Test of BESIII RPC in the avalanche mode

HAN Ji-Feng(韩纪锋)[1,2;1)] ZHANG Jia-Wen(张家文)[1] CHEN Jin(陈进)[1] ZHANG Qing-Min(张清民)[1,2]
LIU Qian(刘倩)[1,2] XIE Yu-Guang(谢宇广)[1,2] QIAN Sen(钱森)[1,2] MA Lie-Hua(马烈华)[1,2]

1 (Institute of High Energy Physics, CAS, Beijing 100049, China)
2 (Graduate University of Chinese Academy of Sciences, Beijing 100049, China)

Abstract The installation of the BESIII RPC system has been completed. Cosmic ray test results show that they perform very well in streamer mode and meet the BESIII requirements. We have tested several RPCs in the avalanche mode with the addition of extra SF_6 in the gas mixture. We find an efficiency plateau that reaches ~95%, and a time resolution of 1.8 ns. This demonstrates that the BESIII-type RPC can work in the avalanche mode as well.

Key words resistive plate chamber (RPC), BESIII, avalanche mode

PACS 29.40.-n, 29.40.Cs

1 Introduction

Resistive plate chambers (RPC) are a type of gas detector that was originally developed by Santonico in the early 1980s[1]. RPCs can work in both the avalanche and streamer modes with appropriate gas mixtures. Due to the large signal size and inexpensive construction costs, streamer mode RPCs have been widely used in the high energy physics and cosmic ray experiments. The large induced signal produced by the streamer obviates the need for an amplifier; on the other hand it also limits the rate capability. The maximum rate that can be handled in the streamer mode RPC is around 100 Hz/cm^2[2]. An RPC in the avalanche mode can tolerate much higher rates and can be used in higher particle-flux environments.

The BESIII RPCs work in the streamer mode with a gas mixture that is 50% argon, 42% R134A ($C_2H_2F_4$) and 8% Iso-butane. Instead of coating the inner surface of the RPC electrodes with the linseed oil, as is commonly done, the BESIII RPC bakelite surface is covered with a layer of special plastic film that has an excellent surface quality[3—5]. In total, about 1200 m^2 of RPCs with different sizes and shapes have been produced and installed into BESIII[6, 7]. Cosmic ray test results demonstrate that the average efficiency is higher than 95% a performance level that meets the BESIII requirements[8, 9].

To see if this type of RPC can operate in the avalanche mode as well, some prototype RPCs that were previously used in the streamer mode were tested in the avalanche mode. The prototypes used for the test are 25 cm×100 cm in size with a bakelite bulk resistivity of 2×10^{10} to 8×10^{10} Ω·cm. The avalanche mode operation is achieved by introducing a small fraction of SF_6 into the $C_2H_2F_4$ and Iso-butane gas mixture. For this test the fraction of SF_6 is fixed at 0.5% and the RPC performance for several different fractions of Iso-butane is studied. For each gas mixture, the efficiency, counting rate and current versus high voltage are tested. For the time resolution and signal charge study, the working gas mixture is $C_2H_2F_4$/Iso-butane/SF_6 (84.5/15/0.5).

2 The test setup

The cosmic ray telescope is composed of two 4 cm × 30 cm scintillation counters. The readout strip used for the test is 10 cm wide and 100 cm long with a strip terminated by a 25 Ω resistor. The small avalanche signal is amplified by a current- sensitive amplifier that was originally developed for BES II main drift chamber by the University of Hawaii. The amplifier outputs are validated by a NIM discriminator module, and recorded by the CAMAC SCALER and TDC modules, from which the efficiency, singles rate and time resolution are derived. The discrimination threshold is set to 30 mV, which roughly corre-

Received 13 August 2007, Revised 9 October 2007
1) Corresponding author, E-mail: hanjf@ihep.ac.cn

sponds to a 0.6 mV signal from the strip output. The environmental parameters such as the room temperature and the relative humility are recorded. Fig. 1 shows a cross section view of the RPC. The RPC and the readout strip are enclosed in an aluminum box, the signal transmission line is formed by the strip on +HV side and the ground on −HV side.

