Search for Gamma Ray Bursts with the ARGO-YBJ detector

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Abstract: ARGO-YBJ is a ”full coverage” air shower detector consisting of a 6700 m^2 carpet of Resistive Plate Chambers, located at Yangbajing (Tibet, P.R. China, 4300 m a.s.l.). Its large field of view ($\sim$ 2 sr) makes ARGO-YBJ particularly suitable to detect unpredictable and short duration events such as Gamma Ray Bursts (GRBs). ARGO-YBJ can search for GRBs using two detection techniques: the ”Scaler Mode”, working in the GeV energy range, and the ”Shower Mode”, at energies above a few hundreds of GeV. The results of the search for emission from GRBs in coincidence with satellite detections are presented.

Introduction

The study of GRBs has been done mainly from space detecting the primary photons. Due to the fast decrease of the energy spectrum, the operating energy is usually in the keV-MeV range, and only EGRET in the past (and now AGILE) reached the GeV region, with a maximum detectable energy of 30 GeV. From ground, the search can be done by means of large area extensive air shower detectors operating at high altitude, detecting the secondary particles generated by the interaction of the primary photons with the atmosphere nuclei. This research started several years ago (see for example [1],[2],[3],[4] and [5]) and requires very stable and reliable detectors; moreover, at lower energies the number of secondary particles reaching the ground, often only one, does not allow the measurement of the arrival direction, making unfeasible an independent detection. Nevertheless this study is usually done as a particular research of an experiment that investigates different physics items, and due to the limited surface of the space detectors the minimum detectable fluences are close to the values obtained by satellite observations in the same energy range.

The Detector

The ARGO-YBJ detector has been completed in spring 2007 and is now fully operational in Yangbajing (latitude 30.11°N, longitude 90.53°E, 4300 m a.s.l., atmospheric depth 606 g/cm^2). It is made by a single layer of Resistive Plate Chambers, covering an area of 6700 m^2. Its modular structure (the basic module being a “cluster” of 5.7×7.6 m^2) has allowed to collect data during the mounting, giving the possibility of starting some physical searches since the beginning of the installation. The detector can operate in two different ways, corresponding to two independent DAQs. In shower mode the arrival time and the location of each particle are recorded using the highest granularity of the detector, the “pad”, equal to 55.6×61.8 cm^2. The current threshold is set to ≥20 fired pads, corresponding to an energy threshold of a few hundreds of GeV, with a trigger rate of $\sim$ 4KHz. In scaler mode the counts of each cluster are recorded every 0.5 s for 4 different levels of coincidence: ≥1, ≥2, ≥3 and ≥4, with a coincidence window of 150 ns. In this case the arrival direction is not measured and the field of view is only limited by the atmospheric absorption. The energy threshold is much lower (about 1 GeV) and is close to the highest energy detected by satellite experiments. A detailed description of the detector can be found in [6], [7], [8] and references therein. Due to the longer setup and certification of the shower mode

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DAQ, the search for GRBs could be performed up to now only with the scaler mode technique.

GRB search

The data presented in this paper have been collected from November 2004 (corresponding to the Swift satellite launch) to April 2007, with a detector active area increasing from 693 to 5632 m^2. In order to extract the maximum information from the data, several GRB searches have been implemented:

- search in coincidence with the satellite detection;
- search for a delayed or anticipated signal of fixed duration;
- phase pile up of all GRBs.

