Study of Scintillator Tiles and SiPMs

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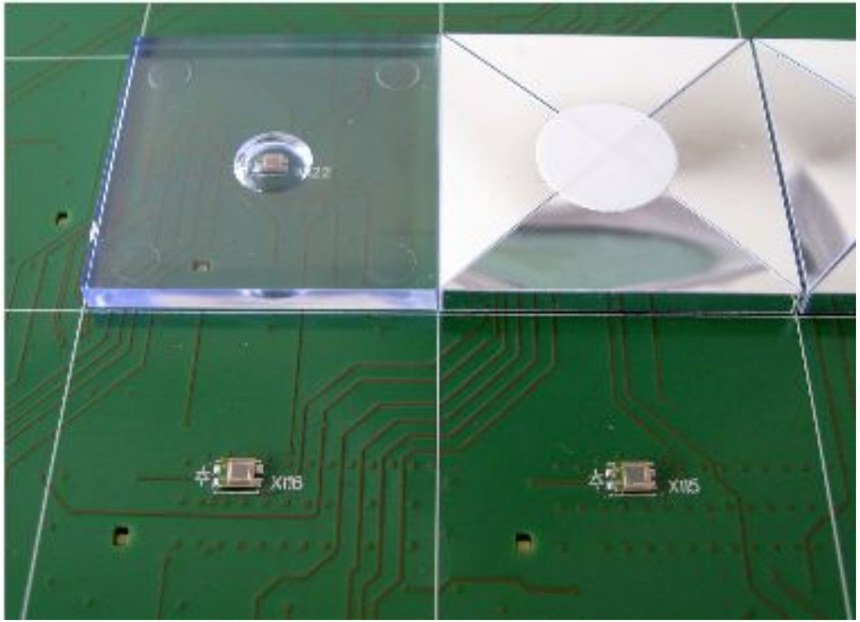
Motivation

- SiPM-on-tile technology involves a scintillator tile placed on a SiPM to work as an active medium and sensor.

- As SiPM and scintillator are separated, they can be tested and optimized separately to increase light yields

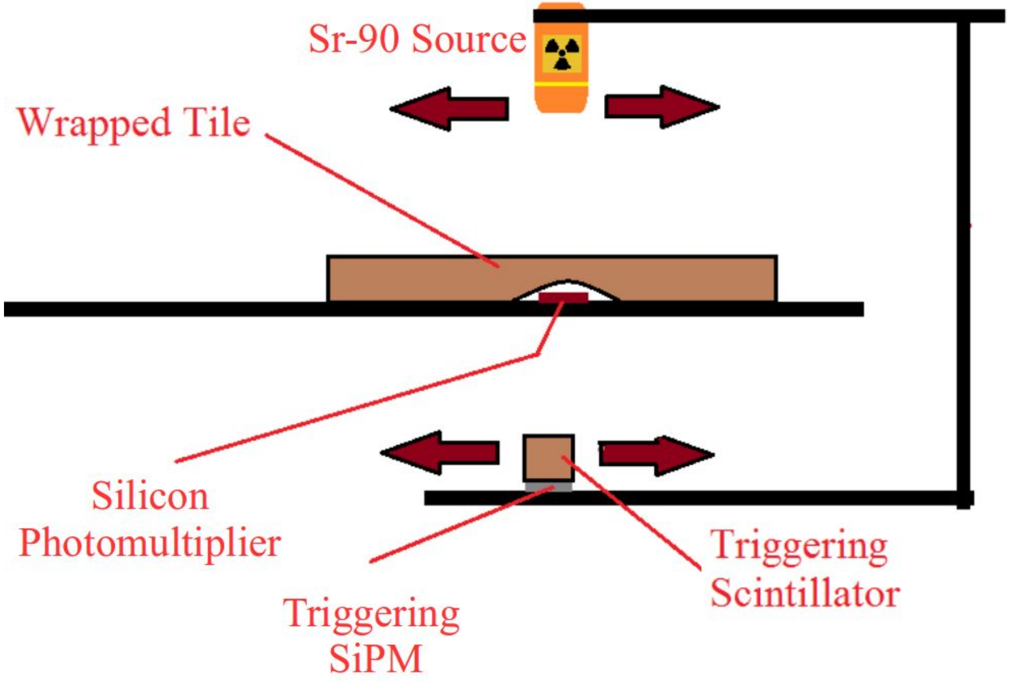
- Objectives of tests
    - Understand impact of mechanical tolerances for SiPM-on-tile
    - Explore further improved SiPMs

- Methodology
    - Test different Scintillator Tiles with different qualities
    - Test different SiPMs



Uniformity Test - Experimental Setup

- Scintillation tile is clamped and precisely placed on top of SiPMs
- Electrons from Sr-90 source scan the tile
- Electrons detected at trigger SiPM/scintillator triggers data collection
- Oscilloscope sampling rate = 1.25 GHz
  (Oscilloscope sampling interval = 800 ps)
- Test done in a climate controlled 20° C environment
- Scan of 30 mm^2 square area
  - at 2 mm steps => ~16 hours
  - at 1 mm steps => ~32 hours

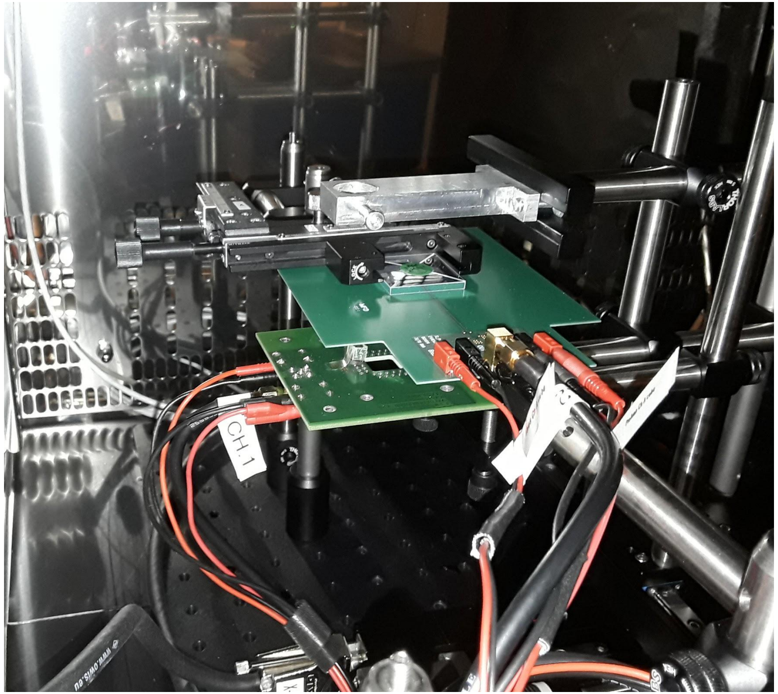


Uniformity Test - Analysis

- 600 captures for 1pe signals are taken
  - Pedestal subtracted integral of signals obtained
  - Median value is taken as 1pe signal

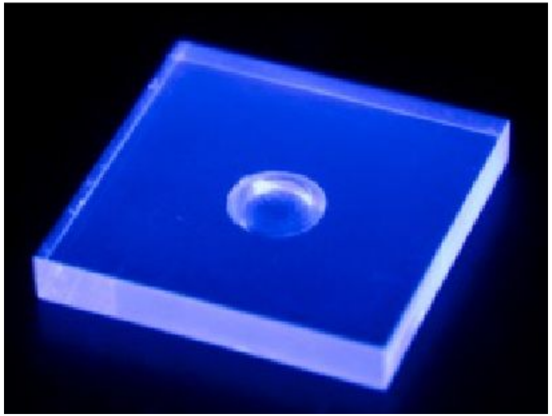
- Trigger threshold of ~7pe triggers data taking from SiPMs
  - 1000 captures taken
  - Pedestal subtracted integral of signals obtained
  - Signals with too low integral values rejected
  - Signals above 97th percentile rejected (remove the tail)
  - Using a Gaussian fit, mean value is taken as signal

$$\text{Light Yield} = \frac{\text{integral of signal}}{\text{integral of 1 pe signal}}$$



