Long-term monitoring of the ARGO-YBJ experiment

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Abstract: The ARGO-YBJ detector is located at YangBaJing (Tibet, P.R. China), at 4300 m a.s.l. and atmospheric depth of 606 g/cm^2. It uses a single layer of Resistive Plate Chambers (RPCs) with a full-coverage area of 78×74 m^2 surrounded by a guard ring, with a total surface of 110×100 m^2. It was designed to detect EAS in the primary energy range between few hundred GeV and a few PeV. The ARGO-YBJ experiment has been running with its complete layout since November 2007 observing more than 5×10^{11} air showers. Here we discuss the stability of the detector with respect to the RPC current absorption, the RPC counting rate and the EAS trigger rate. The RPC efficiency and time resolution were monitored by a cosmic-ray telescope installed by the detector carpet, and are also presented as further evidence for the stability of the RPC detector in its long-term running. The correlation between the detector response and the environmental parameters is also analyzed.

Keywords: Extensive air showers, Resistive Plate Chambers, detector monitoring and control.

1 Introduction

The ARGO-YBJ experiment (Astrophysical Radiation with Ground-based Observatory), hosted in a building at the YangBaJing Cosmic Ray Laboratory (4300 m a.s.l.), has been running since November 2007 providing results in γ-ray astronomy and cosmic-ray physics in the primary energy range between few hundred GeV and ~ 100 TeV [1]. Gamma rays and cosmic rays with energy greater than a few hundred GeV can be observed with a high-altitude, ground-based detector. For gamma-ray astronomy, a suitable pointing angular resolution of the detector is crucial (about 0.4 degrees for 10 TeV gamma rays). This goal can be achieved by using a detector with a single-hit time resolution of 1-2 ns. In addition, to reconstruct even small-size air showers and therefore set the lowest possible energy threshold for the incoming primary radiation, a full-coverage detector layout was devised. Since the full-coverage area is about 6000 m^2, a cost-effective solution for all the basic requirements and the large area to be instrumented was found by choosing Resistive Plate Chambers (RPCs) as the detection units. The choice of RPCs is good when large areas have to be covered, due to their lower cost per unit area compared to the traditional scintillator/photomultiplier technique. The detector has been working regularly all this time, allowing to collect data with almost no interruption. The ARGO-YBJ array is made of single-gap bakelite RPCs with a 2 mm wide gas gap operating in streamer mode with a three-component gas mixture ($C_2H_2F_4$/iC_4H_{10}/Ar = 75/10/15). The resistivity of the high pressure laminates used for manufacturing the ARGO-YBJ RPCs is in the range $(2 \div 4) \times 10^{11}$ Ω cm, which is well suitable for the counting rates observed in the experiment. The ARGO-YBJ RPCs have been operating at constant voltage (7200 V) all this time. Although this was not a problem in the data analysis and in the functionality of the detector, the well-known dependence of the detector response on the environmental parameters was a drive for a more thorough study in view of an optimization of the detector behaviour and stability over a long time.

2 Stability of the ARGO-YBJ RPCs

The stability of the detector response is mandatory in the ARGO-YBJ experiment, which is supposed to run uninterruptedly for at least 5 years. Here we summarize the main operating features of the ARGO-YBJ detector, in connection with their time stability.

The monitored current absorbed by the RPCs in ARGO-YBJ [2] looks pretty stable as shown in Fig. 1, showing the current distributions measured on Jan 1st, 2011 and Jan 30th, 2012. The mean values and R.M.S. are practically the same. The population in the more recent plot is greater due to the addition of a substantial number of chambers in the monitoring chain after a maintenance operation.

In Fig. 2 the time behaviour of the average daily temperature on the RPC cluster 91 of the ARGO-YBJ carpet (a reference cluster) is shown (upper plot) together with the time behaviour of the average daily current absorbed by the RPCs (lower plot). The long-term average temperature is about 16 °C.

In fig. 3 the time behaviour of the ARGO-YBJ duty cycle is shown. It looks stable, with overall value greater than 86%.

