Study on YBJ-ARGO Sensitivity to Crab Source

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YBJ-ARGO experiment will make use of a full-coverage detector consisting of a layer of single gap Resistive Plate Chambers. One of the main goals of YBJ-ARGO is to survey VHE gamma rays from galactic and extragalactic sources in northern sky. In this work, we estimate YBJ-ARGO's sensitivity to Crab source with three statistical methods. According to our analysis, in one year operation, Crab Nebula can be detected by YBJ-ARGO with a statistical significance of about 18 standard deviations.

1.   Introduction

Recently, benefited from the high duty circle and large field of view, ASγ and Milagro experiment performed all sky survey of TeV gamma ray[1][2]. With lower energy threshold and higher data rate, YBJ-ARGO experiment is expected to be more sensitive to gamma ray point sources. Currently the detector is under construction and it will be operated at the end of this year. Detailed information about YBJ-ARGO experiment can be found in the work [3][4].

Crab Nebula source(RA:05h34m32s, Dec:+22°00'52"(J2000)) is regarded as a "standard candle" in gamma ray sky. So far, Many experiments have detected it in multi-wave bands and there is abundant experience and data to study it. YBJ-ARGO array can monitor Crab source for about 5.9 hours per day within zenith angle lower than 40°. Therefore, the sensitivity to Crab is an important measure on the performance of the detector and array, at the same time, the Crab source is the first scientific object for YBJ-ARGO experiment.

In our full simulation, gamma ray signals and nuclei background are generated by CORSIKA[1] software packages and ARGOG[2] which simulate the response of detector to the EAS events. To use better reconstructed events, we set the following criteria on the constructed data: i)Number of fired pad $N_{pad} \geq 20$; ii)Zenith angle $\theta \leq 40°$; iii) Inner events: the core of reconstructed events is within the full covered area. In this work, we "follow" the rising and setting of Crab source, so we can get ARGO array's effect area along its orbit. Here as two major compositions of background, only proton and Helium are considered, the other heavy Nuclear such as Carbon, Nitrogen and Oxygen, are neglected. To compare with a previous study [3], the same Crab and background flux are used. As the array's angular resolution strongly depends on N_{pads}[3], 8 groups by the number of fired pad (N_{pads})is divided from 20 to 450(in table 1). Figure 1 shows the correlation between the gamma ray energy from Crab direction with the number of fired pads. The mode energy is calculated and drawn by the solid line as the function of N_{pads}.

2.   Expected Signal and Background Events Number

For each N_{pads} bins, the optimized window size is determinate by the angular resolution accordingly. In table 1, the expected number of signals(N_{γ}) and background(N_P, N_{He}) events detected by YBJ-ARGO experiment

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1. http://www-ik.fzk.de/˜heck/corsika/
2. http://www.fisica.unile.it/˜argo/analysis/argog/index.html

in one year observation are listed for correspondent N_{pads} bins. Here E_m^γ is the average energy of each bin in Unit of GeV; σ_θ is the angular resolution of the array in the Unit of degree.

Table 1. the events number from the Crab direction detected by YBJ-ARGO experiment in one year. E_m^γ is average energy(GeV) in the corresponding N_{pads} bin. σ_θ is the angular resolution in the unit of degree.

N_{pads}	$20 \sim 30$	$30 \sim 50$	$50 \sim 80$	$80 \sim 120$	$120 \sim 200$	$200 \sim 300$	$300 \sim 450$	$450 \sim$
E_m^γ(GeV)	446	633	868	1196	1539	2432	2998	6464
σ_θ °	1.25	1.00	0.78	0.63	0.55	0.45	0.43	0.39
N_γ	7657	7793	4247	2351	1749	880	554	801
N_p	1866658	1173711	365092	118077	61893	18772	11068	10701
N_{He}	424728	306108	101964	36676	20828	6453	3621	3870

3. Significance Calculation

There are a great deal of cosmic ray background events coming from the sources direction with the γ rays, so we usually use the statistical significance to measure the gamma emission intensity over statistic fluctuation. For a high statistic experiment, the significance is usually calculated with the following equation:

$$s = N_\gamma / \sqrt{N_{bkg}} \tag{1}$$

here N_γ, N_{bkg} means the detected number of the signal and background events within the opening window to the source.

To study the statistic power in combining 8 Npad bins, three methods are used in this work: **Event counting, t value of the "student distribution"** and **Weighted event counting method**. To compare the statistic methods, large number of experiments need to be generated. For this purpose, 2,000 toy MC experiments are generated. For each experiment, the number of events in one on source window and 10 off source windows are randomly generated for 8 N_{pads} bins according to the Poisson distribution, the expected number of Photons and background events in Table 1 are used accordingly.

3.1 Events counting method

This method is to add up signals and background events respectively in eight bins, so the significance can be calculated by

$$s_{sum} = \frac{\Sigma[N_{\gamma+bkg}(\Delta N_{pads}) - N_{bkg}(\Delta N_{pads})]}{\sqrt{\Sigma N_{\gamma+bkg}(\Delta N_{pads}) + \frac{1}{10}\Sigma N_{bkg}(\Delta N_{pads})}} \tag{2}$$

here $N_{\gamma+bkg}$ is the detected event number in the on-source window, including signals and background events. While N_{bkg} means the average number of detected event in off-source windows. And as just mentioned, the event Number of background is made up of Number of protons and Number of Heliums.

