RF System for SuperKeKB *

The 16th KEKB Accelerator Review Committee

2011.02.08

KAGEYAMA, T.

on behalf of

KEKB RF Group

* *SuperKeKB* stands for Nano Beam Scheme.

Contents

- RF system Overview
    - RF-related Machine Parameters
    - Upgrade Plans
- ARES Cavity
- Superconducting Cavity
- New Digital LLRF System

“Cavity for Damping Ring” reported by T. Abe right after my talk.

A big change brought after the previous review.

RF-related machine parameters

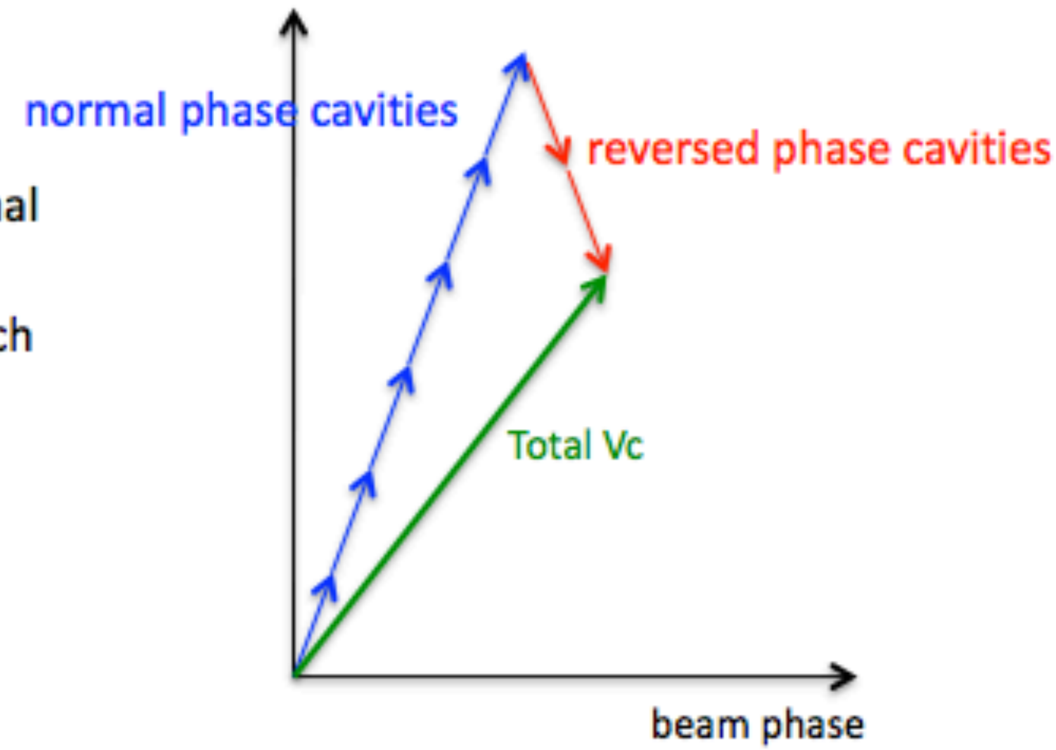
	unit	SuperKEKB (design as of Feb. 2010)		SuperKEKB (design as of Nov. 2010)			
Ring		LER	HER	LER	HER	HER	HER
Wiggler		Full	None	Full	None	60 %	Full
Beam Energy	GeV	4.0	7.0	4.000	7.007	7.007	7.007
Beam Current	A	3.60	2.62	3.6	2.6	2.6	2.6
Number of Bunches		2503	2503	2500	2500	2500	2500
Bunch Length	mm	6	5	6	5	5	5
Energy loss/turn	MV	2.15	2.50	1.87	2.07	2.43	2.67
Momentum compaction		2.74E-4	1.88E-4	3.49E-4	4.55E-4	4.55E-4	4.54E-4
Radiation Loss	MW	7.74	6.55	6.73	5.38	6.32	6.94
Loss factor, assumed	V/pC	25	40	30	40	40	40
Parasitic Loss	MW	1.30	1.10	1.56	1.09	1.09	1.09
Total Beam Power	MW	9.04	7.65	8.30	6.47	7.41	8.03
RF Voltage	MV	8.4	6.7	9.4	12.4	14.7	15.8

HER RF Voltage almost doubled or more!

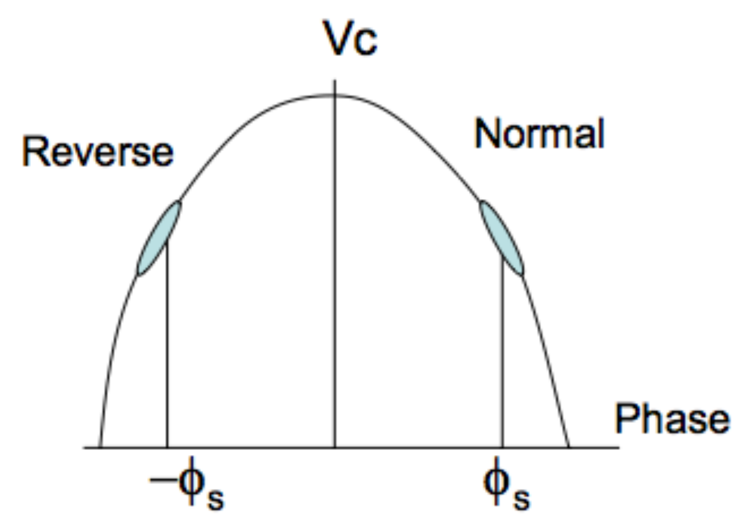
Consequently, the reversed-phase operation of SCC not being needed although successfully demonstrated in KEKB.

Reversed phase operation of SCC

- **What is this scheme?**
  - Phase of some SC cavities are set on the time-rising side (reversed phase), while others on the time-descending side (normal phase).
  - Low total RF voltage is obtained, while each cavity is operated at a high voltage.
  - Beam power is shared by all cavities, including the reversed phase ones.



- **Merits**
  - No need to change the input coupling.
  - Detuning frequency is relatively small. Furthermore, the impedance of the reversed-phase cavities cancels that of normal phase ones. Then the -1 mode instability growth rate becomes acceptably small.
  - Gap transient also cancels out.



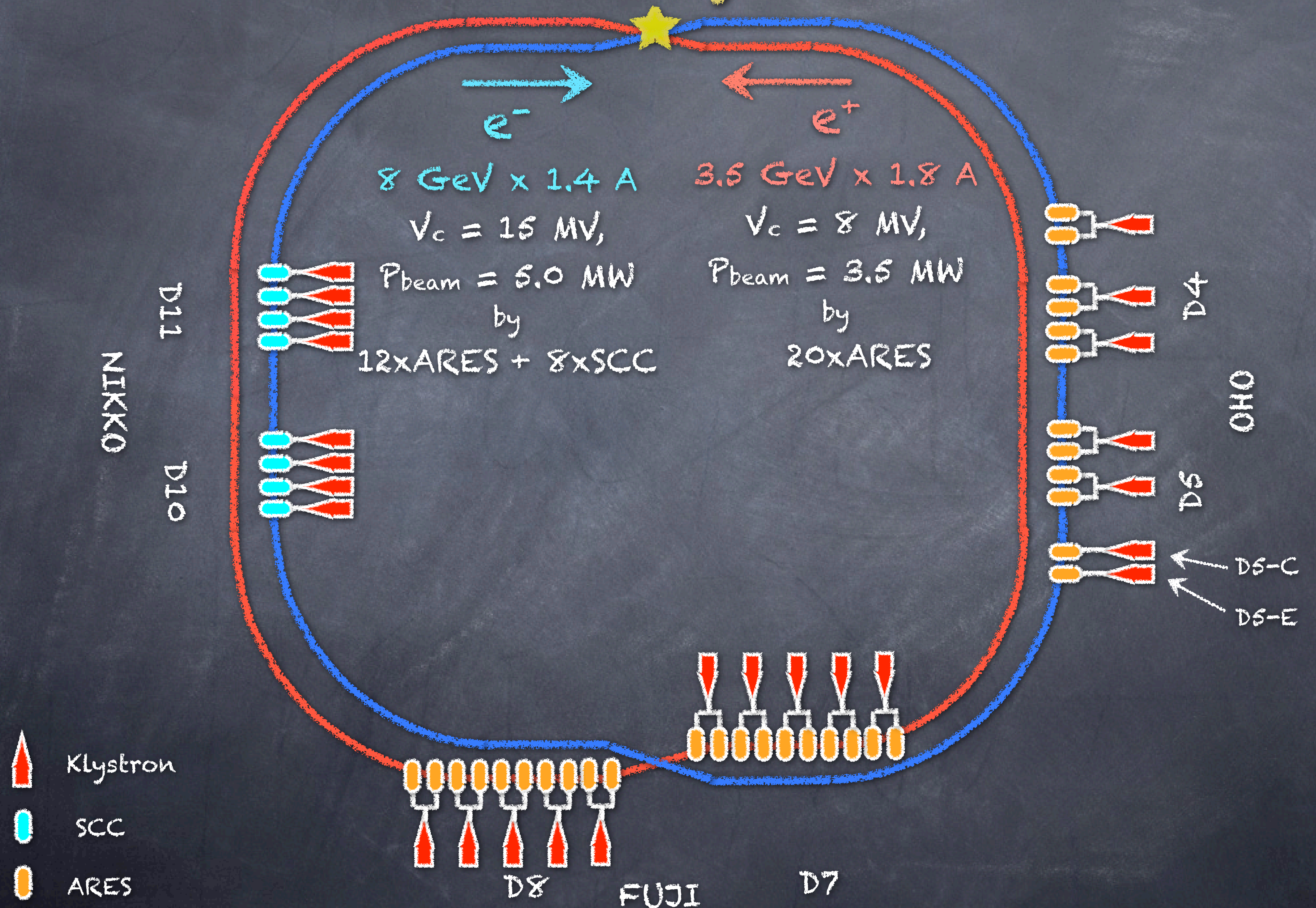
Details reported by Y. Morita last year.

RF-related machine parameters

K. Akai (Nov. 25, 2010)

	unit	KEKB (operation)		SuperKEKB (design as of Nov. 2010)			
Ring		LER	HER	LER	HER	HER	HER
Wiggler		Full	None	Full	None	60 %	Full
Beam Energy	GeV	3.5	8.0	4.000	7.007	7.007	7.007
Beam Current	A	1.8	1.4	3.6	2.6	2.6	2.6
Number of Bunches		1585	1585	2500	2500	2500	2500
Bunch Length	mm	6 ~ 7	6 ~ 7	6	5	5	5
Energy loss/turn	MV	1.5	3.5	1.87	2.07	2.43	2.67
Momentum compaction				3.49E-4	4.55E-4	4.55E-4	4.54E-4
Radiation Loss	MW	2.7	4.9	6.73	5.38	6.32	6.94
Loss factor, assumed	V/pC			30	40	40	40
Parasitic Loss	MW			1.56	1.09	1.09	1.09
Total Beam Power	MW	~ 3.5	~ 5.0	8.30	6.47	7.41	8.03
RF Voltage	MV	8.0	15.0	9.4	12.4	14.7	15.8

