BESIII RPC Aging Study

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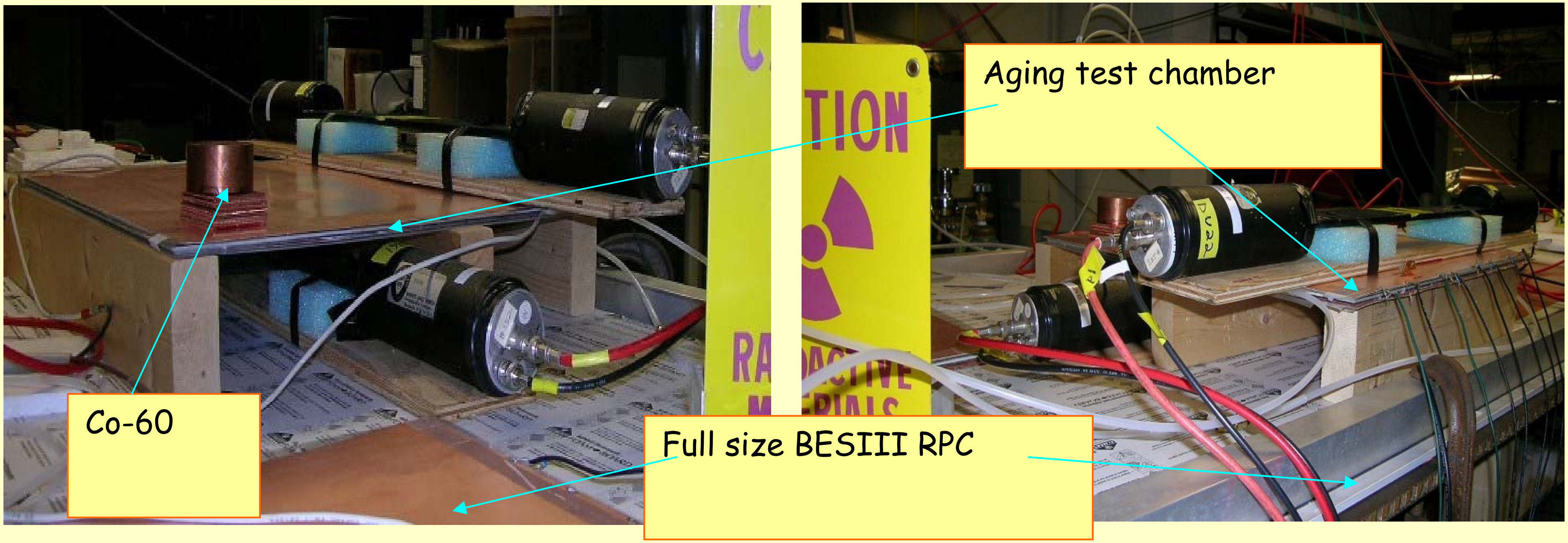
Outlines

- Aging test on one new RPC prototype:
  - First round of the source test results;
  - Second round of the aging test results;
  - HV training studies;
- Aging test on four new RPC prototypes;
- Aging test on an oiled RPC prototype;

(1) Aging test on one new RPC prototype

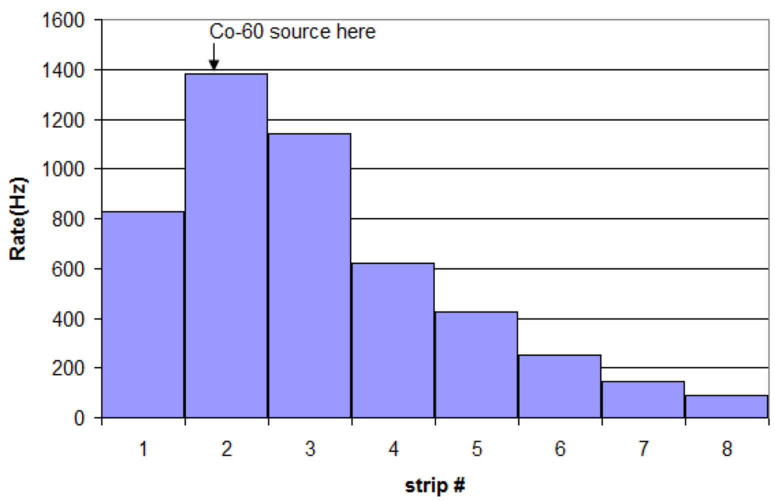
Aging test setup

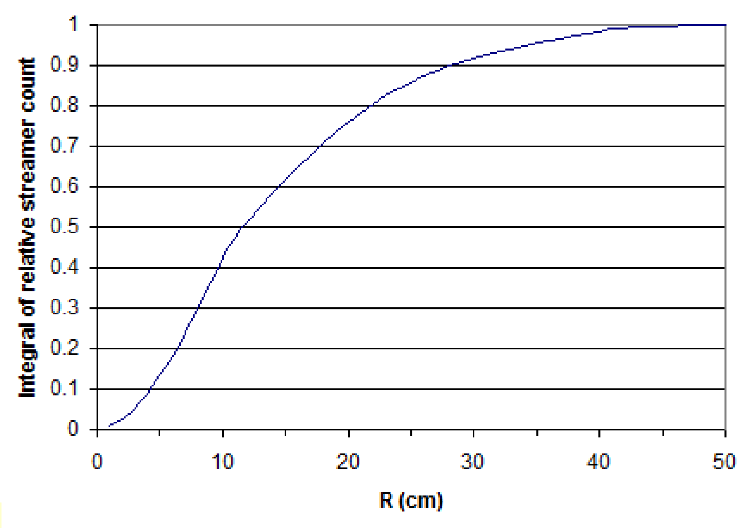


Aging test chamber and a full size BESIII RPC with the Co-60 source and trigger counters.

Measured streamer distribution

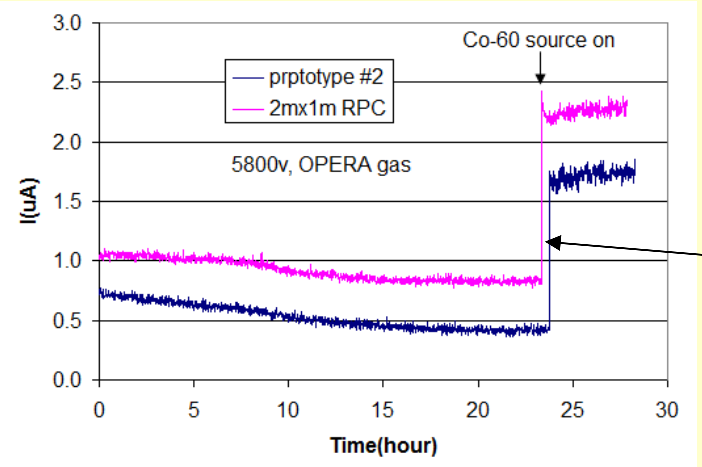
The measured streamer-rate distribution among 8 strips (6cm wide each) was surprisingly broad, did not resemble the gamma-ray distribution.





Due to the limitation of the streamer-mode RPC rate capability, this distribution does not reflect the γ ray intensity distribution. We use the measured rate distribution among the strips to simulate the streamer distribution in the RPC, then use this distribution to estimate the aging dose for the RPC. It indicates 40% of total dose is concentrated in a 10cm radius circle.

Aging dose

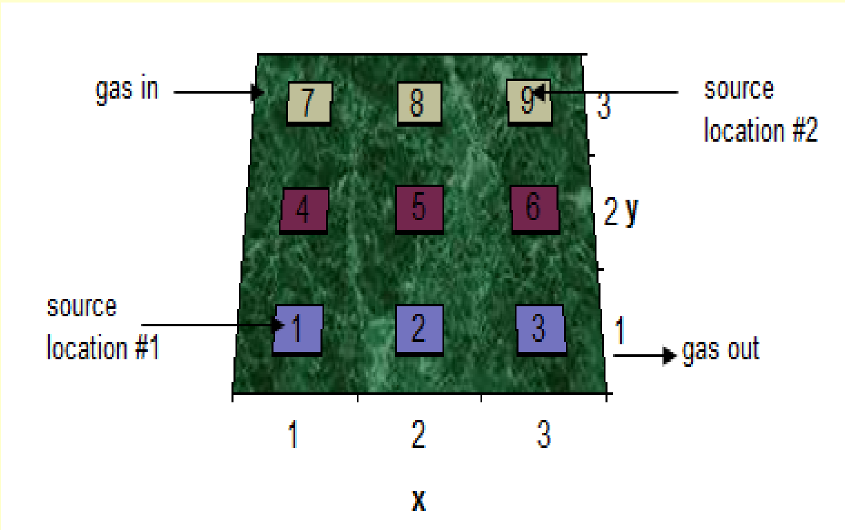


This jump is due to the source, 1.3μA x 40% = 0.5μA concentrated on 10cm radius circle area.

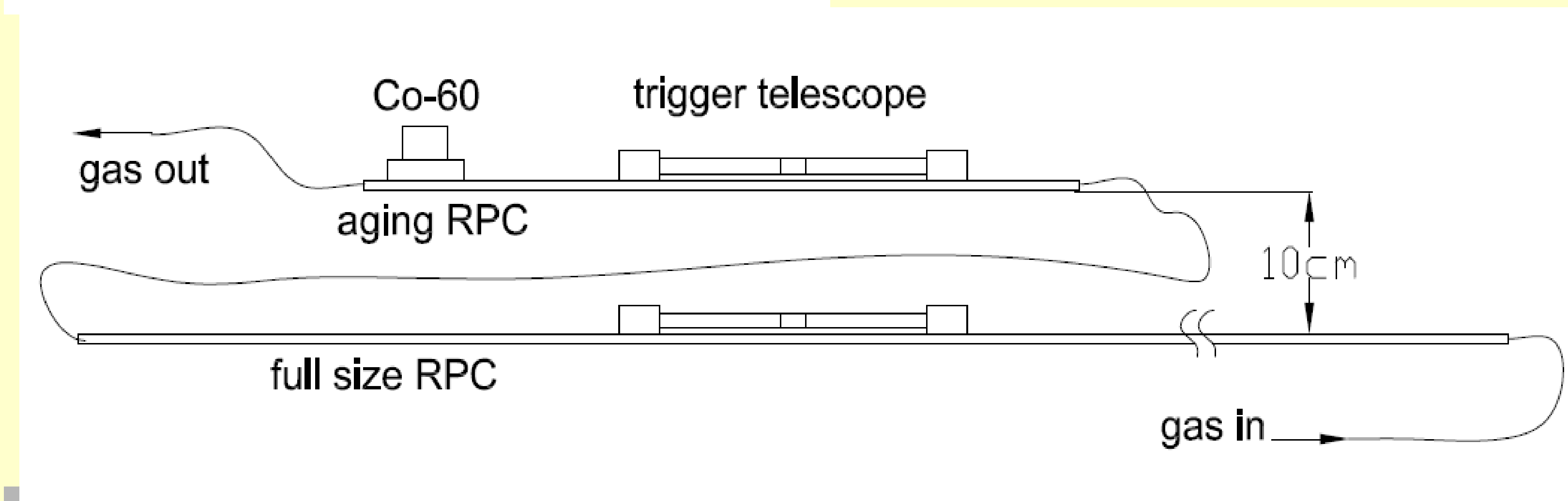
The chamber currents, before aging, showed a jump of about *dI* ~ 1.3 μA when the Co-60 source was applied at hour 24.

~ 40% of the streamers were concentrated in a circular region of radius R = 10cm. The current dose/area can be calculated: $0.5\mu A \cdot 3600 \cdot 24/\pi R^2$ ~ 140 μC/cm2/day ~ 4.1 mC/cm^2/month. If we assume 500 pC/streamer, the noise rate of RPC was ~ 2kHz/2m^2 ~ 0.13mC/cm^2/month. Thus the aging-test dose was ~ 30 times the background dose. Roughly speaking, one month of the aging test was equivalent to 30 months of normal background operation..

Aging test chamber

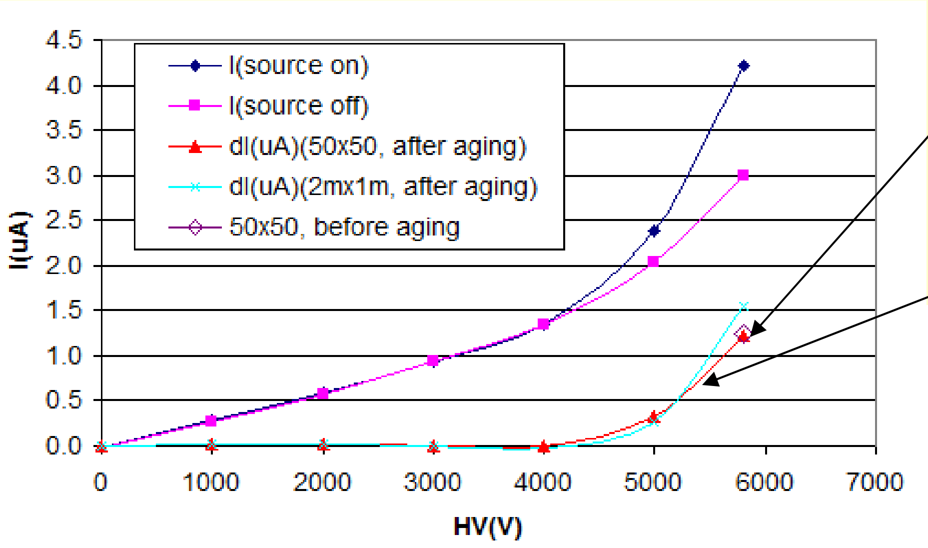


9 regions marked as 1, 2, …9 for efficiency and dark current test. Two source locations. Notice the gas inlet and outlet locations.



First round aging test results

Aging chamber dark current at 5800V, w/ and w/o source.

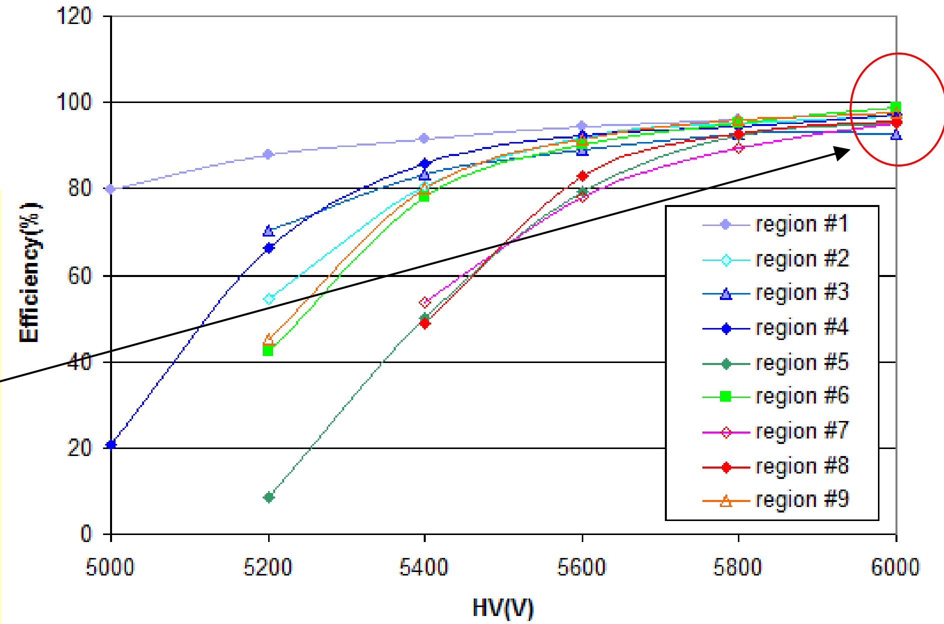


Before aging

There is no noticeable change after the first round aging test.

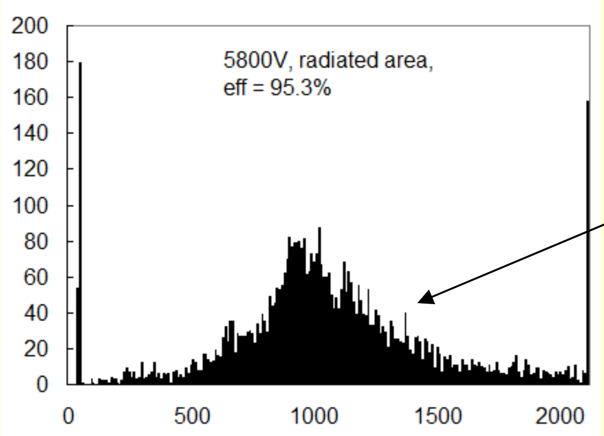
After 30 days aging,

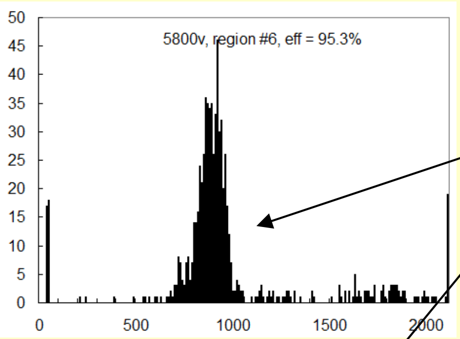
efficiency plateau curves of 9 regions.

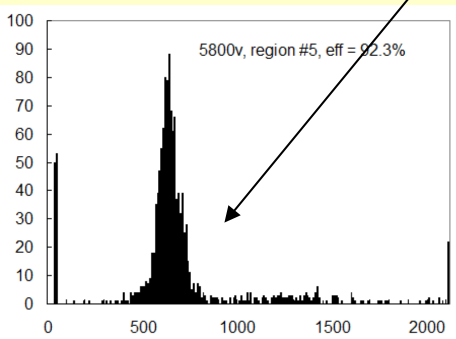


Efficiency plateau starting points are quite different for different regions, but at 6000V all of them are above 90%.

First round aging test (cont'd)







We also measured the peak spectrum for 9 regions.

A noticeable spectrum distortion can be seen for the aged region #1. The spectrum on radiated region shows a very broad distribution, although the efficiency is still high, but the distorted spectrum may reflect the aging damage to the internal electrode.

