Identification of Showers with Cores Outside the ARGO-YBJ Detector

G. Di Sciascio,[1] C. Bleve,[2] T. Di Girolamo,[1] D. Martello,[2], E. Rossi,[1] for the ARGO-YBJ Collaboration [3]
(1) Dip. di Fisica Universitá di Napoli and INFN sez. di Napoli, Napoli, Italy
(2) Dip. di Fisica Universitá di Lecce and INFN sez. di Lecce, Lecce, Italy

Abstract

In any EAS array, the rejection of events with shower cores outside the detector boundaries is of great importance. A large difference between the true and the reconstructed shower core positions may lead to a systematic miscalculation of some shower characteristics. Moreover, an accurate determination of the shower core position for selected internal events is important to reconstruct the primary direction using conical fits to the shower front, improving the detector angular resolution, or to performe an efficient gamma/hadron discrimination.

In this paper we present a procedure able to identify and reject showers with cores outside the ARGO-YBJ carpet boundaries. A comparison of the results for gamma and proton induced showers is reported.

1. Introduction

Showers of sufficiently large size can trigger a detector even if their core is located outside its boundaries. The corresponding core positions are generally reconstructed not only near the carpet edges but also well inside the boundaries. As a consequence, sofisticated algorithms able to reduce the contamination of external events are needed. The goal is to identify and reject a large fraction of external events before exploiting any reconstruction algorithm, only by using some suitable parameters.

In this paper we present a reconstruction procedure able to identify and reject a large fraction of showers with cores outside the ARGO-YBJ detector.

2. Identification of external events

The ARGO-YBJ detector consists of a single layer of RPCs with dimensions of $\sim 74 \times 78\ m^2$. The area surrounding this central detector (*carpet*), up to $\sim 100 \times 110\ m^2$, is partially ($\sim 50\%$) instrumented with RPCs (*guard-ring*). The basic element is the logical *pad* ($56 \times 62\ cm^2$) which defines the time and space granularity of the detector. The detector is divided in $6 \times$ 2-RPC units

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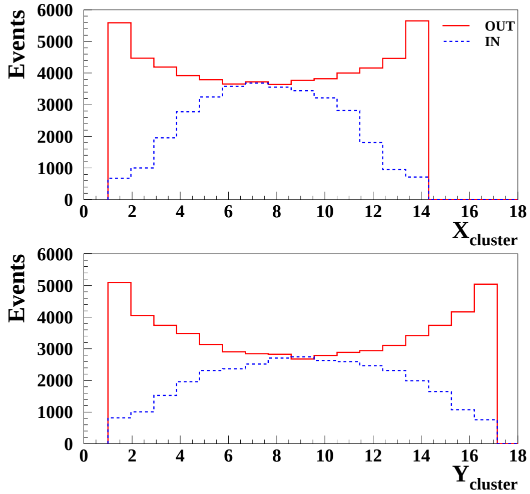

Fig. 1. Coordinate distributions of the cluster with the highest particle density for γ-induced events with a pad multiplicity $N_{hit} > 100$.

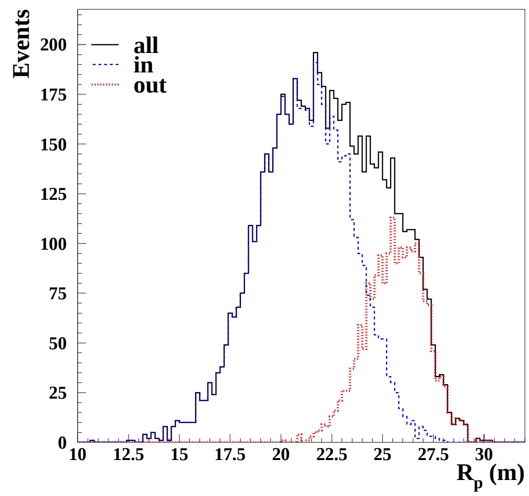

Fig. 2. Distributions of the parameter R_p (solid histograms) for IN reconstructed showers, for γ-induced events ($N_{hit} > 100$).

(clusters): the central carpet contains 10×13 clusters. For a detailed description of the ARGO-YBJ detector see [3].

Various parameters based on particle density or time information are under investigation to identify showers with core position outside a given fiducial area. The most interesting ones are the following: (1) position of the cluster with the highest particle density, (2) position of the cluster row/column with the highest total particle density, (3) mean distance R_p of all fired pads to the reconstructed shower core.

To perform these calculations we have simulated, via the Corsika code [1], gamma and proton induced showers with energy spectra ($\sim E^{-2.5}$ and $\sim E^{-2.75}$, respectively) ranging from 100 GeV to 50 TeV. The detector response has been simulated via a GEANT-3 based code.

As an example, in Fig. 1 we show the distributions of the position of the cluster with the highest particle density for γ-induced showers. In the plots we compare the events with the core really external to a 80×80 m^2 fiducial area (solid histograms) and the truly internal ones (dashed histograms). To investigate the discrimination power of this particular parameter we have simulated a detector completely instrumented up to $\sim 100 \times 110\ m^2$, i.e., containing 14×17 clusters. Therefore, the cluster coordinates run from 1 to 14 (X view) and from 1 to 17 (Y view) starting from the lower left corner of the carpet.

