Horizontal HPR in SuperKEKB at KEK

KEK –SuperKEKB

TTC 2022@Aomori in Japan

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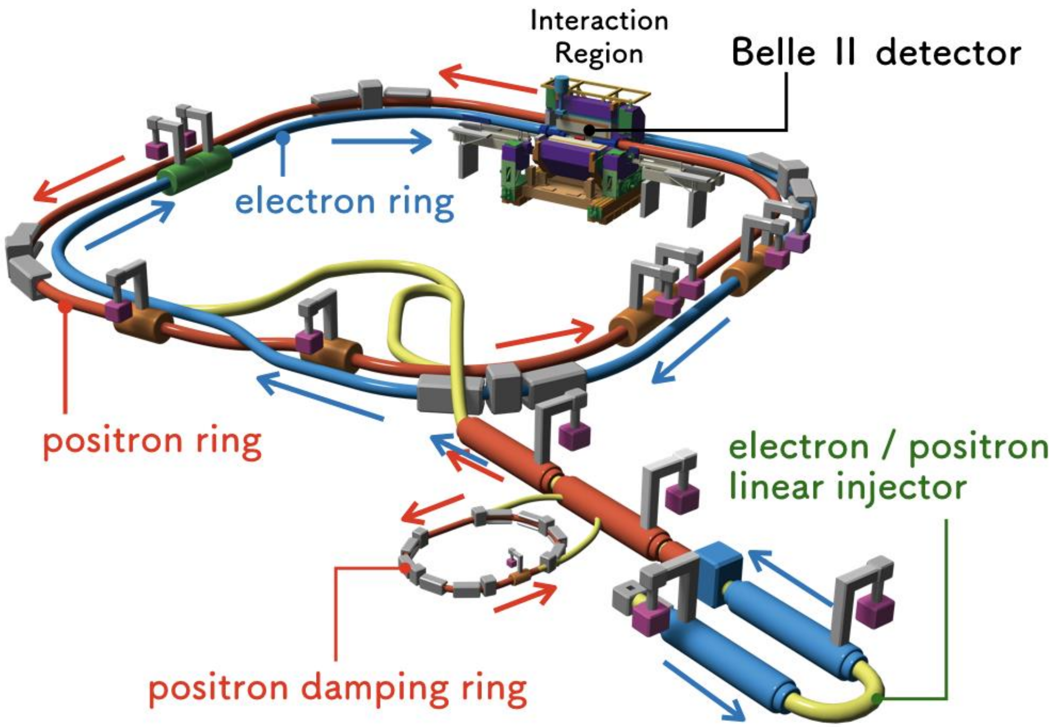
What is SuperKEKB?

- e-/e+ asymmetric energy collider for B-mesons production
- Belle II is an upgraded detector to allow the experiment to record the enormous numbers of particle processes
- SuperKEKB is the successor accelerator that based on KEKB
- To achieve the highest luminosity $8 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, Nano-beam scheme and almost twice beam current as KEKB
- Phase III beam operation started in 2019
- Peak luminosity of $4.65 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ has been recorded in June 2022
- 508.876 MHz superconducting cavities accelerate the only electron (HER ring)



	LER (positron ring)	HER (electron ring)
Energy	4 GeV	7 GeV
Beam current	3.6 A (design) 1.32 A (2022 June)	2.6 A (design) 1.1 A (2022 June)
Bunch current	1.44 mA (design) 0.59 mA (2022 June)	1.04 mA (design) 0.49 mA (2022 June)
Circumference	3016 m	
Luminosity	4.65×1034 $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$	
Int. Luminosity	0.41 ab^{-1}	

Y. Funakoshi, presented at IPAC'22, Jun. 2022, MOPLXGD1

RF System of SuperKEKB

2 type cavities installed SuperKEKB (Frequency is 508.876 MHz)

- **ARES cavity (normal conducting)**

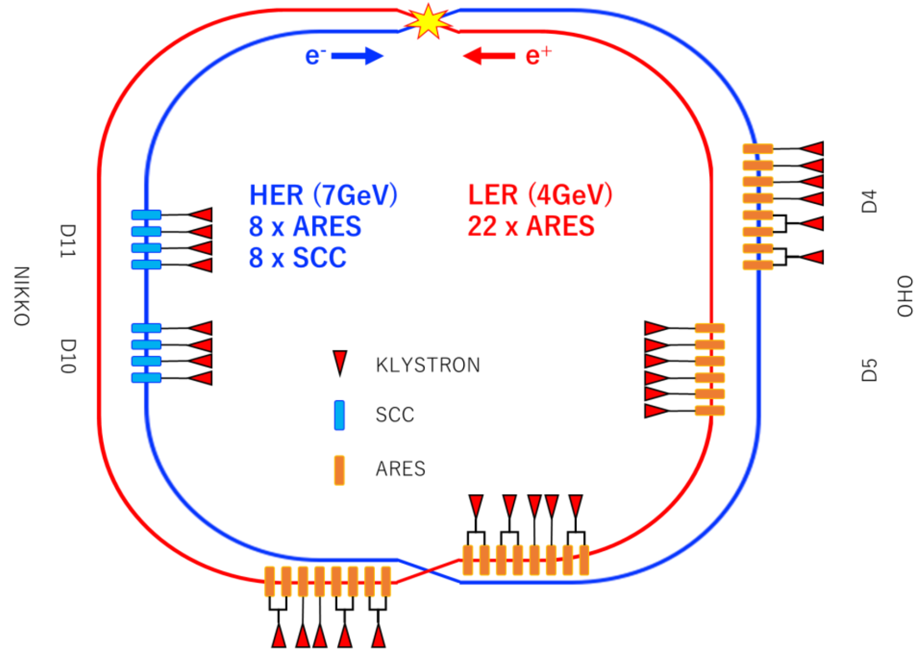
  The three cavity system consist of energy storage cavity, accelerating cavity, and resonant coupling cavity

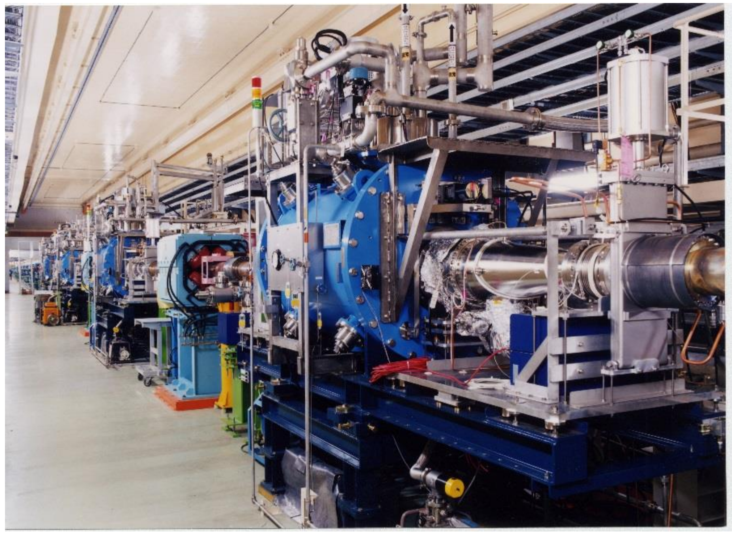
- **HOM damped superconducting cavity**

  This cavity was developed for KEKB. And It reused until now

  508.876 MHz single cell cavity, made of Nb

  Total number of cavity is 8 (+1 spare). All cavities installed on the Nikko straight section of the tunnel