In Fig. 4 the time behaviour of the average daily ARGO-YBJ trigger rate is compared with the time behaviour of the average daily atmospheric pressure: the two trends look anti-correlated, and the long-term average value of the atmospheric pressure at the ARGO-YBJ experimental site is about 600 mbar. A slow and small decrease of the average trigger rate with time can be observed. Many different causes may contribute to this effect, whose explanation is still under investigation.

3 Operating voltage of the ARGO-YBJ RPCs

As reported in previous works, the gas gain in RPCs depends on the environmental conditions, namely on the local temperature and barometric pressure [3]. The algorithm devised to stabilize the gas gain inside the RPCs was al-

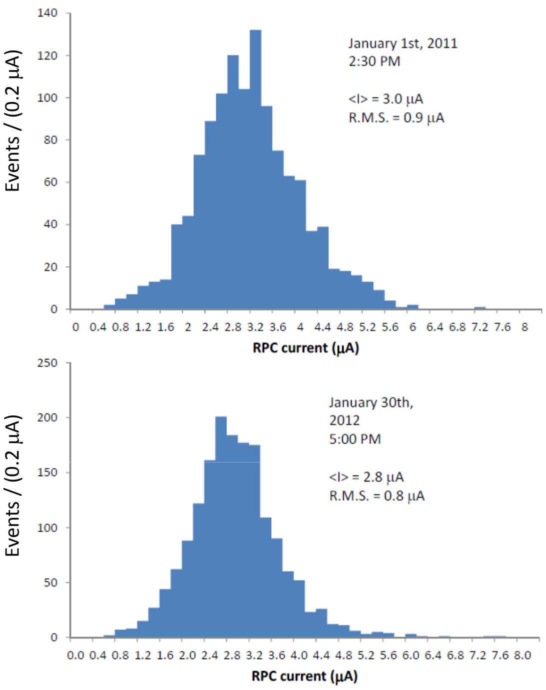

Fig. 1: Current distributions of the ARGO-YBJ RPCs recorded on Jan 1, 2011 (upper plot) and Jan 30th, 2012 (lower plot).

ready described in detail [4, 5]. However, it must always be kept in mind that this procedure only concerns the gas gain in the RPCs, and does not account for possible further effects connected to temperature changes in the whole acquisition chain.

4 Test and monitoring facility at the ARGO-YBJ site

A small-size cosmic-ray telescope was installed close to the South side of the ARGO-YBJ carpet as a monitoring and testing facility for the RPCs. It has been already used to study the dependence of the detector efficiency and time resolution on the monitored temperature [6]. For the present study [5] the basic layout is shown in Fig. 5. Cosmic-ray tracks are triggered by a coincidence of chambers 0, 1 and 4. These three chambers, together with chambers 2 and 3, are powered at 7200 V which is the standard voltage applied to the RPCs in the ARGO-YBJ carpet. The telescope has been running since 2008, using chambers 2 and 3 as the test chambers.

5 Extension of the test with the monitor telescope

In the present layout, RPCs 6 and 7 were powered according to the algorithm mentioned previously. This way, a continuous comparison could be made between a "standard" behaviour in which the applied voltage is left unchanged and a "corrected" behaviour in which the applied voltage is suitably regulated to compensate the gas-gain changes. It is

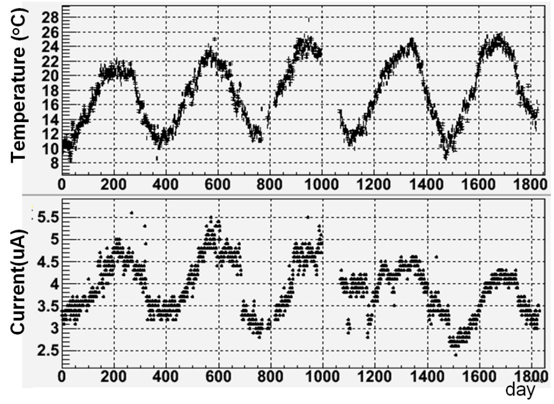

Fig. 2: Upper plot: average daily temperature on the reference RPC cluster 91 since November 2007. Lower plot: average daily current absorbed by the ARGO-YBJ RPCs since November 2007.

