Development of a compact-size, novel wide Field of View VHE Gamma-Ray Imaging Air Cherenkov Telescope with a SiPM-based camera for energies above 10 TeV for operation in the TAIGA installation.

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Abstract

The TAIGA [1] complex-detector is designed to study gamma and cosmic rays in the energy range above 30TeV. We are developing a novel wide-angle telescope with a SiPM-based imaging camera of a FoV of 15-20° and of an aperture of not more than 1m². In this report we intend to present the design of such a camera (optical system and DAQ), based on 1000-1200 SiPMs. The prototype of such a camera, based on 49 SiPMs, is operating at the TAIGA's site in Tunka valley since September 2019. The design of the prototype and the preliminary results of data analysis will be presented.

Introduction

For the energy range of gamma-rays above 30 TeV (ultra high energy gamma astronomy), there are a number of fundamental questions that are yet not answered and, above all, the question of the sources of Galactic cosmic rays in the region of 1PeV - the region immediately adjacent to the classical "knee" in the energy spectrum of all particles.

Until now, the bulk of knowledge about the fluxes and sources of high-energy gamma-rays has been obtained by using the imaging atmospheric Cherenkov telescopes (IACT). An IACT consists of a set of spherical mirrors and a detector camera in which an image of a flash of Cherenkov light from extensive air showers (EAS), initiated by primary gamma rays, is created. The sensitivity level of existing and currently operational gamma-ray telescopes is optimized for the energy range 50 GeV - 50 TeV

A modern gamma-ray telescopes for this energy range is an expensive, complex engineering product, difficult to operate. A serious drawback of a high-energy atmospheric gamma-ray telescope is its small diameter of the field of view (FOV), not more than 5 degrees. Such FoV allows one to observe only several sources during a single observational night.

At present, the deployment of the first phase of the TAIGA gamma experiment is being completed in the Tunka Valley (Republic Buryatia). The main goal of the TAIGA experiment is to study gamma rays with energies above 30 TeV.

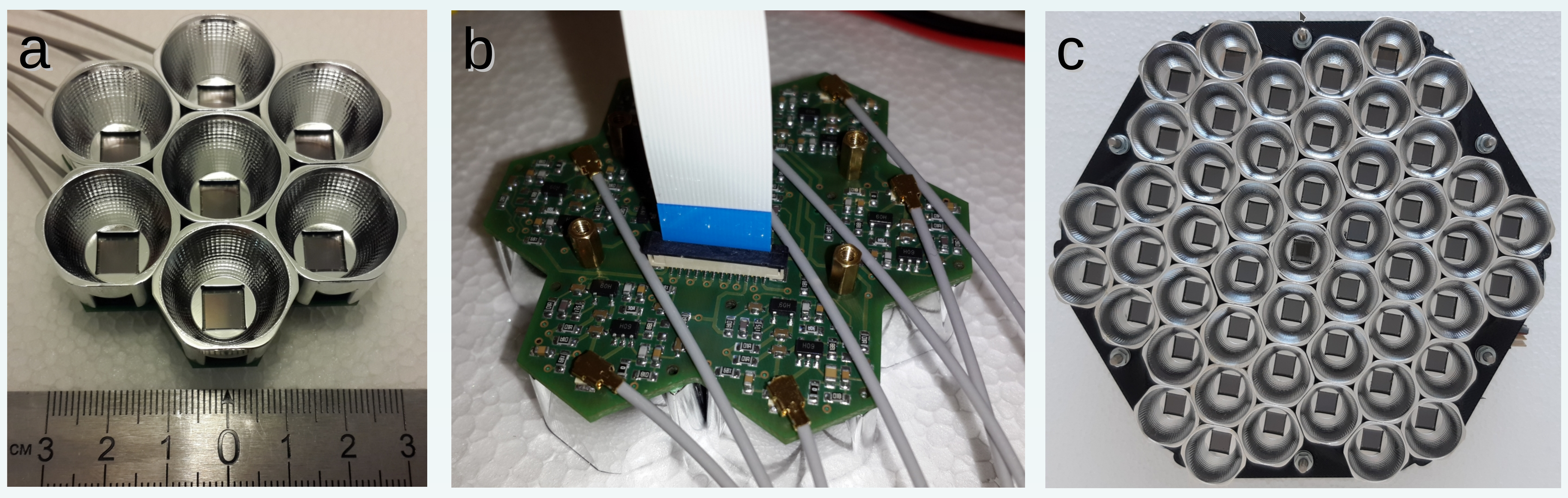
The experiment will consist of a regular network of wide-angle (0.6 ster) optical stations located on an area of 1km² (TAIGA-HiSCORE installation) and 3 IACTs. According to the TAIGA-HiSCORE data, it is possible to reconstruct with high accuracy the direction and energy of EAS initiated both by gamma-rays and charged cosmic rays.

