Failure modes of resistive plate chambers

Outline

- Resistive Plate Chamber (RPC) operation
- Mechanical tolerances
- Failures due to resistivity changes – eg Oil bridges
- Aging in new production BaBar RPCs
- Malter effect
- Water in glass RPCs
- Conclusions

RPC operation

- Number of electrons at the head of shower is given by

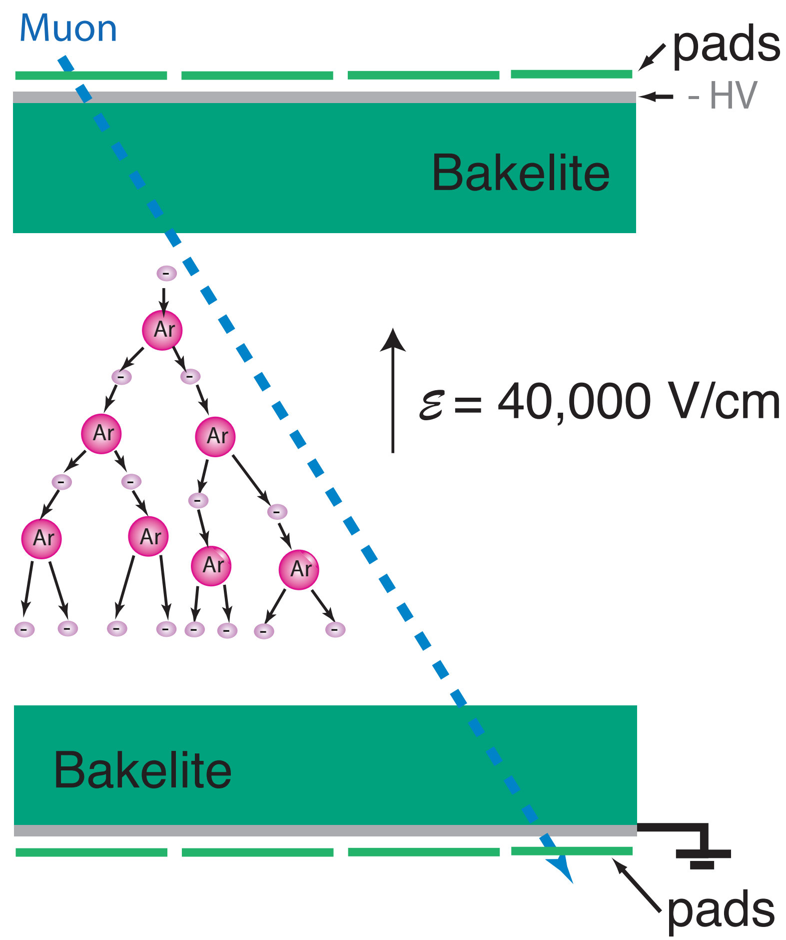
$$n_e = e^{\alpha \ell}$$

where α is the Townsend coefficient (depends on gas and $\mathcal{E}$) and ℓ is the shower length

- Streamer mode (space charge dominated discharge) occurs when

$$\alpha \ell \simeq 20 \qquad \Rightarrow n_e = 5 \times 10^8$$

- Streamer is limited in part by the high resistivity of the bakelite



Typical gas mixture

- Argon to provide for efficient gas amplification
- Isobutane (or another hydrocarbon) to absorb UV photon
- Freon (e.g. 134a , $C_4H_2F_4$) "quench gas", controls charge and physical size of streamers

- The detectors will operate over a very wide range of these gases.
- The Isobutane fraction can be as low as 4%

Caution: flammable mixtures easily produced, especially at low 134a fractions!

- Streamer production relatively tolerant to N_2, O_2 and H_2 O contamination

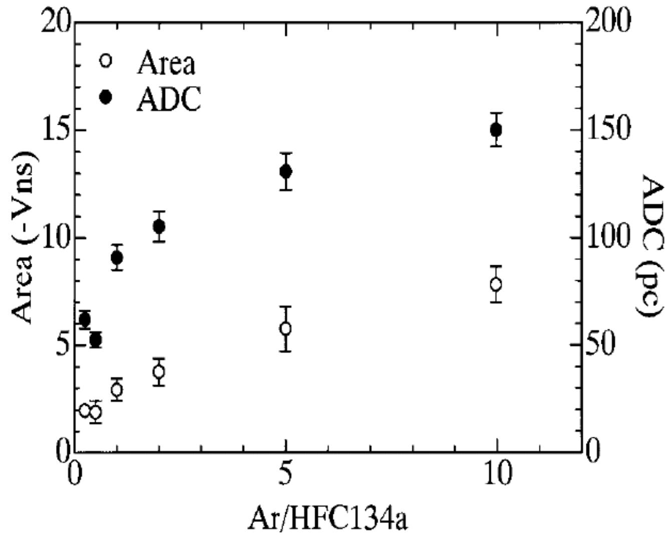
• The ratio of Ar/134a can vary from 10 to 0.25

• Streamer charge and size (area is in mm^2) increase with Ar fraction.

