Assembly and validation of SiPM optical modules for the SCT Medium Size Telescope proposed for CTA observatory

Valerio Vagelli, University and INFN of Perugia

and the INFN-SCT group:

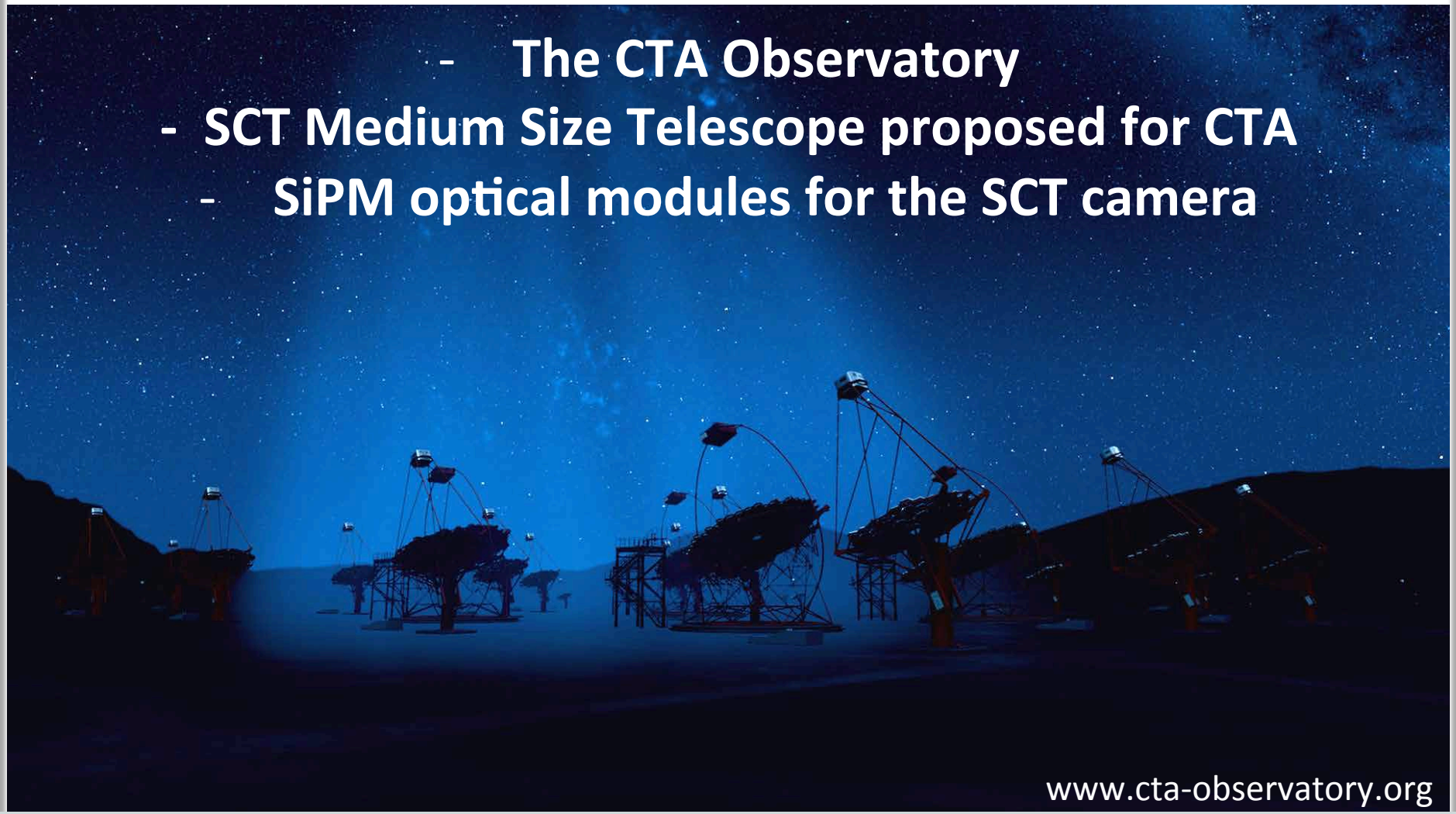
G. Ambrosi, M. Ambrosio, C. Aramo, B. Bertucci, E. Bissaldi, M. Bitossi, A. Boiano, C. Bonavolontà, M. Caprai, L. Consiglio, L. Di Venere, E. Fiandrini, N. Giglietto, F. Giordano, M. Ionica, F. Licciulli, S. Loporchio, R. Paoletti, A. Rugliancich, L. Tosti, V. Vagelli

for the CTA SCT Project

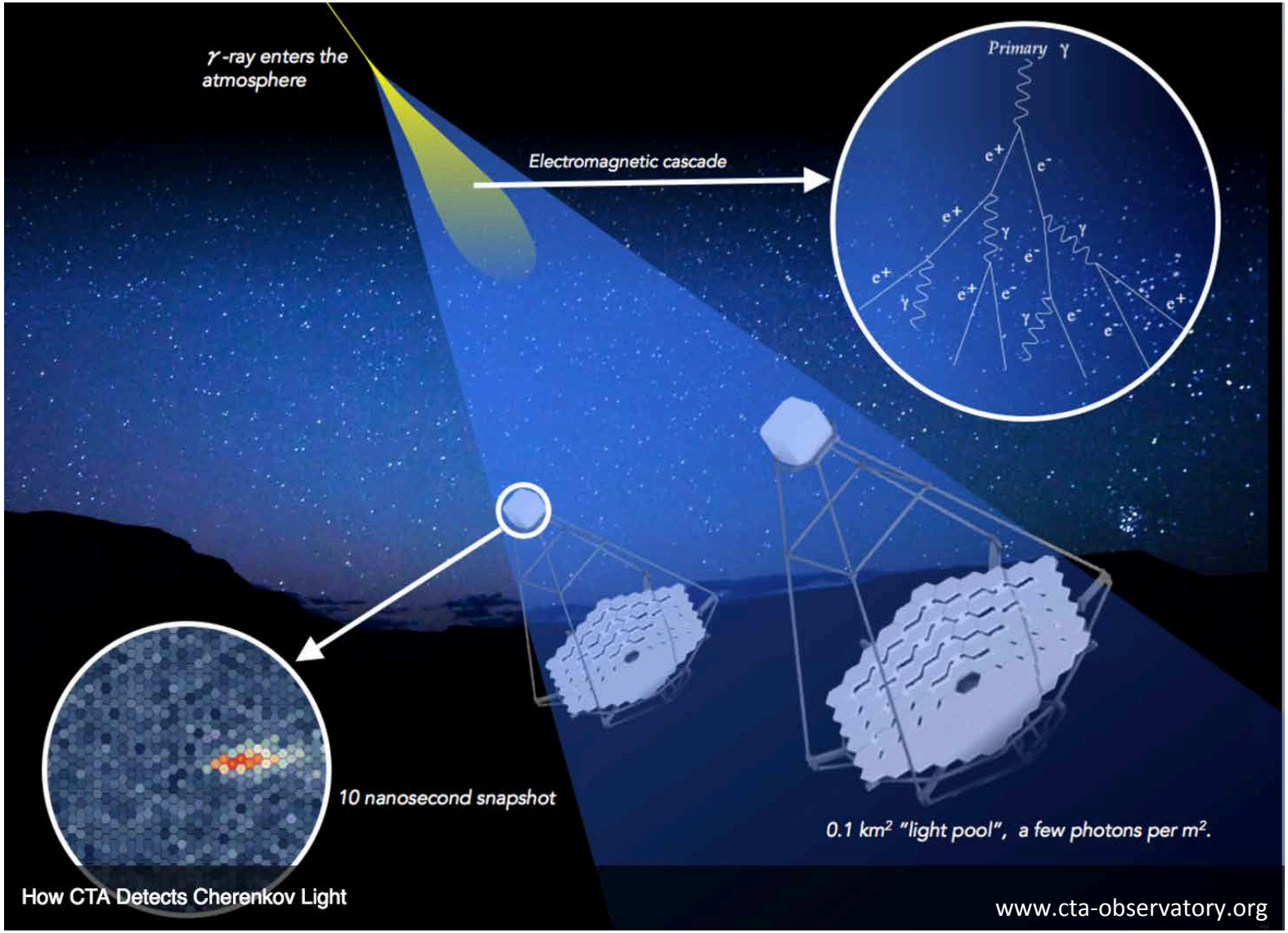
www.cta-observatory.org

Assembly and validation of SiPM optical modules for the SCT Medium Size Telescope proposed for CTA observatory

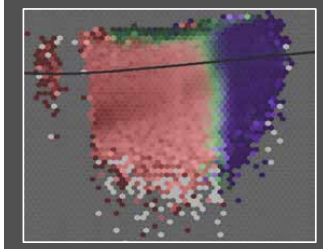
- The CTA Observatory
- SCT Medium Size Telescope proposed for CTA
- SiPM optical modules for the SCT camera



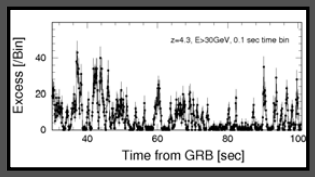
Cherenkov Telescopes



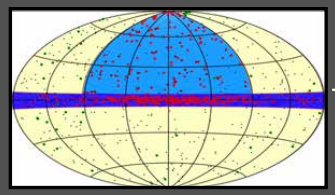
Exploring the Universe at the Highest energies



