RPC Experience: Belle, BaBar and BESIII

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In this article the performance and experience of three large RPC systems in the running/future experiments are summarized: Belle, BaBar and BESIII.

1. SURVEY OF LARGE RPC SYSTEMS IN RUNNING AND FUTURE EXPERIMENTS

In the following table G. Bruno has surveyed several large RPC systems in the running and future experiments[1]. There are few experiments missing from the table: The OPERA[2] experiment at Gran Saso; ARGO-YBJ[3] at Yangbajing International Cosmic Ray Observatory in China; BESIII[4] at BEPC, Beijing.

Table 1. RPC characteristics in running and future collider experiments.

Experiment	Operating mode	# gaps	Gap width(mm)	Electrodes material, ρ(Ωcm)	Gas mixture (%)	Readout
BaBar	Streamer	1	2	Oiled bak, $10^{11} \sim 10^{12}$	$60Ar/35C_2H_2F_4/5C_4H_{10}$	strips xy
Belle	Streamer	2	2	glass, $10^{12} \sim 10^{13}$	$30Ar/62C_2H_2F_4/8C_4H_{10}$	strips xy
ALICE TRI	Streamer	1	2	oiled bak., $\approx 3 \times 10^9$	$51Ar/41C_2H_2F_4/7C_4H_{10}/1SF_6$	strips xy
ATLAS	Prop.	1	2	oiled bak., $\approx 10^{10}$	$96.7C_2H_2F_4/3C_4H_{10}/0.3SF_6$	strips xy
CMS	Prop.	2	2	oiled bak., $\approx 10^{10}$	$96C_2H_2F_4/3.5C_4H_{10}/0.5SF_6$	strips x
STAR	Prop.	5	0.22	glass, $\approx 10^{13}$	$95C_2H_2F_4/5C_4H_{10}$	pads
ALICE TOF	Prop.	10	0.25	glass, $10^{12} \sim 10^{13}$	$90C_2H_2F_4/5C_4H_{10}/5SF_6$	pads

2. EXPERIENCE OF BELLE GLASS RPC[1]

2.1. Structure of the glass RPC

Belle's glass RPC[5] is a good example of glass RPC application in high energy physics experiment. Its structure is shown in figure 1.

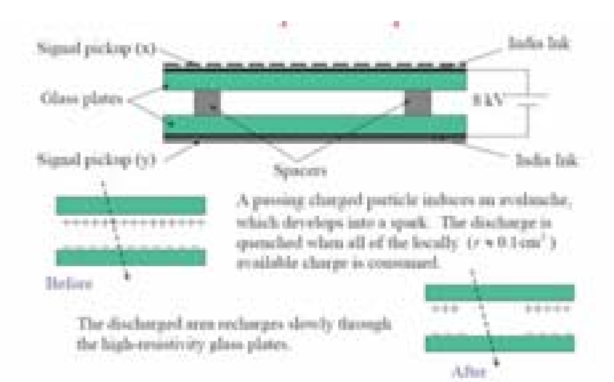

Figure 1. Belle's glass RPC.

2.2. Belle RPC's problem

[1] All figures and plots on Belle RPC are taken from D. Marlow's talk at NuMI Off-axisWorkshop and Eiichi Nakano's talk at IEEE, 2003.

In Summer 1998, the first signs of trouble showed up shortly after installation and looked something like the plot in figure 2. Some of the RPCs showed huge dark current increase and loss of efficiency. By the end of August, 1998 they decided to turn off HV for further investigation.

Large dark current is a serious problem in glass RPCs, it induces a significant IR voltage drop across the glass plates, which lowers the voltage across the gap, causing the chamber to slide off the efficiency plateau. Increasing the applied voltage doesn't help, since it merely results in increased dark current, which will further damage the chamber. As a result the chamber would enter "RPC Death Spiral".

