The optical calibration system for the CTA-North Large Sized Telescope camera

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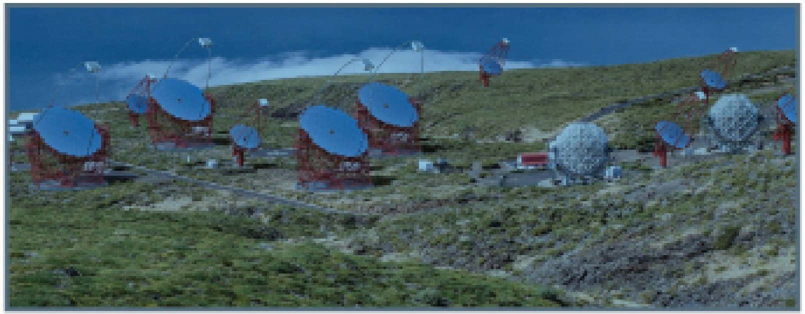
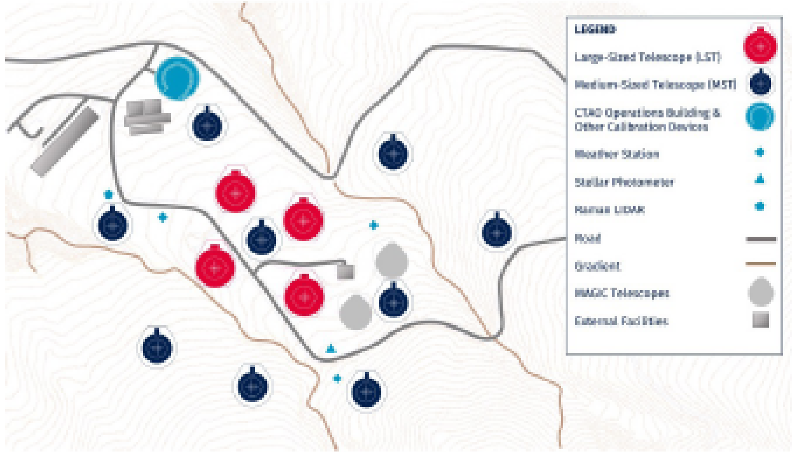
- ✓Cherenkov Telescope Array Observatory (**CTAO**) will be the next generation ground-based high energy (20 GeV to 300 TeV) gamma ray observatory.
- ✓It's an international collaboration formed by 31 countries, more than 200 institutes and more than 1400 members.
- ✓It will be located in the North Hemisphere (La Palma de Tenerife) and South Hemisphere (Chile, Paranal) to have a full sky coverage.
- ✓The 2 sites will be equipped on an area respectively of 1 and 3 square km with 3 different sizes of telescopes: Large (LST - 23 m diameter), Medium (MST - 12 m dia) and Small (SST - 4 m dia).