Dark Matter Programme



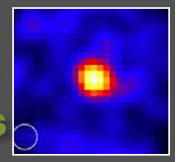
Transients



ExGal Survey

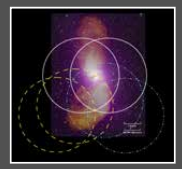
Extragalactic

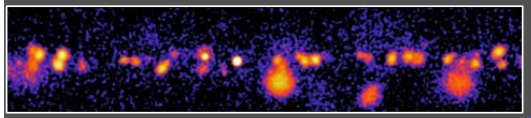
Galaxy Clusters



Star Forming Systems

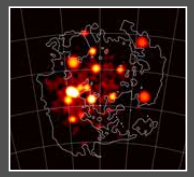
AGN



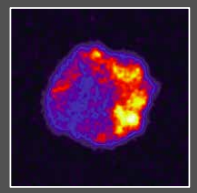


Galactic

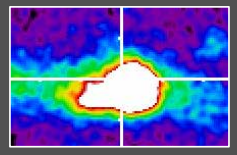
LMC Survey



Galactic Plane Survey



PeVatrons



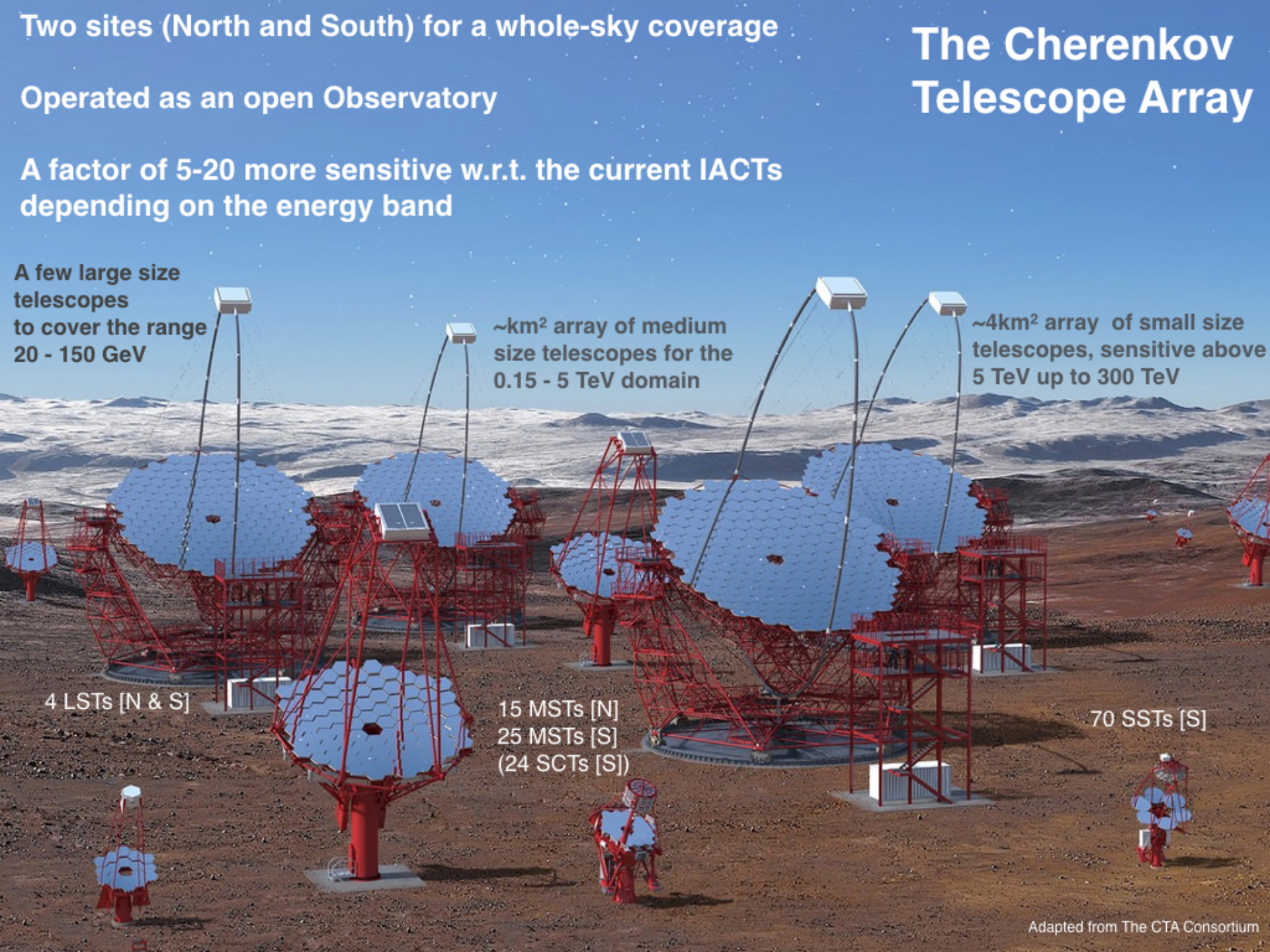
Galactic Centre Survey

The Cherenkov Telescope Array

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

Operated as an open Observatory

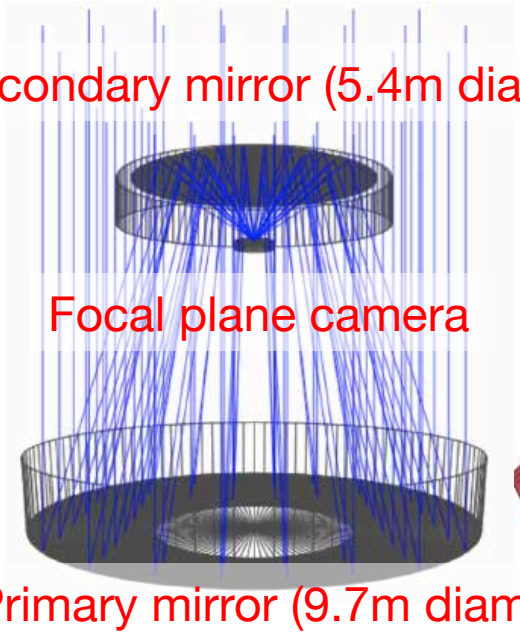
A factor of 5-20 more sensitive w.r.t. the current IACTs depending on the energy band



Adapted from The CTA Consortium

SCT Telescope

Schwarzschild-Couder dual mirror optics Medium Size Telescope

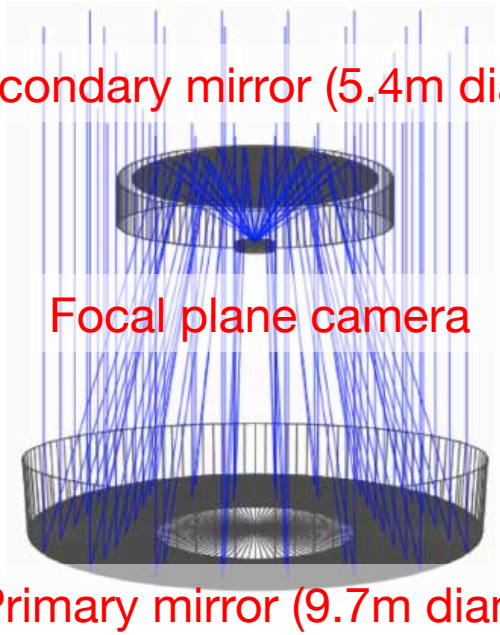


Dual mirror optics: cancel aberration and de-magnify images, compatible with **compact high-resolution SiPM camera** -> a smaller point spread function (PSF) and **improved angular resolution**

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

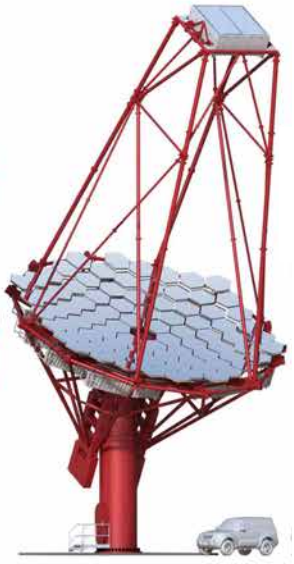
1 university

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

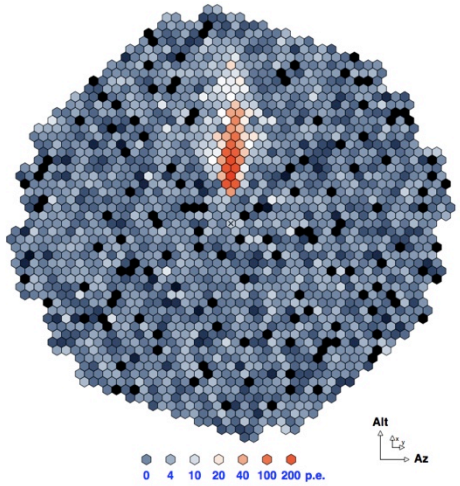
Single and Dual mirror MST

MST
Single mirror
Davies-Cotton

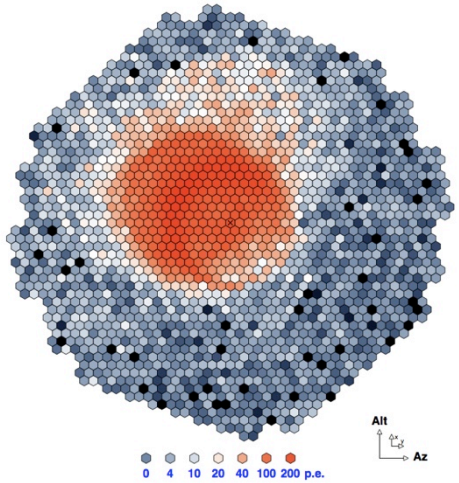
approx 2k PMTs



1 TeV γ-ray Shower
Impact Distance: 100m



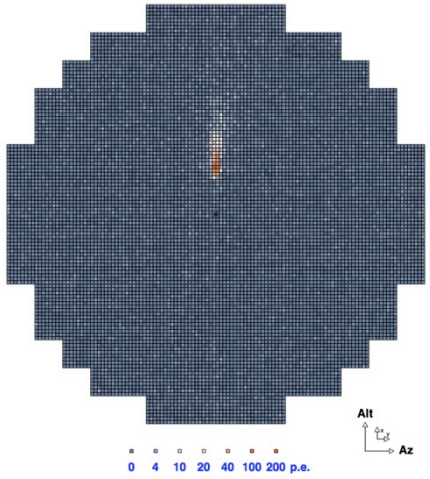
3.16 TeV Proton Shower
Impact Distance: 0m



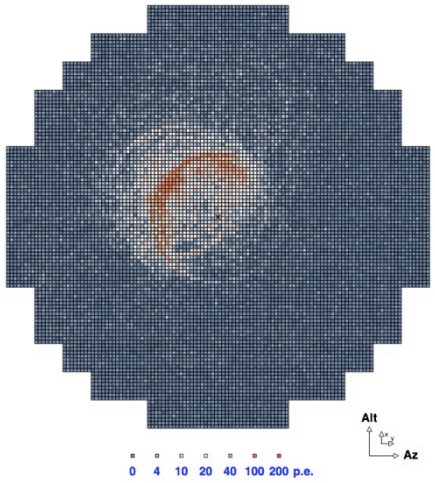
SCT
Dual mirror
Schwarzschild-Couder

approx 12k SiPMs

1 TeV γ-ray Shower
Impact Distance: 100m



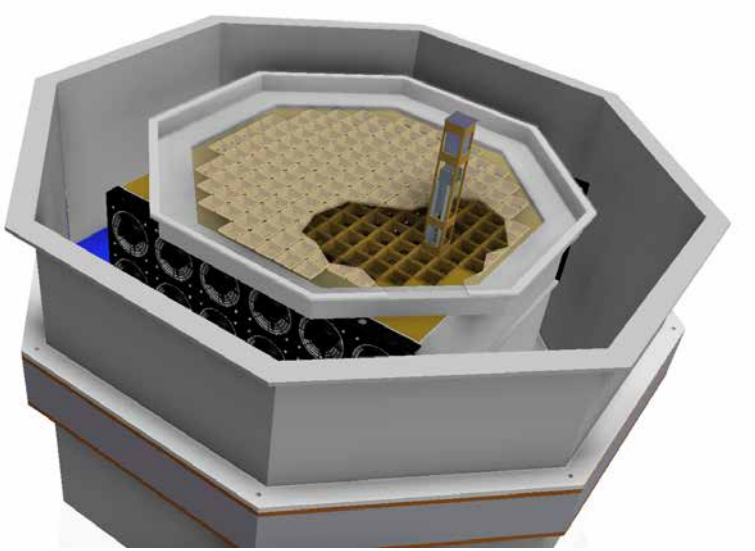
3.16 TeV Proton Shower
Impact Distance: 0m



pSCT Telescope

Prototype demonstrator for the Medium Size SCT solution

0.4m^2 active area per telescope



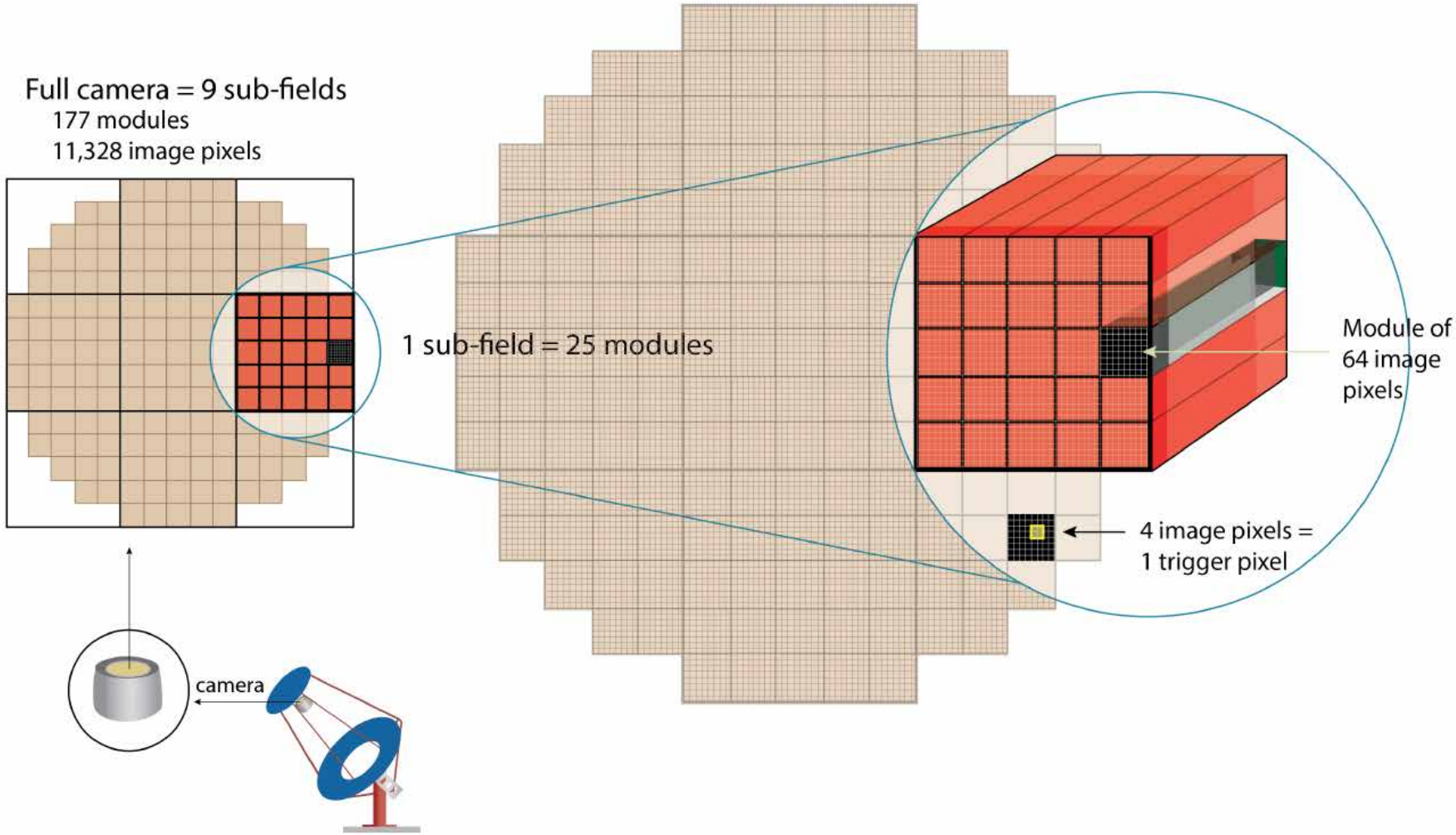
8° field of view, 81 cm diameter

- 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

Prototype main goals:

