Simulation of a prototype underground water Cherenkov array for the TAIGA Gamma Observatory

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This report presents the concept and results of simulation of a system of underground water Cherenkov detectors, which is planned to be added to the TAIGA astrophysical complex for joint operation with the TAIGA-HiSCORE Cherenkov array. It is shown that this system, by registering the muon component of extensive air showers, will make it possible to more accurately measure the mass composition of cosmic rays and effectively separate cosmic gamma rays from the background of charged cosmic rays with energies above 1 PeV.

Keywords: TAIGA Gamma Observatory, cosmic rays, extensive air showers, CORSIKA, water cherekov detectors.

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1. Concept of water Cerenkov array

Currently the experimental TAIGA [1] complex includes five independent arrays: TAIGA-HiSCORE, Tunka-133, Tunka-Grande, TAIGA-Muon and TAIGA-IACT. They are used to do research on cosmic rays (CRs) and gamma rays of high and ultrahigh energies by the method of registration of extensive air showers (EAS) components. The joint operation of a wide-angle Cerenkov array TAIGA-HiSCORE [2], comprising 120 optical stations and 3 atmospheric Cerenkov telescopes of TAIGA-IACT [3] setup is aimed at detailed research of cosmic gamma-quanta with energy above 40 TeV. To research the region above 1 PeV, in addition to these setups within the astrophysical complex

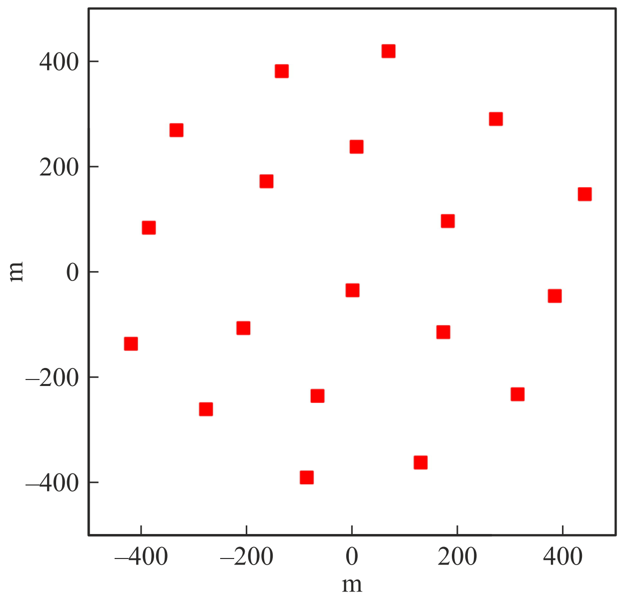

Figure 1. Spatial distribution of water Cerenkov setup detectors.

in the area of $0.5\,km^2$ it is planned to deploy a system of water Cerenkov detectors of cylindrical shape to record the muonic component of EAS. Water detectors will be located under the layer of soil of 2 m, sufficient to screen the electromagnetic component of EAS. The height of an individual detector would be 1.5 m, and the surface area — at around $40\,m^2$. The threshold energy for the vertical muons at the same time is 1 GeV. It is assumed that in the hybrid mode of operation the experimental data of the Cerenkov array TAIGA-HiSCORE will be used for high-precision recovery of EAS parameters and the energy of the primary particle. Data of the water detectors will provide information on the type of the core that produced this EAS, and will make it possible to identify the EAS from the primary gamma-quanta from the background events initiated by charged CRs. The main idea of this method consists in the fact that the number of muons depends on the type of the particle that produced EAS.

2. Monte Carlo modeling of water Cerenkov array

To assess the effectiveness of the registration and separation of gamma-quanta from the background of the charged particles using water detectors, computer modeling of their operation by Monte Carlo method was done. Using CORSIKA 7.7401 [4] software, two sets of EAS events were modeled: 20 thousand events at primary energies 1–10 PeV and zenith angle of shower arrival 0–30° and 20 thousand events at primary energies 1–10 PeV and zenith angle of shower arrival 30–45°. Both sets are formed from the primary particles at the following ratio: 50% gamma-quanta, 25% protons, 12.5% nucleus of CNO group and 12.5% iron nucleus. Energy spectrum inclination — 2.7. The model of hadron interactions at high energies was QGSJET-II-04 model [5]. Water detectors in the quantity of 19 pieces were evenly located in a circle with a radius of 400 m in close proximity to the stations of scintillation Tunka-Grande array [6] (fig. 1). Axes of calculated EAS were distributed within the circle of that setup. Information about the artificial secondary particles was used to model the detector response. Model calculations were made on the equip-

