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The resistive plate chambers for CMS and their simulation

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Abstract

In this paper some results obtained by the CMS Resistive Plate Chamber collaboration during its five years long period of research and development are reported. The importance of the simulation in the design of the Resistive Plate Chambers for CMS is stressed. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The CMS experiment will rely on a "very good redundant muon system" [1]. Its first level muon trigger should guarantee "an almost complete coverage of the solid angle around the interaction point", and "to be robust and very fast" (with a decision time less than 1 μs) [2].

To achieve this very difficult task, about 1000 m^2 of double gap Resistive Plate Chambers (RPCs) operated in avalanche mode will be used. The basic CMS-RPCs parameters (re-elaborated from Ref. [1]) are reported in Table 1: in particular, two 2 mm gaps with readout strips in the middle, a freon based gas mixture (97% $C_2H_2F_4$, 3% isobutane), and bakelite electrodes characterised by a $2\text{–}3 \times 10^{10}$ Ω cm bulk resistivity will be used.

To ensure that, using this configuration, the requirements about redundancy, robustness and velocity will be achieved, the CMS-RPC group has carried out a series of tests on, among other important points, bakelite resistivity [3] and surface roughness [4], different kinds of gas mixtures [5], different gap sizes [6], RPC performance as a function of the particle rate [7], and a new front-end electronics [8]. A complete list of the publications on the test performed, and their results, can be found at the web-site: http://www.ba.infn.it/˜cmsrpc/activities.html.

However, even if this list is as complete as it could possibly be, it could never cover all the conceivable configurations for RPCs in CMS.

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Table 1
Basic parameters of the RPCs employed for CMS

# of gaps	2
Gas mixture	97% $C_2H_2F_4$ 3% iso-C_4H_{10}
Gap width	2 mm
Operating voltage	8.5–9.0 kV
Bakelite thickness	2 mm
Bakelite bulk resistivity	2–3 $\times 10^{10}$ Ω cm

There was the need to add to the experimental part, a Monte Carlo program that, simulating the main physical processes taking place in an RPC, could explain the reasons of the observed behaviour and predict the detector performance in new situations. Details about this program are reported in Ref. [9]. In this paper the configuration chosen for the RPCs in CMS will be discussed and justified at the light of the results obtained by this MonteCarlo simulation, opportunely tuned on experimental data.

2. Results

Charge spectra in RPCs depend on the gap width; two simulated charge spectra, corresponding to a narrow (2 mm) and wide (9 mm) single gap RPC operated in the same "gain" conditions $G = \eta g = 18$ (where η is the first effective Townsend coefficient and g is the gap width), are reported in Fig. 1. Avalanche saturation effects are neglected here, because not relevant for the considerations that will follow. In the narrow gap case ($\eta = 9$ mm^{-1}) the spectrum is monotonically decreasing, while it is increasing for the wide gap ($\eta = 2$ mm^{-1}). It can be demonstrated mathematically that the driving parameter, in this case, is the ratio $R = \lambda/\eta$ (where λ in the number of primary clusters generated by the ionising particle, which is around 5.5 cl mm^{-1} for the gas mixture employed): the two situations, in fact, correspond to $R < 1$ or $R > 1$, respectively. In the narrow gap case a greater quantity of events (with respect to wide gap) lies in the region near the origin; to detect these "low" charge events, (that can be lower than the electronic threshold) a "noise free", low threshold electronics is required; the effort needed to equip the chamber with this electronics is largely compensated by obtaining a better time resolution (see later).

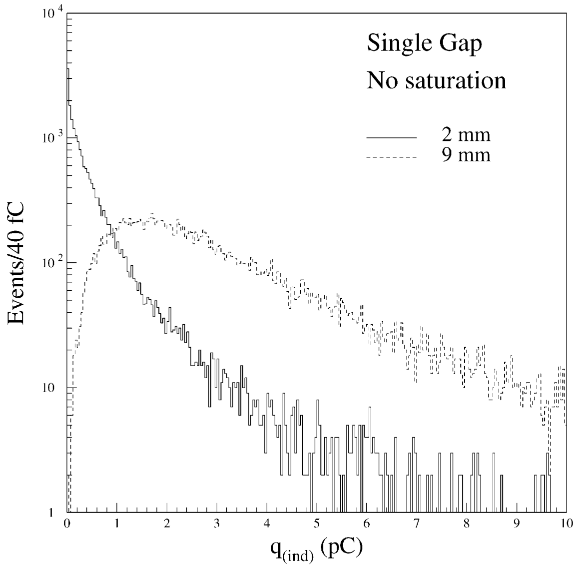

Fig. 1. Single gap spectra, for gap width of 2 and 9 mm; avalanche saturation effects are here neglected.

