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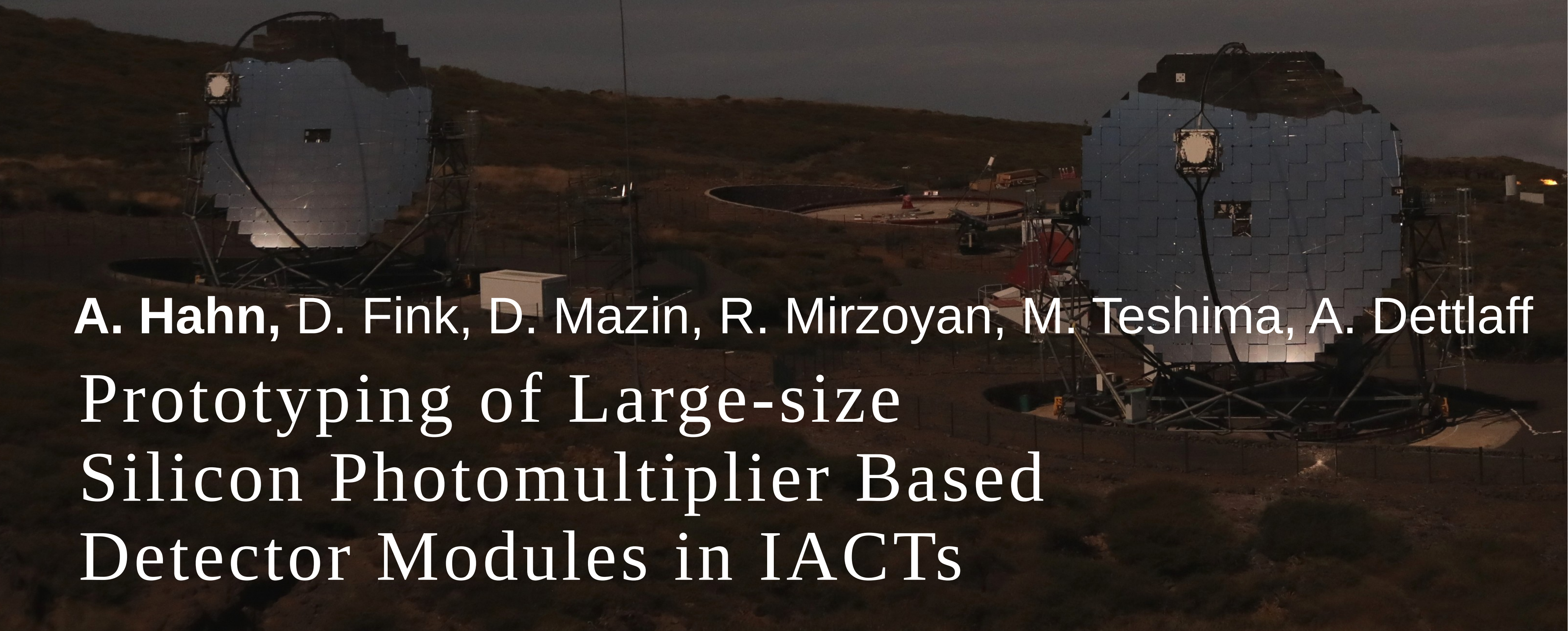
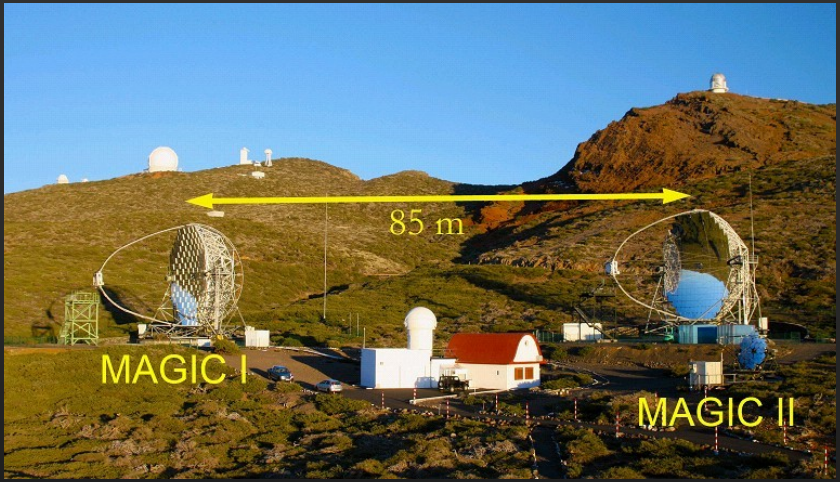


A. Hahn, D. Fink, D. Mazin, R. Mirzoyan, M. Teshima, A. Dettlaff

Prototyping of Large-size Silicon Photomultiplier Based Detector Modules in IACTs

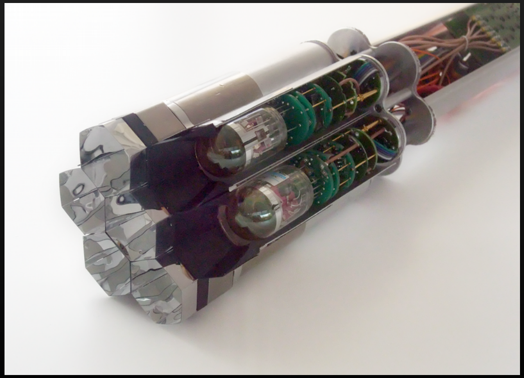
The MAGIC telescopes

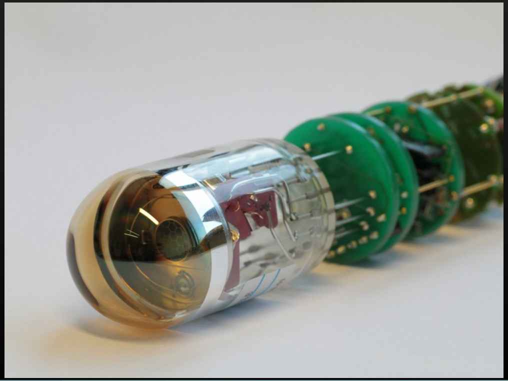
[1]



