CONSTRUCTION AND PERFORMANCE TESTS OF THE PROTOTYPE QUARTER-WAVE RESONATOR AT RIKEN

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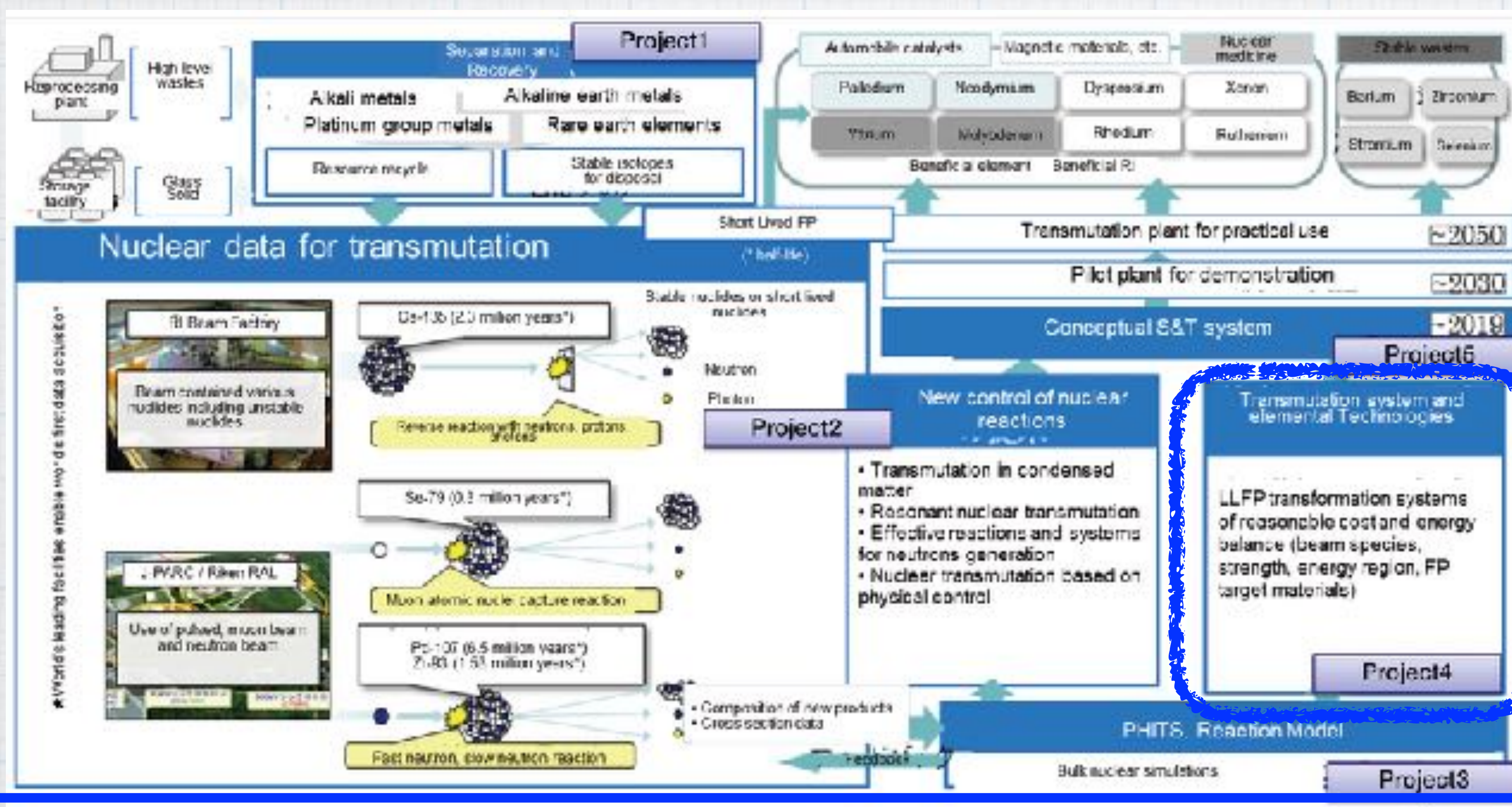
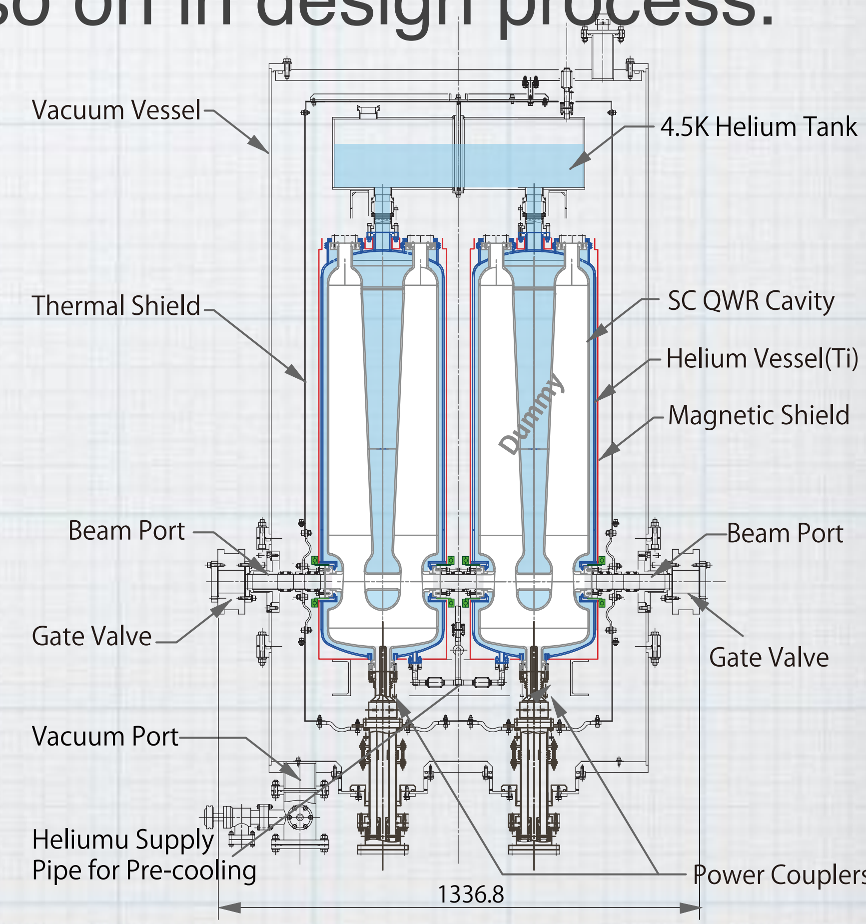
Acknowledgement

Development of SC linac

- Since 2014 the accelerator group of Nishina Center joined the ImPACT program led by Dr. Fujita aiming at having a grand design of a system to process so-called Long- lived Fission Products (LLFPs) via nuclear reaction and nuclear transmutation induced by ion beams.
  http://www.jst.go.jp/impact/en/program/08.html

- As a part of this program, project 4, development of a superconducting cavity (SC-QWR) and its cryostat for an accelerator of ion beams (CW) was proposed and accepted. It is crucial to determine the feasibility by making research on its performance, manufacturability and so on in design process.

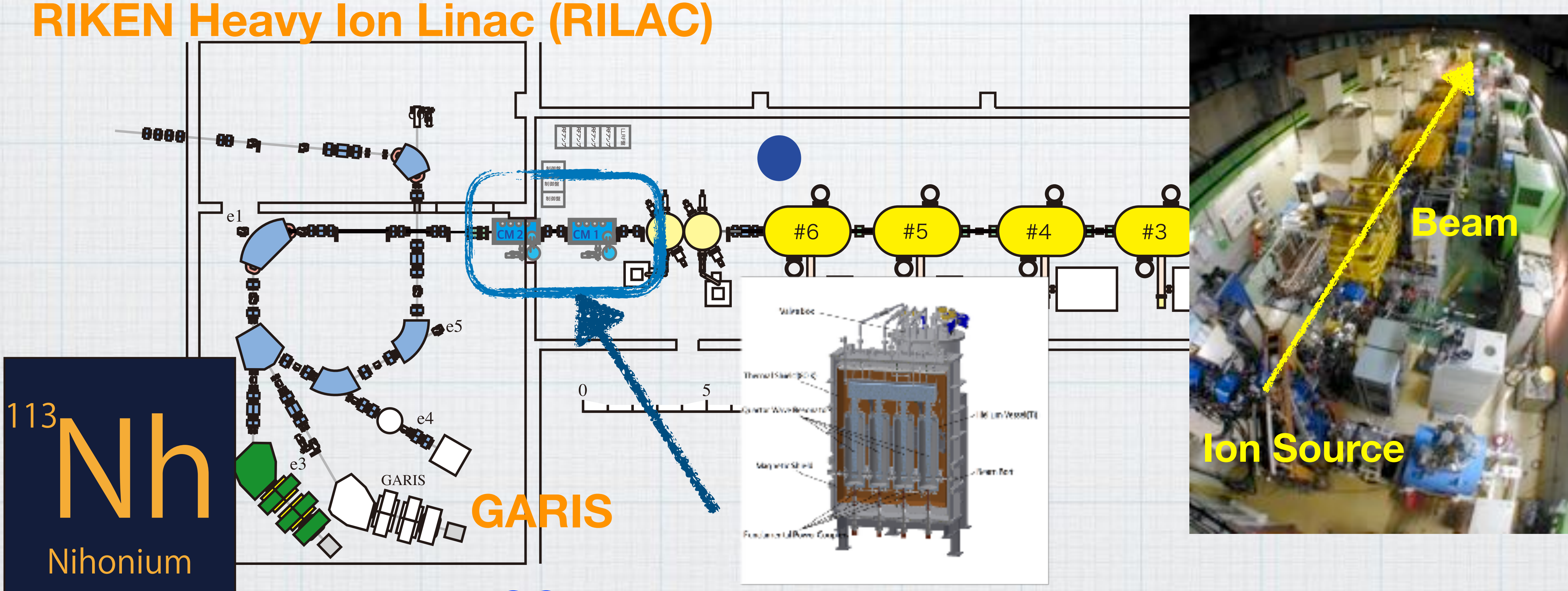




Upgrade of the RIKEN Heavy Ion LINAC (RILAC)

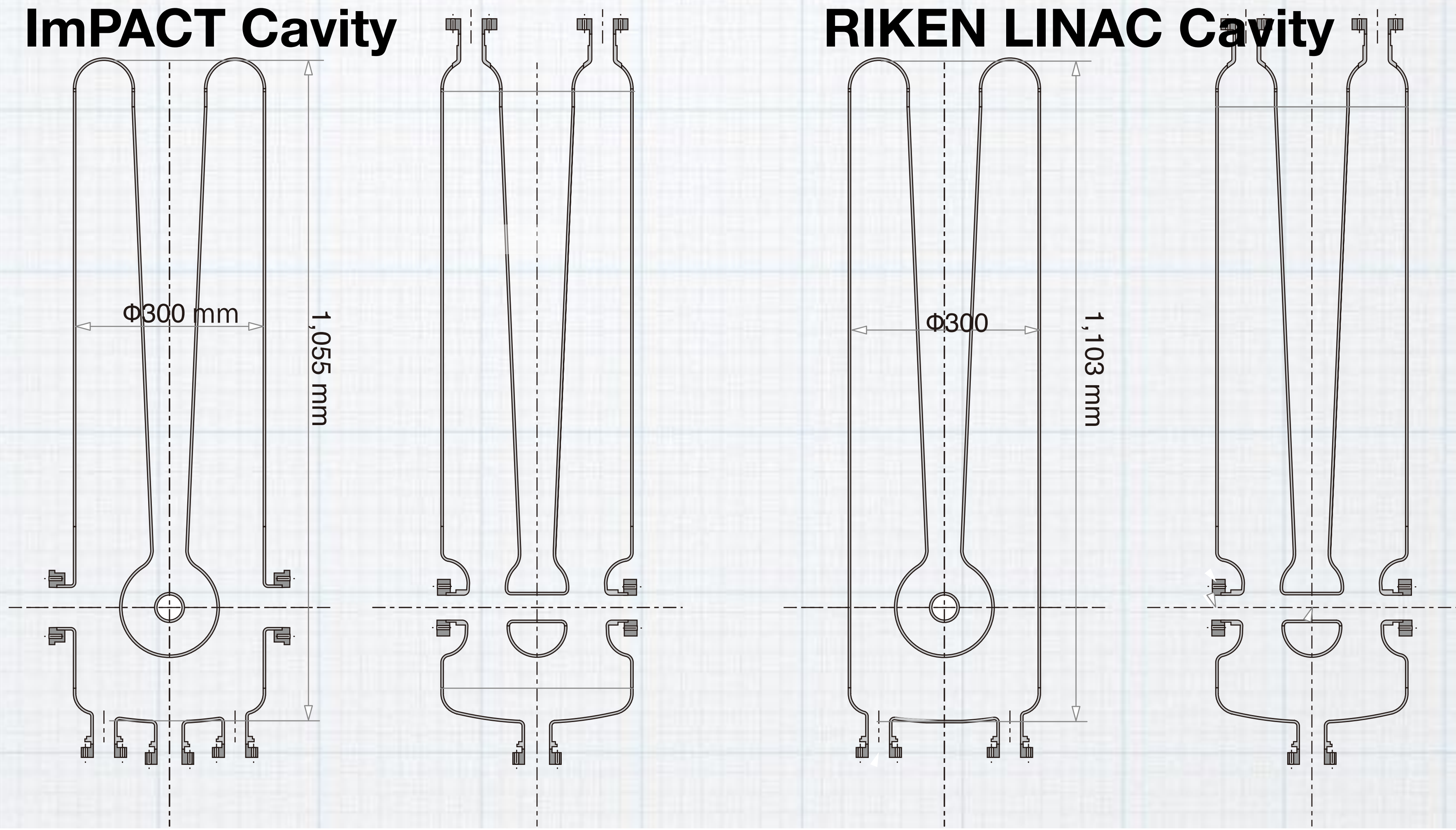
- The RILAC is going to have upgrade aiming to provide intense heavy-ion beams to continue super heavy element search (SHE) experiment challenging the 8th row of the periodic table of elements (A>119).
- The ions A/q of 5 will be accelerated up to more than 6 MeV/u.
- The last four DTL tanks will be replaced by two cryomodules each of which hosts four QWRs.

