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Sky survey with the ARGO-YBJ detector

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The ARGO-YBJ experiment is planned to detect gamma ray sources with an energy threshold of a few hundreds of GeV. The large field of view of the detector and its high duty cycle allow the continuous monitoring of a large part of the sky, searching for both unknown stable sources and transient emissions as AGN flares and Gamma Ray Bursts. In this work we present the first data obtained with a subset of the detector (covering $\sim$1900 m^2) concerning the search for stable and transient sources in the declination range $-20° < \delta < 80°$.

1. The ARGO-YBJ experiment

ARGO-YBJ is a "full coverage" air shower detector under construction at the Yangbajing High Altitude Cosmic Ray Laboratory (Tibet, China) at 4300 m a.s.l. (lat=30.11° N, long=90.53° E). One of the main goals of the experiment is the detection of γ rays from galactic and extragalactic sources with an energy threshold of a few hundreds of GeV. The extreme altitude of the detector and the use of a large full coverage layer of counters, allow the detection of showers in the primary energy range typical of the Cherenkov technique. However, unlike Cherenkov telescopes, ARGO-YBJ has a large field of view ($\sim$ 2.2 sr) and a duty cycle $\sim$100%, allowing the continuous and simultaneous observation of a large fraction of the sky, making thus easier the detection of previously unknown γ ray emitters and transient events like Gamma Ray Bursts and AGN flares.

ARGO-YBJ consists of a 74 × 78 m^2 "carpet" realized with a single layer of Resistive Plate Counters (RPCs), surrounded by a partially instrumented " guard ring", for a total active area of 6400 m^2. The detector is divided into 18480 basic elements, of dimensions 56 × 62 cm^2, the "pads", providing the space-time pattern of the shower front. The time resolution is $\sim$ 1 ns. The detector will be covered by a 0.5 cm thick layer of lead, in order to convert a fraction of the secondary gamma rays in charged particles, and to reduce the time spread of the shower front, increasing the angular resolution. A detailed description of the experiment is given in [1].

A subset of the detector (1900 m^2 of RPCs, $\sim$30% of the complete layout) is taking data since December 2004. In this paper we present our first sky survey results searching for stable gamma ray sources and short transient events as high energy GRBs.

2. The data

The data used in this analysis have been recorded by a detector subset consisting of a $\sim$47 x 41 m^2 RPC carpet, without the lead converter layer. The minimum number of fired pads N_{pad} required to trigger the detector is 60. This temporary trigger configuration (used to debug the detector) corresponds to an energy threshold relatively high: according to simulations, given a γ ray source with a power law spectrum of index α=2.5 (2.0) extending up to 50 TeV and zenith angle $\theta = 20°$, the median energy of the detected γ rays is $\sim$4 ($\sim$8) TeV.

The arrival direction of the primary particles have been reconstructed by fitting the shower front with a conical

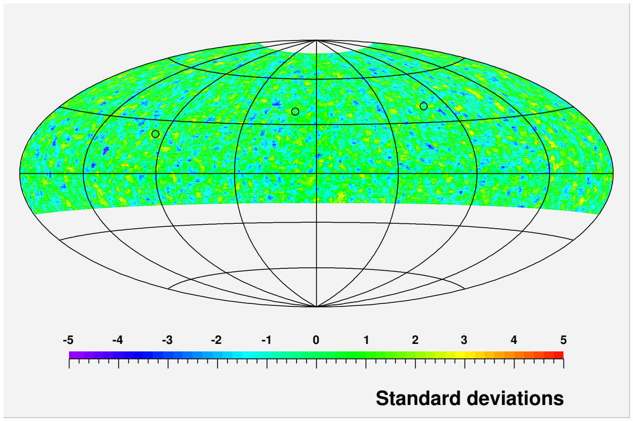

Figure 1. Preliminary sky map obtained in 1.0 10^3 hours of data taking. The three small circles indicate the positions of the Crab Nebula, Mrk 421 and Mrk 501 (from left to right).

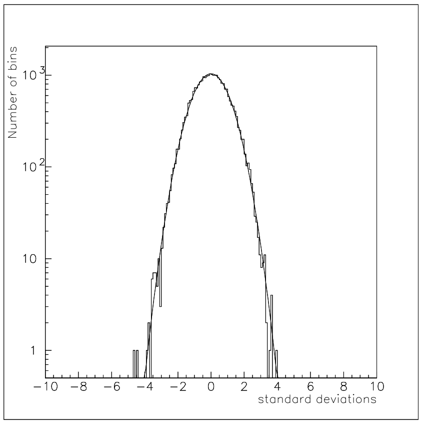

Figure 2. Distribution of the excesses in the 26670 bins of the map in unit of standard deviations, with the Gaussian fit overlapped.

shape of slope 0.03 ns m^{-1}. The position of the shower core has been calculated by means of the Maximun Likelihood Method applied to the lateral density profile of the shower[2]. According to simulations, the angular resolution depends on the number of fired pads: for N_{pad} >60, a circular window around the source with a half opening angle $\Psi = 1.5°$ contains $\sim$70% of the events induced by a gamma ray of energy 1-10 TeV and zenith angle $\theta = 20°$.

