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Systematic study of phenolic multigap RPCs for high-rate triggers in CMS

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We report a systematic study of phenolic multigap Resistive Plate Chambers (RPCs) for high-rate triggers in CMS. In the current R&D, prototype RPC modules have been built with four- and six-gap structures and tested with cosmic muons and gamma rays irradiated from a 200-mCi ^{137}Cs source. The detector characteristics of the prototype multigap RPCs were compared with those of the double-gap RPCs currently used in the CMS experiment at LHC. The mean values for detector charges of the cosmic-muon signals drawn in the four- and six-gap RPCs for the efficiency values in the middle of the plateau were about 1.5 and 0.9 pC, respectively. We concluded from the current R&D that use of the phenolic multigap RPCs is advantageous to future high-rate triggers in CMS in virtue of the smaller detector pulses.

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1. Introduction

The Compact Muon Solenoid (CMS) has been constructed at the European Center for Nuclear Research (CERN) to explore Higgs and SUSY particles and to address new physics in general using the Large-Hardron-Collider (LHC) beams. In CMS, Resistive Plate Chambers (RPCs) play an important role in the efficient detection of muon signals [1, 2].

The required detection rate capability of the present CMS double-gap RPCs to perform muon triggers in the LHC collision runs with a designed maximum luminosity of 10^{34} cm^{-2}s^{-1} is 1 kHz cm^{-2} [2]. However, the maximum background rate in the CMS RPCs in the highest η region is expected to exceed 1 kHz cm^{-2} when the luminosity increases to a level of 10^{35} cm^{-2} s^{-1} in future.

During the last decades, gas mixtures composed of tetrafluoroethane ($C_2H_2F_4$, R134a Freon) and isobutane (iC_4H_{10}) have been widely used for the operation of the phenolic trigger RPCs. A relatively large gain of the ionization avalanche and stability with a wide operational plateau have been the advantages of the use of the Freon-based gas mixtures. However, the detector current drawn in a double-gap RPC with a typical size of 2 m^2 would far exceed the limit of the RPC operation when the particle rate reaches a few kHz cm^{-2} [3]. Furthermore, it was found from past aging studies [4] that the degradation of the detector performance due to Freon radicals contained in the detector gas [5] was dramatically acelerated when the background particle rate exceeded 3 kHz cm^{-2}.

Size reduction of the avalanche signals drawn in the trigger RPCs, therefore, lessens the probability of degradation due to the high-rate beam background. Here, we propose a development of multigap RPCs whose detector pulses and the particle-induced currents are significantly smaller than those drawn in the present CMS double-gap RPCs.

In this paper, details for prototype four- and six-gap RPCs are described in Section 2. The electronics setup to examine the prototype multigap RPCs with cosmic muons and gamma rays emitted from a 200-mCi ^{137}Cs gamma-ray source is briefly explained in Section 3. In Section 4, the detector characteristics of the multigap RPCs obtained in the tests are compared with those of the current double-gap RPCs. Finally, the conclusions for the phenolic multigap RPCs developed in the present R&D are summarized in Section 5.

2. Description of phenolic multigap RPCs

Phenolic high-pressure-laminated (HPL) was the basic resistive-plate material for the multigap RPCs developed in the present study, while thin glass is typically used for timing RPCs [6, 7]. In the present research, prototypes detectors with four- and six-gap structures have been constructed for a systematic study of detector charges and the responses to intense gamma-ray background.

As illustrated in Fig. 1, a four-gap RPC was composed of two separated 1-mm-thick double-layer gas volumes. In a similar way, a six-gap RPC was composed of two separated 0.66-mm-thick triple-gap gas volumes. The HPL plate(s) placed in the middle of each gas volume were automatically biased at an intermediate potential(s) when an electrical potential is applied to the graphite electrode coated on the two outmost HPL plates. The mean values of the bulk resistivities for the 2- and 1-mm thick HPL sheets measured at T= 20^{o}C were 0.95 and 6.9 x 10^{10} $\Omega\cdot$cm, respectively.

