A New Damper for Coupled-Bunch Instabilities caused by the accelerating mode at SuperKEKB

Presenter : Kouki Hirosawa
SOKENDAI (The Graduate University for Advanced studies) and KEK (High Energy Accelerator Research Organization)

Table of Contents

Contents tree

An Overview of SuperKEKB

Contents tree

Motivation

SuperKEKB: upgrade from KEKB

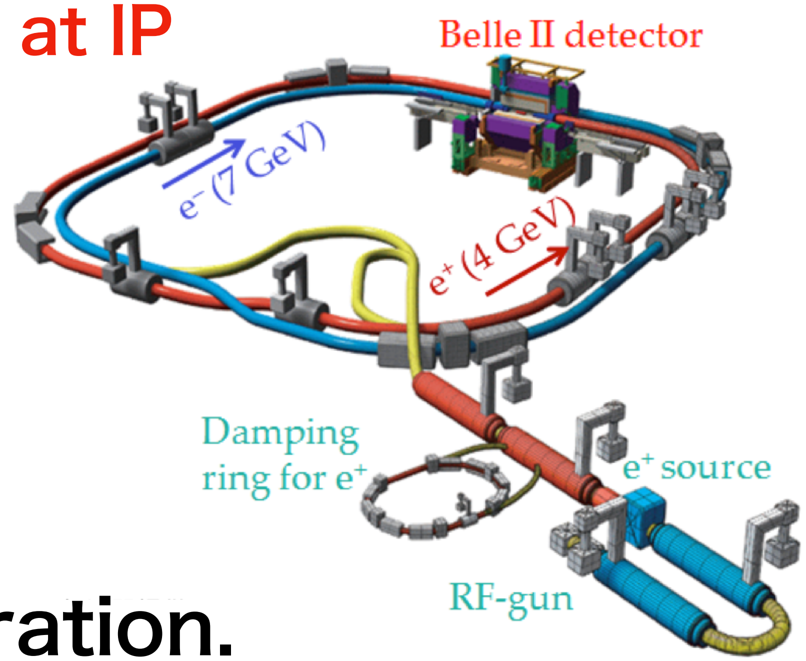
Asymmetric Energy Electron-Positron Circular Collider

Purpose: to find new physics beyond the Standard Model.
(from point of view of events probability)

Main Strategy at accelerator section: High Luminosity

Large Beam Current and Nano Size Beam at IP

Instabilities !



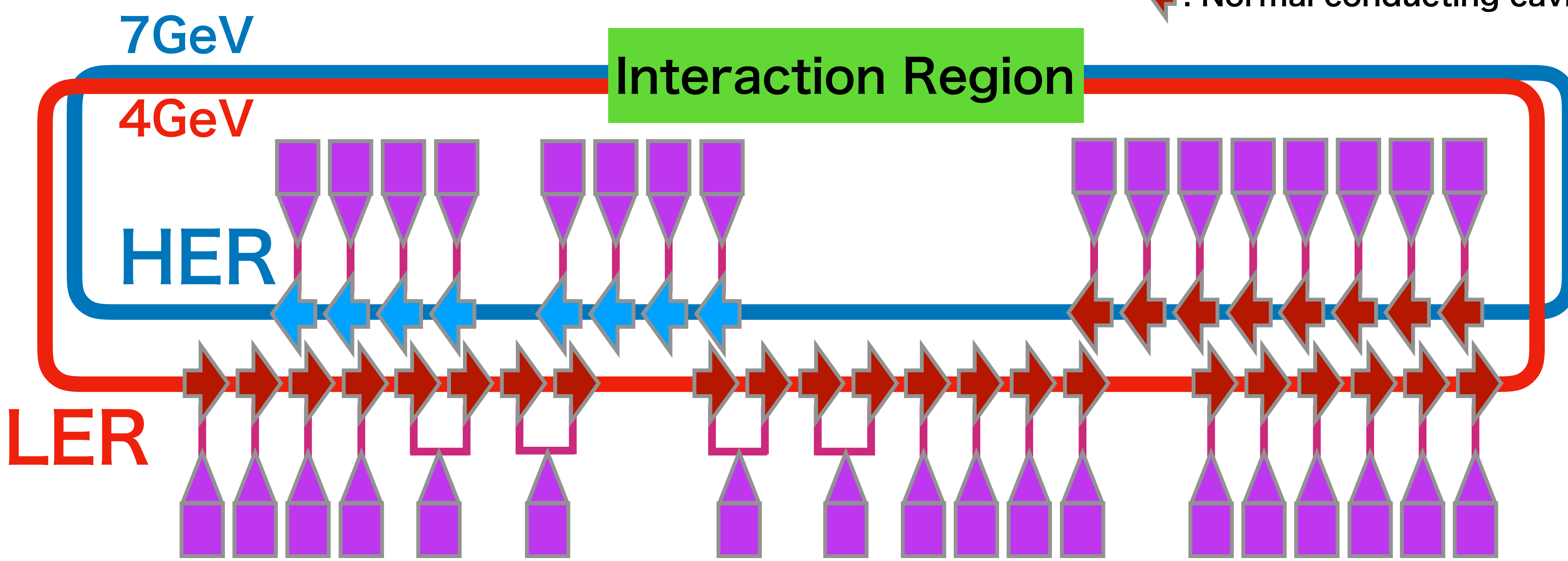
This study is one of solutions
for problems of beam current saturation.

An Overview of SuperKEKB

Contents tree

RF System for SuperKEKB

: Klystron + LLRF station
: Superconducting cavity
: Normal conducting cavity



HER → SC × 8 + NC × 8 : Total Vc = 15.0 MV

LER → NC × 22 : Total Vc = 9.4 MV

Cavities of accelerating section are single cell.

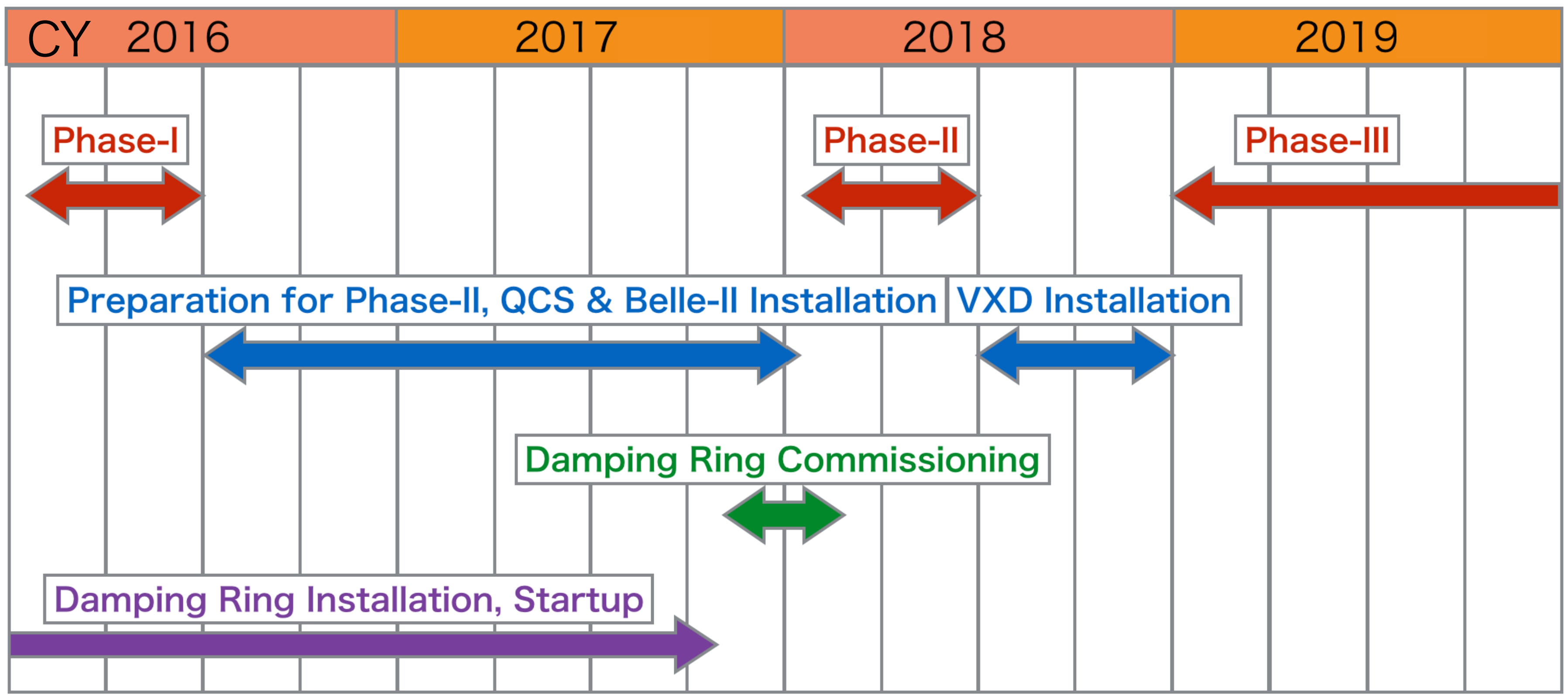
Most of RF system of KEKB are reused and improved for SuperKEKB.

LLRF control systems were newly developed (FPGA + μTCA) for NC stations.

