First high gradient test of KEK SRF gun cavity in horizontal test cryostat

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Taro Konomi, Kensei Umemori, Eiji Kako,

Hiroshi Sakai, Yoshinari Kondo, Kazufumi Hara

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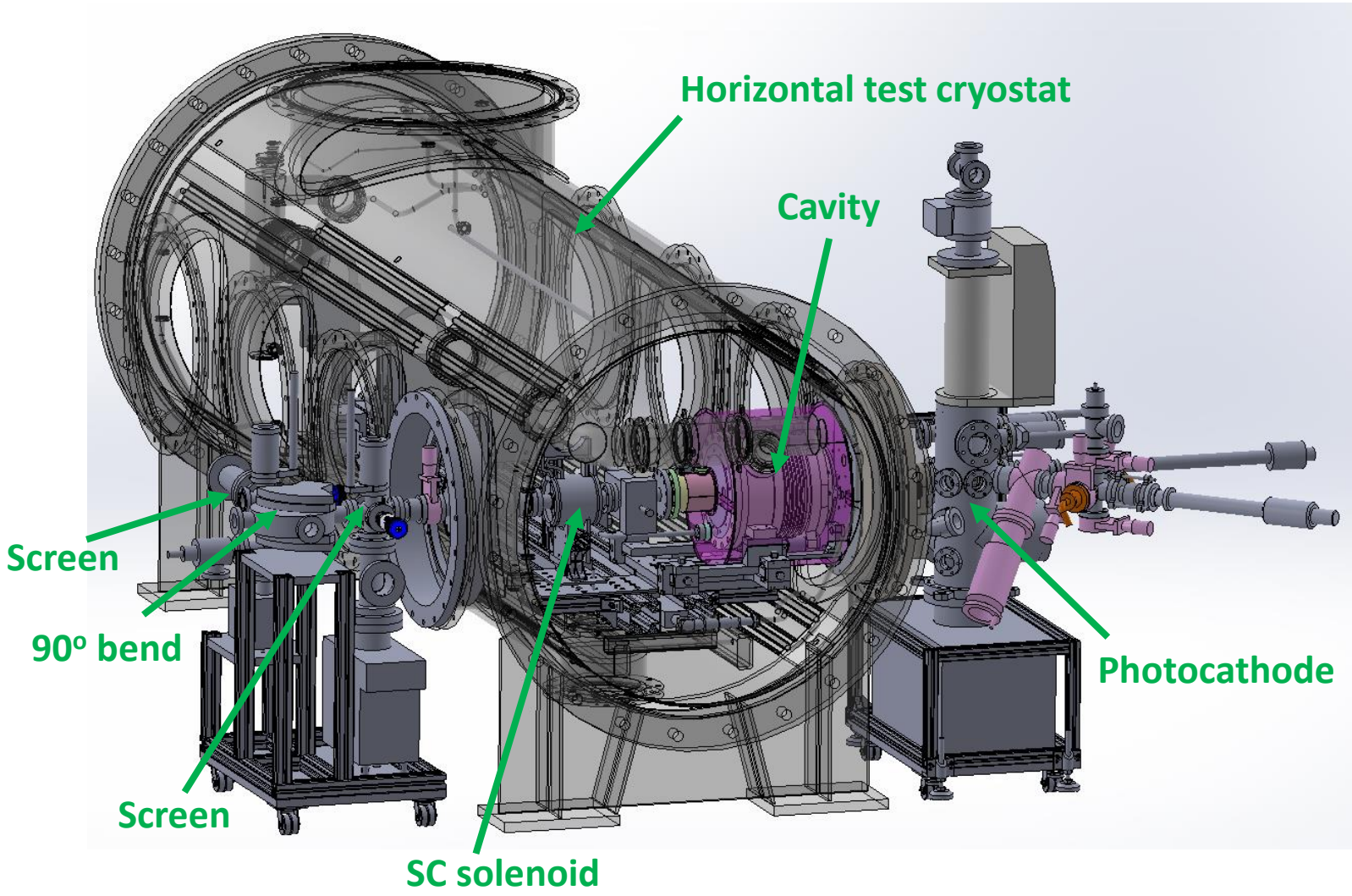


Merits of SRF gun

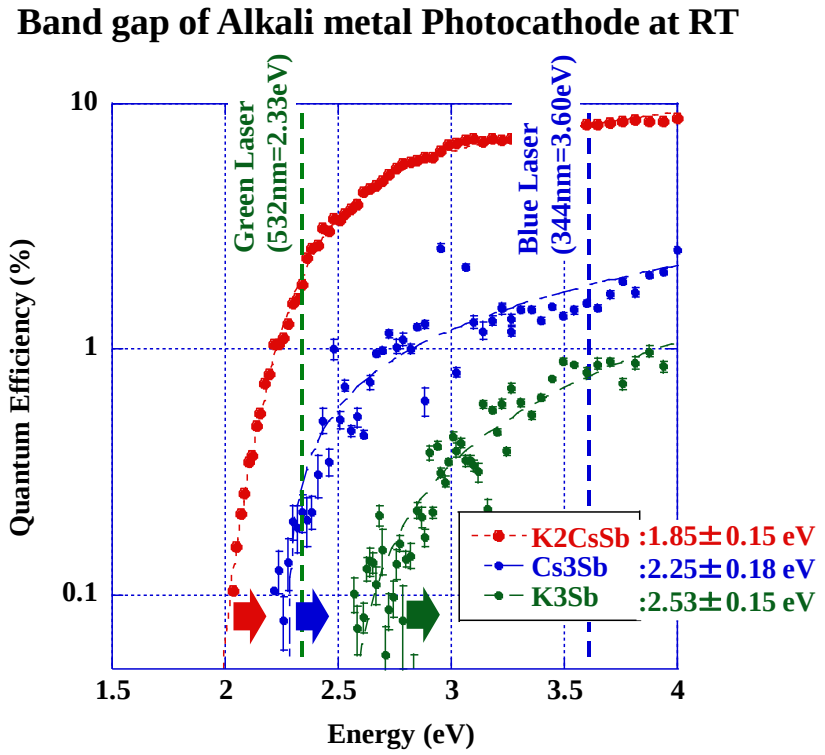
Linac base accelerator requires low emittance and high current (high repetition) electron gun.

Emittance growth:

- Thermal Emittance: $\varepsilon_{th} = \sigma_r \sqrt{\frac{2(h\nu - \phi_{eff})}{3m_e c^2} + \frac{2k_B T}{m_e c^2}}$
- RF Emittance: $\varepsilon_{rf} \propto \omega_{rf}^2 E_o \sigma_r^2 \sigma_z^2$
- Space Charge: $\varepsilon_{sc} \propto \sqrt{\frac{I}{\beta\gamma}}$

$h\nu$: Laser Energy
ϕ_{eff}: Cathode band gap

	DC gun	Norm. RF gun	SRF gun
Gradient on cathode	<10 MV/m	>100 MV/m	~100 MV/m
Repetition	DC~CW	<1 kHz	< 1.3 GHz
Cathode temperature	RT ~ 2000K	RT~2000K	2K ~ RT
Vacuum	<1E-10 Pa	~ 1E-6 Pa	<1E-8 Pa

