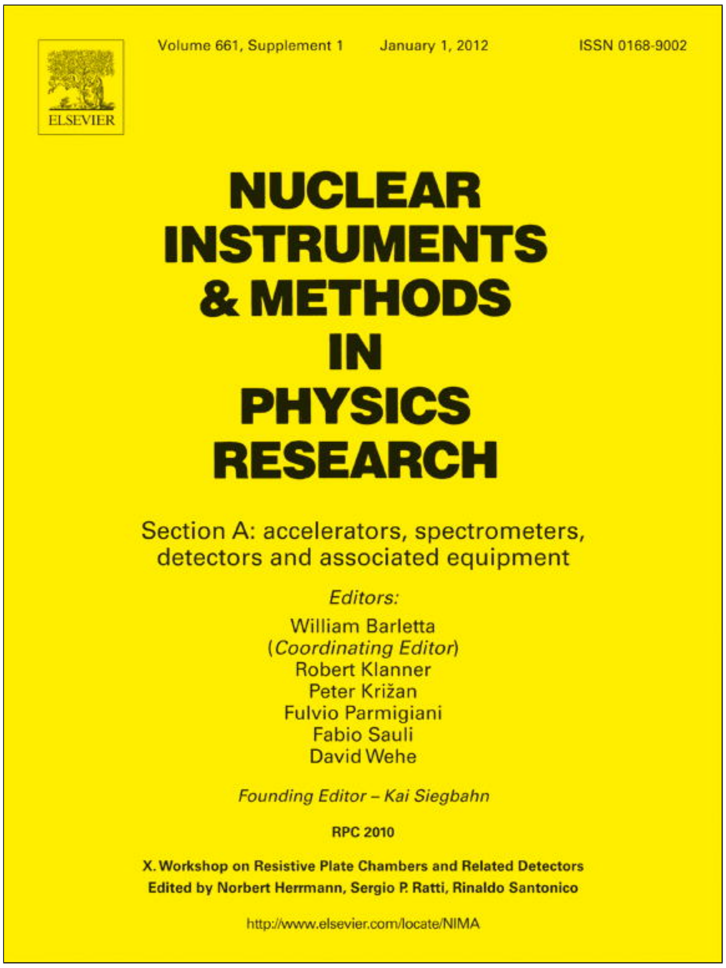
Volume 661, Supplement 1 January 1, 2012 ISSN 0168-9002

ELSEVIER

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

Section A: accelerators, spectrometers, detectors and associated equipment

RPC 2010

X. Workshop on Resistive Plate Chambers and Related Detectors
Edited by Norbert Herrmann, Sergio P. Ratti, Rinaldo Santonico

http://www.elsevier.com/locate/NIMA

Nuclear Instruments and Methods in Physics Research A 661 (2012) S90–S93

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Six-gap resistive plate chambers for high-rate muon triggers

K.S. Lee *

Department of Physics and Korea Detector Laboratory, Korea University, Seoul 136-701, Republic of Korea

On behalf of CMS Collaboration

ARTICLE INFO

Available online 27 August 2010

Keywords:
Compact Muon Solenoid
Large Hadron Collider
Muon trigger detector
Aging effect
Rate capability

ABSTRACT

This paper reports the development of oiled multi-gap RPCs for use as high-rate triggers in high-energy physics experiments. The current R&D aims to improve the detector performance of RPCs in high pseudorapidity, η, in a CMS experiment of the LHC. In this study, six-gap prototype RPCs made from 1-mm thick high pressure laminated (HPL) resistive plates were designed and built. The detector characteristics of the prototype RPCs obtained from a series of tests with cosmic muons and gamma rays are discussed.

1. Introduction

The main physics goal of the Compact Muon Solenoid (CMS) experiment of the Large Hadron Collider (LHC) is to explore Higgs and SUSY particles. Resistive plate chambers (RPCs), muon trigger detectors, covering a pseudorapidity range up to $|\eta| = 1.6$, play an important role in achieving the goal of the proposed CMS experiment [1,2].

