The Tunka experiment: status 2013

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FOR THE TUNKA COLLABORATION, TUNKA-REX COLLABORATION AND TUNKA-HISCORE COLLABORATION

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Abstract: The Tunka experiment is a complex cosmic ray experiment which is located in the Tunka Valley in Siberia. Presently the experiment consists of three main parts: EAS Cherenkov array Tunka-133, EAS radio-detection array Tunka-REX and a prototype of Tunka-HiSCORE (HiSCORE: Hundred Square-km Cosmic Origin Explorer) a new Cherenkov EAS array for multi-TeV gamma-ray astronomy and cosmic ray studies. A current update of the array includes the deployment of scintillation stations, new radio antennas, as well as the low threshold optical stations of a first stages Tunka-HiSCORE.

Keywords: Tunka-133, Tunka-HiSCORE, Cherenkov detection, radio detection.

1 Introduction

The method of recording Cherenkov light induced by Extensive Air Showers (EAS) is one of the most precise methods of high-energy cosmic ray studies. The Earth's atmosphere is used as a giant calorimeter and provides much better intrinisuc energy resolution ($\sim$15%) than EAS arrays detecting charged particles only.

In 2009 Tunka-133 the high density Cherenkov array, with 133 detectors has been deployed on 1 km^2 area [1]. In 2010 - 2011 it were deployed six additional remote clusters of Cherenkov detectors, which increased the effective area of Tunka-133 for registration of cosmic rays with energies above 100 PeV in the 3 - 5 times [2].

The main disadvantage of the Cherenkov technique is that the observations are possible only on clear moonless nights. Another calorimetric method is to record EAS radio emission, in contrast to the Cherenkov it is the all-weather (more accurately, almost all-weather are excluded relatively rare periods of high radio background). To test an experimental capabilities of EAS radio method we deployed 20 radio radiation detectors based EAS antenna type SALLA (Short Aperiodic Loaded Loop Antenna) for combined operation with Tunka-133 Cherenkov array. The antennas are located near the centre of the electronics cluster of Tunka-133 and external clusters.

To detect the charged components of EAS we plan to deploy network of 19 scintillation stations with 18 scintillation counters in each. Creating the network of scintillation detectors will allow for the absolute energy calibration of Tunka-133, similar to those presented earlier in the joint work of Cherenkov detectors in an installation EAS-TOP (experiment QUEST [3], but only for the energy range of 100 PeV. They will also be used to work with a system of radio antennas in the periods when the Cherenkov observations are not possible.

The most ambitious project, which is expected to be realized in the coming years in Tunka valley is to create a wide range of large-area telescope Tunka-HiSCORE (HiSCORE - Hundred Square-km Cosmic Origin Explorer), operating on non-imaging (without creating an image) technology [4]. Tunka-HiSCORE will solve a wide range of tasks - astronomy, cosmic ray physics and particle astrophysics in general: to search for new sources of gamma-ray high-energy, including the galactic PeVatrons, explore new mechanisms for acceleration of charged particles and to study the absorption gamma rays in the background radiation (infrared and microwave), to search for new forms of matter, including the search for axion-photon transitions of

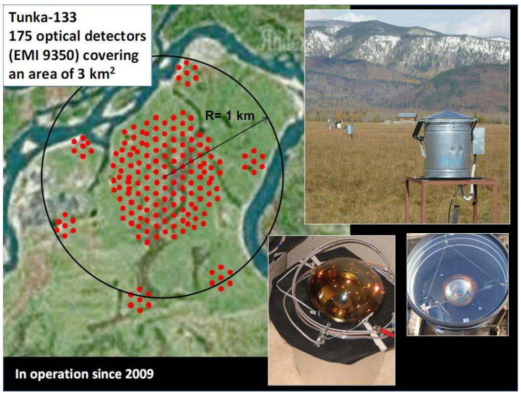

Figure 1: Layout of the Tunka-133 array.

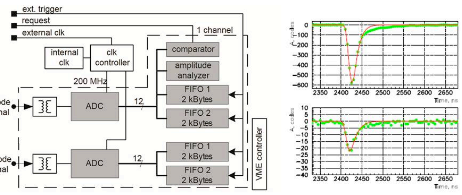

Figure 2: Internal structure of FADC board (shown only one channel, the second one is identical) (left). Example of signals from anode and dynode (right).