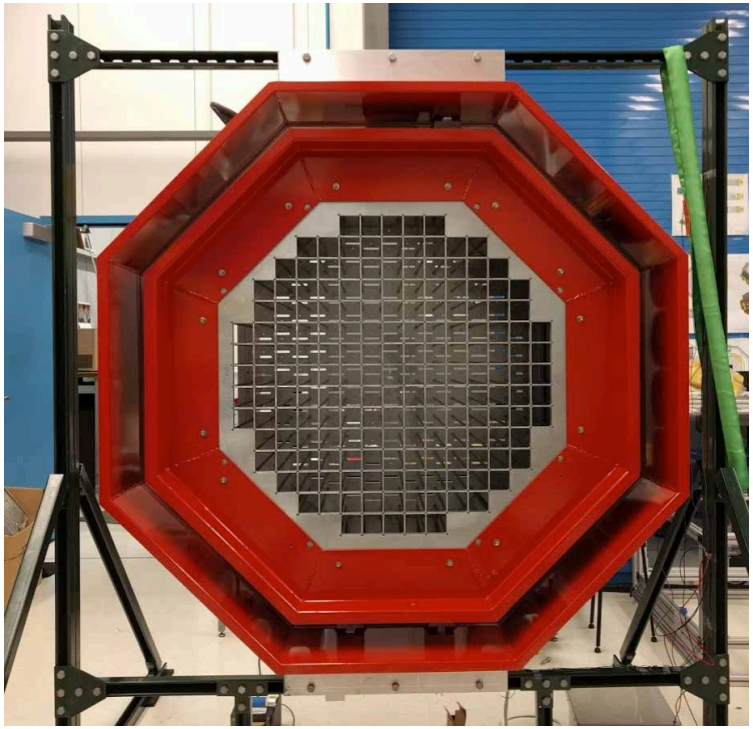
- Demonstrate the performances of the optical system
- Gain experience with the optical alignment and operation of the SiPM camera

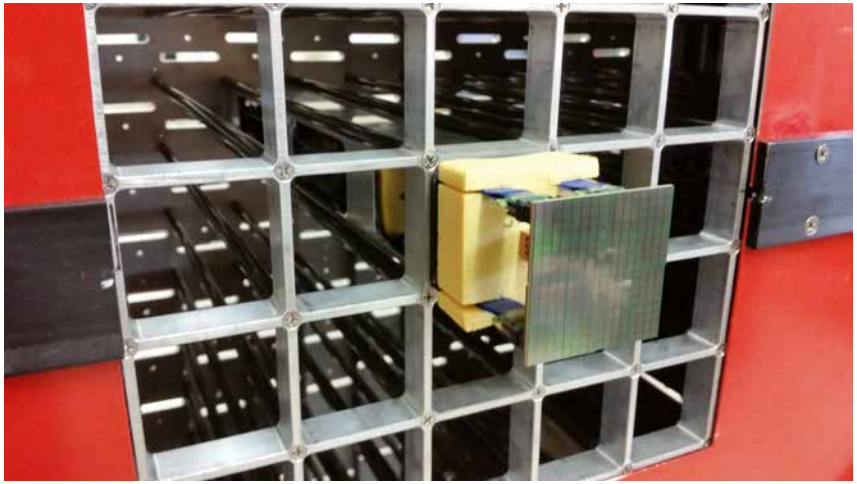
Focal Plane camera



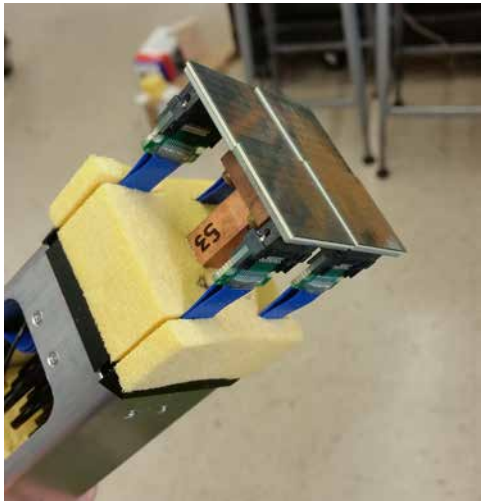
pSCT Telescope camera

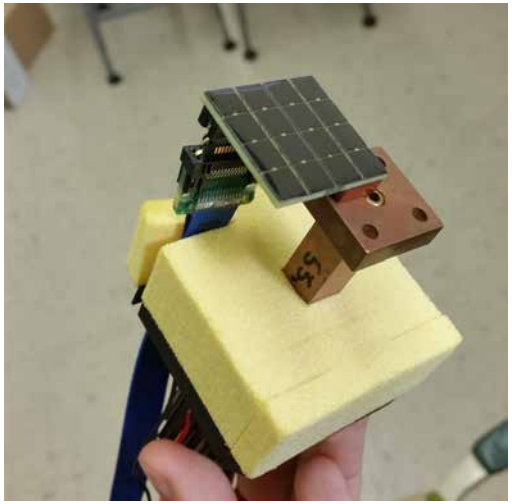
pSCT camera frame in Univ. of Wisconsin





- Originally planned with Hamamatsu MPPC modules
- Possible upgrade with **FBK NUV-HD SiPM modules**

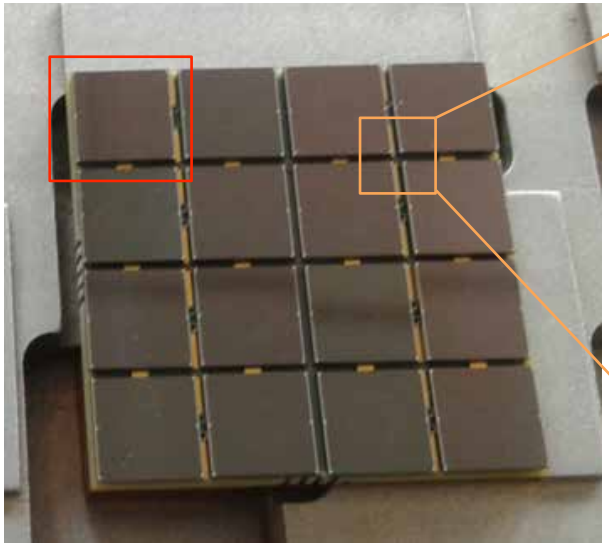


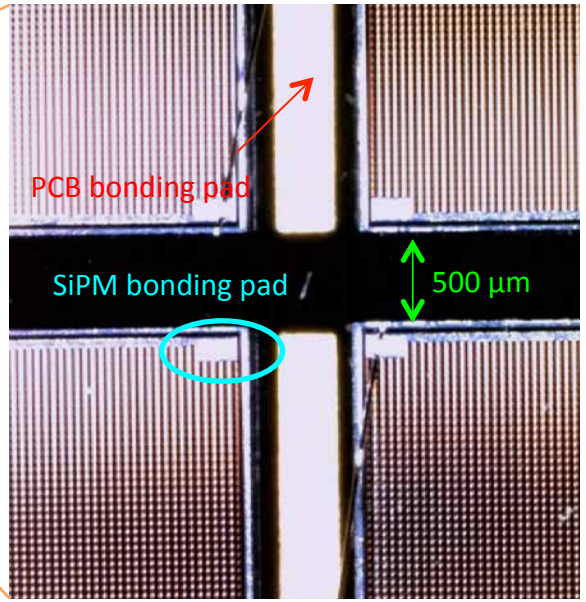


US Hamamatsu module **INFN FBK prototype**

pSCT module upgrade (FBK)

6x6mm^2

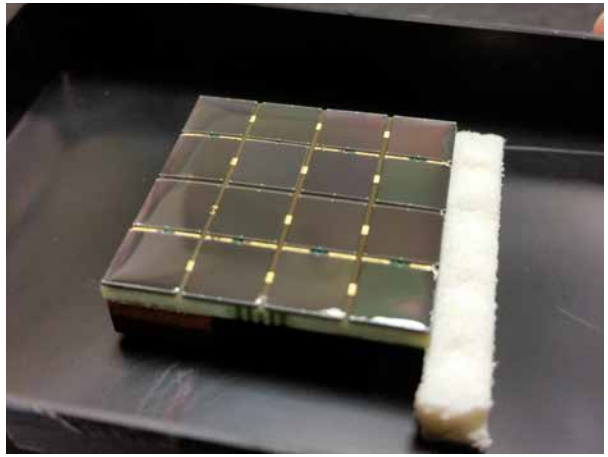




27x27mm^2 PCBs are equipped with 16 SiPMs to cover uniformly the exposed area

NUV-HD SiPM produced by Fondazione Bruno Kessler (FBK-IT) in collaboration with INFN

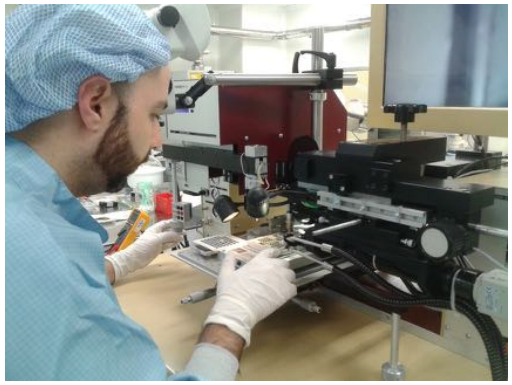
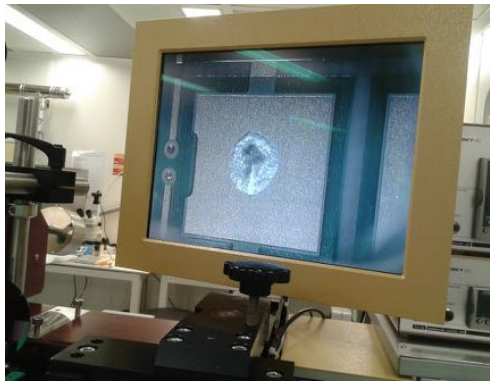
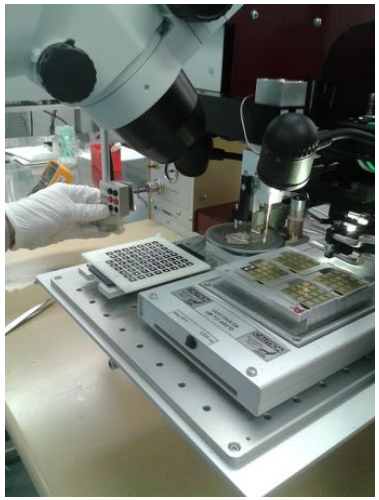
Details on SiPM performances: L. Consiglio (this conference)

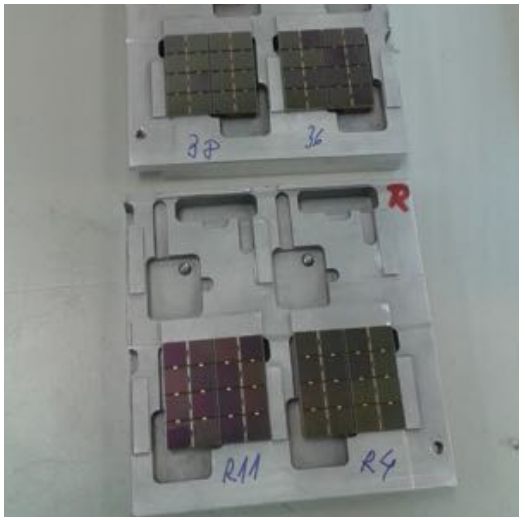


SiPM module assembly and tests

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

R&D activities in 2016/2017 (INFN and Univ. of Perugia, IT).

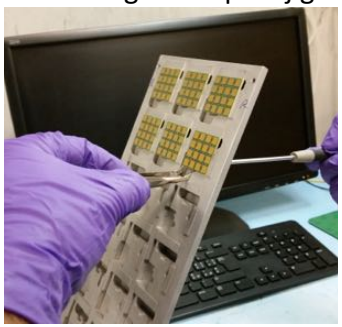







SiPM module assembly and tests

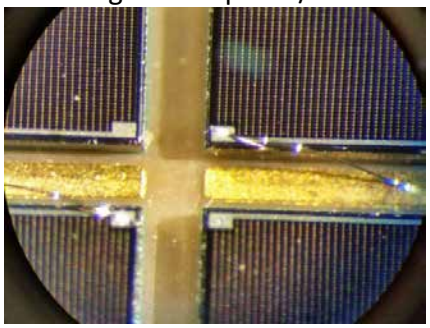
After quality checks, SiPMs are wire-bonded and the PCBs are protected with UV-transparent epoxy layer

