PROCEEDINGS OF SCIENCE

Search for diffuse gamma radiation with energy > 100 TeV at the Carpet-3 experiment

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An experiment for measuring the flux of gamma rays of cosmic origin with energy above 100 TeV (the Carpet-3 experiment) is currently being prepared at the Baksan Neutrino Observatory. The experimental setup suggests substantial increase of the areas of both muon detector and surface air shower array. We present some results of calculations of selection efficiency of air showers from primary gamma rays for different configurations of the array. It is demonstrated that by increasing the muon detector area up to 615 m^2 (the maximum possible value) one can reach with the Carpet-3 the world-best sensitivity to 100 TeV gamma rays. The preliminary values of upper limits on the flux of cosmic diffuse gamma rays with energy higher than 930 TeV are also presented, derived from experimental data of the Carpet-2 shower array for a net exposure time of 9.2 years.

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1. Introduction

To measure the flux and spectrum of diffuse 100 TeV cosmic gamma rays is of great importance for solving the problem of cosmic ray origin, one of central problems in high energy astrophysics. Unlike ordinary cosmic rays (protons and nuclei of heavier elements), which are charged particles deflected in interstellar magnetic fields, primary gamma rays give information about spatial distribution of places where cosmic rays are accelerated and about their characteristics, as well as about cosmic ray density in the interstellar space. Studying diffuse gamma-ray emission with energies higher than 100 TeV has become especially topical due to detection of astrophysical neutrinos in the IceCube experiment. If these neutrinos are a result of decays of charged pions, neutral pions of the same energy should exist, and their decays must generate considerable flux of gamma rays with energies above 100 TeV. In order to confirm these expectations, one should carry out new high-precision experiments in this energy range [1].

Search for primary gamma rays of energies higher than 100 TeV using the extensive air shower (EAS) method started in 1960s. A lot of experiments were made in this line of research until the present time, different types of detectors and different methods of isolating showers produced by primary gamma rays being used. One can apply the EAS detection method to studies of the diffuse gamma ray emission of cosmic origin, if there is a way of efficient separation of showers produced by primary photons from EAS generated by primary protons and nuclei. Such a separation is possible due to the fact that showers from primary photons are essentially less abundant with hadrons (and, as a result, they are muon-poor) in comparison with showers from primary protons and nuclei. Thus, if one selects muon-poor EAS, theoretically, it is possible to separate the showers initiated by primary gamma rays with reliable efficiency.

Maze and Zawadski were the first who put forward the idea of searching for high-energy gamma rays by way of detecting muon-poor showers [2]. The results of experiments made later at Mt. Chakaltaya [3], Tien Shan [4], Yakutsk [5], and Lodz [6] were interpreted by their authors as detections of gamma ray showers in the energy range $10^{14} - 5 \cdot 10^{17}$ eV. It should be noted, however, that these results had low statistical significance, and at a later time their statements were not confirmed. In subsequent experiments made by collaborations EAS-TOP [7], CASA-MIA [8], and KASCADE [9] primary gamma rays were searched for in the energy range $3 \cdot 10^{14} - 5 \cdot 10^{16}$ eV. For energies above 10^{18} eV the search for gamma rays was performed by the air shower arrays Haverah Park [10], AGASA [11-13], Yakutsk [14, 15], Pierre Auger [16, 17], and Telescope Array [18]. In all these experiments only upper limits on the flux were obtained, and they appeared to be much lower than those fluxes of diffused cosmic gamma rays that were reported to be measured in earlier papers. In the Moscow State University experiment [19, 20] showers from primary gammas in the energy range $5 \cdot 10^{15} - 2 \cdot 10^{17}$ were searched for by the method of selection of muon-poor showers. Upper limits on the flux of diffuse gamma rays were derived for the entire energy range under study, with the exception of narrow region $5 \cdot 10^{16} - 10^{17}$ eV, where the number of muonless showers significantly exceeded their expected background number. This made it possible to estimate the flux of diffuse gamma rays with such energies. But the KASCADE-Grande experiment [21] derived for the same range of primary energies only upper limits on the flux of diffuse gamma rays, in contradiction with the MSU results. It should be noted, however, that the full-scale reanalysis of the MSU data with modern simulations of the installation does not confirm previous indications of the excess of gamma-ray candidate events. So, the final results of the MSU experiment are also only upper limits on the flux of diffuse gamma rays in the energy range of $\sim (10^{16} - 10^{17.5})$ eV [22, 23].

