# Search for (10,100) GeV GRB with double shower front events from ARGO-YBJ

**Yiqing Guo***, **Hongbo Hu***, **Liu Cheng** *, **Zhou Xunxiu**†
**on behalf of the ARGO-YBJ Collaboration**

* *Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, CAS, Beijing 100049, China*
† *South West Jiaotong University, 610031 Chengdu, Sichuan, China*

***Abstract*. ARGO-YBJ, located at YangBaJing High Altitude Cosmic Ray Observatory (Tibet, China) at 4300 m a.s.l, is a full coverage air shower detector made of Resistive Plate Chambers (RPCs) which are capable of high precision time measurement. Owing to its carpet structure and high altitude, ARGO-YBJ has a very high efficiency in detecting the secondary particles and can significantly decrease the threshold energy for gamma rays astronomy. And being a wide field of view detector, ARGO-YBJ is particularly useful in searching for the Gamma Rays Bursts (GRBs). In this paper, very high energy gamma ray emissions in coincidence with satellite GRBs are searched with the Low-Hit showers in the Double-Front events of ARGO-YBJ data. For the 25 satellite GRBs in the field of view of ARGO-YBJ, no significant emission is observed. The 95% CL upper limits on the fluence are derived accordingly.**

***Keywords*: ARGO-YBJ, GRB, Extensive Air Shower**

## I. Introduction

Gamma Ray Bursts (GRBs) are one of the most intriguing objects since their discovery over three decades ago. The satellite experiment BATSE on board of CGRO was launched in 1991 and found thousands of GRBs. While the spectrum of the majority of GRBs observations are typically at sub-MeV, no cut-off has been observed and suggest that the spectrum extends to high energy. In GRB940217 [1], EGRET observed 2 photons with energy of ∼3 GeV and detected an 18 GeV photon 90 minutes later. Very High Energy (VHE) emission up to TeV from GRBs are expected to be produced by a number of processes which could occur in the relativistic fireball model [2] and afterglow phase [3]. One of the most likely mechanisms capable of producing VHE photons is the inverse-Compton scattering from the internal shock or the external shock. In those models, the predicted spectrum of high energy photons depends on the choice of fireball parameters. So observation of the high energy emission of Gamma Ray Bursts will provide very important information and put constrain to the GRB models.

In fact, several searches of TeV emission from GRBs have been made by ground based experiments. The Tibet air shower array performed search for TeV burst-like events either coincident with the BASTE bursts [4] or blindly. The ARGO-YBJ has attempted to search for GeV GRBs in scale mode and no significant event was observed[5][6]. Rapid follow-up observations by the Air Cerenkov telescope Whipple [7] and MAGIC [8] were performed. No significant detection of high energy emission was observed. Hint of VHE emission from GRB970417 at $3\sigma$ confidence level was found by Milagrito array, the prototype for Milagro detector [9]. While several of these attempts have presented the hint of TeV emission coincident with GRBs, none of them are considered as the convincing evidence. More excited is the lanch of Fermi Gamma Ray Space Telescope in June of 2008 and have found several GeV GRBs until now. It would provide important information for our understanding of GRBs emission mechanisms in the coming days.

This work studies the GRB sensitivity of ARGO-YBJ with the energy from 10 to 100 GeV. The searches of high energy GRBs are performed in association with 25 satellite GRBs coincident which are in ARGO-YBJ's field of view. The data used in this work were taken from June 2006 to December 2008.

## II. ARGO-YBJ Experiments

ARGO-YBJ works in two operation modes. One is the 'shower mode' which has an energy threshold of a few hundreds of GeV when requiring 20 or more pads being fired and the other is the 'scaler mode' [11] which has an energy threshold of a few GeV as it counts the single particle rate. The main part of events collected in shower mode is due to single showers (called triggered events) as that shown in Fig. 1. However, for 5% of the events, two randomly arriving showers may be recorded in the same time window. These events are called double-front events (e.g. Fig. 2). For the smaller shower in double front event, it is recorded without need to satisfy the trigger condition and has an energy as low as a few tens of GeV(as shown in Fig3). This shower is defined as the Low-Hit shower. According to current observation results from EGRET and Fermi Satellite, no high energ emission from GRBs has been observed (The highest energy is 18GeV from EGRET and 13.2GeV from FERMI satellite). So the Low-Hit shower in double front event can be served to search for GRBs with the energy of tens GeV.

