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The design and mass production on Resistive Plate Chambers for the BESIII experiment

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Abstract

A new type of the phenolic paper laminate is used as the resistive electrodes of BESIII RPC. The surface smoothness of these laminates is comparable to that of the bakelite plates with linseed oil treating. A technique to adjust the bulk resistivity of the laminates within the range of 10^9–$10^{13}\,\Omega$ cm is developed. Nowadays, about 1000 bare chambers (1200 m^2) have been produced and used for BESIII MUON, and the rejection rate is only 1.5%. In this paper, we will discuss the mass production and quality control procedures of these RPCs.

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Keywords: Resistive Plate Chamber (RPC); BESIII; MUON; Mass production

1. Introduction

BESIII is a spectrometer which will work in the upgrade Beijing Electron-Positron Collider [1]. The Resistive Plate Chamber (RPC) [2] is chosen as its active detector of the muon identifier. Approximately 1200 m^2 RPCs of different sizes and shapes have been constructed at Beijing Gaonengkedi Co., Ltd., a detector R&D and manufacturing company affiliated with the IHEP, Beijing. BESIII RPC operates at 8000 V in streamer mode with a gas mixture of 50% argon, 42% $C_2H_2F_4$, and 8% iso-butane [3–8]. The mass production of BESIII RPC can be divided into two periods: the production of the end cap RPCs was started in June 2004, and finished in September 2004, while that of the barrel RPCs was started in October 2004, and finished in June 2005. The performance of barrel RPCs is better than that of the end cap RPCs due to the experiences and skills acquired during production such as the new training process, etc. In this paper, the materials, the structure, the construction, and the quality control procedures of the BESIII RPC are reported. The end cap and barrel result will be reported separately.

2. Electrode material and RPC structure

The thickness, the bulk resistivity, and the surface smoothness of the resistive plate are the few most critical parameters for a good RPC. The electrodes of BESIII RPC are made of bakelite plate coated by a layer of special plastic film without using linseed oil [3], which is proved to have excellent surface quality. The bulk resistivity of the plate is controlled in the range of 2×10^{11}–$2\times10^{13}\,\Omega$ cm at $22\pm2\,^{\circ}$C based on the prototype R&D test [7]. The RPC structure is shown in Fig. 1. The thickness of the bakelite plate is 2 ± 0.02 mm, and the gas gap between the two plates is 2 mm that is ensured by the spacers. The distance between the two neighboring spacers is 125 mm. The central part of the spacer is 1.8 mm thick, a little thinner than the 2 mm thick outer ring, which is used to contain certain amount of glue, therefore to guarantee the binding

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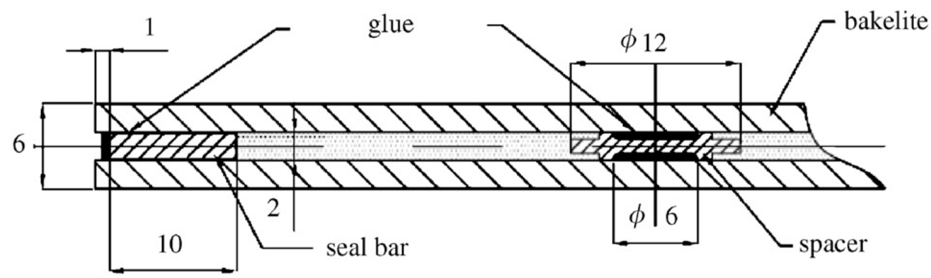

Fig. 1. The cross-sectional view of the RPC; the thickness of the electrode plate is 2 mm, and the thickness of the gas gap is 2 mm.

strength. The glue is 508 epoxy colophony (made in China), which is tested to have high bonding strength and good radiation resistance.

A special graphite paint that we co-developed with the industry is painted on the outer surface of the electrodes to distribute high voltage. The graphite paint is proved to have excellent adhesion to the electrodes. The graphite layer's thickness is 0.5 mm, and the surface resistivity is 2×10^5–$1 \times 10^6\,\Omega/\square$.

