Status on BESIII-type RPC aging study

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- BES-III RPC aging test results;
- Observation of HF corrosion to the Bakelite surface and its effect on RPC aging;
- Solutions:
  - Linseed oil coating;
  - Develop new variant HF-resistant Bakelite;
  - Search for Freon-less gas mixture to operate RPC.

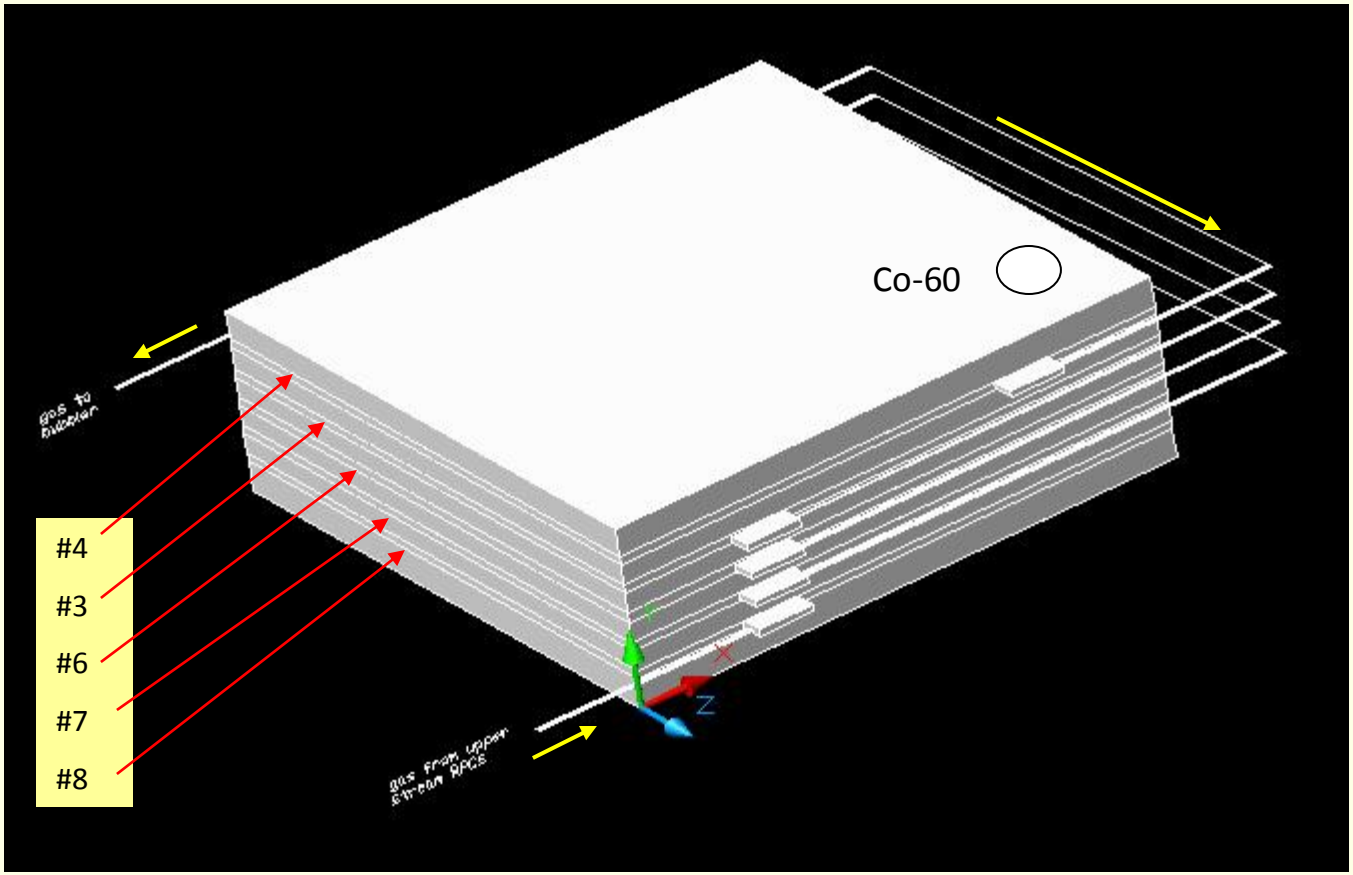
ILC R&D program: original motivation of project 6.19

• The RPCs built from the new type of Bakelite developed by the BESIII Muon group of IHEP (Beijing) and a Beijing Bakelite manufacturer for use in the BES III and Daya Bay Muon Systems have achieved acceptable dark noise rates without Linseed oil coating, but aging effects have not been thoroughly studied;

• Our preliminary study of Daya Bay Muon System prototype RPCs has indicated a significant aging effect that must be understood and mitigated prior to use it for SiD;

• In the longer-term, a collaboration with IHEP and Beijing Bakelite manufacturer might lead to develop new variants of Bakelite that are more resistant to aging.

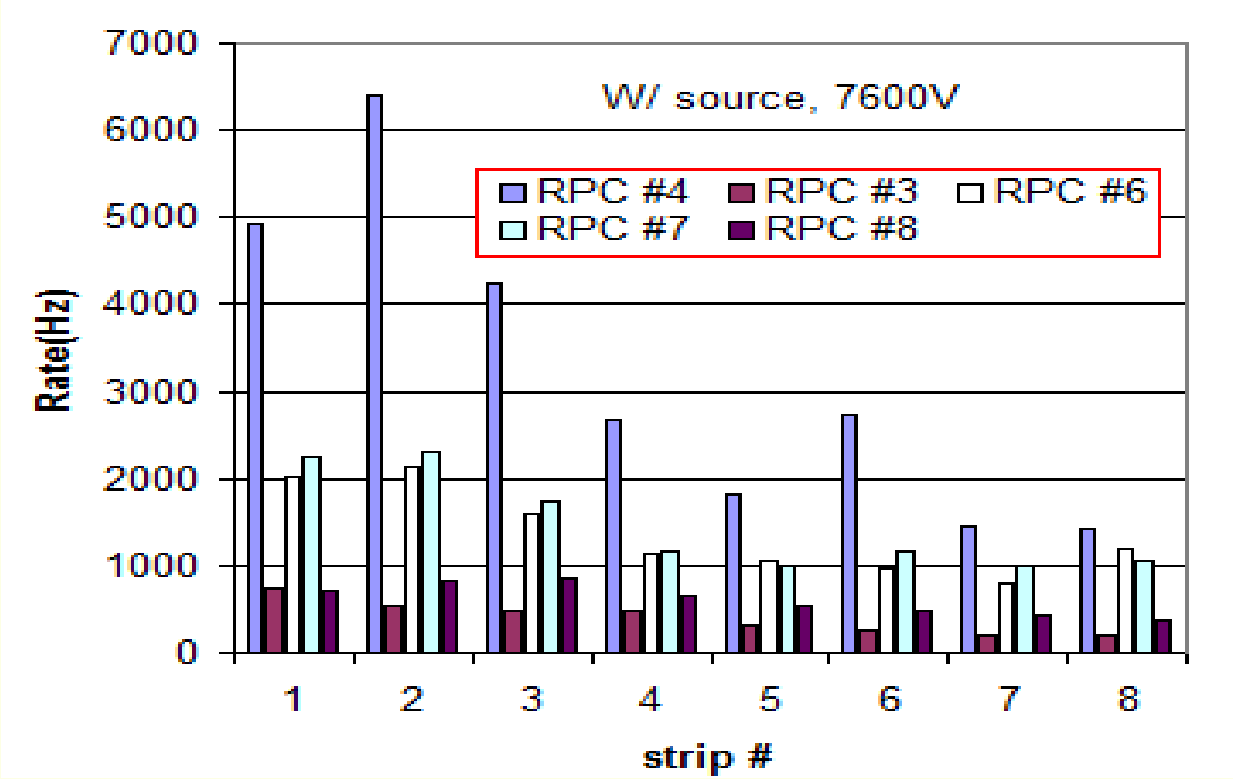
Test set-up: five RPC chamber stack



The entire RPC area is divided into 16 regions, which are defined by two sets of scintillation trigger counters located on top and bottom of the test RPCs.

All RPCs are connected in a series.

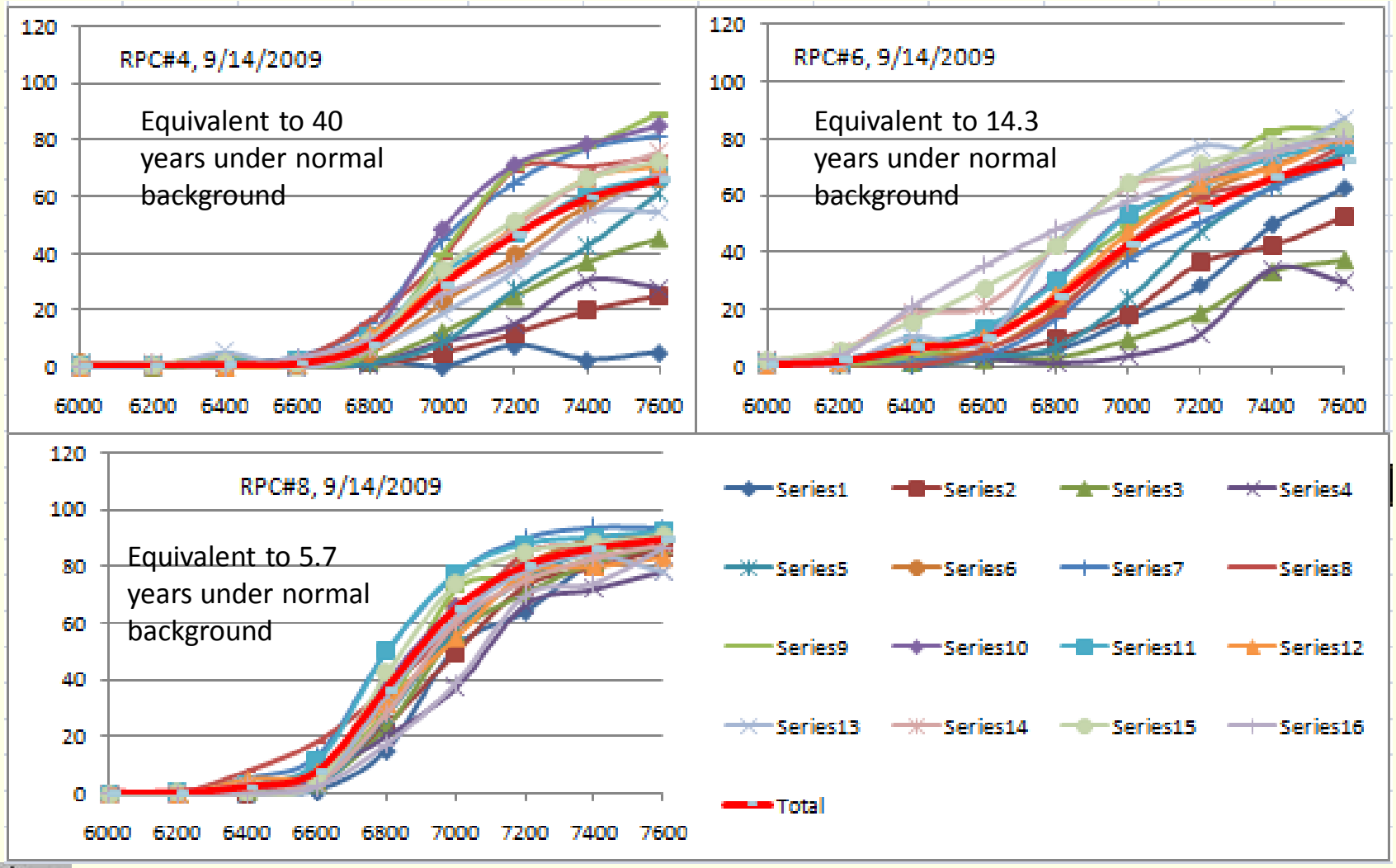
Aging test: Single's rate



Singles' rates w/ source are quite different for RPCs. RPC #4 is the noisiest, ~6kHz for strip #2. RPC #8 is the quietest, ~0.8kHz for strip #2. Strip dimension: 48 X 6 cm^2.