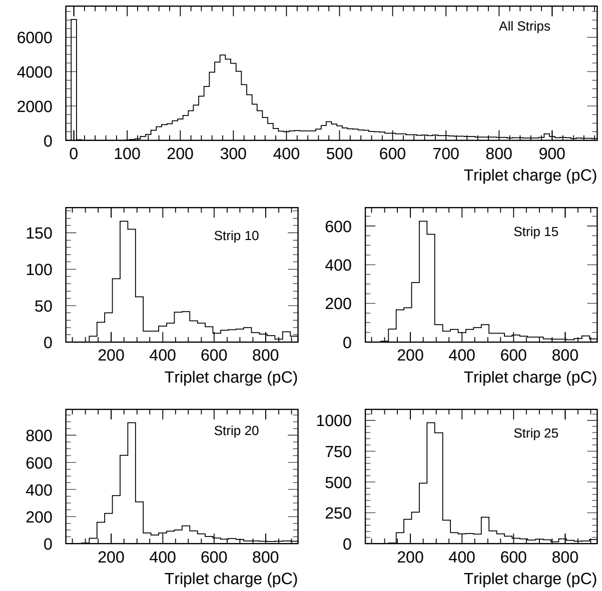
• Charge distributions of streamers is relatively narrow

• Fraction of double streamers small

• Charge distributions of avalanches exponential in parallel plate geometry



2001 NSS, Onodera, et al.



Bakelite (or glass) resistivity controls time needed (typically milliseconds) to rebuild field after a streamer occurs

In BaBar bakelite was required to have

$$\rho = 28 - 120 \times 10^{10} \Omega\text{cm}$$

at 20° C. Resistivity of bakelite varies substantially with both humidity and temperature. Higher resistivities can be used for cosmic ray detectors.

The temperature effect is large:

$$\Delta\rho/\rho \sim -10\%/\ ^{\circ}C$$

It is speculated that at high temperature streamers lower values of ρ can lead to large discharges and significant aging of the detectors.

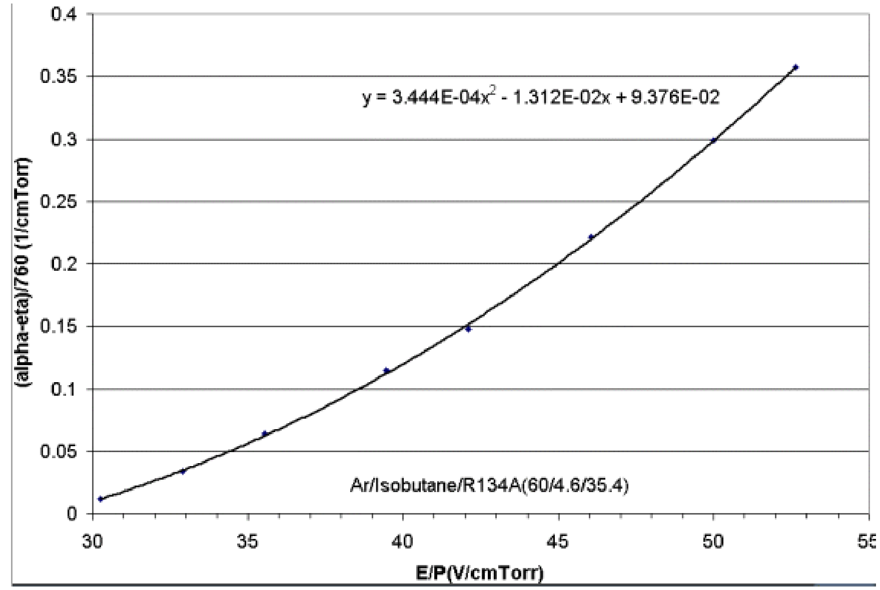
Mechanical Tolerances

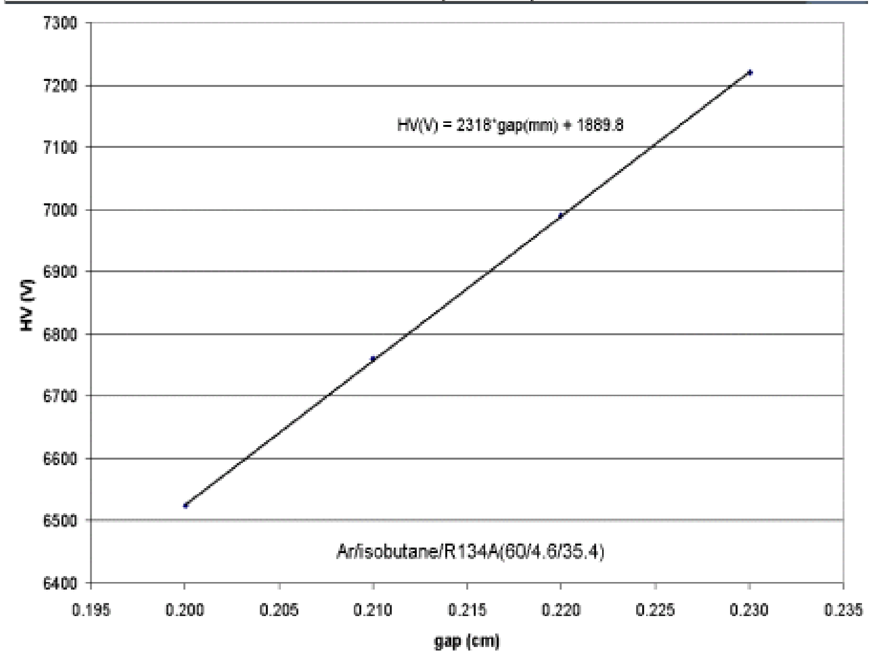
- Townsend coefficients rapidly increase with electric field (from Imonte simulation)

- If gap width increased, Townsend coefficient decreases faster than streamer length ℓ increases

- Chamber becomes inefficient when $\alpha\ell < 20$

- This analysis courtesy of C. Lu, Princeton





Basic result:

$$\frac{\mathrm{d}V}{\mathrm{d\ gap}} \simeq 2300\mathrm{V/mm}$$

In Babar a few "popped buttons" (unglued spacers) can easily lead to a 3mm gap width rather than the nominal 2 mm width.

