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Development of high-rate timing RPCs

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Abstract

For many applications of RPCs to time-of-flight counters in heavy ion experiments the expansion to much higher values of the counting rate capability, so far limited to around 2 kHz/cm^2 is of fundamental importance. To address this issue we developed single-gap timing RPCs with resistive electrodes made from a commercially available plastic material. Tests performed in photon beams yielded a time resolution around 90 ps σ, essentially unchanged from 2 kHz/cm^2 to 27 kHz/cm^2. This result establishes the basic feasibility of timing measurements with RPCs at rates of tens of kHz/cm^2, keeping a time resolution below 100 ps σ and using plastic electrode materials.

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Keyword: RPC; TOF; High-rate

1. Introduction

The extension of the counting rate capabilities of Resistive Plate Chambers (RPC) has been often an important part of the requirements for new applications. Currently, the detection of MIPs over large areas can be made at rates close to 3 kHz/cm^2 [1,2], while at medium gas gains, around 10^5, and small active areas counting rates over 10^7 Hz/cm^2 [3,4] have been demonstrated.

For timing RPCs [5]—RPCs used for time-of-flight measurements—the current maximum counting rate capability is close to 2 kHz/cm^2 [6]. However, these counters operate at rather extreme conditions (enormous gas gain over 10^{12} and avalanche development in a deeply space-charge saturated mode [7]), which may make the operation at high counting rates difficult due to instabilities arising from the cathodes [3].

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In practice, the counting rate capability of RPCs is also strongly conditioned by the availability of suitable electrode materials with medium resistivity and good mechanical characteristics. Bulk resistive materials used so far include bakelite and glass (the most common RPC materials), doped ABS plastic [8], silicon or galium arsenide [4] and other ad hoc materials [9]. Layers of germanium [10] or SiC [11] deposited on insulating substrates have been also considered.

Difficulties may also arise from the possible appearance of permanent discharges at medium electrode resistivities (roughly 10^4–$10^8\,\Omega$cm [4]), while at lower resistivity values the sparks progressively become more powerful.

Having in mind medium-scale applications of hightiming RPCs we tried to identify suitable commercially available materials of reasonable cost and with some perspectives for long-term durability. In this work we addressed the so-called antistatic plastics, which are available with catalogue resistivities ranging from 10^8–$10^{12}\,\Omega$cm.

2. Experimental setup

The detectors, with an active area of $9\,\mathrm{cm}^2$, were constituted by a stainless-steel cathode and an ENSITAL®SD [12] plastic anode, defining a single 0.3 mm wide gas gap (Fig. 1). The 5 mm thick electrodes had the active surfaces lapped and polished, the edges smoothed and were externally glued to support columns [13]. Electrical contact with the plastic was made via a uniform layer of silver-loaded epoxy glue.

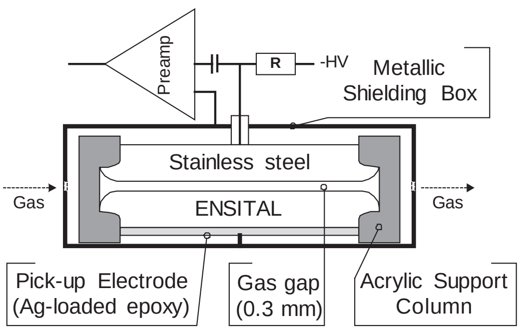

Fig. 1. Schematic view of the detector structure.

The assembly was made under strict clean conditions, which are essential to avoid permanent discharges.

Each counter was enclosed in a metallic shielding box (Fig. 1) and the assembly placed in a gasmetallic box. A continuous gas flow of tetrafluorethane ($C_2H_2F_4$) with 10% of sulphur hexafluoride (SF_6) was piped into the shielding boxes through dust filters. A schematic view of the set-up is shown in Fig. 2.

Both chambers produced very similar currents when irradiated, suggesting a precise gap spacing. The dark count rates were typically inferior to 1 Hz.

Chamber signals were sensed by a 3 GHz bandwidth, gain 10, preamplifier [14] and digitised by a 1 GHz bandwidth, 10 GS/s TEK000 oscilloscope. Signal analysis was done offline by software.

