RPC operational stability in the ARGO-YBJ experiment

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***Abstract*. The peculiar environmental condition that the ARGO-YBJ detector has to face at the YangBaJing experimental site (4300 meters a.s.l.) affects the operation of the ARGO-YBJ Resistive Plate Chambers both on a daily and a seasonal basis. The operational stability of the ARGO-YBJ RPCs is checked by the Detector Control System which monitors the significant parameters related to the detector and to the environment state. In particular, it is crucial to consider both temperature and barometric pressure changes in order to monitor the changes in the density of the gas mixture of the ARGO-YBJ RPCs while the experiment is running. The detailed monitoring of temperature, atmospheric pressure and RPC absorption current was studied over a long time period, in order to determine how these quantities are correlated with one another and to assess the stability of the RPC operation.**

***Keywords*: Resistive Plate Chambers, Extensive Air Showers, Environmental Parameters**

I. Introduction

The ARGO-YBJ experiment was designed to detect Extensive Air Showers generated by primary cosmic rays, with a threshold of few hundreds of GeV both for primary protons and gamma rays in shower reconstruction mode, an experimental layout optimized around the TeV region for gamma rays, and the possibility to lower the threshold further to few tens of GeV with the scaler technique [1], [2], [3]. This goal was achieved with a suitable choice both for the experiment location (YangBaJing, P.R. of China, 4300 m a.s.l., longitude 90° 31′ 50″ East, latitude 30° 06′ 38″ North) and for the detector layout.

The structure scheme of the ARGO-YBJ setup is shown in Fig. 1. The central section of the experiment is a a full-coverage array (78×74 m^2) of Resistive Plate Chambers (RPCs) operated in streamer mode with a three-component gas mixture ($C_2H_2F_4$/Ar/iC_4H_{10} = 75/15/10) [4]. For an applied voltage of 7.2 kV the ARGO-YBJ RPCs work at full efficiency (about 98%) and with time resolution between 1 ns and 2 ns. Since October 2007 ARGO-YBJ has been taking data with its complete layout, also including a "guard ring" of RPCs around the central carpet. A group of 2×6 adjacent RPCs is named cluster. Overall the ARGO-YBJ array contains 153 clusters, with 1836 RPC detectors. Uninterrupted monitoring of the RPC detectors, of the high-voltage power supplies and of the environmental parameters provides the information which is needed to check the regular operation of the experiment [5].

The response of gaseous particle detectors is dependent both on the applied voltage and on the gas density. Theoretical computations described this behaviour [6] and experimental results confirmed it concerning the temperature dependence [7]. In particular, in a uniform electric field the first Townsend ionization coefficient α can be expressed by

$$\alpha = \varrho \cdot f\left(\frac{V}{\varrho}\right) \quad (1)$$

where ϱ is the gas density and f is a specific increasing function of the quantity V/ϱ, V being the applied voltage. Therefore at fixed applied voltage, as it is the case for the ARGO-YBJ experiment, it is expected that the detector response, as far as the absorption current is concerned, is strictly related to the gas density and more specifically to the ratio T/p, where T is the absolute temperature of the gas inside the RPC detector and p is the local barometric pressure at the experimental site, since the gas filling the RPC detectors circulates in an open flow. The long operational time of ARGO-YBJ allows checking this correlation in detail.

II. Environment at the ARGO-YBJ site and RPC current monitoring

The high-voltage control and the monitoring tasks for ARGO-YBJ are performed by the Detector Control System (DCS). The DCS structure was described in [5]. The environmental parameters which are constantly monitored are the following:

- barometric pressure;
- temperature external to the experimental hall;
- temperature near the center of the ARGO-YBJ carpet, 1 m above the ground;
- temperature and relative humidity on the upper face of one of the chambers close to the carpet center;
- temperature and relative humidity on the lower face of one of the chambers close to the carpet center;
- temperature and relative humidity on the input gas pipe of one of the chambers close to the carpet center;
- temperature and relative humidity on the output gas pipe of one of the chambers close to the carpet center;

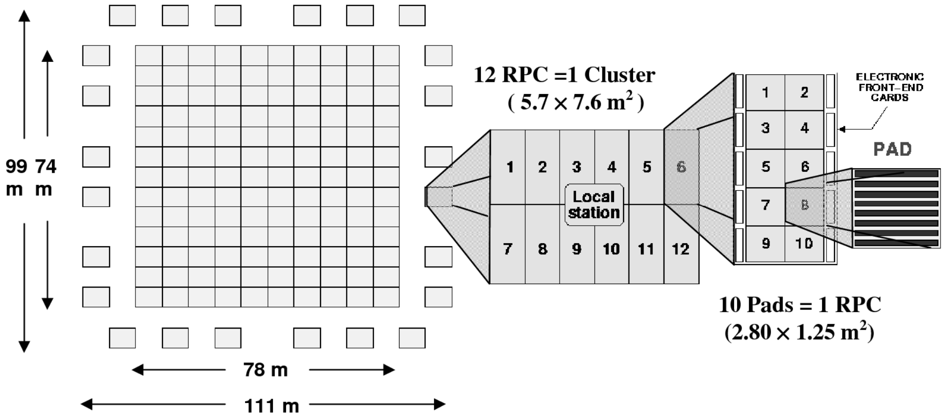

Fig. 1: Scheme of the ARGO-YBJ detector layout, with the details of its structure.

