Advanced Accelerator Technology (Japan-side)

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US-Japan Meeting 2023 in Hawaii

Topics in this program

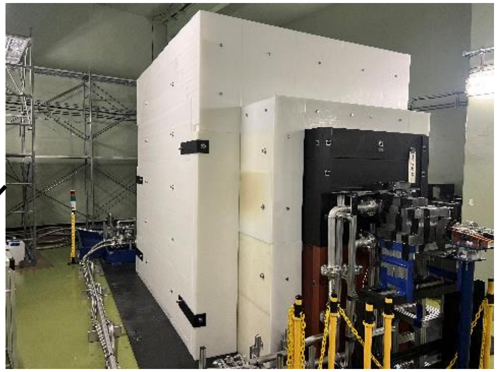
1. Advanced SRF cavity technologies
   a. Thin-film coating technologies for transformational performance of SRF cavities
   b. New SRF cavity shapes for high gradient and low field emission
   c. SRF cavities fabricated from large- and medium-grain ingot niobium
2. Advanced SRF cryomodule technologies -> STF
   a. Cryomodule assembly technologies, cryogenic and RF operation
   b. Advanced SRF cavity and cryomodule instrumentation
   c. Advanced in-situ mitigation techniques to improve SRF cryomodule performance – plasma processing of SRF cryomodules
3. Nanobeams -> ATF
   a. Beam instrumentation for extremely small vertical emittance beams
   b. Extremely small vertical beam size realization

This program focuses on SRF accelerator technologies (cavity and cryomodule) and nanobeams which are both important for the advanced accelerator.

2. Advanced SRF cryomodule technologies (STF)

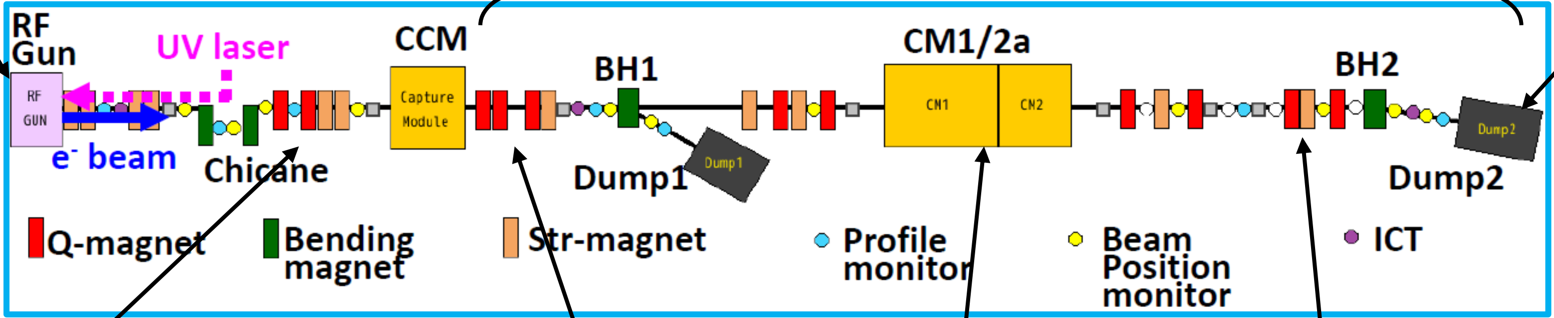
In 2022, the beam current of the STF accelerator was increased. Since beam power became 7 times larger than previous operation, an end beam dump was upgraded and additional beam monitors were installed. In addition, since the beam width was increased, the laser was adjusted and the RF gun was RF-conditioned for a long time to produce a stable beam. <u>Finally, the ILC specification was achieved.</u>

Beam dump upgrade



Laser adjustment & RF gun conditioning

Beam loss monitor installation

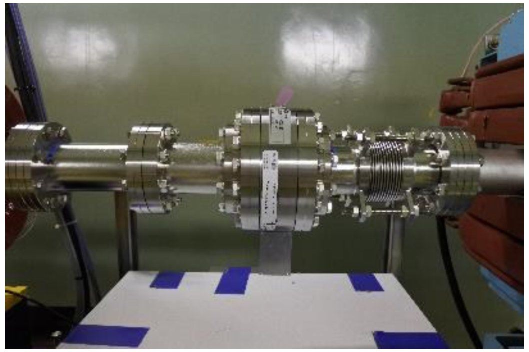


Alignment

Magnet replacement

3-axis fluxgate magnetic sensor installation

Beam current monitor replacement



3. Nanobeams (ATF)

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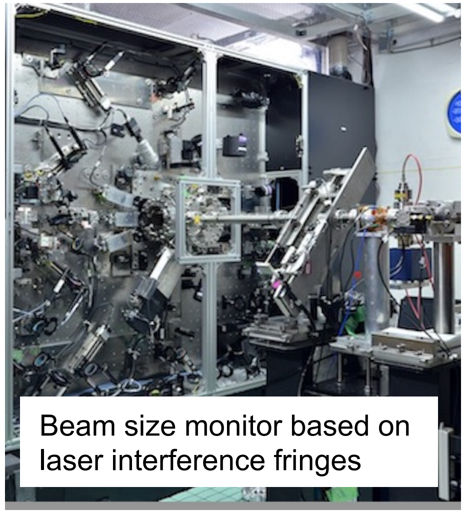
Aiming at research and development of higher-order aberration correction technology for nanobeam focusing optics, beam operation was carried out while upgrading the beamline facilities. 10 weeks of beam operation was carried out in total in FY2022.

