Compact tuner designed to minimize the intervals of QWRs for RIKEN heavy-ion linac

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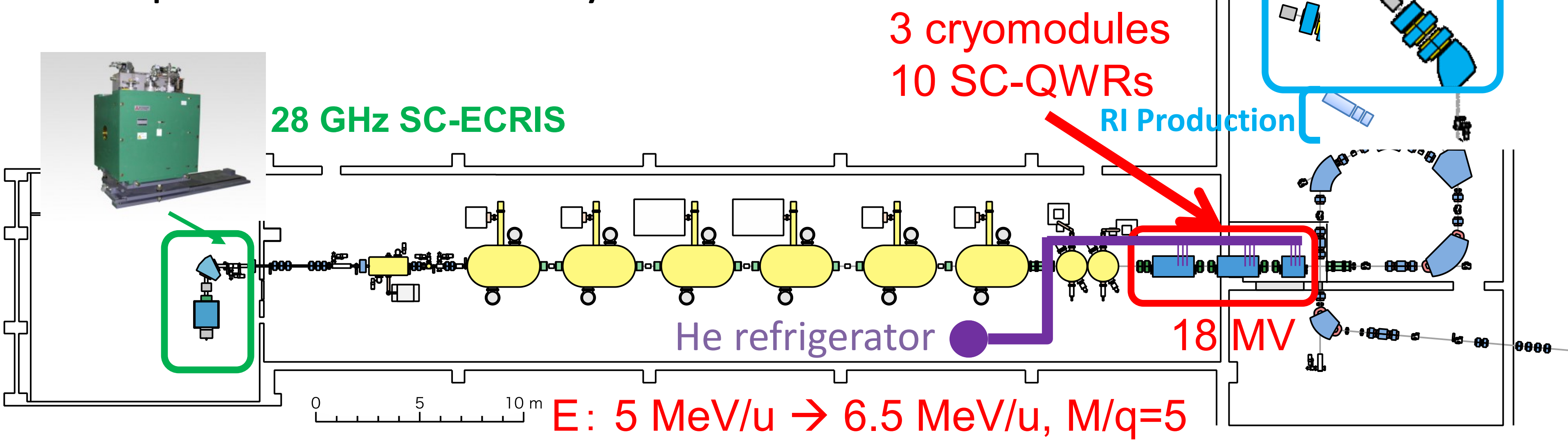
Upgrade of the RIKEN heavy-ion linac

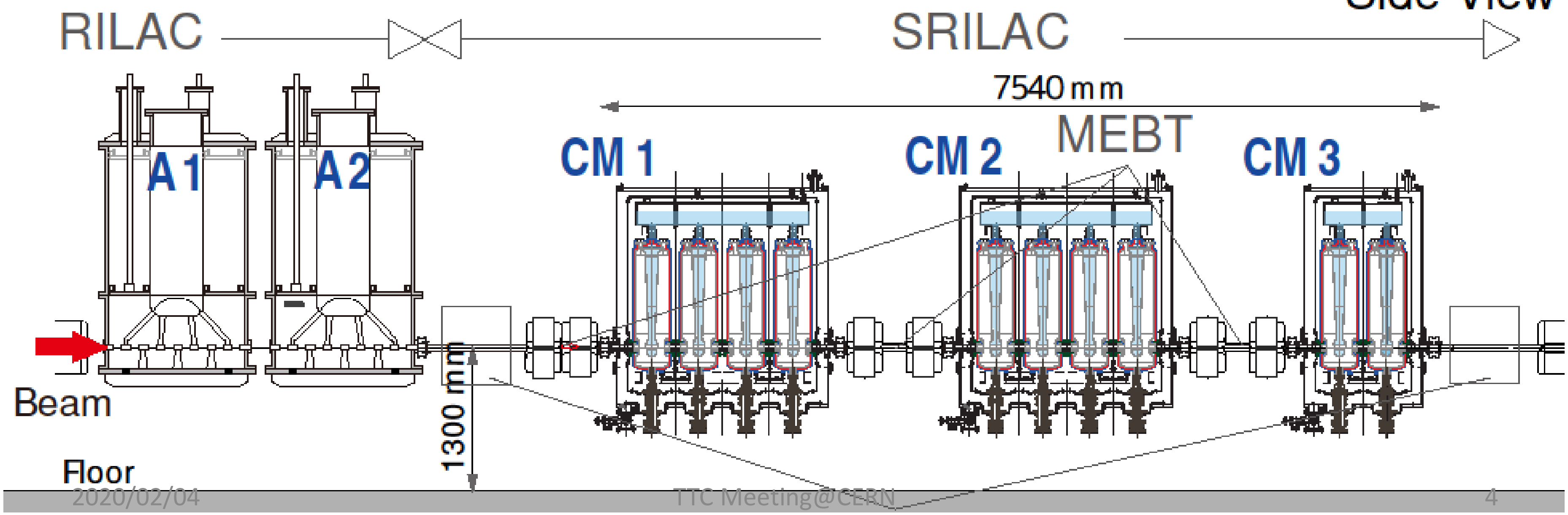
- The heavy-ion linac, RILAC, originally consists of normal conducting cavities.
- A superconducting linac (SRILAC) is introduced to upgrade beam energy for the experiment of super heavy element synthesis and RI production.
- SRILAC has ten Quarter-Wave Resonators (QWRs) made of bulk niobium. Beam commissioning was successfully performed in January 2020.



