A SiPM Multichannel ASIC for high Resolution Cherenkov Telescopes (SMART) developed for the pSCT camera telescope

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for the CTA SCT Project

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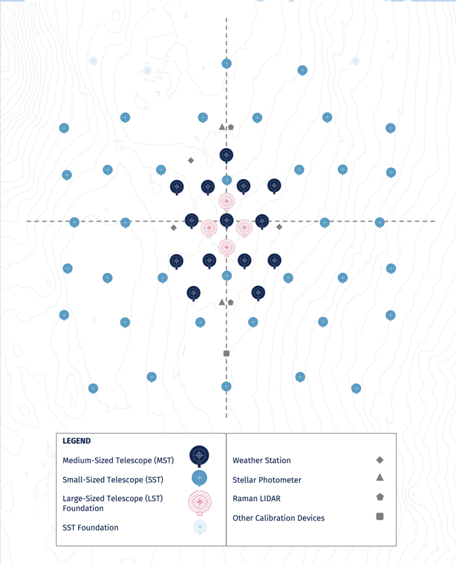
cherenkov telescope array

Gamma-ray detection with Cherenkov telescope array

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

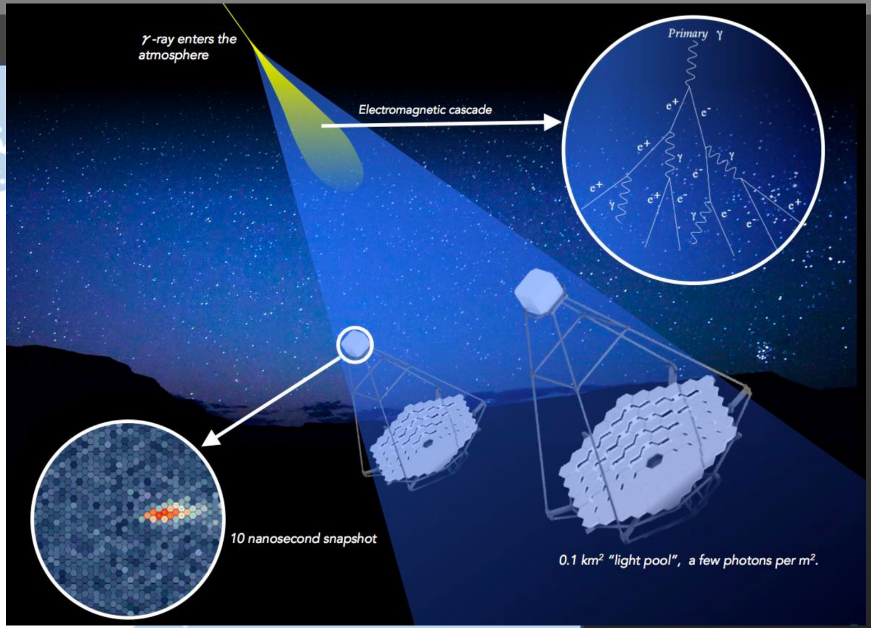
Observatory planned to be operated by 2025

Chile



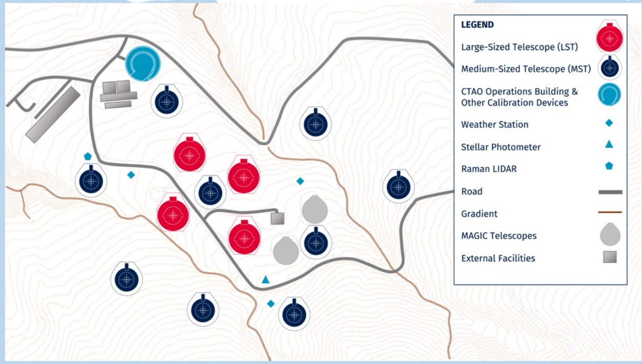
Cherenkov Telescope Array:

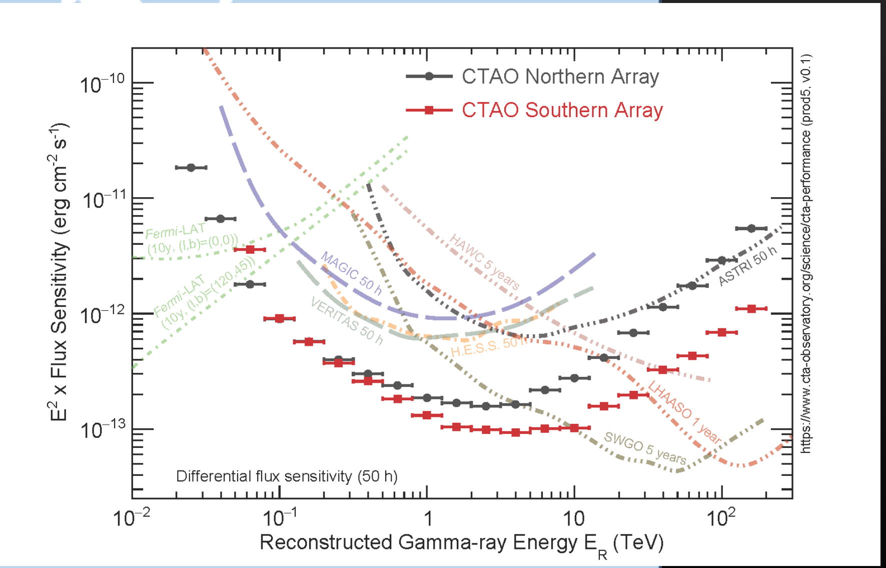
- ~100 + telescopes involved
- Increased detection area
- Improved sensitivity
- 2 telescopes sites
- 3 sizes of telescopes



Energy range: 20 GeV-300 TeV

La Palma

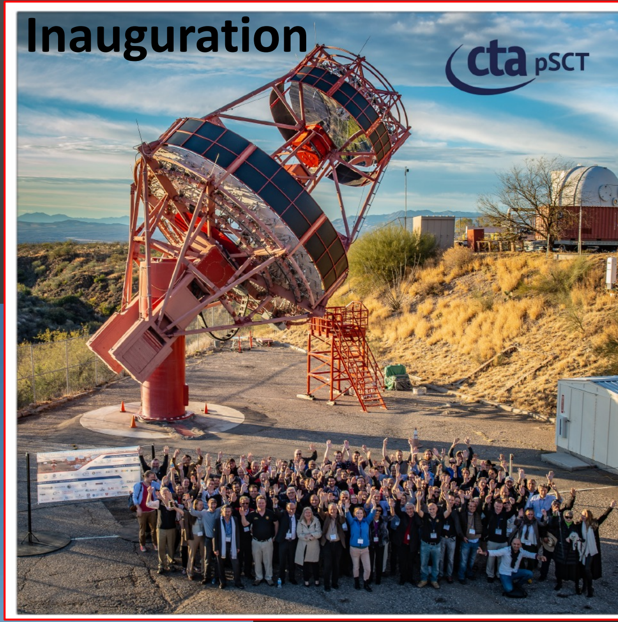




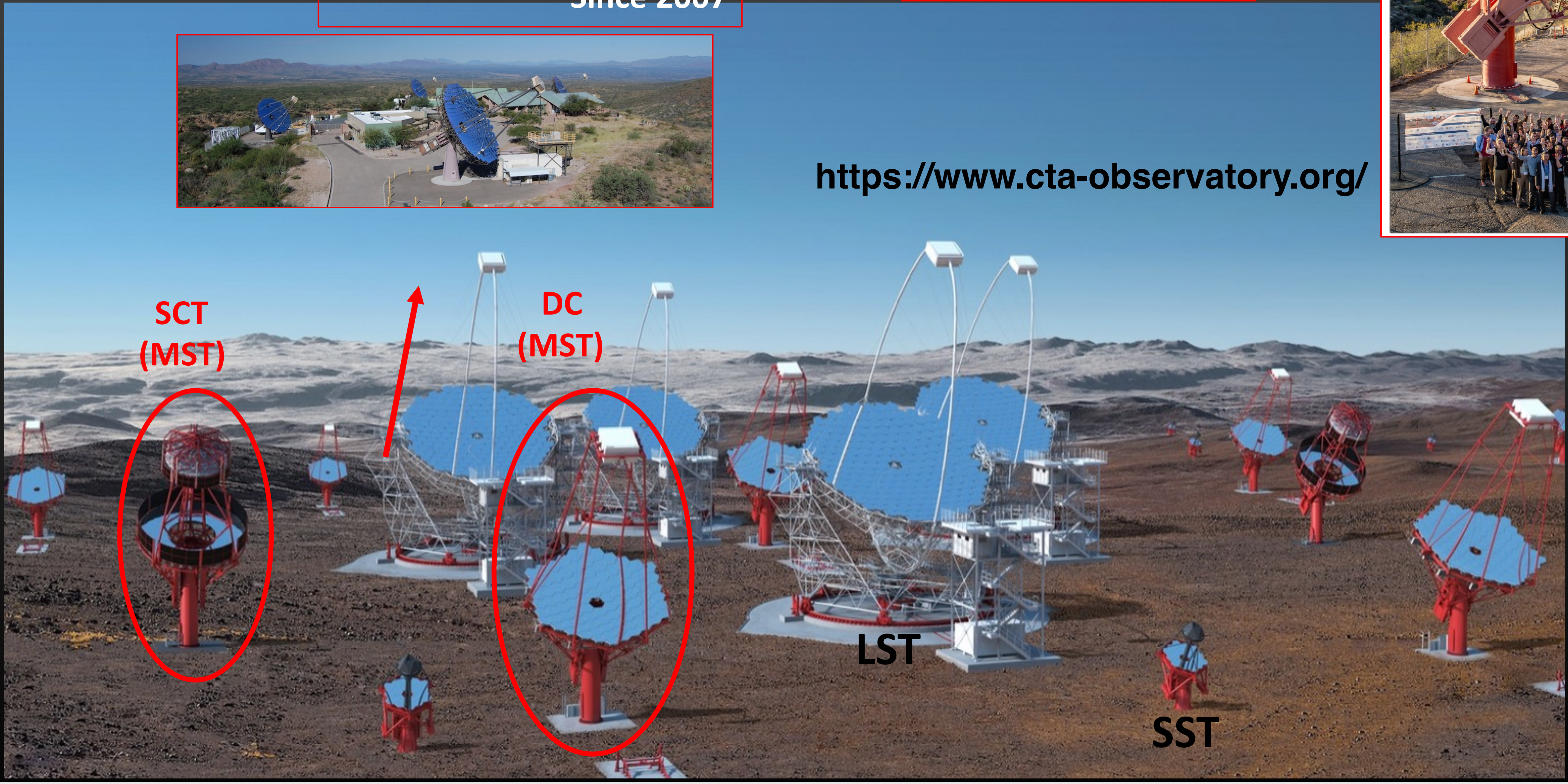
https://www.cta-observatory.org/science/ctao-performance/#1472563157332-1ef9e83d-426c

