WG-4, Session 1
Machine availability and reliability –electron machine–

SRF operation in SuperKEKB

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Overview of SuperKEKB

- Searching for "new physics" beyond the Standard Model
- e-/e+ asymmetric energy ring collider for B-meson physics
- Circumference of 3 km
- Target Peak Luminosity

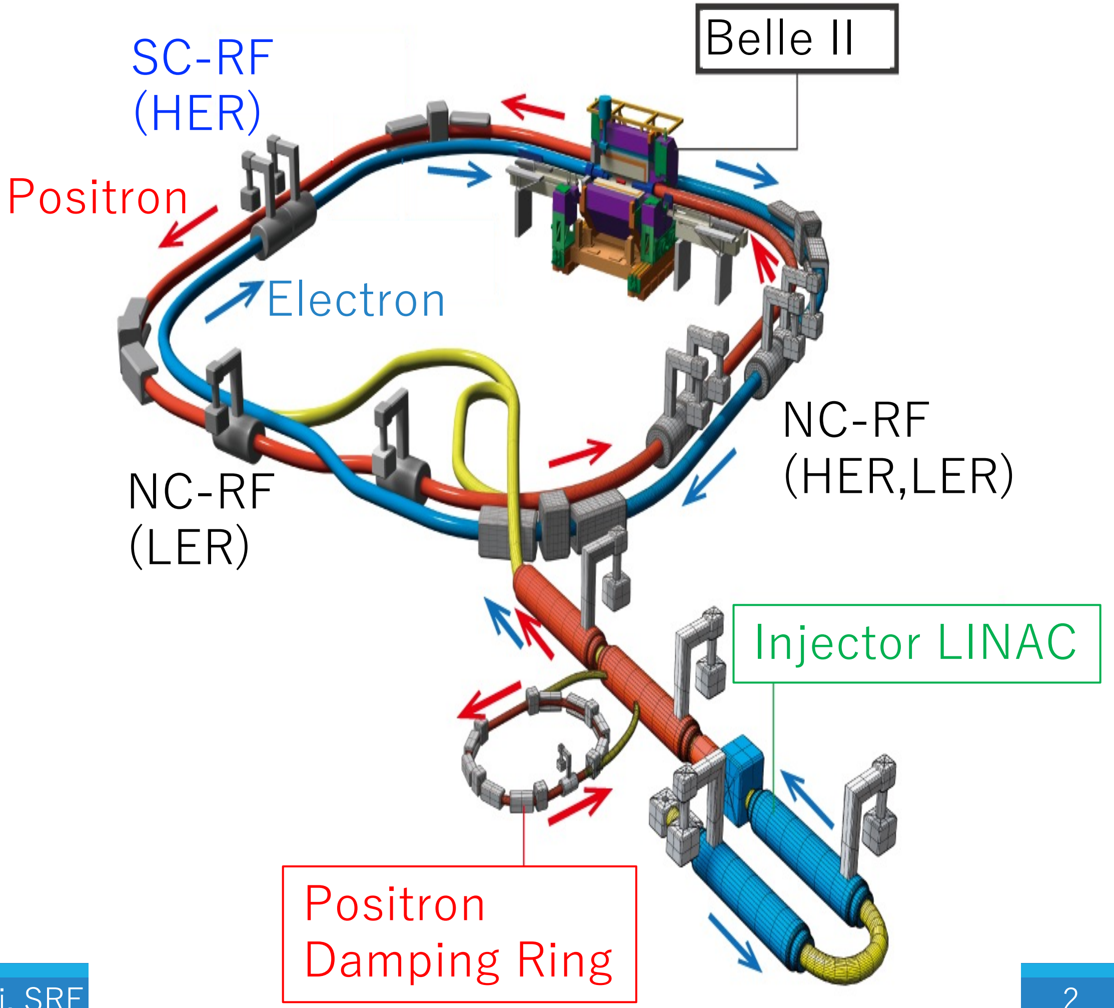
  8×10^{35} /cm^2/s = 800 /nb/s

  40 times of KEKB achieved

  - **Nano-beam scheme** with colliding beams of 10μm x 40nm
  - **Increase of Beam Intensity**
    - **(achieved) 1.14 A for HER, 1.46 A for LER**

