Sep 16th -Sep 20th 2019, Berlin Germany
WECOWBS01, ERL2019
30min. talk

Vertical Test Results and Preparation for Horizontal Test of the KEK SRF Gun #2

SEPTEMBER 18TH , 2019

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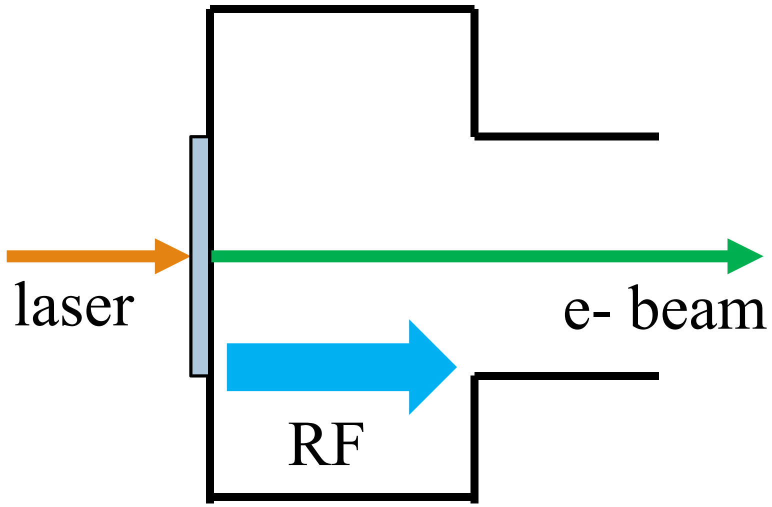
Outline

- KEK SRF gun design
- Performance of Prototype SRF gun (cavity #1)
- Progress of SRF gun cavity #2
- Preparation for Horizontal test
- Summary

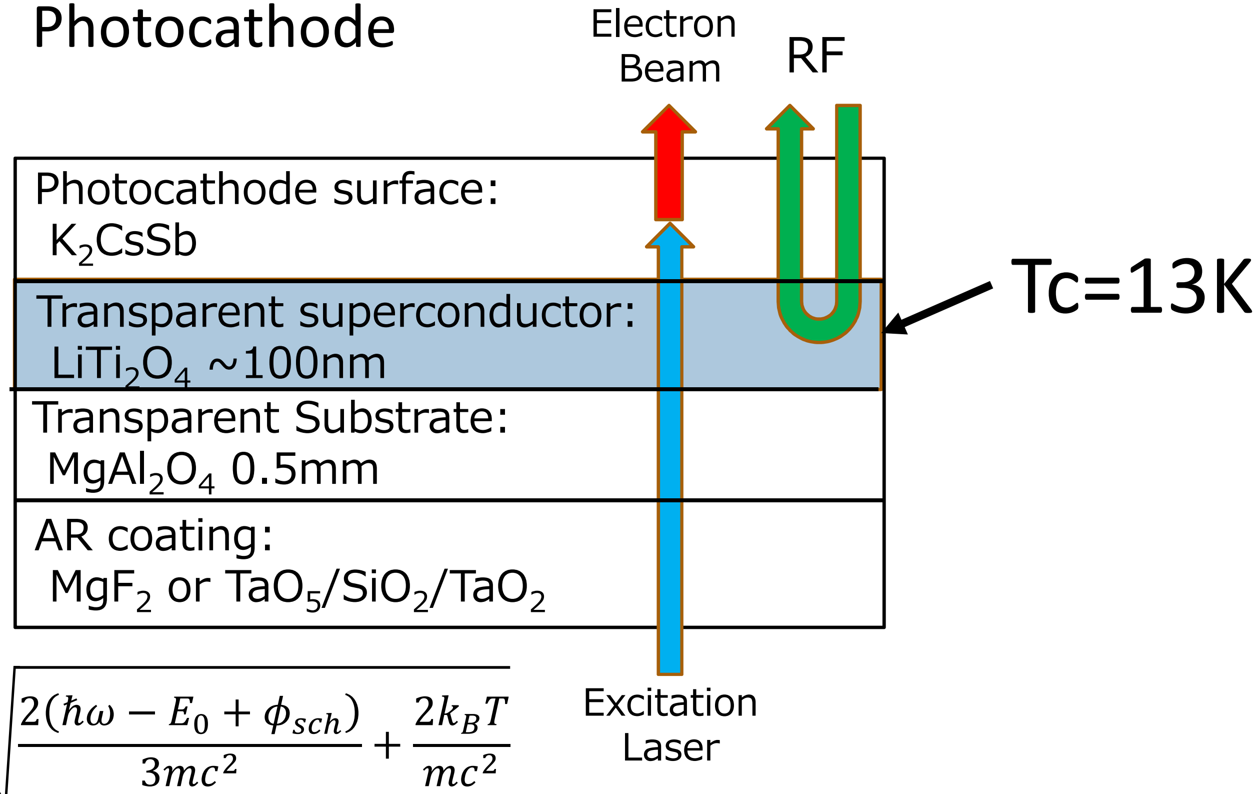
Concept of KEK SRF gun

- We are developing the SRF gun for KEK ERL project.
- The feature is transparent photocathode for simple transport line and easy laser spot control.
- Cathode rod should be kept around 2K because transit temperature of the transparent superconductor is 13 K.

SRF gun cavity



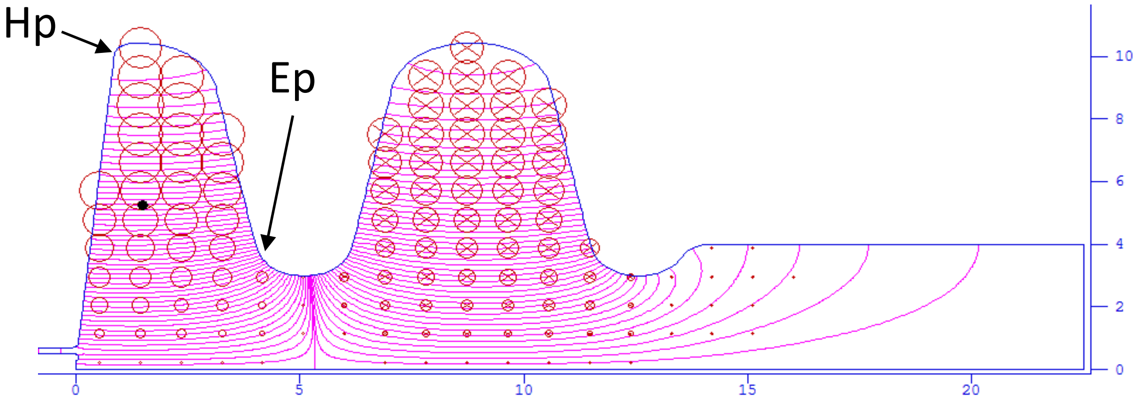
Photocathode

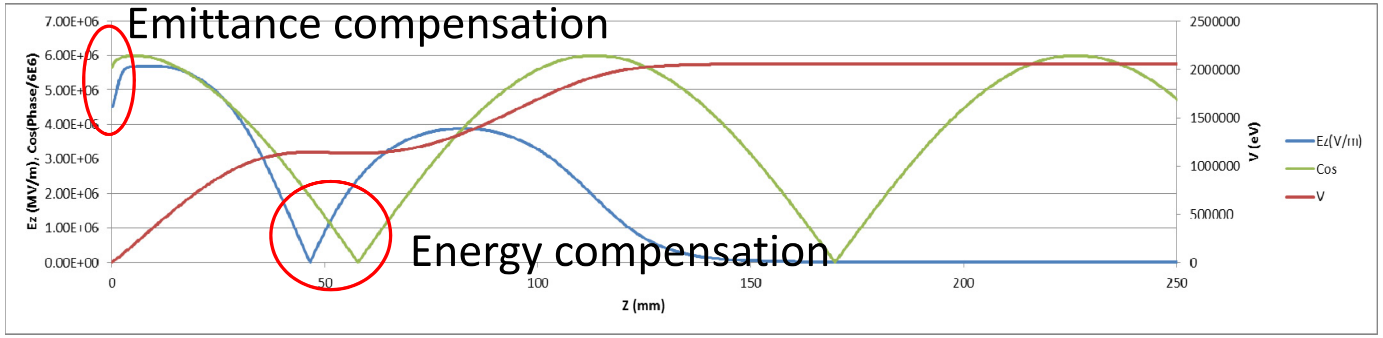


Thermal emittance: $\varepsilon_n = \frac{R}{2}\sqrt{\frac{2(\hbar\omega - E_0 + \phi_{sch})}{3mc^2} + \frac{2k_BT}{mc^2}}$

Gun cavity design

- The KEK gun cavity was designed for KEK ERL.
- Cell number is 1.5 cell because input power is 2 MeV x 100mA =200kW by using two input couplers.
- Surface peak electric and magnetic field are about half of ILC target.
- The cavity shape was designed with only gun cavity without booster cavities etc.
  - It is necessary to compensate emittance and energy spread at same time.
  - It will achieve better value with adding boosters and bunchers.



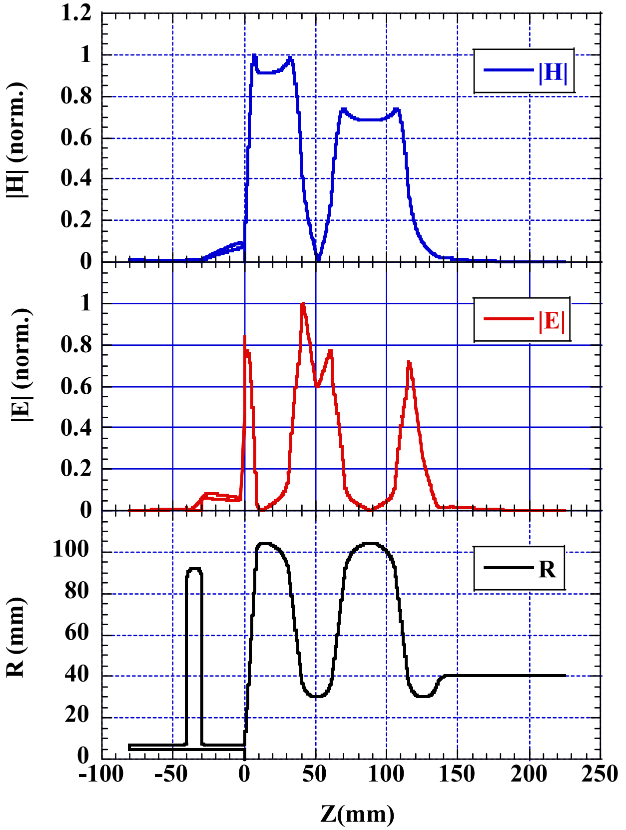


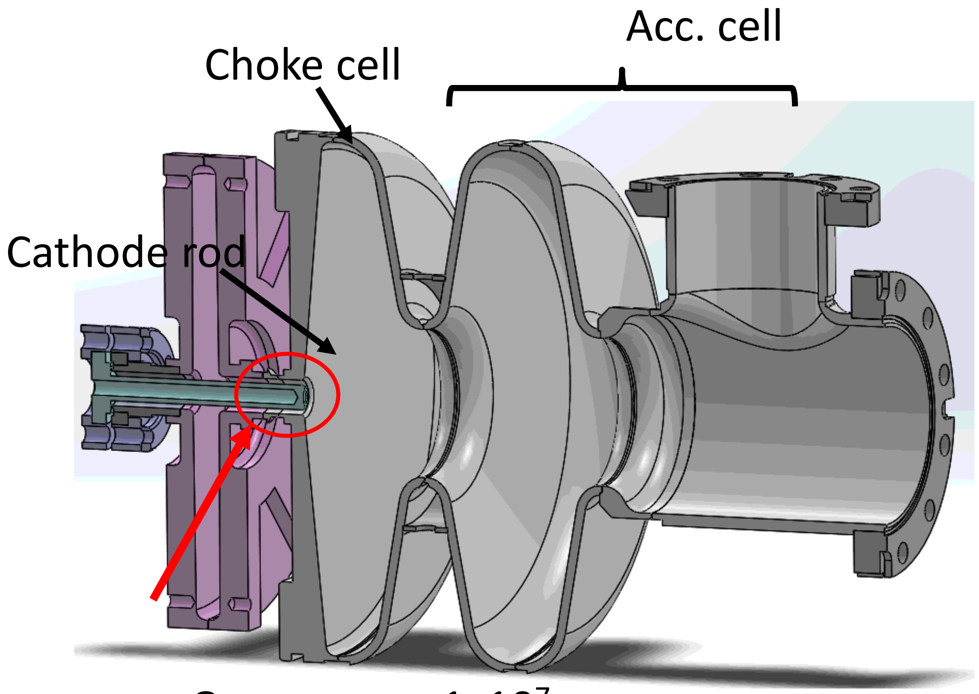
Designed by MHI

Parameter	Value
RF frequency	1.3 GHz
Beam energy	2 MeV
Projected emittance	0.6 mm.mrad
Projected energy spread	0.09%(1.84 keV)
Peak electric field	41.9 MV/m
Peak magnetic field	95.2 mT
RF phase	55°
Geometrical Factor	135.6 Ω (TESLA 270 Ω)
Target surface resistance	30 nΩ (ILC target)
Target Q value	4.5×10^9
Target cavity loss	8 W

RF design

- Choke cell is the ¼ wave structure to reflect the RF leakage from the cathode rod.
- RF loss at cathode rod is $1x10^7$.
- The requirement of the attenuation is more than $1x10^3$.



