J. Phys. G: Nucl. Part. Phys. **26** (2000) 1291–1298. Printed in the UK PII: S0954-3899(00)10860-6

Study of an avalanche-mode resistive plate chamber

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Received 11 January 2000, in final form 1 June 2000

Abstract. Resistive plate chambers (RPCs) are widely used to detect high-energy charged particles, especially muons, due to the high gain, moderate time and spatial resolution, simple design and low cost of these detectors. While the simple streamer mode is adequate for cosmic-ray and low-rate accelerator experiments, the avalanche mode is required for high-rate experiments such as CMS at LHC. In this paper construction of a medium-sized double-gap RPC made of Chinese materials is reported. The experimental set-up of cosmic-ray and muon beam tests are introduced. The avalanche mode was clearly observed. Good efficiency and time resolution were obtained from the beam test at CERN under normal irradiation conditions. At very high radiation background the chamber efficiency decreases, indicating the necessity to change the resistivity value of the Chinese bakelites.

1. Introduction

Over the last few years resistive plate chambers (RPCs) have been a subject of great interest since they were considered or chosen for many accelerator-based high-energy physics experiments, such as CMS and ATLAS at LHC, BarBar at PEPII and BELLE at KEKB, as well as for many cosmic-ray experiments, such as Cover_Plastex in the UK and the Pierre Auger Cosmic Ray Observatory in the USA [1]. The main advantages of RPCs are: high gain, moderate time and spatial resolution, simple design and low cost. Basically, an RPC detects the avalanche or streamer signal generated in a thin gas volume, following the ionization produced by a primary charged particle. The gas flows between two parallel plates made of resistive material (bakelite in our case), which serves to switch off the electric field around the discharge point [2]. In principle, RPCs are suitable for detecting all kinds of charged particles, but in practice, due to their performance and operation conditions, they have mostly been placed behind many other detectors to detect muons.

Originally RPCs were operated in streamer mode, i.e. the electric field inside the gap is kept intense enough to generate limited discharges localized near the crossing of the ionizing particle. Due to the relatively long relaxation time of the resistive electrode, this mode is suitable for low-rate experiments, especially for cosmic-ray experiments. Over the last few years a significant improvement has been achieved by operating the detector in the so-called avalanche mode [3]. In this mode the electric field across the gap (and consequently the

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gas amplification) is reduced and a robust signal amplification is introduced at the front-end electronics level. The substantial reduction of the charge produced in the gap improves the rate capability by more than an order of magnitude, allowing application of RPCs to high-rate experiment such as CMS at LHC [4].

The Peking University HEP group has recently joined the CMS experiment at LHC. According to the agreement signed by the Chinese funding agency and CERN, we are in charge of assembling and testing about one-third of the total RPCs for CMS, using the gas gaps supplied by the international community [5]. In order to accomplish this job we have initialized some research and development work in order to gain a deep understanding of RPC and to test the possibility of using Chinese materials to build RPCs.

This paper gives the description of our first avalanche-mode RPC chamber made of Chinese materials and tested with cosmic rays at Peking University and with high-energy muon beams at CERN.

2. Chamber structure

One of the important parameters of the RPC is the surface smoothness of the resistive plate, which has a large impact to the reduction of the electric background. A useful variable, *the average roughness* R_{a}, has been introduced as a quantitative description of the quality of the electrode surfaces. The definition of R_{a} is [6]

$$R_{\mathrm{a}} = \frac{1}{l_{\mathrm{s}}} \int_0^{l_{\mathrm{s}}} |y|\,\mathrm{d}x$$

where l_{s} is the total sampling length and y is the vertical profile displacement from the *average line of the profile*, which is defined by the relation $\int_0^{l_{\mathrm{s}}} y\,\mathrm{d}x = 0$. The specially made Chinese bakelite, covered with melamine films, has an *average roughness* R_{a} of 0.1617 μm, which is equivalent to the value obtained for the best bakelite on the international market.

Another important parameter is the resistivity of the plate. The bulk resistivity coefficient we measured for a two week time scale is around 5×10^{12} Ω cm. This is obtained by painting graphite [3] onto an area of 100×100 mm^2 on both sides of the sample bakelite plate, and applying a voltage of about 100 V. The resistivity value of the Chinese bakelite is one order of magnitude higher then that of widely used Italian bakelite and would affect the rate capability of the chamber [3].