To select events from gamma rays against the background of EAS from cosmic rays, data from the TAIGA-HiSCORE installation are combined with data on the image of EAS from IACT. Such a hybrid approach is effective for selection of events induced by gamma rays. A disadvantage of the existing installation is a significant difference in the apertures of the TAIGA-HiSCORE installation and the Cherenkov telescopes.

With a camera FoV of 10 degrees, the solid angle of IACT is 25 times smaller than the solid angle of the TAIGA-HiSCORE installation and, accordingly, only 4% of events detected by the TAIGA-HiSCORE installation fall into IACT FoV.

Methodology

To study the range of energy above 30 TeV we suggest using a wide-angle camera with a field of view of 15 degrees and an effective recording area of no more than 1m², which will allow observing at least 5-7 sources during the night. The energy threshold of such camera will be approximately 10 TeV. The percentage of joint with the installation of TAIGA-HiSCORE events will increase by 2-3 times. In the future, the diameter of the field of view could be increased up to 60 degrees and become very comparable with the aperture of TAIGA-HiSCORE. Details of such a wide angle telescope and of a relevant camera are already since some time matter of discussions and studies.



Example of implementing a photo sensor matrix on 49 SiPM (c) from 7 SiPM segments (a,b) with light collectors LEDiL CA10929_BOOM-W.

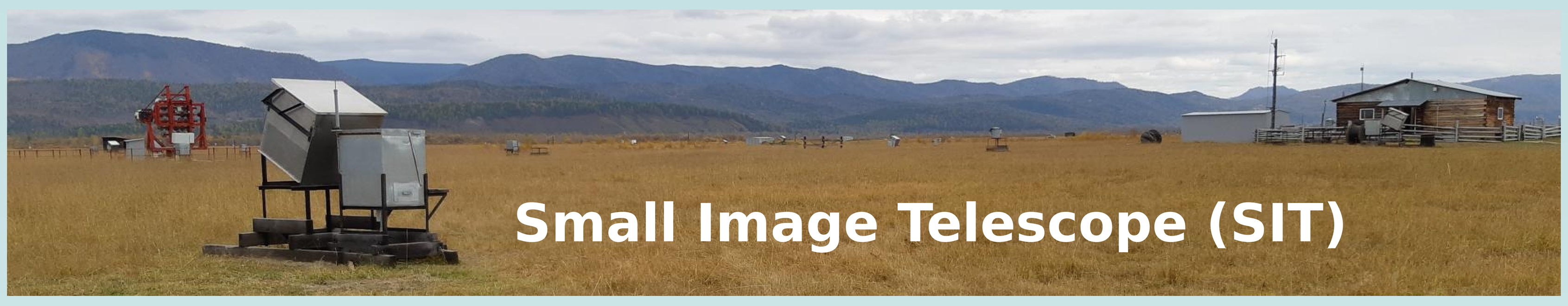
The silicon photomultipliers (SiPM) will be used as light sensors in the imaging camera. Its developed more than 20 years ago at the MEPhI in the laboratory of B.A. Dolgoshein and also in other Russian laboratories. In 2002–2010 Dolgoshein's group worked closely on improving SiPM and using it in astrophysics with a group of researchers from the Max Institute for Physics (MPI) in Munich, led by R. Mirzoyan.