The R_p distribution for showers reconstructed inside a 80×80 m^2 fiducial area is shown in Fig. 2 (solid histogram). The dashed line refers to truly IN events while the dotted histogram refers to OUT showers erroneously reconstructed as internal. The shower cores have been calculated by means of the simple center of gravity method. As can be seen, the parameter R_p identifies quite well the events with core outside the carpet. Large distances between the truly and the reconstructed shower axis lead to larger R_p values. This fact offers the possibility to define a cut in R_p to identify these events. A conservative choice is to reject showers with $R_p > 25$ m.

From these studies it follows that the identification of a large fraction of external events can be achieved by defining a suitable fiducial area togheter with a combination of cuts in the parameters discussed above.

3. Maximum Likelihood Method (LLF)

Different algorithms have been investigated to reconstruct the shower core position in the ARGO-YBJ experiment [2]. The most performant is the Maximum Likelihood Method. We point out that expression for -LLF of [2] refers to the case of a Poisson distribution in which the pads are not fired with probability $P_i(0)$ or fired with probability $P_i(>0) = 1 - P_i(0)$ (hereafter 'LLF1 method'). In our study almost always the fired pads have particle multiplicity 1, and therefore such a simple discrimination can be made. However, if we consider a larger area as the whole RPC, the multiplicity can be > 1, and the proper Poisson distribution on the fired RPCs appears more adequate. In this case the sum on fired elements is:

$$-\Sigma_j lnP_j(>0) = -\Sigma_j N_j ln(\rho_j) - ln(S_{RPC})\Sigma_j N_j + \Sigma_j ln(N_j!) + S_{RPC}\Sigma_j \rho_j \quad (1)$$

where $N_e \cdot \rho_j$ is the particle density expected on the j-th RPC at a distance R_j from the core, N_j is the recorded particle number and S_{RPC} is the RPC area. The shower size can be calculated via the equation

$$N_e = \frac{\Sigma_j N_j}{S_{RPC}\Sigma_j \rho_j}. \quad (2)$$

We define this calculation the 'LLF2 method'. As a consequence, we expect that the differences between LLF1 and LLF2 increase with the particle density, for a fixed area. In Fig. 3 we compare the shower core position resolution calculated by applying the LLF1 and LLF2 methods on the RPCs for γ-induced showers with the core randomly sampled inside a 80×80 m^2 area. As expected, the resolution worsens with multiplicity if the LLF1 approach is applied when the number of particles hitting the RPC is > 1. We note that for very low multiplicities ($N_{hit} < 80$) the method LLF1 is more performant than LLF2. In fact, the algorithm based on RPC occupancy (LLF1) provides a better representation of the hit distribution in very poor showers.

For very high multiplicities ($N_{hit} > 10^3$) the shower core position is determined by LLF2 with an uncertainty < 1 m.

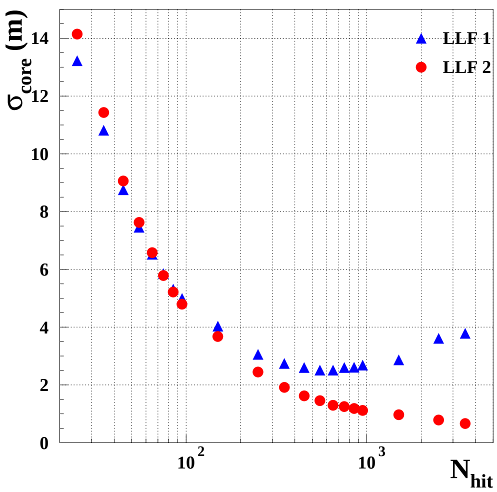

Fig. 3. Comparison between the shower core position resolutions obtained using LLF1 and LLF2 methods.

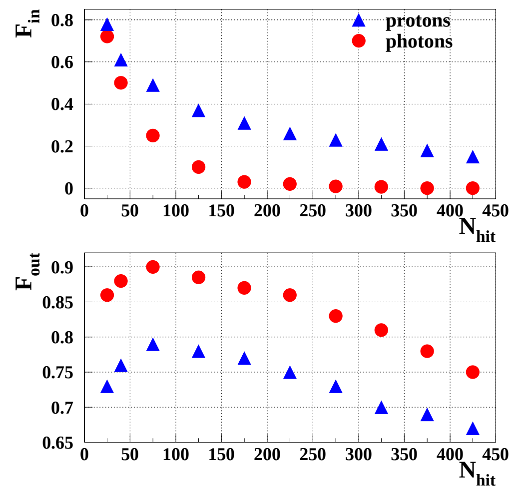

Fig. 4. Fraction of truly internal and external events rejected by the selection procedure (1) - (4).

4. Results

A possible procedure to reject external events in the ARGO-YBJ detector is the following one: (1) Rejection of the events whose highest density clusters are on the guard ring (X = 1, 14; Y = 1, 17) or on the boundaries of the central carpet (X = 3, 12; Y = 3, 15). (2) Rejection of the events whose highest total density rows or columns are respectively in positions $\{1, 3, 15, 17\}$ or $\{1, 3, 12, 14\}$. (3) Reconstruction of core coordinates $\{X_c, Y_c\}$ using the Maximum Likelihood Method. (4) Further rejection of events with $R_p > 25$ m.

In Fig. 4 the fraction of events (internal and external to an area of 80 × 80 m^2, respectively) rejected after the steps (1) - (4) is reported. As can be seen, this procedure is able to identify and reject a large fraction of external events. For low multiplicities ($N_{hit} < 100$) a significative fraction of internal events is erroneously rejected, especially in proton-induced showers.

5. References

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