The double-gap RPC has the shape of an isosceles trapezium, with a height of 50 cm and an average width of 58 cm. This is the 1/4 prototype of the CMS ME1/2 chamber. A cross section of the prototype is shown in figure 1. The chamber consists of two gas gaps, each is built with two 2 mm thick bakelite plates which enclose a 2 mm gas gap. The gas volume is sealed at the edge with bakelite bars. 16 spacers ($\phi = 10$ mm) are glued between two plates to ensure the accuracy of the gap width to less than ± 10 μm. The active region would then be reduced by about 2% due to these spacers. The outer surfaces of the two bakelite plates were painted with liquid graphite with a surface resistivity of about 100 kΩ cm^{-2}. A high voltage is supplied to one side of the graphite sheets, while the other side is grounded. The two gas gaps have independent high-voltage connections, so that the chamber can also be operated in a single-gap mode. The signal pick up layer, located between the two gaps, is composed of 32 copper strips. The average width of the strips is 16.3 mm, with a separation of 1.5 mm between two nearby strips. One end of the strip is terminated on a 50 Ω resistor, while the other end is connected to the electronics. The readout strips layer is insulated from the graphite by PET films. Two 100 mm thick foam boards with aluminium skins are used to protect the chambers

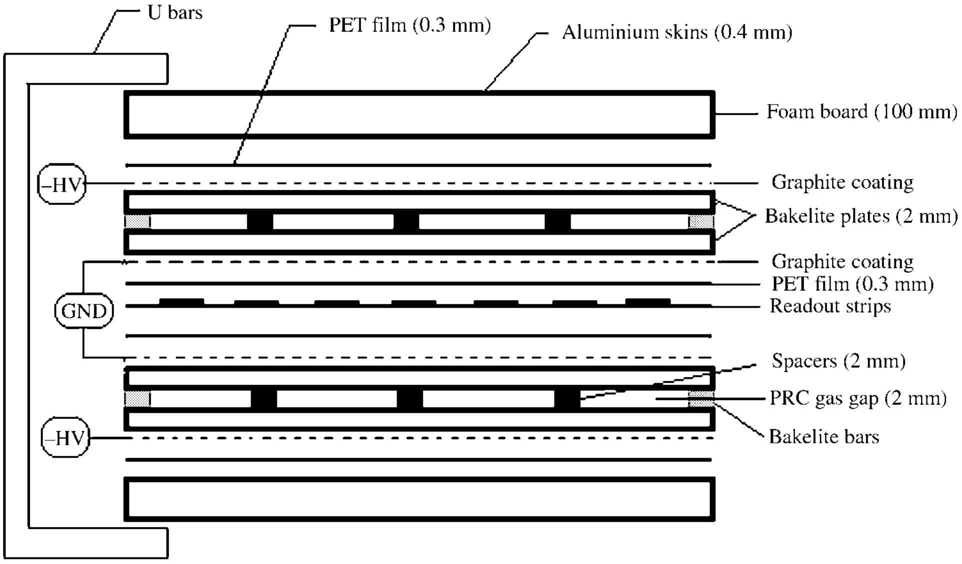

Figure 1. Cross section of the double-gap RPC.