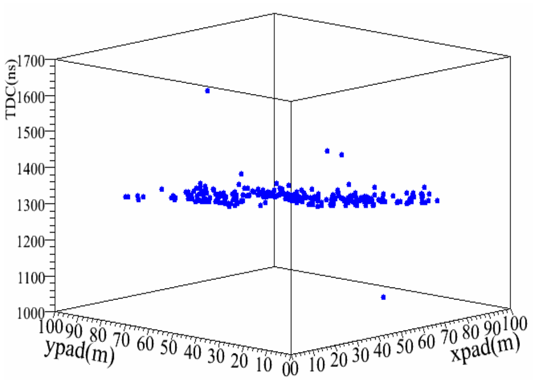


Fig. 1. TDC values vs pad coordinates for a typical triggered event.

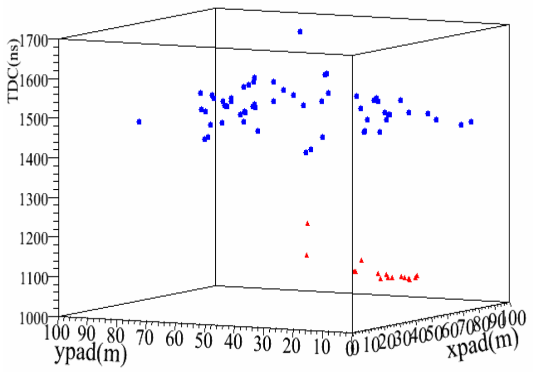


Fig. 2. TDC values vs pad coordinates for a double-front event.

## III. MC Simulation

The sensitivity of ARGO-YBJ experiment to search for high energy GRBs is determined by the effective area and the angular resolution of gamma rays at different energies, which can be estimated from a full Monte Carlo simulation. The Corsika program [12] is used to simulate the extensive air showers initiated by gamma rays.The ARGO-G, which is based on GEANT3, is used to simulate the response of the ARGO-YBJ detector [13]. The EAS events are sampled in an area of 200 $\times$ 200 m$^2$.

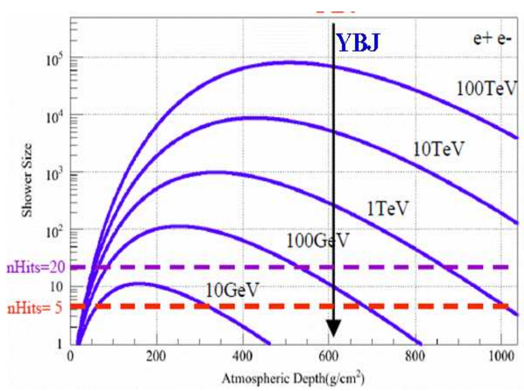


Fig. 3. The shower size as a function of Atmospheric Depth at different gamma ray initiated energy. If we set the trigger at 5Hit, the threshold can be greatly decreased in comparison with current trigger condition of 20 Hits.

### A. *Event Selection*

To ensure the quality of event reconstruction, event selection criteria are applied as following.

(1) $\chi^2$ Selection

The primary direction shoud be reconstructed successfully requiring that both planar and conical fit of the shower have been performed. In order to reject the badly reconstructed events, the $\chi^2$ selection is also applied. In fact, as the environmental condition changes (particularly the temperature), the RPC time response will be affected and consequently the $\chi^2$ will change. Therefore we apply a loose cut ($\chi^2 < 10$) for both data samples: triggered events and Low-Hit events.