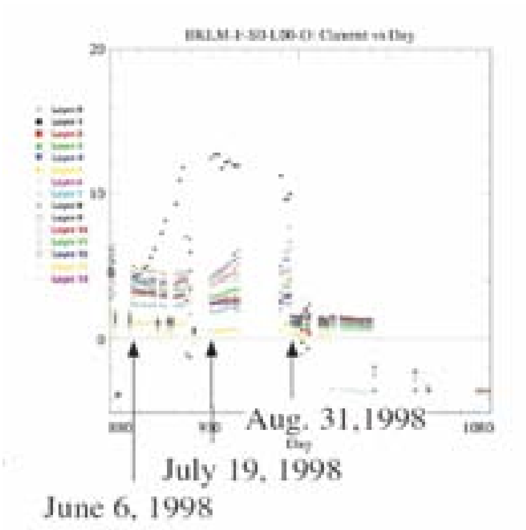

Figure 2. Dark current increased dramatically.

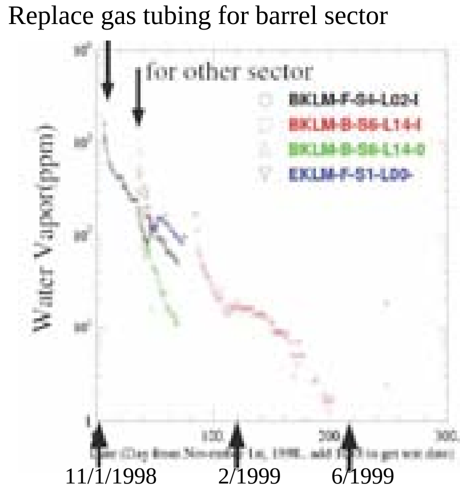

Figure 3. Humidity change after replacing the gas tubing.

2.3. Diagnostic and remediation

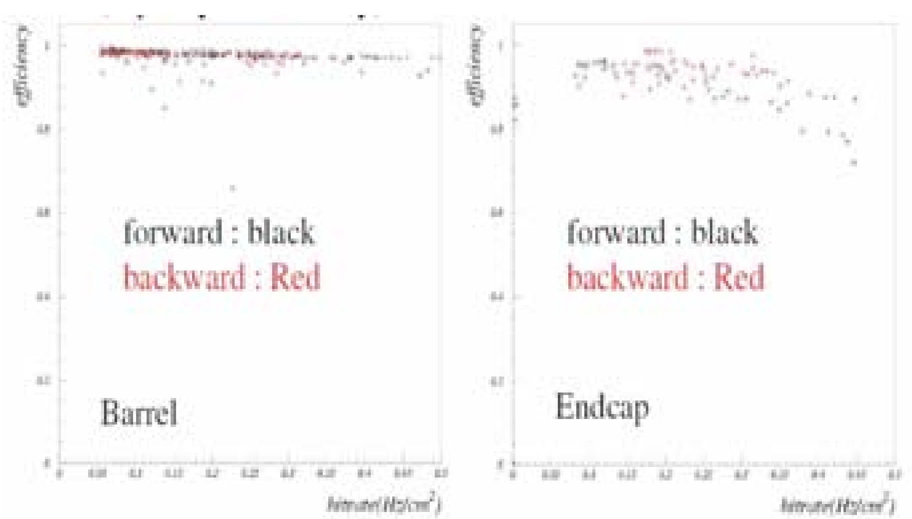

Figure 4. Efficiency shows the rate dependency.

After several weeks of study they determined that the problem was due to high levels of water vapor in the gas. The water was coming in through plastic (Polyflow) tubing. Actually the solution was (conceptually) simple: Replace the plastic gas lines with copper. Figure 3 shows the humidity dropping after the replacement of the tubing.

Three months later the relative humidity dropped to ~10ppm. The efficiency recovered, also the dark current returned to normal.

2.4. Rate limitation of the glass RPC

Figure 4 shows the efficiency vs. hit rate. The rate dependency can clearly be seen, especially for the endcap RPC. At present Belle, the hit rate for barrel is ~ 0.1 Hz/cm^2, for endcap is 0.1 ~ 0.3 Hz/cm^2. At SupperKEKB hit rate will rise: for barrel ~ 2 Hz/cm^2, for endcap 2 ~ 6 Hz/cm^2. From figure 4 the projection of the efficiency would be: for barrel ~ 90%, for endcap < 50%. Therefore glass RPC won't be a right choice for such application.