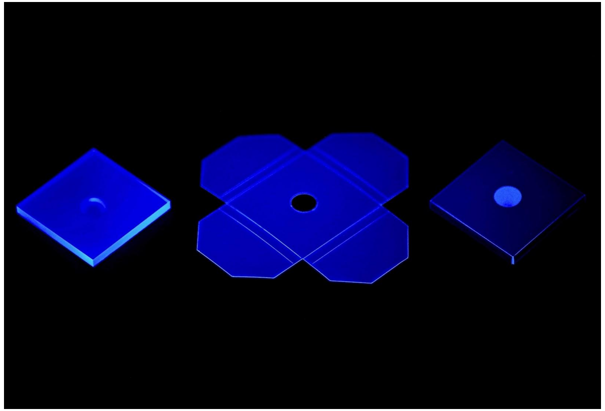
Scintillator Tiles Tested

Tile of CALICE AHCAL technological prototype

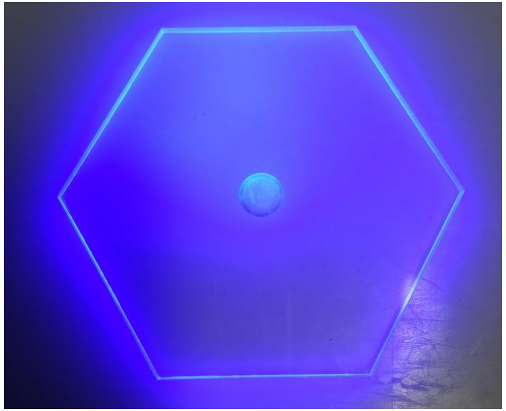


Square Polystyrene Tile
30 mm length
3 mm thickness

Tiles produced at Max-Planck-Institut, Munich



Square BC-408 Tile
30 mm length
3 mm thickness

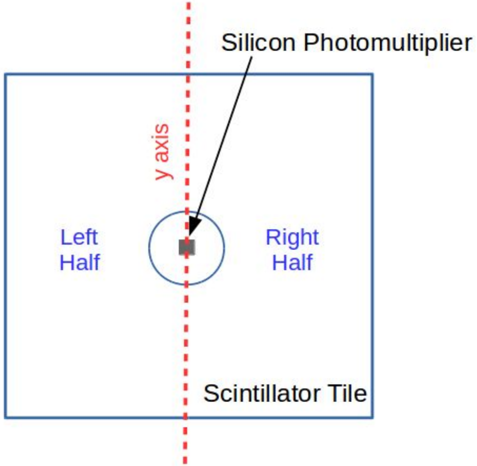


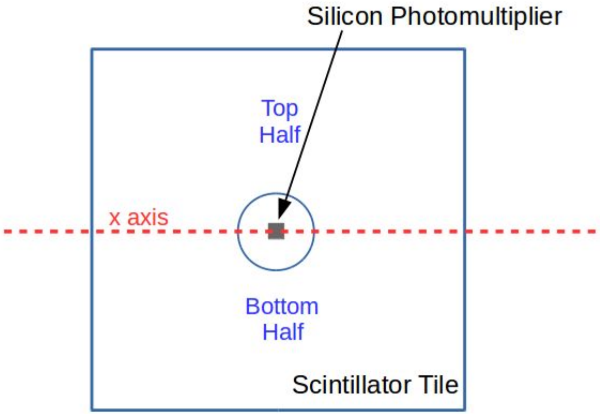
Hexagonal BC-408 Tile
14 mm edge length
3 mm thickness

- All wrapped in 3M foil
- Tiles tested using Hamamatsu S13360-1325PE SiPM

Impact of Misalignment

- Methodology
  - Shift of scintillator tile position in 100 um steps in x and y directions and compare light yields
  - Average light yield
    - For square 3x3 cm^2 tiles - average of light yields in 25x25 mm^2 center
    - For hexagon of length 1.4 cm - average of light yields in 14x14 mm^2 center
  - Calculation of misalignment in position
    - $\text{Misalignment}\ (r) = \sqrt{(x_{\text{SiPM center}} - x_{\text{tile center}})^2 + ((y_{\text{SiPM center}} - y_{\text{tile center}})^2}$
  - Calculation of Light yield (LY) asymmetries
    - $\text{LY}_{\text{asym}}(\text{top-bottom}) = \overline{\text{LY}_{\text{top}}} - \overline{\text{LY}_{\text{bottom}}}$
    - $\text{LY}_{\text{asym}}(\text{left-right}) = \overline{\text{LY}_{\text{left}}} - \overline{\text{LY}_{\text{right}}}$





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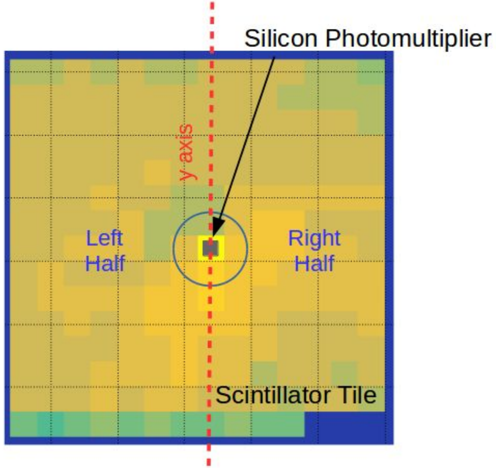
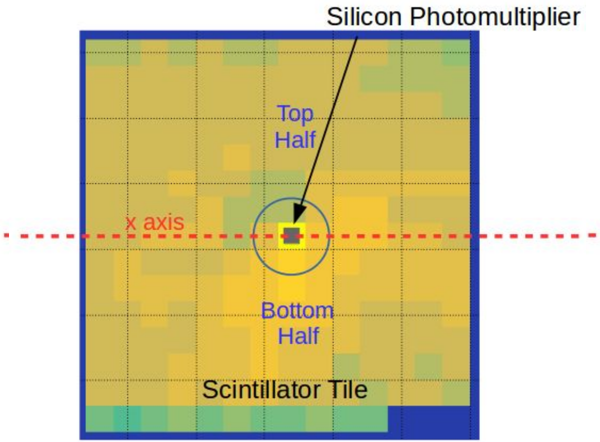
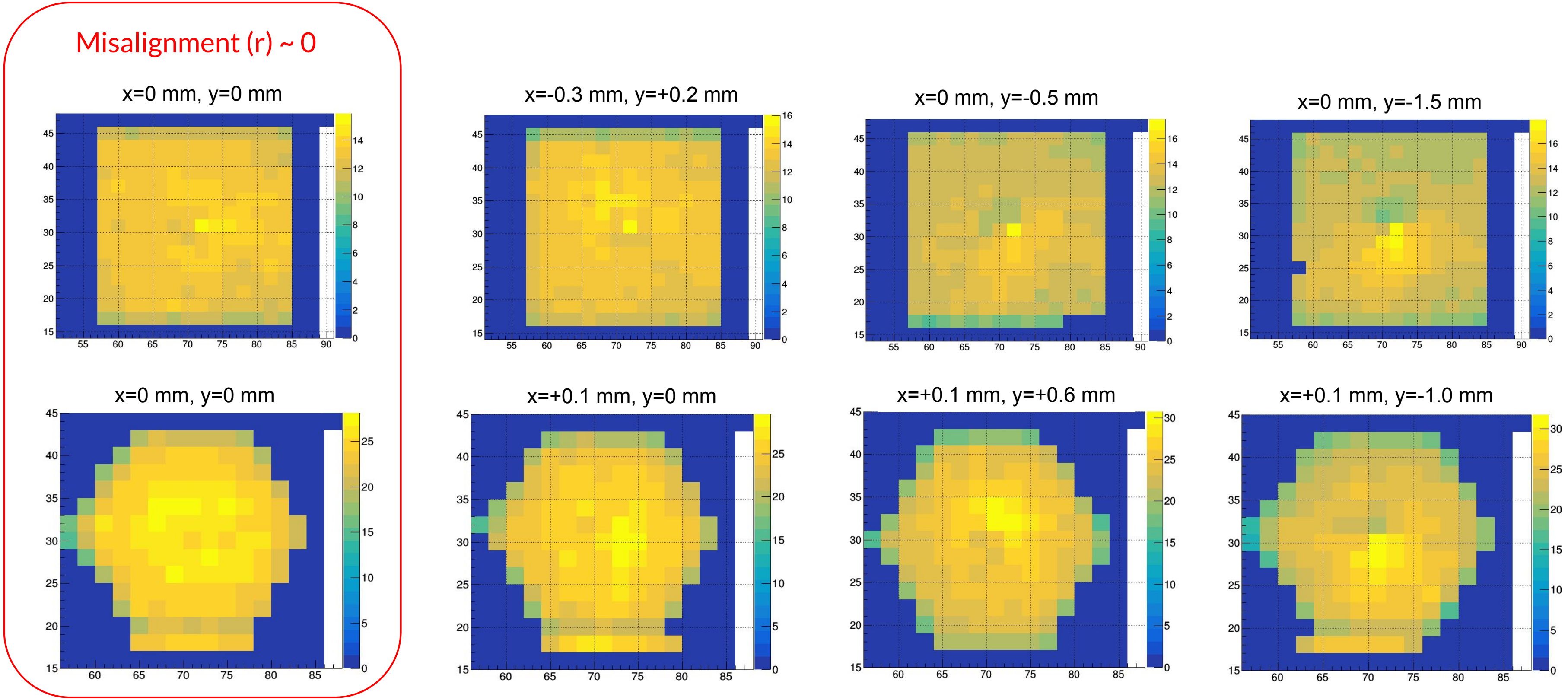