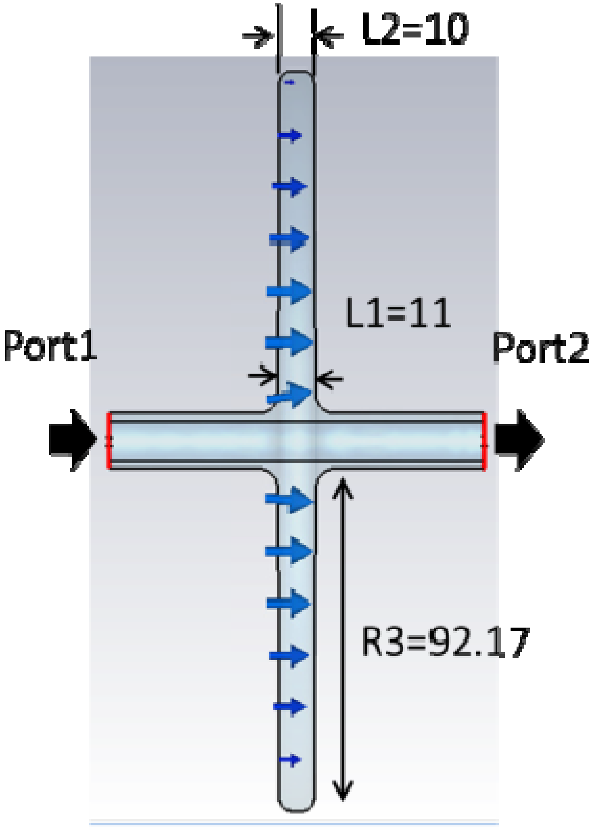


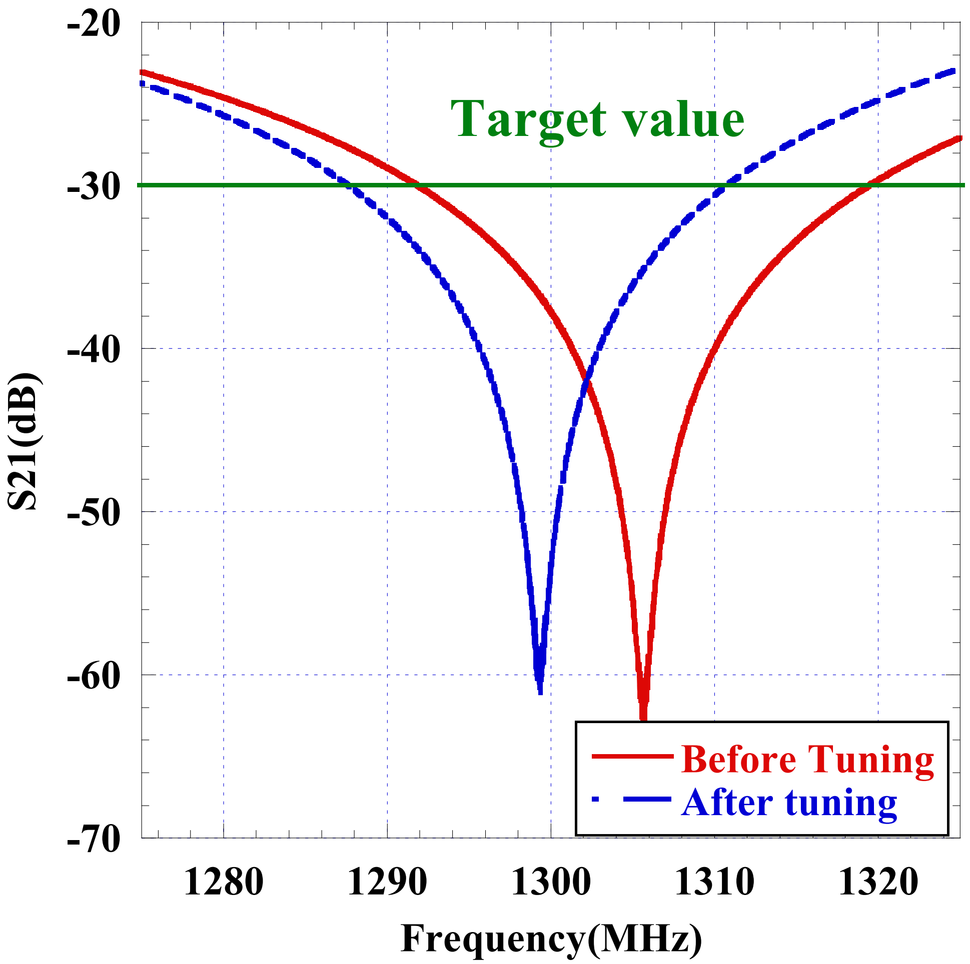
$Q_{loss@cathode} = 1x10^7$

Parameter	Value
Beam energy	2 MeV
Beam current	100mA
Bunch charge	80 pC
Laser length (uniform)	10ps
Projected emittance	0.6 mm.mrad
Projected energy spread	0.09% (1.84 keV)
Peak electric field	41.9 MV/m
Peak magnetic field	95.2 mT
RF phase	55°
Geometrical Factor	135.6 Ω (TESLA 270 Ω)
Target surface resistance	30 nΩ (ILC target)
Target Q value	4.5×10^9
Target cavity loss	8 W

Choke design

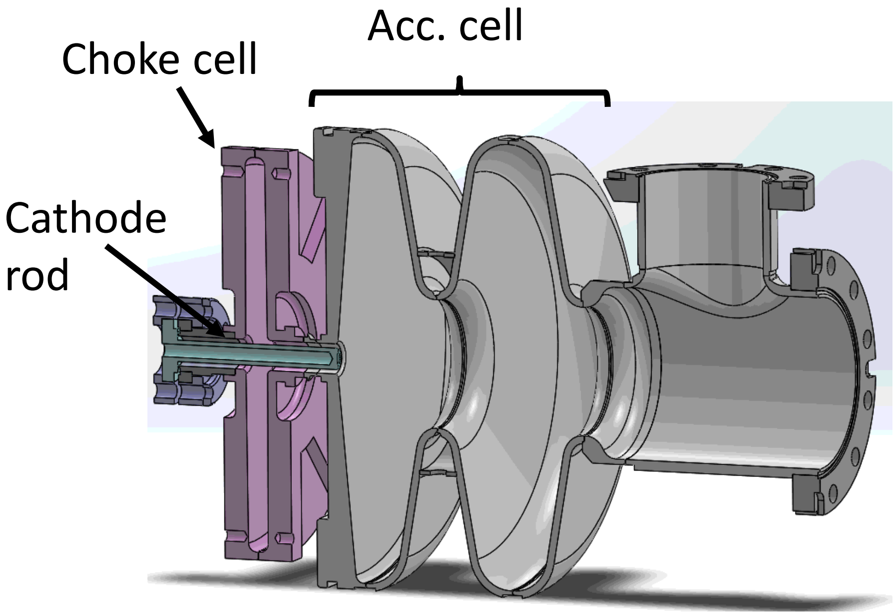
- The choke is a simple parallel shape. The parallel two face has slight taper for cleaning easily.
- Choke was machined from large grain ingot Nb, and has high stiffness.
- The tuning range is wide enough to accept the target attenuation (-30dB)



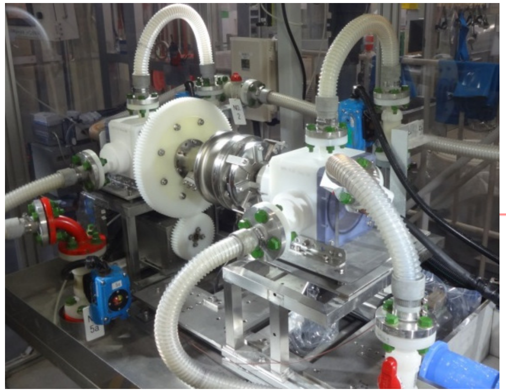


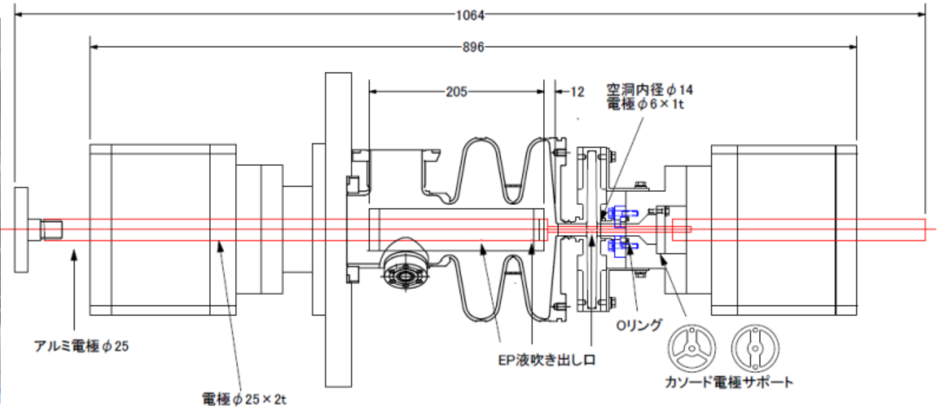
Prototype gun cavity #1

- We established the cavity treatment procedure by using cavity #1.
- Choke cell is parallel shape to make HPR easily.
- EP rod and HPR nozzles were modified for KEK SRF gun cavity.

