Precise studies on He-Processing and HPR for Recovery from Field Emission by using X-ray Mapping System

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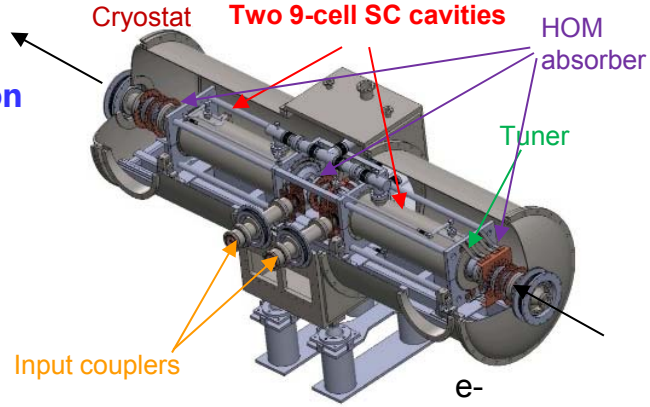
Our status of cERL Main linac cryomodule

TUAA01 TUPB021

Main linac module

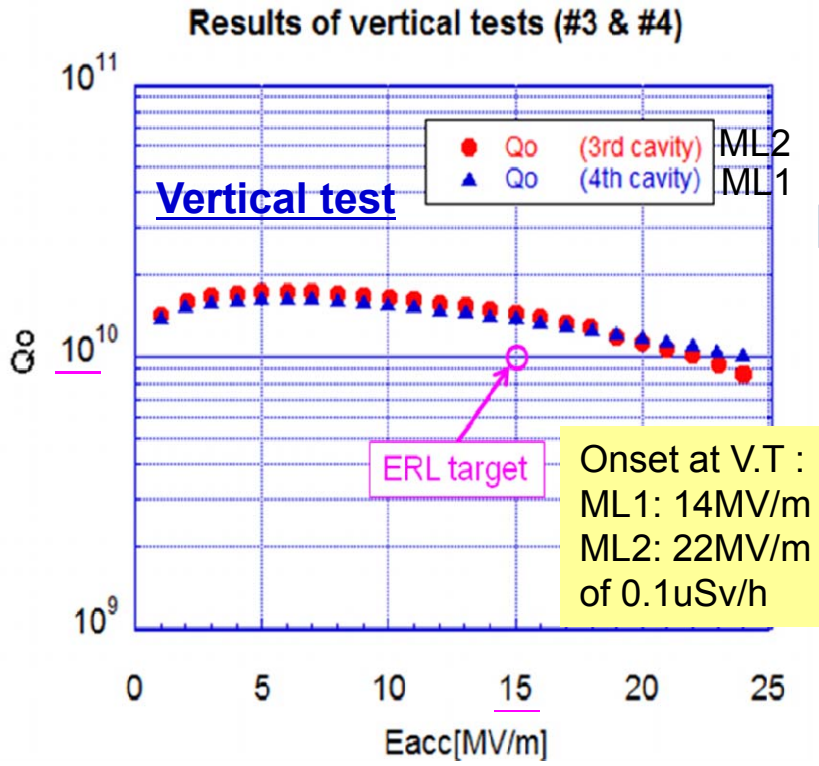
HOM damped (for 100mA circulation to suppress HOM-BBU in design)
9-cell cavity (ERL-model2)× 2

RF frequency: 1.3 GHz
Input power : 20kW CW (SW)
E_{acc}: 15 MV/m（design）
Unloaded-Q: $Q_0 > 1\times10^{10}$

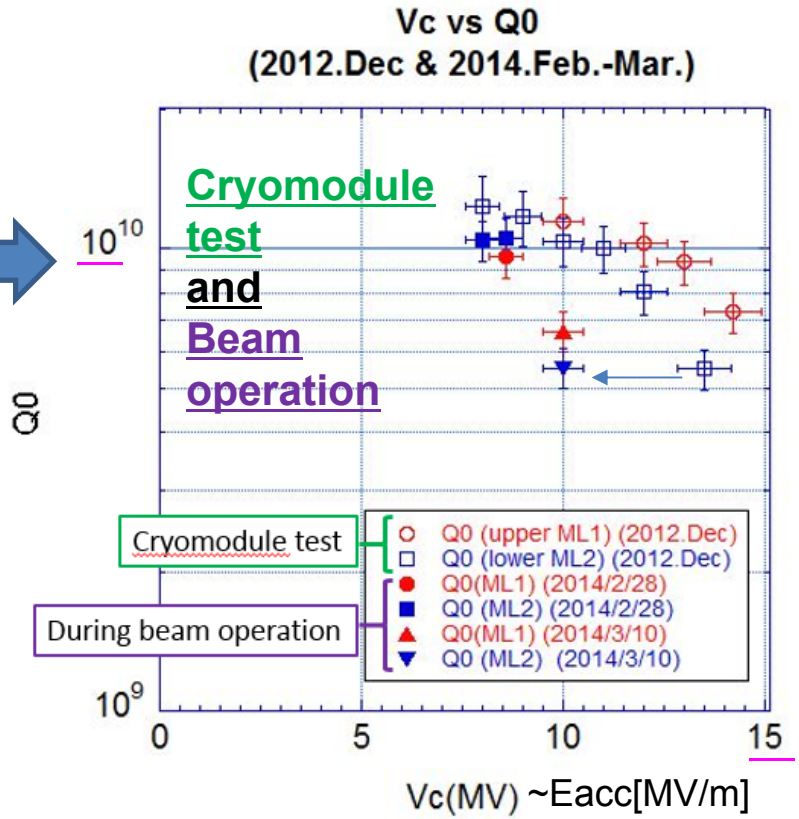


cERL Commissioned started in Dec. 2013.
20MeV 10uA (Dec.2013 – Jun.2014)
20MeV 100uA (Jan.2015 – Jun.2015)

Requirement was satisfied at V.T.
Heavy F.E was met. Onset is 8 MV/m after string assembly.



Onset at V.T :
ML1: 14MV/m
ML2: 22MV/m
of 0.1uSv/h

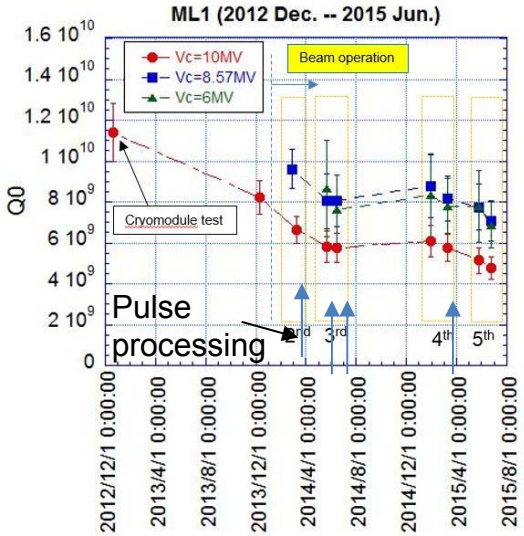


Degradation was observed not only on string assembly but also beam operation

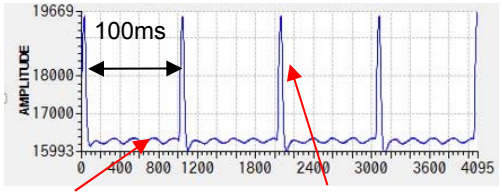
Motivation of study (He process)

- For recovering from bad performance of cavities, there are several ways;
  - without disassembly: RF processing , **He processing**, plasma processing(?)
  - with disassembly: **HPR**, EP, CP
- High power pulse processing was applied to our cERL main linac cryomodule and suppressed Q-degradation now. But Q did not recovered now.
- It was reported that He processing would worked effectively (Jlab). But it might be risky for directly applying He processing in our cryomodule. And we want to know
  - what is happening on He processing? And how is it effective or risky?

1) Pulse processing (KEK cERL cryomodule) TUPB021

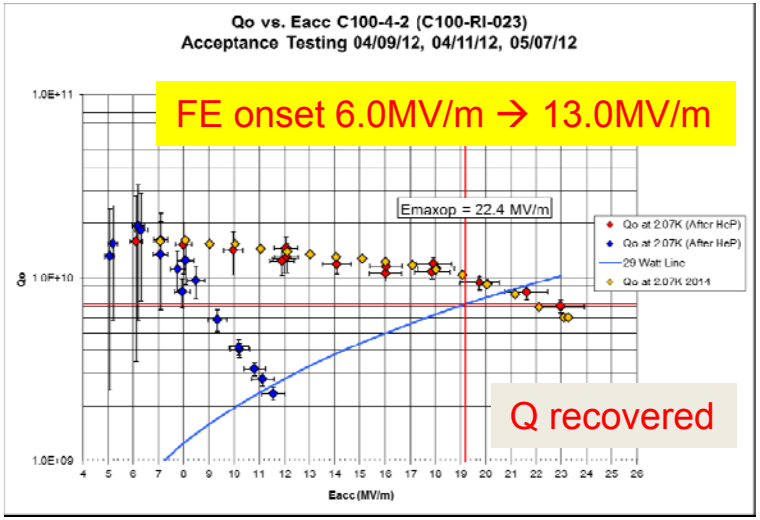


Duty 10Hz 4ms [peak:11MV] (pulse)



Radiation reduced to half by high power pulse processing and Q-value was kept stable now

2) He processing (CEBAF)

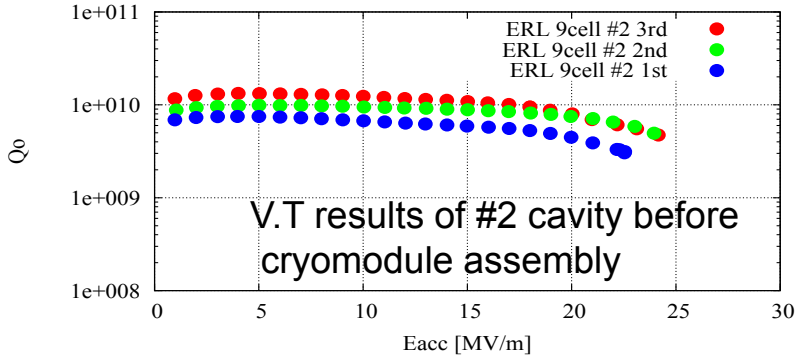


He process results on C100 cryomodule test @H.T
M.Drury, TTC meeting 2014 March @ DESY

First we try to understand the mechanism of He processing and effectiveness of HPR to reduce the field emission by using X-ray rotating mapping system in vertical tests

Study by using KEK-ERL #2 cavity

- We fabricated the prototype of cERL main linac cavity as #2 cavity before cERL ML cryomodule assembly.
- This cavity have good performance.
- We start the field emission study in V.T by using this cavity with X-ray mapping system.



