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Temperature effect on RPC performance in the ARGO-YBJ experiment

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The ARGO-YBJ Collaboration

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A B S T R A C T

The ARGO-YBJ experiment has been taking data for nearly 2 years. In order to monitor continuously the performance of the Resistive Plate Chamber detectors and to study the daily temperature effects on the detector performance, a cosmic ray muon telescope was setup near the carpet detector array in the ARGO-YBJ laboratory. Based on the measurements performed using this telescope, it is found that, at the actual operating voltage of 7.2 kV, the temperature effect on the RPC time resolution is about

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0.04 ns/°C and on the particle detection efficiency is about 0.03%/°C. Based on these figures we conclude that the environmental effects do not affect substantially the angular resolution of the ARGO-YBJ detector.

1. Introduction

The ARGO-YBJ experiment, located at Yangbajing, Tibet, China, at an altitude of 4300 m a.s.l., and atmospheric depth of 606 g/cm^2, is mainly designed for the observation of gamma-ray sources at energies from it a few hundred GeV to some tens of TeV [1,2] gamma-ray bursts and cosmic-ray showers with energy up to the PeV range. In order to detect Extensive Air Showers (EAS) with a high angular resolution, a full coverage Resistive Plate Chamber (RPC) array (see Fig. 1) is used in the experiment. The array consists of 154 clusters of 12 RPCs each. Every RPC has 80 strips ($6.75 \times 61.80\,cm^2$) to collect induced charges when particles pass through. The chambers work in streamer mode with a gas mixture of $C_2H_2F_4/Ar/i\text{-}C_4H_{10} = 75/15/10$ and a voltage of 7.2 kV applied to the 2 mm gas gap. The signals from the strips are digitized using purposely designed front-end electronics [3,8] strips are OR-ed as a single output channel (referred to as a pad) providing timing and position information for the particles. Time resolution and particle detection efficiency are the crucial quantities to be measured for the evaluation of the ARGO-YBJ detector performance. It is well known that the "knee" voltage varies with the temperature due to the gas gain which changes following the environment parameters. The "knee" voltage is defined as the value where the efficiency reaches typically 90% of the plateau efficiency. The correlation between gas gain and environment temperature pressure was extensively studied [4–6], showing that the gas gain depends on the voltage-to-gas density ratio. Moreover the gas-density changes due to temperature/pressure changes can be compensated by a proper high voltage change keeping the voltage-to-gas density ratio constant. This is a first approximation rule valid for small temperature and pressure changes, that should, however, be enough to stabilize the detector working point [7]. So far the operating voltage of the ARGO-YBJ carpet was kept constant at 7.2 kV and no automatic stabilization of the working point was applied. The purpose of the present work is to measure the temperature effect in the real working conditions of the experiment. The effect of the barometric pressure is comparatively small mainly in the daily cycle. In order to study the temperature effects on the ARGO-YBJ detector, we built a multi-layer telescope using five RPCs located near the ARGO-YBJ array, which constantly monitors the efficiency and time resolution by using cosmic ray muons.

2. Apparatus

The telescope (see Fig. 2) is constructed by stacking five RPCs on top of each other with a layer of walking floor (8 cm thick plastic foam) and a 0.05 cm thin steel sheet used as a support for the screening material (0.5 cm thick lead plates). The RPCs used in the monitor telescope have the same structure and gas mixture as those used in the ARGO-YBJ array [8] and a gas flow of 4 volumes/day. The event trigger for the monitor telescope is provided by the air-shower trigger of the central ARGO-YBJ carpet, so that the data from the telescope can be merged into the main data acquisition (DAQ) stream as for any other cluster in the array. The detectors are numbered as in Fig. 2. The chambers RPC0, RPC1 and RPC4 are used to select vertical cosmic ray muons through a coincidence of their signals within 20 ns. RPC2 and RPC3 are supplied by a separate high voltage channel (HV1) for testing. The signals from RPC2 and RPC3, triggered by the coincidence signal, are used to estimate the detection efficiencies. The single-chamber time resolution is also estimated by measuring the time-of-flight of particles between RPC2 and RPC3, according to the procedure described later. The laboratory temperature is measured with sensors having an accuracy of $\pm 0.25\,^\circ C$, placed at different locations, and recorded using the Detector Control System (DCS) of the ARGO-YBJ experiment [9]. The sensor closest to the telescope is used for the analysis in this paper.

