Astrophys Space Sci (2007) 309: 537–540
DOI 10.1007/s10509-007-9423-x

ORIGINAL ARTICLE

GRBs search results with the ARGO-YBJ experiment operated in scaler mode

G. Di Sciascio · T. Di Girolamo

Received: 7 July 2006 / Accepted: 1 November 2006 / Published online: 24 April 2007

Abstract The ARGO-YBJ experiment is almost completely installed at the YangBaJing Cosmic Ray Laboratory (4300 m a.s.l., Tibet, P.R. China). The lower energy limit of the detector (E $\sim$ 1 GeV) is reached with the scaler mode, i.e., recording the single particle rate at fixed time intervals. In this technique, due to its high altitude location and large area ($\sim$6700 m^2), this experiment is the most sensitive among all present and past ground-based detectors. In the energy range under investigation, signals due to local (e.g. solar GLEs) and cosmological (e.g. GRBs) phenomena are expected as significant enhancements of the counting rate over the background. Results on the search for GRBs in coincidence with satellite detections are presented.

Keywords Gamma-ray sources: gamma-ray burst · Cosmic rays · Extensive air showers

PACS 98.70.Rz · 98.70.Sa · 96.40.Pq

1 Introduction

Gamma Ray Bursts (GRBs) have been deeply studied in the keV–MeV energy range, but only little information in the GeV range has been provided in the past decade by EGRET measurements. Only 3 bursts have been detected at energies >1 GeV, with one photon reaching 18 GeV (Catelli et al. 1998). The study of the high energy emission of GRBs could provide extremely useful data able to constrain the emission models and the value of the ambient parameters. At these high energies the detection from space is hampered by the very low fluxes, requiring large collection areas. From ground the last generation Cherenkov telescope MAGIC (Albert et al. 2006), designed also to point at the detected GRB direction in a very short time, is still making efforts to lower the threshold at energies $\leq$100 GeV. Its duty cycle and field of view are however very small: a wide field detector, able to cover simultaneously and continuously a significant ($\sim$1 steradian) fraction of the sky, is thus necessary. With such a detector the Milagro Collaboration reported evidence for TeV emission from GRB 970417a with a significance slightly greater than 3σ (Atkins et al. 2000). The study of the high energy spectrum of GRBs is perhaps the strongest motivation for an all-sky VHE detector. The study of transient phenomena can be successfully performed at energies down to 1 GeV by air showers arrays working in "single particle mode" (Vernetto 2000), i.e., counting all the particles hitting the individual detectors during fixed time intervals. The observation of an excess in coincidence with a GRB detected by satellites would be an unambiguous signature of the nature of the signal. Both the sensitivity and the energy threshold improve with larger detection areas and higher observation levels, making air shower detectors at very high altitude the most suitable.

The ARGO-YBJ experiment, located at the YangBaJing Cosmic Ray Laboratory (4300 m a.s.l.) with a detection area of $\sim$6700 m^2, is an air shower array exploiting the full coverage approach at very high altitude, with the aim of studying the cosmic radiation with a low energy threshold. In this paper we present results on the search for GRBs in coincidence with satellite detections performed in the December 2004–May 2006 period with the ARGO-YBJ experiment.

For the ARGO-YBJ Collaboration.

G. Di Sciascio (✉) · T. Di Girolamo
INFN, sez. di Napoli, Naples, Italy
e-mail: giuseppe.disciascio@na.infn.it

2 The detector

The ARGO-YBJ detector is constituted by a single layer of Resistive Plate Chambers (RPCs) with ∼93% of active area. This carpet has a modular structure, the basic module being a cluster (5.7 × 7.6 m^2), divided into 12 RPCs (2.8 × 1.25 m^2 each). Each chamber is read by 80 strips of 67.5 × 618 mm^2, logically organized in 10 independent pads of 55.6 × 61.8 cm^2 which are individually acquired and represent the high granularity pixel of the detector (Aielli et al. 2006). The carpet is composed by 154 clusters for a total surface of ∼6700 m^2.

