The ARGO–YBJ sensitivity to GRBs

T. Di Girolamo*, G. Di Sciascio* and S. Vernetto†

*INFN, Napoli, Italy
†IFSI-CNR and INFN, Torino, Italy

Abstract. ARGO–YBJ is a “full coverage” air shower detector under construction at the YangBaJing Laboratory (4300 m a.s.l., Tibet, P.R. of China). Its main goals are γ-ray astronomy and cosmic ray studies. In this paper we present the capabilities of ARGO–YBJ in detecting the emission from Gamma Ray Bursts (GRBs) at energies $E > 10$ GeV.

THE EXPERIMENT

The ARGO–YBJ detector is currently under construction at the YangBaJing High Altitude Cosmic Ray Laboratory in Tibet (P.R. of China), 4300 m above the sea level. It is a full coverage array of dimensions $\sim 74 \times 78$ m$^2$ realized with a single layer of Resistive Plate Counters (RPCs). The area surrounding this central detector (“carpet”), up to $\sim 100 \times 110$ m$^2$, is partially ($\sim 50\%$) instrumented with RPCs (“guard ring”), for a total active area of $\sim 6400$ m$^2$ (see left side of Figure 1). The detector basic element is the “pad”, of dimensions $56 \times 62$ cm$^2$, which defines its space-time granularity in observing shower fronts. Moreover, the detector is divided in $6 \times 2$ RPCs units (“clusters”) and covered by a 0.5 cm thick layer of lead, in order to convert a fraction of the secondary γ-rays in charged particles, and to reduce the time spread of the shower particles [4].

OBSERVATIONAL TECHNIQUES

ARGO–YBJ will perform two different types of measurements:

a) Shower technique
Detection of showers with a trigger threshold $N_{pad} \geq 20$, where $N_{pad}$ is the number of fired pads on the detector (“multiplicity”). For these events the position and time of any fired pad will be recorded. An example of shower with $N_{pad} \sim 500$, recorded with $\sim 10\%$ of the whole carpet during a test run, is shown in the right side of Figure 1 note the very detailed view of the shower front pattern. From the pads data the shower parameters (core position, arrival direction and size) can be reconstructed.

The trigger condition $N_{pad} \geq 20$ corresponds to a primary γ-ray energy threshold of a few hundreds GeV, the exact value depending on the source spectrum and on the zenith angle of the observation. A vertical γ-ray of energy $E \sim 120$ GeV gives a mean number of particles $N_e = 20$ at the ARGO–YBJ altitude.
FIGURE 1. Left: Layout of ARGO-YBJ, showing the central RPCs carpet and the outer ring. The rectangles are subsets of the detector (“clusters”) of area $\sim 42 m^2$. The shaded area (36 clusters) is already installed. Right: Example of a shower recorded with 16 clusters.

b) Single particle technique
Every 0.5 s the rate of the single particles hitting the detector is recorded. This measurement allows the detection of the secondary particles from very low energy showers ($E > 10 GeV$) that reach the ground in a number insufficient to trigger the detector operating with the shower technique.

HIGH ENERGY EMISSION FROM GRBS

So far the only existing data reporting high energy $\gamma$-rays from GRBs come from the observations of EGRET (however, there are also possible TeV emissions claimed in the past by various ground-based experiments, in particular that from GRB970417a recorded by the Milagrito detector $[1]$). During its lifetime it detected 16 intense events, with a maximum photon energy of 18 $GeV$ $[2]$. All their spectra show a power law behaviour without any cutoff, suggesting that a large fraction of GRBs could emit GeV or even TeV $\gamma$-rays.

However, high energy $\gamma$-rays undergo pair production with infrared and optical stellar photons in the intergalactic space, and are strongly absorbed during their travel towards the Earth. The optical depth of this process $\tau(E,z)$ increases with the source redshift $z$ and the $\gamma$-ray energy $E$. The majority (57%) of the GRB redshifts measured so far (November 2003) is located at $z > 1$ and only 2 GRBs have a redshift $z < 0.2$. According to $[3]$, at a distance of $z = 1(0.1)$ the optical depth becomes larger than 1 for $\gamma$-ray energies $E > 50(800) GeV$. Therefore it seems unlikely to detect TeV emission from GRBs and most of the efforts must be concentrated in the $10 - 1000 GeV$ energy range.