Cryomodules of SRILAC

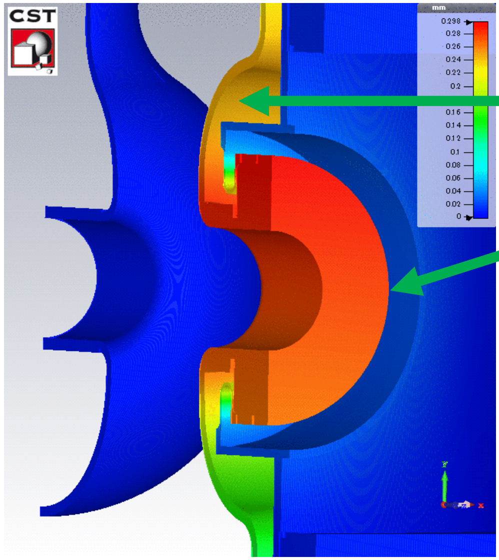
- Warm quadrupole magnets between CMs.
- Distance between the beam port flanges of the QWRs was set as small as 110 mm, in order to keep good beam quality.

→ The dimension of a tuner mechanism should be minimized.



Design of QWR and tuner

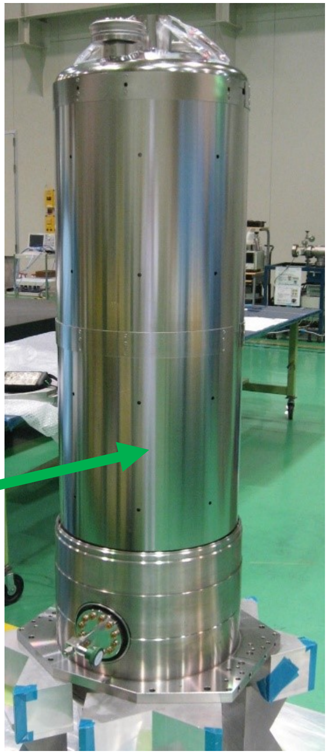
- The purpose of the tuner is to shift frequency
  (1) by a few kHz at the beginning of cavity excitation
  (2) by a few Hz to compensate Δf caused by He pressure
- Cavity was designed to be rigid (thick Nb sheets of 3.5, 4 mm, conical stem) so as to comply with the High-Pressure Gas Safety Act in Japan. Stiffness helps to decrease microphonics.
- Tuning is done by squeezing beam ports; necessary to apply 7,500 N for each port to tune 0 -- -14 kHz (Δx=0.37 mm).