Now SCT is installed at VERITAS site
Arizona-1270 m asl
4 x 12 m Ø
Since 2007

Fred Lawrence Whipple Obs.
Amado, AZ(USA)
January 17-18 2019



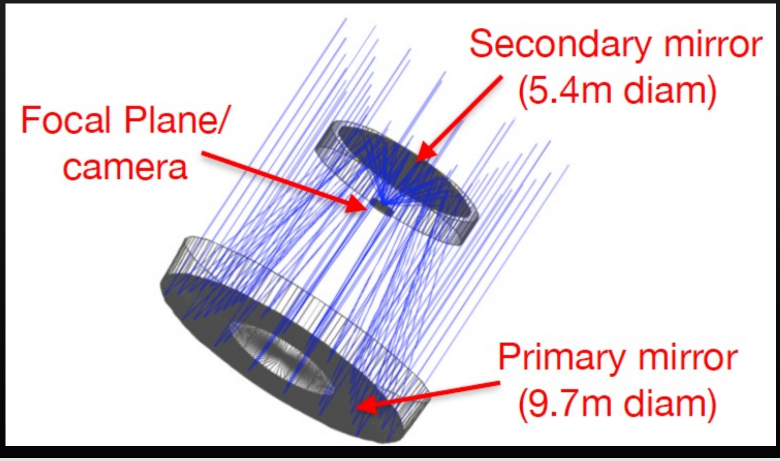
https://www.cta-observatory.org/

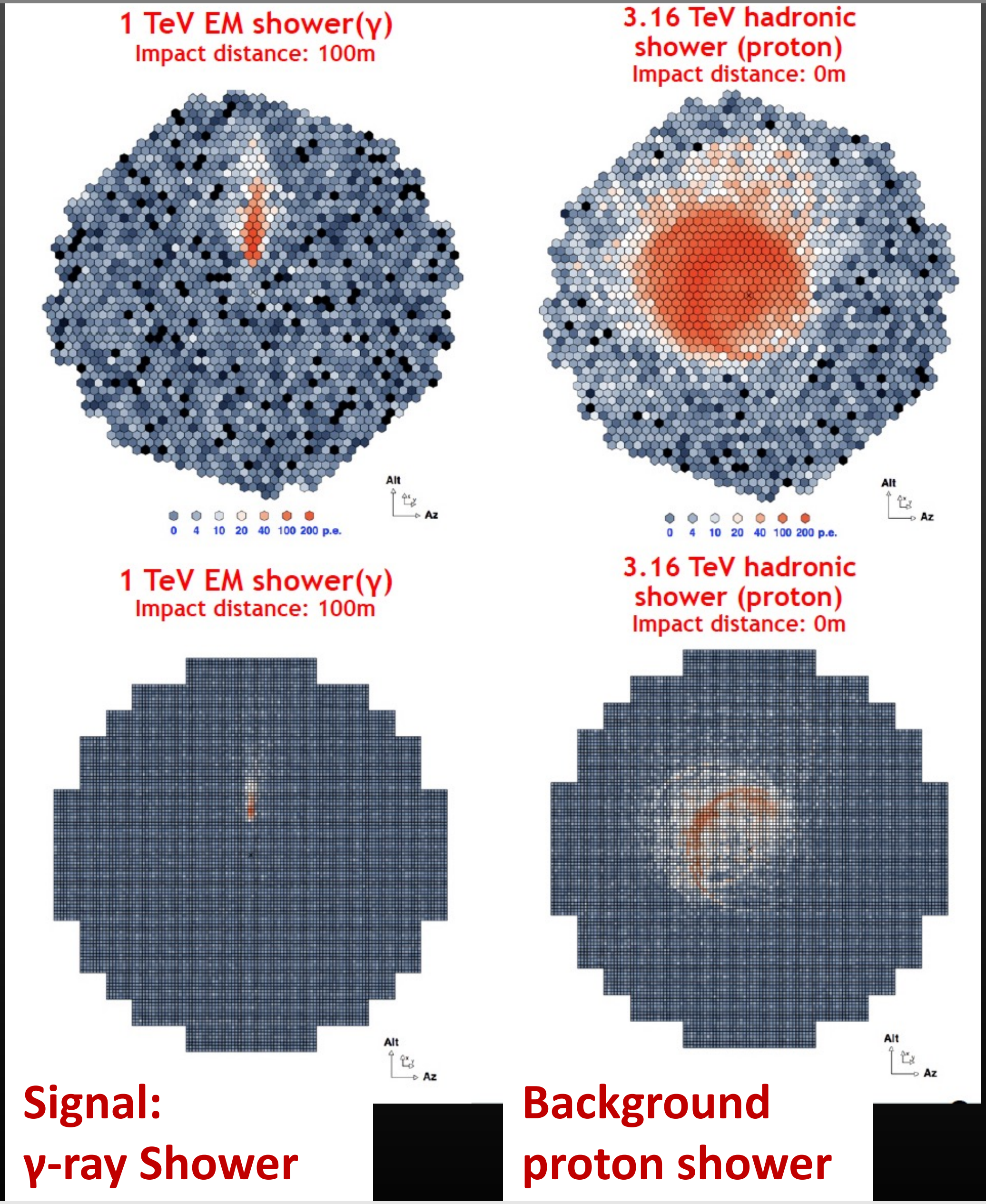


The Schwarschild Couder Telescope (SCT)

MST
Single mirror
Davies-Cotton
~ 2k PMTs

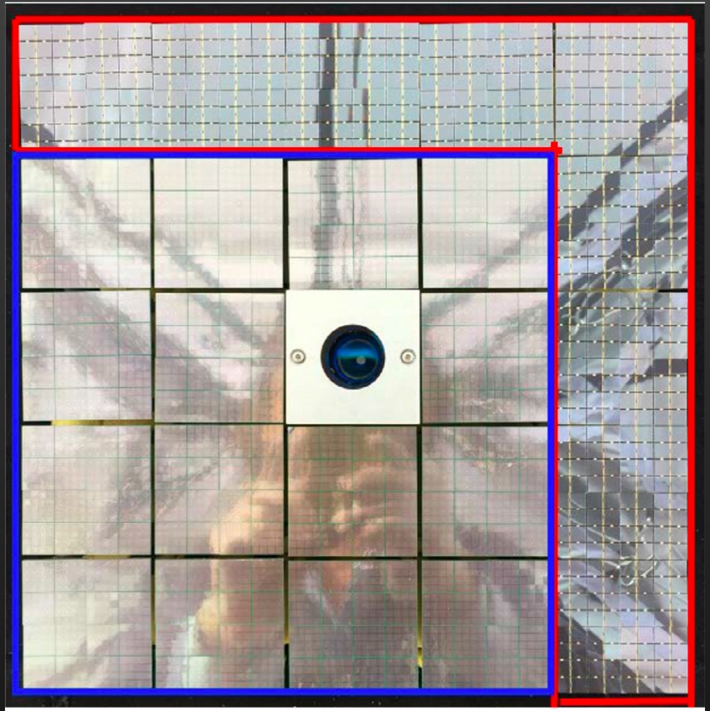
SCT Double mirror
Schwarzschild-Couder
~ 12k SiPMs (8°FoV)

