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Characterization and commissioning of the SST-1M camera for the Cherenkov Telescope Array

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ABSTRACT

The Cherenkov Telescope Array (CTA), the next generation very high energy gamma-rays observatory, will consist of three types of telescopes: large (LST), medium (MST) and small (SST) size telescopes. The SSTs are dedicated to the observation of gamma-rays with energy between a few TeV and a few hundreds of TeV. The SST array is expected to have 70 telescopes of different designs.

The single-mirror small size telescope (SST-1 M) is one of the proposed telescope designs under consideration for the SST array. It will be equipped with a 4 m diameter segmented mirror dish and with an innovative camera based on silicon photomultipliers (SiPMs).

The challenge is not only to build a telescope with exceptional performance but to do it foreseeing its mass production. To address both of these challenges, the camera adopts innovative solutions both for the optical system and readout.

The Photo-Detection Plane (PDP) of the camera is composed of 1296 pixels, each made of a hollow, hexagonal light guide coupled to a hexagonal SiPM designed by the University of Geneva and Hamamatsu. As no commercial ASIC would satisfy the CTA requirements when coupled to such a large sensor, dedicated preamplifier electronics have been designed. The readout electronics also use an innovative approach in gamma-ray astronomy by adopting a fully digital approach. All signals coming from the PDP are digitized in a 250 MHz Fast ADC and stored in ring buffers waiting for a trigger decision to send them to the pre-processing server where calibration and higher level triggers will decide whether the data are stored. The latest generation of FPGAs is used to achieve high data rates and also to exploit all the

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flexibility of the system. As an example each event can be flagged according to its trigger pattern. All of these features have been demonstrated in laboratory measurements on realistic elements and the results of these measurements will be presented in this contribution.

1. Introduction

The Cherenkov Telescope Array (CTA) collaboration—about 1400 scientists (31 countries)—proposes to build two arrays in the Northern and Southern hemispheres to explore our Universe in depth in Very High Energy gamma-rays and investigate cosmic non-thermal processes in the energy range 10 GeV < E < 300 TeV. The southern hemisphere array of CTA will consist of more than 100 telescopes of three types with different mirror sizes in order to cover the full energy range. The SSTs are designed for maximum sensitivity in the 5–300 TeV energy region. Different SST designs are being proposed, among which is a single mirror Davies–Cotton design (SST-1 M) whose camera is based on SiPM. The other two projects [1,2] are dual mirror telescopes of Schwarzschild–Couder type.

The geometry of the SST-1 M camera is determined by the optical properties and geometry of the telescope, as discussed in Ref. [3]. According to the CTA requirements for the SST [4], the optical PSF (Point Spread Function) cannot exceed 0.25° at 4° off-axis and the telescope must focus light (over 80% of the required camera field of view, FoV) with an rms optical time spread of less than 1.5 ns. To realize the required PSF with a Davies–Cotton design, a focal ratio of 1.4 was achieved with a telescope focal length of 5.6 m (and mirror of 4 m equivalent diameter) for the required FoV of 9°. These dimensions fix the diameter of the sensitive region of the camera to about 88 cm, the linear pixel size to 23.2 mm flat-to-flat for hexagonal pixels, and the cut-off angle to 24°.

The camera is a critical element of the proposed SST-1 M telescopes, and has been designed to address the CTA specifications for the sensitivity of the array, its angular resolution, the charge resolution and dynamic range of single cameras, for the FoV and the uniformity of the response, for the maintenance time consumption and the safety, while keeping the cost of single telescopes well below 1 M €. The SST-1 M camera has been conceived for achieving adequate optical performance with a very compact, lightweight, low power and low cost system. Its components are made with standard industrial techniques, with high reproducibility and suited for large scale production.

2. The SST-1 M camera

As can be seen in Fig. 1, the camera has a hexagonal shape with a distance vertex-to-vertex of 1120 mm and thickness of 735 mm. It weighs less than 200 kg.

The camera is composed of two main parts: the PDP (described in more detail later in Section 3), based on SiPM, and the trigger and readout system, DigiCam (see Section 4). The PDP uses 1296 pixels composed of a hollow light concentrator coupled to a custom monolithic hexagonal SiPM of 1 cm^2 area to match the desired pixel size [5]. It has been designed in collaboration with Hamamatsu[1] using their low-crosstalk technology (LCT) (50% PDE, low dark count rate 50 kHz/mm^2).

DigiCam uses a quite innovative approach in gamma-ray astronomy, which is its fully digital design with a programmable trigger logic, based on latest generation FPGA. Its compact digital readout/trigger (micro-crates have a volume of 65 × 30 × 30 cm^3) can sustain high trigger rates with no dead-time for trigger rates up to tens of kHz.

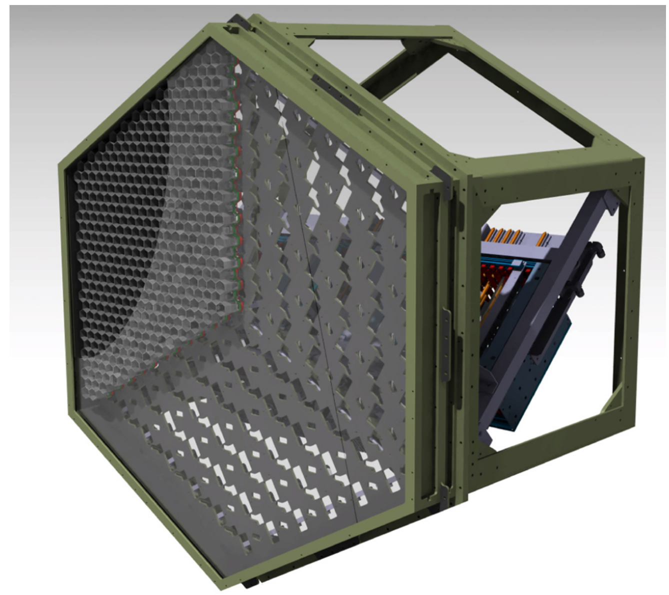

Fig. 1. Rendering of the camera structure. The PDP backplate is clearly visible together with some of the modules installed on it and the window covering them. On the back the 3 DigiCam micro-crates are visible.

3. The photo-detection plane

The PDP sensitive area has a hexagonal geometry with dimensions of 87.7 cm side-to-side and is composed of 1296 pixels distributed in 108 modules of 12 pixels each. Its mechanical stability is conferred by an aluminum backplate, to which the modules are screwed. The backplate also serves as a heat sink for the PDP cooling system. The PDP weights 35 kg, including the borofloat front windows.

The use of SiPM technology is new in the field of gamma-ray astrophysics and is an important innovative feature of the SST-1 M camera. For the case of the CTA SSTs, operating in the multi TeV domain, the capability of SiPMs to work with high levels of light without any aging, allows us to take data under moonlight conditions, increasing the duty cycle of the telescope, hence improving the discovery potential and sensitivity in the high-energy domain.

The PDP pixels are formed by an industrial hexagonal hollow light-funnel with a compression factor of about 6 coupled to a large area, hexagonal SiPMsensor (see Fig. 2).

The choice of a hexagonal shape is important for trigger purposes. For an easy implementation of selection algorithms based on pattern recognition, it is desirable that no preferred direction in the PDP exists, so that the trigger can operate under fully symmetrical conditions. The hexagon provides such a feature since the center of each pixel is at the same distance from the centers of all its neighbors as in the ideal case of circular pixels. At the same time, the hexagon guarantees the highest density of pixels on a

[1] http://www.hamamatsu.com.

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