No ribs at end drift tube and beam port

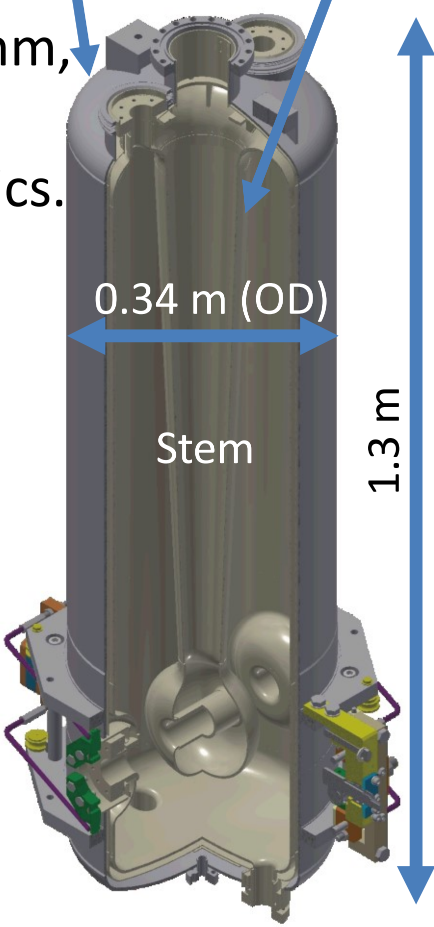
Beam port flange

Magnetic shield
(Permalloy, t=1.5 mm)
on cavity before jacketing



Ti jacket

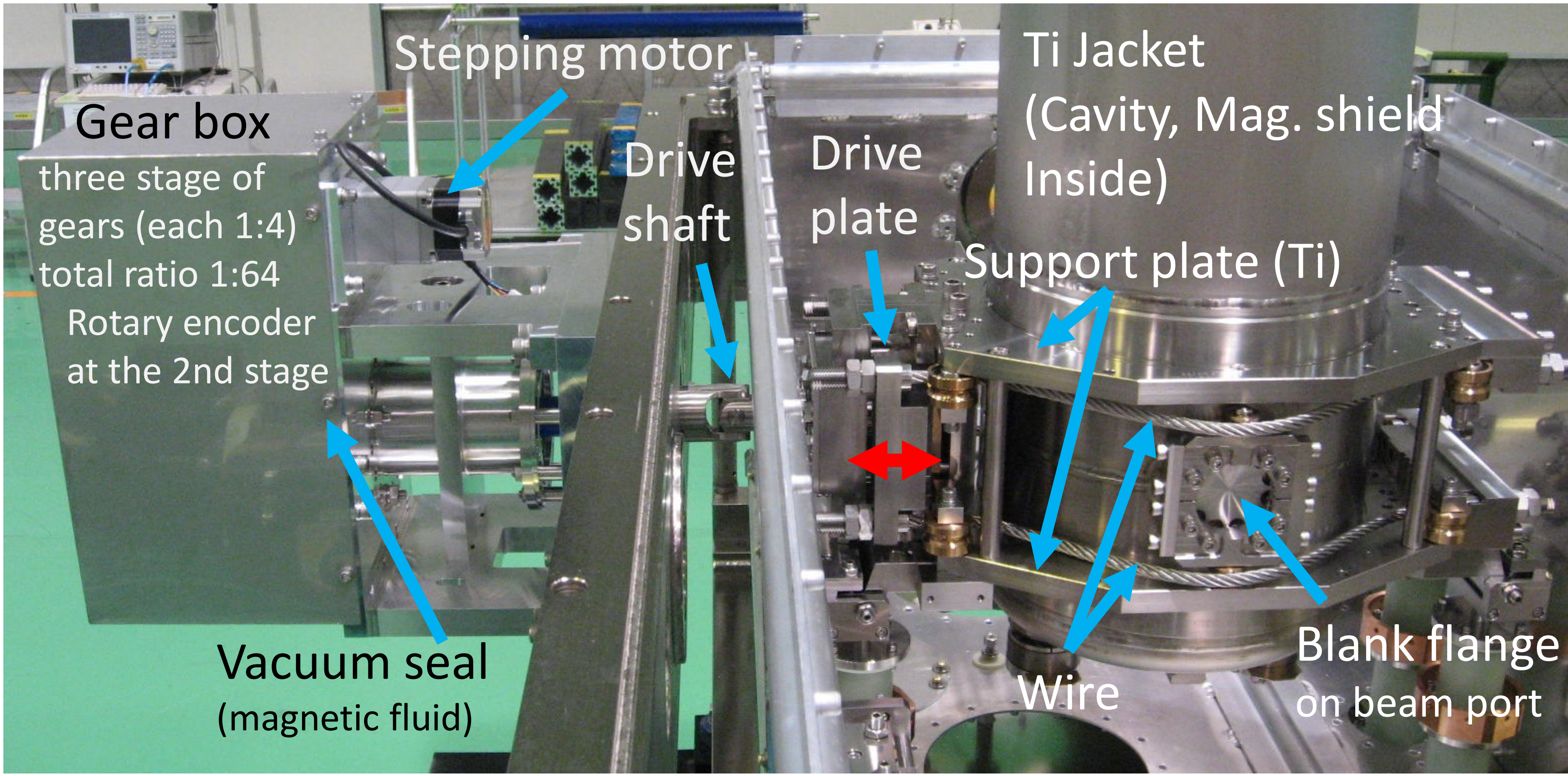
Nb cavity



No stiffener in stem

Tuner mechanism

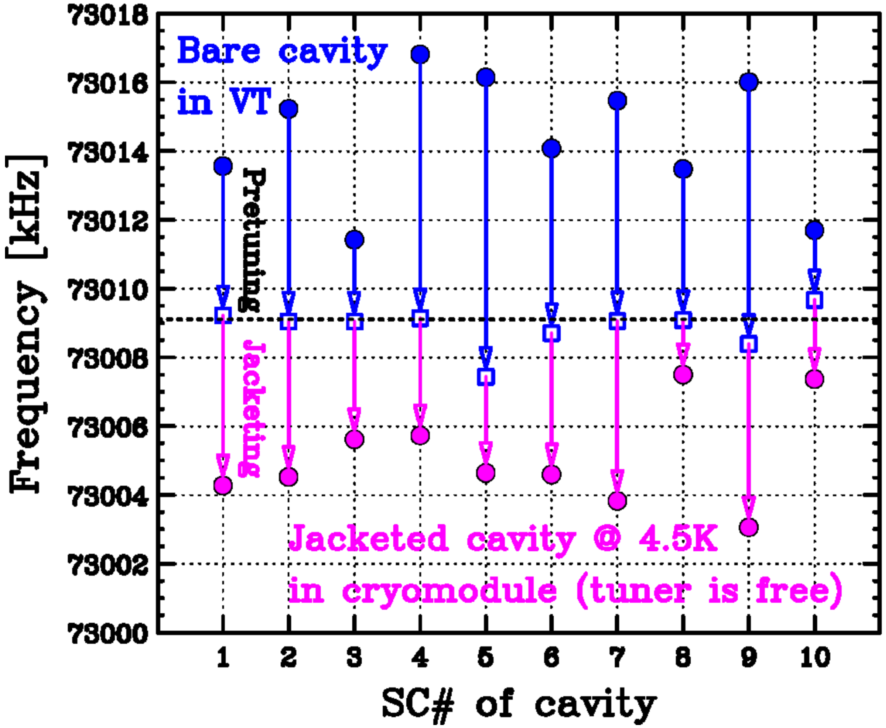
- Each beam port is pressed by pulling two ϕ 10 mm wires (Max. 10,000 N).
- A drive plate with the wires is driven through a shaft (Δx of plate: 2 mm/rev).
- No piezo actuator was used.



