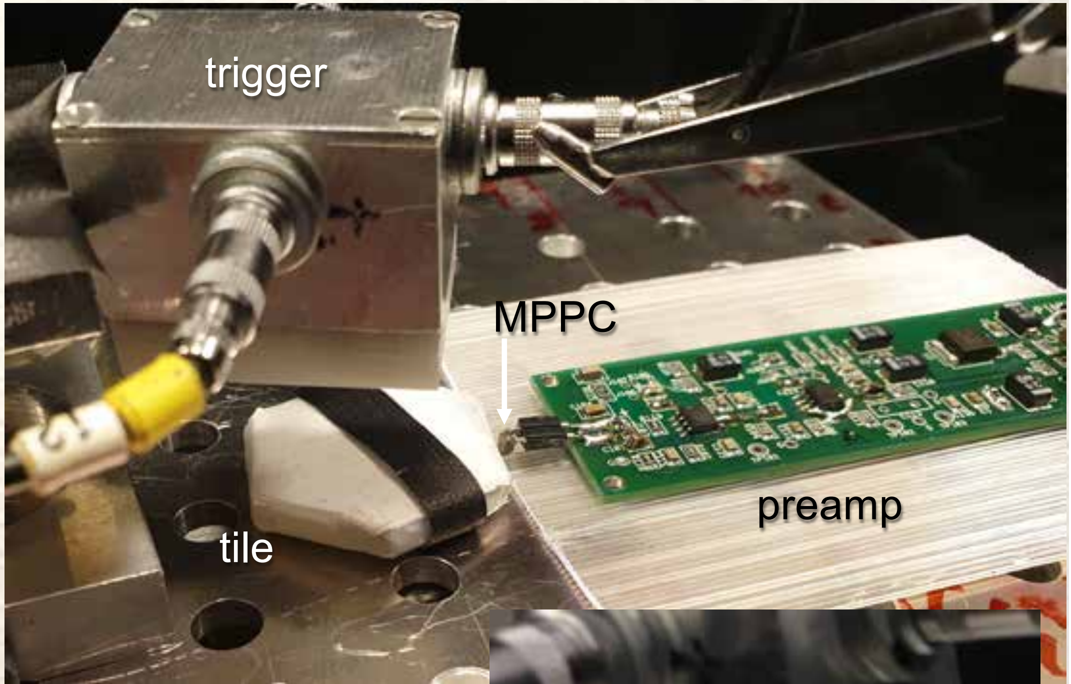
- Graham also showed first uniformity measurements of hexagonal tiles read out with MPPCs
  - We consider them for an AHCAL since less tiles need to summed over wrt square tiles ➔ better S/N
  - Show light yield of hexagonal tiles with 3 SiPM readout schemes compared to that of square tile

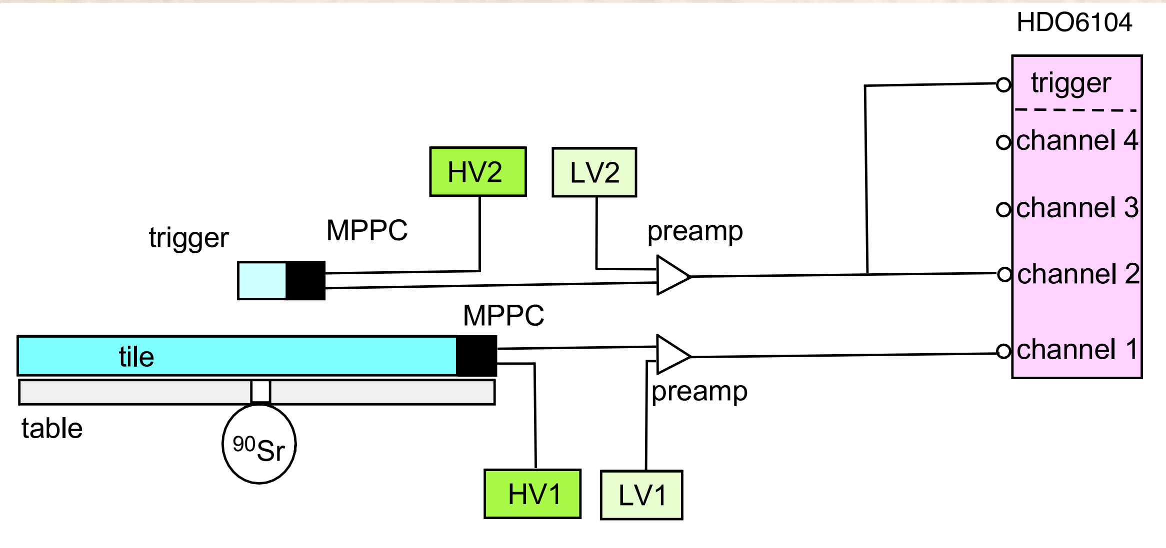
- In the fall 2019, we started to test 4th generation MPPCs from Hamamatsu
  - Gain versus bias voltage
  - IV curves
  - noise
  - afterpulsing



Measurement Setup

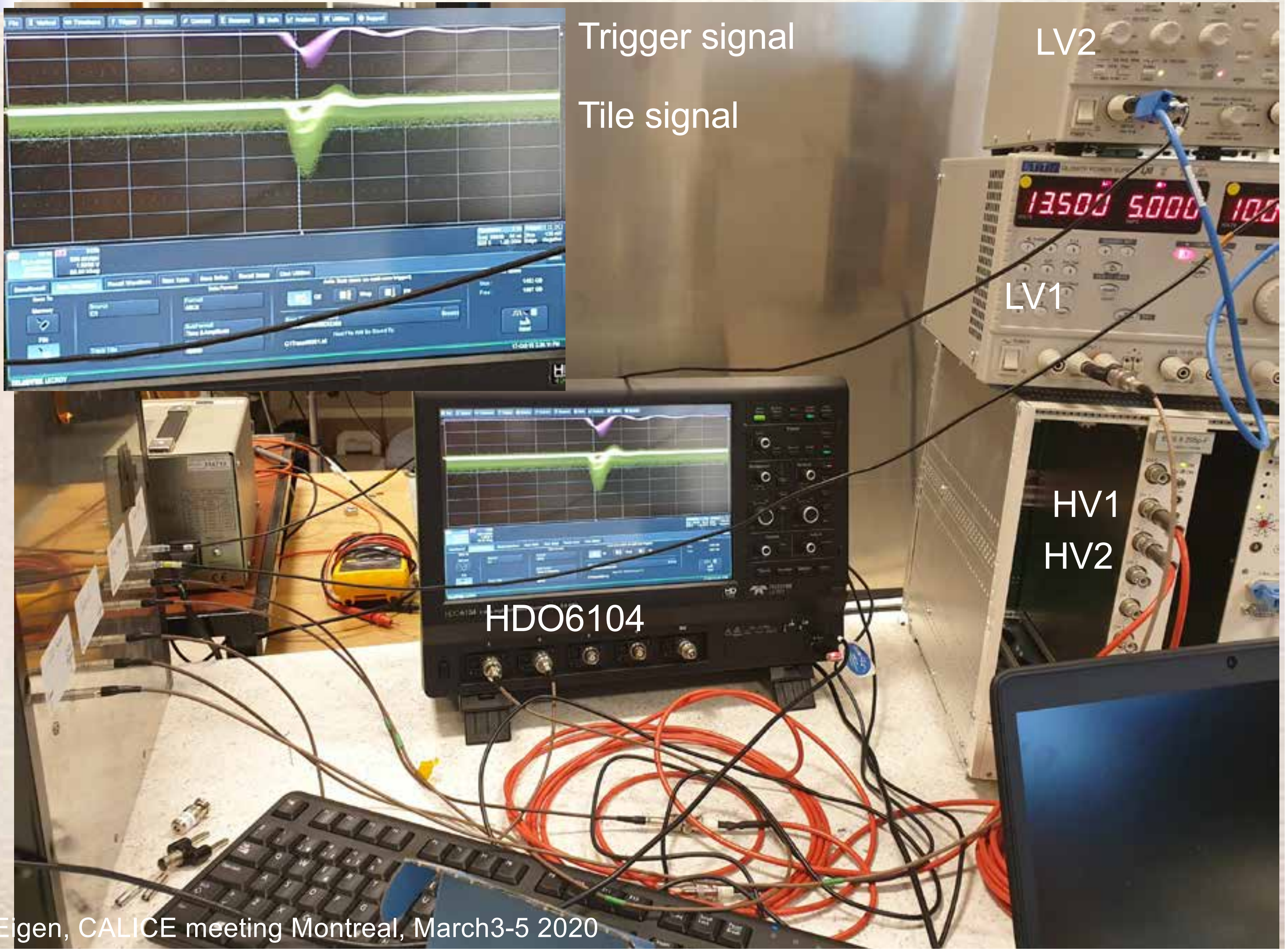
- Work in black box
- Use MIP of electrons from ^{90}Sr source
- MPPC is loosely coupled to tile
- Trigger on second tile
- Record 50k waveforms





Signal Recording

- Take 50k wave-forms in a run
-

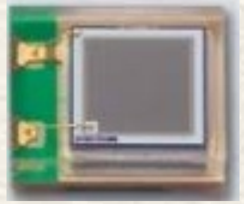


Properties of 4th Generation MPPCs S14160

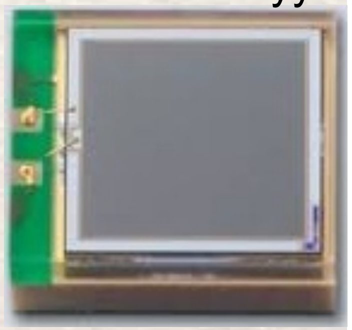
- We have 11 working MPPCs from Hamamatsu (2 of each type)

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	1.8x10^5	1.8x10^5	3.6x10^5	3.6x10^5
C at Vop	100 pF	530 pF	100 pF	530 pF

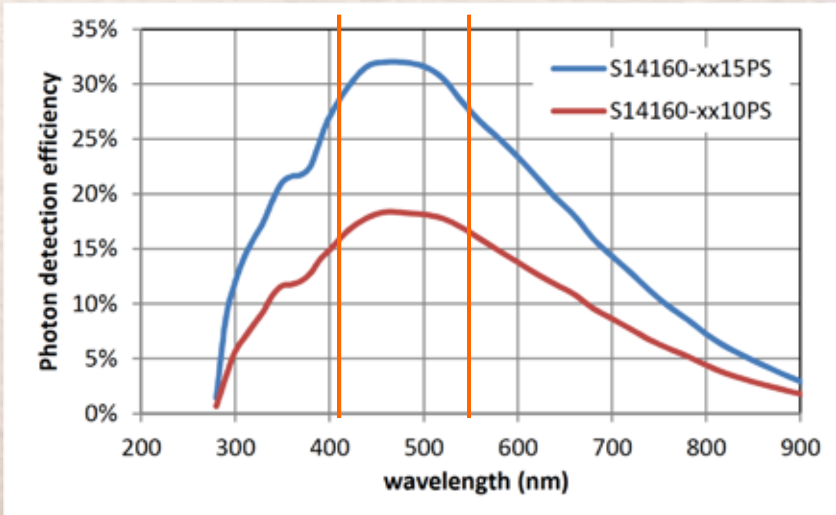
S14160-13yy



S14160-30yy

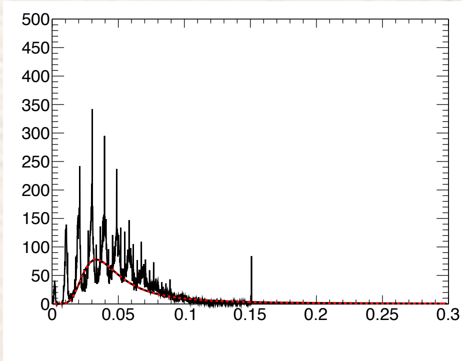


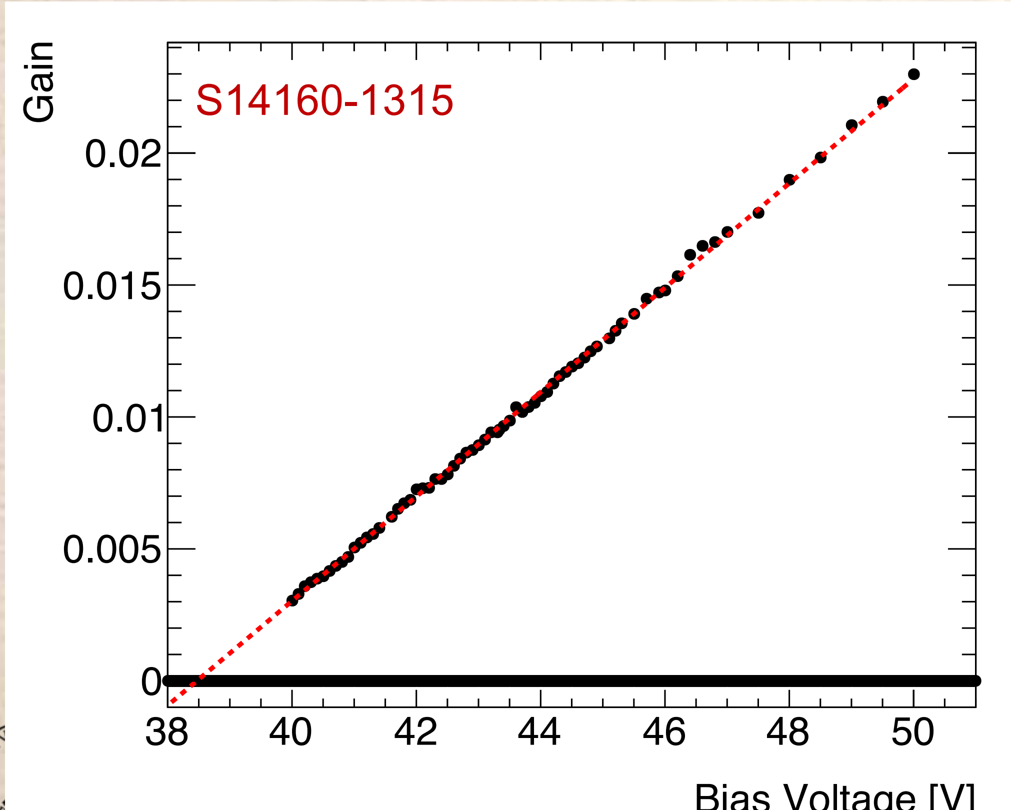
- Photodetection efficiency is high for green light from Y11 fiber and UV light from BC404
- BC404 has maximum wavelength at 408 nm
- Photon detection efficiency of 10 μm pixel is about half of that of the 15 μm pixel sensors



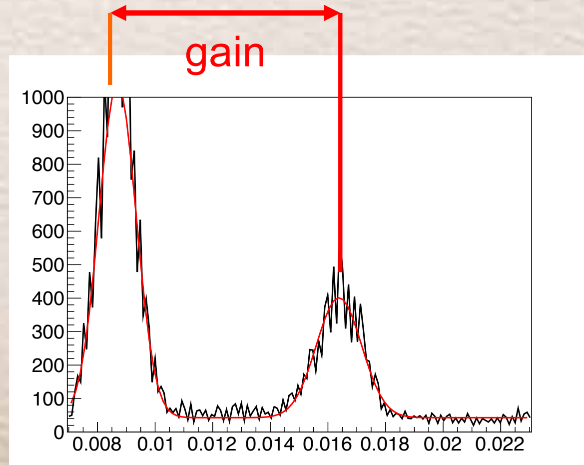
Gain versus Reverse Bias Voltage V_b

- Use ^{90}Sr source on hexagonal tile read out with fiber and S14160
- Determine peak of photoelectron distribution
- Extract gain from distance between 2 adjacent photoelectron peaks
- Gain can be fitted with linear dependence, slope = 0.002/V
- Deviations from line may come from small temperature fluctuations





