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Beam Test Results of the First Full-Scale Prototype of CMS RE 1/2 Resistive Plate Chamber *

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Abstract We reported the muon beam test results of the first full-scale prototype of CMS RE 1/2 Resistive Plate Chamber (RPC). The bakelite surface is treated using a special technology without oil to make it smooth enough. The full scale RE 1/2 RPC with honeycomb supporting frame is strong and thin enough to be fitted to the limited space of CMS design for the inner Forward RPC. The muon beam test was performed at CERN Gamma Irradiation Facility (CIF). The detection efficiency of this full scale RPC prototype is >95% even at very high irradiation background. The time resolution (less than 1.2 ns) and spatial resolution are satisfactory for the muon trigger device in future CMS experiments. The noise rate is also calculated and discussed.

Key words resistive plate chamber, avalanche mode, muon beam test, noise rate

1 Introduction

Resistive Plate Chambers (RPCs) are gaseous parallel-plate detectors[1]. RPCs are proposed to build large trigger detectors for future CMS experiments at LHC. A common design of RPC is a gas gap bounded by two parallel resistivity plates made of Bakelite[1, 2]. High voltage is applied to a carbon film painted onto the outer sides of these Bakelite plates to produce a high electric field across the gap between the plates. The gap between the plates is sealed and a suitable mixture of gas flowed. Electrons generated in the gas near the crossing of the ionizing particle avalanche in high electric field, and initiate a spark discharge in the gas. Finally the signal induced on the external readout strips can be picked up by electronic set and recorded. Originally RPCs have been operated in streamer mode. However, streamers produce a large amount of charge in the gas gap and thus there is a severe rate limitation. Due to the high particle flux expected at LHC, RPCs at LHC experiments will have to be operated in avalanche mode. In avalanche mode there is a substantial reduction of the charge produced in the gas gap, and the rate capability is improved by more than one order of magnitude than that in streamer mode.

2 Material performance and chamber structure

The CMS experiment proposes a double gap design with the read-out strips sandwiched between two of these RPC modules (double gap RPC). The layouts of gas gaps are shown in Fig.1. There are altogether three single modules in this full-scale prototype of CMS RE 1/2 RPC, one is big (Chamber C) and the other two are small (Chamber A and Chamber B). Each single RPC module has a shape of isosceles trapezia. The read-out strips are divided into three sections. One section covers the Chamber A area. The Chamber B area is divided into two sections. Each section is composed of 32 copper strips whose average width varies from 1.5cm to 2.1cm according to the size of chamber. A cross section of the prototype is also shown in Fig. 1. A single module is

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built with 2 mm thick Bakelite plates which enclose a 2 mm gas gap. The Bakelite surface is treated using a special technology to improve the smoothness. The high voltage is supplied to one side of graphite sheets, while the other side (close to the read-out strips layer) is grounded. The three gas gaps have independent high voltage connections. The read-out strips' layer is insulated from graphite coating by PET films. The aluminum honeycomb panels are used to protect the chambers from deformation. The use of the honeycomb panel ensures that the large full scale RPC prototype is strong and thin enough. Finally the whole chamber is fixed by an aluminum frame to ensure the rigidity.

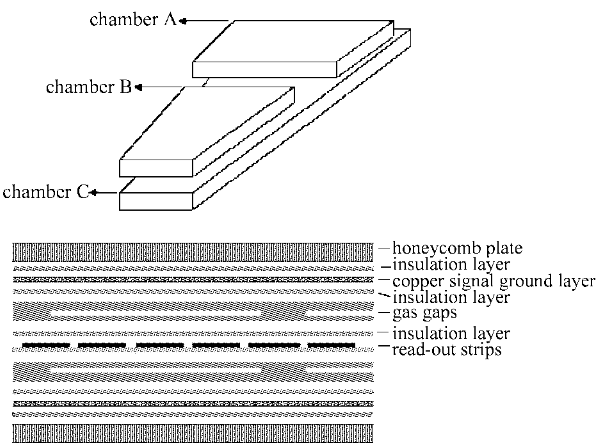

Fig.1. The schematic view of CMS RE 1/2 full-size RPC prototype. TOP: The layout of gas gaps; Bottom: The cross section of the double-gap RPC.

The volume resistivity of the bakelite plate has a large impact on the rate capability of RPC. The volume resistivity of the Bakelite plate used here is around $5\times10^{10}\Omega\cdot cm$.