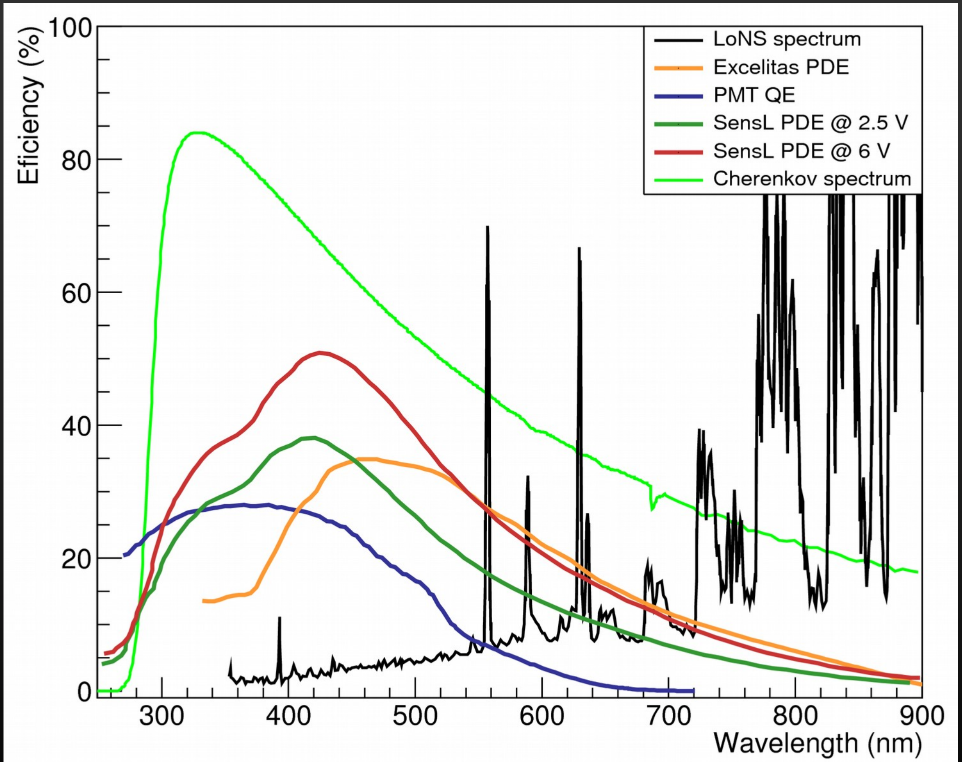
- Canary island of La Palma
- 2200 m above see level
- Two imaging atmospheric Cherenkov telescopes (IACTs)
- Each camera equipped with 1039 PMTs
- Up to 7 pixels partitioned in 169 clusters plus 6 open corner locations

[2]



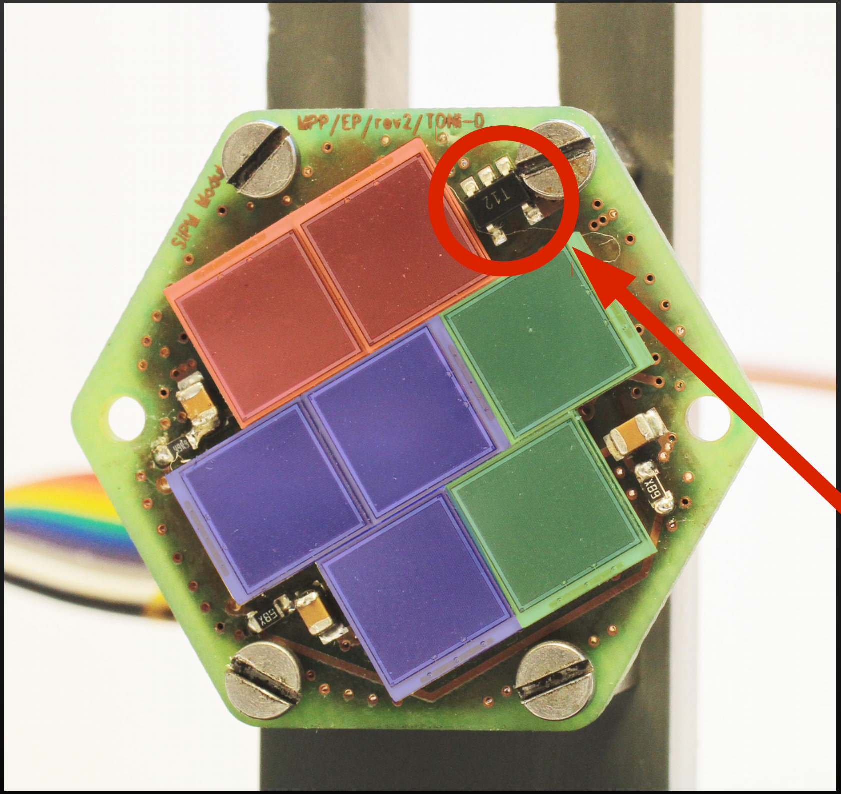


Motivation



- SiPMs are competing with PMTs in terms of detection efficiency
- No HV necessary
- No ageing
- Potentially SiPMs can be operated during moon time similar to MAGIC PMT cameras
- Drawbacks: temperature dependence, high background rate due to broad wavelength sensitivity
- **Goal:** Compare performance of PMT and SiPM based detectors during real telescope operation

First Pixel Design

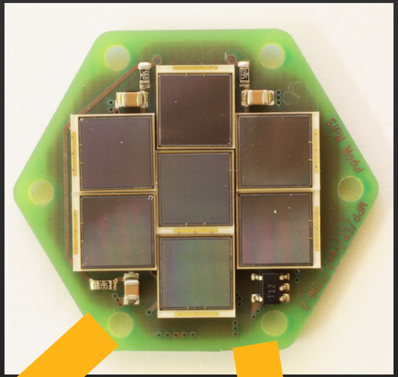


- Excelitas C30742-66 SiPM
- Three groups (2-3-2) of Excelitas 6x6 mm² SiPMs with same breakdown voltage
- Single, summed output of all SiPMs
- Only one high voltage per cluster
- One offset voltage per group used to disable the pixel (star in FOV), adjust gain
- One temperature sensor next to sensors
- Dedicated light guide design
- 31 % dead area