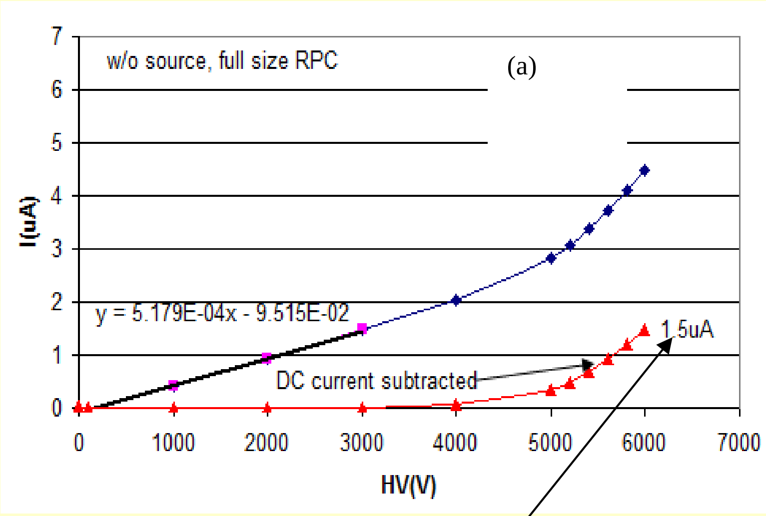
The other two spectra, triggered on the unradiated regions, show a narrow distribution, which is a typical streamer distribution.

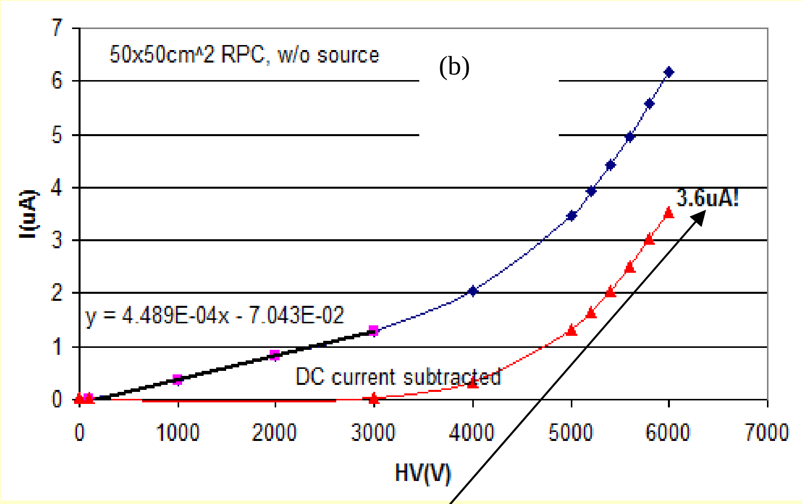
We didn't record the peak spectrum before the aging, not sure if this is solely due to the aging, or may be just due to the bad region originally.

Second round of aging

To make sure if the aging effect (charge spectrum distortion) is real, we started a second round of aging test on 8/18/2008, this time placing the Co-60 source on region #9. The second round of aging lasted for ~ 30 days. The HV was set at 6000V.

After only 16 days another aging effect took place: the dark current of the aged RPC became much larger.



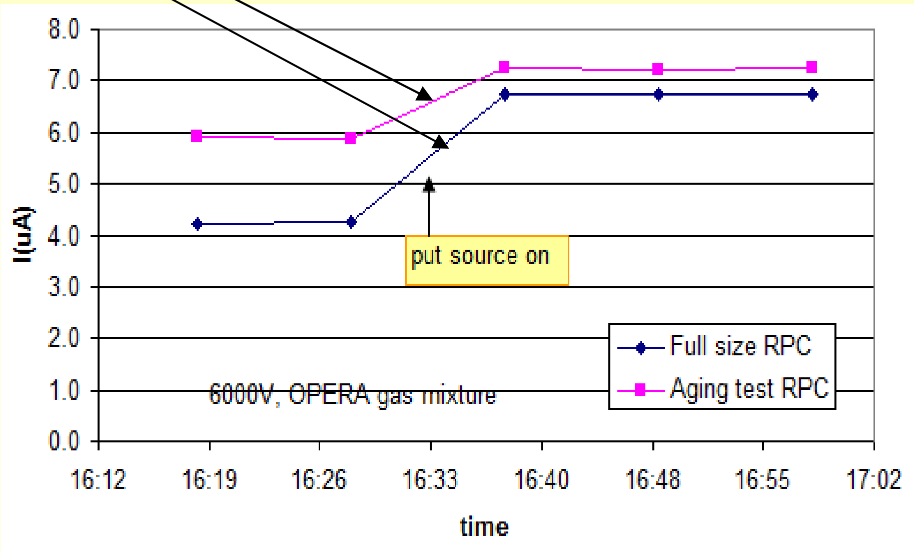


Full size RPC, 1.5μA @6000V, w/o source.

Aging RPC, 3.6μA @6000V, w/o source.

Second round of aging (cont'd)

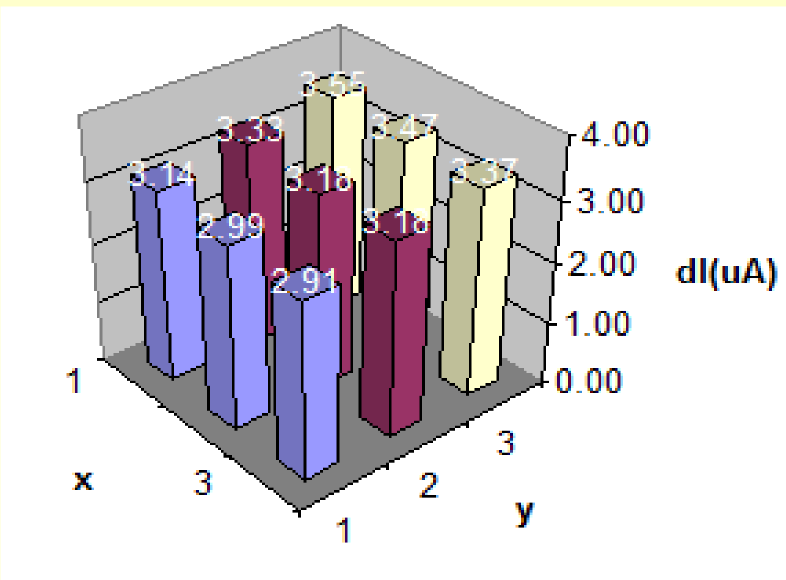
In addition, the current jump due to the source is smaller for the small RPC. On 9/3/2008, the 16th day in the second round of aging, the current in the small chamber jumped from 5.89μA to 7.25μA, so *dI* ~ 1.36μA, but the current in full-size RPC jumped from 4.26μA to 6.74μA, *dI* ~ 2.48μA. On 9/22/2008, the 34th day, the current jumps were *dI* ~ 1.12μA, and *dI* ~ 2.27μA, respectively,



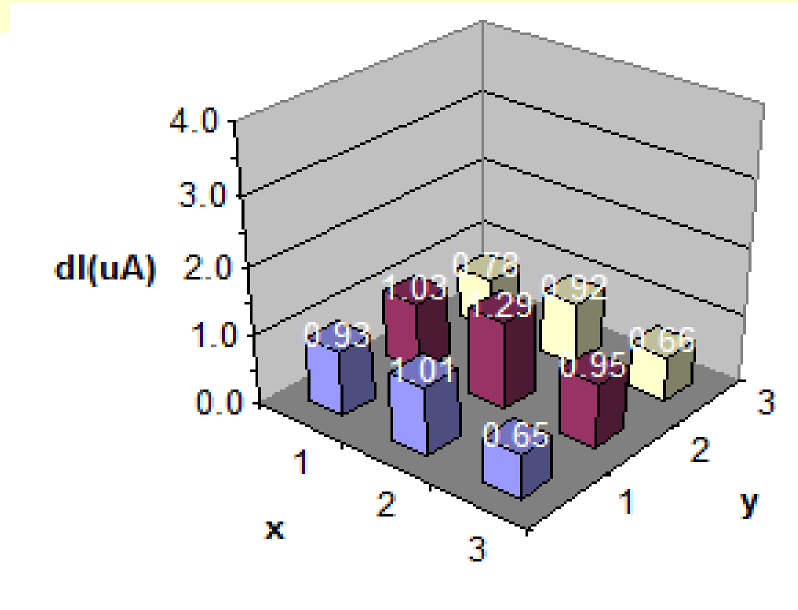
Apparently the aging RPC had higher background current, which was very much likely due to the damaged Bakelite inner surface.

Dark current jump map after 2-nd round aging

At the end of the second round of aging we surveyed the dark current response in 9 regions. By placing the source on each region and measuring the dark-current jump *dI*.



(a)

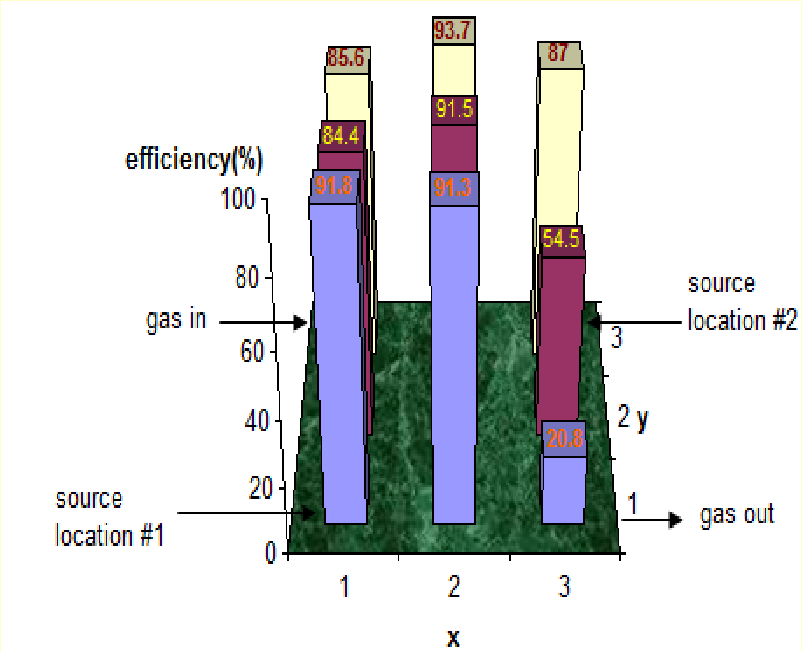


(b)

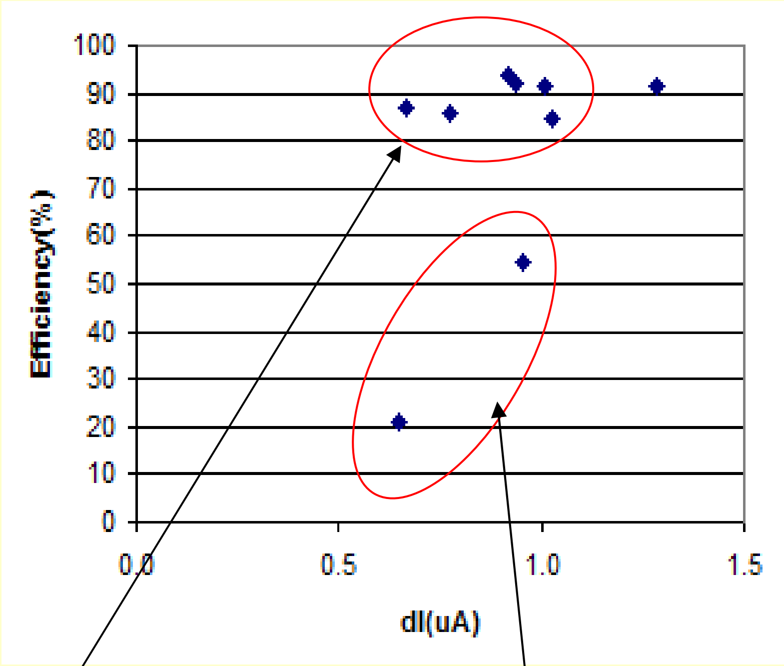
Full size RPC, dI larger, small relative variation.

Aging RPC, dI much smaller, larger relative variation.

Efficiency map after 2-nd round aging



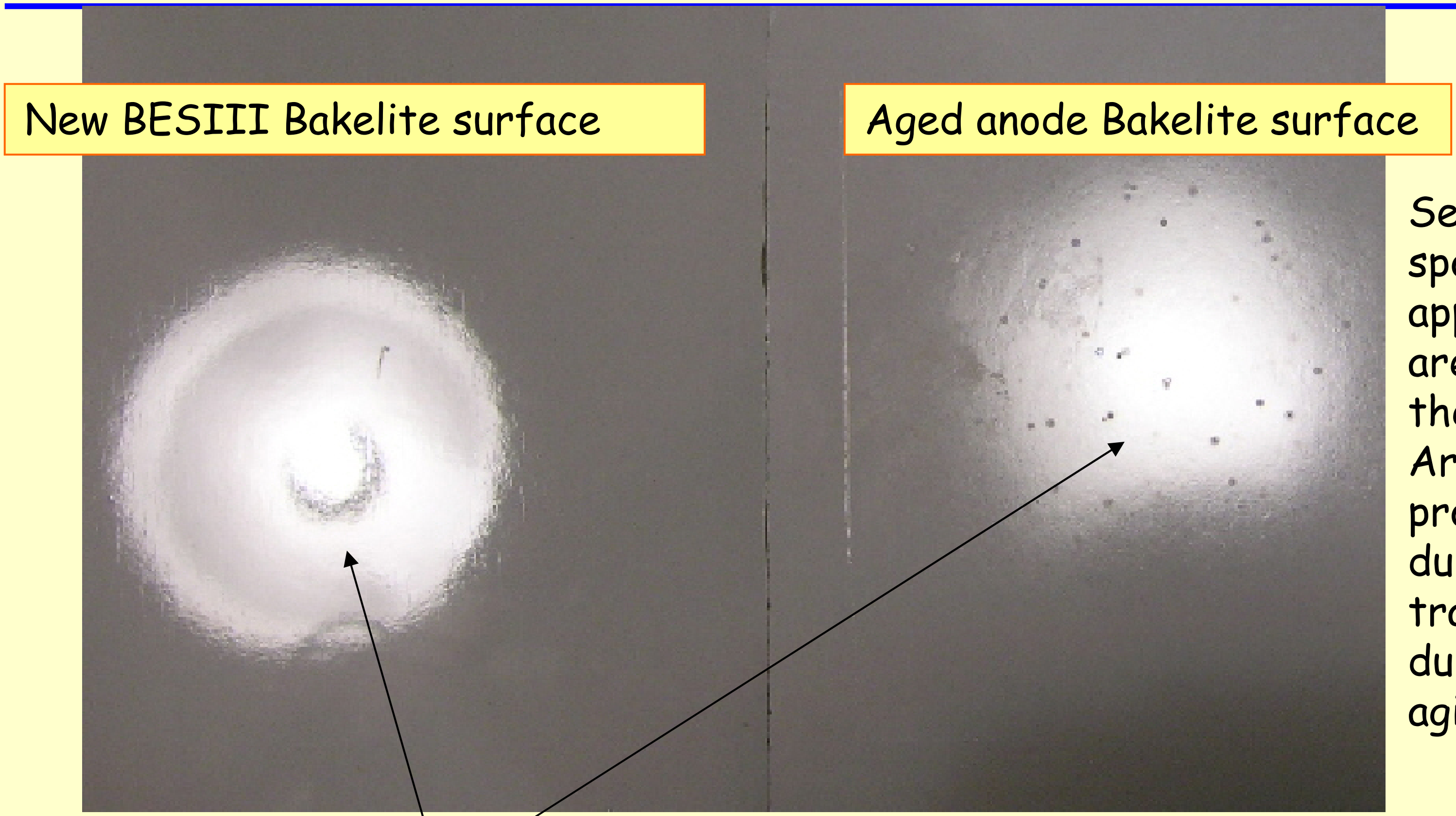
Efficiency survey results at the end of second round of aging tests.



Scatter plot of efficiency *vs.* current jump, *dI*, for 9 regions.

Two lowest-efficiency points show a correlation: lower efficiency related to lower current jump, but the other regions did not follow this trend.

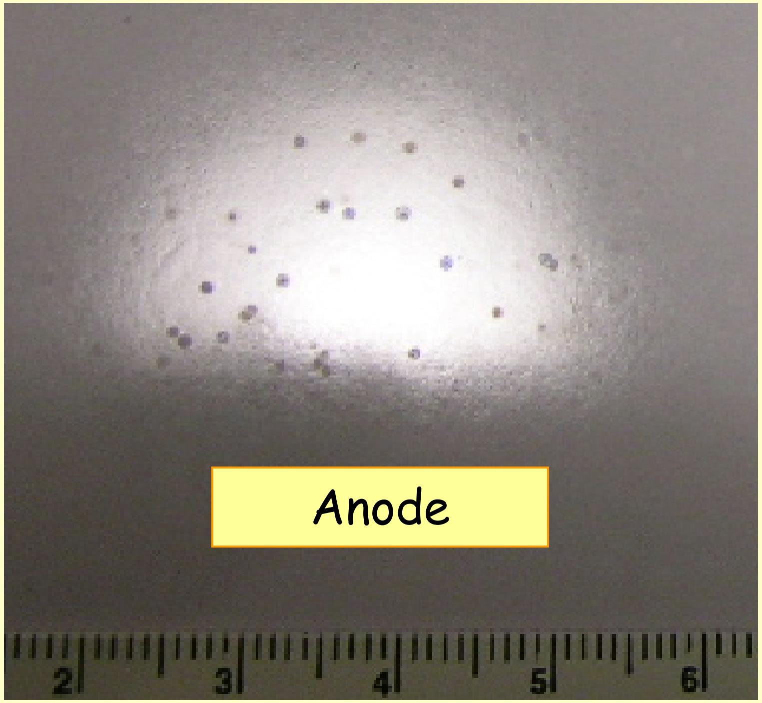
Inner surface of the aged RPC



See a lot of spots, which apparently are due to the discharge. Are they produced during the Ar training or during the aging test?

