2019.11.21 (木)- 22(金), KEK2号館大会議
15min. Talk + 5min.Discussion

SRF gun development at KEK

NOVEMBER 21ST , 2019

許斐　太郎 (KEK)

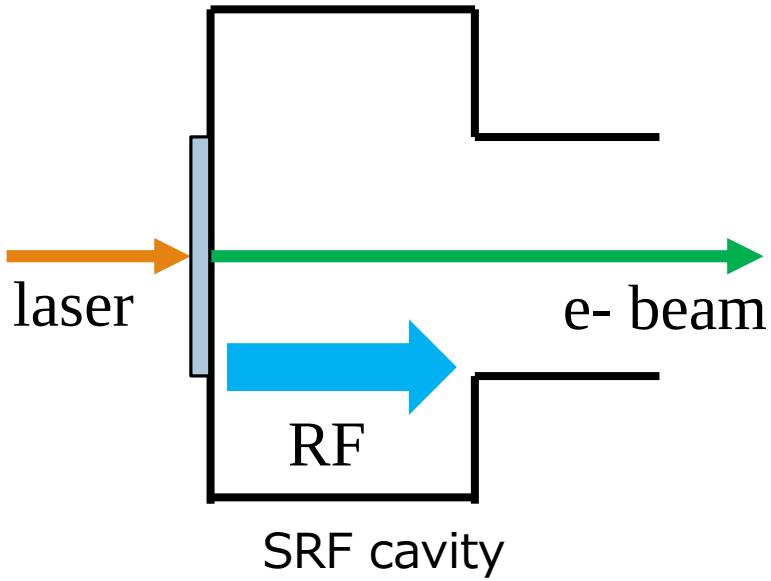
Outline

- KEK超伝導RF電子銃のコンセプト
- プロトタイプ空洞の性能(Gun #1)
- GUN#2の開発状況
- まとめ

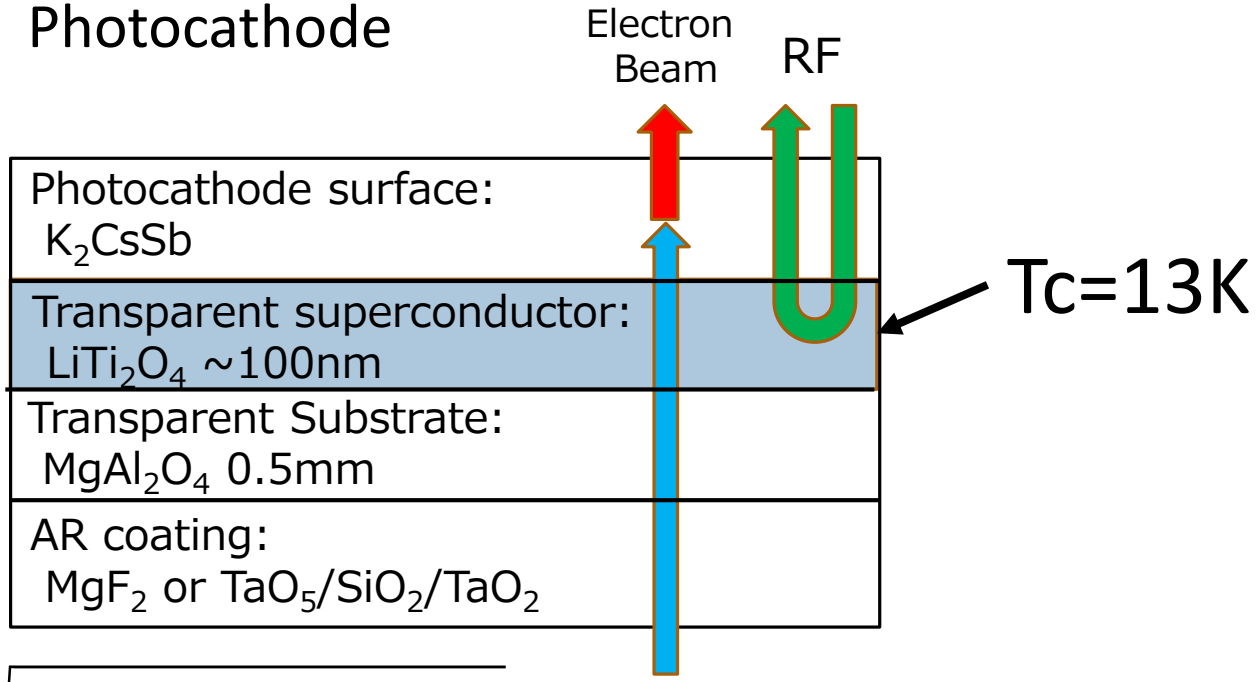
Concept of KEK SRF gun

- 3GeV-ERLを目標に設計を開始。
- カソードの発熱を守るために透明超伝導を使うコンセプトとした。

SRF gun cavity



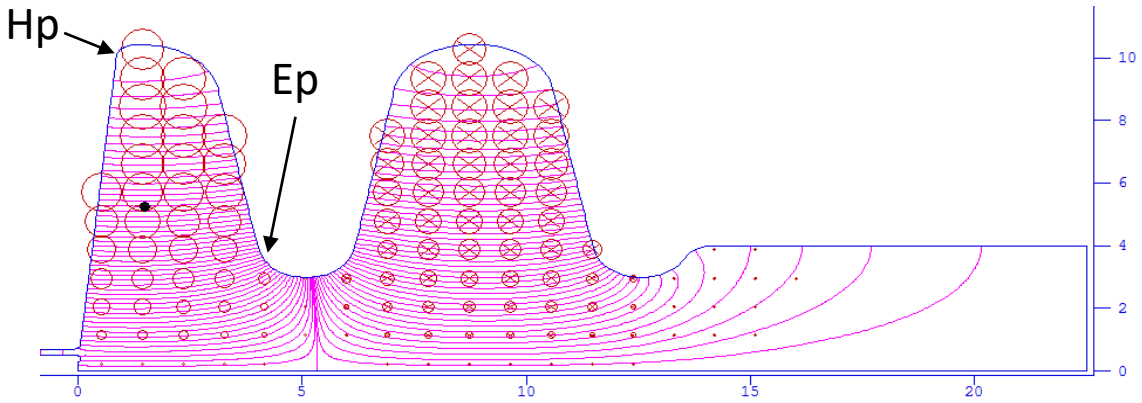
Photocathode

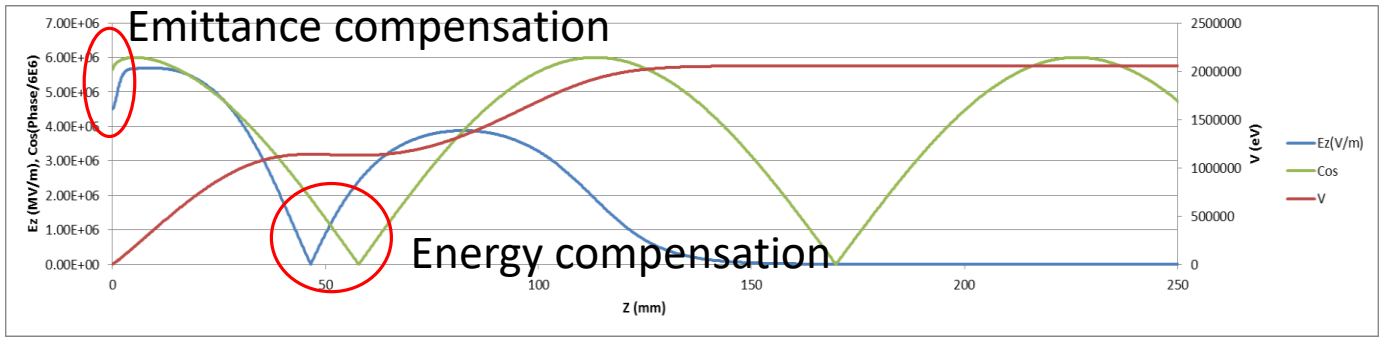


Thermal emittance: $\varepsilon_n = \frac{R}{2}\sqrt{\frac{2(\hbar\omega - E_0 + \phi_{sch})}{3mc^2} + \frac{2k_BT}{mc^2}}$

Gun cavity design

- ERLがターゲット　2 MeV x 100mA =200kW が目標.
- 表面磁場はILCパラメータの半分



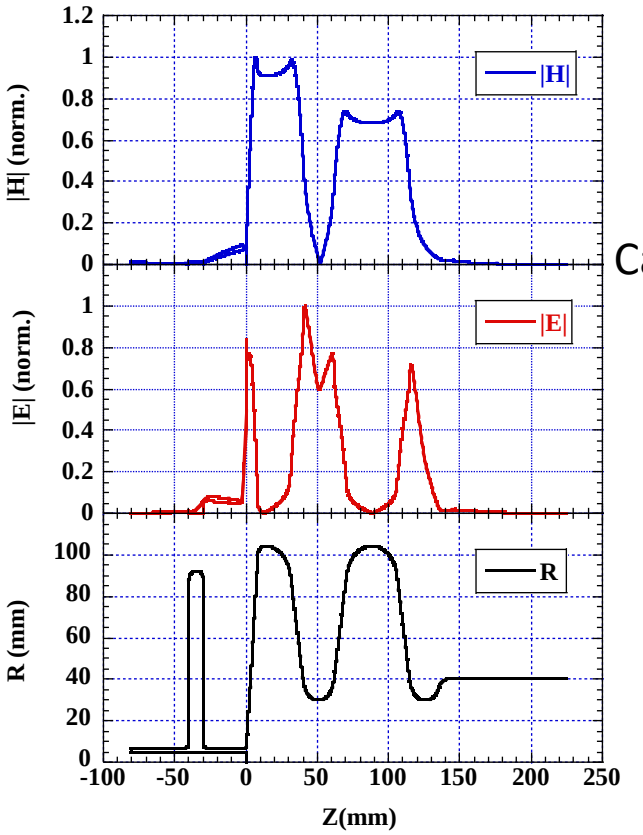


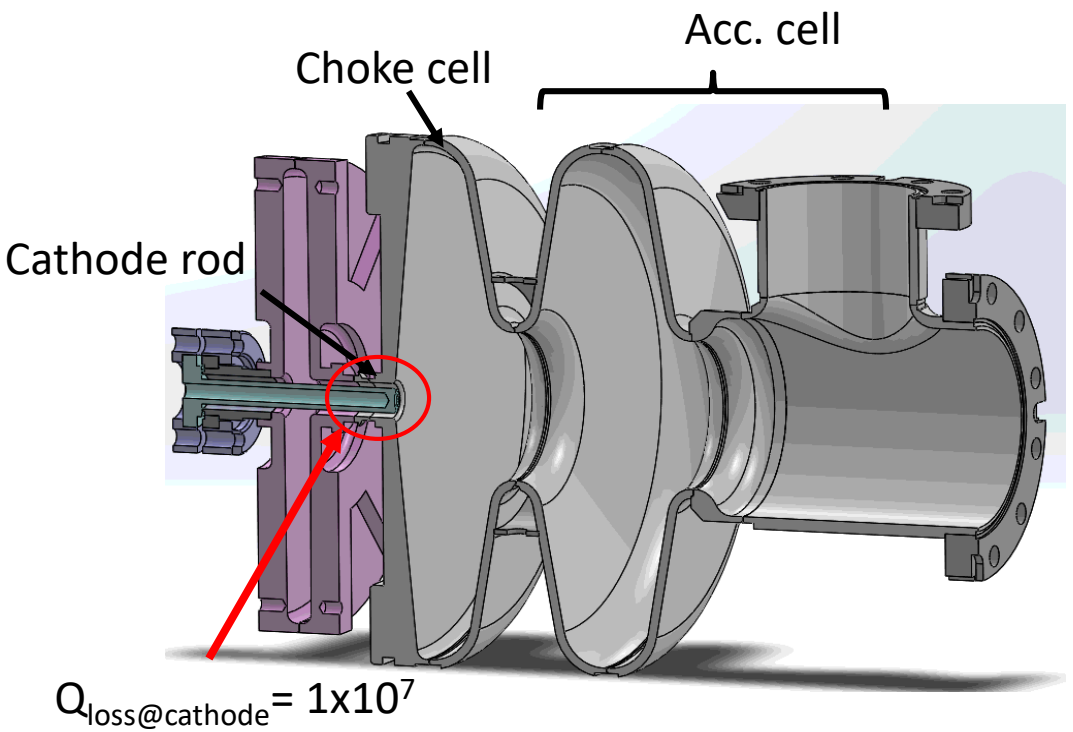
Designed by MHI

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

KEK SRF gun #1

- 高電界特性テストのためにKEK SRFGUN#1を設計。



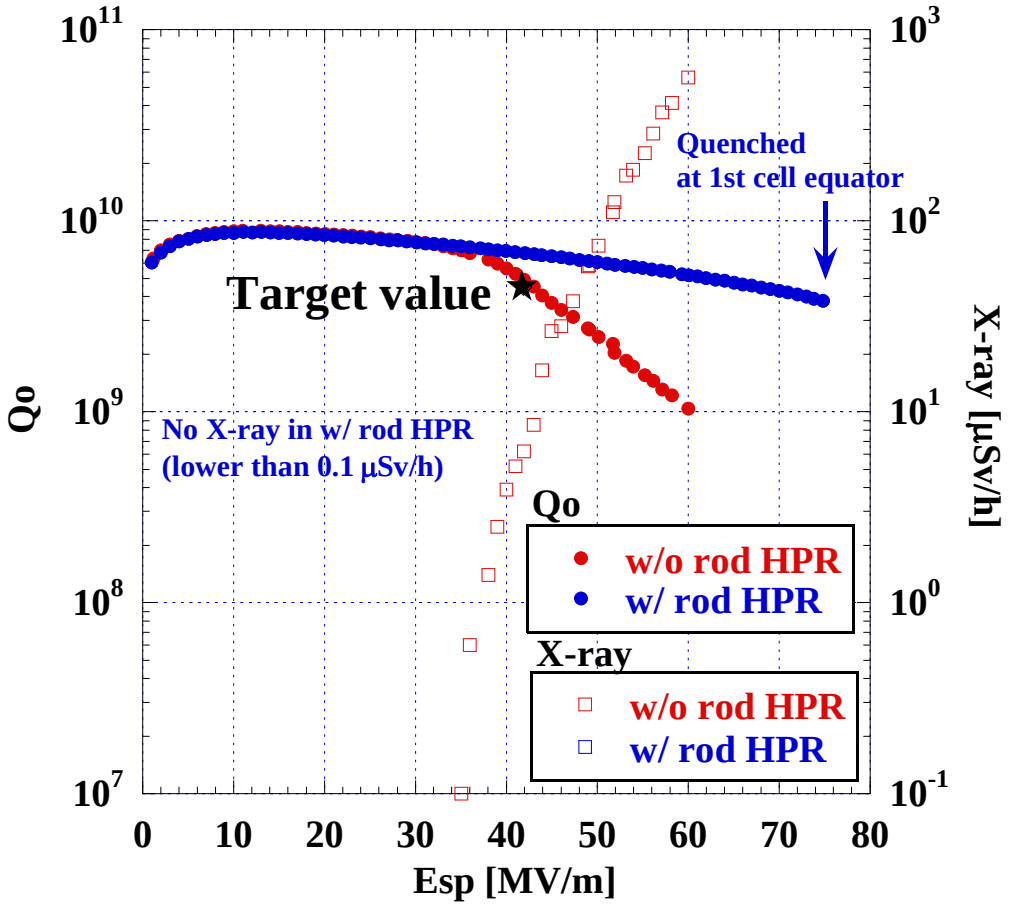


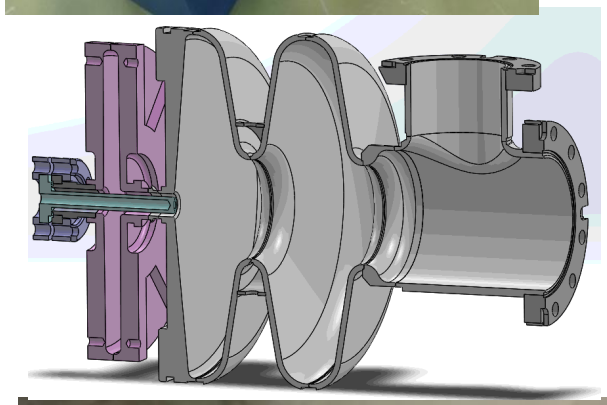
$Q_{loss@cathode} = 1x10^7$

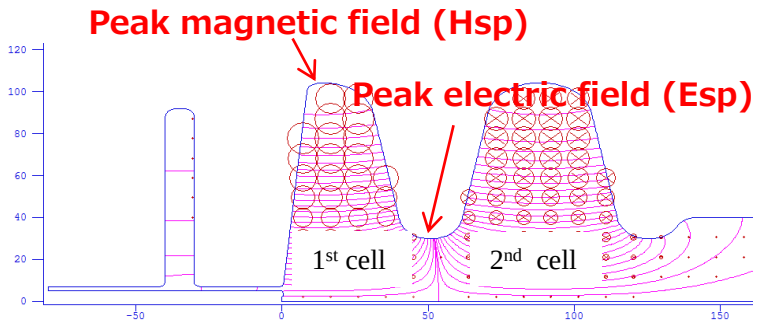
Parameter	Value
Beam energy	2 MeV
Beam current	100mA
Bunch charge	80 pC
Laser length (uniform)	10ps
Projected emittance	0.6 mm.mrad
Projected energy spread	0.09% (1.84 keV)
Peak electric field	41.9 MV/m
Peak magnetic field	95.2 mT
RF phase	55°
Geometrical Factor	135.6 Ω (TESLA 270 Ω)
Target surface resistance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