RPCs charge spectra depend also on the employed gas mixture, in particular on the number of primary clusters per mm λ. In general, the effect of a high λ gas mixture is twofold: on one hand a higher efficiency with the same gas gain can be achieved; on the other, a lower streamer probability can be obtained. In operating RPCs, streamer events need to be reduced, since these events cause high strip multiplicity hits that reduce the detector space resolution.

The effect of λ can be deduced from Figs. 2a and b; the simulated efficiency ε and streamer probability P_{str} are reported in Fig. 2a, as a function of λ, for a 2 mm single gap RPC; both ε and P_{str} increase as λ increase, but the relative rate is much steeper for ε, and therefore high efficiency with a reasonably low streamer probability can be achieved. Another way to look at the same effect is reported in Fig. 2b, where again ε and P_{str} are plotted vs. λ, but now the chamber is operated at changing operating voltages, so that the global

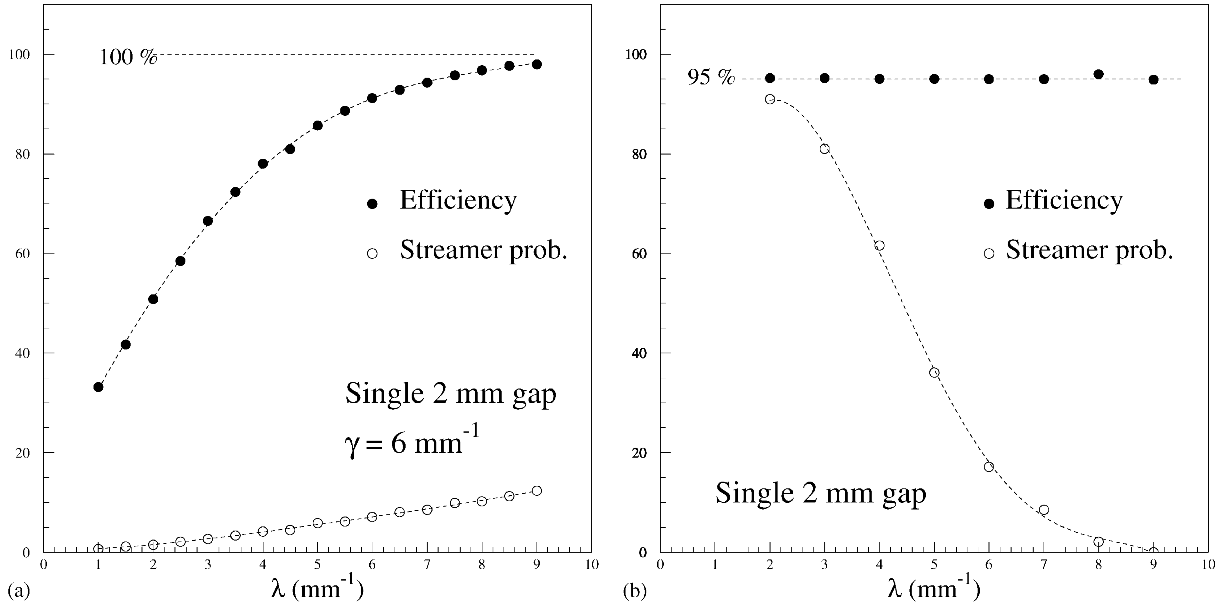

Fig. 2. (a) Efficiency and streamer probability for a single gap 2 mm RPC, vs. primary ionization coefficient; (b) streamer probability vs. ionization coefficient, at constant efficiency.

efficiency is constant at 95%. Only when $\lambda > 6\ \text{mm}^{-1}$ P_{str} can be lower than 10%. This effect is at the base of the present choice of freon-based gas mixtures ($\lambda \approx 5.5$ cl mm^{-1}).

The third important point is that, going from single to multi-gap, two effects must be taken into account. The first is "geometrical" in origin. The charge q_{ind} induced on a pick-up strip is computed by means of the Ramo theorem; as shown in Ref. [9], the ratio between q_{ind} (proportional to the signal generated by the detector) and the charge q_{drift} which is actually drifting in the gap is maximum for the double gap design (or for configurations where the signals coming from more gaps are coupled electronically). Having a high q_{drift} in the gap increases the streamer probability which in turn, if too high, can limit the rate capability of the chamber; this means that the double gap design, which maximises the signal/q_{drift} ratio, should be particularly suitable to withstand high rates of incident particles. The second effect is "statistical" in origin; it is related to the fact that charge spectra for double and multi-gap are the n-fold convolution (n number of gaps) of single gap spectra. This has the result to detach more and more, as the number of gaps increases, the spectrum from the origin and to increase the efficiency. This is discussed in details in Ref. [9].