Time-resolution tests were performed either by irradiation with simultaneous 511 keV photon pairs emitted by a 0.8 mCi ^{22}Na source placed between the chambers or by exploiting almost simultaneous events pertaining to Compton cascades initiated by 662 keV photons from a 200 mCi ^{137}Cs source.

The time resolution (σ) of the high-rate chamber was estimated by subtracting quadratically the resolution of the reference chamber (kept at low rate) from the measured time difference resolution.

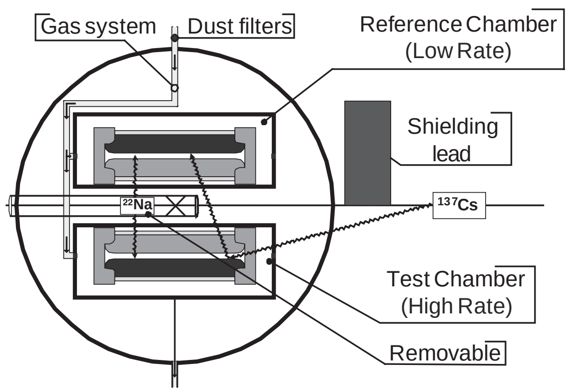

Fig. 2. Schematic representation of the experimental set-up. Almost simultaneous events were generated either by photon pairs emitted by a ^{22}Na source or by Compton cascades initiated by photons from a ^{137}Cs source.

The resolution of the reference chamber was measured using the ^{22}Na source (therefore in a symmetric situation) and assuming that both chambers were identical.

3. Results

3.1. Currents and counting rate

The chamber current and counting rate per unit area as a function of the applied voltage is shown in Fig. 3.

For currents below 70 nA/cm^2, corresponding to a saturation counting rate of 27 kHz/cm^2, the chamber follows a linear current growth law. Although gas counters should in principle follow an exponential law, it is well known that RPCs follow a linear law at high gains due to the space-charge effect.

Using the method suggested in [15] it was estimated that during the measurements shown in Fig. 4 the resistive electrode presented a resistivity around 20 GΩ cm.

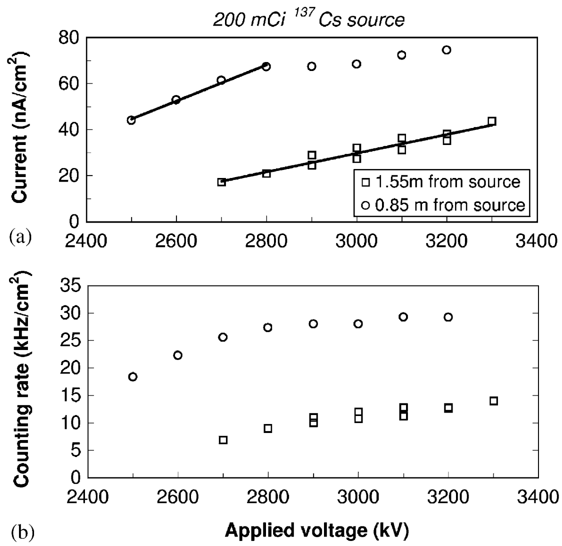

Fig. 3. Current and counting rate per unit area as a function of the applied voltage. The chamber deviates from the linear current growth close to 70 nA/cm^2, corresponding to a saturation counting rate of 27 kHz/cm^2.

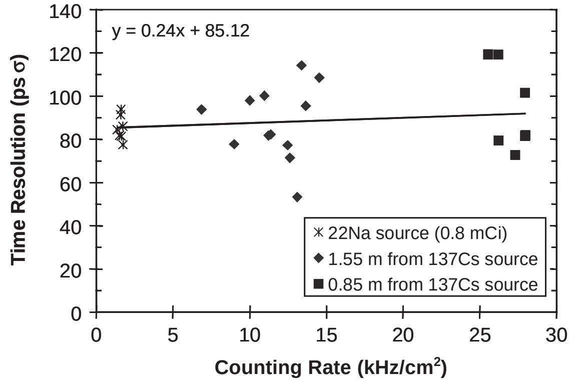

Fig. 4. Time resolution as a function of the counting rate, essentially unchanged from 2 to 27 kHz/cm^2 at a level around 90 ps σ. The vertical spread of the points is mainly due to statistical fluctuations and the horizontal spread due to the different working voltages at which the points have been taken.