RIKEN Heavy Ion Linac (RILAC)



Test of the SC cavity and cryomodule were made extensively.

Prototypes of SC-QWR (RIKEN)

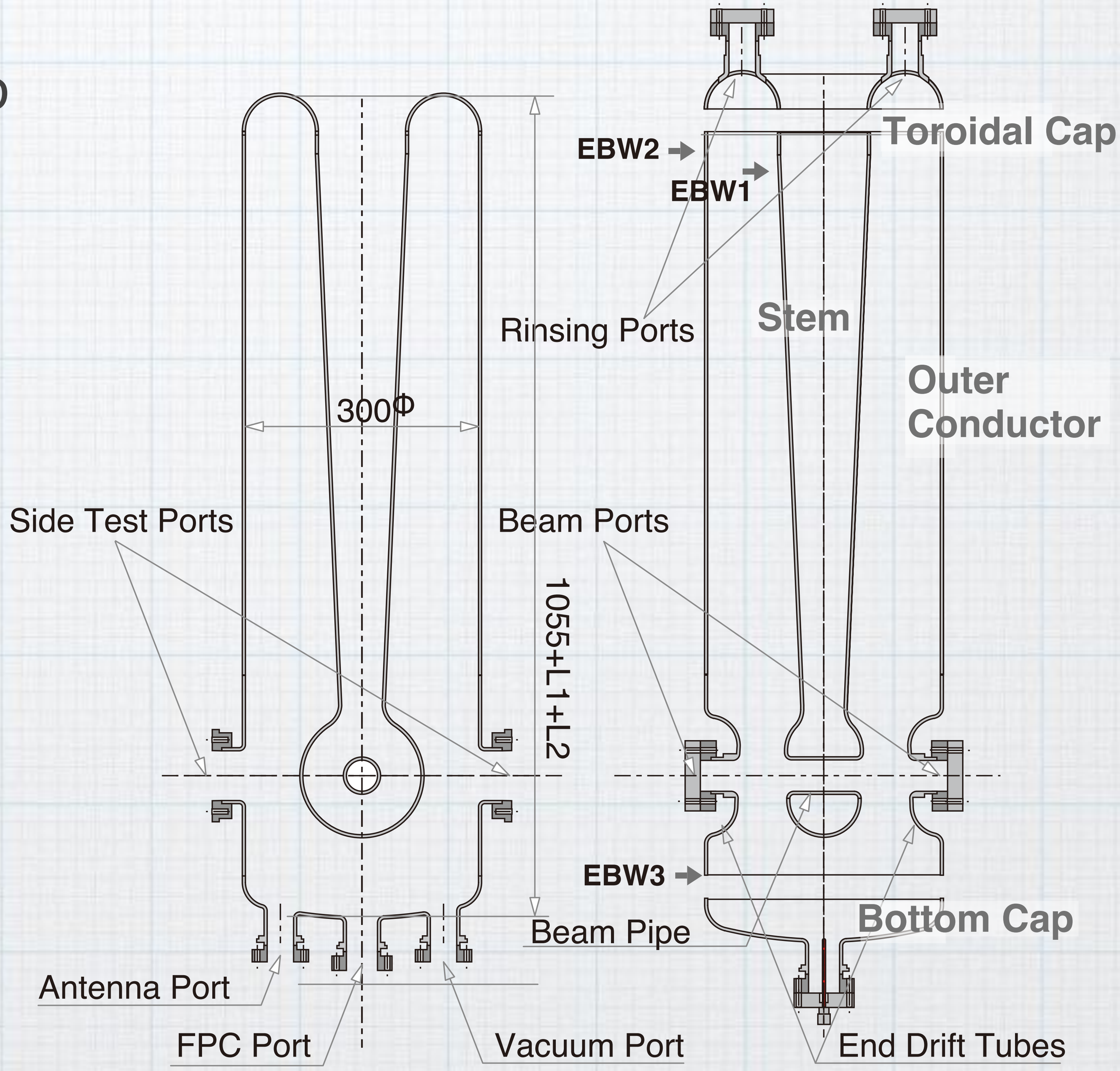


	ImPACT Cavity	RIKEN LINAC Cavity
Frequency [MHz]	75.5	73.0
G[Ω]	23.5	22.4
R_a/Q_0 [Ω](β=0.078)	578	579
Q_0 (R_S=25 nΩ)	9.4E+08	9.0E+08
E_{acc}	4.5	4.7
E_{peak}/E_{acc}	6.2	6.2
B_{peak}/E_{acc} [mT/(MV/m)]	9.7	9.6
Prototpe	Completed	Under assembly

Manufacturing of Cavity (QWR)

SC-QWR: f_0:75.5 MHz, Q_0:9.4E8(4.5 K), E_{acc}=4.5 MV/m @4W, $P_{cool.}$:8W

- The prototype cavity is made from pure niobium sheets with RRR of 250 provided by Tokyo Denkai Co., Ltd.(TD).
- The cavity consists of four parts and are welded by EBW(1→2→3).



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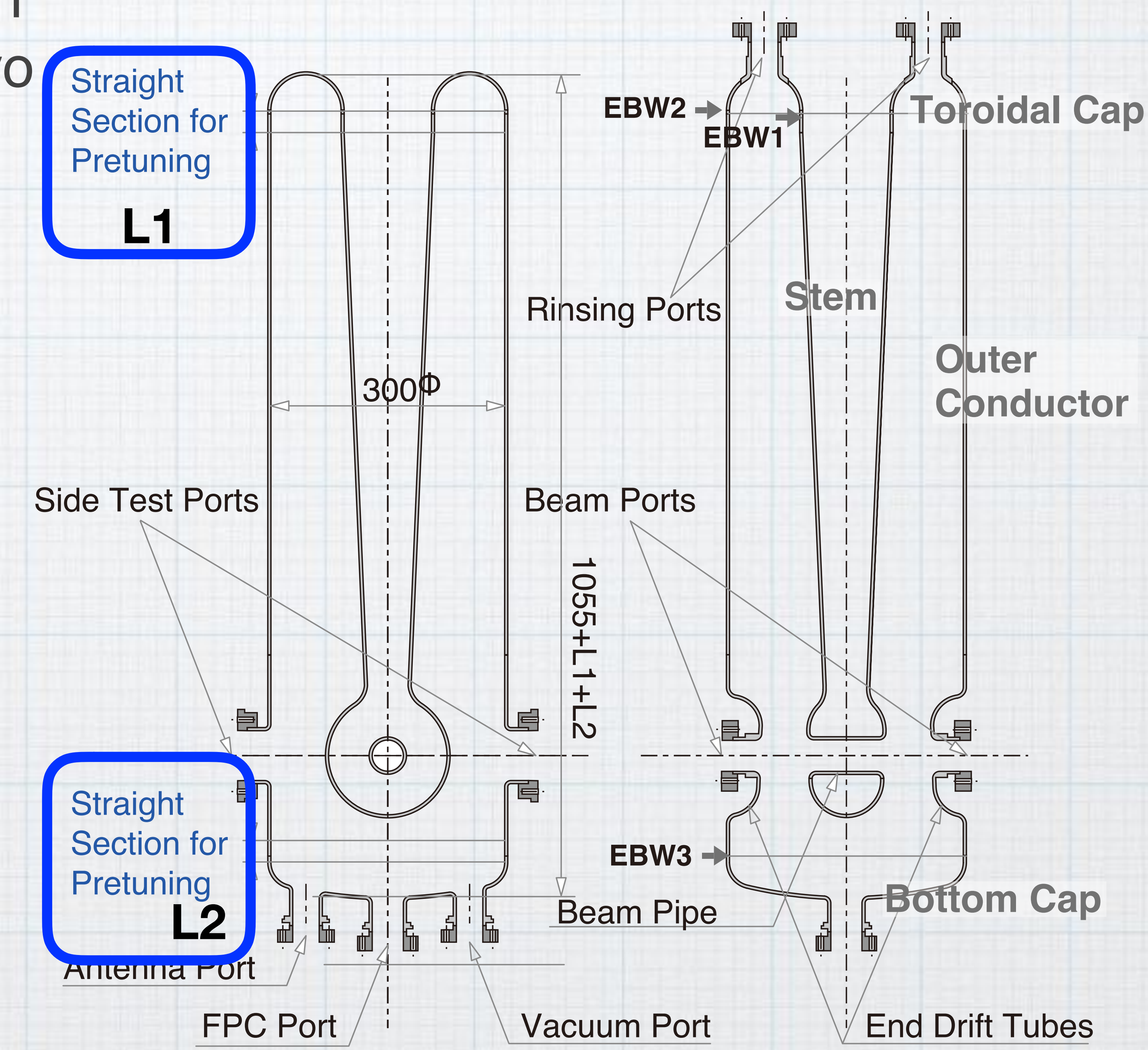
- Frequency tuning was realized by adjusting the length of upper and lower straight sections.



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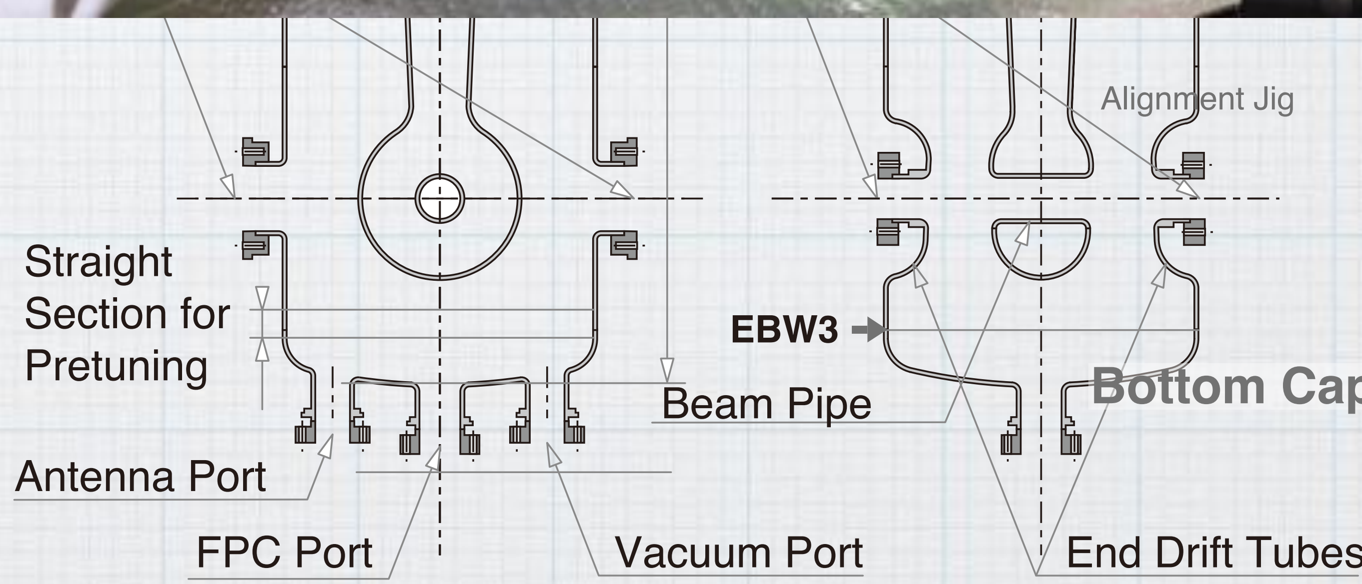
- Careful inspection of inner surface before EBW3.



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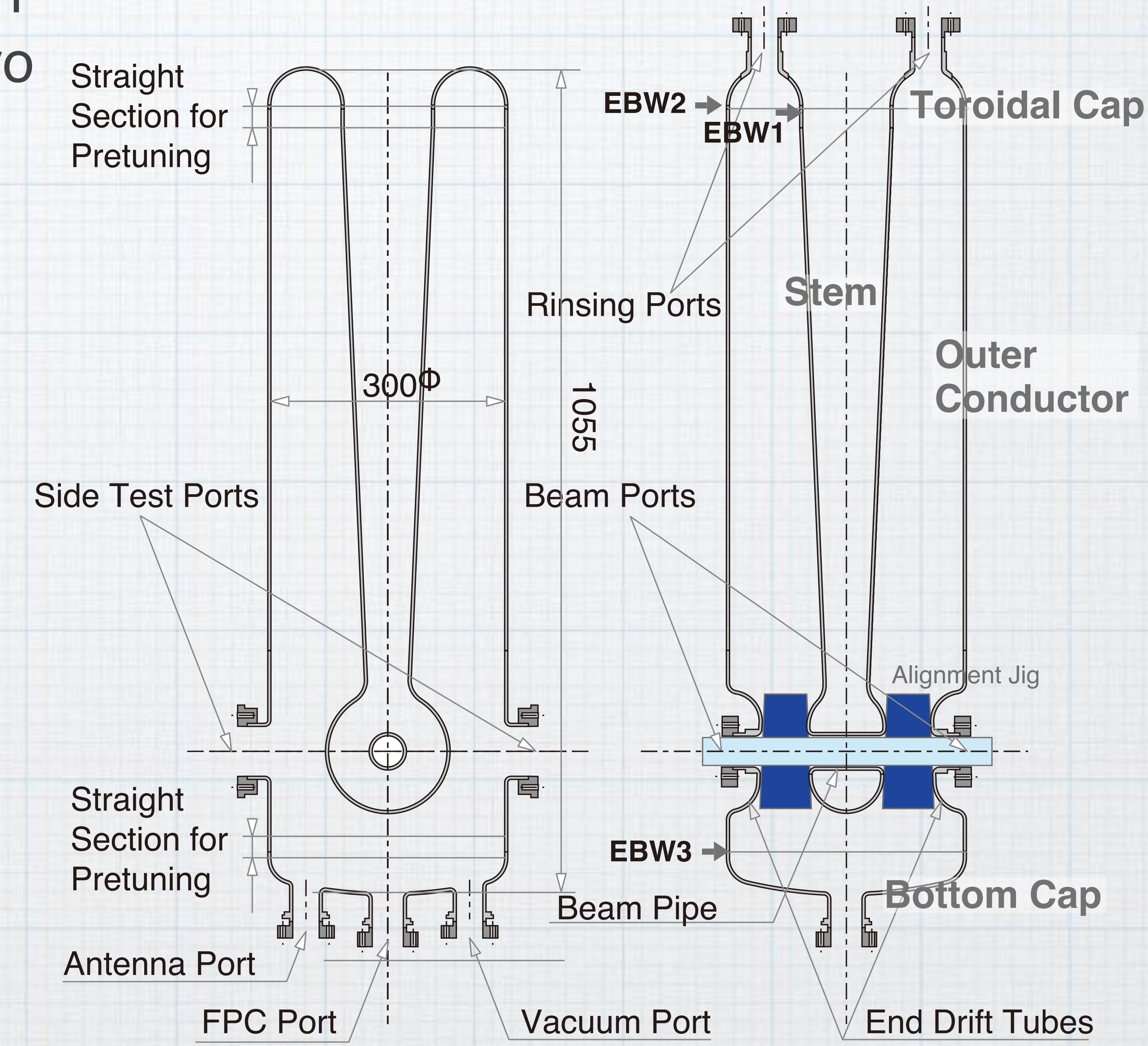
- The prototype cavity is made from pure niobium sheets with RRR of 250 provided by Tokyo Denkai Co., Ltd.(TD).
- The cavity consists of four parts and are welded by EBW(1→2→3).
- Frequency tuning was realized by adjusting the length of upper and lower straight sections.
- Careful inspection of inner surface before EBW3.
- Wedge-shaped spacers are used to align the Stem together with a cylinder rod.



