Production and Performance Evaluation of a Compact Deflecting Cavity to Measure the Bunch Length in the cERL

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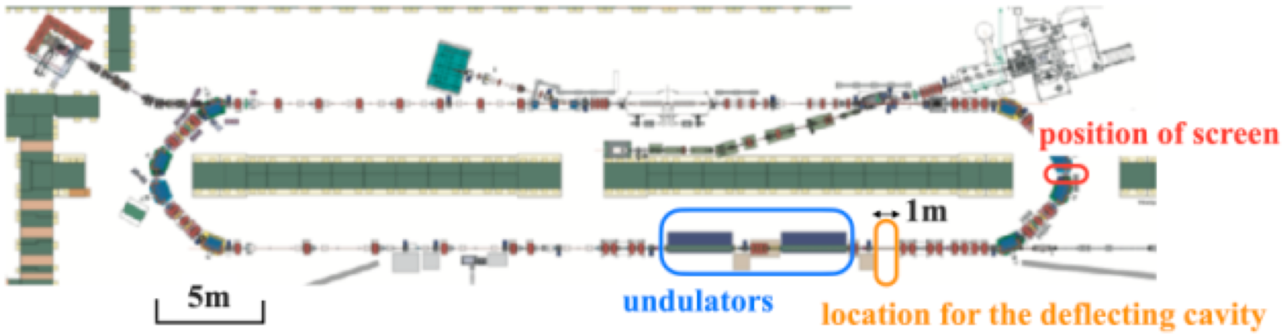
abstract

At the KEK compact energy recovery linac, we have generated an infrared free-electron laser (FEL) using the process of self-amplified spontaneous emission. In the generation of the FEL, an electron bunch should be compressed along the longitudinal direction. To confirm the bunch compression, we plan to measure the bunch length by deflecting cavities in the burst mode. The deflecting cavities are required to be a time resolution of 33 fs in order to not only measure the bunch length but also resolve the structure inside the electron bunch. To achieve the requirement, we have developed a c-band cavity. The deflecting cavity is a single cell and normal conducting cavity. The deflection mode of the cavity is the TM110. RF power was input to the cavity by a compact loop antenna in order to prevent the decrease of the transverse shunt impedance. The 12 cavities will be located at the exit of undulators. In this presentation, we reported the production of the prototype cavity. We also performed the evaluation of the resonance frequency, the unloaded Q and the RF coupling. From the measurements and simulations, the transverse shunt impedance was estimated to be 1 MΩ. The time resolution of the cavity was expected to be 400 fs when the input RF power was 1 kW and the beam energy was 20 MeV.

Measurement of the bunch length at the cERL(compact Energy Recovery Linac)

<cERL and configuration of bunch-length measurement>

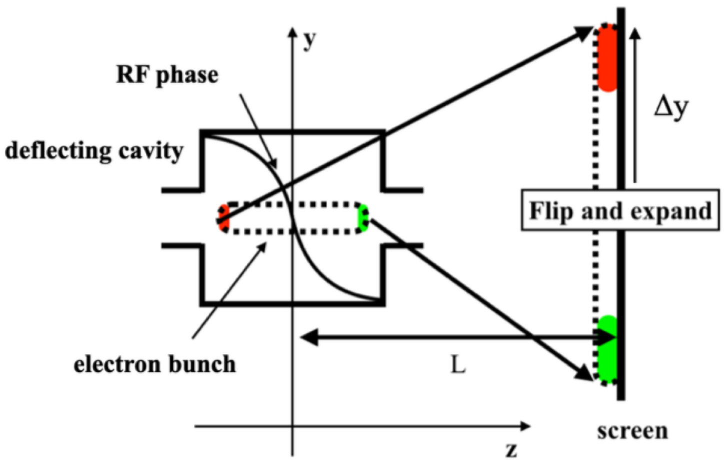


<Beam parameters assumed in this study>

Parameters	**Symbole**	**Value**
Energy	E	20 MeV
Beam size at the undulator exit	σ_{off}	200 μm
Distance between the screen and the cavity	L	10 m
Bunch length	–	500 fs
Micro-bunch interval	–	50 fs
Fundamental RF frequency	–	1.3 GHz
Beam hole radius	–	8 mm

・IR-FEL in the cERL : develop a light source to process various resin materials.
・To generate the FEL, electron bunch should be compressed along longitudinal direction.
・We plan to measure the bunch length by deflecting cavities.

