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Tunka-133 EAS Cherenkov Array: Status of 2007

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Abstract: The new EAS Cherenkov array Tunka-133, with about 1 km^2 sensitive area, is being installed in the Tunka Valley since the end of 2005. This array will permit a detailed study of the cosmic ray energy spectrum and the mass composition in the energy range 10^{15} - 10^{18} eV with a unique method. The array will consist of 19 clusters, each composed of 7 optical detectors. The first cluster started operation in October 2006. We describe the data acquisition system and present preliminary results from data taken with the first cluster.

Introduction

The elaborate study of the energy range 10^{16} – 10^{18} eV is of crucial importance for understanding of the origin and propagation of cosmic rays in the Galaxy. The maximum energy of cosmic rays, accelerated in SN remnants, seems to be in this energy range [1]. As pointed out in [2], in this energy range the transition from Galactic to extragalactic cosmic rays may occur.The new EAS Cherenkov array under construction in the Tunka Valley (50 km from Lake Baikal), with 1 km^2 area, was named Tunka-133 [3,4]. It will allow to study cosmic rays by covering with a single method uniformly the energy range from 10^{15} to 10^{18} eV. During one year of operation (400 hours) Tunka-133 will record ~$5\cdot10^5$ events with energy above $3\cdot10^{15}$ eV, ~300 events with energy higher than 10^{17} eV and a handful events with energy higher than 10^{18} eV. Tunka Valley is famous for its good weather conditions (especially during winter). Various EAS Cherenkov arrays – from Tunka-4 [5] to Tunka-25 [6,7] – operated at this place.

The new array will be methodically complementary to the "dense" 1 km^2 arrays KASCADE-Grande [8] and IceTop [9].

The Tunka-133 array

The Tunka-133 array will consist of 133 optical detectors on the basis of PMT EMI 9350 (diameter of photocathode 20 cm). The 133 detectors are grouped in 19 clusters, each composed of seven detectors – six hexagonally arranged detectors and one in the center. The distance between the detectors is 85 m. In addition to the Cherenkov detectors, 5-6 Auger-like (S = 10 m^2, depth = 90 cm) water tanks will be constructed for common operation with the Cherenkov array. Two water tanks have been constructed up to now. The optimal distance between the water tanks is under discussion.

An optical detector (fig.1) consists of a metallic cylinder with 50 cm diameter, containing a PMT. The container has a plexiglass window at the top, heated against frost. The angular aperture is defined by the shadowing of PMT. The efficiency is close to 100% up to 30° and reduces to 50% at zenith angles > 45°. The detector is equipped with remotely controlled lid protecting the PMT from sunlight and precipitation. Apart from the PMT with its high voltage supply and the preamplifiers, the detector box contains a light emitting diode for both amplitude and time calibration and the controller. The controller is connected with the cluster electronics via twisted pair by an RS-485 protocol. To provide the necessary dynamic range of 10^4, two analog signals one from anode and another 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 at low temperature (down to –40°C).

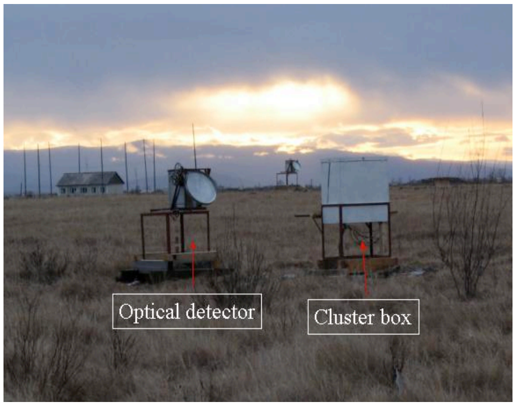

Figure 1: View on optical and cluster detector

The cluster electronics (fig.2) consists of the cluster controller, 4 blocks of four-channel FADCs, an adapter module connecting with optical detector controller and temperature controller. All electronic modules (except the temperature controller) are in VME standard. Each cluster is connected to the DAQ center through a multi-wire cable containing four copper wires and four optical fibers.

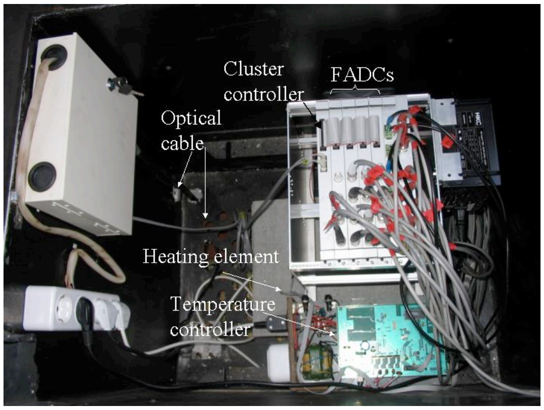

Figure 2: Inside view of cluster box.

The cluster controller contains optical transceiver, synchronization module, local time clock and cluster trigger module. Optical transceivers operating at 1000 MHz are responsible for data transmission and forming of synchronization signals with frequency 100 MHz for cluster clock. The cluster trigger (the local trigger) is formed by the coincidence of at least three pulses from optical detectors above threshold within a time window 0.5 μs. The time of the local trigger is measured by the cluster clock. The accuracy of the time synchronization between different clusters is about 10 ns. The FADC modules are designed on the basis of 12-bit 200 MHz ADCs and XILINX microchip FPGAs.

The temperature controller is used to maintain, with the help of heating elements, the necessary temperature within container. Only when the temperature in the container becomes greater than 15 degrees, the temperature controller switches on power on VME crate.