Two sites for all sky observatory

Initial configurations foreseen

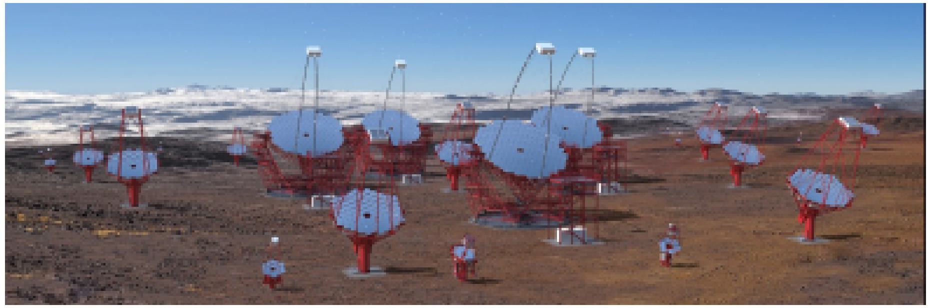
ORM, La Palma, Spain

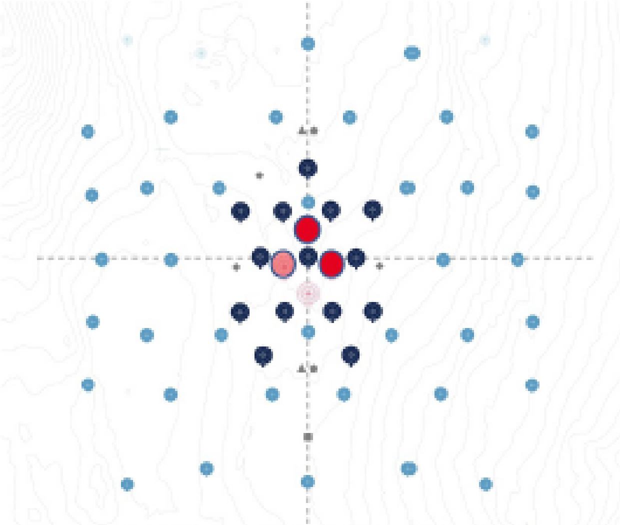




4LSTs, 9MSTs

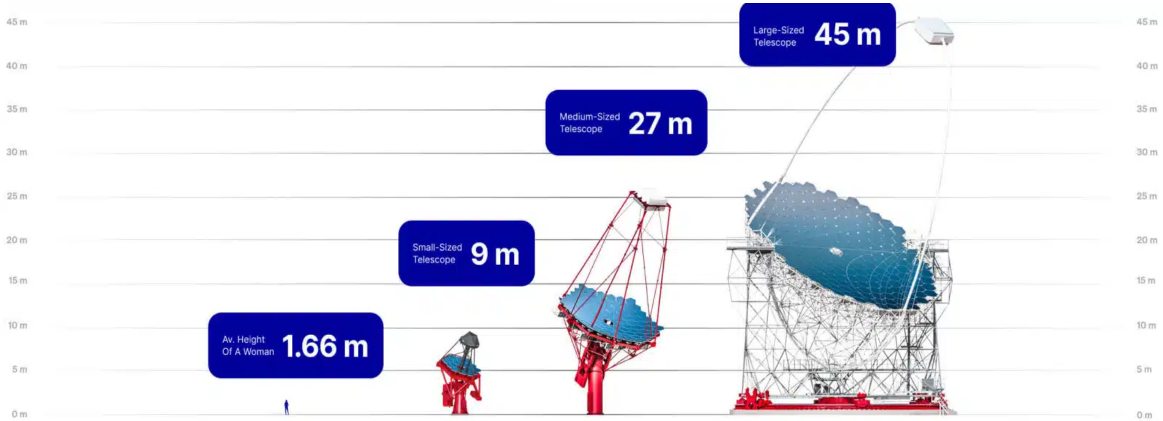
Paranal, Chile





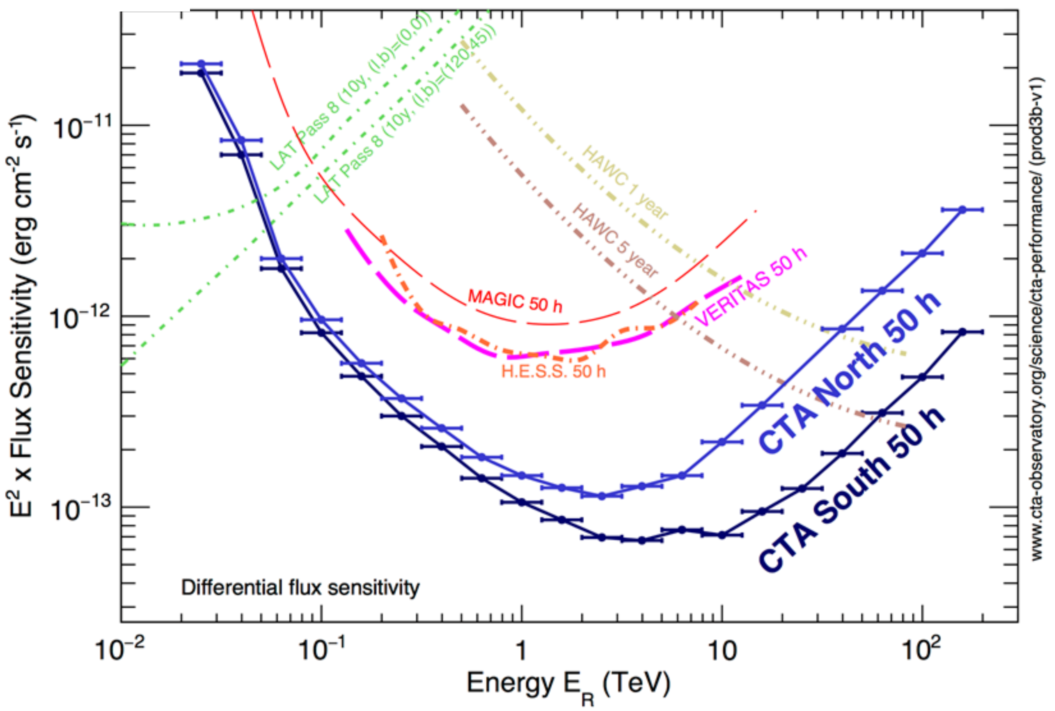
2 LSTs, 14 MSTs, 42 SSTs ← (PNRR)

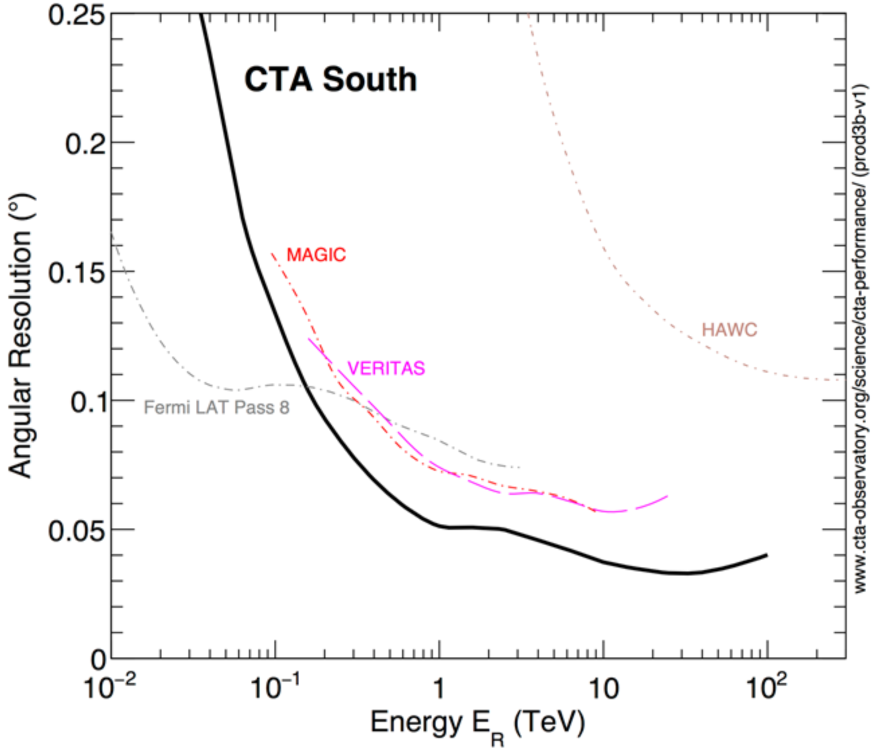
Screenshot



Compared sizes of the 3 telescopes used in CTAO

CTAO sensitivity

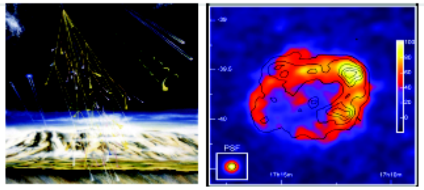




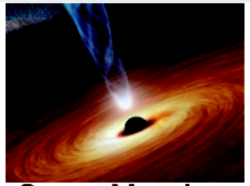
- “Science with the Cherenkov Telescope Array”, https://www.worldscientific.com/worldscibooks/10.1142/10986
- Observations of the Crab Nebula and Pulsar with the Large-sized Telescope Prototype of the Cherenkov Telescope Array, H. Abe *et al* 2023 *ApJ* **956**, 80
- First detection of VHE gamma-ray emission from FSRQ OP 313 with LST-1, ATel #16381