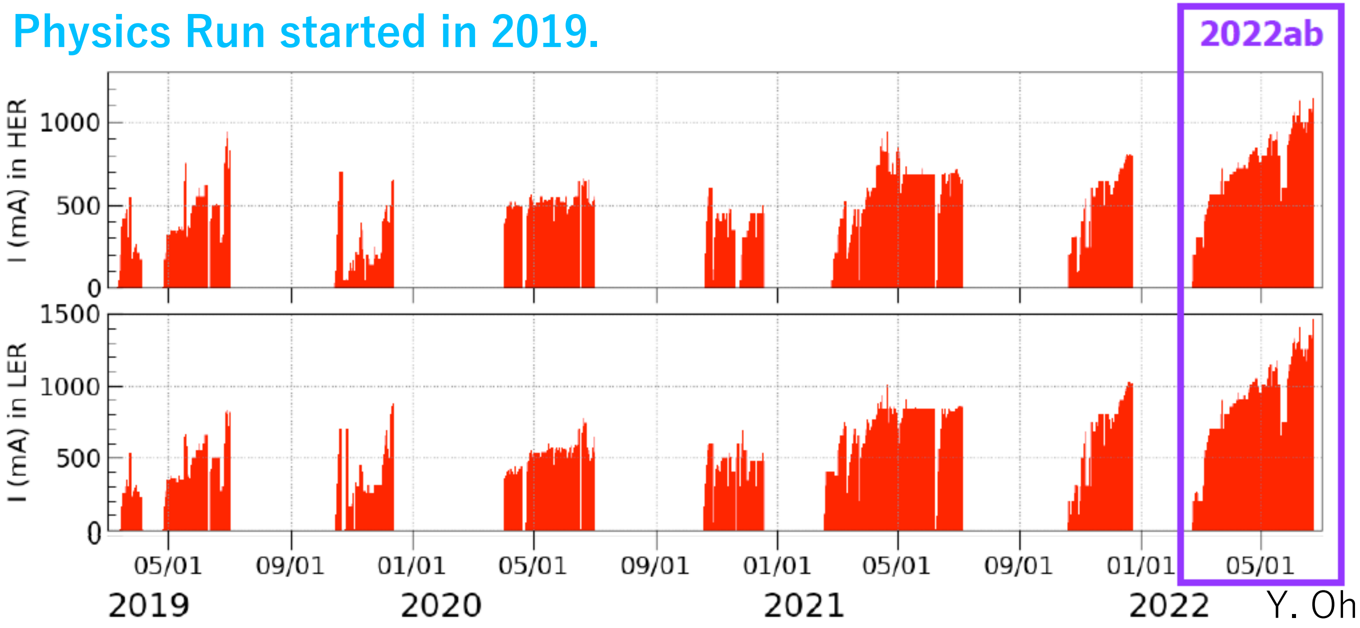
Peak luminosity of 4.65×10^{34} /cm^2/s was recorded in June 2022.

	LER	HER
Particle	positron	electron
Energy	4 GeV	7 GeV
Beam Current (design)	3.6 A	2.6 A



Overview of Beam Operation and RF System

Physics Run started in 2019.

