HarmonLIP, 19 March 2024, ESRF

Status and development of harmonic-cavity project at KEK

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25 minutes, including questions

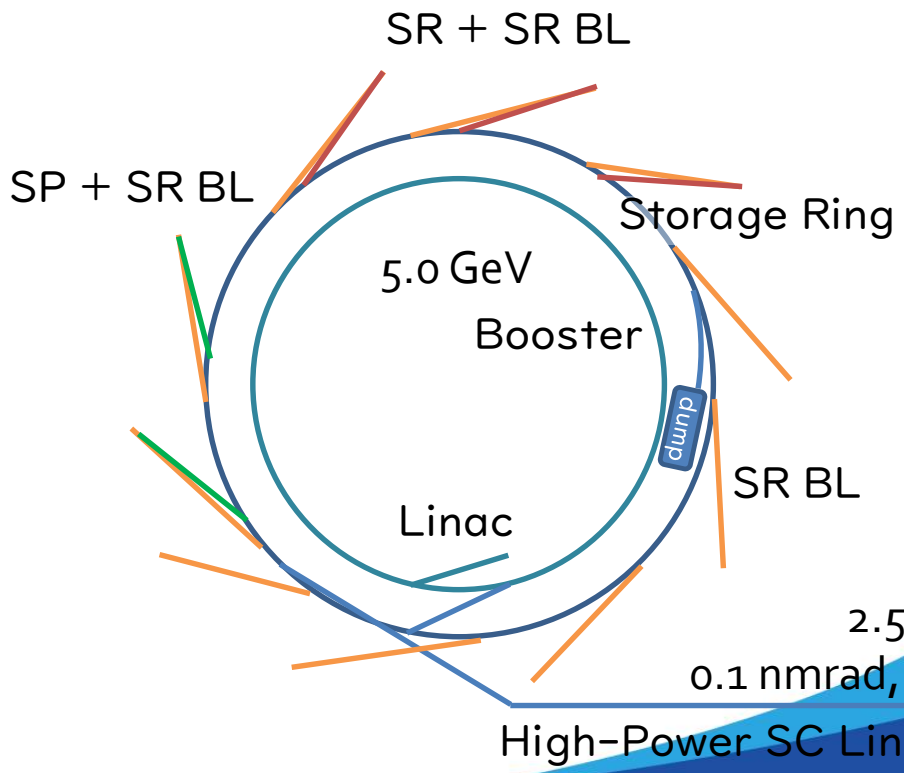
Insight through Accelerators.
KEK

Future Light Source at KEK

- PF-HLS (Green field project at KEK Tsukuba campus, Japan)
  - 2.5 / 5.0 GeV energy switchable ring with pulsed SC injector
    - To obtain wide energy-range photons at one BL/measurement system
    - Two photon beams having different energy/size,,, are used simultaneously.
  - Bunch lengthening system for storage beams is needed (BLF > 3,0)
  - RF system for PF-HLS
    - FC: SKEKB Damping Ring 500MHz cavity
    - HC: TM020 1.5 GHz cavity

Table： Tentative PF-HLS Ring Parameter

Energy [GeV]	2.5	5.0
Circumference [m]	749.5	
Lattice	Double DDBA/8BA	(modified)
Stored current [mA]	500	200
Natural emittance[nmrad]	0.208	0.832



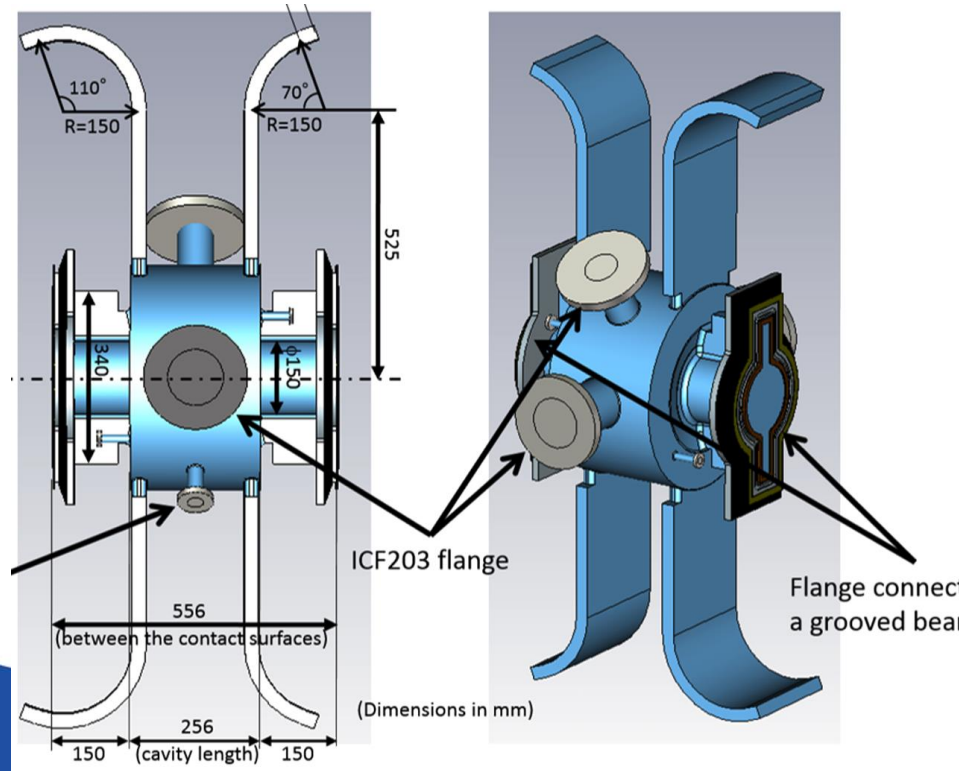
Candidate of Fundamental Cavity for PF-HLS

