



Time calibration by exploiting the continuous carpet feature of ARGO-YBJ

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Abstract: A continuous detector offers the opportunity of a software calibration based on the assumption of locally flat shower front, provided small portions of the detector (tens of m^2) are considered and sufficiently high density events are selected. On these detector portions a simple time-position fit of the arriving particles provides the time calibration constants of that part of detector. Then, if a procedure is available that can measure the time offset among the different portions, the entire detector can be calibrated in time. We will describe here the method applied to the ARGO-YBJ detector along with the results that have been obtained.

Keywords: Time Calibration, Continuous Detector, High Particle Density

1 Introduction

Time calibration is a crucial item for a shower array performance as it uses the time of flight method to reconstruct the arrival direction of the primary particle. That requires all detectors to provide the same time in case of shower front perfectly horizontal and exactly plane; time calibration would just guarantee the equal time among detectors, or detector parts. The shower detectors, being typically focalized toward the high energies and operating well above TeV energies, have historically operated by sampling charged particles. The sampling approach and the reduced number of electronic channels for arrival time measurements, has allowed a hardware time calibration. A continuous detector instead, as the ARGO-YBJ carpet, besides a lower energy threshold, needs a different approach to the time calibration. That has been accomplished by means of the technique reported in [2] whose main features are:

- a)** it is based on the conical fit of the shower (also the core position is required);
- b)** at least 1-day data are used and the validity is of the order of 10 days;
- c)** the day-night variations are not reproduced and average corrections are used.

Here we present an alternative approach in which the small and contiguous portions (tens of m^2) of the detector, where the structure of the shower front is essentially flat, are taken into account. Provided the detector is segmented in the above mentioned portions and has high density of electronic channels, a simple plane fit of time versus position on each detector part allows the determination of the time calibration constants. Then, if an algorithm is available that

can compensate for the time offsets among these different parts, the entire detector can be time calibrated. The advantages envisaged by applying this approach are:

- a)** possibility of determining the calibration constants without preliminary shower core determination;
- b)** independency of the shower conicity determination;
- c)** low processing times and calibration in a few hours;
- d)** definition of a "suited" time frequency for calibration, if environmental parameters affect the detector performance;
- e)** "a posteriori" possibility of defining the noisy or inefficient channels;
- f)** possibility of continuous monitoring of the detector performance.

The ARGO-YBJ experiment has been in stable data taking since November 2007 at the YangBaJing Cosmic Ray Laboratory (Tibet, P.R. China, 4300 m a.s.l.). Its main fields of research are γ -astronomy and cosmic ray physics with an energy threshold of a few hundred GeV. The ARGO detector [1], shown in Fig.4, consists of a central carpet $\sim 78 \times 74 m^2$, made by a single layer of Resistive Plate Chambers (RPCs) with $\sim 93\%$ of active area, enclosed by a guard ring partially ($\sim 20\%$) instrumented up to $\sim 110 \times 100 m^2$. The apparatus has a modular structure, the basic data acquisition unit being a Cluster ($7.6 \times 5.7 m^2$), made by 12 RPCs ($1.25 \times 2.8 m^2$ each). Each RPC chamber has 10 independent pads of $61.8 \times 55.6 cm^2$ which represent the sampling unit of the particle arrival time (time pixel). The full detector has 153 clusters with a total active surface of $\sim 6700 m^2$, while the continuous central carpet has 130 clusters. The high density of readout channels, namely 120 time measurements in about $43 m^2$, allows the shower front reconstruction with an high space-time resolution. In this paper we describe an approach to the time calibration that

exploits just the continuity of the carpet, paying attention to the general advantages of such a method.

2 The method

The space unit for time calibration is the cluster. The calibration process starts with the selection of events with high particle density. Events with at least one cluster having more than 60 fired pads (*hits*) are selected, then a plane fit of time vs position is performed on each cluster which satisfies the high particle density condition ($N_{hit} > 60$). The times used in the fit are those of the first particle hitting the pad, later times measured on the pad are not considered. At the end of the plane fit, the difference (residual) between the time provided by the fitting plane and the time measured on each fired pad is available; moreover the procedure provides the director cosines of the plane ($\cos x$, $\cos y$), the χ^2/N_{fit} and the root mean square (RMS) of the time residuals in the event defined with respect to the surviving hits after fit (N_{surv}); in fact, given an event, the plane fit is iterated in a loop where, at each iteration, the pads that have time residuals $> 3RMS$ are excluded. In order to define the ending condition of the loop, the RMS, χ^2/N_{fit} , N_{surv} , $\cos x$, $\cos y$ have been studied with respect to the iteration index. Accordingly, the ending condition has been defined as the logical OR of: 1) the iteration number reached 5 ($n_{max} = 5$); 2) the number of surviving hits remains constant ($(\Delta N_{surv})_{n,n+1} = 0$). Having the distributions of the pad residuals, it is possible to define the time calibration constant of each pad. Moreover, at the end of the event sample processing, also the mean values of $\cos x$ and $\cos y$ are available. The reason for the mean director cosines to be different from 0 are manifold, namely it may be due to the earth magnetic field, to the electronics or to the detector itself. The values of the mean cosines of the single cluster have been used to apply a rotation to the plane of the calibration constants so to have, within the error, 0 values of the mean director cosines in each cluster.

