The Tunka-Grande array simulations for the primary cosmic rays identification - status and prospects

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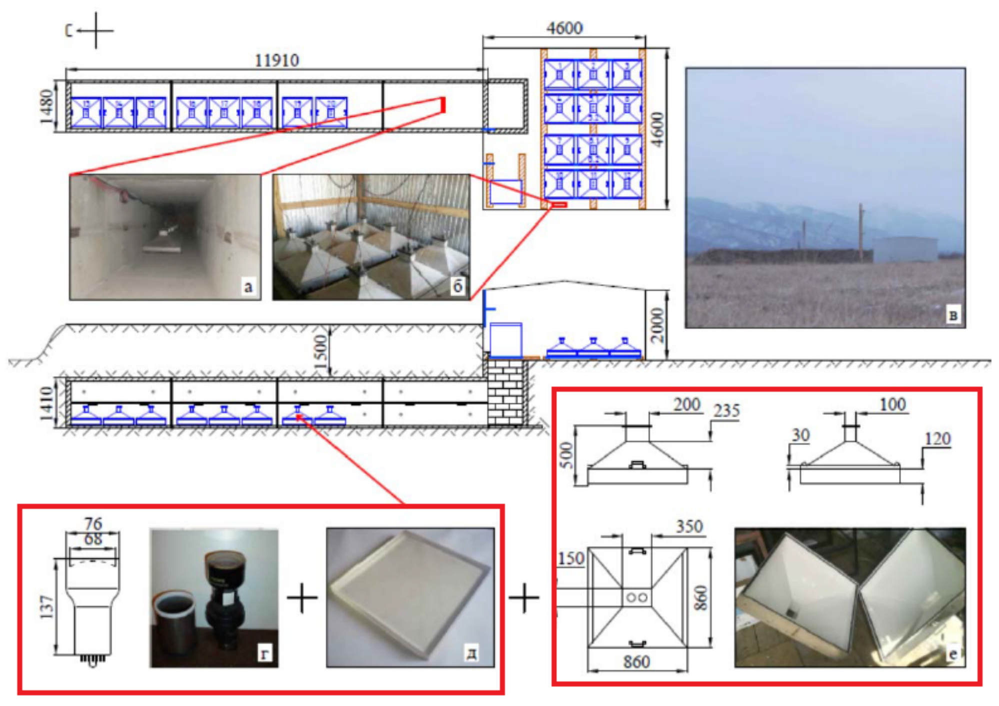
The Tunka-Grande scintillation array is a part of the TAIGA experimental complex, located in the Tunka Valley (Buryatia Republic, Russia)[1]. The array is intended to study the energy spectrum and the mass composition of charged cosmic rays (10-1000 PeV) and search for diffuse gamma rays above 10 PeV by detecting charged components of extensive air showers. This report describes the current state of the array simulations based on the CORSIKA and Geant4 toolkits, as well as some of the results obtained from the simulations.

Tunka-Grande array[2]



380 scintillation counters, placed in the area of 0.5 km^2, gathered into 19 stations.

Each station consists of two parts:

The ground part consists of 12 counters (S ~ 8 m^2) and detects charged air shower particles at the level of observation;

The underground part consists of 8 counters (S ~ 5 m^2), placed into a concrete tunnel under a soil layer with 1.5 m depth, and detects muonic air shower particles.

The goal of the simulation

1. To improve the precision of measuring the parameters of air showers and primary cosmic radiation, which will make it possible to obtain high-quality results on the energy spectrum of cosmic rays in the energy range of 10-1000 PeV;

2. To develop a method of identifying primary particles for a detailed study of the mass (elemental) composition of cosmic rays and the search for diffuse gamma rays in the energy range of 10-1000 PeV.

Air shower simulation scheme

For air shower simulations the famous **CORSIKA (v.77400)**[3] program is used. The parameters of the simulations:

- **QGSJET-II-04**[4] high-energy hadronic interaction model;
- **No thinning;**
- **Primary energies** up to 1000 PeV;
- **Zenith angles** from 0 to 45°;
- **Primary particles**: proton, gamma, iron.

All calculations were perfomed on HPC-cluster «Akademik V.M. Matrosov» (Irkutsk Supercomputer Center of SB RAS)[5].