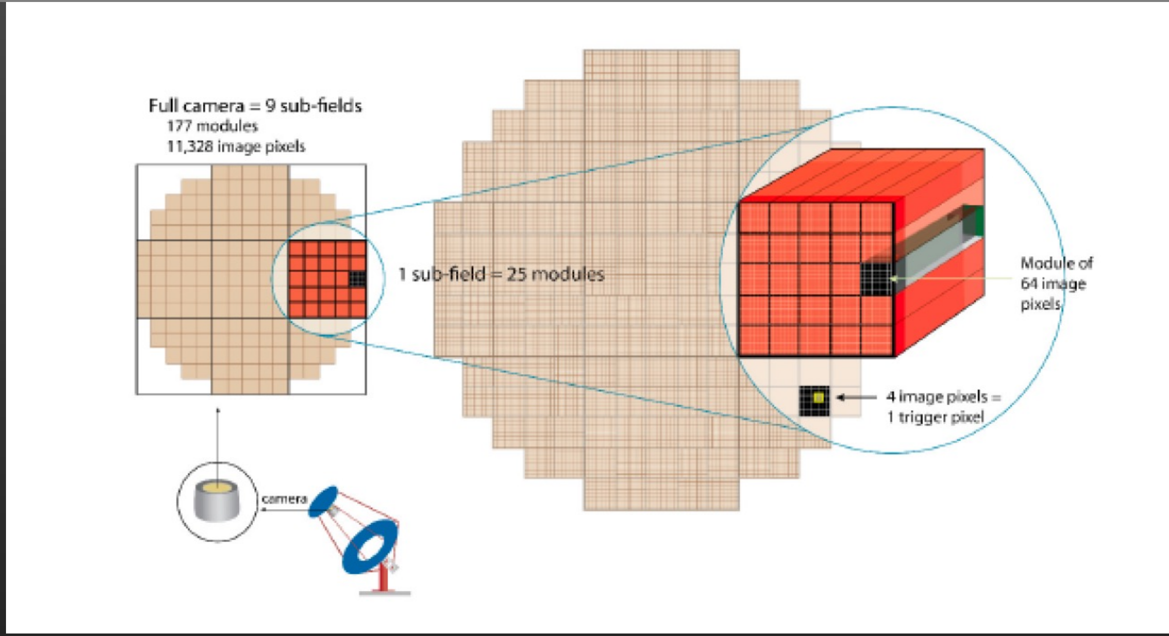




The pSCT design

177 modules (64 pixels)

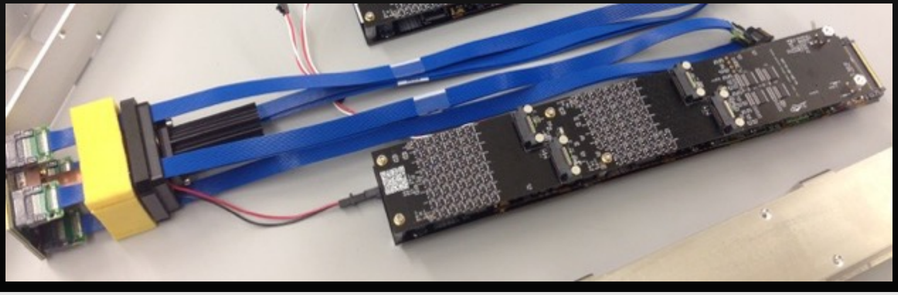




Current camera: 1600 pixels~2.7° FOV

- 15 modules equipped with Hamamatsu MPPC
- 9 modules equipped with FBK HD-3 SiPMs (top and right corner)
- central slot used for allocate a special module for the telescope pointing procedure

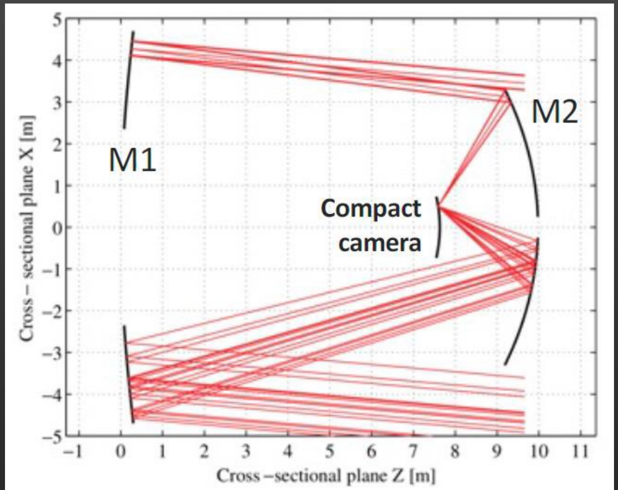
- **Current camera:**
  - Focal plane module (FPM)
  - FEE based on discrete pre-amplifier + TARGET-7

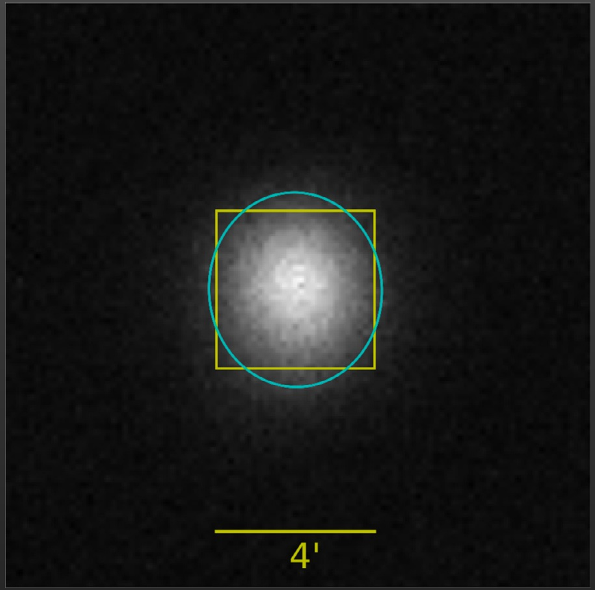


The pSCT Optical System

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

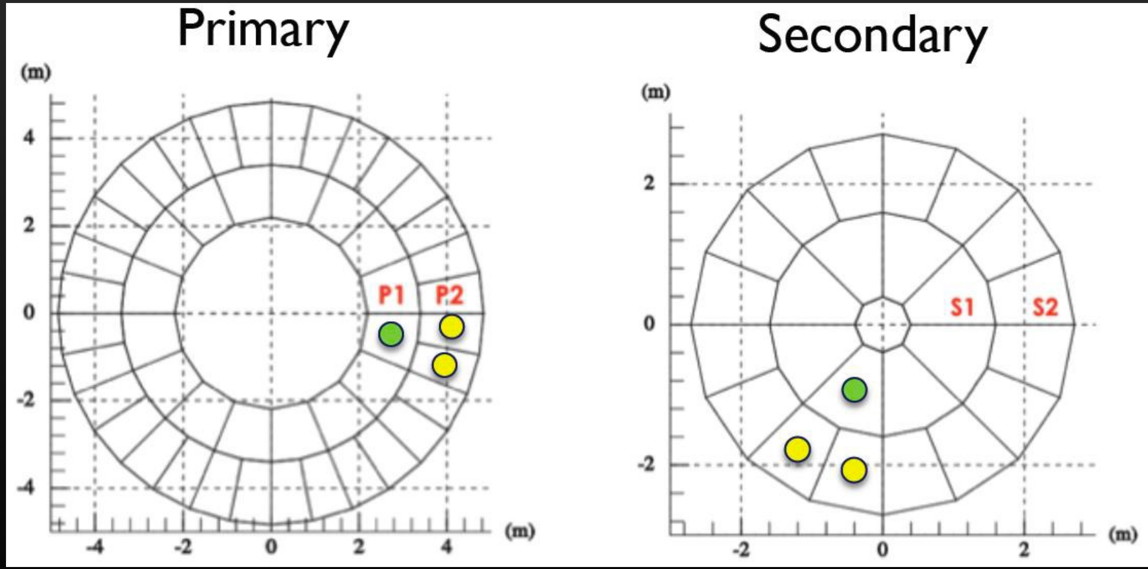
- **Focal length: 5.586 m**
- **Achieved PSF design goal of 2.9 arcmin**





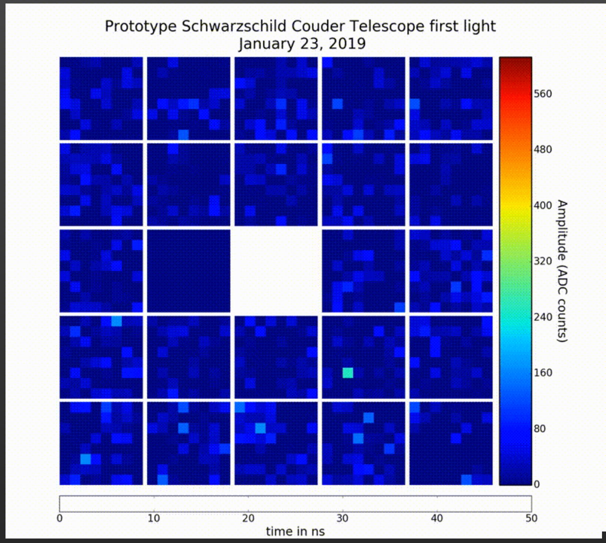
- The alignment depends on the pointing elevation
- A database of aligned panel positions is being built to allow us to maintain the PSF through the full range of elevations

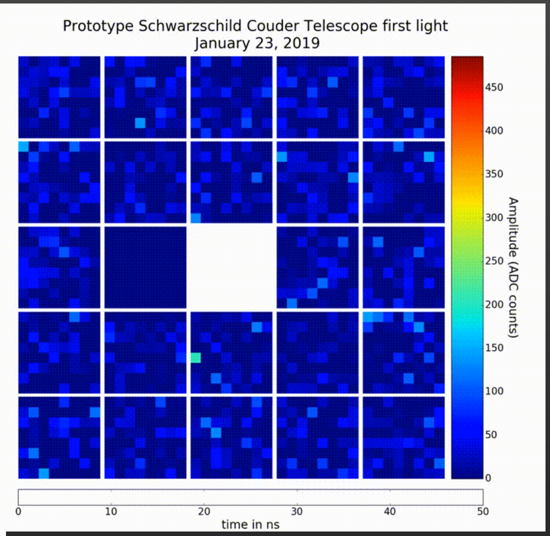
- **Achieved PSF of ~3' across an elevation range of 77°-40°**