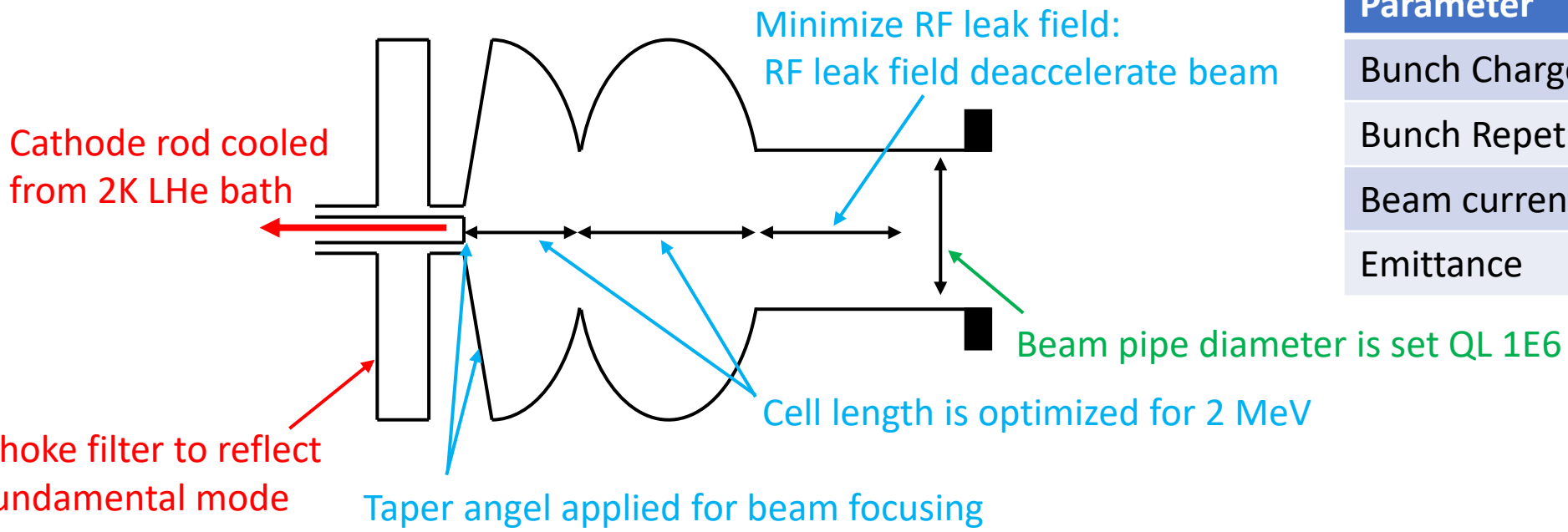


Merits for using low thermal emittance cathode.

- **SRF gun combine the best properties of DC gun and Norm. RF gun.**
- **SRF gun can operate delicate photocathode.**
  - **Spin-polarized photocathode may be operated with SRF gun in future.**

KEK SRF gun cavity Concepts

KEK SRF gun was designed based on KEK-ERL parameter.

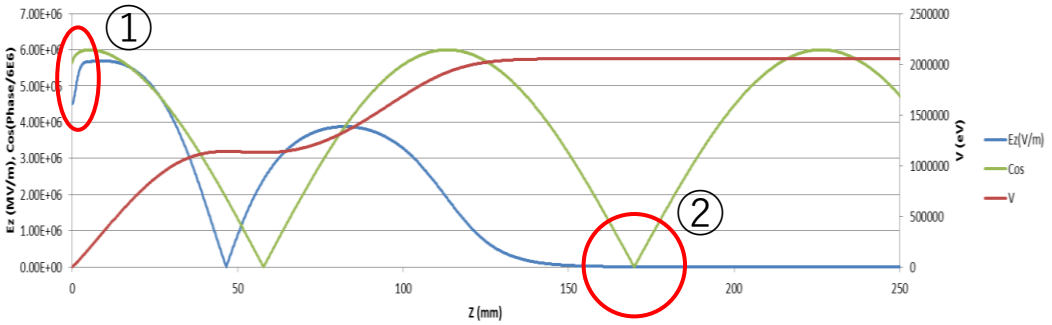


ERL parameter

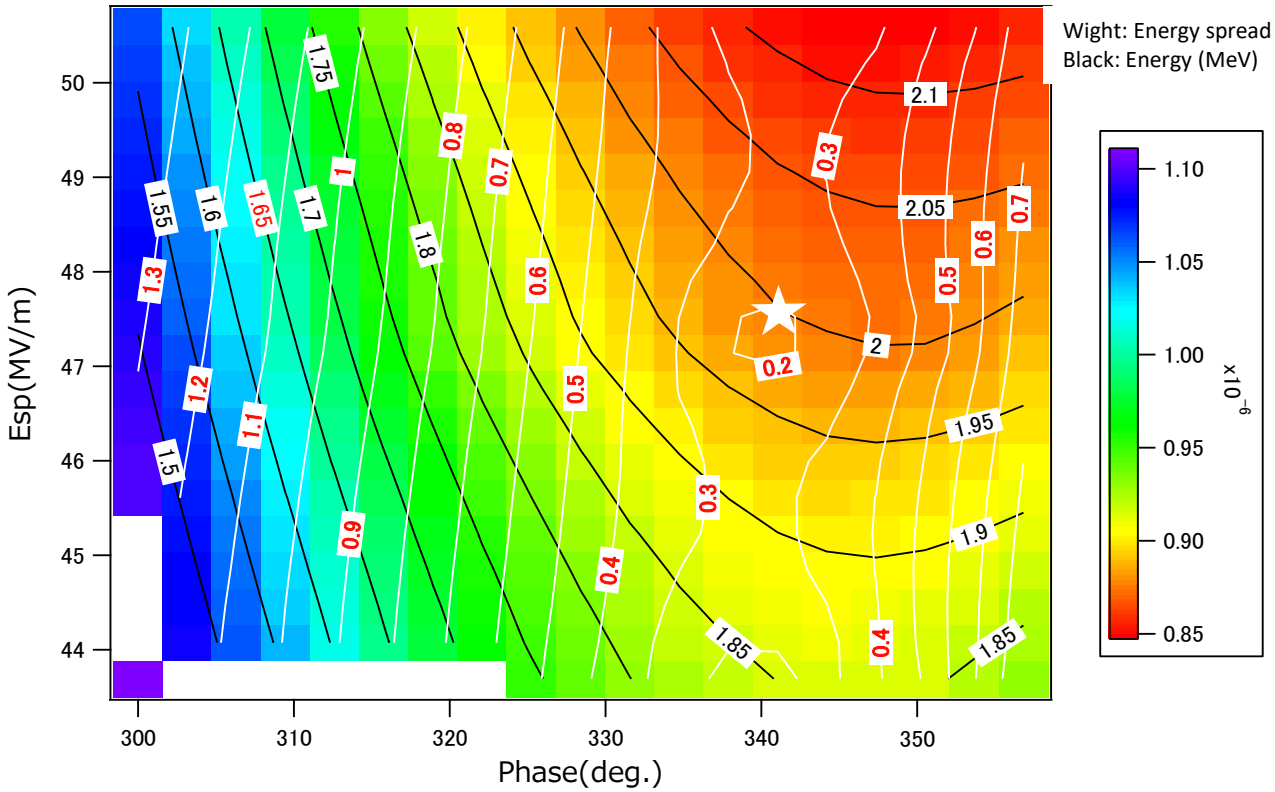
Parameter	Value
Bunch Charge	77 pC
Bunch Repetition	1.3 GHz
Beam current	100 mA
Emittance	< 1 mm.mrad

- **Gun voltage is set 2MeV by assuming use of two 100kW CW input coupler developed for KEK cERL injector cavity.**
- **DC solenoid field can not be applied to SRF gun.**
  - **RF pattern is optimized to compensate RF emittance and space charge effect.**
- **Photocathode operation temperature is set to 2K for low thermal emittance.**