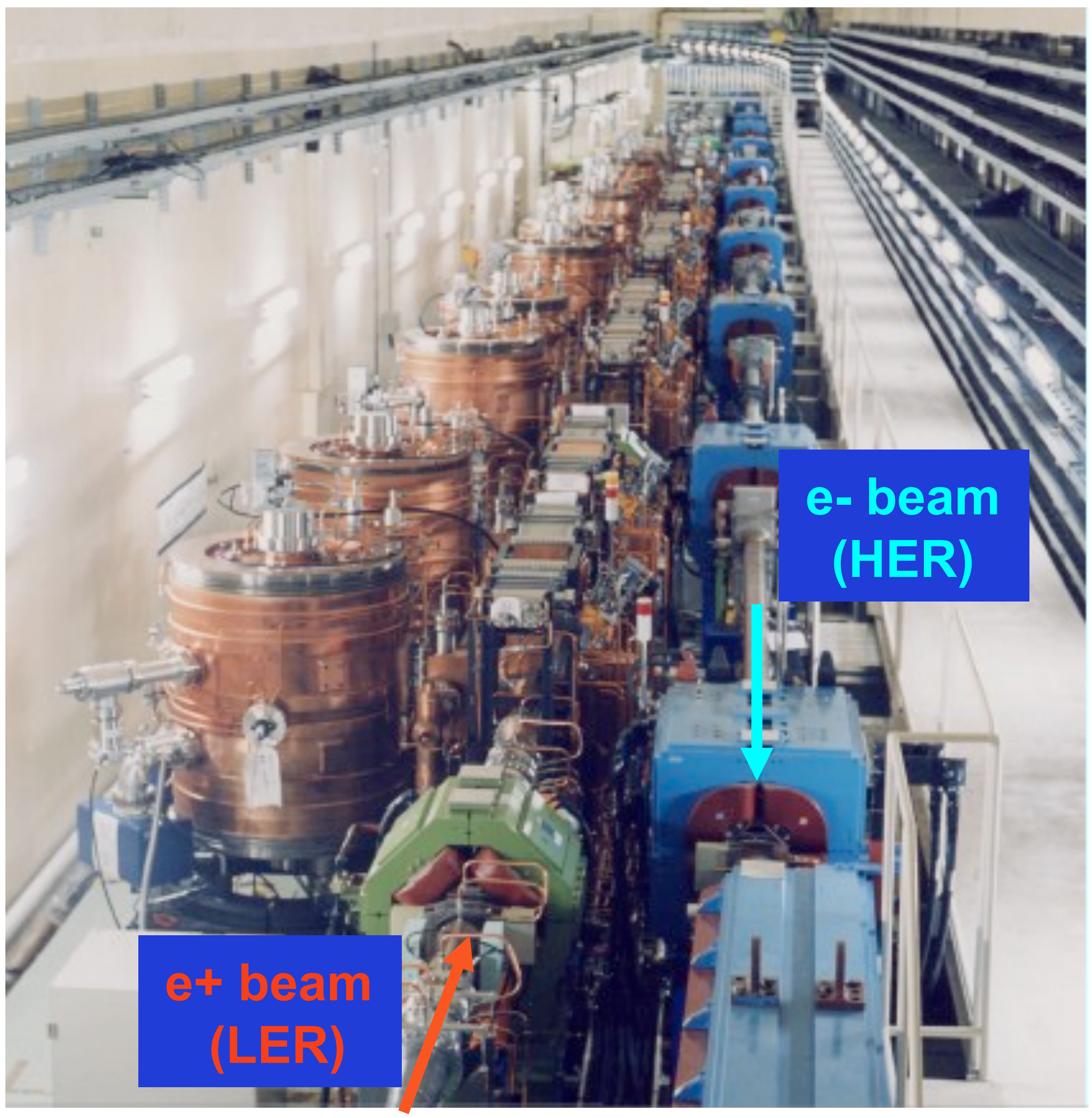
KEKB RF System



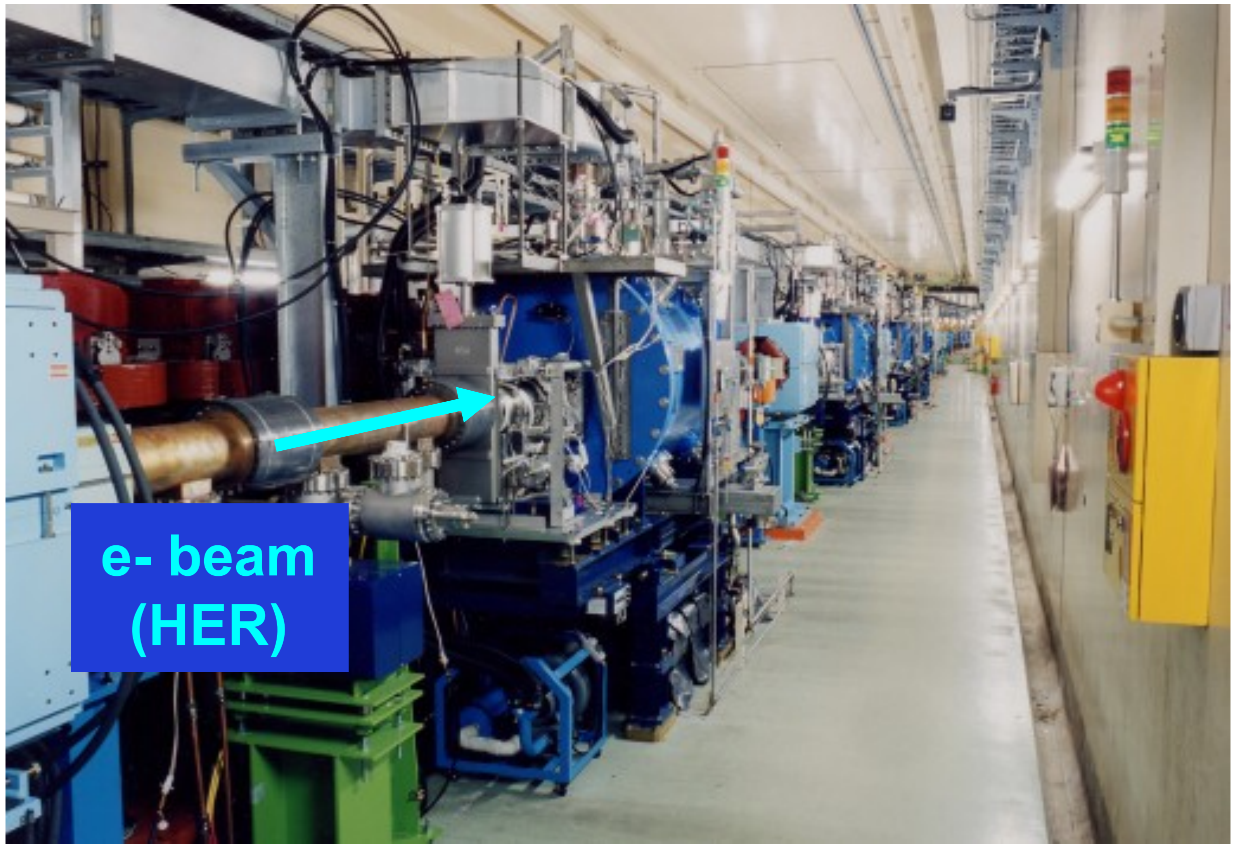
Two Types of Accelerating Cavities for KEKB