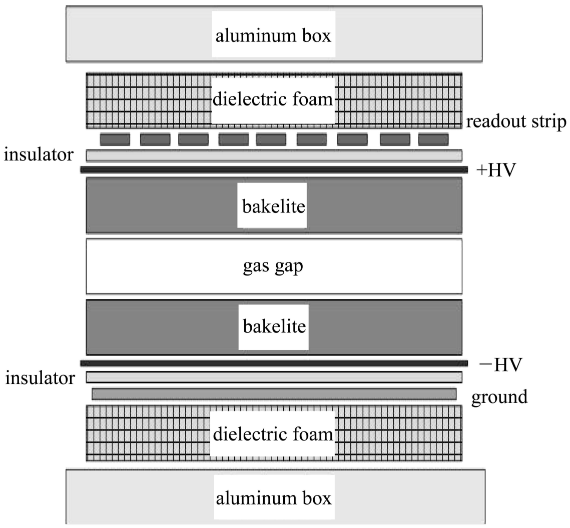

Fig. 1. The cross-section view of the RPC prototype, the thickness of the electrode plate is 2 mm, and the thickness of the gas gap is 2 mm.

3 Test results

3.1 Tests of different gas mixtures

The performance of the RPC for gas mixtures of 5%, 10%, 15% and 20% Iso-Butane have been tested. For each gas mixture, the efficiency, singles rate and dark current are measured. As is well known, the ambient temperature can greatly affect the performance[2]; all tests mentioned in this report are done at 23—24℃, and a relative humility of 40%—50%. The dark current was less than 2 μA for all tests, the current versus voltage curves for the different gas mixtures were very similar.

Figure 2 shows the efficiency and singles rate versus high voltage for different gas mixtures. The singles rate is determined by counting the number of signals that are above the discrimination threshold within a given time interval. This includes both cosmic ray signals and the RPC noise background. The singles rate is desired to be as small as possible in order to improve the signal-to-noise ratio. It is found that:

1) When the voltage is higher than 10.2 kV the RPC reaches the plateau for all gas mixtures. The plateau efficiency is 94%—96%.

2) When the fraction of Iso-butane increases from 5% to 10% the efficiency curve shifts to the lower voltages; when the fraction increases beyond 10% to 15% and 20% the efficiency curve shifts back to the high voltage side. The efficiency curves are almost identical for 5% and 20% Iso-butane gas mixtures.

3) The behaviour of the singles rate is similar to that of the efficiency. The singles rate reaches its highest value in the 10% Iso-butane gas mixture; all other gas mixtures have lower singles rates. In any case the singles rate is less than 1 Hz/cm^2 for all tested gas mixtures.

It seems that the single rate curve is a little strange for 5% and 15% Iso-butane gas mixture, which might be caused by the material of the Bakelite electrode. This result will be checked after new type of Bakelite electrodes are manufactured in the near future.

For the rest of the tests, a gas mixture of $C_2H_2F_4$/Iso-Butane/SF_6 (84.5/15/0.5) is used, because the efficiency plateau is higher and the counting rate is lower.

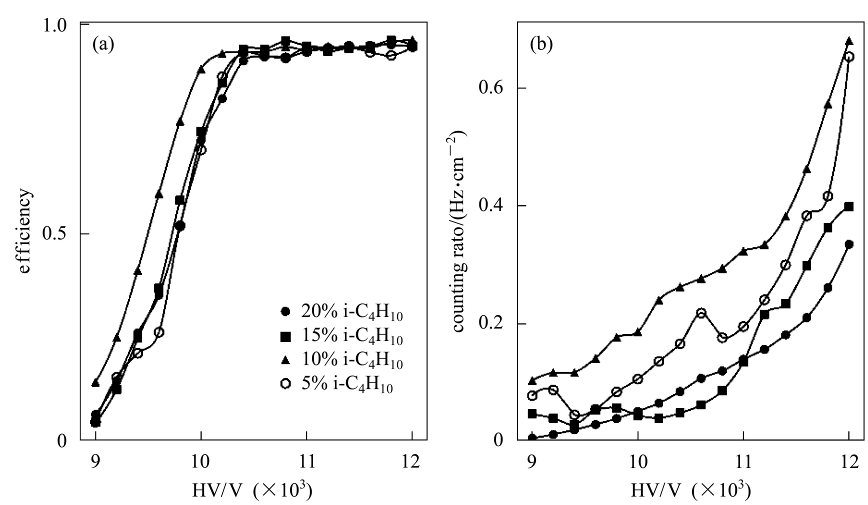

Fig. 2. (a) The efficiency and (b) single rate versus high voltage with different gas mixtures.

3.2 Time resolution

The arrival time versus high voltage distribution is measured with a 30 mV discrimination threshold. In order to determine the time resolution of the avalanche signal, a selection of the signal charge is applied: the avalanche-induced signal charge on the readout strip is required to be less than 10 pC. The signal charge spectrum is discussed in detail below in section 3.3. Fig. 3(a) shows the arrival time distribution of RPC avalanche signals at 11 kV; Fig. 3(b) shows the T_0 distribution of the trigger scintillation counters. After correction for the time jitter in T_0, the time resolution of the RPC signal at 11 kV is 1.8 ns. The time resolution would be even better if a constant fraction discriminator were used.