<Principle of the bunch-length measurement>



Time resolution

$$\sigma_{\text{res}} = \frac{E\sigma_{\text{off}}}{eL}\frac{1}{\omega_{\text{RF}}n\sqrt{PR_T}}$$

E : energy
σ_{off} : beam size at the undulator exit
w : resonance frequency
P : input power
R_{sh} : transverse shunt impedance

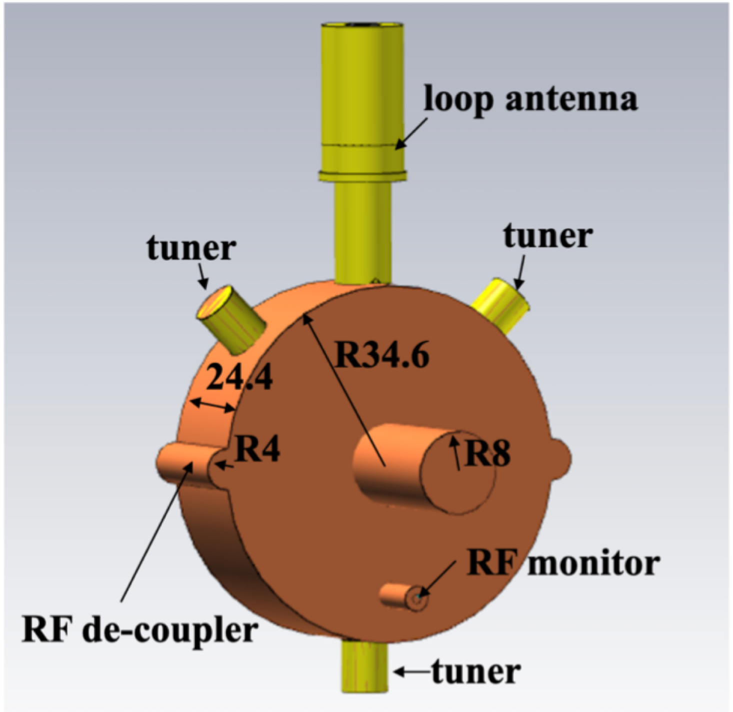
・The longitudinal distribution is rotated and projected on the rear screen.
・We plan to measure the longitudinal distribution with a time resolution of 33 fs.

Design of the deflecting cavity

- We designed the cavity using 3D electromagnetic simulation (CST).
- To reduce the input RF power, the resonance frequency is set to be 5.2 GHz and 12 of single-cell cavities are aligned.
- Advantage of small RF power :
  - Cost down.
  - Size down of the input coupler.

    =>Suppress the decrease of the shunt impedance caused by a through hole of the input coupler.
- Simple Pill-box shape, no nose cone.

  =>Simplify the production and manufacturing of the cavity.
- The time resolution is estimated to be 404 fs when the input RF power is 1 kW and the beam energy is 20 MeV.

