The Tunka Experiment: Towards a 1-km^2 Cherenkov EAS Array in the Tunka Valley

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The project of an EAS Cherenkov array in the Tunka valley/Siberia with an area of about 1 km^2 is presented. The new array will have a ten times bigger area than the existing Tunka-24 array and will permit a detailed study of the cosmic ray energy spectrum and the mass composition in the energy range from 10^{15} to 10^{18} eV.

1. Introduction

Over the last decade, an impressive set of experimental data in the energy 10^{14}–10^{16} has been collected([1], [2], [3], [4]). They yield a rather consistent picture and confirm the rise in average mass of primary cosmic particles when passing the region of the "knee" at $3 \cdot 10^{15}$ eV. The situation is dramatically different at higher energies. The energy range between 10^{16} and 10^{18} eV has been covered by very few experiments. Our knowledge about mass composition above a few 10^{16} eV is rudimentary. Energy spectra determined by different experiments differ significantly, mostly due to the difficulties in proper energy calibration. To the other hand the region above 10^{16} eV is of crucial importance for understanding of the origin and propagation of cosmic rays in the Galaxy. A careful investigation of this region is mandatory and would answer the following questions:
1. Is there an "iron knee" above the classical knee at $3 \cdot 10^{15}$ eV? The identification of an iron knee could provide a final understanding of this region.
2. What is the mass composition above a possible iron knee? Is this region dominated by the sources different to supernova remnants?
3. What is the nature of the observed "second knee" at $3 - 5 \cdot 10^{17}$ eV? Is it caused by the end of the galactic component?
4. What is the relation between cut-off due to leakage out of the Galaxy and cut-off effects due to maximum energies in sources?
A careful investigation of the region 10^{16} – 10^{18} requires arrays with area ~ 1 km^2 or more, but with with much smaller spacing than that of arrays for ultra-high energies like AGASA, Yakutsk or AUGER.

2. The Tunka-133 array

The most reliable and accurate method of cosmic ray energy measurement in the specified energy range is the method of EAS Cherenkov light observation. A series of such experiments has been carried out in the Tunka Valley (50 km from Lake Baikal) since more than 10 years: Tunka-4 [5], Tunka-13 [6] and Tunka-25 [7].
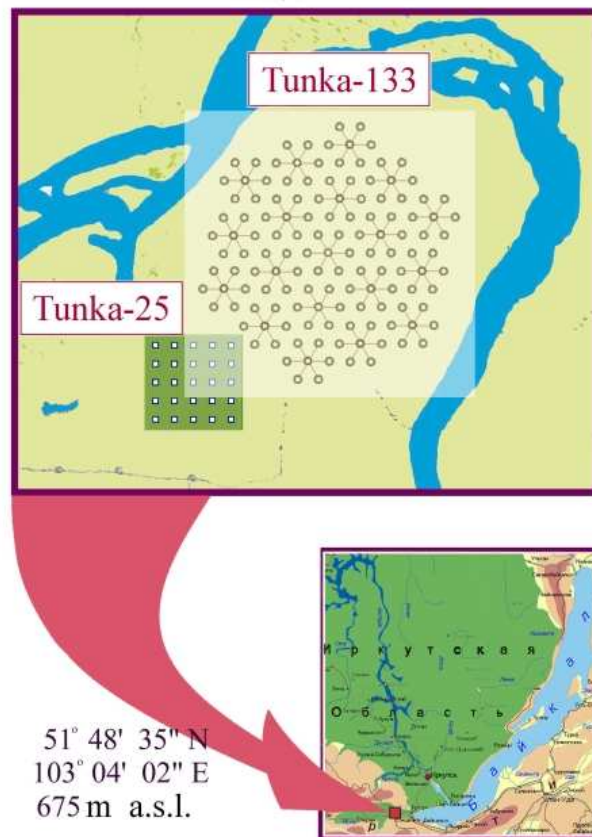
Figure 1. Location of Tunka-25 an the proposed Tunka-133 array.

The latter array consists of 25 detectors on the basis of PMT QUASAR-370 and 4 detectors with pulse shape recording on the basis of PMT Torn-EMI D669. To study charged particles at the surface, an Auger-like water Cherenkov detector was added to the array. The detectors cover an area of $\sim$ 0.1 km^2. The new array Tunka-133 [8] will consist of 133 optical detectors on the basis of PMT EMI 9350 (diameter of photocathode of 20 cm). The plan of the array is shown on fig.1. The 133 detectors are grouped in 19 clusters, each composed of seven detectors. The distance between detectors will be 85 m, similar to Tunka-25. Due to this fact the accuracy of EAS parameter reconstruction will be the same as for Tunka-25 [4]. The accuracy of the core location is $\sim$6 m, that of energy determination $\sim$ 15%. The accuracy of the X$_{max}$ determination (from the lateral disribution sharpness and pulse duration) is $\sim$ 25 g/cm^2.

The construction of Tunka-133 will expand the area of the existing array with energy threshold of $\sim 10^{15}$eV by almost ten times. During one year of operation (400 hours), Tunka-133 will record $\sim 5 \cdot 10^5$ events with energy above $3 \cdot 10^{15}$eV, $\sim$ 300 events with energy higher than 10^{17} eV and a handful events with energy higher than 10^{18} eV.