SKEKB DR Cavity

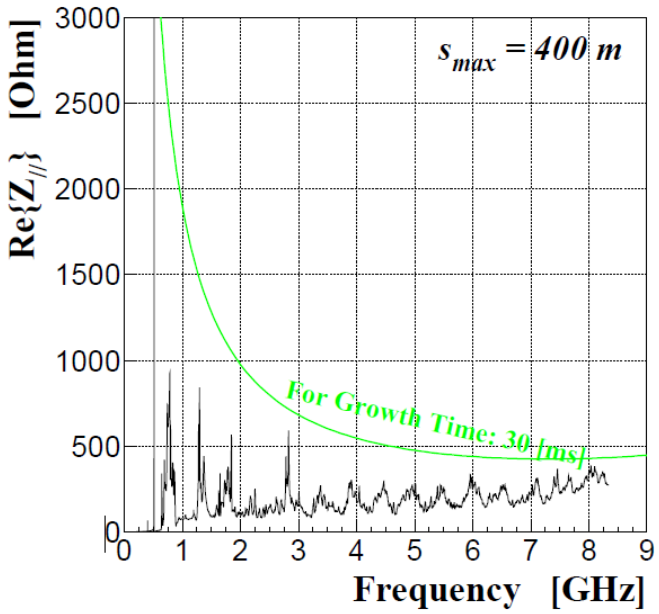
*SKEKB DR: SuperKEKB Damping Ring

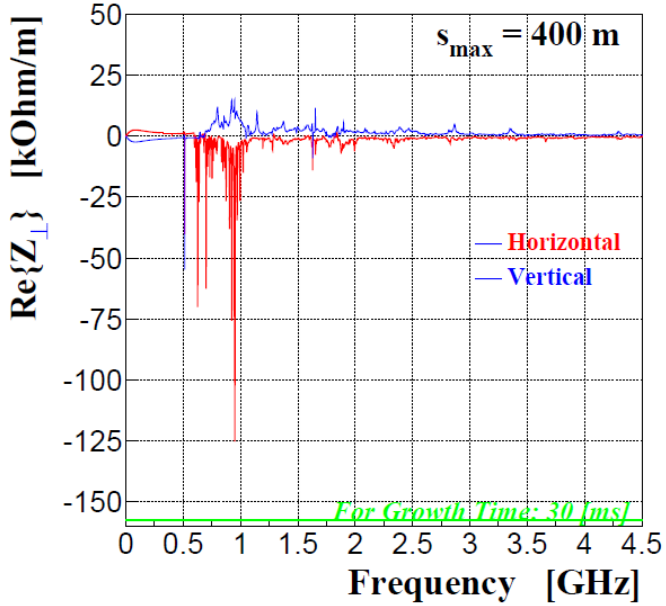
Developed by Prof. Abe (KEK) based on the HOM damped structure of KEK ARES cavity, which used for the KEKB Main Ring.

- Strong HOM-damped performance
- fr = 508.9 MHz, R/Q = 75 Ω, Qo = 30,000, Design Vc ~ 0.8 MV



Impedances of one SKEKB DR cavity





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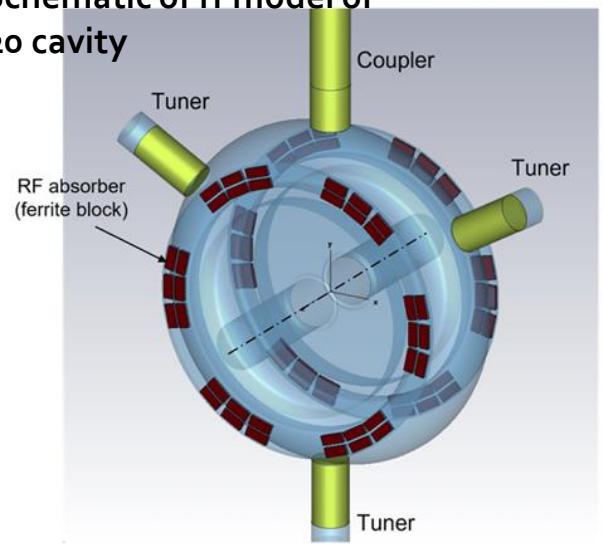
Candidate of Harmonic Cavity for PF-HLS

* T. Yamaguchi et al., "Design and low-power measurement of 1.5 GHz TM020-type harmonic cavity for KEK future synchrotron light source," NIM A, 1053 (2023) 168362.

