Status of the SPHERE experiment 2013

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Abstract: Here is presented the current state of the SPHERE balloon-borne experiment. The detector is elevated up to 1 km above the snow surface and registers the reflected Vavilov-Cherenkov radiation of extensive air showers. This method has good sensitivity to the mass composition of the primary cosmic rays due to its high resolution near the shower axis. The detector SPHERE-2 consists of an 1500 mm spherical mirror with a 109 PMT cluster in its focus. The electronics records a signal pulse profile in each PMT. Measurements in 2012 showed high sensitivity of the method to chemical composition of primary cosmic rays. Characteristics for more than 300 events of EAS were reconstructed. In March, 2013 an additional series of measurements for better reliability of results was carried out

Keywords: SPHERE-2, balloon, Lake Baikal, Vavilov-Cherenkov radiation, EAS.

1 Introduction

The SPHERE experiment is based on the method proposed by A.E. Chudakov [1]. The Vavilov-Cherenkov radiation generated by an extensive air shower (EAS) is reflected from the snow surface and is then registered by a detector. The detector is lifted by a tied balloon to the altitude ranging from several hundred meters up to several kilometers [2]. The detector system works like a camera and registers the images of Vavilov-Cherenkov radiation spots produced by EAS. At the altitude of 1 km and below the detector can register the EAS images corresponding to primary cosmic rays with energies about 5 – 500 PeV, at alitudes about 3 kilometers energy range up to 5 EeV is accessible. Current measurements were carried out on Lake Baikal (Figure 1).

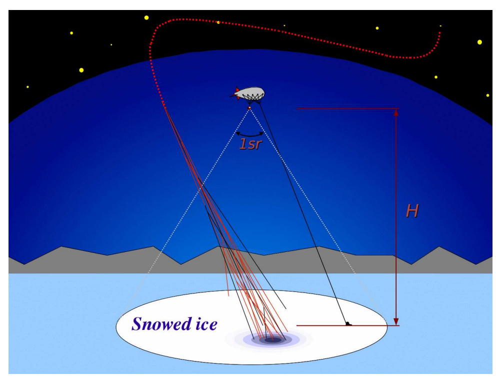

Figure 1: Scheme of the experiment with a tied balloon on Lake Baikal. The surveyed area $S \approx 0.75H^2$

2 The SPHERE-2 detector

The SPHERE-2 detector consisted of an 1500 mm diameter and 940 mm curvature radius seven segment spherical mirror and a mosaic of 109 PMTs FEU-84-3 [3](Figure 2) in the mirror focal plane. PMTs were arranged hexagonally. The diameter of a FEU-83-3 photocathodes sensitive area is 28 mm. For better optical characteristics of the detector the diaphragm was placed in front of the mirror. The detectors field of view was about 1 steradian.

The electronic part of the detector [4] (with modifications [5]) consisted of a data acquisition system (DAQ), trigger system (TS), calibration system (CS) and a control block. DAQ system contains 109 10-bit FADC channels with 12.5 ns steps. The TS allows to detect a Vavilov-Cherenkov radiation spot image on the PMTs mosaic (at least 3 adjacent PMTs have signal above threshold within $1\mu S$ interval). The CS contains 7 UV light emitting diods (LED) that produce independently controlled light pulses onto the mosaic after each EAS event.

3 Expedition of 2013

A new mirror with improved reflection characteristics for Vavilov-Cherenkov radiation was mounted.

In March, 2013 5 launches of a tied balloon with the SPHERE-2 detector to altitudes 400 and 600 meters were carried out. The overall time of exposition was about 30 hours. 3813 triggers were registered, and 459 of them were classified as events caused by Vavilov-Cherenkov light from EAS.

4 Absolute sensitivity of the detector

In order to reconstruct the energy of the primary particle it was necessary to precisely measure the sensitivity of the detector. From Monte-Carlo simulations it is possible to calculate the amount of photons which have reached observation level (snow surface). Further, knowing the properties of the surface, geometrical parameters of the

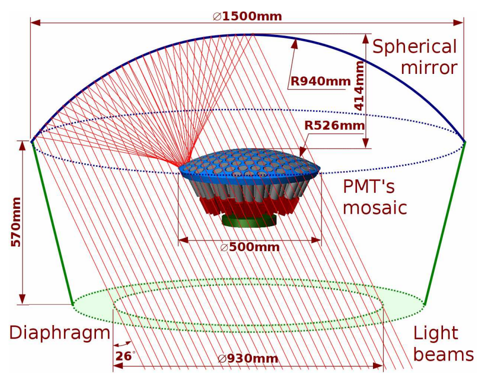

Figure 2: Optical scheme of SPHERE-2 detector.