The time resolution of the same RPC under streamer mode was tested with the standard BESIII streamer gas mixture Argon/$C_2H_2F_4$/Isobutane (50/42/8). It is found that the time resolution in the avalanche mode is much smaller than in the streamer mode. Fig. 4(a) shows the time resolution of avalanche operation versus high voltage, and Fig. 4(b) shows the same results for streamer operation. In both cases, the time resolutions are corrected for the T_0 jitter. In the avalanche mode, the time resolution improves with increasing high voltage; at the efficiency plateau region it is 1—3 ns.

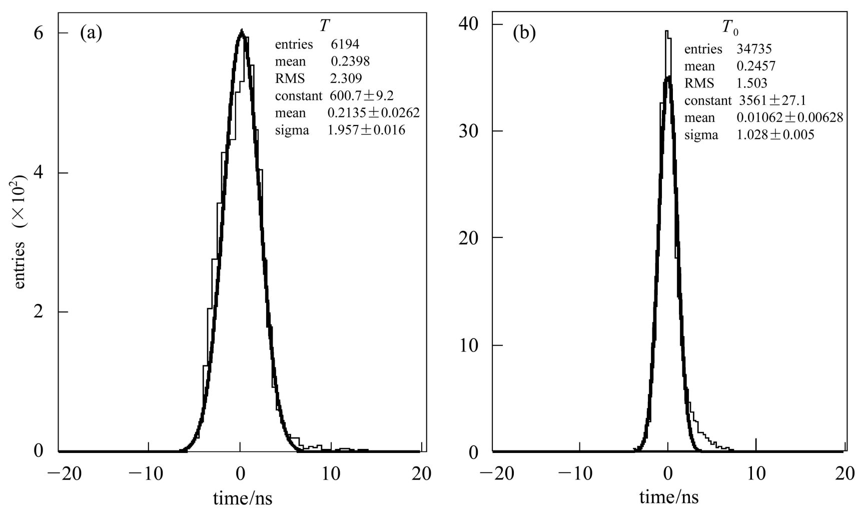

Fig. 3. (a) The arrival time distribution of RPC signals at 11 kV, (b) the scintillation counter time resolution T_0.

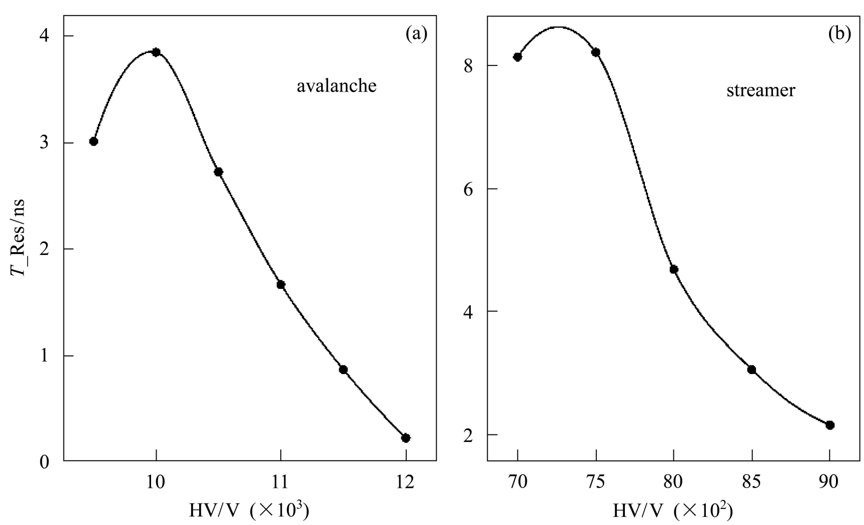

Fig. 4. Time resolution vs. high voltage, (a) in avalanche mode (b) in streamer mode.

3.3 The charge spectrum

A LeCroy 612A NIM-based linear amplifier with a gain of 10 is used to measure the charge spectrum. Fig. 5 shows the signal charge distributions for 10.5 kV and 11 kV. The first peak is fitted with a Landau distribution. There is only one peak found in the 10.5 kV spectrum, and the most probable value (MPV) of the Landau fit is 4 pC, which corresponds to an original signal from the strip of 0.4 pC. In addition to the first Landau peak, a second peak around 150 pC is found for 11 kV operation. It is summarized that the first peak is for avalanche-mode signals and the second peak is for streamer-mode signals. If so, the avalanche signal on the readout strip is less than 10 pC. When the voltage is higher than 12.5 kV, the fraction of the second peak is above 70%, as the avalanche-mode operation changes to the streamer mode.