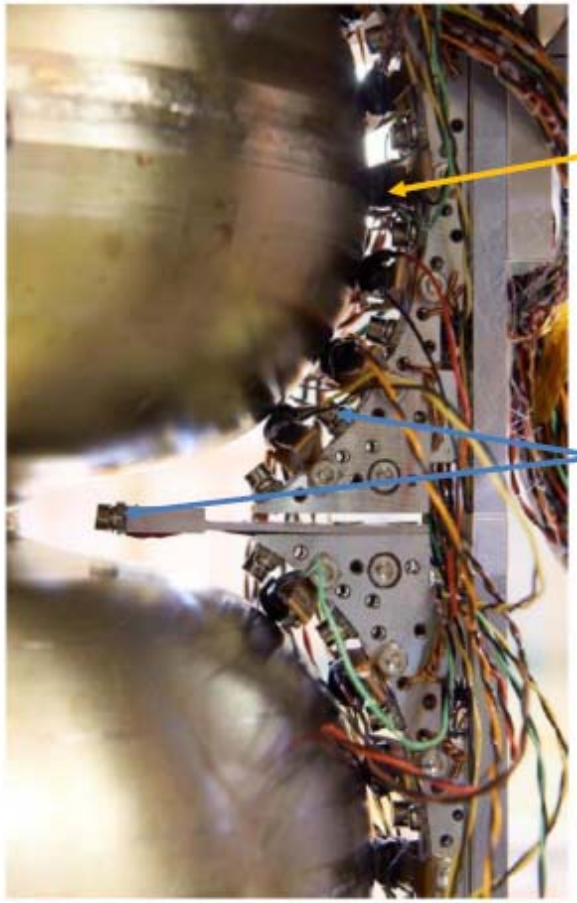
KEK-ERLmodel-2cavity #2 at V.T stand with xray mapping system

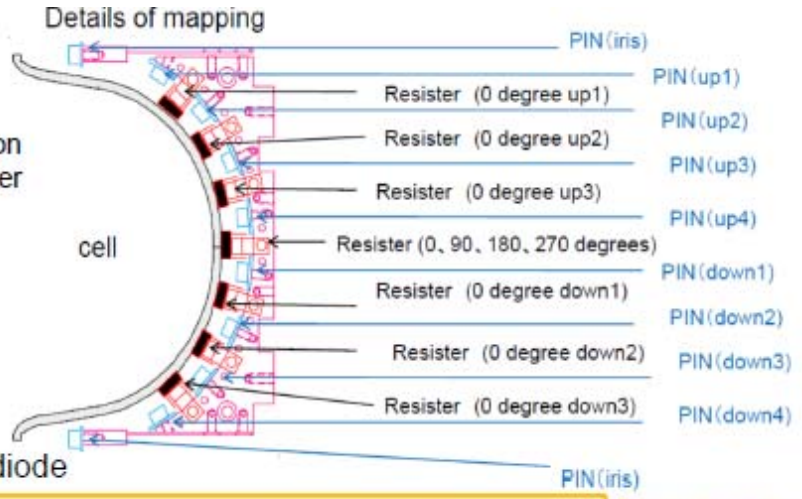
- Field emission onset is about 16MV/m.
- Quench free up to 30MV/m.

VT	Surface treatment etc.	Aim of VT	
7th VT	**(Warm-up)**	**System check of He processing**	**(1)**
8th VT	**(Warm-up)**	**Study on He processing**	
9th VT	Flange disassembly/assembly (not apply HPR)	Check flange disassembly/assembly procedure to simulate module assembly	
10th VT	**(Warm-up)**	**Study on He processing (2)**	
11th VT	**HPR (assembly all flanges)**	**HPR study**	

Precise study of He processing (2 times) from 7th VT & HPR from 11th VT .

Rotating X-ray and T-mapping system





PIN diodes (HAMAMATSU S1231) for X-ray mapping with current Amplifier

Carbon resisters for Temperature map

82 PIN diodes and 93 Carbon resistors are mounted on the mapping system along a meridian to detect 9cell radiation and temperature mapping precisely

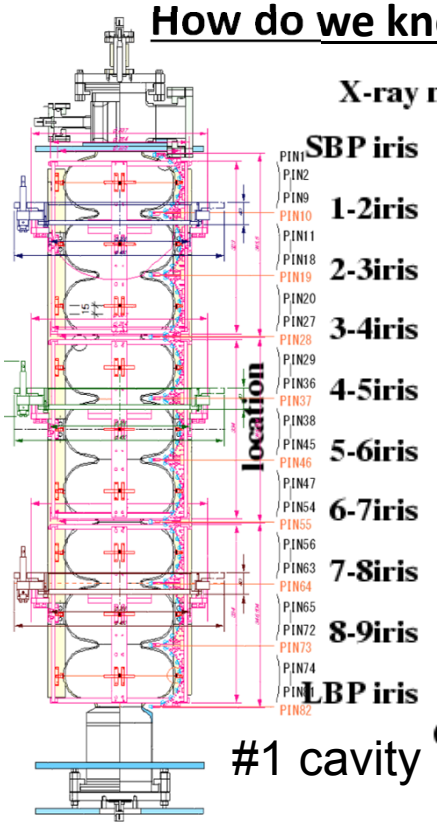
H.Sakai et al., Proc. of IPAC 2010 ,p2950

The sensor array can turn around the cavity surface using stepping motors via gear and data taking every 0.5s by logger

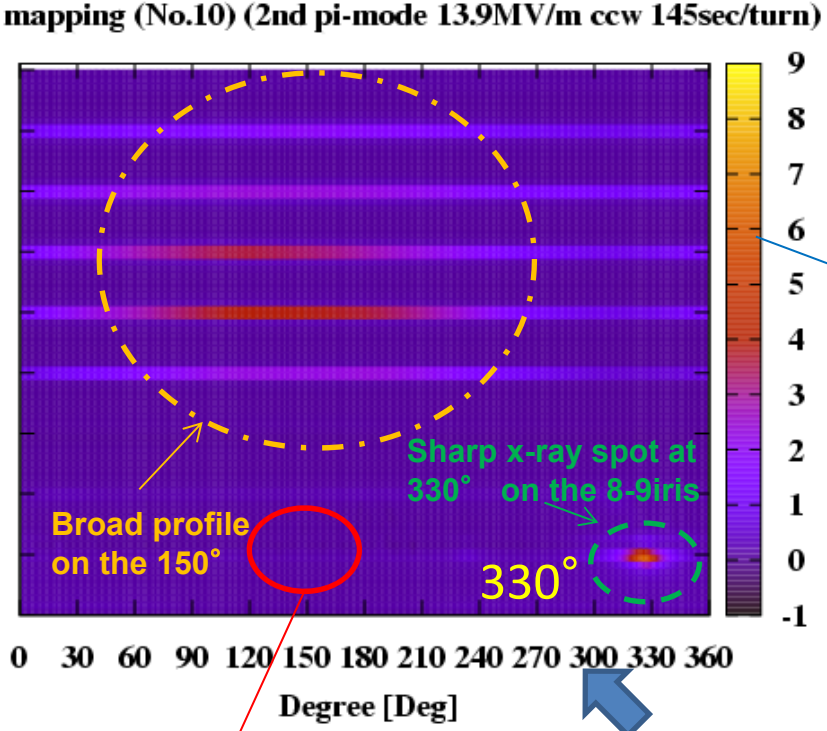
Figures of merit
(compared with fix mapping)
- Resolution 0.5°
- Small number of sensors

Radiation profile of 9cell cavity could be obtained by using PIN diode all over 360°

How do we know and identify the local field emission source? (previous measurement)

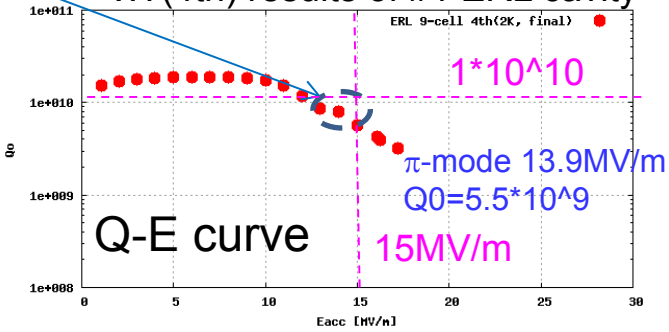


#1 cavity



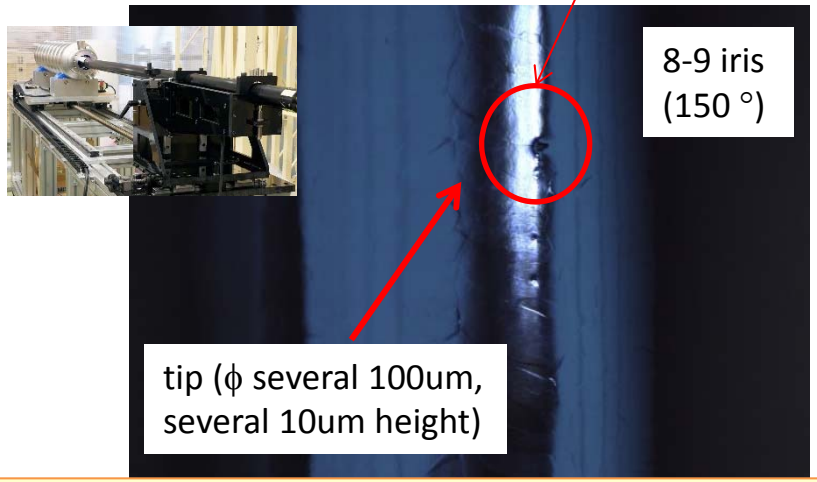
Opposite side of local sharp radiation peak show the field emission source with help of both measurement and simulation.

