GRBs search results with the ARGO-YBJ experiment operated in Scaler Mode

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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 \((E \sim 1 \text{ GeV})\) 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 \((\sim 6700 \text{ m}^2)\), 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

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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 \(> 1 \text{ GeV}\), with one photon reaching 18 GeV \([1]\). 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 \([2]\), designed also to point at the detected GRB direction in a very short time, is still making efforts to lower the threshold at energies \(\leq 100 \text{ GeV}\). Its duty cycle and field of view are however very small: a wide field detector, able to cover simultaneously and continuously a significant \((\sim 1 \text{ steradian})\) 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 \(3\sigma\) \([3]\). 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" \([4]\), 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 \(\sim 6700 \text{ m}^2\), 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.

2 The detector

The ARGO-YBJ detector is constituted by a single layer of Resistive Plate Chambers (RPCs) with \(\sim 93\%\) of active area. This carpet has a modular structure, the basic module being a cluster \((5.7 \times 7.6 \text{ m}^2)\), divided into 12 RPCs \((2.8 \times 1.25 \text{ m}^2 \text{ each})\). Each chamber is read by 80 strips of \(67.5 \times 618 \text{ mm}^2\), logically organized in 10 independent pads of \(55.6 \times 61.8 \text{ cm}^2\) which are individually acquired and represent the high granularity pixel of the

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The carpet is composed by 154 clusters for a total surface of ∼6700 m².

The detector is connected to two different DAQ systems, which work independently: in shower mode, for each event which fulfill the trigger conditions the position and time of each detected particle is recorded, allowing the reconstruction of the lateral distribution and of the arrival direction [i]; 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 space 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 the scaler mode DAQ, for each cluster the signal coming from the 120 pads is added up and put in coincidence in the scaler mode DAQ. 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_{i+1} - n_{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 [7]. 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. 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 \(\sigma^2\) given by:

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

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 \(\theta = 0^\circ, 10^\circ, 20^\circ, 30^\circ, 40^\circ\). The CORSIKA/QGSJet code 6.204 [3] has been used with a full electromagnetic component development down to \(E_{th_{e}} = 0.05\) MeV for both electrons 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" [6]. The sampling area \(A_{S} \sim 5000 \times 5000\) m² 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. Fig. 2 shows the effective areas for primary photons and protons with zenith angle $\theta = 20^\circ$ in the four multiplicity channels for the complete ARGO-YBJ detector constituted by 154 clusters ($\sim$6700 m$^2$ sensitive area). 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 \( A \). 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 absorption by the Extragalactic Background Light (EBL) and taking into account the local geomagnetic cutoff \( \mu \). 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, $\theta \leq 40^\circ$). 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 I).

For every GRB, the number of counts $N$, recorded in each of the four multiplicity channels during the duration time $T_{90}$ measured by the satellites, is compared with the number $B$ expected from the background (obtained from the average counting rate in $\pm 10 \cdot T_{90}$ around the burst). The difference $N - B$ in units of standard deviations, i.e., $(N - B)/\sqrt{B + B/20}$, gives the statistical significance $n_{\sigma}$ of the excess, which we report in column 8 of Table I 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 $3\sigma$ 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 I. 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) \( \mu \) and the corresponding values printed in bold. For the other GRBs $z = 0$ was assumed (below 300 GeV the $\gamma\gamma$ absorption is almost negligible for $z < 0.2$).
Table 1 List of GRBs in the field of view ($\theta \leq 40^\circ$) of ARGO-YBJ (Dec. 2004 - May 2006), with preliminary fluence upper limits.

| GRB   | Sat. | T90/Dur. (s) | $\theta^*$ (deg) | Redshift | Spectral Index | $n_p^\dagger$ | UL† (Fluence) |
|-------|------|-------------|------------------|----------|----------------|-------------|--------------|
| 041228 | Swift | 62          | 28.1             | –        | 1.56           | 693         | -1.3         |
| 050408 | HETE | 15          | 20.4             | 1.24     | 1.98           | 1820        | -2.2         |
| 050509A | Swift | 12          | 34.0             | –        | 2.1            | 1820        | 0.29         |
| 050528 | Swift | 11          | 37.8             | –        | 2.3            | 1820        | -0.012       |
| 050802 | Swift | 20          | 22.5             | 1.71     | 1.55           | 1820        | 0.74         |
| 051105A | Swift | 0.3         | 28.5             | –        | 1.33           | 3379        | 0.90         |
| 051114 | Swift | 2           | 32.8             | –        | 1.22           | 3379        | 2.8          |
| 051227 | Swift | 8           | 22.8             | –        | 1.31           | 3379        | 0.93         |
| 060105 | Swift | 55          | 16.3             | –        | 1.11           | 3379        | 3.6          |
| 060111 | Swift | 13          | 10.8             | –        | 1.63           | 3379        | 0.82         |
| 060115 | Swift | 142         | 16.6             | 3.53     | 1.76           | 4505        | -2.2         |
| 060421 | Swift | 11          | 39.3             | –        | 1.53           | 4505        | -0.46        |
| 060424 | Swift | 37          | 6.7              | –        | 1.72           | 4505        | 1.9          |
| 060427 | Swift | 64          | 32.6             | –        | 1.87           | 4505        | -1.8         |
| 060510A | Swift | 21          | 37.4             | –        | 1.55           | 4505        | 3.7          |
| 060526 | Swift | 14          | 31.7             | 3.21     | 1.66           | 4505        | 0.75         |

* Zenith angle.
§ Significance of the signal for the single event.
† Upper Limit on the fluence (1 – 100 GeV) in erg cm$^{-2}$. The numbers in bold take into account absorption by the EBL.

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 ($\theta \leq 40^\circ$) of ARGO-YBJ in the Dec. 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 $\sim 2$ converting the secondary photons with a 0.5 cm thick layer of lead.

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