3. Experiment and results

The events for the telescope test were selected by requiring a vertical alignment of fired pads on layers RPC0, RPC1 and RPC4 for the efficiency measurements (then checking the hits on the

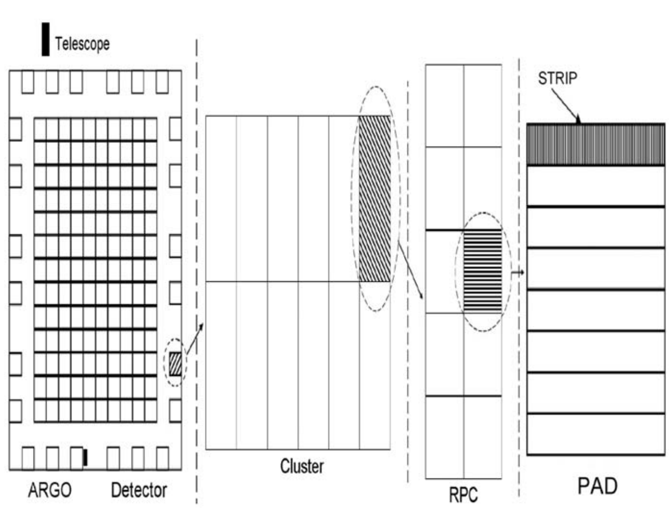

Fig. 1. Layout of the ARGO-YBJ experiment.

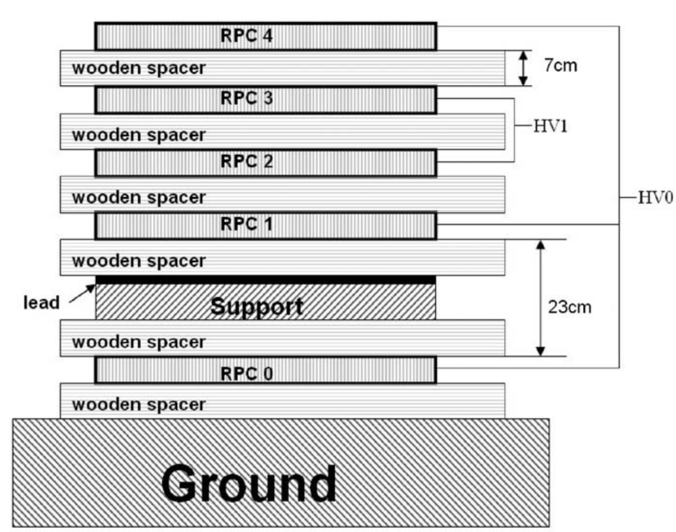

Fig. 2. Configuration of the telescope.

corresponding pads of RPC2 and RPC3), and on all the five layers for the time resolution measurements.

3.1. Efficiency

As mentioned above, the RPC detection efficiency vs. applied voltage varies with the ambient temperature [4] which, inside the YBJ laboratory, has a daily excursion in the range 7−10 °C. Fig. 3 (upper panel) shows two efficiency vs. voltage curves. Each efficiency value was measured during 1 h chosen around the time of the highest (H) and the lowest (L) temperature during a day. The daily maxima and minima for the temperature (lower panel in Fig. 3) ranged within a few degrees each. Above about 7.0 kV, the temperature effect on the efficiency becomes very small due to the high plateau efficiency of about 98%.

