Aging Studies of 2nd Generation BaBar RPCs

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***Abstract*–The BaBar detector, operating at the PEPII B factory of the Stanford Linear Accelerator Center (SLAC), installed over 200 2nd generation Resistive Plate Chambers (RPCs) in 2002. The streamer rates produced by backgrounds and signals from normal BaBar running vary considerably (0.1->20 Hz/cm^2) depending on the layer and position of the chambers, thus providing a broad spectrum test of RPC performance and aging. The lowest rate chambers have performed very well with stable efficiencies averaging 95%. Other chambers had rate-dependant inefficiencies due to Bakelite drying which were reversed by the introduction of humidified gases. RPC inefficiencies in the highest rate regions of the higher rate chambers have been observed and also found to be rate dependant. The inefficient regions grow with time and have not yet been reduced by operation with humidified input gas. Three of these chambers were converted to avalanche mode operation and display significantly improved efficiencies. The rate of production of HF in the RPC exhaust gases was measured in avalanche and streamer mode RPCs and found to be comparable despite the lower current of the avalanche mode RPCs.**

I. Introduction

THE BaBar detector[1] collaboration installed over 200 2nd generation Resistive Plate Chambers (RPCs) as part of an upgrade[2] of the forward endcap muon and neutral hadron detector (IFR) in 2002. BaBar RPCs are constructed from Bakelite treated with linseed oil and operate in limited streamer mode, using a gas mixture of 4.5% isobutane, 60.6% argon and Freon 134a.

The original BaBar RPCs constructed in 1996-7 suffered from multiple problems[3]; increasing current and noise rates and declining efficiency. Many chambers were found to have incompletely cured linseed oil coatings. Other chambers contained construction debris from the drilling of the gas inlets. Finally, degradation of the graphite layer which distributes the HV on the outside of the Bakelite caused the complete failure of many RPCs.

The production of the 2nd generation chambers was carefully planned and monitored to eliminate many of these problem areas[2]. Molded gas inlets, improved graphite coatings[4], thinner linseed oil coatings, and stringent quality control procedures were implemented. Since these 2nd generation BaBar RPCs share many construction details with the LHC RPCs and will integrate comparable charge per unit area, their aging is of particular relevance to the world-wide RPC detector community.

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The forward endcap RPCs are installed in 16 layers with 12 HV modules per layer. Two HV modules are joined by pickup strips in one view and are connected in series into a single gas volume. The layers are numbered from the side closest to the interaction region as seen in Fig. 1. The average RPC efficiencies per chamber were measured by μ pairs during colliding beam data and periodically by cosmic ray runs. Chamber currents, streamer rates, gas flow, and temperature were recorded every 5 sec. into a conditions database. These data covering the time period from Nov. 2002 to Aug. 2006 allow BaBar to track changes in the RPC performance with time and to correlate changes in efficiency or current with environmental factors.

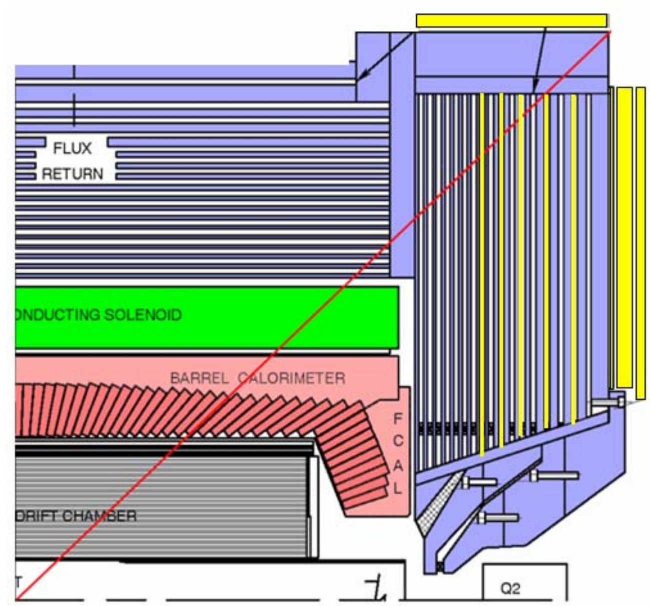

Fig.1.Quarter section view of the BaBar detector. During the upgrade in 2002 the RPCs in the forward endcap were replaced and additional brass and steel absorber was added. The RPC detector planes are numbered from left to right from 1 to 16.

