Design features and Data Acquisition System of the TAIGA-Muon scintillation array

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ABSTRACT: The TAIGA-Muon scintillation array is located in the Tunka Valley. It is a part of the single TAIGA experimental complex. Its construction has started in the summer of 2019. By the autumn of 2019, the first three clusters were installed. We describe the design of the TAIGA-Muon array, the data acquisition (DAQ) sistem, reading and control systems.

KEYWORDS: Scintillation detectors; Data acquisition and control system.

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1. Introduction

The advantage of gamma quanta as a messenger of information about galactic and extragalactic energy sources compared with cosmic rays (CR) is that the gamma quanta are electrically neutral and retain the direction to the source, and in comparison with neutrinos – the gamma quanta are relatively easy to detect.

For these reasons, in recent years gamma-ray astronomy has become the most dynamically developing area of astrophysics. One of the most important fundamental results was the detection of gamma radiation with energies above 1 TeV from more than 200 local sources [1]. Also, there was appeared the first information about detection of 100 TeV astrophysical gamma quanta [2, 3].

The main competitors of Imaging Atmospheric Cherenkov Telescopes (IACT) for study of astrophysical gamma quanta in the energy range of 10 TeV and higher are the arrays detecting the charged component of EAS. In this case, the selection of showers from gamma quanta from the background of hadron showers is most often based on the presence of a muon component. The main advantages of such installations that detect the charged component of the EAS are a wide field of view (up to 45 degrees) and full observation time, whereas for Cherenkov telescopes the effective operation time does not exceed 10%.

A promising direction today is a search for gamma radiation with an energy higher than 100 TeV using complex installations of a large area (1 sq. km. and more) based on new, optimized for this energy range approaches. One of such experiments is the Siberian experimental complex, located in the Tunka Valley, about 50 km from Lake Baikal [4]. This complex includes Tunka-133 and TAIGA-HiSCORE Cherenkov arrays, Tunka-Grande and TAIGA-Muon scintillation arrays, Tunka-Rex radio experiment and atmospheric Cherenkov telescopes designed for analyzing the EAS images. Due to the combination of "under one roof" of six independent experiments that record EAS using various methods it is possible to develop, further test and improve methods for studying cosmic rays and gamma quanta in the energy range of 30 TeV-1EeV.

2. TAIGA-Muon scintillation array

In the summer of 2019, in addition to the existing Tunka-Grande scintillation array [5], the deployment TAIGA-Muon low-threshold scintillation array, which is a network of surface and underground detectors for the detection of charged particles of EAS, has been started. It is assumed that in the future the total area of the installation will be about 2000 sq. m. and it will search for cosmic gamma-rays in the energy range from 50 TeV together with the Cherenkov experiments of the TAIGA Gamma Observatory.

By the autumn 2019, the first three TAIGA-Muon clusters were installed (fig. 1). They consist of 8 surface and 8 underground large-area scintillation detectors each (fig 2). Surface and underground detectors in clusters are located in pairs, surface detectors are strictly above the underground ones at a depth of 1.6 m, along the perimeter of the square with the side of 5 m.

Figure 1. Appearance of the TAIGA-Muon cluster and location of the array (red circles) relative to the Tunka-133 (black circles) and Tunka-Grande (blue rectangles) arrays.

Figure 2. Scheme of scintillation counters in the cluster and scintillation detector scheme: 1 - scintillator, 2 - shifter bar, 3 - diffuse reflector, 4 - PMT, 5 - container.

Scintillation detectors were developed specifically for this experiment in NSU and BINP [6]. Due to light and water impermeability, resistance to large temperature differences, structural strength and high reliability of the elements, they are adapted to use in the harsh climatic conditions of the Tunka valley. The design of the scintillation detector [6]: 1 – scintillator (polystyrene (98.49%), p-Terphenil (1.5%), POPOP (0.01%)), 2 –wavelength shifting bars (acrylic glass with BBQ dye), 3 – reflector, 4 – PMT (FEU-85) (photocathode $\varnothing 25$ mm)), 5 – container. The size of the active surface is 1×1 m² (fig.2).

In addition to the detectors, each cluster is equipped with a thermal insulation container (electronic box), which contains the electronics for signal read-out, synchronization and the experimental data transfer.

Since December 2019, the first TAIGA-Muon cluster has started operation in test mode.

3. Electronics of TAIGA-Muon array

The electronics of the TAIGA-Muon array for functional purpose consists of three parts: DAQ system, control system and monitoring system (fig. 3).

Figure 3. The main components of the electronics of the TAIGA-Muon array and their relationship.

3.1 DAQ system

The DAQ system consists of two parts: Central DAQ and Cluster DAQ. Central DAQ is located in the main building of TAIGA Observatory. Cluster DAQ is located in the electronic box close to each cluster. These two DAQ parts are connected by multi-mode fiber optic cables, with a length, depending on the distance from the main building to the cluster.

