Vertical test results for RAON SSR cavities

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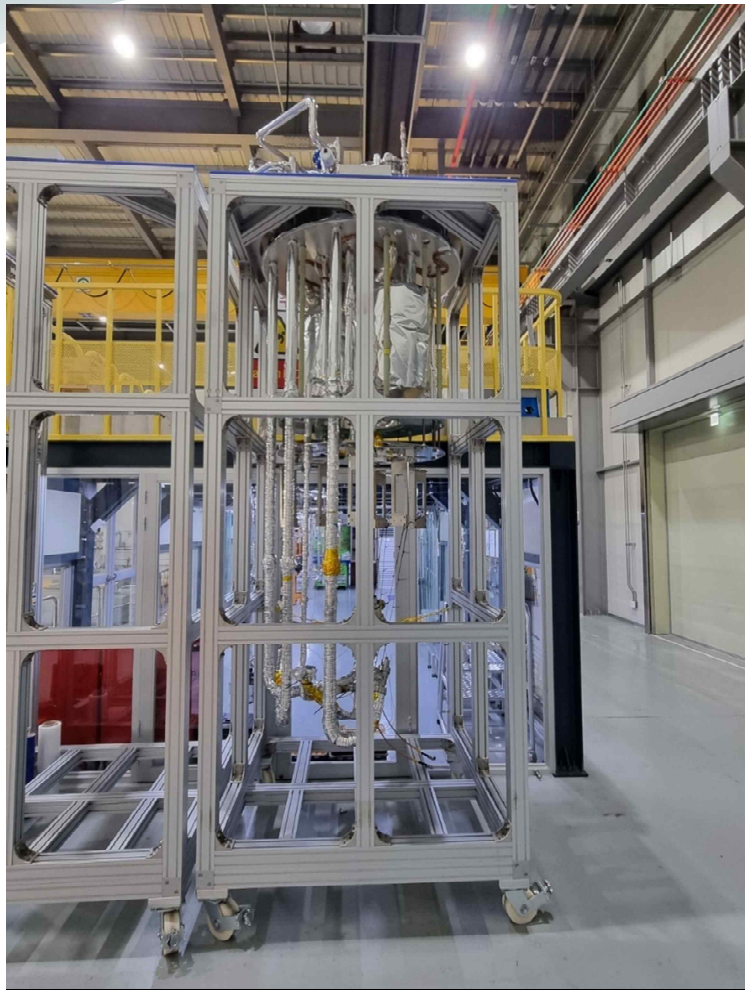
Overview for RAON vertical test facility

- Vertical test facility includes hanging booth, pits, solid state power amplifier (SSPA), control racks, and control room.

Vertical test facility

- Top view of hanging booth, top flange inserted into the pit, control racks, and control room are shown in the picture.

Vertical test facility



- Top flanges are shown outside and inside of the hanging booth.
- Superconducting cavities are installed to the top flange.

Superconducting cavity

- Quality factor of a superconducting cavity is expressed as

$$Q_o = \frac{\text{Stored Energy}}{\text{Energy Lost Per Cycle}} = \frac{2\pi \mathrm{U}}{P_{dis}T} = \frac{\omega U}{P_{dis}} = \frac{f}{\Delta f} = \frac{G}{R_{\mathrm{Sur}}}$$

- Generalized surface resistance is

$$R_{\mathrm{Sur}} = R_{\mathrm{Res}} + R_{\mathrm{BCS}} + R_{Flux} + R_{FE}$$

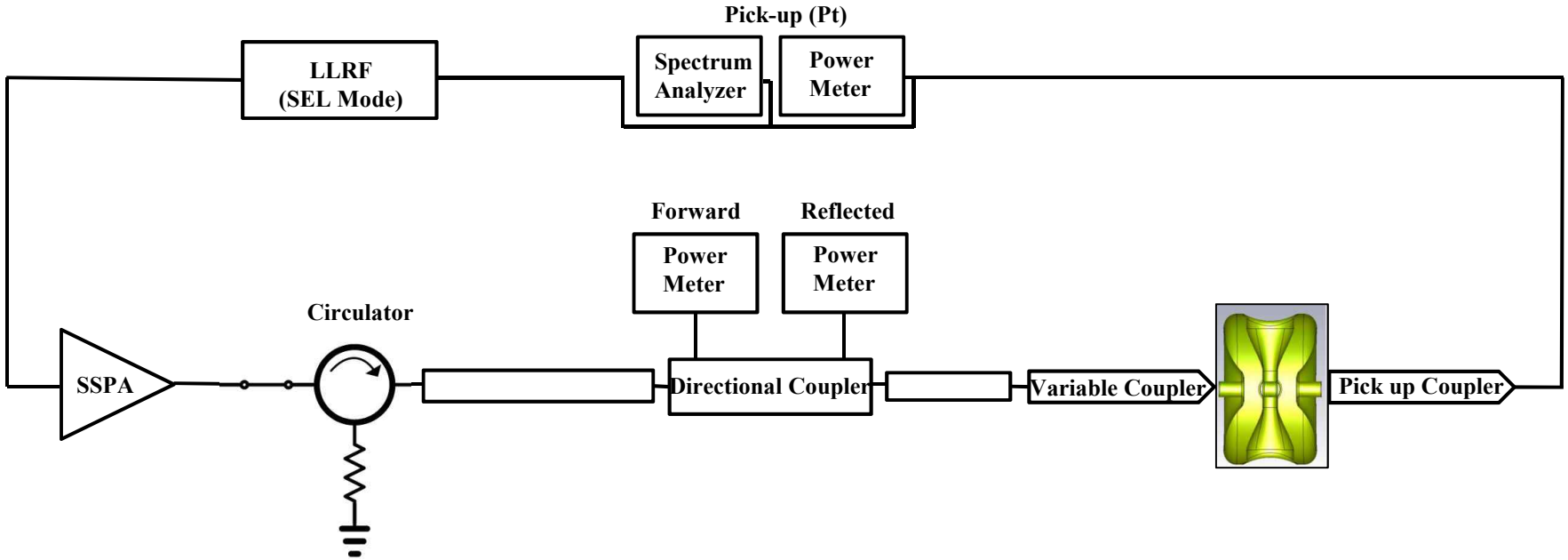
- BCS resistance coming from AC current is