M. Nishiwaki, presented at eeFACT2022

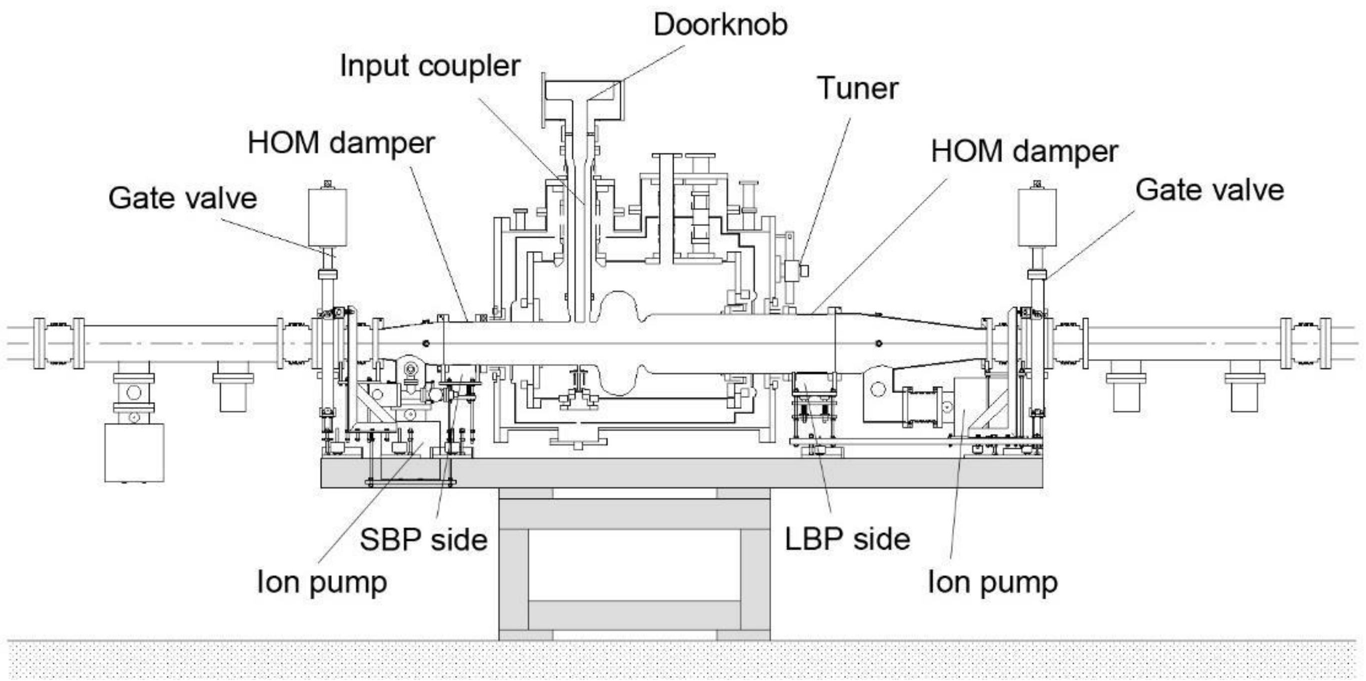
SRF system re-used for SuperKEKB

However, the beam current will be over twice.

HOM power will be increase greatly

Superconducting cavity

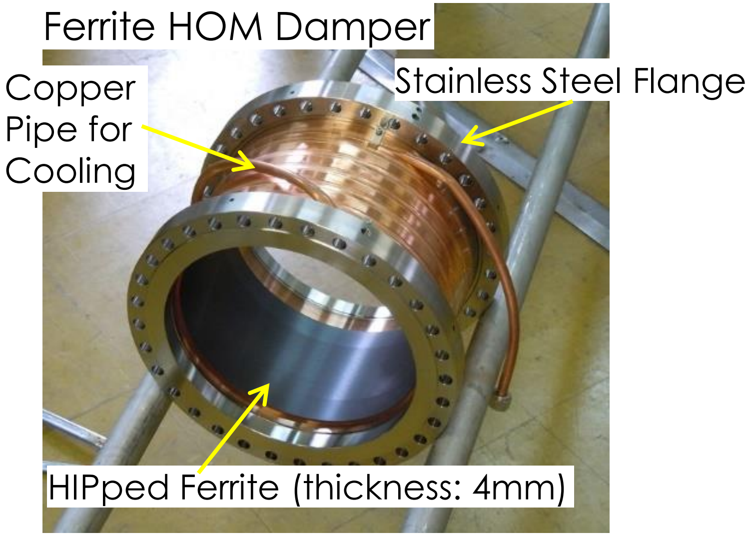
- The superconducting cavity installed in SuperKEKB was developed in the 1990 s for the previous ring of KEKB.
- The cavity has been optimized to achieve a CW acceleration of 1.5 MV at a large beam power of 400 kW.
- The temperature is 4.4 K by immersion cooling with liquid helium.
- The single cell has been chosen to reduce the number of HOMs



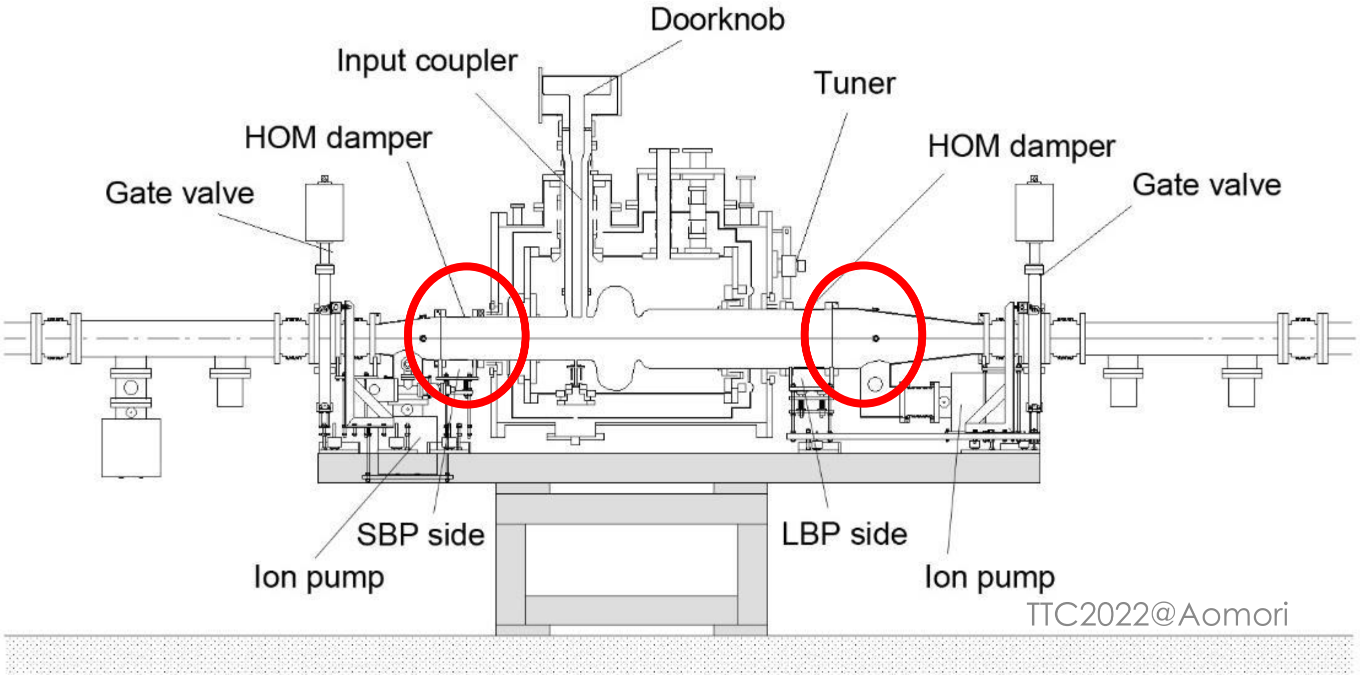
	Parameters
No. of cavity	8 (+1)
Frequency	508.876 MHz
Gap length	243 mm
R_{sh}/Q	93 Ω
Geometrical factor	251 Ω
E_{sp}/E_{acc}	1.84
H_{sp}/E_{acc}	4.03 mT/(MV/m)
External Q	5×10^4
Unloaded Q at 4.4 K	1×10^9 @2 MV (8 MV/m)
Beam loading	400 kW/cav.
HOM loading	37 kW/cav.
RF voltage	1.5 MV/cav.