(2) Internal Event Selection

For most of the recorded gamma showers, when the primary energy is less than 100 GeV, they should be the internal events. Tt is hard for an low energy external event to fire more than 20 pads as requied by trigger. Moreover, the angular resolution is much poor for the external events as only part of secondary particles are measured by the detector. So,in this paper, we select internal events, which can reject high energy external cosmic ray background effectively and lead to better angular reconstruction for $\gamma$ ray showers.

(3) To Select 10-100 GeV Events

Considering the cosmological origin of GRB and the EBL is opacity to TeV $\gamma$ rays, this work is dedicated to the search of GRBs with energy in the range 10-100 GeV. We select the events with pad multiplicity , those used in the direction resconstruction, to be less than 15 for the Low-Hit events and less than 40 for the triggered events. After applying those selection criteria, the angular resolution ($\psi_{50}$) of ARGO-YBJ detector is 1.7° for triggered shower events and 6.5° for low hit showers in double front events. The corresponding optimal angular radius [14] is 2.3° and 8.7° respectively.

### B. *Effective Area*

The effective area, which depends on the primary energy and zenith angle, is calculated as following:

$$A_{eff}(E,\theta) = A_s \times \frac{n_s(E,\theta)}{N(E,\theta)} \tag{1}$$

Here, $A_s$ is the sampling area (200 $\times$ 200 m$^2$), $n_s$ is signal events that satisfy the above selection criteria, N is the number of events generated and $\theta$ is the zenith angle (0°, 10°, 20°, 30°, 40° for triggered events and 10° for Low-Hit events). Fig. 4 is the $A_{eff}$ of gamma events for triggered shower events and Low-Hit shower events at different zenith as a function of primary energy. It can be seen that there are some advantagement to search GRB using Low-Hit events at low energy. Given a zenith angle, assuming the spectrum power law index of primary gamma (-2.0 for our simulation), and the cutoff energy E$_{max}$, the mean effective area $\langle$A$_{eff}\rangle$ of

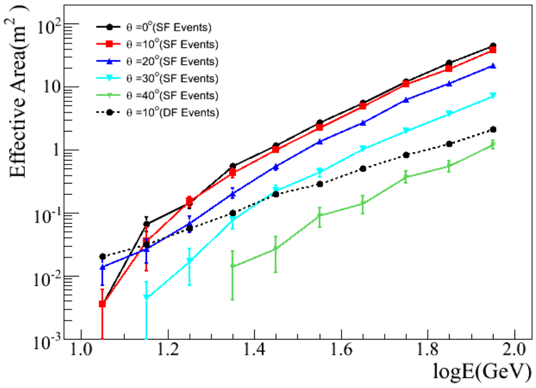


Fig. 4. The $A_{eff}$ from different zenith as a function of primary energy for triggered shower events and double front shower events

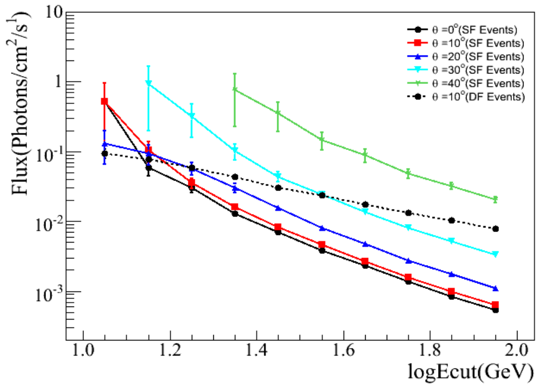


Fig. 6. The $F(E_{min}, E_{max})$ from different zenith as a function of $E_{cut}$ for triggered and double front data

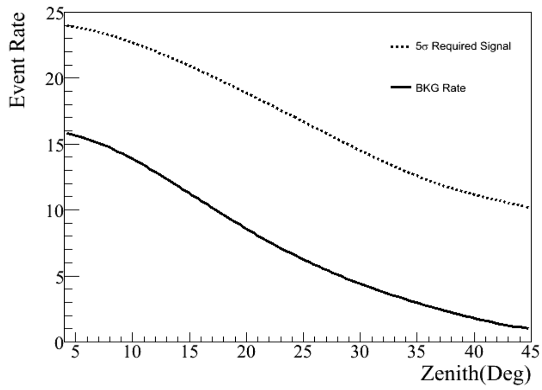


Fig. 5. The background event rate and the minimum signal event required $5\sigma$ significance as a function of zenith angles for double front data.