Placement in bonding&transport jig

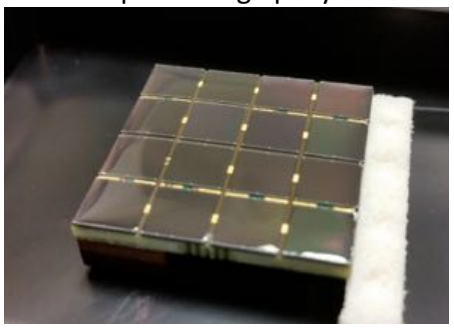


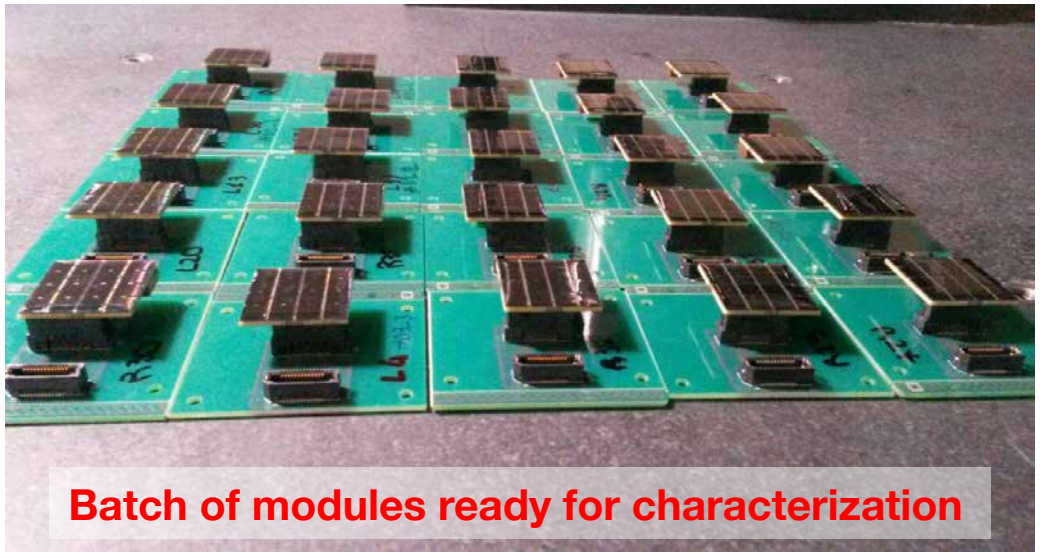
Bonding (approx. 15 mins/matrix)

Bonding with 20µm Al/Si wire



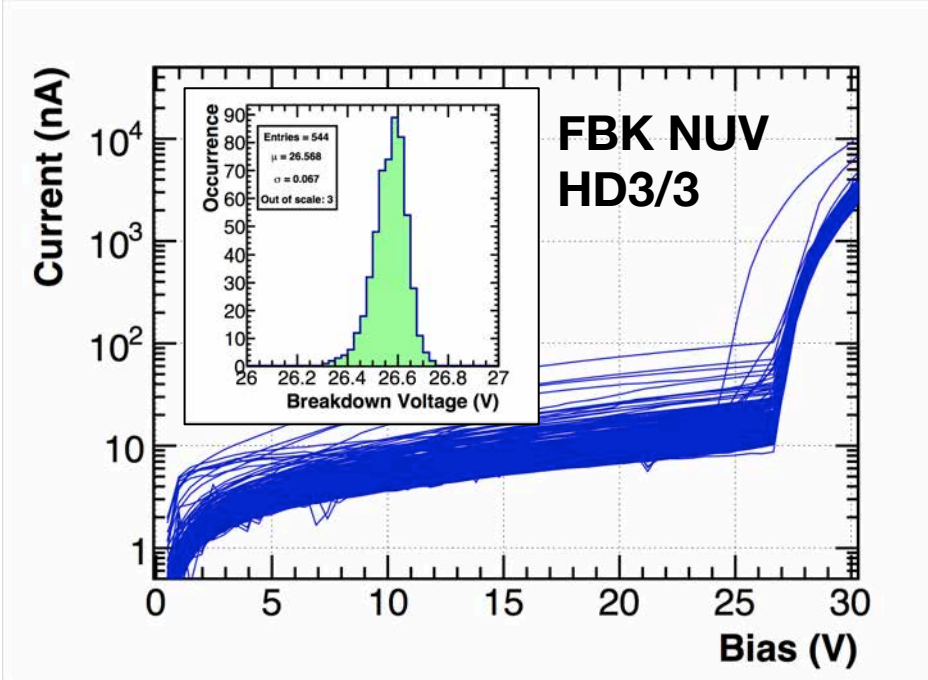
Dispensing of UV-transparent protecting epoxy

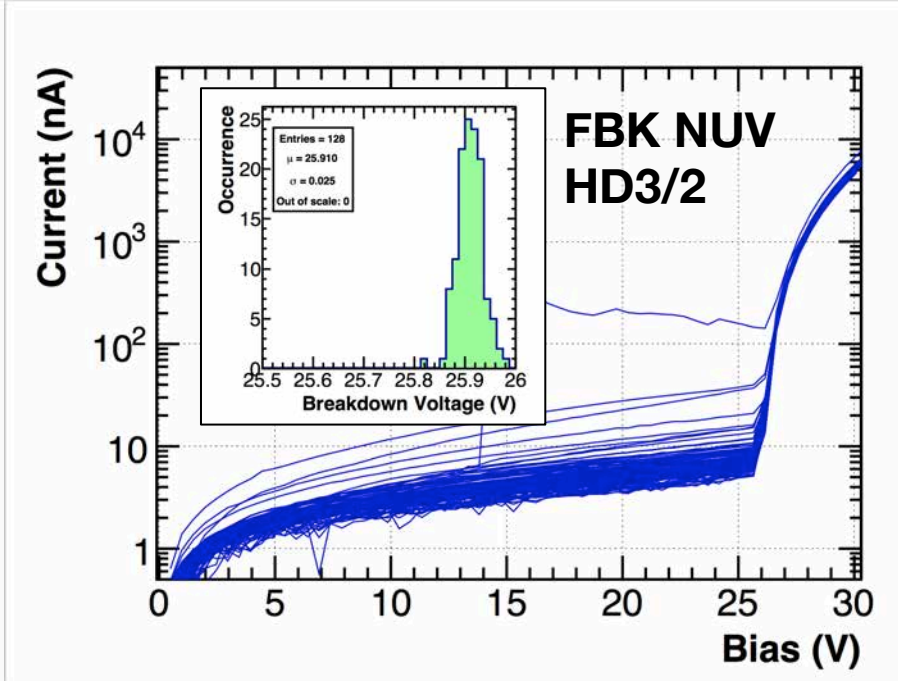




Batch of modules ready for characterization

Electrical verification





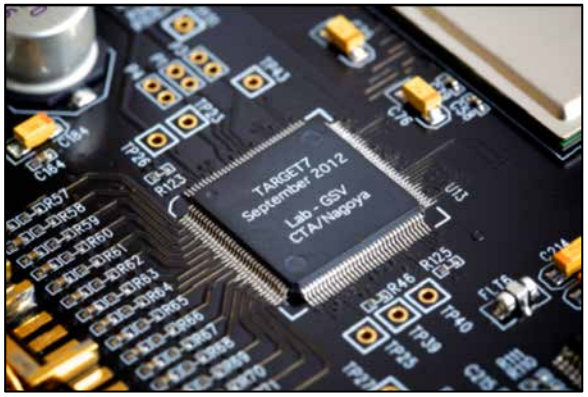
2017/2018:

- 100 units assembled (including prototypes and mechanicals)
- 56 units tested electrically
- **36 units selected to equip 9 modules for the pSCT camera.**

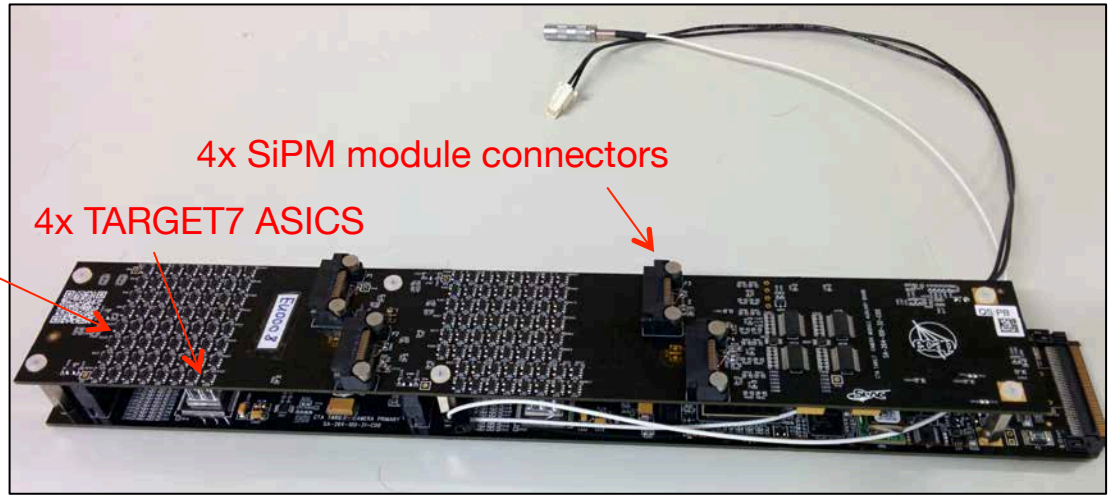
SiPM module readout

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

- **Compact chip for high density channel camera**
- 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



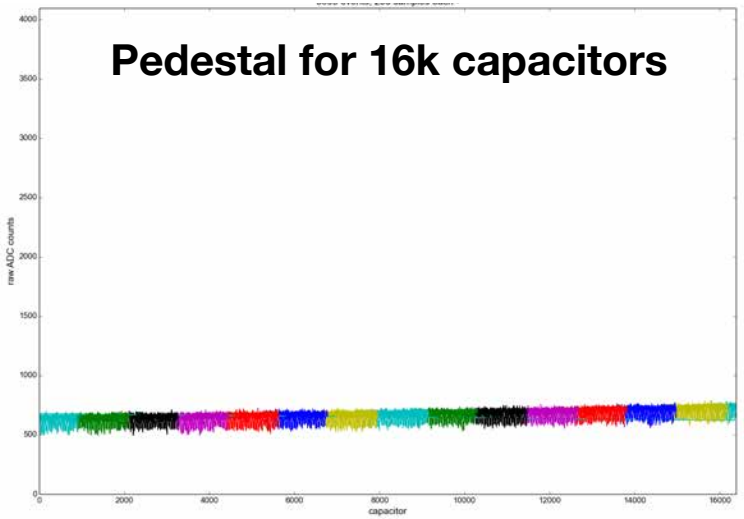
Pre-amplifier stage
pulse shaping
pole zero cancellation network



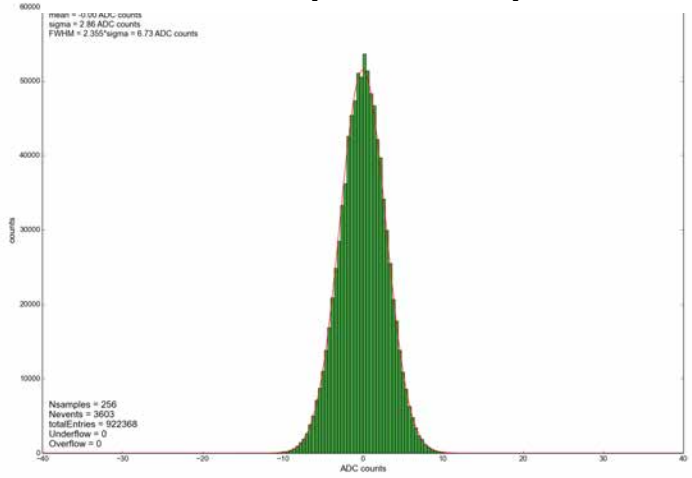
Electronics QC and Tests

- 5 TARGET 7 modules produced in IT
- 4 TARGET 7 modules processed to adapt FEE to FBK SiPMs
- Quality controls in INFN Pisa+Bari including
  - **Pedestal calibration**
  - Waveform acquisition (laser)
  - Trigger verification

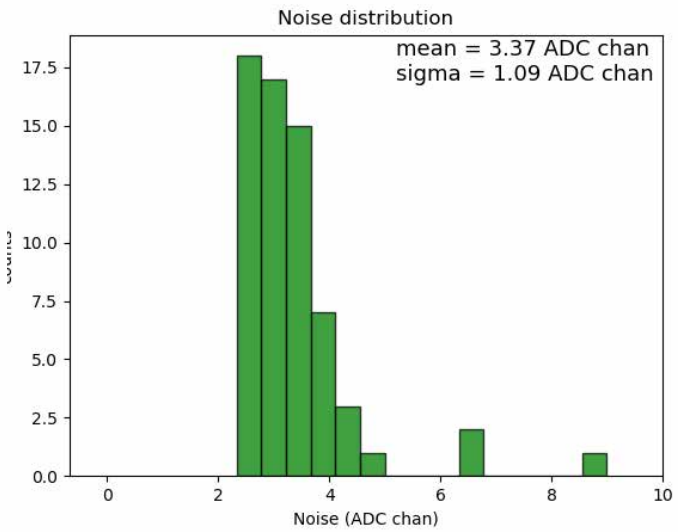
Pedestal for 16k capacitors



ADC after pedestal subtraction (1 channel)



Noise for 64 channels (1 ASIC)