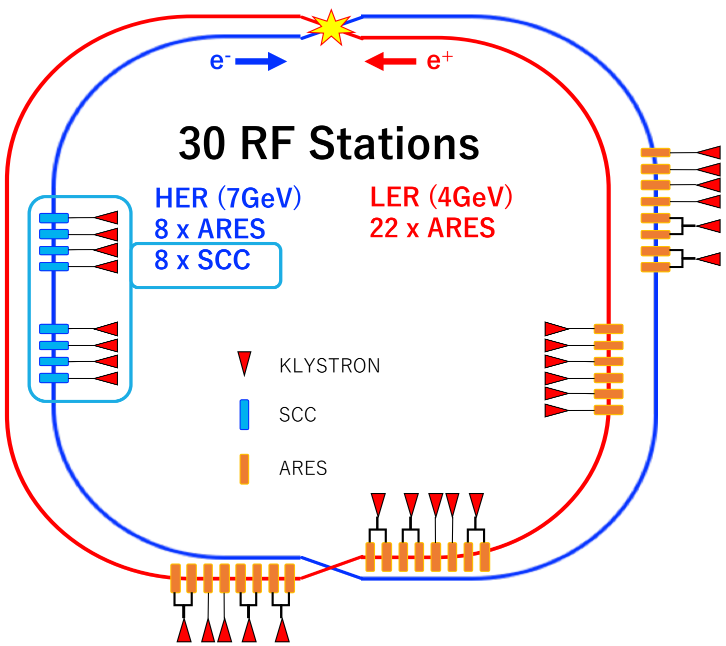


Y. Ohnishi

Basic Beam Operation Schedule

- Beam operation (Physics Run) : 6~7 months/year (with summer and winter shutdown)
- SCC cooling and warm-up : 2 cycles / year
- Regular maintenance day in operation term : 8 hours every 2 or 3 weeks

Layout of RF system



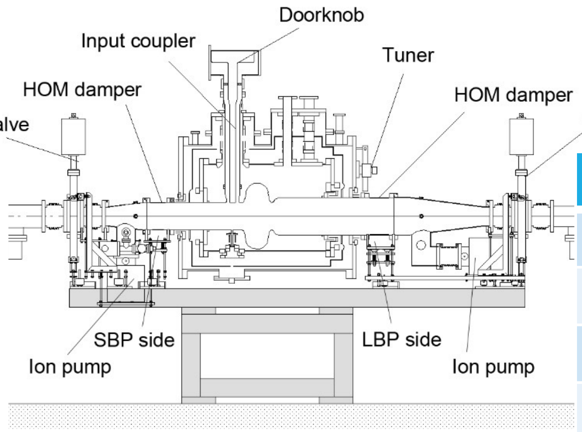
Re-using RF system with reinforcements to handle twice high beam current and large beam power

RF-Related Parameters

Parameter	KEKB (achieved)				SuperKEKB (design)				SuperKEKB (achieved)				
Ring	HER			LER	HER		LER		HER			LER	
Energy [GeV]	8.0			3.5	7.0		4.0		7.0			4.0	
Beam Current [A]	1.4			2	**2.6**		**3.6**		**1.14**			**1.46**	
Number of Bunches	1585			1585	2500		2500		2346			2346	
Bunch Length [mm]	6-7			6-7	**5**		6		~6			~6	
Total Beam Power [MW]	~5.0			~3.5	8.0		8.3		~3.1			~3.2	
Total RF Voltage [MV]	15.0			8.0	15.8		9.4		14.2			9.12	
	ARES		SCC	ARES	ARES	**SCC**	ARES		ARES		**SCC**	ARES	
Number of Cavities	10	2	8	20	8	8	8	14	4	4	8	12	10
Klystron : Cavity	1:2	1:1	1:1	1:2	1:1	1:1	1:2	1:1	1:2	1:1	1:1	1:2	1:1
RF Voltage [MV/Cav.]	0.5		1.5	0.5	0.5	1.5	0.5		0.45		1.35	0.45	
Beam Power [kW/Cav.]	200	550	400	200	600	**400**	200	600	130	170	**260**	190	230