■ Improvement of the nanobeam measure-ment system

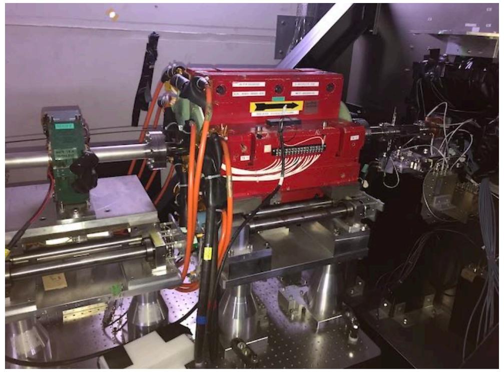
- Stabilization of laser and electron beam collisions
- Stabilization of laser control system
- Vibration and thermal fluctuation measures
- Stabilization of electron beam



Beam size monitor based on laser interference fringes

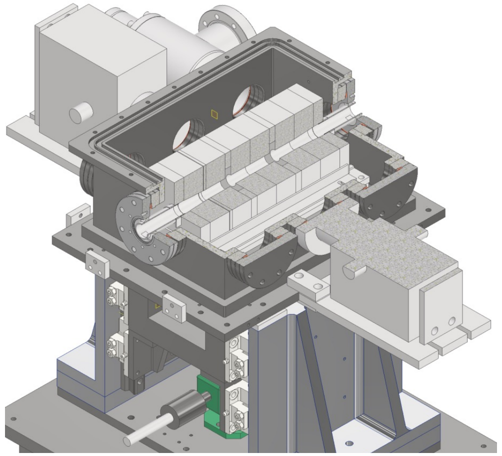
■ Fabrication of the final focusing quadrupole magnet

- Reduction of higer-order magnetic field components



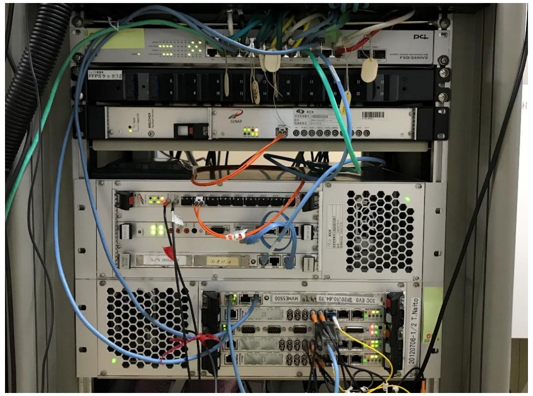
■ Research on wake field effects

- Introduced a vacuum system with an arbitrarily configurable wakefield source and a mechanism to change the relative position of the wakefield source and the beam.