Performance of prototype #1 cavity

- 電子銃構造に適した、電解研磨電極、高圧水洗ノズルを用いることで、FEを抑制できる。

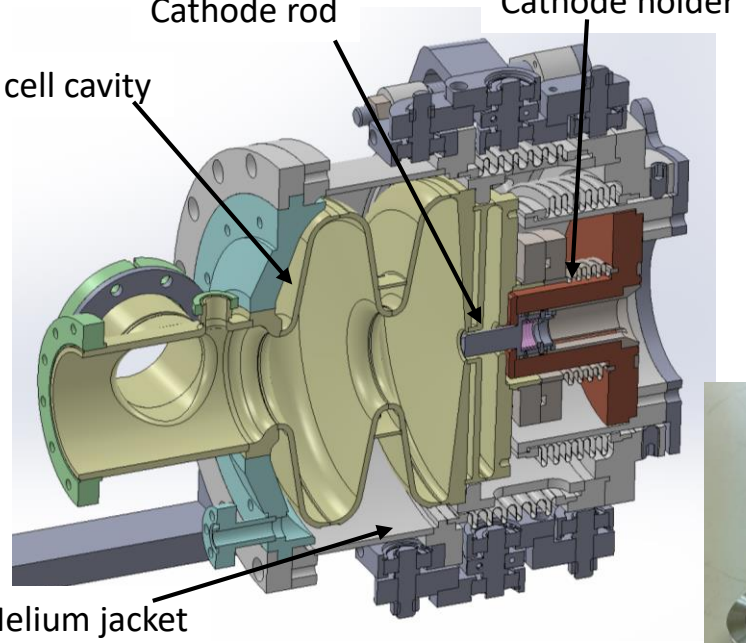


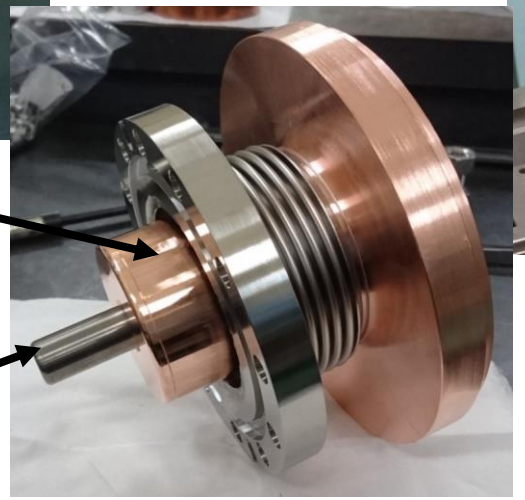




Fabrication of Gun cavity #2

- #2 のRF構造は#1と同じ。ただし、カソードロッドを脱着可能な構造に変更。
- ヘリウムジャケットを持ち、微少電流引き出しが可能。





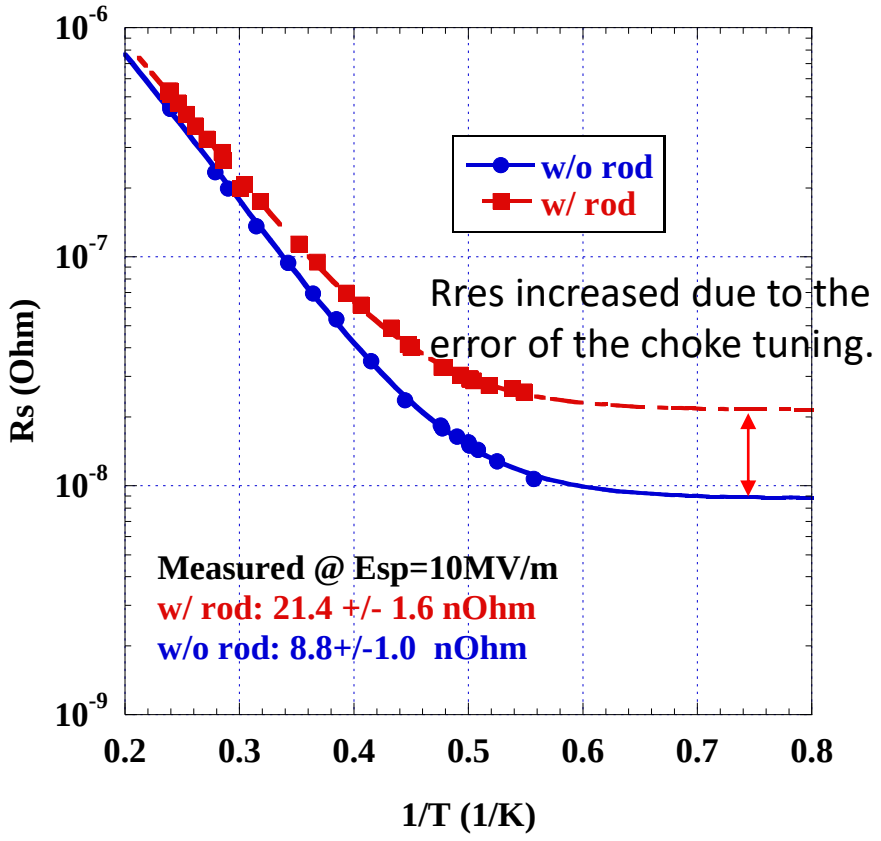
Cathode holder

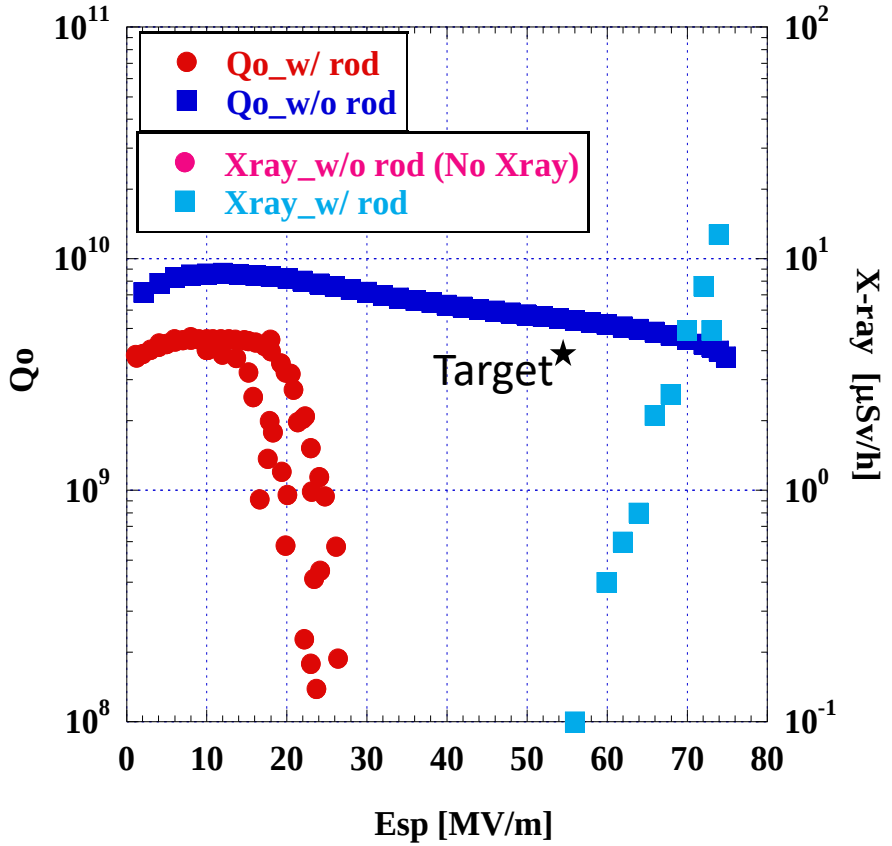
Cathode rod

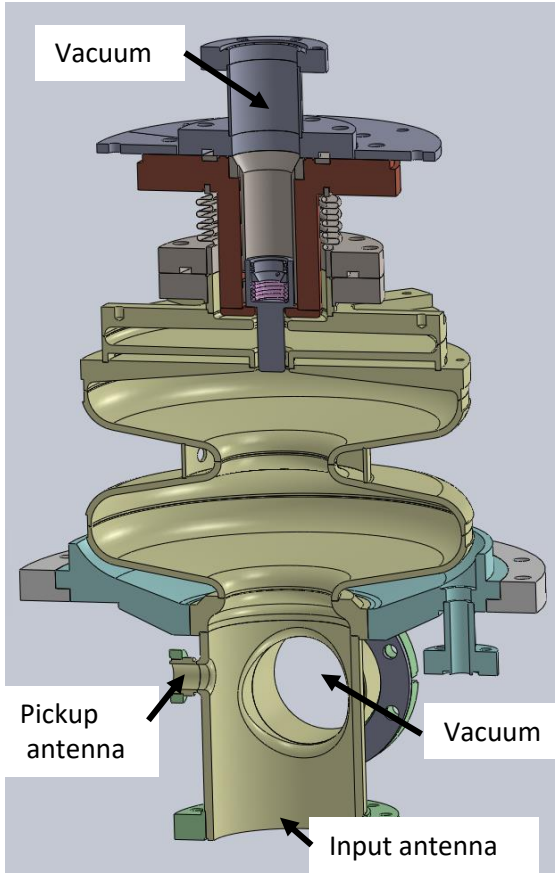
Helium jacket

Vertical test with cathode rod (4th VT)

