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RPC operation at high temperature

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Abstract

The resistive electrodes of RPCs utilised in several current experiments (ATLAS, CMS, ALICE, BABAR and ARGO) are made of phenolic/melaminic polymers, with room temperature resistivities ranging from 10^{10} Ω cm, for high rate operation in avalanche mode, to 5×10^{11} Ω cm, for streamer mode operation at low rate.

The resistivity has however a strong temperature dependence, decreasing exponentially with increasing temperature. We have tested several RPCs with different electrode resistivities in avalanche as well as in streamer mode operation.

The behaviours of the operating current and of the counting rate have been studied at different temperatures. Long-term operation has also been studied at $T = 45°C$ and 35°C, respectively, for high and low resistivity electrodes RPCs.

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Keywords: RPC; High temperature operation

1. Introduction

High temperature operation was the main cause of Babar RPCs fast ageing. With respect to the first production of RPCs for Babar, a number of improvements were proposed in view of the LHC experiments [1]. The edge frames are now made of polycarbonate, the same material used for the gas gap spacers. The lineseed oil inner coating is much thinner and well polymerized. Also the plate surface has been improved.

We report in this paper the results of high temperature tests performed on three RPCs of the last generation: two with high electrode resistivity (5×10^{11} Ω cm at room temperature) operated in streamer and in avalanche mode, respectively, and the third with low electrode resistivity (4×10^{10} Ω cm at room temperature) operated in avalanche mode.

2. Experimental set-up

The experimental set-up is composed of two RPCs of size 50×50 cm^2, one of which is tested at different temperatures and the other one, kept at room temperature, is used for reference. The RPC under test is placed horizontally inside a climatic chamber, and the reference one is positioned just

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on top of the climatic chamber, 15 cm above the other.

The reference RPC is operated in streamer with a gas mixture composed of $Ar/C_2H_2F_4/i-C_4H_{10} = 48/48/4$. The resistivity of the electrode plates is $5 \times 10^{11}\ \Omega$ cm at room temperature. The signal is picked up by means of a single pad covering the whole sensitive area and it is discriminated with a threshold of 30 mV.

The RPC under test was flushed with the same gas when operated in streamer mode. In the avalanche mode tests, the gas was $C_2H_2F_4/i-C_4H_{10}/SF_6 = 96.5/3/0.5$. The efficiency of the tested RPC is monitored by the twofold coincidence rate with the external RPC. At the end of the tests, a measurement of the chamber efficiency was performed using a hodoscope similar to the one described in Ref. [2], which allowed to track cosmic rays with a resolution of 1 cm.

To obtain a noise map after the long-term streamer mode operation test, the read-out pad has been replaced by a smaller one, $3 \times 3\ cm^2$ wide, composed of two copper electrodes, one facing the chamber surface and the other referred to ground, separated by 3 mm of PVC. The small pad is surrounded by a copper frame referred also to ground.

With the purpose of studying the humidity effects in the gas mixture, a water bubbler was inserted in the gas system, and subsequently replaced by a silica gel humidity filter. At the end of the test, a humidity sensor was also added into the gas circuit near to the RPC inlets and outside the climatic chamber.

3. Streamer operation of a high resistivity RPC

The first RPC tested inside the climatic chamber was operated in streamer with a gas mixture composed of $Ar/C_2H_2F_4/i-C_4H_{10} = 48/48/4$ and flushed at 5 ml/min. The signals were picked up by a single pad, in a way similar to the external RPC. The electrode resistivity was $5 \times 10^{11}\ \Omega$ cm at room temperature.

In Fig. 1 the measured coincidence rates vs. the operating voltages are shown for different temperatures. The plateau efficiency is reached at

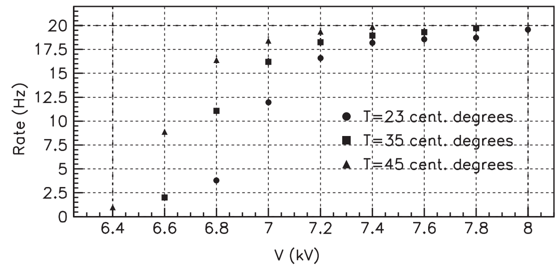
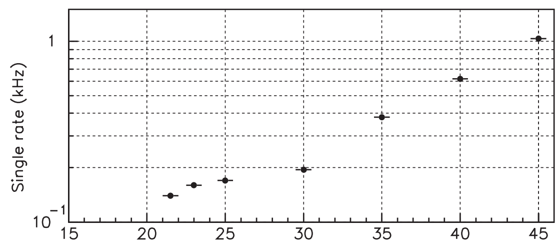


Fig. 1. Double coincidence rates vs. operating voltage measured at different temperatures for the high resistivity RPC operated in streamer. The reference RPC is kept at a fixed voltage of 7.6 kV.



