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Balloon-borne measurements of the CR energy spectrum in the energy range 10–100 PeV.

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Abstract. Preliminary results of the 2000 year measurements using balloon-borne detector SPHERE are presented. Detector was lifted by fastened balloon above snow field to 1km altitude. EAS Cherenkov light reflected from the snow was detected. Some indication of spectrum peculiarity near the energy 3-4$\times 10^{16} eV$ was obtained. The first attempt to estimate the Cherenkov light lateral distribution by means of this new method has been made.

1 Introduction

The aim of experiment SPHERE is study of primary CR energy spectrum structure in the region above $10^{15} eV$. One of the most adequate calorimetric methods of the primary particle energy measurement in this energy region is the full flow of EAS Cherenkov light measurement. Experiment SPHERE is based on the prof. E.A. Chudakov's [A.E.Chudakov(1972)] suggestion to detect the Cherenkov light reflected from the snow surface by means of small device lifted above the surface. Cerenkov light of EAS forms a light spot on a snow-covered surface. SPHERE "makes photo" of this spot. Detector lifted to the altitude H make it possible to have sensitive area $\sim H^2$.

Realization of experiment SPHERE was planned in three stages. At the first stage(see Fig.1), the technique improvement was planned by means of detector lifting to the height $1km$ (the reduction of the energy threshold, study of background events, etc).

At the second stage study of the energy spectrum up to energy $\sim 10^{18} eV$ was planned by means of the device lifting to the height of $3 - 4km$. At the third stage study of the energy spectrum up to above $10^{20} eV$ was planned during long time winter flight around South Pole of a balloon above Antarctica at height $30 \div 40km$.

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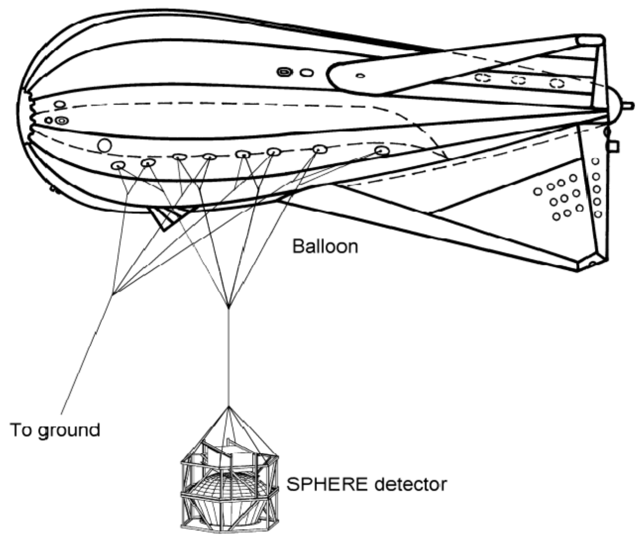

Fig. 1. Experiment configuration (not for scale).

The first measurements of the energy sperctrum in the energy range $10^{16} - 10^{17} eV$ [R.A.Antonov et al.(1997), R.A. Antonov et al.(1999)] were carried out in two sessions of measurements (February 1997 and 1998). Accuracy of measurements was low, mainly because of light pulses caused by particles, crossing the violet filters of the detector. Array was improved and in the present session of measurements, the effect was rejected practically.

2 Technique

The optical part of array consists of a $1.2m$ diameter spherical mirror, the mosaic of 19 photomultipliers (PMT) FEU-110 and Shmidt diaphragm for the image correction. At height of lifting $1km$ each of PMT observed the area in diameter $\sim 200m$. The electronic worked in two modes. In the first the trigger condition - was excess of the given threshold level of PMT pulse amplitude simultaneously in any of two