- カソードロッドを入れなければ＃１と同じEsp=75MV/mまで到達。
- しかし、カソードロッドを入れるとEsp~26MV/mで制限される。

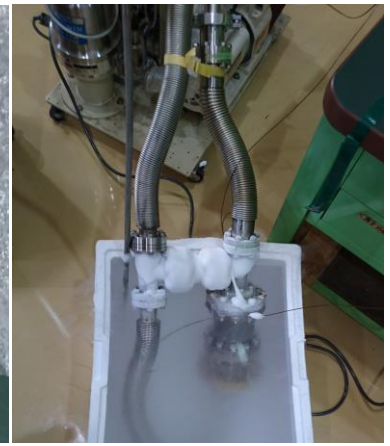


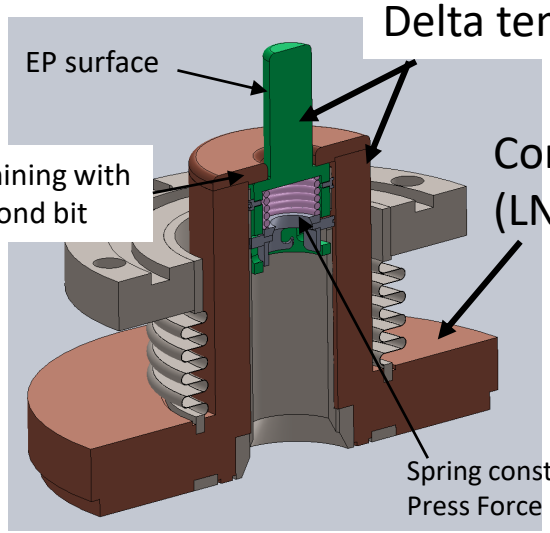


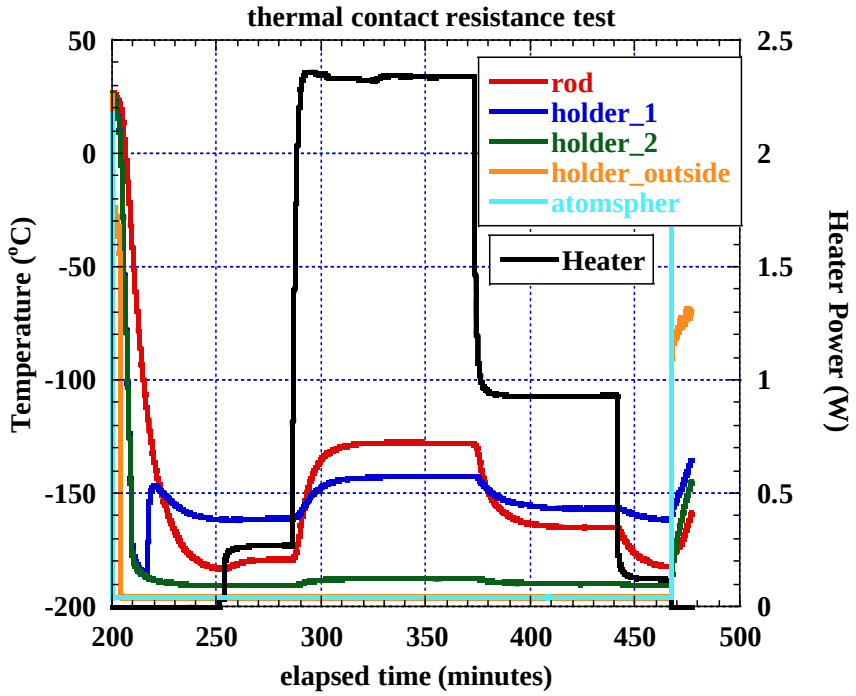


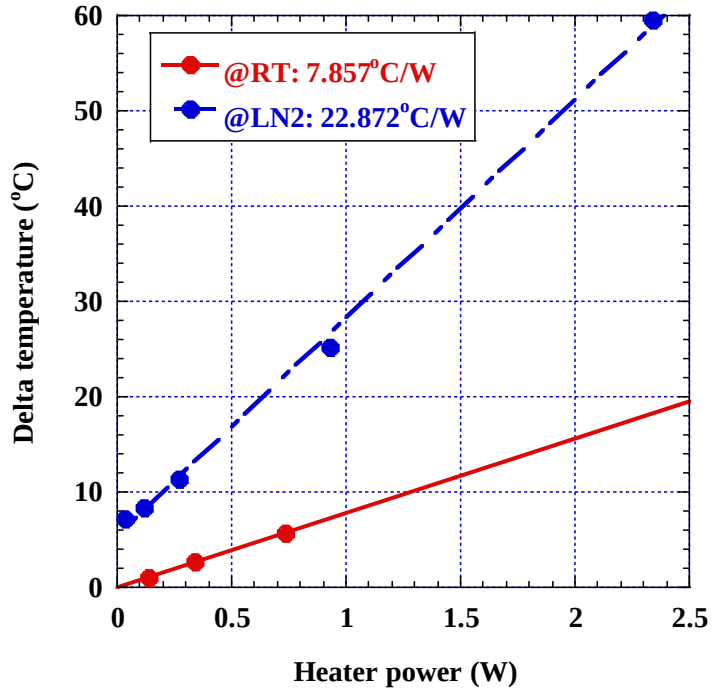
Thermal contact resistance measurement

- カソードホルダーとロッドの接触熱抵抗を測定。





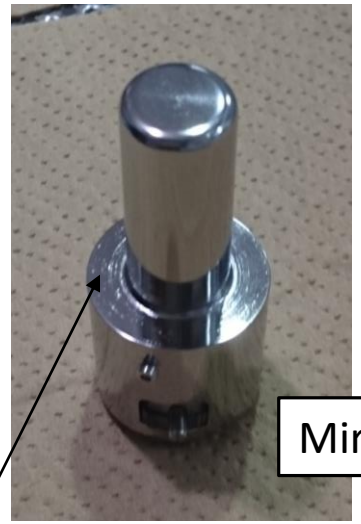




Thermal contact resistance measurement

カソードロッドとホルダーの接触面を鏡面する。

Before mirror polishing

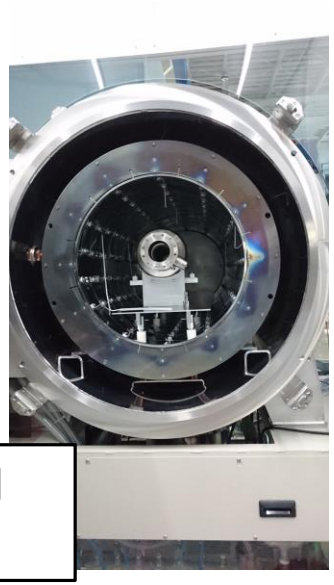


Ra~0.45nm
Rz~3nm

Mirror polishing

After mirror polishing

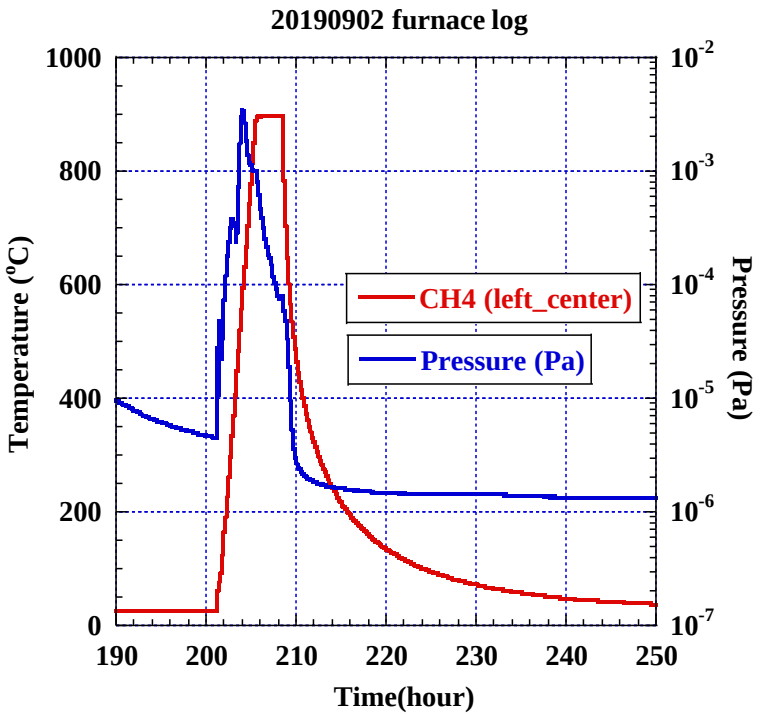
900℃x3h Anneal
(w/ 9cell cavity)



The turning track remained on the contact surface.