3.   Technical description

The optical detector will be similar to that of Tunka-25. The angular aperture is defined by the shadowing of the container. It is 20^0 for 100% efficiency and reduces to 50% at zenith angles $> 45^0$. Apart from the PMT, the detector box contains the high voltage supply, the preamplifier, a light emitting diode for both amplitude and time calibration and the control mechanics of the lid protecting the PMT from sunlight and precipitation. To provide the necessary dynamic range (10^4), two analog signals - one of them pre-amplified by a factor 20, the other without amplification - will be transfered to the central electronics hut of each cluster.

The functional scheme of the cluster electronics is shown in fig.2. Each cluster is connected to the DAQ center through a multi-wire cable containing four copper wires and four optical fibres.
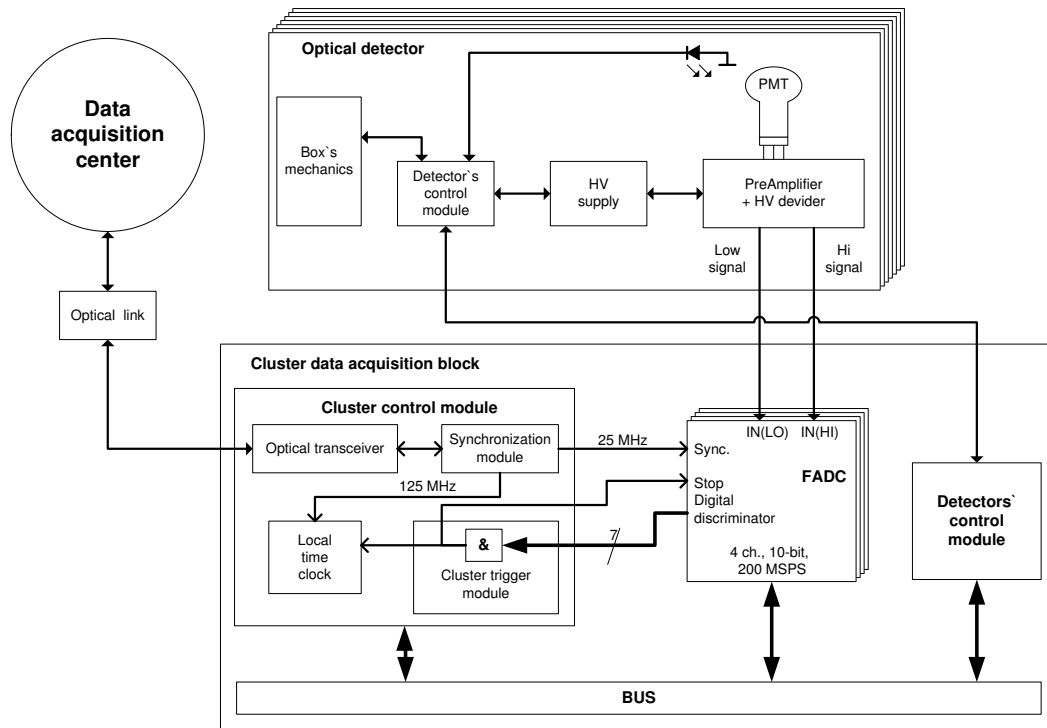

Figure 2. Functional scheme of cluster electronics

The cluster data acquisition block contains optical transceiver, synchronization module, local time clock and cluster trigger module. Optical transceivers operating at 1250 MHz are responsible on data base transmition and forming of synchronization signals on the frequency 125 MHz for cluster clock. A special procedure will be used to measure absolute time shifts between the clock in the DAQ center and the cluster clocks.

The cluster trigger(the local trigger) is formed on the coincidence of pulses above threshold in three optical detectors in a time window of 0.5 μs. The time of local trigger is measured by cluster clock.

Measuring channels are designed on the basis of 10 bit ADC AD9410 and XILINX microchips FPGAs. High-speed ADC with 5 ns step width are used for the pulse shape digitization and allow to discard traditional TDC approaches to determine the arrival time. The ADC output data are writing to cyclic memory. The cluster

trigger starts the readout 256x10 bits (256x5ns $\approx$ 1.2 μs) from each ADC to the buffer memory of cluster control model. A clock freguency 200 MHz is generated from the 25 MHz signals delivered form control model to all measuring boards.

4. Schedule of the array deployment

The cluster electronics with its software is prepared and tested. A test of the first optical detectors and analog electronics in the Tunka valley will be carried out in October 2005.

The first 4 clusters (Tunka-28) will be deployed in the fall of 2006. The test operation of the array will extend over the winter season 2006-2007.

The further installation of array depends on the financial support. In case of sufficient support, the rest of array could be constructed in 2006 and 2007 and installed in Summer/Autumn 2007.

5. Conclusion

A 1-km^2 array in the Tunka valley (Buriatia,Siberia) is planned to record EAS from cosmic rays of super-high energies by their Cherenkov light. It will allow to study cosmic rays by a single method covering uniformly the energy range $10^{15} - 10^{18}$ eV. This includes the classical knee at $\sim 3 \cdot 10^{15}$ eV as well as the second knee at a few 10^{17} eV, allowing to study features of the spectrum probably connected with the transition from galactic to extra-galactic cosmic rays. With this installation we are going to study up to which maximal energy particles in supernova remnants are accelerated and will also provide a low-energy calibration to much larger installations like AUGER.

6. Acknowledgements

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