The prototype Schwarzchild Couder Telescope: A medium-sized telescope for the Cherenkov Telescope Array

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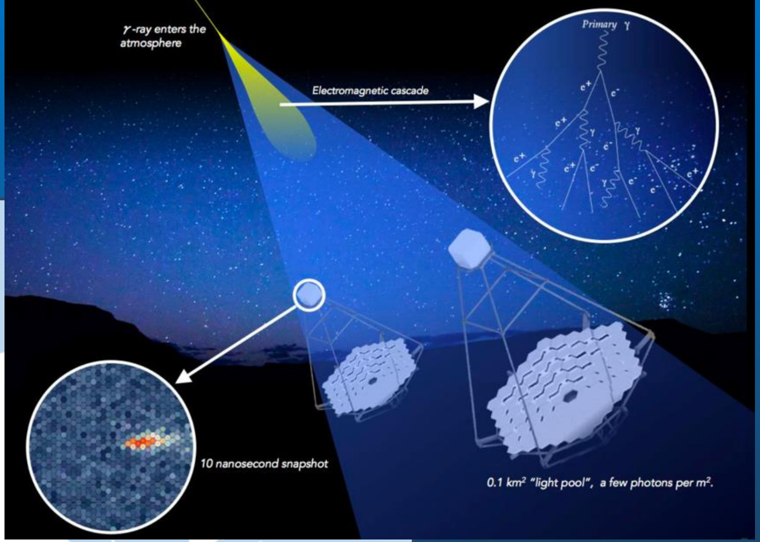
RICAP-24 Roma International Conference on AstroParticle Physics 23-27 Sept 2024

Gamma-ray detection with Cherenkov Telescope Array

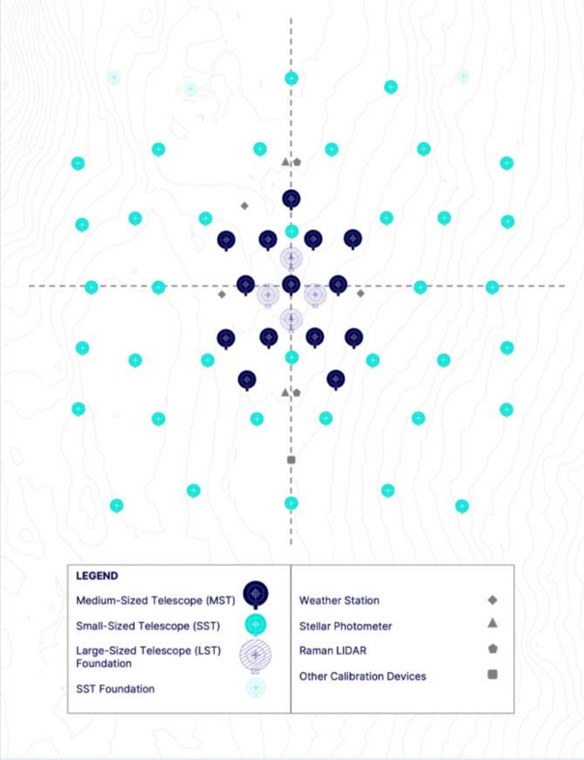
https://www.cta-observatory.org/ctao-releases-layouts-for-alpha-configuration/



Cherenkov Telescope Array:

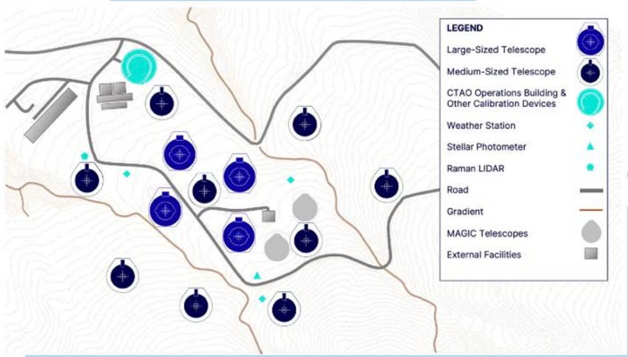
- ~100 + telescopes involved
- Increased detection area
- Improved sensitivity
- 2 telescopes sites
- 3 sizes of telescopes

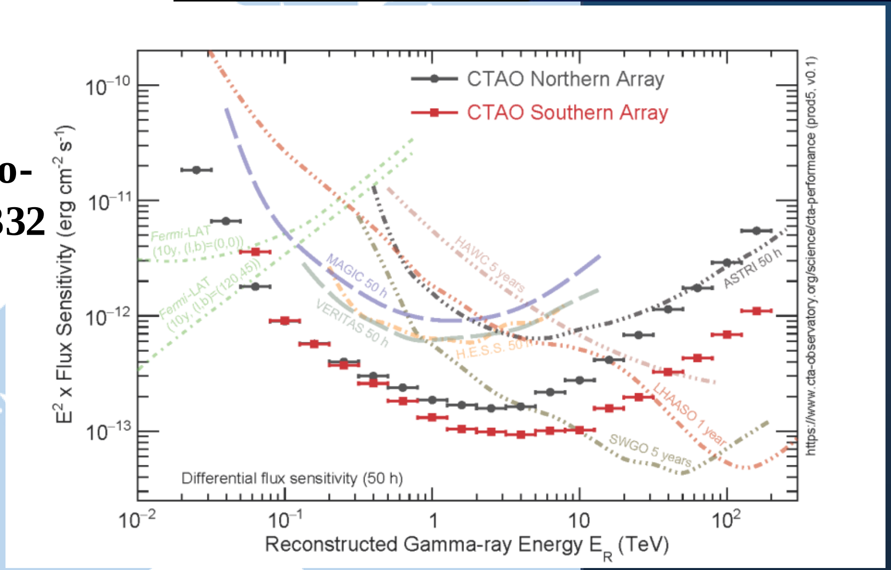
Paranal,Chile



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

ORM, La Palma, Spain

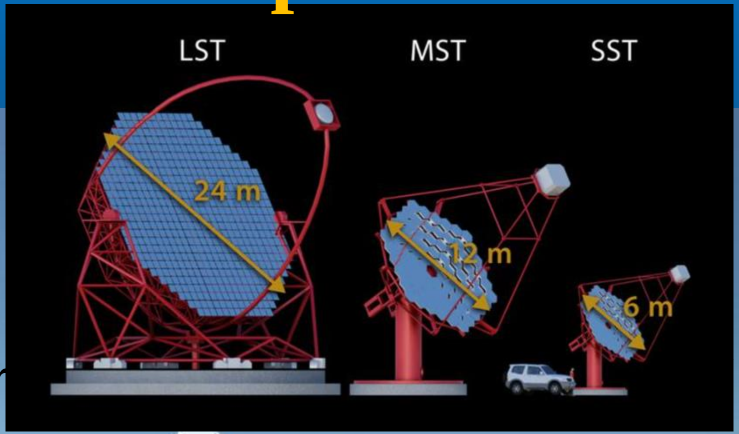


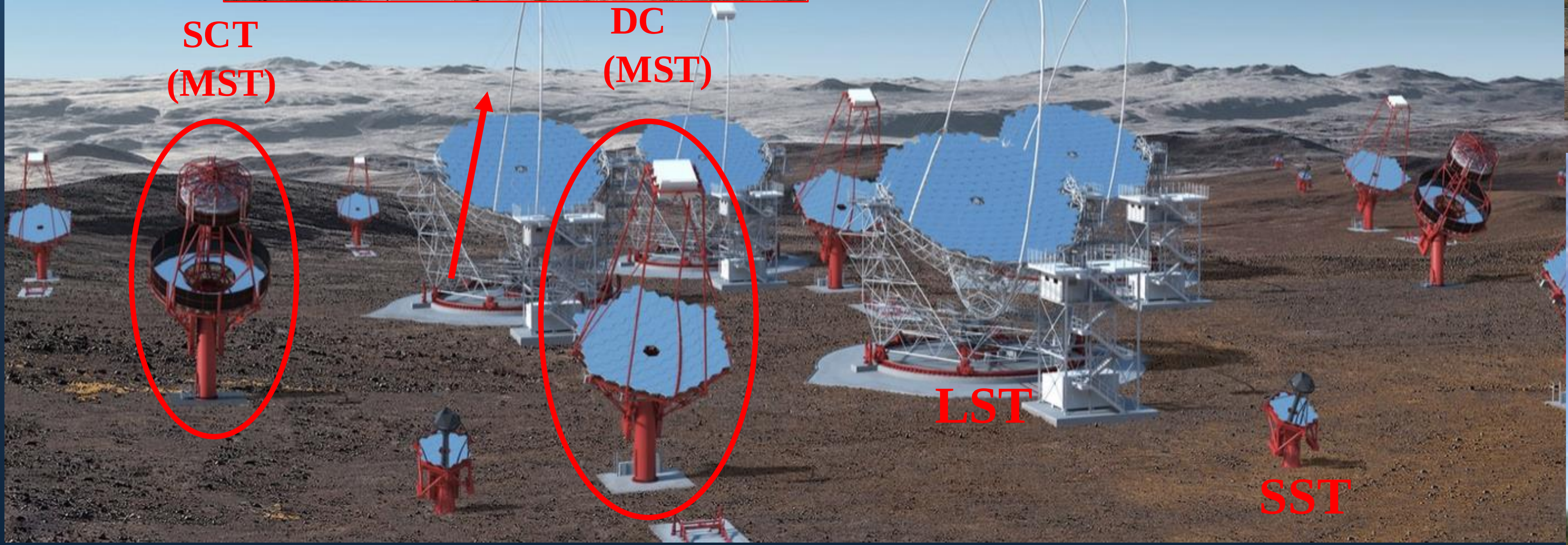


- LSTs, from ~20 GeV to ~1 TeV
- MSTs, from ~100 GeV to ~10 TeV
- SSTs, from ~few TeV to ~100 TeV