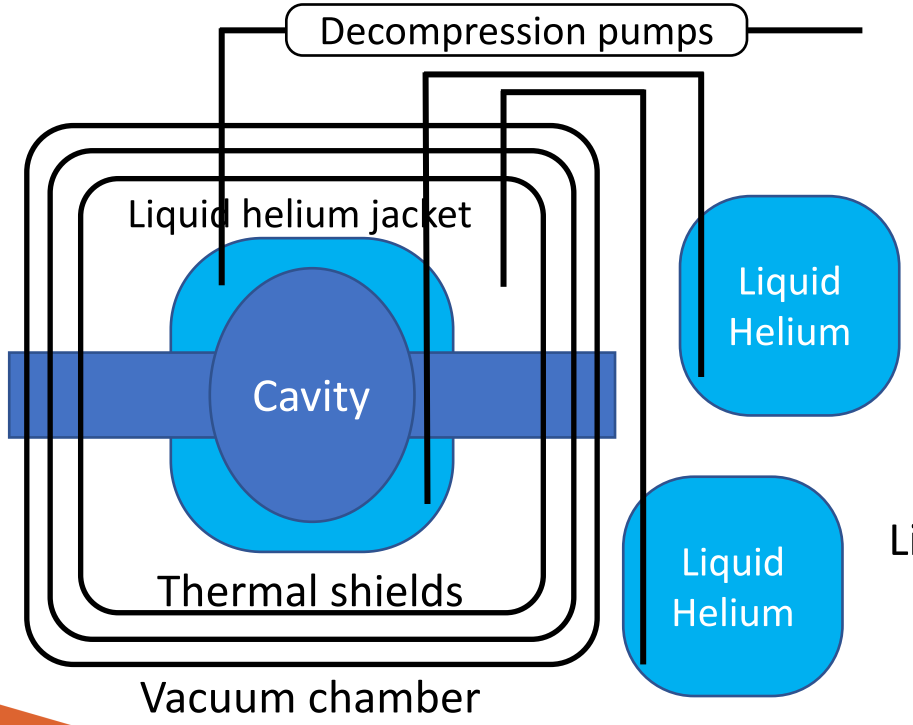
■ Beam tuning by machine learning

■ Improvement of control system for reference timings



1. Advanced SRF cavity technologies
- Nb_3Sn coating and its conduction cooling -

Nb_3Sn is one of the most promising alternative materials for SRF application. The BCS surface resistance of Nb_3Sn at a given temperature is much smaller than Nb, hence it allows very efficient operation at 4K, which can be also produced without liquid helium. Researches on high quality Nb_3Sn coating and conduction cooling by cryocoolers are essentially important to lower the wall to introduce SRF technologies into various accelerators.

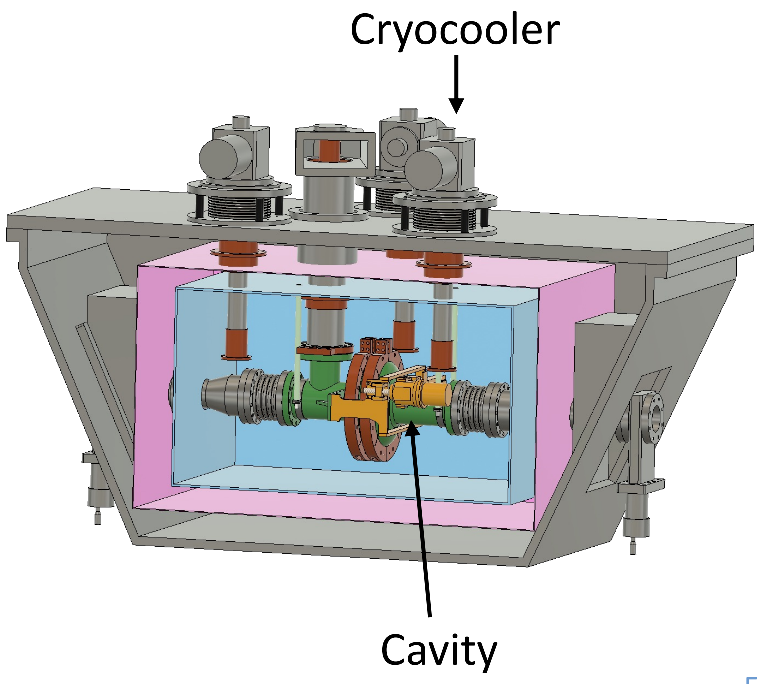


High pressure safety
Constrained → Free

Cryomodule design
Complex → Simple

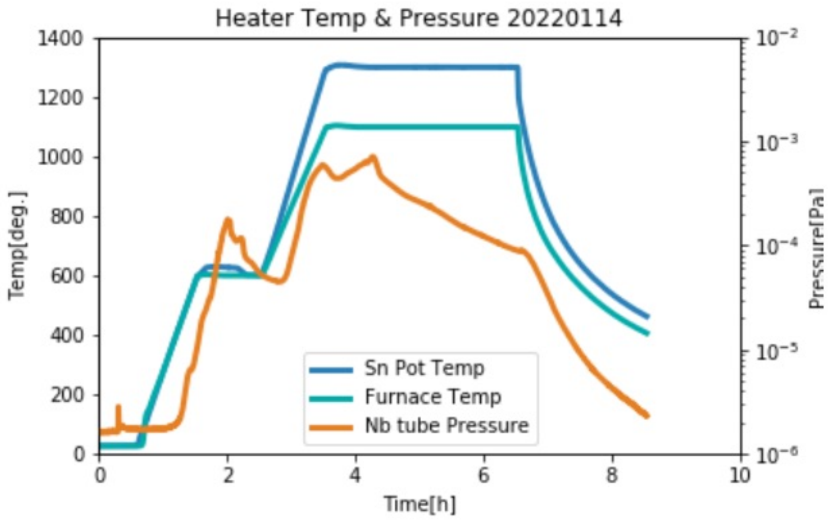
Cryogen
Liquid helium, Liquid Nitrogen → Nothing