Aging dose per day is different among these RPCs, their ratio is (#8): (#6, #7): (#4) ~ 1: 2.5: 7.5.

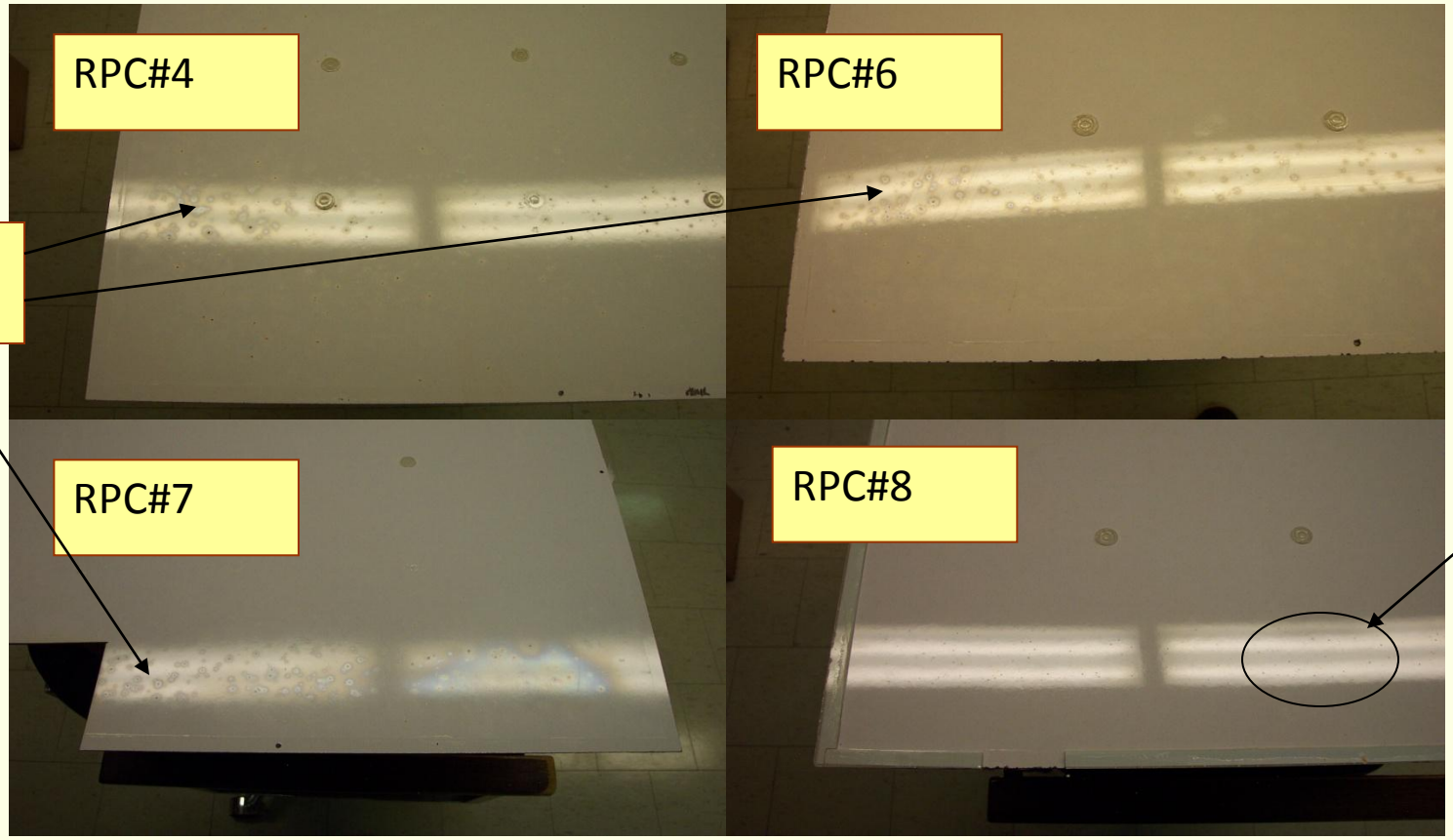
Efficiency



We assume the background noise rate is 0.2Hz/cm^2

Aged RPC inner surface

Opened the aged RPCs we can see very dense sparking marks distributed all over the inner surface. RPC#8 has much smaller size sparking marks.

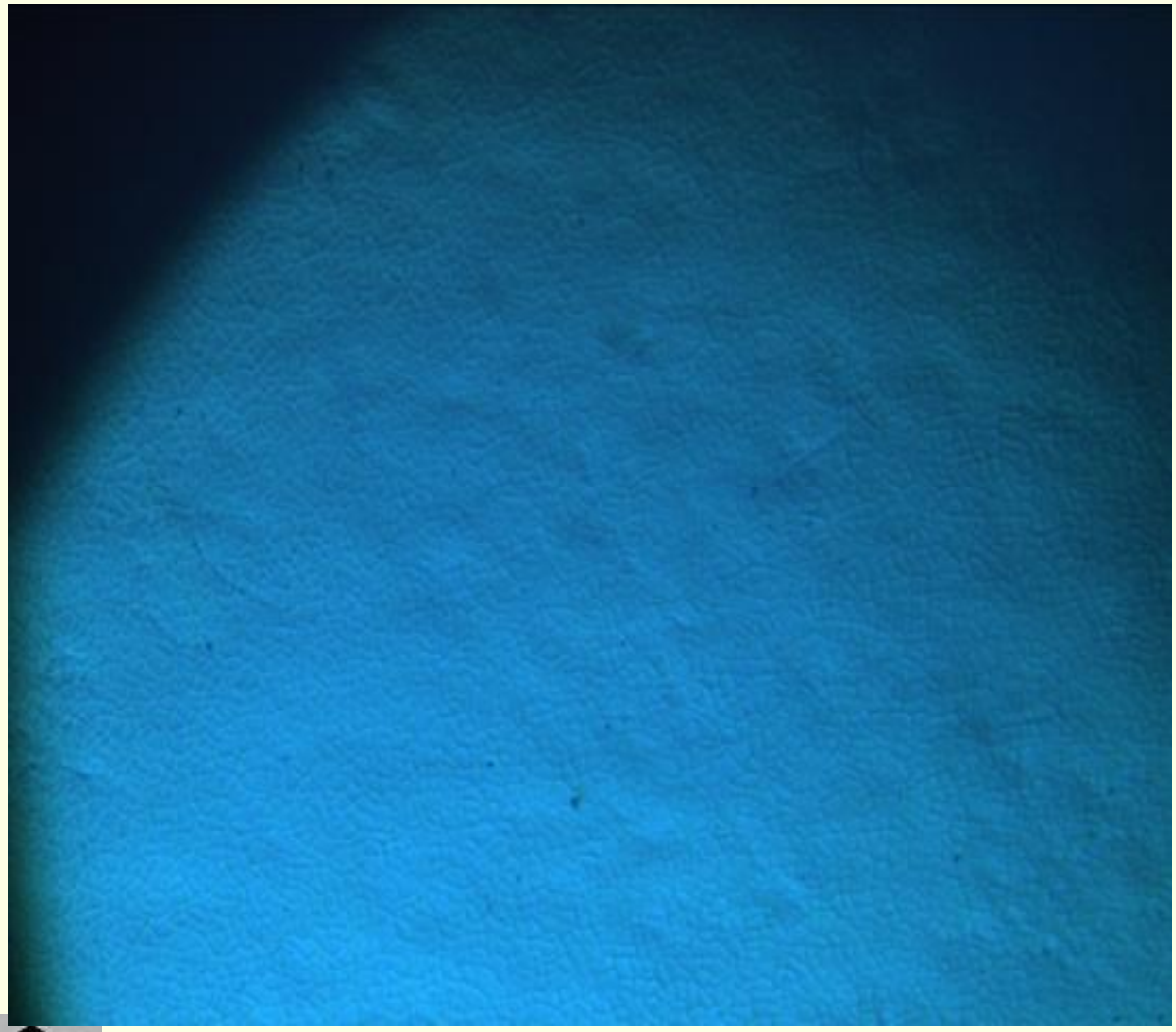


Surface comparison at various stages of aging

We investigate the surface image under the microscope for various aging chamber samples and try to give a plausible working hypothesis of the BESIII-type RPC aging.

- Virgin Bakelite surface;
- Exposed to HF vapor surface;
- Less aged RPC inner surface;
- Serious aged RPC inner surface;
- BaBar aged RPC inner surface.