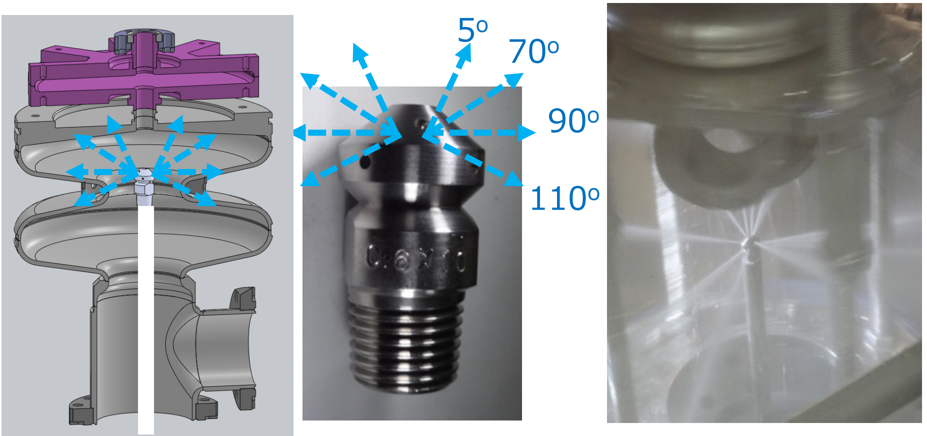


EP





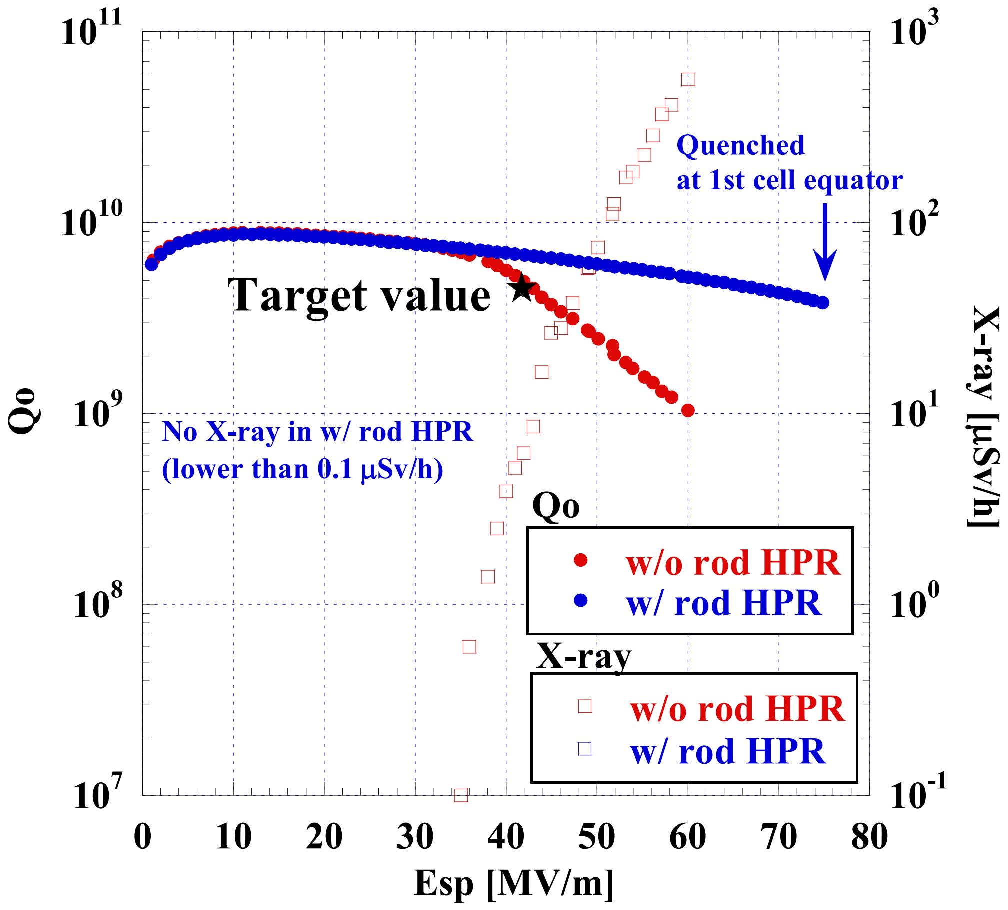
HPR nozzle for Acc. cell

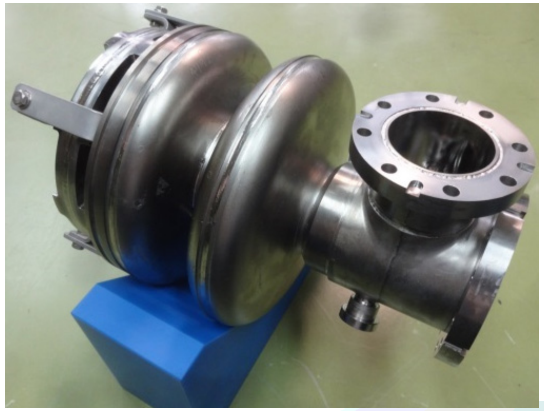


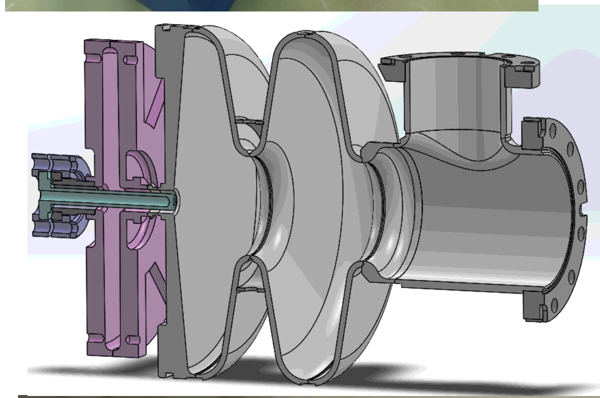
HPR nozzle for choke cell

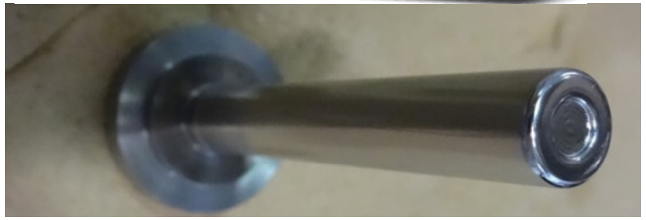
Performance of prototype #1 cavity

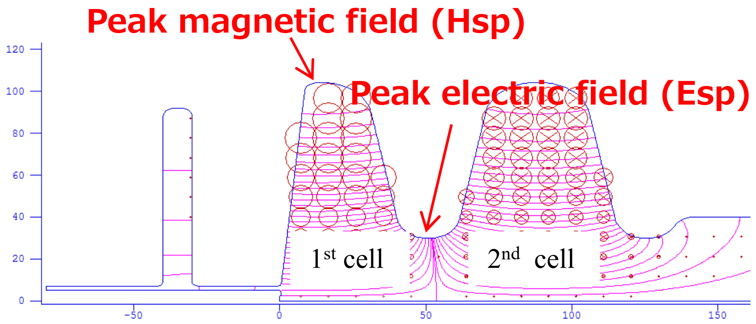
- It is important to apply HPR to the cathode rod.

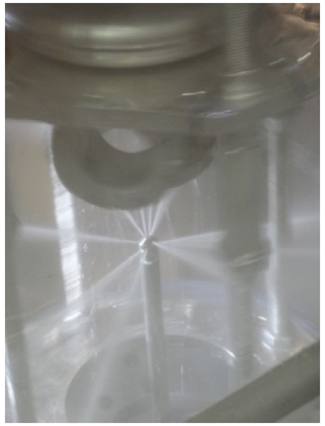






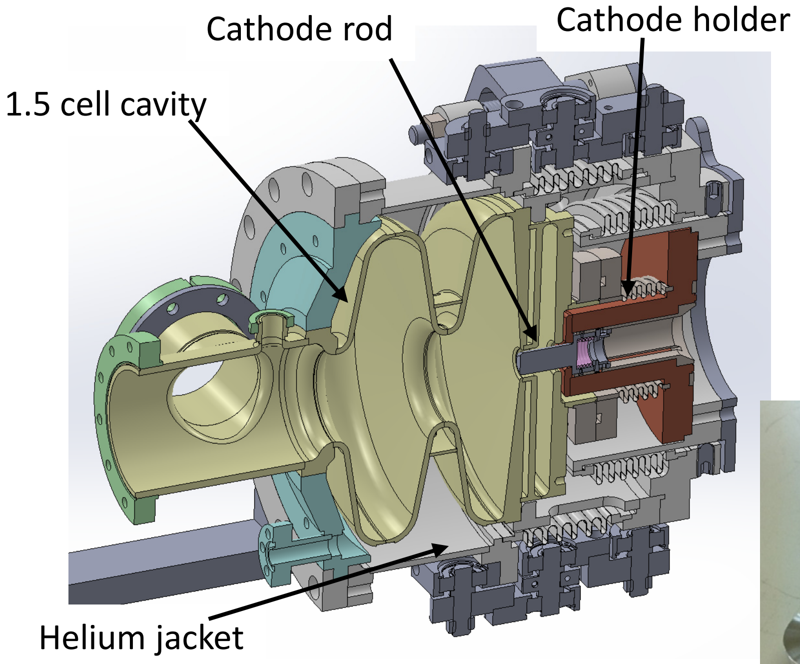


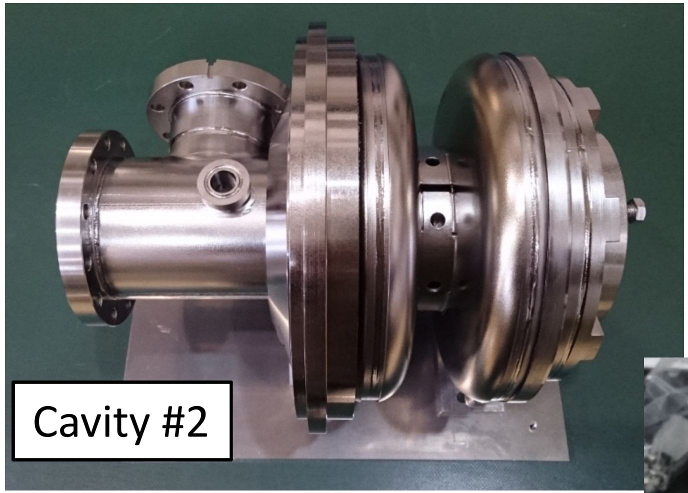


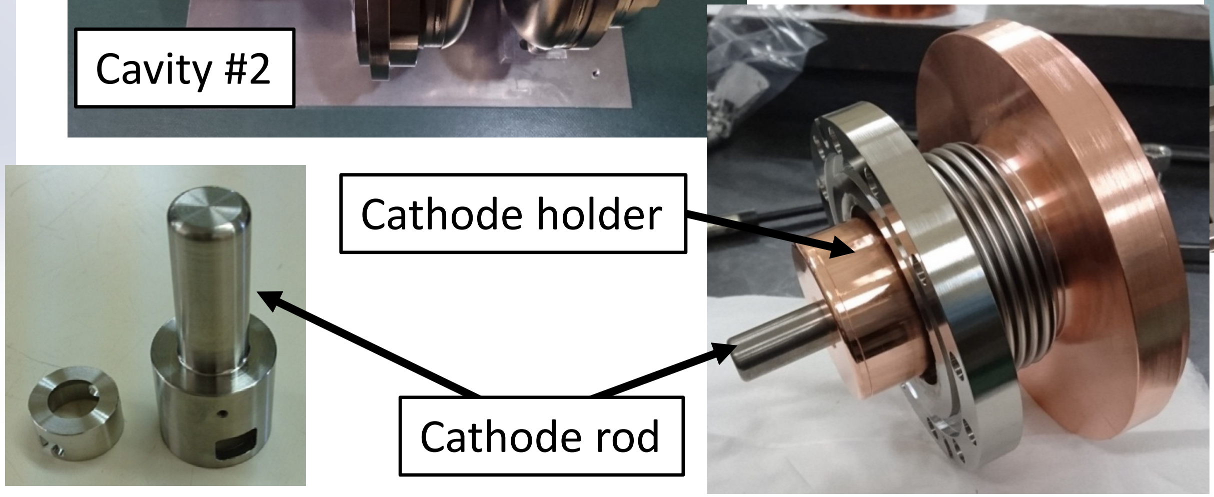


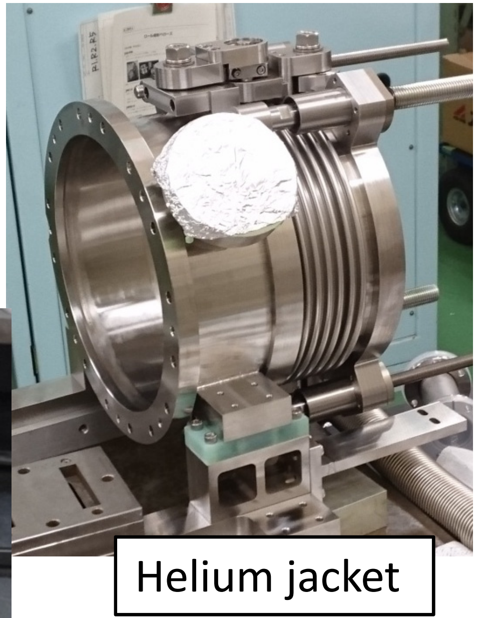
Fabrication of Gun cavity #2

- #2 cavity is modified from #1 to add the helium jacket for beam test.
- The cathode rod is mounted on the cathode holder to remove from the cavity.



