SST-1M: Design, Performance, and Commissioning Results of a Single-Mirror Small Size Telescope for Gamma-ray Astrophysics

Thomas Tavernier,
on behalf of the SST-1M collaboration

FZU

thomas.tavernier@fzu.cz

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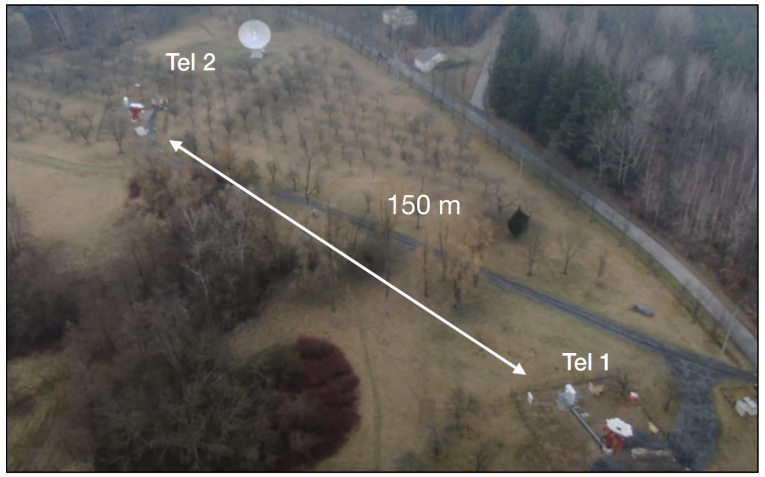
Outline

1. Instrument Overview
2. Analysis Pipeline
   - On site Calibration
   - Monte-Carlo Simulation
   - Performances
3. 1st Commissioning result : Crab observation

SST-1M project

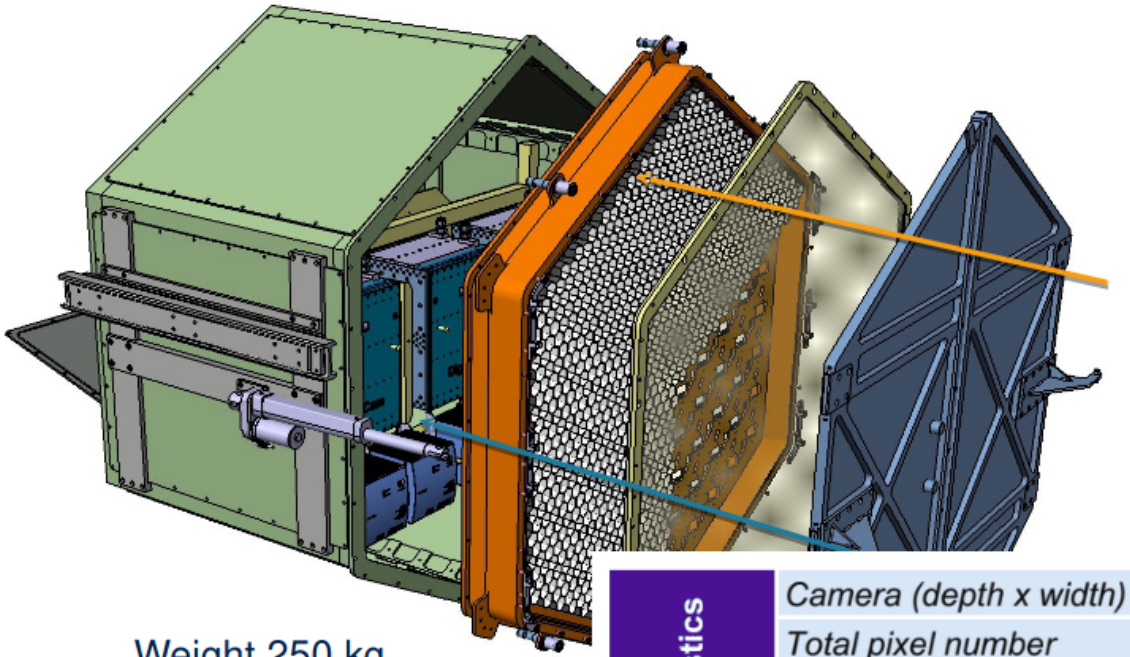
- Consortium of research institutions from Poland, Switzerland and Czech Republic
- SST-1M was initially designed to be part of The CTA Observatory.
- It was reviewed and satisfied all the CTA requirements. Another design was however chosen during the "harmonization" process.
- Two SST-1M prototype telescopes were relocated from Poland to the Czech's Republic and are being commissioned in the Ondrejov Observatory (alt 500m).
  - Telescope 2
    first light : 2022/02/28
  - Telescope 1
    first light : 2022/03/16