To improve the trigger efficiency of the forward regions of the CMS, an extension of the coverage of the RPC system up to $|\eta| = 2.1$ was planned, as initially proposed in the CMS Technical Design Report [3].

The current double-gap RPCs (Fig. 1), covering up to $|\eta| = 1.6$, are expected to effectively perform muon triggers for the LHC runs with a maximum beam luminosity ($\sim 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$). The rate capability of the CMS double-gap RPCs is as high as $2\,\mathrm{kHz\,cm}^{-2}$. Furthermore, extensive gamma-irradiation tests were carried out to prove the radiation hardness against the long-term aging effect [4]. However, a further intensive aging study with rates $> 3\,\mathrm{kHz\,cm}^{-2}$ showed a serious negative result for radiation hardness [5].

The aging effect of RPCs is expected to be proportional to the accumulation of avalanche charges induced in the detectors. The probability of detector degradation due to the aging will be lower when the avalanche charges are smaller. Therefore, this paper proposes RPCs with a six-gap structure, whose mean fast charge is approximately one fifth of the one induced in the typical 2-mm-thick double-gap RPCs. Furthermore, the rate capability is also expected to be enhanced when multi-gap RPCs are constructed with 'less resistive' resistive plates.

In this paper, Section 2 provides details of the structure of the gas gaps and prototype detector modules. Section 3 reports the test results of the detectors with cosmic rays to examine the fundamental detector characteristics and rate capability. Finally, we conclude the discussions for the six-gap RPCs in Section 4.

2. Description of the detector

Prototype RPCs equipped with six gas gaps were manufactured to perform fundamental detector research. The base material of the six-gap RPCs, the resistive plate, is a high-pressure-laminated (HPL) plate composed of three inner layers of phenol sheets and two outer layers of melamine sheets. The thickness of each HPL plate is 1.0 mm. The initial mean bulk resistivity of the HPL samples measured at a temperature of 20 °C and a humidity of 75% was $6.9 \times 10^{10}\,\Omega\,\mathrm{cm}$.

Fig. 2 shows the structure of the prototype RPCs. A six-gap RPC module consists of two separate gas volumes, each of which is composed of three 0.65-mm gaps. Two HPL plates placed in the middle of the gas volume lie at intermediate potentials when a high-voltage bias is placed on the cathode-side outer HPL plate. The prototype RPCs were coated with linseed-oil to suppress spurious detector hits.

The strip readout was implemented by etching the strip pattern on a 0.6-mm-thick copper-printed epoxy-glass plate. As shown in Fig. 2, the strip board was placed to pick up the signals induced from both three-gap volumes. The pitch of the eight strips was set to 20-mm to cover the active detection width of 16.0 cm.

* Tel.: +822 3290 4277.
E-mail address: kslee0421@korea.ac.kr

0168-9002/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2010.08.030

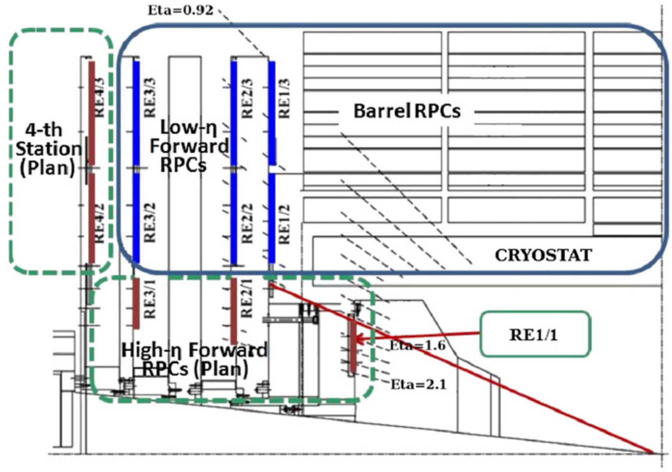

Fig. 1. A quadrant view of the CMS RPC system. The current RPC system, as shown in the solid line, covers the muon trigger in a $|\eta|$ range up to 1.6. A further construction of the RPCs (in the dashed line) was planned to extend the range of the muon trigger to $|\eta| = 2.1$.