32 Normal Conducting (NC)
ARES Cavities:
20 for LER and 12 for HER

8 Superconducting (SC) Cavities
for HER



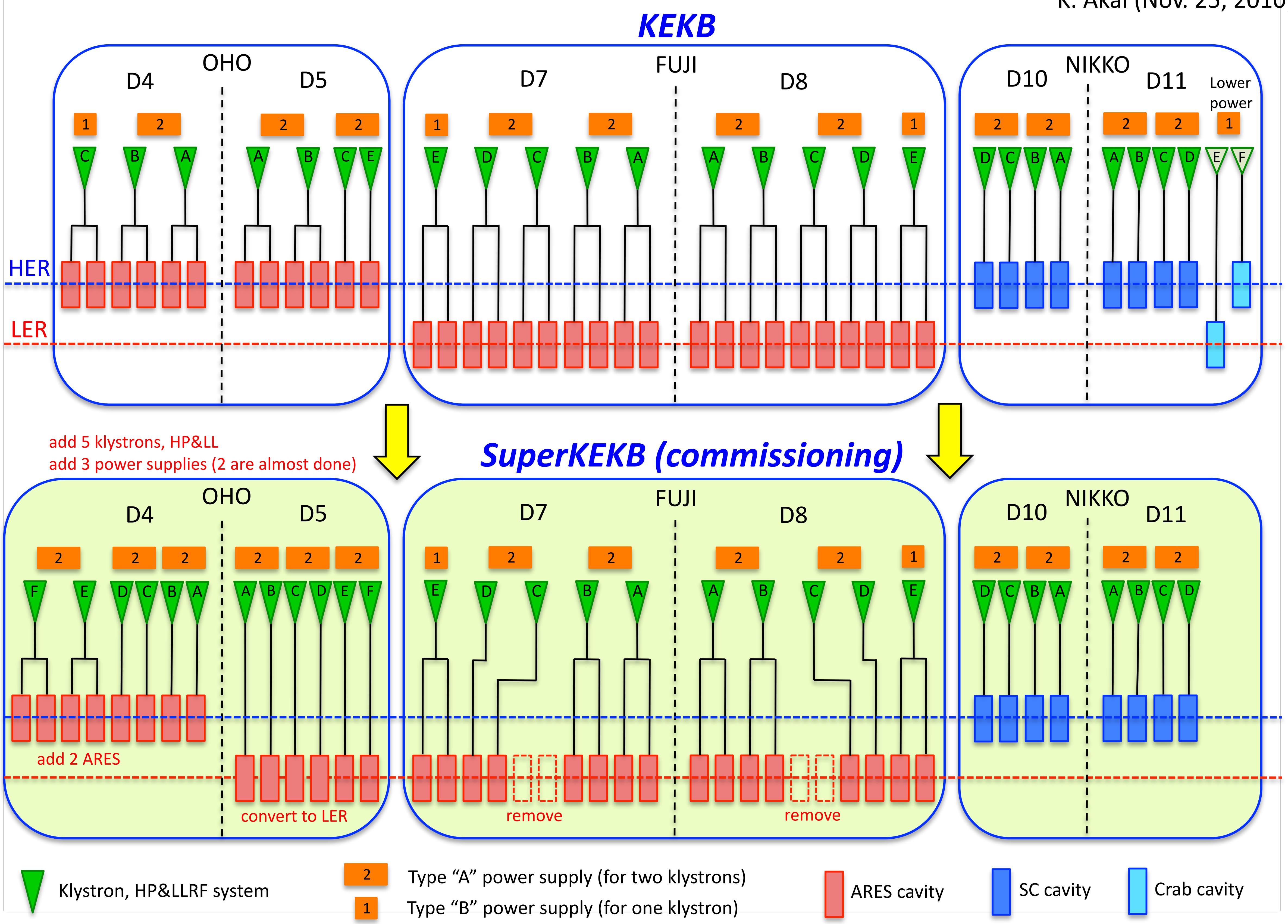
Fuji RF Section D7



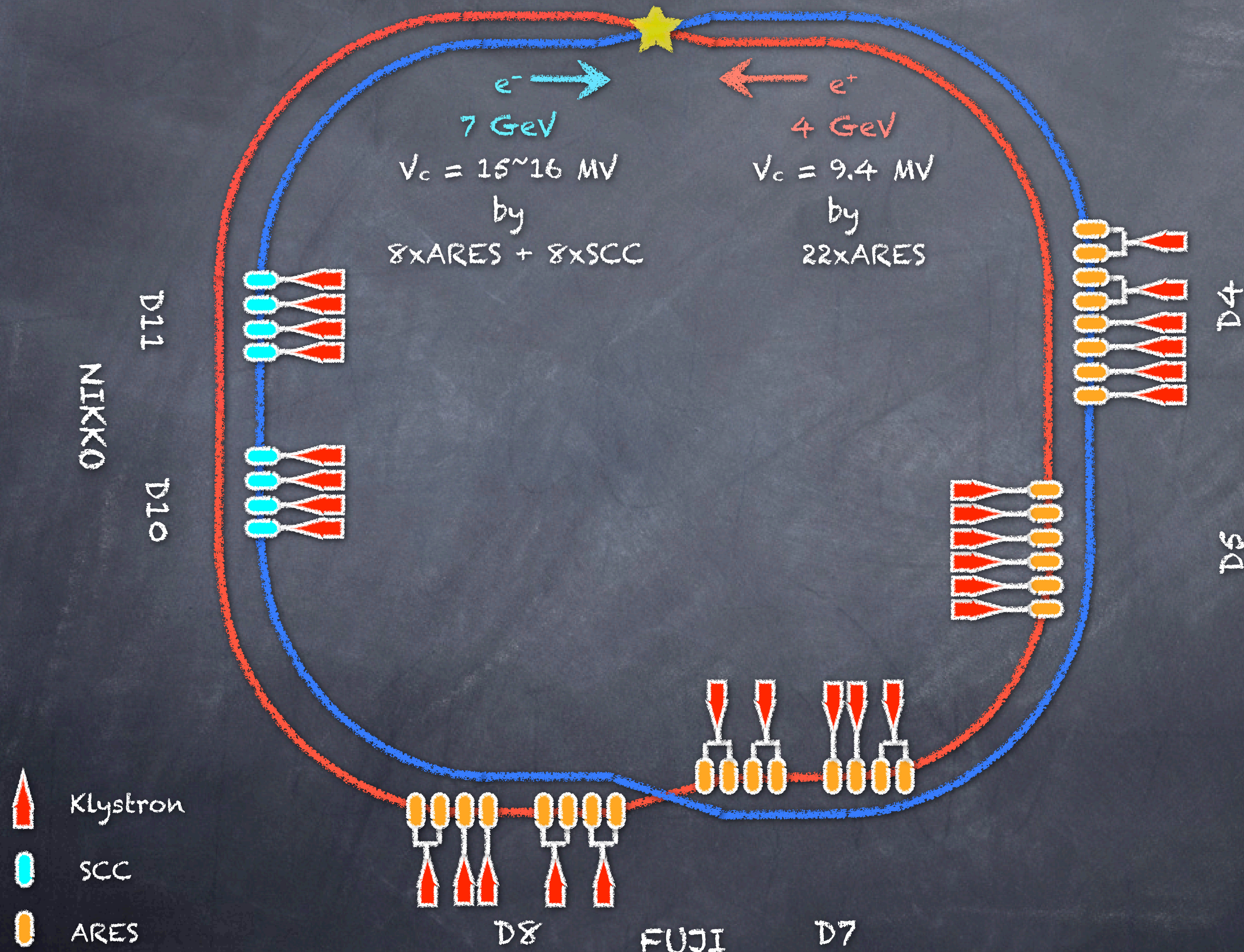
Nikko RF Section D11

RF Upgrade Plan (commissioning stage)

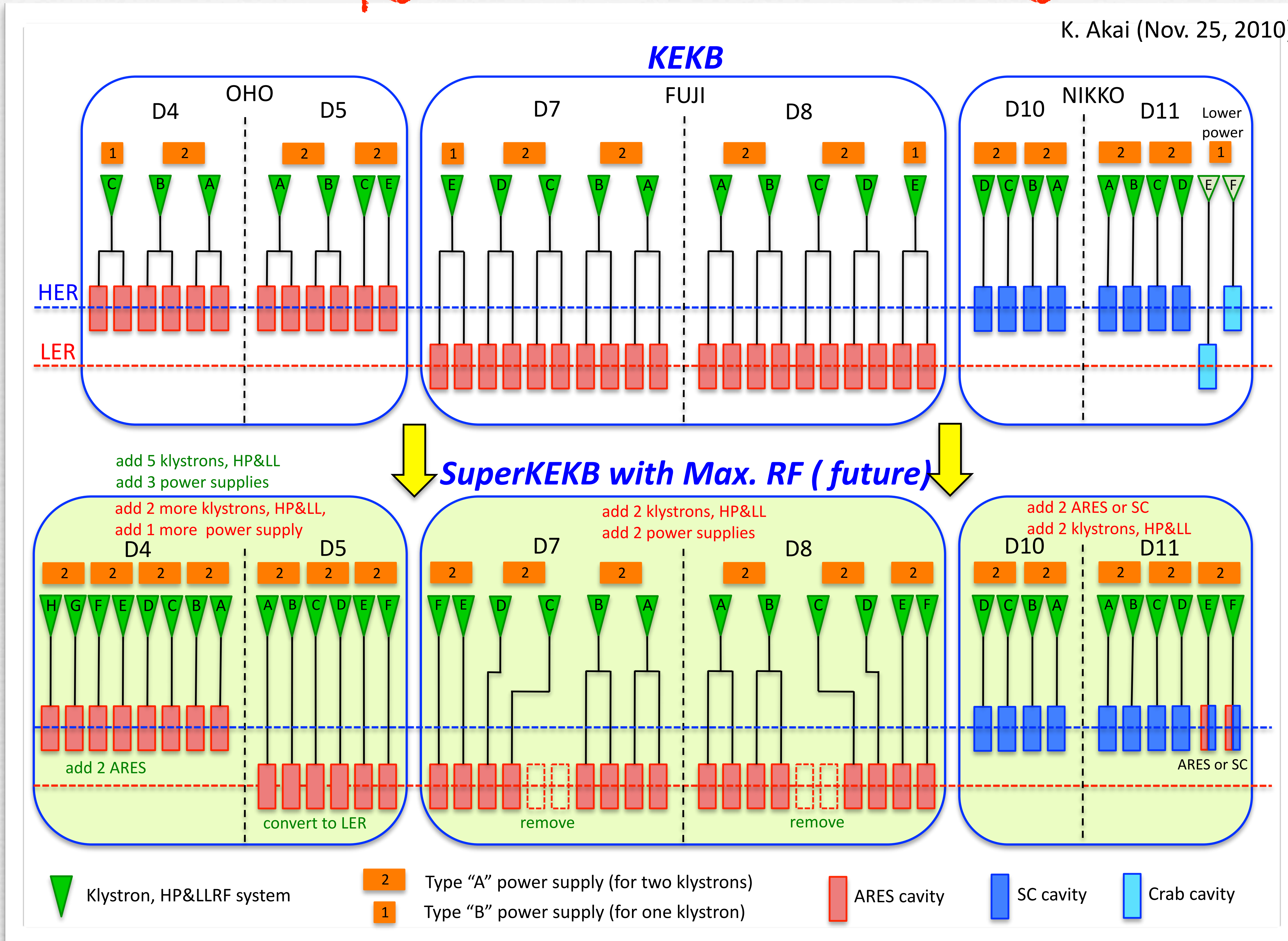
K. Akai (Nov. 25, 2010)



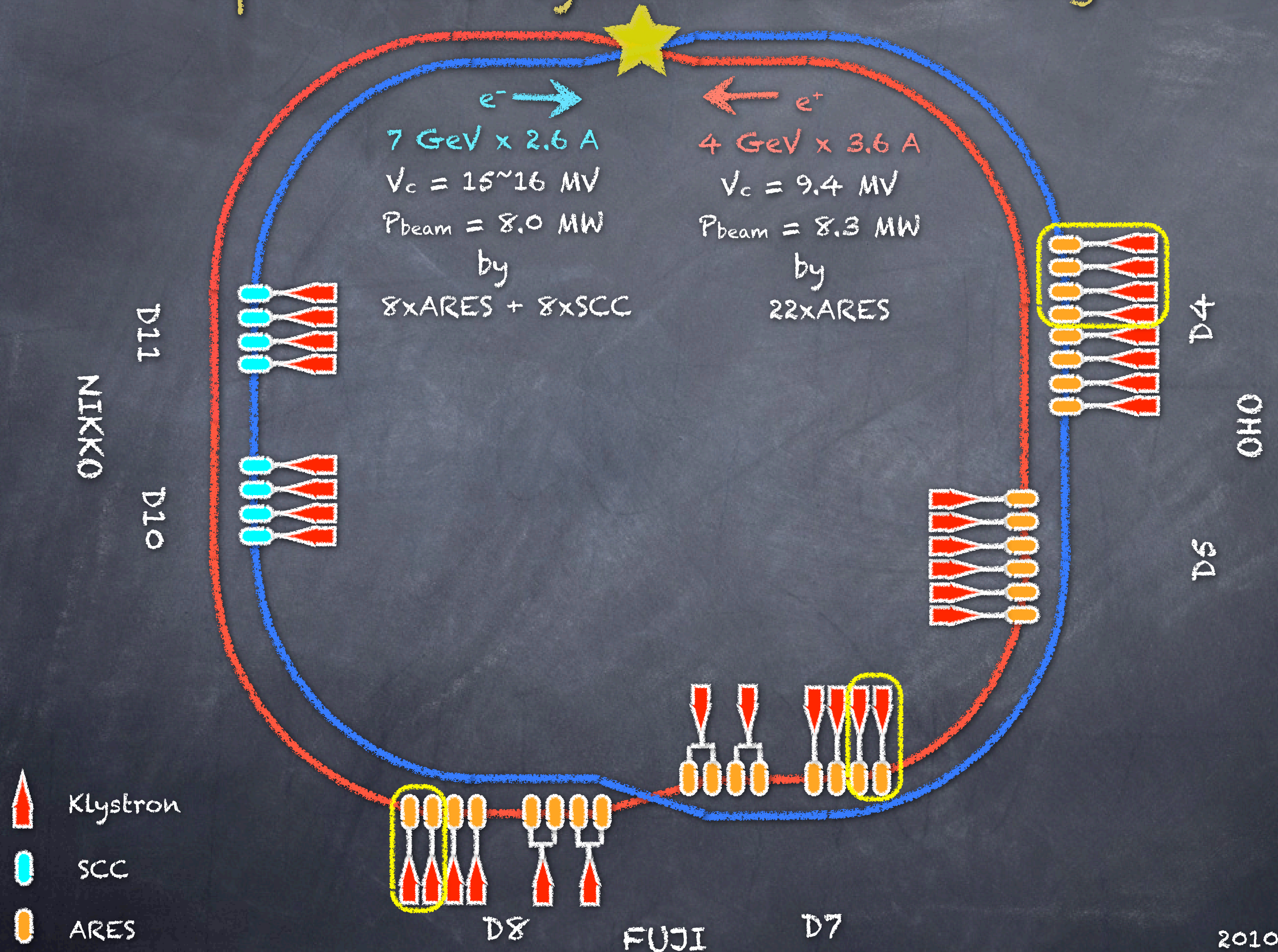
SuperKEKB will start up with



RF Upgrade Plan (ultimate stage)