$$R_{\mathrm{BCS}} = \frac{C_1 f^2}{T} \exp(-\frac{\Delta}{k_B T})$$

- Surface resistance at zero temperature becomes

$$R_{\mathrm{Sur}} = R_{\mathrm{Res}} + R_{Flux}$$

Vertical test system



- Low Level Radio Frequency (LLRF) Self Excited Loop (SEL) mode is used.
- Two SSPAs are 200 and 500 W.
- RF conditioning is performed after cable calibration.

Quality factor and accelerating field

- From decay time measurement, we can get

$$Q_L = \frac{w\tau_{3dB}}{\ln 2}$$

- Acceleration field is

$$E_{acc} = \sqrt{Q_t P_{tran} [\frac{(R/Q)}{L_{eff}^2}]}$$

- Quality factor is

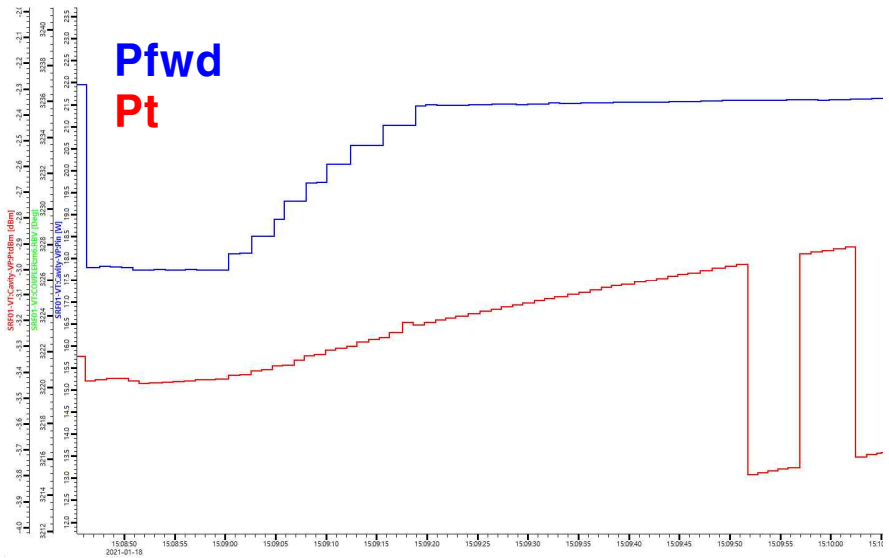
$$Q_o = \frac{Q_t P_{tran}}{P_{dis}} = \frac{Q_t P_{tran}}{P_{fwd} - P_{ref} - P_{tran}}$$

Procedures of vertical test

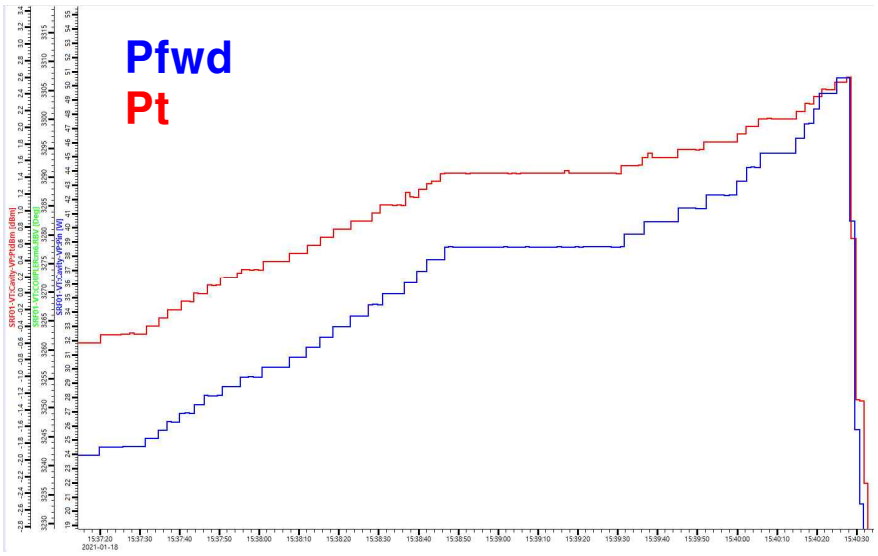
- Visual inspection for cavity
- Frequency measurement with VNA
- Assemble cavities to top flange in hanging booth
- Check variable couplers
- Low temperature baking
- Insert the top flange into a pit
- RF calibration at room temperature; check RF connections
- Supply liquid nitrogen and helium
- Cool down; fast cool down from 150 K down to 50 K
- RF calibration @4.2 K
- RF conditioning
- Q slope measurement @4.2 K, which includes LFD measurement
- Pressure sensitivity measurement
- 2K pumping
- Q slope measurement @ 2K, which includes LFD measurement

RF conditioning

- RF conditioning is a process to clean the RF surface of the superconducting cavity in order to make the highest quality factor in the range of all possible accelerating field.