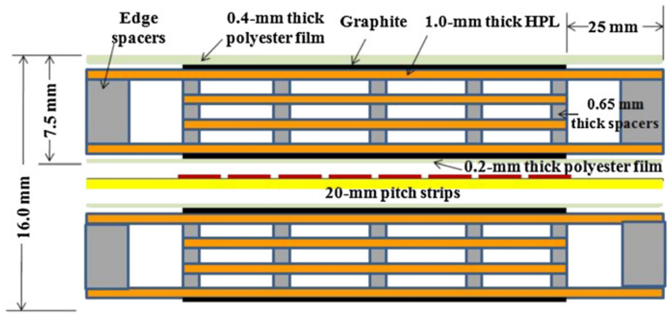

Fig. 2. Schematic diagram of the structure of the prototype RPCs.

3. Results

Fig. 3 shows the electronics setup to test the prototype RPCs with cosmic muons. Each RPC signal was amplified 10 times with a linear amplifier (CAEN N412). One of the amplifier outputs of each channel was discriminated using a 10-mV voltage threshold (equivalent to a 1-mV threshold for the raw RPC pulses), and was fed a single-hit time-to-digital converter (TDC, LeCroy 2228) after being properly delayed to satisfy a common-start-mode acquisition. The other amplifier output was also properly delayed and fed into a single-hit analog-to-digital converter (ADC, LeCroy 2249) to perform the charge measurements. The time window applied to the ADC gate was set to 30 ns.

The cosmic muons were triggered by a triple coincidence of plastic scintillators whose signals were digitized with a 30-mV voltage threshold. The prototype RPCs were operated in avalanche mode with the following gas mixture: 96.2% $C_2H_2F_4$, 3.5% i-C_4H_{10}, 0.5% SF_6, and 0.3% water vapor.

Fig. 4 shows a typical charge distribution of the cosmic rays measured by the ADC at an effective high voltage [6] of 11.84 kV. The ADC charge distribution was properly corrected for the pedestal position of the data.

Fig. 5 shows the efficiencies (ε's) and mean fast charges ($\langle q \rangle$'s) measured at a 10-mV TDC threshold (open circles), ADC thresholds of 80 (triangles), 100 (squares), and 150 fC (full circles) as a function of the effective high voltage. The TDC efficiencies were obtained with cosmic-ray hits within a 20 ns time window centered at the mean arrival time of the fastest strip. The ADC efficiencies were estimated by selecting the data, in which at least one strip charge exceeds the given charge threshold. The digitization of the data with the ADC threshold, $Thr_{ADC} = 100$ fC, was equivalent to those with the TDC threshold, $Thr_{TDC} = 10.0$ mV.

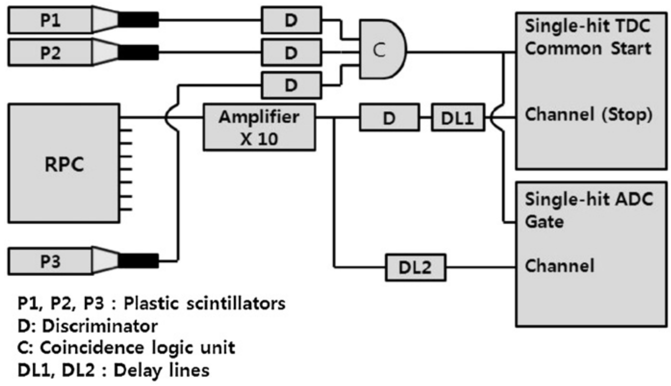

Fig. 3. Schematic diagram of the electronics setup for the cosmic-ray tests.

