# A Wide Sky Survey for TeV $\gamma$-ray Sources by Using the Tibet-III Air Shower Array

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**Abstract**

Two techniques for an all-sky survey based on the equi-zenith method were developed. By which the data of phase 1 and 2 of the Tibet-III array have been analyzed. Preliminary results show the significant excesses from the Crab Nebula and Markarian 421 (Mrk 421). A few interesting candidate TeV $\gamma$-ray sources are listed.

## 1. Introduction

Up to now, several TeV $\gamma$-ray sources have been detected by some ground based experiments, such as atmospheric Cherenkov telescopes (ACT) and extended air shower (EAS) arrays. The Tibet air shower array has successfully observed TeV $\gamma$-ray emission from the Crab Nebula [1], Mrk421 [2] and Mrk501 [3].

With good angular resolution and capability to eliminate proton background, ACTs are very sensitive in steady emission from TeV point sources. In contrast to ACTs, EAS arrays have their own advantages. Their wide field of view and high duty cycle make the following researches possible: (i) searching for unknown sources and monitoring many sources at same time; (ii) providing a sky map of TeV sources so as to realize jointed detection with other experiments; (iii) studying anisotropy phenomena of cosmic rays. Here we present two methods and a few preliminary results to those goals.

## 2. Experiment

The Tibet air shower array is located at Yangbajing (90.53° E, 30.11°N) at an altitude 4,300m a.s.l, an atmospheric depth of 606 g/cm$^2$, in Tibet, China. After about thirteen years operation, it has been developed from Tibet-I, Tibet-II/HD to Tibet-III. The Tibet-III array was enlarged with many more scintillation counters from 1999 to 2001, with a 7.5m lattice interval. It consists of 533 scintillation counters with event rate to be about 680 Hz and mode energy to be about 3 TeV for proton-initiated showers. Its angular resolution was estimated from Monte Carlo simulation and confirmed by observing the Moon shadow to be better than 0.9° above the mode energy [4].

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## 3. Techniques for all-sky survey

In EAS experiments, the azimuth distribution of showers is usually uniform and most importantly very stable. The so-called equi-zenith method was therefore developed to estimate the background number in searching for $\gamma$-ray sources. The method is almost free from the time varying of the atmosphere condition and the detector's performance. In this work, two techniques based on the equi-zenith method are employed to analyze the data so as to cross check each other.

### *3.1. Method (I)*

The sky is divided into 0.25° (right ascension, $\alpha$) × 0.25° (declination, $\delta$) cells in celestial coordinate. Denote $1/\beta_{i,\,j}$ the cosmic ray's relative intensity in the $(i,\, j)^{\rm th}$ bin with central position $(\alpha_i,\, \delta_j)$. At a certain local sidereal time (LST) bin $m$ (1 minute as bin width), for a given zenith bin $n$ (0.2° as bin width) and a azimuth bin $l$ (1°/sin(zenith) as bin width), the corresponding relative intensity $1/\beta_{i,\,j}(m,n,l)$ is taken from the celestial cell $(\alpha_i,\, \delta_j)$ which covers the center of the zenith and azimuth bin. Denoting $N(m,n,l)$ the number of observed events for these bins, the equi-zenith condition leads to the following $\chi^2$ equation

$$\chi^2 \;=\; \sum_{m,\,n,\,l} \frac{\Big[\, N(m,\,n,\,l)\;\beta_{i,\,j}(m,\,n,\,l)\;-\;\sum_{l'} N(m,\,n,\,l')\;\beta_{i,\,j}(m,\,n,\,l')\,/\sum_{l'} 1\,\Big]^2}{N(m,\,n,\,l)\;\beta^2_{i,\,j}(m,\,n,\,l)}\,, \tag{1}$$

from which $1/\beta_{i,\,j}$ and its error $\sigma_{1/\beta_{i,\,j}}$ can be solved numerically by iteration method. Consequently, the significance in each celestial bin can be calculated as

$$S(\alpha_i,\, \delta_j) \;=\; \frac{1\,/\,\beta_{i,\,j}\;-\;1}{\sigma_{1/\beta_{i,\,j}}}\,. \tag{2}$$

### *3.2. Method (II)*

All events are binned into sky map of 0.1° (declination) × 0.1° (right ascension) cells. In every bin, the equi-zenith method is used to estimate the background. Using the expected value, one can compute the significance in each bin:

$$S(\alpha_i,\, \delta_j) \;=\; \frac{N_{\rm obs}(\alpha_i,\, \delta_j)\;-\;N_{\rm bkg}(\alpha_i,\, \delta_j)}{\sqrt{N_{\rm bkg}(\alpha_i,\, \delta_j)}}\,. \tag{3}$$

When evaluating the number of background, we use the 0.1° zenith band to compute the mean intensity of cosmic rays in that zenith angle direction.