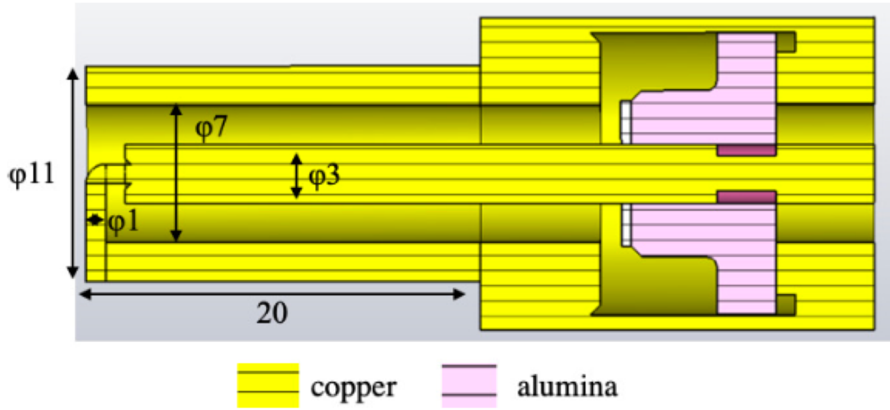


<Parameters of the deflecting cavity>

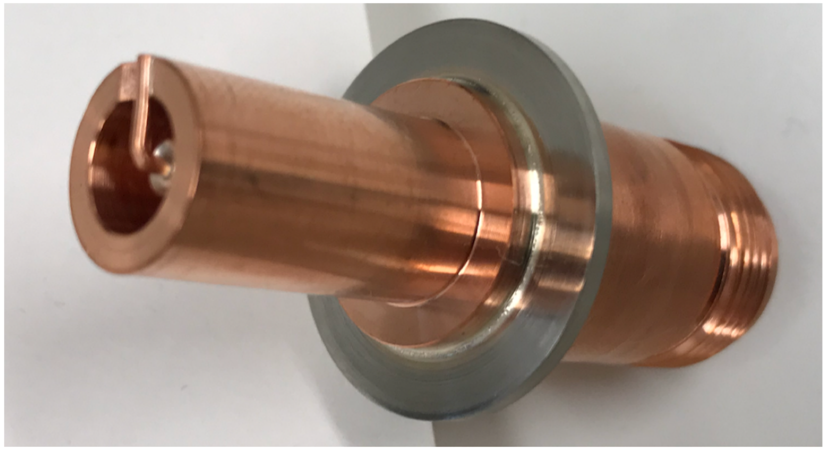
Parameters	Value
Resonance frequency	5.2 GHz
Deflecting mode	TM110
Unloaded Q	14800
Transverse shunt impedance per single cavity	0.98 MΩ
Coupling β	1
Input power per single cavity	1 kW
Resolution per single cavity	400 fs
Number of cavity	12

Design of the input coupler (skip in the video)

