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Search for TeV gamma rays from GRBs at Baksan Underground Scintillation Telescope

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It is possible to register the GRB radiation by detecting secondary muons. The response of the Baksan Underground Scintillation Telescope (BUST) was calculated using CORSIKA Monte Carlo code and it was shown that the BUST is able to detect muons from primary gamma rays of TeV energies and above. The study was performed by searching for short transients in the muon intensity using data of the BUST collected during 2001-2004 yrs. We discuss the method and the results obtained both in sky survey and in correlation with satellite events. The observed fluctuations in the event rate obtained in the sky survey are compatible with the statistical fluctuations of the cosmic ray background. 33 GRBs reported in GCN Circulars with locked coordinates occurred in the field of view of the BUST. In the search for events coinciding with the satellite data no significant signals have been observed.

1. Introduction

Since publication of the EGRET's results [1] the efforts to search for VHE γ-radiation have been intensified. Many EAS installations such as Tibet, INCA, EAS-TOP and Milagro [2-5] were used in search for GRBs. The possibility to register γ-radiation from GRBs at energy $E_\gamma \geq 1$ TeV by detecting muons was discussed by J. Alvarez-Muñiz and F. Halzen [6]. Registration of muon bursts caused by space γ - radiation bursts was carried out at the Baksan Underground Scintillation Telescope (BUST). The BUST is located at Baksan Valley (1900 m altitude, 43.3ºN, 42.7ºE). The BUST was created to solve a set of various tasks (namely, measurement of atmospheric neutrino flux from the bottom hemisphere, anisotropy of CR with energy $\sim 10^{12}$ eV, angular distribution of muons and their interactions with substance, underground registration of muon groups, etc.) which determined its design and location. The telescope as a whole and its separate units were repeatedly as to specific physical problems [7]. During a long period of its operation (since November, 7, 1977) the telescope was modernized several times). The BUST is located under a slope of Andyrchy mountain in an underground excavation of 24x24x16 m^3 dimensions and at a distance of 550 m from the main entrance into the horizontal gallery. The effective thickness of the ground is 850 gg/cm^2. The BUST is a four-level building with 16.7 m, 16.7 m and 11.1 m. dimensions. Thickness of its walls and floors is equal to 0.8 m (≈160 g/cm^2). Distance between the floors is equal to 3.6 m. Six external and two internal planes of the telescope are all entirely covered with standard scintillation detectors. Full number of detectors in the telescope is 3150. Standard detector represents the aluminum container with a size of 0.7m x 0.7m x 0.3m. The container is filled with liquid scintillator. The detector is viewed by one PMT, its photocathode diameter is 150 mm. The most probable energy loss from relativistic particle is about 50 MeV. The threshold energy of muons is $E_\mu \approx 220$ GeV.

The search for GRBs is performed using the muon events selected under the condition of coincidence of more then two planes. The frequency of such coincidences is 7.3 Hz. Muon arrival directions were calculated for each event. Data period 2001-2004 (pure time is ~1240 days) encloses $7.8 \cdot 10^8$ events. The effective angular resolution of the telescope for such events is σ = 2.5°. We use CORSIKA (v.6.03 model QGSJET) [8] to calculate a response of the BUST to primary gammas. The calculation was performed for zenith angle of 40°

and threshold energy of muons, E_μ = (220 ÷1000) GeV. To estimate fluence we use a power law spectrum for gammas in GRB $I(E)\sim E^{-\gamma}$, where γ=2.0. Using this shape of spectrum we obtain an interval of the BUST's sensitivity for primary gammas, $E_{0.95}$ –$E_{0.05}$, where we have registered 90% events; $E_{0.95}$=0.5 TeV, $E_{0.05}$=70 TeV. With the observed excess of events, N, inside an angular window in which a photon from a point source is detected with efficiency ε, and a power-law spectrum of photons of the burst in the energy range $E_{min} < E < E_{max}$, the corresponding energy fluence in the energy range $E_{0.95} < E < E_{0.05}$ is given by

$$W = \frac{N \int_{E_{0.95}}^{E_{0.05}} E^{-\gamma+1} dE}{\varepsilon \cdot S \int_{E_{\min}}^{E_{\max}} E^{-\gamma} P(E) dE} \qquad (1)$$