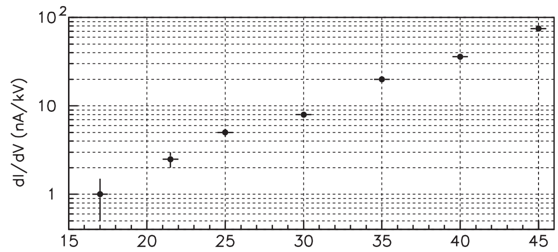


Fig. 2. Upper plot: Counting rates measured at different temperatures for the high resistivity RPC operated in streamer mode with an applied voltage of 500 V above the 50% efficiency point. Lower plot: Dark current slope, dI/dV, measured at different temperatures for the same RPC.

lower voltages for higher temperatures in agreement with Refs. [3,4].

Fig. 2(a) shows the counting rate vs. temperature at a fixed operating point. Therefore the applied voltage had to be readjusted for each temperature to take into account the different gas density [3,4]. For this purpose the 50% efficiency voltage, corresponding to 10 Hz coincidence rate, was taken as a reference point and the single rate reported in Fig. 2(a) was measured 500 V above this reference voltage. The counting rate is dominated by the physical counting below 30°C, and by noise effects exponentially increasing with the temperature above 30°C. A similar behaviour is observed for the total current.

At low operating voltages, for which charge multiplication phenomena do not occur in the gas, the current is dominated by a "dark" contribution, linearly increasing with the voltage. The dark current increase per unit voltage, $\mathrm{d}I/\mathrm{d}V$, represents the inverse of the isolation resistance between the electrode plates and is plotted in Fig. 2(b) as a function of the temperature. The comparison with Fig. 2(a) shows that the counting rate and the dark current scale with a similar slope which is about a factor of 3 and 4, respectively, for a 10°C temperature increase. A similar scaling is observed for the electrode plates bulk resistivity (a factor 4.4 for 12°C).

With the purpose of testing the long-term operation at high temperature, the RPC was kept at 45°C, with an applied voltage of 7.1 kV. In Fig. 3 it is shown the time evolution of the current, the counting rate and the dark current slope. Both the counting rate and the operating current have increased in the first 15 days of operation and remained constant for the last 7 days of the test.

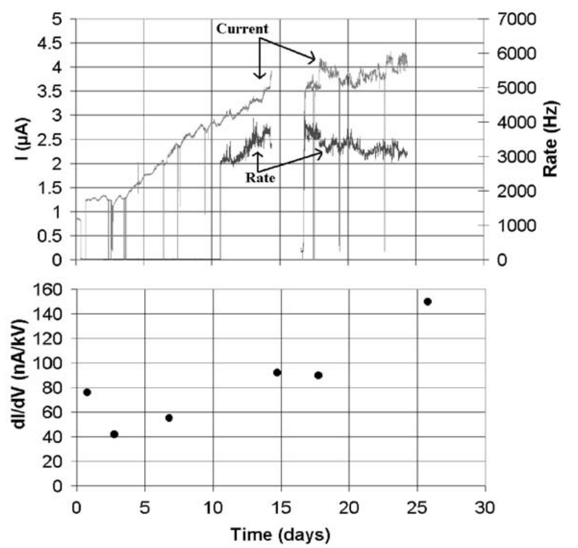


Fig. 3. Time evolution of the operating current and of the counting rate (upper plot) for the high resistivity RPC operated in streamer mode at $T = 45°\mathrm{C}$ and $P = (1005 \pm 10)$ mbar. In the lower plot the dark current slope is also reported.

In Fig. 4(a) comparison is made between the double coincidence rates at 45°C before and after high temperature operation. In the same figure, the comparison between the single counting rates measured at room temperature ($T \simeq 20°\mathrm{C}$) is also shown. No significant shift of the operating point is observed, while the counting rate of the chamber has increased for voltages as low as 6.5 kV even at room temperatures.

