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SST-1M
Single-Mirror
Small Size Telescope

The SST-1M stereoscopic Cherenkov telescope system

M. Heller on behalf of the SST-1M collaboration

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SST-1M
Single-Mirror Small Size Telescope

The SST-1M stereoscopic Cherenkov telescope system

- Outline
  - ✦ The SST-1M Project
  - ✦ The SST-1M telescopes at the Ondrejov observatory
  - ✦ Telescope operation and commissioning
  - ✦ First Science results

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The SST-1M Project

SST-1M

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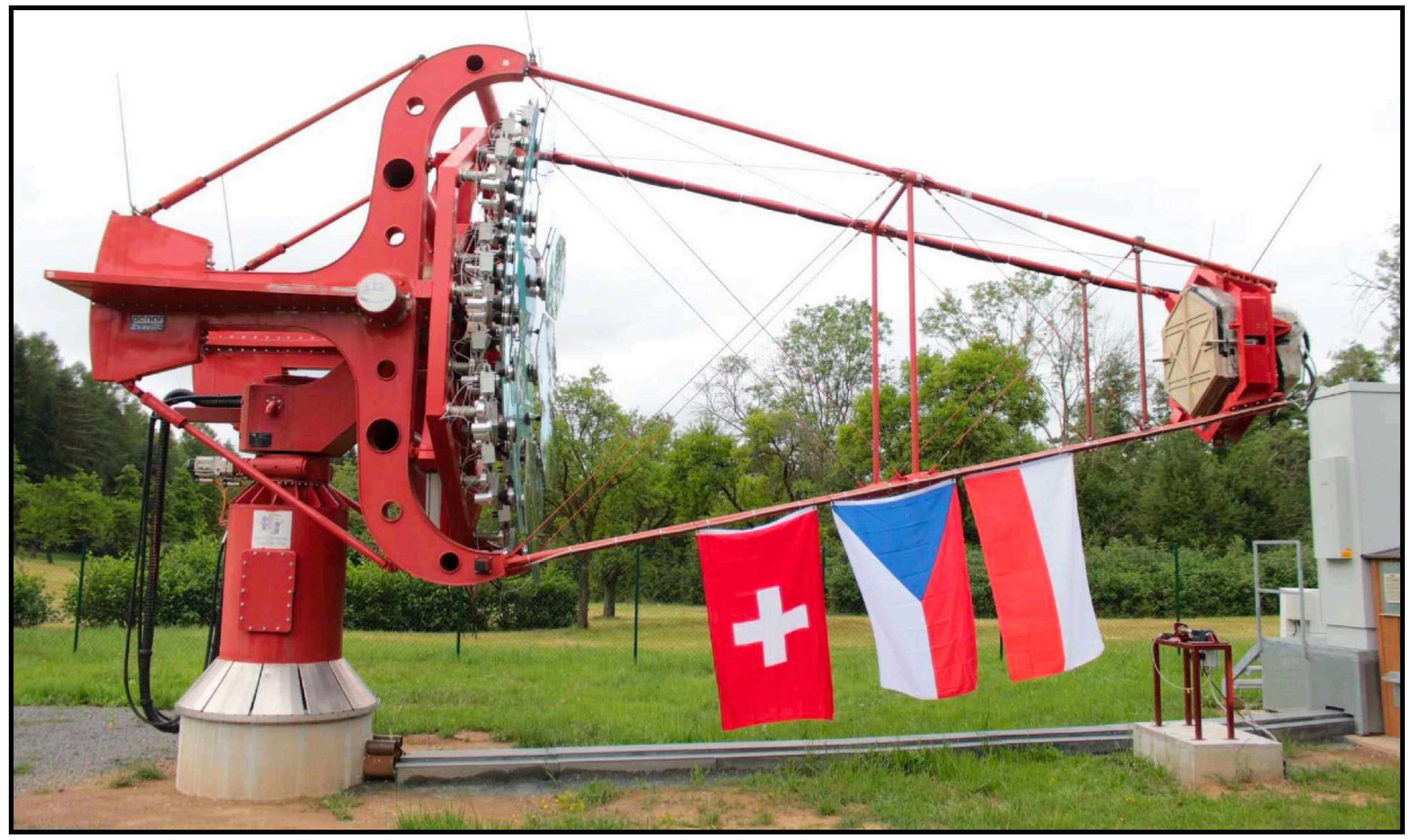
- Consortium of research institutions from Czech Republic, Poland, and Switzerland

- Initially developed for Cherenkov Telescope Array as prototypes of SSTs
  - ✦ Reviewed and satisfied all CTA requirements, nevertheless an other design was selected

- Two full telescopes built and assembled:
  - ✦ One prototype
  - ✦ One pre-production
    - Improved camera mechanics and entrance window coating



Nicolaus Copernicus Astronomical Center

CBK PAN – *Centrum Badań Kosmicznych* Space Research Centre

THE HENRYK NIEWODNICZAŃSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

AGH University of Science and Technology

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ISDC DATA CENTRE FOR ASTROPHYSICS

JAGIELLONIAN UNIVERSITY IN KRAKOW

FZU Fyzikální ústav Akademie věd České republiky

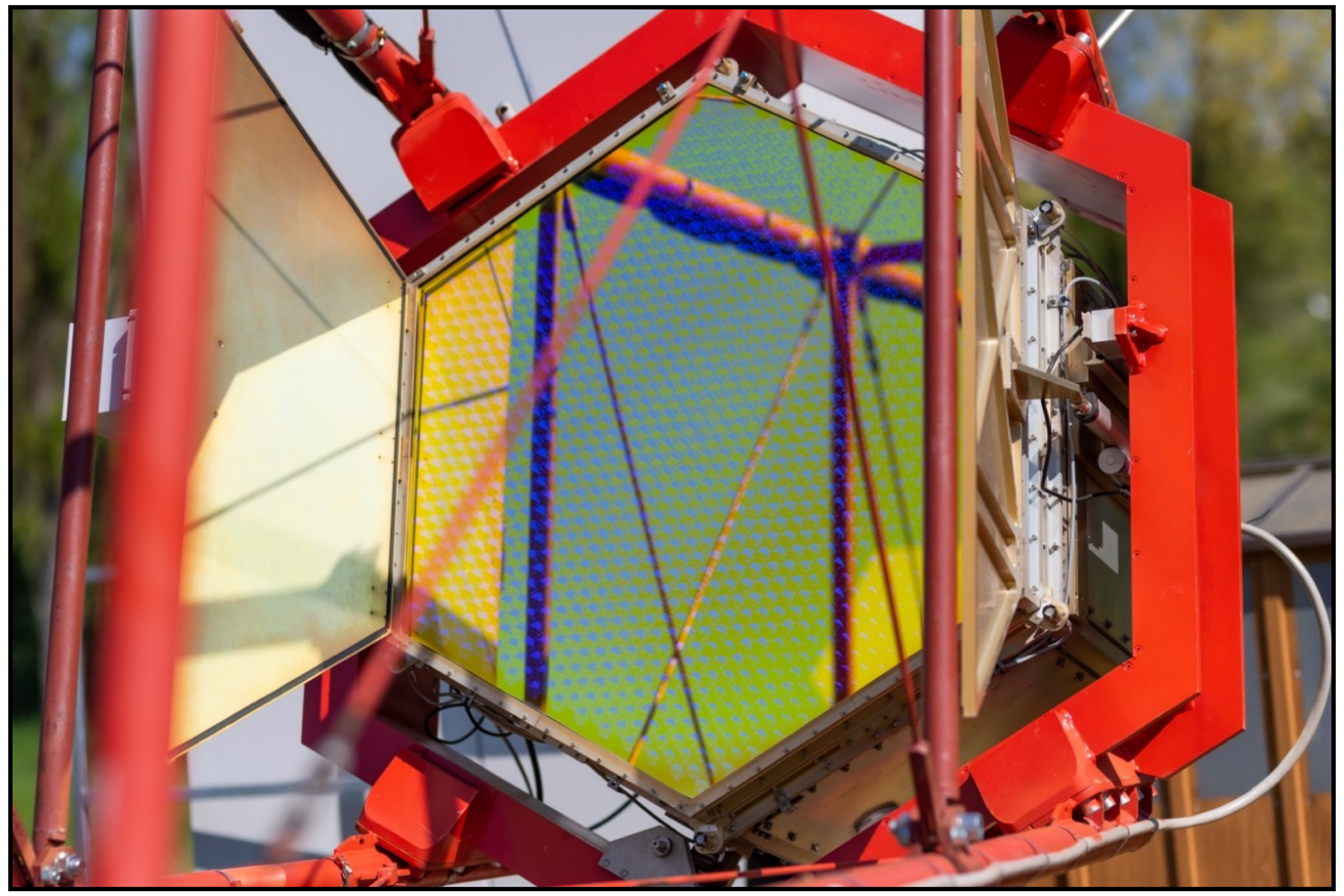
UNIWERSYTET WARSZAWSKI

asu Astronomický ústav AV ČR

Palacký University Olomouc

The SST-1M telescope

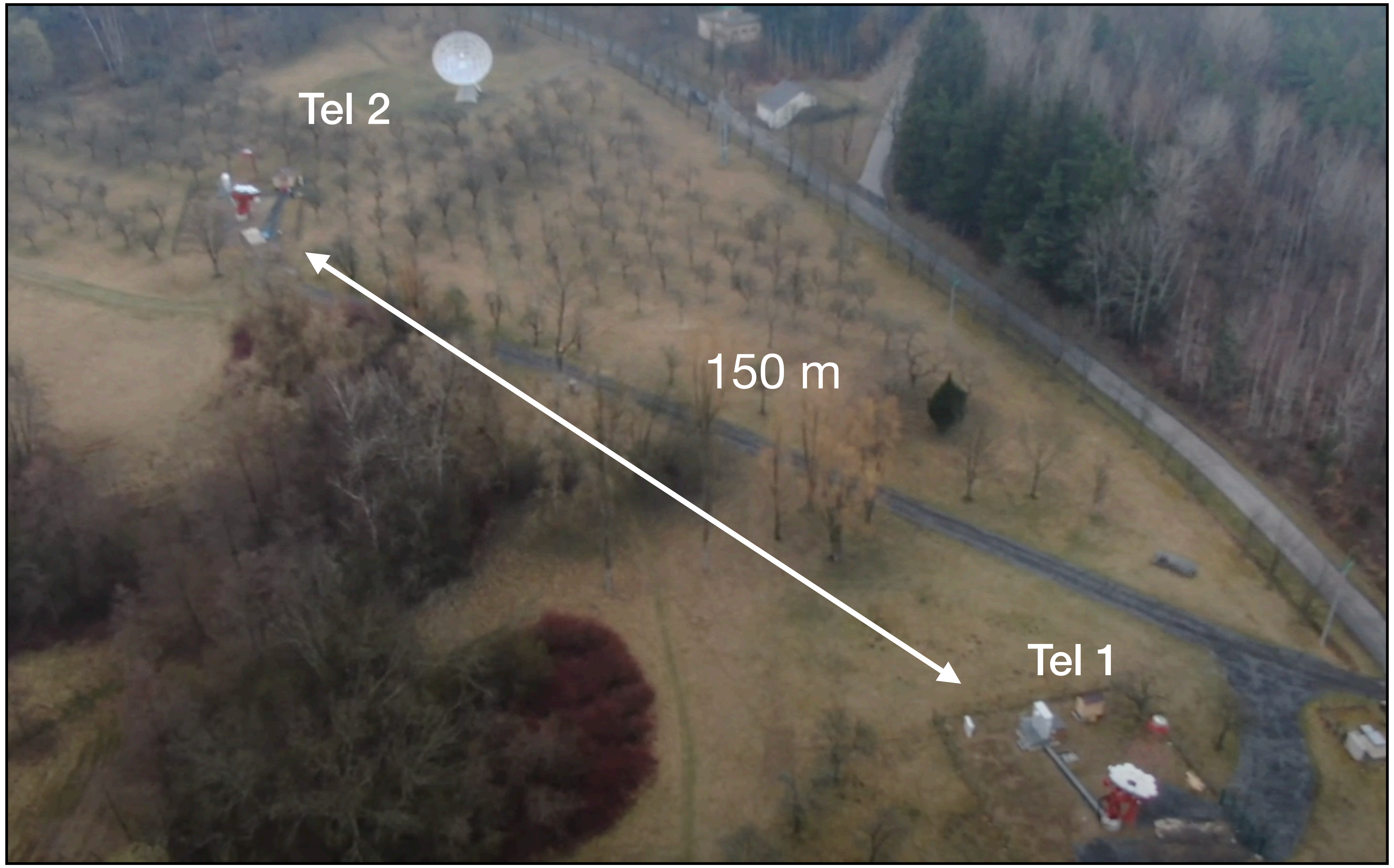
- Davies-Cotton proven optical design
  - ✦ Innovative SiPM-based camera
  - ✦ Digital electronics with fully digital trigger and readout architecture
  - ✦ Fully programmable
  - ✦ Highly performing large-area SiPMs with dedicated slow control
- Optimized for gamma-ray sensitivity above 500 GeV in stereo mode
- Lightweight (~ 8.6 t) and compact structure;
- Designed for fully robotic operation with minimal maintenance in harsh environment
- Low Cost

