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Study of RPCs for autonomous field stations in cosmic ray research

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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 of gas flow rate, equivalent to 1 kg/year of R-134a. Arbitrary readout electrodes can be applied externally.

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1.Introdution

The abundance of available literature confirms that Resistive Plate Chambers [1] have been applied with great success in many High Energy and Nuclear Physics experiments over the

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last two decades. In cosmic ray physics, RPCs have been already used in the COVER-PLASTEX [2] and ARGO/YBJ [3] experiments.

The previous referred experiments are all running indoors, where all environment variables are continuously monitored and/or adjusted assuring that the detectors will operate under safe conditions. When outdoors, in an uncontrolled environment, large daily temperature and humidity variations should be accommodated. High voltage insulation and gas tightness should be assured very reliably. The chambers must be able to operate for long periods of time without maintenance, calling for a much reduced gas flow. The present work tries to address some of these issues. We first assure the correct indoor operation of the prototype and show some preliminary outdoor results.

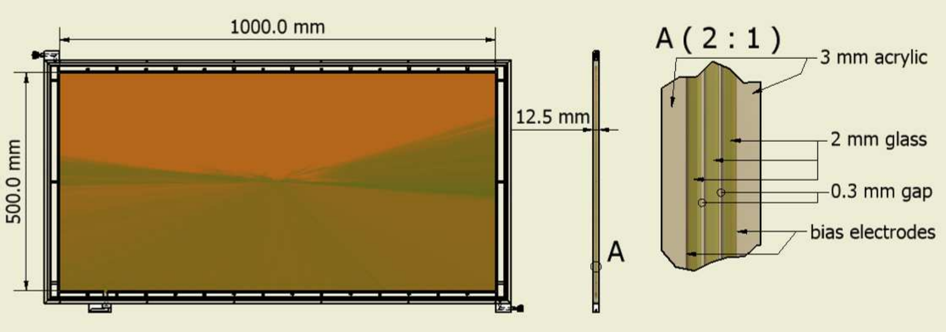

Figure 1: Schematic drawing of the detection module. Three 1000×500×2 mm^3 glass plates define two 0.3 mm gas gaps. The high voltage is applied by means of a layer of resistive acrylic paint on the outer glass electrodes. Gas tightness and high voltage insulation is provided by the permanently glued acrylic box.

2. Prototype development

The design of the detector follows an approach in which the sensitive volume is physically separated from the signal pickup electrodes [4-6]. The main idea behind this approach is to solve at once the high voltage insulation and gas tightness issues. 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 (fig.1) consists in two 0.3 mm gas gaps defined by 1000×500×2 mm^3 glass electrodes separated by Mylar monofilaments (phishing line). The stack is then closed inside a permanently glued acrylic box. The high voltage is applied by means of a layer of resistive acrylic paint [7] on the outer glass electrodes. Only four feedthroughs are needed, two for the high voltage and two for gas input and output.

Since for remote outdoor applications complex gas systems are undesirable, all tests were performed using pure R-134a (tetrafluoretane). In a first moment it is used at a flow rate of 10 cc/min to renew the gas volume and after stabilization the flow rate is reduced to 0.4 cc/min. Previous measurements [8] confirm the possibility to operate RPCs with pure tetrafluoretane with only 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.