First lights and Crab nebula detections with the pSCT

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



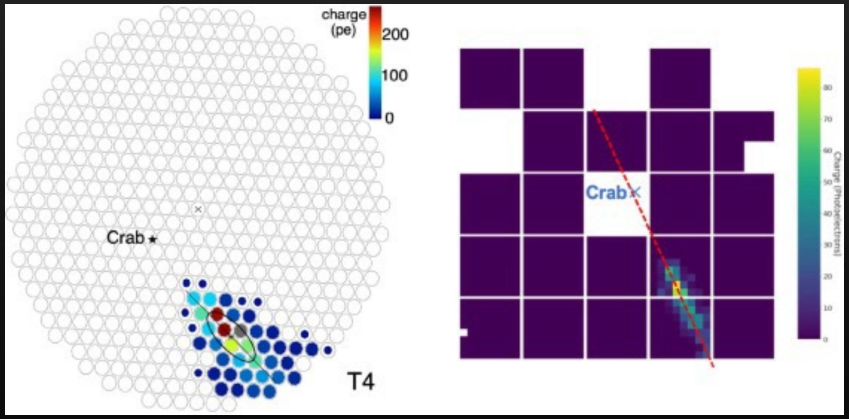


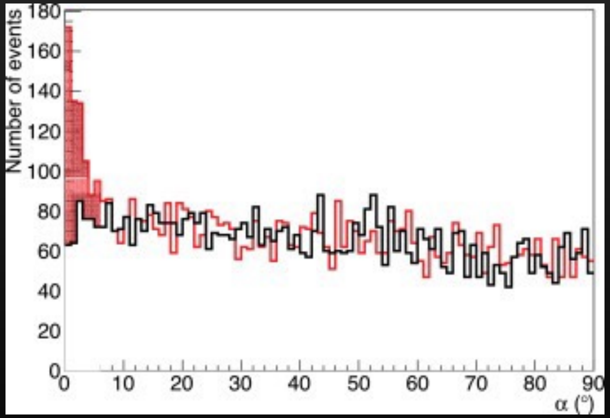
Detection of the Crab Nebula with the 9.7 m prototype Schwarzschild-Couder telescope

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

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

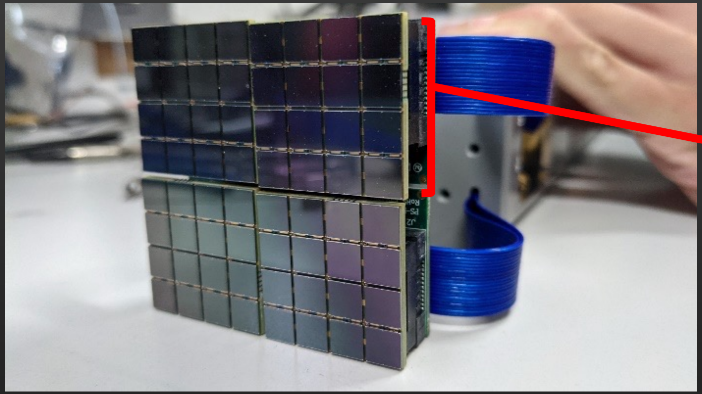
Analysis of pSCT – VERITAS coincident data





The pSCT design

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

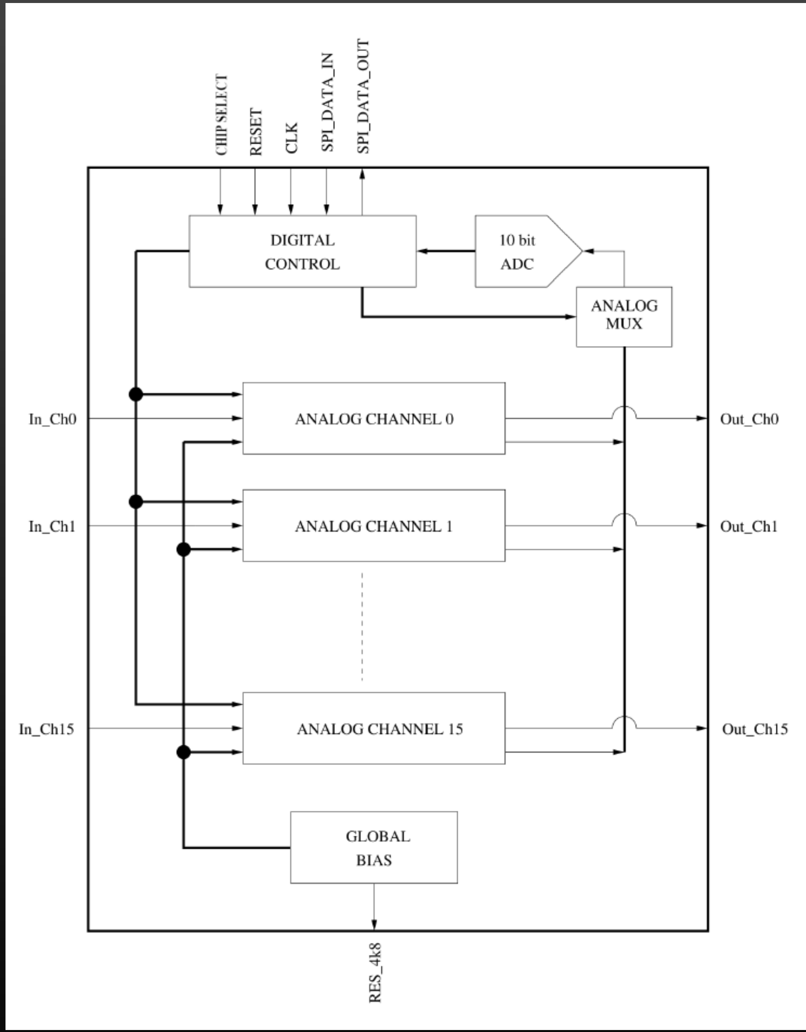


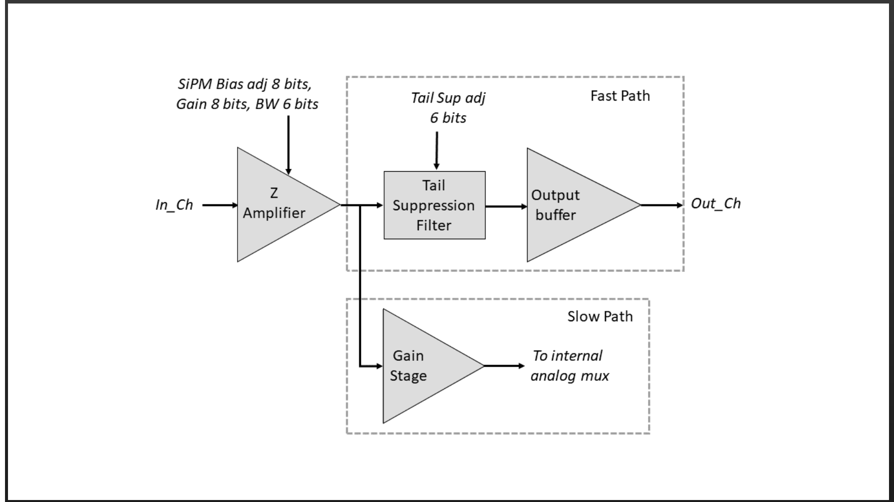
Upgraded sensors (INFN-FBK)

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

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





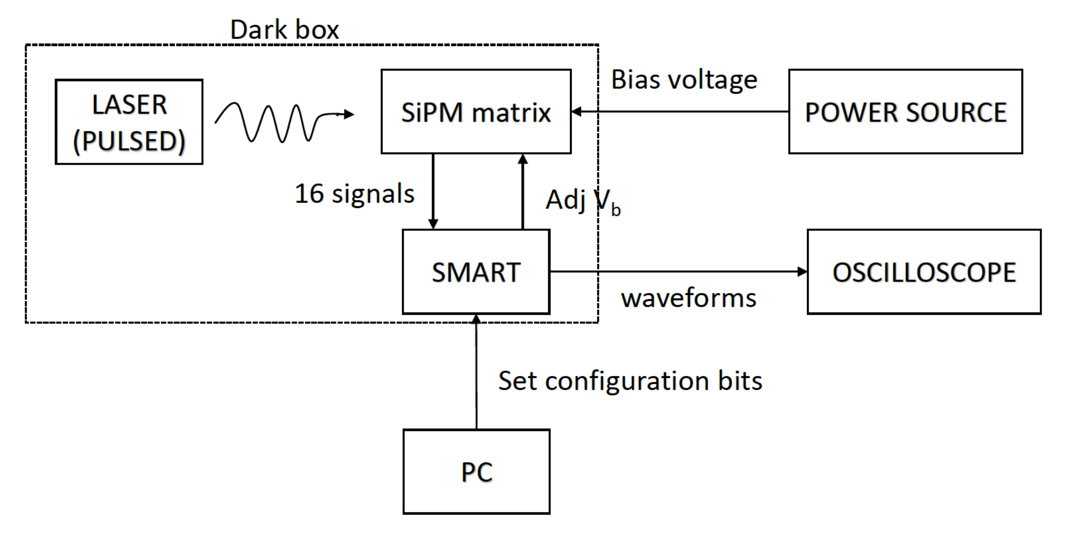
Pre-amplifier designed for photon counting