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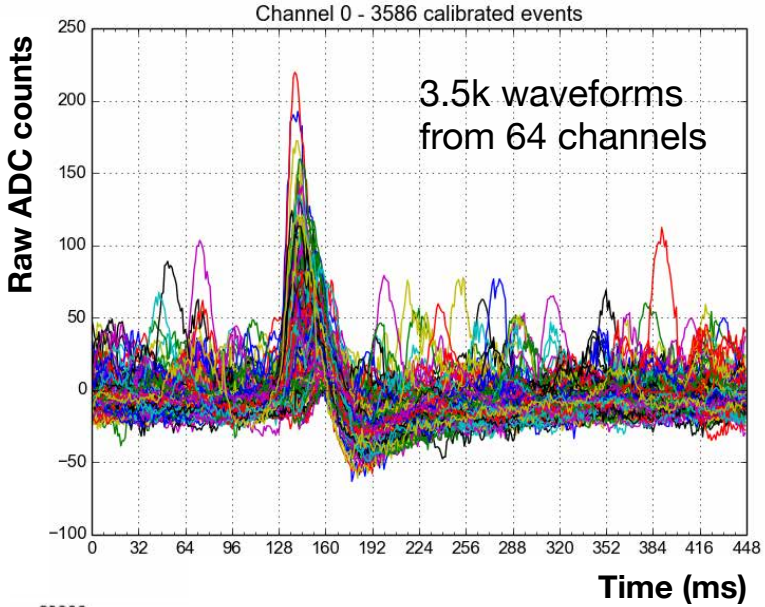
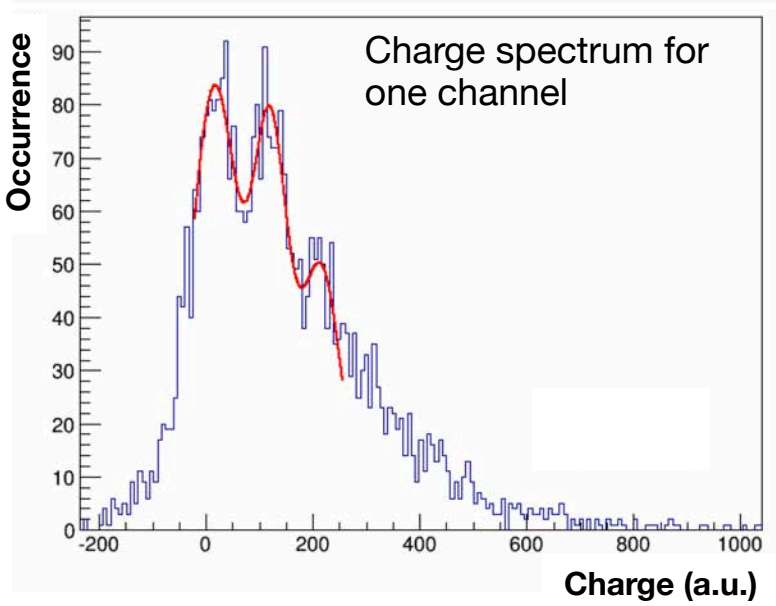
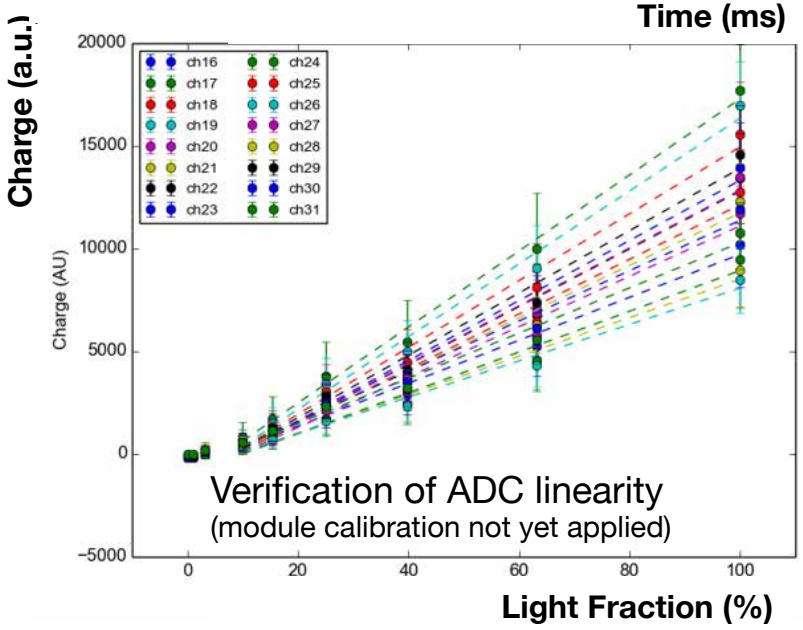
  - Trigger verification







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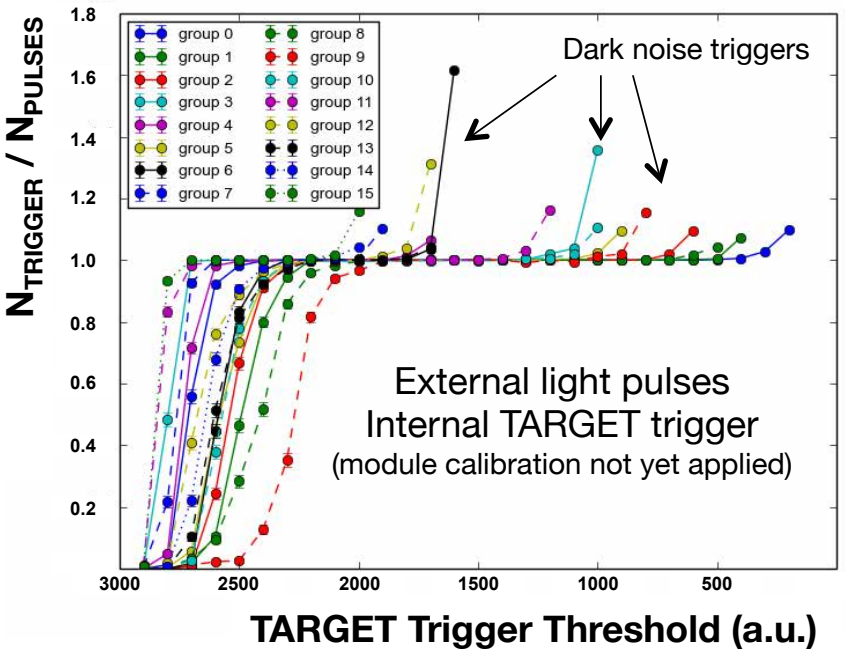
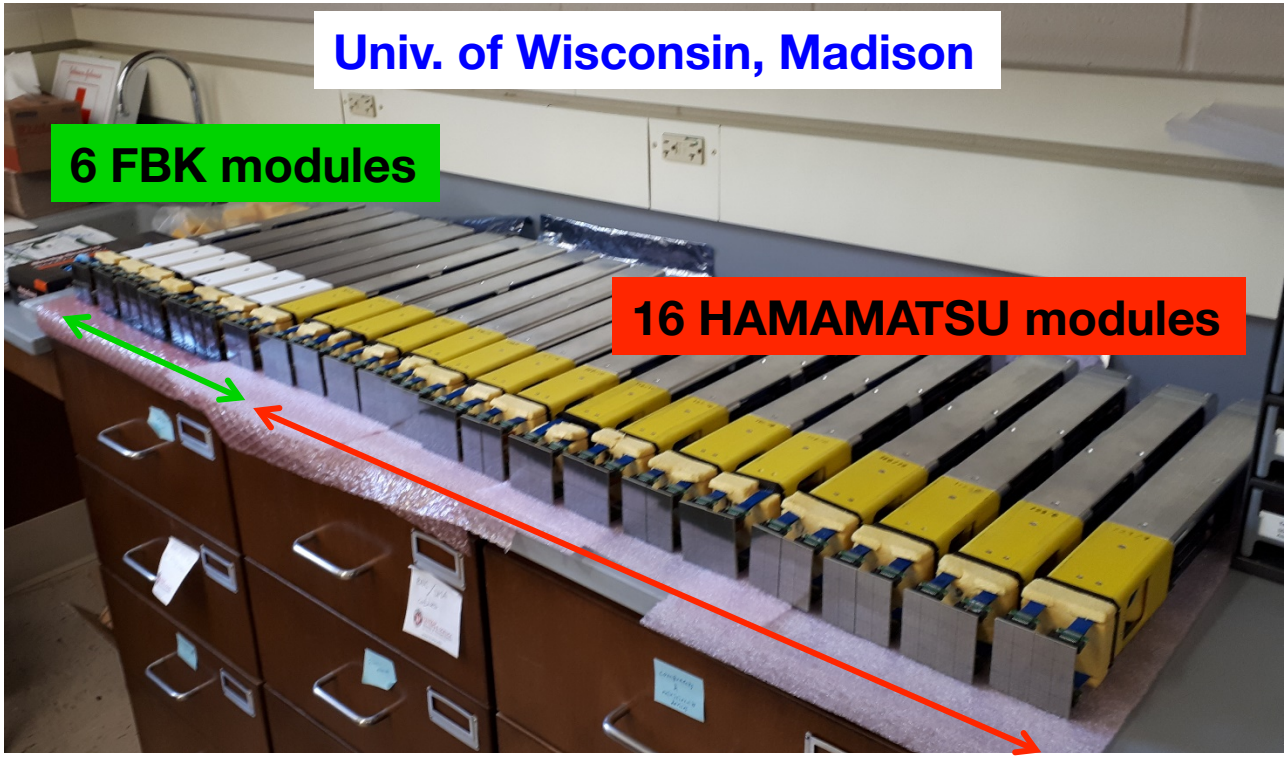


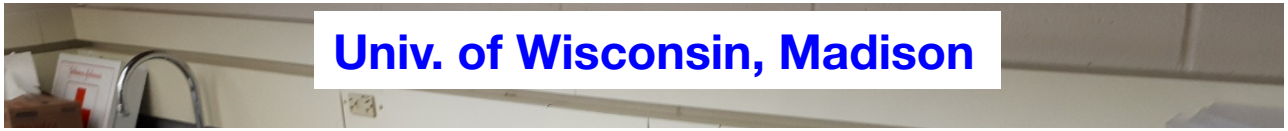
All measurements repeated on 9 fully assembled modules
4 FEE channels out of 576 channels failed the tests (99% yield)

6 modules selected for integration on the pSCT camera
3 additional modules are currently being integrated and verified