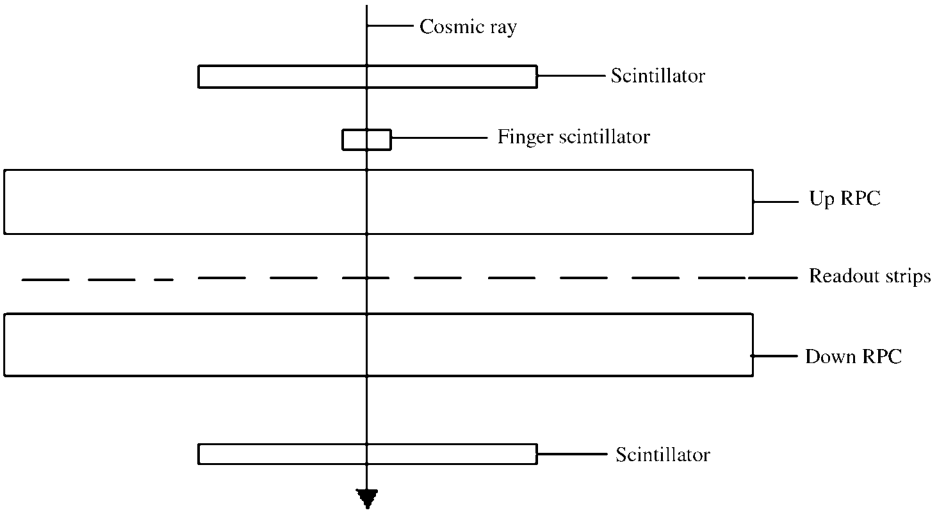

Figure 2. Cosmic-ray test system at Peking University.

from deformation. Finally, the whole chamber is fixed with an aluminium frame to ensure rigidity.

3. Cosmic-ray and beam test set-up

The schematic view of the cosmic-ray test system located at Peking University is shown in figure 2. A set of big scintillators placed above and below the RPC together with a finger

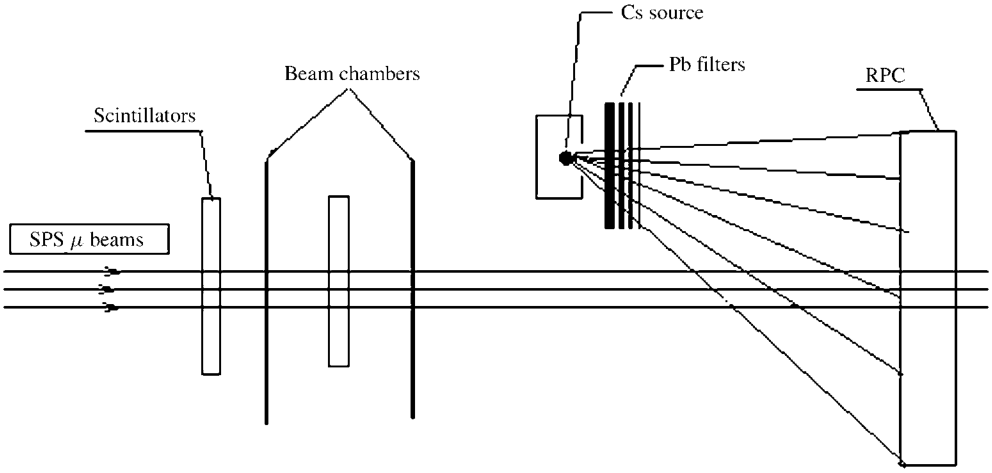

Figure 3. Muon beam test system at CERN.

scintillator were used to trigger on the cosmic rays. The ratio of coincidence counting between the trigger and the RPC signal to the pure trigger counting gave the chamber efficiency.

After the cosmic-ray test at Peking University, the RPC was shipped to CERN in Europe for a beam test. Figure 3 shows the schematic view of the muon beam test facility at CERN. Muon beams with a momentum of about 120 GeV c^{-1} were provided by the SPS accelerator, with a maximum rate of 250 Hz cm^{-2}. A strong ^{137}Cs radioactive source was used to simulate the uniform gamma irradiation background which will be present in the future LHC experimental environment. The intensity of the irradiation background can be controlled by movable Pb filters. The data acquisition system was triggered by a set of scintillators located in front of the RPC and the incoming muon trajectory can be determined by the beam chambers. The timing difference between the trigger signal and the RPC readout signal is recorded within a predefined time window and the chamber efficiency was defined as the ratio of counts with good RPC signal, to the total counts corresponding to the number of triggers.

4. Experimental results

During the cosmic-ray test, the RPC was filled with the gas mixture of 95% $C_2H_2F_4$ + 5% i-C_4H_{10}. The RPC pulse was observed on a digital oscilloscope from the readout strips. When the high voltage was at 10 500 V, the RPC operated under avalanche and streamer mixture mode. Figure 4 shows an avalanche signal together with a streamer signal, which coincides with the trigger signal. The amplitude of the avalanche pulse is about 4 mV, while the streamer pulse is much higher. The electronics noise is as low as 0.7 mV, which indicates a good make-up of the chamber. As the high voltage decreased, the streamer signal was less probable, and a pure avalanche signal could appear as shown in figure 5 for 10 100 V. The pure avalanche mode is required to ensure a high counting rate for the CMS experiment. Therefore, during the beam test, we added a small portion of SF_6 gas to quench the streamer signal for a wide voltage range.

