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Search for high energy gamma-ray bursts

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Abstract. We report results of the search for high energy GRBs and high energy radiation in correlation with GRBs. The search has been performed at ”Andyrchy” EAS array, for this purpose the single particle counting rate of the array has been used. The data were collected during 1996 - 2006 years with a live time 2290 days. The search for high energy radiation in correlation with GRBs detected by space-born experiments operated in 1996 – 2006 has been also performed. We considered 189 GRBs occurred in the field of view of ”Andyrchy” array with a zenith angle $\theta \leq 50°$. Using epoch folding method around trigger time of bursts the upper limits on the fluence during the prompt emission were obtained.

1 Introduction

Emission of gamma ray bursts (GRBs) with photon energy more than a few GeV can be registered by ground based air shower arrays operating in the “single particle” operation mode (Aglietta et al., 1996; S. Vernetto , 2000). In such experiments the total count rate of all detectors of the array is measured. With single particle technique, the energy and arrival direction of the primary gamma-rays cannot be measured. The GRBs can be detected only, if the secondary particles generated by the primary gamma-rays give a statistical significant excess of event over all-sky background due to cosmic rays. In this case the study of the temporal behaviour of the high energy emission can be possible .

A search for high energy GRBs and high energy emission in correlation with GRBs has been performed by “Andyrchy” air shower array. For this purpose the single particle counting rate of the array has been used (Petkov et al., 2004). The data were collected during 1996 – 2006 years with the total live time of 2290 days. In the sky survey the high energy GRBs were searched as short duration increases ($\Delta t \leq 1$ s) in the flux of secondary charged particles. The limits on the rate of GRBs with different fluences have been obtained. The search for high energy radiation in correlation with GRBs detected by space-born experiments operated in 1996 – 2006

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2 The experiment

The Andyrchy array is located at altitude of 2060 m above sea level (the atmospheric depth is 800 g cm^{-2}) and consists of 37 scintillation detectors (Petkov et al., 2006). A plastic scintillator 1 m^2 in area and 5 cm in thickness is viewed by one photomultiplier tube. The most probable energy release in a detector from single particles is ~ 10 MeV, the detector triggering threshold is 5 MeV. To detect a single cosmic ray component, the total count rate of all array detectors is measured every second. The search for GRBs based on this technique is conducted against a high cosmic ray background ($\bar{\omega} = 11390$ s^{-1} over the observing period), which requires a highly stable and reliable operation of the equipment. The monitoring is performed through simultaneous measurements (also every second) of the count rates in four parts of the array containing 10, 9, 9, and 9 detectors. Using such information allows us to eliminate the 1 s points with unreasonably large deviations of the count rate between the different parts of the array (Petkov et al., 2010).

3 Array's response

Most of the shower particles generated in the atmosphere by primary gamma-rays with energies less than ~ 1 TeV are absorbed before reaching the array level. The detection probabilities $P(E,\theta)$ of the secondary particles produced by primary gamma-ray photons with energy E incident on infinite area array at zenith angle θ were determined by simulating electromagnetic cascades in the atmosphere and on the array

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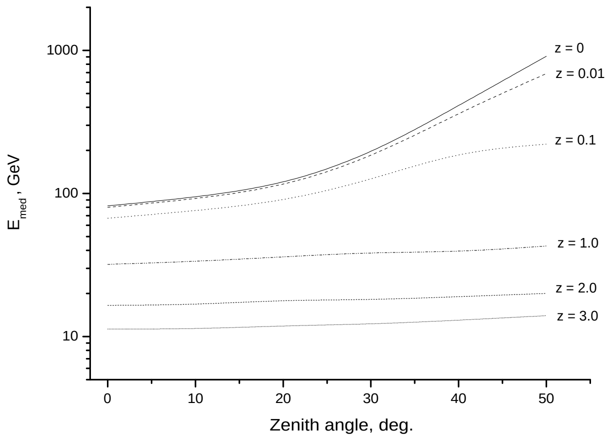

Fig. 1. Median energy as a function of zenith angle for different z.