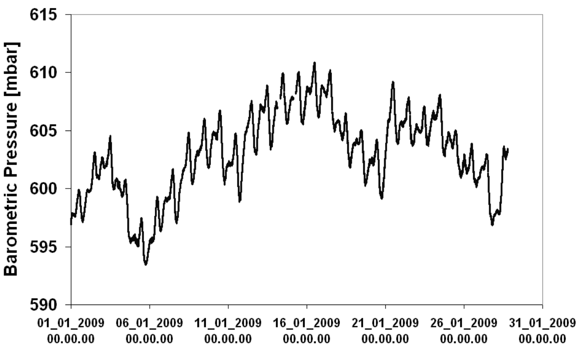

Fig. 2: Monitoring of the barometric pressure at the YangBaJing site from January 1 till January 28, 2009.

- atmospheric vertical electric field over the roof of the ARGO-YBJ building.

In order to check the long-term stability of the ARGO-YBJ detector, the reference period from January 1 till January 28, 2009 was considered. In Fig. 2 the monitored barometric pressure over this period is shown. The daily change of this quantity shows the usual behaviour characterized by two main harmonic components, with typical daily change of about 4 mbar, with values ranging between 593 mbar and 611 mbar during the whole period.

The temperature monitoring at the YangBaJing experimental site was already exploited in order to establish a correlation between the environmental parameters and the detector response [8], with further specific emphasis on detection efficiency and time resolution [9]. In addition, a detailed study of the correlation between the RPC absorption current and the temperature measured outside the detector allowed to establish a typical delay of the order of 70-80 minutes for the detector response to air temperature changes inside the experimental hall (but outside the RPC detectors) [10]. In this analysis we use the temperature measured in the output gas pipe of a chamber. Fig. 3 shows the simultaneous monitoring of the external temperature, of the air temperature inside the experimental hall close to the carpet center and of the temperature in the output gas pipe of a sample RPC. The daily excursion of the external temperature is typically greater than 20 °C, which is reduced to less than 8 °C for the air temperature inside the experimental hall. The temperature in the gas pipe has even smaller daily excursion, typically less than 6 °C.

The monitoring of the RPC absorption current is performed in two independent ways:

1) measurement of the current absorbed by each single RPC by measuring the voltage drop across a 100 kΩ shunt resistor on the high-voltage return line;
2) measurement of the current absorbed by each high-voltage channel directly in the power supplies; each high-voltage channel powers the 12 chambers of one ARGO-YBJ cluster.

Fig. 4 shows the monitored current absorbed by each RPC cluster during the period taken into account. Each point represents the mean value over one minute. The range of the cluster current is between 35 μA and 47 μA, which is in perfect agreement with the typical measured values of the single-chamber current (between 3 μA and 4 μA). The daily excursion of the RPC cluster current is about 5 μA.

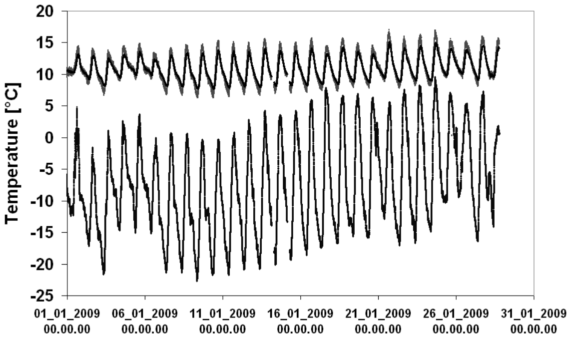

Fig. 3: Monitoring of the external temperature (lower plot), of the inner temperature close to the ARGO-YBJ carpet center (upper plot, background), and of the temperature on the output gas line of a chamber (upper plot, foreground) at the YangBaJing site from January 1 till January 28, 2009.

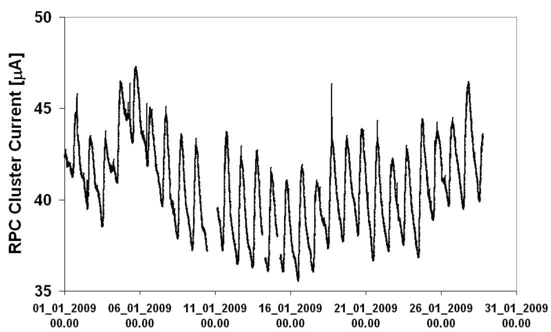

Fig. 4: Time trend of the ARGO-YBJ RPC cluster current over 29 days in January, 2009. Each point represents the mean value over one minute. An interruption in the monitoring due to maintenance operations on the detector is visible.

