The SST-1M Cherenkov telescope for high-energy gamma-ray astronomy

and its SiPM-based camera

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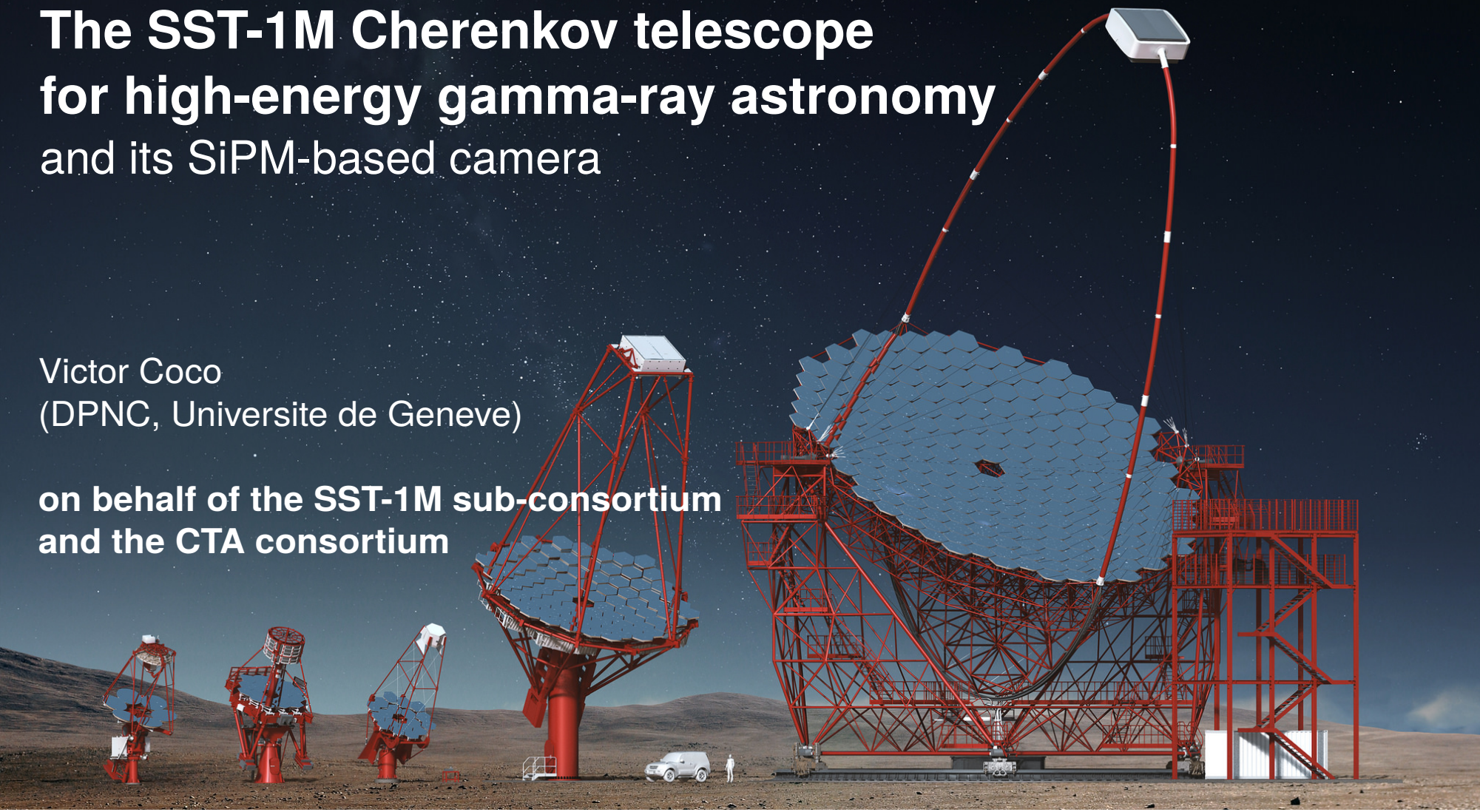
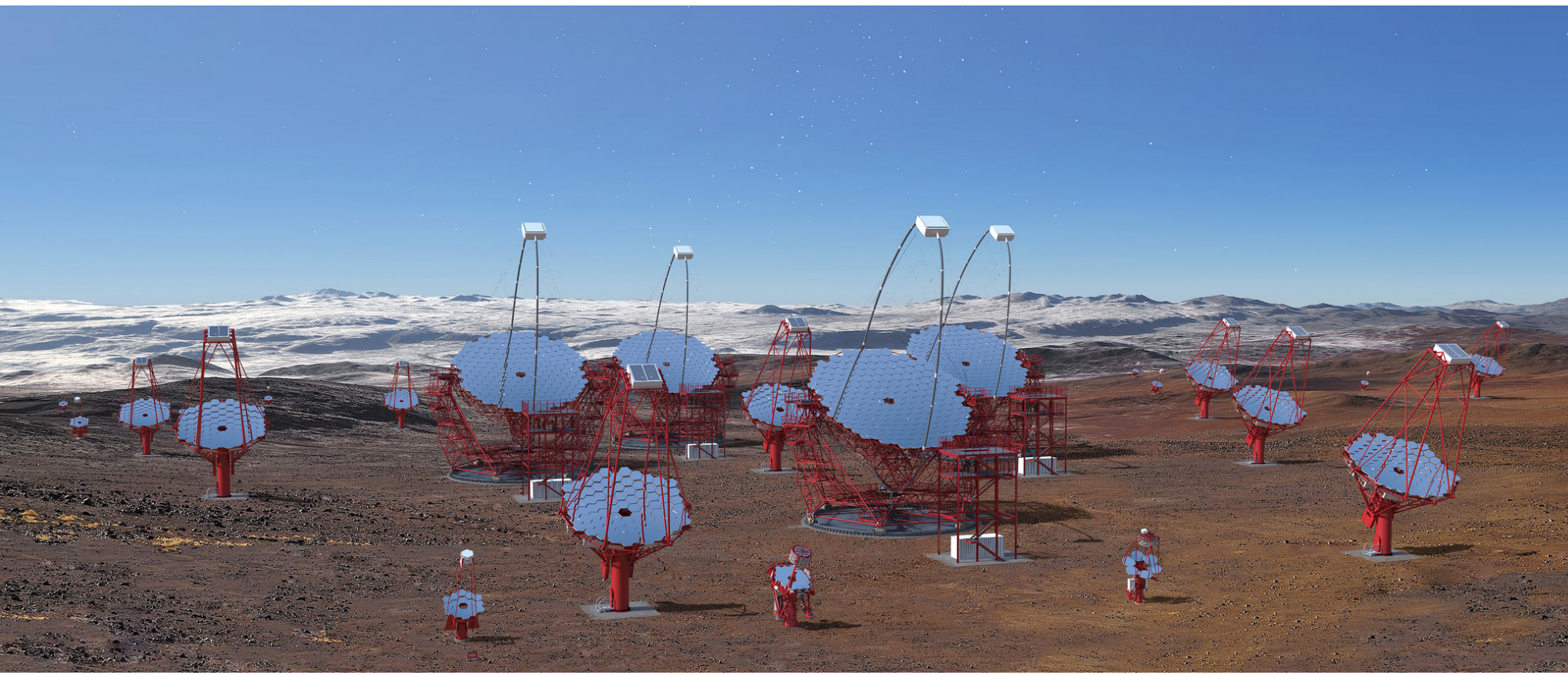
on behalf of the SST-1M sub-consortium and the CTA consortium



The Cherenkov Telescope Array

Ground-based observatory for gamma-ray astronomy at very-high energies.