→ 10/17 Poster (P-60) : "LLRF controls in SuperKEKB Phase-1 commissioning" , T. Kobayashi

An Overview of SuperKEKB

SuperKEKB commissioning schedule and important parameters for this study



	LER	HER	Unit
E (Particle Energy)	4.000	7.007	GeV
I (Beam Current)	3.6	2.6	A
Harmonic Number	5120		
RF Frequency	508.877		MHz
Revolution Frequency	99.39		kHz
Synchrotron Frequency	2.43	2.78	kHz

Model of Coupled-Bunch Instabilities

Equation of synchrotron oscillations

$$\ddot{\phi}_n(t) + \tilde{\omega}^2 \dot{\phi}_n(t) - \mathcal{F} = 0$$

Action of Wake Fields

Solve the eigenvalue problem

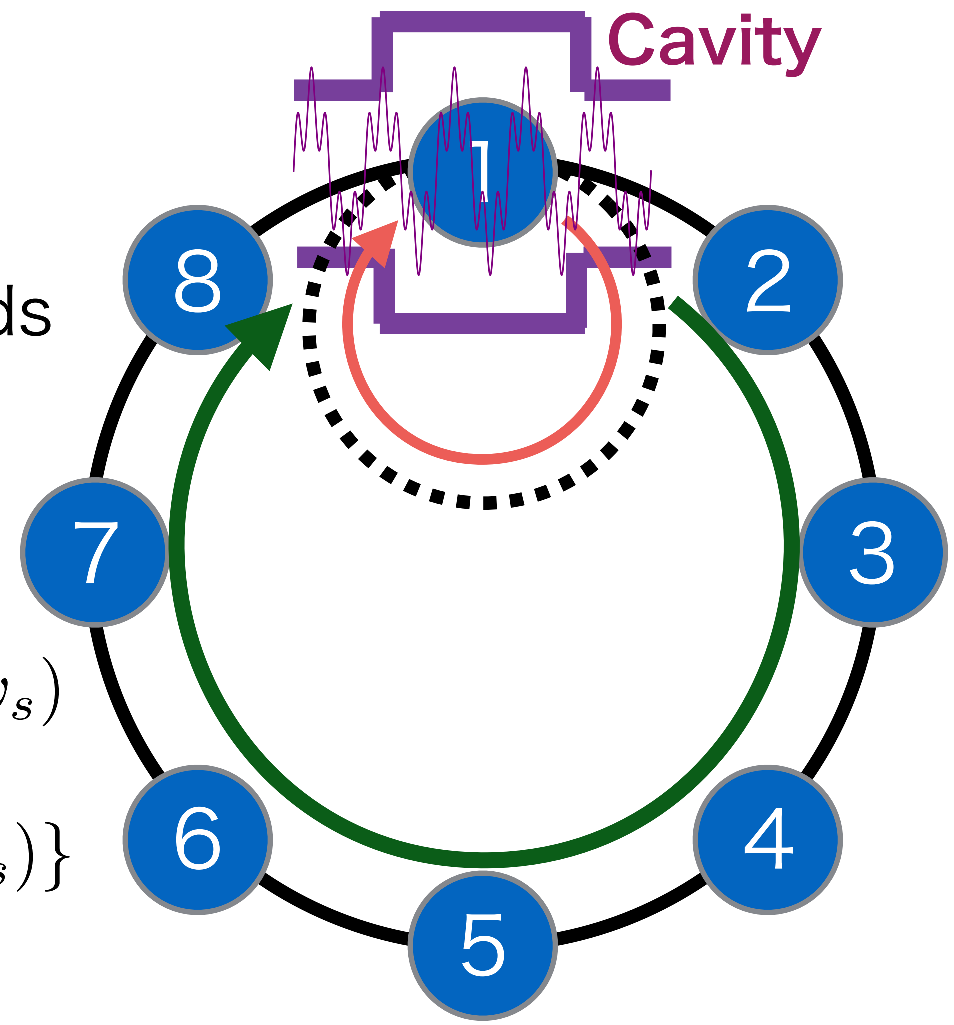
$$\tau^{-1} = AI_b \sum_{p=0}^{\infty} \{[C_1\omega_0 + \omega_s]\mathrm{Re}Z(C_1\omega_0 + \omega_s) - [C_2\omega_0 - \omega_s]\mathrm{Re}Z(C_2\omega_0 - \omega_s)\}$$

$$C_1 = (Mp + \mu)$$

$$C_2 = (M(p+1) - \mu)$$

[Amplitude] $\propto e^{-t/\tau}$

M : the number of bunch (bucket)



Bunches are filled every other bunch at even interval and have uniform distribution for each bunches.

Coupled-Bunch Instabilities

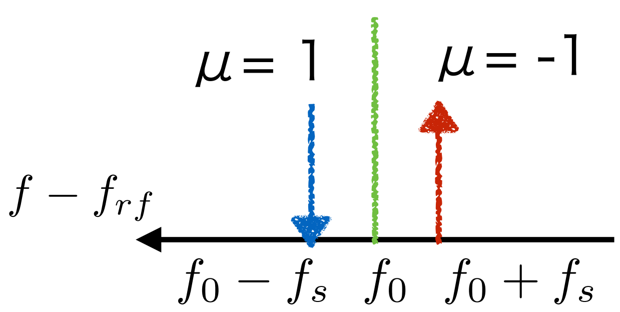
Contents tree

Mechanism of destabilization

Growth Rate

$$\tau^{-1} = AI_b \sum_{p=0}^{\infty} \{[C_1\omega_0 + \omega_s]\mathrm{Re}Z(C_1\omega_0 + \omega_s) - [C_2\omega_0 - \omega_s]\mathrm{Re}Z(C_2\omega_0 - \omega_s)\}$$

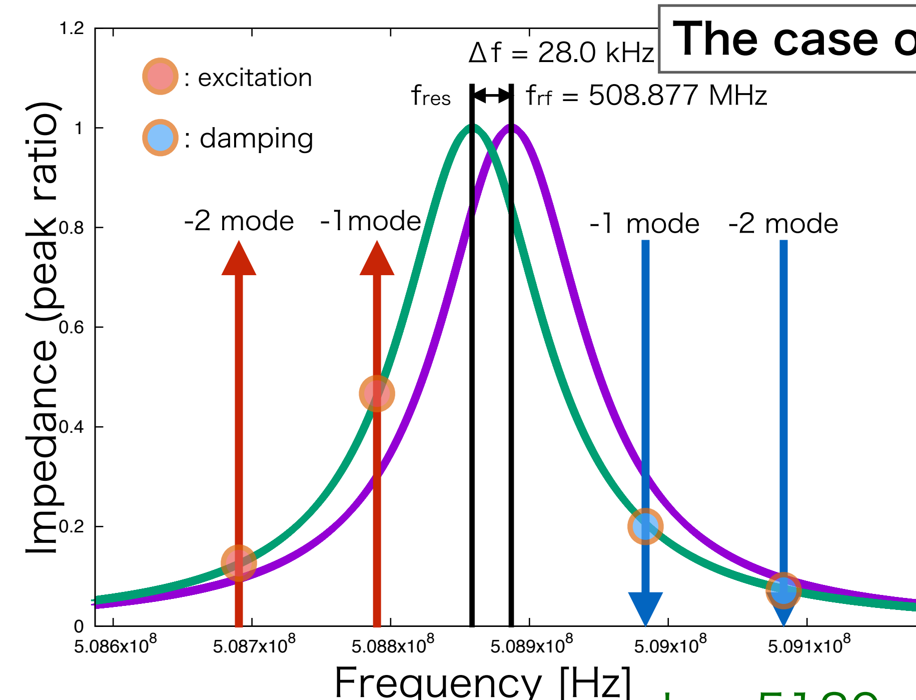
$$C_1 = (Mp + \mu)$$
$$C_2 = (M(p+1) - \mu)$$



Red arrow : excite
Blue arrow : damp

We can see this structure every revolution frequencies.

The case of NC



h = 5120
f_{rf} ~ 509MHz
f_0 ~ 100kHz
f_s ~ 2kHz

Asymmetric impedance by cavity detuning yields instabilities around accelerating frequency. Cavities in SuperKEKB have small detuning value, but some lowest modes can be excited (μ = -1, -2, -3 mode).

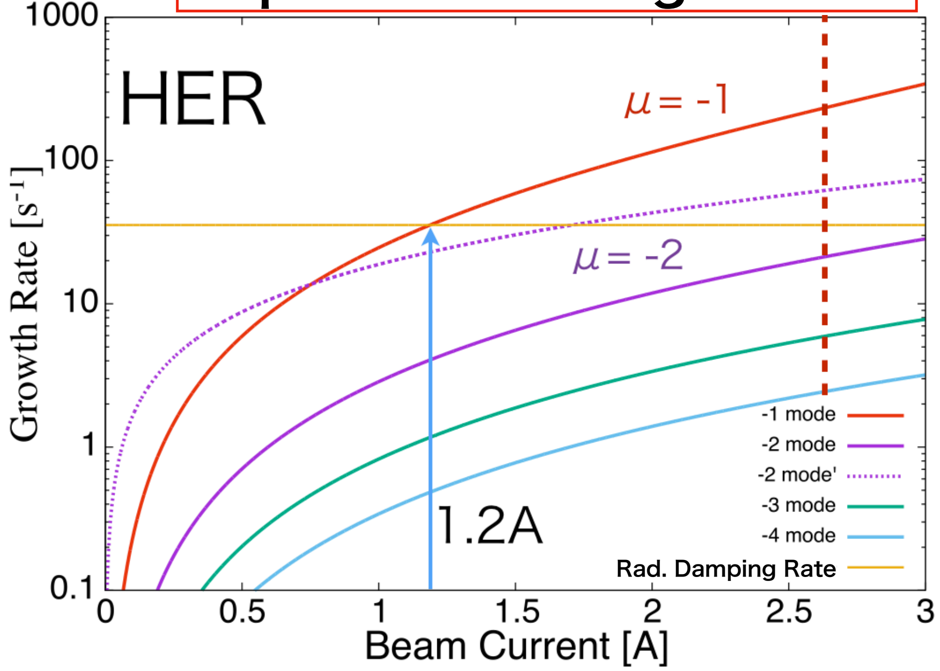
(we call μ = M-1→ μ = -1, μ = M-2→ μ = -2, ⋯)

Coupled-Bunch Instabilities

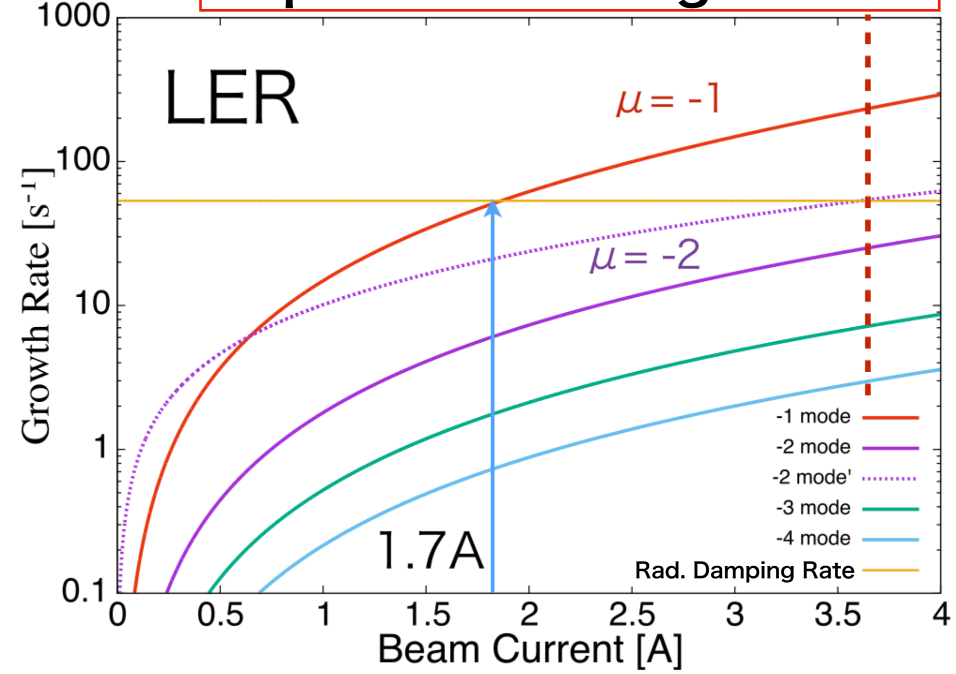
Contents tree

Estimation and plot of CBIs growth rate

SuperKEKB design : 2.6A



SuperKEKB design : 3.6A



Unstable

Stable

Calculate result of μ = -1, -2, -3, and -4 mode for SuperKEKB.