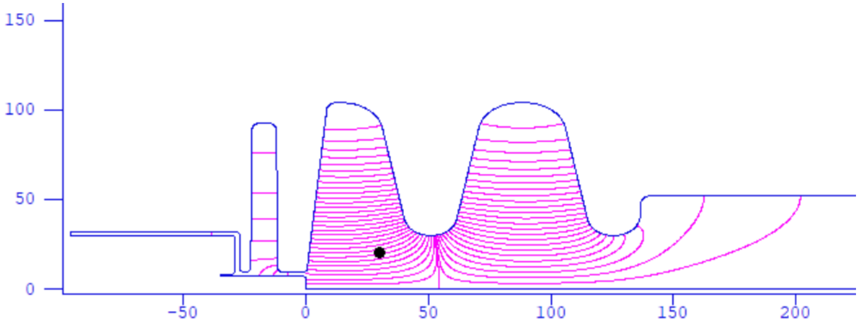




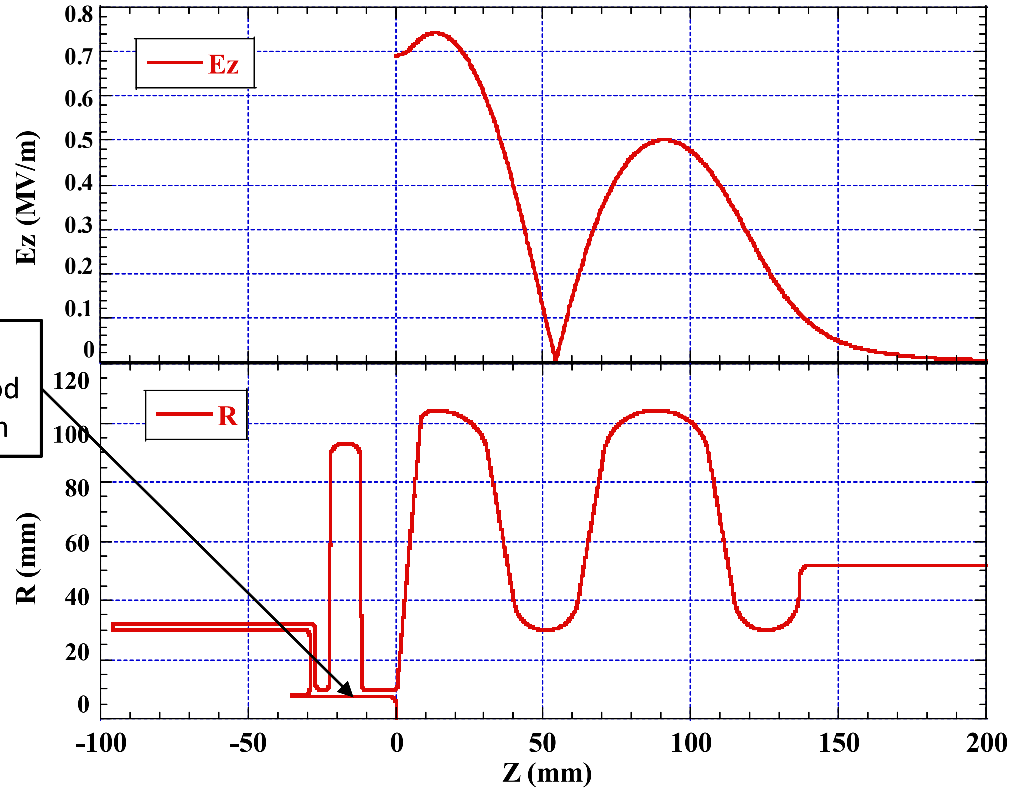


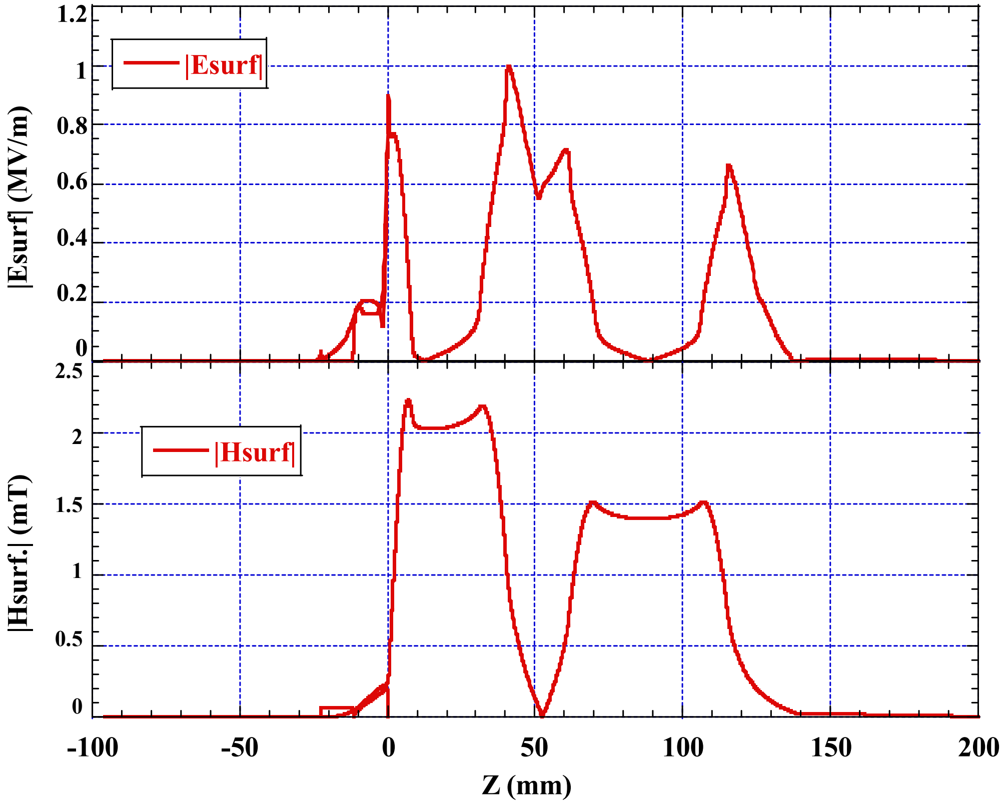
RF design of Gun cavity #2

- RF design of Gun cavity #2 is same as cavity #1 except choke area.
- The cathode rod was designed as possible as short for the heat path shorter.
- RF heat load on the cathode rod is ideally 240 mW at 2K



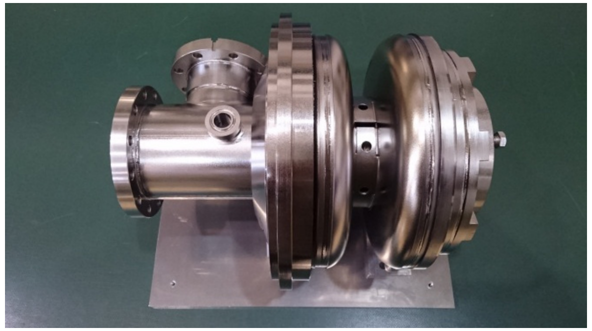
240mW
@cathode rod
Esp=42MV/m



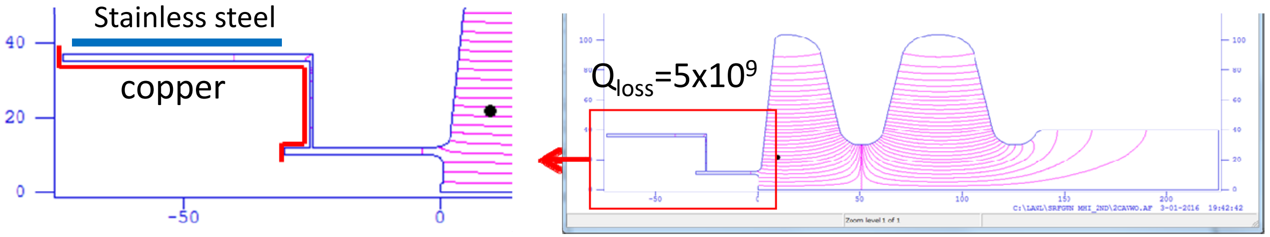


Preparation for vertical test

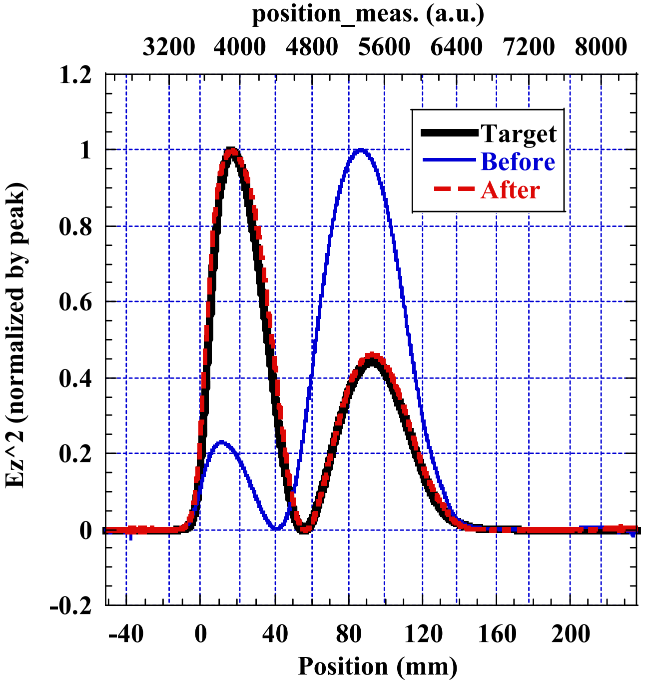
- The surface treatment was followed with the experience of the gun cavity # 1.
  - EBW in KEK
  - EP 100 um
  - Anneal 800Cx3h
  - Field tuning
  - Final EP 20um
  - USR, HPR
  - Assembly



- Loss Q at cathode rod and holder is 5×10^9 if there is no choke filter.
- Target attenuation of choke filter is 30dB for 1% loss.
- The choke attenuation was adjusted to be minimum.



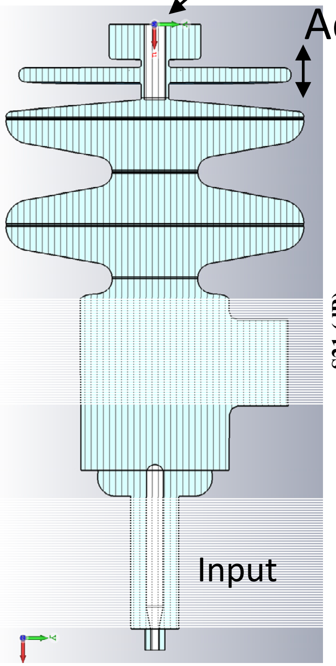
Acc. cell tuning

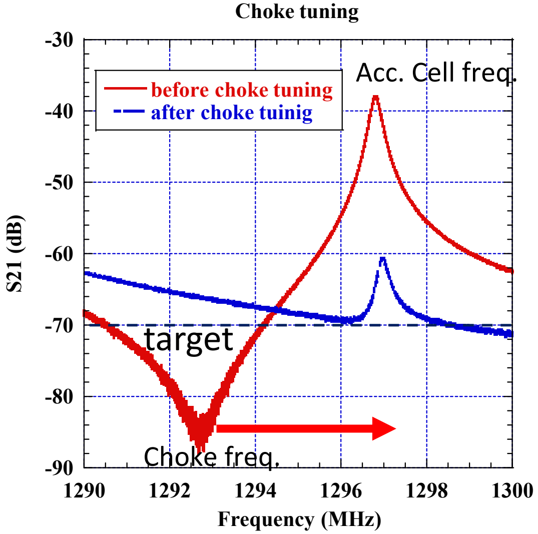


Choke cell tuning

Dummy rod for pick up

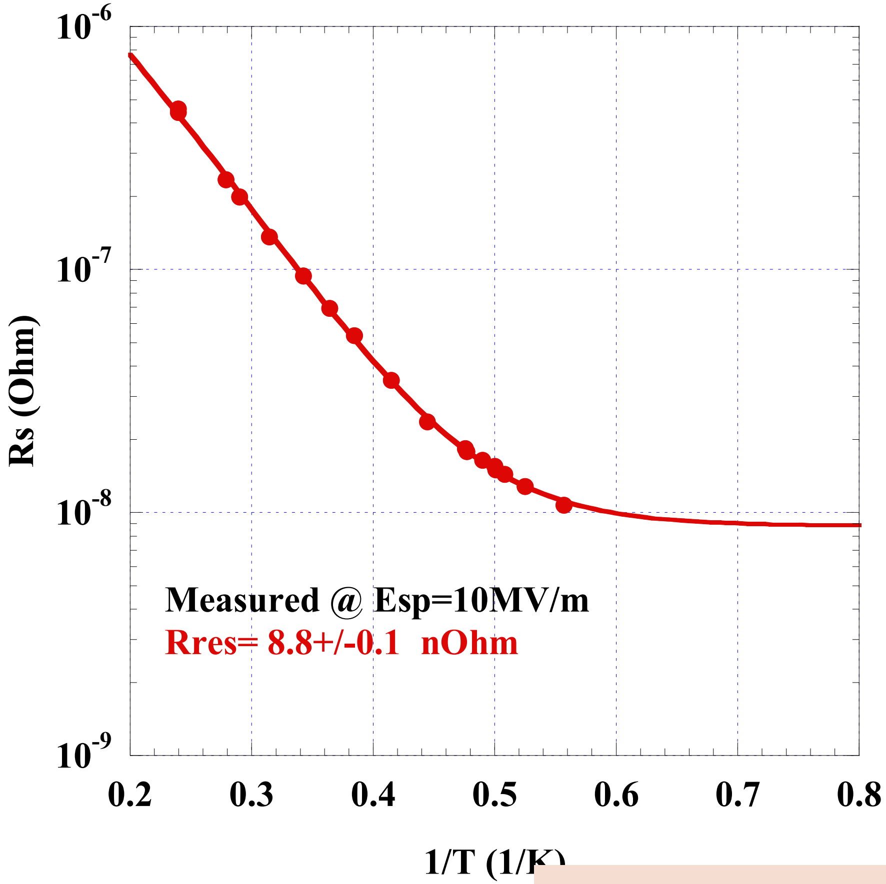
Adjust this length

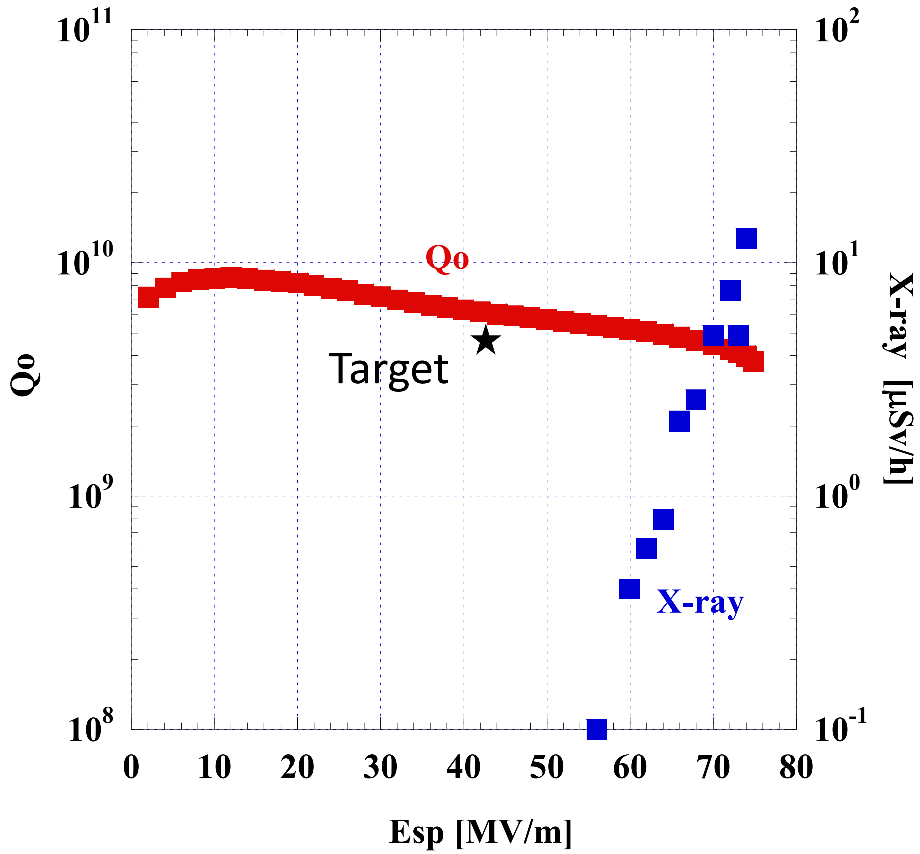


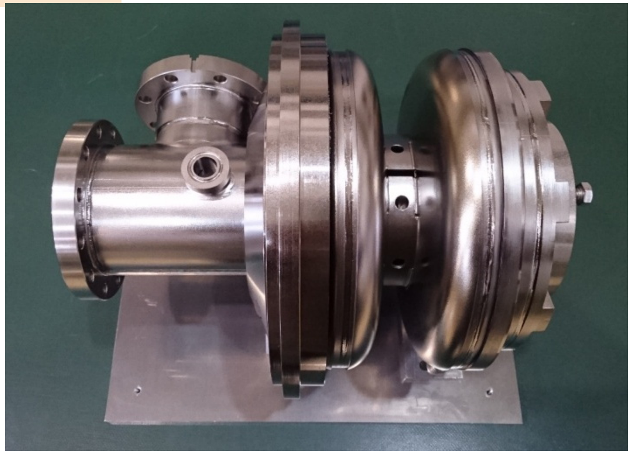


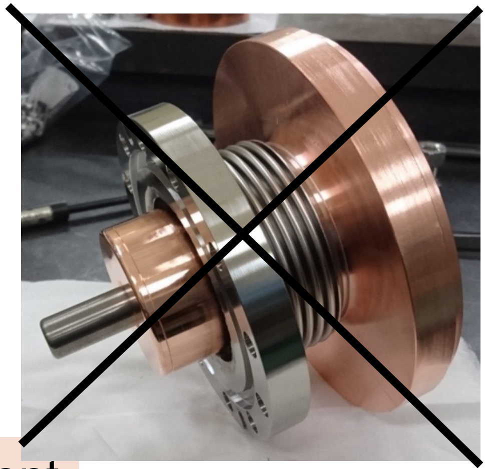
Vertical test of the 1.5 cell type SRF gun

- The maximum gradient without cathode rod reached to target value.