Fig. Schematic of rf model of TM020 cavity



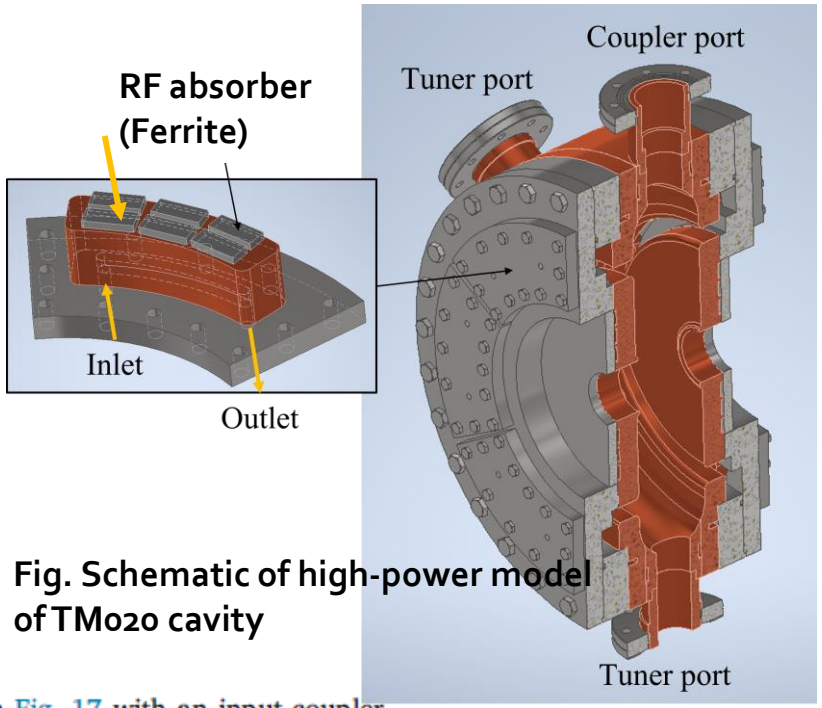
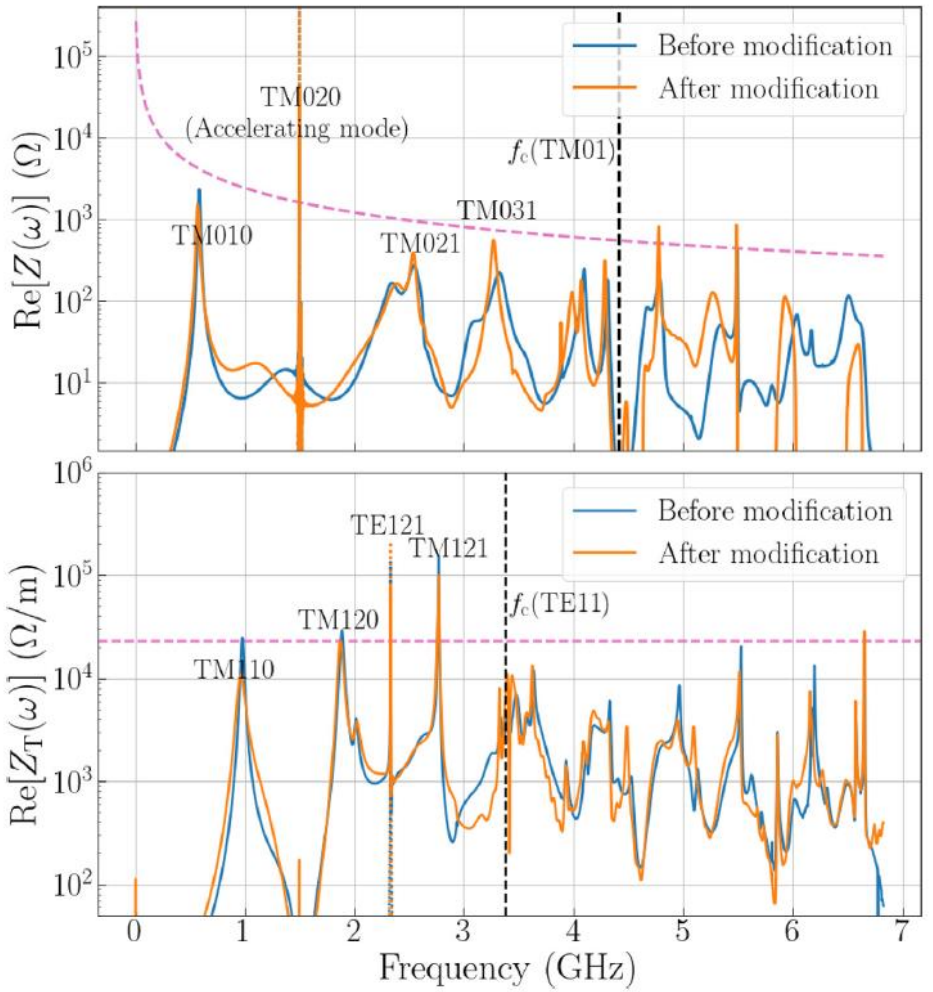


Fig. Schematic of high-power model of TM020 cavity

Table 6
Principal parameters of the final cavity design shown in Fig. 17 with an input coupler design given in Fig. 8(b). Frequency-domain simulation was used.

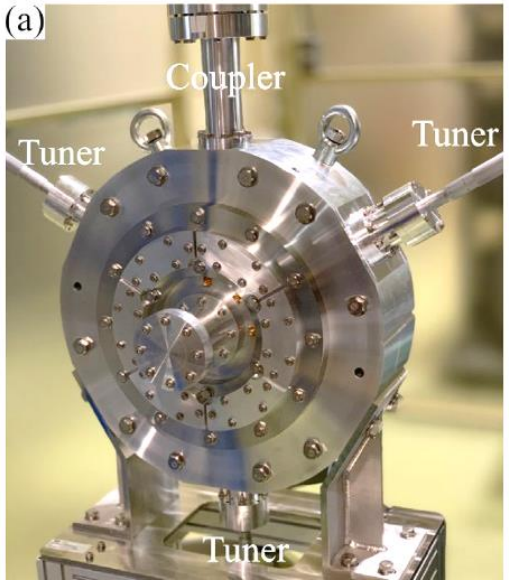
Parameter	Value
Resonant frequency of TM020 mode	1.500 GHz
R/Q (R_{sh}/Q_0)	68.0 Ω
Unloaded Q (Q_0)	31400
Shunt impedance ($R_{sh} = V_c^2/P_c$)	2.14 MΩ
Harmonic RF voltage (V_c)	155.4 kV/cavity
Wall-loss power (P_c)	11.3 kW/cavity
Max. wall-loss density	11.0 W/cm^2
Max. electric field	6.7 MV/m

