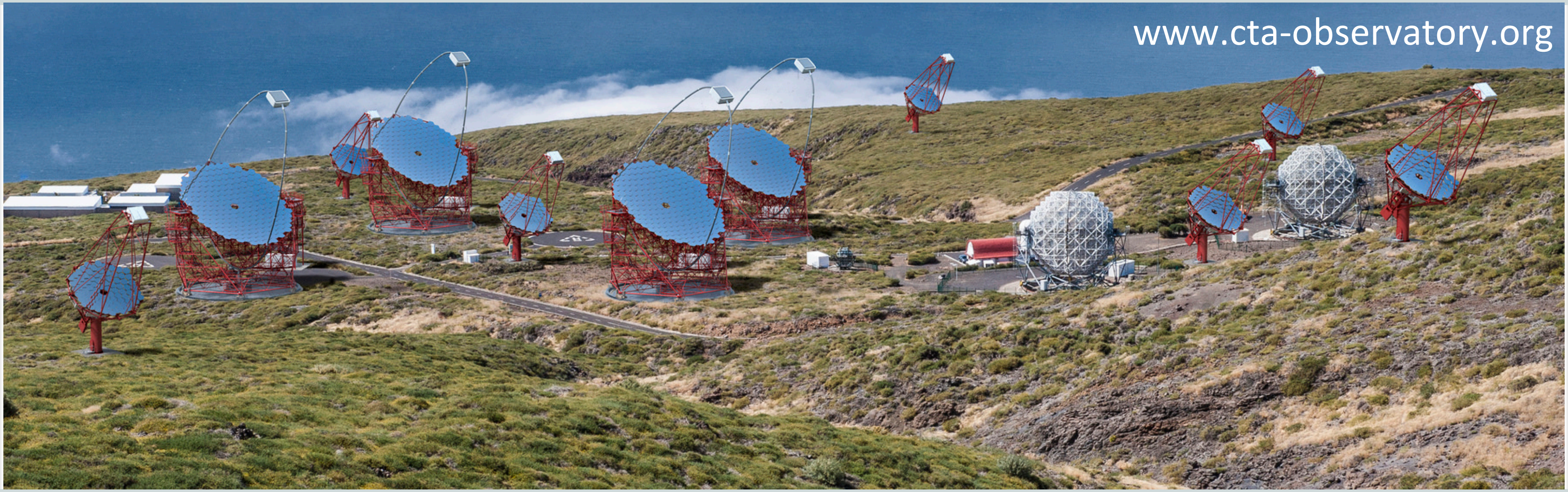
Development and characterization of near-UV sensitive Silicon Photomultipliers for the Schwarzschild-Couder Telescope prototype for the CTA collaboration

Emanuele Fiandrini University of Perugia - I.N.F.N. Perugia (IT)

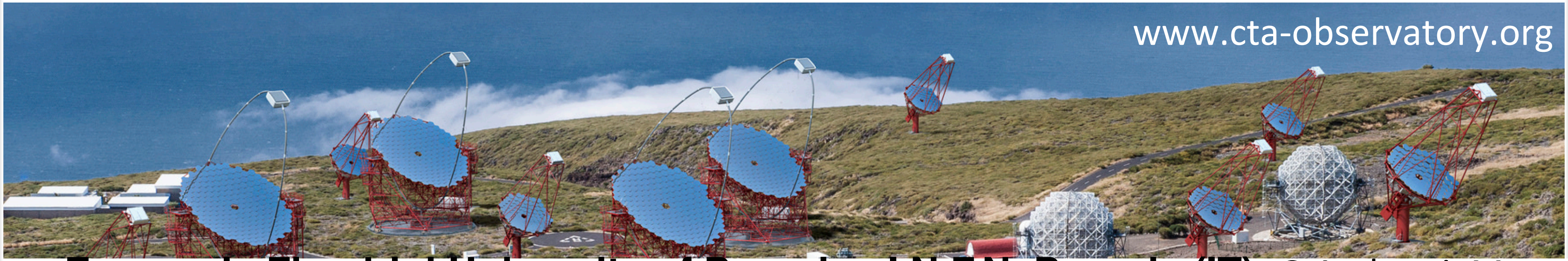


Development and characterization of near-UV SiPM for the Schwarzschild-Couder Telescope prototype for the CTA collaboration

CTA Cherenkov Telescope Array observatory

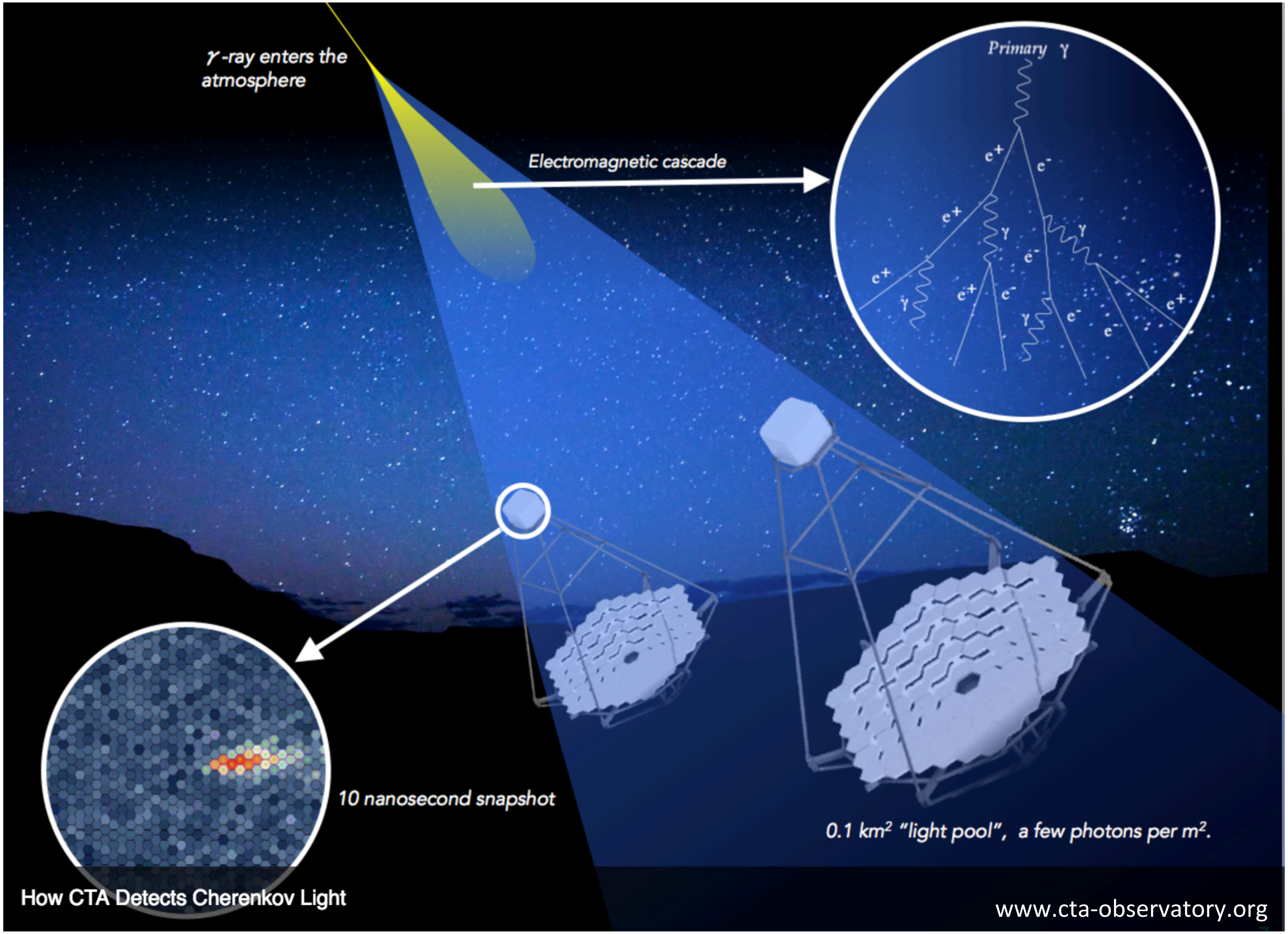
SiPM sensors for Cherenkov radiation detection

Packaging, assembly & performances

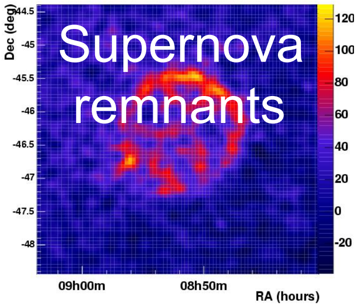


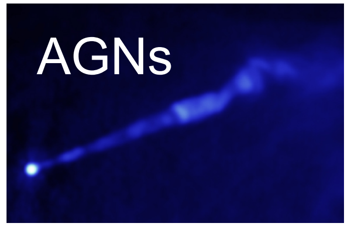
Emanuele Fiandrini University of Perugia - I.N.F.N. Perugia (IT), G.Ambrosi, M. Ambrosio, A. Aramo, E.Bissaldi, B. Bertucci, A.Boiano, C.Bonavolontà, M. Caprai, N.Giglietto, F.Giordano, M.Ionica, C. de Lisio, L.Di Venere, V.Masone, R.Paoletti, V.Postolache, D.Simone, L. Tosti, V.Vagelli, M.V alentino

