# Latest results of treating and testing the RAON HWR SRF cavities

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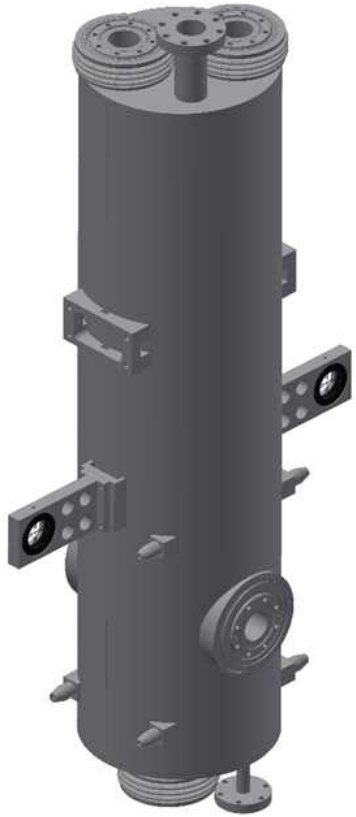
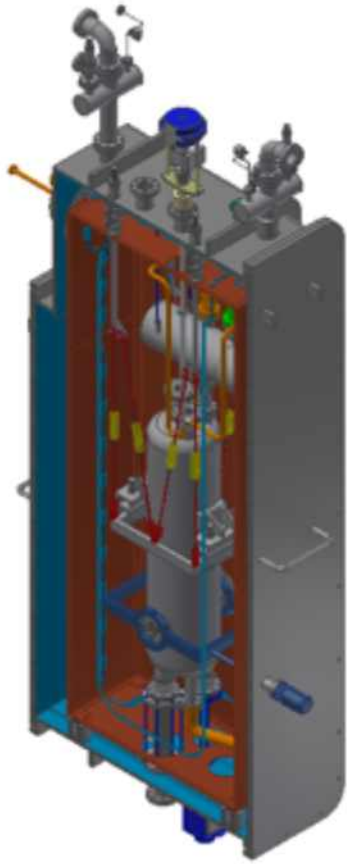
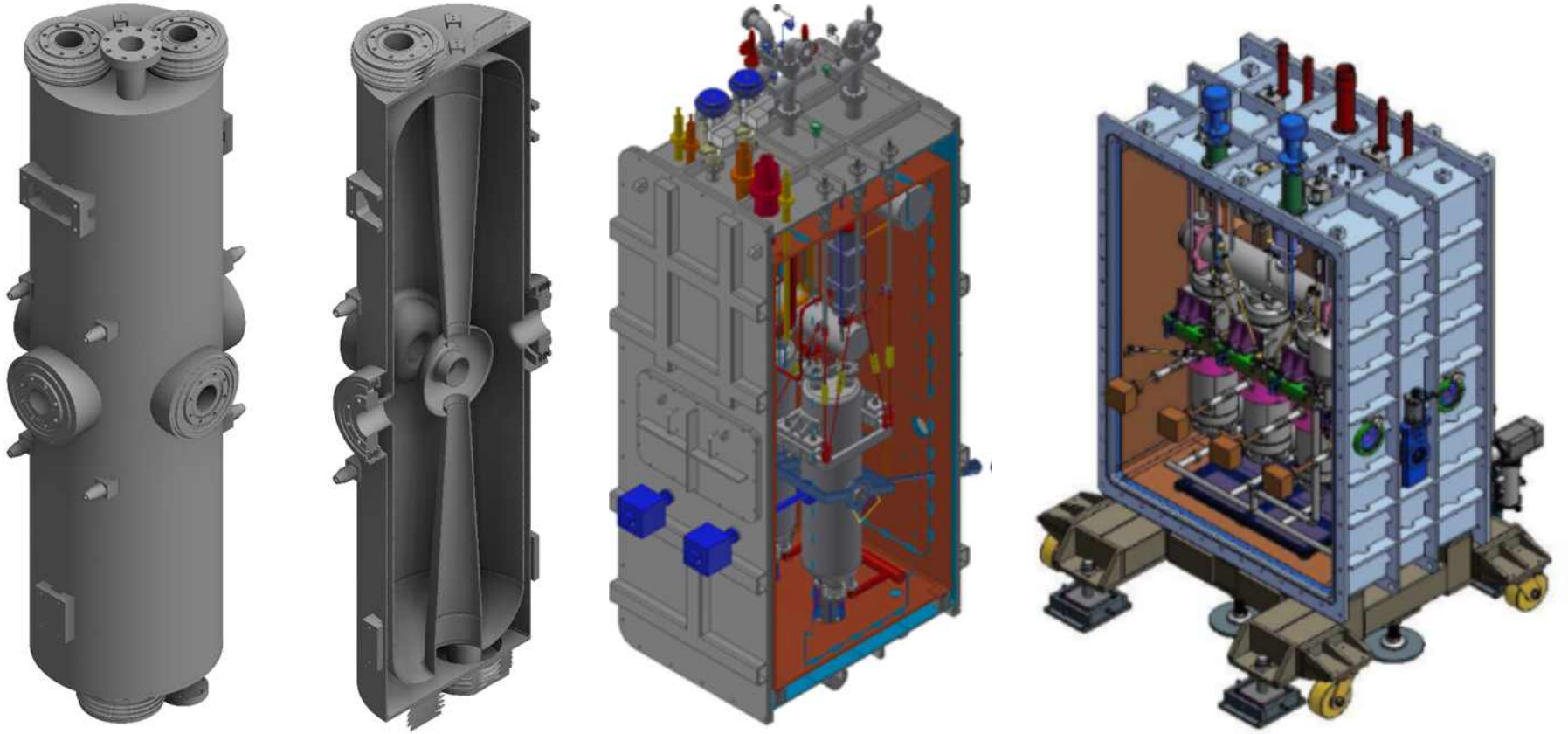
# Design of quarter-wave resonator cryomodule