Surface Treatment

■ Surface treatment processes follow a fairly standard recipe.

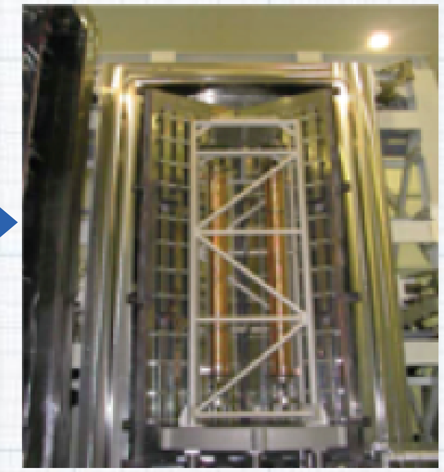
BCP1→Annealing→BCP2→HPR→Baking

Surface Treatment

- Surface treatment processes follow a fairly standard recipe.
- All the facilities for these processes are developed by MHI at Hiroshima.
- Inspection of the inner surface was made carefully after BCP.

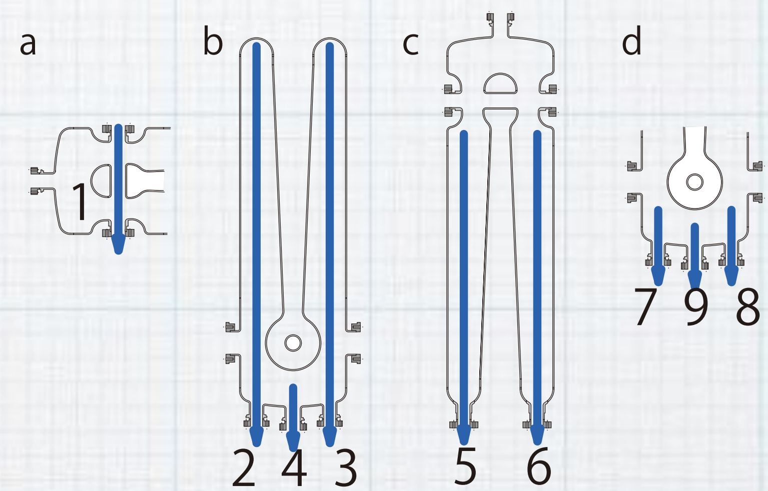
BCP1

Annealing



BCP2

HPR



Baking

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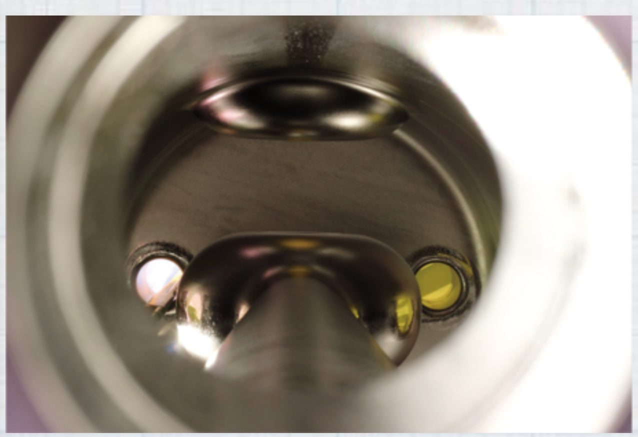
Stem



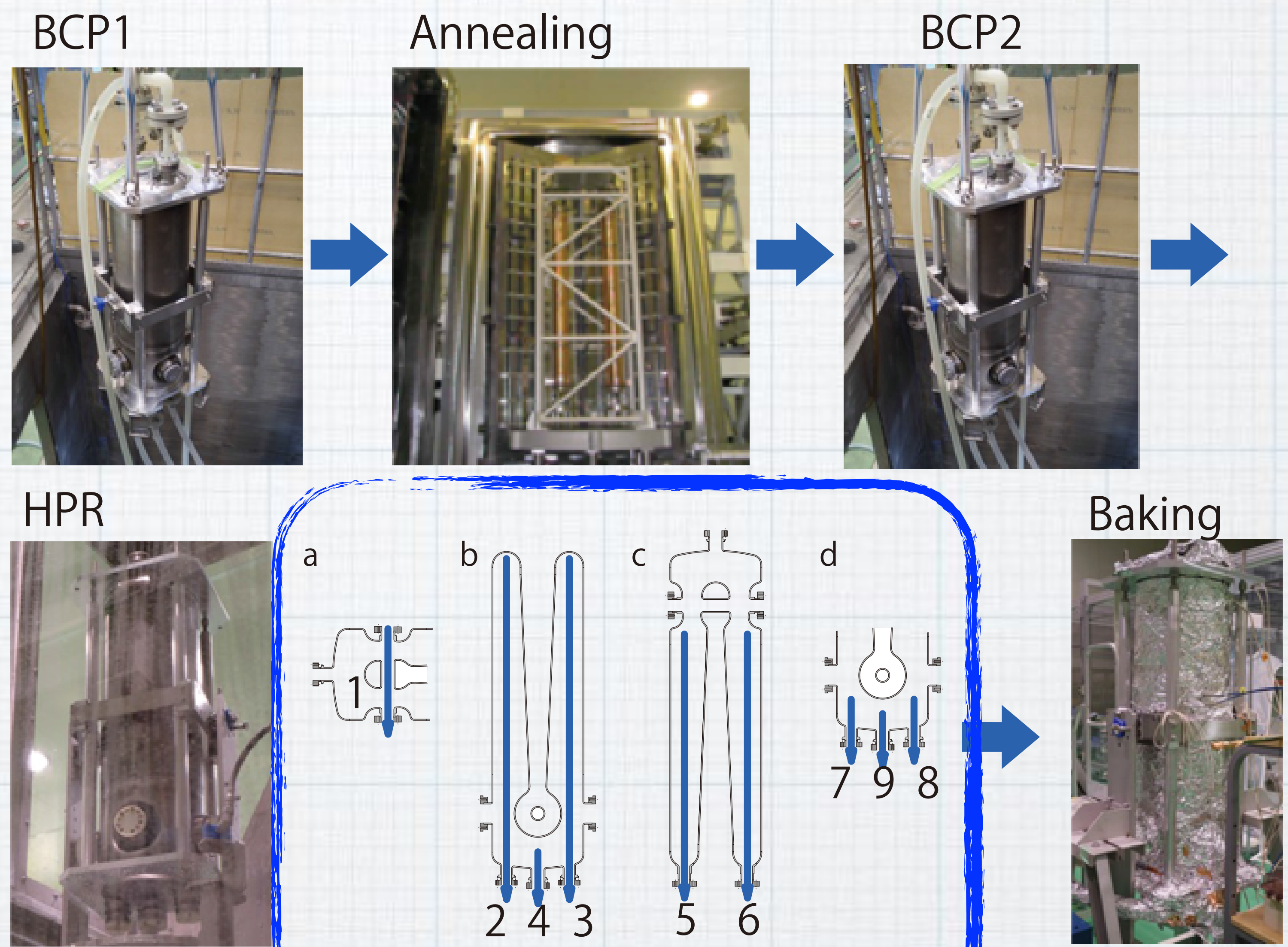
Rinsing port

End Drift Tube

Coupler port

Surface Treatment

- Surface treatment processes follow a fairly standard recipe.
- All the facilities for these processes are developed by MHI.
- Inspection of the inner surface was made carefully after BCP.
- A rotating jet nozzle scans the interior surface of the cavity in a predetermined pattern.



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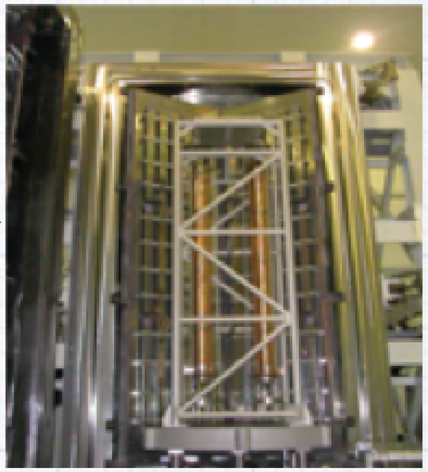
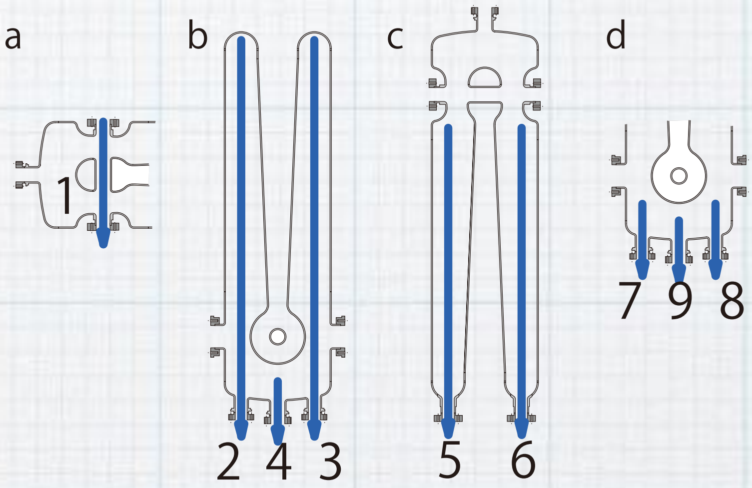
BCP1

Annealing

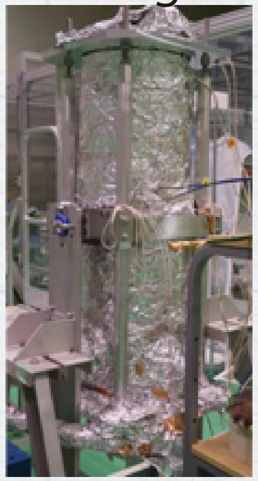


BCP2

HPR



Baking



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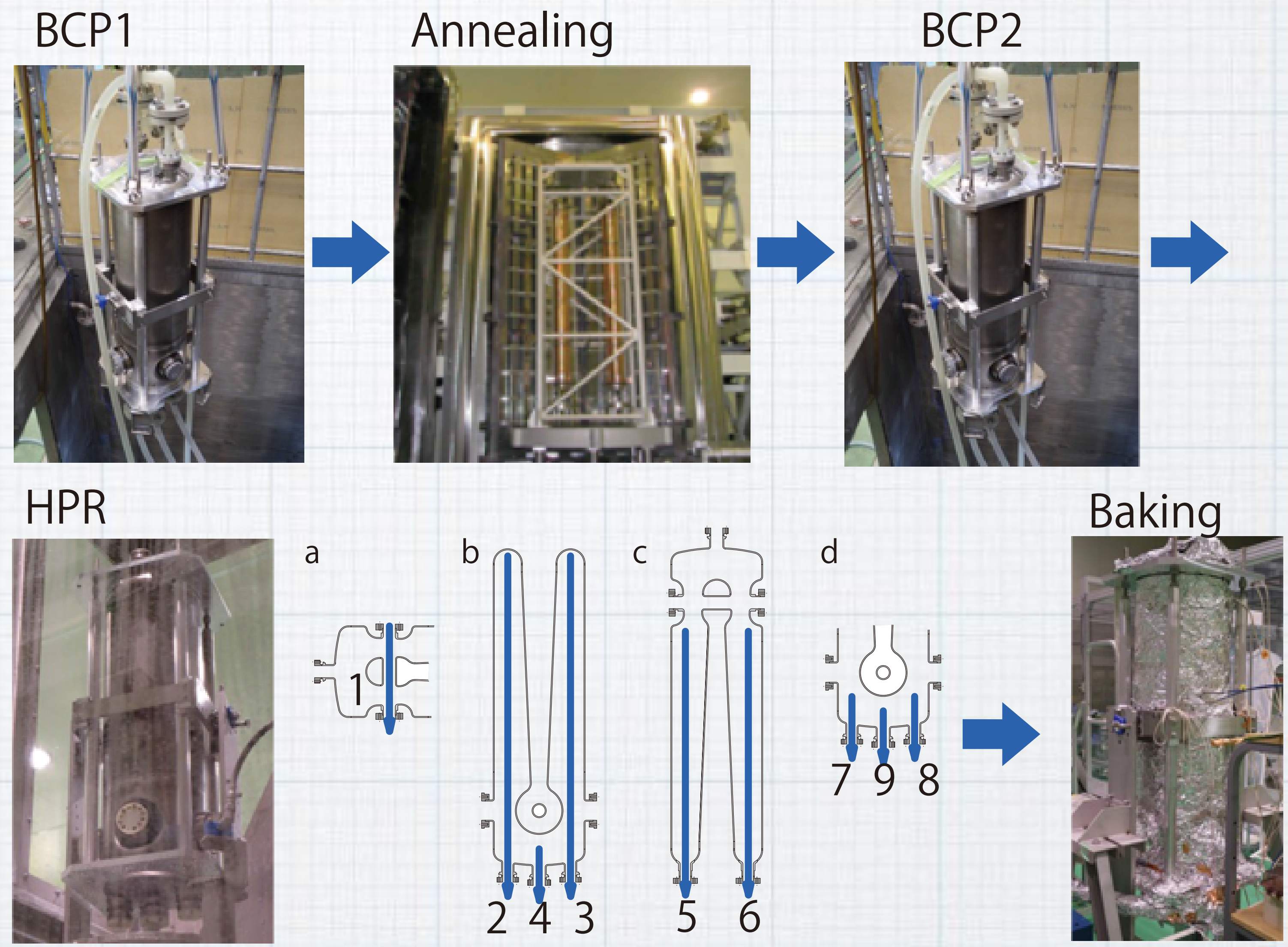
Each process was required to have feasibility test.