The detector is connected to two different DAQ systems, which work independently: in shower mode, for each event which fulfils the trigger conditions the position and time of each detected particle are recorded, allowing the reconstruction of the lateral distribution and of the arrival direction (Di Sciascio et al. 2005); in scaler mode, where there is no trigger, the counting rate of each cluster is measured every 0.5 s, with no measurement of the lateral distribution and arrival direction of the detected particles. In the scaler mode DAQ, for each cluster the signal coming from the 120 pads is added up and put in coincidence in a narrow time window (150 ns), giving the rate of counts ≥1, ≥2, ≥3, ≥4, read by four independent scaler channels. The corresponding measured rates are, respectively, ∼40 kHz, ∼2 kHz, ∼300 Hz and ∼120 Hz for each cluster. The counting rates for a given multiplicity are then obtained with the relation $n_i = n_{\geq i} - n_{\geq i+1}$ for $i = 1, 2, 3$. The use of four different scalers may give an indication of the source spectrum in case of signal detection. In order to correctly handle the data, it is very important to evaluate the response to particles hitting the detector. For scaler mode operations, the most important effect is the strip cross-talk, i.e., the probability of having more than one strip fired by a single particle, giving fake coincident counts. Due to the front-end logic, this can happen only for strips belonging to different pads, since the maximum number of counts for each pad is 1 independently of the number of particles hitting simultaneously the pad. An analytical calculation based on the measured "occupancy," i.e., the mean number of strips fired by 1 particle, has been made and checked experimentally.

From the experimental point of view, it is important to take into account the background counting rate variations due to changes in environmental parameters such as the atmospheric temperature and pressure (which modify the shower development in the atmosphere) and the detector temperature (instrumental effect). More troublesome are other possible instrumental effects, such as the electronic noise, that could simulate narrow signals in time, producing spurious increases in the background rate. Working in single particle mode requires very stable detectors, and a very careful and continuous monitoring of the experimental conditions. By comparing the counting rate of the single detectors and requiring simultaneous and consistent variations in all of them, it is possible to identify and reject most of the fake excesses due to instrumental effects. Short variations in the single particle counting rate have been measured in coincidence with strong thunderstorms and have been ascribed to the effects of atmospheric electric fields on the secondary particles flux (Aglietta et al. 1999). The static electric field is measured on the roof of the ARGO-YBJ building with an EFM100 Boltek atmospheric field monitor. Anyway, we note that the occurrences of these events are very rare and even in this case the observed time scales (∼10–15 minutes) are longer than the typical GRB duration. The study of the counting distribution for each cluster is important in order to monitor the stability of the detector and its statistical (Poissonian) behaviour. In Fig. 1 the total counting rate of a typical cluster, added up on the 4 multiplicity channels during a period of 30 minutes, follows a Poissonian distribution with a σ^2 given by:

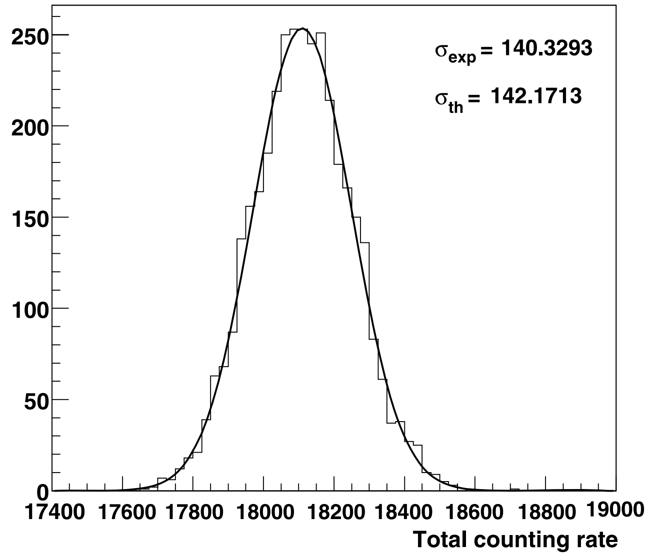

Fig. 1 Total counting rate summed over the 4 multiplicity channels for a typical cluster

$$\sigma^2(C_{\text{tot}}) = \sigma^2(C_1) + 4 \cdot \sigma^2(C_2) + 9 \cdot \sigma^2(C_3) + 16 \cdot \sigma^2(C_4).$$

