CTAO | LST COLLABORATION

CTAO報告 255: LSTカメラ初号機での長期性能評価と 2-4号機でのカメラ試験の現状

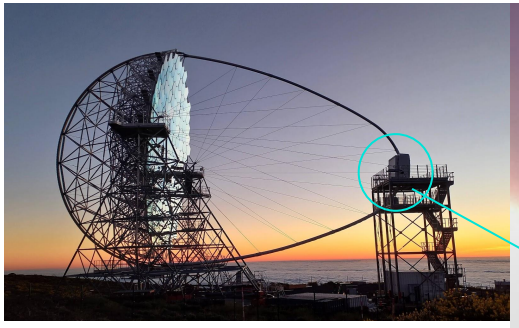
CTAO Report 255: Long-Term Performance Evaluation of the LST-1 Camera and Current Status of LST 2-4 camera

Seiya Nozaki (ICRR)

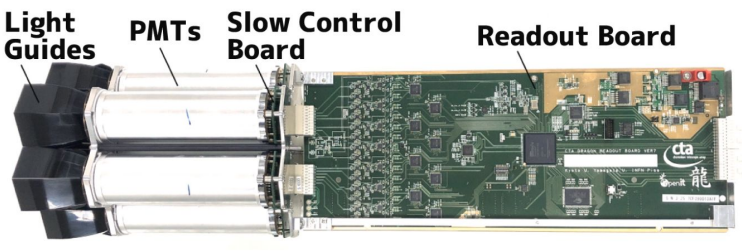
Yusuke Inome, Hideyuki Ohoka, Tomohiko Oka, Akira Okumura, Reiko Orito, Hideaki Katagiri, Junko Kushida, Hidetoshi Kubo, Shuichi Gunji, Yukiho Kobayashi, Takayuki Saito, Shunsuke Sakurai, Mitsunari Takahashi, Manobu Tanaka, Masahiro Teshima, Yukikatsu Terada, Fuyuki Tokanai, Takeshi Nakamori, Kyoshi Nishijima, Koji Noda, Daniela Hadasch, Daniel Mazin, Masaya Mizote, Kai Morita, Tokonatsu Yamamoto, Tatsuo Yoshida on behalf of the CTAO-Japan Consortium

LST Camera

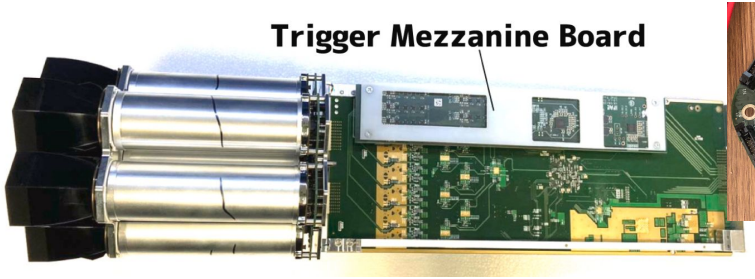
- PMT-based camera
  - 1855 pixels
  - 0.1 degree/pixel
    (4.5 degree FoV)
- **~1 GHz waveform sampling** using **DRS4** analog memory chip
- **2 Gains** for wider dynamic range (upto a few thousands p.e.)
- Power consumption: 7–8 kW
- Japanese contribution
  - Light guide, PMT, Slow Control board, Readout board (Dragon) etc

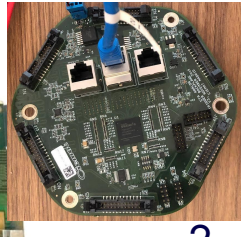






Backplane board (BP)