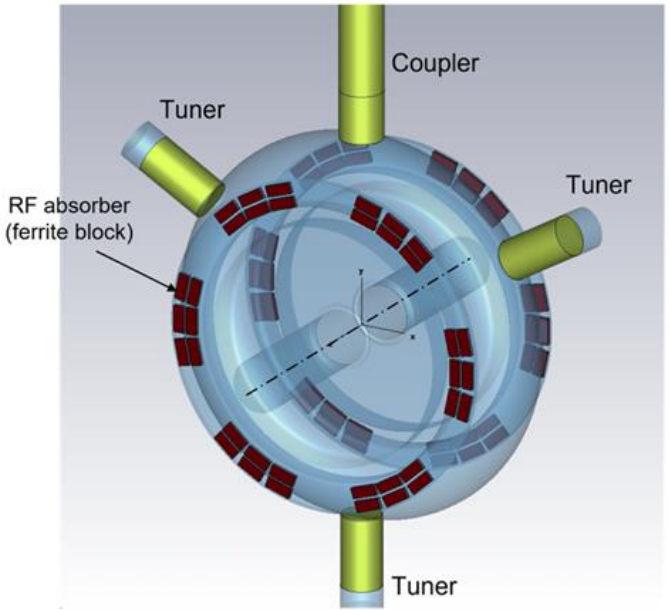
Impedances of one cavity



Low power model study of 1.5GHz-TM020 cavity

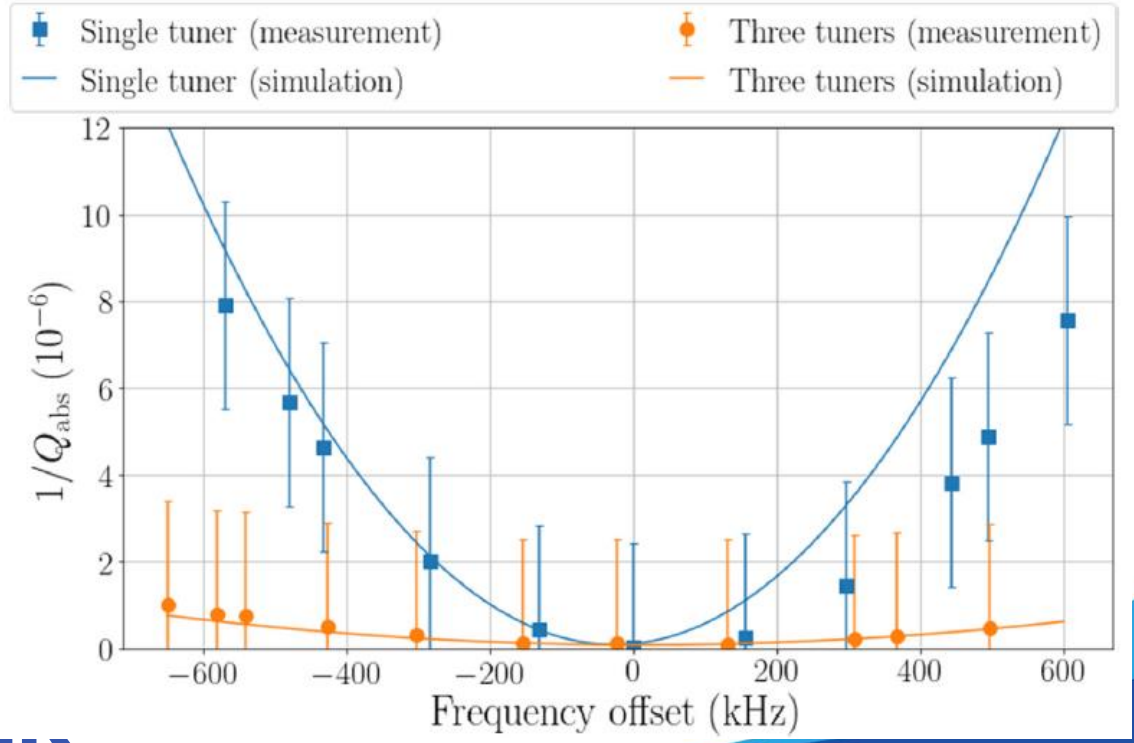
- As a result of investigations, we found that maintaining the axial symmetry of the cavity is essential for minimizing the leakage power of the accelerating mode into the coaxial slots.
- To this end, we have symmetrically arranged three frequency tuners, and designed an input coupler loop that produces only a small perturbation on the accelerating mode.





Parameter	Value
Resonant frequency	1.5 GHz
R/Q, ($R_s = V_c^2/2P_c$)	34.0 Ω
Unloaded Q	31400
Tuning range, $(P_{abs}/P_{wall})^1 < 2\%$	-0.5 ~ 0.5 MHz

Measurement result of the accelerating mode power loss ($1/Q_{abs}$) at RF absorber.

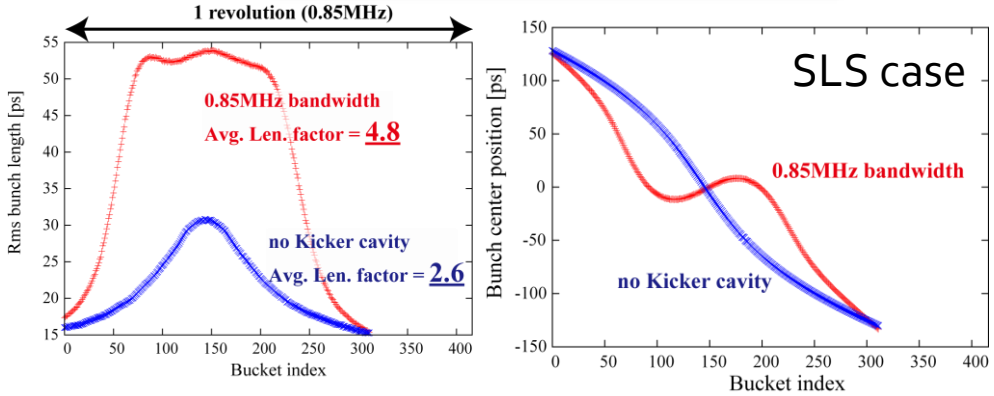


* N. Yamamoto et al., PRAB 21, 012001, 1 2018.