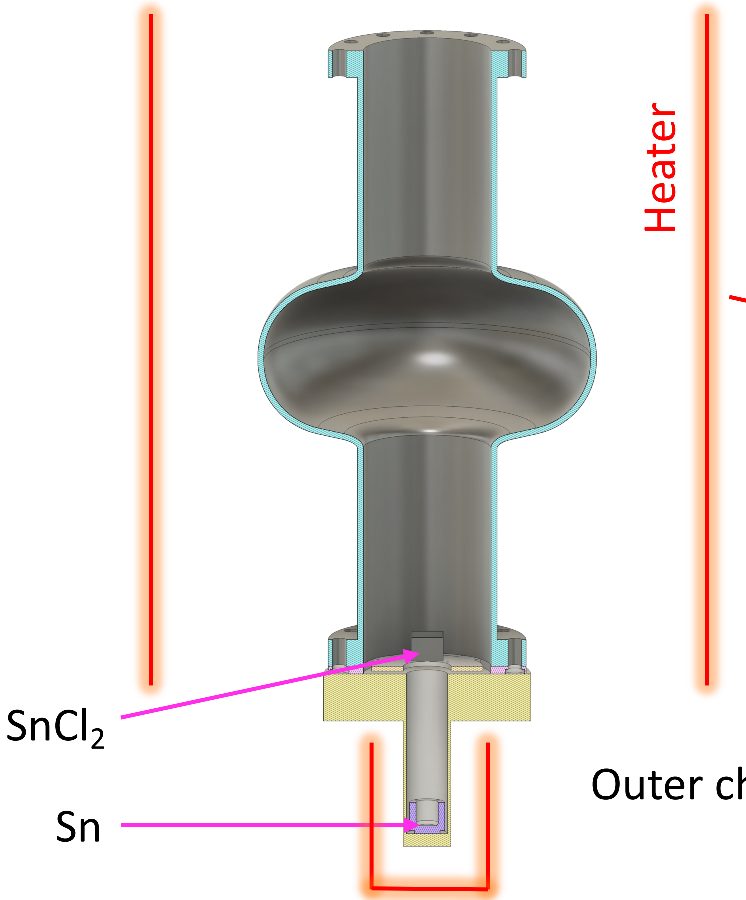
Price
Expensive → Cheap

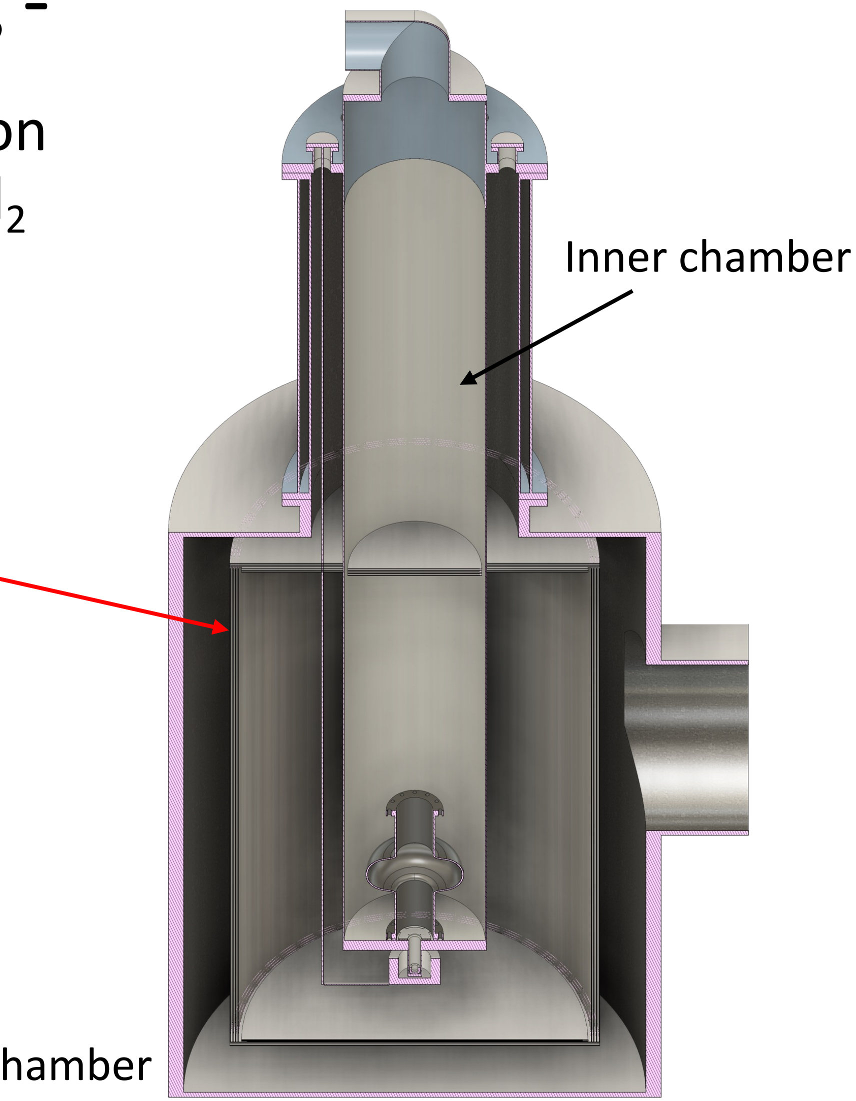


1. Advanced SRF cavity technologies
- Nb_3Sn coating and its conduction cooling -

4 times of Nb_3Sn coating were done so far by vaper diffusion method in KEK. Coating temperatures and amounts of $SnCl_2$ and Sn were studied.