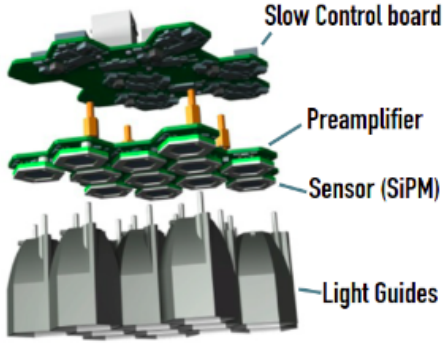
SST-1M telescope

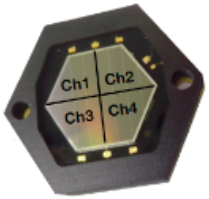
# Mirrors	18
# Pixels	1296
Field of View	9.1°
Focal length	5.6 m
Pixel angular size	0.24°
Pixel linear size	23.2 mm
Mirror area	9.42 m^2
Mirror effective area	6.47 m^2

SST-1M camera : Digicam



Weight 250 kg

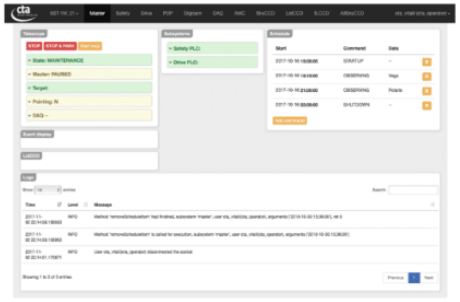




Camera Characteristics	
Camera (depth x width)	60 cm x 90 cm
Total pixel number	1296
Pixel linear size	23.2 mm
Pixel angular size	0.24°
FoV	9.1°
Photosensors PDE	> 30%
Sampling frequency	250 MHz
Readout rate	0.6-1 kHz
Time Spread RMS	< 0.25 ns

SST-1M Operation

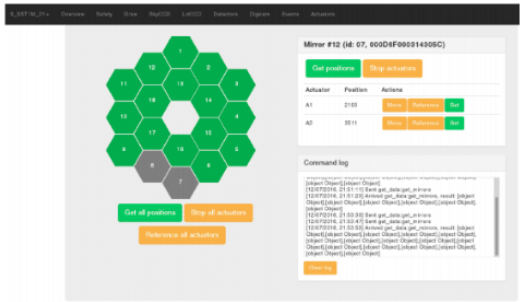
- Observations can be carried out entirely remotely



SST-1M master controller

Safety PLC subsystem

Drive system control



Active mirror control

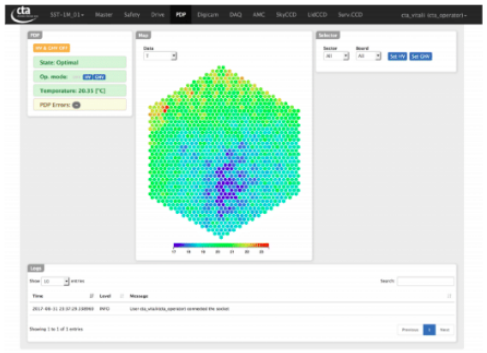
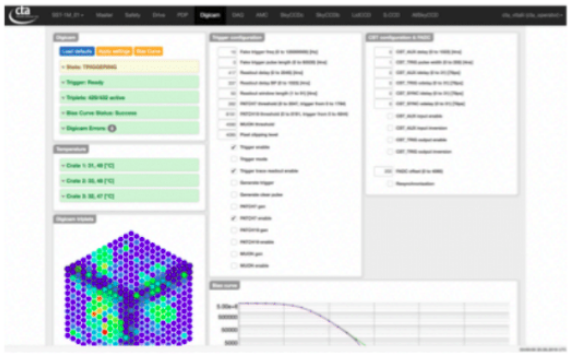
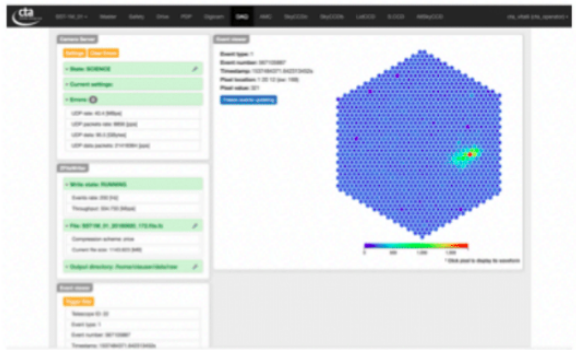