3. THE STORY OF BABAR BAKELITE RPC

BaBar RPC's experience has provided several important lessons to the Linseed-oiled Bakelite RPC [6,7]. Since BaBar RPC group revealed what they discovered in the autopsy of dead RPCs in summer, 1999, the aging of RPC becomes the focus of RPC study. So far some of previous black magic are no longer scaring people, but some of them still are.

3.1. Deterioration & Remediation

The main aging problems for BaBar Bakelite RPC chamber and their solutions are summarized in the following table:

RPC aging	Remediation
Uncured Linseed oil formed droplets and stalagmites in the gap.	Use thinner Linseed oil coating and thoroughly polymerize the oil film before apply HV; Better surface Bakelite, completely abandon the use of Linseed oil coating.
Vanished graphite coating on the bakelite electrodes after accumulated certain amount of charge through the Bakelite.	Better technology for making the graphite coating; Switch to the avalanche mode operation.
Resistivity increase of the Bakelite electrode with the total accumulated charge.	Add water vapor into the gas mix; Switch to the avalanche mode operation.

3.2. Autopsy of the bad RPC chambers

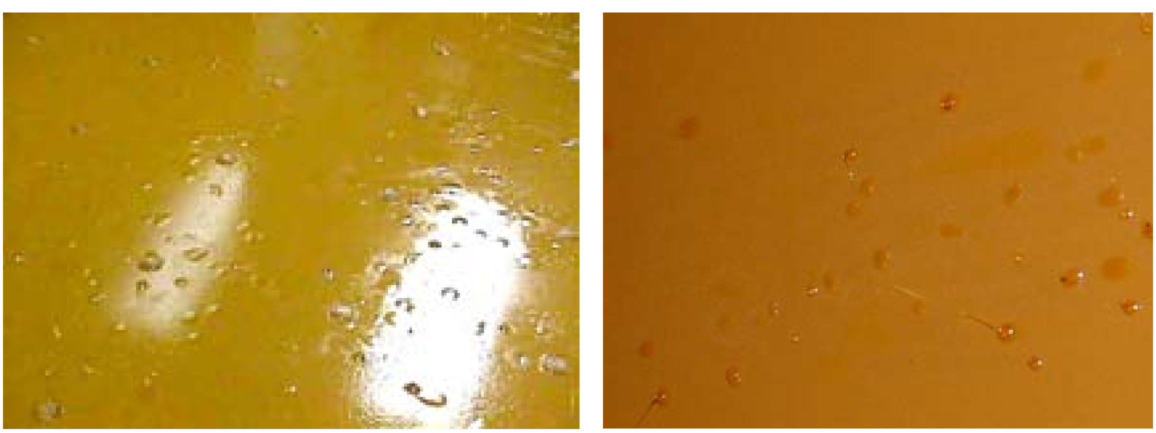

Figure 5. Surface image of an opened RPC electrode.

Figure 5 shows the electrode surface of an opened RPC. Linseed oil droplets can be clearly seen. They also found the stalagmites bridged the gap on some areas. The defected surface would form the low efficient or even dead spots.

3.3. Vanishing of the graphite coating

BaBar RPC group made a very interesting capacitance test that revealed a surprising fact: in a 3D plot for capacitance, efficiency and dark current, number of RPCs gathered at the corner of low efficiency, low dark current and low capacitance. That is just opposite to our previous experience: lower efficiency is a direct consequence of high dark current. Further study discovered that the low capacitance measured with a simple handheld capacitance-meter at the connector end of the high voltage cable is due to the high resistance in series with the capacitor formed by the electrodes. The discontinuity on the graphite paint film is the direct culprit of this extra large resistance. From some dead endcap RPCs BaBar RPC group has found strong support evidence: the original dark uniform graphite coating layer under the Mylar film became light and semitransparent looking.

