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Primary Cosmic Ray Spectrum Measured Using Cherenkov Light Reflected from the Snow Surface*

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The experimental data obtained using Cherenkov light of EAS, reflected from the snow surface of the Big Alma–Ata Lake (Kazakhstan) are presented. This method makes it possible to have a large area using a simple compact detector. About 9000 events were detected within 55 hours. The balloon–borne measurements in the energy range 1–10000 PeV are planned.

1. Introduction

The results of recent cosmic ray energy spectrum measurements in the energy range $10^{15} - 10^{19}$ eV do not agree with each other sufficiently well. The actual problem, for this reason, is to carry out further experiments using various methods.

This work is based on the Prof. A.E.Chudakov's suggestion to detect the Cherenkov light reflected from the snow surface [1]. The intensity of light is proportional to the energy of the primary particle. The wide–angle balloon–borne or airborne small detector makes it possible to have a sensitive area up to some hundred km^2. The first unaccomplished attempt of such an experiment was undertaken by G.Navarra et al. [2].

2. Detector Array

SPHERA detector array was elaborated for ballon–borne experiment [3–5]. Fig. 1 shows the scheme of this array. The light spots are detected by 19 photomultipliers (FEU–110) situated on the focal surface of the spherical mirror. The angular aperture is about 50×50^o. Dark violet filters and shifters were used to decrease the influence of the starlight background.

The first measurements were carried out in the Thien–Shan mountains in 1993 (fig. 2). Detector

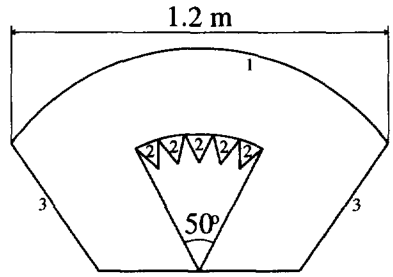

Figure 1. SPHERA optical scheme: 1 – mirror surface, 2 – PMT, 3 – diaphragm

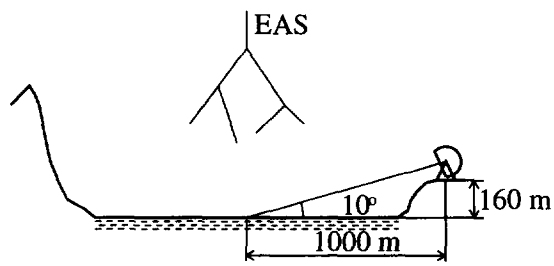

Figure 2. Geometry of experiment on B. Alma–Ata lake.

was situated on the 160 m-high mountain ledge nearby the B.Alma–Ata lake (2500 m above sea level). The area of the lake is ≈ 0.7 km^2. The average inclination angle of the detector opticall axis to the horizon was 10^o. Master condition was — pulse amplitude in one of central PMTs and one neighbour must exceed the threshold. Time stability of the detector and transparency

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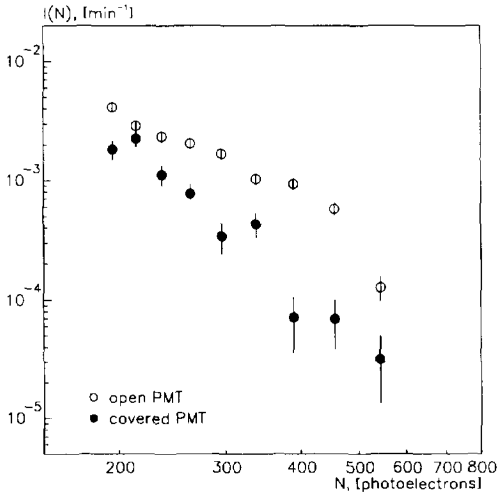

Figure 3. Amplitude spectra of detected events : opened PMT – 4871 events, exposition 1510 min; covered PMT – 1613 events, exposition 956 min.

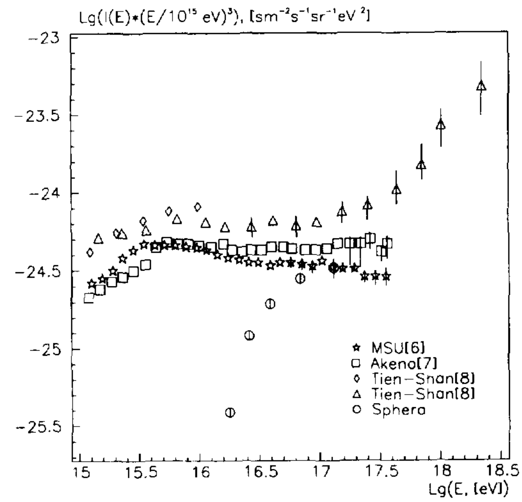

Figure 4. The differential energy spectrum:

of the atmosphere were monitored by the periodical PMTs current measurements and by the EAS counting rate.