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

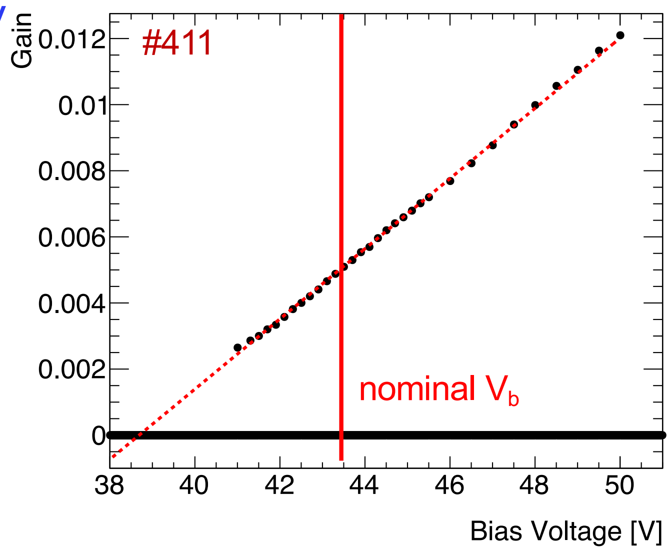


Gain versus Reverse Bias Voltage V_b

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

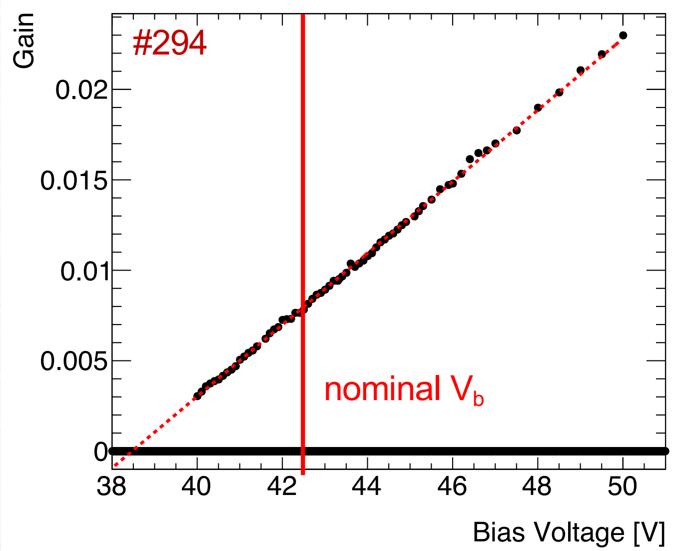
S14160-1310

slope=0.00106/V
V_{break}=38.5 V



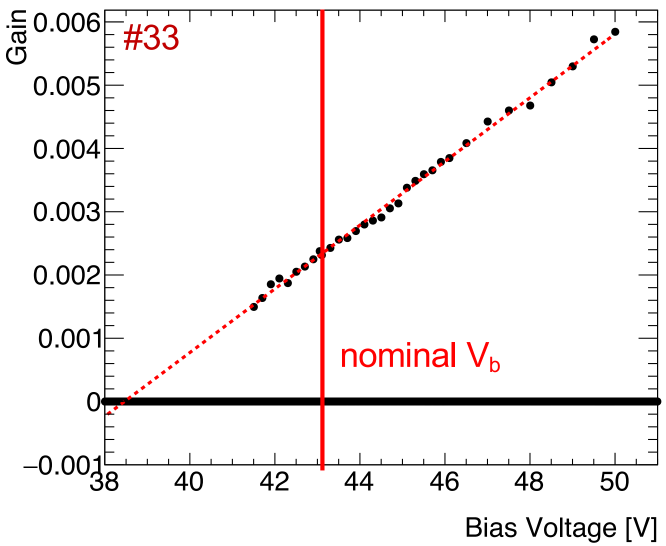
S14160-1315

slope=0.002/V
V_{break}=38.5 V



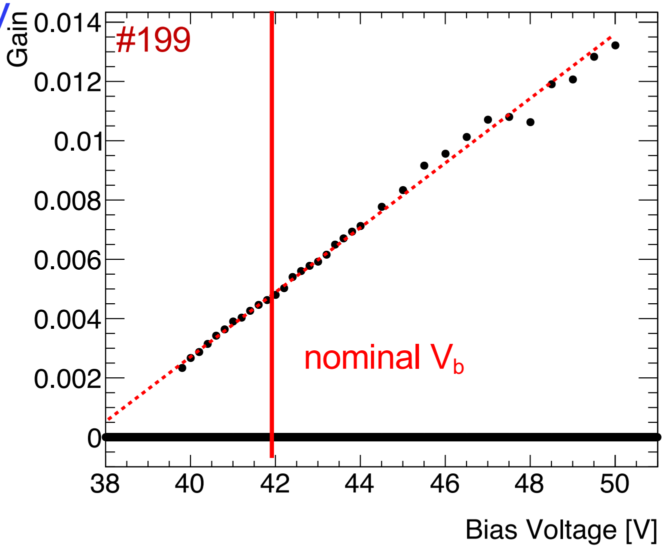
S14160-3010

slope=0.0005/V
V_{break}=38.5 V



S14160-3015

slope=0.0011/V
V_{break}=37.5 V



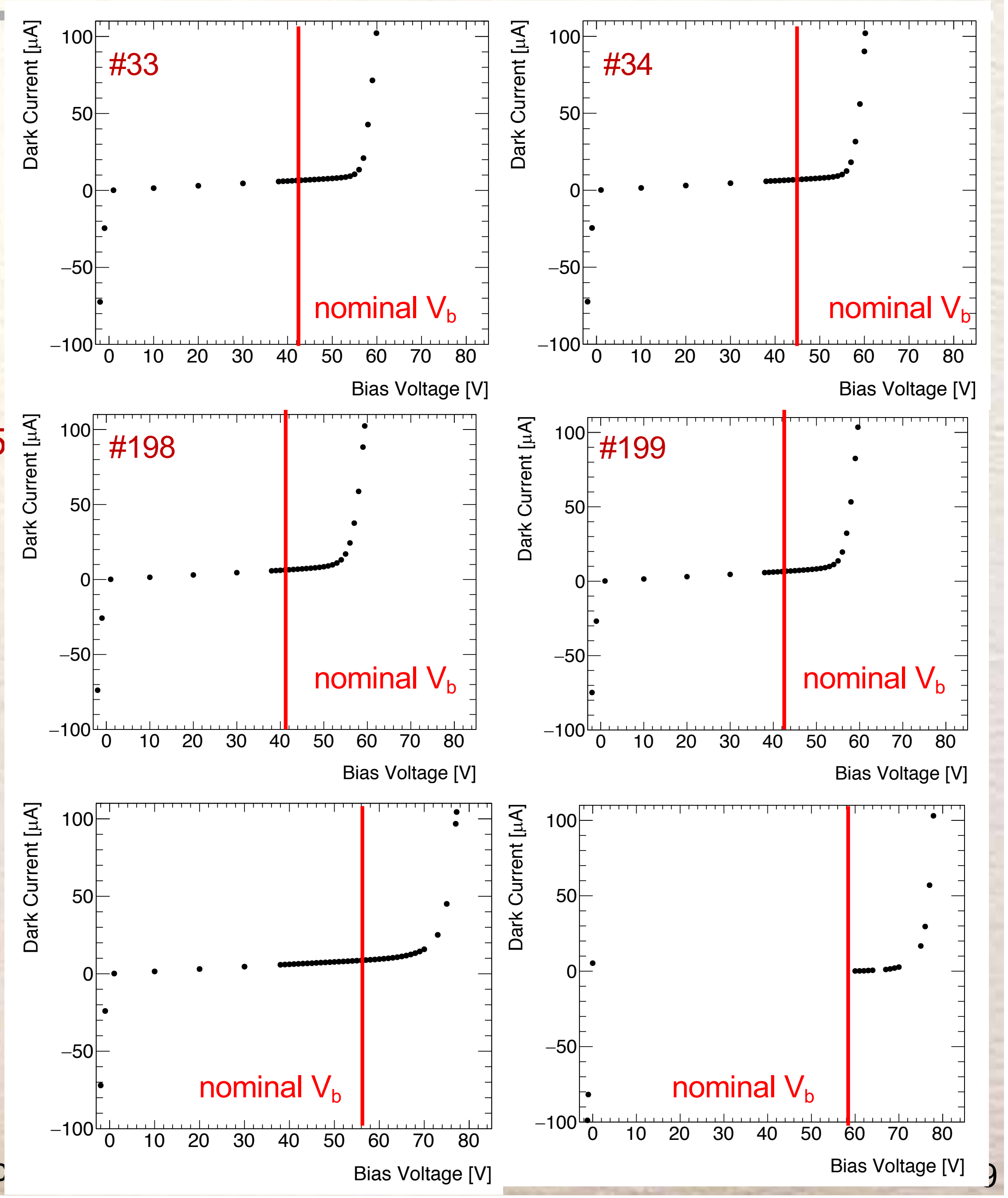
I-V Curves for S14160-3010 and S14160-3015

- Measure IV curves of S14160-3010/15 sensors in comparison to that of S13360-3025 sensors with Keithley 2400 source meter
- For the nominal V_b the dark current is rather low
- For the 4th generation MPPCs the nominal bias voltage is about 15 V lower

S14160-3010

S14160-3015

S13360-3025



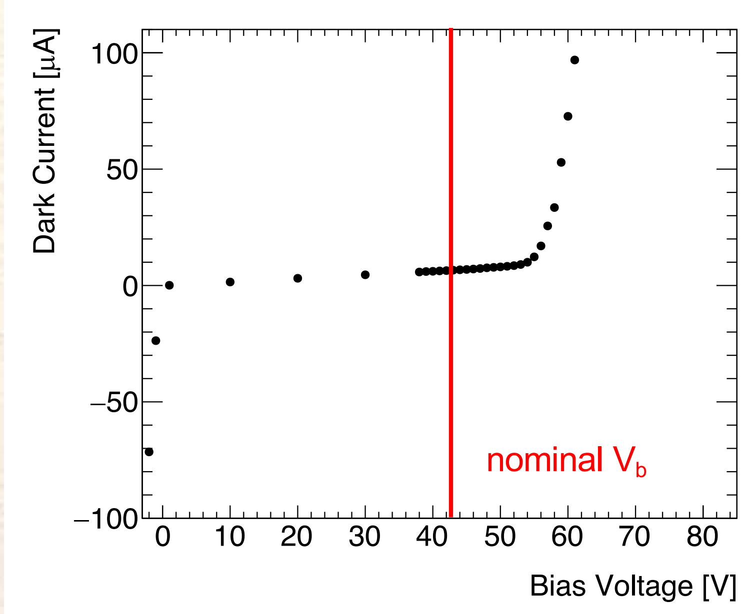
I-V Curves for S14160-1310 and S14160-1315

- Measure IV curves of S14160-3010/15 sensors with Keithley 2400 source meter
- Since one sensor is in Prague and the other one broke, we have no comparison
- For the nominal V_b, the dark current is rather low
- For the 4th generation MPPCs, the nominal bias voltage is about 15 V lower