The thicknesses of the circular spacers to support the gap thickness for the four- and six-gap RPCs were 1.0 and 0.66 mm, respectively. The thickness of the HPL plates used for the four and six-gap RPCs was 2 and 1 mm, respectively. Copper strips were attached on a 190 μm-thick polyethylene film, and were placed between the two gas volumes for signal readouts. The pitches of the strips for the four- and the six-gap RPCs were 27 and 20 mm, respectively.

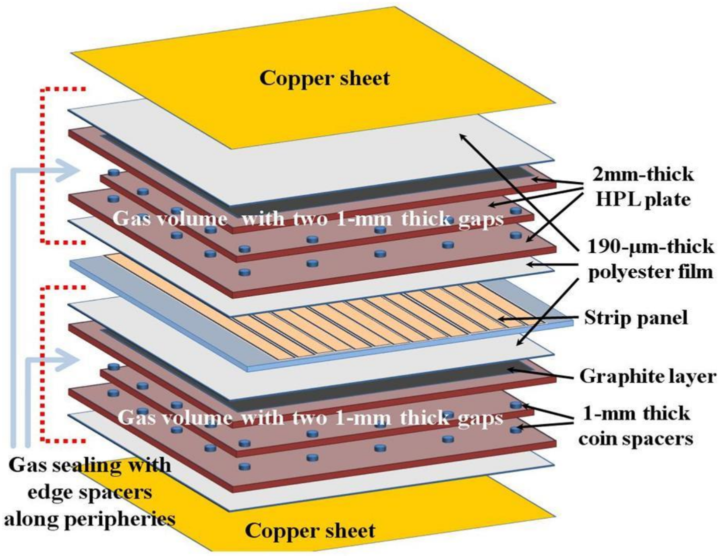

Fig. 1. Schematic diagram for a 1-mm-thick four-gap RPC.

3. Experimental setup

The electronics setup to test the prototype multigap RPCs was optimized for precision measurements of detector charges for muon and gamma-ray signals, and the gamma-induced currents drawn in the detectors. The voltage thresholds applied to digitize the four and six-gap RPC pulses were 1.3 and 1.0 mV, respectively, which were estimated to be approximately equivalent to charge thresholds of 150 and 100 fC, respectively, from the offline data analysis.

Cosmic muons were triggered by a triple coincidence of plastic scintillators equipped with photomultipliers (Hamamatsu model H2431). The scintillator signals were digitized with a 30-mV voltage threshold, and were fed into the TDC Start and the ADC Gate. Data for noises and gamma rays were obtained by 1-kHz clock triggers provided by using a 2-GHz pulse generator.

The prototype multigap RPCs were examined in avalanche mode using a gas mixture of 95.7% $C_2H_2F_4$, 3.5% *i*-C_4H_{10}, 0.5% SF_6, and 0.3% water vapour in mass ratio. In order to draw consistent test results, applied high-voltage (HV_{app}) values were converted to effective values (HV_{eff}) under the standard conditions, P = 1013 hPa and T = 293 K [8]. The prototype multigap RPCs were installed at a mean distance of 45 cm from a 200-mCi ^{137}Cs gamma source to examine detector responses to high-rate gamma-ray background. The actual activity of the 10-year old gamma source was expected to be about 150 mCi (5.5 GBq).

4. Results

Figures 2 shows efficiencies (ε, full circles) and mean charges ($<q_e>$, open circles) for muon signals, as functions of HV_{eff}, measured by the four- (left) and six-gap (right) RPCs. Muon hits having streamer pulses ($<q_e> \geq 10$ pC) were not included in the calculation of the mean charges in Fig. 2. The streamer probabilities occurred in the four and six-gap RPCs at their maximum HV_{eff}'s in the tests were 0.09 and 0.03, respectively. As shown in Fig. 2, the mean charges of the muon signals drawn in the four- and six-gap RPCs, measured at the efficiency values in the middle of the plateau, were 1.5 and 0.9 pC, respectively. They were respectively about one third and one fifth of that drawn in a typical 2-mm-thick double-gap RPC when measured with a threshold of 200 fC [9].