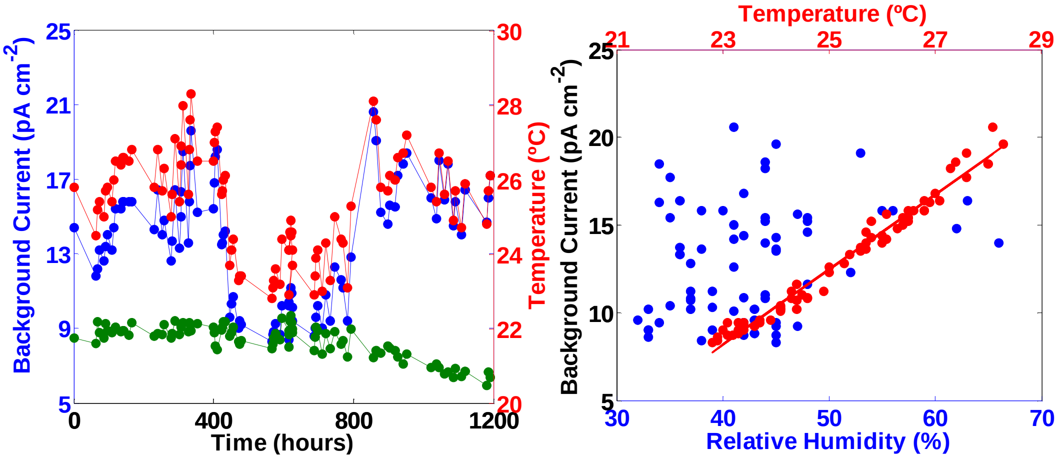

Figure 2: Left panel: background current at a constant gas flow rate of 0.4 cc/min (blue line), showing also the temperature (red line) and the current normalized to a temperature of 23 ºC (green line). Right panel: background current vs. ambient temperature (top x scale, red) and background current vs. relative humidity (bottom x scale, blue). The background current is well correlated with temperature but it is unaffected by relative humidity.

3. Indoor measurements

Before testing the chamber outdoors some measurements of the relevant parameters were carried out in the laboratory. We consider the dark current to be the most relevant single parameter to easily monitor the correct operation 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.

3.1 Dark Current

After a conditioning period (20 days, not shown in the plots) at 10 cc/min the gas flow rate was reduced to 0.4 cc/min. The working point was set to 5600 V (2800 V/gap).

In fig. 2 (left panel) it is shown the background current (blue) and the temperature (red) variations along 50 days. It is apparent that the background current is very well correlated with the ambient temperature. This is further illustrated in fig. 2 (right panel) were we plot the background current as a function of the temperature (top x scale, red). The green curve in the left panel show the background current corrected by the temperature for a reference temperature of 23 ºC. 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.

Acrylic has a very small but not negligible water absorption coefficient [9], consequently it is wise to look for the influence of moisture on the performance of the detector. In fig. 2 (right panel) we plot the background current as function of relative humidity (bottom x scale, blue), showing no correlation between them. To further this observation we performed a quite radical test (fig. 3) placing the chamber underwater while keeping the HV on for more than 15 days, observing no increase in the background current.

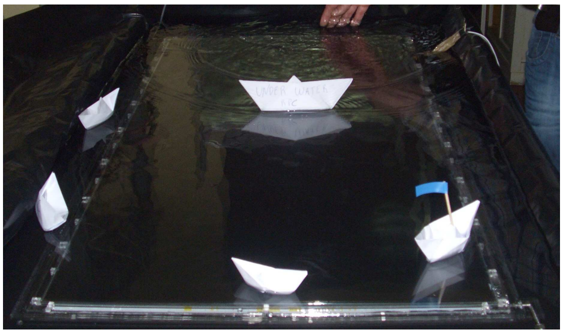

Figure 3: Humidity sensitivity test with the chamber underwater with HV applied for 15 days, confirming that the detector is quite impervious to humidity.

3.2 Efficiency for cosmic rays, charge spectra and streamer fraction

The setup to measure the efficiency consists of two external plastic scintillators and a small trigger RPC with 99 % efficiency to cosmic rays. The test area defined by the setup is around 12 cm^2. The chamber in test is placed between the trigger RPC and the bottom scintillator. Between both RPCs it was placed a lead block with 5 cm thickness to absorb the softer muons. Two square metallic electrodes with 100 cm^2 were used to collect the signal from the detector to a slow charge amplifier with 10 µs CR-RC shaping. The trigger is generated from the coincidence between the two scintillators and the trigger RPC. The signals were recorded by a digital oscilloscope (1 GHz BW, 400 ps/sample) and analyzed by software.

In fig. 4 (left panel) we plot the efficiency as a function of the applied voltage. In black we have the extrapolated curve from an equivalent measurement made with a single gap RPC [8]: 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. Higher efficiency values can be achieved by increasing the number of gaps or/and the gap width, depending on the timing requirements.

The observed charge spectra of all efficient events (fig. 4, right panel) show a well defined separation between avalanches and streamers. The avalanche's peak moves to the right as the high voltage increases, showing a clear decrease on the contribution of the smaller events. Also from the observation of the charge spectra the streamers fraction as function of the applied voltage can be evaluated. We define 10 % as the operability limit, which was reached for 6000 V (3000 V/gap). So we were able to operate the chamber at the efficiency plateau (400 V wide) with less then 10 % of streamers, reinforcing the impressions of chamber good health and robustness.