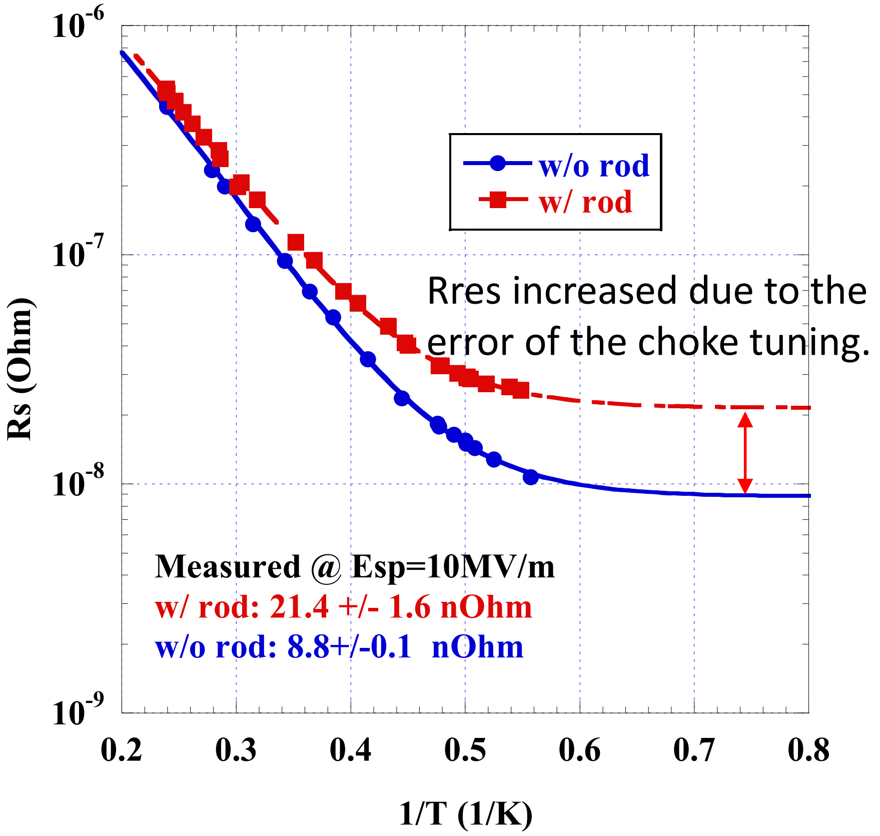


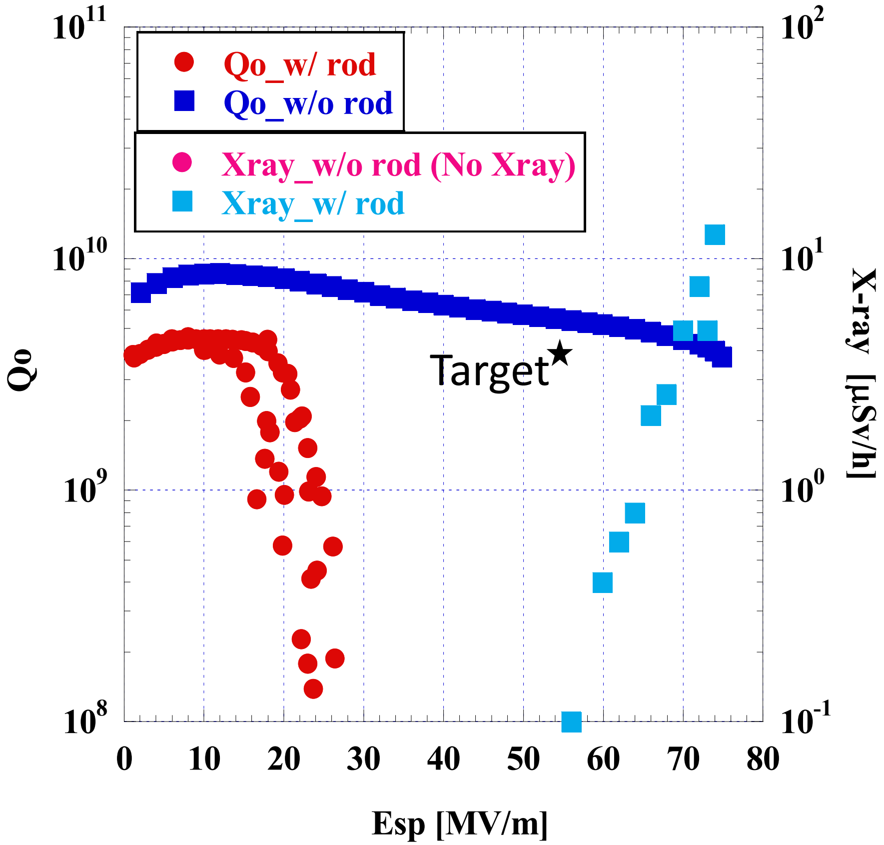
We can shift the main target to cathode rod and holder development

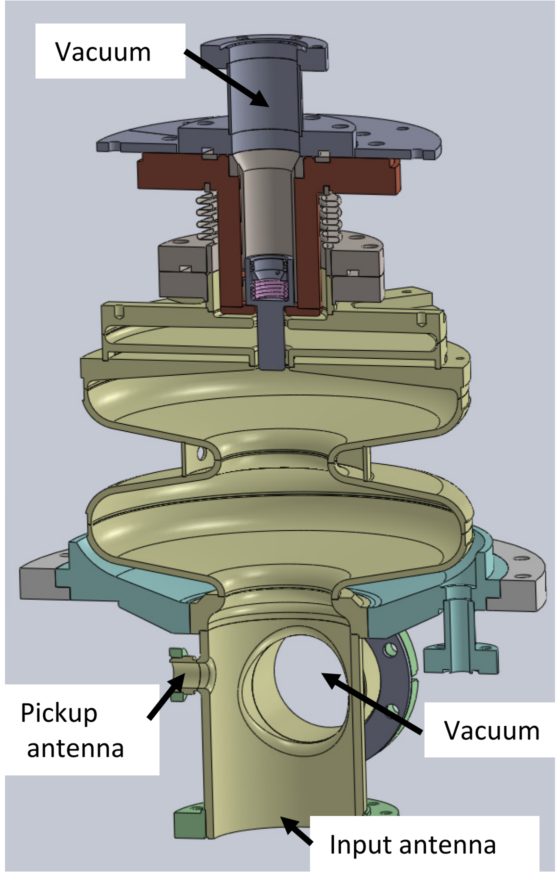
- Effective cooling structure to keep the cathode rod around 2K.
- Particle free cathode transport method.

Vertical test with cathode rod (4^{th} VT)

- The maximum gradient without cathode rod reached to target value.
- However the Q value is dropped at 15 MV/m with cathode rod.
    - We suspect it is because the thermal contact resistance between cathode rod and holder is higher than expected.