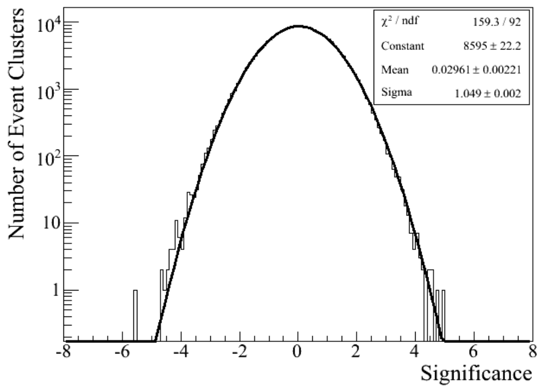


Fig. 7. The significance to 25 GRBs in ARGO-YBJ field of view using double front data sample

ARGO-YBJ can be defined as:

$$\langle A_{eff} \rangle = \frac{\int_{10GeV}^{E_{max}} A_{eff}(E, \theta) \cdot E^{-\alpha} \cdot dE}{\int_{10GeV}^{E_{max}} E^{-\alpha}} \quad (2)$$

Where, $\alpha$ is the spectrum power law index.

### C. Sensitivity of ARGO-YBJ to Search for GRB

According to the optimal angular radius, the background events number $N_b$ can be estimated from data as a function of Zenith angle with 1s duration and the minimum number of signals $N_{on}$ required for a $5\sigma$ observation can be calculated as shown in Fig. 5 for the Low-Hit shower event. So the integral flux $F(E_{min}, E_{max})$ to required for $5\sigma$ observation can be defined as:

$$F(E_{min}, E_{max}) = \frac{N_{on}}{\langle A_{eff} \rangle} \quad (3)$$

Here $F(E_{min}, E_{max})$ characterizes the sensitivity to detect GRB as the function of energy cutoff $E_{max}$ shown in Fig. 6.

## IV. Data Analysis

From the observation of satellites experiments,we get to know the information about GRBs' trigger position , direction, time and the duration of $T_{90}$. Compared to the low energy $\gamma$ rays (for satellites typically energy range is keV∼MeV), high energy emission may be origined from other processes. So different time windows (t) is tried in analysis to cover more possibilities. We either choose the time duration as $T_{90}$, or a set of independent values such as t = 0.01, 0.1, 0.5, $2^1$, $2^2$,... $2^7$s. In both cases, the time window are shifted by a step of 1s inside a $\pm$500 s interval around the starting time T0 recorded by satellite experiments. On source events are counted in each of the time window and denoted as $N_{on}$.

As is mentioned above, optimal angular radius (R) of the on-source window is 8.7° for Low-Hit shower in double front event. For Low-Hit shower events, considering nouniform azimuth angle for Low-Hit shower events and poor angular resolution the background is estimated by equi-declination method. There are two off source windows, both have time interval as 200 s. One is 500 s before the trigger time of GRB and the other is 500 s after the trigger of GRB. The distribution of significance for all the time windows for all the GRBs is shown in Fig. 7, compared to the expected standard normal distribution.

## V. Results and Discussion

The search of high energy emission for 25 GRBs coincident with satellite in ARGO-YBJ detector view with the data collected from July of 2006 to December of 2008 are performed using the Low-Hit shower in Double-Front event and none of these bursts show

TABLE I
THE INTERGRAL FLUX OF GRB AT 95% CONFIDENCE LEVEL FOR THE ENERGY RANGE 10∼100GEV.