KEK SRF gun cavity Design: RF

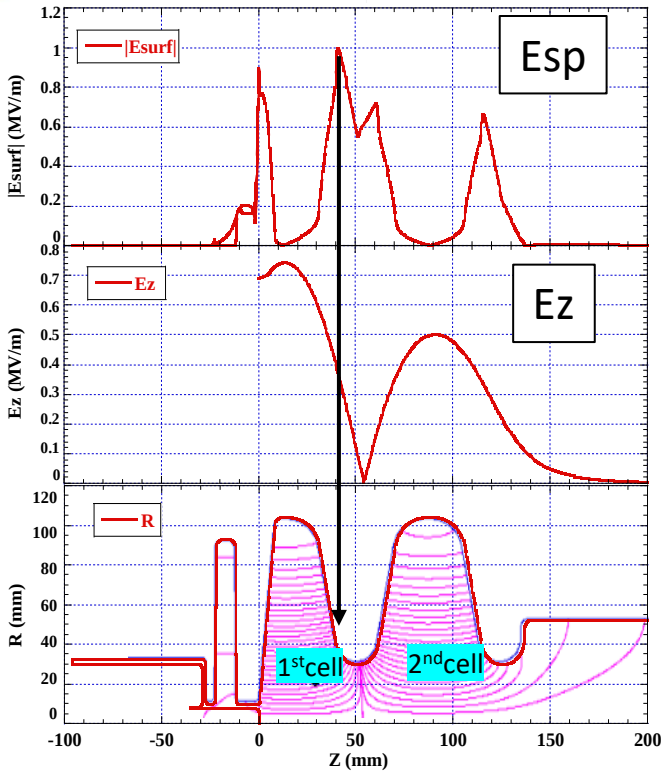


Emittance and Energy spread



Design parameter of KEK RF gun

Parameter	Value
Beam energy	2 MeV
Emittance	< 0.6 mm.mrad
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)
Surface resistance	30 nΩ (ILC target)
Q value	4.5×10^9
Target cavity loss	8 W



- Cell shape was optimized independently without injector line (injector cavity and so on).
- Emittance and Energy spread are minimized simultaneously by controlling focusing field ① and leak field ②.
- Peak electric field on the cavity wall located on 1st cell equator.

Vertical test results

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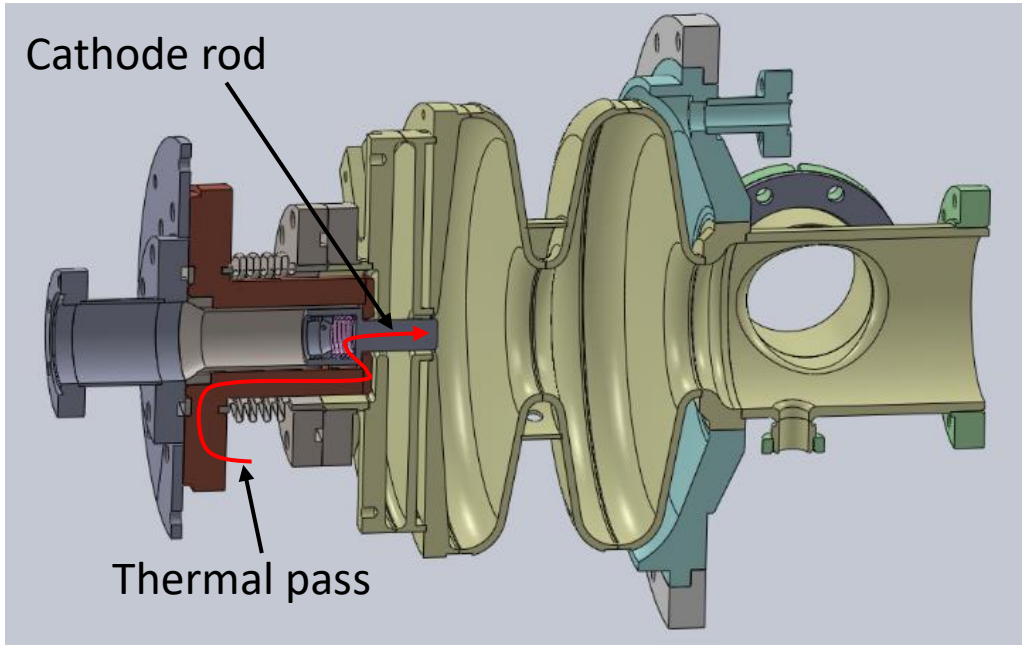
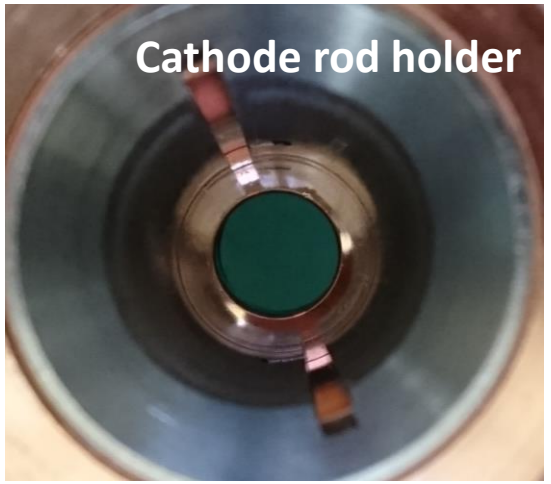
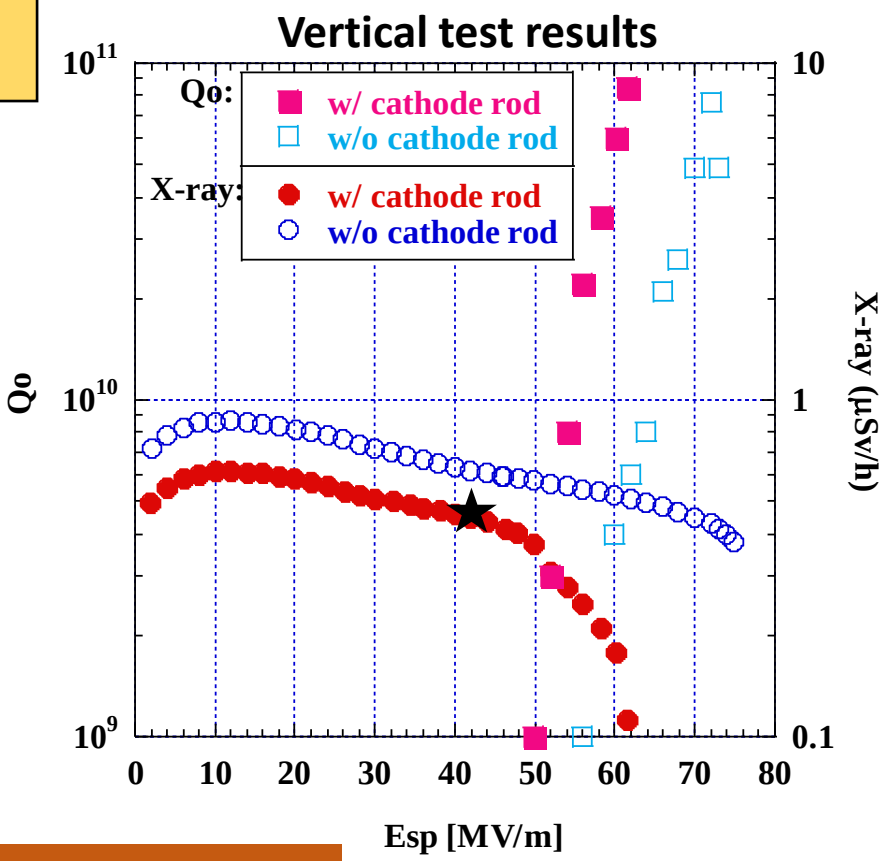
Vertical test set up