Lorentz-invariance as a new approach to the search for dark matter in the universe.

2 Tunka-133 Cherenkov array

The Tunka-133 array consists of 175 wide-angle optical detectors placed in an area of approximately 3 km^2 [1], [2]. The detectors are grouped into 25 clusters, each with 7 detectors – six hexagonally arranged detectors and one in the center. The distance between the detectors in the cluster is 85 m. 19 clusters are installed in a inner circle of 500 m radius – "inside" clusters, 6 clusters were placed at the distance of 700 – 1000 m from the center – "outside" clusters (Fig. 1).

An optical detector consists of a metallic cylinder with 50 cm diameter, containing the PMT (PMT EMI 9359 or Hamamatsu R1408) with hemispherical photocathode of 20 cm diameter. The container has a plexi-glass window on the top, heated against frost. The angular aperture is defined by geometric shadowing of the PMT. The detector is equipped with a remotely controlled lid protecting the PMT from sunlight and precipitation. Apart from the PMT with its high voltage supply and pre-amplifiers, the detector box contains a light emitting diode (LED) for both amplitude and time calibration and a controller. The controller is connected with the cluster electronics via twisted pair (RS-485). To provide the necessary dynamic range of $3 \cdot 10^4$, two analog signals, one from the anode and another one from the dynode, are read out. They are amplified and then transmitted to the central electronics hut of each cluster. The ratio of amplitudes of these signals is about 30. It is not planned to heat the inner volume of the optical detector boxes, therefore all the detector electronics is designed to operate over a wide temperature range (down to $-40°$C). The signals from PMTs are sent via 95 m coaxial cable RG58 from detectors to the center of each cluster. This leads to a broadening of the signals, the minimum value of FWHM is close to 20 ns.

The cluster electronics [7] includes the cluster controller, 4 four-channel FADC boards, adapter unit for connection with optical modules and temperature controller. The 12 bit and 200 MHz sampling FADC boards are based on AD9430 fast ADCs and FPGA XILINX Spartan XC3S300 microchip (Fig. 2). The cluster controller consists of an optical transceiver (type V23826-K305-C363-C3 for inside clusters and type SNR-SFP-LX-20 for outside clusters), a synchronization module, a local time clock and a trigger module. The optical transceiver operating at 1000 MHz is responsible for data transmission and formation of 100 MHz synchronization signal for cluster clocks. The cluster trigger (the local trigger) is formed by the coincidence of at least tree pulses from optical detectors exceeding the threshold within a time window of 0.5 mks. The time mark of the local trigger is fixed by the cluster clock.

The accuracy of the time synchronization between different clusters is of about 10 ns. Each cluster electronics is connected to the DAQ center with a power cable (4-copper wires) and optical cables (multi-mode fibers for inner clusters and single mode for outer ones).

The central DAQ station consist several DAQ boards synchronized by a single 100 MHz oscillator. On each board 4 optical transceiver are installed, and so one board can operate with 4 clusters. The full number of boards may be increased to 20 (now only 7 are used), and hence, the DAQ can work with up to 80 clusters. The boards are connected to the master PC by 100-MHz-Ethernet lines.

The energy spectrum of cosmic rays in the range of $6 \cdot 10^{15} - 10^{18}$ eV has been reconstructed using data from 3 winter seasons of measurements with the Tunka-133 array. The spectrum points out reliably the existence of a "knee" at $\sim 3 \cdot 10^{17}$ eV, where at this energy the spectral power-law index changes by 0.3. More detailed information will be presented in work [6] on this conference. These results ([6], [8]), confirm earlier findings of the KASCADE-Grande experiment [9]. The spectral steepening at $3 \cdot 10^{17}$ eV could be interpreted as a "second knee" in the energy spectrum related with a transfer from galactic to extragalactic origin of the cosmic rays. The decrease of the mean logarithm of the atomic number or composition lightening at energies higher than 10^{17} eV ([6]) also points out such a trasition to extragalactic cosmic rays. It may hint to the fact that cosmic rays of higher energies are of extragalactic origin.

