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# Tunka-Grande array: status of 2023 and latest result

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The Tunka-Grande array is a network of 19 scintillation stations and is a part of the TAIGA experimental complex (Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy) in Eastern Siberia, near Lake Baikal. The array is designed to study the energy spectrum and mass composition of cosmic rays, as well as to search for astrophysical gamma quanta in the energy range of 10–1000 PeV. We present the latest results for 2016–2022 on the study of the energy spectrum of cosmic rays.

**Keywords:** cosmic rays, extensive air shower, Tunka-Grande scintillation array, TAIGA experimental complex.

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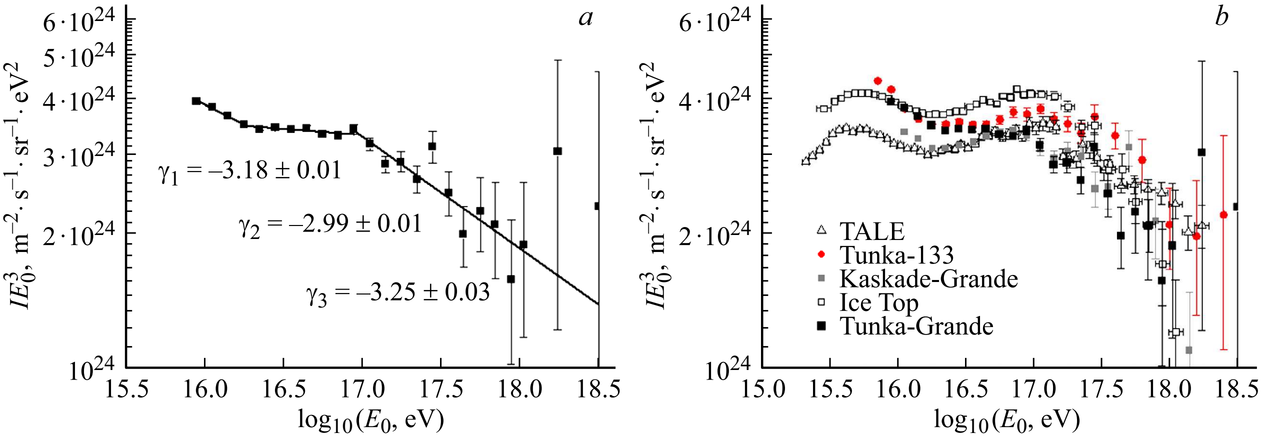
## 1. Tunka-Grande Scintillation Facility

The Tunka-Grande scintillation facility is part of the TAIGA [1] gamma-ray observatory and is a network of 19 observation stations distributed over an area of $0.5\,\mathrm{km}^2$. Each station includes a surface detector of the charged component of extensive air showers (EAS) with a total area of $\sim 8\,\mathrm{m}^2$ and an underground muon detector with a total



*a* — differential energy spectrum of the CR according to the data of the Tunka-Grande unit for 5 seasons of observation; *b* — comparison of the energy spectra obtained at Tunka-Grande, TALE [7], Tunka-133, Kascade-Grande [8] and Ice Top [9].

area of $\sim 5\,\mathrm{m}^2$. The distance between the adjacent stations is about 200 m.

The main objectives of the Tunka-Grande facility are the study of cosmic rays (CR) and the search for diffuse gamma rays in the primary energy range of 10–1000 PeV. A detailed description of the Tunka-Grande facility is given in the articles [2–4].

## 2. Data Set and Processing of 2016–2022

Regular observation sessions at the Tunka-Grande facility began in the autumn of 2016, with a total operating time of 13,500 h. Of these, $\sim$ 11900 h the Tunka-Grande array maintained an independent data set. The total number of recorded events was about 5,700,000. The rest of the time, the Tunka-Grande experiment worked under the trigger of the Cherenkov Tunka-133 [5] experiment. During this period, about 410,500 events were recorded by the installation.

Based on the data of the first observation season in 2016–2017, an analysis of joint events of the Tunka-Grande facility and the Tunka-133 Cherenkov facility was carried out. The main results of the analysis of joint events include the experimental dependence between the energy of the primary particle and the density of charged particles at a distance of 200 m from the EAS axis — parameter $\rho_{200}$ [6], as well as the assessment of the quality of recovery of the parameters of the EAS and CR parameters according to the data of the Tunka-Grande [6] experiment.

The method of processing the experimental data of the Tunka-Grande facility is described in the papers [2,6]. Let us remind us that during the reconstruction, the arrival direction and the core position of the shower, the total number of charged particles and muons in the shower, the parameter $s$ that determines the EAS age, as well as the parameter $\rho_{200}$ are reconstructed in each event of the EAS. The energy of the shower $E_0$ is determined by the parameter $\rho_{200}$ using the formula obtained from the analysis of the joint events „Tunka-Grande — Tunka-133“ [2,6]:

$$E_0 = 10^b \cdot (\rho_{200}(0))^a, \tag{1}$$

where $\rho_{200}(0)$ — scaled to the vertical direction relative to the measured zenith angle $\theta$ parameter $\rho_{200}$ [2], $a = 0.84$, $b = 15.99$.

For an independent assessment of the quality of recovery of the parameters of the EAS and CR, the Tunka-Grande experiment searched for and analyzed the joint events of the Tunka-Grande experiment and the TAIGA-HiSCORE Cherenkov array [1]. The obtained values practically coincided with the results of the analysis of joint events with the Tunka-133 Cherenkov facility: for events with energies above 10 PeV, the angular resolution of Tunka-Grande — is not worse than 2.0°, the accuracy of restoring the core position — 26 m, the energy resolution — 36%, including the values of the coefficients in the formula for the relationship between the primary energy and the parameter $\rho_{200}$ : $a = 0.83 \pm 0.01$, $b = 16.00 \pm 0.01$ coincided with the accuracy of 0.01.

## 3. Energy spectrum according to 2017–2022

About 1 226 500 events with a zenith angle $\theta \leq 35^\circ$ and the position of the axis in a circle with a radius of 350 m were selected to construct the energy spectrum from the data of the Tunka-Grande scintillation facility. Of these, $\sim$312 200 events have energies greater than 10 PeV, $\sim$2 500 events — more than 100 PeV.

The differential energy spectrum, constructed from the data of 5 observation seasons, is shown in Fig. 1, *a*. The initial part of the spectrum (8–20 PeV) can be approximated by the power law with the index $\gamma = 3.18 \pm 0.01$. The first feature is observed at an energy of 20 PeV. In the range of energies 20–100 PeV, the energy spectrum obeys a power law of degree $\gamma = 2.99 \pm 0.01$. At an energy of 100 PeV, a second feature. is observed, after which the energy spectrum is strengthened to the value of $\gamma = 3.25 \pm 0.03$.

A comparison of the energy spectrum recovered in the Tunka-Grande experiment with the energy spectra constructed from the data of TALE [7], KASCADE-Grande [8], Ice Top [9] and Tunka-133 arrays showed good agreement with the results of experiments operating in the energy range from 10 PeV to 1000 PeV. (see figure *b*).

# Conclusion

The work presents the energy spectrum based on the data of the Tunka-Grande facility accumulated over 5 seasons of observation. The energy spectrum of all particles obeys a power law with an index of 3.18 in the energy range of 8–20 PeV, 2.99 in the energy range of 20–100 PeV and 3.25 at energies above 100 PeV, and shows good agreement with the data of the TALE, KASCADE-Grande, Ice Top, and Tunka-133 experiments.

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## Conflict of interest

The authors declare that they have no conflict of interest.

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*Translated by 123*