Effect of the integrated time of the induced current signal on the position resolution of the RPC detector *

YE Jin(叶瑾)[1,2] YUE Qian(岳骞)[1,2;1)] LI Yuan-Jing(李元景)[1,2] CHENG Jian-Ping(程建平)[1,2] LI Jin(李金)[1,2] WANG Yi(王义)[1,2]

1 (Department of Engineering Physics, Tsinghua University, Beijing 100084, China)
2 (Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education, Beijing 100084, China)

Abstract A prototype RPC with position resolution less than 1 mm has been produced and studied. Based on this RPC detector, the effect of the width of the integrated FADC time window on the position resolution of a RPC has been studied experimentally and theoretically. The results of theoretical calculation and experimental measurement have shown good agreement.

Key words RPC, FADC, Gaussian function, position resolution, charge distribution

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1 Introduction

Different kinds of Resistive Plate Chamber (RPC) have been applied popularly as fast trigger systems and/or charged particle detectors with high time resolution in high energy physics[1—3]. Due to its high detective efficiency, moderate position resolution and low cost, the RPC has also exploited many potential applications in the domain outside of particle physics[4]. A RPC with high position resolution has been studied indepth for charged particle tracking and medical imaging[5]. The position resolution of a RPC can be less than 0.5 mm[6]. In this article, we will study the effect of the width of the integrated time window on the space dispersion of induced charge of a RPC detector. Experiments and theoretical calculation have been tried to get the optimal parameters for the selection of the integrated FADC time window in order to obtain the charge distribution on adjoined readout channels and optimal position resolution.

2 The detector structure and experimental setup

A 2 mm gas-gap RPC has been constructed with plate glass, which has a resistance of about 10^{12} Ω·cm, as the resistive layer and carbon film, whose surface resistivity is about 300 kΩ/□, as a high voltage provider. The thickness of the resistive glass is 700 μm and the carbon film is 150 μm. Two carbon films are attached to the outside surfaces of two parallel resistive glasses. In this work only a one-dimensional readout strip structure has been designed as the pick-up for anode induced charge. The width of a readout strip is 1 mm and the gap between strips is 1 mm as well. The 2 mm gas gap is maintained by poles made of polycarbonate with a diameter of 2 mm. A whole copper film has been designed to act as the readout structure for the cathode induced charge pick-up. The signals coming from the cathode readout film were connected to the ground and not used in this work. A 350 μm-thick layer of Mylar film has been used as insulation between the carbon film and the readout structure. In order to maintain the rigidity of the RPC structure, a 5 mm-thick honeycomb plate is stuck to the outside surface of each readout PCB of the RPC. High voltage was supplied to the carbon film via a small copper flake stuck to the carbon film with conductive glue. The total sensitive area of the RPC detector is about 100 mm×100 mm. The structure of our RPC can be seen in Fig. 1. A non-flammable gas mixture has been used as the working gas, which contains two ingredients: tetra-

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1) Corresponding author. E-mail address: yueq@mail.tsinghua.edu.cn

fluoro-ethane (92%) and iso-butane (8%). The working gas flow was maintained at a suitable speed when the detectors were tested.

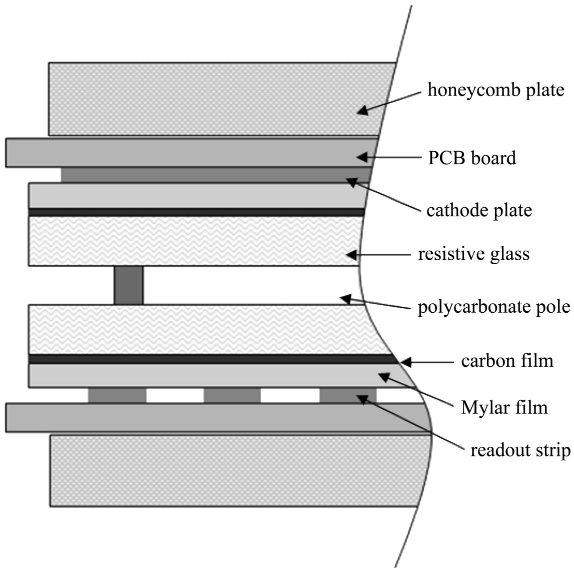

Fig. 1. The layout of our prototype RPC detector.