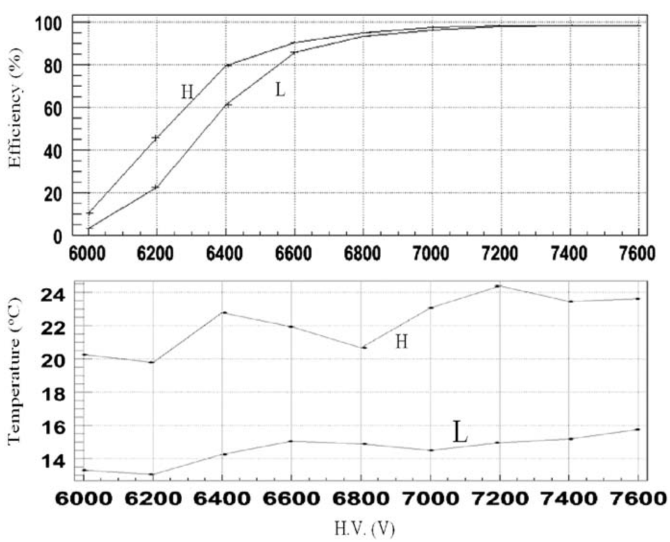

Fig. 3. Upper panel: detection efficiency vs. high voltage at different temperatures (H: high temperature and L: low temperature). The precise temperature values are shown in the lower panel.

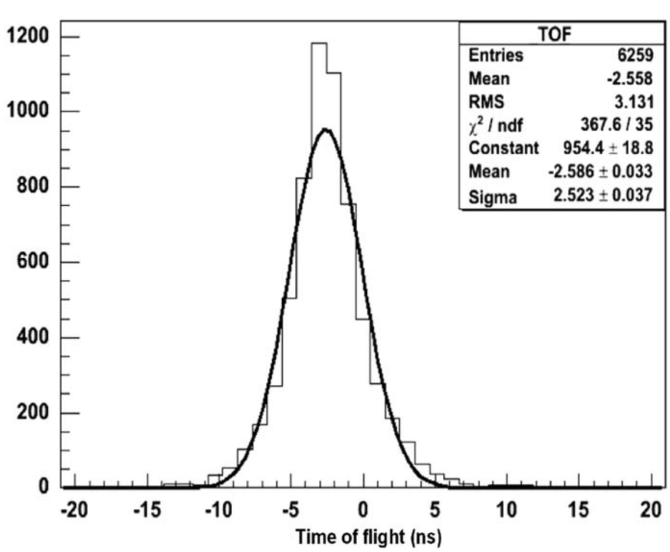

Fig. 4. Experimental distribution of the time-of-flight between RPC2 and RPC3 on one pad, at an applied voltage of 7.2 kV. The distribution shows a narrow peak and relatively long tails which are not well fitted by a single Gaussian distribution, also displayed in the figure.

3.2. Time resolution

As previously mentioned, the distribution of the time-of-flight between RPC2 and RPC3 is used here to estimate the time resolution of the ARGO-YBJ carpet. In Fig. 4 a typical experimental time-of-flight distribution at an applied voltage of 7.2 kV is shown. Here the bin width of 1.042 ns is the TDC clock period. The same pad of the two detectors was chosen for this measurement. It should be stressed that the distribution shown in Fig. 4 does not account only for the detector time jitter, but also for the jitters of the whole electronics chain from the front-end boards up to the TDC used in the DAQ to record the time of each hit. The Gaussian fit to the distribution in Fig. 4 gives about 2.5 ns for its sigma. However, the corresponding χ^2-test gives a probability as small as 10^{-4} which is dominated by the non-Gaussian distribution tails. In order to estimate the peak width in an unbiased way we used the width of the interval containing 68% of all events around the peak. The single-detector time resolutions reported in the following are given by the relation $\sigma = (68\%\ \text{width})2\sqrt{2}$, which takes into account that the overall jitter is determined by the resolutions of both the detectors used for the time-of-flight measurements. The time resolution is a function of the applied high voltage, and is also affected by temperature changes as shown in Fig. 5, where two different sets of measurements are represented on the same plot: the upper and lower points correspond to average temperatures of about 14 and 22 °C, respectively. Both the efficiency and the time resolution of a RPC detector improve by increasing the applied voltage, as expected. In particular, the daily average time resolution changes from about 1.8 ns at 7200 V to about 1.1 ns at 7400 V. At the working point chosen for the ARGO-YBJ experiment (7.2 kV) the daily excursion for the time resolution is about than 0.5 ns. The results reported here concern only the two chambers under test. It should be stressed, however, that these results show effects that are typical of the whole ARGO-YBJ detector.

