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Simulation study of TAIGA experiment

The Tunka-Grande - scintillation counter array of the TAIGA experiment in Tunka valley, is expanding with the new TAIGA-Muon stations. Several simulation studies were conducted. In the first stage, the optimization of the new station positioning and performance has studied. The extensive air showers (EASs) were simulated with the CORSIKA simulation tool, and the detector response was simulated with the GEANT4 package. Extensive air showers induced by gamma quanta or a proton in the range from 100 TeV to 1 PeV at a zenith angle of 0° were used for these studies. Based on the developed simulation, the capabilities of identification of high energy extensive air showers were studied. The soil thickness, the detector and station positions, the lowest measurable energy range of the cosmic rays, and different methods of air shower identification were investigated. In the second stage, the identification performance of the array has studied. EASs induced by gamma quanta or protons in the energy range from 1 PeV to 10 PeV and the zenith angle range from 0° to 45°, are used for these studies. For the identification of high energy extensive air showers, a method based on a neural network was suggested. With this method, the proton identification efficiency is more than 90%, while the gamma identification efficiency not less than 50%.

A Monte Carlo simulation model was developed for the scintillation arrays of the TAIGA experiment (Tunka-Grande and TAIGA-Muon installations). Extensive air showers with energies less than 1 PeV were simulated with the CORSIKA package and utilised for this optimisation study. The arrangement of the surface counters of the TAIGA-Muon system has been analysed for maximization of the station detection efficiency. It has been shown that station efficiency does not depend on the arrangement of the surface detectors. The soil thickness was chosen to yield optimal identification of gamma- and proton- induced EASs. It was shown that the optimal soil thickness for this task should be around 2 m. The lowest energy threshold for the TAIGA-Muon station was studied. According to these simulations, cosmic ray showers with energies above 50 TeV are detectable. The arrangement of the TAIGA-Muon stations has been optimised with the use of event efficiency. For ~ 30% EAS detection efficiency at 100 TeV with at least three stations, the distance between the stations should be around 100 m. ~ 100% efficiency can be achieved with 50 m spacing at 100 TeV. As part of the optimisation of the TAIGA-Muon station, two identification approaches were studied, the 'threshold' and the 'ratio' methods. The 'ratio' method showed a better suppression factor than the 'threshold' method did. In the energy range 100 TeV–1 PeV, the 'ratio' method would achieve the identification of primary particles for a higher granularity of the muon detector array, with distances between stations not exceeding 30 m.
In this simulation study, possible separation of gamma quanta-induced EASs is calculated. To study EASs in the energy range > 100 TeV, we modeled 48 counters in one TAIGA-Muon station (8 surface and 40 underground counters). From the suppression factor for 100 TeV EASs it is clear that a very dense station arrangement is necessary for achievement of the γ/p separation. This required additional budget. Up to now, three new TAIGA-Muon stations were deployed, each with eight surface and eight underground counters.

A neural network method for differentiation of a high energy gamma induced extensive air shower (EAS) from a background proton induced EAS was suggested. The identification efficiency for gamma and proton EASs has been analysed in the energy range from 1 PeV to 10 PeV. EASs with energy of 7.0 PeV - 10.0 PeV show a proton induced EAS identification efficiency of more than 98% along with a gamma induced EAS identification efficiency of ~50%. This result confirms that a twofold increase in the detection area allows achieving a gamma/proton suppression coefficient of more than 1000 in this energy range. For this purpose, it is planned to add about 200 scintillation detectors to the existing ones in the next two years. The study with implementation of external trigger from the TAIGA experiment systems has started.