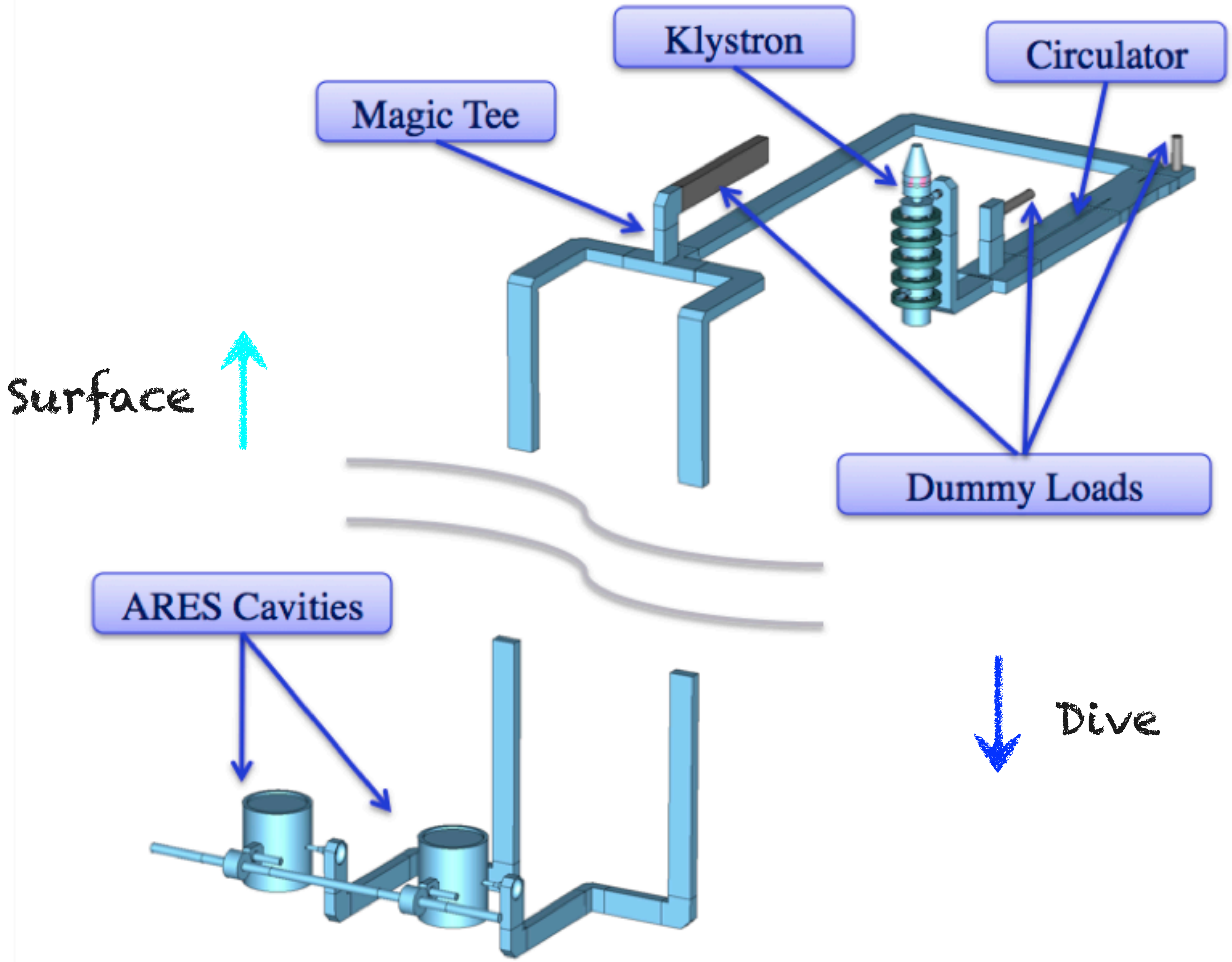


SuperKeKB RF System at Ultimate Stage



2010.11.25

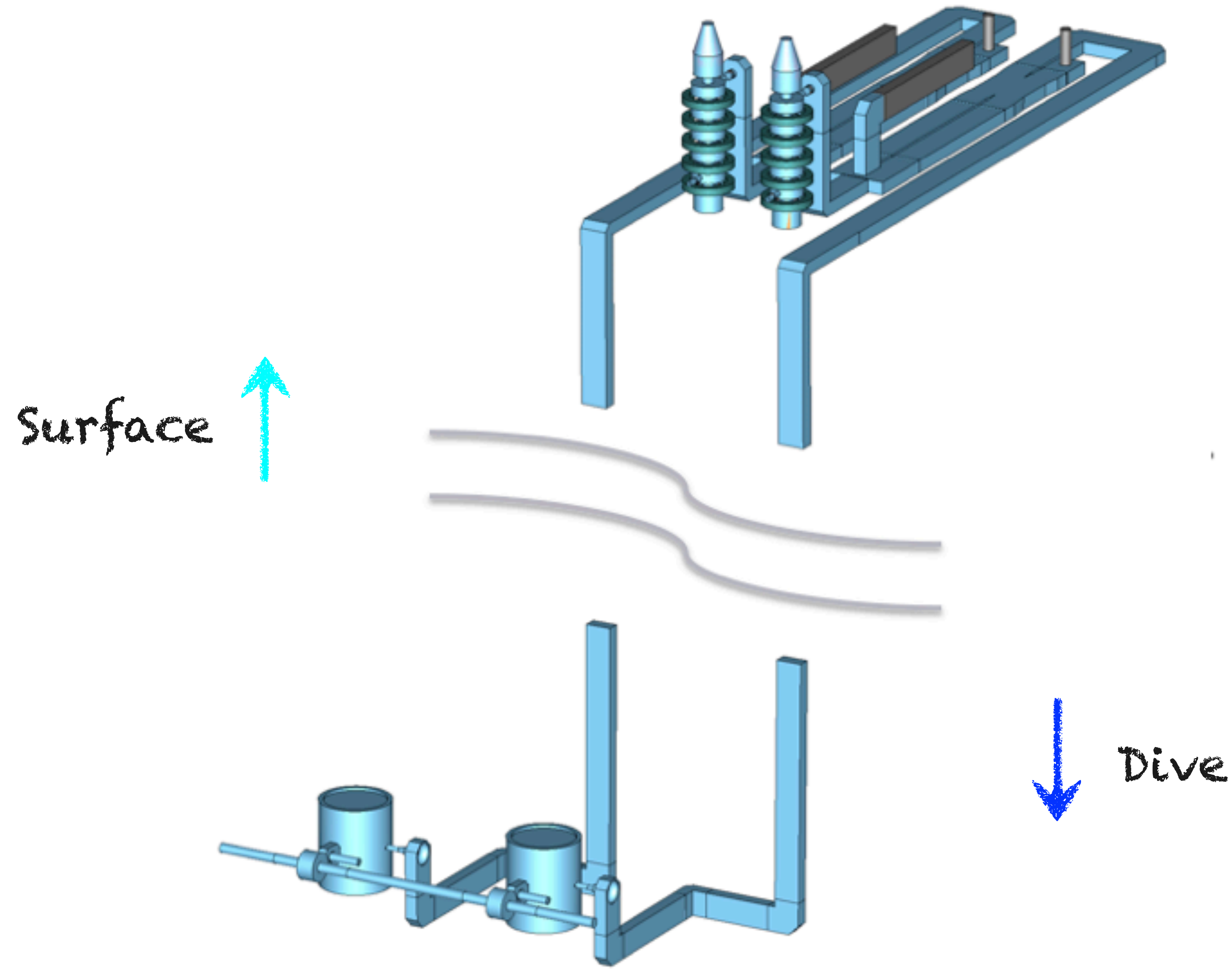
One-to-Two Configuration of NC RF System (regular in KEKB)



2 x P_{wall}(~150kW) + 2 x P_{beam}(~200kW) = ~700kW / Klystron

One klystron drives two ARES cavities.

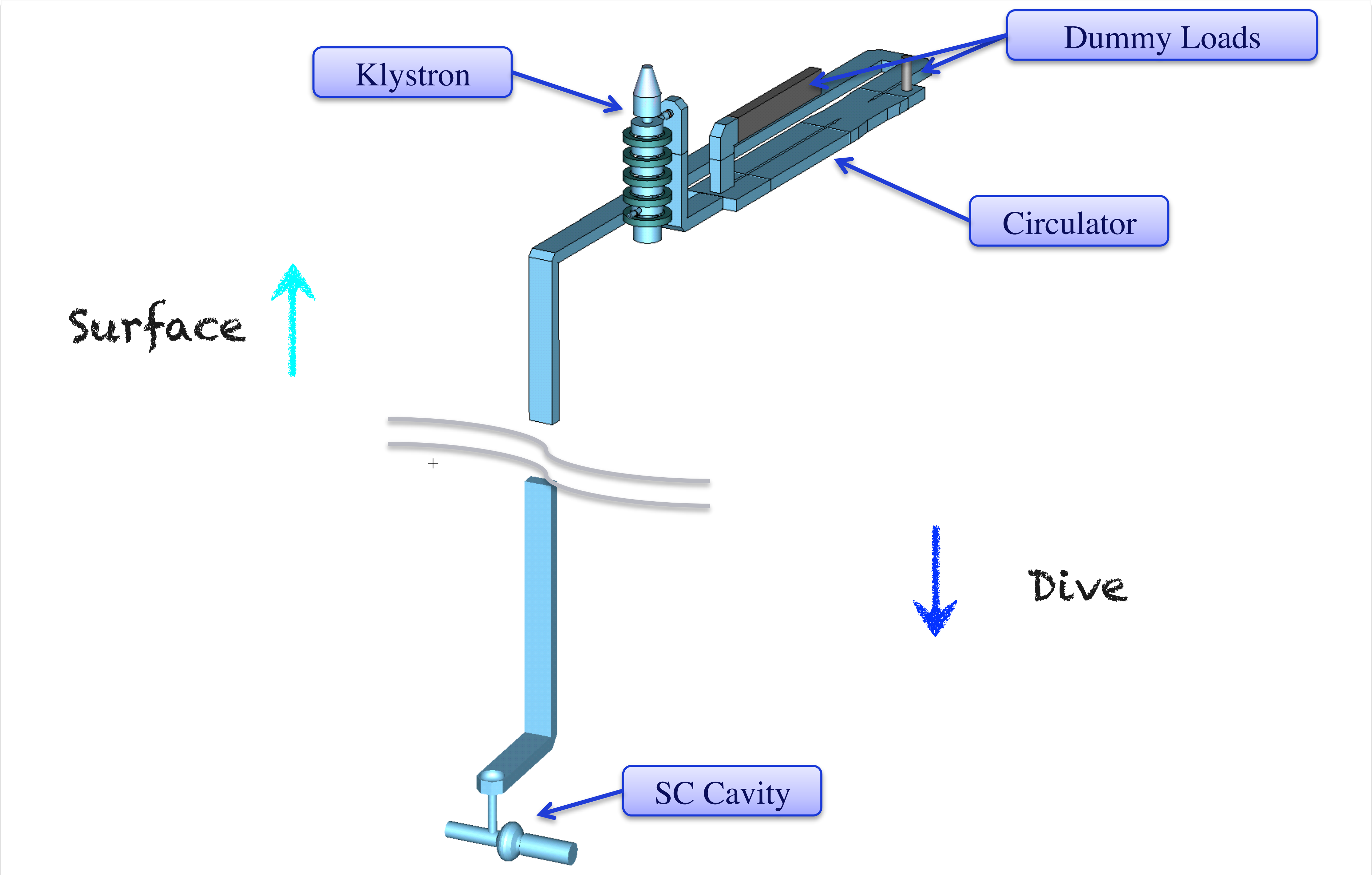
One-to-one configuration of NC RF system (major in SuperKeKB)



P_{wall}(~150kW) + P_{beam}(~550kW) = ~700kW / Klystron

One klystron drives one ARES cavity to deliver more power to the beam.
Two RF stations D5-C & E had been operated with this configuration
from Sep. 2005 through June 2010.

