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Full Length Article

The Resistive Cylindrical Chamber

R. Cardarelli [a], A. Rocchi [a,*], G. Aielli [b], P. Camarri [b], A. Di Ciaccio [b], L. Di Stante [b], B. Liberti [a], E. Pastori [a], L. Pizzimento [a], G. Proto [a]

[a] INFN Roma Tor Vergata, Via della Ricerca Scientifica 1, Roma, 00133, Italy
[b] Università di Roma Tor Vergata, Via della Ricerca Scientifica 1, Roma, 00133, Italy

A R T I C L E I N F O

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A B S T R A C T

A new generation of gaseous particle detectors named Resistive Cylindrical Chamber (RCC) (Cardarelli, 2021; Rocchi, 2022) [1,2] has been developed to overcome the limitations of Resistive Plate Chambers (Santonico and Cardarelli, 1981) [3] and broaden their application range. The principle behind this new technology consists in the transition from a planar to a cylindrical geometry while maintaining an almost planar electric field. The cylindrical structure of the electrodes allows to reach the following goals: increase the gas pressure to improve the intrinsic efficiency of the detector even for thin gas gaps or light gas mixtures; design the detector in order to produce an electric field gradient possibly useful to contain the development of the avalanche discharge. These features could lead to design detectors of simple mechanical realization with time resolution comparable with that of MRPCs maintaining a high efficiency of detection on a single thin gas-gap. The device pressurization could also allows to use new gases in view of the transition to eco-friendly gas.

1. Planar vs. cylindrical geometry

The planar geometry is not suitable to be pressurized unless significantly increasing pillars redundancy or building a complex tight mechanical containment structure. Indeed, in a planar gaseous detector, the force exerted on the bonding surfaces of the pillars increases proportionally to the difference in pressure with respect to the outside of the gas volume and with respect to the size of the detector.

In a uniform electric field, (Santonico and Cardarelli, 1981) [3], the quenching of the avalanche discharge is mainly due to the gas mixture, the electrode properties and the electric field strength. The geometric factor affects the discharge growth only through the space charge effect. In the cylindrical geometry the electric field gradient contributes to the gas discharge quenching or growth depending on the polarization. Combination of pressurization and geometrical quenching would allow to: increase the gas target density, with a consequent increase in intrinsic efficiency; possibly increase the charge collection efficiency enhancing the multiplication in the initial part of the gas gap. These features could lead to very high time response with thin single gap configuration without loss of efficiency, in addition to the compatibility with light eco-friendly CO_2 based gas mixtures and new eco-friendly gas components. A further advantage that introduces the cylindrical geometry is the natural possibility to detect two points for the track reconstruction with a single gas-gap.

2. Detector general description

As shown in Fig. 1, the RCC detector (Cardarelli, 2021; Rocchi, 2022) [1,2] consists of two concentric cylindrical electrodes of resistive material which define a gas gap whose thickness is almost negligible with respect to the cylinders radii. The cylinders surface on the opposite side from the gas, is coated with high resistivity graphite layer which distributes the High Voltage potential on the whole electrode surface. The transparency of the electrodes to the prompt electrons signal allow to read-out the induced signal on the metallic pick-up strips or pads which can be positioned both in the internal cavity and on the external surface of the cylinder, decoupled from the graphite layer through a layer of insulating material. A layer of insulating foam separates the read-out pick-ups from the external shielding. The two end caps are designed to provide gas inlet and outlet up to gas pressure order of 10 bars, and to keep the cylinders in concentric position. This feature allow to reduce the dead area of the detector avoiding pillars inside the gas gap. Nonetheless it is always possible to improve the cylinders position by adding a calibrated fishing line into the gas gap that winds the internal cylinder in a spiral, this at the expense of the active area. In Fig. 2 the process of track reconstruction is described. For tracking application it is essential that the pick-up is optimized to minimize the cross-talk between adjacent strips or that the electronics is designed to evaluate the centre of gravity of the charge distribution, increasing

* Corresponding author.
E-mail address: alessandro.rocchi@roma2.infn.it (A. Rocchi).

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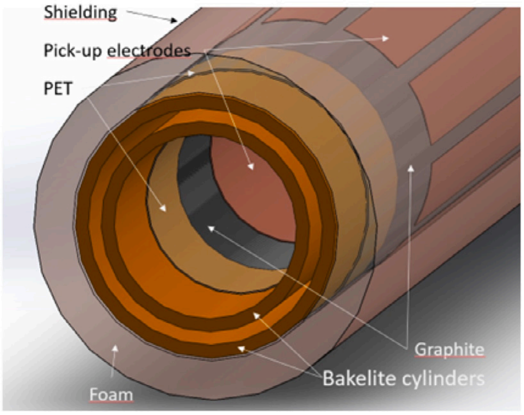

Fig. 1. Sketch of a Resistive Cylindrical Chamber with read-out strips on the external electrode and pad read-out within the cylinder cavity.