Dotted curve : There is one parked cavity (out from operation).

Horizontal yellow line is radiation damping rate.

CBIs μ = -1and -2 mode will become serious at least.
Especially μ = -1 mode will have so large amount of growth rate.

In Phase-I commissioning, μ = -1 mode was excited by parked SCs at 0.5A storage in HER.

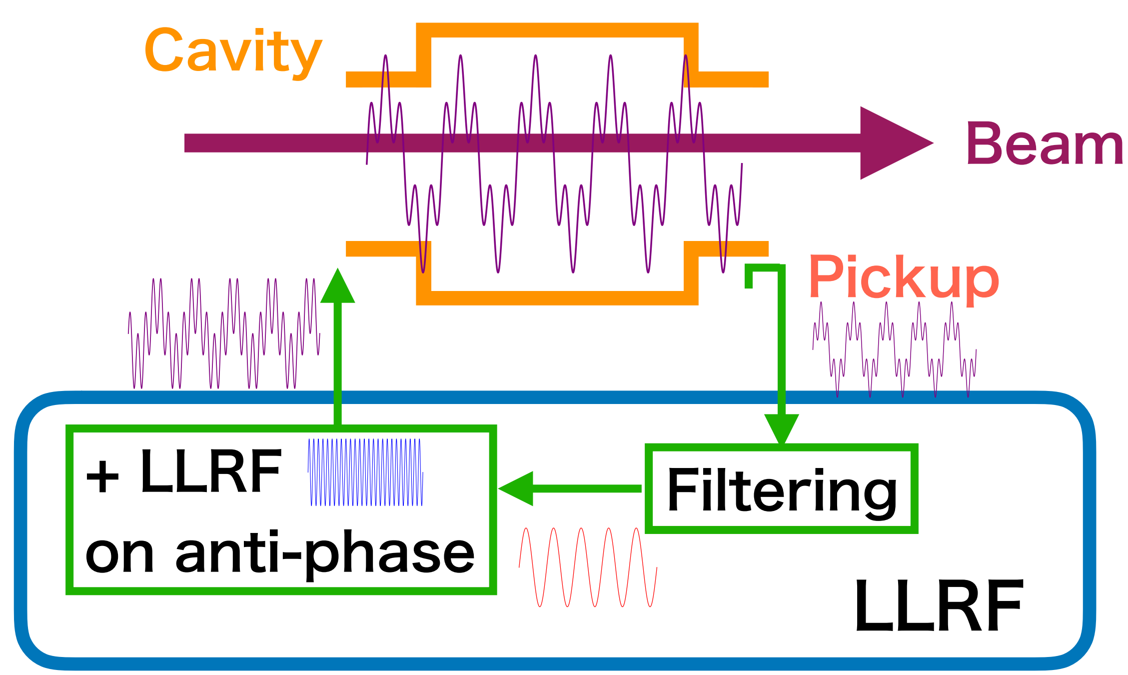
New CBIs Damper

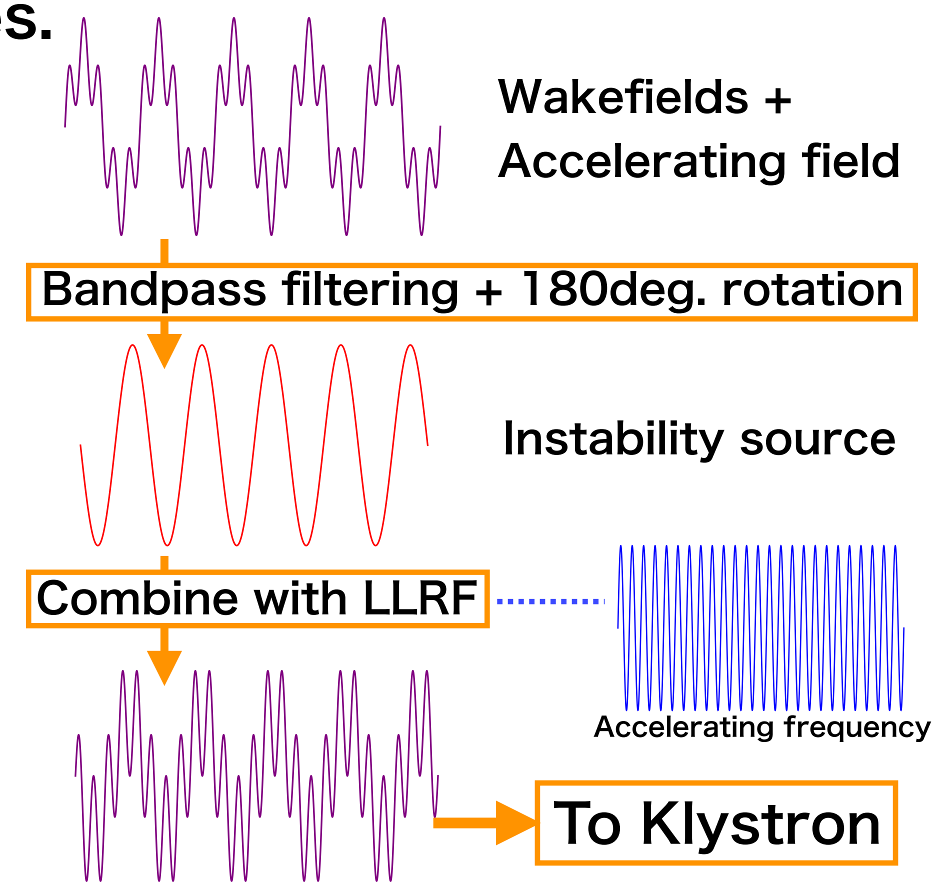
Contents tree

The main strategy for suppressing CBIs is RF feedback.

It is difficult to use other kicker cavity for this instabilities,
because instability source is too large to suppress by other cavity.
(accelerating cavity have a largest impedance in storage ring.)

This CBIs are caused by known frequencies.





System is well known for 20 years.

We have CBI damper for KEKB, but this supports only μ = -1 mode.
So we need a new damper to suppress additionally destabilized modes.

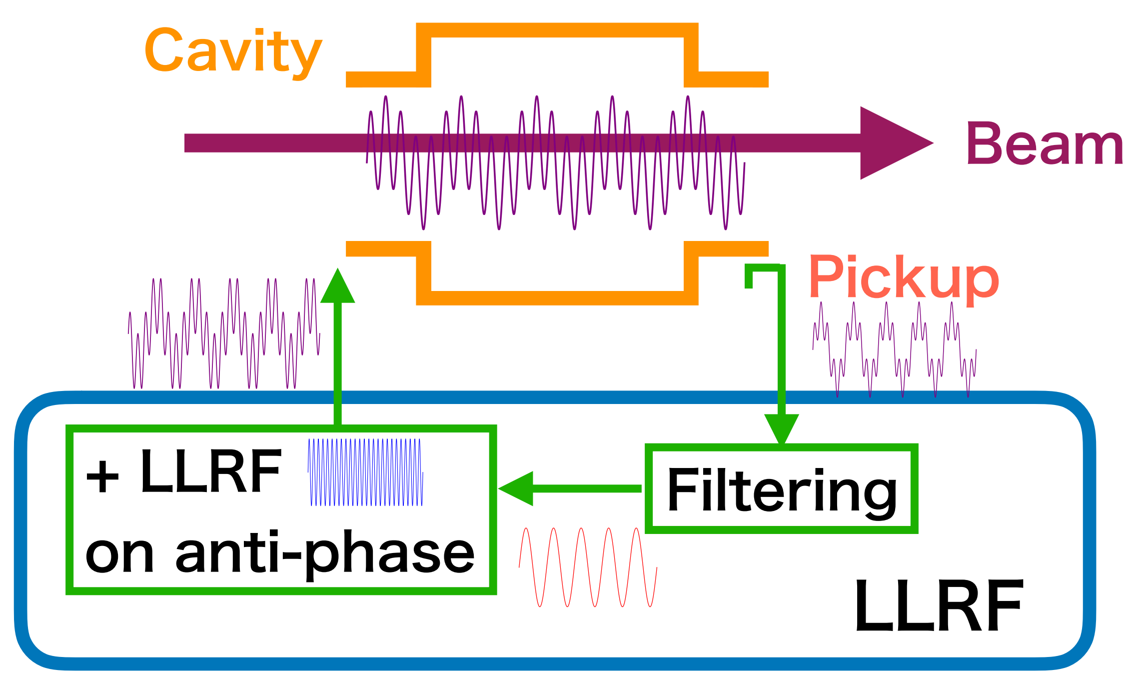
New CBIs Damper

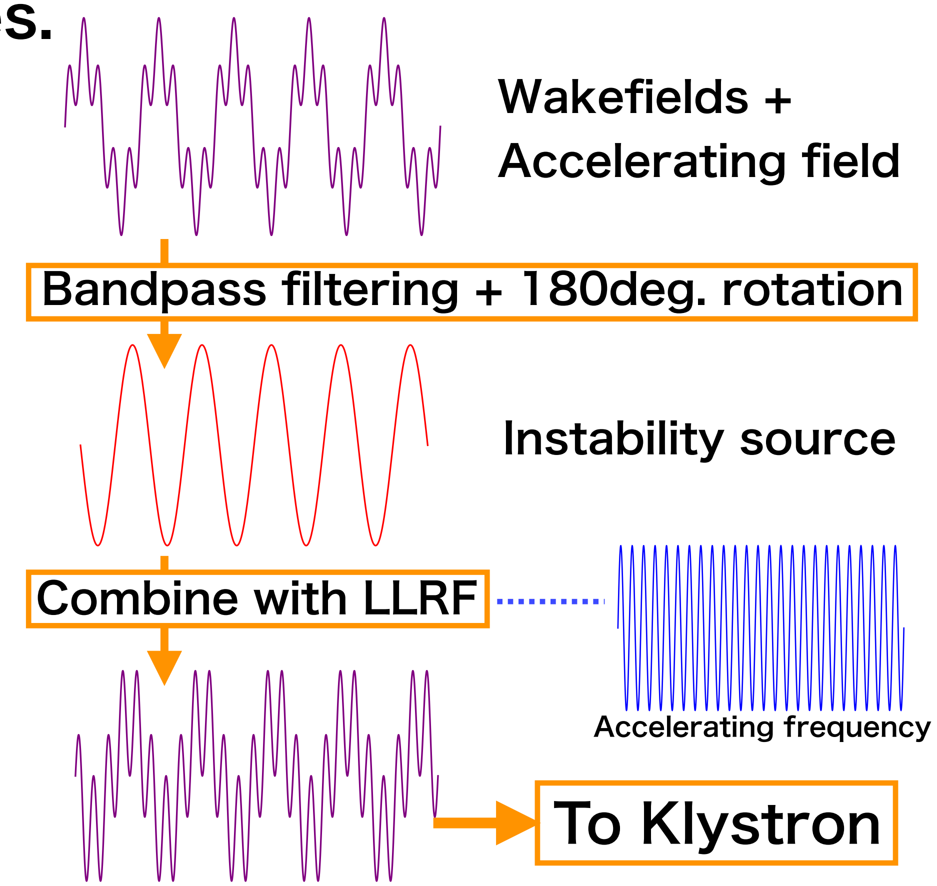
Contents tree

The main strategy for suppressing CBIs is RF feedback.

