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Abbrescia, M. ; Bruno, Giacomo Luca

Abstract

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Performance of Resistive Plate Chambers for the muon detection at CMS

M. Abbrescia[a], A. Colaleo[a], G. Iaselli[a*], F. Loddo[a], M. Maggi[a], B. Marangelli[a], S. Natali[a], S. Nuzzo[a], G. Pugliese[a], A. Ranieri[a], F. Romano [a] S. Altieri[b], G. Bruno[b], G. Gianini[b], S. P. Ratti[b], L. Viola[b], P. Vitulo [b]

[a]Dipartimento Interateneo di Fisica and Sezione INFN, v. G. Amendola 173, 70126 Bari, Italy

[b]Dipartimento di Fisica Nucleare e Teorica and Sezione INFN, v. U. Bassi 6, 27100 Pavia, Italy

The latest results, still preliminary, of tests dedicated to study the performance of Resistive Plate Chamber for the CMS experiment are presented. Full efficiency with a 2 ns time resolution in conditions of incident flux up to 2 kHz/cm^2 has been obtained. Detector uniformity has been studied and found to be well within the constraints due to the large surfaces used in the experiment. An aging test is currently being carried out and shows no significant performance variation with time.

1. INTRODUCTION

This paper summarises the results obtained in a series of tests devoted to study the performance of Resistive Plate Chambers (RPCs), vith a view to verify their possible use as the dedicated detector for the first level muon trigger at CMS [1].

Good efficiency and timing properties will be crucial for the performance of the trigger algorithm; the latter, in particular, will play a very delicate role, since individual hits have to be correctly assigned to the right bunch-crossing. In Fig. 1 and 2 the achievable trigger efficiency, computing making use of a full simulation of the CMS detector and trigger procedure, is shown as a function of the RPC time resolution and efficiency, respectively. A global efficiency > 95 % and a time resolution better than 3 ns are necessary to achieve a bunch identification efficiency > 99%. A more detailed description of the trigger system and performance is presented in [2], while the simulation is extensively described in [5].

To meet the very demanding requirements imposed by the use of this device in CMS, the choice has fallen on RPCs in the double gap configuration, i.e. two equal gaps with the common pick-up strips positioned in the middle. As already shown, double-gap RPCs are characterised by a charge spectrum and a time resolution improved with respect to single gaps [2]. Two fundamental parameters, namely the gap width and bakelite resistivity, have been fixed at the values of 2 mm and $\sim 2 \times 10^{10}$ Ωcm, respectively, on the basis of a long work of optimisation. Finally, it has been chosen to operate RPCs in avalanche mode, keeping the gas gain relatively low, and using front-end preamplifiers.

Several requirements are to be fulfilled if these detectors are to be employed successfully in CMS.

First of all, since RPCs will operate in an environment characterised by a huge background of diffuse neutrons and γ-rays, they have to stand high fluxes of incident particles without any sensible performance degradation. This is particularly important in the regions located near the end-caps of the experiment. A first series of tests devoted to investigate this problem is briefly described in Sect. 2.

RPCs in CMS will cover a surface of approximately 4000 m^2. This means that it will be crucial to have a homogeneous response from the various chambers composing the apparatus. In addition, various part of the same chamber will be subjected to different operating conditions. It

*Corresponding author. Tel. 39 080 5442440, fax 39 080 5442470, e-mail: Giuseppe.Iaselli@ba.infn.it

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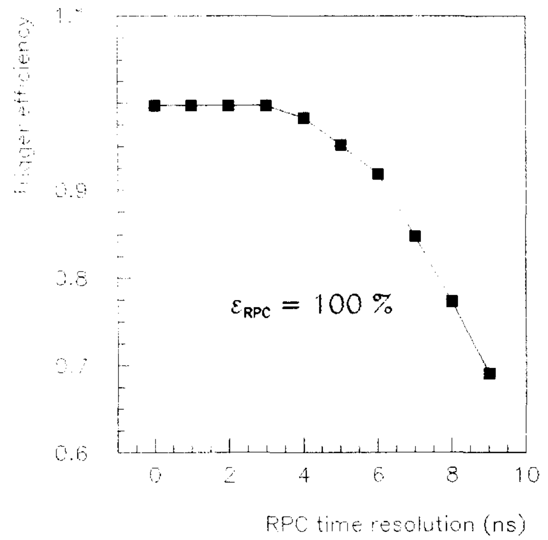