We tested the CMS RE 1/2 full-size RPC prototype on the Gamma Irradiation Facility (GIF) at CERN, the schematic view of this muon beam test facility can be found in our previous papers[3,4].

3 Experimental results

3.1 Efficiency

As the fast muon trigger device of CMS experiment at LHC, one crucial parameter is the detection efficiency. The detection efficiency of the RPC was determined as the ratio of the number of RPC responses to the number of triggers at each HV and gamma irradiation background setting. Some care was taken in the calculation of the efficiency in order to remove the spurious hits. For the windows (200 ns) containing the signals and spurious hits in a given time, the number of observed events N_{obs} is:

$$N_{obs}=\varepsilon N_t+P_s(1-\varepsilon)N_t,$$

where ε is the real RPC detection efficiency, N_t the number of triggers and P_s the probability of the spurious hit. We can calculate P_s by counting the number of spurious hits in the same time window (200 ns) but out of the signal window (500ns before the trigger signal). So the efficiency is given by:

$$\varepsilon=[(N_{obs}/N_t)-P_s]/(1-P_s).$$

Fig. 2 shows the detection efficiency of the beam test results. The RPC exhibits full efficiency with a plateau width of several hundred volts under every gamma irradiation background. This implies a good rate capability of this RPC prototype. For the operation without the gas SF_6, RPC reaches its full efficiency (>95%) at 9.0kV under every gamma irradiation background (ABS 1, ABS 5, source off which are corresponding to the strongest gamma irradiation, the medium gamma irradiation, the gamma irradiation turned off respectively), we choose 9.2 kV as the working high voltage point; For the experiment operated with the gas SF_6, RPC reaches its full efficiency (>95%) at about 9.75 kV under every gamma irradiation background (source off, ABS 1), we choose 9.8 kV as the working high voltage point. All the comparisons in this paper later are based on these two working high voltage points.

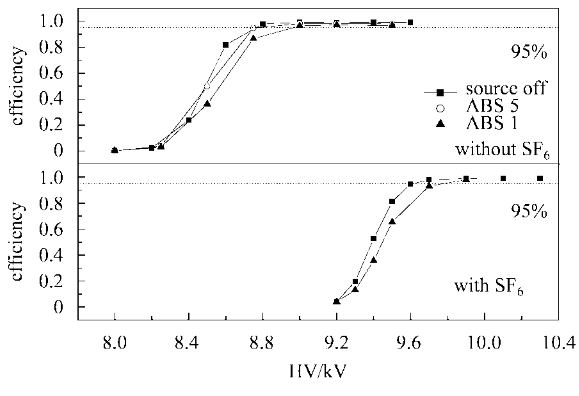

Fig.2. Efficiency as a function of high voltage under different gamma irradiation backgrounds. Top: The gas mixture of 97.5% $C_2H_2F_4$ + 2.5% i-C_4H_{10}; Bottom: The gas mixture of 95.7% $C_2H_2F_4$ + 3.5% i-C_4H_{10} + 0.8% SF_6. Source off means no ^{137}Cs gamma irradiation source during the beam test; ABS 1 means the strongest gamma irradiation flux without any Pb filter before ^{137}Cs gamma irradiation source; ABS 5 means there are some Pb filters before ^{137}Cs gamma irradiation source, the gamma irradiation flux is less than ABS 1.

3.2 Dark current and power consumption

Fig. 3 shows the variation of the dark currents of individual gas gap modules as a function of applied high voltage under different gamma irradiation backgrounds. The gas mixture is 97.5% $C_2H_2F_4$ + 2.5% i-C_4H_{10} for the solid experiment point and 95.7% $C_2H_2F_4$ + 3.5% i-C_4H_{10} + 0.8% SF_6 for the open experiment point. The maximum power consumption of gas gap at working high voltage point (without SF_6, ABS 1) is 2.1 W/m^2, satisfies the CMS requirement of less than 3 W/m^2 for RPC. The power consumption is decreased when a small portion of SF_6 gas is added to the chamber.

