Study of RPCs for autonomous field stations in cosmic ray research

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Abstract

The capability of covering very large areas at low cost, besides showing excellent performance in many aspects, motivated the application of RPCs to Nuclear and High-Energy Physics and also to Cosmic Ray research in experiments such as COVER-PLASTEX and ARGO/YBJ.

Such detectors, however, require indoor conditions and support systems. For very high energy cosmic ray research, where shower sampling is mandatory, it would be convenient to develop detectors that could be deployed in small standalone stations, with very sparse opportunities for maintenance, and with good resilience to environmental conditions.

With this aim we developed glass RPCs that are confined to a sealed plastic box housing all high voltage and gas distribution. The detector is impervious to humidity and requires only 0.4 cc.min^{-1} of gas, equivalent to 1 kg.year^{-1} of R-134a. Arbitrary readout electrodes can be applied externally.

I. Prototype development

The design of the detector follows an approach in which the sensitive volume is physically separated from the signal pickup electrodes, [1-3]. The main idea behind this approach is to solve at the same time the high voltage insulation and gas tightness issues. The resulting sensitive volume (detection module) could be seen as a pulse generator. This will considerably reduce the amount of feedthroughs, thus easing the achievement of a gas tight volume, and also decouples the high voltage from the front end electronics.

The detection module (figs.1-2) consists in two 0.3 mm gas gaps defined by 1000x500x2 mm^3 glass electrodes. The stack is then closed inside an acrylic box. The high voltage is applied by means of a layer of resistive acrylic paint on the outer glass electrodes. Only four feedthroughs are needed, two for the high voltage and two for gas input and output.

Since for outdoor applications we can not have complex gas systems, all tests were performed using pure R-134a. In a first moment it is used at a flow rate of 10 cc.min^{-1} to renew the gas volume, and after stabilizing the current flow rate it is reduced to a 0.4 cc.min^{-1}. Previous measurements [4] confirm the possibility to operate RPC with pure tetrafluoretane only with a small decrease in the efficiency when compared with binary and ternary mixtures. This could be compensated by increasing the number of gaps or the gap width, depending on the timing requirements.

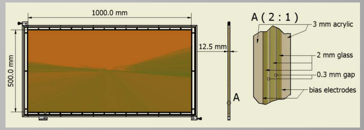

Figure 1: Schematic drawing of the detection module. Three 1000x500x2 mm^3 glass plates define two 0.3 mm gas gaps. The high voltage is applied by means of a layer of resistive acrylic paint on the outer glass electrodes. Gas tightness and high voltage insulation is provided by the acrylic box.

Figure 2: Photo taken during the production of a detection module. All the components are easily identified.

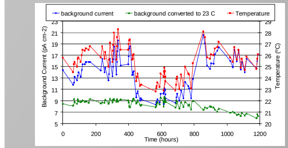

Figure 3: Background current at a constant gas flow of 0.4 cc.min^{-1}.

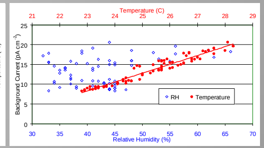

Figure 4: Background current vs. ambient temperature (top x scale, red). A linear correlation is observed between them. Background current vs. ambient temperature (bottom x scale, blue). No correlation between them is observed.

II. INDOOR, DARK CURRENT

Before testing the chamber outdoors, we carried out some measurements of the relevant parameters in the laboratory. We consider the dark current to be the most relevant parameter to monitor the health of this kind of detector. Since the variations in the ambient pressure (few tens of mbar) have very little effect on the detector gas gain, we only consider at this stage the possible influence of temperature and relative humidity.

After an initial period (20 days, not show in the plots) with a gas flow rate of 10 cc.min^{-1} to reach a stable operation and uniform gas renovation inside the acrylic box we reduced the flow rate to 0.4 cc.min^{-1}. This flow rate is equivalent to spending 1 kg.year^{-1} of gas. The working point was set to 5600 V (2800 V.gap^{-1}).

Figure 3 shows the background current (blue) and the temperature (red) variations along 50 days. As we can easily conclude, the background current is very well correlated with the ambient temperature. To confirm the dependency we can look to figure 4 were we plot the background current as function of the temperature (top x scale, red). In figure 3 we also plot (green) the values of the background current corrected by the temperature for a reference temperature of 23 °C. The stability of the current at a constant temperature demonstrates the operation of the chamber at a very low gas flow rate, equivalent to 1 kg.year^{-1}.

Acrylic has a very small but not negligible water absorption coefficient, consequently is wise to look for the influence of moisture on the performance of the detector. In figure 4 we show the background current as function of the relative humidity (bottom x scale, blue). No correlation can be found between them. To clarify this observation we performed a radical test (fig. 5) for more then 15 days, and no increase in the background current was observed.