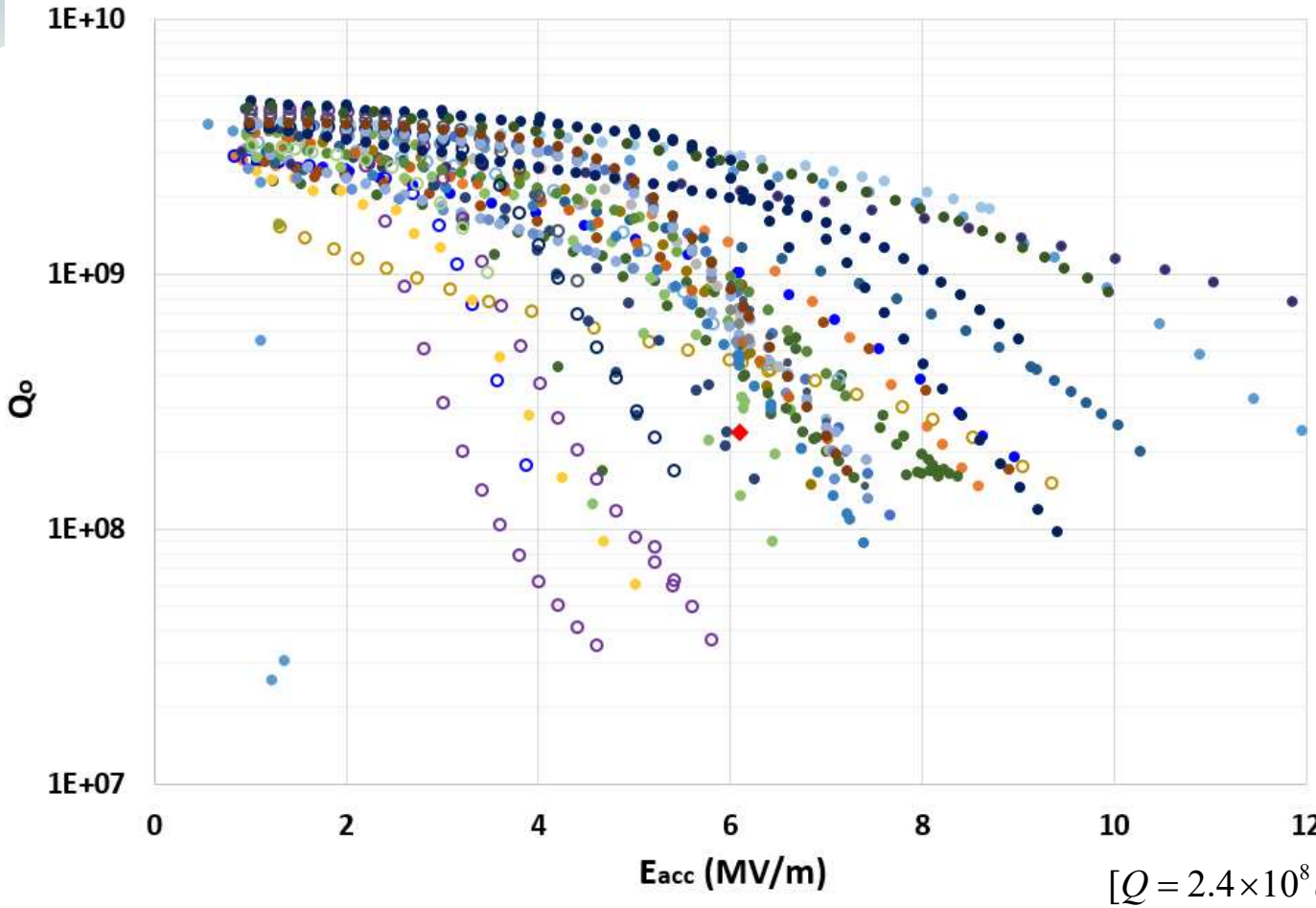
During conditioning



Completed conditioning

- RF conditioning starts at over coupled in which variable coupler is inserted the most into the inside of the cavity, 0 pulse.
- By watching the transmitted power(Pt), we change the forward power(Pfwd) and the phase of LLRF SEL mode to increase the Pt.
- The forward power and transmitted power are increased together after finishing RF conditioning.