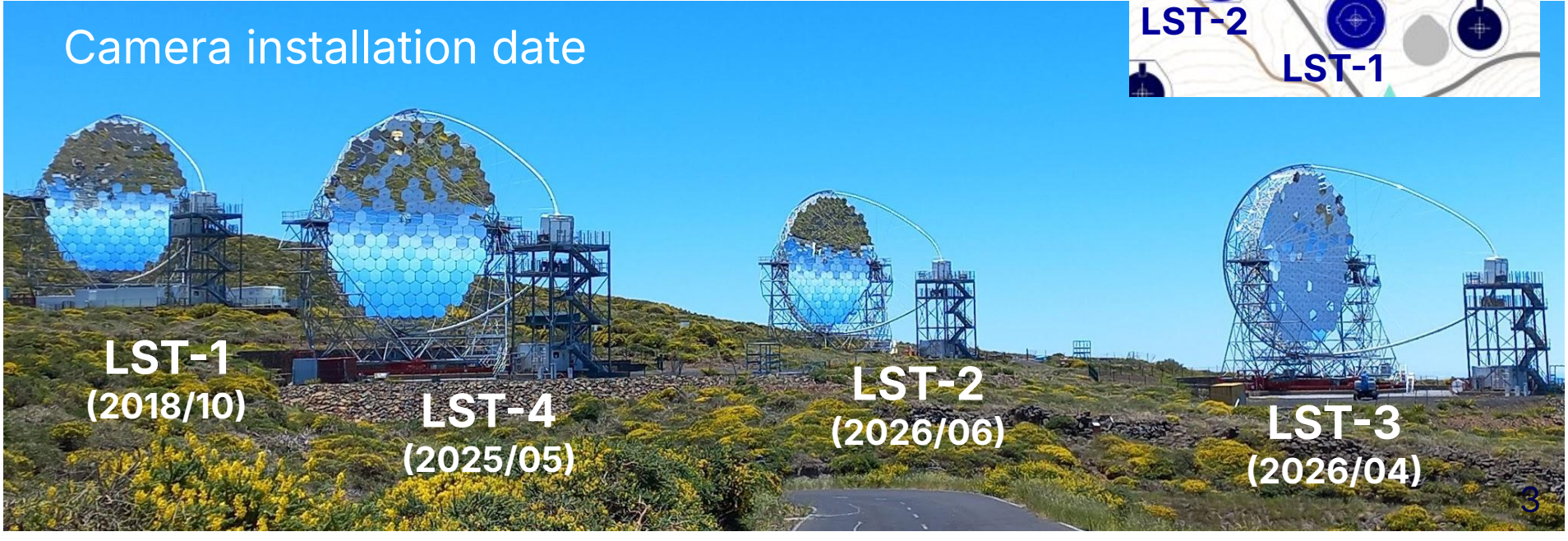
265 modules/camera
7 pixels/module

Current Status of the LST cameras

- All cameras are already installed into LST telescopes
- LST-1: operational since 2018
- LST2–4: preparation and commissioning test ongoing



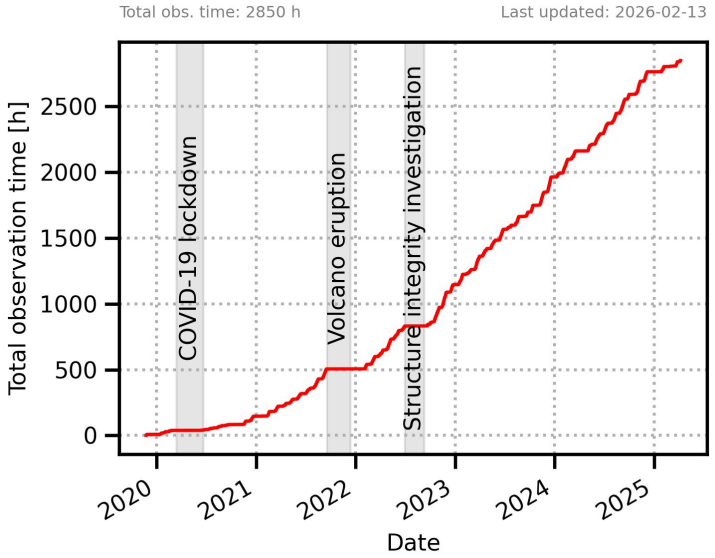
Camera installation date



LST-1 Camera

- Installed in 2018
- Standard observation since 2020
- Making the camera operation more stable and automatic for hand-over to CTAO
  - Online calibration applied since 2026/06
    - DRS4 offset calibration
    - ADC → p.e. conversion
    - Gain selection