Photo detector plane control and monitoring



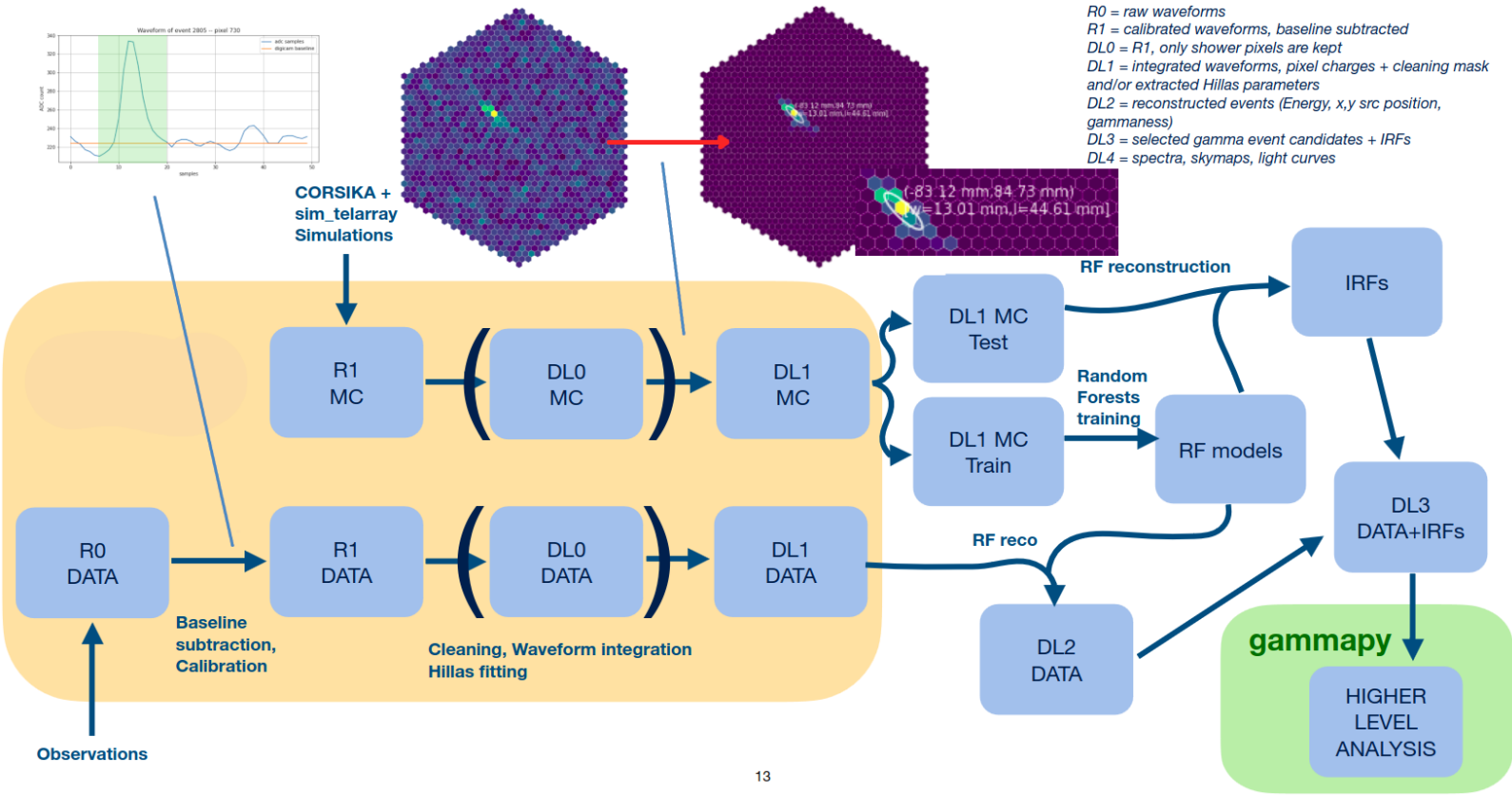
Digital readout configuration



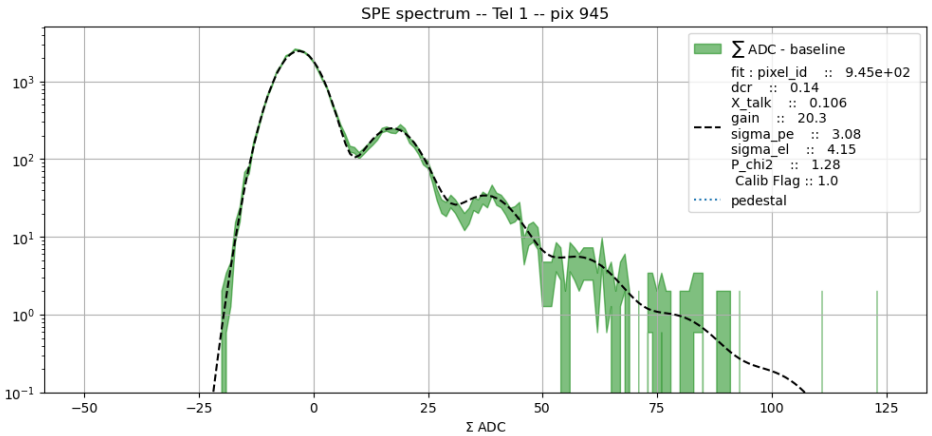
DAQ control and monitoring

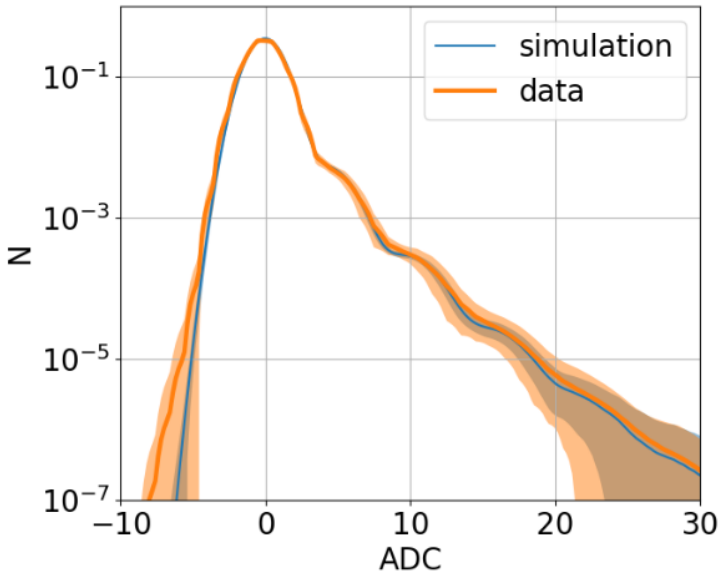
SST-1M analysis pipeline

- Analysis pipeline is heavily based on `ctapipe` and inspired by `lstchain` and `magic-ctapipe`
- Event reconstruction and classification is done using random forest trained on Monte-Carlo



Calibration from Dark runs





