Talk at SLAC
January 25,2003

Some comments about the BaBar RPC experience. What to do next?

J. Va'vra

Content

- Touch some basic principles.

- Particle rates in BaBar.

- Facts: Problems encountered in BaBar and Belle RPC chambers.

- Discussion of problems.

- Conclusion.

References

- Original RPC references:

R. Santonico and R. Cardarelli., Nucl. Instr. & Meth., 187(1981)377.
R. Santonico and R. Cardarelli., Nucl. Instr. & Meth., A263(1988)20.
R. Santonico, Scient. Acta XII N2(1997)1.

- Other references:

I. Crotty et al., Nucl. Instr. & Meth., A337(1994)370.
R. Cardarelli., V. Makeev and R. Santonico, Nucl. Instr. & Meth., A382(1996)470.
R. Arnaldi et al., Nucl. Physics B (Suppl) 78(1999)84.
M. Abbrescia et al., Nucl. Instr. & Meth., A431(1999)413.
M. Abbrescia et al., Nucl. Instr. & Meth., A394(1997)13.
P. Camarri et al., Nucl. Instr. & Meth., A414(1998)317.
G. Aielli et al., submitted to Nucl. Instr. & Meth. June 2002.
A. Sharma, CERN Detector Seminar, Nov. 22, 2002.

- BaBar references:

Ch. Lu et al., VI RPC Workshop, Coimbra, Portugal, November 26 – 27, 2001.
F. Anulli et al., IEEE Trans. Nucl. Sci., San Diego, CA, USA, November, 2002.

- Belle references

D. Marlow, Princeton Univ., Rice University Seminar, July 9, 1999.
D. Marlow, "B-Factories," The9-th Vienna Wire Chamber Conference, Feb. 23, 2001.
M. Ueki, Tohoku University Master's thesis, Jan. 1999.
K. Abe et al., IEEE Trans. Nucl. Sci., Norfolk, USA, November, 2003.
H. Sakai et al., Nucl. Instr. & Meth., A484(2002)153.

- My work on this problem (a 2000-2003 period):

J. Va'vra, http://www.slac.stanford.edu/~jjv/activity/my_rpc_conclusions.pdf.
J. Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary.pdf.
J. Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf.
J. Va'vra, http://www.slac.stanford.edu/pubs/icfa/spring02/paper1/paper1a.html.
J. Va'vra, "Physics and Chemistry of Aging – Early Developments", DESY Aging Workshop, 2000,
To be published in Nucl. Instr. & Meth.

Major RPC systems

L3 - finished.
- Streamer mode
- High resistance Bakelite & "old" Linseed oil BaBar treatment
- Rates consistent with the cosmic ray rates

Belle - in progress.
- Streamer mode
- Float glass
- Rates up to 10-20 Hz/cm^2
- 2000m^2

<u>Streamer mode</u>:
~200mV pulses

<u>Proportional mode</u>:
~10mV pulses

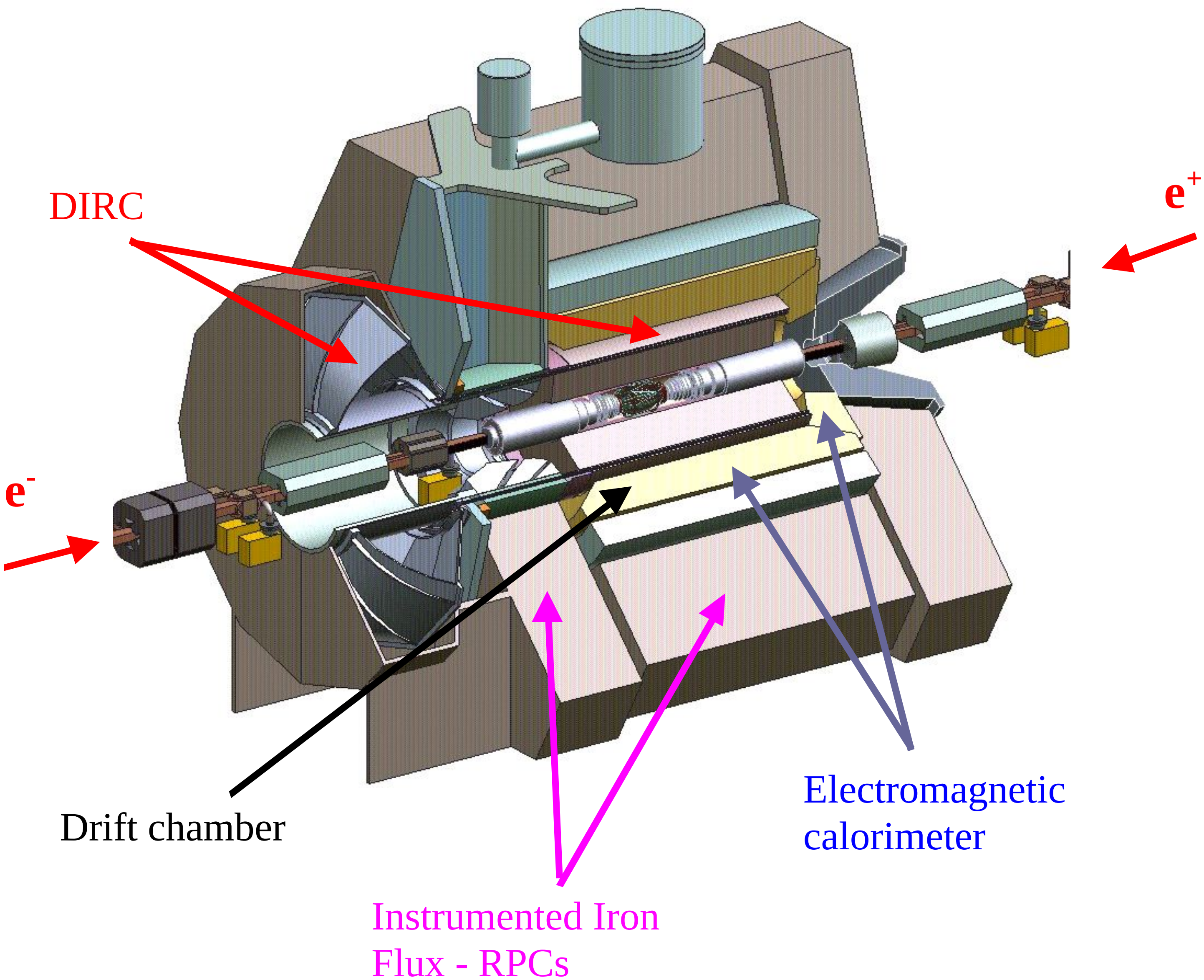
BaBar - in progress.
- Streamer mode (~1000pC/track deposit)
- High resistivity Bakelite with Linseed oil
- Rates up to 10-20 Hz/cm^2
- 2000m^2

Atlas - planned.
- Proportional mode (<1% probability to have a streamer)
- Low resistivity Bakelite & "new" Linseed oil BaBar treatment
- Rates up to 1kHz/cm^2
- 7000m^2

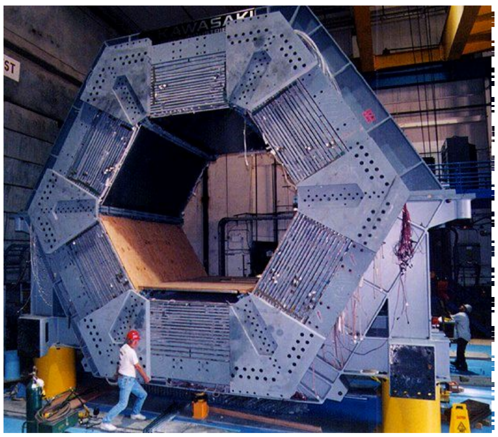
CMS - planned.
- Proportional mode (<1% probability to have a streamer)
- Low resistivity Bakelite & "new" Linseed oil BaBar treatment
- Rates up to 1kHz/cm^2
- 6000m^2

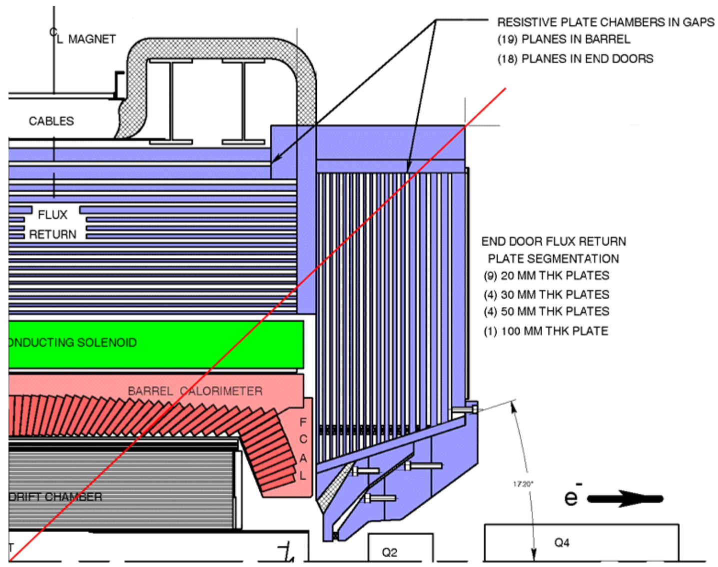
Non-accelerator experiments.

BaBar Detector



BaBar iron absorber design:





BaBar:

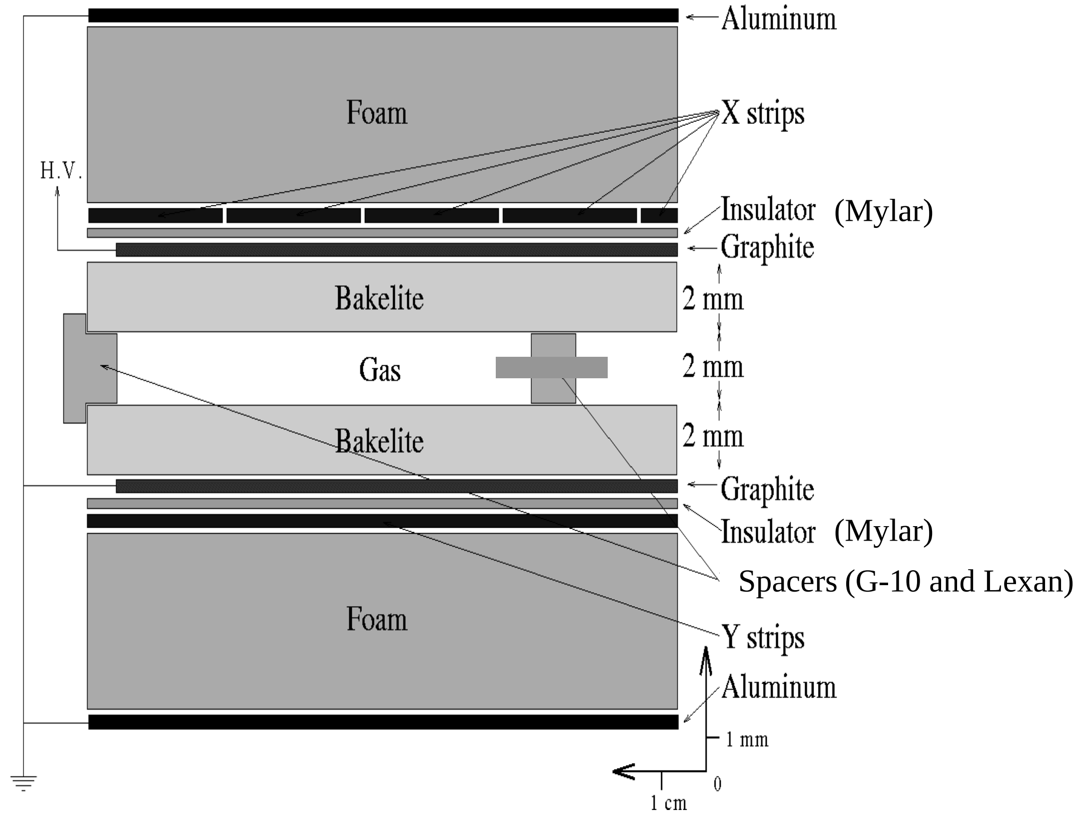
- 774 RPC chambers (342 in barrel and 432 in endcaps),
- Total area covered: ~2300 m^2,
- 18 layers,
- single-gap RPC design in each iron gap,
- 18 layers of iron,
- Total iron thickness: ~55cm,

(however, the last 10cm is lost because the layer 18 does not work).

Belle for comparison:

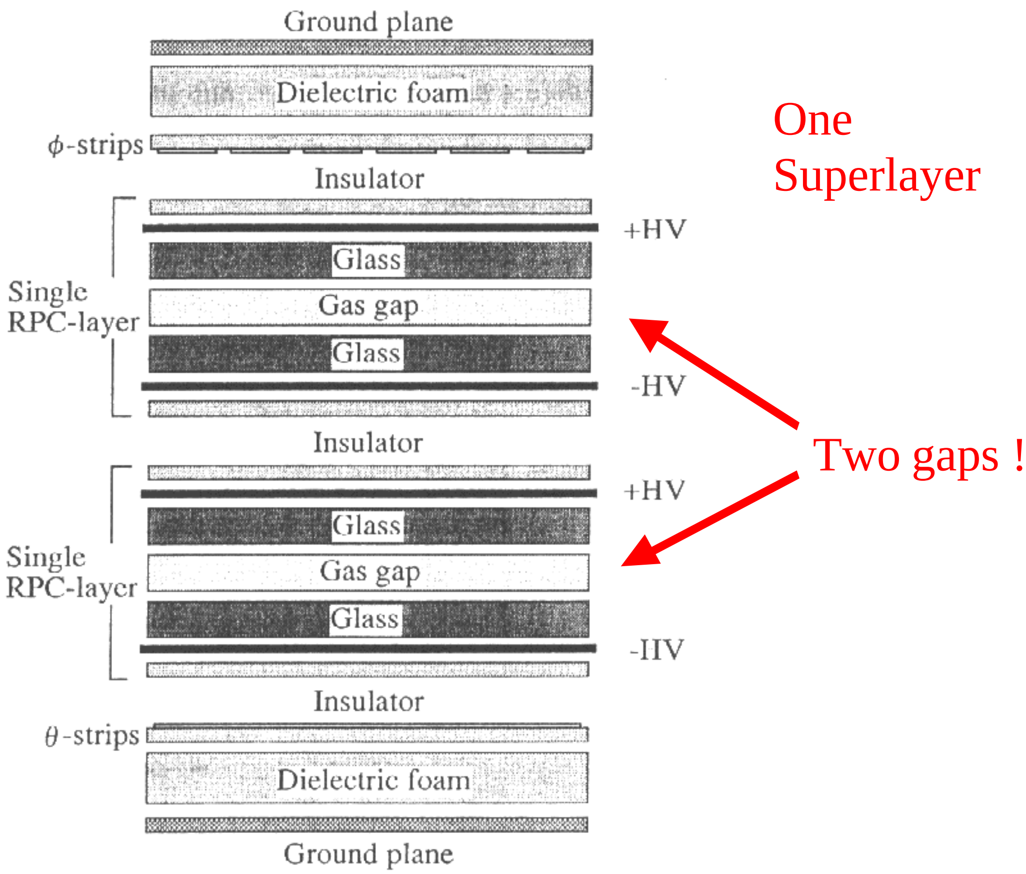
- 14 layers of iron, each 4.7 cm thick,
- Total iron thickness: ~66 cm.

BaBar RPC chamber design:



- G-10 side spacers, Lexan button spacer ($\rho_V \sim 10^{13}$ Ωcm).
- Bakelite electrodes volume resistivity: $\rho_V \sim 10^{11}$-10^{12} Ωcm.
- Graphite surface resistivity: ρ_S ~100 kΩ/®.
- RPCs filled 3-times with Linseed oil/n-pentane (70:30 mix); flushed with air for 60 hours after each filling.
- 60.6% Ar + 34.7% $C_2H_2F_4$ + 4.7%C_4H_{10} (since June 2000),
- gas flow: 2 volumes per day (20-30cc/min).
- Streamer mode operation: ~1000pC/track deposit.
- Spatial resolution ~1cm.
- Each slot has only single RPC layer (a big mistake!).
- Electronics has 53000 channels; threshold ~40mV.
- The RPCs are very simple devices, and cheap.

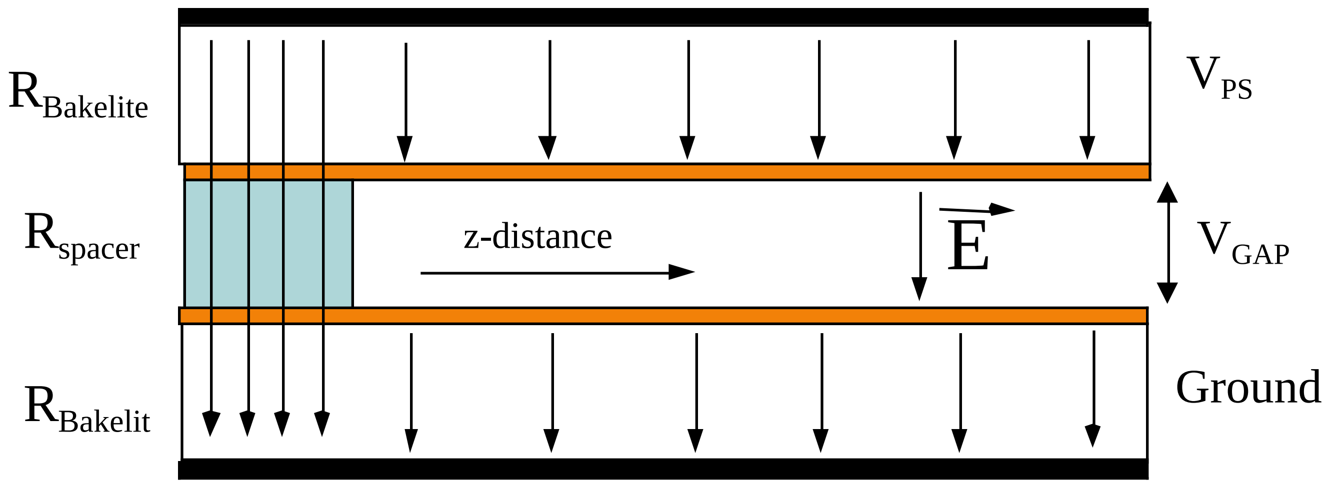
Belle RPC chamber design:



- Noryl spacers ($\rho_V > 10^{13}$ Ωcm).
- Float glass electrodes volume resistivity: $\rho_V \sim 10^{12}$-10^{13} Ωcm.
- 30% Ar + 62% $C_2H_2F_4$ + 8%C_4H_{10}.
- Streamer mode operation.
- Strip widths: 4.3-5.5cm (Barrel) and 1.86-3.6cm (Endcap).
- Gap width: 2mm.
- Each steel slot has a superlayer containing two independent RPC layers.
- Electronics has 37984 channels.

"Ohmic" model of BaBar RPCs:

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/my_rpc_conclusions.pdf.)