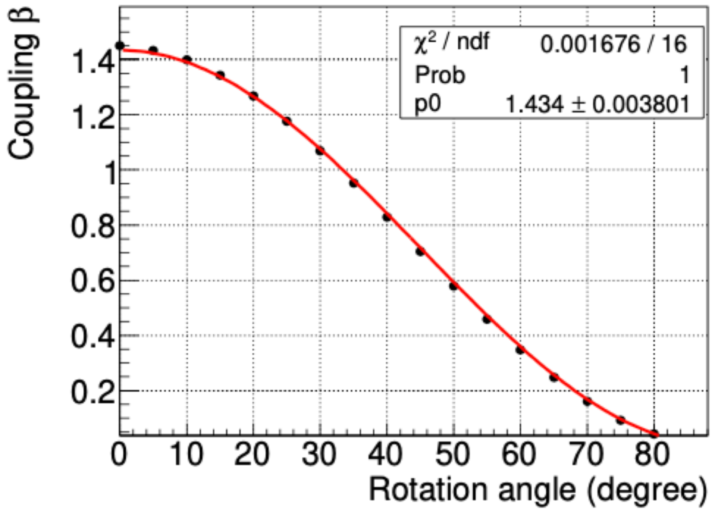
<Schematic view of the input coupler>



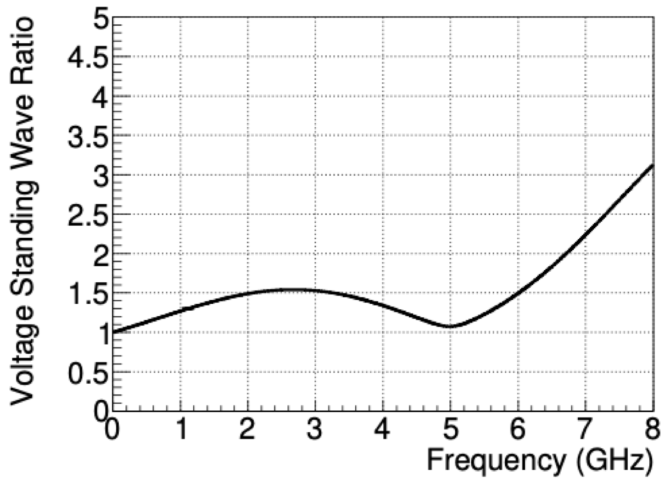
<Photo of the input coupler>



<Rotation angle and β (CST)>



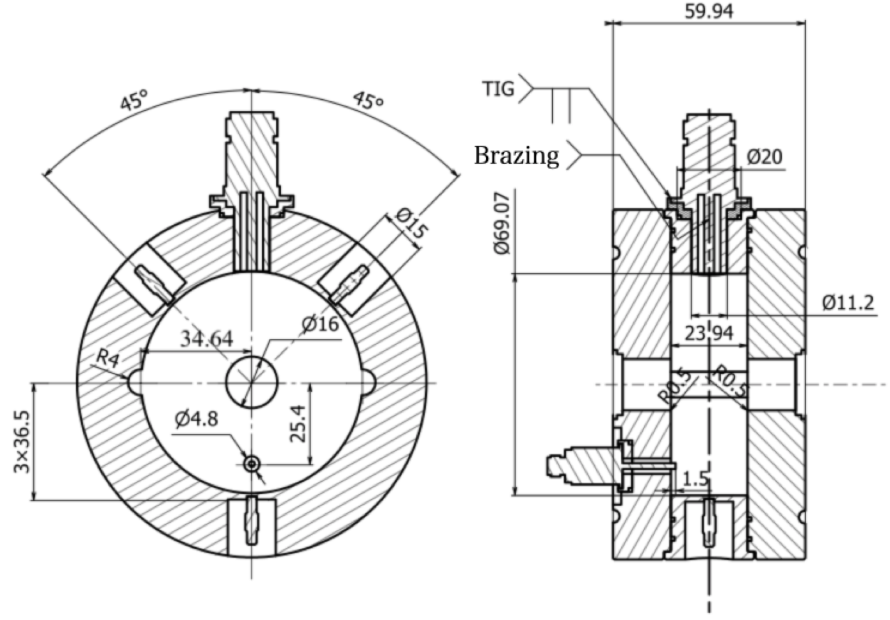
<VSWR vs resonance frequency (CST)>



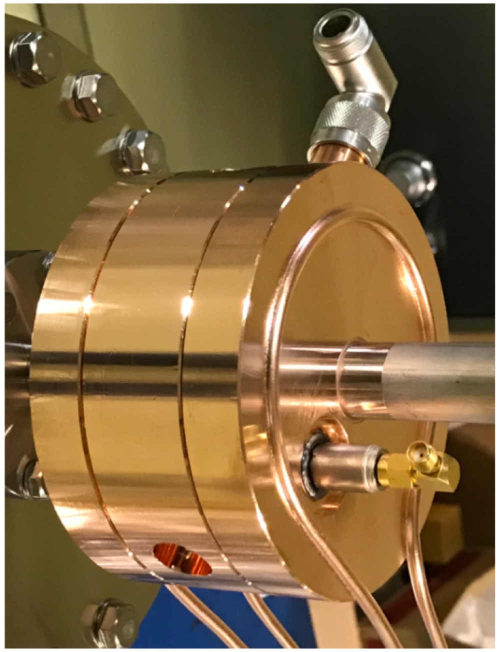
- The RF power is input to the antenna through a N-type connector.
- The coupling β is set to be 1 with the rotation angle of 33 degree.
- After optimizing the shape of the vacuum window, VSWR is estimated to be 1.1 at 5.2 GHz.