Imaging Air Cherenkov Telescopes

pSCT installed at VERITAS site
Arizona-1270 m

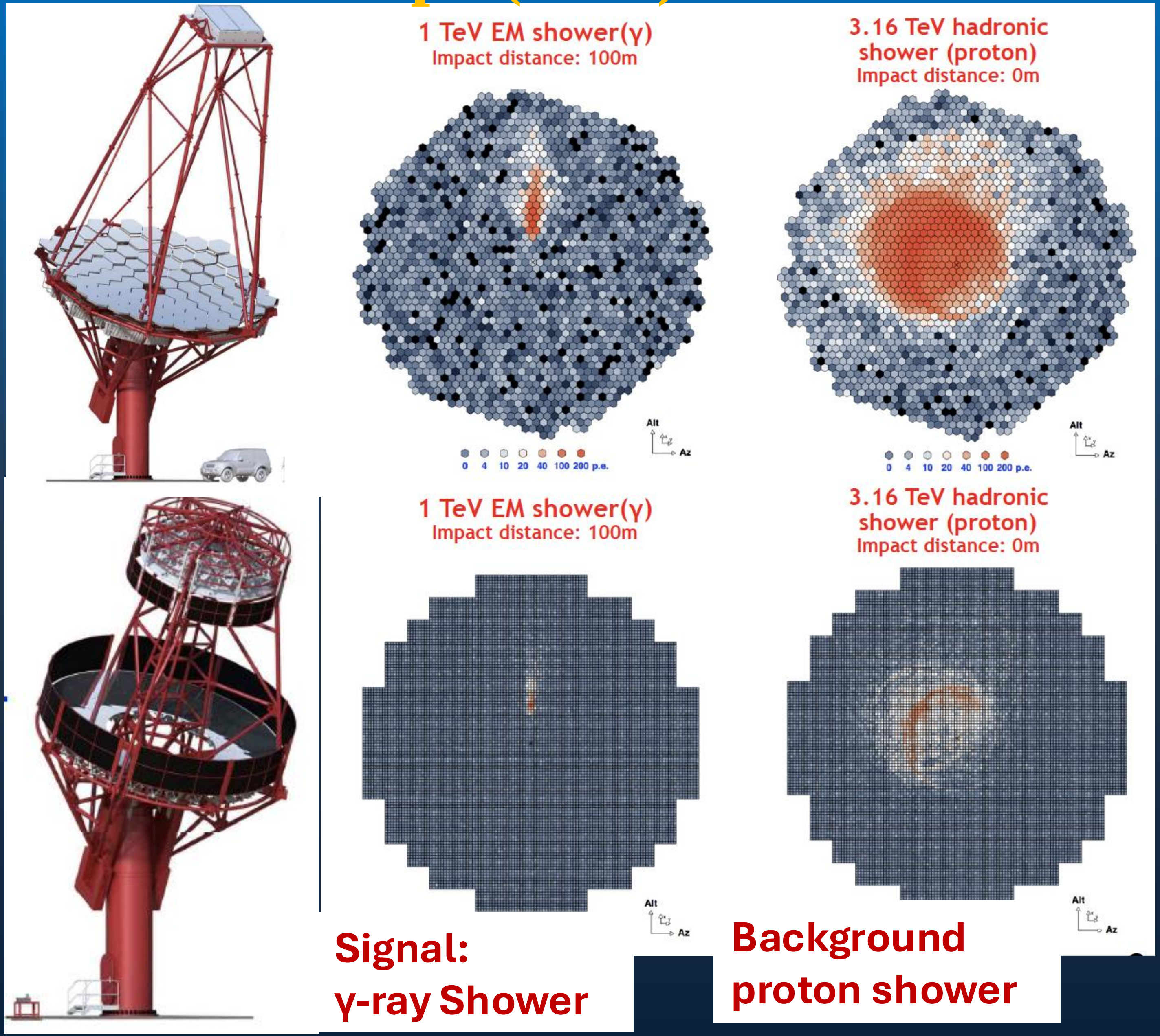




The Schwarschild Couder Telescope (SCT)

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)

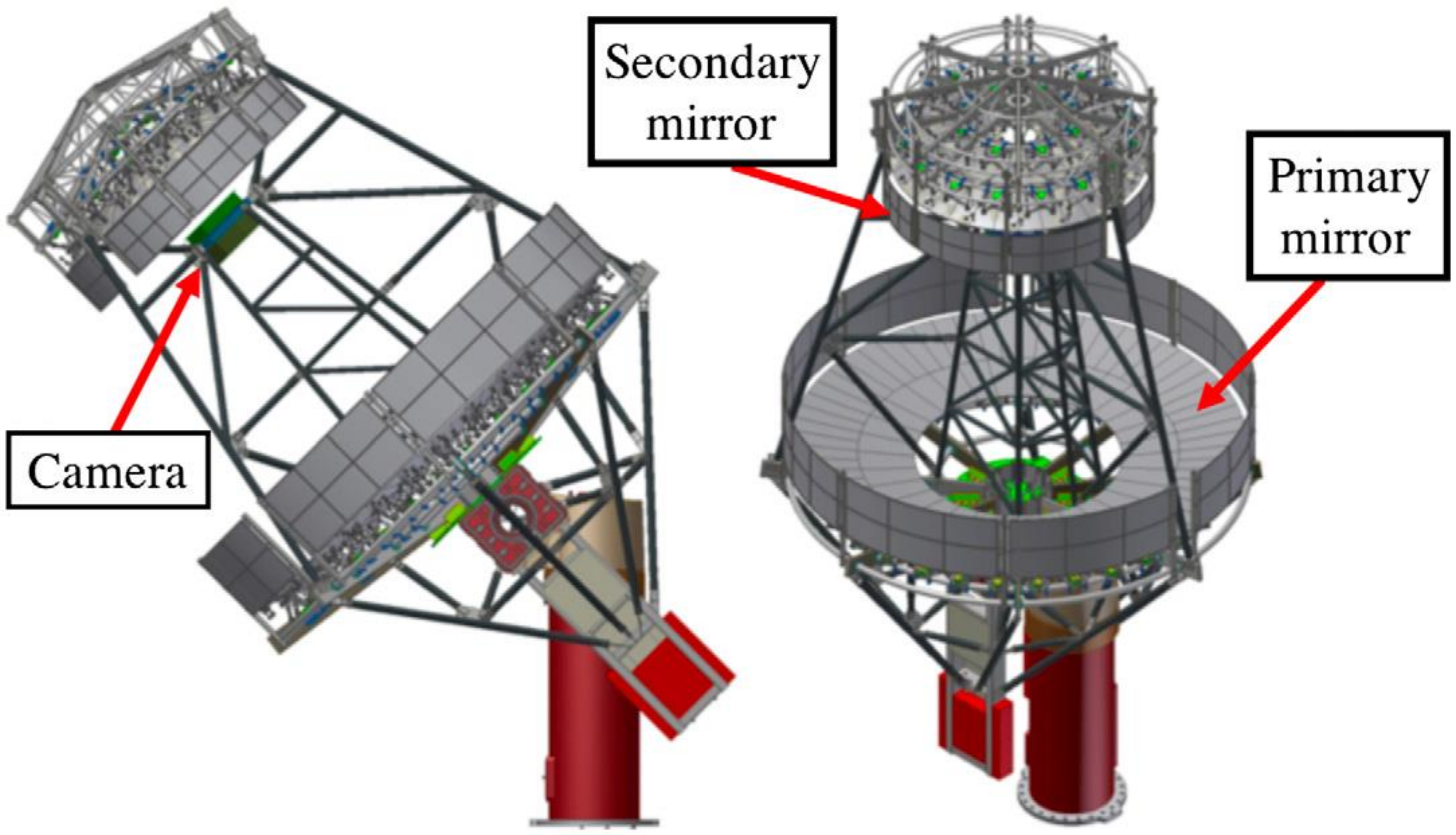
Dual mirror medium size telescope

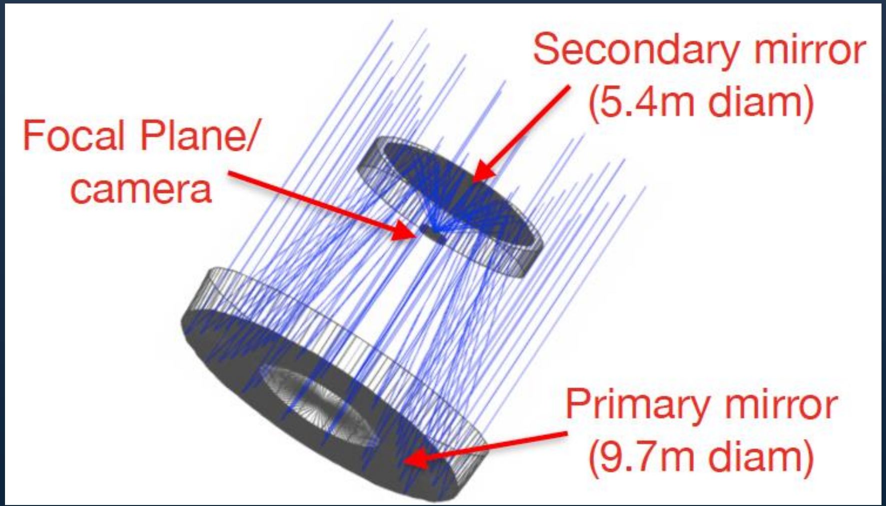
Improvements:

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

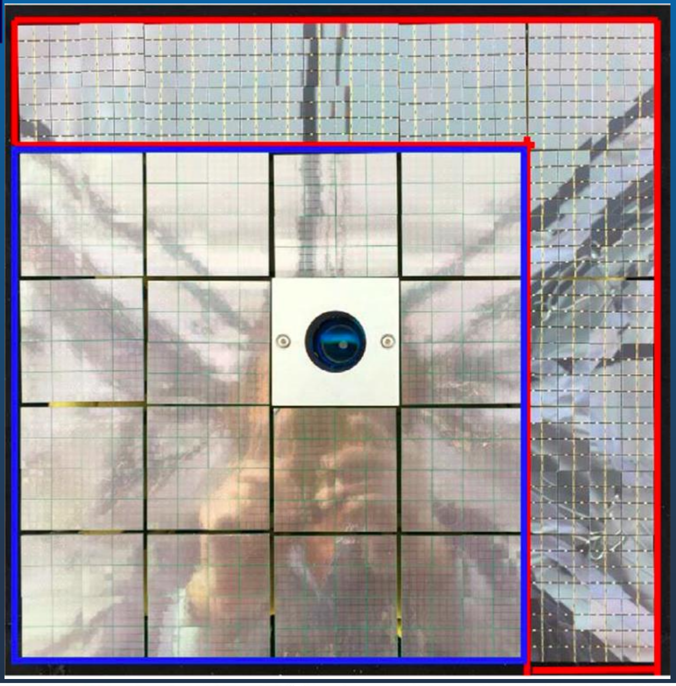
Limitations:

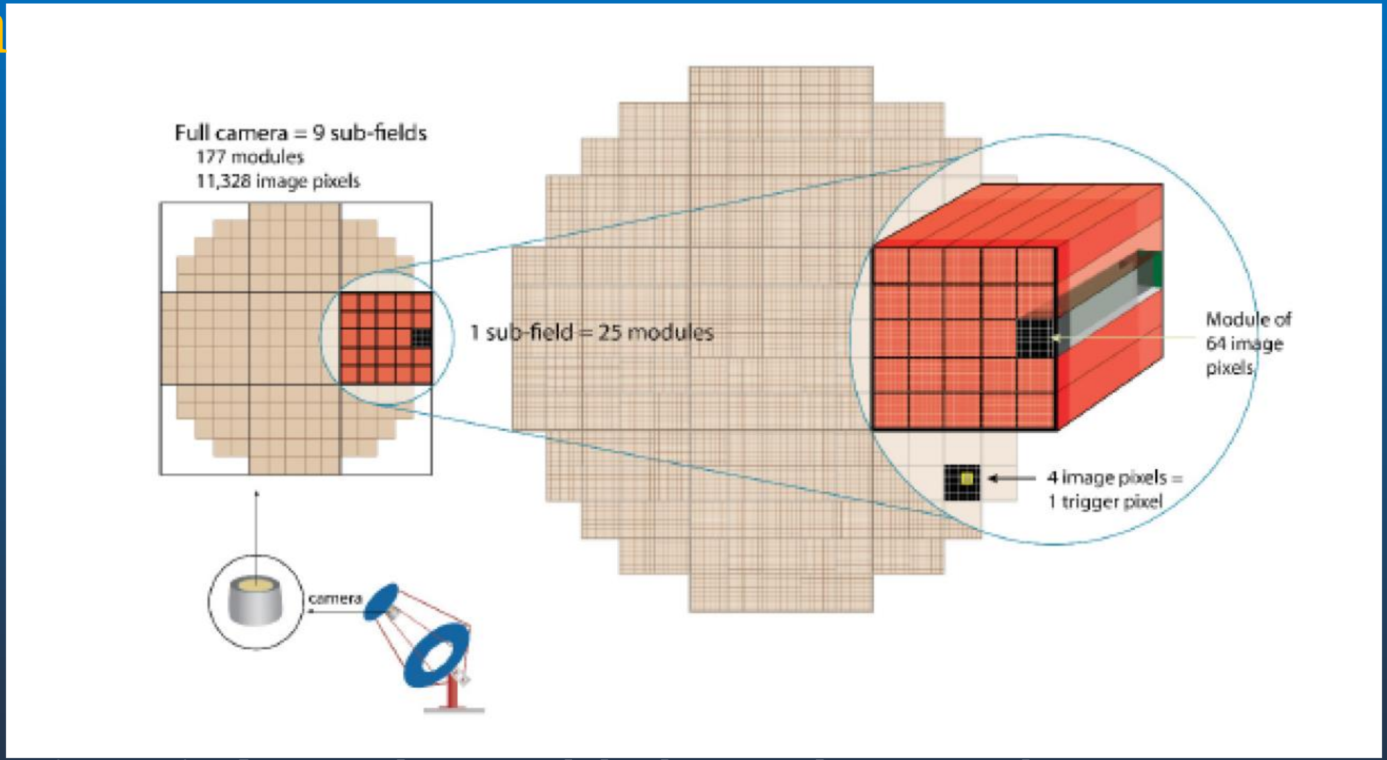
- mechanical stability and mirror alignment





Current pSCT camera





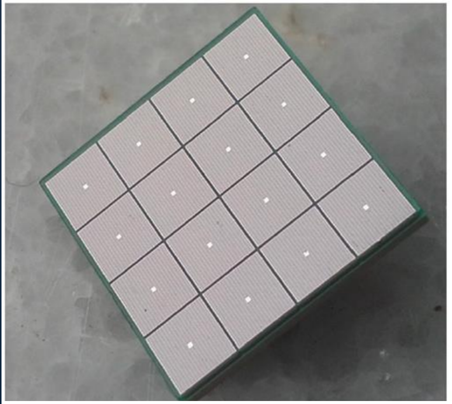
SiPM pixels providing much higher resolution air shower image

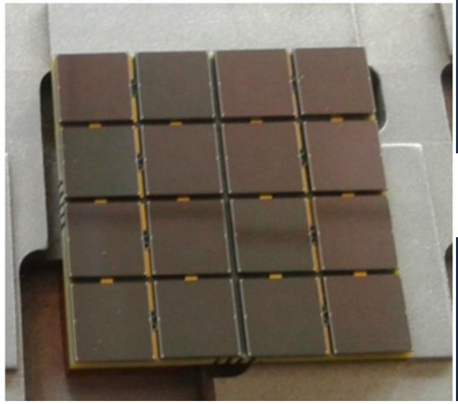
Better angular resolution

Better background rejection

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





Hamamatsu MPPc **FBK HD3**

The CTA SCT project

CTAO

8 June 2015

September 2016

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

~30 participating Institutions 

Milestones:

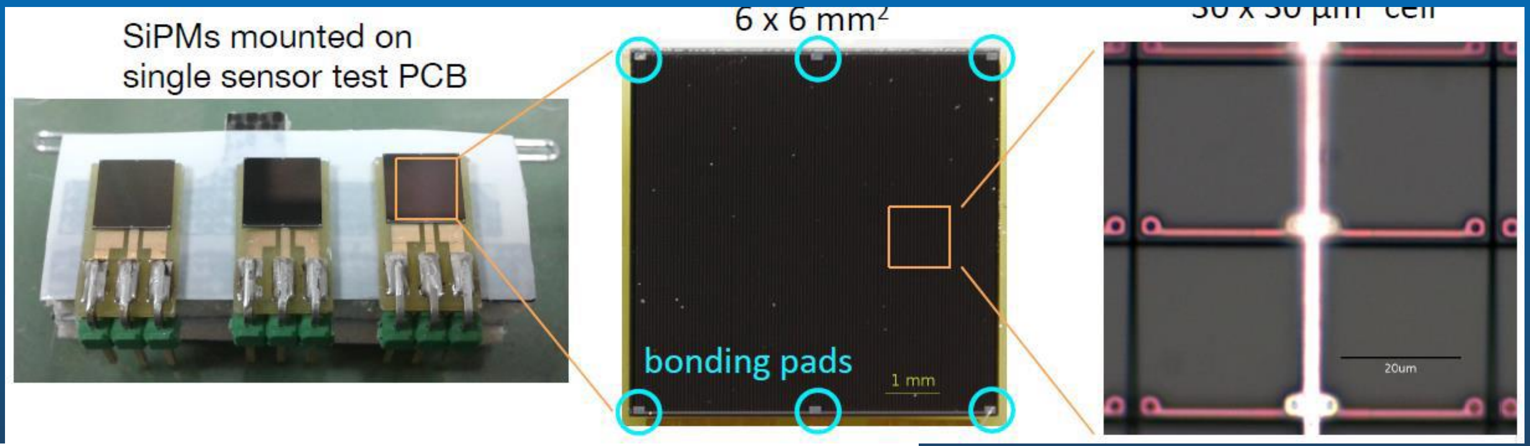
- 1st construction: 06-23-2015
- Inauguration: 01-17-2019
- 1st light: 01-23-2019
- December 2019: optical alignment achieving preconstruction estimated PSF
- January 2020: significant detection of the Crab Nebula (presented at 236th AAS) **https://doi.org/10.1016/j.astropartphys.2021.102562**
- Endorsement by the CTA Consortium for supporting the development and construction of SCTs to add to the array and complement single-mirror MSTs

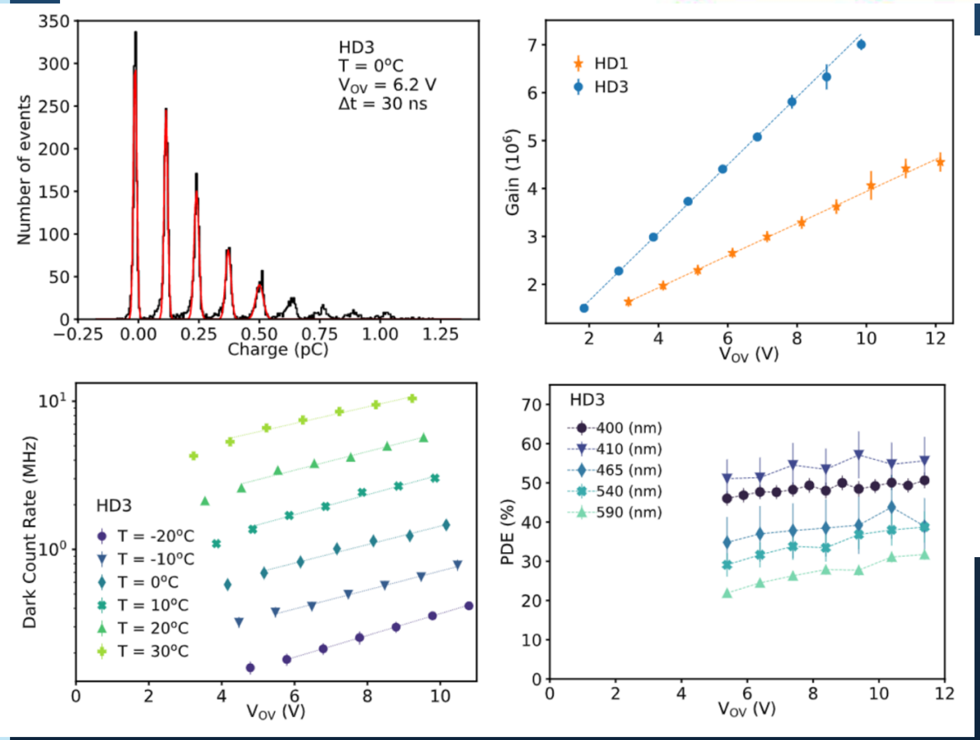
Next steps:

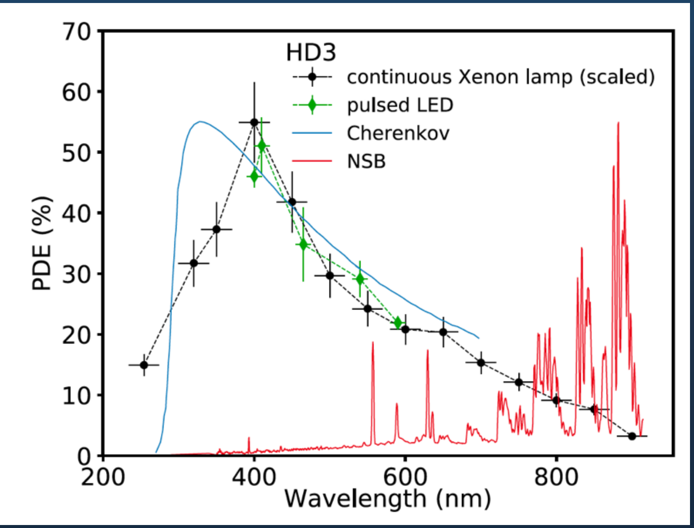
- Ongoing (funded MRI): population of the focal plane to ~11k channels with upgraded SiPMs and electronics

FBK NUV-HD SIPMs

- INFN involved in the development and testing of SiPMs suitable for Cherenkov light detection in the Near Ultraviolet (NUV SiPMs)
    - NUV High-density (HD) SiPMs produced by Fondazione Bruno Kessler (FBK, Trento, Italy)
- Main features:
    - Wide dynamic range
    - High Fill Factor (FF)
    - Increased PDE at NUV wavelengths
    - Low correlated noise
    - 40 x 40 mm^2 cell
    - 6 x 6 mm^2 area



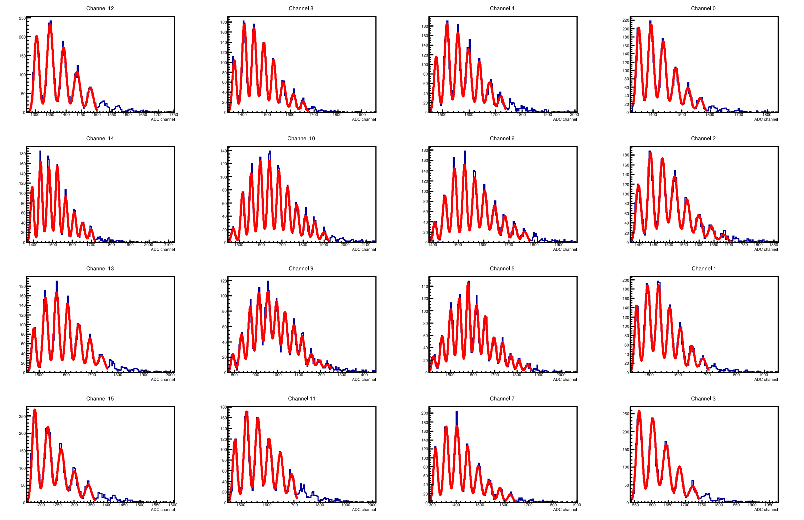


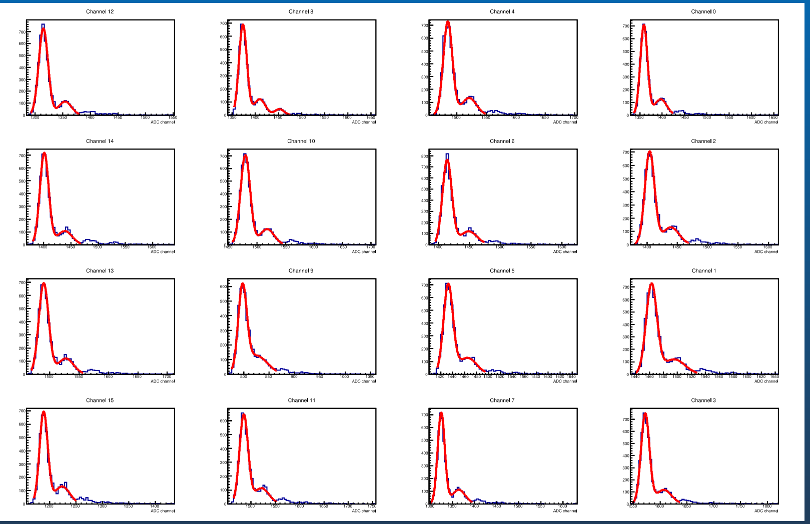


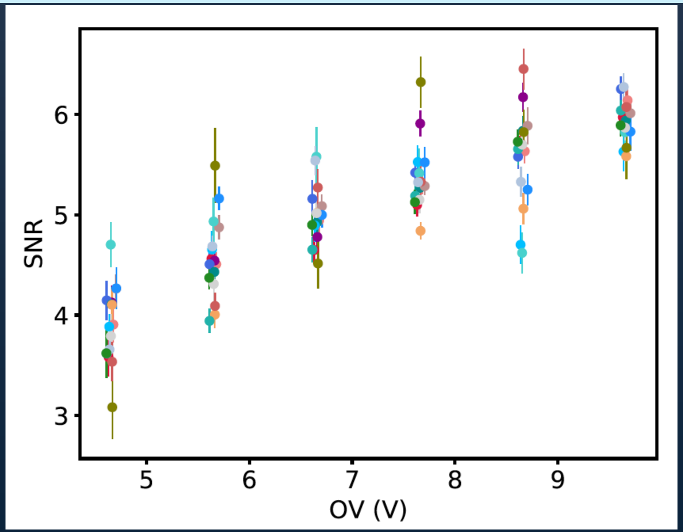
G. Ambrosi et al. 2023, NIMA 1049(2023)168023

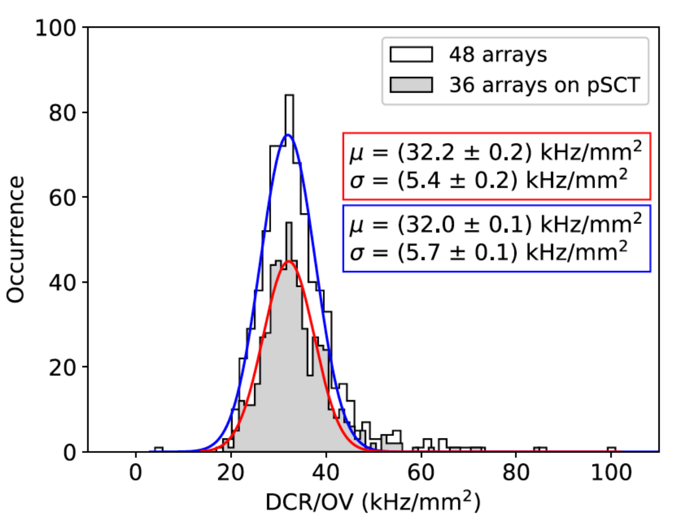
FBK matrices quality check

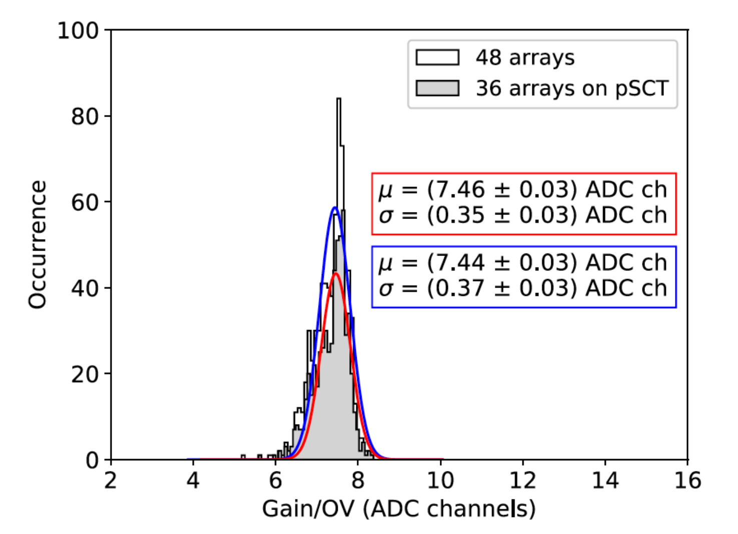
- NUV-HD3 single 6 x 6 mm^2 SiPM arranged in 4 x 4 matrices and tested covering the voltage range 31-36 V
- 36 FBK NUV HD3 optical units assembled, tested and characterized at INFN laboratories in Italy
- Study of performance and homogeneity in terms of breakdown voltage, gain, signal to noise ratio (SNR), and dark count rate (DCR)