Before Mirror polishing

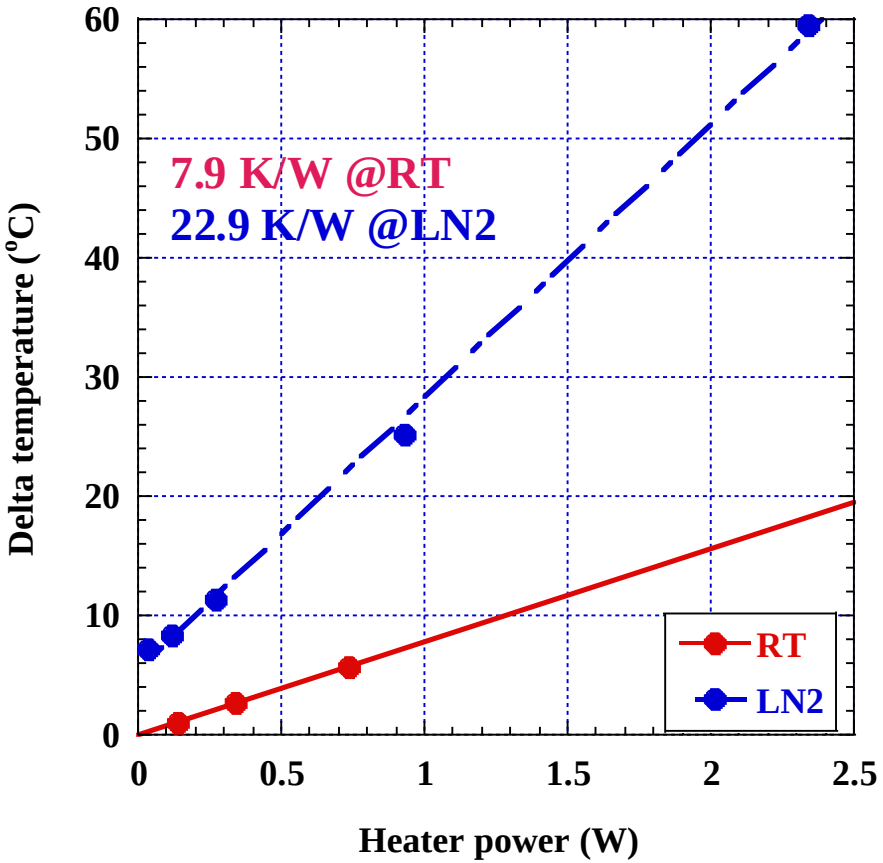
After Mirror polishing



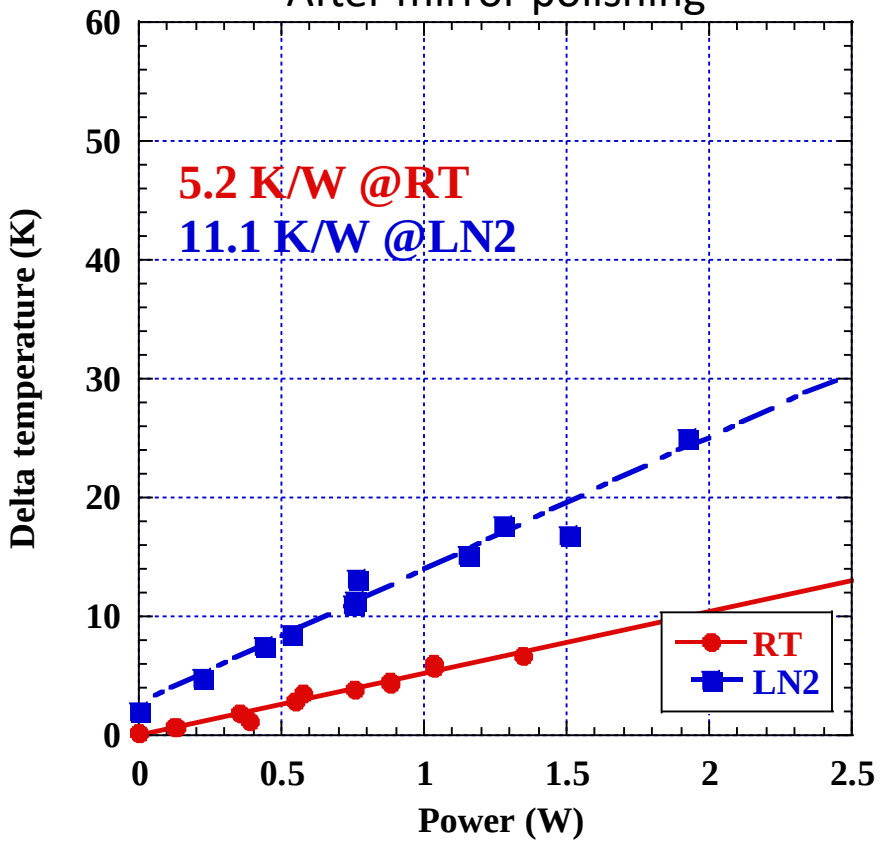
Thermal contact resistance measurement

- 鏡面研磨により接触熱抵抗はおよそ半分になった。
- 電界はEsp=40MV/m　程度まで向上できる見込み。

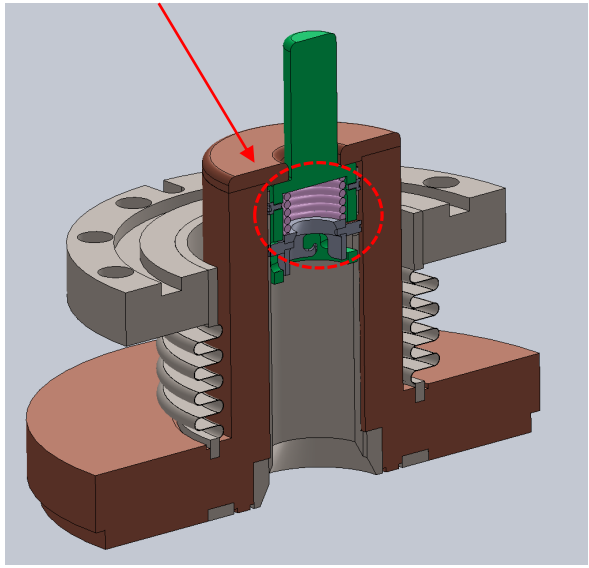
Before mirror polishing



After mirror polishing

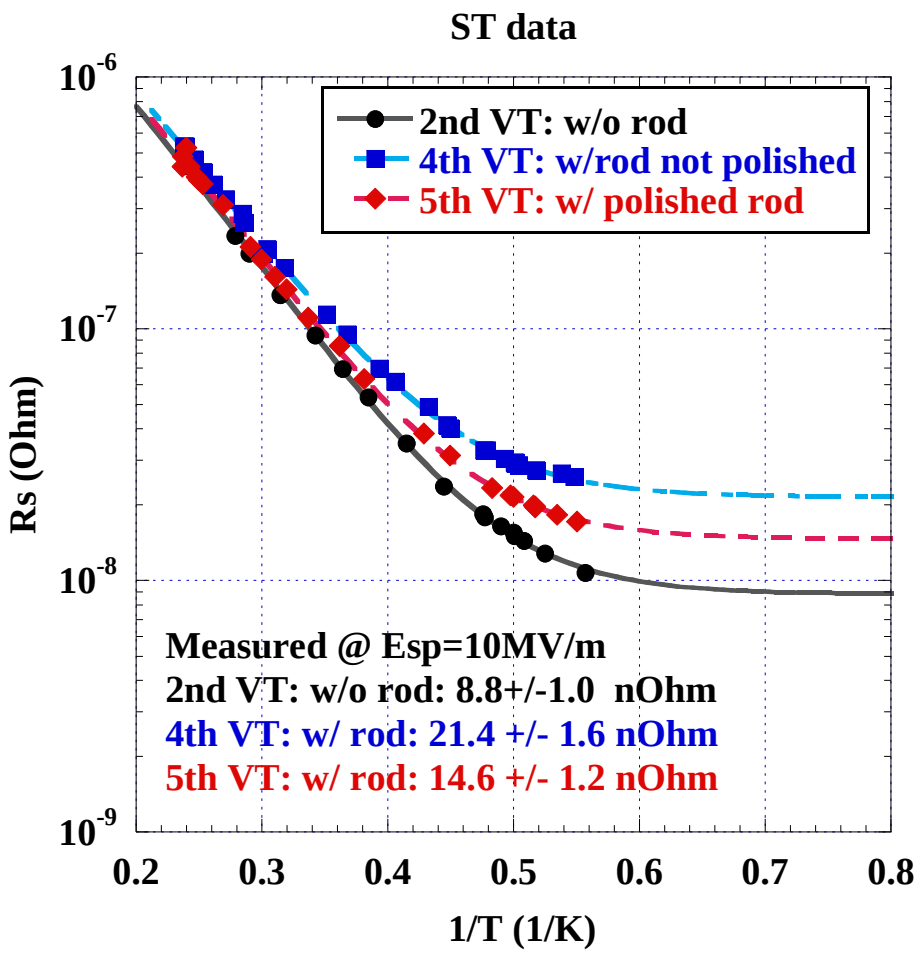


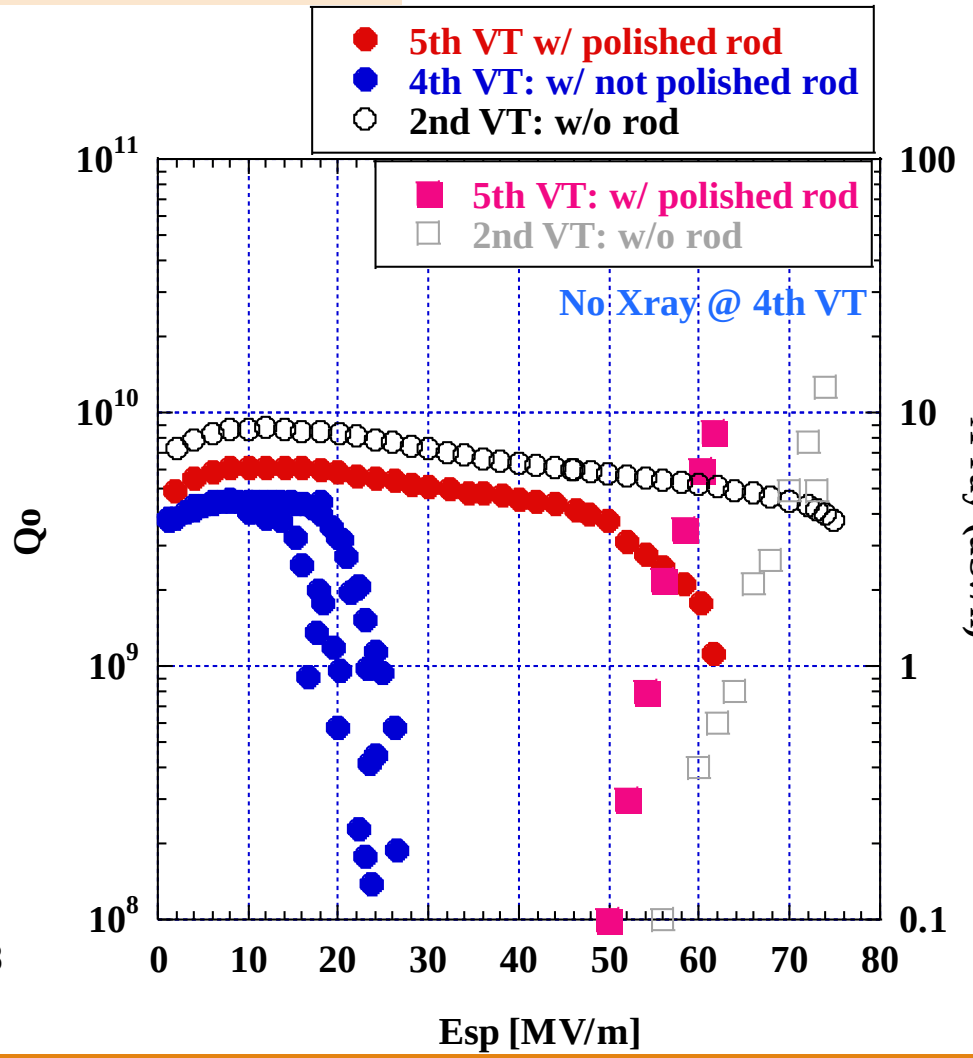
Spring to generate pressing force

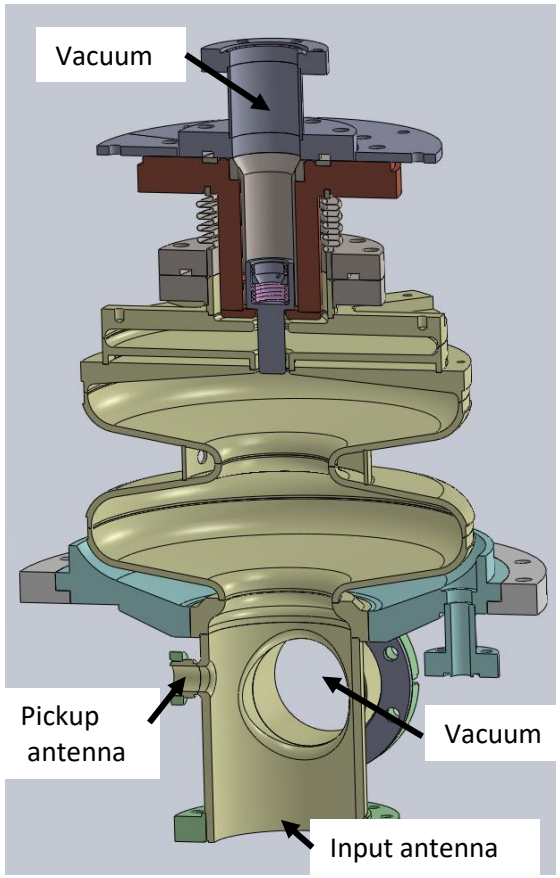


Vertical test with mirror polished cathode rod

- 鏡面研磨により電界は予想を上回る62MV/mまで到達
- カソード位置のずれも大きいか？

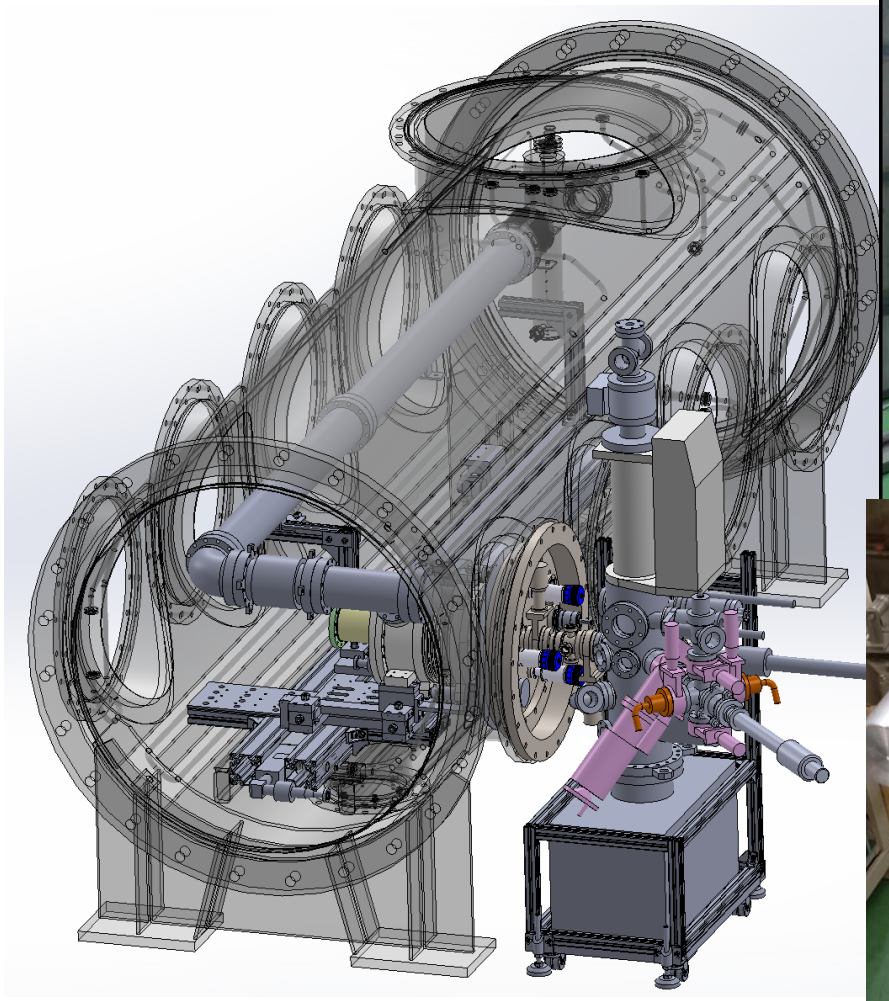


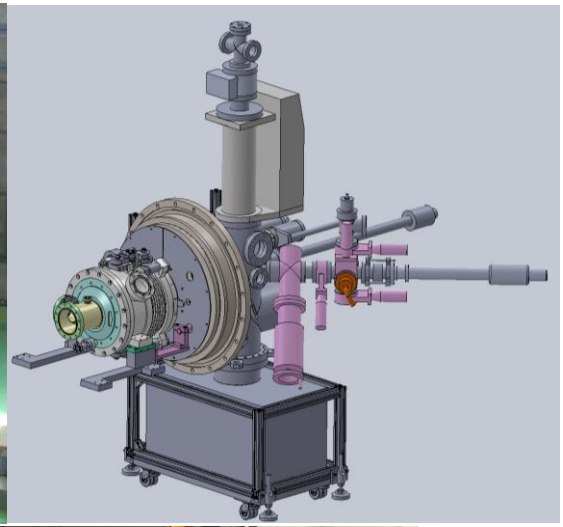


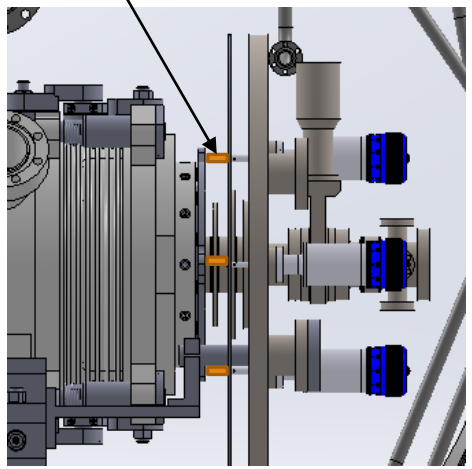


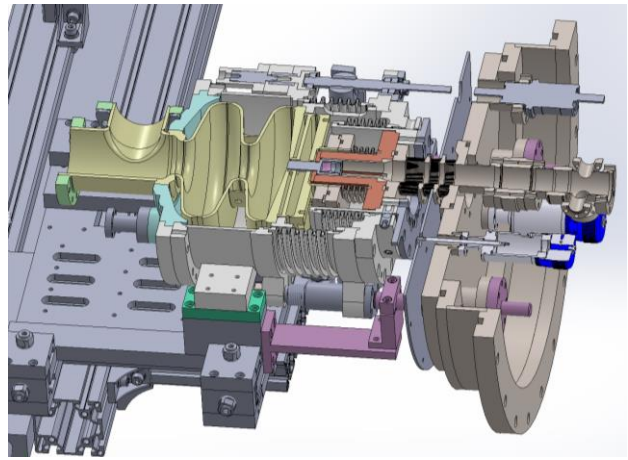
Plan for horizontal test

- 今後は横型クライオスタットでの高電界試験・ビーム試験に向けて準備を進めている。









まとめ

- KEK SRF Gun cavity #1 は Esp=75 MV/m に到達.
- KEK SRF Gun cavity #2 の空洞本体も Esp=75 MV/mに到達.
  - 鏡面研磨カソードロッドを入れると62MV/mに到達。
  - 目標の42MV/mを満足している。
- KEK SRF GUN cavity #2を横型クライオに入れて高電界・ビーム試験を行う準備を進めている。

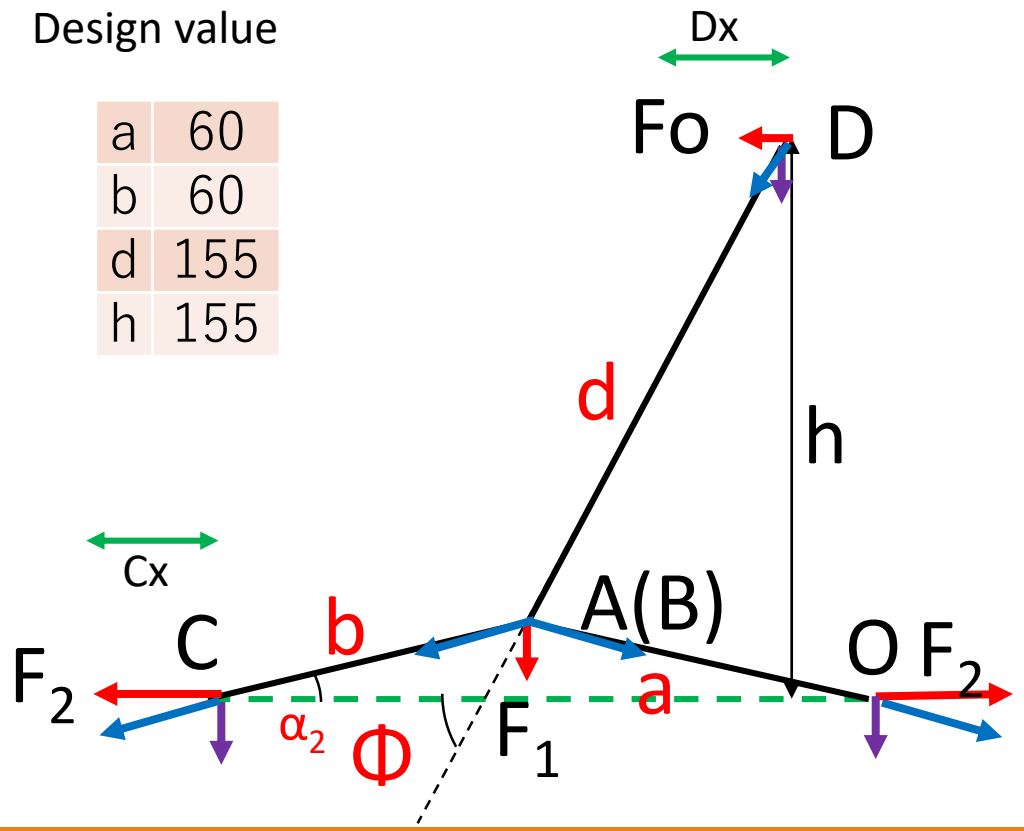
ご清聴ありがとうございます。

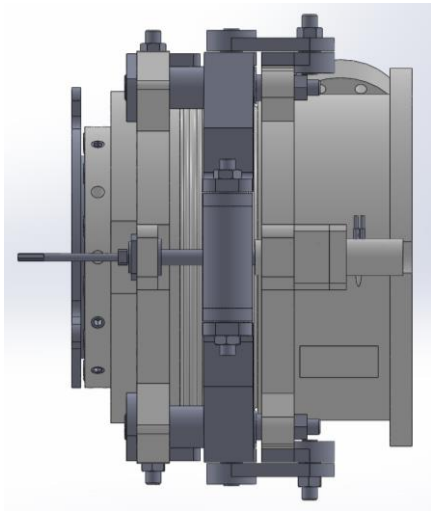
Mechanical tuner test

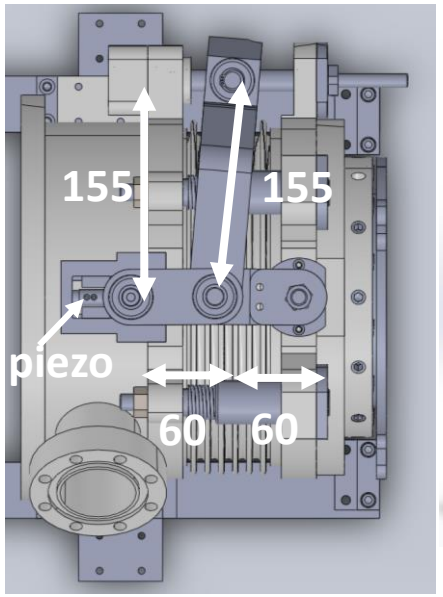
- Tuner type is toggle mechanism (Blade type tuner?).
- All arm length is fixed. C and D can be move parallel to horizontal.

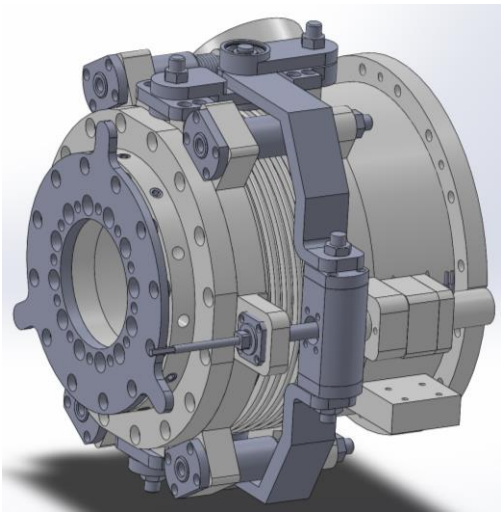
Design value

a	60
b	60
d	155
h	155









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

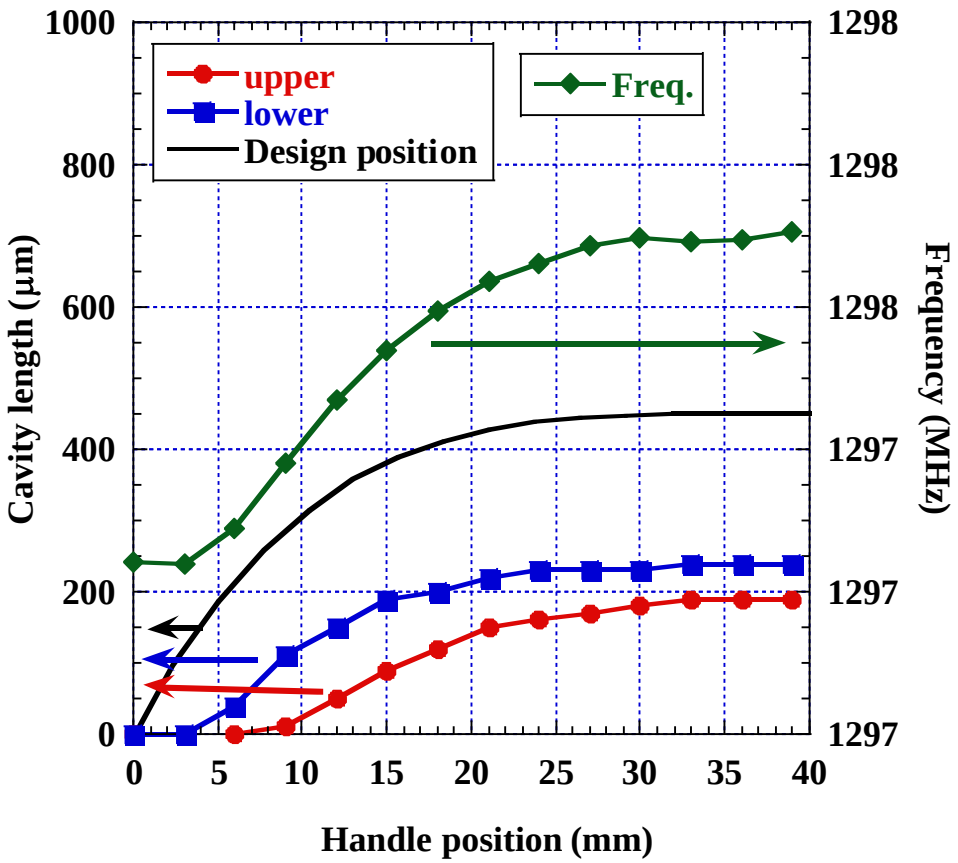
$$\sin\alpha_2 = \frac{-a\sin\alpha_1}{b} = \frac{-d\sin\phi + h}{b}$$