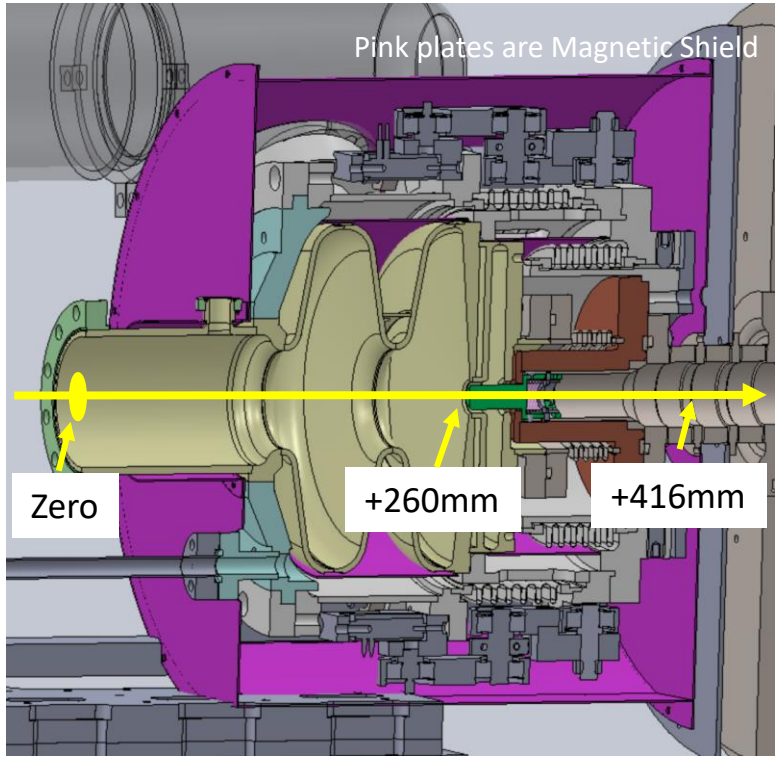


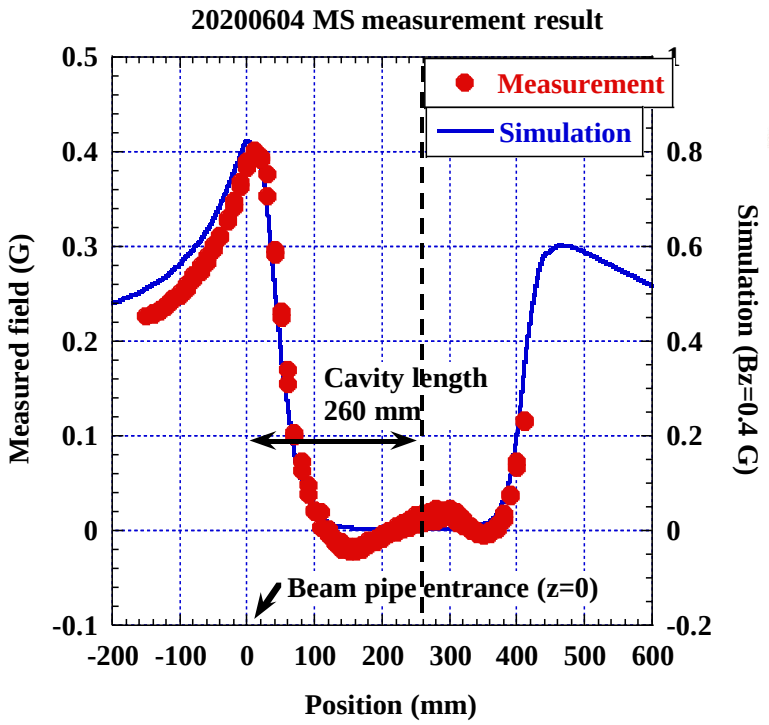


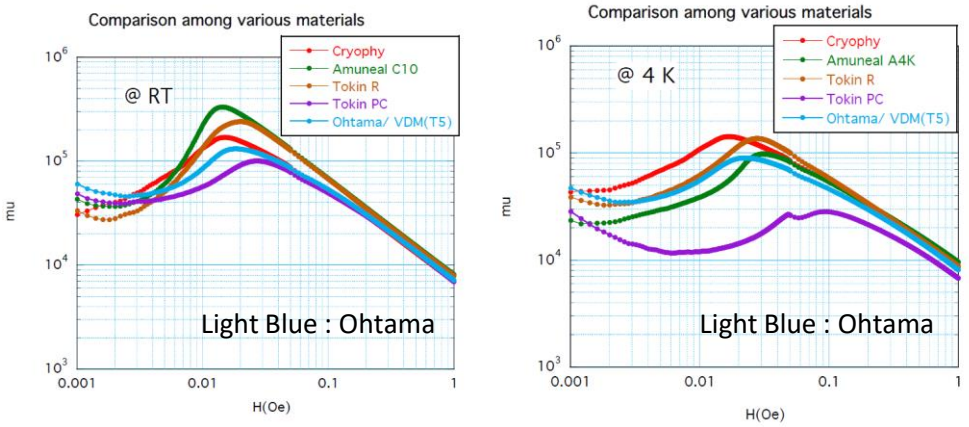


- **Thermal pass for cathode rod cooling include thermal contact resistance.**
  - **Cathode rod and cathode rod holder was mirror-polished.**
- **Surface peak gradient reached to target gradient.**
  - **Choke filter could not perfectly reflect fundamental mode in vertical test.**

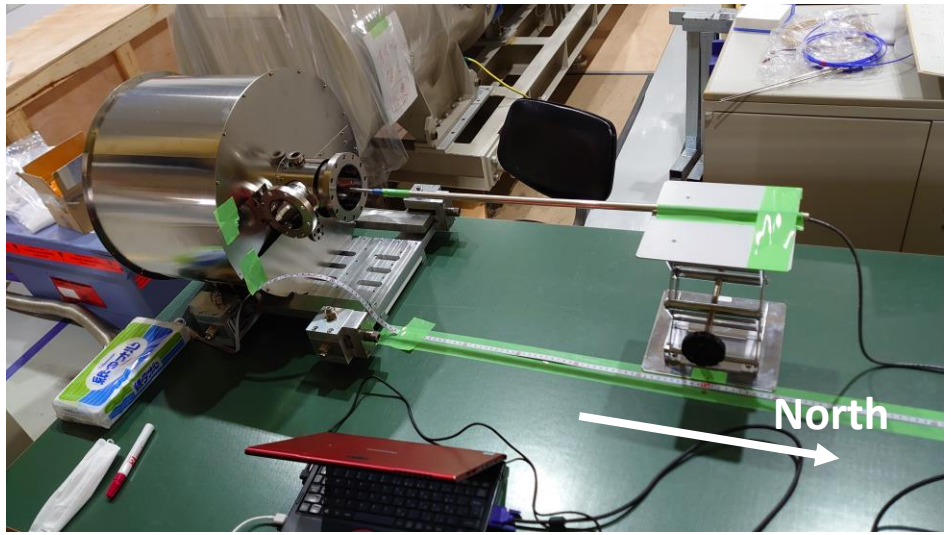
KEK SRF gun cavity Design: Magnetic Shield