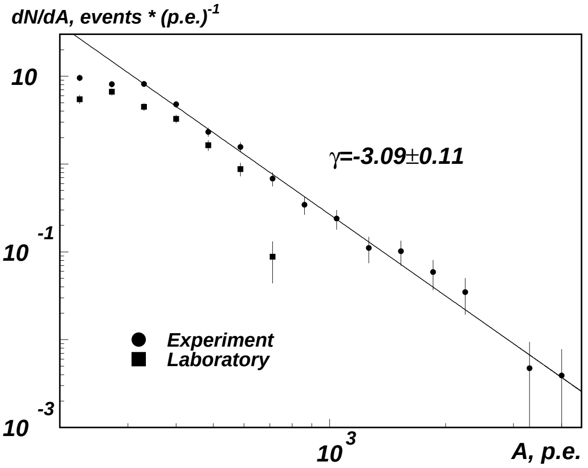

Fig. 2. Differential spectra for experiment (1) and laboratory (2) with an equivalent level of background light.

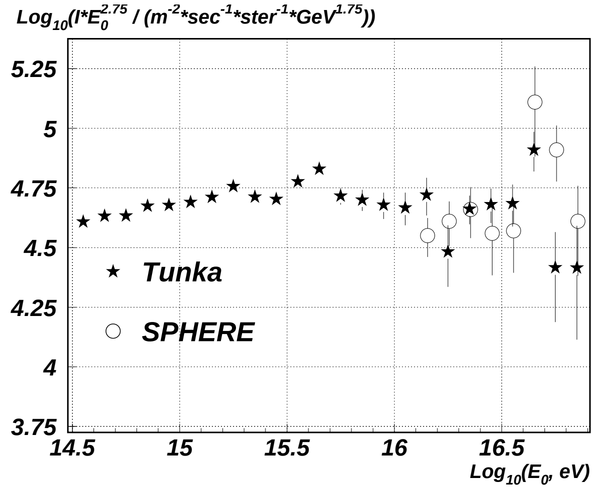

Fig. 3. Energy spectrum primary CR

PMTs (trigger 2), in the second it was enough excess of a threshold in anyone PMT (trigger 1).

The number of the photons inside $2.0\mu s$ strob and the pulse duration with step $30ns$ were registered. Control of electronics was carried out in automatic mode with the help of onboard computer. The setup of PMTs high voltage and threshold levels were carried out automatically in dependency of PMTs currents and rate of the events account.

Threshold levels, PMTs current, voltage of accumulators and temperature inside the container with electronics are periodically supervised. Stability of PMT amplification is supervised by periodic submission through fiber of the light pulses of various intensity from LEDs on each PMT. The data were accumulated on a hard disk of the computer.

3 Results

SPHERE array was lifted to height of $H = 1km$. Full time of measurements was $t = 457$ minutes (164 min. at trigger 1 and 293 min. at trigger 2). The full number of the registered events was, accordingly, 228327 and 102239. The main part of events is caused by the starlight background. Preliminary results of processing show, that in case of triggers used in experiment, the events caused by the star sky practically are completely excluded under condition of duration at least one of pulses exceeding of $30ns$. Fig. 2 shows the spectrum of Cherenkov light pulses selected by such criterion - circles and laboratory spectrum with the same level of light background - squares. The values of the sums of the photoelectrons registered by three photomultipliers with the greatest amplitudes are plased on the X axis. When we select the showers which axes have got in the central part of area observed mosaic (the greatest pulse located in one of seven central PMTs) the transition from the Cherenkov light registered Q to the primary particle energy (E_0) is the most simple:

$$E_0 \sim \frac{Q \cdot 2\pi H^2}{s \cdot K \cdot \eta} ,$$

and differential energy spectrum:

$$I = \frac{\Delta N}{\Delta E} \cdot \frac{1}{\Omega \cdot S \cdot t} , \text{ where}$$

$s = 0.4m^2$ - diaphragm area,

K - light losses (snow surface, PMT's glass, atmosphere, PMTs spaces),

$\eta = 0.18$ - the PMT quantum efficiecy (with shifter),

$\Omega \simeq 1.5sr$ - the effective solid angle for EAS track registered.