3.3. Monitoring of the detector performance

The telescope described above enables a continuous monitoring of the detectors which are working at the same voltage, 7.2 kV, of the ARGO-YBJ carpet array. Between operational day 258 and day 263 of year 2008, the temperature inside the laboratory

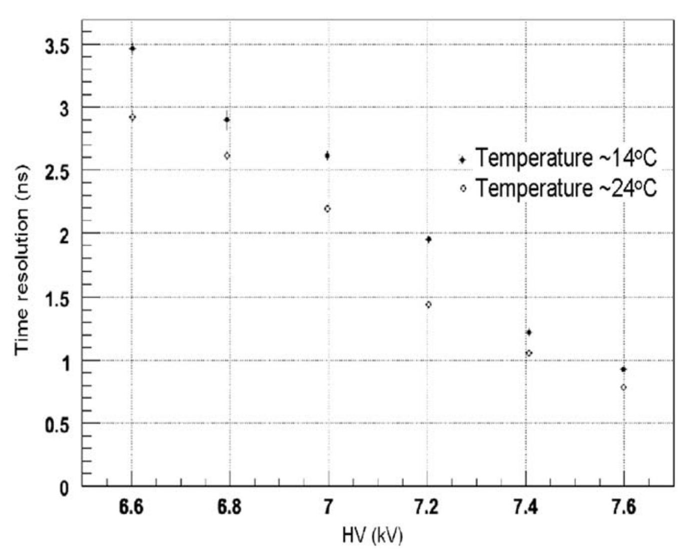

Fig. 5. Single-pad time resolution as a function of the applied voltage at two different temperatures (14 and 22 °C).

changed between 18–19 and 25−27 °C with a daily period. As a consequence of the temperature effect, the efficiency and time resolution of the detector changed correspondingly. It has already been shown [10] that the correlation between the RPC performance and the room temperature is maximum if a delay of 78 min is accounted for. This delay is taken into account in all the reported results. In Fig. 6(a), (b) and (c), respectively, the particle detection efficiency of both test chambers and the single-chamber time resolution are plotted as a function of the operational time. The monitored room temperature is also shown. The duration of all measurements is about 1 h. The efficiency is measured by averaging over one chamber, while the time resolution is obtained from the time-of-flight distribution on a specific pad number of the two test chambers, as previously mentioned. Using all the data taken in that period, the particle detection efficiency for RPC2 and RPC3 (Fig. 7(a) and (b), respectively) and the single-chamber time resolution (Fig. 7(c)) are found to be well correlated with the room temperature, where the above mentioned delay of 78 min is considered. In order to account for the accuracy of the temperature measurements, in this correlation study the experimental data were grouped in temperature bins of 0.5 °C. Therefore, each efficiency point corresponding to a given temperature bin is obtained as the weighted average of the efficiency measurements within this bin, and the straight line correlation fit was performed by using the weighted least squares method. Concerning the single-chamber time resolution, the value corresponding to a given temperature bin was obtained as the simple average of the time-resolution measurements within this bin, and the straight line correlation fit was performed by using the basic least squares method. The resulting expressions are:

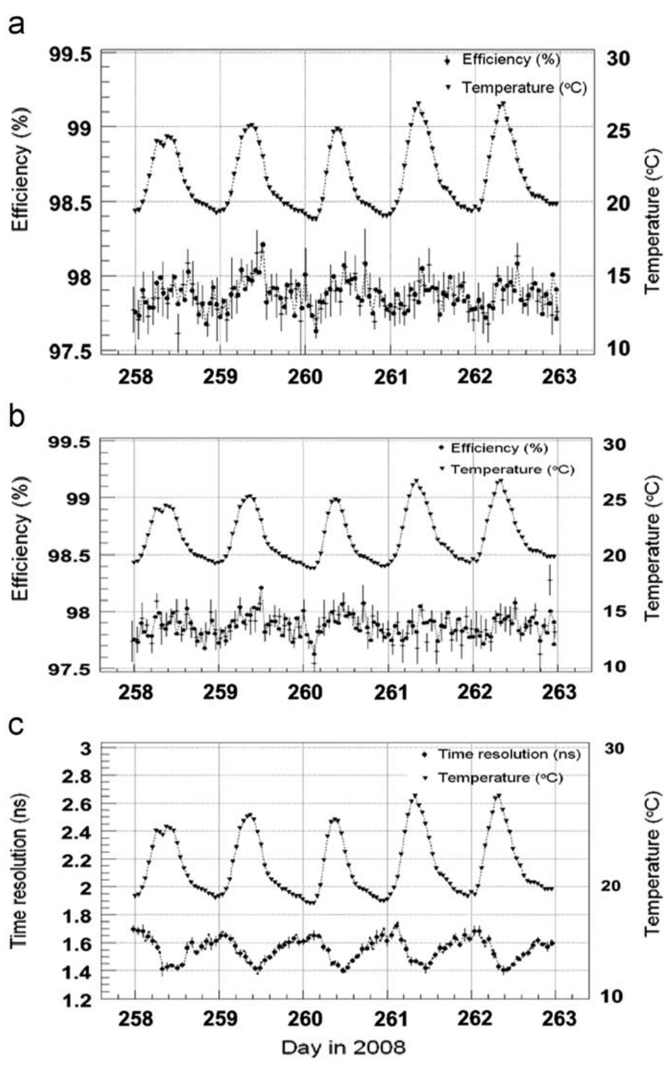

Fig. 6. Monitoring over 6 days of the room temperature inside the ARGO-YBJ hall, compared with the monitoring over the same period of the RPC2 (a) and RPC3 efficiency (b) and of the single-chamber time resolution as obtained from the time-of-flight measurement (c).