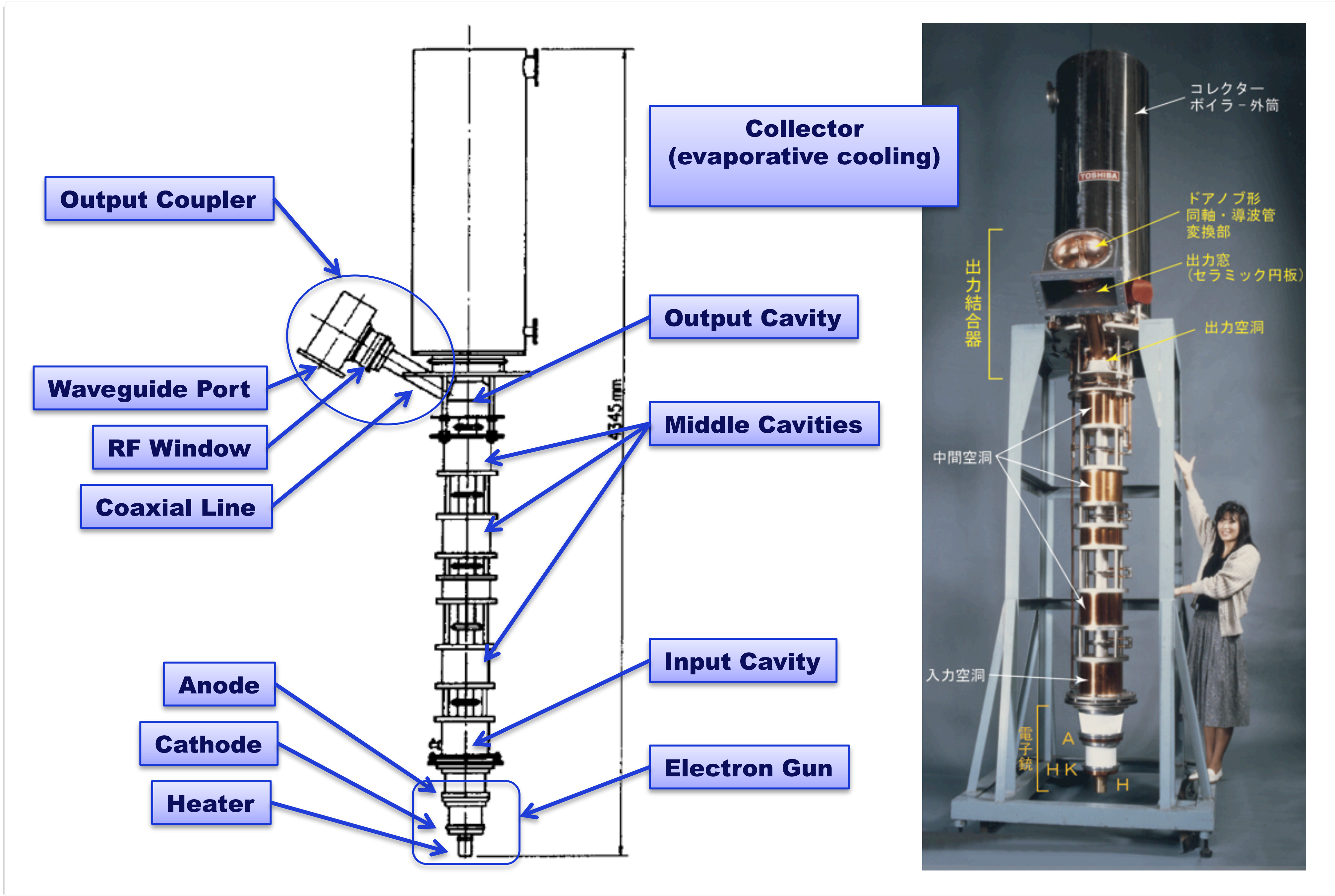
SC RF system for SuperKEKB (the same as for KEKB)



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

One klystron drives one SC cavity.

Toshiba CW Klystron E3732 (1 MW, 509 MHz)



As for the klystron, operation at around 800 kW is feasible, especially for the NC RF station.

- Klystrons, power supplies and high-power RF system can be operated stably.
- Existing components can be used without modifications.
- Sufficient margin to saturation of klystron.

Instability due to RF cavities and cure

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.

reported by K. Akai last year

Bunch gap transient

- Phase modulation along a bunch train caused by an abort gap

$$\Delta\phi = \frac{\omega_{rf}}{2V_c}\left(\frac{R}{Q}\right) \times I_b \Delta t = \frac{P_b \Delta t}{2\cos\phi_s U}$$

- KEKB
  - Owing to high stored energy of the ARES and SCC, transient phase modulation (also longitudinal position change of beam) is small, about 3 to 5 degrees. No luminosity degradation along a train is observed.
  - Calculation and measurements agree well.
- SuperKEKB
  - Since the beam current is twice, the gap length should be reduced to about half (500ns --> 250ns) to keep the same phase modulation. Rise time of the abort kicker needs to be improved.

K. Akai (Nov. 25, 2010)

RF system reinforcement strategy

	Total number of HP&LL	LER					HER							
Property		Number of cavities		Max. RF volt.	Max. beam pwr.	Max. beam cur.	Number of cavities			Max. RF volt.	Max. beam pwr.	Max. beam current		
Unit				MV	MW	A				MV	MW	A		
Cavity type		ARES					ARES		SC					
Klystron : Cavity		1:1	1:2				1:1	1:2	1:1					
Wiggler option						Full						None	6/10	Full
Design parameters (*Full wiggler case)					8.3	3.6					*8.0	2.6	2.6	2.6
Present system (no change case)	25	0	20	10	4.0	1.7	2	10	8	18	6.3	2.5	2.2	2.0
Commissioning • Convert HER-D5 to LER • Add 5 HP&LL at D4&D5 • Add 2 ARES at D4 • Remove 4 ARES in Fuji	30	10	12	11	7.9	3.4	4	4	8	16	6.2	2.5	2.2	2.0
Maximum RF (future) • Add 2 HP&LL at D4 • Add 2 HP&LL at D7&D8 • Add 2 ARES (or SC) with 2 HP&LL at D11	36	14	8	11	9.3	4.0	10 (8)	0	8 (10)	17 (19)	8.7 (8.4)	3.5 (3.4)	3.1 (3.0)	2.8 (2.7)

Beam power of 200 kW/ARES (1:2), 550 kW/ARES (1:1) and 400 kW/SC cavity is assumed.

Summary for RF System Upgrade

- A new upgrading strategy is presented, responding to a big change in the beam optics design. The RF voltage required for SuperKeKB HER has been almost doubled and settled around the same level as for KEKB HER. Concerning the beam loading issues reported last year, the balance between the beam power and the RF voltage has been normalized. Consequently, the reversed-phase operation of SCC is not being needed.

– The beam powers required for HER (with wiggler magnets newly added) and LER increase 1.5 times and 2.5 times as high as for KEKB, respectively. On the other hand, the total RF voltages for both rings remain almost the same level.
  - Need to increase the beam power per cavity by two times or more, especially for ARES cavity.
  - Need to increase the number of RF stations where one klystron feeds one ARES cavity with RF power up to 800 kW.

– At each RF station, operation at around 800 kW is feasible:
  - Klystrons, power supplies and high-power RF system can be operated stably.
  - Existing components can be used without modifications.
  - Sufficient margin to saturation of klystron.

– The beam power per ARES cavity to be increased from 200 kW (KEKB) to 550 kW or more (SuperKeKB).
  - The input coupler for ARES cavity needs to be upgraded: The handling power 400 kW → 800 kW, and the input coupling factor 3 → 6.

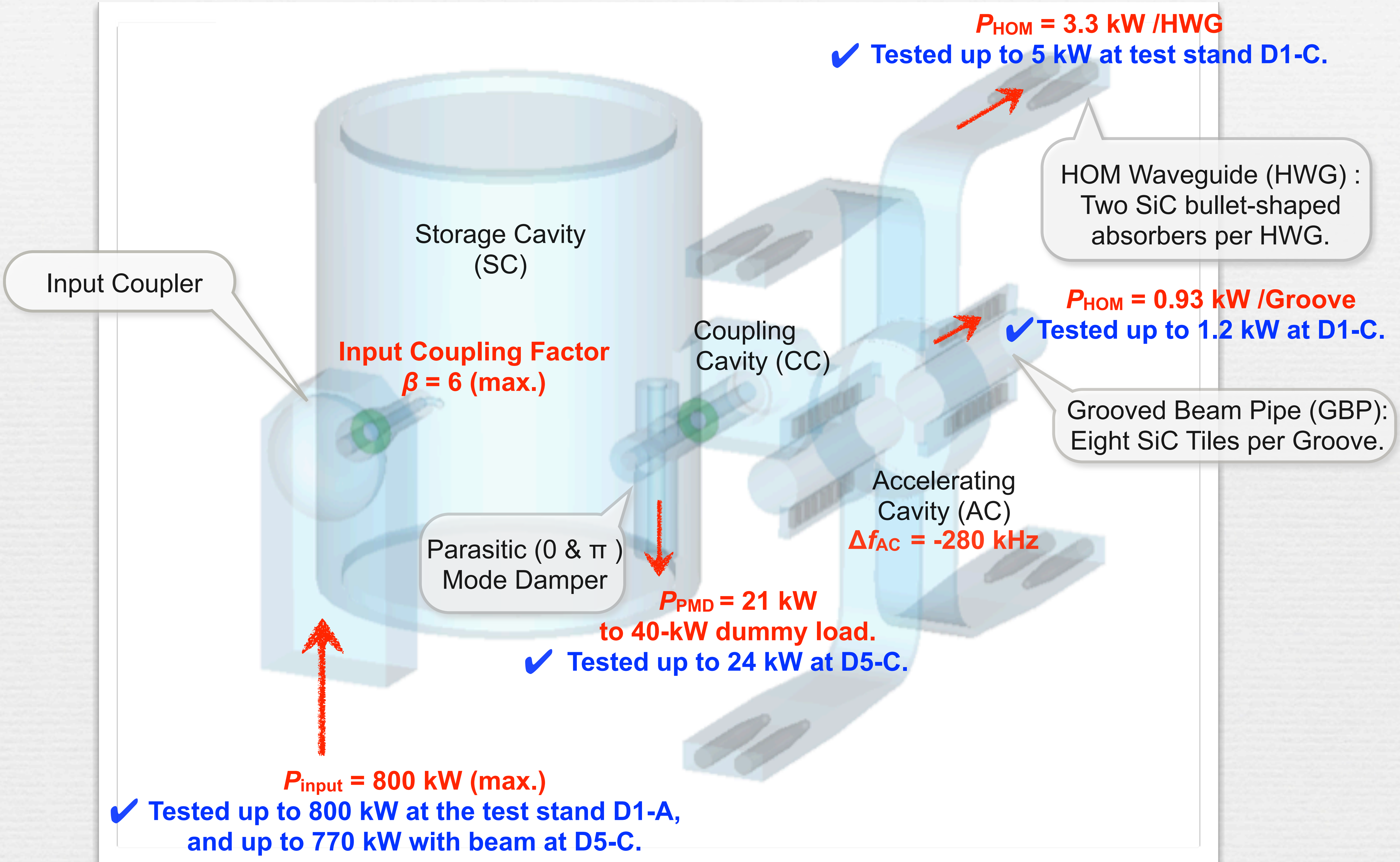
– OHO RF section D4 for HER:
  - Increase the number of ARES cavities from 6 to 8, and every ARES cavity to be driven by one klystron at the ultimate stage.

– OHO RF section D5 for LER:
  - Convert 6 ARES Cavities from HER to LER, and every ARES cavity to be driven by one klystron from the commissioning stage.

– FUJI RF sections D7 and D8 for LER:
  - Remove 4 ARES cavities to optimize the ratio of beam power per RF voltage for LER.