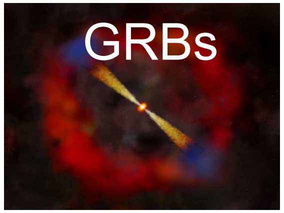
Imaging Air Cherenkov Telescopes

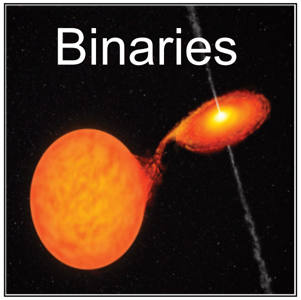


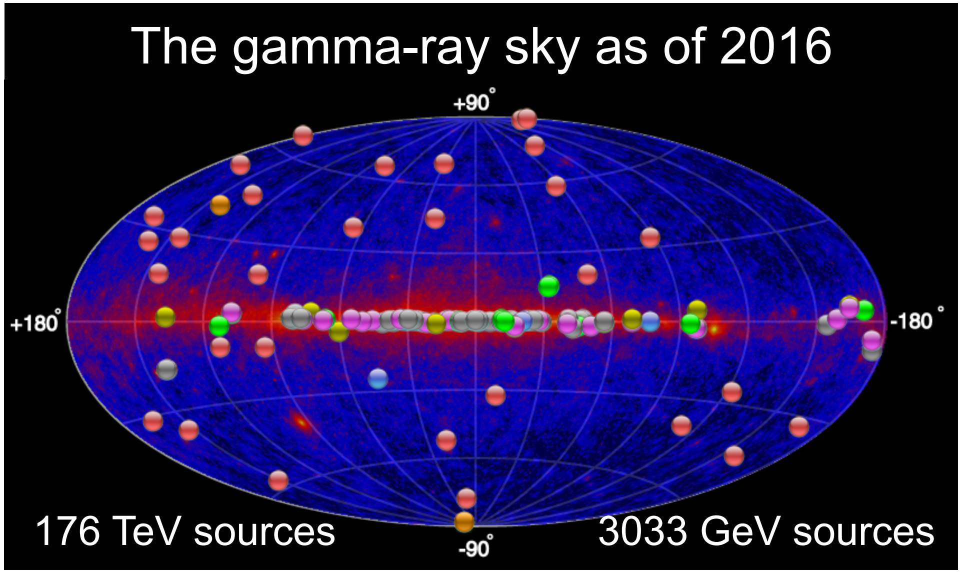
Physics of TeV γ-ray Telescopes

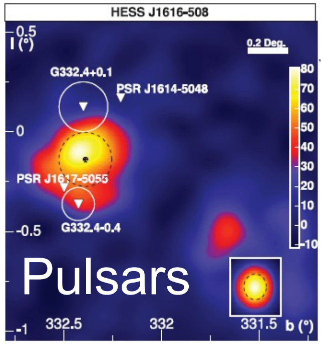


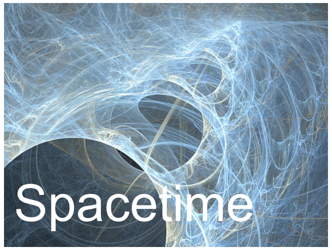




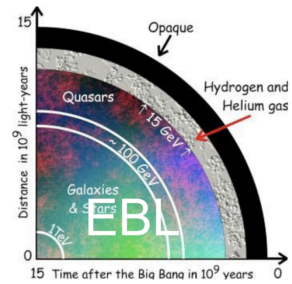








Axions, …



The CTA Project

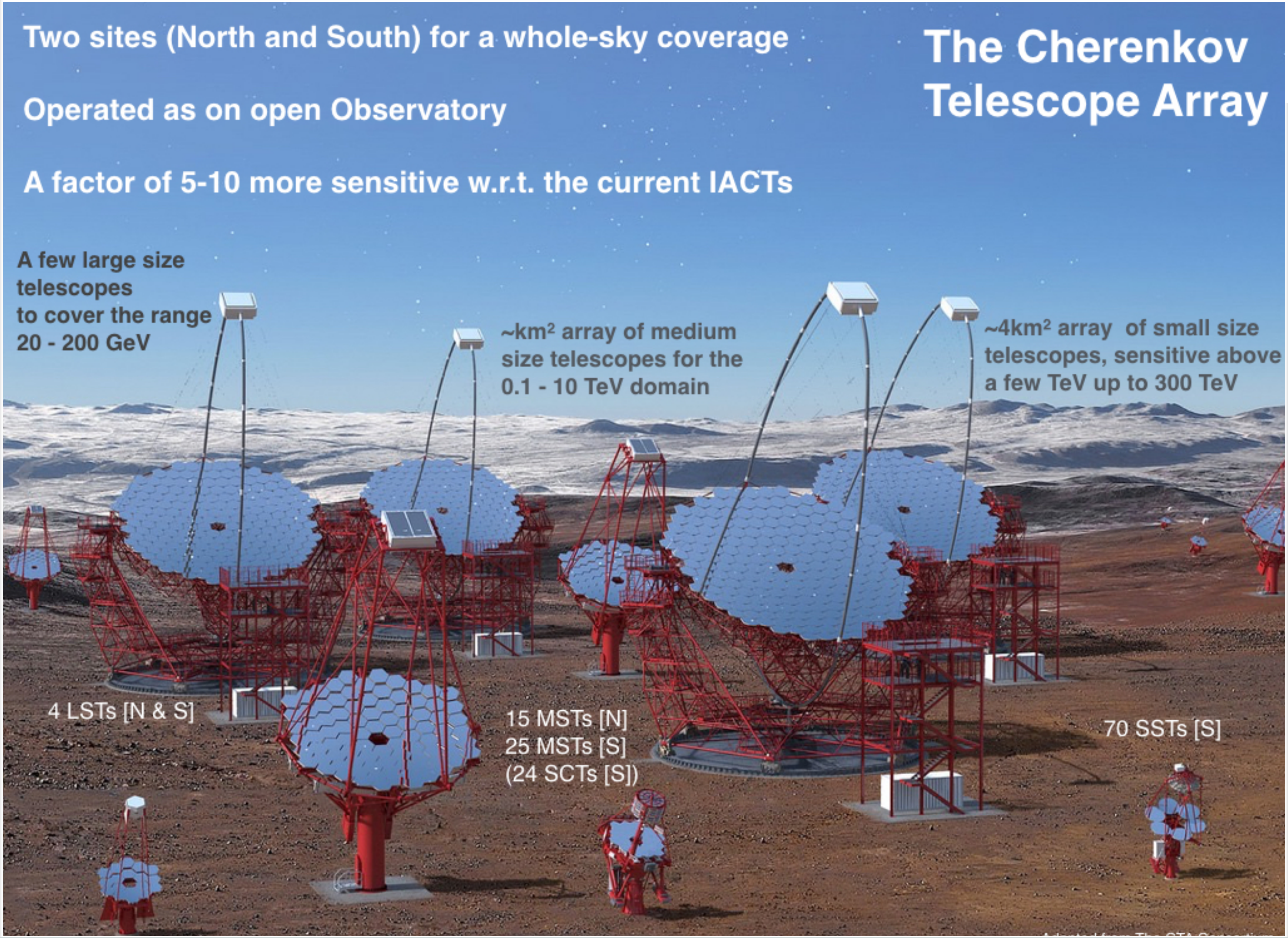
1,350 members from 210 institutes in 32 countries

The Cherenkov Telescope Array

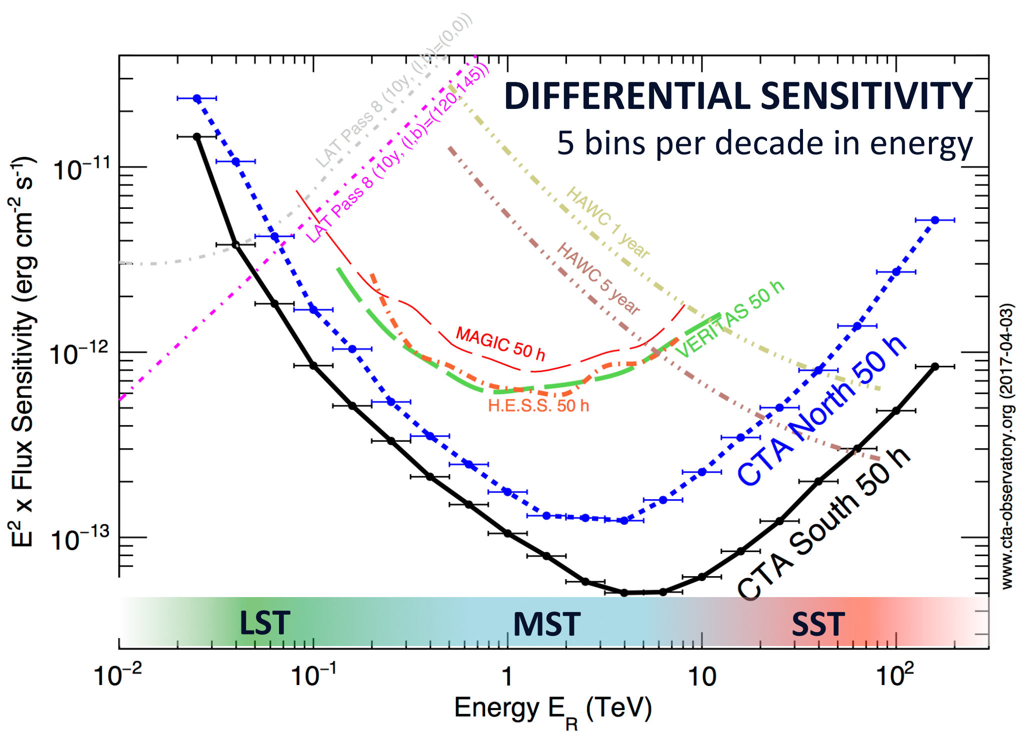
Two sites (North and South) for a whole-sky coverage