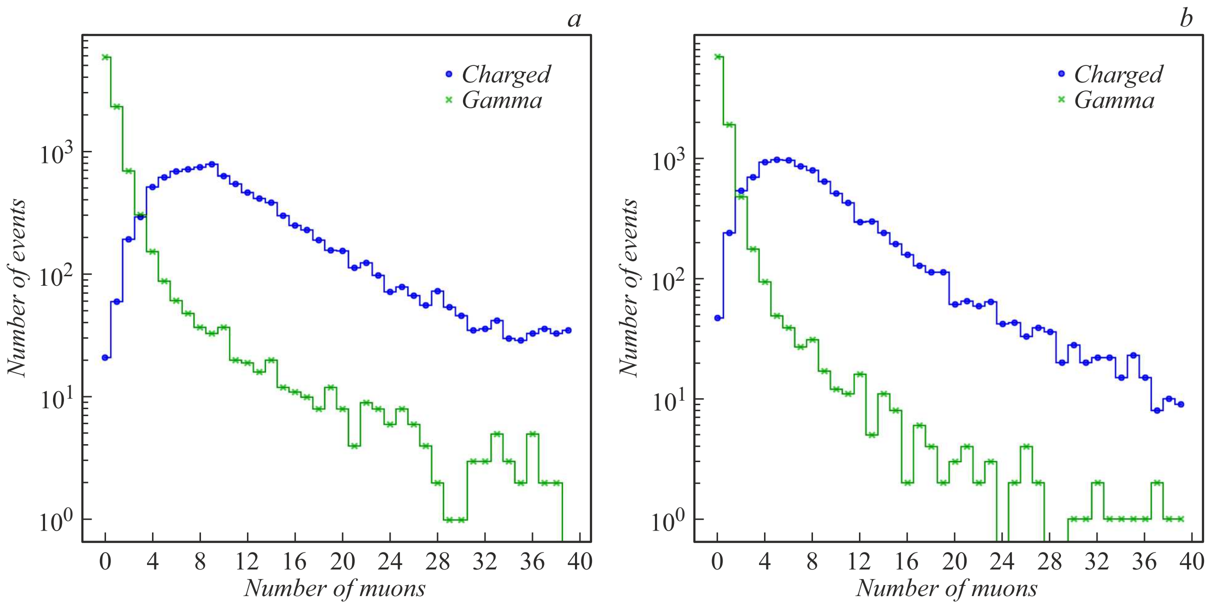

Figure 2. Distribution of a number of events by number of registered muons of water Cerenkov setup for two primary compositions (charged CRs and gamma-quanta) under the following parameters: *a* — $1 < \lg(E/PeV) < 10$. $\theta < 30°$, *b* — $1 < \lg(E/PeV) < 10$, $30° < \theta < 45°$.

ment of the collective use center „Irkutsk Supercomputer Center of the Siberian Branch of the Russian Academy of Sciences“ [7].

Fig. 2 shows the distributions of the number of EAS events by the number of recorded muons from two primary compositions of the cosmic rays in two variants by angles of arrival. From the produced distributions it follows that muon-free events are observed in 0.5% cases for hadron showers and in 70% cases for photon EAS. These results certify high efficiency of the proposed method of gamma-hadron separation.

Conclusion

Computer modeling of a water Cerenkov array was made, which is planned for introduction into the TAIGA astrophysical complex for joint operation with the Cerenkov array TAIGA-HiSCORE. It was shown that the selected configuration enabled the new plant to potentially effectively register EAS muons and separate gamma-quanta from the background of the charged CRs in the energy range of primary particles $1-10$ PeV. In 2025 it is proposed to make the detector prototype and add it to the set of the experimental data.

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Conflict of interest

The authors declare that they have no conflict of interest.

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