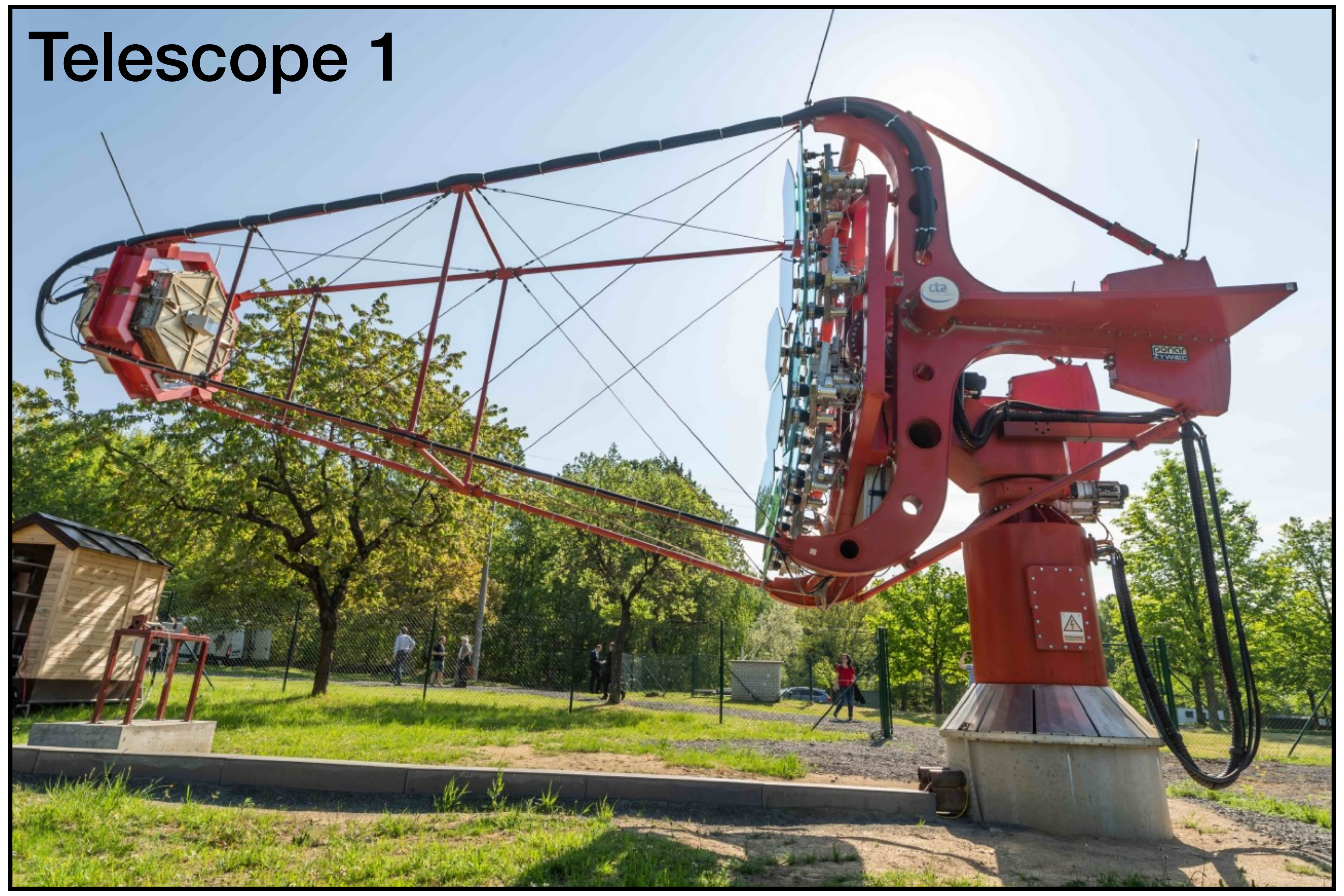


Optical properties	*Focal Length*	5600 ± 5 mm
	f/D	1.4
	Dish diameter	4 m
	Mirror Area (*)	9.42 m^2
	Mirror Effective Area(*)	6.47 m^2
	Hexagonal Mirror facets	780 ± 3 mm
	Preliminary on-axis PSF real optical parameters	0.07°
	PSF (80% of FoV@ 4° off-axis)(**)	0.21°
Camera Characteristics	*Camera (depth x width)*	60 cm x 90 cm
	Total pixel number	1296
	Pixel linear size	23.2 mm
	Pixel angular size	0.24°
	FoV	9.1°
	Photosensors PDE	> 30%
	Sampling frequency	250 MHz
	Readout rate	0.6-1 kHz
	Time Spread RMS	< 0.25 ns

The SST-1M stereoscopic telescope system

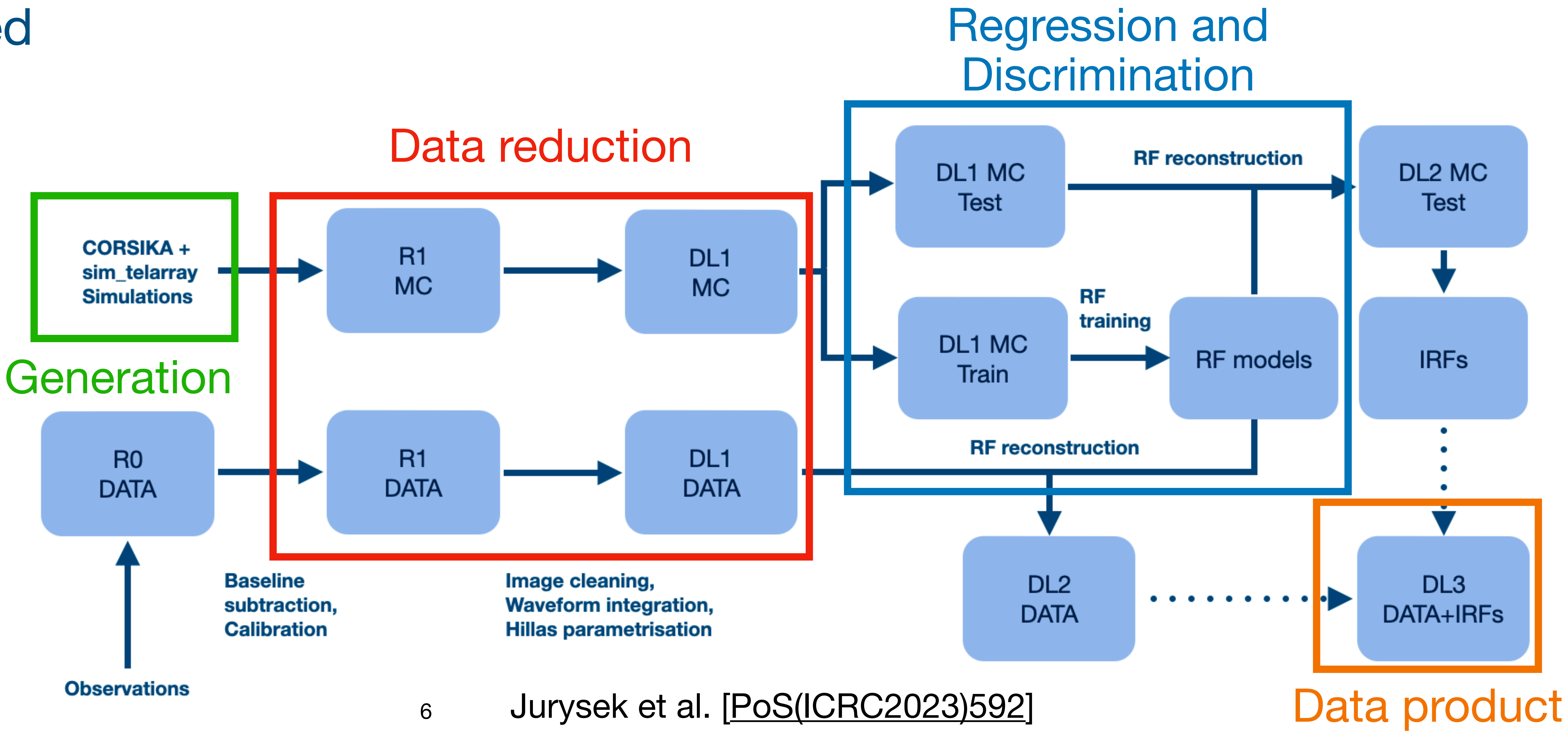
- Two telescopes, separated by ~150 m, fully deployed on the test and validation site, the Ondrejov Observatory in Czech Republic (~40 km from Prague), 550 m.a.s.l.





Simulation and analysis pipelines

- Developed dedicated pipeline for the analysis of the SST-1M data: mono, stereo, MC and real data.
  - ✦ The backbone of the data analysis pipeline is ctapipe (maintain by CTAO) and inspired by lstchain (maintain by LST collaboration)
  - ✦ For calibration specific to the SST-1M telescope, methods derive from digicampipe (C. Alispach et al 2020 JINST 15 P11010)
  - ✦ Stereo treatment based on magic-ctapipe