The streamer rates produced by backgrounds and signals varied considerably (0.1->20 Hz/cm^2) depending on the layer and position of the chambers. In the inner layers (1-12) the chamber occupancy was highest around the beam line. Signal rates, currents, and occupancy were proportional to the PEPII luminosity and were typically 30 to 50 kHz per chamber in layer 1 with peak rates above 20 Hz /cm^2. The rates decreased with increasing layer number, reaching a minimum in layer 11 about 1/4 of the layer 1 rate. The rates in the outer layers (13-16) were sensitive to backgrounds from PEPII entering the outside of the endcap. The rates in 13-14 were typically ~2 Hz / cm^2. Rates in layers 15-16 were even higher (sometimes > 10 Hz/cm^2) and prevented normal operation of these layers

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until a shielding wall was installed in the fall of 2004. Two dimensional occupancies during a normal data run are shown in Fig. 2 for layers 1 and 14.

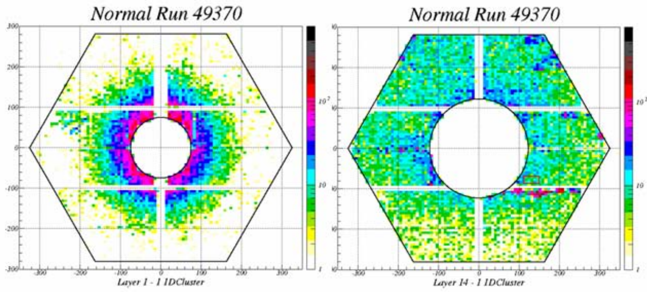

Fig. 2. Typical two-dimensional chamber occupancy for layers 1 and 14. Six HV modules make up each detector plane in each door and are numbered from 1 to 6 counting from the floor.

II. Current And Noise Rate History

Trends in the time evolution of the RPC HV current, noise rate, or efficiency were generally correlated with the observed noise rates and integrated charge. Since the noise rates varied with position, dividing the chambers into several groups based on RPC position was useful. Chambers exposed to low background and signal rates were generally stable. Thus RPCs in the top(6) or bottom(1) positions in the inner layers(1-12) were the most stable. The current history of the lowest RPC in Layer 1 is shown in Fig. 3. Only in the last 150 days was a small current increase seen.

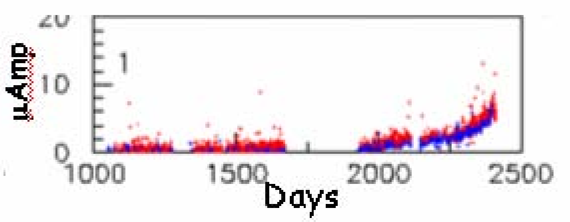

Fig. 3. Current history of Module 1 in east layer 1 is shown for the time period of Nov. 2002 to Aug. 2006. The red points are the current in µAmps with beam. The blue points are the current with no beam (cosmic ray backgrounds only).

RPCs in positions 3 and 4 around the beam-line had continually evolving currents and noise rates. The current history of RPC 4 in layer 1 is shown in Fig. 4. The difference between the red(beam) and blue(cosmic) curves reflects the high beam related signals seen during normal data taking. Large current increases were seen in many of these RPCs after only 6 months of running.

