**PAPER** • **OPEN ACCESS**

# SiPM-based camera for gamma-ray imaging air Cherenkov telescope

To cite this article: D. Chernov *et al* 2022 *J. Phys.: Conf. Ser.* **2374** 012045

# SiPM-based camera for gamma-ray imaging air Cherenkov telescope

**D. Chernov[1*], E. Bonvech[1], I. Astapov[1], P. Bezyazeekov[3], A. Borodin[4], M. Brueckner[5], N. Budnev[3], D. Chernukh[3], A. Chiavassa[6], A. Dyachok[3], O. Fedorov[3], A. Gafarov[3], A. Garmash[7,8], V. Grebenyuk[4,9], O. Gress[3], T. Gress[3], O. Grishin[3], A. Grinyuk[4], D. Horns[10], A. Ivanova[3,7], N. Kalmykov[1], Y. Kazarina[3], V. Kindin[2], S. Kiryuhin[3], R. Kokoulin[2], K. Kompaniets[2], E. Korosteleva[1], V. Kozhin[1], E. Kravchenko[7,8], A. Krykov[1], L. Kuzmichev[1], A. Lagutin[11], Yu. Lemeshev[3], B. Lubsandorzhiev[12], N. Lubsandorzhiev[1], R. Mirgazov[3], R. Mirzoyan[3,13], R. Monkhoev[3], E. Osipova[1], A. Pakhorukov[3], A. Pan[4], L. Pankov[3], A. Petrukhin[2], D. Podgrudkov[1,14], V. Poleschuk[3], M. Popescu[15], E. Popova[1], A. Porelli[5], E. Postnikov[1], V. Prosin[1], V. Ptuskin[16], A. Pushnin[3], R. Raikin[11], G. Rubtsov[12], E. Rybov[3], Y. Sagan[4,9], V. Samoliga[1], A. Silaev[1], A. Silaev (jr)[1], A. Sidorenkov[12], A. Skurikhin[1], V. Slunecka[4], A. Sokolov[7,8], Y. Suvorkin[3], L. Sveshnikova[1], V. Tabolenko[3], A. Tanaev[3], B. Tarashansky[3], L. Ternovoy[3], L. Tkachev[4,9], M. Tluczykont[10], N. Ushakov[12], A. Vaidyanathan[7], P. Volchugov[1,14], D. Voronin[12], V. Vorobiov[7,8], R. Wischnewski[5], I. Yashin[2], A. Zagorodnikov[3] and D. Zhurov[3].**

1 Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia
2 NRNU MEPhI (Moscow Engineering Physics Institute), Moscow, Russia
3 Institute of Applied Physics ISU, Irkutsk, Russia
4 JINR, Dubna, Russia
5 DESY, Zeuthen, Germany
6 Dipartimento di Fisica Generale Universiteta di Torino and INFN, Torino, Italy
7 Novosibirsk State University, NSU, Novosibirsk, Russia
8 Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia
9 Dubna State University, Dubna, Russia
10 Institut für Experimentalphysik, University of Hamburg, Germany
11 Altai State University, Barnaul
12 Institute for Nuclear Research of RAN, Moscow, Russia
13 Max-Planck-Institute for Physics, Munich, Germany
14 Lomonosov Moscow State University, Faculty of Physics, Moscow, Russian Federation
15 ISS, Bucharest, Romania
16 IZMIRAN, Moscow, Russia

E-mail: chr@dec1.sinp.msu.ru

**Abstract.** The current status of the equipment development for the new wide-angle gamma-ray imaging air Cherenkov telescope for TAIGA hybrid installation is presented. A front-end electronic and data acquisition system board based on the Zynq family Xilinx FPGA chips specially designed for this project have been produced and are being tested. A detailed description if presented for internal structure of the four main subsystems: four 8-channel 100 MHz ADCs, board's control system, internal clock and synchronization system and the power supply system. Additionally, the current status of a small scale prototype telescope SIT consisting of 49 SiPM is presented. The telescope includes a digital camera for observing the stars and weather condition. The SIT-HiSCORE synchronization systems and the telemetry information collection had been tested.

## 1. Introduction

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 [1]. The experiment [2] will consist of a regular network of wide-angle (0.6 ster) optical stations located on an area of 1 km$^2$ (TAIGA-HiSCORE installation) and 3 IACTs with FoV 9.6°. Presently a new IACT is being designed with a 15-20° maximum viewing angle and effective area of around 1 m$^2$. The energy threshold of such IACT will be approximately 10 TeV. The new detector utilizes around 1000—1200 SiPMs for its imaging camera.