- Photo-sensor's response can be estimated trough the multi-photoelectron's spectrum produced by thermal photons.
- Conversion factor from ADC counts to photo-electrons is given by :

$$\frac{1-\mu}{g}$$

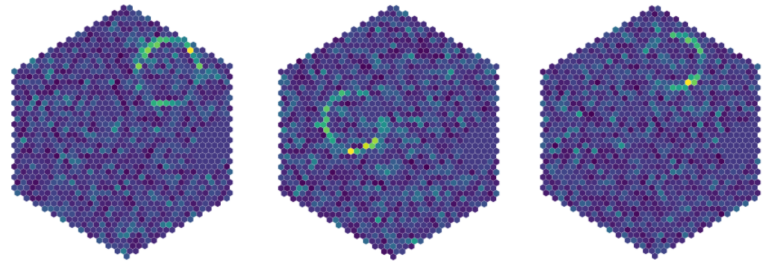
  - g : gain
  - μ : X-talk

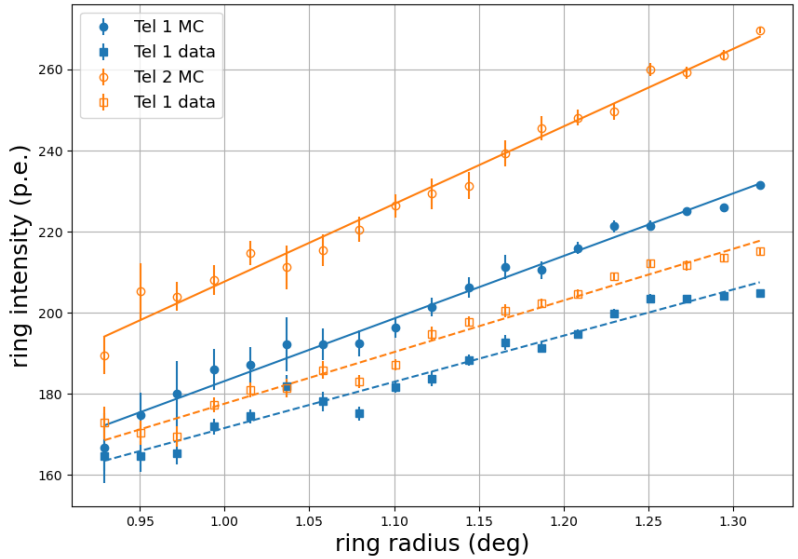
X-talk $\rightarrow$ modified Poisson law :

$$P_{\lambda,\mu}(n) = e^{-\lambda-n\mu} \times \frac{\lambda(\lambda+n\mu)^{n-1}}{n!}$$

