



## Experiment SPHERE-2 status 2007

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**Abstract:** New SPHERE-2 detector basic parameters are described. New calorimetric method is used to study the primary cosmic rays energy spectrum and chemical composition at energy region 10 PeV - 1 EeV. The method is practically independent of the particle interaction model. Results of CORSIKA simulation of detector are presented. Lifted by the tethered balloon to the 1 km altitude detector will detect EAS Cherenkov light reflected from the snow frozen surface of Baikal lake. First measurements are planned to the beginning of 2008.

## Introduction

The main goal of SPHERE-2 experiment on the present stage is an investigation of the primary cosmic ray (CR) energy spectrum and nuclear composition at the energy range  $10^{16} - 10^{18}$  eV. There are serious indications that the main part of CR at this energy range is formed by extragalactic CR. The sharp change of CR nuclear composition must be detected in this case [1].

The experimental data about CR nuclear composition at energies of  $10^{16} - 10^{18}$  eV are rather poor and controversial. One of way to clarify the problem is to study the EAS Cherenkov light (ChL) lateral distribution function (LDF) shape by means of large array of Cherenkov light detectors covered area more then 1 km<sup>2</sup>.

A. E. Chudakov suggested another technique [2]. Small device (photo camera and electron-optic transformer) lifted above the snow-covered surface of the Earth detects the EAS Cherenkov light reflected from the snow. Later R. A. Antonov proposed to use more sensitive and more informative de-

vice (spherical mirror with Shmidt diaphragm and retina of photomultipliers) [3] named SPHERE. The first measurements by means of SPHERE-1 detector were carried out in 1997–2000 years [4, 5, 6, 7, 8, 9]. The improved SPHERE-2 detector creation to be finished this year. The measurements above the Baikal lake snow-covered surface are planned to start next year. The detector will be lifted by the tethered balloon to a height of 1–3 km. The new method of CR composition determination is presented here. The preliminary results of the simulation calculations are discussed. The possibility of the CR mass composition estimation without  $X_{max}$  reconstruction is shown.

## SPHERE-2 detector

The SPHERE-2 detector consists of the 7-segment 1500 mm diameter spherical mirror with 940 mm curvature radius and the retina of 109 photomultipliers (PMT) FEU-84-3. The 930 mm Shmidt diaphragm is installed in front of the mirror to better spatial resolution. The visual angle is equal to

Energy, PeV	Nuclear	Event number	$Q_{total}$		$Q_{0-500}$		$Q_{150}$		$\bar{\eta}$	$\sigma_{\bar{\eta}}$
			$Q/Q_{Fe}$	$\sigma, \%$	$Q/Q_{Fe}$	$\sigma, \%$	$Q/Q_{Fe}$	$\sigma, \%$		
1	$p$	12	1.36	9	1.56	12	1.45	10	3.065	0.474
	$Fe$	10	1	2.2	1	5	1	4	2.062	0.220
10	$p$	13	1.20	4	1.34	6	1.21	5	4.317	0.860
	$N$	33	1.08	2.7	1.12	5	1.09	3	3.173	0.377
	$Fe$	16	1	2.5	1	5	1	3	2.731	0.267

Table 1: Average values and standard deviation of  $Q_{total}$ ,  $Q_{0-500}$  and  $Q_{150}$ , normalized to  $Fe$  nucleus

52 degrees. The device is lifted up to the altitude of 1–3 km by balloon during moonless nights and registers images of EAS light spots on the snow surface. The diameter of surface area observed by each PMT varies from 60 m at 1 km height to 180 m at 3 km.

Light pulse profiles in each channel are detected with 25 ns discreteness. The range of each channel is  $10^4$  due to use of two 10-bit ADCs and two amplifiers with rates 1 and 10. Three (soft master) or seven (hard master) tangent PMT pulses coincidence during  $1 \mu s$  is required for the trigger to start.