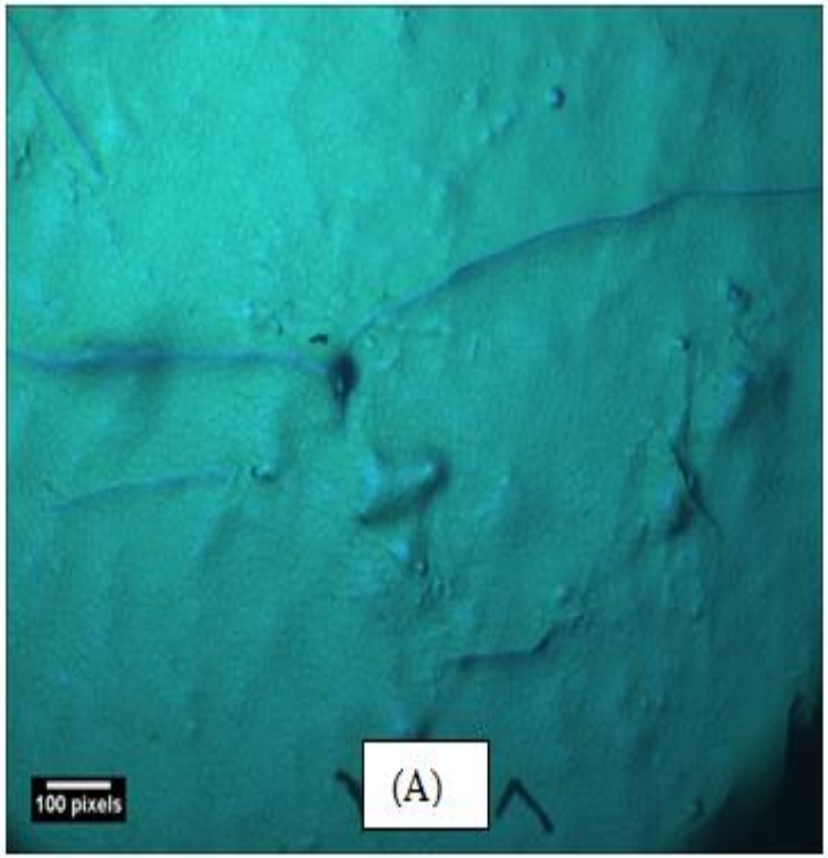
Virgin BESIII Bakelite surface



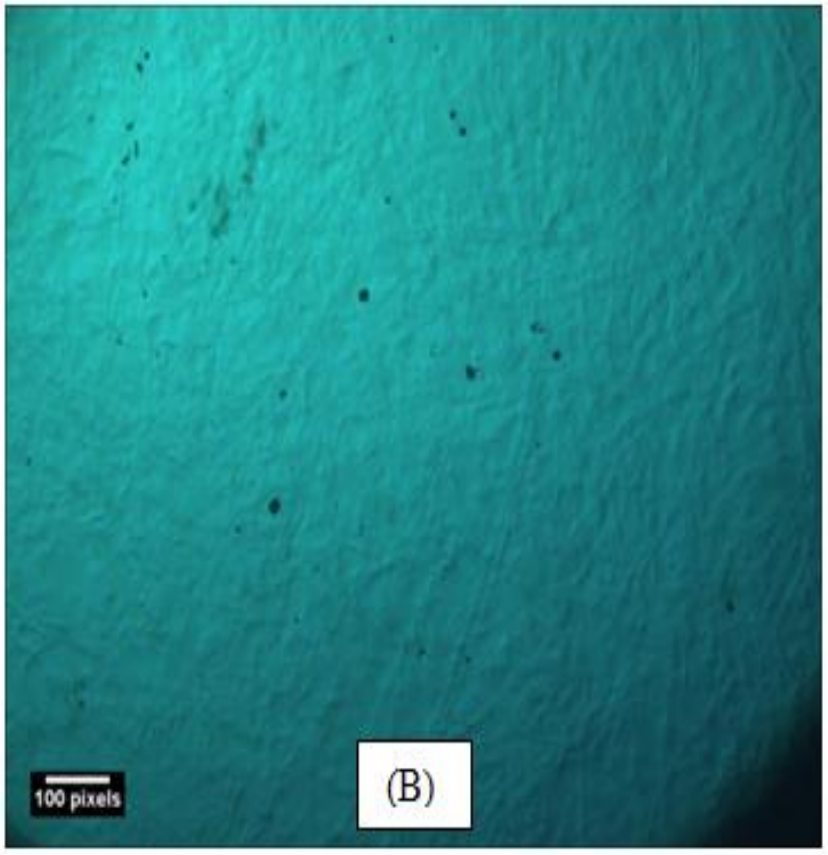
Characteristic:

- Smooth;
- Dense and uniformly distributed "skin-like" texture;
- No broken surface.

HF vapor exposed surface

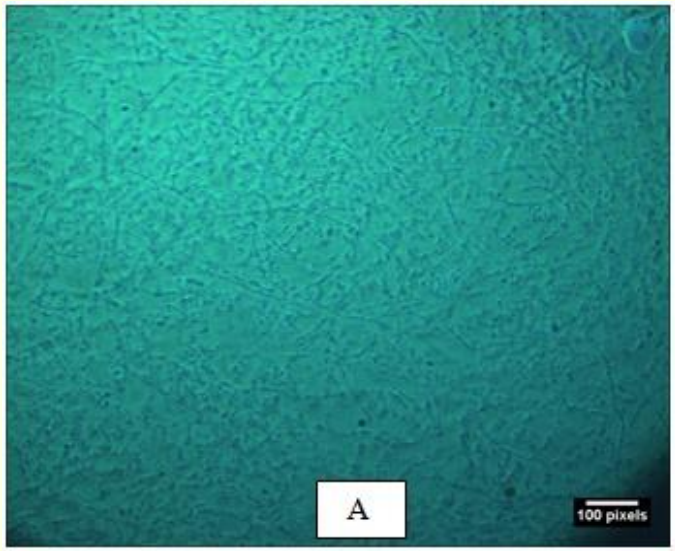


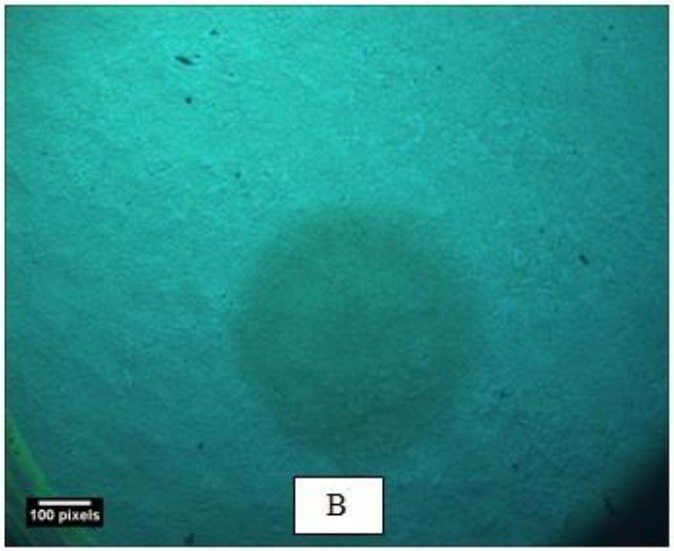
Bumps, cracks, but still can see "skin-like" texture.

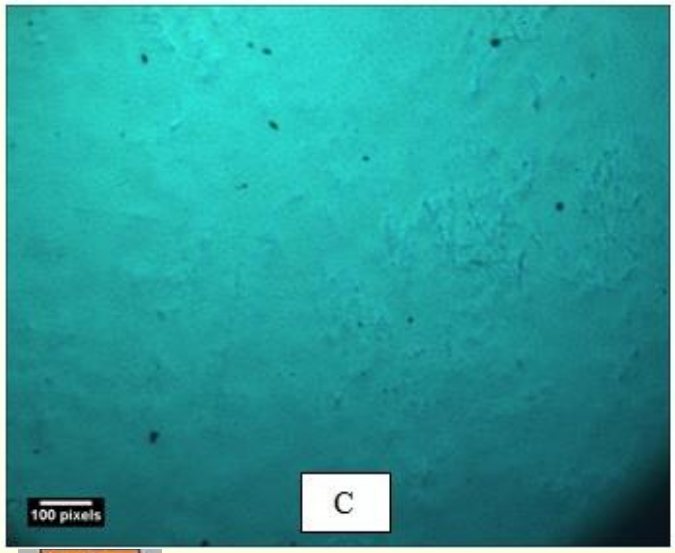


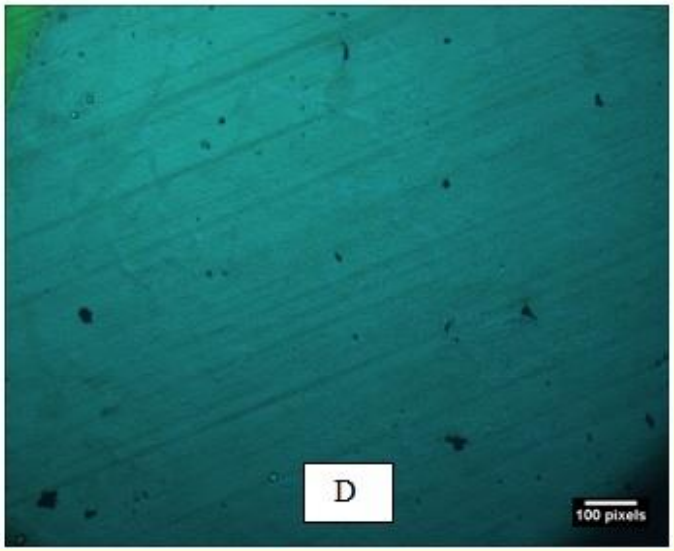
No more "skin-like" texture can be seen.

Various aged RPCs' inner surface







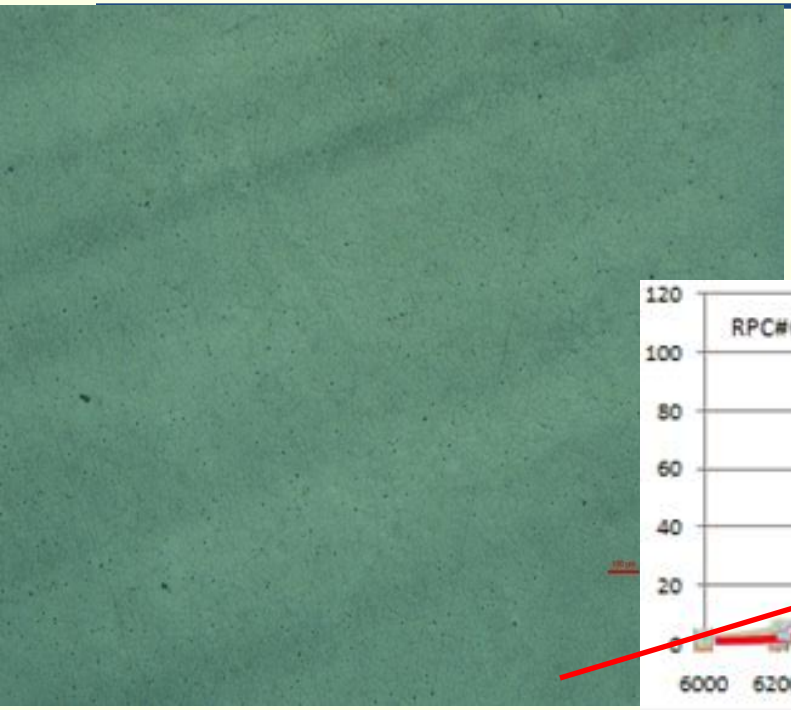


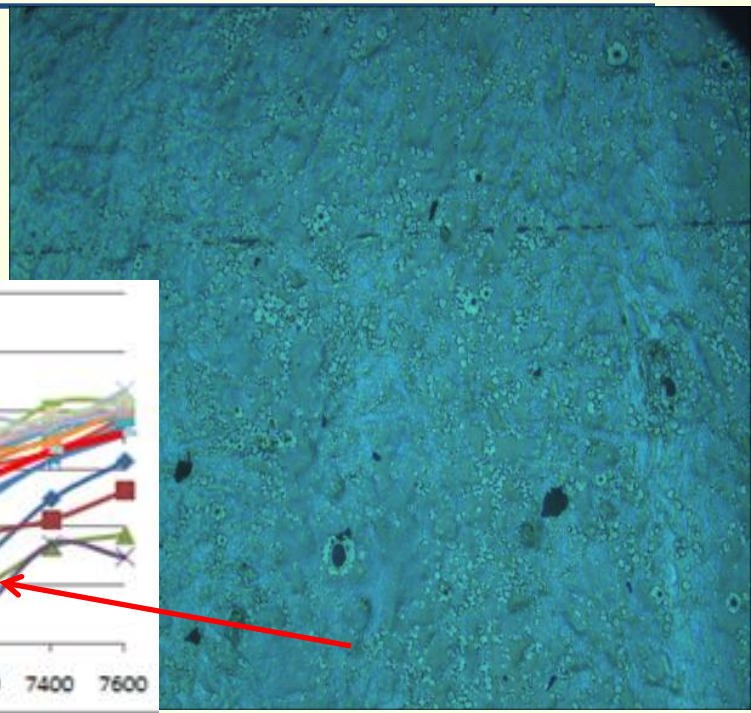
(A)RPC#4.
entire surface corroded, no more "skin-like" texture;

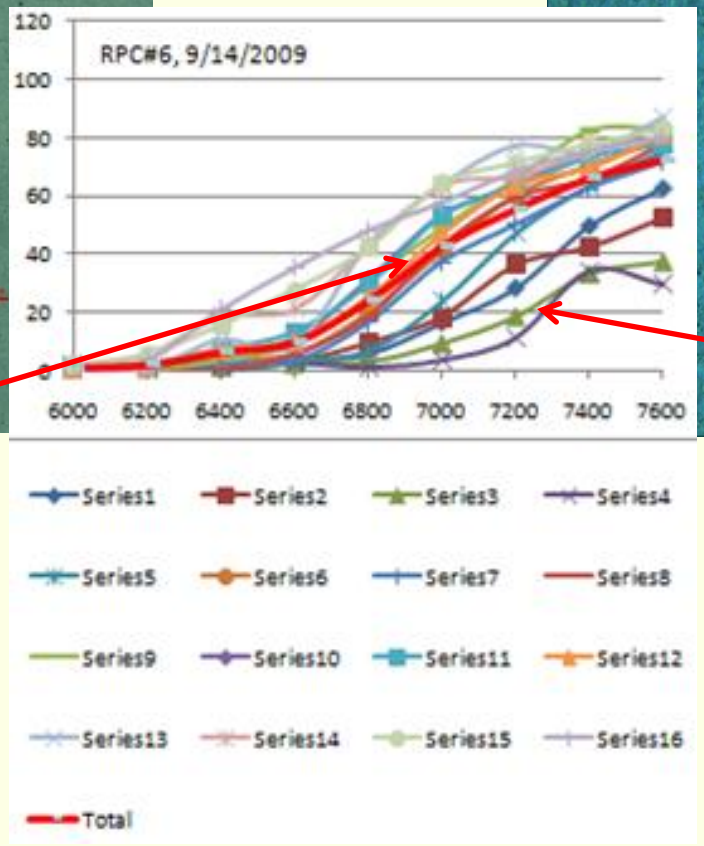
(B) (C) RPC#6/#7.
"skin-like" texture still can be seen, but start to show "veins";

(D) RPC#8.
Very faint "veins" on top of the "skin-like" texture.