Surface Treatment

- Surface treatment processes follow a fairly standard recipe.
- All the facilities for these processes are developed by MHI.
- Inspection of the inner surface was made carefully after BCP.
- A rotating jet nozzle scans the interior surface of the cavity in a predetermined pattern.
- Processing was made for four times, and vertical test was performed at KEK after each cycle.



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VT #	BCP1 µm	Annealing	BCP2 µm	HPR	Baking
VT1	n/a	n/a	19.5	yes	120°C,48hrs
VT2	97.7	750°C,3hrs	23.0	yes	120°C,48hrs
VT3	n/a	n/a	21.9	yes	120°C,48hrs
VT4	n/a	n/a	n/a	yes	120°C,48hrs

Vertical Test Facility

■ We prepared the test infrastructure at AR-Higashi the 2nd experimental bldg. at KEK.

- *There was no pit at RIKEN!!* -

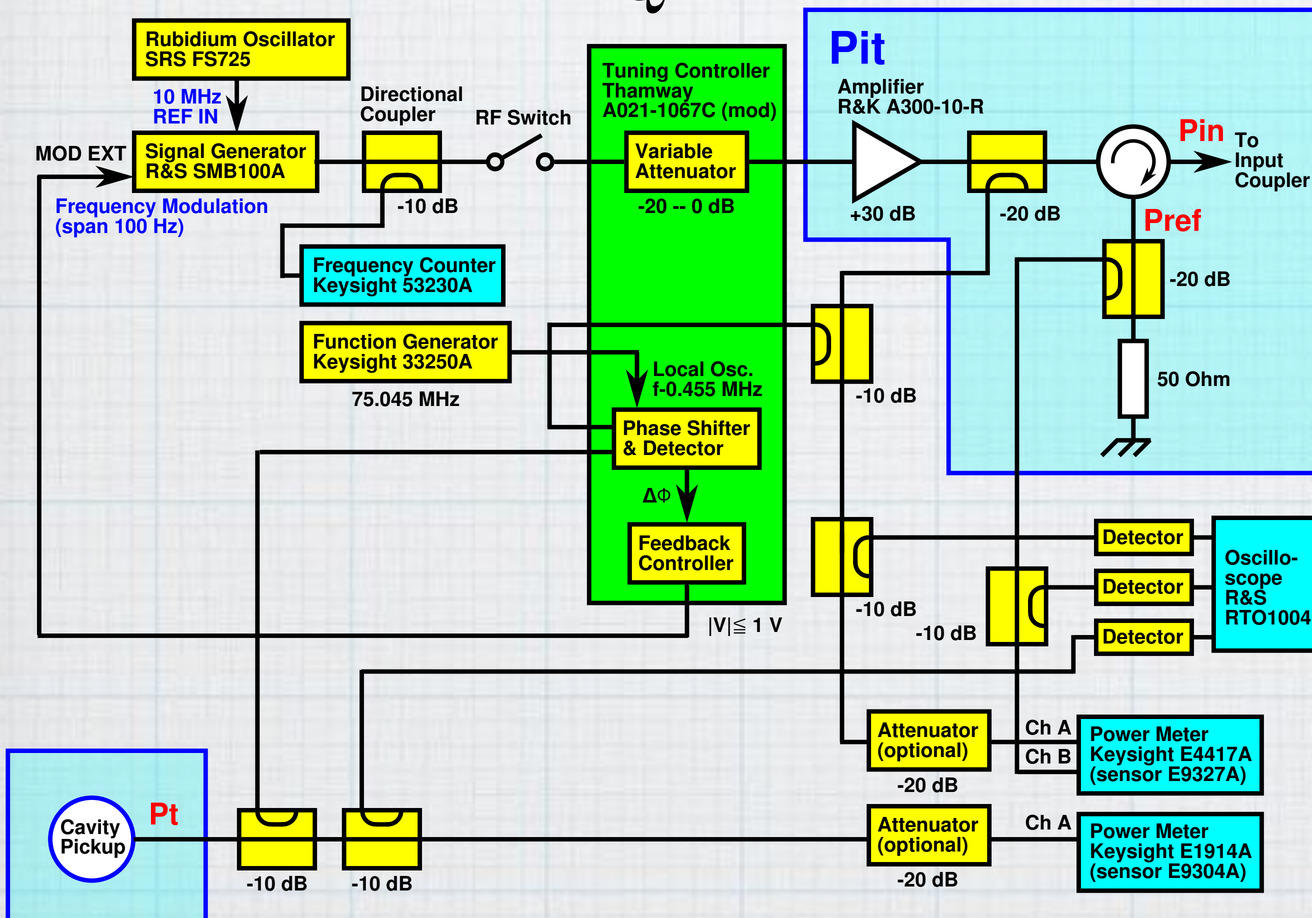
Vertical Test (Q_0 measurement)

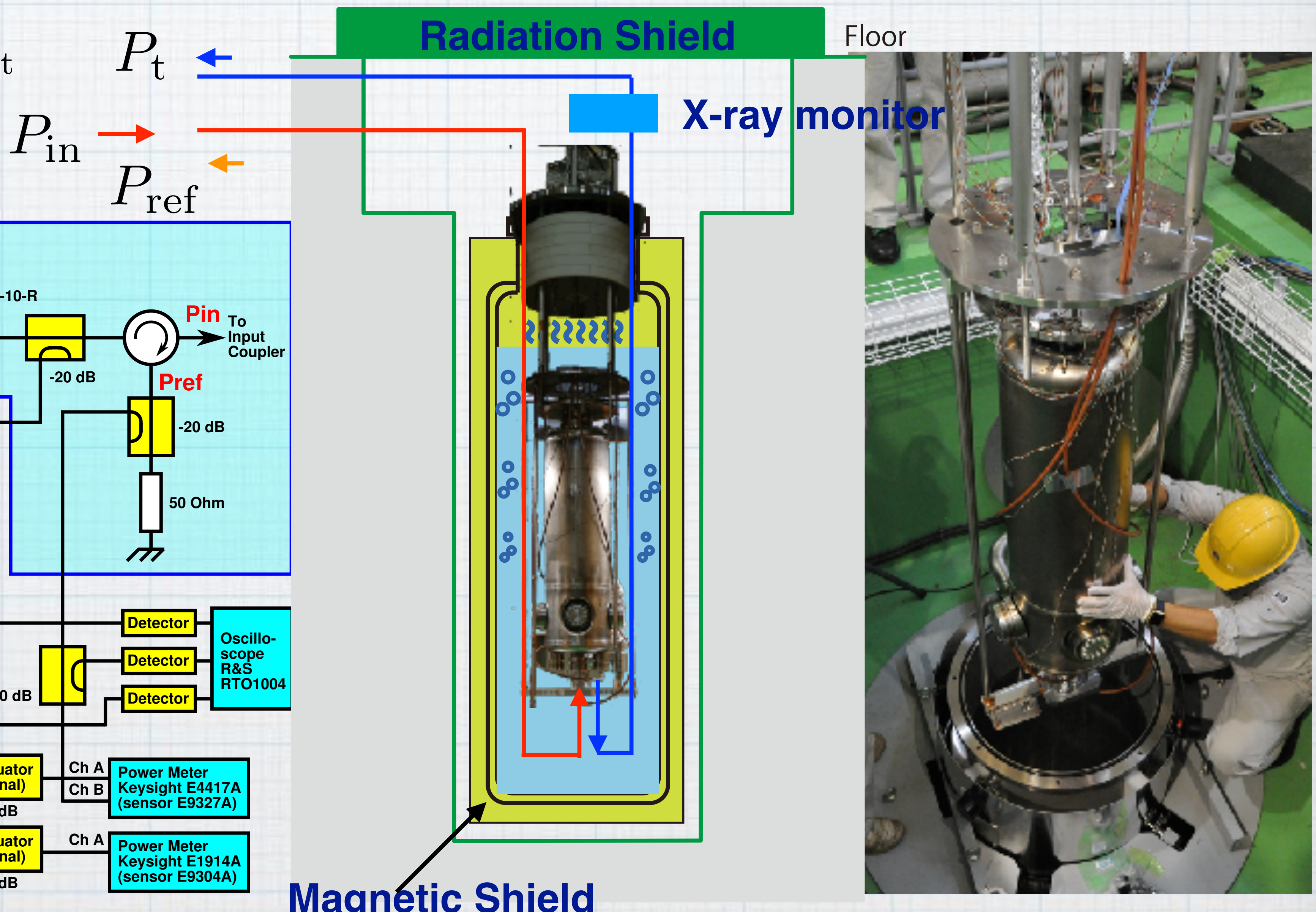
- After each processing, vertical test was performed.
- Q_{ext} was measured by observing the decay rate of P_t after rf power was turned off. Then Q_0 was extracted using the following formulas.

$$P_{\mathrm{in}} = P_0 + P_{\mathrm{ref}} + P_{\mathrm{t}}$$

$$1/Q_{\mathrm{in}} = 1/Q_0 + 1/Q_{\mathrm{ref}} + 1/Q_{\mathrm{t}}$$

$$U = U_0 \exp\left(-\frac{\omega t}{Q}\right)$$

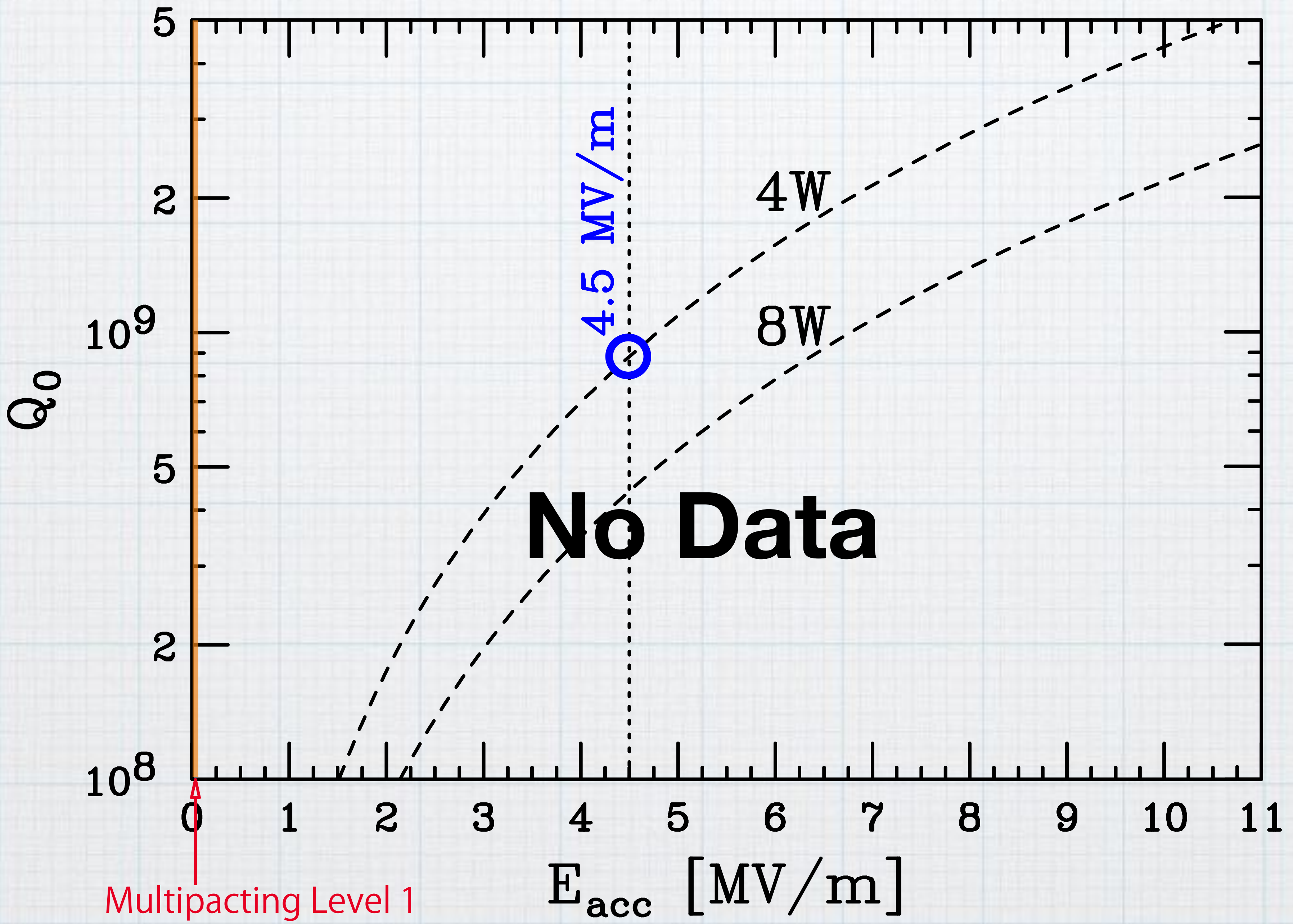




Vertical Test (Q_0 measurement)