3. Data Analysis and Results

The differential spectrum of pulse amplitude total over the four central PMTs is shown in fig. 3. It shows the spectrum for PMTs with the covered photocathodes too. In this case the pulses are caused by Cherenkov light emission in PMT tube and light filter glass of single charged particles.

To obtain energy spectrum it was necessary to take into account that some part of light spot falls outside the lake area. It was necessary to determine effective registration area also. For this two purposes Monte–Carlo simulation was done.

Primary cosmic ray flux at the energy 10^{17} eV obtained in this experiment is in agreement with other experimental data (fig. 4).

Energy threshold in this experiment was determined by the high dead time of the device, not by starlight background.

4. Further measurements

Further measurements will be carried out with fasten balloon. During 1994–95 the detector SPHERA was improved significantly.

The amplitude measurements are complimented by the time analysis of PMT pulses. It will allow us to analyse the detected events more completely.

The trigger rate ability is increased up to 50 Hz by using fast electronics and microcomputer. In balloon–borne experiment the reflected light intensity increases by 10 times according to the Lambert reflection law. This two reasons allow us to decrease energy threshold to $\sim 10^{15}$ eV. The size of detector storage is sufficient to store $\simeq 3.6 \cdot 10^6$ events.

The detector electronics measures the integral of light pulsein PMT, pulse duration and intervals between pulses. The 25-ns discreteness allow to reliably reject events simulated by charged particles in the PM tubes and filter glass. It makes possible to determine the arrival direction of EAS too.

The ground–based test runs of apparatus were carried out in winter 1995–96 under conditions similar to those in flight (low temperatures etc.)

We plan to carry out measurements at altitudes

Table 1
Estimation of EAS witn $E > E_o$ number to be detected by SHERA detector

			fasten balloon	fasten balloon at the South Pole	4 flights of balloon around the South Pole
		H, km	1	10	40
		S, m^2	$\simeq 10^6$	$\simeq 10^8$	$\simeq 1.6 \cdot 10^9$
E_o, eV	$I(> E_o)$, $(m^2 \cdot \text{hour} \cdot \text{sr})^{-1}$	E_{thr},eV	$\simeq 10^{15}$	$\simeq 3 \cdot 10^{16}$	$\simeq 5 \cdot 10^{17}$
		t, hour	$\simeq 100$	$\simeq 2500$	$\simeq 500$ (20 days)
$1 \cdot 10^{15}$	$5 \cdot 10^{-3}$		$1.5 \cdot 10^6$	—	—
$1 \cdot 10^{16}$	$6.5 \cdot 10^{-5}$		$2.0 \cdot 10^4$	$5.0 \cdot 10^7$	—
$1 \cdot 10^{17}$	$6.5 \cdot 10^{-7}$		$2.0 \cdot 10^2$	$5.0 \cdot 10^5$	$1.6 \cdot 10^6$
$1 \cdot 10^{18}$	$6.5 \cdot 10^{-9}$		2.0	$5.0 \cdot 10^3$	$1.6 \cdot 10^4$
$1 \cdot 10^{19}$	$6.5 \cdot 10^{-11}$		—	50	$1.6 \cdot 10^2$
$3 \cdot 10^{19}$	$6.5 \cdot 10^{-12}$		—	5	16

1–3 km above snow surface using the fasten balloon in winter 1996–97. In the future it is desirable to perform the large-scale measurements in the Arctic or Antarctic to detect EAS with energy up to the $\sim 10^{20}$ eV. One such session will be enough to get the amount of data on EAS with $E \geq 10^{19}$ eV comparable with that of Yakytsk array. Table 1 shows the estimated event number to be detected by SPHERA detector for given flight height H and detection time t.

5. Conclusion

The experiment showed that the method of detection of Cherenkov light reflected from the snow surface is appropriate to the cosmic ray energy spectrum measurement. It is possible to have large sensitive area and to measure cosmic ray energy spectrum in wide range of energies ($10^{15} - 10^{20}$ eV) with small wide-angle balloon-borne detector.

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