Operated as on open Observatory

A factor of 5-10 more sensitive w.r.t. the current IACTs

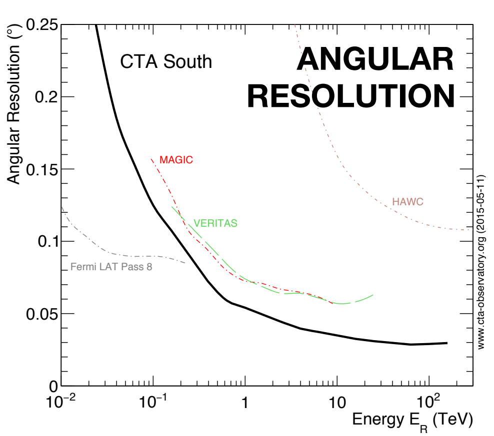


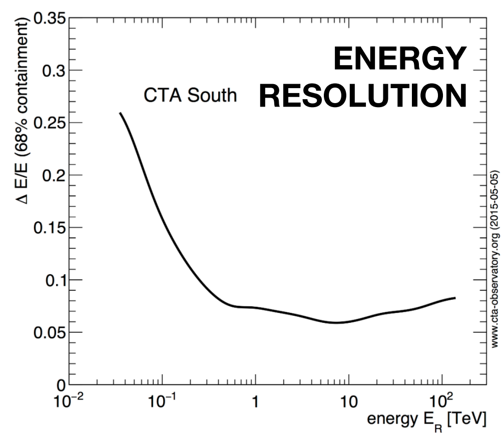
CTA performances

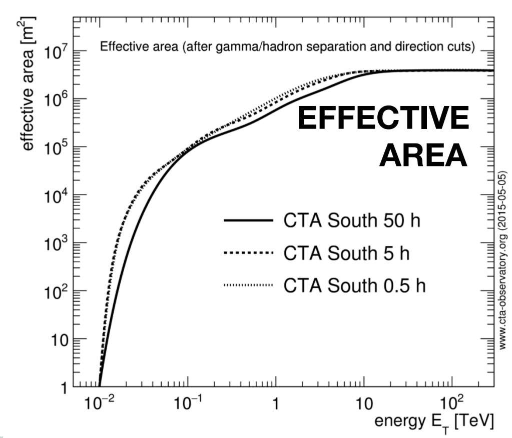


Improvement of a **factor 5-10 in sensitivity** w.r.t. the current IACTs in the core energy range

Extension of the **accessible energy range below 100 GeV and above 50 TeV**







Camera Sensors

The current IACT generation cameras are equipped with PMTs.

CTA is evaluating the possibility to **equip the focal plane camera of Small and Medium size telescopes with SiPMs**

SiPM features for Cherenkov light detection:

√ Smaller areas (<1cm²), hence higher pixel angular resolution

√ Higher photo-detection efficiency at UV wavelengths (~ 50@ 350 nm)

√ Fast response O(1-10) ns

√ Not damaged by moonlight, can be operated during bright Moon nights, enhancing the DAQ duty cycles

√ Can be operated with bias voltages <100V

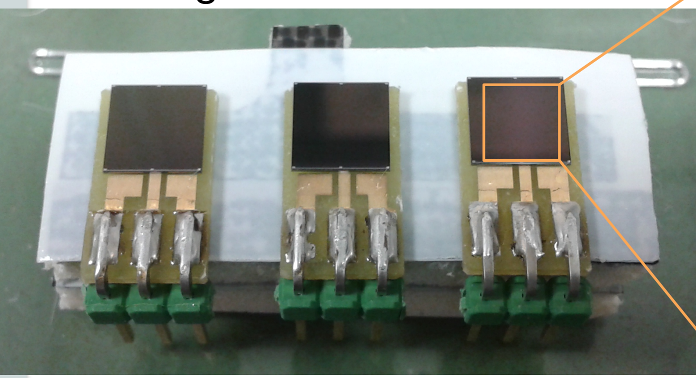
√ Low power consumption (μW)

√ Light-weight

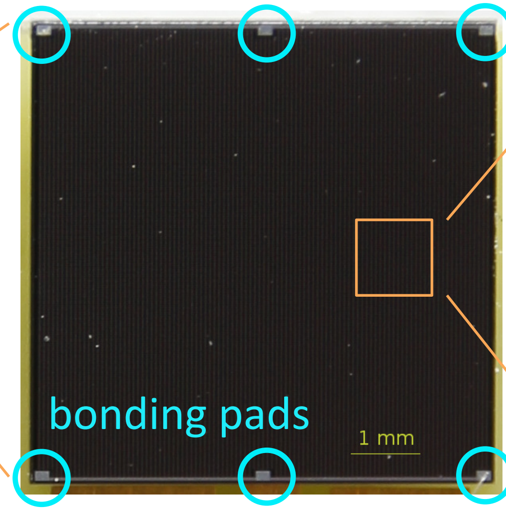
X Noisy, dark count rates O(10-100) KHz/mm² at room temperature, but below the expected average night sky background.

FBK NUV-HD SiPM sensors

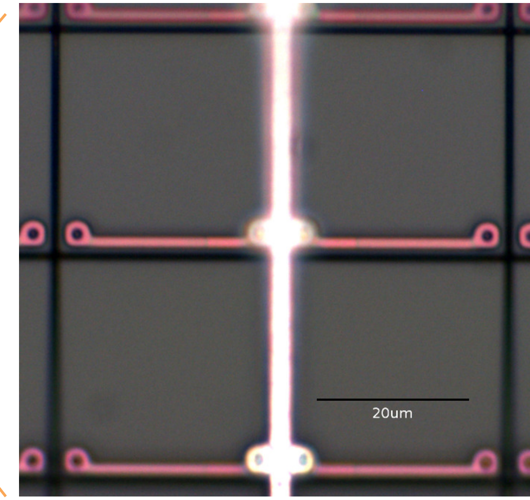
SiPMs mounted on single sensor test PCB



6 x 6 mm^2



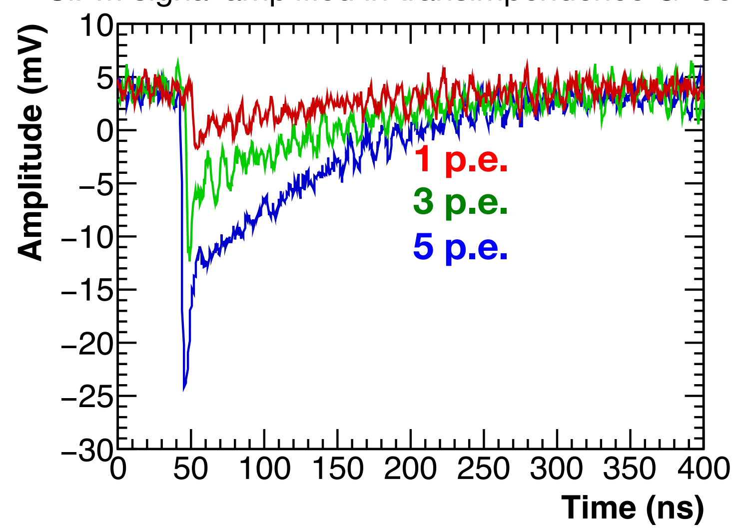
30 x 30 μm^2 cell



- Produced at FBK(Trento, IT)
- p-n SiPM
- Active area: 6.03 x 6.06 mm^2
- Microcell size: 30 x 30 μm^2
- Fill Factor: 76%
- High PDE (50%) for UV photons

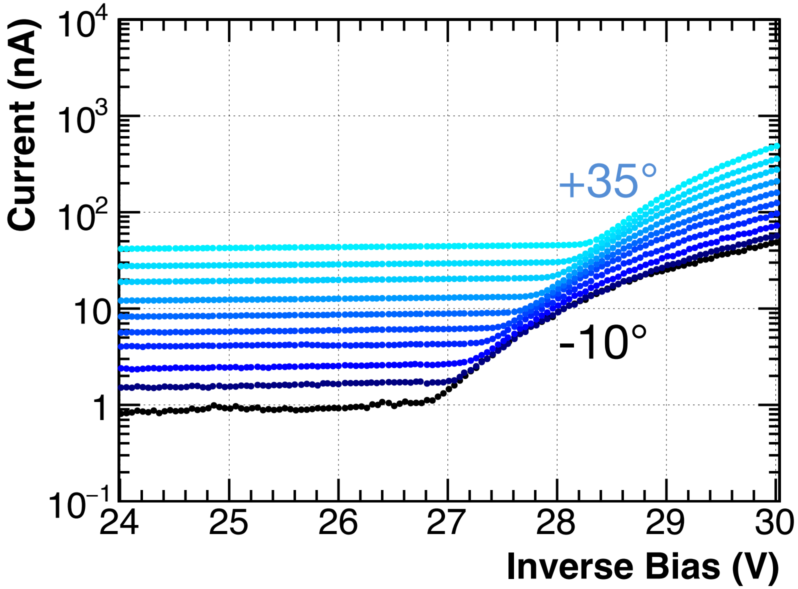
- **NUV-HD technology successful, development of further improvements are ongoing**