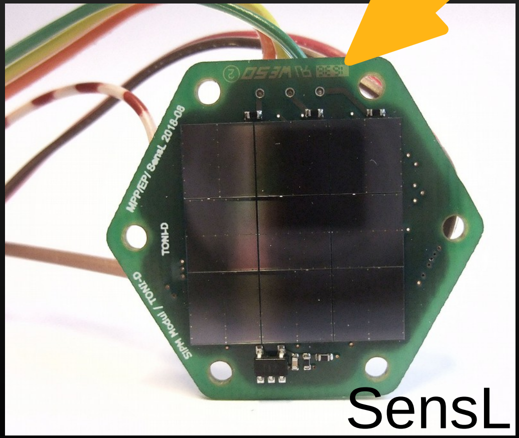
Second Generation Design

- Using Hamamatsu and SensL SiPMs
  ⇒ comparison of three major suppliers
- Increased active area to 9 SiPMs/pixel
  (< 10 % dead area)
- Similar electronics
- Optimized heat flow using Aluminium core PCBs
- Lower breakdown voltage

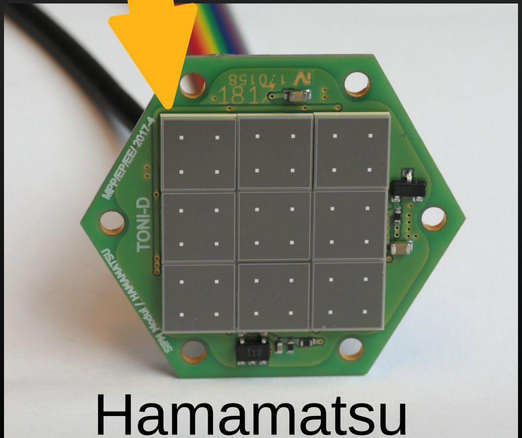
Sensor type	Breakdown voltage
Excelitas C30742-66	~ 95 V
Hamamatsu S13360-6075VS	~ 50 V
SensL MicroFJ-60035-TSV	~ 30 V