Superconducting cavity

- **HOM due to high beam current is absorbed by the HOM dampers installed at both side of the cavity.**
- **The HOM damper is located outside the cryostat and the temperature is room temperature.**
- **HOM of kW is absorbed and damper cooled by water cooling.**



M. Nishiwaki, presented at eeFACT2022



	SBP	LBP
Absorber material	Ferrite (IB004)	
Jacket material	Copper	
Diameter (mm)	220	300
Length (mm)	120	150
Thickness	4-3	4-3

Status of operating

- **The superconducting cavities are operating very stably and low trip rate.**
- **We applied RF aging as maintenance every two weeks.**
- **SuperKEKB will increase e$^-$ current to over 2 A.**
- **These cavities have no experience as high beam current**

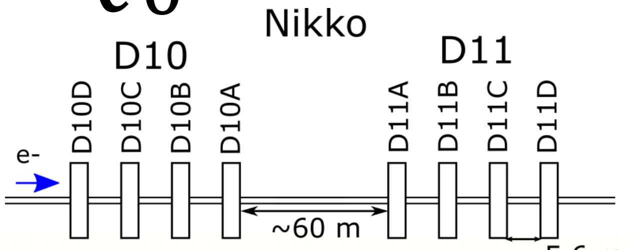
Parameter	SuperKEKB (achieved)				
Ring	HER			LER	
Energy [GeV]	7.0			4.0	
Beam Current [A]	**1.14**			**1.46**	
Number of Bunches	2346			2346	
Bunch Length [mm]	~6			~6	
Total Beam Power [MW]	~3.1			~3.2	
Total RF Voltage [MV]	14.2			9.12	
	ARES		SCC	ARES	
Number of Cavities	4	4	8	12	10
Klystron : Cavity	1:2	1:1	1:1	1:2	1:1
RF Voltage [MV/Cav.]	0.45		1.35	0.45	
Beam Power [kW/Cav.]	130	170	260	190	230

Resent operation status (2022ab, 4months)
# of Beam Aborts caused by RF system : 72
: 0.6 aborts/day
(Total # of beam aborts : >1300)

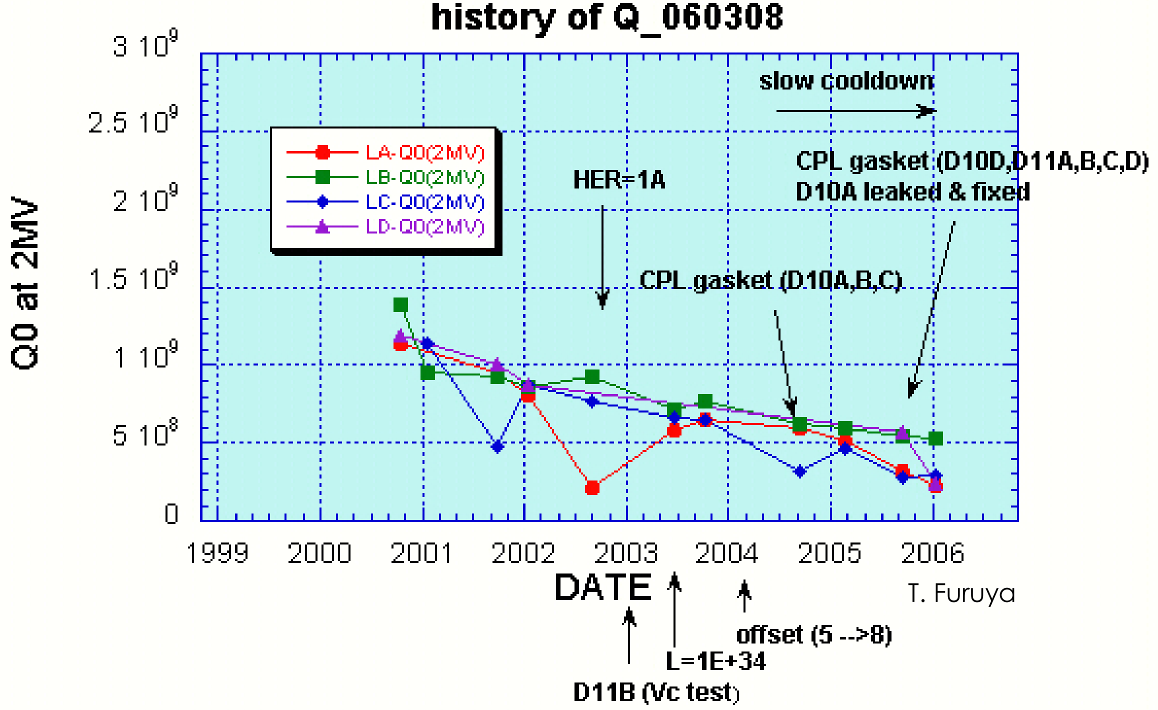
Detailed in M. Nishiwaki, presented at This TTC2022