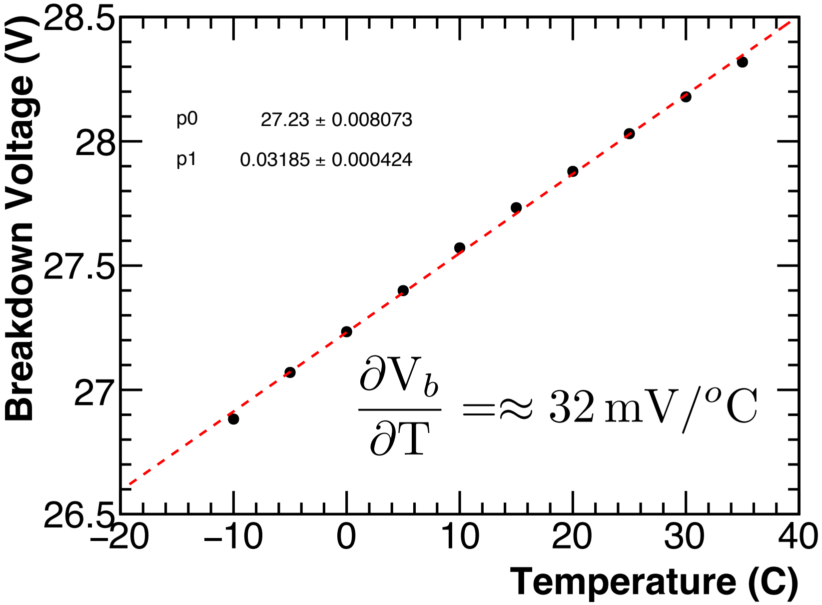
SiPM signal amplified in transimpendence G=500Ω



FBK NUV-HD SiPM sensors

Samples of sensors are thoroughly studied in different temperature ranges in a climatic chamber to extract sensor performance informations (gain, dark count rates, crosstalk, …)

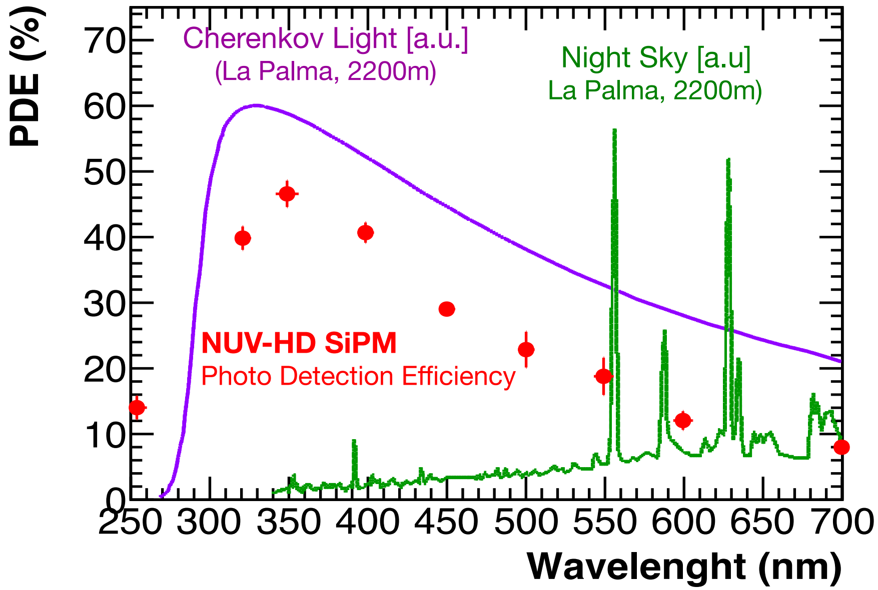


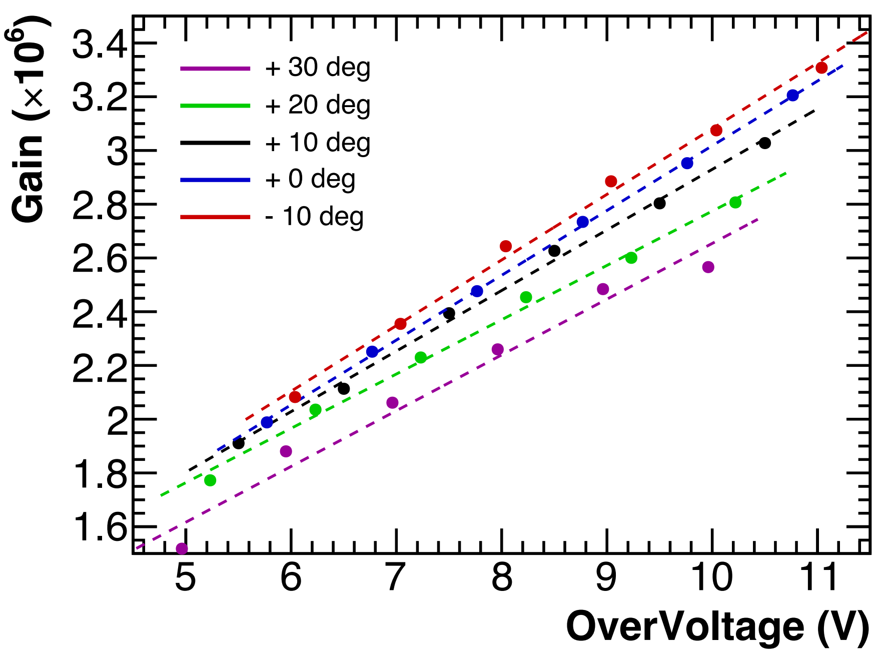


- Breakdown Voltage < 30V
- Small temperature dependence

FBK NUV-HD SiPM sensors

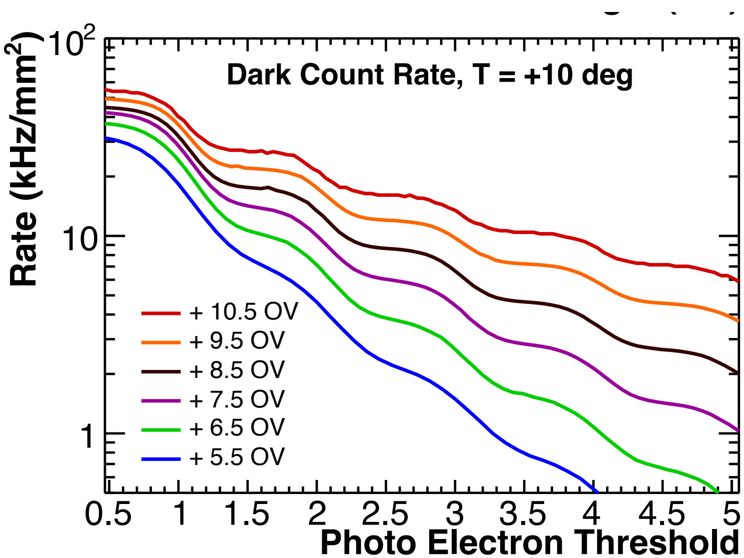
NUV-HD SiPM sensitivity peaks towards NUV (Cherenkov signals) with maximum PDE ≈ 50%

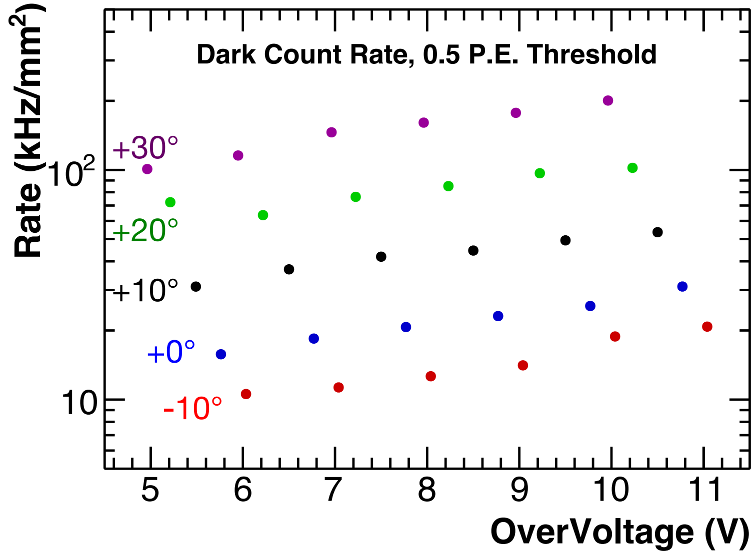




- Wide dynamic range
- gain $G=O(10^6)$

FBK NUV-HD SiPM sensors



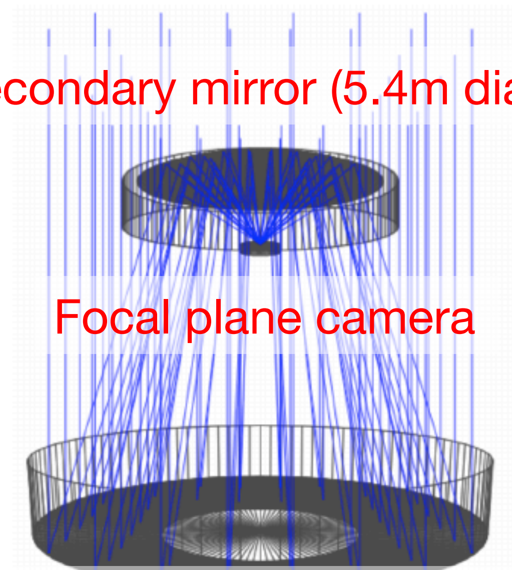


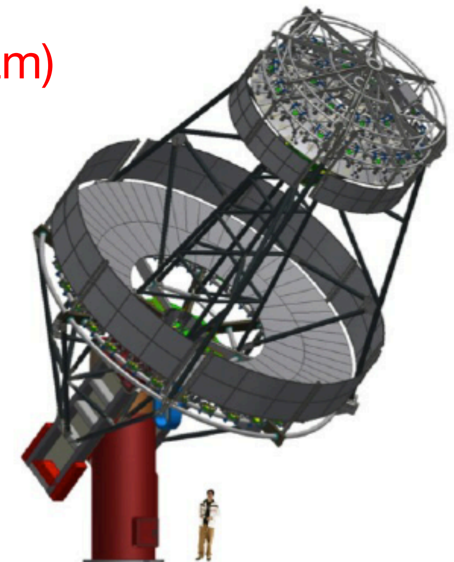
- NUV-HD dark count rate DCR << 100kHz/mm² up to 20 deg
- DCR doubles every 7.0°