Excelitas



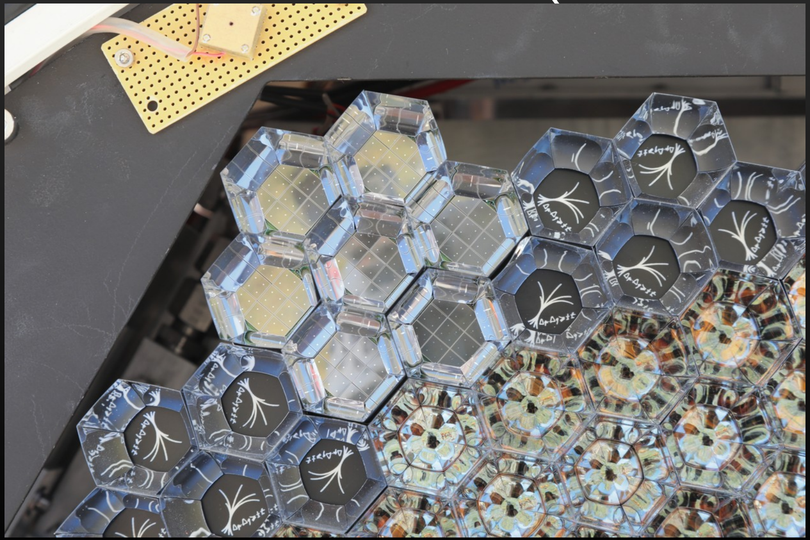
SensL

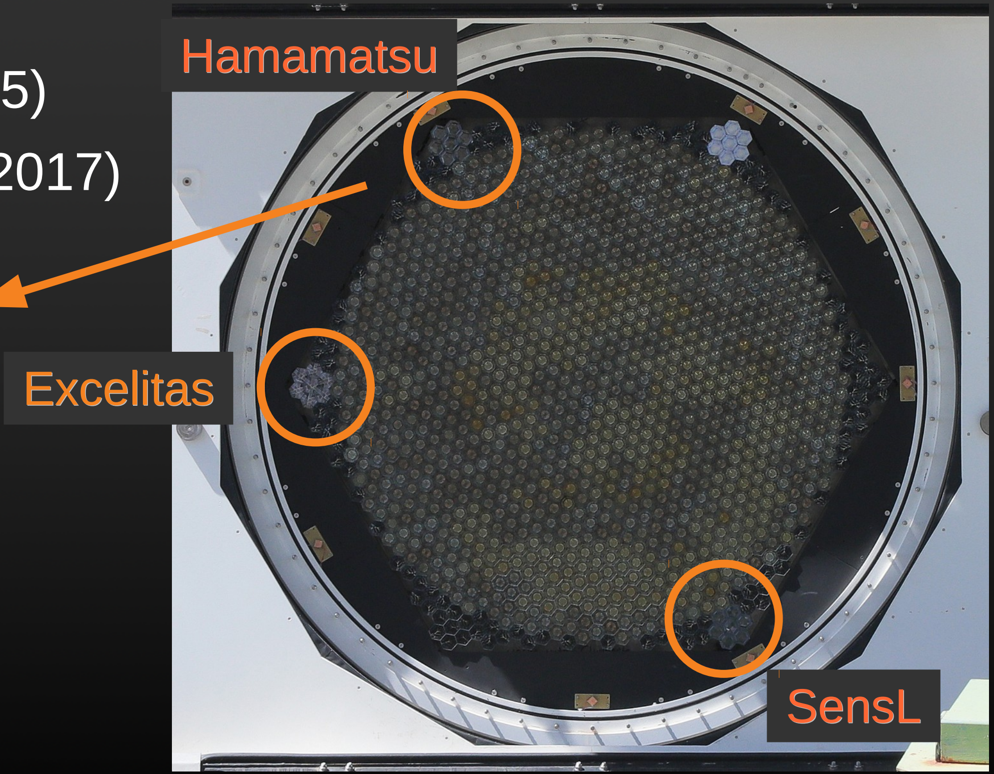


Hamamatsu

Installation of SiPM clusters

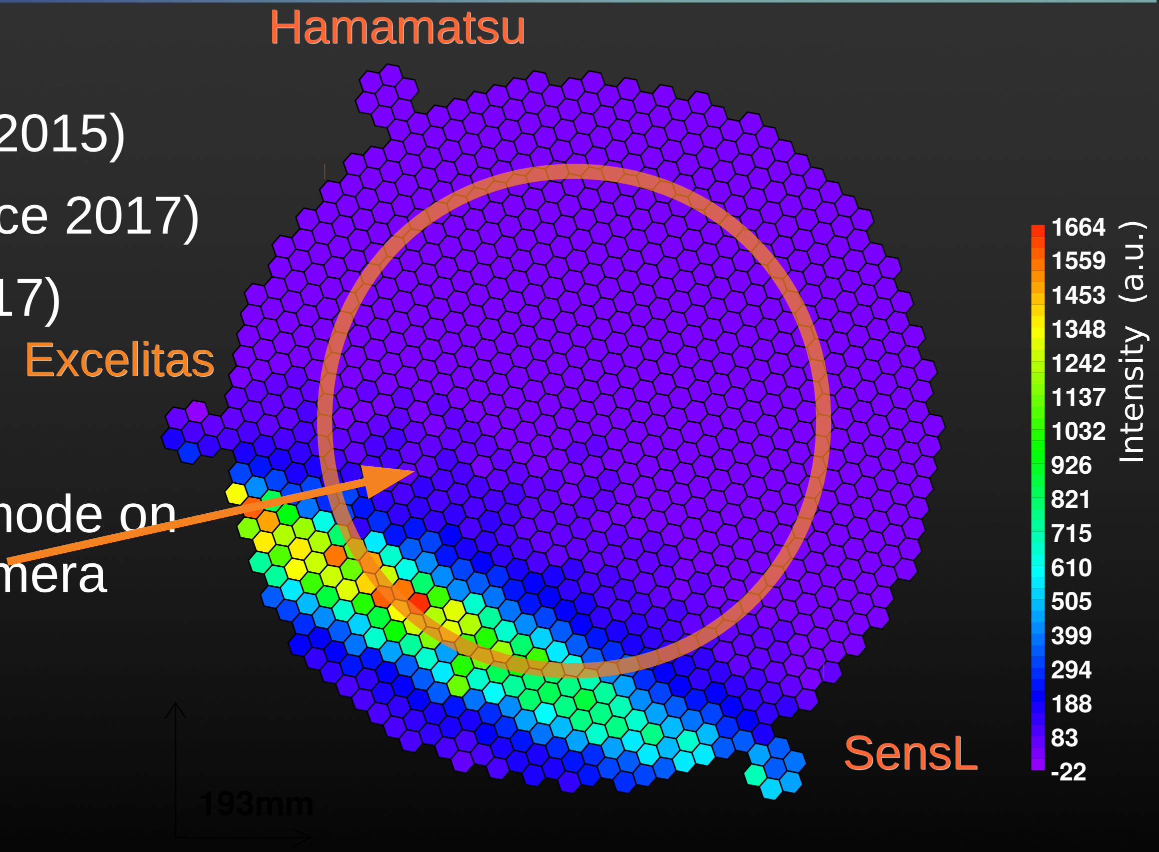
- Installed
  - 1 cluster Excelitas (since 2015)
  - 1 cluster Hamamatsu (since 2017)
  - 1 cluster SensL (since 2017)





Installation of SiPM clusters

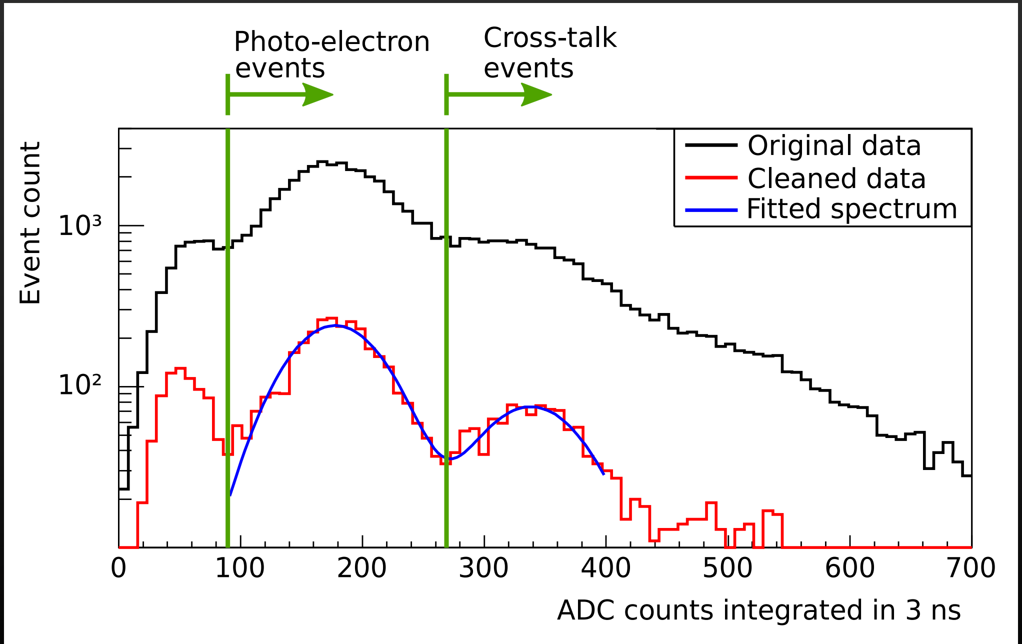
- Installed
  - 1 cluster Excelitas (since 2015)
  - 1 cluster Hamamatsu (since 2017)
  - 1 cluster SensL (since 2017)
- Integrated to standard readout and data taking
- Operated in parasitic trigger mode on events triggering the inner camera region