Figure 1. Dependence of the trigger efficiency on the RPC time resolution, for muons generated in the region $-0.09 < \eta < 0.09$, with $50 < p_t < 70$ GeV/c and subject to a p_t^{cut} of 5 GeV/c.

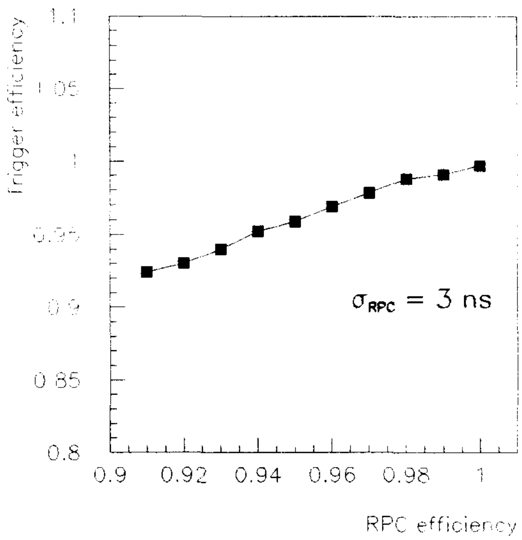

Figure 2. Dependence of the trigger efficiency on RPC efficiency, for muons generated with the same constraints of Fig. 1.

is very important, therefore, to verify if the detection and time performance evidenced by RPCs is uniformly obtainable on the whole chambers surface. This issue has been extensively treated in [3] and [4], and no further discussion will be presented here.

Finally, since RPCs are supposed to operate in the experiment for about 10 years, it is crucial to verify if its performance is constant during such a long period of time. An aging test is currently being carried out, by irradiating the RPCs with a background much more severe than the one expected in CMS. This is described in Sect. 3.

2. TESTS OF RATE CAPABILITY

These tests have been carried out during summer 1998 at the Gamma Irradiation Facility (GIF), which has been recently built downstream the CERN X5 muon beam line. Here the detectors can be irradiated by a 740 GBq ^{137}Cs source, and the performance of the chambers can be studied by looking at the response to the 200 GeV trough-going muons provided by the SPS beam (for a complete description of the set-up and methods used in a previous run, see [6]).

One of the crucial parameters which could affect the performance of RPCs operated in conditions of high flux is the bakelite resistivity. To find the optimum value of this parameter, two double-gap chambers, 1.2×1.3 m^2 in dimensions, were used. The bakelite bulk resistivity was 10^{11} Ωcm (chamber named MEL11) and 10^{10} Ωcm (MEL10); their 2 mm wide gaps were filled with a $C_2H_2F_4$/iso-C_4H_10 97/3 gas mixture. Both chambers were operated in avalanche mode, with the front-end amplifiers characterised an approximate charge sensitivity of 1.6 mV/fC; the threshold was 40 mV.

