The 23rd KEKB Accelerator Review Committee (2019.07.08)

RF System Status

T. Kobayashi from SKB RF Team

Outline

1. Introduction (Overview Of RF system)
2. Beam Operation Summary
3. Normal Conducting Cavity (ARES Cavity, DR Cavity)
4. Superconducting Cavity
5. High Power RF System (Kly, KPS, WG)
6. Low Level RF Control System
7. Damper of Longitudinal Coupled Bunch Instability
8. Summary

Cavity Types of MR

ARES
@Oho, Fuji

Basically, KEKB RF systems are reused with reinforcement for SuperKEKB.

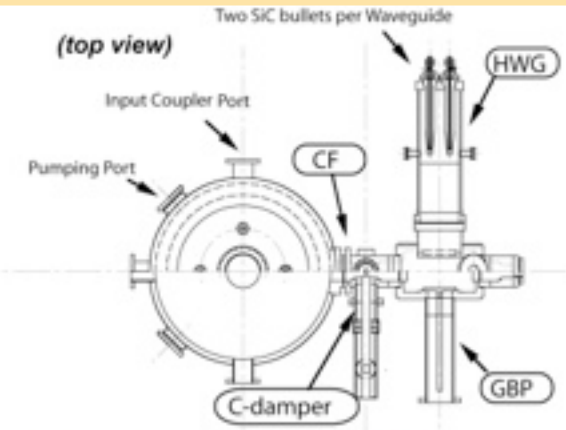
SCC
@Nikko

Accelerator Resonantly-coupled with Energy Storage

3-cavity system stabilized with the π/2-mode operation

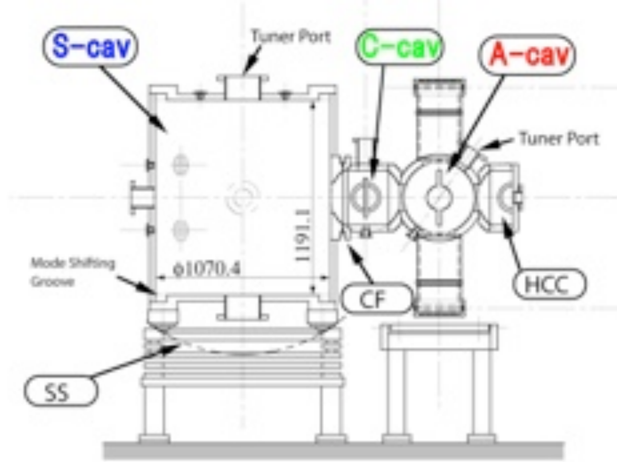
Successful Operation of the 32 ARES Cavities at KEKB

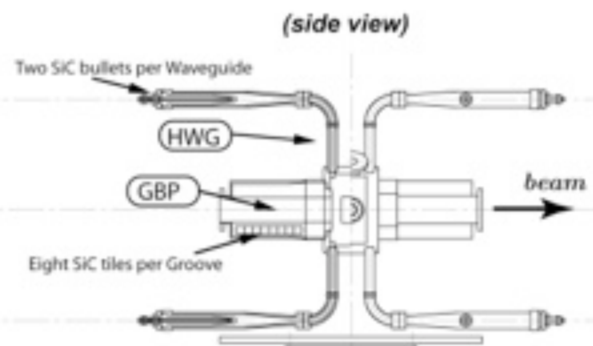
T. Abe



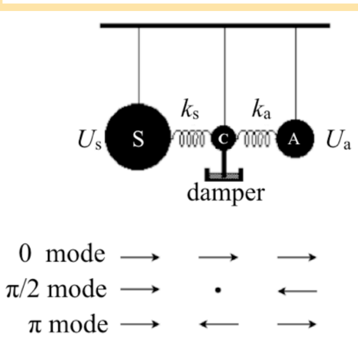
consists of

- HOM-damped accelerating cavity (A-cav),
- Energy-storage cavity with TE013 (S-cav),
- Coupling cavity (C-cav) with a parasitic-mode damper.





Vc = 0.5 MV, P_{beam} = 600 kW



$U_s/U_a = k_a^2/k_s^2$ for π/2 mode

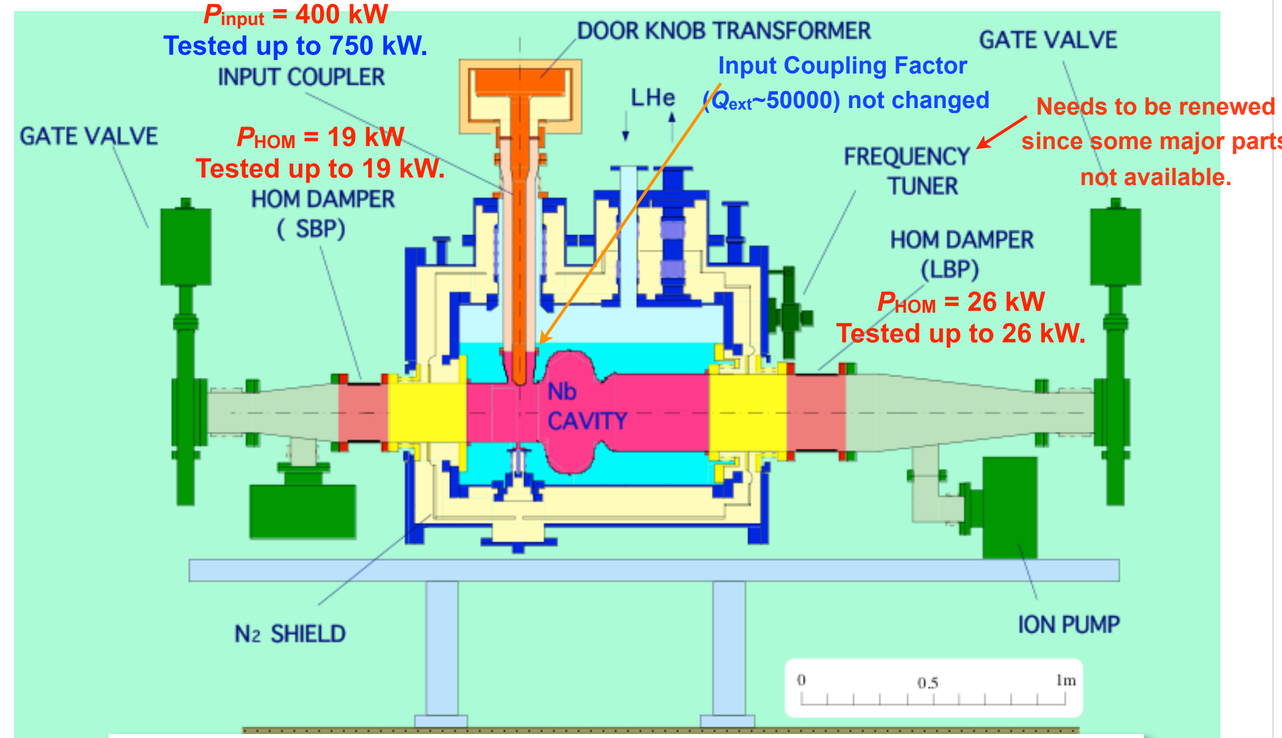
$\Delta f_{\pi/2} = \Delta f_a / (1 + U_s/U_a)$

ARES parameters

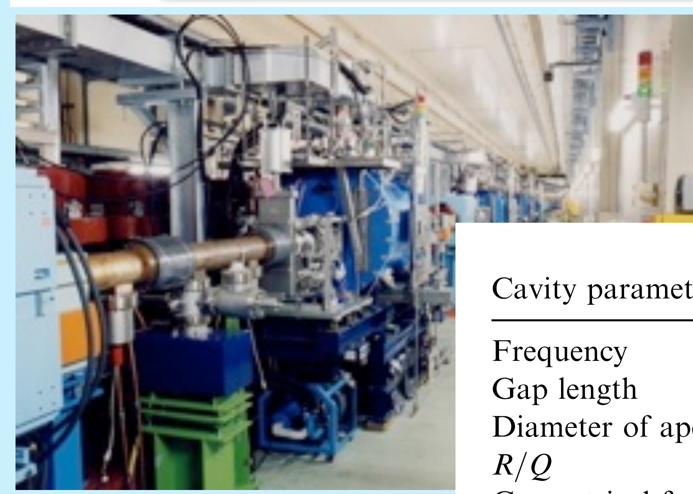
f_{RF}	508MHz	
U_s / U_a	9	
R/Q_0	15Ω	for the π/2 mode
Q_0	1.1 x 105	
V_c	0.5 MV	
P_c	150 kW	60 kW (A) + 90 kW (S)

8 modules have been installed in Nikko for HER.

Y. Morita



Vc = 1.5 MV, P_{beam} = 400 kW



Cavity parameters of the KEKB Superconducting cavity

Frequency	508.8	MHz
Gap length	243	mm
Diameter of aperture	220	mm
R/Q	93	Ohms
Geometrical factor	251	Ohms
E_{sp}/E_{acc}	1.84	
H_{sp}/E_{acc}	40.3	Gauss/(MV/m)

RF Related Parameters (design value)

Parameter	unit	KEKB (achieved)				SuperKEKB (design)			
Ring		HER			LER	HER		LER	
Energy	GeV	8.0			3.5	7.0		4.0	
Beam Current	A	1.4			2	2.6		3.6	
Number of Bunches		1585			1585	2500		2500	
Bunch Length	mm	6-7			6-7	5		6	
Total Beam Power	MW	~5.0			~3.5	8.0		8.3	
Total RF Voltage	MV	15.0			8.0	15.8		9.4	
		ARES		SCC	ARES	ARES	SCC	ARES	
Number of Cavities		10	2	8	20	10	8	8	14
Klystron : Cavity		1:2	1:1	1:1	1:2	1:1	1:1	1:2	1:1
RF Voltage (Max.)	MV/cav.	0.5		1.5	0.5	0.5	1.5	0.5	
Beam Power (Max.)	kW/cav.	200	550	400	200	600	400	200	600

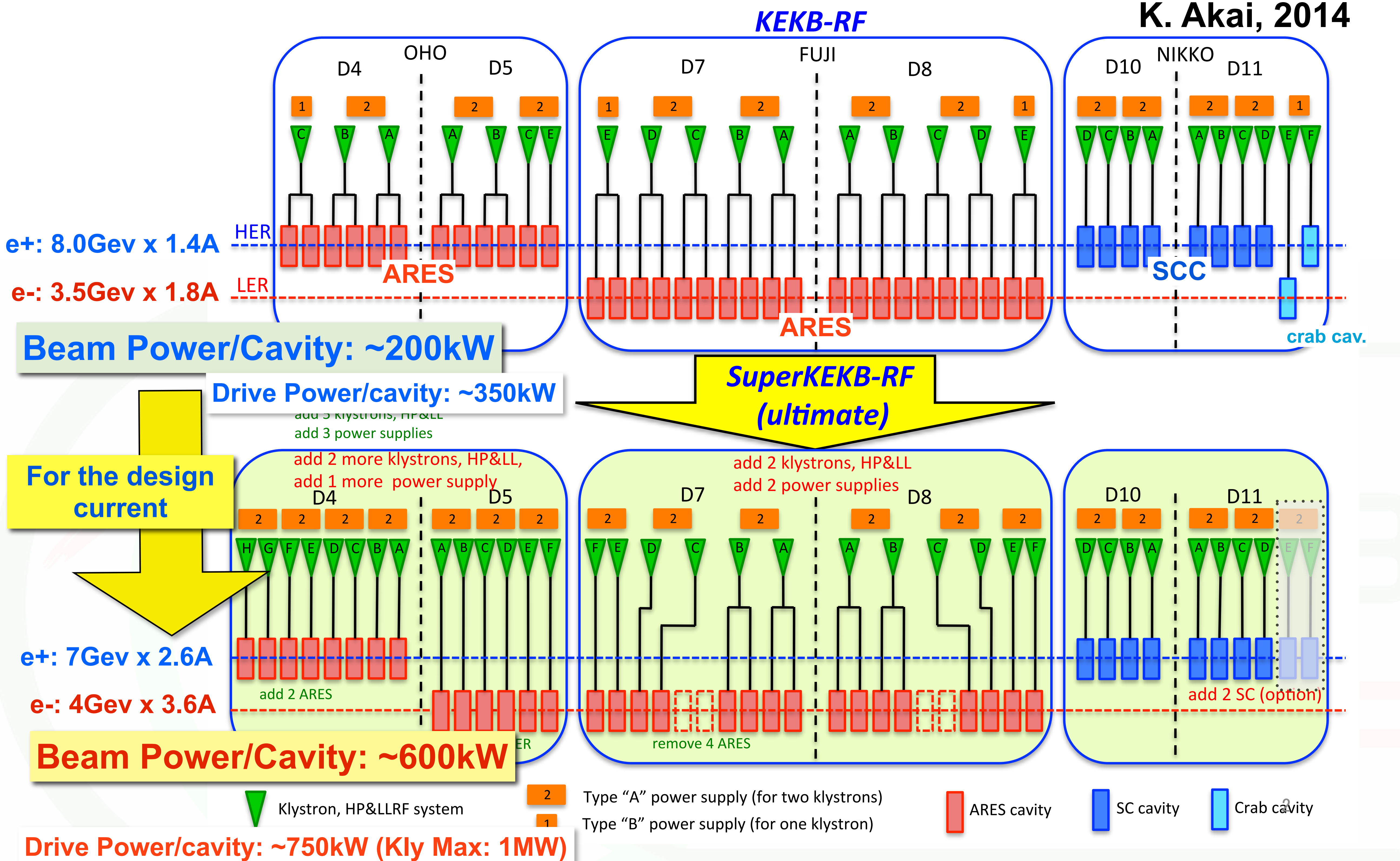
Issues for RF systems

- Beam current will be twice of KEKB.
- Beam power/cavity will be 3 times higher than KEKB for ARES cavity.
- Bunch length will be shorter than KEKB. HOM Power will be increased.

Reinforcement and reconfiguration of RF system are required.

RF System Arrangement (ultimate)

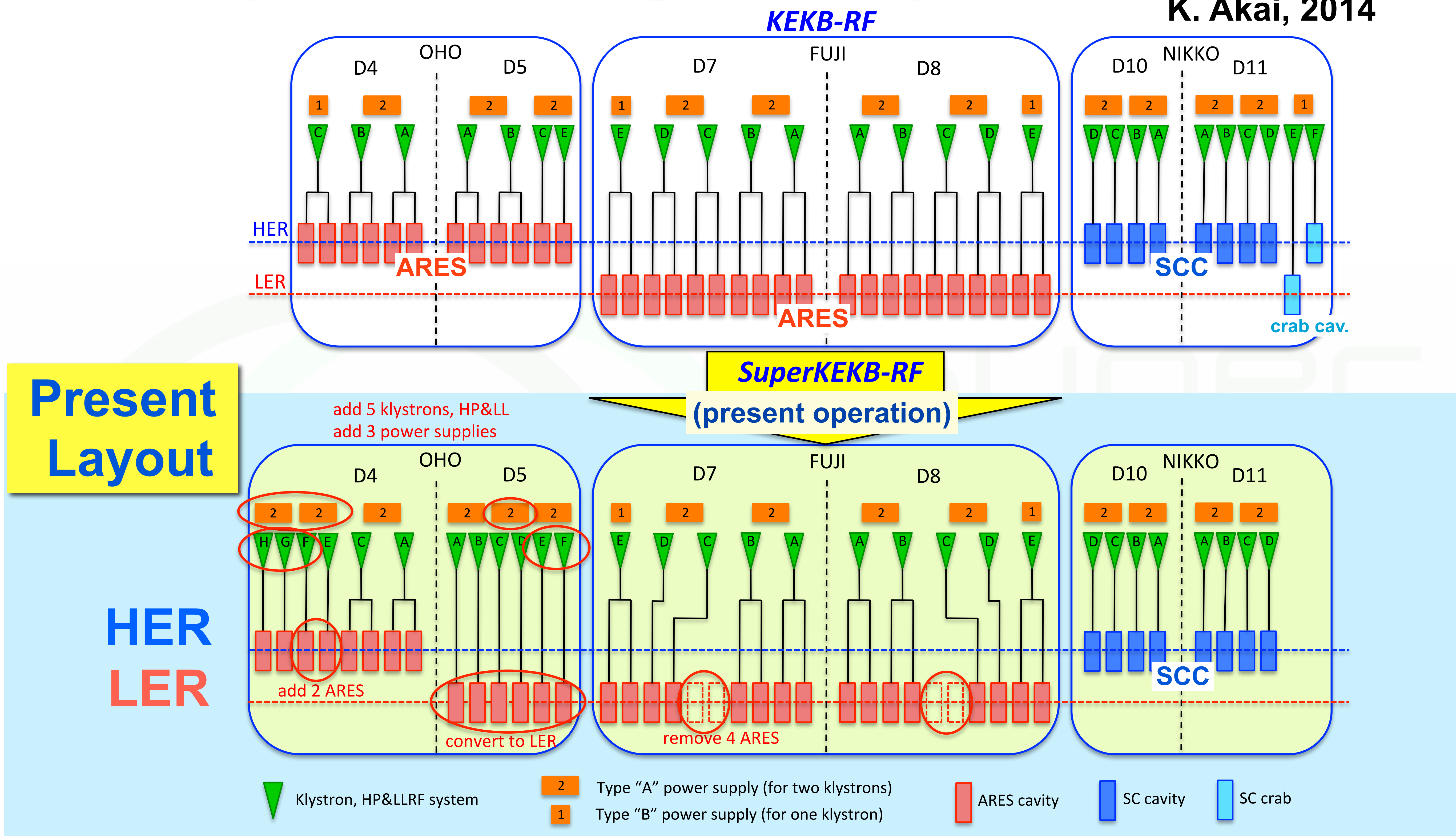
K. Akai, 2014



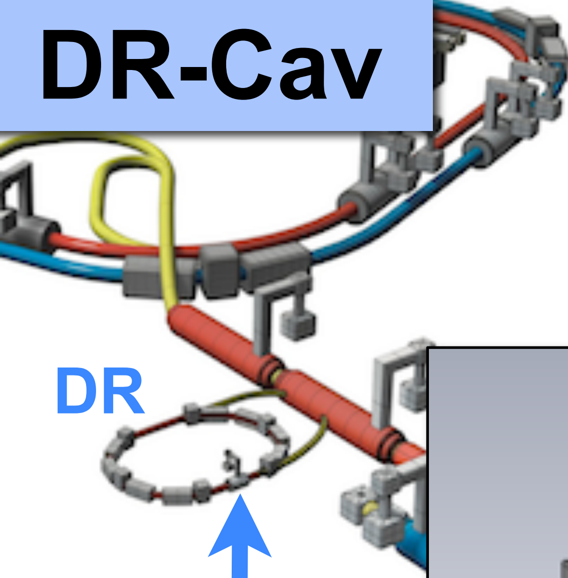
- ➡ **One-to-one configuration** for every ARES (One klystron drives one cavity unit). ➡ •add 9 klystrons and 3 PS's more.
- ➡ **Input coupler was reinforced** for the ARES (β=5, 800-kW input power capable) at "1:1" stations
- ➡ **Addition** of **new HOM Damper** for the SCC as a measure against beam-induced HOM-power rising.

RF System Arrangement (Present State)

K. Akai, 2014



At the OHO D4 section, two cavities were added.
At the D5 section, all ARES cavities were moved from HER to LER, and changed to the one-to-one configuration.
At the Fuji D7: two cavities were removed. And also at D8: two cavities were removed.
Accordingly, some klystrons and LLRF systems were added at D4 & D5.

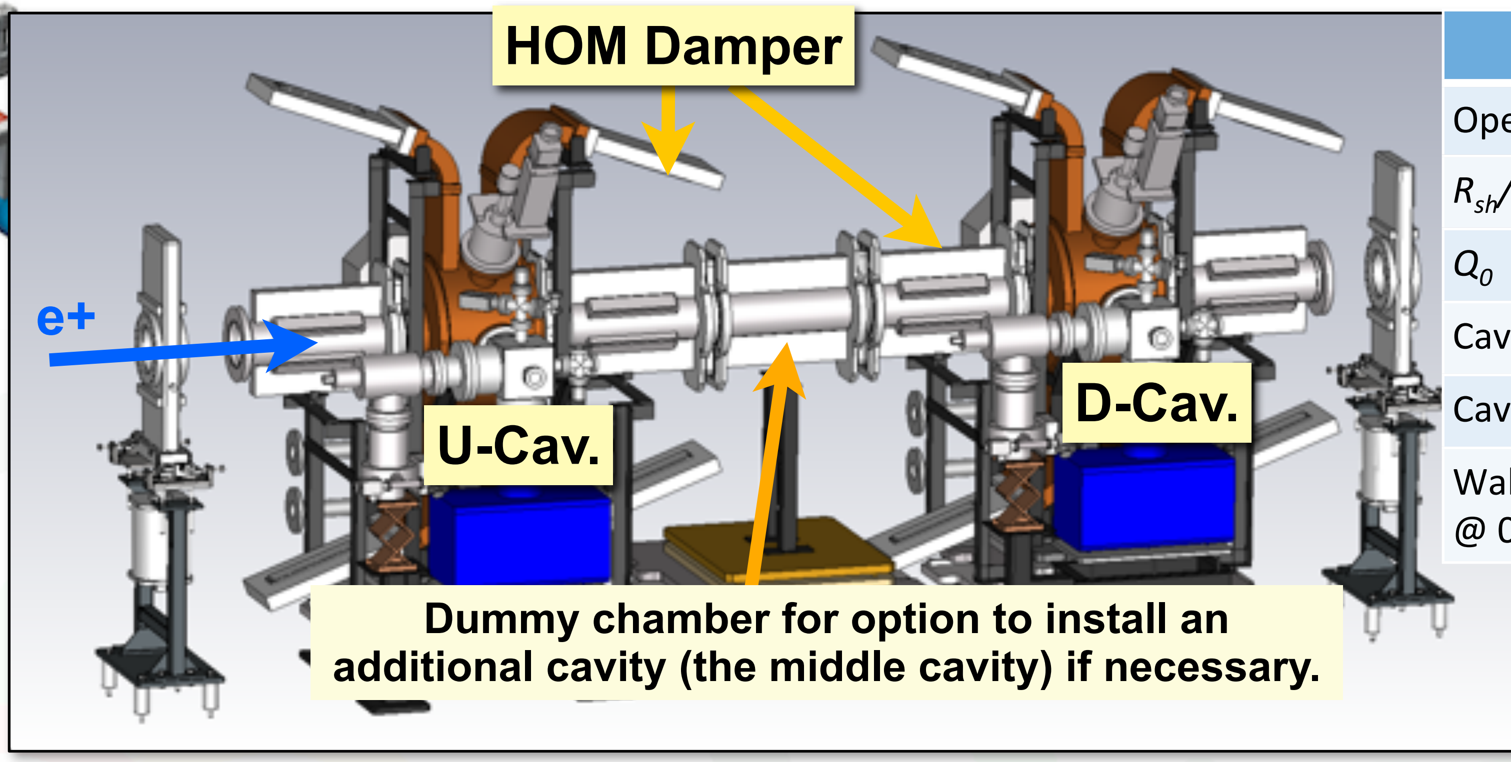


DR Cavity

Installed November, 2016

DR has an RF station with 2 cavities

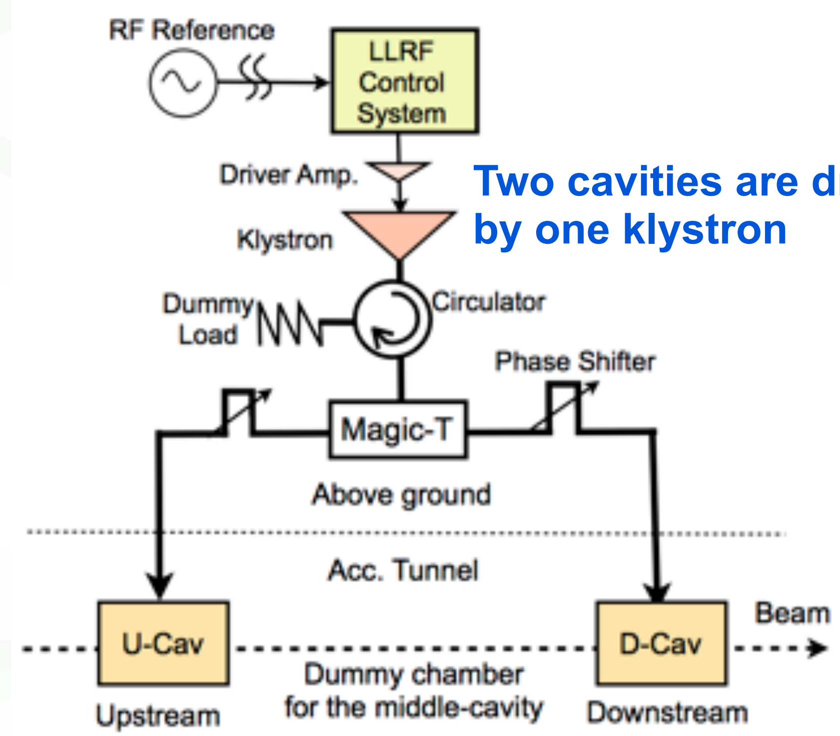
(the Up-stream and the Down-stream cavity)



Design Parameters	
Operational frequency	508.9 MHz
R_{sh}/Q_0	150 Ω
Q_0	~30000
Cavity Voltage (DR spec)	0.7 MV / cavity
Cavity Voltage (Cavity spec)	0.8 MV / cavity
Wall-loss power @ 0.7 - 0.8 MV / cavity	~110 - 140 kW / cavity

0.95 MV/cavity has been achieved by RF conditioning

Operation Freq. : 508.9MHz
Cavity Voltage: Total 1.4 MV (0.7 MV/cavity) for the design

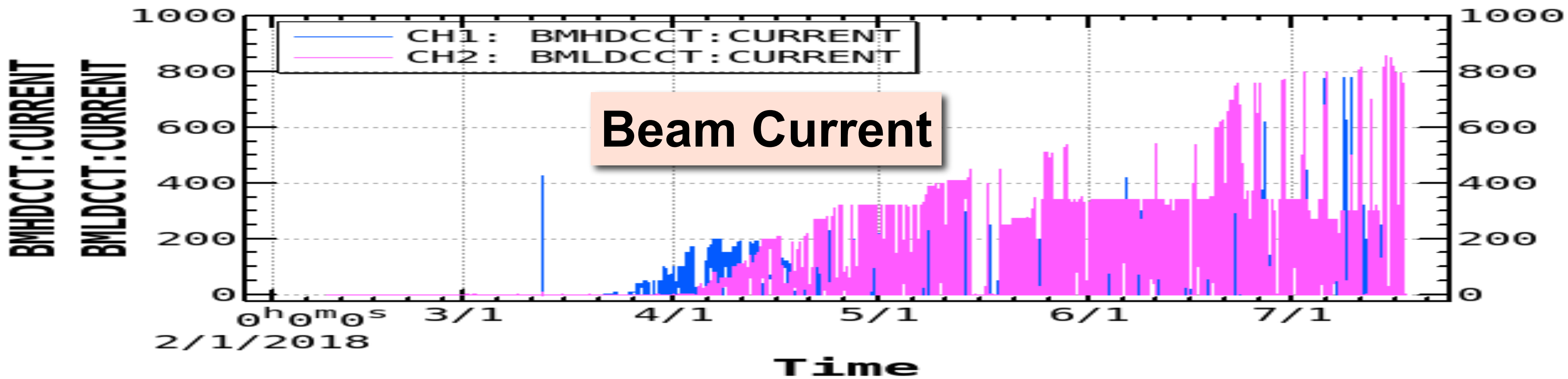


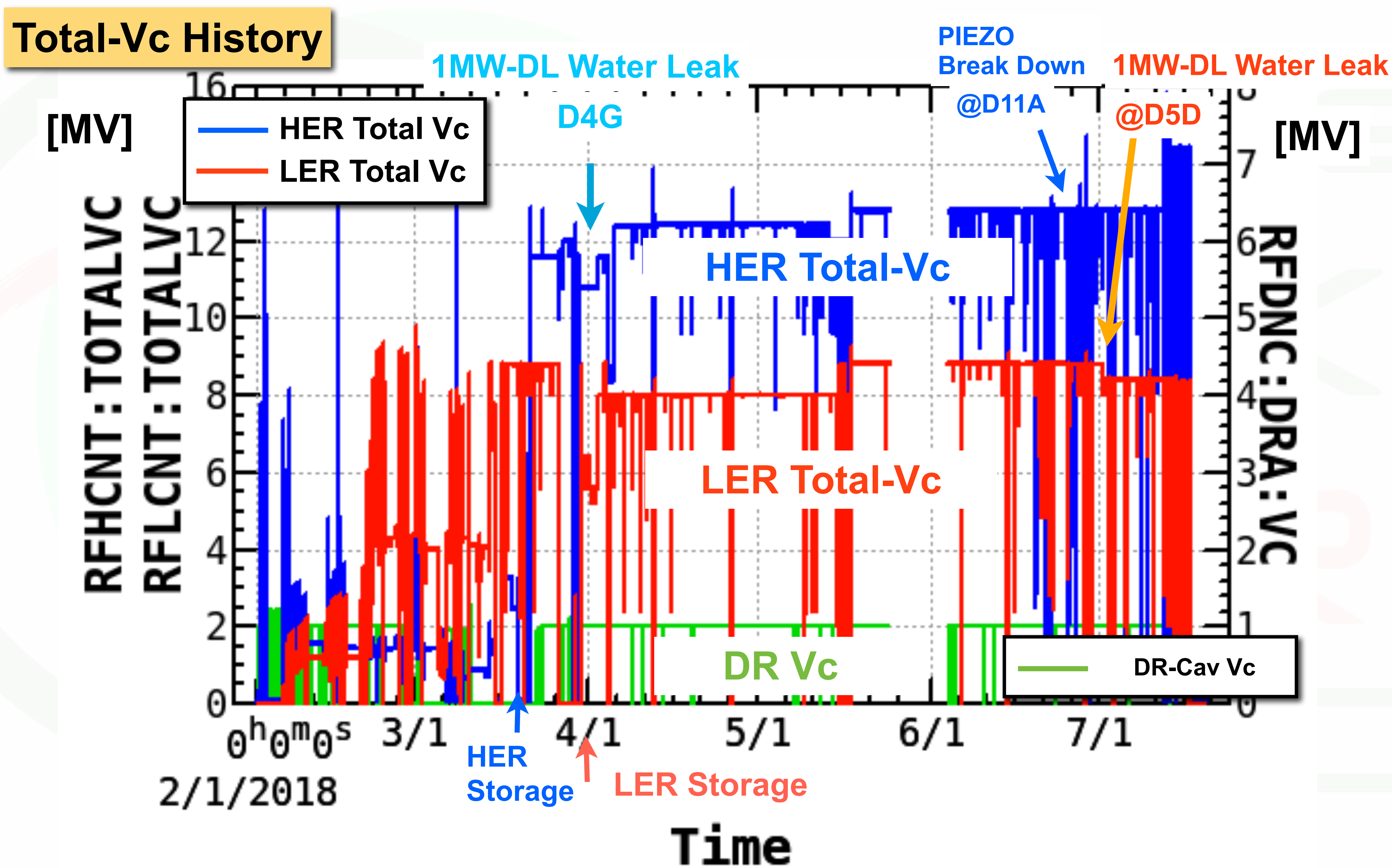
Two cavities are driven by one klystron

So far, this system has been successfully operated at 1 MV (0.5 MV/cavity) without problem !