It is difficult to use other kicker cavity for this instabilities,
because instability source is too large to suppress by other cavity.
(accelerating cavity have a largest impedance in storage ring.)

This CBIs are caused by known frequencies.





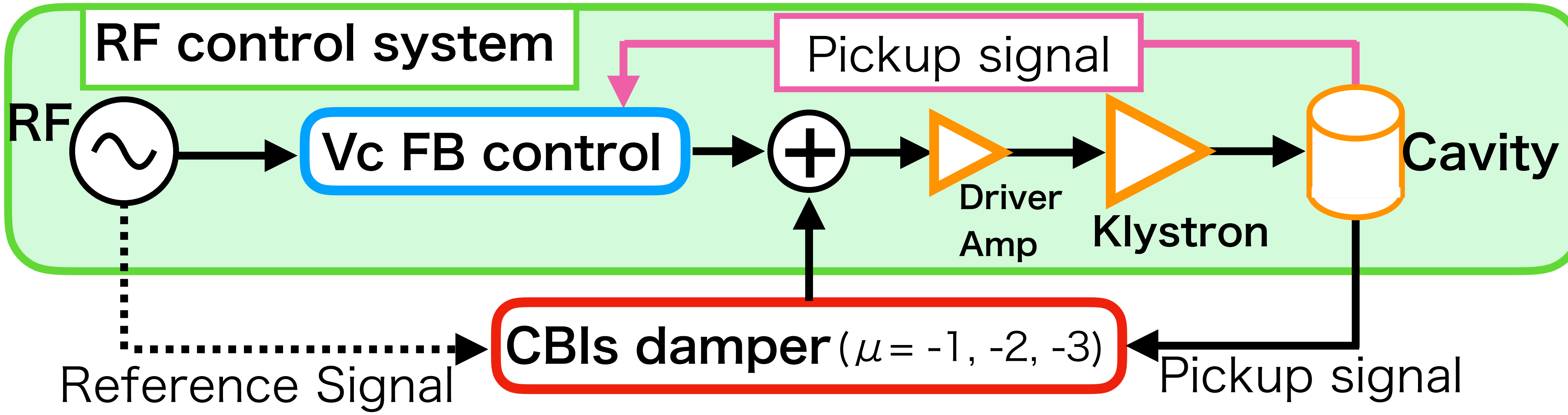
System is well known for 20 years.

We have CBI damper for KEKB, but this supports only μ = -1 mode.
So we need a new damper to suppress additionally destabilized modes.

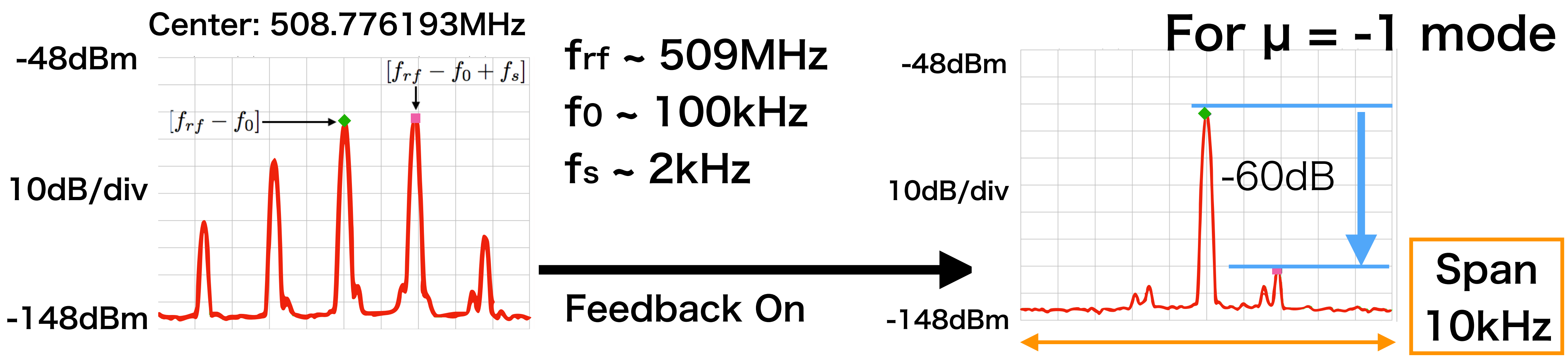
New CBIs Damper

Contents tree

Block diagram of RF system and CBIs damper for SuperKEKB.



CBIs damping test with existing damper at SuperKEKB Phase-1 commissioning

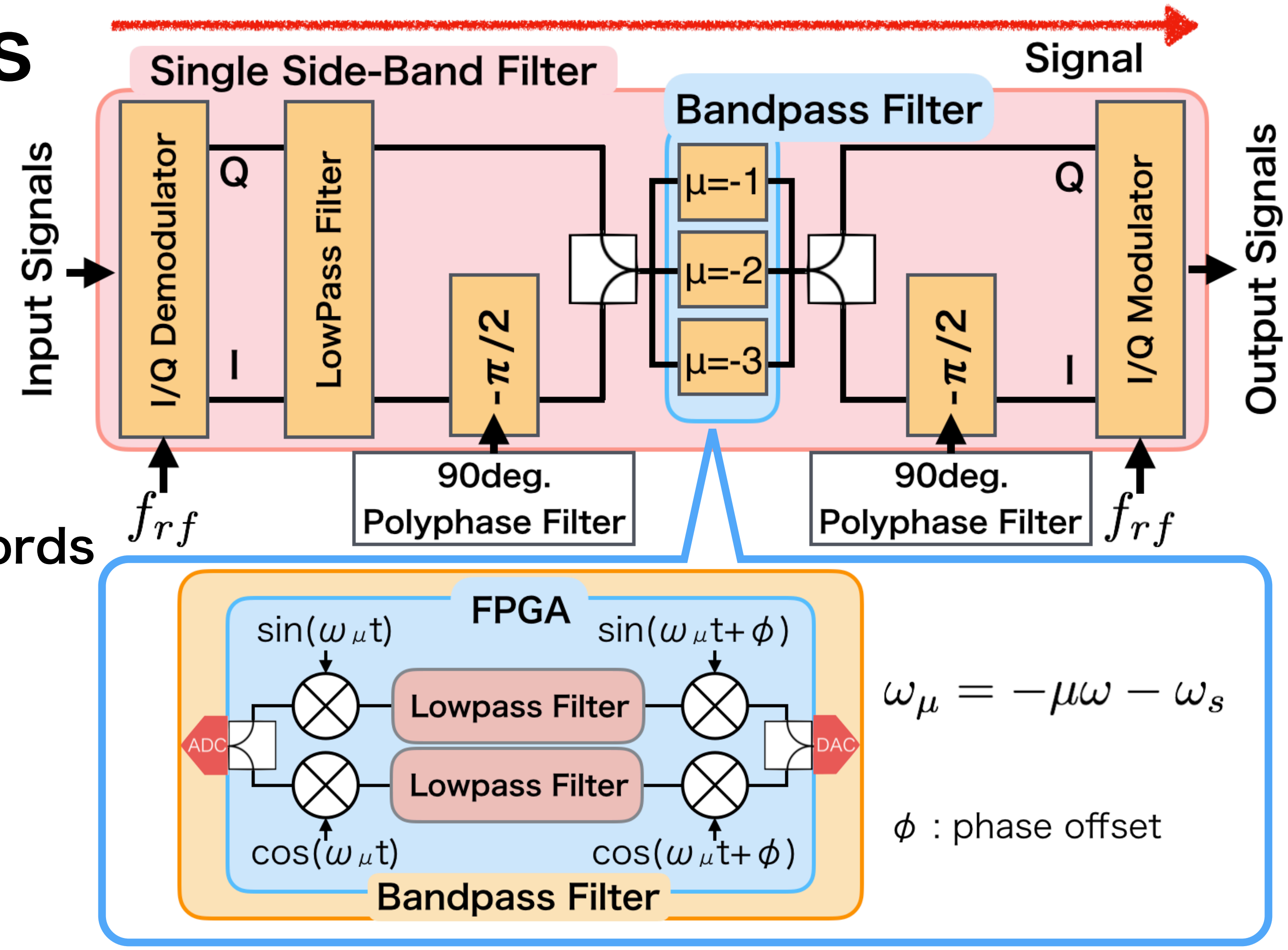


This system can suppress CBIs.
→ The remaining issue is improvement for SuperKEKB design parameters.

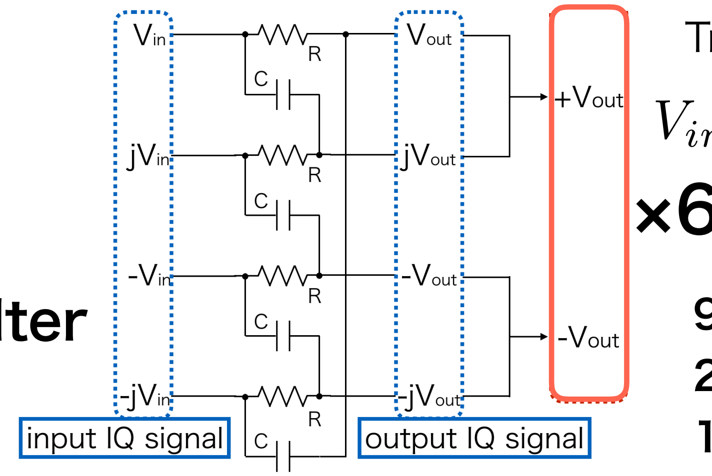
Improvement points

- I/Q modulation
- 90deg. rotation filter
- mode frequency (ω_μ)
- whole of BPFs
- remotely control via EPICS records (Frequency, Phase, Amplitude, and parameters of LPFs.)

Resolution of signal
Frequency : ~10Hz
Phase : ~0.7deg.