The efficiency curves of MEL11 and MEL10 are reported, respectively, in Fig. 3 and Fig. 4. Efficiency has been computed requiring, on the strip determined by the beam chambers, a detectable signal in a 20 ns time window opportunately delayed with respect to the trigger. In the figures, the efficiency corresponding to an absorption factor $ABS = 100$ or $ABS = 1$ are reported; these values refer to a series of filters which was possible to place in front of the source to reduce the actual

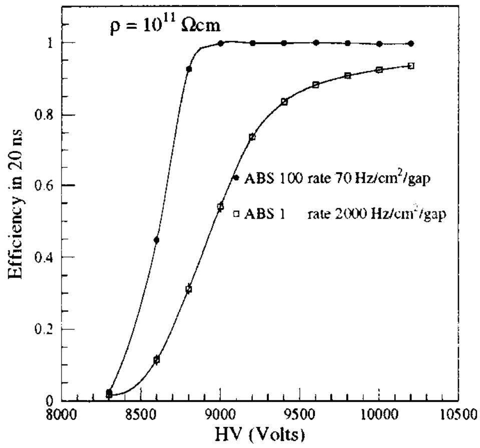

Figure 3. Efficiency of chamber MEL11, computed in a 20 ns time window.

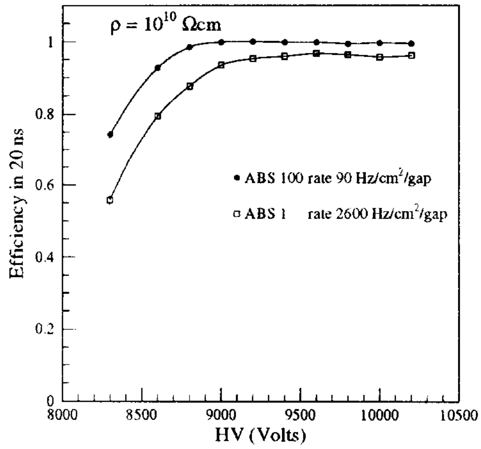

Figure 4. Efficiency of chamber MEL10, computed in a 20 ns time window.

γ flux impinging on the detectors. Since MEL11 was farther from the source than MEL10, the impinging flux was slightly lower. $ABS = 100$ corresponds to a rate of hits effectively revealed by the chambers of 70-90 Hz/cm^2/gap, while $ABS = 1$, no filters, corresponds to about 2000 Hz/cm^2/gap for MEL11, and 2600 Hz/cm^2/gap for MEL10.

At low rate, the efficiency of both chambers reaches 99 % at 8.7 kV, the remaining 1 % mainly due to the dead areas given by the spacers. Passing from low to high rate, both chambers exhibit a shift of the efficiency curves toward higher operating voltages; the maximum achieved efficiency is slightly lower at $ABS = 1$, as expected. This is due to the reduction of the effective electric field inside the gap, with respect to the nominal setting, because of the passage of the current through the bakelite plates, necessary to charge up again the zones discharged by the avalanches. This current is proportional to the particle rate, while the corresponding voltage drop should be directly proportional to the bakelite resistivity. However, while for chamber MEL11 full efficiency is slowly reached, and the shift is quite pronounced (about 500 V at 50 % efficiency), for MEL10 this effect is much reduced (down to $\sim$ 200 V); in addition, no efficiency drop is present at the maximum voltage applied of 10.25 kV, so that the efficiency plateau is more than 1 kV wide. These results are significantly better than required for CMS; in fact, the highest rate foreseen for RPCs in CMS, in the maximum pseudo-rapidity region of $\eta = 2.1$, will be $\sim$ 300 Hz/cm^2.

A way to study the effect of RPC time resolution on the trigger performance is to look at the so-called time efficiency plateau, reported in Fig. 5 and 6 for MEL11 and MEL10, respectively. Here the operating voltage is fixed at 10 kV, and the starting edge of the 20 ns gate window, where RPCs signals are searched for, is shifted before and after its optimal value. Maximum efficiency is reached when the window is positioned around the actual bunch crossing; the width of the region where maximum efficiency is obtained gives an estimate of the error that can be done in the timing of the window. The fact that, for MEL10, the curves obtained at $ABS = 100$ and $ABS = 1$ approximately coincide reassures on the fact that, even in different regions of the apparatus, where the operating conditions will be different, this time window can be opened at the same time. A