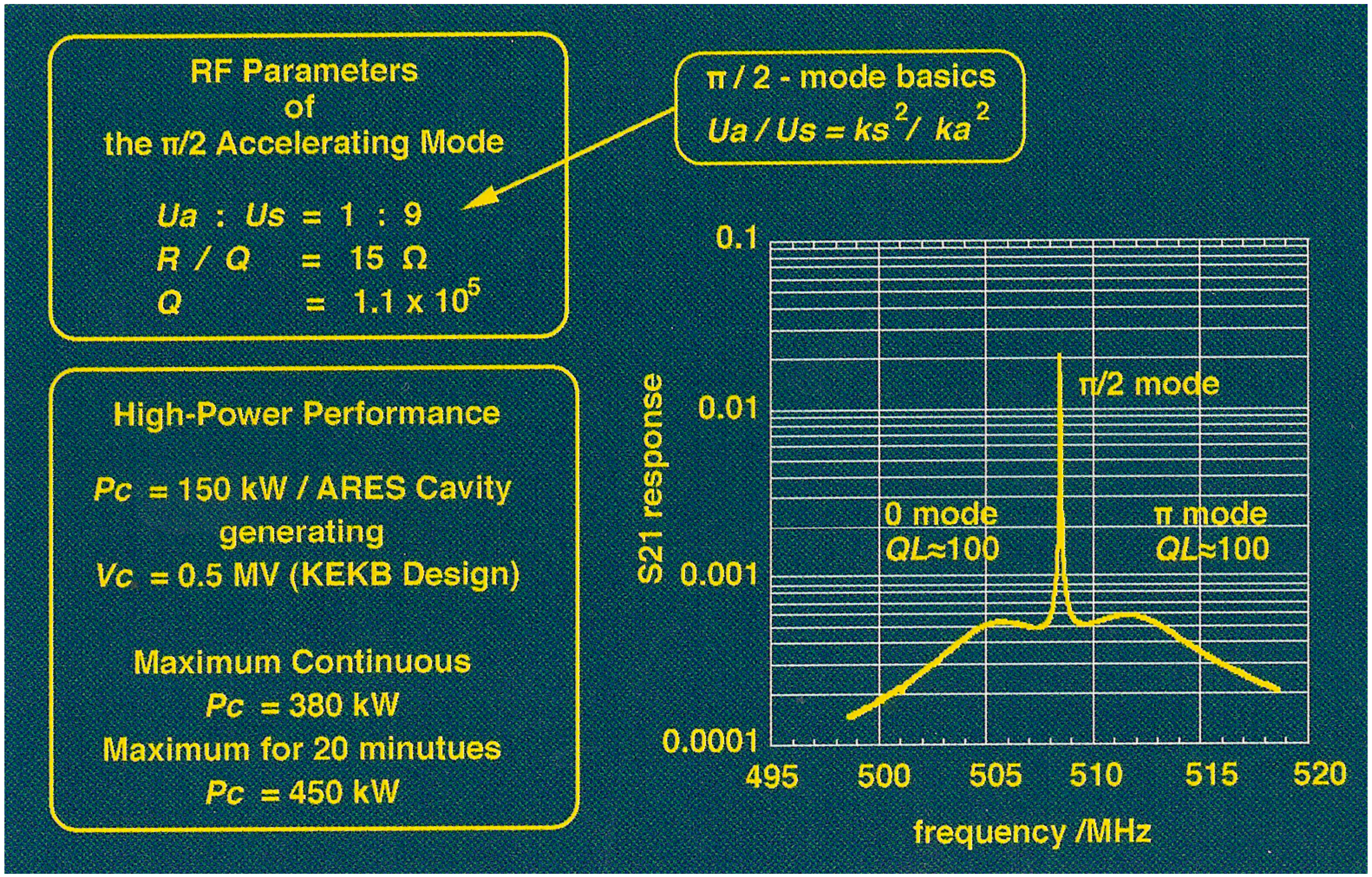
– NIKKO RF sections D10 and D11 for HER:
  - All of the 8 superconducting cavities remain the same as for KEKB.
  - Every SCC to be operated with V_c = 1.5 MV and P_{beam} = 400 kW.

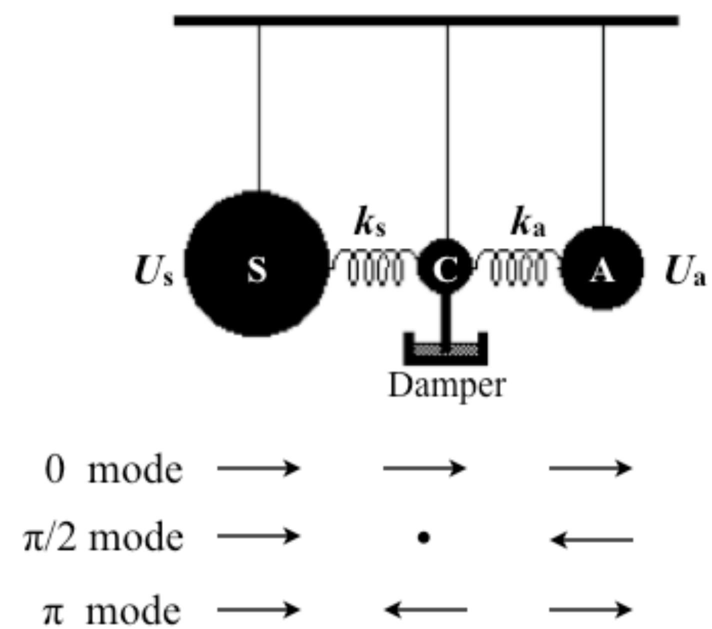
ARES Cavity System



P_{wall} = 150 kW (V_c = 0.5 MV), P_{beam} = 550 kW, P_{PMD}= 21 kW

Fundamentals of ARES Cavity System





$$\Delta f_{\pi/2} = \Delta f_A \,/\, (1+U_S/U_A)$$

↑ -28 kHz ↑ -280 kHz ↑ 9

Flywheel Energy Ratio U_S/U_A = 9 not changed.

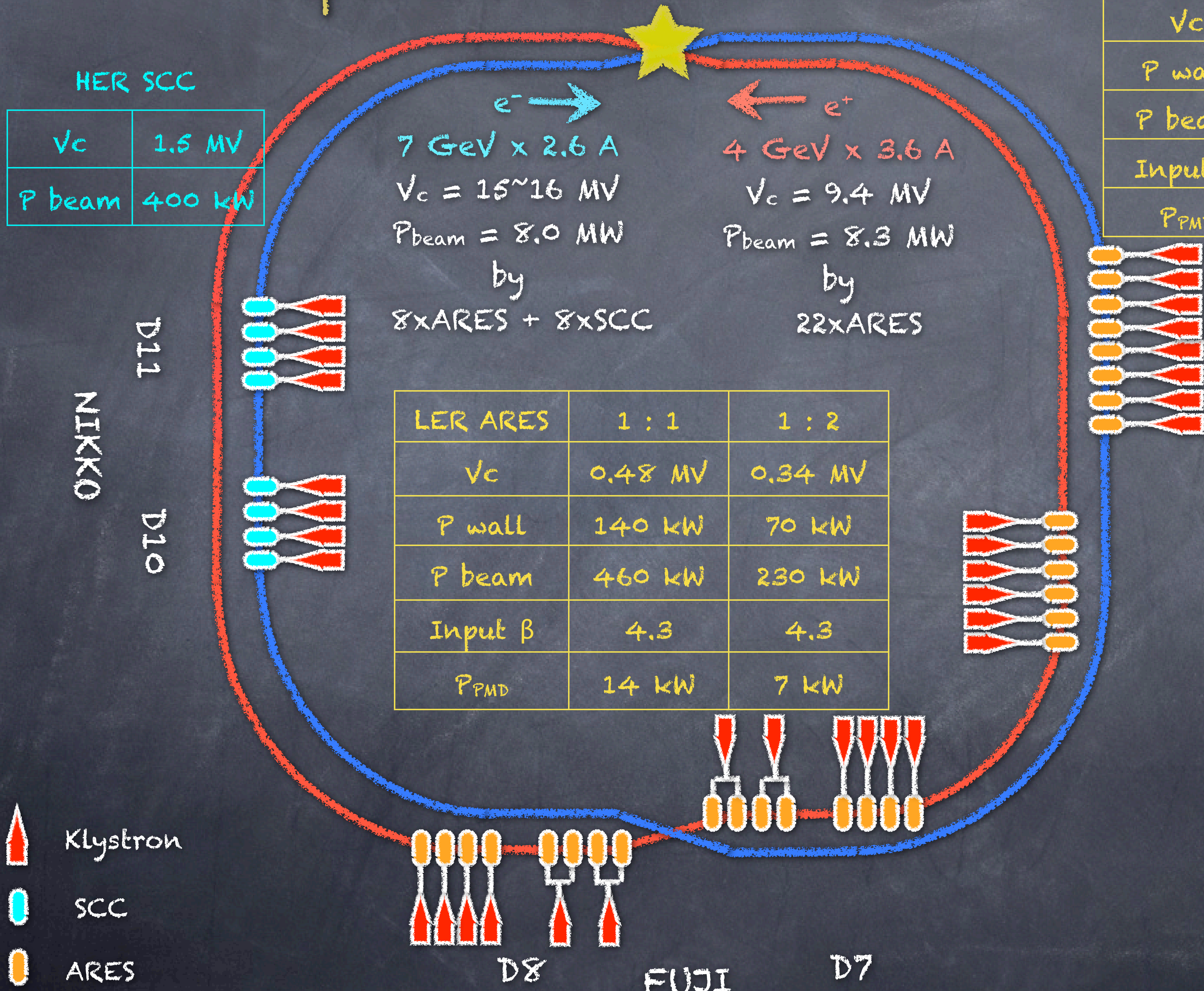
SuperKeKB $L = 8 \times 10^{35}\ cm^{-2}s^{-1}$