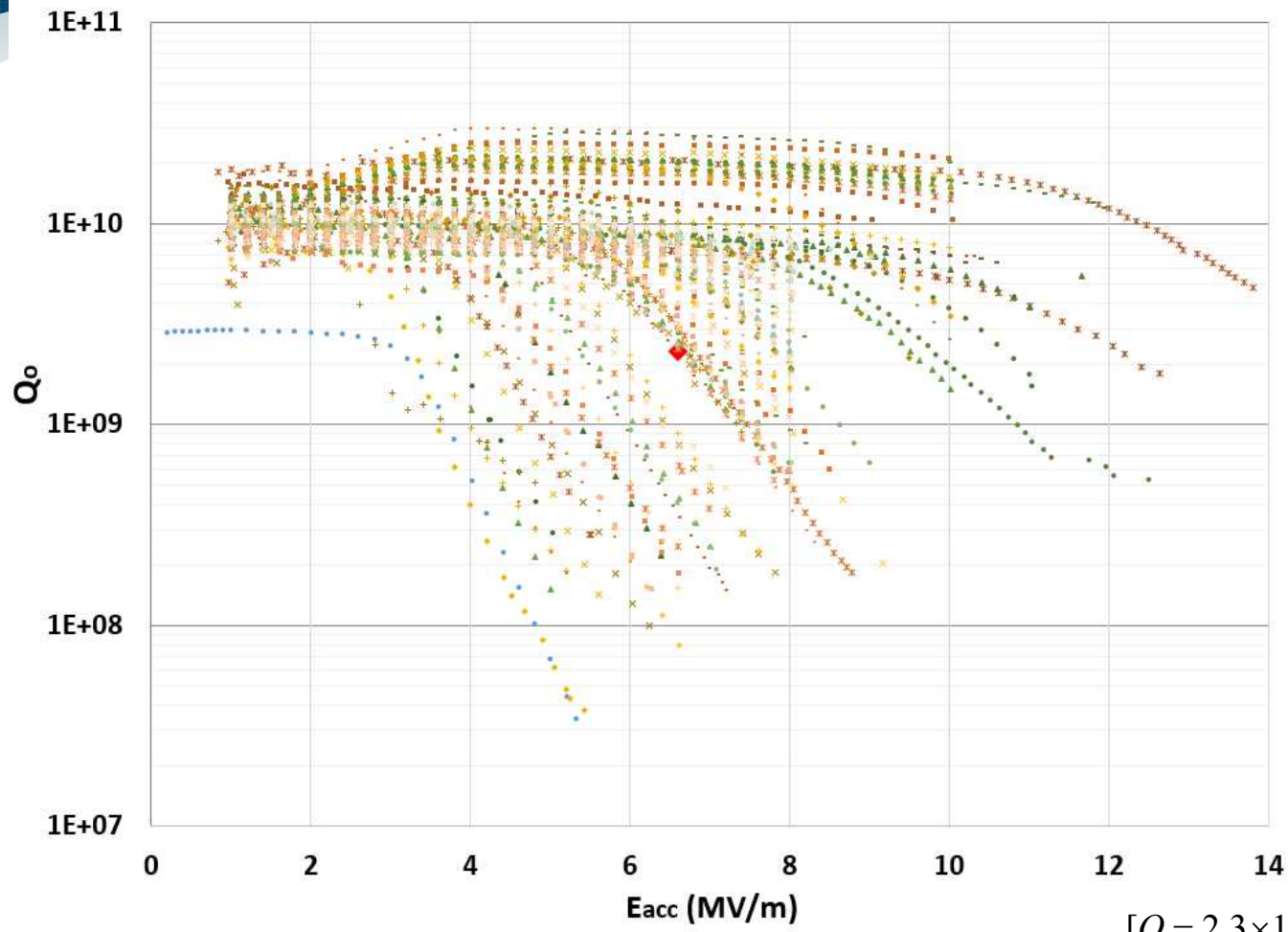
Q slope measurement for QWR



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

- **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.**

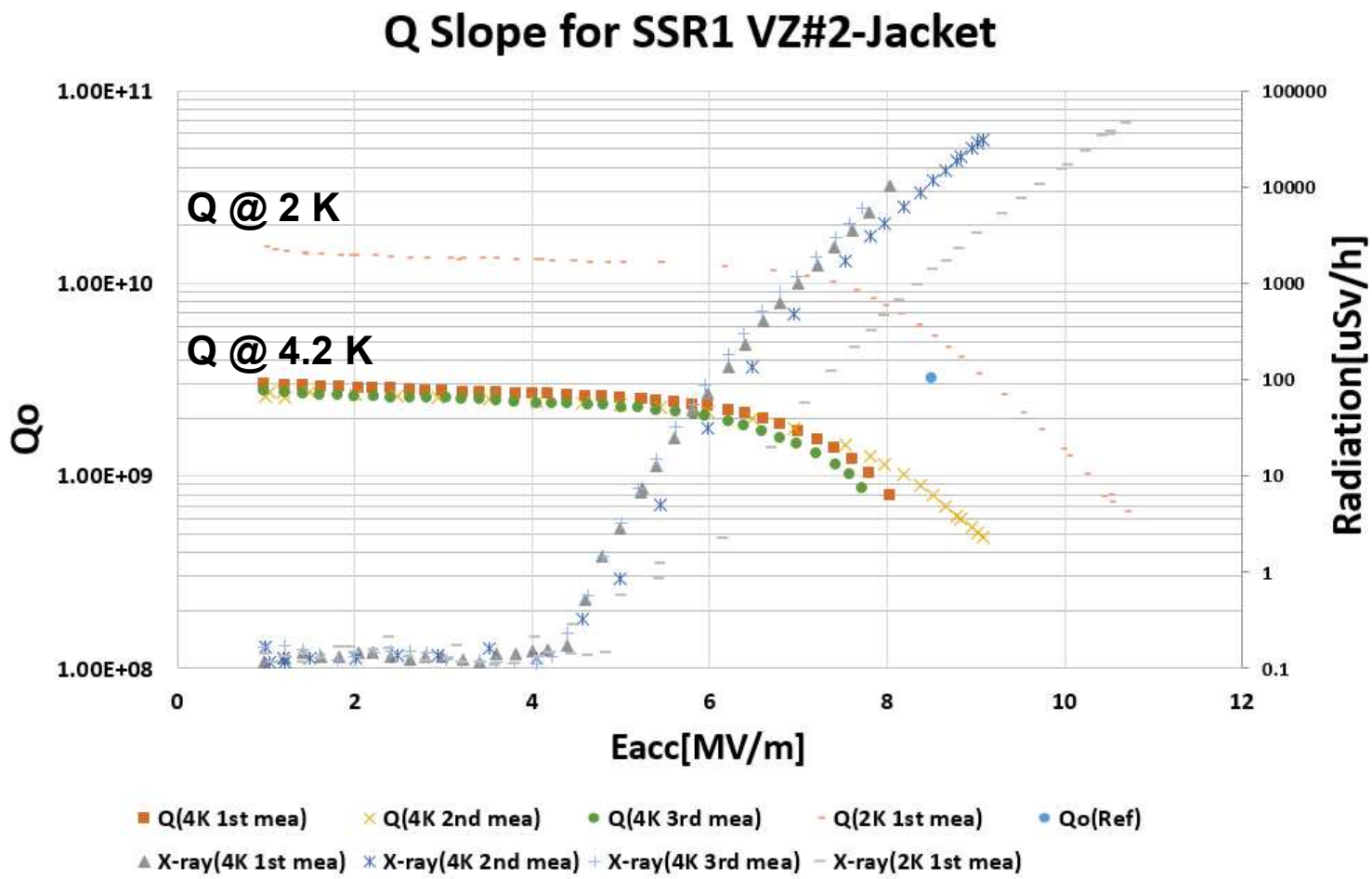
Q slope measurement for HWR



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

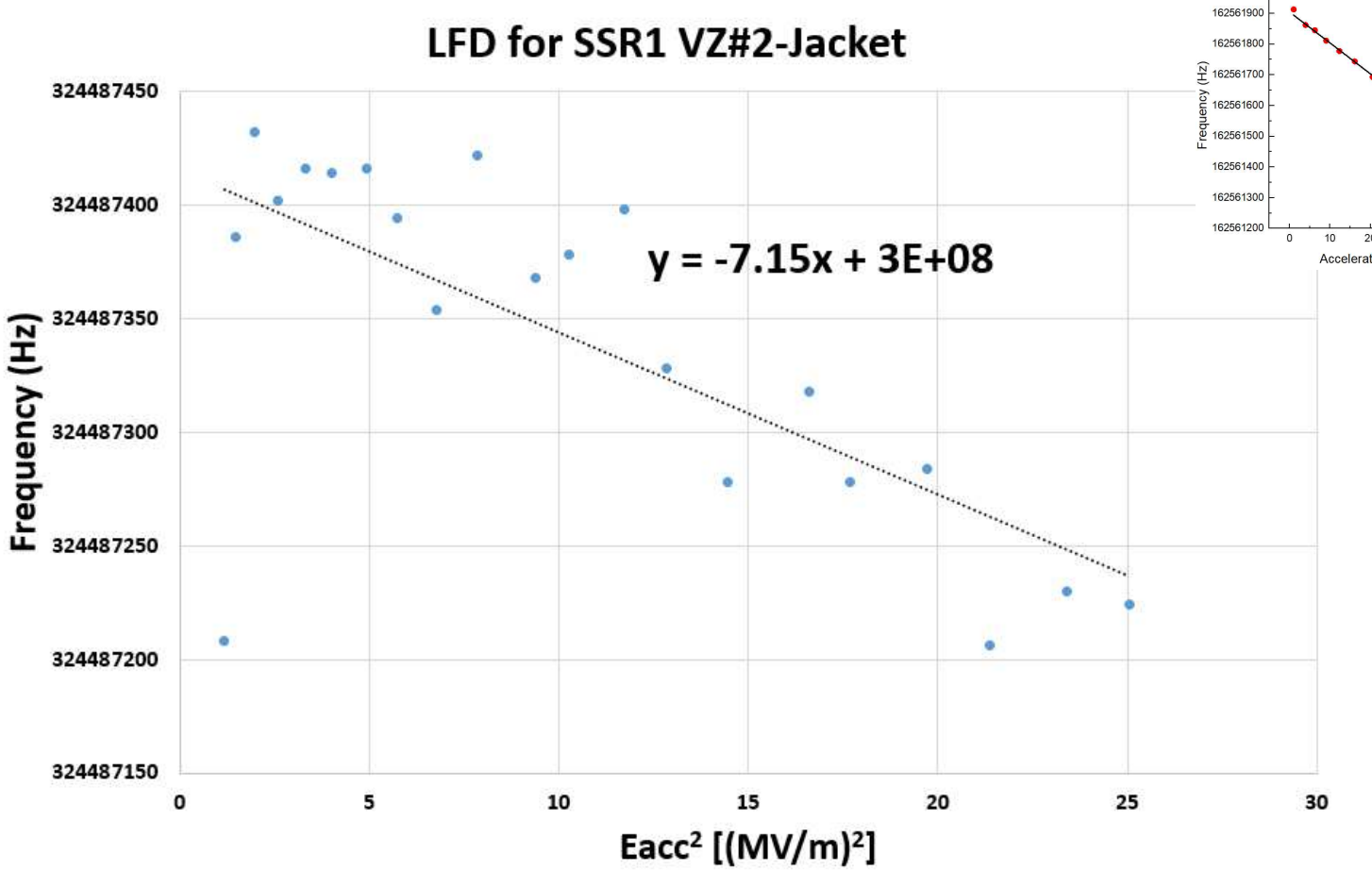
- Q slope measurement as a function of accelerating electric field for the half-wave resonator (HWR) cavities at 2 K. This data shows the failed and passed HWR. The total number of the HWRs is 106 and all of them are passed.

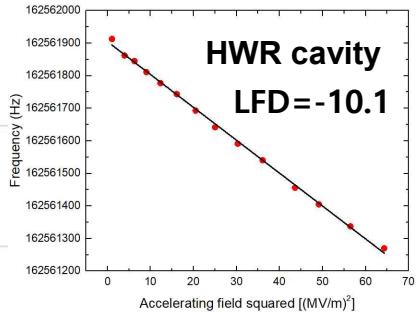
Q slope measurement for SSR1



- Q slopes are measured three times at 4.2 K.
- Q slope is measured once at 2 K.
- Quality factor decreases as the radiation is increased.