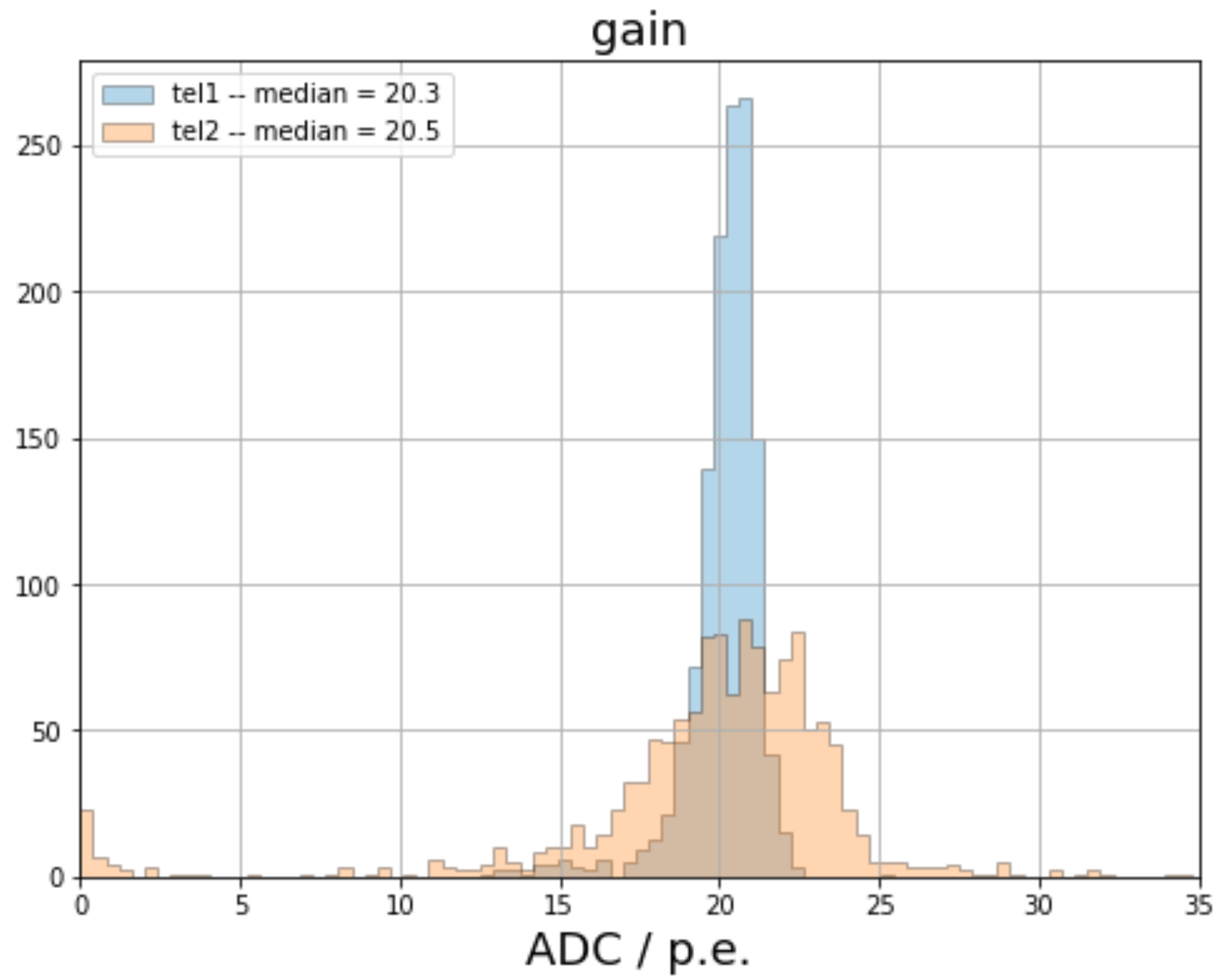


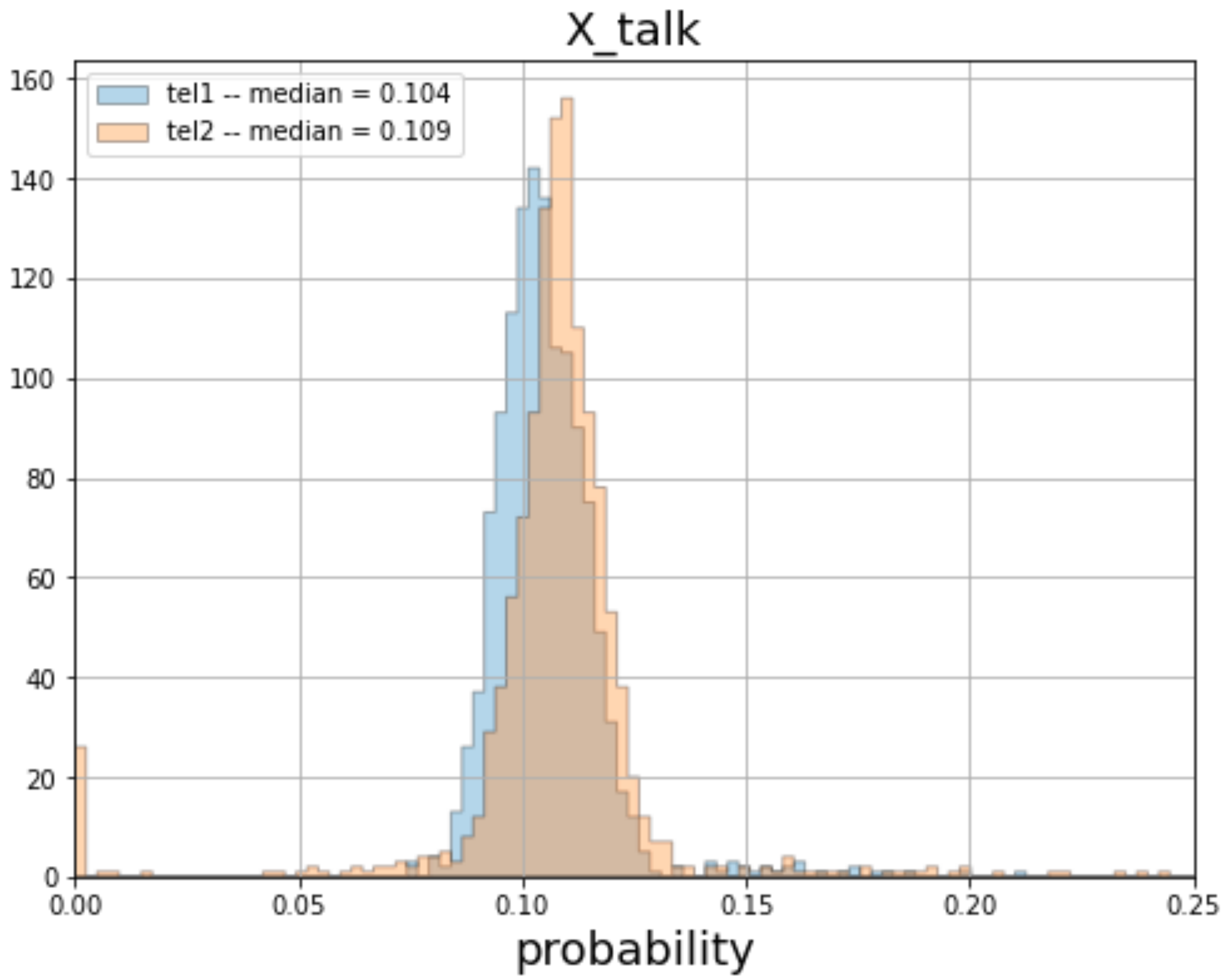
Jurysek et al. [PoS(ICRC2023)592]

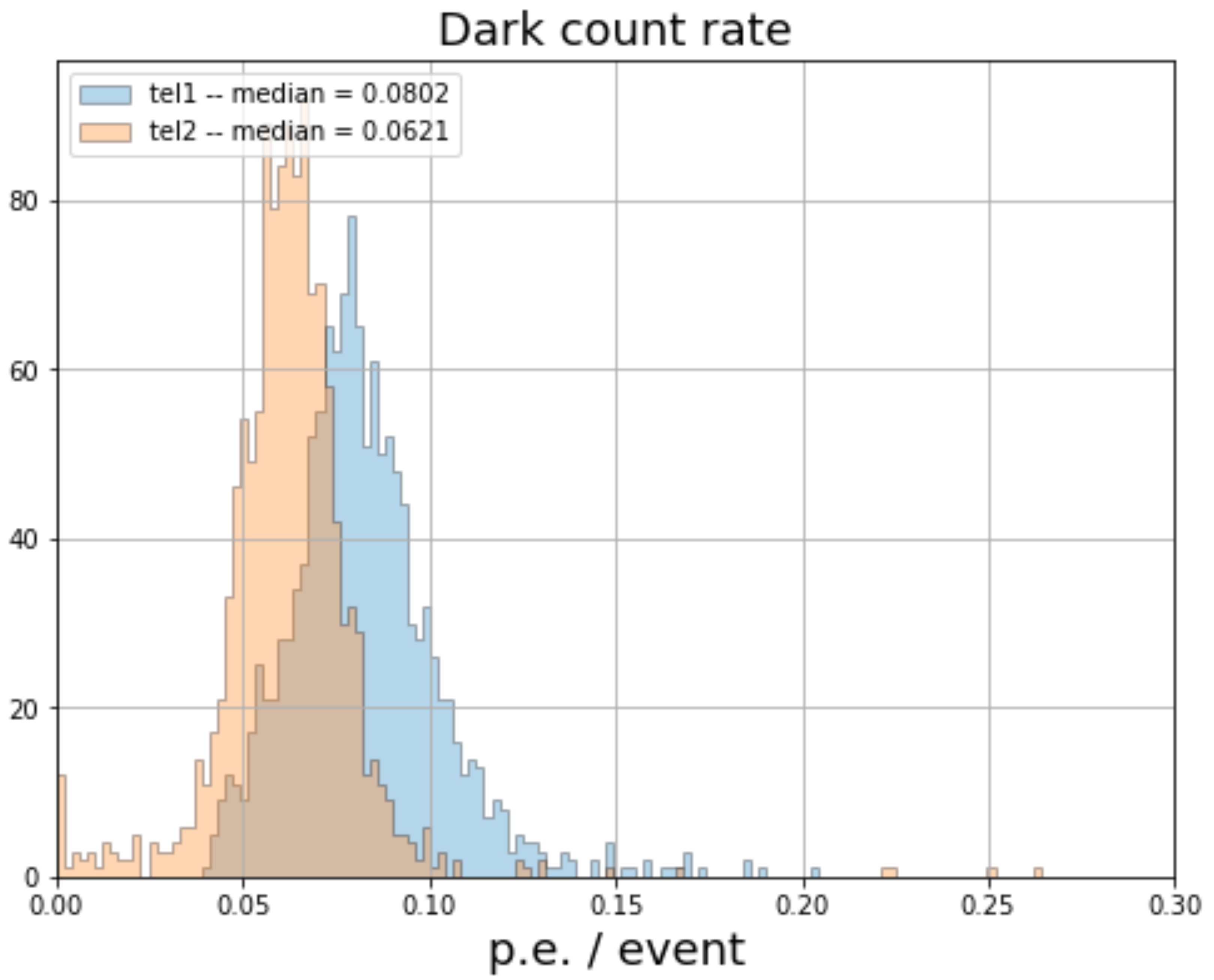
The SST-1M commissioning

Extraction of telescope parameters

- Before running any simulation, configurations must be tuned based on commissioning results:
  - ✦ Mirror reflectivity
  - ✦ Entrance window transmissivity
  - ✦ Different sources of noise:
    - Night sky background
    - Electronics
    - Sensor (DCR, optical cross talk)







Gain difference explained by faulty cables, fixed this summer at UniGe

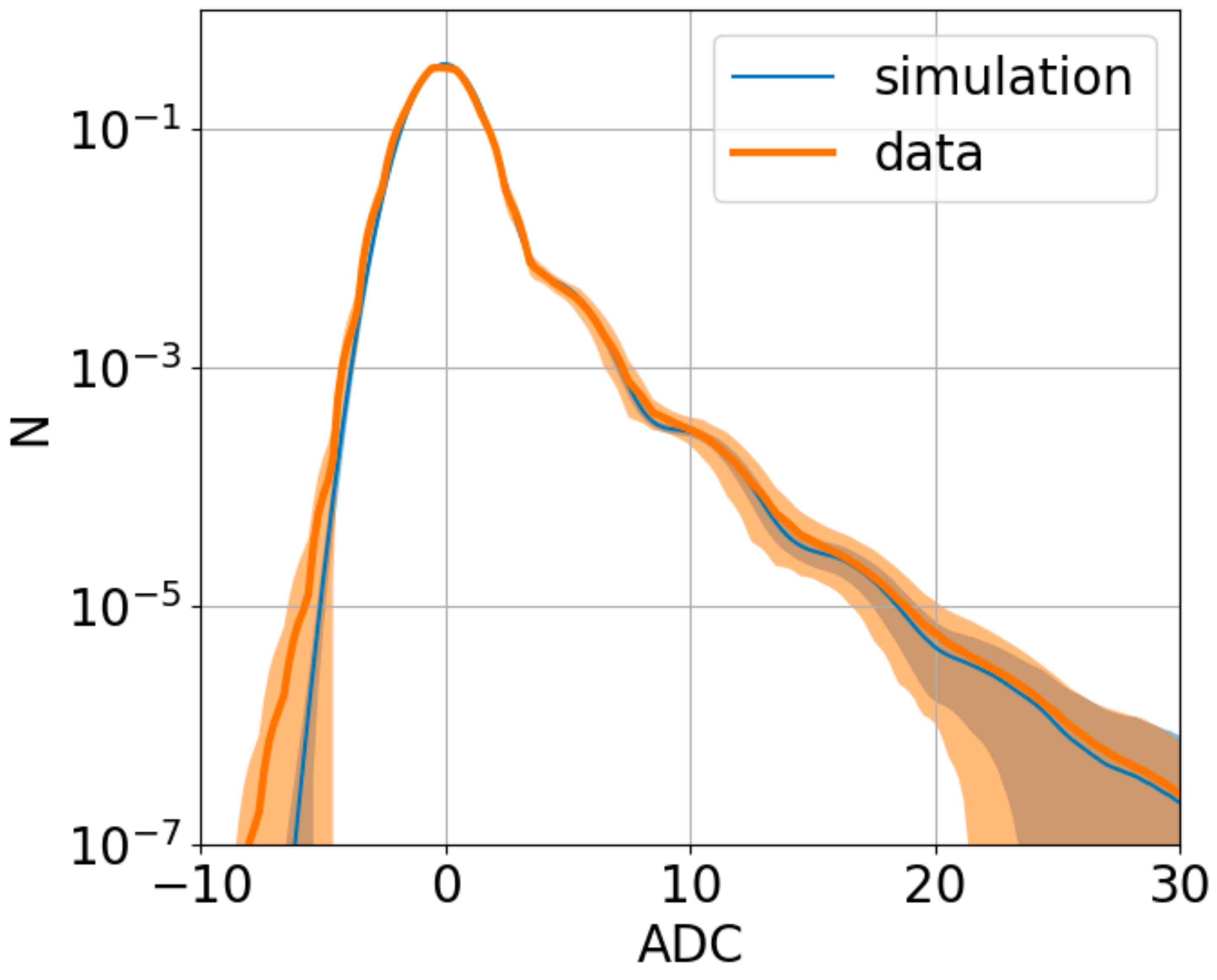
Tavernier et al. [PoS(ICRC2023)741]