Test results of tuner at 4.5K

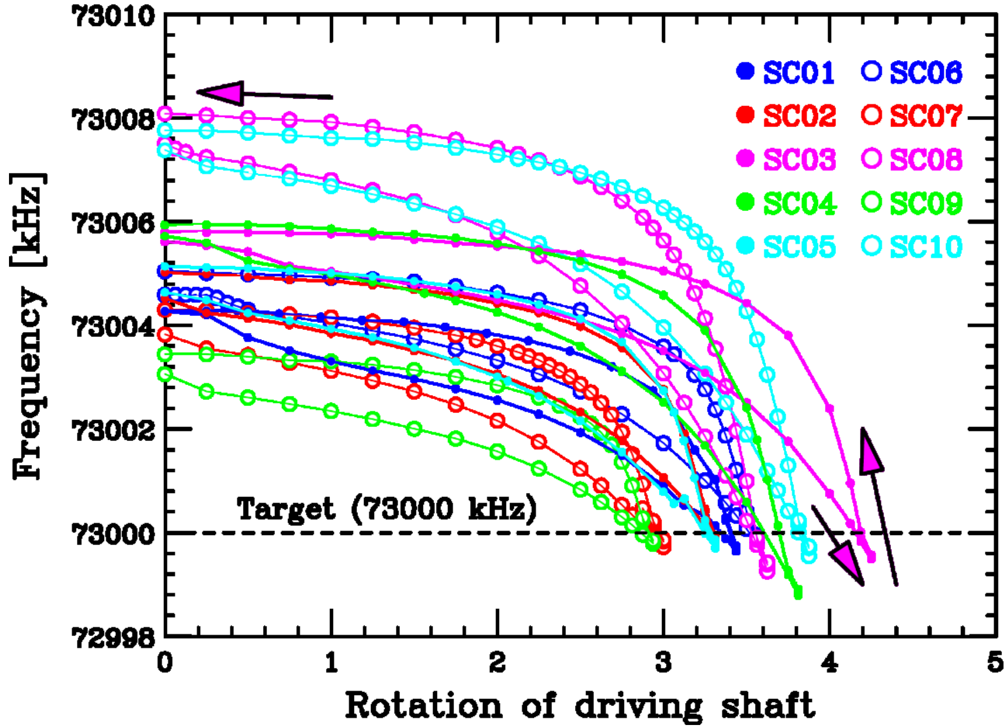
- Each cavity was fabricated so that the frequency is a few kHz higher than a target (73 MHz). [Tuning during fabrication: SRF2019, MOP055]
- All the cavities were smoothly tuned to the target frequency.

Fabricated cavities



Pretuning: tuning by plastic deformation around beam ports in fabrication process

Tuning of cold cavity



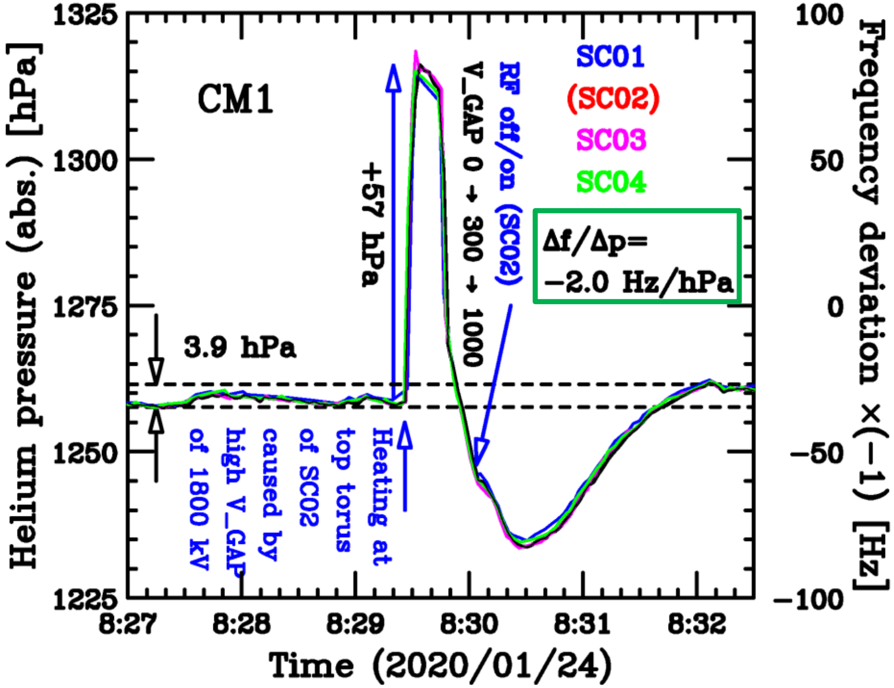
Frequency measured by network analyzer; S21: coupler → pickup, power: 0 dBm

Stability of frequency against helium pressure

- Frequency sensitivity against the He pressure was measured: Δf/Δp=-2.0 Hz/hPa. It was in a good agreement with the calculation : -1.9 Hz/hPa.
- He pressure is finely controlled by a refrigerator (|Δp| < 4.3 hPa in a day). Cavity excitation at a fixed frequency can be kept without tuning at least one day (Δf << cavity bandwidth of 50 Hz).

