Antarctic Balloon Measurements of UHE CR (SPHERE Experiment)

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Abstract

The preparations to the measurements of UHE CR on the base of Russian Antarctic Station Novolazarevskaja using detectors SPHERE-1 and SPHERE-2 are fulfilled now.

In this connection Monte-Carlo simulation was applied to estimate the accuracy of reconstruction of the EAS arrival direction and the Cherenkov light lateral distribution measured using the SPHERE-1 and SPHERE-2 balloon borne detectors at a height of 1 km by EAS Cherenkov light reflected from the Earth snowed surface.

1. Introduction

The main experimental problems in the energy range 10^{15} - 10^{18} eV are the possibilities to measure the energy spectrum structure and nuclear composition more exactly. It is important in this connection to have high angular resolving of the EAS arrival direction and to measure the pulse shape of the EAS Cherenlov light lateral distribution sufficiently good.

In June–August, 2003, we schedule to begin a series of measurements of the energy spectrum and the lateral distribution of EAS Cherenkov light in the energy range from 10^{15} to 10^{18} eV, using a novel method, i.e., detection of EAS Cherenkov light reflected from the Earth snowed surface [1]. Measurements will be carried out using the SPHERE-1 balloon borne detector [2,3] and the more sophisticated SPHERE-2 setup developed currently [4,5]. Both optical instruments consist of a spherical mirrors (1.2 m and 1.5 m diameter accordingly), a Schmidt correcting diaphragm, and a mosaic of photomultipliers (19 and 110 accordingly), onto which the image of the scanned surfaces is projected. The total angle of observation is

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52°. The setups will be lifted using an anchored balloon up to a height of 1–3 km. Timing system make it possible to measure time intervals between pulses and time durations of pulses in both detectors. Our estimations show (1 - be published) that in the energy range over 10-30 PeV timing data make it possible to determine the EAS arrival direction with accuracy not worse then 5°.

Therefore, artificial EASs were simulated and processed to determine the accuracy of reconstruction the parameters of experimentally detected showers the shower axis direction, the lateral distribution function of Cherenkov light (LDF), and the total flux of EAS Cherenkov light.

2. Results and Discussion

In the calculations, the basic parameters of the SPHERE-1 and SPHERE-2 were taken as follows. The efficient area of the Schmidt diaphragm is 0.4 and 0.6 m, the number of photomultipliers is 19 and 110, the total angle of a photomultiplier aspect is 10° and 4.06°, the total angle of aspect of the setups is 52°, the time of photoelectron detection by each photomultiplier is 2000 and 200 ns, and the photomultiplier quantum efficiency is 0.18. Arrays of one hundred events were formed for a few values of the total quanta number (Q) of EAS Cherenkov light photons at the sea level in the wavelength range of 300–600 nm and three zenith angles (θ) of the EAS axis. The coordinates of the shower axis crossing with the Earth surface (X_0, Y_0) were simulated uniformly within a circle 1 km diameter. The azimuth angle (φ) of the EAS axis was simulated uniformly in the range from 0 to 360°. The initial LDF form was written as:

$$Q(R) = A \cdot \left(1 + \frac{R}{R_0}\right)^{-4/3}, \, where \, R_0 = 200\, m \tag{1}$$

Such a one-parametric approximation well describes the average LDF measured at the Yakutsk array [6]. According to these data, the LDF at an energy of 50 PeV is described well at $R_0 = 200$m.

We introduced Poisson fluctuation in the number of photoelectrons in each photomultiplier, caused by EAS Cherenkov light and the starry sky background. The latter value in wavelength range of 300–600 nm was taken as $5 \cdot 10^{12} quant \cdot m^{-2} \cdot s^{-1} \cdot sr^{-1}$.

The light reflection losses for snow and mirror were also taken into account. The processing procedure was reduced to searching for the parameters X_0, Y_0, θ, φ, R_0, and Q best approximating the found numbers of photoelectrons, i.e., pulses of each actuated photomultiplier. The value Q is a good measure of the primary particle energy (E).

When processing the detected events, the value equal to one standard deviation from the sky background fluctuation was subtracted from the number of photoelectrons in each photomultiplier and only the data of photomultipliers,

Table 1. Accuracy of reconstructed EAS parameters for SPHERE-1

Initial value Q, [quanta]	10^{12} (E∼30PeV)			10^{13} (E∼300PeV)		
Initial value θ, [degs]	8	37	60	8	37	60
$\sigma(\theta)$, [degs]	5	5	5	4	2	2
$\sigma(\varphi)$, [degs]	5	5	5	5	2	2
$\sigma(R_0)$, [m]	14	26	72	2	5	14
$\sigma(X_0, Y_0)$, [m]	5	8	22	1	2	6
σ(Q)/Q, [%]	7	8	17	5	3	3

Table 2. Accuracy of reconstructed EAS parameters for SPHERE-2

Q, [quanta]	$3 \cdot 10^{11}$ (E∼10PeV)			10^{12} (E∼30PeV)			10^{13} (E∼300PeV)		
Initial value θ, [degs]	8	37	60	8	37	60	8	37	60
$\sigma(\theta)$, [degs]	5	5	4	5	2	2	4	1	1
$\sigma(\varphi)$, [degs]	5	5	5	5	3	2	5	1	1
$\sigma(R_0)$, [m]	7	13	28	3	5	8	1	1	3
$\sigma(X_0, Y_0)$, [m]	2	3	6	1	1	5	1	1	3
σ(Q)/Q, [%]	10	8	15	6	1	6	4	1	2

whose number of photoelectrons exceeded one standard deviation from the sky background fluctuation, were taken into account. The events were processed in two stages. At the first stage, it was supposed that θ, φ are determined from timing data (Poisson distribution was used with standard deviation 5° and mean value equal accepted for artifical EAS). the least-squares method was applied to determine the values X_0, Y_0, as well as (to a first approximation) the values R_0 and Q. Only the events were accepted for processing, where the position of a photomultiplier with the greatest number of detected photoelectrons was not at the mosaic edge.

At the second stage, the least-squares method was applied to determine more accurate values θ, φ, Q and R_0 for the found fixed values X_0, Y_0.

Tables 1 and 2 list the standard deviations (σ) of the reconstructed EAS parameters for the SPHERE-1 and SPHERE-2, respectively.

The calculations carried out show that the X_0, Y_0 and θ, φ determination accuracy for both setups in the energy range above 30 PeV is few meters and few degrees, respectively. The R_0 determination accuracy will allow to analyze the LDF of individual EAS in the energy range above 10 PeV for detector SPHERE-2 and above 30 PeV for detector SPHERE-1.

The calculations [6] shows that it is possible to determine the depth of EAS maximum with accuracy 20 g/cm^2 if we determine R_0 with the accuracy 10 g/cm^2. Such accuracy make it possible to analyse the nuclear composition of the primary cosmic rays.

3. Acknowledgements

The work was supported by the Russian Foundation of Basic Researches (Project 01-02-16080a) and the Federal Program "Russian Universities - Basic Research".

4. References

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