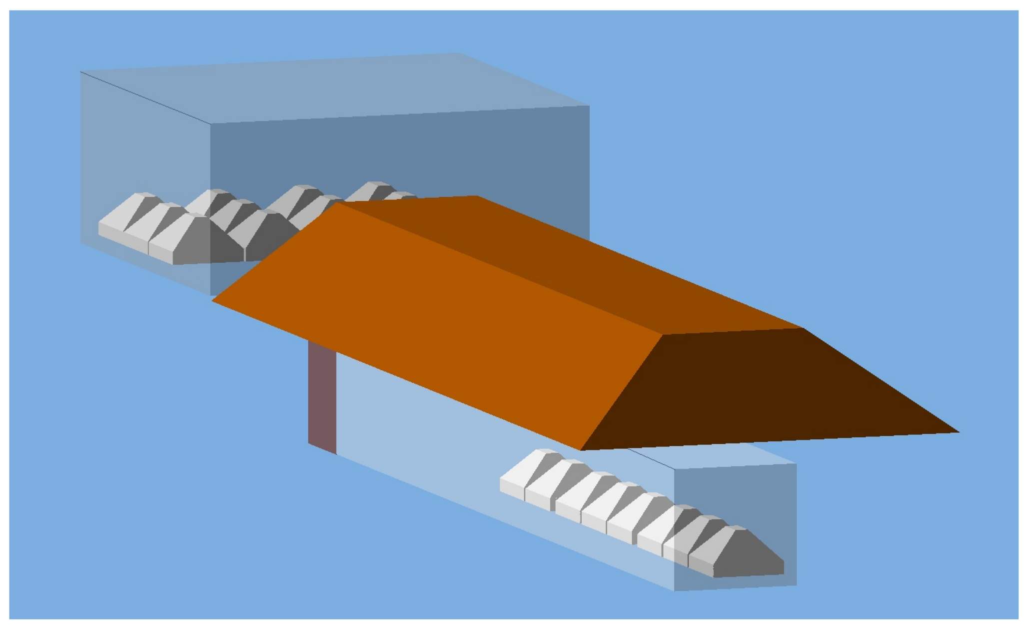
The Tunka-Grande array simulation

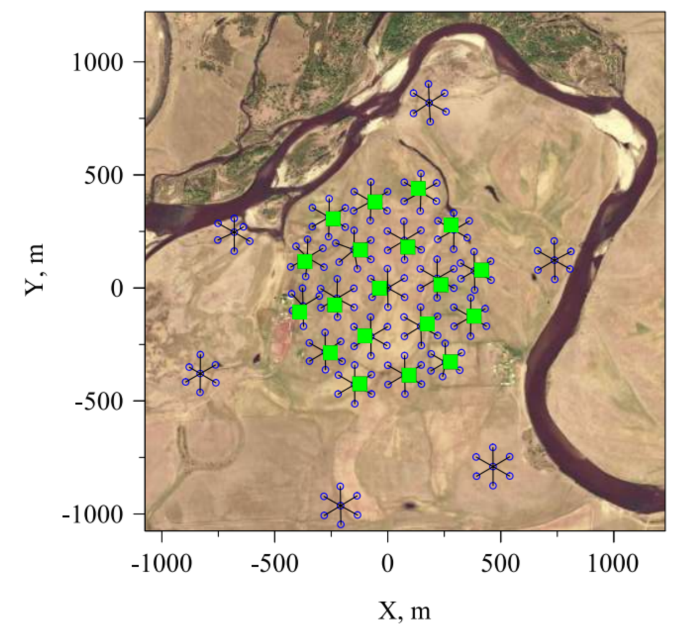
To simulate the response of the array to secondary air shower particles, the **Geant4**[6] Monte Carlo toolkit is used:

- An accurate model of the array was created, taking into account all the geometry and materials used;
- Includes **FTFP_BERT** physics list;
- Information about air shower secondary particles is taken from CORSIKA simulations. We know the type of particles, their location, energy and momentum projections.

Simulation makes it possible to obtain general information about the energy losses of registered particles separately for each counter of the entire array.