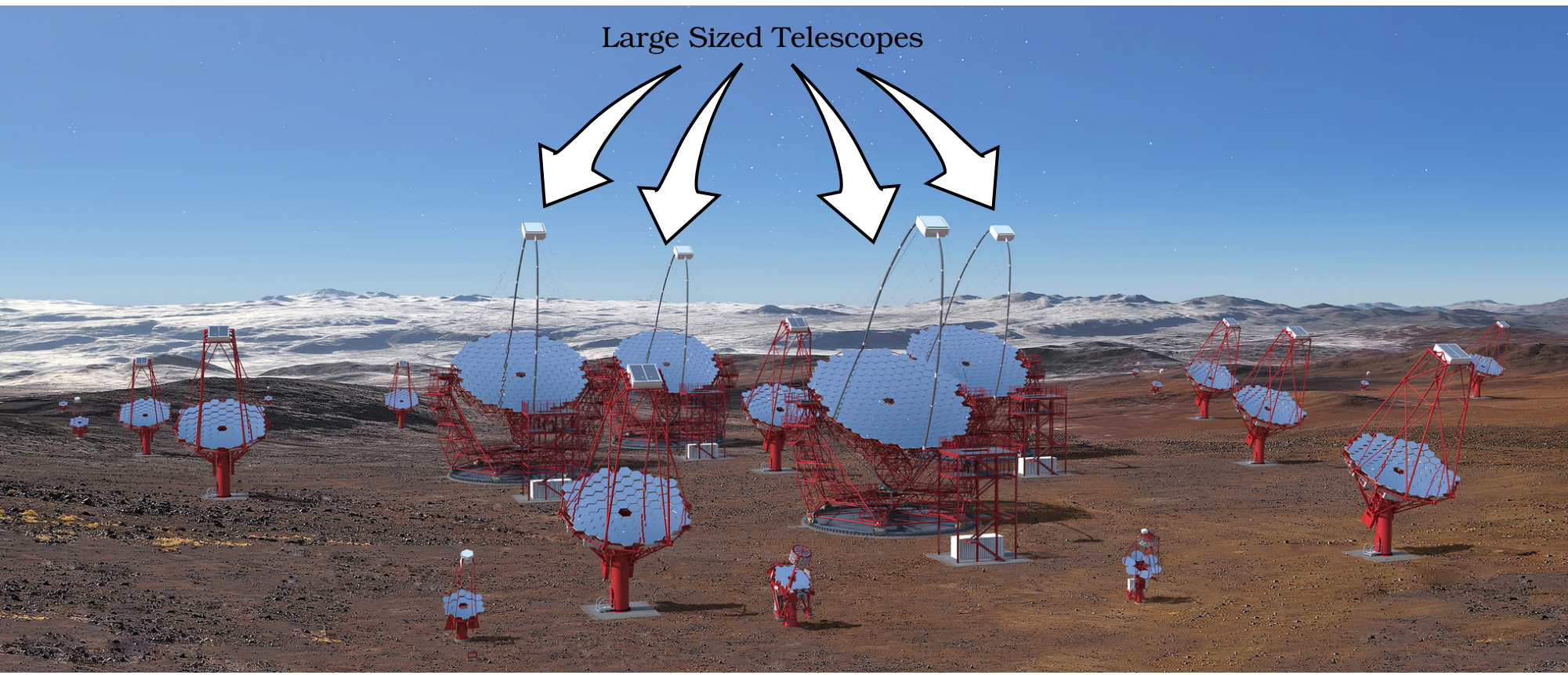
- Northern site in **La Palma, Canary Islands, Spain**
- Southern site in **Paranal, Chile**.
- **See talk on Tuesday by Werner Hofmann**



The Cherenkov Telescope Array

Large Sized Telescopes to cover 20-200 GeV energy range.

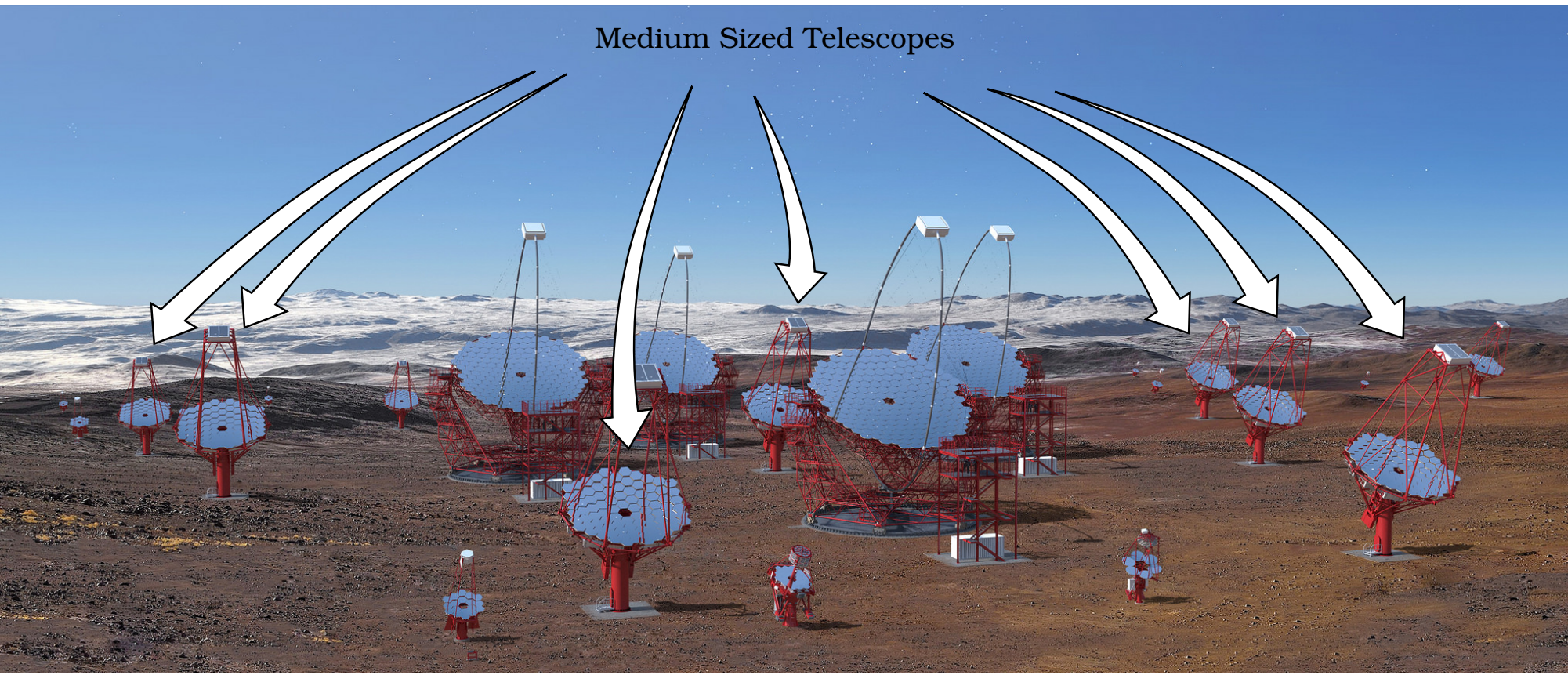
- 23 m Davis-Cotton telescopes.
- Expected to have 4 on each sites (one in construction at the northern site)