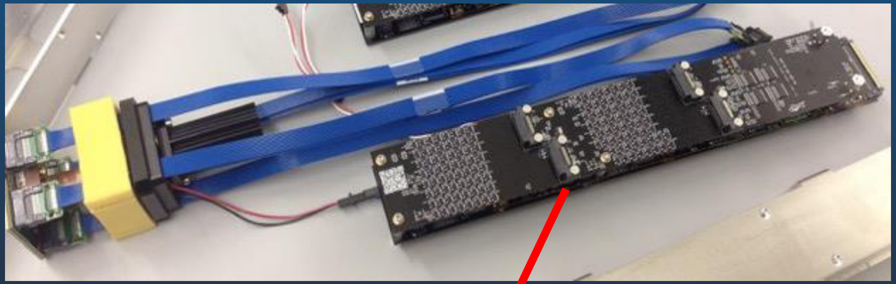


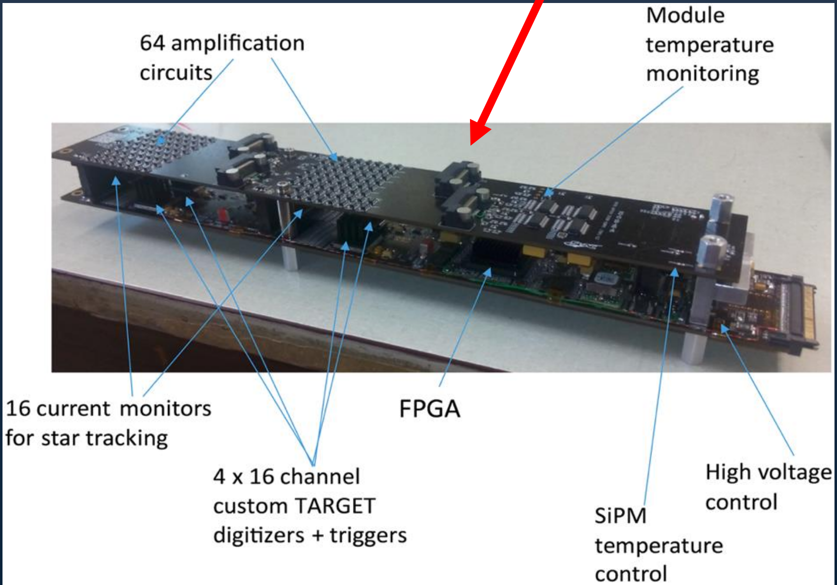


https://doi.org/10.1016/j.nima.2022.167359

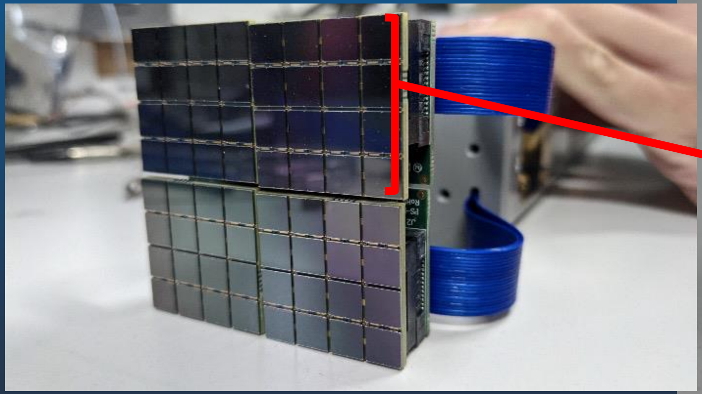
The upgrade of the pSCT camera

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

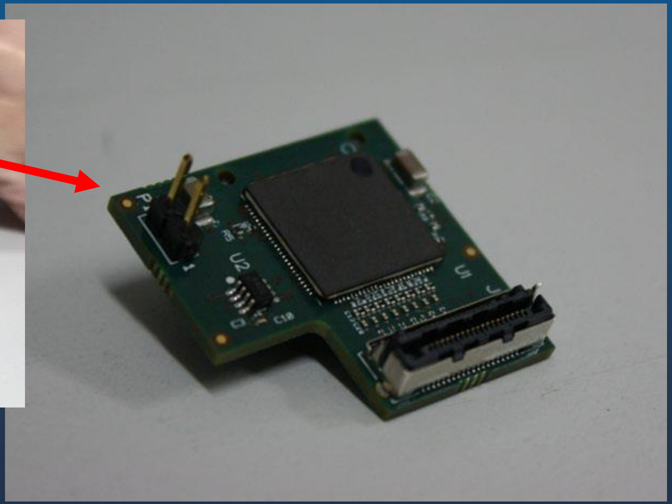




- **Upgraded camera (work in progress)**
  - Focal plane module (FPM)
  - Full camera (>11k pixels) with FBK NUV-HD SiPMs



Upgraded sensors (INFN-FBK)



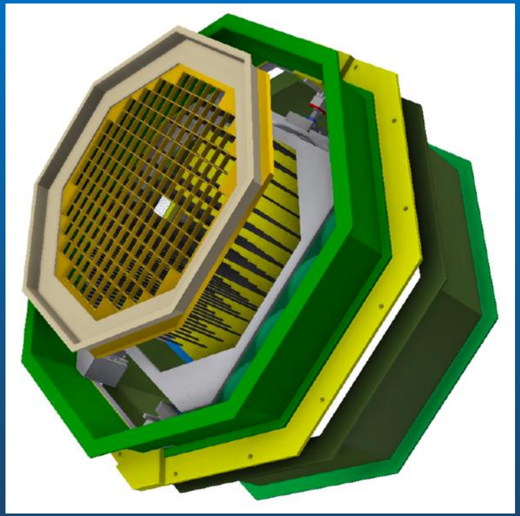
Custom SiPM preamplifier ASIC (SMART)

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

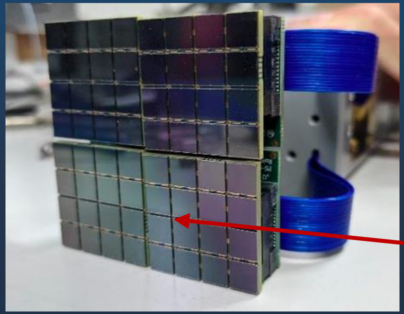
Camera mechanical design

Updated inner camera

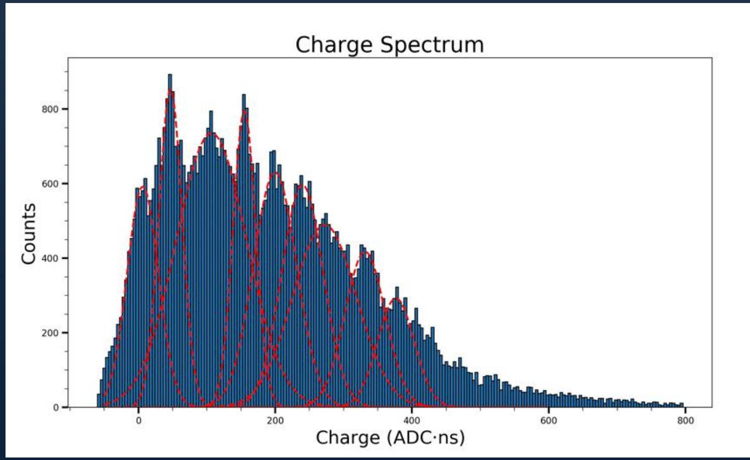
- 177 modules
- 9 backplanes
- Motion control
- Heat exchanger



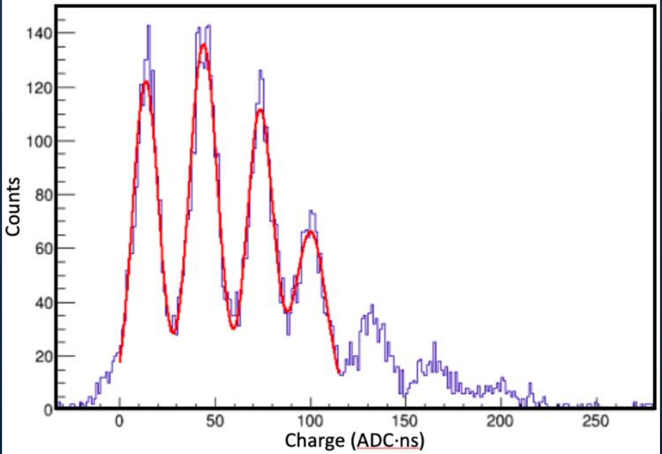
https://doi.org/10.1117/1.JATIS.8.1.014007



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

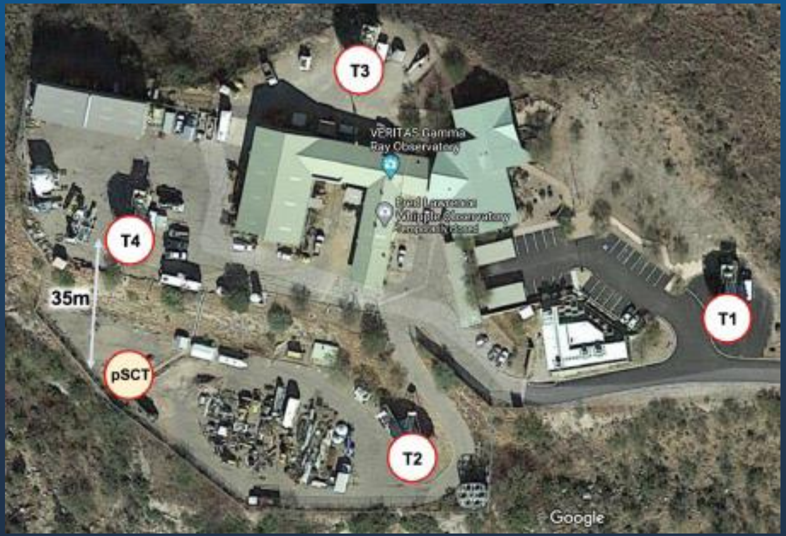


Charge spectrum obtained with current modules + upgraded FBK SiPMs and upgraded FEE