3.2. Time resolution

As shown in Fig. 4, the time resolution remained essentially unchanged, at a level around 90 ps σ, from 2 to 27 kHz/cm^2.

It should be noted that previous experience with timing RPCs in particle beams and with annihilation photons has shown that while single-gap counters may reach a time resolution of 60 ps σ in particle beams [16], similar counters irradiated with 511 keV photon pairs reach only about 90 ps σ. This fact may be attributed to the larger statistical variance of the primary currents arising from the later irradiation method (see Ref. [17]).

4. Brief characterization of the resistive material

External tests to the resistive material were performed for obtaining some information about its long-term dynamic behaviour.

A second conductive electrode made with silver-loaded epoxy was formed over the ENSITAL plate and the sample placed in a temperature-controlled enclosure (the resistivity sharply decreases with temperature) under a steady flow of tetrafluorethane. A fixed voltage was applied across the sample and the current continuously monitored. After some time the voltage was set to zero, except for a few brief moments to allow a fast resistivity measurement.

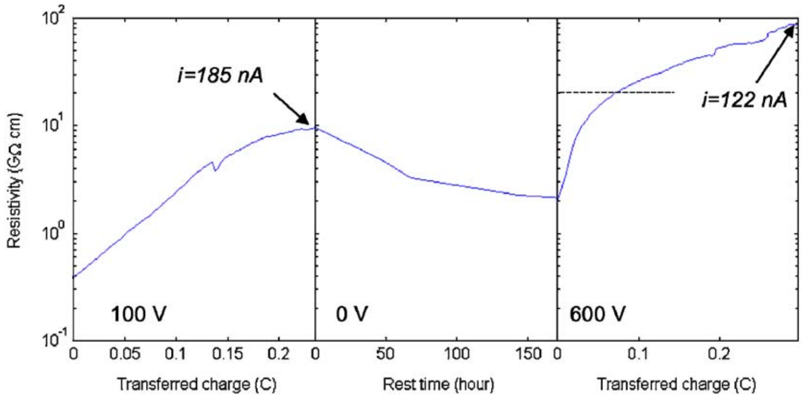

Fig. 5. Externally measured resistivity of the ENSITAL plastic as a function of the transferred charge. Tests were done with applied voltages of 100 and 600 V and the electrodes allowed to rest for 170 h between measurements. The horizontal dashed line marks the indirect measurement mentioned in Section 3.1.

The results can be seen in Fig. 5. Initially the resistivity rises exponentially with the transferred charge but seems to progressively approach a stable value. This value depends on the applied voltage but, remarkably, the final currents are similar for different applied voltages. When the voltage is removed the resistivity recovers slowly in time, eventually recovering its initial value.

Although such measurements may not rigorously represent the behaviour of the material when used as an electrode (namely given the different current injection method) it seems that a qualitative agreement can be perceived. For instance, at the highest counting rates the chamber current was up to 15% higher at the beginning of each run and then decayed rapidly to its equilibrium value. The runs lasted typically for 20 min, followed by a low current period of about 10 min. For such intermittent use a kind of equilibrium may be reached between resistivity increase due to current flow and its recovery by resting, allowing a reasonable agreement between the indirect resistivity measurements mentioned in Section 3.1 (dashed line in Fig. 5) and the external ones.

5. Conclusions

The present result establishes the basic feasibility of timing measurements with RPCs at rates of tens of kHz/cm^2 while keeping a time resolution below 100 ps σ. This represents an improvement of over one order of magnitude in the counting rate as compared to the highest rates reported so far.

For this particular study we used a commercially available plastic material, showing that small-area timing RPCs can be made with plastic anode electrodes.

A severe, but reversible, increase of the plastic resistivity with the transferred charge was observed. While this characteristic may not be of much importance, if the counters are to be used in a low duty cycle situation, further research is needed on suitable resistive materials.

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