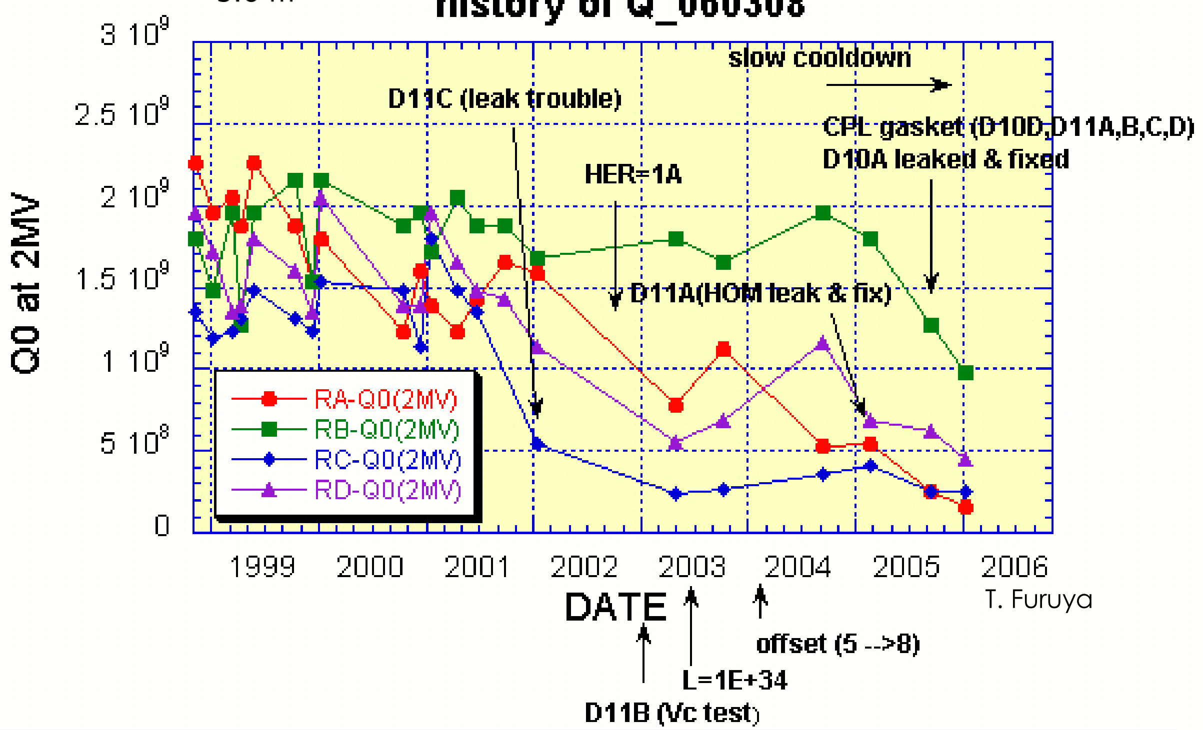
Degradating of Q_0 from KEKB era

Left side



Right side



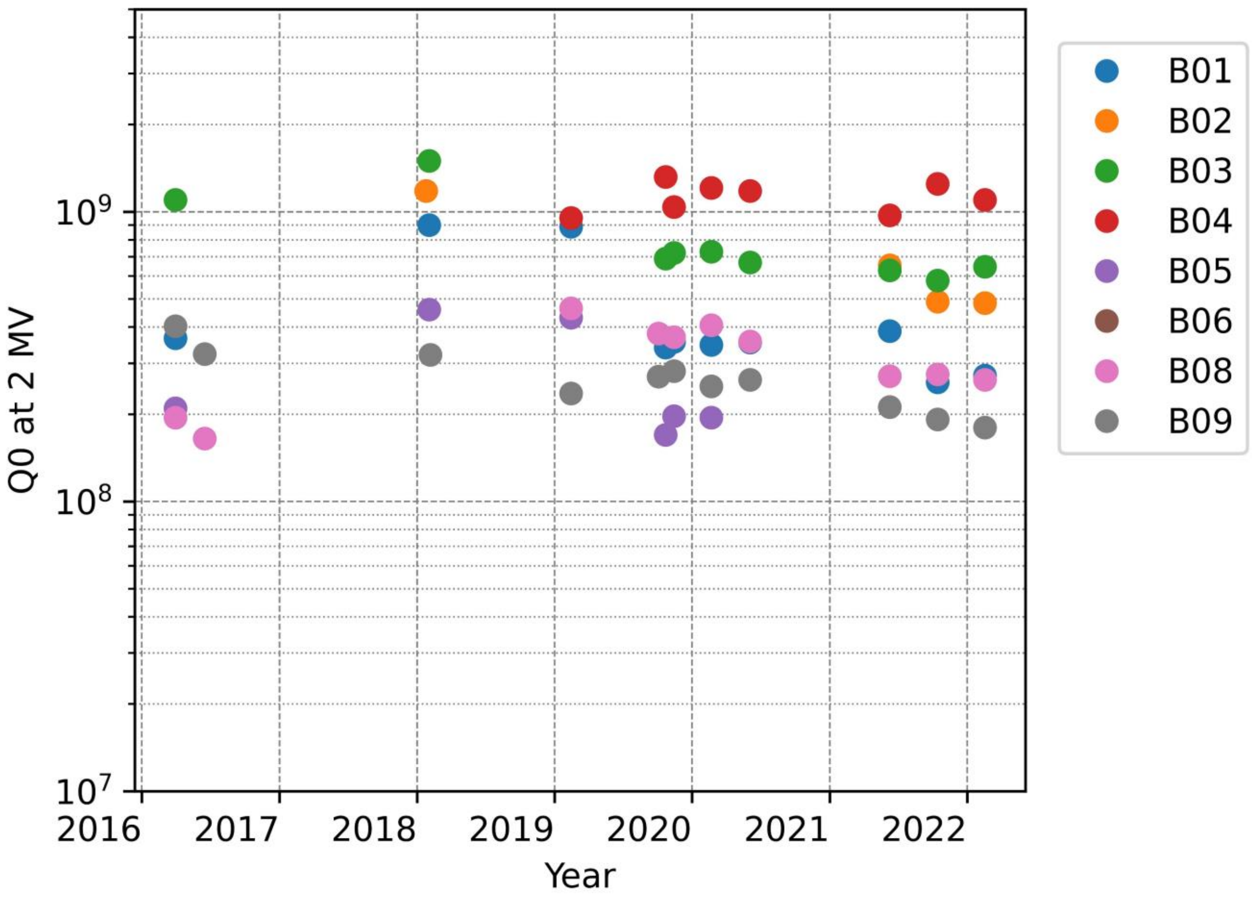


From the KEKB operation, the performance gradually degraded with time.

There was a leak trouble, and a gasket was changed to change the coupling of the coupler, However, the performance was not greatly affected.

The cause of Q degradation seems to have occurred due to contamination of particles.