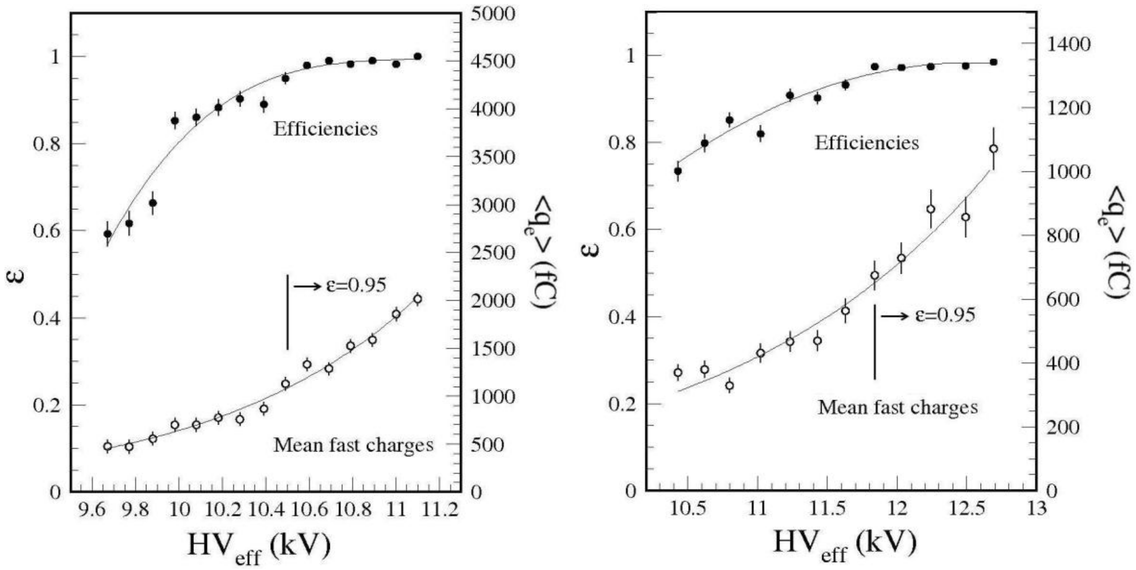

Fig. 2. Efficiencies (ε, full circles) and mean charges ($<q_e>$, open circles) of muon signals, as functions of HV_{eff}, measured by four- (left) and six-gap (right) RPCs. The solid lines in both figures were drawn to guide the trends of data.

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Comparison of charge distributions of muon signals drawn in double-, four-, and six-gap RPCs allows us to envisage their different scopes in the usable ranges of the avalanche-mode pulses. Figure 3 shows the charge distributions drawn in the four- (left) and six-gap (right) RPCs at four different HV_{eff}'s. As Fig. 3 shows, the upper limits of the avalanche pulses for the four- and six-gap RPCs were about 10 and 6 pC, respectively, while it extended to 25 pC for the double-gap RPCs [9].

Considering the charge distributions and the upper limits of the avalanche pulses, the choices of the threshold values of 150 and 100 fC, respectively, for the four- and six-gap RPCs were expected to be relevant. We also expect that lowering the thresholds below the chosen values would make the detectors more sensitive to gamma-ray background signals with smaller charges.