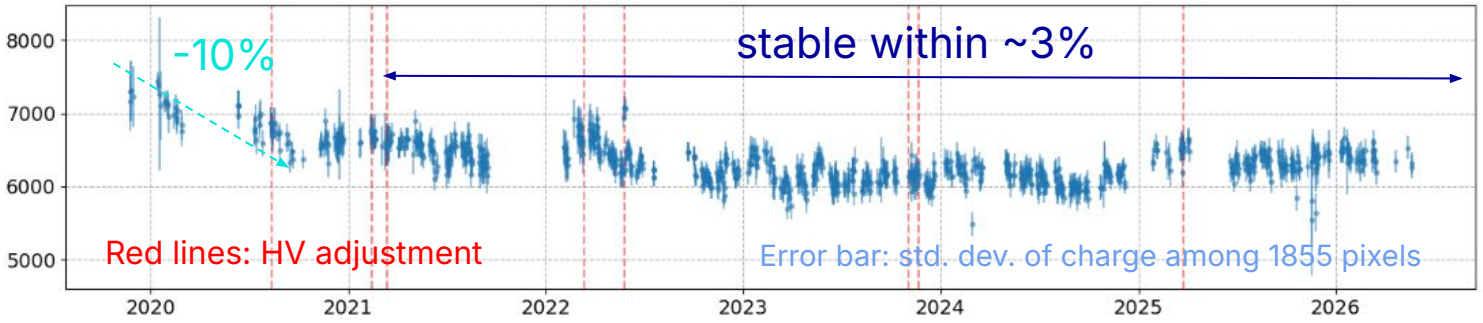


PMT performance evolution

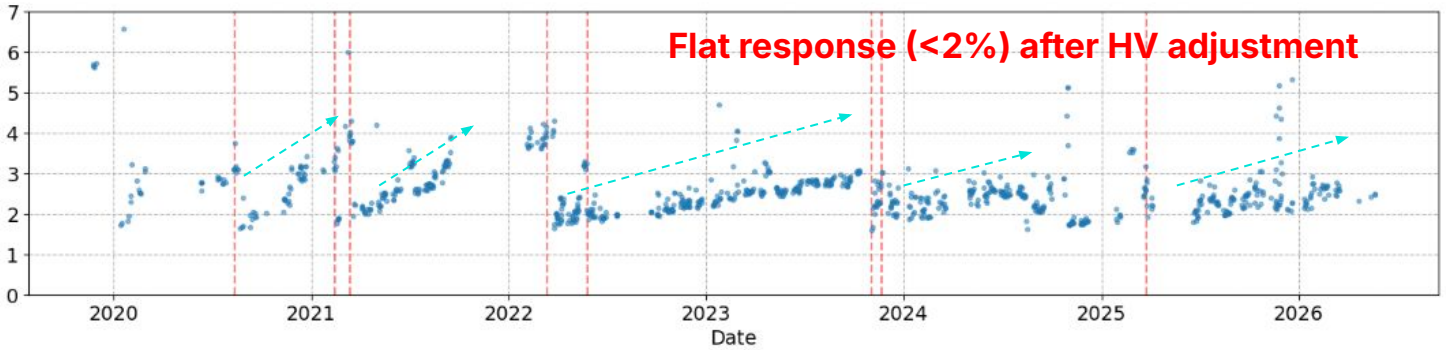
- Stable performance after a few years with HV adjustment (once per year)

Calibration laser data

Mean charge among the 1855 pixels [ADC]



Std. dev. of charge among the 1855 pixels [%]