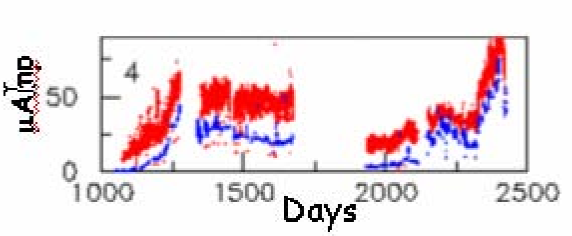

Fig. 4. Current history of Module 4 in layer 1 west is shown for the time period of Nov. 2002 to Aug. 2006. The red points are the current in µAmps with beam. The blue points are the current with no beam (cosmic ray backgrounds only).

III. Efficiency History

The efficiencies of chambers in positions 1 and 6 (signal and noise rates < 2 Hz/cm^2) were particularly stable. Fig. 5 shows the efficiency of the chambers in position 1 or 6 at five different times between installation in Nov. 2002 and Aug. 2006. The average efficiency of these chambers has remained about 95%.

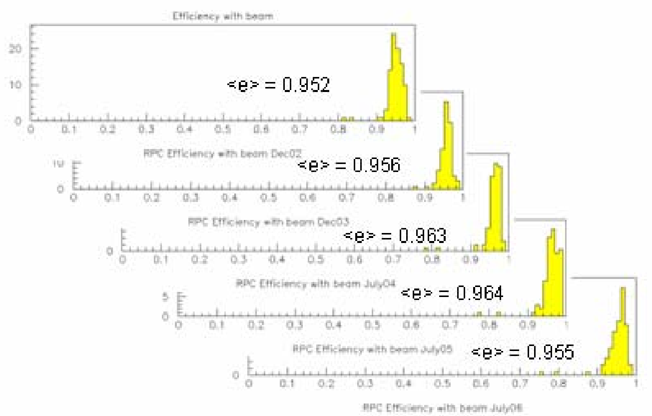

Fig. 5. Efficiencies of RPCs in positions 1 or 6 at Dec. 2002, Dec. 2003, July 2004, July 2005, and July 2006 measured by µ pairs in data.

In contrast the efficiencies of RPCs in positions 3 and 4 have declined with time. The efficiencies of these RPCs was measured in Dec. 2005 with muon pairs and plotted in Fig. 6. The average efficiency had dropped from 92% at the time of installation to 81%. There was a large spread in the measured efficiencies. The lowest efficiencies were in RPCs with poor gas flow. However, many RPCs with good gas flow had efficiency less than 80% under normal data taking conditions. When measured with cosmic rays the efficiencies of these chambers was near normal, indicating that the inefficiency was rate related.

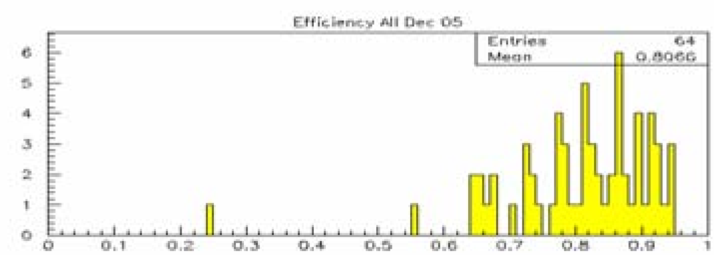

Fig. 6. Efficiencies of RPCs in positions 3 or 4 at Dec. 2005 measured by µ pairs in data.

Using a large sample of µ pair events the efficiency of each chamber was mapped in two dimensions. The region of low efficiency was found to coincide with the high rate ring around the beam-line as seen in Fig. 2. The efficiency is plotted as a function of the distance from the beam-line in Fig. 7. At small radii the efficiency is steadily decreasing with time.

