PROCEEDINGS OF SCIENCE

Performance of the SST-1M telescope for the Cherenkov Telescope Array observatory

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The single mirror small-size telescope (SST-1M) is one of the telescope projects being proposed for the Cherenkov Telescope Array observatory by a sub-consortium of Polish and Swiss institutions. The SST-1M prototype structure is currently being constructed at the Institute of Nuclear Physics in Cracow, Poland, while the camera will be assembled at the University of Geneva, Switzerland. This prototype enables measurements of parameters having a decisive influence on the telescope performance. We present results of numerical simulations of the SST-1M performance based on such measurements. The telescope effective area, the expected trigger rates and the optical point spread function are calculated.

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1. Introduction

The Cherenkov Telescope Array (CTA) observatory is an international initiative to build the next generation of ground-based very high energy gamma-ray instruments. Full sky coverage will be assured by two arrays, with one site located in each of the northern and southern hemispheres, and three main classes of telescopes (large, medium, small) will cover the wide energy range from tens of GeV up to hundreds of TeV [1].

The single mirror small-size telescope (SST-1M) is one of the telescope projects being proposed for the CTA observatory by a sub-consortium of Polish and Swiss institutions. Its design is based on the Davies-Cotton concept of multi-segment mirror composed of spherical facets focused at twice the focal length of the telescope. In case of the SST-1M telescope the mirror of 4 m diameter is composed of 18 hexagonal facets of 78 cm dimension (flat-to-flat). The focal length of the telescope is 5.6 m.

The prototype SST-1M telescope structure was installed at the Institute of Nuclear Physics in Kraków, Poland in November 2013 and is currently being tested and equipped with mirrors [2]. In parallel the SST-1M camera, named DigiCam, is being constructed in the Université de Genève, AGH University of Science and Technology, and Astronomical Observatory of the Jagiellonian University [3]. The DigiCam utilizes silicon photo-multipliers, which use in imaging atmospheric Cherenkov telescopes was pioneered by the FACT telescope [4], and fully digital read-out and trigger electronics.

Based on measurements taken during the prototyping phase a series of numerical simulations has been undertaken to determine the SST-1M telescope performance. During the simulations such parameters as optical point spread function, night sky background trigger rate, single telescope effective area and expected gamma-ray trigger rate have been determined.

2. Optical point spread function

The telescope optical point spread function (PSF) is a crucial parameter to determine the ability to correctly image the air showers. A ray tracing feature of the `sim_telarray` software package [5] has been used to determine the PSF of the SST-1M telescope. First a sample of 14 mirror facets delivered for the prototype has been measured in the Space Research Center in Warsaw to provide initial values for the simulations. An average spot size D_{80} at twice the focal length f of 5.7 ± 1.1 mm (D_{80} being a diameter of the smallest circle containing 80% of the light rays) has been measured. This value has been used to fix the simulation parameters. The result of such a procedure is presented in Fig. 1. As a next step an additional measurement of the average focal length of the mirror facets – $<f>= 5.60 \pm 0.03$ m has been used to simulate the PSF of the whole mirror. A value of $D_{80}(f) = 0.81 \pm 0.05$ cm has been obtained, which corresponds to the angular scale of $D_{80}(f) = 0.083 \pm 0.005$ deg for the on-axis rays. An example of the PSF shape is presented in Fig. 2.

Additionally PSF values have been analysed for the off-axis rays in the 80% of the camera field of view as required by the CTA Consortium and compared to the case where all mirror facets are just perfect. The results are presented in Fig. 3. A fraction of encircled energy has been also calculated as a function of the off-axis angle and is presented in Fig. 4.

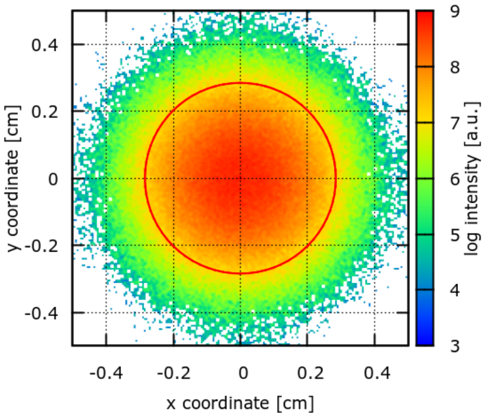

Figure 1: Simulated PSF shape for a single mirror facet – real case corresponding to measured spot size $D_{80}(2f) = 5.7\,\mathrm{mm}$ marked with a red circle.