3.4. Bakelite resistivity increase: adding water vapor

Many RPC groups have found that the resistivity of Bakelite electrode increases with the total accumulated charge flowing through the plate. BaBar new version of endcap RPCs clearly show the efficiency at the gas inlet region is worse than other area. They attribute this effect to the drying process at inlet region being most profound. Add water vapor into the gas mixture to maintain an adequate humidity inside of RPC is therefore advocated[8]. But the disadvantage is water vapor helps to form hydrofluoric acid, which could cause damaging of the inner surface.

4. A PROSPECTIVE GOOD NEWCOMER IN RPC FAMILY ─ BESIII RPC

Through several years R&D effort IHEP, Beijing has developed a new material for the RPC electrode. With this new type of Bakelite they can produce RPC without Linseed oil coating. The dark current and single's rate can reach the same level as Linseed oil coated RPC.

4.1. Study on IHEP's resistive electrode

Standard bakelite surface is made of a layer of fine paper impregnated with melamine or phenolic resin. IHEP Bakelite is covered by a layer of specially formulated plastic film. The prefabricated film laminated onto the surface of the phenolic paper plate to reduce the surface defects. The thickness of the film is 50 μm and the resistivity of the film can be customer-specified to optimize the performance of RPCs. In another word this film plays the role of Linseed oil coating, but is integrated into the fabrication of the Bakelite plate.

The morphological feature of IHEP and BaBar Bakelite surface under the atomic force microscope shows IHEP's sample is about three to four times smoother than BaBar's as shown in figure 6[2].

As we can see from the pictures that the feature surface morphological structures are: "pin-like" protrude; "ridge-like" long directional trace and longer wavelength wave. Linseed oil coating covers submicron surface imperfection. The author has performed some FEA calculations, which show that "pin" is the most serious surface defect in respect of the surface electric field variation. IHEP's Bakelite smoother surface may have its advantage in this regard, therefore they can abandon the oil coating on the inner surface.

[2] This work was done by Nan Yao, PRISM of Princeton University and the author.

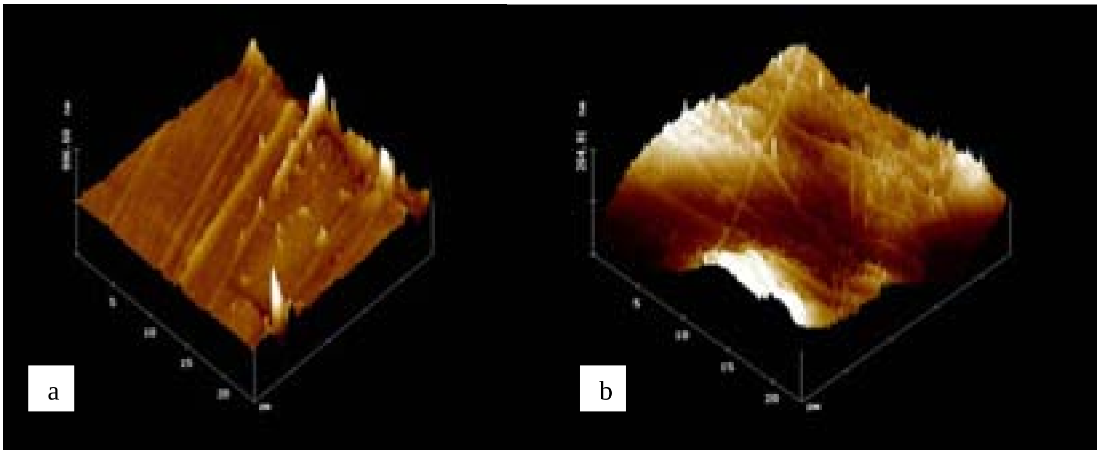

Figure 6. Bakelite surface under atomic force microscope: (a) BaBar sample; (b) BES III sample. Note the vertical scale in (a) is 966nm that is ~4 times larger than (b) 264nm.