Crab nebula detected with the pSCT

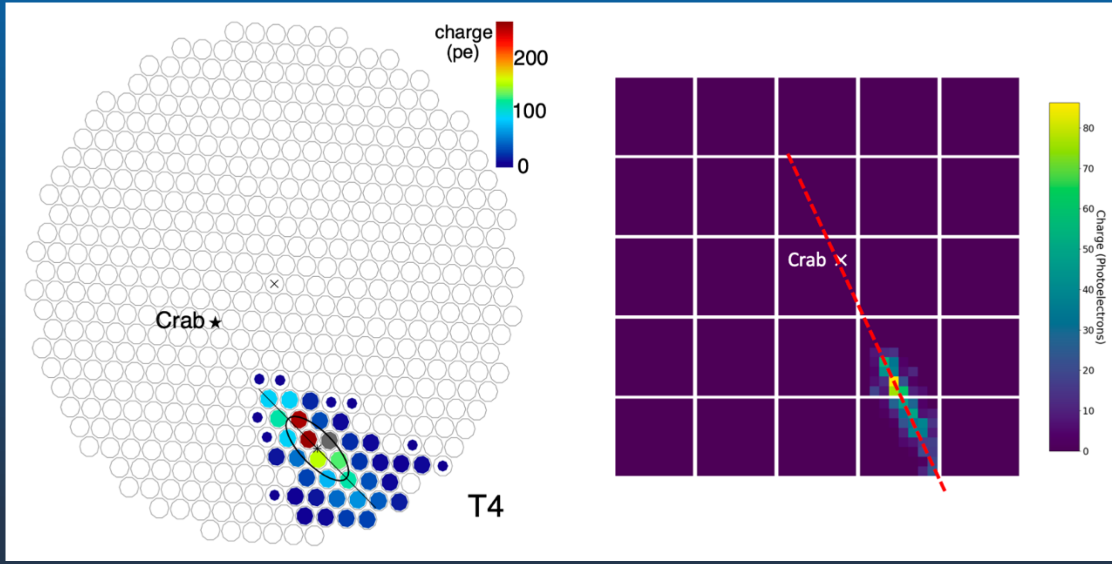
Detection of the Crab Nebula with the 9.7 m prototype Schwarzschild-Couder telescope

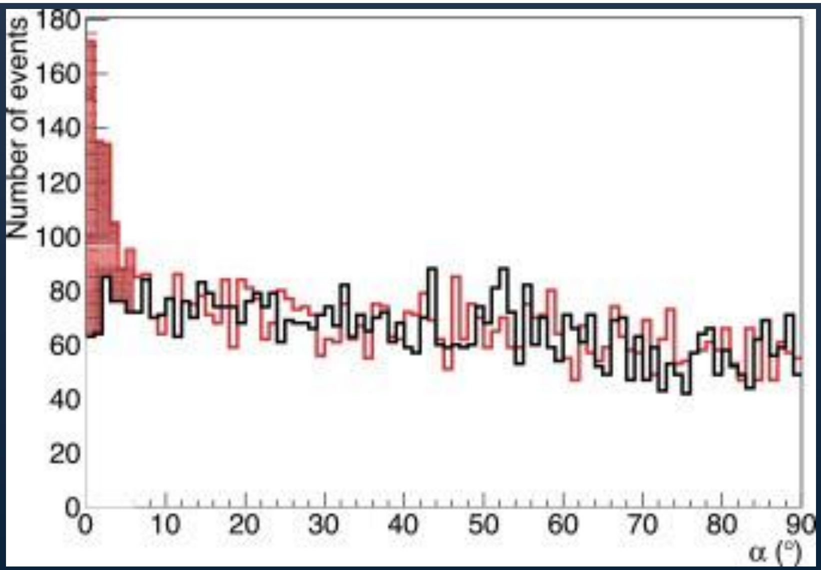


- ~20 hours ON/OFF observations
- 8.6σ detection
- Main limitation: electronics noise
- High energy threshold -> low cosmic and gamma-ray rates

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

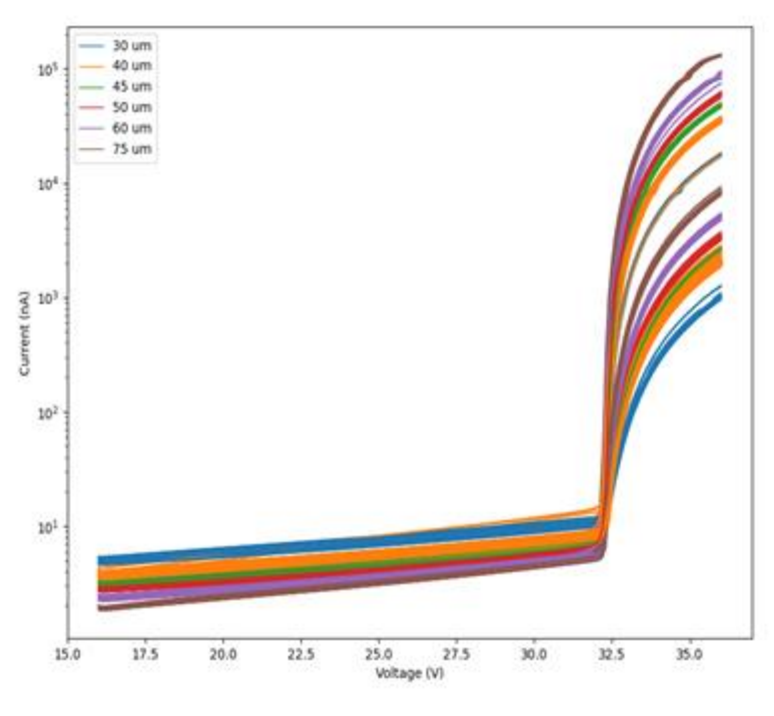
Analysis of pSCT – VERITAS coincident data

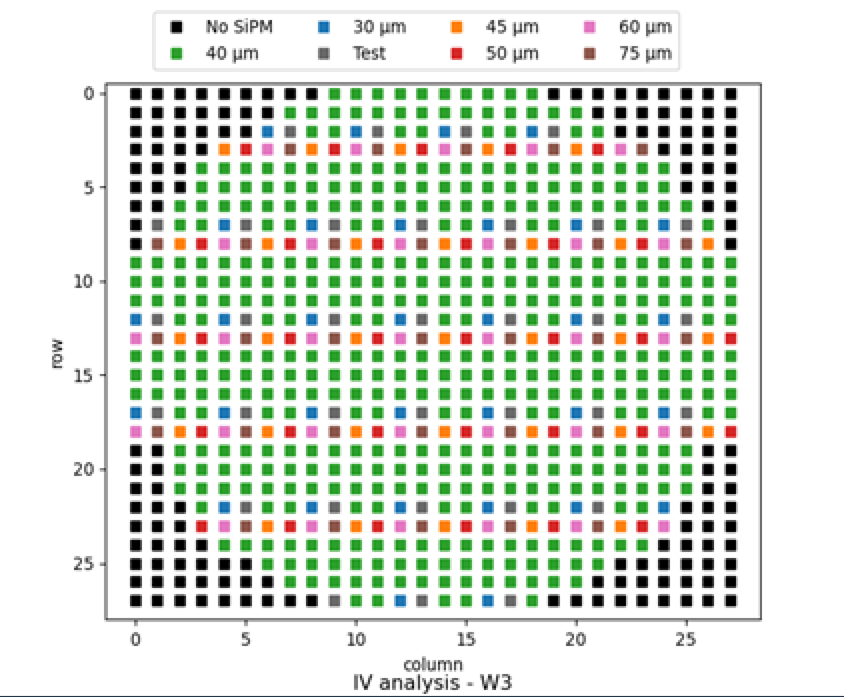


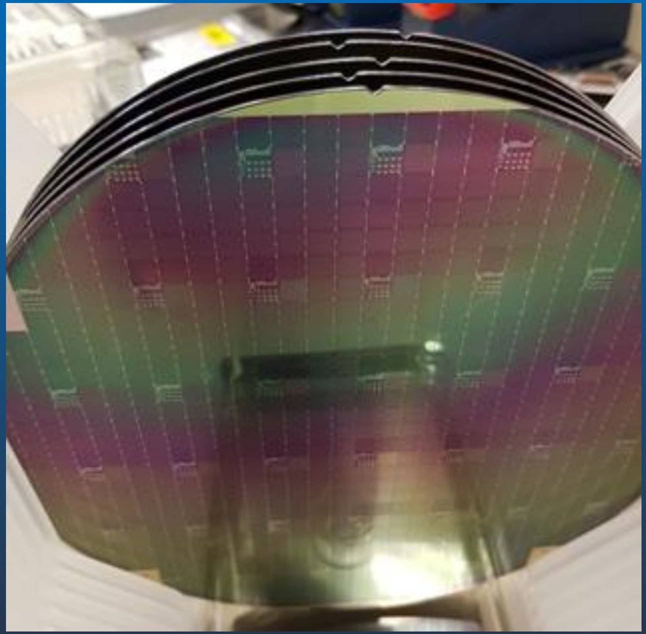


SiPM mass production

- 48 wafers of SiPMs produced in Lfoundry for a total amount of about 20k SiPMs
- Quality check with IV measurements on wafer performed
- Assembly on SiPM matrices for pSCT telescope ongoing