The search for a signal in coincidence with the events detected by satellites (mainly Swift) is done for all GRBs in the ARGO field of view (i.e. with zenith angle $\theta \leq 45°$). For each event, the total number of counts in the Δt_{90} time window given by the satellite detector (corresponding to the detection of 90% of the photons) is compared with the total number of counts in a time interval corresponding to $10{\cdot}\Delta t_{90}$ before and after the GRB. The calculation is made for the 4 multiplicity channels of all the clusters. In this operation, the Poissonian behaviour of all the clusters is checked for a period of $\pm$12 h around the GRB time and all the anomalous clusters are discarded. This guarantees that our data fulfill the requirements on stability and reliability of the detector. Due to the correlation between different clusters (given by the air shower lateral distribution), the true statistical significance of an excess is obtained from the experimental distribution of the sum of all the cluster counts in the same interval of $\pm$12 h around the GRB time. Figure 1 shows the distribution of these significances for the set of GRBs studied with this technique compared with a standard normal distribution. The fluence upper limits are obtained assuming a power law spectrum up to $E_{max} = 100 GeV$ and a 4 σ significance. For this calculation, two different assumptions are used for the power law spectrum: a) extrapolation from the keV-MeV region using the index measured by the satellite experiments, and b) same as before, but with a sharp index change to α

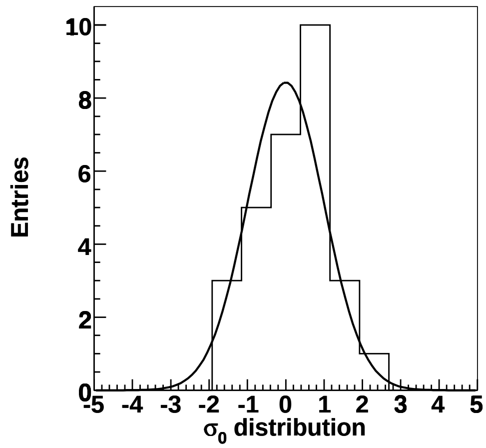

Figure 1: Distribution of the statistical significances of the set of GRBs studied in coincidence with the satellite detections, compared with a standard normal distribution.

= -2.5 at the mean break energy $E_0 = 230 keV$ obtained by Band et al. using the BATSE data [9]. This second model is more realistic in the fact that from CGRO data we know that most of the GRBs show a change in the energy spectrum, but implies a common behaviour that has not been verified. Figure 2(a,b) shows the fluence upper limits in the energy range 1-100 GeV obtained for the two different hypotheses as a function of the local zenith angle. For those GRBs for which the redshift is known, an exponential cutoff is considered to take into account the effects of the extragalactic absorption. The extinction coefficient is calculated using the values given in [10], and the corresponding upper limits are represented with red triangles in Figure 2. Using the same two models of the GRBs spectra, the upper limit to the cutoff energy can be determined at least for some GRBs: the expected fluence is plotted together with our fluence upper limit as a function of the cutoff energy. If the two curves cross in the 2-100 GeV energy range, the intersection gives the upper limit to the cutoff energy for the assumed spectrum. Figure 3 shows the distribution of these cutoff upper limits as a function of the measured spectral index in the case of the extrapolated spectrum (if the bend is applied all the values are over the 100 GeV cutoff limit). For these GRBs we obtain that, if their