Science of HE γ-ray astronomy is **very** wide

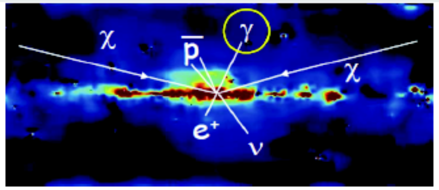
Energy frontier in Astrophysics



Cosmic Ray Origin

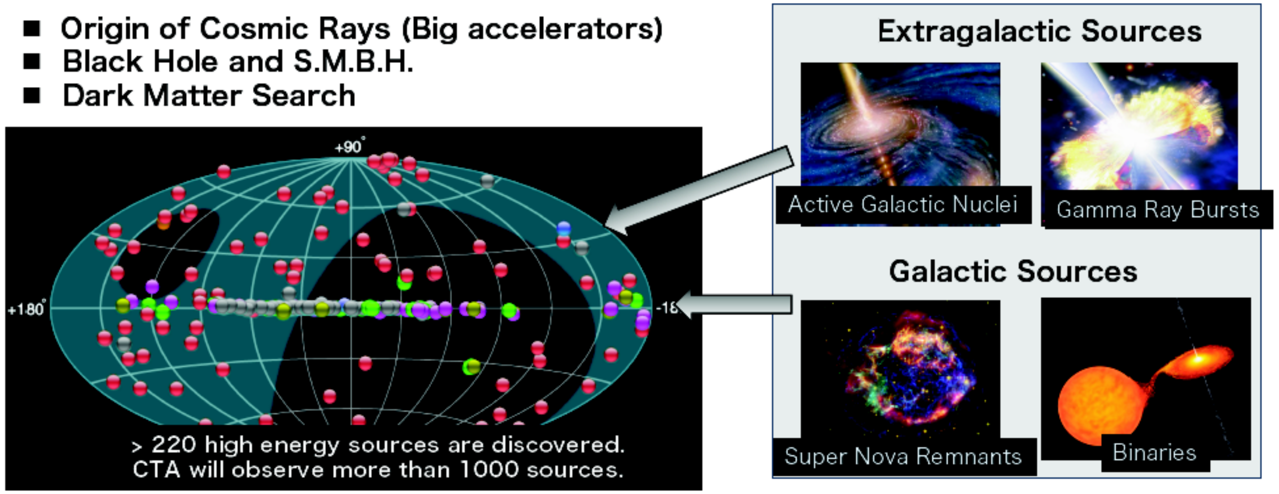


Super Massive Black Holes

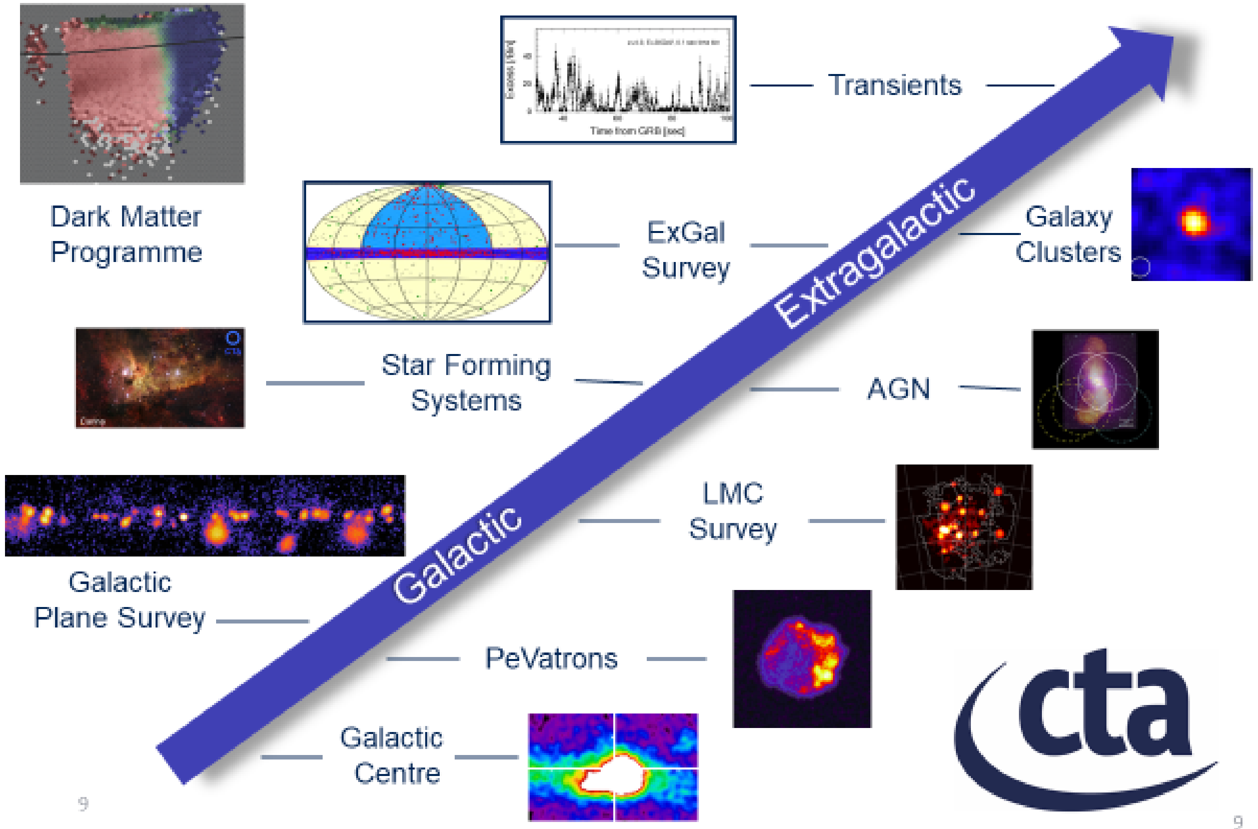


Dark Matter Search (Discovery)

- Origin of Cosmic Rays (Big accelerators)
- Black Hole and S.M.B.H.
- Dark Matter Search



Key Science Projects (KSPs)

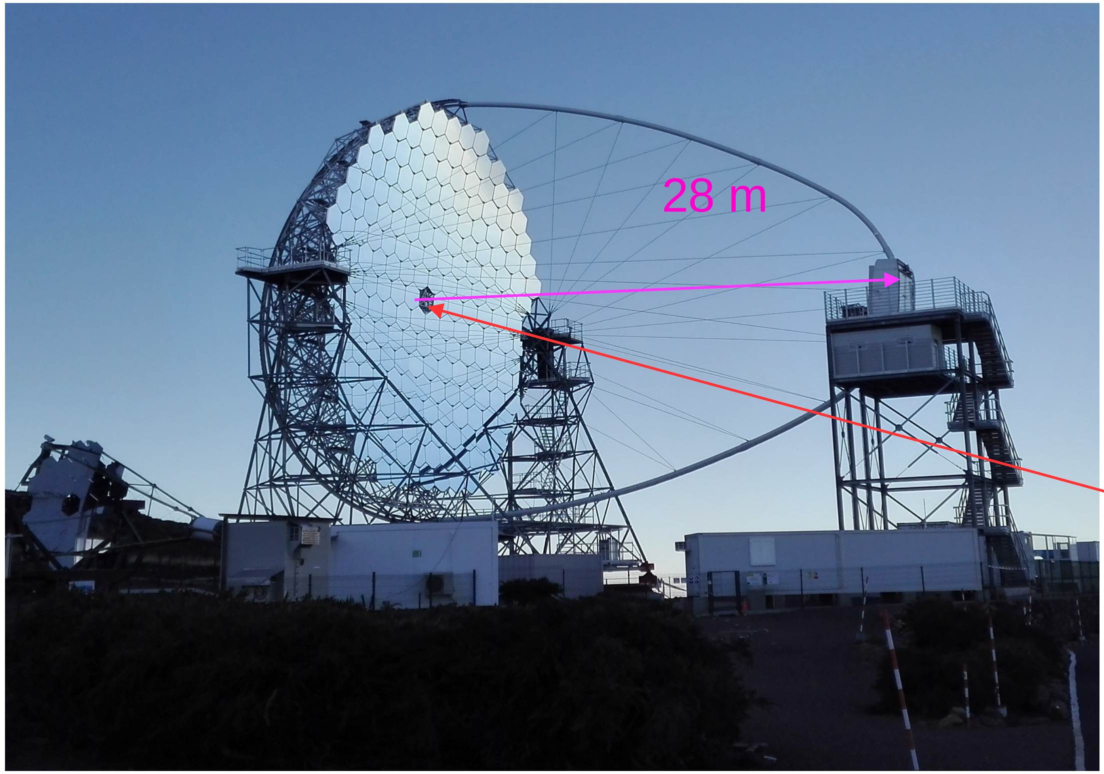


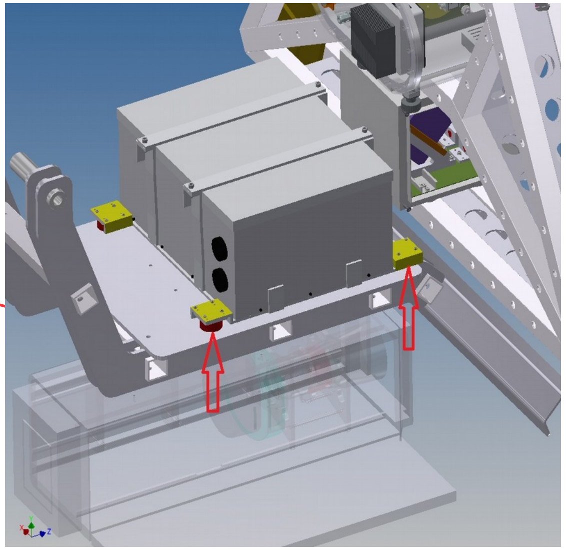
CTAO

- LST-1 is the first Large Sized Telescope installed at CTA-North on December 2018 and taking data since 2019.
- **Calibration Box** (**CaliBox**) installed in the center of the LST-1 dish, firing on the PMT camera 28 m away (1855 1" Ø PMTs over ~4.5 m^2) .
- Calibration done **before** all runs **and** at 100 Hz also **during** data taking.