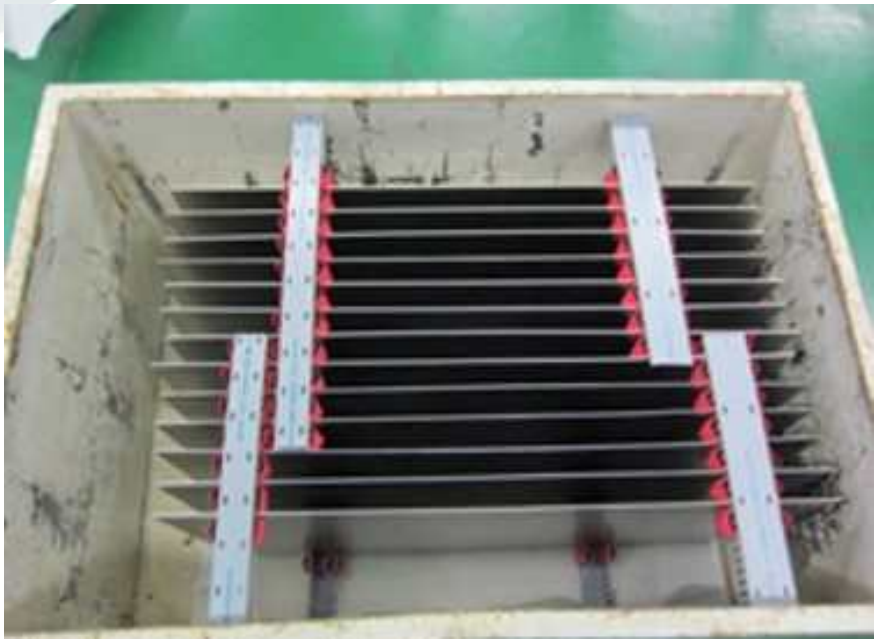
# Design of half-wave resonator cryomodules



# Fabrication process

- Processes for manufacturing QWR and HWR are follows:
  1. Raw material
  2. Single and sub parts
  3. Stack-up test
  4. Electron beam welding
  5. Fabricated bare cavity
  6. Ultrasonic cleaning
  7. Buffered chemical polishing
  8. Inspection for inside of the cavity
  9. High temperature baking
  10. High pressure water rinsing
  11. Vertical test
  12. Frequency change
  13. Cryomodules

# Inspection of Nb raw material



Picture of Nb raw material

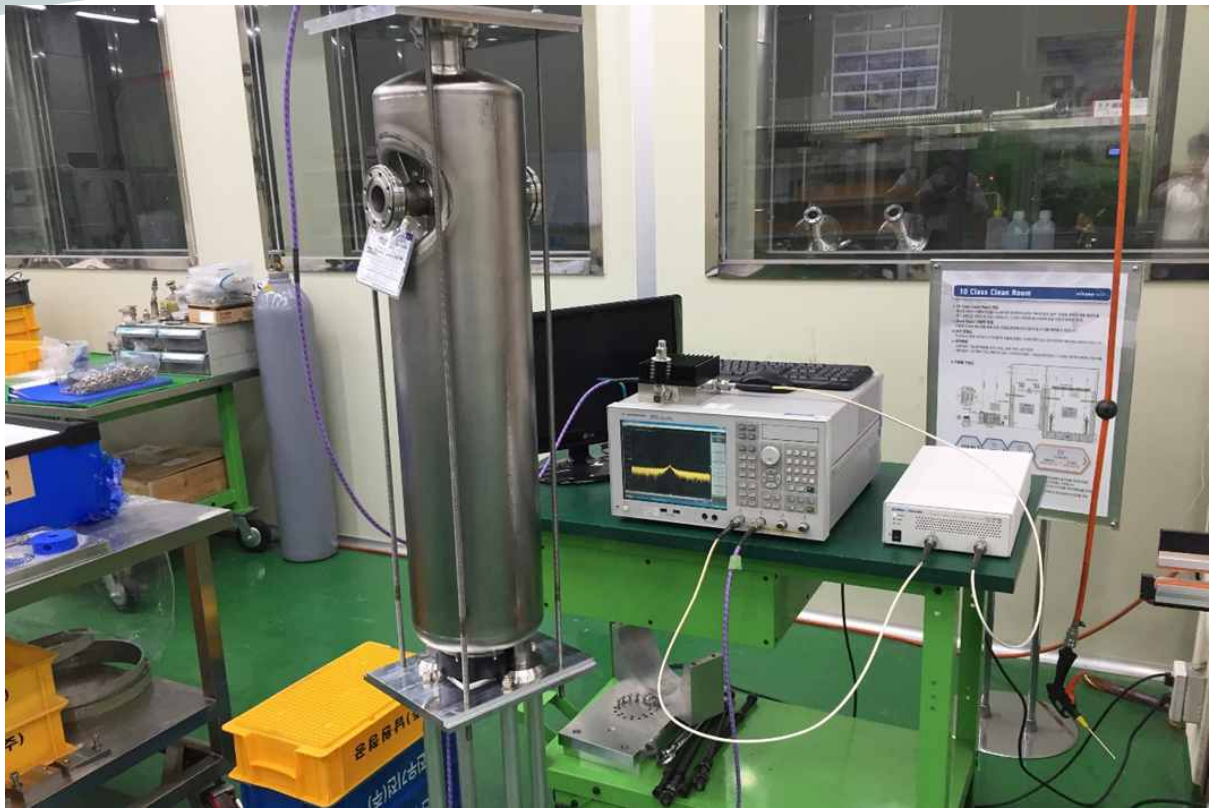
- RRR 300 grade niobium is used for superconducting cavities.
  The thickness of Nb sheet is 3 mm.
  Dimensions, mechanical properties, and electrical properties are checked.

# Single and sub parts

Picture of cavity components

- Single and sub parts are made by EDM wire cutting, deep drawing, press forming, and brazing.