A coincident telescope of cosmic-ray was set up in order to get the muons to track one by one with two plastic scintillaters (5 cm×5 cm×25 cm) whose light was collected by two PMTs (CR105, Hamamatsu). The signals from the PMTs are discriminated and they must be coincident in order to get the trigger signal for the testing system for RPC signal selection. More details can be found in our another paper[6].

The signals from the RPC anode readout strips were fed into home-made current-sensitive preamplifiers. The outputs of the preamplifiers were sent to the main amplifiers for shaping and stretching from a typical FWTM (full width tenth maximum) of 50 ns to about 1us width. Then the stretched signals were sent to a 40 MHz Flash ADC to be digitized, and the total charge of each current pulse from one strip was obtained by integrating the pulse with an on-board FPGA chip. The 32 main amplifiers with corresponding FADC channels and FPGA chips were integrated into a set of home-made PCB units, which were inserted into a VME64 bus crate for data transfer. The data from the VME64 bus was read out by a PowerPC (MVE5100, Motorola) interface and sent to DAQ system by net line.

The width of the FADC integrating time window can be set via an online DAQ system before each run and the induced charge from each strip can be obtained by integrating the current pulse in the corresponding FADC time window when one external trigger signal has been gotten. The total charge of one event can be obtained by adding the charge from the whole 32 channels (a pitch of 2 mm).

3 Signal charge with different integrated time windows

Different widths of the FADC time window have been chosen to do the data taking in order to study its effect on the charge dispersion of each event. The distributions of the total charge from all the 32 channels for one event are shown in Fig. 2 with three different FADC integrated time windows. These distributions can be fitted by a two-Gaussian function in order to get the position of an incident charge particle. The Gaussian functions with narrower width $\sigma1$ and wider width $\sigma2$ describe respectively the charge expansion when the avalanche is evolving in the gas gap and the dispersion of induced charge when it passes through the resistive carbon film[6, 7]. The distributions of the $\sigma1$ and $\sigma2$ from one run in Fig. 3 is shown and one can see that the distribution of $\sigma1$ just gets a little worse when a wider time window of FADC has been chosen. At the same time, $\sigma2$ has a wider expansion than $\sigma1$ for each FADC time window.

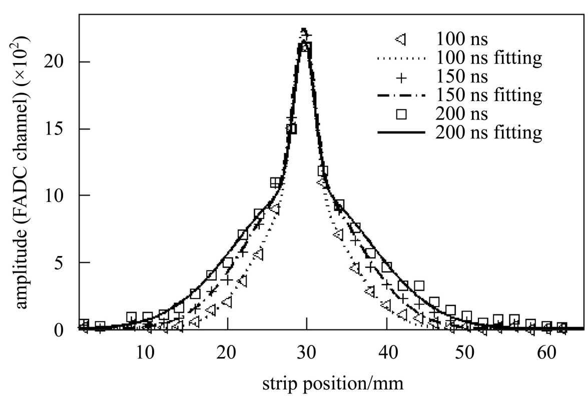

Fig. 2. The charge distribution from the whole 32 readout channels with different FADC time windows for the same event and fitting results by a two-Gaussian function.

4 The theoretical calculation of charge distribution

The dispersion of induced charge of a RPC can be simulated and calculated. One can consider that the resistive carbon film and the readout strip plane can be approximately considered as a distributed two-dimension RC network. For the long strip readout structure, the phenomena can be described simply as one-dimension dispersion vertical to the strips. The avalanche signal in a RPC gas gap is described as a Gaussian distribution with a width ω due to its

