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Time Calibration of the ARGO-YBJ experiment

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The ARGO-YBJ detector has the capability to measure the arrival direction of the primary cosmic rays by means of detailed space-time pictures of the air showers. Therefore the time calibration of the apparatus is crucial for astronomical observations. Here a software procedure for the time-calibration is presented. It has been applied to the portion of the apparatus currently in data-taking (~ 5000 space-time pixels).

1. Introduction

The ARGO-YBJ detector is a full coverage carpet made by Resistive Plate Chambers (RPCs) devoted to cosmic ray studies and γ-astronomy [1]. Currently a portion of $\sim 1900\ m^2$ is instrumented and takes data since 2004. At the end of the construction the dimensions of the detector will be $74 \times 78\ m^2$. The fiducial area will be enlarged with a partially covered ring and the geometrical dimensions will reach $100 \times 110\ m^2$.
The RPCs are equipped with pick-up strips and the fast-OR-signal of 8 strips constitutes the logical pixel (called *pad*) for triggering and timing purposes. Planar and conical fits are used in the space-time view (Fig. 1) in order to reconstruct the arrival direction of the primary rays. For the purposes of the time-calibration only the planar fit has been used. The front of the incoming particles is parameterized by a plane and the arrival times of the particles are fitted by minimizing the following quantity:

$$\chi^2 = \sum_i w_i \left(t_i - t_0 - \frac{l}{c} x_i - \frac{m}{c} y_i \right)^2 \tag{1}$$

where the sum is over the fired pads, w_i is the number of strips fired in the i-th pad, t_i is the measured time and x_i, y_i are the pad coordinates. The parameters reconstructed by the fit are the direction cosines l, m and the time constant t_0. The accuracy in the reconstruction of the shower direction depends on the measurement of the arrival times of the particles on the pads. The goal of the calibration is to remove systematical time-offsets among the read-out channels due to differences in the length of the cables, in the discharge time in the RPCs, in the electronic circuits and so on.

2. Software calibration

The calibration has been performed on a data set of ~ 6.5 millions of events collected in January 2005 with a trigger requiring at least 60 fired pads. The first step of the procedure is to reduce the residuals for each pad, that is the difference between the measured time and the fit-time (see formula 1). The correction is estimated fitting the peak of the residual distribution for each pad, as shown in Fig. 2. The mean value of the Gaussian curve is the pad-residual and it is used to correct the times measured by that pad. The distribution for all the pad-residuals before the calibration has a range of $\sim 25\ ns$ (Fig. 3). Some portions of the apparatus present strong time-offsets in the range $5 - 12\ ns$.

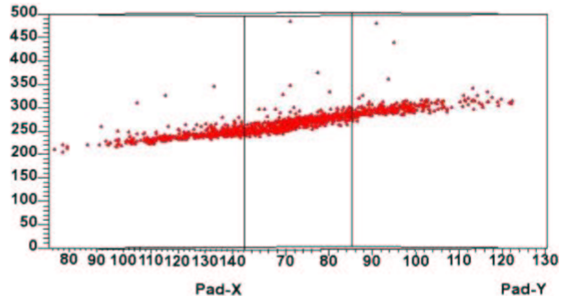

Figure 1. Space-time view of a shower.

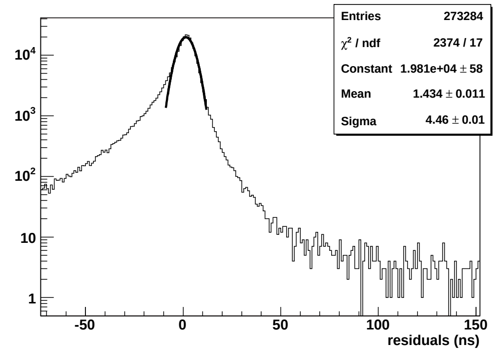

Figure 2. Residual distribution for a pad. The Gaussian fit is superimposed on the peak.

The residual correction strongly improves the quality of the shower reconstruction: the mean value of χ^2 decreases from $121.3\ ns^2$ down to $94.2\ ns^2$, the new pad-residual distribution (Fig. 4) is narrower than the previous one and the anomalous structures disappear. Also the mean value of the reconstructed zenith angle (θ) decreases as expected [2]. But these improvements do not demonstrate that the absolute pointing is correct. In first approximation we expect that the primary flux is symmetrical with respect to the azimuth angle (this assumption will be further discussed in Sec. 3). As a consequence the azimuth distribution has to be uniform and the mean values of the direction cosines have to be null. This is not the case and a planar time-correction is needed [2, 3, 4]. This characteristic-plane correction will not modify the pad-residual distribution of Fig. 4. We have determined the correction by exploiting the additive character of direction cosines:

$$< l >=< l_0 > + a = a \qquad < m >=< m_0 > + b = b \tag{2}$$

where $< l >$, $< m >$ are the mean reconstructed direction cosines, l_0, m_0 are the ”true” direction cosines with null mean values and a, b are the direction cosines to be used to correct the times. Finally the complete

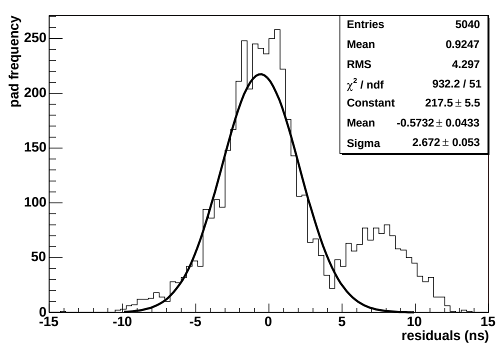

Figure 3. Pad-residual distribution before the calibration. A Gaussian fit is superimposed. These pad-residuals are used to calibrate the detector.