To cross-calibrate our methods of energy and X_{max} reconstruction we plan to deploy fuoresccent detector(FD) for joint operation with Tunka array[10]). FD will be placed at the disstance 7-10 km from Tunka array and based on the mirrow with area 2 m^2.

3 Tunka-Rex

The relatively young, digital radio detection technique makes possible a new type of detectors for air showers, based on the detection of the radio emission in the atmosphere. Its principal applicability was proven, e.g. by LOPES [11]. The next step is to investigate the achievable precision in determination of primary energy and the shower maximum. Therefore, the Tunka-Radio-Extension (Tunka-Rex) was deployed in the Tunka valley in 2012 [12].

Tunka-Rex [21] currently consists of 20 stations (Fig. 3) with a typical distance of 200 m, one next to each cluster center of Tunka-133. Each station consists of two crossed

Figure 3: The Tunka-Rex antenna station in front of a cluster center and its central PMT

Figure 4: A scintillation counter to be deployed at Tunka-133.

antennas to measure two components of the polarization. As antenna we chose an active version of the SALLA [13]. Unlike most other radio experiments, the antennas are not aligned along the North-South and East-West direction, but rotated by 45°. Thus, we have a slightly higher detection threshold, but on the other hand more events with polarization information.

30 m of RG213 cable connect the antennas to the cluster center. This lead to a distance of about 20 m to the cluster centers to avoid possible interferences from electronics. In the cluster center the signal is amplified and filtered to a bandwidth of 30-80 MHz. Then the signal is digitized by the Tunka-133 DAQ system at a sampling rate of 200 MHz. The temperature in the cluster center is regulated to ensure stable operating conditions for the electronics.

Tunka-Rex uses free channels on the Tunka-133 ADC boards. Hence, it has the same DAQ system. A 5 μs trace of the Tunka-Rex antennas is recorded with each single cluster trigger of Tunka-133. Events are then combined afterwards from single clusters by the time information. This common DAQ system allows us a simple cross-calibration between the radio and the air-Cherenkov signal for individual events.

Starting this year, the radio extension detected already more than 100 coincident events with energy above 10^{17} eV. The analysis of the radio data has shown that Tunka-133 is also sensitive to inclined, nearly horizontal showers at very high energies. The directions of these showers were reconstructed by both, the Cherenkov detector and the radio detector with consistent results.

4 Scintillation detectors

The deployment of scintillation counters within Tunka-133 will provide a cross-calibration of different methods of air shower parameter reconstruction. We plan to install 19 scintillation stations from the former and dismounted KASCADE-Grande array [14]. Each station consists of 16 scintillation detectors (Fig. 4)). Each scintillation detector consists of a plastic scintillator (800x800x400 cm^3), a light collecting cone, and XP3462 PMTs.

The detectors of each station will be fixed in two containers. One of them will be located on the surface and will consist of 10 detectors, another one will be put under 1.5 m ground and will incorporate 8 detectors. The goal of the surface detector is to register the electron-photon component of EAS, whereas the underground detector will detect muons. Both containers will not be heated. The stations will be fixed at small distances from each other.

The scintillation station electronics will be put into a heated container analogous to the cluster container of the Cherenkov array. The electronics coincides practically completely with electronics of the cluster center of the Tunka-133 array. It gives an opportunity to switch scintillation detectors to the DAQ as additional clusters. Additional electronic units are 2 adjustable 16-channels summators and 20-channels high voltage power supply. Detectors with odd numbers are connected to the first summator and even detectors to the second one. The output signals are fed to the input of a FADC. Signals of the underground detectors are connected directly with FADC inputs. A trigger signal of scintillation station is formed when signals corresponding to a relativistic particle going through the scintillator appear from outputs of two summators.

So, with the deployment of the scintillation station, we will have in the Tunka experiment a unique complex array with a possibility to detect simultaneously Cherenkov light, radio signal, electrons and muons for each individual air shower event.