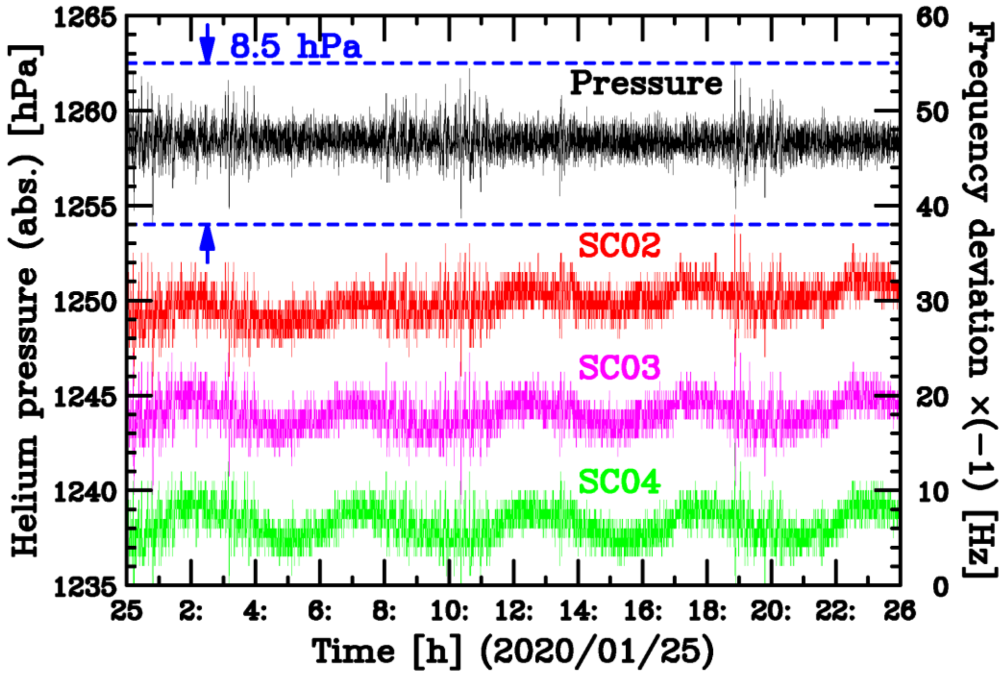
Frequency shift by helium pressure

Cavities other than SC02 were excited by Self Excited Loop to determine frequency



Stability of pressure and frequency

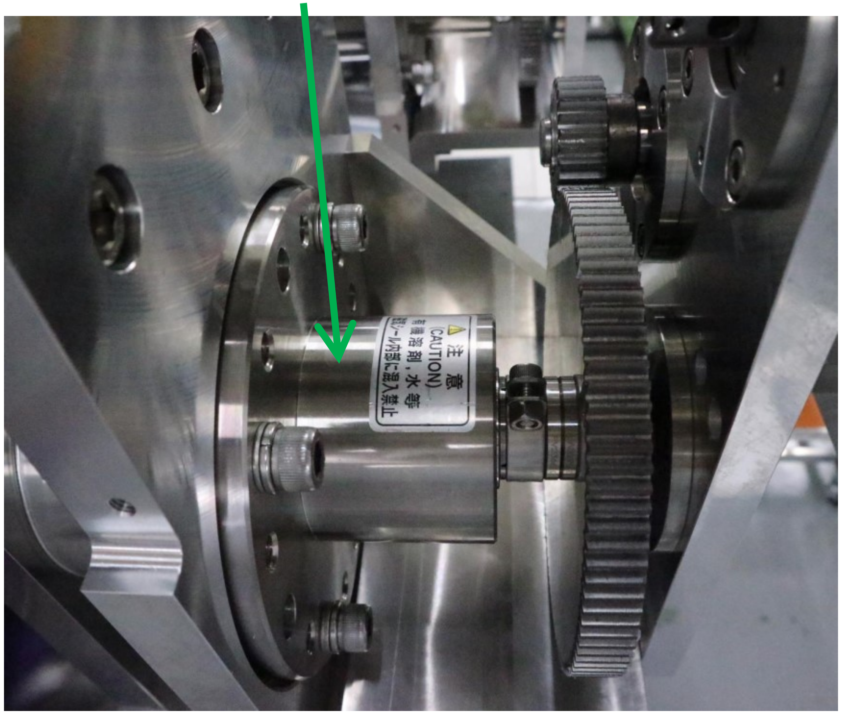
Three cavities were excited by SEL for a day.



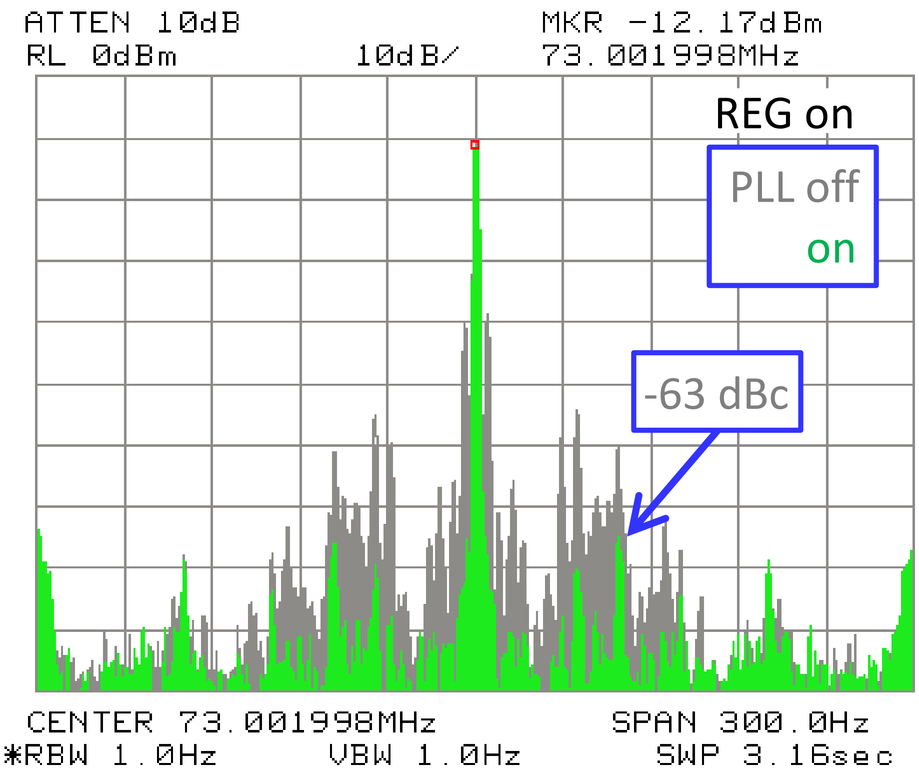
Controls and features

- Speed of stepping motor is 1 rev/s to prevent step-out (4 min to normal).
- No vacuum leakage from a magnetic fluid seal for driving shaft.
- Phase noise due to microphonics is reduced by PLL (no piezo needed).
- Auto tuning control will be tested. A hysteresis (backlash) of ~ 10 Hz is a potential problem.