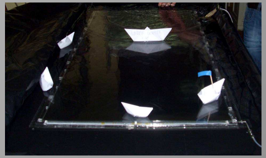

Figure 5: Humidity sensitivity test, the chamber is actually on, confirming that the detector is impervious to relative humidity.

III. INDOOR, EFFICIENCY FOR COSMIC MUONS

The setup to measure the efficiency consists of two external plastic scintillators, with a small “sniffer” RPC with four 0.3 mm gaps and 16 cm^2 efficient area between them. The chamber in test is placed between the “sniffer” RPC and the bottom scintillator. Between the RPCs was placed a block of lead with 5 cm thickness to stop the soft muons. Two metallic electrodes with 100 cm^2 were used to collect the signal from the detector to a slow charge amplifier. The trigger comes from the coincidence between the two plastic scintillators and the “sniffer” RPC. The signals were record by a digital oscilloscope (1 GHz BW, 400 ps/sample) and analyze by software.

In figure 6 we plot the efficiency as function of the applied voltage. In black we have the extrapolated curve from an equivalent measurement made with a single gap RPC [4]. The expected efficiency at the plateau should be around 87 % for our double gap RPC. We are able to reach the expected efficiency, however at a slightly higher applied voltage. Concerning efficiency the detector seems ok.

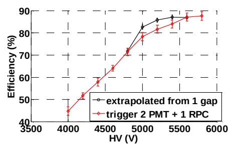

Figure 6: Efficiency as function of the applied voltage. We achieve the expected efficiency of 87% for double gap with pure R-134a. The black curve is the expected efficiency extrapolated from single gap measurements.

IV. INDOOR, CHARGE SPECTRA AND STREAMER FRACTION

In figure 7 we have the total charge spectra (for cosmic muons) in arbitrary units for the voltages considered in the efficiency measurement. The avalanches are well separated from the streamers. The avalanche’s peak moves to the right as the high voltage increases, showing a clear decrease on the contribution of small charge events. This can be understood as another sign of good health of the detector.

The inset plot shows the streamer fraction vs. high voltage. As expected, the streamer fraction sharply increases for pure R-134a. We define a maximum of 10% as the limit of operability of the detector. More information is needed to evaluate the effect of such streamers fraction on the time resolution.

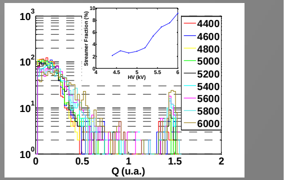

Figure 7: Charge spectra in arbitrary units for the voltages considered in the efficiency measurement. The avalanches are well separated from the streamers. The inset plot shows the streamer fraction vs. high voltage. As expected, the streamer fraction sharply increase for pure R-134a. We define a maximum of 10% as the limit of operability of the detector.

Figure 8: Photos of the thermal amplitude reduction box placed on the building’s roof. On the right we can see the test module inside.

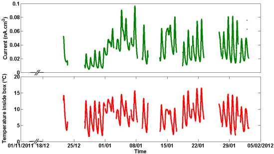

Figure 9: Top panel. Background current vs. time, no systematic increase is observed along operation time. Bottom panel, temperature inside the box vs. time, showing that the background current follows the temperature variation.

V. OUTDOOR, THERMAL BOX AND FIRST RESULTS

In order to protect the chamber from the more pronounced temperature variations found in outdoor conditions we built a “thermal amplitude reduction box” (fig. 8, left).

The aim is to get inside this box a temperature variation similar to the one found in the laboratory, or, at least, an equivalent daily gradient, as we know from laboratory measurements that the efficiency plateau of 200 V/gap absorbs the 25 °C daily variation in the temperature without affecting the detector performance, at least for the observed cosmic rays counting rates.

In figure 9 we show the background current (top panel) and the temperature inside the box (bottom panel) both as function of time, for a chamber operating at a nominal voltage of 5600 V and at a gas flow rate of 0.4 cc.min^{-1}. The chamber is now on for more than three months without any registering any abnormal behaviour. The background current did not increase and it seems very well correlated with temperature as in the laboratory. We also recorded the ambient pressure and relative humidity and no correlation between these and the current was found. More time in operation is needed to mature these observations.

VI. CONCLUSIONS

We developed glass RPCs that are confined to a sealed plastic box housing all high voltage and gas distribution. The detector is impervious to humidity and requires only 0.4 cc.min^{-1} of gas, equivalent to 1 kg.year^{-1} of R-134a. Arbitrary readout electrodes can be applied externally.

The observations made indoor and outdoor suggests an healthy detector. We intend to verify the range of the efficiency plateau as function of temperature and perform also measurements of the time resolution.

Outdoor tests will continue to run, the next steps are the monitoring of the practical quantities, such as efficiency, time resolution and streamers fraction. The objective is to find any correlation between these quantities and environmental conditions.

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