The readout strip is made of copper clad G10 by the factory. The thickness of G10 layer is 0.1 mm, and that of the copper cladding is 0.025 mm. This type of readout strip has also been used for the CMS RPCs [8].

3. Production

The mass production of RPCs contains the following steps.

3.1. Bakelite electrodes production and preparation

The bakelite electrodes are produced by the factory, and the parameter under control is the bulk resistivity. The produced electrode is of the size $1.2 \times 2.4\,m^2$, and the maximum usable area is $1 \times 2\,m^2$. The bulk resistivity of each plate is measured in five different points, and the average resistivity is used to represent the electrode bulk resistivity. Only the plates that the bulk resistivity is within the range of 2×10^{11}–$2 \times 10^{13}\,\Omega\,cm$ are accepted.

3.2. Paint the graphite layer

Before the gas gap assembly, one graphite layer is coated on one side of the bakelite electrodes. Certain amount of graphite is prepared according to the surface resistivity requirement, and it is painted to the bakelite surface uniformly using the airbrush. One exhaust fan is used to suck out the extra vapor, and dry the graphite layer quickly. After 1 day, the graphite surface resistivity is tested, and only the ones within the range of 2×10^5–$1 \times 10^6\,\Omega/\square$ are accepted.

3.3. The gas gap glue and assembly

The assembly is performed in a temperature, humidity controlled and air filtered clean room. After a preliminary cleanness treatment, the graphite coated resistive plates enter the clean room, and go through another cleanness treatment. A special module to hold the plate is used during the assembly to avoid the surface contamination by hands and to ensure the assembling precision. Just before the assembly of the two plates, nitrogen gas is used to blow the entire surface as the last cleanness process. After assembly, one glass plate is put on top and a pressure of $500\,kg/m^2$ is loaded for 24 h until the glue dries up.

4. Quality control

There are quality control procedures in each step of the production chain. A production database is built to save all the quality control data. After the assembly, the quality control procedures such as gas leakage and press test are taken to reject unqualified RPCs, and finally cosmic ray test is taken to check the performance of the efficiency, counting rate, and dark current.

4.1. Quality control during production process

The quality control process includes the raw material performance such as geometry size, the bakelite surface quality and the bulk resistivity, the graphite painting quality and surface resistivity, the test temperature and humility, the gap assembly and PET gluing, etc.

Fig. 2 shows the bulk resistivity distribution of all RPCs, Fig. 2a is for all end cap RPCs and Fig. 2b is for all barrel RPCs. The bulk resistivity of barrel RPCs is much bigger than that of the end cap RPCs, which is better for BESIII experiment because it renders the counting rate and current much smaller while the efficiency could be still high. Fig. 3 shows the graphite surface resistivity distribution of all RPCs, Fig. 3a is for all end cap RPCs and Fig. 3b is for all barrel RPCs.

4.2. Leakage and push tests

These tests are designed to check the RPC gas leakage and unglued spacers. A simple tool based on a pressure