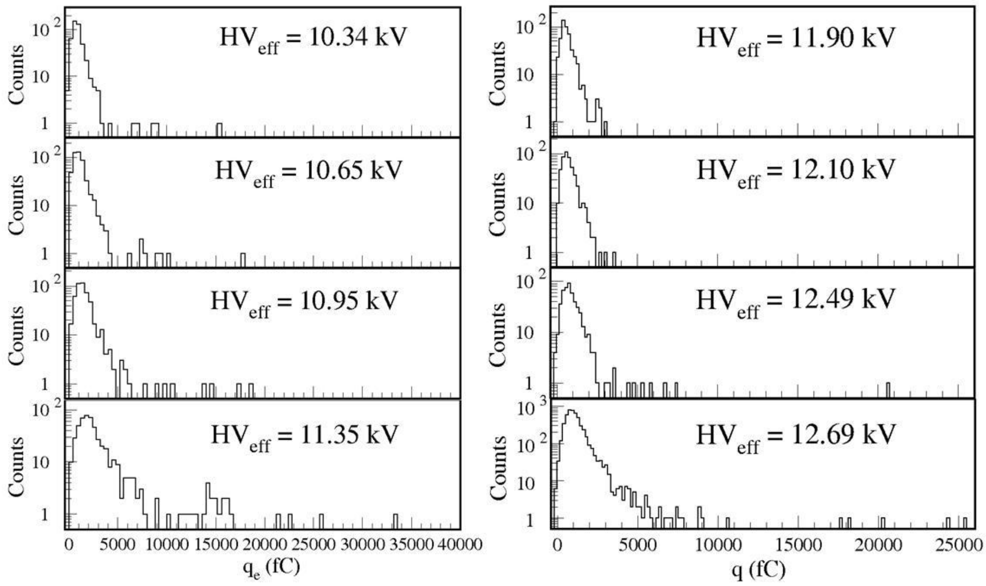

Fig. 3. Charge distributions of muon signals measured by four- (left) and six-gap (right) RPCs at four different HV_{eff}'s.

The left figure in Fig. 4 shows efficiencies (ε) and mean charges ($<q_e>$) of the muon signals, measured by the four-gap RPC, as functions of HV_{eff}, with (open circles) and without the presence of gamma-ray background (full circles). The right figure in Fig. 4 shows the gamma-signal rates also measured as a function of the HV_{eff}. The rates of the gamma-ray background signals appeared in the muon efficiency plateau ranged from 0.7 to 1.5 kHz cm^{-2}. The shift of the efficiencies and the mean charges in the HV_{eff} due to the background rate of ~ 1 kHz cm^{-2} was about 400 volts, which was comparably smaller than the size of the muon efficiency plateau (≥ 600 V).

Figure 5 shows gamma-ray induced currents drawn in unit areas of double-gap (left) and four-gap (right) RPCs as functions of the gamma-background rate. The charge threshold to digitize the gamma-ray signals drawn in the double-gap RPC was set to 200 fC [10]. We

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conclude from Fig. 5 that the radiation-induced current by the neutral background particles could be reduced by a factor three when the four-gap detector configuration is adopted instead of the current double-gap one for the CMS trigger RPCs.

