Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: D D Dzhappuev *et al* 2017 *J. Phys.: Conf. Ser.* **934** 012022

IOP Conf. Series: Journal of Physics: Conf. Series **934** (2017) 012022 doi:10.1088/1742-6596/934/1/012022

The "Carpet-3" air shower array to search for diffuse gamma rays with energy E_γ>100TeV

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Abstract. At present an experiment for measuring the flux of cosmic diffuse gamma rays with energy higher than 100 TeV (experiment "Carpet-3") is being prepared at the Baksan Neutrino Observatory of the Institute for Nuclear Research, Russian Academy of Sciences. The preparation of the experiment implies considerable enlargement of the area of both muon detector and surface part of the shower array. At the moment the plastic scintillation counters with a total continuous area of 410 m^2 are installed in the muon detector (MD) underground tunnels, and they are totally equipped with electronics. Adjusting of the counters and their electronic circuits is in progress. Six modules of shower detectors (out of twenty planned to be installed) have already been placed on the surface of the MD absorber. A new liquid scintillation detector is developed for modules of the ground –surface part of the array, whose characteristics are presented. It is shown that the "Carpet-3" air shower array will have the best sensitivity to the flux of primary gamma rays with energies in the range 100TeV – 1PeV, being quite competitive in gamma-ray astronomy at such energies.

1. Introduction

The interest to search of primary gamma rays with energies higher than 100 TeV has recently greatly increased in connection with the results of the IceCube experiment, where high energy neutrinos of astrophysical origin were found. In [1] it was suggested that such neutrinos are a result of decays of charge pions in the Galaxy. If so, the neutral pions of the same energy should exist, whose decays produce a considerable flux of gamma rays in the energy range 10^{14} - $5{\cdot}10^{17}$ eV. Investigation of diffuse gamma radiation at such energies is carried out by the EAS method in experiments in which one can separate the showers from primary protons and nuclei. Such a separation is possible due to the fact that showers produced by primary photons are essentially less abundant with hadrons (and, as result, they are muon-poor) in comparison with showers from primary protons and nuclei. Thus, if one selects hadron poor or muon –poor EAS, there is a hope to effectively distinguish between the showers produced by primary gamma rays and by nuclei. The "Carpet-3" multipurpose shower array which is constructed in the Baksan Neutrino Observatory of INR of RAS, already has the muon detector of an area of 410m^2 with possibility of increasing this area up to 615m^2. For increasing an area of detection for axes of EAS ground-surface modules of scintillation detectors will additionally be placed around

IOP Conf. Series: Journal of Physics: Conf. Series **934** (2017) 012022 doi:10.1088/1742-6596/934/1/012022

the “Carpet”. The preliminary estimates show that the new array will has the best sensitivity to the flux of primary gamma rays with energy in region 100TeV-1PeV [2-3].

2. ”Carpet-3” array

The “Carpet-3” air shower array (Fig.1) is created on the bases of operating “Carpet-2” array. The Carpet-2 shower array of the Baksan Neutrino Observatory is located in the North Caucasus region near Mount Elbrus at an altitude of 1700m above see level (the atmospheric depth 840 g/cm^2) (Fig.1). Its coordinates are 43°25′N and 42°40′E, the respective vertical cutoff magnetic rigidity being 5.6 GV.

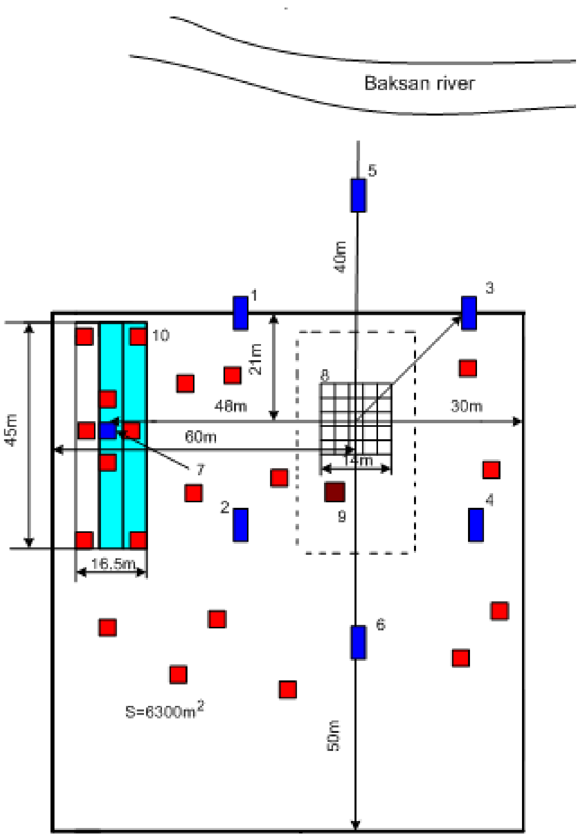

Figure 1. Layout of the “Carpet-3” air shower array: 1-7 are the outdoor huts with scintillators, 8 is the “Carpet”, 9 is neutron monitor, 10 is the muon detector and red squares show new modules with scintillation detectors.