Camera tests

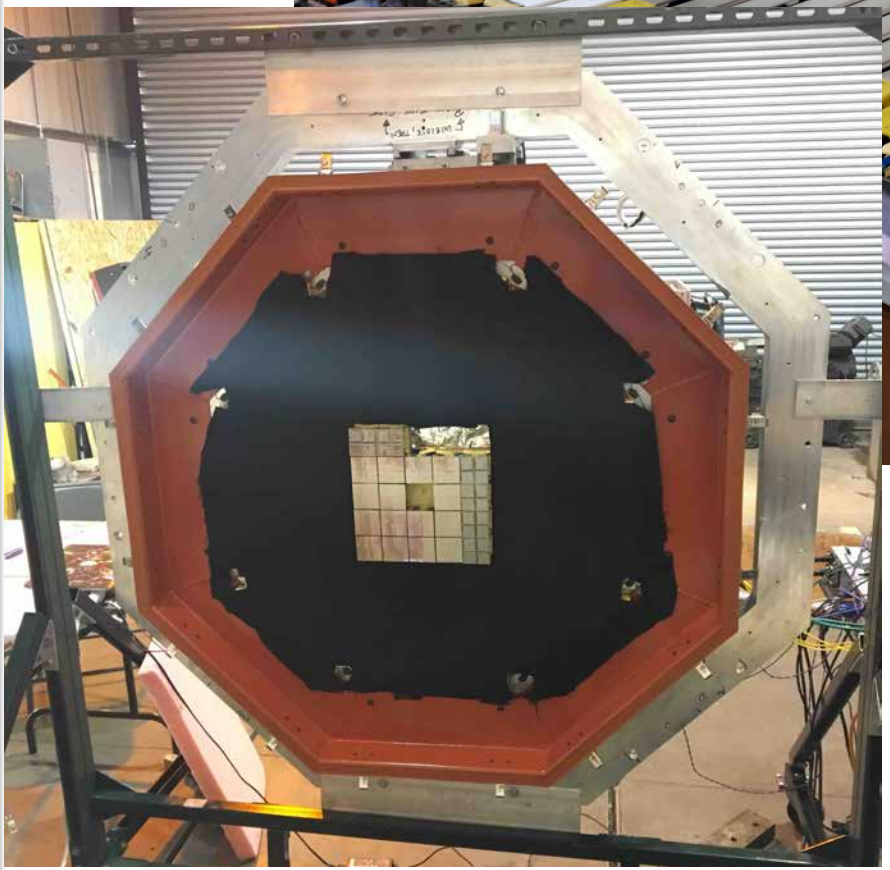


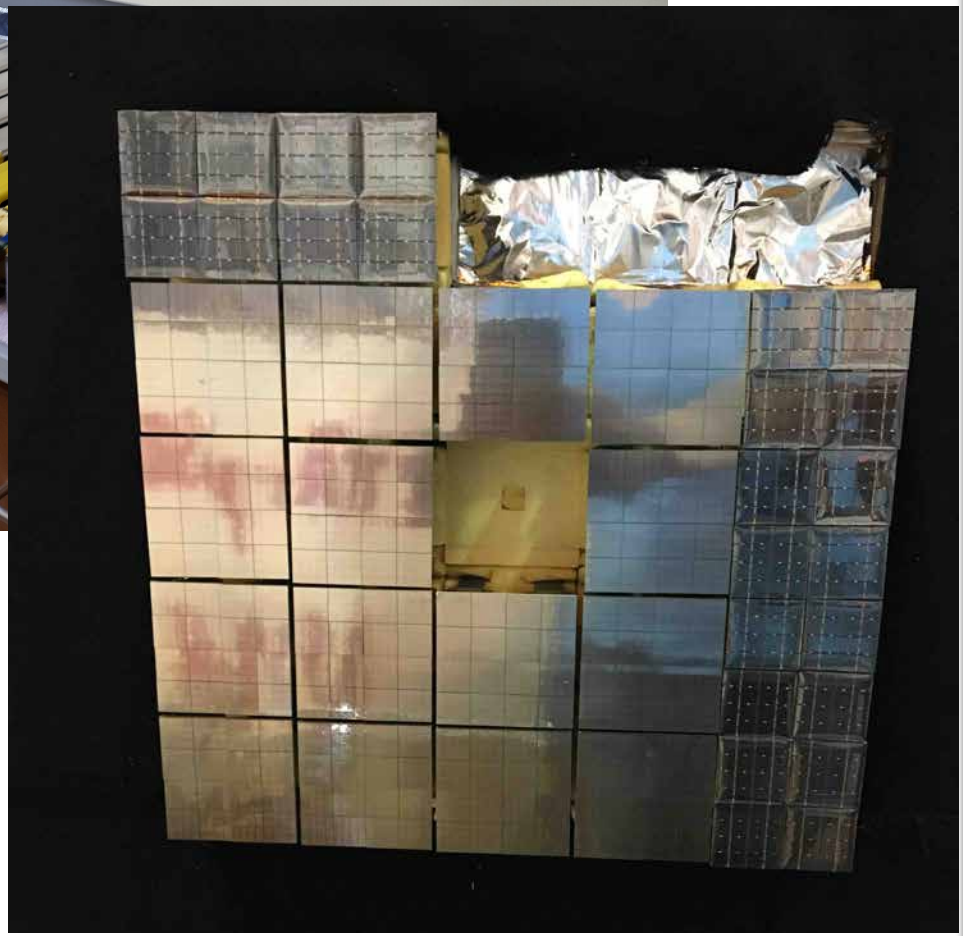
Camera tests



Univ. of Wisconsin, Madison

15 US + 6 INFN modules integrated (1408 total pixels)

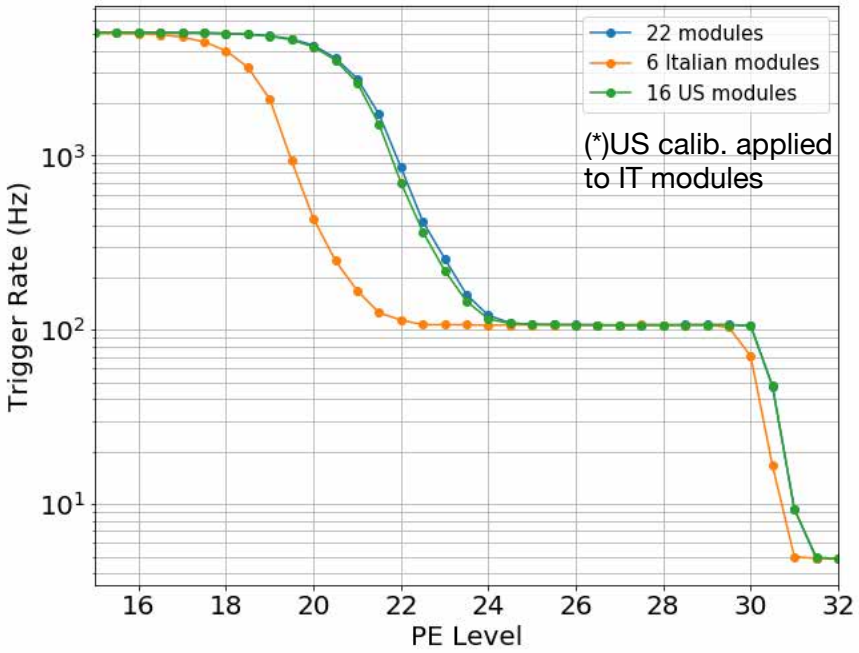


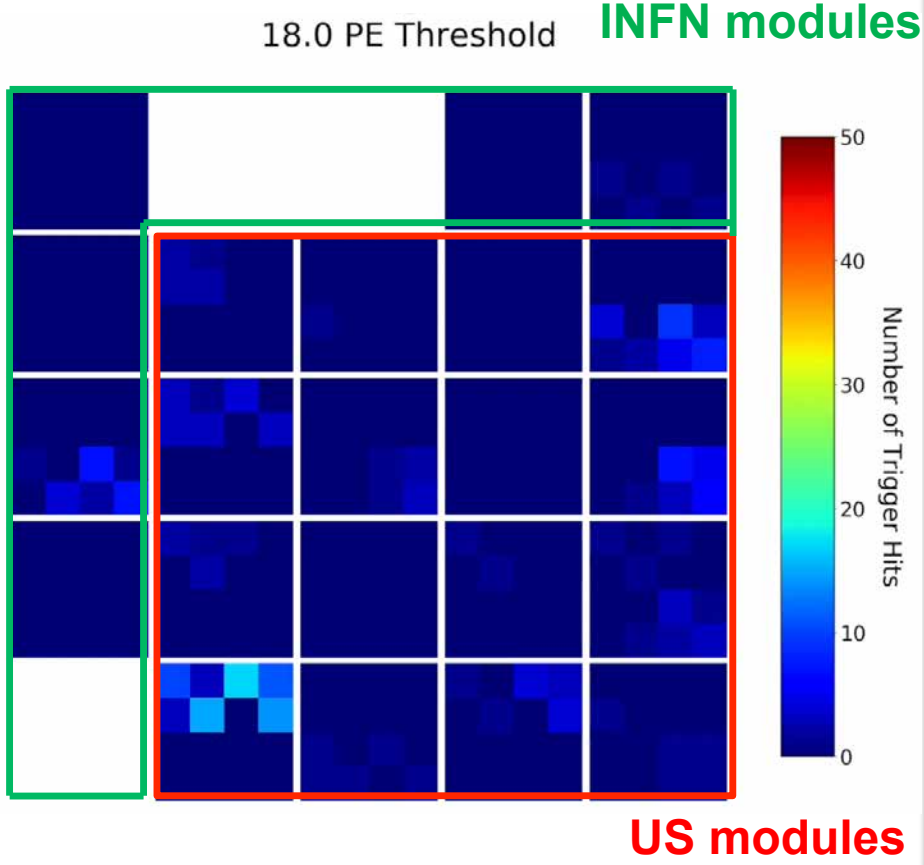


Camera tests

LED flashed at 100 Hz, camera self triggered (using TARGET 7 internal trigger)
Trigger applied to analog sum of 4 pixels (equivalent to 5.5 pe per pixel)

Nominal operating point: 1 kHz readout at 22 photoelectron threshold



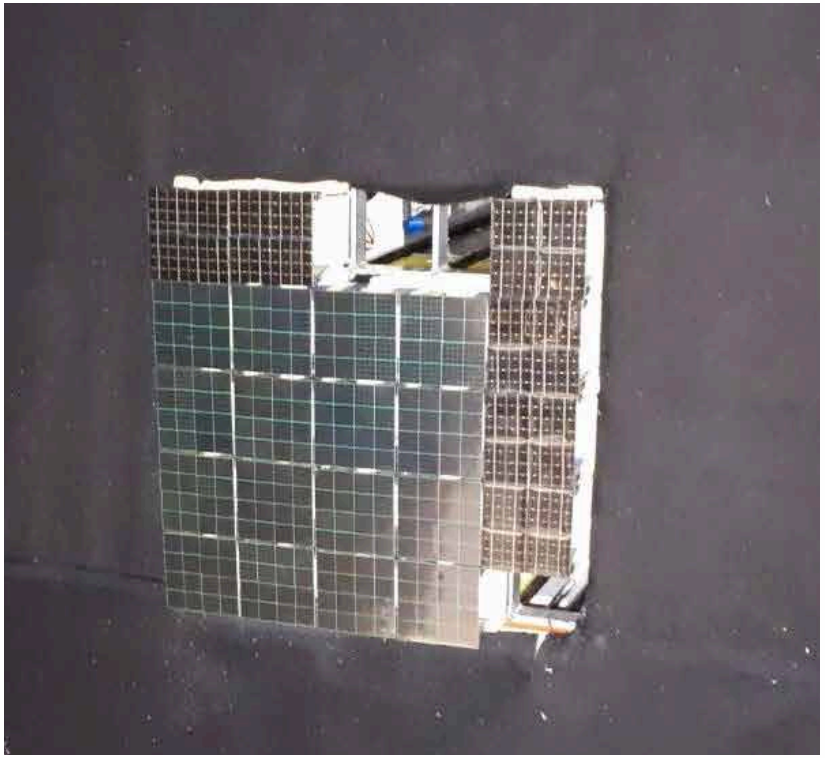


Study of noise occupancy and comparison to waveform-based images is underway

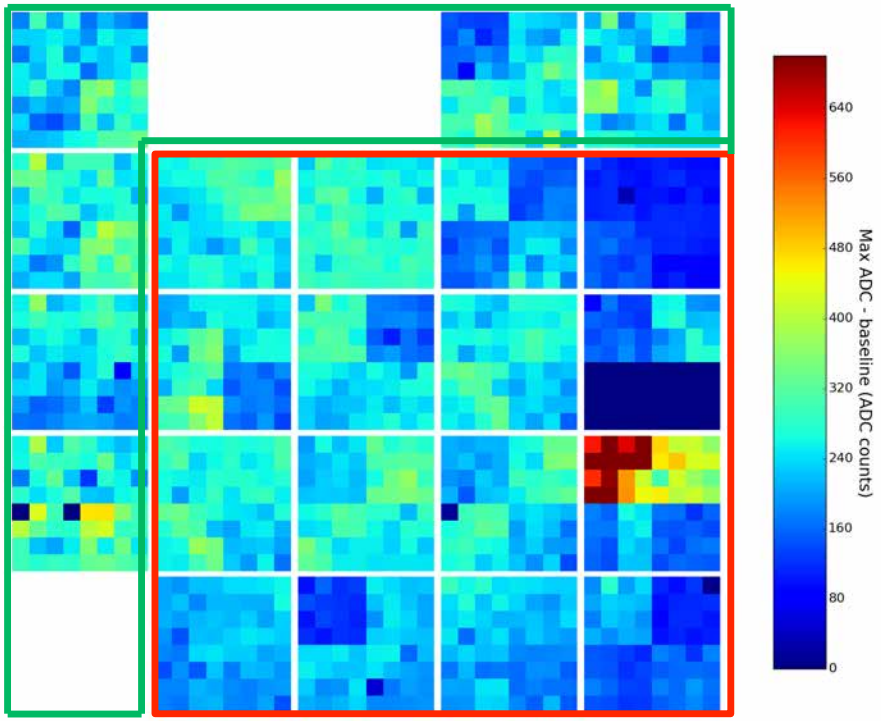
Camera tests

LED flashed at 100 Hz, camera self triggered (using TARGET 7 internal trigger)
Raw, uncalibrated ADC amplitudes (INFN divided by 2 for gain compensation)

Further characterization of the camera after installation on the telescope



INFN modules



US modules

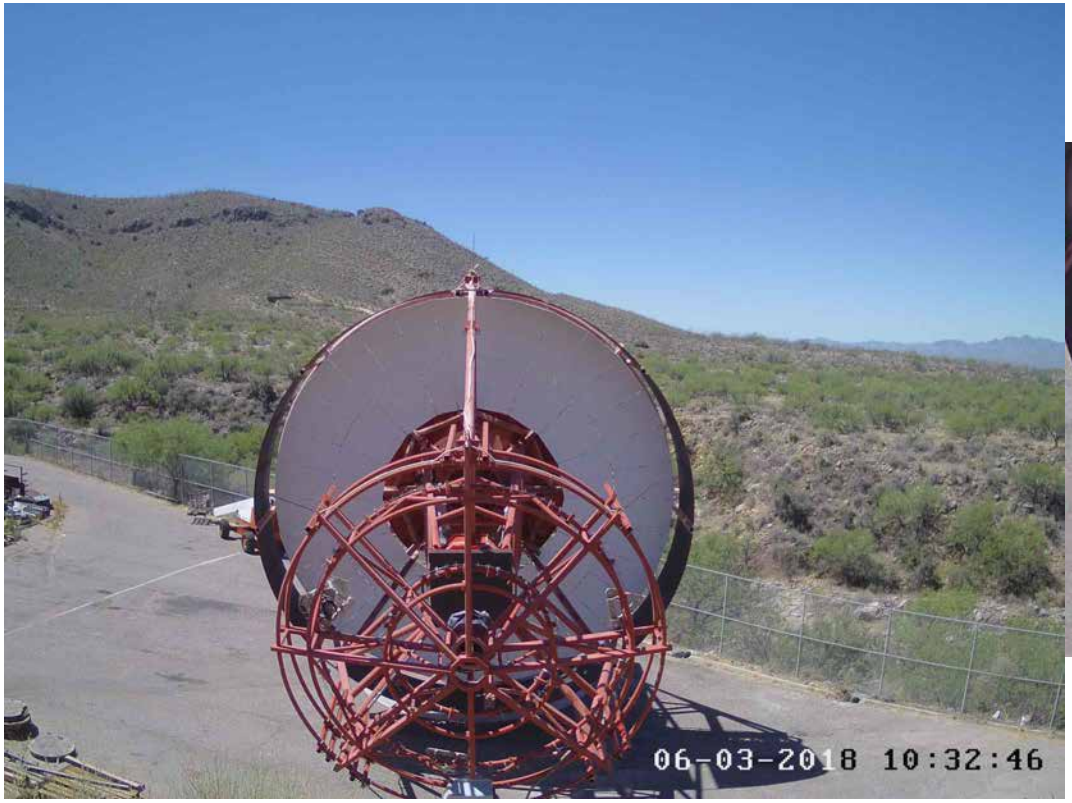
Main Installation milestones:

- Primary mirror installation: done
- Camera commissioning (primary mirror only): Summer 2018
- Secondary mirror installation: Summer 2018
- Camera commissioning (complete optics): Fall 2018
- Integration of one additional camera sector (25 modules): End of 2018 / 2019

Image credits: B. Humensky & J. Vandenbroucke

Camera Installation

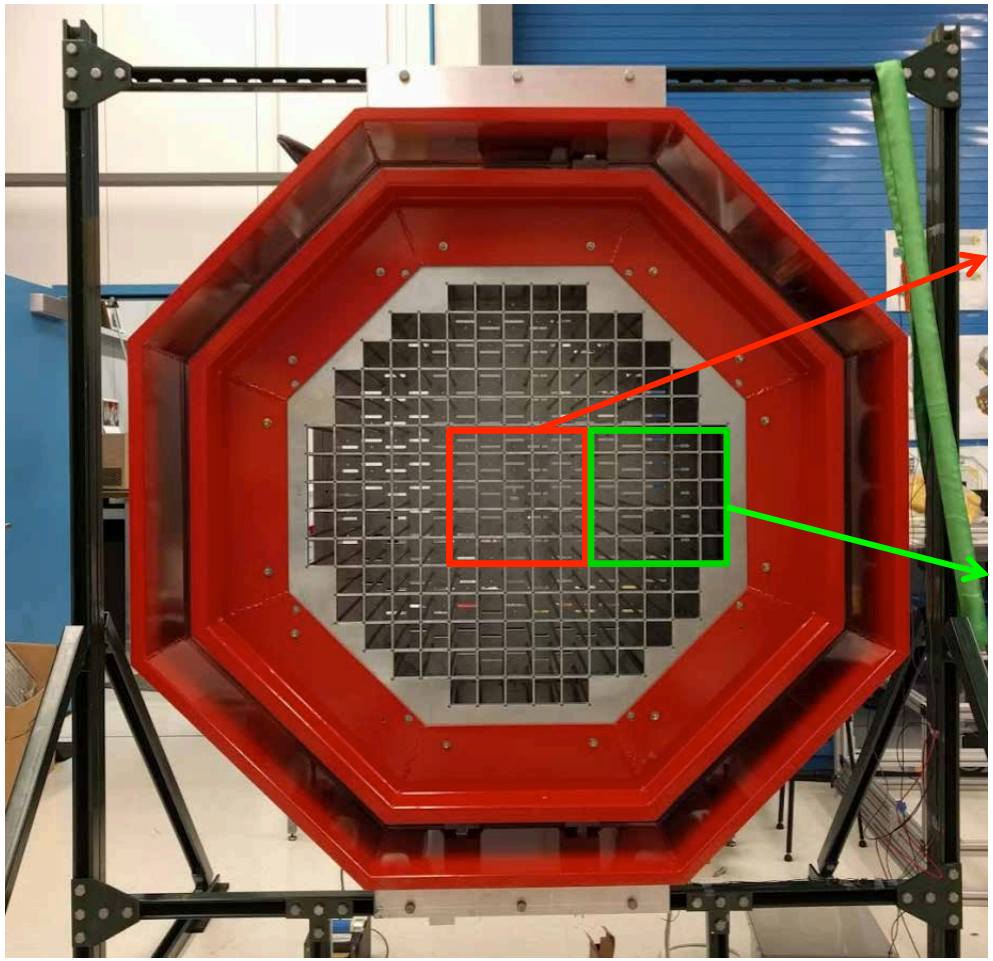
Camera lift and successfully installed on 30 May 2018



pSCT webcam: http://cta-psct.physics.ucla.edu/

Module integration pt. II

One additional quadrant (25 modules, 1600 pixels) scheduled to be integrated with FBK SiPMs and upgraded electronics by end of 2018.



25 modules equipped & in commissioning
(9 FBK NUV-HD, 16 Hamamatsu)

25 modules to be equipped
(25 FBK NUV-HD)

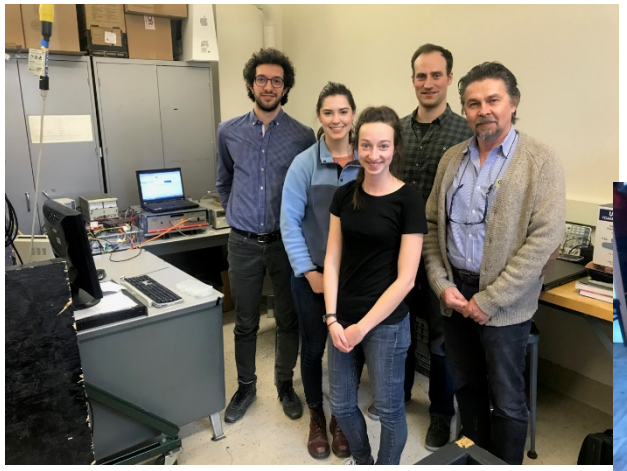
Overview & Outlook

Assembly, packaging and tests of optical modules based on FBK SiPMs

- 6 modules installed in the pSCT camera, 3 additional modules foreseen

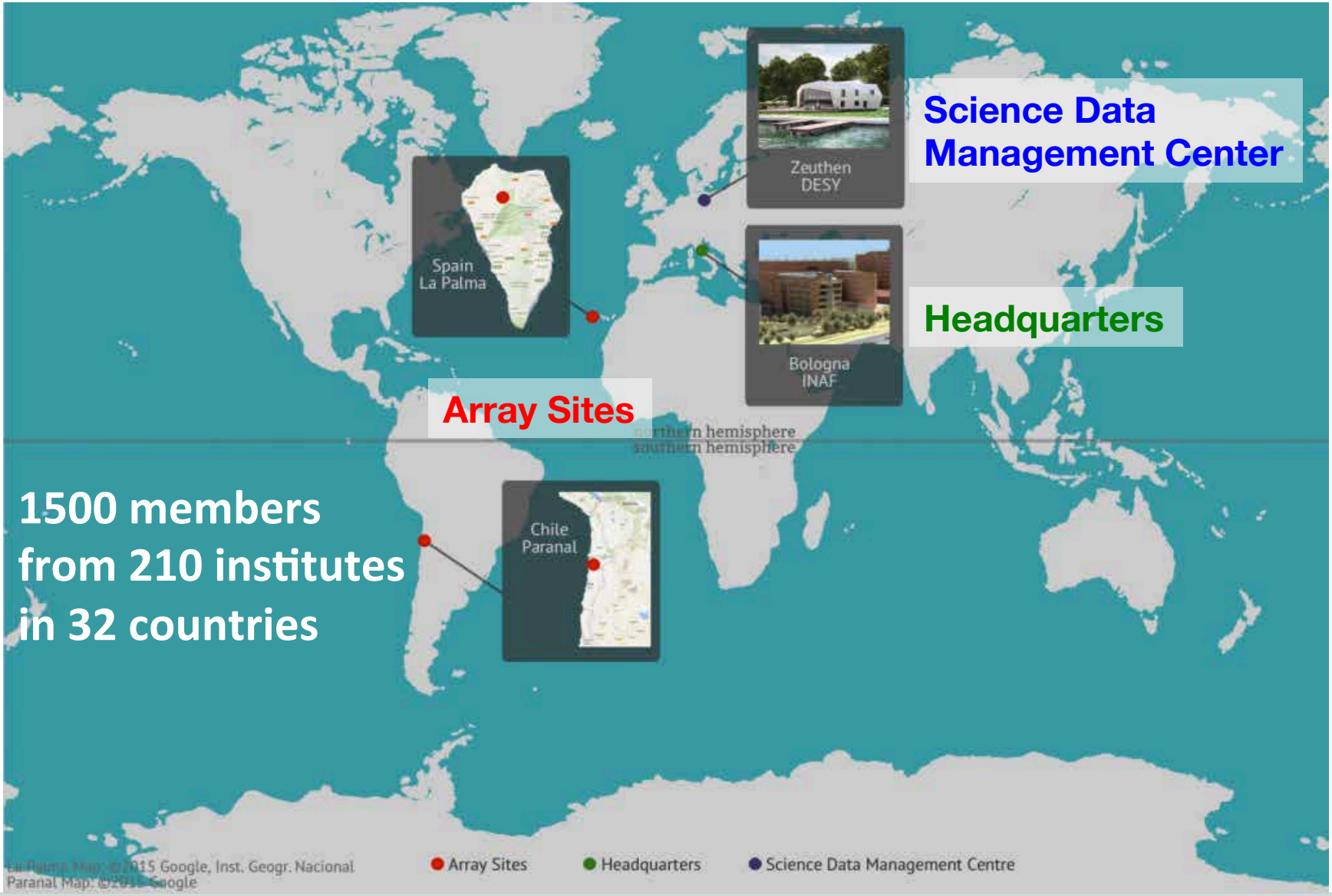
- Commissioning of telescope + camera starting in summer

- One additional quadrant (25 modules, 1600 pixels) scheduled to be integrated with FBK SiPMs and upgraded electronics by end of 2018.