The data set of this analysis has been recorded from 2004 Dec 24 to 2005 Mar 23, for a total run time of 1006.5 hours. The event rate is $\sim$160 Hz. Since in this work we consider the events with zenith angle $\theta \leq 50°$, we are monitoring the declination band $-20° < \delta < 80°$, corresponding to 8.3 sr (66% of the celestial sphere). No gamma-hadron discrimination is performed on these preliminary data.

3. Search for stable gamma ray sources

The search for point gamma ray sources consists in filling a sky map with all the detected showers and comparing each bin content with the expected background due to cosmic rays. Taking into account the angular resolution of the detector in the 1-10 TeV energy range discussed in the previous section, we adopt squared bins of size $3° \times 3°$, i.e. $3°$ in declination (δ) and $3°/cos\delta$ in right ascension. Since the position of possible sources is unknown we oversample the sky in order to detect a possible source near the edge of a bin. Every bin thus is shifted by $1°$ in both δ and α. Each map contains a total of 26670 non independent bins. The content of each bin N_s is compared with the expected background N_b. The background map has been built using a method similar to the "time swapping method" [3], randomly changing the time of each real event inside a time interval of a few hours, during which both the background and the response of the detector can be assumed constant. Each real event is used to generate 10 different background events, in order to increase the statistics of the background map.

Fig. 1 shows the sky map obtained with the whole set of data, corresponding to 5.7 10^8 events. For each bin the value of the variable $n_\sigma = (N_s - N_b)/\sqrt{N_b}$ is reported. The distribution of n_σ is well fitted by a Gauss distribution with σ=1.02 (see Fig.2). No excess larger than 4.0 σ is observed. Given the limited run time of the present data, the Crab Nebula is expected to give a signal of $\sim$0.8 standard deviations. Assuming a source

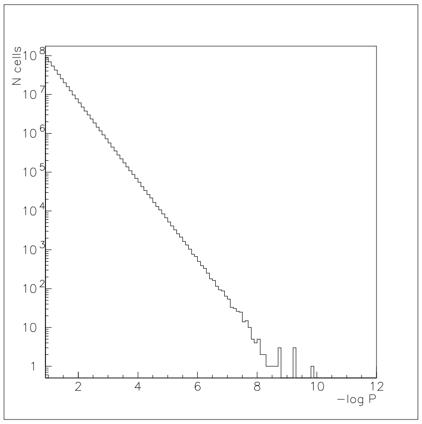

Figure 3. GRB sky survey: distribution of the integral probability obtained in the sky maps of duration Δt=10 s.

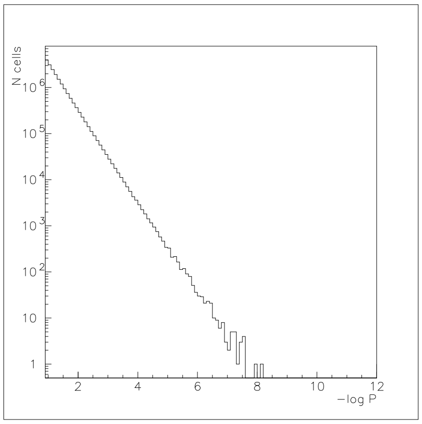

Figure 4. GRB sky survey: distribution of the integral probability obtained in the sky maps of duration Δt=300 s.

with a Crab-like spectrum (i.e. spectral index α=2.59) at a declination $\delta = 30°$, where ARGO-YBJ is most sensitive, the gamma ray flux corresponding to 4.0 σ is $F_{4\sigma} \sim 5$ Crab units. The flux limit increseas as the declination moves from 30°, being $F_{4\sigma} \sim 7(\sim 6)$ Crabs at $\delta = 10°$ (50°) and $F_{4\sigma} \sim 10\,(\sim 12)$ Crabs at $\delta = 0°$ (60°).