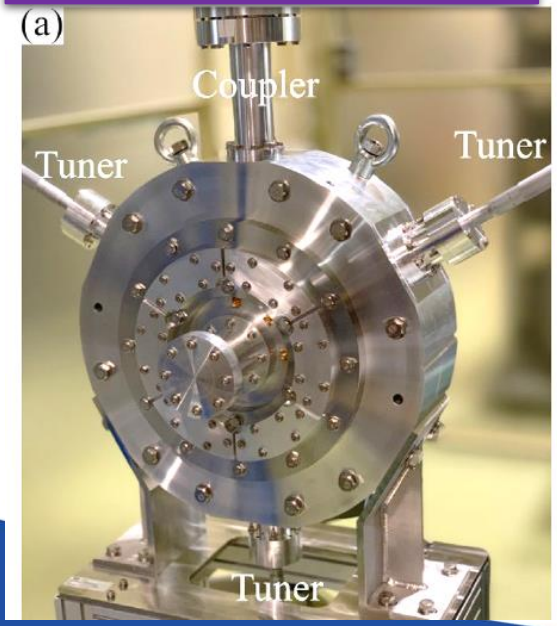
Device Developments for TBL compensation

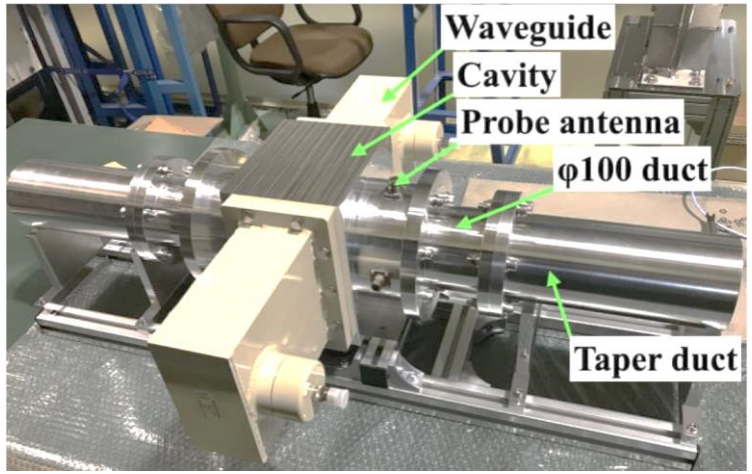
- Active Harmonic cavities with small total R/Q.
- A broadband kicker cavity
- Advanced LLRF system with integrated bunch phase monitor

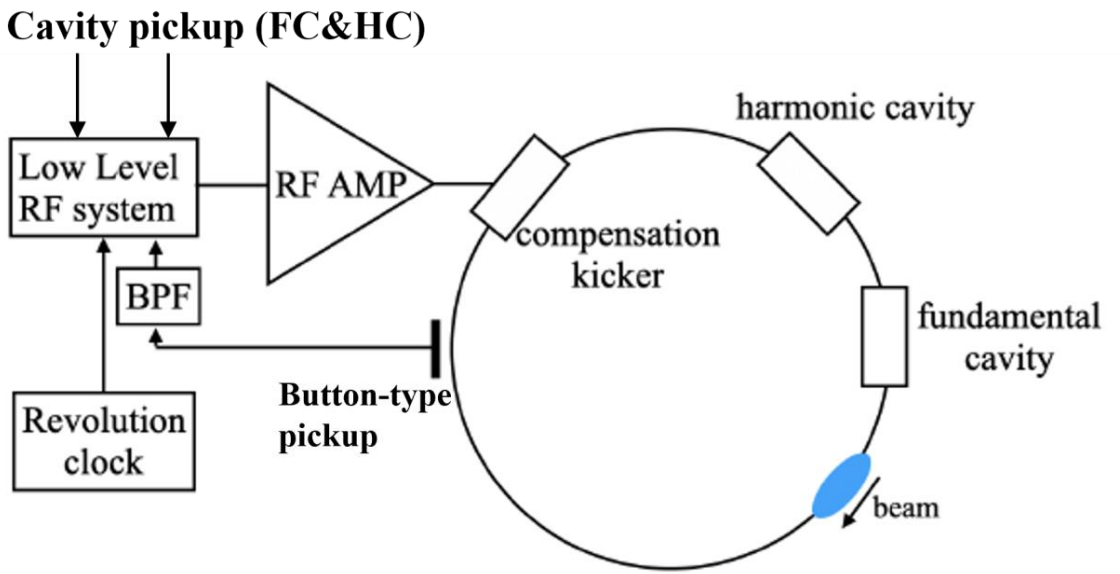
Code development & Tracking Simulation study (MBTRACK2)



Development of 1.5GHz-TM020 cavity





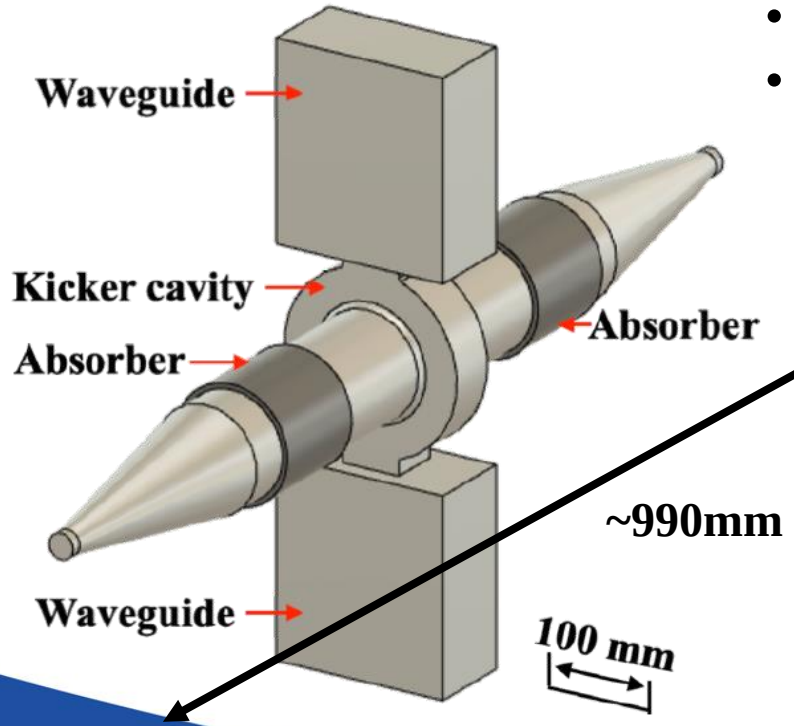


Insight through Accelerators.
KEK

Development of a broadband Kicker cavity

The use of a kicker cavity with a 3dB bandwidth of about 5 MHz, instead of FC & HC, is one solution to improve the TBL compensation performance.