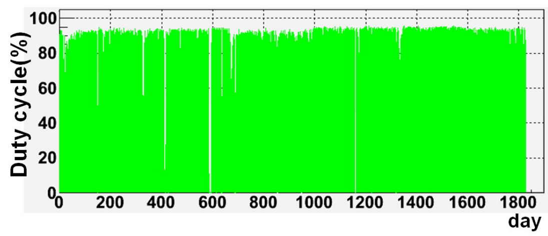

Fig. 3: Average daily trigger duty cycle of the ARGO-YBJ experiment since November 2007.

necessary to point out that the trigger configuration of the telescope, as described previously, is not optimized for the geometrical acceptance of the two added chambers. Therefore every efficiency measurement performed on chambers 6 and 7 will actually give a value of the efficiency times the geometrical acceptance. However, this is not a crucial issue in this test. The reference values for the absolute temperature and the barometric pressure are chosen to be close to the yearly average values over the whole ARGO-YBJ carpet provided by the monitoring system (DCS), namely $T_0 = 288.65$ K and $p_0 = 600$ mbar.

The DCS, which includes all the monitoring and control procedures of the ARGO-YBJ experiment, must act on RPCs 6 and 7 at regular time intervals so that the voltage change to be applied each time is not greater than a few Volts. In this test, the time interval was chosen to be 15 minutes. The "new" voltage to be applied is used only if it is close enough to the previous applied voltage, to avoid critical mistakes induced by possible failures in the readout of the environmental sensors. In addition, limits on the current absorbed by the power supply are set, so that the detectors are protected against any possible dangerous increase of current.

6 Implementation of the high-voltage control on the test facility

The voltage-control procedure on the chambers 6, 7 in the cosmic-ray telescope started on January 12th, 2011. The behaviour of these two chambers immediately before and immediately after this was compared.

Figure 6 shows the distributions of the time resolution obtained from the measurement of the time of flight between chambers 6 and 7, for the period January 9-12, 2011 (shaded) and for the period January 12-15, 2011. Each entry is the average time resolution in a 3-hour interval. The voltage-control procedure led to an improvement in the r.m.s. of the distribution, which decreased from 133 ps to 98 ps.

Figure 7 shows the distributions of the average efficiency times the geometrical acceptance for chambers 6 and 7 for the period January 9-12, 2011 (upper, black) and for the period January 12-15, 2011 (lower, red). Each entry is the average efficiency in a 3-hour interval.The voltage-control procedure led to a significant narrowing of the distribution: the r.m.s. decreased from 1.1 % to 0.5 %.

On January 31st, 2012 the role of the tested RPC pairs in the telescope was exchanged: RPCs 6 and 7 were set at fixed applied voltage (7200 V) and RPCs 2 and 3 were put under regulated applied voltage.

Fig. 8 shows a 5-day time trend (from February 2nd till February 7th, 2012) for the five chambers with fixed voltage and for the two chambers with voltage regulation. The effectiveness of the regulation algorithm is clearly apparent.

Fig. 9 shows the current vs effective voltage plots for the RPCs with fixed applied voltage and for the RPCs with regulated applied voltage (from February 2nd till February 7th, 2012). These plots confirm that the "voltage follow-up" algorithm is working correctly, since the current measured in the regulated RPCs looks constant, highly uncorrelated with the effective high voltage corresponding to a fixed applied voltage of 7200 V.

7 Conclusions

The ARGO-YBJ RPCs exhibited very good stability over a time span greater than 5 years, as the monitoring of the most significant operating parameters of the experiment shows. This allowed the experiment to take a huge amount of data for many detailed studies in gamma-ray astronomy and cosmic-ray physics.