SCC in SuperKEKB

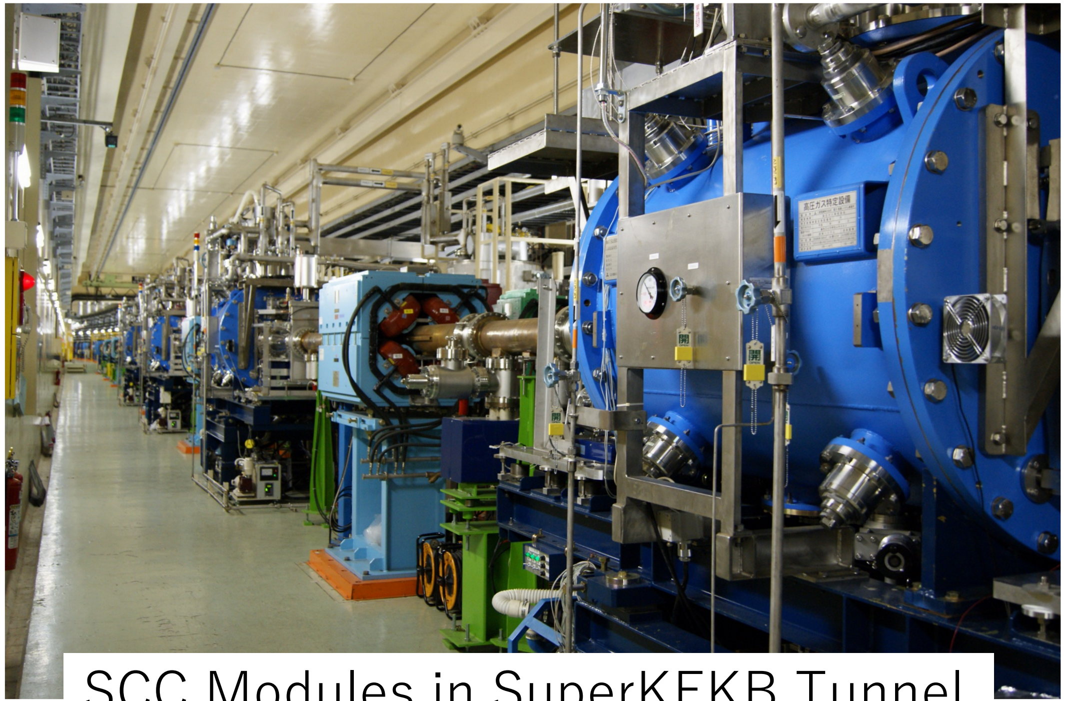
- 509 MHz Nb Single-cell HOM-damped Cavity, 4.4 K Operation
- 8 SCC Modules in HER (electron ring) & One Spare Module
- Reused from KEKB (including Cryogenic system)
- Sharing the beam power and accelerating voltage with ARESs by giving phase-offset.
- Main Issues in SuperKEKB for SCC
  - ➢ Large HOM power is expected due to twice high beam current and shorter bunch length.
    - ◆ Additional SiC HOM damper
  - ➢ **Degradation of RF performance of Qo**
    - ◆ **Horizontal High-Pressure Rinse** **←Okada-san's talk**



SuperKEKB-SCC Design Parameters	
Number of Cavities	8
Max. Beam Current [A]	2.6
RF Voltage [MV/cav.]	1.5
External Q	5E+4
Unloaded Q at 2MV	1E+9
Beam Loading [kW/cav.]	400
HOM Loading [kW/cav.]	37

Usual Operation of Cavity

- **Warming up to room temperature twice a year**
  - Safety inspection of cryogenics; pressure gauge, safety valve, etc
  - Cavity free from frequency tuner during warming up and cooling down
  - **Coupler conditioning with bias voltage before cooling**
- **Regular maintenance day of every 2 or 3 weeks**
  - Visual inspections
  - **Cavity conditioning**



SCC Modules in SuperKEKB Tunnel

Availability of SRF system in SuperKEKB

1. How is the availability defined? Is there requirement for the availability?

   We have no concrete requirements for the availability. We are always prepared to operate the cavity stably and to minimize downtime. The regular cavity conditioning every 2 or 3 weeks is effective to obtain stable cavity operation.

2. What are the top 3 SRF failure modes?

- Beam Aborts caused by SRF system
  - Collect signals of RF, beam, LM, etc to find the last message from a beam to know the real reason of each trip

● **Multipacting breakdown of Cavity**

● **Electric breakdown of Piezo actuator for freq. tuner**
- Insulation failure due to humidity
- Cavity can be operated without piezo by changing tuner control settings. Recovered in 30 min.
- Fixed by dehumidification using desiccant (silica gel)

● **Failure of Chiller for HOM dampers**
- Due to aging degradation. Replacement is on going.
- By bypass piping to the spare and the next chillers. Recovered in 30 min.