• To avoid excess aging chambers should be kept no more than 500 V above streamer threshold

$\Rightarrow$ **mechanical tolerance of only 200 μm**

Problems associated with linseed oil coating

- Linseed oil coatings of inner surface lower the current drawn through the gas and singles of rates of the detectors by a factor of 5 to 10.

- The linseed oil is thought to provide two functions:

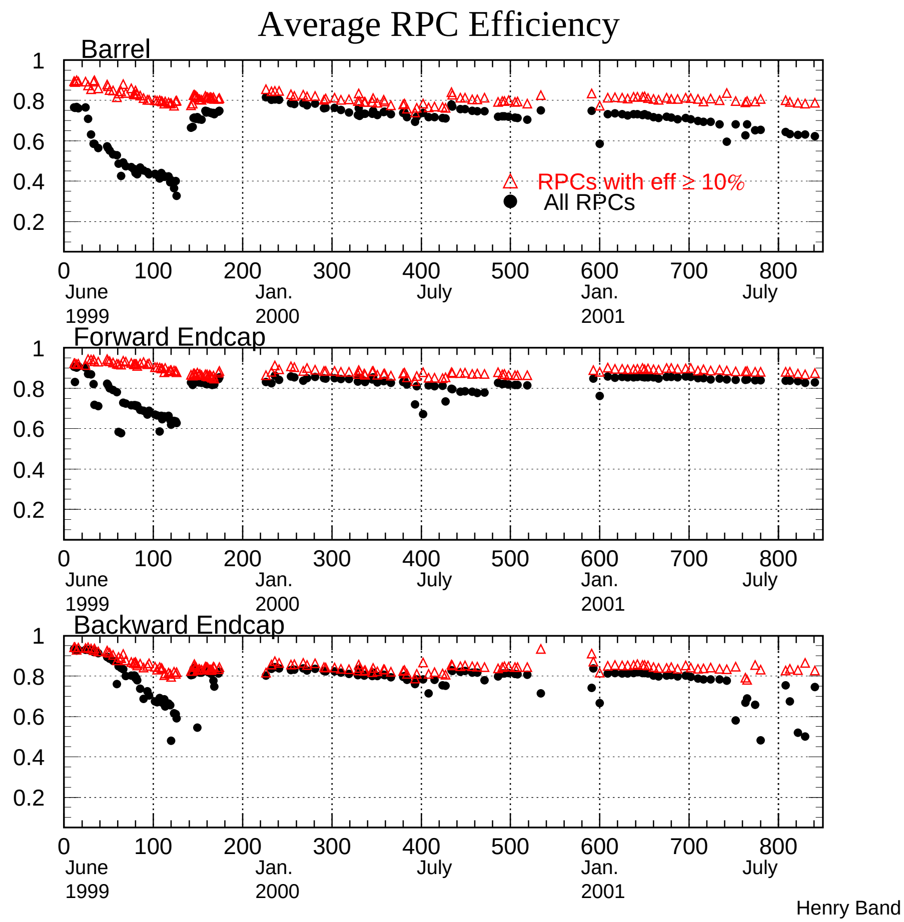
    - It makes a smooth inner surfaces leading to a more uniform electric field
    - It can absorb UV photons produced in the avalanche

- Main advantage of glass RPCs is that they avoid this coating

Babar problems
Possibly due to linseed oil bridges

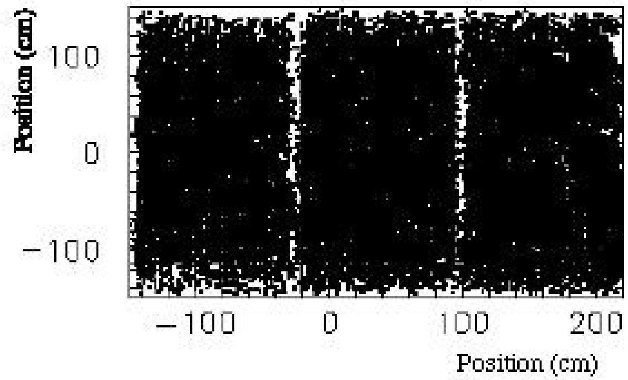
- Temperature rose to 36° C in the experimental hall
- Currents increased
  ⇒ Many chambers temporarily disconnected
- Efficiency can be increased by lowering amount of Freon
  ⇒ See 200 and 420 days
- But efficiency still declines continuously