Schematic & Parameters of the designed cavity
Fig. & table from N. Naito et al, IPAC2023, WEPA119



- A single-mode cavity concept
- Strongly loaded by means of two external waveguides, connected through large coupling slots.

Low power model

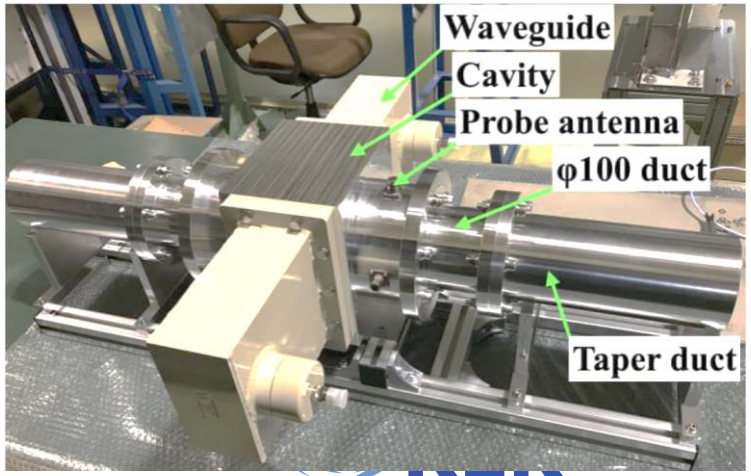


Table 1: The parameters of the kicker cavity

Parameter	Value
Resonant frequency	1.500 06 GHz
R/Q	60.38 Ω
Q_0	17937
Q_L	292.41
Synchronous phase	0 degree
Generator voltage	53 kV
Cavity voltage	44.2 kV
Generator power	40.4 kW
Power loss in cavity	2.59 kW
Reflecting power	15.7 kW
Max power density	21.7 W/cm^2
Absorber loss	3.38 %

3dB-bandwidth : 5.1 MHz

Development of a broadband Kicker cavity

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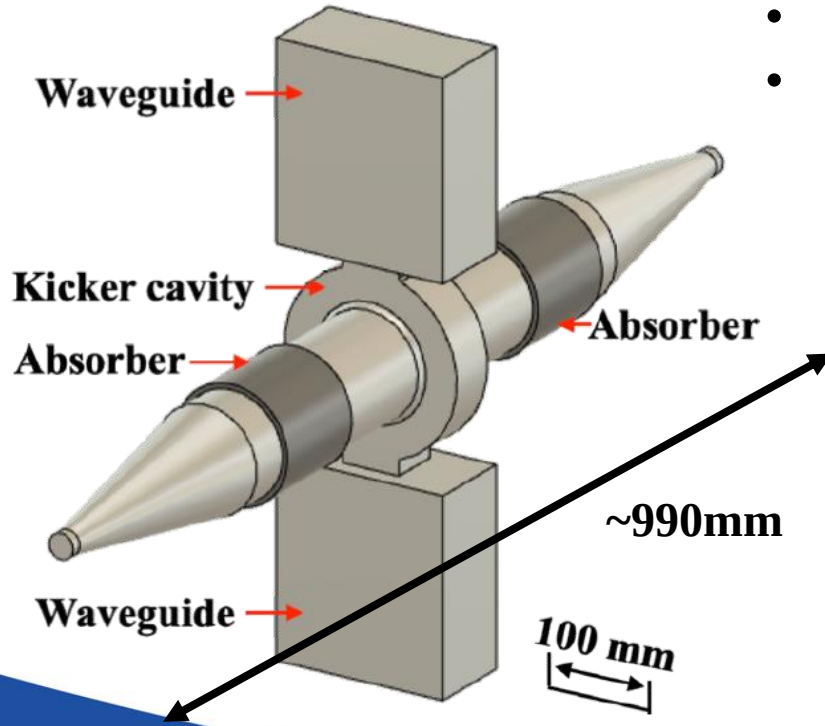

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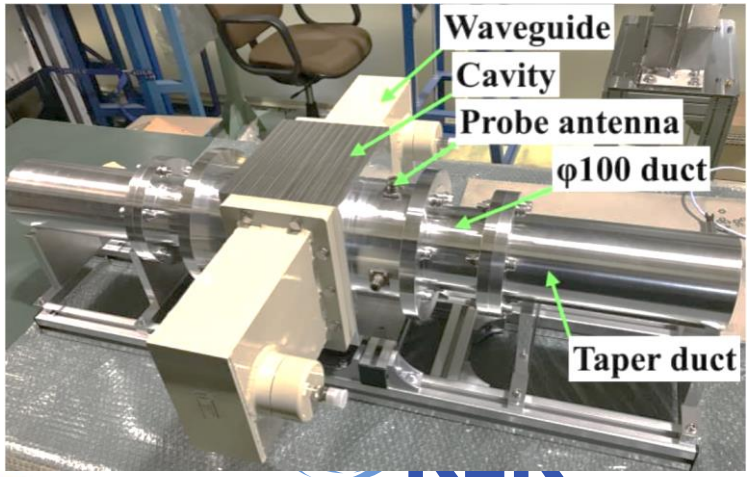