VT1

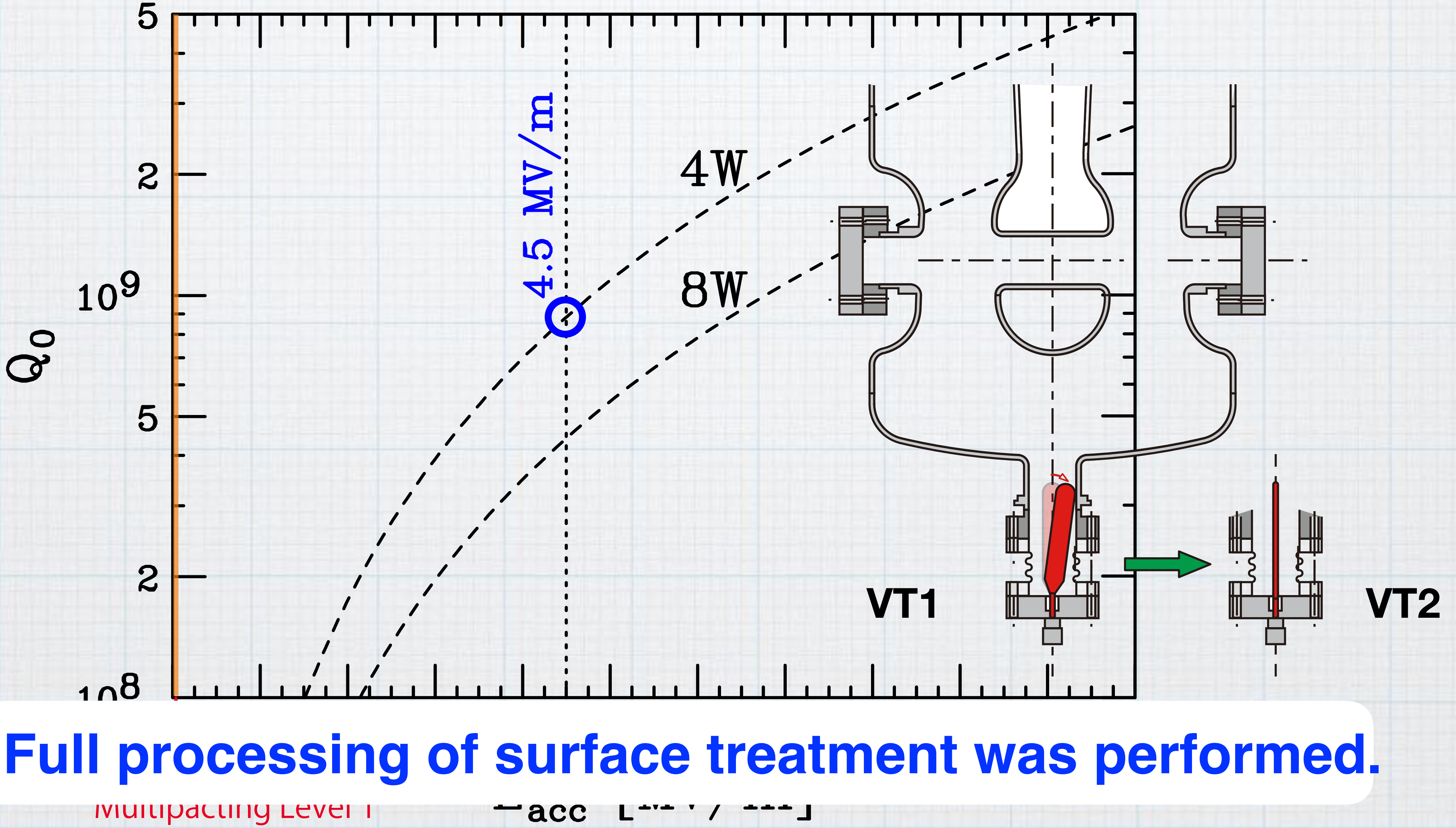
- No data were taken.
- Multipacting at very low level could not be overcome.



Vertical Test (Q_0 measurement)

VT1

- No data were taken.
- Multipacting at very low level could not be overcome.
- There found a trouble with a power coupler.

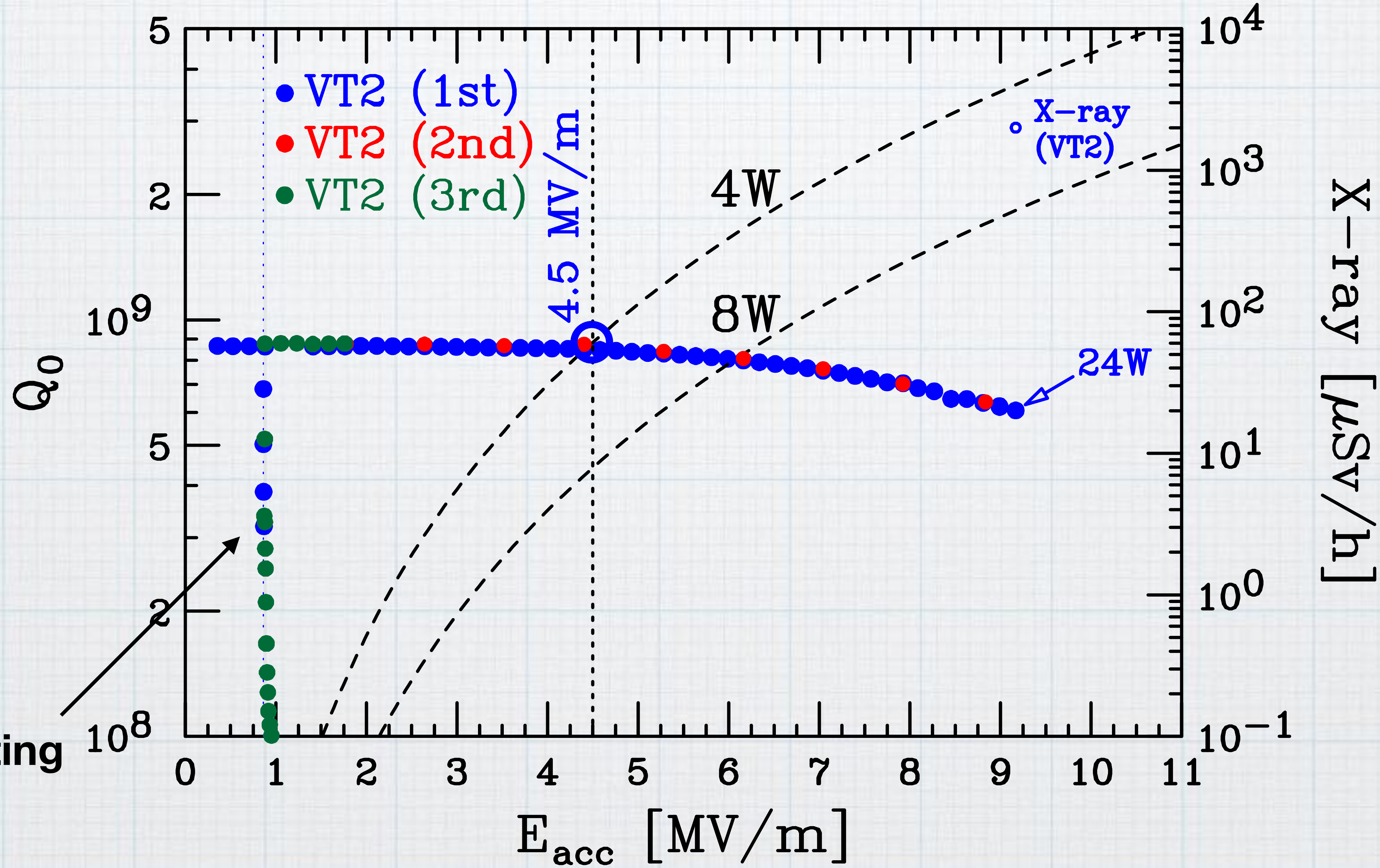


→**Full processing of surface treatment was performed.**

Vertical Test (Q_O measurement)

VT2

- Q_O of 8.7×10^8 was obtained at E_{acc} = 4.5 MV/m. Rs = 27 nΩ
- No X-ray emission was observed blow 9 MV/m.
- Multipacting at 0.9 MV/m was observed.



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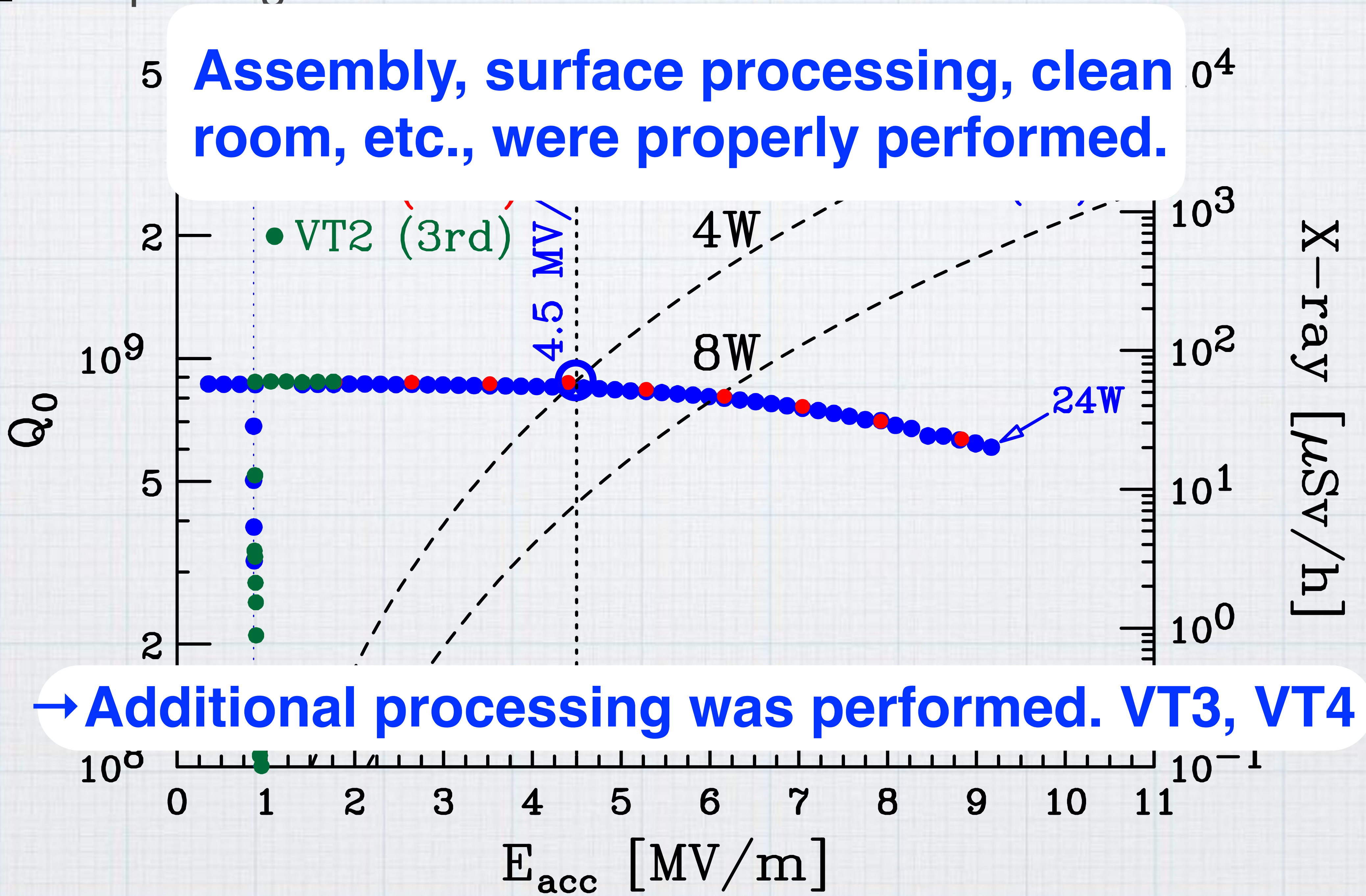

Vertical Test (Q_0 measurement)

VT2 Q_0 of 8.7×10^8 @4.5 MV/m

VT3 **Q0 fell to 54% of VT1.**

VT4 X-ray emission was suppressed.