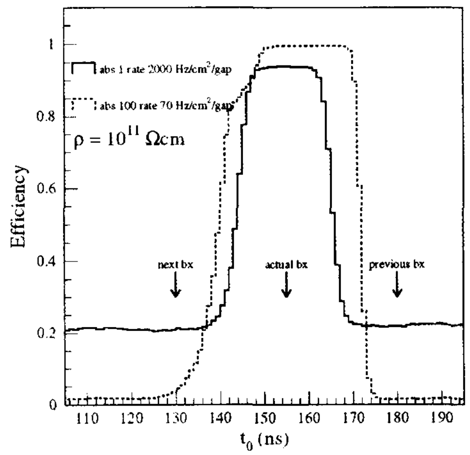

Figure 5. Time efficiency plateau for chamber MEL11.

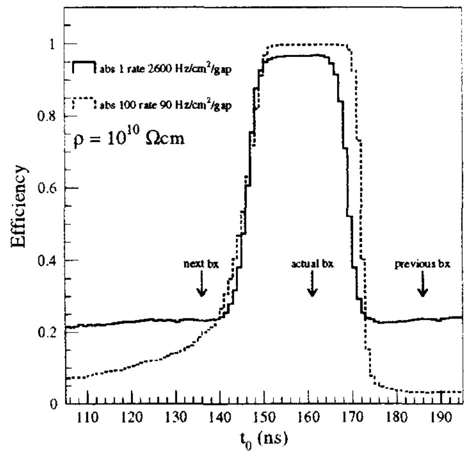

Figure 6. Time efficiency plateau for chamber MEL10.

slightly worse performance is reached by MEL11, characterised by a narrower time plateau; however, it is still in the limits required for CMS.

3. TESTS OF AGING

A reliable test of chamber aging is currently being carried out at the Irradiation Facility of the Department of Physics in Bari. Here two double gap RPCs, front-end electronics included, have been enclosed in a concrete bunker where they can be irradiated by means of three ^{60}Co sources for a 0.4 GBq total activity. The sources are positioned in containers at about 40 cm distance from the chamber, so that, when they are in the outside position, the average γ hit rate is about 200 Hz/cm^2/gap. The two chambers, 1.3 × 1.2 m^2 in dimensions, characterised by 2 and 3 mm gap widths and bakelite resistivity $\rho = 5 \times 10^{11}$ Ωcm, are filled with a $C_2H_2F_4$/iso-C_4H_{10} 97/3 mixture and are operated in avalanche mode (see, for a complete description, [7]).

Outside the irradiation bunker, a horizontal muon telescope, equipped with 8 other 2 ×2 m^2 RPC chambers operated in streamer mode, and interleaved with four walls of concrete, 1 m each thick, is present. 4 of these chambers have horizontal strips, and the others vertical ones, and this allows a 3-D reconstruction of the tracks of near horizontal muons (see Fig. 7).

The efficiency of the avalanche operated chambers has been measured predicting the tracks intersection points and counting the fraction of events where a hit has been detected in a 5 cm range. Efficiency curves for the detection of single muons are reported in Fig. 8 and Fig. 9, for the two cases of collimators closed and opend, respectively. The repeated measurement of the efficiency, or other characteristics, in different periods of the year, allows to verify if a deterioration of the chamber performance is in progress. In Fig. 8 and Fig. 9 four of such efficiency measurements, for the 2 mm chamber, are reported; the last measure, performed during September 1998, corresponds to a total irradiation dose equivalent to the one accumulated by a chamber in the barrel of CMS during about 6 years. The curves obtained in condition of "source off" show a nice plateau at a value close to 99 %, and approximately coincide. The curves obtained with the chamber exposed to the source are characterised by 1 ÷ 2 % lower efficiency plateau and by a ~ 100 V shift toward higher operating voltages.