Two different areas in same aged RPC







RPC #6, area #8, less aged area.

RPC #6, area #4, severely aged area.

Working hypothesis of BESIII-type RPC aging

- With the gas mixture of Freon and others, the gas avalanches will produce HF molecules.

- These HF molecules are adsorbed on the inner surface, form HF acid with the water molecules released from the Bakelite electrodes.

- The corrosive action will take place on the inner surface. As the results the bumps may help to initiate the sparks.

- With the progress of the HF corrosion the inner surface is getting worse and worse, it would destroy the virgin Bakelite surface completely, the characteristic "skin-like" texture is then completely disappeared.

What to do next?

The surface of BESIII-type Bakelite is vulnerable to the HF attack, **our study clearly pointed out that the corroded surface is related to the efficiency drop**. There might be three solutions:

- We have found an indication that Linseed oil coating film may have good resistance to the HF, we are going to make systematic study for this solution;
- To develop new variant of Bakelite sheet, which is less sensitive to the HF corrosion;
- Search for Freon-less gas mixture for RPC. If we can completely avoid to use Freon in the gas mixture, we can remove the source of HF.

Coating Linseed oil to the inner surface of RPC

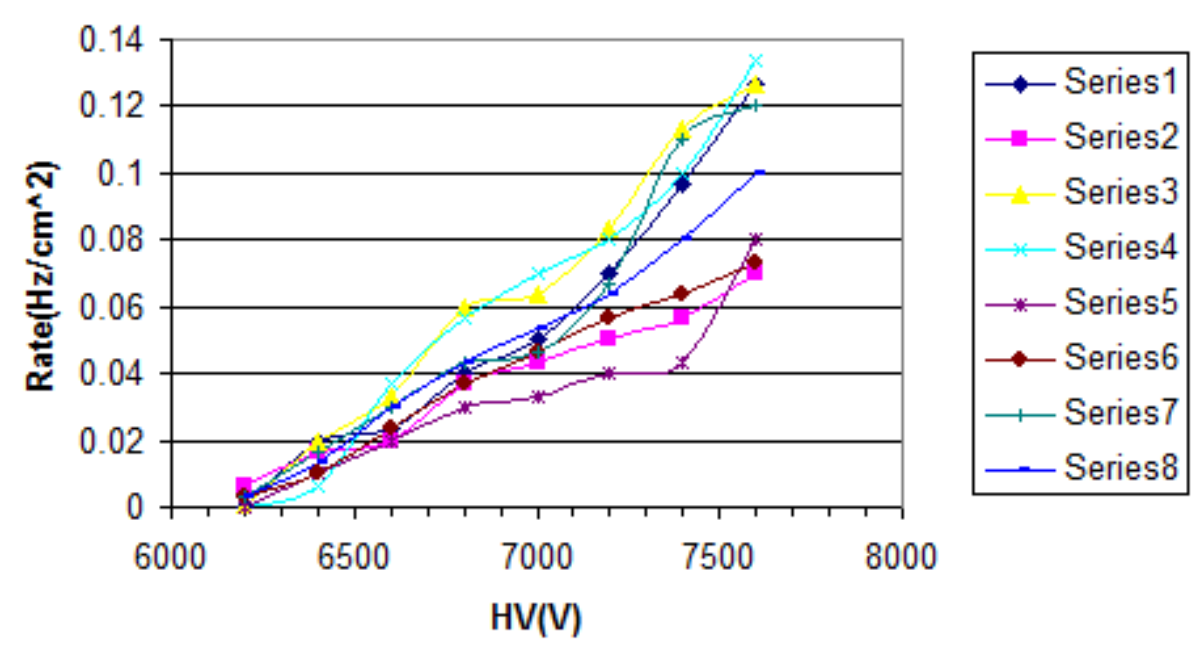
It is the common practice for Italian Bakelite RPC that always has Linseed oil coated the inner surface, otherwise it would be too noisy to operate.
We also found that the Linseed oil could have another role – to defend the bare Bakelite surface from HF attack.
To confirm this observation we have exposed the Linseed oil coated Bakelite surface to the HF vapor to compare it with bare Bakelite surface.

Performance of BES-III prototype w/ Linseed oil coating

We have chosen one RPC prototype from the same batch of IHEP RPC small prototype (50x50cm^2), which is used in the above mentioned aging test. The volume resistivity of its Bakelite is ~1.5×10^{11} Ωcm. We fill in 35% Linseed oil/65% n-pentane mixture for one hour, then completely drain and flow filtered air at 50 sccm rate through the chamber for 3 days.

Test result of oiled RPC – single's rate

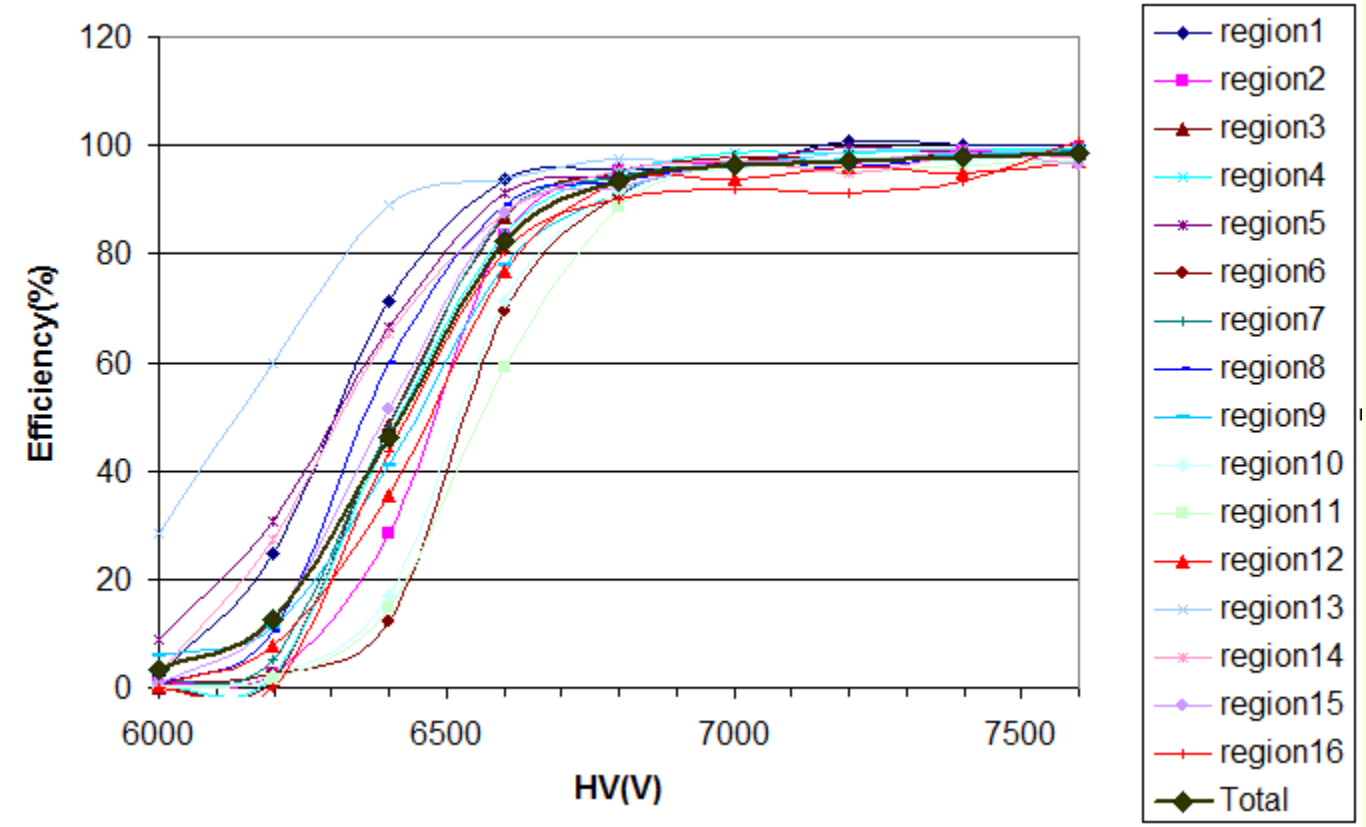
Set threshold at 30mV, we measure the single's rate for 8 strips, which covers the entire chamber.



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

Test result of oiled RPC - efficiency

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



Real aging test for Linseed oil coated prototype

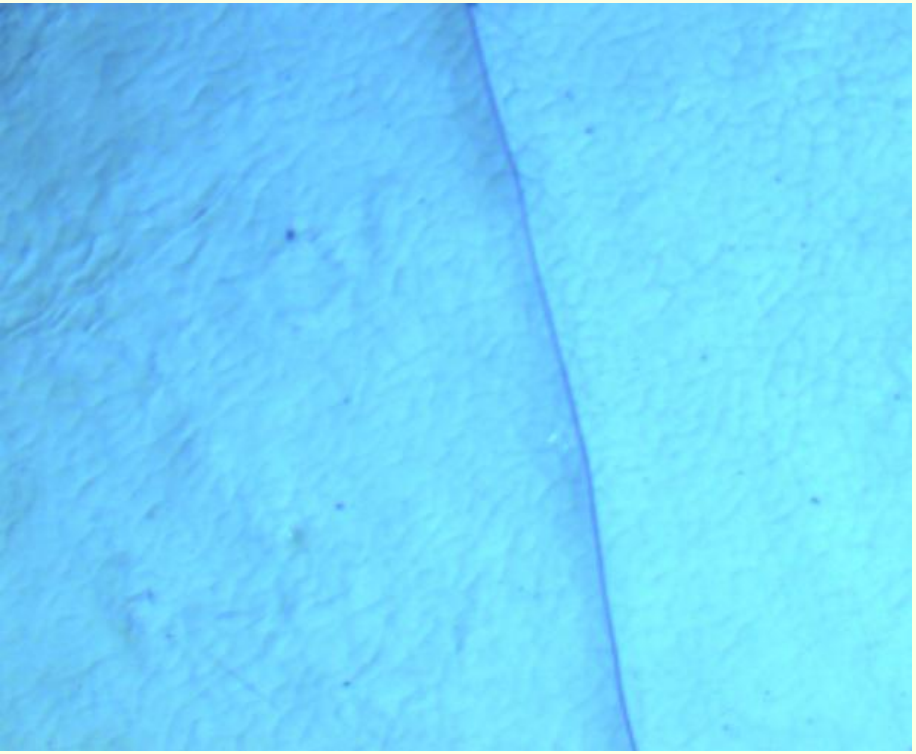
We have done some test for the oil coated BES-III type RPC, although the results are positive, but we found that the coating technique has to be improved before conclusive results can be drawn. We have obtained several new prototypes from Beijing, we are going to coat their inner surface with 35% Linseed oil/65% n-pentane mixture, then run the aging test as before to make sure if it is better than bare BES-III RPC.