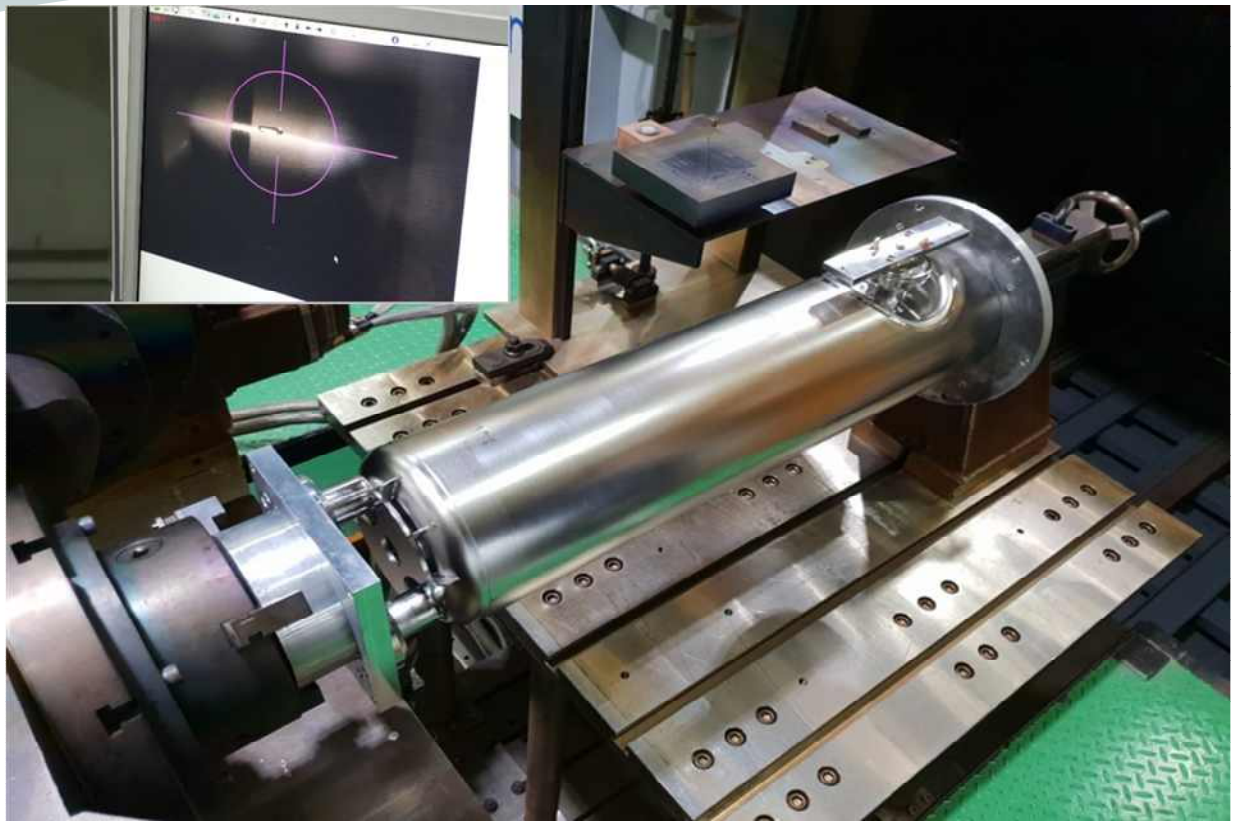
# Stack-up test



Stack-up test showing clamp up assembly

- Resonance frequency is checked in stack-up test.

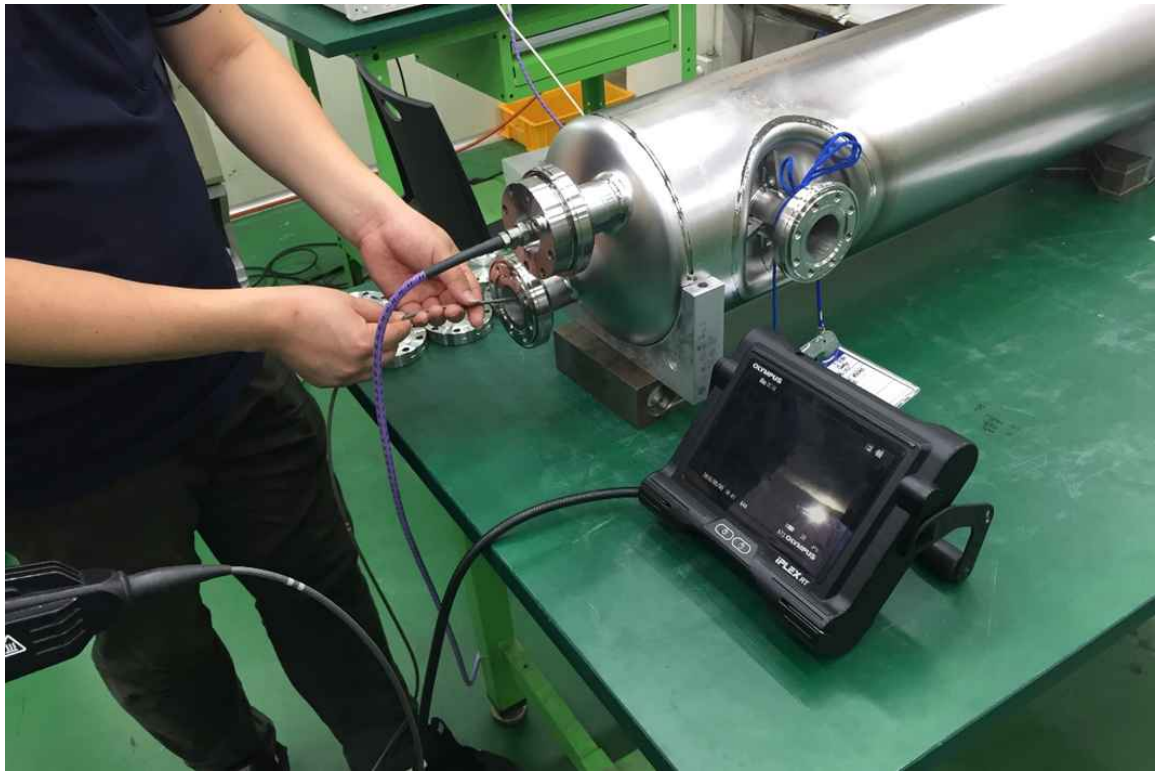
# Electron beam welding



Electron beam welding

- Vacuum pressure should be below $10^{-6}$ mbar for electron beam welding. Welding shrinkage needs to be considered.