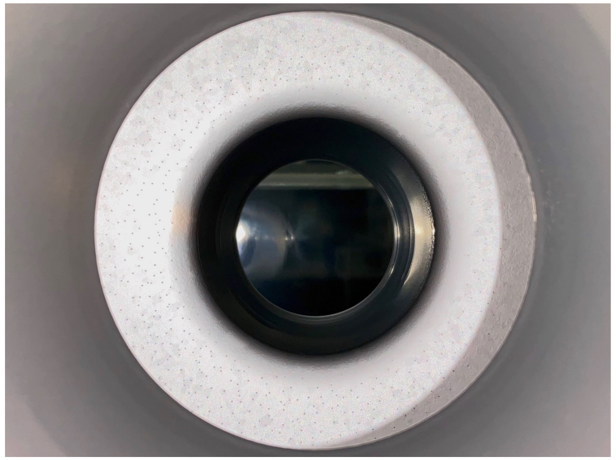


Nb_3Sn coating furnace

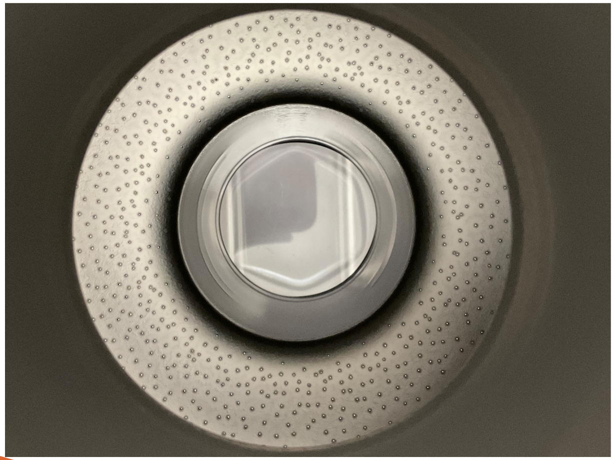
1. Advanced SRF cavity technologies
- Nb_3Sn coating and its conduction cooling -

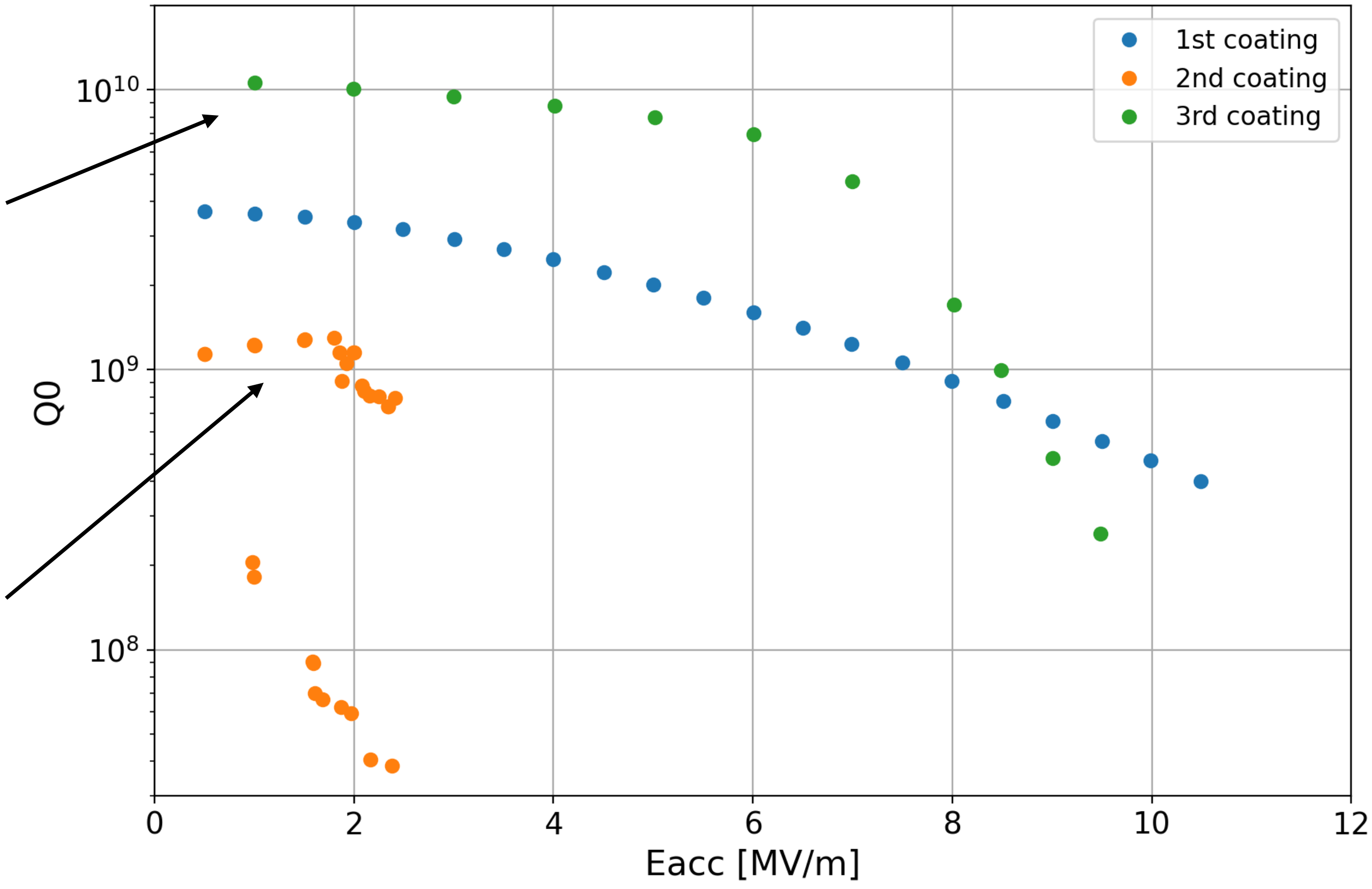
3rd Nb_3Sn coating achieved Q > 1E10, which is one of our target. We pursue higher accelerating gradient with high Q.

