# The prototype Schwarzschild Couder Telescope: a Medium-Sized Telescope for the Cherenkov Telescope Array

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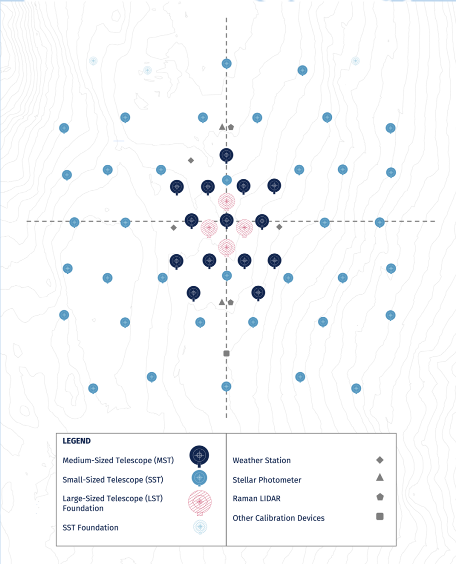
# Gamma-ray detection with Cherenkov Telescope Array

https://www.cta-observatory.org/ctao-releases-layouts-for-alpha-configuration/

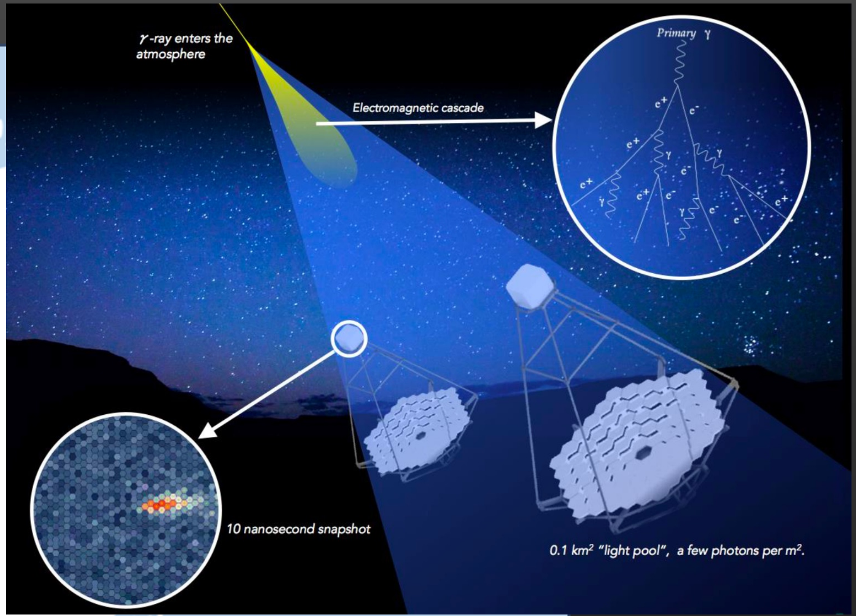
*Observatory planned to be operated by 2025*

**Chile**

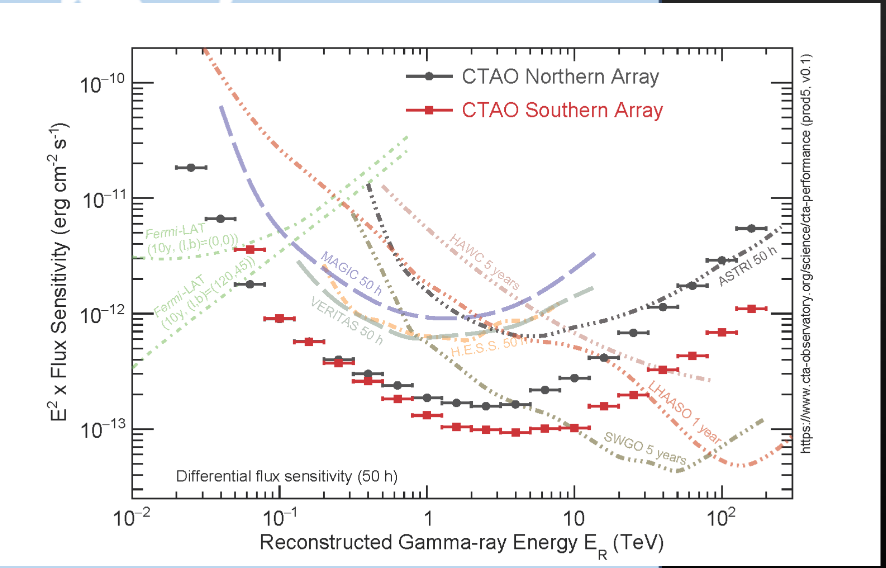



**Cherenkov Telescope Array:**

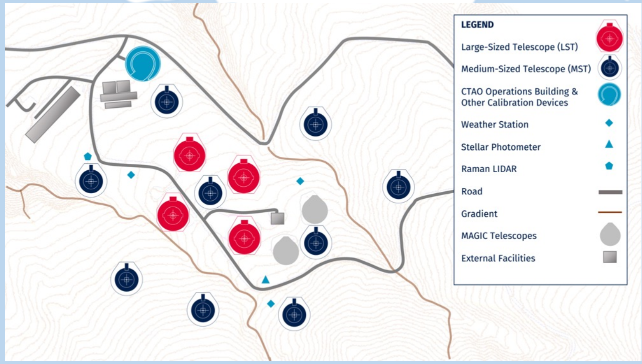
- ~100 + telescopes involved
- Increased detection area
- Improved sensitivity
- 2 telescopes sites
- 3 sizes of telescopes




**Energy range: 20 GeV-300 TeV**

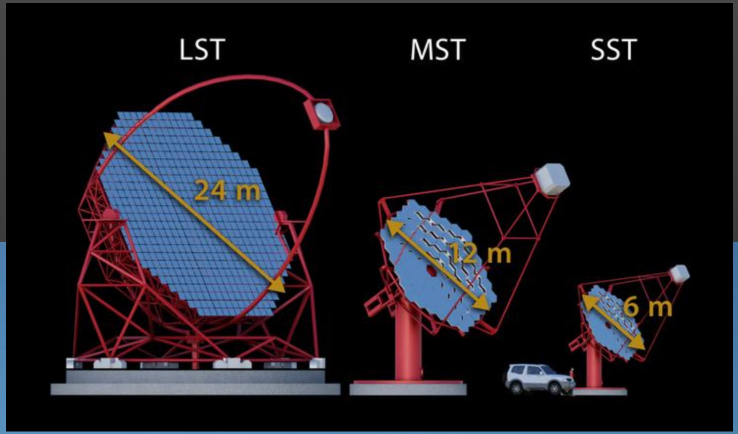



**La Palma**

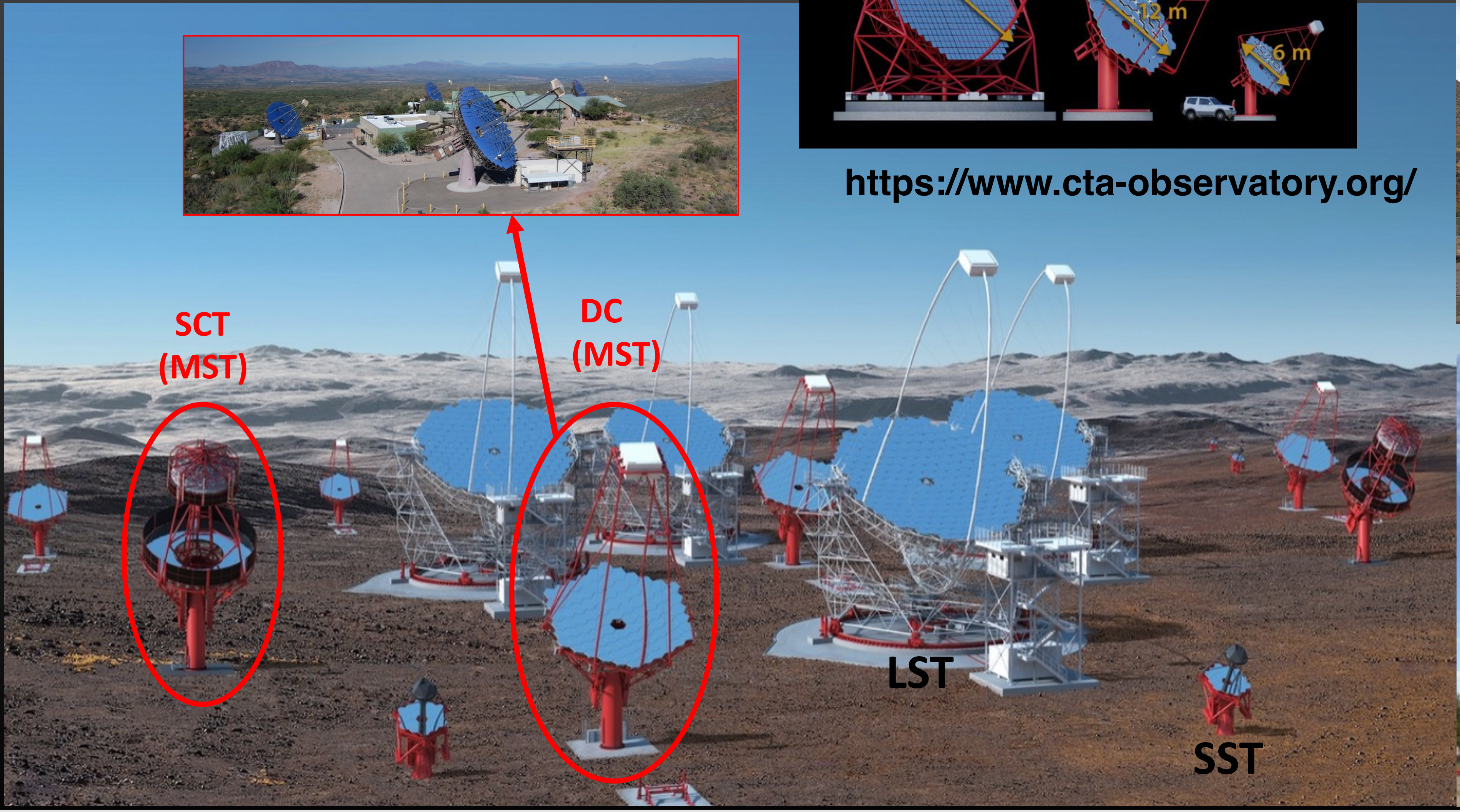



https://www.cta-observatory.org/science/ctao-performance/#1472563157332-1ef9e83d-426c

**Now pSCT is installed at VERITAS site**
**Arizona-1270 m asl**




https://www.cta-observatory.org/

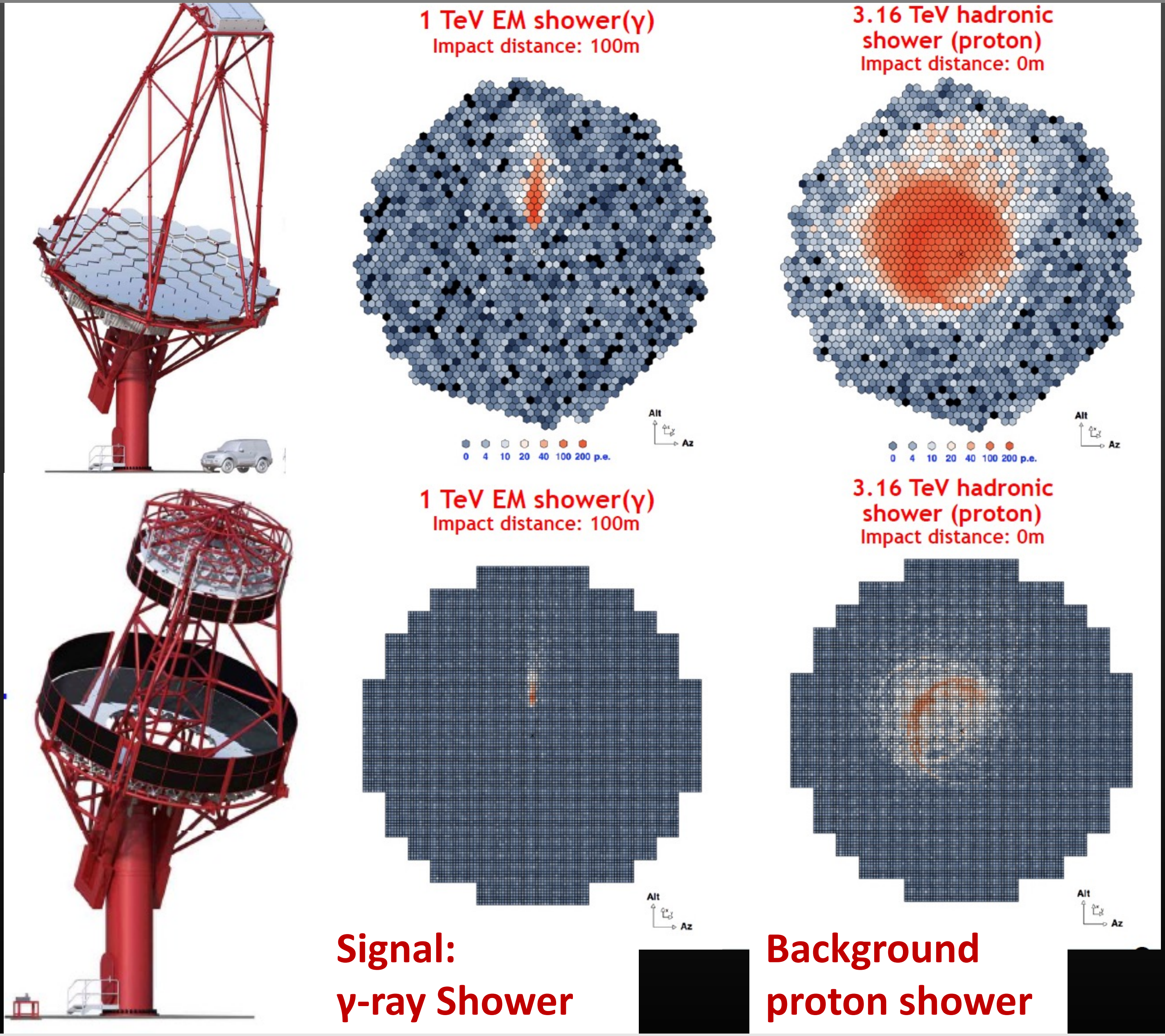




# The Schwarschild Couder Telescope (SCT)

MST
Single mirror
Davies-Cotton
~ 2k PMTs 1800 ~ 0.17° pixels

SCT Double mirror
Schwarzschild-Couder
~ 12k SiPMs ~ 0.067° pixels
(8°FoV)