VT #	BCP1 μm	Annealing	BCP2 μm	HPR	Baking
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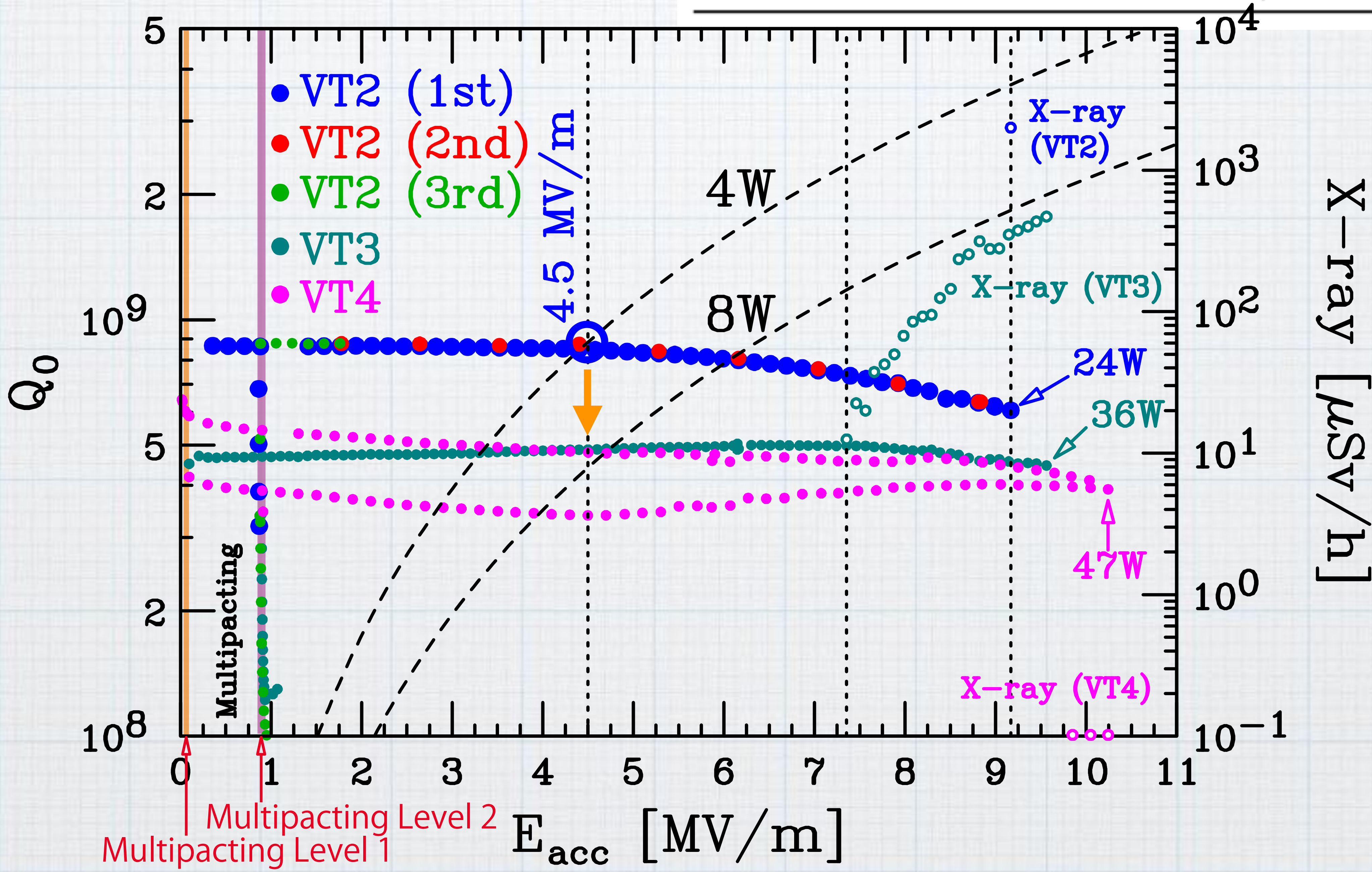
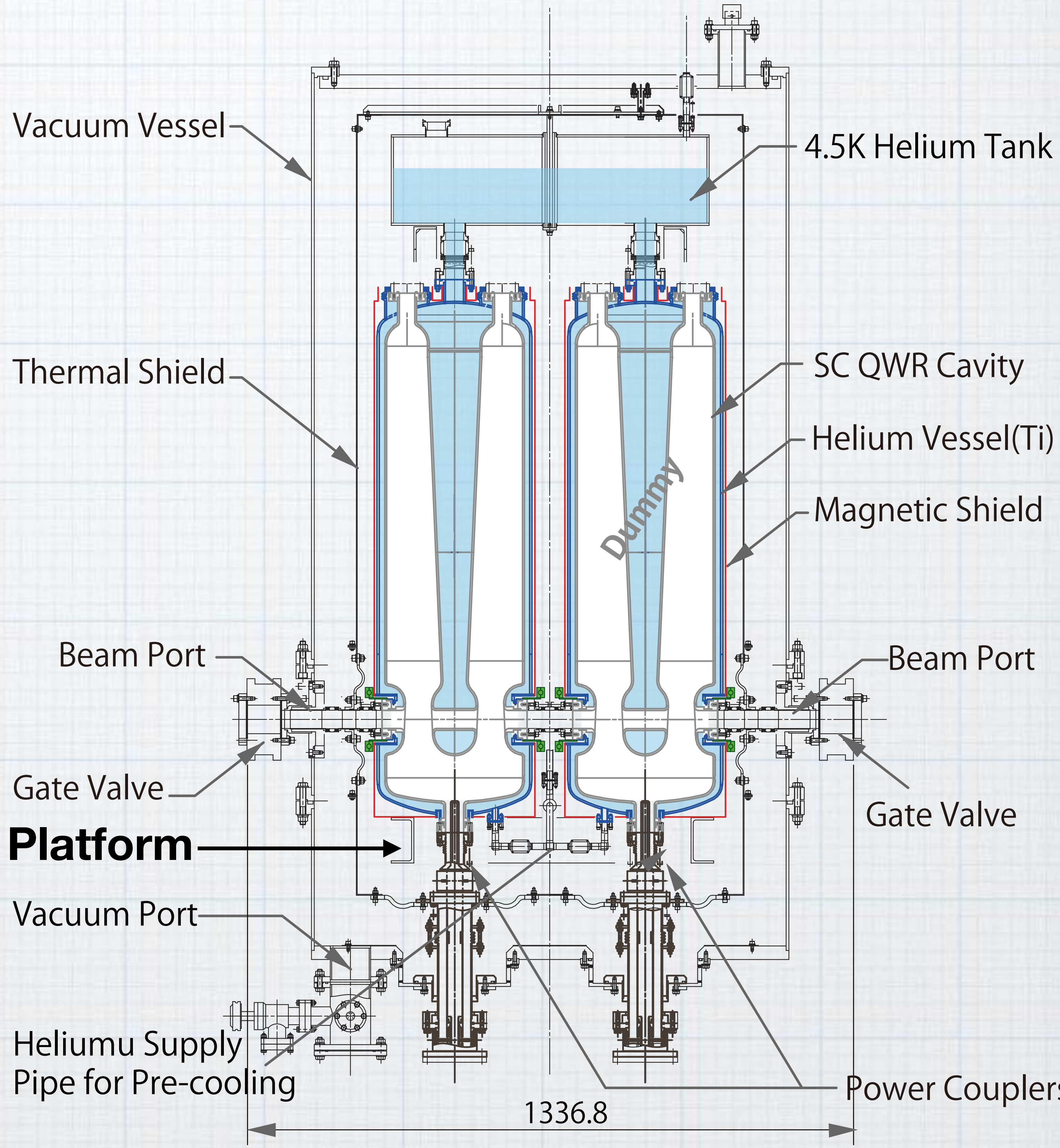
VT2	97.7	750°C,3hrs	23.0	yes	120°C,48hrs
VT3	n/a	n/a	21.9	yes	120°C,48hrs
VT4	n/a	n/a	n/a	yes	120°C,48hrs



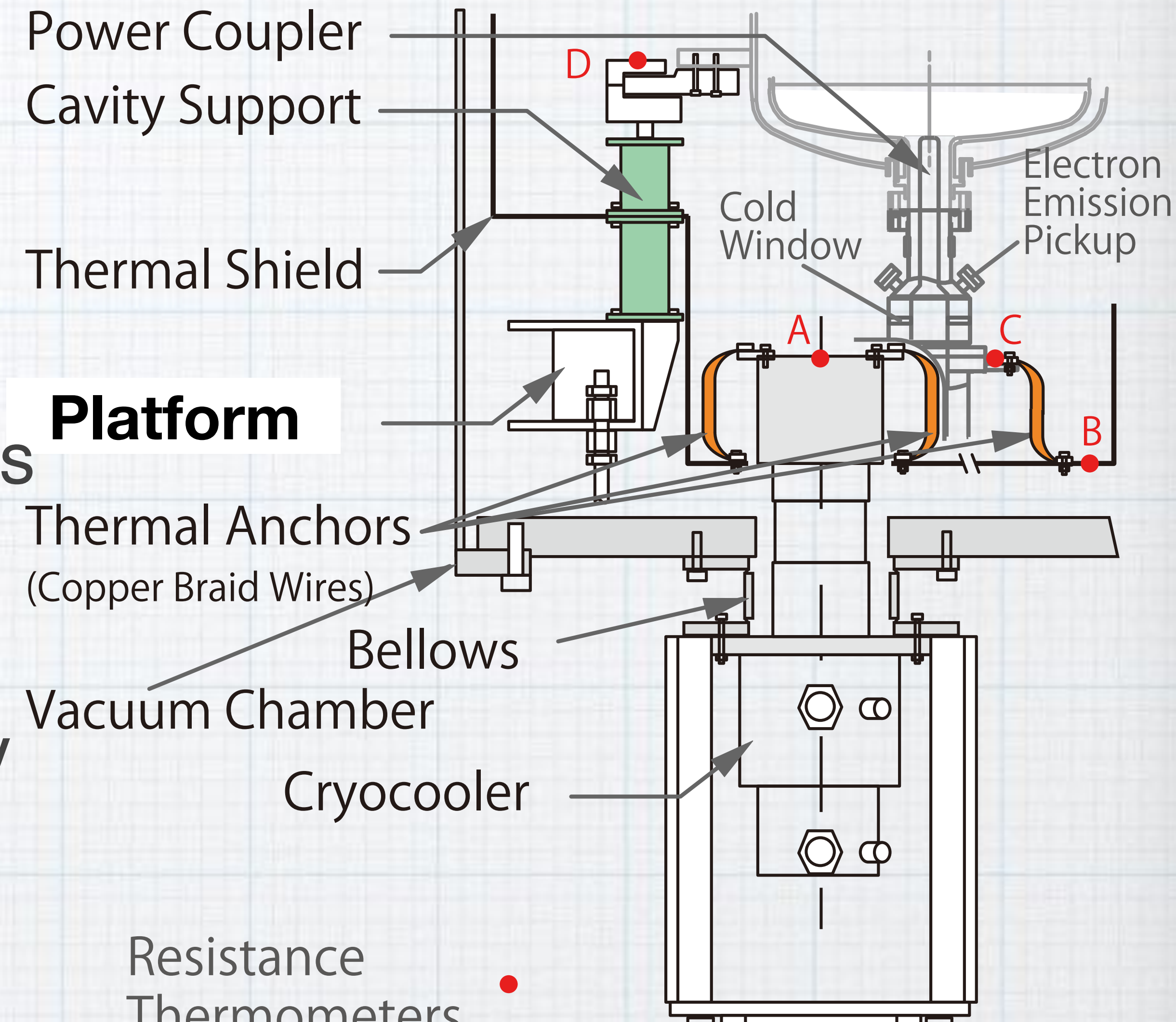
Cryomodule

- The manufactured prototype cavity was installed together with a dummy cavity.
- The cavity is enfolded in the helium jacket made of titanium.
- The cavity is installed on the basis of the bottom platform.
- The thermal shield is cooled by Cryocooler.
- After assembly the cryomodule was transferred to RIKEN.
- The cavity was successfully cooled to 4K.



Cool-Down Test of the Cryomodule at RIKEN

- The cyocooler is connected with the thermal shield by copper braid wires.
- The thermal shield intercepts the cavity support to reduce heat flow from RT.
- The temperature of the thermal shield was rather high as 70K-100K while the temperature of the cold head was 40K.
- The sc-cavity was successfully excited by both SEL mode and GD mode up to 4.5 MV/m without X-ray emission.
- Wall loss was estimated from the falling rate of liquid helium level of the buffer tank as **13 W**. (From the result of VT4 7W!!)
- No vibration effect by the cryocooler for the thermal shield was observed.
- 7-8 Hz modulation of the pickup signal was observed.



Cool-Down Test of the Cryomodule

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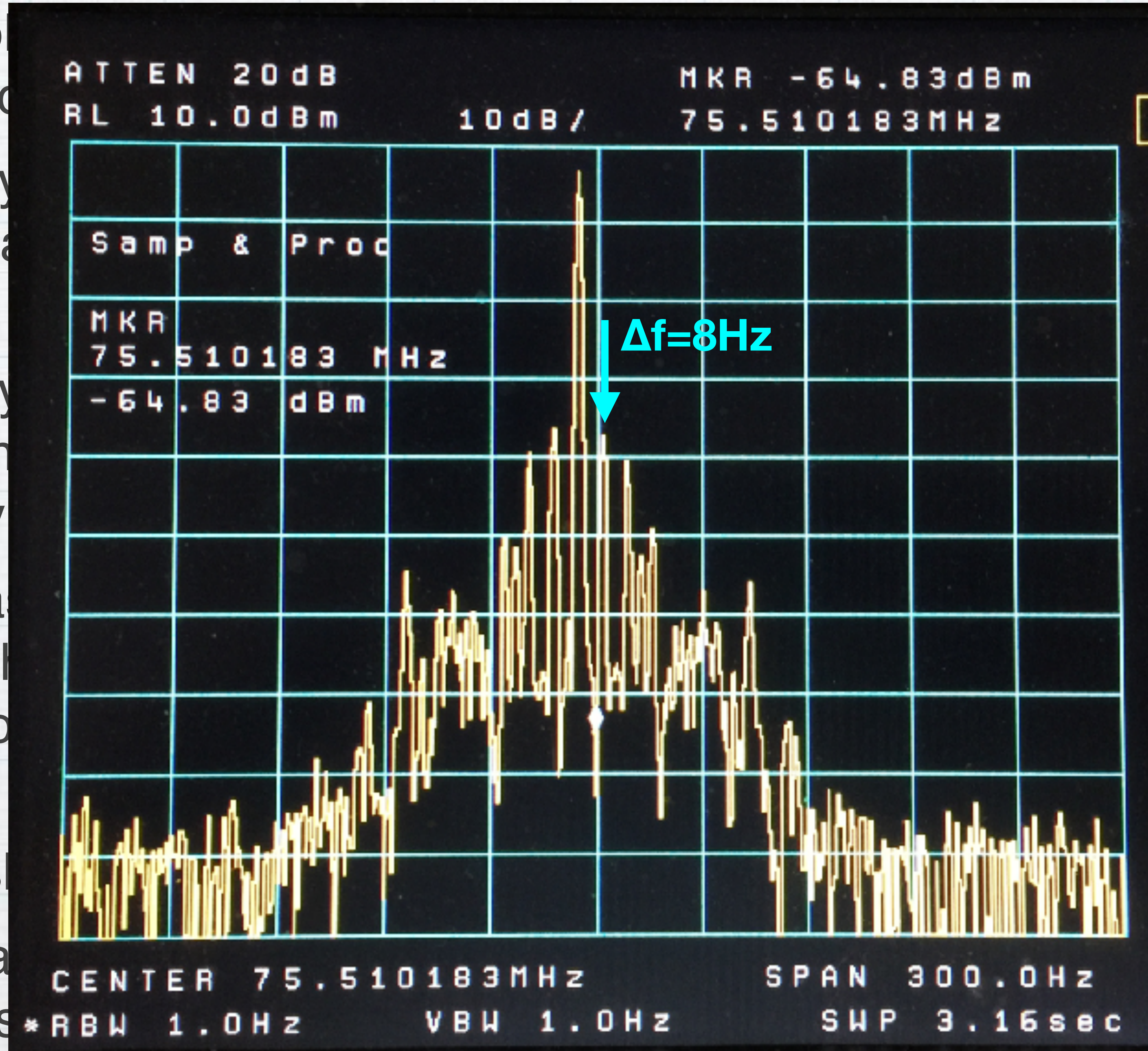