NUV-HD performances are compliant with minimum requirements specified to equip the focal planes of CTA telescopes

SCT Telescope

Schwarzschild-Couder dual mirror optics Medium Size Telescope



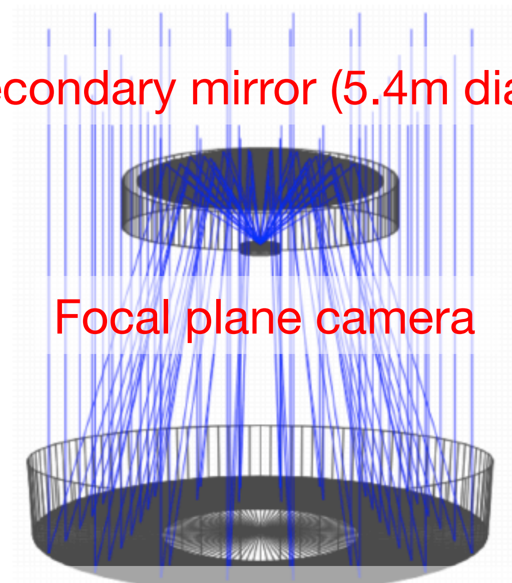


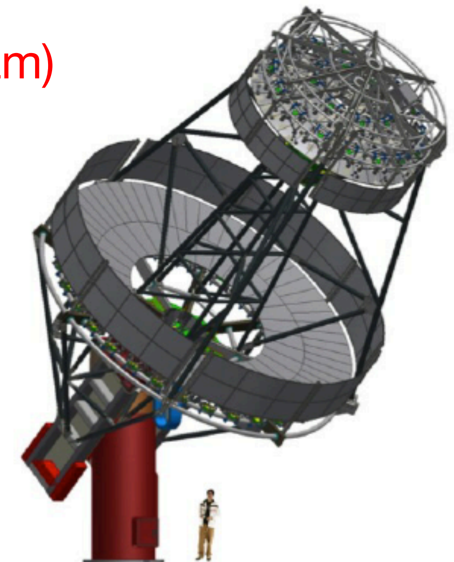
Dual mirror optics designed to cancel aberration and de-magnify images, to be compatible with compact high-resolution SiPM camera and resulting in a smaller point spread function (PSF) and improved angular resolution compared to the classical single mirror Cherenkov Telescope.

Mechanical stability and mirror alignment are the main challenges.

SCT Telescope

Schwarzschild-Couder dual mirror optics Medium Size Telescope





22 institutes, universities and observatories

5 institutes, universities and observatories

3 institutes and universities

1 university

1 university

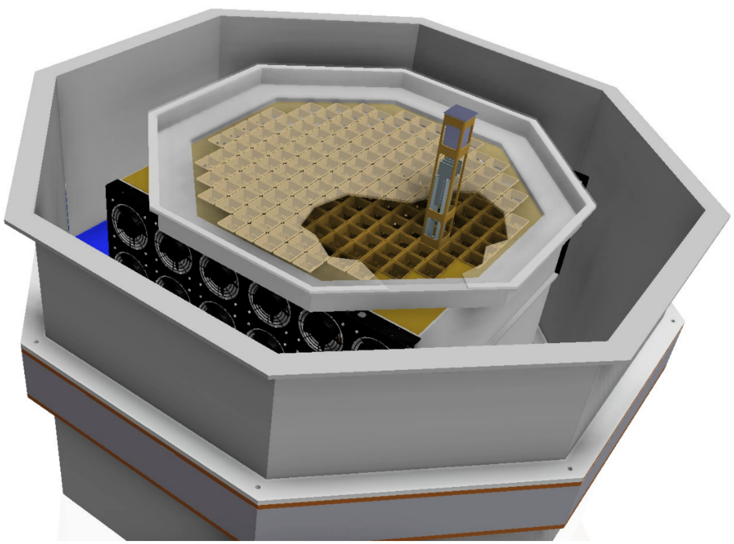
- Optical Support Structure and Positioners installed in September 2016
- Complete assembly planned by end of 2017

SCT is the unique proposal of the innovative SC optics for the CTA Medium Size Telescope

pSCT Telescope

Prototype demonstrator for the Medium Size SCT solution

0.4m^2 active area per telescope



8° field of view, 81 cm diameter

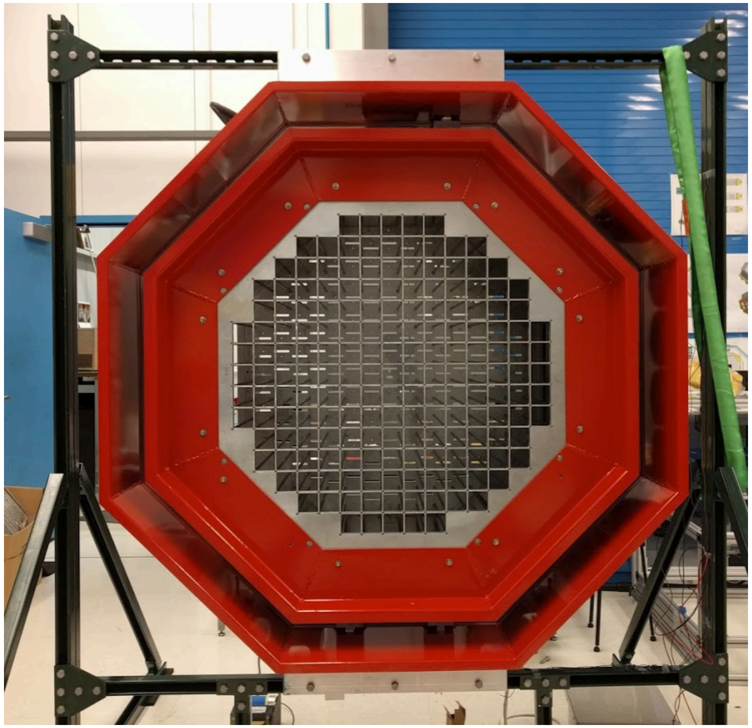
- Excellent optical resolution, small plate scale of dual-mirror telescope well matched to fine pixelation supported by silicon photomultipliers and TARGET readout electronics
- 11,328 6x6 mm^2 pixels (temperature-stabilized silicon photomultipliers)
- Pixel size 0.067° (high- resolution imaging)
- Readout directly behind focal plane
- 1 GSa/s, 10 bits effective (TARGET 7)
- 3 kW power budget
- Shares many common components with the Compact High Energy Camera for CTA Small Size Telescopes

Prototype main goals:

- Demonstrate the performances of the optical system
- Gain experience with the optical alignment and operation of the SiPM camera

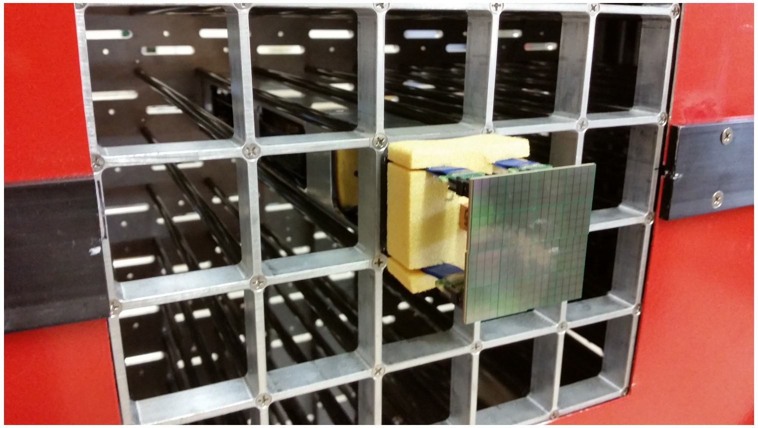
pSCT Telescope

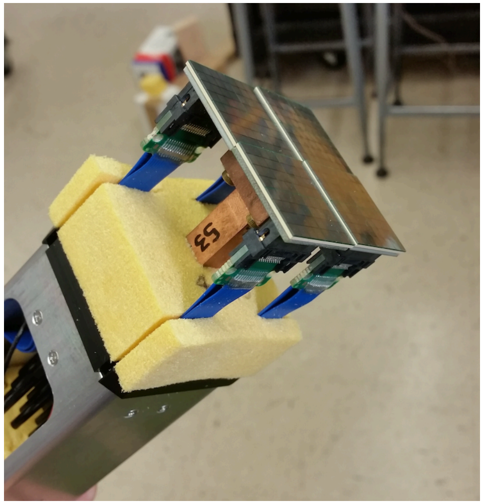
pSCT camera mechanics in Univ. of Wisconsin



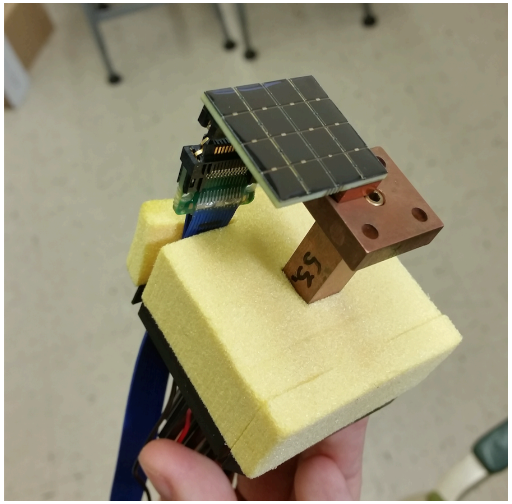
FBK 6x6mm^2 SiPM intented to replace the original Hamamatsu MPPC solution and equip a possible upgrade of the pSCT camera

pSCT camera currently equipped with Hamamatsu MPPC S12642-0404PA-50(X)



