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SHORT COMMUNICATIONS

Development of the GAMMA-400 Gamma-Ray Telescope to Record Cosmic Gamma Rays with Energies up to 1 TeV

V. L. Ginzburg[1], V. A. Kaplin[2], A. I. Karakash[2], L. V. Kurnosova[1, †], A. G. Labenskii[1], M. F. Runtso[2], A. P. Soldatov[3], N. P. Topchiev[1], M. I. Fradkin[1], S. K. Chernichenko[3], and I. V. Shein[3]

[1] *Lebedev Physical Institute, Russian Academy of Sciences, Leninskii pr. 53, Moscow, 119991 Russia*
[2] *Moscow Engineering Physics Institute, Kashirskoe sh. 31, Moscow, 115409 Russia*
[3] *Institute of High-Energy Physics, Protvino, Moscow oblast, 142284 Russia*

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Detection of gamma radiation of space origin gives unique opportunities to study the processes occurring on distant astronomical objects at high and superhigh energies. Direct measurements of cosmic gamma rays have been carried out only up to energies of 30–50 GeV. At the same time, there is a reason to think that measurements in the higher energy range (up to 1 TeV) will enable us to obtain information on a number of problems which are not yet solved. In particular, in order to construct a model of high-energy gamma-ray generation, observation data about the form of the spectrum of diffuse gamma radiation are required. The information about the spectra of discrete sources would allow us to understand the specific character of high-energy gamma-ray generation in them. The issue of the day in modern astrophysics is the problem of nature of the "dark matter" in the Galaxy and in the Universe as a whole. It is supposed in one of the most popular models that "dark matter" is formed by particles (neutralinos) not yet found, whose existence and properties are predicted by the theory of supersymmetry. During annihilation of two neutralinos, the emission of two monoenergetic gamma rays with energy exceeding a few hundred GeV occurs. Detection of such gamma-ray lines will confirm, on the one hand, the correctness of the theory of supersymmetry, and on the other hand, will advance us in solving the problem of the "dark matter" nature.

The GAMMA-400 gamma-ray telescope is developed to measure directly gamma rays in the energy range of 30–1000 GeV onboard a spacecraft [1–2].

Structure of the GAMMA-400 gamma-ray telescope. The GAMMA-400 gamma-ray telescope (Fig. 1) is formed by the system of detectors, which records particles and determines the nature of particles having passed through it, and by a device for energy measurement, scintillation calorimeter (SC). There are two detection systems located on two SC ends in order to increase the telescope geometric factor. Every detection system consists of an anticoincidence detector (AC), lead converter (C), scintillators (upper SU and lower SL) recording conversion products and triggering the time-of-flight system that determines the direction of particle incidence, and the system of coordinate detectors (CD).

The anticoincidence detector (AC) enables one to single out gamma rays on the background of charged particle flux. Note that measurements at energies higher than a few hundred GeV are accompanied by the appearance of back-scattered particles, which are capable to imitate a primary charged particle passing through the anticoincidence detector, thus excluding from recording a real gamma-ray passed through the telescope. In the GAMMA-400 gamma-ray telescope, the identification of such events is realized by the comparison of signal appearance times in detectors AC and SU.

The important elements of the gamma-ray telescope are the coordinate detection and calorimeter, some parameters of which were determined by simulations and measurements.

The GAMMA-400 gamma-ray telescope calorimeter. The GAMMA-400 gamma-ray telescope calorimeter is assembled from modules, each of which measures energy released in it, and the total particle energy is determined as a sum of measurements in all modules. The single module has dimensions $110 \times 110 \times 411$ mm^3 and represents serial (sampling) structure from the three-layer package (forming elements), each of which consists of a layer of lead (0.55-mm thick), scintillator, and light-reflecting material. On the plane of the forming element, there are holes made for putting there wavelength shifter (WLS) fibers. Each