The Cherenkov Telescope Array

Medium Sized Telescopes to cover 100 GeV-10 TeV energy range.

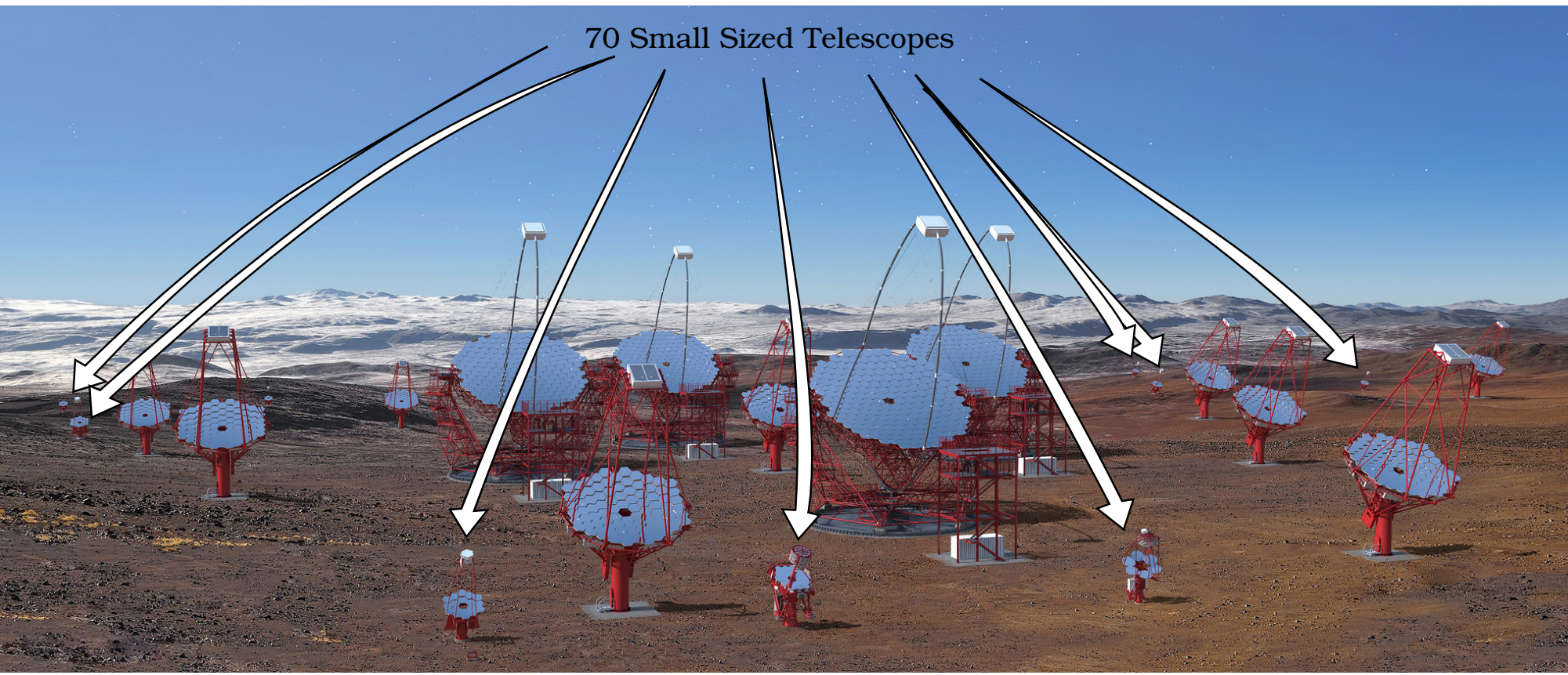
- 12 m Davis-Cotton design and Schwarzschild-Couder (10 m dish) design.
- Expected to have 25 at the southern and 15 at the northern site.



The Cherenkov Telescope Array

Small Sized Telescopes to cover 1-300 TeV energy range.

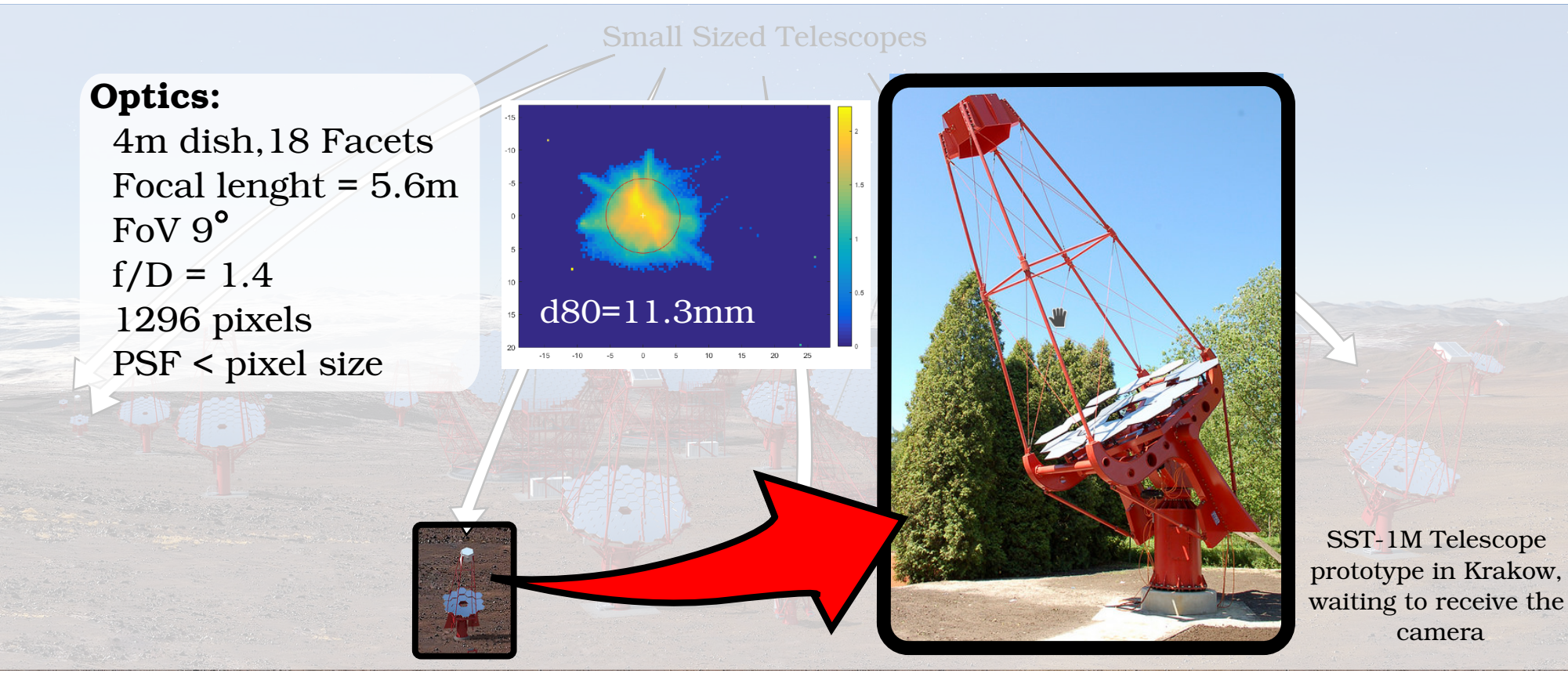
- 2 SC-design (ASTRI,GCT), 1 DC-design (SST-1M)
- Expected to have 70 at the southern site.