SiPM NUV-HD MT

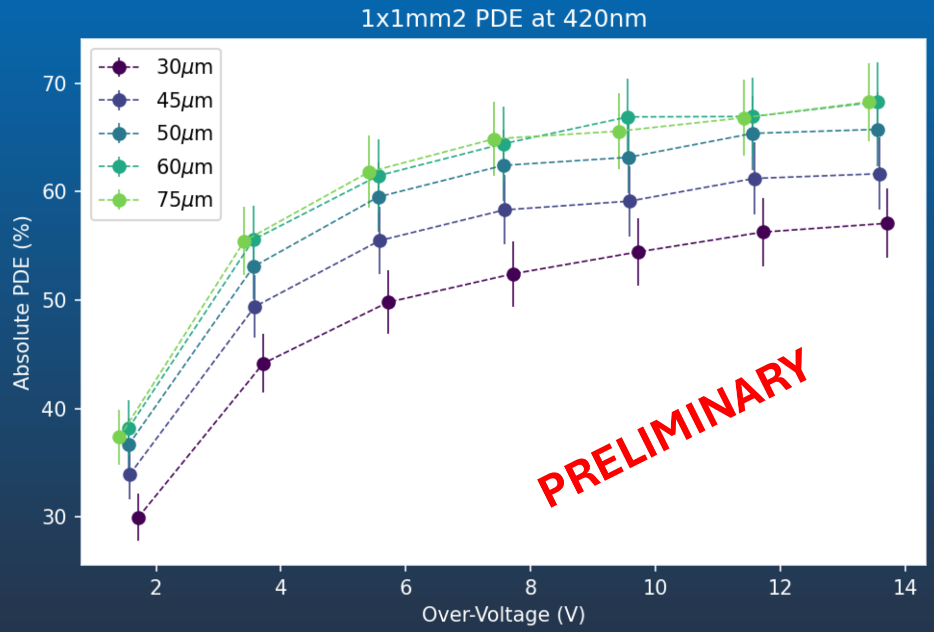
SiPM technology developed by FBK

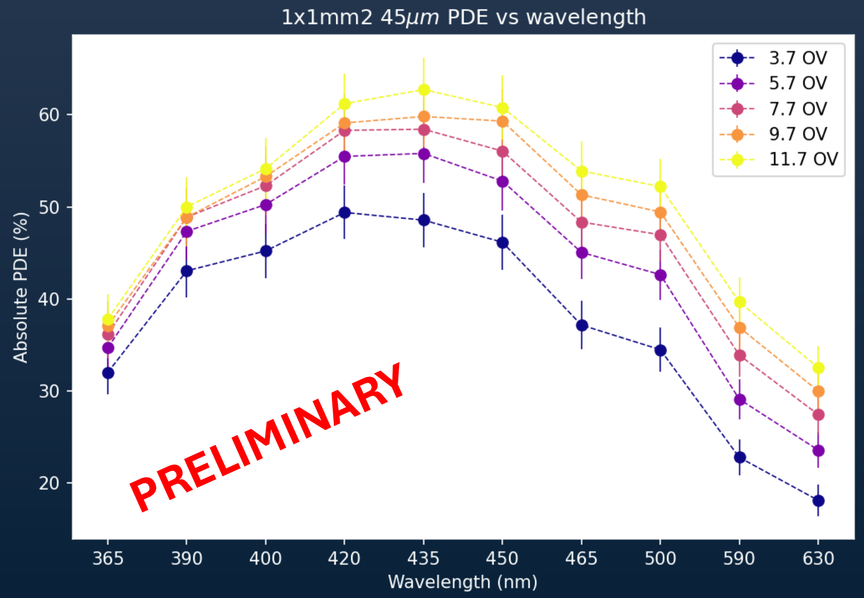
- Reduced Cross Talk probability (<5%)
- Maximum Photon Detection Efficiency (PDE) for wavelengths ranging between 420 nm to 450 nm

NUV-HD MT technology is well suited for Cherenkov light detection

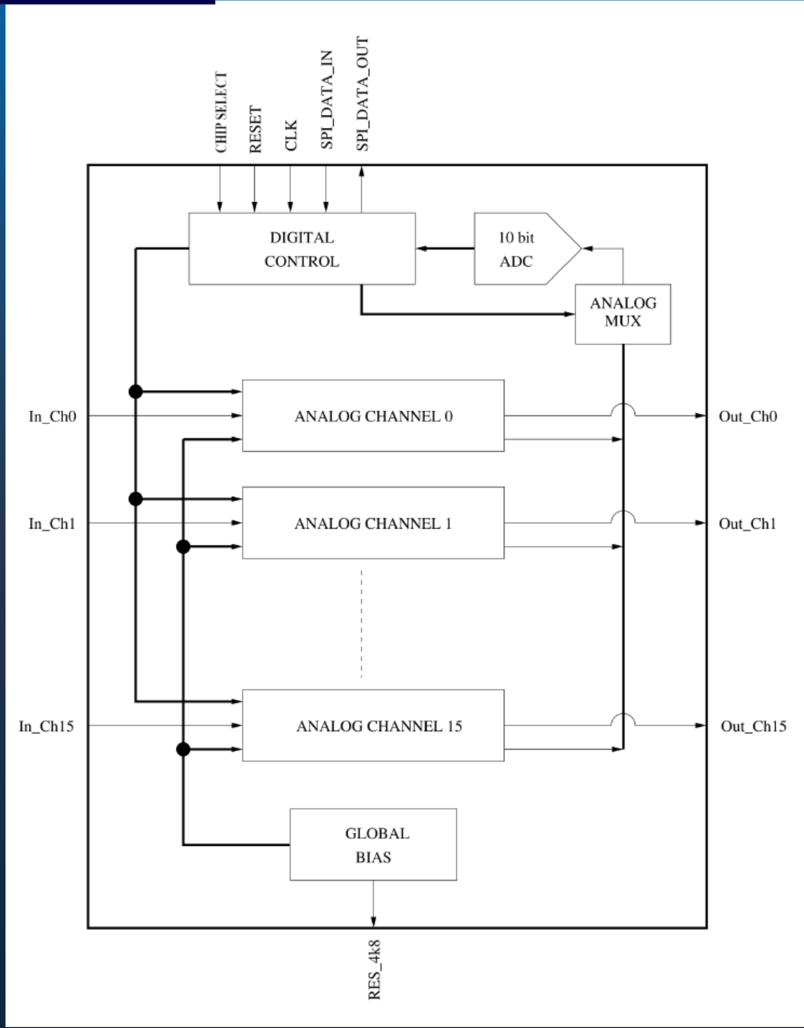
- Maximum PDE >60%
- Close to 50% at 400 nm

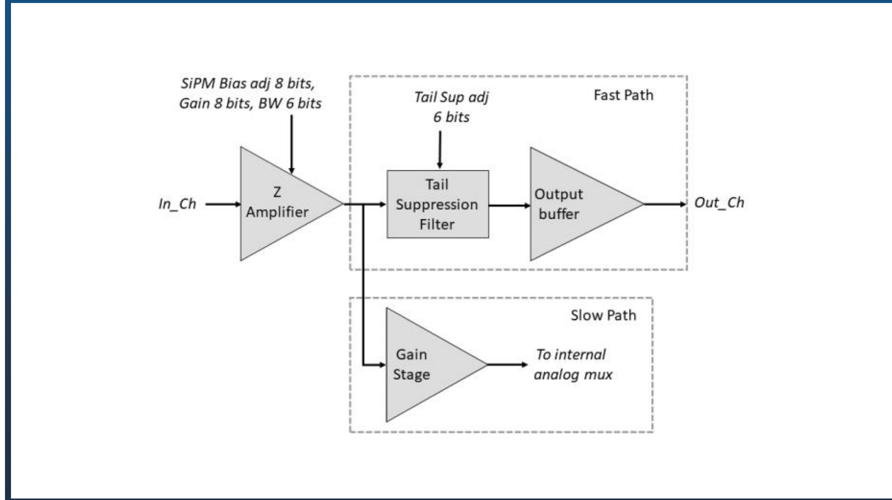
P. Loizzo, Master’s thesis





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





Designed by F. Licciulli & G. De Robertis at the Electronics CAD INFN Bari

Contact: francesco.licciulli@ba.infn.it

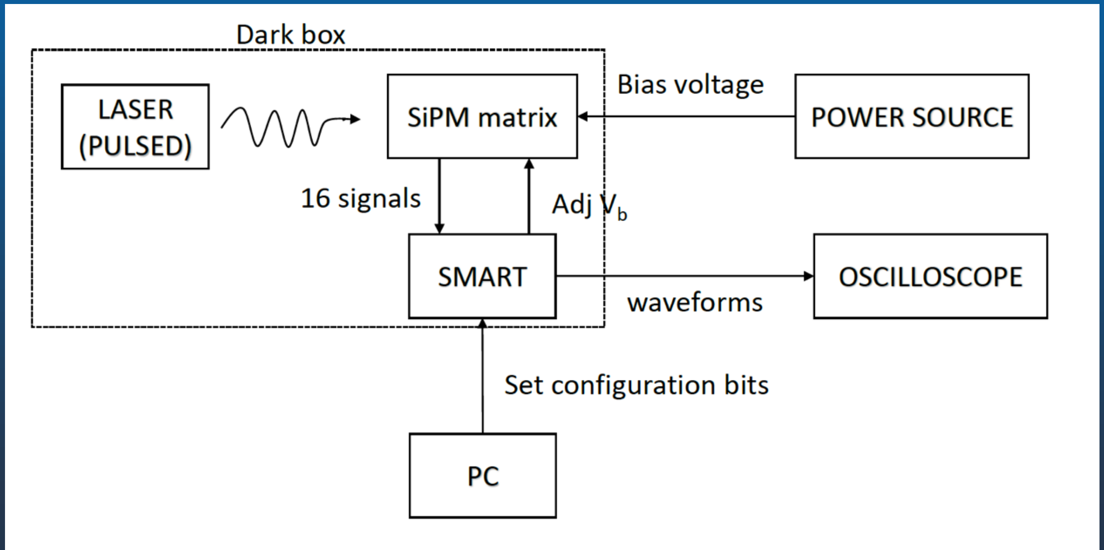
Pre-amplifier designed for photon counting

- 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

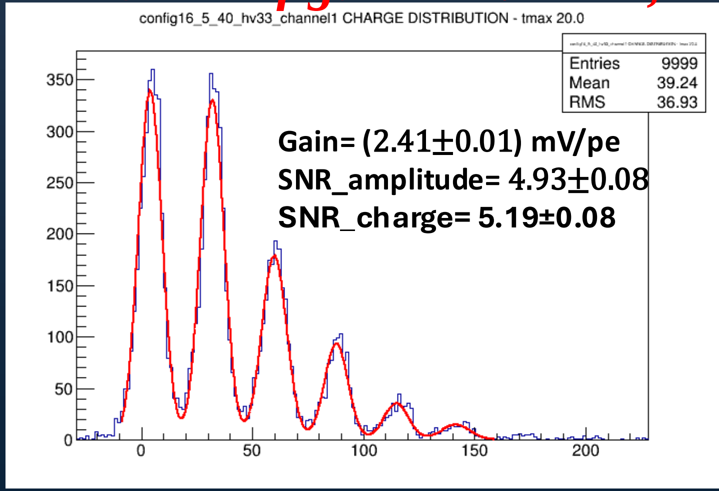
Laboratory SMART characterization

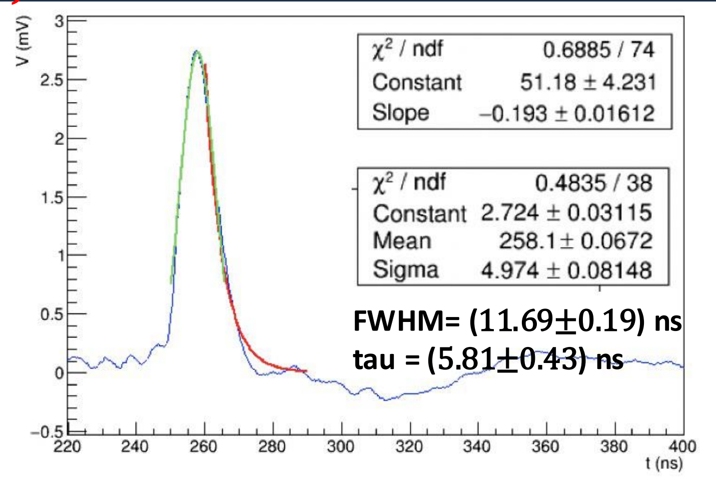
SMART performances tested with FBK NUV-HD 6x6mm^2 SiPM (HV=33V)