The detection efficiency was measured before ($97.59 \pm 0.20\%$) and after ($97.01 \pm 0.23\%$) the long-term test using the cosmic-ray hodoscope with an applied voltage of 7.8 kV at room temperature. The inefficiencies were uniformly distributed on the active chamber area. A noise map of the tested RPC, obtained with a small pad $3 \times 3\ \mathrm{cm}^2$ wide, shows that the noisy points are located at the corners of the chamber, near the gas inlets. The systematic increase of the counting rate and of the current during the operation at 45°C could be explained as a damage due to impurities that were trapped inside the gap in drilling gas inlet holes in the construction. With the purpose of avoiding the ageing effects just mentioned, the construction

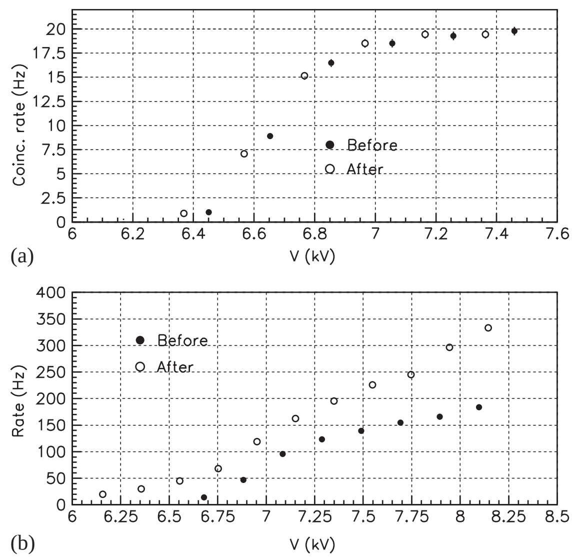


Fig. 4. Performance comparison before and after the long-term streamer mode operation at high temperature of the high resistivity RPC: double coincidence rates measured at $T = 45°\mathrm{C}$ (upper plot) and counting rates measured at room temperature (lower plot). Note the different voltage values in abscissa.

procedure was improved and the gas inlet holes were integrated in the corners of the RPC edge frame, using molding techniques.

4. Avalanche operation of a high resistivity RPC

A second RPC with the same electrode resistivity but working in avalanche mode was tested at 45°C during more than 100 days. The chamber has been operated at 10.1 kV with a gas mixture composed of $C_2H_2F_4/i-C_4H_{10}/SF_6 = 96.5/3/0.5$ flushed at 10 ml/min. The signal was picked up with 16 strips 3 cm wide, served by two ATLAS Front-End boards [5]. The discrimination threshold was 1.3 mV.

The time evolution of the operating current, the counting rate and the slope of the dark current is shown in Fig. 5. The three plots show a clear correlation with the gas humidity, regulated by a water bubbler and a silica gel filter that were introduced starting from day 30. Before that time, the amount of water in the gas, measured with the humidity sensor, was about 1%, consistent with the air humidity propagating to the chamber gas

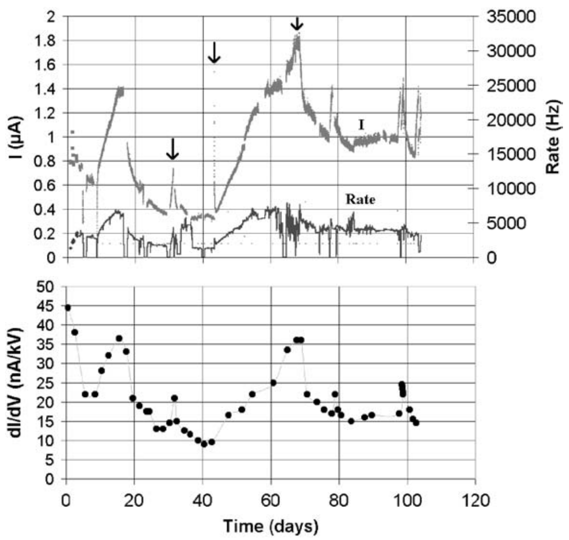


Fig. 5. Time evolution of the current and of the counting rate (upper plot) for a high resistivity RPC operated in avalanche mode at $T = 45°C$ and $P = (1002 \pm 10)$ mbar. In the lower plot the dark current slope is also reported. The peaks of current around days 80 and 100 are due to accidental gas flow stops.

through the plastic pipes. The water bubbler was inserted in the gas system, at first for few days (see first arrow around the 30th day in Fig. 5), and then from day 44 to 68 (indicated by the other two arrows). In both cases all the plotted quantities increased. A decrease was observed only after the bubbler removal. The water bubbler was replaced by a silica gel humidity filter, at first kept at room temperature, and subsequently refrigerated in order to improve its efficiency, starting from day 99. All of the plotted quantities remained stable with the filter applied.