4.2. Performance of IHEP RPCs

So far they have fabricated ~1000 RPCs for BES III, the average area for the endcap RPC is 1.3m^2, barrel RPC 1.4m^2. Maximum RPC they can make is 1.2m×2.4m. The performance of the tested 444 barrel RPCs[3] is summarized in figure 7. It is comparable to the oil-coated Bakelite RPC.

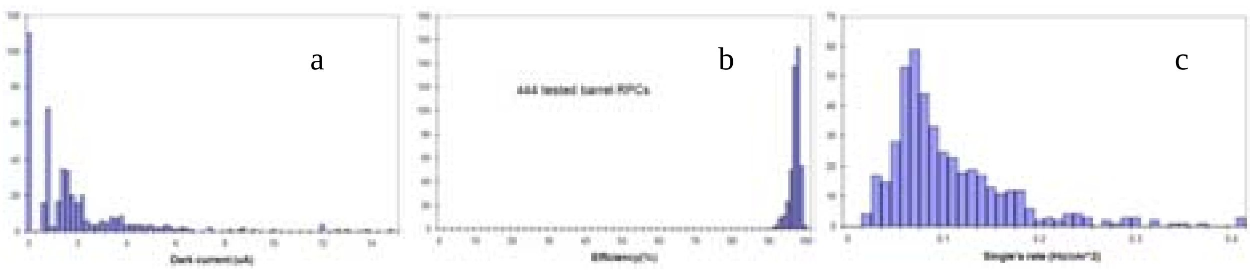

Figure 7. Statistics of the performance of BESIII RPCs: (a) Dark current; (b) Efficiency; (c) Single's rate.

4.3. Test BESIII RPC prototype at Princeton

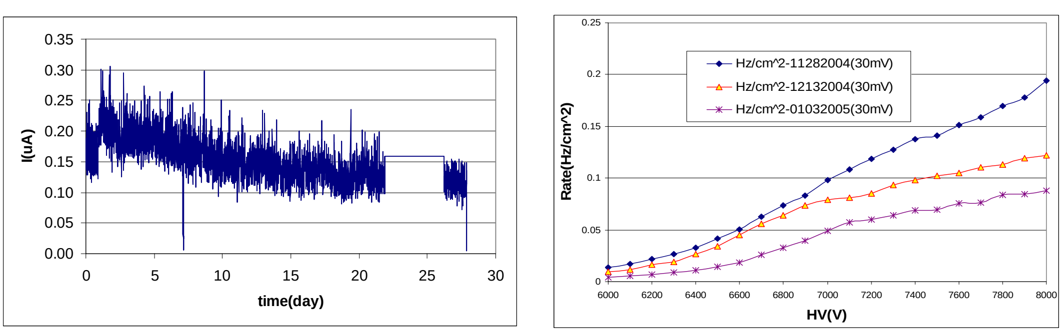

Figure 8. The evolution of the dark current and single's rate plateau during the high voltage training for a BESIII RPC prototype.

We have obtained a prototype RPC from IHEP, Beijing, and performed various tests. In figure 8 the evolutions of its dark current and single's rate plateau are shown. The area of this prototype is 50cm x 50cm. The tests show after

[3] By courtesy of Jiawen Zhang, IHEP, Beijing.

~ a month of HV training, the dark current has dropped to 0.5μA/m^2, and the single's rate at its plateau region is ~ 3 times cosmic ray background.

5. CONCLUSION

- Experience of BaBar and Belle RPC has provided valuable expertise on manufacturing and maintaining a large RPC system;
- Stimulated by the running experience of BaBar and Belle, the R&D effort in recent years, mainly due to CMS, ATALAS and ALICE at LHC, has made good progress in understanding the mechanism of RPC operation;
- RPC technology has various options to offer for different experimental circumstances;
- New type of RPC developed by IHEP, Beijing might be a good candidate for ILC muon detector and hadron calorimeter. It combines the advantages of glass smooth surface and Bakelite broad range of available resistivity. But still have a lot of R&D ahead to verify its longevity.

References

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