### CR composition determination method

One of the SPHERE detector advantages is a capacity for the EAS ChL detection both at immediate vicinity of EAS axis and at large distances from the axis. The new CR composition determination method is based on the analysis of the EAS Cherenkov light lateral distribution function (LDF) shape. As calculations show the slopes of the ChL LDF are remarkable differ for EAS generated by the different primary nuclei.

### Simulation calculations

The main goal of the simulation calculations was to search for ChL measurable characteristics strongly correlated with primary particle energy and mass. The program CORSIKA 6.50 with QGSJET option was used for the simulation calculations.

Protons  $p$ , nitrogen  $N$  and iron  $Fe$  nuclei with energies 1 and 10 PeV EAS were simulated on the first stage. EAS with axes within 20 degrees half-span vertical cone were calculated. The distri-

butions of Cherenkov photons within wave-length range of  $\lambda = 310-650$  nm at the reflection level (Baikal Lake, 455 m above sea level) were stored inside the area  $1200 \times 1200 \text{ m}^2$  with  $2.5 \times 2.5 \text{ m}^2$  squares. The arrival time in each square was divided in 100 cells 5 ns each. The total number of Cherenkov photons, reached reflection level  $Q_{total}$ , were calculated as a sum over all squares.

On the second stage calculated Cherenkov light space-time distributions were used for SPHERE-2 response simulation and for processing in order to restore primary particle parameters. The quantization of the PMT pulses, errors of the electron number reconstruction and starry sky background light fluctuations were not taken into account. The EAS detector image was presented as 109 pulses with 25 ns resolution, calculated for actual device configuration.

### Results

Parameters  $Q_{total}$ , integral of the Cherenkov light LDF in 500 m radius circle  $Q_{0-500}$  or light density at the distance 150 m from shower axis  $Q_{150}$  can be used for the primary particle energy  $E_0$  estimation. The average values and standard deviation of  $Q_{total}$ ,  $Q_{0-500}$  and  $Q_{150}$ , normalized to  $Fe$  nucleus, are shown in the Table 1. It shows that the indefinision of nuclear composition can cause additional error to the primary particle energy  $E_0$  determination from 25% at energy 1 PeV to 15% at energy 10 PeV.

Spectral indexes of ChL LDF can be used as a basic indicator of nuclear number [10].

New method is based on the SPHERE capacity for ChL LDF measurement in wide range of distanses from the EAS axis and provides the possibility of

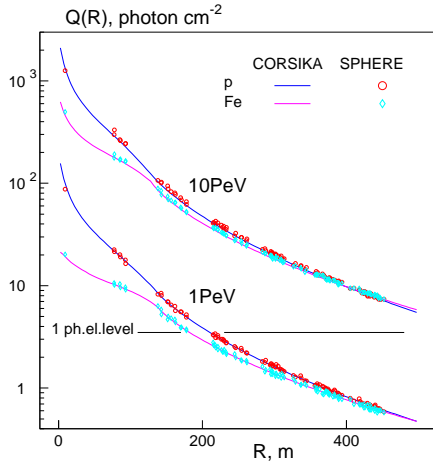


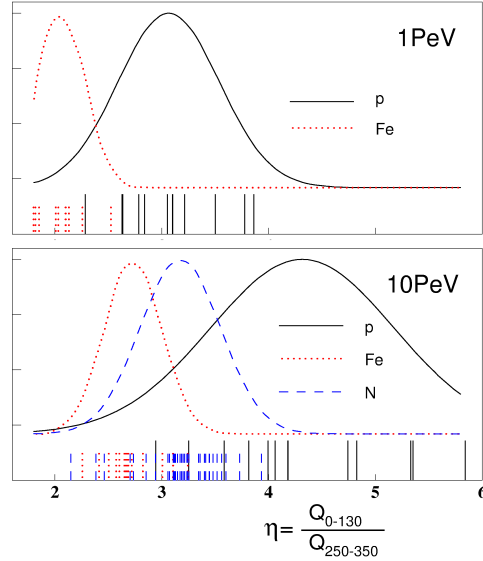
Figure 1: Cherenkov light distribution function

simultaneous primary nuclear energy and kind determination. Fig. 1 shows calculated ChL LDF for  $p$  and  $Fe$  with energies 1 and 10 PeV (curves) and estimations of the ChL densities, derived from the responses of PMT retina cells (circles). Fig. 1 confirms that Cherenkov light densities in centers of retina cell visual fields can be reestablished using integral light signals detected in retina cells. The level of light density corresponding to 1 photoelectron per cell signal is shown on the Fig. 1 too.

