Expected Sensitivity of ARGO-YBJ to Detect Point Gamma-Ray Sources

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Abstract

ARGO-YBJ is a "full coverage" air shower detector currently under construction at the Yangbajing Laboratory (4300 m a.s.l., Tibet, China). First data obtained with a subset of the apparatus will be available in summer 2003 while the full detector operation is expected in 2005. One of the main aims of ARGO-YBJ is the observation of gamma-ray sources, at an energy threshold of a few hundreds GeV. In this paper we present the expected sensitivity to detect point gamma ray sources, with particular attention to the Crab Nebula. According to our simulations a Crab-like signal could be detected in one year of operation with a statistical significance of $\sim$10 standard deviations, without any gamma/hadron discrimination.

1. The ARGO-YBJ experiment

The ARGO-YBJ experiment is a "full coverage" air shower detector, optimized to work at a primary energy threshold of a few hundreds GeV.

It 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, the "pads", of dimensions 56×62 cm^2, providing the space-time pattern of the shower front. The detector is 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 particles. A detailed description of the experiment is given in [6].

ARGO-YBJ is presently under construction at the Yangbajing High Altitude Cosmic Ray Laboratory, in Tibet (China) at 4300 m above the sea level. The full apparatus will be ready in 2005. Presently (spring 2003) a subset of the detector (about 1650 m^2 of RPCs, corresponding to 28% of the central carpet) has been already installed and it is ready to take the first data.

One of the main goals of the experiment is the detection of gamma rays

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from galactic and extragalactic sources. The extreme altitude of the detector and the use of a large full coverage layer of counters, allow the operation at energies that are typical of the Cerenkov technique. However, unlike Cerenkov telescopes, ARGO-YBJ has a large field of view ($\sim$ 2 sr) and a duty cycle $\sim$100%, allowing the simultaneous observation of a large fraction of the sky and making easier the detection of previously unknown gamma ray emitters.

In this paper we evaluate the sensitivity of ARGO-YBJ to detect point gamma ray sources, in particular the Crab Nebula, considered the "standard candle" for gamma ray astronomy.

2. Crab Nebula and background event rates

The daily rate of events from the source has been evaluated by simulating a gamma ray flux on the top of the atmosphere according to the Crab Nebula spectrum dN/dE = 3.2 10^{-7} $E^{-2.49}$ γ m^{-2} s^{-1} TeV^{-1}, measured by the Whipple collaboration [4]. The gamma rays have been simulated at different zenith angles, following the daily path of the source in the sky. At the Yangbajing site (latitude = 30° N) the Crab Nebula culminates at zenith angle $\theta = 8.1°$. We "followed" the source when it was at $\theta \leq 30°$, for a total observation time of 4.3 hours per day.

To evaluate the background rate due to cosmic rays we have taken into account the proton and Helium fluxes on the top of the atmosphere, according to the spectra dN/dE = 8.98 10^{-2} $E^{-2.74}$ protons m^{-2} s^{-1} sr^{-1} TeV^{-1} and dN/dE = 7.01 10^{-2} $E^{-2.64}$ Helium nuclei m^{-2} s^{-1} sr^{-1} TeV^{-1} [2]. In a first approximation the contribution of heavier nuclei can be neglected.

The showers development in the atmosphere has been simulated by means of the Corsika code [3]. The response of the detector has been studied by using a GEANT3-based code, that gives position and time of all the fired pads for every shower hitting the detector.

If a shower gives a number of fired pads $N_{pad} \geq$50, the position of the core is reconstructed and the arrival direction is evaluated by a space-time conical fit of the shower front[1,5]. Only the events whose reconstructed core falls inside a "fiducial area" A_{fid} = 80 × 80 m^2 (centered on the detector) are considered in the analysis, since the determination of the arrival direction is less accurate increasing the distance of the shower core from the center of the apparatus.

For the events with a number of fired pads $30 \leq N_{pad} < 50$ the core reconstruction is less reliable, hence a simple planar fit of the shower front is performed and no selection with the fiducial area is done.

Concerning the determination of the arrival direction of gamma ray showers, we found that the angular resolution of the detector strongly depends on the number of fired pads N_{pad}, while it is almost independent of the energy and zenith angle of the primary gamma ray, at least in the range of energies and angles con-

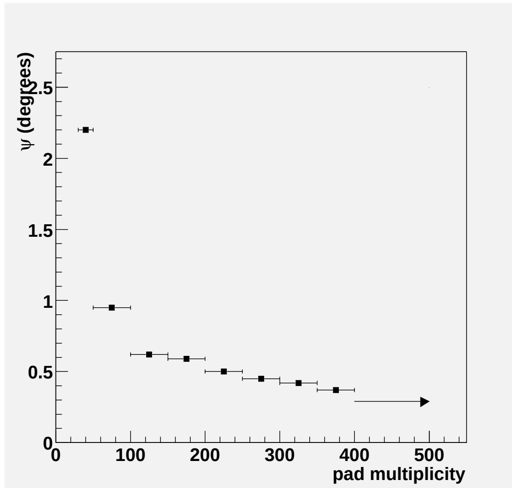

Fig. 1. Opening angle of the circular window around the Crab Nebula position in the sky.