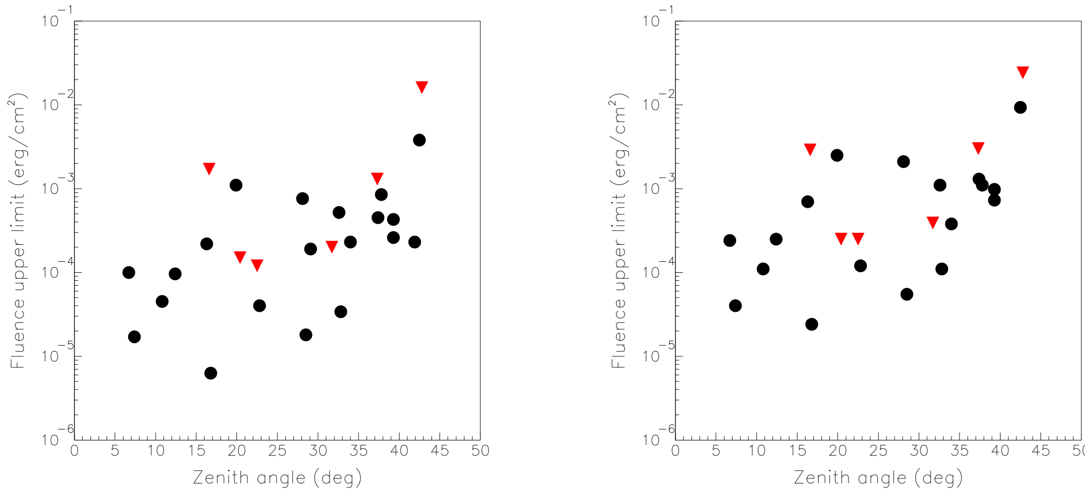

Figure 2: Fluence upper limits as a function of the zenith angle in the 1-100 GeV range obtained extrapolating the measured keV spectra (left) or assuming a change to a spectral index α = -2.5 at the mean energy $E_0 = 230keV$ (right). For those GRBs with known redshift the upper limits are calculated taking into account the extragalactic absorption (red triangles); otherwise $z = 0$ is assumed (black points).

spectra should have extended up to E_{cut}, it would have produced an increase in counts corresponding to 4 σ. Since the high energy emission could

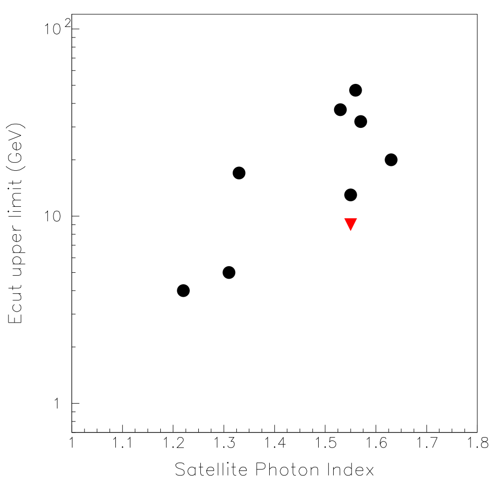

Figure 3: Cutoff upper limits as a function of the spectral index obtained extrapolating the measured keV spectra. The red triangles are obtained taking into account the extragalactic absorption.

happen with features very different with respect to the low energy signal, another search is made in time windows of fixed durations Δt=0.5, 1, 2, 5, 10, 20, 50, 100, 200 s and Δt_{90} shifted by steps of Δt inside a $\pm$ 3600 s interval around the start time T_0 recorded by satellites. The time of 2 hours has been chosen since the highest energy photon from GRBs (18 GeV, GRB940217 [11]) was detected 95 minutes after the low energy emission, while the negative delay was included since some models predict a high energy emission preceding the low energy burst [12]. The distribution of all the excesses for all the GRBs is shown in Figure 4, compared to the expected standard normal distribution. No statistically significant excess is found in any time window. For each GRB, the time duration and shift with respect to T_0 corresponding to the maximum significance are plotted to search for possible aggregations of values. This is done to verify if a common feature of the high energy emission can be identified even if not significant for the single GRB due to the high number of trials. The resulting distributions (see Figure 5) do not show any clustering. Finally, all the GRBs of duration $\geq$ 5 s (i.e. those of the long GRB population) have been added up in phase taking into account their duration Δt_{90}. This search is done to test the hypotesis that high energy emission occurs at a certain phase of the low energy burst, is present for the stack of GRBs, but is lower than the

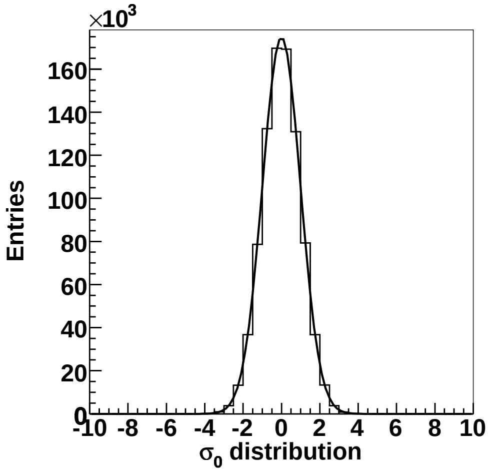

Figure 4: Distribution of the statistical significances of the set of GRBs in a ± 2 hrs interval around the T_0 given by satellite using different time windows Δt (see text), compared with a standard normal distribution.