2.1 Calibration constant definition

Given a certain pad, its residual distribution (Fig.1) provides both a mean residual value and a peak residual value; in principle both of them could be the right choice for defining the calibration constant. Nevertheless choosing one or the other could introduce some systematic effect. We considered two possible choices, that is: 1) mean of the histogram in ± 3 RMS around the mean; 2) peak from a gaussian fit in ± 3 RMS around the mean; we have compared these two definitions and found the corresponding values are typically shifted by a few tenths of ns; therefore they are almost equivalent. The difference distribution all over the carpet (15600 pads, apart from dead or excluded pads) is shown in Fig.2. Actually we defined the calibration constant as the case 1).

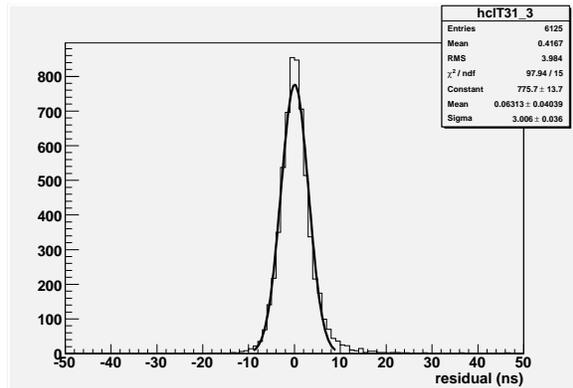


Figure 1: The residual distribution of a pad.

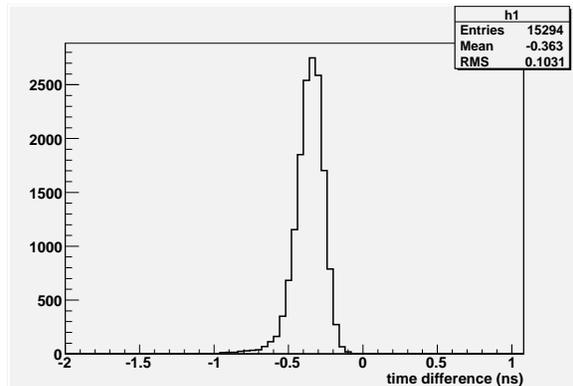


Figure 2: Distribution of the difference (peak residual - mean residual) of a pad, for all the pads of the carpet.

2.2 Inter-cluster calibration

At the end of the procedure described till now, each cluster is in principle time calibrated by itself; a further step is needed to correct for the offsets between clusters so to have the calibration constant of the pad with respect to the entire carpet. The general idea is that close clusters are heavily correlated in case of very dense events and the time offset between two clusters can be estimated. As an estimator we have chosen the difference between the times of the two fitting planes calculated at the center of each cluster. Therefore, given an event, for all the couples of adjacent clusters satisfying the condition $N_{hit} > 60$, the time difference is calculated according to the mentioned rule; the mean value of the difference is the time offset between the two clusters. Accordingly a matrix that contains the time offset between adjacent clusters is produced T_{ij}^v , where i and j are respectively row and column in the carpet, v refers to the way of comparison, that means 1 is for vertical comparison and 0 for left-right as shown in Fig.3. The time offsets so obtained have been compared with the expectation resulting from the calibration in use [2].

We found good agreement both in case of vertical selection (0.14 ns as mean of the offset difference between the two methods, with 0.5 ns rms) and horizontal selection (mean 0.03 ns and 0.5 ns as rms). Having this matrix, the

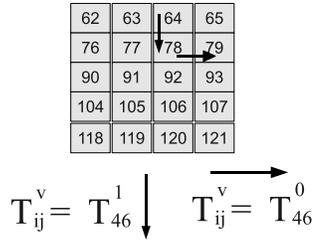


Figure 3: Time difference between adjacent clusters: matrix. Each element represents the time offset between two adjacent clusters, along either vertical or horizontal direction (arrows).