The reflection images of the same ceiling lamp on two surfaces are quite different: the new Bakelite surface has luster looking, the lamp image can be clearly recognized; the aged surface lost the luster, the lamp's image can't be recognized.

Inner surface (cont'd)



The cathode surface has much less discharge spots although the surface also lost its luster.

The scale shown on the bottom of the photo is in mm.

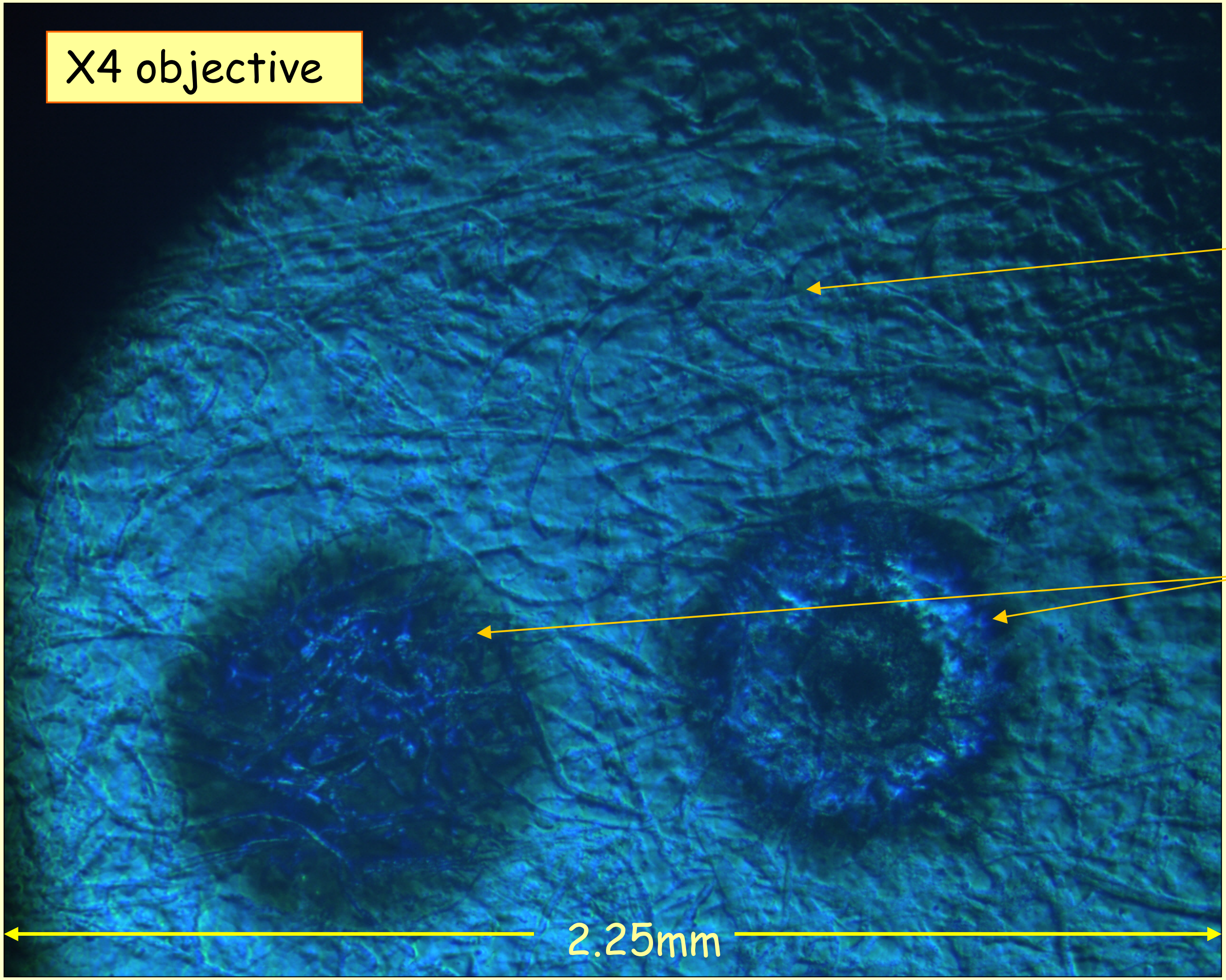
We have tested the surface resistivity on 9 areas, the results show no big difference.

More study with microscope

To understand the surface change better a Nikon Eclipse 90i microscope is employed.

We have cut samples from anode un-radiated region and cathode radiated region. The overall scale for the pictures with x4 objective is 2.25mm wide, x10 objective is 0.9mm wide.

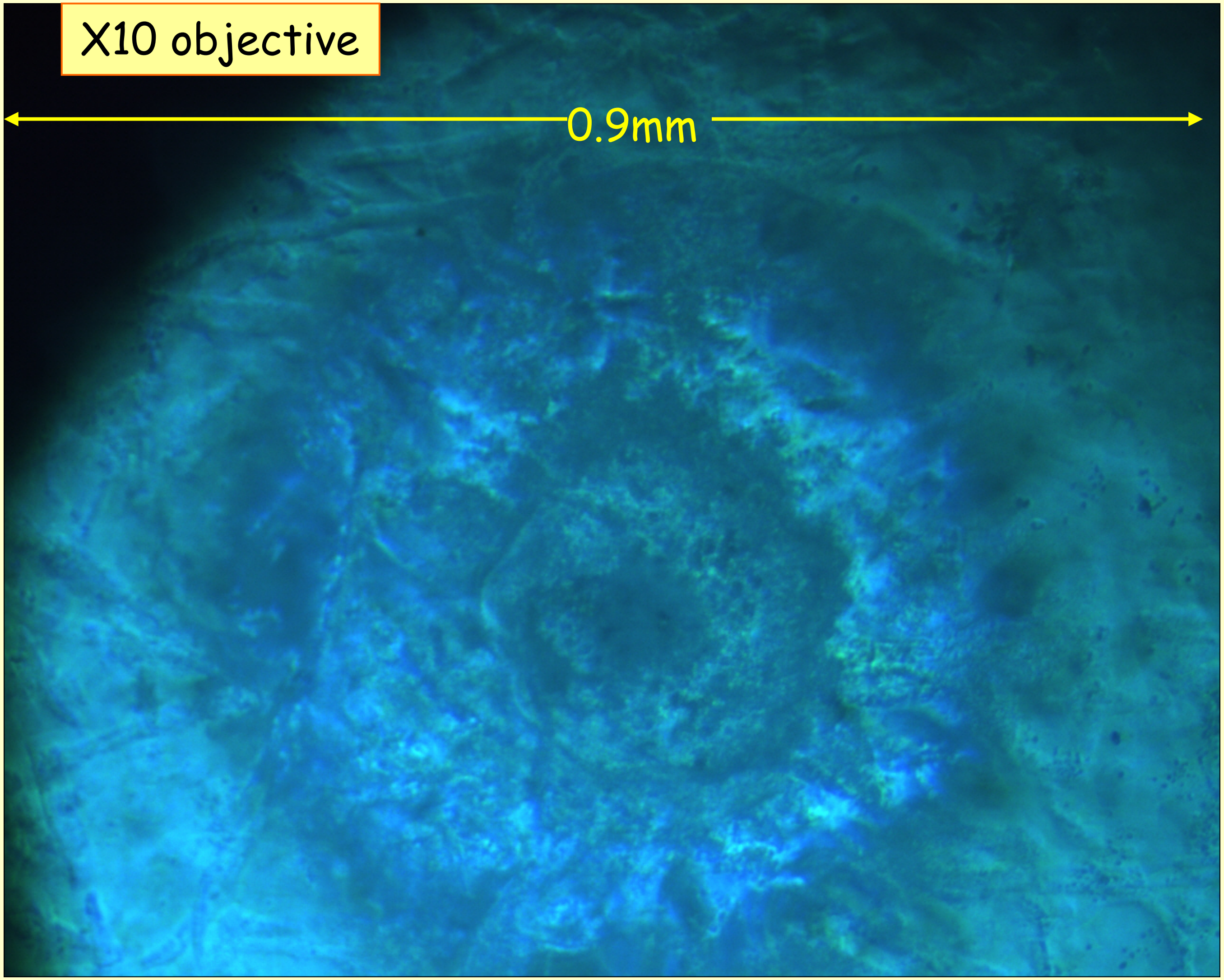
Aging chamber anode



Etched surface

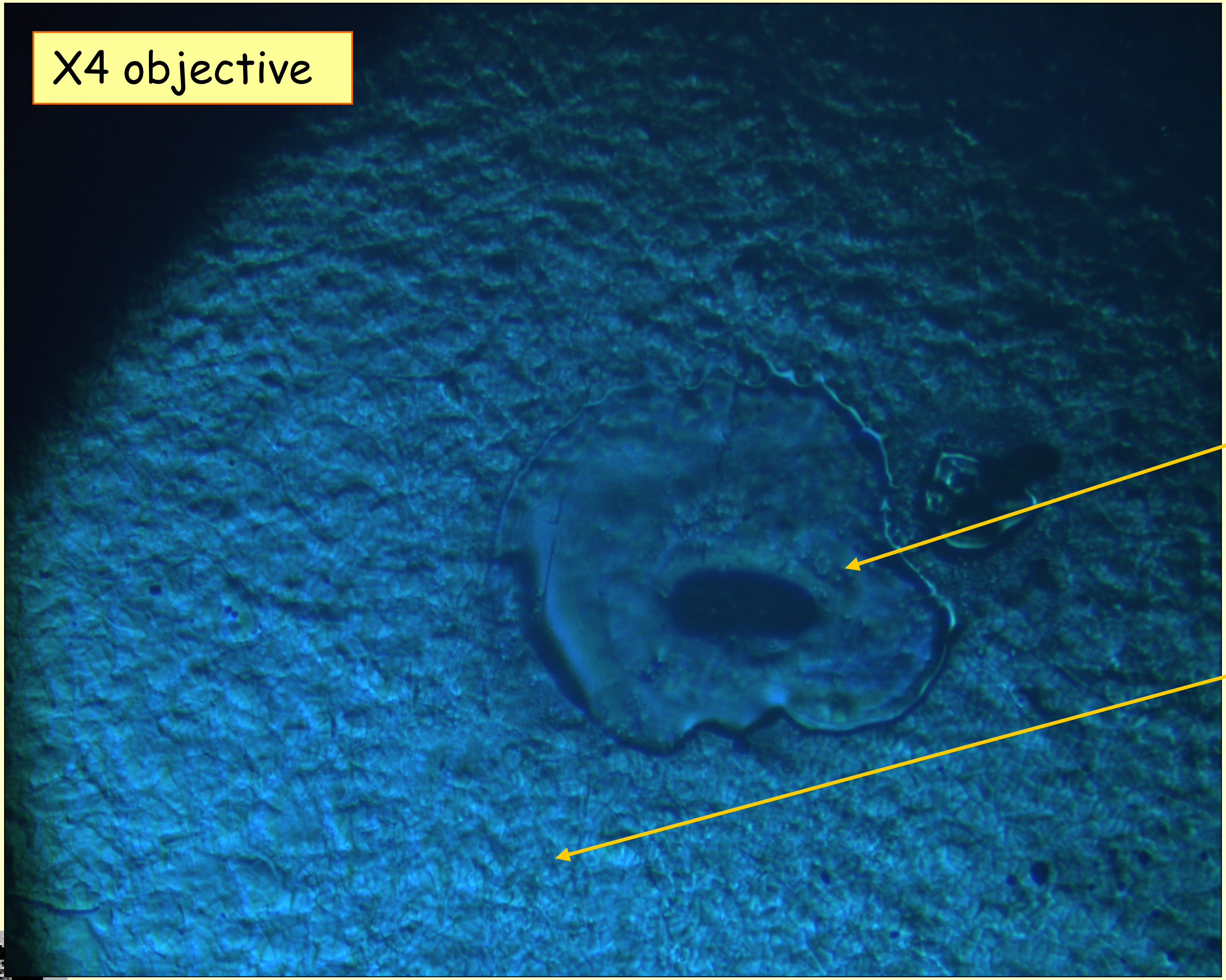
Discharge marks

Aging chamber anode (cont'd)



Same discharge spot as previous picture, but with higher magnification.

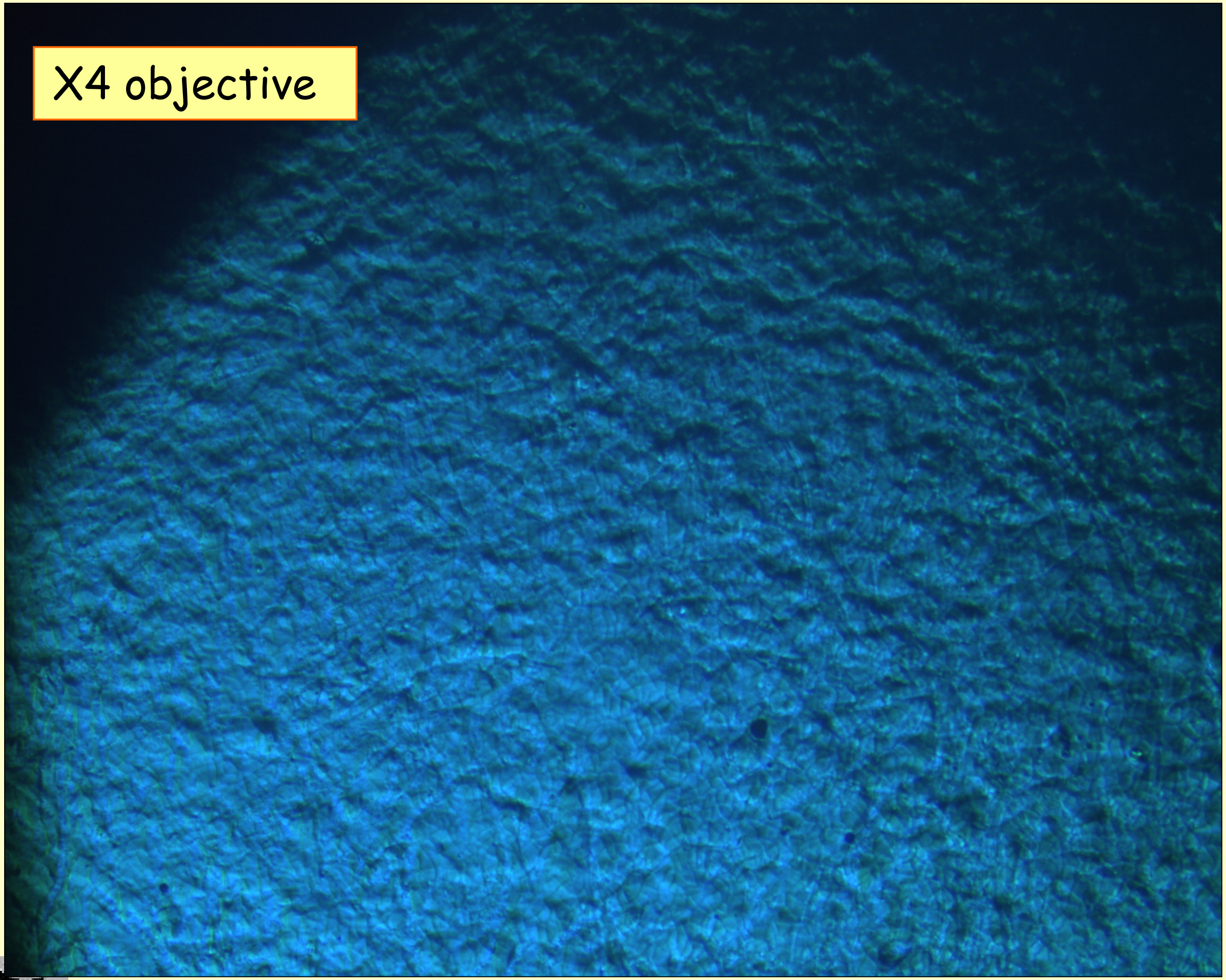
Aging chamber cathode



On cathode electrode the density of discharge spots is much less, but still can see some as shown in this picture.

Notice the etched surface similar to anode.