90deg. Polyphase Filter



Transfer matrix of this filter

$$V_{in} = \begin{pmatrix} \frac{1+i\omega RC}{1+\omega RC} & \frac{R}{1+\omega RC} \\ \frac{2i\omega C}{1+\omega RC} & \frac{1+i\omega RC}{1+\omega RC} \end{pmatrix} V_{out}$$

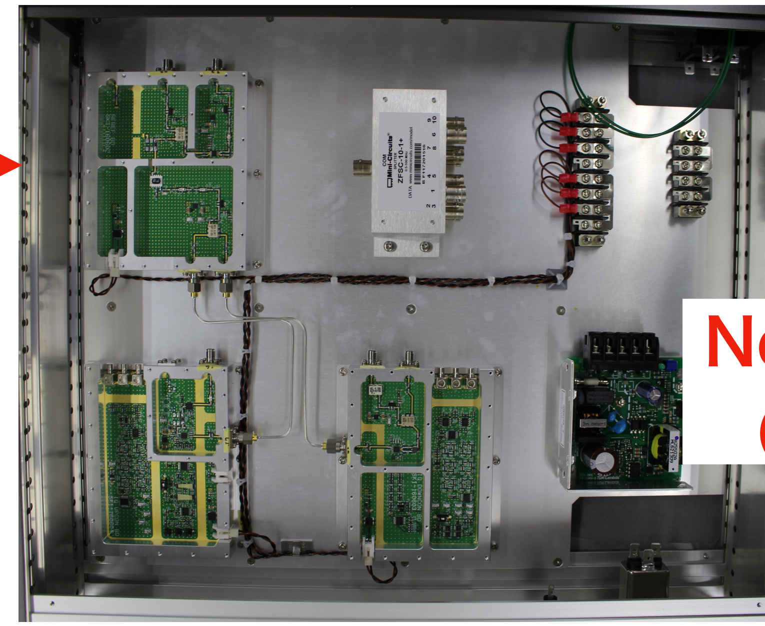
$$f_{peak} = \frac{1}{2\pi RC}$$

90deg. rotations are at 20k, 40k, 80k, 160k, 320k, 900k [Hz]

New CBIs Damper

Pictures of CBIs damper connected with LLRF Sys.