Trigger

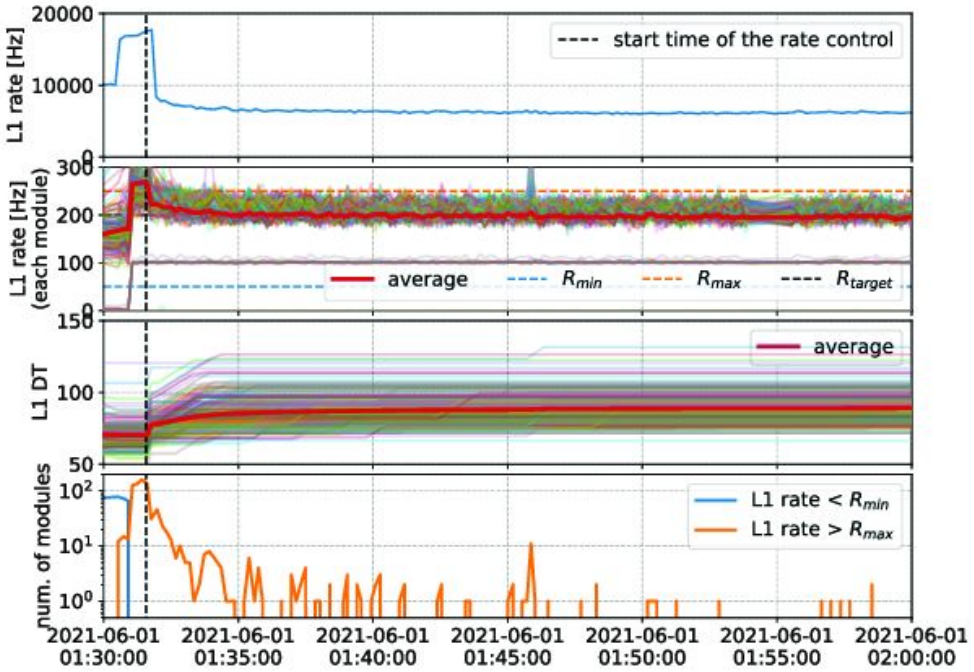
- Trigger threshold is stable thanks to the automatic rate control since August 2021
  - Enable us to apply lower threshold

camera rate

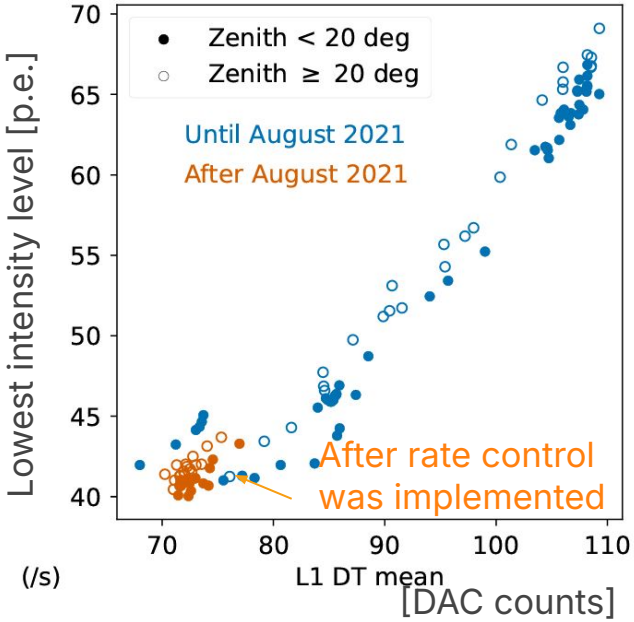
local rate (per module)

Trigger Threshold

# of modules affected by the rate control



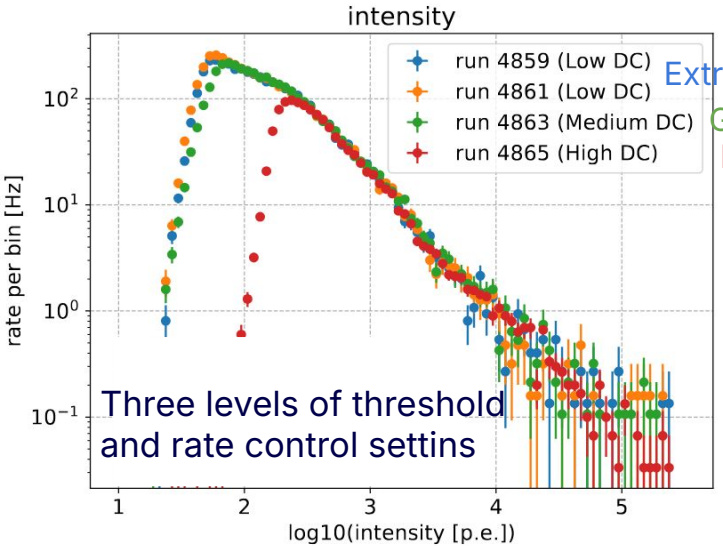
Intensity: total charge of survived pixels after the image cleaning