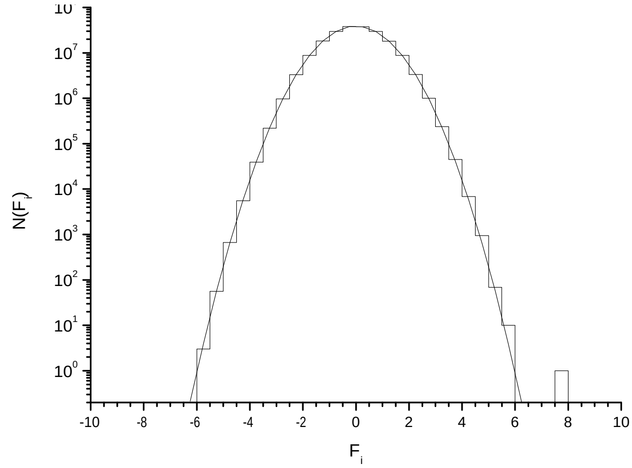

Fig. 2. Experimental distribution on F_i. Line - Gaussian distribution with the mean $V = (0.0025 \pm 0.0004)$ and $\sigma = 1.01$.

detectors. The CORSIKA code (Heck et al., 1998) was used to simulate electromagnetic cascades in the atmosphere. The characteristics of the secondary particles that reached the array level were the input parameters of the code for calculating the detector response, in which the energy release in the detectors was calculated.

We will take the median energy of the primary gamma-ray photons recorded by the array as their effective energy. In this work we use array's response function defined as $R(E,\theta,z) = P(E,\theta) \times I(E) \times exp(-\tau(E,z))$ with energy spectrum of the primary (in the source) γ-rays $I(E) \sim E^{-2.0}$. The optical depth of γ-rays with energy E and redshift z, $\tau(E,z)$, was taken from (Franceschini et al., 2008).

The dependencies of the median energy on zenith angle for different z are presented in Fig. 1. One can see the increase of the median energy with zenith angle as result of atmospheric depth increase, but this effect is less important at large redshifts.

4 Sky survey

The parameter F_i that is the deviation in units of σ (the Poisson standard deviation of the number of counts k_i in the i-th second of a 15-min interval from the mean over this interval $\overline{k}$), $F_i = (k_i - \overline{k})/\sqrt{\overline{k}}$, is used to search for deviations in the Andyrchy count rate. In a first approximation the cosmic-ray intensity variations within 15 min are negligible and the mean count rate is fairly high, therefore one may expect the parameter F_i to have a Gaussian distribution with a zero mean $V = 0$ and an rms deviation $\sigma = 1.0$. Figure 2 shows an experimental distribution in F_i over the data collection time from day 79 of 1996 to day 68 of 2006 (2290.1 days of pure time). The experimental data are well fitted by a Gaussian distribution with the mean $V = (0.0025 \pm 0.0004)$ and rms deviation $\sigma = 1.01$ approximately up to 6σ. The only event with a large excess in the Andyrchy count rate (7.9σ) was recorded on April 17, 2002, at 17:31:29 UT; no GRBs were observed by spacecrafts at this time. This event is, most probable, due to the synchronous electromagnetic noise emerging in the power cables of the recording system or that induced on the signal cables of all array detectors (Petkov et al., 2010).

It should be noted that event like ours was detected at EAS-TOP array (10.6σ) on 15 July 1992, at 13:22:26 UT (Aglietta et al., 1993). Because no GRBs were observed by spacecrafts at this time, it may be assumed that this event is also due to synchronous electromagnetic noise. It is impossible to rule out completely the GRB nature of this event, because the most of space-born experiments have the FOV less 4π.

The absence of large deviations can be interpreted as the absence of GRBs with the emission corresponding to energy fluence in the energy range $E_{\min} \le E \le E_{\max}$, here $E_{\min} = 1\,\mathrm{GeV}$ and $E_{\max} = 100\,\mathrm{GeV}$.

Energy fluence $W(F_i,\theta,z)$ corresponding to deviation F_i can be calculated as:

$$W(F_i,\theta,z) = \frac{N \int\limits_{E_{\min}}^{E_{\max}} I(E) E dE}{S \cos\theta \int\limits_{0}^{\infty} R(E,\theta,z) dE} \quad (1)$$

where $N = F_i \cdot \sqrt{N}$, $S = 37\,\mathrm{m}^2$. Fluences for the $F_i = 6$ are presented in Fig. 3 for different redshifts as a function of zenith angle. The limit on the frequency of short ($\delta t \le 1\,\mathrm{s}$) gamma-ray bursts with corresponding fluences is 0.73 year^{-1} at 99% c.l.