Develop new variants of Bakelite

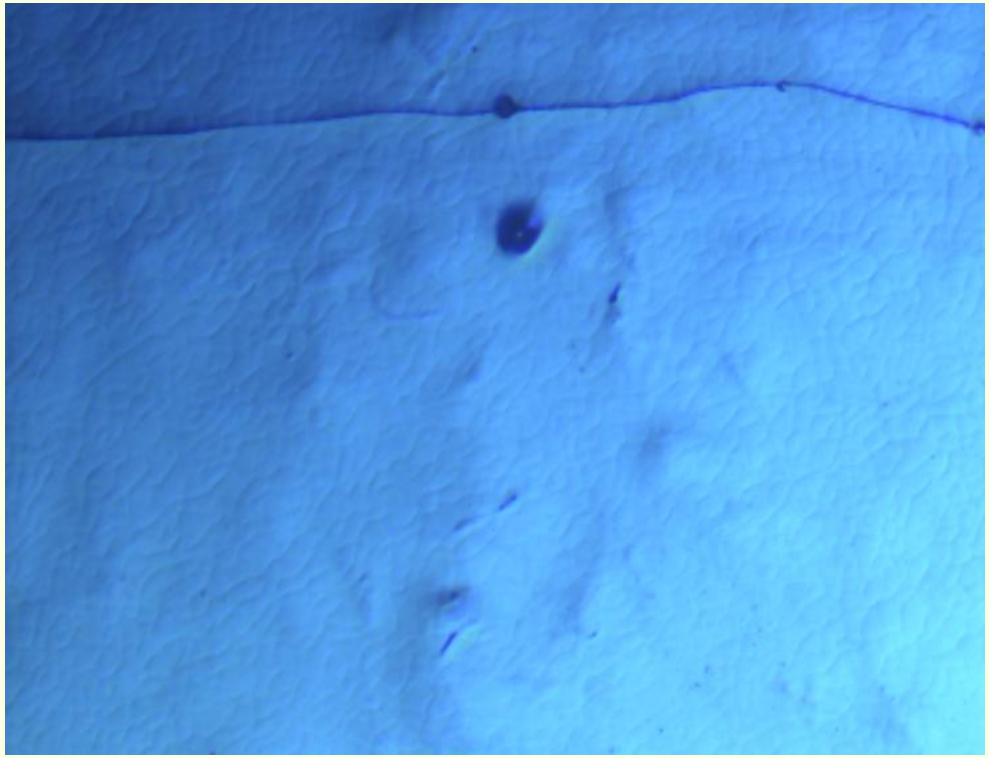
We have developed several variants of Bakelite with different resin/oil mixtures. Our naïve idea is to get the oil coating formed during the Bakelite manufacturing stage. As long as we can form smooth surface with this new resin/oil mixture the Linseed oil coating formed on the surface would protect the Bakelite from HF corrosion.

When we were developing this type of technique soon we found that it is not as simple as we thought. It is very difficult to form smooth oil coated surface. The uneven surface seems vulnerable to HF attack.

Regular BESIII Bakelite sample

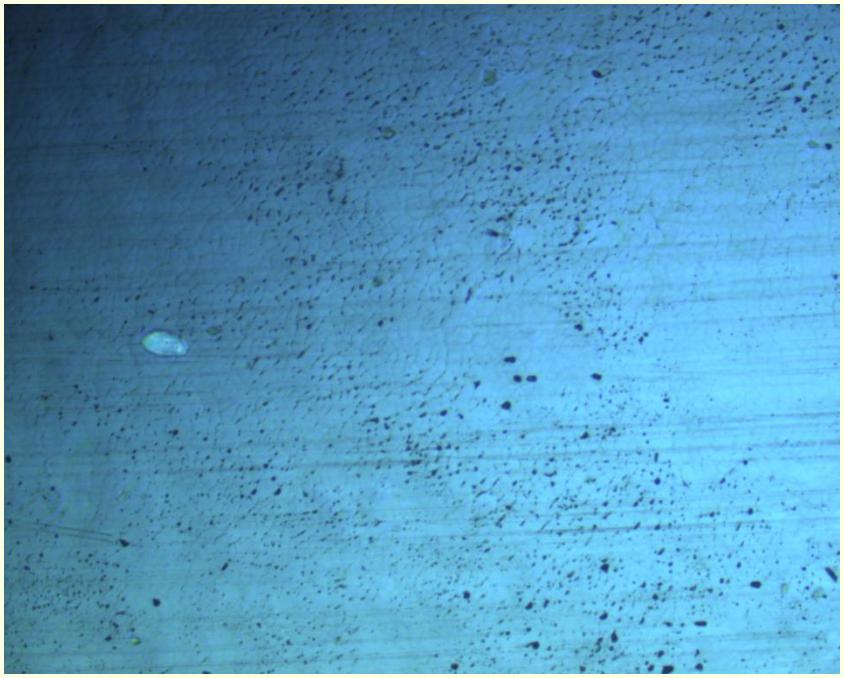


Before exposed to HF vapor.

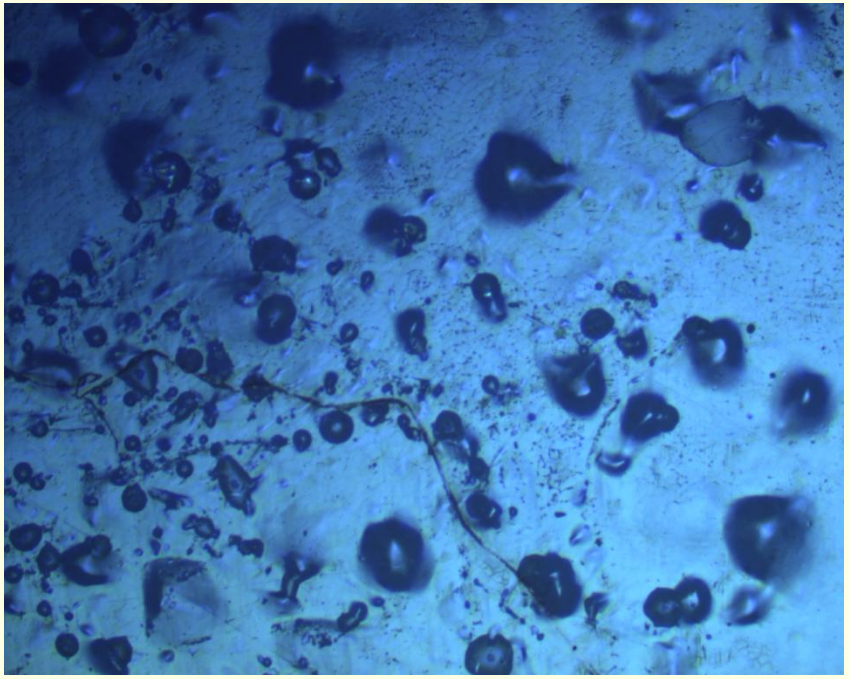


After exposed to HF vapor.

Oil embedded Bakelite



Before exposed to HF vapor. "skin" texture can still be seen, it means the oil coating is very thin (see next slide for comparison).

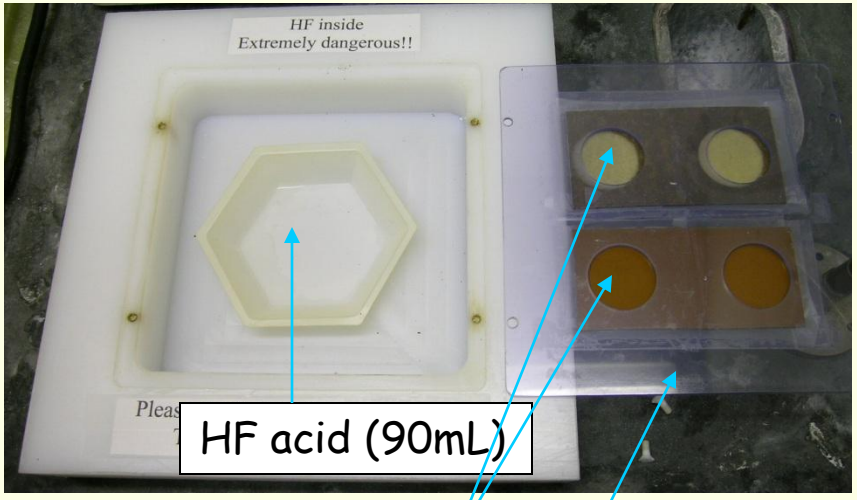


After exposed to HF vapor, surface seriously damaged, looks the embedded oil doesn't do anything good to protect the surface.

Brief summary on oil coating

- Oil embedded Bakelite is clearly out of the game;
- Bare BES-III Bakelite surface is vulnerable to HF corrosion;
- Oil coating on the BES-III Bakelite surface might provide the first defense line and prolong the lifetime of the RPC as demonstrated by the RPC systems in LHC detectors, but preliminary test shows that HF might be able to penetrate thru the Linseed oil coating film and reach the surface of the substrate, therefore choose the HF resistive Bakelite is still essential for the aging.

HF resistance test device



HF acid (90mL)

Testing samples

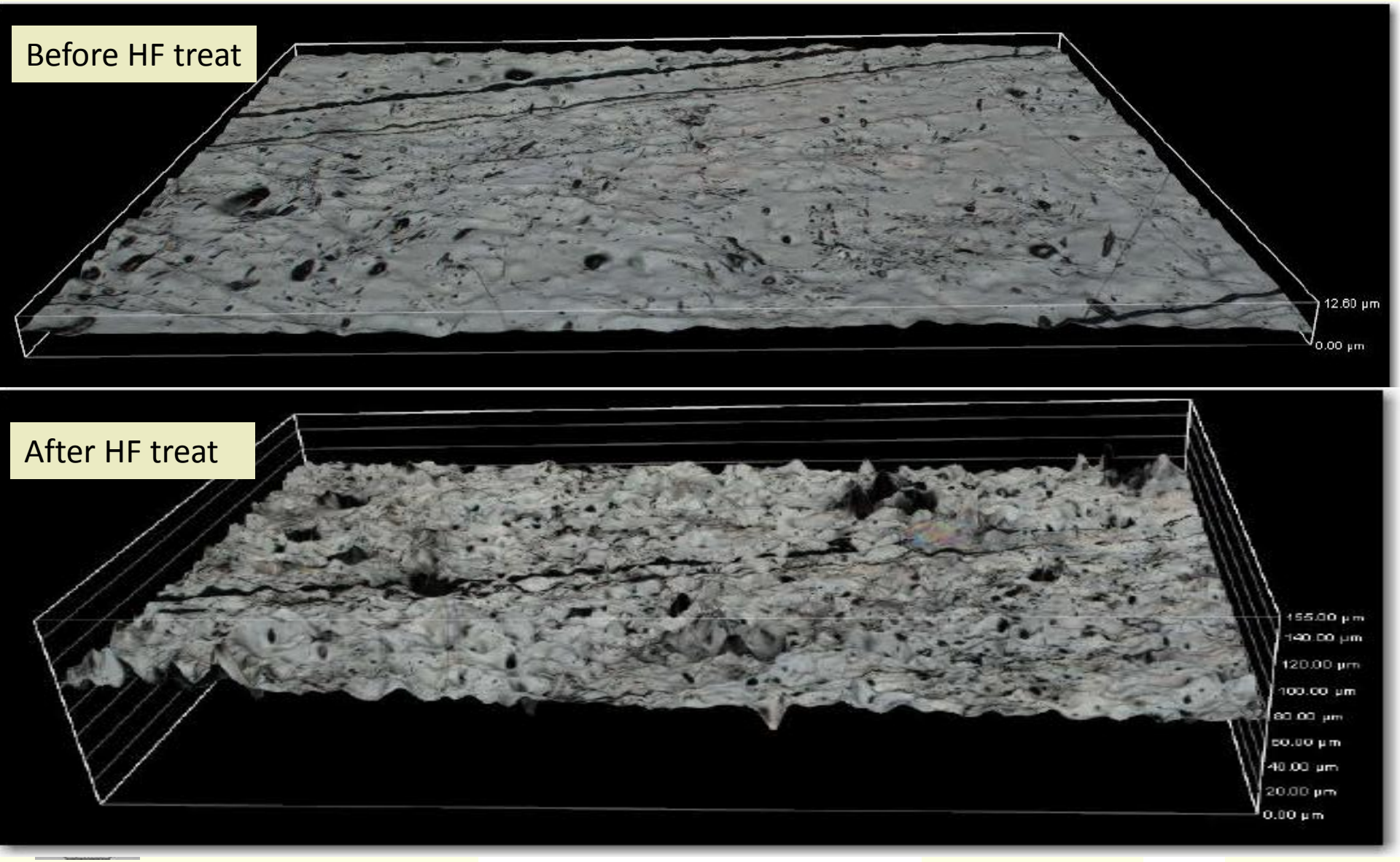
Cover plate with 4 round windows that let the testing samples exposed to HF vapor.