Calibration from Muons

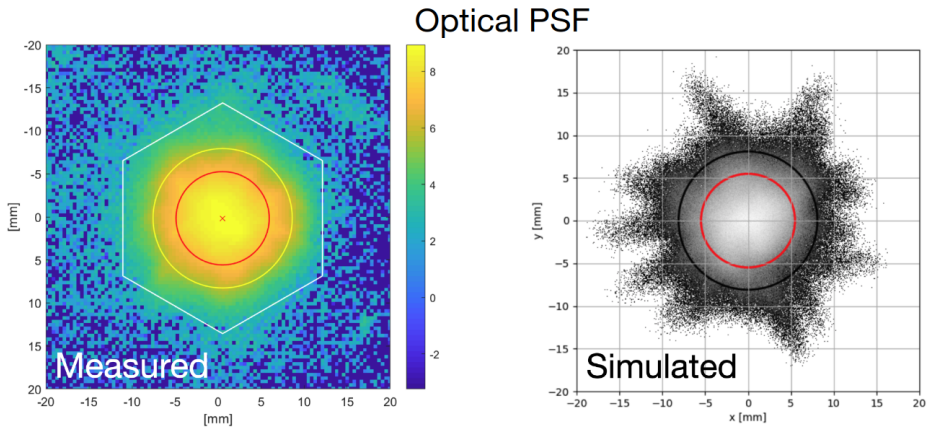
- Muons are known to be valuable test beams for IACT's astronomy
  - Typical ring images at the focal plane
  - Light intensity from muons can be derived analytically
  - Light intensity is proportional to the ring radius
- Optical efficiency is overestimated in the MC (10 to 20%). This will be adjusted in the next MC production.



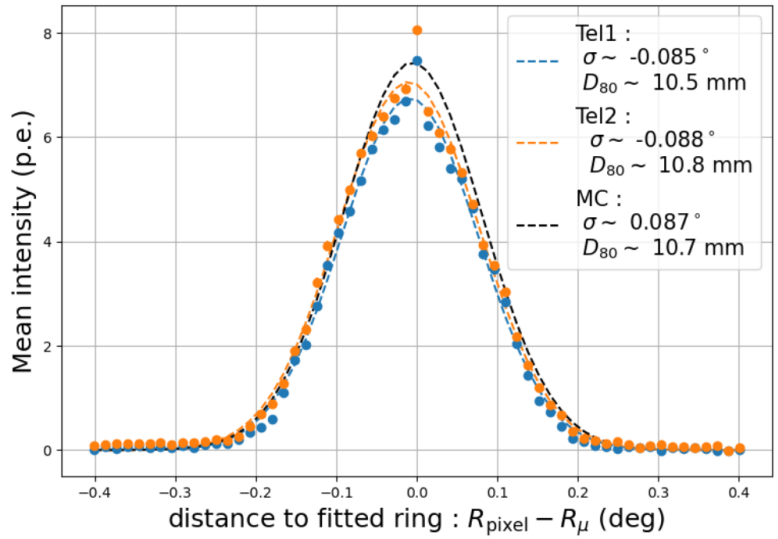


Optical PSF

- Mirrors are aligned using star's image on a target placed on the LID
  - This target is also used to build a pointing correction model for the telescope's structures.
- Optical PSF can also be estimated with muon analysis



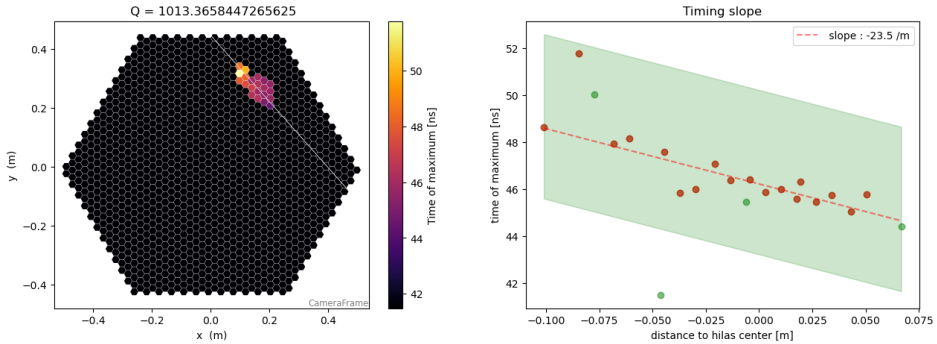
[credit : Miroslav Pech]