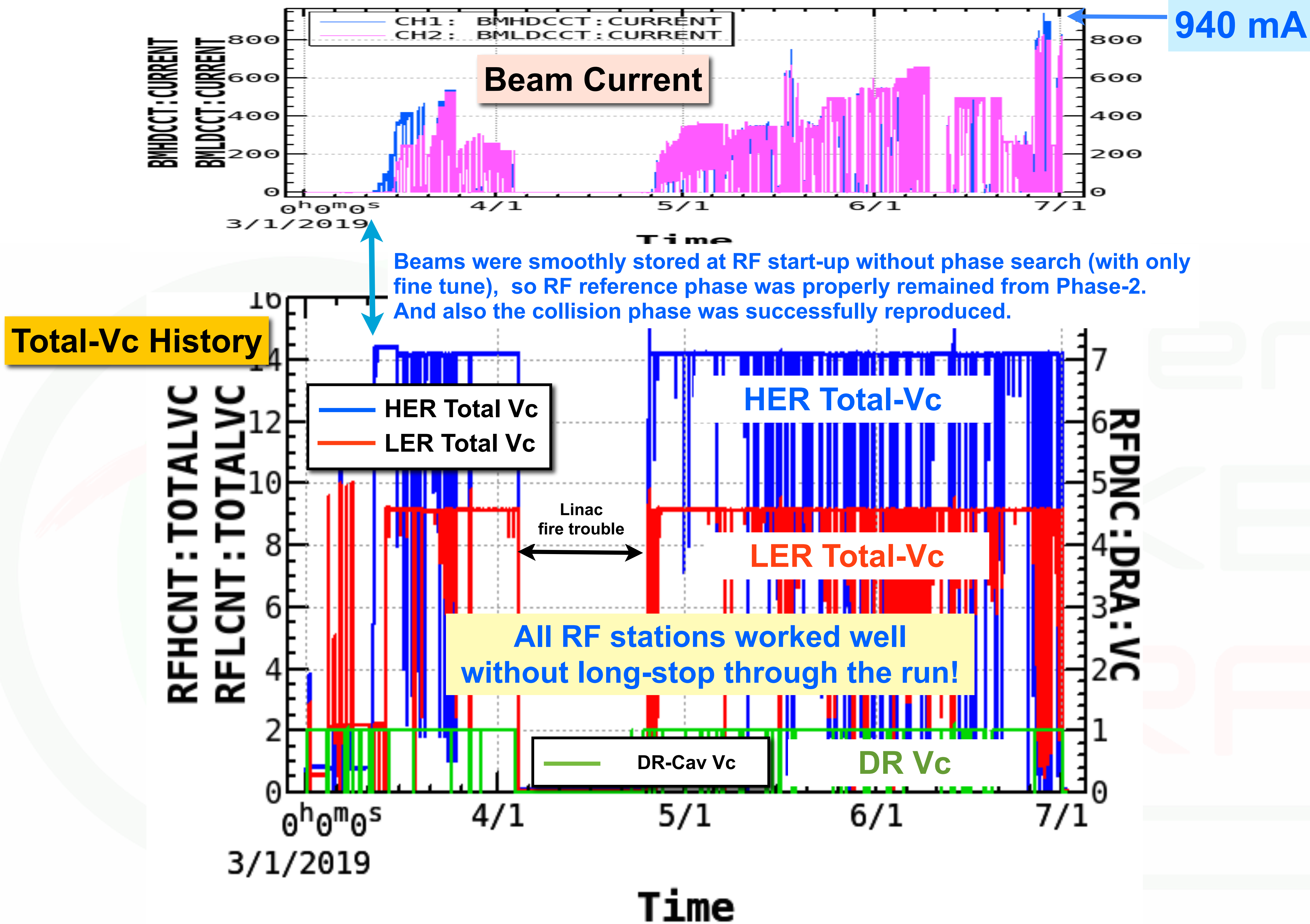
Overview of
Operation Status

History of Total Vc (Phase-2, 2018)





History of Total Vc (Phase-3, spring 2019)



Normal-Conducting Cavity

ARES & DR Cavity

ARES @Oho, Fuji

DR-Cav

NC-Cavities Operation Summary in Phase 3

ARES & DR Cav

2019-03-11 to 2019-06-30

RF failure statistics for each station during Phase-3, 2019

OHO

Area / Station / Cavity	D4-A #1	D4-A #2	D4-C #1	D4-C #2	D4-E #1	D4-F #1	D4-G #1	D4-H #1	D5-A #1	D5-B #1	D5-C #1	D5-D #1	D5-E #1	D5-F #1
HER operation / LER operation														
As of 2019-06-27: Operating Vc [MV/cav]	0.40	0.40	0.40	0.40	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40	0.40
Vac. press. [Pa]	10^-7	10^-7	10^-7	10^-7	10^-6	10^-6	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7
Input Coupler	Used	Used	Used	Used	New	New	New	New	New	New	New	New	New	New
# of Beam Aborts due to: (2019-03-11 to 2019-06-30) Cav. Breakdown														
Vac. press. rise									1					
Arc Coupler														
Coupling-Cav. Damper Power	3		1			2		1		1		1		1
Tuner Trouble														
Chiller Trouble														
Remarks					New inst.	New inst.; Using Oring	Old D4-C-#1,#2 cav.; Had serious multipacting problem reported in the 10th KEKB Review							

Fuji

Area / Station / Cavity	D7-A #1	D7-A #2	D7-B #1	D7-B #2	D7-C #1	D7-D #1	D7-E #1	D7-E #2	D8-A #1	D8-A #2	D8-B #1	D8-B #2	D8-C #1	D8-D #1	D8-E #1	D8-E #2
HER operation / LER operation																
As of 2019-06-27: Operating Vc [MV/cav]	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Vac. press. [Pa]	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7	10^-7
Input Coupler	Used	Used	Used	Used	New	New	Used	Used	Used	Used	Used	Used	New	New	Used	Used
# of Beam Aborts due to: (2019-03-11 to 2019-06-30) Cav. Breakdown																
Vac. press. rise																
Arc Coupler																
Coupling-Cav. Damper Power	1	2			2							1				1
Tuner Trouble																
Chiller Trouble													1			
Remarks																

DR

Area / Station / Cavity	U-Cav	D-Cav
HER operation / LER operation		
As of 2019-06-27: Operating Vc [MV/cav]	0.50	0.50
Vac. press. [Pa]	10^-6	10^-6
Input Coupler	New	New
# of Beam Aborts due to: (2019-03-11 to 2019-06-30) Cav. Breakdown		
Vac. press. rise		
Arc Coupler		
Coupling-Cav. Damper Power		
Tuner Trouble		
Chiller Trouble		
Remarks	New inst.; Using Oring	

Number of trips: 7 — 0.9 /cav

Number of trips: 4 — 0.7 /cav

Number of trips: 5 — 0.6 /cav

Number of trips: 3 — 0.4 /cav

0

RF conditioning performed each maintenance day

No RF conditioning performed during maintenance day (as an experiment)

- ✓ Low trip rates (< 1 / 3_months)
- ✓ No significant difference in the trip rates between the ARES cavities at D5 and D7/D8 for LER

Super-Conducting Cavity

<Topic>
SCC

SCC operation status in 2019 spring operation

Status

- 8 cavities have been operated with good stability.
- Vc : 1.35 MV/cavity in present operation (1.5 MV is standard)
- Beam Aborts caused by SCC
  - Breakdown of Cavity : 1
  - Peripheral problem : 4 (Piezo tuner trouble : 3, Water chiller trouble : 1)
- Cavity performances
  - All cavities almost reproduced the performance of Vc limits and Q factors of Phase-2. (not degraded)
  - Vc.max > 2.0MV, Qo : >1e9 at 1.5 MV

Piezo Tuner Problem

- Six piezo actuators were broken in Phase-1. Then the slower low-pass filter and the voltage limitation were applied in piezo tuner control (reported in the last review) . As the result, piezo actuator failure was dramatically decreased.
- However, the increase of leakage current of piezo actuators is still observed and several piezo actuators were broken by electric breakdown in Phase-2 and 2019-spring-operations. -> The piezo-broken cavities were operated with only mechanical motor tuner if it was possible.

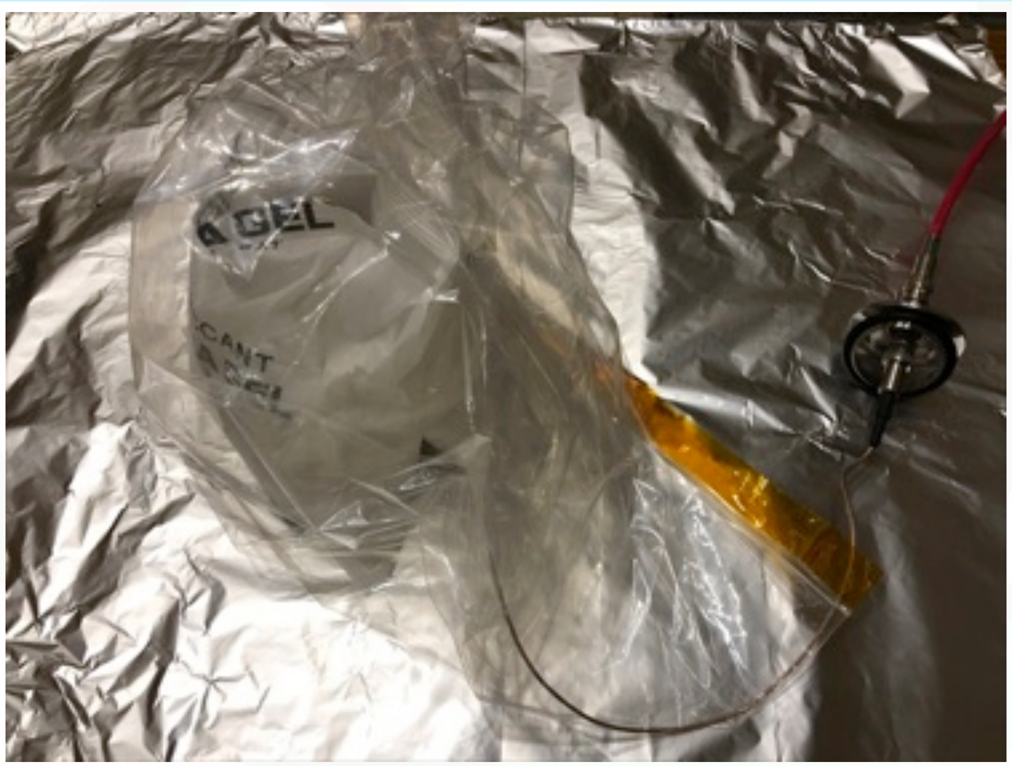
Piezo Problem Study: Exposure Experiment - Drying by silica gel -

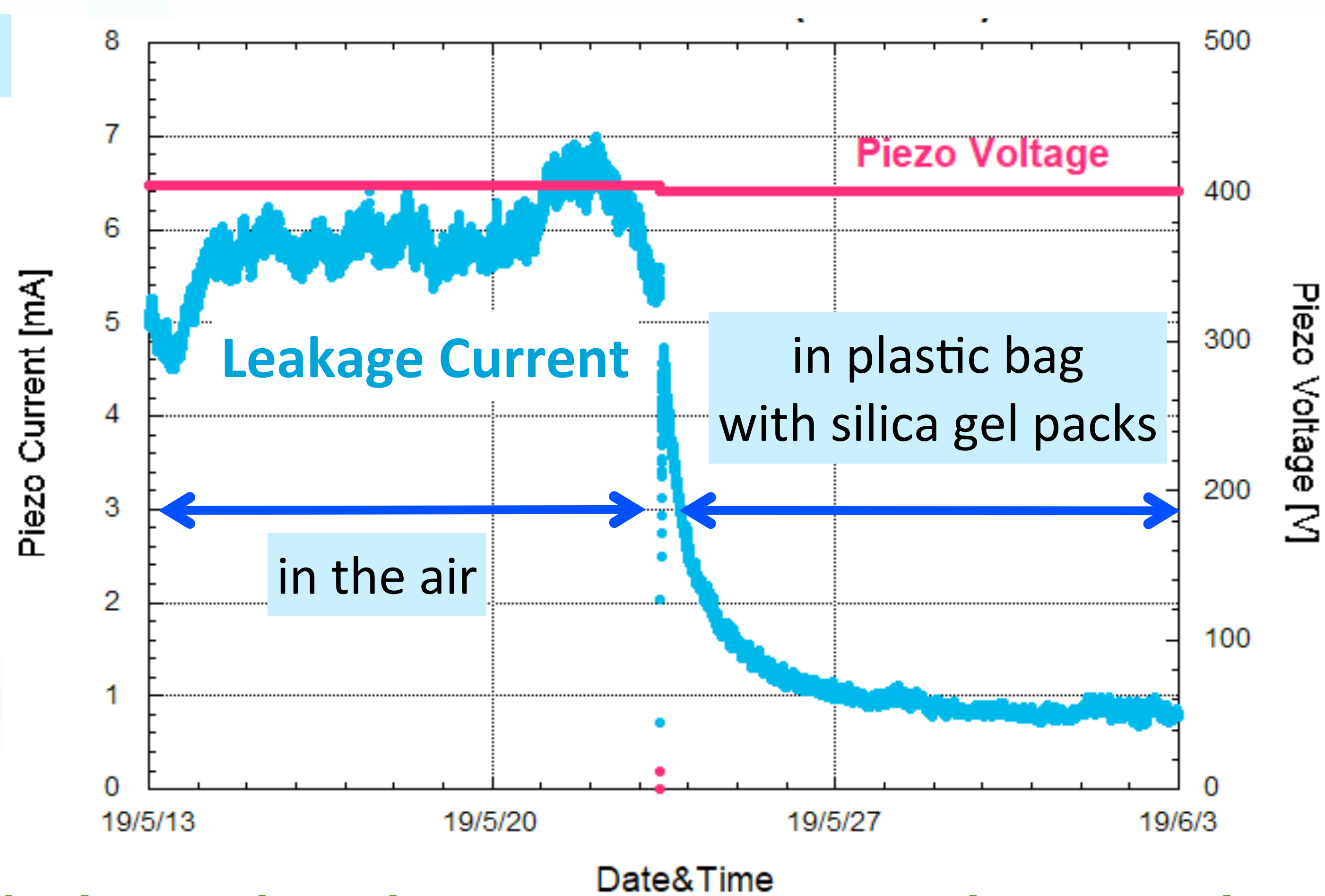
We investigated the effect of environments on piezo insulation.

For the experiment, we tried to expose piezo actuator to various environments, such as vacuum, dry N_2 gas, the air and synchrotron radiation. According to the results, we found that the moisture in the air degrades insulation between electrodes of piezo stacks.

From the exposure test,
It was found that drying by silica gel is effective to reduce leakage current of piezo tuner!

Piezo enfolded in plastic bag with silica gel packs





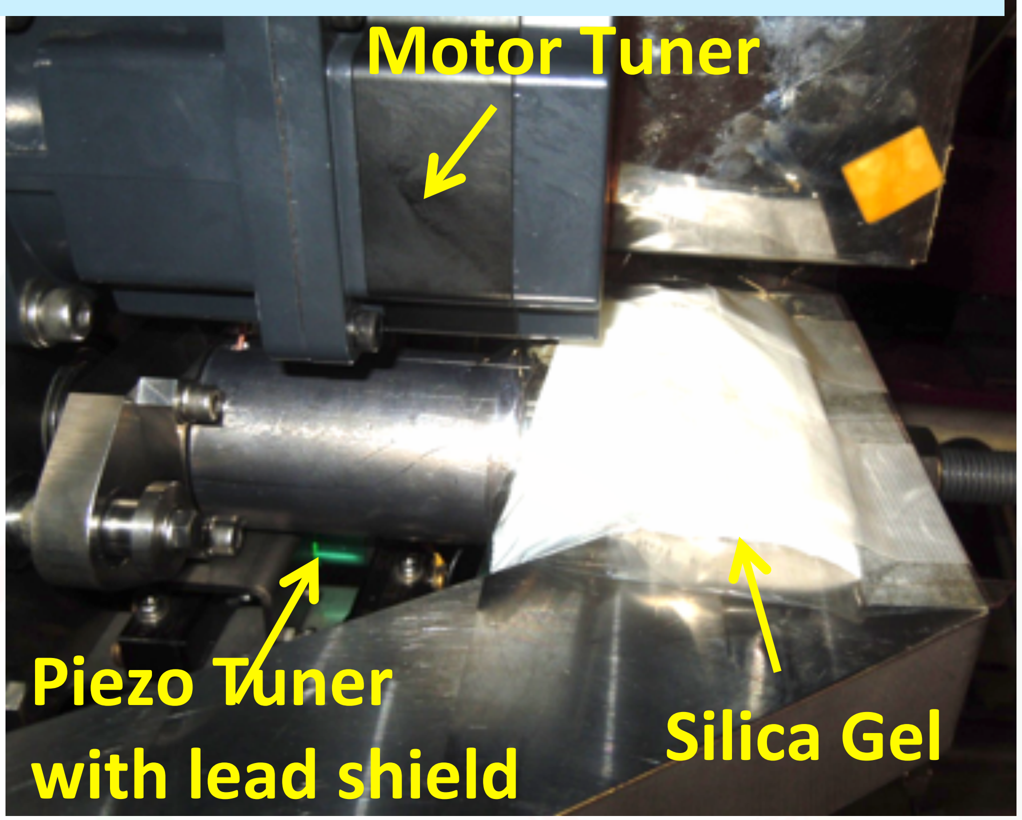
--> As a trial, we attached silica gel packs to piezo tuner in the tunnel.

<Topic>
SCC

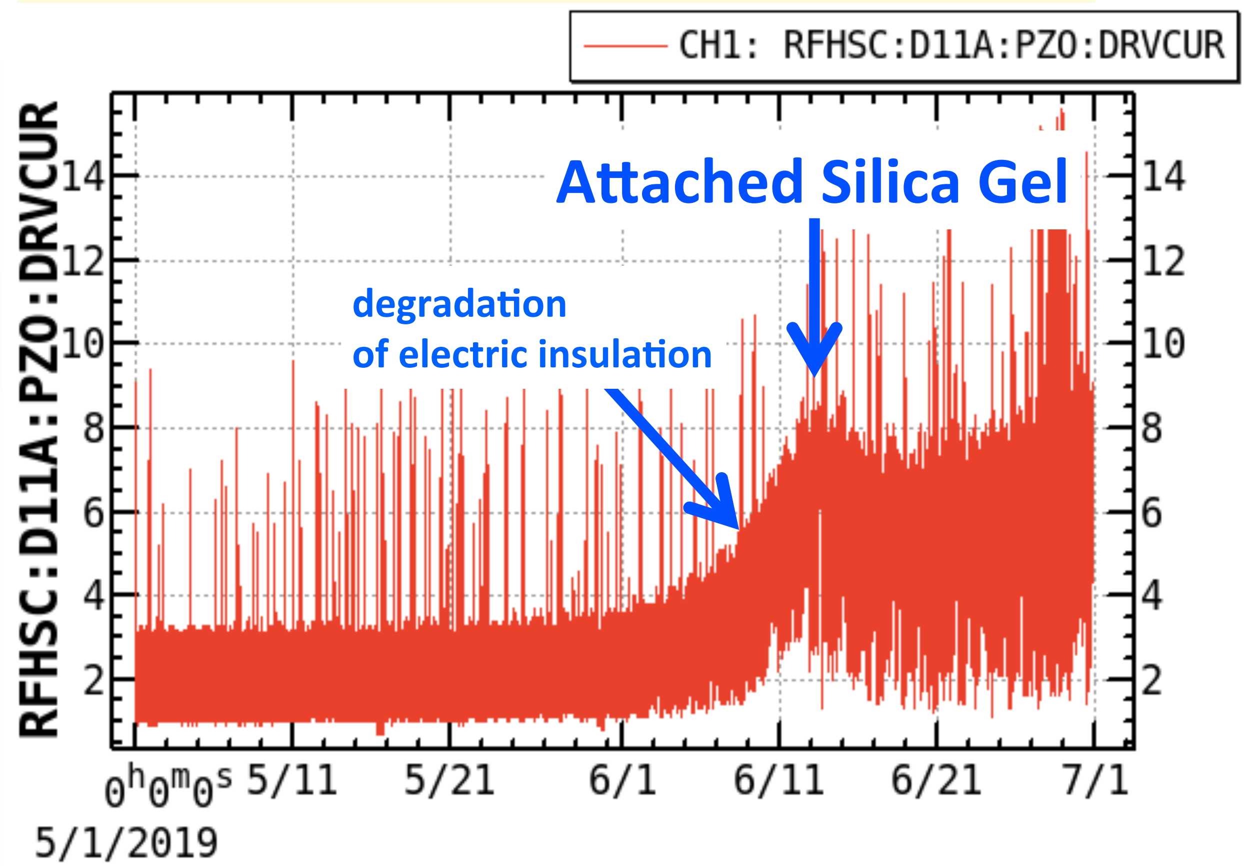
Attaching silica gel to piezo at D11A SCC in the operation

As a trial, we attached silica gel packs to piezo tuner at D11A SCC in the tunnel.

Piezo Tuner with silica gel



Leakage Current of Piezo Tuner



Increase of the leakage current of piezo due to degradation of electric insulation was observed at D11A SCC. Then, silica gel was attached to piezo. After that, the increase of leakage current was effectively stopped.

The good effect of drying by silica gel was also confirmed in the practical operation.

We will continue to study moisture control around the piezo in the tunnel.

High Power RF System

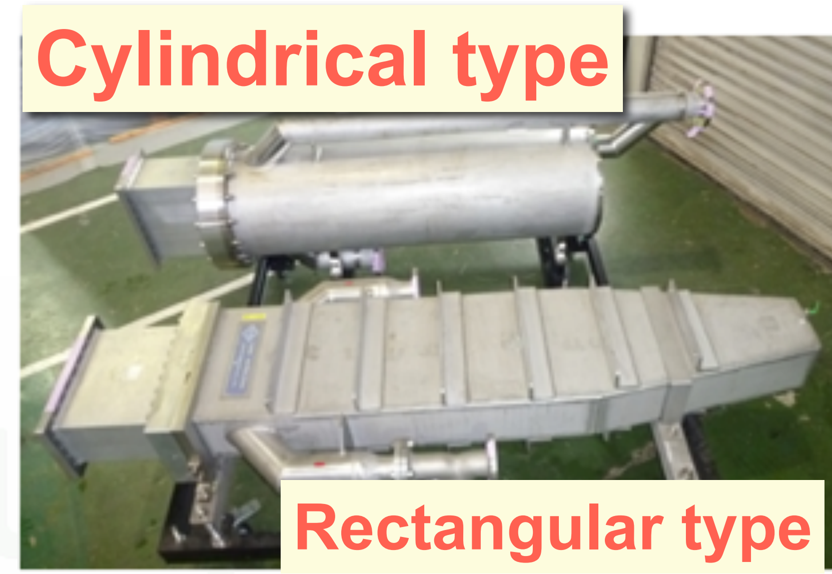
Klystron
Kly. Power Supply
Waveguide system

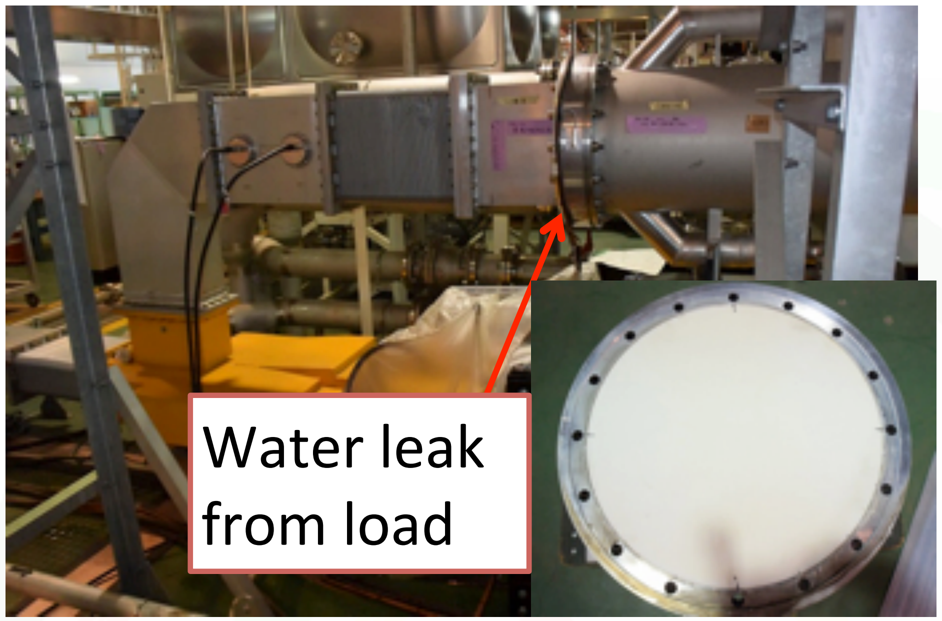
<Topic>
HPRF

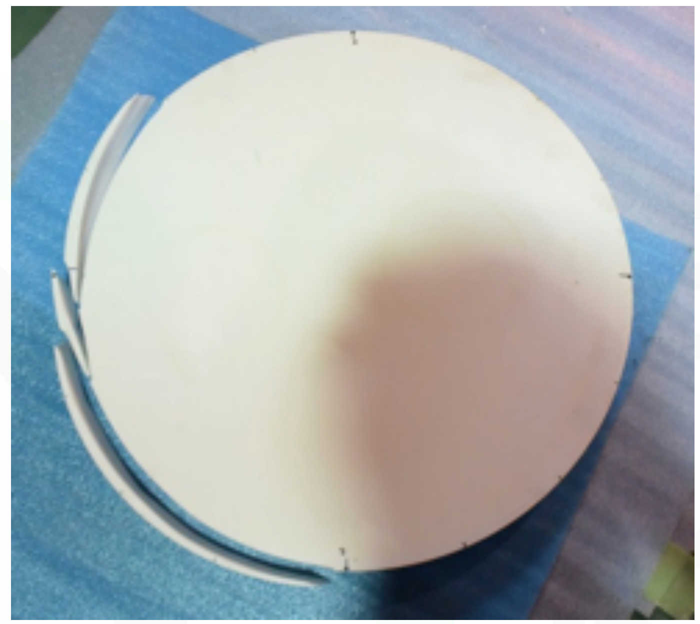
Water Leak from High Power Load

In Phase2,
Water leak troubles occurred in two cylindrical type water loads at D04G (April 2018) and D05D (July 2018),
because, ceramic RF windows were broken by mechanical stress.
They were replaced with spares, and after Phase2, were repaired.

