TheTunka-133 EAS Cherenkov light array: status of 2011

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Abstract: A new EAS Cherenkov light array, Tunka-133, with $\sim$1 km^2 geometrical area has been installed in the Tunka Valley (50 km from Lake Baikal) in 2009. The array permits a detailed study of cosmic ray energy spectrum and mass composition in the energy range 10^{16} - 10^{18} eV with a uniform method. The array consists of 19 clusters. Each cluster incorporates 7 optical detectors based on hemispherical PMTs with 20 cm diameter photocathode. We describe the array construction, DAQ and methods of the array calibration. Preliminary results of joint operation of the Cherenkov array with antennas for detection of EAS radio signals are presented. Plans for future upgrades – deployment of remote clusters, radioantennas and muon detectors network – are discussed.

Keywords: EAS Cherenkov light array, cosmic rays, energy spectrum and mass composition.

1 Introduction

The study of primary energy spectrum and mass composition in the energy range $10^{15} - 10^{18}$ eV is of crucial importance for the understanding of the origin of cosmic rays and of their propagation in the Galaxy.

To measure the primary cosmic ray energy spectrum and mass composition in the mentioned energy range, the new array Tunka-133 ([1], [2]), with nearly 1 km^2 geometrical area has been deployed in the Tunka Valley, Siberia. It records EAS Cherenkov light using the atmosphere of the Earth as a huge calorimeter and has much better energy resolution ($\sim$ 15%) than EAS arrays detecting only charged particles.

2 Tunka-133

2.1 Array description

The Tunka-133 array consists of 133 wide-angle aperture optical detectors based on PMT EMI 9350 with a hemispherical photocathode of 20 cm diameter. The detectors are grouped into 19 clusters, each cluster with seven detectors – six hexagonally arranged detectors and one in the center. The distance between the detectors in the cluster is 85 m.

The Cherenkov light pulses are sent via 95 m coaxial cable RG58 from the detectors to the center of each cluster and digitized. The dynamic range of the amplitude measurement is about $3 \cdot 10^4$. This is achieved by means of two channels for each detector extracting the signals from the anode and from an intermediate dynode of the PMT with different additional amplification factors.

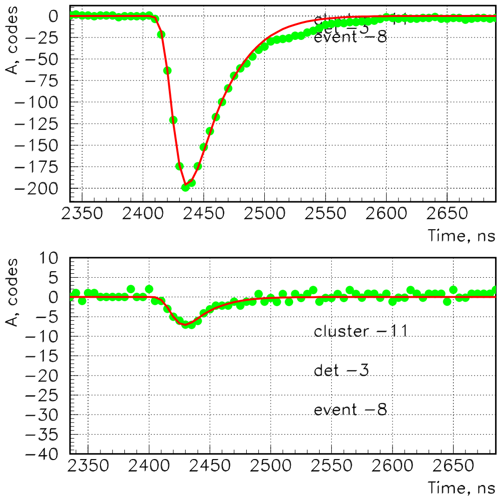

Figure 1: : Example of a pulse from one Tunka-133 detector

The cluster electronics includes the cluster controller, 4 four-channel FADC boards, an adapter unit for connection with optical modules and a special temperature controller. The 12 bit and 200 MHz sampling FADC boards are based on AD9430 fast ADCs and FPGA XILINX Spartan XC3S300 microchips. The cluster controller consists of an optical transceiver, a synchonization 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 last three pulses from optical detectors exceeding the threshold within a time window 0.5μs. The time mark of the local trigger is fixed by the cluster clock. The accuracy of the time synchronization between different clusters is about 10 ns. Each cluster electonics is connected to the DAQ center with a multi-wire cable consisting of four copper wires and four optical fibers.

The central DAQ station consists of 4 DAQ boards synchronized by a single 100 MHz oscillator. The boards are connected to the master PC by 100 MHz Ethernet lines.

2.2 Data processing and reconstruction of EAS parameters

The primary data record for each Cherenkov light detector contains 1024 amplitude values in steps of 5 ns (Fig.1). Thus, the waveform of every pulse is recorded, together with the preceding noise, as a total trace of 5 μs length. To derive the three main parameters of the pulse: front delay at a level 0.25 of the maximum amplitude t_i, pulse area Q_i and full width at half-maximum (FWHM) τ_i, the pulses are fit with a smooth curve. The waveform of the light pulse is rather complicated and can't be fitted with a simple function as e.g. a Gaussian or gamma function. Therefore, a function was constructed which separately approximates front and tail of the pulse [3].

The reconstruction of the EAS core position is performed with two methods – one by fitting the measured charges Q_i with the lateral distribution function (LDF ([4]) and one by a new method of fitting the measured pulse widths τ_i by the width-distance function (WDF)([5].