LST performance paper (Abe+23)

Trigger

- Flat response among the camera above intensity of 50 p.e.
  - default intensity threshold for the standard analysis



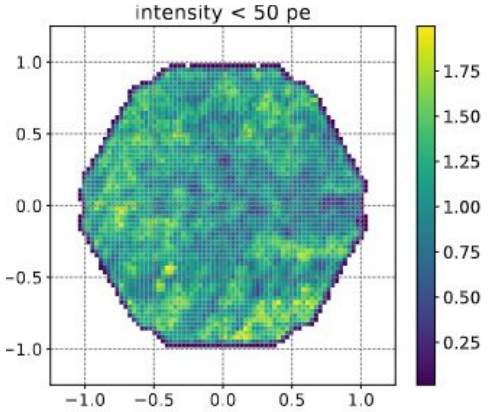
Extragalactic

Galactic

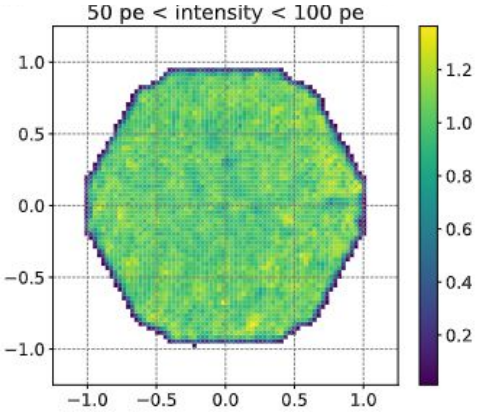
Moon

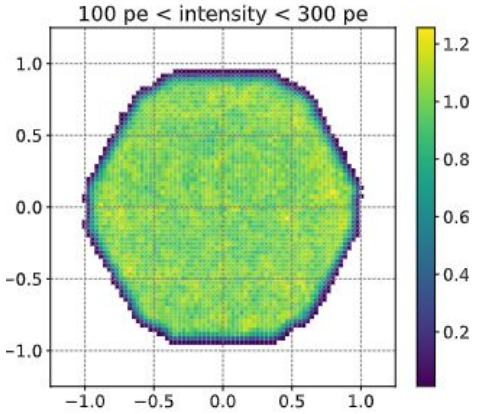
Shower c.o.g. distribution (1 run)

<50 p.e.

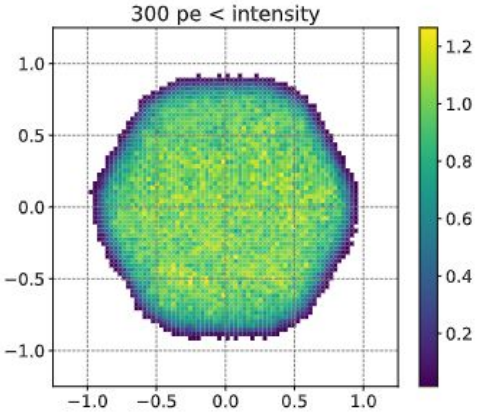


50–100 p.e.





100–300 p.e.



>300 p.e.

Module exchange so far

- Initial failures were found during the first 2–3 years (especially PMT)
- Specific modules had a problem of booting & communication
  - Reason remains unclear, need to exchange modules for the moment

2019/02	**PMT: 1** (HV not applied), **Dragon: 1** (Fuse blown), BP: 1 (not working)
2019/10	**BP: 2** (not calibrated well), **Dragon: 3** (DRS unstable offset, PLL issue, Frequent boot issue), **PMT: 1** (QE lost)
2021/03	**Trigger: 2** (not working), **Dragon: 2** (DRS unstable offset, Fuse blown), **PMT: 1** (QE lost)
2021/08	**Dragon:1** (PLL issue), **PMT: 1** (QE lost)
2022/03	**BP: 1** (Boot issue)
2022/05	**Dragon** + **Trigger:** 1 (suspicious trigger rate)
2023/10	**Trigger: 3** (too high L0 rate [2] & 0Hz L0 rate [1]), **Dragon: 1** (DRS unstable offset)
2025/02	**Dragon 3** (trigger burst problem [1], frequent communication failure [2])
2026/06	**Dragon 1**: (Fuse blown)