- Volume resistance:

Lexan button ("properly" coated with the Linseed oil):

$$\rho_V \sim 1.7\text{x}10^{11}\ \Omega\text{cm}$$

Bakelite:

$$\rho_V \sim 2.5\text{x}10^{11}\ \Omega\text{cm.}$$

- Equivalent resistances for the BaBar geometry:

$R_{Bakelite} = \rho_V\ (t_{gap}/\text{Area}) \sim 5\text{x}10^8\ \Omega$, and

$R_{Lexan\ button} = \rho_V\ (t_{gap}\ /\ \text{Area}) \sim 3.4 \text{ x } 10^{11}\ \Omega$.

- The gap voltage for these parameters:

$$V_{GAP} = V_{PS} / (1 + 2R_{Bakelite} / R_{Lexan\ spacer}) \sim V_{PS}.$$

- To satisfy $V_{GAP} \sim V_{PS}$, we should have $R_{Lexan\ spacer} >> R_{Bakelite}$.

For example, a factor of 60 increase in $R_{Bakelite}$ gives:

$$V_{GAP} \sim 0.85 \text{ x } V_{PS}.$$

Discussion of gas filling.

Requirements:

a) Electronegative, i.e., large electron capture cross-section.
(This is needed to keep the streamer from spreading transversally).

b) A good UV photon absorber.
(This is needed to limit the growth of the multiple streamers).

c) Non-flammable.

d) Gas under normal operating condition.

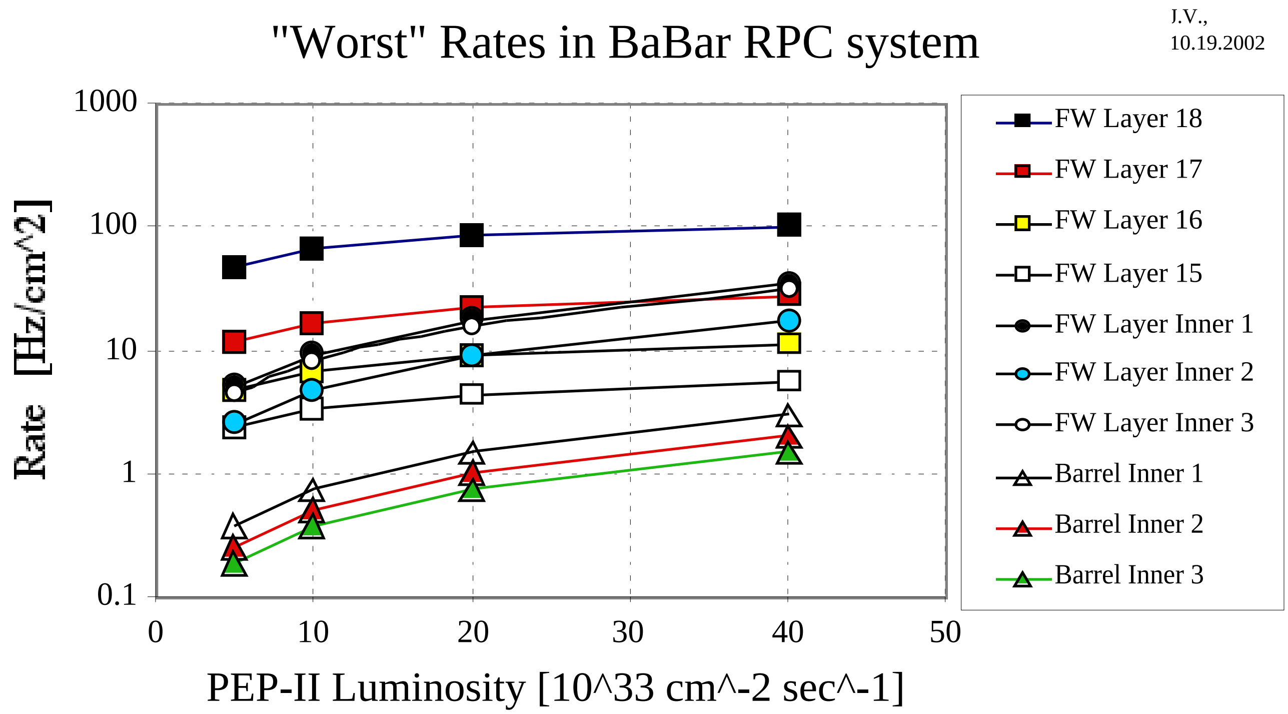
e) Environmentally friendly.
(Good from the global warming point of view).

- Global warming potential:

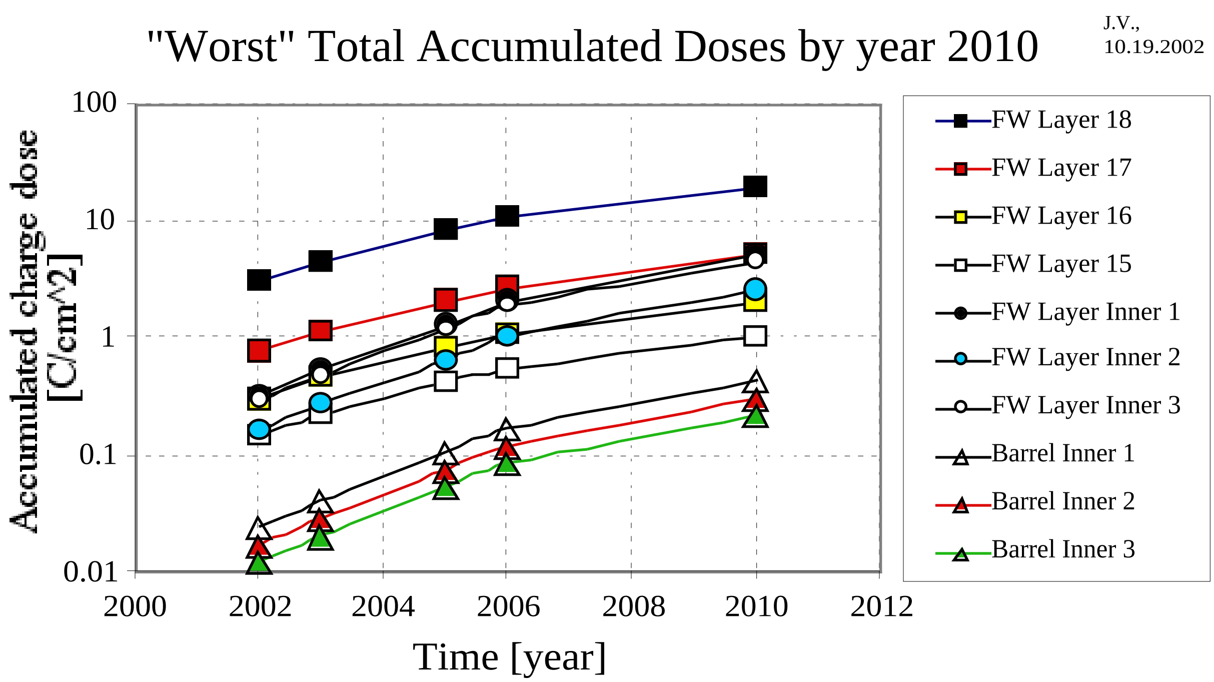
Gas	Global Warming Potential
CO_2	1
$C_2H_2F_4$	1300
SF_6	24900
90%Ar+9%C_4H_{10}+1%SF_6	249
30%Ar+8%C_4H_{10}+62%$C_2H_2F_4$	806

Expected rates and charge doses in BaBar

J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/my_rpc_conclusions.pdf.



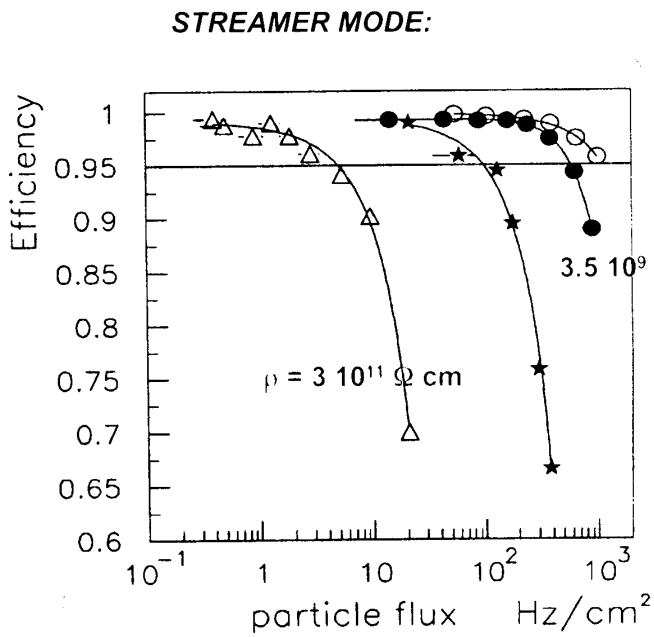
Assuming a charge deposit of ~1000pC/track, one obtains:

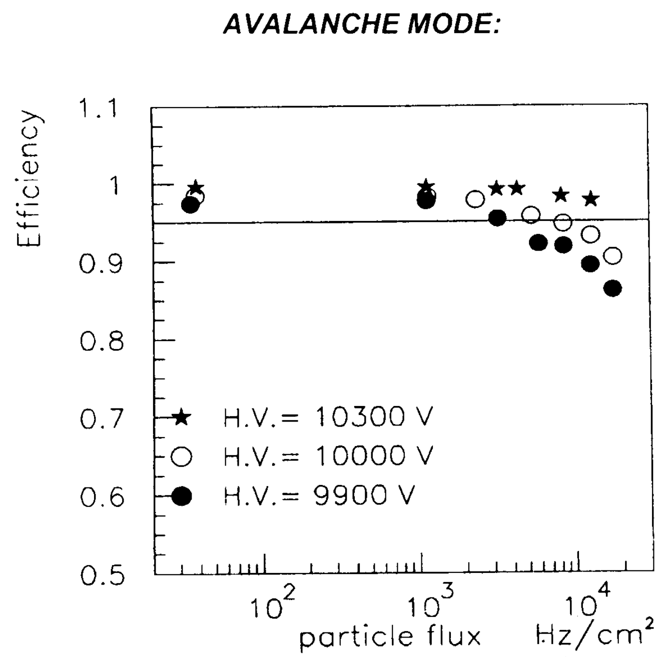


- Barrel layers have very low rates, but not so outer FW Endcap!

How rate affects the efficiency

R. Arnaldi et al., Nucl. Physics B (Suppl) 78(1999)84.





Pestov glass:	10^9-10^{10} Ωcm
Bakelite:	10^{10}-10^{11} Ωcm
Borosilicate (float) glass:	10^{13} Ωcm

- A local sparking at a rate of >20Hz can get you into a trouble, if you operate in the streamer mode. The sparking can occur near buttons or edges or next to whiskers. With a float glass, this is even bigger problem. Some Belle FW RPCs are shut down. The same is true for BaBar.

- Some FW Endcap BaBar chambers get into trouble at present BaBar background rates.

Chronology of bad events at BaBar:

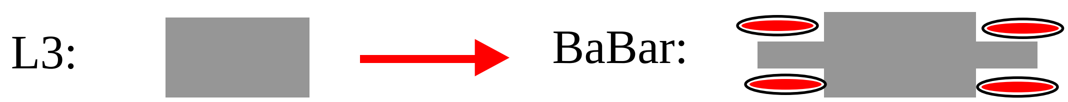
1. Old chambers (original recipe):

A general comment:

a) Not much QC, pretty much rely on the company.
b) Use a high resistivity Bakelite (ρ_V ~10^{11}-10^{12} Ωcm).
c) G-10 side spacers and Lexan buttons defining a 2mm gap.
d) Three applications of the Linseed oil with npentane solvent.

Problems definition:

- Initial efficiency in Frascati and at SLAC was good.
- RPCs were subject to higher temperature at BaBar (30-35°C).
- Chambers started to draw large currents at higher temperature.
- BaBar RPC has buttons trapping uncured Linseed oil:

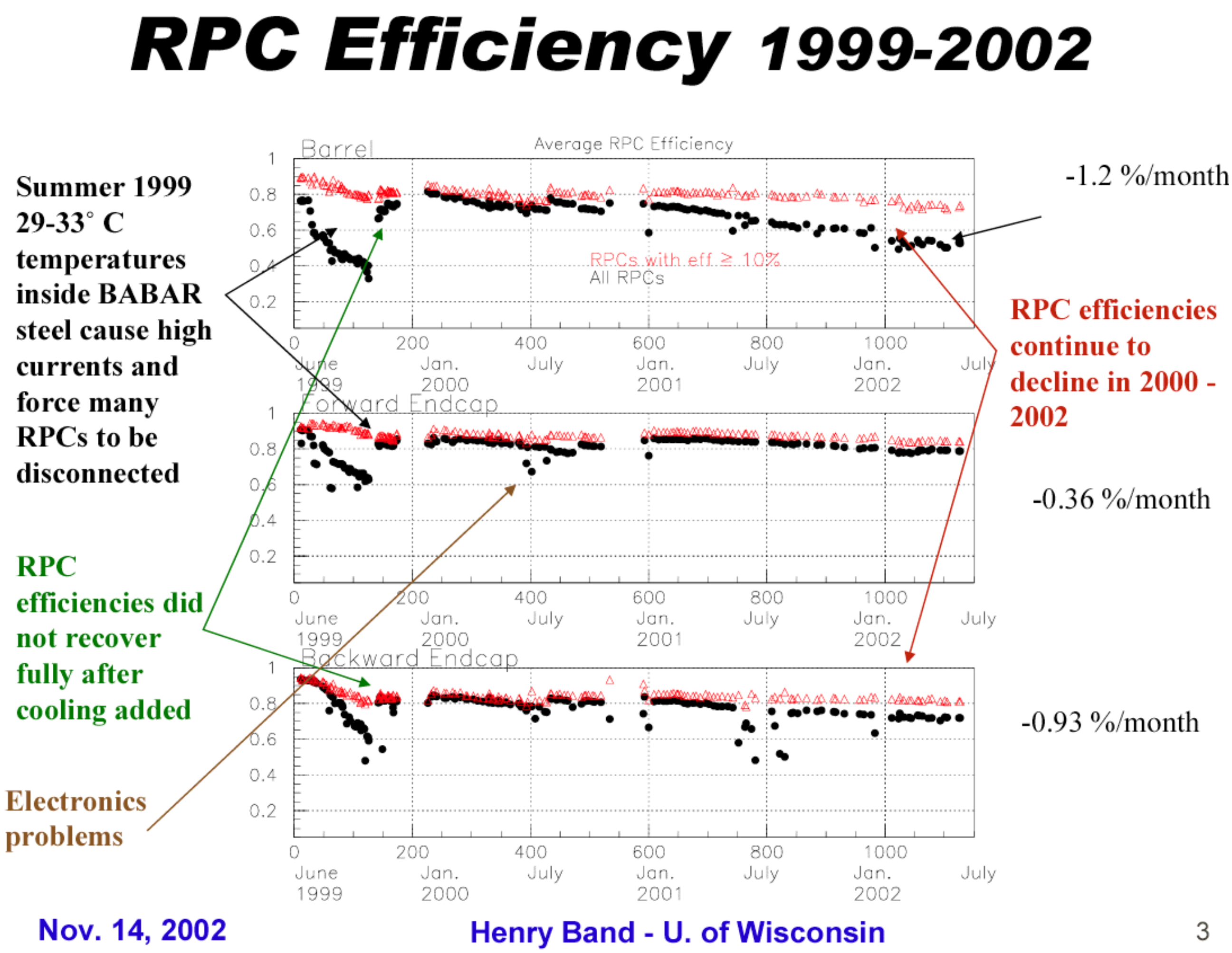


- At higher temperature the Linseed oil leaked out into the active region, thus compromising the anode-cathode gap.
- Oily droplets at the cathode initiated the Corona emission and sparking.
- Whisker formation under high voltage with wet oil.
- Rate of any chemistry is also higher at elevated temperature.
- Wet Linseed oil has low volume resistance, thus there were some voltage divisions of the gap voltage.
- Electrostatic forces acting on the wet Linseed oil created stalagmites or generally rough surface.

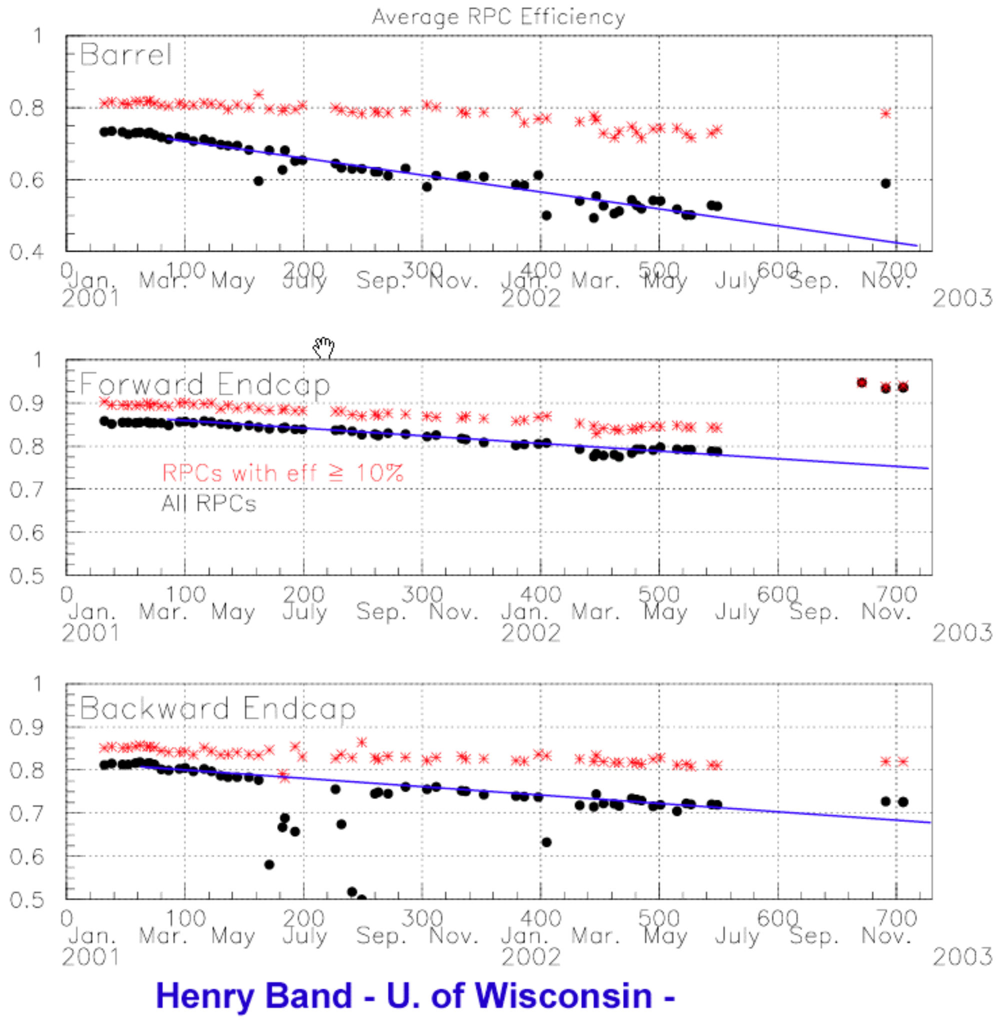
- When the temperature was reduced, the damage was already done. The chambers continued to draw larger currents and they would show poor efficiency, which is still decreasing.