Candidates for the Bakelite substrate

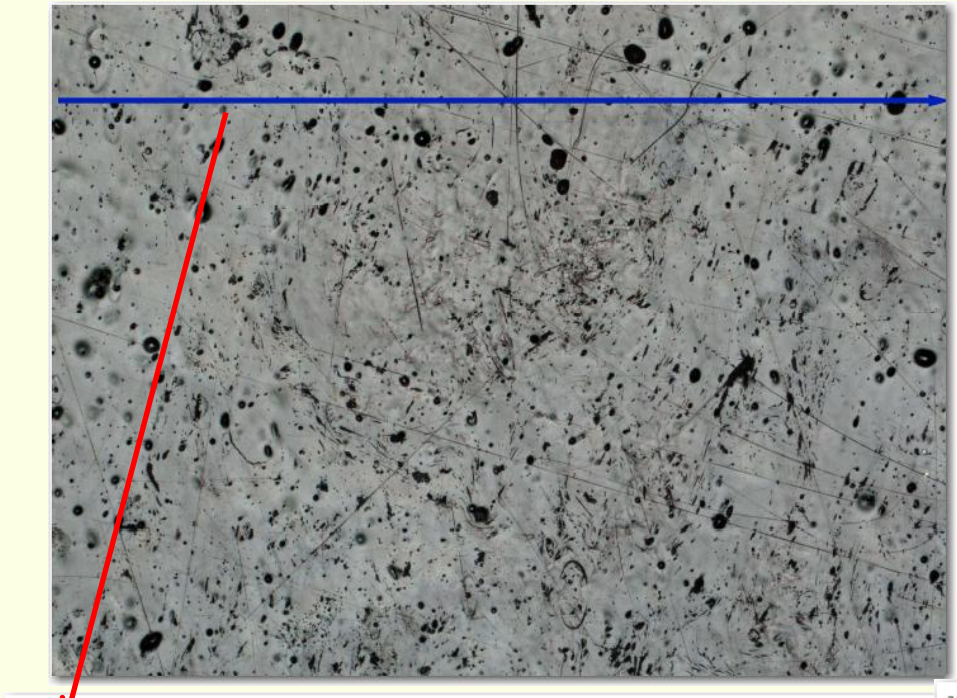
Four Bakelite samples are selected for HF study:

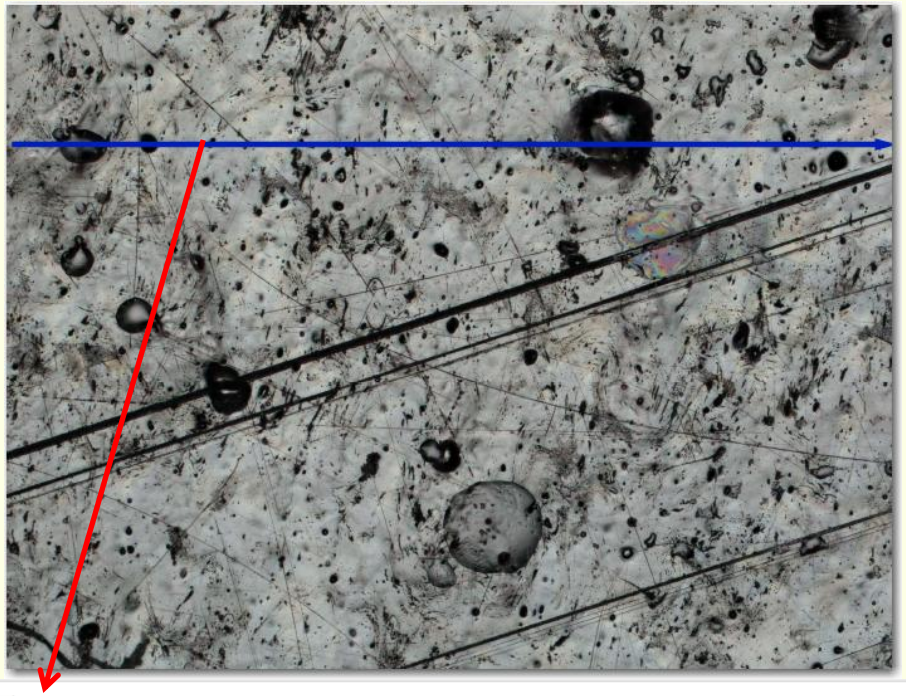
# of sample	Description	$\sigma(\Omega)$(before)	$\sigma(\Omega)$(after)	Ratio
1	Phenol formaldehyde resin (new)	$2X10^{11}$	$2.5X10^{9}$	80
2	Italian Bakelite	$6.6X10^{12}$	$2.0x10^{6}$	$3.3x10^{6}$
3	Melamine (BESIII)	$4X10^{11}$	$7.0X10^{6}$	$5.7X10^{4}$
4	Funan resin (new)	$1.1X10^{11}$	$2.0X10^{7}$	$5.5X10^{3}$