Impact of Misalignment

- Observations
  - As calliper pushes the tile towards the dimple center, light yield asymmetry decreases



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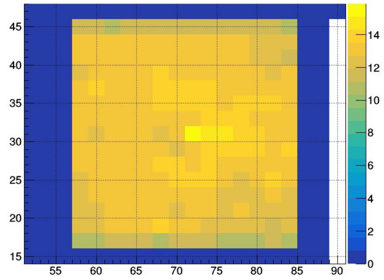
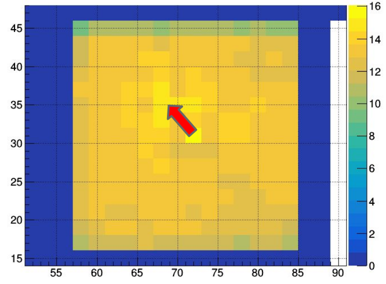
Misalignment (r) ~ 0

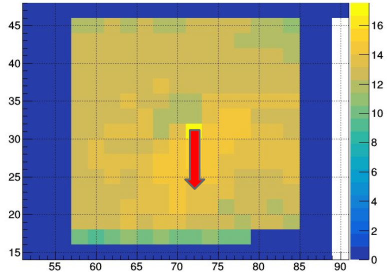
x=0 mm, y=0 mm



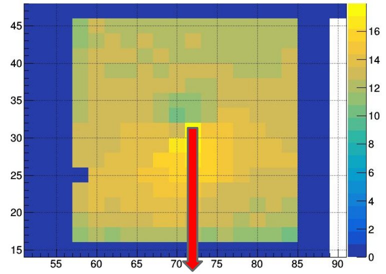
x=-0.3 mm, y=+0.2 mm



x=0 mm, y=-0.5 mm



x=0 mm, y=-1.5 mm



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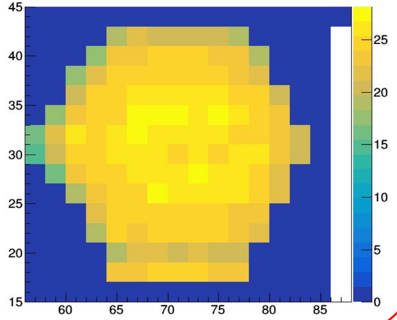
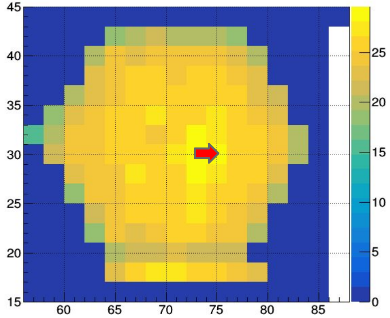
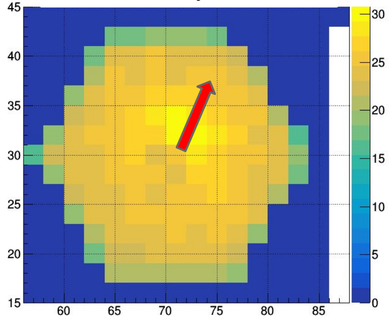


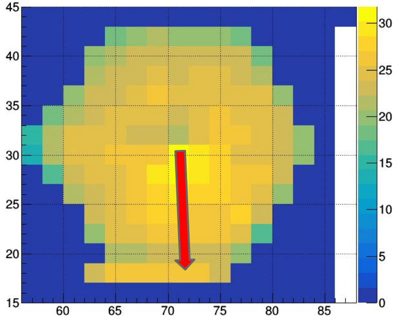
x=+0.1 mm, y=0 mm



x=+0.1 mm, y=+0.6 mm

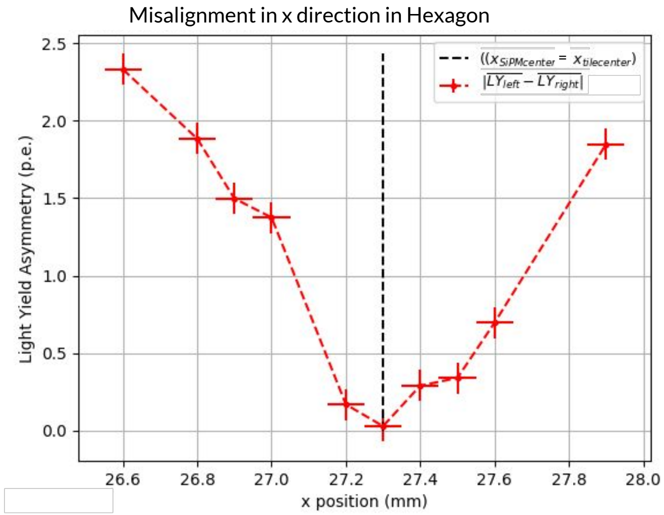


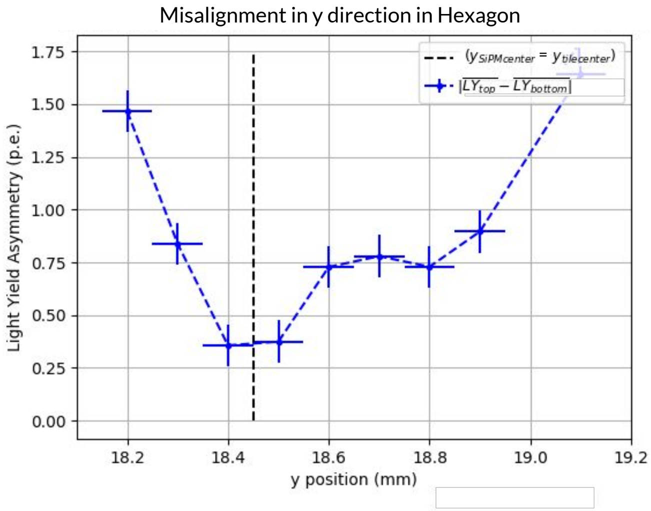
x=+0.1 mm, y=-1.0 mm



Light Yield Asymmetry vs Misalignment in Hexagon

- Average Light Yields taken from top, bottom, left and right halves of the hexagon
- Changes in average light yield in left and right halves observed as x position changes
- Changes in average light yield in top and bottom halves observed as y position changes





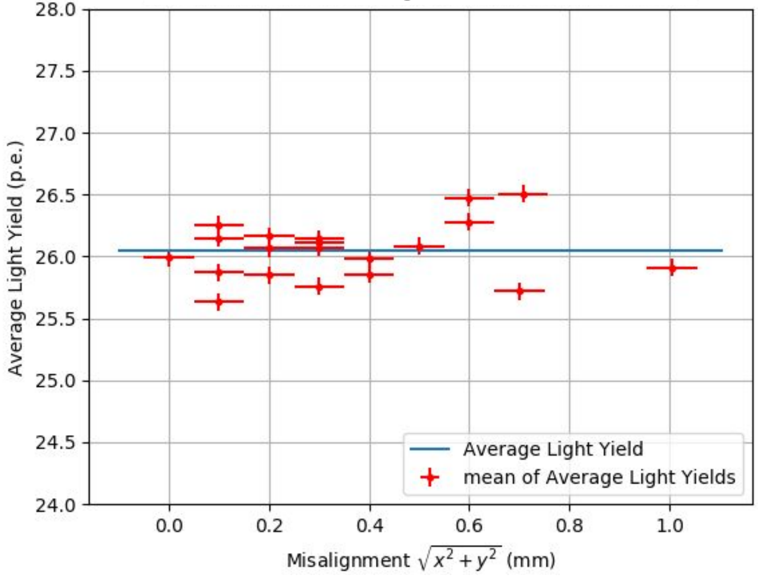
- Preliminary results for square tiles show similar trend