The time resolution is one of the most important parameters of the RPC as a fast trigger device for a muon detection system. Figure 6 shows the typical time distribution from readout strips of RPC. The gas mixture in the chambers was 93.4% $C_2H_2F_4$ + 4.9% C_4H_{10} + 1.7%

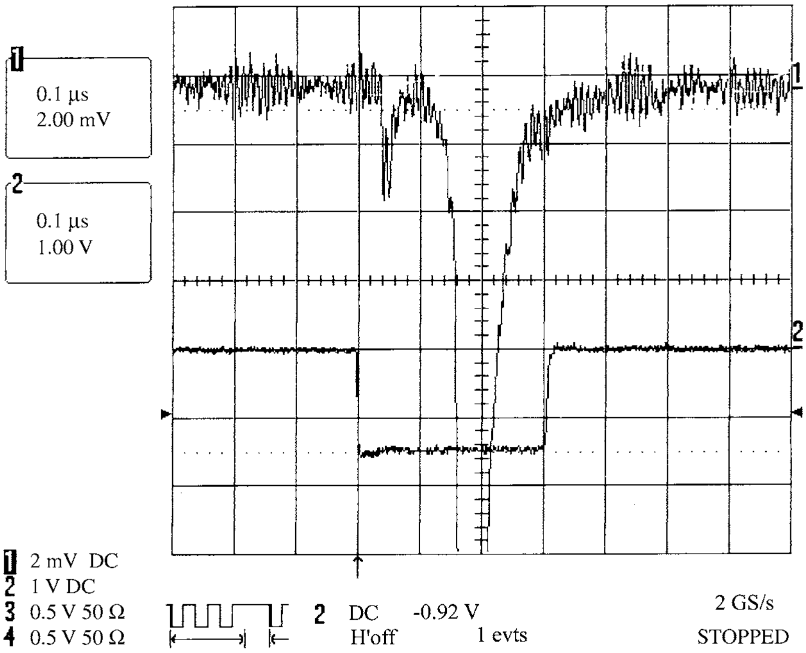

Figure 4. Avalanche and streamer signals from a readout strip of RPC (taken with a digital oscilloscope) with a gas mixture of 95% $C_2H_2F_4$ + 5% i-C_4H_{10} and high voltage of 10.5 kV. (*a*) An avalanche signal (about 4 mV) together with a streamer signal (more than 14 mV); (*b*) trigger signal.

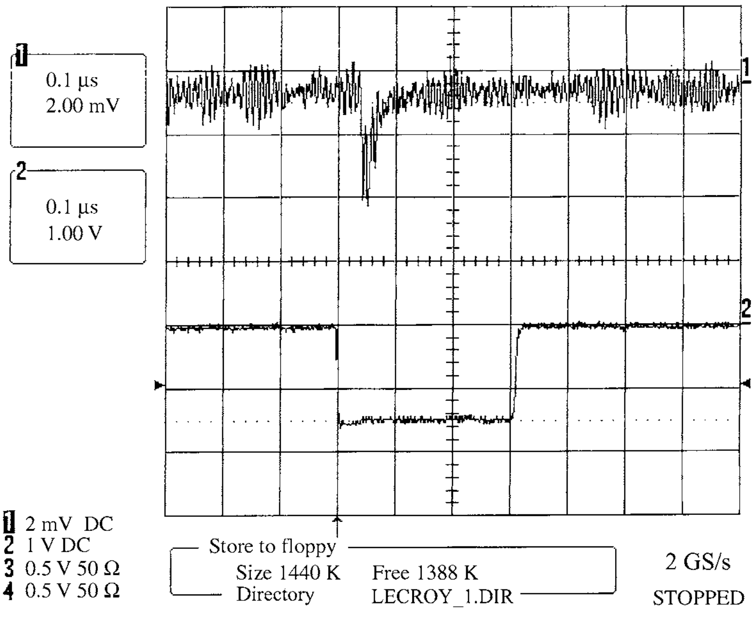

Figure 5. Pure avalanche signal from a readout strip of RPC (taken with a digital oscilloscope) with a gas mixture of 95% $C_2H_2F_4$ + 5% i-C_4H_{10} and high voltage of 10.1 kV. (*a*) An avalanche signal; (*b*) trigger signal.