3 Determination of the detector effective areas

In order to study the detector response to Extensive Air Showers (EASs), a detailed MC simulation has been carried out for both protons and photons with fixed energies in the range 1 GeV–1 TeV and zenith angles $\theta = 0°, 10°, 20°, 30°, 40°$. The CORSIKA/QGSJet code 6.204 (Heck et al. 1998) has been used with a full electromagnetic component development down to $E_{\text{thr}} = 0.05$ MeV for both electrons

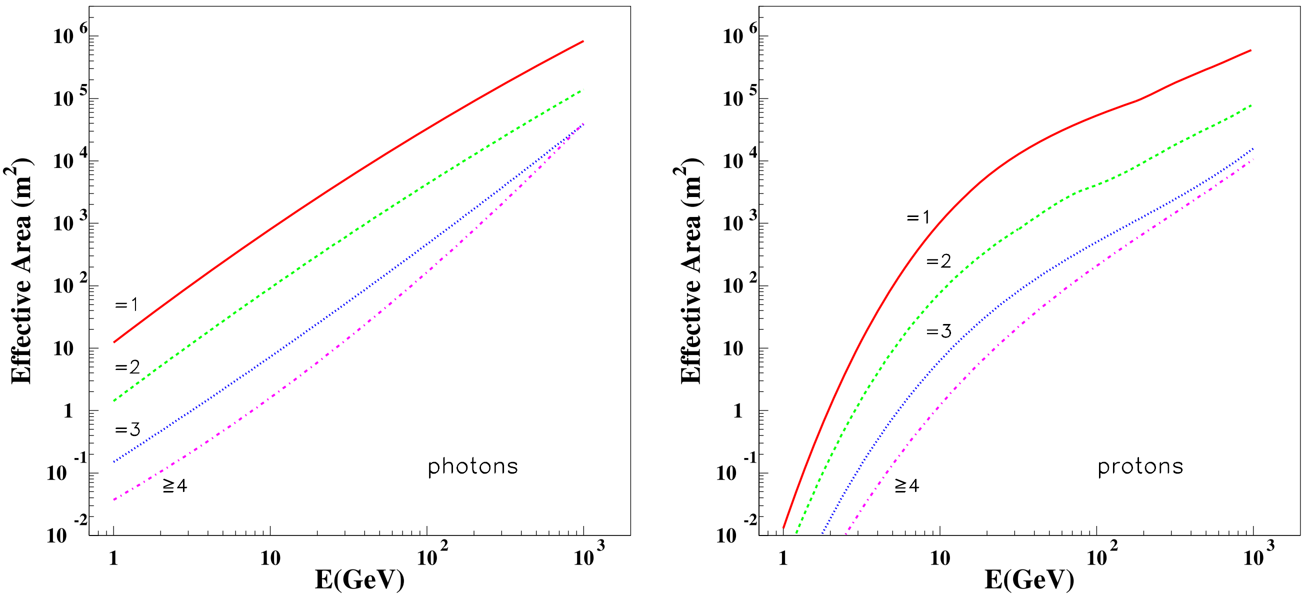

Fig. 2 Effective areas versus energy for primary photons (left plot) and protons (right plot) with zenith angle $\theta = 20°$. The curves refer to different multiplicity channels: $n = 1$, $n = 2$, $n = 3$ and $n \geq 4$