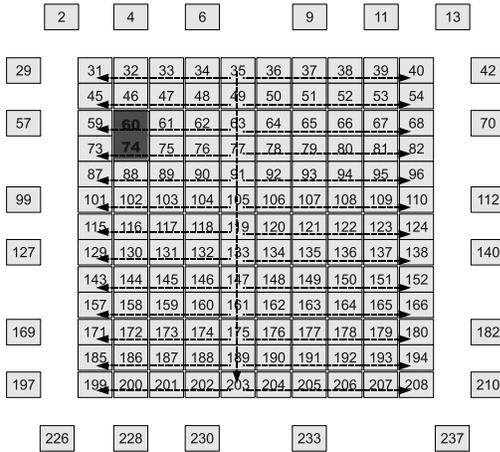


Figure 4: Layout of the ARGO detector. The arrows show the alignment scheme used for inter-cluster calibration.

alignment between clusters has been done according to the scheme shown in Fig.4: the clusters in a row were aligned starting from the central one (the one belonging to the column of cluster 35), that means the calibration constants of each cluster were modified by adding the sum of the "horizontal" offsets with respect to the central one. Once all rows were aligned, the alignment among rows was analogously done by adding the sum of the "vertical" offsets, taken along the column of cluster 35, to the constants of a row. At this point the calibration constant of a pad is defined with respect to the entire carpet and the calibration process is terminated. In order to evaluate the goodness of the method, a sliding window (gray vertical rectangle in Fig.4) containing two adjacent clusters in a column has been considered and a plane fit has been performed on the two calibrated clusters at the same time, provided they both satisfied the high density condition in the event. According to the alignment scheme, one would expect the maximum misalignment between clusters to be on the external columns in case of inefficient calibration procedure. Fig.5 shows the mean residuals (full dot) on each pad after the plane fit has been done on two clusters of the left side

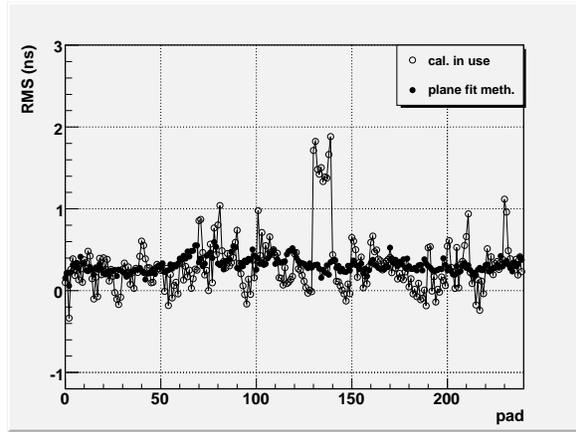


Figure 5: Plot of the mean residuals vs pad index after the plane fit was performed on a "double cluster" (see text).

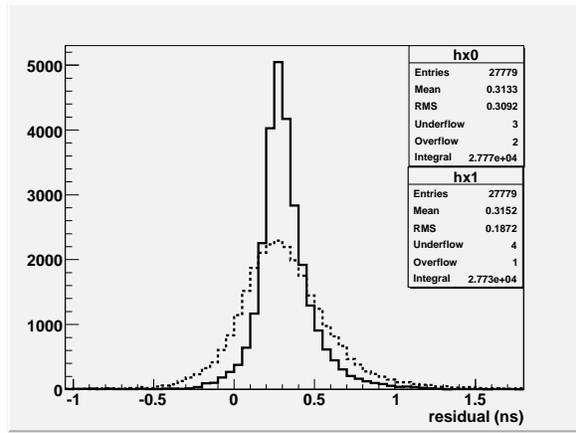


Figure 6: The residual distribution on the carpet from the plane fit on the "double cluster".

external column, namely clusters 45 and 59; for reference the same quantities obtained by using the calibration in use (empty dots)[2] are also reported. The plot refers to data of a single run lasting about 3 hours. It comes out the full dots are better distributed around 0, while the empty ones show a RPC chamber that changed its own calibration constants by about 1 ns. By moving the sliding window all over the carpet and fitting all over the couples of clusters satisfying the high density condition, we get the histogram of residuals as shown in Fig.6, still for the mentioned 3 hour run. The ratio between the full width half maximum (FWHM) values of the residual distribution in the two cases of calibration in use and this method, is around 2.5. Extending this analysis to about 10 days and plotting the RMS of the residual distributions we get interesting results. Plotting the RMS vs time as in Fig.7 (1 is January 1st 2009), we see a better stability in case of the proposed procedure. If the RMS is plotted vs the run-length (or number of files in a run - 1 file corresponds to about 7 minutes), as in Fig.8, one can infer what's the natural minimum time scale for calibration according to this procedure, which results to be about 1-1.5 hour; for shorter runs the RMS increases due