Simulation and analysis pipelines

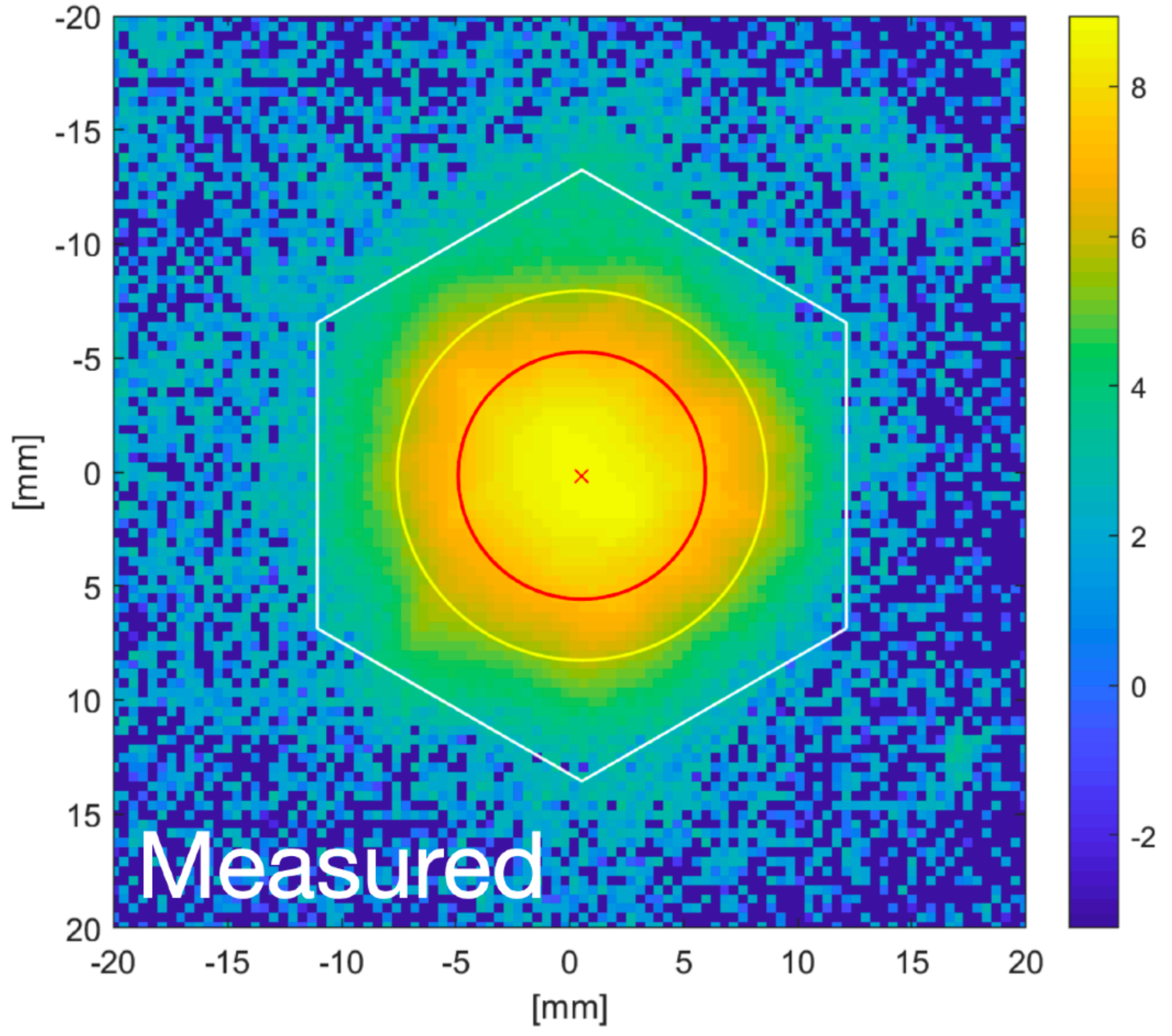
MC tuning

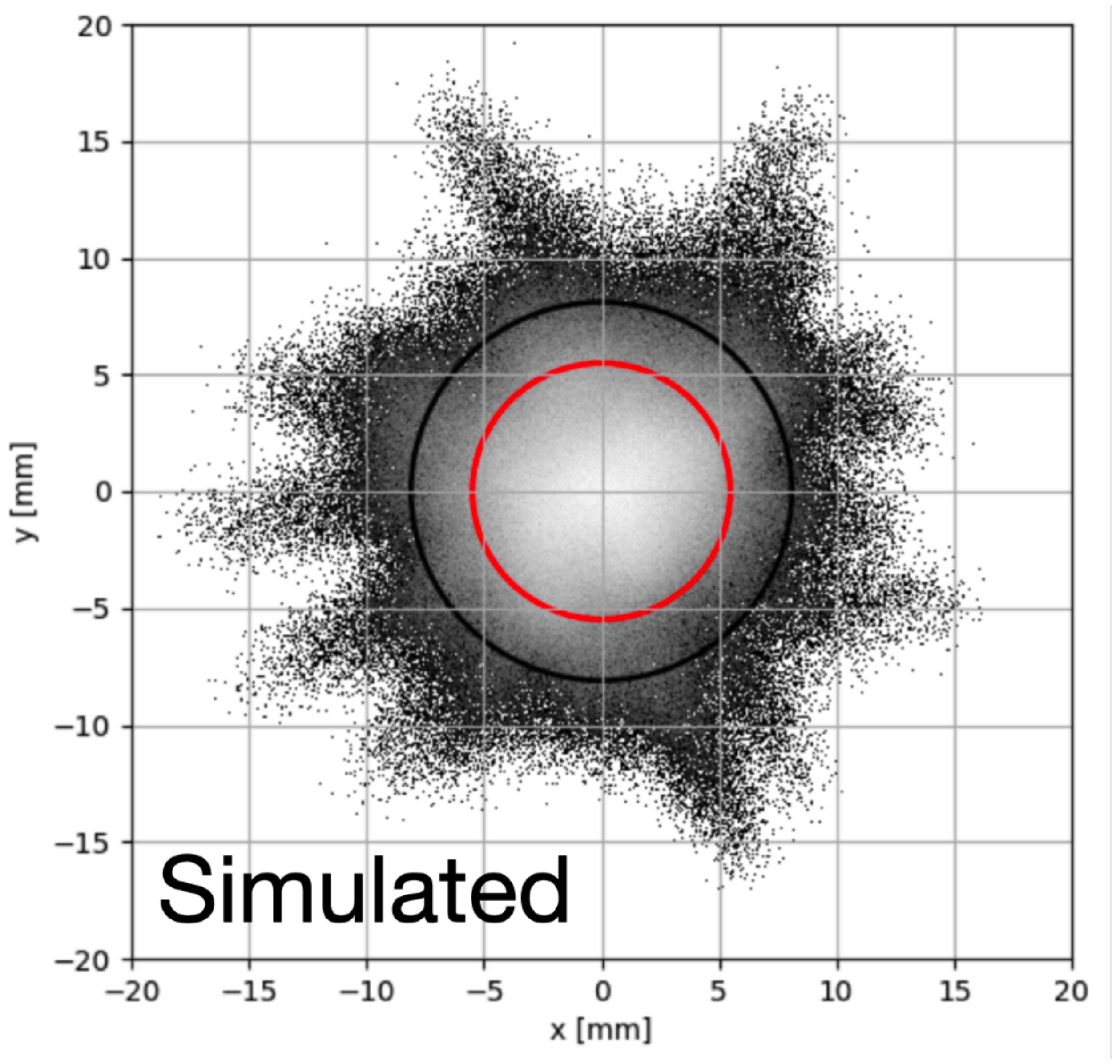
- Configuration parameters tuned to minimize MC/real data mismatch
  - ✦ Mirror reflectivity
  - ✦ Optical point spread function
  - ✦ Pixel characteristics: gain, noise
  - ✦ Night Sky Background level
  - ✦ …

Pixel response



Optical PSF





Jurysek et al. [PoS(ICRC2023)592]

The SST-1M commissioning

SST-1M

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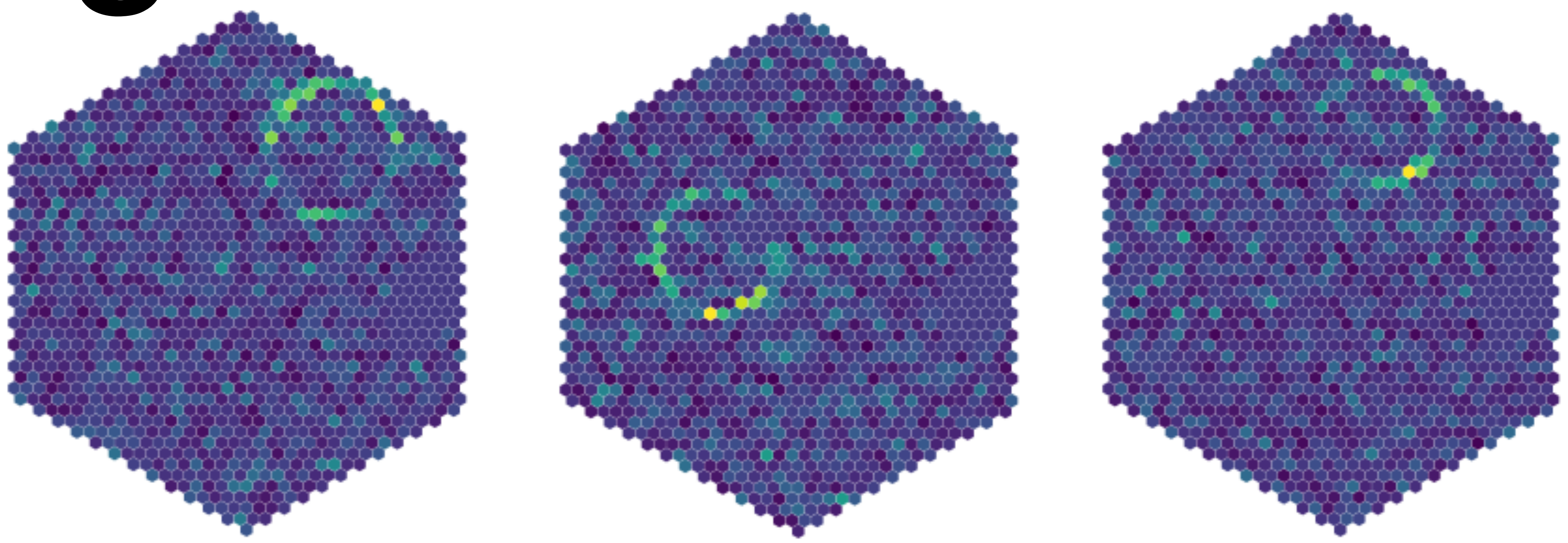
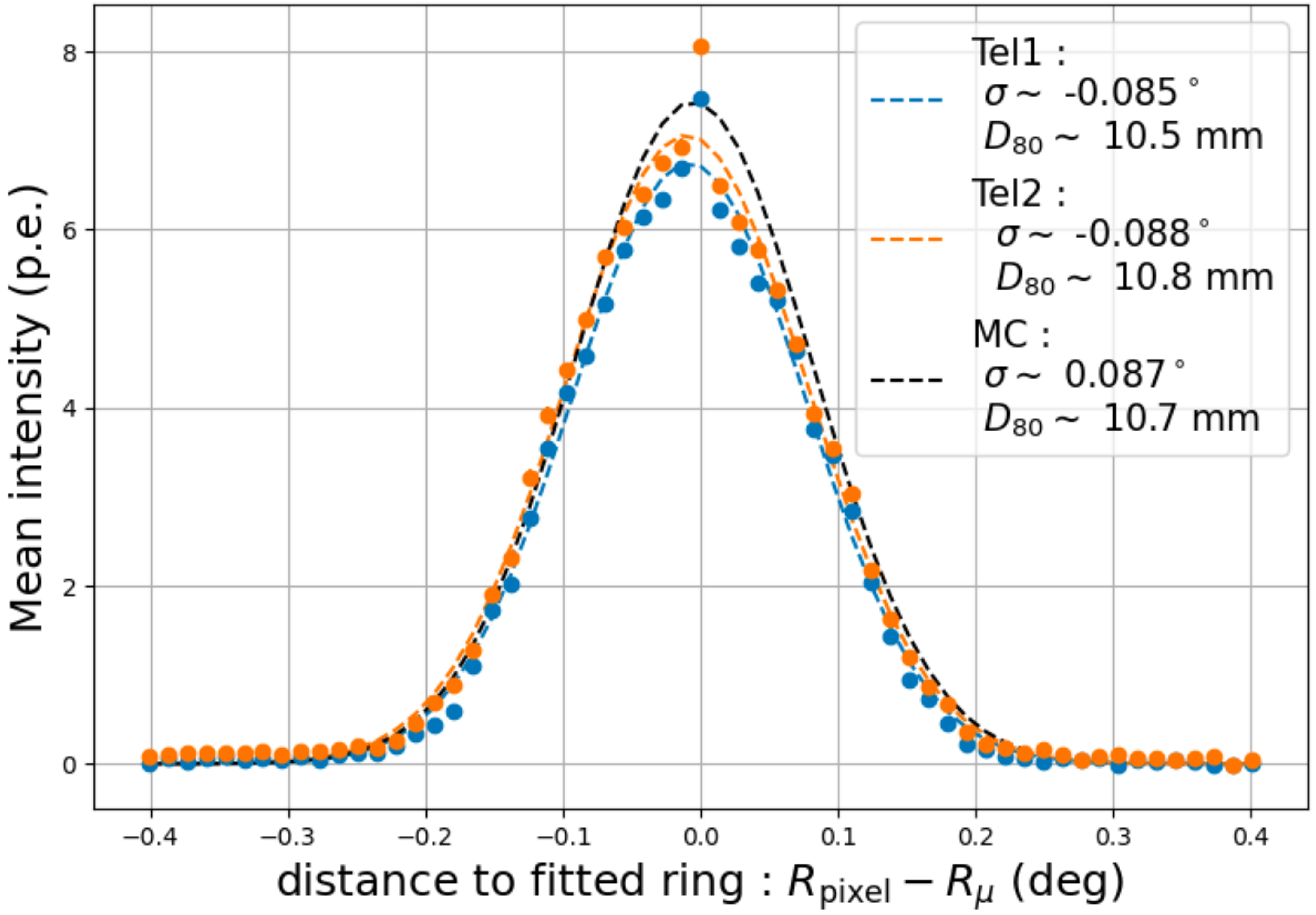
Extraction of telescope parameters



- Muons are very powerful tools to calibrate the optical throughput of the telescope
  - ✦ Radius related to Cherenkov angle, i.e. muon velocity and refraction index
  - ✦ Intensity is related to optical efficiency of the telescope
- Parameters extracted serve to tune the MC
  - ✦ Optical throughput
  - ✦ Optical point spread function
- Yet to be fully propagated to simulation configuration