$S \simeq 3 \times 10^5 m^2$ - the area observed.

Fig. 3 shows the result such processing in comparison with Tunka experiment [O.A.Gress et al.(1999), O.A.Gress et al.(2001)]. It is no contradiction between these data within the limits of accuracy. One may to see slight hint on the spectrum irregularity.

In this experiment we attempted to start study of the individual EAS parameters (coordinates of an axis, a direction of arrival, the form of function of lateral distribution (LDF) of Cherenkov light). The form of the light stain on PMTs mosaic was used for this purpose (see Fig. 4).

19 events from 44 with energy above $3 \times 10^{16} eV$ were selected which axes have got in the central part of the observed area by SPHERE detector (the seven central PMTs). The direction of arrival, position of EAS axis (x_0, y_0) and form LDF were estimated by minimization method. LDF was accepted as:

$$Q(R) = A\left(1 + \frac{R}{R_0}\right)^{-4.3}$$

where R_0 - parameter, and $R-$ distance from EAS axis. The estimation of accuracy of measured parameters was carried out on the basis of processing of modelled events. For events with energy $\sim 3 \times 10^{16} eV$ sets of 50 events with zenith angles $\theta-$ 8, 35 and 60 degrees were modelled. The value R_0 was accepted equal 200 m. Results of processing are given in the table:

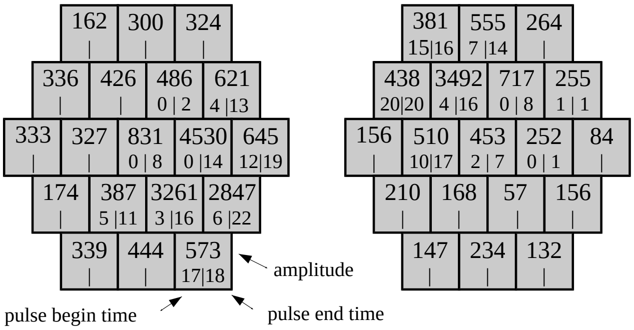

Fig. 4. Example of two registered events. (amplitude in photoelectrons, times in terms of a code $30ns$).

zenith angle, [grad.]	8	35	60
$\sigma\,\theta$, [grad.]	7	7	6
$\sigma\,R_0$, [m]	10	30	40
$\sigma\,(x_0, y_0)$, [m]	5	7	10
$\sigma\,E_0$, [%]	10	10	10

For the events measured in experiment, average value of a zenith angle was 37 degrees and average value $R_0 - 325m$. The form of average LDF, measured in Yakutsk for EAS with zenith angles from 0 up to 30 degrees [M.N.Djakov, et al. (1993)] in this energy range corresponds to $R_0 \simeq 200m$ and R_0 increase with increase of a zenith angle of arrival EAS. So, the received result does not contradict to Yakutsk data.

4 Conclusion

Preliminary processing of the experimental data shows that, as a first approximation, they agree with other experimental data. The further progress in development of this method is connected with the possibility of realization of regular launches of array in more favorable climatic conditions, increase of obseved area and with the further modernization of array. We plan to carry out the next measurements in the Russian Antarctic station Novo-Lazarevskaya. The increase of number of cells in PMTs mosaic up to $\sim$ 100 and an opportunity of measurement in each channel of the form of registered pulses will allow to decrease the energy threshold as a minimum in 3 times, to measure within several degrees the direction of EAS arrival and, in variant of measurements with a fastened balloon, to study LDF of EAS in a wide range of distances from an axis. Long time flight on height of $30 - 40km$ of such array will allow to carry out simultaneous registration Cherenkov and fluorescent light of EAS in the conditions close to orbital and to obtain the data about primary CR in energy range above $10^{20}eV$ [R.A.Antonov et al.(2001)].

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