# The Schwarschild Couder Telescope (SCT)

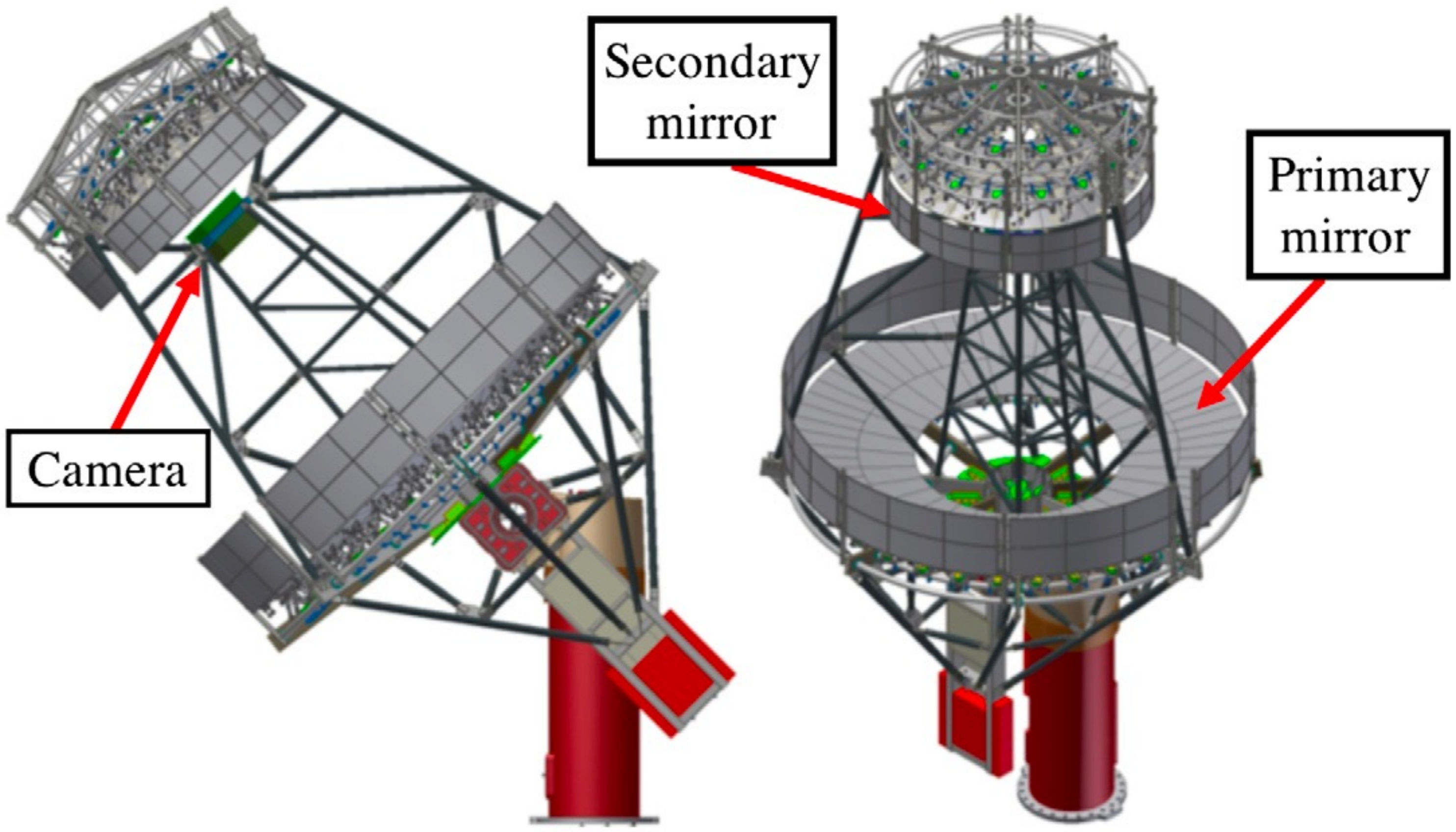
Dual mirror medium size telescope

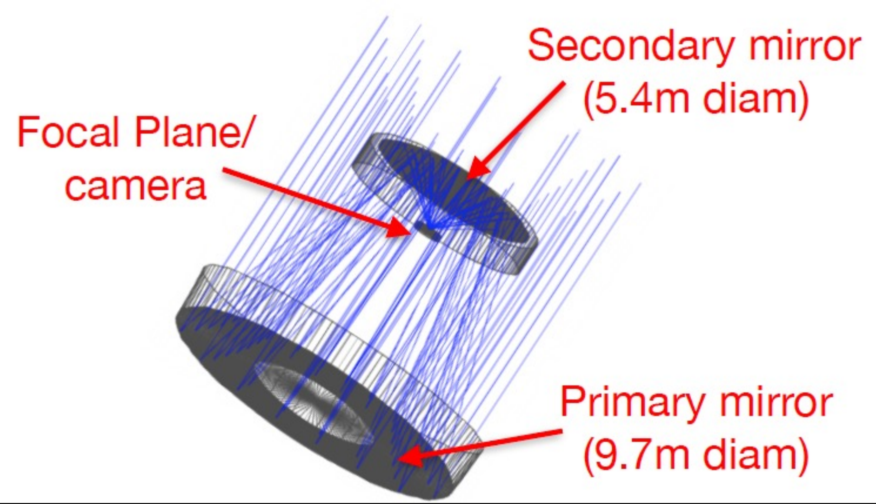
**Improvements:**

- Aberration reduction on the revealed images.
- Compatible with a SiPM ultra-compact high resolution camera (11 pixels)

**Limitations:**

- mechanical stability and mirror alignment



# The CTA SCT project

## The inauguration


~30 participating Institutions

Milestones:

- 1st construction: 06-23-2015
- Inauguration: 01-17-2019
- 1st light: 01-23-2019
- December 2019: optical alignment achieving preconstruction estimated PSF
- January 2020: significant detection of the Crab Nebula (presented at 236th AAS) https://doi.org/10.1016/j.astropartphys.2021.102562

- Endorsement by the CTA Consortium for supporting the development and construction of SCTs to add to the array and complement single-mirror MSTs

. Next steps:

- Ongoing (funded MRI): population of the focal plane to ~11k channels with upgraded SiPMs and electronics

# The CTA SCT project

cherenkov telescope array

~30 participating Institutions

## 8 June 2015


## Design parameters

- Optical system: f/0.58, F=5.59 m
- S Aplanats: q=0.666; a=0.666
- Primary (M1) diameter: 9.66 m
- M1 type: aspheric segmented (16+32)
- Secondary (M2) diameter: 5.42 m
- M2 type: aspheric segmented (8+16)
- Field of View: 8 deg
- Focal plane diameter: 78 cm
- Effective collecting area (including shadowing & reflectance losses): >35 $m^2$
- PSF less than: <4.5 arcmin (across the FoV)
- Photon detector: SiPM
- Number of pixels/channels in the IACT camera: 11,328
- Angular pixel size (imaging): 0.067 deg
- Angular pixel size (triggering): 0.134 deg

## September 2016


Milestones:

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- Inauguration: 01-17-2019
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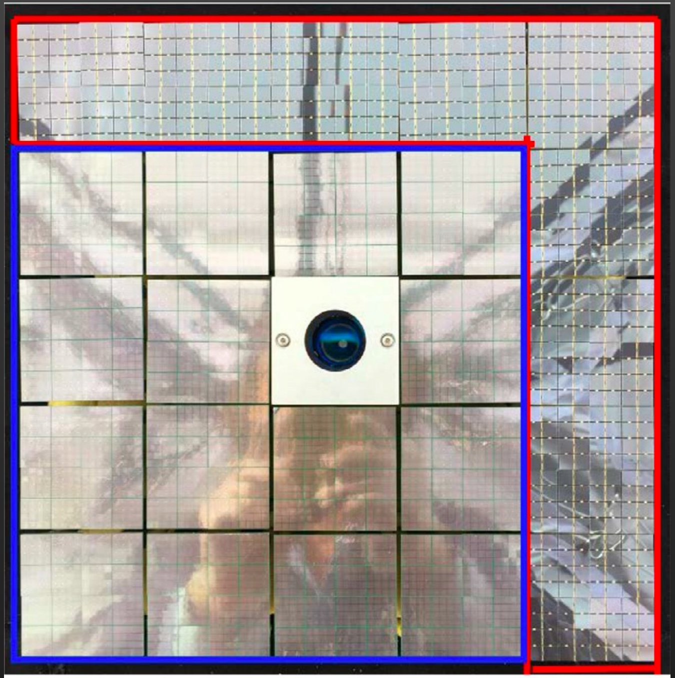
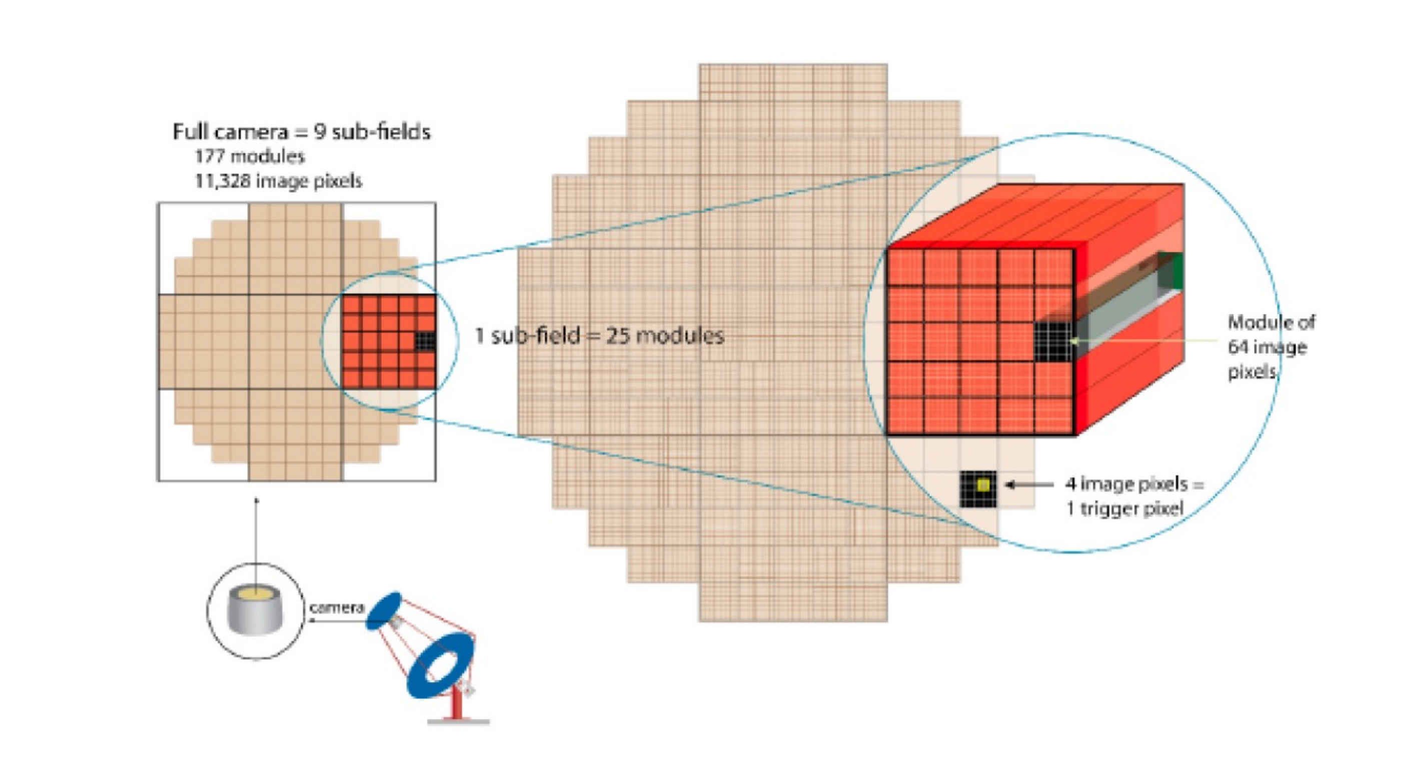
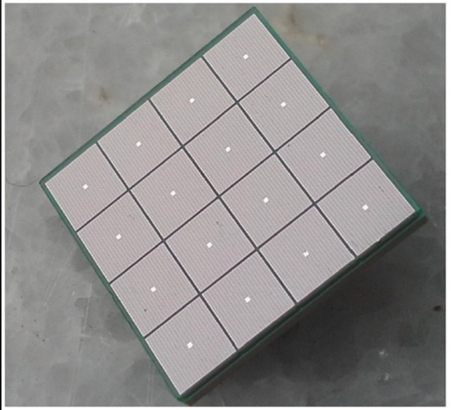
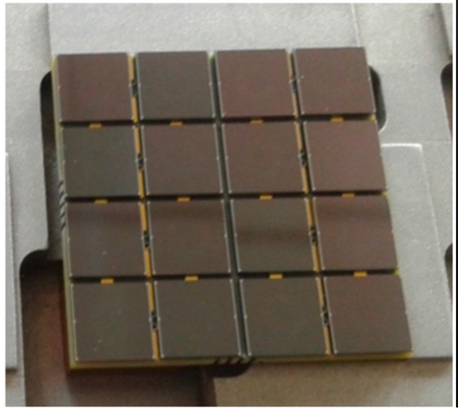
# Current pSCT camera

177 modules (64 pixels)