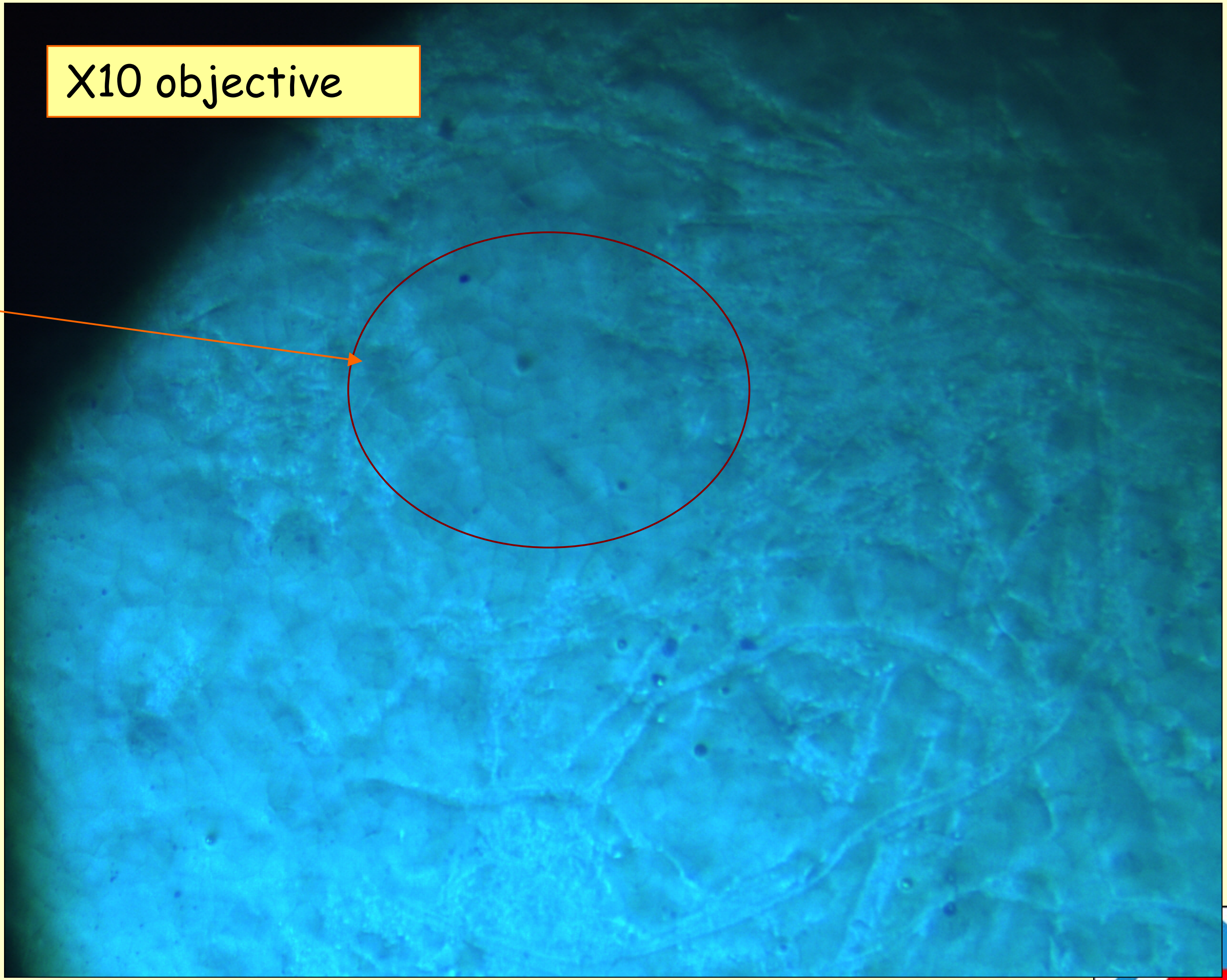
Aging chamber cathode



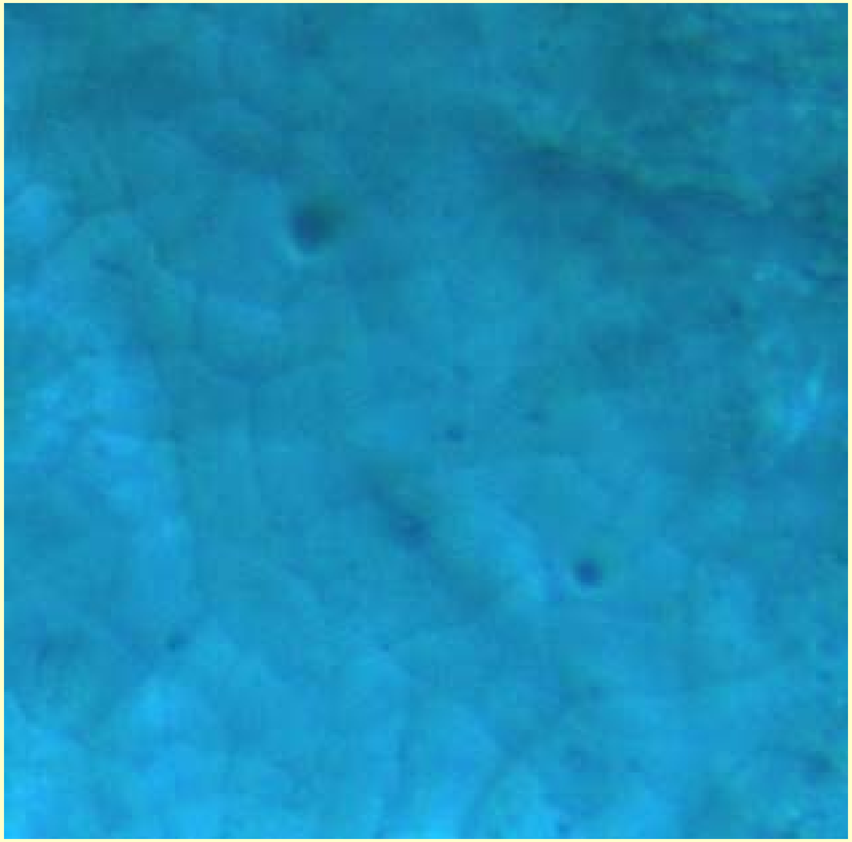
No discharge spot in this picture, but the surface has badly damaged. This is the reason why the aging chamber electrode inner surface lost their luster looking.

Aging chamber anode (cont'd)

In the less severe damaged region, we still can see original "skin" texture (see next slide for enlarged picture of this region.)



Aging chamber anode (cont'd)



Enlarged less damaged region of the anode surface, it shows "skin" texture.

Later we'll show more images of the undamaged "skin" surface.

HV training studies

HV training in pure Argon gas is one of the most critical step to reduce the noise rate for BESIII RPC. Flow pure Argon gas through RPC, then raise HV to over 4,000V, the chamber will be in constant discharge mode for more than 24 hours. The sparking noise can be clearly heard. After this treatment the noise rate is dramatically reduced.

Is the sparking noise coming from RPC gas gap?

Is the discharge spots seen on the anode electrode inner surface related to the "sparking"?

To answer these questions an ad hoc RPC prototype is used. Training this RPC in same steps as above.

We found w/o the pickup strip/ground planes, leave the Mylar covered graphite exposed to air, the sparking noise disappeared. It shows that the sparking noise is not coming from gas gap, it is due to the static discharge happened in the air gaps between graphite coating and grounded pickup strips.

HV training studies (cont'd)

After 24 hours of training, we opened this chamber to search for the discharge spots on the anode electrode inner surface.

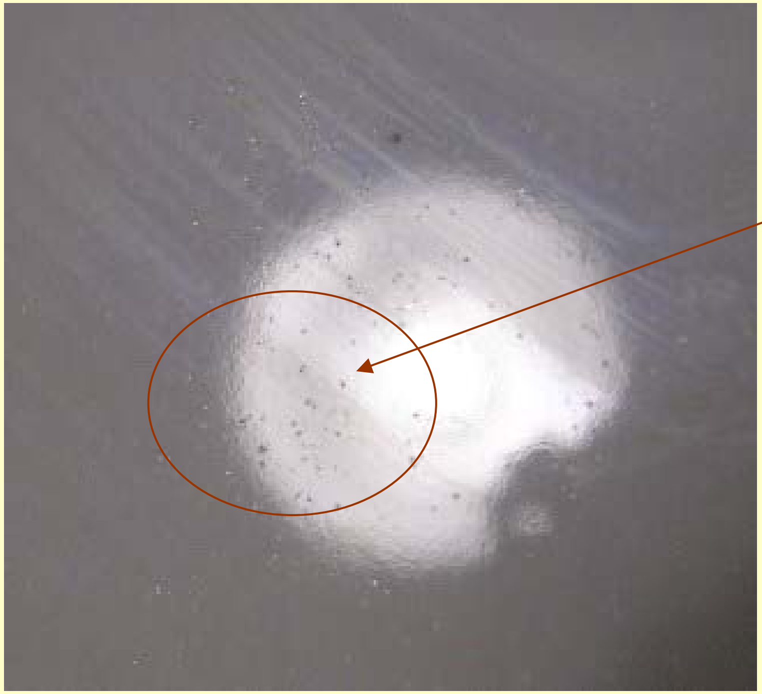
(1) Any discharge spots on anode inner surface?

(2) The luster looking on surface remains?

No mm-scale discharge spots, but a lot of smaller spots, surface remains shine.

Residual epoxy, no discharge spots can be seen! Surface remains shine.

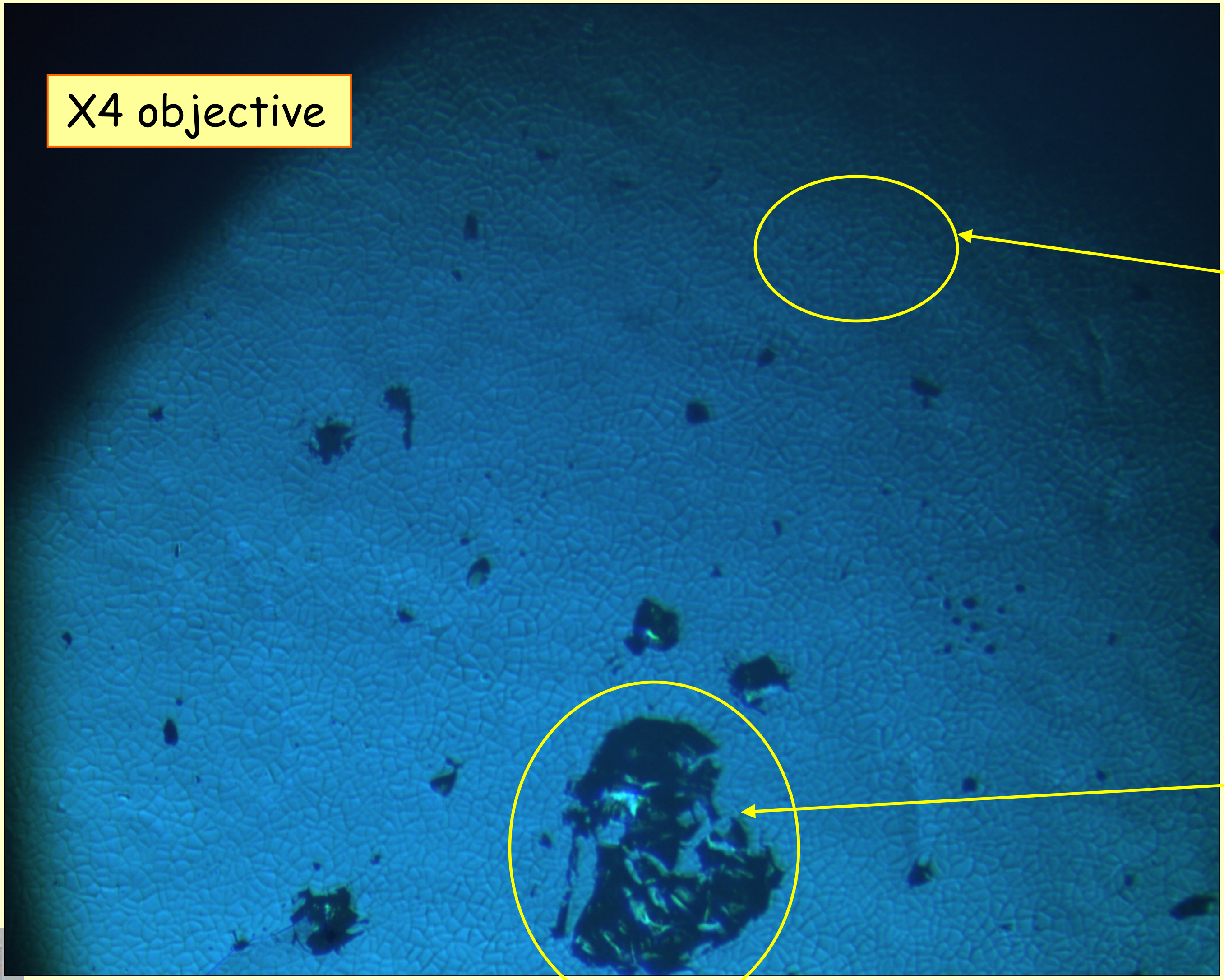
HV training study (cont'd)



Cathode surface has a lot of dark looking spots, the density is not uniform over the entire surface. These spots do not appear on anode surface.

Why on cathode surface only?

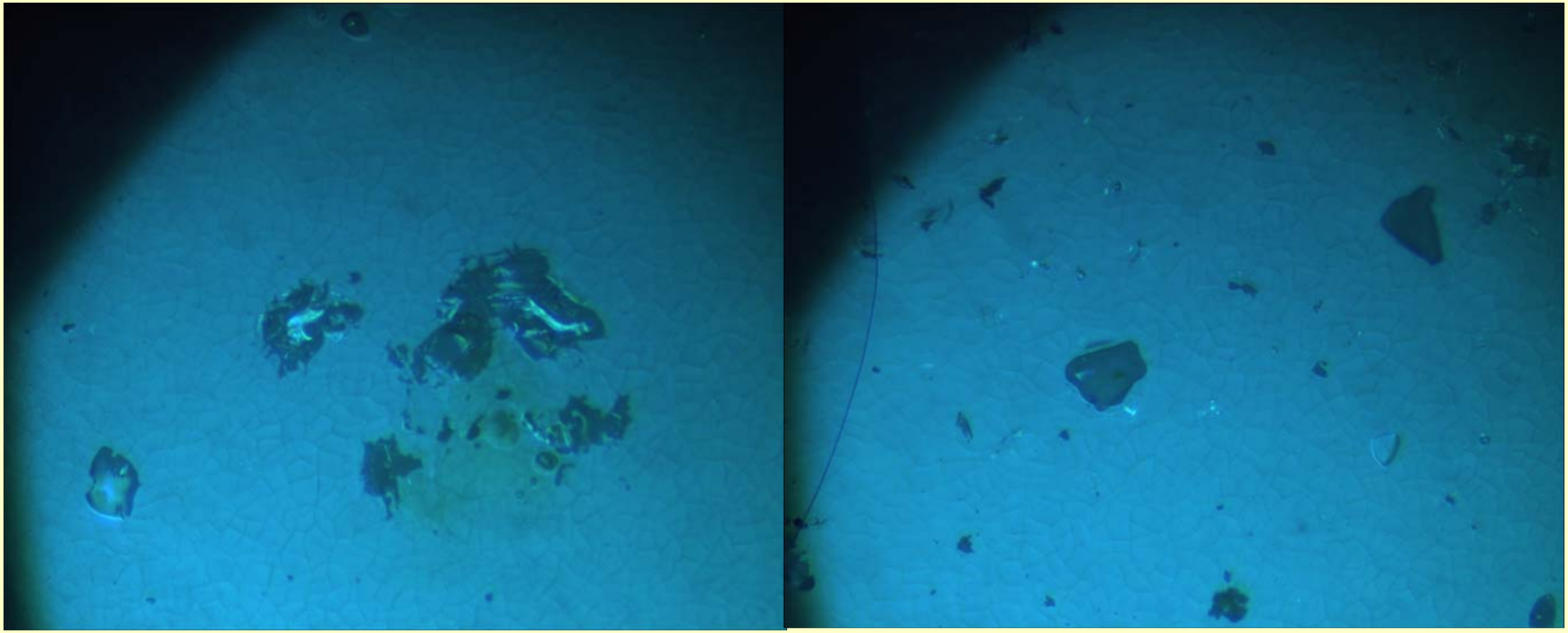
Microscope study of HV training chamber cathode



Undamaged region shows "skin" texture of the Bakelite sheet.

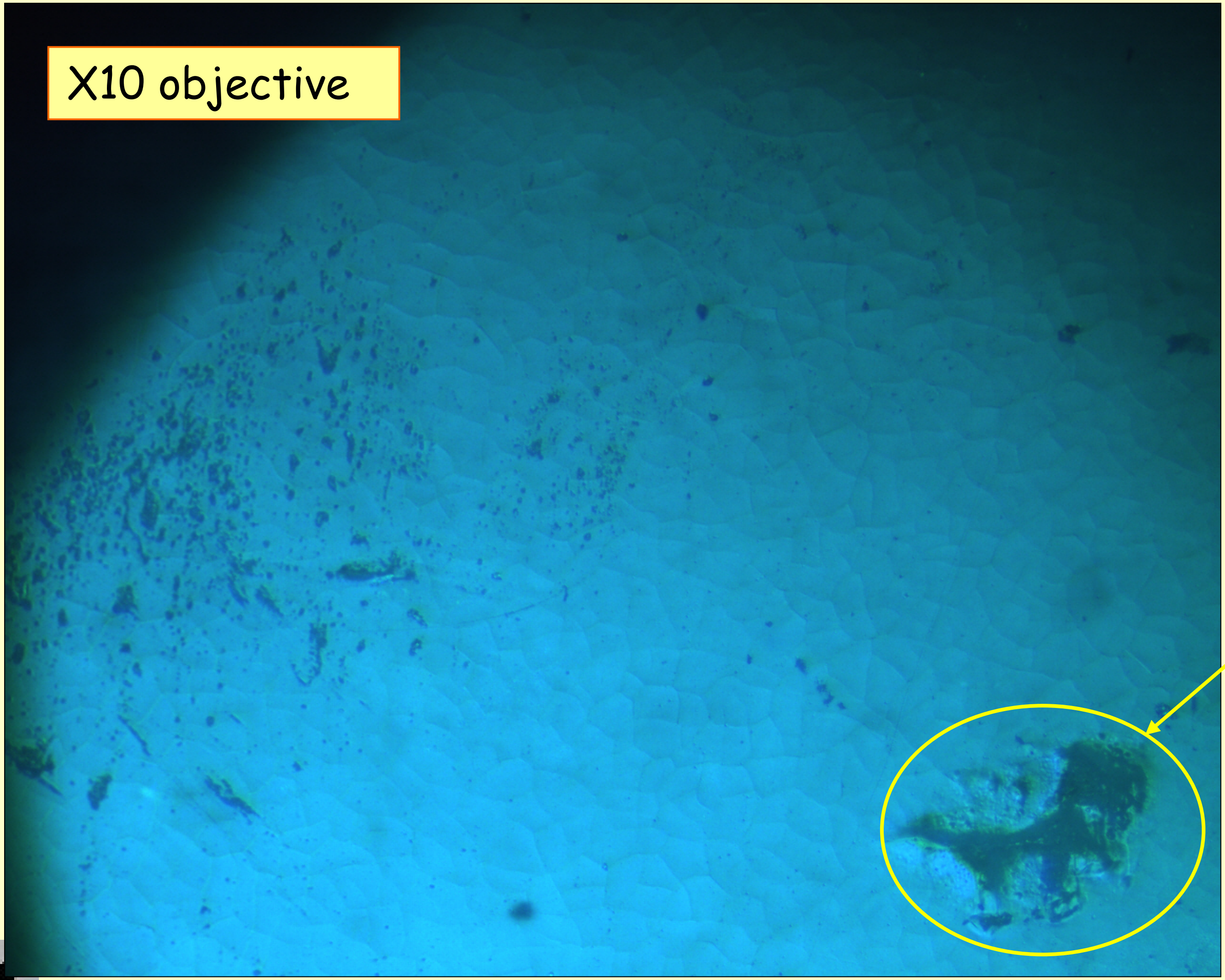
Damaged spot

Microscope study of HV training chamber cathode (cont'd)



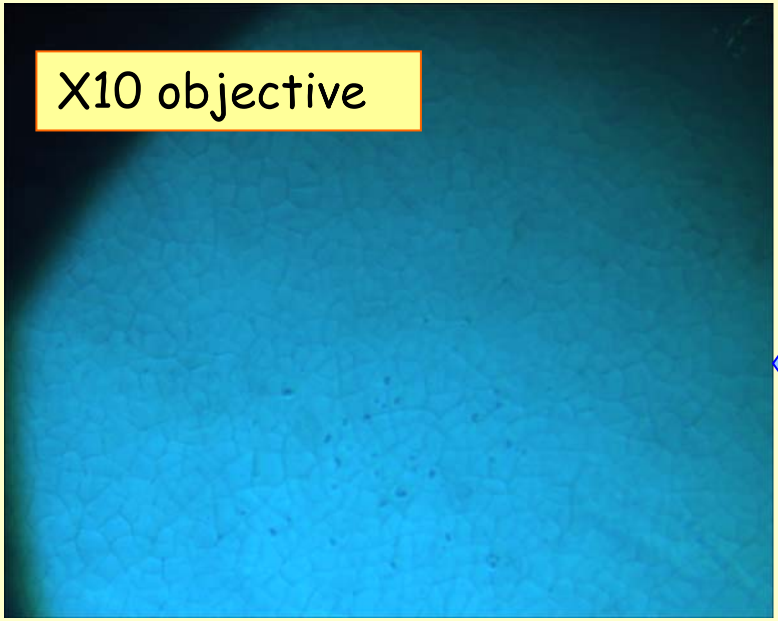
These spots appear on the cathode much more than on the anode. Rest of the region looks still like virgin surface, so it has luster looking.