At the end of 100 days operation at 45°C, the RPC showed the same current, counting rate and dark current measured during the first operation days. The efficiency measured with the cosmic-ray hodoscope at the end of the test was above 98%.

5. Avalanche operation of a low resistivity RPC

Finally we have tested in avalanche mode a RPC with electrode resistivity of 4×10^{10} Ω cm at 20°C. The gas mixture used was composed of $C_2H_2F_4/i-C_4H_{10}/SF_6 = 96.5/3/0.5$, with a flow of 10 ml/min during the long-term operation test. The signals were picked up with 16 strips 3 cm wide, served by two ATLAS Front-End boards with a discrimination threshold of 0.7 mV. All the tests described here have been performed keeping the humidity in the gas low with the refrigerated silica gel filter.

The double coincidence rates measured at different temperatures ranging from 25°C to 45°C are reported in Fig. 6(a) as a function of the voltage applied. Fig. 6(b) shows that all the plots merge into a single one if the voltage V, applied with an absolute temperature T and a pressure P, is rescaled to standard temperature and pressure values, $T_0 = 293$ K and $P_0 = 1010$ mbar, according to the relationship $V_r = V \times T/T_0 \times P_0/P$ [3,4].

With the purpose of studying the chamber behaviour in the limit of zero gas flow, the RPC gas volume was sealed between the bubbler and the input valve, and the chamber was operated at the normal voltage. Fig. 7 shows a fast increase of the operating current, the counting rate and the

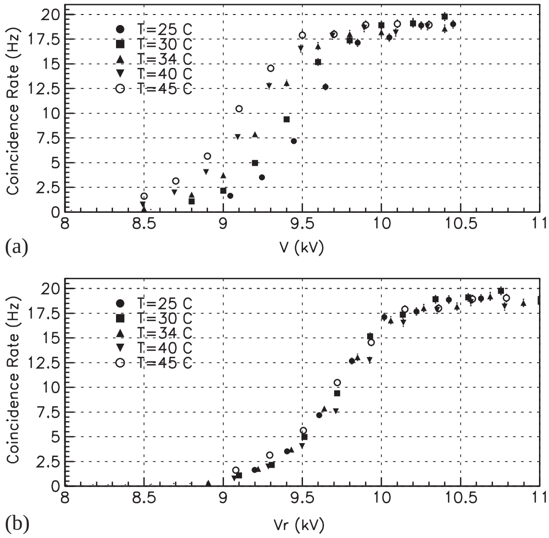


Fig. 6. Double coincidence rates vs. the operating voltage for the low resistivity RPC working in avalanche mode at different temperatures (a). (b) The voltages have been normalized to $T = 20°C$ and $P = 1010$ mbar.

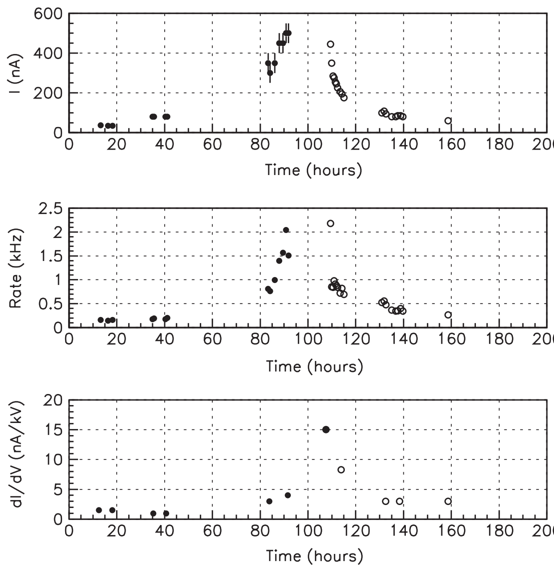


Fig. 7. Zero gas flow test performed at $T = 35°C$ with the standard operating voltage applied. The time evolutions of the current, of the counting rate and of the dark current are reported with full circles. The measurements performed after the reopening of the gas flow are indicated by blank circles.

dark current after about 80 working hours. This increase was shown to be quickly reversible when the gas flow was again open (see Fig. 7). The zero gas flow test was repeated with the voltage off for comparison. The results are shown in Fig. 8, where the coincidence rate and the operating current are reported vs. the voltage. The operating voltage after 5 days is about 400 V lower due to gas contamination. The consequence is an increase of the operating current, as in the case of the powered chamber. On the contrary, the dark current remains stable, as can be deduced from the values of the total current at voltages up to 8 kV. This suggests that the observed increase of the dark current in the test of the powered chamber is due to impurities produced by the chamber operation and not removed by the gas flow.