Hamamatsu MPPc

FBK HD3

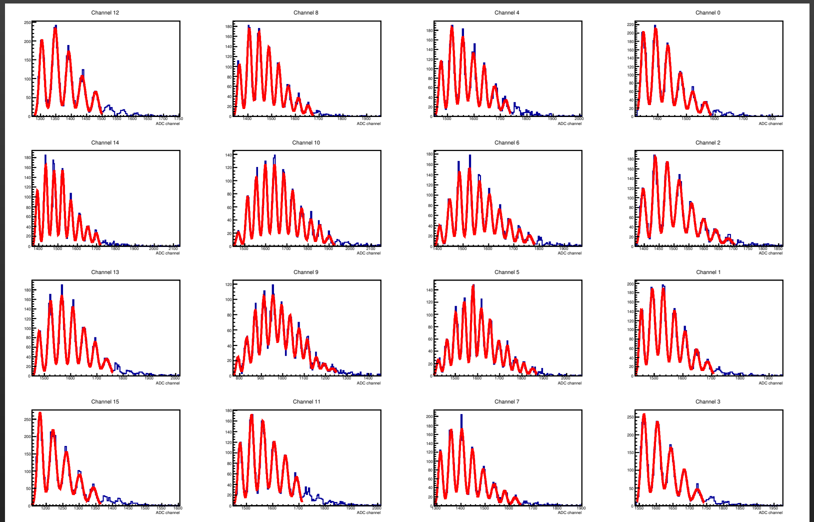
**Current camera: 1600 pixels~2.7° FOV**

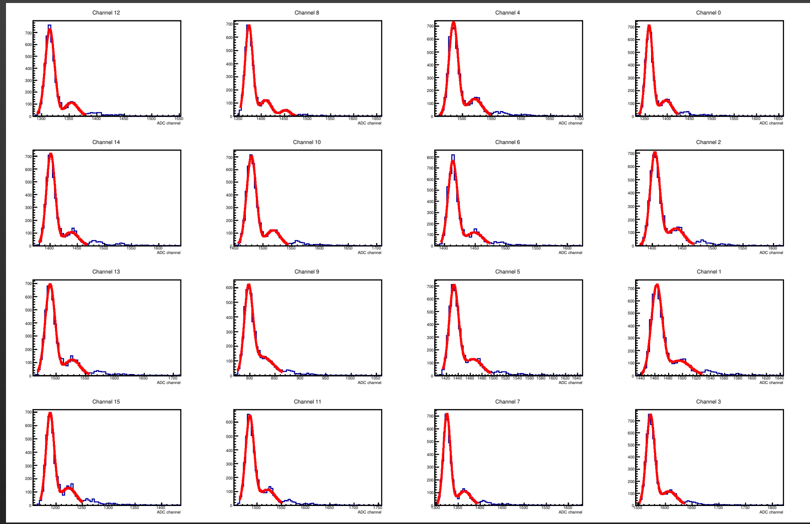
- **15 modules equipped with Hamamatsu MPPC**
- **9 modules equipped with FBK HD3 SiPMs (top and right corner)**
- central slot used for allocate a special module for the telescope pointing procedure

# FBK matrices quality check

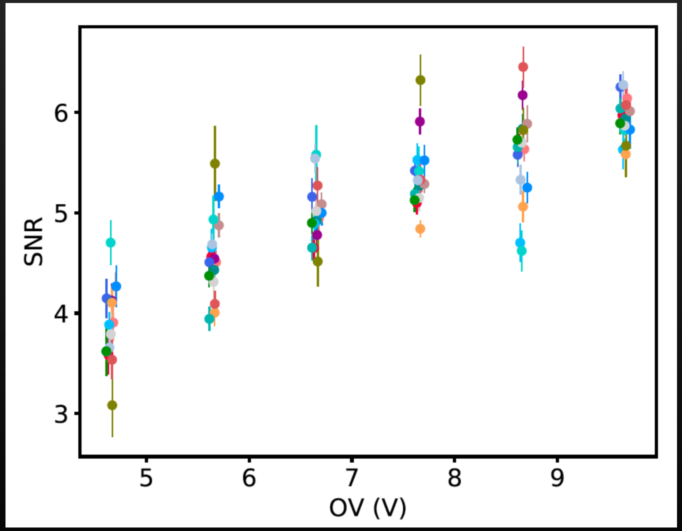
NUV-HD3 single 6 x 6 $mm^2$ SiPM arranged in 4 x 4 matrices

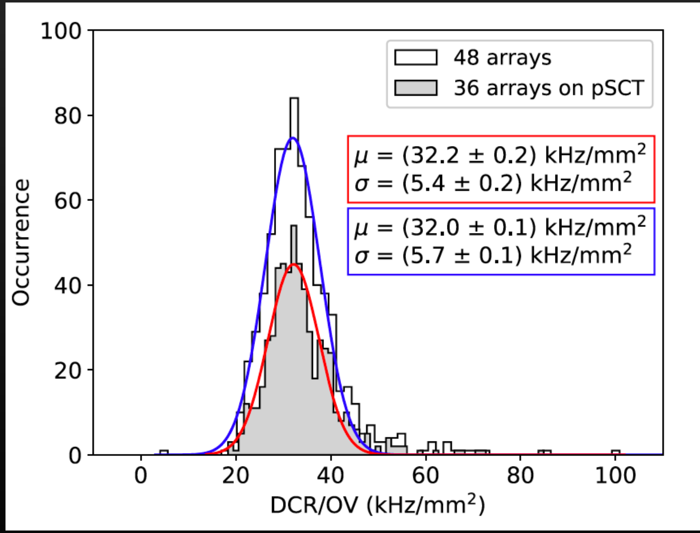
Matrices characterized covering the voltage range 31-36 V

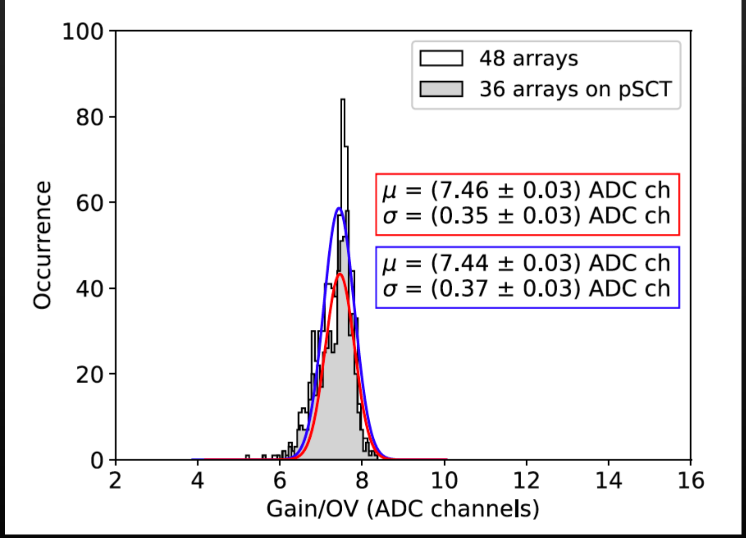




Under dark conditions



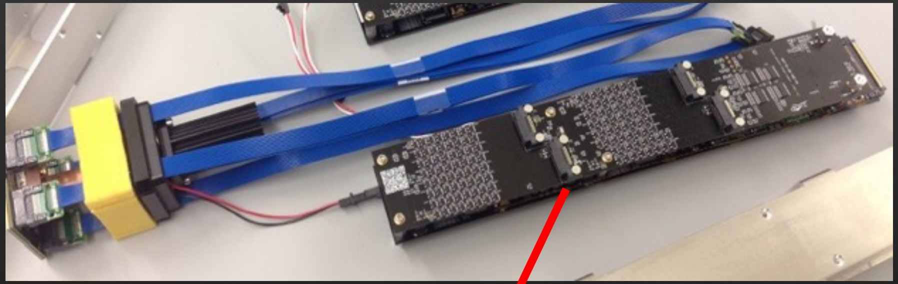



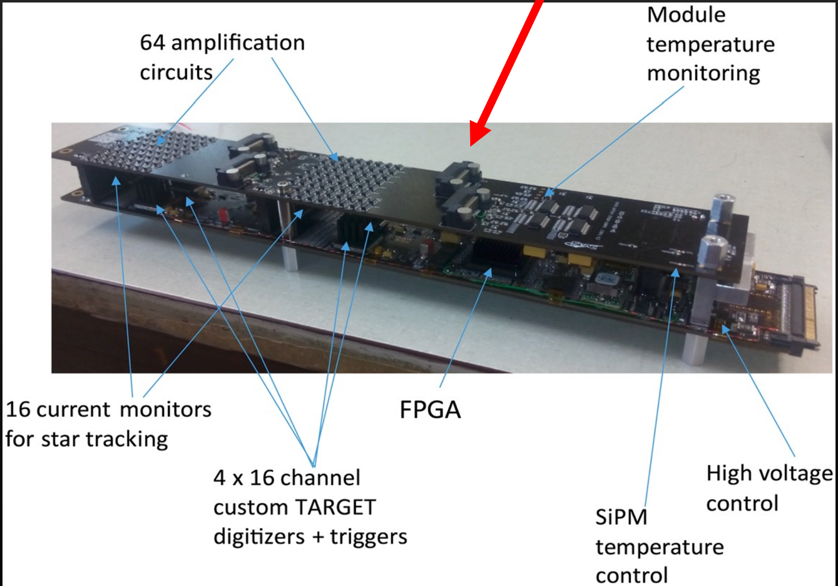




https://doi.org/10.1016/j.nima.2022.167359

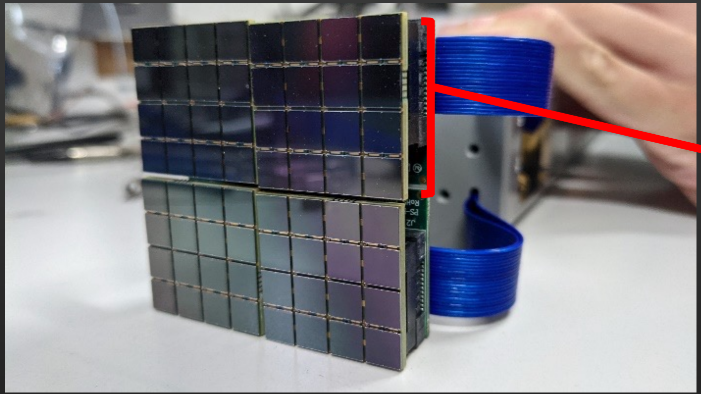
# The pSCT design

- **Current camera:**
  - Focal plane module (FPM)
  - **front-end electronic (FEE)** based on discrete pre-amplifier + TARGET-7

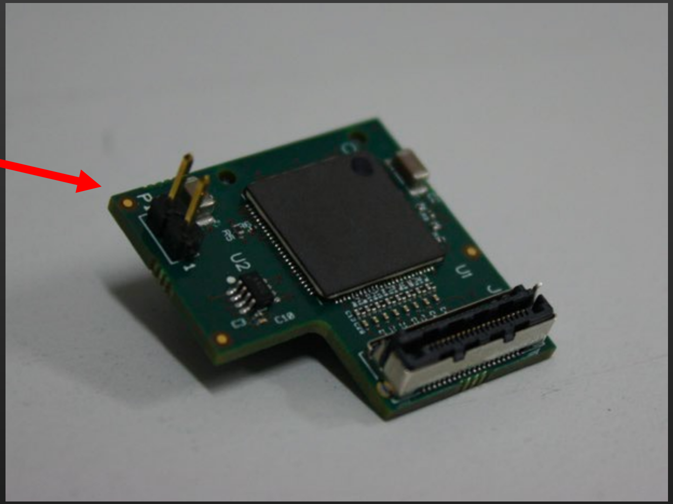





- **Upgraded camera (work in progress)**
  - Focal plane module (FPM)
  - Full camera (>11k pixels) with FBK NUV-HD SiPMs



Upgraded sensors (INFN-FBK)



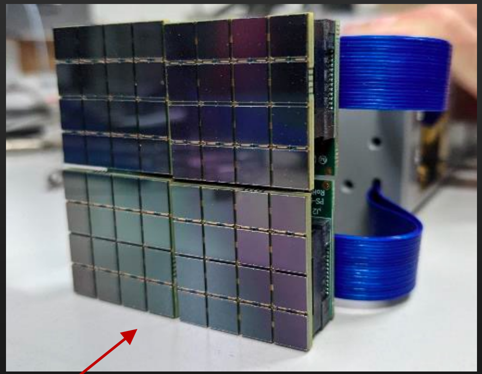
Custom SiPM preamplifier ASIC (SMART)

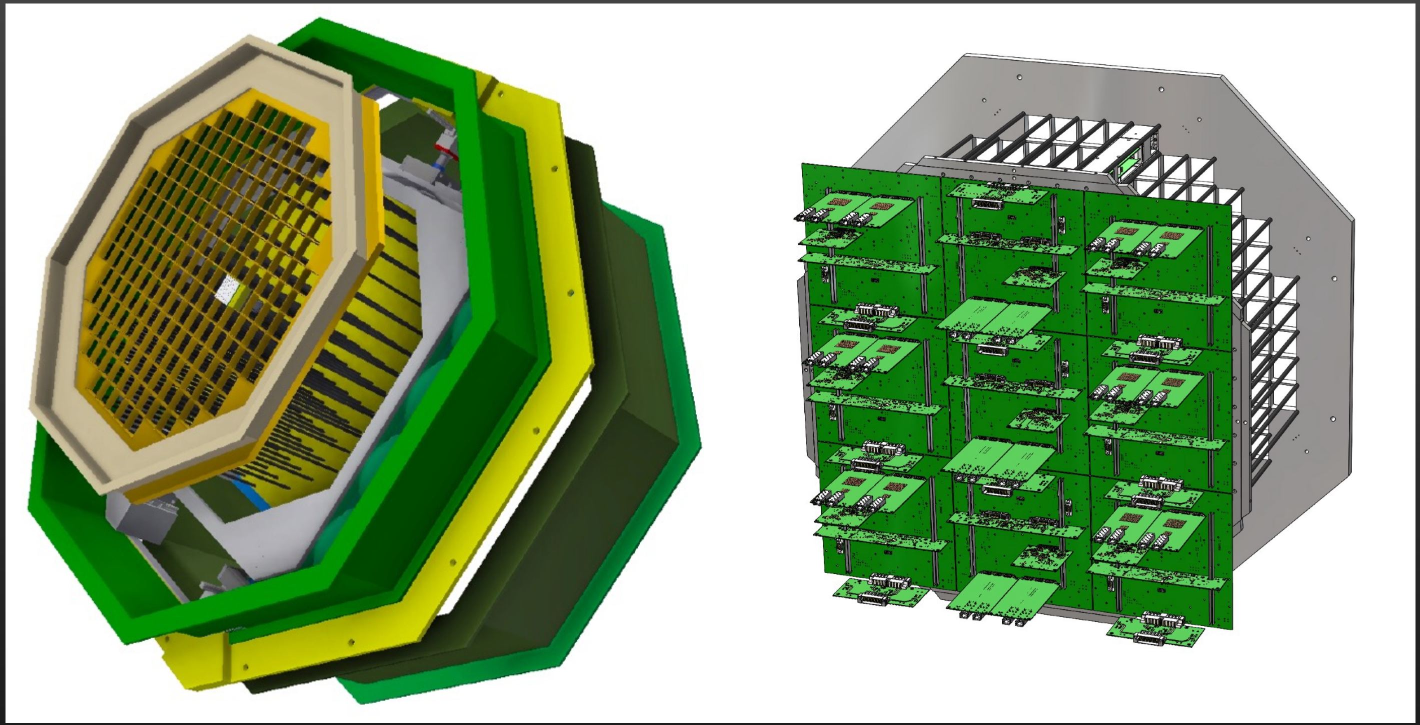
- FEE based on SMART (SiPM Multichannel Asic for high Resolution Cherenkov Telescopes) pre-amplifier +TARGET-C +T5TEA
  Separate digitizer and trigger