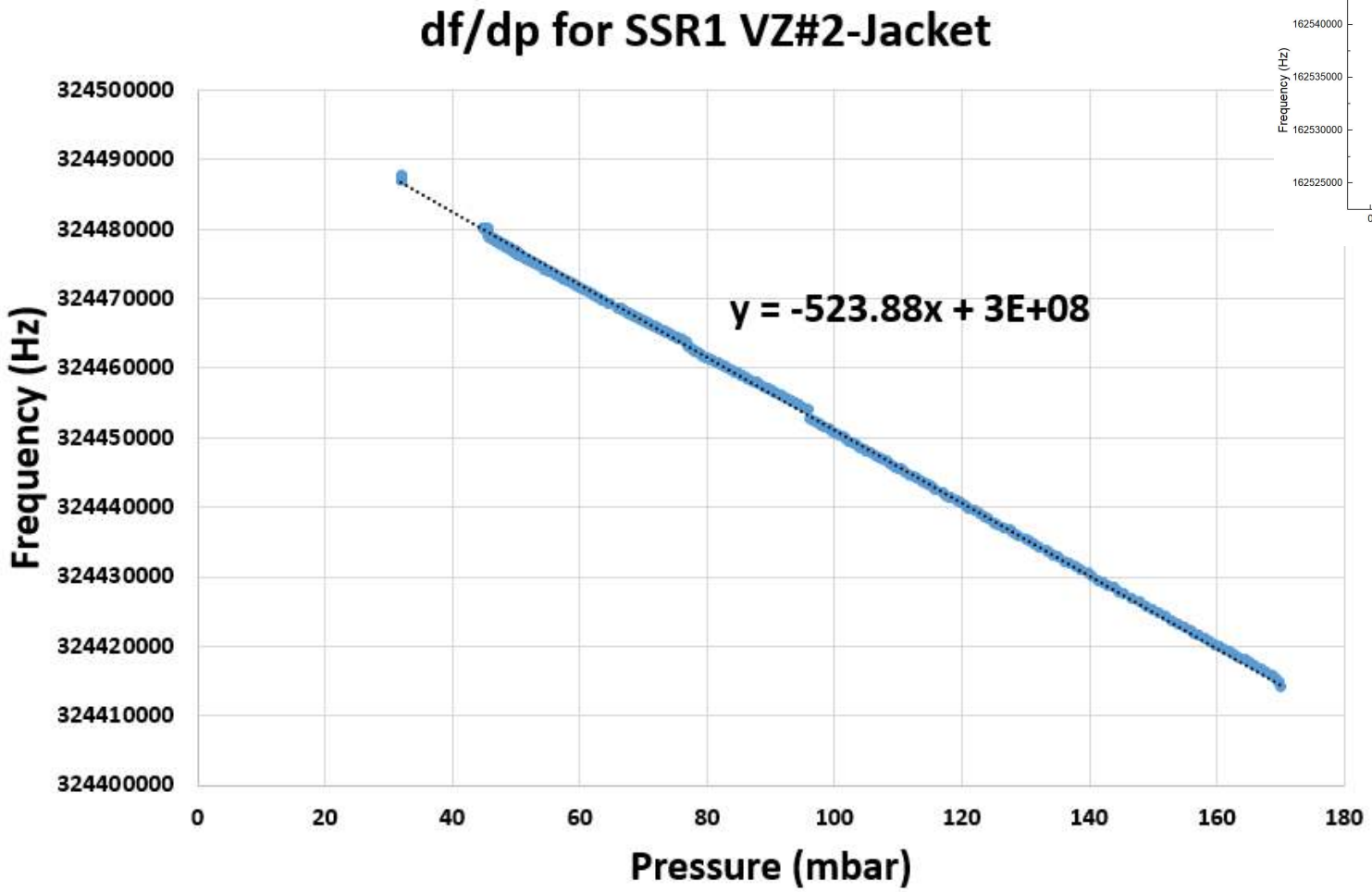
LFD measurement for SSR1

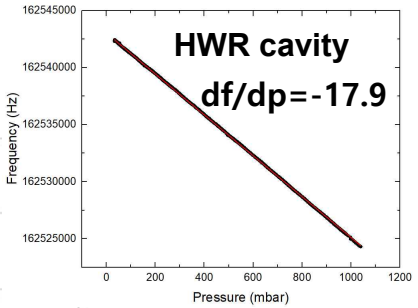




- LFD is measured at 2 K.