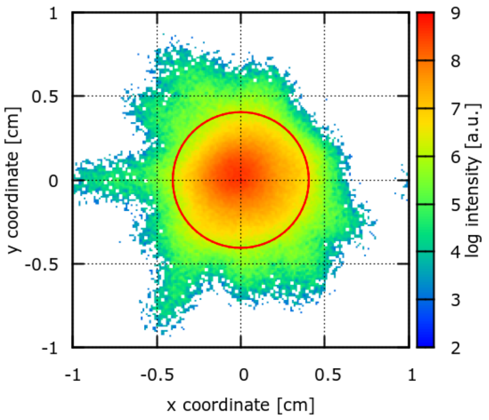

Figure 2: Example of simulated PSF shape for the whole SST-1M mirror. Red circle corresponds to $D_{80}(f) = 0.81\,\mathrm{cm}$.

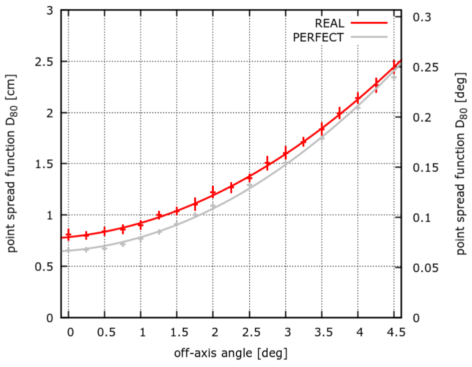

Figure 3: Comparison of PSF dependence on off-axis angle for both perfect and real cases.

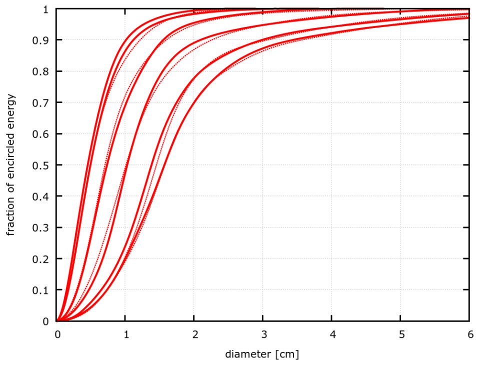

Figure 4: Fraction of encircled energy for off-axis rays at angles 0, 1, 2, 3, 4, and 4.5 deg (from left to right, respectively). Two curves for off-axis rays represent vertical (dotted lines) and horizontal (solid lines) axis.

These studies show a very little PSF degradation as compared to the ideal case and proof that the performance goals are quite easy achievable with current mirror manufacturing techniques.

3. Night sky background trigger rate

A main source of night sky background (NSB) is the zodiacal light being detected together with Cherenkov radiation from air showers. In the CTA framework the lowest flux of NSB light has been estimated to be $0.24\,\mathrm{ph\,ns^{-1}\,sr^{-1}\,cm^{-2}}$. This flux level corresponds to the so called “dark night” conditions, when observations are performed without the presence of the moon light. Taking into account the SST-1M telescope optical transmission, effective collecting area of the mirror, angular size of the pixel, and quantum efficiency of the photo detectors in the camera this value corresponds to NSB level of $33.2 \times 10^{6}\,\mathrm{ph\,s^{-1}}$ per pixel. This estimation does not take into acount additional component coming from dark current counts. Initial measurements show the level of dark current of about 6 MHz, but the final estimation requires additional studies.

Such conditions require efficient trigger system to lower the readout rate and to avoid accidental coincidences. Simulations of SST-1M telescope detection process have been performed to determine the dependence of the NSB trigger rate as a function of the trigger threshold. `Sim_telarray` package has been used and the trigger topology has been defined in such a way that trigger conditions are met if summed signal from a sector containing 7 neighboring pixels is above the threshold. Since DigiCam camera operates at 250 MHz sampling rate this is also the highest NSB trigger rate which may be expected from the system. Due to constraints resulting from the internal bandwidth limits this value needs to be lower to less than about 20 kHz. Results of the simulations are presented in Fig. 5 and in Tab. 1 we list trigger thresholds required to lower the NSB rate to reasonable values.