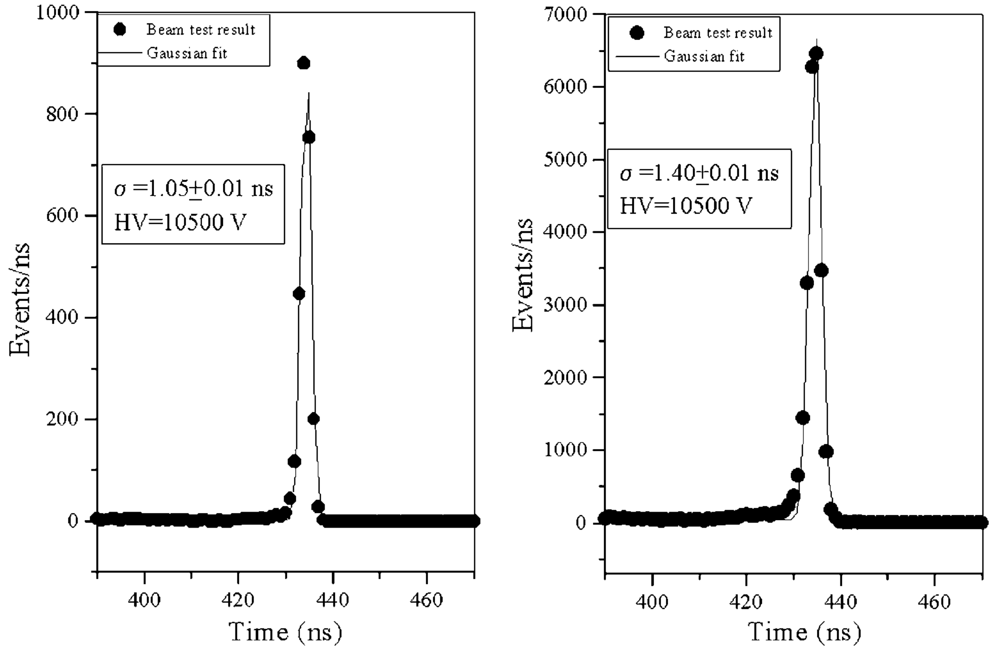

Figure 6. Time distribution from readout strips of RPC. Left, single-strip time distribution, right, all-strips time distribution.

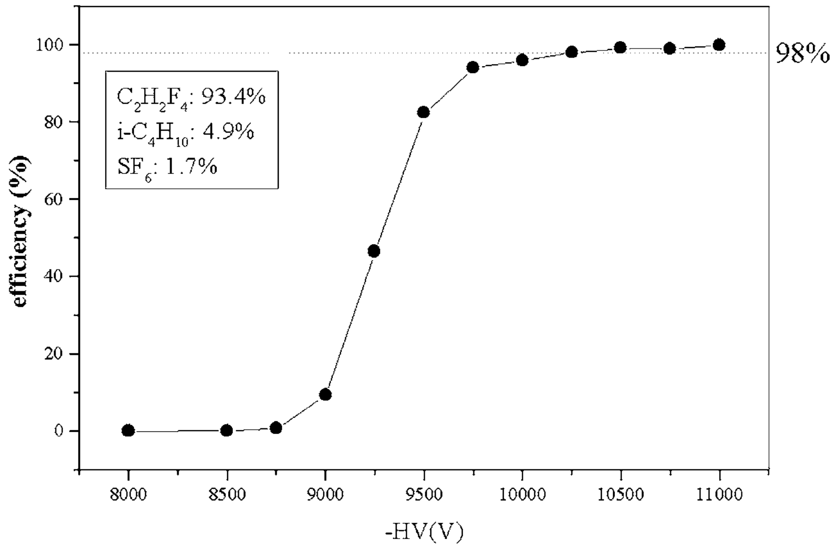

Figure 7. Efficiency versus high voltage.

