EAS Time Structures with ARGO-YBJ experiment

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1. Introduction

The ARGO-YBJ experiment (Astrophysical Radiation with Ground-based Observatory at YangBajing) has been designed to study cosmic rays and cosmic gamma-radiation at energy larger than few hundred GeV, by detecting air showers at high altitude with wide-aperture and high duty cycle[1]. ARGO-YBJ is operating in its complete layout since 2007 allowing a complete and detailed three dimensional reconstruction of the shower front with unprecedented spatial and time resolution. The space-time structure of extensive air showers depends on primary mass, energy and arrival direction and on the interaction mechanisms with air nuclei. Measurements of shower parameters with several detection techniques would be required for a detailed knowledge of the shower front. A flat array like ARGO-YBJ can measure the particles arrival times and their densities at ground. The digital readout allows detecting shower secondary particles down to very low density and the high space-time granularity is able to provide a fine sampling of the shower front close to the core. The time profile of the shower front can be reconstructed by the time of fired pads. The time structure of the shower disc has been studied as a function of the distance to the shower axis and the curvature of the shower front, defined as the mean of the time residuals with respect to a planar fit, is investigated following the approach described in [2] in the energy range between 300 GeV and 100 TeV. A particular attention is devoted to the events that show particularly wide time distribution.

2. Shower front

Shower by shower fluctuations play a key role in understanding the EAS morphology. ARGO-YBJ detector design offers a unique chance to study in detail and with a high resolution the shower front at ground level. Lateral distribution and time profile around the shower core have been analyzed.

In this work a new and wider sample of data have been processed in order to check the data

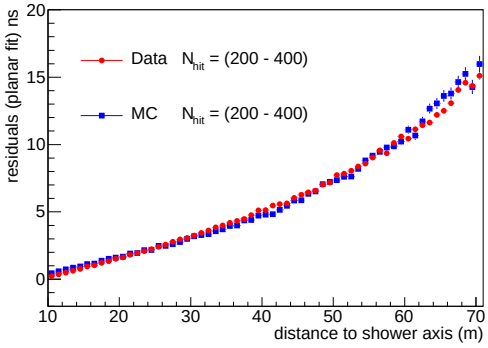

Figure 1. Comparison between data and MC of the shower profile in a multiplicity range between 200 and 400 hits.

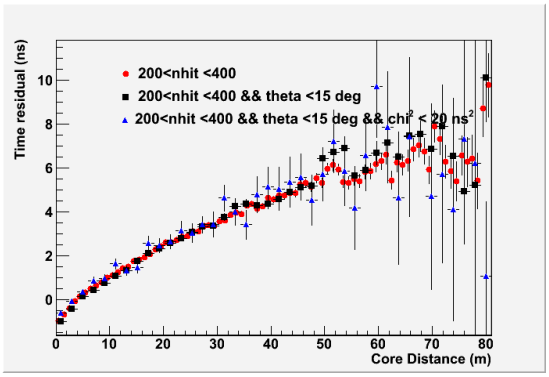

Figure 2. Shower profile with quality cuts only on planar reconstruction

consistency in different sample of data and to study more in detail the systematic due to the reconstruction techniques. The condition to select only well reconstructed showers could bias the shape of the curvature. In figure 1 the distribution of the time residual respect to a planar fit obtained with quality cuts on the conical fit are shown for some multiplicity ranges. Also a comparison with MC data is shown. In figure 2 the same distribution is shown with quality cuts only on the planar reconstruction. The behaviour around the core is similar, while at distances larger than 40 meters from the core the

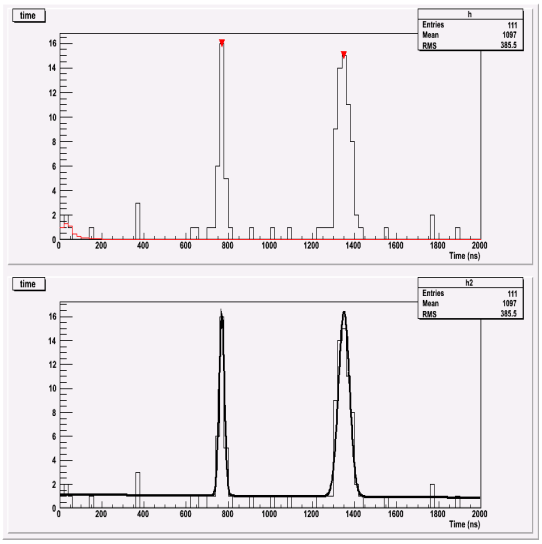

Figure 3. Detection of the peaks in the time distribution(top) and the double peak fit on data (bottom)

two distribution becomes different. The bias introduced by the reconstruction need further and deep analysis. For showers with the core outside the detector it becomes harder to define the correct parameters of the shower profile, as the energy and real core distances of the showers are hard to be defined, and a huge Montecarlo production is needed in order to reproduce well the analysed data.

3. Double Showers

Shower with particular wide time distribution have been investigated by ARGO-YBJ collaboration in the past[3]. Two different classes of events have been identified: *Wideshowers* and *Doubleshowers* The first class indentifies showers with a high number of hits homogeneously distributed in a wide space-time range. In the second class two separated showers are evident. In this work only the second class is studied in details.

The origin of the double showers in ARGO-YBJ events is mainly due to statistical coincidences. The expected number of events has been calculated as the number of coincidences expected in the trigger time window $\tau = 2\mu s$ taking into account the quality selection on subshowers. The expected rate is equal to:

$\lambda_{exp} = 2 \times \lambda_1 \times \lambda_2 \times \tau = 29.0 \pm 0.5 Hz (1)$

where $\lambda_1 = \lambda_2 = 2.69 kHz$ is the observed rate of the showers satisfying the quality requirements for the subshowers. In order to test and check the selection algorithm and the expected distribution of the statistical coincidences a sample of random double showers has been generated putting together in same time window series of real events, shifting randomly the second event. In this work, a new more efficient selection algorithm has been used, based on the time distribution of the events and reconstructing double peaks using techniques used in spectroscopy[4]. In figure 3 a two peaks fit on a double shower is shown. Using this technique an efficiency in double shower reconstruction of 60% has been reached. Applying this selection in a large sample of data an observation rate of double showers of about 9 Hz is expected. The angle and time distribution will be analyzed in order to test the possibility to detect anomalies as a signature of possible effects due to heavy or 'exotic' cosmic ray particles.

4. Conclusions

In this work the shower front time profile and distribution have been presented. The curvature of the showers around the core have been studied, illustrating the reconstruction effect on ARGO-YBJ data. Large time residual have also been investigated, and in particular double showers. A new Algorithm have been introduced, increasing the detection efficiency. The detailed study of the angular and time distribution of the selected events will be useful in studying possible shower anomalies.

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