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ПРОТОТИП ШИРОКОУГОЛЬНОГО ЧЕРЕНКОВСКОГО ТЕЛЕСКОПА И ПРЕДВАРИТЕЛЬНЫЕ РЕЗУЛЬТАТЫ НАБЛЮДЕНИЙ

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PROTOTYPE WIDE-ANGLE CHERENKOV TELESCOPE AND PRELIMINARY OBSERVATIONS

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Представлен принцип работы и предварительные результаты наблюдений широкоугольного черенковского телескопа работающего на совпадение с сцинтилляционными детекторами, интегральными и дифференциальными черенковскими детекторами Якутской комплексной установкой ШАЛ.

Новейшие разработки фотоумножителей дают возможность многократного уменьшения размеров черенковского телескопа при том же самом угловом разрешении, что многократно снижает стоимость такого телескопа, а работа в области энергий 10^{15} эВ компенсирует уменьшение размеров зеркала.

Сигналы с каждого канала многоанодного фотоумножителя непрерывно попадают на предусилители и далее на АЦП и хранятся в буферной памяти (16 мкс) 32-канального промышленного компьютера ОЦЗС-32-250USB. Детально представлены технические характеристики телескопа, а также результаты первых экспериментальных наблюдений.

This report presents the principle of operation and preliminary observations of the wide field-of view (FoV) Cherenkov telescope operating in coincidence with scintillation detectors, integral and differential Cherenkov detectors of Yakutsk complex EAS array.

The latest developments of multiple photomultiplier tubes allows us to reduce the size of the Cherenkov telescope at the same angular resolution, which greatly reduces the final cost of the telescope, and work in 10^{15} eV energy range compensates reduction in the mirror.size.

The signals from multi-anode photomultiplier continuously get to the preamplifier and then to the ADC and stored in the buffer memory (16 μs) of 32-channel industrial PC OCZS-32-250USB.

Specifications of the telescope, and the results of first experimental observations are also presented.

Introduction

The current scenario of CR origin differ on the expected composition in the «knee» range and in the transition region between the galactic and extragalactic components, so the exact estimate of the average mass of the particles / nuclei in addition to the adjusted measurement range of the «knee» and the «ankle» will allow us to discard some scenarios. Interest in the differential Cherenkov light detectors for the study of EAS is due to determine the maximum depth of the cascade curve and the shower age, by means of measuring the shape of the angular and temporal distribution of the Cherenkov signal. The aim of the project was to create a differential detector of Cherenkov light with all-round visibility, allowing to measure the parameters of the cascade development in the atmosphere. The investigation of the galactic component of CR at the Yakutsk EAS array, supplied by the new measurements of atmospheric Cherenkov radiation detector, will provide crucial experimental data to study the source of these particles, their mass composition and distribution of the arrival directions.

Analogs of the Telescope and Advantages Over them

There hasn't been measurement of EAS Cherenkov light, with respect to the angular distribution, up to now, with one exception. The project is based on the idea of creating a small copy of the giant telescopes used in gamma-ray astronomy. The latest developments of photomultiplier tubes (PMT) allows to dramatically reduce the size of the Cherenkov telescope with the same angular resolution, which greatly reduces the final cost of the telescope. The energy work range 10^{16} eV compensate reduction in the size of mirror. For the prototype Cherenkov telescope was selected photomultiplier Hamamatsu R2486 has a coordinate-sensitive anode consisting of 16×16 crossed wires.

Operation algorithm

The wide field-of view (FoV) Cherenkov telescope consists of the spherical mirror and multi-anode PMT as an imaging camera in the focus. Full description of PMT [http://www.hamamatsu.com/].

Data acquisition system (DAQ) includes 32 operational amplifiers and analogue-to-digital converters (ADCs) connected to the industrial PC. To model the focusing of the aluminized spherical mirror in the wavelength interval (300, 600) nm we have used a point source of light placed at infinity, with angle between the line to source and optical axis of the mirror. The image of the point source is calculated on the target plane near the focus of the mirror. The scheme of ray tracing is illustrated in Fig. 1 where the spherical aberration of the point source image is seen on the PMT photocathode surface [Ivanov, 2010; Ivanov, 2013].

Since the photocathode Hamamatsu R2486 radius is equal 3 cm, mirror diameter was chosen equal 26 cm with 22.5 cm radius of curvature. We have found the optimal parameters of the telescope from the viewpoint of providing as wide field of view as possible, but with distortion not exceeding the pixel size d=3.8 mm. As a result, the width of the field of view was $-14 \leq \alpha \leq 14°$. PMT is used as an imaging camera and placed on the focal length in front of a spherical mirror.