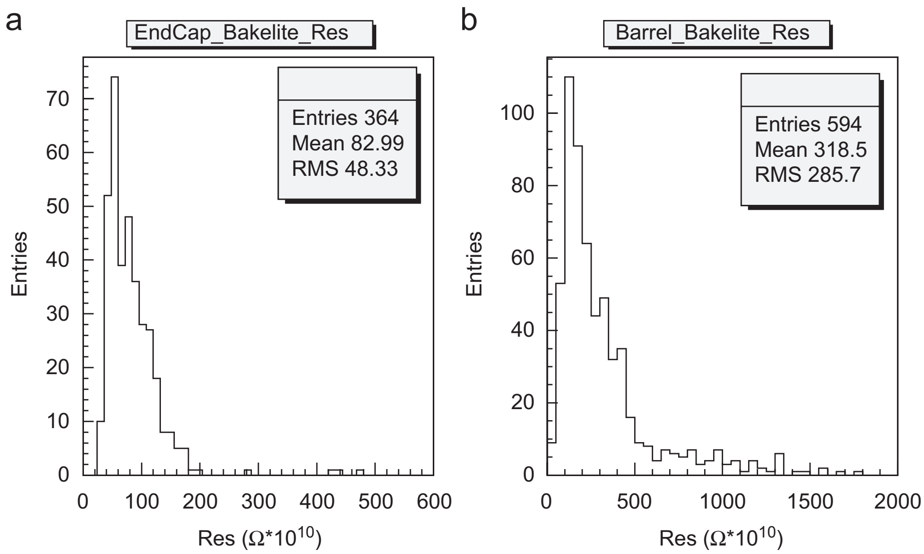

Fig. 2. The electrode bulk resistivity distribution of all end cap (a) and barrel (b) RPCs.

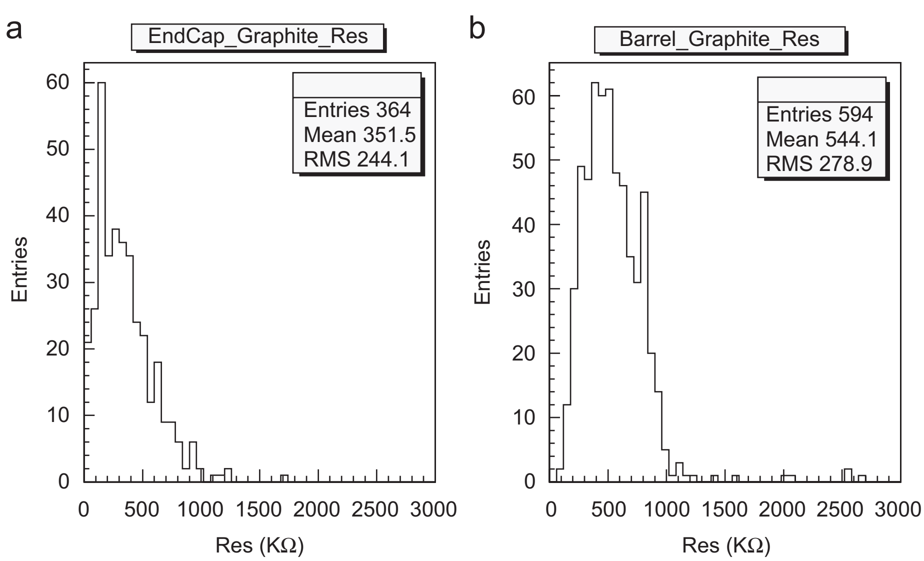

Fig. 3. The graphite surface resistivity distribution of all end cap (a) and barrel (b) RPCs.

sensor is used for the test. An over-pressure of 100 mm H_2O is applied on the gas gap, and then the pressure variation over time is measured. The temperature is also monitored during the test because the system is very sensitive and variable to it. Only RPCs that the pressure loss is less than 5 mm H_2O in a 30 min period can pass the test. The failed RPCs are returned to the factory and repaired.

The same tool is used to test the unglued spacers, which is to monitor the time needed for the over-pressure to grow up. If there are unglued spacers, the pressure grows up slowly and more time is needed, and the pressure will change sharply if weights are put on top of the unglued spacers. Based on this fact, it is easy to find out how many spacers and which spacer is unglued. The RPCs will be rejected if there are more than one unglued spacers.

4.3. Training process

The performance of the newly assembled RPC is bad and the current at working high voltage is very high, so a training process is needed. Normally, the RPCs will be trained with pure argon gas at a high voltage of 10,000 V for at least 24 h, and after training, the current will be smaller than 100 $\mu A/m^2$ in pure argon gas at 10,000 V, or else another 24 h will be trained for the failed ones, and will be rejected if failed again. After the training, the current is more stable although it is still possible for the current to decrease a little during long-term operation.

But the end cap RPCs are trained in a different way because this new training process was not developed at that time. The end cap RPCs are trained with working gas mixture of 50% argon, 42% $C_2H_2F_4$, and 8% iso-butane at a high voltage of 8000 V for 3 days. The current will decrease sharply for the first 3 days, but it is not enough because the prototype tests show that the current will decrease slowly for 1 month until the current is stable during operation. So the 3-day training is still not enough and very time consuming, while the new training process will be better and faster.