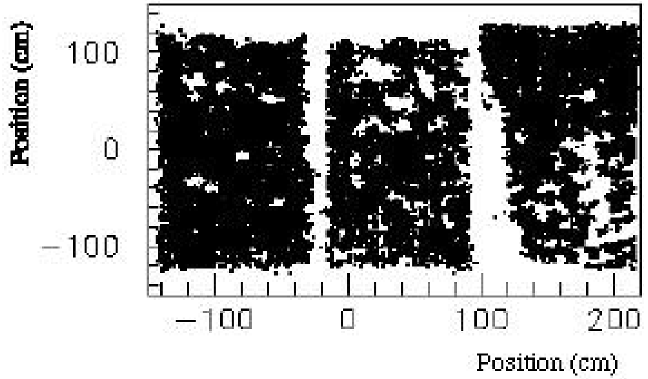
Efficiency History



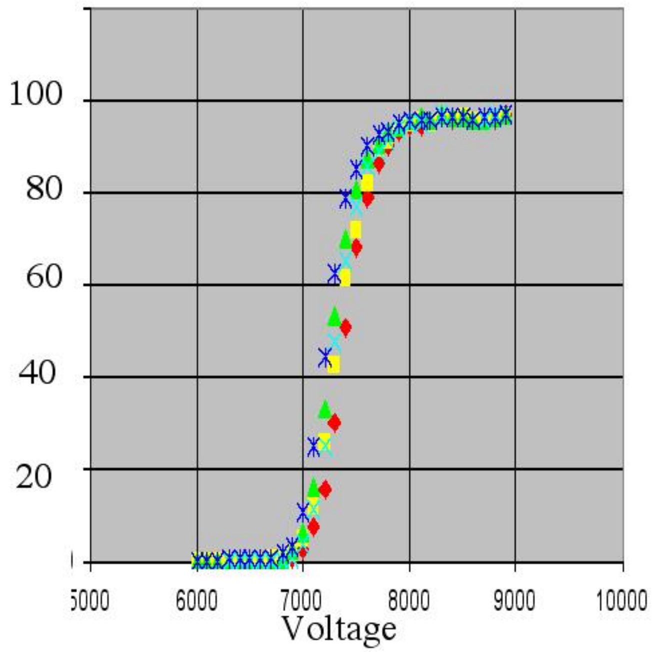
Efficiency Maps

- Inefficiency appears to be mainly concentrated around edges of the chambers
- There is some evidence that the efficiency also occurs near the rows of spacers
- High voltage plateau's become very broad