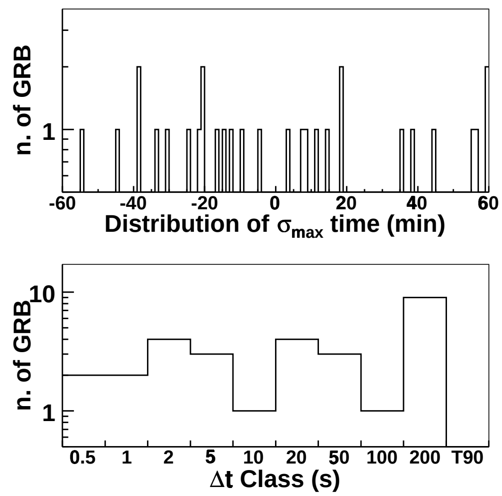

Figure 5: Distribution of time delay (upper panel) and Δt Classes (lower panel) corresponding to the maximum significance for each GRB. The Δt Classes correspond to different fixed time windows ranging from 0.5 s to Δt_{90} (see text).

sensitivity of our detector for each GRB. Even in this case, no significant excess has been obtained, the overall significance of the GRBs stack with respect to the background fluctuations being 1.14 σ.

Conclusions

The search for GRBs both in coincidence and delayed with respect to the satellite detection has shown no deviation from the statistical behaviour. The fluences derived from EGRET measurements in the 1 MeV-1GeV energy range were $\gtrsim 2 \cdot 10^{-5} erg/cm^2$. ARGO-YBJ is providing 4 σ fluence upper limits $\lesssim 10^{-5} erg/cm^2$ in the 1 GeV-100 GeV region. The directional capability of the shower mode at higher energies (a few hundreds of GeV), lower than the dramatic extragalactic absorption occurring at $E \gtrsim 1TeV$, allows the ARGO-YBJ experiment to study the GRB high energy tail in the whole 1 GeV-1 TeV range with the same detector.

References

[1] S. O'Brian and N.A. Porter, Astrophysics and Space Science 42, 73 (1976).

[2] C. Morello, G. Navarra and L. Periale, Il Nuovo Cimento 7C, 682 (1984).

[3] D.E. Alexandreas et al., The Astrophysical Journal 426, L1 (1994).

[4] A. Castellina et al., Proceedings of the 27th ICRC, 2735 (2001).

[5] M. Aglietta et al., The Astrophysical Journal 469, 305 (1996).

[6] M. Abbrescia et al., *Astroparticle Physcics with ARGO*, Proposal (1996), available at http://argo.na.infn.it/.

[7] M. Iacovacci et. al., Proceedings of the XIV Int. Symp. on Very High Energy Cosmic Ray Interaction (Weihai), in press.

[8] P. Vallania et al., Proceedings of the 20th European Cosmic Ray Symposium, in press (2006).

[9] D. Band et al., The Astrophysical Journal 413, 281 (1993).

[10] T.M. Kneiske, T. Bretz, K. Mannheim, D.H. Hatmann, Astronomy and Astrophysics 413, 807 (2004).

[11] J.R. Catelli et al., *Gamma Ray Bursts*, edited by C.A. Meegan, AIP Conf. Proc. 428, 309 (1997).

[12] X. Ma, M. Wu, Q. Zhu, X. Zhou, Proceedings of CCAST (World Laboratory) Workshop, Vol. 153 (2002).