Calibration

Two methods considered

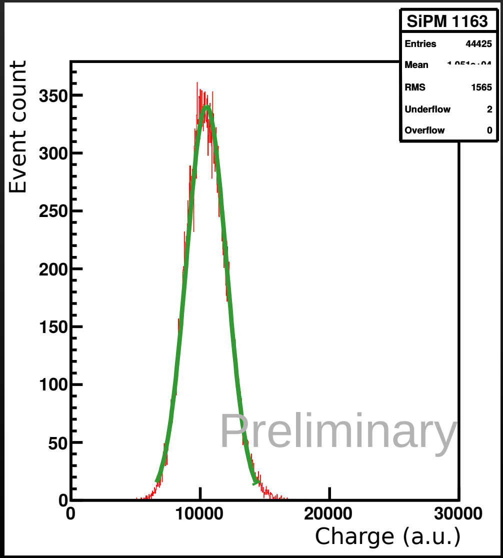
- Single-photoelectron spectrum



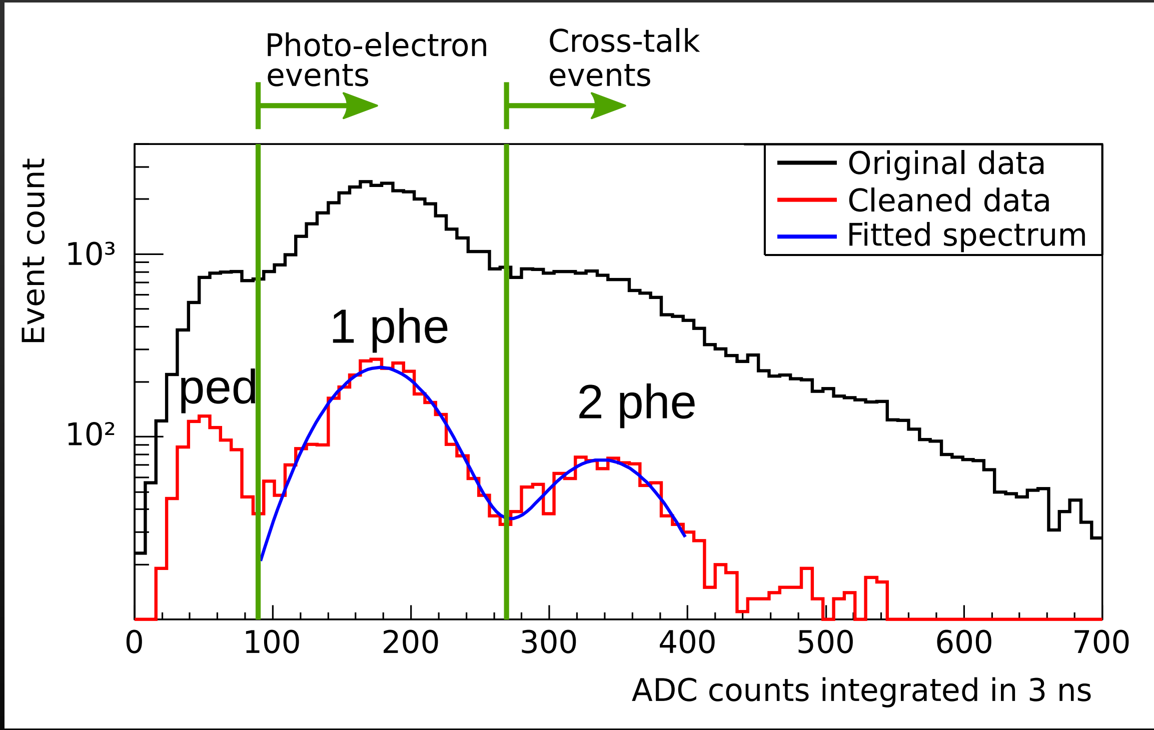
- F-Factor (≡ excess noise)

$$\overline{m_{phe}} = 8 \cdot \ln(2) \cdot F^{2} \cdot \frac{\overline{Q}}{FWHM}$$

- Using position and FWHM of charge distribution



Calibration
Single phe-spectrum



- 100 kEvents @ 300Hz with closed lids
  ⇒ Pedestal / dark count events
- Selection of good events
- Fitting the single pe-spectrum to obtain the gain
- Integrate or fit original data for cross-talk estimation