An advantage of narrow, with respect to wide, gap RPCs is due to their better time resolution. Time resolution in RPCs is closely related to the statistical fluctuations of the processes involved in the generation of the signal; in particular it is related to the number of primary clusters per event, electrons per cluster and to fluctuations in the avalanche growth, all quantities that can vary from event to event. The time resolution σ_t, for single and double gap RPCs, is reported as a function of the gap width in Fig. 3a; here, again, the chamber gain $G = \eta g = 18$ is kept at a fixed value. σ_t vs. the first effective Townsend coefficient η, for the two cases of single and double gap is also reported in Fig. 3b. From the figures it can be deduced that better time resolution is obtained reducing the gap size, increasing the operating voltage, and increasing the number of gaps. This effect is at the base of the present choice to use

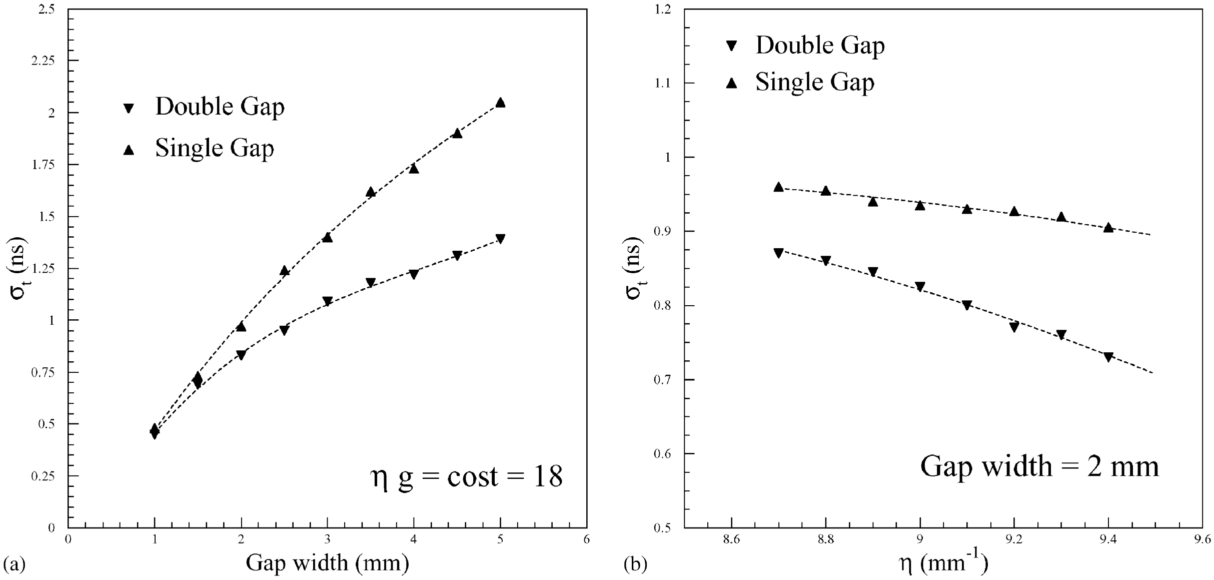

Fig. 3. (a) Time resolution vs. gap width, for single and double gap RPC, at constant gain; (b) time resolution vs. Townsend coefficient for single and double 2 mm gap RPC.

double narrow gap RPCs. Note that there is a limit to the possibility to increase time resolution; the operating voltage cannot be increased too much to avoid the chamber going in streamer mode; moreover, reducing the gap beyond a certain level is a disadvantage, because this reduces also the number of primary electrons, and, consequently, the efficiency.

3. Conclusions

In this paper the results of a detailed study aimed to understand the best possible design of Resistive Plate Chambers for CMS have been presented. This study has been confirmed by the comparison with experimental results on various occasions (see, for instance, [5]). Many characteristics reported in Table 1 can now be explained at the light of their understanding in terms of basic physical processes; this is done, schematically, also in Table 2. One of these parameters, the bakelite bulk resistivity, has not been discussed here. It is related to the time the bakelite electrodes need to get charged again after an avalanche or a streamer process has taken place in the gap. The value of $2–3 \times 10^{10}$ Ω cm is a good compromise between low re-charge time (and therefore high rate capability) and the fact that lower values cause

Table 2
Explanation of the basic parameters of the RPCs employed for CMS

More gaps	Increase time resolution and efficiency
Double gap design	Best ratio (induced charge)/(drift charge) and therefore best signal/charge ratio
Freon based gas mixture	Higher efficiency (at the same gas gain) and lower streamer probability
Gap width 2 mm	Good compromise between good efficiency, good time resolution and good rate capability
Operating voltage 8.5–9.0 kV	Maximum operating voltage compatible with low streamer probability
Bakelite bulk resistivity $2–3 \times 10^{10}$ Ω cm	Good compromise between high rate capability and low current and noise

high currents, power dissipation and noise in the chamber. The fact that the basic mechanisms of the processes taking place in RPCs have been understood has allowed to give a contribution to the optmisation process of its design parameters to the most suitable conditions for CMS.

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