Pressure sensitivity measurement for SSR1

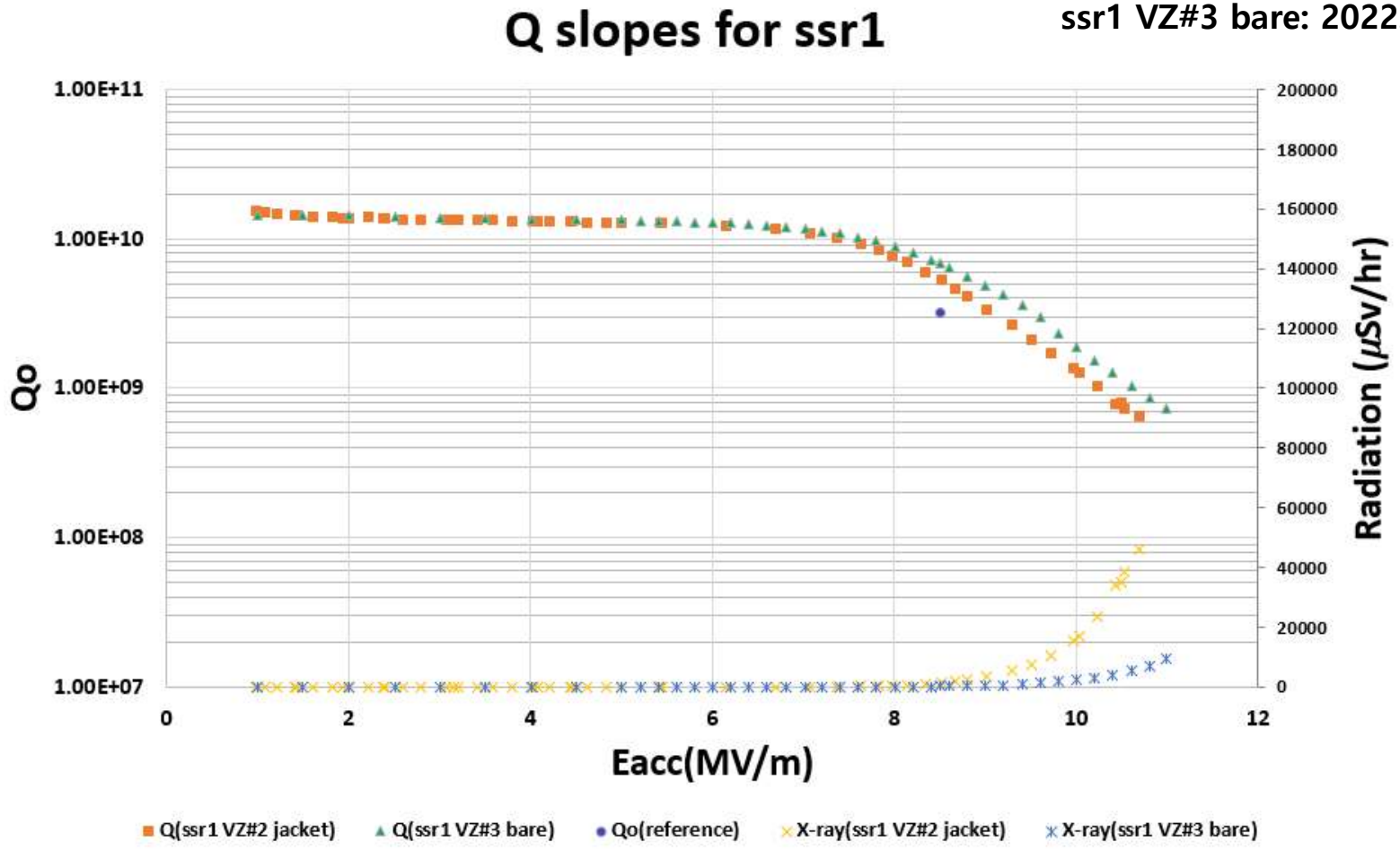




- Pressure sensitivity is measured in the pressure range of 35 and 170 mbar.

Q slopes for SSR1 (passed)

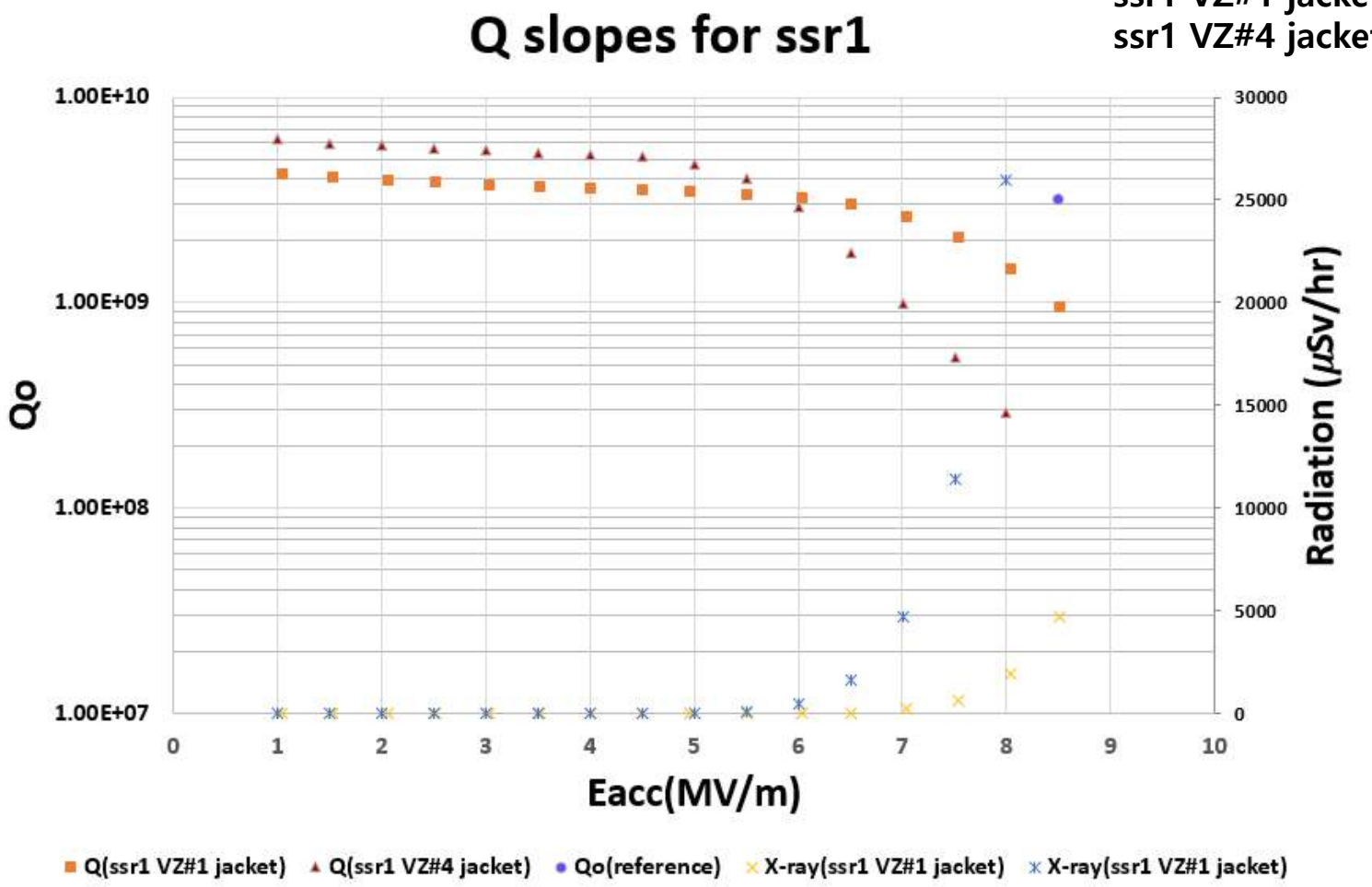
ssr1 VZ#2 jacket: 2020.07.16
ssr1 VZ#3 bare: 2022.08.14



- SSR1 VZ#2 and 3 are passed.
- Quality factor decreases as the radiation is increased.

