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Direct measurement of the avalanche charge in a Resistive Plate Chambers detector

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Abstract

We performed a direct measurement of the avalanche charge with a $10 \times 10\,\mathrm{cm}^2$ prototype resistive plate chambers with a 0.2 cm gas gap. We studied its behaviour with respect to the high voltage and its dependence on the presence of the SF_6 in the gas mixture ($C_2H_2F_4$/i-C_4H_{10}/SF_6 in the ratio 95/4/1 and 96/4/0). The measurements showed a double exponential behaviour of the average avalanche charge with respect to the high voltage. A comparison with other results has been discussed.

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Keywords: RPC; Detector; Avalanche; Charge; SF6

1. Introduction

Resistive plate chambers (RPC) have been used in several experiments with a low flux of particles since 1980s; in order to operate at the expected flux of particles at the future accelerator experiments, it was suggested a low-gas amplification working mode (avalanche mode) [1,2]. This result has been achieved by using in the gas mixture a small percentage of SF_6, a gas with a high electronegativity which can appreciably suppress the streamer formation [3]. The purpose of the present work is the study and the direct measurement of the average avalanche charge with respect to the high voltage and with respect to the percentage of SF_6 in the gas mixture.

2. Experimental set-up

We used an RPC $10 \times 10\,\mathrm{cm}^2$, with 2 mm gas gap and bakelite electrodes with a bulk resistivity about $2 \times 10^{10}\,\Omega\,\mathrm{cm}$, and read out by a separate copper electrode segmented in two pads

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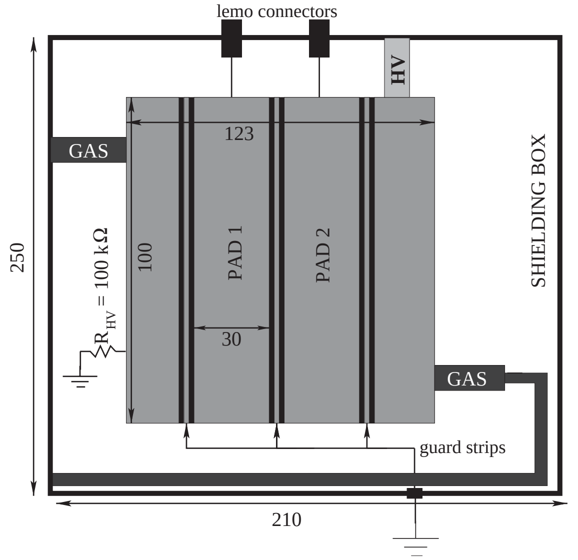

Fig. 1. Schematic view of the prototype RPC.

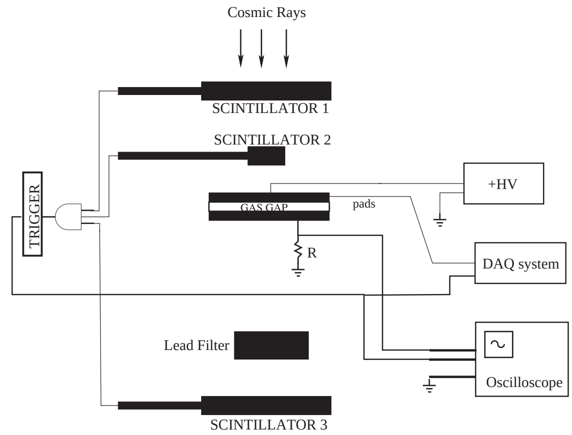

Fig. 2. Experimental set-up.

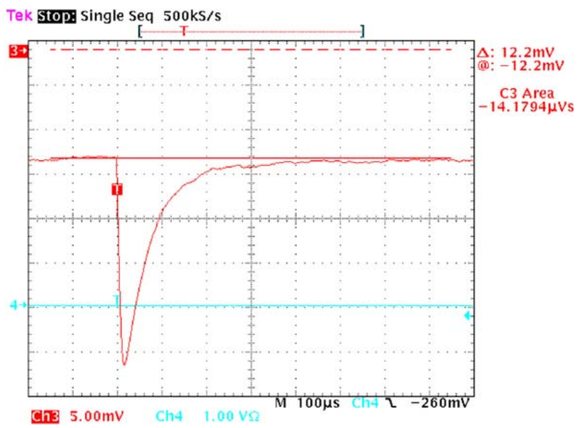

Fig. 3. Typical signal in the RPC collected on the anode plate through a 100 kΩ load resistor.