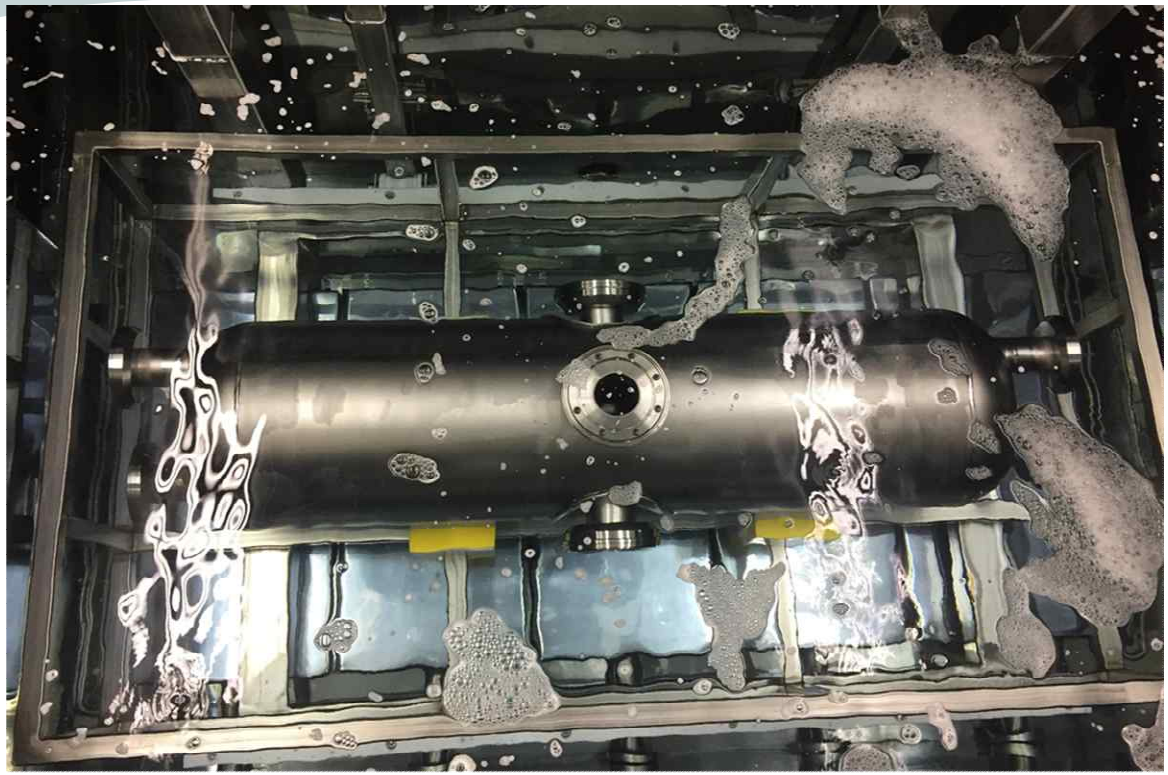
# Fabricated bare cavity



Fabricated bare cavity

- Visual inspection is performed for weld beads.
  Dimension and frequency are checked.
  Leak test is performed.

# Ultrasonic cleaning

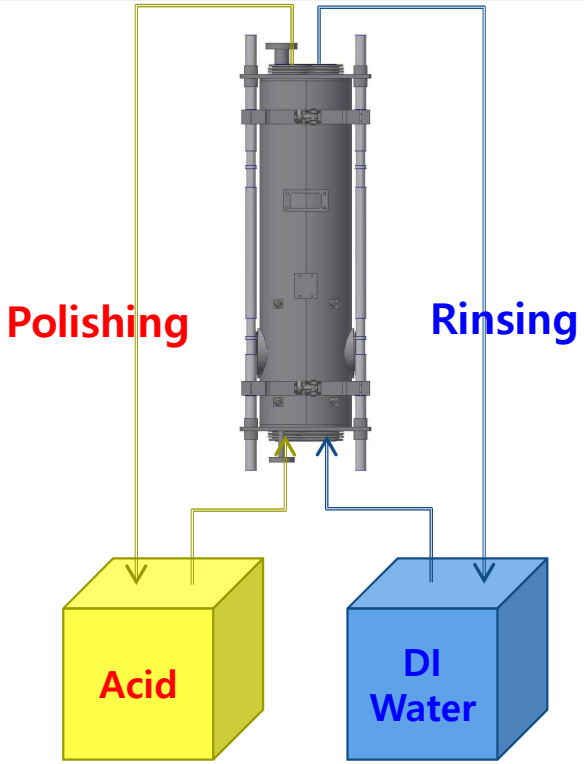


Ultrasonic cleaning

- Ultrasonic cleaning is used to clean the cavity surface.
  First, 1% of liquinox is used at 50℃ for more than half an hour.
  Second, DI water is used at 50℃ for more than half an hour.

# Buffered chemical polishing

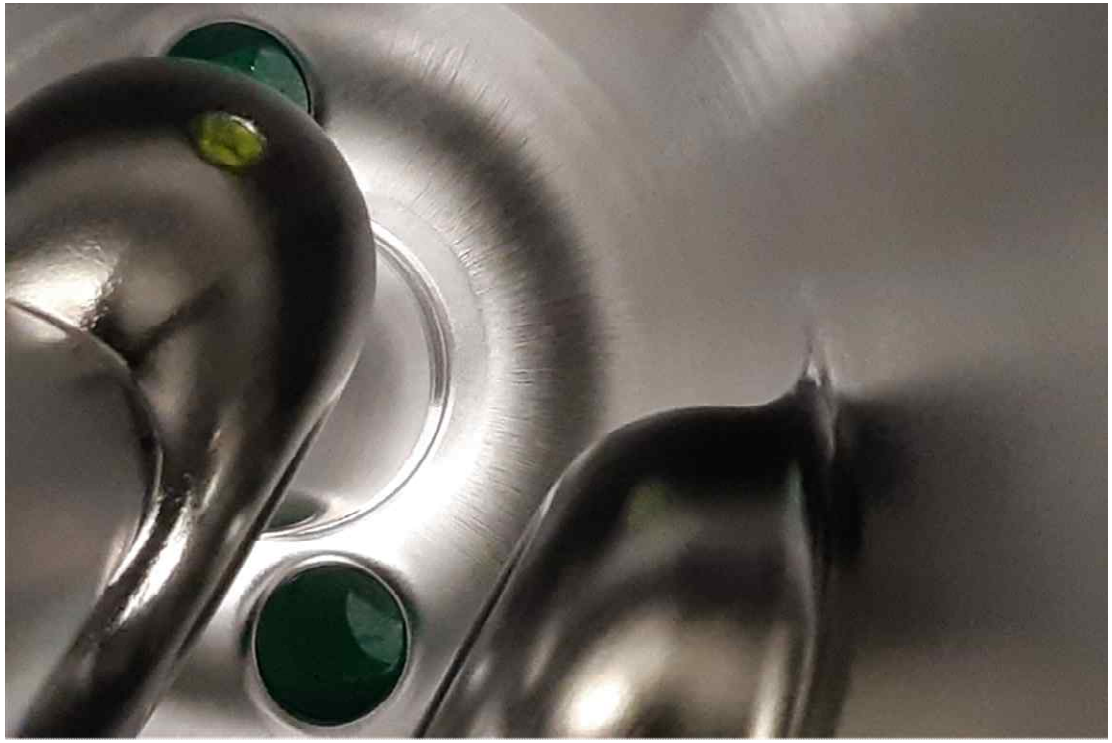
BCP main system




Same ports are used.

- Etchant : 49%HF + 69%HNO3 + 85%H3PO4 (1:1:2 in volume fraction)
  Etch rate : 0.7~1㎛/min
  Etch amount : over 120 ㎛
  Temperature control : lower 15℃
  Nb concentration in acid : lower 15 g/l
  Parts : dipping
  Cavity : closed loop circulation

# Inner surface after BCP

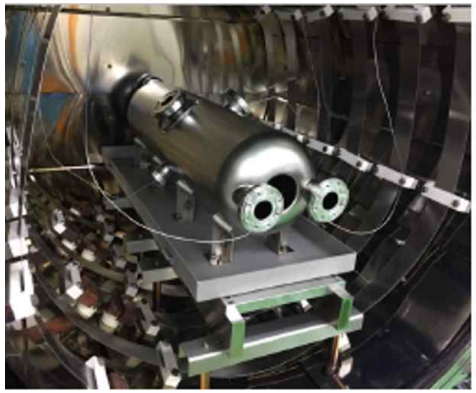
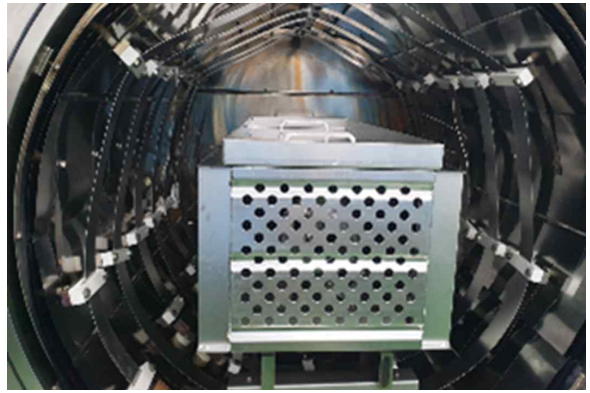


Picture of inner surface of cavity

- Inner surface of the cavity is inspected after BCP.
  Uniform surface roughness is important to prevent the sharp edge on RF surface.