The Cherenkov Telescope Array

SST-1M: Davies Cotton design,

- 4 m dish,
- Proven design, lightweight (∼8.6 t), low cost, easy maintenance.
- Innovative SiPM-based camera [Eur. Phys. J. C (2017) 77: 47]
- Fully digital readout → Flexible, programmable

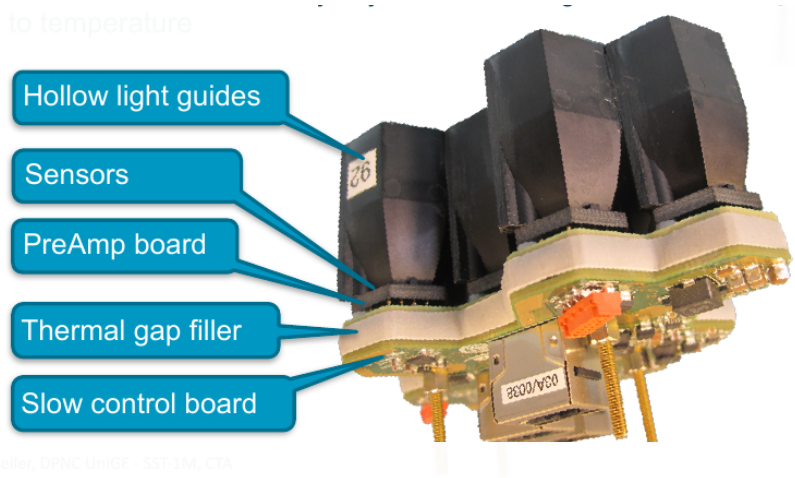


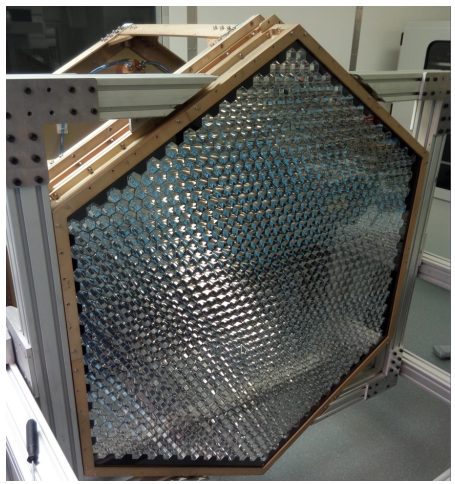
SST-1M Telescope prototype in Krakow, waiting to receive the camera

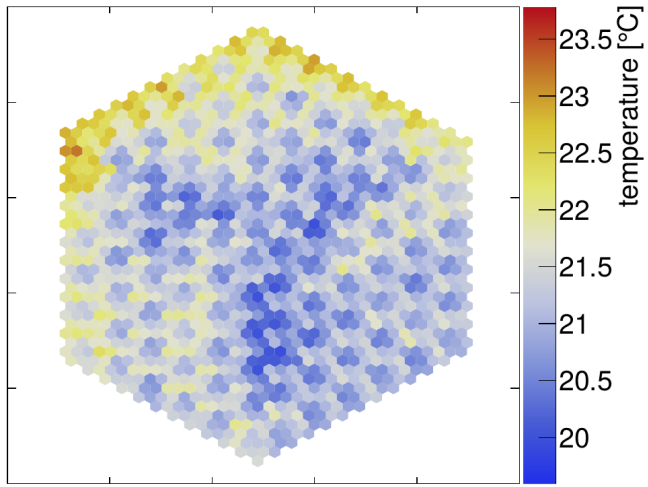
A SiPM based photo-detection plane

[Eur. Phys. J. C (2017) 77: 47]

- 1296 pixels (SiPM + Hollow light guides), splitted in 108 modules.[Astro.Phys. 60(2015) 32-40]
- Entrance window made of borofloat with AR filter coating (cut-off at 540nm).
- Water cooling on the aluminium backplate.
- Bias voltage adjusted automatically by a slow control board to compensate for temperature variations.
- DC coupled electronic will allow to measure NSB from the average noise level.