Degradating of Q_0 during SuperKEKB era

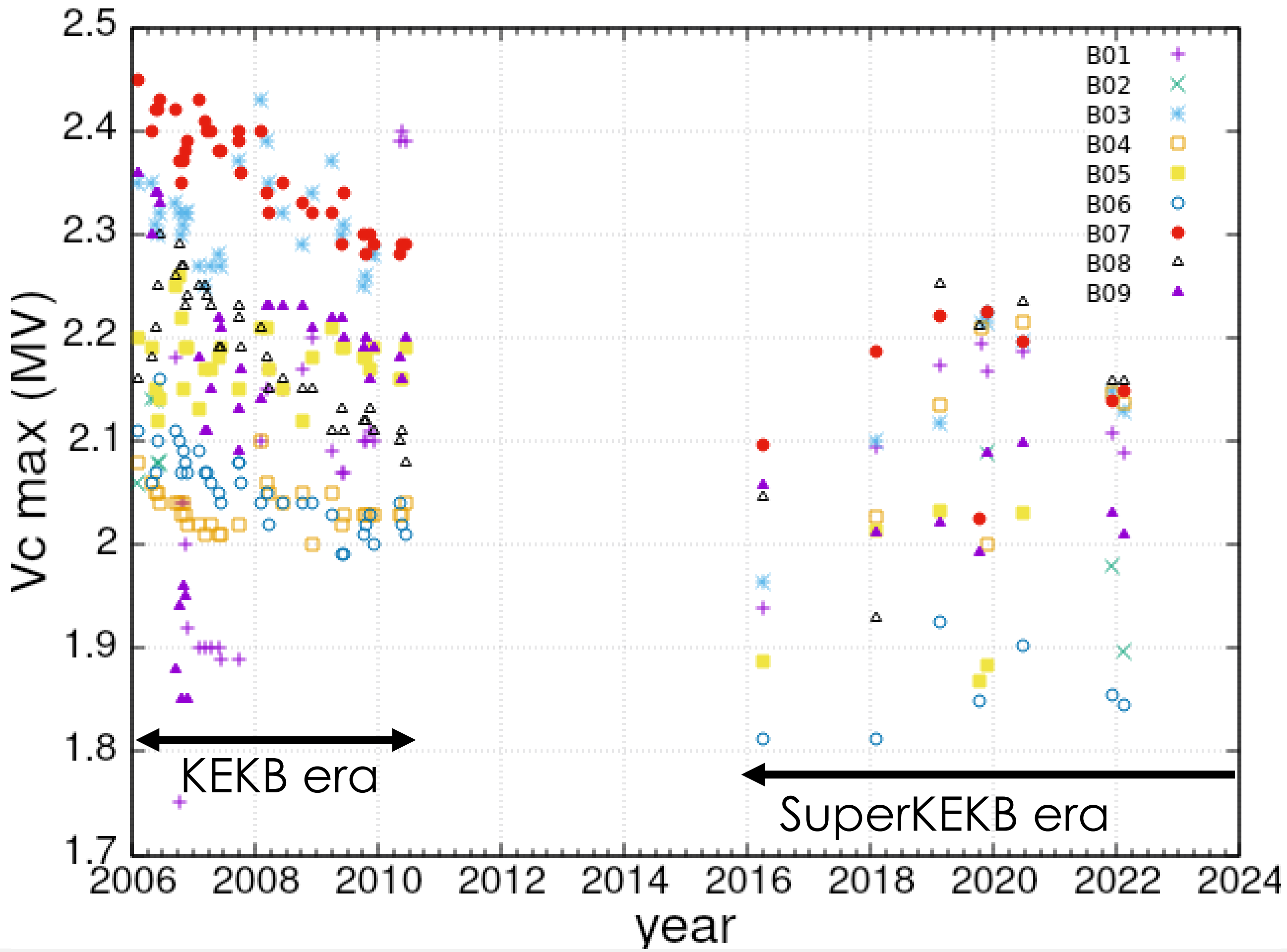


Although there is a tendency of performance deterioration even in this SuperKEKB era,

It is not a very serious.

However, x-ray level increase over time.

Degradating of Vc during SuperKEKB



Maximum accelerating gradient also degraded with field emission over time.

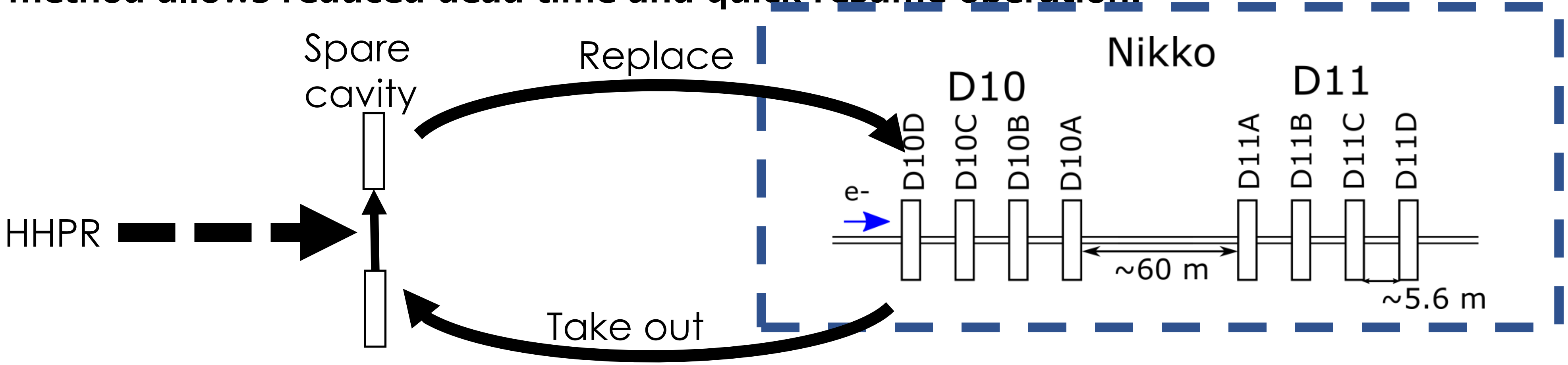
2 MV (8.23 MV/m) is design require cavity voltage for SuperKEKB. Operating gradient is from 1.35 to 1.5 MV.

This degradation did not affect to operation.

RF aging (~a few hours) every two weeks maintenance is effective to keep performance.