S14160-1315

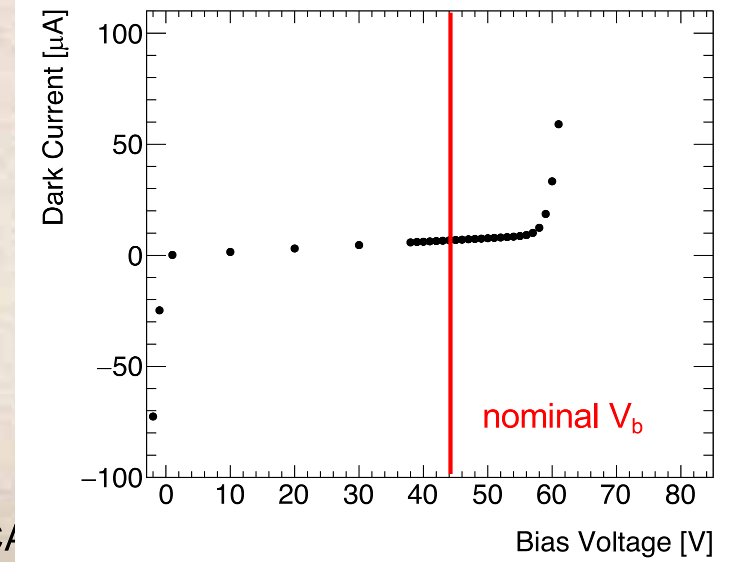
#293 is dead

#294

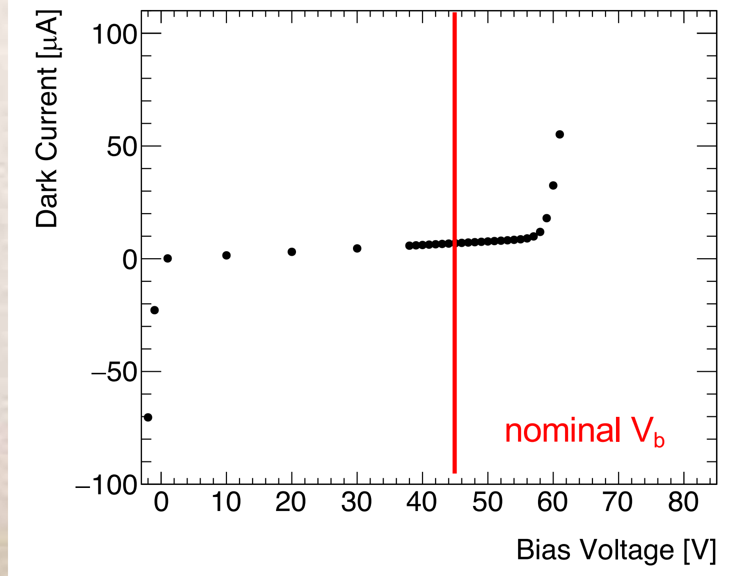


S14160-1310

#411



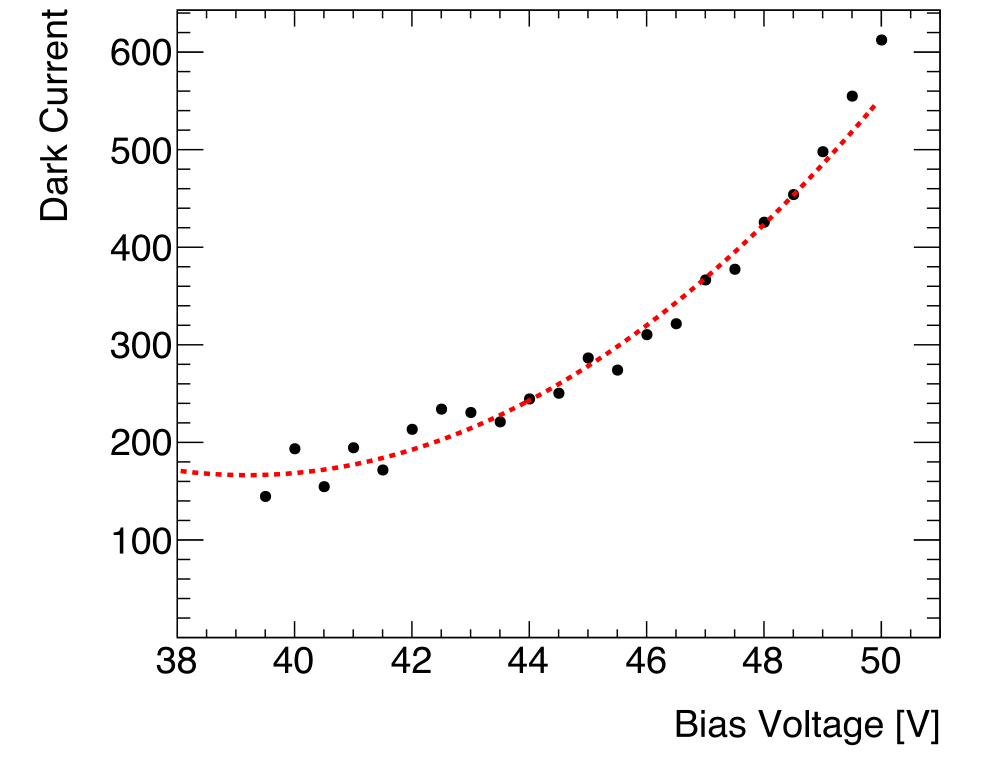
#412

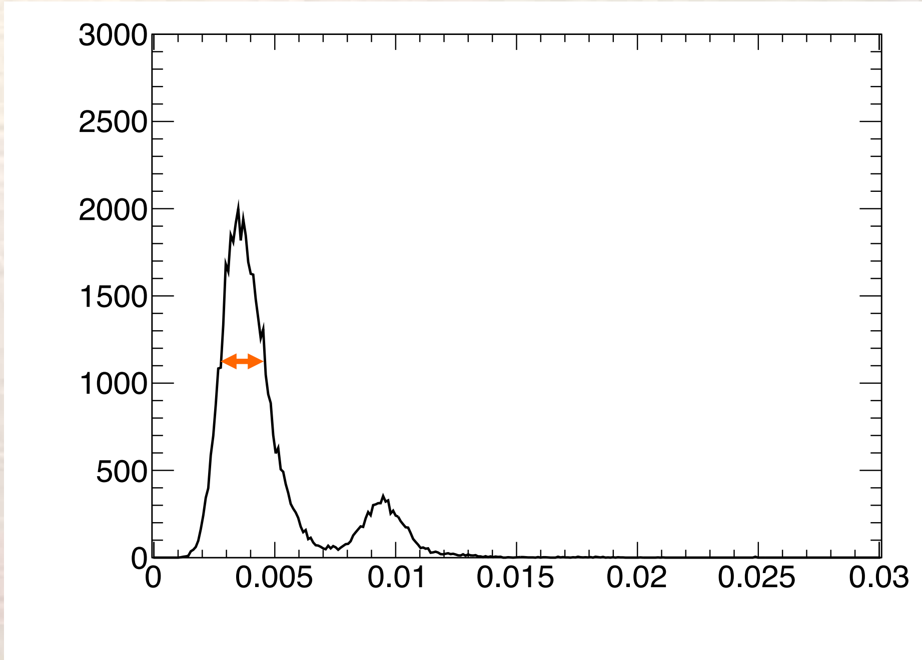


Dark Current vs Reverse Bias Voltage

- Determine noise from the rms of the photoelectron peaks without source
- Noise increases rapidly with increased reversed bias voltage
- Fit to second-order polynomial looks good

S14160-1315

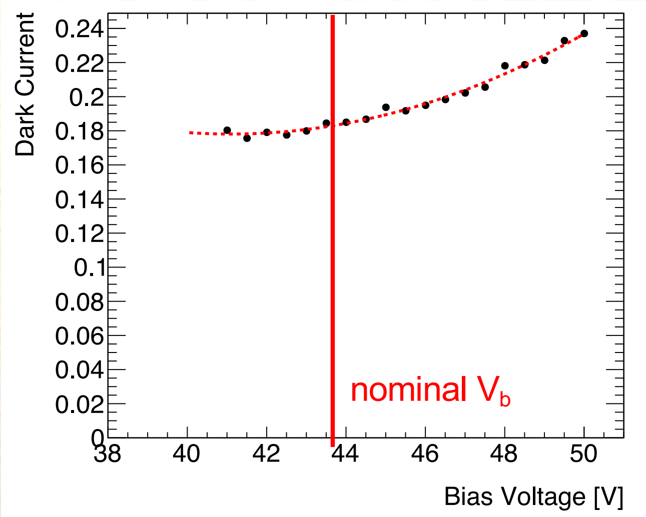




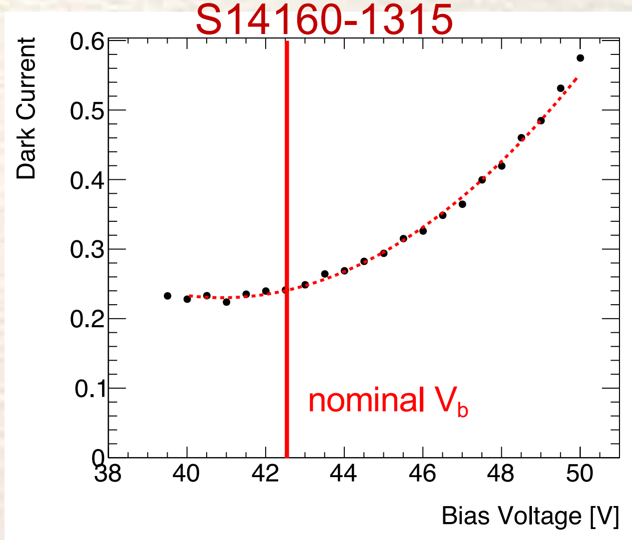
Dark Current versus V_b

- Fit single photoelectron peaks with Gaussians and plot their width as a function of V_b
- For the nominal V_b the width is close to the minimum
- For larger V_b the width increases quadratically
- Fit to second-order polynomial

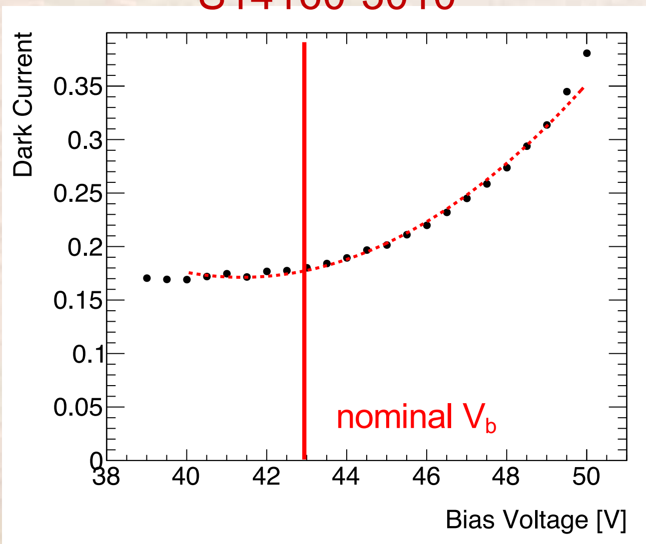
S14160-1310



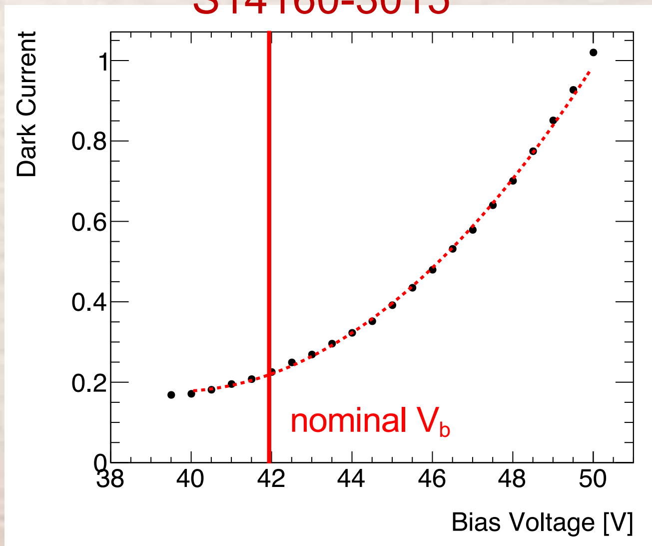
S14160-1315



S14160-3010

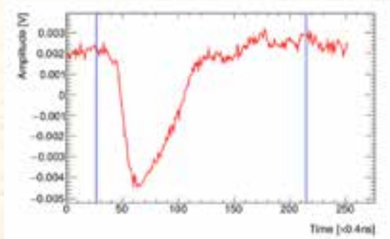


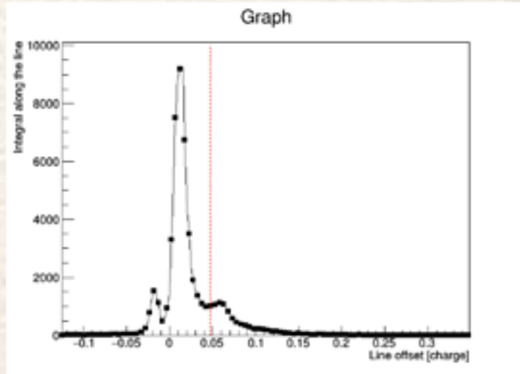
S14160-3015



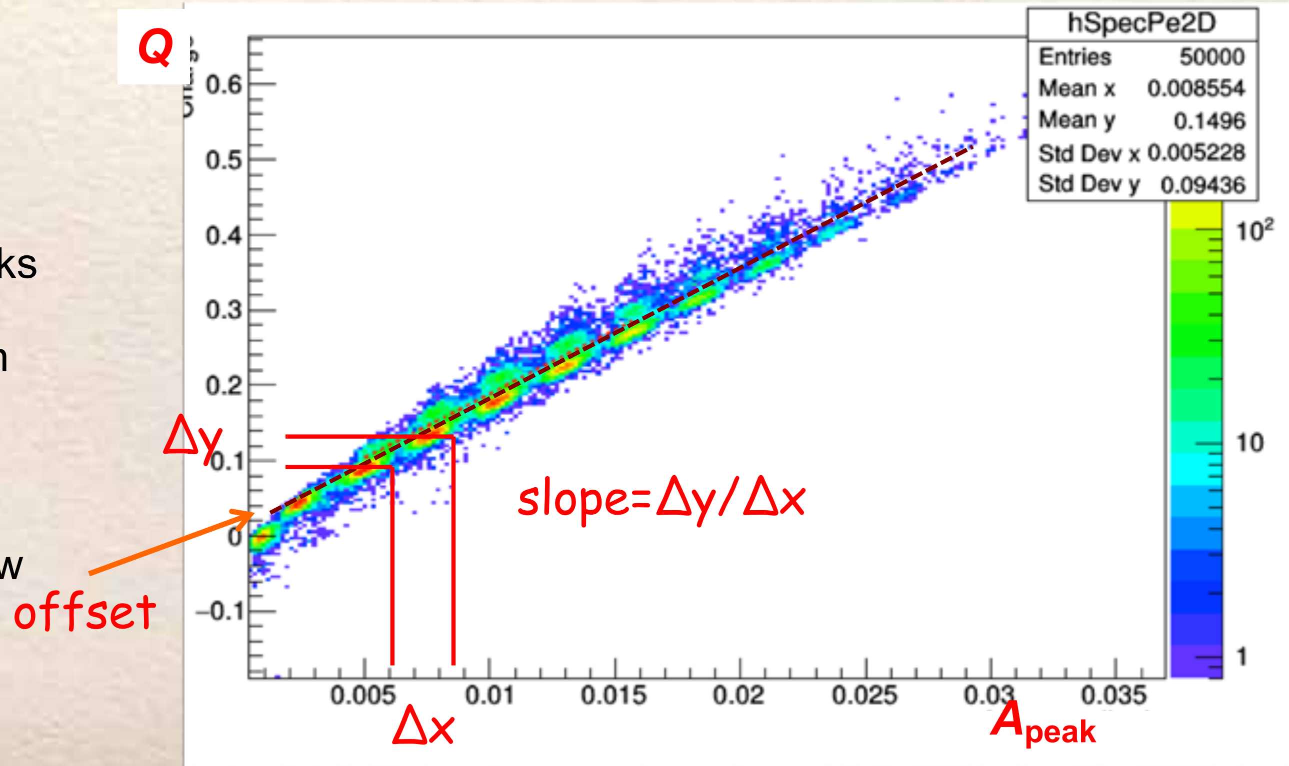
Path to Afterpulsing

- We determine the pe spectra from the waveforms in 2 ways
  - integrated charge ***Q***
  - magnitude of the peak A_{peak}



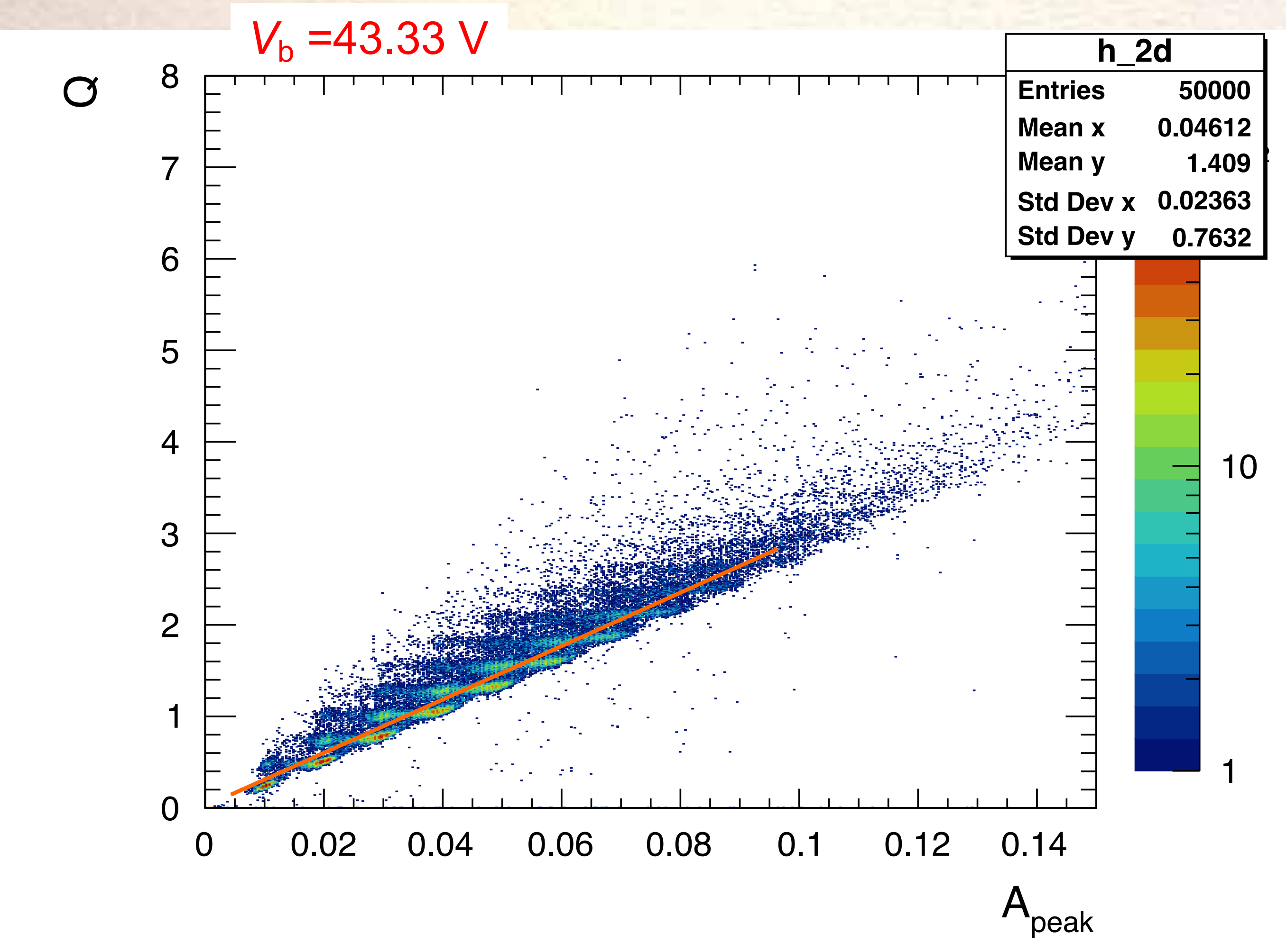


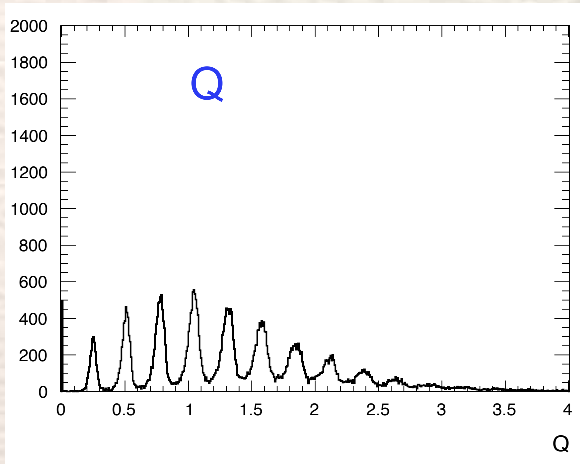
- We analyze the scatter plot of ***Q*** versus A_{peak}
- Signal without afterpulsing lies on the diagonal
- Signal with afterpulsing is shifted upwards since wave-form is broadened due to delayed secondary signal
- Set slope with 2pe & 3pe peaks
- Dashed line is chosen to be in valley between the 2 regions
  ➔ best separation
- Redo analysis for region below dashed line