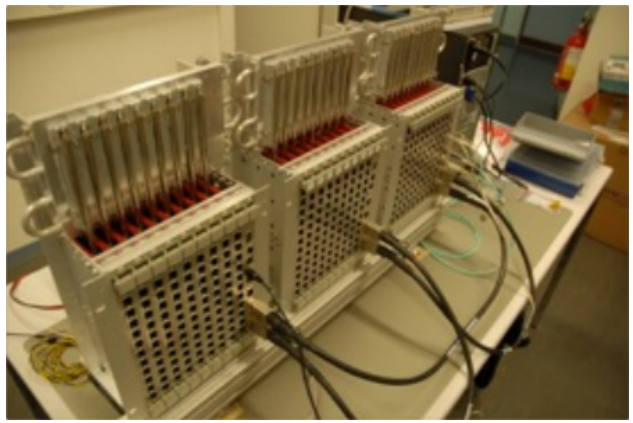
The DigiCam, and its flexible trigger

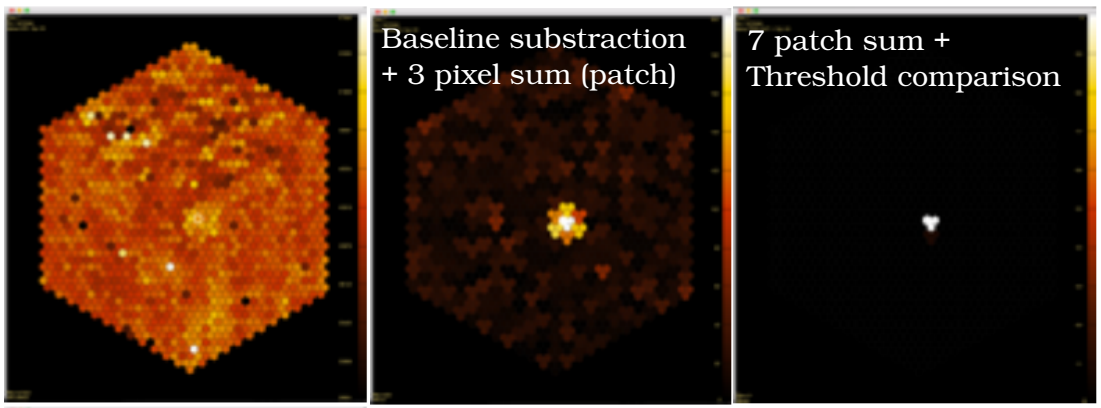
[Eur. Phys. J. C (2017) 77: 47]

- Fully digital readout, sampling at 250 MHz.
- Readout through 10Gb/s ethernet interface, data rate up to 4.5 kHz for 200ns windows.
- Trigger implemented in FPGA

  $\rightarrow$ high flexibility.
- Full trigger information shipped out of the camera

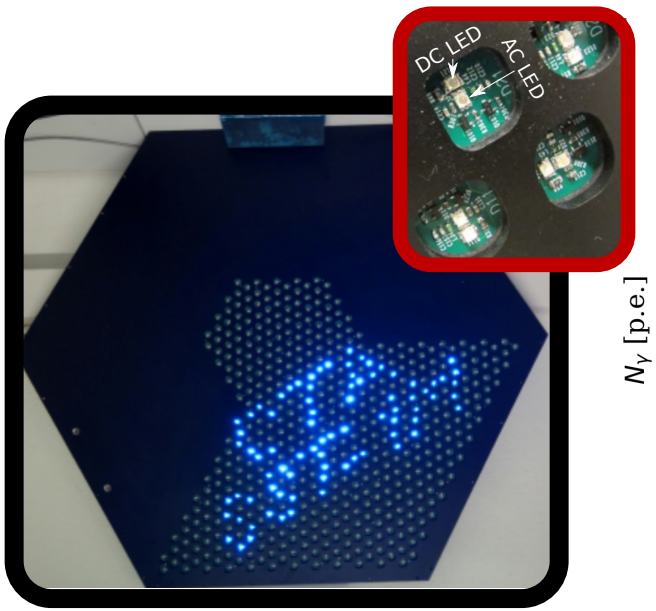
  $\rightarrow$ event-by-event efficiency feasible.
- Digital sum trigger implemented and validated.

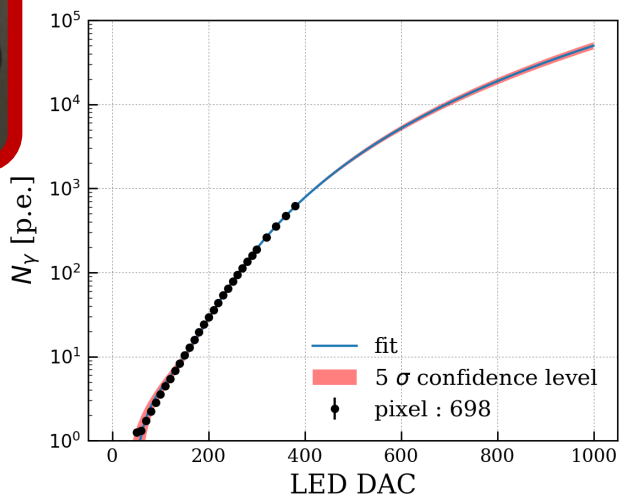


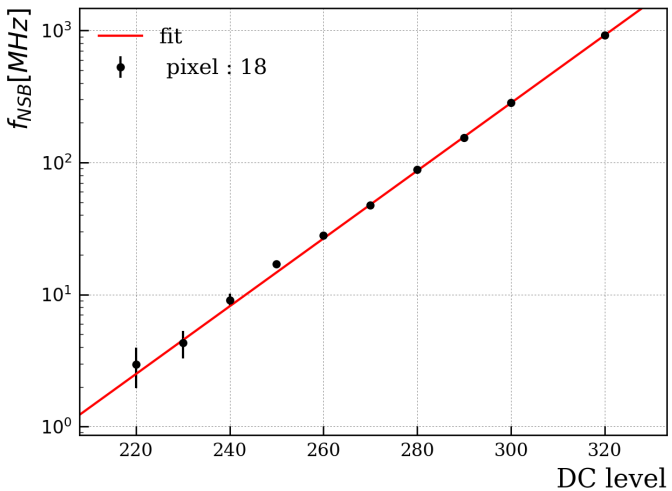


The Camera test setup

- Key tool to commission, qualify and calibrate the camera.
- Emulate signal/background light with AC/DC LEDs.
- Calibration is performed for each LED-SiPM couples.







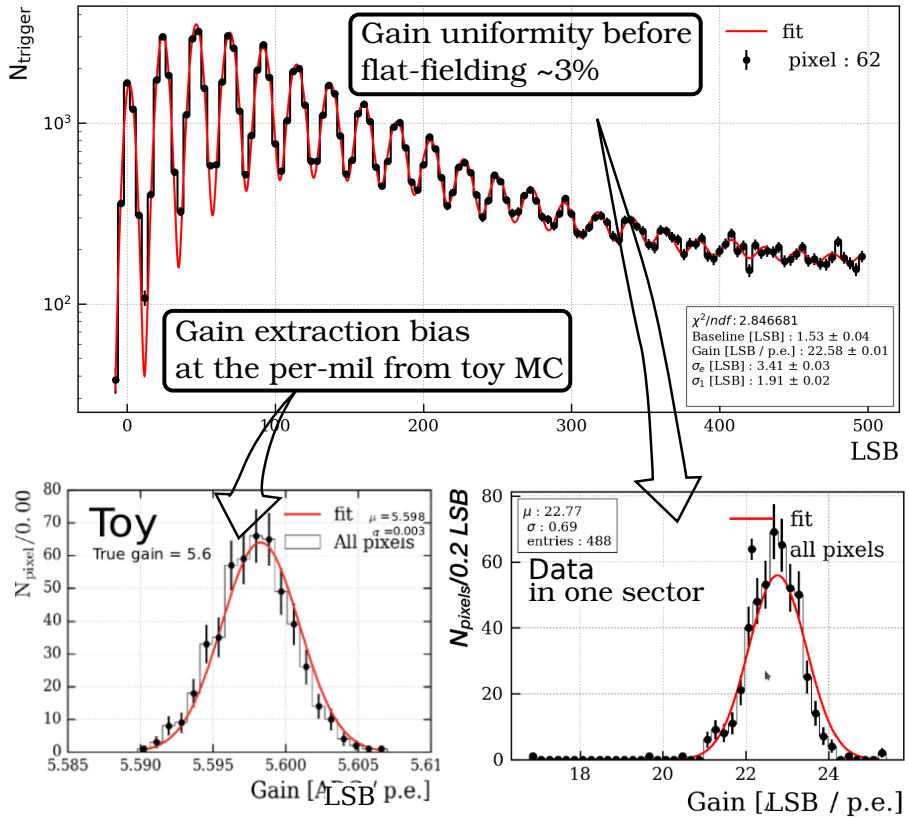
Used to validated the **various hardware mapping**, **readout behaviour**, **trigger algorithm** and extract **SiPM calibration constants**.