Single Side-Band Filter

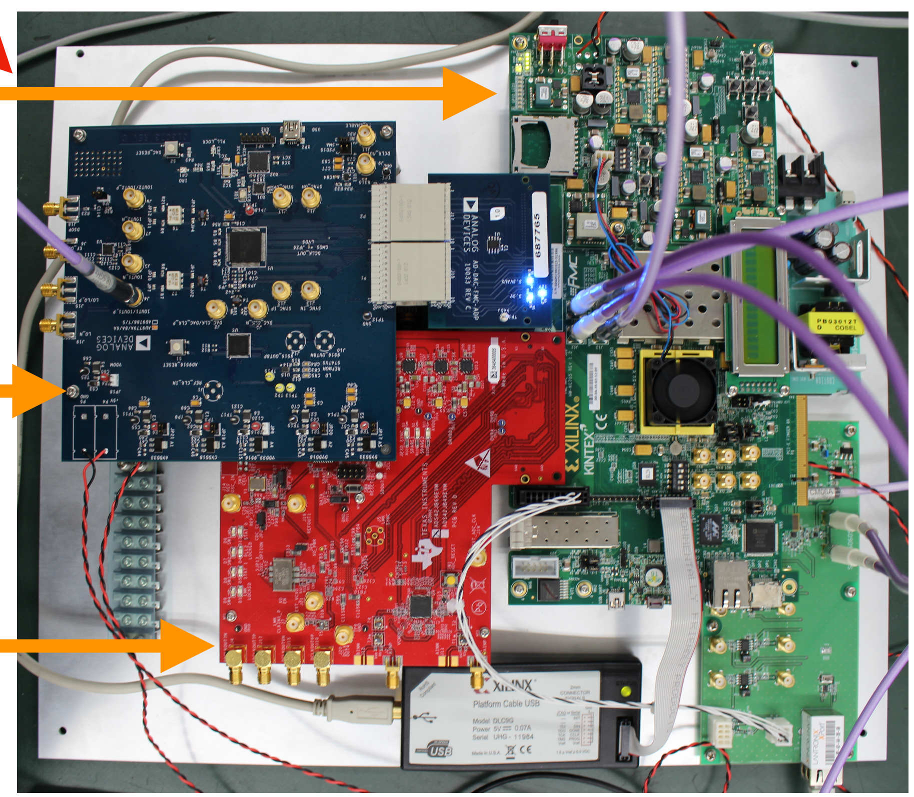


Digital Bandpass Filter

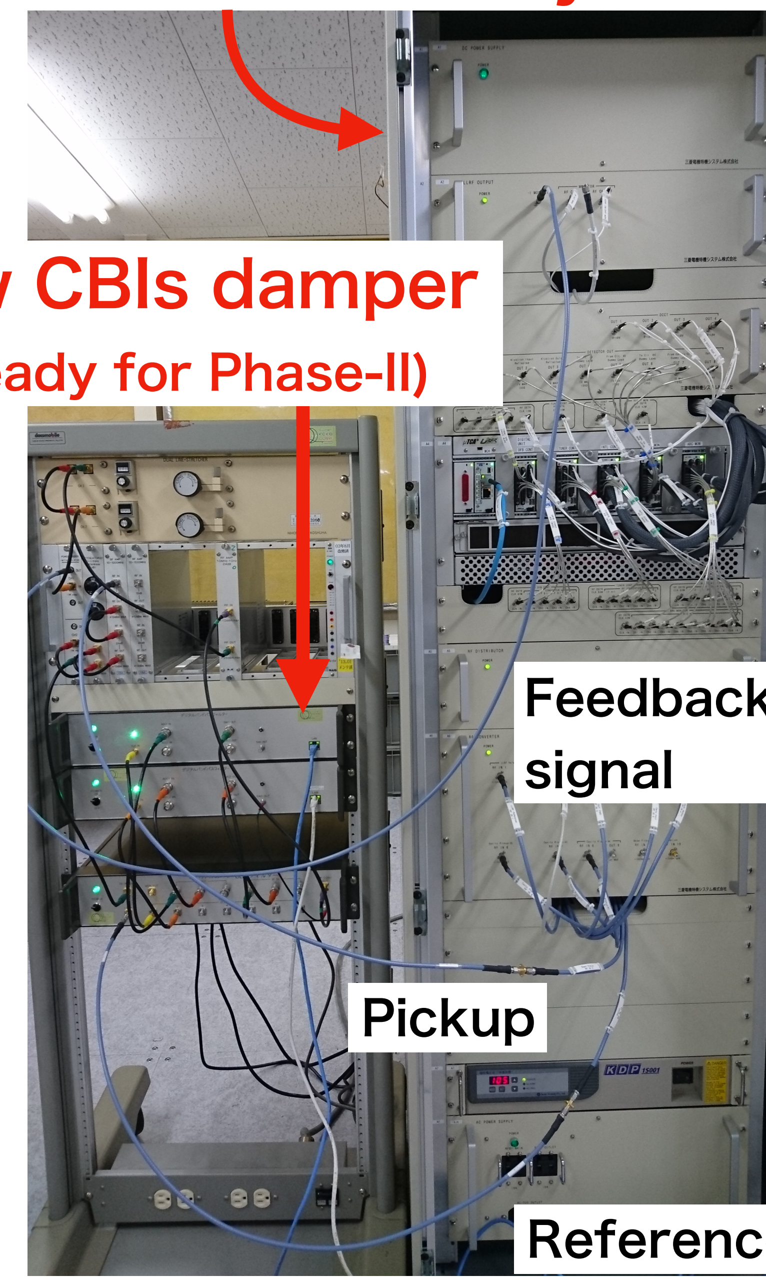
KC705, Xilinx Evaluation Board

ADC Board AD9467

DAC Board AD9779



LLRF control system

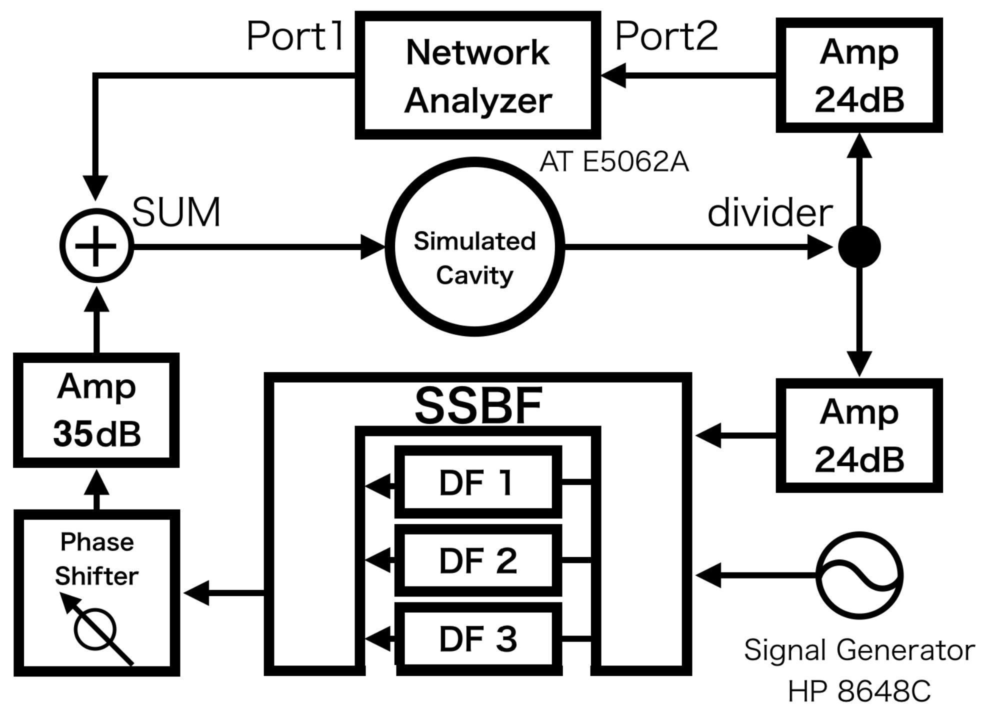


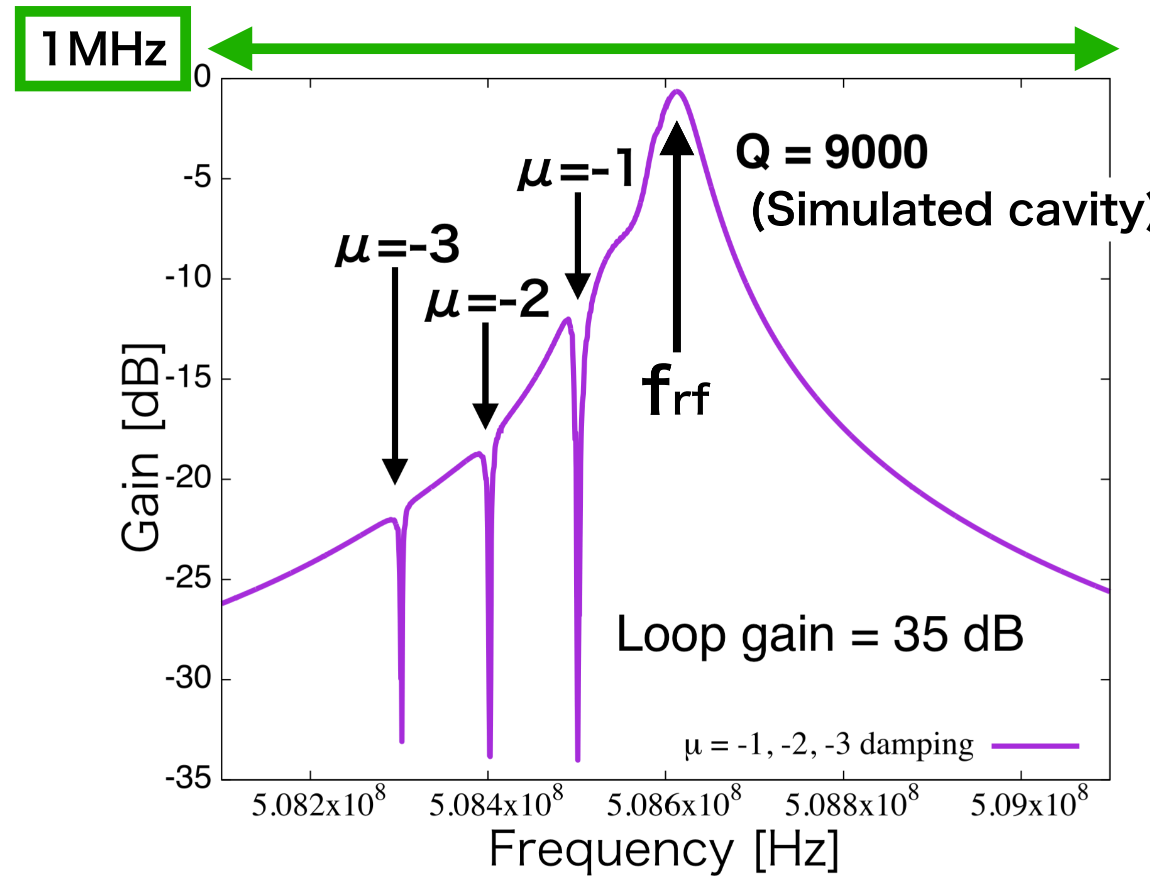
Kouki Hirosawa (hirosawa@post.kek.jp)

New CBIs Damper

Contents tree

The test bench of CBIs damper with simulated cavity.





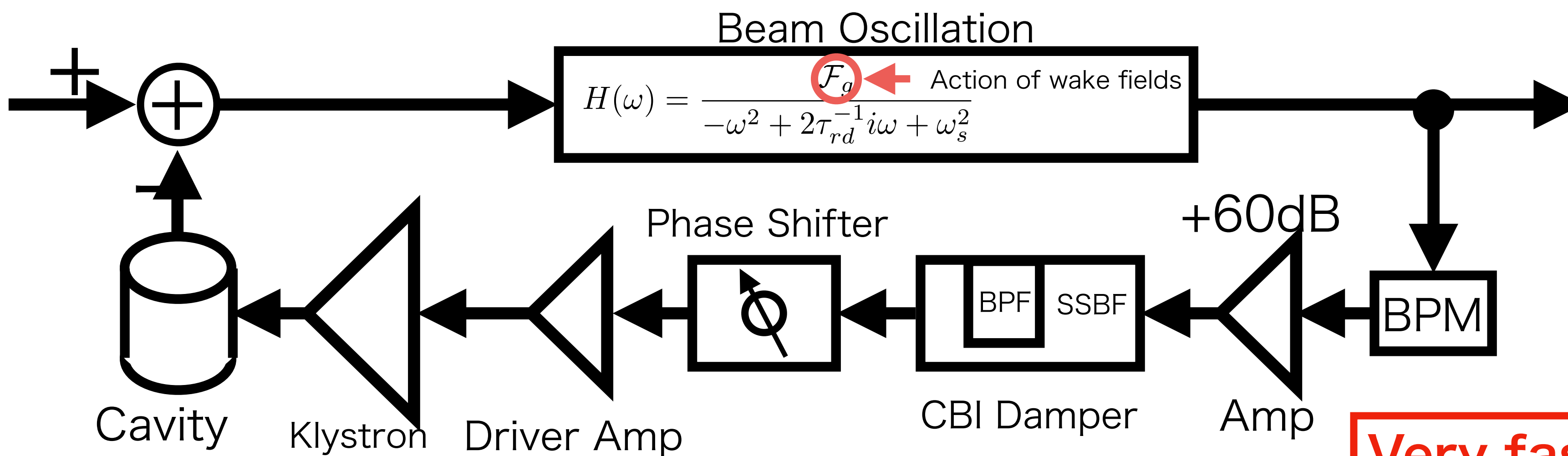
For phase adjustment, we set μ = -1 mode by phase shifter.
Next, μ = -2 and -3 modes were fixed by parameters in FPGA.

Parameters setting and the response of loop gain are good.
In test bench evaluation, our new damper worked very well.

New CBIs Damper

Contents tree

RF Feedback Simulation for suppressing CBIs

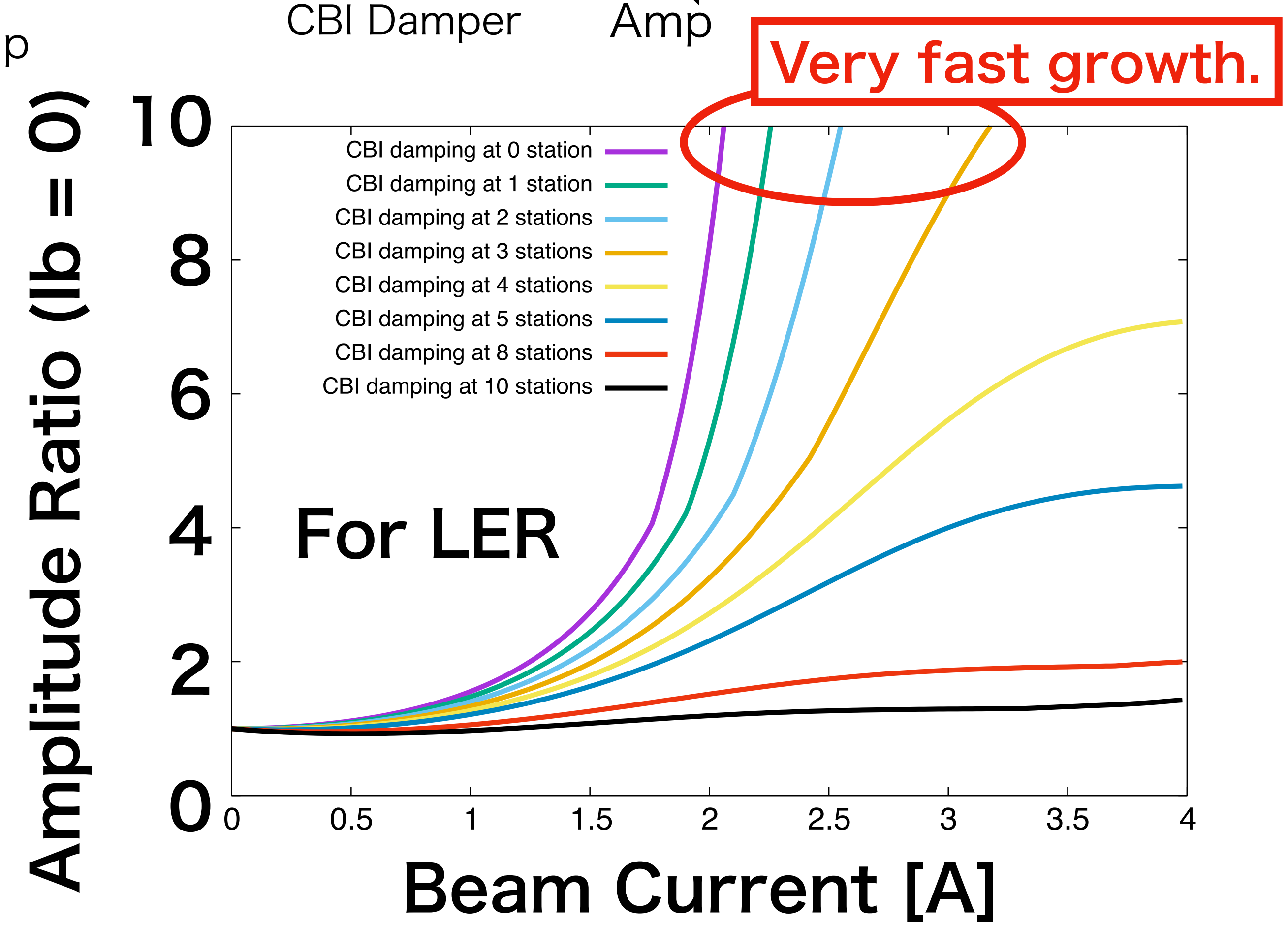


(LER has 18 LLRF stations.)