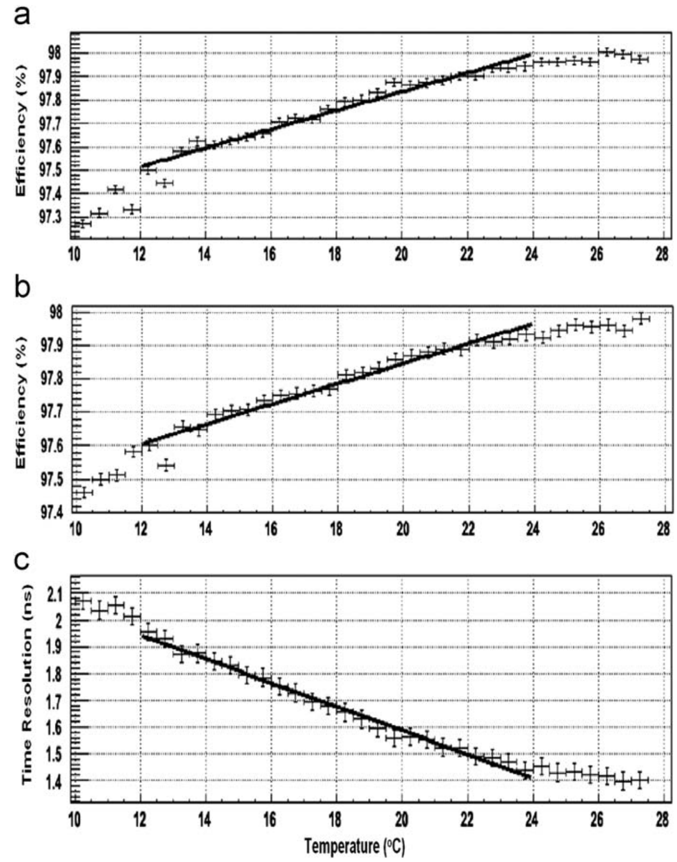

Fig. 7. Correlation plots of the RPC2 (a) and RPC3 efficiency (b) and of the single-chamber time resolution as obtained from the time-of-flight measurement (c) vs. the room temperature. In these plots the data were grouped in temperature bins of 0.5 °C in order to account for the measurement accuracy.

- RPC_2 efficiency(%) $= (0.040 \pm 0.002) \times (T(^\circ C) - 20) + (97.84 \pm 0.01)$,
- RPC_3 efficiency(%) $= (0.030 \pm 0.002) \times (T(^\circ C) - 20) + (97.85 \pm 0.01)$, and
- $R_t(ns) = (-0.045 \pm 0.002) \times (T(^\circ C) - 20) + (1.59 \pm 0.01)$,

where $12\,^\circ C \leq T \leq 24\,^\circ C$.

For a typical daily temperature variation of 6 °C in summer the time resolution changes by 0.2 ns and the efficiency by 0.2%. On average, if the annual thermal excursion is considered, the overall excursions of the single-chamber time resolution and efficiency of the ARGO-YBJ detector are approximately 0.4 ns and 0.3%, respectively.

3.4. Effect on the angular resolution

The effect of the temperature dependency of the time resolution on the angular resolution of the ARGO-YBJ experiment was studied with the CORSIKA software package simulating atmospheric cascades generated by primary protons, and selecting the events with $N_{pad} \geq 60$, $N_{pad} \geq 100$ and $N_{pad} \geq 500$, as shown in Fig. 8. It can be seen that the typical daily variation of 0.4 ns in

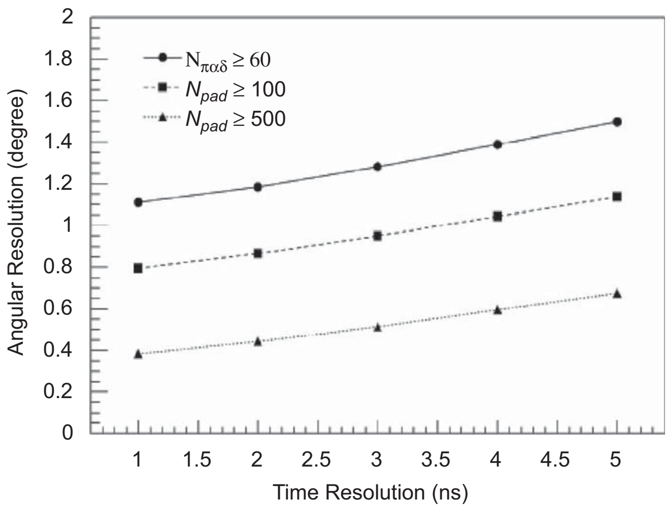

Fig. 8. Angular resolution vs. time resolution.

time resolution (in the range between 1 and 2 ns) corresponds to a daily change of 0.04°, 0.03° and 0.02° in the angular resolution [11] under the three conditions, respectively. These uncertainties are small compared with a typical angular resolution of about 0.5° and the particle detection efficiency of about 98% for the RPCs in the experiment.

4. Conclusions

At the Yangbajing laboratory, 4300 m a.s.l., we monitored the variations of the RPC detection efficiency and time resolution with respect to the temperature at the preset working point of 7.2 kV. RPCs show a slight improvement in efficiency and time resolution at higher temperature, as expected. We found linear correlations of those variables with the temperature. For daily temperature variations of about 10 °C in the laboratory, the efficiency changes are only about 0.3% and those of the time resolution about 0.4 ns. These variations do not affect substantially the ARGO-YBJ carpet performance.

Acknowledgements

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