2. Discussion

According to the sky survey method GRBs were searched for as fluctuations in the event time distribution and spatial concentration inside a sky window of a size related to the angular resolution of the BUST. The search was performed in the sky region with zenith angle of $\theta < 90$ °. For each event i occurring at a time t_i and with arrival angles (θ,φ), we consider all clusters made by events i, $i+1$, ... $i+N-1$ whose arrival directions are inside a circular window centered on the event i, and satisfy the condition $\Delta t \equiv t_{i+N-1} - t_i < 10$ s. Search for clusters in simulated events was also performed. Comparing the simulated and experimental data one can conclude that all the experimental clusters could be explained as random coincidence. Each cluster has N events and duration Δt. The results of a search for such clusters is shown in figure 1:

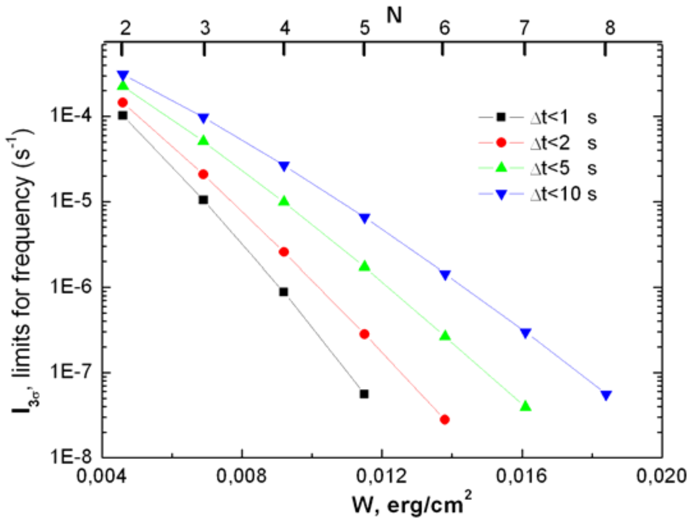

Figure 1. Limits for frequency of GRBs (at 3 standard deviations level) for various numbers of showers in a cluster, N, or for corresponding fluence, W.

Search for γ radiation of ultrahigh energy from the GRBs registered onboard spacecrafts was carried both during T_{90} and 2 hours intervals around a burst trigger. During the period of observation, 33 GRBs registered onboard spacecrafts and described in GCN circulars [8], occurred in the field of view of the telescope (with zenith angle $\theta < 60$ ° and threshold energy of muons for the given direction not exceeding 1 TeV). At larger zenith angles the threshold energy of muons and the appropriate energy of initial γ-ray is too large to be analyzed. Data on GRBs are submitted to the GCN circulars in a 'free' form, that is why we made up for our purposes a special catalogue of the located bursts indicating their date, time, angular coordinates and duration of event. For each event, during period T_{90}, a number of showers, *n*, coming from an angular cell centered at GRB coordinates and with a radius $\alpha_r = 2.5$ ° was found. If duration of a burst in circulars GCN has not been found, the duration was set to be 10s. Using data of all period of observation for each angular cell with radius $\alpha_r = 2.5$ ° and the centre with coordinates (θ, φ), equal to coordinates of the burst, the expected (background) frequency of arrival of showers, *f*, was obtained. For each pair of numbers, i.e. number of showers, *n*, registered by the telescope from a cell (θ, φ) for interval T_{90} and expected number of showers, *f*, reciprocal Poisson distribution $P(n,f)$ were calculated:

$$P(n,f) = \sum_{k=n}^{\infty} \frac{e^{-f} f^k}{k!} \qquad (2)$$

Integrated distribution of number of bursts depending on 1/P (integration from 1/P up to +∞) was calculated. In this distribution only those bursts were used during which (i.e. T_{90}) at least one shower came from the cell. Integrated distribution of events N (1/P) considering only random process in double logarithmic scale is depicted with a straight line with a slope k = -1. The agreement of the experimental distribution with the expected one was obtained. For each event that came in the field of view of the telescope, a limit on a fluence, W, was obtained (for the direction of the burst, corresponding threshold energy of muons and number of showers registered during T_{90}),. All obtained limits are in a range from $4.6 \cdot 10^{-3}$ erg/cm^2 up to $3.7 \cdot 10^{-2}$ erg/cm^2.