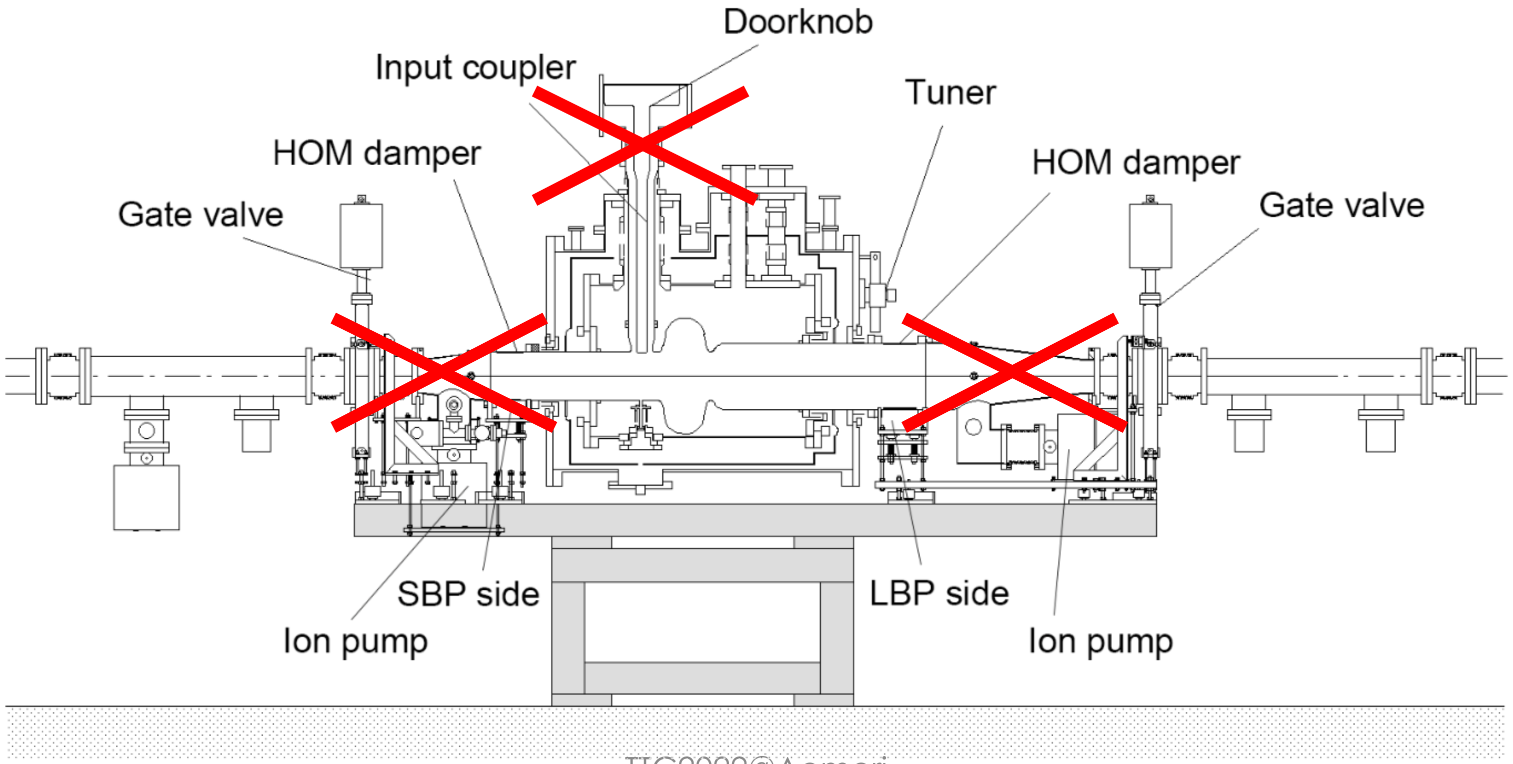
Cavity leak and HHPR method

- **The degradation did not stop operating the accelerator—however, some cavities leaked in 24 years of operation.**
- **Disassembly and assembly of the cavity are performed using a portable clean booth. However, performance degradation sometimes occurs with such strong field emissions. It can not be unrecoverable by RF aging.**
- **We are dealing with the degradation by replacing the cavity with a spare cavity to resume operating the accelerator.**
- **The most effective solution is to disassemble all components and start over with the surface treatment and clean assembly. However, it is very hard work in term of time and money.**
- **The Horizontal High Pressure System developed at SuperKEKB is capable of HPR with the cavity installed in the cryostat without disassembling of cavity.**
- **HHPR method allows reduced dead time and quick resume operation.**



Horizontal High Pressure Rinsing (HHPR)

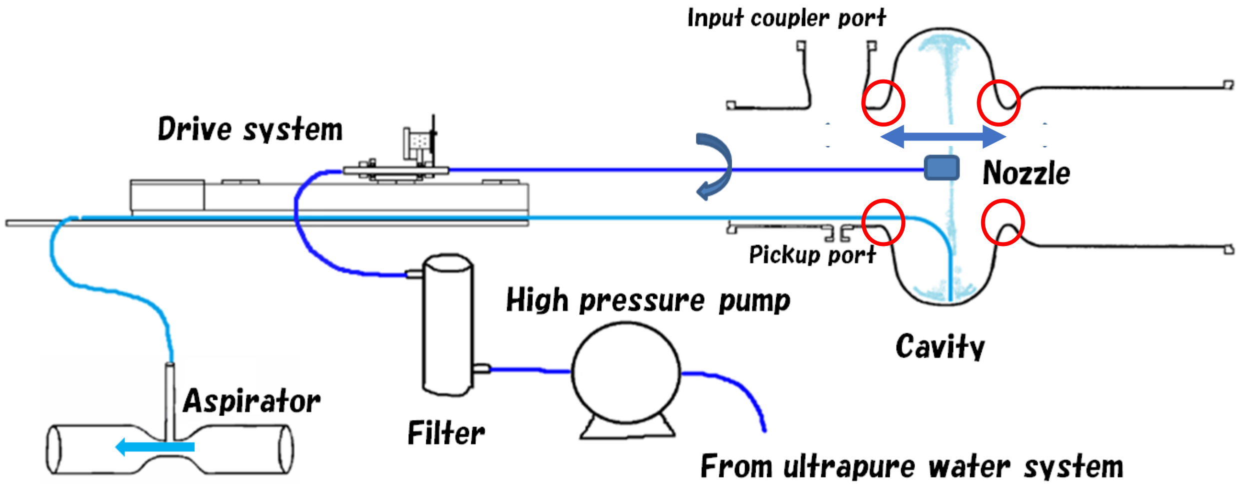
- If the cavity needs to be HPRed as usual, all components, including the cryostat, must be removed.
- Horizontal high pressure rinsing can be applied by simply removing the beam pipe and the coupler port.
- The reliably effective treatment of high pressure rinsing can be applied without reassembly of the module.



Horizontal High Pressure Rinsing (HHPR)

- In the HHPR system of SuperKEKB, an HPR nozzle is inserted from the beam pipe, and cleaning is carried out using ultrapure water with 7 MPa.
- The nozzle has six holes (angle is 60°) and shoots water laterally at little.
- Nozzle can move from equator to both iris (movable range is +/- 200 mm)
- The dirty water in the cell is pumped using aspirator.
- The cleaning time was 15 min, and the drainage volume was ~120 L.
- A clean booth (<0.3 um particle) used for assembly.
- HHPR has been performed for three cavities used for operation
- HHPR can focus on iris of the cavity

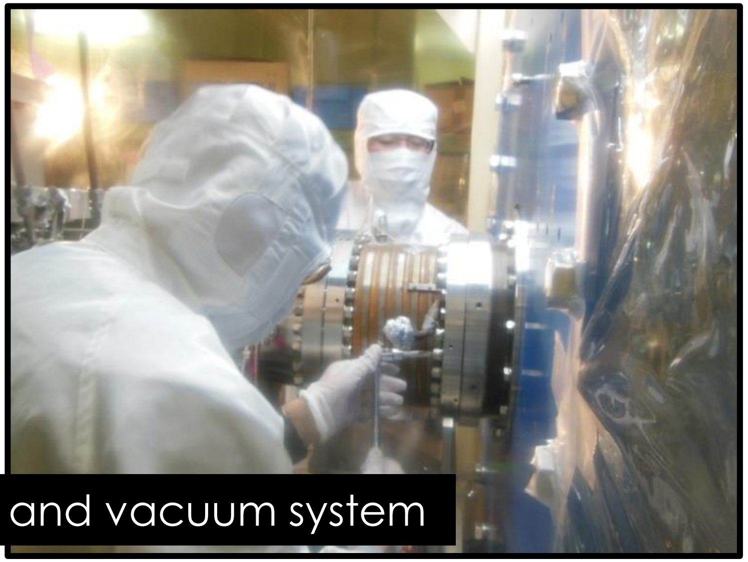
HHPR Parameters	
Water Pressure	7 MPa
Nozzle	ϕ0.54mm x 6
Driving speed	1 mm/sec.
Rotation speed	6 deg./sec.
Rinsing time	15 min.