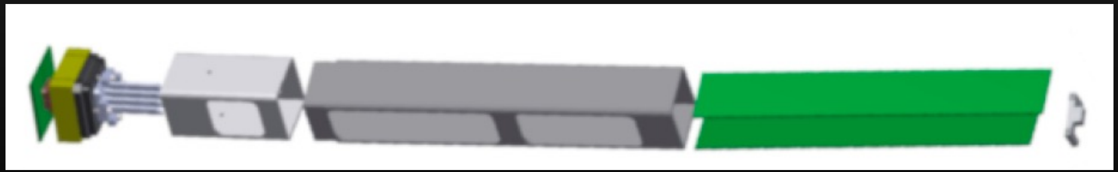
# Camera mechanical design

Updated inner camera

- 177 modules
- 9 backplanes
- Motion control
- Heat exchanger



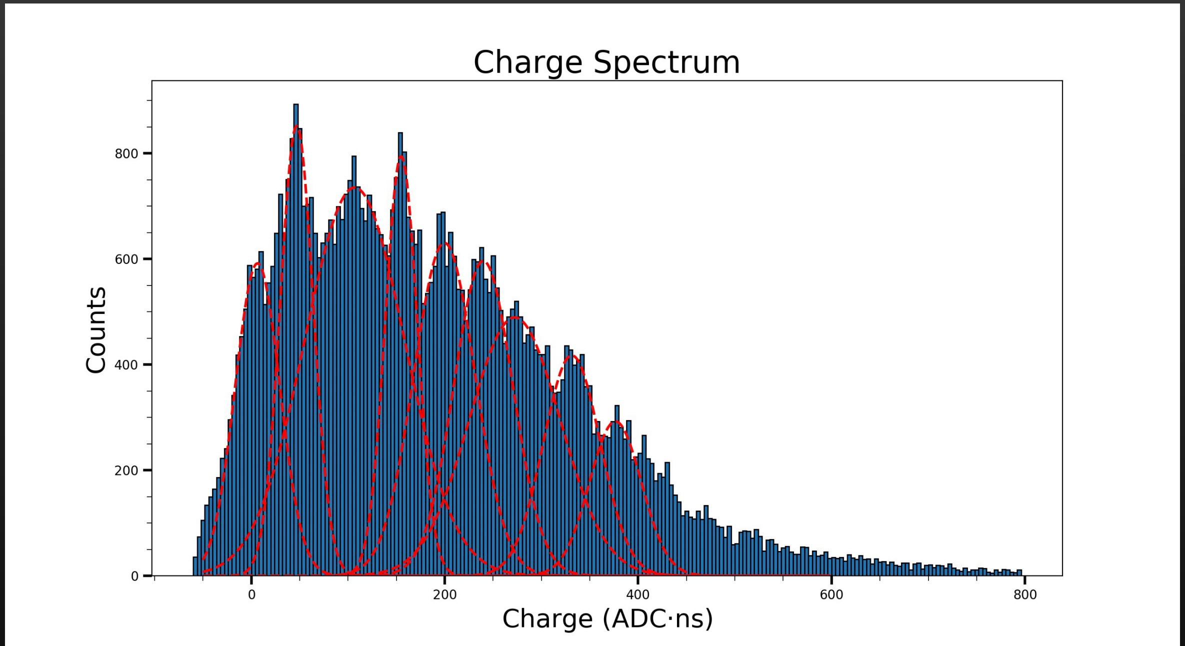




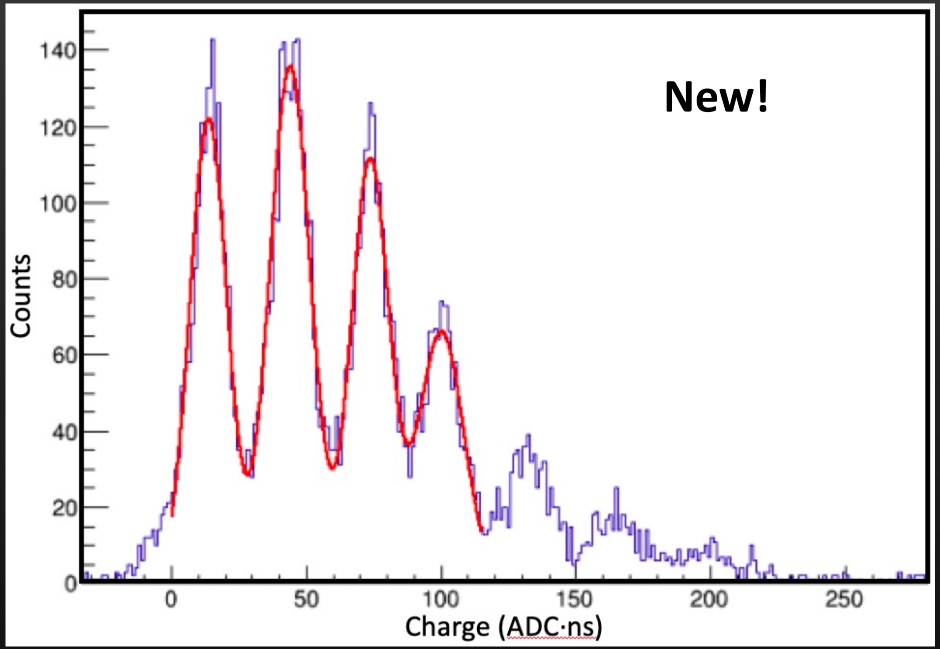
https://doi.org/10.1117/1.JATIS.8.1.014007

# Module performances comparison

- **Charge spectrum obtained with current modules + existing FEE and Hammamatsu SiPMs**

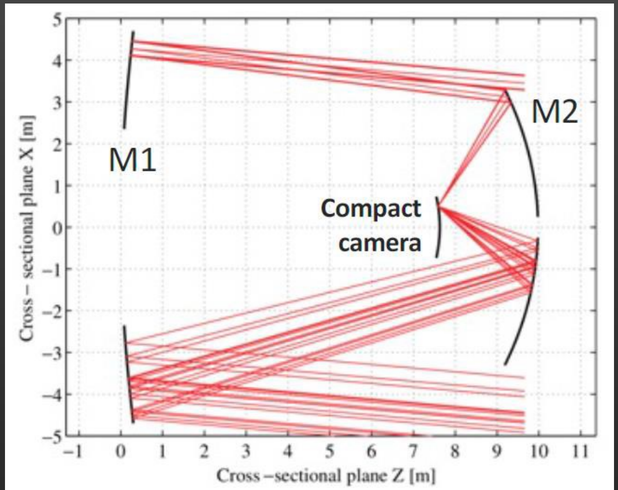


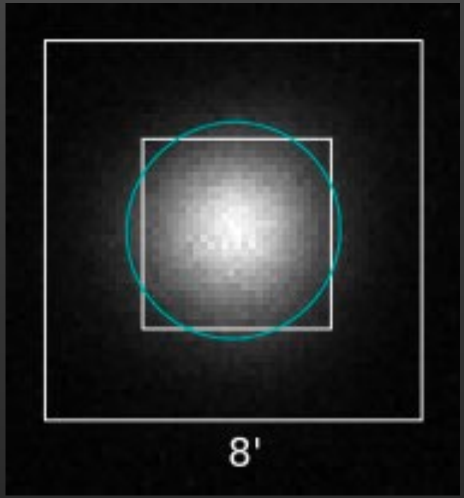

- **Charge spectrum obtained with current modules + upgraded FBK SiPMs and upgraded FEE**



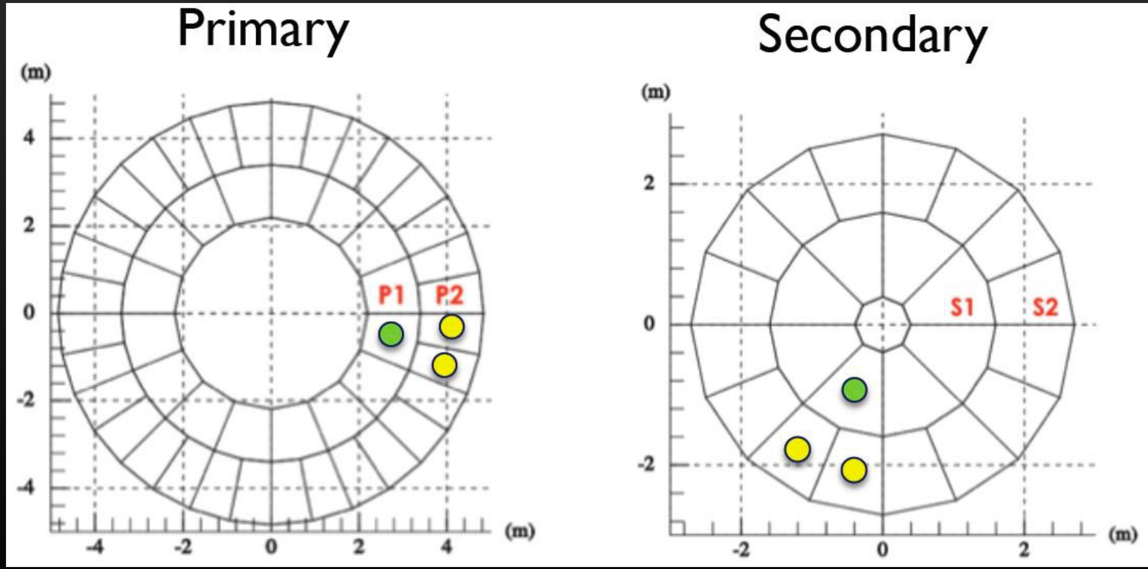
# The pSCT Optical System

To achieve the PSF of the Optical System in the FoV compatible with the SiPM pixel size (6mm) sub-mm and sub-mrad alignment is required




- **Focal length: 5.586 m**
- **Achieved PSF design goal of 2.9 arcmin**

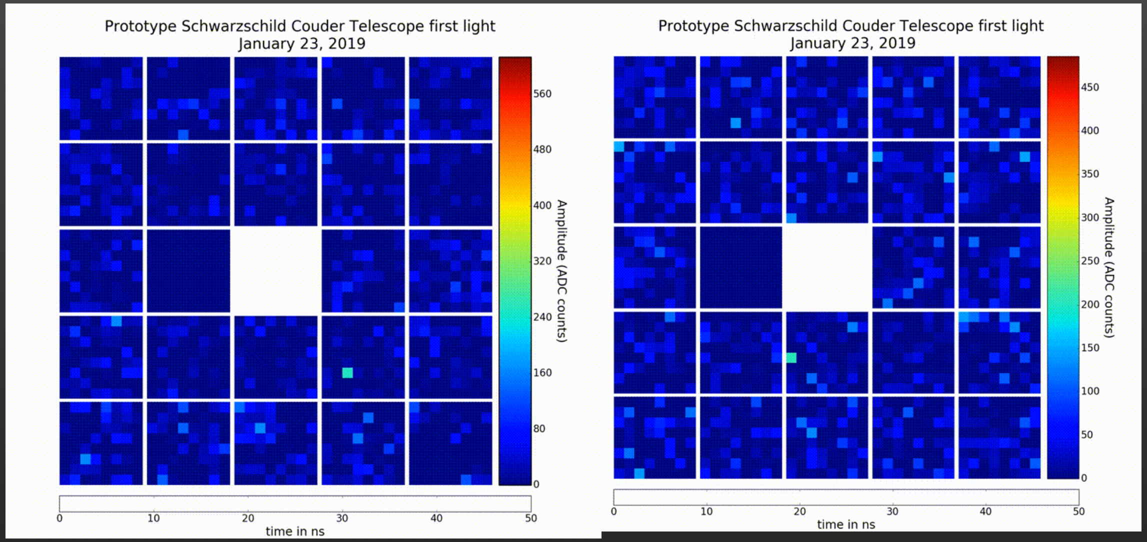



- The alignment depends on the pointing elevation
- A database of aligned panel positions is being built to allow us to maintain the PSF through the full range of elevations