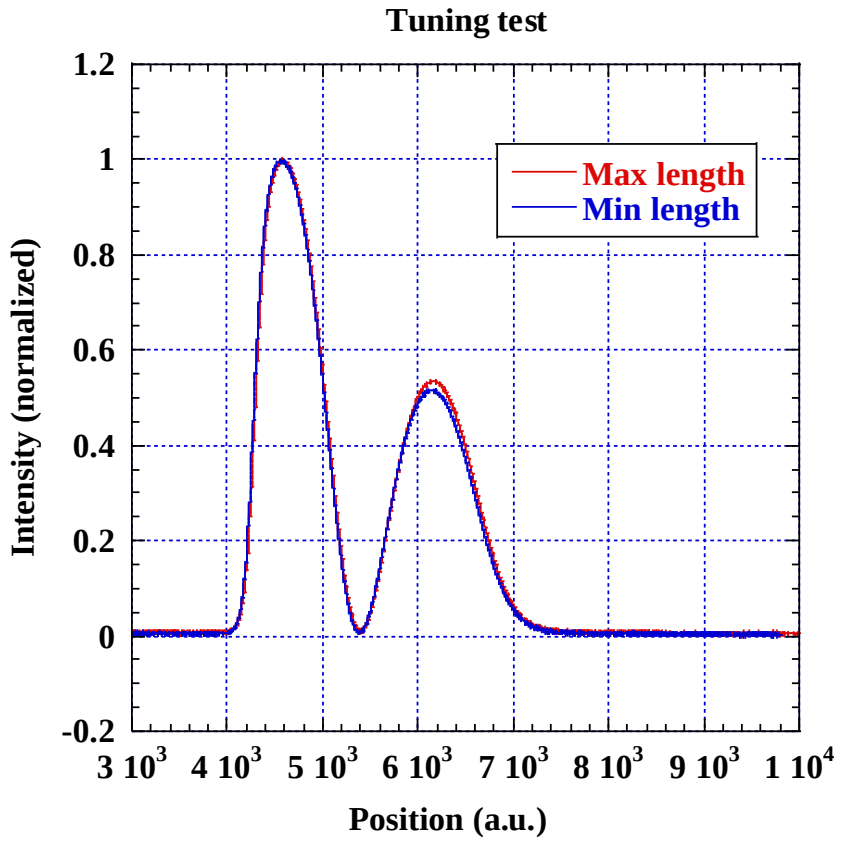
$$D_x = a\cos\alpha_1 - d\cos\phi = \sqrt{a^2 - (d\sin\phi - h)^2} - dcos\phi$$

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

Mechanical tuner test

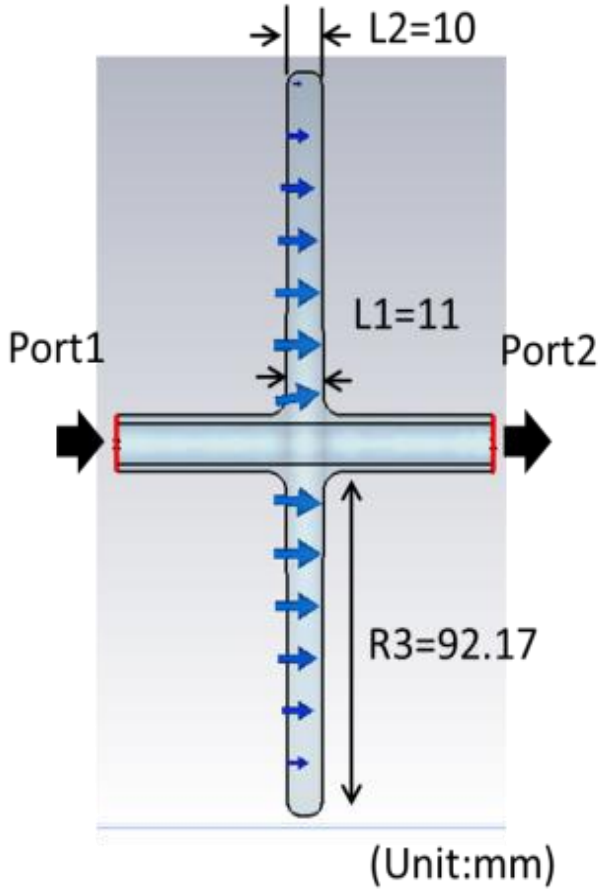
- Stroke of the tuner is about half of the design.
  - We suspect the holder post move to unexpected direction.
  - We will make more tuning to the tuner.

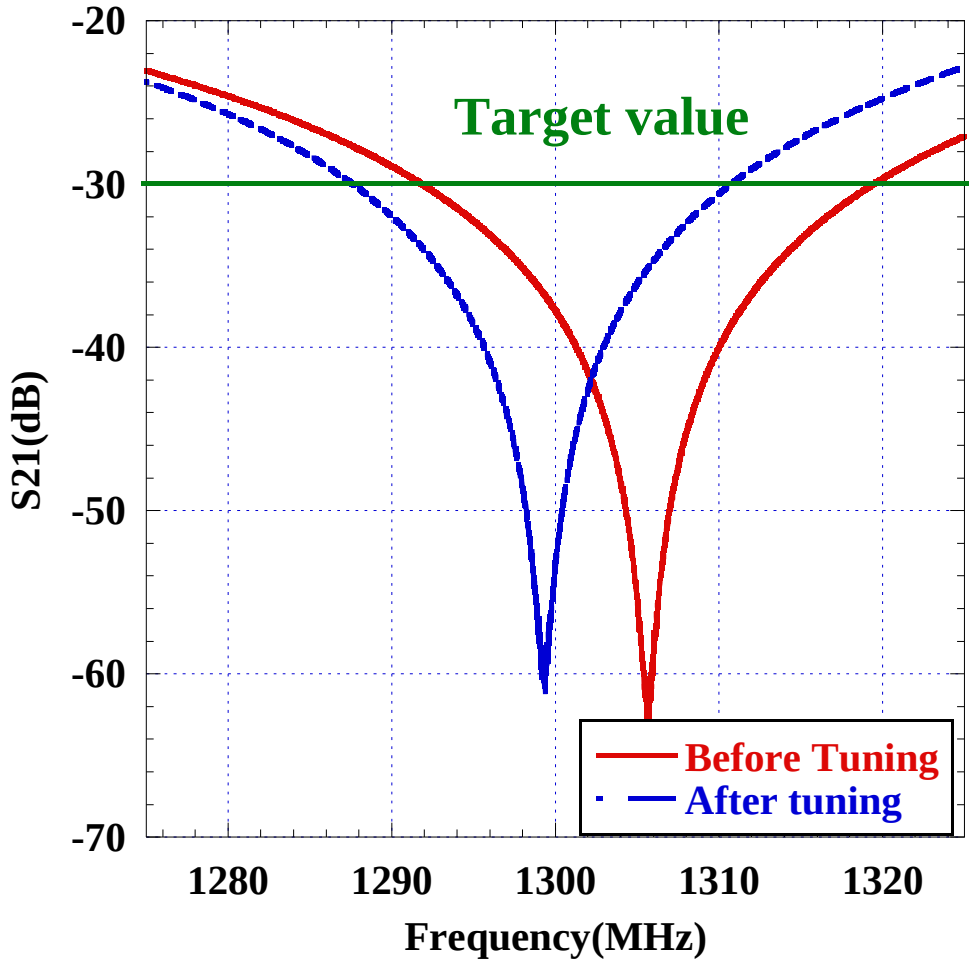




Choke design

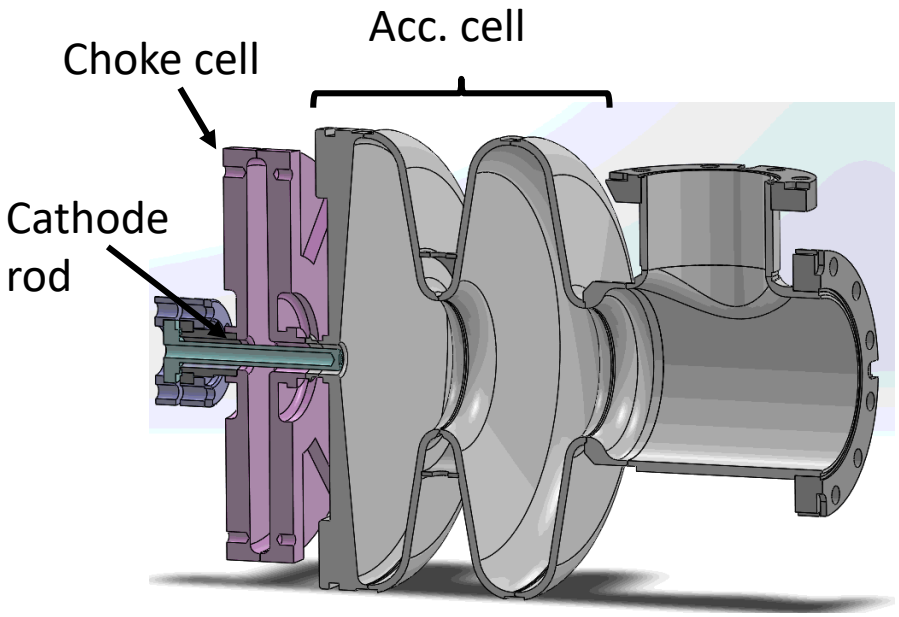
- The choke is a simple parallel shape. The parallel two face has slight taper for cleaning easily.
- Choke was machined from large grain ingot Nb, and has high stiffness.
- The tuning range is wide enough to accept the target attenuation (-30dB)



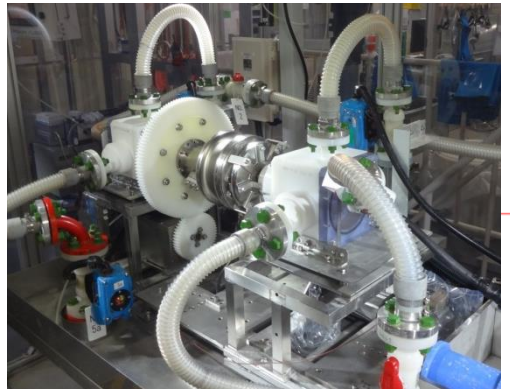


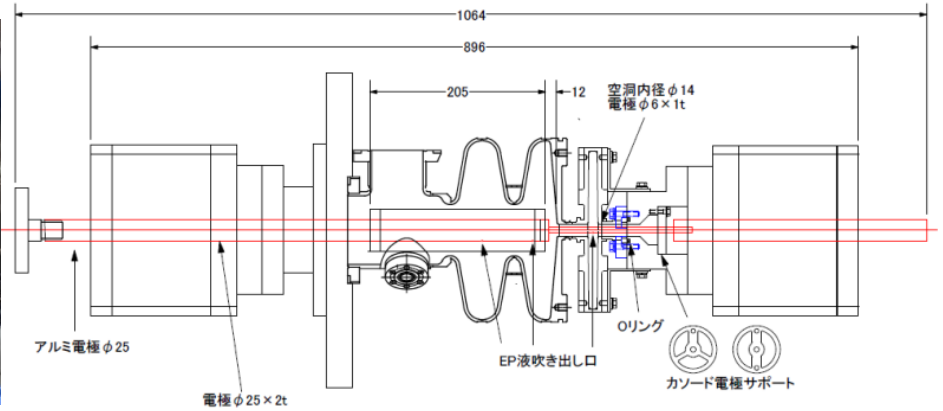
Prototype gun cavity #1

- 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.