($3 \times 10\,cm^2$) connected to an analog front-end amplifier (see Fig. 1), the detector has been flowed with two different gas mixtures: $C_2H_2F_4$/i-C_4H_{10}/SF_6 in the ratio 95/4/1 and $C_2H_2F_4$/i-C_4H_{10} in the ratio 96/4.

In this paper, we describe a direct measurement of the avalanche charge performed by collecting the signal on the anode plate. The method is simple and totally model independent. An alternative solution could be a measurement performed by using the induced signal on the segmented electrode; but, in order to calculate the avalanche charge from the induced charge, one should know exactly the Townsend coefficient and be sure that spatial charge effects are negligible (model-dependent measurement) [4–6].

The data-acquisition system was composed by a 64 channels TDC (Caen V767A) and by a 32 channels ADC (Caen V792); the avalanche charge has been measured using an oscilloscope Tektronix TDS 684 A connected to the anode plate through a 100 kΩ load resistor and it also provided the average measurement over about 1000 pulses. The oscilloscope capacitance is 10 pF, while the cable capacitance (~ 40 cm coaxial cable) is ~ 40 pF ($\tau \simeq 4\,\mu s$), so that the influence on the signal shape was negligible.

The experimental set-up is shown in Fig. 2. A lead filter has been used in order to eliminate the soft component of cosmic rays. Three scintillators have been used to select cosmic rays crossing the RPC in the region covered by two read-out pads connected to the analog front-end amplifier.

3. Experimental results

A typical current pulse recorded by the oscilloscope is shown in Fig. 3. Its duration is determined by the bakelite properties and in our case it was about 100 μs; this value does not agree well with the expected bakelite relaxation time computed through the approximate relationship $\tau = \rho\varepsilon_0(2+\varepsilon_r)$ [7], but it is well known that the bakelite resistivity is strongly dependent on the environment conditions and therefore the resistivity value could differ from the nominal one at the time of construction [8,9].

The charge is obtained by integrating the signal and subtracting the pedestal; the pedestal charge was about 10 pC and in the following figures the measured charges are shown without this subtraction.

The signal amplitude depends on the operating voltage and on the presence of the SF_6 in the gas mixture as shown in Fig. 4, where the detector efficiency is drawn with respect to the high voltage corrected by temperature and pressure. The

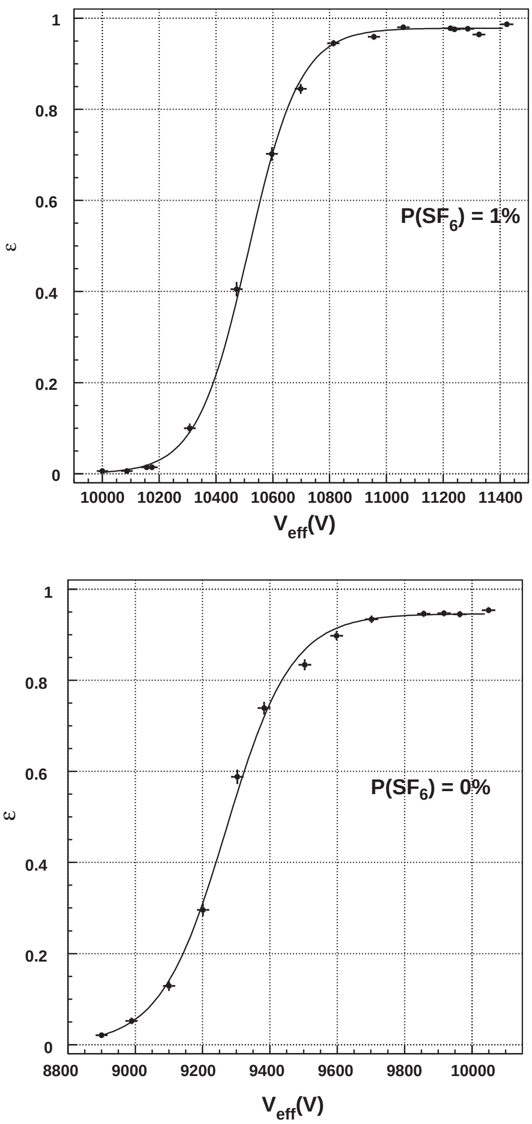

Fig. 4. Detector efficiency with respect to the high voltage corrected by temperature and pressure with SF_6 in the gas mixture (top) and without (bottom).