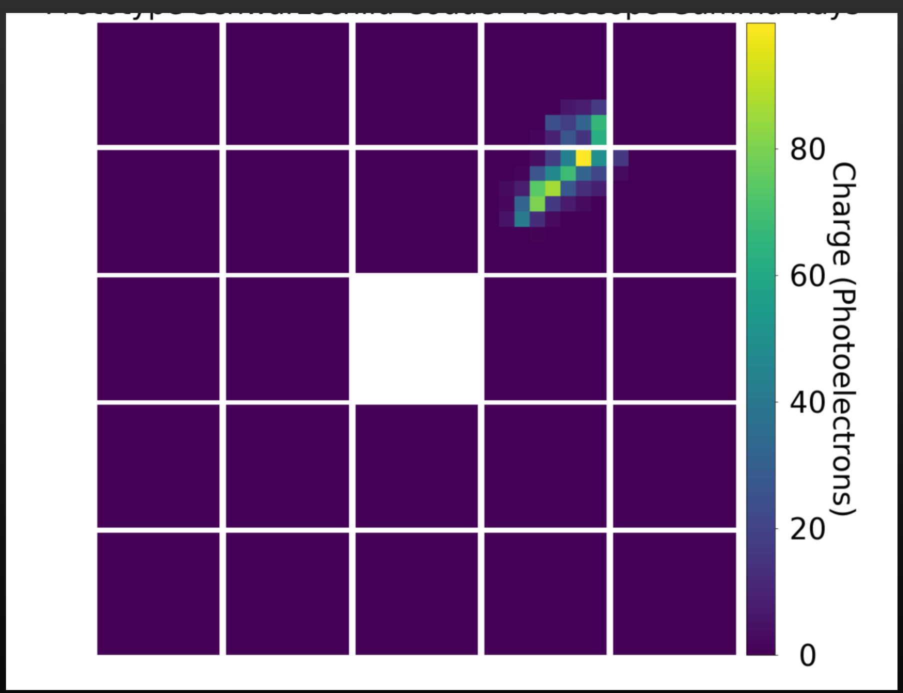
- **Achieved PSF of ~3’ across an elevation range of 77°- 40°**

**Ribeiro+2021 https://doi.org/10.22323/1.395.0717**

# First light and first gamma-ray-like event detected with the pSCT




**January 23rd 2019**
**(mirrored image compared to the photos shown before)**
**https://www.cta-observatory.org/sct-first-light/**




First confirmed gamma-ray-like event recorded by the pSCT. This event was taken on January 17, 2020, with simultaneous observation with VERITAS. This event was confirmed as a gamma-ray via timing coincidence with simultaneous VERITAS observation.

cta cherenkov telescope array

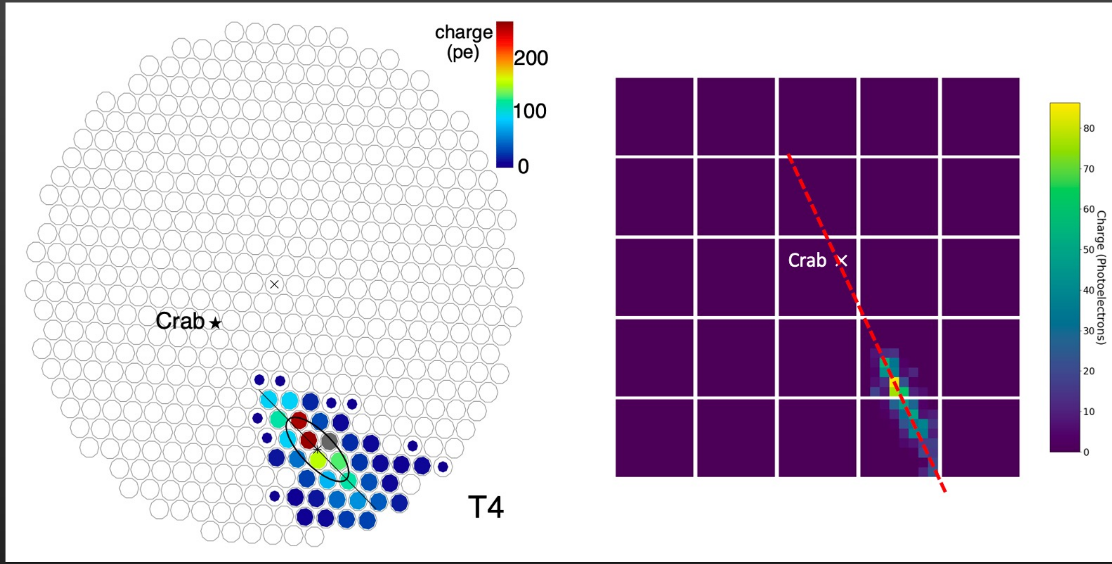
# Crab nebula detected with the pSCT

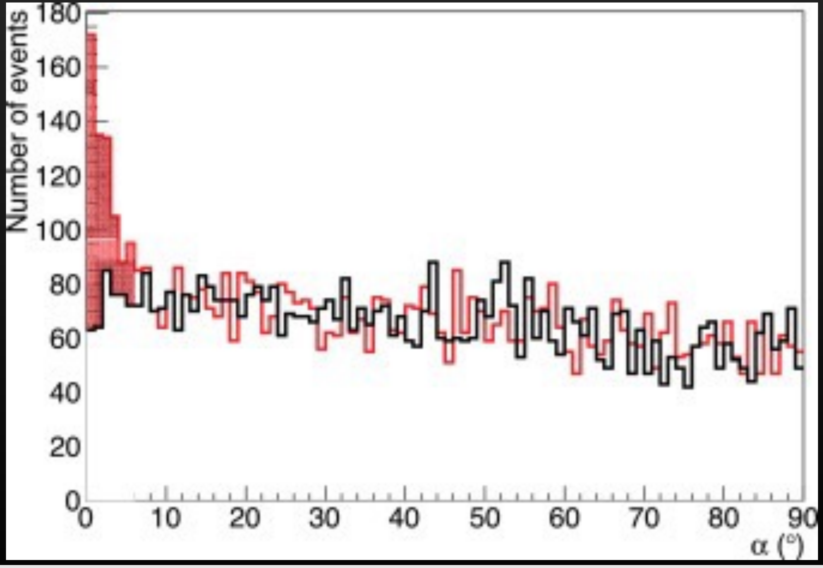
Detection of the Crab Nebula with the 9.7 m prototype Schwarzschild-Couder telescope


- ~20 hours ON/OFF observations
- 8.6$\sigma$ detection
- Main limitation: electronics noise
- High energy threshold -> low cosmic and gamma-ray rates

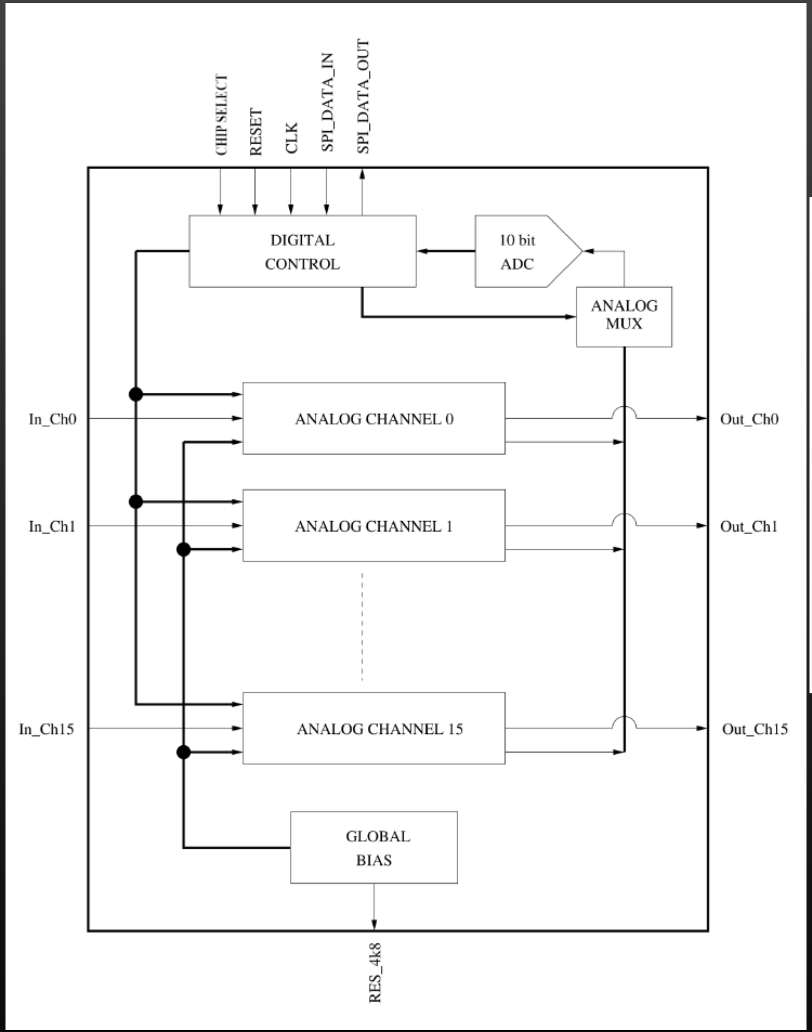
https://doi.org/10.1016/j.astropartphys.2021.102562

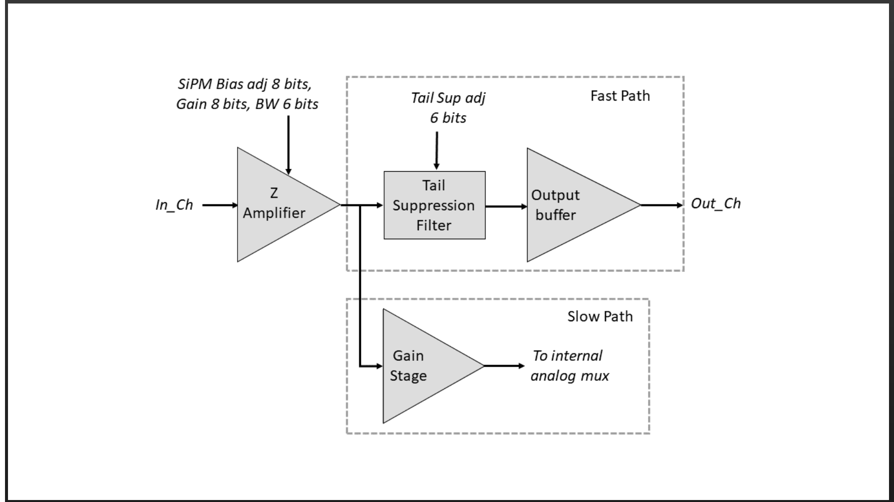
## Analysis of pSCT – VERITAS coincident data



# A SiPM Multichannel Asic for high Resolution Cherenkov Telescopes (SMART) features



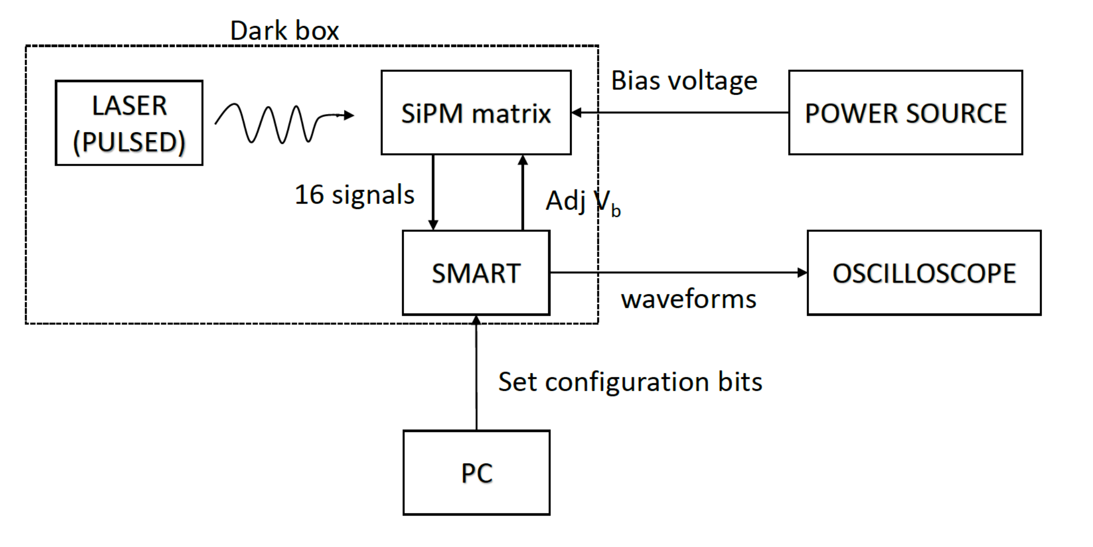

**Pre-amplifier designed for photon counting**

- 16-channel trans-impedance amplifier
- 20-bit global adjustment: gain (8 bits), bandwidth(6 bits), PZ (6 bits)
- 8-bit DAC for SiPM bias adjustment (one per channel)
- Slow monitoring of SiPM mean current (16 channels multiplexed) 10-bit ADC
- SPI interface
- 600 mV dynamic range

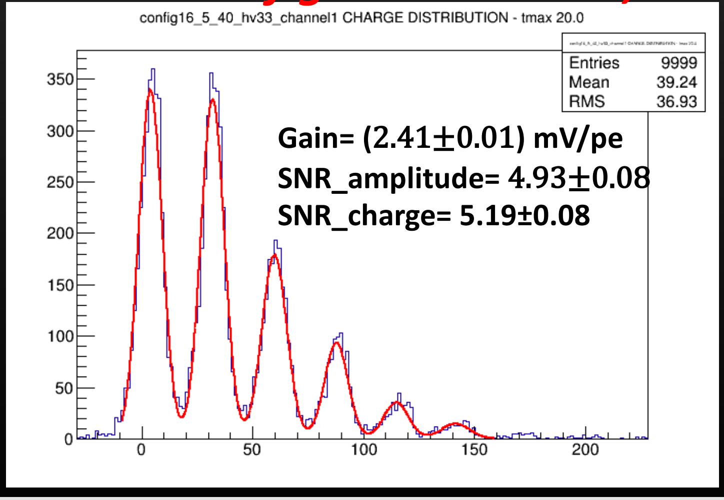
# Laboratory SMART characterization

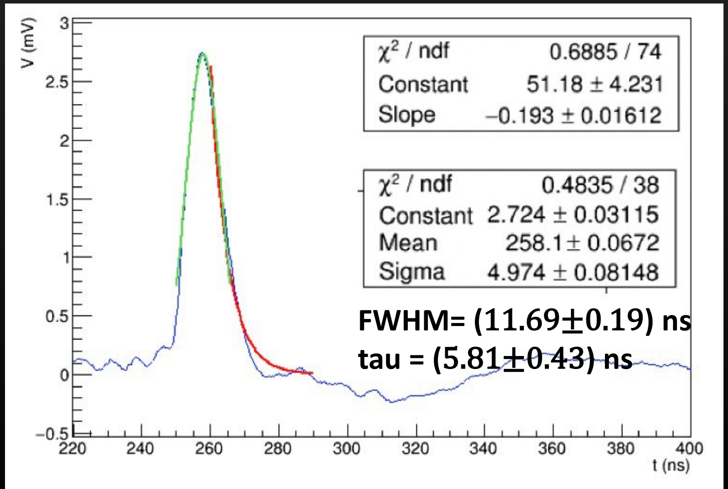
SMART performances tested with FBK NUV-HD 6x6mm$^2$ SiPM (HV=33V)