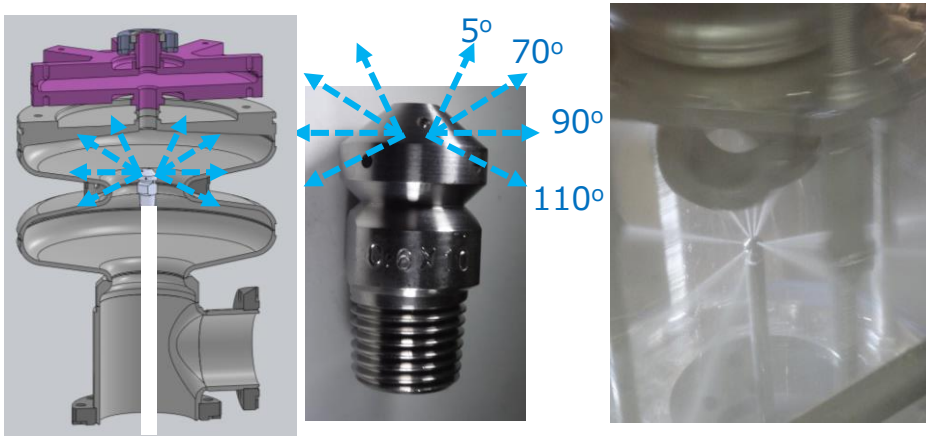


EP





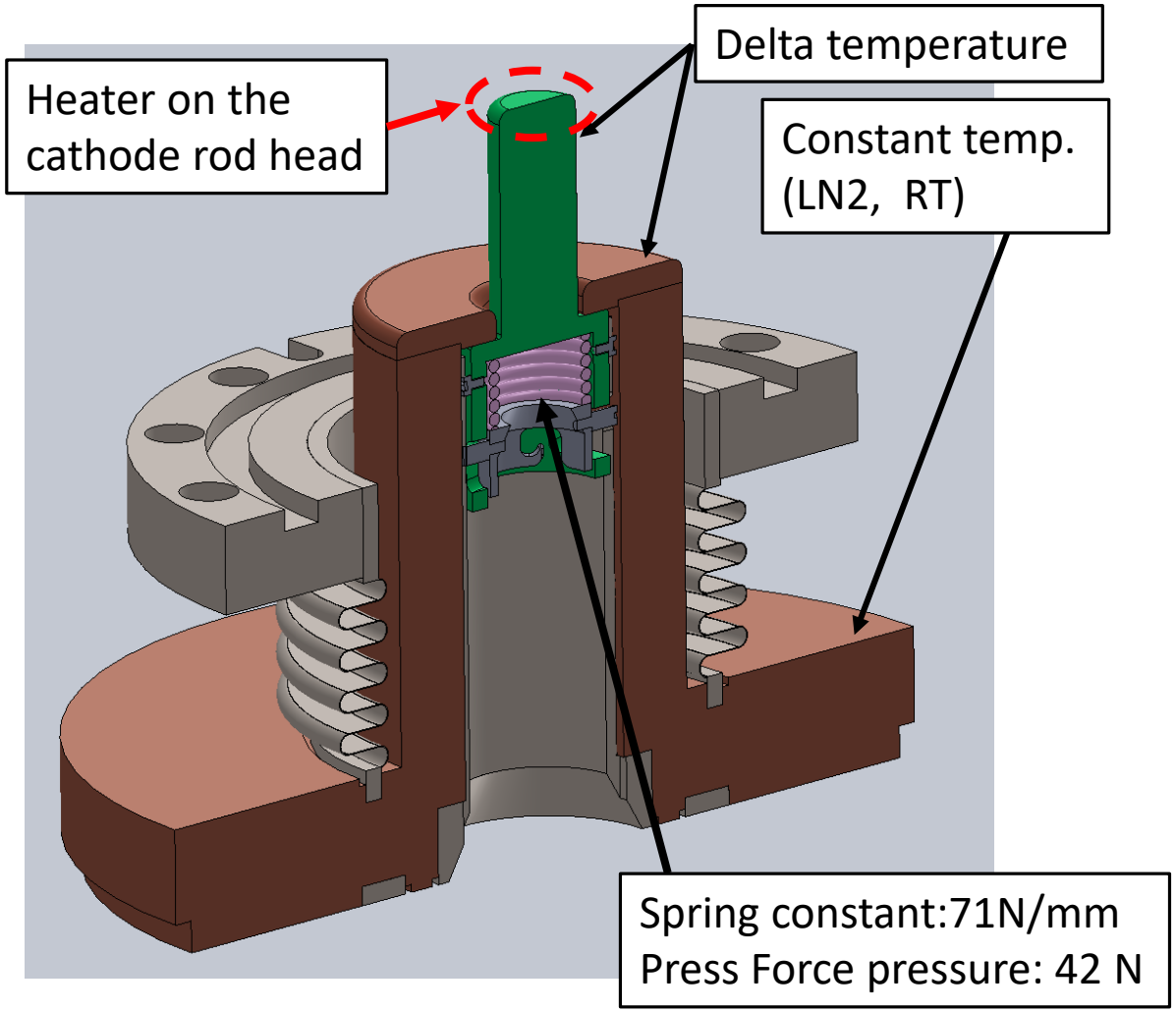
HPR nozzle for Acc. cell



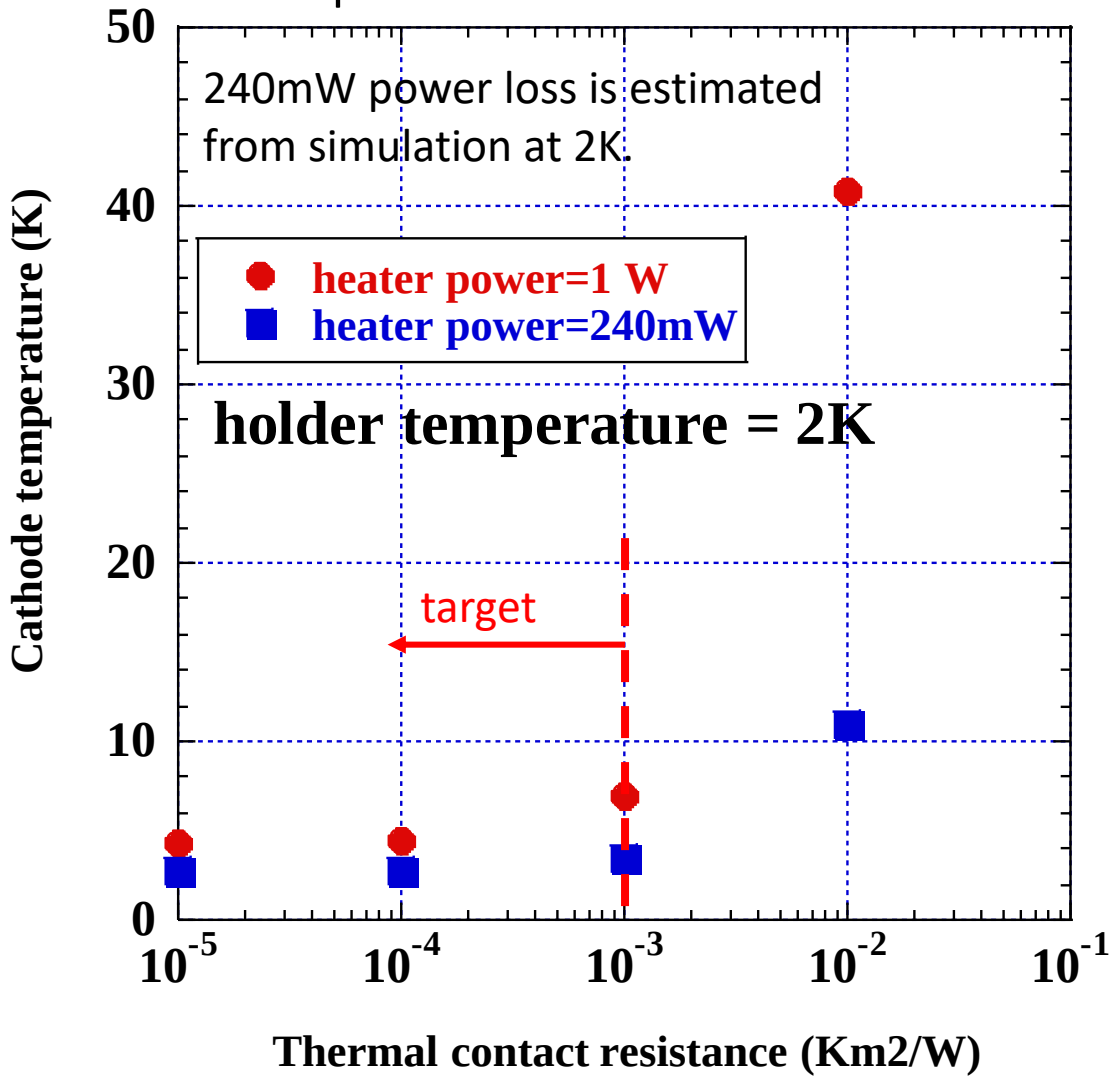
HPR nozzle for choke cell

Thermal contact resistance measurement

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



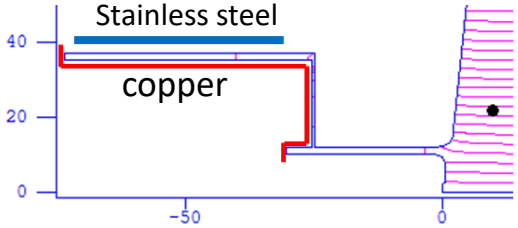
Simulation: dependence of thermal contact resistance

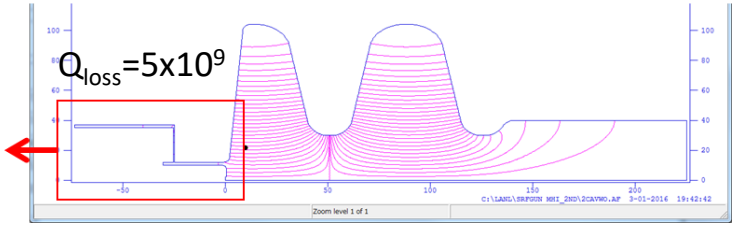


Preparation for vertical test

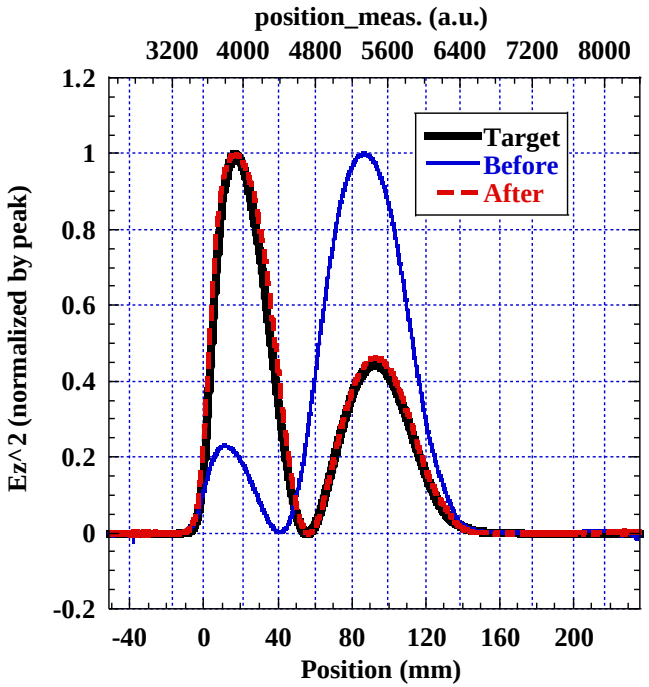
- The surface treatment was followed with the experience of the gun cavity # 1.
  - EBW in KEK
  - EP 100 um
  - Anneal 800Cx3h
  - Field tuning
  - Final EP 20um
  - USR, HPR
  - Assembly

- Loss Q at cathode rod and holder is $5x10^9$ if there is no choke filter.
- Target attenuation of choke filter is 30dB for 1% loss.
- The choke attenuation was adjusted to be minimum.





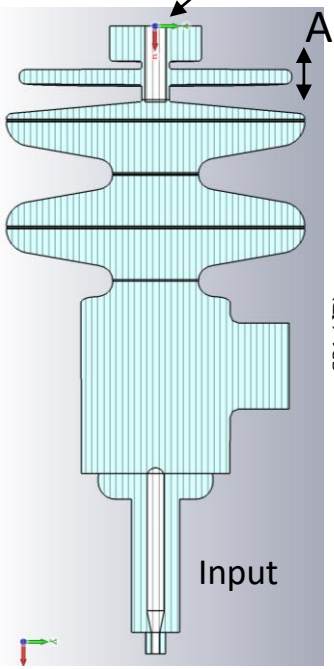
Acc. cell tuning

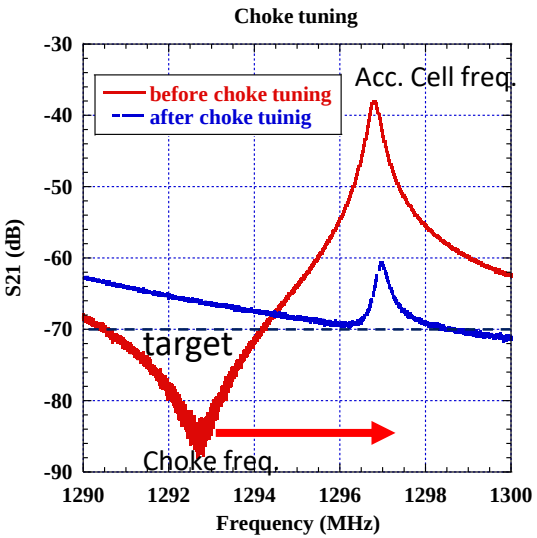


Choke cell tuning

Dummy rod for pick up

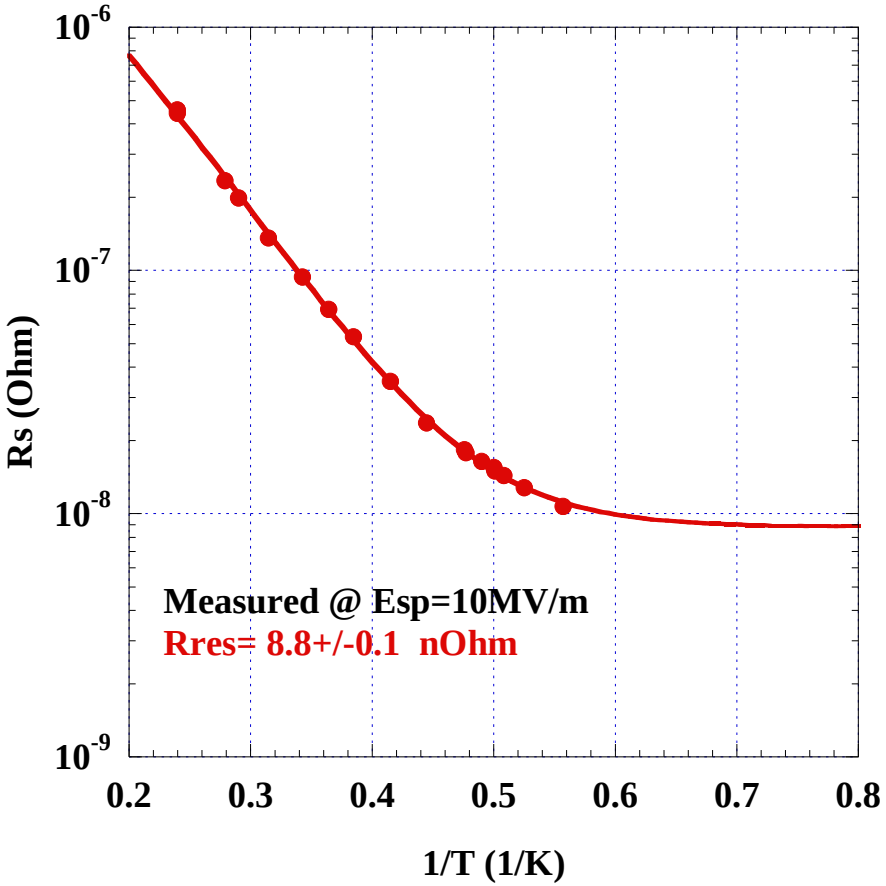
Adjust this length

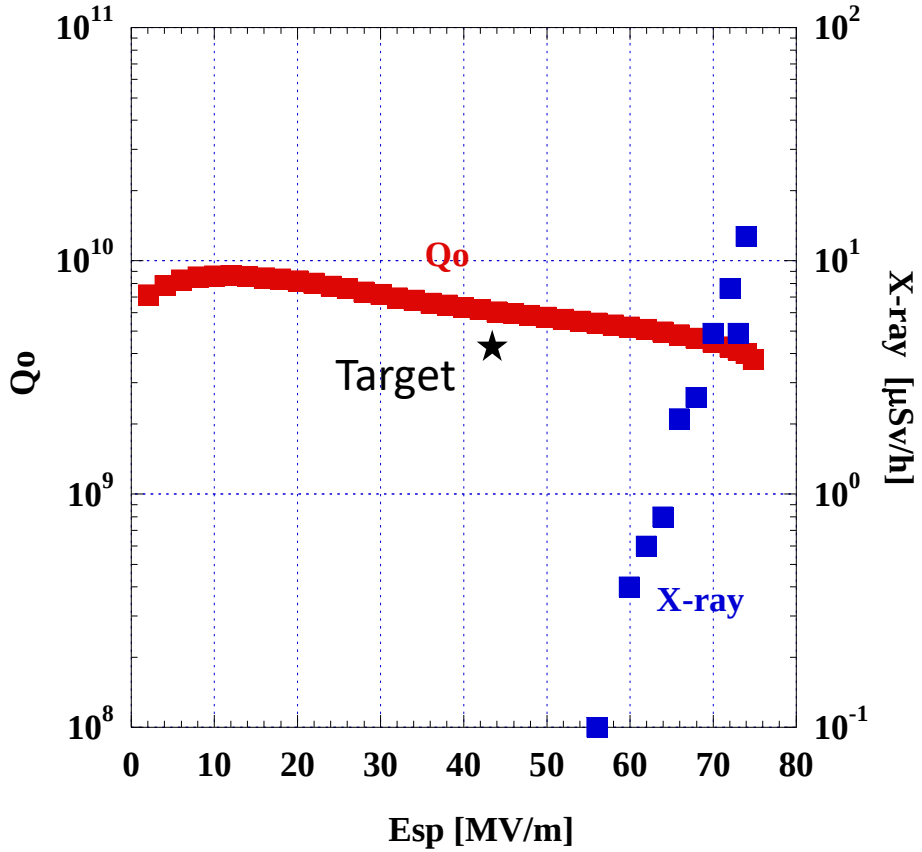


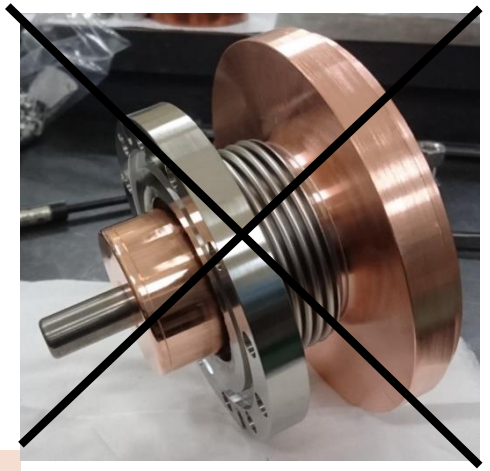


Vertical test of the 1.5 cell type SRF gun

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



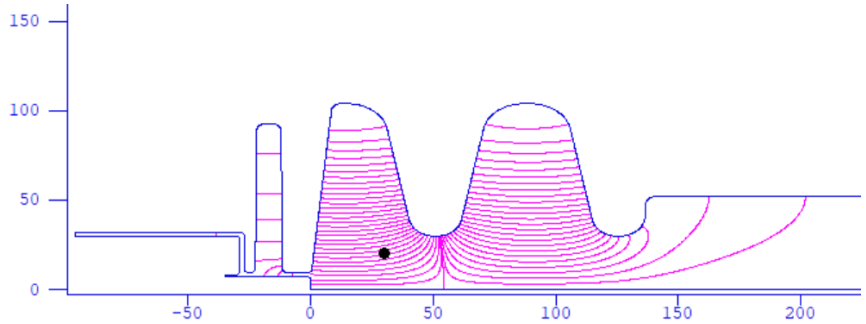


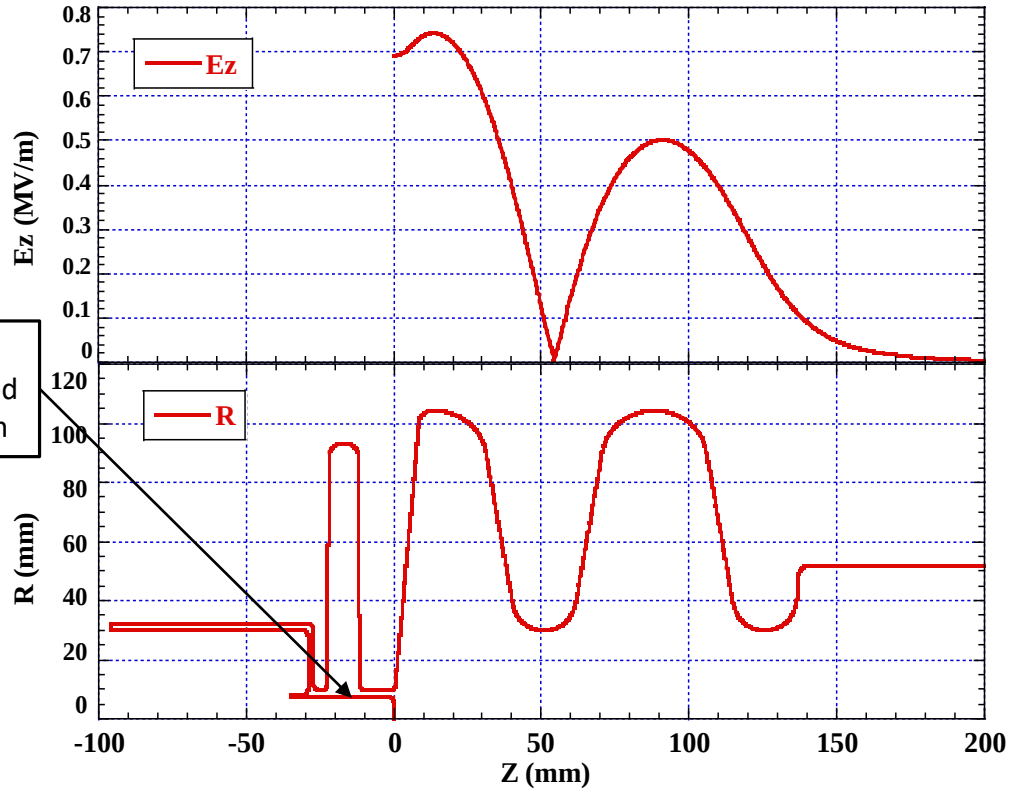


We can shift the main target to cathode rod and holder development
- Effective cooling structure to keep the cathode rod around 2K.
- Particle free cathode transport method.

