Algorithms for the Determination of the Primary Particle Direction with ARGO-YBJ Detector

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Abstract

The ARGO-YBJ detector is a full coverage array that is starting to take data at the Yangbajing Laboratory (Tibet, P.R. China). In the analysis of the collected data, a precise reconstruction of the shower direction is the crucial point to identify a gamma ray source. We report on the algorithms implemented to determine the primary particle direction and on the obtained angular resolution.

1. Introduction

The ARGO-YBJ detector is a full coverage array consisting of a single layer of RPCs with dimensions of $74 \times 78\ m^2$ [3].

The basic element providing the time pattern of the shower is the logical *pad* ($56 \times 62\ cm^2$). It defines the time and space granularity of the detector.

In the study of the sensitivity of ARGO-YBJ to high energy gamma ray sources the angular resolution of the detector plays a crucial role.

In the following we present three different algorithms that we have developed to determine the direction of the gamma-induced showers and the detector angular resolution.

2. Planar fit

The simplest algorithm for the reconstruction of the direction of the incoming primary particle is the planar fit. This algorithm assumes that the front of the incoming particles forming the EAS can be parameterized by a plane. The fit to the arrival times of the EAS particles is accomplished by minimizing the following expression for χ^2:

$$\chi^2 = \sum(c \cdot (T_n - T_0) - X_n \cdot l - Y_n \cdot m)^2 \tag{1}$$

where T_n is the arrival time measured by the n-th pad, X_n and Y_n are the

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coordinates of this pad, l and m are the director cosines of the planar surface and T_0 an absolute offset common to all the pads in the same event.

The minimization is repeated many times. After the first fit, we reject all the hits with more than 50 ns deviation from the fitted shower front. In the following iterations we first calculate the RMS of the residuals of the previous fit (σ_{res}) , then we reject all the hits with a deviation from the fitted shower front larger that N σ_{res}, where N is a tunable parameter. Moreover, we compare the reconstructed direction at step n with the reconstructed direction at step (n-1). If the two directions differ less than P degrees (where P is another tunable parameter) then the minimization procedure ends and the last reconstructed shower front is assumed as that giving the best estimate of the direction of the primary cosmic ray particle.

The main advantage of this algorithm is that the χ^2 minimization has an analytical solution. Therefore, the algorithm is very fast and it can be applied to all showers without any pre-requisite.

The main disadvantage is that the EAS front is not planar, but is better approximated by a cone. The conical shape of the shower front introduces a systematic error in the determination of the shower direction obtained by a planar fit. This error depends on the position of the shower core with respect to the detector centre.

3. Conical fit

A better estimation of the shower direction can be made with a conical model of the shower front. The fit is accomplished by minimizing the following expression of χ^2:

$$\chi^2 = \sum (c \cdot (T_n - T_0) - X_n \cdot l - Y_n \cdot m - R_n \cdot \alpha)^2 \tag{2}$$

In this equation we have used the same symbols as in eq. (1). The α parameter is the cone slope that can be a free parameter of the fit or can be fixed to a Monte-Carlo derived value; R_n is the distance of the pad from the shower axis and thus depends on the shower direction. The main disadvantage using eq. (2) is that the minimization of the χ^2 function can not be analytically solved.

On the contrary, eq. (2) can be analytically minimized if one assumes that R_n is a fixed quantity. Therefore, we have implemented an iterative procedure in which R_n is calculated using the direction reconstructed in the previous step.

In the first step, as starting direction, we use the direction calculated with the planar fit algorithm described in section 2.

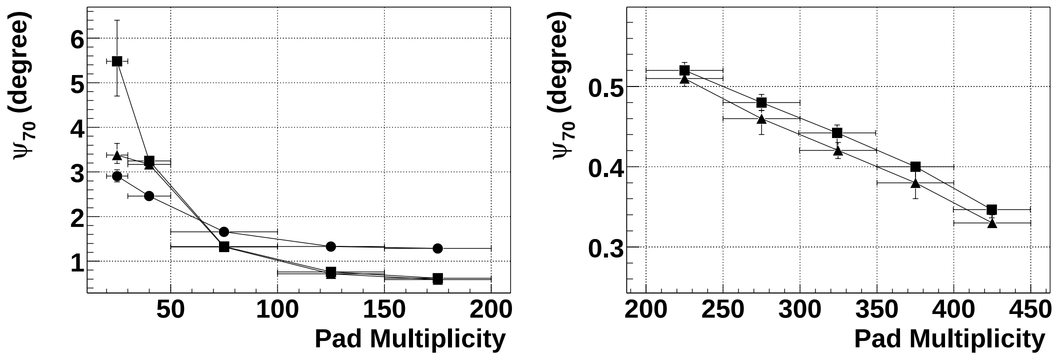

Fig. 1. Ψ_{70} versus pad multiplicity. (Circle: planar; square: conical with free α; triangle: conical with fixed α ($= 0.03\ nsec/m$).