A good **uniformity** and **continuous calibration** are **essential** for the performance of the LSTs.

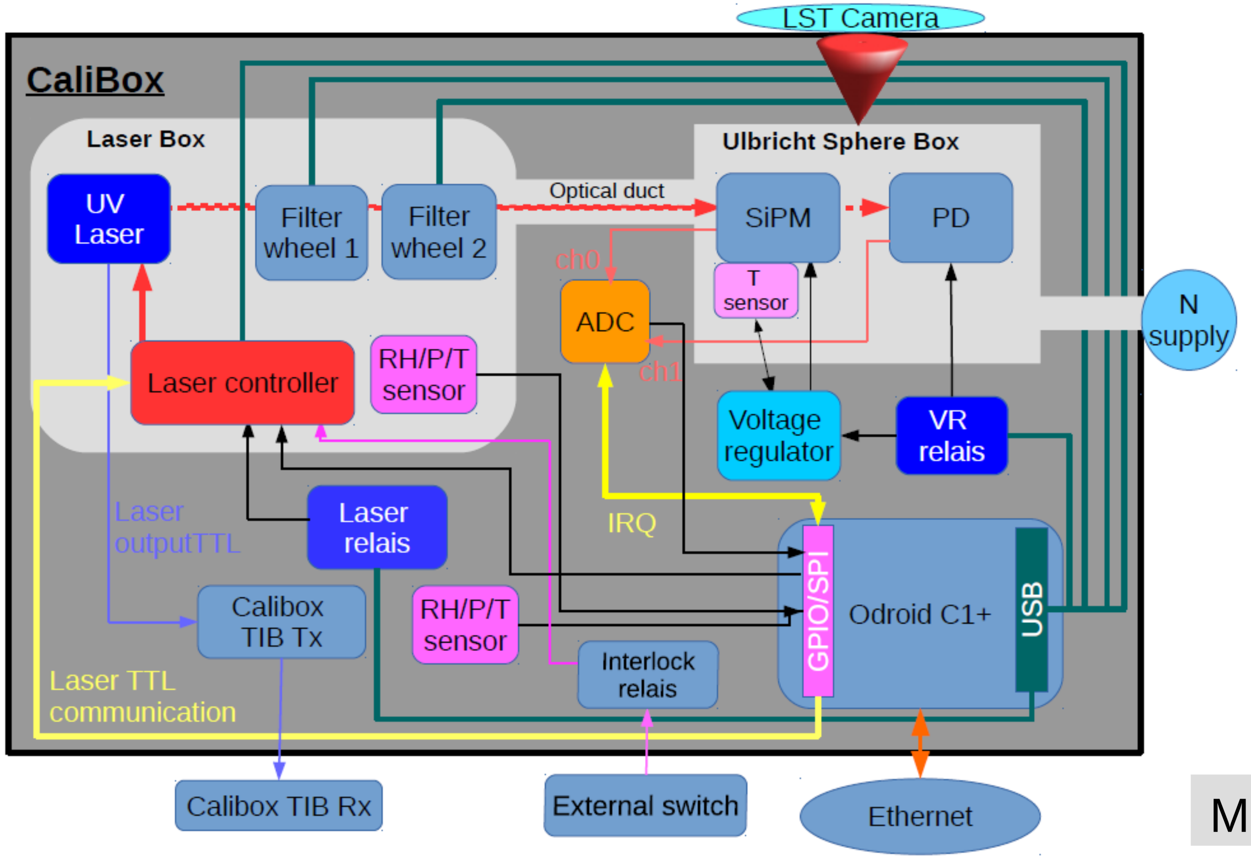
	Large-Sized Telescope (LST)
Energy range (in which sensitivity is optimized)	20 GeV – 150 GeV
Number of LST telescopes	4 (North)
Optical design	Parabolic
Primary reflector diameter	23.0 m
Effective mirror area (including shadowing)	370 m^2
Focal length	28 m
Total weight	103 t
Field of view	4.3 deg
Number of pixels	1855
Pixel size (imaging)	0.1 deg
Photodetector type	PMT
Telescope readout event rate after array trigger	>7.0 kHz
Telescope data rates (readout of all pixels; before array trigger)	24 Gb/s
Positioning time to any point in the sky (>30° elevation)	30 s
Pointing precision	<14 arcseconds
Observable sky	Any astrophysical object with elevation > 24 degrees