- Some dust because of drilling in the active volume.

- There was one unfortunate mistake:
  Instead of insisting to stop running, as Belle RPC group when they experienced difficulties, the BaBar RPC group continued operation even during this condition. This was because they were under a heavy pressure from the BaBar management.



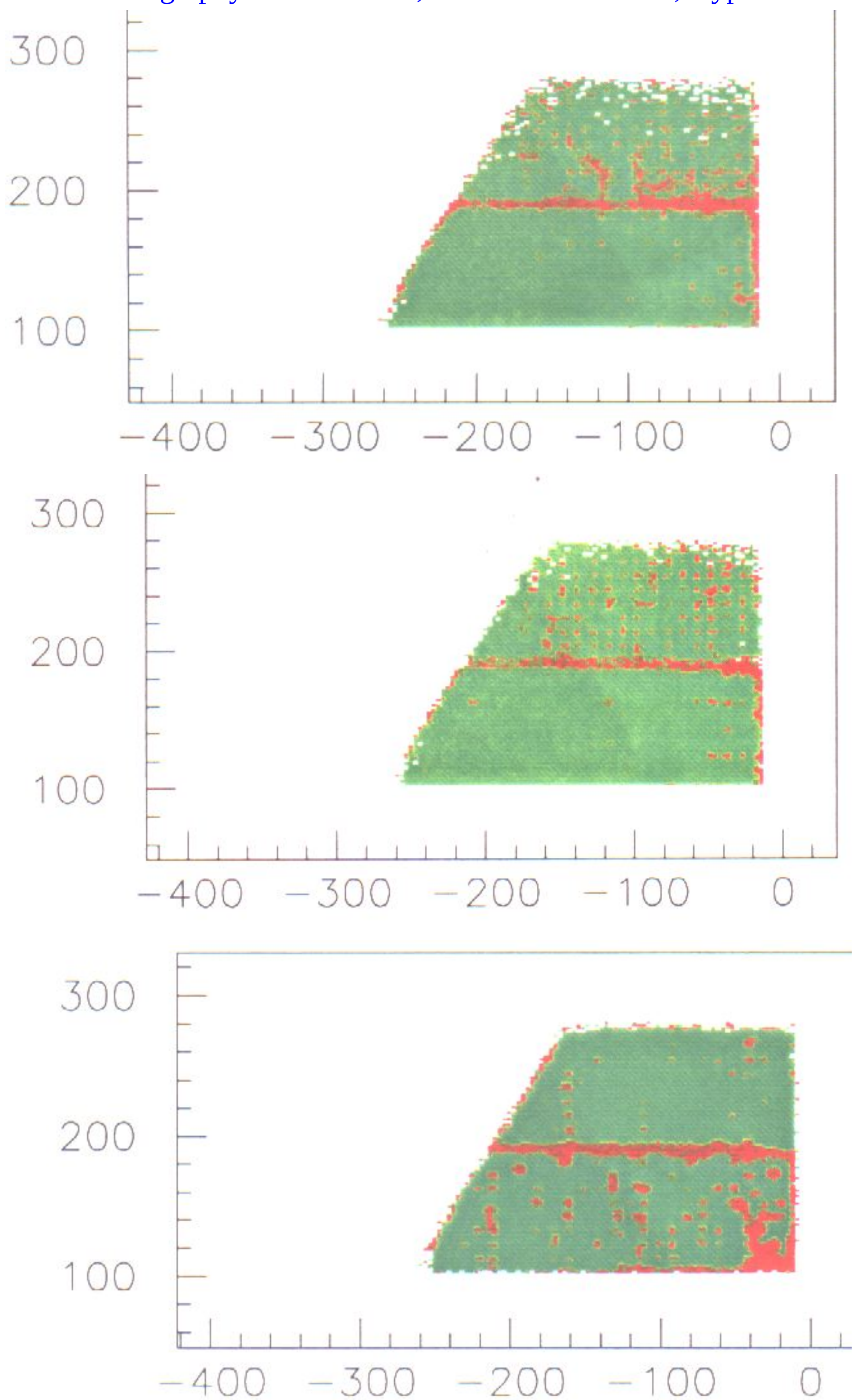
More recent analysis using periodic cosmic ray runs indicates that the average RPC efficiency continues to drop:



- There will be no Barrel available to BaBar by 2004-2005.

Radiography of efficiency of "old style chambers"

Recent radiography: Silvano Tosi, BaBar RPC Review, Hypernews 243, Dec. 8, 2002



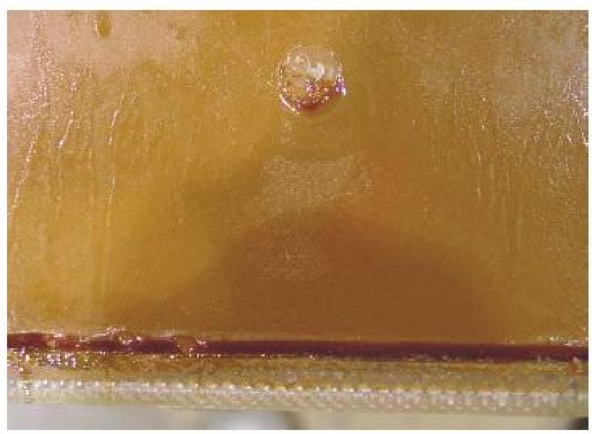
FW Layer 1
- low rate

FW Layer 2
- low rate

FW Layer 10
- low rate

- Typically, observe a loss of efficiency is near buttons and along the edges. Typical reason: too much oil in some areas.

What does "too much of oil" means ?

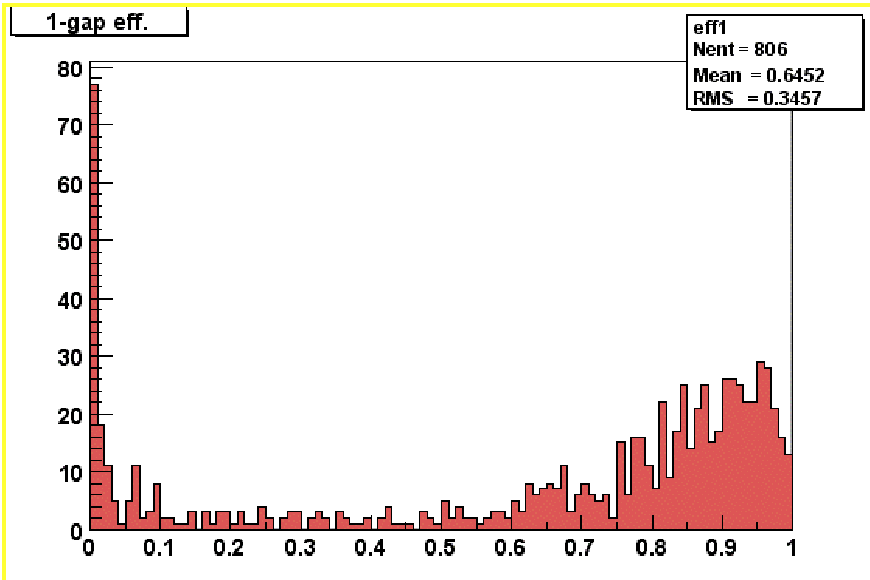


- Excess of oil along the chamber edges, near the support buttons and in the active regions.

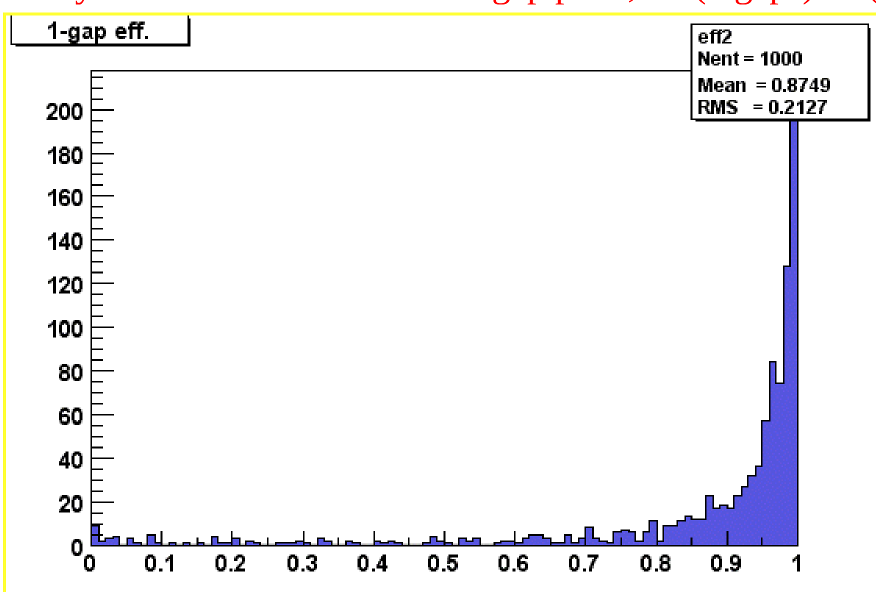
Importance if the double-gap RPC design

Luca Lista, BaBar RPC Review, Hypernews 246, Dec. 8, 2002

BaBar efficiency from June 2002:



Pair it randomly chambers into the double-gap pairs, Eff(2 gaps)=1-(1-eff$_1$)*(1-eff$_2$):



- Average efficiency increased from 65% to 87%.
- However, during the present methods of the construction, the buttons of two gaps would be aligned presently, which would result again in "zero" efficiencies.

2. New chambers – the 1-st "iteration".

(Installed during Nov. 2000)

A general comment:

a) These chambers were supposed to fix the problems.

b) RPCs filled one time with Linseed oil/eptane (40:60 mix). Not known how long flushed after each filling. This means that only 1/3 of Linseed oil was applied compared to the original construction. Different solvent reduced its viscosity and improved its curing, which resulted in much less oil located in the active region. Feels more "dry" now.

c) A better QC, although, there was not much time for this.

d) Still use a high resistivity Bakelite.

e) Use the same G-10 side and Lexan button spacers.

Problems definition:

a) Observe some degradation of efficiency in the past ~2 years.

b) About 5-10% of buttons show signs of large inefficiency. These buttons show evidence of sparking, the Bakelite shows a "beam tree pattern" near such sparking spots on its surface; one also gets a mushy feeling when the surface is touched near these buttons.

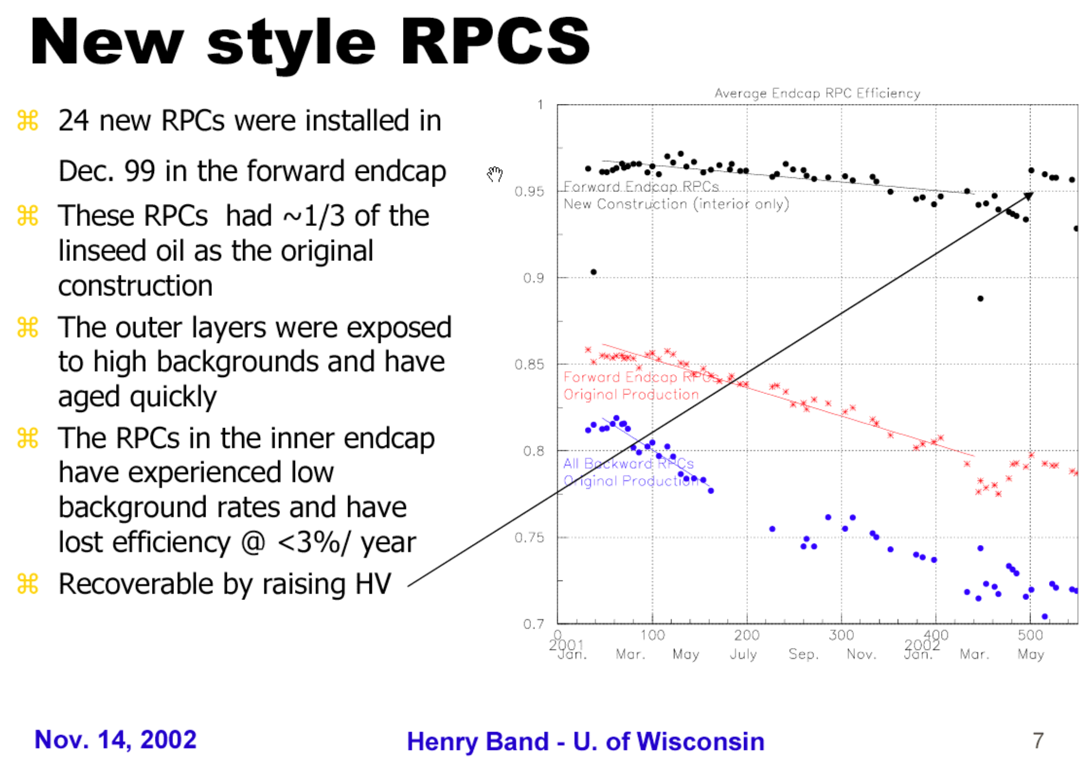
c) Many sparking spots near Linseed oil droplets at cathode, and along the chamber edges.

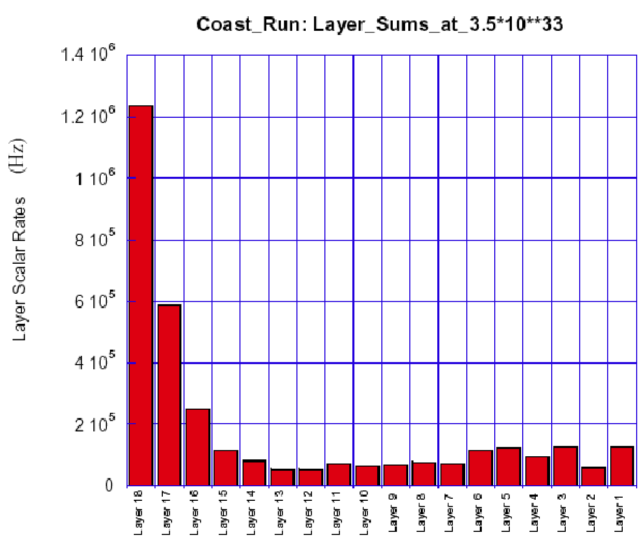
d) Fluorocarbon chemistry in a presence of water and plasma (one example is a formation of HF molecules).

e) Possible changes in the Bakelite and the Linseed oil volume and surface resistance due to ionic motions and lack of water.

- The design of these chambers is supposed to be the same as what LHC plans to use.

The average efficiency of the "new style" RPCs:





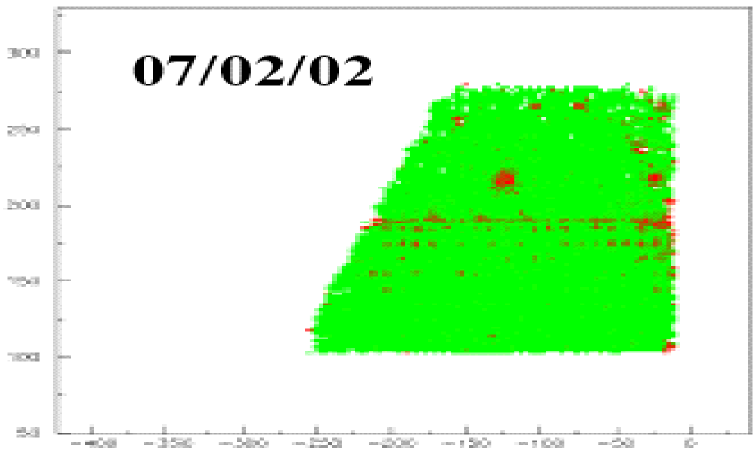
Rates:
~0.4 Hz/cm^2/Layer 14
~1.2 Hz/cm^2/Layer 17
~2.4 Hz/cm^2/Layer 18

- There is still a problem with these "new" style chambers.

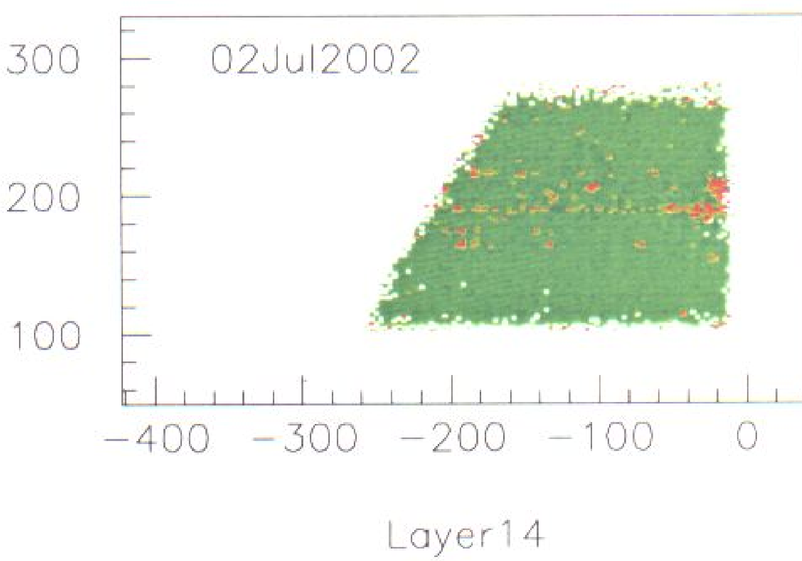
Radiography of efficiency of "new style chambers"

(Installed during Nov. 2000)

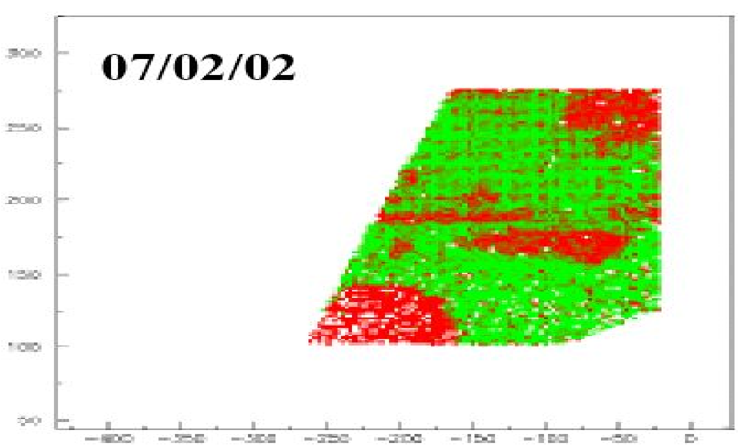
Silvano Tosi, BaBar RPC Review, Hypernews 243, Dec. 8, 2002