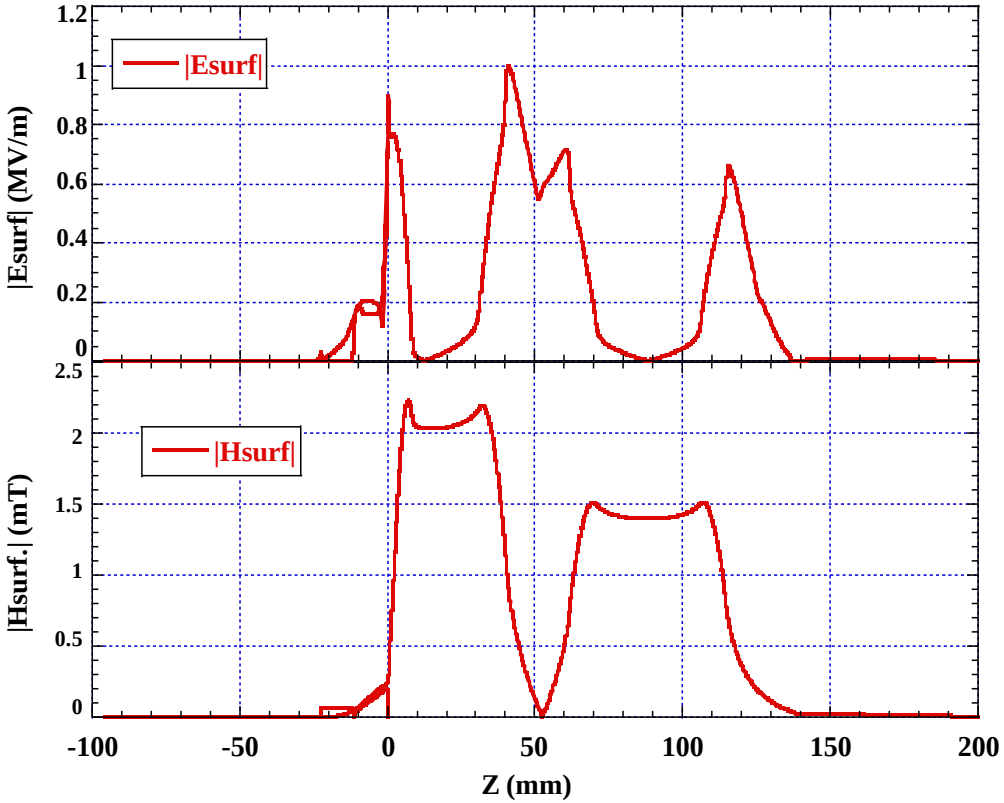
RF design of Gun cavity #2

- 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



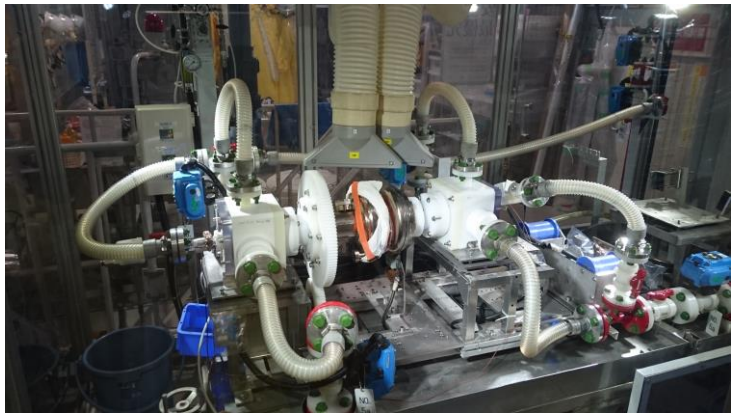


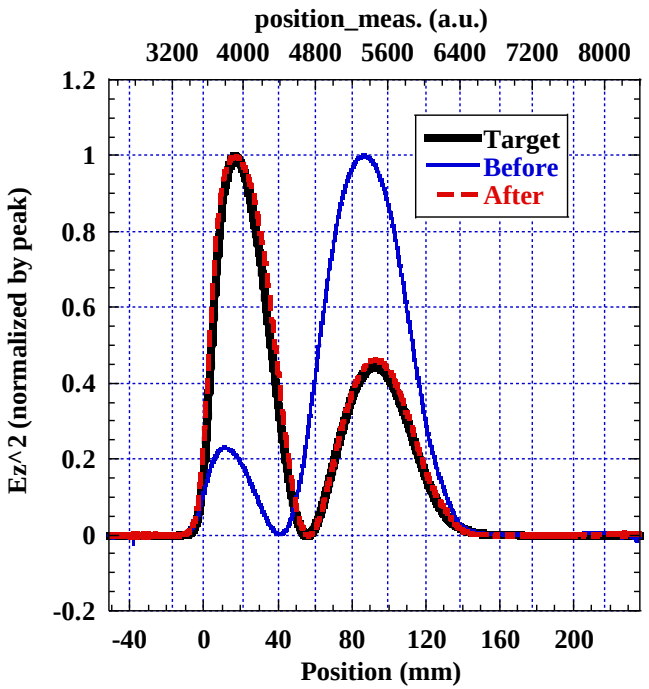
240mW
@cathode rod
Esp=42MV/m

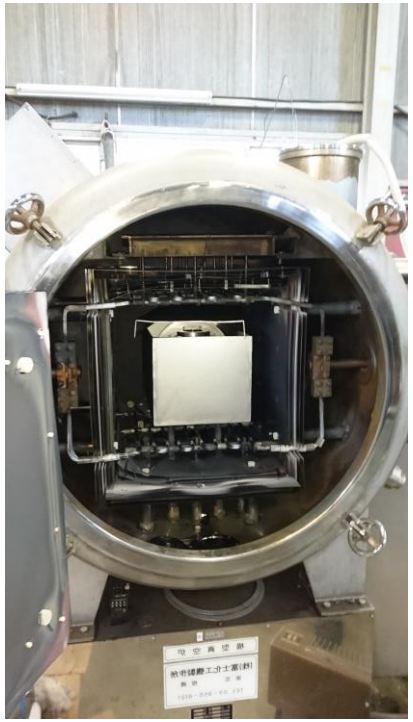


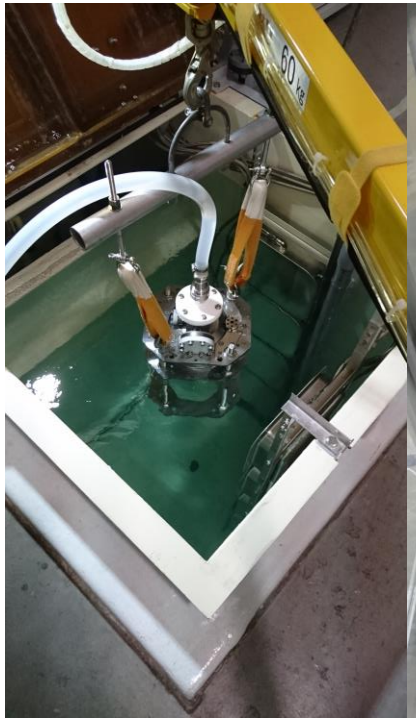
Preparation for vertical test

- EBW at KEK
- EP 100 um
- Annealed 800Cx3h
- Field tuning
- Final EP 20um
- USR, HPR
- Assembly



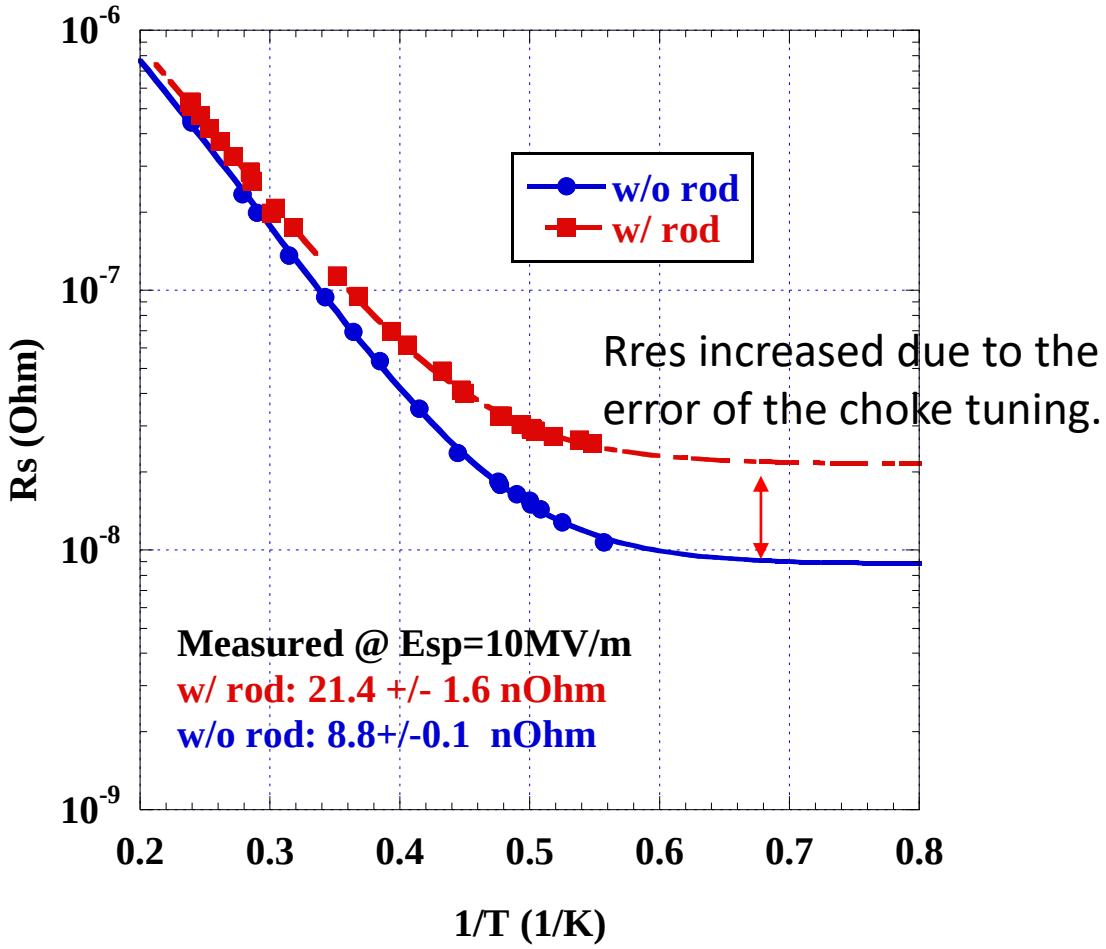


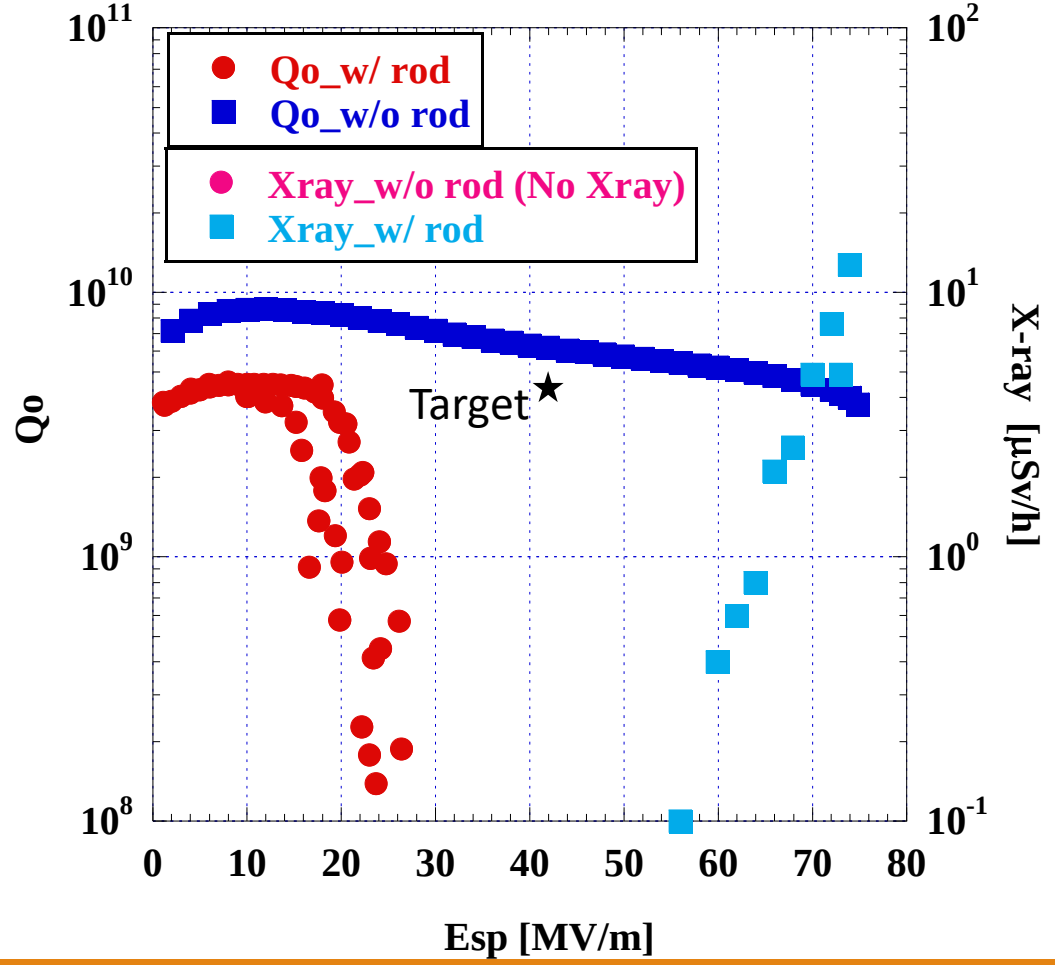




Vertical test of the 1.5 cell type SRF gun

- 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.