Preliminary data analysis

The algorithms for detectors calibration and EAS parameters reconstruction used at Tunka-25 experiment have been adapted to the new array geometry. The methods optimized for Tunka-133 data processing will finally provide an accuracy of about 6 m for the core location of ~15% for the energy. We plan to derive the depth of the EAS maximum from the lateral distribution sharpness and the light pulse FWHM with an accuracy better than ~25 g /cm^2.

Of course, we do not reach this accuracy for the data recorded with the first cluster of 7 detectors. The preliminary data basically allow us to check the cluster performance and to estimate threshold and event rate of the array.

The first cluster operated for about 75 hours from November 2006 to January 2007. The trigger condition was the coincidence of at least three detector pulses above 100 p.e. The trigger rate is close to 0.2 Hz.

All the apparatus has demonstrated stable operation during the whole winter. A total of about 16000 events have been recorded during 19 clear moonless nights. 5400 events have been reconstructed inside the cluster area (a circle with 85 m radius) and inside the solid angle limited by a zenith angle of 45°.

The record of every event from every detector forms a row of 1024 instantaneous amplitude measurements with a time step of 5 ns.

After transition through the preamplifier and cable RG-58 of 100 m length pulse has a front duration of about 15 ns and a FWHM of about 18 ns. The processing procedure selects the points from the start of the front to the end of pulse tail. Usually we have more than 7 points for any pulse.

For large core distances (>300 m), the FWHM of a light pulse can vary from 20 ns to more than 100 ns. An example for waveforms from a very distant experimental event is presented in fig.3. The core distance of this shower from the cluster center is estimated as 600±100 m and the energy as (5±2)□10^{17} eV.

We estimate the arrival time of the Cherenkov light by extrapolating the pulse front to the constant fraction of 25% of the maximum pulse amplitude, and the total flux of light in the pulse by integration over the recorded wave form of the pulse.

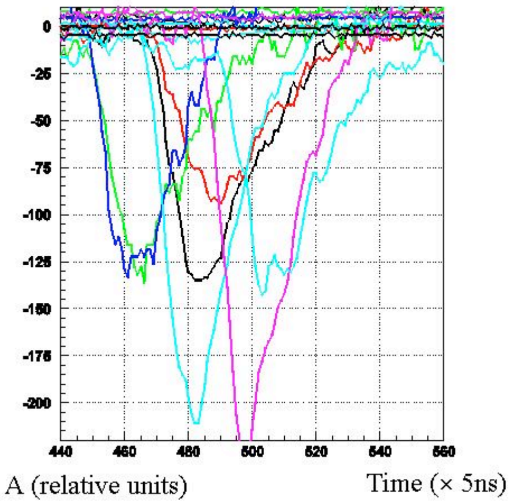

Figure 3: Example of a distant event. Pulses in different detectors are shown in different colors.

An absolute time synchronization of 5 ns has been achieved by equal lengths of all connecting cables. This accuracy was enough for the present preliminary analysis. It will be improved later to an accuracy of about 1 ns.

The relative amplitude calibration was provided by the method of comparison of the density spectra recorded by the different detectors. Usage of this method in previous Tunka experiments was described in [10]. The absolute calibration was done by normalizing the obtained integral energy spectrum to the reference spectrum recorded with the QUEST experiment [11].

The integral energy spectrum of the recorded events is shown in fig. 4. A 100%-efficiency of the array is reached at an energy of about 10^{15} eV. About 350 events have energies above 3□10^{15} eV. This energy is used for comparison with the reference spectrum from the QUEST experiment [11]. The reference point is shown in fig. 4 by the black square. The spectrum is fitted with the different power laws for the energies before and after 3□10^{15} eV.

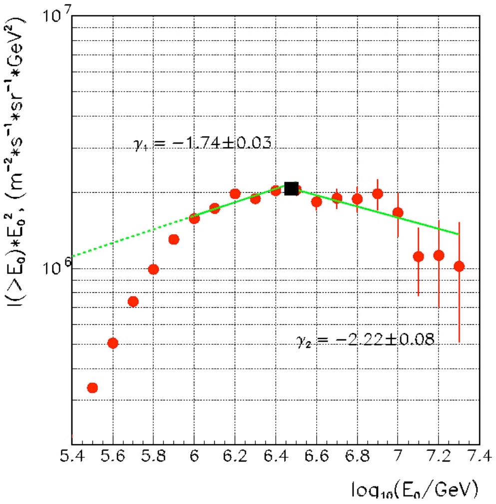

Figure 4: Preliminary integral energy spectrum taken with the first cluster of Tunka-133.

Schedule of the array deployment

- Summer-Autumn 2006 – construction of the building for the central DAQ–system. Deployment of the first cluster (7 optical detectors). Operation of the first cluster during the winter season 2006 – 2007.
- Summer-Autumn 2007 – deployment of optical cables for all clusters and of all cluster boxes. Deployment of 21 optical detectors. Operation of a four-cluster array (Tunka-28) during the winter season 2007-2008.
- Summer-Autumn 2008 – deployment of the main part of optical detectors and the construction of the third water tank. Commissioning of the array and start of operation.
- Summer-Autumn 2009 – deployment of the remaining part of optical detectors and construction of three water tank. Start of operation of the full array.

Conclusion

A 1-km^2 Cherenkov EAS array is under construction in the Siberian Tunka Valley. The first cluster of the array was successfully exploited during the last winter. This proves the appropriate design of all array components. Commissioning of the main part of the array is planed in autumn 2008.

Acknowledgements

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