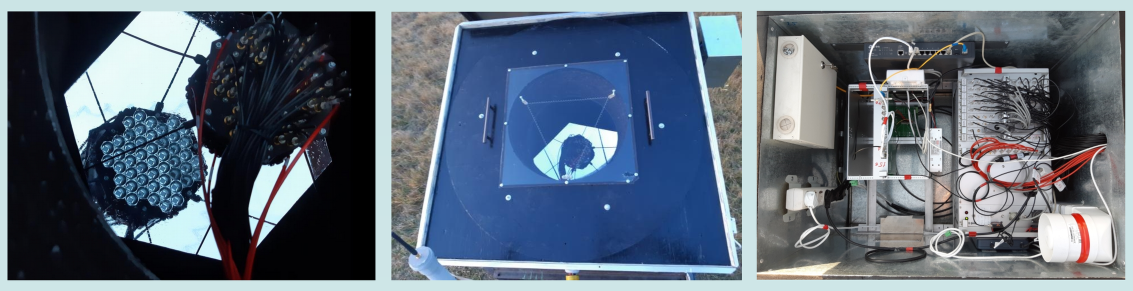
The camera based on SiPM has several advantages. SiPM does not degrade from a strong ambient light and can work even at the presence of full moon. Unlike photomultipliers, SiPMs have identical parameters, they require an operational voltage of only a few tens of volts, are compact, are light-weight and consume low power.

The optical system of the intended telescope can be designed by using spherical mirrors, or by using a system of Fresnel lenses or by a combination of the two mentioned technologies. The final choice will be made in the course of the project.

The project plans to build a so-called "telescope-demonstrator" limiting the FoV to not more than 15°. On such a telescope one can test and fine-tune the production of all the necessary units. At the same time, it will be necessary to investigate in detail the most effective solutions and ways that will allow one to reach a full FoV of the telescope of ±30° with a minimum cost. Such a novel wide-angle telescope will be a huge step forward in the world practice.

Prototype





In September 2019, a prototype of the SIT was installed as part* of the HiSCORE installation.

* The prototype event logging system was synchronized with the HiSCORE trigger system.