# High temperature baking



High temperature baking

- Ultra high vacuum furnace is used to make hydrogen degassing at 650℃ for 10 hours.

# DI water supply

Deionized water (DI) system

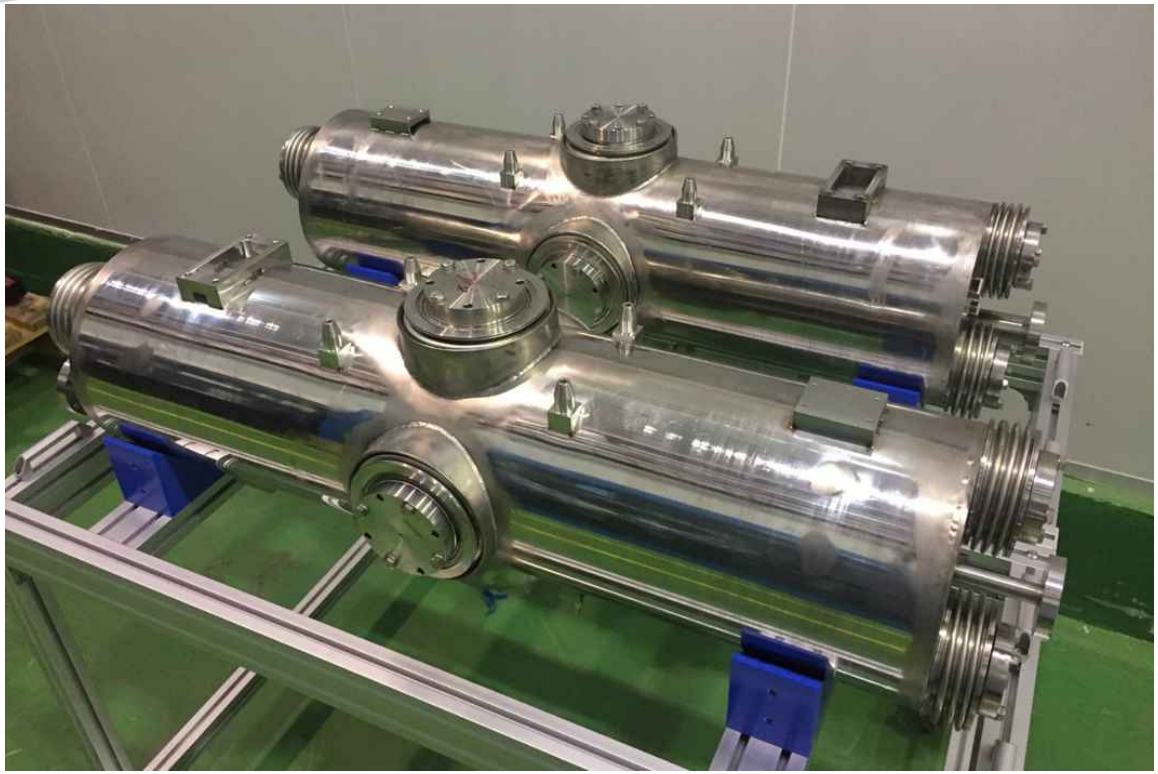
- Resistivity of DI water should be higher than 17.5 MΩ cm at 25℃.

# High pressure rinsing

High pressure rinsing (HPR) system

- HPR is used to remove residual particles on the surface of cavity.
  - High pressure filter : 0.5 ㎛
  - Water pressure : 100~150 bar
  - Nozzle diameter: 0.5 mm
  - Nozzle rotation speed : 20 rpm
  - Nozzle lifting speed : 5 cm/min
  - Rinsing time : over 10 hour/cavity

# Fabricated dressed cavity

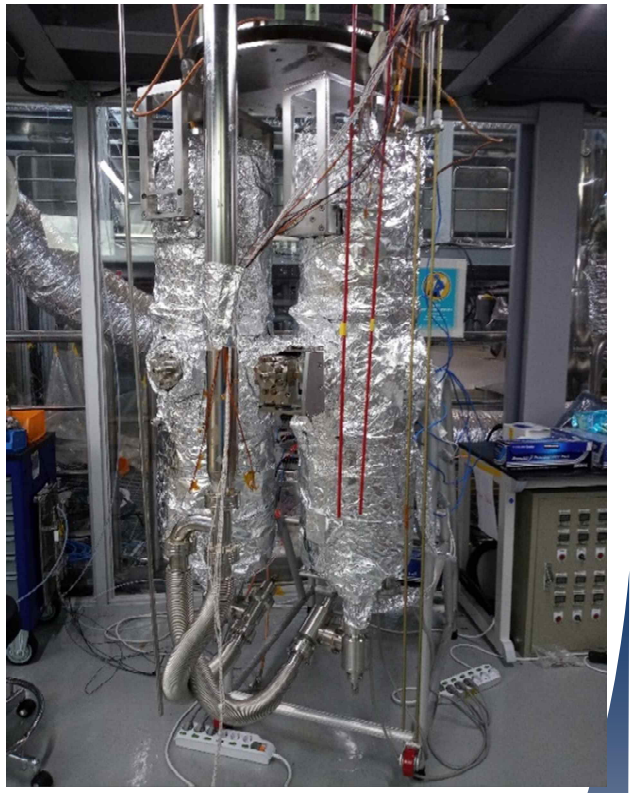


Fabricated dressed cavity

- Liquid helium vessel (jacket) is attached on the outside of the cavity and then additional light-BCP and HPR are performed after attaching the jacket.