Finally a 40 days long-term operation test has been performed at 35°C with an applied voltage of 10.0 kV. The time evolution of the current, of the counting rate and of the dark current slope is reported in Fig. 9. This shows a decrease of the dark and of the operating currents, as well as of the counting rate, because the starting values were still biased by the previous zero gas flow tests. After about 10 days, the above parameters remained stable till the end of the test.

No shift of the operating voltage was observed by comparing the double coincidence rates measured before and after the RPC operation. More-

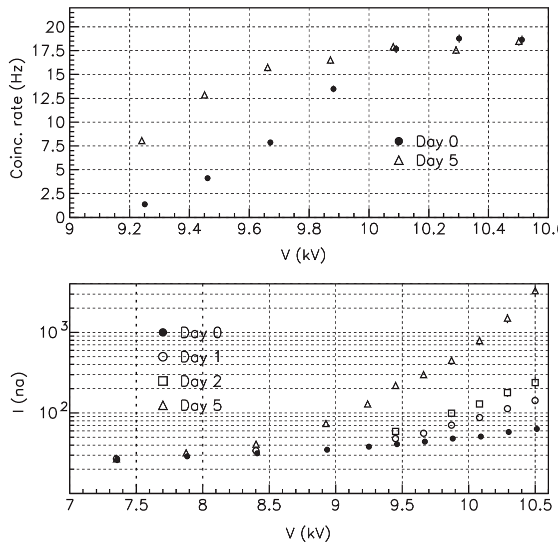


Fig. 8. Zero gas flow test with no voltage applied. Double coincidence rates and currents measured at the beginning and at the end of the test are considered.

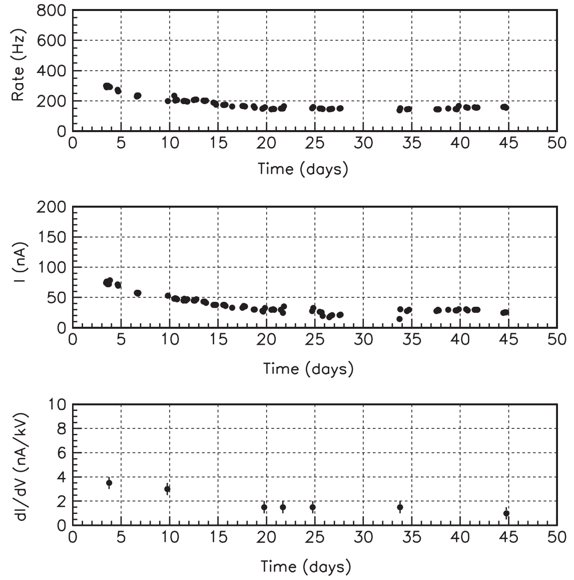


Fig. 9. From top to bottom: time evolution of the current, of the counting rate and of the dark current slope for the low resistivity RPC operated in avalanche at $T = 35°C$ and $P = (1007 \pm 15)$ mbar.

over, the efficiency at room temperature was measured with the cosmic-ray hodoscope after the end of the tests, reaching values greater than 98%.

6. Conclusions

High temperature cosmic-ray tests were performed on RPCs operated both in avalanche and streamer mode with a high gas flow (15–30 refills/day).

The tests in avalanche mode showed a good efficiency also at temperatures as high as 45°C, for high resistivity, and 35°C for low resistivity electrode plates RPCs. The counting rate and the operating current were shown to increase exponentially with the temperature. A comparison of initial and final performance at room temperature did not show any significant change of efficiency, counting rate and operating current even for an uninterrupted operation at high temperature as long as 100 days. A positive correlation between the current and the gas humidity was also observed during the long-term tests.

A similar RPC behaviour was observed for the streamer mode operation test. In this case however, the comparison of room temperature performance before and after the long-term high temperature test has shown a systematic increase of noise and operating current. A detailed map of the noise showed that the noise increase concerns only the chamber corners and can be explained as an effect due to impurities trapped inside the gap in drilling gas inlet holes during the construction.

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