Production of the prototype cavity

<Schematic view of the prototype cavity>



<Photo of the prototype cavity>

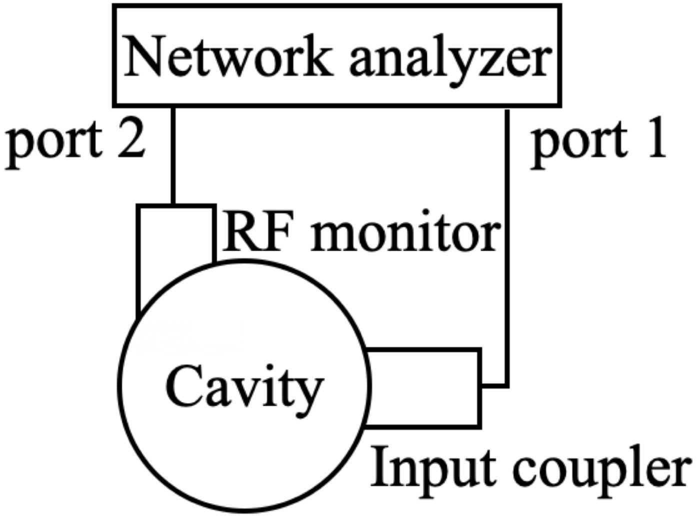


- The cavity is divided into three parts in order to simplify manufacturing and brazing.
- The radius of the cavity is 70 μm larger than that one with the resonance frequency of 5.2 GHz.
  =>The external wall of the cavity was scraped after the measurement of the resonance frequency.
- Production process:
  1. Scraping of the cavity wall.
  2. Brazing of the cavity.
  3. Test of air leakage in vacuum.

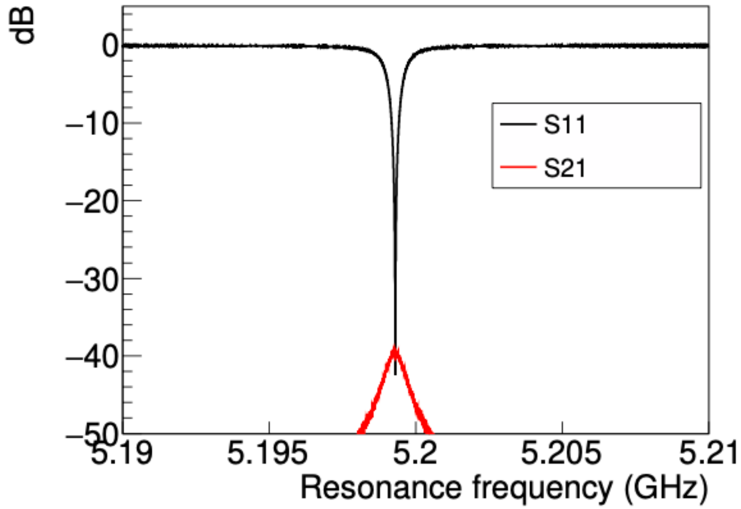
Scraping of the cavity wall

- Measure the resonance frequency of the TM110 mode, S11 and S21 by a network analyzer (25°C, air).
  =>Determine the width of the scraping.