2. Experiment Carpet-2

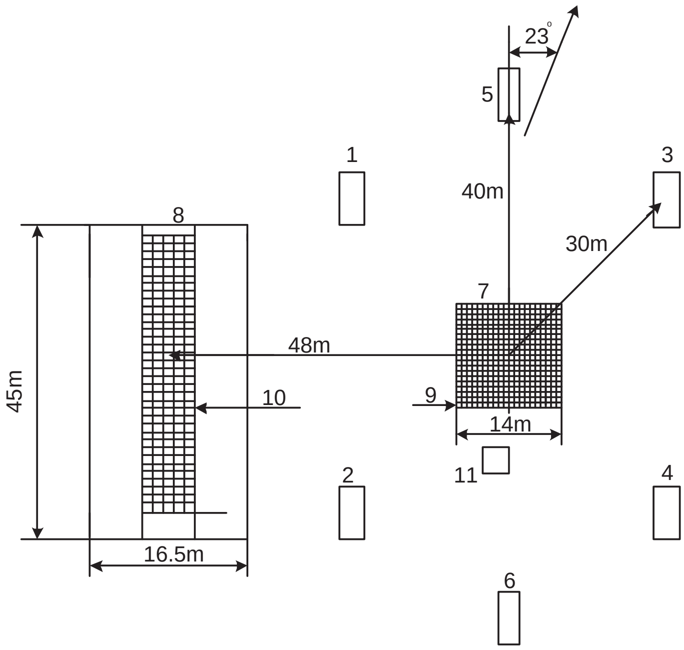

Figure 1: A schematic view of the "Carpet-2". 1-6 - outside points, 7 - "Carpet", 8 - muon detector, 9 - liquid scintillator detector, 10 - plastic detector, 11 - neutron monitor.

The Carpet-2 air shower array [24] of the Baksan Neutrino Observatory is located in the North Caucasus region near Mount Elbrus at an altitude of 1700 m above see level (atmospheric depth 840 g/cm^2) (fig. 1). The geomagnetic cutoff rigidity corresponds to 5.6 GV. The array consists of a ground level detector called the Carpet (200 m^2), six outdoor huts with 9 m^2 of scintillation detectors in each, an underground muon detector and a neutron monitor. The Carpet consists of 400 liquid scintillation detectors, each of 0.5 m^2 area. The range of energy release measured by a single detector is 10-5000 relativistic particles (r.p). One r.p. is the most probable energy release produced by a cosmic ray particle crossing the detector, and it equals 50 MeV. Six outdoor huts have 18 scintillator detectors of the same type. Four of them are placed in the form a square at a distance of 30 m from the array center. The signals from these detectors are used as stopping pulses for the time measurement system to measure delays and reconstruct the arrival direction. The Carpet can measure the shower parameters with a good accuracy: Δx = Δy = 0.35 m, $\Delta N_e/N_e$ = 0.1 in the EAS size interval $N_e = 10^5 - 5 \cdot 10^6$. The MD is located at a distance of 48 m from the array center; it is arranged in an underground tunnel at a depth of 500 g/cm^2, which corresponds to the energy threshold of 1 GeV. The muon detector (MD) is an extended plane with dimensions 5$\times$ 35 m, and it consists of 175 plastic scintillation counters of 1 m^2 area each that are attached to the ceiling of the underground tunnel. Two triggers of the Carpet array and the proper MD