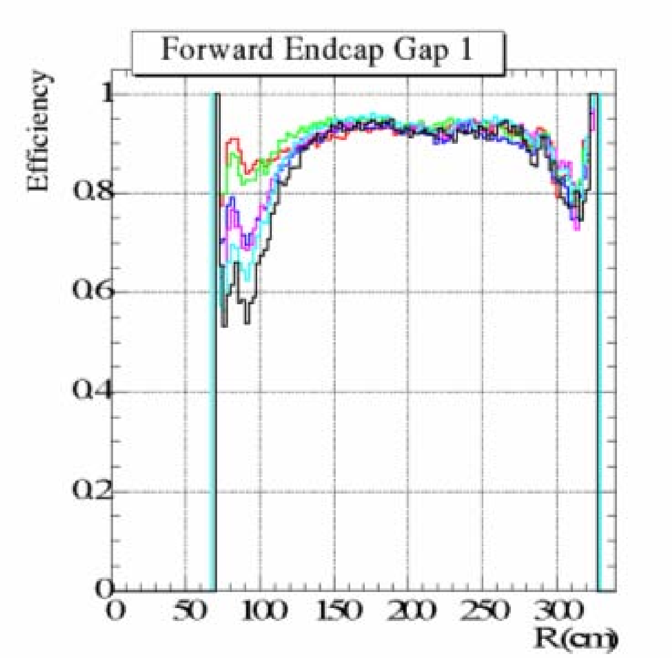

Fig.7. RPC efficiency as a function of r at several times (red shortly after installation, black July 2005). Deviations of the red curve from 94% at large and small radii are the result of geometric acceptance losses and are not evidence of RPC inefficiency

IV. Gas Humidity

Small inefficient regions were seen near the gas inlets of some chambers after several years of running. When layers 15 and 16 were turned on in 2005 much larger inefficient regions were seen as is evident in Fig. 8. These regions were observed in both RPCs with very small integrated running time and in RPCs that were on for all of the data taking in 2002-2005. Measurements with cosmic rays found good efficiency in all areas. Measurements of the relative humidity of the input gas (~0% RH) and the output gas (~30% RH) suggested that drying of the Bakelite as observed in ATLAS test beam RPCs[5] could be the cause.

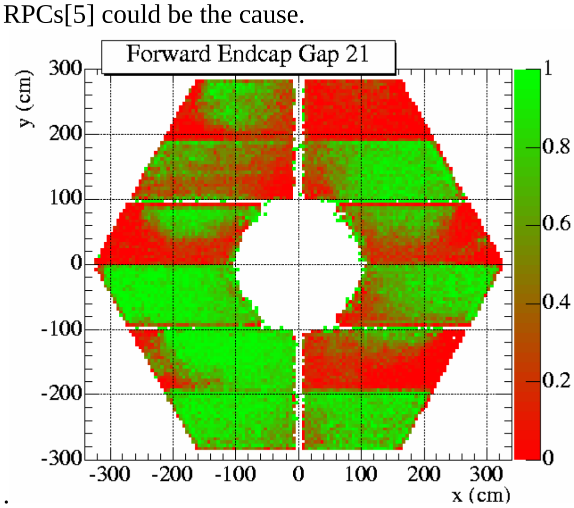

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Fig.8. Two dimensional efficiency of layer 16 measured in April, 2005.

A system to add water to the input gas stream was tested on a subset of forward RPCs in 2005. As shown in Fig. 9 after several months of humidified gas (~33% RH) the efficiency was much improved. During the 2005 fall access all forward RPCs were put on humidified gas. However, the inefficienct areas at small radii did not recover with the introduction of humidified gases.