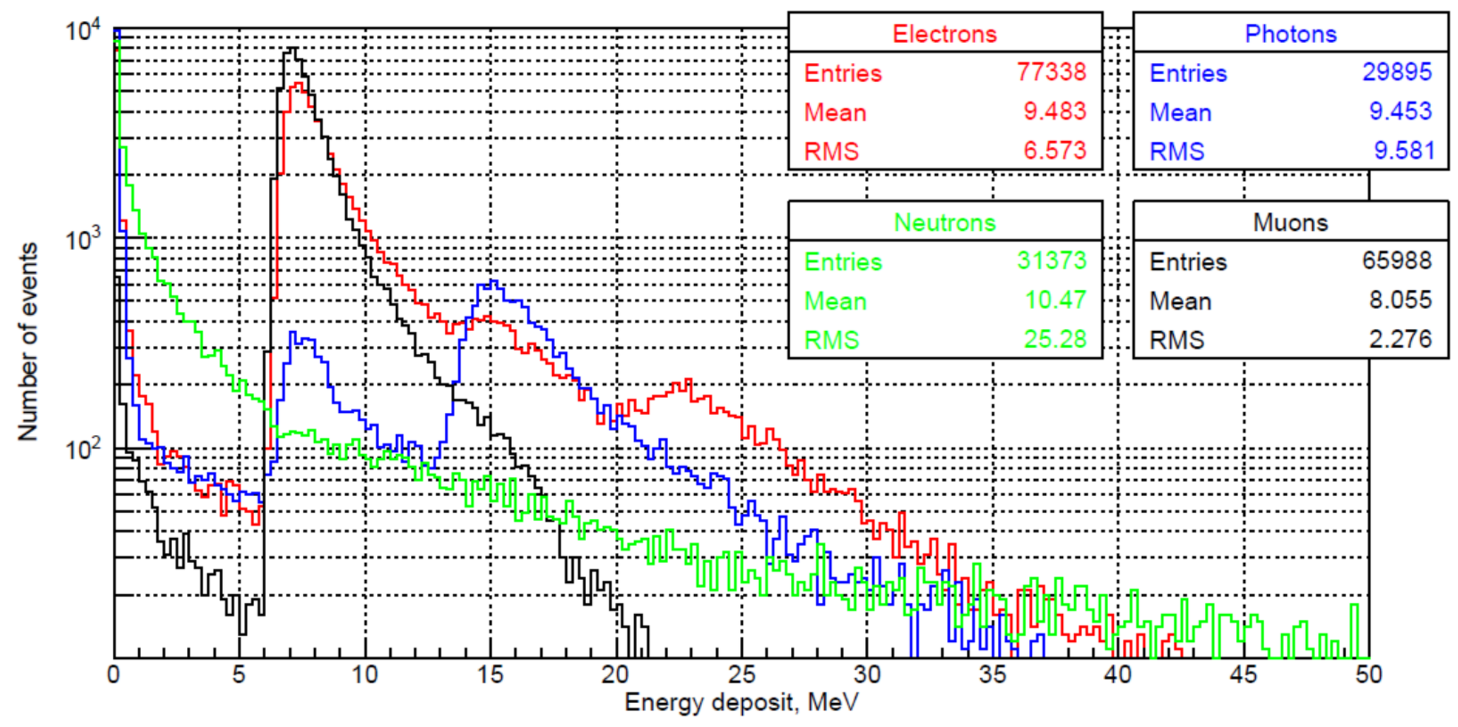
The Tunka-Grande model in Geant4





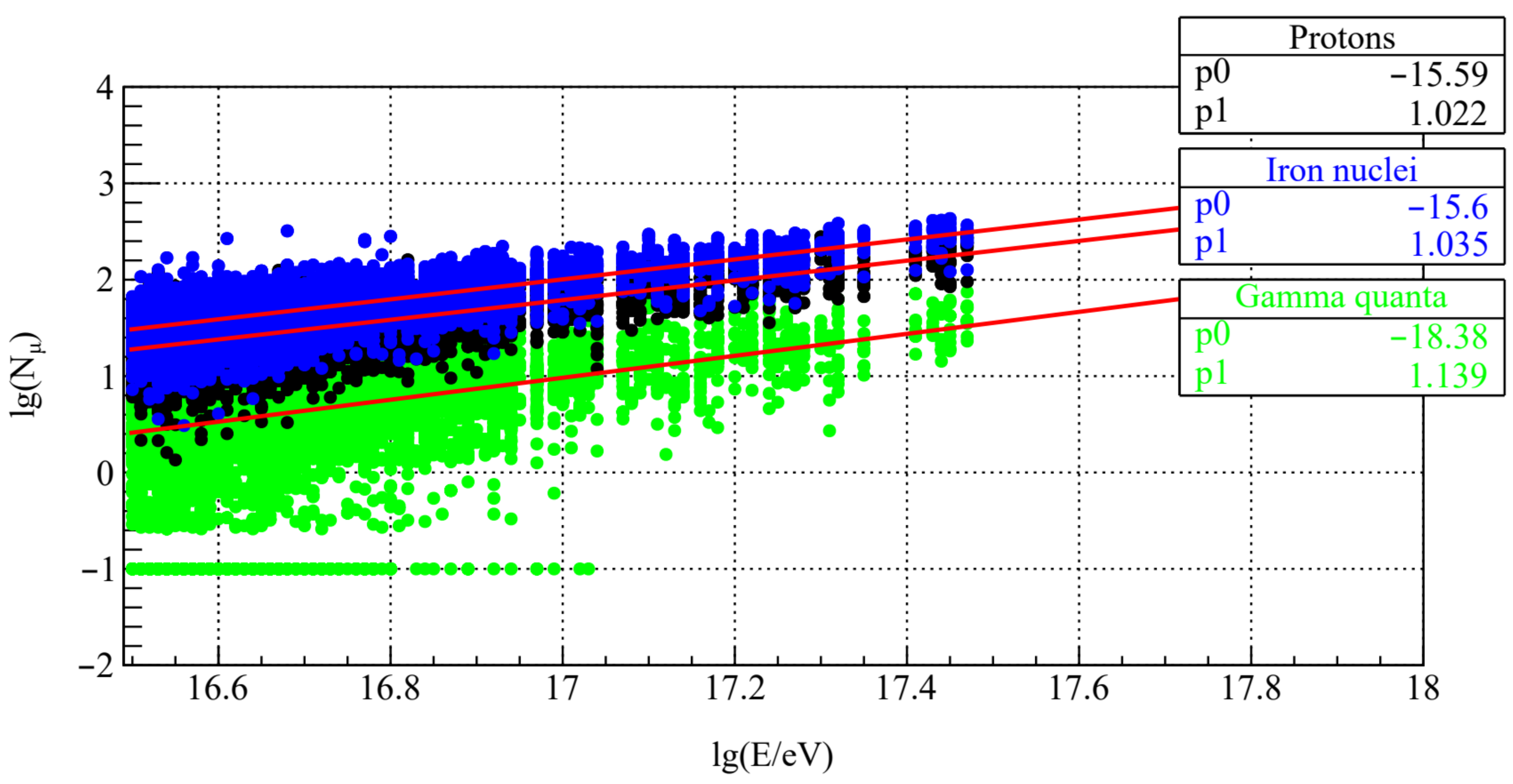
3D visualization of a single Tunka-Grande station (left) and stations positions (green boxes) in the plane of Tunka astrophysical polygon (right)

Energy deposition spectra for incident-falling air shower particles



- Secondary particle types: electrons (red spectrum), photons (blue spectrum), muons (black spectrum), and neutrons (green spectrum) with start energy of about 1 GeV;
- The picture reflects the processes of ionization and radiation energy losses in the scintillator volumes of the Tunka-Grande counters;
- The model does not provide any simulation of the readout electronics operation for the time being;
- Future full simulations of response of the scintillation counters will include the analysis of light-collecting inhomogeneity in the duralumin case as well as fluctuations of energy losses in the scintillation plate.

Distributions of the number of muons depending on the energy of primary particles



The sums of registered particles in the underground parts of all 19 stations are presented for each air shower event (or single dot);

The events are induced by primaries: protons (black dots), iron nuclei (blue dots), gamma quanta (green dots).

Events without any detected muons are plotted with log(N_μ)= -1, so that they are visible on the logarithmic axis. The distributions are approximated by the function:

$$\log(N_\mu) = p_0 + p_1 \cdot \log(E/eV)$$

The number of muons in air showers is an important characteristic that makes it possible to estimate the type of a primary cosmic particle.

It follows from the obtained results that witihn Tunka-Grande experimental sets the separation of gamma candidates and other background candidates of charged cosmic rays is possible with an efficiency of no worse than 50% .

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