V.T(4th) results of #1 ERL cavity



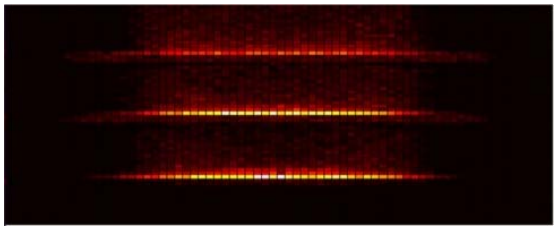
IPAC12, p295,

Inspection results

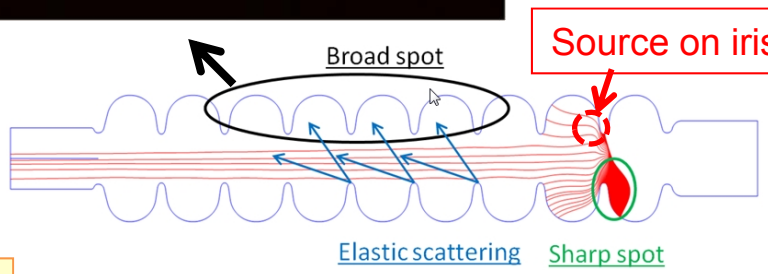


Tip was observed on opposite side of x-ray sharp peak by inspection.

Simulation (with Fowler Nordheim eq.)



Field emission Profile on Nb surface simulated by interaction between e- and Nb iris (EGS5) (Done by Enrico Cenni)

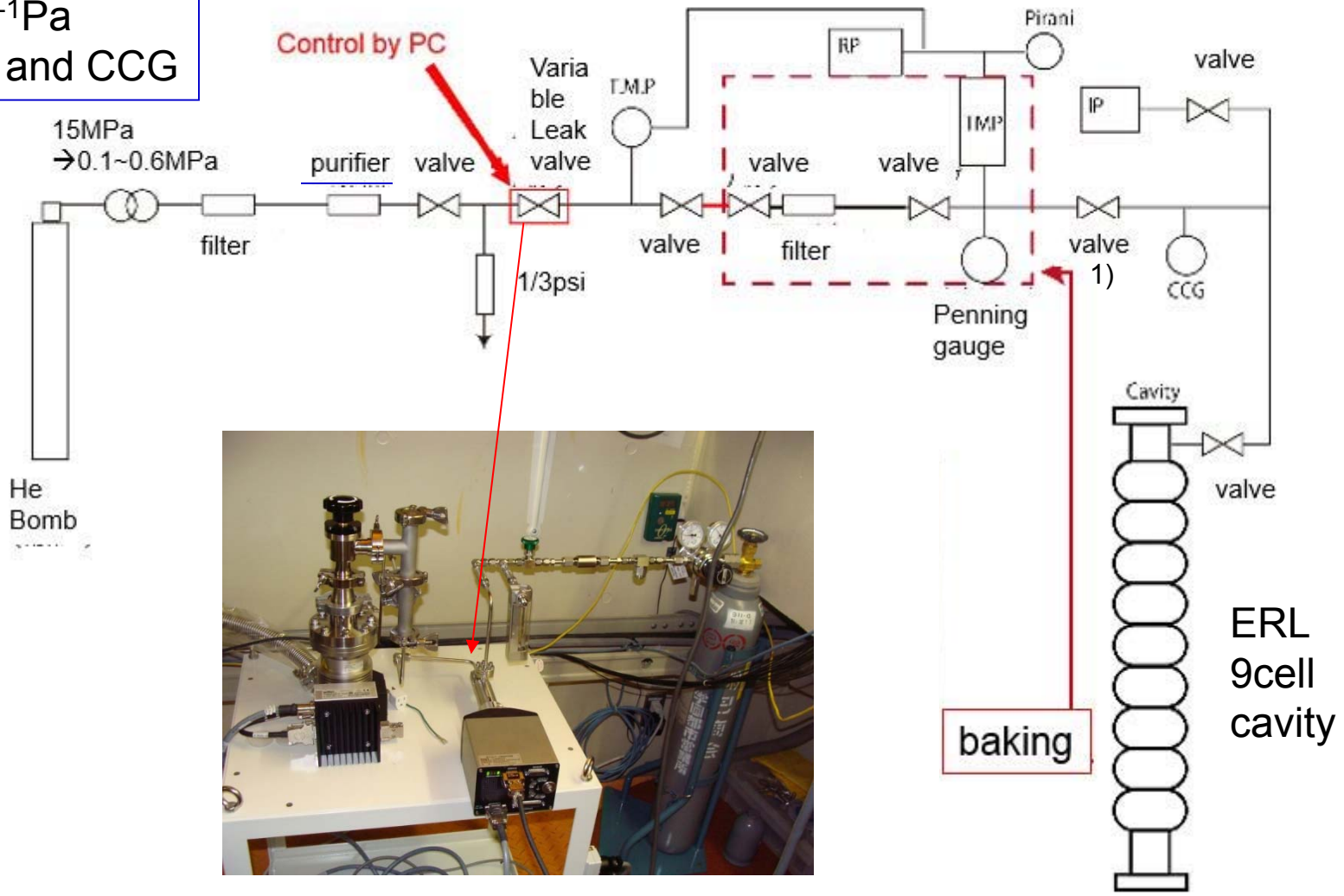


Broad profile was explained by this simulation

System for He processing

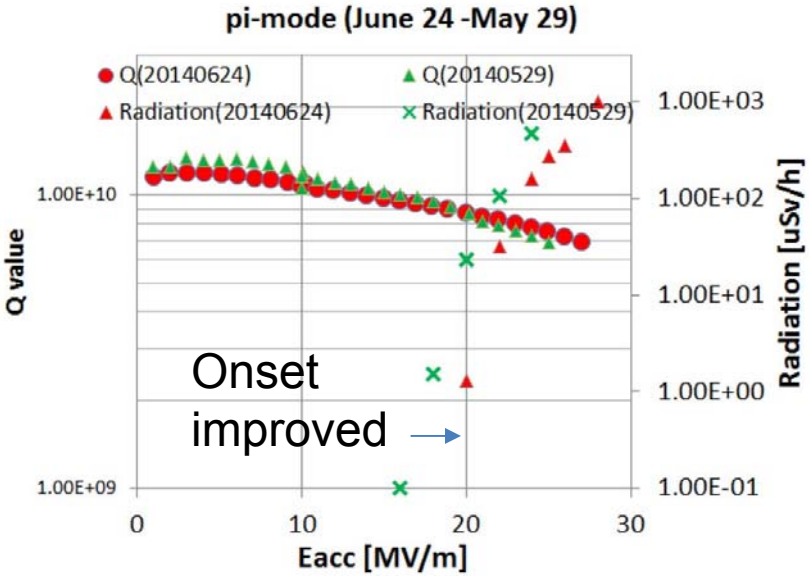
Measured pressure range 10^{-8} ~ 10^{-1}Pa by Pirani and CCG

- Set purifier in front of He bomb.
- Bake He line at 120 °C before V.T for 24 hours.
- He was exchanged three times before valve 1).
- He pressure was controlled by variable leak valve.
- Check the cavity performance before He processing and He slowly inserted by variable leak valve.

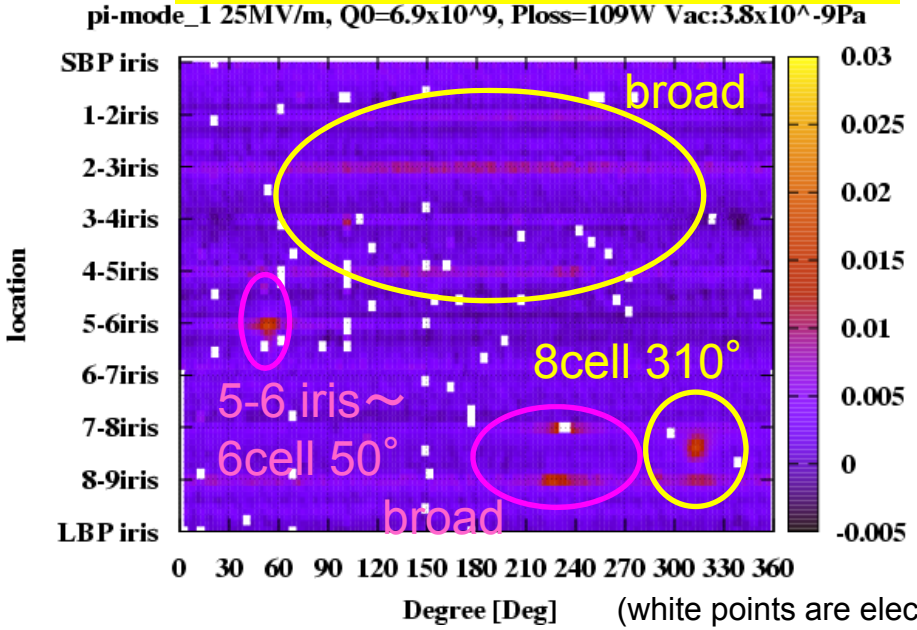


He processing trial (1)