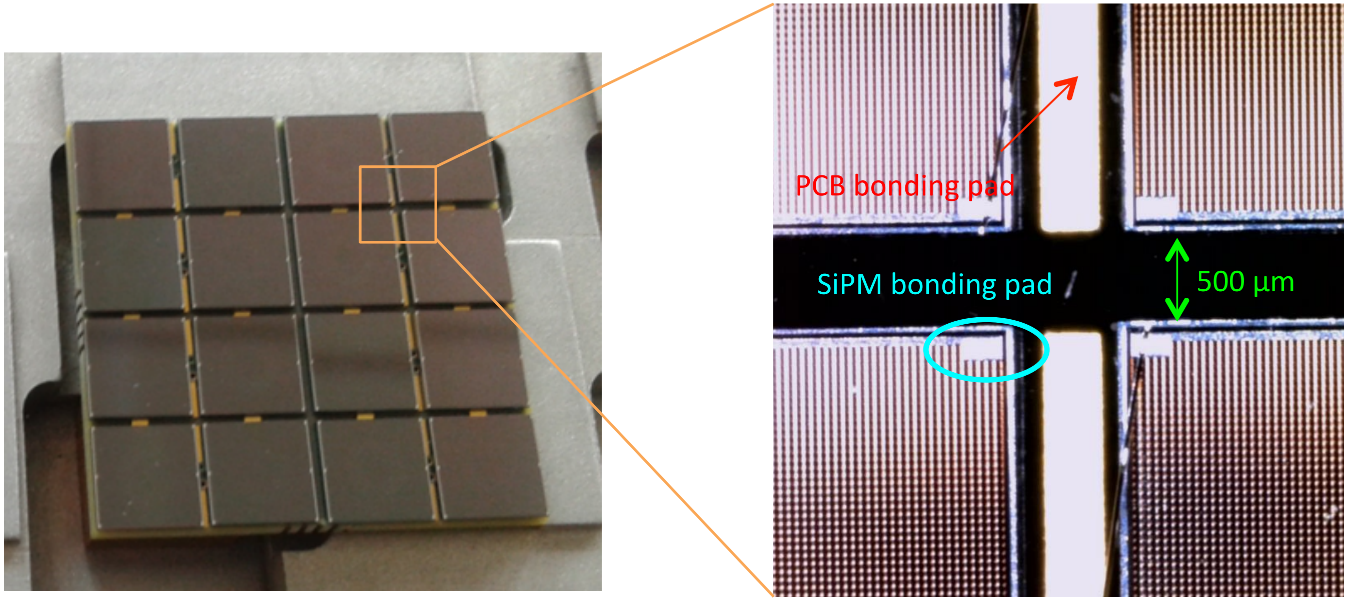


Hamamatsu

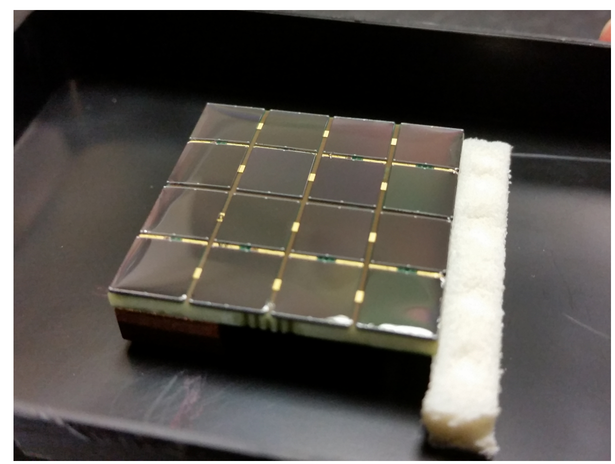


INFN prototype

pSCT focal plane modules



27x27mm^2 PCBs are equipped with 16 SiPMs to cover uniformly the exposed area

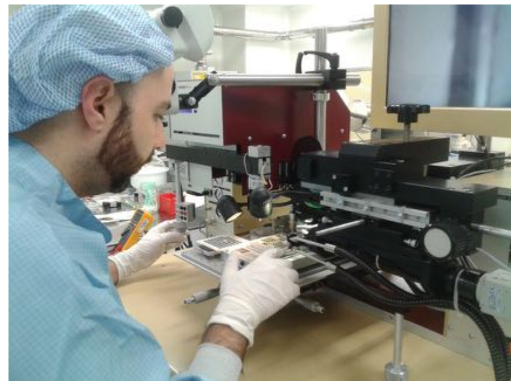
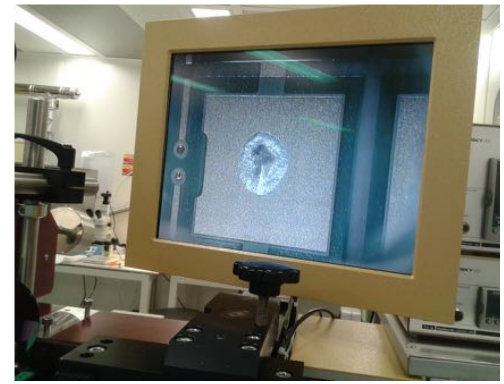
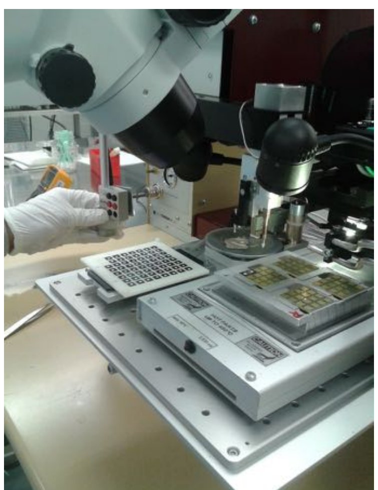
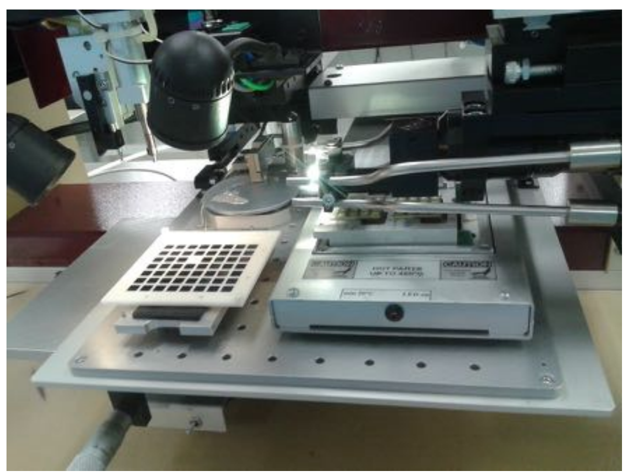
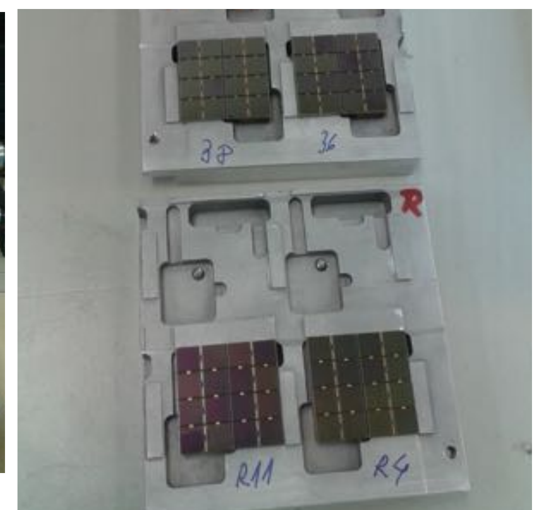


36 modules made of 16 SiPMs will be coupled to the electronic readout and the pSCT camera in the next months, to be tested in situ and to prepare for the next massive production of modules.

pSCT focal plane modules

PCB modules are assembled with SIPM sensors in the laboratories of INFN.

SiPMs are positioned on the PCBs using a die-bonder machine.

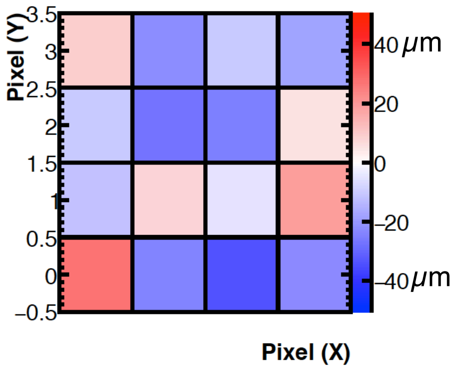







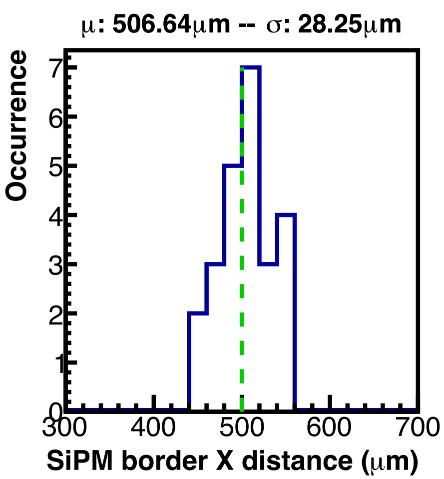
Module assembly and packaging

Inspection with **ruby-head touch probe** and an **optical metrology machine** to verify the quality of the sensor alignment.