4. Results and Conclusions

Extensive Monte Carlo shower simulations have been performed in order to study the response of the detector. We use the Corsika 6.014 ([2]) code to simulate the development of the gamma induced cascades in the atmosphere. The simulation of the detector has been performed using a GEANT3-based code.

Gamma induced showers in the energy range from 10 GeV to 100 TeV with the spectral index of the Crab Nebula were simulated. The incident zenith angle has been sampled between 0 and 30 degrees.

For the analysis we have accepted only the showers reconstructed in a fiducial area of $80 \times 80\ m^2$ (see [1]).

To estimate the performance of the algorithms in reconstructing of the shower direction we have used the Ψ_{70} parameter. It is defined as the value of the opening angle between the true and the reconstructed directions within which 71.5% of the events are contained.

Fig 1. shows the dependece of Ψ_{70} on the pad multiplicity for the different algorithms presented. It is evident that the conical correction of the shower front plays an important role in the reconstruction of the shower direction.

The direction reconstruction by the planar fit does not improve for multiplicities larger than 100, while both the conical algorithms do improve it.

This behaviour is correlated with the position of the shower core. When the shower core is near to the border of the detector only one wing of the shower cone is detected and therefore the direction is mis-reconstructed.

The better performance of the conical fit with fixed α is due to the same effect (see figure 2.). If the shower core is not well reconstructed the advantage due to a better parametrization of the shower front is lost. The algorithm with a free α is more sensitive to this kind of problem since it can find a smaller χ^2 value adapting the slope of the cone to the points, but introducing a larger error in the direction reconstruction.

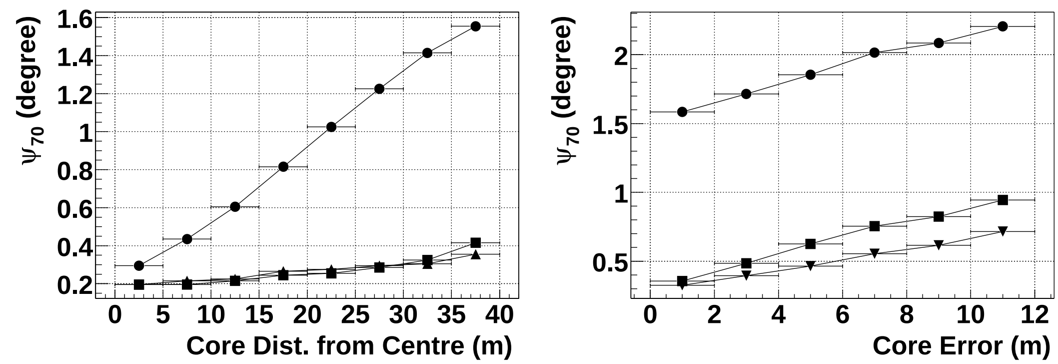

Fig. 2. Dependence of ψ_{70} ($N.\ pad > 150$) on the core distance from the center of the detector (left) and on the error in the core reconstruction (right), for the three algorithms (symbols as in fig. 1).

If the error in the reconstruction of the shower core is large, comparable with the dimension of the detector, then the performance of the planar fit algorithm becomes competitive with the performance of the conical fit algorithms. At low multiplicities, the contamination of external showers reconstructed as internal is relevant ([1]), and therefore the error in the reconstruction of the core position is very large. For this class of events, the planar fit gives better results.

1. G. Di Sciascio et al. (ARGO-YBJ Coll.) 2003, in this proceedings.
2. D. Heck et al 1998, FZKA 6019.
3. A. Surdo et al. (ARGO-YBJ Coll.) 2003, in this proceedings.
4. S. Vernetto et al. (ARGO-YBJ Coll.) 2003, in this proceedings.