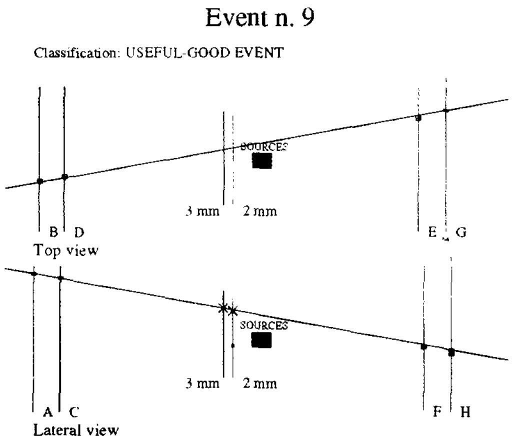

Figure 7. Example of single near horizontal muon reconstructed by the RPC telescope; the position of the test chambers and the ^{60}Co sources are put in evidence.

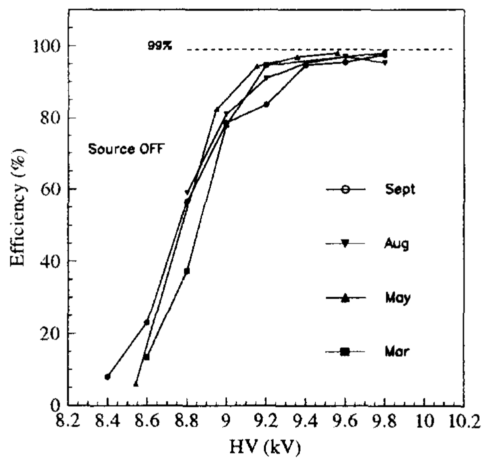

Figure 8. Efficiency curves for the avalanche operated chamber, obtained without source irradiation; results taken in a range of 7 months of operation are shown.

In addition, the slope of the curve corresponding to the last measure taken (Sept. 1998) is lower than the others, and the transition from zero to full efficiency happens less steeply. This could be an indication of a first deterioration of the chamber performance; however more analysis has to be performed before a definite conclusion can be drawn. For instance, temperature or pressure variations, which have been monitored and are known to affect RPC operating point, have to be taken into account, and the corresponding corrections applied.

4. CONCLUSIONS

The Resistive Plate Chambers, in the configuration chosen for the CMS experiment, have undergone a series of different kinds of tests. Each of these has shown that, if the effect searched for was present, it affects the chamber behaviour well in the limits imposed by the experiments requirements.

First of all, it has clearly been demonstrated that double gap RPCs, as proposed for CMS, illuminated with an uniform γ flux corresponding to an hit rate up to 2 kHz/cm^2, can reveal crossing muons with an efficiency very close to 100 % and a time resolution better that 2 ns; the useful range of the operating plateau is more than 1 kV.

The study on uniformity has demonstrated that variations from point to point in the same chamber are clearly detectable; however this are much reduced by the choice of no spacers staggering, and are still well in the limits required for CMS.

For what concerns the aging tests, even if the definitive results are scheduled for the beginning of 1999, when the chambers will have accumulated a 10 years CMS equivalent dose, the very preliminary results presented here are really encouraging, and demonstrate that no significant variation in RPC performance has been noticed in the period up to now.

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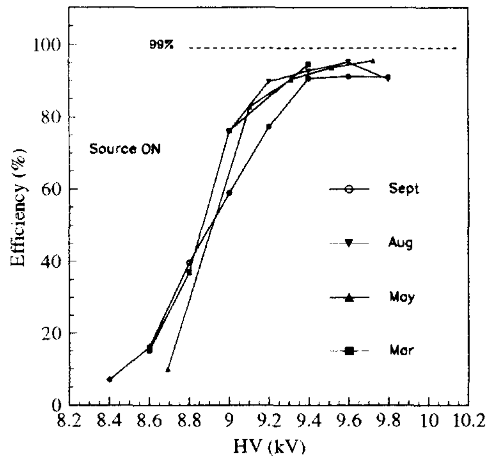

Figure 9. Efficiency curves for the avalanche operated chamber, under irradiation; results taken in a range of 7 months of operation are shown.

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