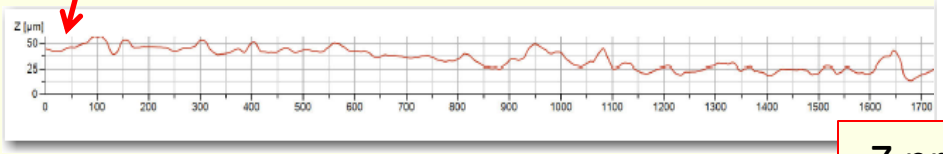
Candidates – funan resin

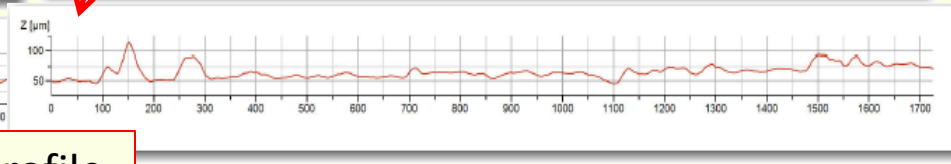


Funan resin – HF corroded







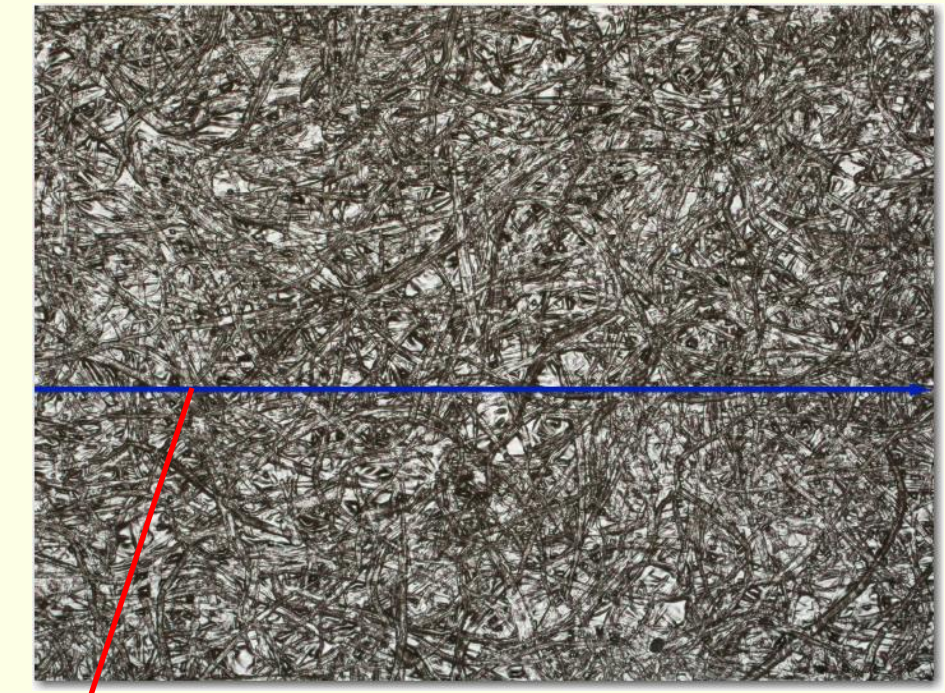


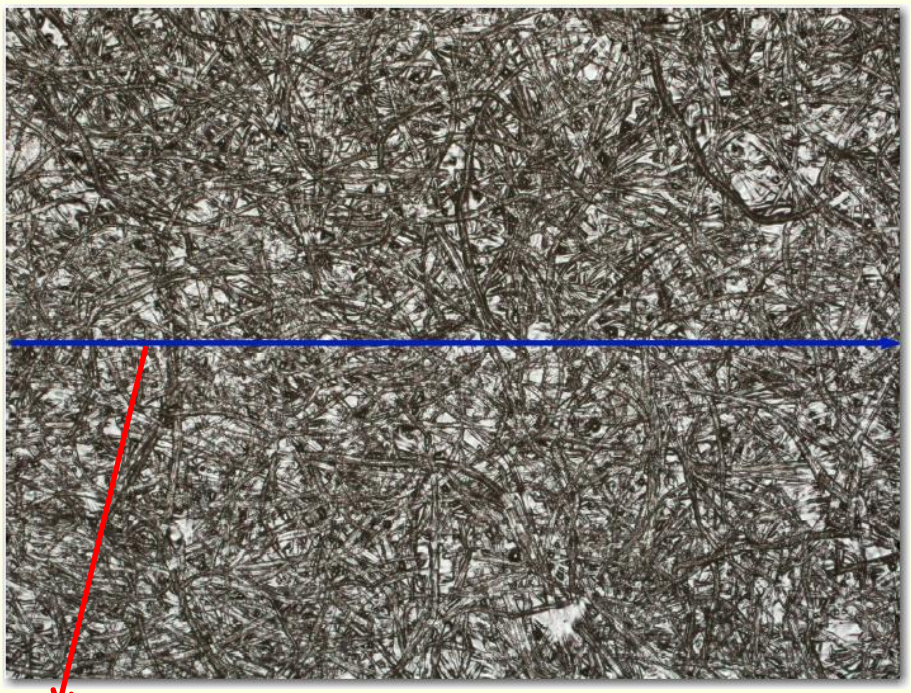
Z profile

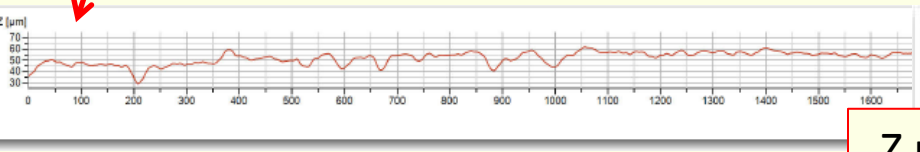
Before HF treatment

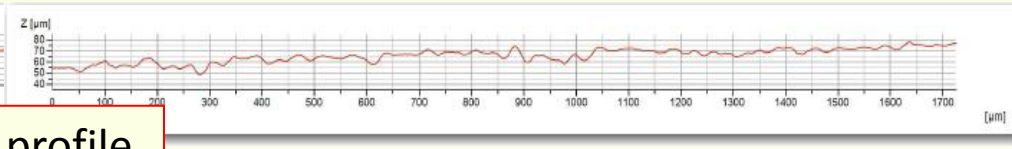
After HF treatment

Candidate – phenol resin







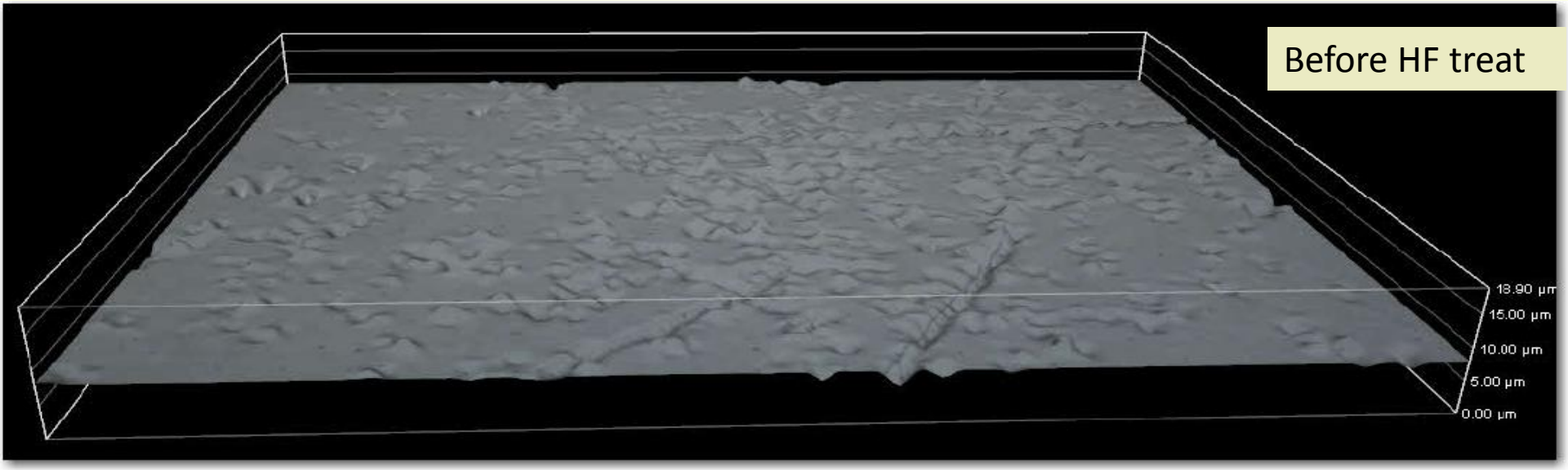


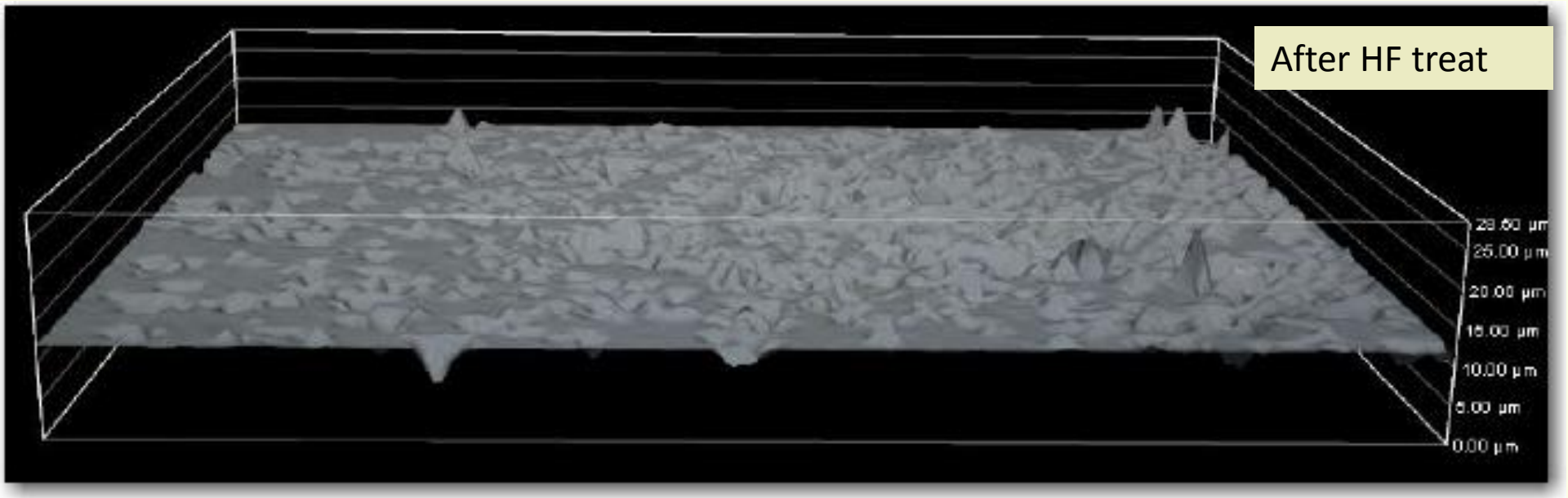
Z profile

Before HF treatment

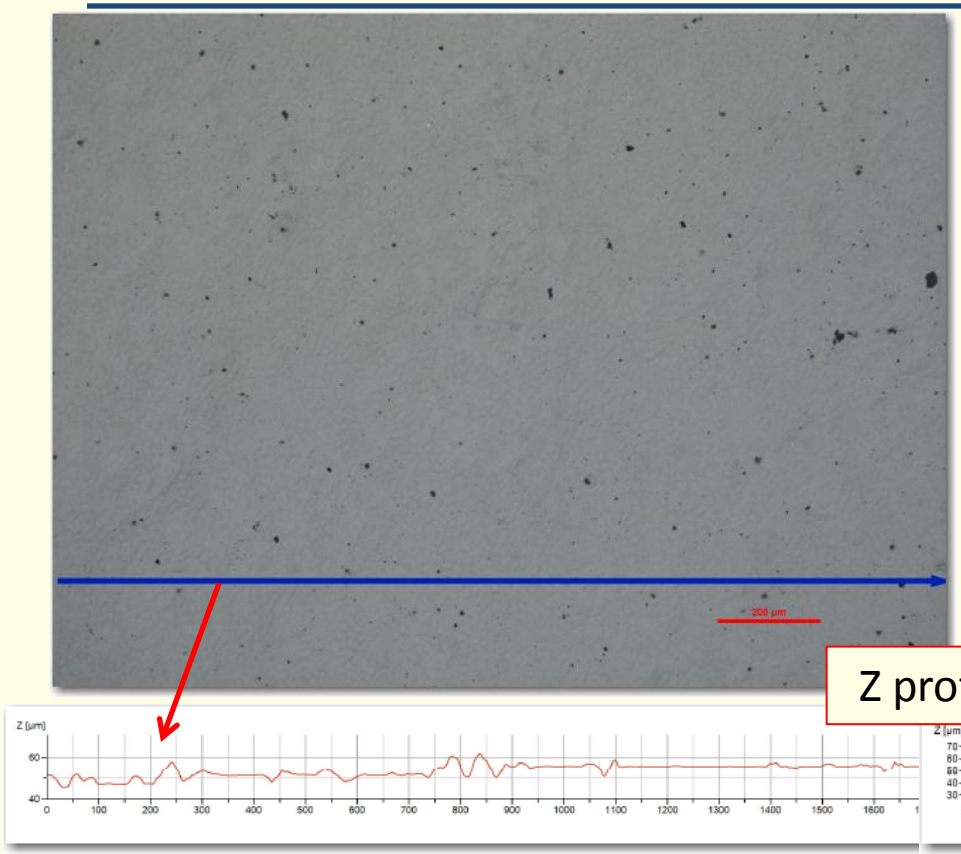
After HF treatment

Candidate – melamine resin

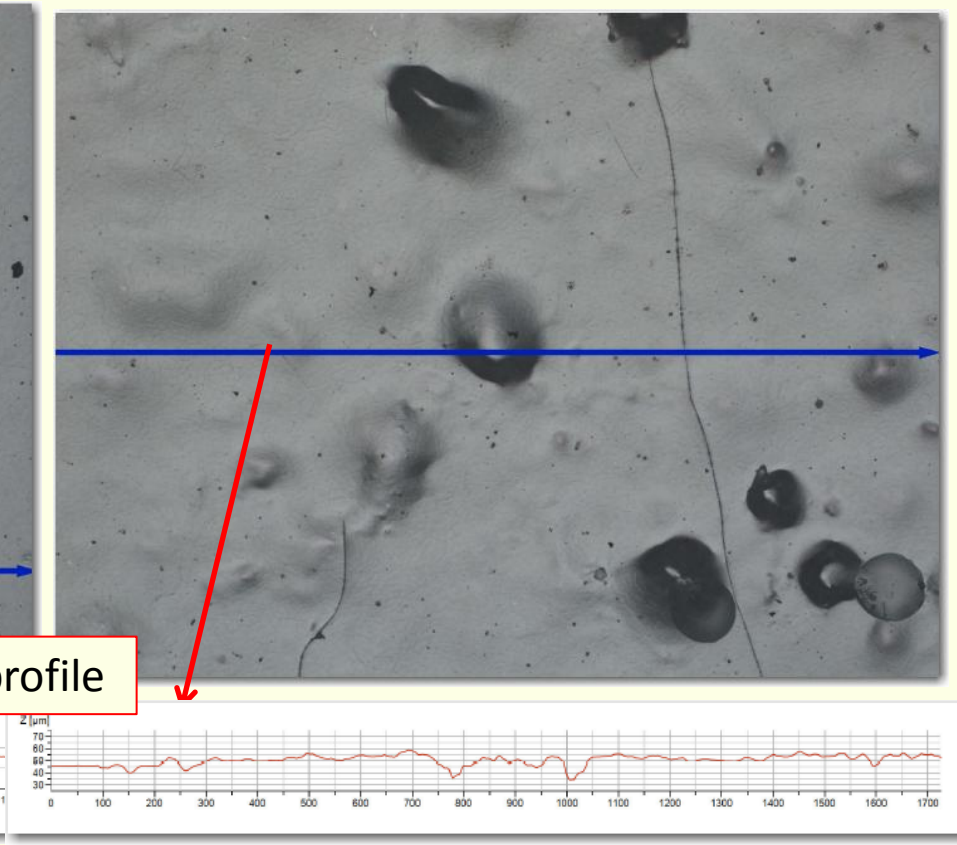




Candidate – melamine resin (cont'd)