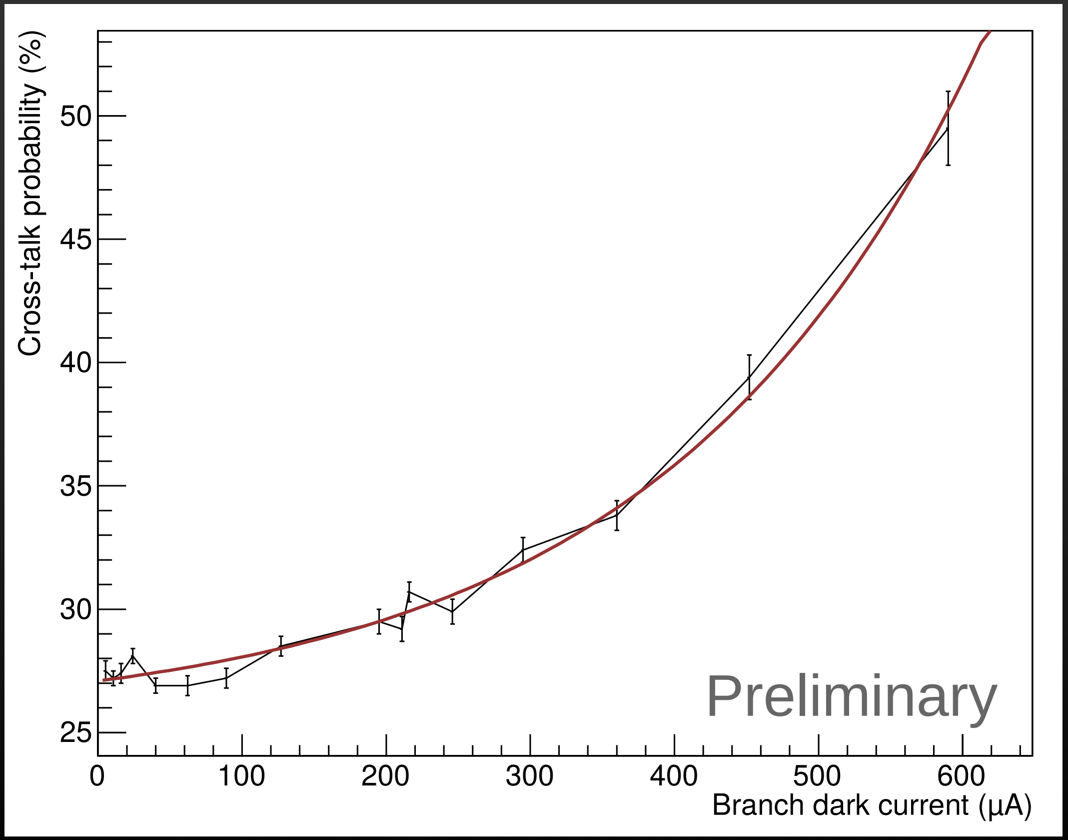
F-Factor
Cross-talk

- Calibration via F-Factor method (like PMTs)
- Cross-talk (p) defines F-Factor of SiPMs

$$F = 1 + p + \frac{3}{2} p + \mathrm{O}\left(p^3\right)$$

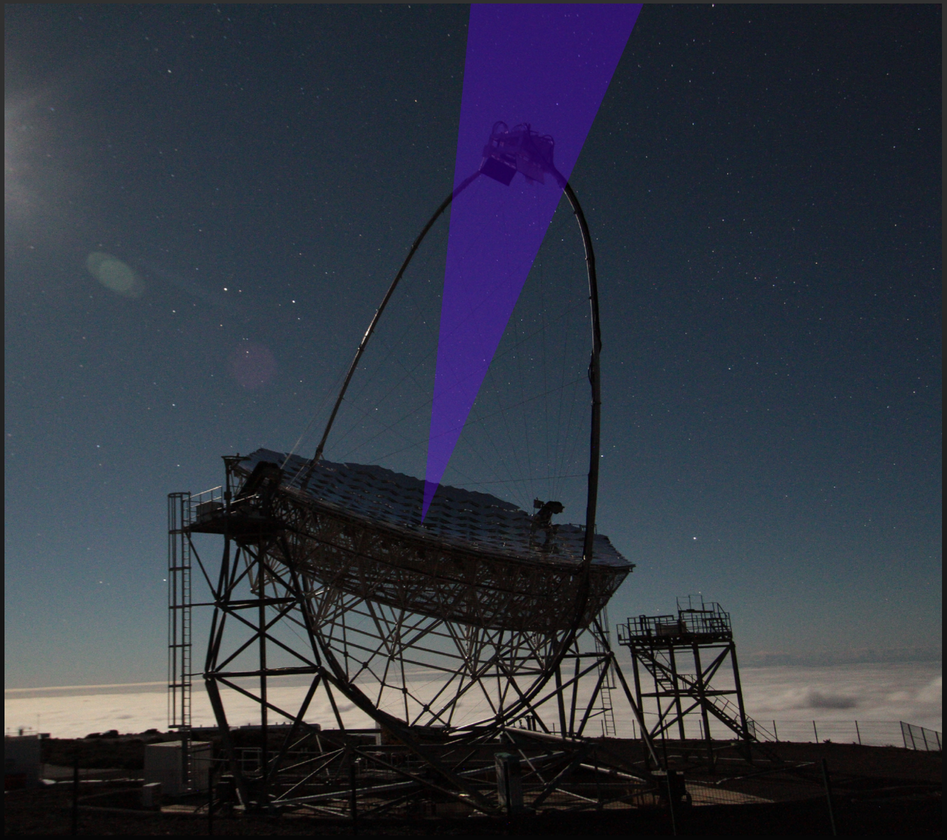
[3, 4]

- Measured cross-talk in lab
- Read dark current during pedestal run
  ⇒ calculate F-Factor
- Higher order terms in SiPM F-Factor lead to a higher uncertainty in converted phe wrt. PMT conversion