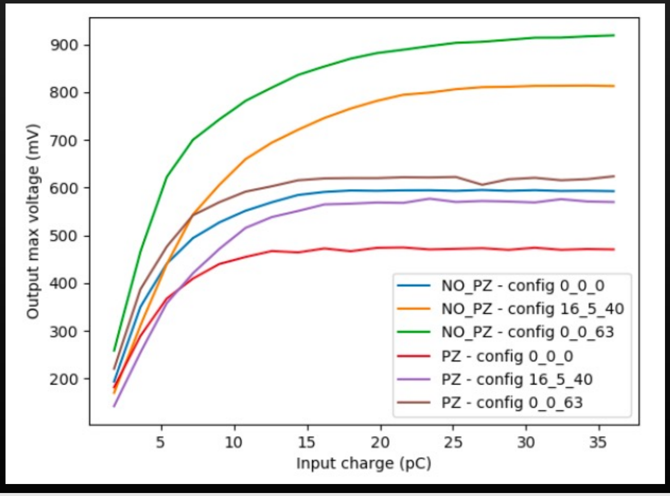
- Gain, signal-to-noise ratio and pulse width as a function of configuration bits were measured.
- 3 parameters changed:
  - ❑ R : gain resistance
  - ❑ C : filtering capacitance
  - ❑ PZ: pole zero cancellation
- External PZ fixed with discrete components
- Tests at different bias voltage (Vbias= 33, 35, 37V)
- We placed a mask on the SiPM array in order to reduce anycross-talk contribution




***Global configuration: R=16, C=5, PZ=40*** **HV = 33 V**



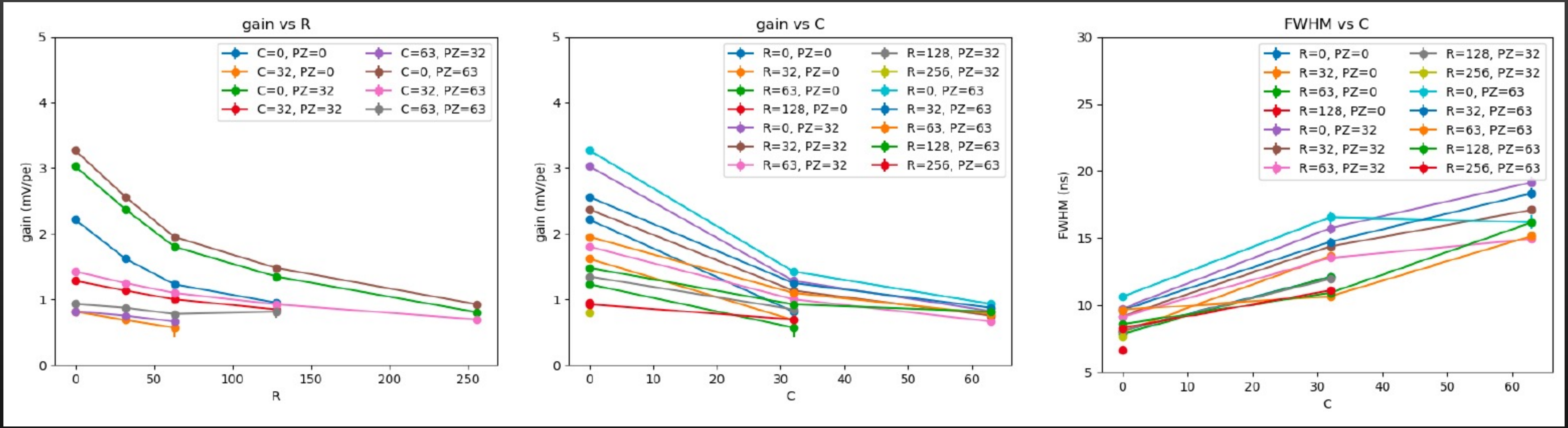




Output dynamic range

- 900 mV without ext. PZ
- 600 mV with ext. PZ

# Global configuration – Summary HV=33V



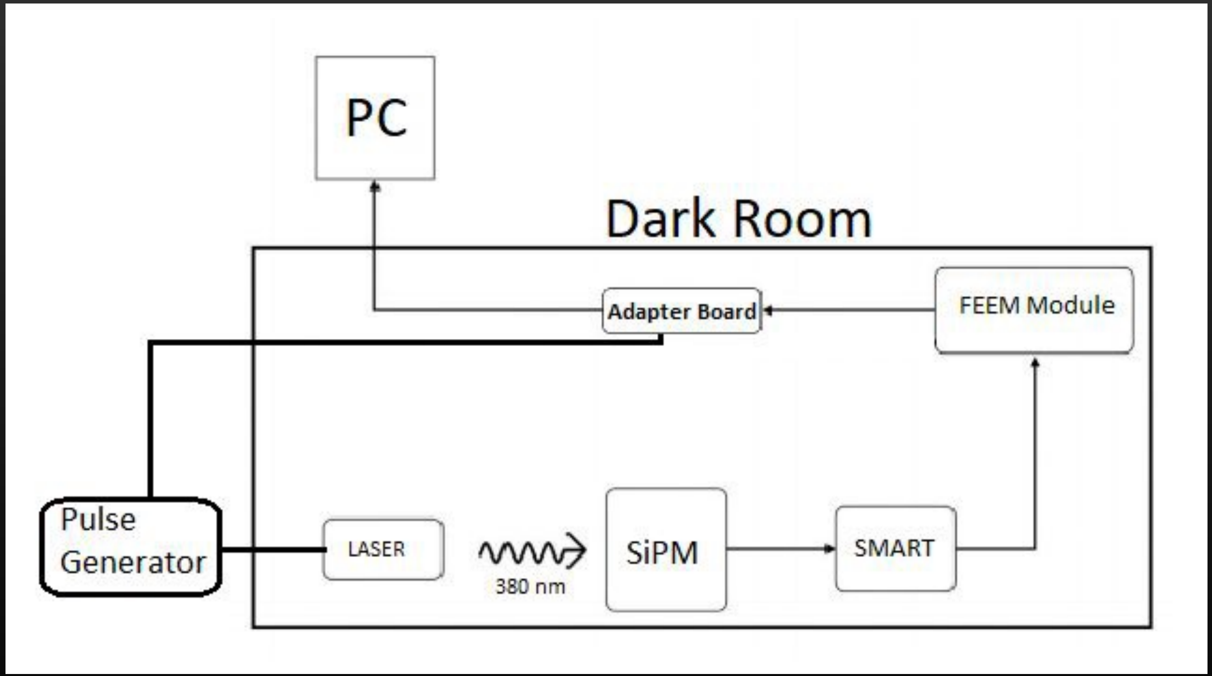

Gain depends mainly on R & C
FWHM depends on C & PZ

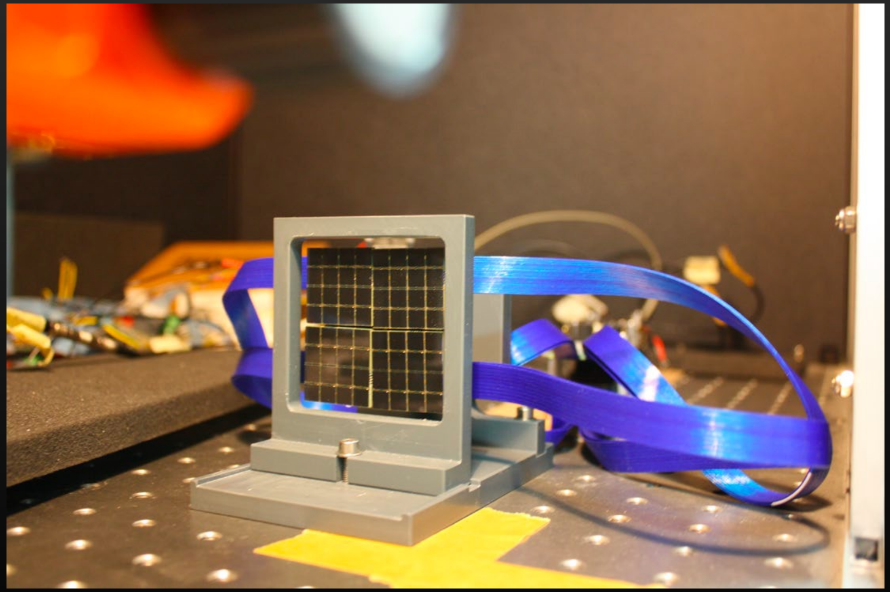
**Gain: [0.57 , 3.27] mV/pe**
**FWHM: [7.68, 19.16] ns**
**Tau : [3.0, 19.58] ns**

# Laboratory SMART quality test

About 750 ASICs produced only 7 ASICs were found to be defective(< 1%).
The main features of the SMART were tested to check basic functionalities:

- ADC calibration for current readout
- Response to a laser pulse
- Variation of pulse shape vs SMART configuration
- Pulse amplitude variation vs DAC for fine SiPM bias tuning



# Conclusions & Future perspectives

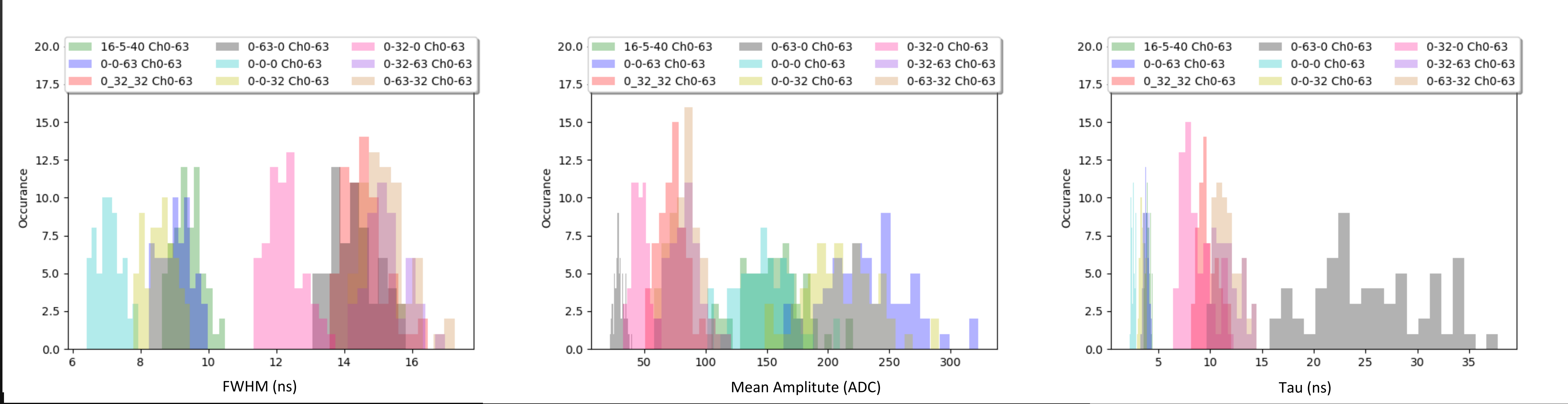
- ✓ Improved optics alignment
- ✓ The Crab Nebula was detected
- ✓ Optimized electronics will equip the camera, that will consist in new (TARGET-C + T5TEA + SMART): pre-amp, digitization and trigger on different ASICs
- ✓ Performances of the SMART ASIC tested and characterized with FBK NUV HD SiPMs
  - Gain and signal shape dependence on R, C and PZ
- ✓ SMART for the full pSCT camera (~750 ASICs) produced and tested in 2021
  - Only 7 ASICs were found to be defective(< 1%)
- ✓ Population of the full focal plane (~11k channels) with FBK sensors, preamplifiers and front-end electronics
- ✓ Upgraded mechanics and backplane

*Thank you for your attention!*

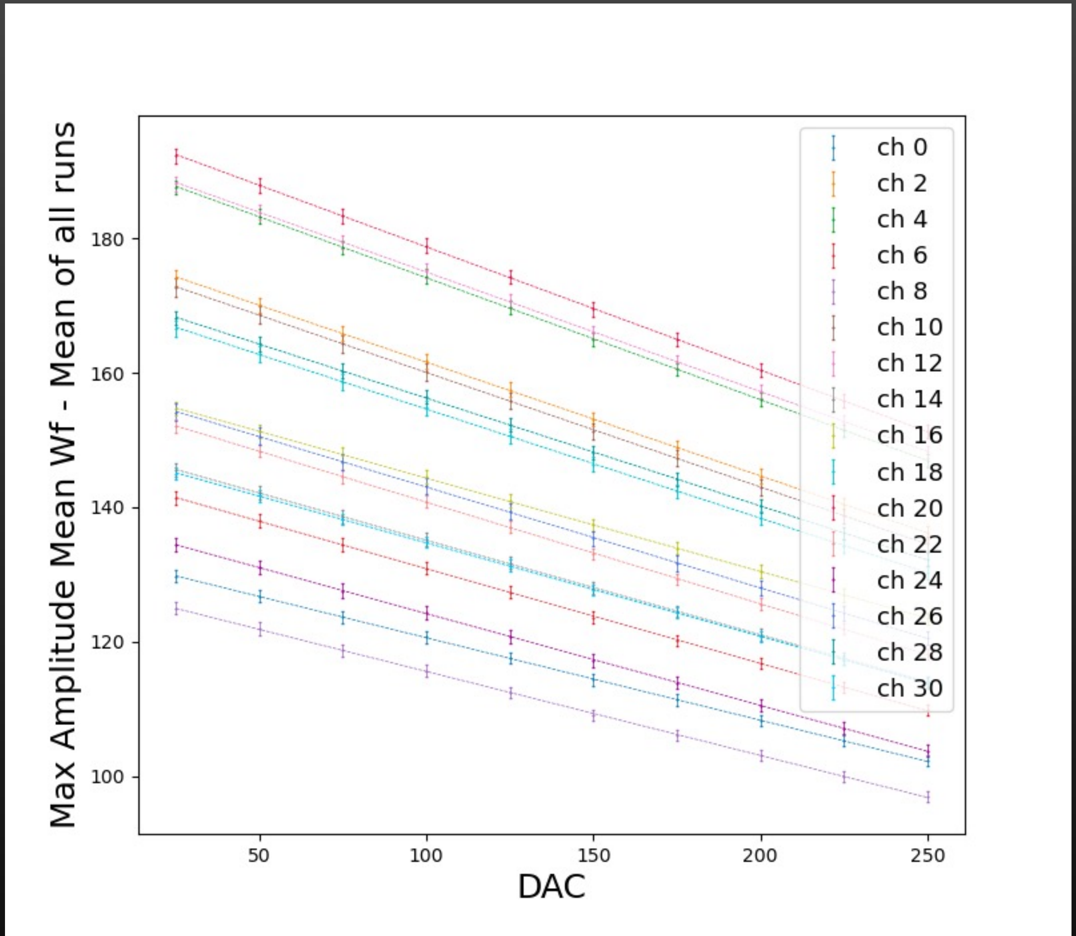
# Backup

# SMART quality test

Globals test: bias (DAC) fixed, and the configuration of the SMART is varied, and the signal run is performed to check the behavior of the device. The results for all configurations are shown in Figs.