Average Light Yield vs Misalignment

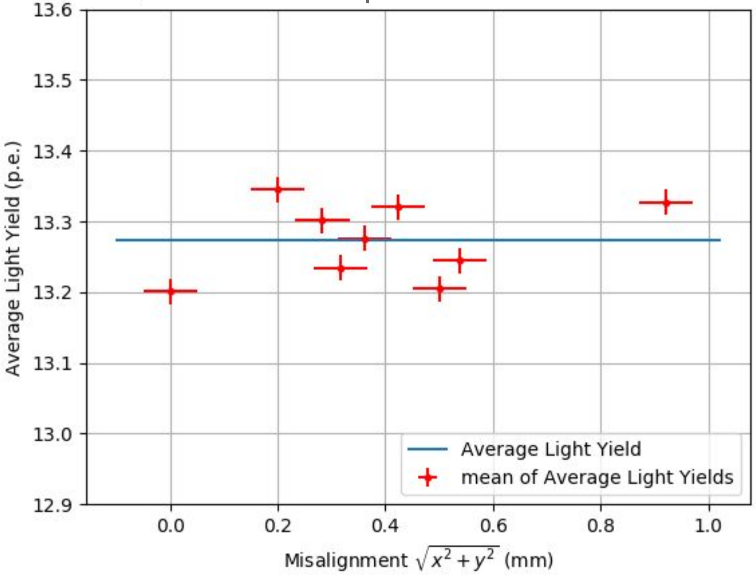
- Average Light yield calculated by taking arithmetic average of light yield
  - For square 3x3 cm^2 tiles - average of light yields in 25x25 mm^2 center
  - For hexagon of length 1.4 cm - average of light yields in 14x14 mm^2 center

- Average Light yield not affected by the misalignment of the tile
- True for both hexagon and square tiles

Hexagon Tile



Square Tile

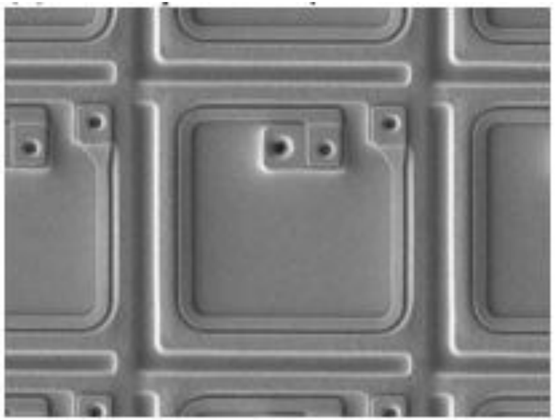


Silicon Photomultipliers Tested

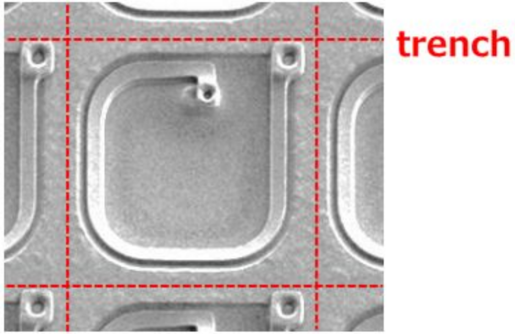
- New generation of MPPCs (HDR2 prototype) => high dynamic range

- Hamamatsu S13360-1325PE - specs
  - Effective photosensitive area = $1.3 \times 1.3 mm^2$
  - 25μm pitch = 2,668 cells
  - Breakdown Voltage = 53 V (20° C)
  - Gain = 7.0×10^5

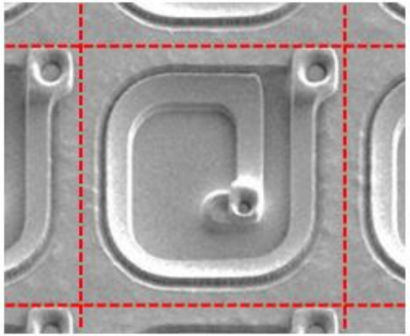
- Hamamatsu S14160 MPPC series - specs
  - Effective photosensitive area = $1.3 \times 1.3 mm^2$
  - Breakdown Voltage = 38 V (20° C)
  - S14160-1310PS
    - 10μm pitch = 16,675 cells (~6 x dynamic range)
    - Gain = 1.8×10^4
  - S14160-1315PS
    - 15μm pitch = 7,296 cells (~2.5 x dynamic range)
    - Gain = 3.6×10^4



S13360-1325PE



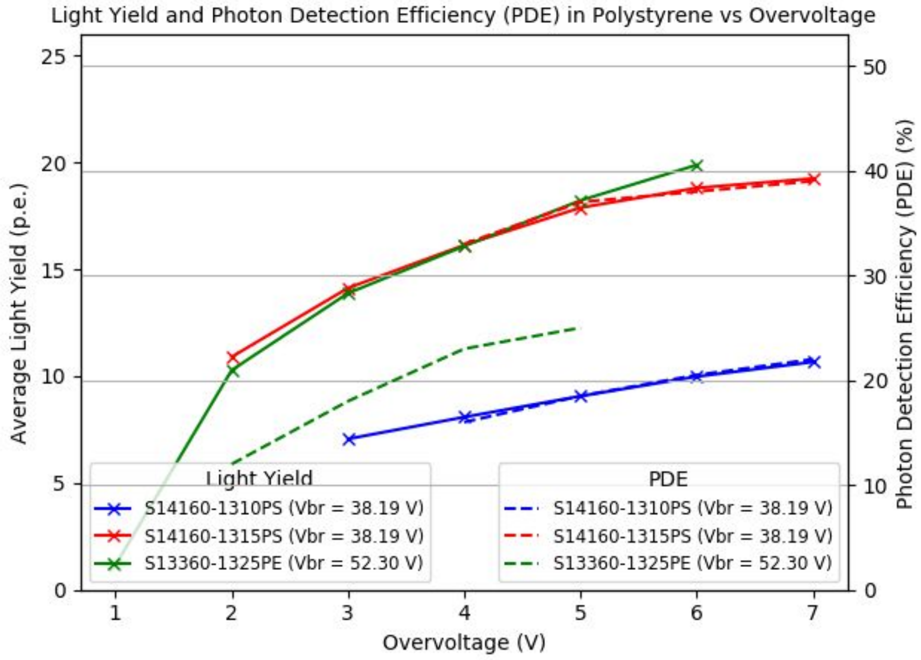
S14160-1315PS



S14160-1310PS

Comparison of SiPMs using Polystyrene Tile

- Test done in a climate controlled 25° C environment using manufacturer supplied SiPM breakdown voltages (Vbr)
- Using CALICE AHCAL square polystyrene tile
- Newer SiPMs require an additional signal amplifier: lower gain due to smaller pixel capacitance



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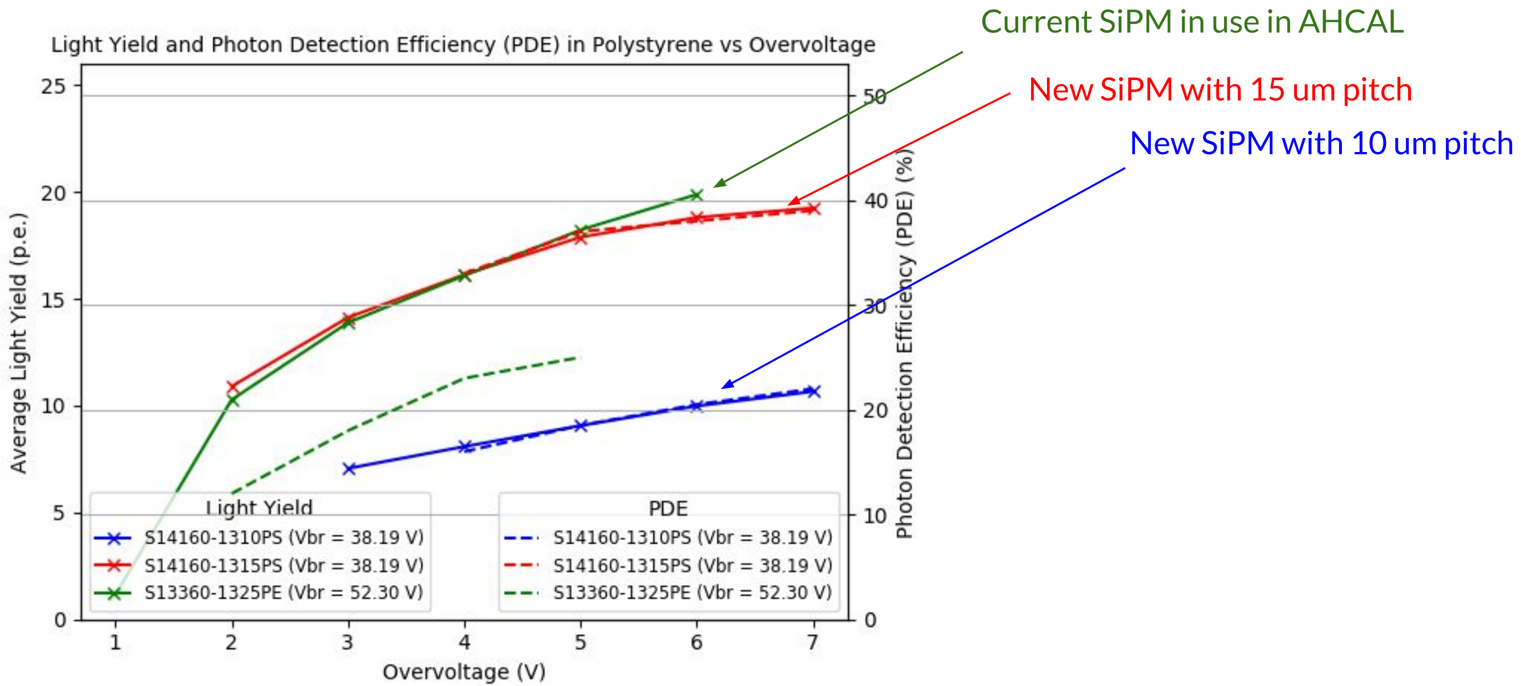