Q slopes for SSR1 (on going)

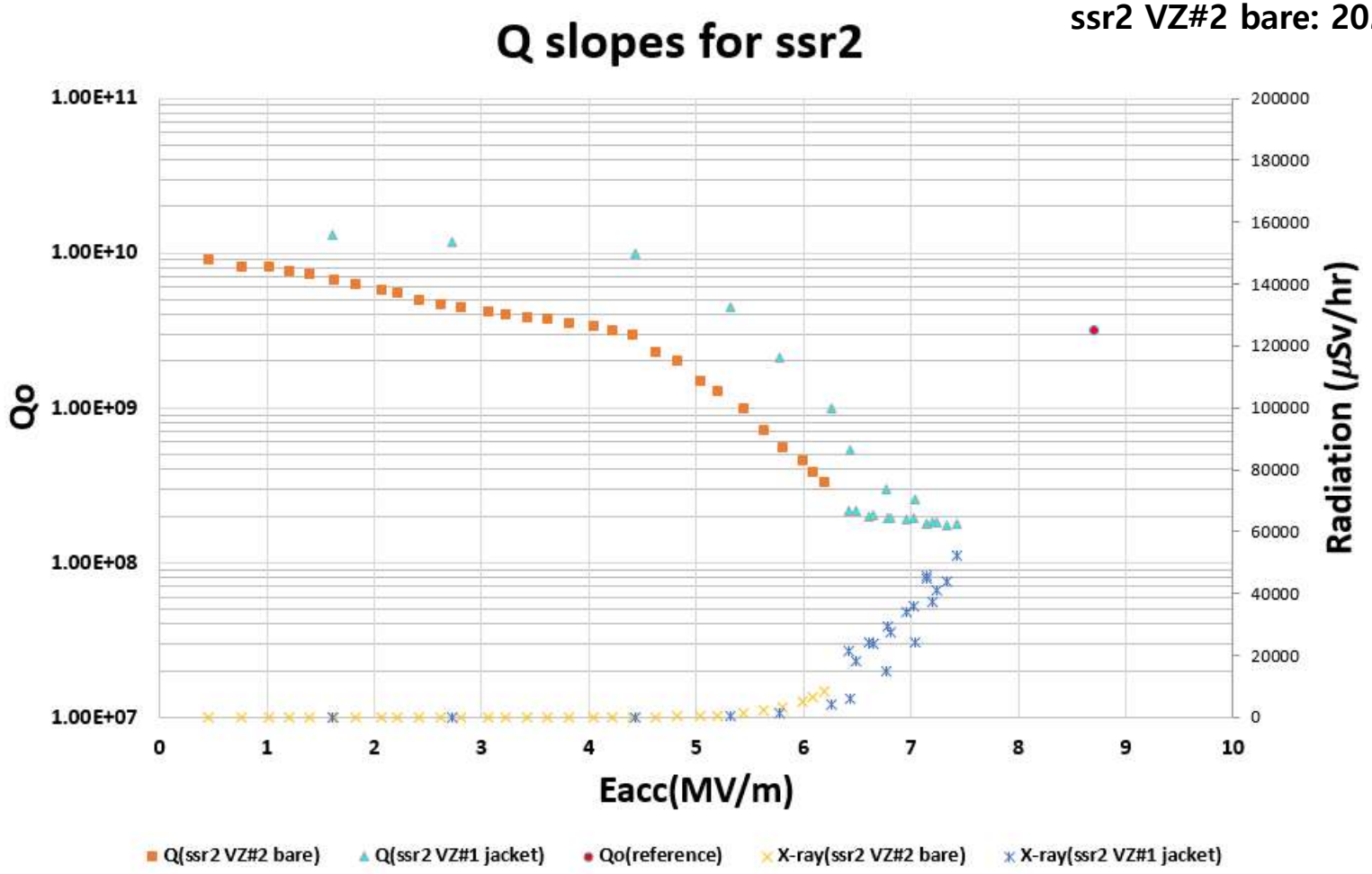
ssr1 VZ#1 jacket: 2021.07.30
ssr1 VZ#4 jacket: 2020.08.08



- SSR1 VZ#1 and 4 are not passed.
- Quality factor decreases as the accelerating field is increased.

Q slopes for SSR2 (on going)

ssr2 VZ#1 jacket: 2021.11.30
ssr2 VZ#2 bare: 2022.01.25



- Field emission conditioning shows some effect.
- Quality factor decreases as the accelerating field is increased.

Pressure sensitivity and LFD for SSR1

ssr1 cavity	df/dp (Hz/mbar)	LFD[Hz/(MV/m)^2]
ssr1 VZ#3 bare	-659	-38.9
ssr1 VZ#1 jacket	-27.9	-12.3
ssr1 VZ#2 jacket	-523.9	-7.2

- **The pressure sensitivity (df/dp) and Lorentz force detuning (LFD) for SSR1 are measured.**
- **Compared to bare cavity, the pressure sensitivity (df/dp) and Lorentz force detuning (LFD) for the jacked cavity are decreased.**
- **Pressure sensitivity measurement for Jacket depends on how the cavity is secured in vertical test. It can be free boundary or fixed boundary.**

Pressure sensitivity and LFD for SSR2

ssr2 cavity	df/dp (Hz/mbar)	LFD[Hz/(MV/m)^2]
ssr2 VZ#2 bare	-231.1	-17.2

- **The pressure sensitivity (df/dp) and Lorentz force detuning (LFD) for SSR2 are measured.**

Summary

- Vertical test facilities are shown.
- S slope measurements for QWR and HWR are shown.
- Q slope is measured for passed SSR1 cavities.
- Q slope is measured for on going SSR1 cavities.
- Q slope is measured for on going SSR2 cavities.
- Pressure sensitivity and LFD are measured for SSR1 and SSR2.

Thank you for your attention