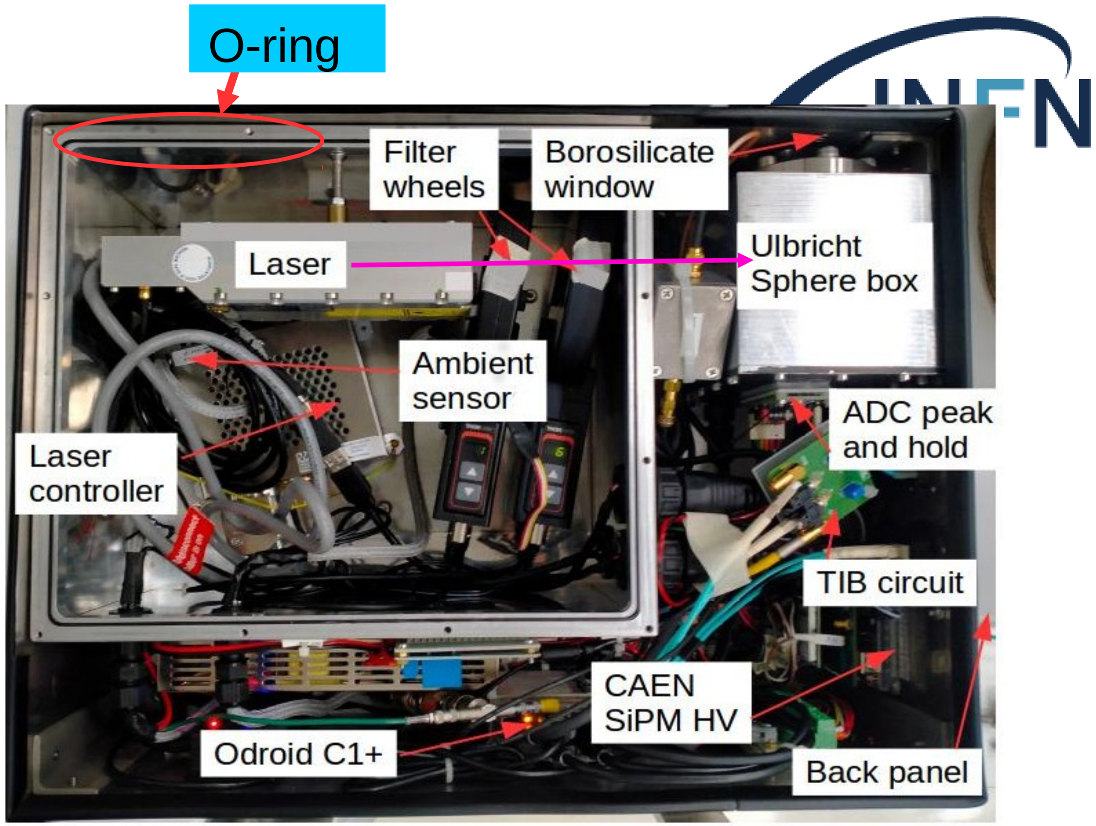




View of PMT camera from Calibox

Block diagram of Calibox





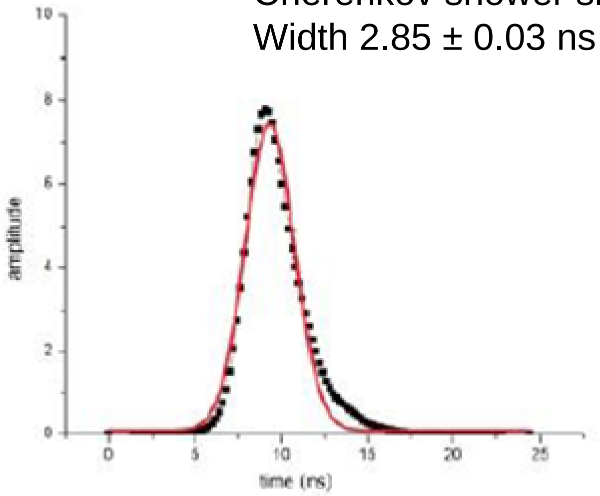
Main concept : disentangle optics – electronics blocks

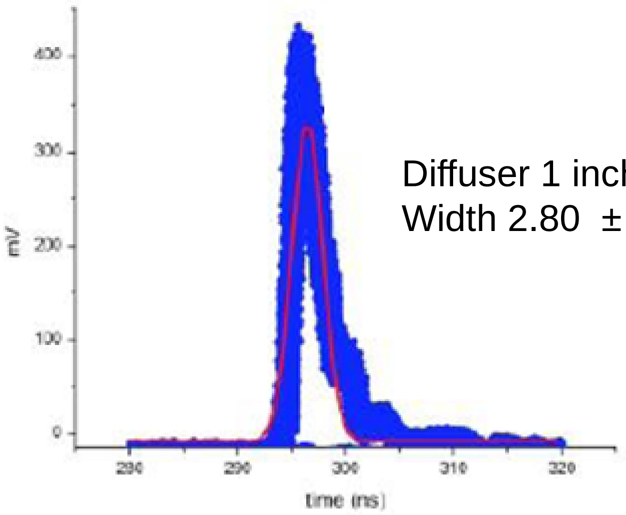
Main hardware :

- UV Laser Teem Photonics - λ = 355 nm - 400 ps signal - embedded Peltier - dedicated laser controller
- 2 Filter wheels - 6 positions each - 5 neutral OD filters each (OD from 1 to 4 each set)
- SiPM and Photodiode for laser signal internal monitoring via dedicated ADC peak and hold circuitry
- Voltage regulator circuitry for SiPM temperature compensation
- Transmitter for optical laser signal to LST Trigger Interface Board
- ODROID C1+ Linux computer to control all components and communication to LST1 system
- Hardware circuitry for interlock to laser

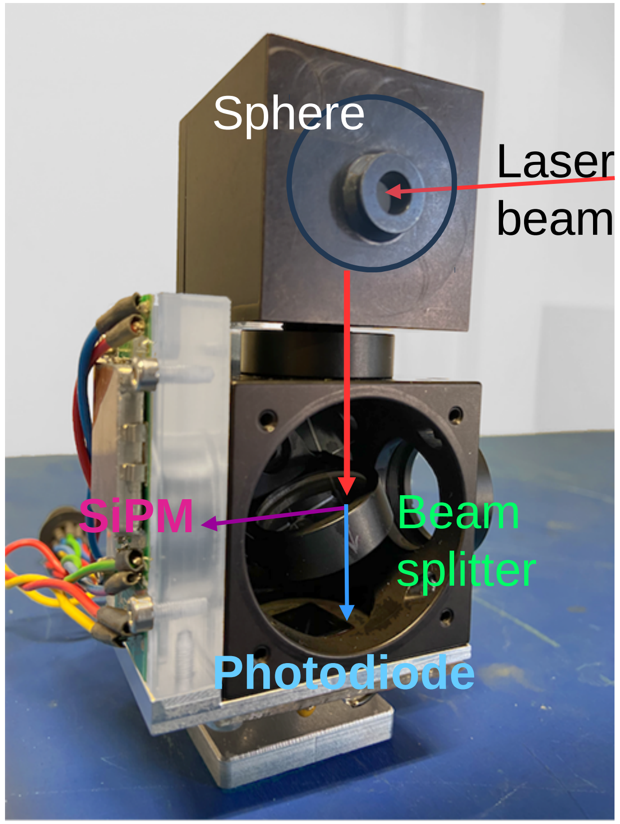
Signal after Ulbricht Sphere comparable with expected Cherenkov shower signal shape

Cherenkov shower signal
Width 2.85 ± 0.03 ns





Diffuser 1 inch diameter
Width 2.80 ± 0.03 ns



Ulbricht Sphere Box with optical path shown

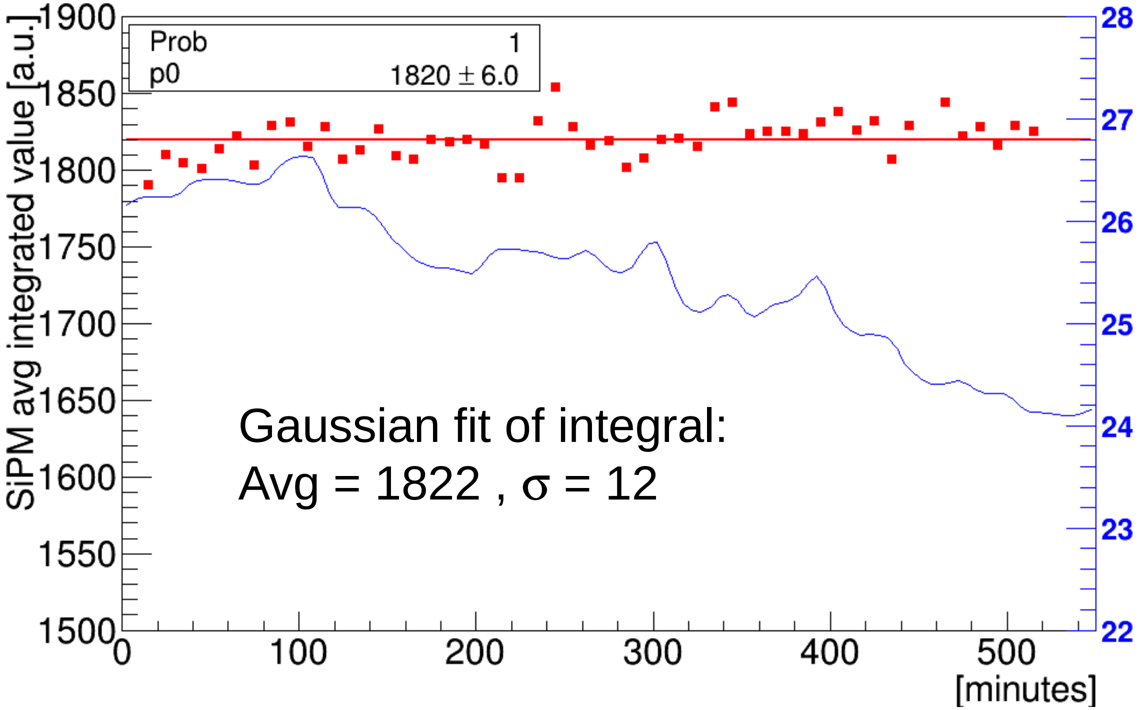
Laser beam diffused by sphere split between SiPM and Photodiode to have sensitivity to both low (SiPM) and high (PD) number of photons.