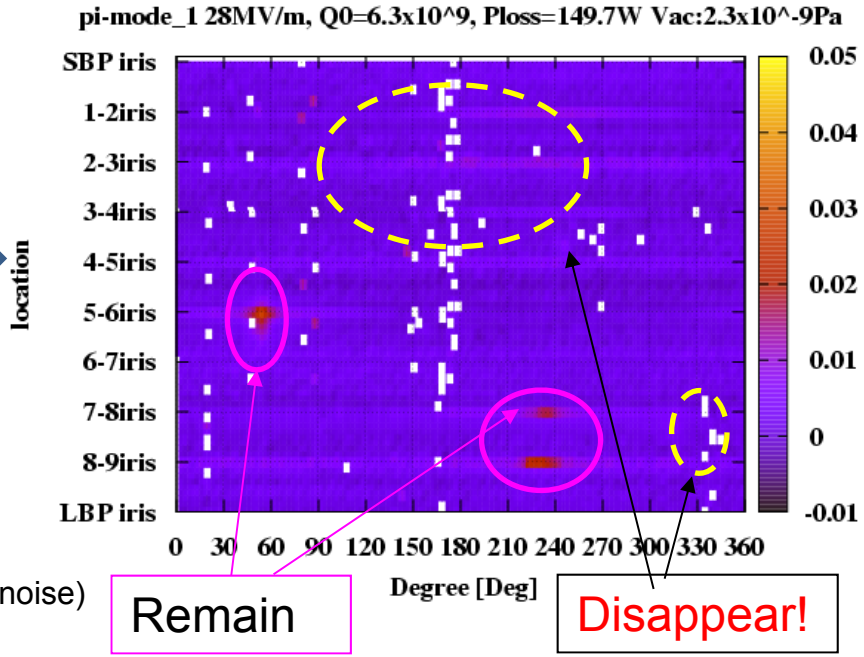
- 2 emitters could be observed before He processing.
- 1 emitters remained and 1 emitter disappeared after He processing.
- Q-value recover little bit and radiation on-set increased from 17MV/m to 19MV/m.



7th V.T Before He processing :10^-8Pa



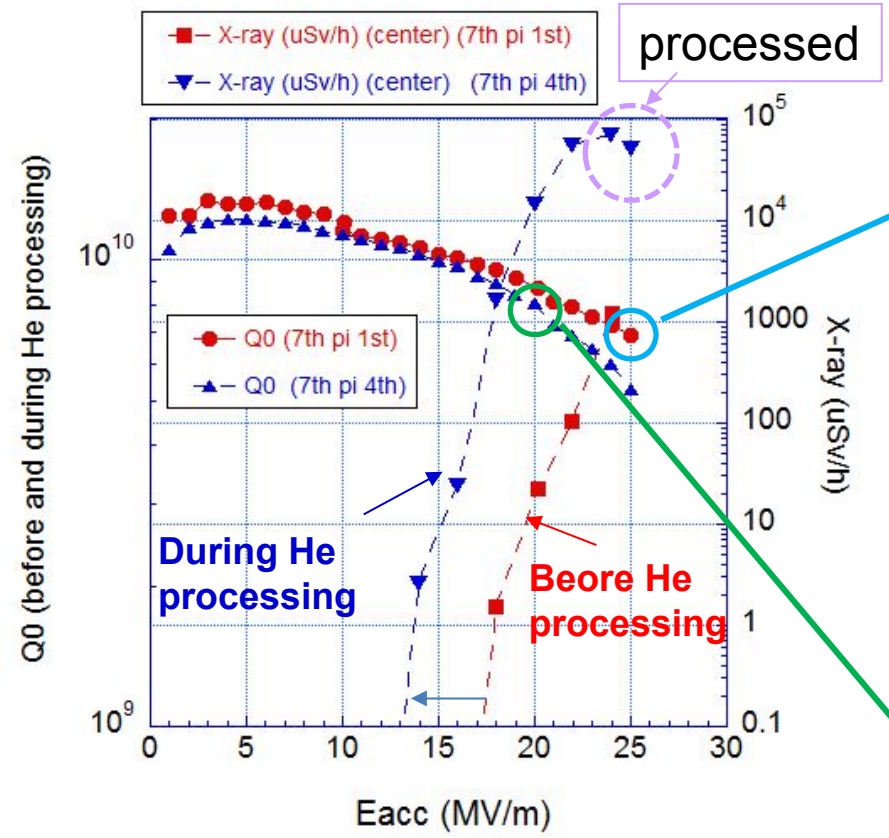
8th V.T After He processing: 10^-8Pa



(white points are electrical noise)

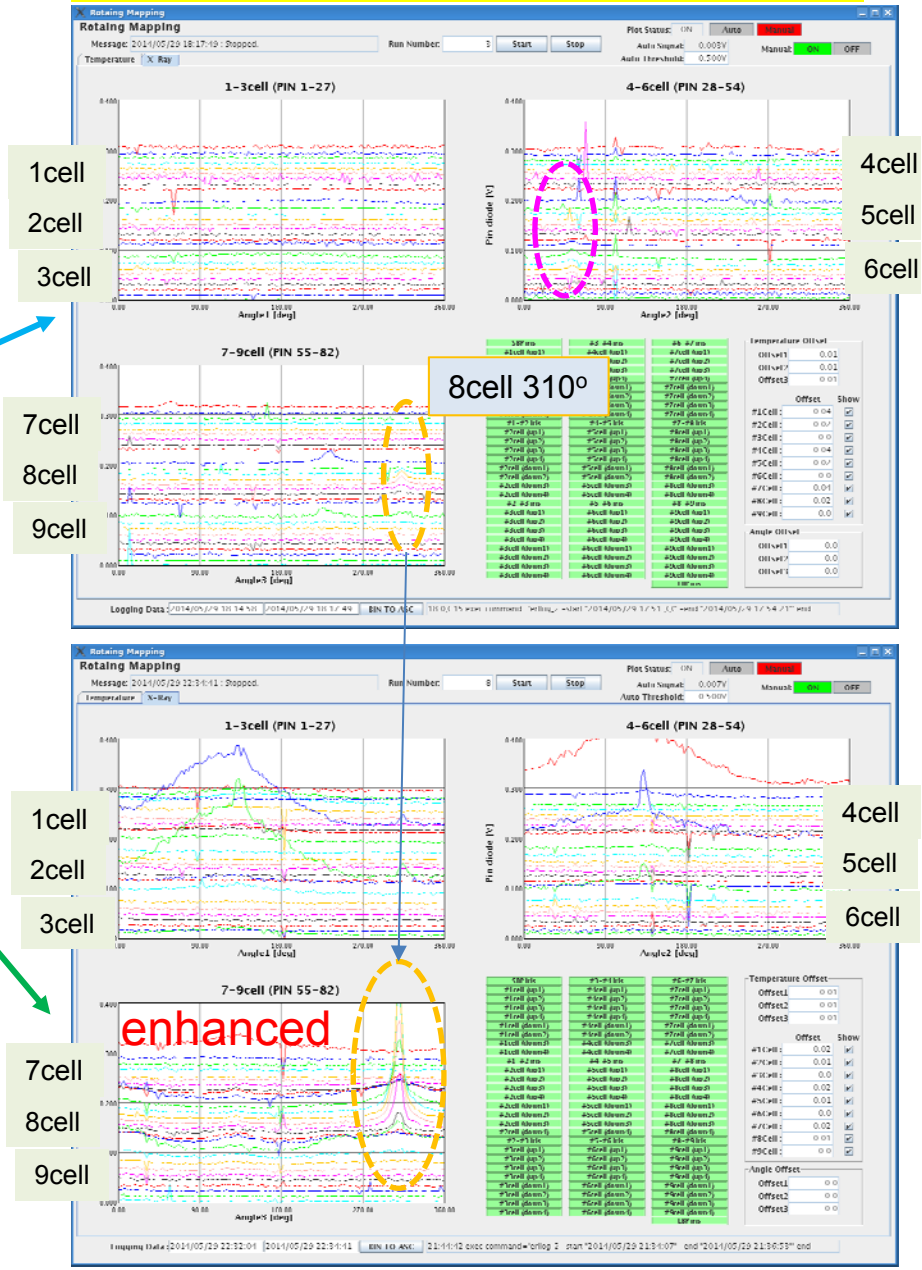
One emitter made lower onset

Detail of He processing (1)
(behavior during He processing)



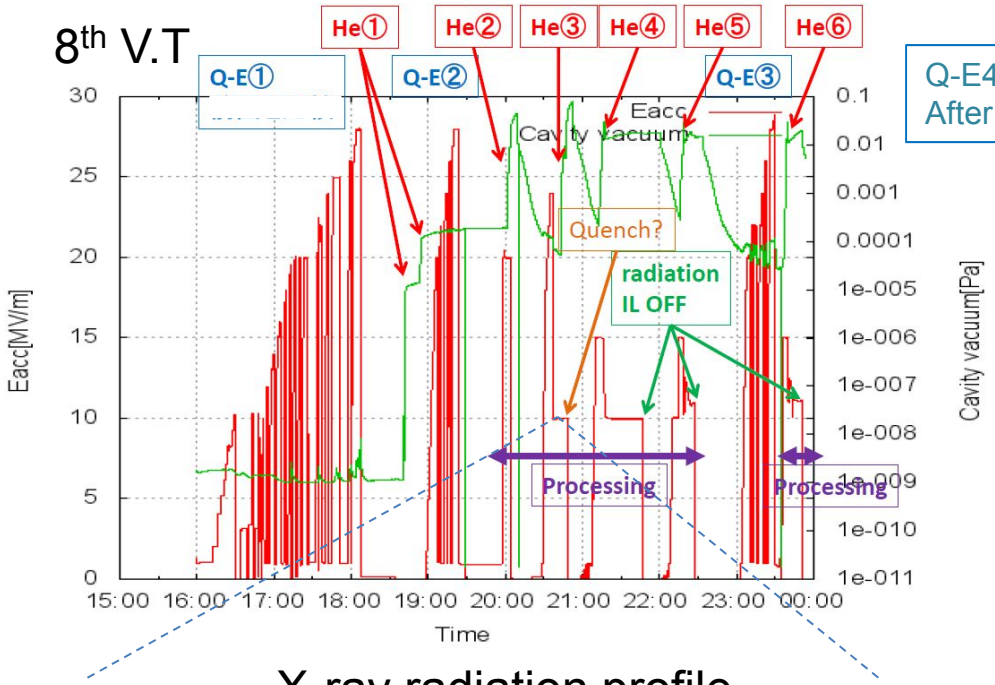
- During He processing, onset was decreased an one radiation peak was enhanced by adding 10^{-3} ~ 10^{-4} Pa level of He.
  We called **"Enhanced mode"** on this condition.
- After increasing the RF field, finally this local radiation was processed during He processing.