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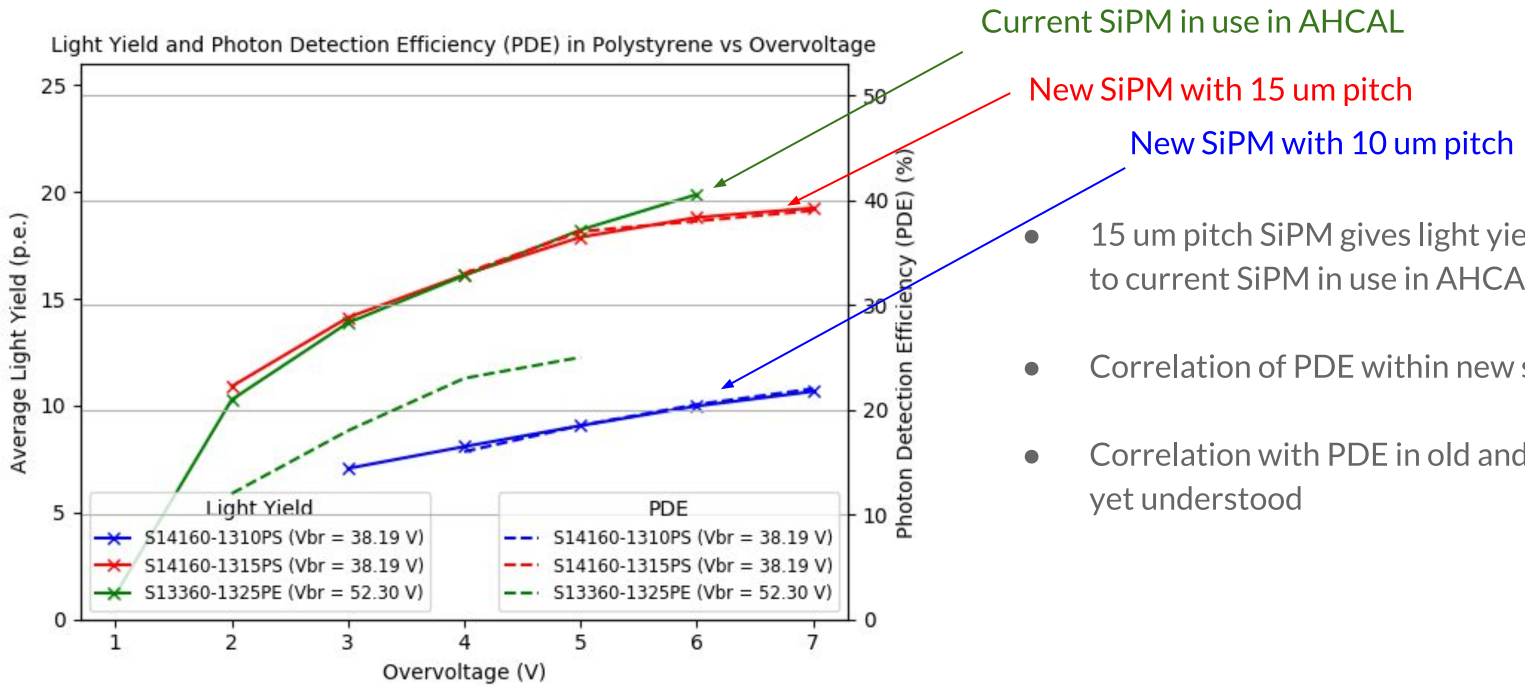
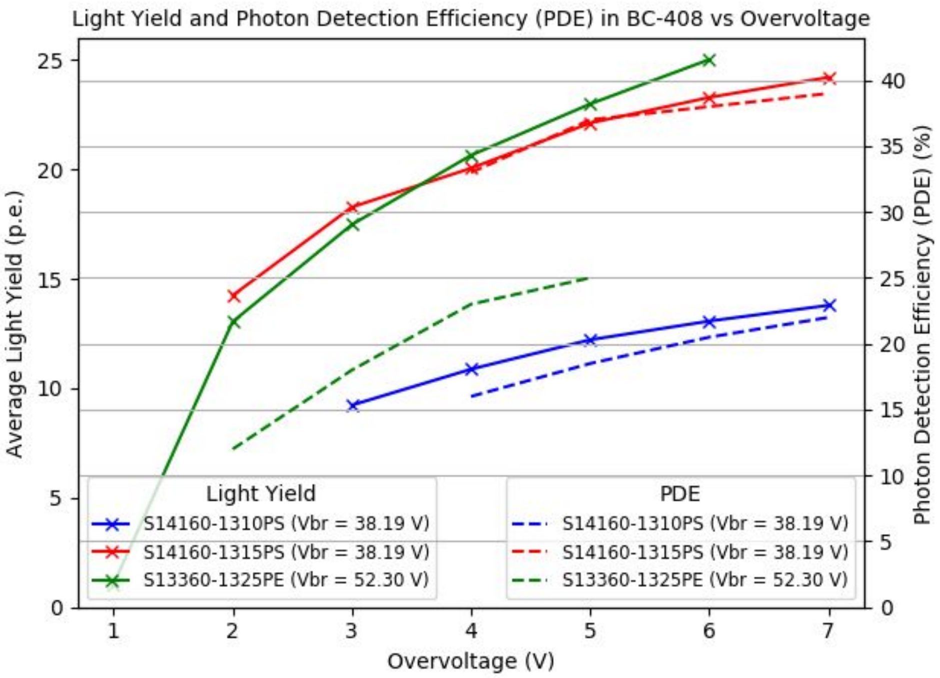


- 15 um pitch SiPM gives light yields comparable to current SiPM in use in AHCAL.
- Correlation of PDE within new series
- Correlation with PDE in old and new series not yet understood

Comparison of SiPMs using BC408 Tile

- Test done in a climate controlled 25° C environment using manufacturer supplied SiPM breakdown voltages (Vbr)
- Using CALICE AHCAL square polystyrene tile
- Newer SiPMs require an additional signal amplifier: lower gain due to smaller pixel capacitance



Current SiPM in use in AHCAL

New SiPM with 15 um pitch

New SiPM with 10 um pitch

- 15 um pitch SiPM gives light yields comparable to current SiPM in use in AHCAL.
- Correlation of PDE within new series
- Correlation with PDE in old and new series not yet understood
- Higher light yield in BC-408 tiles also observed

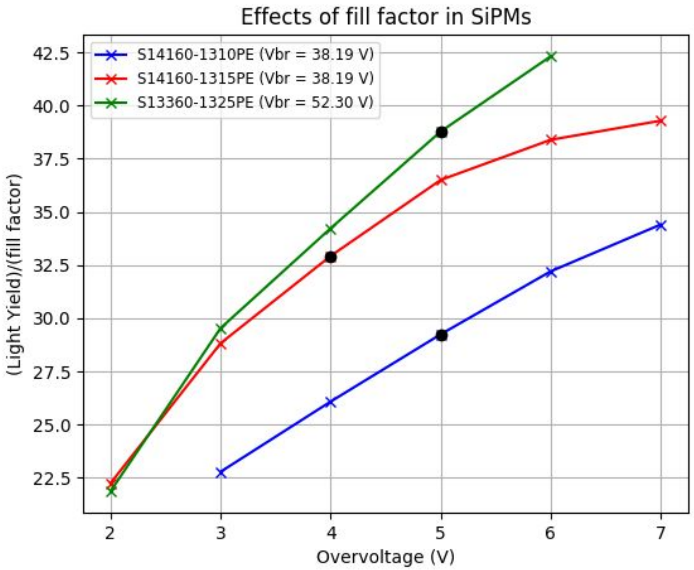
Effects of Fill Factor on Light Yield in SiPMs