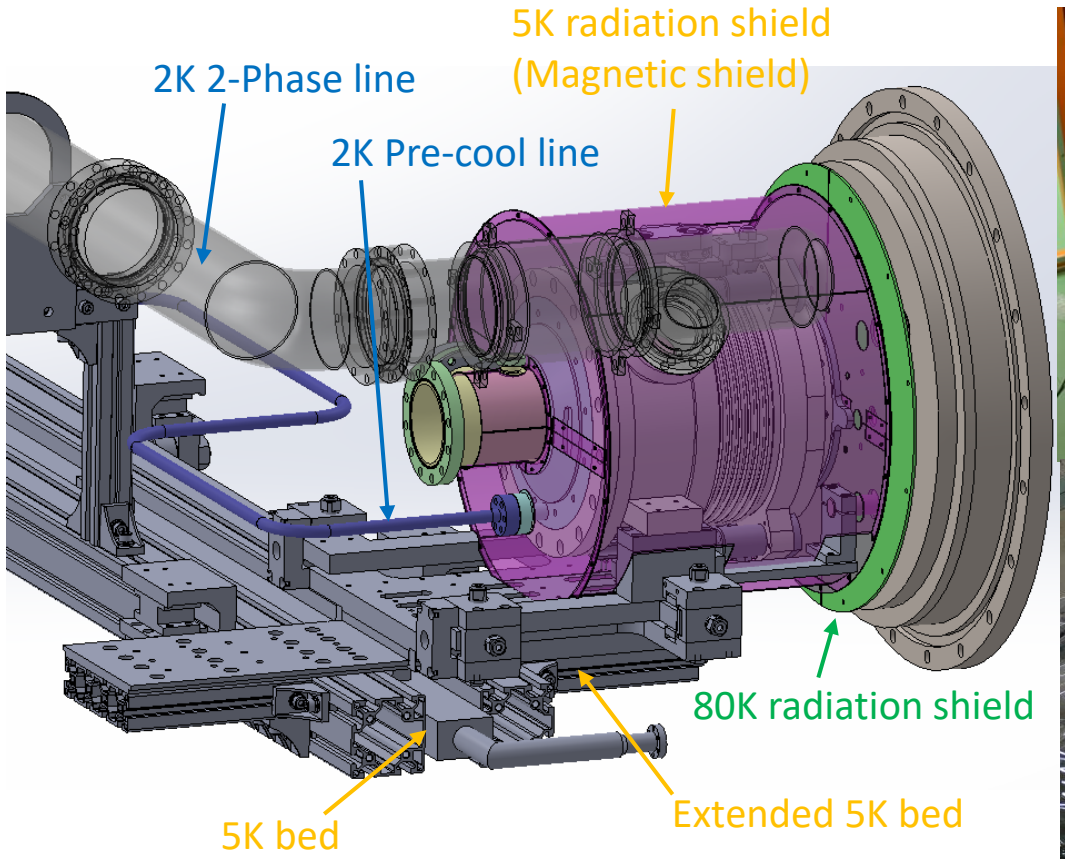


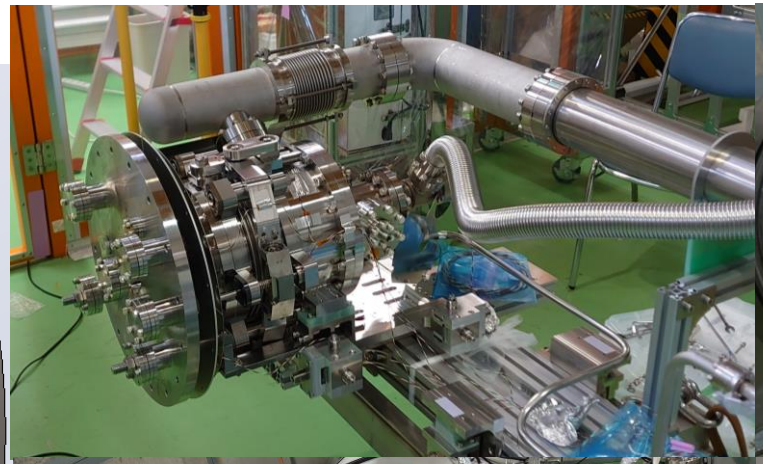
M.Masuzawa et al., ALCW2015

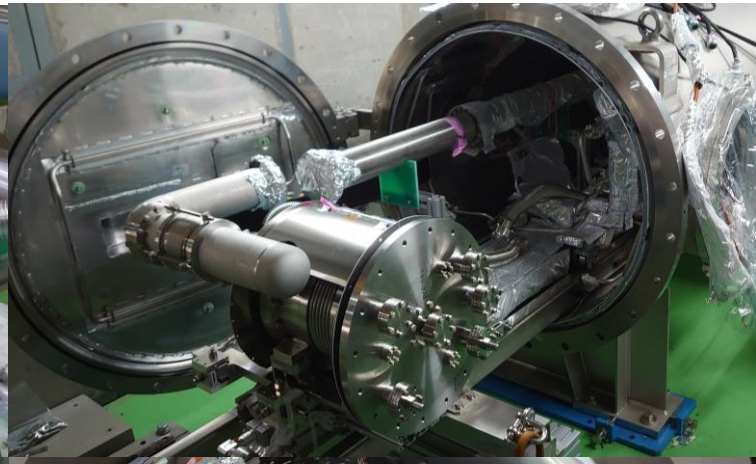


- Magnetic shield material is Otama CO., LTD / Permalloy PC.
- The simulation and measurement results show good agreement.
  - Geomagnetic field in experimental hall is about half of expected.
- Outer Magnetic shield play a role in 5K thermal shield.