In order to evaluate the ARGO-YBJ sensitivity to GRBs we consider a simple model in which the GRB high energy flux is described by a power law spectrum with photon
The value of the GRB spectral normalization factor $K$ necessary to give a $4\sigma$ signal with the LM technique, as a function of the spectrum slope for different values of $E_{\text{max}}$ and $z$. The points represent 14 GRBs observed by EGRET.

index $\Gamma$ extending up to a maximum energy $E_{\text{max}}$ (intrinsic cutoff), and affected by an exponential cutoff due to the intergalactic absorption: $dN/dE = KE^{-\Gamma}e^{-\tau(E,z)}$.

The GRB is assumed at a zenith angle $\theta = 20^\circ$ with an intrinsic energy cutoff in the range $100 \text{ GeV} < E_{\text{max}} < 1 \text{ TeV}$ and a distance in the range $0 < z < 2$. The absorption factor is calculated exploiting the values of $\tau(E,z)$ given in [3].

The sensitivity has been obtained by comparing the number of events expected from the GRB with the number of background events, according to both detection techniques, varying the GRB parameters: spectral normalization factor $K$, spectrum slope $\Gamma$, cutoff energy $E_{\text{max}}$, redshift $z$.

RESULTS

In the case of observation technique a), a GRB candidate will appear as a statistical significant excess of Low Multiplicity (LM) events clustered in time and arrival direction. The angular resolution of the detector (i.e., the opening angle containing 71.5% of the $\gamma$-ray events) for showers with $N_{\text{pad}} \geq 20$ is $\sim 2.7^\circ$.

In the case of observation technique b), no reconstruction of the shower parameters is possible and a GRB is observed as an excess in the Single Particle (SP) background rate, possibly in time coincidence with a GRB satellite detection [5].

Our results are summarized in Figure 2 (for the LM technique) and in Figure 3 (for the SP technique), where the value of $K$ necessary to give a signal with a statistical significance of $4\sigma$ is shown as a function of the spectrum slope $\Gamma$ for different values of $E_{\text{max}}$ and $z$. In these calculations a GRB duration $\Delta t = 1 \text{ s}$ is assumed. The sensitivity for different durations can be easily obtained by multiplying $K$ by $\sqrt{\Delta t}$. To compare the ARGO−YBJ expected sensitivity with real GRBs, the $K$ vs. $\Gamma$ values of 14 EGRET
FIGURE 3. Same as Figure 2 but in the case of the SP technique.

GRBs [2] are plotted in the same figures.

These results show that the SP technique is in general more sensitive to GRBs, in particular for high $z$ where the intergalactic absorption strongly affects the high energy tail of the spectrum. Only in the case $z = 0$ and $E_{\text{max}} = 1$ TeV the LM shower technique is slightly better.

CONCLUSIONS

ARGO–YBJ could observe the high energy emission of the most intense GRBs. Since $\gamma$-rays of energy $E > 1$ TeV emitted by cosmological sources are strongly absorbed during their travel towards the Earth, the SP technique provides the best approach to detect GRBs, being particularly sensitive in the $10 - 1000$ GeV energy range.

The sensitivity and the event rate depend critically on the shape of the GRBs spectra above 10 GeV. This shape is determined by the possible existence of an intrinsic cutoff and by the absorption of $\gamma$-rays in the intergalactic space.

The analysis of 14 EGRET GRBs indicates that if the intrinsic cutoff is not too low ($E_{\text{max}} > 100$ GeV) and the sources redshift is $z < 2$, a fraction of the events ranging from $\sim 20\%$ to $\sim 80\%$ would be detectable.

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