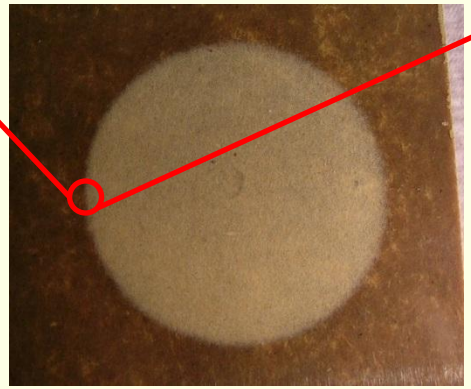
Z profile



Before HF treatment

After HF treatment

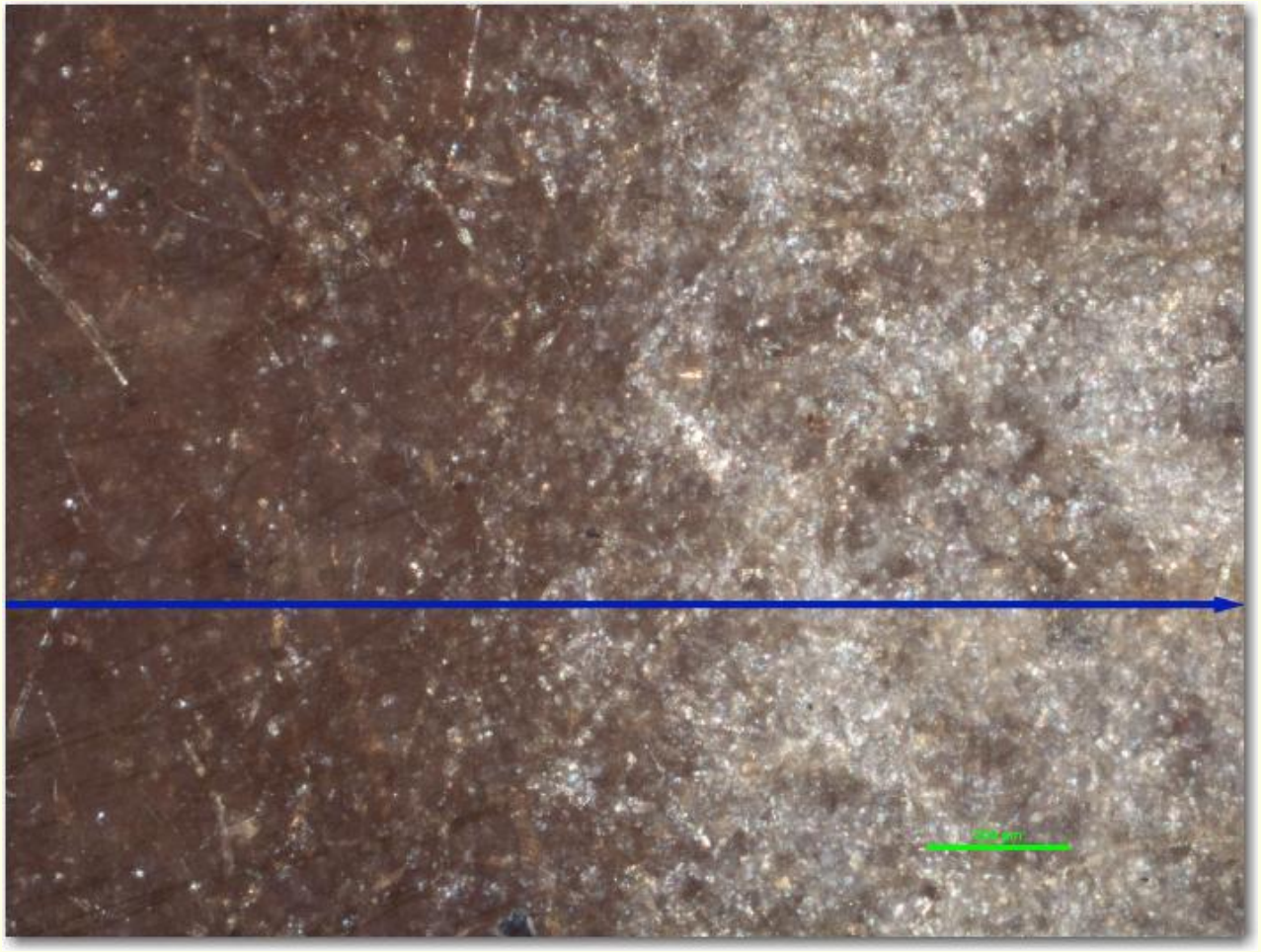
Candidate – Italian Bakelite



The surface is discolored, rough, lost the original luster.

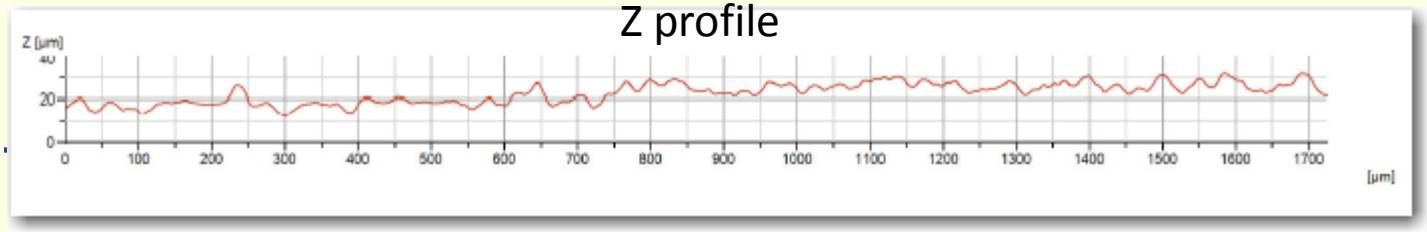
Candidate – Italian Bakelite (cont'd)

Left side area was masked out from exposed to HF vapor, it was not discolored, surface still kept original luster.



Right side area was exposed to HF vapor and discolored, and became rough.

Z profile



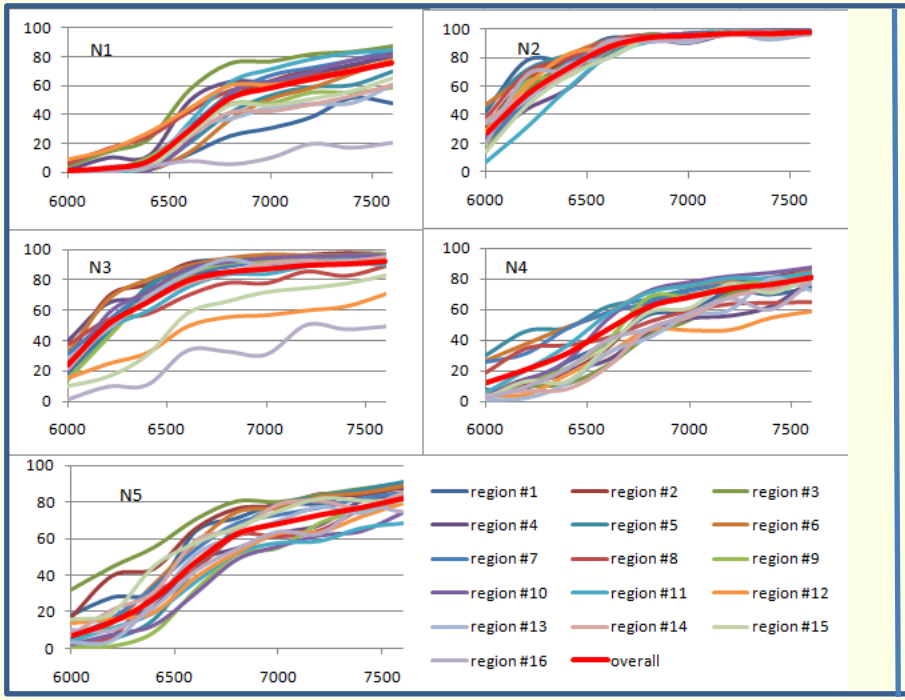
Preliminary comparison of the candidates

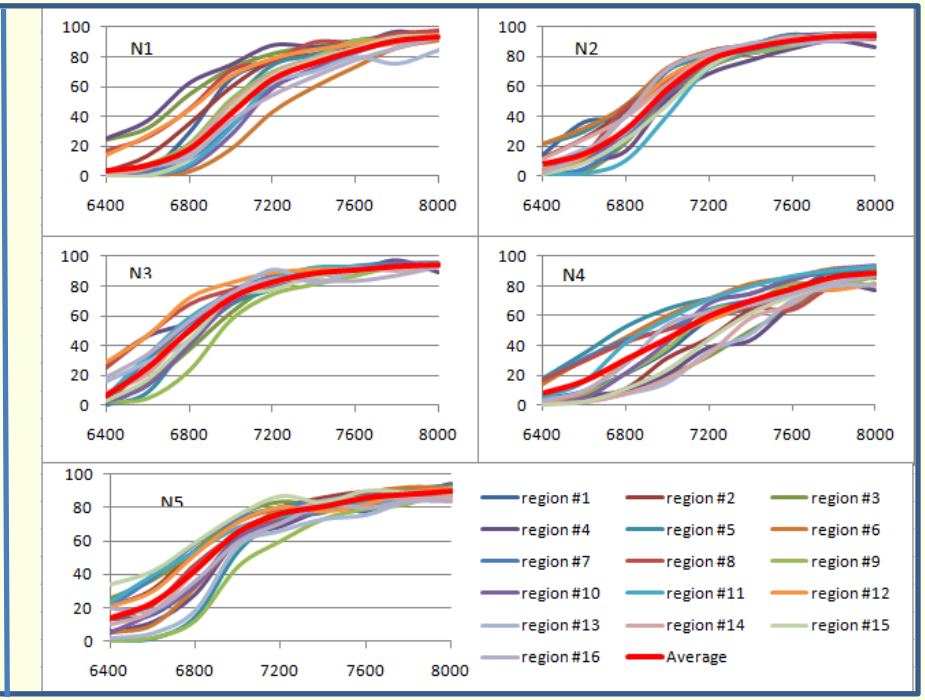
Sample name	Surface smoothness	HF resistance	Possible improvement?
Phenol formaldehyde resin	bad	good	Modify lamination procedure to improve the surface smoothness
Italian Bakelite	Not so good	bad	Linseed oil coating
Melamine	good	bad	Linseed oil coating
Funan resin	Not so good	Not so bad	Modify lamination procedure to improve the surface smoothness

We'll continue work with Beijing Bakelite manufacturer to further improve the surface quality of phenol formaldehyde and funan resin Bakelite.

Freon-less gas mixture study

Search for Freon-less gas mixture used for streamer mode RPC:
One gas mixture has been tested: Ar/CO_2/Isobutane/SF_6 (31/60/8/1).
We use the same RPCs from previous aging test, so we should expect the initial efficiency won't be great due to the already done aging damage.





Efficiency after aging in Dayabay RPC gas mixture

Efficiency in Freon-less gas mixture

Freon-less gas mixture study (cont'd)

- The plateaus are not great, because they have gone through the aging test in regular RPC gas mixture, but an interesting observation is these very bad regions of RPC #1 and #3 do not exist anymore in Freon-less gas mix.
- The high voltage of the overall efficiency plateaus is shifted up ~400V.
- It seems like these chambers have "forgotten" the aging damage when operating in Freon-less gas mixture. It might be due to the "self-curing" process after long idle period.

We'll continue the aging test with this Freon-les gas mixture.

Goal: to confirm if RPC operating in Freon-less gas mixture has much better aging performance.

Although the efficiency performance for this gas mixture is not too bad compared to the Daya Bay RPC gas mixture, but detailed study shows that the streamer charge spectrum in this new gas mixture is much broader, the streamer multiplicity is also higher, which is not good feature for the application in DHCAL, search for better gas mixture is certainly needed.