Geant4 simulation of scintillation experiments of the TAIGA astrophysical complex

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The paper presents a computer model of the Tunka-Grande and TAIGA-Muon scintillation facilities aimed at research in cosmic ray physics and gamma-ray astronomy. The experimental data are compared with the results of modeling.

Keywords: extensive air shower (EAS), cosmic rays, scintillation counter, TAIGA-Muon facility, Tunka-Grande facility, TAIGA experimental complex, Geant4.

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Introduction

A hybrid astrophysical complex TAIGA (Tunka Advenced Instrument for cosmic ray physics and Gamma Astronomy) located in the Tunka valley (Republic of Buryatia, Russia) is designed for detailed study of the primary cosmic radiation (PCR) in the energy range $\sim 0.01-1000$ PeV [1]. The complex includes: wide-angle Cherenkov facilities Tunka-133 and TAIGA-HiSCORE (High Sensitivity COsmic Rays and gamma Explorer), atmospheric Cherenkov

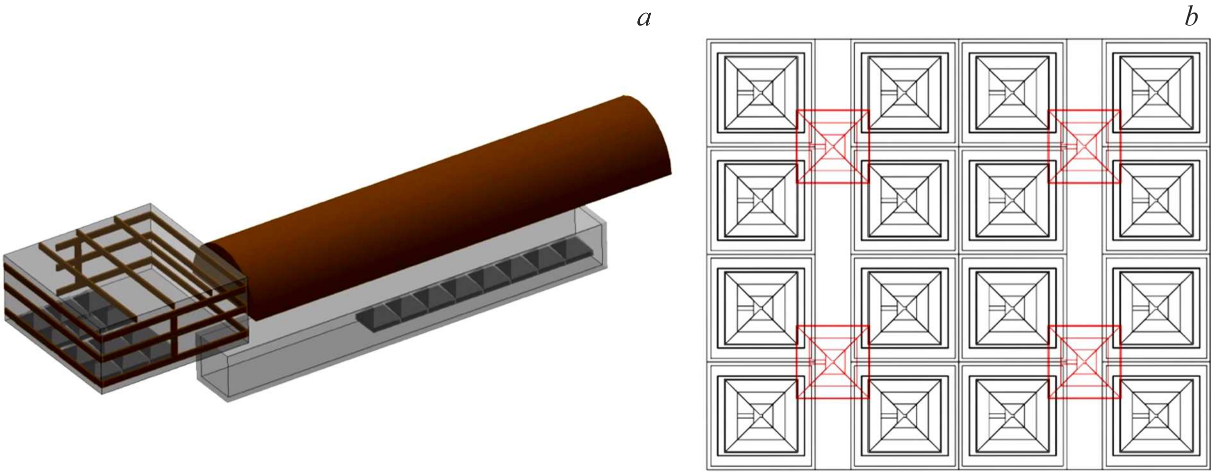

Figure 1. Geometry of Tunka-Grande (a) station and top view of TAIGA-Muon (b) station in Geant4.

telescopes TAIGA-IACT (Imaging Atmospheric Cherenkov Telescopes) and scintillation facilities Tunka-Grande and TAIGA-Muon.

This paper presents the results of Monte Carlo (MC) modeling of Tunka-Grande and TAIGA-Muon stations using Geant4 toolkit [2]. This toolkit is designed in CERN and is widely used in many experiments to model the processes of elementary particles passage through matter.

1. Experimental facilities

Tunka-Grande facility [3] has been in operation since 2016 with the purpose to study the energy spectrum and mass composition of the charged component of PCR, and also to search for diffuse gamma-radiation in the energy range of 10–1000 PeV. The facility comprises 19 stations located in the area of $\sim 0.5\,\mathrm{km}^2$. Each station includes ground and underground parts. The first part consists of 12 detectors with the total area of $7.68\,\mathrm{m}^2$ to record all charged particles of extensive air showers (EAS). The second part is designed to identify a muonic component of EAS and consists of 8 similar counters with the total area of $5.12\,\mathrm{m}^2$, located under a layer of soil of 1.5 m. The MC model of the facility describes in detail the geometry and the chemical composition of the station elements. Based on the measurements [4], a function was additionally introduced for the counters regarding the heterogeneity of their light collection. One of the stations is visualized in fig. 1, a.

In 2019 within the framework of TAIGA astrophysical complex development in addition to the Tunka-Grande facility, deployment of TAIGA-Muon scintillation array [5] was started. The first phase of construction includes the detectors with total area of $\sim 200\,\mathrm{m}^2$. Design of a new scintillation facility on the one hand will improve the efficiency of PCR study in the range of energy values 10–1000 PeV, on the other hand — it will decrease the