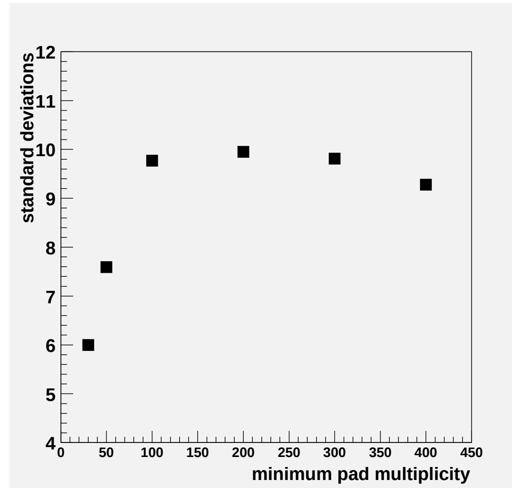

Fig. 2. Significance of the Crab Nebula signal after one year of observation, in terms of standard deviations.

sidered here. For this reason the events have been divided into "classes" defined by ranges of multiplicity N_{pad}, and for each class a different angular resolution has been adopted. In any class with $N_{pad} \geq 150$ the distribution of the angle α between the true direction (given by the simulation program) and the reconstructed one, is well described by a gaussian distribution $dN/d\alpha \propto e^{-0.5\alpha^2/\sigma^2} sin\alpha$, where the parameter σ is defined as the angular resolution. In this case for our "observations" we used the classical circular window of semi-aperture $\psi = 1.58\ \sigma$, that contains 71.5% of the source events and maximizes the signal to noise ratio. For $N_{pad} < 150$, the angle α distribution is not perfectly gaussian and the opening angle that maximizes the signal to noise ratio has been separately evaluated for each class. Fig.1 shows the values obtained for the opening angle ψ, in different N_{pad} ranges.

3. Results and discussion

Table 1 reports the number of events expected in one observation day respectively from the Crab Nebula and from the cosmic rays background (protons and Helium nuclei) for different N_{pad} intervals, using the corresponding observational windows discussed in the previous section. The median energy E_{med} of gamma rays in each multiplicity range is also reported.

Adding the contributions of different intervals one obtains the daily rate of events with N_{pad} larger than a given threshold N_{min}. Fig. 2 gives the number of standard deviations (s.d.) of the Crab signal expected after one year of observation, as a function of N_{min}. According to our calculations, the signal significance

Table 1. Expected event rates from the Crab Nebula and from the background in different N_{pad} intervals. The last column reports the median energy of gamma rays.

N_{pad}	γ rays (ev/day)	Prot (ev/day)	He (ev/day)	E_{med} (TeV)
30-50	58.4	$5.72\ 10^4$	$1.54\ 10^4$	0.55
50-100	16.5	$3.73\ 10^3$	$1.12\ 10^3$	0.60
100-150	4.60	286	87.0	0.95
150-200	2.42	102	33.1	1.30
200-300	2.28	56.9	21.0	1.75
300-400	1.09	16.6	5.8	2.32
> 400	2.50	19.1	7.4	5.10

is equal to 6 s.d. for $N_{min} \geq 30$ (corresponding to a primary energy about E > 500 GeV) then it rapidly increases with N_{min}, reaching ∼10 s.d. for $N_{min} \geq 100$ (about E > 1 TeV) and finally slowly decreases for $N_{min} \geq 300$.

In other words, ARGO-YBJ can observe in one year a source (with a Crab-like energy spectrum) of intensity equal to 0.7 (0.4) Crab units, at energies about $E > 0.5$ (1.0) TeV, with a significance of 4 standard deviations.

We expect a certain improvement in the sensitivity, particularly in the low energy region, by adopting special reconstruction techniques and selection criteria for low multiplicity events, now under investigation.

It should be noted that these results have been obtained without any gamma/hadron discrimination. A further increase of the sensitivity could occur performing a rejection of a large fraction of background events, thanks to the different pattern of the shower front particles in hadronic and gamma ray induced showers. Preliminary results on the possibility to separate background from gamma ray showers are very promising and detailed studies are in progress.

4. References

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