FW Layer 7
- low rate



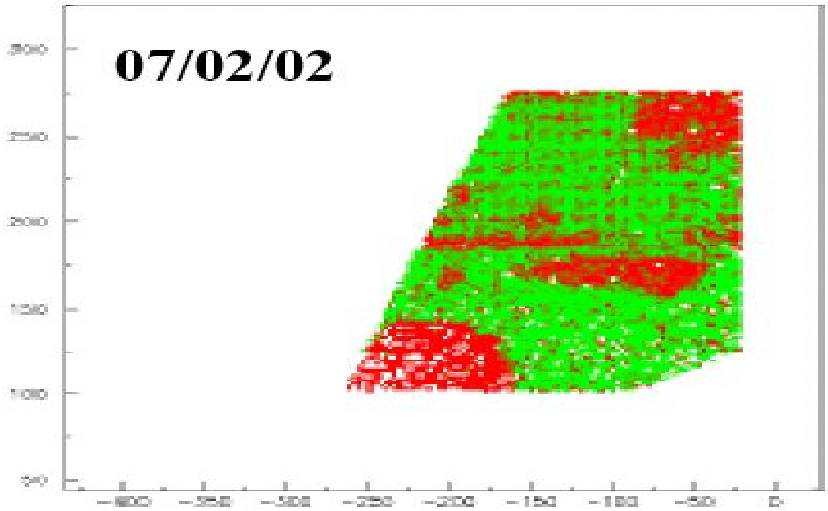
FW Layer 14
- low rate



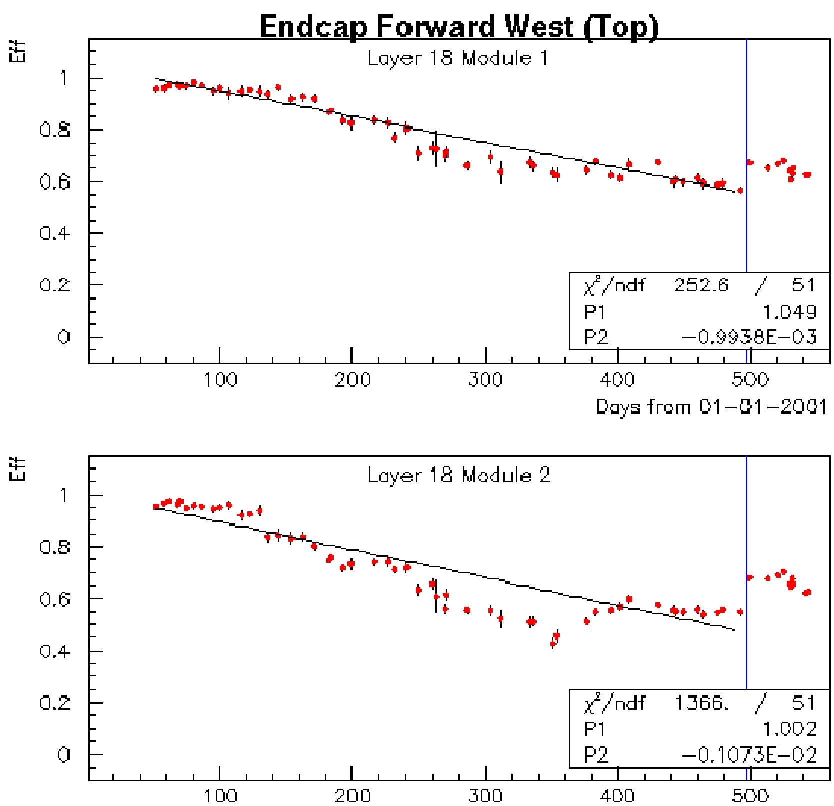
FW Layer 18
- highest rate

Correlation of ave. efficiency and radiography.

Silvano Tosi, BaBar RPC Review, Hypernews 243, Dec. 8, 2002



FW Layer 18
- highest rate

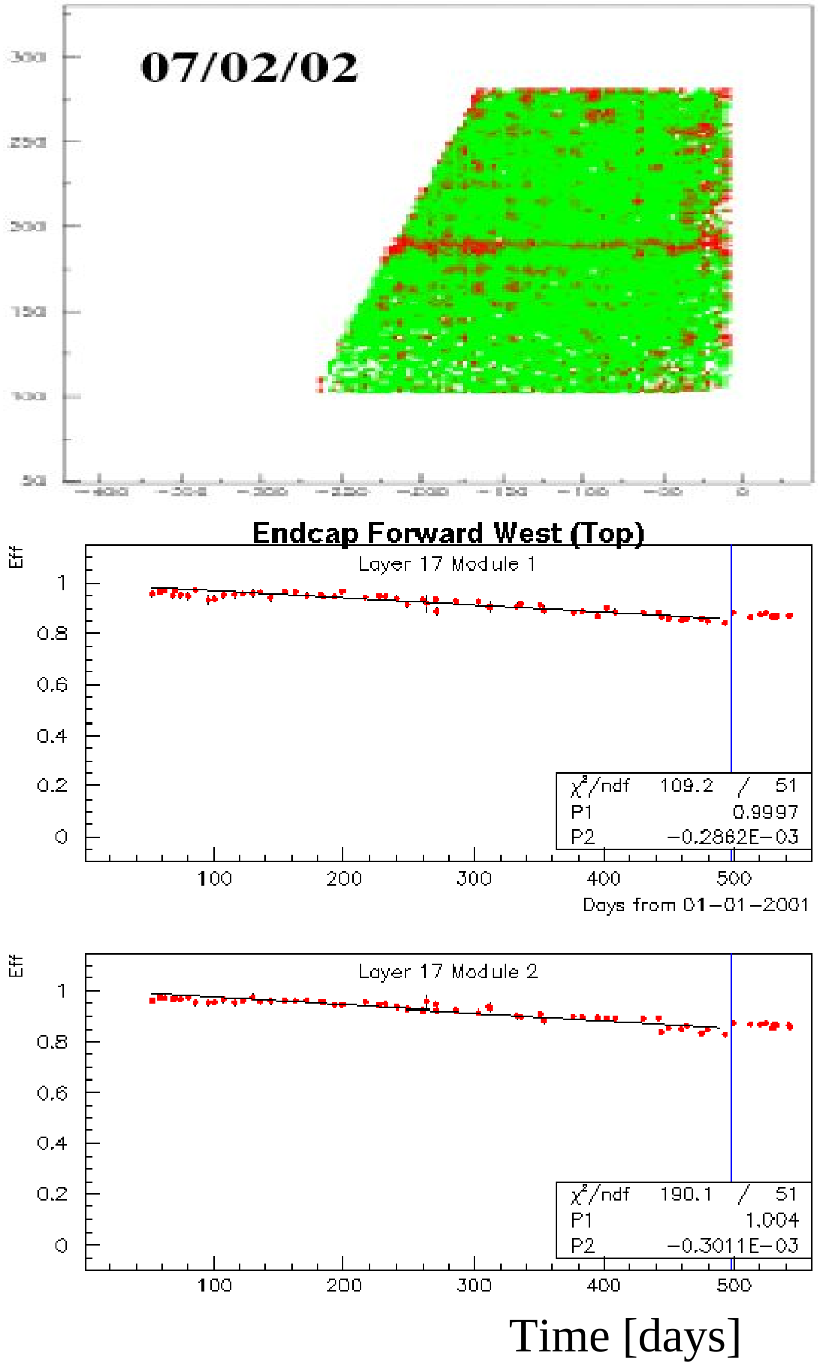


Time [days]

- Ave. efficiency drop: -44.3% (module 1), –47.9% (module 2).

Correlation of ave. efficiency and radiography.

Silvano Tosi, BaBar RPC Review, Hypernews 243, Dec. 8, 2002

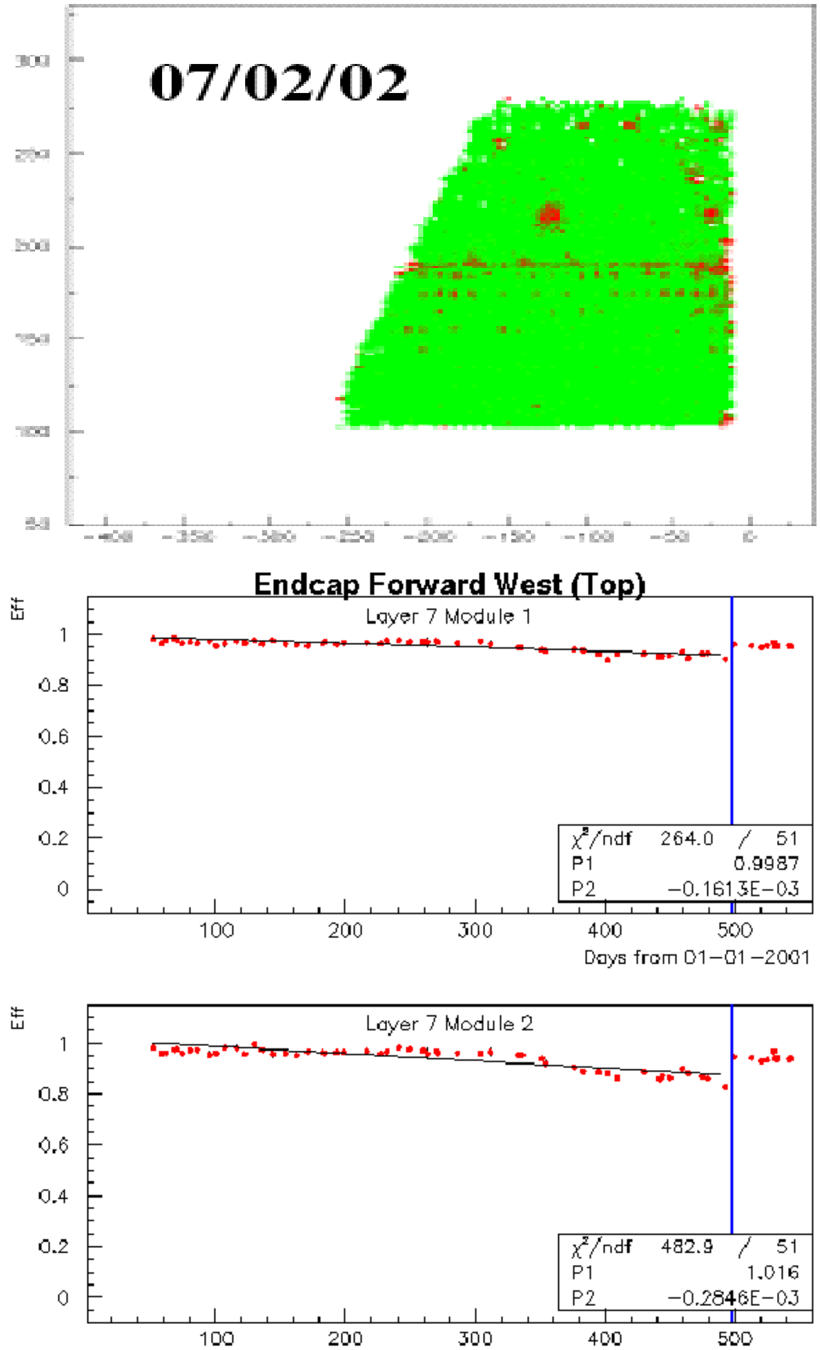


FW Layer 17
- high rate

- Ave. efficiency drop: -12.8% (module 1), –13.4% (module 2).

Correlation of ave. efficiency and radiography.

Silvano Tosi, BaBar RPC Review, Hypernews 243, Dec. 8, 2002



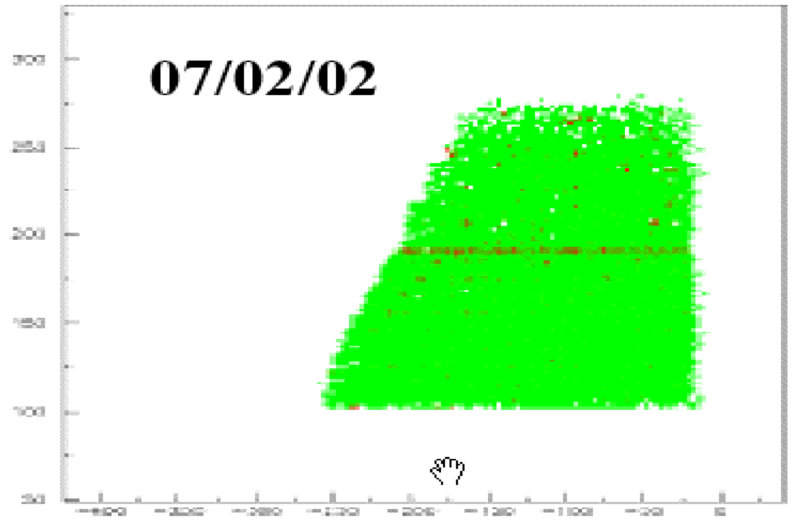
FW Layer 7
- low rate

Time [days]

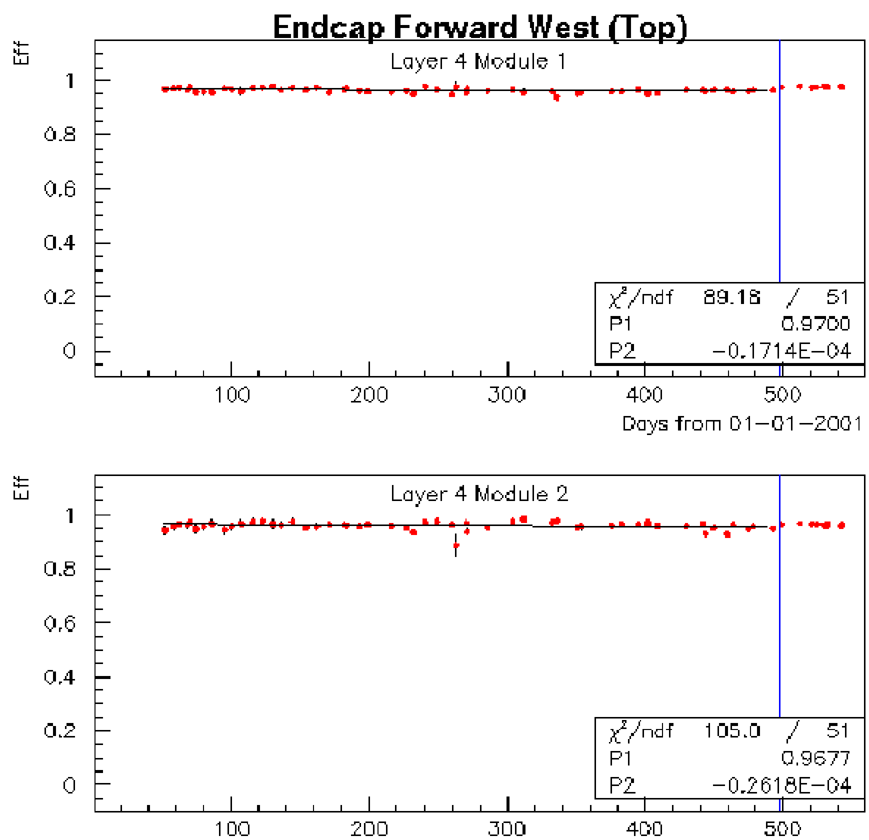
- Ave. efficiency drop: -7.2% (module 1), –12.7% (module 2).

Correlation of ave. efficiency and radiography.

Silvano Tosi, BaBar RPC Review, Hypernews 243, Dec. 8, 2002



FW Layer 4
- low rate



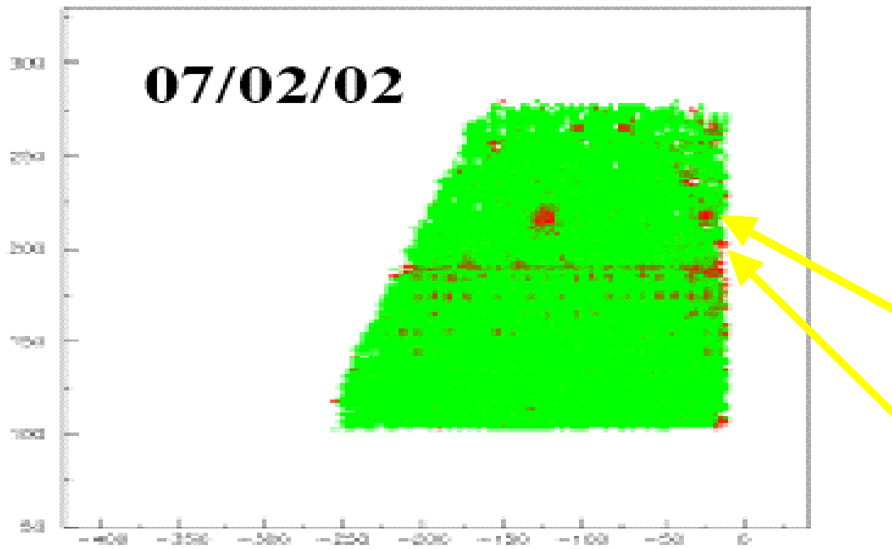
Time [days]

- Ave. efficiency drop: -0.76% (module 1), –1.2% (module 2).

Let's open one of these chambers and see…

Radiography of efficiency:

Silvano Tosi, BaBar RPC Review, Hypernews 243, Dec. 8, 2002



FW Layer 7
- low rate

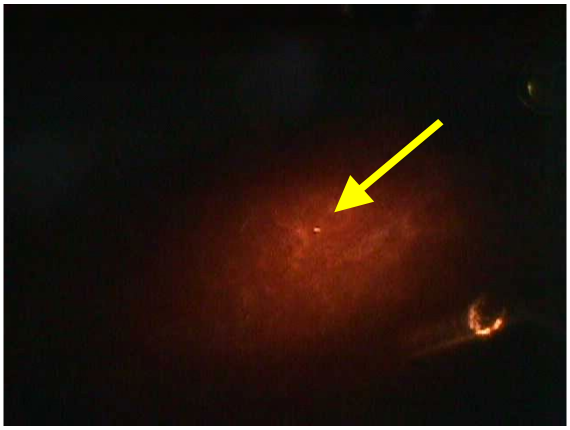
Bad spot #2

Bad spot #1

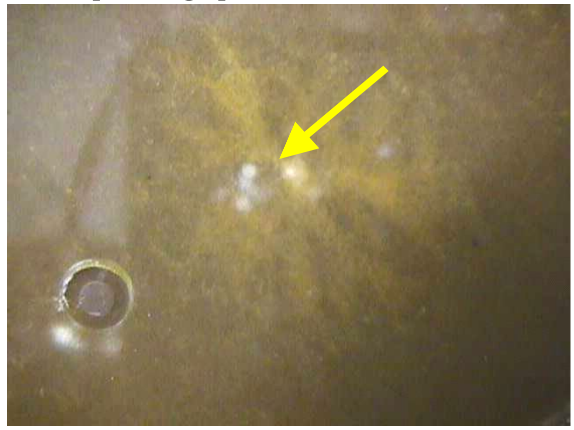
Bad spot #1:

(J.Va’vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf)

Cathode has a whisker

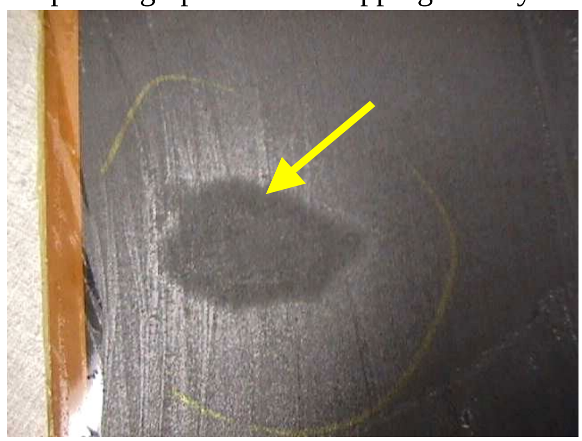


Corresponding spot on anode has a “beam tree”



The corresponding spot on the other side:
A white bubble between a Mylar and graphite

A spot on graphite after stripping the Mylar foil



- One single whisker on cathode can create this trouble. A “beam tree” image appears on the corresponding spot on the anode, the bubble appears between Mylar and graphite on other side, and the graphite is discolored. It did not separate from the Bakelite though, when stripping the Mylar.