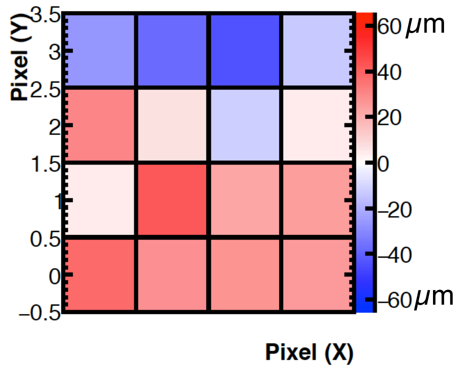
Sensor alignment better than 30/40µm

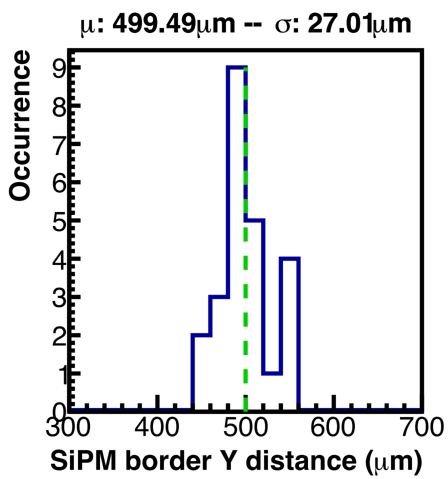
position along X axis
difference w.r.t. nominal position



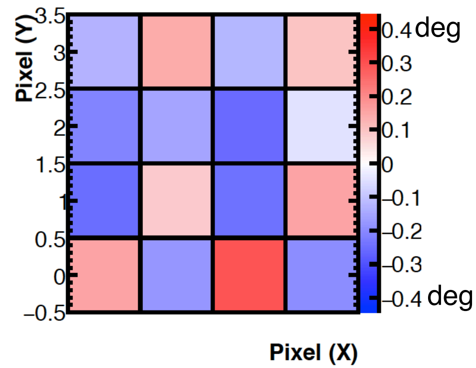


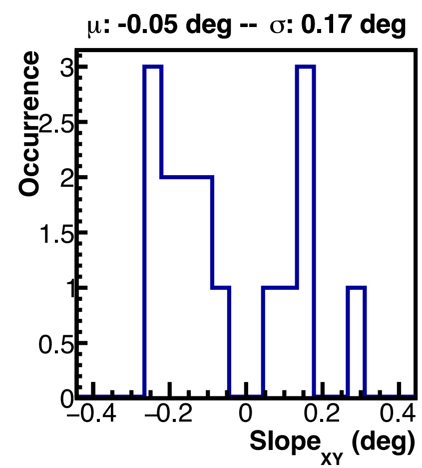
position along Y axis
difference w.r.t. nominal position





sensor XY rotation
difference w.r.t. nominal position

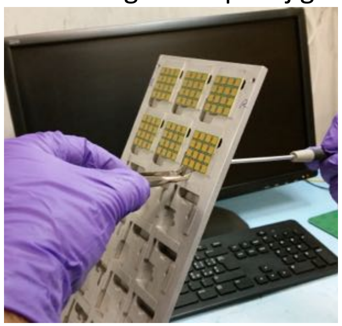




SiPM module assembly tests

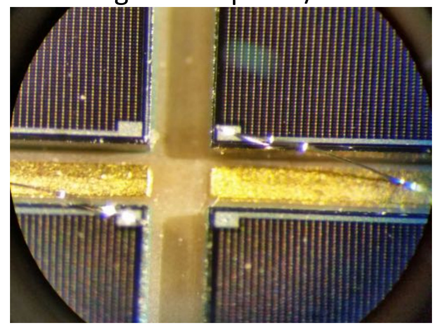
After quality checks, SiPMs are wire-bonded and the PCBs are protected with UV-transparent epoxy layer

Placement in bonding&transport jig

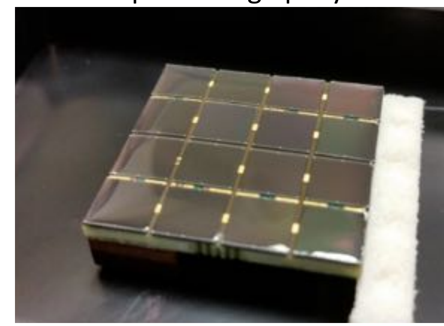


Bonding (approx. 15 mins/matrix)

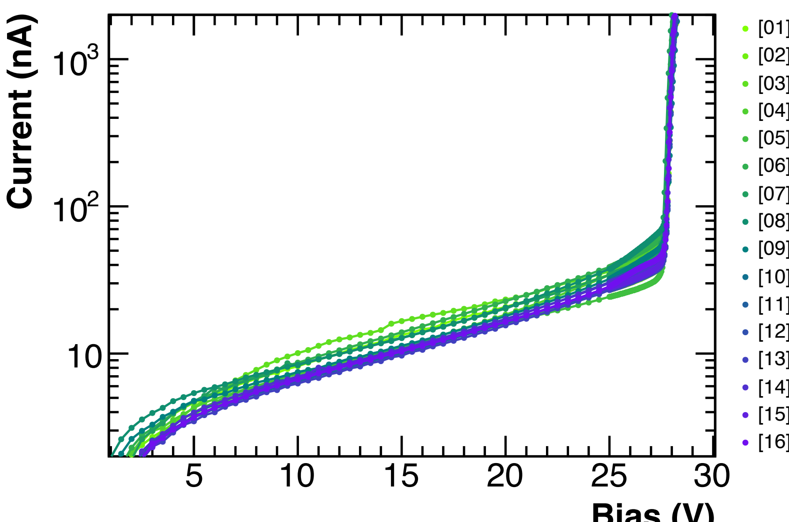
Bonding with 20μm Al/Si wire

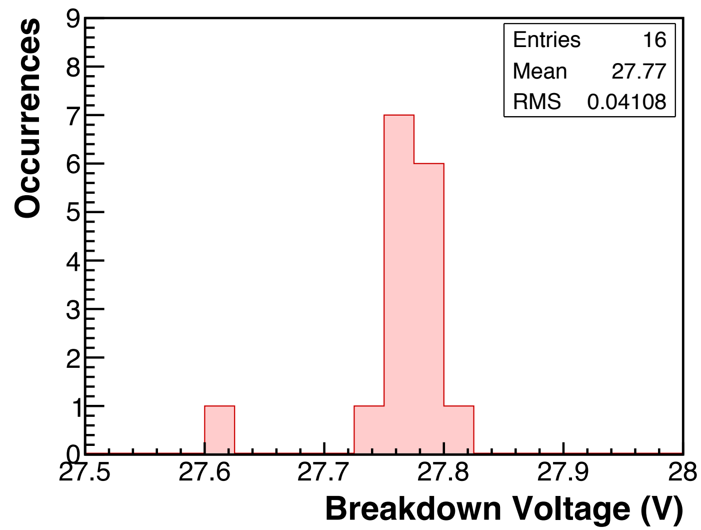


Dispensing of UV-transparent protecting epoxy



Tests of SiPM homogeneity and assembly quality

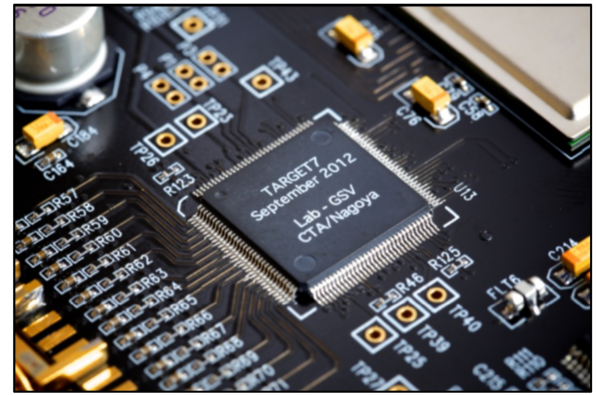




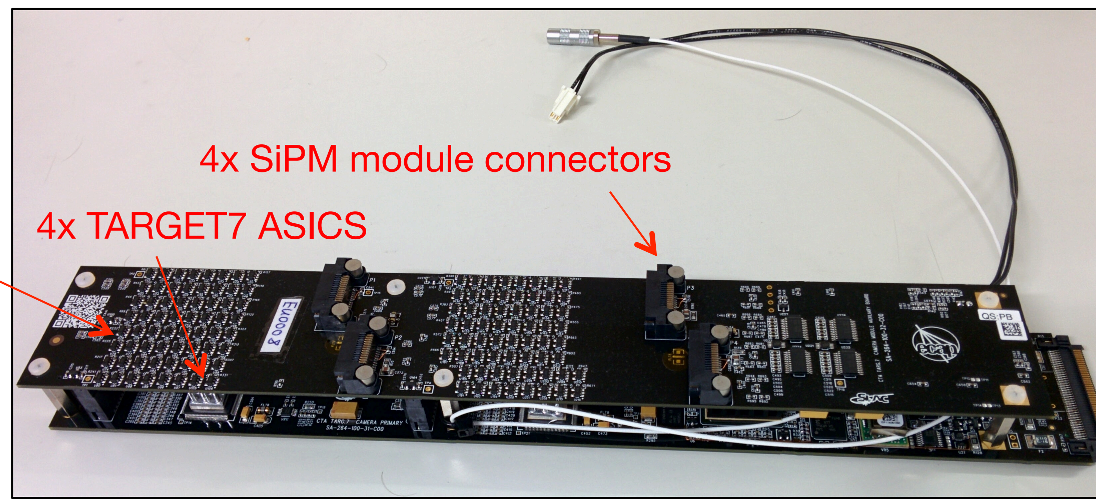
SiPM module readout

Module signal readout using “TeV Array Readout with GS/s sampling and Event Trigger” (TARGET7) board