- 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

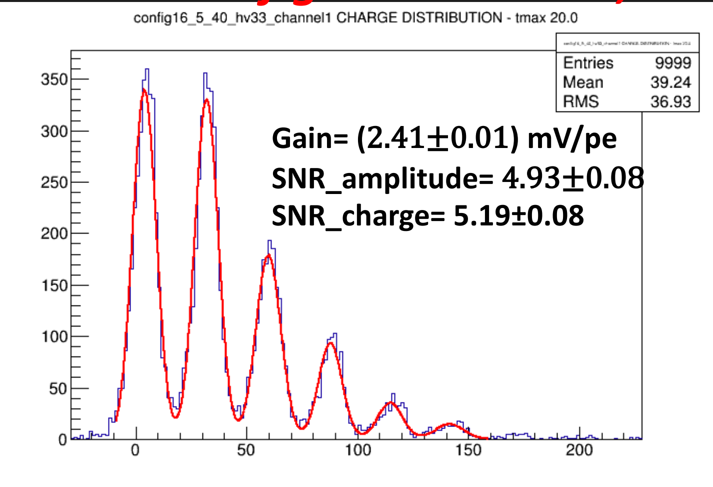
SMART characterization

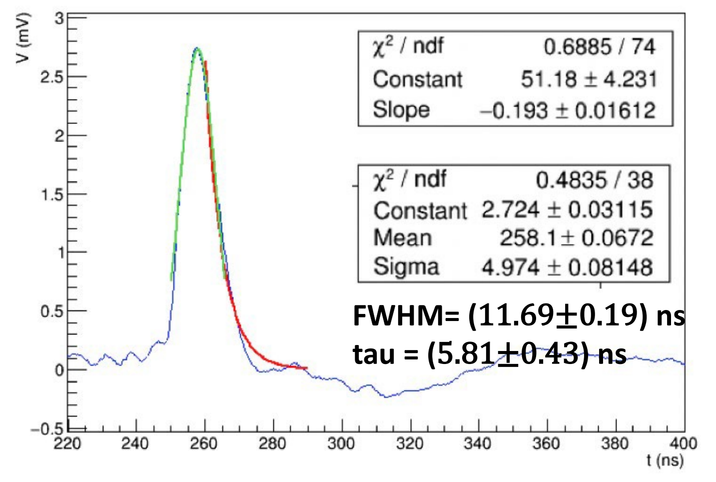
SMART performances tested with FBK NUV-HD 6x6mm^2 SiPM (HV=33V)

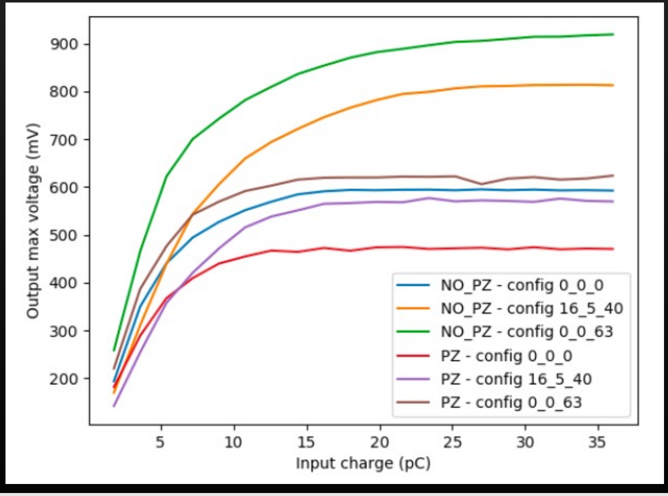
- Gain, signal-to-noise ratio and pulse width as a function of configuration bits were measured.
- 3 parameters changed:
  - ❑ R : gain resistance
  - ❑ C : filtering capacitance
  - ❑ PZ: pole zero cancellation
- External PZ fixed with discrete components
- Tests at different bias voltage (Vbias= 33, 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**