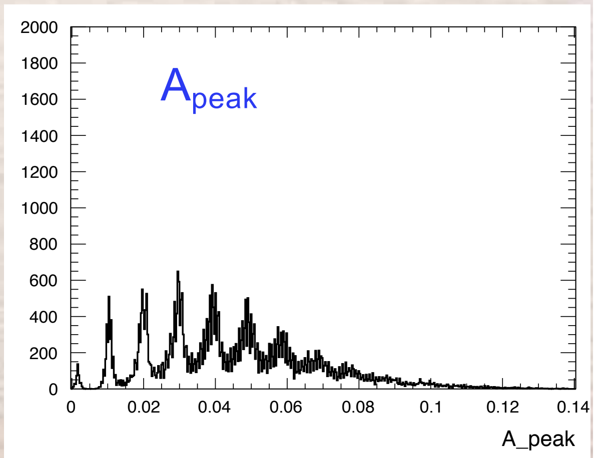


New Afterpulsing Study

- We started to look at afterpulsing for S14160 sensors, plotting Q vs A_{peak}
- We have the waveforms for all sensors from the gain measurements



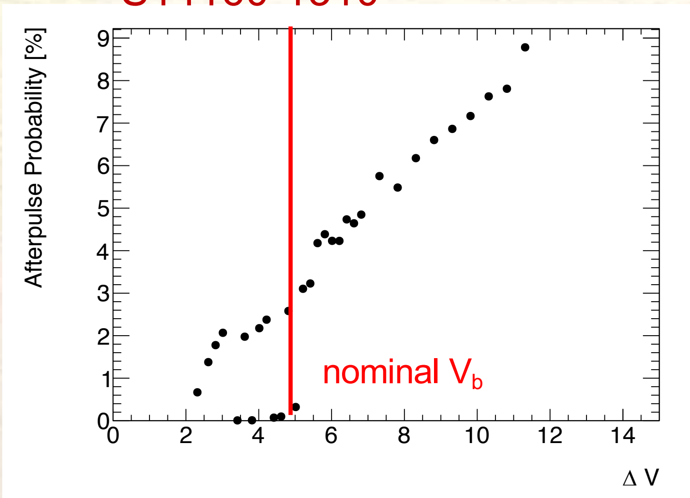




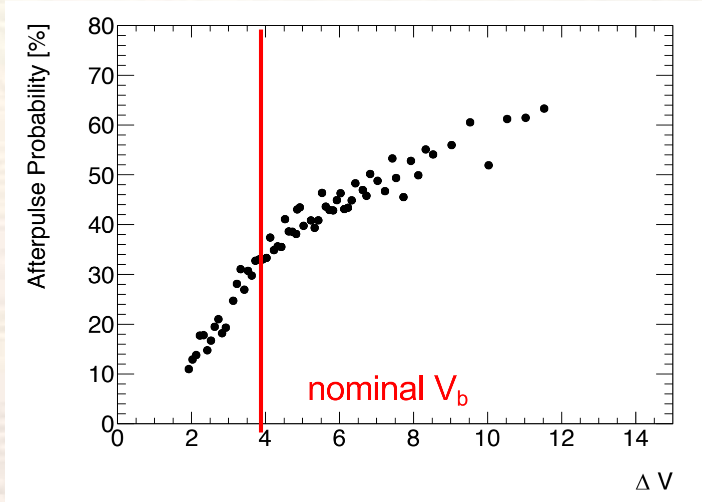
New Afterpulsing Study

- The distributions look strange, something is wrong, except for S14160-1310 afterpulsing looks very large
  I do not trust this!
- We need to check the trigger, as there seem to be uncorrelated hits
- We will remeasure these
-