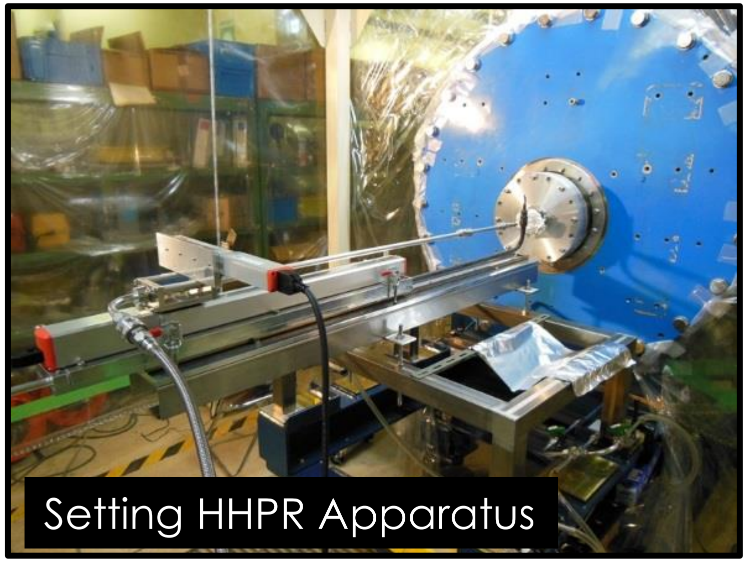


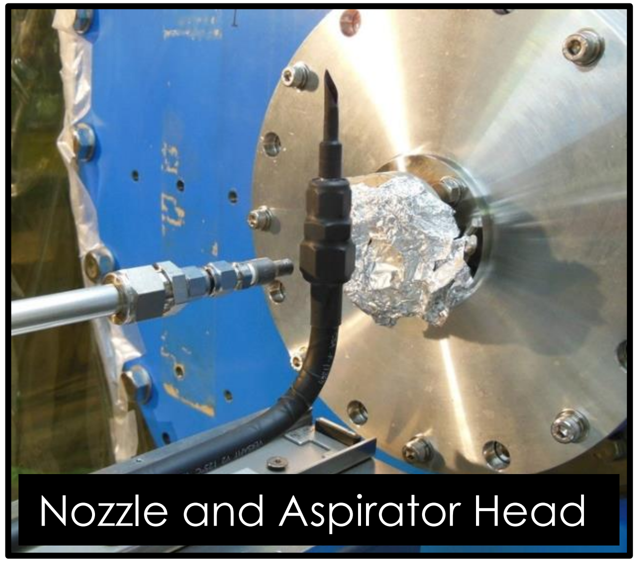
Horizontal High Pressure Rinsing (HHPR)


Removing Coupler

Before HHPR, input coupler and HOM dampers were dismounted in a clean booth.



Removing HOM dampers and vacuum system

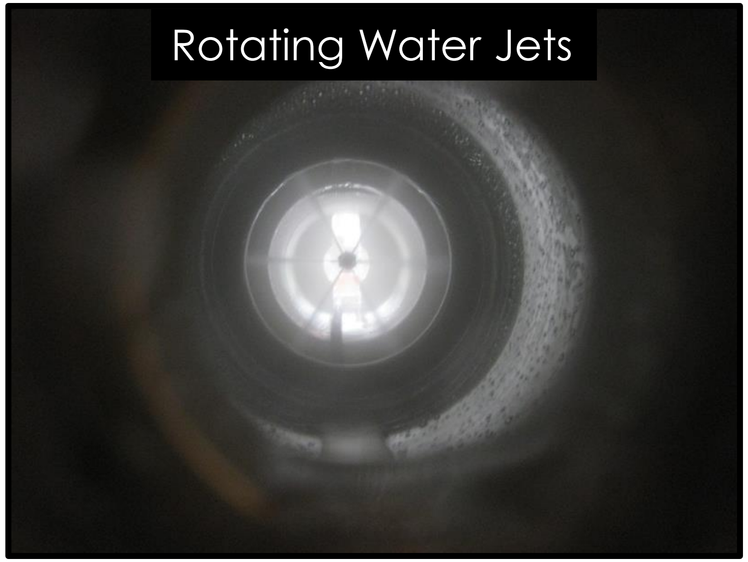

Setting HHPR Apparatus


Nozzle and Aspirator Head

Horizontal High Pressure Rinsing (HHPR)