Totally five end cap RPCs are rejected because they have more than one unglued spacers or the current is too high that failed to pass the training process. While all barrel RPCs passed the selection.

5. Cosmic ray test

Finally RPCs that successfully pass all the former tests are delivered to IHEP and go through the cosmic ray test. The efficiency, counting rate, and current of the RPC are tested and unqualified ones will be rejected to the factory. There are 374 end cap RPC finished tests of which 8 are rejected and 594 barrel RPC finished tests with only 1 RPC is rejected. Most of them are rejected because of the low efficiency. The temperature during the test is from 18 to 25 °C, and the humility is about 20–60%, and the results reported below are not corrected for temperature and pressure.

One cosmic ray test system is built for the test. The cosmic ray telescope is composed of three RPCs each with the dimension of 300 mm $\times$ 1000 mm, which also works in streamer mode and using the same gas mixture as the testing RPCs. Only a part of the area of the RPC is tested to represent the performance of that RPC. The high

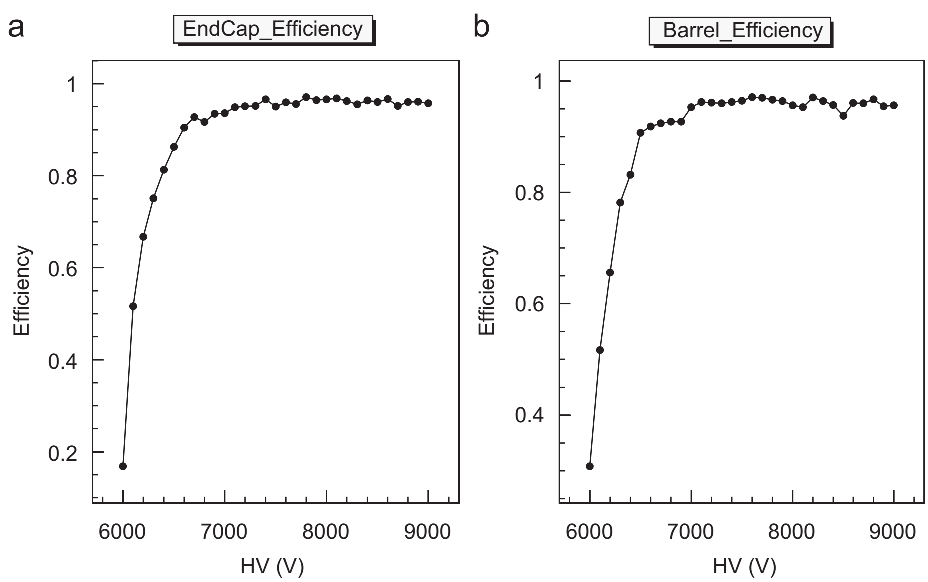

Fig. 4. The efficiency versus high-voltage curve of one end cap (a) and one barrel (b) RPC.

