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The Tunka-133 EAS Cherenkov light array: Status of 2011

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ABSTRACT

A new EAS Cherenkov light array, Tunka-133, with $\sim 1\ \mathrm{km}^2$ geometrical area has been installed at 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. We describe the array construction, DAQ and methods of the array calibration. The method of energy reconstruction and absolute calibration of measurements are discussed. The analysis of spatial and time structure of EAS Cherenkov light allows to estimate the depth of the EAS maximum X_{max}.

The results on the all particles energy spectrum and the mean depth of the EAS maximum X_{max} vs. primary energy derived from the data of two winter seasons (2009–2011) are presented. Preliminary results of joint operation of the Cherenkov array with antennas for the detection of EAS radio signals are shown. Plans for future upgrades – deployment of remote clusters, radioantennas and a scintillator detector network and a prototype of the HiSCORE gamma-telescope – are discussed.

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 cosmic rays origin and 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 $1\ \mathrm{km}^2$ 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

The Tunka-133 array consists of 133 wide-angle optical detectors based on the 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 inside the cluster is 85 m.

The Cherenkov light pulse is sent via 95 m coaxial cable RG58 to the center of a cluster and digitized. The dynamic range of the amplitude measurement is about 3×10^4. 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.

The cluster electronics includes the cluster controller, four 4-channel FADC boards, an adapter unit for connection with optical detectors and a special temperature controller. The 12 bits and

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200 MHz sampling FADC board is based on AD9430 fast ADCs and FPGA XILINX Spartan XC3S300 microchips. The cluster controller consists of an optical transceiver, 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 signals for the cluster clocks. The cluster trigger (the local trigger) is formed by the coincidence of at least three pulses from the optical detectors exceeding the threshold within a time window of 0.5 μs. 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 electronics is connected with the DAQ center by a multi-wire cable containing four copper wires and four optical fibers.

The central DAQ station consists of four DAQ boards synchronized by a single 100 MHz generator. The boards are connected with the master PC by 100 MHz Ethernet lines.

3. Data processing and reconstruction of the EAS parameters

3.1. Data processing

The primary data record for each Cherenkov light detector contains 1024 amplitude values with step of 5 ns (Fig. 1). Thus, each pulse waveform is recorded together with the preceding noise as a trace of 5 μs. 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, each pulse is fitted with a special self-designed smoothing curve [3].

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

3.2. Energy reconstruction

As a measure of energy we used the Cherenkov light flux density at a core distance of 175 m—Q_{175}. Connection between the EAS energy E_0 and Q_{175} may be expressed by the following formula:

$$E_0 = C \cdot Q_{175}^{g}. \quad (1)$$

It was found from CORSIKA simulation that for the energy range of 10^{16}–10^{17} eV and zenith angle range 0°–45° the value of index g is 0.95 for pure proton composition and 0.91 for pure iron composition. For energy reconstruction the value of g equal to 0.93 was chosen.

To reconstruct the EAS energy from Cherenkov light flux one needs to know an absolute sensitivity of Cherenkov detectors and the atmosphere transparency. To avoid these problems, the method of normalization of the integral energy spectrum to the reference one is used. The reference energy spectrum was obtained at the QUEST experiment [6]. In that experiment, five wide-angle Cherenkov light detectors were installed at Gran-Sasso for common operation with the EAS-TOP array. The analysis of CORSIKA simulations shows a strict correlation between the size/energy (N_e/E_0) ratio and the steepness (P) of the EAS Cherenkov light lateral distribution.

The relation between N_e/E_0 and P (Fig. 2) is independent from both the mass of primary particle and the hadronic interaction model used for the simulation and provides the primary energy from the measurement of N_e and P. To reconstruct the LDF steepness P, the knowledge of PMT absolute sensitivity and the atmosphere transparency is not needed. The integral energy spectrum of cosmic rays obtained in the QUEST experiment is used as the reference one now. The integral energy spectra obtained for each night of Tunka-133 operation is normalized to the reference one.

3.3. Reconstruction of X_{max}

Recording the pulse waveform for each detector allows to use two methods of X_{max} reconstruction, which were developed for our experiment. The first is based on the shape of the LDF and called P-method. The second method, the W-method, is based on an analysis of time width of the Cherenkov pulses.

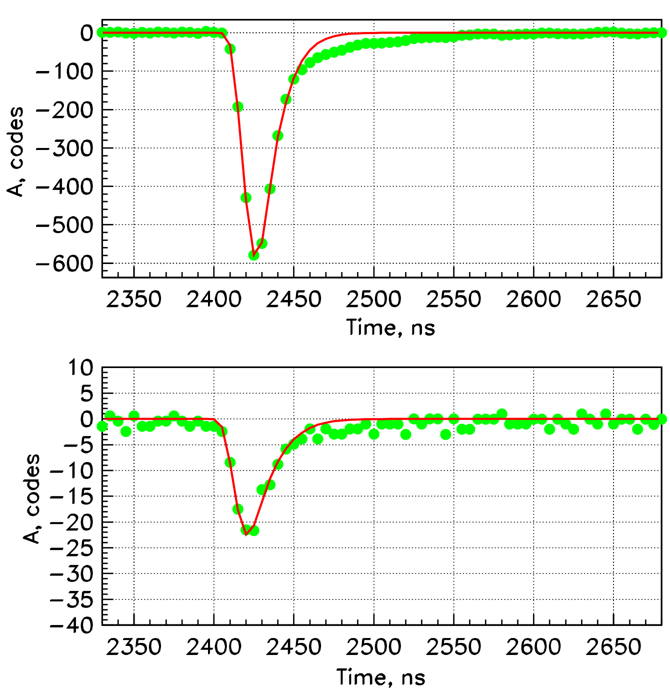

Fig. 1. Example of a pulse from one Tunka-133 detector, recorded by high and low gain channels.

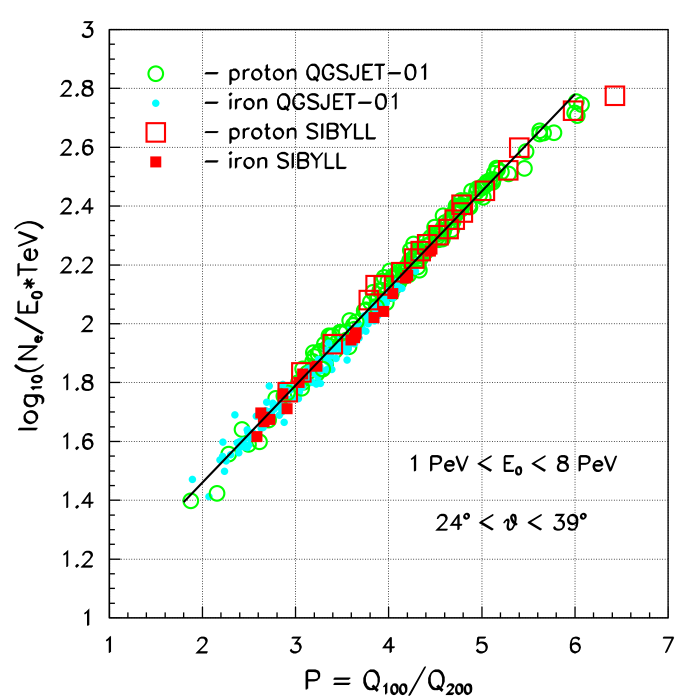

Fig. 2. N_e/E_0 vs. P.