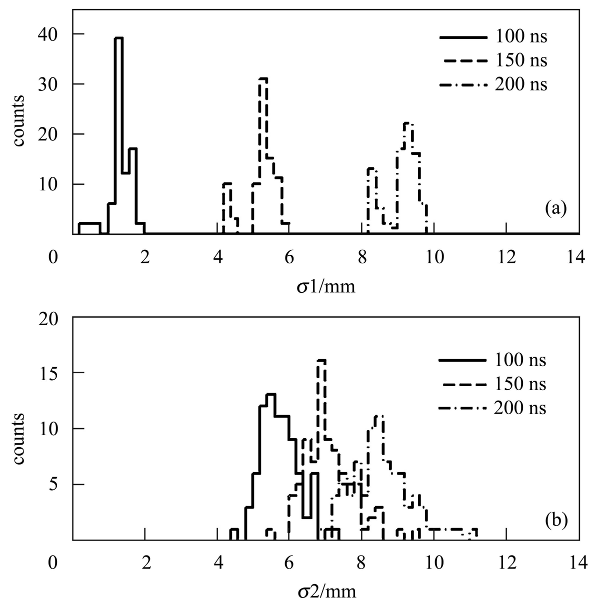

Fig. 3. The distributions of $\sigma1$ and $\sigma2$ when a two-gaussian function has been used to fit the charge distributions along the 32 readout strips. In Fig. 3(a), the $\sigma1$ distribution of 150 ns and 200 ns situation have been added 3 mm and 6 mm for each event respectively in order to display them clearly in the same plot.

transverse diffusion[7]. When a unit charge cluster is deposited at $x=0$ on the glass surface and the edges are infinite, the solution for charge density in the one-dimensional case is given by

$$\rho(x,t)=\frac{1}{\sqrt{2\pi}\cdot\sigma}\exp(-x^2/2\sigma^2). \quad (1)$$

Here $\sigma=\sqrt{2ht+\omega^2}$, $h=1/RC$. It is the result of convolution of two Gaussian functions: avalanche distribution and charge dispersion passing through the carbon film. The charge signal on one strip can be computed by integrating the charge density function over it:

$$Q(t)=\frac{1}{2}\left[\mathrm{erf}\left(\frac{x_2}{\sqrt{2}\sigma}\right)-\mathrm{erf}\left(\frac{x_1}{\sqrt{2}\sigma}\right)\right], \quad (2)$$

where x_1 and x_2 define the strip boundaries. Obviously, RC as a time constant, influences the strip response function during charge dispersion, from which we can study the charge dispersion theory. Different time windows can be chosen to obtain the charge of each channel and the total charge of an event. Fig. 4 shows the charge distribution from 32 readout channels with different time windows and the fitting results. One can see that the charge distribution can be quite well fitted by a two Gaussian function with different $\sigma1$ and $\sigma2$.

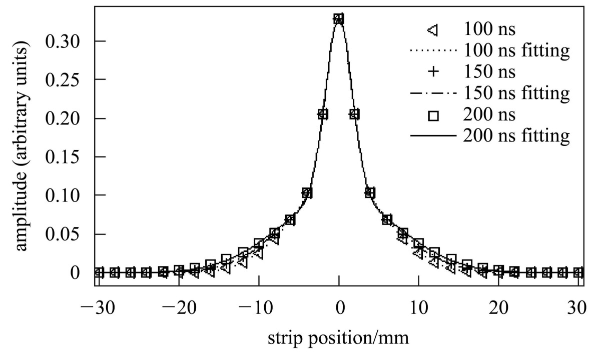

Fig. 4. The charge distribution of the theoretical calculation of a RPC which has the same surface resistivity as our measured RPC.

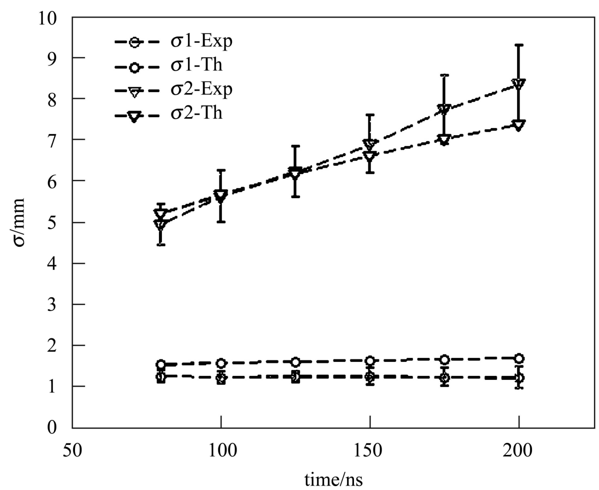

Fig. 5. The comparison of $\sigma1$ and $\sigma2$ for theoretical and experimental results.