# SMART quality test

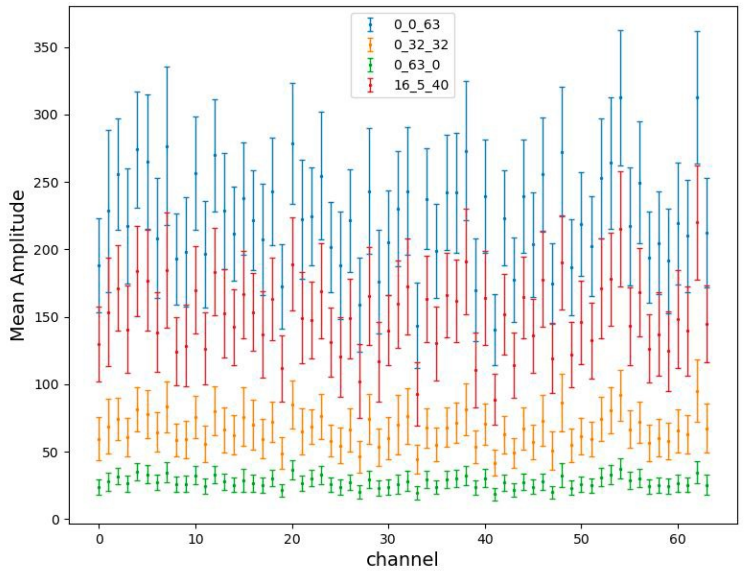


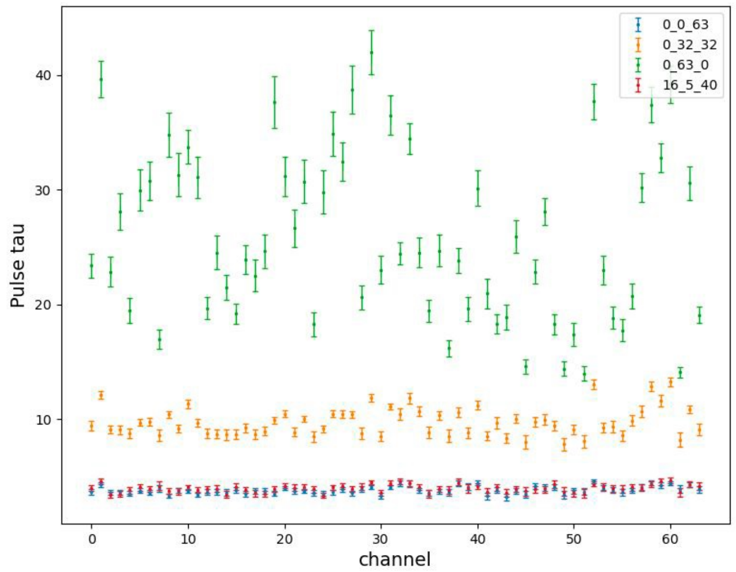

The linear trend of the average of the max amplitudes of the mean waveform as a function of DAC.
Note that increasing DAC value, SiPM bias is decreasing.

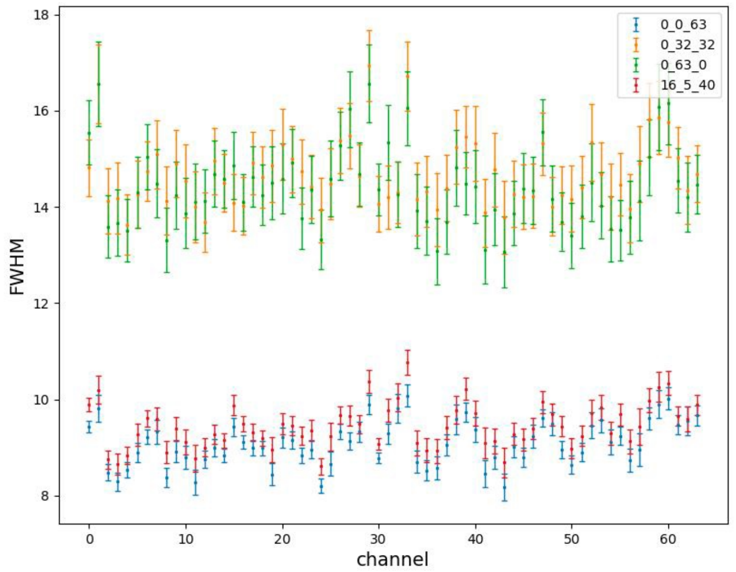
# SMART quality test

A quality control test, made up by 4 parts, has been performed for each SMART

Globals test: bias (DAC) fixed, and the configuration of the SMART is varied, and the signal run is performed to check the behavior of the device. The results for four configuration are shown in Figs

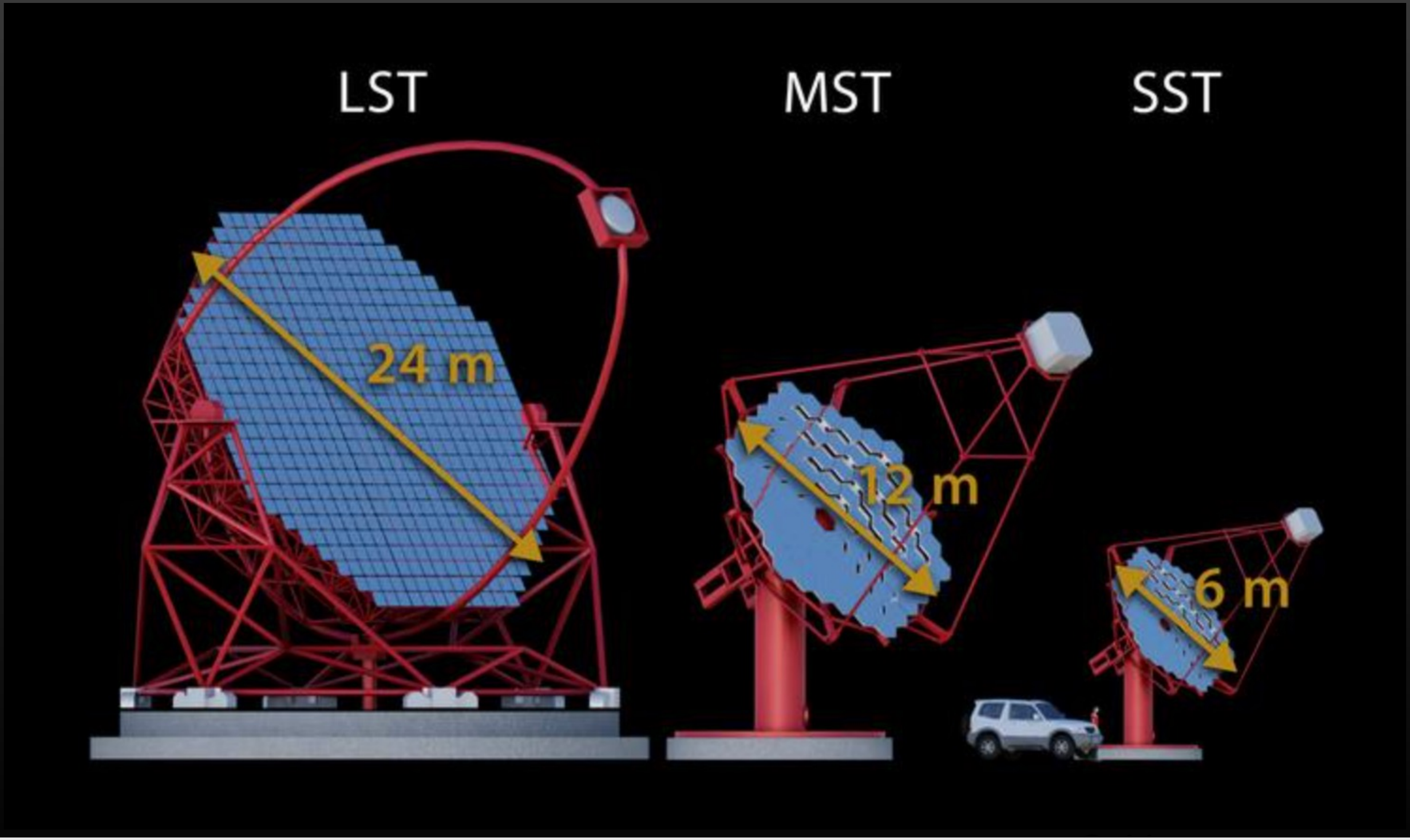


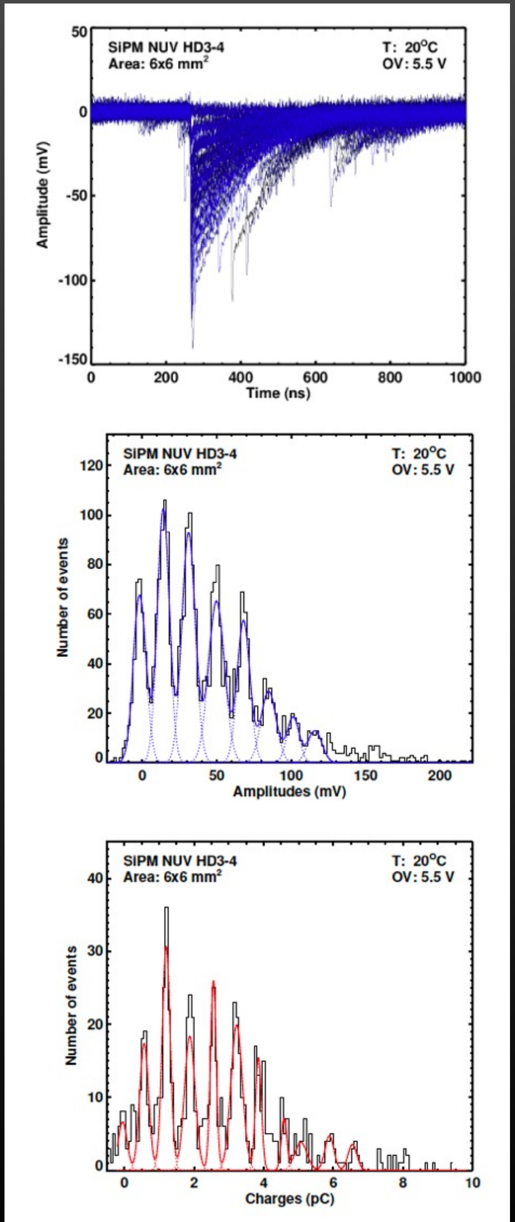
# CTA telescopes

**70 SST, 40 MST, 8 LST**



# FBK single SiPM quality check

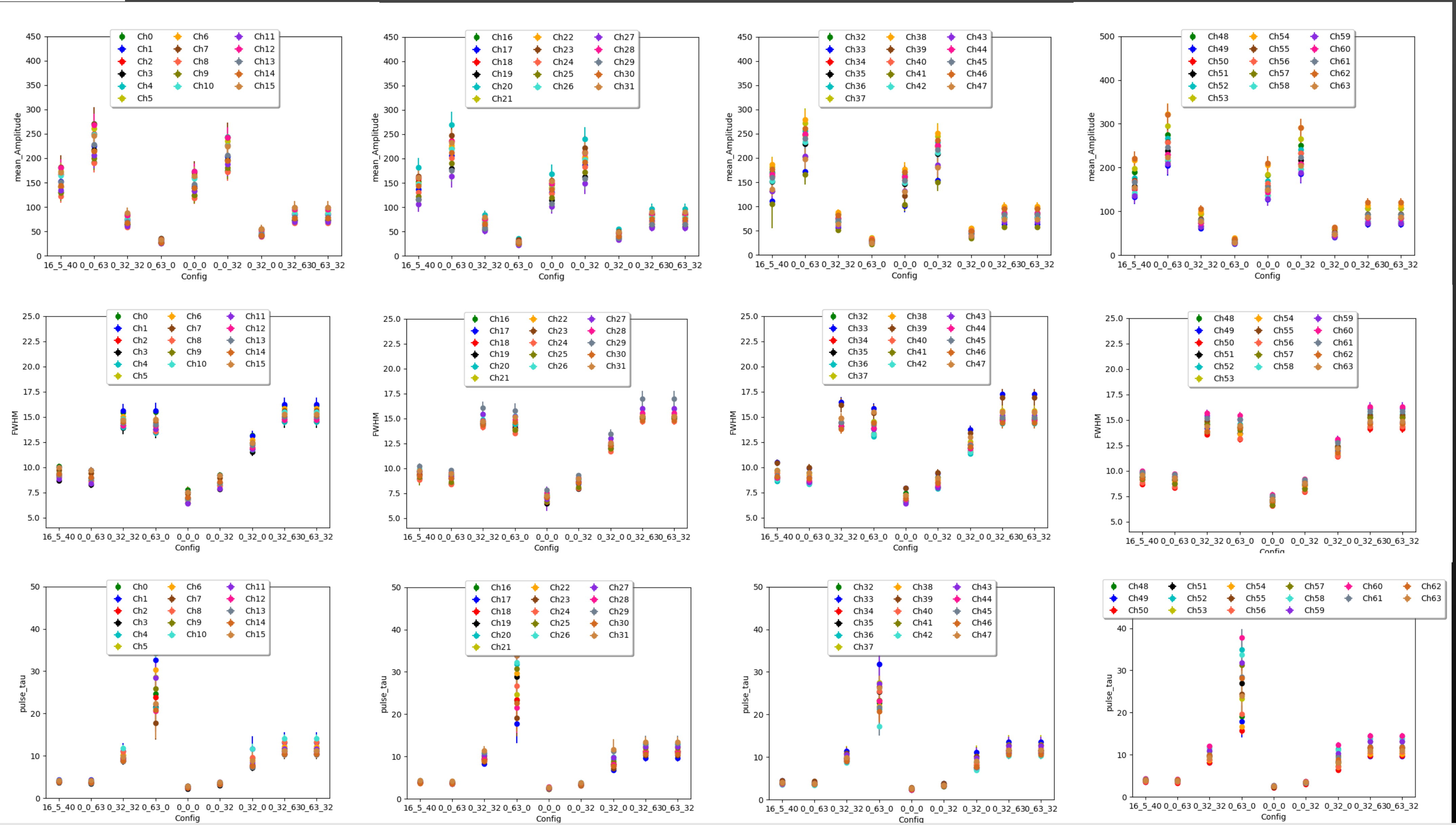
**Waveforms, Amplitude and Charge distribution** for 6 x 6 mm$^2$ SiPM HD3-4. Measurements performed at T = 20C and OV = 5.5V