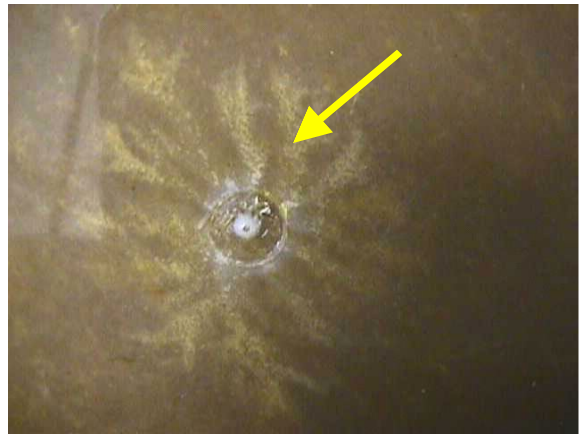
- The “beam tree” may indicate a difficulty to drain the charge from the sparking spot. The electrons channel through the Bakelite and the Linseed oil. The image is similar to the “SLAC famous beam trees”.

Bad spot #2:

(J.Va’vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf)

Nothing obvious on the cathode side

A “beam tree” around the button on the anode



On the corresponding spot on the other side:
A white bubble between a Mylar and graphite

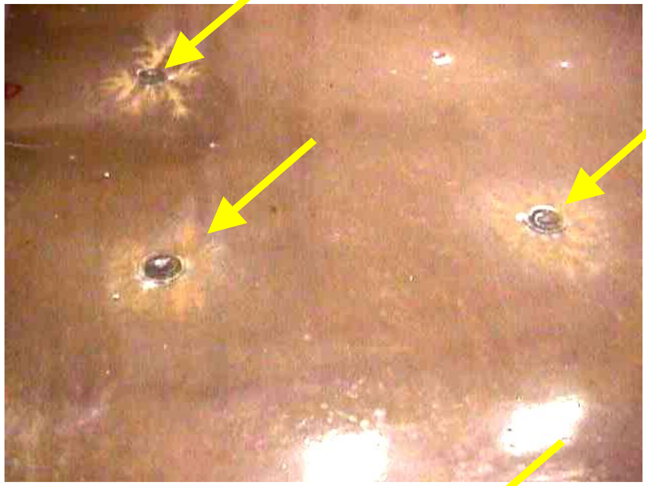
A spot on graphite after stripping the Mylar foil

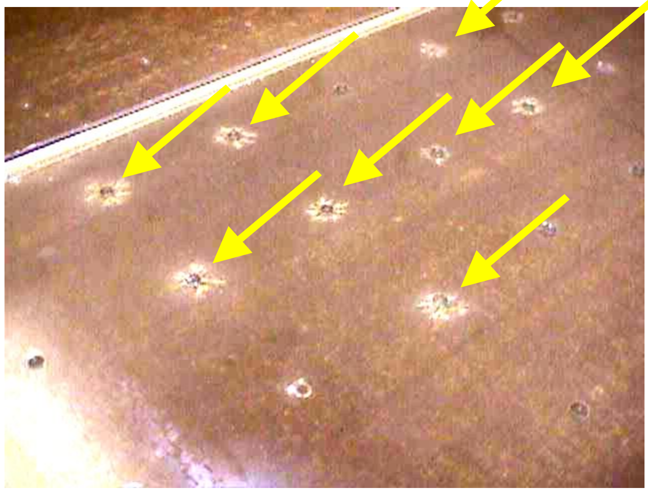
- Breakdown near the button creates a “beam tree” image on the anode side in the Bakelite, the bubble appears between Mylar and graphite on other side, and the graphite is discolored.
- In this case, I see nothing obvious on the cathode.

See many "beam tree" pattern spots:

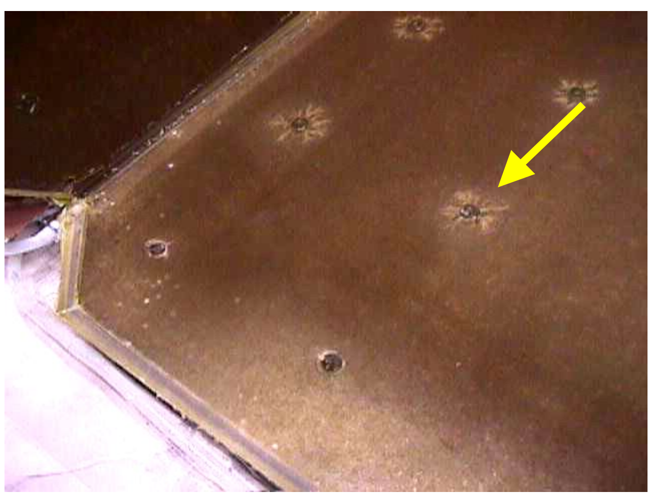
(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf)

- They correspond to tiny red spots in the radiography.





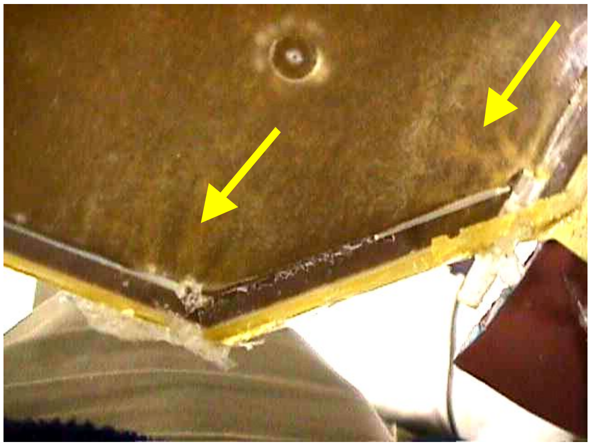
Visually, this looks like a disaster



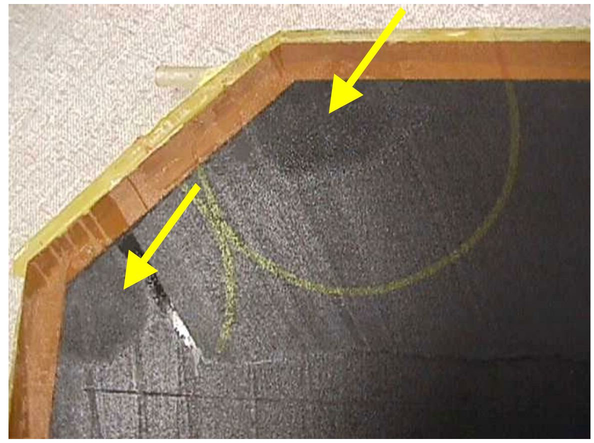
Breakdown along the edges near the bad spot #1:

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf)

Two corners on the anode

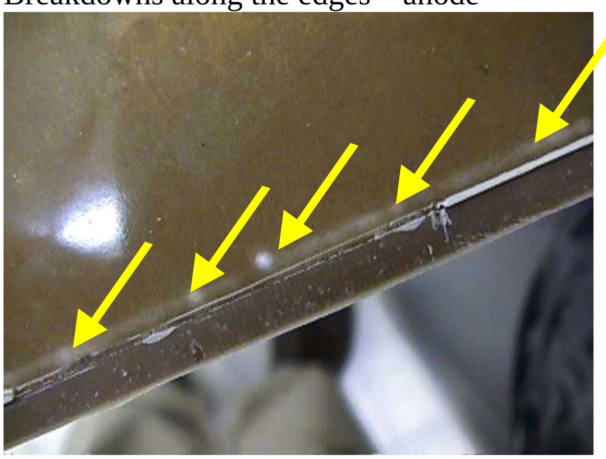


Corresponding spots on graphite (back side)



Breakdown along edges and a gas entry (other sections):

Breakdowns along the edges – anode



Breakdowns near a gas entry point - anode

- Tiny white images correspond to breakdowns along the edges.

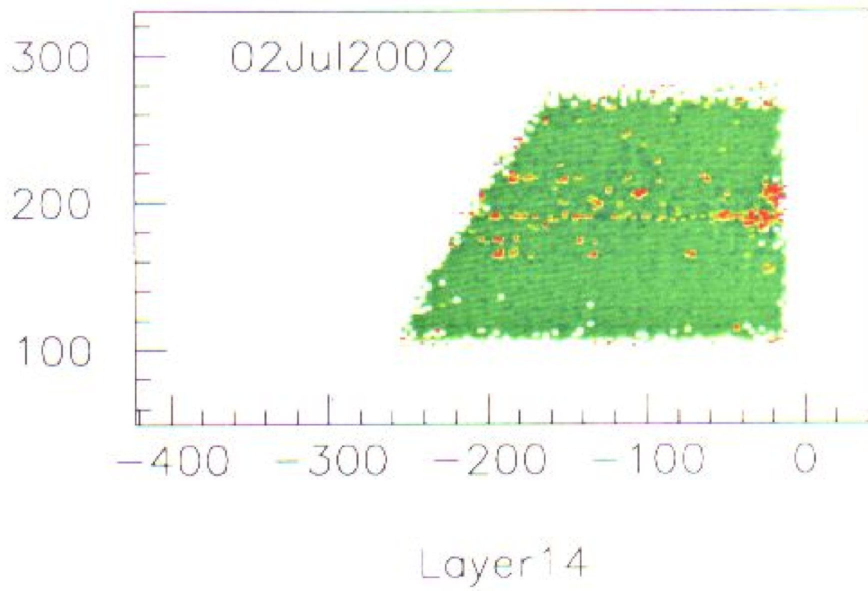
- We see similar red dots in the radiography from June 14, 2002 (after the voltage adjustement) in both the new and old style of chambers.

- Why to worry? The persistent breakdown will sooner or later damage the surface and this will cause a corona/sparking.

Let's open another chamber and see…

Radiography of efficiency:

Silvano Tosi, BaBar RPC Review, Hypernews 243, Dec. 8, 2002



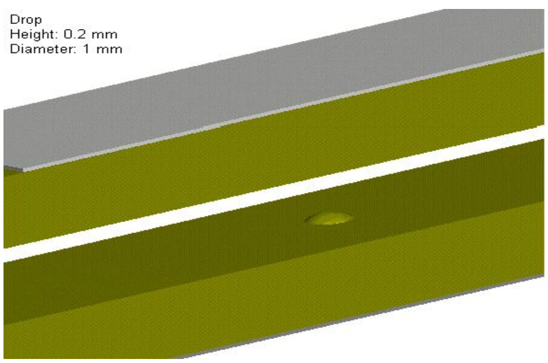
FW Layer 14
- low rate

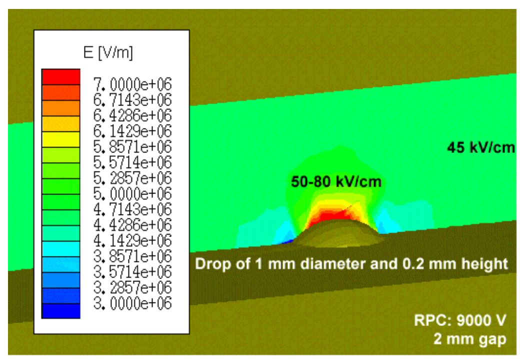
- Open only the larger chamber.
- Most of the red spots correspond to the beam tree pattern.

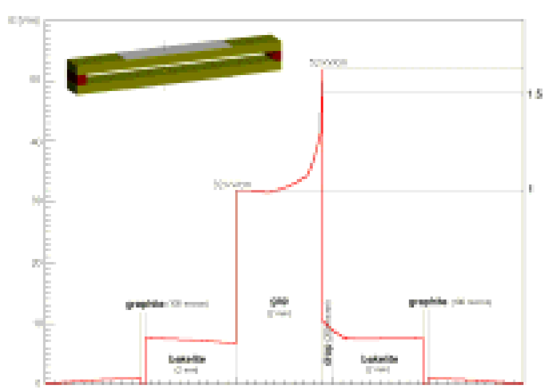
Sparking spot #1:

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf)

Recall a calculation by A. Sharma:



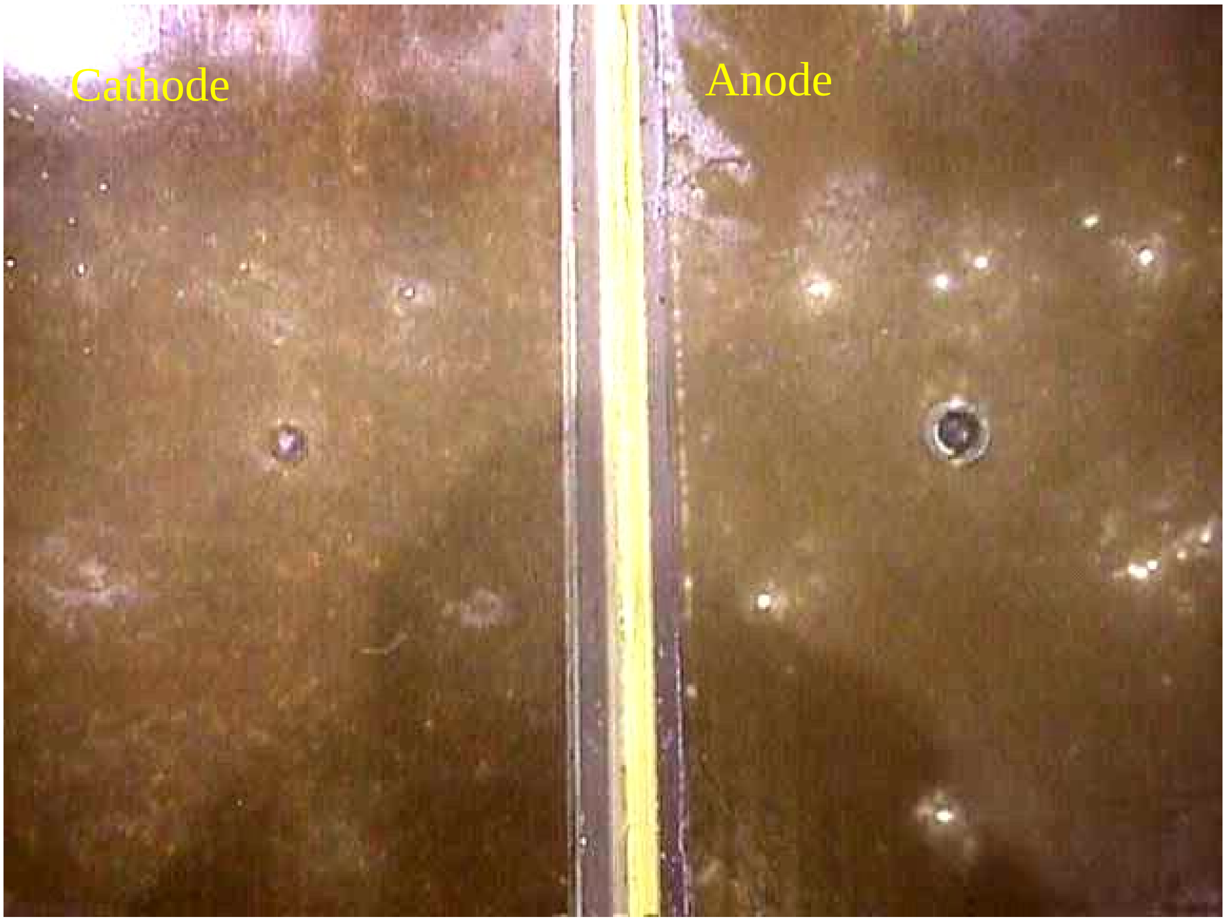




- Anode has visible white spots caused by the sparking.
- No whiskers on cathode, only Linseed oil droplets on cathode !!!
- The Linseed oil droplet son cathode can initiate sparking.

Sparking spot #2:

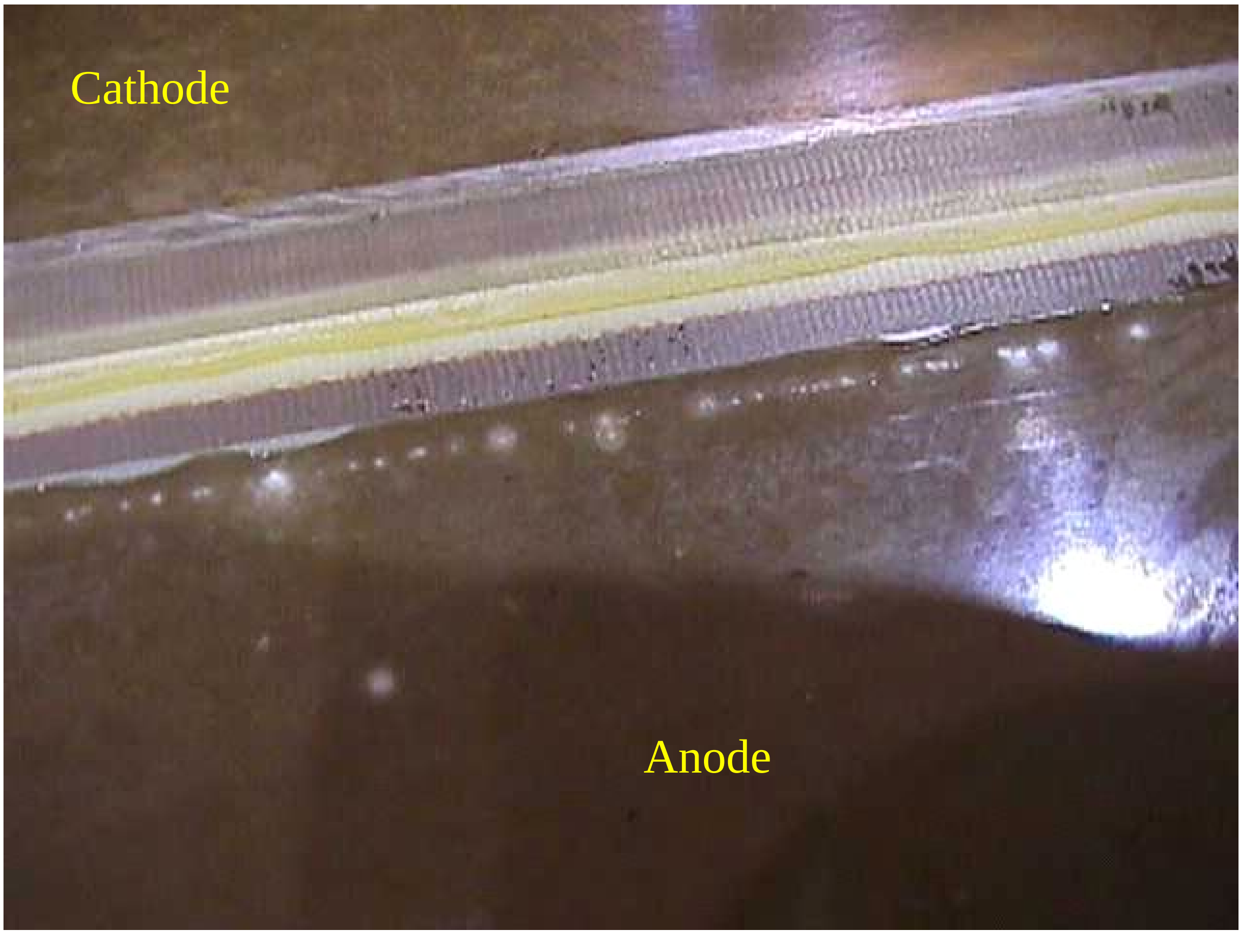
(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf)



- Anode has visible white spots caused by the sparking.
- No whiskers on cathode, only Linseed oil droplets on cathode !!!
- The Linseed oil droplets on cathode can initiate sparking.