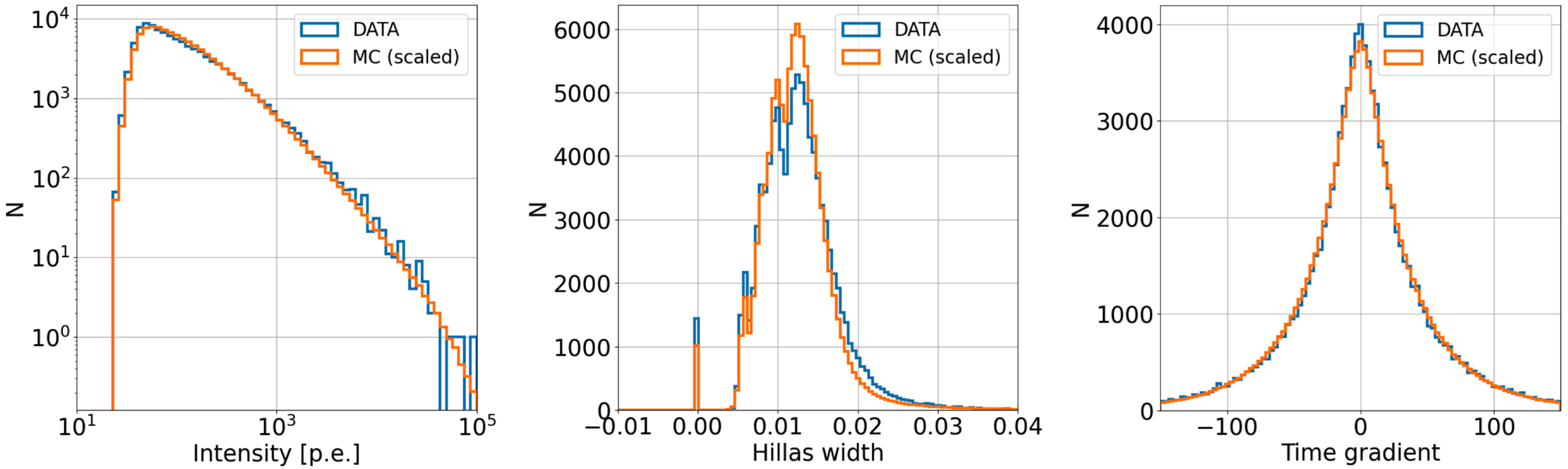


Tavernier et al. [PoS(ICRC2023)741]

Simulation and analysis

MC data comparison

- Comparison of selected Hillas parameters for data taken on June 12, 2023 at zenith angles between 18° and 22° with diffuse proton MC re-weighted on the CR spectrum.
- Distribution of MC simulated events scaled by a factor of 1.04 to account for the actual atmospheric transparency.

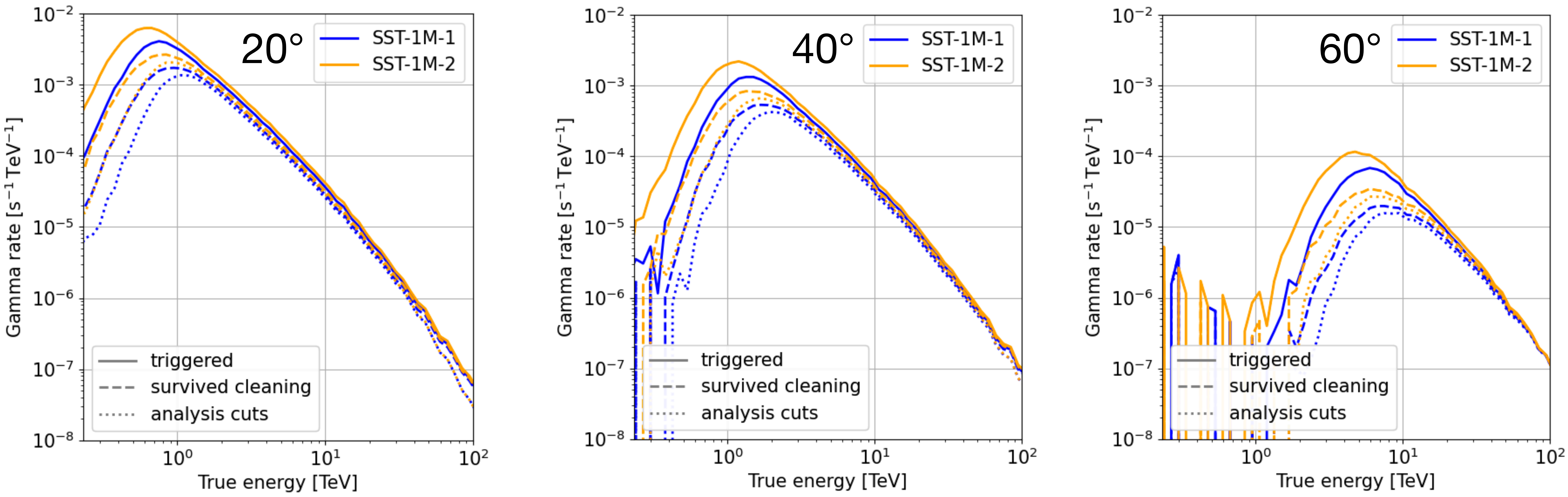


Jurysek et al. [PoS(ICRC2023)592]

Simulation and analysis

MC tuning

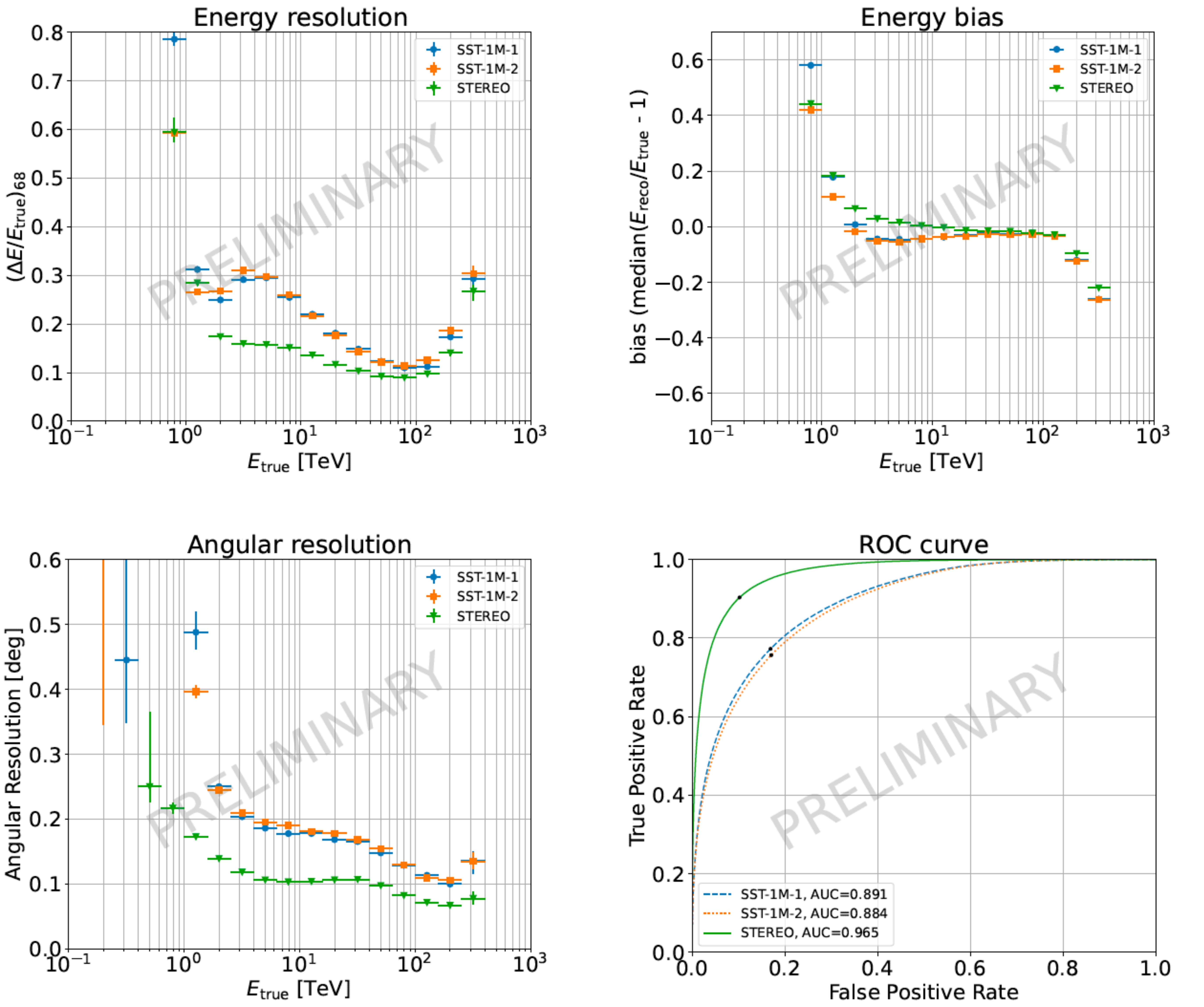
- Differential rate of point-like gamma rays with Crab Nebula spectrum seen with both telescopes



Jurysek et al. [PoS(ICRC2023)592]

Instrument response function

- Low altitude of the site limits the energy threshold to ~1 TeV
- Working in stereo is key to improve performance
  - ✦ Better direction reconstruction especially for “symmetric" showers
  - ✦ Better energy resolution and lower bias due to better reconstruction of the shower geometry, in particular its impact parameter
  - ✦ Better background rejection due to increase in shower features extraction