Magnetic fluid seal and gears

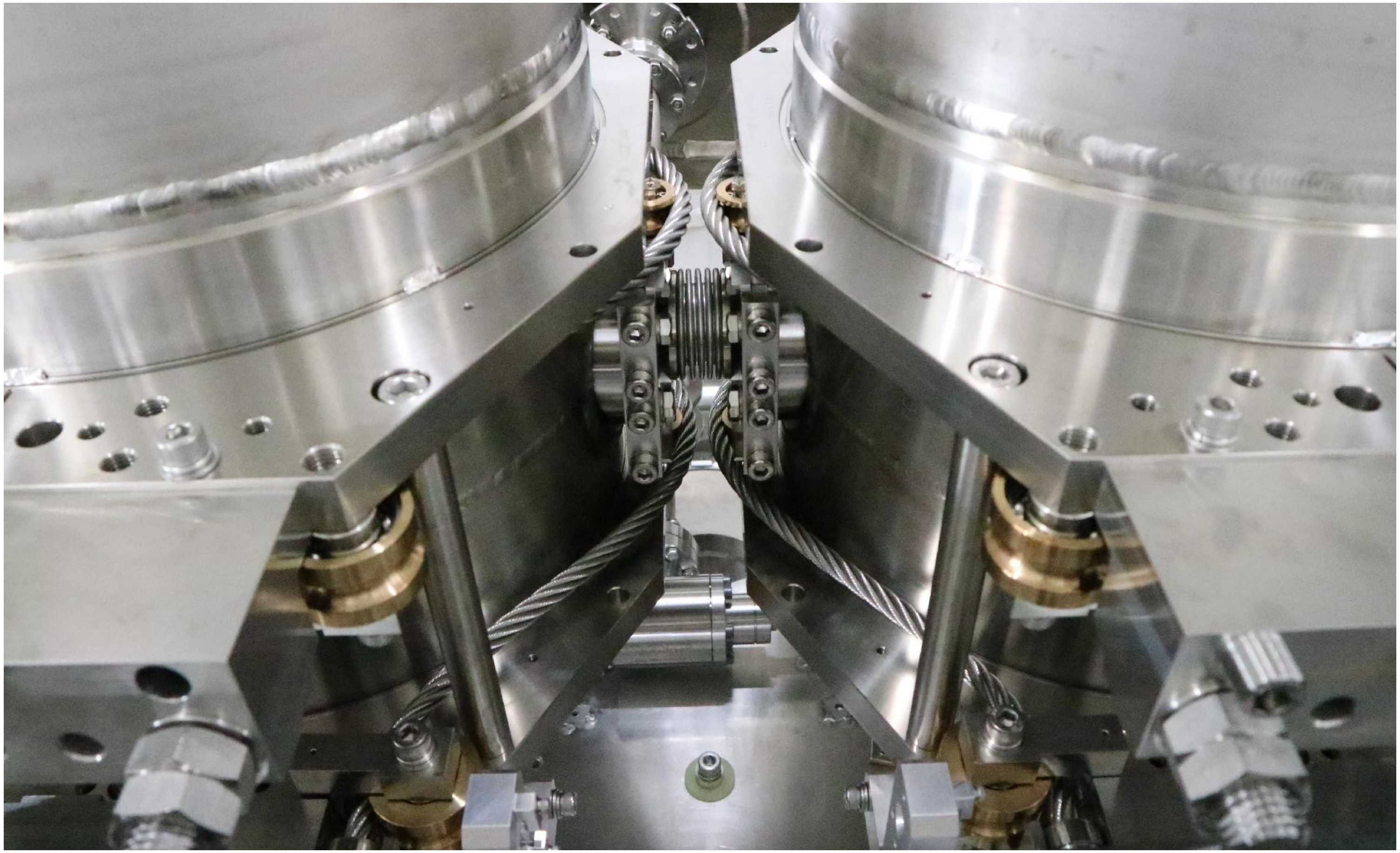


Frequency spectrum



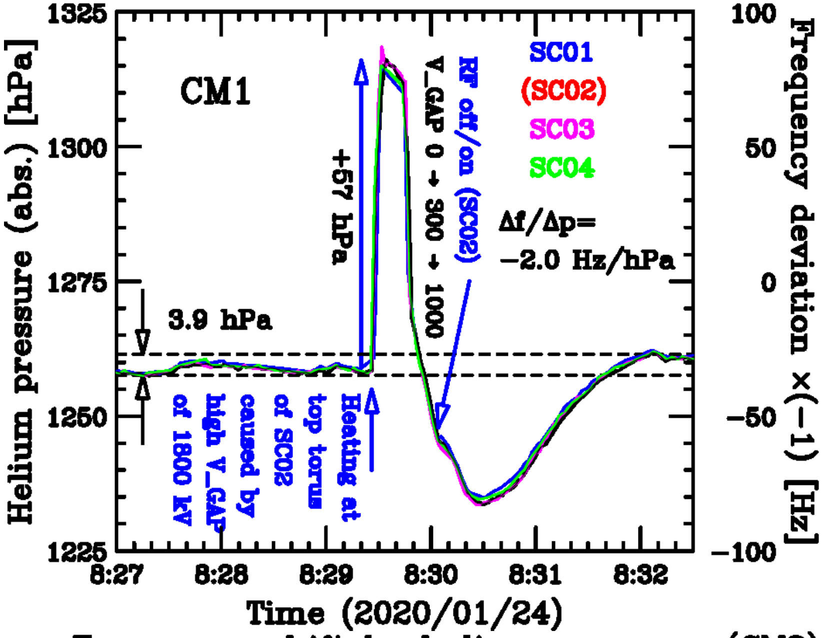
Summary

- A compact tuner was designed and assembled for QWR of SRILAC.
- QWRs were smoothly tuned to the target frequency (73MHz) in a cooling test of cryomodule and the first beam commissioning.