Sparking spot #3:

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf)

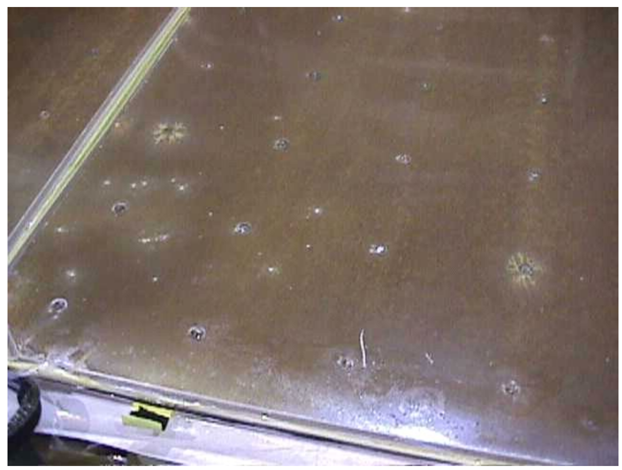


- Anode has visible white sparking spots along the edges.
- Nothing obvious on cathode.
- Clearly, the edges contribute to the noise rate.

"Beam tree pattern" on the anode buttons:

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf)

- Beam tree pattern on ~5% of the buttons on the anode.
- No problem observed on the cathode side of the buttons.



3. New chambers – the 2-nd "iteration".
(Installed during Dec. 2002)

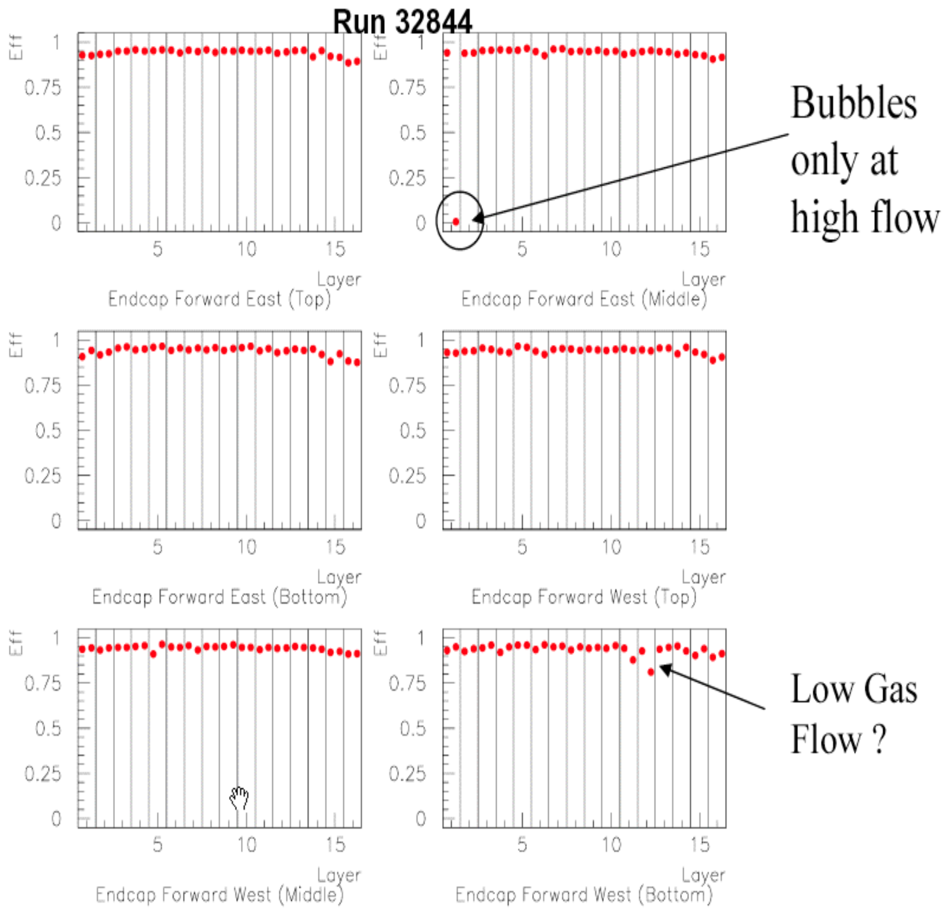
A general comment:

a) The same oil treatment as the Nov. 2000 chambers, i.e., a single oil coating and the new Eptane solvent.
b) Much better QC (a new group)
c) Still use a high resistivity Bakelite
d) The same G-10 side and Lexan button spacers
e) Much less oil in the active volume

Problems definition:

a) All is OK at present with the cosmic ray rates.
b) Two outmost forward layers are still switched off during the present BaBar running because of too high currents causing frequent tripping.

Forward Endcap Efficiency



- The new Dec. 2002 chambers have a good starting efficiency.
- However, outer FW chambers are already off because they are tripping during the regular BaBar running. These chambers have highest background.

II. Belle:

A general comment:

a) Float glass electrodes

b) No Linseed oil

Problems definition:

- Too much water in the gas caused a formation of HF, which in turn caused the corrosion of the glass surface

Possible future problems (my opinion):

- changes in the float glass volume resistance due to ionic motions.

Note:

The "HF" corrosion theory is being disputed by the following reference. Instead, the authors propose a theory of deposits on the cathode.

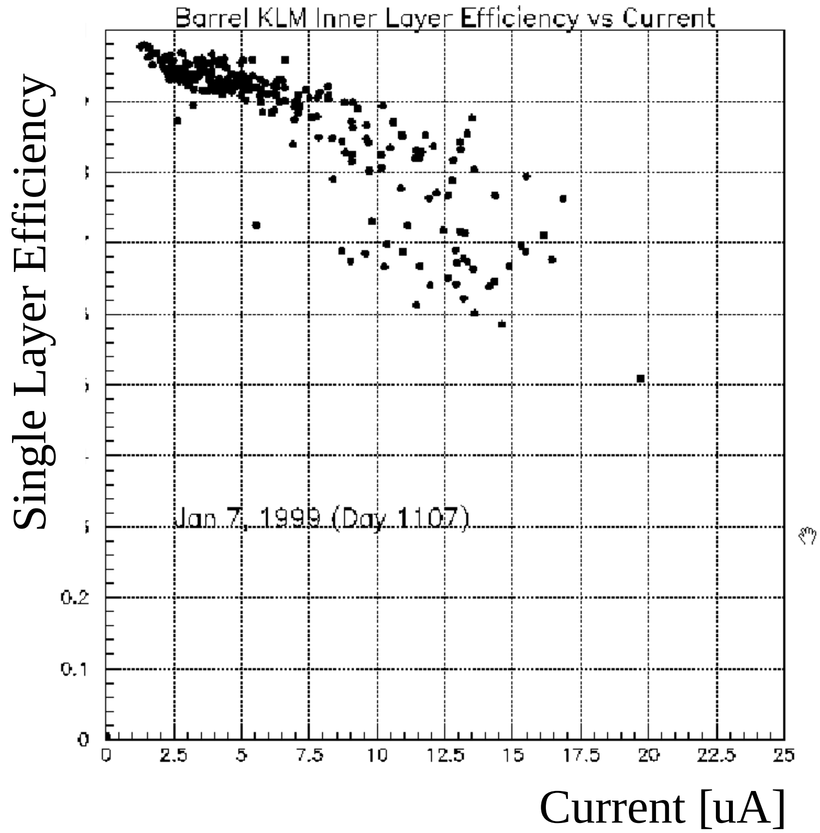
H. Sakai et al., Nucl. Instr. & Meth., A484(2002)153.

Troubles in the Belle RPC chambers

D. Marlow, Rice University Seminar, July 9, 1999

A Major Problem Develops . . .

The correlation between dark current and efficiency loss is readily apparent.



- The problem was traced to a large humidity caused by a plastic tubing permeating too much water into the the chambers.
- The reason why Belle still has the RPCs is that the group said to KEK management: "We will not run until we understand it…"

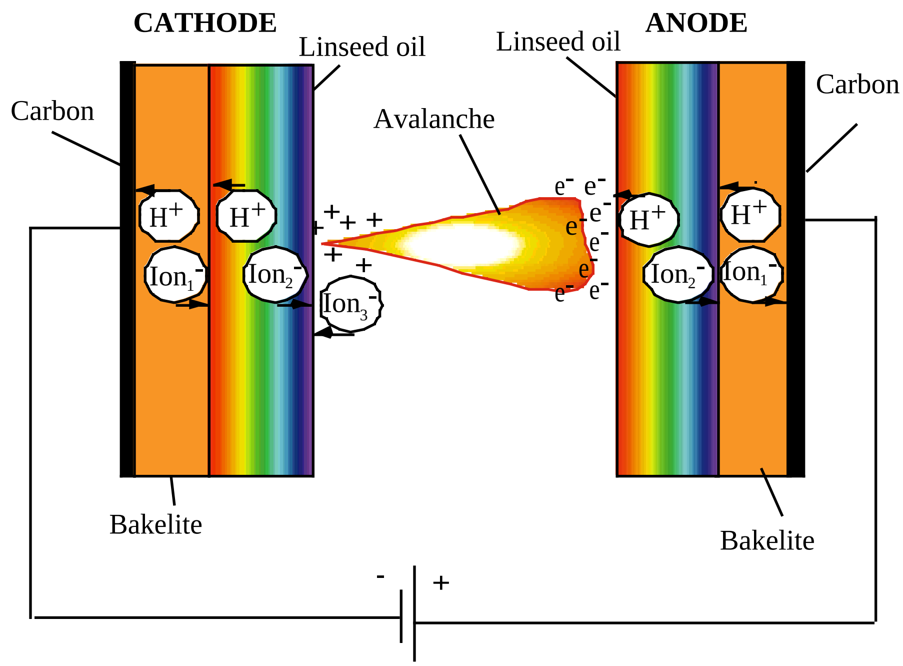
Discussion

- We will concentrate on mechanisms, which change the nominal values of the resistance of the Linseed oil, Bakelite and glass, thus upsetting the voltage distribution.
- In principle, this problem becomes quickly a 3D problem, especially if the resistances change in a non-uniform way.
- Possible new Freonless gases ?

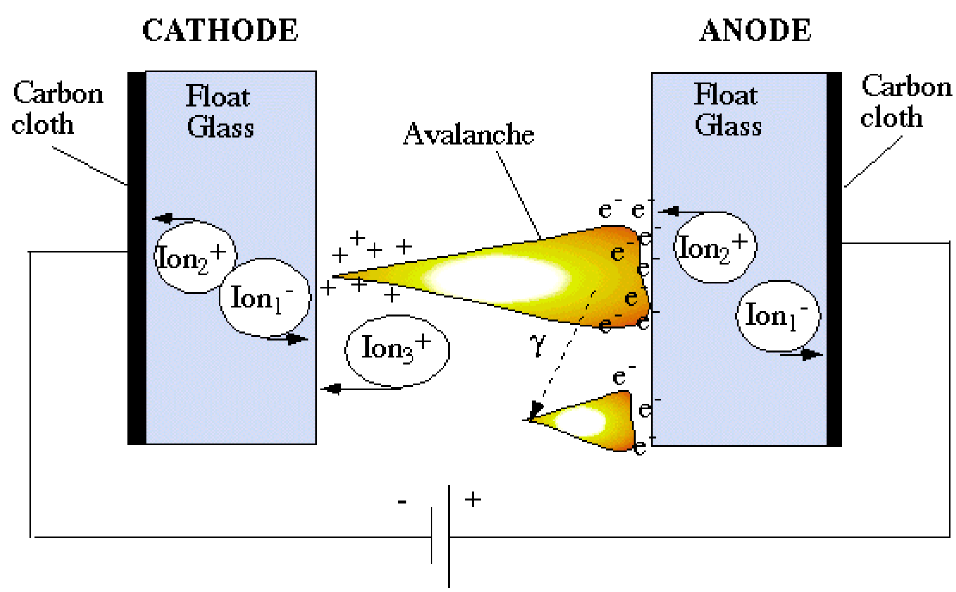
"Ionic" model of BaBar & Belle RPCs:

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary.pdf
and "Physics and Chemistry of Aging – Early Developments", DESY Aging Workshop, 2000).

a) BaBar



b) Belle



- Several ions are involved in the charge hand exchange.
- The charge exchange mechanism must work well to prevent the charging. Any charge buildup may lead to sparking.

- Belle - Electrolytic process in glass

(G. Cicognani, P. Convert, A. Oed and J. Pannetier, ILL Int. Note, Grenoble, France)

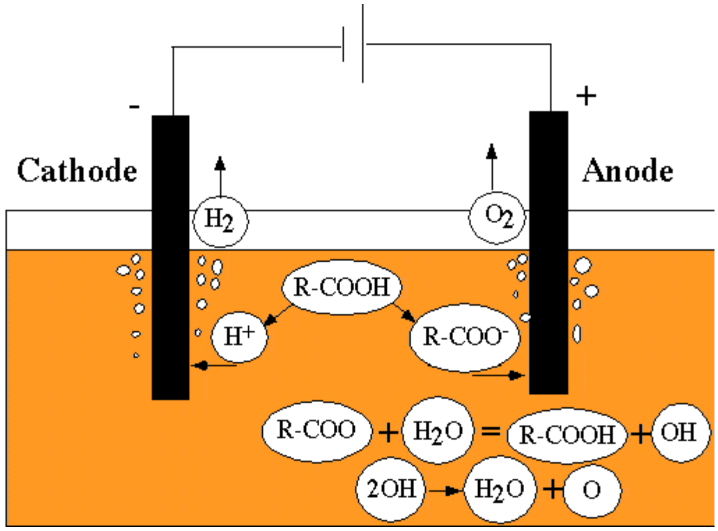
- Long-term instability of the ionic glasses:
  The conductivity in standard glasses is ensured by the movement of the alkaline ions, and for that reason they are called ionic conducting glasses. Typical resistance of these materials is 10^{12}-10^{16} Ωcm. However, during the long-term operation, the alkali ions migrate towards the cathode by the electric field and leave a depleted layer close to anode. This leads to a large and permanent increase of the surface resistance.

- Sodium is a very mobile ion under an influence of electric field.
- Micro-strip detectors would die rapidly when built on a simple float glass initially.
- From BaBar DIRC experience, we know that the alkali ions can leave the glass by "vacuum effect" of the ultra pure water - so-called sodium leaching.

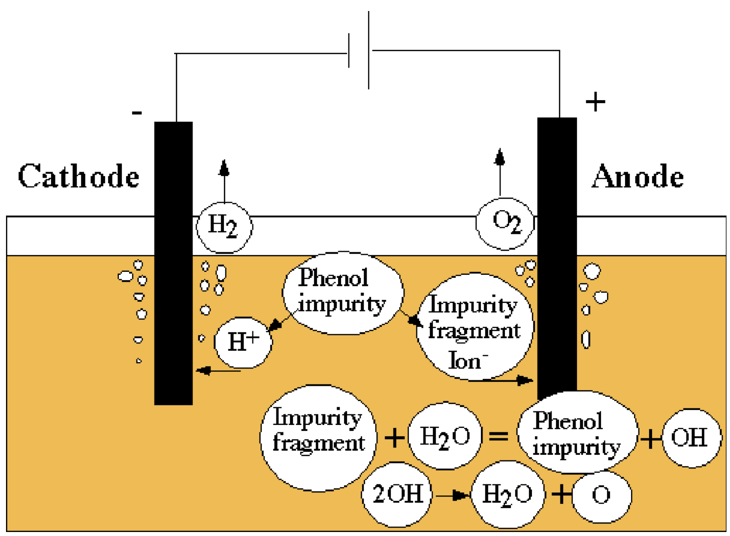
BaBar - A specific example of an ”ionic” model

(J.Va’vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary.pdf and “Physics and Chemistry of Aging – Early Developments”, DESY Aging Workshop, 2000).

a) Linseed oil:



b) Bakelite:



1) If there is no water then R-COO$^-$ just shares a charge:

=>

The current slowly decays as R-COOH is consumed.

2) If there is water then R-COO$^-$ will share a charge and convert back to the fatty acid R-COOH.

=>

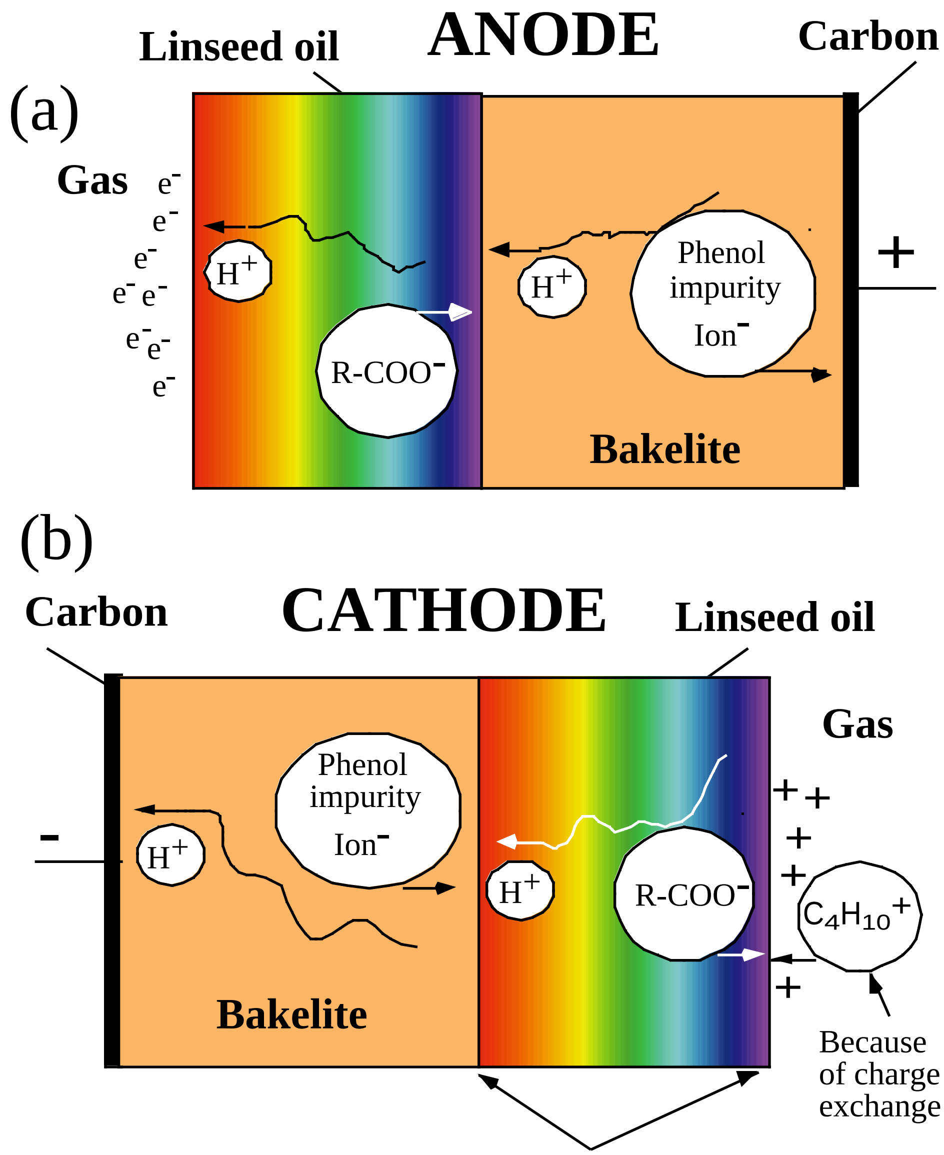
The current will continu e.