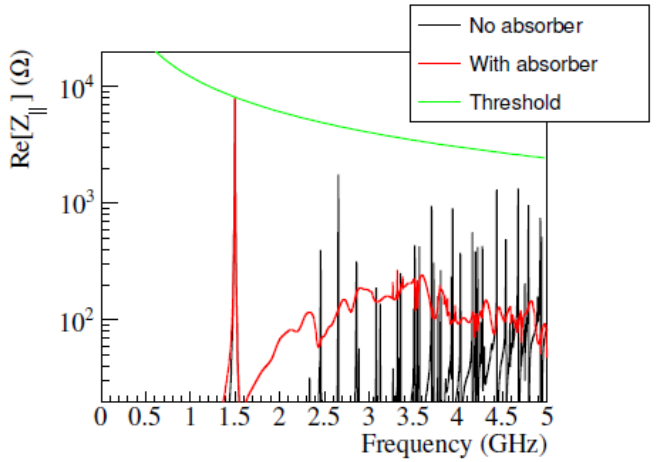


Figure 2: Calculated longitudinal coupling impedances with and without the SiC absorbers.

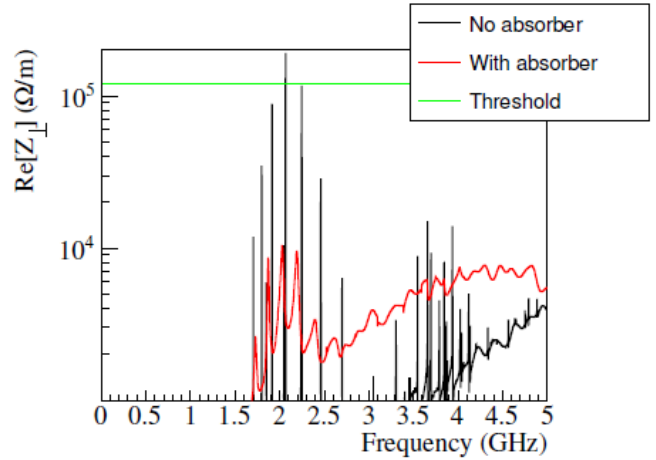


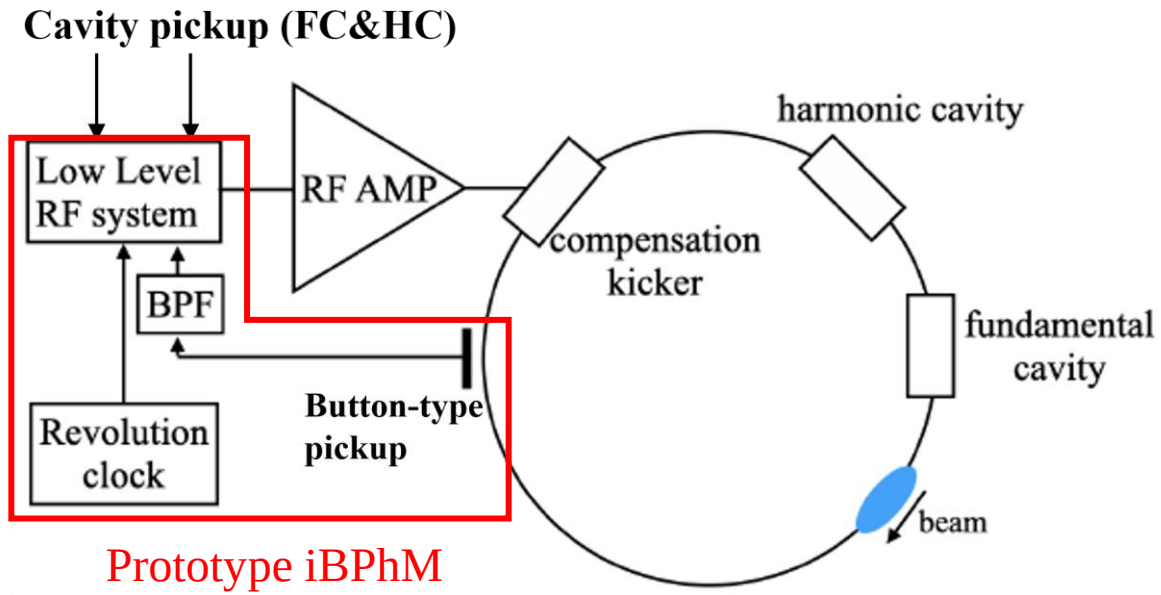
Figure 3: Calculated transverse coupling impedances with and without the SiC absorbers.

Development of Integrated Bunch Phase Monitor (iBPhM)

- To realize adaptive feedforward for TBL compensation, a LLRF control system with integrated bunch phase monitor is being developed and tested at KEK-PF; *D. Naito et al., PASJ2021, THOA01.*

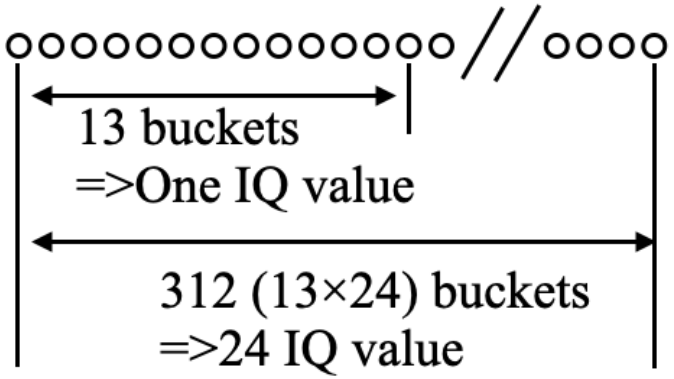
Integraged Bunch Phase Monitor (iBPhM)

Configuration of KEK-PF Digital LLRF system
- µTCA.4 technology
- Non-IQ Direct Sampling method
- Sampling frequency = 307.75 MHz, F_{rf} x 8/13
- Synchronized to Revolution clock (1.6MHz, PF)
- BPhM Data rate = ~ 1kHz (average 100-turn data)