Opening Dummy Flange


Insert Automatic Drive Nozzle


Rotating Water Jets

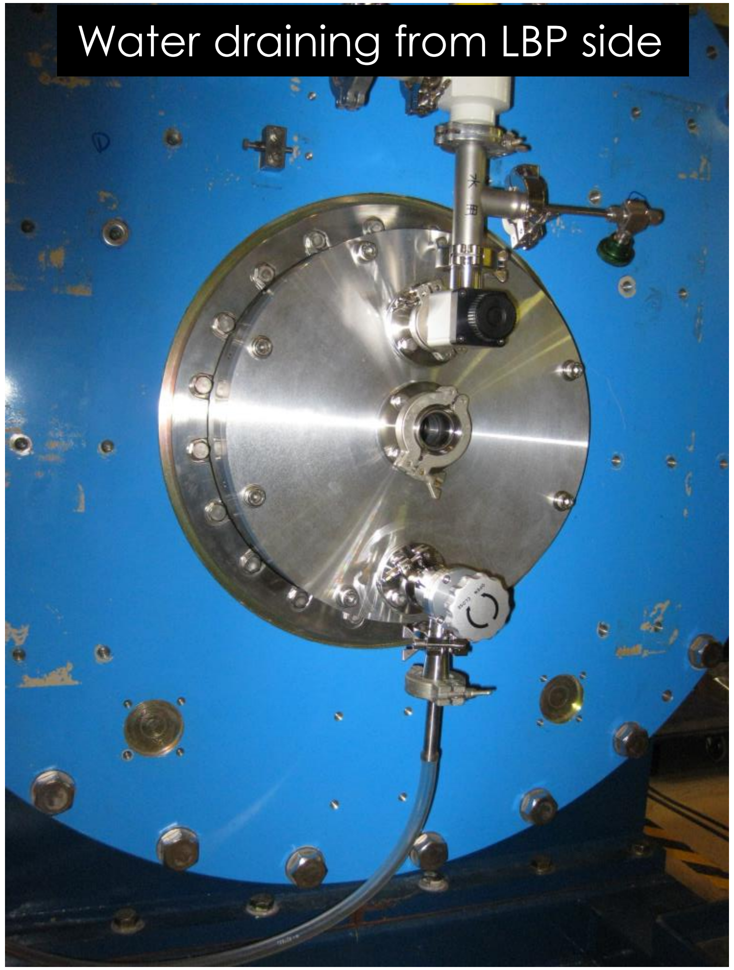

High Pressure Water Pump

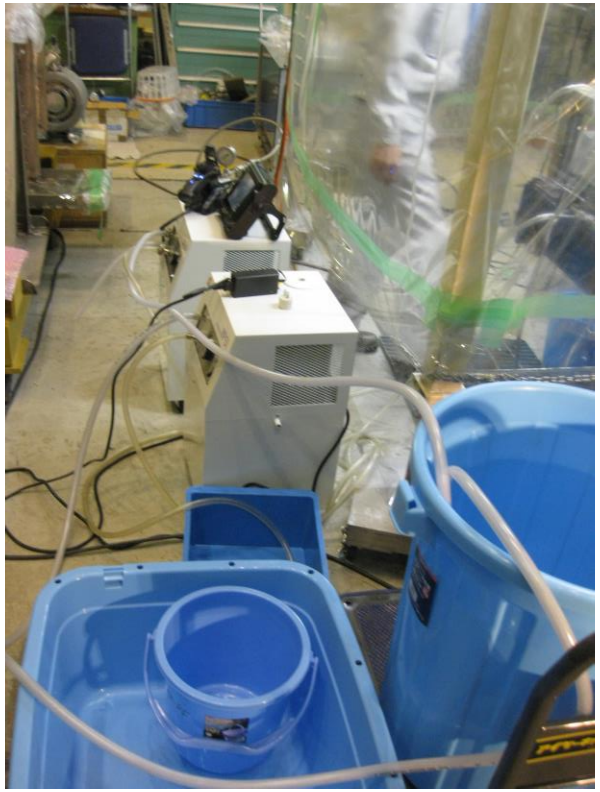
Aspirator Pumps


Cavity was dried up by evacuation before setting the coupler and HOM dampers.

Evacuation after HHPR

Horizontal High Pressure Rinsing (HHPR)


Water draining from LBP side



HHPR Cavity History

- **we have done this HHPR process for three cavities**

➢ **B03**

He leak -> Repairing (Particle contamination) -> Horizontal test (HT) -> HHPR -> HT -> Tunnel

➢ **B04**

Accidental air induction -> HHPR -> HT -> Tunnel

➢ **B02**

Accidental air induction (little) -> HHPR -> HT -> Tunnel

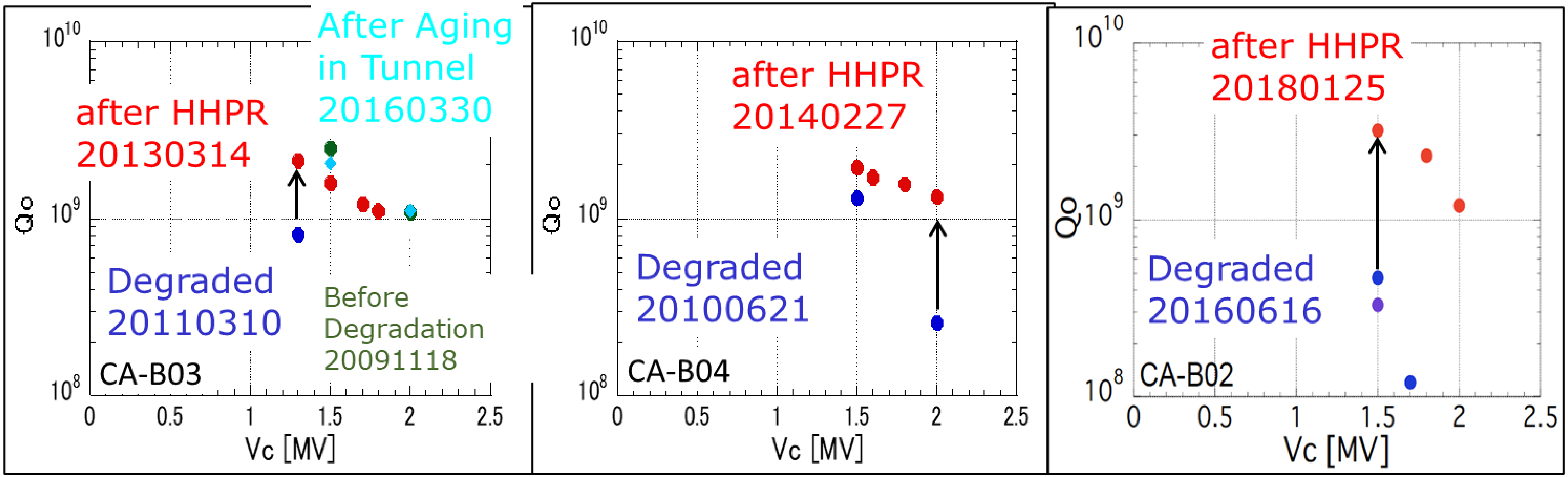
The cause of the degradation of …

These cavities have been found to be contaminating particles during repair or due to atmospheric intrusion.

High pressure rinsing is the most effective and direct solution of field emission due to particle.

These cavities are recovered and install to the tunnel and operation.

Cavity Performance Recovery



All of the Q_0 of cavity recovered after HHPR.

F. E. was reduced by HHPR.

The recovered Q_0 value is close to the Q_0 value at the beginning KEKB.

Summary and Future Plan

Summary

- **The KER-type superconducting cavities are more than 20 years old, but most of them are still operational.**
- **Though the Q_0 value and maximum voltage gradually decreased, there is no problem in operation, and it can be recovered by periodic RF aging.**
- **The major problem that has occurred has been the leakage of some cavities.**
- **The repair of the cavity leak has a high possibility of particle contamination in the cavity, and some cavities have performance degradation due to strong field emission after repair.**
- **These could not be addressed by RF-aging and HPR was required and the HHPR system can recover these cavities performance.**
- **The HHPR system does not require re-construction of modules, which is advantageous in terms of time and cost.**

Summary and Future Plan

Future Plan

- **HHPR applying to backup cavity.**
- **HHPR without coupler removal**

  There is a danger of particle contamination when the coupler is removed, and the coupling may be changed.

  We already tested “wet” coupler aging test.

  1） Coupler and ceramic RF windows set to test-stand in wet condition

  2） Vacuum drying, no baking

  3） Coupler pass the 800 kW P_{tr} RF aging. (pre-aging with bias voltage of ±2kV up to 150kW in total reflection

- **Compact HPR system capable of HPR in tunnels**

  A more simplified HHPR system would benefit from reduced risk of failure and savings in time, so it is planned to be upgraded.

Appendix

Can HHPR recover the Q_0 degradation over time?

- **If the cause was contamination of particles, it can be recoverable by HHPR.**
- **KEKB-type cavity have not experienced HHPR since beginning of KEKB.**

- **To know what the cause is, we need to study the material and size of the particles.**
- **D11D (end of right side of cavities) recently especially performance degradation is large**
  Without leak, accident

- **We plan to apply the HHPR to D11D in the tunnel.**