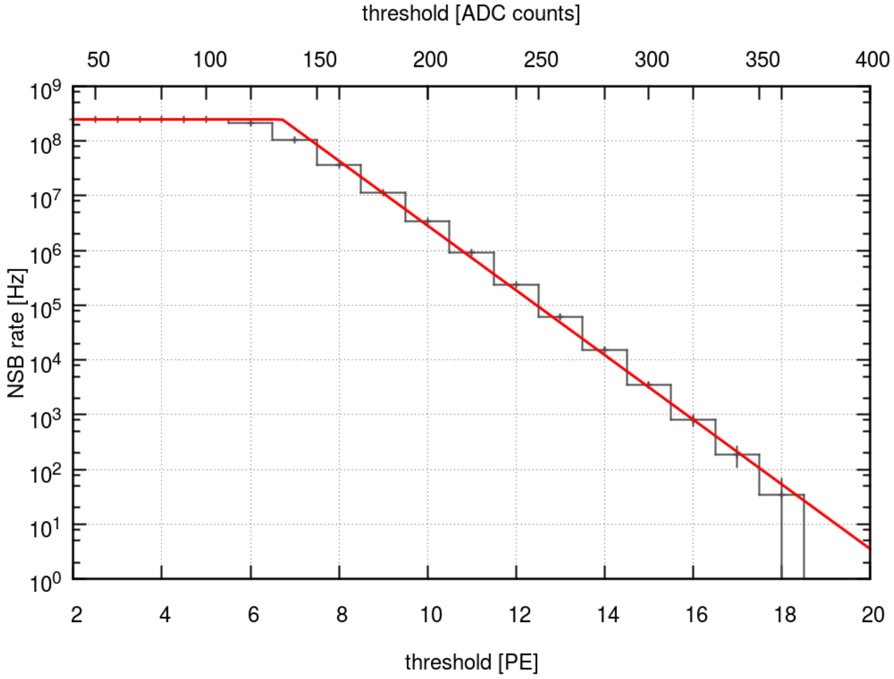

Figure 5: Night sky background trigger rate as a function of trigger threshold for SST-1M telescope.

During massive numerical simulations performed within Monte Carlo Work Package of the CTA Consortium a concept of “safe threshold” has been used [6]. “Safe threshold” is defined as a threshold level at which NSB trigger rate calculated for twice the NSB level equals the cosmic ray trigger rate, which for that purpose is approximated as 1.5 times the proton trigger rate. For the SST-1M telescope prototype the “safe threshold” has been estimated equal to 17.2 PE.

4. Effective area, gamma rate and energy threshold

Single telescope effective area for a point source of gamma-ray photons is defined as

$$A_{\mathrm{eff},\gamma}(E) = 2\pi \int_0^\infty P_\gamma(E,r) r \mathrm{d}r\,, \tag{4.1}$$

NSB rate	threshold [PE]
20 kHz	13.6
10 kHz	14.2
1 kHz	15.8
100 Hz	17.4
10 Hz	19.3

Table 1: Trigger thresholds required to lower the trigger rate due to NSB.

where $P_\gamma(E,r)$ is the detection probability (trigger probability) for a gamma-ray shower induced by a primary photon with energy E and impact parameter r. A total number of 1.6×10^7 gamma-ray showers within energy range $0.05 - 320$ TeV has been simulated with CORSIKA software [7] to estimate the effective area of the SST-1M telescope. The result is presented in Fig. 6.

