Taiga-Muon scintillation array: status and prospects

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The article describes of the TAIGA-Muon scintillation array as part of the TAIGA (Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy) astrophysical complex, a method for reconstructing the parameters of extensive air showers and the results of test data sets.

Keywords: cosmic rays, extensive air shower, TAIGA-Muon scintillation array, TAIGA astrophysical complex.

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Introduction

Studies of primary cosmic radiation (PCR) with energies of more than 100 TeV are carried out with the help of ground-based facilities by the method of recording extensive air showers (EAS). The hybrid astrophysical complex TAIGA [1] is located in the Tunka Valley (Republic of Buryatia, Russia) and is designed for detailed study of PCR in the energy range $0.01-1000$ PeV. The complex includes: wide-angle Cherenkov facilities Tunka-133 and TAIGA-HiSCORE (High Sensitivity COsmic Rays and gamma Explorer), three atmospheric Cherenkov telescopes TAIGA-IACT (Imaging Atmospheric Cherenkov Telescopes) and scintillation facilities Tunka-Grande and TAIGA-Muon.

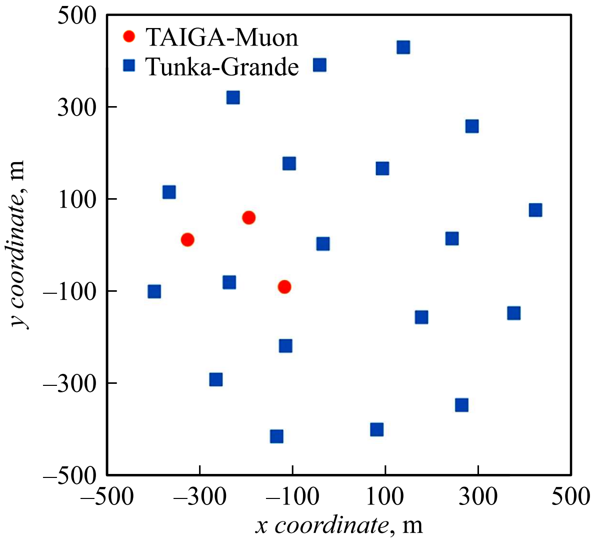

Figure 1. Location of TAIGA-Muon and Tunka-Grande facilities.

The construction of the TAIGA-Muon facility [2] began in 2019 and 3 stations have been deployed so far (Fig. 1). It is planned that the first stage of construction will include 10 stations. For the period 2021–2022 test measurement sessions were carried out and the first experimental data were obtained, on the basis of which, together with the existing Tunka-Grande array, the parameters of the EAS were restored and the accuracy of their reconstruction was assessed.

1. Experimental setup

The purpose of the TAIGA-Muon facility, on the one hand, is to increase the efficiency of the Tunka-Grande [3] facility for the PCR study in the energy range 10–1000 PeV by increasing the number of muon detectors, on the other hand — lowering the energy threshold of the existing scintillation facility to the energy ~ 1 PeV. The location and configuration of the TAIGA-Muon stations are based on model calculations [4]. Each station of the TAIGA-Muon facility includes 8 above-ground and 8 underground scintillation counters [5] with an area of $0.96\,\mathrm{m}^2$ each. Underground counters are located under the soil layer at a depth of 1.7 m strictly under the above-ground without direct access. In 2022, in order to increase the effective detection area of the muon component of the EAS, a new configuration was adopted, which provides for 4 surface and 16 underground counters while maintaining the data collection system [6]. It is planned that in 2023 the configuration of the first three stations will also be upgraded.

2. Reconstruction of the main parameters of the EAS

For the recorded events, the main parameters of EAS are reconstructed, such as θ, φ — zenith and azimuthal angles of arrival of the shower axis; x_0, y_0 — coordinates of the shower axis in the installation plane; N_e, N_μ — the total number of charged particles and muons in the shower; S — the age of the shower; 200, ρ_{200} — the density of particles at a distance of 200 m from the shower axis.

In the first step, all triggered stations of the TAIGA-Muon and Tunka-Grande arrays in the time window $5\,\mu$s are selected. Further, the direction of arrival of the shower axis is calculated under the assumption of a flat front of the EAS and its position in the plane of installations in a zero approximation using the center of mass method. The value of the parameter N_e is determined using the lateral distribution function (LDF) of Nishimura-Kamata-Greisen [7]:

$$f_e(r) = \frac{\Gamma(4.5-S)}{2\pi r_0^2 \Gamma(S)\Gamma(4.5-2S)} \left(\frac{r}{r_0}\right)^{S-2} \left(1+\frac{r}{r_0}\right)^{S-4.5}, \quad (1)$$

where the Moliere radius is $r_0 = 80$ m. The zero approximation for the total number of charged particles is calculated with a fixed parameter $S = 1.1$:

$$N_e = \frac{\sum_i N_i}{\sum_i f_e(r_i) s_i}, \quad (2)$$

where N_i — is the total number of detected particles at the ground $i$the station with an effective area s_i. In the second step, using the obtained value N_e and at $S = 1.1$, the values of x_0, y_0 are specified by the least squares method (LSM) in accordance with the expression (1). In the third step, N_e is recalculated and the LSM is repeated with the free parameters N_e, S, x_0, y_0. The same method is used to find N_μ from underground detectors. In LDF muons, the Greisen function [7] is used:

$$f_\mu = \frac{1.25}{2\pi^2 \Gamma(1.25)} \left(\frac{1}{320}\right)^{1.25} r^{-0.75} \left(1+\frac{r}{320}\right)^{-2.5}. \quad (3)$$