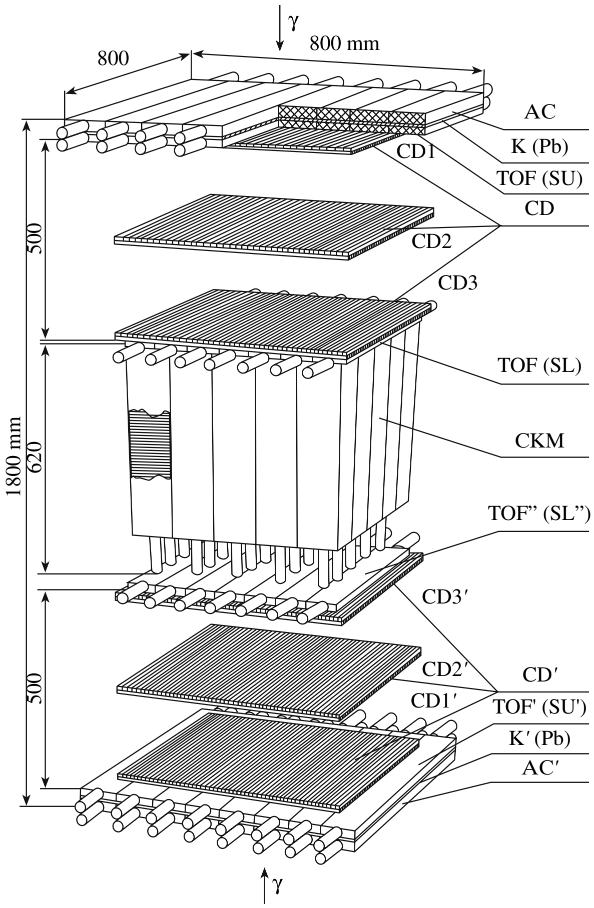

Fig. 1

Table

Gamma-ray energy, GeV	Energy resolution, %	Detection efficiency, %
100	2.08 ± 0.1	75
200	2.09 ± 0.1	82
300	2.49 ± 0.2	89
500	2.54 ± 0.2	95
700	2.42 ± 0.2	93
1000	2.54 ± 0.2	99

module contains 180 forming elements (total thickness is 18 radiation lengths). Scintillation light generated in a scintillator by charged particles of a shower, is transmitted to photoreceiver FEU-115M with the help of WLS fibers BSF-91A of 1-mm diameter.

Measurements of cosmic-ray particles recorded by SC on the Earth's surface, were performed on the SC prototype assembled from 9 modules. Signal distributions from all 9 module outputs of the prototype were taken. The comparison of the data for various modules of the prototype indicates the identity of their characteristics, which allows us to sum reacords of all modules without any corrections.

Simulations of energy resolution of the sampling calorimeter were also carried out. The results of simulations for the calorimeter with 180 layers are presented in Table. Simulations have shown that the energy resolution of the calorimeter with a thickness of more than 180 layers at $E_\gamma = 1000$ GeV is better than 2.5%.

At present, preparations are made for measurements of cosmic gamma-ray spectrum on the Earth's surface with the use of SC.

The GAMMA-400 gamma-ray telescope coordinate detector system. To determine the direction of incidence of recorded primary charged particles and gamma rays there are three two-layer planes of coordinate detectors in the structure of every detecting system. Every detecting layer is assembled from rectangular scintillators with cross section 20×20 mm^2 so that in two layers of one coordinate plane the long axes of scintillators are oriented mutually perpendicular, which allows us to determine two coordinates of the point of intersection of corresponding plane by a particle and to reconstruct its trajectory. Scintillation light arising, when particle passes through the detector, is collected by WLS fibers and transported to the input of SiPM photoreceiver.

Measurements of some characteristics of the coordinate detector were carried out. In particular, the dependence of signal amplitude on the place of particle passage was measured. The results are shown in Fig. 2 (the spectrum, when there are no signals from SiPM, "pedestal", is also presented there). The spectra corresponding to particle detection at three indicated points differ from each other a little. By this it is demonstrated that attenuation of the scintillation light in the detector is small, and its role, when WLS fibers and SiPM are used, is significantly less than in the case of application of vacuum photomultipliers. The developed method can be successfully used when creating the coordinate system. This coordinate system allows us to determine the angle of incidence of a single particle in the telescope with an accuracy of up to ±2°, which is enough for measurements of diffuse cosmic gamma-ray fluxes.

The application of solid-state SiPM and WLS fibers instead of vacuum photomultipliers will allow us to cre-

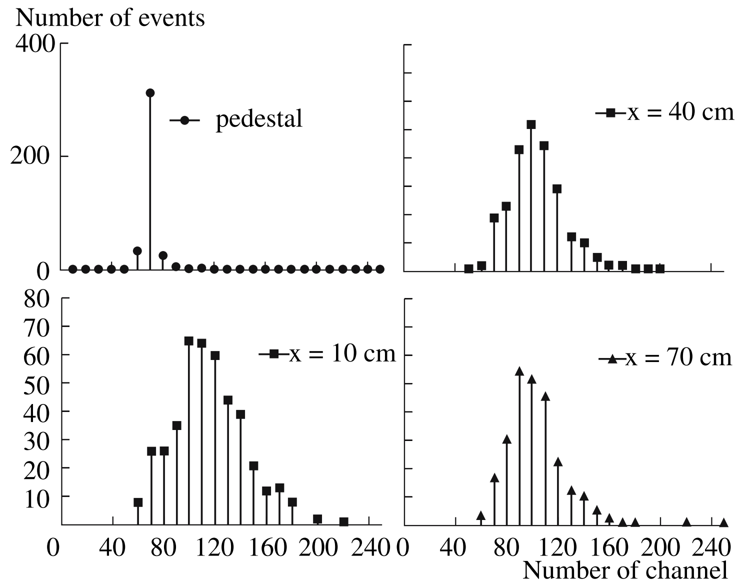

Fig. 2

ate a compact, light, energy efficient, and rather low cost coordinate system, which is essential when realizing spacecraft measurements. The results of measurements and simulations suggest that the developed method is adequate to the problem of investigation of cosmic gamma radiation at energies up to 1 TeV.

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