1 exchange / year

LST 2–4 cameras

- LST4:
  - Cooling chiller had a problem before, preventing us from switching on the camera
  - Commissioning tests ongoing (next pages)

Solved

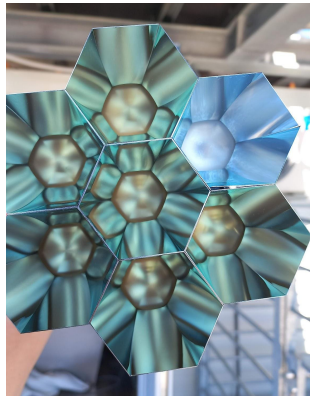
- LST2–3:
  - Thermal test at park-in position done
  - Thermal test at different telescope zenith position is planned in Sep 2026 (LST3)
  - DAQ server setup preparation ongoing
  - Calibration laser to be installed in Oct/Nov 2026

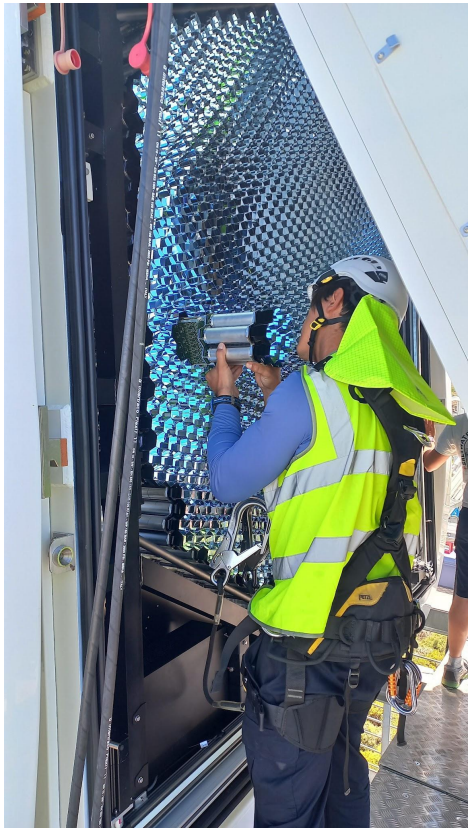


LST4 test - Module replacement -

- All modules have passed QC tests (2019–2021)
- After installation and transportation, there are several problematic modules to be replaced
  - PMT 3: Replaced in June 2026
    - HV not applied (2)
    - Suspicious HV/anode current monitoring (1)
  - PMT 1: (HV only upto 800 V)
  - Dragon:1 (Fuse blown)
  - Trigger: 1 (Not working)

To be replaced in Oct 2026





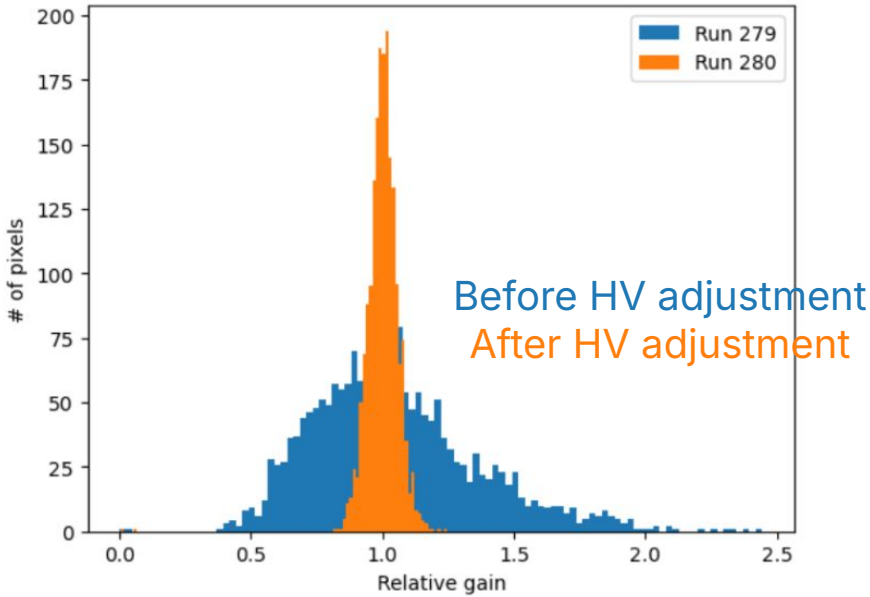
LST4 test - calibration laser run -

- Calibration laser was installed in June 2026
  - Updated version with hardware feedback from laser controller
- HV is adjusted using laser data (std. dev. 5% over the camera)