1.2 MW high-power water loads
Two types:







First time at D04G (April 2018),
There were no interlock systems for water leak. The water went throughout the waveguide system because it was delayed to recognize the water leakage. It took long time to dry it. -> A water-leak detector was mounted for all water-loads.

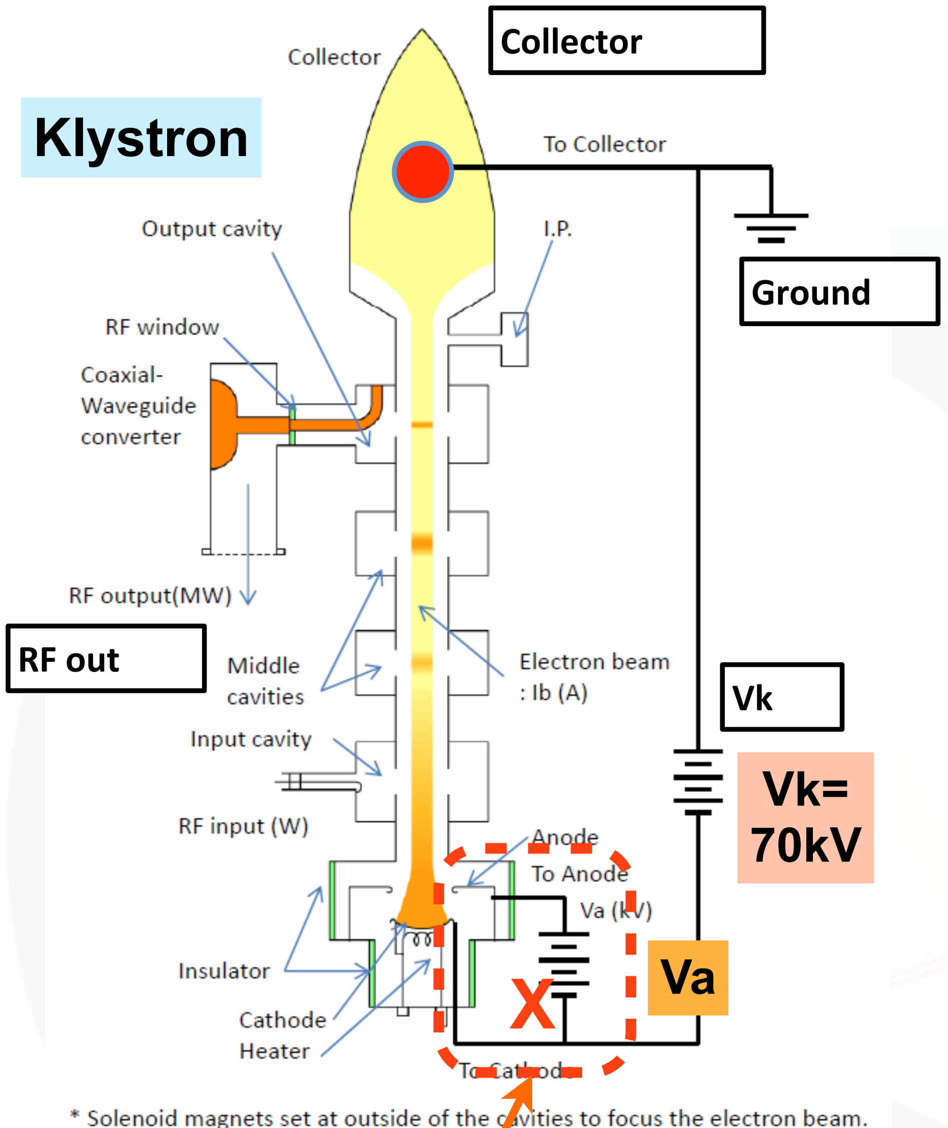
Second time at D05D (July 2018)
The water-leak detector worked well. So the water leakage was able to be found before the water enter the waveguide system. The operation was recovered within few hours.

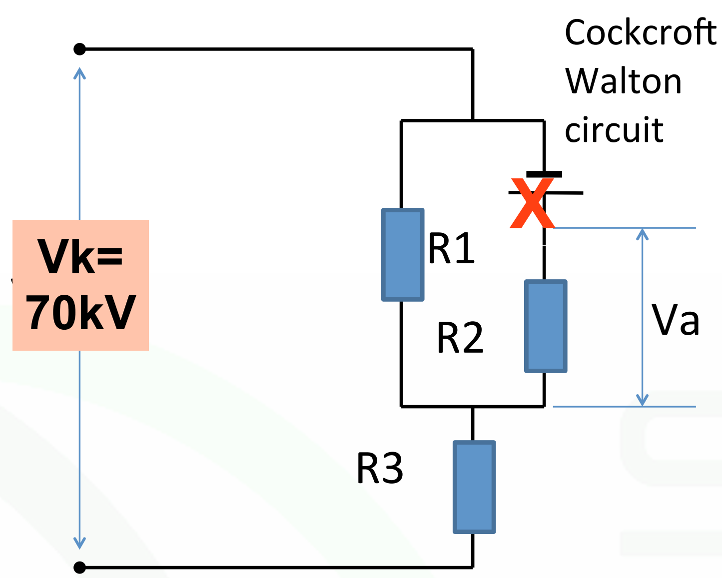
Fortunately, during Phase-3 (2019), no water leak trouble occurred in the water loads.
New design of a ceramic window is under consideration for the robustness against mechanical stress.

<Topic>
HPRF at DR

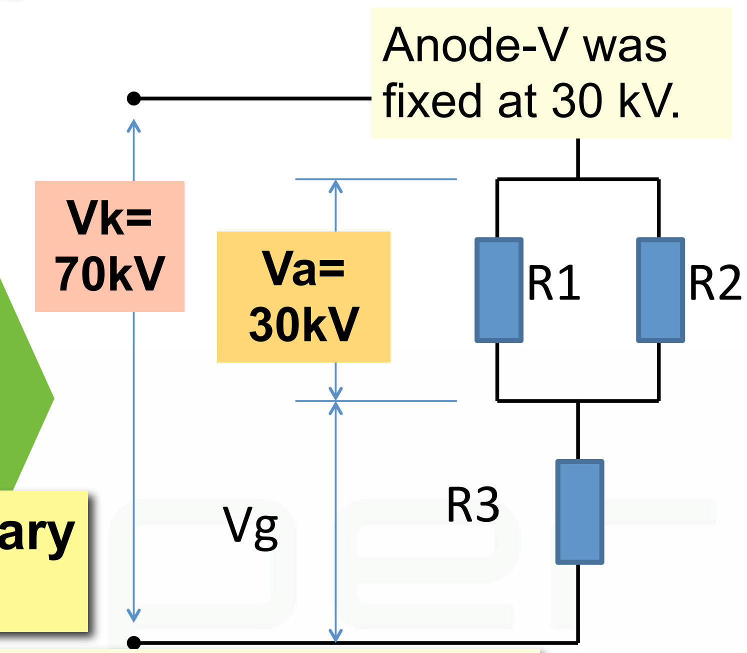
Anode Voltage Controller Failure in Klystron Power Supply at DR

June 18, 2019

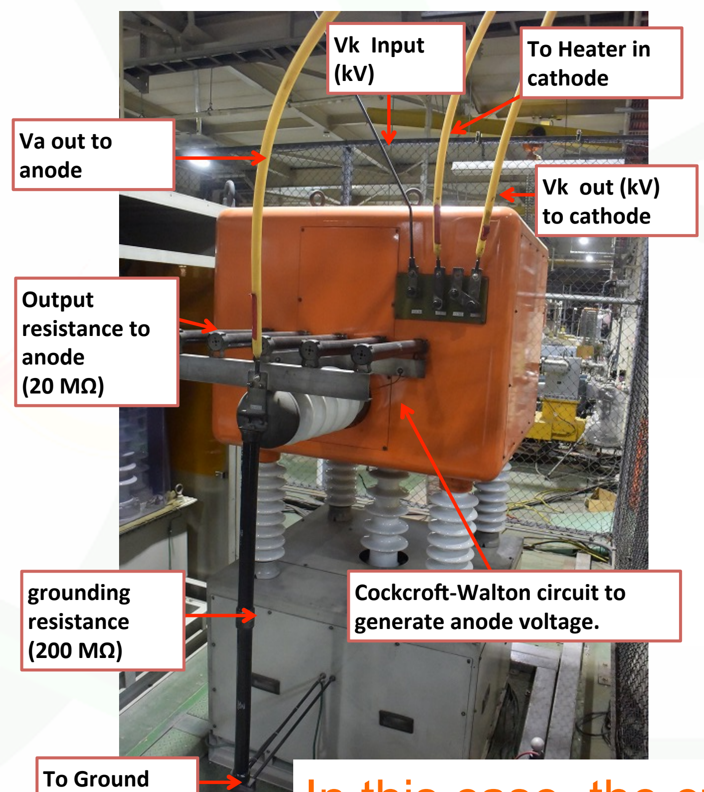


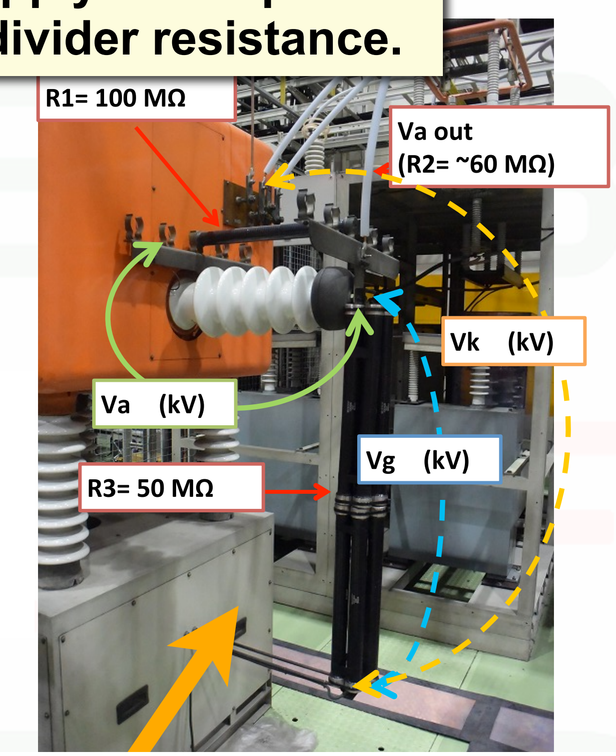


Temporary Cure



The power supply was replaced with voltage divider resistance.





Anode voltage controller failed. The cause of failure could not be identified.

Then we applied temporary cure.

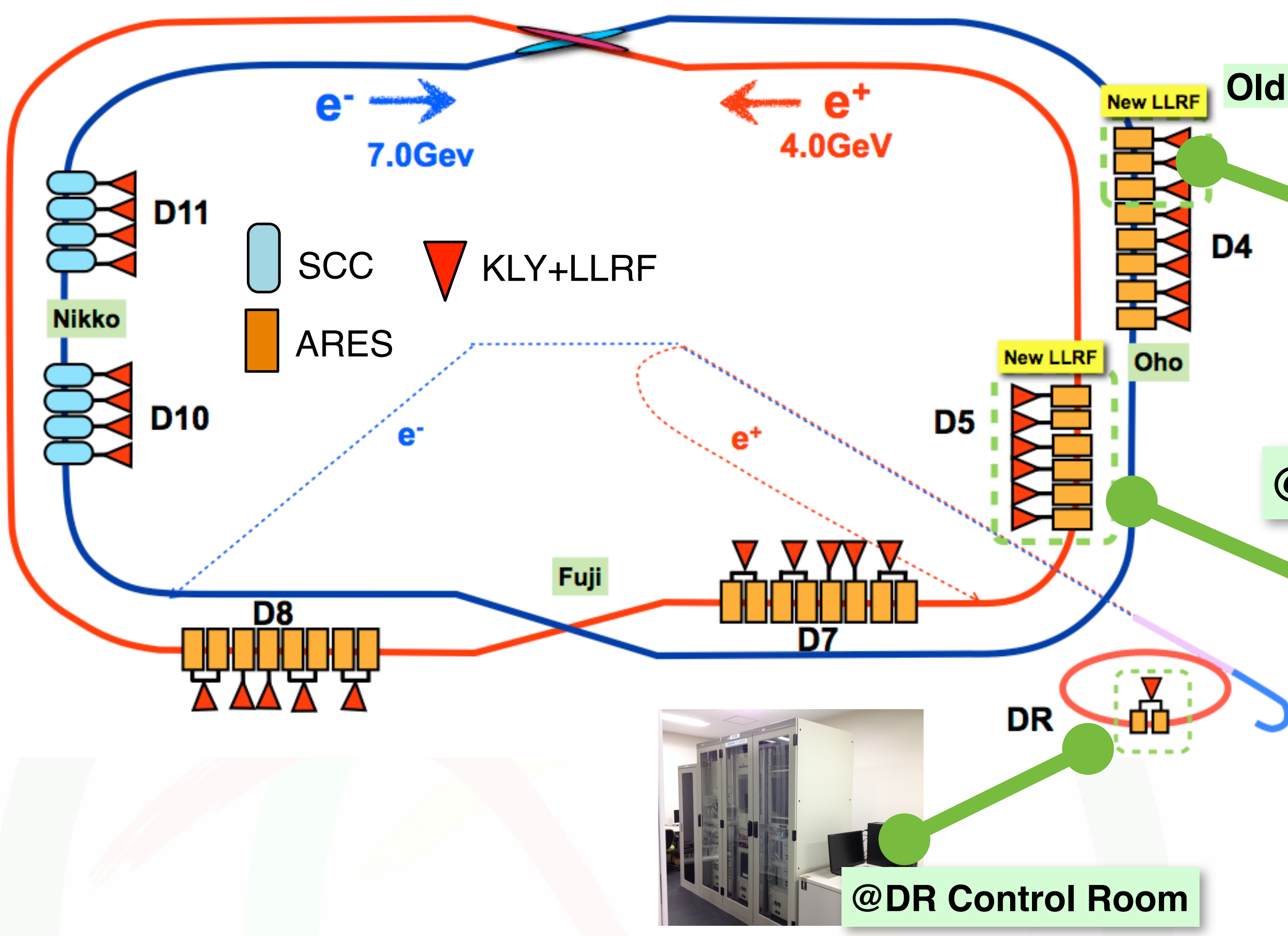
In this case, the efficiency (collector loss) cannot be optimized. So, it is difficult to apply this cure method to MR klystron for large beam loading. Although, idling operation of cavity might be possible with no-loading phase instead of detuning cavity.

Low Level RF Control System

<Topic>
LLRF

New Digital LLRF System

Digital LLRF control system has been newly developed for high accuracy and flexibility.



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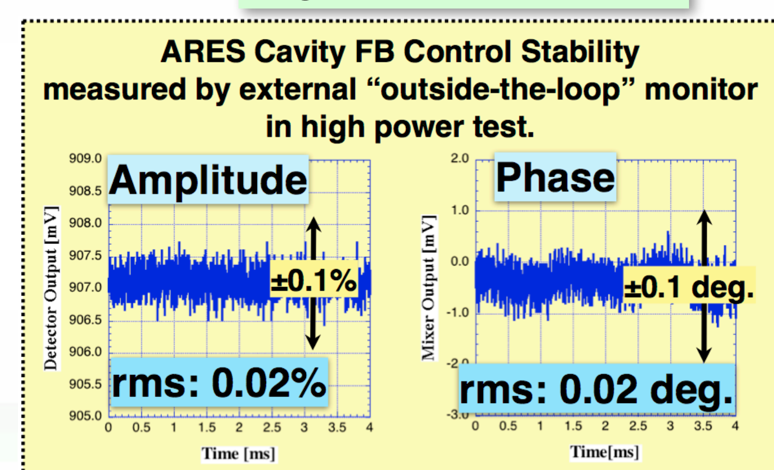
- Consisting of μTCA-platformed FPGA boards & PLC
- I/Q components are handled by FPGA

Status

- 9 stations of Oho D4&D5 (6@D5 + 3@D4) are operated with the new digital LLRF control systems.
- All of new LLRF systems are successfully working well without problem. Some software bugs found during the operation were fixed.
- At DR, also the new digital system is applied, and it is working properly without problem. It is almost the same as MR one, except 2-cavity vector-sum control is needed.

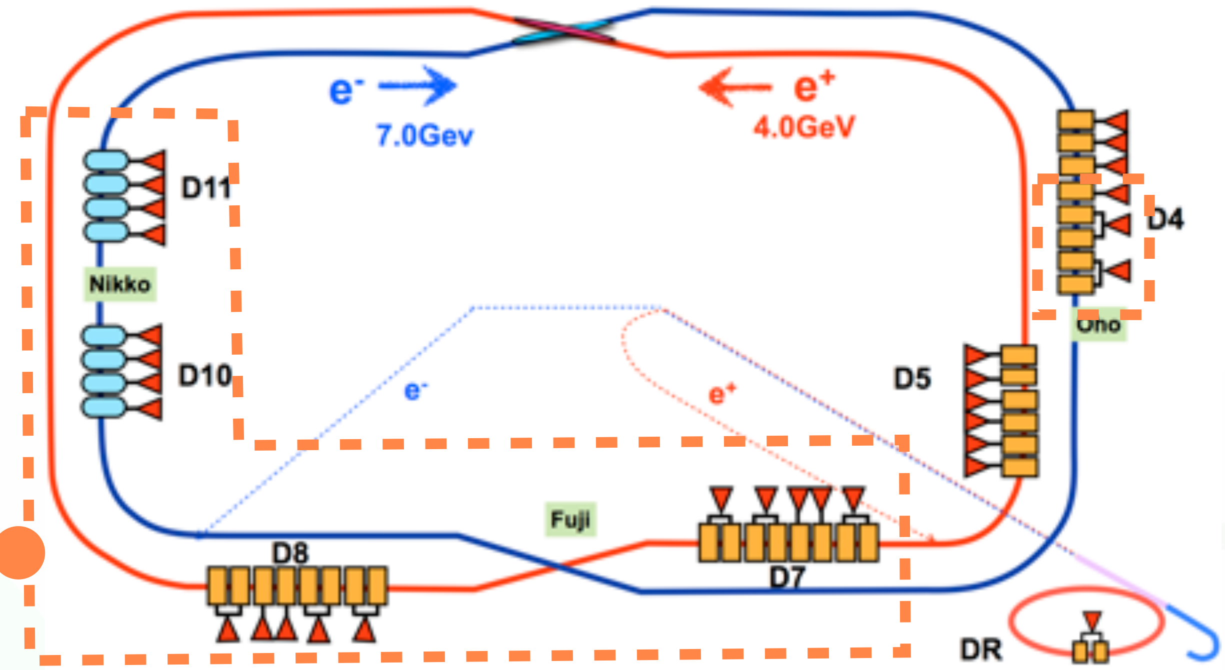
Regulation Performance



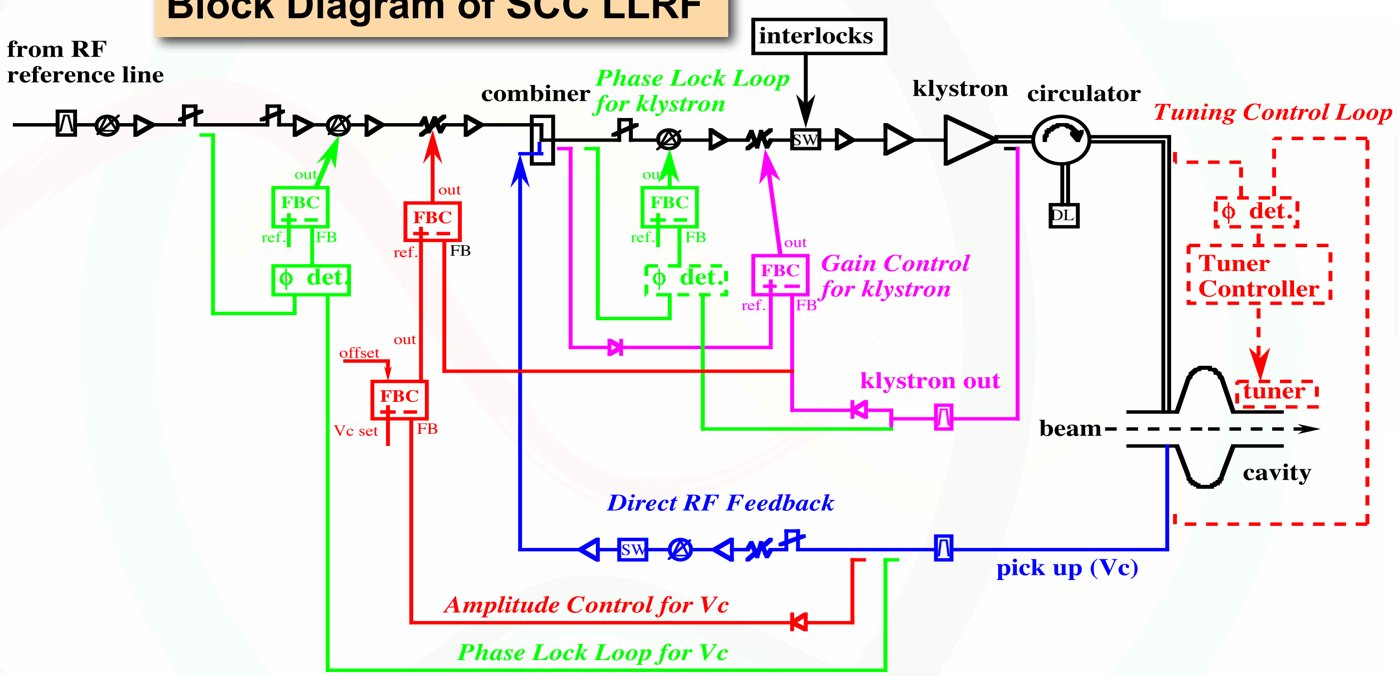
Existing Analog LLRF System

Most stations are still operated with old analog LLRF systems, which had been used in KEKB operation

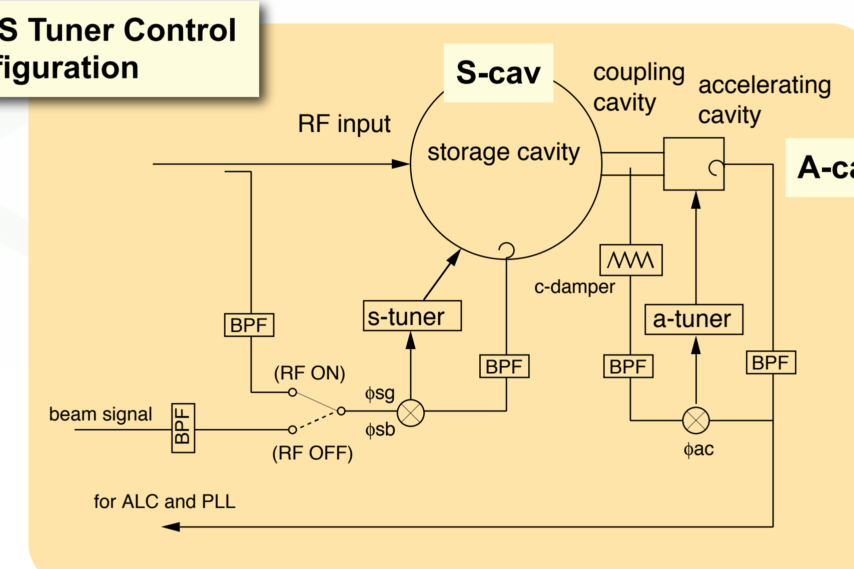
Existing LLRF used in KEKB



Block Diagram of SCC LLRF



ARES Tuner Control Configuration



- These systems are composed of combination of NIM standard analogue modules.
- They are controlled remotely via CAMAC system.
- **All systems are soundly working without serious troubles.**
  However, some NIM modules failed during operation. They were replaced with spares.

Damper System for Longitudinal Coupled Bunch Instability due to Acc. Mode

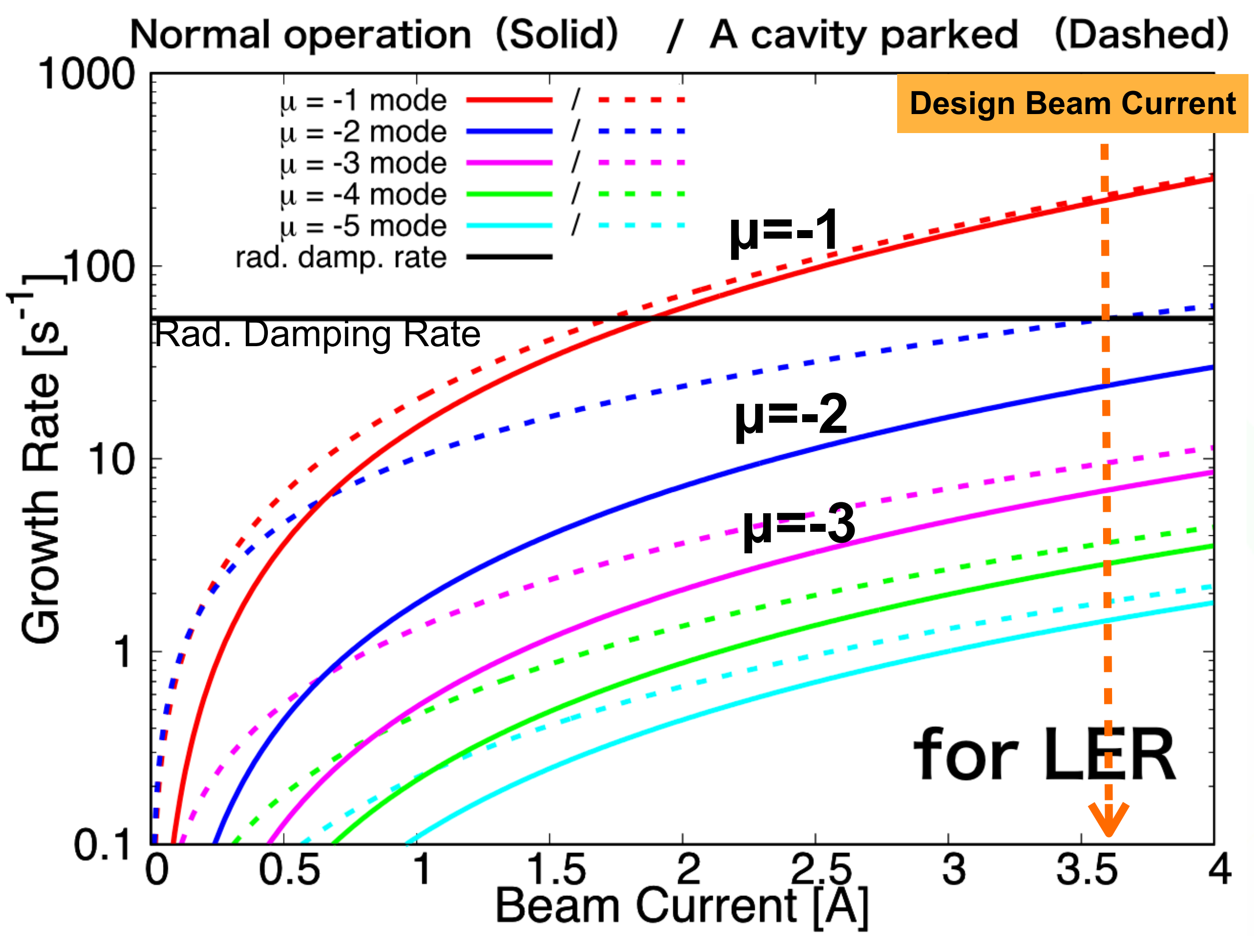
Growth Rate Estimation for SuperKEKB

Estimation of Growth Rate of LCBI due to the Acc. mode

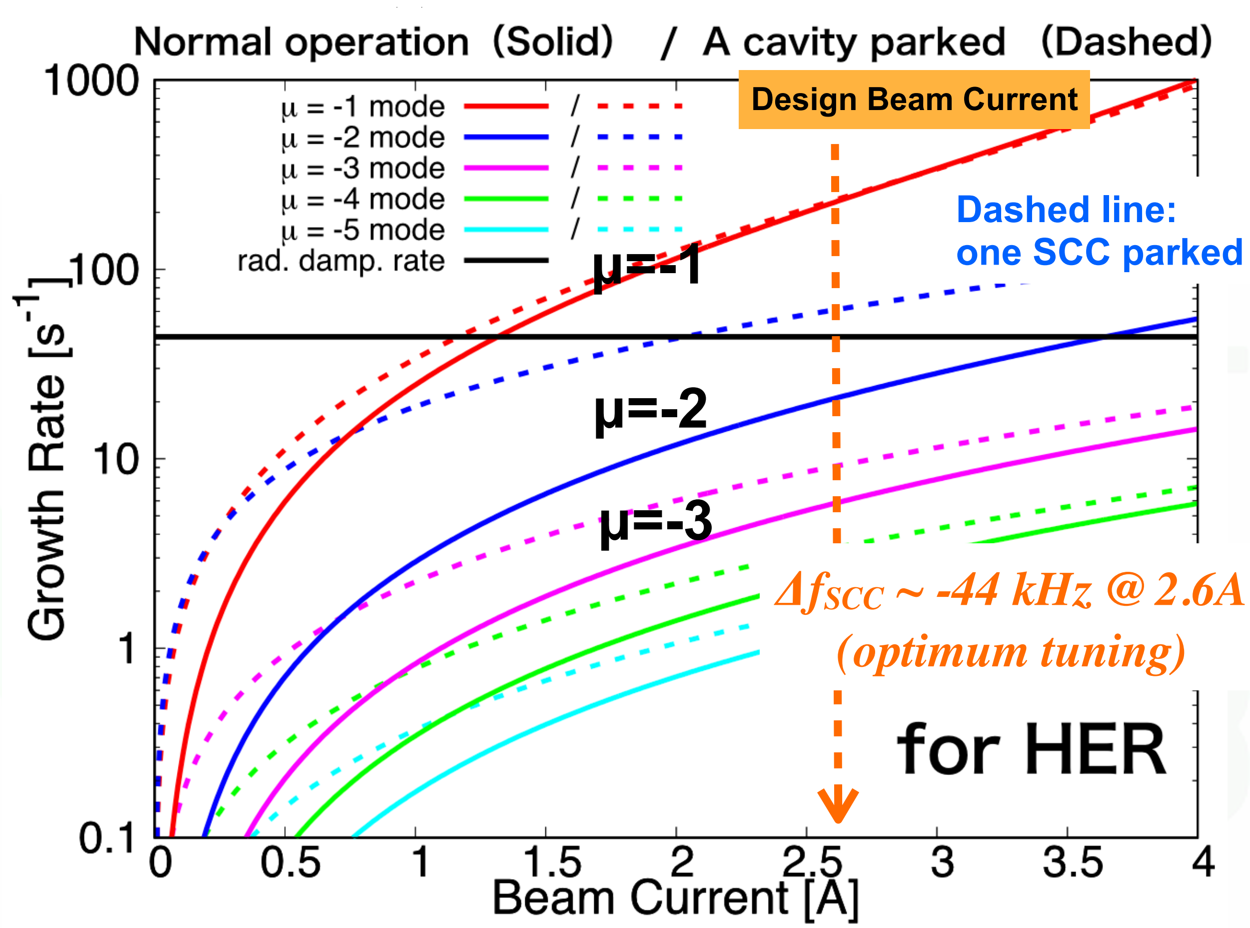
K. Hirosawa

LCBI: Longitudinal Coupled Bunch Instability

LER (22 x ARES)