3 Results

During the two seasons of array operation (winters 2009/10 and 2010/11, with nearly 600 hours of clean weather moonless nights), $\sim 4 \cdot 10^6$ events with E$> 10^{15}$ eV have been collected. Events with core position inside a radius of 450 m from the array center and zenith angles less than 45$\circ$ were selected to construct energy spectrum and mass composition. Among them are $4 \cdot 10^4$ events with E$> 10^{16}$ eV and $\sim$ 450 events with energy more than E$> 10^{17}$ eV. Results of the study of energy spectrum and mass compostion are described in detail in separate papers, presented at this conferense [6], [7].

Together with the registration of Cherenkov light we start studying radioemisstion from EAS as an alternative calorimetric method of EAS registration. First results are shown below.

3.1 Measurements of radio signals from EAS

To study whether, in addition to the Cherenkov light, also the radio emission of air showers can be detected at Tunka, the SALLA antenna [8] was deployed at Tunka cluster 7 in summer 2009. SALLA is read out simultaneously with the PMTs of that cluster. Indeed numerous radio pulses could be detected, but most of them are due to RFI by the Tunka electronics or other background. However, for Tunka events with a high PMT signal, i.e. a high primary energy, an accumulation of events with a radio pulse shortly before the PMT pulses is observed (see Fig 2 for an example). Selecting these events, about 70 radio candidate events have been found within the season 2009/2010.

Several tests have been performed to confirm whether the detected radio pulses are really from air showers or due to any kind of background generated by Tunka. One test was to check for which events in a selection of high quality and high energy Tunka events a radio pulse could be detected (see Fig3). Consistent with the results of other radio experiments (e.g., LOPES [9]), a detection is more likely in the east-west aligned antenna and for high energies. Furthermore, the ratio between the amplitude in the east-west and north-south aligned antenna has been compared to REAS3 [10] simulations. For 7 out of 11 events which show a radio pulse in both polarizations, the amplitude ratio is compatible within the measurement uncertainties estimated with a formula derived for LOPES [11]. This is another indication, that at least most of the detected radio candidates are due to the radio emission of air showers.

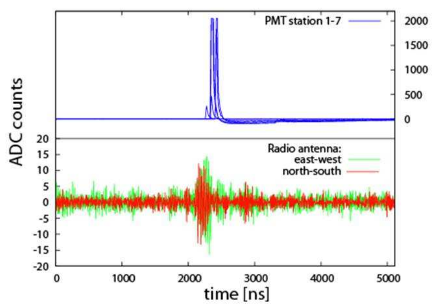

Figure 2: One of the radio candidate events. A radio pulse is detected in both polarizations shortly before the signal of the PMTs.

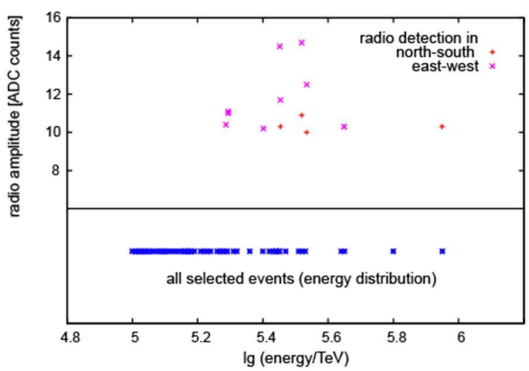

Figure 3: Energy distribution of a selection of Tunka events and the radio amplitude for those of these events which show a radio pulse in at least one polarization.

3.2 Time calibration

For time synchronization of the optical modules of the Tunka-133 array a dedicated calibration system has been developed [12]. The calibration system is based on a powerful nanosend LED light source especially designed for the system. The light source consists of four high InGaN/GaN royal blue (λ_{max} = 450 nm) LEDs with 100° full emission angle. So, the light source as whole covers 2π azimuth angle.

Each LED of the source is driven by its own avalanche transistor driver and provide $\sim 10^{12}$ photons per pulse, with $\sim$4 ns pulse width (FWHM). All LED drivers of the source are triggered simultaneously. Since the light source is installed a few meters above the ground it can, in principle, illuminate the whole array, given that all optical modules of the array are equipped with appropriate reflectors.

4 Plan for upgrading

The Tunka-133 facility will be significantly upraded until fall 2013. In 2011 it is planned to install additional clusters of optical detectors at large distant (”distant clusters”) from the center of array. In 2011-2013 we plan to install radio antennas and scintillation detectors for common operation with Tunka-133.