- 16 input channels
- Analogue ring buffer of 16384 capacitors
- Switched Capacitors Array
- Storage of **analogue** waveforms in a limited period of time @ 1GSa/s sampling frequency
- Compact chip for high density channel camera

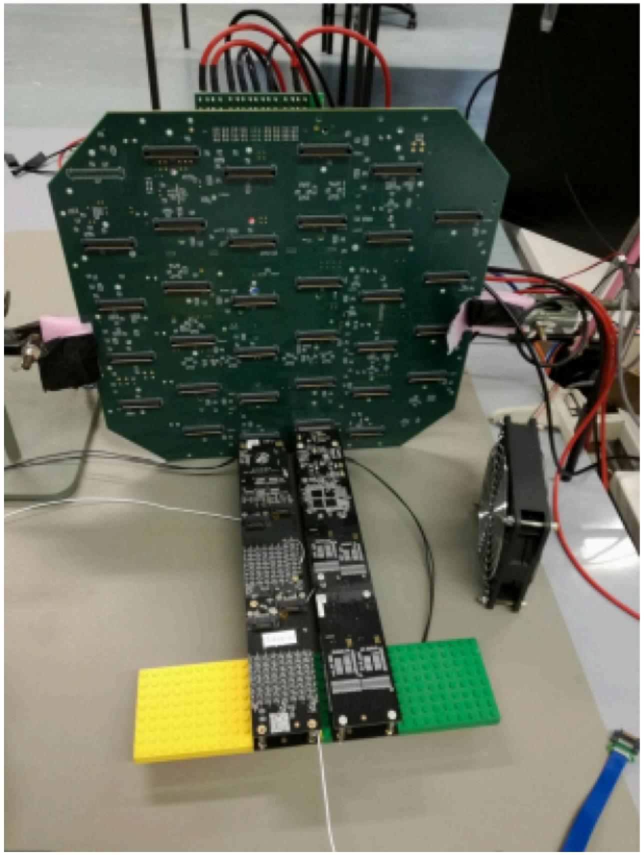


Pre-amplifier stage
pulse shaping
pole zero cancellation network
two-stage AD8014



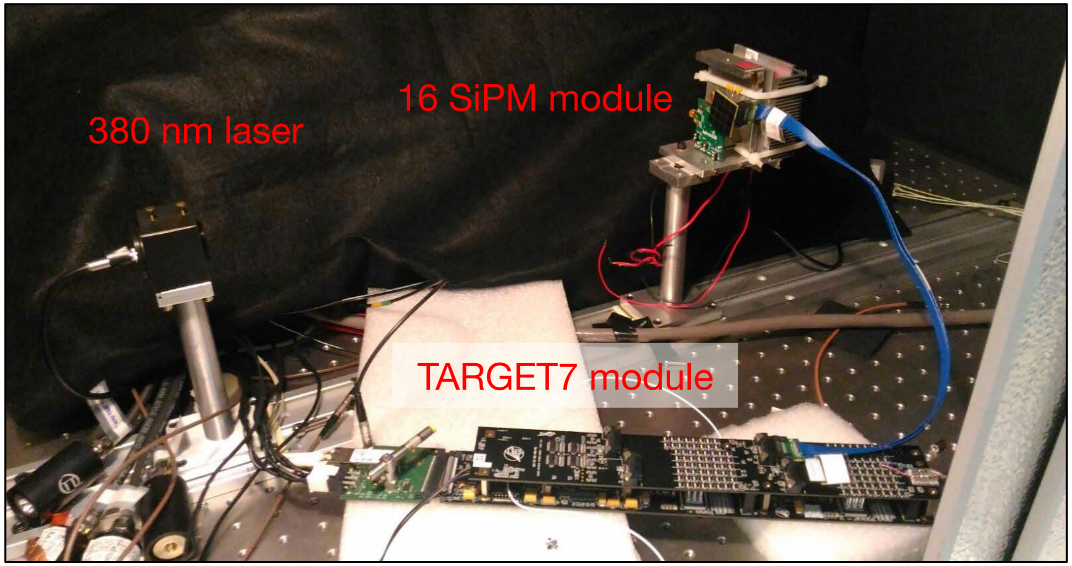
SiPM module readout

Backplane of the pSCT camera hosting 2 TARGET7 modules
@ Univ of Wisconsin (US)

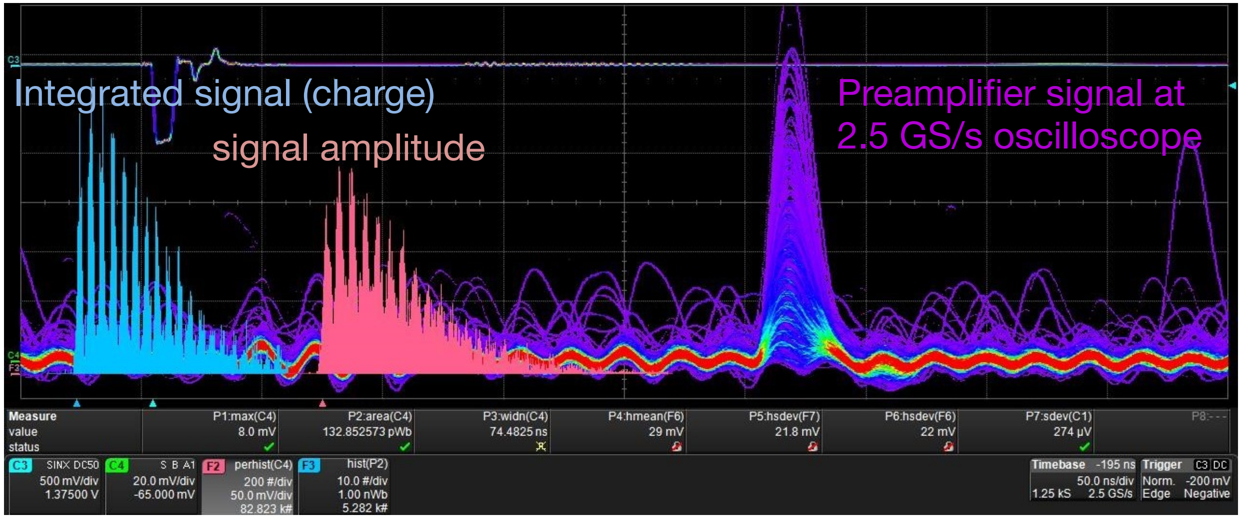


After assembly, SiPM modules are tested simulating the whole pSCT readout chain

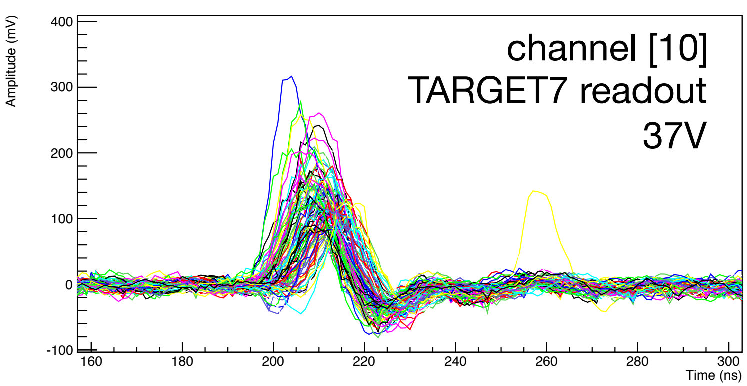
Experimental setup for SiPM module tests and characterization
@ INFN Bari (IT)

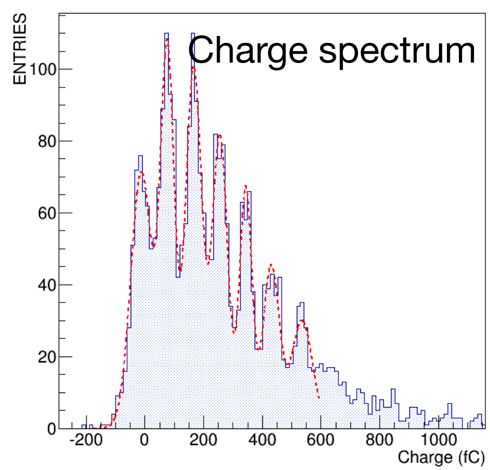


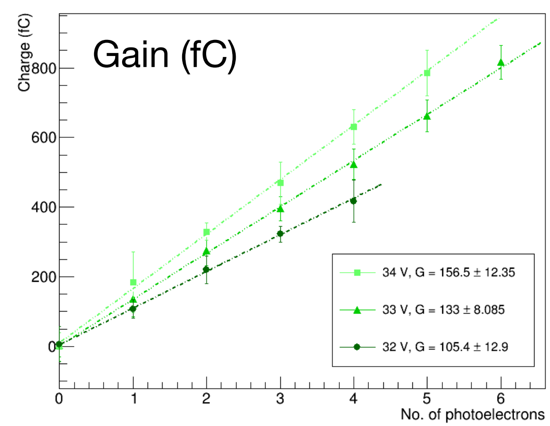
SiPM module readout



Modules are being characterized in terms of gain, dark rate, crosstalk…. at the end of the TARGET7 readout chain







Overview

- **FBK NUV-HD SiPM** technology has been tested and its performances are compatible with the requirements to equip the focal planes of CTA telescopes.
- **Multi-SiPM modules** have been developed to equip a possible upgrade of the Medium Size Schwarzschild-Couder telescope prototype pSCT
- **Assembly, packaging and tests of multi-SiPM modules** is ongoing, and 36 modules are planned to be installed on the pSCT camera by September 2017.