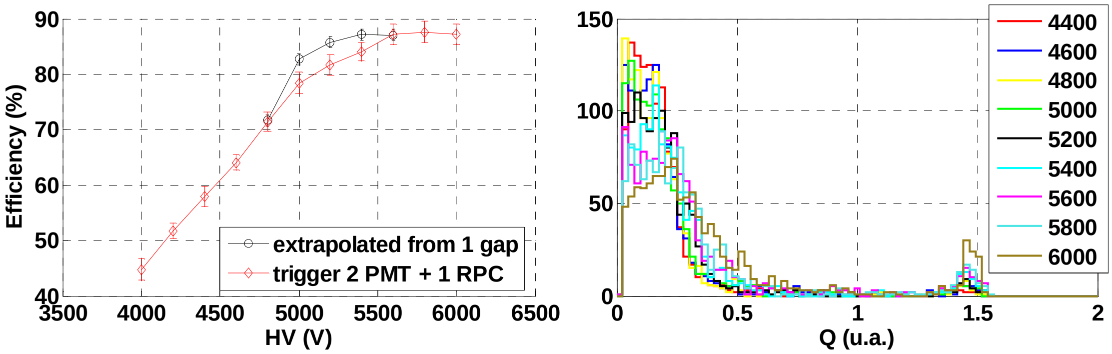

Figure 4: Left panel: efficiency vs. applied voltage. We achieve the expected efficiency of 87 % for a double gap RPC filled with pure R-134a. The black curve is the value extrapolated from single-gap measurements. Right panel: charge spectrum, the minimum is the efficiency threshold; the avalanches are well separated from the streamers. The avalanche's peak moves to the right as the high voltage increases.

4.Outdoor

In order to protect the chamber from the more pronounced temperature variations found in outdoor conditions we built a "thermal amplitude reduction box". The aim is to reach inside this box a temperature variation similar to the one found in the laboratory, or, at least, an equivalent daily gradient. This is because from laboratory measurements it is known that the efficiency plateau of 200 V/gap absorbs the 25 ºC daily variation in the temperature without affecting the detector performance, at least for the observed cosmic rays counting rates.

In fig. 5 it is shown 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. The chamber as been on for more than four months without 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 operation time is needed to mature these observations.

5.Conclusion

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 of gas, equivalent to 1 kg/year of R-134a. Arbitrary readout electrodes can be applied externally.

The observations made indoor and outdoor suggest a well-performing 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 as well. The next steps are the monitoring of the practical quantities, such as efficiency, time resolution and streamers fraction, aiming to find any correlation between these and the environmental conditions.

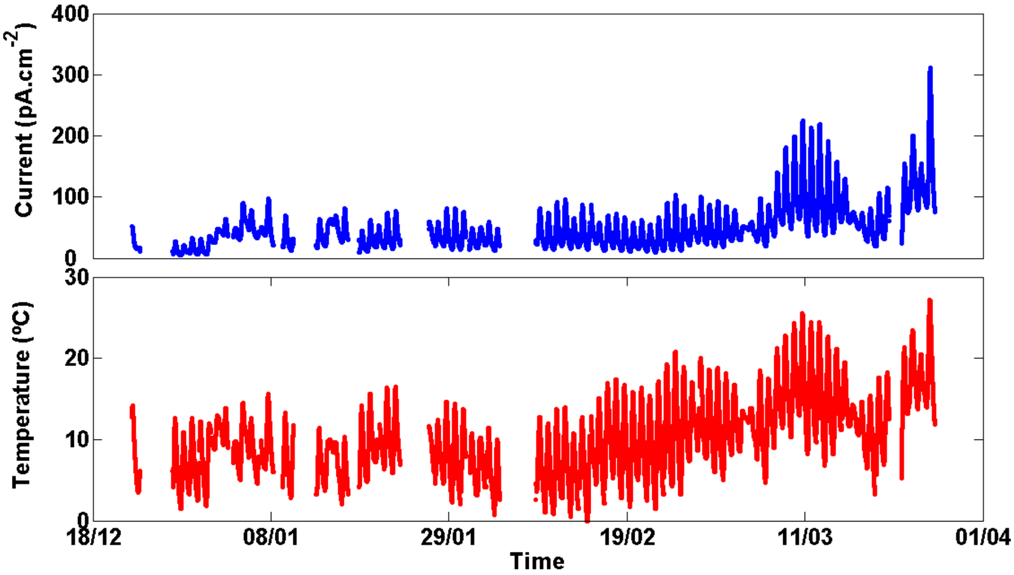

Figure 5: Top panel: background current vs. time, outdoors, with reduced gas flow: no systematic increase is observed along the operation time. Bottom panel: temperature inside the box vs. time, showing that the background current follows the temperature variation.

Acknowledgements

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