Microscope study of HV training chamber anode

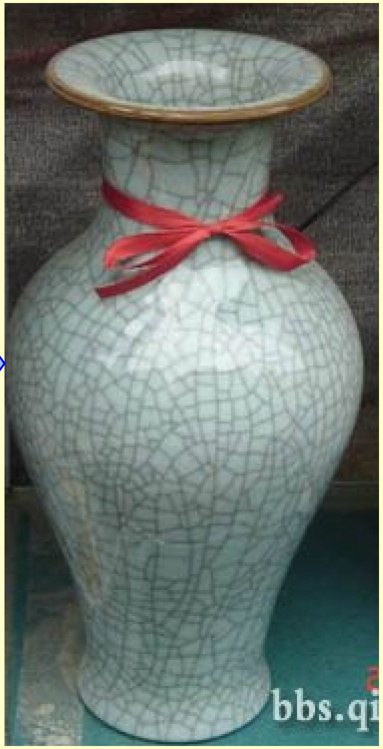


Although anode has much less damaged spots, but we still can find some, one is shown on left.

Microscope study of HV training chamber anode



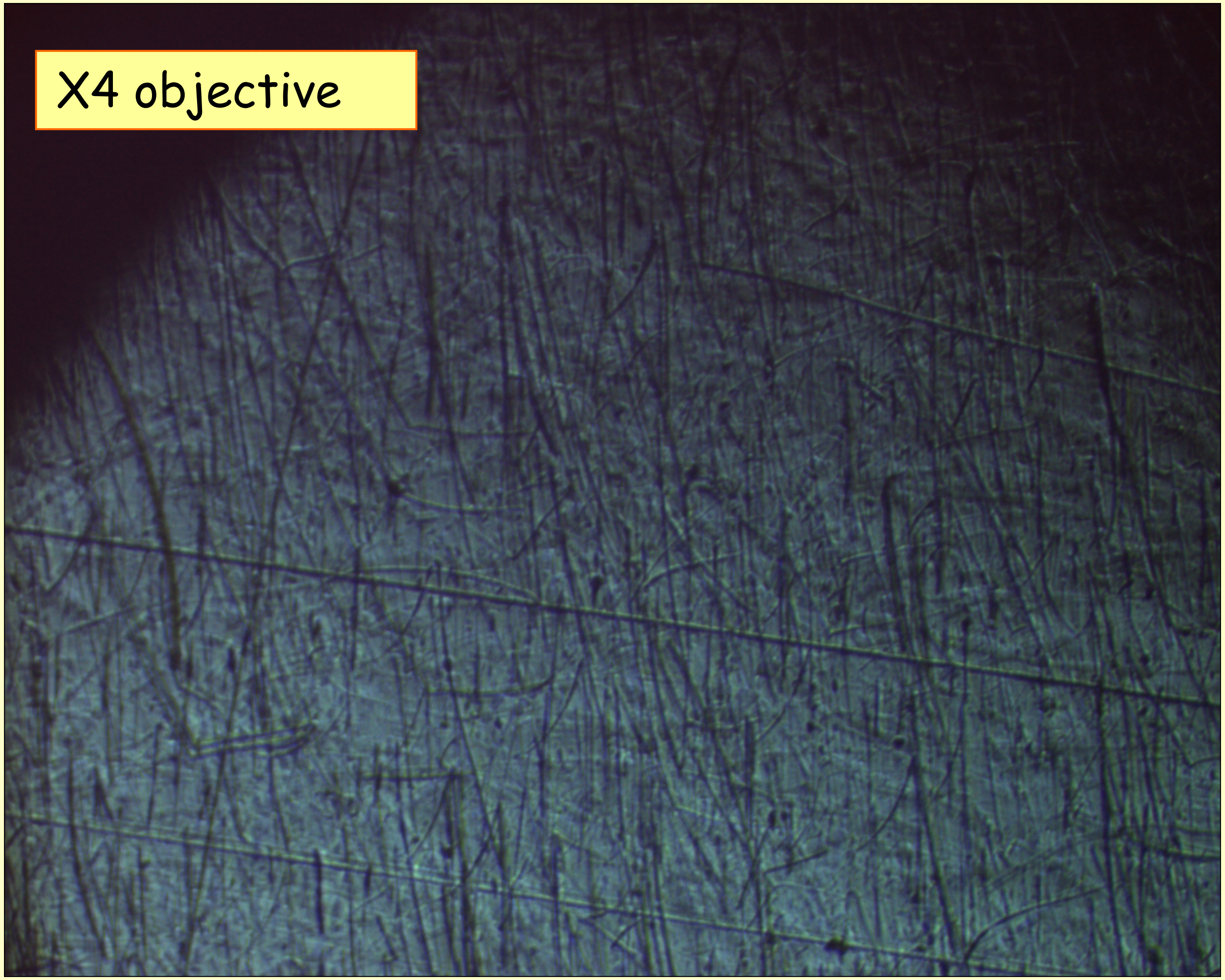
Most of the anode surface looks undamaged, it shows "skin" texture.



The crackle glaze was the result of the inconsistent thermal expansion coefficient between the body and glaze.

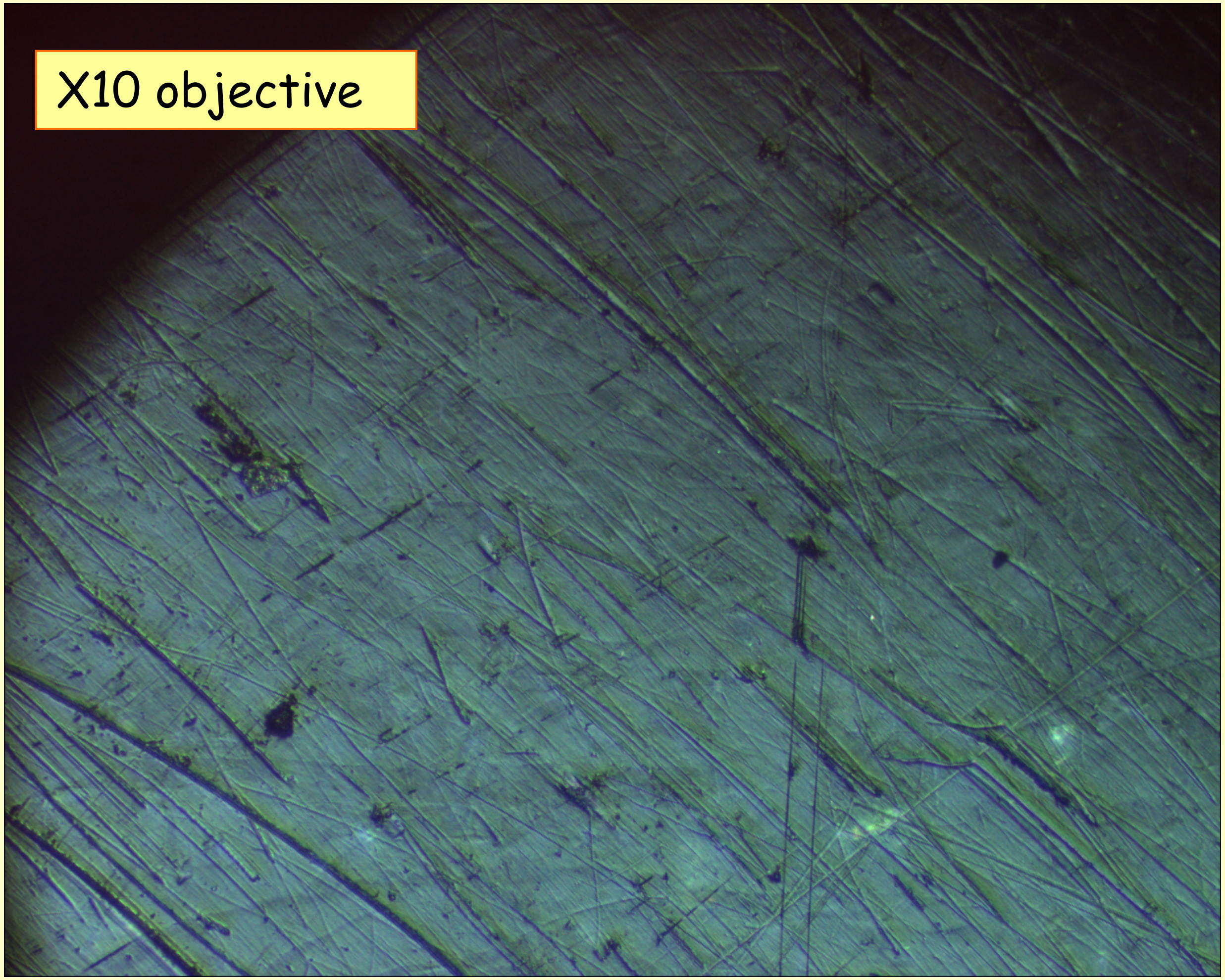
Longquan celadon was produced in Longguan kilns during Song Dynasty (13th Century). The famous Elder Brother ware was thought to be the Geyao crackle glaze ware treasured by collectors throughout history.

Italian Bakelite surface



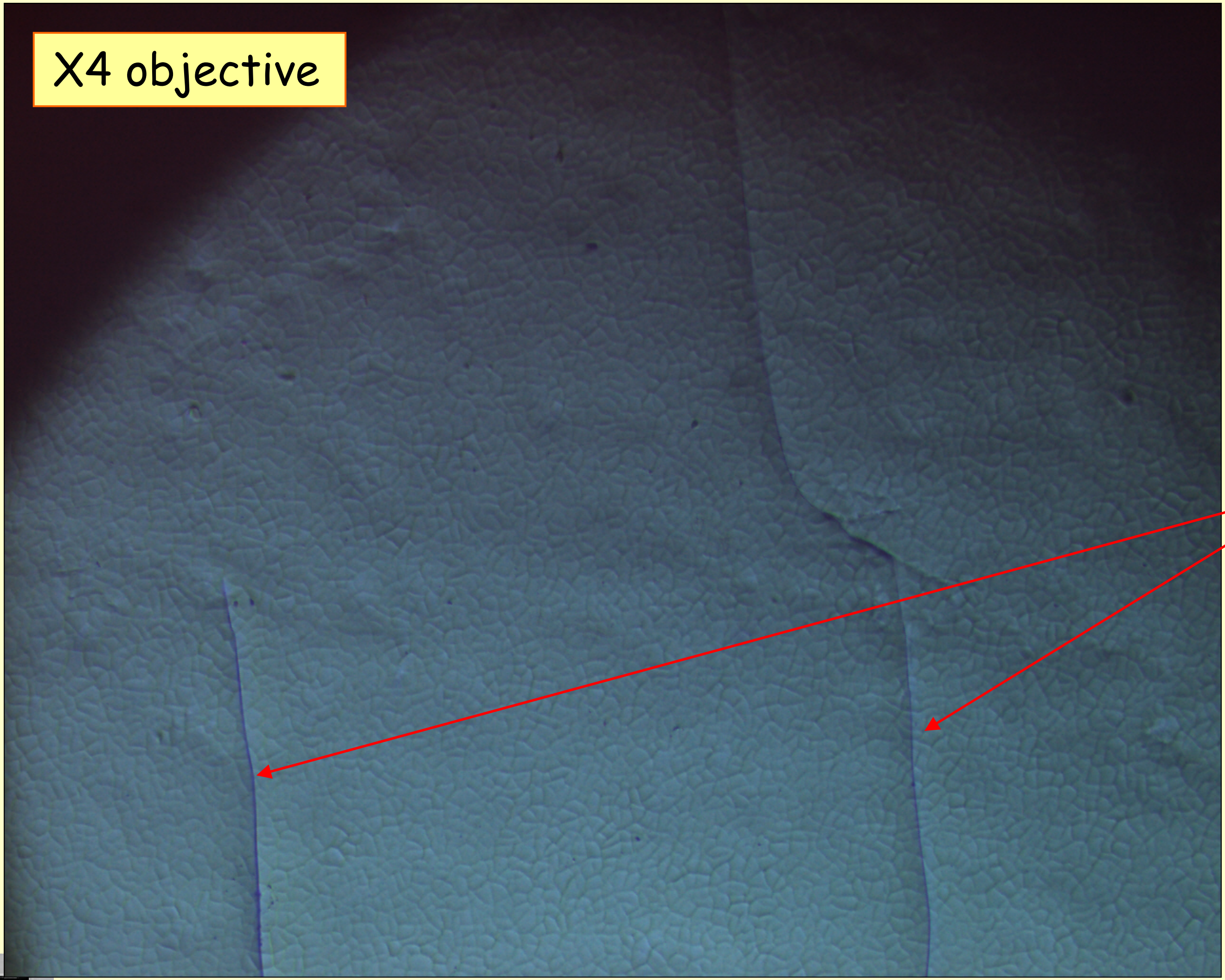
This is a sample from new CMS RPC Bakelite. Compare to BESIII Bakelite sample, much worse surface quality can be seen. There is no similar “skin” structure, which may be related to different material and production procedure.

Italian Bakelite surface



Larger magnification still does not reveal "skin" type structure.

Comparison to new BESIII Bakelite surface



Besides the "skin" structure there is no serious scratch, looks much better than CMS sample, but we see "wrinkle", which is quite unique.

Summary of the two rounds of aging test

One month of aging test is equivalent to 30 months of cosmic-ray background operation. After one month of aging, some aging effect had already appeared. An additional one month aging at a different location caused serious aging; in some regions the efficiency dropped dramatically.

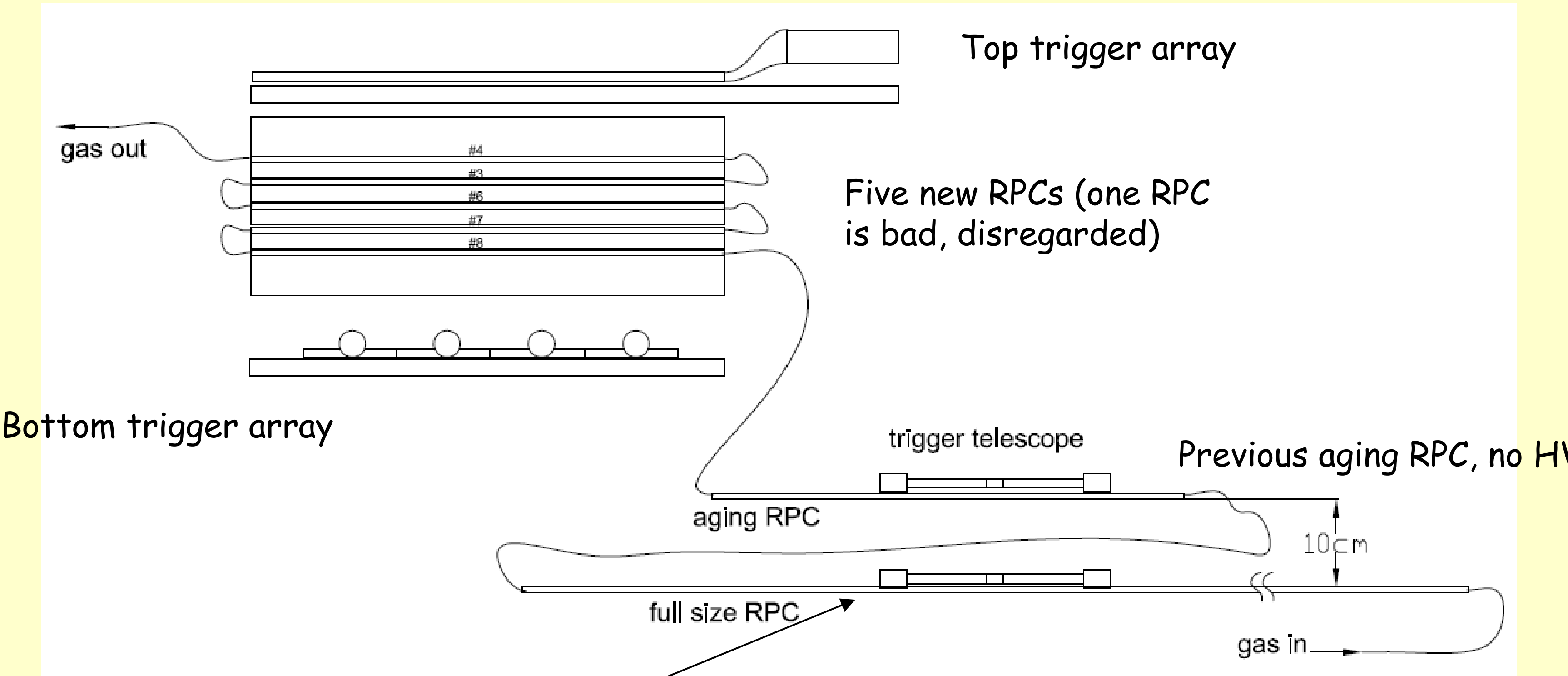
HV training in pure argon does not leave the discharge marks on the anode electrode surface, but it produces a lot of smaller damaged spots on the cathode surface.