- Fill factor = Active area in SiPM/Total area in SiPM
- Photon Detection Efficiency (PDE) = (Quantum Efficiency) x (avalanche probability) x (fill factor)

- Fill factor in values
  - S13360-1325PE - 47 %
  - S14160-1310PS - 31 %
  - S14160-1315PS - 49 %

- Plot the light yields after removing the effects of fill factor (fill factor set to 1)

- **Black dots** = Recommended overvoltages for SiPMs by Hamamatsu



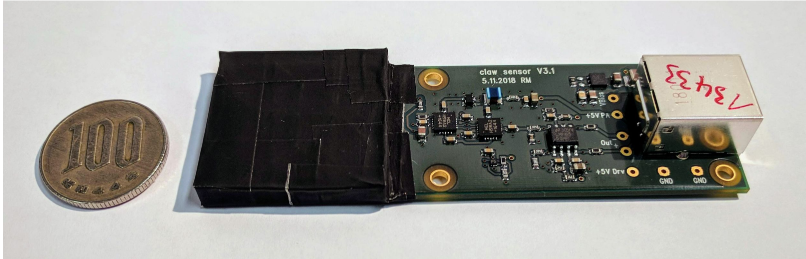
- Observed relative light yield changes approximately track the differences in fill factor between different devices

New SiPM-on-Tile Sensor and Receiver System

- System developed for the CLAWS detector in Belle2 experiment (SuperKEKB) in Japan

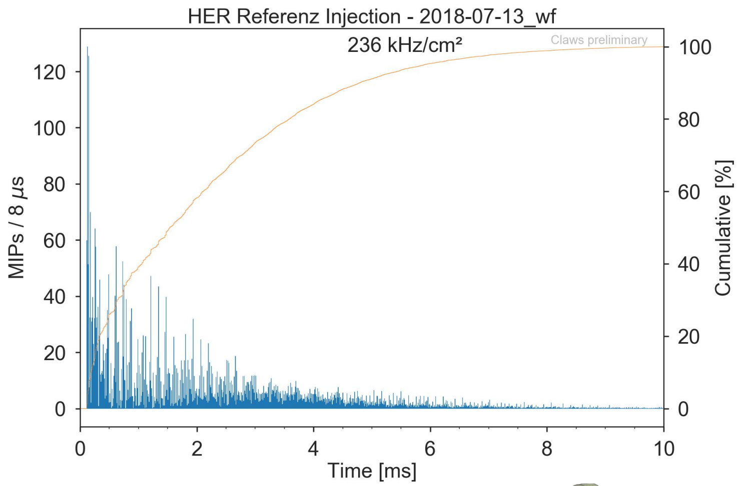
- New sensor board
  - SiPM-on-Tile wrapped
  - On board pre amplifier
  - Single ethernet connector for
    - 3x power (SiPM, preamp, differential amplifier)
    - Signal (sends as differential signal)
  - Ethernet cable CAT 6A or higher needed
    - for signal transmission at frequencies up to 500 MHz
    - To transmit HV up to 60 V

- New Receiver board
  - Capable of powering 16 SiPMs parallelly
  - On board differential amplifier combines the differential signal
  - Sends the signal through BNC output

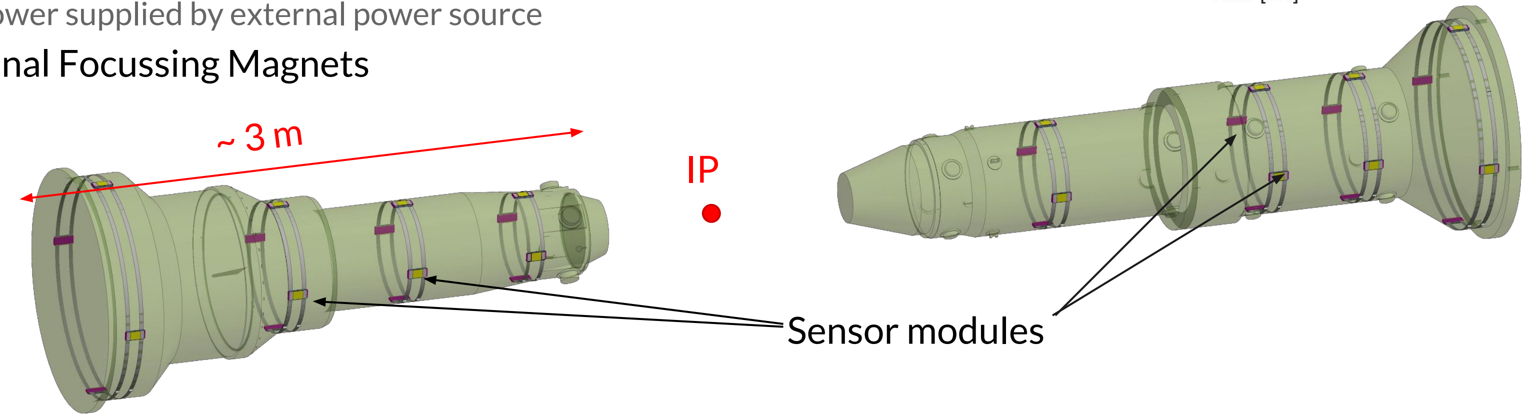


New SiPM-on-Tile Sensor and Receiver System - Belle2

- System developed for the CLAWS detector in Belle2 experiment (SuperKEKB) in Japan
  - Injection background monitor -> CLAWS
- Each of 32 SiPM-on-tile sensors contains a Hamamatsu S13360-1325PE SiPM with BC-408 wrapped scintillator tile
- Sensor modules attached around final focussing magnet
- 30 m long ethernet cables connect sensor to receiver board
- Power supplied by external power source



Final Focussing Magnets



Updated New SiPM-on-Tile Sensor and Receiver System

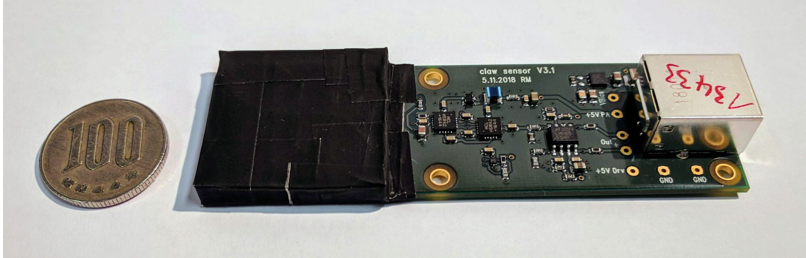
- Created as a spin-off of the CLAWS system

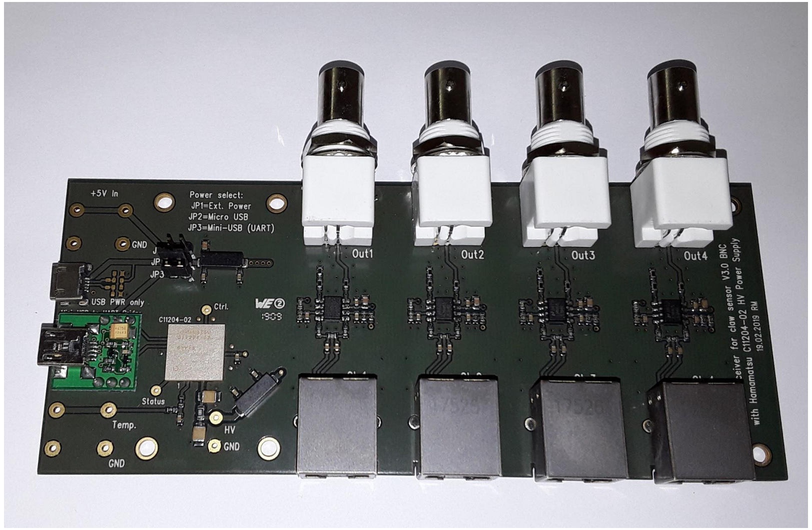
- New sensor board
  - Identical to CLAWS system

- New Receiver board
  - Capable of powering 4 SiPMs
  - Power supplied by Hamamatsu C11204 on-board power supply
    - Steered by computer through USB (Python script)
    - Stable power source
  - Includes BNC outputs for data acquisition

- Can be used in laboratory experiments involving MIP detection as well as for student internships and exhibitions in the institute