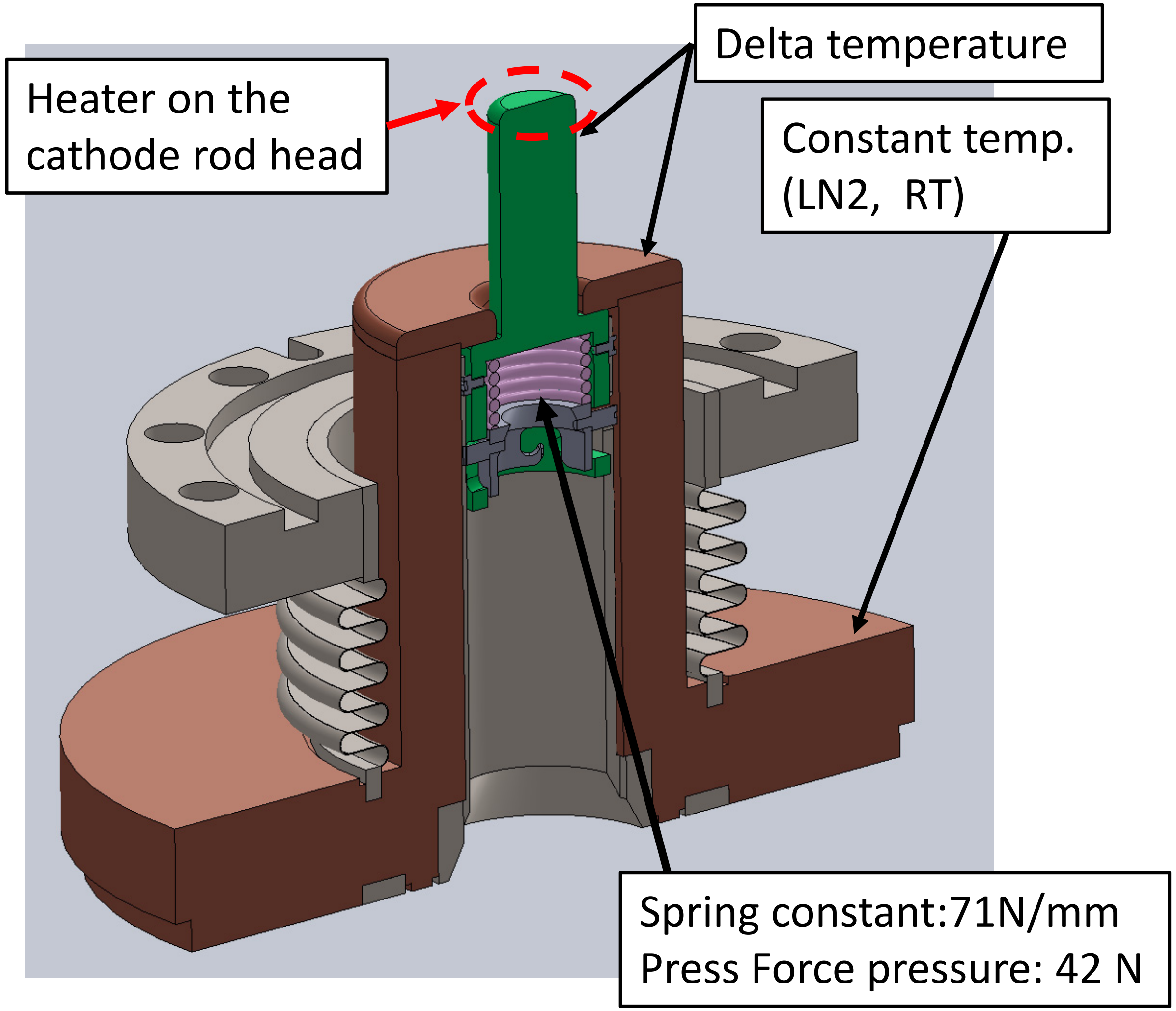




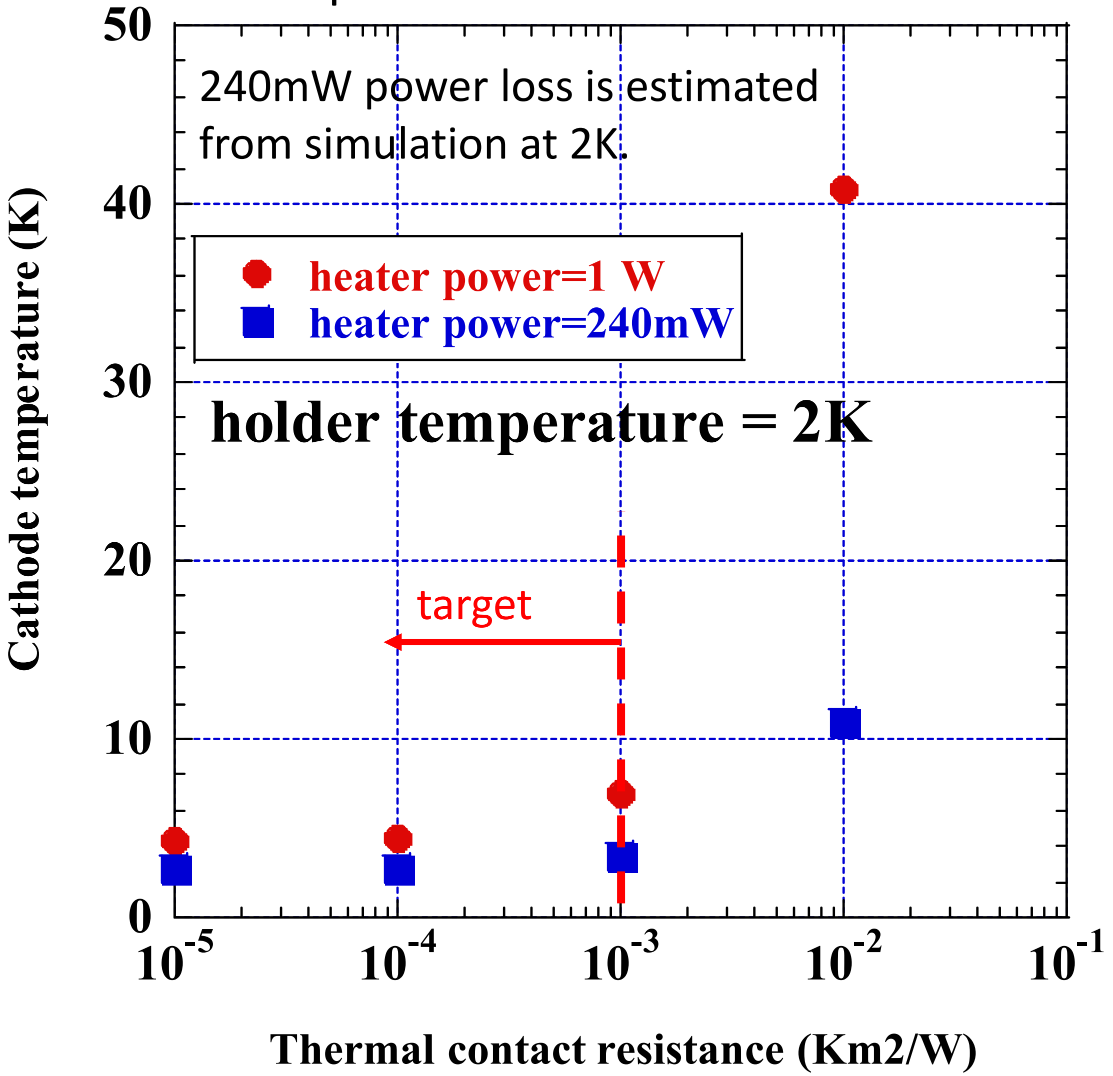


Thermal contact resistance measurement

- We carried out heating test with cathode rod and holder to measure the thermal contact resistance.

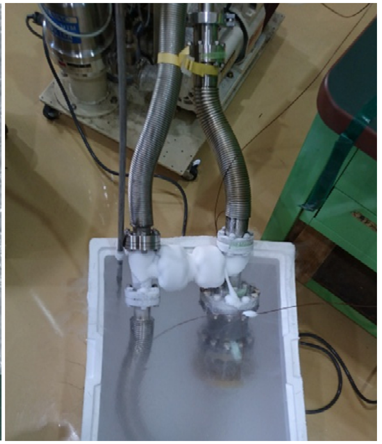


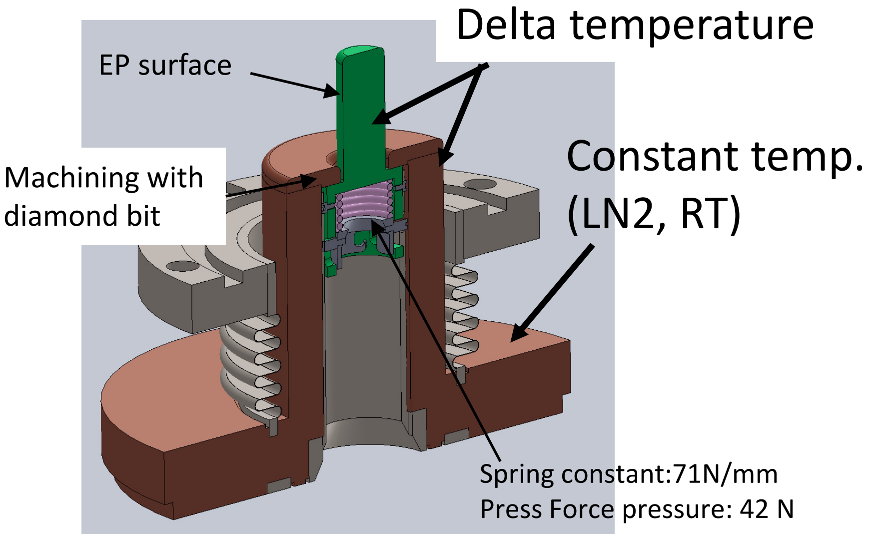
Simulation: dependence of thermal contact resistance

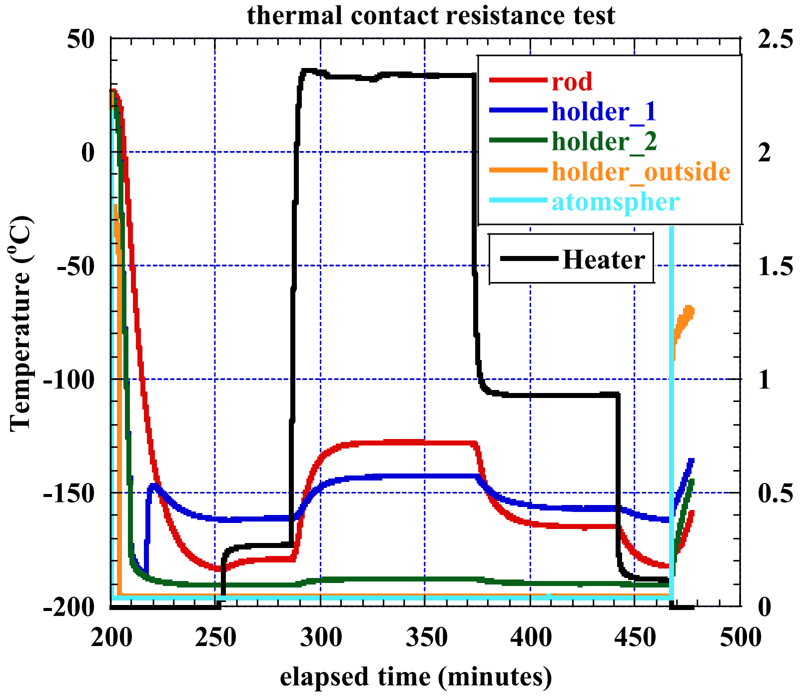


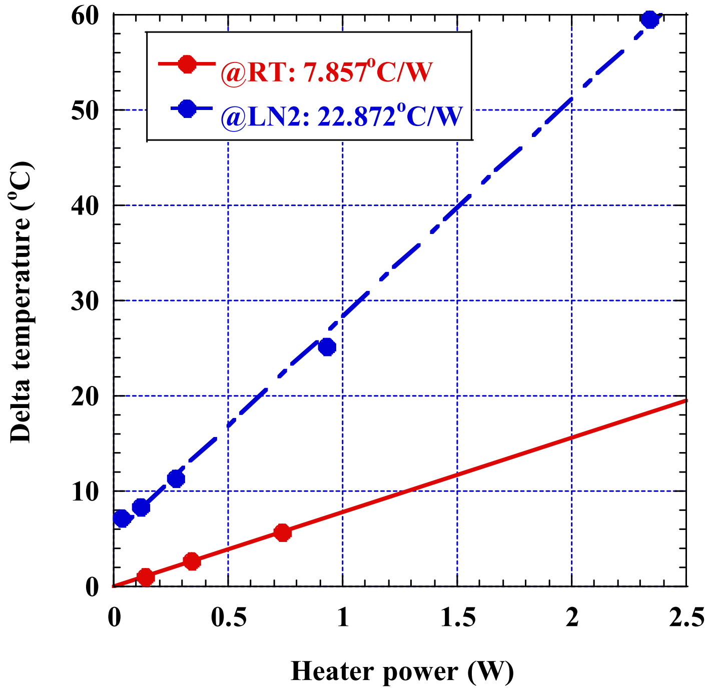
Thermal contact resistance measurement

- The thermal contact resistance is 21.7E-4 [m²K/W] and 63.2E-4[m²K/W] at RT and LN2 respectively .
- The target resistance is 1E-4 [m²L/W]. It is 10~100 times higher than the target.
- We will apply mirror polish (target Ra ~1nm) to contact surface.





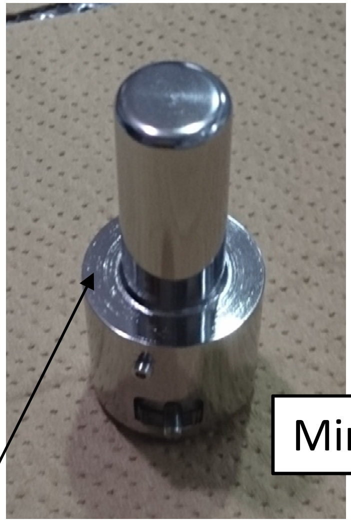




Thermal contact resistance measurement

We applied mirror polish to the contact surface.

Before mirror polishing

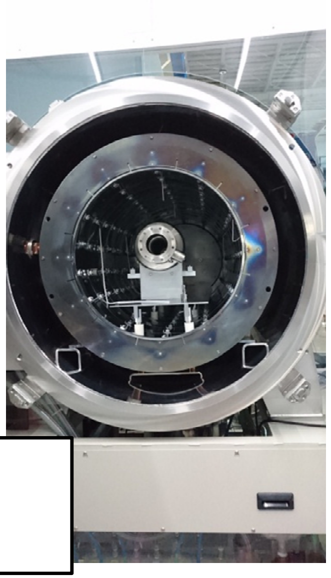


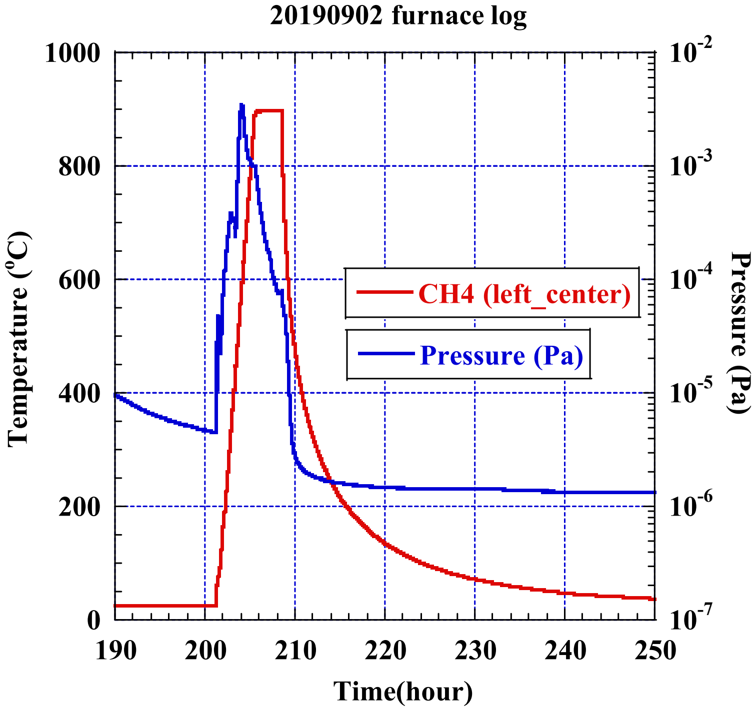
Mirror polishing

After mirror polishing

Ra~0.45nm
Rz~3nm

900°Cx3h Anneal
(w/ 9cell cavity)





The turning track remained on the contact surface.