III. Environmental Correlation

Concerning the ionization current in the RPC detector, the change of temperature T and barometric pressure p can be accounted for by considering an "effective" voltage V_{eff} defined by

$$V_{eff} = V_{app} \frac{T}{p} \frac{p_0}{T_0} \qquad (2)$$

where $V_{app} = 7.2$ kV is the applied voltage and T_0, p_0 are fixed reference values for the absolute temperature and barometric pressure respectively. As explained above, this is the crucial quantity affecting the secondary ionization in the gas under the effect of an electric field due to the obvious connection with the gas density ($\varrho \propto p/T$). Here we chose $T_0 = 285.15$ K and $p_0 = 600$ mbar. However, since the temperature sensor is located outside the gas volume, a possible delay in the effect of the temperature changes on the effective voltage was

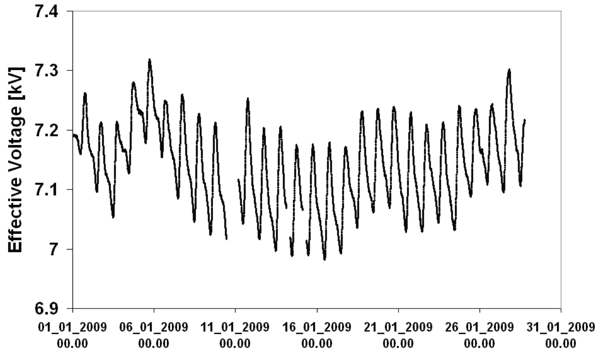

Fig. 5: Time trend of the effective voltage applied to the RPC detectors if reference temperature 12 °C and reference barometric pressure 600 mbar are chosen. The short maintenance break in the detector operation mentioned in the caption of Fig. 4 is visible.

investigated. As a result, a very good linear correlation between the effective voltage and the logarithm of the RPC cluster current was found and the maximum value for the linear correlation coefficient was obtained for a delay of 75 minutes in the temperature effect, in perfect agreement with the already known results [10]. Therefore, the value of V_{eff} at a given time is computed by using the temperature value which had been measured outside the chamber 75 minutes before, while the pressure value is the present one. The resulting behaviour of V_{eff} during the time period under study is shown in Fig. 5.

The scatter plot of the RPC cluster current versus V_{eff} is shown in Fig. 6. No selection cuts were applied to the 3.8×10^4 points in the plot. A very good correlation between the effective voltage and the logarithm of the cluster current can be established, with linear correlation coefficient equal to 0.99, in agreement with the expectation. The fractional change rate of the RPC cluster current versus V_{eff} can be evaluated with an exponential fit of the correlation plot, and is equal to (0.77 ± 0.07) kV^{-1} within the actual range of V_{eff}. The average standard deviation of the RPC cluster current with respect to the exponential fit is about 0.45 μA. This shows that the measured absorption current of the ARGO-YBJ detector is well correlated with the change of the gas density due to the variation of both temperature and barometric pressure.

IV. Conclusion

Correlating the absorption current of the ARGO-YBJ detector with the changes in the environmental parameters is crucial in order to verify that the observed changes are in agreement with the expectations and that the behaviour of the detector is stable over a long time. A careful check of the temperature behaviour monitored at different locations in the experiment showed that by using the temperature measured in the output gas pipe of the RPCs this correlation study is optimized.

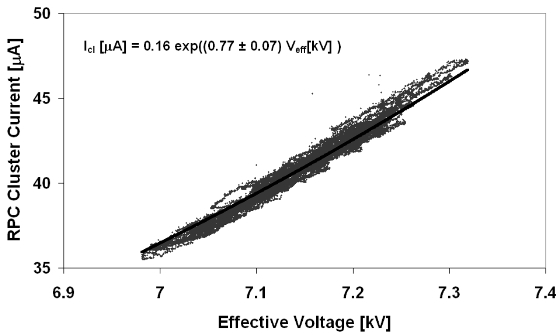

Fig. 6: Scatter plot of the RPC cluster current versus the RPC effective voltage. A very good linear correlation between the effective voltage and the logarithm of the current is established, with linear correlation coefficient equal to 0.99.

Due to this, a very good correlation between the RPC cluster absorption current and the gas density (estimated by using the above mentioned temperature sensor) was obtained, if a delay of 75 minutes for the temperature effect on V_{eff} is accounted for. The exponential fit shows that the RPC detectors have a stable behaviour in the observed range of the environmental parameters.

Consequently this study, which was performed over a 29-day long period, showed that the ARGO-YBJ RPCs are working with remarkable long-term stability. The effect of temperature variations on the resistivity of the RPC plates, given the small average current absorbed by the chambers, is small compared to the effect connected to the variation of the gas density, therefore it was not considered in this study.

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