- Now used by Hamamatsu in their booths at conferences and exhibitions





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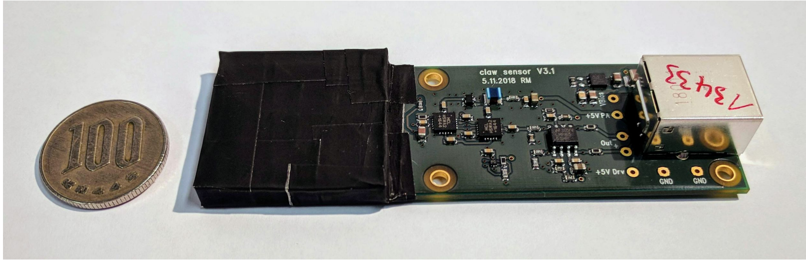
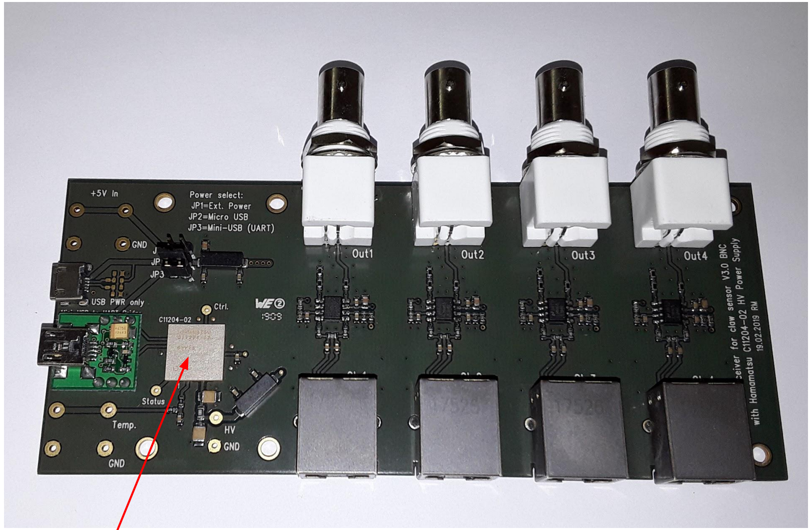
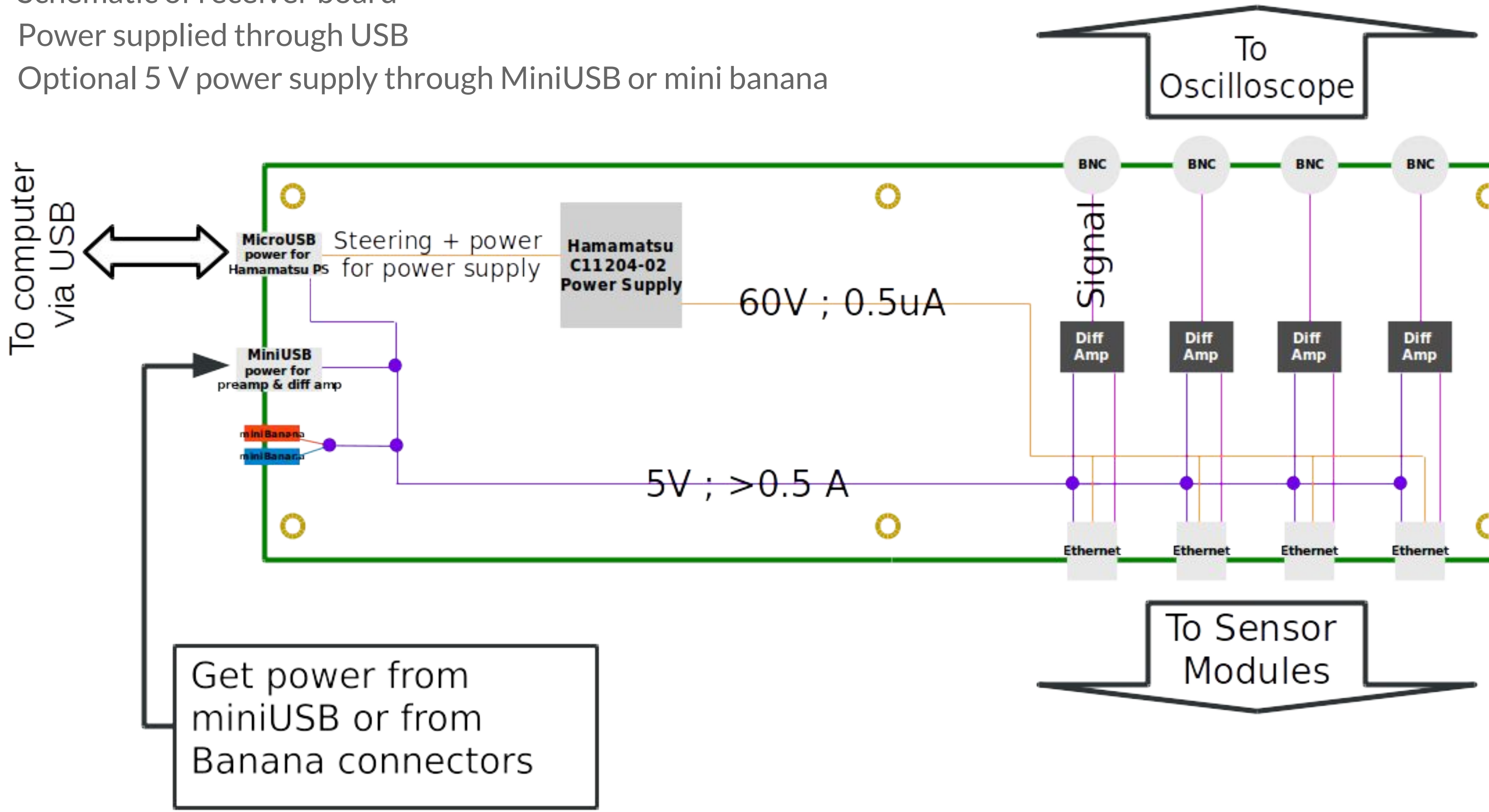




Hamamatsu Power Supply

Updated New SiPM-on-Tile Sensor and Receiver System

- Schematic of receiver board
- Power supplied through USB
- Optional 5 V power supply through MiniUSB or mini banana



New SiPM-on-Tile Sensor and Receiver System -Advantages

- Single ethernet connector for
  - 3x power (SiPM, preamp, differential amplifier)
  - Signal (sends as differential signal)

- Low noise gain through ethernet shielding
  - Ethernet cable maintains signal-noise ratio

- Possible to transfer signal across long distances
  - Signal arriving at receiver board is amplified

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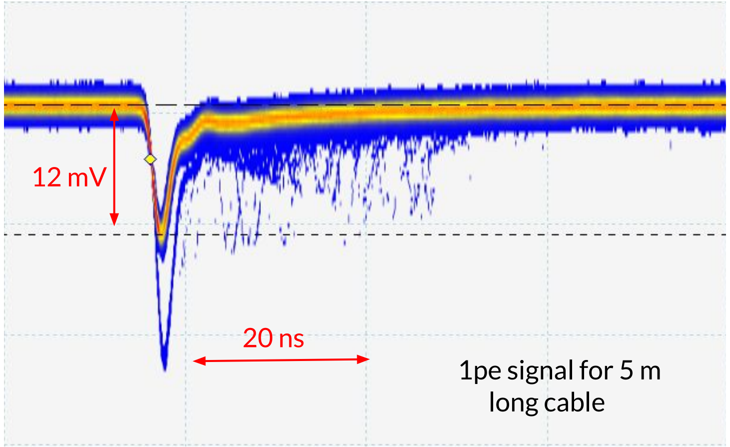

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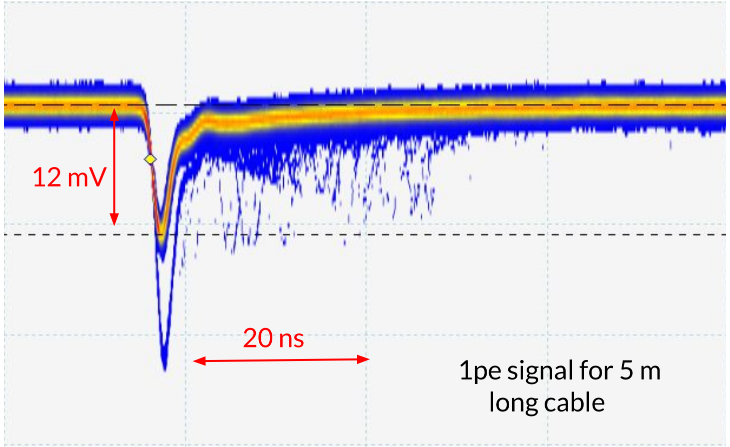