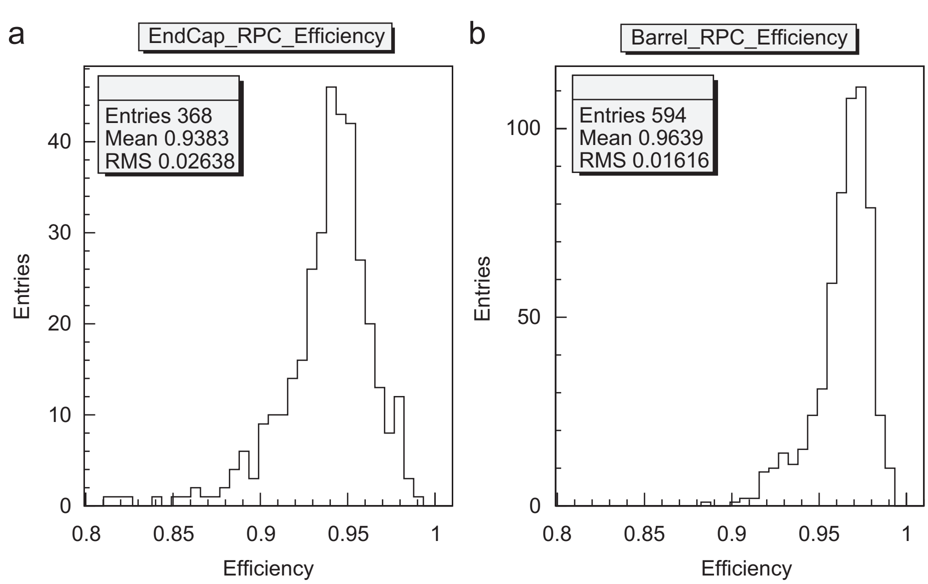

Fig. 5. The efficiency distribution of all end cap and barrel RPCs at 8000 V.

voltage is supplied by CAEN SY127 system, and both positive and negative high voltages are used for RPC in order to reduce the maximum voltage required for each high-voltage power supply, because it is easier to insulation and safer for lower high voltage. The data acquisition system is composed of NIM crate and CAMAC module. The readout strip used for test has a size of 300 mm × 1000 mm, and only one strip is used for each RPC. Then, the RPC signals are connected to NIM discriminators by coaxial cables. Normally, the discriminator threshold is set to 100 mV. Then after some NIM logic, the output signals of the telescope and of the RPC under test are sent to one CAMAC SCALER for efficiency and counting rate calculation. All the data are read out and saved to hard disk by one PC connecting the CAMAC module. The PC is running under Linux operating system, and the DAQ software is written in C+ + language based on CERN ROOT platform.

5.1. Efficiency

The efficiency is tested from 6000 to 9000 V in 100 V step, and a few criteria are used to reject unqualified RPCs. First, the efficiency plateau must be longer than 600 V; second, the working high voltage 8000 V should be near the center of the plateau; and the plateau efficiency should be higher than 85%. Fig. 4 shows the efficiency curve of one end cap RPC (a) and one barrel RPC (b).

Fig. 5 shows the efficiency distribution for all the end cap and barrel RPCs at 8000 V. The average efficiency for end cap RPCs is 94%, and the average efficiency of barrel RPCs is 96%. One reason of the efficiency loss is the dead

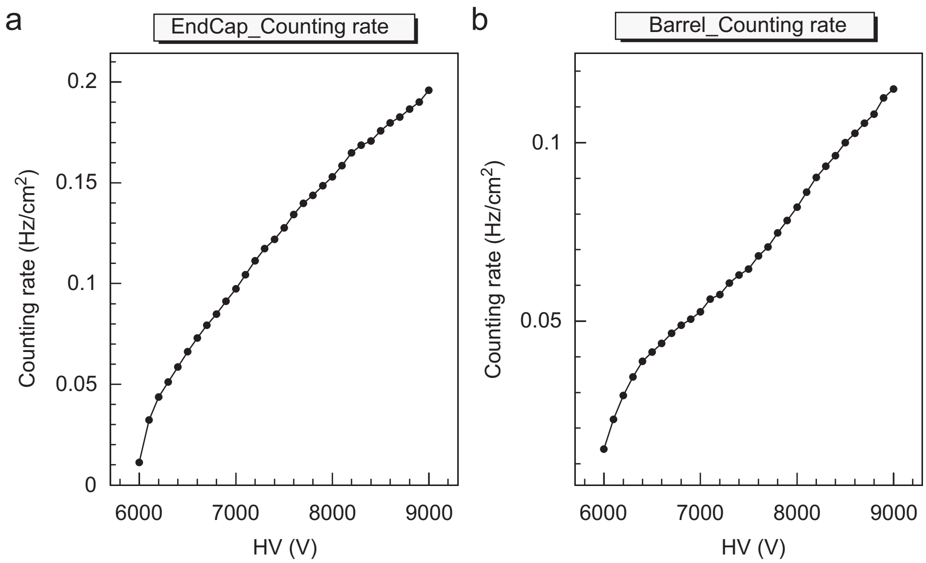

Fig. 6. The counting rate versus high-voltage curve of one end cap (a) and one barrel RPC (b).