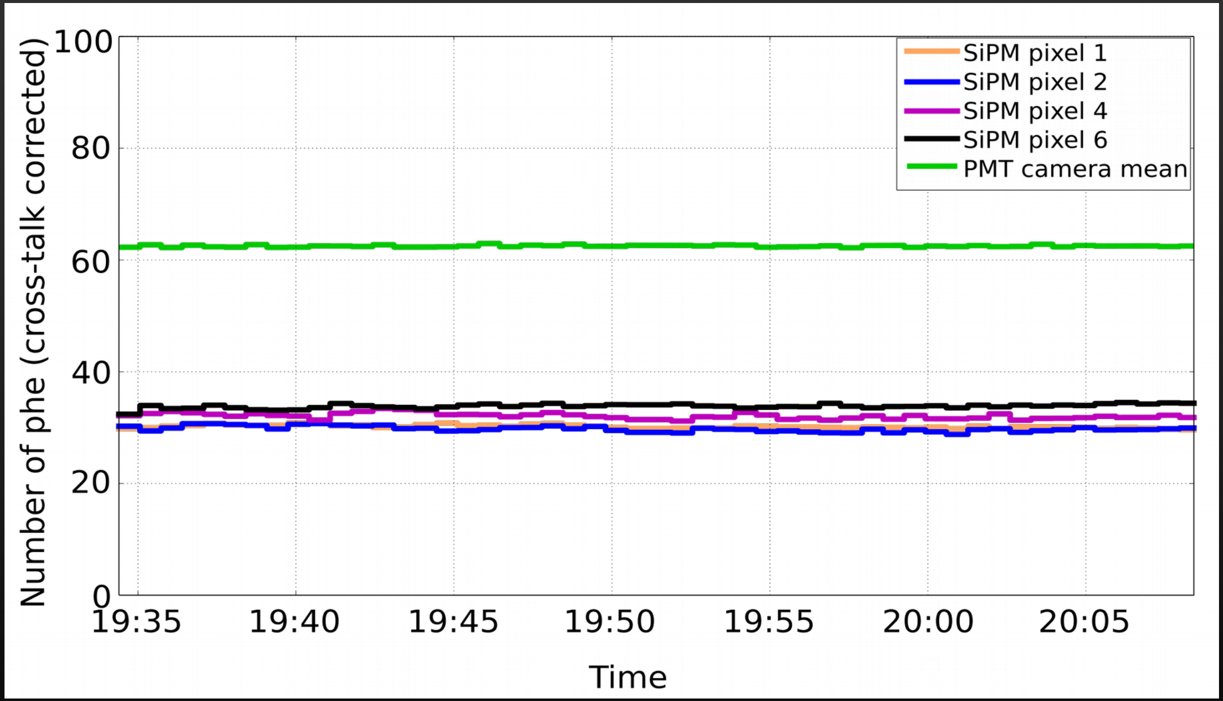


Performance

- Calibration light pulses illuminating the camera
- Fixed frequency (25 Hz)
- Fixed wavelength (355 nm)
- Fixed light content
- Used for PMT calibration
- Used for comparing detection efficiencies of SiPMs and PMTs



Performance Gen. 1
Excelitas



- Calibrated using phe-spectrum
- Dead area of pixel, PDE(λ)
  ⇒ expect ~ 32 phe
- Number of phe is in **expected range**

⇓

- Hamamatsu and SensL clusters expected to perform as good as current MAGIC PMTs in terms of pixel PDE

Performance Gen. 2
Hamamatsu

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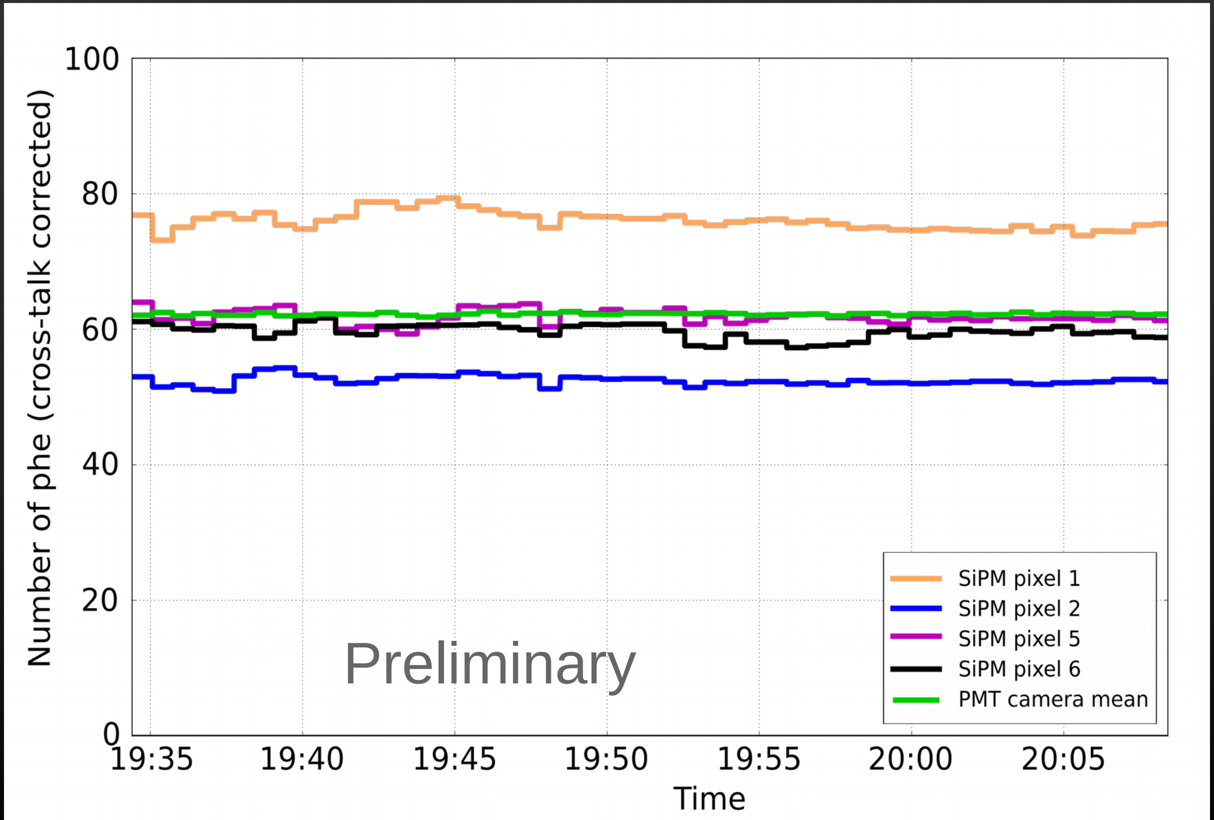
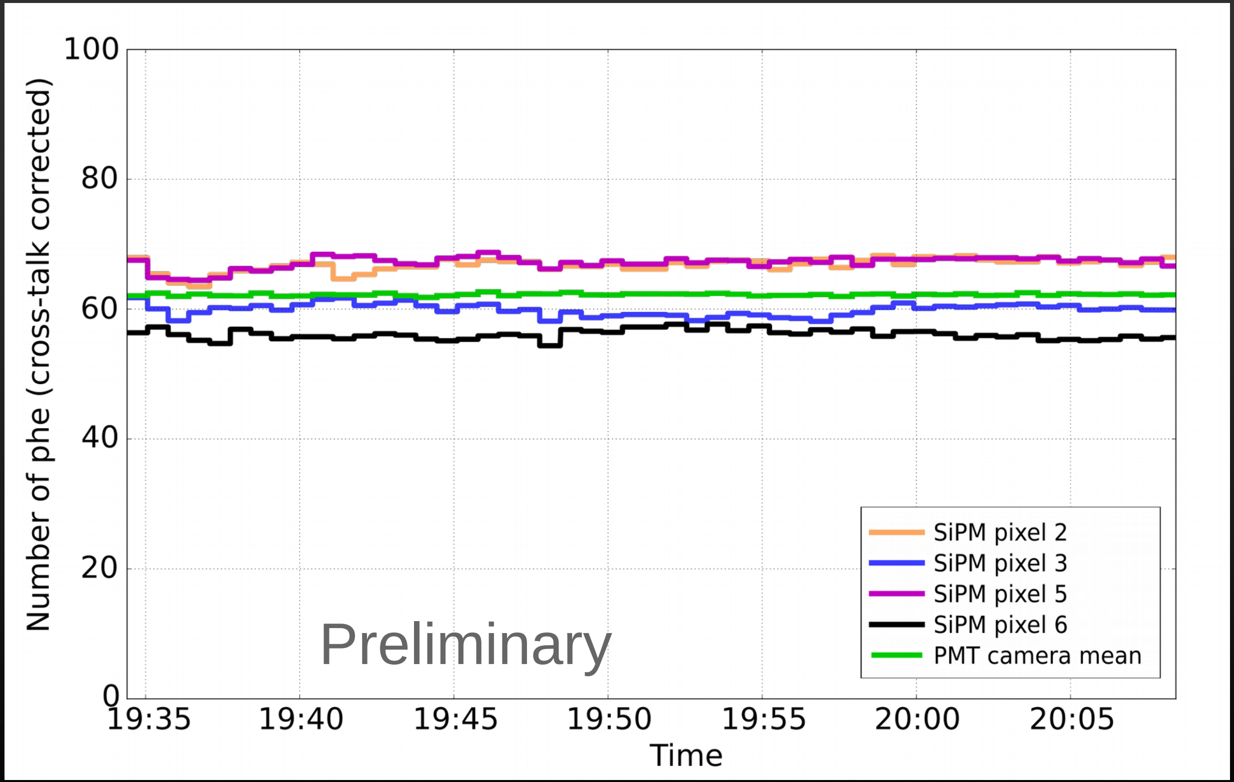