Experimental setup for First HT

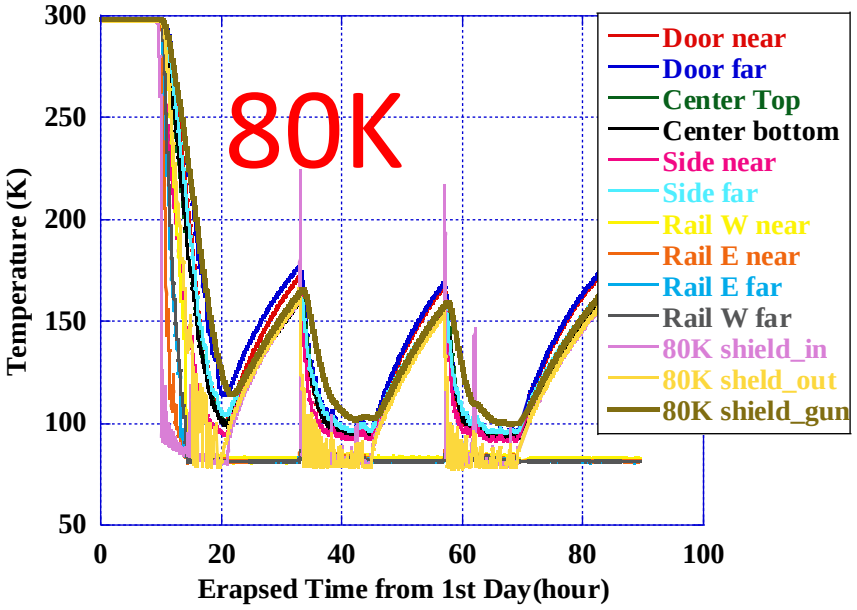


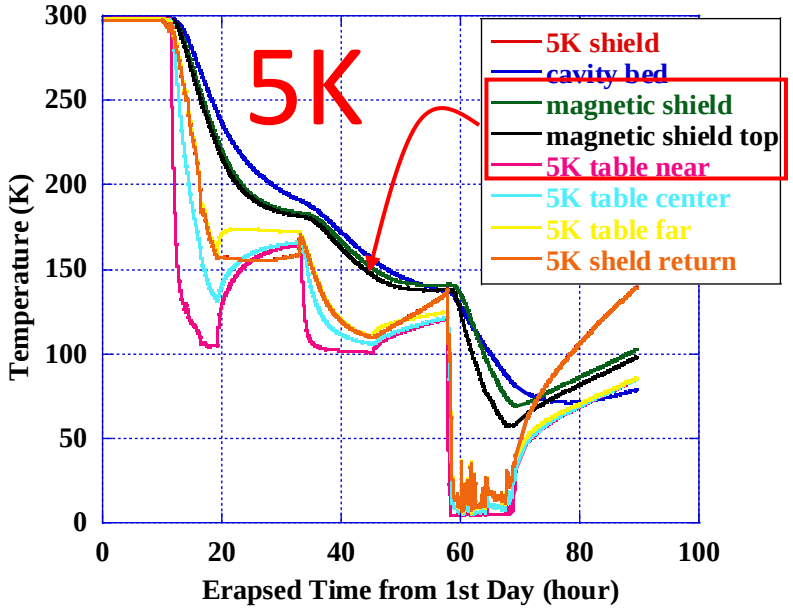


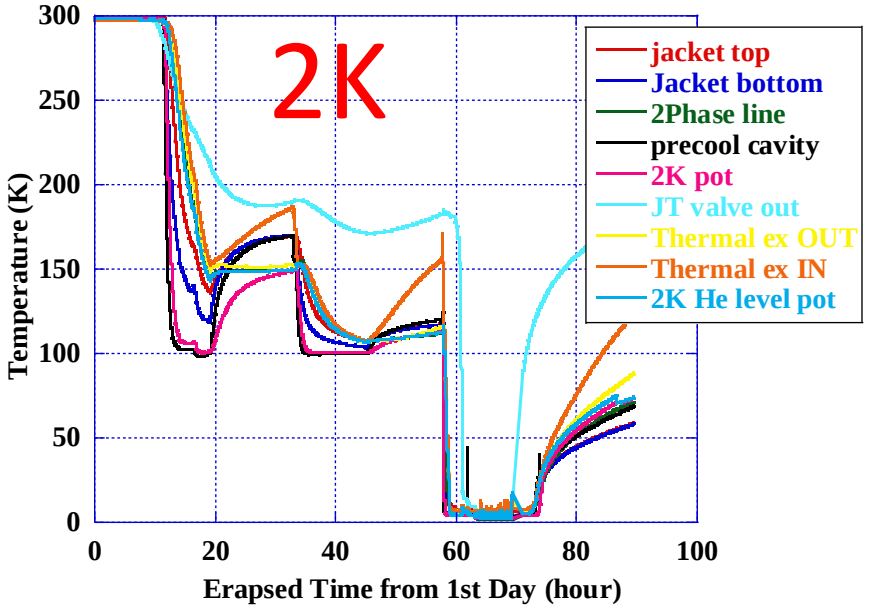


- **5K bed was extended to support gun cavity.**
  - **Extended bed and 5K radiation shield (Magnetic shield) are thermally linked by earth wires.**
- **5K and 2K parts were wrapped with 10 layers SI and 80K parts were wrapped with 30 layers.**
- **Cathode rod was not installed.**

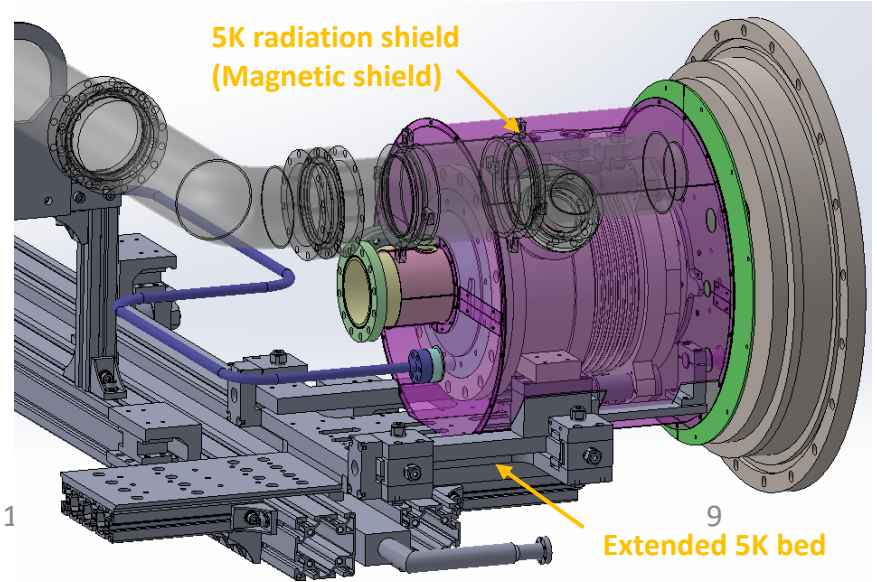
Cooling trend (3 days)



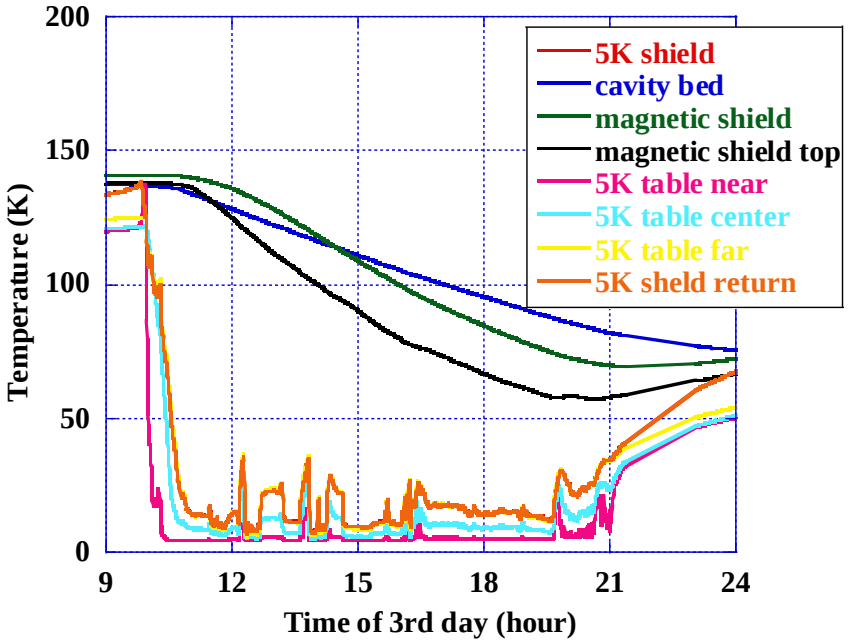


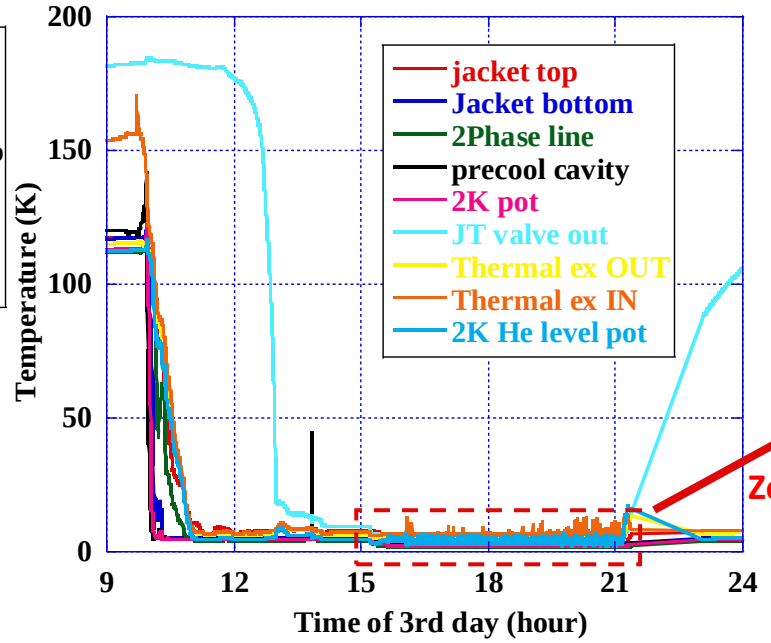


- Horizontal test takes 3 days
  - 1st and 2nd day : pre-cooling
  - 3rd day: cooled by LHe and high gradient test
- Helium gas, which exchanged heat with LN2 was used for precooling.
- 80K and 2K parts are well cooled.
- 5K parts (extended bed and magnetic shield) could not cooled sufficiently.