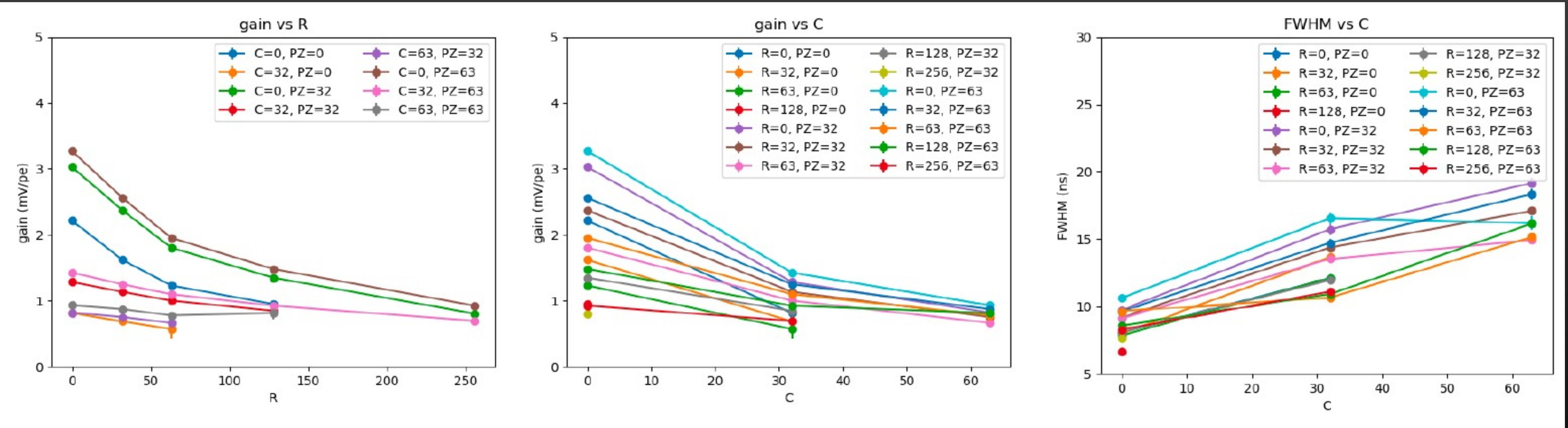




Output dynamic range

- 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

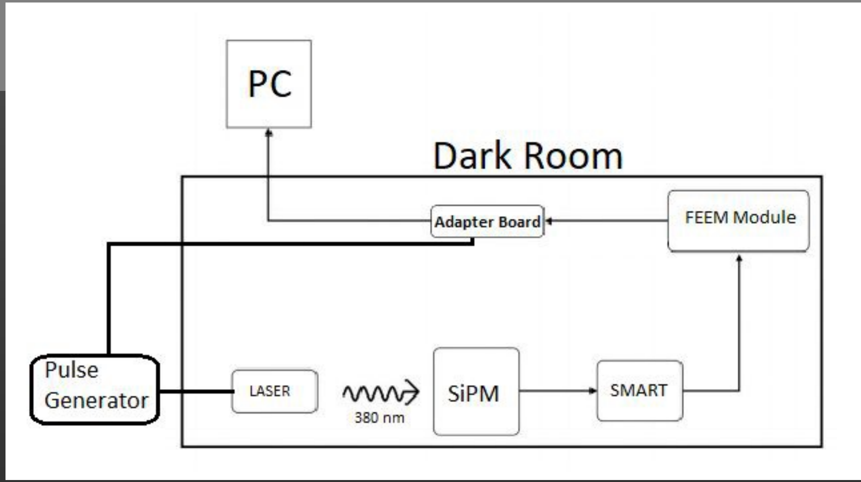
cherenkov telescope array

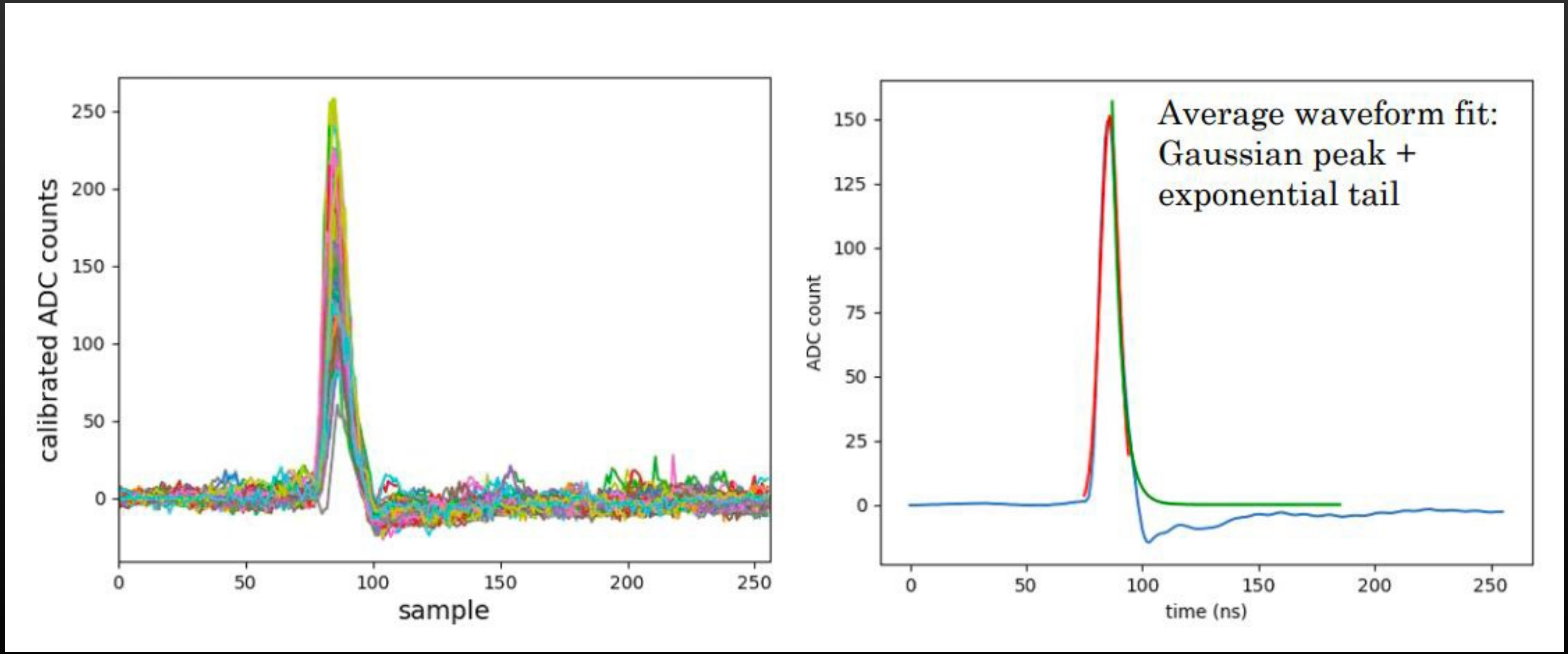
SMART quality test

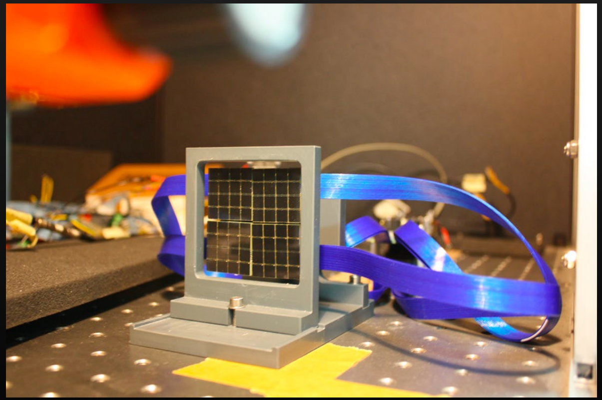
About 750 ASICs produced

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

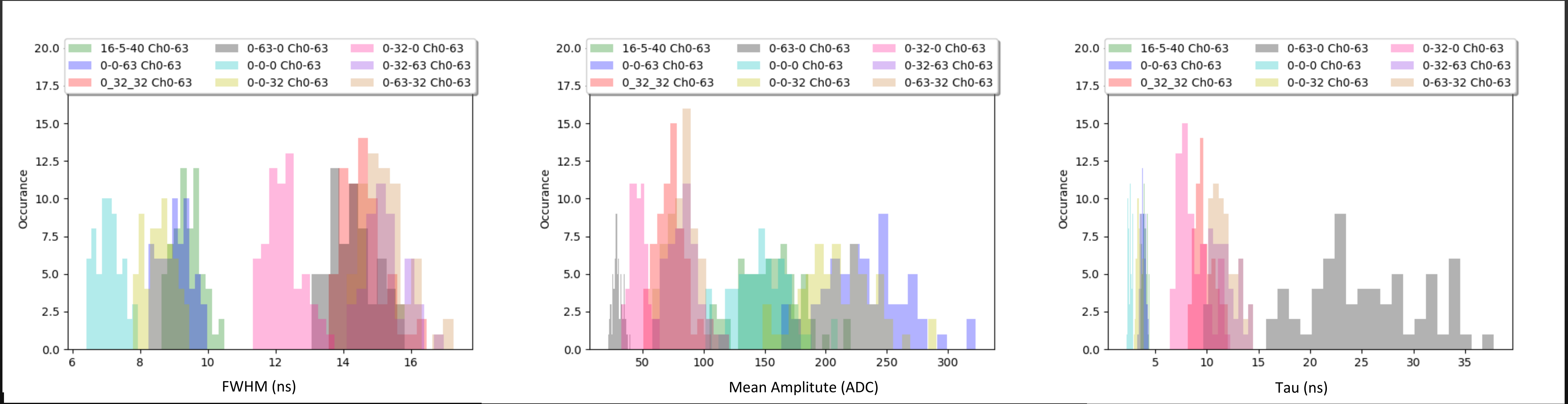






SMART quality test

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.



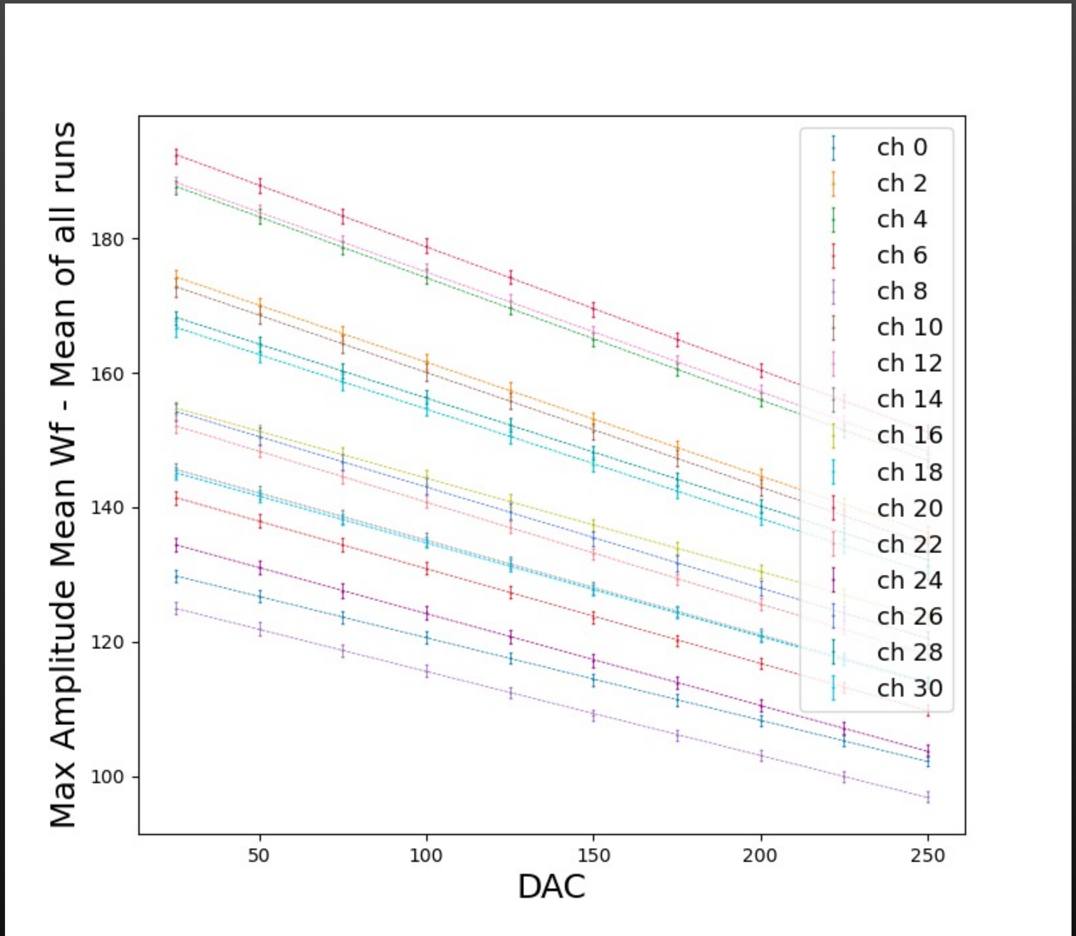
Conclusions & Future perspectives

- ✓ The pSCT camera will be equipped only with FBK matrices
- ✓ The Crab Nebula was detected
- ✓ Optimized electronic 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 dependance 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%)
- ✓ Studies on gain versus DAC dependance ongoing
- ✓ New design ready to be tested for future upgrades

Thank you for your attention!

Backup

SMART quality test

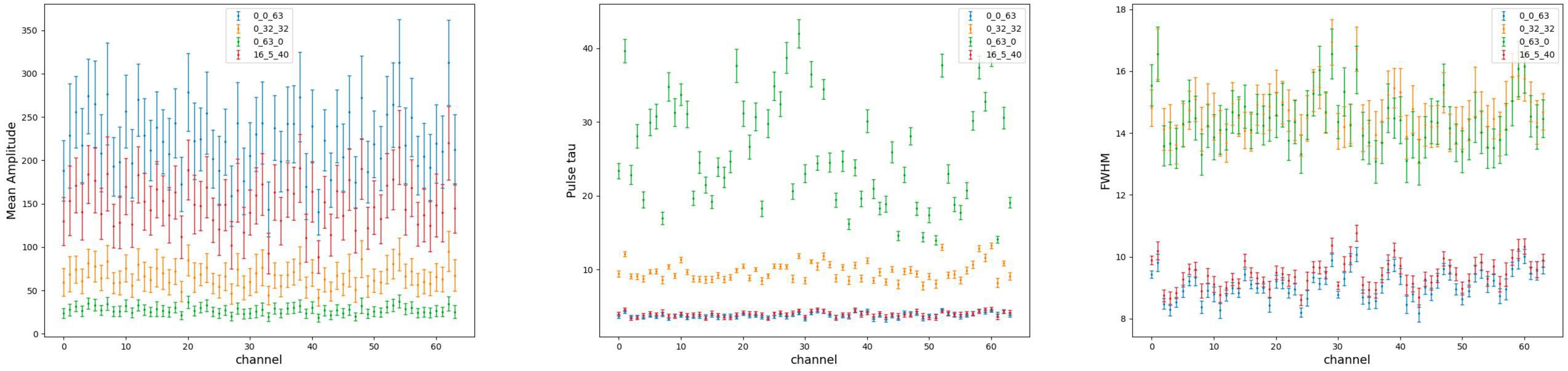


The linear trend of the average of the max amplitudes of the mean waveform as a function of DAC.
Note that increasing DAC value, SiPM bias is decreasing.