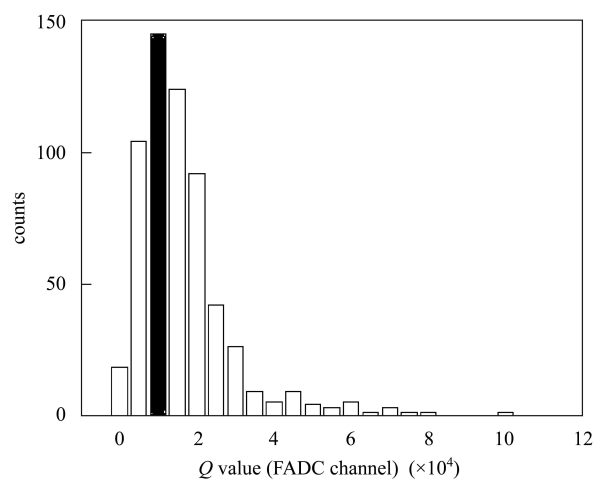

Fig. 6. The charge spectra of events from one run with a 400 ns FADC time window. The events from the third charge bin (the filled charge bin, the total charge value between the 8000 and 12000 FADC channels) have been used to do the study for the optical integrated FADC time window selection.

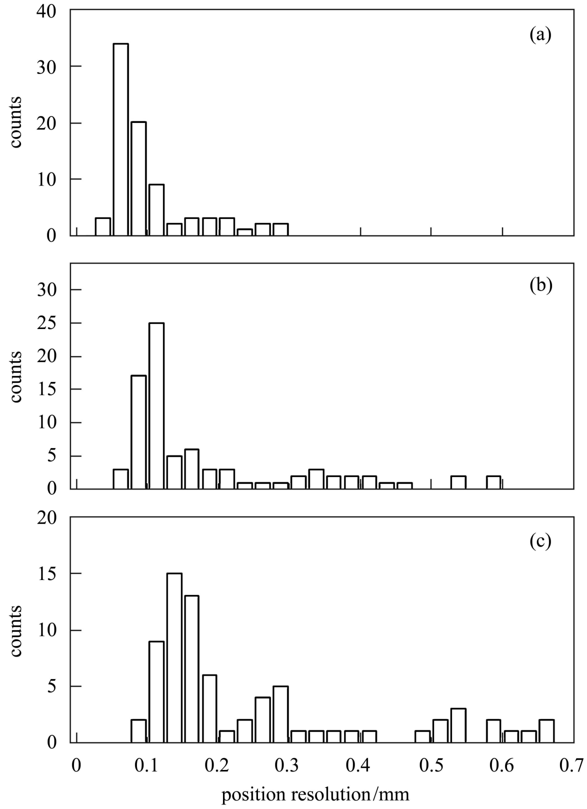

Fig. 7. The distribution of the statistical errors of the events from the same one energy bin with different FADC integrated time windows. (a) 100 ns, (b) 150 ns, and (c) 200 ns.

One can see from Fig. 5 that the calculated and measured results of $\sigma 1$ and $\sigma 2$ are in quite good agreement. In our experiment, it will lose more than half of the total charge of one event if the integrated time window has a value less than 100 ns and this will give a bad charge collection. So in this measurement the 100 ns FADC time window is the least value for us to study. The charge spectrum of the events in one run is shown in Fig. 6 with the maximum integrated FADC time window, which is 400 ns. In order to compare the effect of different integrated FADC windows on the charge distribution and position resolution of our prototype RPC, we choose the events in the same charge bin with the most events (the filled bin in Fig. 6, the total charge value between the 8000 and 12000 FADC channels) to do the analysis.

Figure 7 shows the distribution of position resolution of the events with the same total charge. One can see that the distribution with a 100 ns FADC time window gives a better position resolution than the other two situations. So we can choose the 100 ns FADC time window as the better parameter to get the position resolution of an incident charge particle. The position resolution indexed by the statistical errors for our prototype RPC can be less than 0.5 mm with 100 ns integrated FADC time windows.

5 Summary

The effect of the width of the integrated FADC time window on the position resolution of a RPC has been studied experimentally and theoretically. The results of theoretical calculation and experimental measurement have shown good agreement. In this situation the 100 ns FADC time window can be an optical choice for the position resolution of one incident charge particle. But one should note that the value 100 ns is just a better choice in this special situation. If any experimental condition has been changed, the optimal integrated FADC time window has to be measured again, but this method still can be used properly.

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