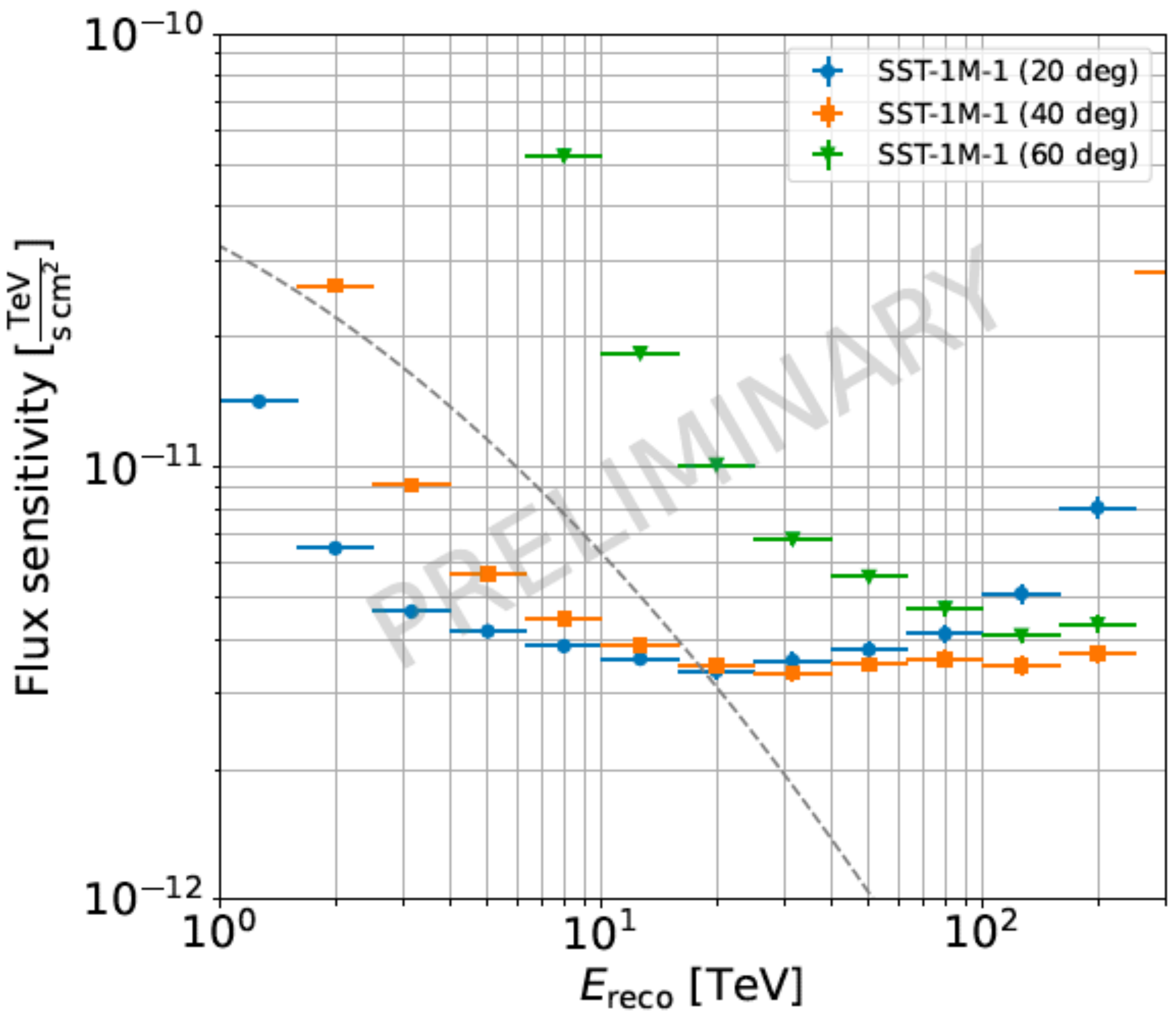


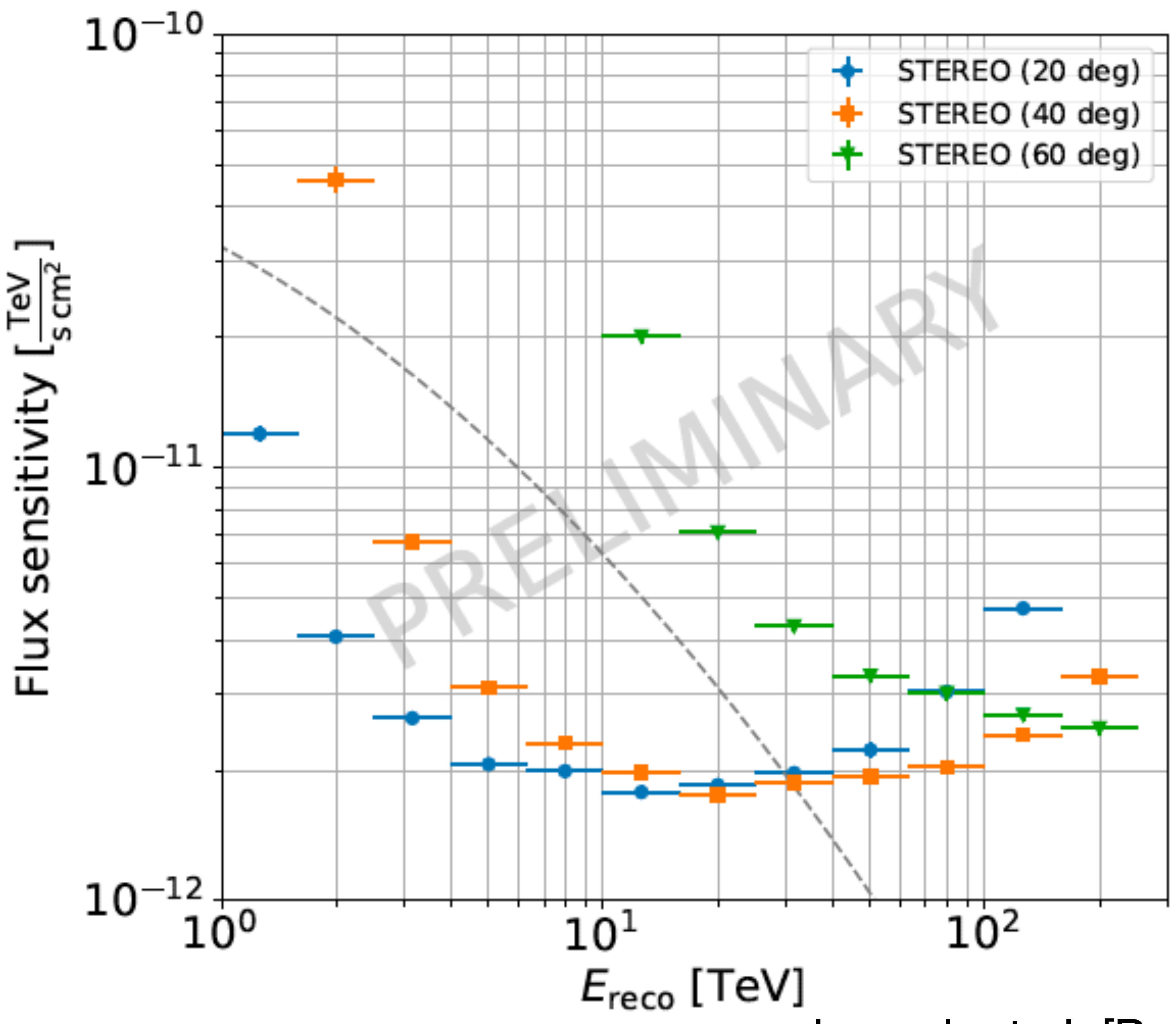
Jurysek et al. [PoS(ICRC2023)592]

Instrument response function

Sensitivity vs. Zenith angle

- Improvements on direction and energy reconstruction added to a better background rejection naturally leads to better sensitivity
- Given the low altitude, observing as close as possible to the zenith is very important !

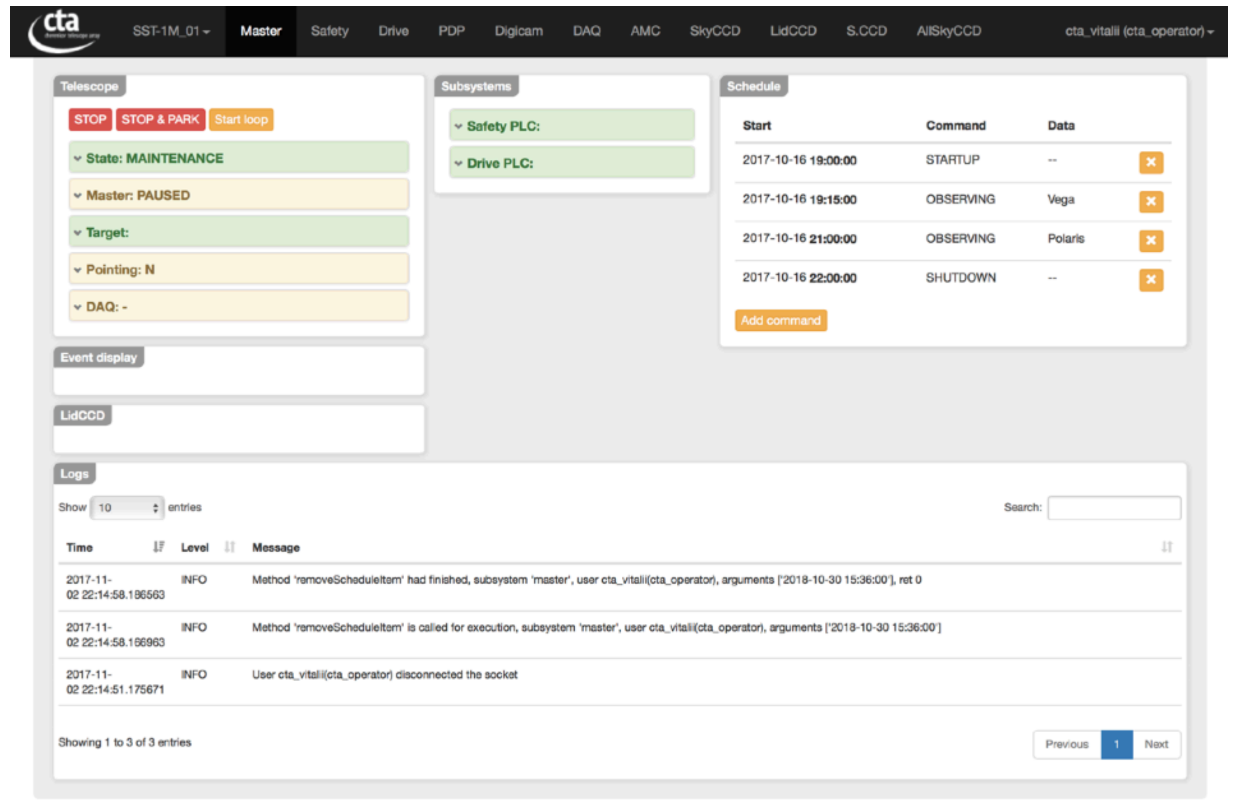




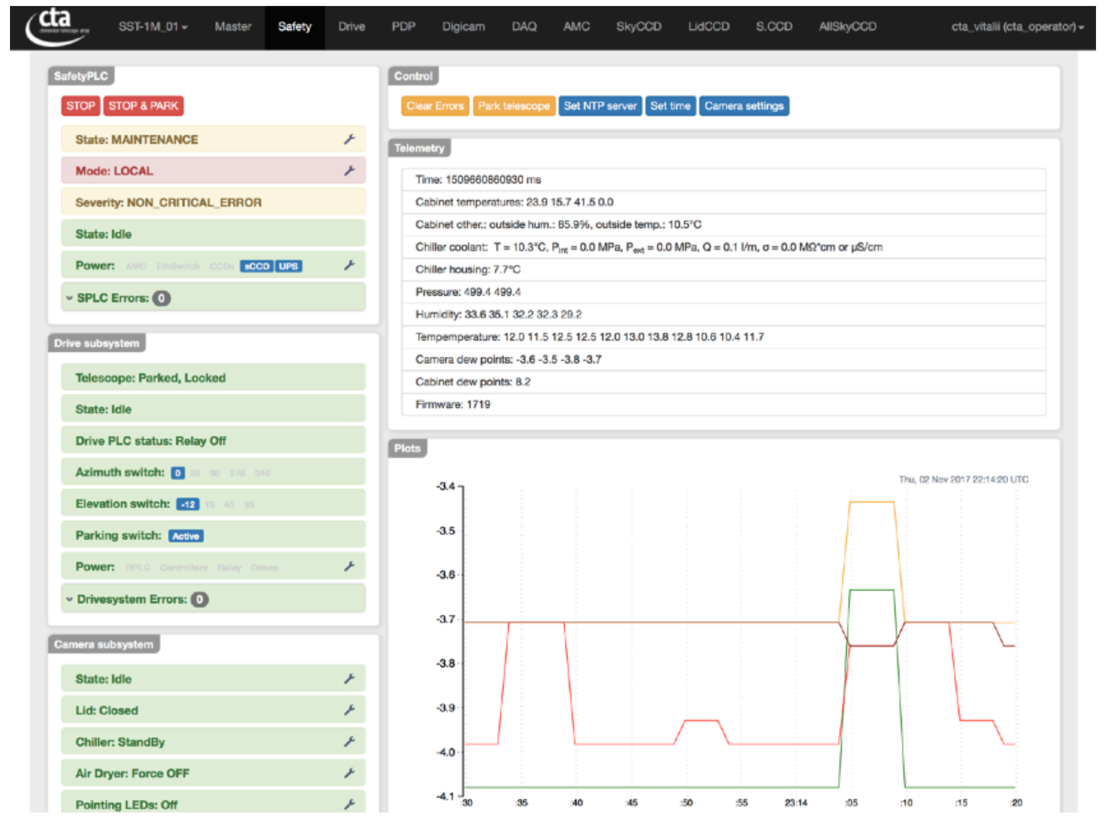
Jurysek et al. [PoS(ICRC2023)592]

The SST-1M operation

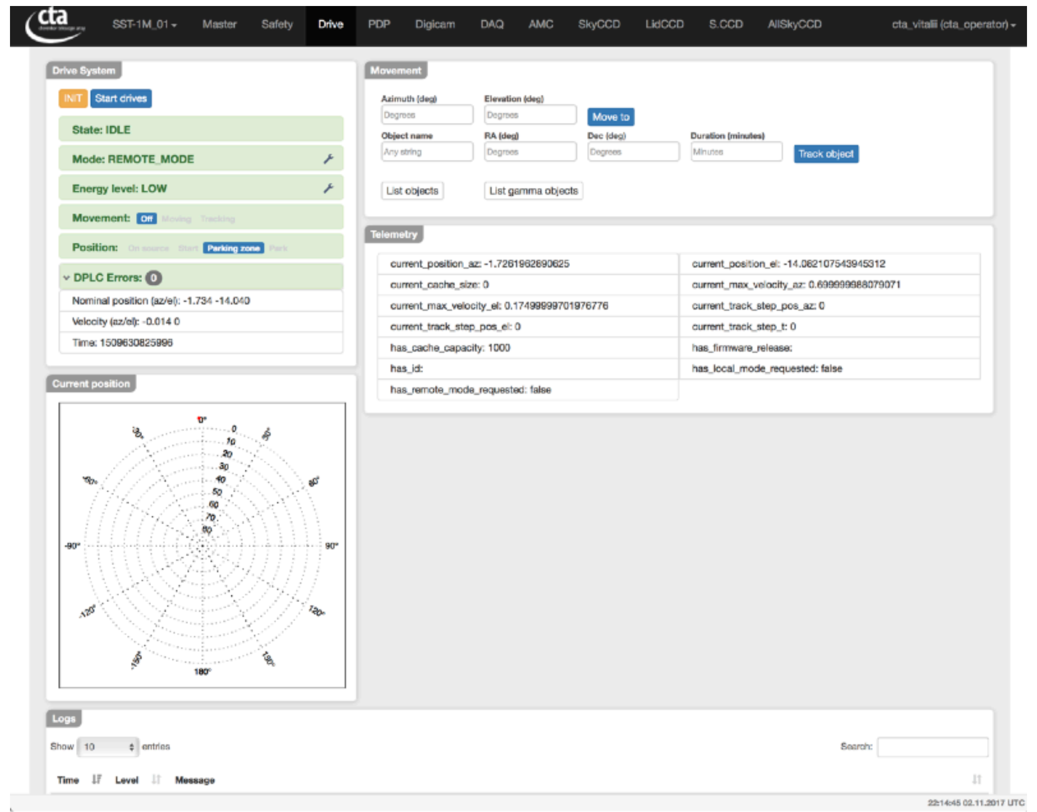
- Remote and nearly fully automatic observations