One of the main goals of the complex array is to carry out an absolute calibration of the energy reconstruction method using measured correlations between LDF and the Q200/Ne ratio [15], where Q200 is the Cherenkov light density at a distance of 200 m from the shower core and Ne – the number of electrons in the EAS.

A possibility to reconstruct energy and shower maximum depth using the Cherenkov array data and evaluate the number of muons will allow us to start search for diffuse gamma-ray radiation in the energy range of $5 \cdot 10^{16} - 5 \cdot 10^{17}$ eV.

5 Low energy extension – Tunka-HiSCORE

The development of the wide-angle Cherenkov gamma-ray observatory Tunka-HiSCORE [4], [5] [18], [19], [20] to study gamma-quanta fluxes from known local sources and unknown new sources has been started. One can find detailed information of this project at the web-site: http://dec1.sinp.msu.ru/ tunka/. A substantial feature of the new project is the combination of detectors of different types in one array: wide-angle Cherenkov detectors (non-imaging technique), narrow-angled Cherenkov detectors with photosensors matrix (imaging technique) and muon detectors. Apart from its main goal (search for and study of local sources of gamma-quanta) the array will study gamma-

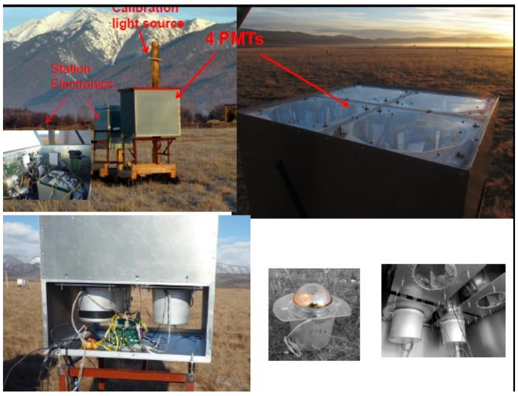

Figure 5: Photograph of one of the first 3 new optical stations.

quanta absorption on background radiation (infrared and microwave) and search for photon-axion transitions.

The optical stations will be put at the distances of 150-200m from each other and will consist of several PMTs with large area photocathodes ($\sim 20-30$ cm in diameter). Effective area of each PMT in the station will be increased by a factor of 4 by Winstone cones, which in turn will result in a decrease of the energy threshold by a factor of 2. The observational solid angle will be approximately 0.6 steradian. To form local triggers, the signal of an optical station from all PMTs are summed in an analogue way. Such an approach will result in additional decrease of energy threshold by $\sqrt{n}$ times, where n – the number of PMTs in one station. For further increase of the array sensitivity a net of Cherenkov detectors allows us to get EAS images based on 2-3 m^2 mirrors with 0.05 steradian field-of-view will be incorporated into the array. Matrices of PMTs (vacuum or silicon PMTs) will be installed in the focal plane of the mirrors. EAS image analysis will permit separate effectively gamma-quanta from events induced by charged cosmic rays. Gamma-quanta from an observed source will be registered by detectors of two types to carry out cross-calibration and to study experimentally methods of suppression of background showers produced by charged cosmic rays. For a further increase of sensitivity the central part of the array will be added by large area muon detectors. It will give a possibility to extract with high efficiency gamma-quanta events from proton and nuclei induced showers.

The project will be implemented in several stages: from 1 km^2 array at the first stage to 100 km^2 array at the last one. In autumn 2012 the first 3 optical stations (Fig. 5) were deployed for joint operation with the Tunka-133 array.

6 Conclusion

At present the Tunka-133 is the largest Cherenkov array for studies of cosmic rays in the energy range of $10^{15}-10^{18}$ eV. Subsequent upgrading of the Tunka experiment facilities including deployment of the Tunka-HiSCORE observatory will allow: to perform search for local Galactic sources of gamma-quanta with energies more than 20-30 TeV (search for PeV-trons) and study gamma-radiation fluxes in the energy region higher than 20-30 TeV at the record level of sensitivity; to study energy spectrum and mass composition of cosmic rays in the energy range of $510^{13}-10^{18}$ eV at so far unprecedented level of statistics; to study high energy part of gamma-rays energy spectrum form the most bright blazars (absorption of gamma-quanta by intergalactic phone, search for axion-photon transition) etc.

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