## 4. Data analysis

We analyzed the data of phase 1 and 2 of the Tibet-III array taken between November 1999 and June 2001. The event selection was done by imposing the

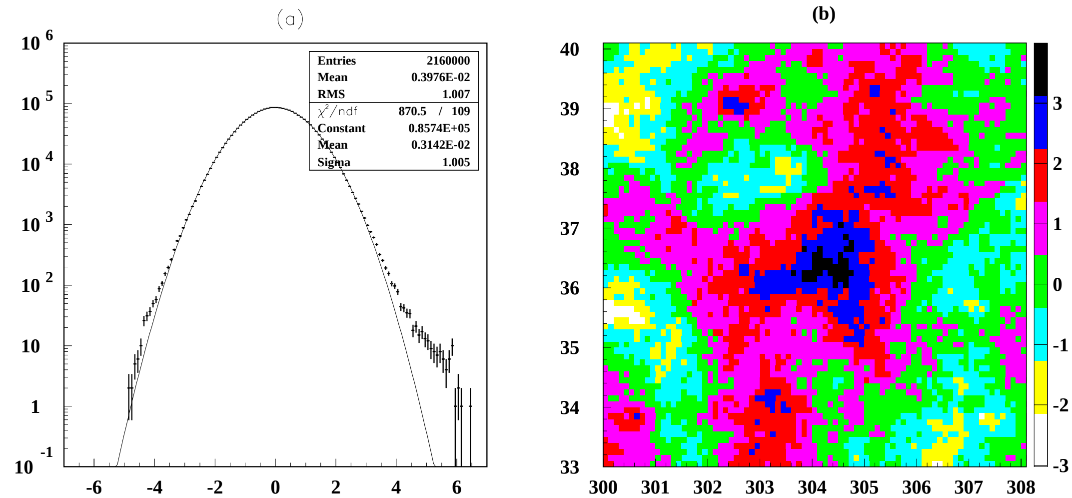


**Fig. 1.** (a) The significance distribution of all directions on the sky map; (b) A candidate TeV $\gamma$-ray source close to the GeV source 3EG 2016+3657.

following five criteria on the reconstructed data: i) each of any four FT detectors should record a signal more than 1.25 particles; ii) the estimated core location should be inside the array; iii) the sum of the number of particles per $m^2$ detected in each detector $\sum \rho_{FT}$ should be larger than 15; iv) the residual error of direction reconstruction should be less than 1.0 m; v) the zenith angle of the incident direction should be less than 40°. After applying these cuts, the total number of events selected was about $4.3 \times 10^9$. In addition, the events with zenith angle of the incident direction less than 5° are also rejected while using method (II).

We did analyses on the northern sky (0° < declination < 60°). When using the equi-zenith method to estimate background, we had respectively counted the zenith-dependent and the LST-dependent azimuth corrections. Considering the angular resolution of the array, for each cell of the sky map, a window of 0.9° angular radius was further used to combine the events and background. Two methods (I) and (II) give very consistent results. For brief, only the results from method (II) are presented here. The analyses without the LST-dependent azimuth corrections give the excesses from the Crab Nebula and Mrk 421 at statistical significance $4.5\,\sigma$ and $6.3\,\sigma$, respectively. They are comparable to our previous results obtained by non-wide sky survey methods [1, 2].

## 5. Results

Fig.1(a) shows the distribution of the statistical significances in all $3600 \times 600$ directions. That the result is quite consistent with standard normal distribution verifies the validity of our background estimation. On the analyzed sky, we find 23 clustered directions whose significances are larger than 4.0 $\sigma$. Our results are also compared with other detected lower energy $\gamma$-ray sources. A

**Table 1.** List of sky cells with maximal excesses in the interesting clustered directions having the statistical significances larger than $3.5\,\sigma$.

| R. A. (°) | Dec. (°) | $S$ ($\sigma$) | Remark (nearby detected source) |
|---|---|---|---|
| 83.85 | 21.85 | 4.1 | Crab Nebula, 3EG 0534+2200 |
| 165.55 | 38.45 | 6.4 | Markarian 421, 3EG 1104+3809 |
| 52.45 | 20.85 | 3.9 | 3EG 0329+2149 |
| 201.05 | 21.15 | 4.0 | 3EG 1323+2200 |
| 286.85 | 5.55 | 4.1 | 3EG 1903+0550, G39.2-0.3 |
| 293.05 | 19.45 | 3.6 | G54.1+0.3, G54.4-0.3, G55.0+0.3 |
| 304.15 | 36.45 | 4.0 | 3EG 2016+3657, G73.9+0.9, G74.9+1.2 |

few prominent directions, including the Crab Nebula and Mrk421, are very close to third EGRET GeV sources [5] or SNRs [6]. Among which 7 directions with statistical significances larger than $3.5\,\sigma$ and angular distance apart from those known sources less than 1.0° are listed in Table 1. As an illustration, a map of significances around the position ($304.15^0$, 36.45°) is presented in Fig.1(b).

## 6. Concluding remarks

We have made a survey on the northern sky for TeV $\gamma$-ray sources with the data of phase 1 and 2 of the Tibet-III array by using two different methods. 23 noticeable directions with statistical significances larger than $4.0\,\sigma$ are found. Besides the well-known Crab Nebula and Mrk 421, other 5 candidate TeV sources close to the third EGRET GeV $\gamma$-ray sources and SNRs are given. All of the results presented here are preliminary. This work is still in progress.

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