The article describes the DAQ system of the future telescope and the detector module with 7 SiPMs. This electronics will be used also in the small imaging telescopes with 200 channels each, with field of view (FOV) comparable that of a TAIGA-HiSCORE array. The use of such telescopes working together with the TAIGA-HiSCORE array will improve the gamma-hadrons separation efficiency of the latter in energy range above 100 TeV. A brief description of the current prototype of such a telescope is given at the end of the article

## 2. DAQ System of the SiPM-based telescope

SiPM-based DAQ is a modular system in which each block consists of a DAQ controller board (see Fig. 1, left) and up to four 7-channel SiPM detector boards SiPM (up to 28 channels total). This approach allows construction of a sensitive area with any number of pixels required. Each DAQ controller board has a separate data and control channel (600 Mbit/s Ethernet) and a separate optical channel used for detector's both internal and external synchronization and

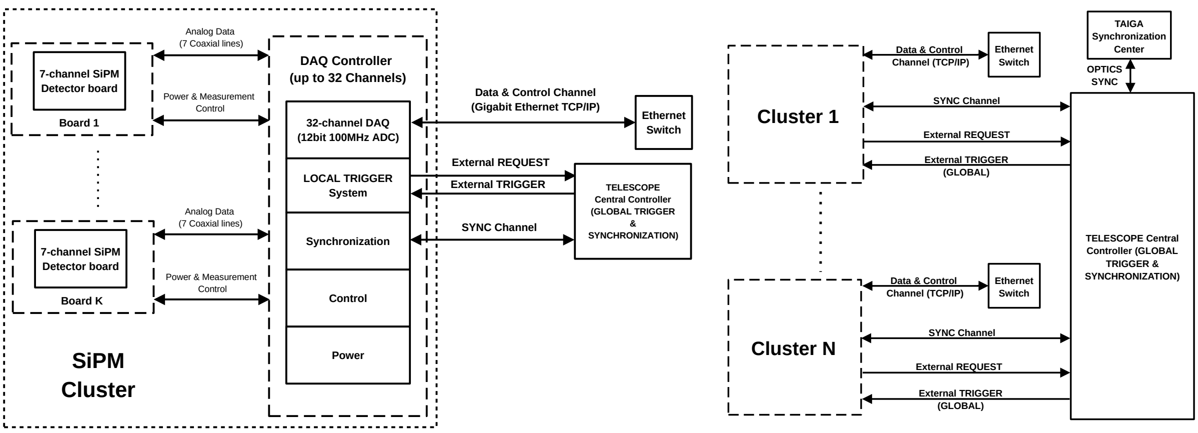


**Figure 1.** The DAQ controller board with SiPM cluster (left) utilizes Zynq-family Xilinx FPGA chips and 32-channel 12-bit 100 MHz ADCs. The DAQ integrated into the TAIGA installation global synchronization system (right).

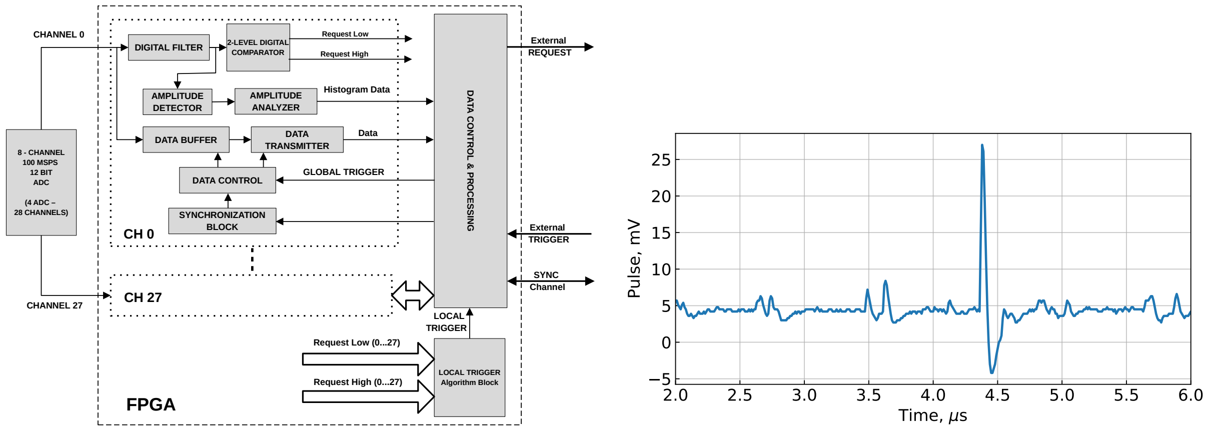


**Figure 2.** Internal organization of DAQ board with local trigger scheme (left). ADC registered impulses from SiPM segment board (right)

timing purposes. Thus, telescope's DAQ in general and each individual DAQ controller board is integrated into the TAIGA installation general synchronization system (see Fig. 1, right).

Each 7-channel SiPM detector board that comprise telescope sensitive camera and is connected to its designated DAQ controller board. Analogue signals from the 7-channel SiPM detector boards are digitized and processed using FPGA-based logic (see Fig. 2) in real time. Each DAQ controller board in turn is connected to the Central Controller board that generates Global Trigger (External Trigger) signal for the whole telescope and serves as an interface between the telescope and TAIGA installation synchronization system.

In order to generate the Global Trigger (External Trigger) for the telescope the DAQ controller board has an 'External Request' output (used if Local Trigger conditions are met) and 'External Trigger' input (for requests from the Central Controller Board if the global telescope's trigger conditions are met). The DAQ controller board also houses power supply units for detectors and other ancillary units for temperature, average SiPM currents measurements etc.