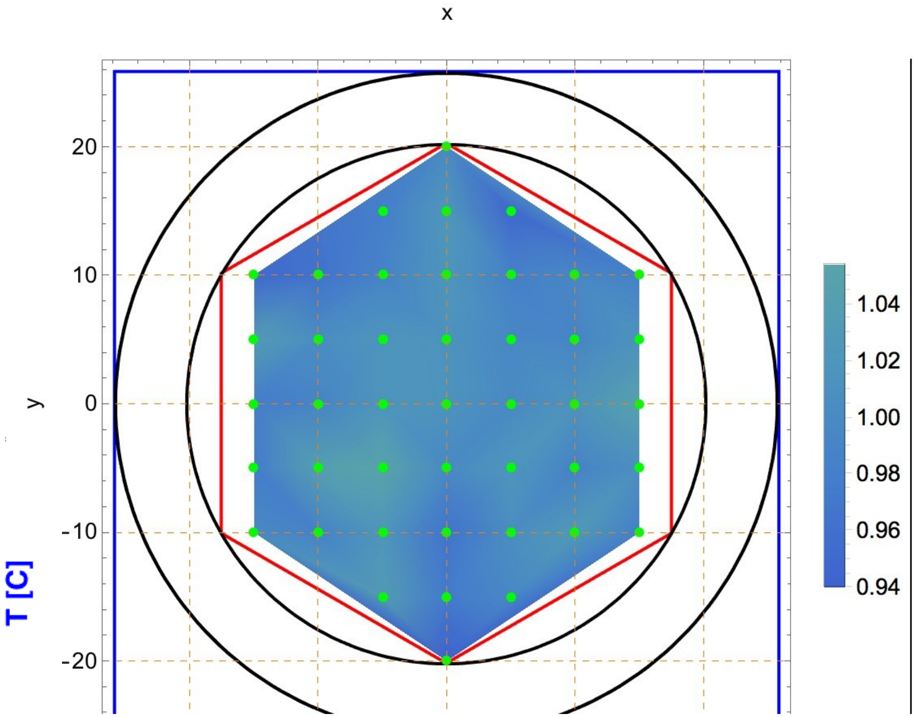
Performances of the CaliBox

- Time stability of the photon flux : peak-to-peak stability 1.2%
- Photon flux Uniformity measured < 1% (at 5 m distance)
- Photon flux range from O(1) to O(10^4) to camera SiPMs with usage of different OD filter combinations
- Monitor photons sent to camera : SiPM/PD detection and Peak and Hold 12-bit ADC (IRQ controlled) measured
- Peak and Hold ADC electronics and integrated signal linearity validated
- SiPM voltage continuously compensated by dedicated temperature controller
- Temperature and RH under control inside internal and external boxes
- Laser trigger TTL optical signal transmitted to camera Trigger Interface Board to keep calibration under control also during DAQ
- System under experiment control via OPC-UA server running on Odroid C1+ controlling all hardware

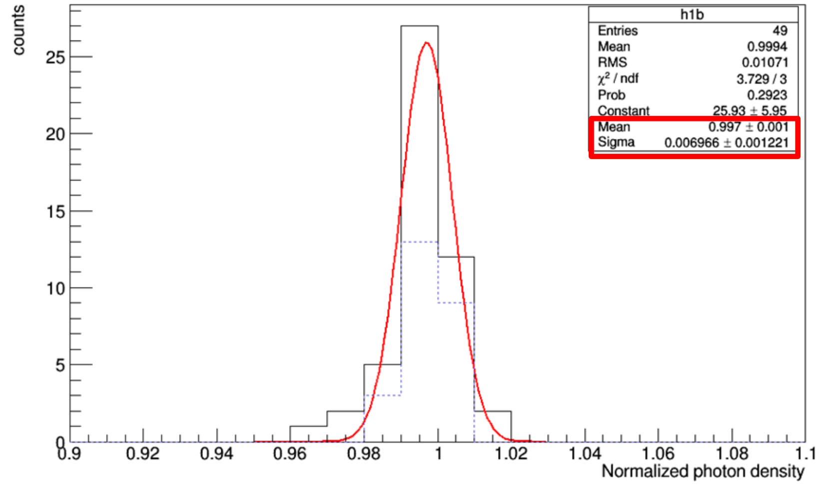
Tests in Laboratory

Laser signal **stability** every 10 minutes with SiPM inegrated signal (sampled by DRS4@1 GHz, 1000 evts/point) : stable **below 1%** during several hours.
Ambient temperature monitored - SiPM Voltage compensated for T by dedicated sensor to voltage regulator.
Peak to peak stability at 1.2%