SMART quality test

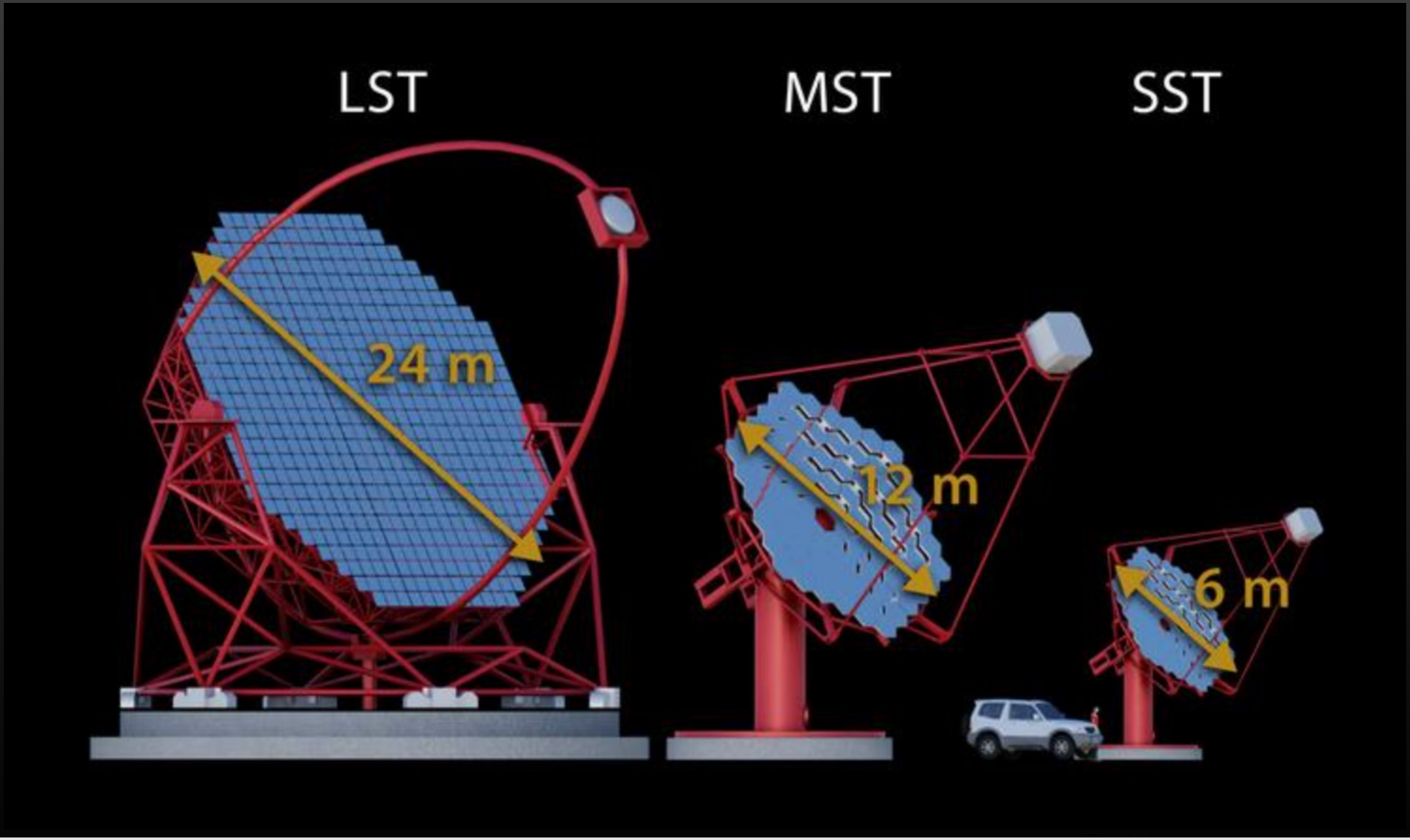
A quality control test, made up by 4 parts, has been performed for each SMART

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



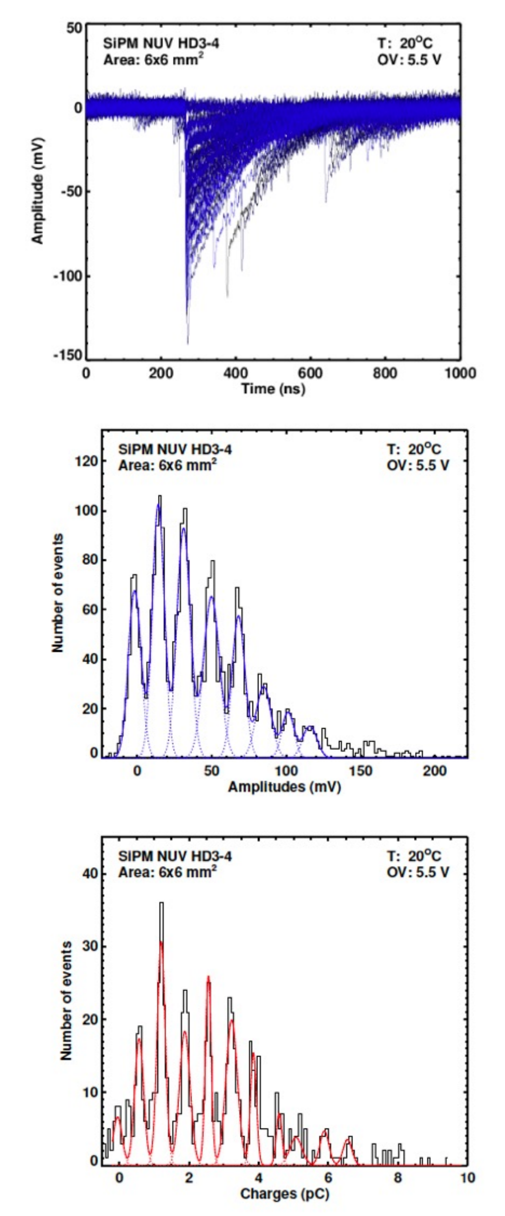
CTA telescopes

70 SST, 40 MST, 8 LST



FBK single SiPM quality check

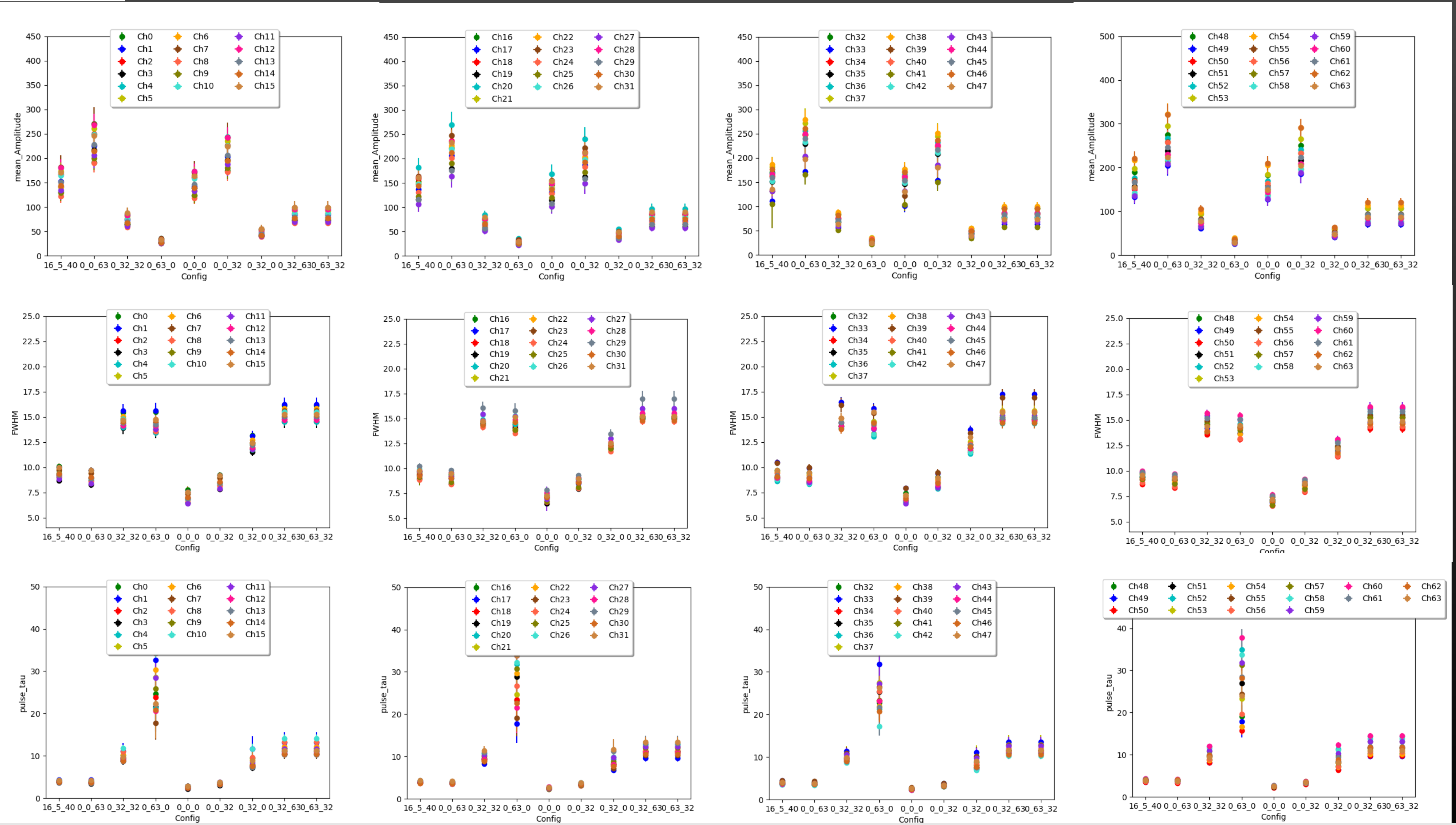
Waveforms, Amplitude and Charge distribution for 6 x 6 mm^2 SiPM HD3-4. Measurements performed at T = 20C and OV = 5.5V



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.