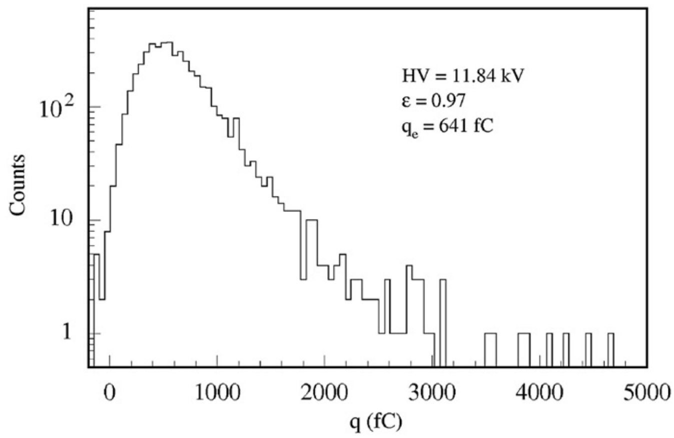

Fig. 4. A typical charge distribution of the cosmic rays measured by the ADC at an effective high voltage of 11.84 kV

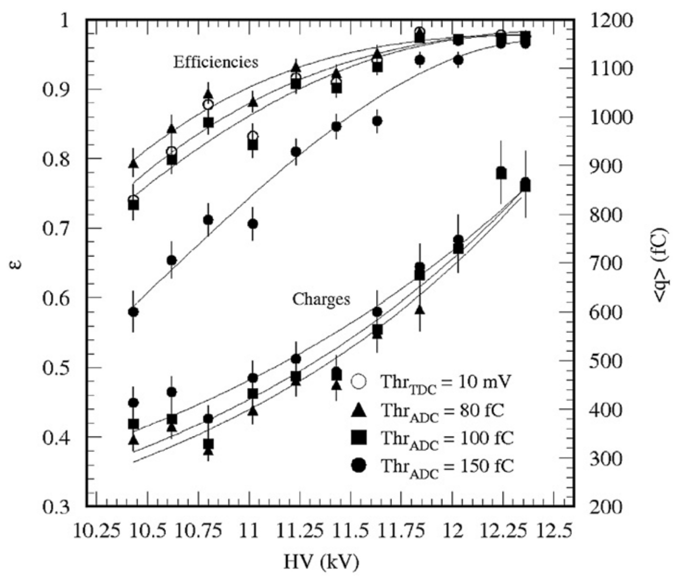

Fig. 5. ε's and $\langle q \rangle$'s measured at $Thr_{TDC} = 10$ mV (open circles), $Thr_{ADC} = 80$ (triangles), 100 (squares), and 150 fC (full circles) as a function of the effective high voltage.