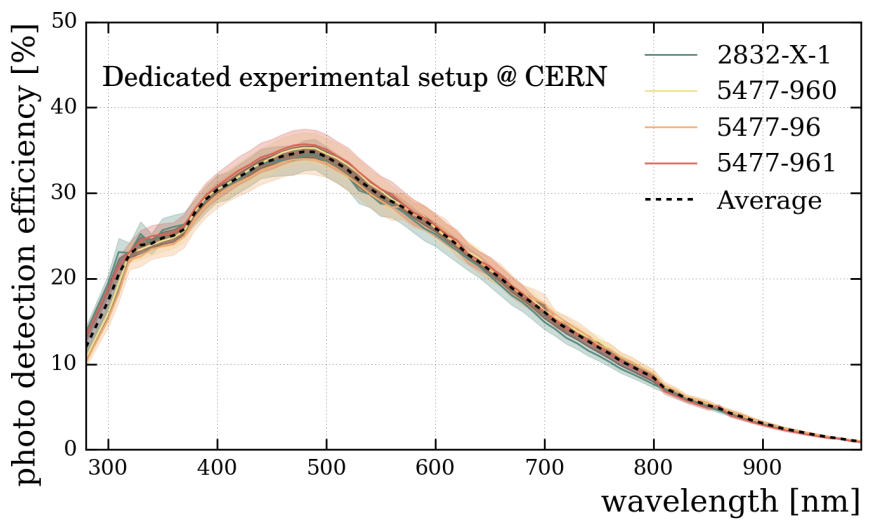
SiPM Calibration

- Parameters to be extracted from the SiPM:
  - Gain and gain variation, electronic noise, dark count rate, optical cross-talk.
  - SiPM photo-detection efficiencies and angular dependence.
  - Pulse shapes in various light conditions.
  - Gain drop as function of background light.

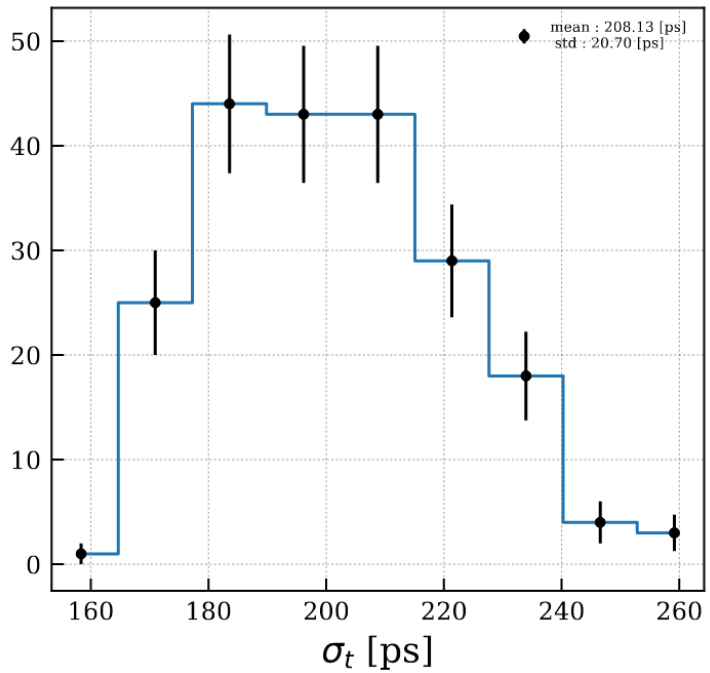
- **Toy MC** developed to **assess each method systematic uncertainty**.

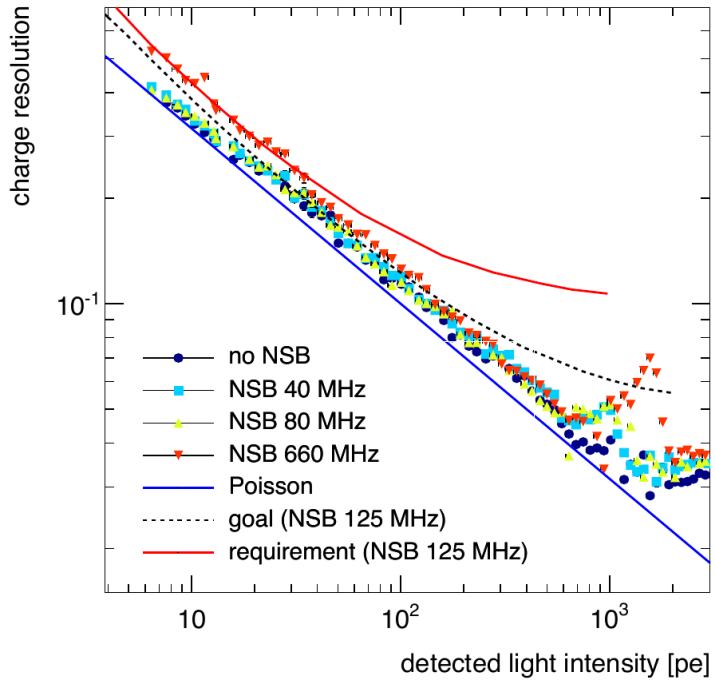
- Plan **on-line calibration** during data-taking, updated at 0.5 Hz.