The discharge noise during HV training is not coming out of the gas gap. The noise is coming from outside of the chamber.

Suggestions to Daya Bay RPC module construction

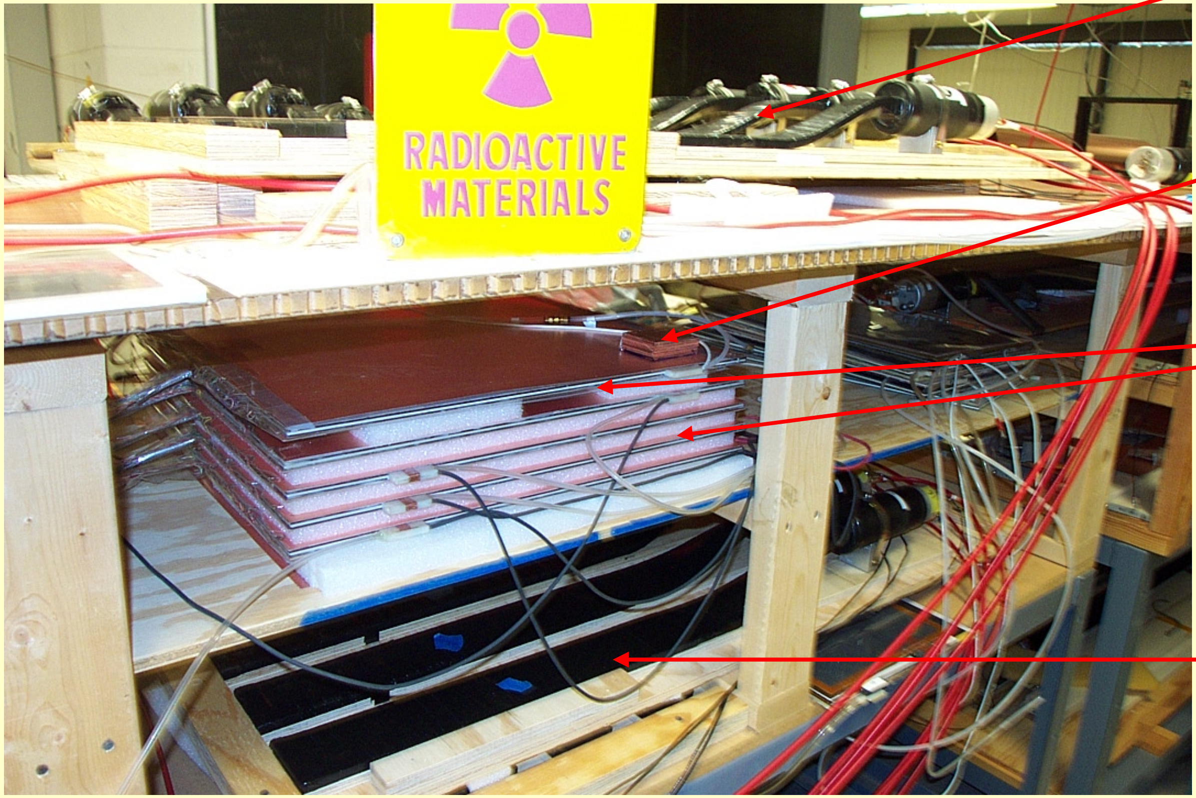
- Keep the gas flow parallel to each RPC, avoid the daisy chain as much as we can;
- Don't use the RPC w/ hot spots, although the hot spot may be just a small region, but the generated pollutant from the "chimney" can damage the entire chamber;
- Higher gas flow rate helps to ease the aging, keep the reasonable gas flow rate, may be 2 vol/day instead of 1 vol/day;
- Gain running experience from BESIII muon system.

(2) Aging test on four new RPCs



The HV of the full size RPC is on, but keeps distance from the Co-60, the counting rate is lower.

Set-up (cont'd)



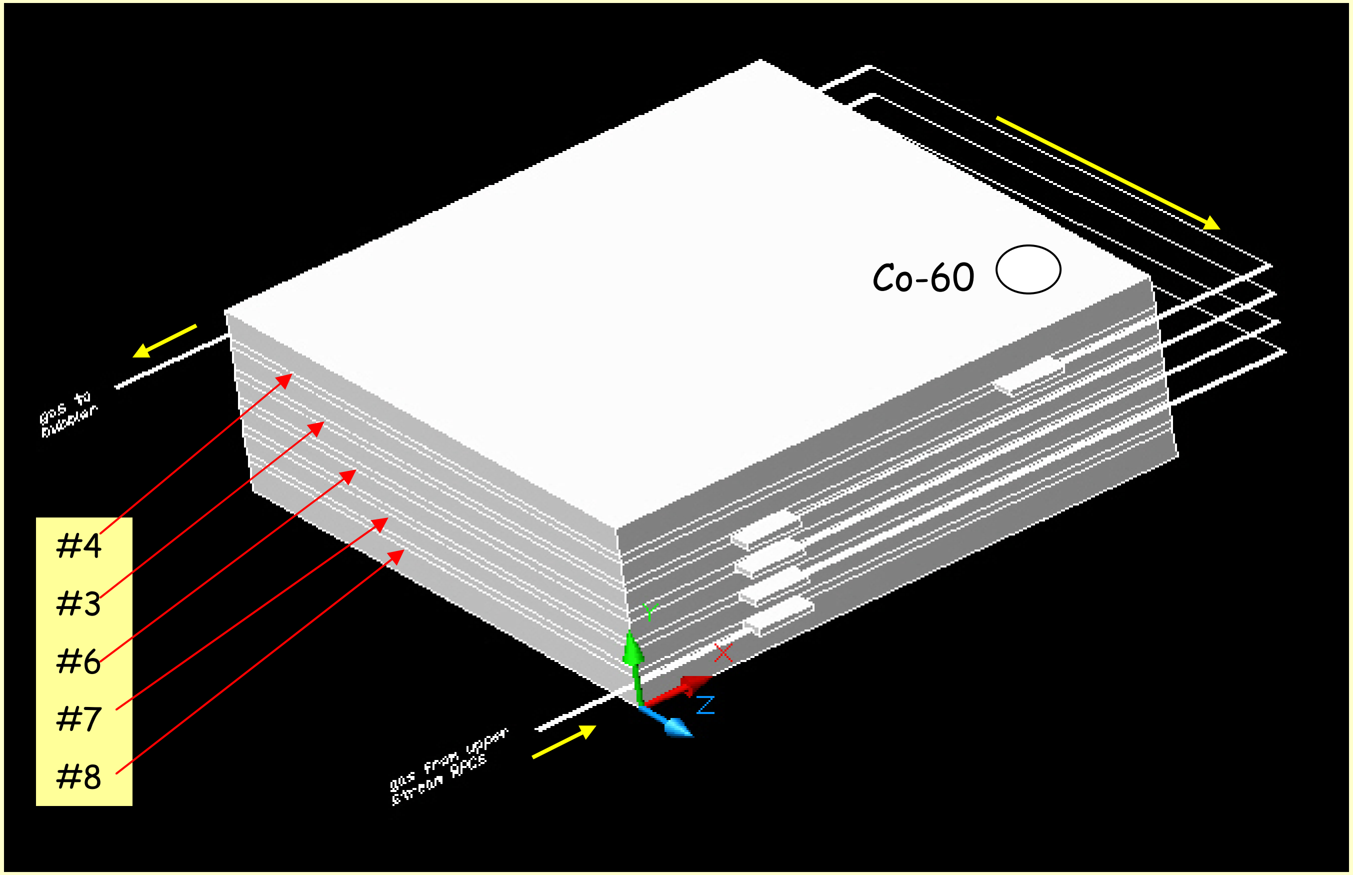
Upper trigger array (x and y, 4 for each).

Copper plates, Co-60 source sits on.

Aging test RPCs.

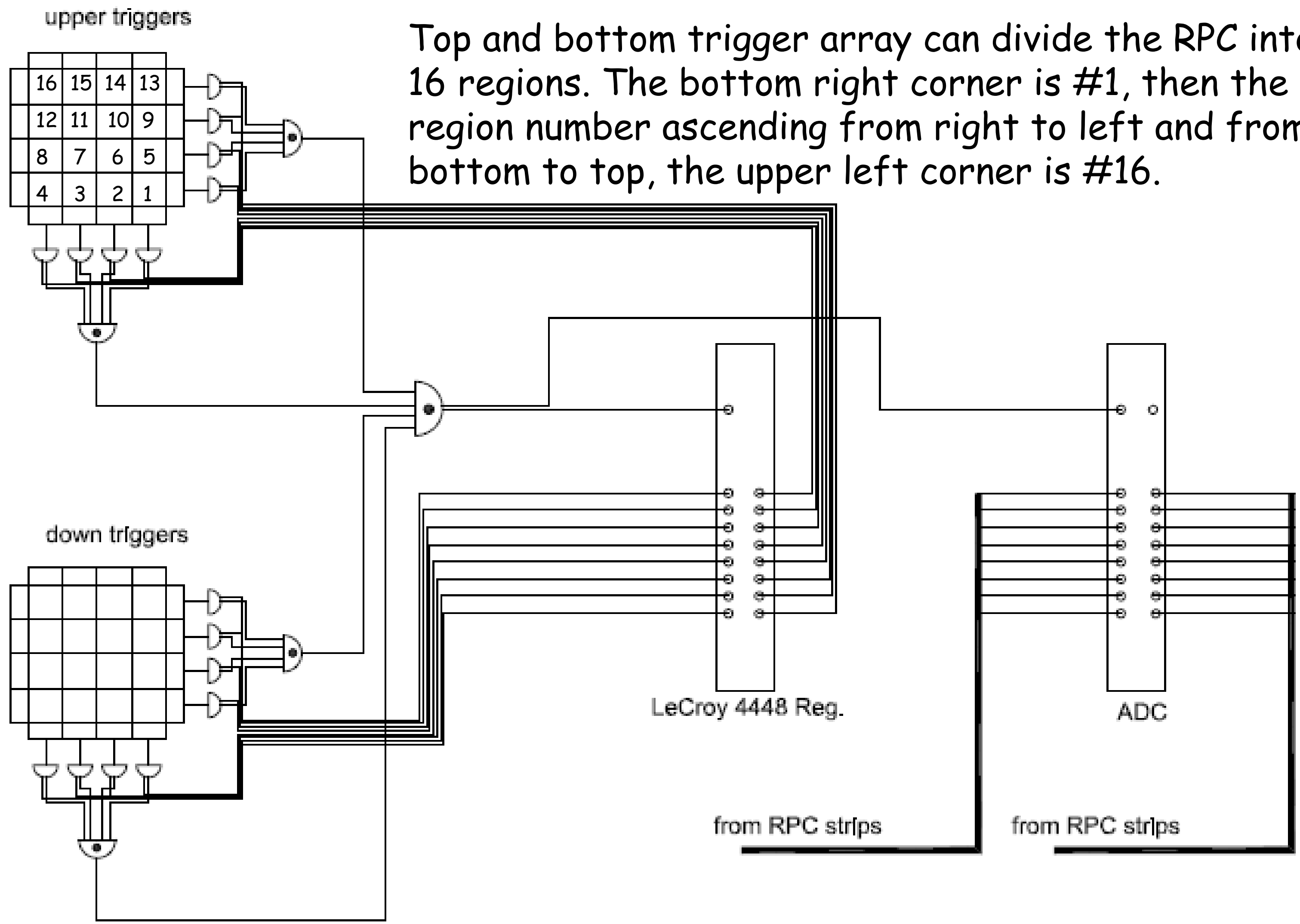
Bottom trigger array (x and y, 4 for each).

Test set-up – five RPC chamber stack



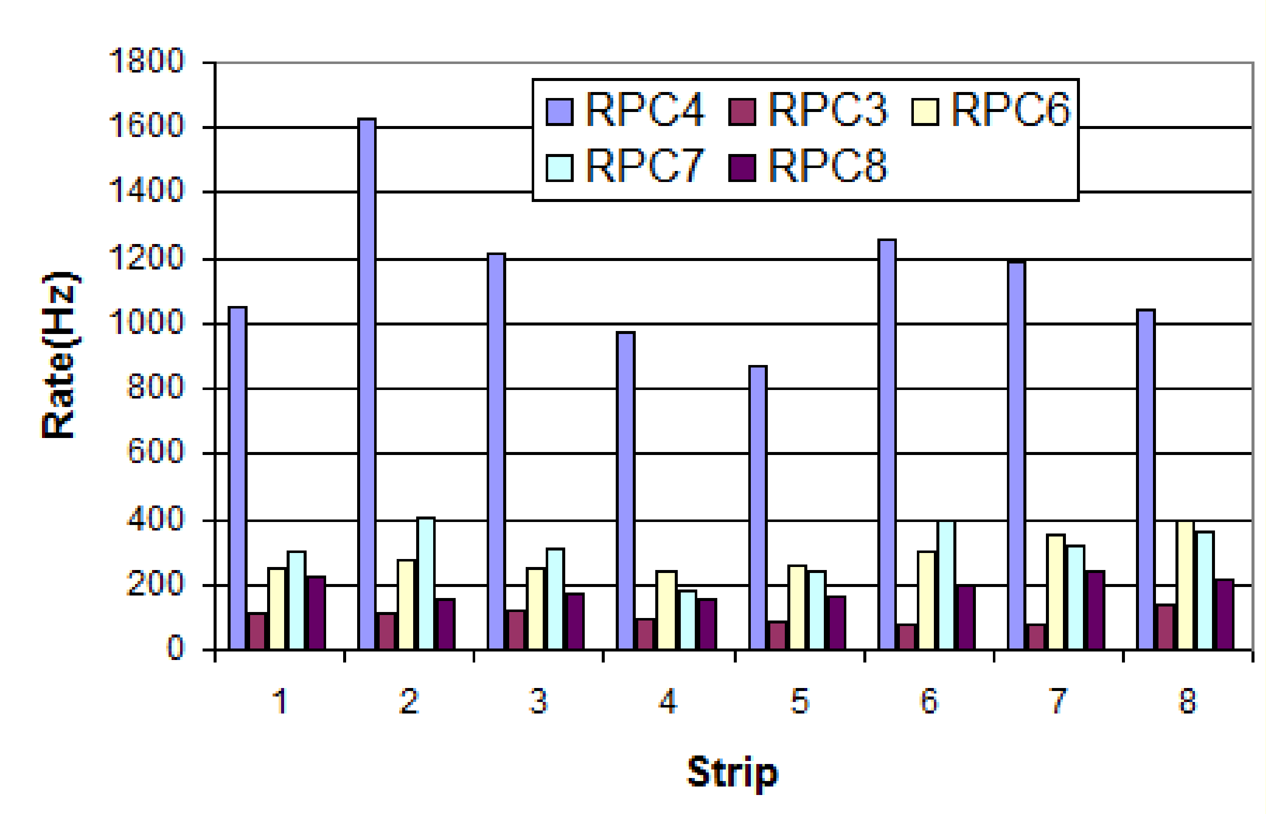
Test set-up trig logic

Top and bottom trigger array can divide the RPC into 16 regions. The bottom right corner is #1, then the region number ascending from right to left and from bottom to top, the upper left corner is #16.



Measured background streamer distribution

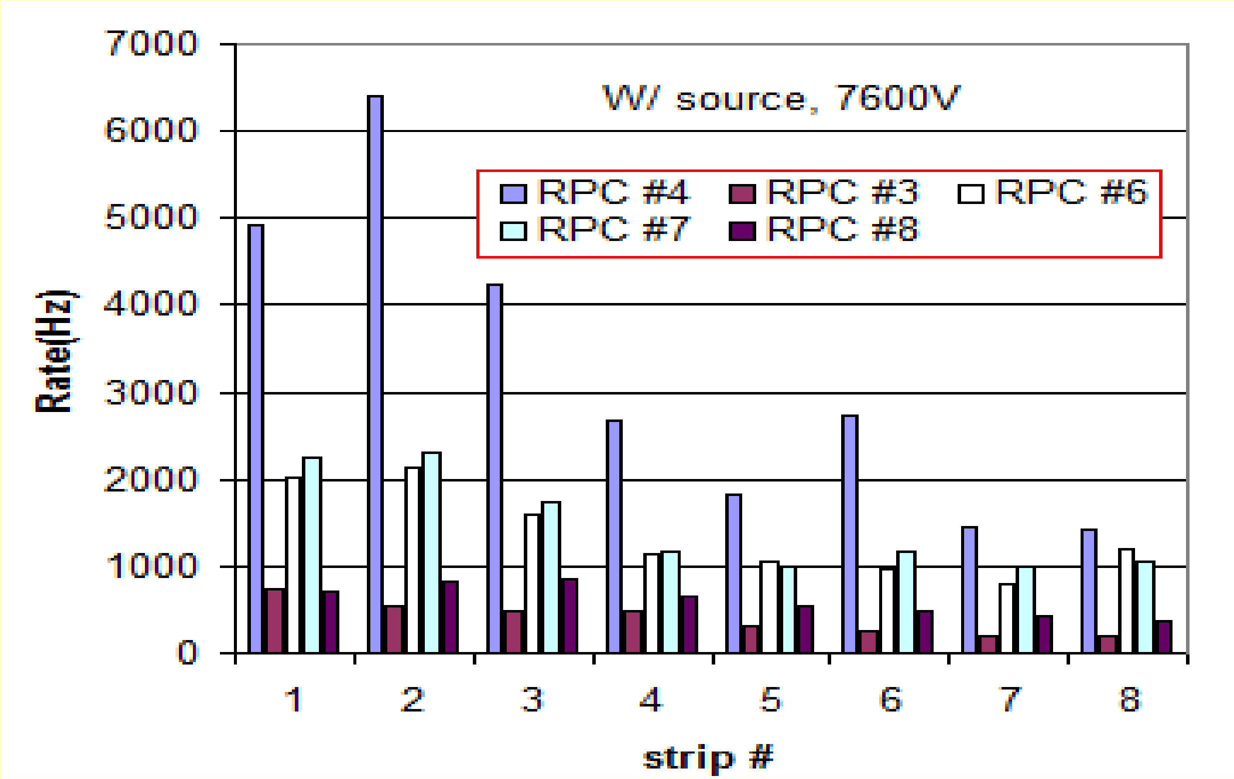
The measured streamer-rate distribution among 8 strips (6cm wide each) with and w/o source: in OPERA gas mixture, 5500V. Each strip is ~300cm^2 in area.