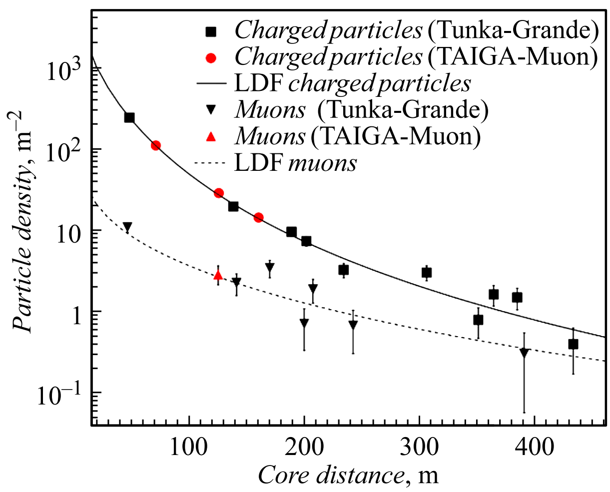

Figure 2. Spatial distribution of particles from Tunka-Grande and TAIGA-Muon ($\lg N_e = 7.04$, $\lg N_\mu = 6.15$, $\theta = 27.40°$, $\varphi = 3.3°$).

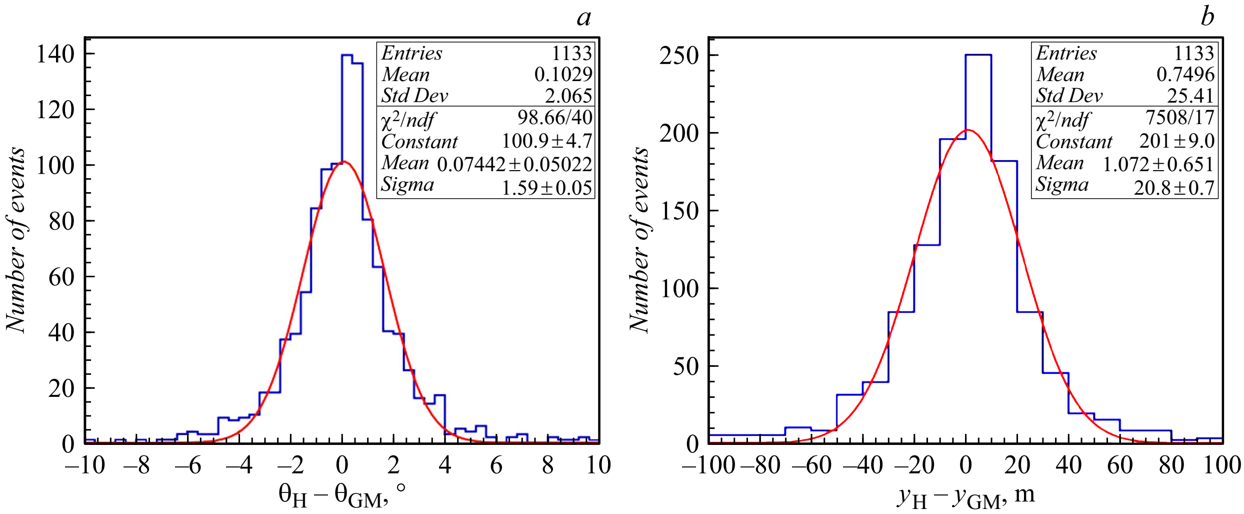

Figure 3. Comparison of the reconstructed zenith angle θ (a) and the coordinates y (b) of the EAS axis according to the TAIGA-HiSCORE (H) and TAIGA-Muon arrays in conjunction with the Tunka-Grande (GM) facilities.

Fig. 2 shows an example of one reconstructed event based on data from the TAIGA-Muon and Tunka-Grande arrays, namely, the restored particle density in the surface (charged particles) and underground (muons) parts of the facilities from their distance to the EAS axis in the plane perpendicular to the shower axis. From Fig. 2 it follows that the experimental data agree quite well with the LDF used.

During the test runs from October, 2021 to April 2022, the total operating time of the TAIGA-Muon and Tunka-Grande arrays was ~ 220 h. In order to assess the accuracy of the reconstruction of the EAS parameters based on the data of scintillation facilities, the analysis of joint events was carried out with the TAIGA-HiSCORE array which has a good angular resolution $\sim 0.1^\circ$ and the accuracy of restoring the position of the axis of the EAS ~ 6 m [8]. A total of 1133 joint events were identified with the following selection criteria: $\theta < 35^\circ$, the position of the axis in a circle with a radius of 350 m from the center of the installation, the recovered energy of the primary particle according to the TAIGA-HiSCORE instrument is higher than 5 PeV, the number of activated stations of TAIGA-Muon together with Tunka-Grande is not less than four. The accuracy of angle reconstruction θ, φ was $\sim 2^0$, coordinates x_0, $y_0 \sim 25$ m (Fig. 3).

Conclusion

The results of test measurements at the TAIGA-Muon array for the period 2021–2022 are presented. The first experimental data were obtained, on the basis of which the parameters of EAS were restored. The accuracy of the reconstruction of the angles θ, φ was $\sim 2^\circ$, coordinates x_0, $y_0 \sim 25$ m. The inclusion of the TAIGA-Muon array in the TAIGA astrophysical complex will make it possible to start a detailed study of PCR in the energy range 1–1000 PeV.

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Conflict of interest

The authors declare that they have no conflict of interest.

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