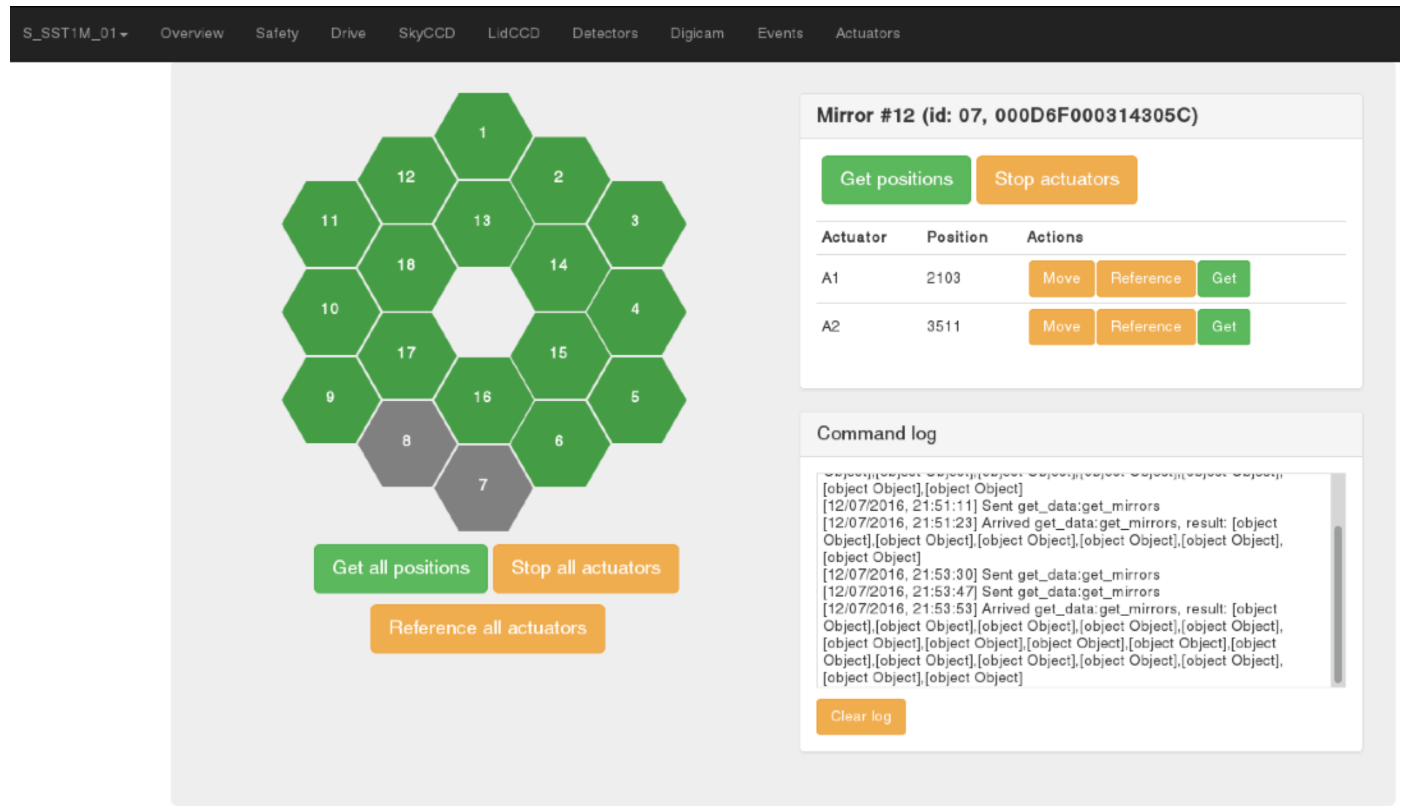
SST-1M master controller



Safety PLC subsystem



Drive system control



Active mirror control

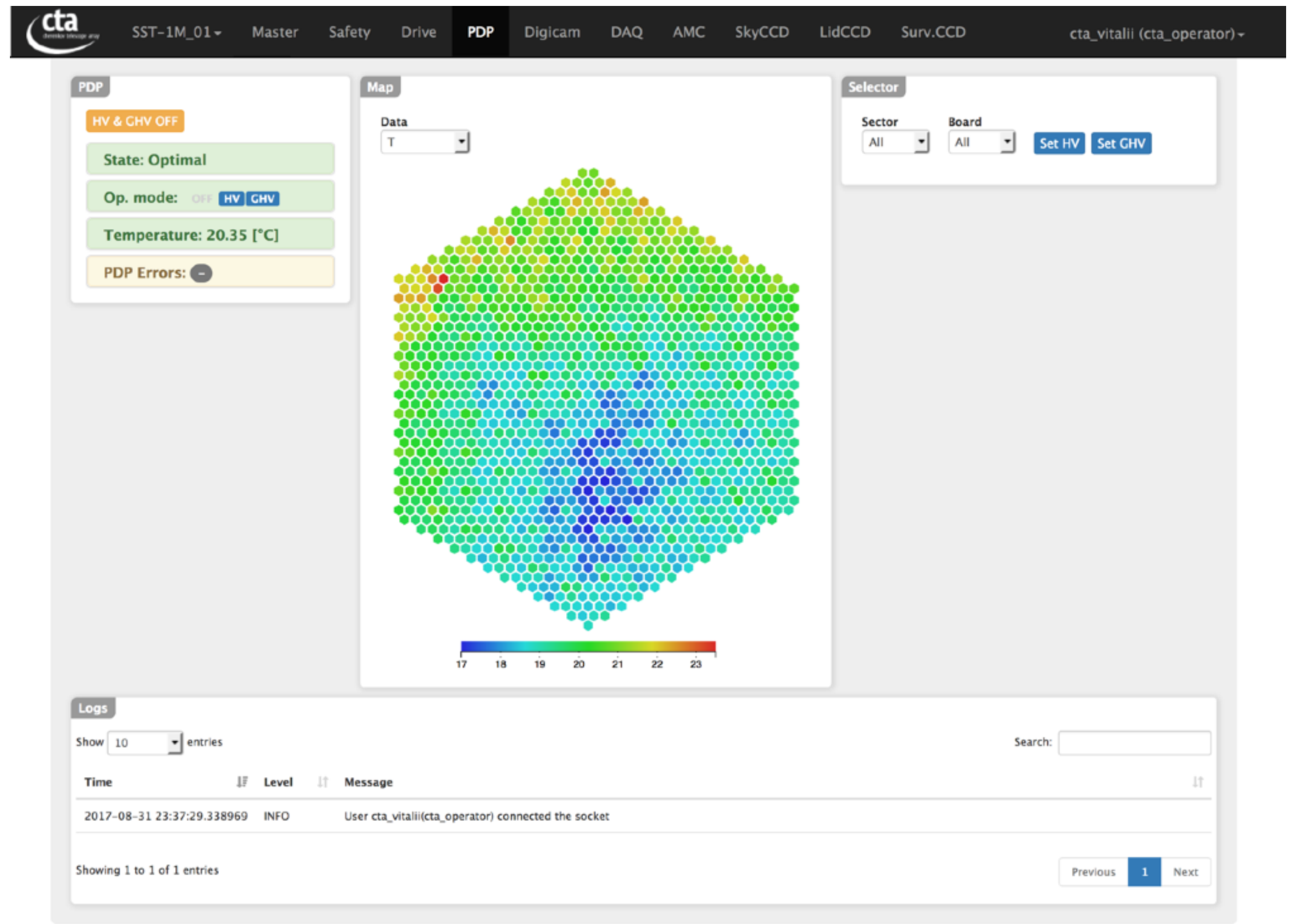
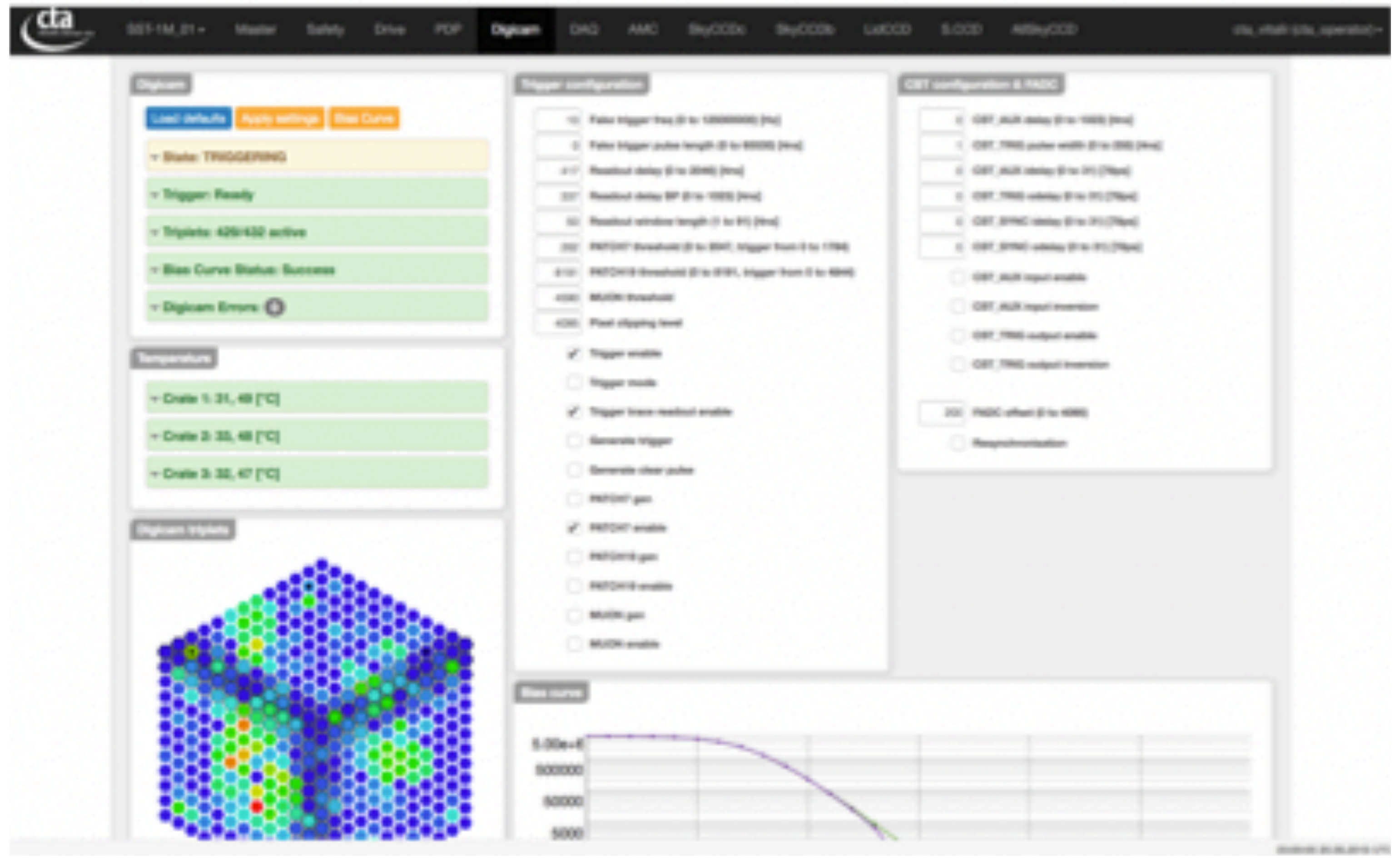
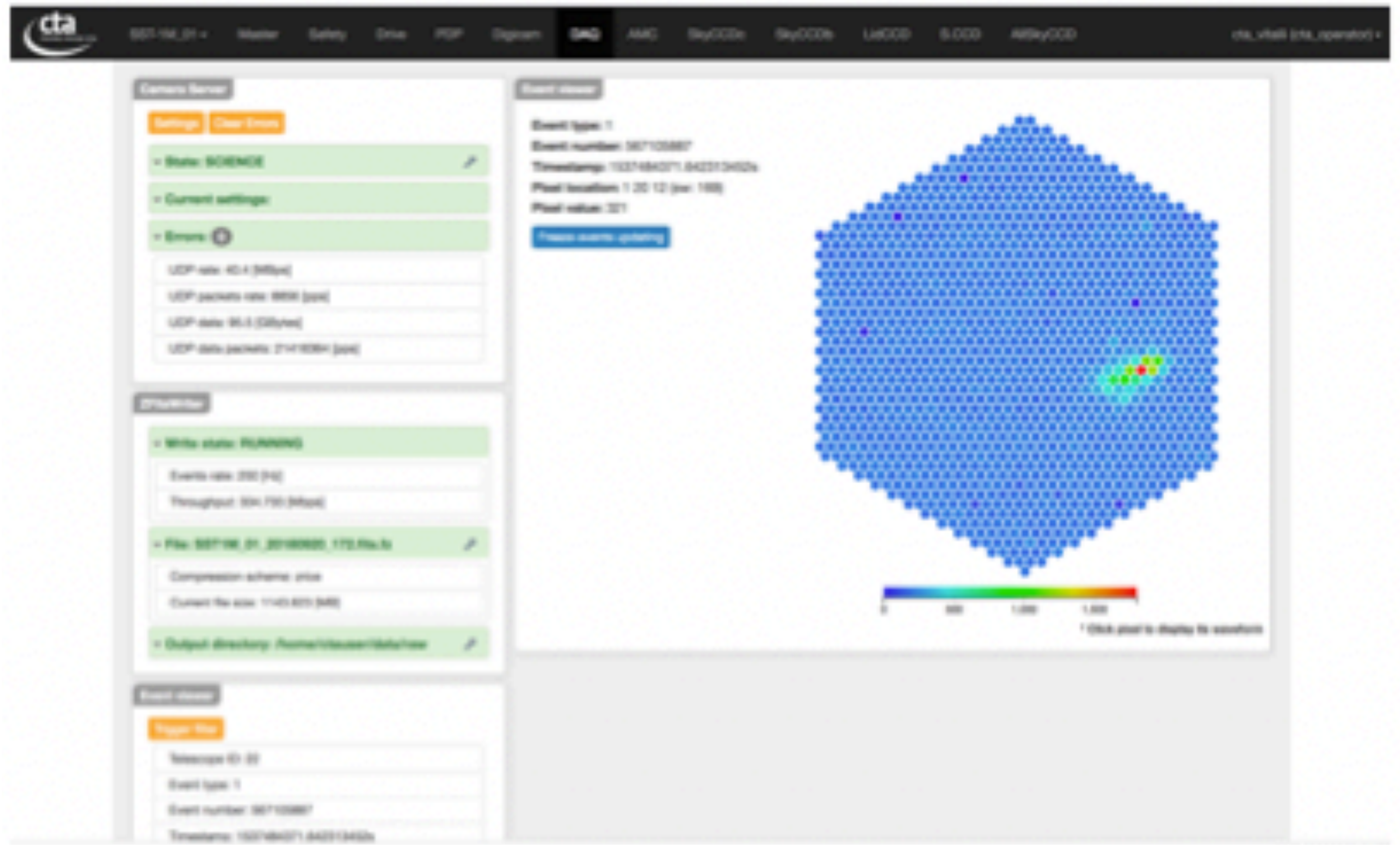