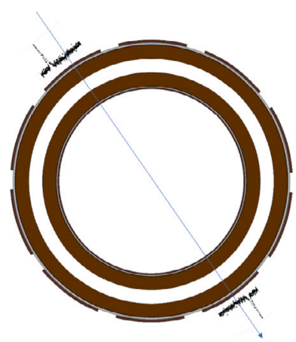

Fig. 2. Cross section of a Resistive Cylindrical Chamber showing the tracking capability for crossing particles.

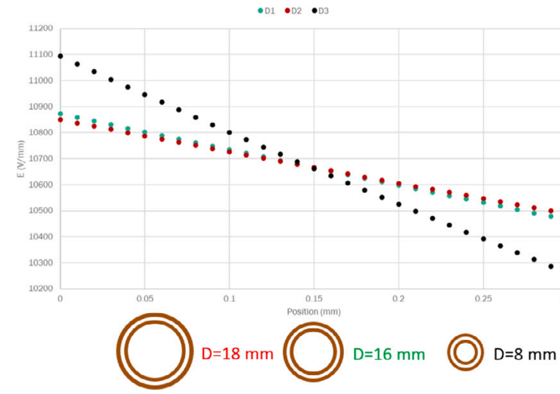

Fig. 3. Electric field calculated with Eq. (1) for three different configuration.

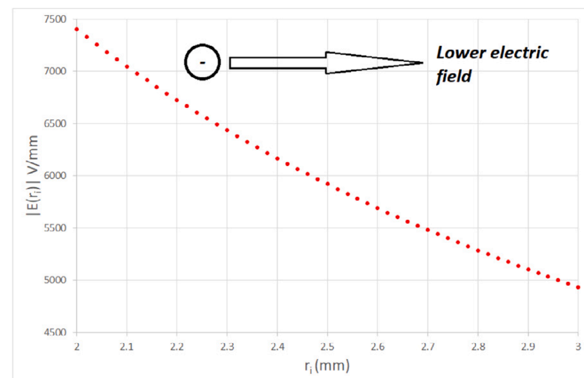

Fig. 4. Electric field calculated with Eq. (1) for the prototype under test and positive bias. The electrons move towards the region with the lower electric field.

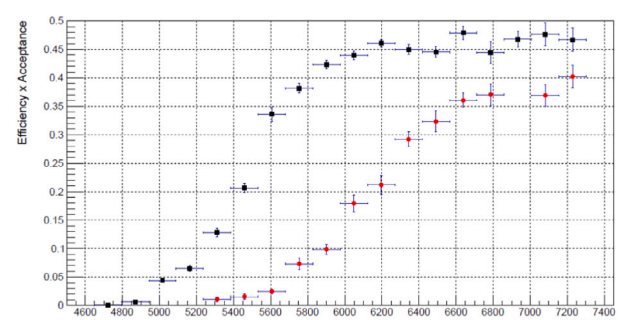

Fig. 5. Efficiency response of the hybrid RCC without front-end electronics in positive (red points) and negative (black points) bias. In that case the efficiency is limited by the geometrical acceptance that is constant for the two polarities.

the spatial resolution up to about 130 μm [4]. The electrostatic field E with respect to the position r inside the gas gap can be calculated for different value of the cylinders radii R_o and R_i with the equation

$$E(r) = \frac{V}{r ln\frac{R_o}{R_i}} \approx \frac{V}{R_i ln\frac{R_o}{R_i}} - \frac{V}{R_i ln\frac{R_o}{R_i}} \frac{r - R_o}{R_i} \qquad (1)$$

with $R_i < r < R_o$.

In Fig. 3, the electric field within a 0.3 mm gas gap is plotted with respect to the distance from the inner surface for three different radii configuration. The electric field gradient increases as the ratio between the thickness of the gas gap, $R_o - R_i$, and the radius of the internal electrode increases (expression depending on the reference system adopted).

3. First tests

Small prototypes of RCC have been built to evaluate the detector performance and the impact of the electric field gradient. The prototypes differ for the cylinders radii and material. Two kind of material have been used for the electrode construction: high resistivity bakelite and aluminium. High resistivity bakelite tubes 1 mm thick with different radii have been purchased at the CERN internal store. The available tubes form factors did not allow to built detectors with a large ratio between the gas gap thickness and the internal cylinder radius, therefore we decide to use bakelite electrodes for thin gas gap prototypes and a hybrid configuration to study the case of thick gas gap and high electric field gradient. This hybrid prototype has the internal cylinder made of aluminium with external radius of 2 mm and the outer cylinder made of high resistivity bakelite with internal radius of 3 mm, so that the ratio between the gas gap thickness and the radius of the internal electrodes is 0.5 and the electric field has the values shown in Fig. 4. This prototype have been extensively studied with muons beam at the H8 beam line of the SPS. The tests aim to demonstrate the correct functioning of the device with a quasi-planar cylindrical geometry and characterizing the efficiency, the time response and the shape of the signals in the two polarization conditions. The external cylindrical electrode will be used as reference for the polarization definition (positive polarization means that positive HV is applied on the external electrode). In positive polarization, multiplication is expected to occur mainly in the region close to the cathode, which can be described, to a rough approximation by a multiplication followed by drift model. On the contrary, in negative polarization, multiplication