Before He processing (25MV/m 10^{-8}Pa)



During He processing (20MV/m 10^{-4}Pa)

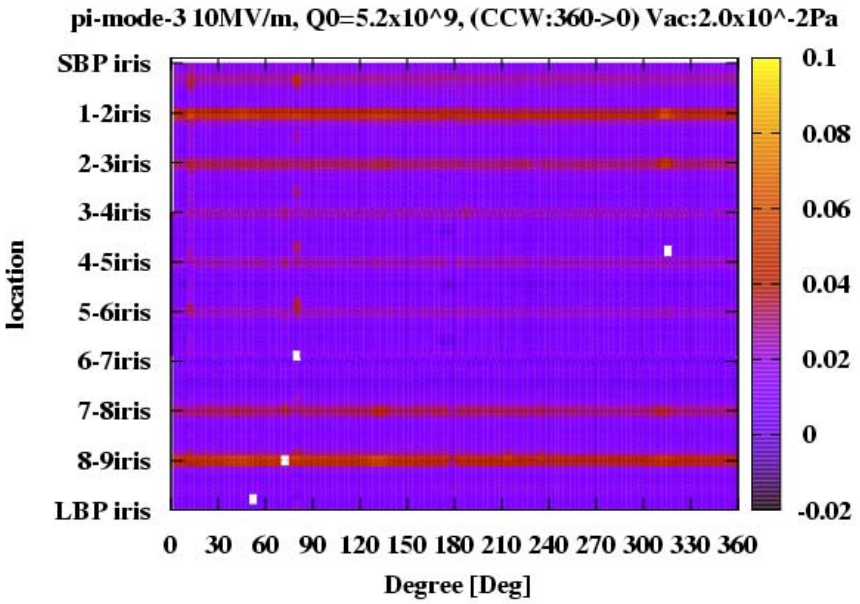
Case 2 (He processing) (8th V.T)

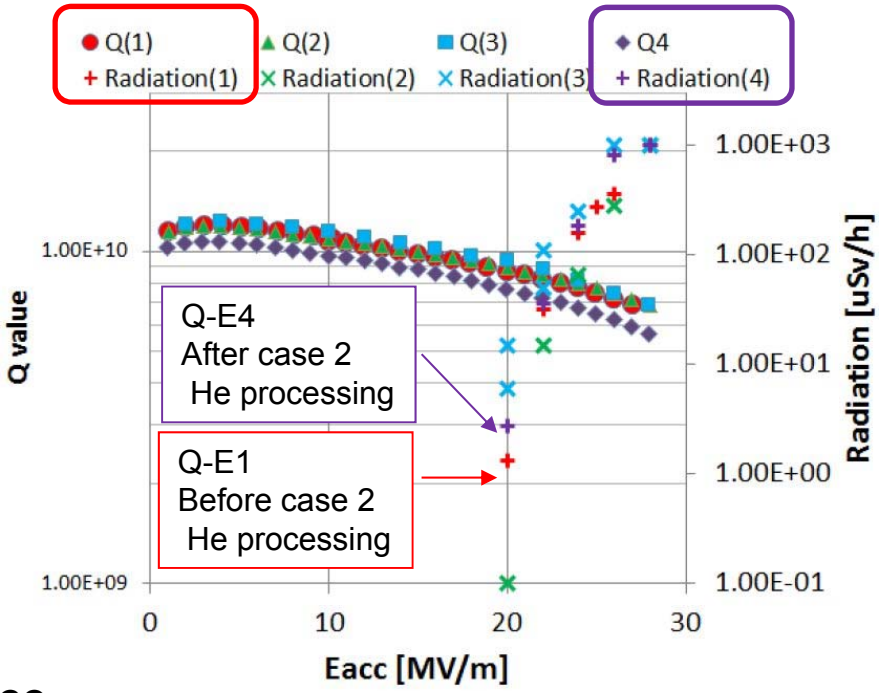


Q-E4
After warm up

- Pressure increased up to 10^{-2} Pa.
- Sudden radiation were appeared even if field is as low as 10MV/m.
- Radiation was irradiated all over cavity surface (All surface mode).
- Unfortunately, we only applied for 50 min in this mode.
- This did not processed and onset did not change within this processing time.

X-ray radiation profile

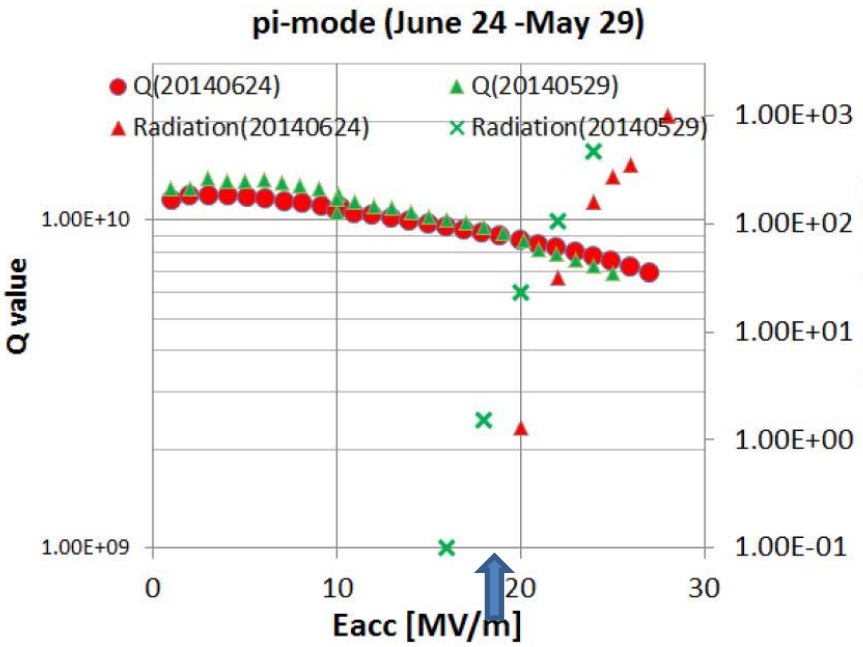




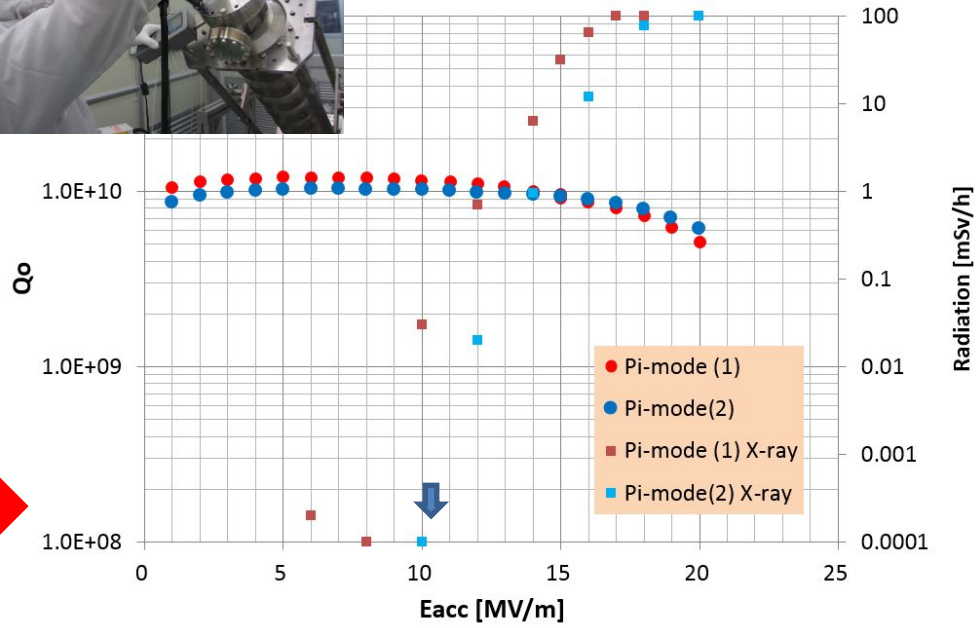
Radiation was irradiated all over cavity surface

Results of reassembly work of (9th V.T)

Before reassembly



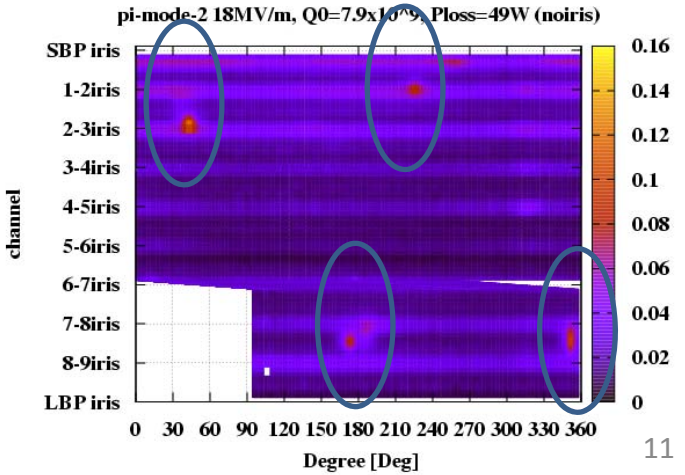
after reassembly



By reassembly work, the onset decreased from 18MV/m to 10MV/m maybe due to our poor reassembly work

We retried He processing to eliminate these radiation sources appeared after reassembly work