Charge and Timing resolution

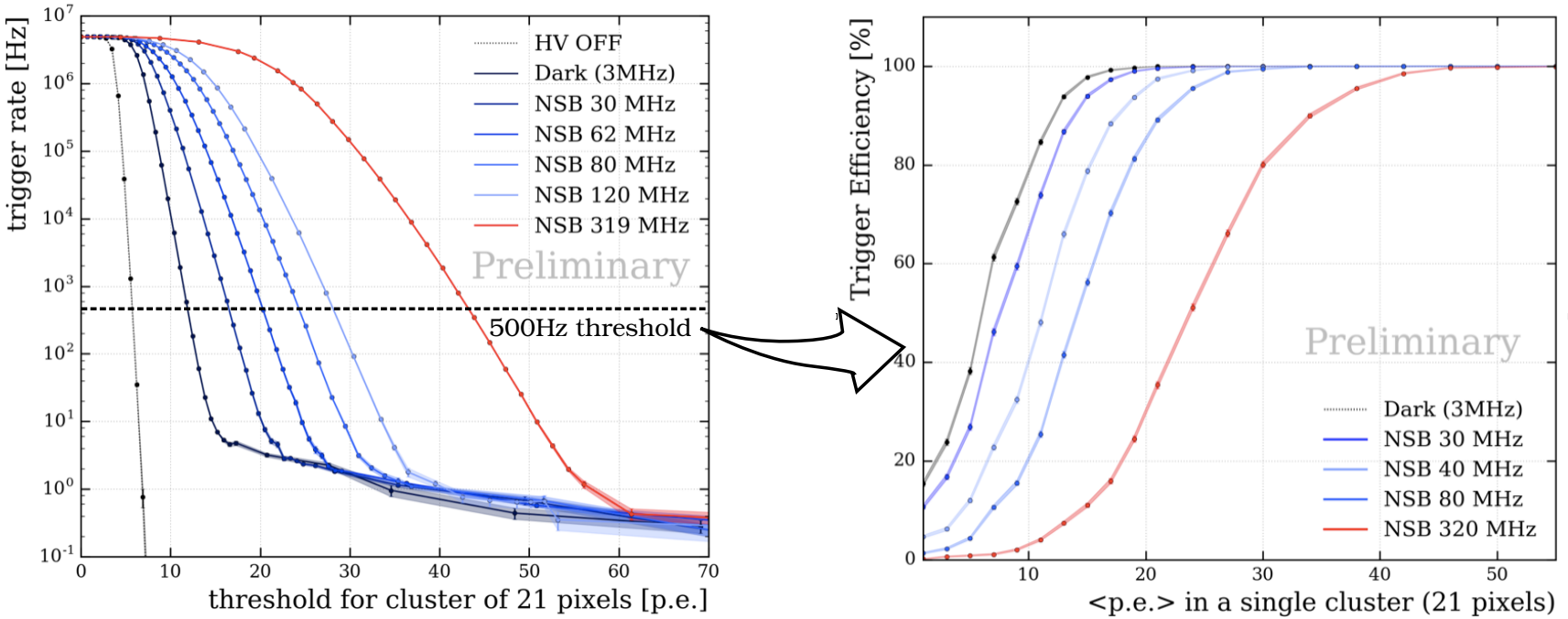




- Timing extracted from fit of the readout trace with pulse template.
- **Relative time resolution between pixels of O(250 ps)**
- Absolute time resolution to be measured with a dedicated setup (ps laser + diffuser) but should be O(180 ps)
- **Charge resolution well below the requirements**, to be repeated for all pixels.

Trigger efficiency and Output rate

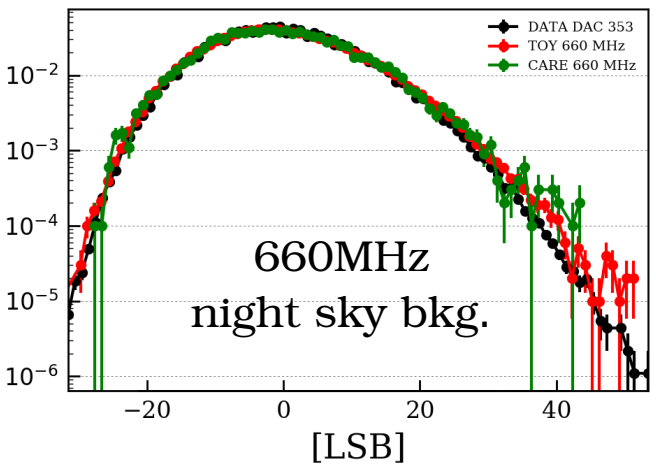
- Output rate studied as function of the cluster threshold and background light.
- Trigger efficiency studied as function of the cluster and background light.

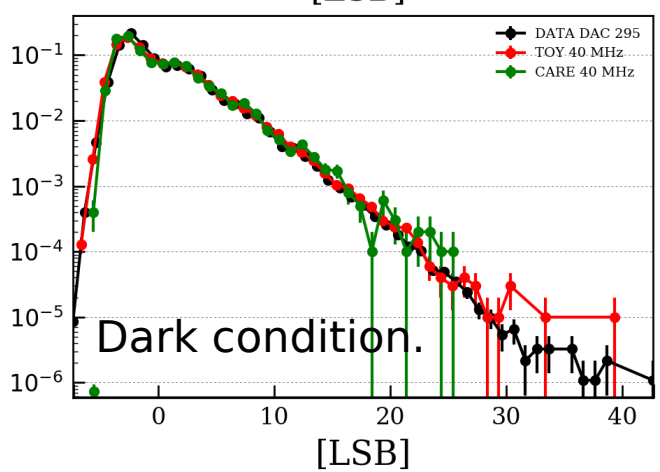


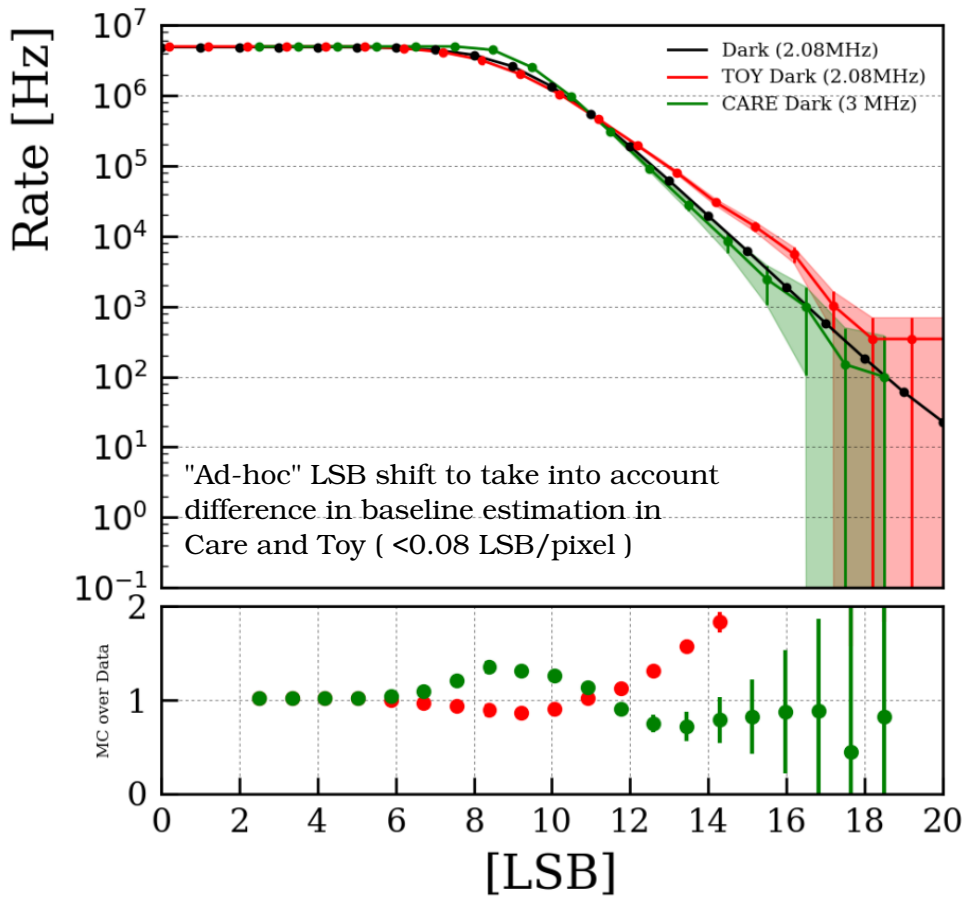
In dark night (40MHz) 100% for events with at least 23 photons clustered in 21 pixels. With high moon (quarter 320 MHz) 100% for events with at least 50 photons clustered in 21 pixels.