Global trigger is based on the local triggers and may use addition information: number of local triggers, position of pixels and etc. Global trigger if generated by the Central Controller Board using incoming 'External Request' signals (produced by Local Trigger Algorithm Block) from each DAQ controller board. Local trigger (and Global trigger) can be produced using different algorithms that can be altered, changed or updated on the fly. The 'topological condition' is planned as a base one (is formed only if a predefined number of neighboring pixels are hit). The 'topological conditions' effectively suppresses (10 times or more) the background from random coincidences.

## 3. SiPM segment for detector's retina

Diagram of SiPM segment shown on Fig. 3. The negative SiPM supply voltage is common to all 7 channels, and the positive voltage can be set separately for each channel. An LMT70 temperature sensor installed next to each SiPM has ±0.23°C accuracy. A cascade of two amplifiers generates an output pulse for FADC with FWHM of 20-25 ns and amplitude of up to 3.5 mV per photoelectron. An example of a SiPM signal recorded by an ADC on DAQ board is shown in the Fig. 2 right.

The DAC also registers the SiPM currents and temperature individually for each channel and can initiate an emergency shutdown of the SiPM power supply if currents exceed predefined limit (which is expected in case of excessive illumination). The common negative breakdown

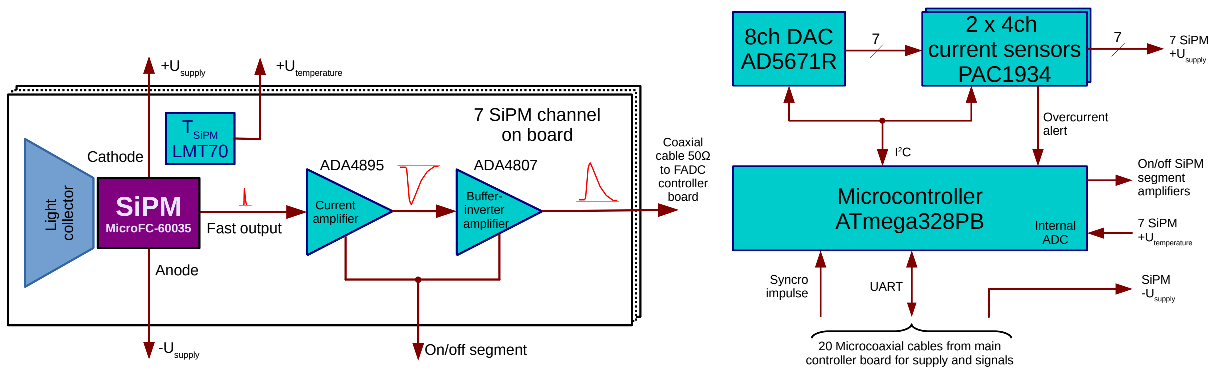


**Figure 3.** Diagram of the SiPM segment with control board.

voltage (-U supply) for all SiPMs is generated on the main controller board, and the overvoltages (+U supply) are generated by the DAC. Two sensors measure direct current through the SiPMs with an accuracy of 0.1 $\mu$A.

## 4. Prototype of Small Image Telescope (SIT)

For SiPM segment testing purpose a small imaging telescope (SIT) prototype based on 49 MicroFC-SMTPA-60035 SiPMs was developed and installed in the Tunka Valley. The telescope uses the Schmidt optical system with a $\pm 8^\circ$ FOV and a 0.1 m$^2$ effective aperture. The SIT prototype is installed in a standard optical container of the TAIGA-HiSCORE station [2] and connected to the DAQ and synchronization system of this array.

Starting September 2019 SIT prototype [3, 4] operated as a part of the HiSCORE installation. The SIT prototype event logging system was synchronized with the HiSCORE trigger system.

## 5. Conclusions

The development of the DAQ and the detector module of the new IACT is almost complete. During this year the telescope prototype with a camera of 28 SiPMs and data acquisition system described in this report will be tested in the laboratory. It is scheduled to be deployed next year in the TAIGA Astrophysical complex.

## 6. Acknowledgments

The work was performed at the UNU 'Astrophysical Complex of MSU-ISU'. The work is supported by the Russian Science Foundation (grant 19-72-20230 (Section 3,4), the Russian Federation Ministry of Science and High Education (projects FZZE-2020-0017, FZZE-2020-0024).

## References

[1] Budnev N, Astapov I, Barbashina N and et al A B 2017 *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **845** 330–333 ISSN 0168-9002 proceedings of the Vienna Conference on Instrumentation 2016 1
[2] Gress O, Astapov I, Budnev N and et al 2017 *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **845** 367–372 ISSN 0168-9002 proceedings of the Vienna Conference on Instrumentation 2016 1, 4
[3] Chernov D, Astapov I, Bezyazeekov P and et al E B 2020 *Journal of Instrumentation* **15** C09062–C09062 4
[4] Podgrudkov D A *et al.* 2021 *Bull. Russ. Acad. Sci. Phys.* **85** 408–411 4