# Low temperature baking





Preparation for the low temperature baking of superconducting cavities

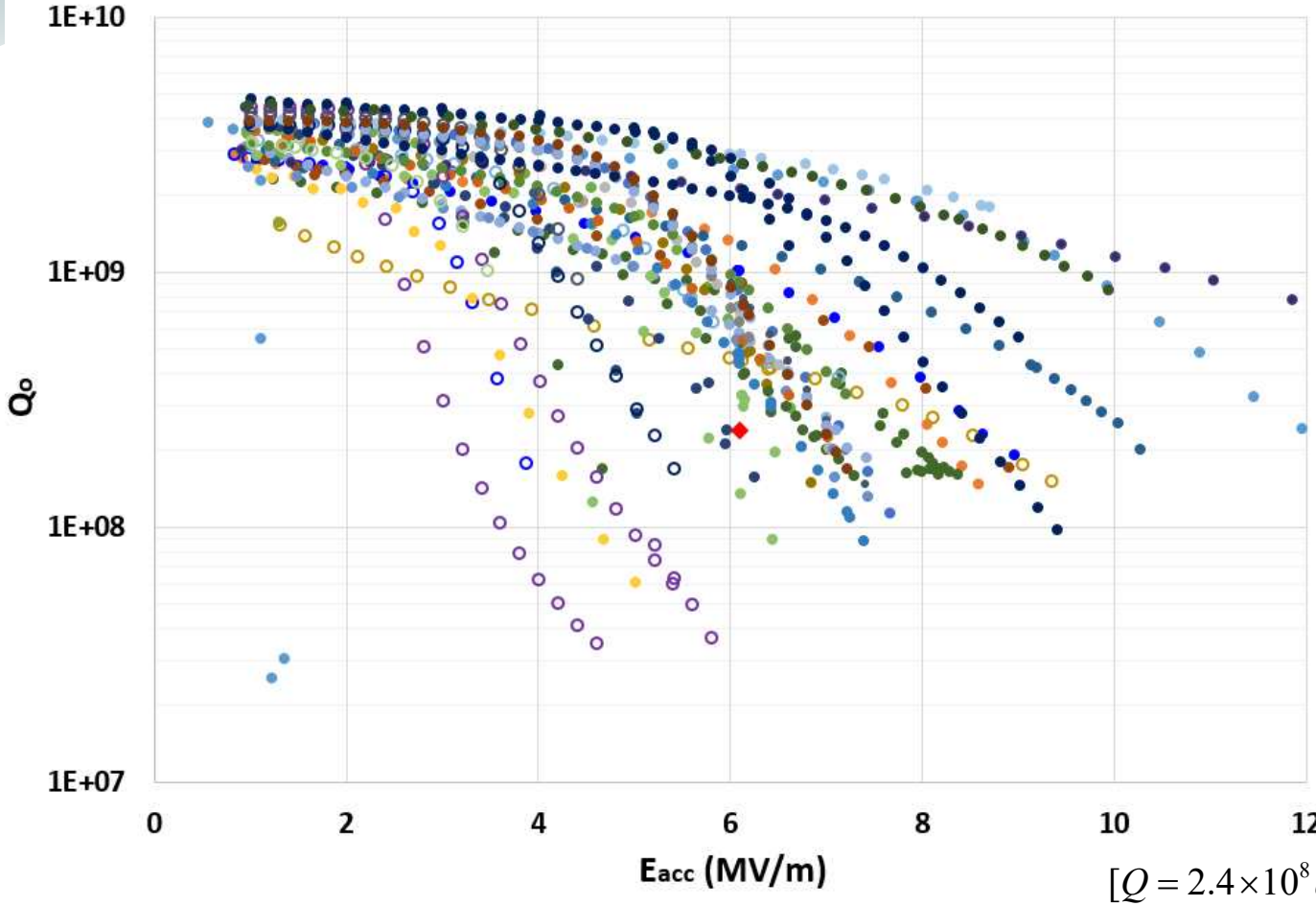
- Low temperature baking is done at 120℃ for 48 hours before vertical test.

# Vertical test facility

Vertical test facility

- Calibration is done at 4.2 K after fast cool down.
  Q slope is measured after cavity conditioning.