Beam Aborts caused by	Recovery time	2019	2020	2021	2022
MP in Cavity	2-3 min.	2	2	12	7
Piezo breakdown	< 1 hour	6	5	1	0
Chiller failure	< 1 hour	1	1	3	0
Others		0	0	2	2
Total		9	8	18	9
Trip Rate [/day/8 cavities]		0.06	0.04	0.09	0.07
Operation days		149	180	196	121
All aborts (>50mA, including LER single) *except injection tuning		-	~650*	~1100	~730

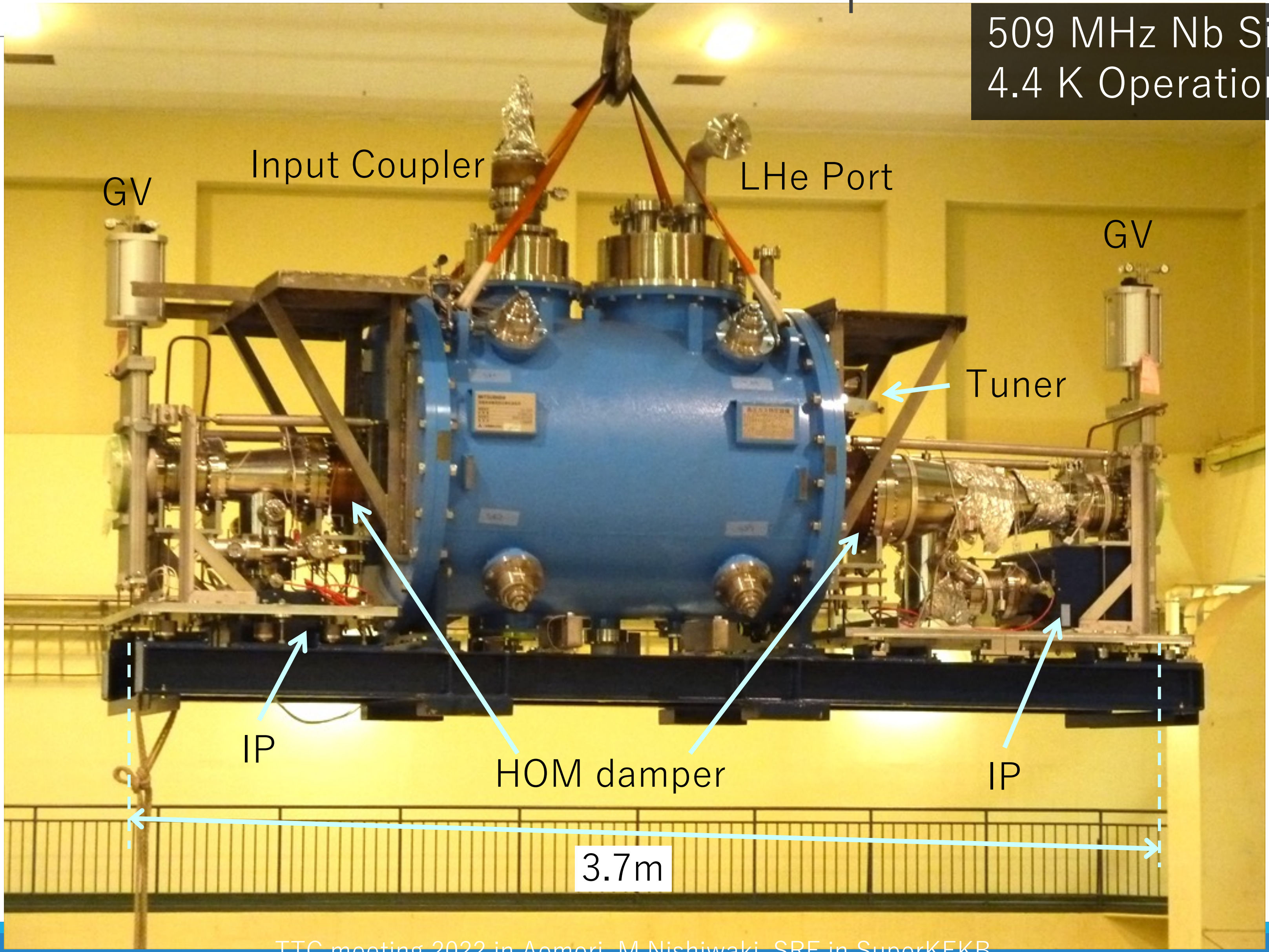
SRF system is stable even at 1-A beam operation.