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

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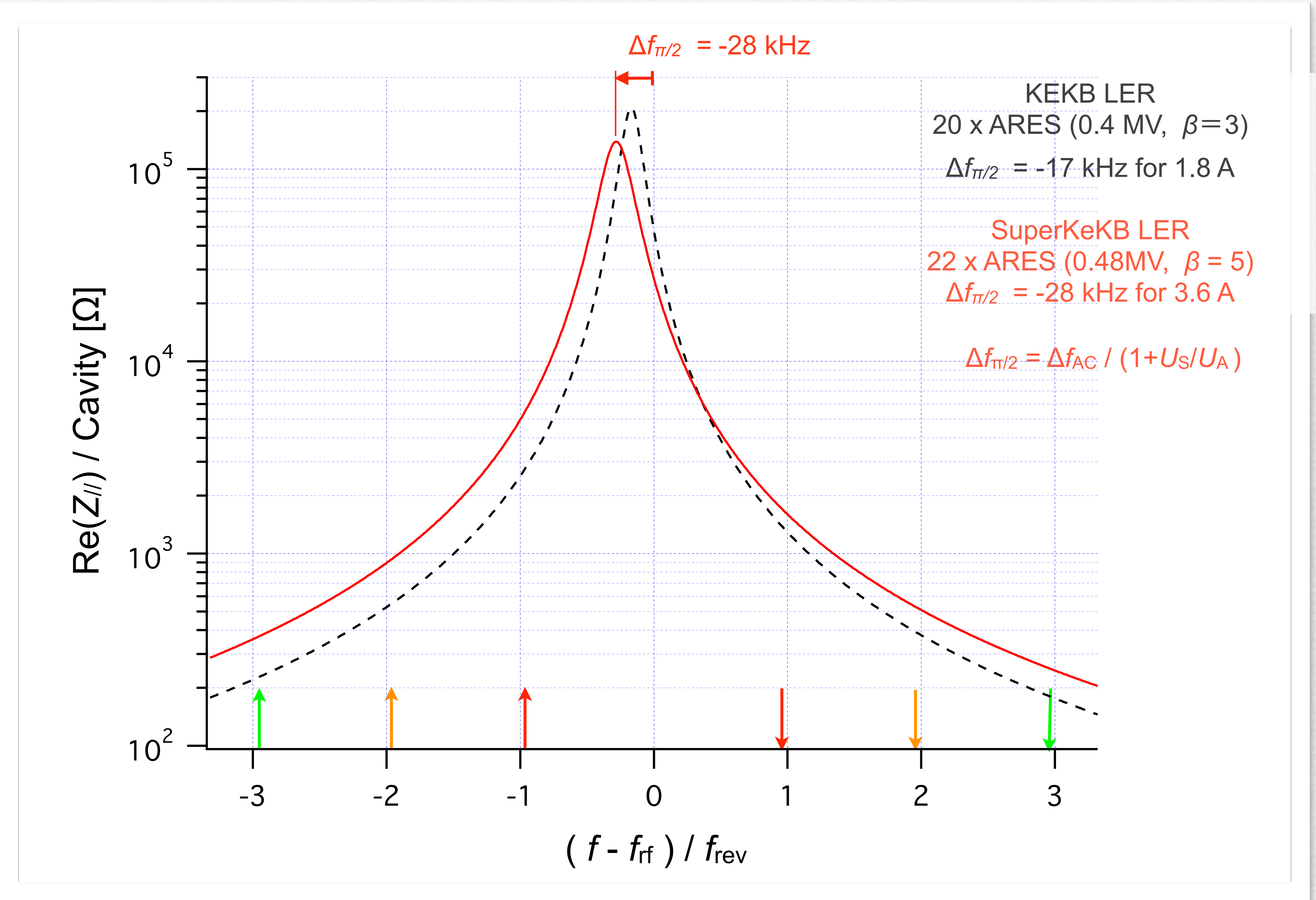
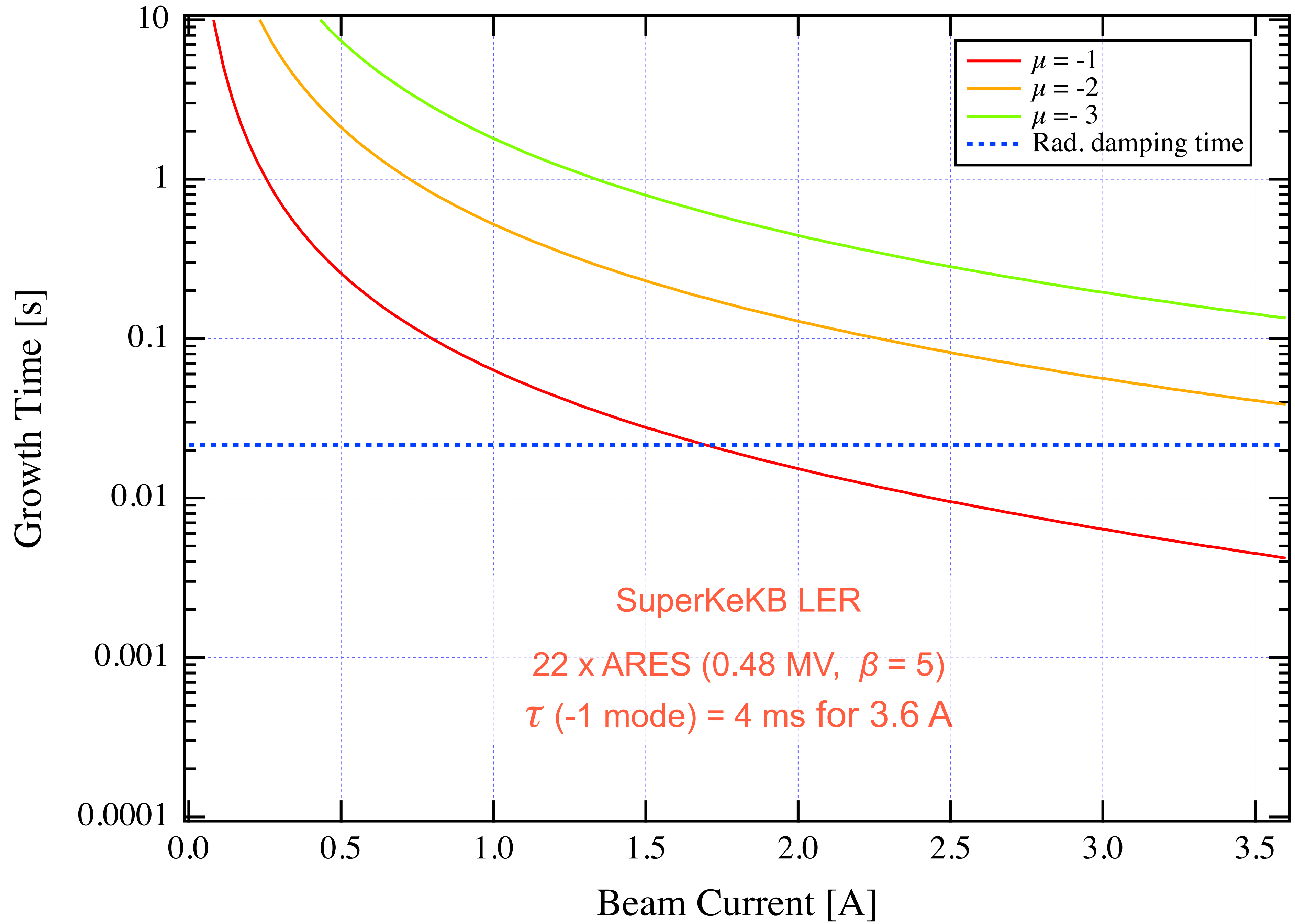
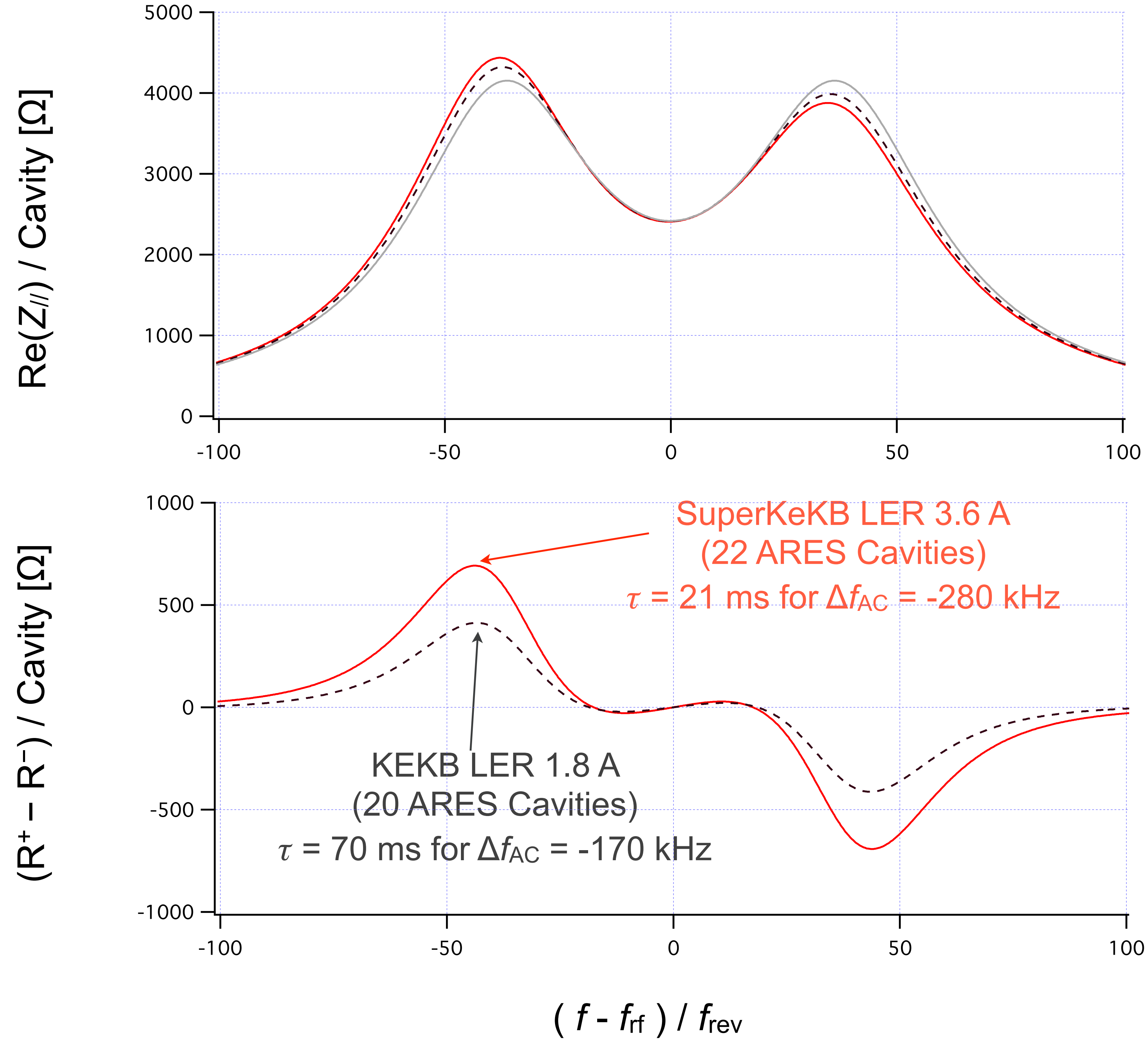
Coupled Bunch Instability (CBI)
driven by the Accelerating Mode (π/2)



CBI due to the Accelerating Mode (π/2)



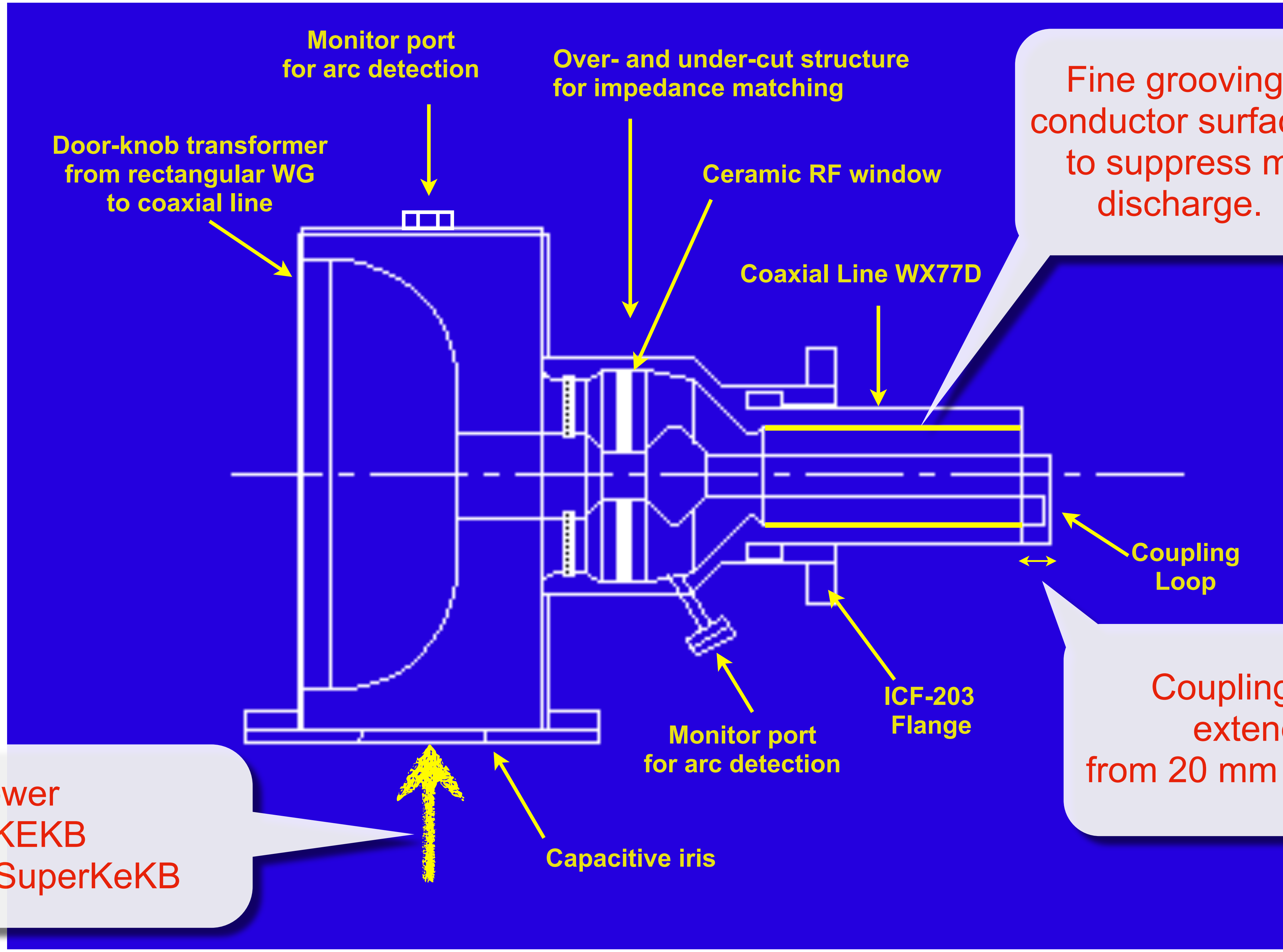
CBI due to the Impedance Imbalance between the Parasitic 0 and π Modes