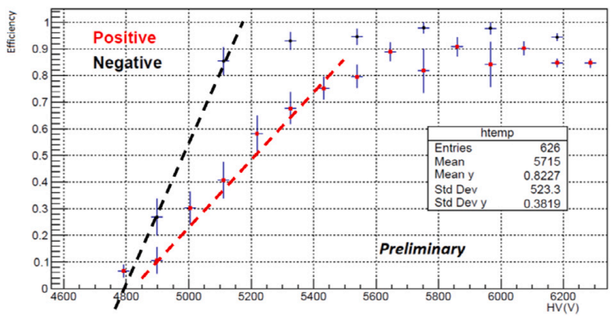

Fig. 6. Efficiency response of the hybrid RCC with front-end electronics in positive (red points) and negative (black points) bias. The coincidence with the UFSD improve the geometrical acceptance despite of loss in statistics.

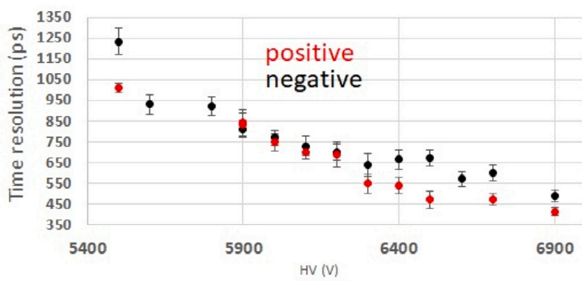

Fig. 7. Time resolution measured in positive (red dot) and negative (black dot) polarities.

increases as electrons approach the anode, roughly approximating a system characterized by drift followed by multiplication.

The system was installed downstream from the beam-line dump platform and the test was performed with a secondary 165 GeV/c muon beam. The experimental set-up consists of three scintillators used as trigger and other prototypes as reference. An Ultra-Fast-Silicon-Detector (UFSD) was placed in front of the RCC to improve geometrical acceptance with respect to the trigger. Nevertheless, given the small dimensions of the prototype compared to the beam profile width and due to the beam intensity, a compromise was chosen between geometric acceptance and trigger rate. The gas mixture was composed for 94.7% by $C_2H_2F_4$, for 5% by iC_4H_{10} and for 0.3% by SF_6 and was fluxed at atmospheric pressure. The prompt signal, read-out directly from the aluminium cylinder,was acquired with the CAEN V1742 12 bit, 5 GS/s Digitizer.

The efficiency was measured using a threshold set at 5 standard deviations from the mean value of the noise pedestal of the digitizer (about 5 mV). In addition to the trigger signal, the coincidence of three other detectors on the beam line was requested off-line. The response have been studied without front-end electronics, Fig. 5, and with front-end electronics [5], Fig. 6.

In both cases the efficiency curves clearly shows the asymmetrical response of the detector with respect to the bias voltage polarity. In the case of positive bias (red curves), in which the multiplication occurs mainly in the first multiplication steps, the efficiency knee shifts towards higher voltage values. A reduction in the plateau value is also observed, indicating that the useful gas-gap is thinner with respect to the negative bias (black curves). The time response was measured with respect to a thin gap RPC with two 0.2 mm gas-gaps read-out on the same pick-up (time resolution less then 150 ps). It improves as the applied voltage increases and for high field values it is systematically better in the case of positive bias, in which multiplication occurs mainly near the cathode (behaviour like that of a thinner gas-gap) (see Fig. 7).

4. Conclusions

The correct operation of a cylindrical geometry device with a quasi-uniform electric field has been demonstrated. All the measured quantities highlighted the asymmetry of the response with respect to the polarity of the supply voltage, highlighting how the electric field gradient impact on the development of the avalanche discharge in the gas. This test represents the first step towards the development of cylindrical geometry detectors with a calibrated field for the intended purpose. Further investigations are necessary to fully understand the link between the temporal evolution of the signal and the electric field. Furthermore tests on devices with both bakelite electrodes and same geometry of the tested hybrid prototypes should be performed to exclude contribution of the metallic electrode in the response asymmetry.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] R. Cardarelli, Future RPC developments, J. Instrum. 16 (2021) C05004.
[2] A. Rocchi, Moderation of the avalanche gas discharge through a quasi-uniform electric field device: the Resistive Cylindrical Chamber, VCI2022.
[3] R. Santonico, R. Cardarelli, Development of resistive plate counters, NIM Sect. A 187 (1981) 377–380.
[4] G. Aielli, et al., The RPC space resolution with the charge centroid method, J. Instrum. 9 (2014).
[5] R. Cardarelli, et al., Performance of RPCs and diamond detectors using a new very fast low noise preamplifier, J. Instrum. 8 (2013).