◆ Recent failures affected beam operation
- Cavity Leak : In Oct. 2020, during cooling. The start of HER beam operation was delayed one day.
  - The cavity was detuned in the 2-months beam operation and replaced with the spare cavity in the winter shutdown.
- Failure of Tuner : Beam operation was suspended for 3 hours to replace the tuner.

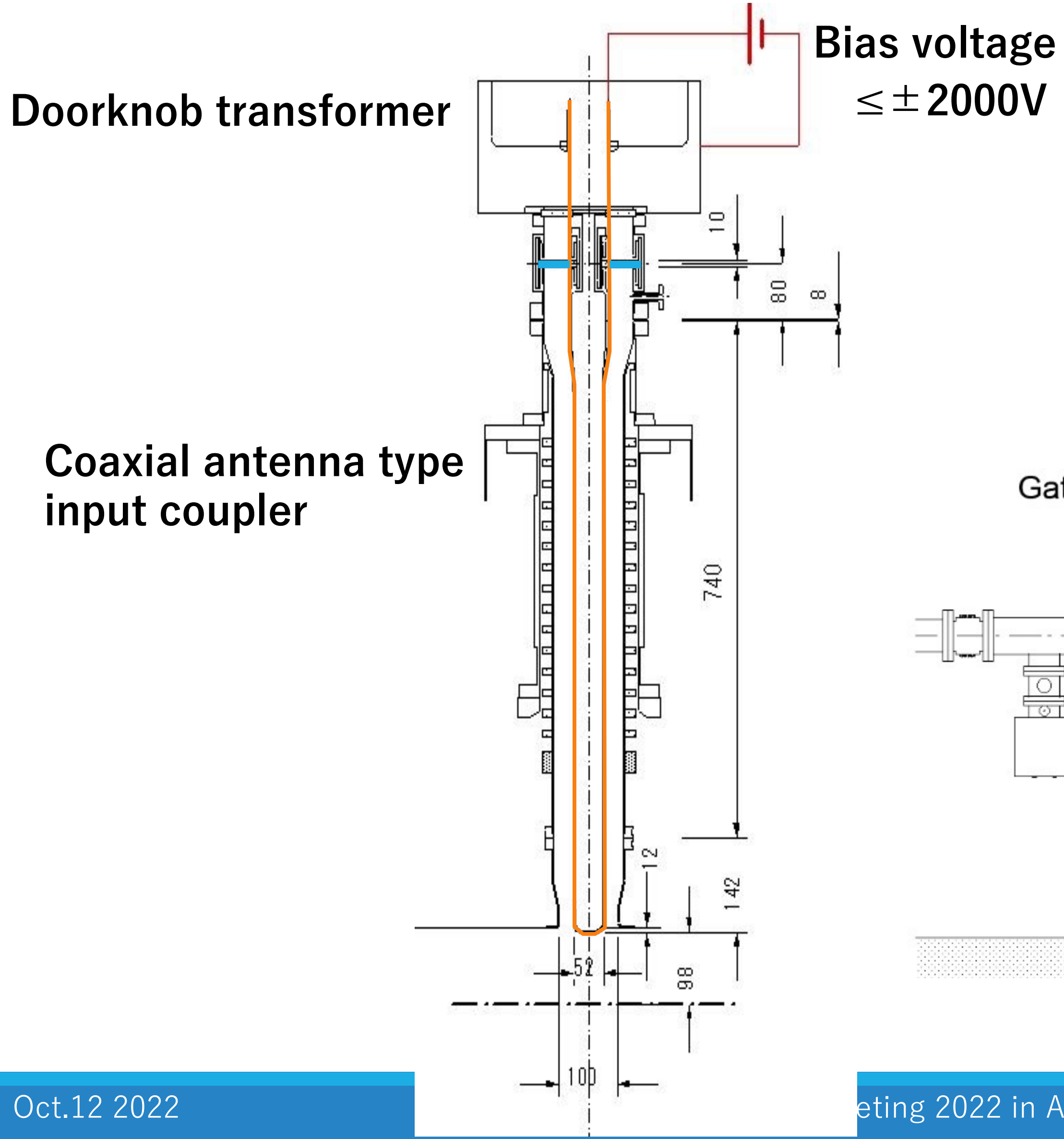
backup

SCC Module of SuperKEKB

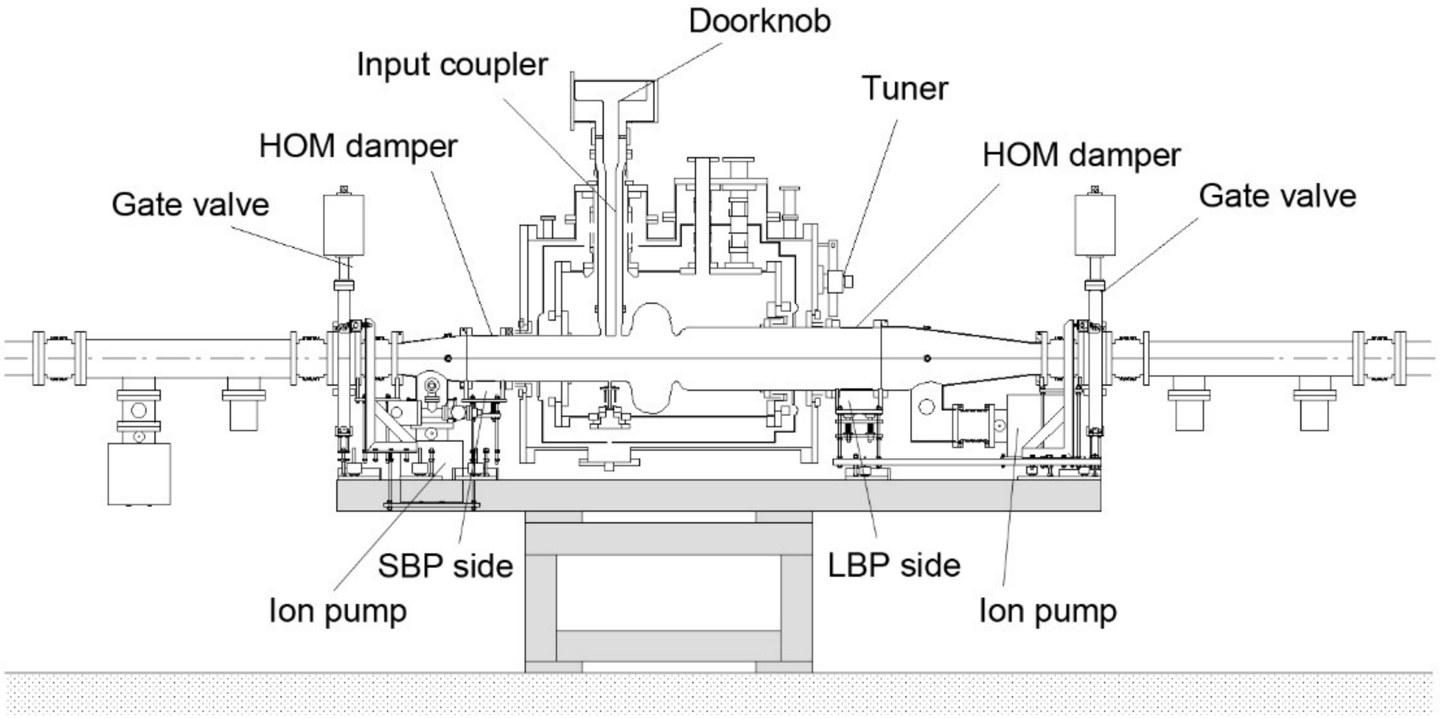
509 MHz Nb Single-cell Cavity
4.4 K Operation



Input Coupler Conditioning

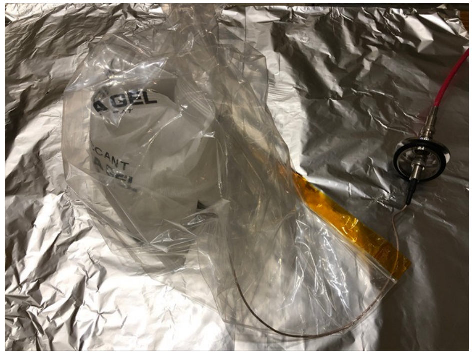


The input couplers are conditioning with bias voltage every before cooling.