3rd



2nd



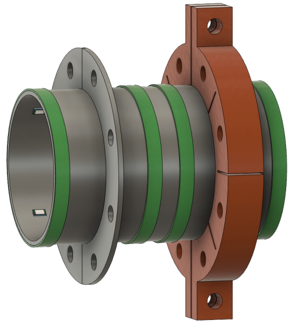


1. Advanced SRF cavity technologies

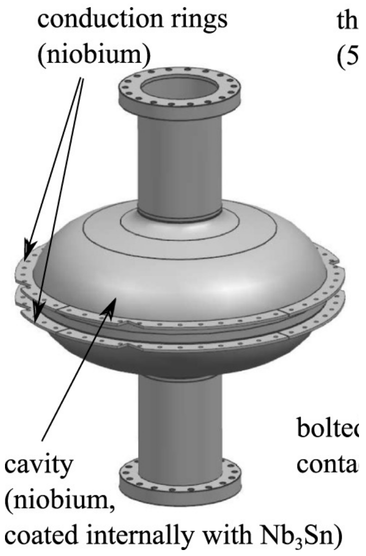
- Nb_3Sn coating and its conduction cooling -

Conduction cooling research was also carried out in parallel with coating research. We compared several cooling schemes with a simplified Nb tube and decided to clamp around cavity equator with sophisticated copper jigs.

Simplified Nb tube for cooling scheme comparison

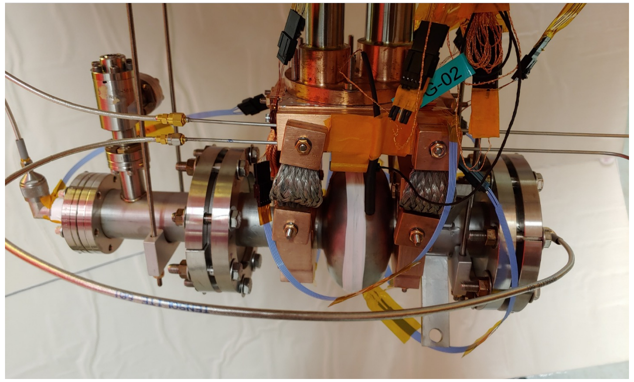


GM-JT cryocooler by SHI (9W@4K)

