An all sky survey for flaring gamma ray sources using ARGO-YBJ data

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Abstract: The ARGO-YBJ detector is characterized by a high duty cycle and a wide field of view. Therefore, it is capable of carrying out a continuous all sky survey for VHE gamma-ray flares. Based on a careful data quality check, using surrounding window method to estimate the background, an all sky survey for VHE gamma-ray flares was implemented using the ARGO-YBJ data from 2008 to 2010.

Keywords: Flaring gamma ray sources, All sky survey, ARGO-YBJ

1 Introduction

Most of VHE extragalactic sources, around 30, belong to a blazar class of active galactic nuclei (AGNs) with a common feature of BL Lac objects. The emission from blazars is highly variable and is characterized by a flaring behavior, in which the flux increases dramatically on various time scales, even down to the scale of hours. Searching and observing VHE gamma flares is very important in gamma-ray astronomy especially in measuring of extragalactic background lights and in constraint of acceleration models.

The high duty cycle ($\sim$95%) and the wide aperture ($\sim$2 sr) of ARGO-YBJ allows the detection of flaring behavior associated with these AGNs, especially during daytime transits when the Imaging Atmospheric Cherenkov Telescopes do not work. Two very interesting flaring events have been observed by ARGO-YBJ. First, in June 2008 [1], ARGO-YBJ successfully observed flares of Mkn421 on a timescale of 3 days, at that time IACTs cannot do so due to the moonlight. Second, in February 2010, an excess signal (around 4 s.d.) from Mkn421 was captured within a one-day transit [2]. These observations confirm that ARGO-YBJ has the ability in all sky survey for gamma-ray flares from variable sources.

This paper introduces a work on all sky survey for gamma-ray flares. Section 2 briefly introduces the experiment setup. The details of survey procedure are described in section 3, including the data quality check, the event selection criteria, the time binnings, the sky divisions, the background determination and the candidate selection. Results of the survey are finally presented in section 4.

2 ARGO-YBJ experiment

The ARGO-YBJ detector is located at the Yang-Ba-Jing Cosmic Ray Observatory ($30.11°$N, $90.53°$E), Tibet, P. R. China, at an altitude of 4300 m a.s.l., corresponding to a vertical atmospheric depth of $606\ \mathrm{g/cm^2}$. It consists of a single layer of Resistive Place Chambers (RPCs), with each RPC ($2.8 \times 1.25\ \mathrm{m^2}$) divided into 10 basic detection units called PADs ($55.6 \times 61.8\ \mathrm{cm^2}$). Each PAD consists of 8 digital readout strips. Twelve RPCs are grouped into a cluster ($5.7 \times 7.6\ \mathrm{m^2}$). The central carpet ($78 \times 74\ \mathrm{m^2}$) of the detector is fully covered by 130 clusters, whereas 23 clusters form a guard ring surrounding the central carpet. The whole array covers a total area of about 11,000 m^2.

To extend the dynamic range, a charge read-out layer has been implemented by installing to each RPC two large-size pads called the Big Pad ($140 \times 122.5\ \mathrm{cm^2}$) [3]. Two independent DAQ systems are implemented in the detector: the scale mode and the shower mode. In this work, only the data from the shower mode, where the arrival time and fired strip pattern of each fired pad are recorded for subsequent geometric reconstruction, are used. The trigger condition refers to the number of fired pads greater than 20 within the 420 ns triggering window, whereas the trigger rate is about 3.5 kHz [4]. The completed ARGO-YBJ has been collecting data since November 2007.

3 All sky survey

3.1 Data quality check

The timescale of flares from VHE gamma-ray Blazar is short, ranging from several hours to several days. In such a short timescale, the detection is apt to be affected by abrupt abnormal situation of the detector, either giving an inaccurate estimation of the signal intense, or reporting a false flare. Therefore, rigorous data quality checks are obligated.

First, the logbook of the data-taking is read to remove runs apparently in bad conditions, like runs with gas or electronics problems. Not all the bad runs could be covered by the logbook; then a more stringent check based on distributions of a variety of parameters, considered to reflect the running status of the detector, is carried out. Two cucial parameters, the overall event rate and averaged χ^2 of the shower front fitting, are chosen for the study. The procedure of overall rate checking has not brought any bias, because the signals from any flaring point source contribute only a marginal enhancement to the overall event rate, unless it is unexpected strong that can be detected with a significance of thousands of standard deviations.