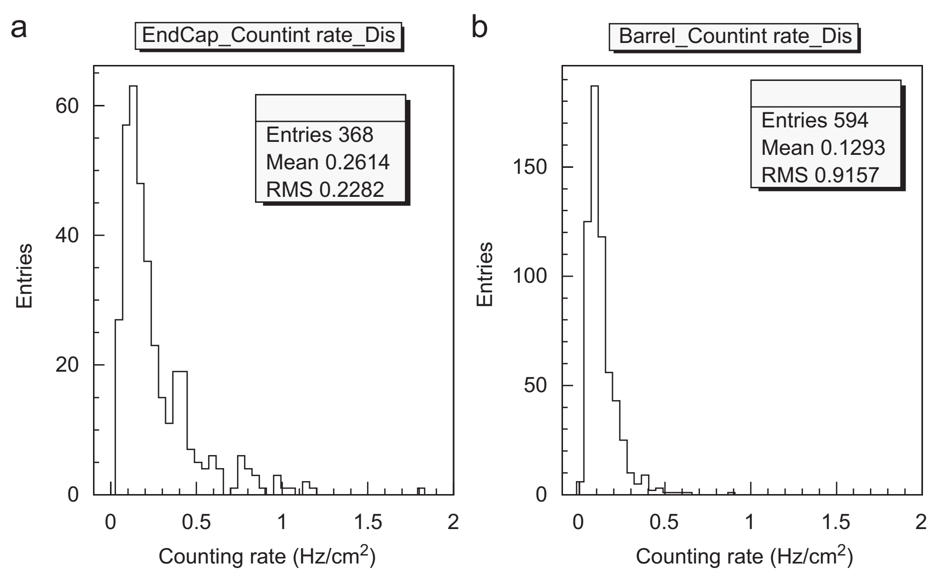

Fig. 7. The counting rate distribution at 8000 V of all end cap (a) and all barrel (b) RPCs, the counting rate of barrel RPCs are much smaller than that of the end cap RPCs.

area by the spaces, which can cover a maximum of 1.6% of the whole area.

5.2. Counting rate

Counting rate indicates the RPC's noise level, it is considered to be as low as possible. The bakelite resistivity and the surface smoothness and cleanness are all important factors for counting rate. During the test, it is found that the counting rate will decrease to a constant value during long-term high-voltage operation, sometimes the process could be as long as 1 month [3]. So, the RPCs for BESIII are not trained enough and it is foreseen that the counting rate will decrease during the running. The RPC's counting rate must be smaller than 1 Hz/cm^2 at 8000 V, or else the RPC will be rejected.

Fig. 6 shows the counting rate versus high-voltage curve of one end cap RPC (a) and one barrel RPC (b), and Fig. 7 shows the counting rate distribution at 8000 V of all end cap RPCs (a) and barrel RPCs (b). The counting rates of barrel RPCs are much smaller than that of end cap RPCs because the resistivities of barrel RPCs are much higher than end cap RPCs.

5.3. Dark current

Dark current is another important parameter for RPC performance. The current versus high-voltage curve is similar to the counting rate curve, and it is found that the