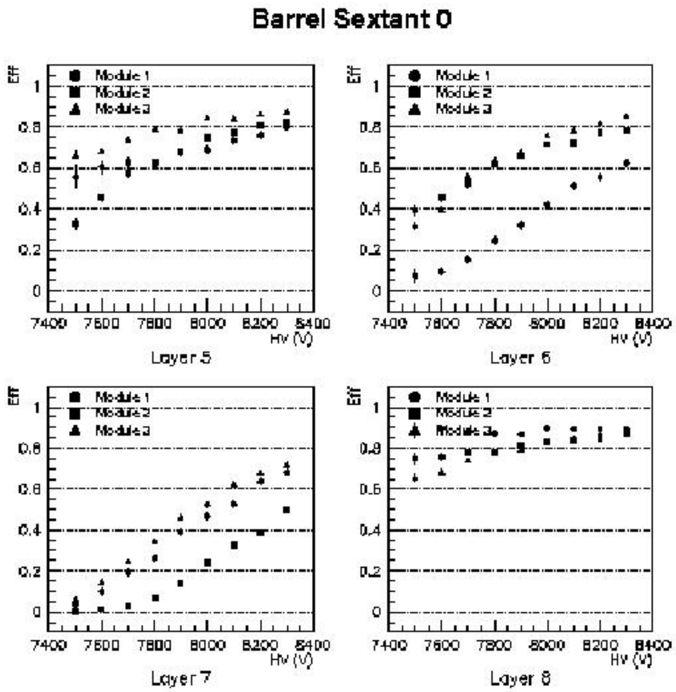




Efficiency Plateaus



During original testing

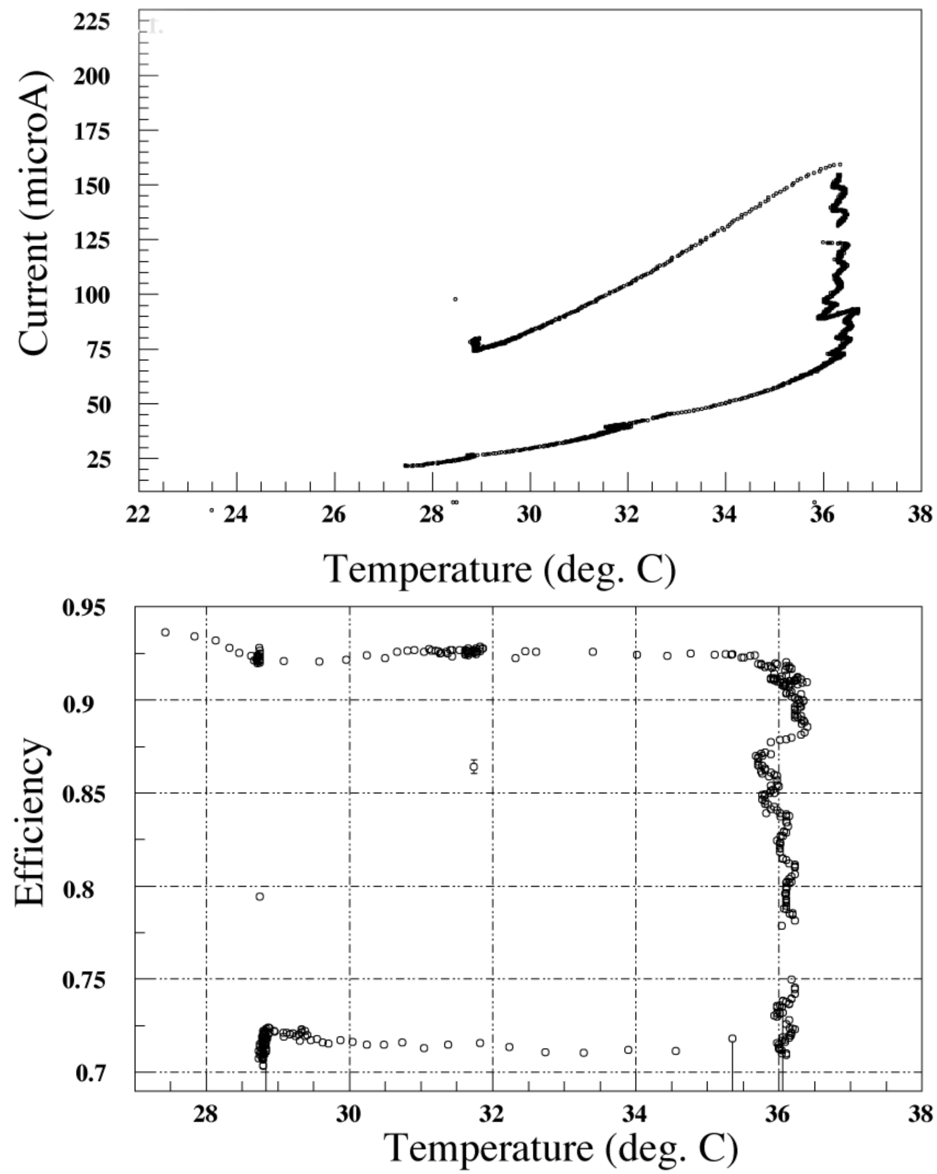


After operation in BaBar

Test Stand Studies

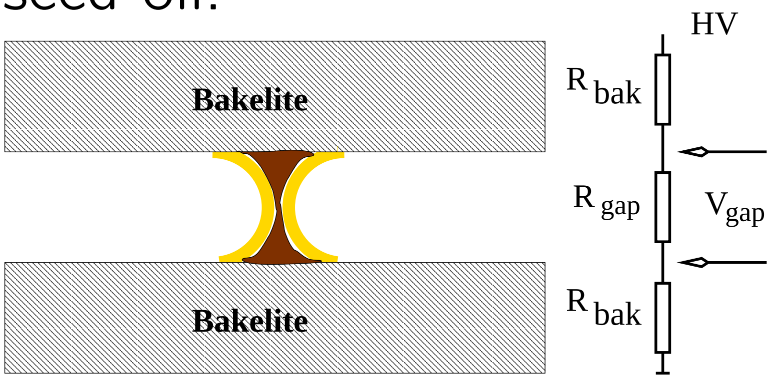
- Can we reproduce the problems in the lab?
- SLAC test stand shows that trigger chambers made prior to the BaBar production are sensitive to heat.
- Other tests (e.g. at Oregon) show that damage can be done to chambers at temperatures of only 28° C

  ⇒ **Problems could occur even at moderate temperatures!**

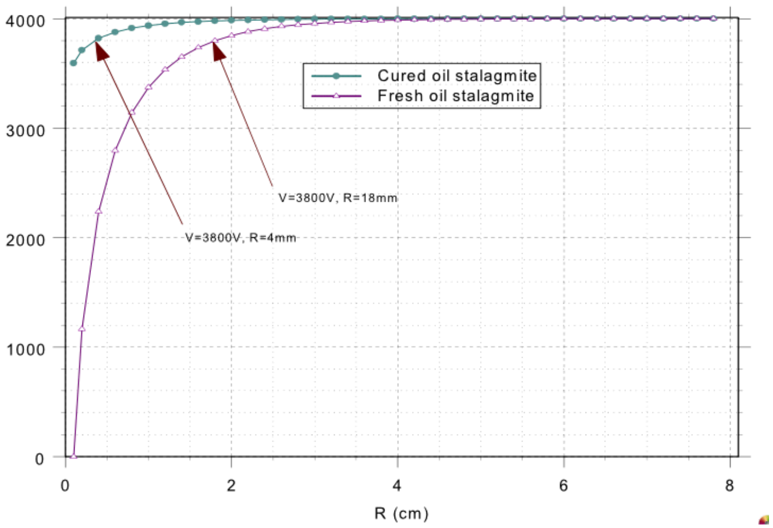


Materials Studies and Models

- Effects of linseed oil columns will depend on the resistivity of the linseed oil:



- A model of high and low resistivity linseed oil columns:



⇒ The resistivity of linseed oil depends on how it has cured and if contaminants are present