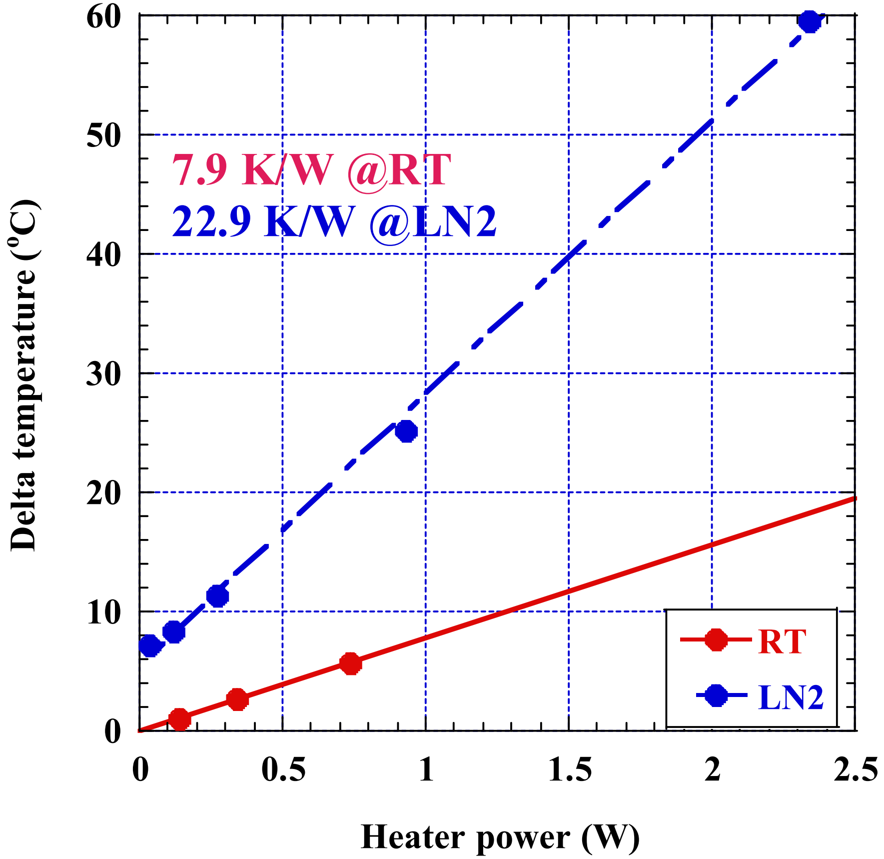
Before Mirror polishing

After Mirror polishing

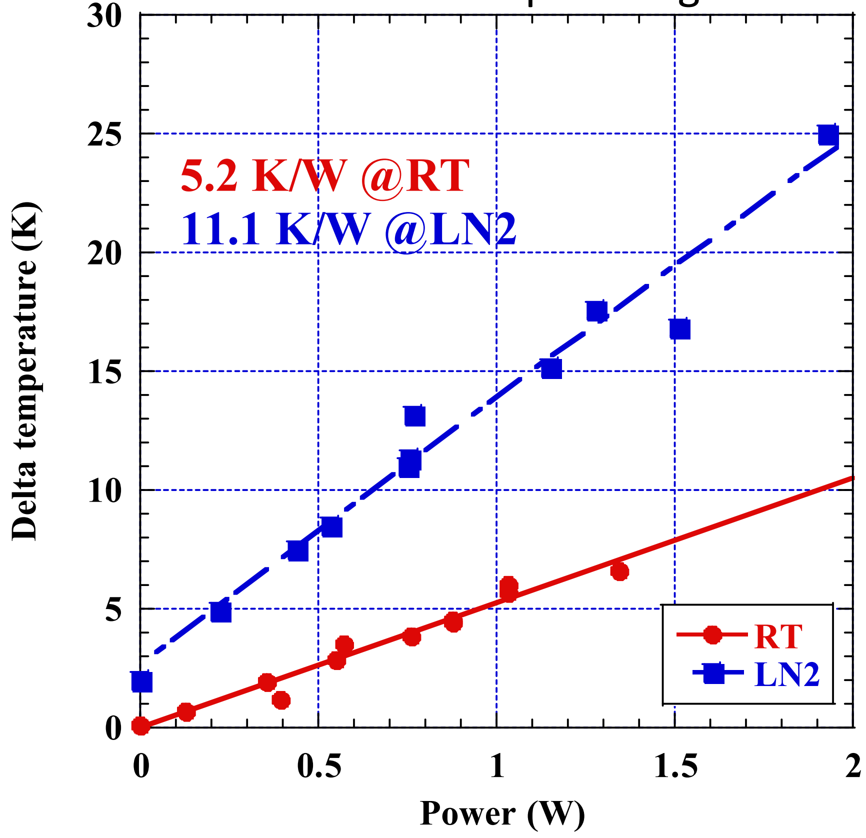
Thermal contact resistance measurement

- Thermal contact resistance become about half by mirror polishing.
- However, This is still insufficient, we plan to increase the pressing force by changing the spring in the cathode.

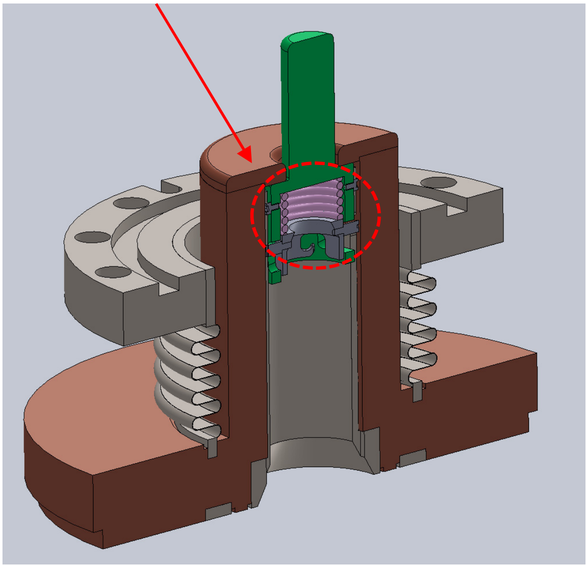
Before mirror polishing



After mirror polishing



Spring to generate pressing force



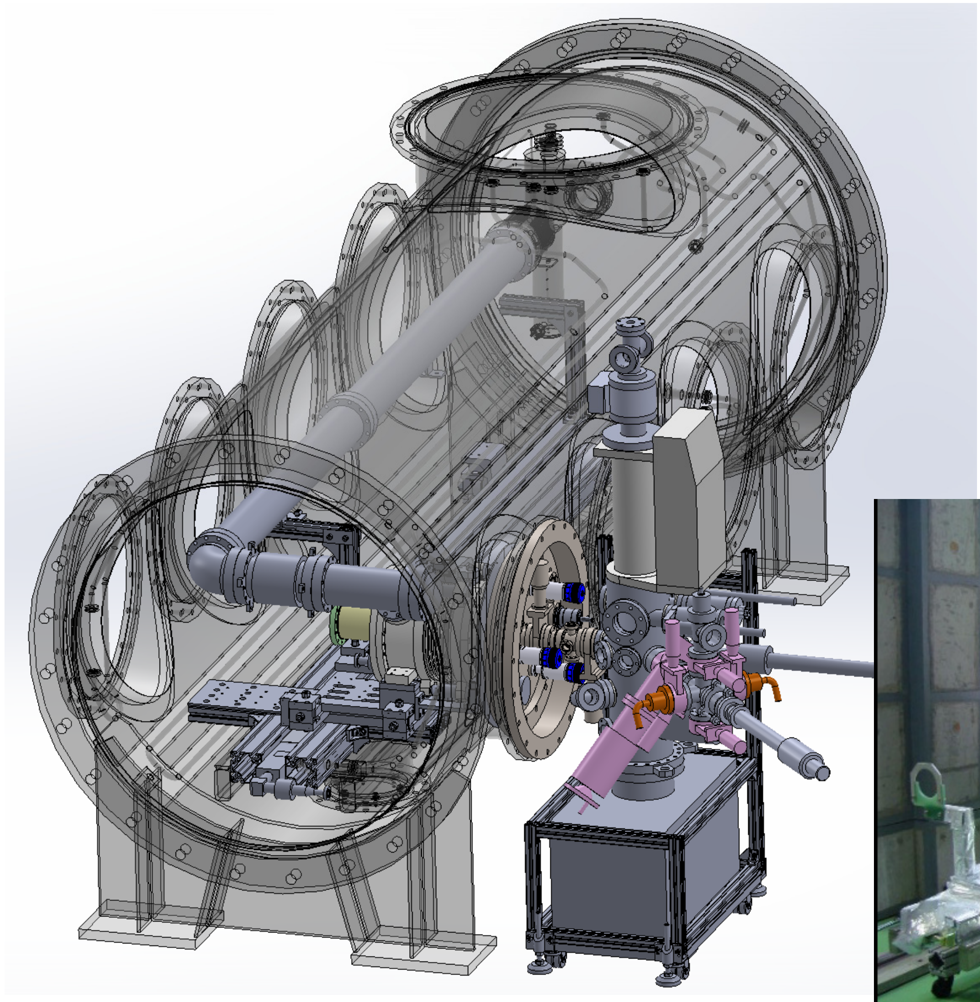
Plan for horizontal test

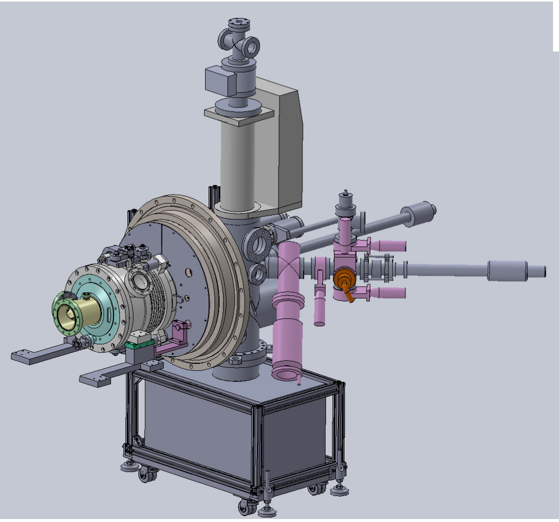
- We are planning beam test with small current in the horizontal test cryostat.
- Support Jigs to install cavity are under fabrication.
- Short diagnostic (beam energy and emittance) line will be designed.

Cooling test
- Heat loss of cathode rod adjuster.

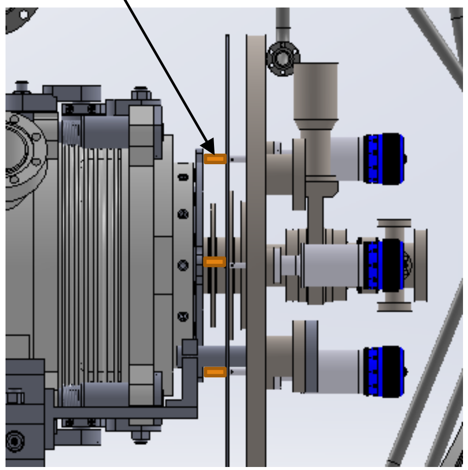
High voltage test
- Particle free cathode rod transportation.
- Q-E curve with cathode rod.

Small current beam test
- Dark (and beam) lifetime of the photocathode.
- Measure the RF field distribution error.



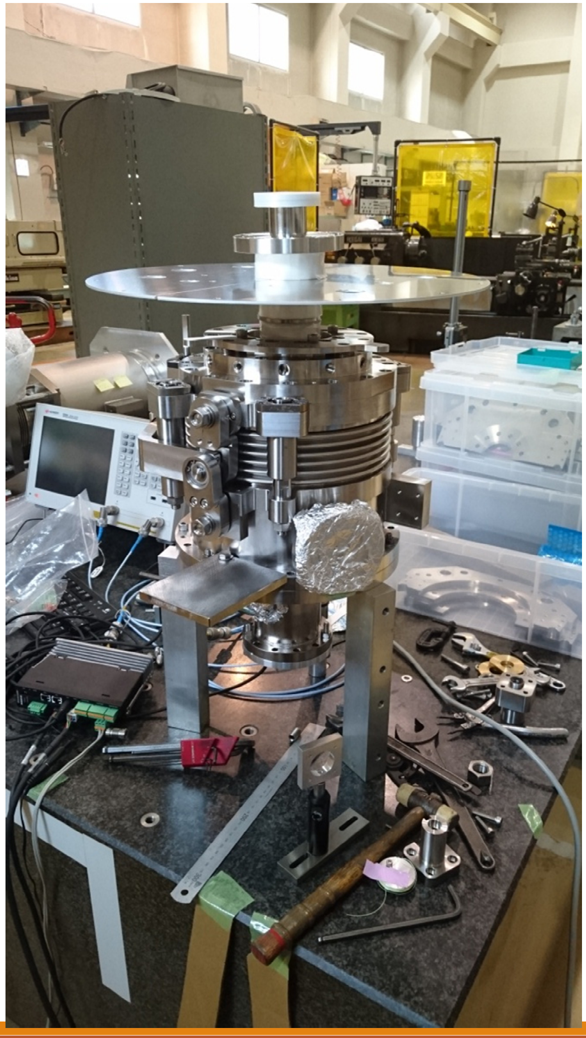


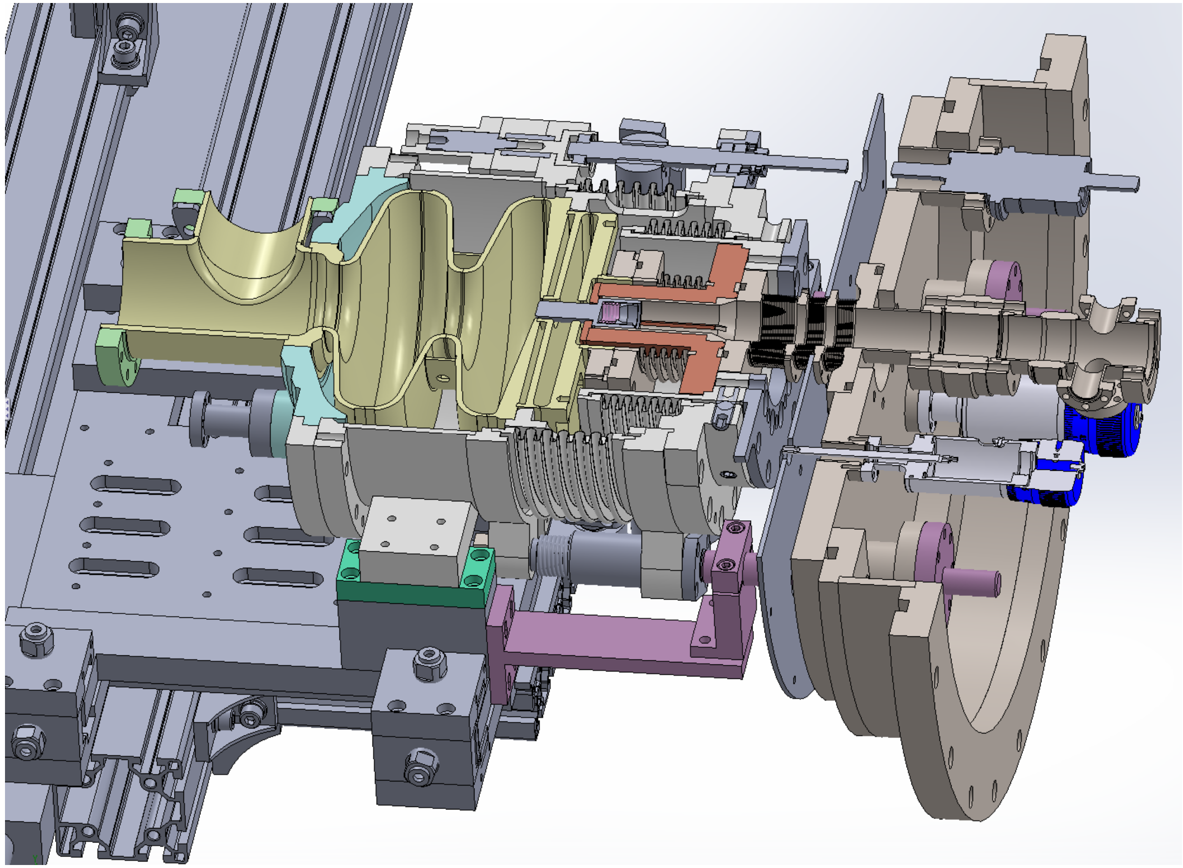
Cathode rod adjuster



Assembly test

- We checked the fitting of gun assembly.
- Almost all the parts for the cooling test are prepared, except for Helium 2 phase line and magnetic shield.