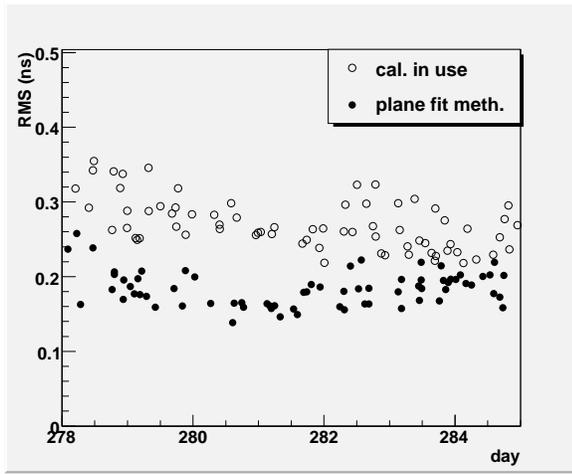


Figure 7: RMS of the residual distribution, on the entire carpet, as from the plane fit on the "double cluster" vs time (day in 2009).

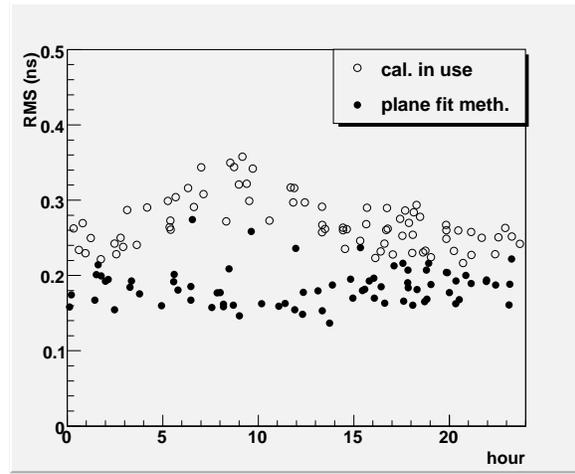


Figure 9: RMS of the residual distribution, on the entire carpet, as from the planar fit on the "double cluster" vs UT hour (local time at YBJ is UT + 8 hours).

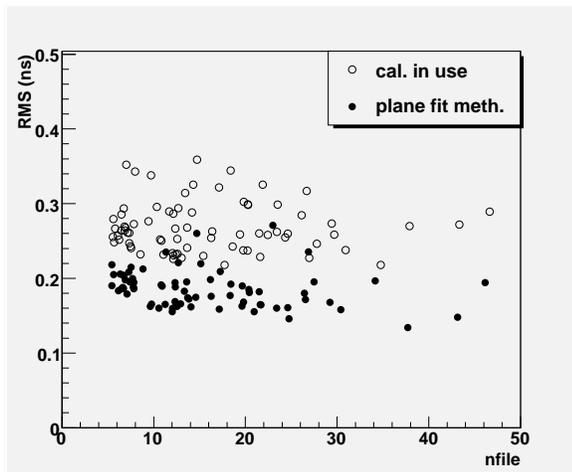


Figure 8: RMS of the residual distribution, on the entire carpet, as from the plane fit on the "double cluster" vs number of files in a run, that is run length as 1 file corresponds to about 7 minutes.

to lack of statistics. Finally in Fig.9 the plot of the RMS is done vs the day-time; we see the full dots do not show any evident dependence on the day-time, instead of the empty dots which show a maximum at about 5 pm YBJ local time. The analysis has been repeated on a different data set and the results shown in the previous have been confirmed.

3 Conclusions

A procedure for the time calibration of the ARGO-YBJ detection channels exploiting the continuity and segmentation of the detector has been studied. This procedure provides automatically the exclusion of the inefficient or noisy channels and is able to determine the calibration constants in a few hours of data taking avoiding any average effect on the

variability of the detector performance induced by the variation of the environmental parameters.

References

- [1] G. Aielli, *et al.*, NIM A **562** (2006) 92;
- [2] G. Aielli, *et al.*, Astroparticle Physics **30** (2009) 287.