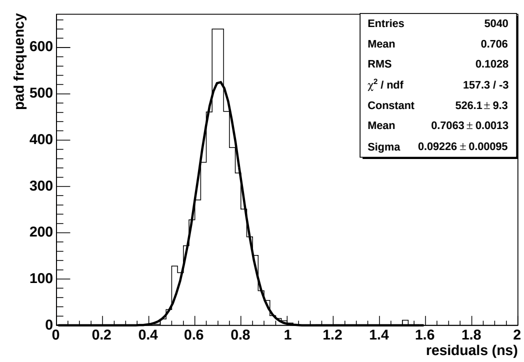

Figure 4. Pad-residual distribution after the calibration. A Gaussian fit is superimposed.

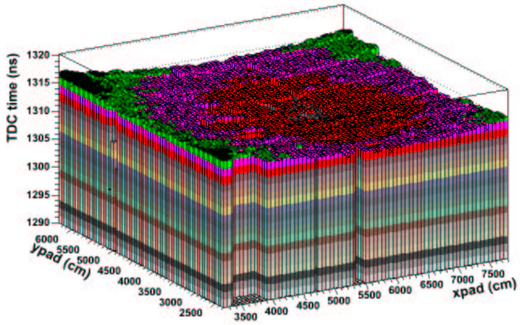

Figure 5. TDC peak distribution versus the pad position (after the calibration).

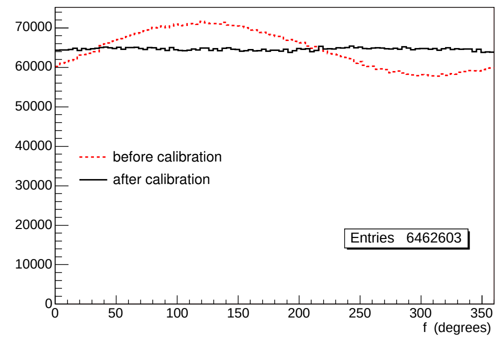

Figure 6. Azimuth distribution before and after the calibration.

time-correction for the i-th pad results

$$t_i \rightarrow t_i - \delta_i - \frac{a}{c} x_i - \frac{b}{c} y_i \tag{3}$$

where the residual correction is δ_i and the plane correction depends on a, b and on the pad coordinates x_i, y_i. Some results of the complete time-correction are shown in Fig.s 5 and 6. The TDC mean values are shown in Fig. 5 with respect to the position of the pads. A circular symmetry is present as foreseen, the shape of the distribution depends on the trigger requirement and the TDC values are in a range of few ns. In Fig. 6 the azimuth distribution is shown before and after the calibration. A simple geometrical simulation permitted to verify that the sinusoidal shape is the effect of a tilted characteristic plane and the direction cosines of this plane are those expected from the $< l >$ and $< m >$ values and used for the time-correction.

3. Azimuth symmetry

The assumption that the azimuth (ϕ) angle has a uniform distribution has been checked with a preliminary Corsika-simulation in order to study the effect of the geomagnetic field ($\theta_H \simeq 46^0$ at the YBJ site) on the secondary particles in the shower [5, 6]. The ϕ-distributions for real data before the calibration and for simulated data have been fitted with a two-harmonics function

$$\frac{dN}{d\phi} = K \left[1 + A_I cos(\phi - \psi_I) + A_{II} cos(2\phi - \psi_{II})\right]. \tag{4}$$

The results of these fits in different θ-ranges are reported in Table 1. It is evident that the coefficients A_I of the real distributions are much higher than those of the simulated data. Then we can conclude that the geomagnetic effect is much lower than the effect of a tilted characteristic plane. This fact confirms the necessity of the characteristic-plane correction.

4. Hardware and software checks

A hardware procedure has been used to calibrate 6% of the pads in data-taking. A movable reference RPC has been placed above standard RPCs and the time-measurements have been compared with the measurements by

Table 1. Harmonic amplitudes as a result of ϕ-distribution fit for simulated and real data before calibration.

θ-range	A_I^{simu} (%)	A_{II}^{simu} (%)	A_I^{real} (%)	A_{II}^{real} (%)
$0^0 - 10^0$	0.23	0.15	1.0	0.5
$10^0 - 20^0$	1.2	0.25	3.4	0.2
$20^0 - 30^0$	2.0	0.30	6.8	0.2
$30^0 - 40^0$	2.8	0.28	13.8	0.4
$0^0 - 40^0$	1.4	0.22	7.0	0.3

the reference pads. The corrections suggested by this hardware calibration are in agreement with those of the software calibration (the σ of the difference distribution is $\sim 1\ ns$).
Another software calibration has been performed on a different data-set, selecting events with more than 500 fired pads. So we have selected high energy events in order to reduce the effect of the geomagnetic field on the secondary particles. The resulting time-corrections are very close to the other ones (the difference distribution has $\sigma \simeq 0.7\ ns$).
Also the stability in time of the calibration has been checked. After 3 months of data-taking the pad-residuals result stable within $0.3\ ns$.

5. Conclusions

The time-calibration of the ARGO-YBJ detector has been performed with a software procedure and checked with hardware measurements. This work has been an occasion to study deeply the detector performance. The quality of the primary direction reconstruction improves as a consequence of this calibration. The effect of geomagnetic field on secondary particles in the shower has been studied in a preliminary way. The Moon shadow analysis will be the conclusive test for the calibration procedure.

References

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