The results of the test on the monitoring facility were positive and led to the following conclusions:

- Before starting the voltage-control procedure, the efficiency times the geometrical acceptance of the chambers 6 and 7 varied between 67 % and 73 % with a r.m.s. greater than 1 %. The time resolution obtained from the measurement of the time of flight between the RPCs 6 and 7 varied between 1.8 ns and 2.5 ns with a r.m.s. of 133 ps.

- After applying the voltage-control procedure, the efficiency times the geometrical acceptance of the chambers 6 and 7 varies between 70 % and 72.5 % with a r.m.s. about 0.5 %. The time resolution ob-

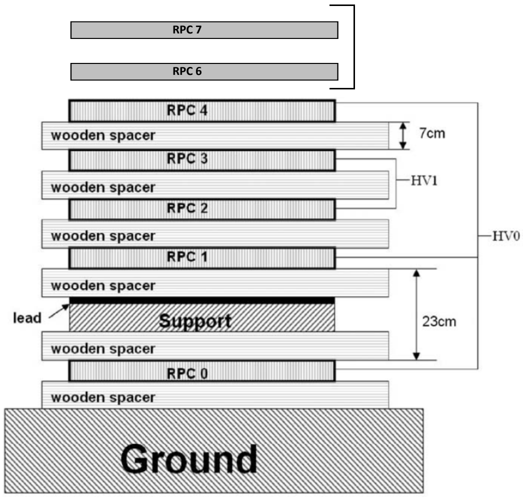

Fig. 5: Layout of the cosmic-ray telescope located by the ARGO-YBJ RPC carpet.

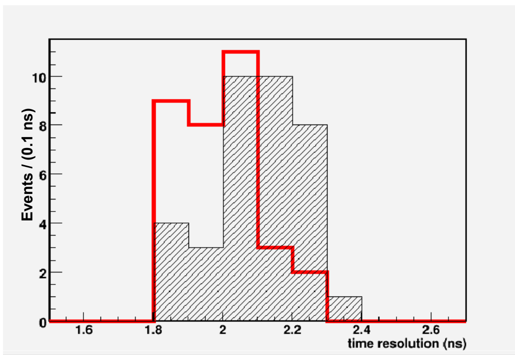

Fig. 6: Distribution of the RPC time resolution as obtained from the measurement of the time of flight between chambers 6 and 7. Each entry is the average time resolution in a 3-hour interval. The black-filled distribution refers to January 9-12, 2011, with a r.m.s. of 133 ps. The white-filled distribution refers to January 12-15, 2011, with a r.m.s. of 98 ps.

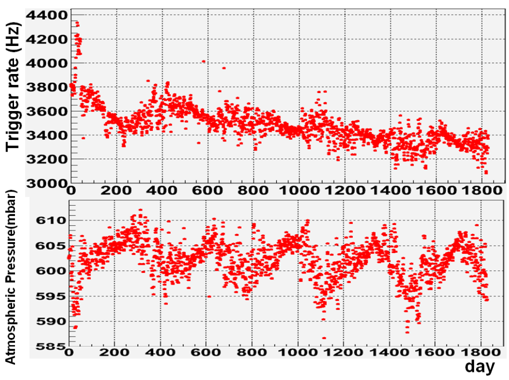

Fig. 4: Upper plot: average daily trigger rate of ARGO-YBJ since November 2007. Lower plot: average daily barometric pressure since November 2007.