Sample	resistivity $[10^9 \Omega cm]$
polymerized US linseed oil (skin/oil mix)	145.9
US linseed oil (cured in air for 30 days)	42.3
US linseed oil (cured in air for 3 days)	27.9
uncured US linseed oil	14.4
uncured linseed (production oil)	7.7
uncured oil (removed from bad RPC)	0.21

measurements from SLAC and Princeton

Unclear why oil removed from bad RPC has so low resistivity

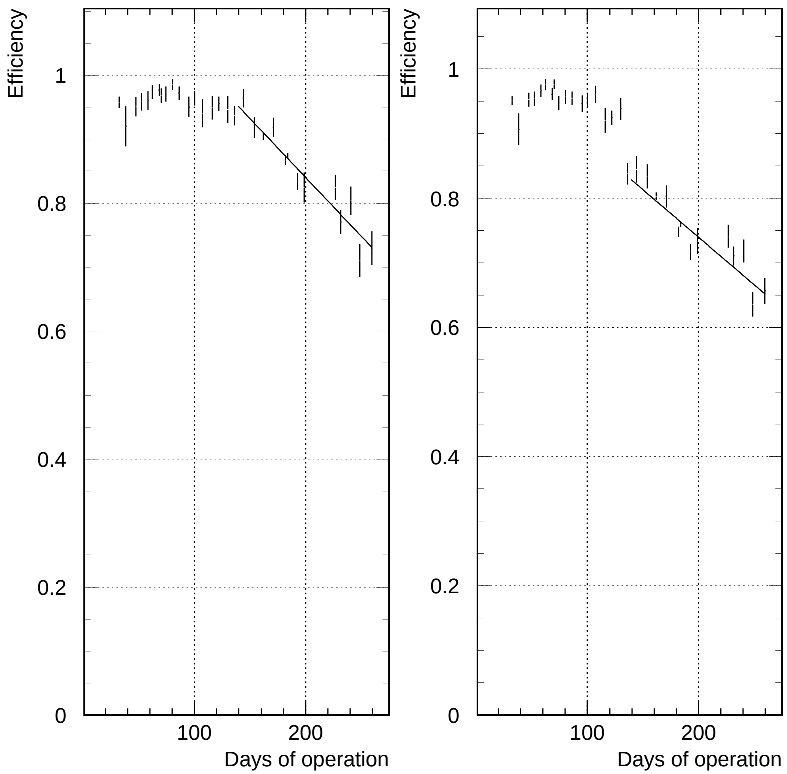
Experience with prototypes for endcap replacement

- 24 endcap modules (12 chambers) were replaced with prototypes 12/00
- The prototype chambers have a **single** coat of **30% linseed oil**, 70% pentane.
- Inner surface of opened chambers smooth
- Some damage seen in one of two chambers heated in test stand

⇒ Thinner linseed oil surface more sensitive to dust, contamination

- Modules in the shallow layers of the detector have stable, good efficiency

Efficiency (no beam) for layer 18 prototypes



• Modules in the deepest layer of the calorimeter show significant damage after ~ 120 **days of operation.**

• The layer 18 prototypes were exposed to high levels of background from beam processes.

• Since detailed monitoring began, the charge through the gas has grown linearly with time.

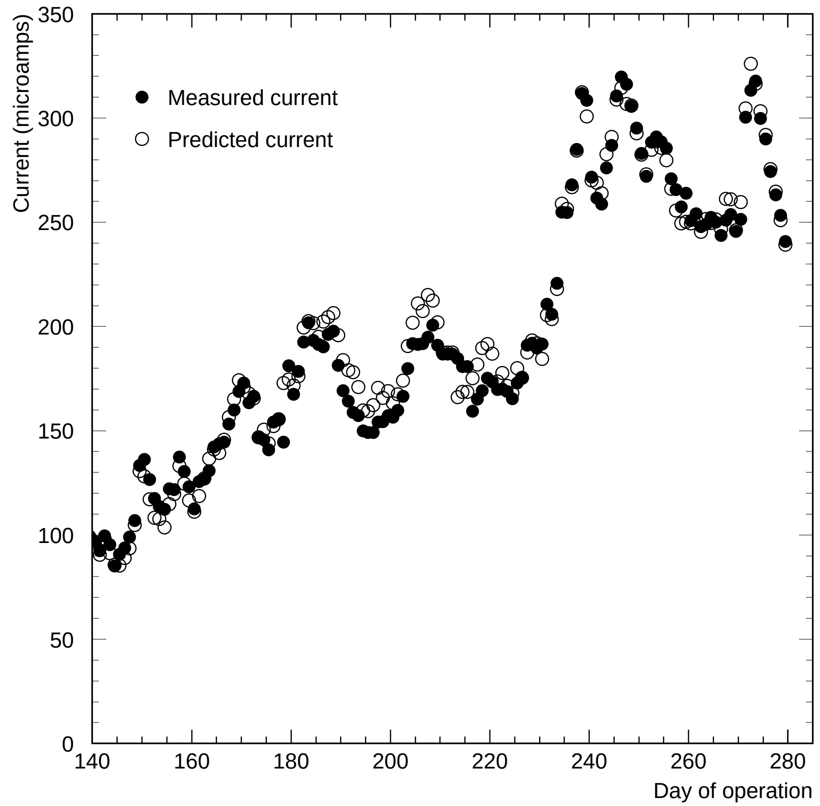
• The decline in efficiency started at about 120 days corresponding to $\sim$500 C/m^2 ($\sim 10^8$ streamers/cm^2) in the gas.

• A model which takes the temperature of the leakage current into account and which assumes that

$$I_{\text{leakage}} \propto Q_{\text{gas}}$$

describes the data well.

⇒ Can this model explain the decline in efficiency?