trigger formed by the coincidence scheme upon the actuation of any three out of five MD modules are used to record information. The Carpet and MD operate independent of each other and have different dead times of recording electronics. But time markers of events in the MD and Carpet are produced by one and the same clock, so that coincident events are reliably identified within a time interval $\Delta t = 1$ ms. The total number of relativistic particles within the Carpet ($N_{r.p.}$) and the number of muons recorded by the MD are experimentally measured quantities used to determine the energy of EAS and the total number of muons in it, respectively. The events satisfying the following conditions are included into processing:
1) shower axes are located to be well within the Carpet;
2) shower zenith angles $\theta < 40^{\circ}$;
3) the total energy release in the Carpet is $\geq 10^4$ r. p.;
4) the number of detectors of the Carpet exceeding a threshold of 10 r.p. is ≥ 300.
After such a selection, the number of showers, detected in the period from 1999 to 2011 and survived this procedure, is equal to $1.3 \cdot 10^5$. The net time of data accumulation is 3390 days ($\approx$ 9.2 years). The CORSIKA code v. 6720 (models QGSJET01C and FLUKA 2006 for high and low energies, respectively) was used for shower simulation [25]. In total, 5400 showers from primary protons with energies in the interval (0.316 – 31.6) PeV were simulated, and 815 showers from primary gamma rays with energies (0.3 – 9) PeV. As a result of this modeling for primary protons and gamma rays, the energy dependence of N_e was determined, as well as n_μ as a function of E_0 and N_e.

In order to distinguish showers from primary gamma rays against the background of ordinary showers, the analysis of correlated dependence in the $n_\mu - N_e$ plane of detected and simulated events has been carried out. To estimate the efficiency of isolating the gamma-ray showers at each N_e, the areas are selected on the plane $n_\mu - N_e$, where only simulated showers are present, and there are no really detected EAS. The efficiency of gamma-ray showers detection is defined as the ratio of the number of simulated showers in each region to their total number. Based on the fact that there are no detected events in the selected region (i.e., no background exists), the upper limits for the flux of diffuse cosmic gamma rays with energies $E_\gamma \geq 9.3 \cdot 10^{14}$ eV ($N_e \geq 6.0 \cdot 10^5$), $E_\gamma \geq 1.4 \cdot 10^{15}$ eV ($N_e \geq 10^6$), $E_\gamma \geq 2.2 \cdot 10^{15}$ eV ($N_e \geq 5 \cdot 10^6$) were obtained. Figure 2 presents the upper limits on the integral flux of cosmic diffuse gamma rays obtained in our experiment as functions of primary photon energy together with the results of other experiments.

3. Experiment Carpet-3

Preparation of this experiment suggests step by step increase of the continuous area of the MD, first up to 410 m^2 and then up to 615 m^2. In order to increase the detection area for EAS axes, 20 modules will be additionally installed with 9 scintillation counters in each, the area of a counter being equal to 0.92 m^2 (figure 3). At the moment, 410 plastic scintillation counters are installed in the MD underground tunnels (total continuous area 410 m^2), and they are fully supplied with electronic circuits. The work on equipment checkout and adjustment of electronics of scintillation counters is in progress, as well as design of the data acquisition system for the given configuration of the MD.

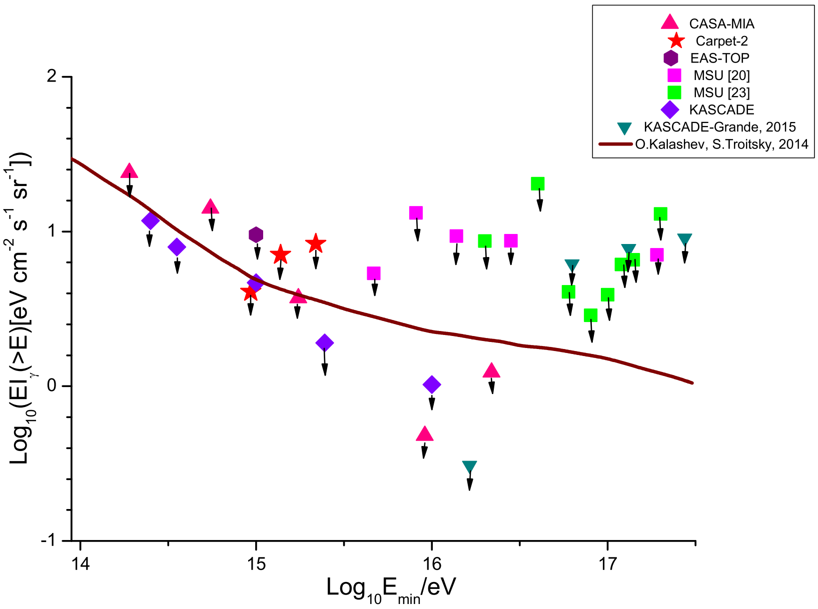

Figure 2: Limits on the integral flux of gamma rays versus their energy.