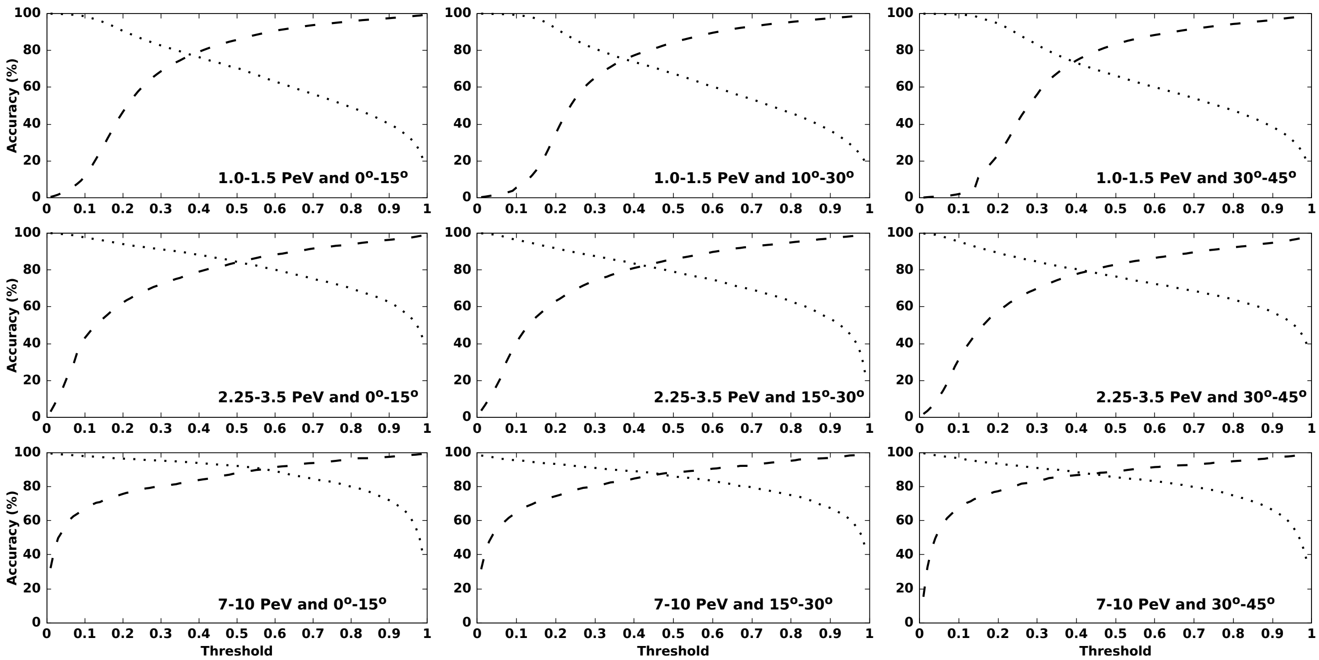

Figure: Identification efficiency for gamma (dash) and proton (dot) EAS at various threshold conditions. (Energy and zenith angle ranges are noted in the legend of each plot.)

energy	zenith angle	Threshold	identification	efficiency
			gamma	proton
1.0–1.5 PeV	0–15	0.25	54.7	88.4
	15–30		53.2	86.5
	30–45		48.2	87.2
2.25–3.5 PeV	0–15	0.15	61.8	93.7
	15–30		52.0	94.3
	30–45		49.1	91.0
7.0–10.0 PeV	0–15	0.06	59.5	98.3
	15–30		54.5	98.3
	30–45		48.4	98.4

Table: Identification efficiency (in percentage) of gamma and proton induced EASs, calculated with fixation of different threshold values for different sets of energy and angle.

List of publications:

1) Optimisation studies of the TAIGA-Muon scintillation detector array, preprint stage – JINST (2022).

2) Astapov I, et al. Identification of electromagnetic and hadronic EASs using neural network for TAIGA scintillation detector array (2022) Journal of Instrumentation, 17 (5), art. no. P05023.

3) Chernukh D, et al. An approach for identification of ultrahigh energy extensive air showers with scintillation detectors at TAIGA experiment (2020) Journal of Instrumentation, 15 (9), art. no. C09037.

Astapov I, et al.

4) Optimization of electromagnetic and hadronic extensive air shower identification using the muon detectors of the TAIGA experiment (2020) Nuclear

Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 952, art. no. 161730.