Complex EAS Array for Super-high Energy Cosmic Ray Research

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Abstract

The project of a new complex array for super-high energy ($> 10^{14}$ eV) cosmic ray research is considered. The new array will be constructed on the basis of the EAS MSU array. It will be modified and extended by new scintillation detectors located at 1–2 km from the center of EAS MSU array. Neutron and Cherenkov detectors will be added to the scintillation detector system.

1. Introduction

The new complex EAS array is designed for high ($> 10^{14}$ eV) and super-high energy cosmic ray researches by means of extensive air shower (EAS) registration.

The main scientific goals of this project are the studies of primary cosmic ray spectrum at energy about $3 \cdot 10^{15}$ eV (the knee region) and at ultra high energy range of 10^{18}–10^{19} eV, the studies of cosmic ray anisotropy and a search for chaotic features in time series of successive EAS arrival time intervals originated in mechanisms of cosmic ray generation and propagation.

The continuous EAS registration will permit to investigate EAS correlations with such astrophysical phenomena as gamma ray bursts, supernova flares and gravitational events registered with the gravitational antenna placed near the array at Sternberg Astronomical Institute of Moscow State University.

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2. Description of the array

The new array will be constructed on the basis of the EAS MSU array [3]. The distinguishing feature of the array is a possibility of the EAS registration as in the moderate energy region $\sim 10^{14}$ eV so in the ultra-high energy region $\sim 10^{18}$ eV. The array consists of several parts, aimed for cosmic ray study in different energy regions on the basis of analysis of different EAS components.

For study of cosmic rays at energies of 10^{14}–10^{17} eV 40 scintillation detectors of 1 m^2 area each will be constructed. These charged particle detectors are combined in three groups: 8 detectors separated by 8–10 m are in the central part of the array (placed in the laboratory building and on its roof); 16 detectors separated by 20 m are near laboratory building (8 detectors are in operation); 16 detectors will be placed at distance $\sim$ 100–120 m from the array center, see Fig. 1. New type of detectors : neutron detector and Cherenkov EAS detector of "camera-obscure" type [2] will be added. Information from all Detector Units (DU) are transmitted to the Intermediate Registration Unit (IRU) placed near the Central Registration Unit (CRU) where the data via a special adapter are transmitted to the computer.

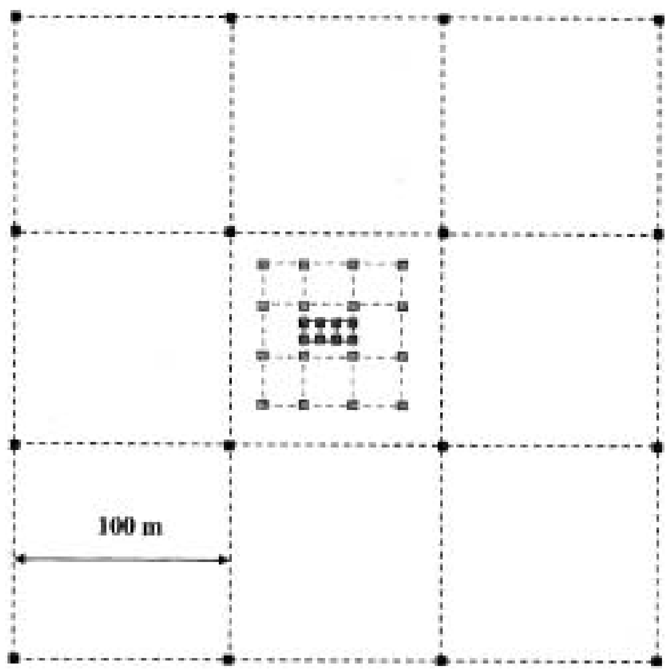

Fig. 1. Geometry of the central part of the array (cluster No 1).

For increase of the array effective area for ultra-high energy cosmic rays (10^{17}–10^{19} eV) the array will be added with several detector groups (clusters) placed at distances of 1–2 km from the central part of the array. Each cluster consists of 16 scintillation detectors of 1 m^2 area and 5 cm thickness located on the orthogonal net with separation of 50–100 m. Each cluster has an own trigger system. A similar cluster has been in operation during several years at the EAS MSU array as the Prototype of EAS–1000 array [1].