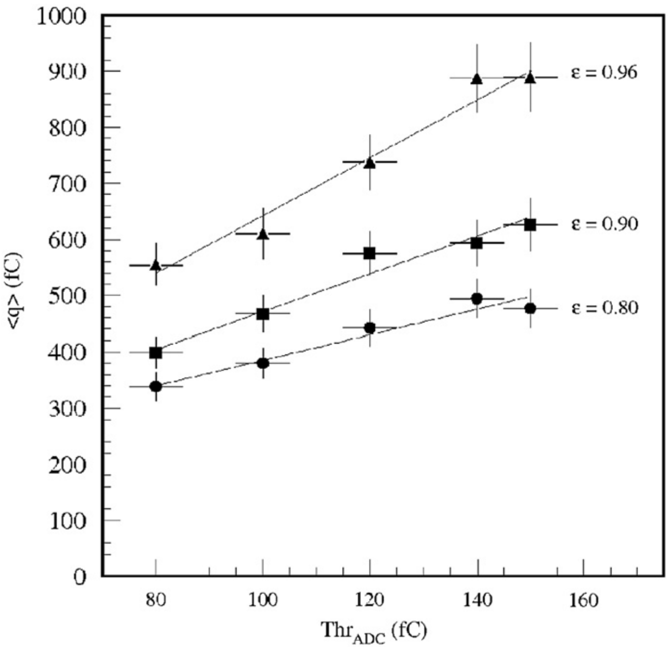

Fig. 6. ε's as a function of the ADC threshold. The three solid lines explain the tendencies of $\langle q \rangle$'s at $\varepsilon=0.80$ (circles), 0.90 (squares), and 0.96 (triangles), respectively, to the ADC threshold.

As shown in Fig. 5, $\langle q \rangle$, whose ε measured at $Thr_{ADC}=100$ fC reaches 0.95, was approximately 650 fC.

Fig. 6 shows the dependence of the efficiencies on the ADC threshold. $\langle q \rangle(\varepsilon=0.95)$ measured at $Thr_{ADC}=150$ fC was 890 fC, which is about one third of the one for the 2-mm-thick double-gap RPCs measured at a typical charge threshold of 200 fC [7].

One of the prototype RPC with a 200-mCi ^{137}Cs source was also tested to investigate the detector characteristics when high-rate gamma backgrounds are present together with cosmic rays. Fig. 7 shows the RPC installed at a mean distance of 45 cm from the gamma source with an angle of 45°. Three 30-cm-long and 14-cm-wide plastic scintillators were installed close to the prototype RPC to properly tag both cosmic muons and gamma rays emitted from the source. The efficiency of the RPC was not expected to exceed 0.9 due to geometrical mismatch between the trigger area of the cosmic muons and the active area of the RPC.

Fig. 8 shows the ε's with $Thr_{TDC}=10$ mV and $\langle q \rangle$'s with $Thr_{ADC}=100$ fC as a function of the high voltage. The data marked by the open and the full circles were measured with and without the presence of gamma-ray backgrounds, respectively. The number marked at each full circle indicates the mean rate of gamma-ray backgrounds (* Hz cm^{-2}). Because the variation in the flight distance of the gamma rays, as shown in Fig. 7, the actual rates induced in the RPC at 13.97 kV, whose mean rate was 2.02 kHz cm^{-2}, are expected to range from 1.4 to 3.4 kHz cm^{-2}.

The current induced by the high-rate background causes voltage drops across the resistive plates placed inside the RPC gaps, whose sum should be equivalent to a shift in the operational high voltage. As shown in Fig. 8, the shift at a mean rate of 2.02 kHz cm^{-2} was approximately 1.5 kV. The reason for the relatively large shift accounts for the increase in bulk resistivity of the resistive plates due to polymerization. The bulk resistivity increased gradually with time, and four months later, the mean value became saturated at 3.3×10^{11} Ω cm. The bulk resistivity of the resistive plates inside the prototype RPCs was also expected to increase because the first cosmic-ray test with the water–vapor containing gas mixture was performed approximately two months after detector construction. Despite the increase in bulk resistivity, it was expected that the current six-gap RPCs are capable of detecting muons with a rate capability as high as 3 kHz cm^{-2}.