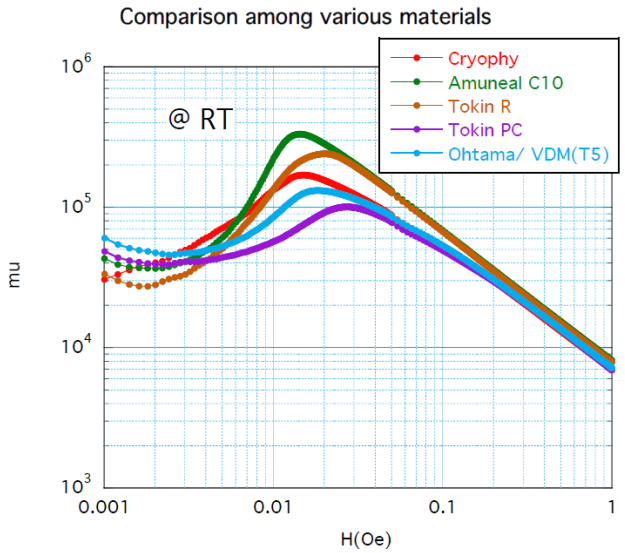


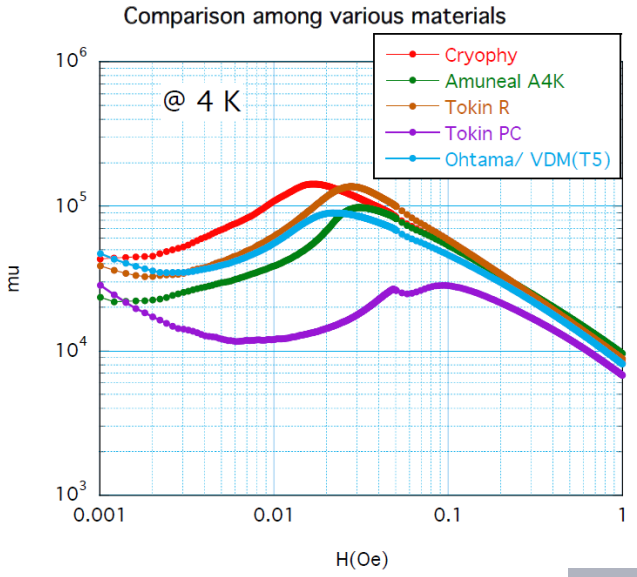


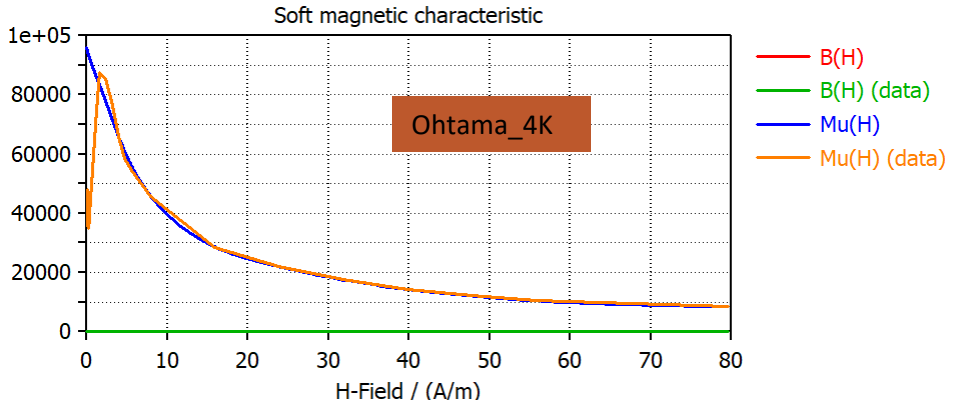
Magnetic Shield

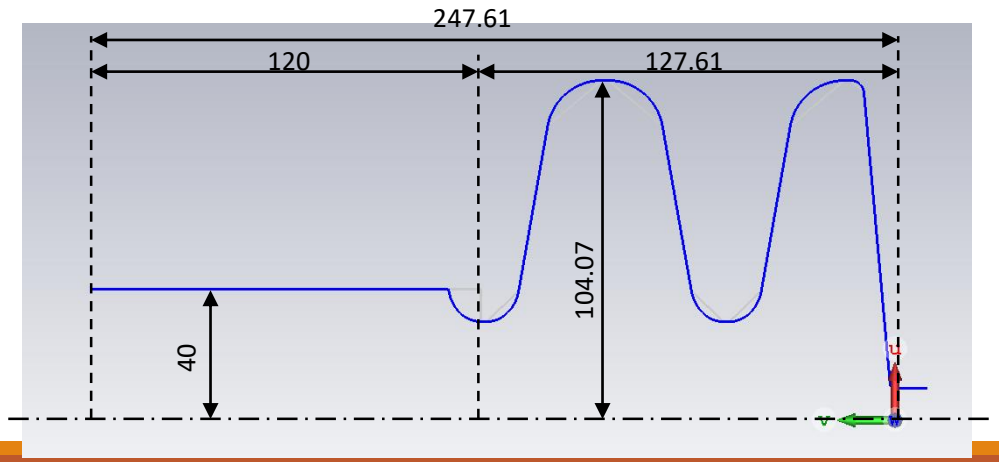
Unit	Conversion
Gauss	1
Tesla	1e-4
A/m	79.58
Oe	1

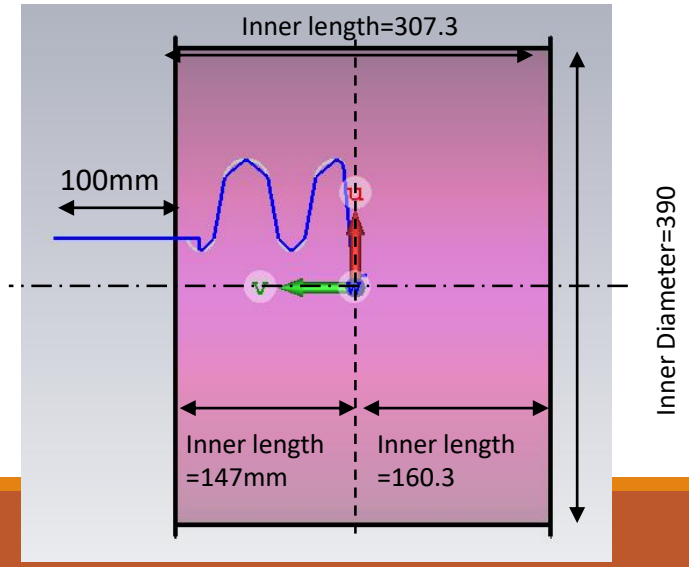
- We will use Ohtama/VDM(T5) at 4K for Magnetic shield design. This data was measured by M. Masuzawa.
- Target magnetic field is less than 10 mGauss. External magnetic field is 0.4 Gauss.
- The shape of the cavity inner wall is approximated by lines for easy calculation.
- The magnetization curve is approximated by monotonously decreasing and used to CST simulation.





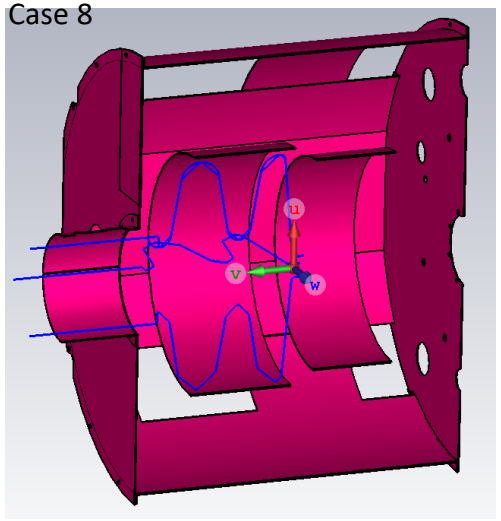


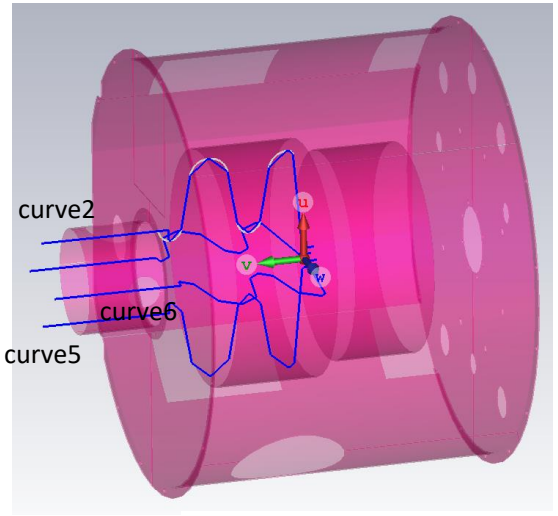


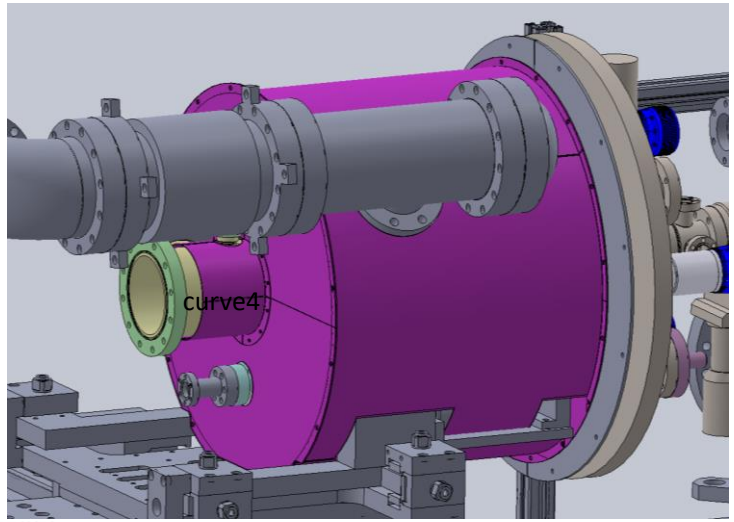


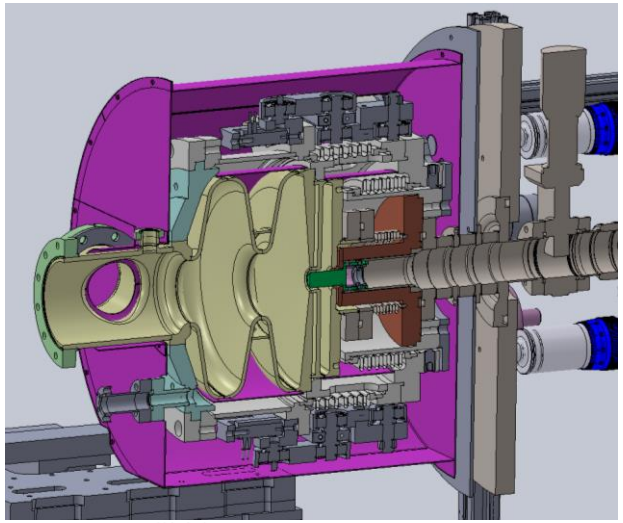
Thickness=1mm

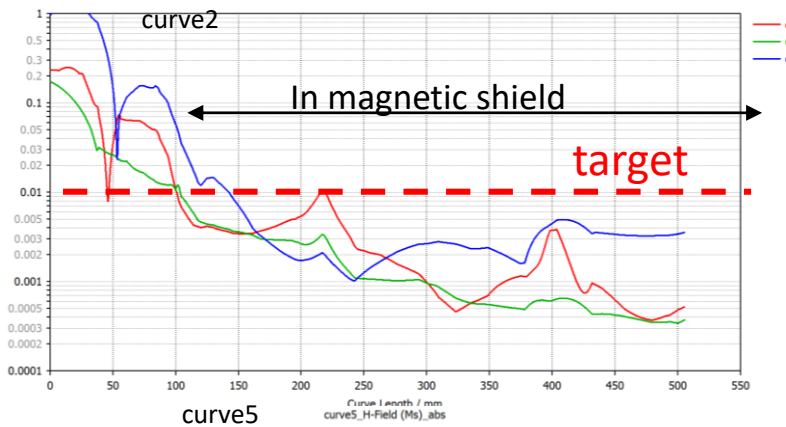
Case 8

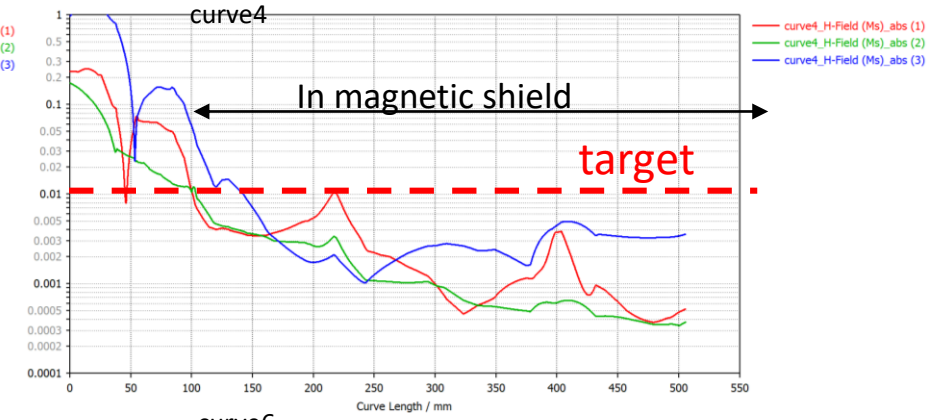


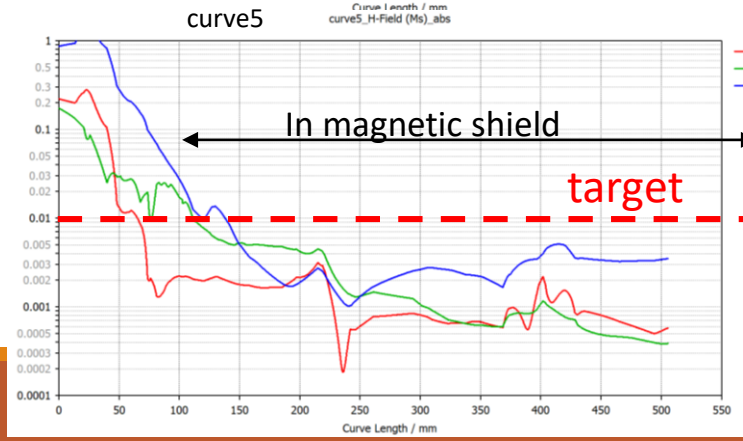

curve2
curve6
curve5

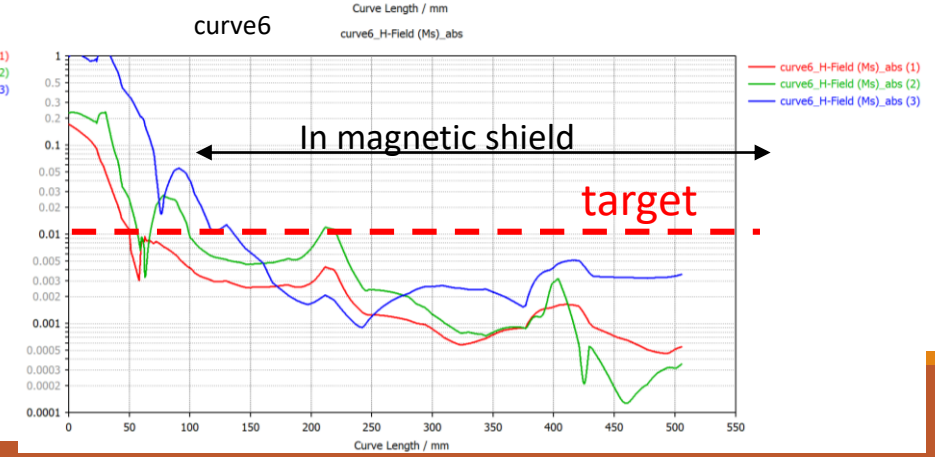

curve4




curve2
In magnetic shield
target
curve2_H-Field (Ms) (1)
curve2_H-Field (Ms) (2)
curve2_H-Field (Ms) (3)
Curve Length / mm


curve4
In magnetic shield
target
curve4_H-Field (Ms)_abs (1)
curve4_H-Field (Ms)_abs (2)
curve4_H-Field (Ms)_abs (3)
Curve Length / mm


curve5
In magnetic shield
target
curve5_H-Field (Ms)_abs (1)
curve5_H-Field (Ms)_abs (2)
curve5_H-Field (Ms)_abs (3)
Curve Length / mm


curve6
In magnetic shield
target
curve6_H-Field (Ms)_abs (1)
curve6_H-Field (Ms)_abs (2)
curve6_H-Field (Ms)_abs (3)
Curve Length / mm