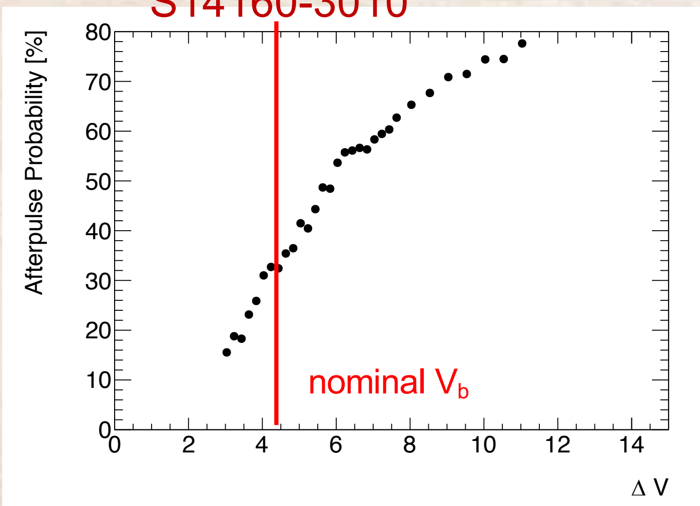
S14160-1310



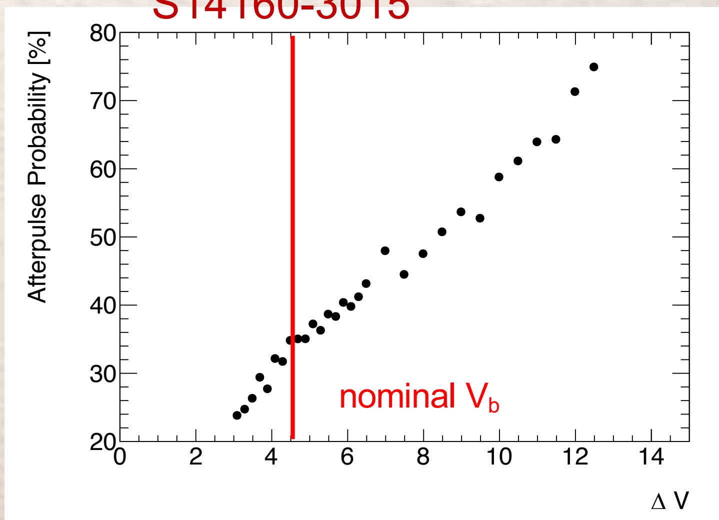
S14160-1315



S14160-3010



S14160-3015



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

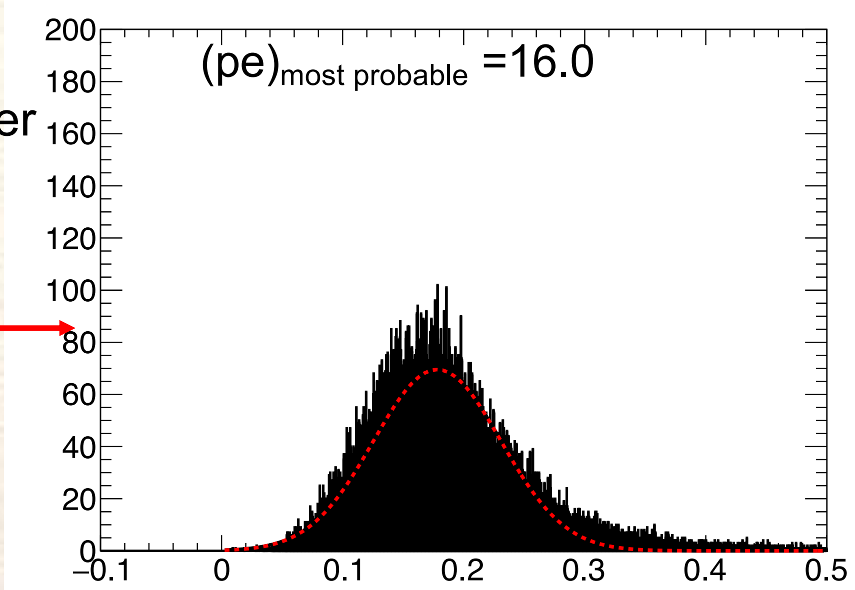
S14160-1315

S13360-3025

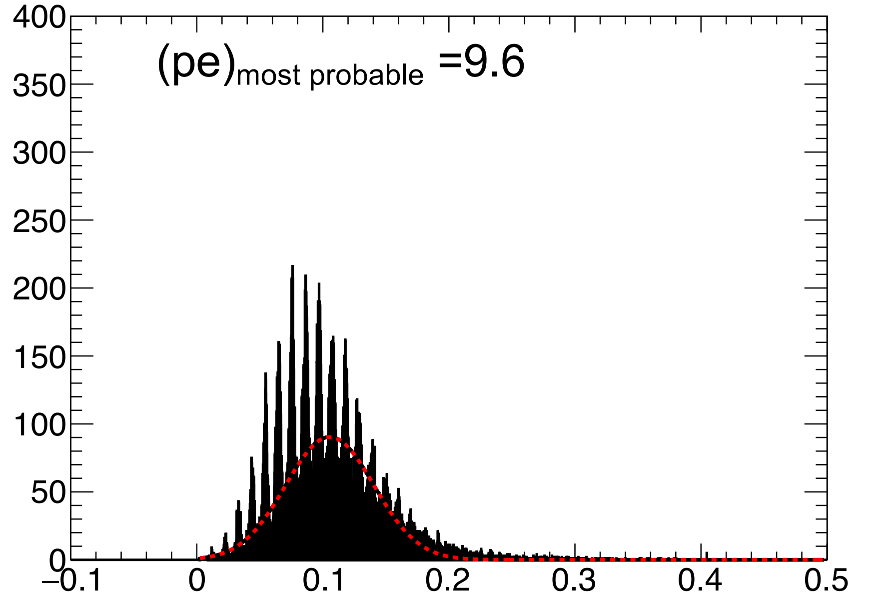
Comparison of the 3 Readout Schemes

- 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

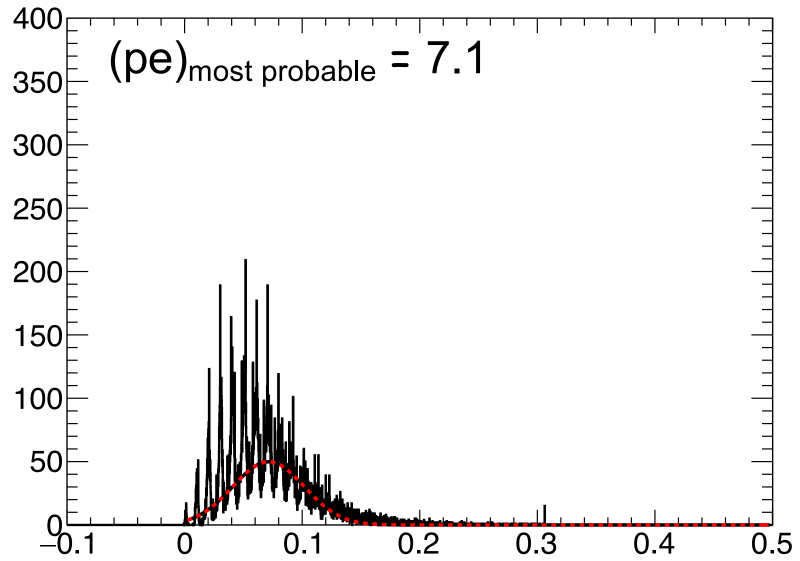
SiPM read out with fiber



SiPM's mounted on the side

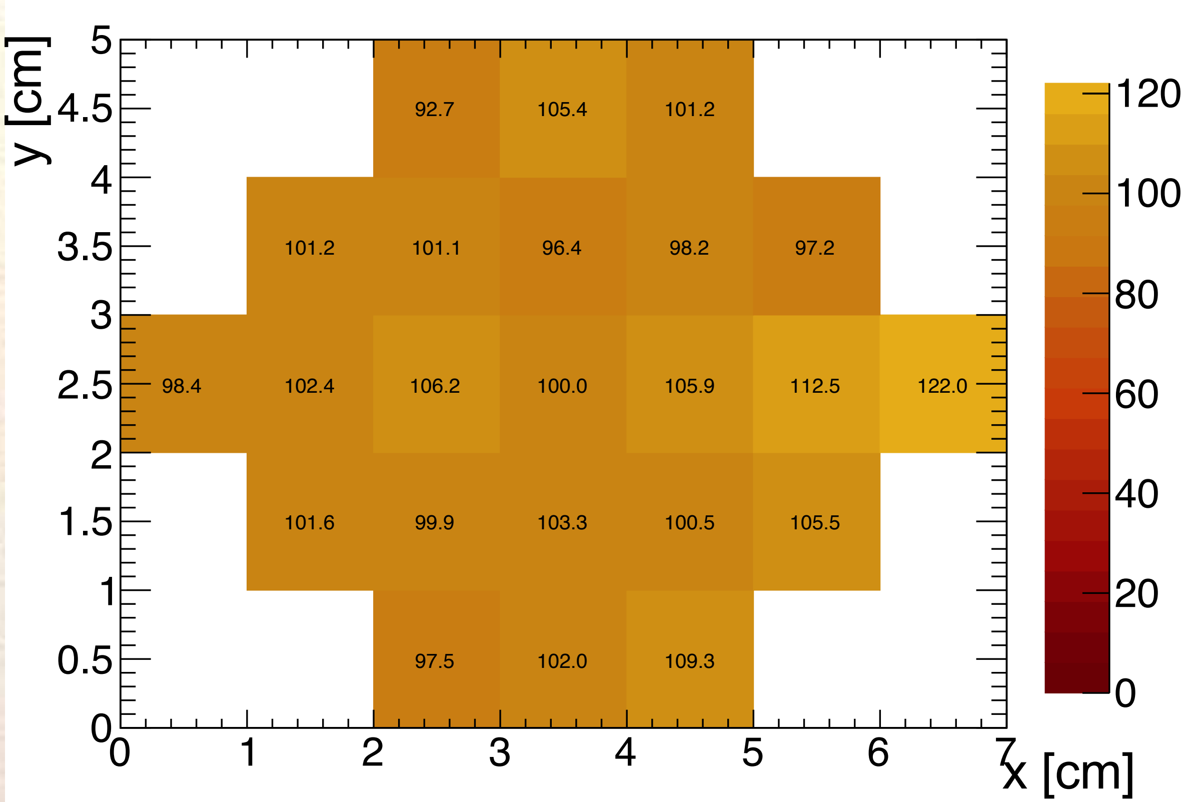


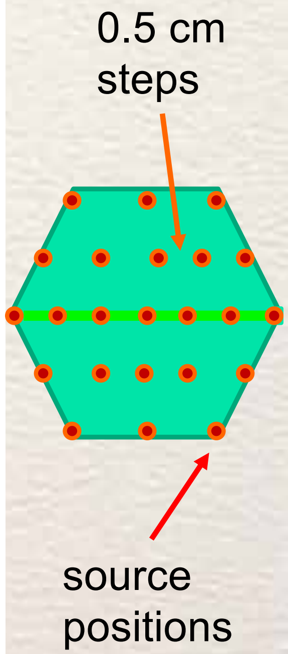
SiPM's mounted in the center

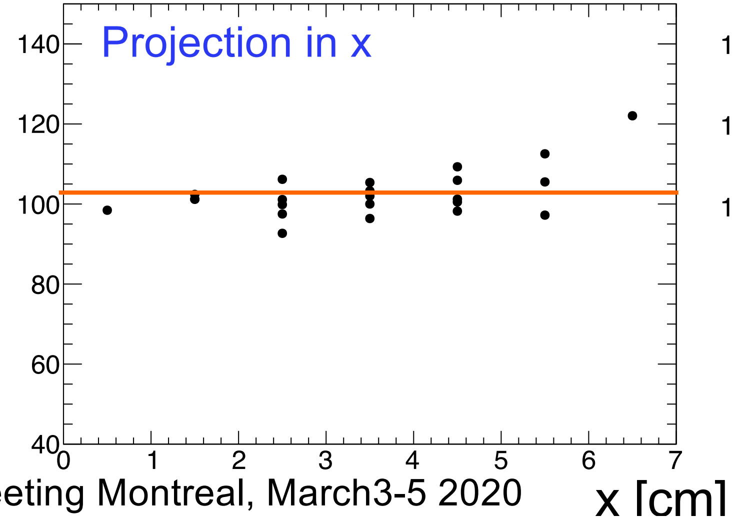


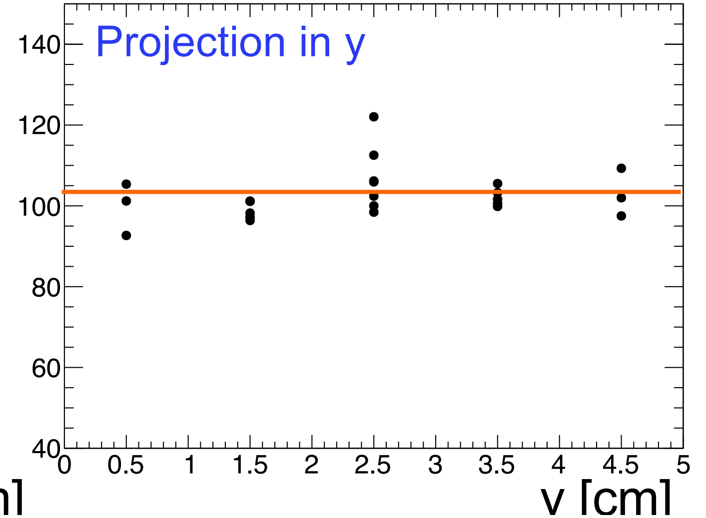
Uniformity Measurement of Fiber Readout

- 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)



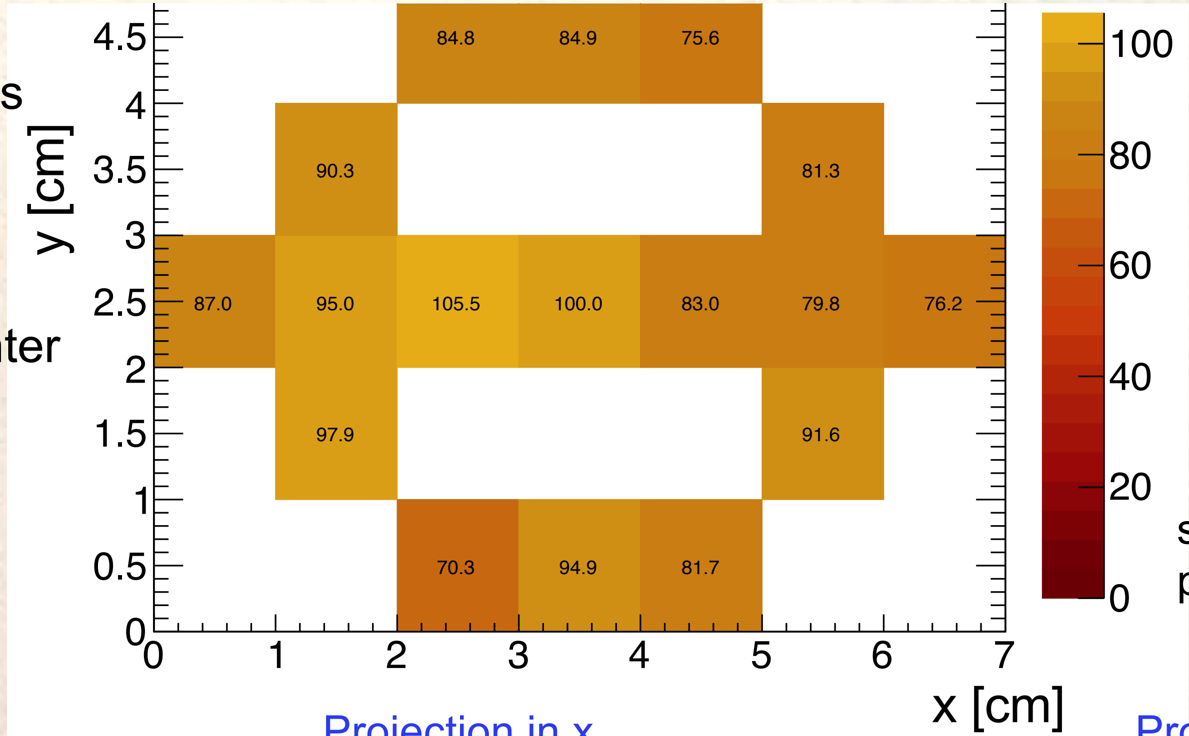


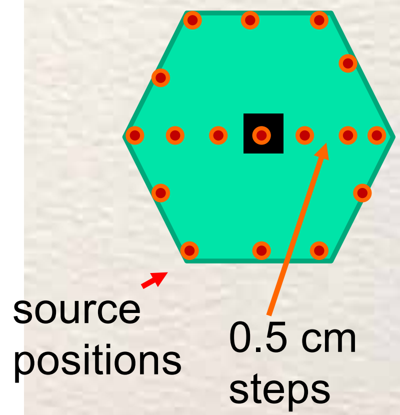




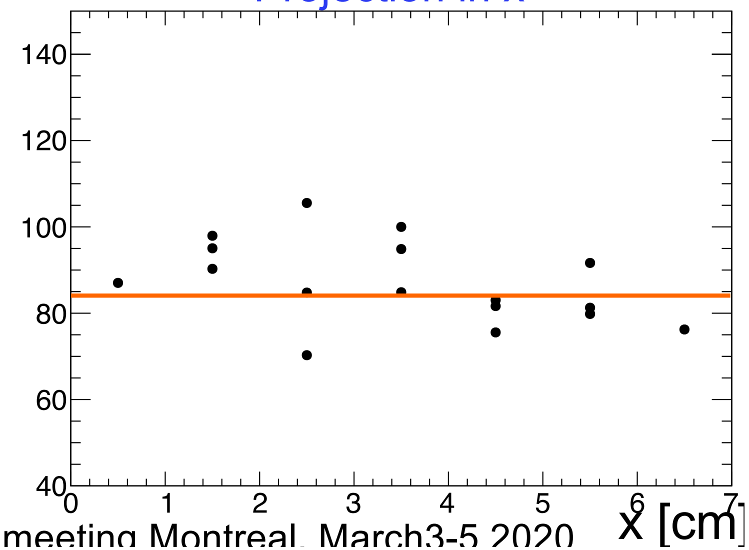
Uniformity Measurement of Center-mount MPPC

- 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!

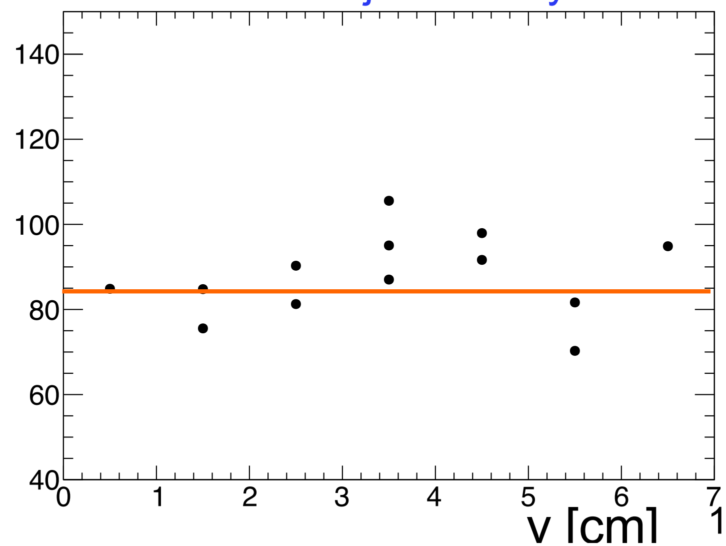




Projection in x

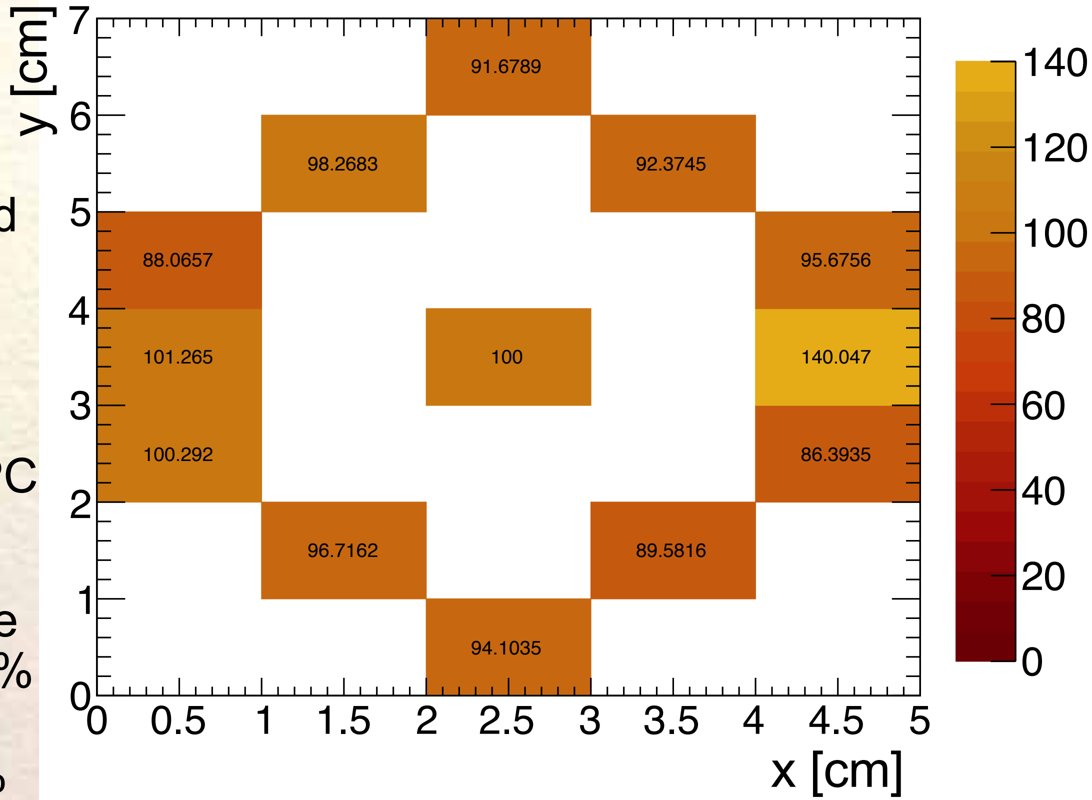


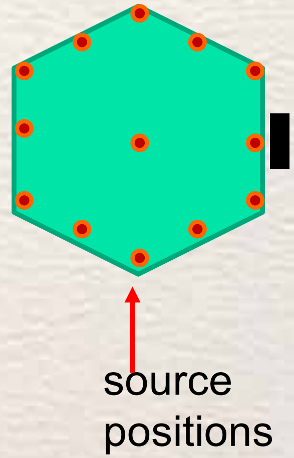
Projection in y

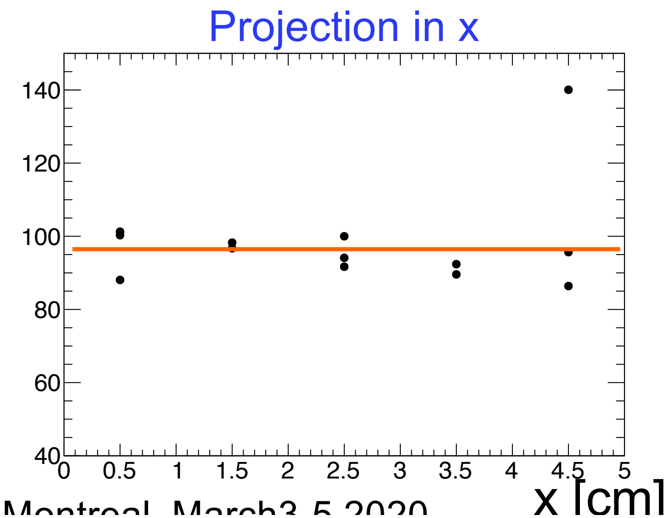


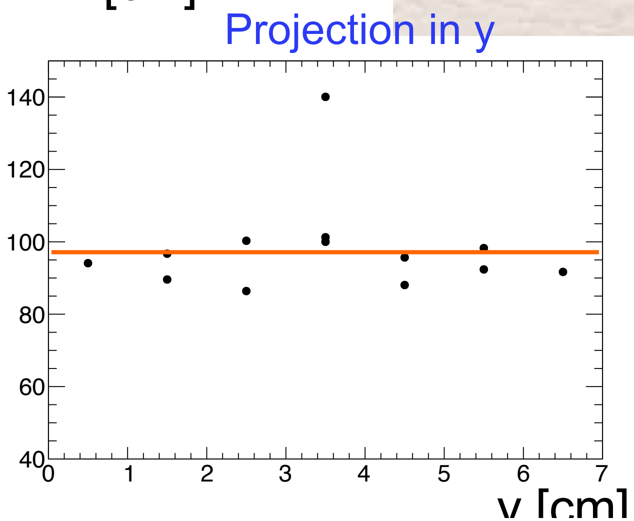
Uniformity Measurement of Side-mount MPPC