In this design telescope provides the effective aperture $D_{\mathrm{eff}}(00)=10.9$ cm due to shadowing of the mirror by the PMT and support. Angular dependence of the telescope aperture is given in Fig. 2. We calculated it through a ratio of the light intensity on the photocathode surface to the initial intensity falling into actual aperture of the telescope, taking into account the reflectance of aluminium, 92.4 %, in the PMT sensitivity interval 300–600 nm. The quality of the optical system is characterized by the spot size, where the spot is an image of the point source at infinity, on the focal plane. We have measured the spot size of the image on the photocathode formed by the laser pointer at 3 m from the telescope. Angular dependence of the spot size is shown in Fig. 3. Its approximately consistent with results of our modeling. Corresponding angular resolution of the telescope is ~1:40 within FoV.

Data Acquisition System

The signals from multichannel photomultiplier continuously get to the preamplifier and then converting by ADC with a sampling frequency of 250 MHz and stored in the buffer memory (16ms) 32-channel industrial PC OCZS-32-250USB (Industrial PC description can be found in [http://www.rudshel.ru/]).

On the arrival of a master signal generated by the Yakutsk EAS array, industrial computer keeps a buffer of accumulated pre-history in a file marked time and assignment of the serial number. Yakutsk EAS array description can be found in [Ivanov, 2007; Ivanov, 2009]. The flowchart of such system is shown in Fig. 4.

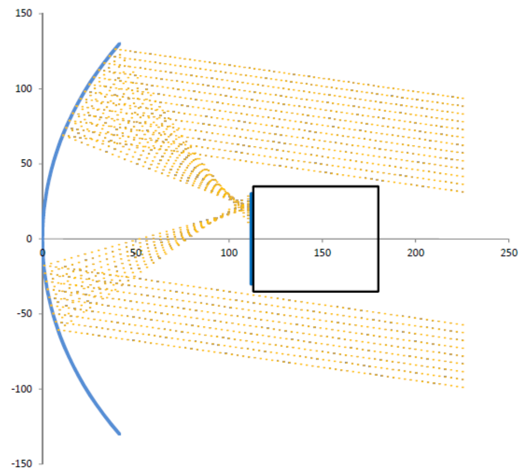

Fig. 1. Modeling rays (yellow points) from a distant point source in the telescope. Blue curves illustrate the mirror and photocathode surface. Black rectangle imitates shadowing by the PMT case.

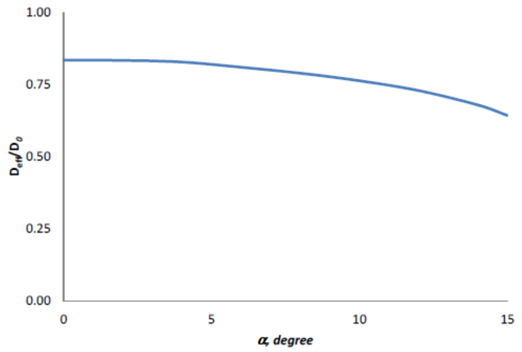

Fig. 2. Shadowing of the mirror by the PMT and support + cables. The ratio of unshielded effective mirror diameter to the actual diameter is given as a function of incidence angle, *a*.

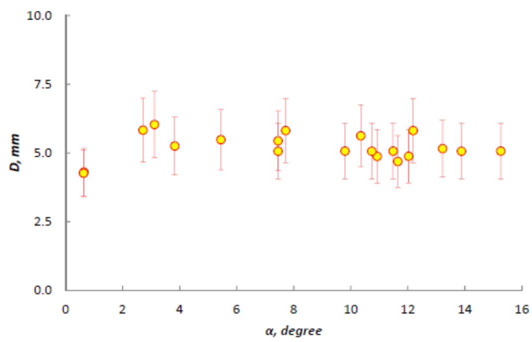

Fig. 3. Fuzzy image diameter of the distant point source on the photocathode surface as a function of incidence angle, *a*.

Preamplifier transmission ratio is compatible with a long fiber line is estimated as 2.9. Measurement of dependence between transmission ratio and the power supply voltage of preamplifier (5, 10 V) are not exceed noise level ±6mV. Measurement of voltage induction between channels of preamplifiers are not exceed ±6mV. Coordinate-dependent sensitivity of the photomultiplier in range from 900 V to 1300 V is shown in Fig. 5 which shows the radial nonuniformity of sensitivity [Ivanov, 2007; Ivanov, 2009]. Also we found that the amplitude of the dark current of the PMT at a voltage less than 1100 V lies within ±6 mV range.