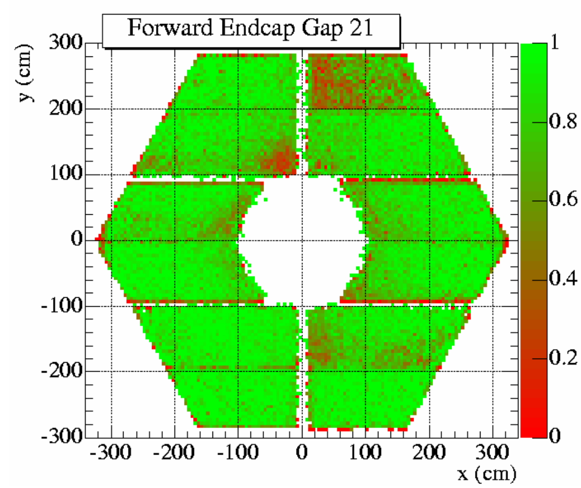

Fig.9. Two dimensional efficiency of layer 16 measured in Aug., 2005 after nearly 4 months of operation with humidified input gas.

V. Avalanche Mode Operation

The RPCs with efficiency loss at small radii are of grave concern for several reasons, not only was the declining efficiency unaffected by the gas humidification , but projection of the integrated charges expected at small radii for the rest of BaBar data-taking exceeded 1 C/cm^2 , well above the damage thresholds for the RPC graphite[4]. Reversal of the HV in 2005 presumably extended the life of the graphite layers by degrading both the anode and cathodes but could not prevent further damage. For these reasons it was decided to test several chambers in saturated avalanche mode which was expected to dramatically reduce the charge per track.

Three middle chambers in the east door were converted to avalanche mode operation in Nov. 2005. Charge preamps were installed to boost the signal into the normal front end electronics. The gas mixture was changed to 4.5% isobutane, 22.0% argon, 72.9% Freon 134a and 0.6% SF6. The chambers typically were run at 9500 Volts. Tests to date are very encouraging. As shown in Fig. 9 the efficiency at small radii was much improved. Also the total current drawn by the chamber is reduced by a factor of 4. BaBar will convert the highest rate RPCs in layers 1-8 to avalanche mode in the summer 2006.

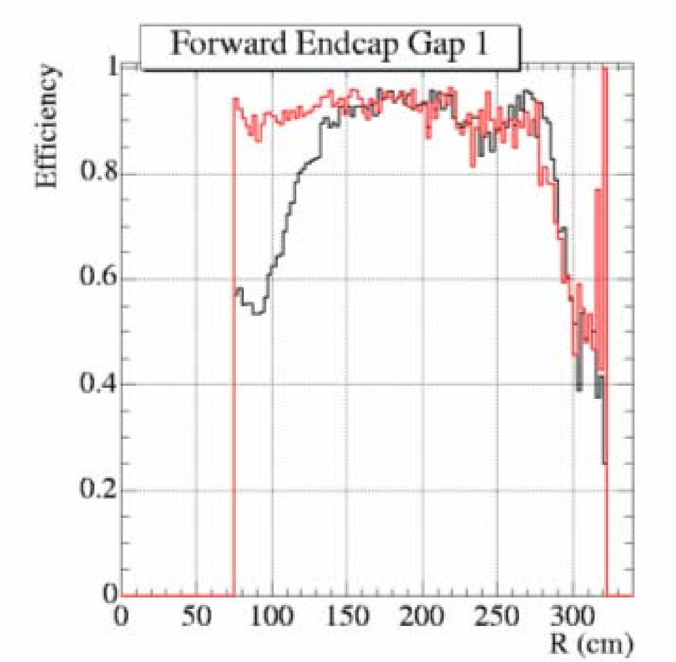

Fig.9. RPC efficiency as a function of r when the middle east chamber of layer 1 was operating in streamer mode (black) and in saturated avalanche mode (red).

VI. Fluorine Studies

One of the early BaBar observations of RPC aging[6] suggested that pollutants produced in the gas in the highest rate areas were being transported to other regions and producing increased noise rates. One candidate for a gas-born pollutant is HF which can be produced by the disassociation of the Freon component in the RPC gas. F^- ions in the RPC exhaust gas have been measured by ATLAS RPC aging studies[7] and by BaBar[8]. The RPC exhaust gas was bubbled through a mixture of TISAB and water. A fluorine specific ion probe measured the F^- concentration as a function of time. No free F^- ions were measured in the RPC input gas. Studies showed that the F^- was collected with > 95% efficiency. Other studies measured the acidity of a water solution versus time and found that the measured F^- ions in the RPC exhaust gas were consistent with HF production .