- 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



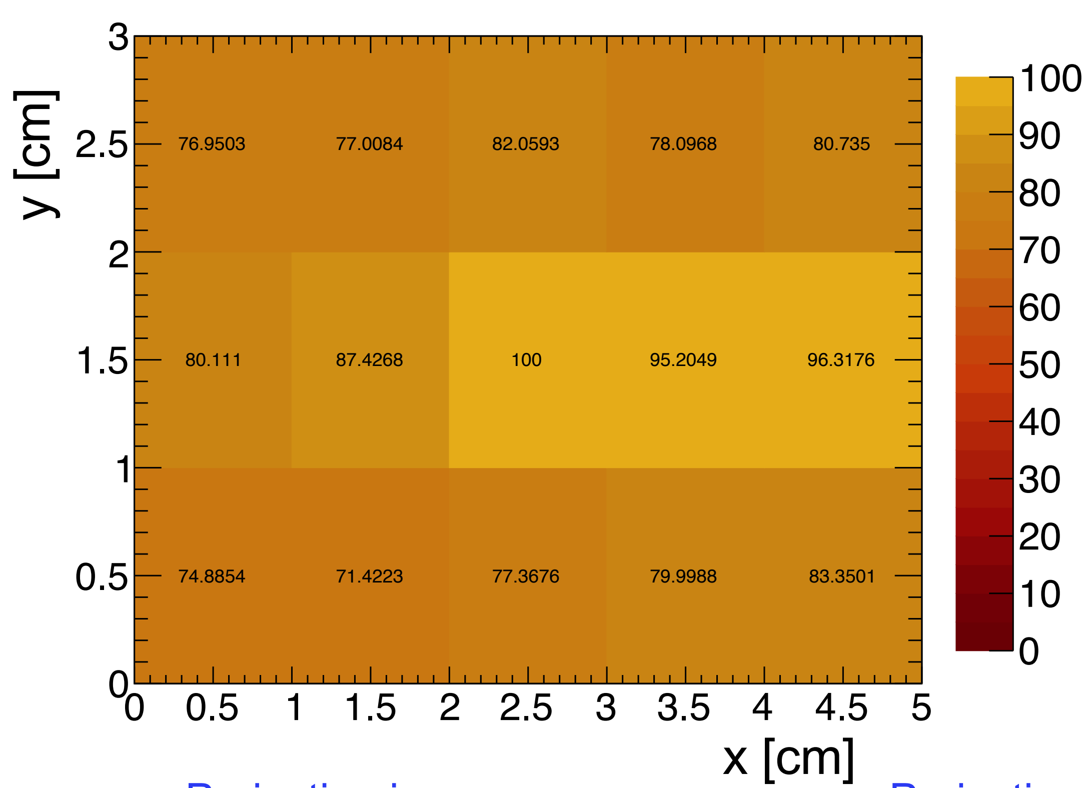


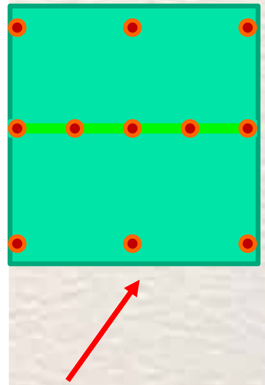


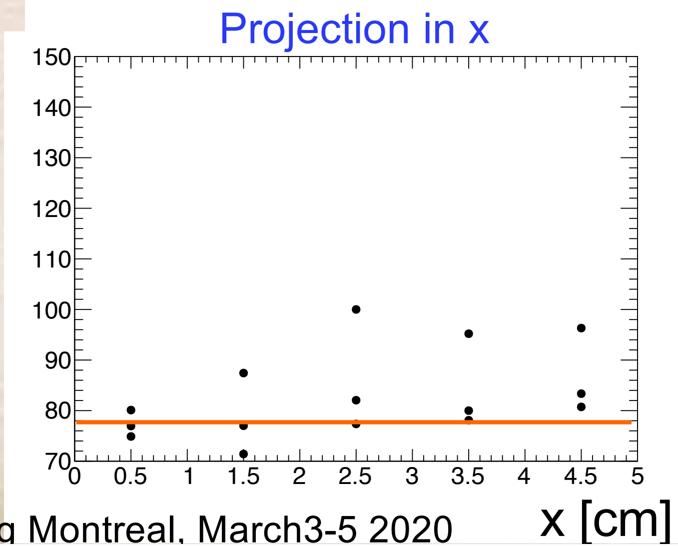


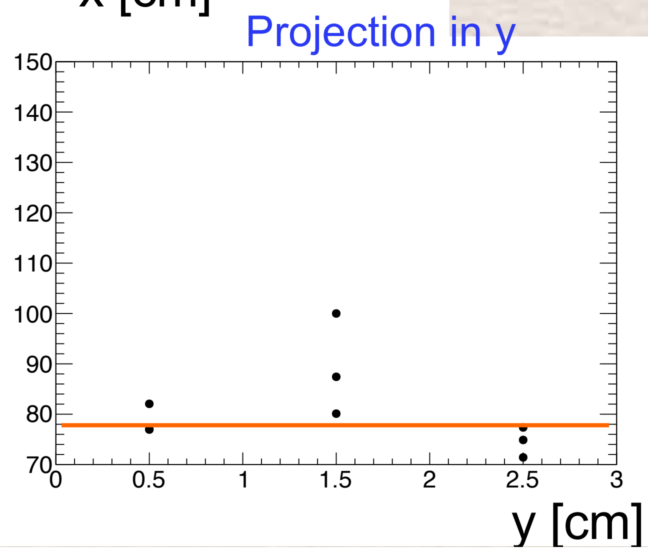
Uniformity of Square Tile with Fiber Readout

- 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



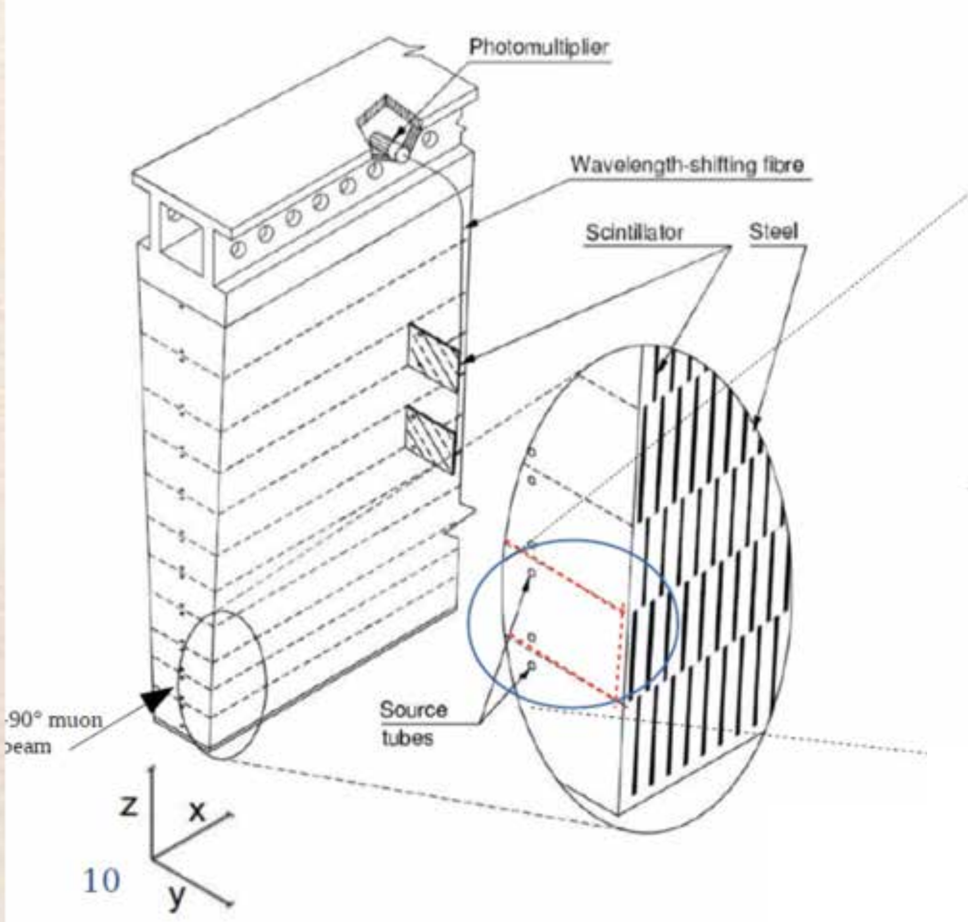


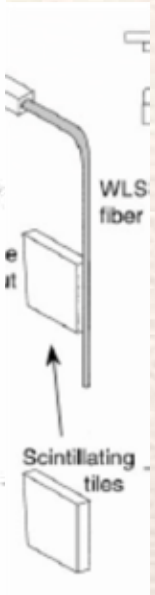


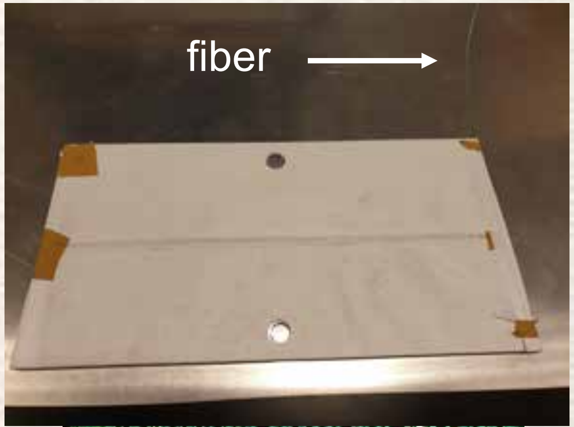


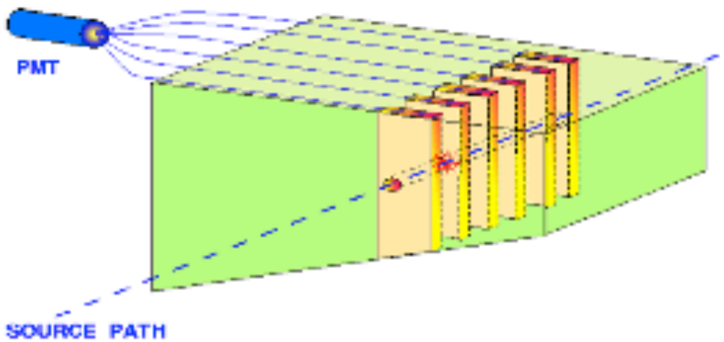
ATLAS Tile Calorimeter

- 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





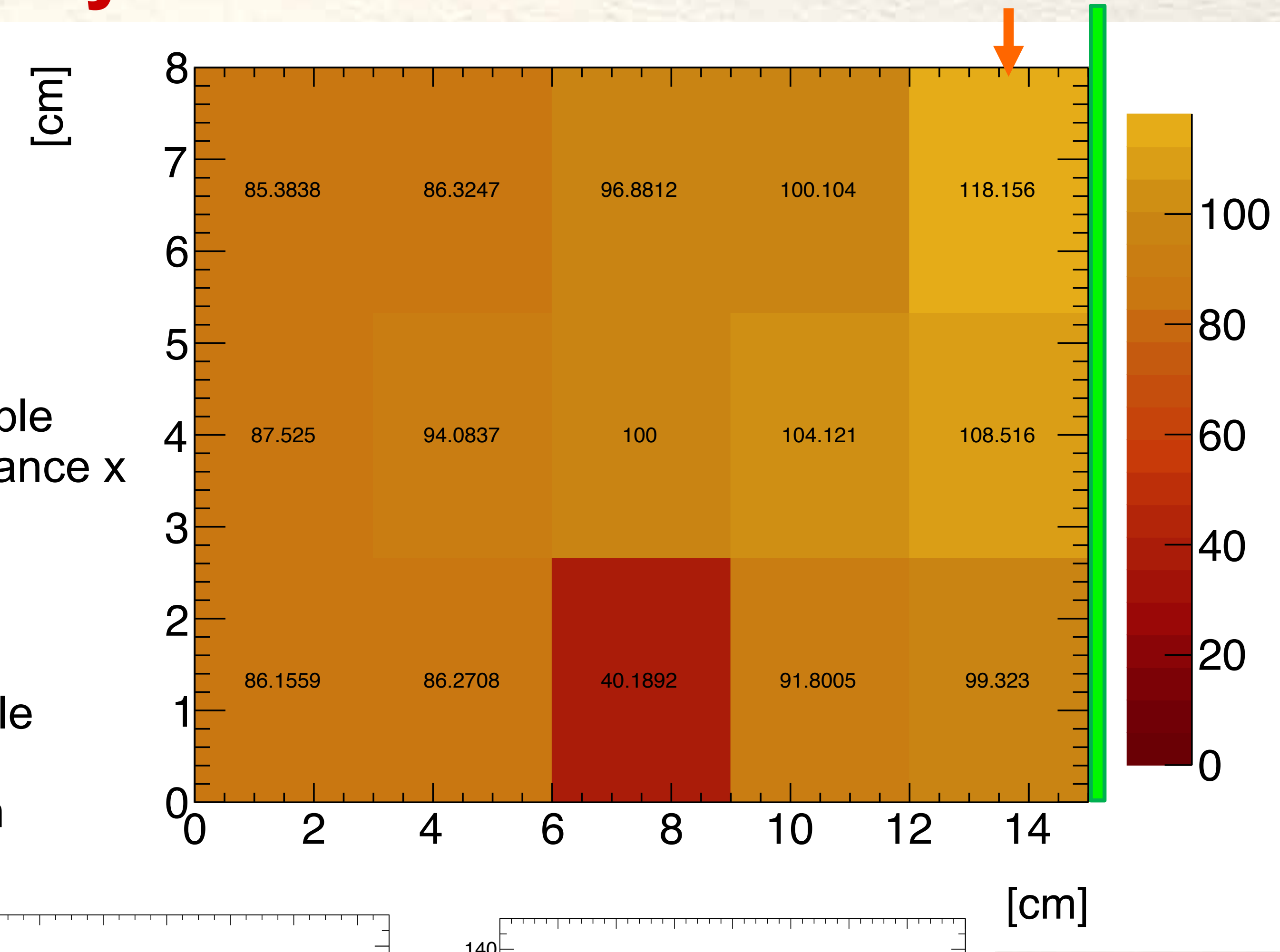


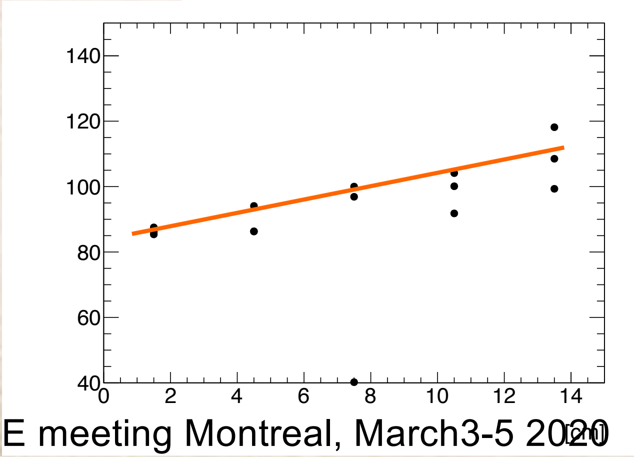


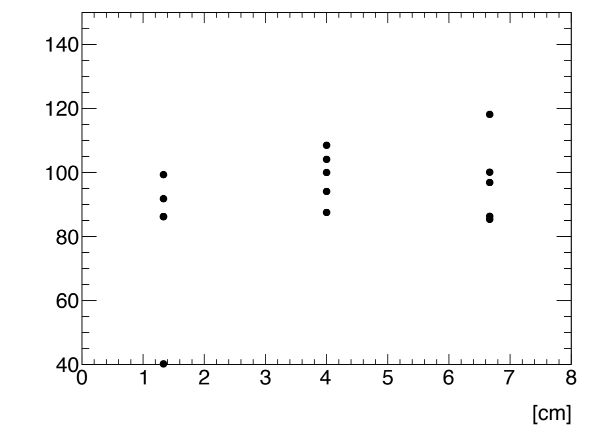
Tile	Size [cm^2]
small	12x 26
medium	14.5x30
big	18.5x35