For the telescope was designed external safe box. Currently, the telescope is set at the Yakutsk EAS array, near the station «obscura-3» (500 m from the center of the array), where the telescope has completed field testing.

Preliminary Observation Results

For the telescope was designed external safe box. Currently, the telescope is set at the Yakutsk EAS array, near the station obscura-3 (500 m from the center of the array), where the telescope has completed field testing. Testing took place in winter period 2013. In this period Cherenkov telescope get 11124 EAS master signal, from which 424 gave nonzero simultaneous signal in the telescope. Also, we were able to detect the LIght Detection and Ranging (LIDAR) signal, located at a distance from the Cherenkov telescope (Fig. 6). The distance between the LIDAR and the Cherenkov telescope measured by GPS is equal 490±6 m. Fig. 7 shows the average LIDAR signal for 95 events. In which one can see that the signal amplitude dramatically increases when entering into the aperture of the telescope height ~2 km than reaching a maximum value and attenuation according to the square of the distance. The obtained data indirectly confirms the proper functioning of the Cherenkov telescope as a measuring device.

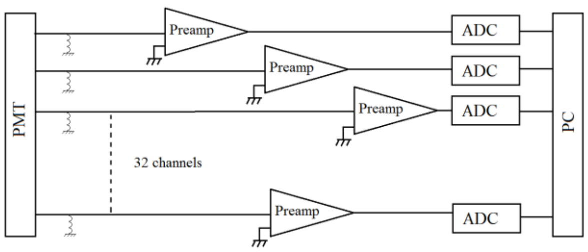

Fig. 4. Data acquisition system flowchart between transmission ratio and the power supply voltage.

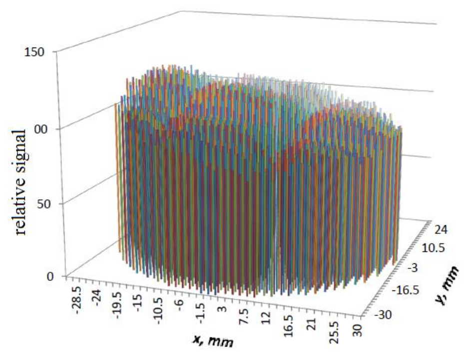

Fig. 5. Normalized coordinate-dependent sensitivity of the photomultiplier.

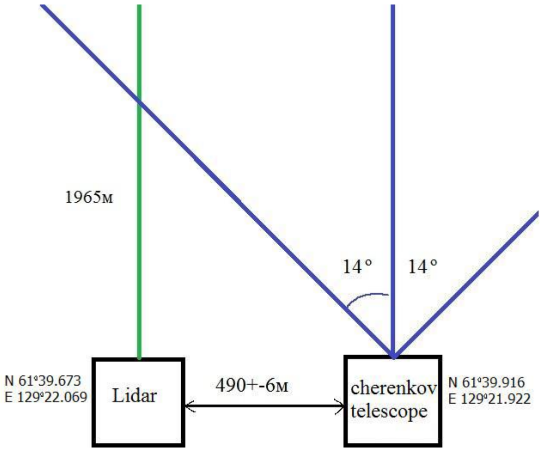

Fig. 6. LIDAR signal entering into the aperture of the telescope flowchart.

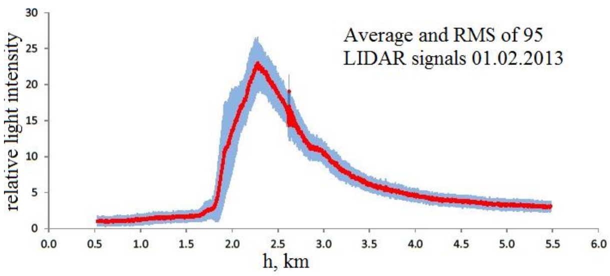

Fig. 7. Average and RMS of 95 LIDAR signals 01.02.2013.

Conclusion

We have developed and built an experimental prototype of a wide FoV Cherenkov telescope working in collaboration with scintillation detectors, integral and differential Cherenkov detectors of the Yakutsk EAS. Cherenkov telescope successfully completed field testing in the period from 19.10.2012 to 11.04.2013 we had 604 hours of clear moonless nights, 11124 EAS events detected with scintillator subset of the array, from which 424 gave non-zero simultaneous signal in the telescope. Analyzing this experimental data can sufficiently exceed possibilities of Yakutsk EAS array to determine the parameters of galactic cosmic rays.

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