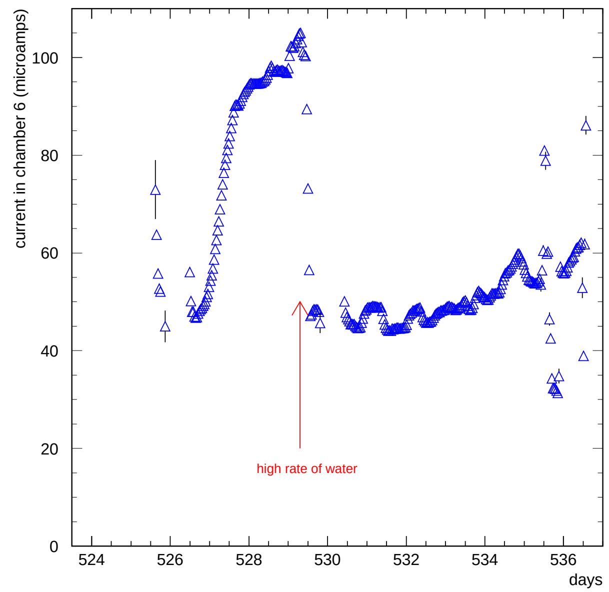


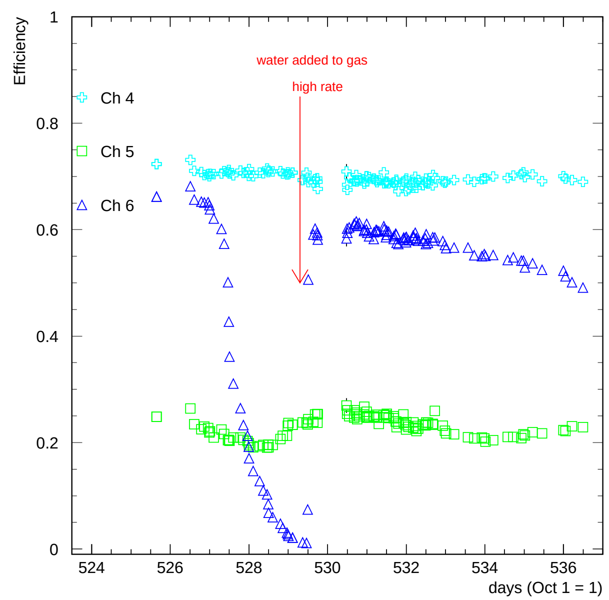
Predicted and measured current at injection.

Voltage 7250 V

- Water vapor (70% relative humidity at 20°) was added to the gas of test stand chamber 6 on day 528. Rate was nominally 1 cm^3/min, but was much lower for chamber 6 because it is somewhat leaky.
- **On day 529 a high rate of gas was flown through chamber 6**

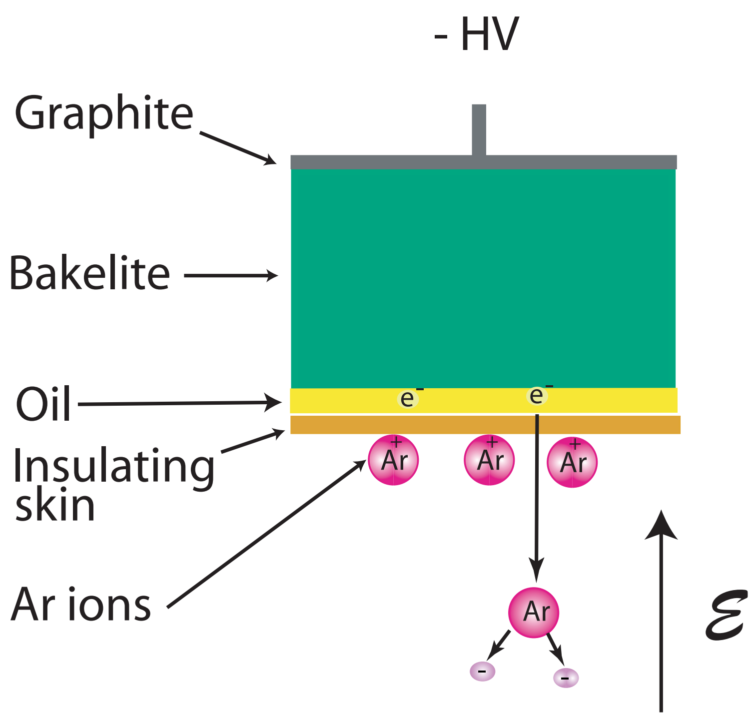
  (flow rate off-scale on flow meters, $\sim$ 15 cm^3/min)
- **Current immediately decreased in 6**
- **Efficiency immediately improved in 6**





Discussion

The observed behavior of chamber 6 is consistent with the Malter effect:



- Chamber current locally depletes charge carriers in linseed oil skin

- Ions collect on the insulating linseed oil surface

- Accumulated ions will produce a large electric field across the linseed oil surface

- Electrons can then be accelerated into the gas volume where avalanches are produced (Malter Effect)

- The large current from Malter electrons keeps the gap voltage below streamer threshold. **A large current and inefficiency is observed**

- Adding water vapor to the gas decreases the surface resistivity of the linseed oil and prevents the accumulation of ions

- The Malter Effect also explains a common phenomena observed with many chambers: when the chambers are first switched on their efficiency decreases and the current increases