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 with distance x
- MIP peak is around 2-3 photoelectrons
- Note that the hole in the tile has a large affect on the light collection (exclude in average)
- Average LY: (98.9±2.8)
- Uniformity for 90% of points <±14%

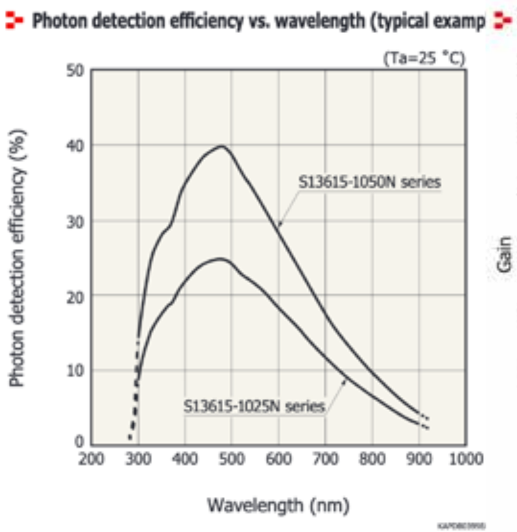


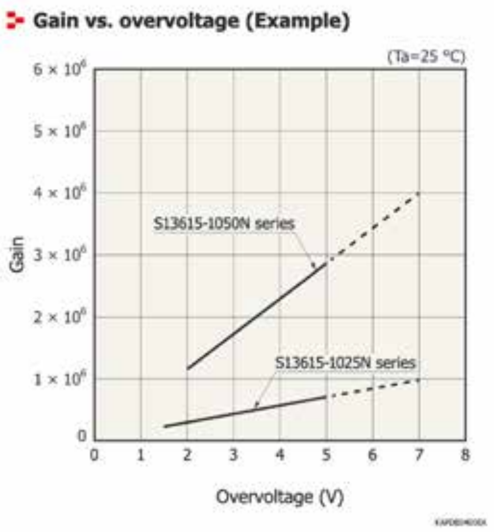


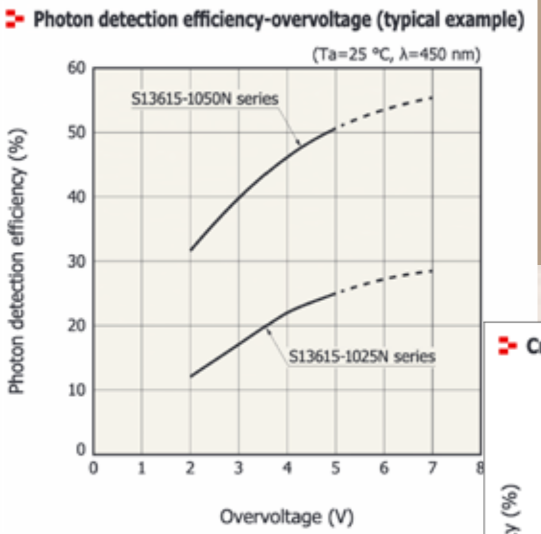


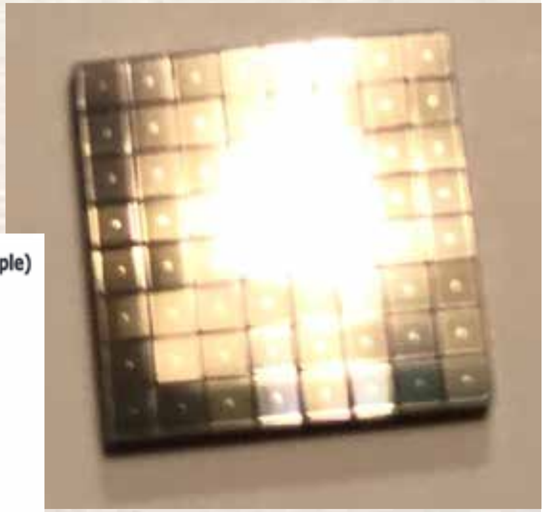
Plan to Readout Fiber Bundle with MPPC Array

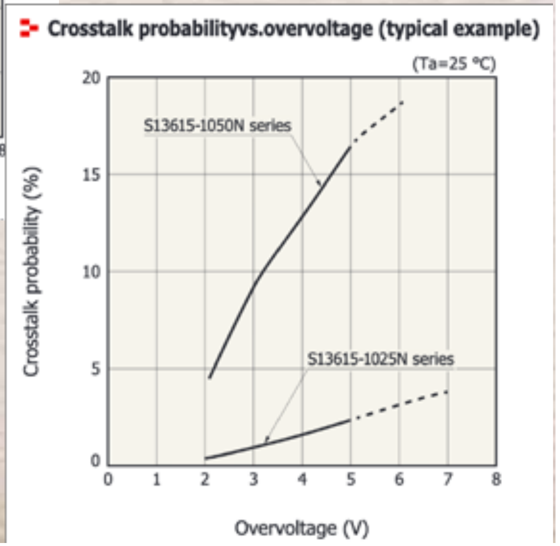
- We have one S13615-1050 MPPC array in hand & ordered 2 S13615-1025 arrays
- These arrays have 64 individual MPPCs (1 mm x 1 mm)
- The goal is to replace the PM with an MPPC array
- We are setting up a readout at CERN in the lab that will be moved into the experiment if it is successful











Electrical and optical characteristics (Typ. Ta=25 °C, unless otherwise noted)

Type no.	Spectral response range λ (nm)	Spectral response range λp (nm)	Photon detection efficiency PDE λ=λp (%)	Dark count (kcps) Typ.	Dark count (kcps) Max.	Crosstalk probability (%)	Terminal capacitance Ct (pF)	Gain M	Breakdown voltage VBR (V)	Recommended operating voltage Vop (V)	Operating voltage fluctuation between channels (V) Typ.	Operating voltage fluctuation between channels (V) Max.	Recommended operating voltage temperature coefficient ΔTVop (mV/°C)
S13615-1025N series	300 to 900	450	25	90	270	3	40	7.0×10^5	53 ± 5	VBR + 5	±0.05	±0.15	54
S13615-1050N series			40			10		1.7×10^6		VBR + 3			

Conclusions and Outlook

- First test of 4th generation MPPCs, 14160 series
  - Gain of S14160 sensors is linear with V_b between 40 and 50 V
  - Dark current and noise increases rapidly with V_b
  - Afterpulsing looks strange and needs to be remeasured
- 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 (in the works), uniformity within 6-7% except near sensor
- ATLAS TileCal tiles with present fiber couplings can be read out with MPPCs
  ➔ MIP peak produces enough photoelectrons
- Do further studies with new MPPCs (bought 2 S14160-1310 & 2 S14160-1315 sensors)
  - Remeasure afterpulsing, look at linearity, T dependence
- Do more performance studies of hexagonal/square tiles
  - Study wrapping (3M, different Tyvek, …), RO location, half-hexagons
- Setup readout of ATLAS fiber bundle with MPCC arrays in bld 175 at CERN
  - Bond MPPC array to a readout board, test individual channels, get Spiroc/HGCROC
  - Study performance in the lab
  - Move into ATLAS experiment replacing 2 PMTs with MPPC arrays and study performance in beam conditions

Backup

Slides

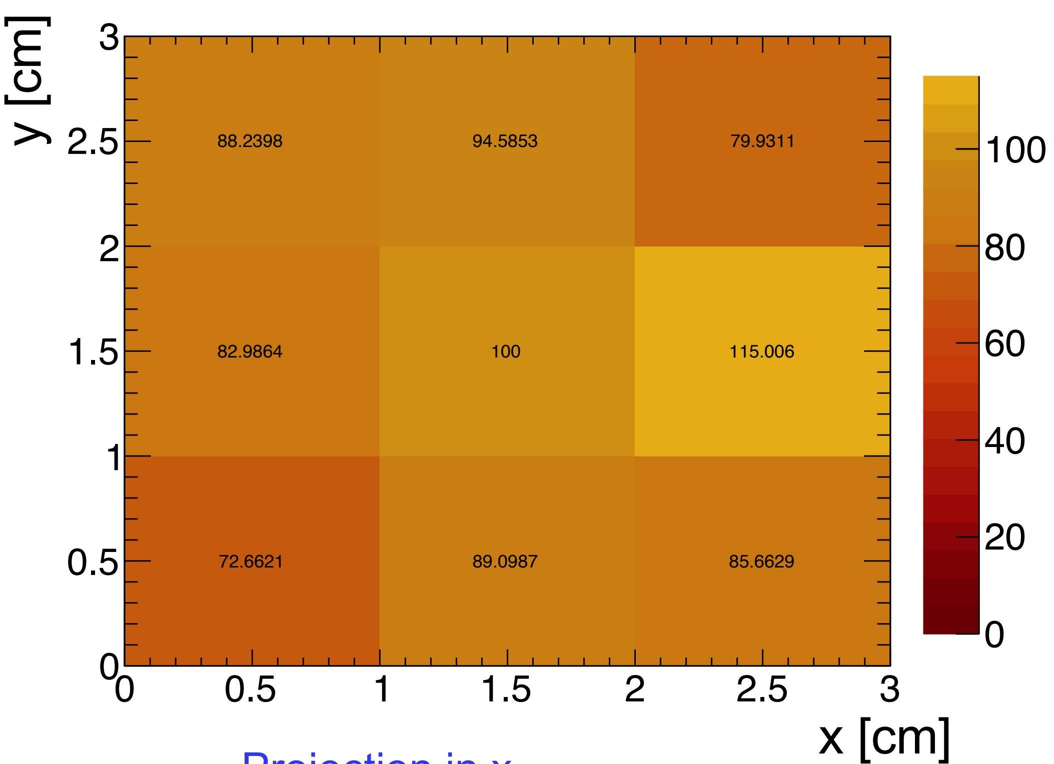
Tile Layouts

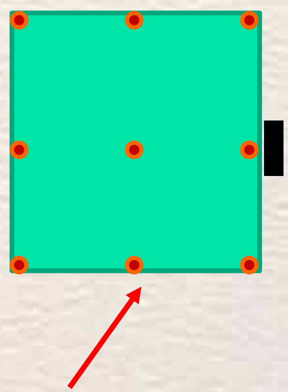
- Our machine shop produced 9 hexagonal-shaped tiles (a=1.86 cm) and 9 square-shape tiles (3 cm × 3 cm), which have the same area, thickness 3 mm
- Scintillator material is from St Gobain (Bicron) BC404
- We use 3 different readout schemes
  - Via Y11 fiber inserted into a groove located in the middle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

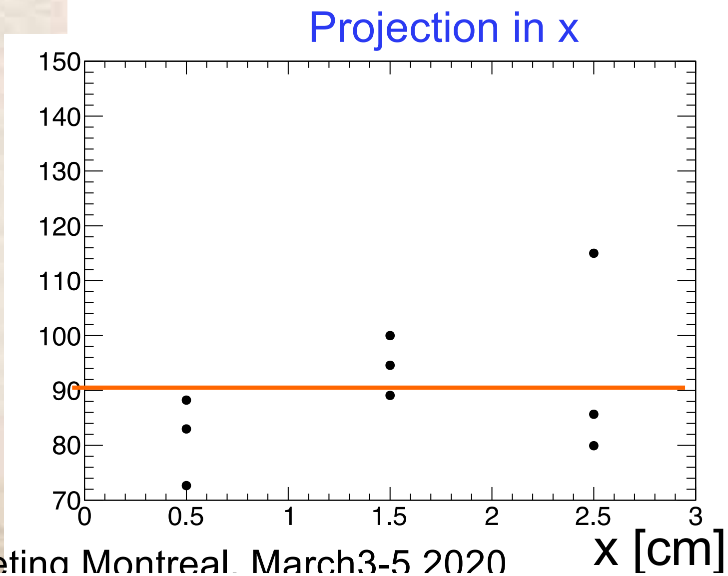
Uniformity of Square Tile with MPPC on Side

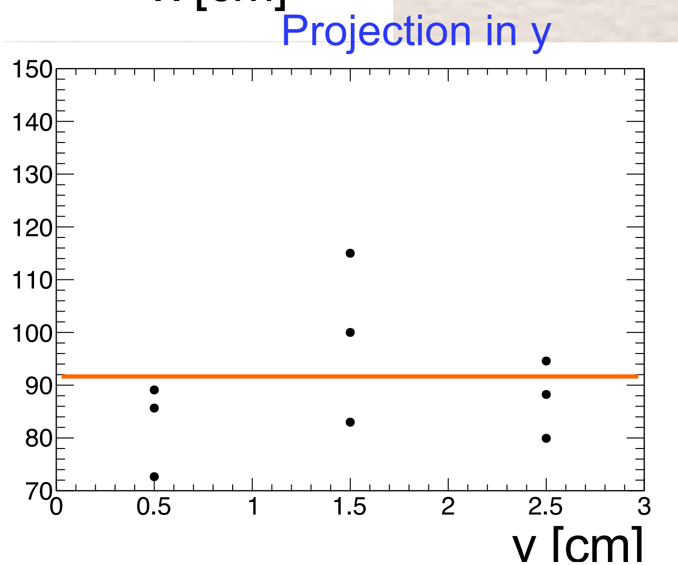
- Mean value of fitted Gaussian for each position is divided by the light yield measured at the center position
- Most probable light yield at the center position $(pe)_{most\ probable}$ =7.91 pe
- Average relative light yield is (86.7±3.2)%
- Tile is uniform within ±13% (cause is probably non homogeneous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