The number of CBIsD are changed for each simulations. (0, 1, 2, 3, 4, 5, 8, 10)

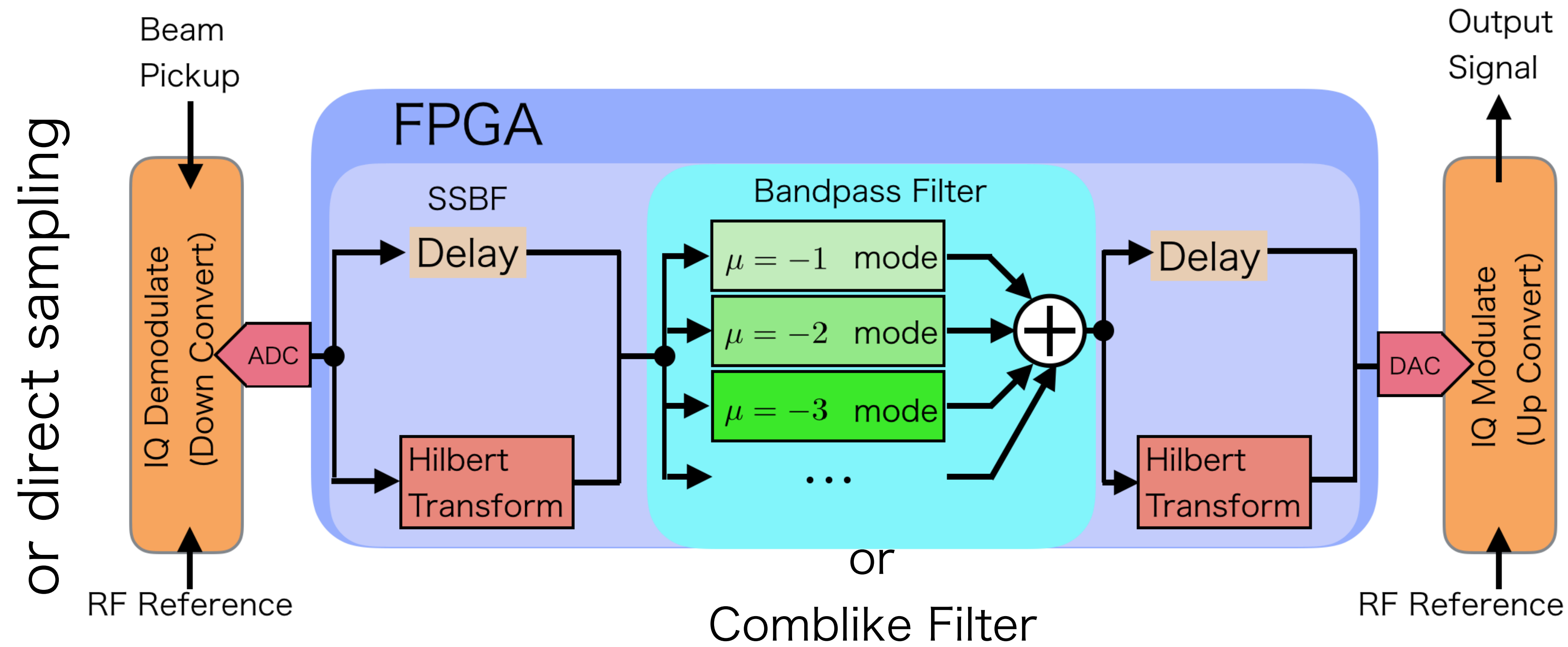
From this estimation,
At least, we need 4 dampers.

Curves are envelop of amplitude.



Contents tree

Next Step of improvement



- We consider above system (FPGA works as SSBF and BPF) for future improvement.
- It is better that we use direct RF sampling method instead of down converter if it is possible.
- BPF may be changed comblike filter, because it is more applicable for other accelerator.

Conclusion

CBIsD : coupled bunch instabilities damper

Summary

- We improved CBIsD to suppress newly-destabilized modes. (IQ conversion, 90° rotation, Bandpass filter, …)
- The performance of CBIsD satisfied our requirement in test bench.

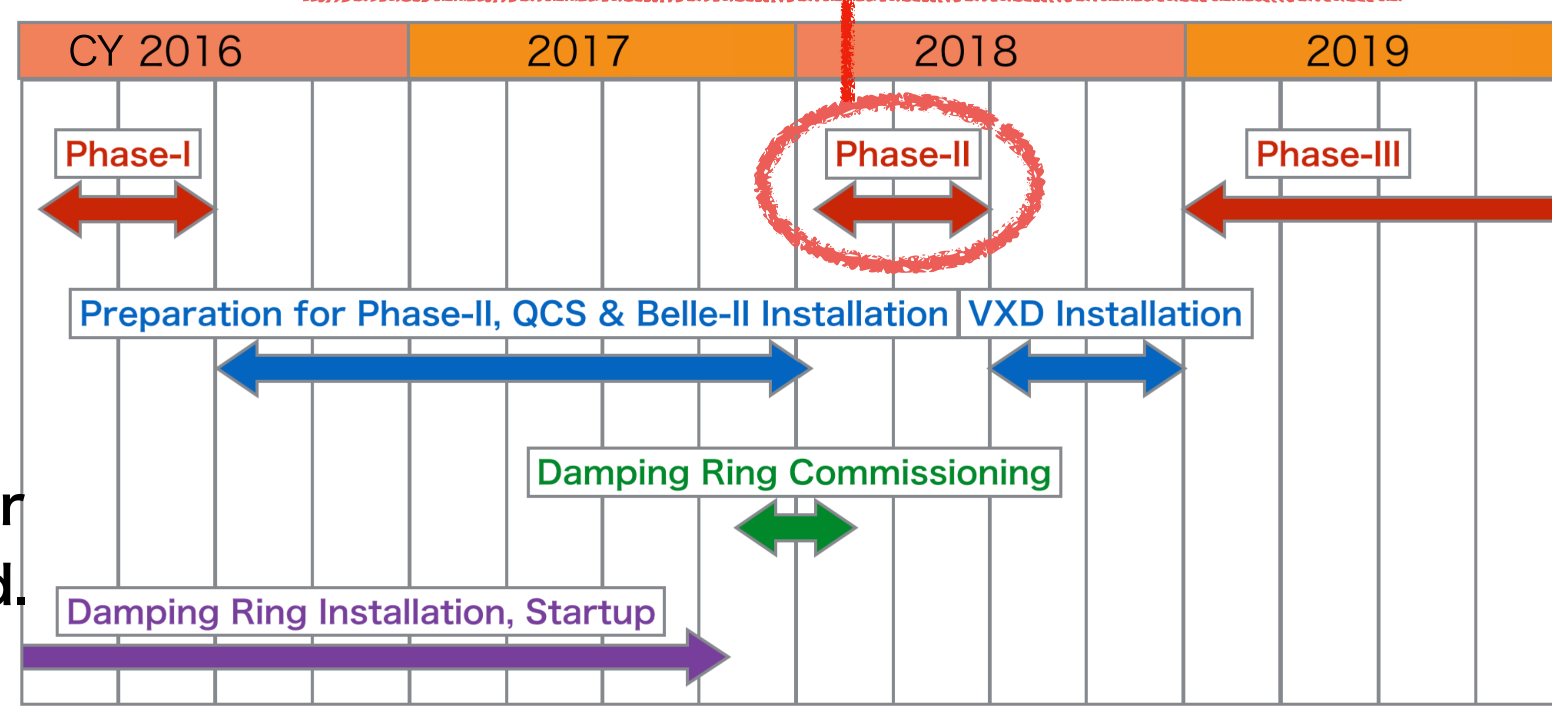
The remaining problem

- According to feedback simulation, we need many CBIs dampers.

On beam test for CBIs damper

In this commissioning

We will fix parameters for damping CBIs, and estimate the number of CBIs damper required.



Kouki Hirosawa (hirosawa@post.kek.jp)

Contents tree

Thank you for your attention!

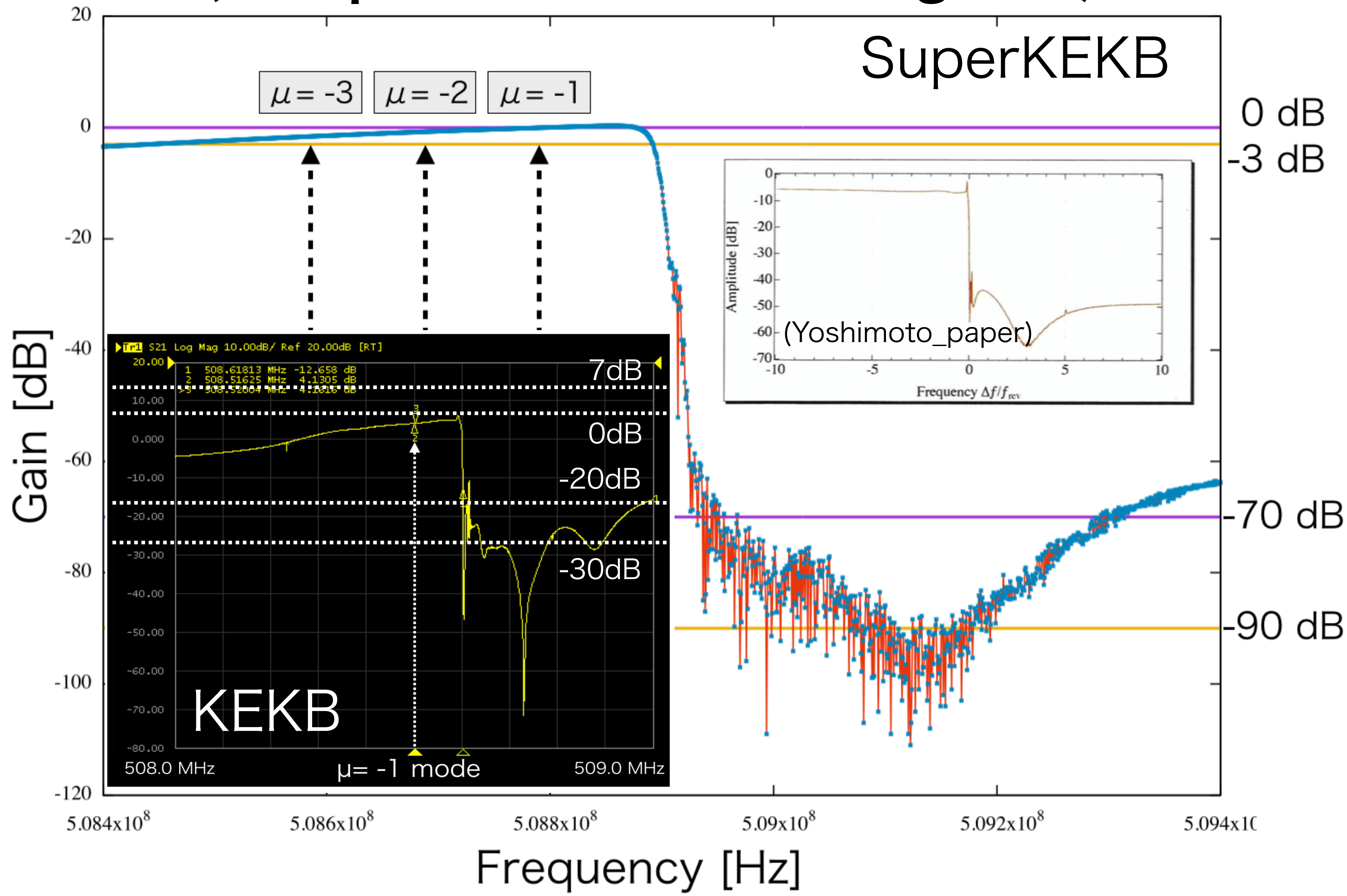
Kouki Hirosawa (hirosawa@post.kek.jp)