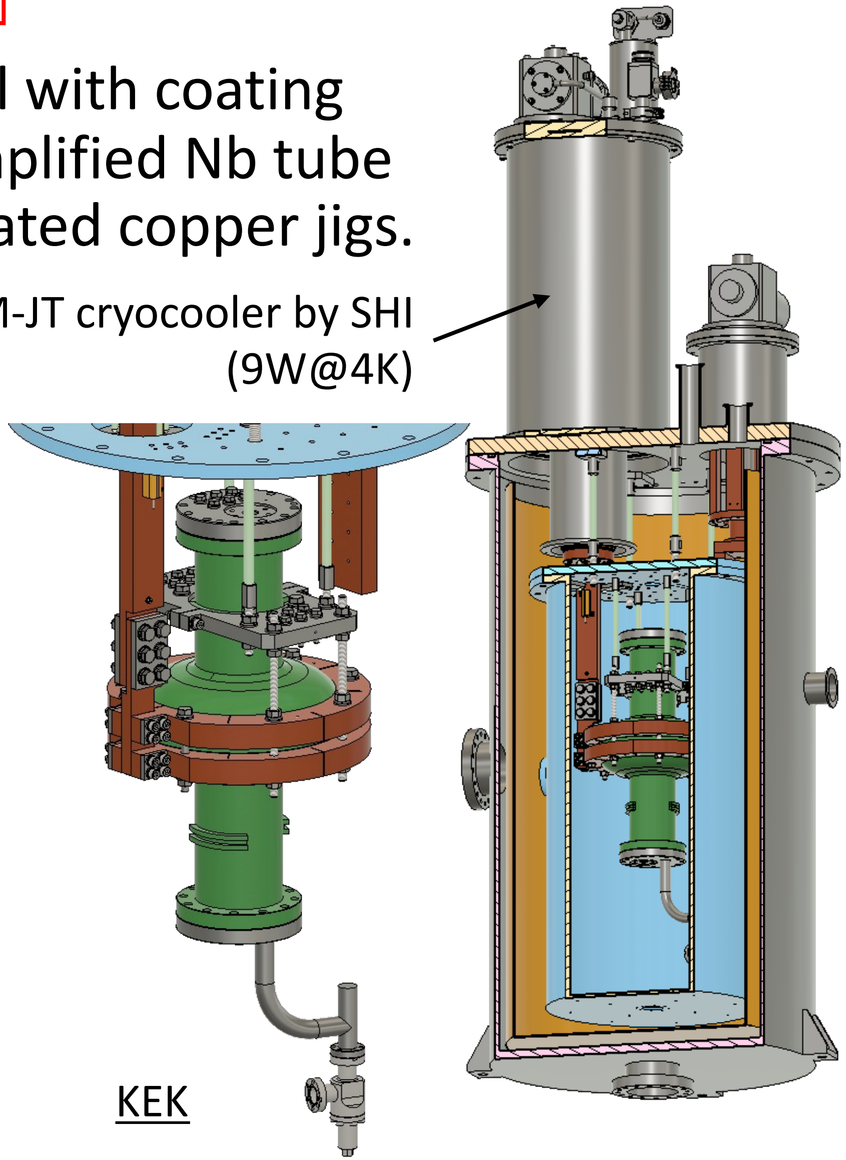


Fermi Lab

Jefferson Lab



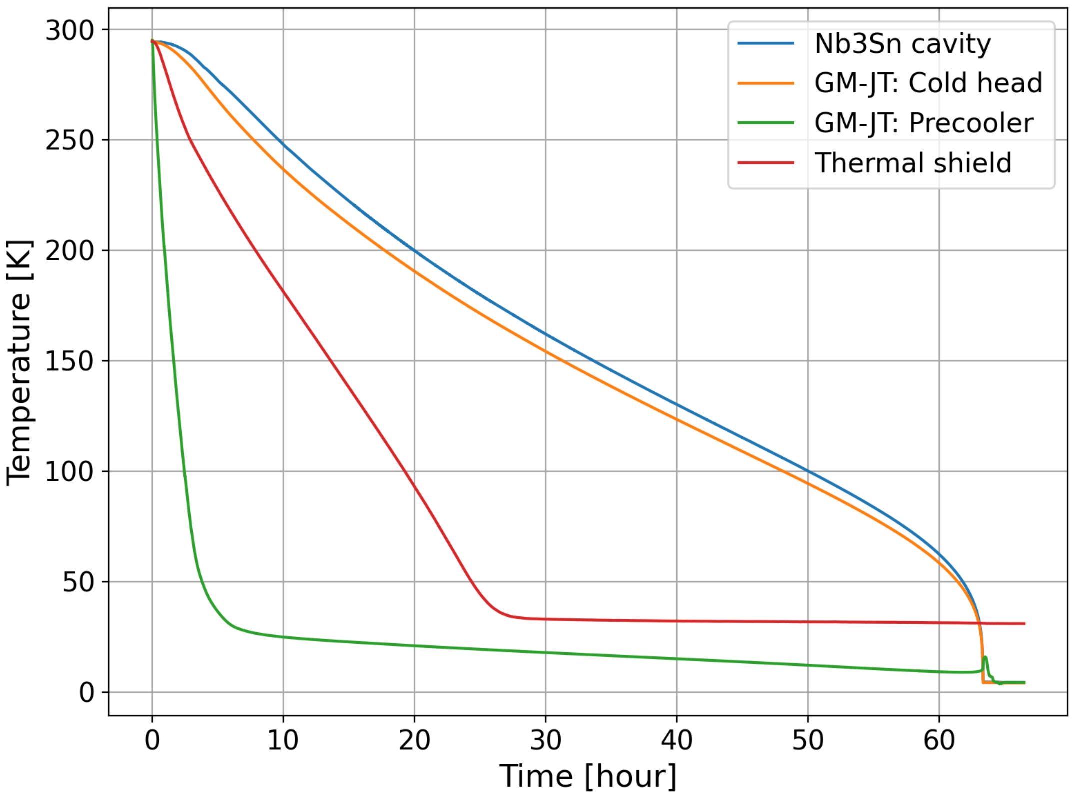
Cornell Univ.