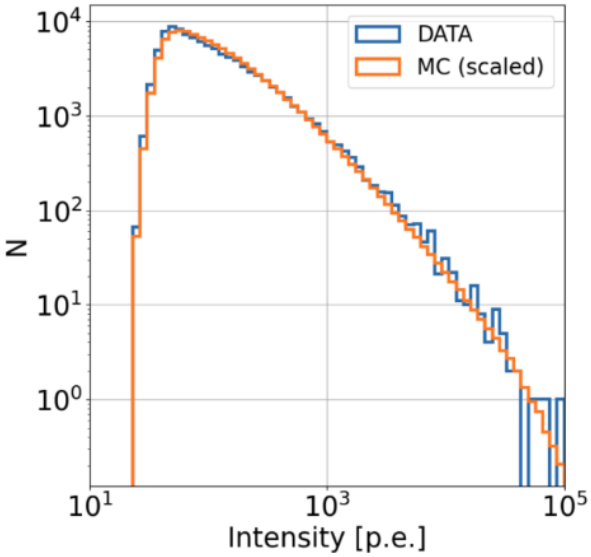


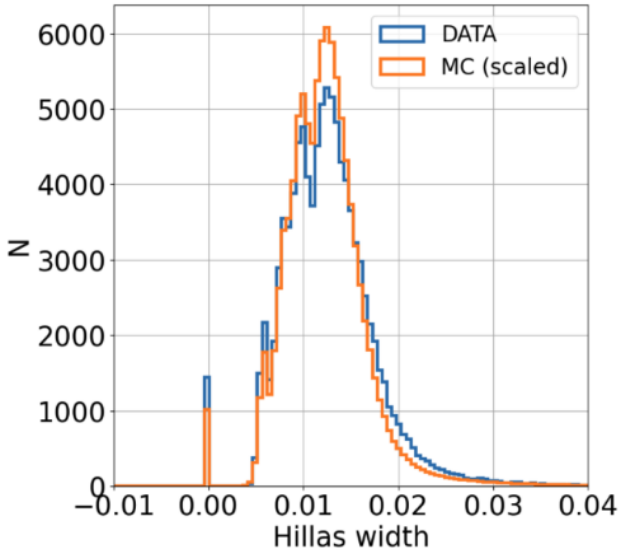
MC-Data comparison

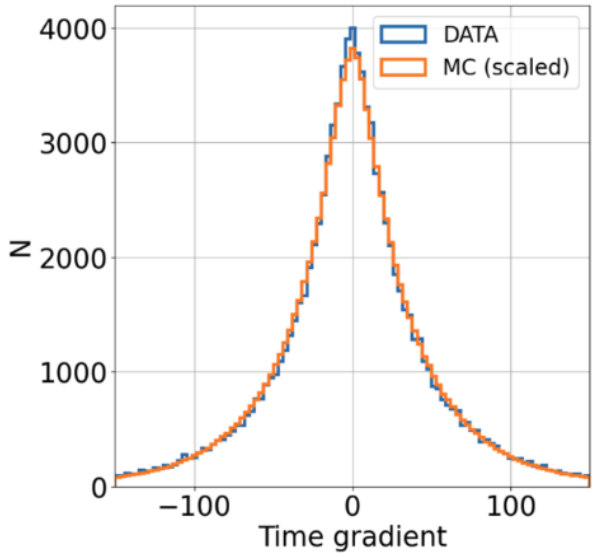
- Data : taken at zenith angle between 18° and 22°
- MC : Proton spectrum at 20° zenith angle

Time gradient :









Jurysek et al. [PoS(ICRC2023)592]