The “Carpet-3”array consists of a ground level detector called the “Carpet”, six outdoor huts with 9m^{2}of scintillation detectors in each, an underground muon detector and neutron monitor. The twenty modules with liquid scintillation detectors (Fig1, red squares) will be installed on the ground around the “Carpet” array. At present six modules without scintillation detectors are installed on the surface above the MD absorber. The “Carpet” consists of 400 liquid scintillation detectors 0.7×0.7×0.3 m in size each, placed in the form of continuous square that has the side length of 14m and, accordingly, the total area of 196m^2 [4]. The measured range of energy release values in an individual liquid detector of the “Carpet” is 10-5000 relativistic particles (r.p.), where 1 r.p. is the most probable energy release produced by a cosmic ray particle crossing the detector, and it equals 50 MeV. Six outer stations (1-6 in Fig.1) intended for determining shower arrival directions are placed around the central part of the array. Four of them are positioned at a distance of 30m in such a way that square geometry is formed.

The remaining two are situated at a distance of 40m from the geometric center of the array. Each outer station has dimensions of 2.1×4.2 m and contains 18 liquid scintillation detectors, which are similar to those used in the "Carpet". The muon detector is arranged at a distance of 48m from the central part of the array; it is situated in underground tunnel at a depth of 500g/cm^2, which corresponds to the energy threshold of 1GeV[5]. The accuracy of determination of coordinates of EAS axes hitting the "Carpet" is no worse than 0.7m, while the arrival direction of showers are measured with an accuracy of better than ~ 3^o.
The MD is an extended plane 5×35 m in size and it consists of 175 standard scintillation counters of 1m^2 area in each that are attached to the ceiling of the underground hall. Each counter comprises four plastic scintillators of size 0.5×0.5×0.05 m placed in a light proof casing. The plastic scintillators are viewed by FEU-49 PM tubes with 12 dynodes. The energy release upon the passage of one relativistic particle through the detector corresponds to about 280 photoelectrons. PM tubes are arranged in groups, five modules, each including 35 detectors.
A signal from the 12th dynode is recorded by a RC logarithmic converter with a threshold of 0.5Aμ generating a standard variable-duration signal delivered to hodoscope. The RC converter used is an amplitude logarithmic encoder whose performance relies on charging a C capacitor with a pulsed current from PM tubes and on its exponential discharge through a resistor R. The converter time constant τ=RC is 1μs. The filling of a converter signal with pulses of frequency 10 MHz ensures a 10% precision of respective measurements. The energy release values measured by the converter lie in the range between 6 and 20000 MeV. Two triggers of the "Carpet-3" array and the proper MD trigger developed by the coincidence scheme upon the actuation of any three of five MD modules are used to record information from the detectors. The view of the second tunnel of MD with the plastic detectors is presented in Fig.2.

Figure 2. First stage of the Muon Detector, 175m2, in operation since 1999.

Preparation of the experiment suggested that continuous area of MD should be increased at first up to 410m^2 and then up to 615m^2 .In order to enlarge the detection area for EAS axes, additional 20 modules are to be installed, each including 18 liquid scintillation detectors of area of 0.5 m^2 each. At the present stage 410 scintillation counters with total continuous area of 410m^2 are installed in the MD underground tunnels, and they are totally equipped with electronics. The work on adjusting the electronics of scintillation counters and on constructing data acquisition system for the given configuration of MD is in progress. On the surface MD absorber six modules for scintillation counters are installed. They are made of heat-insulated material and supplied with heating elements. In each module the detectors will be installed in three rows and under each one three 200 W heating elements will be placed. The total power of heating elements for a module is 1.8 kW. The electric scheme of thermostatic system will provide stabilization of temperature for detectors at a level of ±0.25°C all the year round, which ensures stabilization of signals from new detectors at a level of 0.1%.