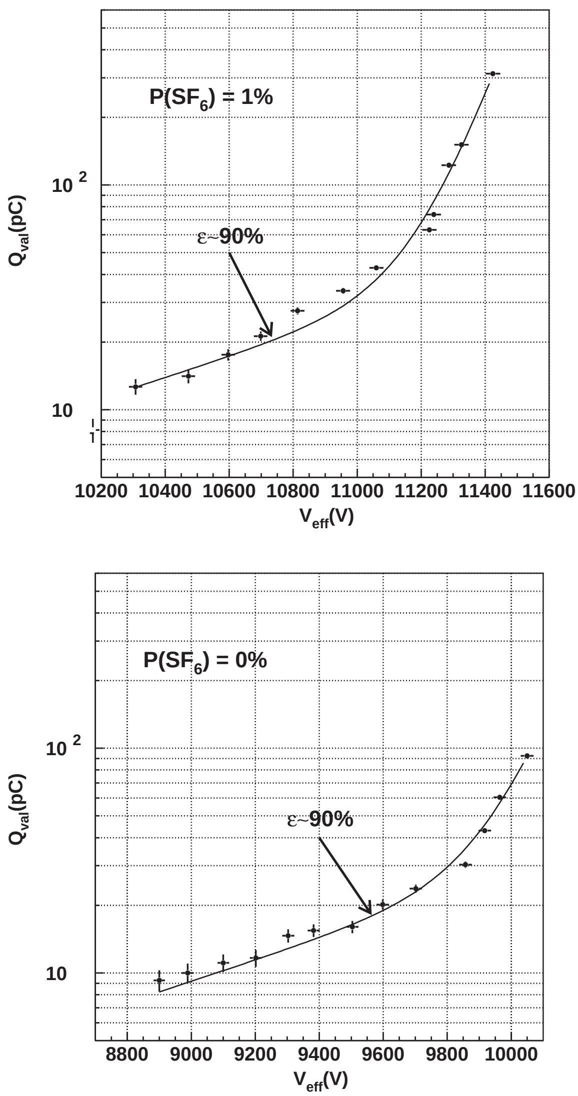

Fig. 5. Average avalanche charge (pC) with respect to the high voltage corrected by temperature and pressure with SF_6 in the gas mixture (top) and without (bottom). The pedestal charge (~10 pC) has not been suppressed.

presence of the SF_6 has shifted the efficiency curve of about 1.2 kV towards higher voltages.

The detector had also been tested with a 100 GeV/$c$muons beam at CERN and we observed a 99.5% plateau efficiency. Due to limitation of the cosmic rays set-up, the efficiency shown in Fig. 4 have the plateau at a slightly lower value.

The average avalanche charge with respect to the high voltage is shown in Fig. 5. The figure shows the double exponential behaviour of the average avalanche charge since the used fitting function is $f(x) = e^{ax+b} + e^{cx+d}$; the black arrows show the average charge when the efficiency is approximately 90%: the presence of the SF_6 in the gas mixture allows to reach a good efficiency without going too close to the knee. This result shows a good agreement with previous studies [10], where, in similar conditions, was found a very similar behaviour. We observed an avalanche charge value between ~1 and ~30 pC in the lower-operating voltage region, and up to ~300 pC in the higher region, as expected (see also [11]). This could be a first hint that we observed a transition from the avalanche mode to the streamer mode.

4. Conclusions

We have performed a direct measurement of the avalanche charge with a $10 \times 10\,cm^2$ prototype RPC with a 0.2 cm gas gap. Its behaviour with respect to the high voltage and its dependence on the presence of the SF_6 in the gas mixture ($C_2H_2F_4$/i-C_4H_{10}/SF_6 in the ratio 95/4/1 and 96/4/0) has been studied.

We observed a double exponential behaviour of the average avalanche charge with respect to the high voltage. We confirmed that the presence of the SF_6 in the gas mixture allows to work with a more safe operating voltage.

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