HER (8 x ARES + 8 x SCC)



Dashed line indicates the case that one SCC is parked with detuning at -150 kHz.

f_0 = 100 kHz (revolution frequency) (center between -1 and -2 modes)

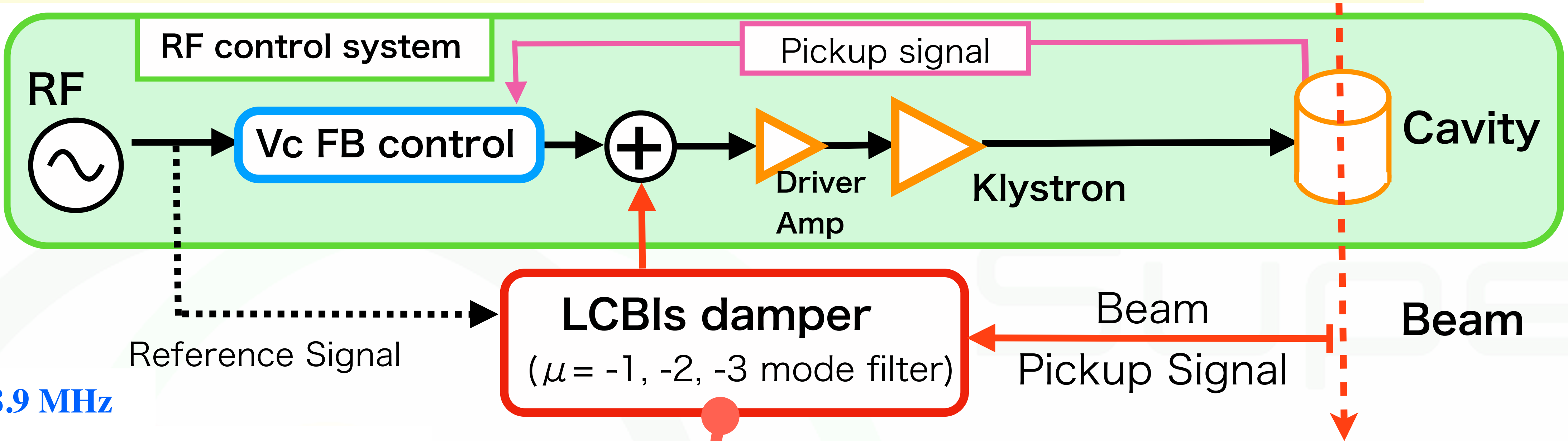
In SuperKEKB, the μ=-1 and -2 modes of LCBI will be serious problem for the design current.

New LCBI damper system with new digital filters has been developed for SuperKEKB. It can suppress the μ=-1, -2 and -3 modes in parallel.

New LCBI Damper System for SuperKEKB

For SuperKEKB, new LCBI damper was developed.
It can suppress μ=-1, -2 and -3 in parallel by new digital filter.

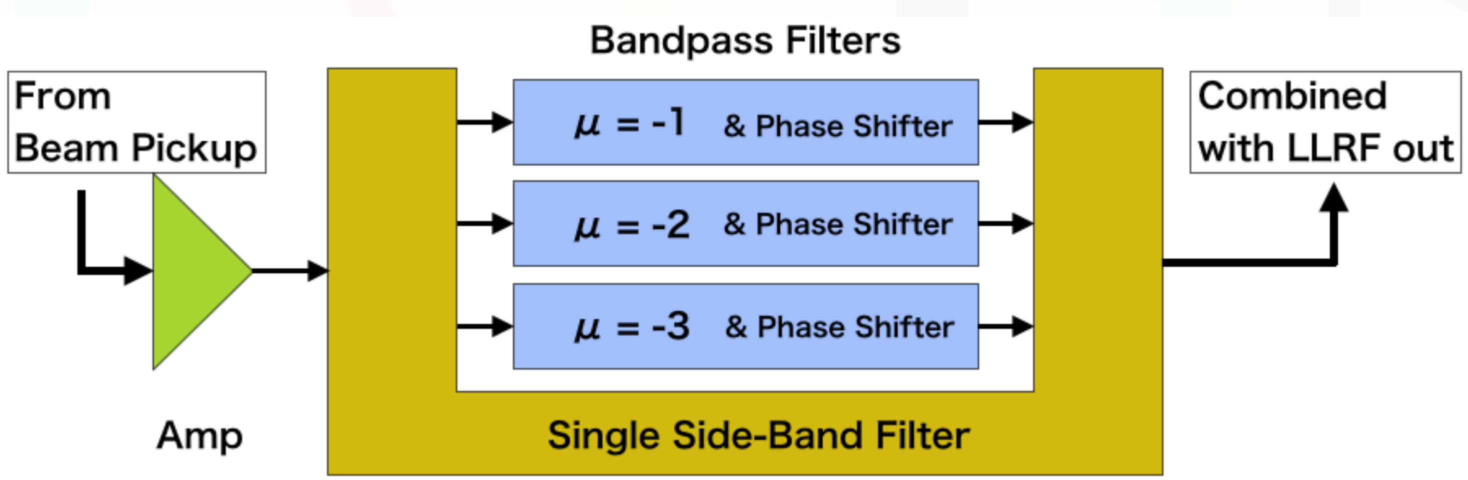
Block diagram of FB loop of RF system with LCBIs damper for SuperKEKB.



f_{rf} =508.9 MHz

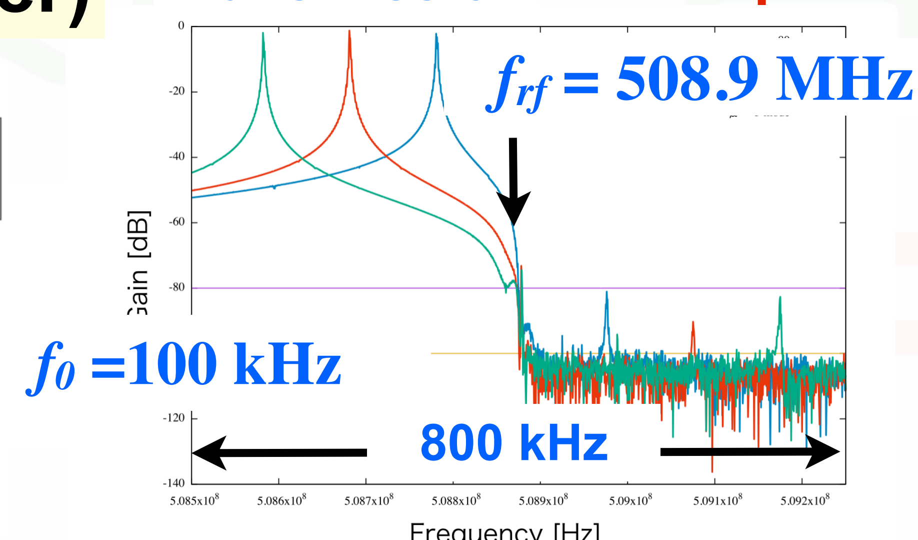
f_0 = 100 kHz (revolution frequency)

Newley developed LCBI damper (mode filter)



Single sideband filter and digital band pass filters (a parallel comb filter)

Transmission



Our klystron bandwidth is about 100 kHz (The gain and phase are not flat at μ=-2 and -3 modes).

The feedback gain and phase can be controlled independently for each mode by the digital filter.

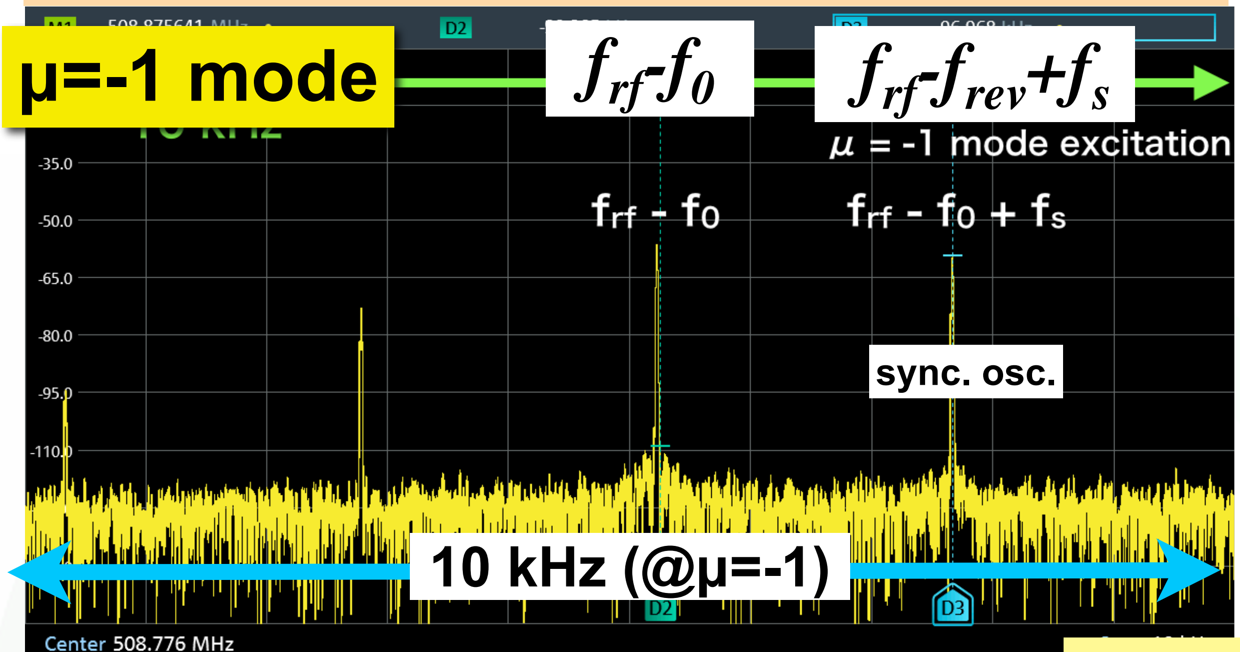
Demonstration of the new LCBI Damper

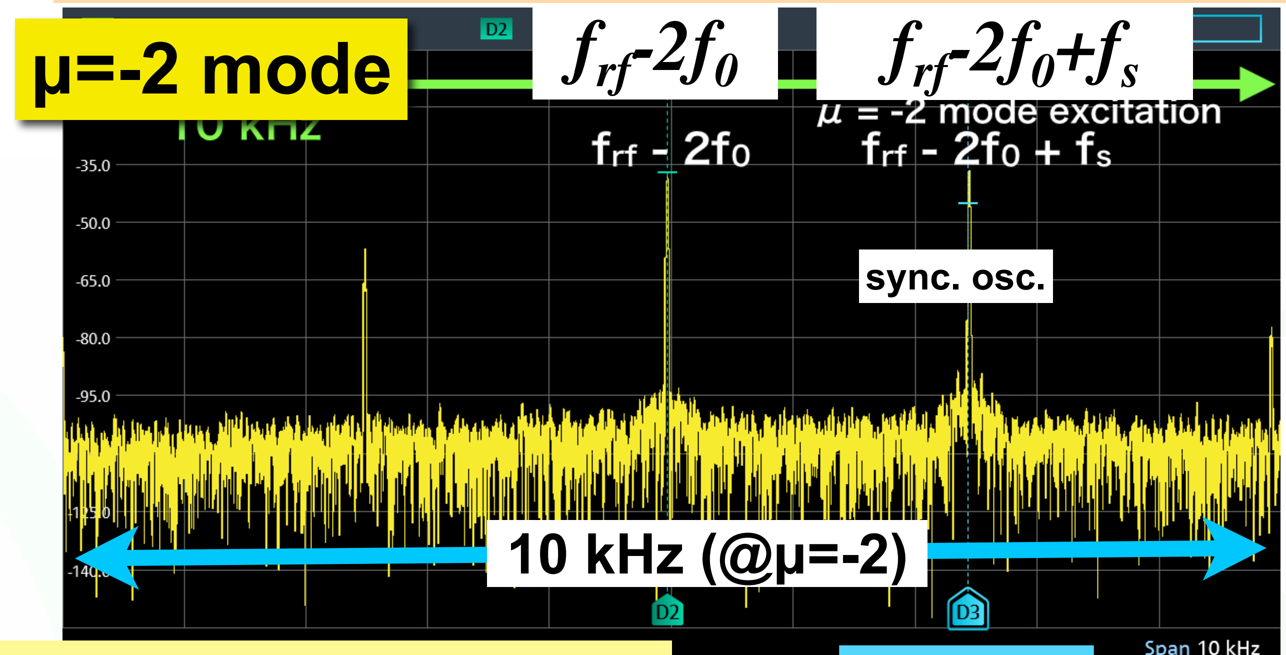
in HER in Phase-2 Operation (I_b ~ 0.7 A)

f_{rf} = 508.9 MHz f_0 = 100 kHz f_s = 2.3 kHz

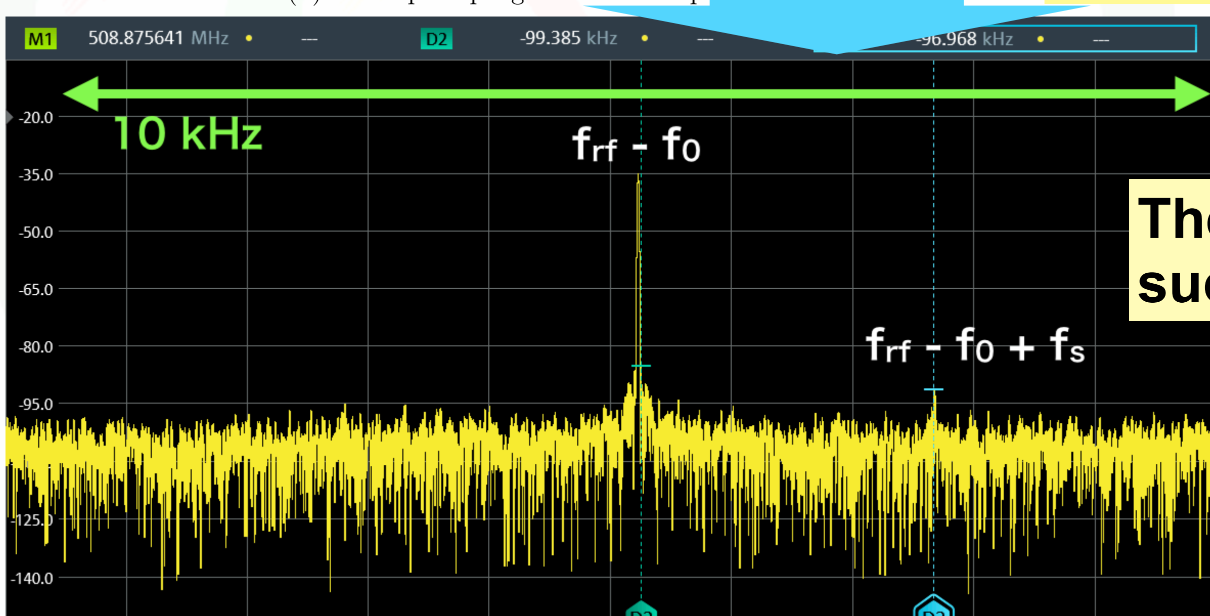
The μ=-1 mode was excited by a parked SC cavity of Δf~-150 kHz.

We purposely excited the μ=-2 mode by detuning a SC cavity manually at Δf=-200 kHz.





The new LCBI damper applied



The μ=-1, -2 modes were successfully damped.

This new damper was also practically used in Phase-3 (2019) and worked well to damp the μ=-1 mode in HER, even though I_b < 1 A.

Summary

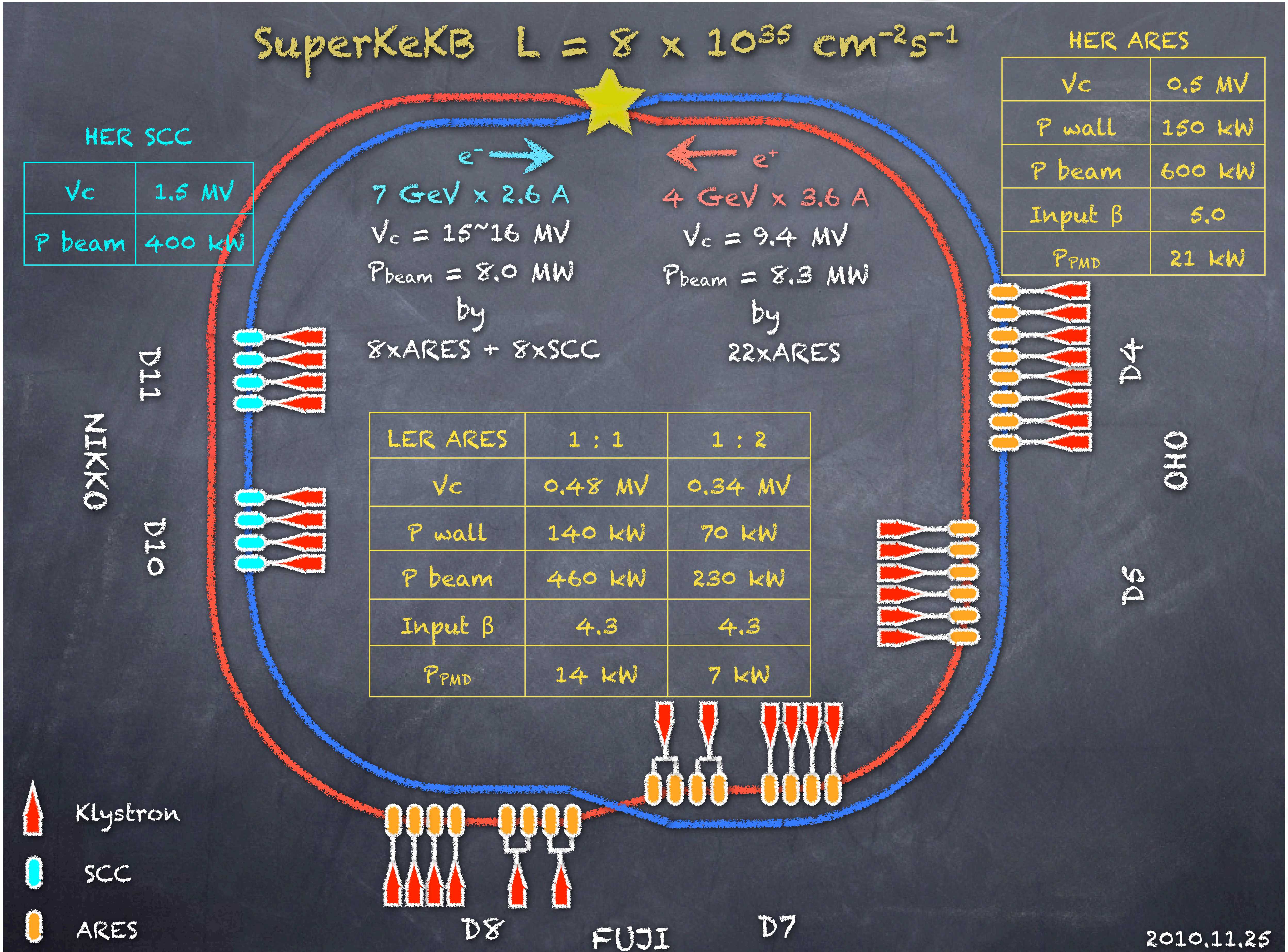
- Steady operation has been continued without serious problem in RF systems.
- ARES cavity and DR cavity has also operated without trouble and the trip-rate is enough low at present.
- In SCC operation, piezo actuator frequently failed with electric breakdown. From our study, it was found that the moisture degrades its insulation, and that drying piezo with silica gel is effective to prevent from the degradation.
  We ill continue to study moisture control around the piezo in the tunnel.
- Newly developed digital LLRF control systems, applied to 9 stations at OHO section, is properly working without fatal trouble.
- New LCBI damper system with new digital filters has been developed. It can suppress the μ=-1, -2 and -3 modes in parallel. In Phase-2, successful damping of μ=-1 and -2 was demonstrated by the new damper.

Thank you
for your attention!

Backup Slides

RF Power for Ultimate Stage

T. Kageyama, 2011.02



HER SCC

Vc	1.5 MV
P beam	400 kW

HER ARES

Vc	0.5 MV
P wall	150 kW
P beam	600 kW
Input β	5.0
P_{PMD}	21 kW

LER ARES	1 : 1	1 : 2
Vc	0.48 MV	0.34 MV
P wall	140 kW	70 kW
P beam	460 kW	230 kW
Input β	4.3	4.3
P_{PMD}	14 kW	7 kW

Instability due to RF cavities and cure

T. Kageyama, 2011.02

Ring	Longitudinal/Transverse	Cause	Frequency (MHz)	Growth time (ms)	Cure
LER	Longitudinal	ARES-HOM	1850	12	B-by-B FB
		ARES-0/π	504	21	B-by-B FB
		-1 mode	508.79	4	-1 mode damper
LER	Transverse	ARES-HOM	633	7	B-by-B FB
HER	Longitudinal	ARES-HOM	1850	59	(no need)
		SCC-HOM	1018	58	(no need)
		-1 mode	508.79	4	-1 mode damper
HER	Transverse	ARES-HOM	633	39	(no need)
		SCC-HOM	688	14	B-by-B FB

Longitudinal bunch-by-bunch FB will be needed
to suppress coupled bunch instabilities driven by RF cavities.

22 ARES Cavities operated for LER (I_b=3.6A)

T. Kageyama, 2011.02

RF frequency	508.869 MHz	
Flywheel Energy Ratio U_S / U_A	9	unchanged
Cavity Voltage V_c	0.48 MV	P(wall) = 140 kW
Detuning Frequency $\Delta f_{\pi/2}$ / Δf_{AC}	-28 kHz / -280 kHz	P(beam) = 460 kW
Input Coupling Factor β	5.0	β (optimum) = 4.3
CBI (-1 mode) due to the Acc. mode	τ = 4 ms	RF feedback
CBI due to the 0 and π modes	τ = 21 ms	bunch-by-bunch FB

HOM Power Estimation for LER

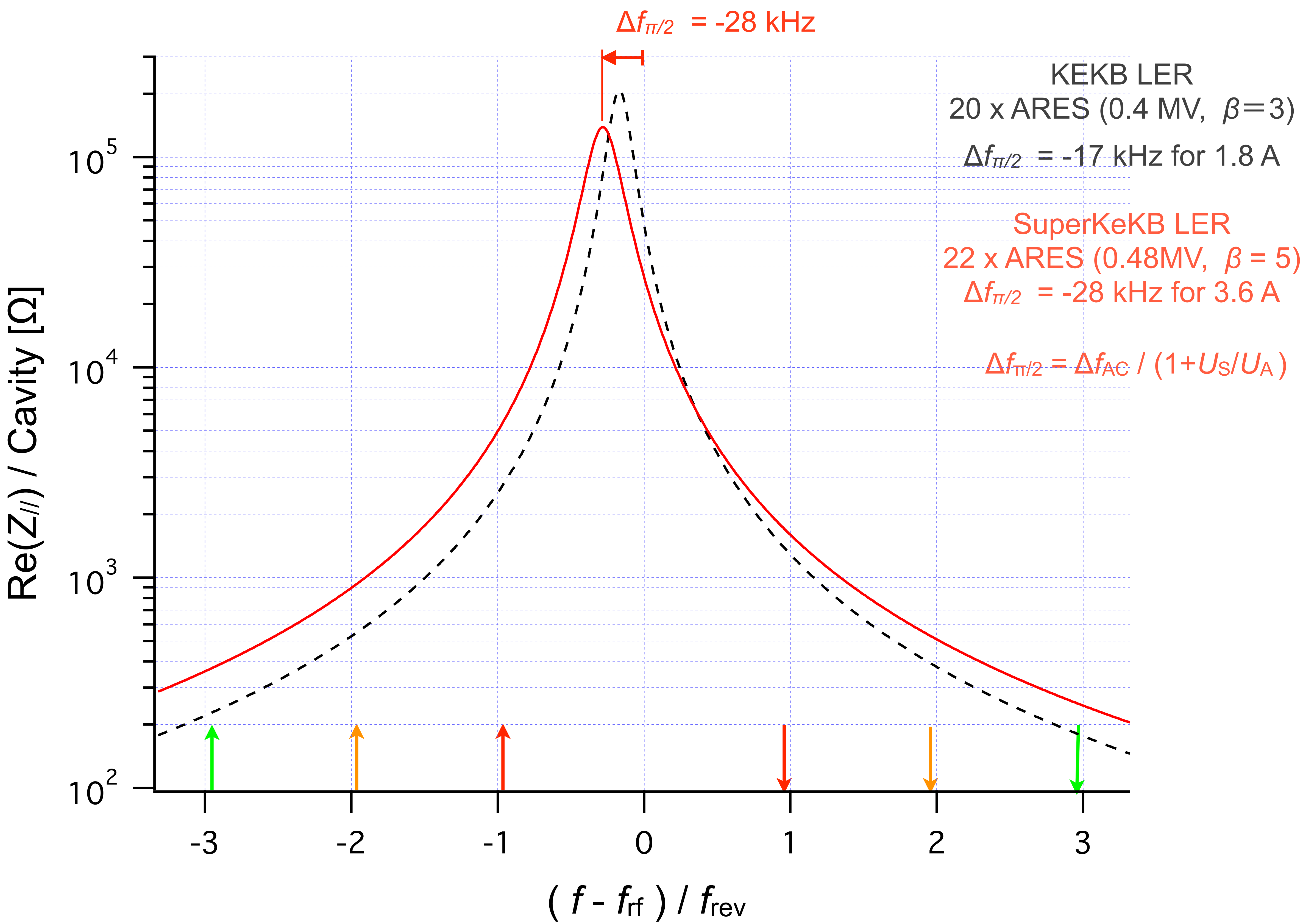
T. Kageyama, 2011.02

	KEKB LER Sep. 21, 2004	SuperKeKB LER	Power Handling Capability verified at 1.25 GHz	Factor of Safety
I_{beam} [A]	1.6	3.6	-	-
N_{bunch}	1293	2503	-	-
σ_z [mm]	7	6	-	-
k [V/pC]	0.40 (0.39†)	0.44	-	-
P_{HOM} /ARES [kW]	5.4†	17	-	-
P_{HOM} /HWG [kW]	1.05†	3.3	5.0	5.0/3.3 = 1.5
P_{HOM} /Groove [kW]	0.3†	0.93	1.2	1.2/0.93 = 1.3