Information from all 16 DU is transmitted to IRU computer for analysis of experimental data and for data exchange with CRU computer. GPS-receivers in each clusters are used for time synchronization between clusters.

At the first stage computers of all clusters will be connected by fiberglass cables. In future the array will be extended and new clusters of 4 DP with distance between them of 50–100 m will be added. Cluster separation will be about 1–2 km. At this stage, radio channels will be used for the connection with the CRU. The working out and adjustment of these channels will be done during the running of the first stage of the array.

In perspective, territories of some schools, educational and scientific institutes in Moscow will be available for arrangement of our clusters. So that the total area of the array will grow up to 1000 km^2, necessary for detail study of ultra-high energy cosmic rays with energy $> 10^{20}$ eV. Some clusters may be equipped with special detectors for atmosphere monitoring and radiation control.

3. Estimation of shower count rate

For given geometry the shower count rate was calculated by Monte Carlo method. The shower number spectrum was taken with knee at $N_e \sim 5 \cdot 10^5$ (at the knee the spectrum exponent increases by 0.5). The charged particle lateral distribution function was taken in form of modified NKG–function with dependence of parameter s on a distance from shower axis [4]. The experimental zenith angle distribution of showers was taken into account. The calculation was performed for the 4 trigger-systems for different thresholds of shower primary energy: $\sim 10^{14}$ eV, $\sim 5 \cdot 10^{14}$ eV, $\sim 5 \cdot 10^{15}$ eV and $\sim 5 \cdot 10^{16}$–$5 \cdot 10^{17}$ eV

The area of array with registration effectiveness greater 90% and shower count rate were estimated for all these triggers (Table 1).

4. Estimation of EAS parameter accuracy determination

The accuracy of EAS parameter determination in individual showers is very important in planning of experiments. The main EAS parameters are: EAS size, the particle density at given distance from shower axis for large distances between detectors, the axis position in the array plane, the shower zenith angle and the particle lateral distribution. The central part of the array will be used for registration of small showers with size from $2 \cdot 10^4$ to 10^6. The other clusters will be used for study of showers with size greater 10^6 .

Table 1. Shower count rate for registration probability > 90%.

No	N_e	$\bar{E}_0$	S_{eff}, m^2	$I(>N_e)$ cm^{-2}s^{-1}sr^{-1}	Count rate
1	$10^4 \div 10^5$	$1.5 \cdot 10^{14}$	500	$5 \cdot 10^{-9}$	46 h^{-1}
2	$10^5 \div 10^6$	$1.1 \cdot 10^{15}$	10 000	10^{-10}	133 h^{-1}
3	$10^6 \div 10^7$	$8.2 \cdot 10^{15}$	500 000	$2 \cdot 10^{-12}$	18 h^{-1}
4	$10^7 \div 10^8$	$6.2 \cdot 10^{16}$	1 500 000	$2 \cdot 10^{-14}$	14 day^{-1}
5	$10^8 \div 10^9$	$4.7 \cdot 10^{17}$	3 000 000	$2.5 \cdot 10^{-16}$	11 month^{-1}
6	$> 10^9$	$3.5 \cdot 10^{18}$	4 000 000	$2.5 \cdot 10^{-18}$	2.7 year^{-1}

For showers with rather large particle number we deal with events with responses of detectors in two or more clusters. Here the axis position is at considerable distance from clusters. Event time determination is made with GPS-receivers in each cluster. In this case an inaccuracy in time determination is estimated as 50–100 ns. EAS parameters in events with detector responses only in two clusters are determined with bad accuracy. For detector responses if only in three clusters (particle number $N_e > 5 \cdot 10^8$) the inaccuracy of EAS zenith-angle determination is 2–5° and for axis position—about 50 m. The inaccuracy of particle number is 15–20%.

5. Conclusion

The upgrading of MSU EAS array on the modern technological level will give the possibility for fundamental scientific investigations in the field of super-high energy cosmic rays and in future—in the field of ultra-high energy. The EAS complex will help to improve a training of young scientists for super-high energy cosmic ray study.

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