4.1 Deployment of six distant clusters.

It seems that for small random fluctuations of the signal width, the use of WDF instead of LDF will allow a good reconstruction of events with their core position outside the geometric area of the array. In this case X_{max} can be measured via $\tau(400)$, and the energy of the shower by the density of Cherenkov light at core distances of 400-600 m. To increase the accuracy of the core reconstruction for such events, we plan to install six new clusters at 1 km radius around the center of Tunka-133. These additional 42 optical detectors will increase the effective area at 10^{17} eV by a factor of 4. The first distant cluster was deployed in autumn 2010, an example of an event hitting both Tunka-133 detecors and the distant cluster is presented in Fig 4. The next five clusters will be deployed in autumn 2011.

4.2 Net of radio anntenas at Tunka

The positive results of common operation of the first SALLA antenna and the Tunka-133 array suggest that it would be interesting to install a whole net of the same type of antennas at Tunka. The principle aim of such a radio-array is to show whether radio measuremnts of cosmic ray air showers allow the same precision for cosmic ray measurements as Cherenkov light measurements. In particular, the precision of the energy and mass determination of primary cosmic-ray particles will be investigated. The determination of the precision is a crucial input for the design of the next-geneneration large cosmic-ray observatories, since radio measurements are not limited to dark, moonless nights as other calorimetric detection techniques, like Cherenkov or fluorescence light measurements.

In summer 2011 we plan to install additional 4 antennas, further $\sim$20 antennas will be installed in 2012.

4.3 Scintillation detectors

The deployment of scintillation counters within the Tunka array provides a cross-calibration of different methods of air shower measurements since all shower components will be recorded simultaneously. In 2010 a test variant of a scintillation detector was installed [13]. It can operate independently as well as triggered by Tunka-133. The mass production of detectors will start at the end of 2011. We plan to produce 20 scintillation detectors with 10 m^2 area each.

In a first stage, all scintillation detectors will be arranged with small spacing (50 m) to measure the total number of

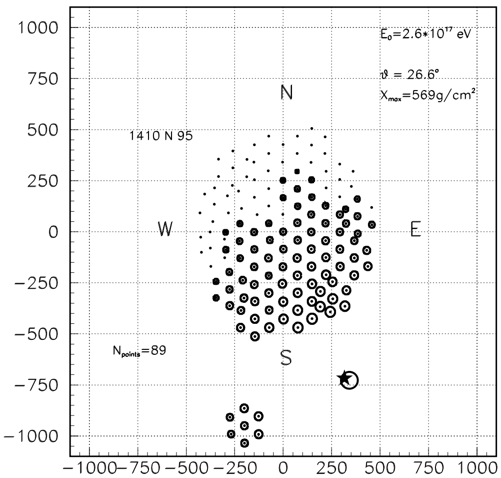

Figure 4: Example of an event, that hit the first distant cluster and detectors of Tunka-133. The full number of hit detectors is 89. The radii of the circles are proportional to the logarithm of the detected Cherenkov light flux. $E = 2.6 \cdot 10^{17}$ eV, $X_{max} = 569 g/cm^2$. Cross - core position: $\star$ (reconstructed by using LFD), $\bigcirc$ (reconstructed by using WDF).

electrons (N_e) in the EAS. The simultaneous measurement of N_e permits to check the accuracy of the absolute energy calibration - as was done on a statistical level by the experiment QUEST [14]. In a next stage the distances between detectors will be increased up to 120-150 m. We then will compare the Tunka-133 method of energy recontruction with an estimate based on the density of charged particles at 500 m from the core, used in KASCADE-Grande [15].

After cross-calibration of energy measurements scintillation counters will be buried under a layer of 1.5-2 m of ground and give an estimate of the number of muons. This results in a higher precision for mass composition at 10^{17} - 10^{18} eV. Monte Carlo simulations showed ([16]) that the measurement of the muon number with an accuracy of 5-10%, together with the accuracy in energy and X_{max} achieved with Tunka-133, allow distinguishing showers produced by heavy (Fe, Si) and light (proton, He) nuclei. This is a key information to identify the transition from Galactic to extragalactic cosmic rays.

4.4 HiSCORE station

The aim of the HiSCORE project [17] is to explore the gamma-ray skymap beyond 10 TeV with a future large-area (10-100 km^2), wide-angle (> 0.6 sr) non-imaging cosmic rays and gamma-ray air shower detector.

HiSCORE is a net of detector stations with 4 PMT-channels equipped with Winston cones. The station light-collecting area (0.5 m^2) will be a factor 16 larger than that of an Tunka optical detector, resulting in a significantly lower energy threshold. The first such a station will be installed in autumn at the Tunka side. In 2012-2013, a net of such stations (HiSCORE Engeneering Array) will be installed for common operation with Tunka-133. The aim of HiSCORE EA is to prove methods of EAS reconstruction before deployment of a full scale array.

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