Photo detector plane control and monitoring



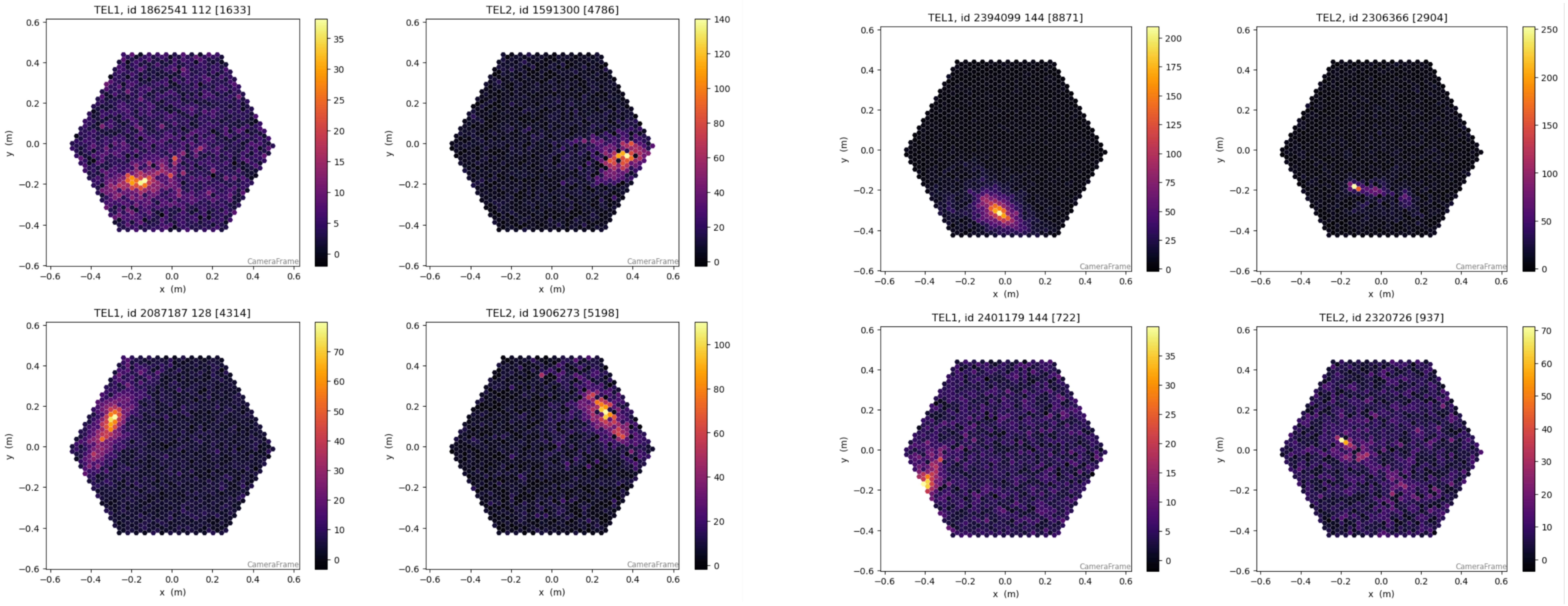
Digital readout configuration



DAQ control and monitoring

Stereo observations

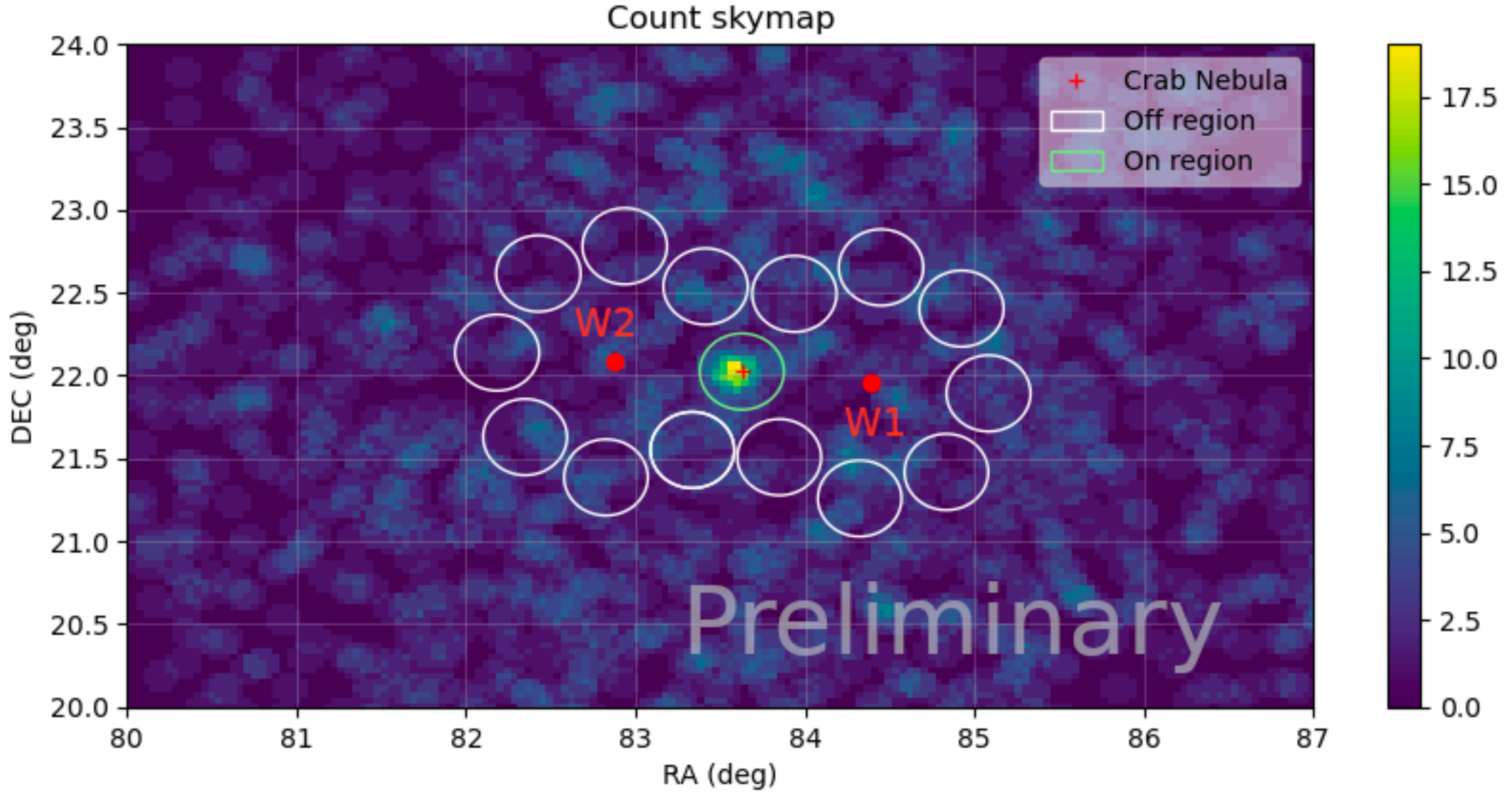
- Both cameras connected to White Rabbit switch for synchronisation, system still being commissioned
- Stereo trigger managed by Software Array Trigger (SWAT), soon deployed with ACS

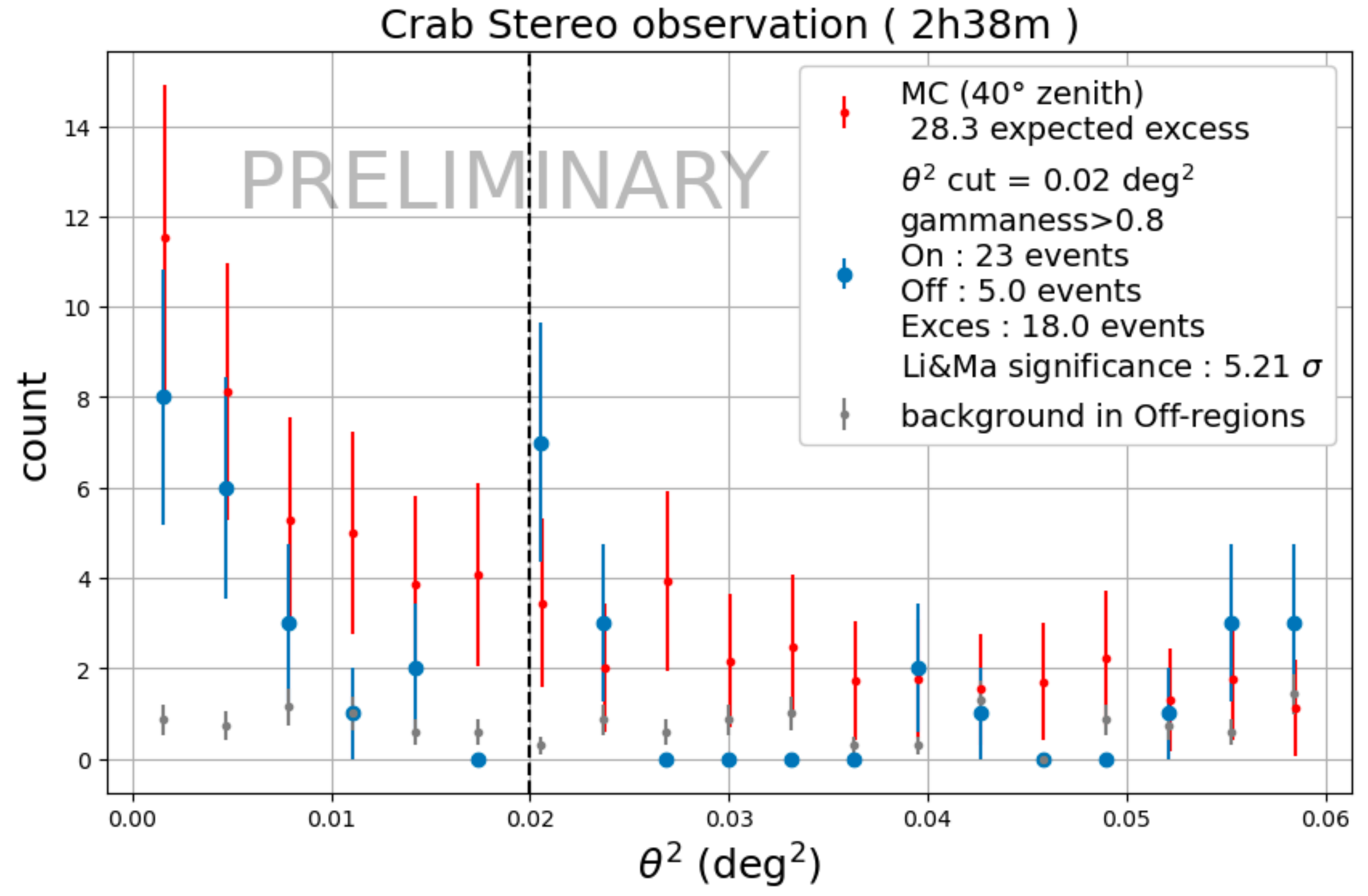


Observations

Stereoscopic observation

- White rabbit was not fully commissioned at the time of data taking, coincidences derived from time clustering of events
- Crab stereo data set acquired with two wobbles configuration
- Crab detected with 5.21σ significance in 2h38 (MC prediction is 5σ in 2h at 40 deg Zenith)





Tavernier et al. [PoS(ICRC2023)741]

Conclusion and Prospects

- Finalise the commissioning for the stereo observations
  - Telescope description
  - Synchronisation
  - Fully remote and automatised telescope control

- The SST-1M concept has already proven to meet the performance requirements it was designed for

- Continue with scientific program:
  - Crab observation
  - Monitoring of the brightest blazars
    - Recent 5σ detection of extragalactic blazar 1ES1959+650
    - Accumulating data for Mrk 421, 501
  - Exploring advanced triggering and measurements methods exploiting the fully digital readout and large field of view

- The collaboration is exploring new possibilities for observation sites:
  - Two of them can only do so much …
  - … but when complementing another Cherenkov of CR observatory, they are a great asset.