- Calibrated using phe-spectrum
- Number of phe in expected range (dead area of pixel, PDE(λ))
- Number of phe is comparable to installed MAGIC PMTs
- One pixel higher than PMT (same gain as other pixels but lower cross-talk)
- Big spread is caused by differences in cross-talk
  → Under investigation

Performance Gen. 2
SensL

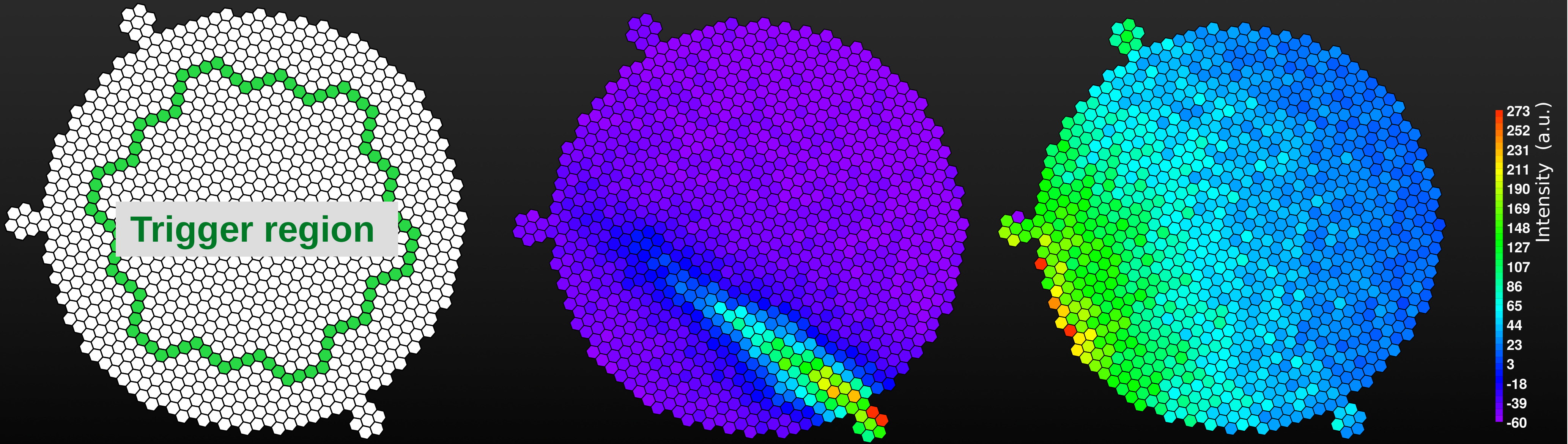


- Calibrated using F-Factor
- Number of phe in expected range (dead area of pixel, PDE(λ))
- F-Factor calibration method gives plausible results
- Number of phe is comparable to installed MAGIC PMTs

Performance
Cherenkov Events

Camera is triggered on inner region
⇒ strong bias due to shower shape

Select only very large showers for the performance comparison



Summary and Outlook

Goal: SiPM pixel to replace 1'' PMT

Achievements

- Three prototypes of different SiPMs installed in MAGIC camera
- Demonstrated two calibration procedures
- Measurements of calibration pulses are all in expected range

Further tasks:

- Comparison of detection efficiencies of real Cherenkov events
- Move SiPM pixels inside trigger region (avoid bias on light distribution)
- Cross-calibration using muon events


Thank you for your attention
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References

- [1] R. Wagner. Picture gallery of the MAGIC telescopes. https://magicold.mpp.mpg.de/gallery/pictures/ . Retrieved 10-2014
- [2] D. Nakajima, et al. New Imaging Camera for the MAGIC-I Telescope, 2013. Proc. of 33rd International cosmic ray conference.
- [3] D. Renker, et. al., Advances in solid state photon detectors, J. Instrum., 4, 2009.
- [4] S. Vinogradov, Analytical models of probability distribution and excess noise factor of solid state photomultiplier signals with crosstalk, NIM-A, 695:247-251, Dec. 2012