The distributions of these parameters in two time scales – every run and every minute – are studied. After that, three levels of event selections, such as period, run and slice, are applied to the data. If the values of any parameter, averaged in the run scale, of a batch of consequential runs in a period lasting for several days are far away (5 s.d.) from the linear fitting of all runs, the data in this period is removed; Samilar as above, if that of a single run are far away (5 s.d.) from the moving average of nearby days, the run is removed; If the value of any parameter, averaged in the minute scale, in a time slice of 1 minute, is far away (5 s.d.) from the fitted average of nearby slices (spanning a day), the slice is removed.

A total of 9.52% of events are excluded from all above levels of data quality checks.

ARGO-YBJ data from December 2007 to October 2010, amounting to about 170 M events, are used for the all sky survey. Two event selection criteria are used, as follows:

(a) zenith angle: $< 60°$;

(b) Hit multiplicity:$> 20, > 40, > 60, > 100$.

In above four hit multiplicity thresholds are particulally adopted for the purpose of better detecting sources with different spectra.

3.2 Time binnings

The purpose of the work is to search flaring signals from VHE gamma-ray sources. The whole running period of the ARGO-YBJ is divided into time windows with equal length of 2^n minutes (n is from 7 to 14). That is to say, the flares are surveyed with time scales ranging from 2.1 hours to 11.4 days. All these time binnings start at 00:00:00, MJD 53736 (January 1, 2006).

3.3 Sky cells

The whole sky is subdivided into rectangular cells in the following manner: the declination is divided into n bands $\delta_i (i = 1, 2, \ldots, n)$ with equal width $\Delta\delta = 180°/n$. For each declination band δ_i, the right ascension is further divided into m_i cells with equal width $\Delta\alpha_i$, where m_i is the best integer to satisfy $360°/m_i = \Delta\delta/\cos\delta_i$ and $\Delta\alpha_i = 360°/m_i$. $\Delta\delta$ is the only parameter used for defining the sky cells. Usually it should be set to match the optimized bin size. But the following considerations must be concerned beforehand:

- A flaring source may not locate at the center of a sky cell due to the fact that the division of the sky is applied beforehand, and not optimized for any source;
- The significance changes slowly with the width of the sky cell according to the simulation;
- Decreasing or increasing the sizes of the sky cells for several iterations, a source in an arbitrary location have rather big chance to approach the center of a cell, being detected with nearly same significance as an optimized cell around it.

Therefore, three cell sizes for each hit multiplicity threshold are applied to the survey. Besides the size near to the optimized value, another two, approximately 1.4 and 1/1.4 times the optimized value, are adopted. Table 1 shows the sky cell sizes for every hit multiplicity thresholds.

Table 1: Selection of cell sizes for 4 hit multiplicity thresholds. Size A, B, C are the 3 selected sky cell sizes.

Pad multiplicity	Optimized size	Size C	Size A	Size B
> 20	2.55	2.5	1.8	3.6
> 40	2.43	2.5	1.8	3.6
> 60	1.93	2.0	1.5	3.0
> 100	1.57	1.5	1.0	2.0

3.4 Background determination

The surrounding region method was used for the determination of the background. That means that every sky cell is assigned a hollow background region around it, from which the background can be determined. In brief, this method relies on the fact that the acceptance ratio, $1/R$, bewteen a center cell and a hollow region around the cell in a fixed direction with respect to the detector, remains nearly constant, unless very big hardware change is applied to the detector. This ratio can be calibrated by the experimental data over a long stable period. By counting the number of events in the background region within the same time interval and by knowing R, the expected number of background events in the cell of interest can be calculated. This method is discussed in details in [5]. After that, the Li-Ma prescription [6] was adopted to calculate the significance.

3.5 Selection of candidates

In the work, there are four hit multiplicity windows, for each hit multiplicity window, there exists three different cell size; and eight time bins are implemented for every selection, totally it gives rise to $4 \times 3 \times 8 = 96$ selections. For given time binning and for given cell size, the number of time bins for each sky cell is calculated individually. Only the time bin with the most significant excess (deficit) is selected out. These selected cells composes a most significant excess (deficit) sky map, shown in 1

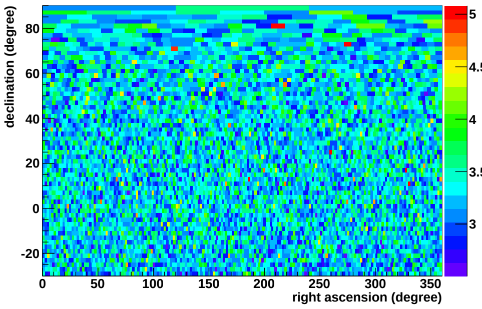

Figure 1: A significance-maximum sky map.