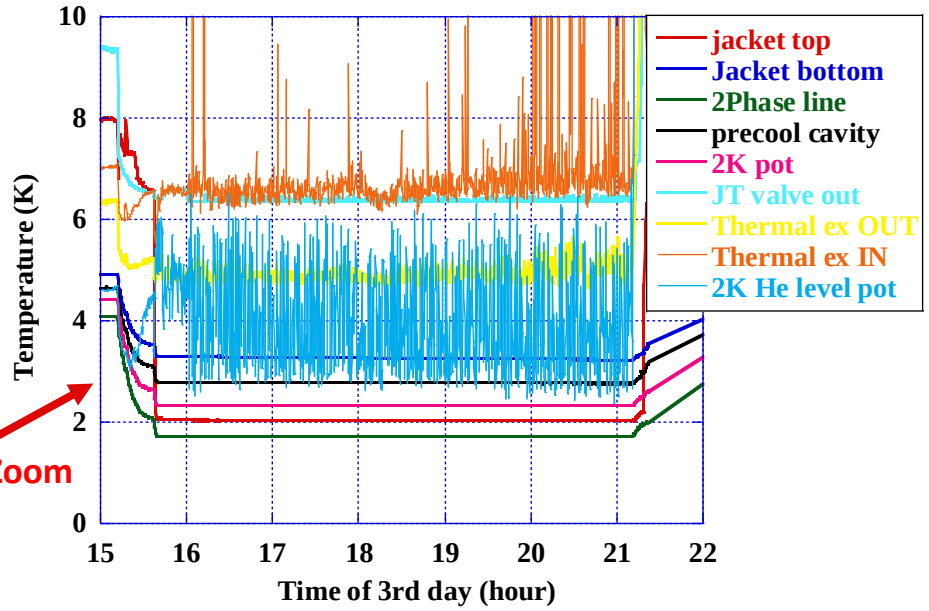


Cooling trend (3rd day)



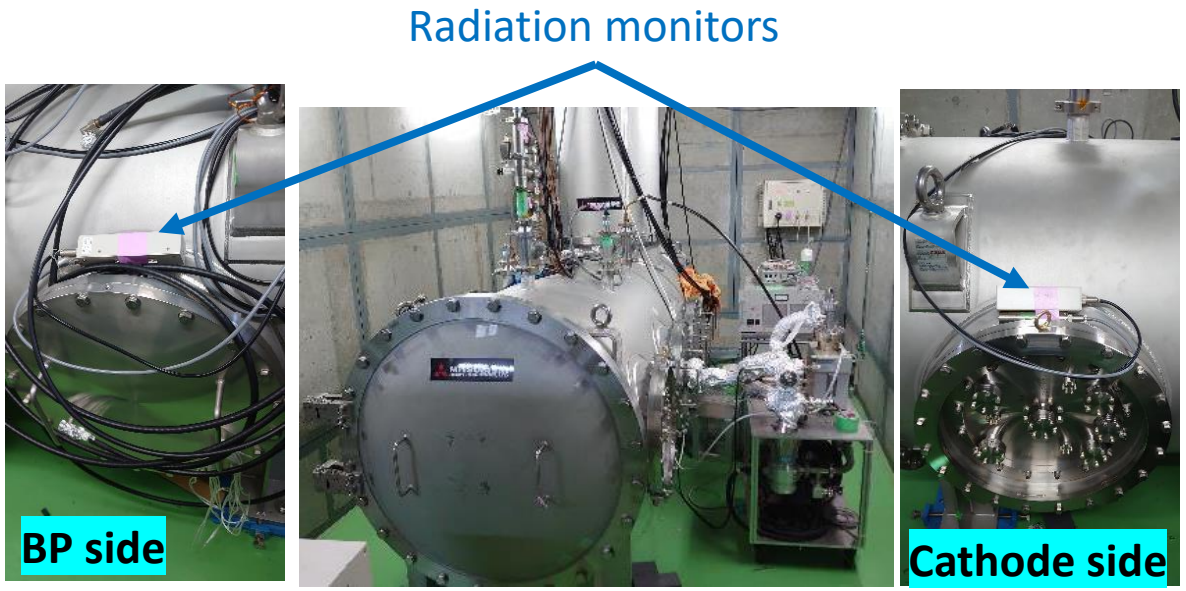


Zoom



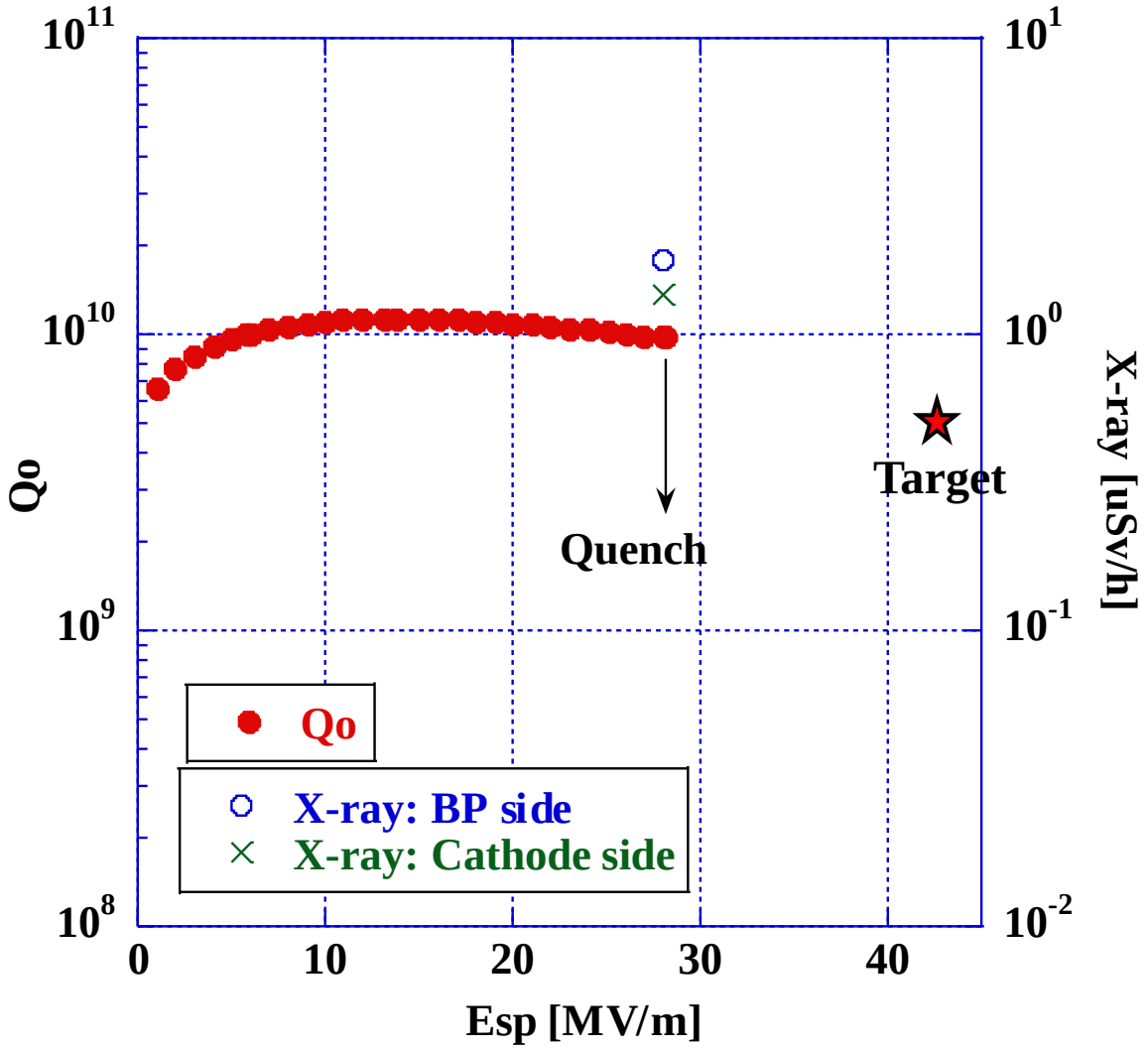
- LHe cooling was started from 3rd day 10 am with using 1000 L LHe.
- Filling LHe takes about 6 hours.
- 2K can be kept more than 6 hours.
  - It is enough long time for future beam test.