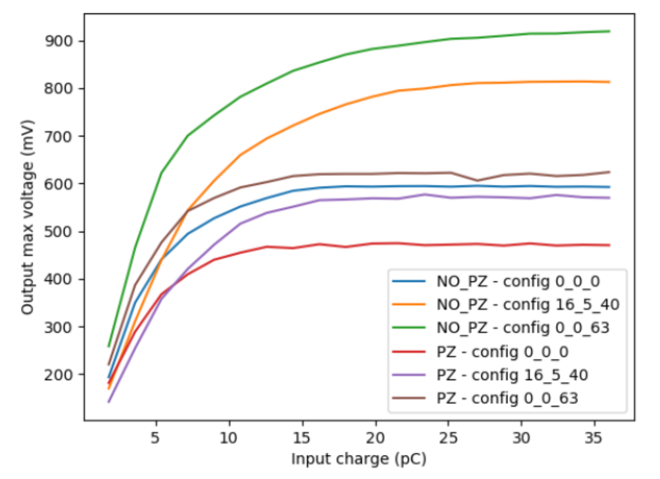
- Gain, signal-to-noise ratio and pulse width as a function of configuration bits were measured.
- 3 parameters changed:
  - ❑ R : gain resistance
  - ❑ C : filtering capacitance
  - ❑ PZ: pole zero cancellation
- External PZ fixed with discrete components
- Tests at different bias voltage (Vbias= 33,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







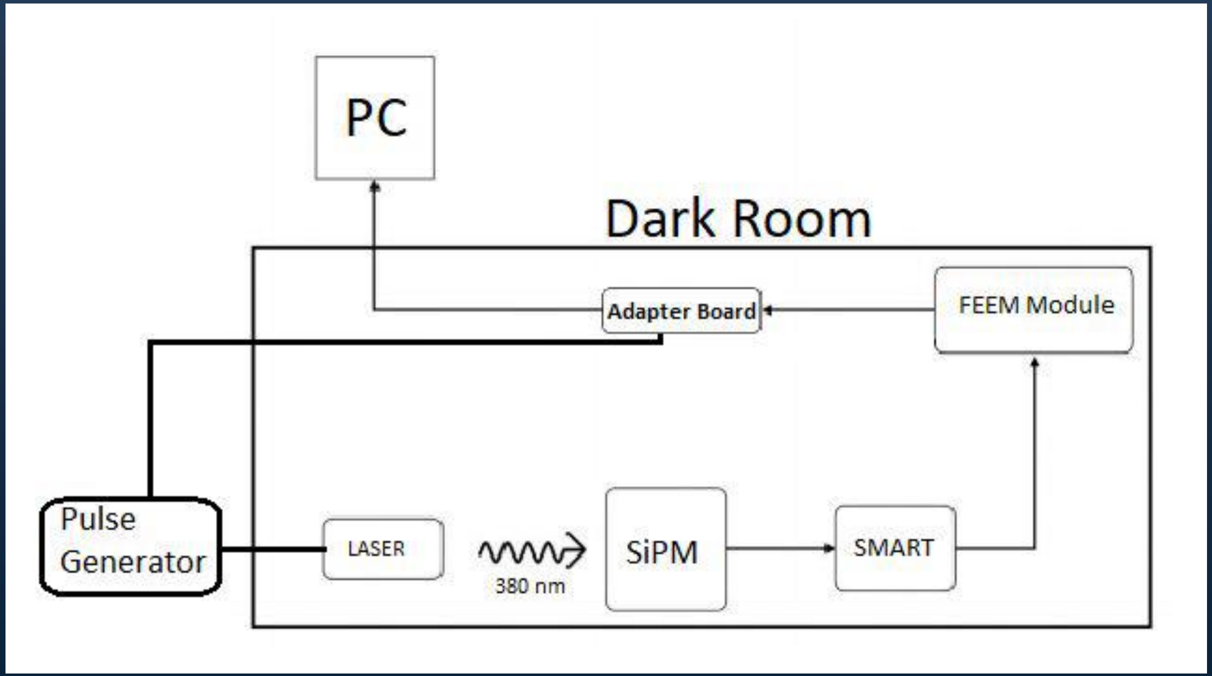
Output dynamic range

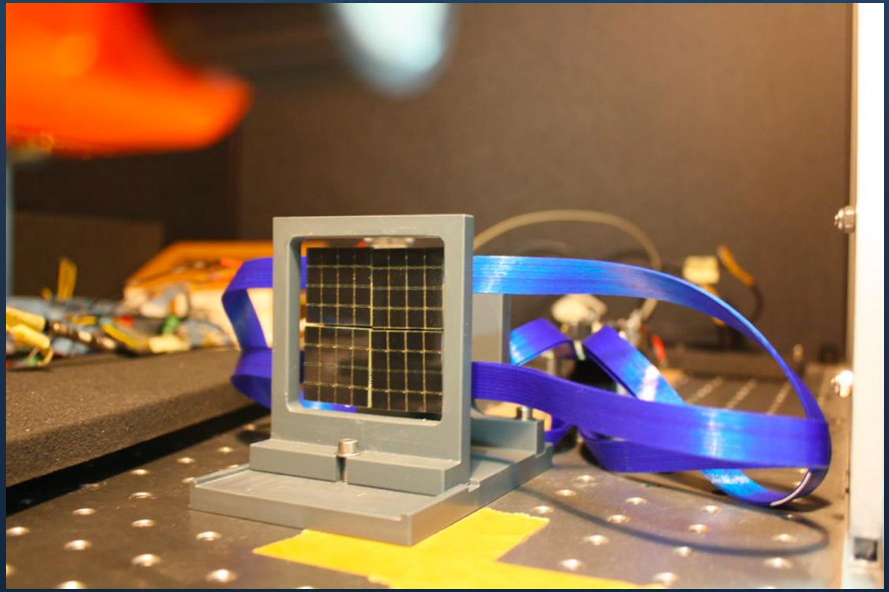
- 900 mV without ext. PZ
- 600 mV with ext. PZ

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





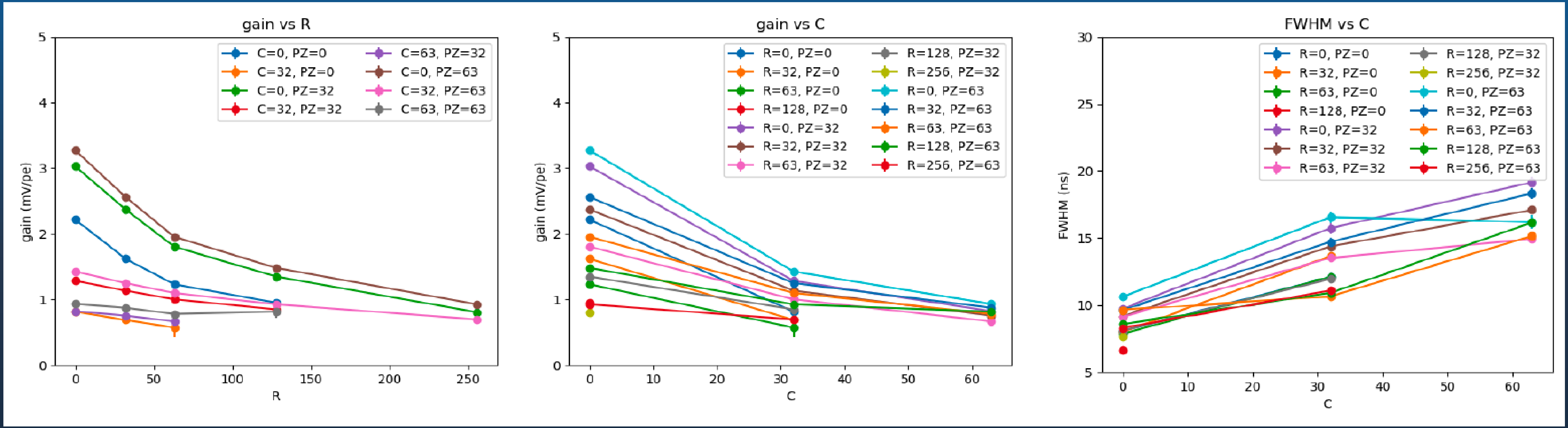
Summary

- The Schwarzschild-Couder Telescope is one of the proposed designs for the Medium-Sized Telescopes for CTAO
  - Improved angular resolution and sensitivity with respect to single-mirror telescope
- First prototype installed at the FLWO in Arizona and inaugurated in Jan 2019
  - Optics aligned reaching pre-construction estimated PSF – Dec 2019
  - Crab detection – May 2020
- Camera upgrade ongoing
  → install new camera on pSCT in 2024-2025

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

Thanks!

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

Upgraded electronics performance

- Trigger on SiPM dark noise on groups of 4 pixels
- Rate scan in threshold value trigger on one group
  - Possibility to disable individual channels through SMART
- Single p.e. plateaux in the rates visible