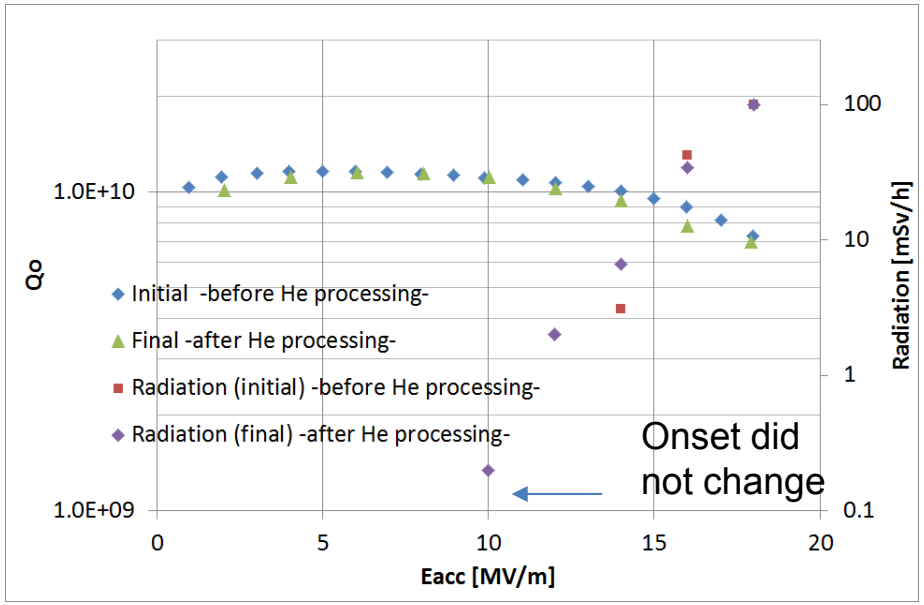
Xray mapping



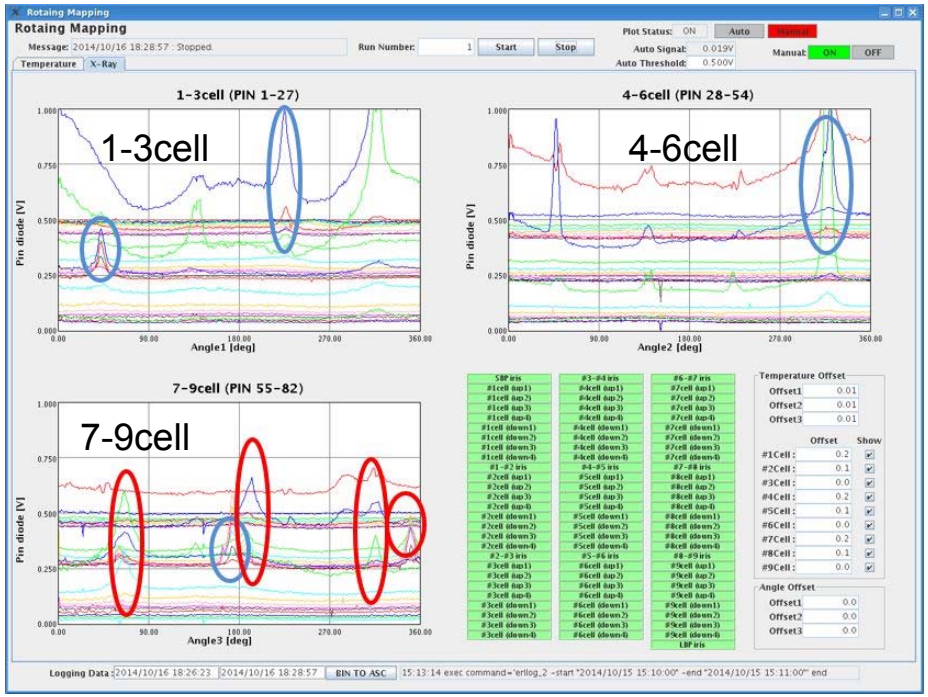
Many radiation emitters were appeared even at 18MV/m

He processing trial (10th)

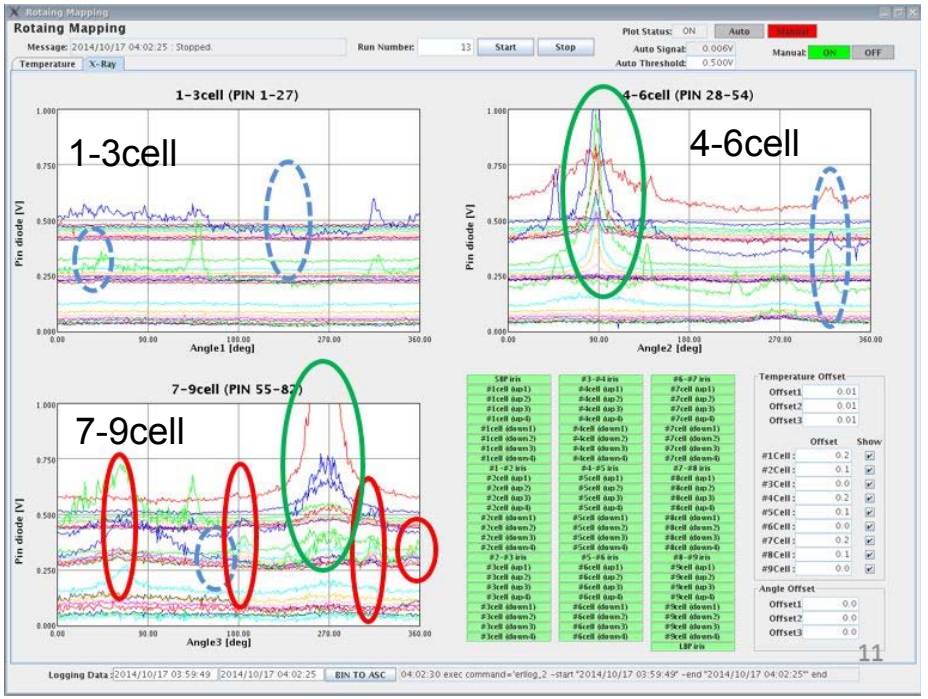
- We applied “Enhance mode” of He processing.
- 4 emitters remained, other 4 emitters disappeared or decreased and new 2 emitter appeared after He processing.
- Q-value and radiation on-set did not change.



Before He processing 18MV/m ($1.3*10^{-8}$ Pa)



After He processing18MV/m ($8.2x10^{-5}$ Pa)



Two status of He processing

Two status appear during He processing

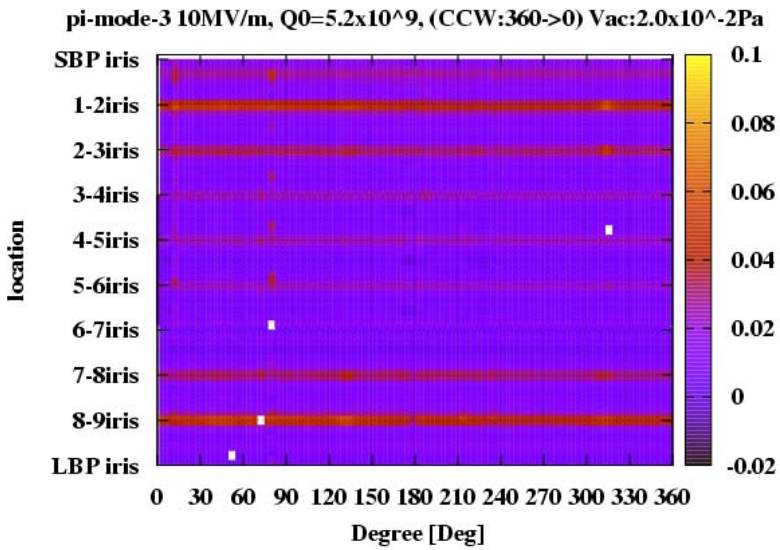
① Radiation all over cavities. ～All surface mode～

- Like discharge? Plasma?
- It occurs at vacuum level around 10^-2 Pa.

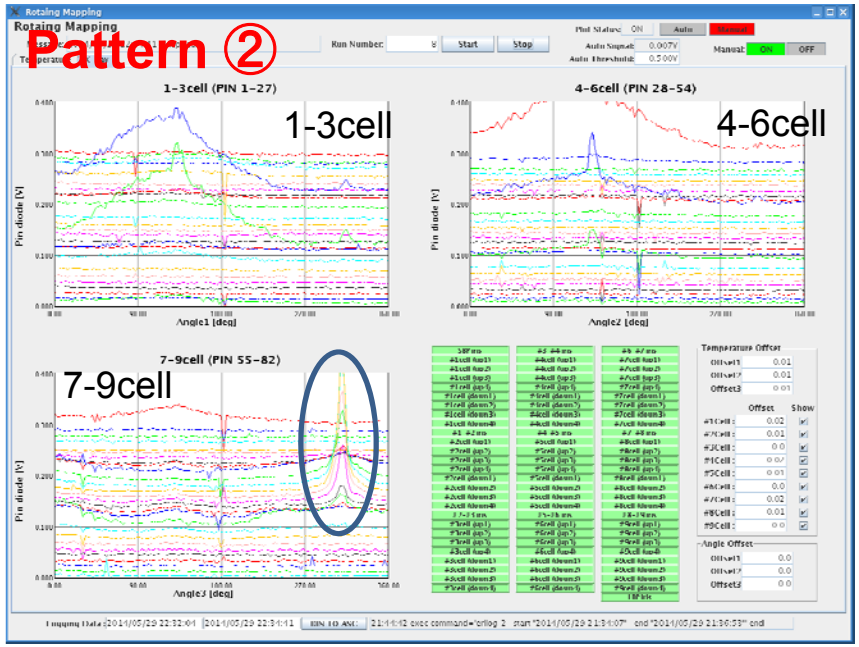
② Radiation are strongly activated. ～Enhanced mode～

- Some emitters can be activated. But some can not.
- It occurs at vacuum level of 10^-3 ～ 10^-4 Pa.