Contents tree

SuperKEKB design parameters

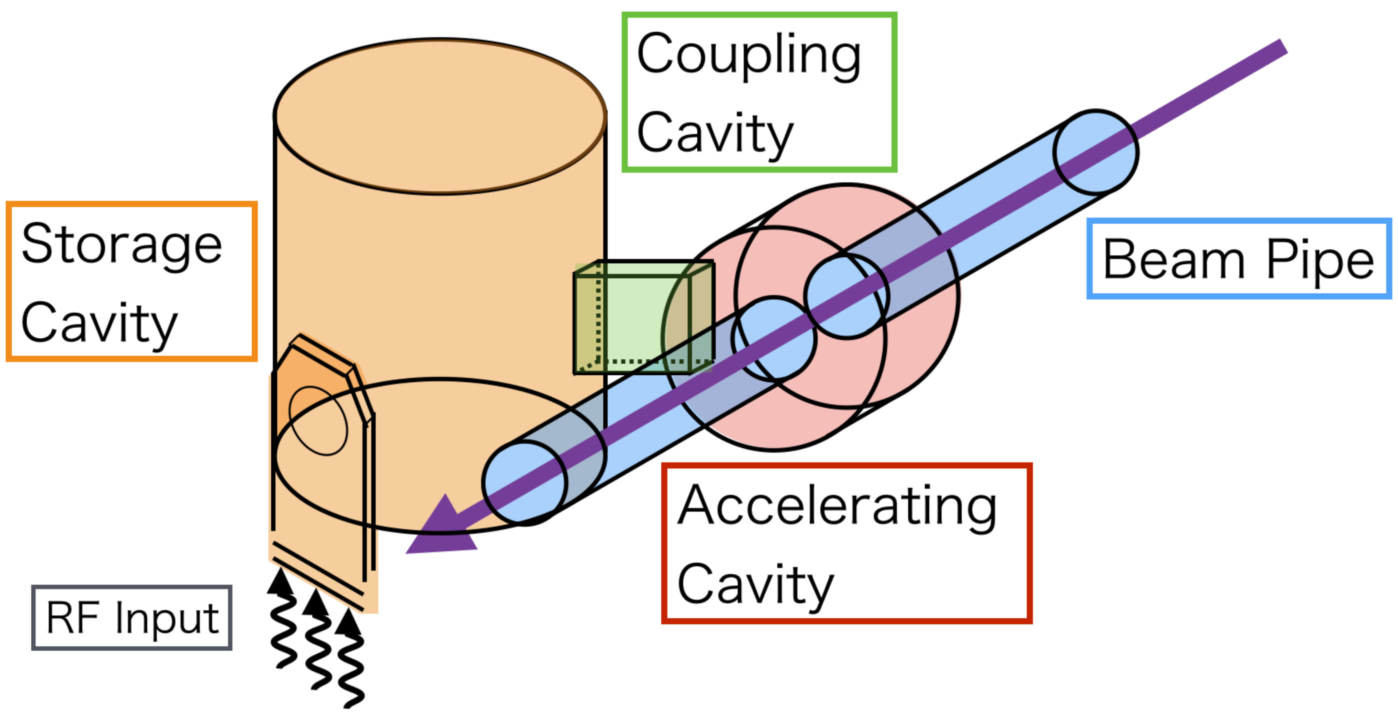
Update @ 31/Aug/	LER	HER	Unit
E (Particle Energy)	4.000	7.007	GeV
I (Beam Current)	3.6	2.6	A
Number of bunches	2500		
Bunche Current	1.44	1.04	mA
Circumference	3016.315		m
$\varepsilon x/\varepsilon y$	3.2/8.64	4.6/12.9	nm/pm
$\sigma x/\sigma y$ at IP	10/48	11/62	µm/nm
$\beta x/\beta y$ at IP	32/0.27	25/0.30	mm
Crossing angle	83		mrad
αp	3.2×10^{-4}	4.55×10^{-4}	
Vc	9.4	15.0	MV
σz	6.0	5.0	Mm
νs	-0.0245	-0.0280	
$\nu x/\nu y$	44.53/46.57	45.53/43.57	
U0	1.76	2.43	MeV
$\xi x/\xi y$	0.0028/0.0881	0.0012/0.0807	
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$

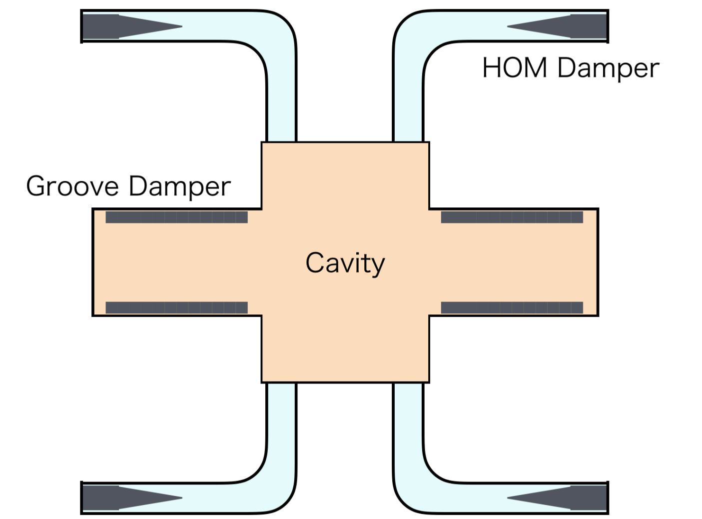
Single Side-Band Filter specifications (comparison with existing one)



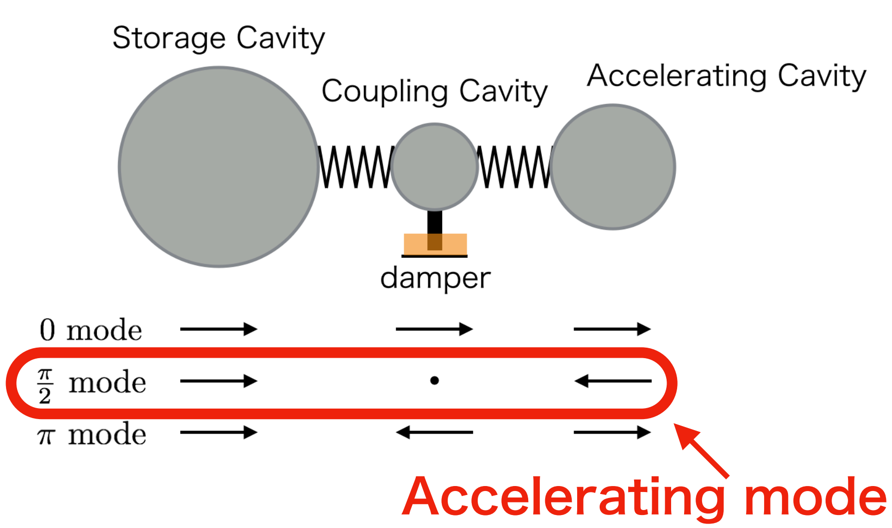
Contents tree

ARES Cavity (Normal conducting cavity)





Dampers for HOMs



Stored Energy → Ua : Us = 1 : 9

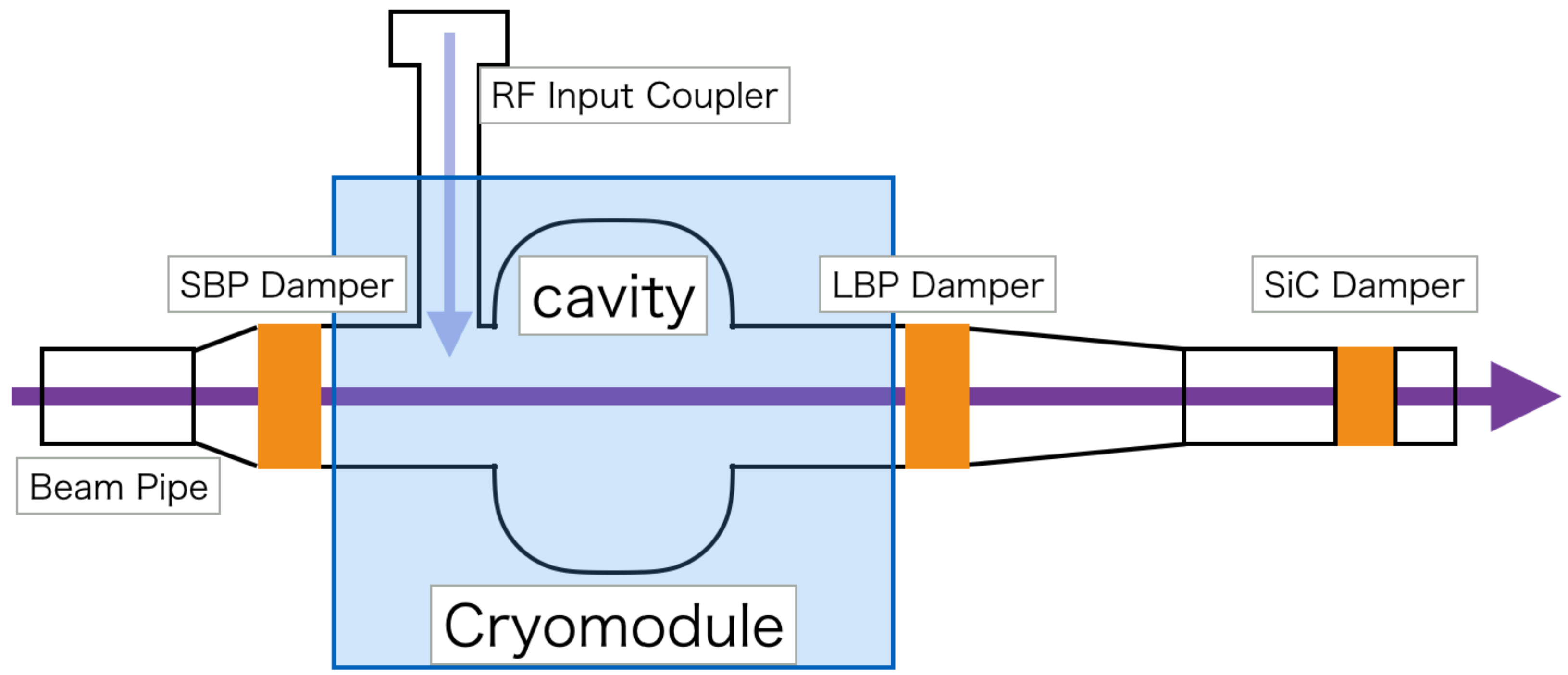
(Ua = Stored Energy in Accelerating cavity
Us = Stored Energy in Storage cavity)

Detune amount for beam loading

$$\Delta f_{\frac{\pi}{2}} = \frac{\Delta f_a}{1 + \frac{U_s}{U_a}} = \frac{\Delta f_a}{10}$$

Contents tree

Superconducting Cavity



Kouki Hirosawa (hirosawa@post.kek.jp)