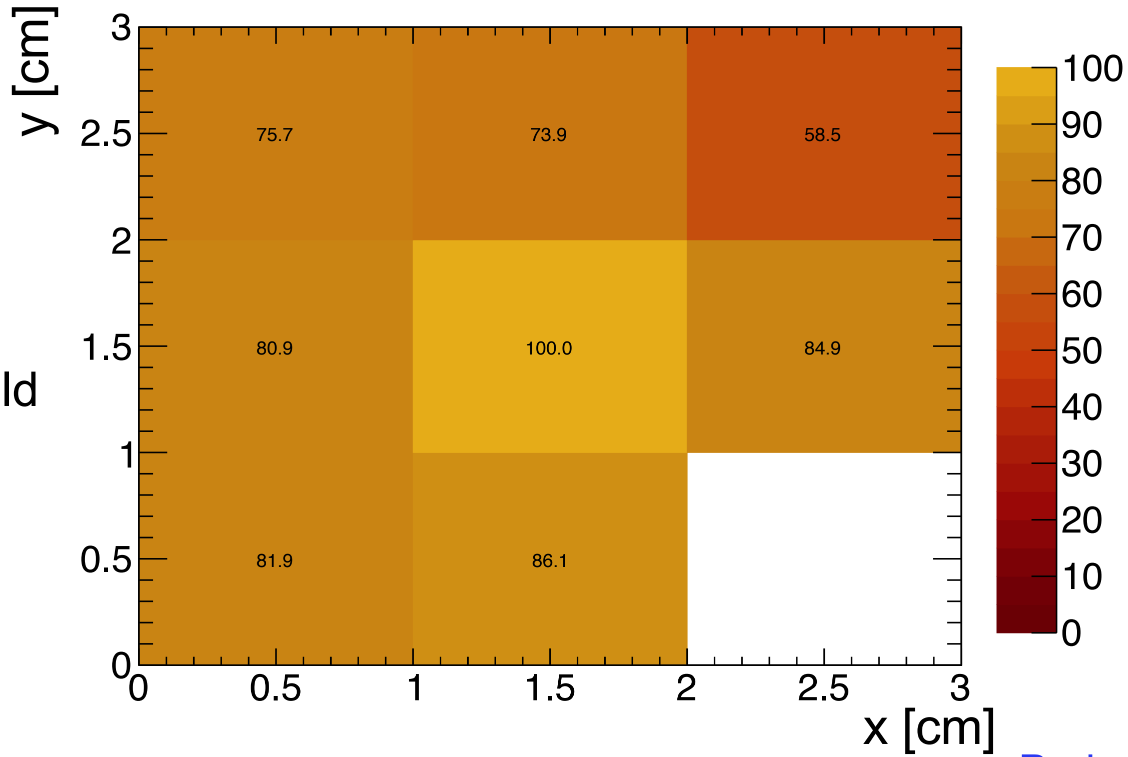
source positions

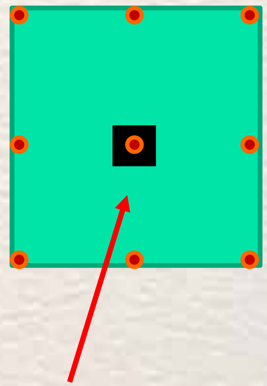




Uniformity Measurement of Center-mount MPPC

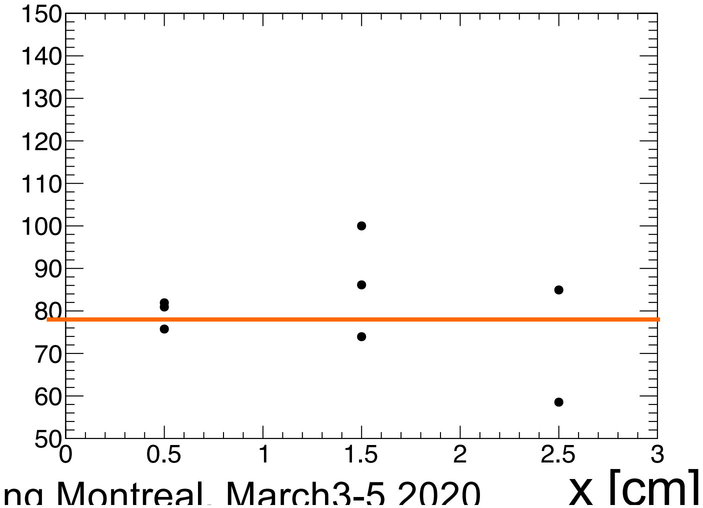
- Mean value of fitted Gaussian for each position is divided by the light yield measured at the center position
- Most probable light yield at the center position $(pe)_{most\ probable}$ = pe
- Average relative light yield is (77.4±8.8)%
- Tile is uniform within ±9% (cause is probably non homogeneous wrapping)



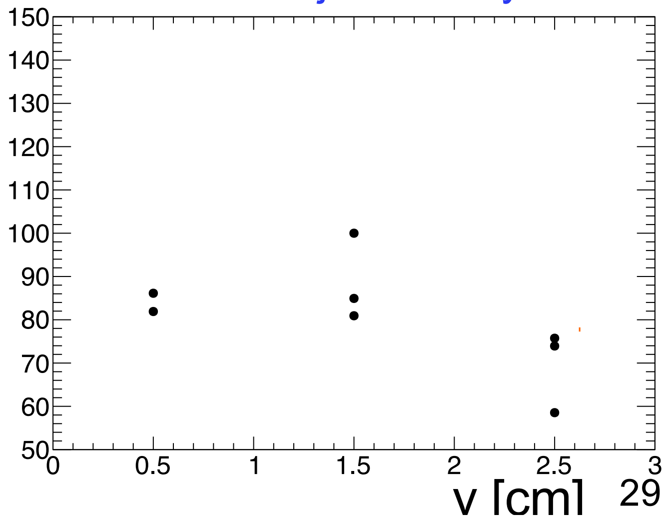


source positions

Projection in x

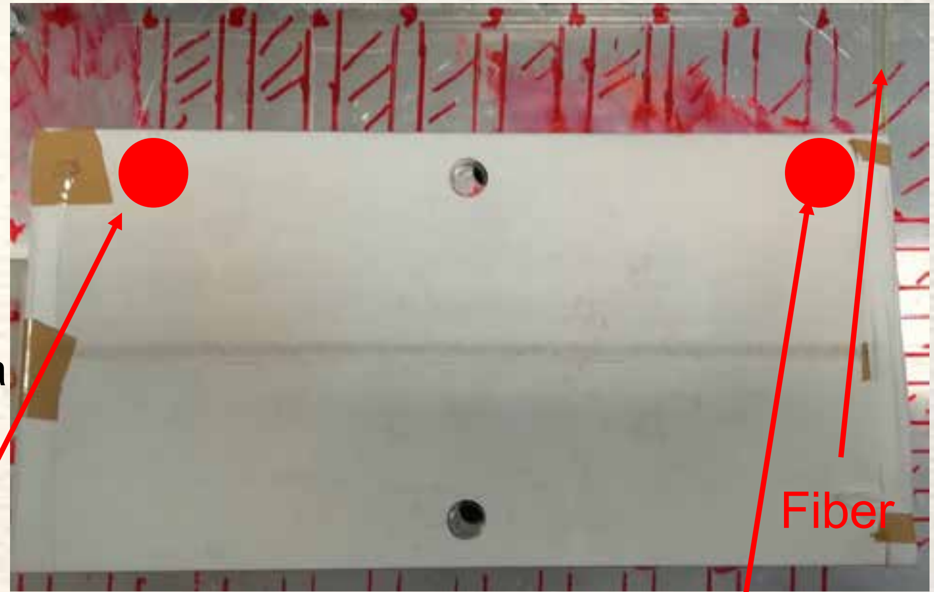


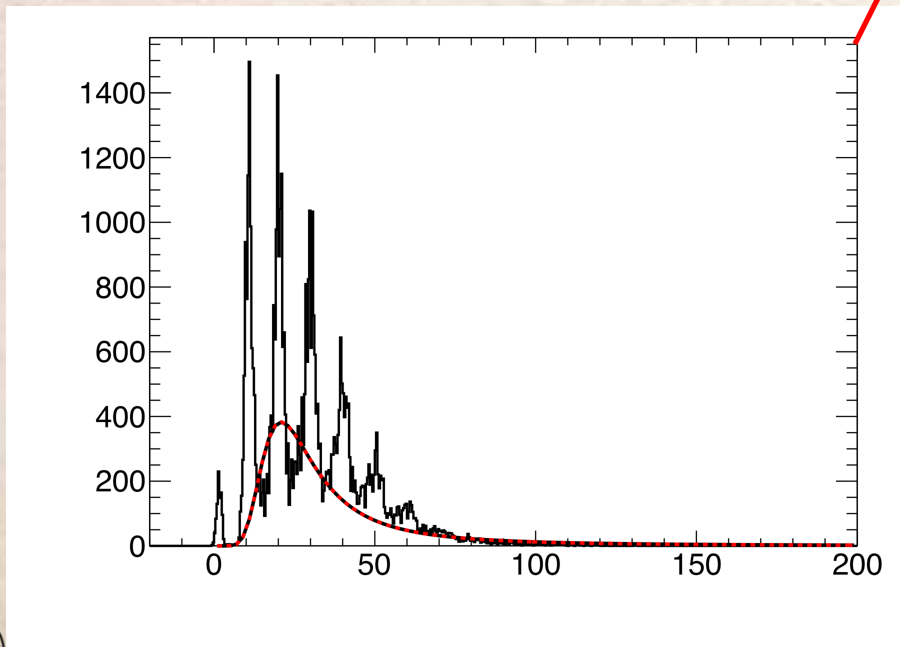
Projection in y

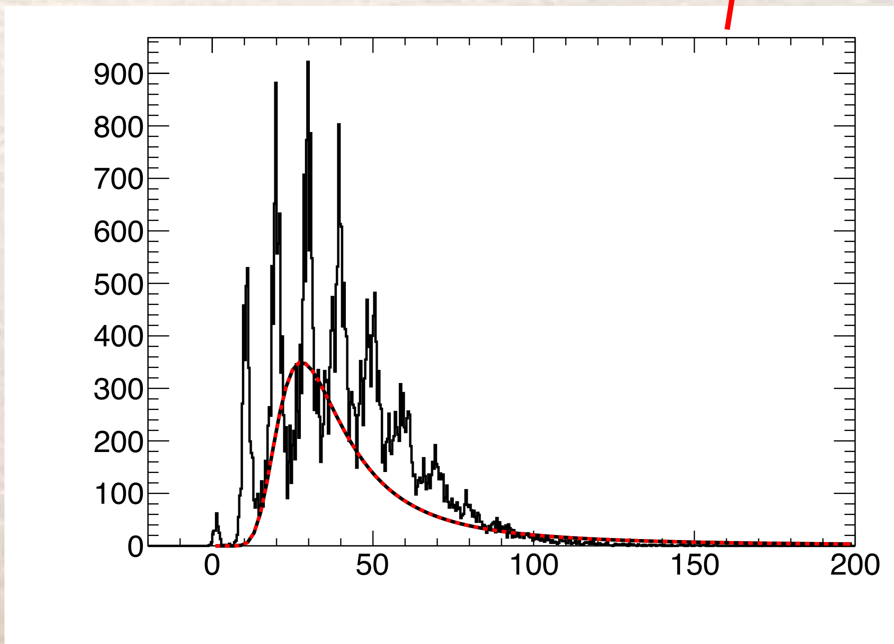


ATLAS Tile Uniformity Measurements

- 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

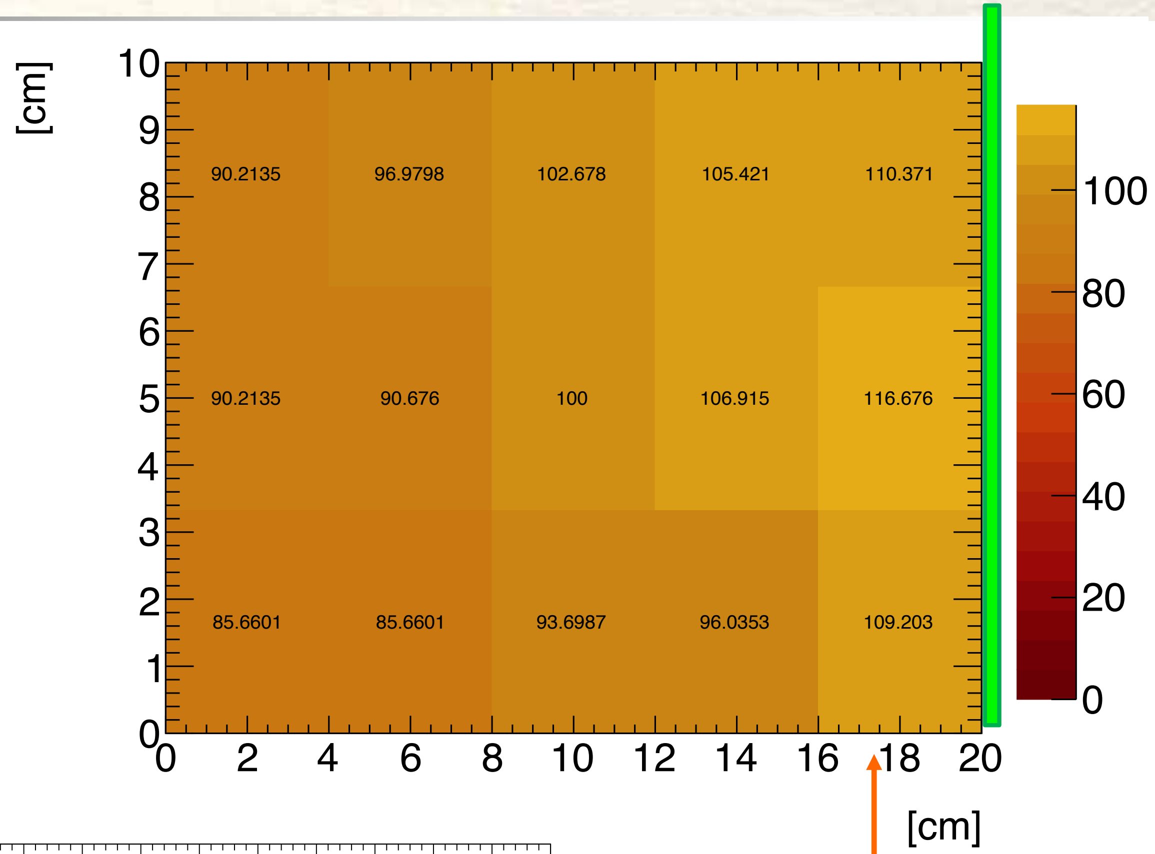


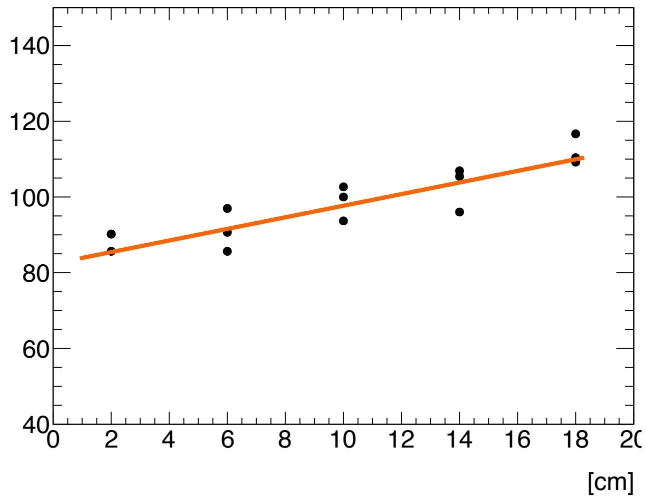


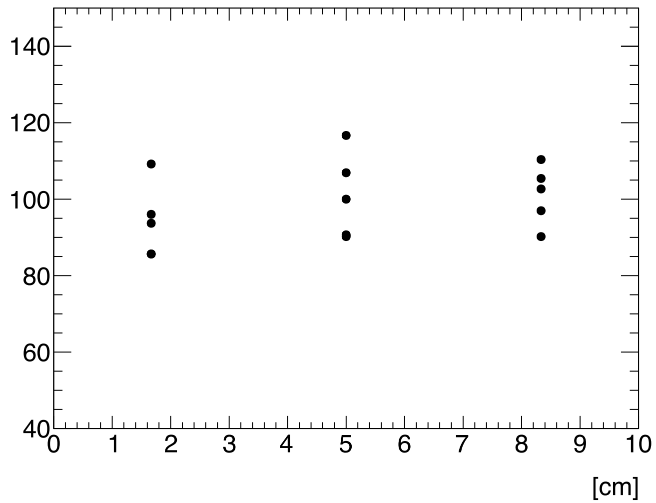


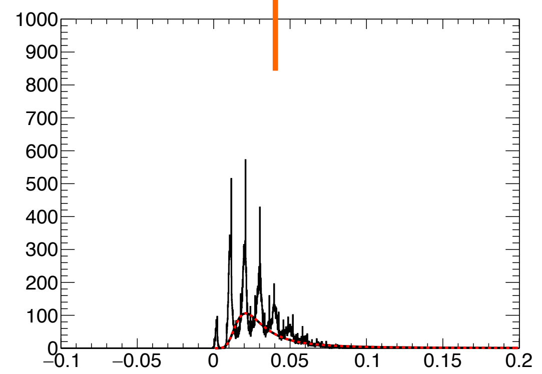
Uniformity of ATLAS Medium Tiles

- We measured uniformity of 3 tiles
  ➔ we get similar results for the other tiles
- Average LY:
  (98.7±2.6)
- Uniformity
  for 90% of points
  <±14%









Uniformity of ATLAS Large Tiles

- We measured uniformity of 3 tiles
  ➔ we get similar results for the other tiles
- Average LY: (109.7±4.7)
- Uniformity for 90% of points <±25%
-