| GRB | R.A.(deg) | Dec.(deg) | $\sigma_{max}$ | UL($erg/cm^2$) |
|---|---|---|---|---|
| 060717 | 170.86 | 28.95 | 3.46 | 4.63e-4 |
| 060801 | 213.02 | 16.98 | 4.93 | 7.46e-4 |
| 060805 | 272.52 | 58.16 | 3.90 | 1.28e-3 |
| 060807 | 252.53 | 31.59 | 4.02 | 7.58e-4 |
| 060927 | 329.55 | 5.35 | 3.65 | 2.15e-3 |
| 061110 | 336.30 | -1.73 | 3.39 | 1.77e-3 |
| 061122 | 303.91 | 15.52 | 3.71 | 1.01e-3 |
| 070201 | 114.85 | 23.83 | 3.64 | 1.03e-3 |
| 070219 | 260.20 | 69.36 | 3.41 | 1.23e-3 |
| 070306 | 148.08 | 10.47 | 3.51 | 6.80e-4 |
| 070615 | 44.39 | -3.63 | 4.02 | 4.26e-3 |
| 080328 | 80.48 | 47.51 | 3.47 | 1.86e-3 |
| 080207 | 207.51 | 7.50 | 4.08 | 1.07e-3 |
| 080613 | 173.80 | -6.89 | 4.77 | 1.08e-3 |
| 080727 | 32.64 | 64.13 | 2.58 | 2.49e-3 |
| 080830 | 158.25 | 33.60 | 3.60 | 4.59e-4 |
| 080903 | 86.80 | 51.26 | 3.71 | 8.94e-4 |
| 081016 | 255.57 | 23.33 | 3.42 | 7.38e-4 |
| 081025 | 245.30 | 60.47 | 4.12 | 2.34e-3 |
| 081028 | 121.90 | 2.31 | 3.43 | 6.15e-4 |
| 081102 | 231.20 | 35.20 | 3.44 | 5.37e-3 |
| 081105 | 3.95 | 3.47 | 3.21 | 1.74e-4 |
| 081122 | 338.75 | 38.40 | 4.06 | 3.98e-3 |
| 081128 | 20.81 | 38.13 | 3.75 | 7.75e-4 |
| 081130 | 14.10 | 4.20 | 3.76 | 2.80e-4 |

significant emission. The upper limits of intergral flux at 95% confidence level are measured as shown in Table 1. In addition, the search of GRBs using single front events are also performed and the results are consistent with another analysis[15]. If we combine the two channels, the sensitivity can be further improved at about 10GeV.

## VI. ACKNOWLEDGMENTS

This paper is supported in part by the National Natural Science Foundation of China (NSFC) under the grant No. 10120130794, the Chinese Ministry of Science and Technology, the Key Laboratory of Particle Astrophysics, Institute of High Energy Physics (IHEP), Chinese Academy of Science (CAS), and the National Institute of Nuclear Physics of Italy

## REFERENCES

[1] K. Hurley, et al., Nature, 372, 652 (1994)
[2] Pe'er, A., et al. and Waxman, E., Astrophys. J., 613, 448 (2004)
[3] Rm'em Sari, et al., Astrophys. J., 548, 787 (2001)
[4] Amenomon, A., et al., Astron. Astrophys. 311, 919 (1996)
[5] G. Aielli et al (ARGO-YBJ Collaboration), Astroparticle Physics 30 (2008) 85
[6] G. Aielli et al (ARGO-YBJ Collaboration), to be published on Astrophysical Journal, also arXiv:0905.1189v1
[7] Connaughton, V., et al., Astrophys. J., 479, 859 (1997)
[8] Albert, J. et al., Astrophys. J., 641, L9 (2006)
[9] Atkins, G., et al., Astrophys. J., 533, L119 (2000)
[10] C. Bacci et al, ARGO-YBJ Collaboration, Astropart. Phys. 17, 151 (2002)
[11] Girolamo, T. et al. Nucl. Instr. and Meth. A 588, 14 (2008)
[12] http://www-ik.fzk.de/corsika/
[13] The ARGO-YBJ Collaboration, Nuclear Instruments and Methods A 562 (2006) 92
[14] Chen Xin, et al., HEP & NP, Vol.28, No.10(2004)
[15] Chen Songzhan et. al., this Conference.