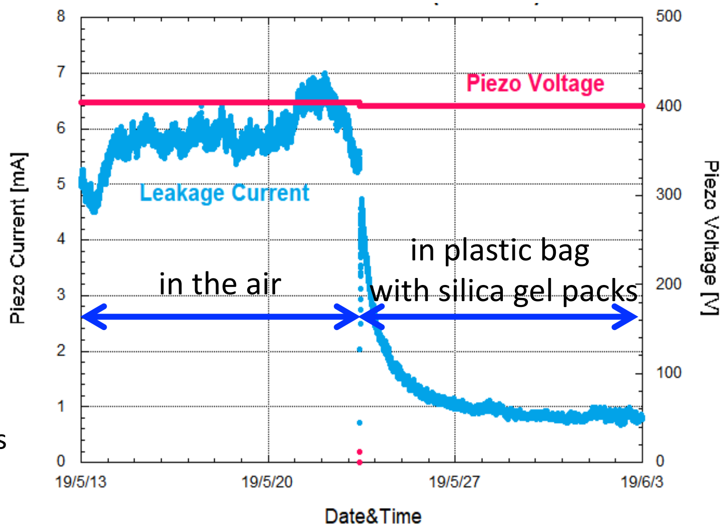


Piezo leak current due to humidity

Exposure Experiment
- Drying by silica gel -



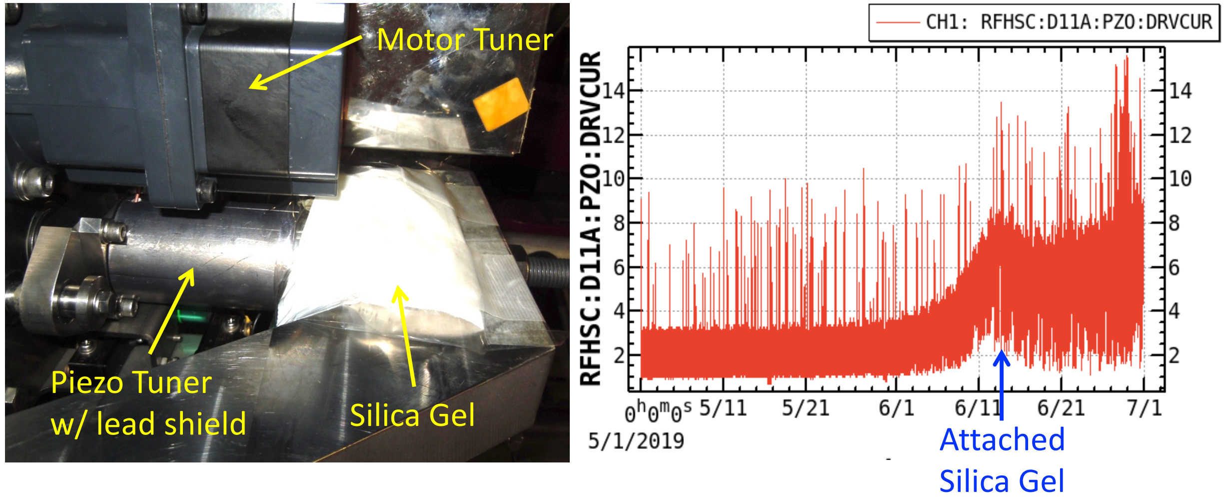
Piezo in plastic bag with silica gel packs



From the results of exposure experiments, we found that drying by silica gel is effective to reduce leakage current of piezo tuner. As a trial, silica gel packs were attached to piezo tuner in the tunnel.

Piezo Tuner with silica gel

Leakage Current of Piezo Tuner



The leakage current of piezo tuner increased caused by degradation of electric insulation.
After attaching silica gel to piezo, the increase of leakage current was stopped.
The good effect of drying by silica gel is consistent with the results of exposure experiments of piezo tuner.
We will continue to study moisture control around the piezo in the tunnel.