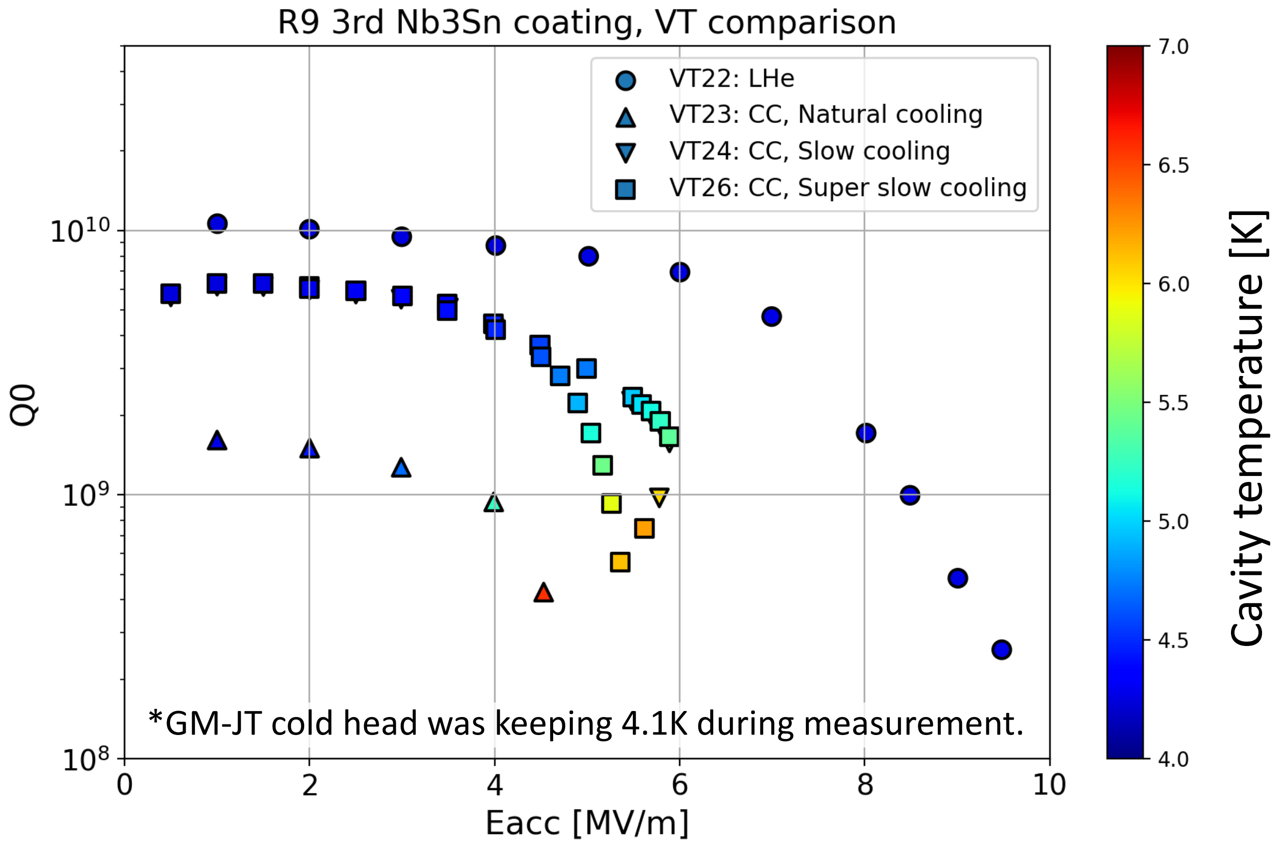


KEK

1. Advanced SRF cavity technologies
- Nb_3Sn coating and its conduction cooling -

The 3rd Nb_3Sn coated cavity was successfully cooled down by the GM-JT cryocooler in 2.5 days and the first conduction cooled RF test for the Nb_3Sn cavity was conducted.





Cavity performance was improved by cooling slowly. Degradation of Q is considered to be due to high residual magnetic field. Next cavity performance measurement with improved magnetic environment will be done soon.

Summary

1. Advanced SRF cavity technologies

- The 3rd Nb_3Sn coating achieved Q>1E10 with LHe measurement. It was conduction-cooled to 4.3K by the GM-JT cryocooler and RF-tested.
- Other studies on thin-film and high performance cavity are also carried out in KEK.

2. Advanced SRF cryomodule technologies -> STF

- The beam current of STF accelerator was increased in FY2022.
- An end beam dump was upgraded and additional beam monitors were installed. In addition, the laser was adjusted and the RF gun was conditioned for a long time.
- Finally, the ILC specification was achieved.

3. Nanobeams -> ATF

- R&D of higher-order aberration correction technology for nanobeam focusing optics is proceeding in ATF.
- 10 weeks of beam operation in total was carried out in FY2022.

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Kirk Yamamoto, LINAC2022

Beam Parameters in STF-2 Accelerator

iCASA Center for Applied Superconducting Accelerators 応用超伝導加速器イノベーションセンター

STF-2

Specifications to be reported to nuclear regulatory agency

1st upgrade (F.Y.2018 → F.Y.2020); 2nd upgrade (F.Y.2021 → F.Y.2022)

	F.Y.2018	F.Y.2020	F.Y.2021	F.Y.2022	ILC spec.
Max. beam energy [MeV]	500	500	500	500	500 GeV
Max. beam intensity [μA]	0.30	3.00	3.00	21.05	21.0
Max. beam power [kW]	0.135	1.350	1.350	6.750	14 MW
Max # of bunch / train	1000	1000	16260	118048	1312
Bunch spacing [nsec]	6.15	6.15	6.15	6.15	554 nsec
Max train length [μsec]	6.15	6.15	100	726.00	726.848 μsec
Max. RF repetition rate [Hz]	5	5	5	5	5 Hz
Bunch charge [pC]	60	600	36.90	35.66	3.21 nC
Bunch current [mA]	9.756	97.561	6.00	5.799	5.8 mA

We are approaching our goal!

This FY's target: Increase beam current. Beam operation mid. Nov ～ mid. Dec.