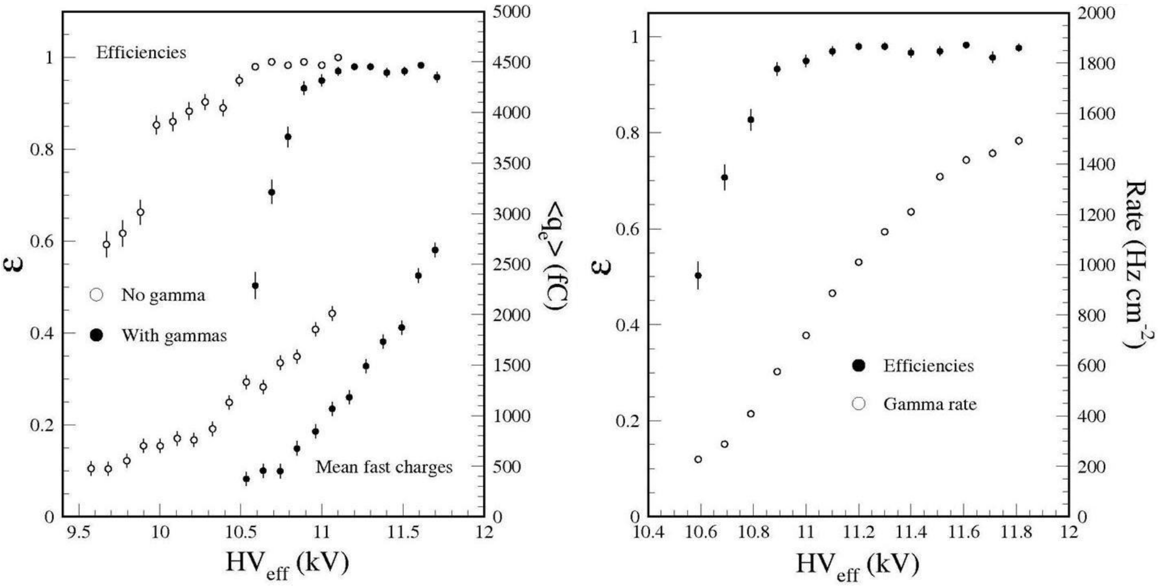

Fig. 4. Left: efficiencies (ε) and mean charges ($<q>$) of muon signals as functions of HV_{eff}, measured by a four-gap RPC, with (open circles) and without the presence of gamma-ray background (full circles). Right: gamma-signal rates measured as a function of the HV_{eff}.

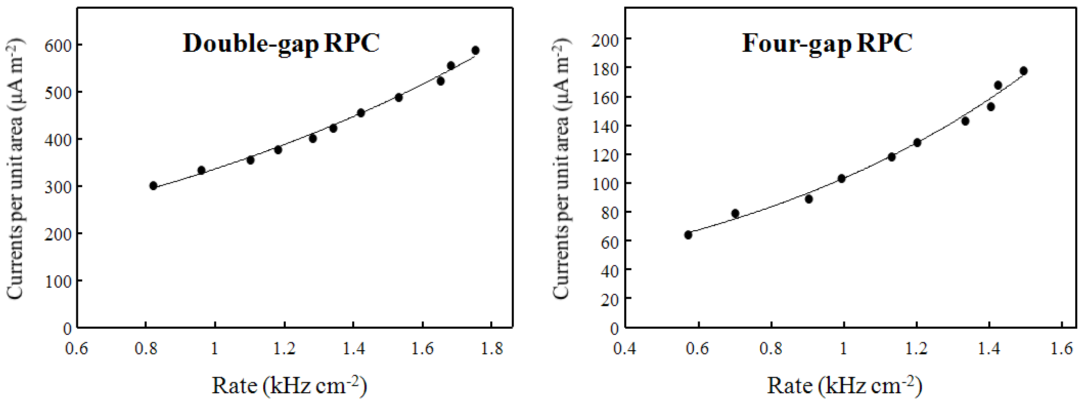

Fig. 5. Gamma-ray induced currents drawn in unit areas of double-gap (left) and four-gap (right) RPCs as functions of the gamma-background rate. The solid lines drawn in both figures were only to guide the trends of data.

5. Conclusions

The goal of the present R&D was to improve detection performances of panel-type trigger RPCs constructed with phenolic HPL when they are to be operated together with high particle-background rates exceeding a few kHz cm^{-2}. We drew the following conclusions from the present research:

(1) The mean charges drawn in the four- and six-gap RPCs measured for the efficiency values in the middle of the plateau were about 1.5 and 0.9 pC, respectively, when digitized with charge thresholds of 150 and 100 fC, respectively. They were respectively about one third and one fifth of that drawn in a double-gap RPC with a charge threshold of 200 fC.

(2) The usable sizes of the muon efficiency plateaus for the four- and six-gap RPCs were at least 600 V, which were relatively wider than that for the current CMS double-gap RPC (~ 400 V) operated with the approximately same gas mixture.

A systematic study on the digitization thresholds is required to find optimal conditions for the muon detection while allowing minimal sensitivities to the gamma-ray and neutron background particles. Furthermore, development of real-size detector modules is essential to optimization of the detector structure for the CMS RPC trigger system.

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