High gradient test

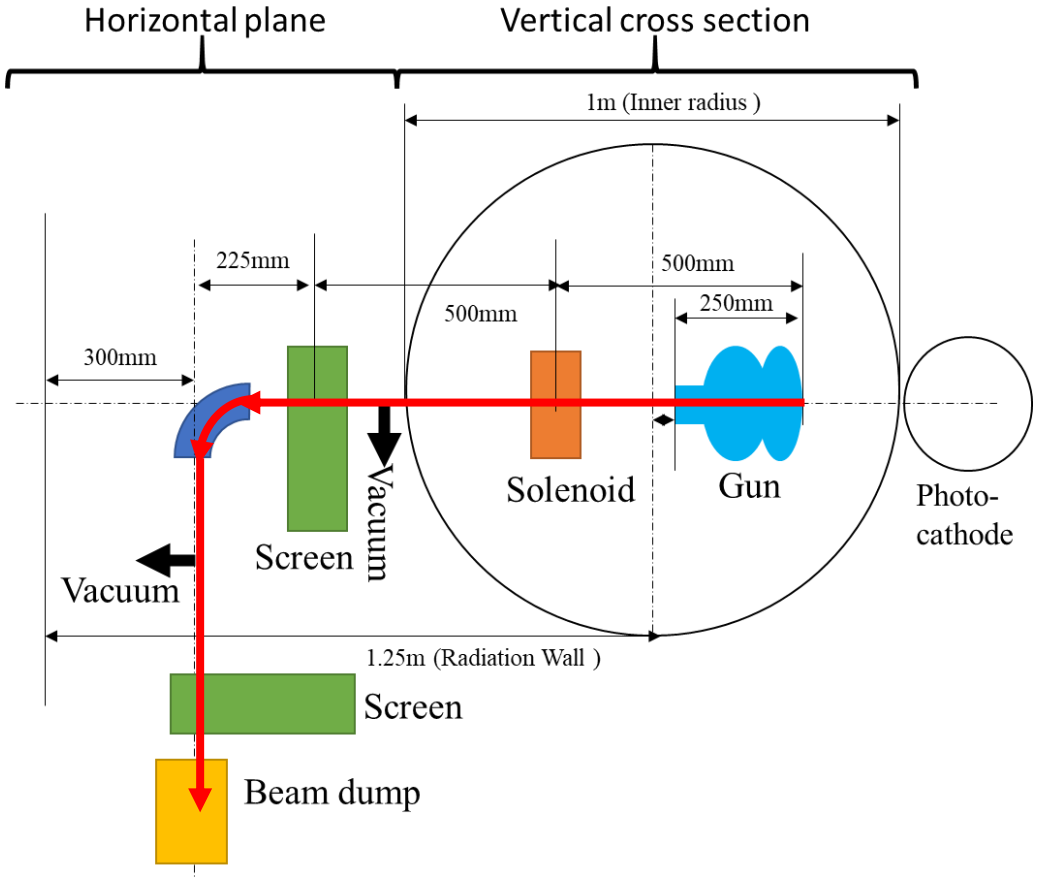


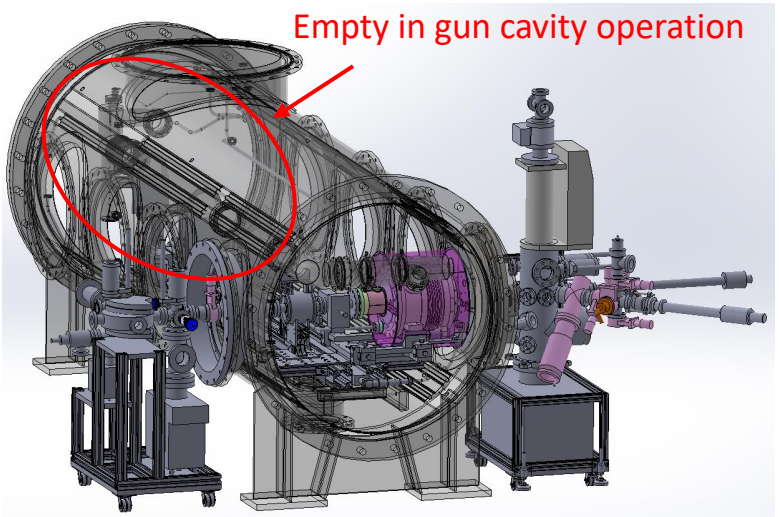
	Pi-mode		Pi-mode
4.2K	1300.991 MHz	Qin	1.57×10^{10}
2K	1300.1060 MHz	Qt	2.63×10^{11}

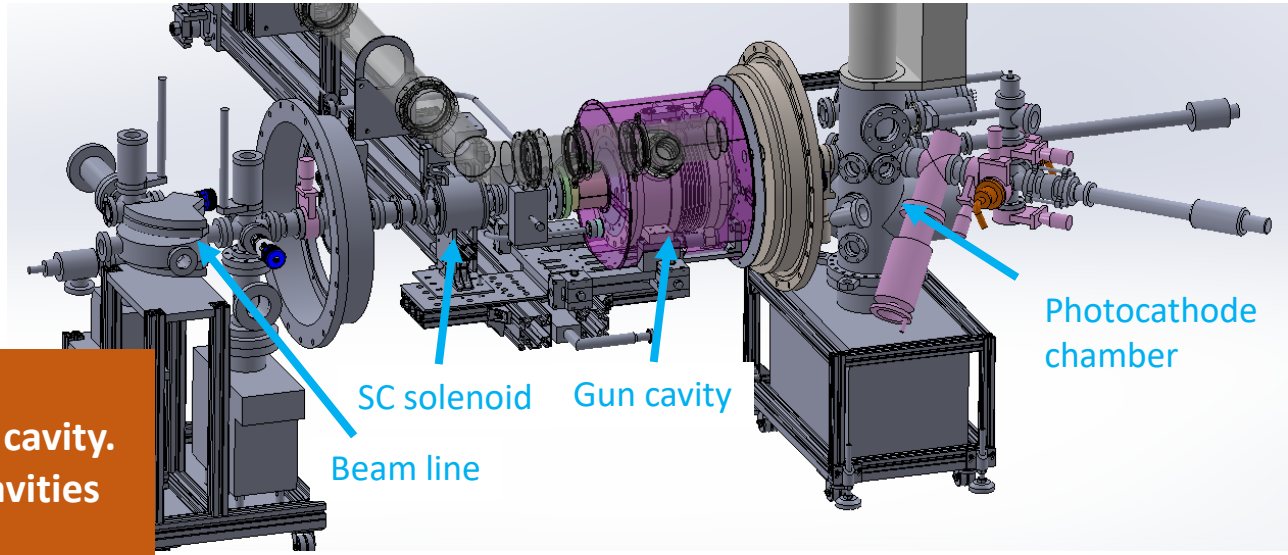
- Strong multipacting observed at low gradient (<1MV/m).
- Esp reached to 28 MV/m and quenched.



Experiment setup in future







- **Final target of the horizontal test is small current beam test.**
  - **Evaluate thermal emittance and RF emittance of KEK gun cavity.**
- **KEK horizontal test cryostat system was designed for various cavities high gradient test.**
  - **KEK gun use only 1/4 space of horizontal cryostat test.**

Summary

- KEK has been developing SRF gun
- The first high gradient test in horizontal test cryostat was performed.
- Gradient reached 28 MV/m. It's lower than target 42MV/m, but high enough for the first test.
- Next step is high gradient test with cathode rod.
  - We will test in January 2021.