and photons and 50 MeV for muons and hadrons. A detailed description of the detector has been carried out to correctly simulate the "cluster size", i.e., the correlation between the number of particles hitting the detector and the number of signals generated in the different multiplicity channels. Since the actual efficiency depends essentially on the shower particle lateral distribution, a huge quantity of showers must be simulated over a very large area to completely contain it. To save the computing time the shower sampling can be performed by means of the "*reciprocity technique*" (Battistoni et al. 1997). The sampling area A_S ($\sim$5000 × 5000 m^2) is uniformly filled with replicas of the same ARGO-YBJ carpet, one adjacent to the other. Following the reciprocity concept, we sample the shower axis only over the area covered by the carpet located at the center of the array, with the prescription of considering the response of all the detector replicas. On an event-by-event basis we calculate the number of clusters which contain more than 1, 2, 3, 4 fired pads, summed on the entire grid. Figure 2 shows the effective areas for primary photons and protons with zenith angle $\theta = 20°$ in the four multiplicity channels for the complete ARGO-YBJ detector constituted by 154 clusters ($\sim$6700 m^2 sensitive area). Using the position of the GRB in the sky given by the triggering satellite, the corresponding effective area can be used to properly evaluate the GRB fluence. We note that for a multiplicity $n = 1$ the detector sensitivity does not depend on its geometrical features, like the area of the single counters or their relative positions, but only on the total sensitive area (Vernetto 2000). Therefore, the effective areas for any carpet dimension can be scaled from the plotted values. The effective areas for primary protons are then convoluted with the following spectrum: $dN_p/dE \propto E^{-\Gamma}$ with $\Gamma = 2.7$ (Gaisser and Honda 2002) and taking into account the local geomagnetic cutoff (Storini et al. 2001). The resulting counting rates, considering an opening angle of 60 degrees around the zenith, are the following: 21 kHz for $n = 1$, 1.7 kHz for $n = 2$, 180 Hz for $n = 3$ and 80 Hz for $n \geq 4$. Comparison with the measured rates, i.e., 38 kHz for $n = 1$, 1.7 kHz for $n = 2$, 180 Hz for $n = 3$ and 120 Hz for $n \geq 4$, shows that the values obtained by our simulations are lower in the multiplicity channels $n = 1$ and $n \geq 4$. The discrepancy for $n = 1$ is expected because of dark counting and natural radioactivity. Since from both of them we expect mostly single counts, these effects are expected to influence only the $\geq$1 scaler channel.

4 Data analysis and results

The search for emission from GRBs started with the first GRB detection by the Swift satellite on December 17, 2004, when only 16 clusters ($\sim$693 m^2 of sensitive area) out of the total 154 were in data taking. Up to May 2006, 28 GRBs detected by satellites were within the ARGO-YBJ field of view (for this search, $\theta \leq 40°$). Because of detector installation and debugging operations, the duty cycle of data taking has been reduced and reliable data are available only for 16 of these GRBs (see Table 1). For every GRB, the number of counts N, recorded in each of the four multiplicity channels during the duration time $T90$ measured by the satellites, is compared with the number B expected from the background (obtained from the average counting rate in

Table 1 List of GRBs in the field of view ($\theta \leq 40°$) of ARGO-YBJ (Dec. 2004 - May 2006), with preliminary fluence upper limits.

GRB	Sat.	T90/dur. (s)	θ[a] (deg)	Redshift	Spectral index	Carpet area (m^2)	n_σ[b]	UL[c] (fluence)
041228	Swift	62	28.1	–	1.56	693	−1.3	$3.3 \cdot 10^{-4}$
050408	HETE	15	20.4	1.24	1.98	1820	−2.2	$\mathbf{9.6 \cdot 10^{-5}}$
050509A	Swift	12	34.0	–	2.1	1820	0.29	$1.6 \cdot 10^{-4}$
050528	Swift	11	37.8	–	2.3	1820	−0.012	$6.5 \cdot 10^{-4}$
050802	Swift	20	22.5	1.71	1.55	1820	0.74	$\mathbf{1.10 \cdot 10^{-4}}$
051105A	Swift	0.3	28.5	–	1.33	3379	0.90	$1.4 \cdot 10^{-5}$
051114	Swift	2	32.8	–	1.22	3379	2.8	$1.9 \cdot 10^{-5}$
051227	Swift	8	22.8	–	1.31	3379	0.93	$2.5 \cdot 10^{-5}$
060105	Swift	55	16.3	–	1.11	3379	3.6	$5.9 \cdot 10^{-5}$
060111	Swift	13	10.8	–	1.63	3379	0.82	$2.5 \cdot 10^{-5}$
060115	Swift	142	16.6	3.53	1.76	4505	−2.2	$\mathbf{2.3 \cdot 10^{-4}}$
060421	Swift	11	39.3	–	1.53	4505	−0.46	$1.6 \cdot 10^{-4}$
060424	Swift	37	6.7	–	1.72	4505	1.9	$4.1 \cdot 10^{-5}$
060427	Swift	64	32.6	–	1.87	4505	−1.8	$1.8 \cdot 10^{-4}$
060510A	Swift	21	37.4	–	1.55	4505	3.7	$2.3 \cdot 10^{-4}$
060526	Swift	14	31.7	3.21	1.66	4505	0.75	$\mathbf{1.2 \cdot 10^{-4}}$