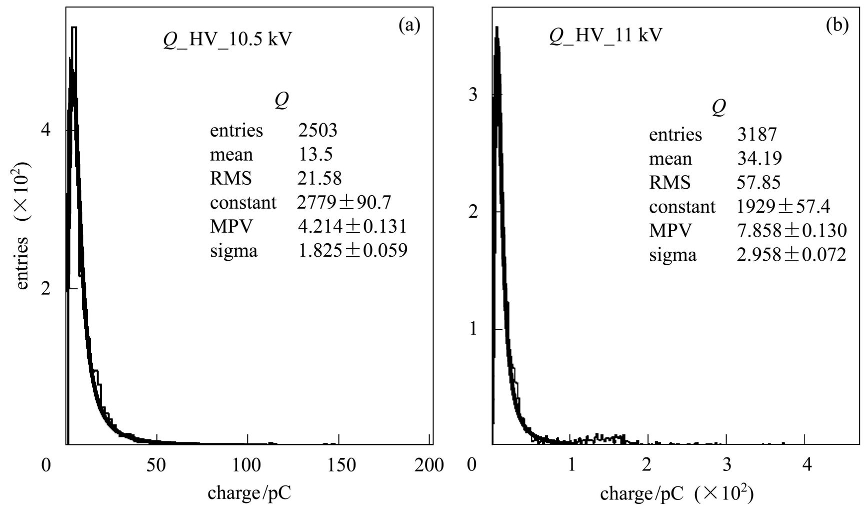

Fig. 5. The charge spectrum of the RPC signal after the amplifier with gain ×10, the first peak is fitted with Landau distribution. (a) HV=10.5 kV; (b) HV=11 kV.

Figure 6 shows the MPV of the Landau peak vs. high voltage. The MPV doesn't increases linearly with voltage. When the voltage is less than 10.5 kV the MPV increases slowly with high voltage, and when the voltage is higher than 10.5 kV the MPV increase becomes more rapid.

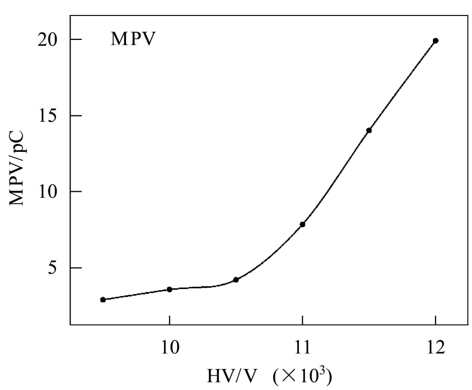

Fig. 6. The most probable value of the first Landau peak vs. high voltage.

4 Conclusion and discussion

The BESIII RPC can be operated in the avalanche mode with the proper gas mixture of $C_2H_2F_4$, Iso-Butane and SF_6. The plateau efficiency is ∼95%, the plateau length is about 1 kV, and the time resolution is about 2 ns.

Since the bulk resistivity varies a lot for different areas even for the same bakelite — for example, the RPC used for BESIII varies from 10^9 to 10^{13} Ω·cm — further tests are needed to check the influence of the resistivity variation in avalanche operation. The other performance parameters of avalanche-mode operation, such as rate capability, etc., will be tested in the near future.

The authors would like to take this opportunity to express deep appreciation to Dr. Changguo Lu for helpful and useful discussions and suggestions throughout this work.

References

1 Santonico R et al. Nucl. Instrum. Methods A, 1981, **187**: 377
2 XIE Yu-Guang et al. HEP & NP, 2007, **31**(1): 70 (in Chinese)
3 ZHANG J et al. Nucl. Instrum. Methods A, 2005, **540**: 102
4 ZHANG Jia-Wen et al. HEP & NP, 2003, **27**(7): 615 (in Chinese)
5 ZHANG Jia-Wen et al. HEP & NP, 2003, **27**(11): 1019 (in Chinese)
6 ZHANG J et al. Nucl. Instrum. Methods A, 2007, **580**: 1250
7 HAN Ji-Feng et al. The Quality Control and Database on Resistive Plate Chambers for the BESIII Experiment. Chin. Phys. C. to be published
8 LIU Qian et al. HEP & NP, 2006, **30**(4): 327 (in Chinese)
9 HAN J et al. Nucl. Instrum. Methods A, 2007, **577**: 552