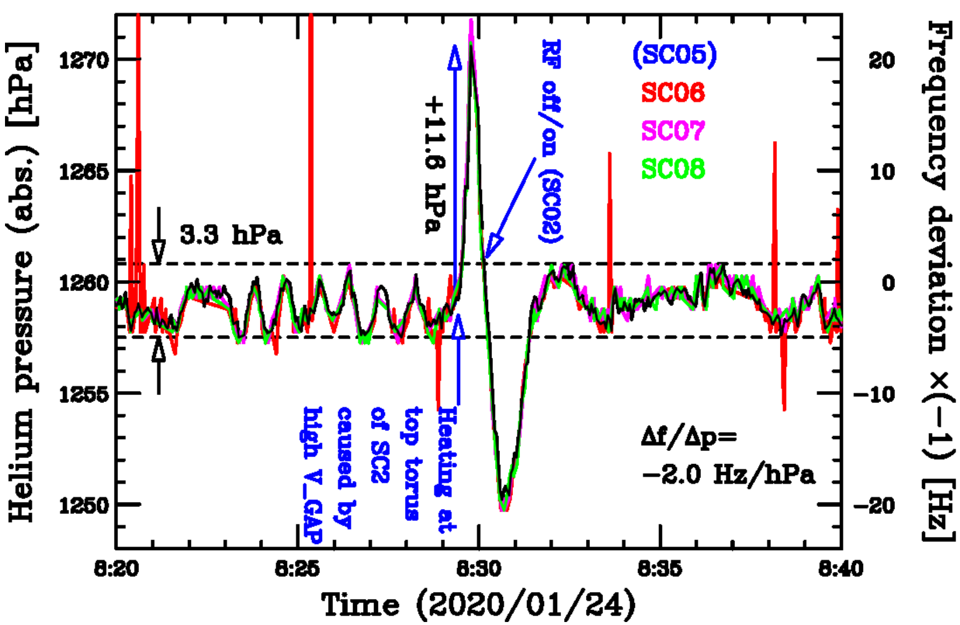


Backup

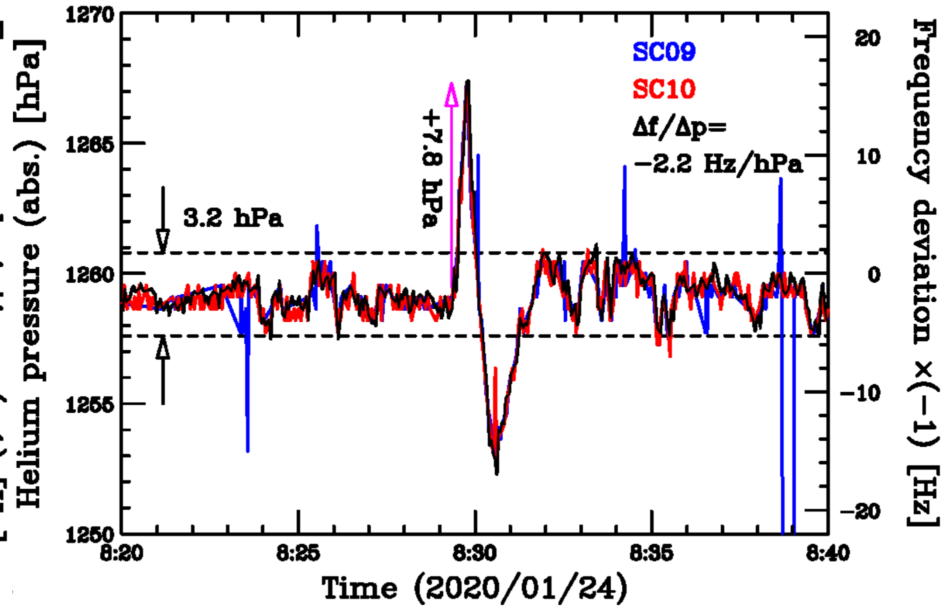
Frequency sensitivity against helium pressure