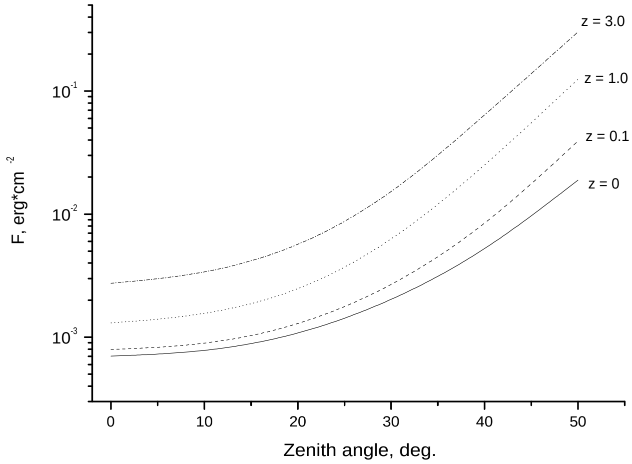

Fig. 3. Energy fluencies ($F_i = 6$) as a function of zenith angle for different z.

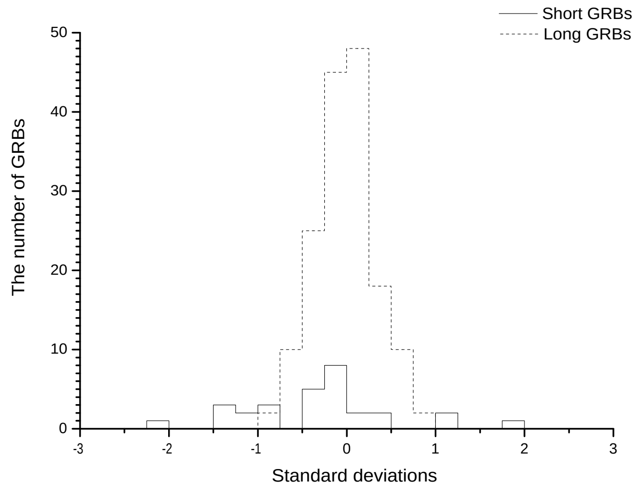

Fig. 4. Distribution of the excesses, in unit of standard deviations, observed in coincidence with 29 short (solid line) and 160 long (dashed line) GRBs.

5 Search for correlations with space-born experiments

In this work the GRBs occurred only in the field of view (i.e. with $\theta \leq 50°$) of "Andyrchy" array were taken into account. During the observing period (1996 – 2006) the total count rate of all array detectors was measured in the interval [-650, +900] seconds around trigger time of bursts for the 189 such GRBs. The signal from GRBs was searched in the 350 s interval (between -50 s and +300 s), for background measurements two 600 s intervals around it was used. Since the primary cosmic ray spectrum is steep, the background consists of secondary particles generated by primary low energy cosmic rays. Because all sources of background modulation have typical time scales about hours, the linear fit have been used for background.

5.1 Prompt emission - individual events

The light curve for each studied GRB was obtained as total count rate of the array around trigger time after background substraction. For each light curve the counts during T_{90} interval were summed and the significance of the sum for each GRB was calculated in a standard way using two background intervals. No significant excess has been observed (Fig. 4) and the distribution of the excesses is fully explained by statistical fluctuations of the cosmic-ray background. For each event the upper limit on the energy fluence in the range 1 GeV – 100 GeV was obtained at the 3σ level in the time window T_{90}. The median values of redshifts, 0.41 for short and 1.61 for long GRBs, were taken into account. The median values of z were obtained using all GRBs with available redshifts in the observing period (1996 – 2006). Fig. 5 shows the obtained upper limits, for the 160 long and 29 short GRBs, as a function of zenith angle. The marked difference in the fluence limits between short and long bursts results from two reasons. The first one is due to the more background counts for the long bursts (owing to difference in the burst durations). And second one is due to difference in the redshifts.