†based on calorimetric measurement

Coupled Bunch Instability (CBI) driven by the Accelerating Mode (π/2)

T. Kageyama, 2011.02



Cavity Impedance and LCBI modes

Longitudinal Coupled Bunch Instability

LER - ARES Cavity Impedance (I_b=3.6 A)

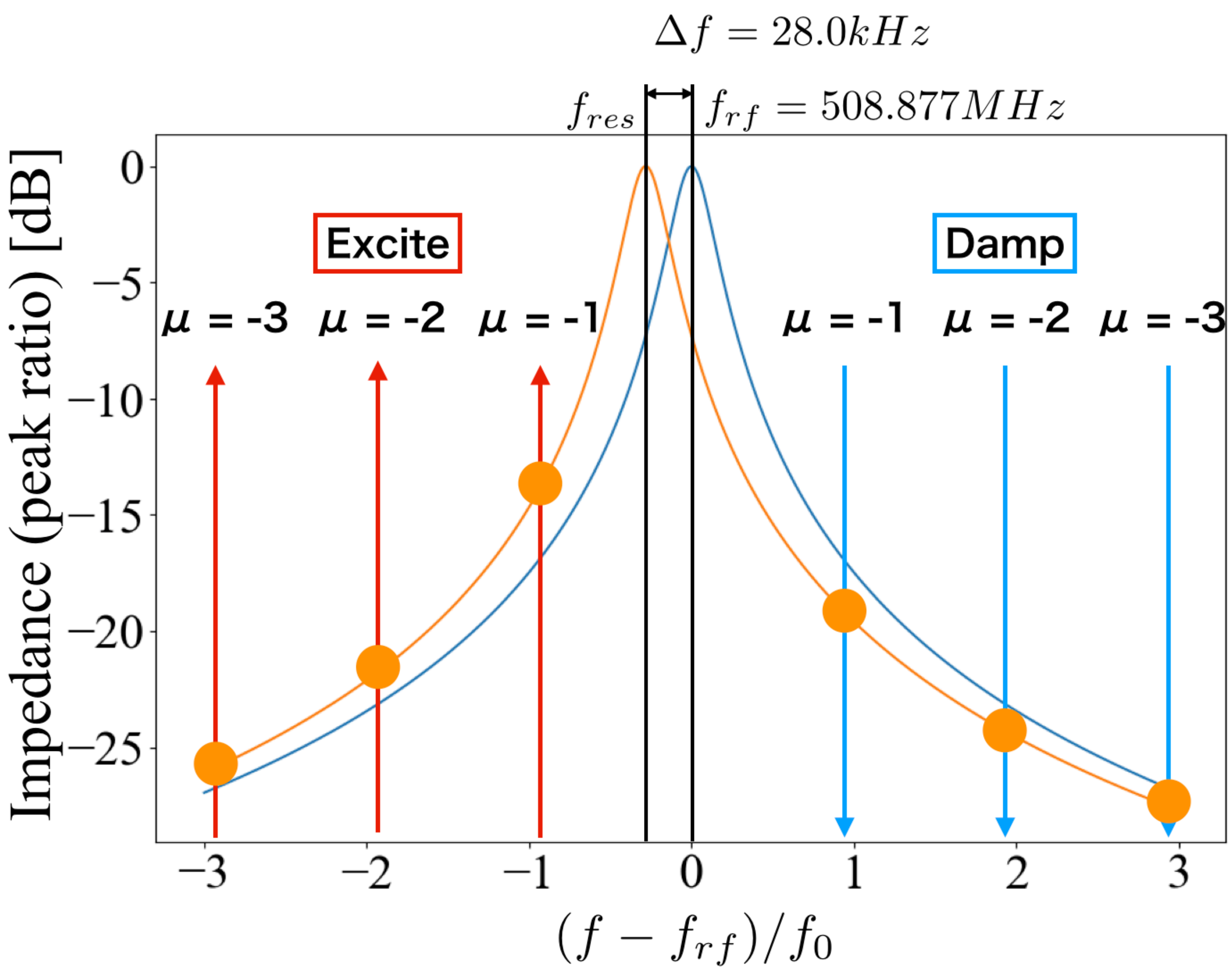


Figure 1: The illustration of the relation between LCBIs modes and longitudinal resonant impedance of an RF cavity.

$$\frac{1}{\tau_\mu} = AI_b \sum_p^{\infty} \left\{ f_p^{(\mu+)} \mathrm{Re}\, Z\left(f_p^{(\mu+)}\right) - f_p^{(\mu-)} \mathrm{Re}\, Z\left(f_p^{(\mu-)}\right) \right\}$$

$$f_p^{(\mu+)} = pf_{rf} + \mu f_0 + f_s$$

$$f_p^{(\mu-)} = (p+1) f_{rf} - \mu f_0 - f_s$$

f_{rf} =508.9 MHz

Revolution freq.
f_0 = 100 kHz

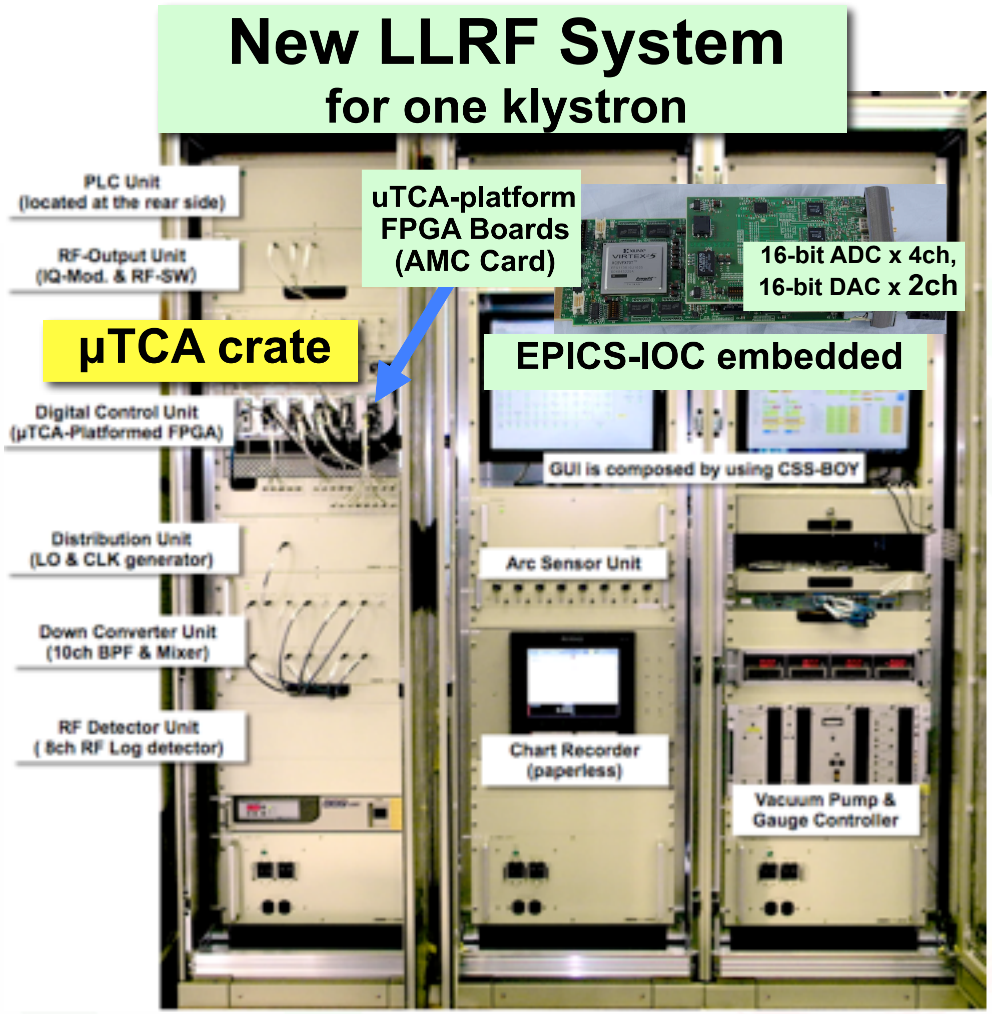
Synchrotron osc. freq.
f_s = 2~3 kHz

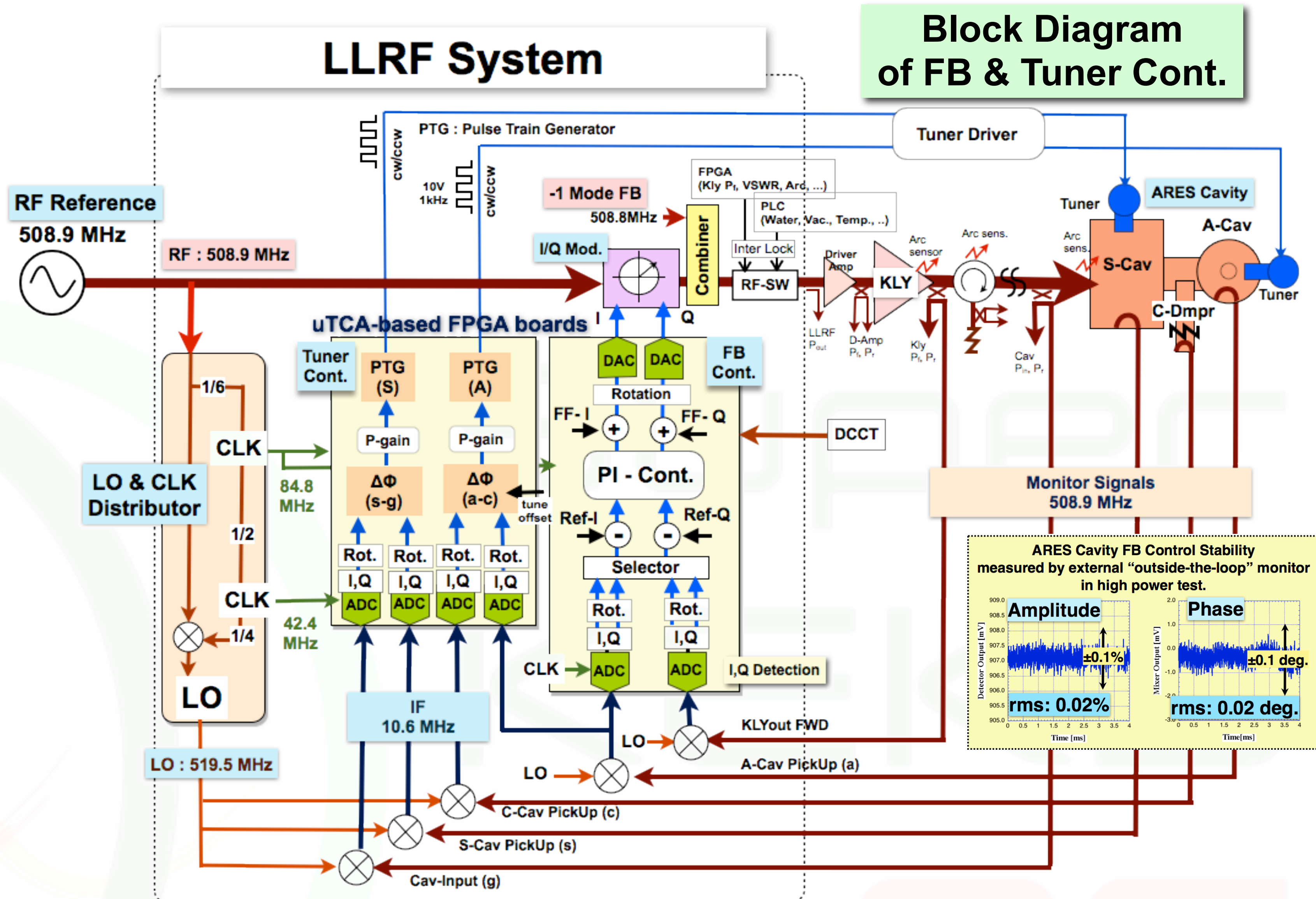
SCC Operation Parameters and Trip

SuperKEKB-SCC Parameters		Design	Phase-1 achieved	Phase-2 achieved	2019 spring
Number of Cavities		8	8	8	8
Max. Beam Current [A]		2.6	0.87	0.8	0.94
RF Voltage [MV/cav.]		1.5	1.2	1.35	1.35
External Q		5E+4	4.3 - 6.8E+4	4.3 - 6.8E+4	4.7 - 7.2E+4
Beam Loading [kW/cav.]		400	80 - 170	100 - 120	80 - 100
Unloaded Q at 2MV		1E+9	1.6E8 - 1.1E9	1E8 - 1.6E9	0.2 - 1.5E9
at 1.5MV			3.3E8 - 2.2E9	3.1E8 - 3.0E9	1.0 - 2.8E9
Max. Vc [MV] at aging			1.74 - 2.36	1.75 - 2.48	2.00 - 2.49
Beam Aborts	cavity trip		9	1	1
	peripheral		16	4	4

New LLRF Control System

was developed for higher accuracy and flexibility for SuperKEKB.





- Consisting of μTCA-platformed FPGA boards (AMC), & PLC.
- EPICS-IOC with Linux-OS is embedded in each of them.
- Common hardware for both of ARES & Superconducting Cavity.
- Klystrons (LLRF) : Cavity unit = 1 : 1 (SuperKEKB)

Completely remote controllable

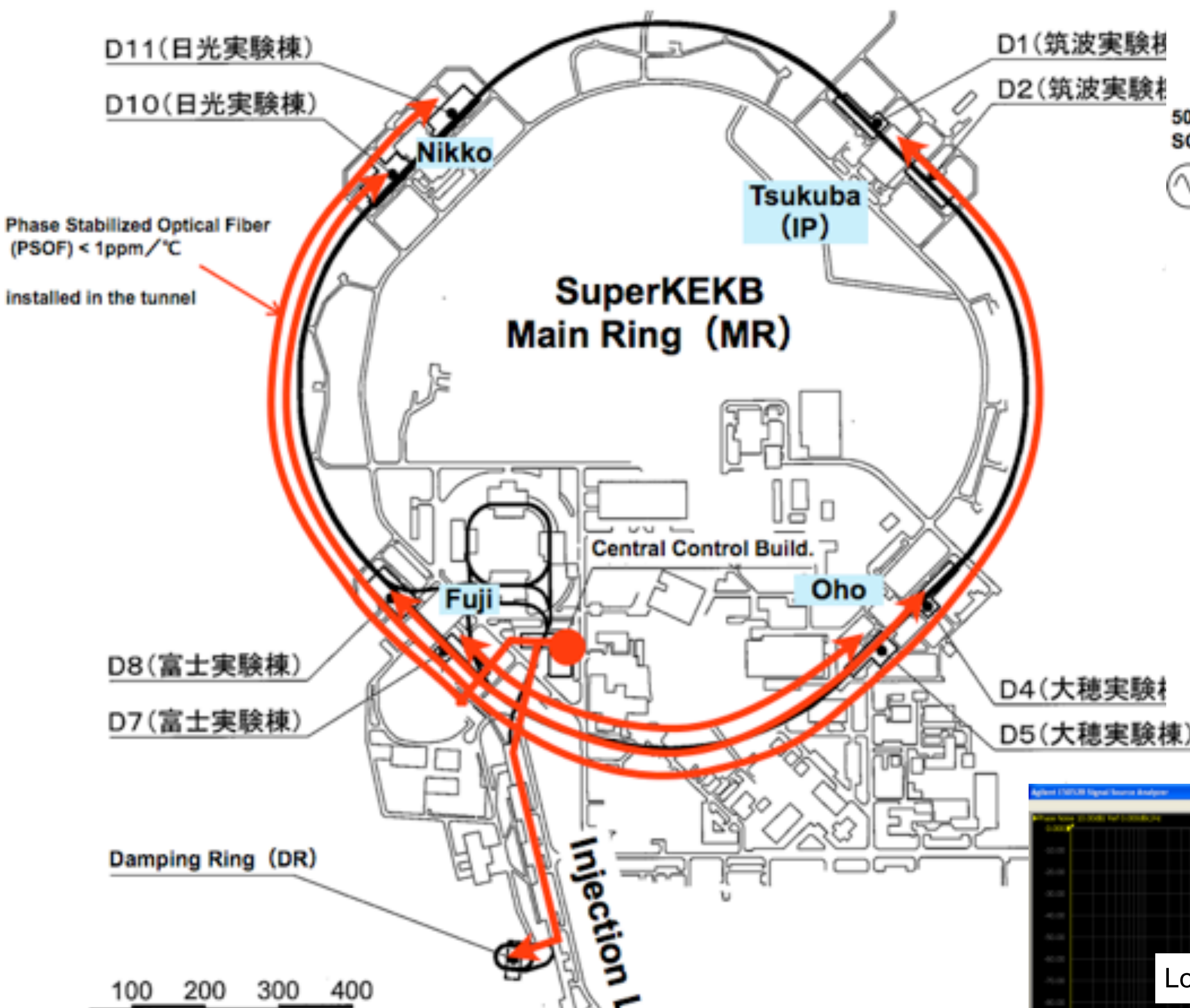
- New LLRF control system is built on recent digital technique. It is dominated by μTCA-platformed FPGA boards for higher accuracy and flexibility.
- In this system, I/Q components are handled by FPGA for vector control instead of amplitude and phase.
- The good performance was demonstrated in the high power test with ARES cavity., The regulation stability was 0.02% in amplitude and 0.02 deg. in phase.

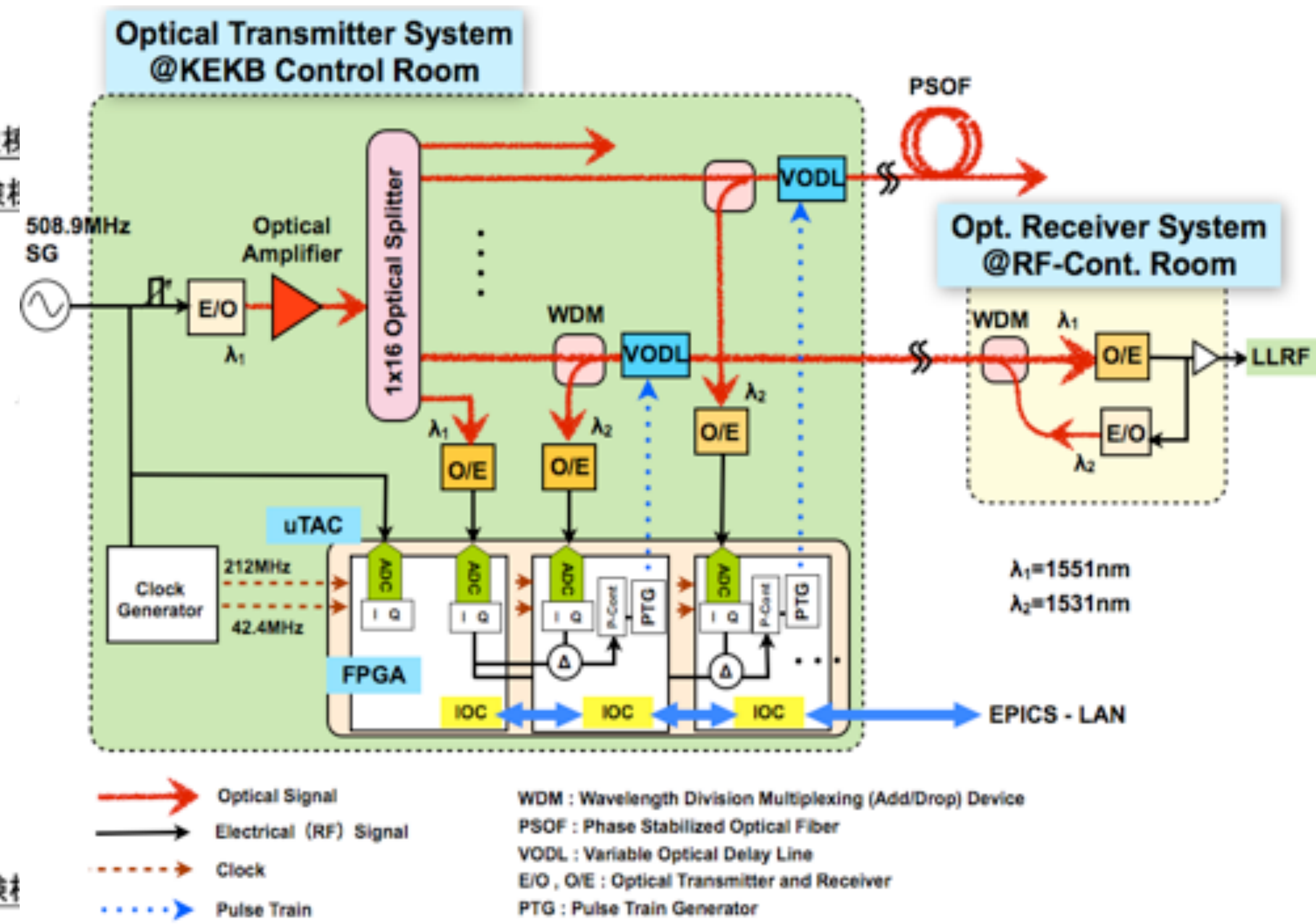
<Topic>
LLRF

RF Reference Distribution

with digital optical delay control for phase stabilization

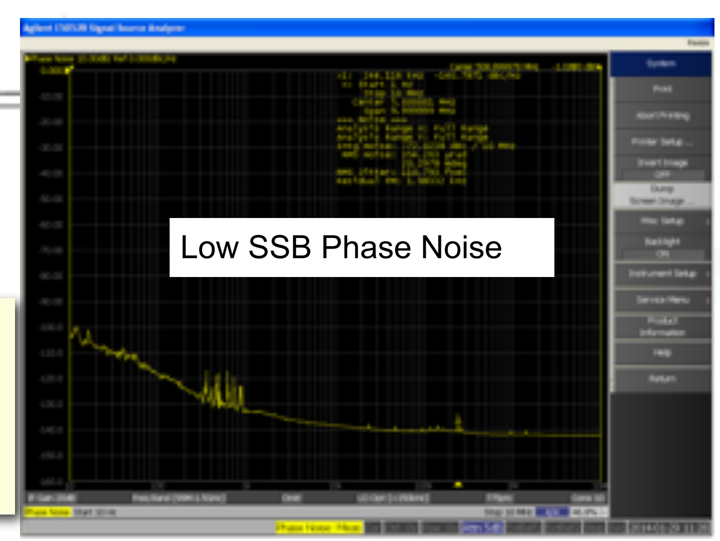
- RF reference signal is optically distributed into 8 sections by means of “Star” topology configuration from the central control room (CCR).
- “Phase Stabilized Optical Fiber”, which has quite small thermal coefficient, is adapted : < 1ppm/°C
- For the thermal phase drift compensation, optical delay line is controlled digitally at CCR for all transfer lines.
- The phase noise (time jitter) is enough low.





Short term stability (time jitter) : ~0.1 ps (rms)

Long term stability (pk-pk) : ±0.1° @508.9MHz = ±0.55 ps (expected by the optical delay control)

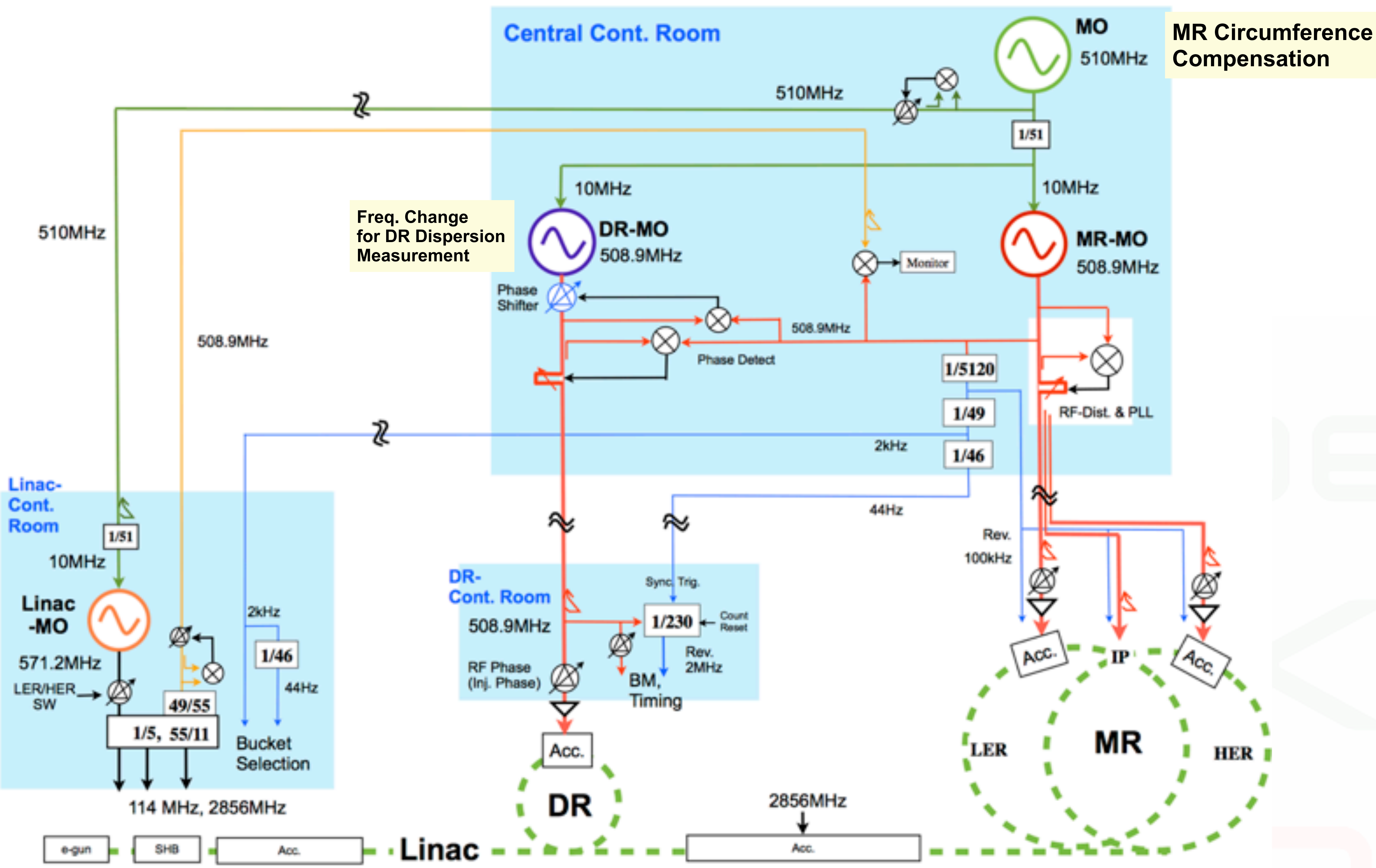


Low SSB Phase Noise

Variable Optica Delay Lines (VODLs) for 8 transmissions

uTCA-platformed FPGAs for the VODLs control

Linac/DR/MR Synchronizing MO System



For dispersion measurement in DR, the RF frequency has to be controlled independently for only DR.
->A dedicated master oscillator for DR (DR-MO) is required.

Linac-MO, DR-MO and MR-MO are synchronized each other by the external 10-MHz reference generated by frequency dividing of 510-MHz into 1/51, which is distributed from the central control room.