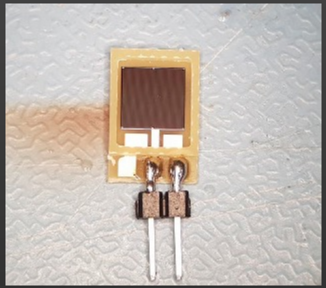

**Experimental Setup**

- Each sensor illuminated by laser at 380 nm
- Data taking performed over a wide bias voltage range: 1-2 V to 13-14 V of over-voltage (OV).
- Readout electronics: trans-impedance preamplifier followed by a gain stage.
- Characterization by a recovery time.

# SMART quality test



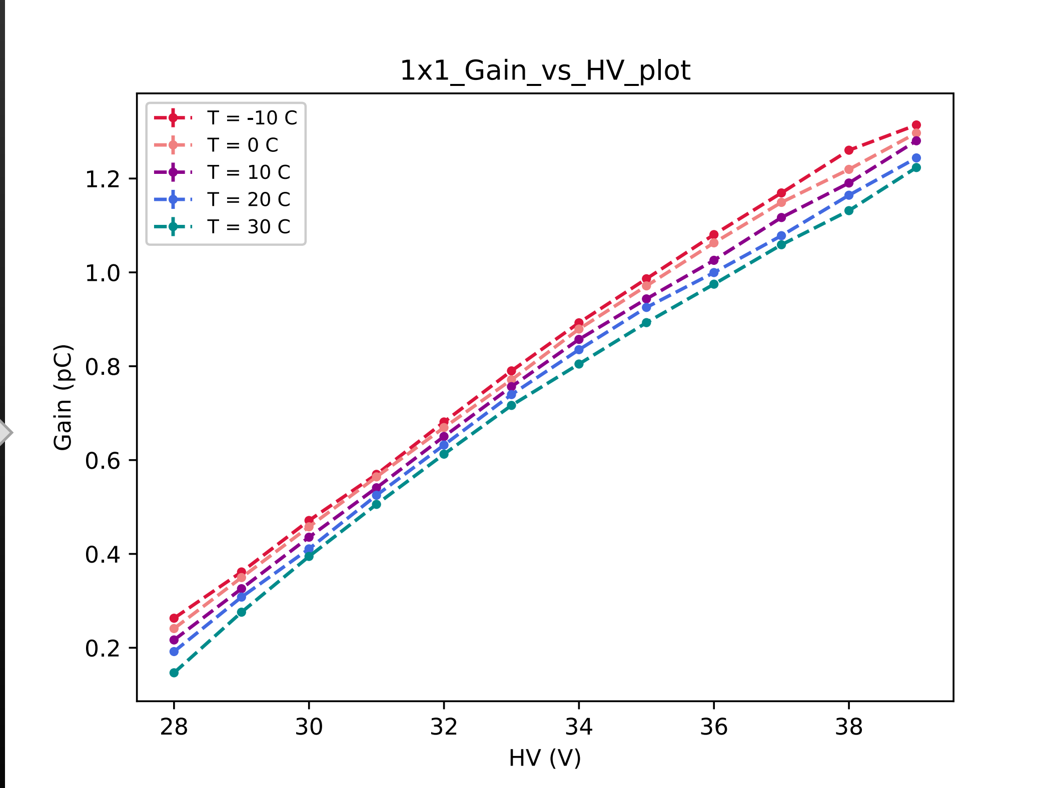
# Gain, SNR and DCR uniformity for single SiPM



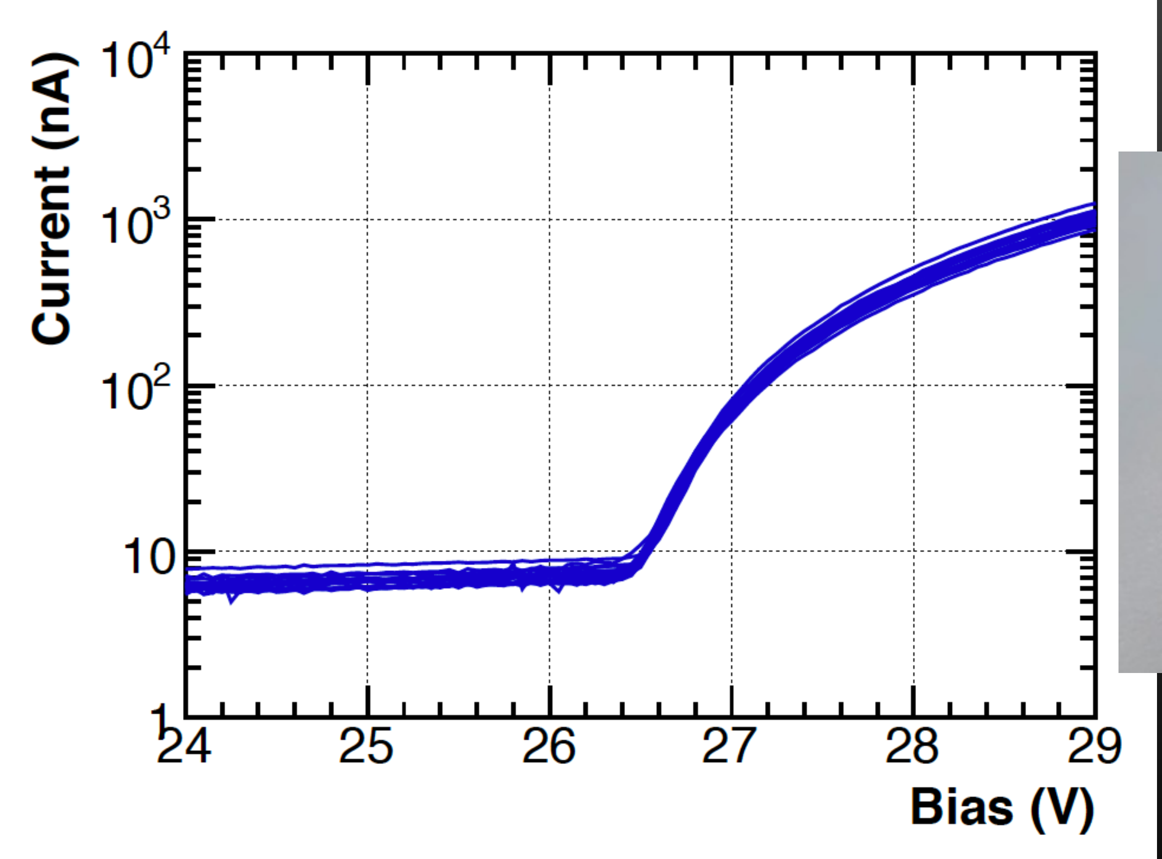
PDE ~ 50 % at 350 nm
PDE ~ below 20 % above 500 nm

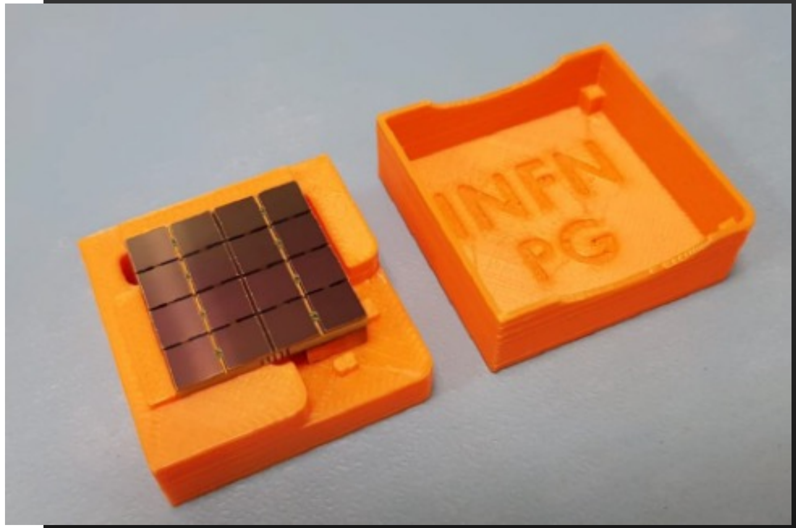
Test of 6 x 6 $mm^2$ SiPM HD3-4.
Less noisy than SiPM HD3-2 and HD3-3 ones, used for development of the assembly and test procedures

Integrated charge measured for the 1 x 1 $mm^2$ SiPM HD3-4, less noisy than the 6 x 6 $mm^2$ ones.



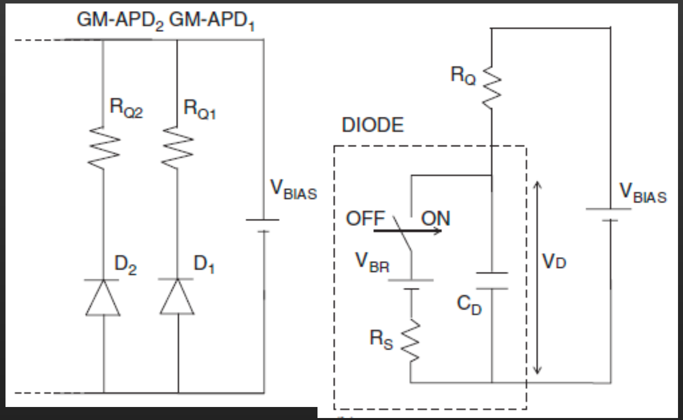
# I-V profile for 16 SiPMs integrated on one PDU



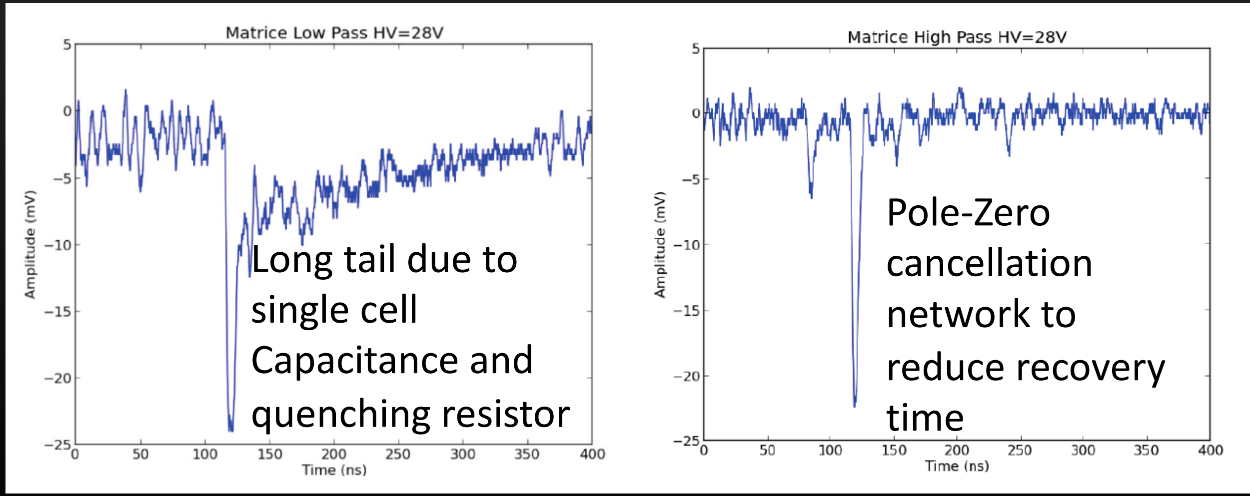
# Why SiPMs?

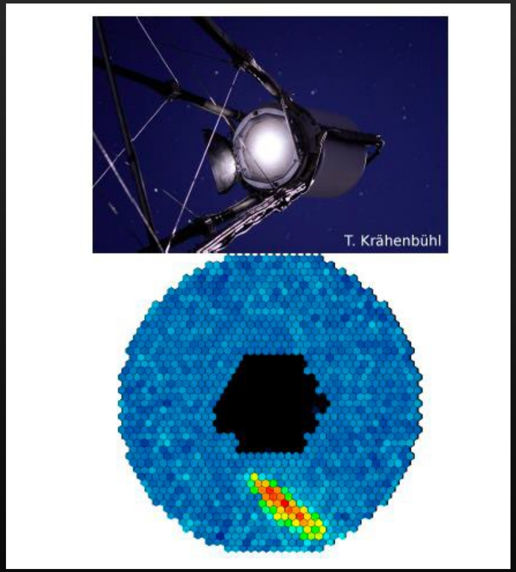
….Why not?




Endurance to night sky
Background light offers the possibility of operating during bright moon nights

The duty cycle of the telescope is increased



# Optical System

On-axis PSF as a function of elevation
(Arcturus, April 2021)