Interest to the search for high energy γ-radiations during a time interval around GRB arose after the EGRET has registered γ-ray of 18 GeV in about 1.5 hours after GRB [1]. Moreover standard models of high energy GRB radiation predict their delay from the basic low energy radiation [10]. To detect ultrahigh energy γ-rays the search for clusters during two hours around the registered onboard GRB was carried out. Search was carried out with a method of a sliding interval. Duration of intervals, Δt, was 1, 2, 4, 10, 50, 100, 200, 500, 1000 seconds, the step is equal to half of the interval. The number of the showers that came from an angular cell with radius $\alpha_r = 2.5°$ and centre of the GRB, was counted up each second. Then summation in an interval of duration Δt was performed. The expected (background) number of events for each GRB and each interval Δt was obtained after processing the information collected during 30 day when in the field of view of the telescope GRBs were absent. Then for each pair of number - number of showers n, registered by the telescope from a cell (α, δ) for an interval Δt and expected number of showers, *f*, reciprocal Poisson distribution, P(n,f), was calculated. In figure 2, dependence on the number of intervals, Δt, in which at least one shower is registered, from the probability, P, for intervals before and after the moment of burst are shown. Thus, no excess of showers over a background in time windows around GRBs was found.

3. Conclusions

Search for GRBs in a sky survey and ultrahigh energy γ-radiation of GRBs registered onboard spacecrafts was carried out using data of the BUST for 2001 – 2004 years. Limits on frequency of GRBs with duration from 1 to 10 seconds and fluence in a range of $4.6 \cdot 10^{-3}$ erg/cm^2 ÷ $1.8 \cdot 10^{-2}$ erg/cm^2 was obtained: $\Omega_{\mathrm{lim}} = (2 \cdot 10^{-4} \div 1 \cdot 10^{-7})$ c^{-1}. Search for ultrahigh energy γ-radiation from GRBs registered onboard spacecrafts was carried out both for the observed duration of the burst, and for time interval ± 2 hours around the burst. No significant excess above a background of random coincidences was observed. Obtained limits on a fluence which is carried away in γ-rays of ultrahigh energy at the time of the bursts ranges from $4.6 \cdot 10^{-3}$ erg/cm^2 to $3.7 \cdot 10^{-2}$ erg/cm^2.

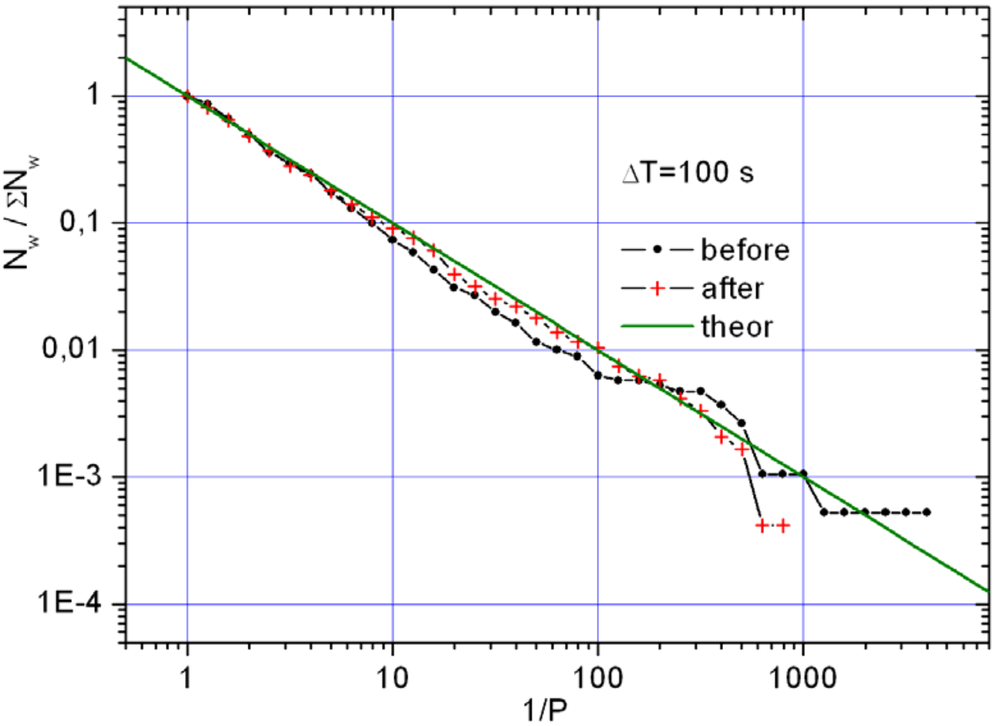

Figure 2. The dependence of the integrated distribution of number of time windows, N_w, of random coincidence probability in observation of *n* showers from an angular cell with background *f (*e.g. Δt=100s) during a time window.

4. Acknowledgements

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