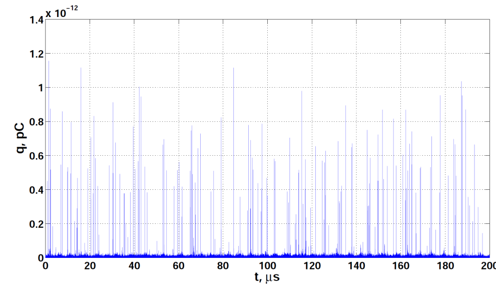

Figure 3: The oscillogram of the charge impulses on the PMT anode collected when lighted by the Hamamatsu L11494-430 light source.

experiment and optical system it is possible to calculate how many photons reached the photocathode of each PMT.

Since the DAQ system measures the charge on PMT's anode in arbitrary units ("code" units, where one unit is equal to approximately 33 fC), it is necessary to determine the amount of photons on the photocathode that corresponds to one code unit in the output. For this a Hamamatsu L11494-430 light source with emission intensity 1.002 pW ($\sim$2 million photons per second) in the HI mode was used [6]. The diameter of the emission area of the light source was 7 mm, the emission peak maximum was at 430 nm, spectral half width was 65 nm and the stability was $\pm 2\%$.

The source worked in the continuous emission mode. To calculate the quantity of photoelectrons 20 oscillograms of the PMT anode signals, each 200μs in length (Figure 3) with 2 Gs/s rate (e.g. 0.5 ns discretization), were registered by external oscilloscope at random timepoints within a 10 minute interval. The single photoelectron peaks can be clearly seen, the minimal distance between two peaks was about 100 ns. From these oscillograms the distribution of charge from a single photoelectron was built (see Figure 4). In the left part of the figure is the omitted noise peak (red crosses), in the center is a single photoelectron peak (black dots) and on the right is the omitted part from particles (red crosses), that were observed even with light source turned off. The blue line on the figure represents Gaussian fit of this peak.

From the fit we have the number of photoelectrons and the average charge on the anode from single photoelectron. The first gives us quantum efficiency of PMT, the second gives us the amplification coefficient of the PMT with given dynodes voltage. The absolute sensitivity of the PMT was calculated as the number of photons in one code unit, e.g. as the product of the quantum efficiency and amplification coefficient of the dynode system. This procedure was done for maximum possible dynode voltage (thus maximum amplification) of the PMT. Then using controlled LED flashed and a second PMT for LED flash intensity control we had measured the absolute sensitivity of the PMT with dynode voltage equal to ones set during EAS registration.

The average value for PMT mosaic was determined to be about 6.5 photons per "code" unit.

4.1 Relative calibration

Absolute sensitivity calibration was carried out for one PMT (Hamamatsu R3886A [7]) placed in the center of the mosaic. The sensitivity of other PMTs (FEU-84-3) was calculated relative to it using the data of relative on-line calibration during EAS registration.

The LED calibration system consisted of 7 FYL-5013VC1C LEDs with a maximum of the emission peak at 405-410 nm and peak width of 15 nm. The duration of the light pulse and emission intensity for each diode was set by the LED control board. The specially developed driver allowed to form light impulses of a correct rectangular shape with a rise and fall time (at 20% and 80%) not more than 15 ns.

Light pulses are transferred from the LED to the PMTs mosaic by seven optical fibers. Optical fibers were fixed in the holes in the mirror at a distance of 414mm from the mosaic. At the ends of optical fibers special diffusers with a known diagram of light dispersion (Lambertian diagram, $I = I_o \cdot \cos\alpha$) were mounted. Optical fibers were also hexagonally arranged (6 around the one in the center) to illuminate all PMTs in the mosaic.