[a]Zenith angle

[b]Significance of the signal for the single event

[c]Upper Limit on the fluence (1–100 GeV) in erg cm^{-2}. The numbers in bold take into account absorption by the EBL

$\pm 10 \cdot T90$ around the burst). The difference $N - B$ in units of standard deviations, i.e., $(N - B)/\sqrt{B + B/20}$, gives the statistical significance n_σ of the excess, which we report in column 8 of Table 1 for $n = 1$. The data analysis of 3 GRBs (GRB051114, GRB060105 and GRB060510A) gives 2.8, 3.6 and 3.7 as the statistical significance of the signal, respectively. Taking into account that we considered a sample of 16 GRBs, these values correspond to a post-trial probability $P(>1.7\sigma)$, $P(>2.8\sigma)$ and $P(>2.9\sigma)$, respectively, of being a background fluctuation. As a consequence, no convincing excess in the scaler counts was observed in the duration time measured by the satellites. Therefore 3σ upper limits to the fluence of these events were calculated in the 1–100 GeV energy range using the spectral indices determined at lower energies by satellites. Our results are reported in the last column of Table 1. For those GRBs whose redshift has been also determined, the upper limit was calculated including a model for $\gamma\gamma$ absorption by the Extragalactic Background Light (EBL) (Kneiske et al. 2004) and the corresponding value printed in bold. For the other GRBs $z = 0$ was assumed (below 300 GeV the $\gamma\gamma$ absorption is almost negligible for $z < 0.2$).

5 Conclusions

A search for VHE emission from GRBs has been performed with an increasing detector area of the ARGO-YBJ experiment. A total of 16 satellite-triggered GRBs in the field of view ($\theta \leq 40°$) of ARGO-YBJ in the December 2004–May 2006 period has been analyzed. No significant emission was detected and typical fluence upper limits of $\approx 10^{-4}$ erg cm^{-2} in the 1–100 GeV energy range were obtained using the measured counting rates and GRB parameters determined by the satellite observations. We expect to increase the sensitivity by a factor ~ 2 converting the secondary photons with a 0.5 cm thick layer of lead.

References

Aglietta, M., et al.: In: 26th ICRC, Salt Lake City, **7**, 351–354 (1999)
Aielli, G., et al.: Nucl. Instrum. Methods A **562**, 92 (2006)
Albert, J., et al.: Astrophys. J. Lett. **641**, L9 (2006)
Atkins, R., et al.: Astrophys. J. Lett. **553**, L119 (2000)
Battistoni, G., et al.: Astropart. Phys. **7**, 101 (1997)
Catelli, J.R., et al.: In: Meegan, C.A. (ed.) AIP Conferences Proceedings, vol. 428, p. 309. AIP, New York (1998)
Di Sciascio, G., et al.: In: 29th ICRC, Pune, vol. 2, 33–36 (2005)
Gaisser, T.K., Honda, M.: Ann. Rev. Nucl. Part. Sci. **52**, 153 (2002)
Heck, D., et al.: Report FZKA 6019, Forschungszentrum Karlsruhe (1998)
Kneiske, T.M., et al.: Astron. Astrophys. **413**, 807 (2004)
Storini, M., Smart, D.F., Shea, M.A.: In: 27th ICRC, Hamburg, vol. 10, 4106–4109 (2001)
Vernetto, S.: Astropart. Phys. **13**, 75 (2000)