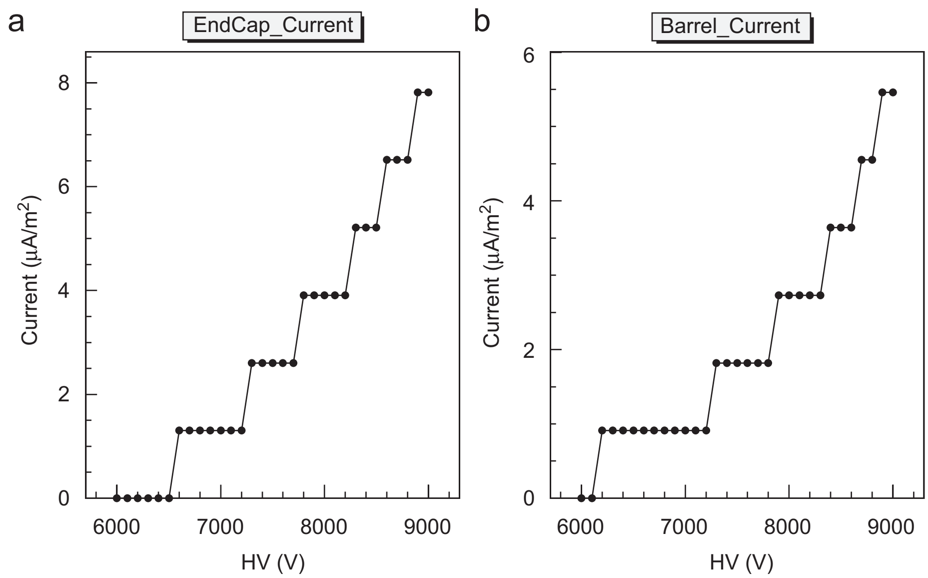

Fig. 8. The current versus high-voltage curve of one end cap (a) and one barrel RPC (b).

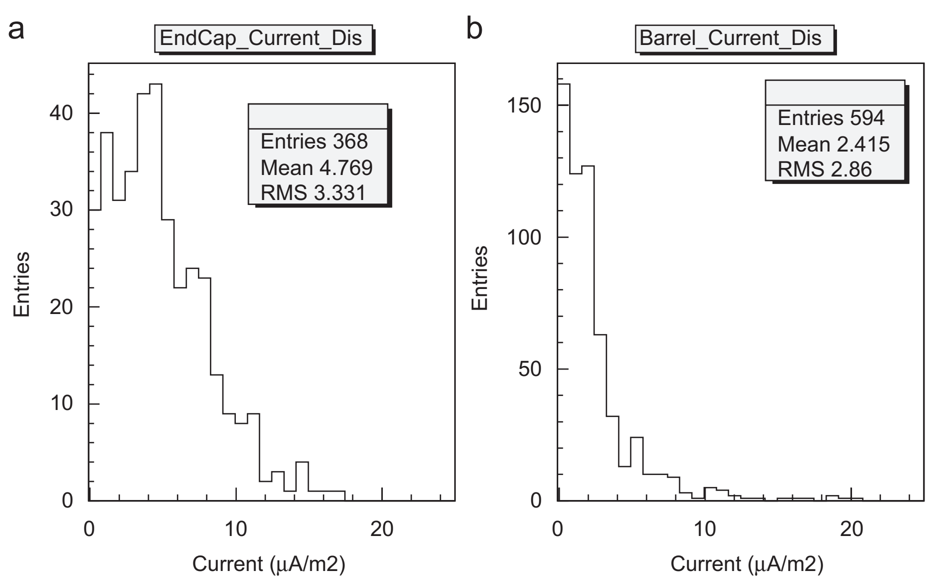

Fig. 9. The dark current distribution at 8000 V of all end cap (a) and barrel RPCs (b).

dark current could decrease during long-term operation too. Small dark current means little power supply needed, so the dark current is required to be as small as possible. The dark current at 8000 V must be smaller than 20 $\mu A/m^2$, the failed RPC will be rejected.

Fig. 8 shows the dark current versus high-voltage curve of one end cap RPC (a) and one barrel RPC (b), and Fig. 9 shows the dark current distribution at 8000 V of all end cap (a) and barrel (b) RPCs.

6. Conclusion

A substantial quality control procedure has been developed to certify the quality of RPC chambers during production. Each step during the production is well monitored and controlled. The production and testing of all the 374 end cap RPCs and 594 barrel RPCs have been finished, only five are rejected before cosmic ray test and nine are rejected during cosmic ray test, so the final rejection rate is only 1.5%.

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