The lower charge per track of RPCs operated in avalanche mode compared with RPCs operated in streamer mode suggests that less F^- is produced in avalanche mode. Measurements were made of the F^- production rate in two typical RPCs, one operating in streamer mode and the other operating in avalanche mode. Since the F^- rate depends on the chamber noise rate, the amount of F^- production in a day is plotted against the integrated RPC HV current in Fig. 10 for the two RPCs. The F^- production rate for the streamer chamber was 1.42 ± 0.11 μmole/Coulomb. The F^- production rate for the avalanche chamber was 3.82 ± 0.23 μmole/C. The avalanche chamber produces more F^- per unit charge than the streamer chamber. However, since the average charge per track is 4 times less for the avalanche RPC the relative F^- production rates for streamer and avalanche RPCs were found to be similar.

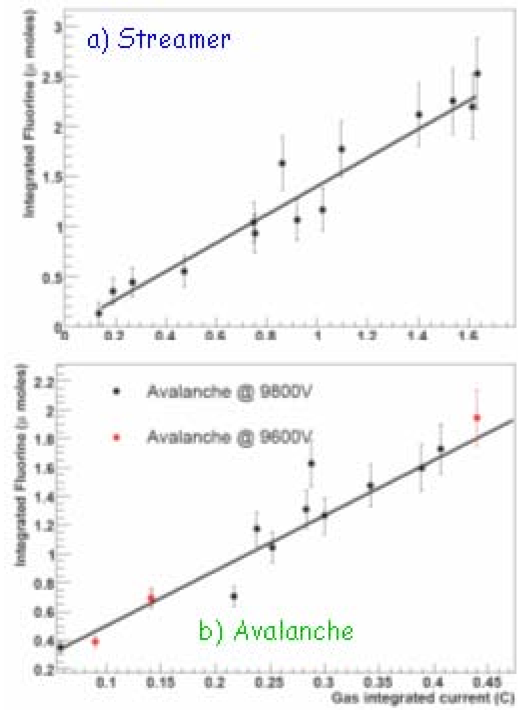

Fig.10. The integrated fluorine production in μmoles per day is plotted against the integrated HV current for that day. The current is corrected for bulk resistance effects to represent the current due to the gas gain. The streamer data in a) are fit by a linear dependence of 1.42 ± 0.11 μmole/C. The avalanche data in b) are fit by a linear dependence of 3.82 ± 0.23 μmole/C.

As described in an earlier section the ohmic current of some RPCs has increased with time. Since ATLAS[5] studies measured a reduction in the ohmic current after processing the RPCs with argon (which removed F^- from the RPC surface), it seemed likely that chambers with high ohmic currents have large amounts of F^-. A series of F^- measurements was made of RPCs after the end of data taking in Aug., 2006 to test this hypothesis. However, no correlation was found between the measured F^- rate in the exhaust gas and the ohmic current of the RPC.

VII. Summary

At low signal and background rates the 2^{nd} generation BaBar RPCs have proven to be reliable and stable muon detectors, maintaining an average efficiency of 95%. At higher rates several different problems have emerged. Moderate rate regions are sensitive to the resistivity of the Bakelite which can be controlled by adding water to the input gas. The highest rate regions have shown efficiency losses that were not recovered by raising the input gas humidity. After promising tests with RPCs converted to avalanche mode operation, BaBar plans to convert the highest rate RPCs to avalanche mode operation. Tests showed that the F^- production rates in streamer and avalanche RPCs are comparable for the gases used in BaBar.

Acknowledgment

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