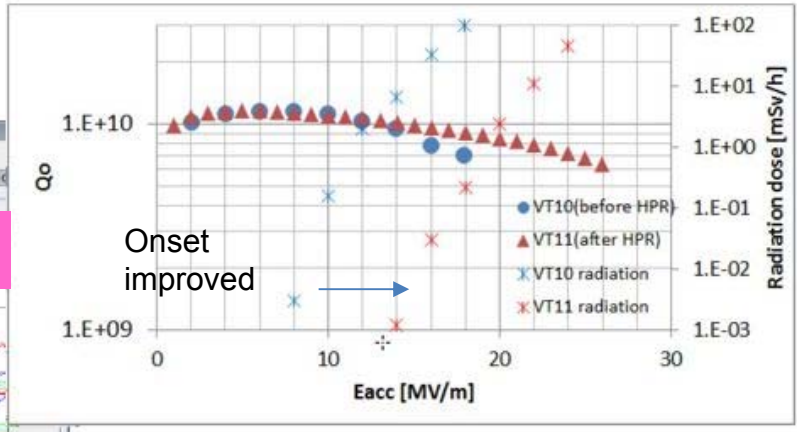
Pattern ①

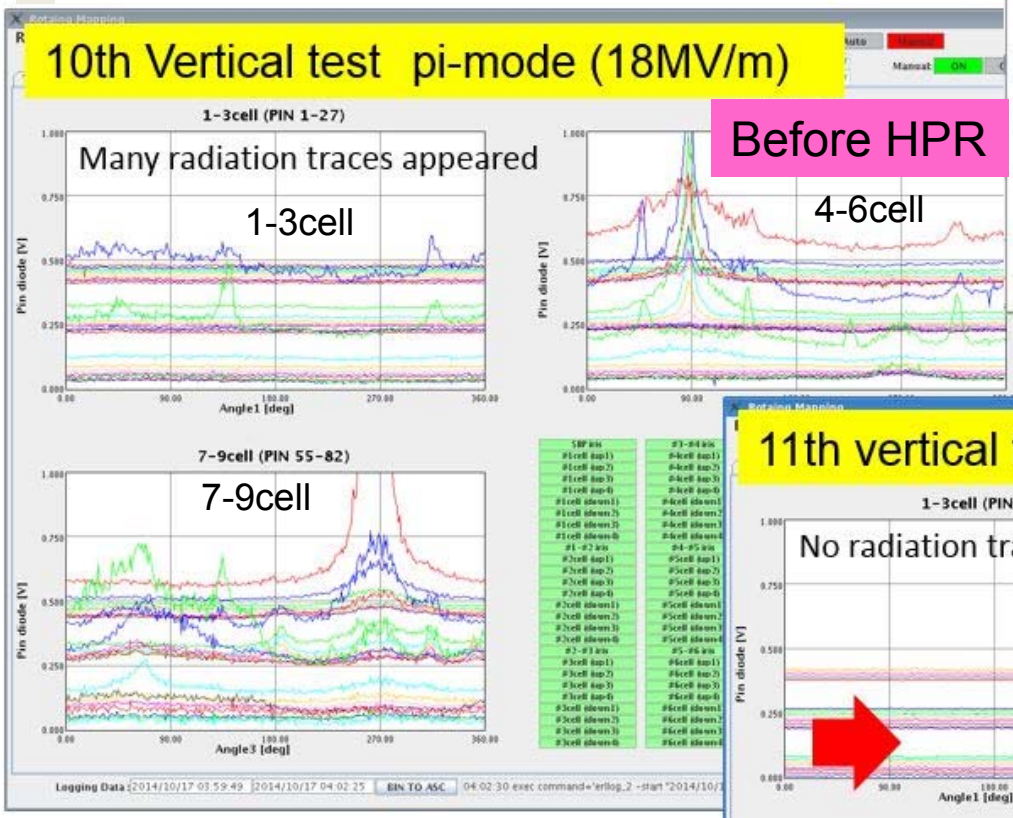


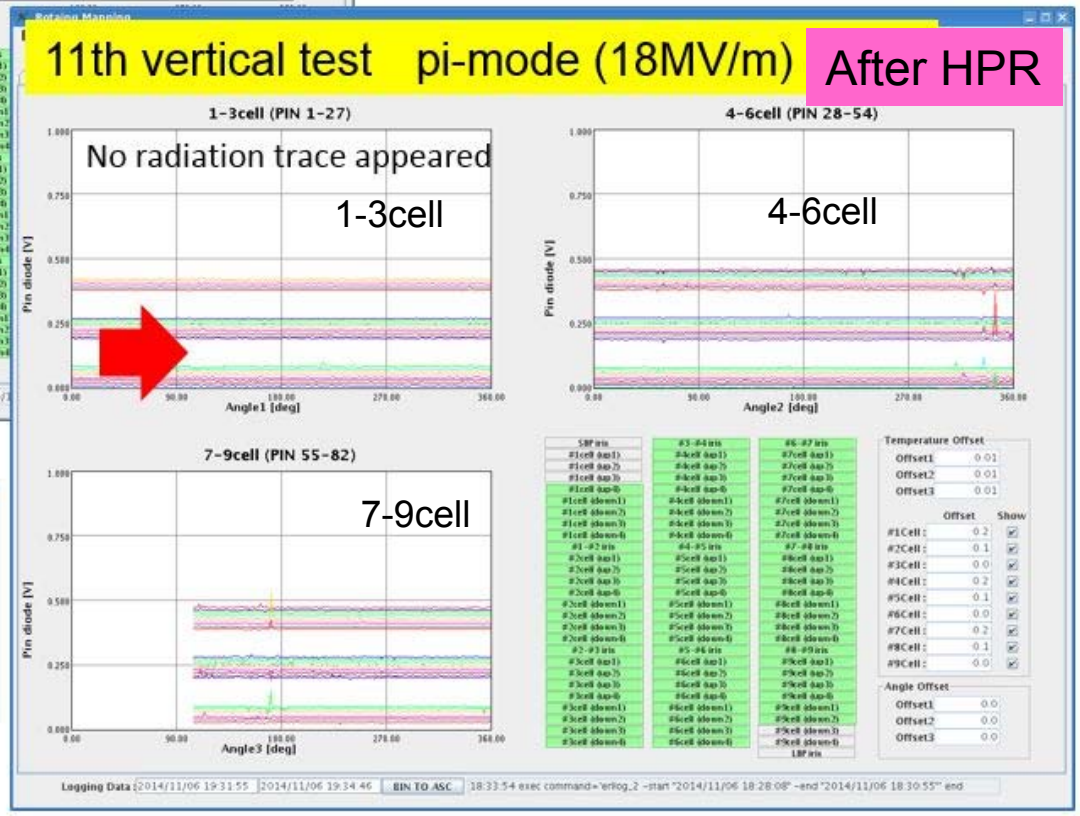
Pattern ②



Effect of HPR (10th & 11th VT)







Finally every emitter disappear at 18 MV/m after RF process

HPR works well to remove FE sources and gain of onset was 6MV/m.

Summary

[He processing]

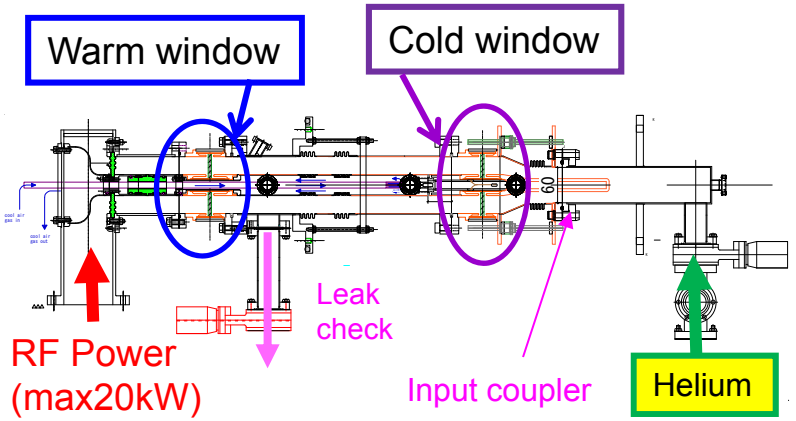
- We tried He processing twice at vertical test.
  - Condition time is limited by radiation safety and He consumption.
- Two states of enhanced radiation status were observed.
  - **" All surface mode "** ,which was appeared at 10^{-2} Pa and irradiated all surface.
  - **" Enhanced mode",** which was appeared at $10^{-3\sim-4}$ Pa and enhanced locally.
- At moment , our statistics are too small to make conclusion. However, it indicates;
  - "Enhanced mode" seems to be effective,
  - about half of emitter could be processed,
  - sometimes new emitter appear. → we will correct more statistics.
  - "All surface mode" did not processed within our limited time → need more long time ?

[HPR]

- The observed emitters were drastically removed after HPR.
- It indicates HPR is effective to remove field emission sources finally.