SST-1M performances

Energy Threshold

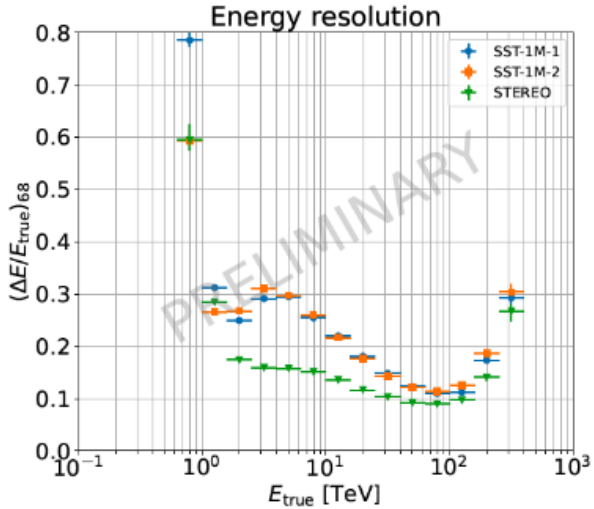
- $\sim$ 1 TeV

Energy resolution at 5TeV

- mono : $\sim$30 %
- stereo : $\sim$15 %

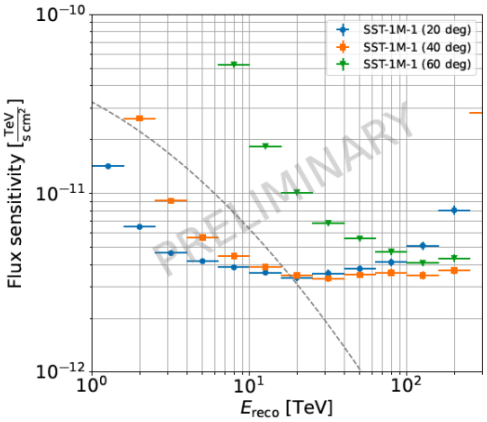
Angular resolution at 5TeV

- mono : $\sim$0.2°
- stereo : $\sim$0.1°

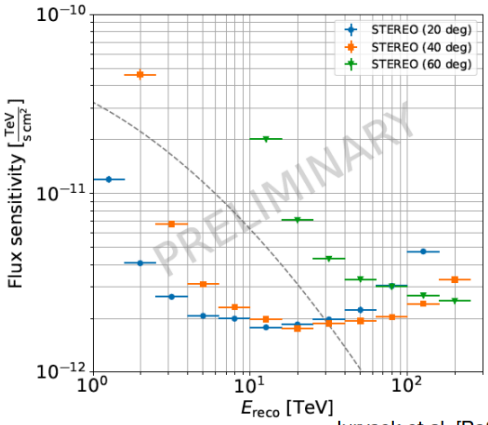


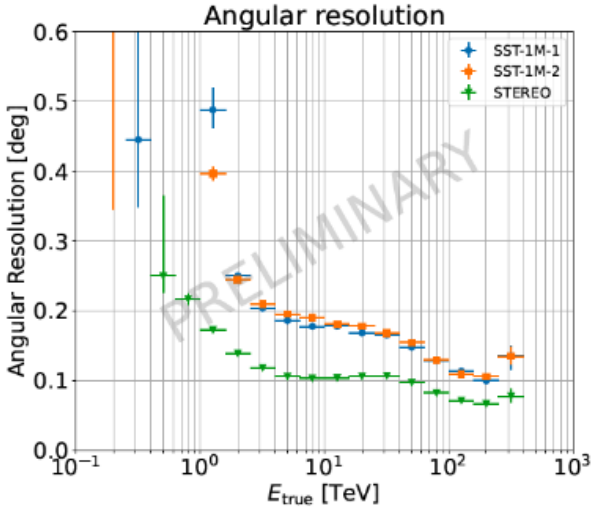
Sensitivity (50h) :

mono



stereo



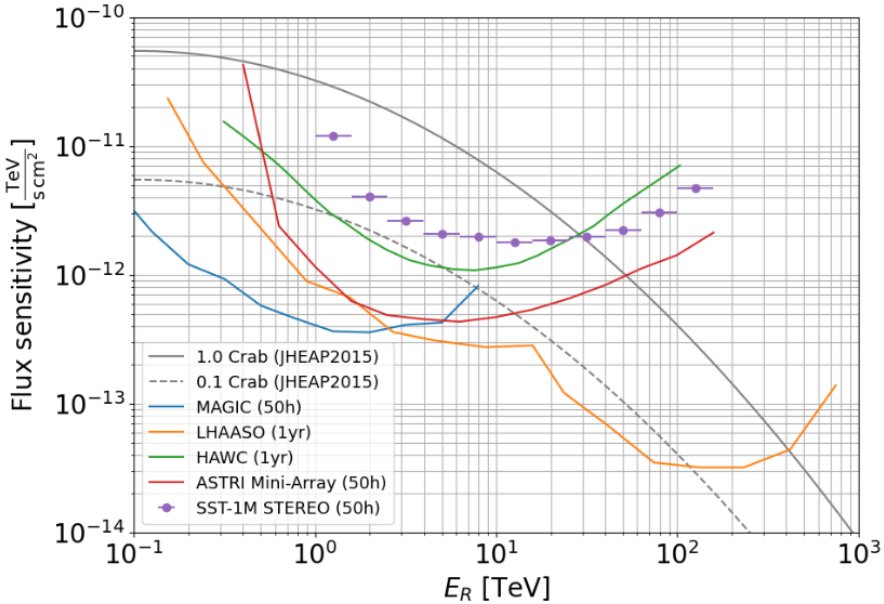


Jurysek et al. [PoS(ICRC2023)592]