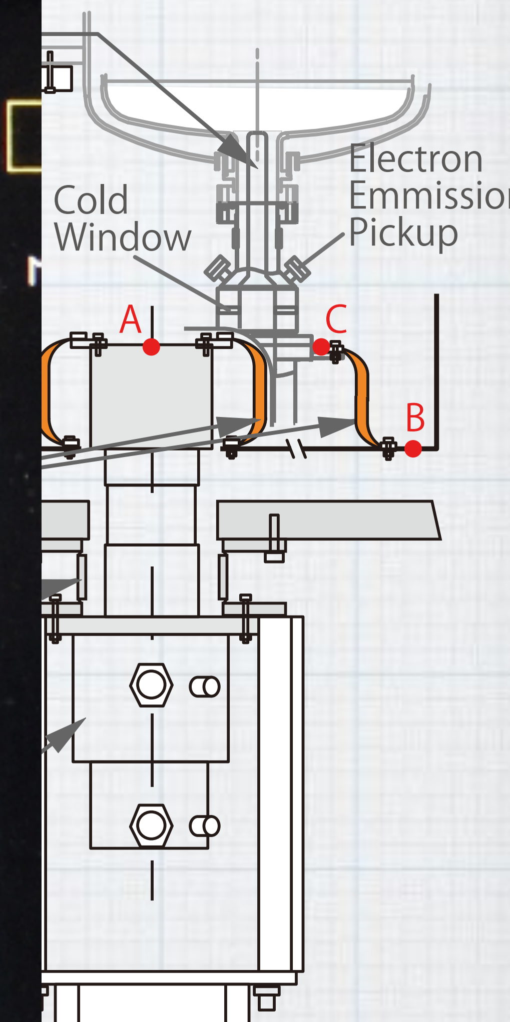

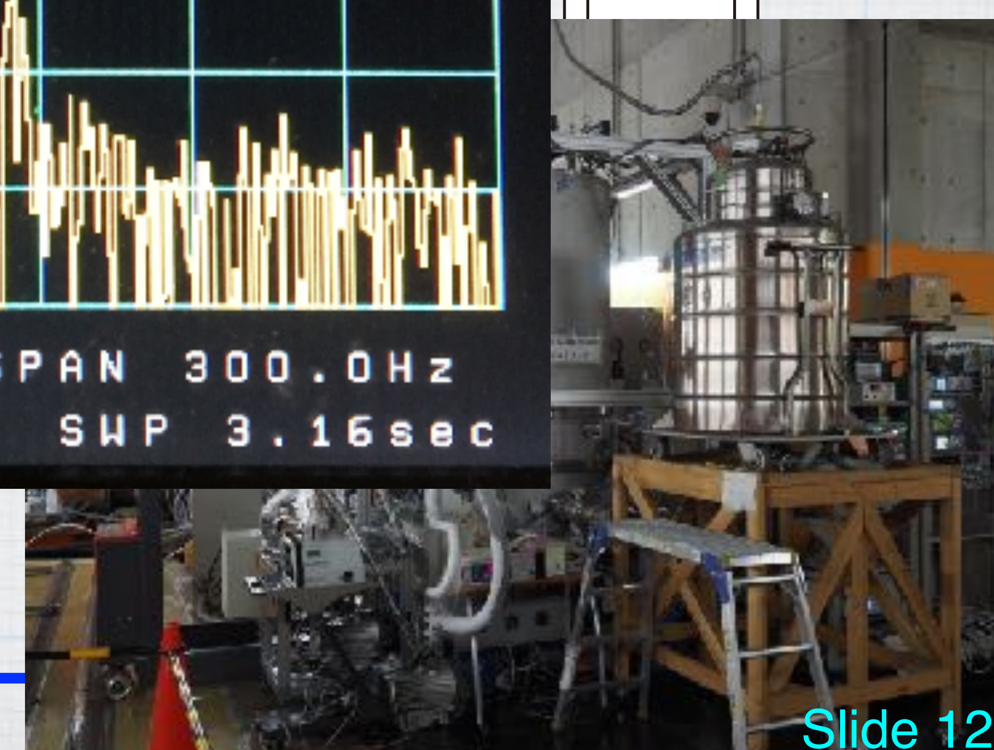

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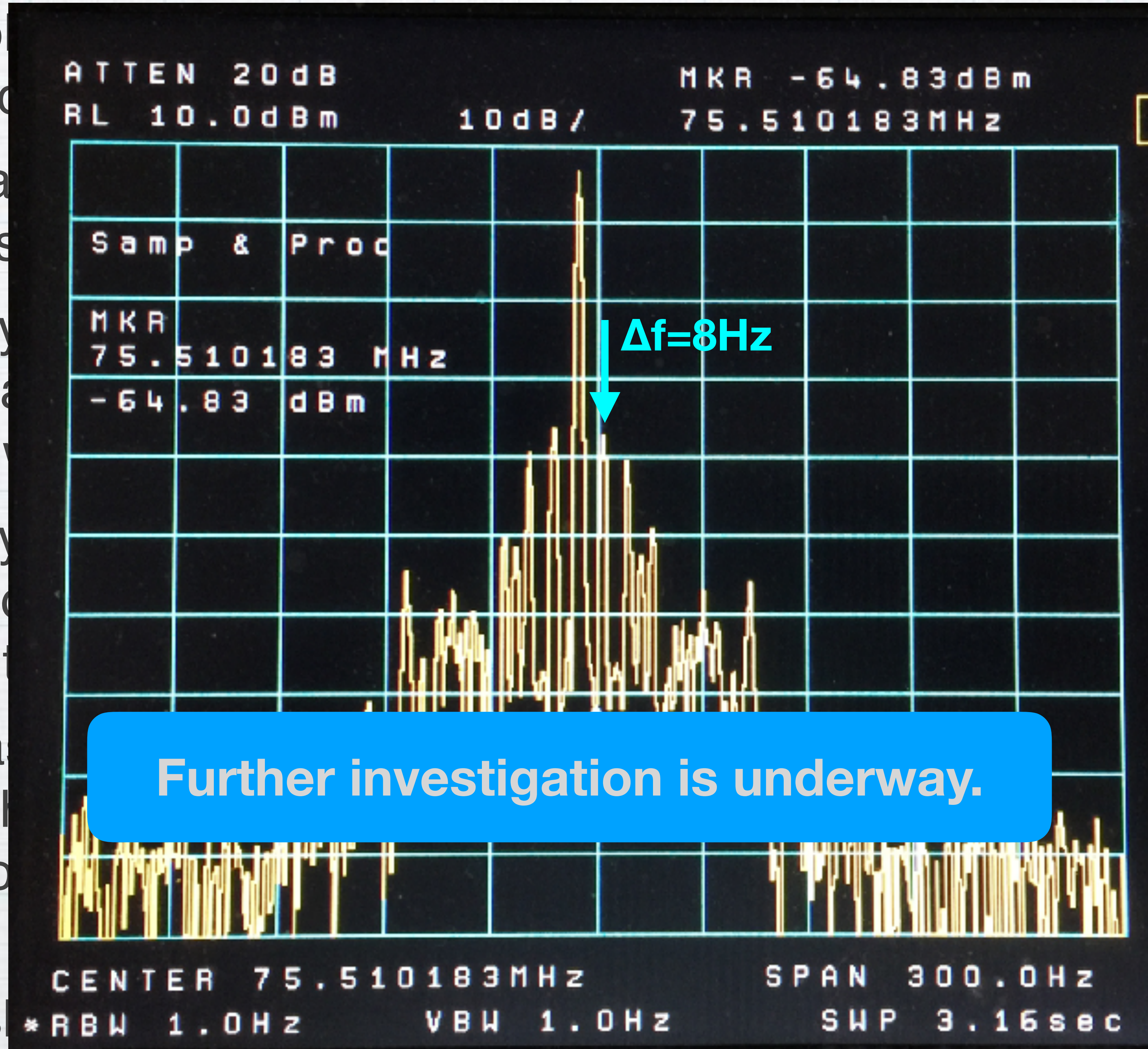
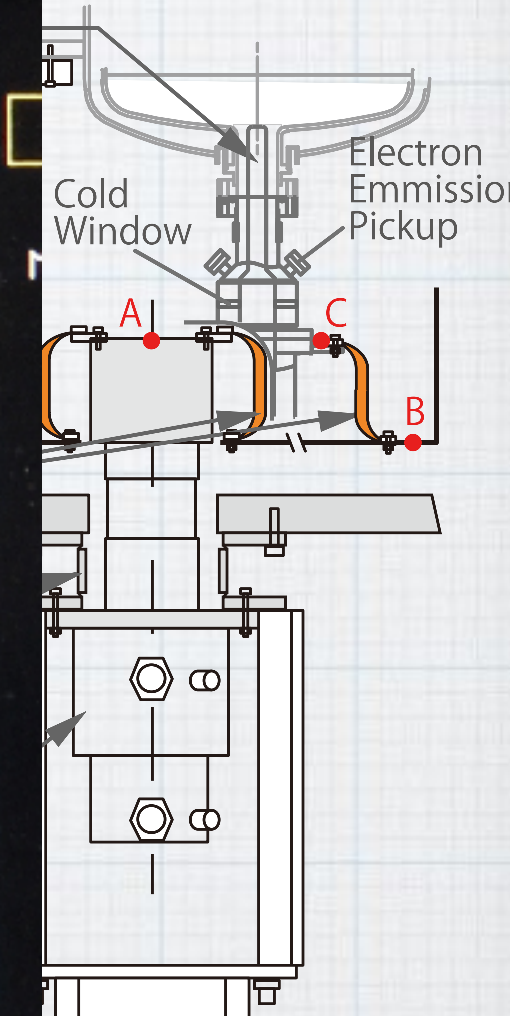


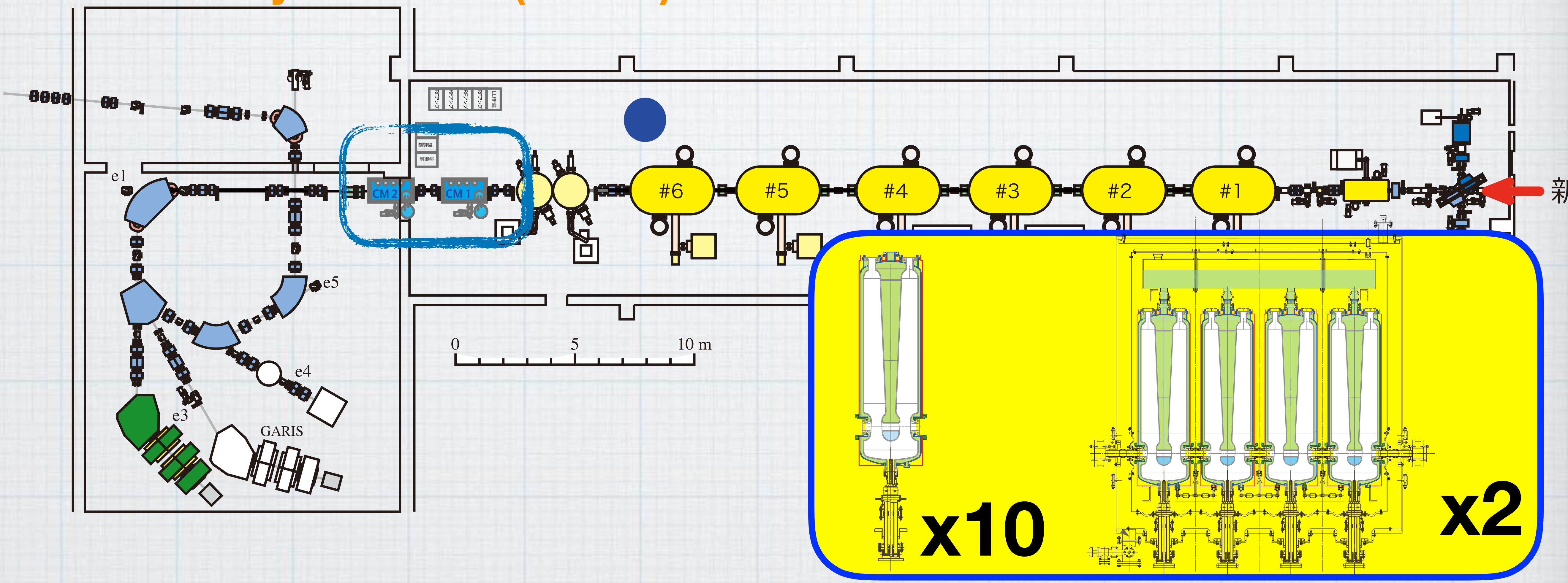
Further investigation is underway.



Upgrade of the RIKEN Heavy Ion LINAC (RILAC)

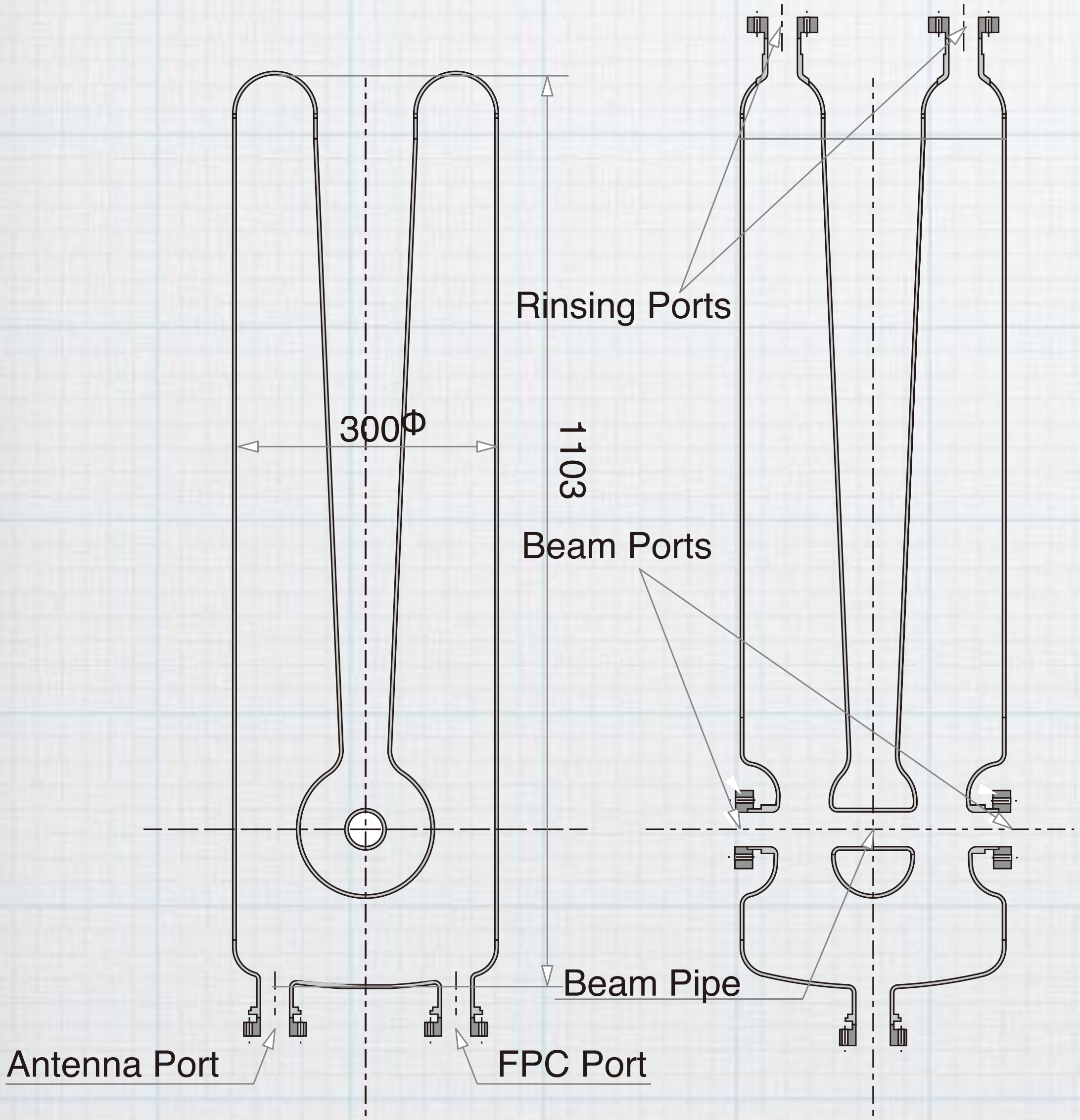
- Based on what we have learned with the development of the QWR, we are proceeding with the upgrade of the RIKEN Heavy Ion Linac (CW).
- Ten SC-QWR cavities operating at 4.2 K will be manufactured, and two cryomodules will be constructed.