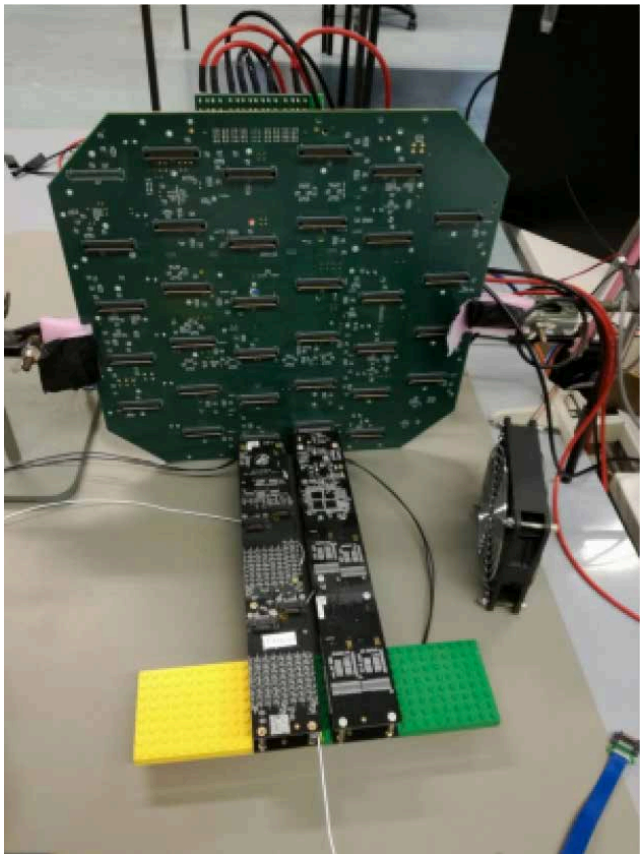
Additional Slides

The CTA Project

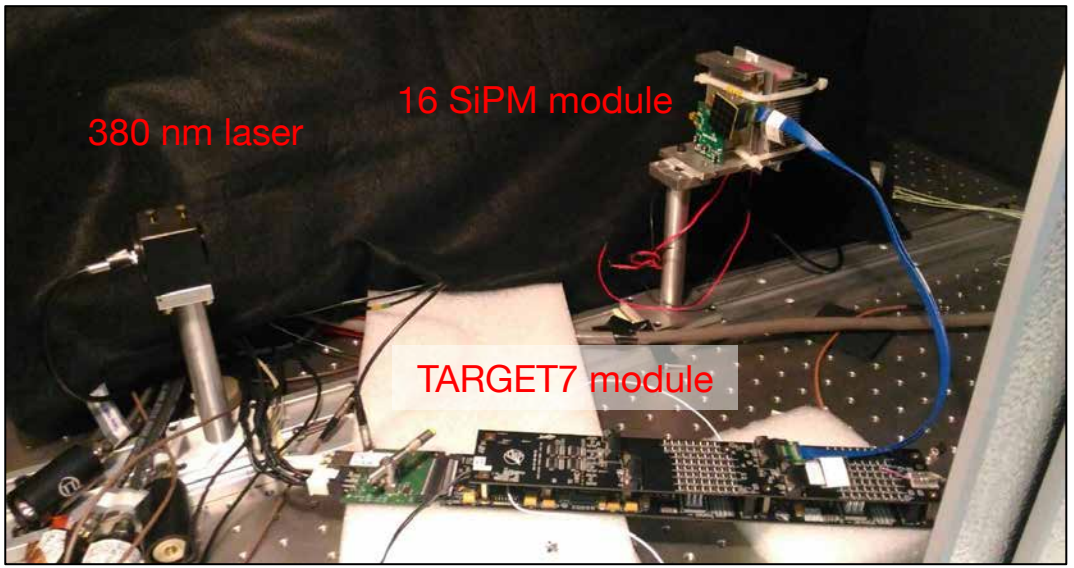


SiPM module readout

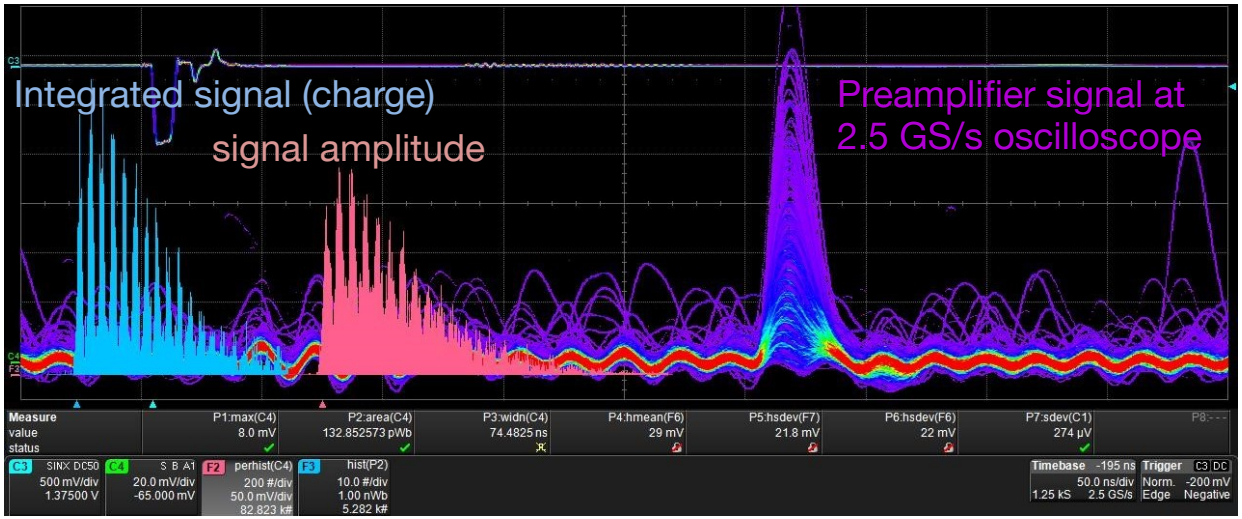
Backplane of the pSCT camera hosting 2 TARGET7 modules
@ Univ of Wisconsin (US)



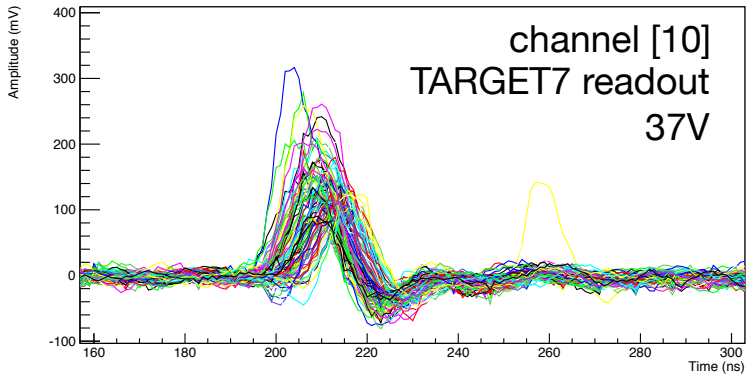
Experimental setup for SiPM module tests and characterization
@ INFN Bari (IT)

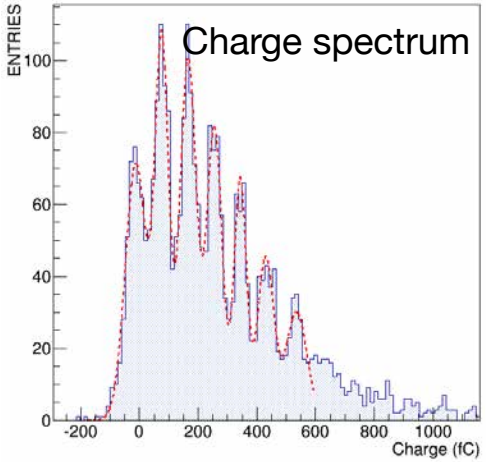


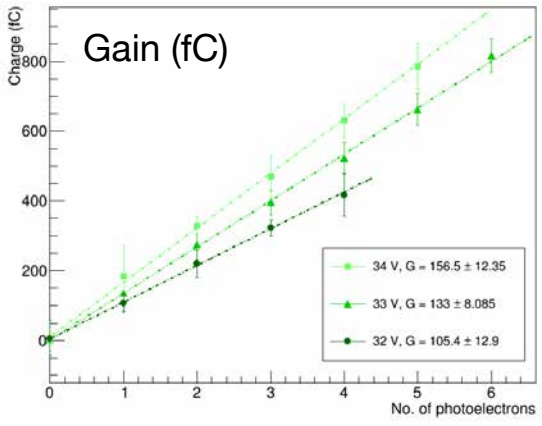
SiPM module readout



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







SCT Telescope

Schwarzschild-Couder dual mirror optics Medium Size Telescope

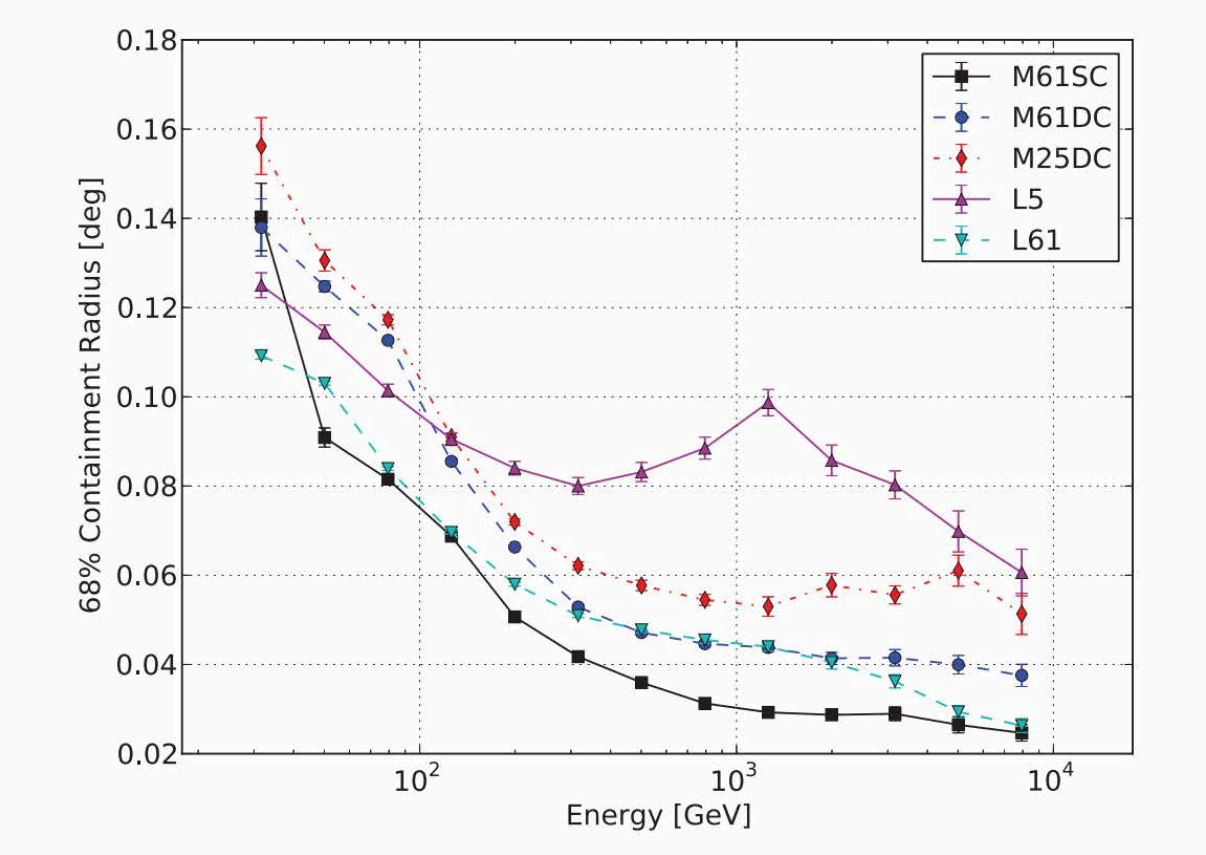
Required energy range	80 GeV – 50 TeV
Energy range (in which subsystem provides full system sensitivity)	150 GeV – 5 TeV
Number of MST/SCT telescopes	25 (South) 15 (North) (*)
Optical design	Schwarzschild-Couder
Primary reflector diameter	9.7 m
Secondary reflector diameter	5.4 m
Effective mirror area (including shadowing)	41 m^2
Focal length	5.6 m
Total weight	80 t
Field of view	8.0 deg

Number of pixels in Cherenkov camera	11328
Pixel size (imaging)	0.067 deg
Photodetector type	SiPM
Telescope readout event rate (before array trigger)	>3.5 kHz
Telescope data rates (readout of all pixels; before array trigger)	12 Gb/s
Positioning time to any point in the sky (>30° elevation)	90 s
Pointing precision	<10 arcseconds
Observable sky	Any astrophysical object with elevation > 24 degrees

(*): Plan to install 10 SCTs either in the CTA North site or CTA South as an upgrade to MST. The positioning system of two telescopes is identical and can be used for installation of both MST-DC or MST-SC optical systems and associated cameras.

SCT Telescope

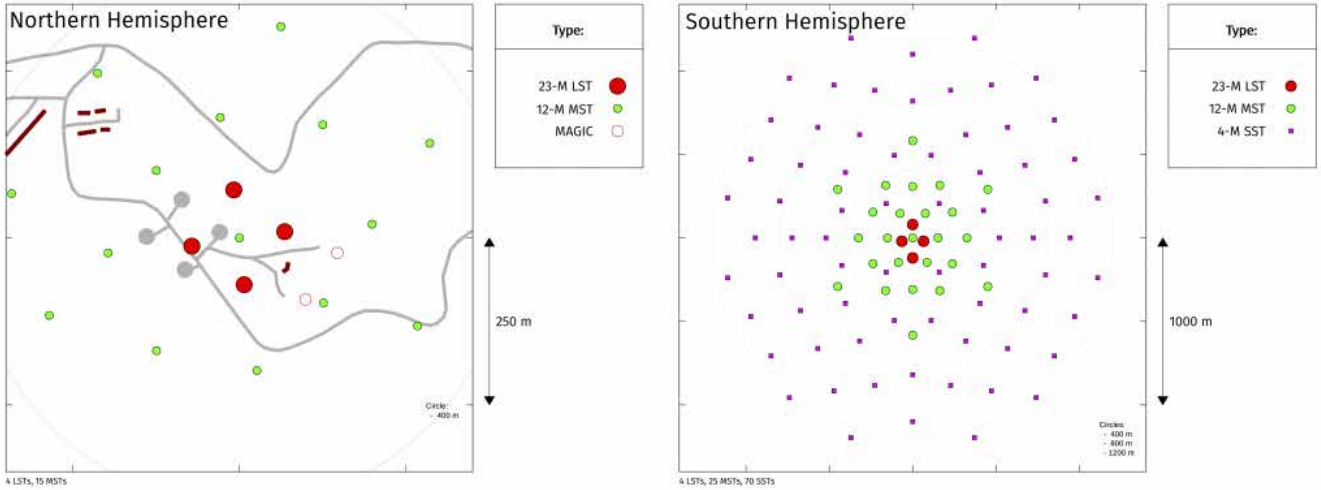
Angular resolution



CTA Telescopes

Telescope	Large	Medium		Small		
	LST	MST	SCT	SST-1M	ASTRI SST-2M	GCT SST-2M
Number North array	4	15	TBD		0	
Number South array	4	25	TBD		70	
Optics						
Optics layout	Parabolic mirror	Davies-Cotton	Schwarzschild-Couder	Davies-Cotton	Schwarzschild-Couder	Schwarzschild-Couder
Primary mirror diameter (m)	23	13.8	9.7	4	4.3	4
Secondary mirror diameter (m)	–	–	5.4	–	1.8	2
Eff. mirror area after shadowing (m^2)	368	88	40	7.4	6	6
Focal length (m)	28	16	5.6	5.6	2.15	2.28
Focal plane instrumentation						
Photo sensor	PMT	PMT	silicon	silicon	silicon	silicon
Pixel size (degr.), shape	0.10, hex.	0.18, hex.	0.07, square	0.24, hex.	0.17, square	0.15-0.2, square
Field of view (degr.)	4.5	7.7/8.0	8.0	9.1	9.6	8.5 - 9.2
Number of pixels	1855	1764/1855	11328	1296	1984	2048
Signal sampling rate	GHz	250 MHz / GHz	GHz	250 MHz	S&H	GHz
Structure						
Mount	alz-az, on circular rail	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner
Structural material	CFRP / steel	steel	steel	steel	steel	steel
Weight (full telescope, tons)	100	85	~85	9	15	8
Max. time for repositioning (s)	20	90	90	60	80	60

CTA sites



Differently from current generation experiments,

CTA will be operated as a proposal-driven open observatory