SST-1M performances

- Low altitude of the site lead to an energy Threshold of $\sim$ 1TeV
- Ongoing work to lower the instrument threshold
  - Cleaning optimization
  - Trigger algorithm

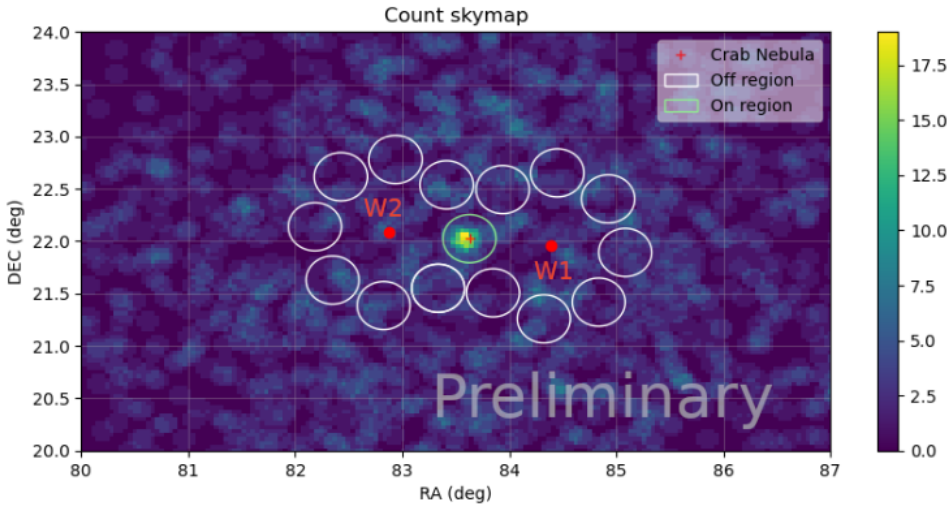
SST-1M sensitivity (50h at 20° zenith) :

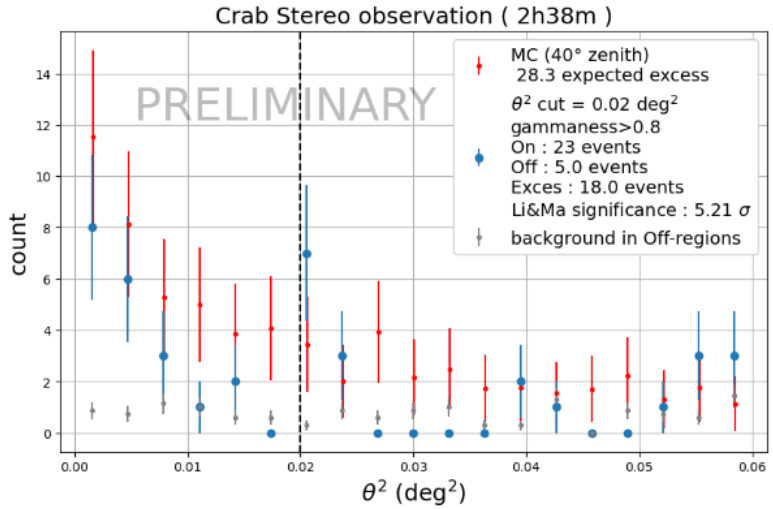


Crab stereo observation

- Observation in wobble (0.7° offset)
- Data set zenith angles range from 35° to 45°
- Crab is seen at 5.21σ in 2h38 of observation.
- Main livetime limitation : bad weather.

- Agreement between the MC prediction and the real data is good
- The SST-1M stereoscopic system meets the performances derived from the MC simulations





Conclusion & perspectives

- The SST-1M meets the expected performances
  - Crab seen at 5.21σ in 2h38 at 40° zenith angle
- We have data accumulated on other sources :
  - Mrk 421, 501, 1ES1959+650
  - NGC 1275 flare in winter 2023
- New crab observation campaign will start soon
- Future science prospect
  - TOO (Flaring blazar, GRB, GW NS merger..)
  - Extended sources (Pulsar halo, SNR)
- Future of SST-1M telescopes ?
  - 2 SST-1M alone can't do much
  - Exploring new possibilities for observation sites, complementing another γ-ray observatory,