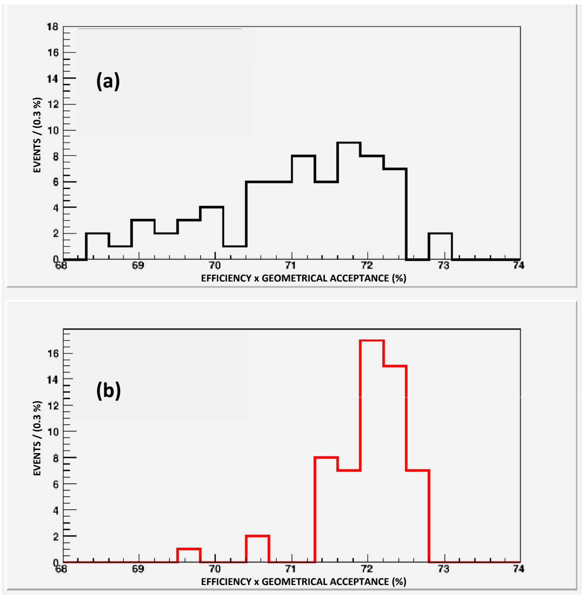

Fig. 7: Distribution of the RPC efficiency times acceptance (in %) for chambers 6 and 7. Each entry is the average efficiency in a 3-hour interval.The upper distribution refers to January 9 12, 2011, with a r.m.s. of 1.1 %. The lower distribution refers to January 12-15, 2011, with a r.m.s. of 0.5 %.

tained from the measurement of the time of flight between the RPCs 6 and 7 varies between 1.8 ns and 2.2 ns with a r.m.s. of 98 ps.

- The effect of the voltage-control procedure on the absorbed current of the test RPCs is completely successful in the sense that the absorbed current becomes stable.

The positive result of this study is promising towards the final goal of extending the voltage-control procedure to the whole ARGO-YBJ detector.

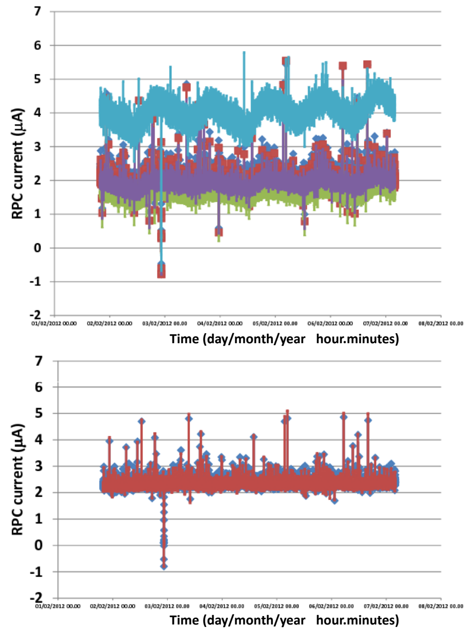

Fig. 8: Recorded trends for the currents of the test RPCs with fixed applied voltage (upper plot) and regulated applied voltage (lower plot), from February 2nd till February 7th, 2012.

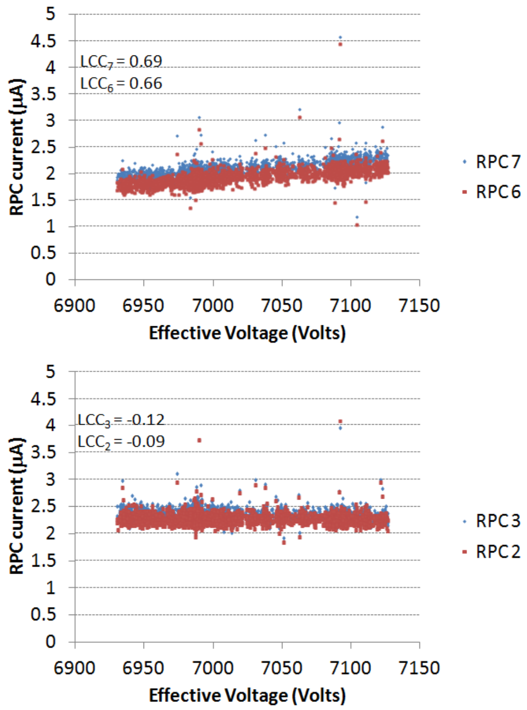

Fig. 9: Current vs effective voltage plots for the test RPCs with fixed applied voltage (upper plot) and regulated applied voltage (lower plot), from February 2nd till February 7th, 2012. The effective high voltage corresponds to a fixed applied voltage of 7200 V.

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