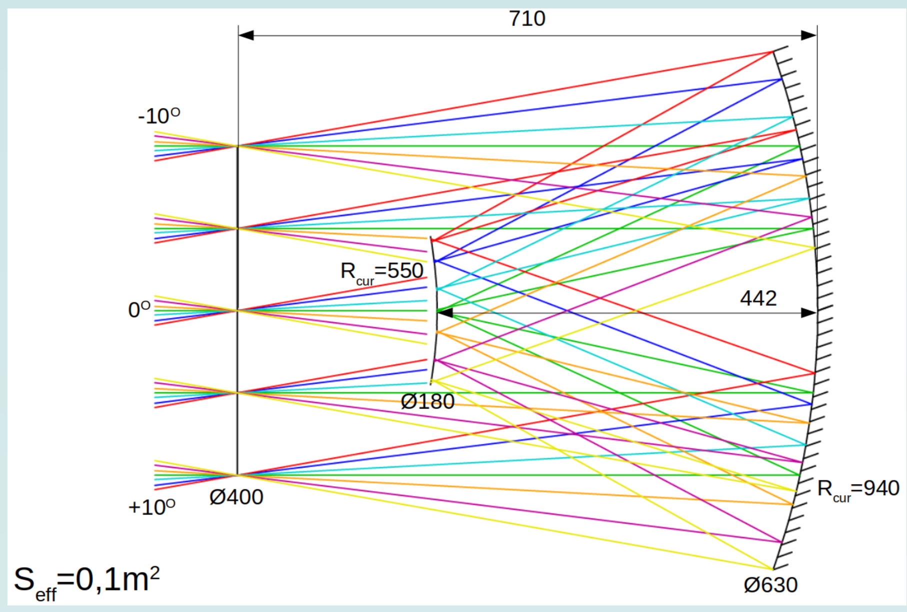
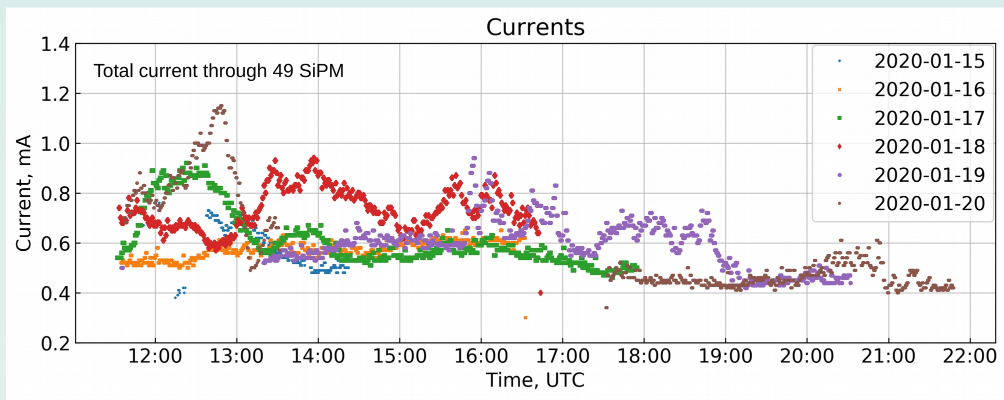
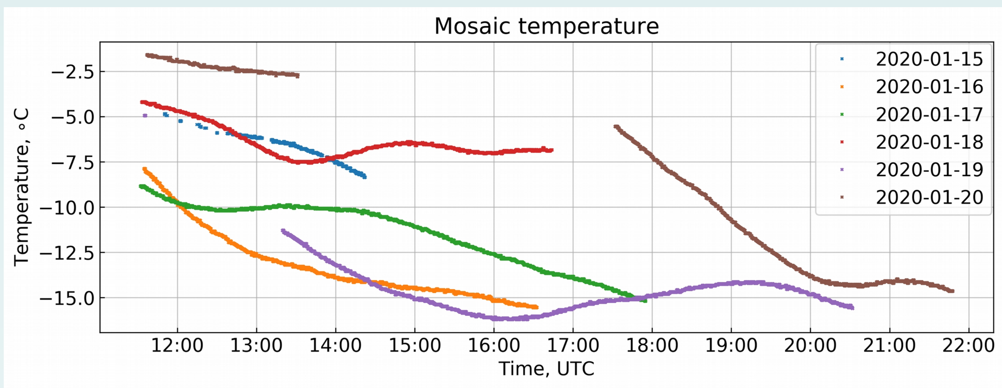


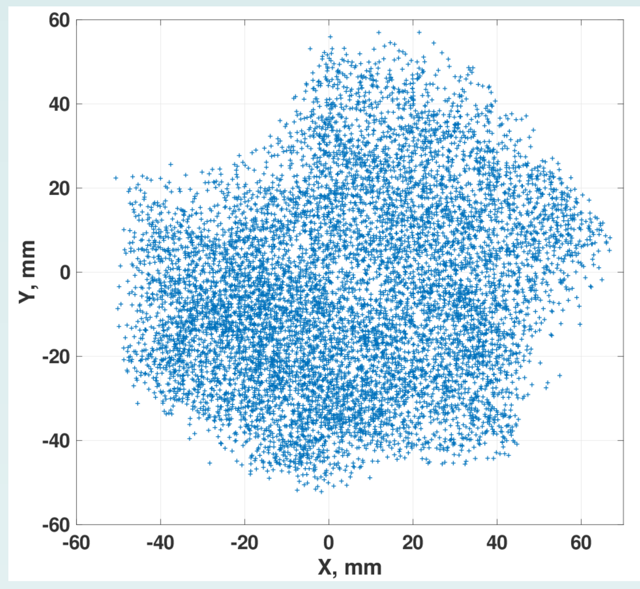
Diagram of the prototype optical system (left). Alignment of the optical system (right).