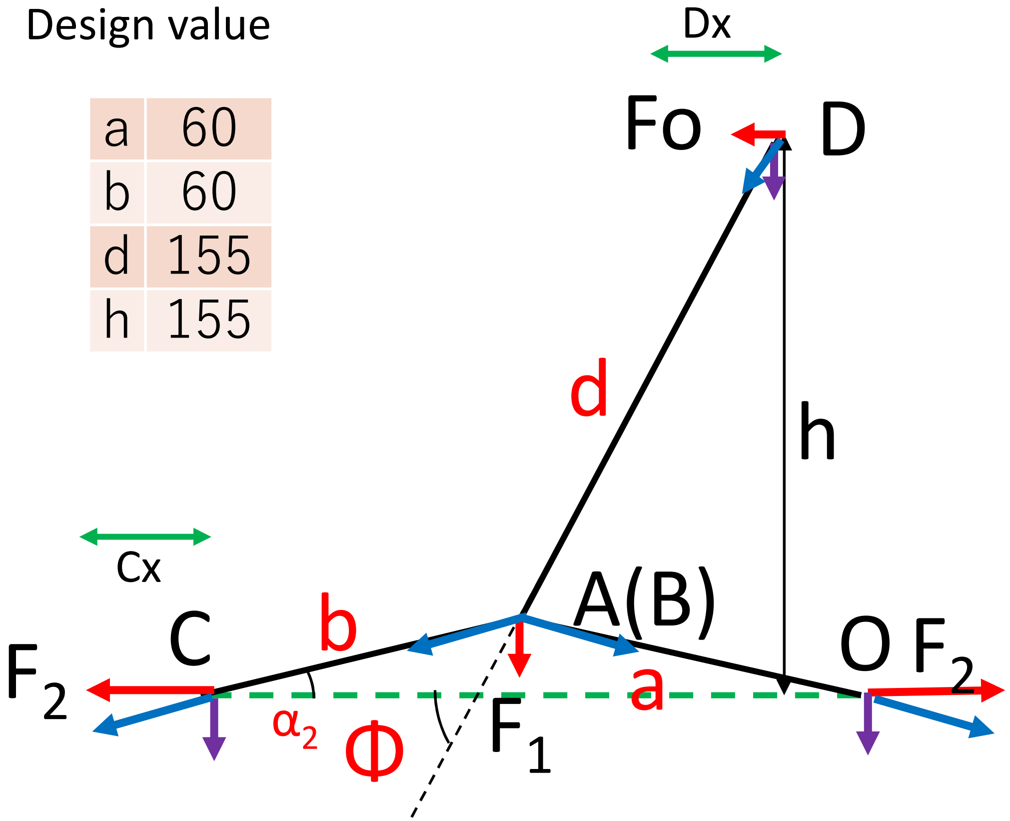


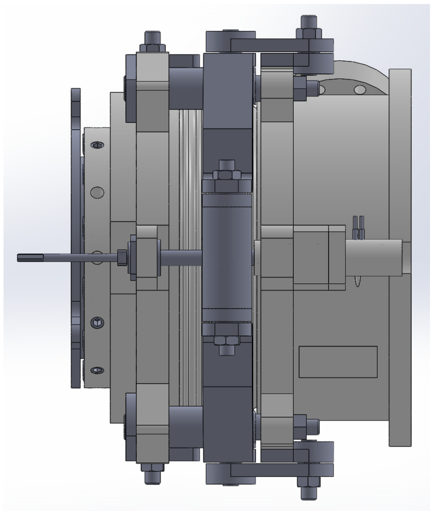
Mechanical tuner test

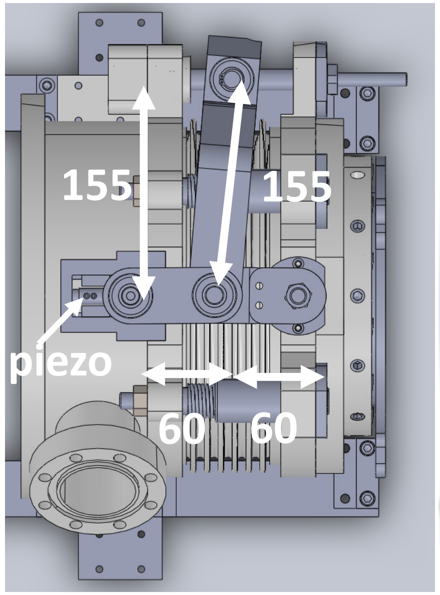
- Tuner type is toggle mechanism (Blade type tuner?).
- All arm length is fixed. C and D can be move parallel to horizontal.

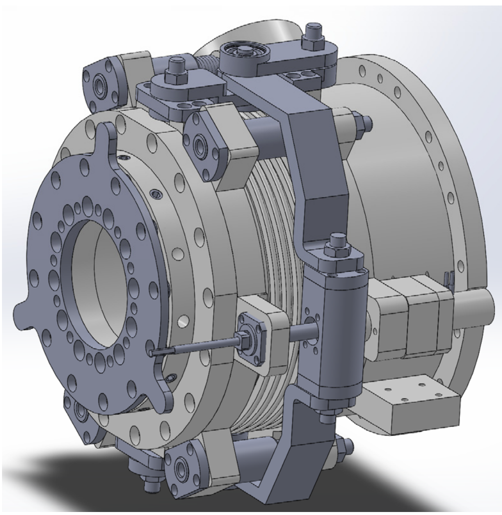
Design value

a	60
b	60
d	155
h	155









$$\sin\alpha_1 = \frac{d\sin\phi - h}{a}$$

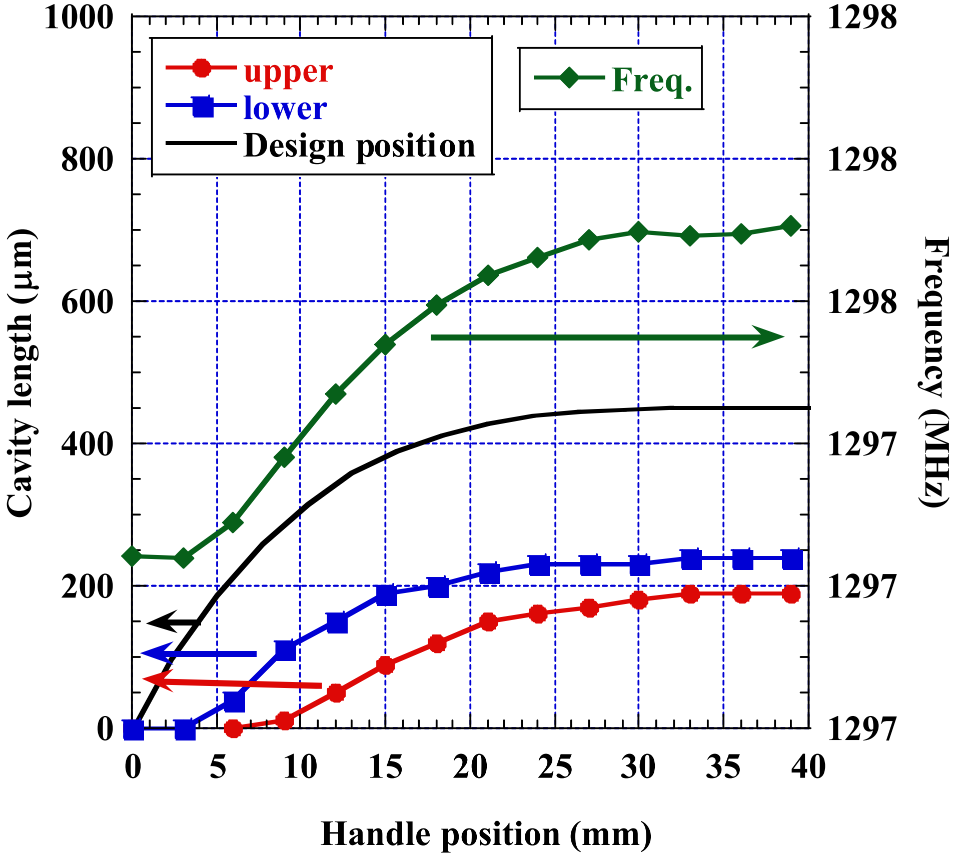
$$\sin\alpha_2 = \frac{-a\sin\alpha_1}{b} = \frac{-d\sin\phi + h}{b}$$

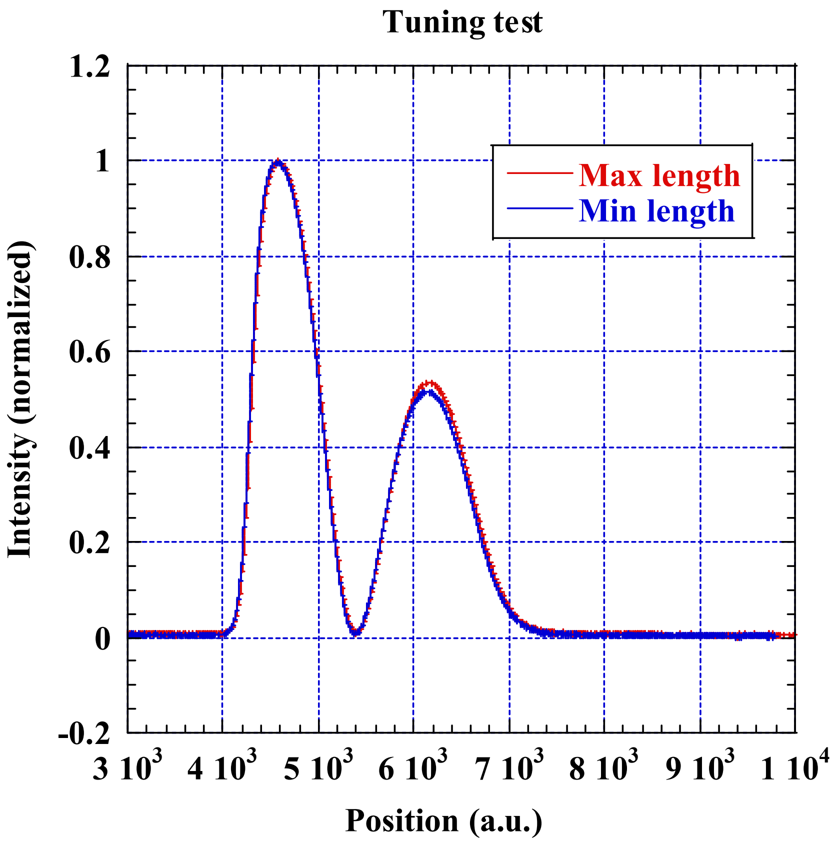
$$D_x = a\cos\alpha_1 - d\cos\phi = \sqrt{a^2 - (d\sin\phi - h)^2} - d\cos\phi$$

$$C_x = a\cos\alpha_1 + b\cos\alpha_2 = \sqrt{a^2 - (d\sin\phi - h)^2} + \sqrt{b^2 - (-d\sin\phi + h)^2} - d\cos\phi$$

Mechanical tuner test

- Stroke of the tuner is about half of the design.
  - We suspect the holder post move to unexpected direction.
  - We will make more tuning to the tuner.





Summary

- KEK SRF Gun cavity #1 reached to Esp=75 MV/m with cathode rod.
- KEK SRF Gun cavity #2 itself reached to Esp=75 MV/m with FE.
  - Gun cavity #1 and #2 are same RF design.
  - Gun cavity #2 can be connect to helium jacket.
- We are preparing for horizontal test.