3. The new liquid scintillation detector for modules of “Carpet-3” shower array

For twenty modules of “Carpet-3” shower array a new liquid scintillation detector has been designed (Fig.3). The detector represents a container with dimensions 66x74x30cm, made from veneer with a thickness of 10mm. AT the bottom of the container 10 plastic bottles are placed. The plastic bottles with dimensions 14×14×31 cm each are filled with liquid scintillator using as a solvent the jet engine fuel T-6 with a density 0.82g/cm^3.The inner surface of the container is covered either by white paint (in one case) or by aluminium foil (in another) in order to choose the detector with the best light collection. The amplitudes spectra, taken with the digital oscilloscope LeCroy WaveJet , are shown in Fig.4. The high voltage for a detector is U=-1700V.

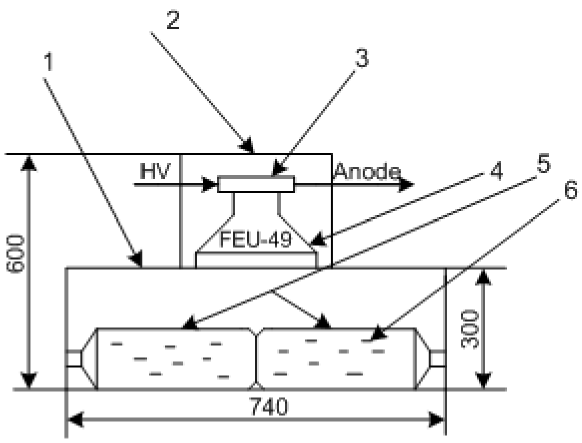

Figure 3. Scheme of the new liquid scintillation detector: 1 – container from veneer, 2 – light protective coat, 3 – divider of high voltage, 4 – PM tube FEU-49, 5 – plastic bottle, 6 – liquid scintillator.

As is seen in fig.4 the maximums of the first and second spectra correspond, respectively, to 8.5mv and 12.5 mV. This means that in the second case the efficiency of light collection is by 32% higher than in the first case. Hence, it follows that it is better to use for the new detector the inner surface covered by aluminium foil.

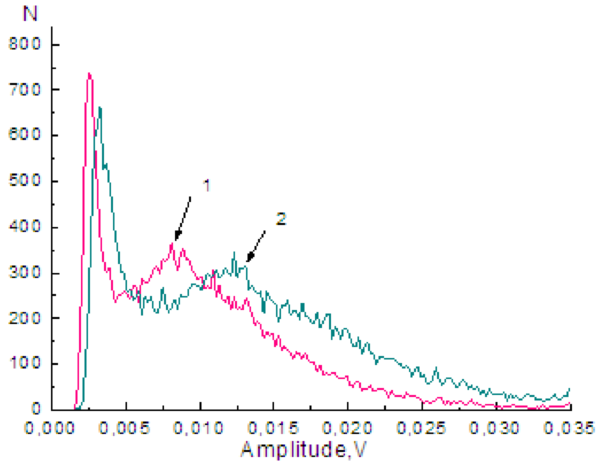

Figure 4. Comparison of amplitude spectra for single muons obtained for the new detector when coating its inner surface with 1 – white paint, 2 – aluminum foil.

The following characteristics were obtained for the new liquid scintillator detector:

- The amplitude of the anode signal is equal to12mV;
- Inhomogeneity of light collection of the detector is27%;
- The total number of photoelectrons at the photocathode is 360;
- Energy resolution equals 45%.

In addition, the cost of the new detector will be several times lower than that of the standard plastic scintillation detector, which is used in the MD of the “Carpet-3” air shower array.

4. Conclusion

Many years ago the experiment aimed at searching for local sources of gamma rays with energy higher than 100 TeV was made with the “Carpet” air shower array of the Baksan Neutrino Observatory of INR of RAS. A burst of gamma radiation with energy $E\gamma \geq 100$ TeV was detected from Crab Nebula [6], while for such possible sources of gamma rays as Cyg X-3, Her X-1, Cyg X-1, Geminga, and 4U115+63 the flux upper limits were obtained. The typical upper limit of the flux for them was $I_\gamma=(1-5)\times 10^{-14}$ $[cm^{-2}\times s^{-1}]$ [7]. After that the “Carpet” array was seriously modernized (the“Carpet-2” experiment). Now the new version of gamma - ray astronomy experiment is dedicated to searching for diffuse cosmic gamma ray emission. The “Carpet-3” array will have greatly increased area of the MD and enlarged area of surface detectors. This work is now in progress. A new type of liquid scintillation detector is designed to be used in modules of the “Carpet-3” array in order to increase the area of location of shower axes, thereby increasing the statistics of detected events and decreasing the energy threshold for primary cosmic radiation

Acknowledgments
The work was supported by the Russian Foundation for Basic Research, project numbers 16-02-0687-a and 16-29-13049.

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