The greatest difference between  $p$  and  $Fe$  nuclei LDF takes place at distances 0–130 m and 250–350 m from the EAS axis. The parameter  $\eta = Q_{0-130}/Q_{250-350}$  was chosen to distinguish the nuclei kind.

The Normal  $\eta$  distributions with mean values  $\bar{\eta}$  and dispersions  $\sigma_{\eta}$  of calculated ones for energies 1 and 10 PeV are shown on the Fig. 2. Values of  $\bar{\eta}$  and  $\sigma_{\eta}$  are listed in two last columns of Table 1. Distributions for  $p$  and  $Fe$  showers for fixed  $E_0$  on Fig. 2 intersects only at wings. Real  $\eta$  distributions are more like gamma ones, they have a sharp boundary on the left and exponential tail on the right. Anyway, parameter  $\eta$  allows to distinguish  $p$  and  $Fe$  showers with uncertainty less than 10%.

Fig. 3 shows correlation between  $\eta$  and  $Q_{0-500}$  at three values of  $E_0$ . One can see that boundary value of  $\eta$  between  $p$  and  $Fe$  groups (solid line) depends of  $E_0$  weakly. This calculated boundary curve may be used for separation of  $p$  and  $Fe$  groups in the experiment. Measured parameter

Figure 2:  $\eta$  distributions for energies 1 and 10 PeV

$Q_{0-500}$  indicates an average value of  $E_0$  (averaged for all nuclei),  $p$ -group and  $Fe$ -group are separated by parameter  $\eta$  as on Fig. 2, then the  $E_0$  is defined more exactly taking into account the particle kind.

## Conclusions

There are two different methods to analyse the nuclear composition in SPHERE-2 experiment. The main parameter in the first method is  $X_{max}$  [11]. The main parameter in the second new method of LDF analysis described here is  $\eta = Q_{0-130}/Q_{250-350}$ . It take into account cascade differences of different nuclei better than  $X_{max}$  parameter. Calorimetric integral parameters are used for LDF analysis in the method and it caused the lesser dependence of the model parameters of CORSIKA calculations.

The simulation calculations show that second method can improves the estimation of the CR nuclear composition at energy range  $10^{16} - 10^{18}$  eV. Furthermore perhaps it will give a new possibility to measure the individual energy spectra for distinct nuclei groups.

The devising of new ChL LDF method is at the beginning and all results are substantially preliminary.

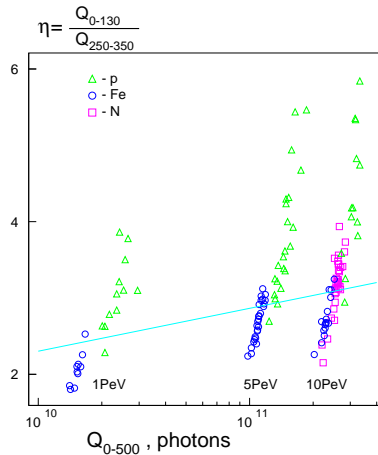


Figure 3: Correlation between  $\eta$  and  $Q_{0-500}$

The measurements at Baikal Lake with SPHERE-2 device are scheduled to start next year and a few expositions sets are planned during 2008–2010 years.

## Acknowledgements

This work is partially supported by the Russian Foundation for Basic Research grant 06–02–16198 and National Programm Neutrino Physics.

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