Prototype iBPhM

IQ sampling synchronized to the revolution clock



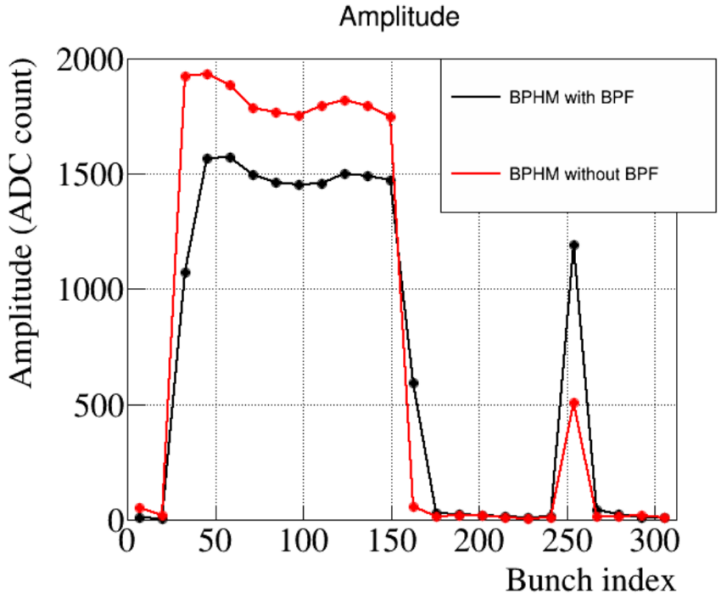
The IQ sampling is performed every 13 bunches, and 24 samples are obtained during one revolution period.
*KEK-PF: Harmonic = 312 , RF frequency = 500.1 MHz

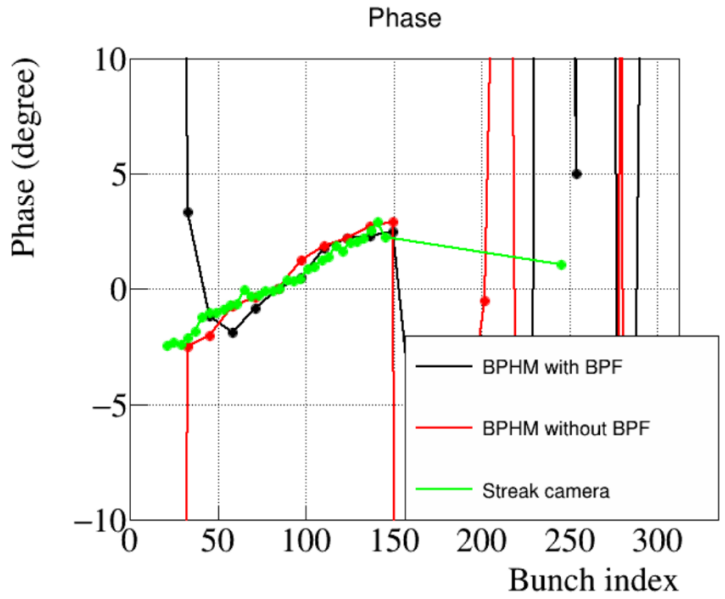
The LLRF system of PF-ring was already replaced to this new digital system in 2023.

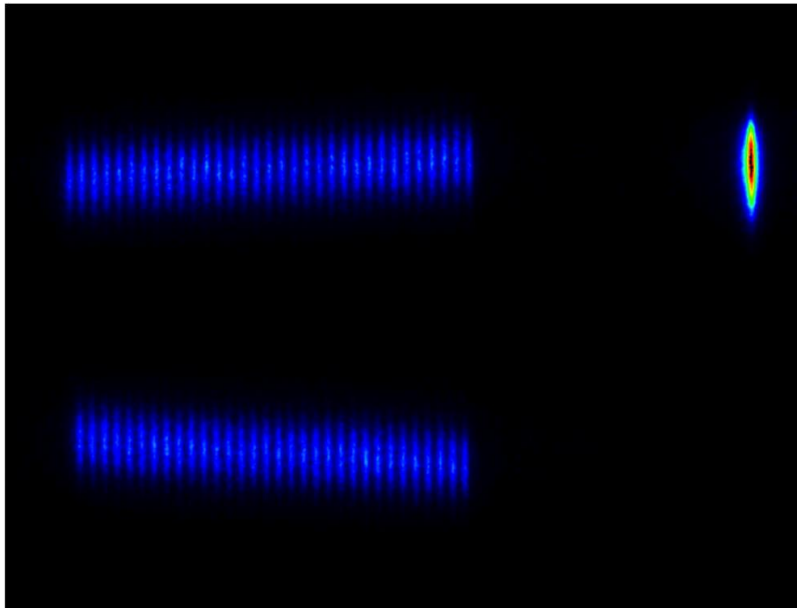
Preliminary result of DLLRF system and iBPhM at KEK-PF

*Courtesy of Daichi Naito

- Digital low level RF system
  - Successful stable operation from Nov. 2023
    - Amplitude : < 0.05 %, Phase : < 0.05 deg at 450mA (250 bunches 62 gaps)
- Integrated bunch phase monitor is tested at Hybrid filling mode w/o. HC







The bunch phase shift in the bunch train can be monitored with only 100-turn averaging data (1 turn = 0.625 us).

Summary

- At KEK, a bunch lengthening system; 500MHz SKEKB DR-type FCs, 1.5GHz active TM020 HCs with a TBL compensation system, is being considered.
- For the TBL compensation, a DLLRF-integrated bunch phase monitor and a broadband kicker cavity is being developed.

- Issues for SKEKB DR cavity,
  - ➢ Resonant frequency scaling from 508 to 500 MHz is needed.
  - ➢ Detailed analysis of the HOM damped performance is underway
- Issues for TM020 cavity and Kicker cavity,
  - ➢ Design & low-power-model tests for a TM020 HC and a broadband kicker cavity are almost done. -> High power Test ?

Thank you for your attention!