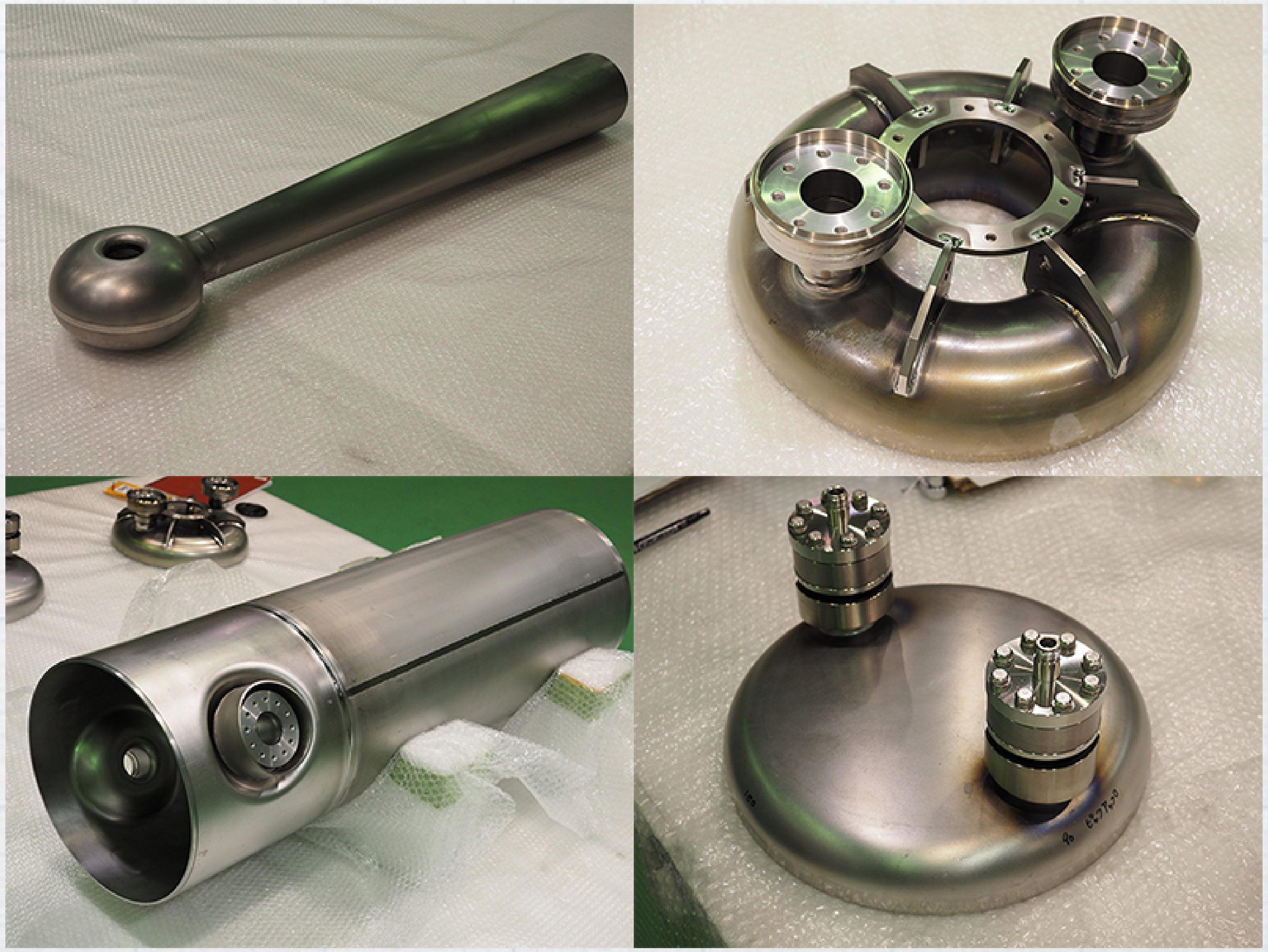
RIKEN Heavy Ion Linac (RILAC)



QWRs for the RIKEN LINAC Upgrade

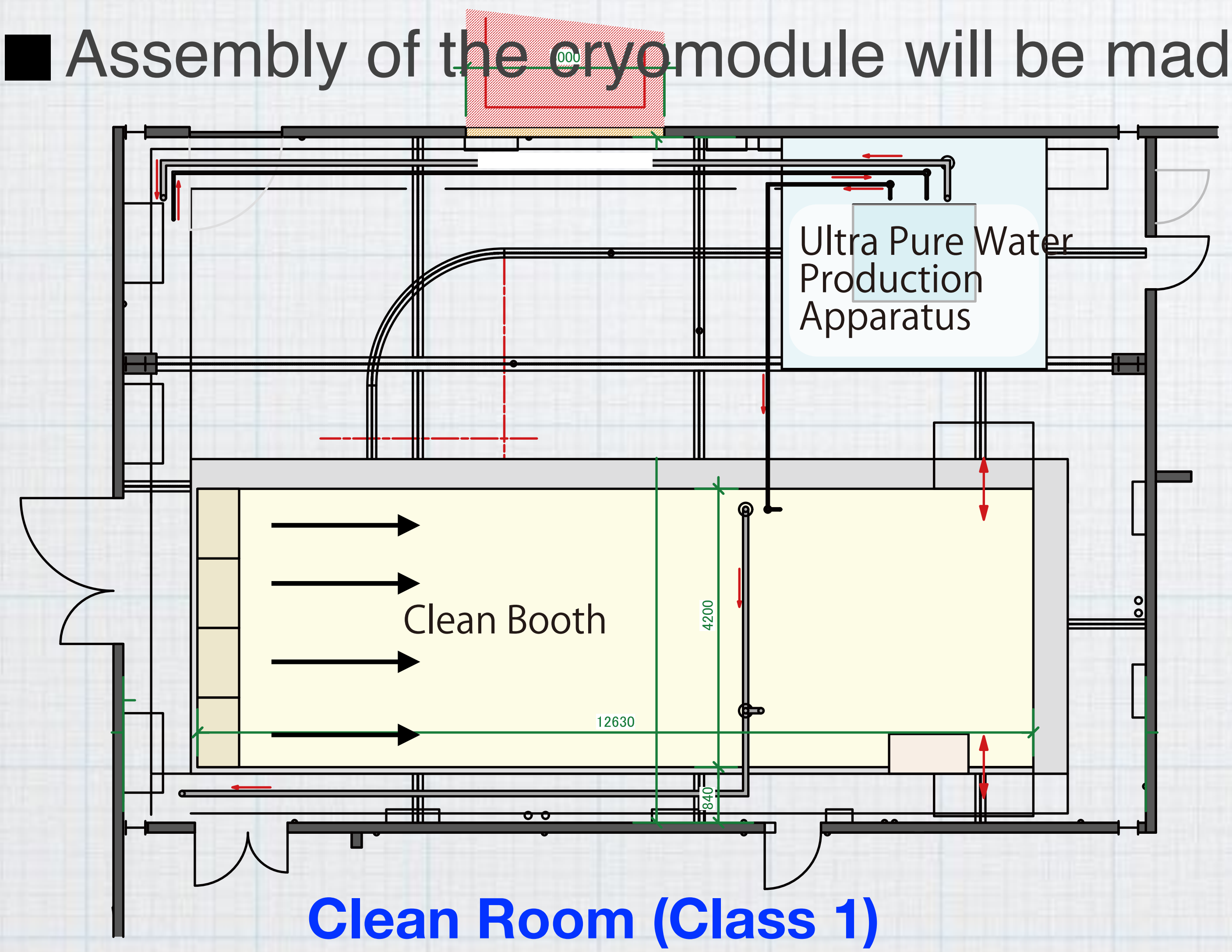
- QWRs with a frequency of 73 MHz instead of 75.5 MHz will be made.
- The size of the cavity was modified according to the frequency.
- The first prototype cavity is under construction prior to series of the ten cavity production.
- The first VT of the prototype cavity is scheduled in October 2017 at KEK.



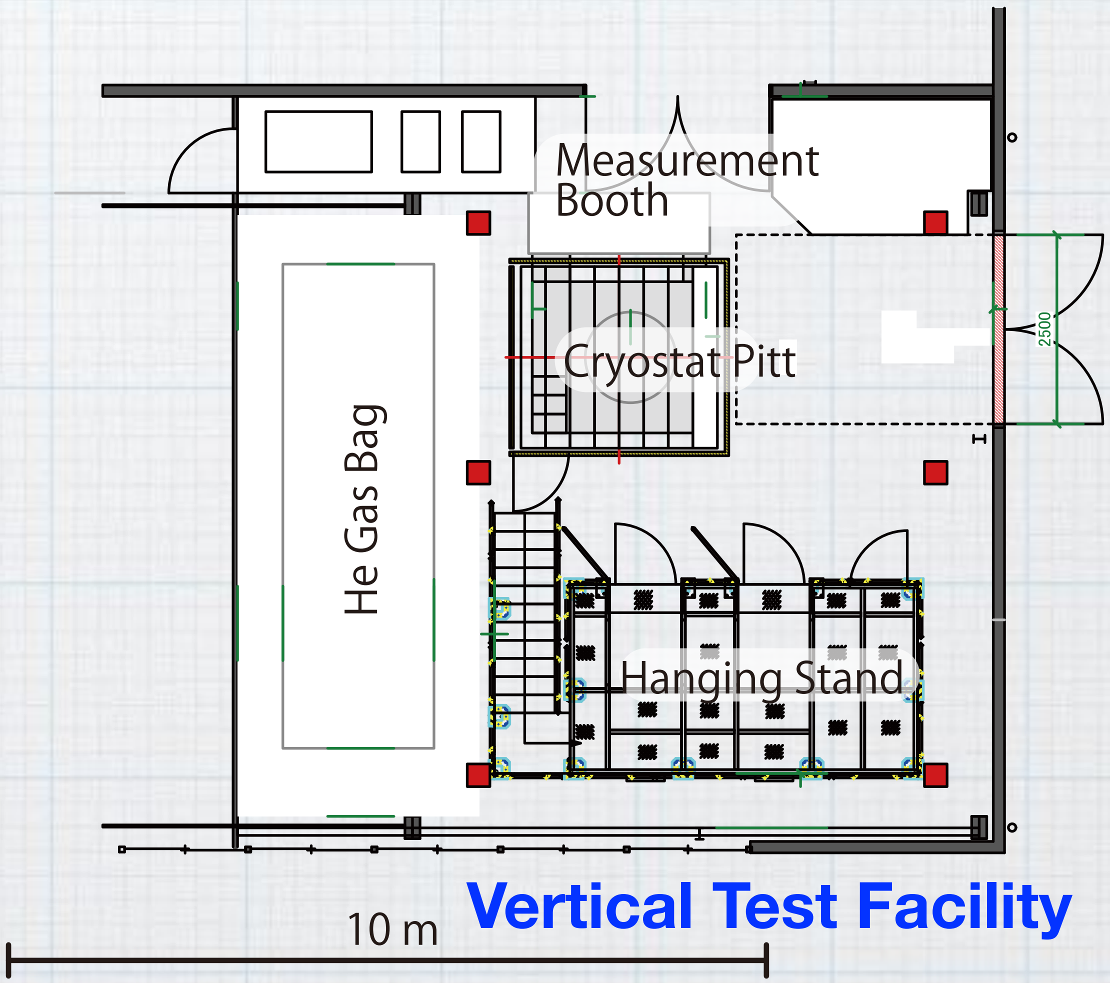


SRF Facility in RIKEN

- To accept ten sc-cavities a VT facility and a Clean Booth (class 1) utilizing horizontal Laminar flow system (TUPB096, A. Miyamaoto)are under construction in the existing building in RIKEN Wako cite.
- Ten cavity is planned to be tested at the facility at RIKEN in the next year.
- Clean room is planned to be ready in the end of this year together with rinsing system with ultra pure water.
- Assembly of the cryomodule will be made at RIKEN.



Clean Room (Class 1)



Vertical Test Facility

Summary

- The prototype cryomodules based on SC-QWR was developed.
- The SC-QWR is a bulk niobium cavity and its process of manufacturing and surface treatment was successfully made.
- At the vertical tests, though the Qo consistent with the original design was obtained once, after that Q_O became small.
- Cooldown test with the prototype cryomodule is underway.
- Upgrade of the RILAC is in progress aiming to start the SHE experiment in FY2019.

Acknowledgement

Development of a prototype superconducting resonator and its cryomodule was funded by the ImPACT Program of the Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

Thank you for your attention.