Simulation of the camera

- `CARE` allows full simulation (`+CORSIKA+GrOptics`), used to compare with `simtel_array` (default CTA MC).
- A toy MC to emulate the digital electronic behaviour in a flexible way.
- Low level distributions in **good agreement** between **data and MC**.
- Trigger response under study.

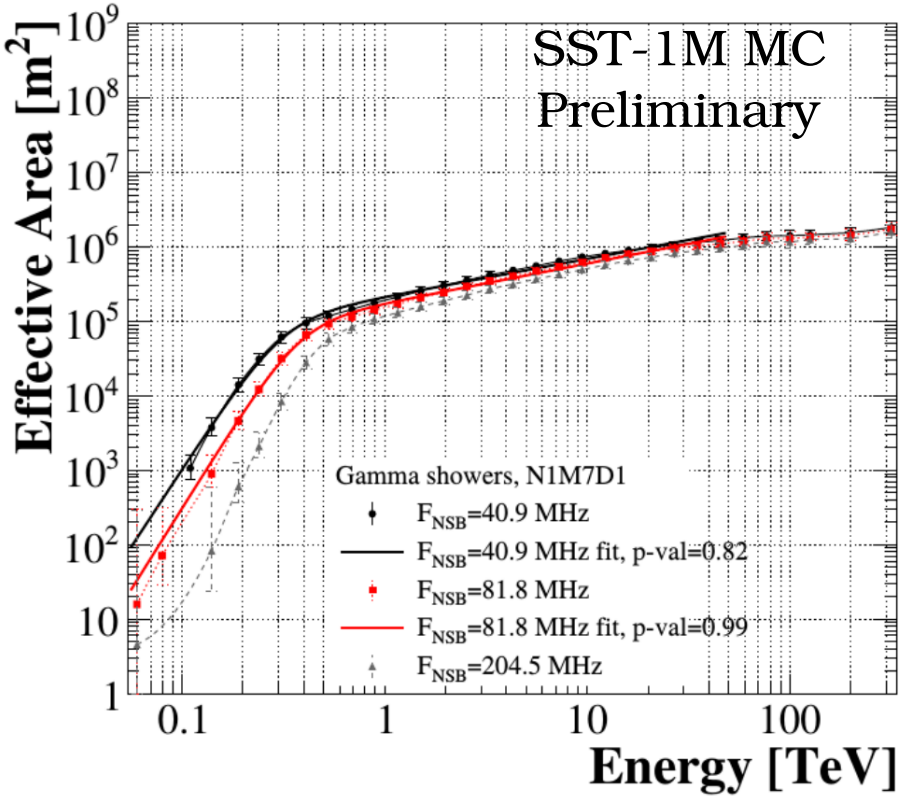


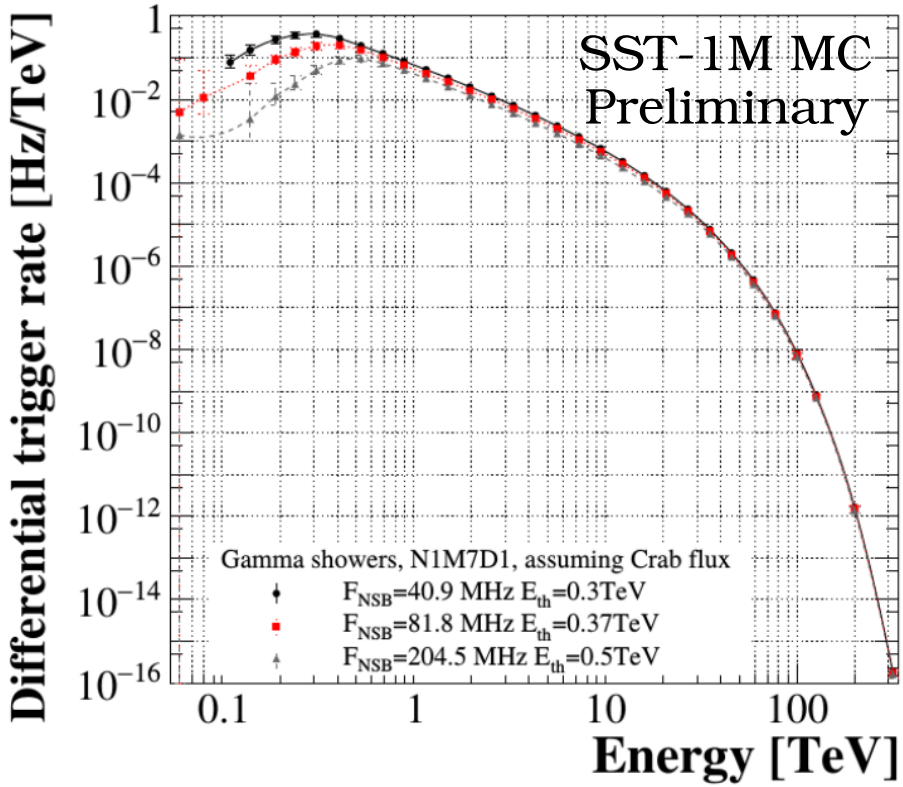




Expected performances

- Simulation of SST-1M with `CORSIKA+GrOptics+CARE`
- Trigger threshold set for readout rate of 500 Hz.





- Trigger **Energy threshold @ 0.3-0.5 TeV** for 40.9-250 MHz background photon rate.
- **Improvement still possible** thanks to the flexible FPGA implementation.

Outlook

- Full qualification to be wrapped up before the end of the summer.
- The camera outperform several of the CTA performance requirements (readout capabilities, time and charge resolution)

  $\rightarrow$ A plus for VHE gamma-ray physics (better timing and energy resolution)!

- **Second camera under production**, with slight modifications.
- PDP plane design reused in LHAASO.
- Camera to be **installed on the telescope in August**.

First light from the sky at the end of the summer!