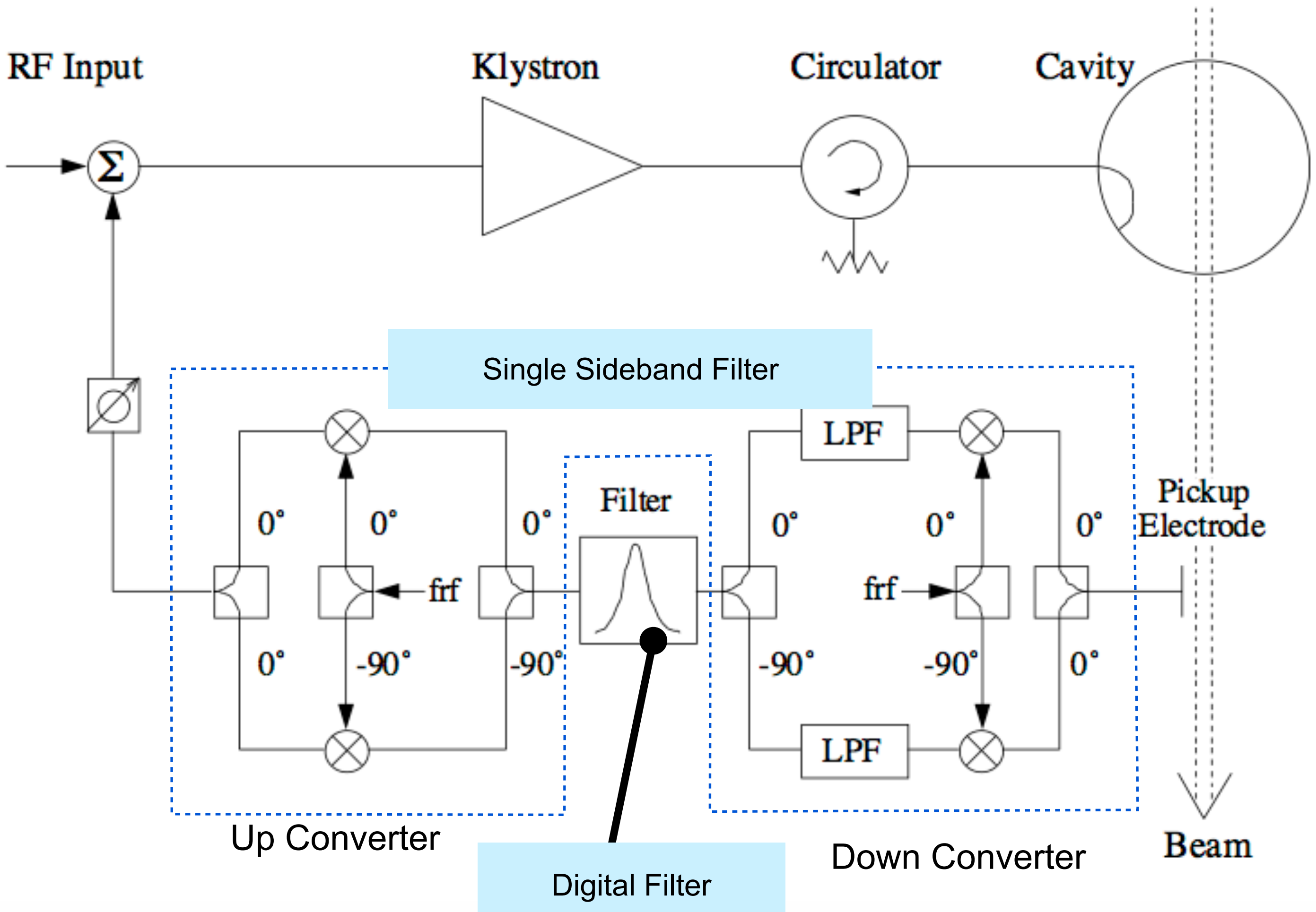
After the end of the dispersion measurement (frequency change), RF phases between each other can be immediately recovered by a phase shifter, and bucket-ID (the revolution signal) is reset for successive injection.

LCBI Damper System

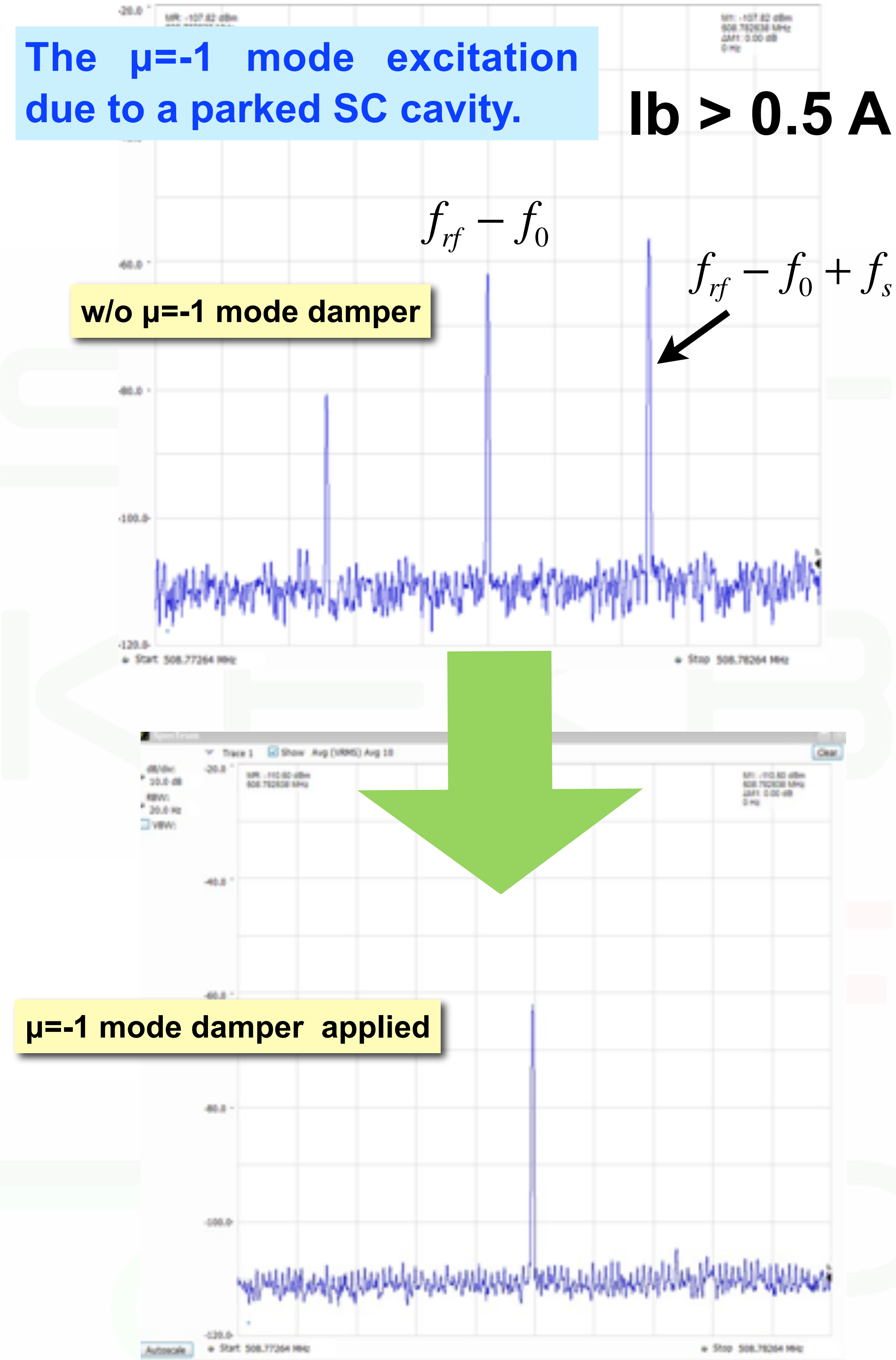
In KEKB operation, the μ=-1 mode damper has been used to suppress the LCBI due to the Acc. Mode in KEKB operation.

In SuperKEKB operation, the LCBI damper is also needed:
at I_b > 800 mA, the μ=-1 mode was excited in HER, and a parked cavity also excites μ=-1 mode at I_b > 500 mA in both rings.

Block diagram of the -1 Mode Damping System



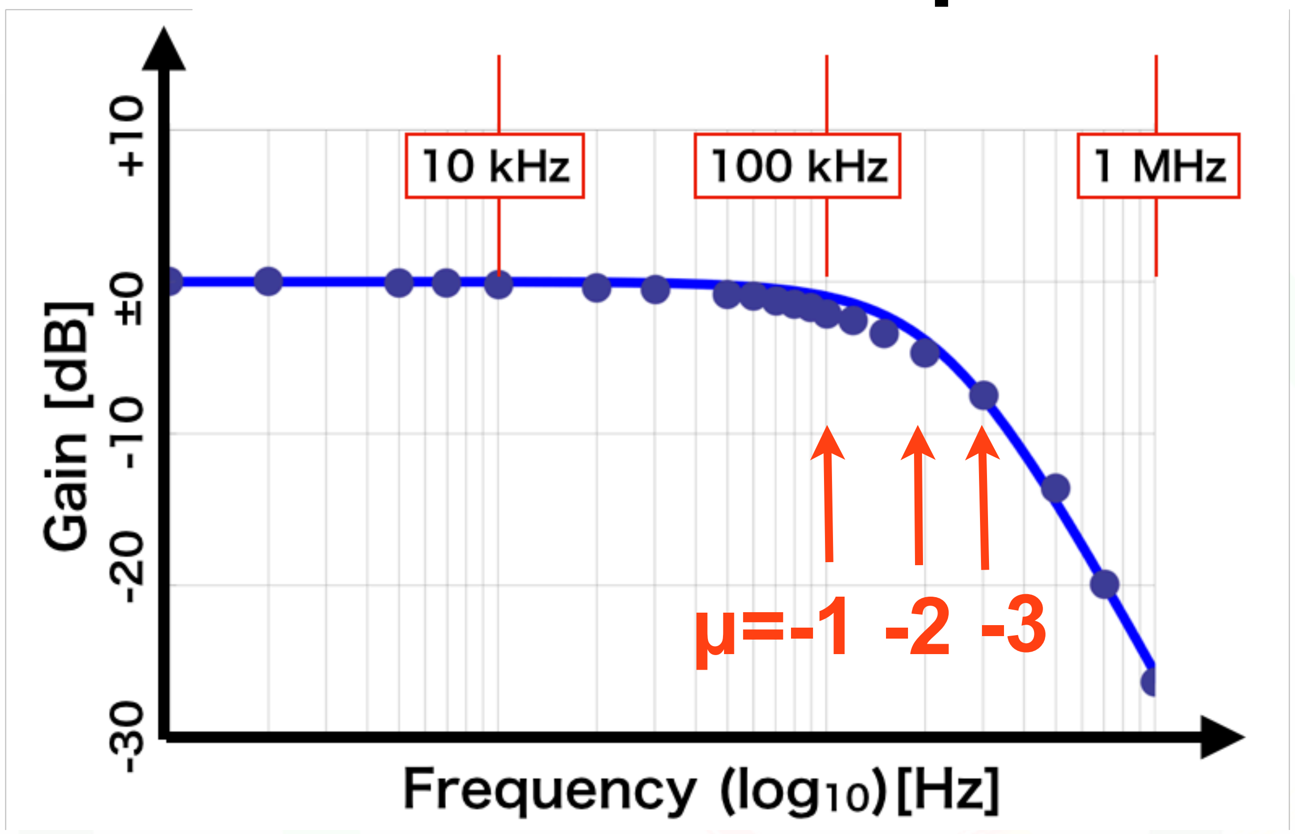
Example of SKB Phase-1 operation



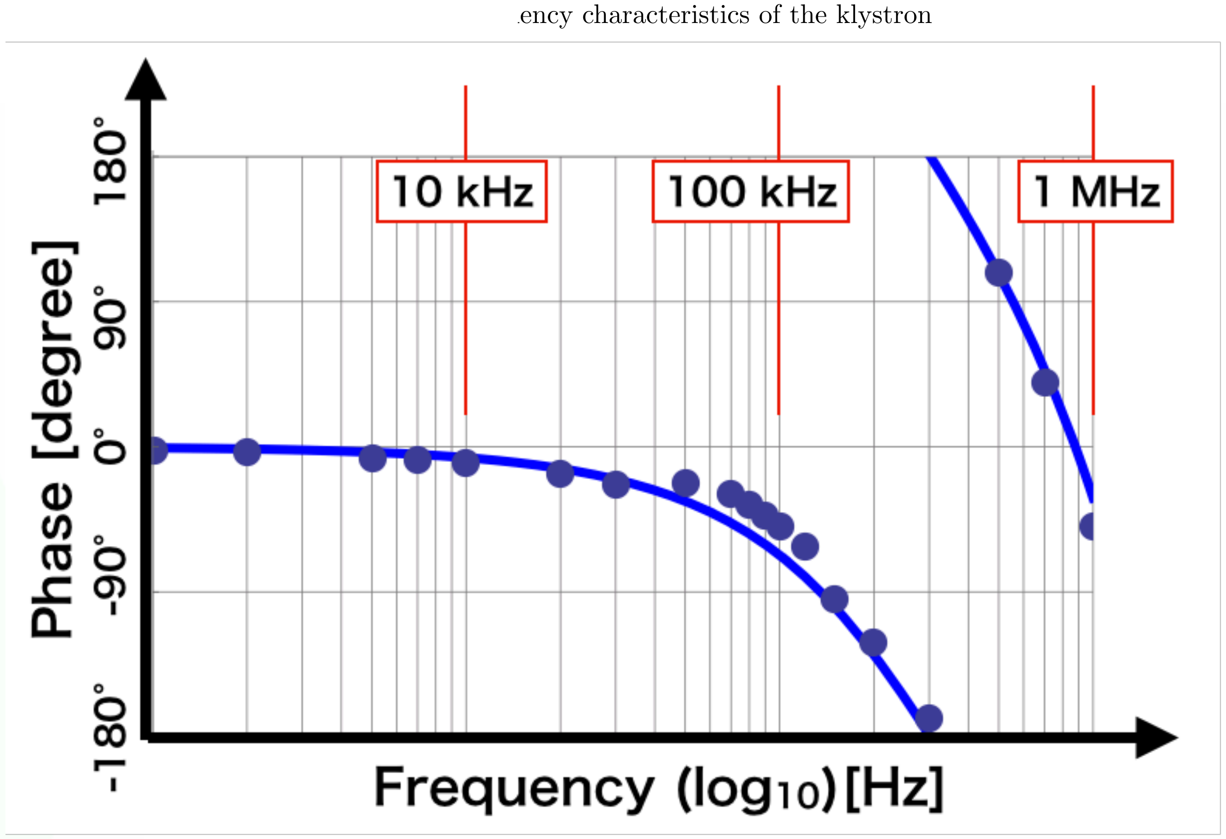
Klystron Characteristics

Our klystron bandwidth ~ 130 kHz

Modulation Amplitude



Phase



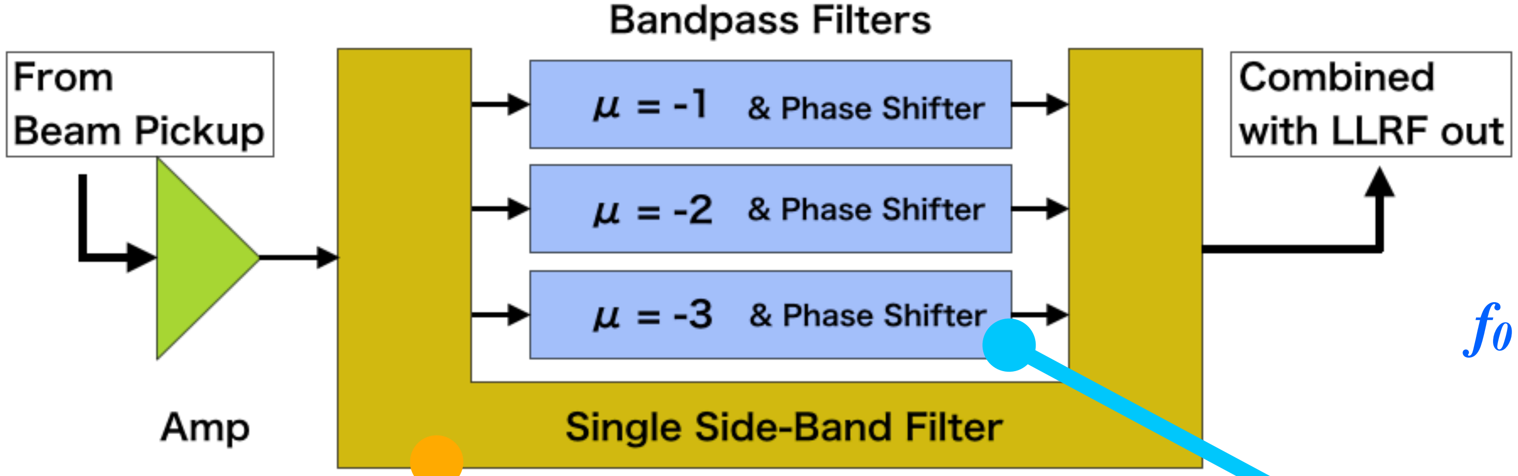
$f_{rf} = 508.9$ MHz

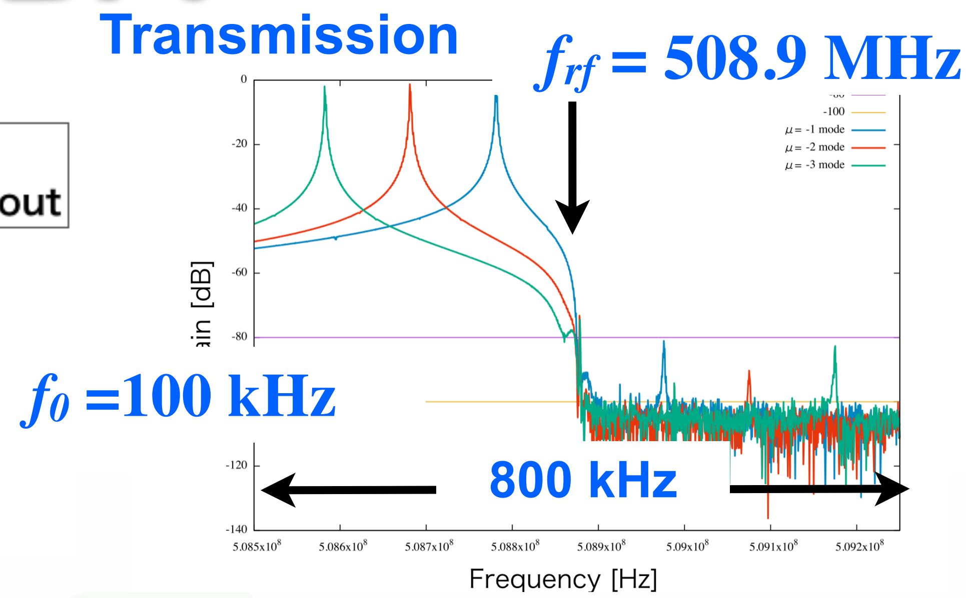
$f_0 = 100$ kHz (revolution frequency)

Klystron bandwidth is not so wide (gain and phase are not flat). The feedback phase and gain should be controllable for each LCBI mode independently in our RF system.

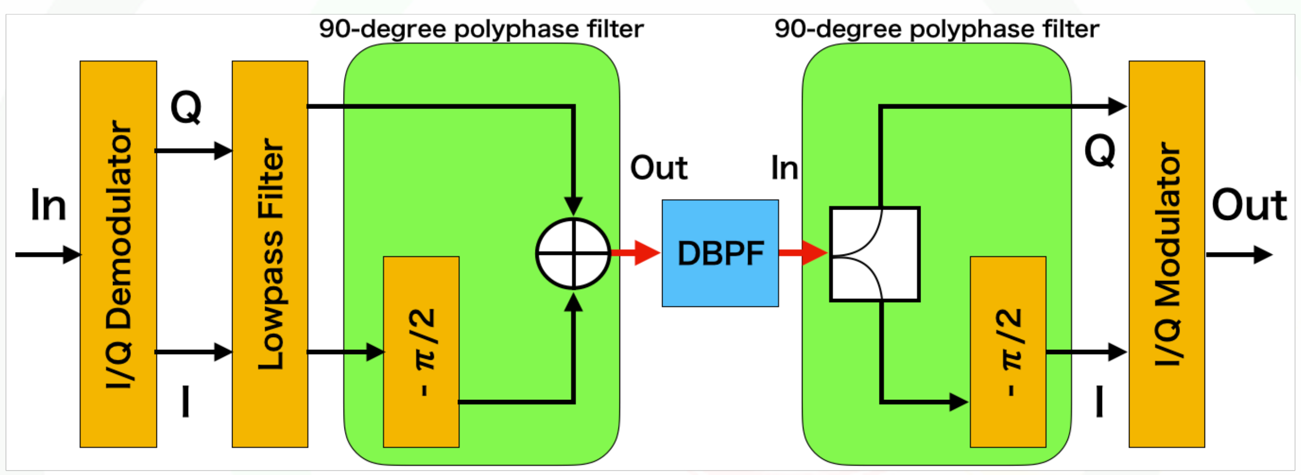
SSBF and DBPF

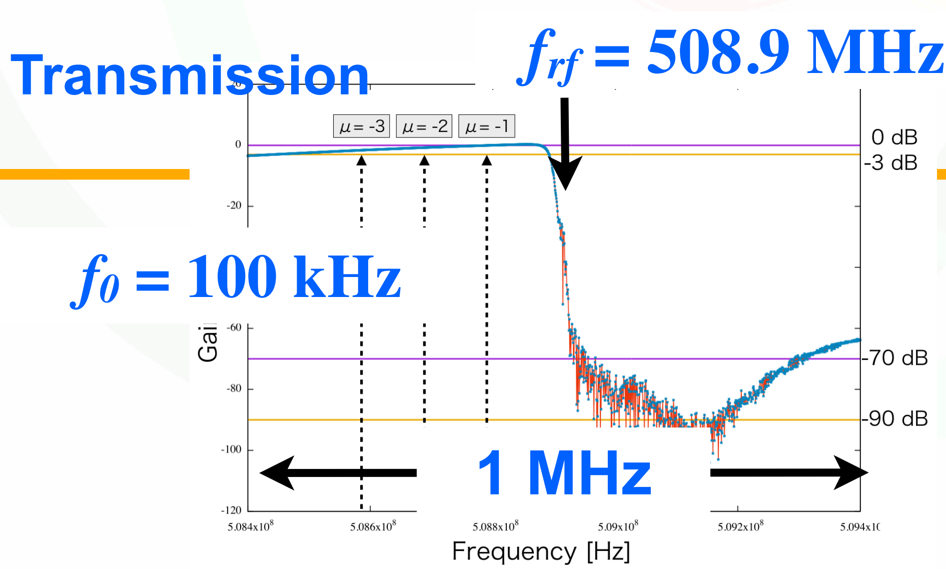
K. Hirosawa





Single Side-Band Filter (SSBF)





Digital Band Pass Filter (DBPF)

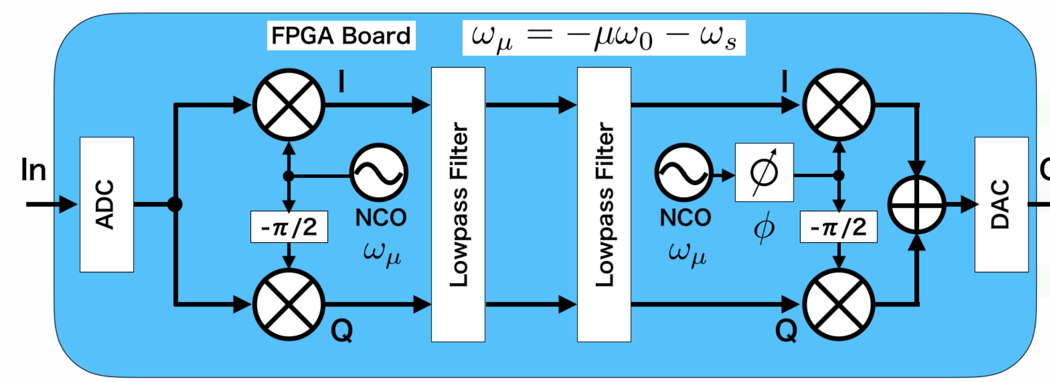


Figure 11: A functional block diagram of the digital bandpass filter on the FPGA.

$$\omega_\mu = -\mu\omega_0 - \omega_s \qquad \mu = -1, -2, -3$$

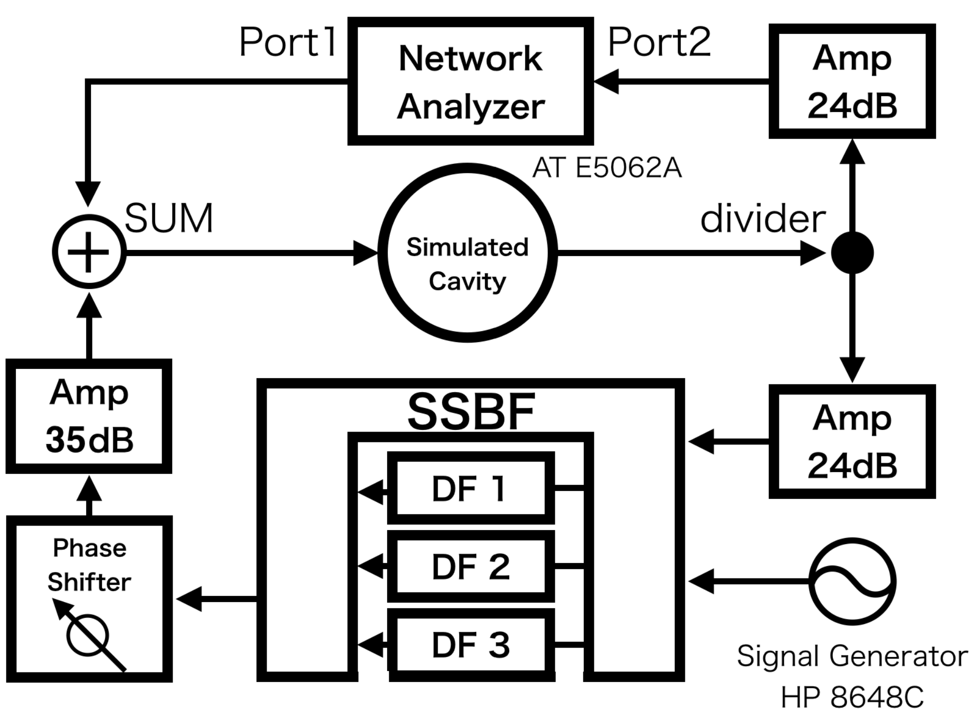
The center frequency($-\mu f_0 - f_s$) of BPF, phase and gain are precisely adjustable for each mode individually by remote control

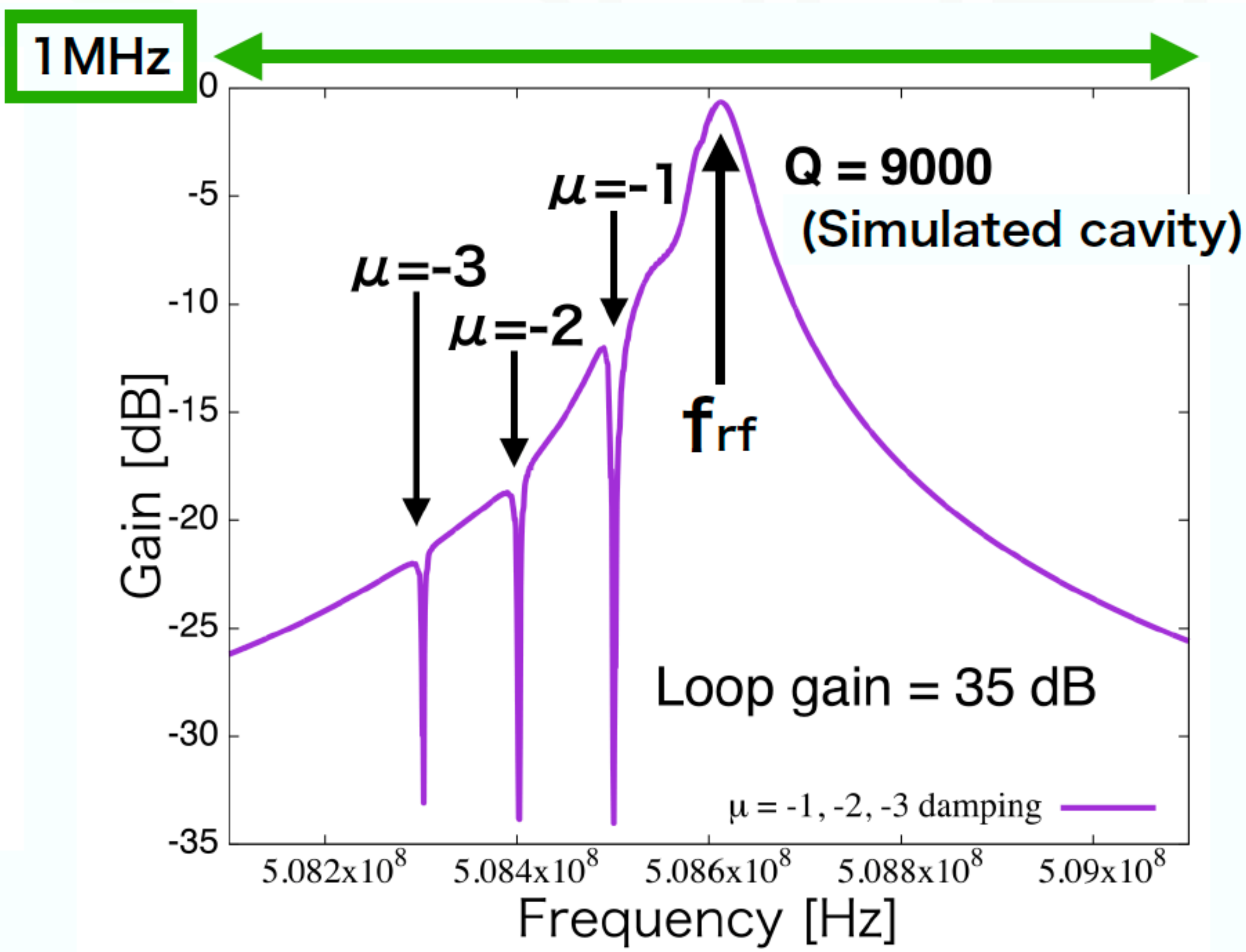
Feedback Loop Test with a Simulant Cavity

f_{rf} = 508.9 MHz

f_0 = 100 kHz (revolution frequency)

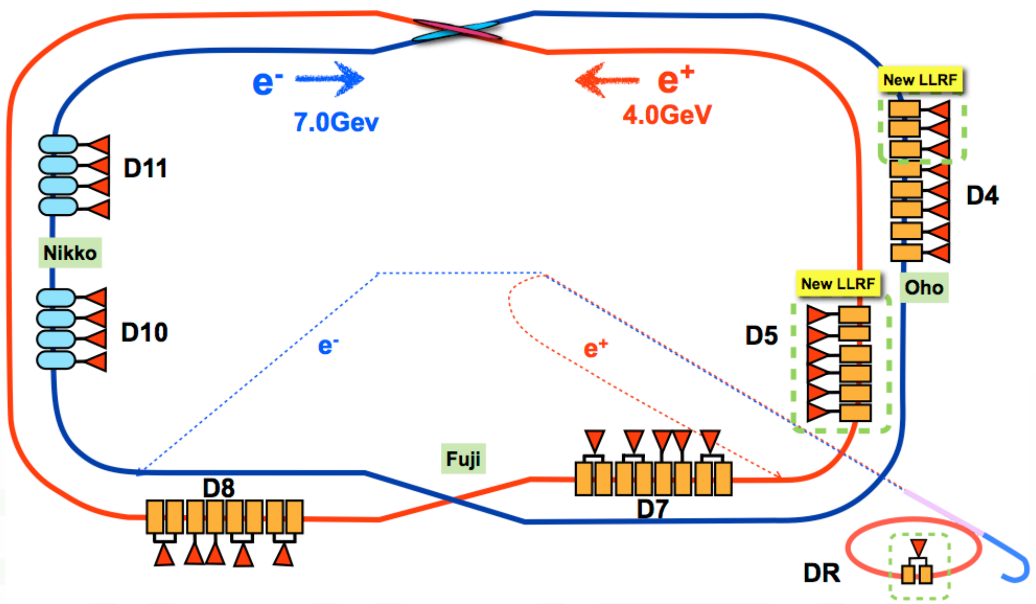
f_s = 2~3 kHz (synchrotron osc. freq.)