¡Source of water:
Bakelite, gas, etc.

- A common bottom line of this particular model is that if you remove water, the current will stop. Many tests I have done are basically consistent with this point.
- The water can me “removed” either by a high current operation or by drying the outer Bakelite layer in a relatively dry gas.

BaBar - A specific example of an "ionic" model

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary.pdf).



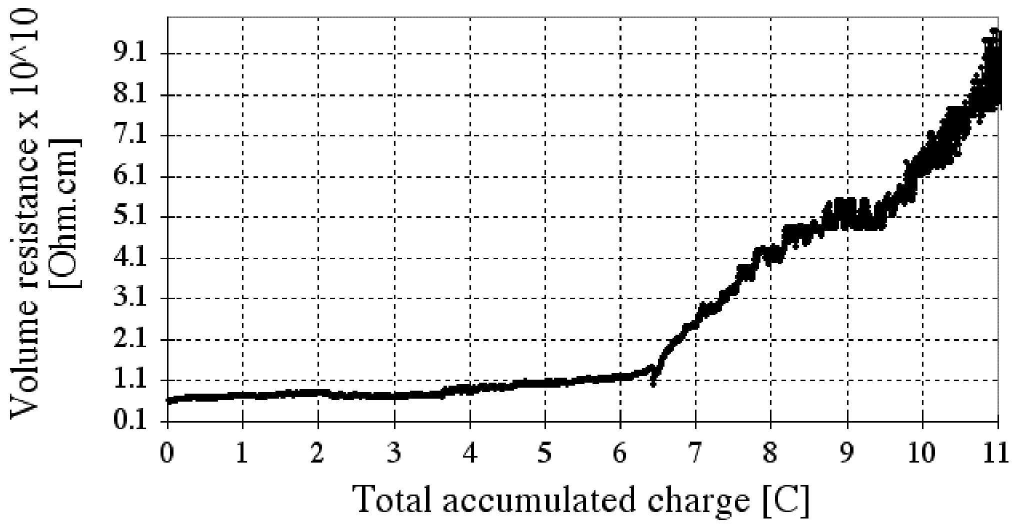
EXPECT BUILD UP OF "R-COO" AND "PHENOL IMPURITY" FILMS AT VARIOUS BOUNDARIES

- There may be a build up of molecular layers at various boundaries, just like during a plating process.
- This process may cause a non-uniform distribution of resistance throughout the electrodes depending where the currents goes.

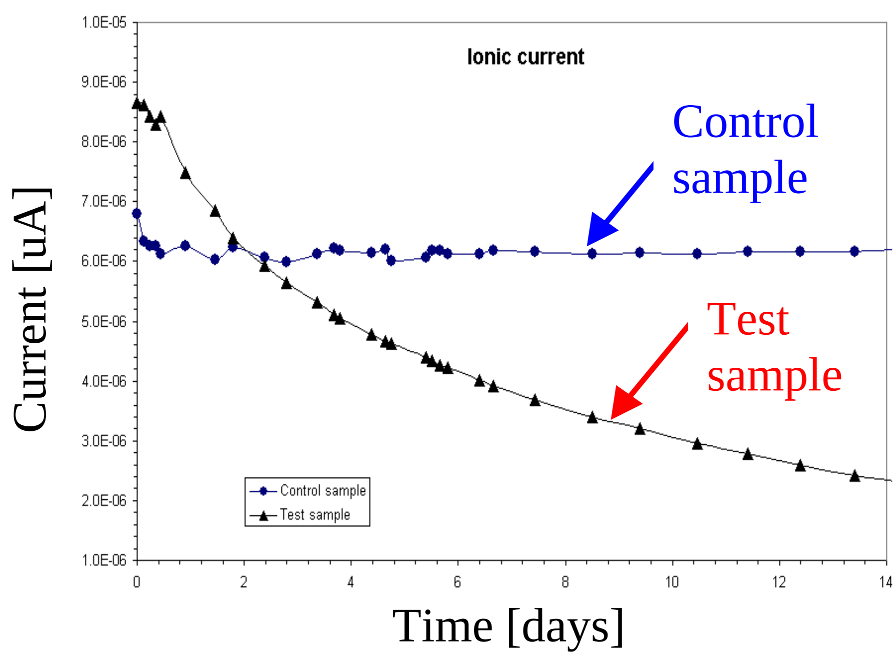
Indirect support of the Electrolytic model

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf and "Physics and Chemistry of Aging – Early Developments", DESY Aging Workshop, 2000).

Linseed oil:



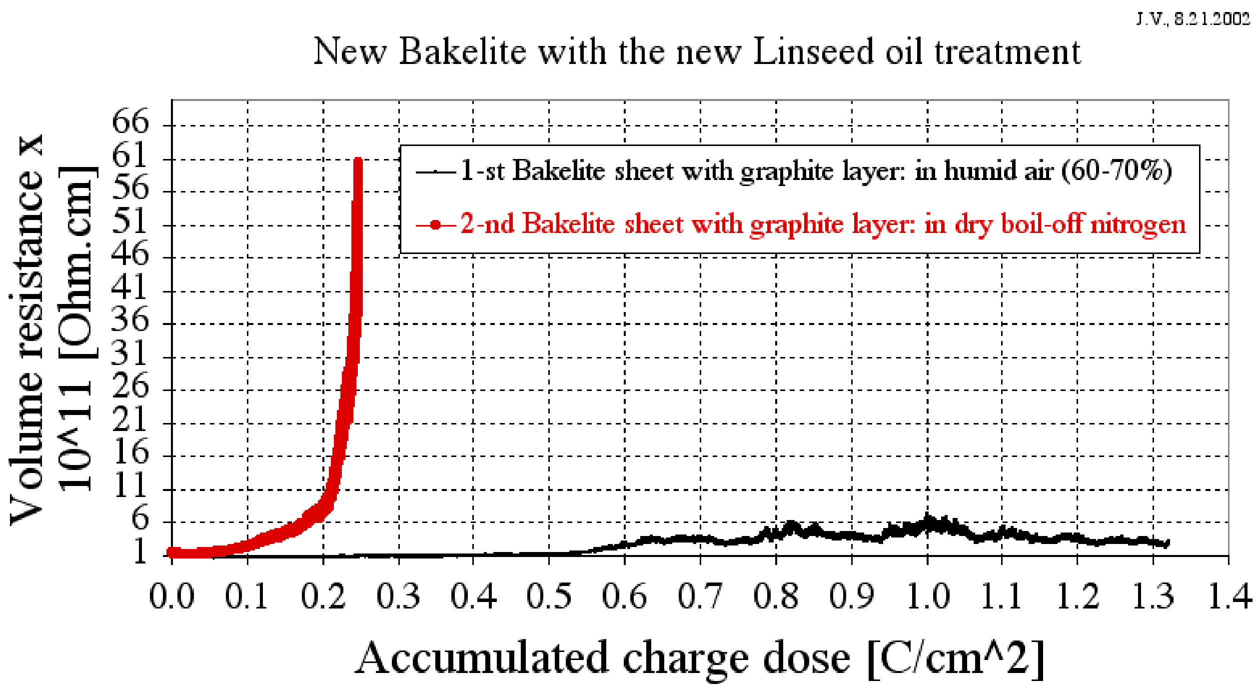
(Ch. Lu, Princeton University, VI RPC Workshop, Coimbra, Portugal, November 26 – 27, 2001)



- The Linseed oil ionic current decays as the charge accumulates, i.e., its resistance is not a constant in time.

Indirect support of the Electrolytic model

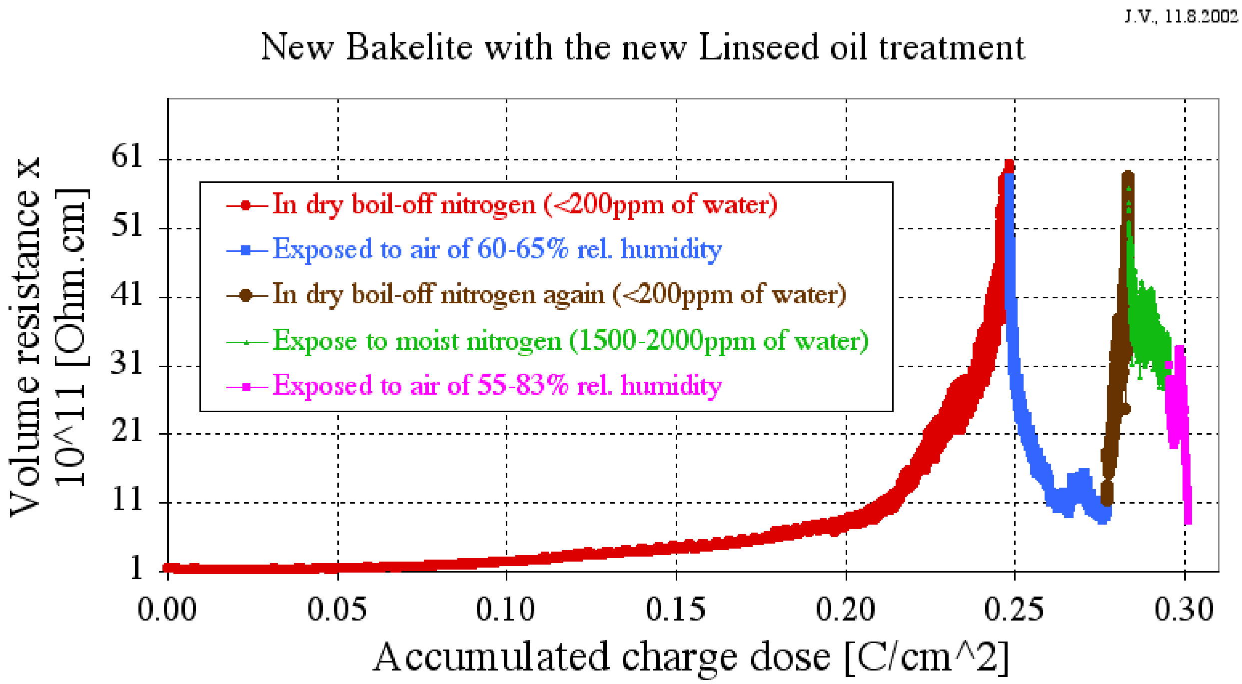
(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf
and "Physics and Chemistry of Aging – Early Developments", DESY Aging Workshop, 2000).



- The resistance increase of the Bakelite in the dry nitrogen is much larger than that of Bakelite in the humid atmosphere.
- Water could be removed from a thin outer layer of the Bakelite by a dry nitrogen.

Indirect support of the Electrolytic model

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf
and "Physics and Chemistry of Aging – Early Developments", DESY Aging Workshop, 2000).

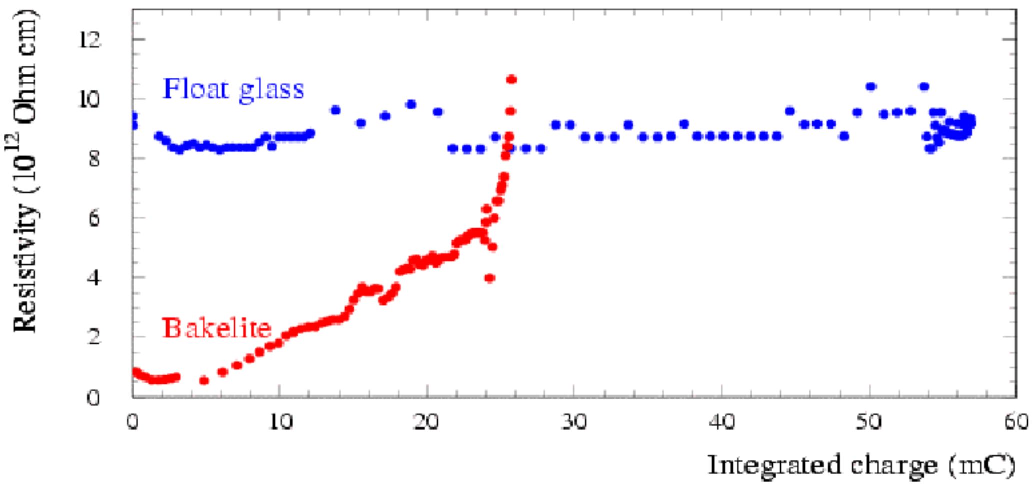


- The Bakelite volume resistance can be modulated by water.
- During the first run one needed ~0.25 C/cm^2 to increase the Bakelite volume resistance by a factor of ~60. The RPC would not tollerate such increase.
- Adding a humid air brings is back to operating range.
- During the second run one needed only ~0.05 C/cm^2 to increase the Bakelite volume resistance by a factor of ~60.
- Running 1500-2000ppm of water will not bring the resistance back. One needs much higher humidity (70-80% relative humidity).

Is the volume resistance of the float glass more stable than that of Bakelite ?

A. Sharma, CERN Detector Seminar, Nov. 22, 2002:

Resistivity of float glass and bakelite samples measured as a function of integrated charge.



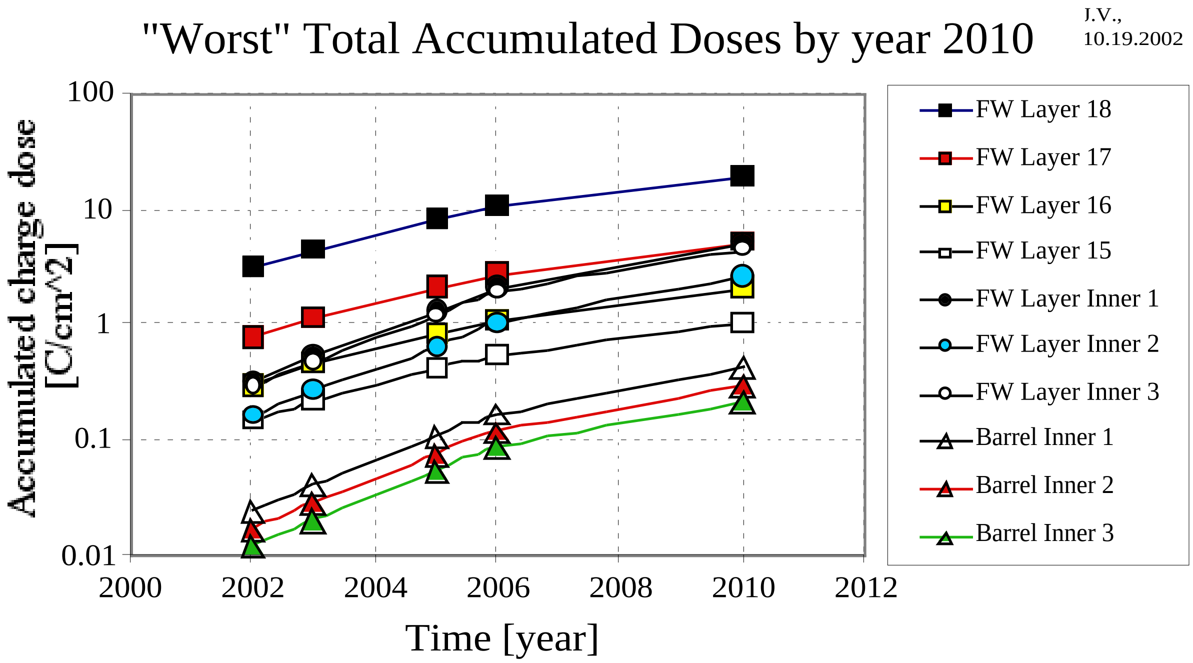
A. Tonazzo IEEE 2002

→Glass resistivity is unchanged
→Bakelite resitivity increases irreversibly

- In this charge dose domain, the float glass is more stable.
  However, it may not be true for larger charge doses!!!

Is BaBar in this charge dose regime ?

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/my_rpc_conclusions.pdf.)



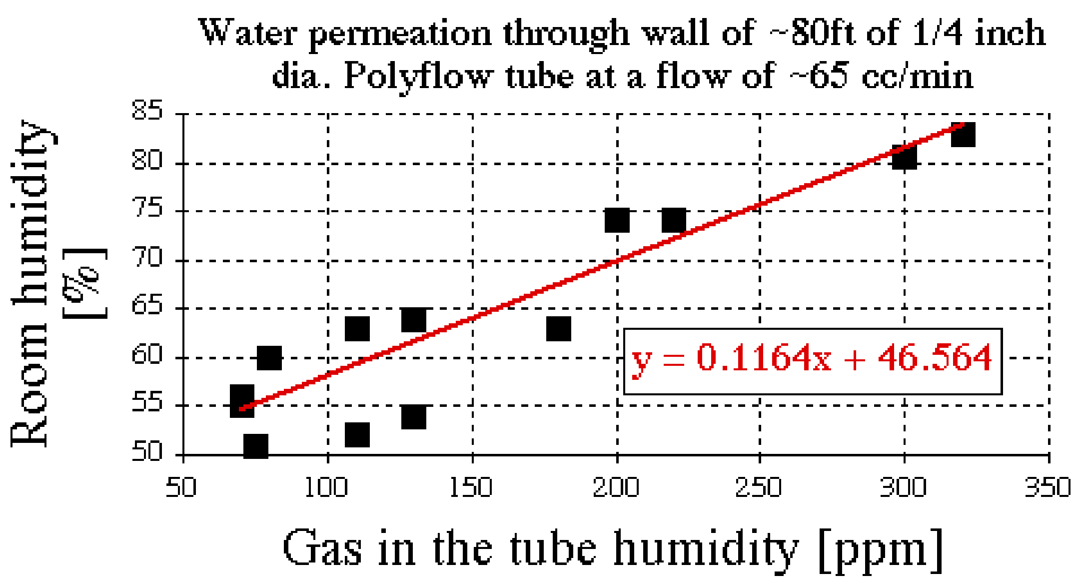
- If a value of 0.25 C/cm^2 is the relevant limit, the Barrel Inner Layer 1 will reach it sometimes around 2007.

- If a value of 0.025 C/cm^2 is the relevant limit, we would start getting into trouble already.

How much water permeates through a wall of the 80ft-long 1/4 inch dia. Polyflow tubing ?

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary.pdf).