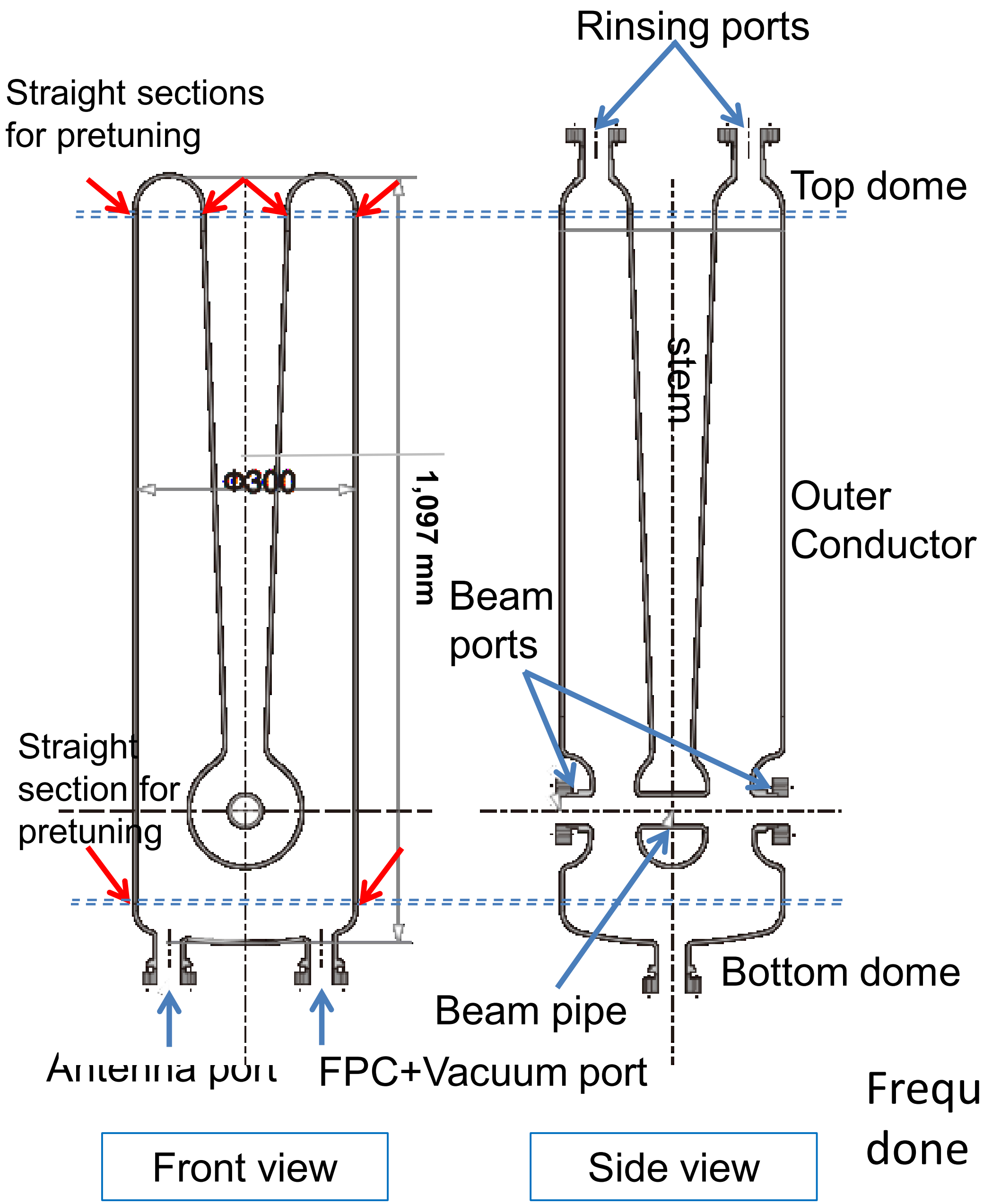
Frequency shift by helium pressure (CM2)



Frequency shift by helium pressure (CM3)



Design parameters of QWR

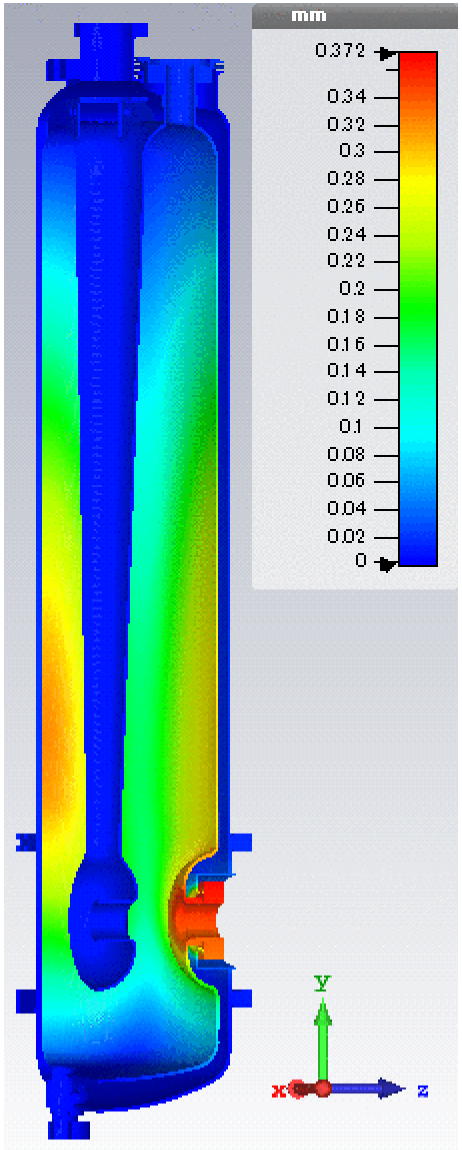


Frequency (@4K)	73.0 MHz
Duty	100 %
βopt	0.078
Inner diameter	300 mm
Height	1097 mm
Aperture	40 mm
$G = Q_0 R_s$	22.4 Ω
R_{sh} / Q_0	579 Ω
Q_0	1.0×10^9
P_0	8 W
Eacc	6.75 MV/m
Epeak /Eacc	6.2
Bpeak /Eacc	9.6 mT/(MV/m)

Frequency tuning at cold operation will be done by beam port tuner (range is 14 kHz)

Beam port tuner

- Frequency sensitivity for beam port tuner was calculated by MWS.
- Δf/Δx=-37.4 kHz/mm (Δx is a displacement of a beam port flange)
- To tune by -14 kHz, required displacement is Δx = 0.37 mm.



Nb cavity with Ti vessel:
Each beam port is pressed by 7,500 N.