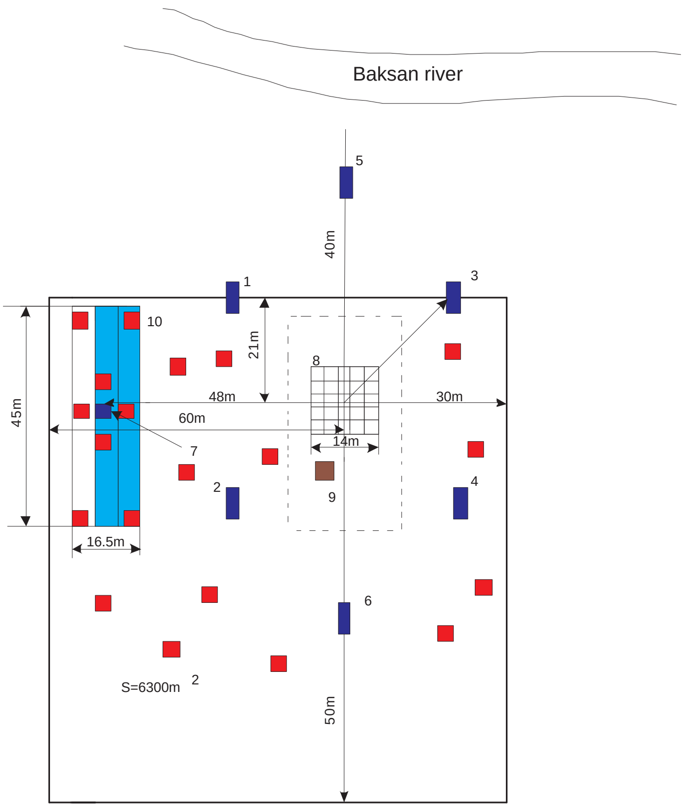

Figure 3: Layout of the Carpet-3 air shower array: 1-7 are the outdoor huts with scintillators, 8 is the Carpet, 9 is neutron monitor, and 10 is the muon detector, red squares represent new modules with scintillation detectors.

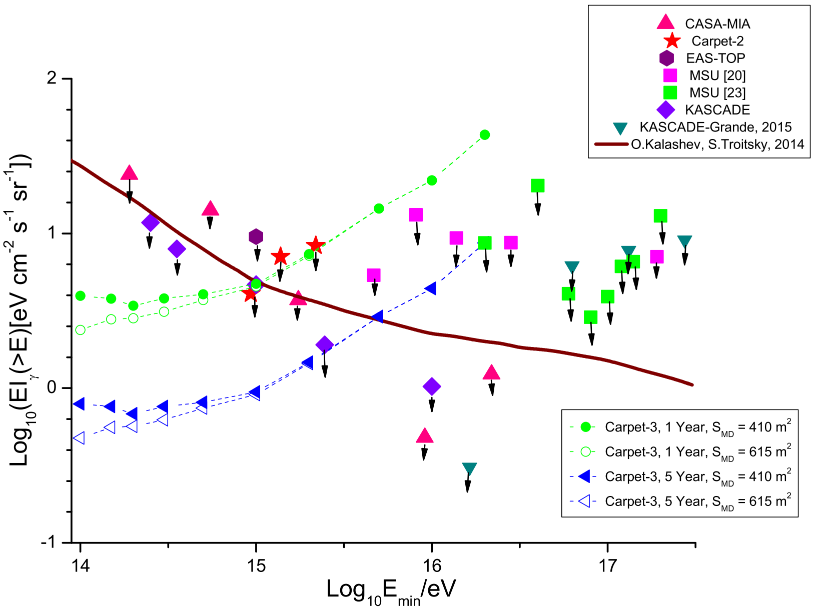

Figure 4: Limits on the integral flux of gamma rays versus their energy and sensitivity of the Carpet-3 air shower array.

The efficiency of selection of gamma rays and sensitivity to the showers from primary gamma rays were calculated for different configurations of the array. Figure 4 presents expected limits on the flux of cosmic diffuse gamma rays for two configurations of the Carpet-3 array and for two values of the time of data accumulation. One can see that even at the MD area of 410 m^2 the new array will have the world-best sensitivity to the flux of primary gamma rays with energies in the range 100 TeV – 1 PeV.

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