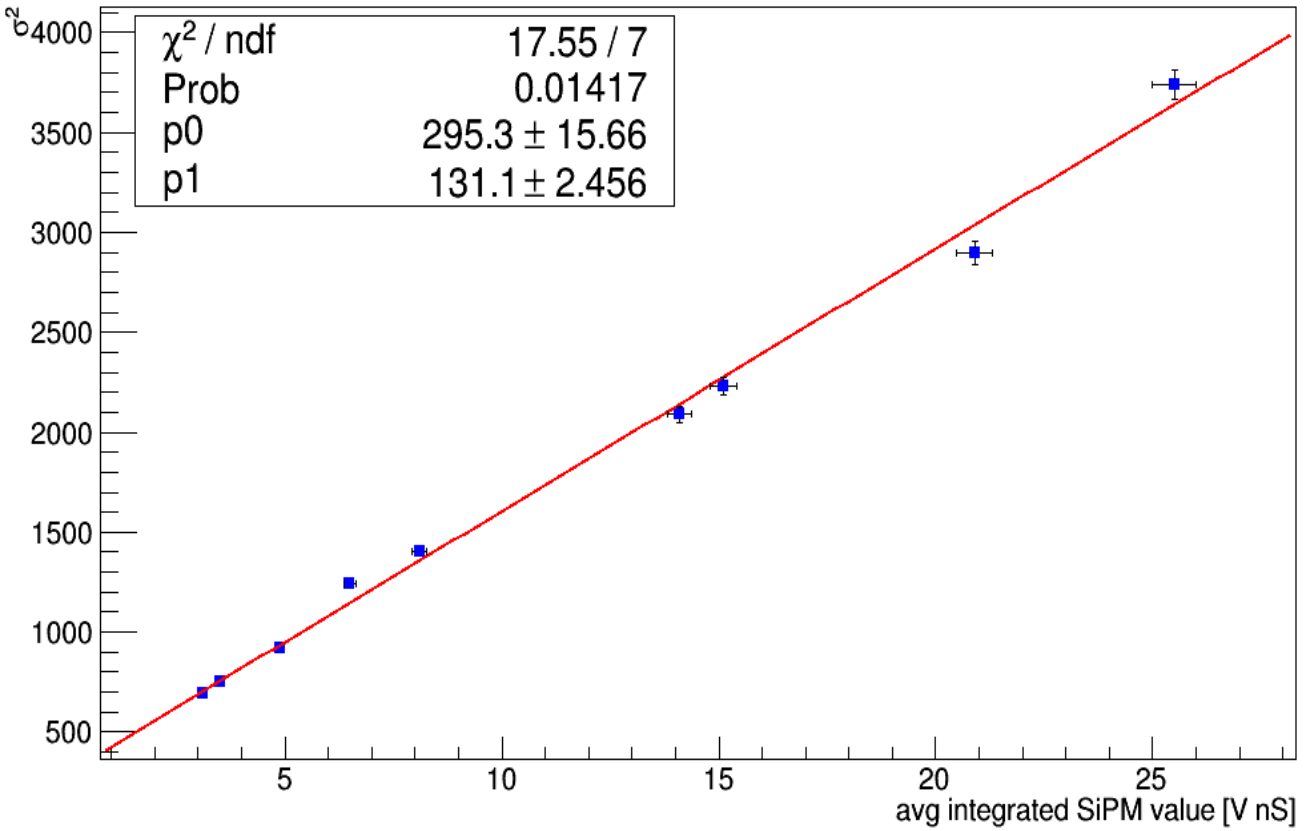




Photon uniformity measured at 5 m distance from Calibox **at better than 1%**



Tests in Laboratory



Integral variance σ^2 vs mean SiPM integrated signal (sampled by DRS4@1GHz - 1000 evts) for several filter combinations (3-4 filter optical density).
Linear fit P1 parameter equal to the pulse-integral/pe.

This is used in the evaluation of CaliBox photon flux sent to the camera.

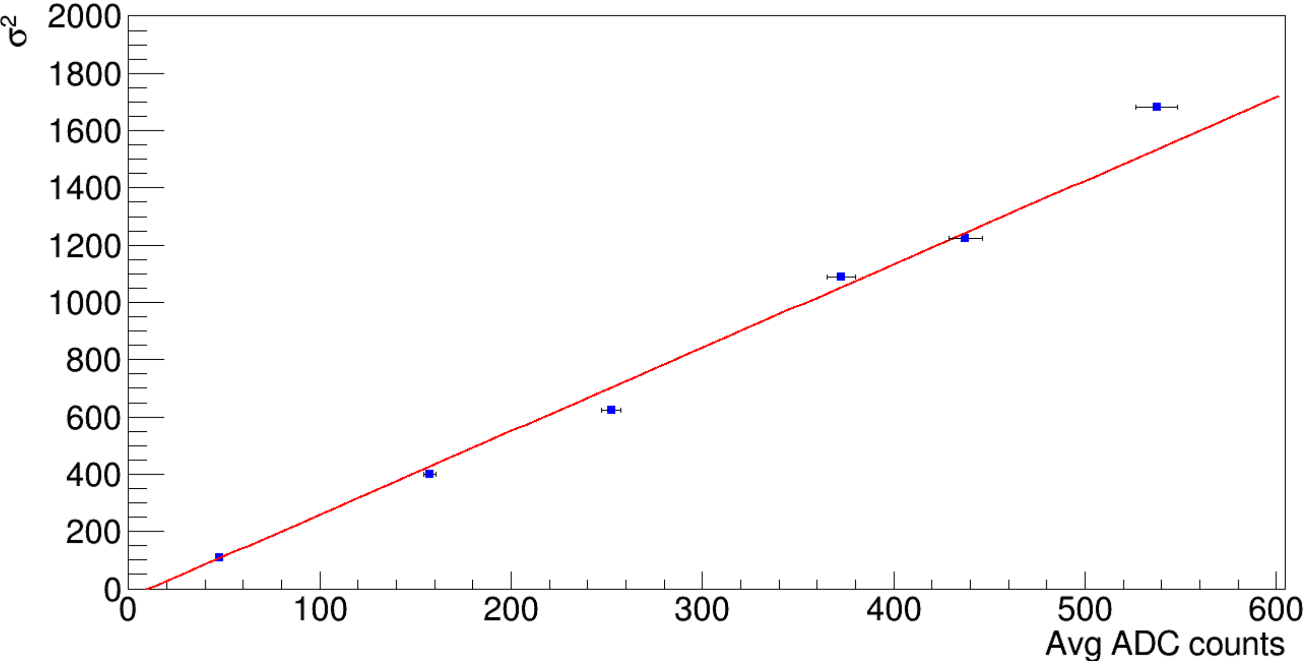
At 6 cm from center of Ulbricht sphere estimated $(3.3 \pm 0.2) \times 10^7$ ph/cm^2

guarantees the dynamics of photons sent to the camera

Tests in Laboratory

σ² ADC measurement vs ADC avg (1000 evts) measured for several filter combinations (3-4 filter optical density).
Error includes the error due to the jitter of the CS.
From this we evaluate the p.e./ADC conversion factor.

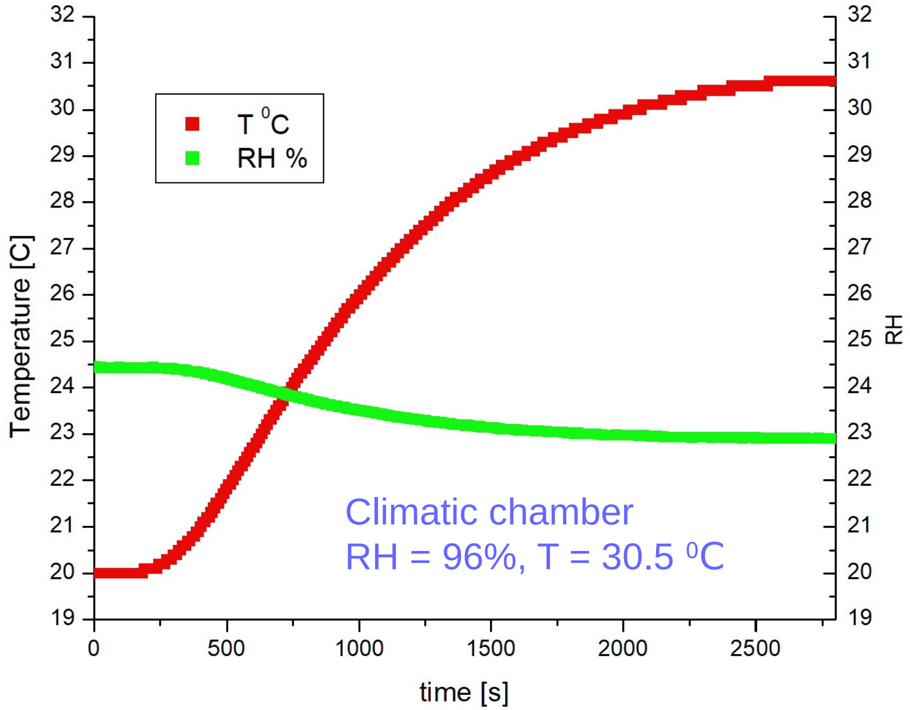
Measurement of photons on SiPM



Climatic chamber test

Temperature (⁰C, red) and relative humidity (%, green) inside the box (optical system filled with Nitrogen) as function of time.
The decrement of humidity during the test is due to the temperature rise of the electronics components by the laser firing.