$$N_{bkg} = N_p + N_{He}$$

This method is simple, but lead to only a modest sensitivity as all events in the cells are treated equally. In figure 2 curve **a** is the significance distribution from 2,000 experiments using this method, the average value of significance is 11.7.
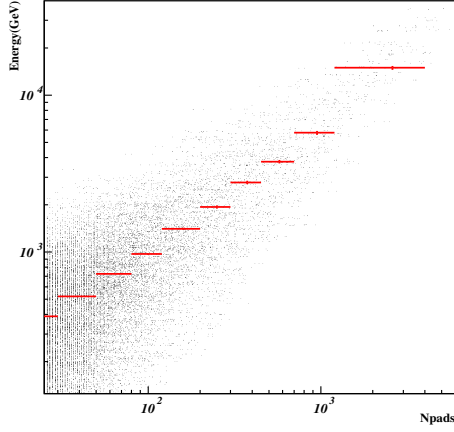
Figure 1. The scatter plot shows the correlation of γ ray energy with number of fired pads N_{pads}, while the line shows the averaged energy as a function of number of fired pad.
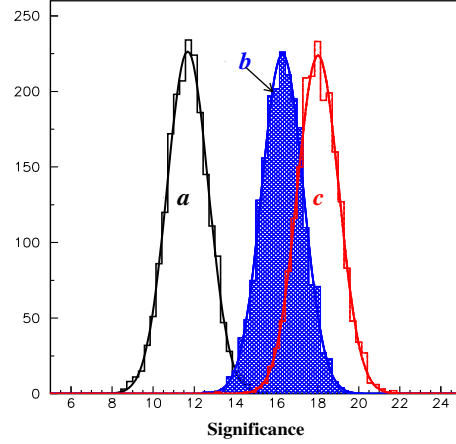
Figure 2. One year's running, YBJ-ARGO experiment could detect γ events excess significance from Crab source in 2000 times fast MC test. The distribution a, b, c is the results from three statistical method, Gaussian fitting signs their width all are very close to 1.

3.2 t value of the "Student distribution" counting method[5][6]

Considering the signal excess in eight N_{pads} bins which correspond to eight energy regions, there would be eight on-source windows and eighty off-source windows. In this method not only the significance values are calculated for on source windows, but also the off source window. Denoting $< s_{on} >$ and $< s_{off} >$ as their average significance

$$< s_{on} >= \frac{\sum_i s_{on,i}}{8} \quad , \quad < s_{off} >= \frac{\sum_j s_{off,j}}{80} \tag{3}$$

in addition their variance can be calculated as

$$\Delta s_{on}^2 = \frac{\sum_i (s_{on,i} - < s_{on} >)^2}{8 - 1} \, , \, \Delta s_{off}^2 = \frac{\sum_j (s_{off,j} - < s_{off} >)^2}{80 - 1} \tag{4}$$

so the value of t can be calculated by

$$t = \frac{< s_{on} > - < s_{off} >}{\sqrt{\frac{\Delta s_{on}^2}{8} + \frac{\Delta s_{off}^2}{80}}} \tag{5}$$

In figure 2, curve **b** is the distribution of the significance over 2,000 times tests with this algorithm, the average significance is 16.3, it is better than **a** algorithm.

3.3 Weighted event counting method[7]

There are two event variables which can be used to construct the event weight. In this work, one is N_{pads}, another is the angular distance from the candidate source which distributes as two dimension Gaussian function

because of experiment's angular resolution. so the on source window is divided into 10 regions similar to archery target, to equally split the event sample, each region is required to cover same size of the solid angle, then we use the Likelihood Ratio of signal to background as event weight:

$$\omega(N_{pads}, k) = ln(\frac{N_{\gamma+bkg}(N_{pads}, k)}{N_{bkg}(N_{pads}, k)}) \tag{6}$$

here k runs from 1 to 10, indicating the regions. Similar to event counting method, for both on and off source windows, the event weight and its uncertainty can be summed as following:

$$N'_{obs} = \sum N_{obs}(N_{pads}, k) \cdot \omega(N_{pads}, k) \tag{7}$$

the variance is calculated by

$$\Delta N'^2_{obs} = \sum (N_{obs}(N_{pads}, k)) \cdot \omega^2(N_{pads}, k) \tag{8}$$

so we can get the significance with the below equation

$$s_\omega = \frac{N'_{obs,on} - N'_{obs,off}}{\sqrt{\Delta N'^2_{obs,on} + N'^2_{obs,off}}} \tag{9}$$

In figure2, curve **c** shows the distribution of significance over 2,000 times tests calculated with this algorithm. It is easy to see that it can give the maximum significance, the distribution average value is about 18.0.

4.   Conclusion

With full Monte-Carlo simulation, we know that angular resolution of YBJ-ARGO experiment mainly depend on the number of fired pad(N_{pad}). By the comparison of the three algorithms on the average sensitivity with 2,000 toy MC experiments, we conclude that YBJ-ARGO experiment can detect TeV gamma ray emission from Crab source in one year at the best at a standard level of 18σ. In other words, if taking 5σ/year as a criterion, the YBJ-ARGO experiment is expected to be sensitive to observe a point source with $0.3I_{crab}$ flux.

5.   Acknowledgements

References

[1] M.Amenomori.et al., 2005,[arXiv:astro-ph/0502039]
[2] Atkins., et al., 2004, ApJ, 608, 680-685
[3] He Hui-Hai, et al., HEP & NP, 2001, 25(1): 79-85 (in chinese)
[4] Silvia Vernetto, et al., Proc. 28th ICRC, Tsukuba(Japan), 2003, 3007-3010
[5] Wang Bao-Shenget al., HEP & NP , 2004(in Chinese)
[6] XU Chun-Xian et al., HEP & NP, 2001, 25(9):807-811(in Chinese)
[7] HU.HongBo, Proc. 28th ICRC, Tsukuba(Japan), 2003, 3027-3030