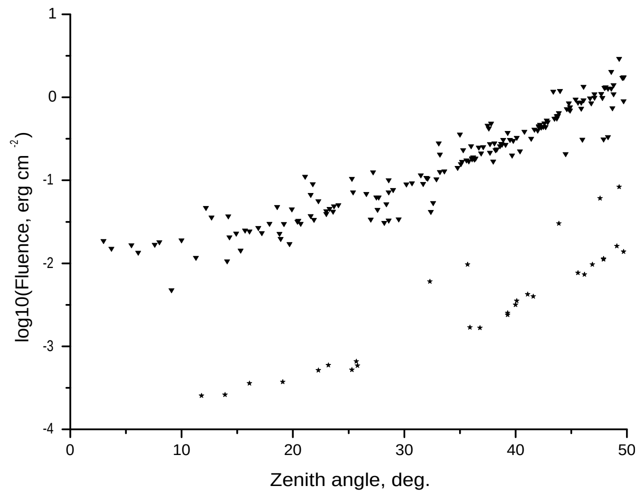

Fig. 5. Upper limits on the 1 GeV – 100 GeV energy fluence for the prompt emission obtained for 160 long (triangles) and 29 short (stars) GRBs events as a function of the zenith angle.

5.2 Prompt emission - epoch folding method

Selected events were divided into 5 groups under the five zenith angle ranges with 10° step. The number of events and mean zenith angle are presented in Table 1 for the each range. Individual light curves were summed for different zenith angle ranges separately. The significance of any deviation in combined light curves was calculated in a standard way using the same background intervals. Because search for the prompt emission was performed for the GRBs with

Table 1. The number of GRBs and mean zenith angle for different zenith angle ranges.

θ range	N_{short}	$\overline{\theta}_{short}$	N_{long}	$\overline{\theta}_{long}$
0 - 10	0	–	8	6.6°
10 - 20	4	15.2°	19	16.2°
20 - 30	5	24.5°	30	24.9°
30 - 40	6	36.5°	47	35.9°
40 - 50	14	45.5°	56	45.4°

different T_{90}, overall counts during T_{90} interval were normalized to T_{90} for each GRB and then summed for each zenith angle range. No significant excess has been observed for the summed signals. Fig. 6 shows the obtained upper limits on the energy fluence in range 1 GeV – 100 GeV at the 3σ level, for the long and short GRBs. Owing to difference in the burst durations and the number of summed events the normalized fluence limits are appreciably better for the long GRBs.

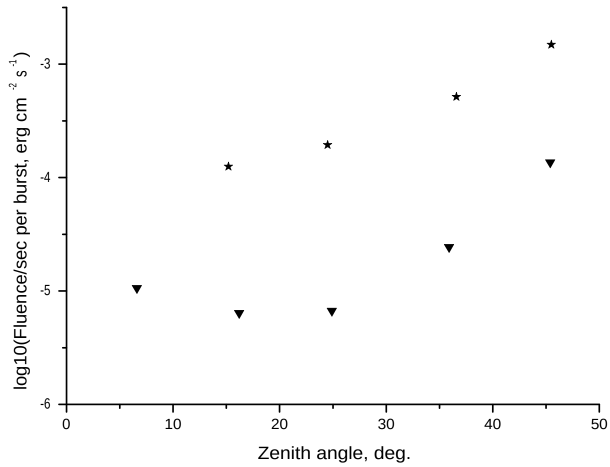

Fig. 6. Upper limits on the 1 GeV – 100 GeV energy fluence for the prompt emission (per second and per burst), obtained by epoch folding method for the long (triangles) and short (stars) GRBs events.

6 Conclusions

Using the single particle technique, the search for gamma ray bursts with photon energies higher than a few GeV has been performed at “Andyrchy” EAS array. In the sky survey the constraints on frequency of the high energy gamma ray bursts have been obtained. No candidates have been observed in the coincidence with 189 GRBs recorded in the space board experiments in the field of view of our array. No significant excess has been observed for the summed light curves too. The limits on the prompt high energy emission have been obtained taking into account median values of redshifts for short and long GRBs.

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