Results

During the preliminary measurements from September 2019 to January 2020, more than 650,000 events were recorded over 220 hours of observation.

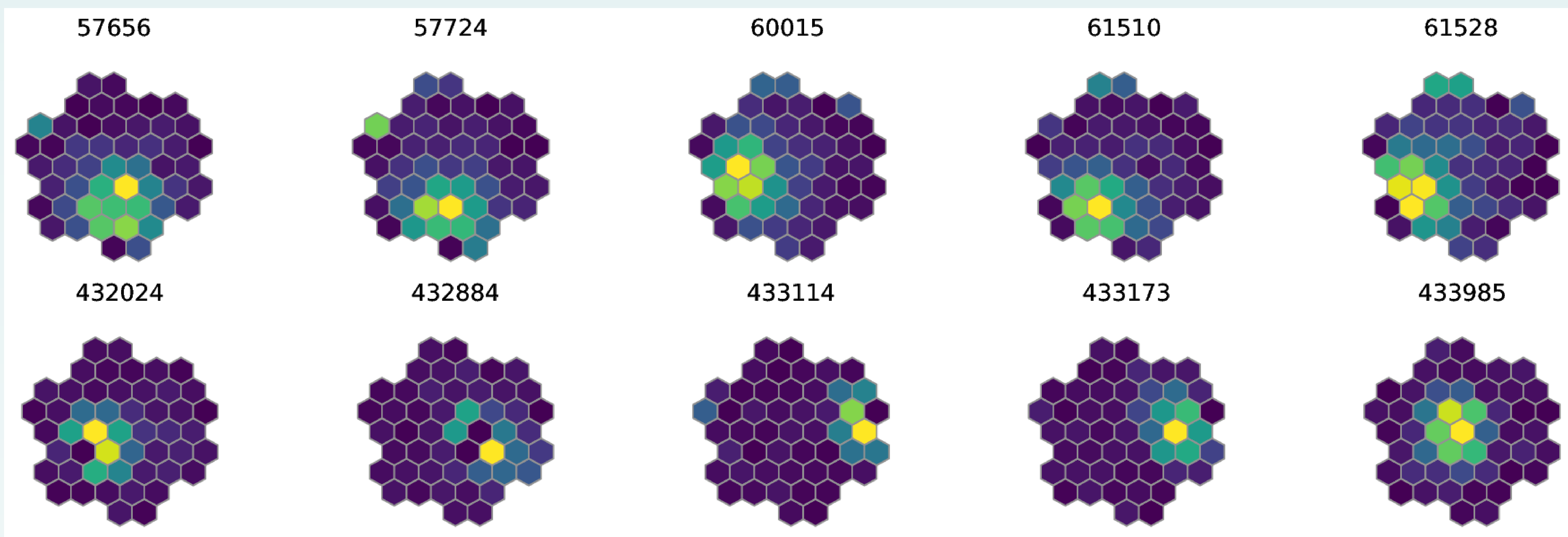






Distribution of the event images centers on the mosaic with the threshold 200 photoelectrons.

(One SiPM segment is excluded from processing due to high noise.)



Examples of registered events by the SIT prototype

Conclusion

To conduct long-term tests of the SIPM and the measuring system, the small imaging telescope (SIT) based on the SIPM MicroFC-SMTPA-60035 was installed in the Tunka Valley to work together with the TAIGA-HiSCORE array and is regularly switched on together with other installations of the Astrophysical Complex. The telescope's viewing angle is ±10 degrees, the effective area of the telescope's entrance window is 0.1m². According to the TAIGA-HiSCORE array, it is possible to reconstruct the arrival direction, the position of the core and the energy of EAS. This makes it possible to study experimentally the response of the SIT Cherenkov light flux from EAS with these characteristics.

Acknowledgements

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References

[1] Budnev et al. The TAIGA experiment: From cosmic-ray to gamma-ray astronomy in the Tunka valley // Nucl.Instrum.Meth. A845 (2017) 330-333.
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