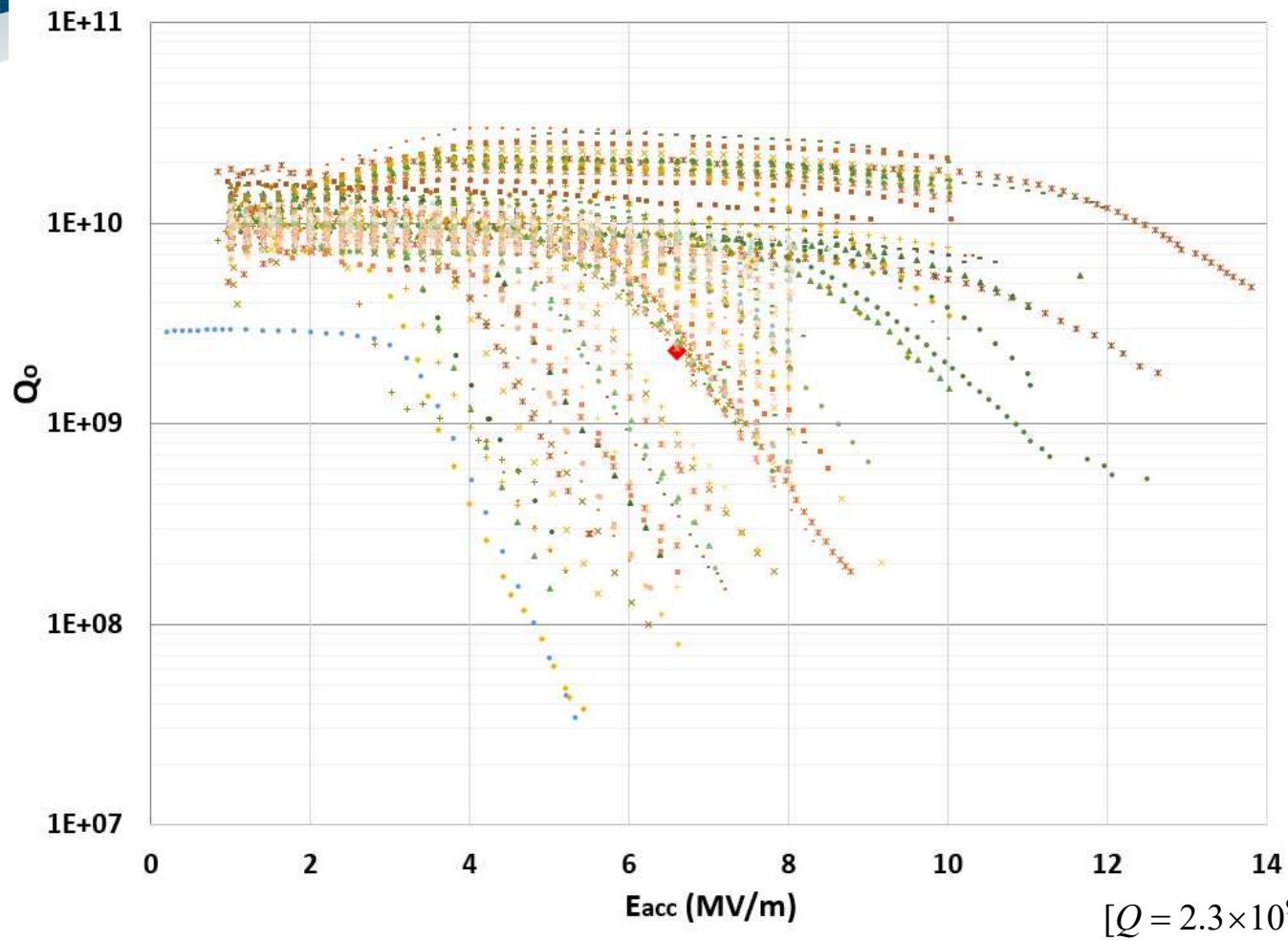
# Q slope measurement for QWR




$[Q = 2.4 \times 10^8 \, at \; E_{acc} = 6.1 \, MV/m]$

**Q slope measurement as a function of accelerating electric field for the quarter-wave resonator (QWR) cavities at 4.2 K. This data shows the failed and passed QWR. The total number of the QWRs is 22 and all of them are passed.**