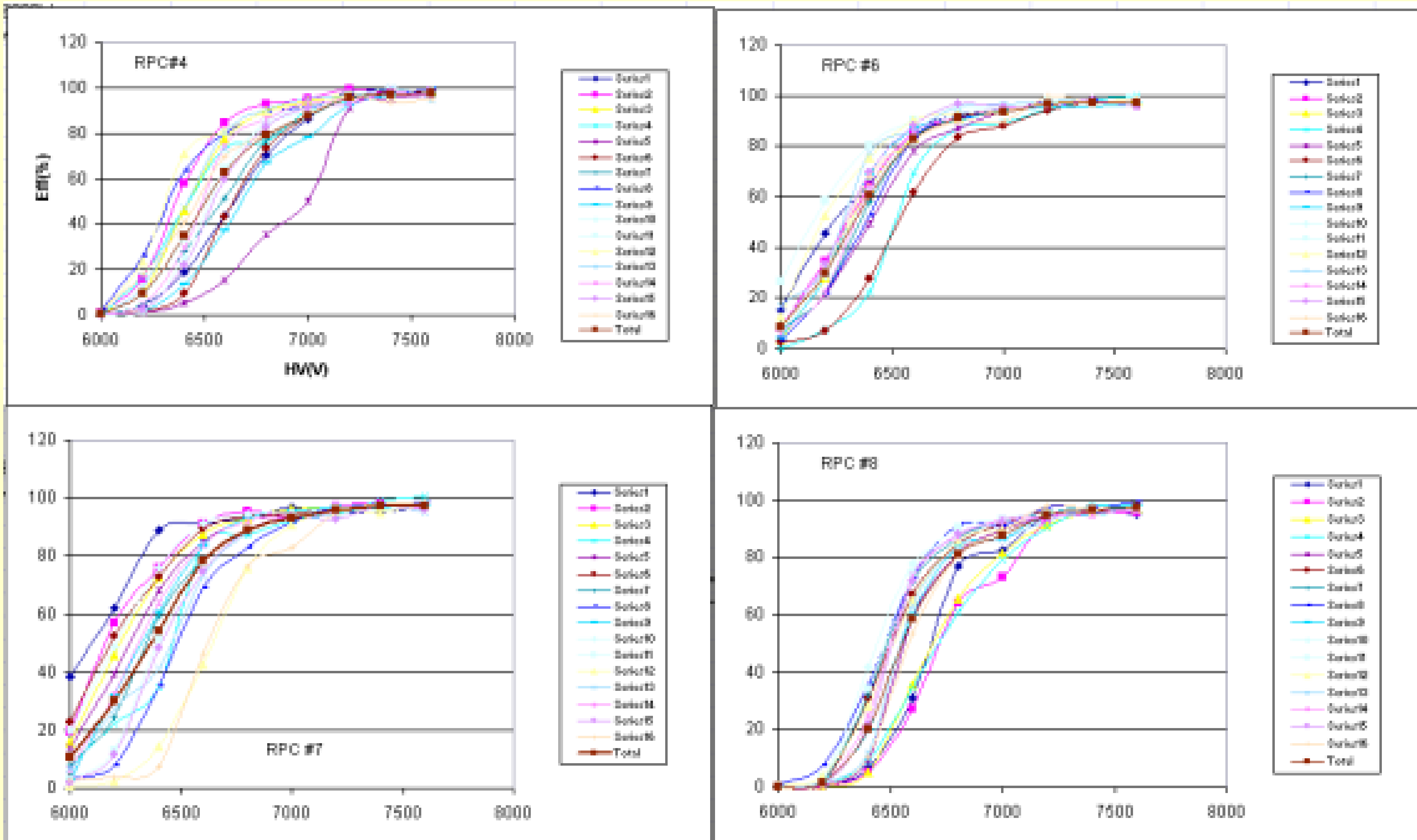
We can see that RPC4 is much noisier than others. All of them look noisy, probably not "trained" enough.

Streamer distribution with source on

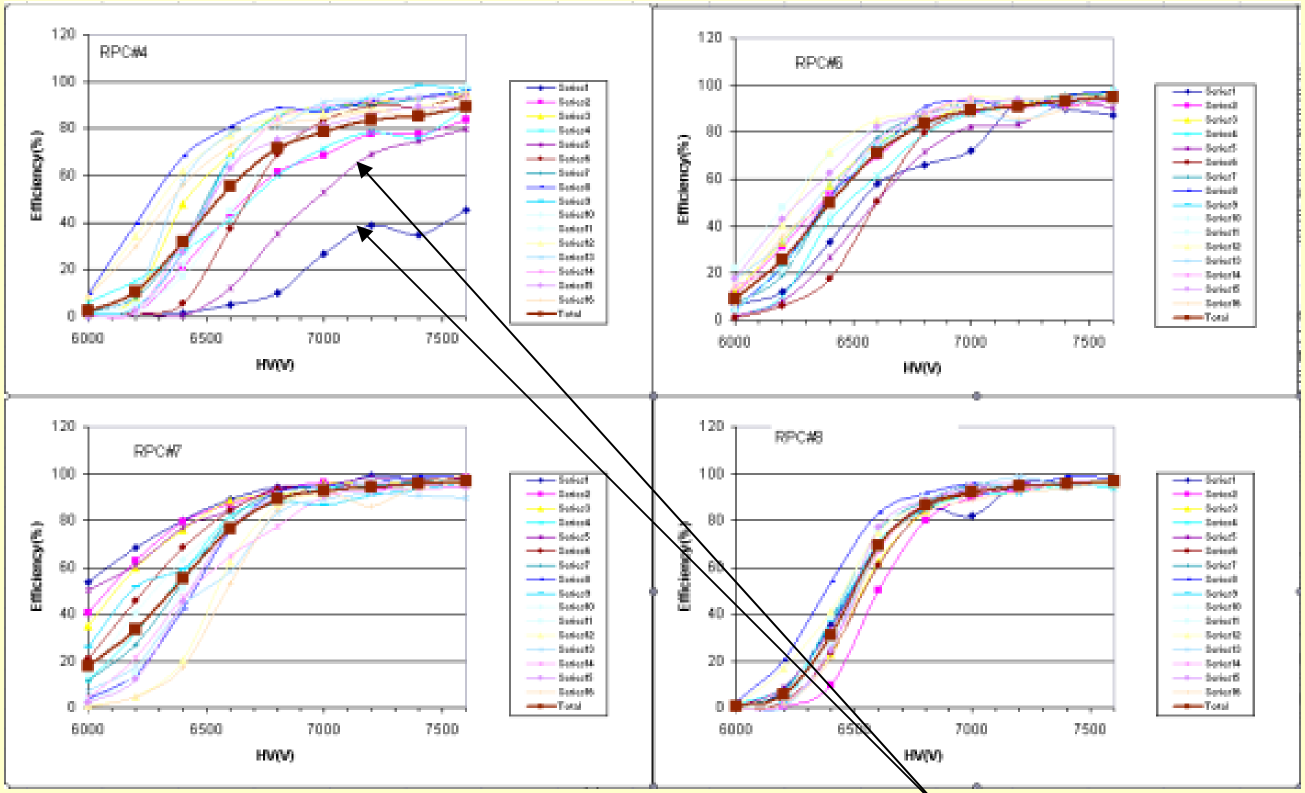
Switch gas to Daya Bay RPC gas mixture, put source on region #1, HV = 7600V.



Initial RPC efficiency



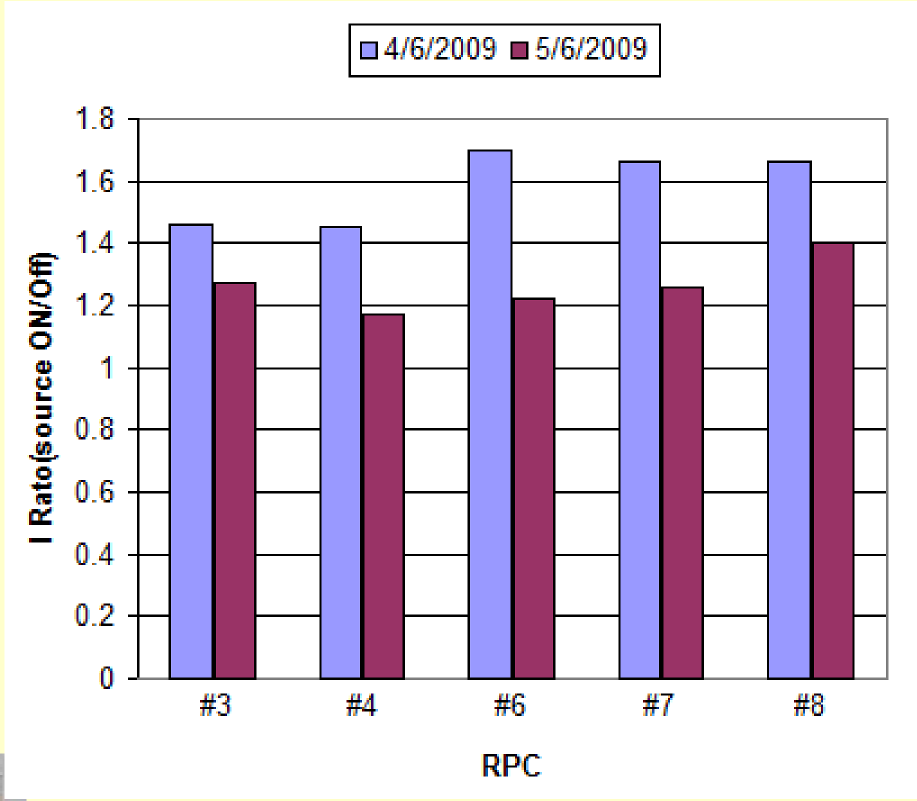
After one month of aging



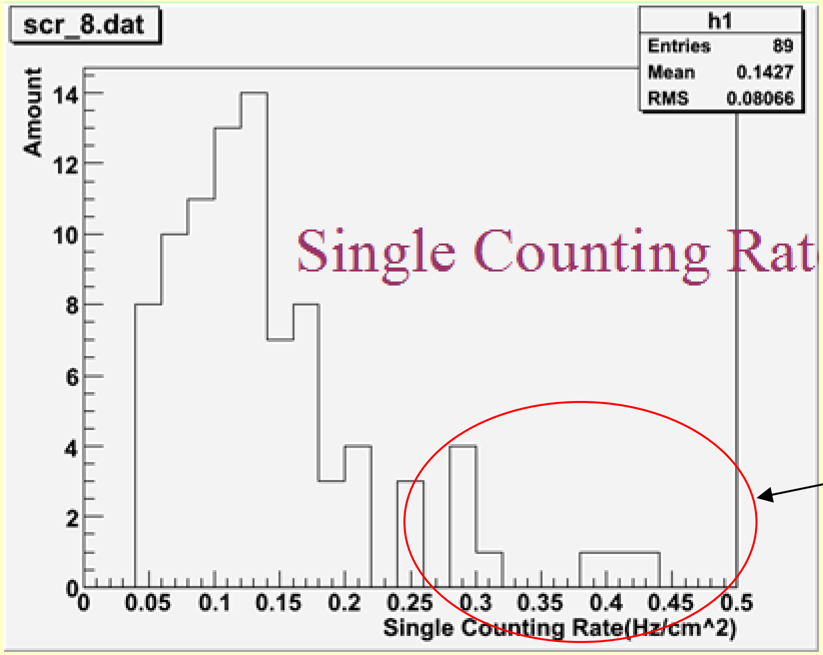
Most dramatic efficiency degrading regions are #1 and #5 in RPC #4, they are just the radiated area. RPC #6, 7 and 8 are having some aging effect, but the seriousness is clearly correlated to the distance from the source.

Degradation of current jump due to source

As we previously observed that the current jump due to the source is also degrading. We plot the ratio of I (source ON/OFF) at the begin and end of one month aging test. We can see that all five RPCs current ratios are dropped, which is an indication of aging.



How serious of the aging?



Left is the mass production RPC test results reported by Liehua Ma, Logan Lebanowski, Viktor Pec on 7/2008. Although the majority of the chambers are having low single's rate, but still have non-negligible fraction of RPCs, of which the single's rate is 0.3 – 0.45 Hz/cm^2.

With Co-60 source the measured counting rate on strip #1 and #2 is ~ 5500Hz/300cm^2 = 18Hz/cm^2, ~ 40 times higher than these RPC's background counting rate (0.45). One month of aging test is about 40 months of normal operation. The aging test results show for the radiated region #1 after one month of aging its efficiency drops from 94% to 40%!! We do need take the aging seriously.

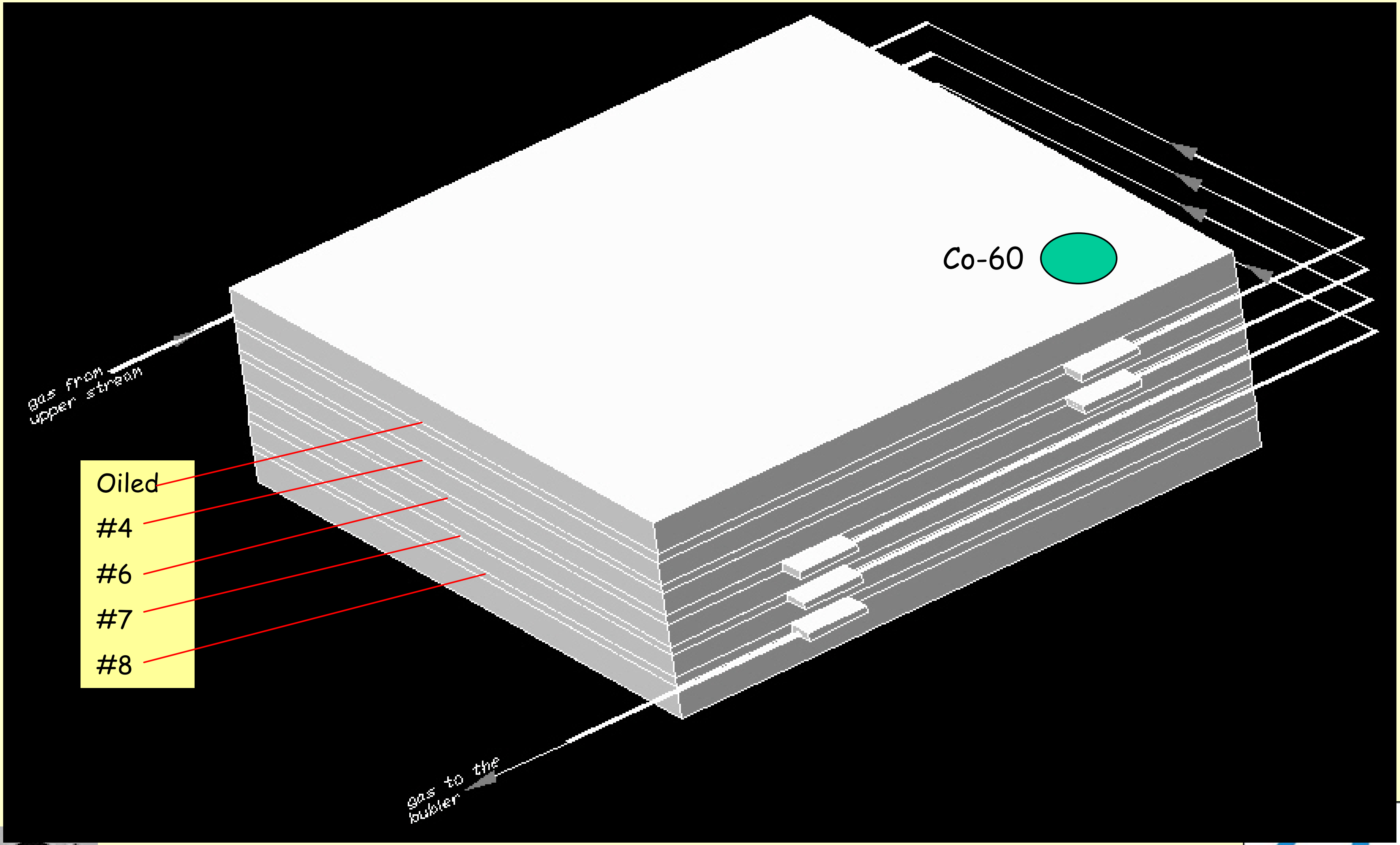
(3) Solution – Linseed oil coating

While we are still working on making better Bakelite that has better resistance to the HF corrosion, an existing solution is Linseed oil coating. This is a well developed and proven technique, can greatly improve the performance and aging for the RPC.

One prototype RPC from same batch is Linseed oil coated and put into test. We flow pure argon gas into the chamber, apply HV to 3000V, keep the current at 5uA level that is much less than IHEP used current 100uA for only one hour. We also can hear sparking noise coming out of the chamber, that we believe actually happens in the air gap between the graphite coating and pickup electrode, not inside of the chamber.