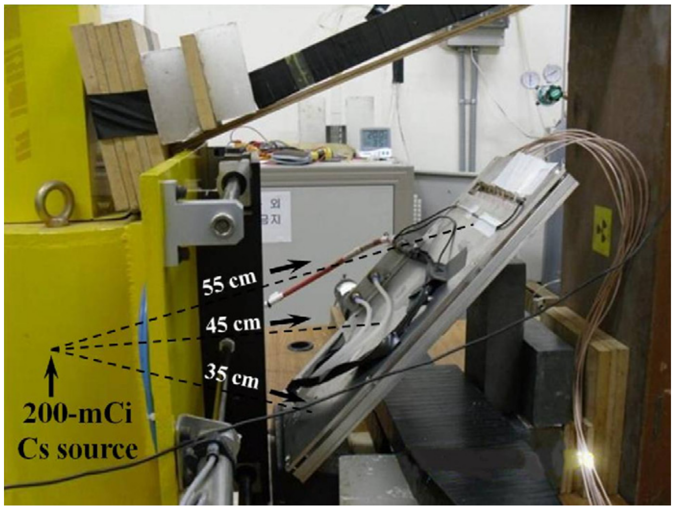

Fig. 7. The prototype RPC installed at a mean distance of 45 cm from the gamma source and with an angle of 45°.

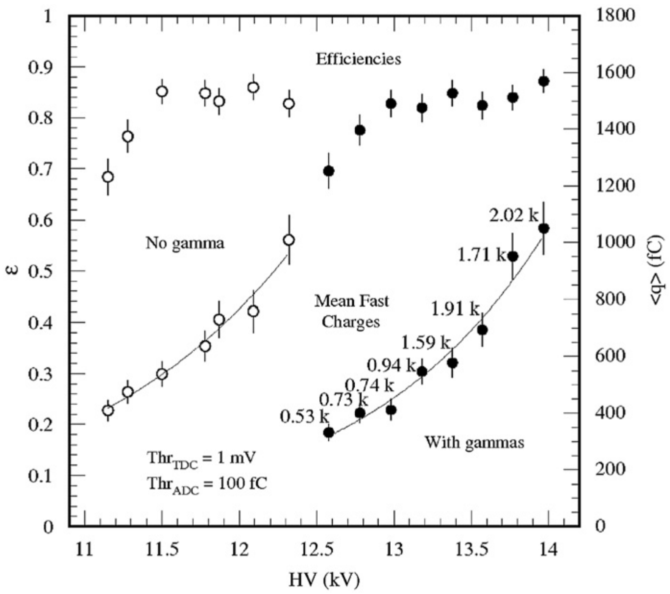

Fig. 8. ε's with $Thr_{TDC}=10$ mV and $\langle q \rangle$'s with $Thr_{ADC}=100$ fC, as functions of the high voltage. The details for the data are explained in the text.

4. Conclusions

Oiled-HPL RPCs with a six-gap structure were developed and tested, and the following conclusions were made:

(1) The mean fast charges of the current six-gap RPCs measured at $Thr_{ADC}=100$ fC were approximately one fifth of the ones for the current 2-mm-thick double-gap CMS RPCs measured at a 200-fC threshold. As discussed in the previous section, smaller detector signals (i.e., smaller avalanche charges) would be conducive to a lower probability of radiation-induced aging when the CMS RPCs are operated with a beam background whose rate exceeds a few kHz cm^{-2}.

(2) The current six-gap RPCs can manage rates as high as 3 kHz cm^{-2}. However, the rate capability can be improved when the bulk resistivity of the resistive plates is kept below $10^{11}\,\Omega\,cm$.

Acknowledgements

This study was supported by the Korea Foundation for International Cooperation of Science and Technology (KICOS) with a Grant provided by the Korean Ministry of Education, Science and Technology (MEST) (K20716000001).

References

[1] CMS Collaboration, Detector performance and software, Technical Design Report, vol. I, CERN/LHCC 2006-01, February 2006.
[2] CMS Collaboration, J. Phys. G 34 (2007) 995.
[3] CMS Collaboration, The muon project, Technical Design Report, CERN/LHCC 97-32, December 1997.
[4] S.H. Ahn, et al., J. Korean Phys. Soc. 47 (2005) 427.
[5] H.C. Kim, et al., Nucl. Instr. and Meth. A 602 (2009) 771.
[6] B. Hong, et al., J. Korean Phys. Soc. 48 (2006) 515.
[7] B. Hong, et al., J. Korean Phys. Soc. 45 (2006) 1490.