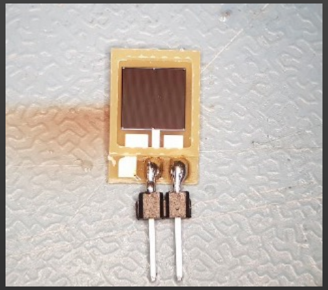
SMART quality test



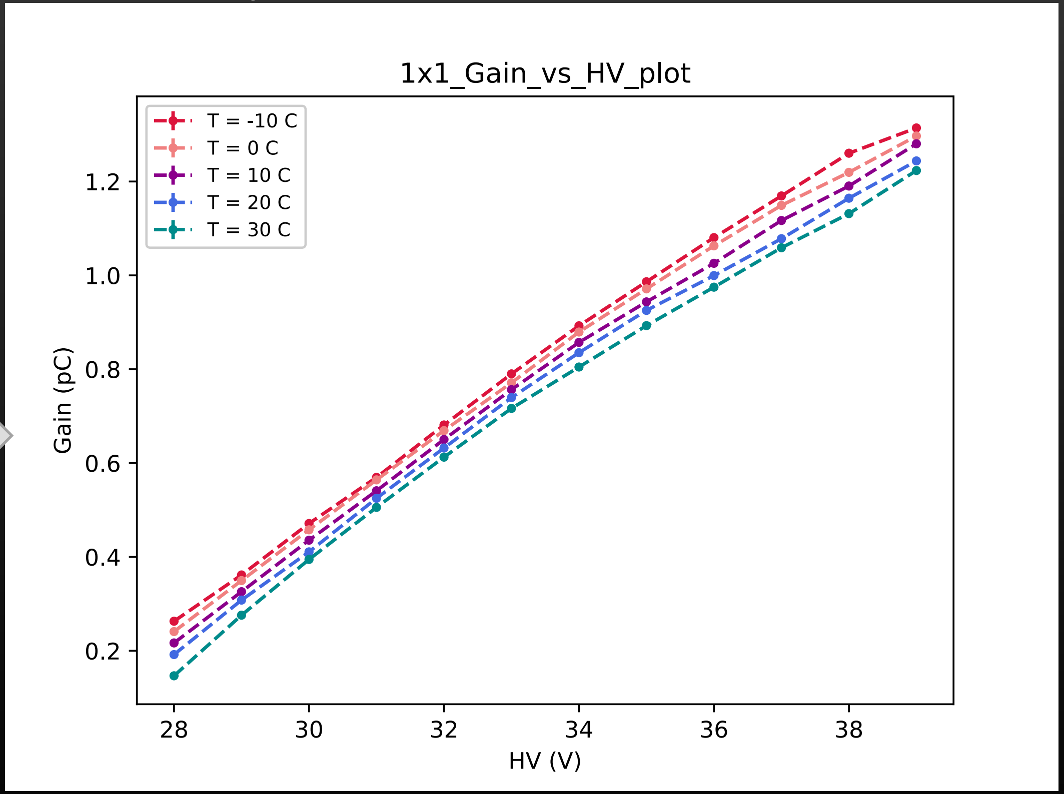
Gain, SNR and DCR uniformity for single SiPM

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

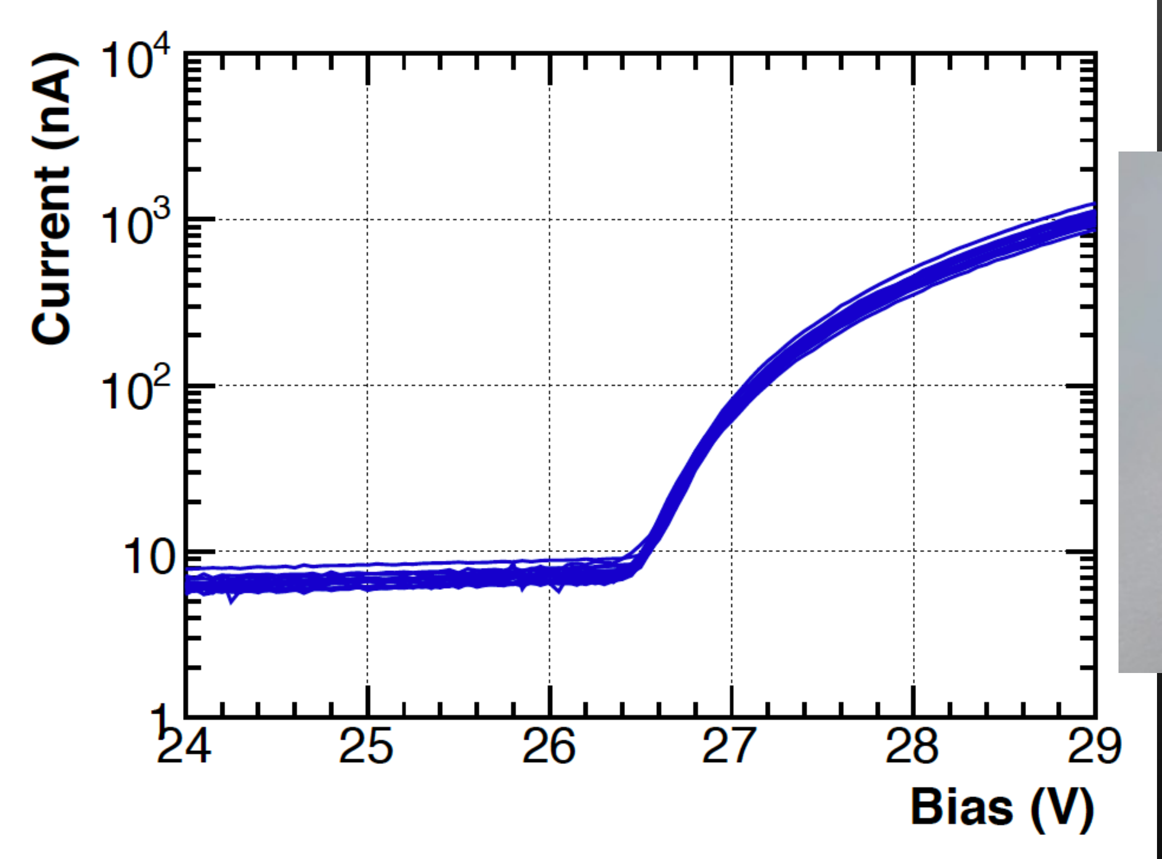
Test of 6 x 6 mm^2 SiPM HD3-4.
Less noisy than SiPM HD3-2 and HD3-3 ones, used for development of the assembly and test procedures

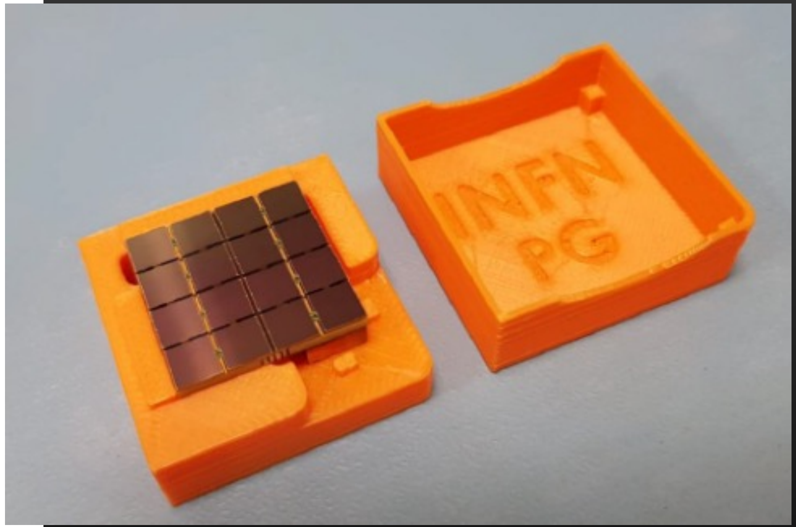


Integrated charge measured for the 1 x 1 mm^2 SiPM HD3-4, less noisy than the 6 x 6 mm^2 ones.



I-V profile for 16 SiPMs integrated on one PDU






Oct 10 2018

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