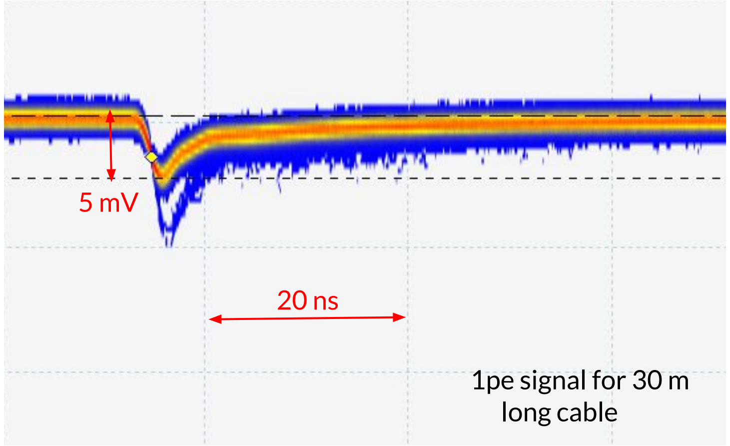

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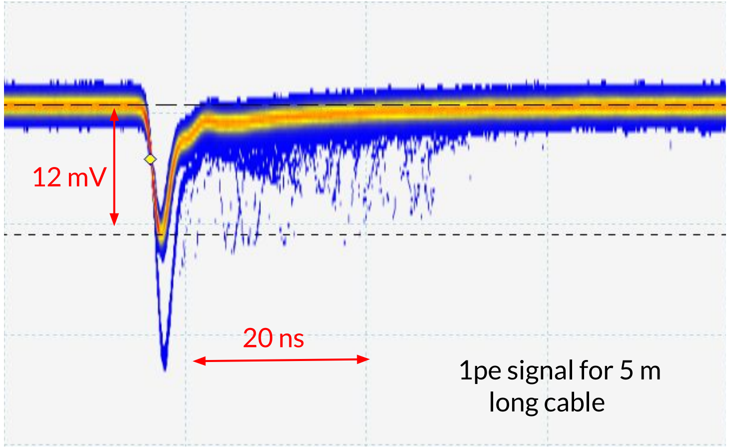

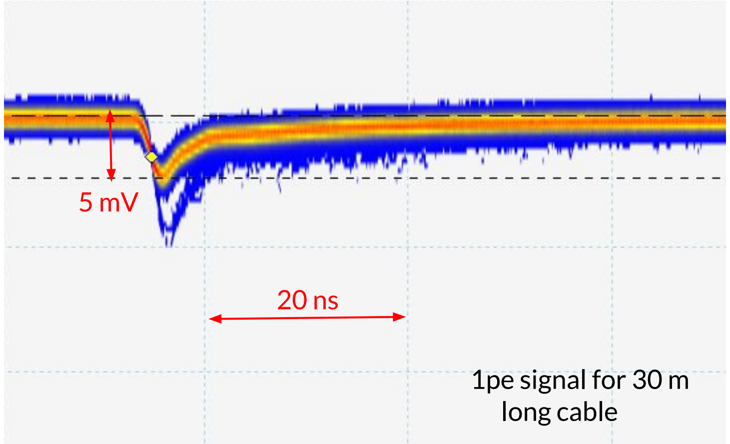

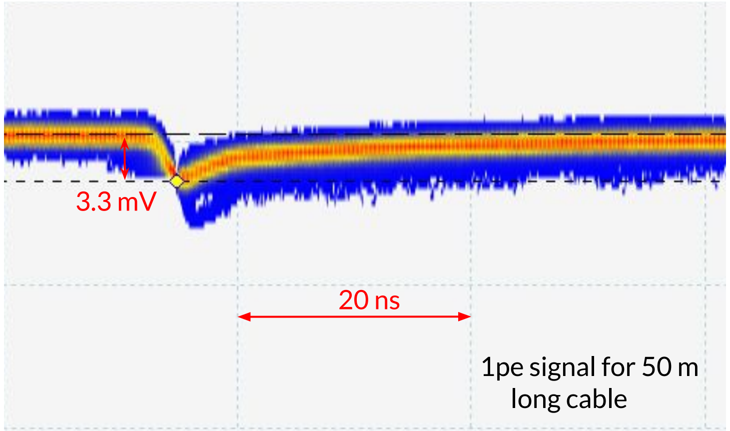

Conclusions

- Misalignment of SiPM and scintillator tile center
  - Negligible impact on the average light yield.
  - Misalignments under 200 um from center gives low asymmetry of light yield

- Comparison of silicon photomultipliers
  - Hamamatsu S14160-1315PE exhibits same light yield as S13360-1325PE for 2.5 x increased dynamic range.
  - Manufacturer supplied photon detection efficiencies correlated well with measured average light yields for newer Hamamatsu S14160 series SiPMs
  - Deviation in average light yield in S13360-1325PE from manufacturer given photon detection efficiency - still in the process of understanding observations

- New SiPM-on-tile sensor and receiver system successfully made, tested and now operational at the Belle2 detector in Japan
  - A spin-off system tested and implemented as a demonstration board capable of powering using a single USB cable and python script

Conclusions

- Misalignment of SiPM and scintillator tile center
  - Negligible impact on the average light yield.
  - Misalignments under 200 um from center gives low asymmetry of light yield

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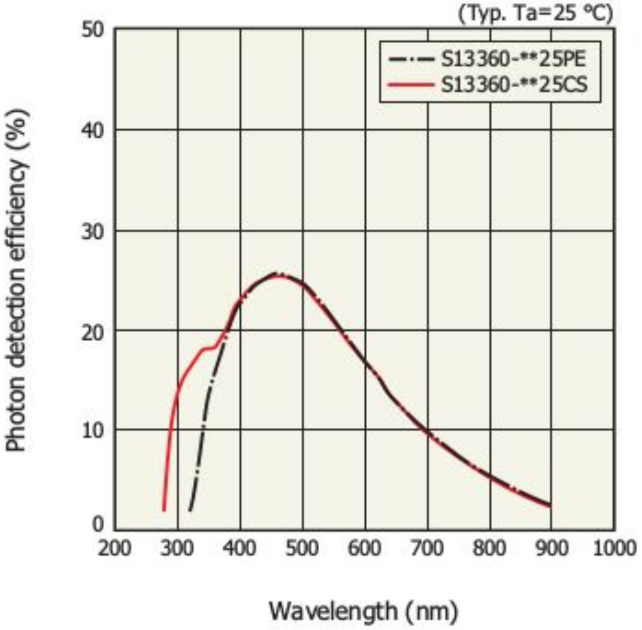
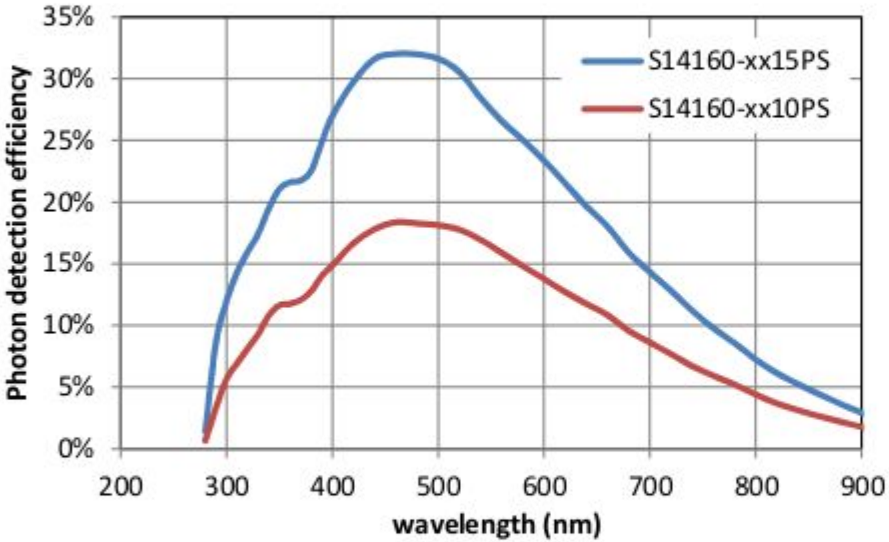
Thank you for your attention!

Backup - Photon Response of SiPMs

S13360-1325PE





Peak wavelength	= 450 nm
Cross talk probability	= ~1 %

Peak wavelength	= 460 nm
Cross talk probability	< 1 %

Backup - Analysis plots

- Example plot of light yields fitted as Gaussian
- Trigger threshold of ~7pe triggers data taking from SiPMs
  - 1000 captures taken
  - Pedestal subtracted integral of signals obtained
  - Signals with too low integral values rejected
  - Signals above 97th percentile rejected (remove the tail)
  - Using a Gaussian fit, mean value is taken as signal