SF_6. The pure avalanche mode was tested up to 13 000 V. The Gaussian fit shows that the time resolution is $\sigma = 1.05 \pm 0.01$ ns for a single strip, and $\sigma = 1.40 \pm 0.01$ ns when adding all strips together. Figure 7 shows the chamber efficiency as a function of high voltage, corrected by the dead area as described above. A plateau of 750 V (from 10 250 to 11 000 V) at full

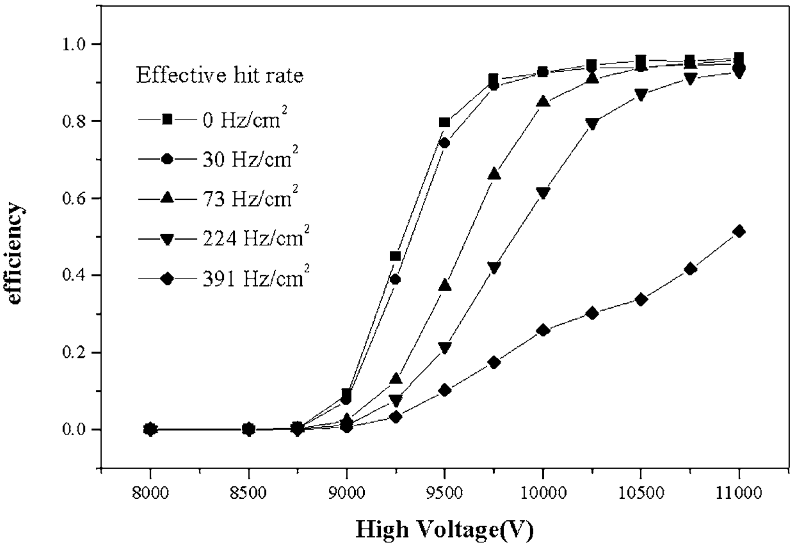

Figure 8. Efficiency versus high voltage under different gamma irradiation.

efficiency was obtained. The measurement stopped at 11 000 V due to limited beam time, but according to previous studies the full efficiency plateau could persist for a range of 2000 V [4], although a smaller range of 500 V is enough to ensure safe operation of the chamber. It is robust to operate our chamber at around 11 000 V since the dark current is still as low as 13 μA. These results indicate that the performance of our PRC under normal radiation conditions is as good as RPCs reported by other groups [7].

However, under strong irradiation background the efficiency decreased dramatically, as shown in figure 8. The effective hit rate in figure 8 is due to electrons coming from Compton processes. The measurement of the observed rate was performed with the same method as reported in [8]. According to the previous study, this decrease of efficiency should be attributed to the higher resistivity of the bakelite we used.

5. Conclusion and discussion

A medium-sized double-gap RPC was built using all Chinese materials. The key technologies of making the chamber were realized in the local laboratory. During the cosmic-ray test, avalanche and streamer signals were clearly observed which indicate the normal operation of the chamber. Then we manipulated the operation mode by changing the gas mixture and high voltages. One of the most important factors of the chamber is its very low noise which makes it possible to pick-up a small avalanche signal. The muon beam test at CERN shows that this RPC worked very well in avalanche mode under a normal radiation background. The time resolution and efficiency are as good as previously reported results by the international community. However, under a strong irradiation environment, the performance of this RPC is worse than others, possibly due to the higher resistivity value of the present Chinese bakelite. We conclude that it is necessary to use the internationally provided gas gaps to assemble the RPC chambers for the LHC experiment, while the much cheaper Chinese bakelites might be used to build RPCs for low-rate experiments, especially cosmic-ray experiments. Effort should be devoted to decreasing the resistivity of the Chinese bakelite in the future. Also a larger prototype should be built to study the uniformity over a larger size, which is also required for physics experiments.

Acknowledgments

We would like to acknowledge Ian Crotty from CERN, who helped us in making the RPC. This work was supported by the National Natural Science Foundation of China under grant number 09910140934.

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