Graphic representations of the registered events similar to the one given in Figure 5 were used for the preliminary analysis. Each pixel on the Figure 5a corresponds to one measurement of the signal in one PMT with a step of 12.5 ns. Color indicates the measured intensity. The picture shows that an event caused by an EAS forms a sine-like curve in such representation. This is due to the numeration of the PMTs in the mosaic. Each subsequent period of the curve in the figure corresponds to signals from PMTs in the same "ring" on the mosaic surface (the first "ring" is formed by PMTs numbers 2 to 8, the second "ring" — 8 to 19 and so on). The time amplitude of the curve correlates with the

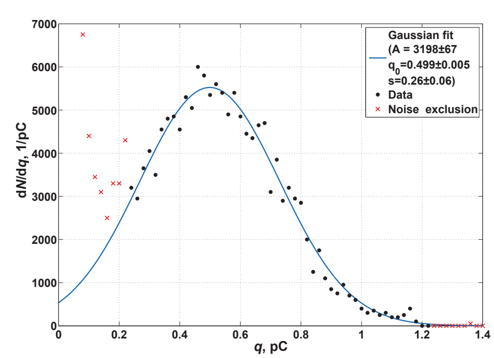

Figure 4: Distribution of the charge collected from the anode produced by one photoelectron. The blue curve presents the Gauss function distribution approximation.

x	x							x						
x	x	x							x					
x	x	x	x							x				
x	x	x	x	x							x			
x	x	x	x	x	x							x		
x	x	x	x	x	x	x							x	
x	x	x	x	x	x	x								x

Table 1: The sequence of flashes of the light-emitting diodes. Duration of each cell — 375 ns.

zenith angle of the EAS axis. Phase shift of the curve reflects the azimuthal angle of the EAS axis in detector coordinates (the angle between the axis projection and a line connecting PMT 1 and PMT 62). The given method of analysis wais used for preliminary event classification (definitive sine-like curve indicates an event, and the absence of such curve indicates noise of any origin) and rough estimations of the EAS parameters. Also this reflected the overall performance of the equipment. At the end of each data frame there was a LED signal for the precise synchronization of the PMT's signals.

After each EAS frame in 6 μs the calibration frame was recorded (e.g. the calibration system generated a sequence of impulses shown in Figure 5b according to Table 1 in 18 μs after the TS signal). Relative sensitivity coefficients were calculated basing on the data from the calibration frame. Linear characteristics for each PMT and for each registered event were determined. Accuracy of the relative calibration for neighboring PMTs reaches a few percent for the whole mosaic.

5 Conclusions

In March, 2013 an expedition dedicated to the registration of cosmic rays in the energy range of about 5 – 500 PeV was carried out successfully.

The absolute sensitivity of the detector was determined using the Hamamatsu L11494-430 light source.

SPHERE-2 has a simple but effective system of on-line LED calibration of the relative sensitivity of the detector mosaic PMTs with an accuracy of up to several percent.

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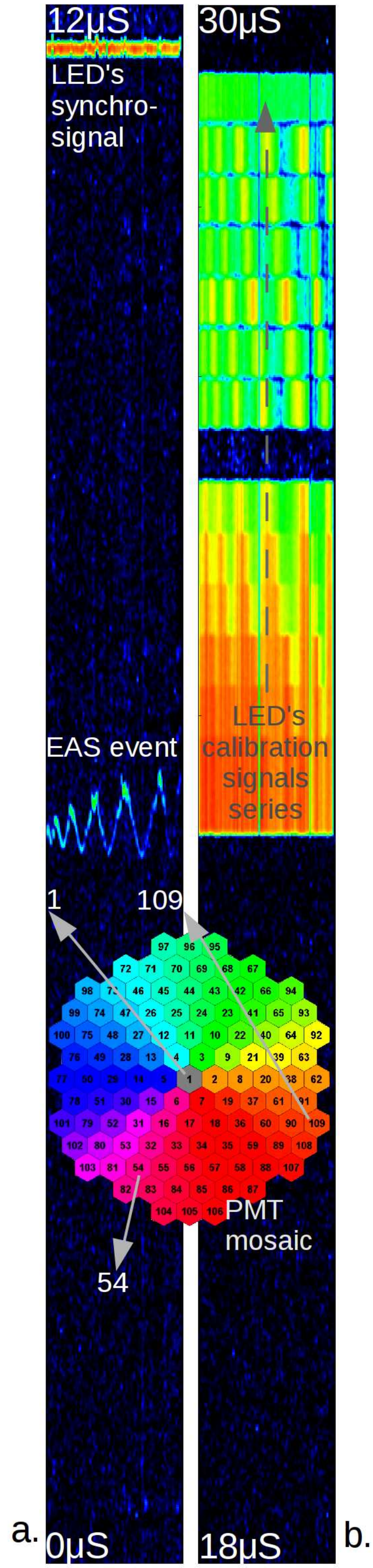

Figure 5: Graphic raw data presentation. The oscillogram for 109 signals of PMT (full event frame), where vertical lines - signals from separate PMTs. The intensity of the signal is shown by color. In *a*. a registered EAS frame and in *b*. the calibration frame are presented.