- Before doing this measurement prep the tubing by a very high flow until two humidity meters, one upstream and one downstream of 80ft-long black Polyflow tubing (1/4 inch dia.) were reading almost the same value. Then reduce the flow.
- Keep the tubing at constant temperature of 23-23°C.
- Gas flow ~65cc/min (corrected after a calibration with the HP Soap Film Flowmeter on 11.18.2002).



- This proves that only small amount of water permeates.
- Switch to BaBar Teflon tubing @ 65cc/min, 61-74% rel. humidity and 93ft long tubing:

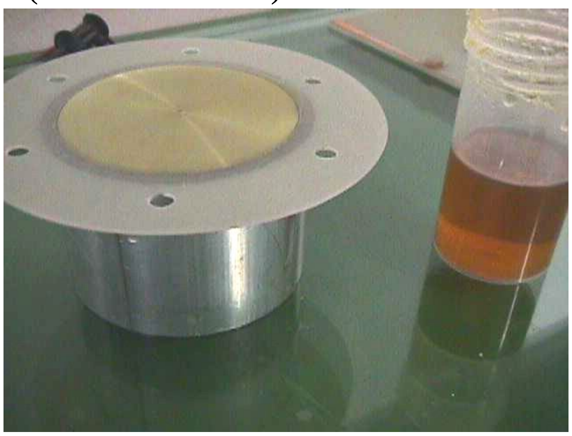
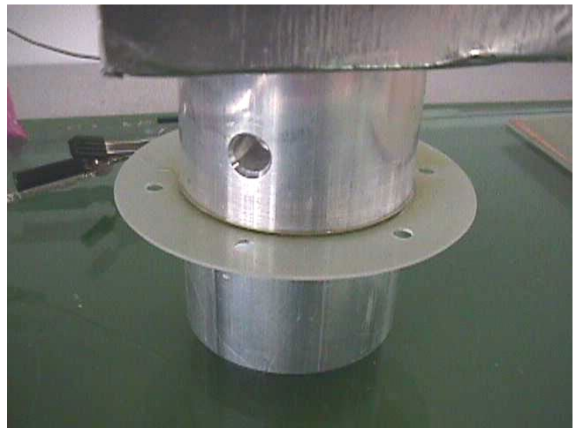
  Already after ~8 hours get only ~200 ppm at 74% humidity.
  After ~16 hours get only ~120 ppm at 71% humidity.
  After ~5 days get only ~30 ppm at 61% humidity !!!!!

- The gas flowing into the BaBar RPCs is rather dry !!!

Is there some evidence for the Freon-based chemistry affecting the Linseed oil volume resistance in the old-style chambers ?

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary.pdf).

- Volume resistance of fresh Linseed oil:
  (Italian Linseed oil)

- Volume resistance of the Linseed oil removed from FW Layer 7:
  (An old-style RPC removed from BaBar in Nov. 2000)

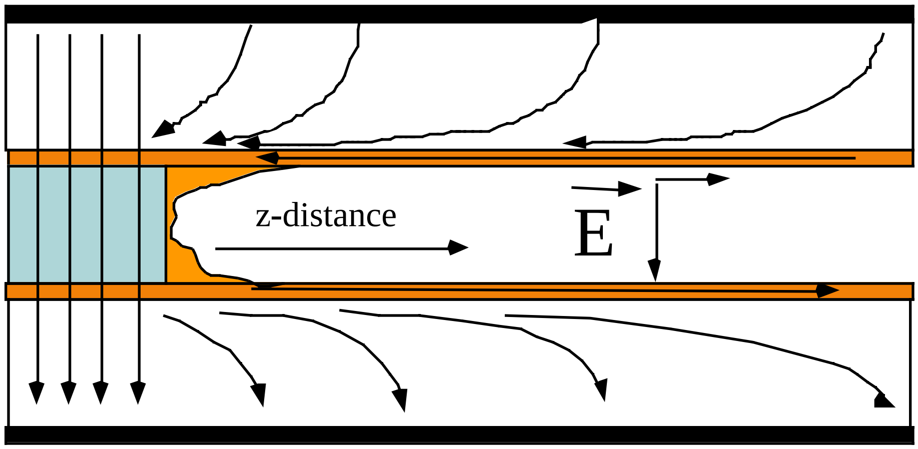

Average values:

Linseed oil sample (at room temperature of ~ 22degC)	Volume resistivity [10^8 Ohms.cm]
Fresh Italian Linseed oil (uncured)	**76.7 +- 1.0**
Brown Linseed oil taken from Layer7 (uncured)	**2.1 +- 1.0**

- The brown "sticky" Linseed oil found along the edges of the old-style FW Layer 7 has an extremely low resistance.

Combine two bad effects: one being an increase of the Bakelite resistance, and one being lowering the Linseed oil resistance ?

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary.pdf).



A button is covered by the "brown gui Linseed oil blob" and the Bakelite resistance changed by a factor of 3x:

$$R_{Bakelite} = \rho_V\,(t_{gap}\,/\,\text{Area}) \sim \mathbf{3\ x}\ 2.5\ \text{x}\ 10^{11}\ \Omega.\text{cm x}\ (0.2\text{cm}/100\text{cm}^2) \sim 1.5\text{x}10^{9}\ \Omega$$

$$R_{\text{Linseed oil blob}} = \rho_V\,(t_{gap}\,/\,\text{Area}) \sim \mathbf{2.5*10^{8}\ \Omega.cm}\ \text{x}\ (0.2\text{cm}/0.1\text{cm}^2) \sim 5\ \text{x}\ 10^{8}\ \Omega$$

$$\Rightarrow \mathbf{V_{GAP} = V_{PS}\,/\,(1+3*2*5*10^{8}\,/\,5\text{x}10^{8}) \sim V_{PS} * 0.14}\quad \mathbf{!!!!!!!!}$$

Is there some evidence for the Freon-based chemistry affecting the Linseed oil surface resistance in the new-style chambers ?

(J.Va'vra, http://www.slac.stanford.edu/~jjv/activity/babar_rpc_my_summary_1.pdf)

- Study of an area near spots resembling the beam tree pattern. It feels "mushy and sticky" to a touch in these sections.

Method:

Results:

Anode spot #	Description	R [Ohm/square] at 1000 Volts
1	Whisker with a beam tree	~6 x 10^10
2	Button with beam tree	~5 x 10^10
3	Reference spot #1	~20 x 10^10
4	Reference spot #2	~30 x 10^10

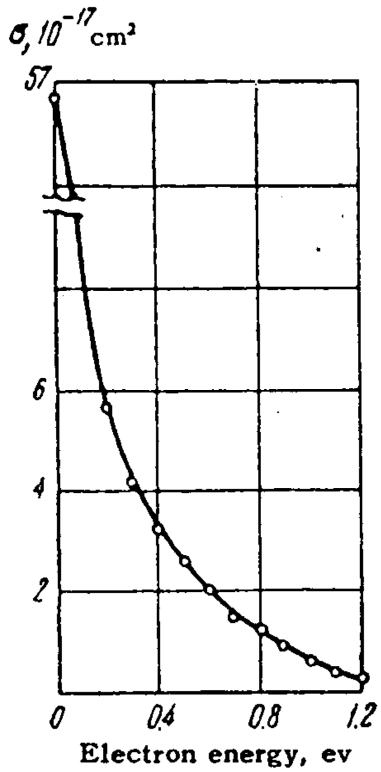
- The region close to a beam tree spot has 5-times smaller surface resistance compared to the reference spots.

Alternative "Freonless" gas mixtures

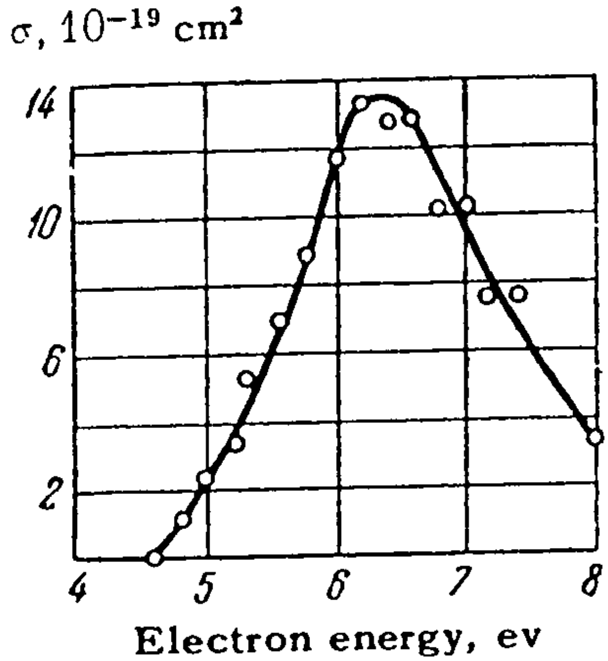
- Examples of gases with a large electron capture cross-sections:

I.S. Buchelnikova, Soviet Phys. JETP 35(8)(1959)783.

a) SF_6



b) Oxygen

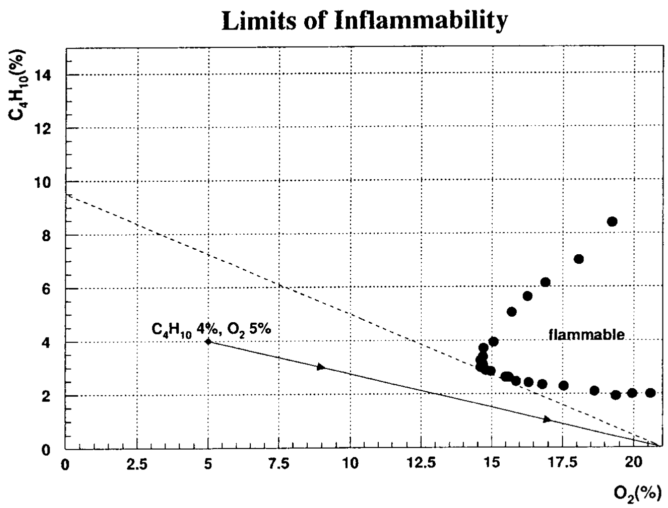


- Oxygen starts capturing electrons when they reach energy of 6-7eV. The CF_6 cross-section peaks already at 0eV.

1. Oxygen – based mixtures:

- Oxygen-based mixtures can be flammable:

M. Ueki, Tohoku University Master's thesis, Jan. 1999.



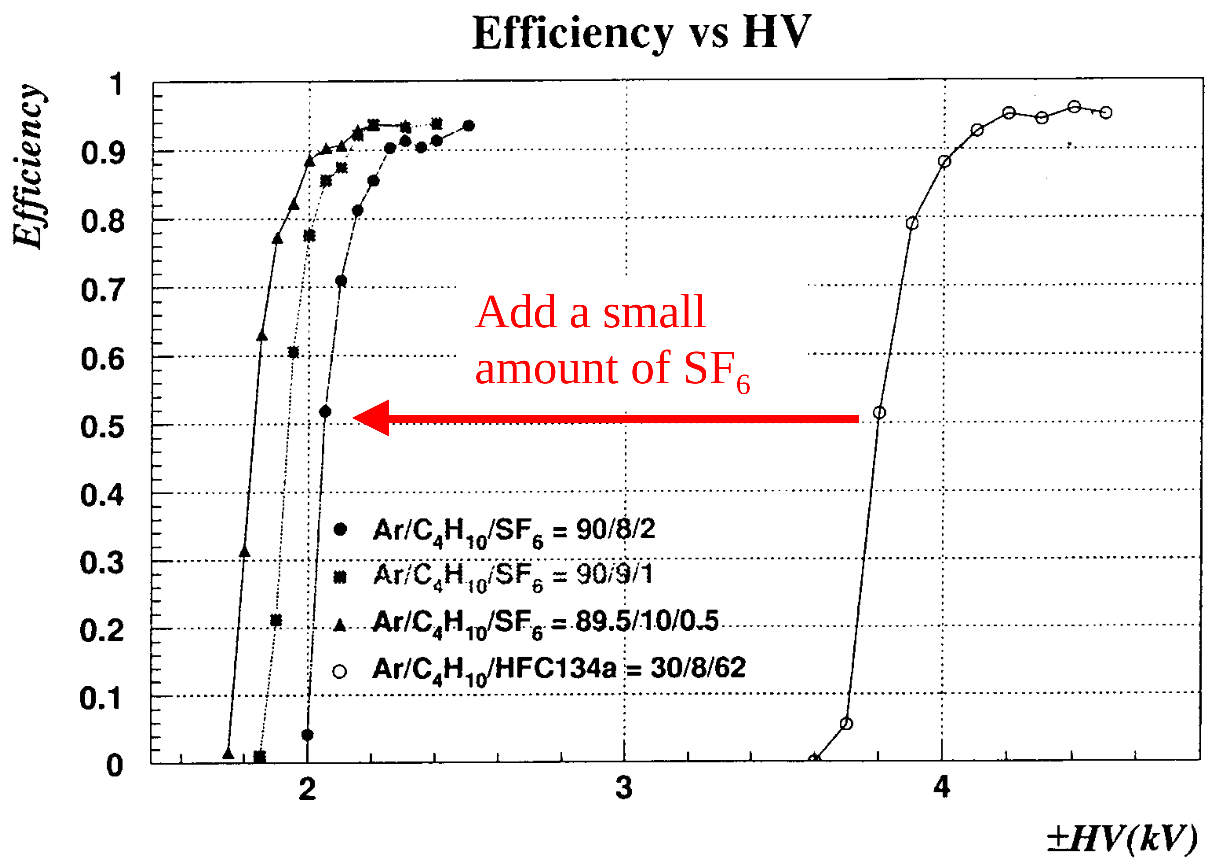
M. Ueki, Tohoku University Master's thesis, Jan. 1999.

gas fraction (%)				*efficiency (%)*	*flammablity*
C_4H_{10}	Ar	CO_2	O_2		
8	30	31	31	88	Yes
		60	2	77	No
4	20	56	20	77	Yes
		66	10	66	No
		76	0	60	No
	10	86	0	60	No
0	20	40	40	10	No
	10	45	45	12	No
	4	48	48	12	No
	0	50	50	13	No
		10	90	14	No
C_4H_{10}	Ar	$HFC134a$			
8	30	62		93	No

- Oxygen-based mixtures are less efficient.

2. SF_6 – based mixtures:

M. Ueki, Tohoku University Master's thesis, Jan. 1999.



Advantage of SF_6 gas additive:

- Smaller voltage.

Obvious question:

- Is there some complicated chemistry?

Present R&D with SF_6-based mixtures:

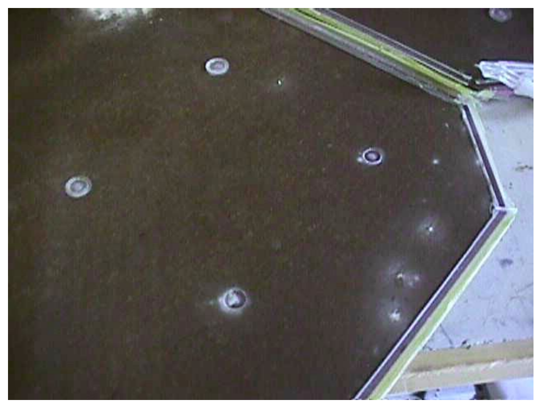
- Santonico: (83% Ar/10%$C_2H_2F_4$/7% iC_4H_{10})$_{premixed}$ + 0-1.6% SF_6.
(R. Santonico, Scient. Acta XII N2(1997)1, and
G. Aielli et al., submitted to Nucl. Instr. & Meth. June 2002.).
- ATLAS: 96% $C_2H_2F_4$ + 3.5% iC_4H_{10} + 0.5% SF_6.
- ALICE: 49% Ar + 40%$C_2H_2F_4$ + 7% iC_4H_{10} + 1% SF_6.

Whiskers and the gas choice?

BaBar "belt" chamber

New RPC chamber installed in 2002 (it has developed a large noise rate right away).

- Observe whiskers on the cathode only.
- Anode has mating marks.

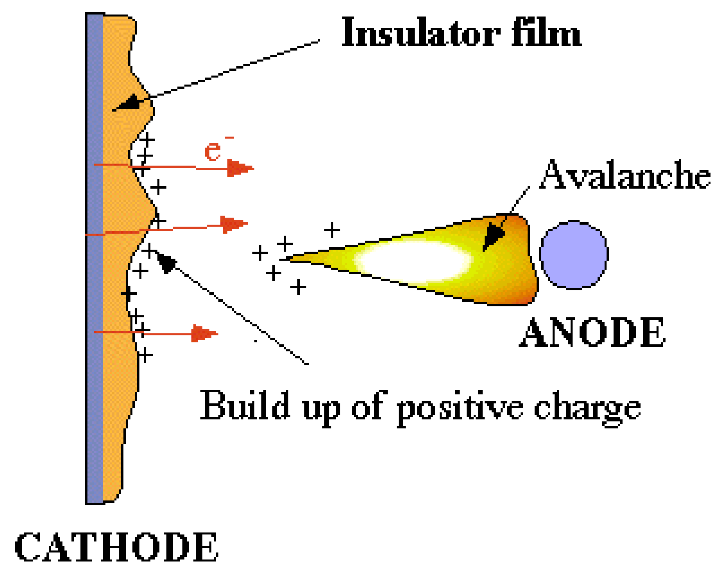


- Example a remedy using a gas:
  MarkIII treatment of whiskers with HRS gas (90% Ar+9%CO_2+ 1%CH_4). I would use 90Ar+10%CO_2.

- Should we have a large content of argon the mixture ?

Malter effect & insulator on the cathode:

Metallic chamber:



- The time constant describing the neutralization of the positive charge is RC ~ $\varepsilon_r \varepsilon_0 \rho_V$, where ρ_V is resistance of the film, and ε_r is relative dielectric constant.

1) For $\varepsilon_r \sim 4$, $\varepsilon_0 = 8.87$ pF/m, $\rho_V \sim 10^7\ \Omega$.cm:
RC ~ 350 μsec
2) For $\rho_V \sim 10^{11}\ \Omega$.cm: RC ~ 3.5 sec
3) For $\rho_V \sim 10^{13}\ \Omega$.cm: RC ~ 350 sec ~ 5-6minutes !

- This may lead to the Malter effect, which is a secondary electron emission from cathode.

- Is there an equivalent mechanism in an RPC chamber?
(I can certainly see a micro-crack in the Bakelite as a model of a relaxation sparking oscillator).

Conclusion:

- Clearly, to build a new "high rate" RPC system, one needs more R&D work. LHC chambers has only 5 minutes before 12!

- To keep the Bakelite resistance within limits, I propose to flush the RPC chambers with very humid air or nitrogen of ~80% relative humidity during the long summer shutdowns while high voltage is off (~60% rel. humidity might not do it).
- I would not try to add humidity into the chambers while operating at high voltage because of a possibility of the Freon-based chemistry in plasma environment.
- I would not add large humidity while running high voltage also because of a possible breakdown on the buttons.

- I would choose lower resistance Bakelite. However, my latest tests indicate that its resistivity also change!

- Need to study the alternative gases.

- A float glass RPC may perform just well enough at <u>low rates</u>.

- A Bakelite RPC may also perform well at <u>low rates</u>. I would redesign the buttons though.

- Sparking can cause local problems. It can be triggered by defects such as dirt, whiskers, poor construction, or possibly even the Malter effect (the "RPC style").