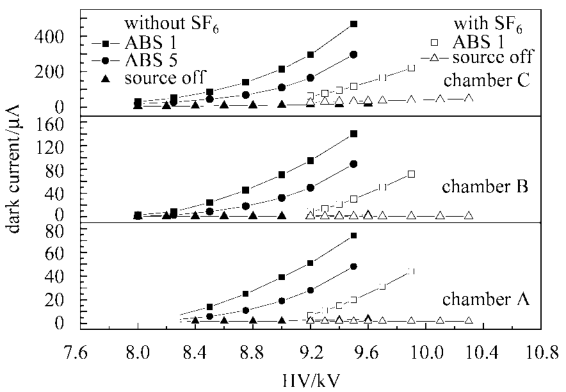

Fig.3. Dark current of single gap as a function of applied high voltage under different gamma irradiation backgrounds. Solid point: gas mixture of 97.5% $C_2H_2F_4$ + 2.5% i-C_4H_{10}; Open point: gas mixture of 95.7% $C_2H_2F_4$ + 3.5% i-C_4H_{10} + 0.8% SF_6.

3.3 Cluster size

The cluster size is defined as the number of hits recorded within 10 ns following the fastest one. The 10 ns time window is wide enough to cover all possible signals from one real event. The cluster size corresponds to the spatial resolution of RPC. It should be kept as small as possible in order to achieve the required spatial resolution. Fig.4 shows the cluster size as a function of applied high voltage under different gamma irradiation backgrounds. For the operation without SF_6, the cluster size is 2.5 for ABS 1 and 3.7 for source off at working high voltage (9.2kV), while for the operation with SF_6, the cluster size is about 1.5 for ABS 1 and 2.1 for source off at working high voltage (9.8kV). A small portion of SF_6 gas can also decrease the cluster size of RPC.

3.4 Time resolution

Time resolution is one of the most important parameters

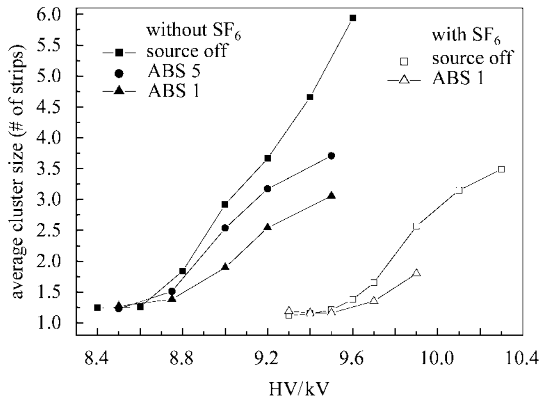

Fig.4. Cluster size as a function of applied HV under different gamma irradiation backgrounds for the operation with and without SF_6.

for a fast muon trigger device. The time resolution is defined as the RMS width of a Gaussian function fit to the signal time distribution. Fig.5 shows the time resolution as a function of high voltage under different gamma irradiation backgrounds. The time resolution is less than 1.2 ns for all kinds of settings. This indicates that the time performance of this full scale RE 1/2 RPC prototype is good enough to fulfill the requirements of CMS experiment.

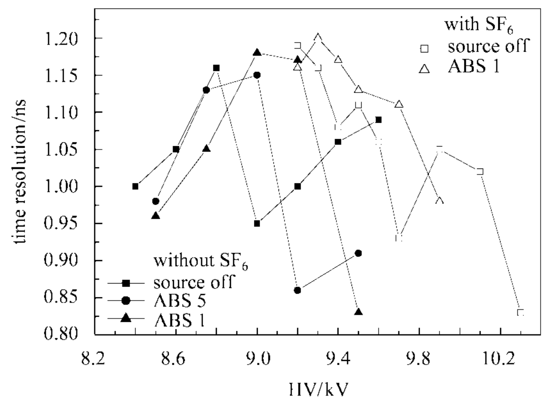

Fig.5. Time resolution as a function of applied HV under different gamma irradiation backgrounds.

3.5 Noise rate

The organic material used in RPCs causes the subsequent excitation and ionization via secondary processes (mainly Compton scattering and photoelectric effect). The chamber rate measured under gamma irradiation is generated mainly by the Compton electrons coming from the photons emitted by the source and interacting with hydrogenated compounds of the Bakelite layers. Time differences between random events with uniform time distribution are like the decays of a long-lived radiation source. They can be well described by an exponential distribution characterized by a probability density function[5]:

$$f(t) = r \cdot \exp(-rt),$$

where t is the time and r represents the average rate at which events are occurring. We use this method to calculate the chamber rate of RPC. Fig. 6 shows the time difference between two consecutive clusters over 16 strips' area under the gamma irradiation ABS 5. The slope r gives directly the overall counting rate (in ns^{-1}). Thus the averaged rate over the 16 strips' area is 320Hz/cm^2. For the operations at low HV while the gamma irradiation is turned off (source off), this method is not suitable, the rate is experimentally measured by counting the total number of clusters per event not associated with the extrapolated muon tracks in a given time window, and then divided by the effective area and time window length. It was checked that the rate values calculated by these two methods are consistent within error range at high HV and strong gamma irradiation background. It was also checked that the cluster rate values with and without gamma irradiation are not affected by the choice of the time window. In Fig.7 the counting rates for ABS 1, ABS 5 and source off are plotted vs. the applied high voltage. Under the strongest gamma irradiation (ABS 1), the measured rate at working high voltage is 922Hz/cm^2 for the operation without SF_6 gas (9.2kV), and about 800 Hz/cm^2 for the operation with SF_6 gas (9.8kV). If the gamma irradiation is turned off (source

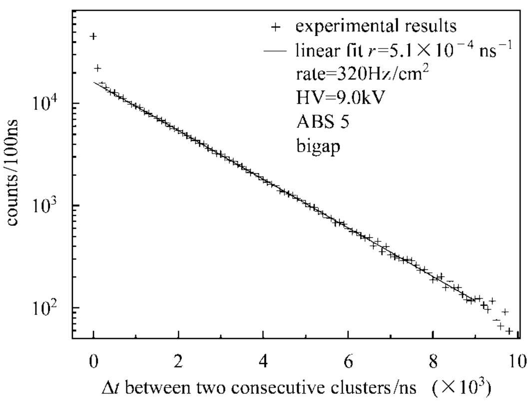

Fig.6. Time difference between two consecutive clusters.

off), the measured rate at working high voltage is 20.7Hz/cm^2 for the operation without SF_6 gas (9.2kV), and less than 10Hz/cm^2 for the operation with SF_6 gas (9.8kV). Since this chamber rate is not triggered by gamma irradiation (source off) and muon beam (out of signal time window), we call it noise rate. A small portion of SF_6 gas could decrease the noise rate.

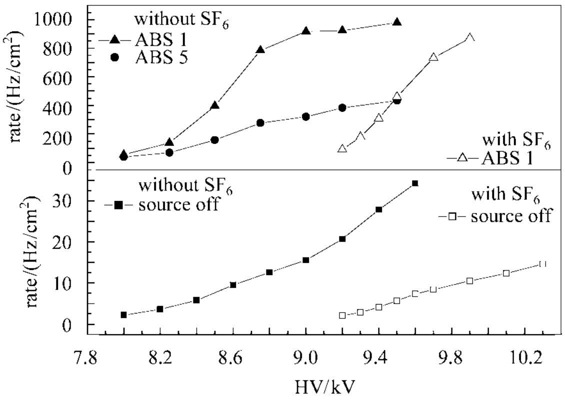

Fig.7. Measured chamber rate as a function of applied HV under different gamma irradiation backgrounds.

4 Conclusion and discussion

A full-scale prototype of CMS RE 1/2 RPC using honeycomb support frame was assembled and beam tested at CERN GIF. The analysis of the data shows that this RPC had a good performance as a fast muon trigger device for CMS experiment at LHC. The RPC prototype can reach full detection efficiency (> 95%) easily under every gamma irradiation background. The dark current and power consumption are small and meet the requirement of CMS experiment. The spatial resolution is good, and the time performance is very well contained within 25 ns of the bunch crossing period expected at LHC. The beam test results show that a small portion of SF_6 gas helps reduce the dark current, power consumption and noise rate, but the RPC reaches full detection efficiency at higher voltage. The small portion of SF_6 gas also helps improve the spatial resolution while the time resolution almost remains the same.

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全尺寸CMS RE 1/2阻抗板探测器样品束流测试结果*

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摘要　介绍了CMS RE 1/2全尺寸阻抗板探测器的束流测试结果.探测器气体室的阻抗板表面采用不需要淋油的特殊光洁处理,外支撑框架采用铝质蜂窝板,以保证足够的强度以及整个RPC所占空间尽量小.在CERN GIF的束流测试结果表明该样品在高辐射本底下能够达到满探测效率.时间分辨率以及噪声水平都符合CMS实验的要求.

关键词　阻抗板探测器　雪崩模式　束流测试　本底噪声

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