Central DAQ includes data collection and storage devices (File Storage, DAQ PC), synchronization devices (MEGA Host, Host, and Super Host), and elements responsible for data collection and transmitting of control information (Switches and Control PC). MEGA Host is connected to the GPS station and sends a clock signal with a frequency of 100 MHz to the cluster via Super Host and Host (synchronization accuracy is 10 ns).

Cluster DAQ consists of a 12-channel data acquisition module (BSD-12), two 10-channel high-voltage power sources (HV power supply), a device for the high-voltage sources control (Ethernet RS485 Converter), four 2-channel analog signal summators (Σ), and a switch required for data receiving and transmitting. The main difference from the electronics of the TAIGA-HiSCORE array [7] is the use of the 12-channel data acquisition module and two-channel analog signal summators. The 12-channel BSD-12 module is designed for the digitization of the input analog signals, analysis of the presence of a signal in the input lines, writing the digitized signal to the internal memory and transmitting it to the Ethernet network under certain conditions (finding pulses from different channels that exceed the specified amplitude values in a specified time range, or using an external trigger). This module is implemented on the basis of FPGA (XILINX Spartan-6) and contains 6 two-channel ADCS with a 12-bit width and a sampling frequency of 200 MHz; optical synchronization channel with the MVS8-1 time synchronization module; clock frequency generation circuits; DDR2 memory to ensure the operation of the FPGA processor part and to implement a data buffer; Ethernet, RS-485, I2C interfaces; the "external request" and "external trigger" signal system for interaction with external devices.

3.2 Control and monitoring systems

The control system is designed to control HV power supply of the PMTs. The control system provides data communication between Cluster controllers and main control program of the personal computer (Control PC) in the main building of the data collection and storage.

The monitoring system includes a Heating controller and a computer (Monitoring PC) in the central DAQ. Heating controller is connected to XBee-PRO ZB RF router located at the electronics box near to each cluster. It maintains a stable temperature of DAQ inside the electronics box. XBee-PRO ZB RF Module coordinator is connected to Monitoring PC via USB-connector. Heating controller is designed on the basis of 16-Bit Flash Microcontroller PIC24FJ64GA004I-PT to control the power load (on/off power, heating and cooling). The XBee-PRO ZB RF Modules operate within the ISM 2.4 GHz frequency band with a low data rate (250 Kbps).

The main functions of the monitoring system are remote monitoring of the temperature and the current consumption of the electronics in electronics boxes during its operation. Additional functions are the temperature changing at which the controller turns on power to the cluster DAQ, setting the heater on/off temperatures and turning on of the cooling fan, capability to turn on the power supply of the cluster DAQ by the operator.

3.3 Test measurements

During the test measurements of the data collection system, it was found that in order to obtain reliable values when digitizing the analog signal from the counter output, it is necessary to integrate it. For this purpose, 4 two-channel analog signal adders were assembled based on ad8058 operational amplifiers, similar to the Tunka-Grande [7]. According to the preliminary activation scheme, signals from 8 surface counters are going directly to the inputs of the 12-channel data collection module (fig. 4), while underground counters are connected via analog adders (fig. 4). In fig. 4. the examples of signals from counters when charged particle passed through them are given. In this case, 1h is an example of a pulse from a ground counter, 1l - from an underground one.

Preliminary Monte Carlo simulation has shown that the selected geometry and location of TAIGA-Muon clusters will reduce the threshold for detection EAS from 10 PeV to 1 PeV or

even lower for operation together with the Tunka-Grande installation. In turn, this will make it possible to detect events with energy below 1 PeV in conjunction with the low-threshold Cherenkov installation TAIGA-HiSCORE. Since the EAS parameters reconstruction quality using TAIGA-HiSCORE array data is higher [8], the position of a EAS core, a direction of EAS axis, and the energy of the primary particle in joint events will be taken from HiSCORE-HiSCORE data. The number of muons in the EAS from primary photons is 20-30 times less than in the EAS caused by primary nuclei and protons. In addition, the simulation showed that at energies above 1 PeV, the number of secondary charged particles in the shower with increasing of a distance from the EAS core depends on the type of primary particle [9]. Therefore, data on the electron-photon and muon components of the EAS from the Tunka-Grande and TAIGA-Muon installations will allow us to distinguish events from gamma quanta from the total flux of recorded information on the number of muons in the EAS.

Figure 4. Example of signals from counters when muon pass through them : 1h - a pulse from a surface counter (is connected directly to the input of the 12-channel data collection module), 1l - from an underground counter (is connected via analog adder).

4. Conclusion

Since December 2019, the first TAIGA-Muon cluster has been put into operation in test mode. After testing all systems for collecting and processing experimental data in conditions of real experiment, the first and then subsequent TAIGA-Muon clusters will be included in the TAIGA gamma-ray Observatory. One of the goals of the scintillation complex will be to work together with the Tunka-Grande and TAIGA-HiSCORE arrays to separate astrophysical gamma quanta from the hadron component of cosmic rays.

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