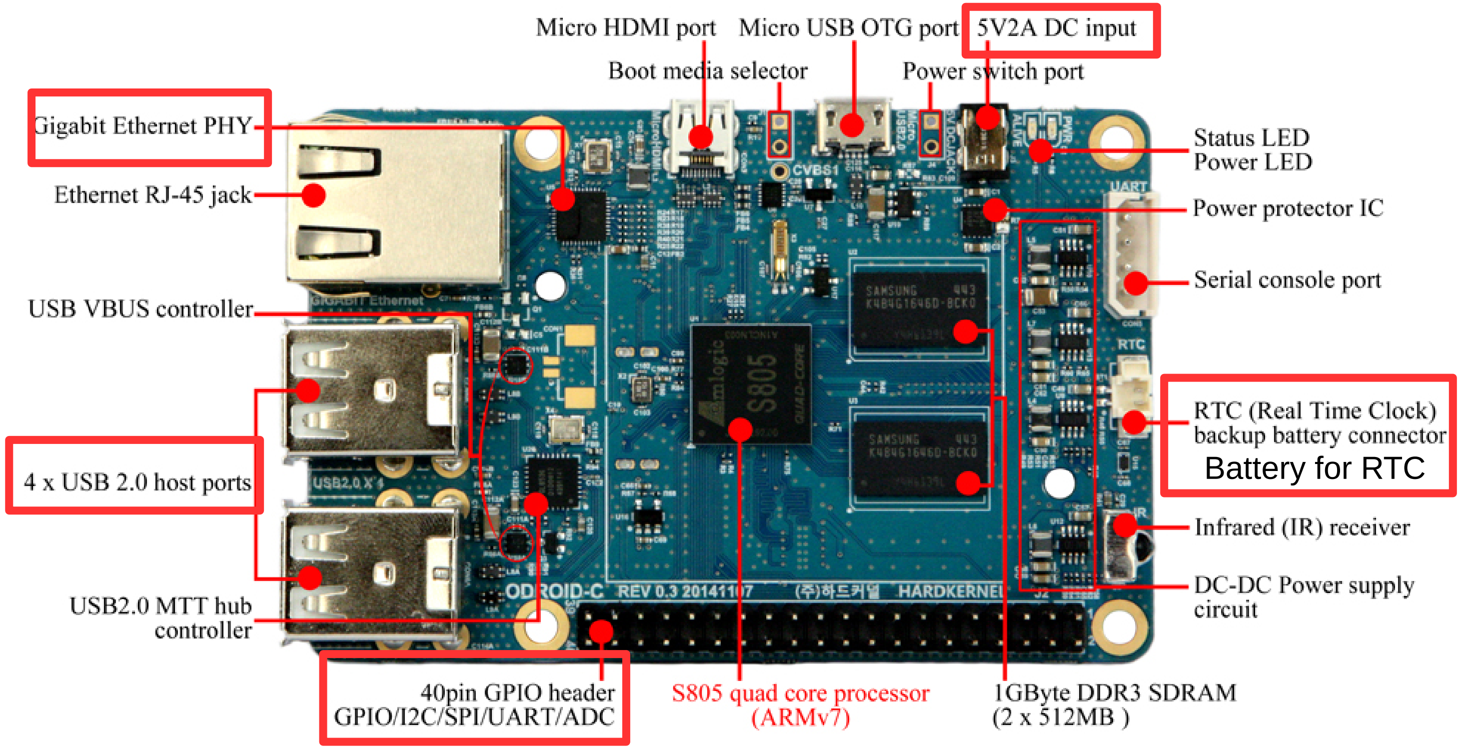
Controlled performance in high RH environment



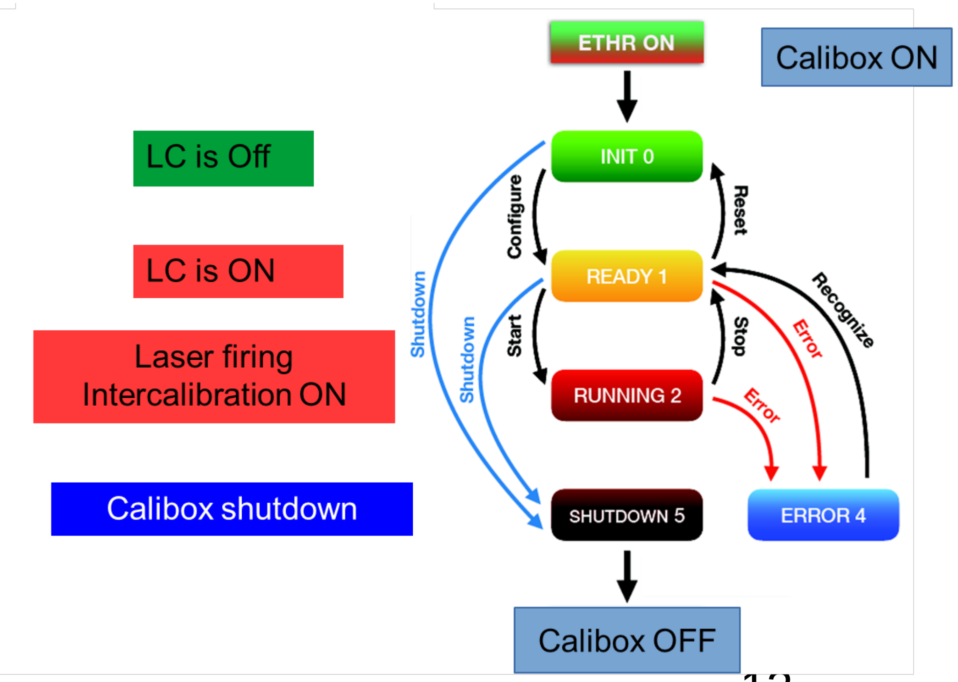
Odroid C1+ Hardware and software

Quad Core Cortex™-A5 processor with Dual Core Mali-450 GPU
4-core ARM processor : 1 GB RAM + 64 GB EMMC (+ SD slot)
OS : Linux Ubuntu 13.10.96-151 SMP **with OPC-UA version installed : V8.0.0**
Running STANDALONE (no external mouse/monitor/keypad)

Powered by internal power supply



CaliBox operations controlled by OPC-UA Finite State Machine transitions (LST Camera Control)



Conclusions

The measurements, performed in the Laboratory, show:

- The photon flux at the exit of the diffuser has been kept constant within 1.0 %
- In the tests of the CaliBox we have measured a pulse width at the exit of Calibox consistent with the Cherenkov signal read by the camera.
- The measurements of the illumination pattern has a dispersion of 1% within a field of view of about 3.4 degrees
- The tests of the CaliBox in a climatic chamber show the device is free of water vapor condensation since the optics system is isolated from the electronics components and with Nitrogen filling

One CaliBox is working on LST-1 since 2018 and 3 CaliBox are in Roma1 LabE and ready to be mounted in 2025 in LST2-4 at CTA-North

These results are under publication