Chance occurrence of a fluctuation of the background, $Q(c_i, M_j)$ can be calculated:

$$Q(c_i, M_j) = Q_{sig}(c_i) \times N_{eff}(M_j)$$

Where $Q_{sig}(c_i)$ is the chance occurrence relative to the particular significance of the most significant time bin, $N_{eff}(M_j)$ is number of effective cells for this selection. And according to Poisson distribution and every selection treated equally, the final chance probability, P can be calculated as $P = 1 - e^{-Q^{final}}$, where $Q^{final}(c_i, M_j) = Q(c_i, M_j) \times N_{selection}$, here $N_{selection}$ is 96 for all selections.

4 Result

Table 2 is the top 9 candidates with the smallest probability, P.

The distribution of chance occurrence of top 1000 most significance excesses is consistent with the expected one, as shown in Figure 2

The position of sun might almost resides at a certain cell during the time window on a scale from several hours to several days, and deficit of cosmic rays would be observed form this cell. The efforts taken by sun shadow is excluded in the analysis. Figure 3 shows the distribution of chance occurrence of top 1000 most significance deficits which are consistent with the expected one.

Table 2: The detail of excesses with smallest probability P.

N_{hit}	cellsize (°)	T_{dur} (min)	sig.	N_{eff}	Q_{final}	P
> 20	3.6	2^{14}	5.46σ	215555	0.49	0.39
> 20	3.6	2^{14}	5.42σ	215555	0.60	0.45
> 40	2.5	2^{7}	6.12σ	22811083	1.01	0.64
> 40	2.5	2^{8}	5.80σ	13971154	4.30	0.99
> 20	1.8	2^{10}	5.78σ	12965471	4.54	0.99
> 40	3.6	2^{10}	5.52σ	3132346	4.96	0.99
> 20	3.6	2^{12}	5.27σ	840470	5.35	0.99
> 20	2.5	2^{13}	5.28σ	929471	5.72	0.99
> 20	1.8	2^{9}	5.79σ	18008986	5.79	0.99

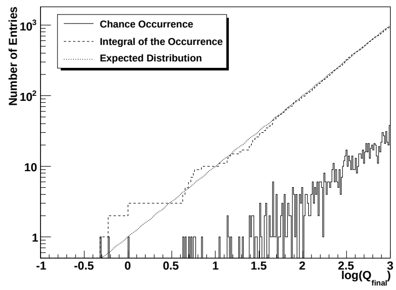

Figure 2: The distribution of chance occurrence of top 1000 most significance excesses. The lower line is the differential distribution. The higher line is the cumulative distribution. The straight line is the fitting line.

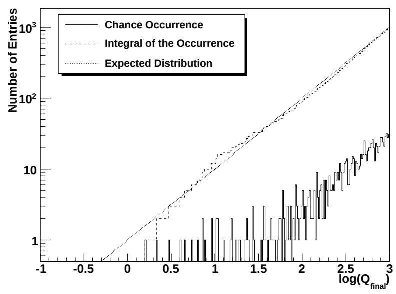

Figure 3: The distribution of chance occurrence of top 1000 most significance deficits. The cells hosting the Sun are excluded, thus the efforts of sun shadow is excluded. The lower line is the differential distribution. The higher line is the cumulative distribution. The straight line is the fitting line.

Due to no significant excess has been observed, a flux upper limits calculation is calculated for all 96 sky maps. For every sky map the maximum significance sky cell in a given declination band is used to estimate the upper limites of this specfic band, The details of the method can be found in [7]. In this work, the flux upper limits are c onverted into the unit of Crab Nebula flux, where Crab Nebula flux is $4.2 \times 10^{-11}\ E^{-2.57}(TeV\ cm^2\ s)^{-1}$. Figure 4 shows the upper limit of an sky map with N_{hit} >60, cell size 3.0 degree, time binning= 2^{12}minute.

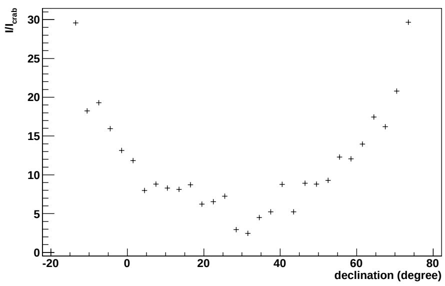

Figure 4: Distribution of flux upper limit of a sky map (trigger multiplicity $>$60, cell size 3.0 degree, time window = 2^{12}minute).

5 Summary

With careful data-quality checks to ARGO-YBJ data, an all sky survey for gamma-ray flares was implemented successfully. No significant excess was found, however, flux upper limits were set for every declination band of every set of sky map on a confidence level of 90%.

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