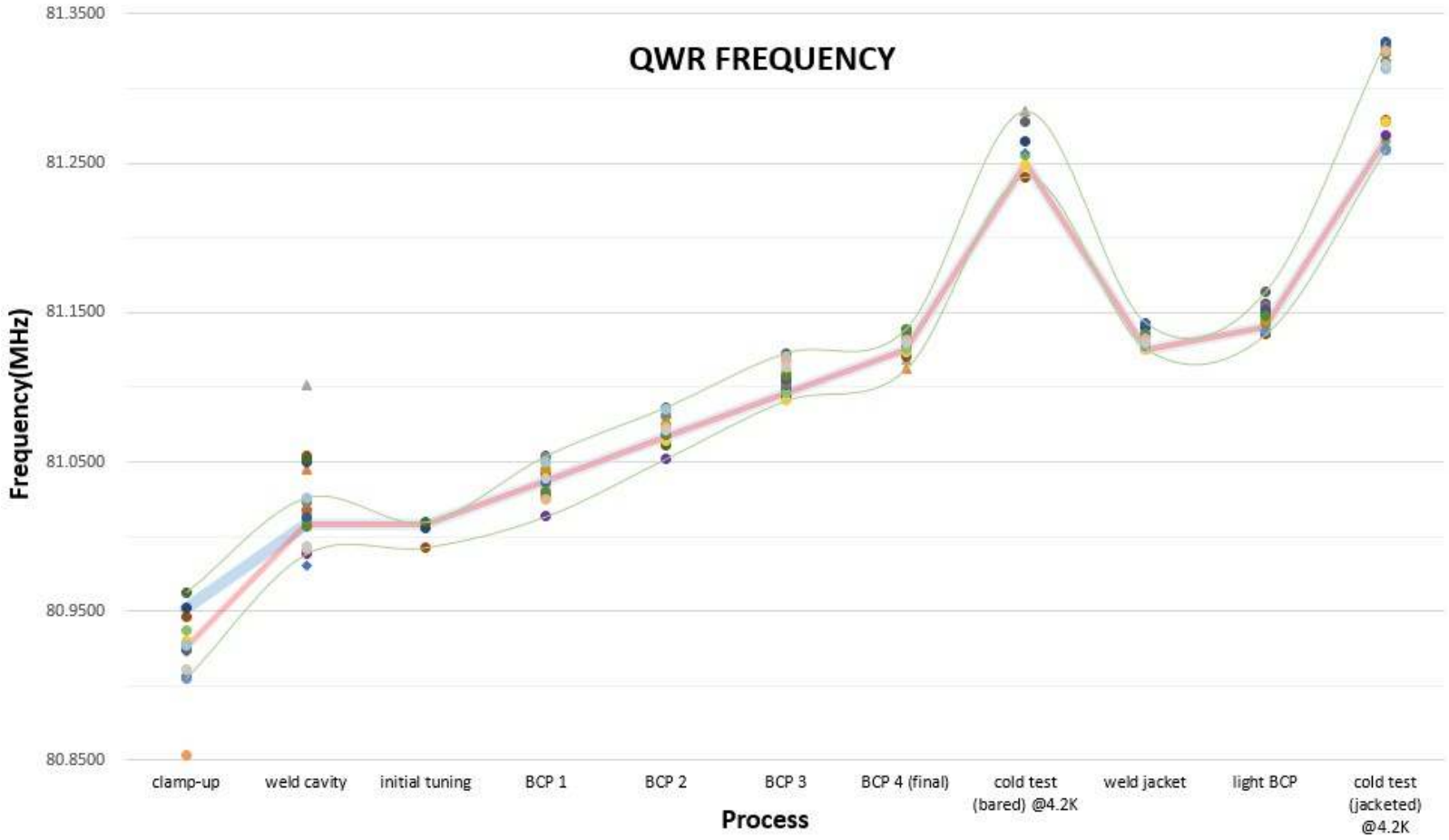
# Q slope measurement for HWR




$[Q = 2.3 \times 10^9 \text{ at } E_{acc} = 6.6\ MV/m]$

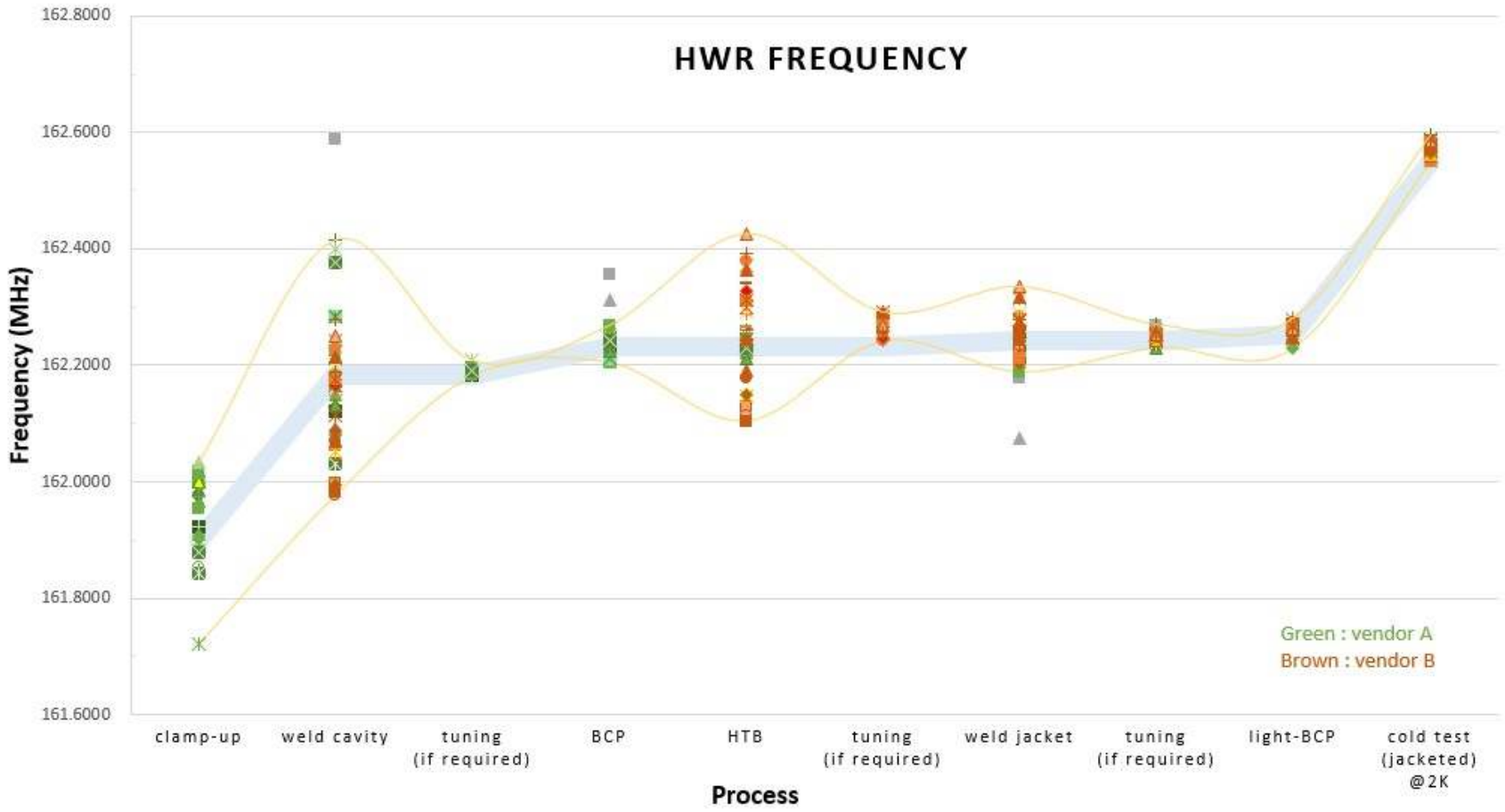
**Q slope measurement as a function of accelerating electric field for the half-wave resonator (HWR) cavities at 2 K. This data shows the failed and passed HWR. The total number of the HWRs is 106 and all of them are passed.**

# Frequency change for QWR




**Frequency change of QWRs is shown in terms of process.**

# Frequency change for HWR




HTB: high temperature baking

**Frequency change of HWRs is shown in terms of process.**

# Parameters for QWR and HWR

| Parameter | Unit | QWR | HWR |
|---|---|---|---|
| Frequency | MHz | 81.25 | 162.5 |
| Beta | | 0.047 | 0.12 |
| $L_{eff}$ | m | 0.173 | 0.221 |
| $Q_0$ | $10^9$ | 0.24 | 2.3 |
| $Q_0$*Rs | Ω | 18 | 37 |
| R/Q | Ω | 470 | 295 |
| $E_{acc}$ | MV/m | 6.1 | 6.6 |
| $E_{peak}/E_{acc}$ | | 5.7 | 5.3 |
| $B_{peak}/E_{acc}$ | mT/(MV/m) | 10.4 | 9.0 |

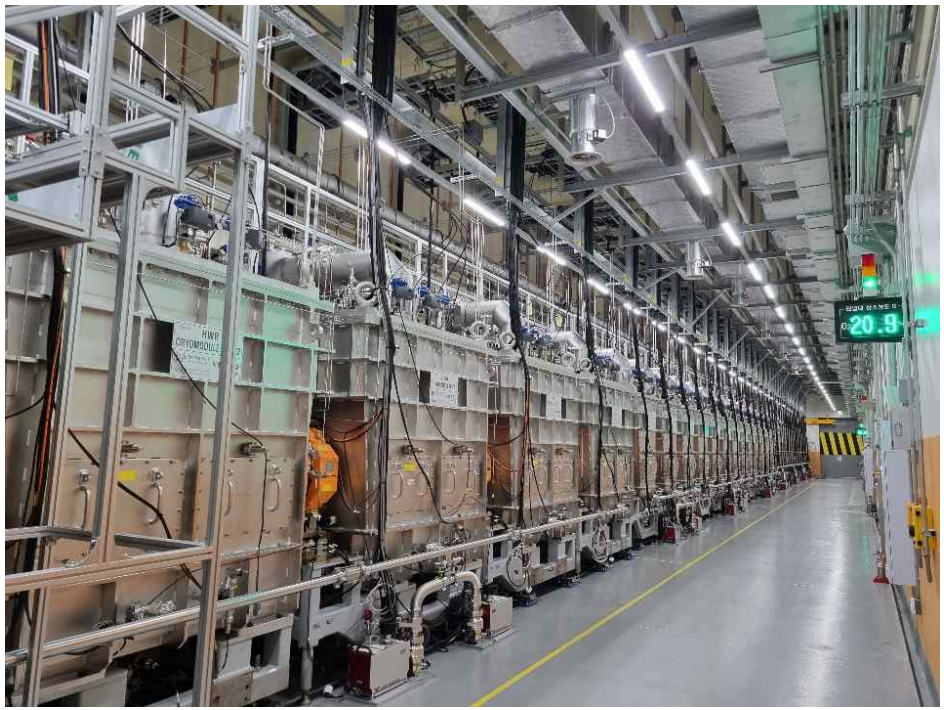
# QWR and HWR cryomodules


QWR cryomodule


HWR A cryomodule

HWR B cryomodule

# Pictures for installed QWR and HWR CM in tunnel



- **RAON first beam was observed with the beam energy of 0.7 MeV/u and the beam current of 30 uA for Ar(9+) through five QWR CMs at 15:00 on October 7, 2022.**

# Summary

- We have shown the procedures to make superconducting cavities.
- Raw material, single and sub parts, stack-up test, electron beam welding, fabricated bare cavity, ultrasonic cleaning, buffered chemical polishing, inspection for inner part of the cavity, high temperature baking, high pressure water rinsing, vertical test, Q slope measurement, frequency change for process, and cryomodules are presented in this talk.

# Questions

- IHEP in China, improved the quality factor of superconducting cavity higher than $10^{10}$ by applying electro polishing (EP) techniques, which remove field emission site effectively on the surface of the superconducting cavity.

- Let us know how the electro polishing (EP) techniques are performed.

# Acknowledgement


- We thanks to Jongdae Joo, Yoochul Jung, Juwan Kim, Sungmin Jeon, Hyunik Kim, Myeun Kwon, and Seung-Woo Hong.

# Thank you for your attention