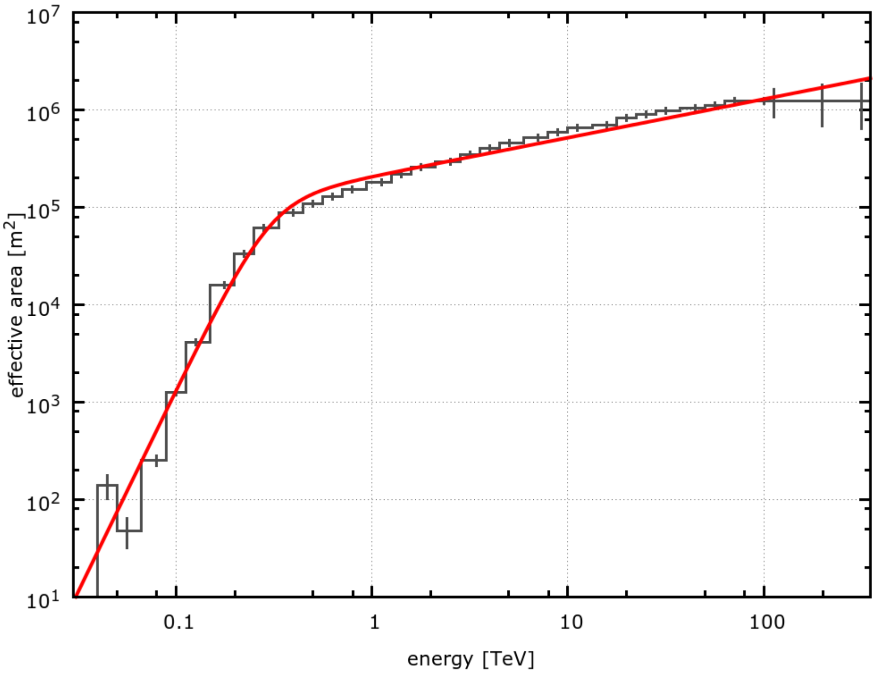

Figure 6: SST-1M telescope effective area as a function of energy.

To estimate the expected gamma-ray trigger rate the above effective area has been folded with a Crab-like source spectrum giving the differential gamma rate plotted in Fig. 7. Thus the total gamma-ray trigger rate, being the integral of the differential trigger rate over all energies, for the SST-1M telescope is 0.27 Hz.

Energy threshold, defined as the energy for which the differential trigger rate reaches its maximum is 0.3 TeV.

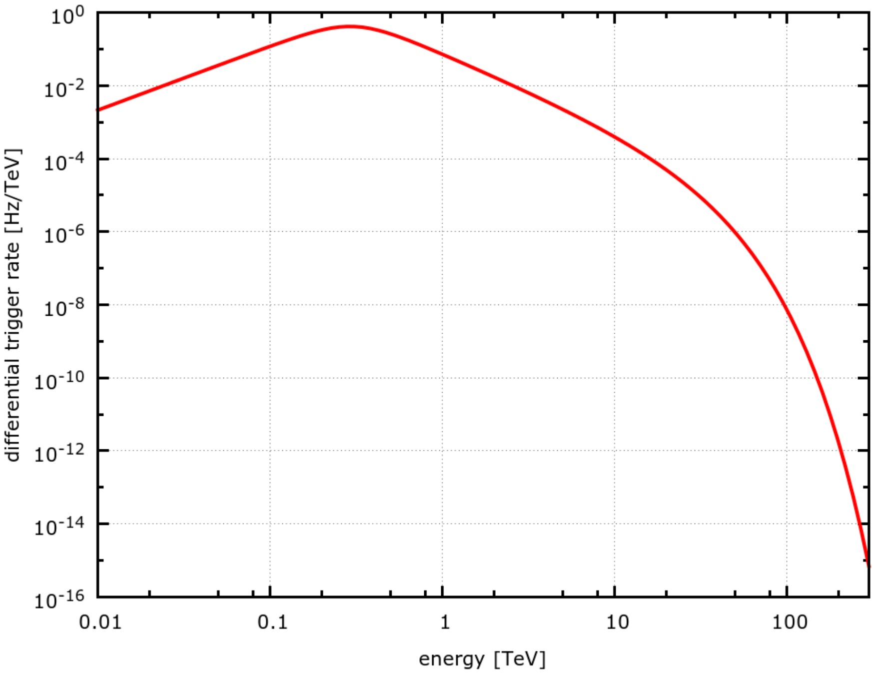

Figure 7: SST-1M telescope gamma-ray differential trigger rate for Crab-like point source as a function of energy.

5. Summary

SST-1M is a well advanced project. Measurements of the system components taken during the construction of the prototype allowed us to perform a series of numerical simulations of the expected performance of the telescope. Results show that a network of SST-1M telescopes is a valuable proposal for one of the sub-arrays of the small size telescopes for the CTA Observatory. In the near future SST-1M parameters estimated during presented studies will be used in a massive numerical simulations of the whole CTA array to determine the final performance characteristics of the SST-1M sub-system.

Acknowledgments

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