Concern Issue of CBI damper

In the demonstration,
the new damper was applied to only one klystron station at the D04G station in HER or at the D05F in LER. (In these stations, one klystron drives one ARES cavity) .



Then, the instabilities were suppressed as expected at up to about 0.9-A beam current in Phase 2.

However, the target current of SuperKEKB design is 3.6 A which is much higher.

According to the calculating evaluation, there is possible that applying the damper to only one station could not reach the required loop gain to damp instabilities for the nominal beam current.

We will try to apply the damper system to two or more klystron stations.

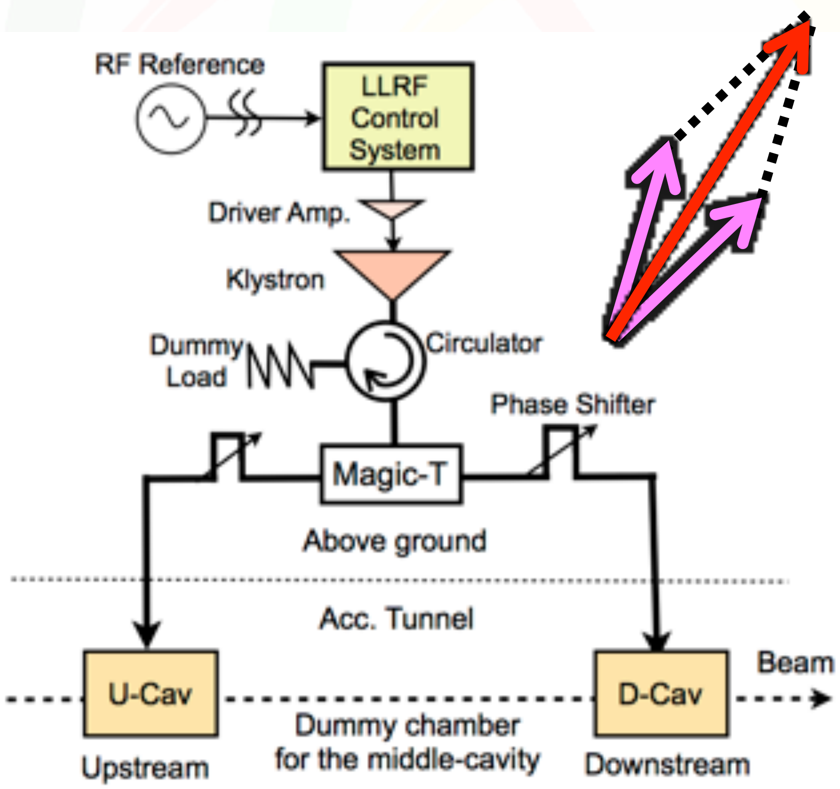
We need enough time for tuning of several dampers systems to apply them to several klystron stations.

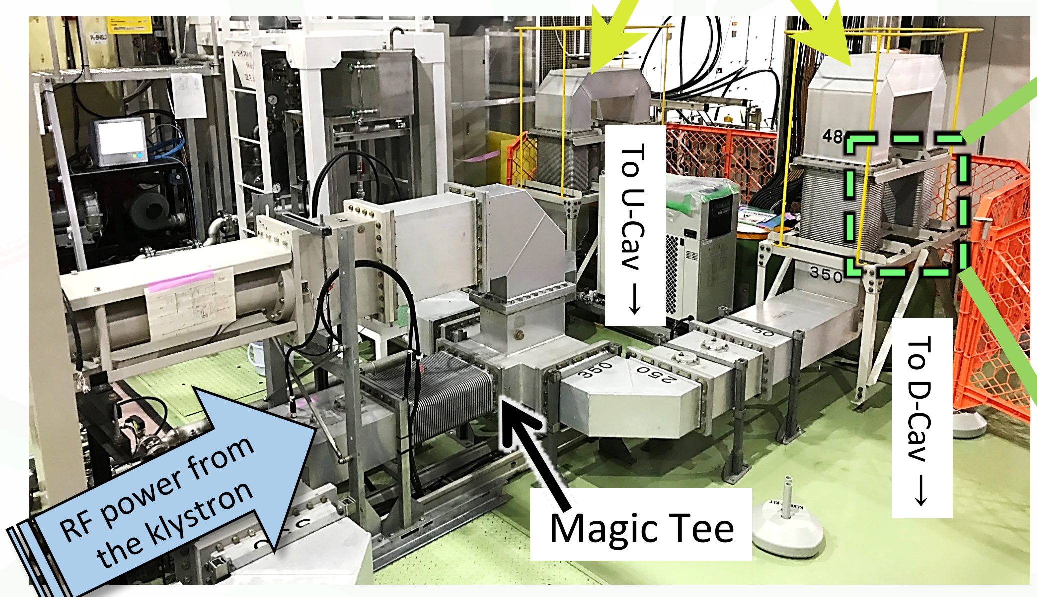
Damping Ring Cavity

Check of the relative cavity phase between Upstream and Downstream Cavities for the DR

- The relative phase was adjusted during the advance low-power RF measurement.
  ➔ This time, we verified the result by using the beam.
- Method based on the beam
  ① Operate the cavities with a constant RF power based on klystron-loop feedback
    - To establish that the synchrotron frequency (fs) does not change

  ② Change the relative cavity phase by moving the <u>phase shifters</u>
  ③ Record fs from the spectrum analyzer



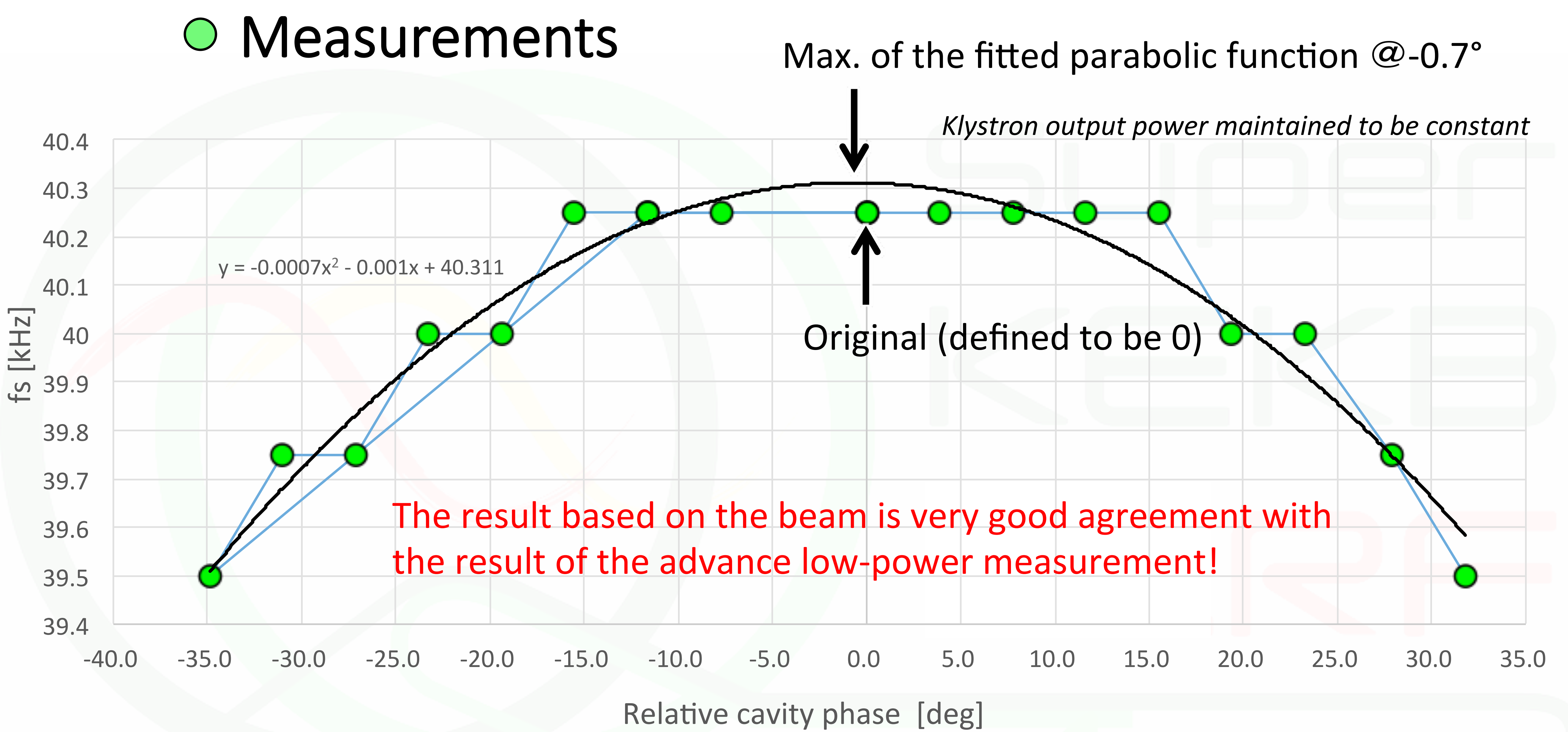


The adjustment of the WG phase shifter was confirmed by using the beam.

<Topic>
DR-Cav

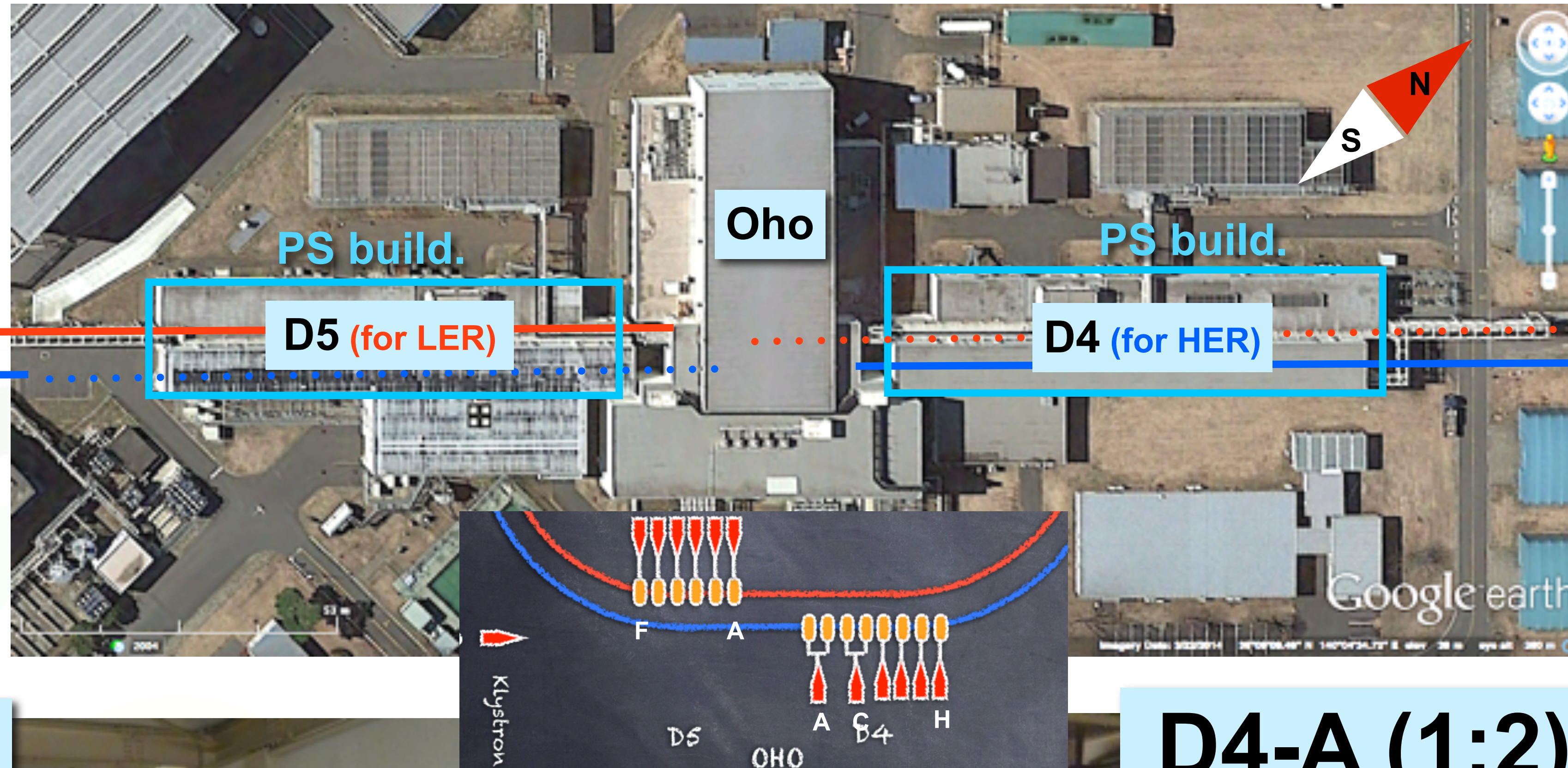
Check of the relative cavity phase between Upstream and Downstream Cavities for the DR

Measurement Results

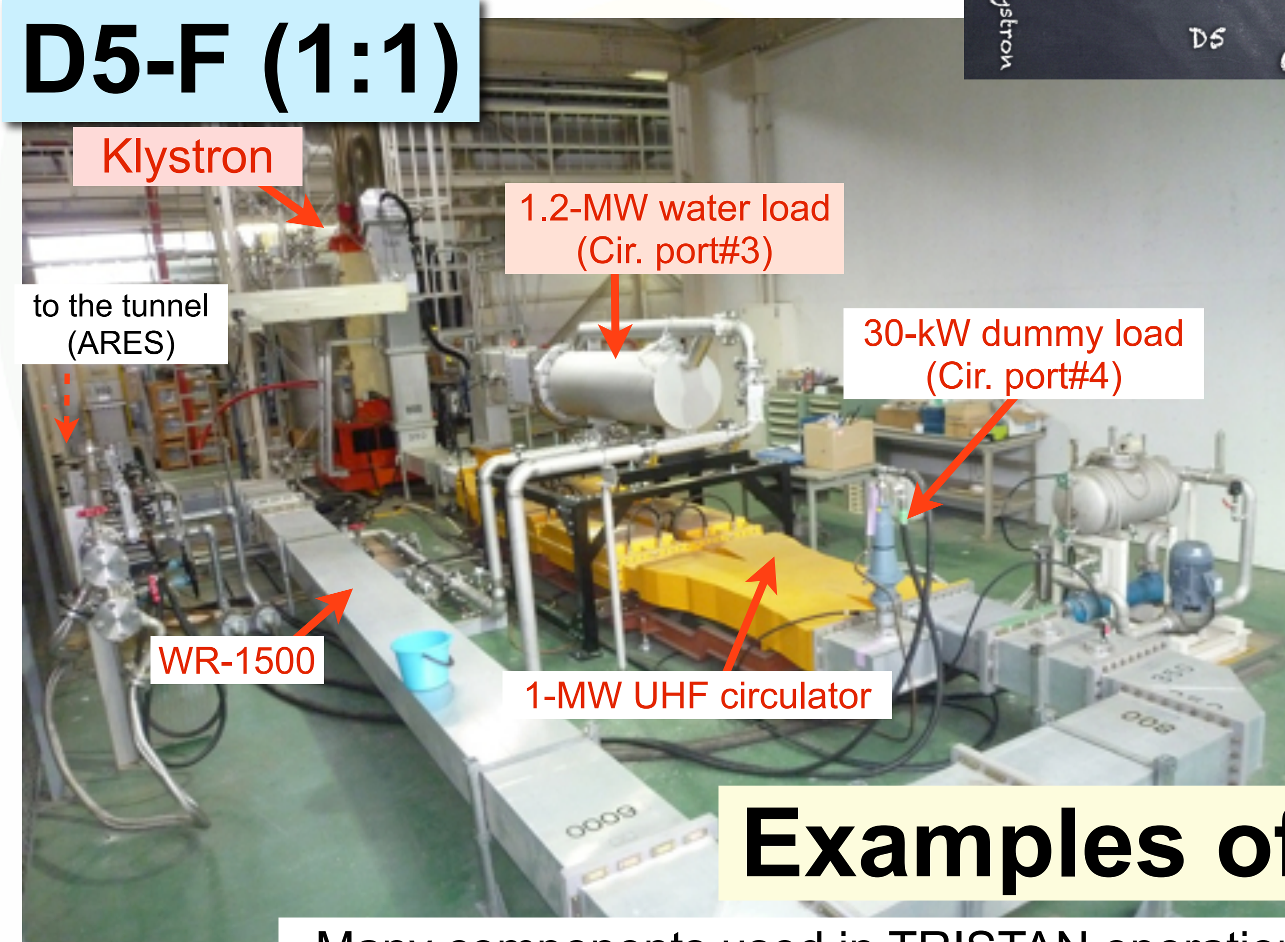


<Topic>
HPRF

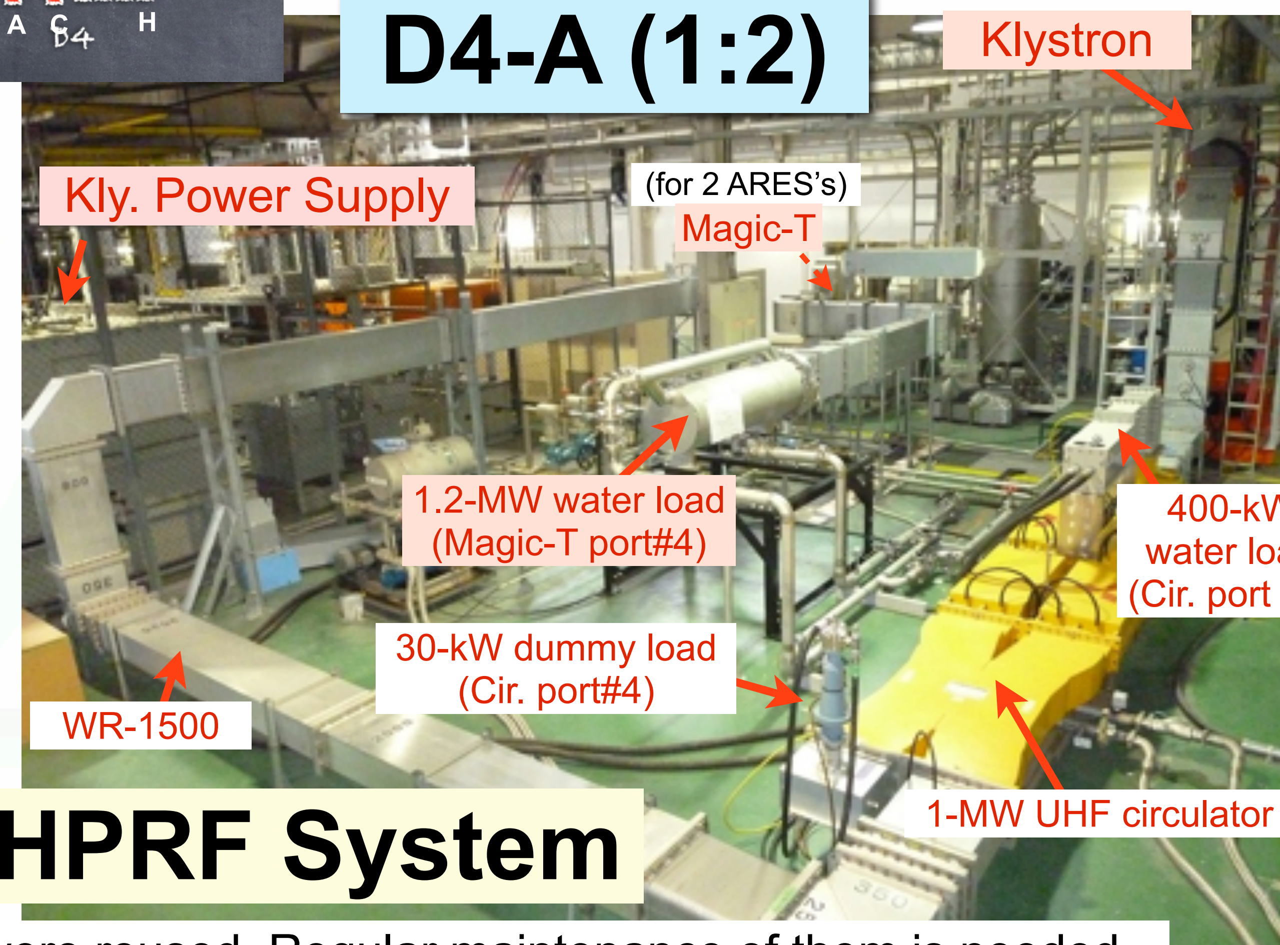
High Power RF System
(above-ground part)



D5-F (1:1)



D4-A (1:2)



Examples of HPRF System

Many components used in TRISTAN operation were reused. Regular maintenance of them is needed.

<Topic>
HPRF

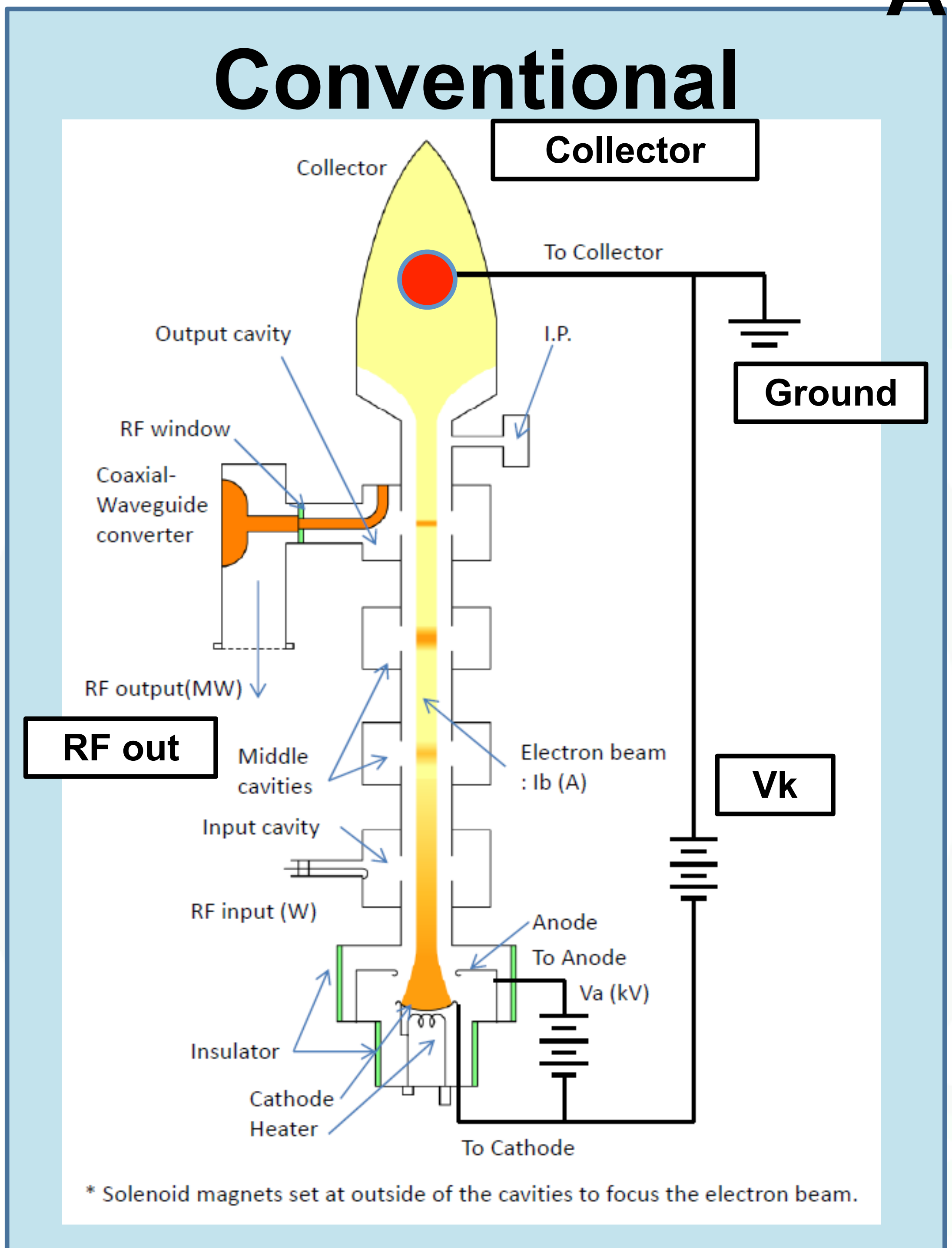
KPS Issues

In Phase 2 (2018),
MR
: One KPS (D4-GH) was tripped due to reducing a ground resistance in anode power supply by leaking of rain from the roof at May 13, then an interlock to detected anode over-current was worked. At May 16, this KPS was retuned to operation after set-up a simple rain cover on this KPS in the building.
: A stucco work to repair on a part of outer wall at D4 building was made until March 2019 before Phase 3 commissioning. We will continue the repair work for other region of outer walls.
DR
: Successfully operation.