<Experimental set up>



<Measurement example of the S11 and S21>



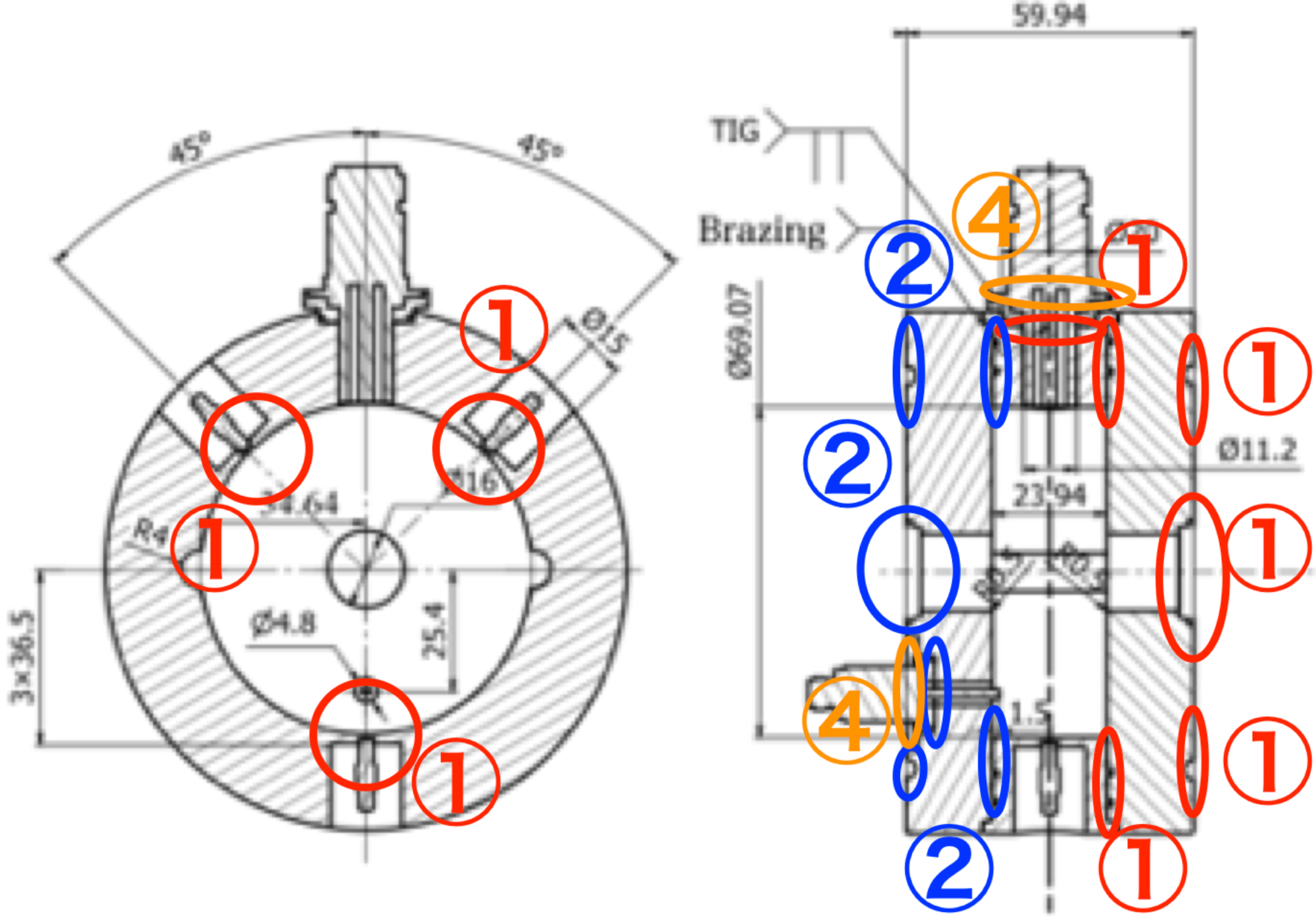
<Change of the resonance frequency after scraping>

Cut of radius	Δf (CST)	Δf (Measured)
$32^{+2}_{-2.5}$ μm	$-4.66^{+0.29}_{-0.36}$ MHz	-5.1 MHz
$30^{+0.5}_{-0.5}$ μm	$-4.37^{+0.07}_{-0.07}$ MHz	-4.2 MHz
$9^{+0.5}_{-0.5}$ μm	$-1.17^{+0.07}_{-0.07}$ MHz	-1.15 MHz

- The measurement and scraping were carried out 3 times.
- All processes agreed well with their expectation.
- The resonance frequency was expected to be 5.2 GHz in vacuum of 35 ℃.