Calibration laser installation at the dish center



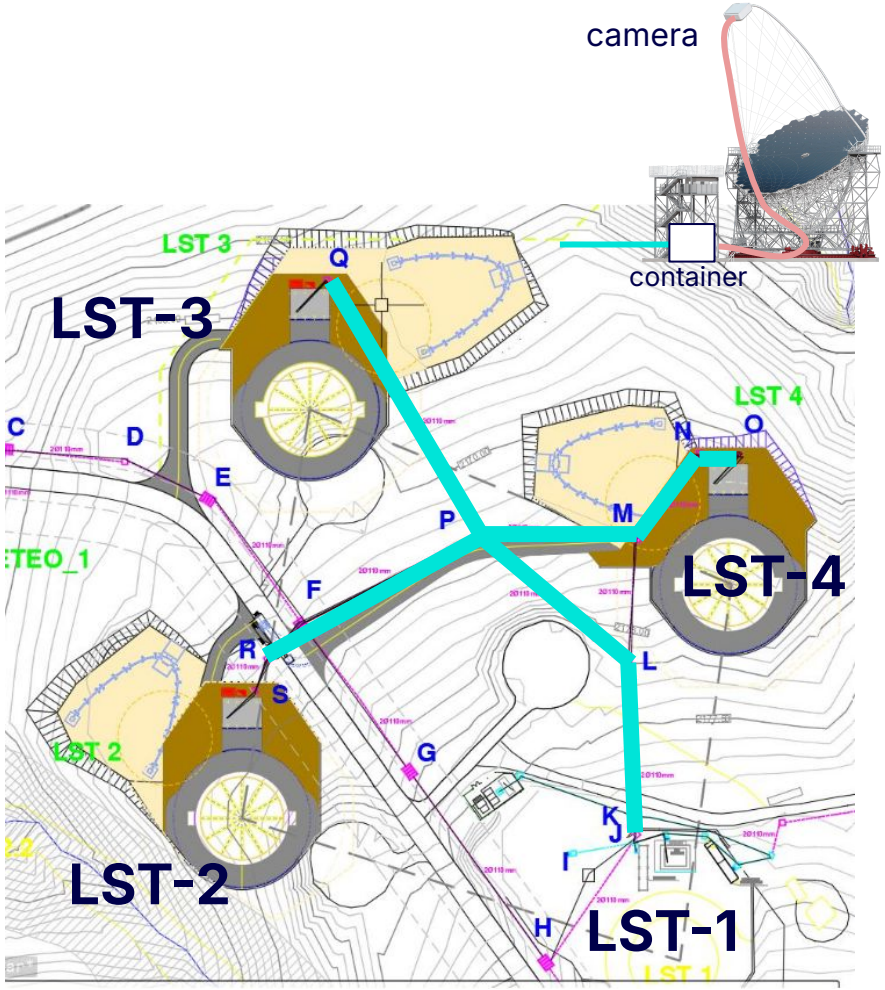
Credit: Federico Di Pierro, Carlo Vigorito



Plans

- All optical fibers for **stereo trigger** was already installed between telescope sites in July 2026
  - Connection between container and camera is still missing
  - Experts plans to go to onsite to install patch cords and characterize LST1-LST4 hardware stereo trigger

Stereo trigger test starts in November!



Summary

- We have been developing and commissioning the LST camera, especially PMT units and the readout board
- LST1 camera has been operational since 2018 and long-term performance is evaluated using the regular observation since 2020
  - Stable performance in terms of PMT and trigger
- LST2–4 cameras are already installed to the telescopes and commissioning is already started
  - LST4: calibration laser installed, HV adjusted
  - LST2, 3: thermal test ongoing
- Optical fiber for the stereo trigger is installed and the dedicated stereo trigger test is planned in November