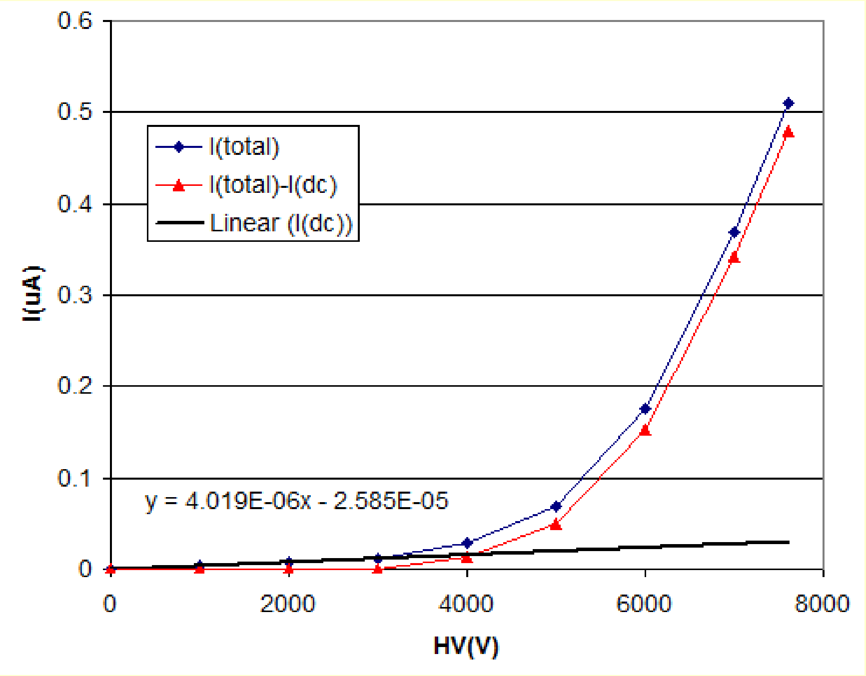
After such short training the RPC already performs very well (probably we don't need the HV training at all for the oiled RPC).

Gas flow path



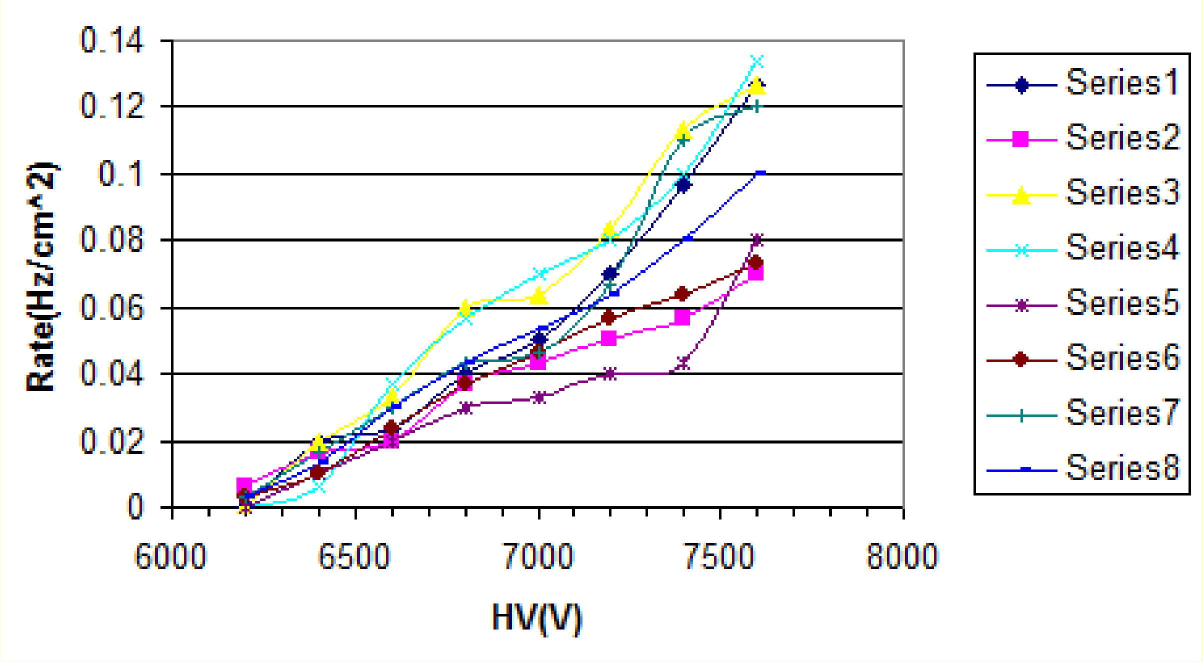
Test result of the oiled RPC – dark current

We flow 10 sccm Daya Bay gas mixture through the chamber, measure the dark current vs HV.



Test result of oiled RPC – single's rate

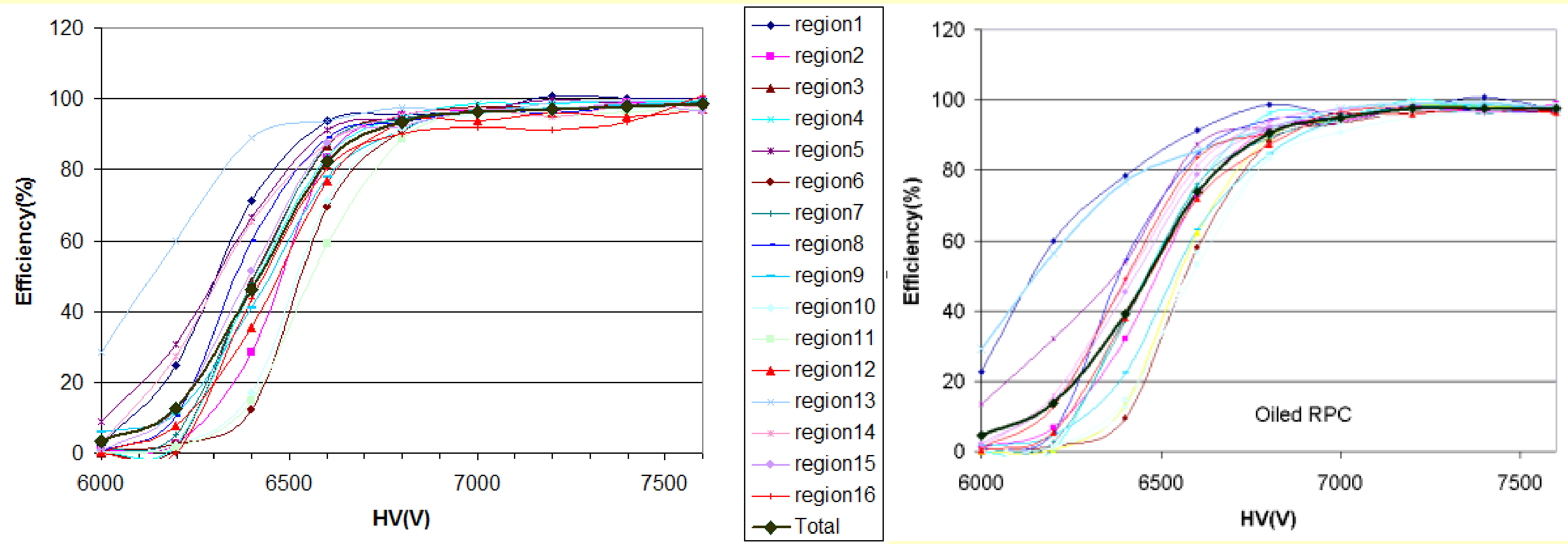
Set threshold at 30mV, we measure the single's rate on 8 strips, which covers the entire chamber.



Compare to the same batch RPCs, the single's rate is 10 – 100 times less.

Test result of oiled RPC - efficiency

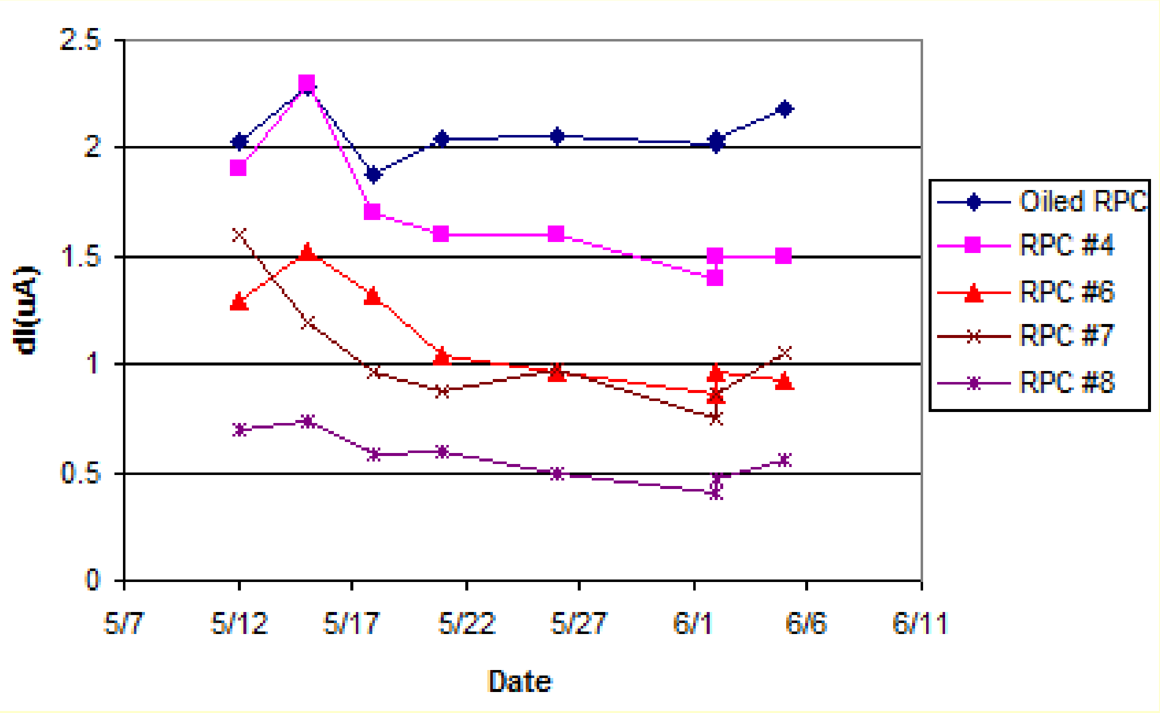
We divide the RPC to 16 regions, measured the efficiency plateaux: above 6800v, all regions reach better than 90% of efficiency. The bold line shows the RPC's overall efficiency, @6800V it reaches 93%.



At beginning of aging, 5/12/09

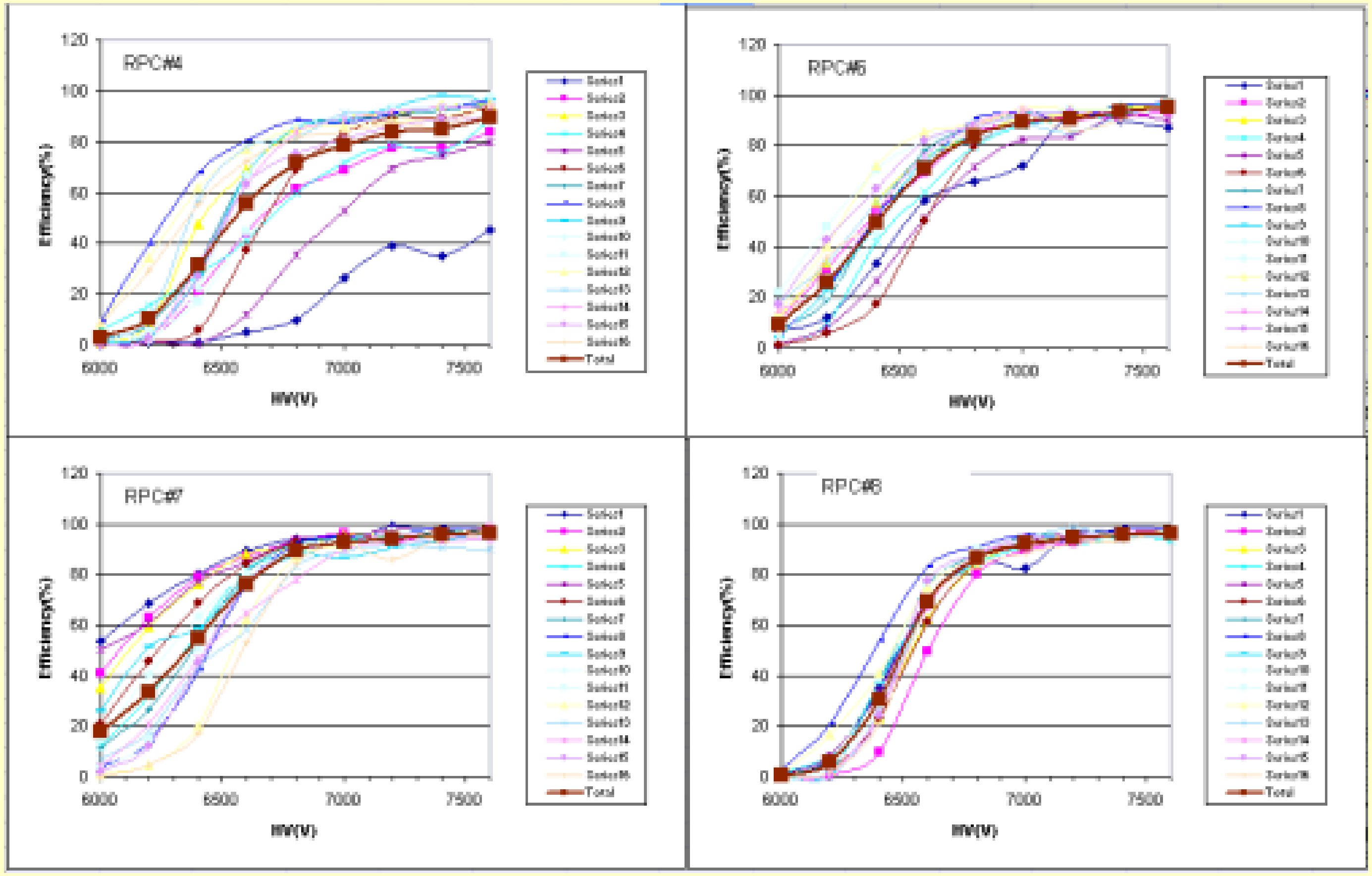
After 23 days of aging, 6/4/09

Evolution of source current jump

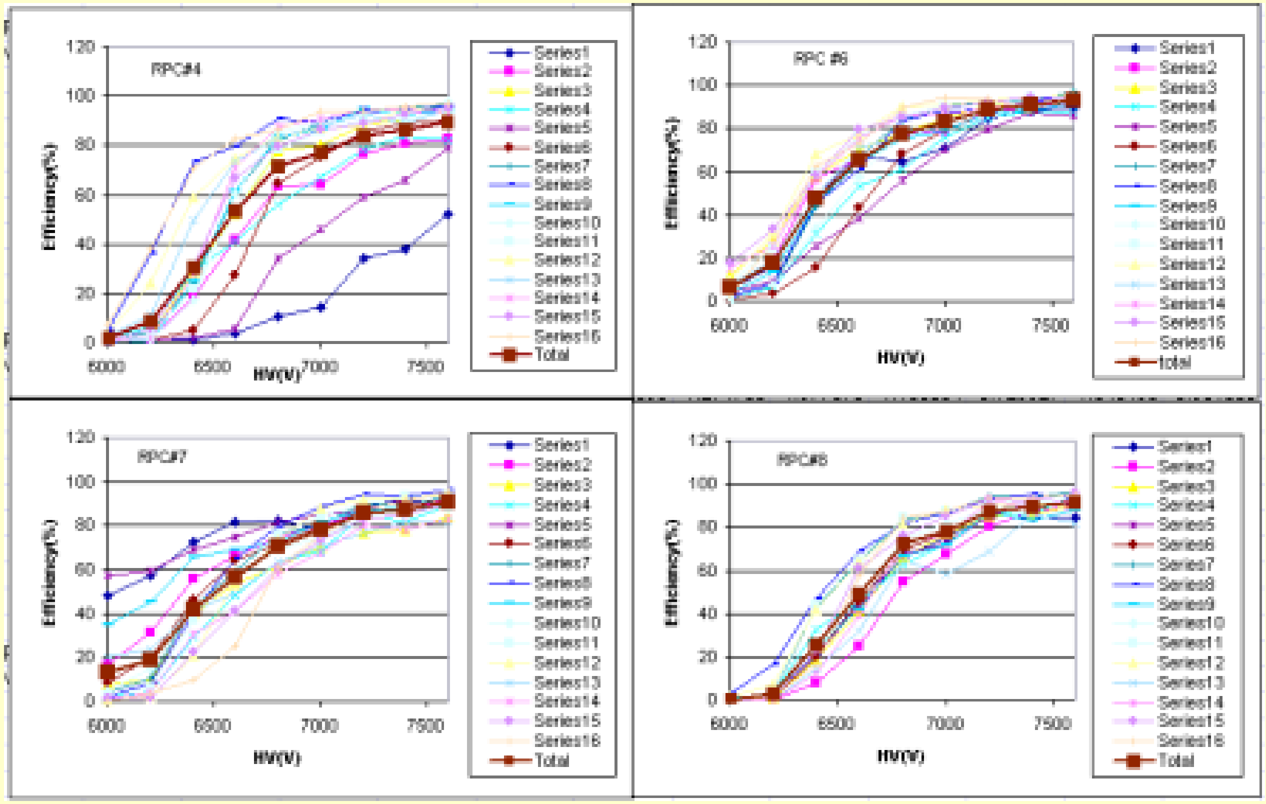


The overall trend of the current jump due to source for all other RPCs is decreasing with the aging days, but the oiled RPC is quite stable.

5/10/2009 Efficiency data (one month aging)



Efficiency change for other 4 RPCs (23 more days)



They show further efficiency degradation, but with slower pace.

Summary of oiled RPC

The initial test shows the following features for the oiled RPC :

• The dark current is dramatically less, almost ten times smaller;

• The noise rate also has big reduction. After the oiling it is not necessary to train the chamber in pure Argon gas with very large current;

• After 23 days of aging there is no noticeable performance degradation for the oiled RPC chamber, but the other four aged RPCs are showing further degradation (Current jump due to Co-60 source and efficiency are decreasing).