Next

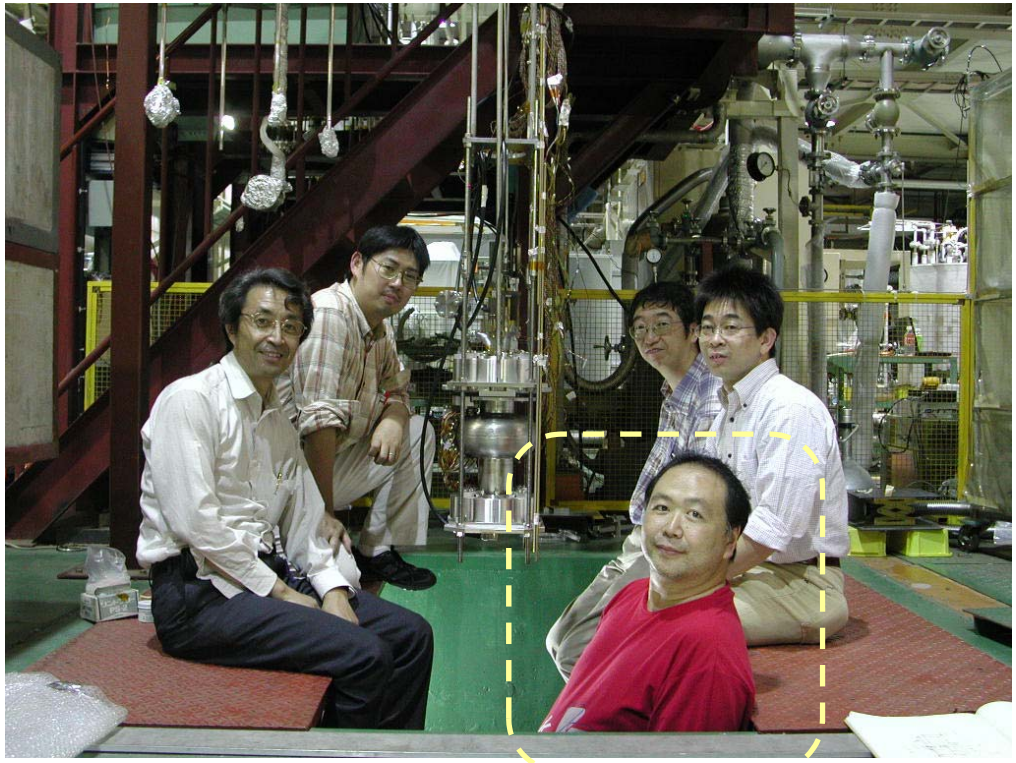
We will try to He processing to our cERL ML cryomodule after testing of input coupler conditioning with He line not to break the ceramic window by He processing



Input coupler He processing setup

Acknowledge & …

- First of all, I'd like to thank Compact ERL Grp member.
- I'd like to thank Mike Drury (Jlab) for the support and discussing about He processing.



To the memory of **Kenji Shinoe** who was decreased yesterday.
He mainly worked all He line construction in these experiments

(b) Reassembly work for jacket welding (with Ar purge 8/18)

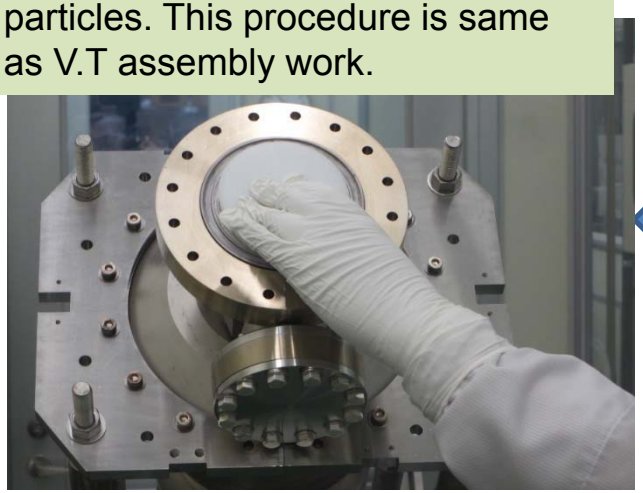
Seal : viton , flange : SS316L flange all components were browed by ion gun so that particles remain 0 @ 0.3um.
Class 10 Nitrilile ambidextrouse Glove used

Ar purge at input port ad blowed at 200ml/minn

Change Ar purge point to LBP, before the flange open, we change the flow 200ml/min to a few l/min not to enter the other particles from the flange

Before changing flange, we blow the hole of screws by ion gun so that the particle count is 0 except for the 4 screw port.

Before changing flange, we use Teflon pad not to enter other particles. This procedure is same as V.T assembly work.



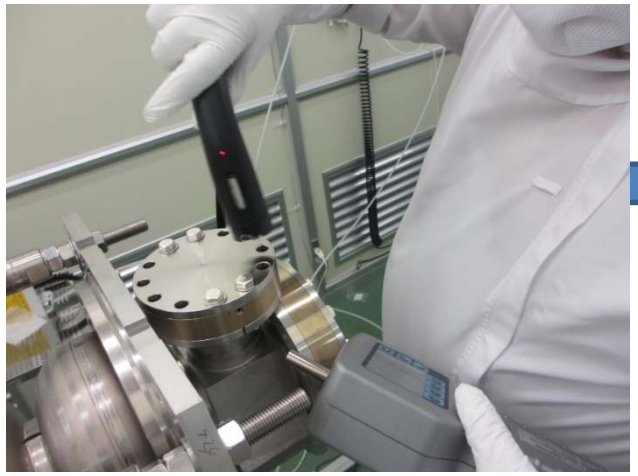
finish

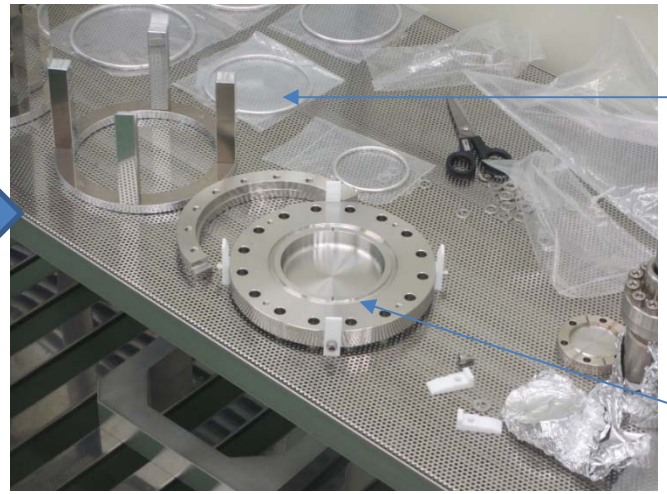
All screws of flanges of SS316L were plated by silver and ultrasonic cleaned and browed by ion gun to particles 0

(b) Reassembly work for jacket welding (to VT stand 8/21)

Seal : Tin coated helicoflex ,
flange : SS316L flange , Class 10 Nitrilile ambidextrouse Glove used .
All screws of flanges of SS316L were plated by silver and ultrasonic cleaned
all components were blowed by ion gun so that particles remain 0 @ 0.3um

Input port Screw hole blowd so that particle is 0 except for 4 screws.sam e procedure were done at all flanges

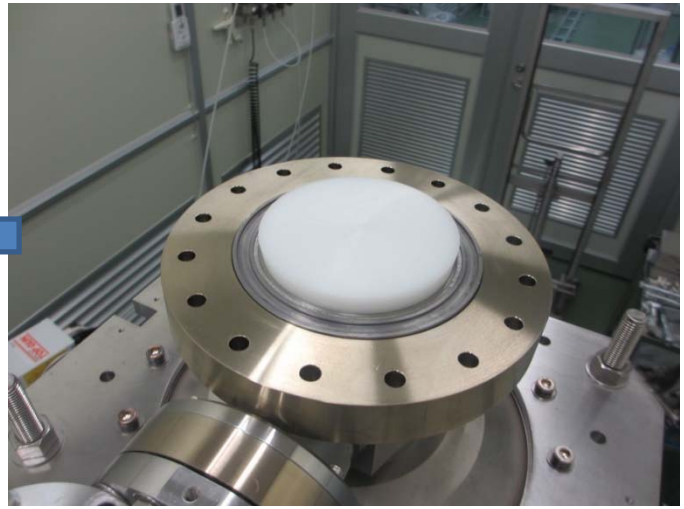




Tin coated Helico flex

Flange of SBP side

LBP side



SBP side

Before setting helicon, wiped by archol

Summary of recovery work

- We simulate the assembly work during cryomodule assembly of Ar purge and reassembly work of flange exchanges and did the vertical test after this individual work one by one.
- First we tried only Ar purge work (pump & purge) twice. This work did not make worse the cavity performance by V.T.
- Next we simulated the reassembly work. After reassembly work, we measure the cavity performance again. Field emission was started on 10MV/m, which was lowered from before reassembly (onset 18MV/m).
- Furthermore, we measured the X-ray mapping after reassembly work. Many radiation traces were observed after reassembly.
- From these results, during reassembly work, we enter some particles and/or the dust ?

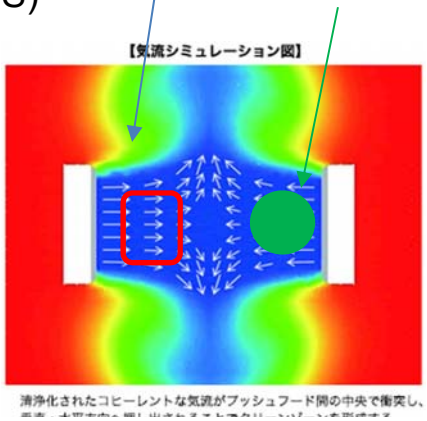
Future plan

- To investigate the particle contamination process through the string assembly, we continue V.T by applying each procedure.
- We will try the test bench in clean room in detail (particle enter , air flow survey).
- Furthermore, we also doubt the assembly work of the outside connection of GV. So we try new open clean bench.

Flow measure by fog generation in clean room (AVIS)

Cavity assembly

human



New clean bench
Class 1 (open clean bench)
KOACH (Koken camany)

History of #2 cavity

VT	Surface treatment etc.	Aim of VT
1st VT	EP(100um), Annealing,EP2(20um), HPR, Baking	Performance check
2nd VT	EP(20um), HPR, Baking	Performance check
3rd VT	Warm-up	Check Q-value after warm-up
4th VT	**HPR (assembly input and bottom flanges)**	**HPR study**
5th VT	Keep with vacuum condition	Check reproducibility
6th VT	Ar purge (No flange assembly)	Check Ar purge procedure
7th VT	**(Warm-up)**	**System check of He processing (0)**
8th VT	**(Warm-up)**	**Study on He processing (1)**
9th VT	Flange disassembly/assembly	Check flange disassembly/assembly procedure
10th VT	**(Warm-up)**	**Study on He processing (2)**
11th VT	**HPR (assembly all flanges)**	**HPR study**

Precise study of He processing from 7^{th} VT & HPR from 4^{th} VT.

Field emission pattern (KEK-ERL-model-2)