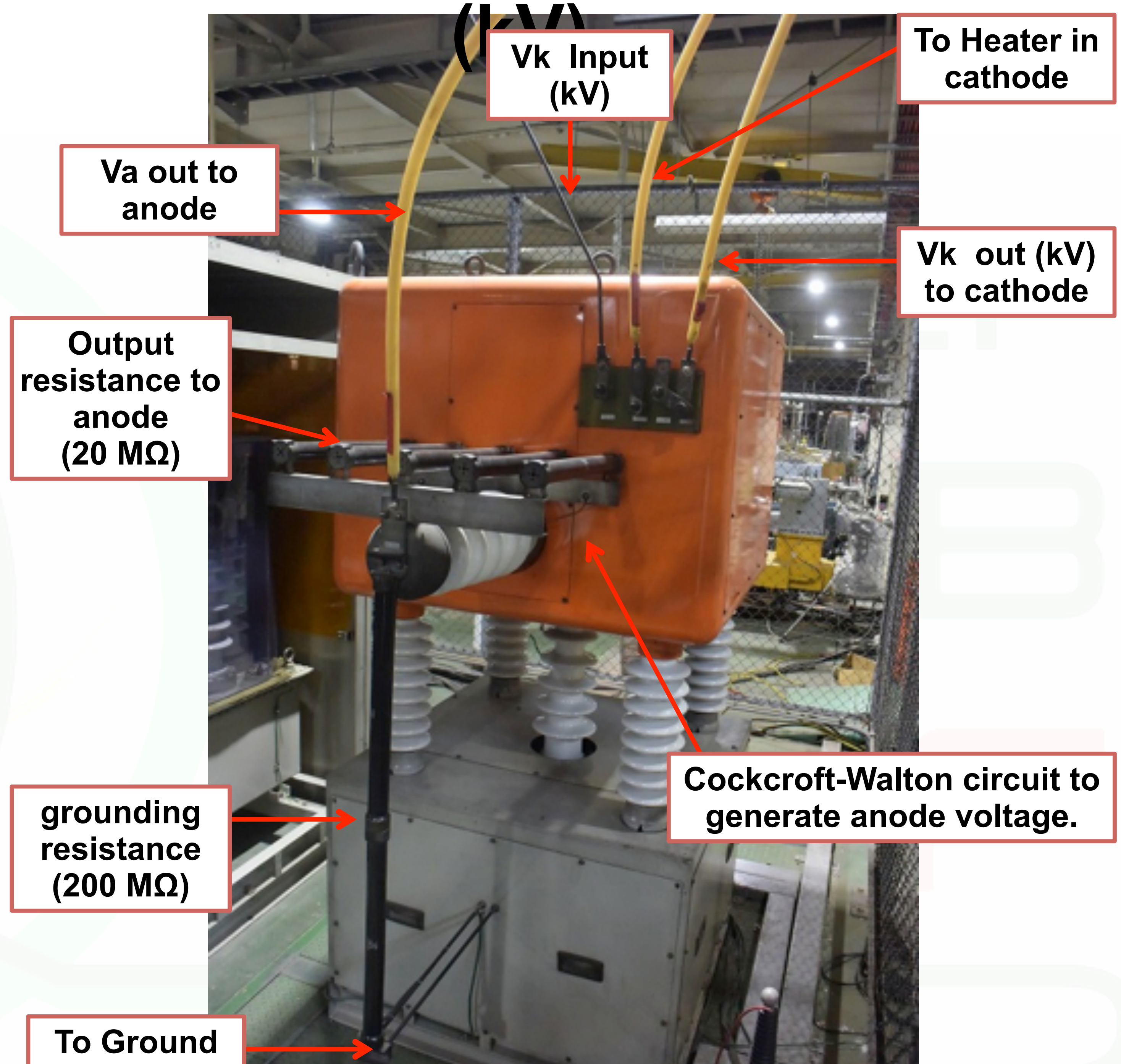
In Phase 3 (2019),
MR
: Troubles did not happened during Phase 3. -> Successfully operation.
DR
: A failure of control board in anode power supply was happened at June 18. We could not search immediately specifying a failure point in control board. To retune for operation without taking time, the anode voltage power supply was disconnect to KPS. Then, the voltage divides to anode by changing the value of resistance between the cathode, anode and ground. The anode voltage can controls roughly as a function of ratio of resistances. It was worked well, therefore, the KPS of DR was retuned at evening in June 19.
: We are planning a repair work for this KPS in this summer.

<Topic>
HPRF

KPS : connection of anode power supply

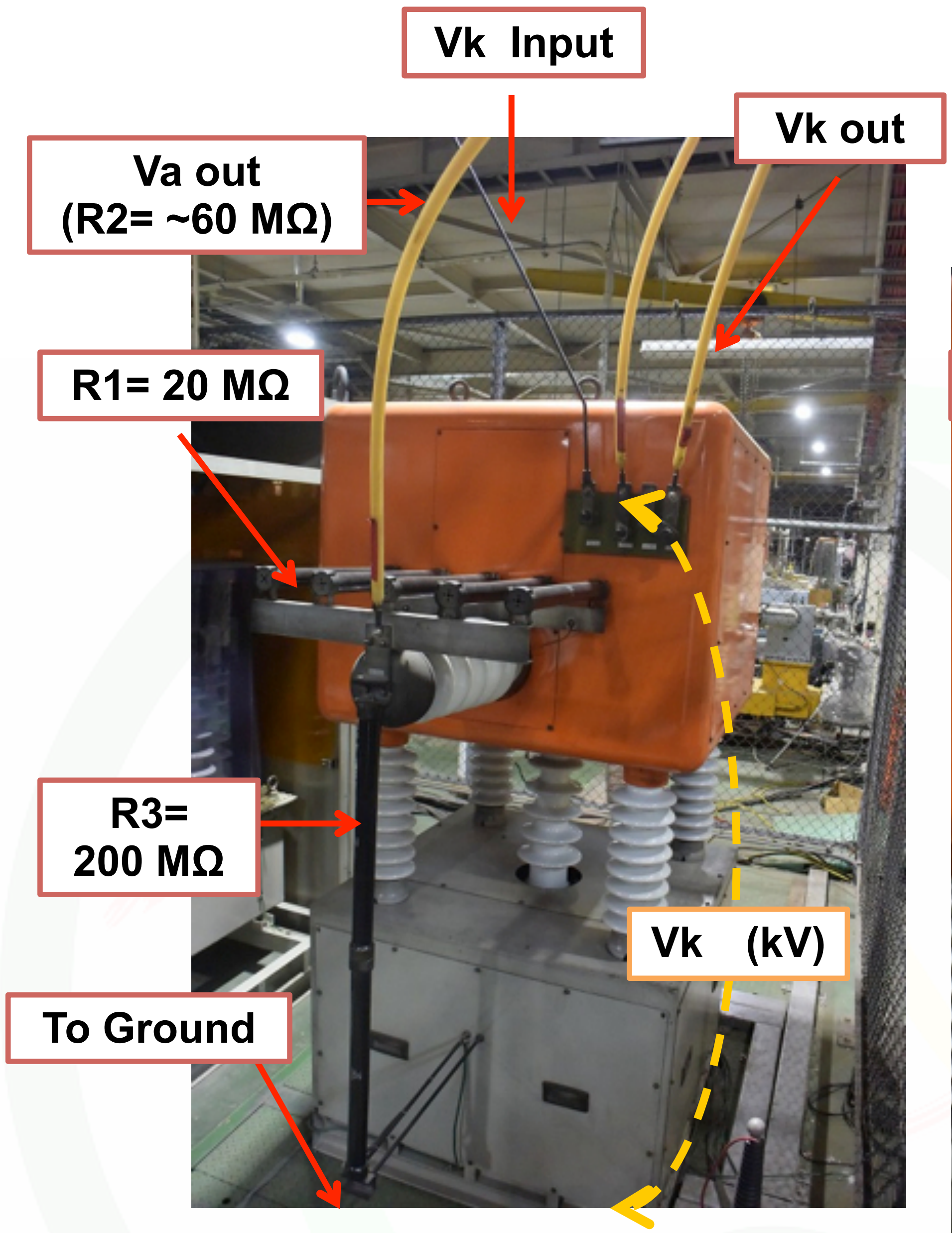


Anode power supply to generate Va (kV)

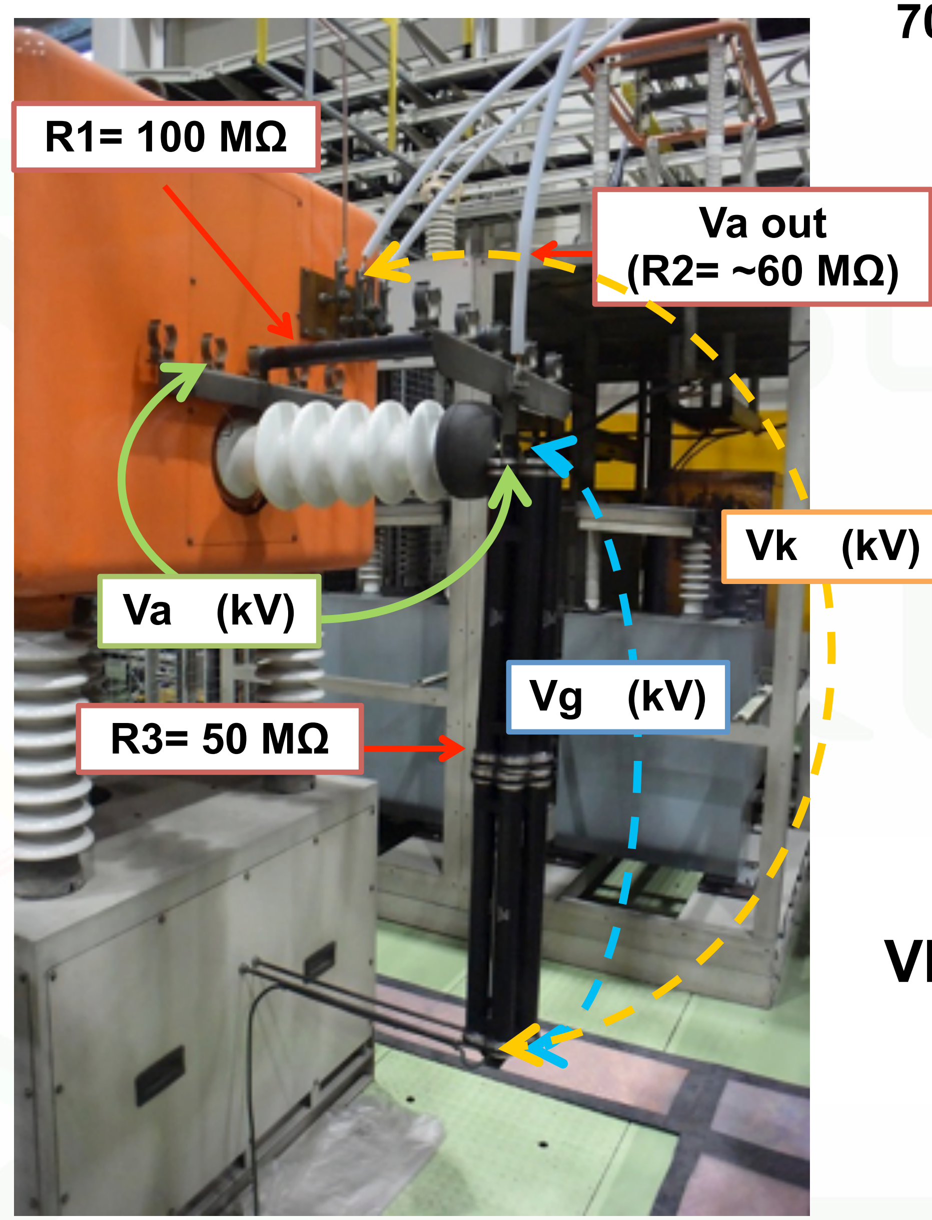


<Topic>
HPRF

Anode Voltage divides replacing by resisters after disconnect the Cockcroft-Walton circuit

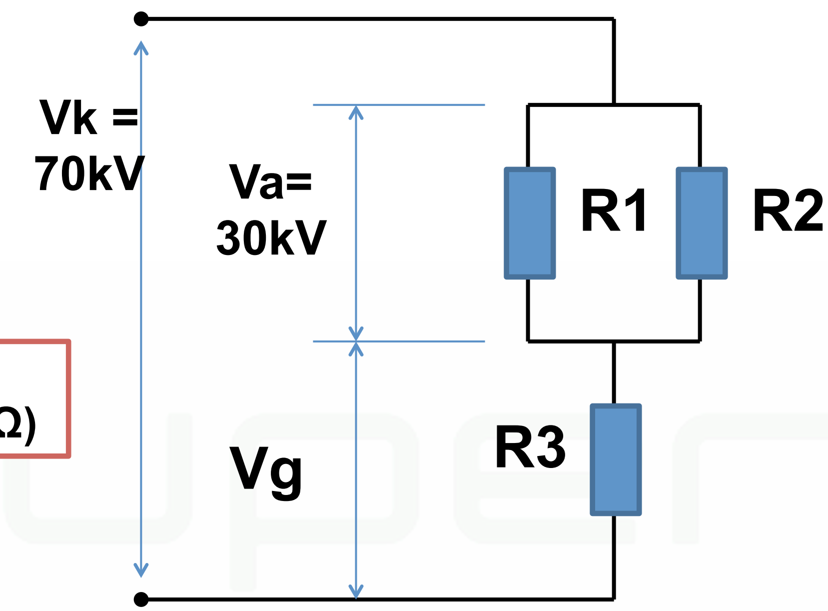


Conventional

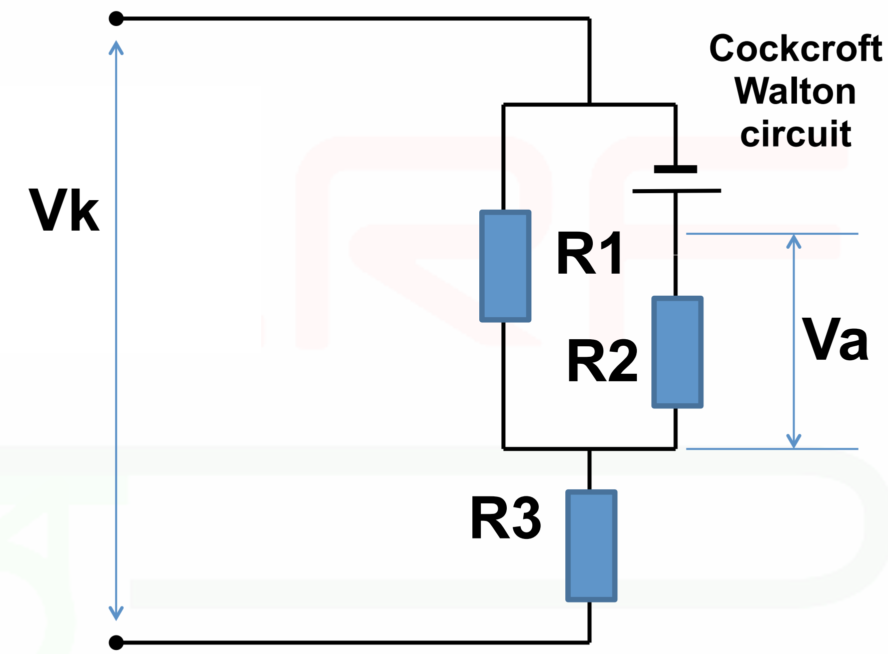


After disconnect the Cockcroft-Walton circuit and replacing the resistors.

Equivalent circuit
Without Cockcroft-Walton circuit



Equivalent circuit (Conventional)



<Topic>
HPRF

High-power components Issue 1

•1MW UHF Circulator (Total 31 circulators used for SuperKEKB)

Number of overhaul: Three circulators repaired from April 2018 to March 2019.
Before starting Phase2, they were replaced to other circulators which a repair should be necessary. We are planning that two circulators repair until Dec 2019.

New production: One circulator was manufactured until March 2019.
We propose the next production for one circulator until March 2022.

<Topic>
HPRF

High-power components Issue 2

•1.2 MW high-power water loads
(Two type loads used which are the rectangular type (18) and the cylindrical type (12).)

In Phase2,
-> Water leak trouble was happened from two cylindrical type water loads.
A cause of water leak is that a ceramic rf windows was broken by mechanical stress.
After Phase2, the broken loads were repaired.

D4-G (HER) -> At April 5, a water leak trouble happened, then the leaked water was infiltrated to inside waveguide system. It was detected by checking with eyes, after judged the monitoring values of LLRF are abnormal. The cavity was detuned and removed to operation after drying inside waveguide by blower.
At evening on April 6, the operation of HER was restarted.
-> The load changed to spare until May 16, then rf station was retuned to operation.
-> After this trouble, a water-leak detector was installed for all water-loads.

D5-D (LER) -> At July 1, a water leak trouble happened.
-> Water-leak detector worked well before infiltrating leaked water to inside waveguide system.
-> So, the cavity was detuned and removed to operation within few hours.

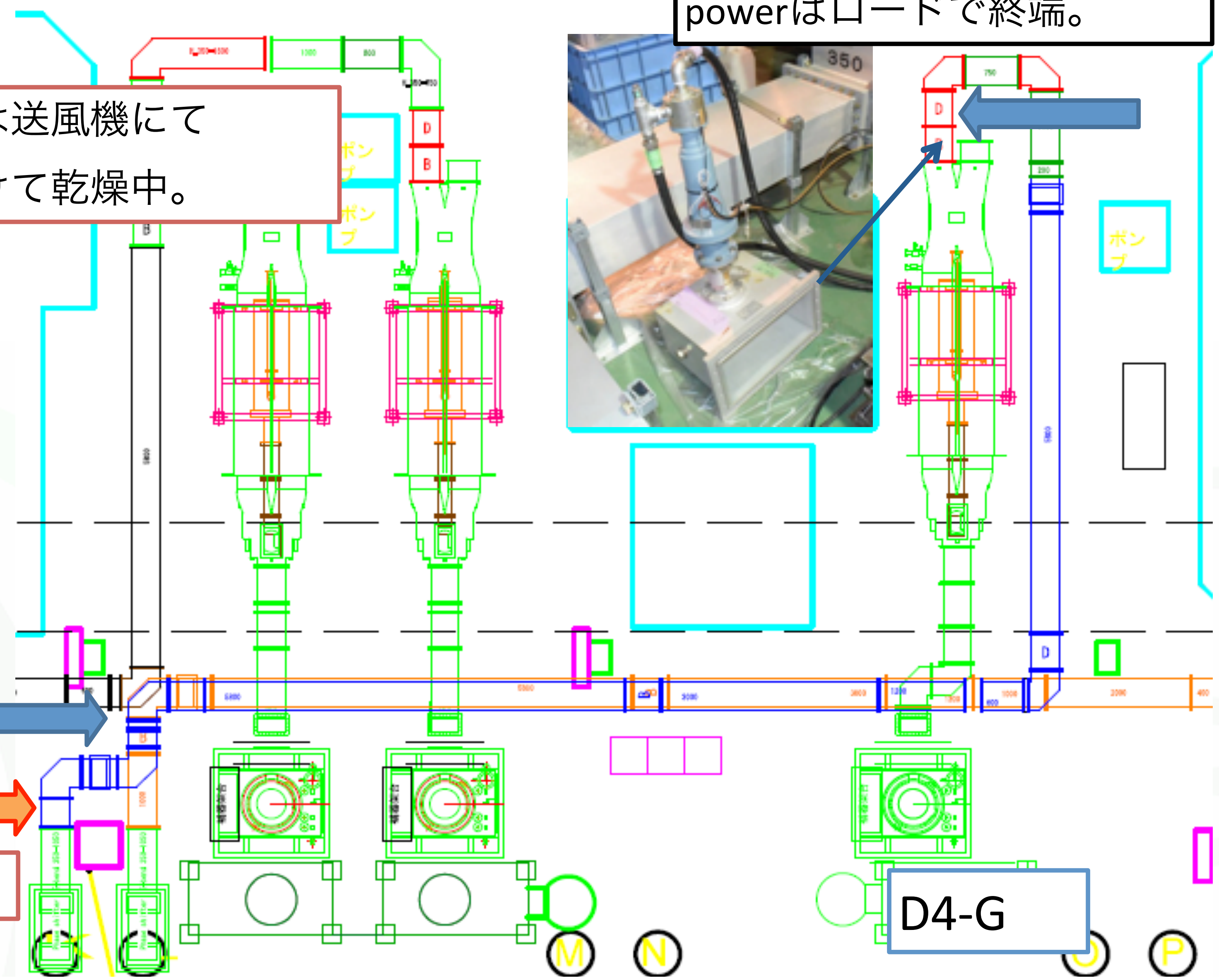
In the Phase3, the trouble of loads are not happened never.

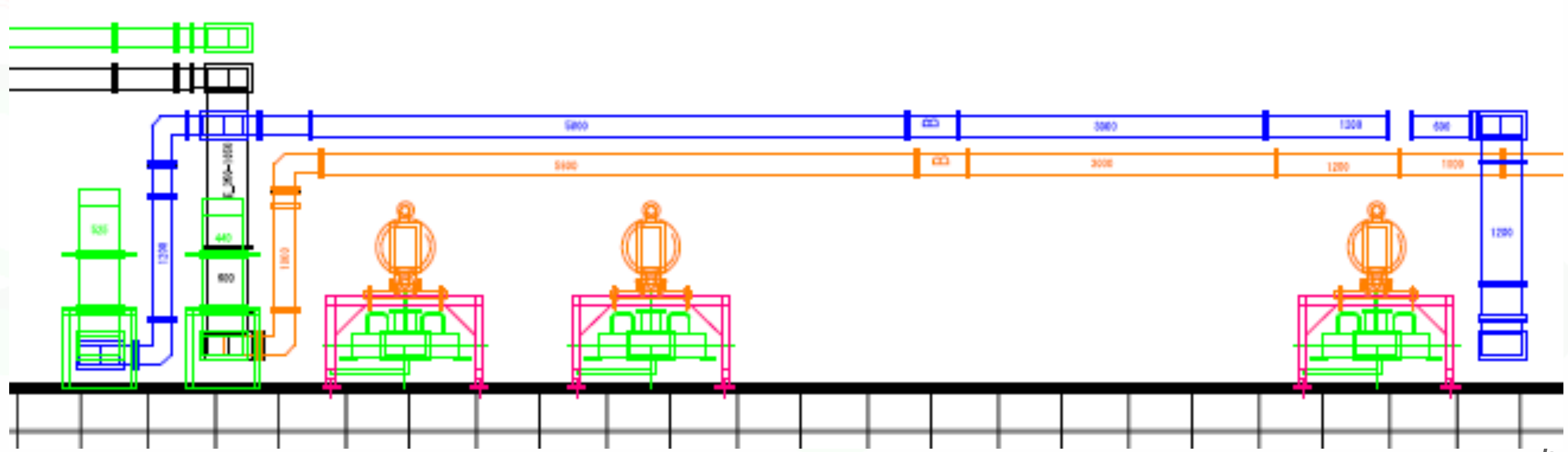
<Topic>
HPRF

To the tunnel

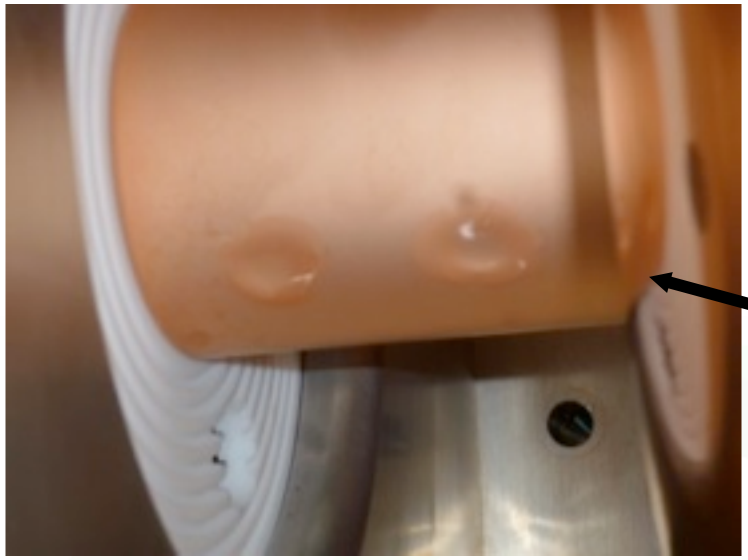
導波管内は送風機にて
区間を分けて乾燥中。

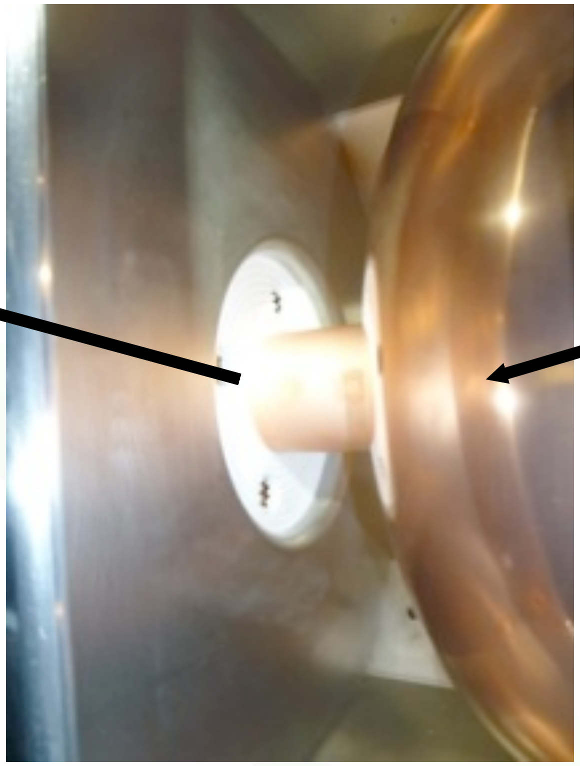
空洞からのBeam induce
powerはロードで終端。

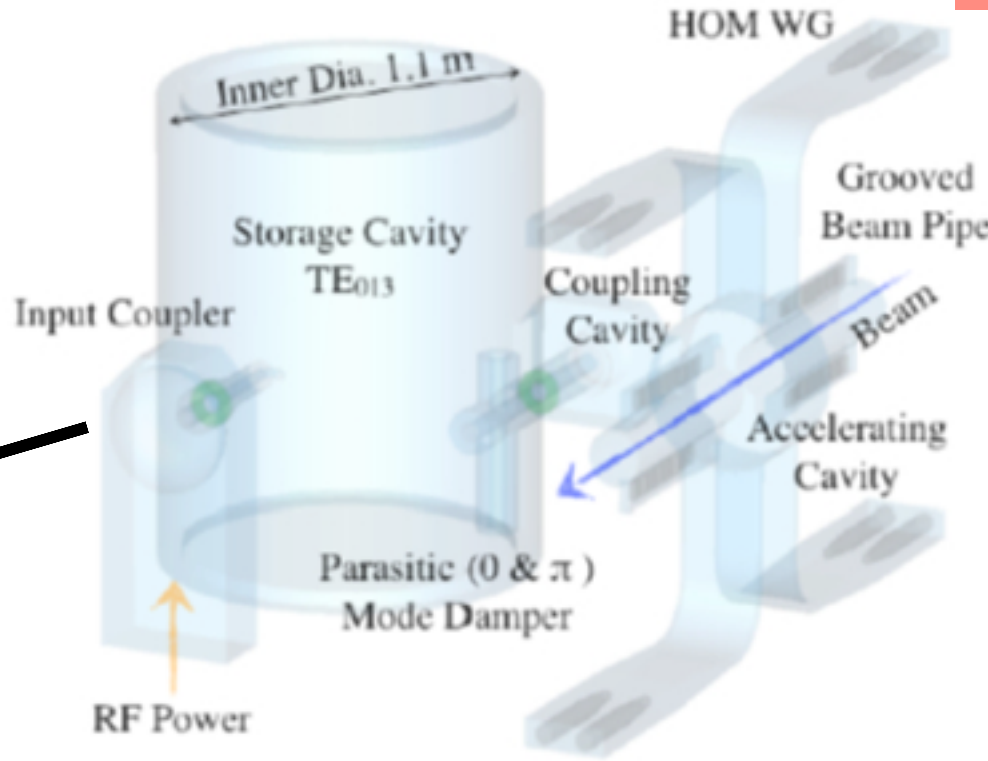


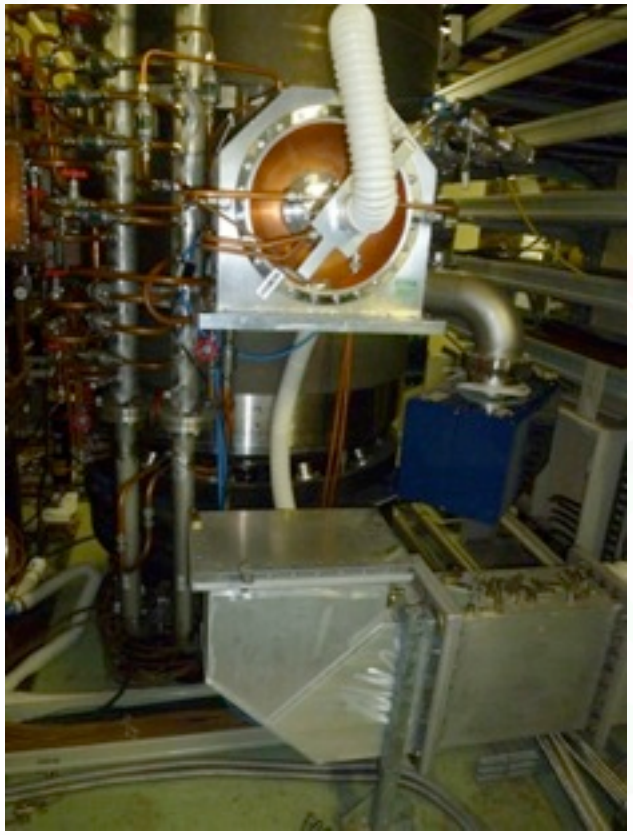


<Topic>
HPRF






HOM WG
Inner Dia. 1.1 m
Grooved
Beam Pipe
Storage Cavity
TE_{013}
Input Coupler
Coupling
Cavity
Beam
Accelerating
Cavity
Parasitic (0 & π)
Mode Damper
RF Power




To cavity