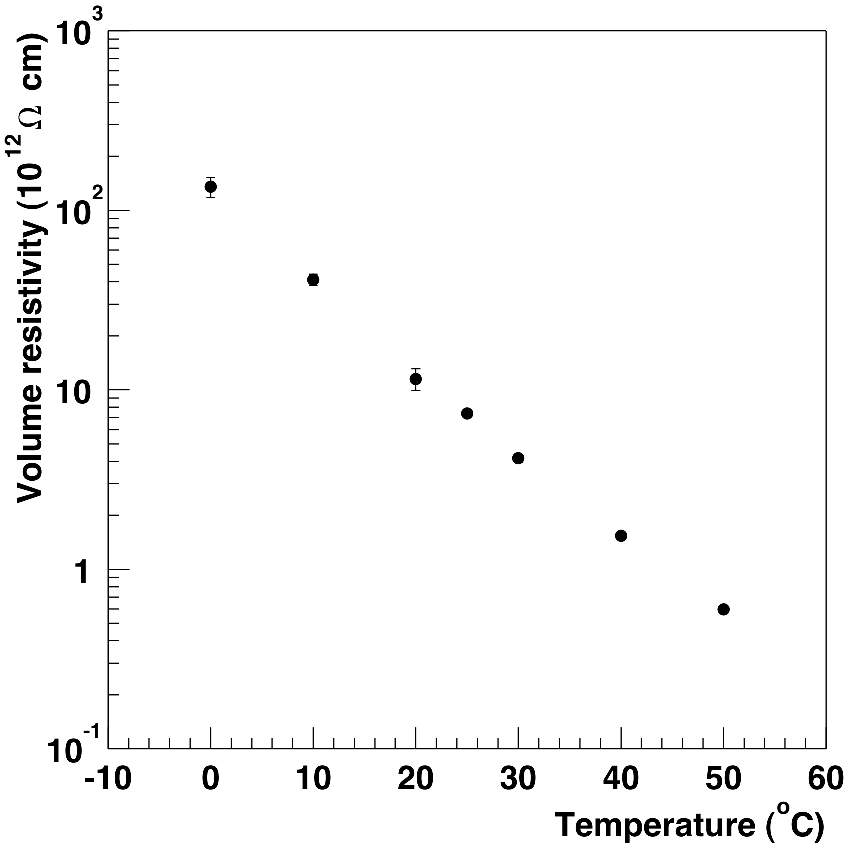
- The increased current occurs as the ions collect on islands of insulator on the linseed oil surface causing the Malter Effect

- As the chambers become drier, these islands become larger due to the depletion of ion conductivity (see Jerry's Notebook).

- On 2 of 3 chambers tested, the water had no effect

Glass RPCs

• "Float glass" has resistivity of roughly 10^{12} Ω cm, comparable to the higher resistivity bakelite



Hoshi, et al

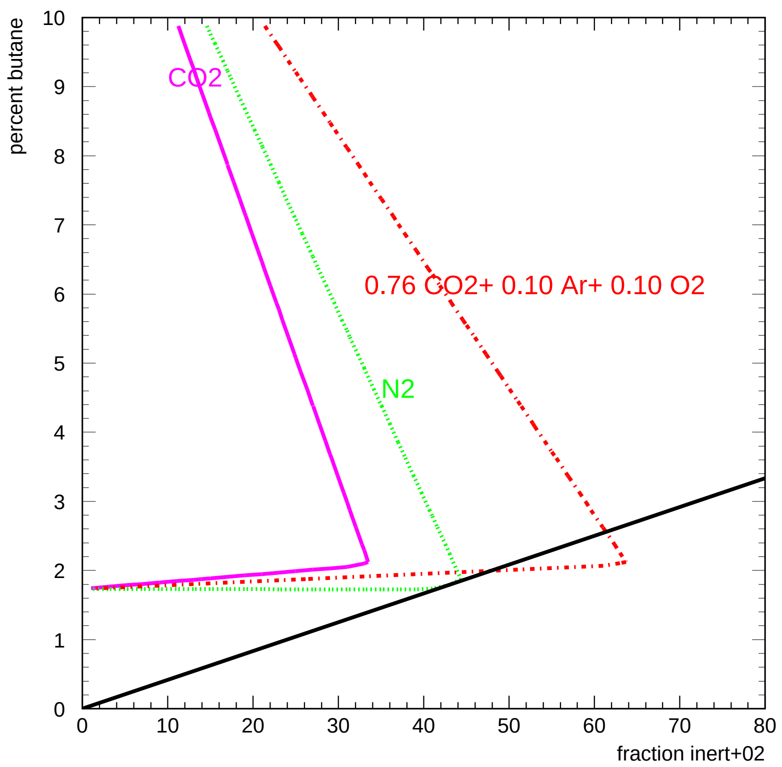
• In the Belle experiment, it was found necessary to control any mosture in the glass very tightly. Reportedly

- Water can combine with Fluorine which forms in the streamers to produce HF
-HF can etche the glass allowing for the adsorption of water onto the glass etch
-The water forms a conducting layer which "shorts" the surfaces to nearby spacers, reducing the gap voltage below streamer threshold.

Gas without freon 134a can be used (Hoshi et al.,) eg:

4% isobutane, 10% O_2, 10% Ar and 76% CO_2 has 90% efficiency instead of 95% for freon based mixtures.

Caution: a simple analysis based on adiabatic flame temperatures and complete combustion indicates that this mixture may still be flammable.



Conclusion

- Results are mixed for large scale deployment of RPC
- Detectors are relatively inexpensive, but are not "easy to build" – careful QA/QC needed during production
- Double gap chambers are more robust against failure
- Must be able to replace faulty RPC chambers during the lifetime of the experiment.