Brazing of cavity

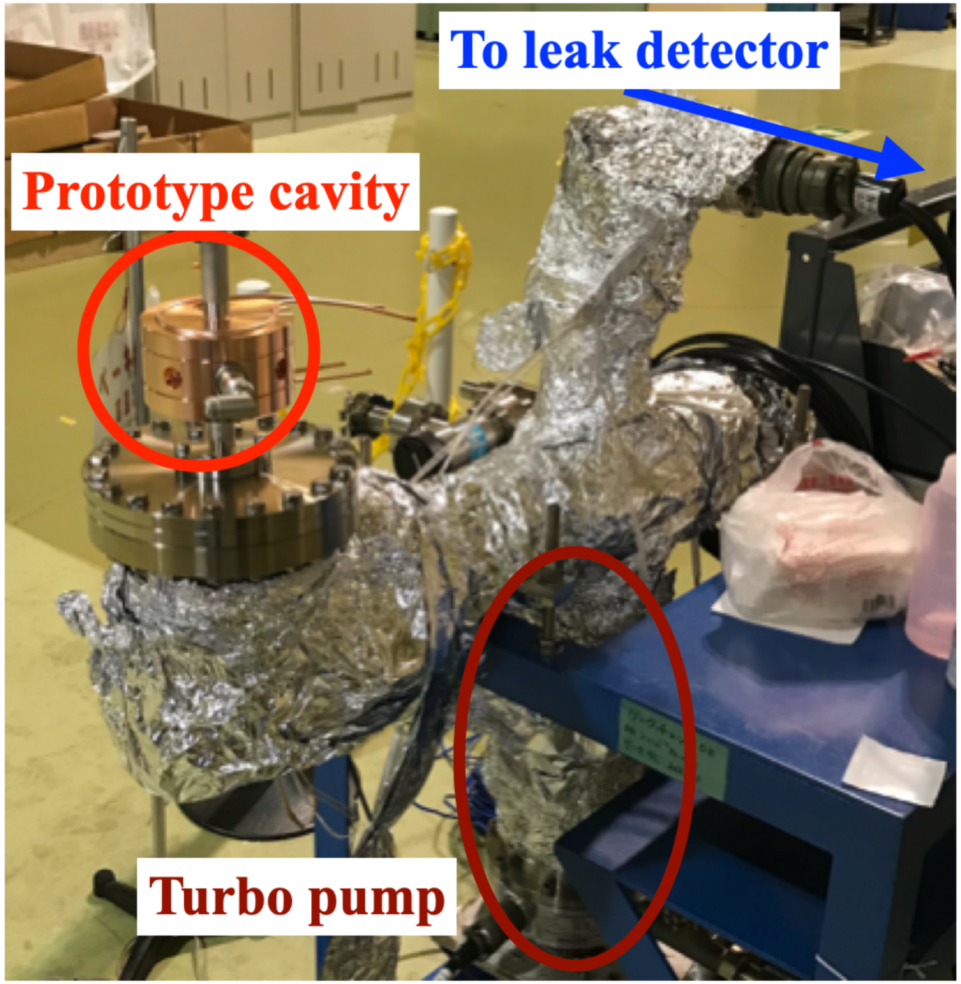
1 . Braze the center part with the rear part, the three tuners, a base plate, beam pipe and water pipe.
2 . Braze the center part with the front part, a base plate, beam pipe and water pipe.
3 . Adjusted the rotation angle of the loop antenna and rod length of the RF monitor by measuring the β and the S21 , respectively.
4 . Solder the loop antenna and the RF monitor to their base plates.



Air Leakage test

- Check an air leakage of the cavity in vacuum condition (24.2°C).
- Degree of the vacuum : 3×10^{-6} Pa
- Leak late：3×10^{-11}Pa m^3/s
- Measure the resonance frequency of the TM110 mode, S11 and S21 by a network analyzer.
  =>calculated Q_L, β, Q_0 and the transvers shunt impedance.

<Photo of setup>



Parameter comparison.

Parameters	Measurement	Simulation
Frequency (GHz)	5.2005	5.2011
Transmission coefficient (dB)	-58.2	-35.0
Unloaded Q	14009	13981
Shunt impedance (MHz)	0.96	0.96
RF coupling	1.02	1.01

- Difference of the resonance frequency:
  the frequency was not changed by the brazing.
- Difference of the S21 :
  the rod antenna could be damaged.
- Measured value of the Q_0 was agreed well with the simulated one.
  =>Transverse shunt impedance is expected to satisfy our requirement of the time resolution.

Summary

・To measure the bunch length in the cERL, we newly developed a c-band deflecting cavity.
・The resonance frequency of the TM110 mode was set to be 5.2 GHz.
・The RF power was input to the cavity by a compact loop antenna in order to prevent the decrease of the transverse shunt impedance.
・We produced the prototype of the cavity and evaluate its performance.
・The resonance frequency was 5.2005 GHz in vacuum of 24.2 °C and estimated to be 5.2 GHz in vacuum of 30 °C.
・The transverse shunt impedance was estimated to be 0.96 MΩ.
・The time resolution was estimated to be 404 fs when the input RF power was 1 kW and the beam energy was 20 MeV.
・Using 12 cavities, we could achieve the time resolution of 33 fs.

Acknowledgments

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