4. Search for transient gamma ray sources

A very high energy Gamma Ray Burst is observable as a transient excess of showers with arrival directions consistent with a point source. In order to single out an excess without knowing the position in the sky, the time duration nor the occurrence time, for every run we built a set of sky maps (as described in the previous section) each one characterized by a start time t_i and a time duration Δt consistent with the possible GRB duration. In this analysis we choose Δt = 10, 50, 100 and 300 s. The start time of the i^{th} map of duration Δt is defined as $t_i = t_{i-1} + \Delta t/2$, where t_1 correspond to the run start time. In this way the maps oversample the time, in order to detect more efficiently a GRB with unknown time occurrence. In order to single out possible excesses, each map must be compared with the corresponding "background map" containing the events expected from the cosmic ray background. To build the "background" maps of so short time duration we use the following procedure. First we build a total map in local equatorial coordinates (declination δ and hour angle h) containing all the events recorded during a time interval of a few hours. The "background" map corresponding to a single map of duration Δt and start time t_i, is then obtained transforming the total local map in a celestial coordinate map (in δ and α), via the relation $\alpha = t_{sid} - h$, where t_{sid} is the sidereal time corresponding to the map central time $t_i + \Delta t/2$. Finally we project this transformed map onto the "background map" and we renormalize the bin contents according to the map duration Δt. After filling the "signal" map, the content N_s of each bin is compared to the corresponding value N_b of the background map and the Poisson probability of a background fluctuation producing a bin content $\geq N_s$ (when N_b is the expected value) is calculated.

For any time duration Δt the obtained probability distributions follow the expected behaviour of a uniform background. As an example Fig.3 and 4 show the distributions of the probabilities obtained for all bins and all maps of duration Δt=10 s and Δt=300 s. No excesses with probabilities less than $P_{min} = 10^{-10}$ have been observed for any timescale. To evaluate the sensitivity of this measurement we calculate the flux that would produce an excess with probability equal to P_{min}, using a simple model where the GRB has a spectrum dN/dE

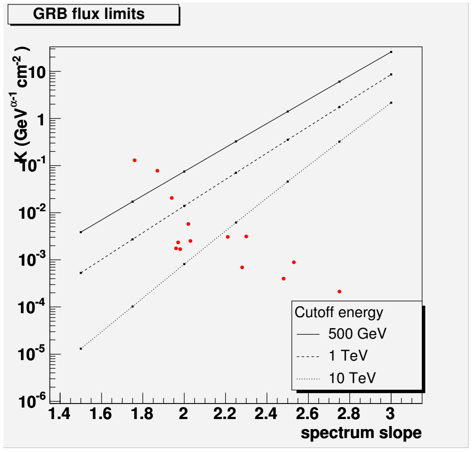

Figure 5. Sensitivity to GRBs of the present ARGO-YBJ detector subset: the lines indicate the value of the normalization factor K of the GRB spectrum K E$^{-\alpha}$ producing an excess of Poisson probability $P_{min} = 10^{-10}$, as a function of the spectral index α. The GRB has a duration Δt=10 s and a zenith angle $\theta = 20°$. K values are given for different cutoff energies. The points represent the values of K and α of 14 EGRET GRBs.

= K E$^{-\alpha}$ extending from 100 GeV to a cutoff energy E$_{max}$. The cutoff can be intrinsic at the source and/or due to Extragalactic Background Light (EBL) absorption. The GRBs duration is set to 10 s and the zenith angle to 20°. Fig.5 shows the values of the normalization factor K corresponding to $P_{min} = 10^{-10}$ as a function of the spectral index α, for E$_{max}$= 0.5, 1 and 10 TeV. For comparison in the same figure the values of K and α of 14 EGRET GRBs are shown [5]. These results indicate that GRBs comparable with the most energetic events seen by EGRET can be observed by the present detector configuration, if their the spectrum extends with the same slope at least up to 500 GeV. This assumption implies that only relatively close GRBs should be detected, since at larger redshifts gamma rays of higher energy are absorbed by the EBL. According to [6] the flux of 500 GeV gamma rays decreases by a factor ∼2 (∼180) if the source distance is z=0.1 (0.5), and the absorption increases with the gamma ray energy.

5. Conclusions

The analysis of the first data taken by an ARGO-YBJ subset of area ∼1900 m^2 shows that the detector is working properly. A preliminary sky survey searching for point sources and gamma ray transients of duration between 10 and 300 s shows no statistically significant excess during 1.0 10^3 hours of measurement in the declination range $-20° < \delta < 80°$.

We expect for the final detector configuration (with an area more than 3 times larger and the lead converter layer) an improved angular resolution, a lower energy threshold and a a significant increase in the gamma ray detection sensitivity.

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