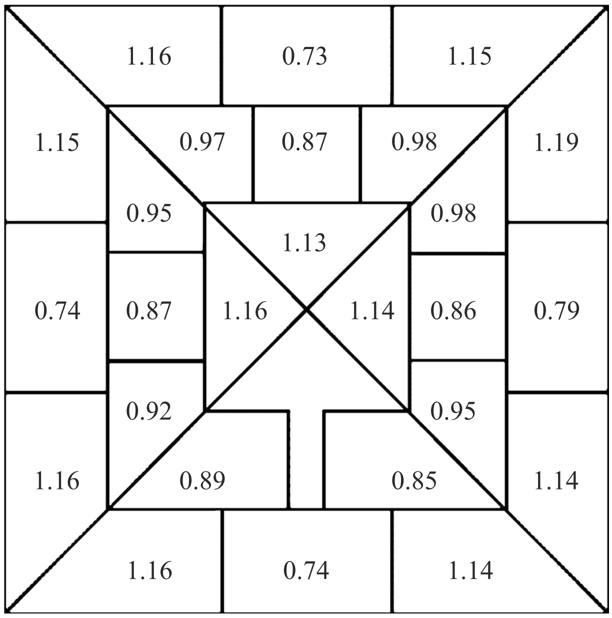

Figure 2. Heterogeneity of TAIGA-Muon counter light collection

energy threshold for the recording of the primary particles down to ~ 1 PeV. The TAIGA-Muon station [6] represents 16 underground (black in fig. 1, b) and 4 ground (red in fig. 1, b) scintillation counters with area of $0.96\,\mathrm{m}^2$ each [7]. Currently one station has been fully deployed, and another four have the ground part only. The MC model of the counters, as in the case of the Tunka-Grande facility, accounts for their average heterogeneity of light collection produced using the data of the laboratory studies. In these measurements the effective area of the detector was divided into sectors, for each of which a response was determined in the form of a numerical coefficient when the vertical atmospheric muons (fig. 2) are passed through.

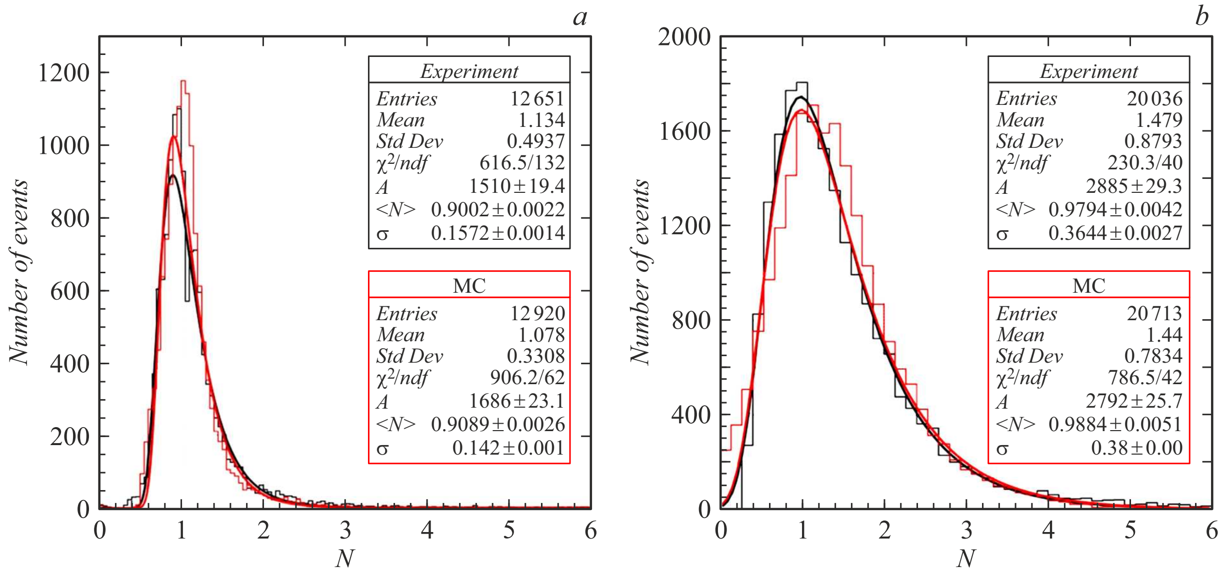

Figure 3. Differential amplitude distributions from scintillation counters of Tunka-Grande (*a*) and TAIGA-Muon facility (*b*) compared to energy release spectrum in MC.

2. Comparison of experimental and modeled data

Experimental and modeled data were compared using the comparison of detector responses for passage of vertical atmospheric muons through them. For this purpose two Tunka-Granda counters were spaced vertically relative to each other at the distance of 5 m and included into the coincidence scheme with a time window of 100 ns. As a result, differential amplitude distributions of signals were obtained. For comparison with MC, they are normalized to the most probable amplitude value. A similar experiment was done with two counters of TAIGA-Muon facility at the distance of 3.5 m from each other.

In the MC method the muons were modeled as directed vertically downwards with energy of 1 GeV in 2 m from the detector evenly to its entire surface area. The energy release spectrum is also normalized to the most probable value (fig. 3). The histograms are approximated with Moyal function:

$$f_M(N) = A\exp\left[-\frac{1}{2}\left(\frac{N-\langle N\rangle}{\sigma}\right)+\exp\left(-\frac{N-\langle N\rangle}{\sigma}\right)\right], \quad (1)$$

where A, σ — scale parameters, $\langle N\rangle$ — most probable value of the measured value.

The given fig. 3, *a* shows that the developed model of the counter of Tunka-Grande facility agrees quite well with the experiment. For TAIGA-Muon facility, due to the complex design of the detector, to account for the heterogeneity of its light collection was not sufficient for the credible MC. In connection with this each response point of the counter, the total amount of energy deposited are additionally scattered according to the Gaussian distribution with the mean square deviation of 0.5 (fig. 3, *b*).

Conclusion

The models of Tunka-Grande and TAIGA-Muon facilitys were made using Geant4 software suite. Comparison of the experimental and modelled data demonstrated the consistency of the models, which makes it possible to further use them to improve the accuracy of the measurements of EAS and PCR in the energy range of 1−1000 PeV, and also to develop the method for identification of the primary particles.

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Conflict of interest

The authors declare that they have no conflict of interest.

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