22 ARES Cavities operated for SuperKeKB LER (I_{beam} = 3.6 A)

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

Input Coupler Upgrade

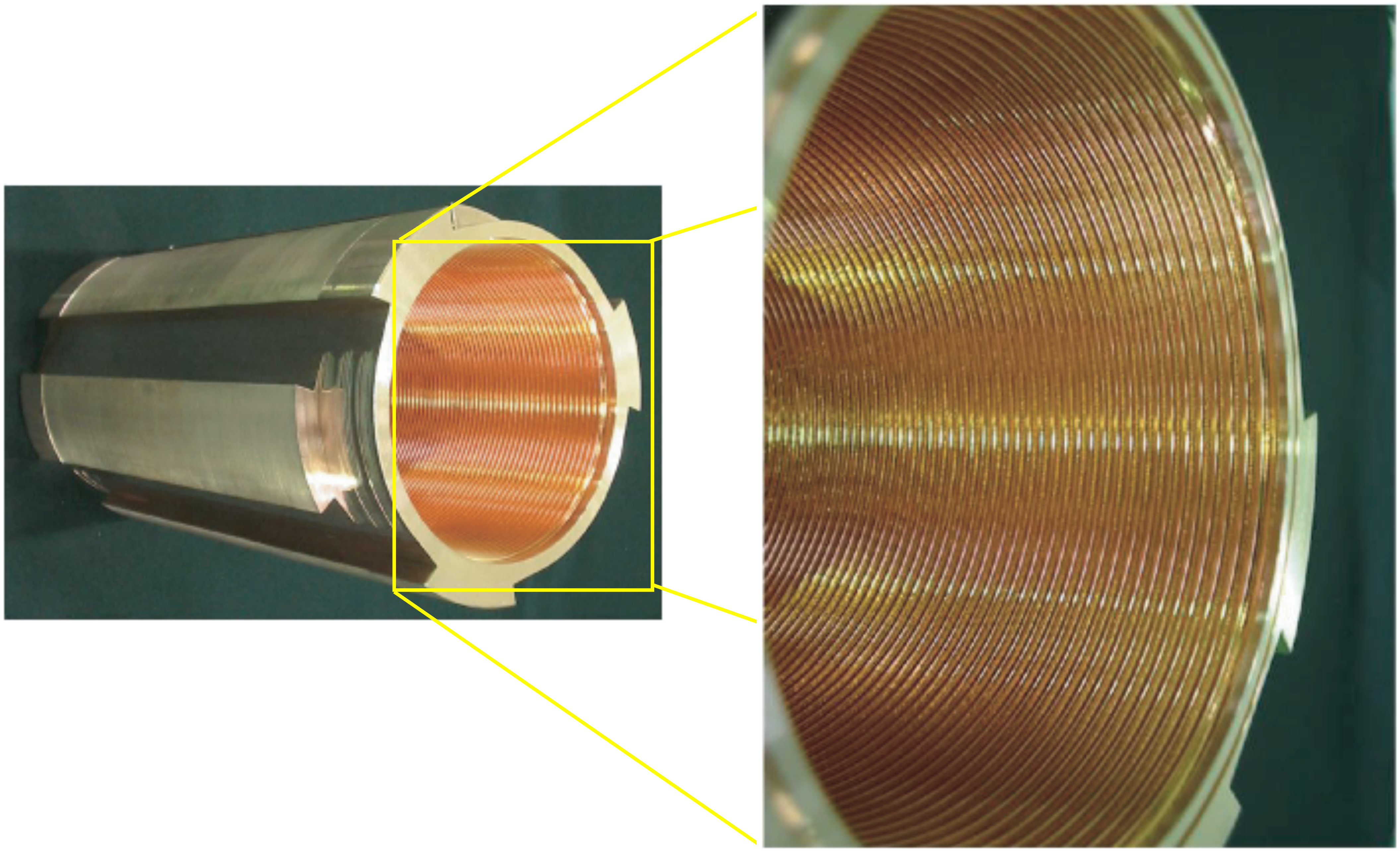


Fine grooving on the outer conductor surface (yellow part) to suppress multipactoring discharge. (by T. Abe)

Coupling Loop extended from 20 mm to 60 mm.

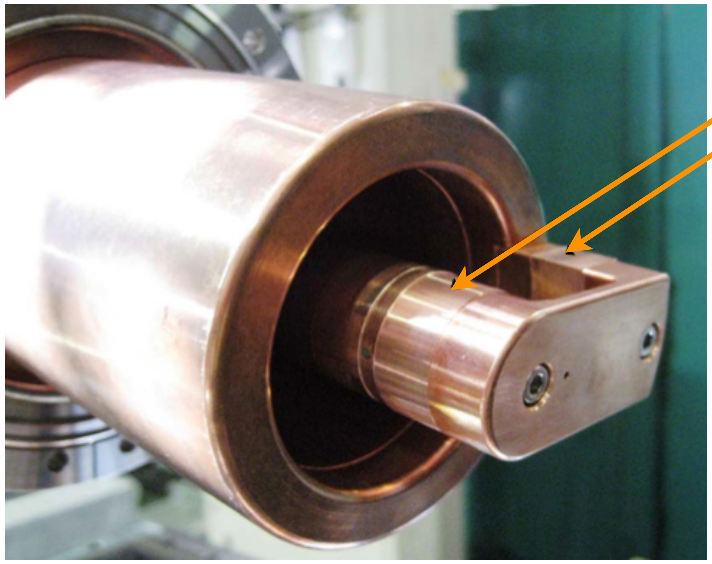
RF Power
400 kW for KEKB
800 kW for SuperKeKB

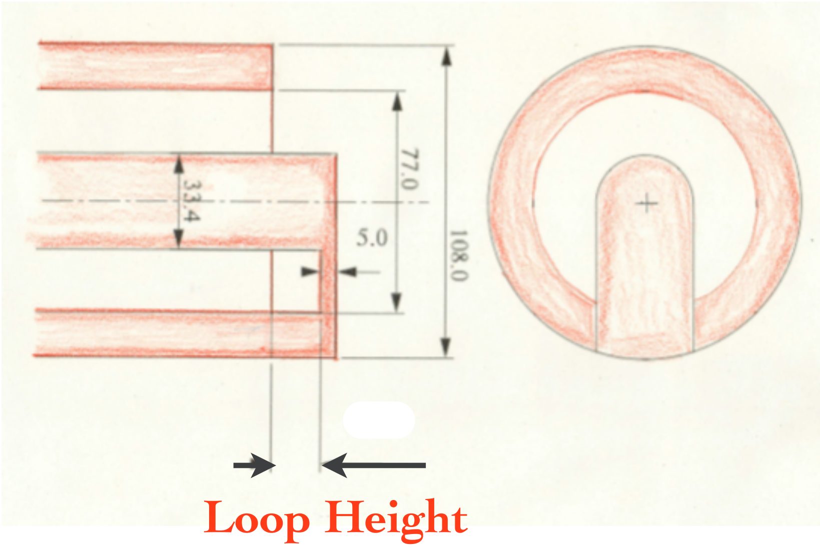
Fine circumferential grooving on the outer conductor surface in order to suppress multipactoring discharge.

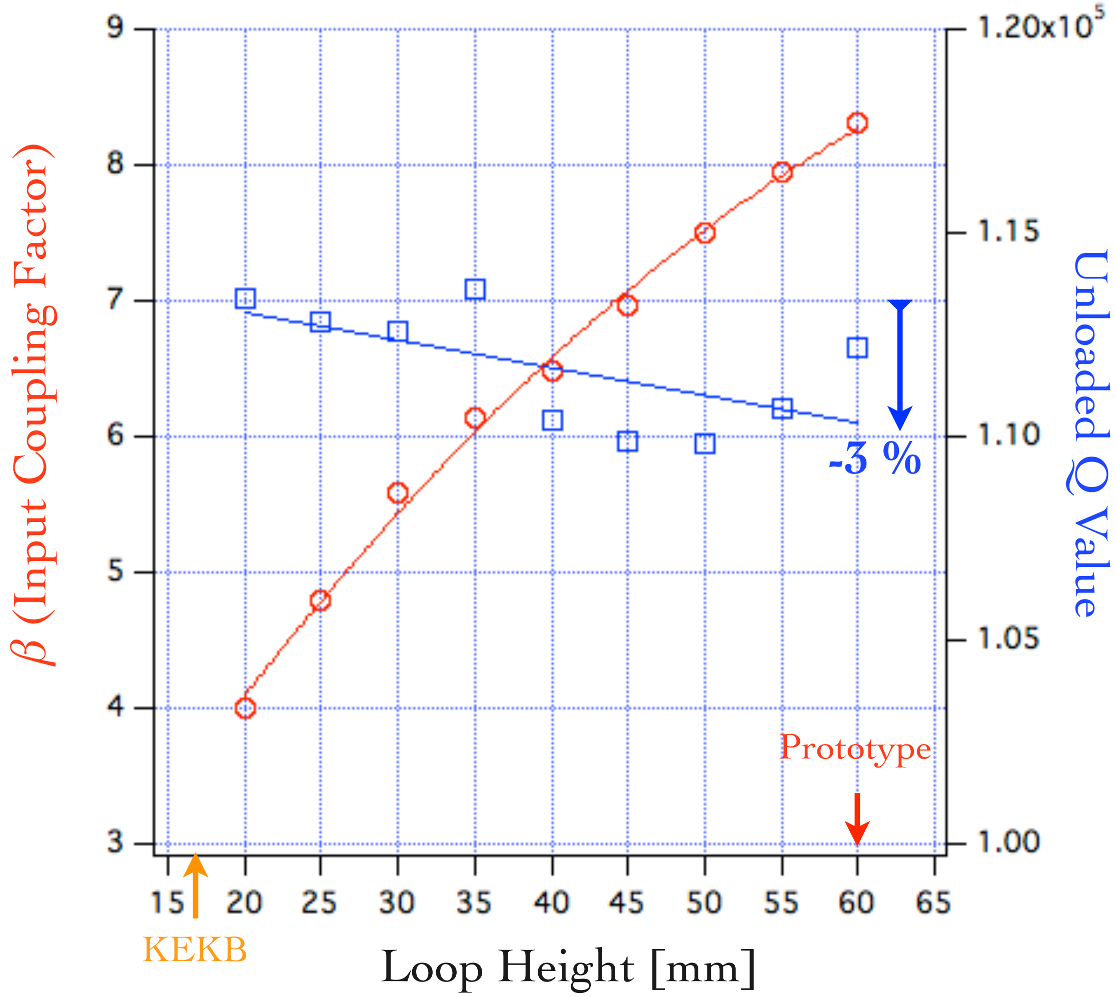


Successfully tested and used in actual KEKB operation.

Input Coupling Factor vs. Loop Height



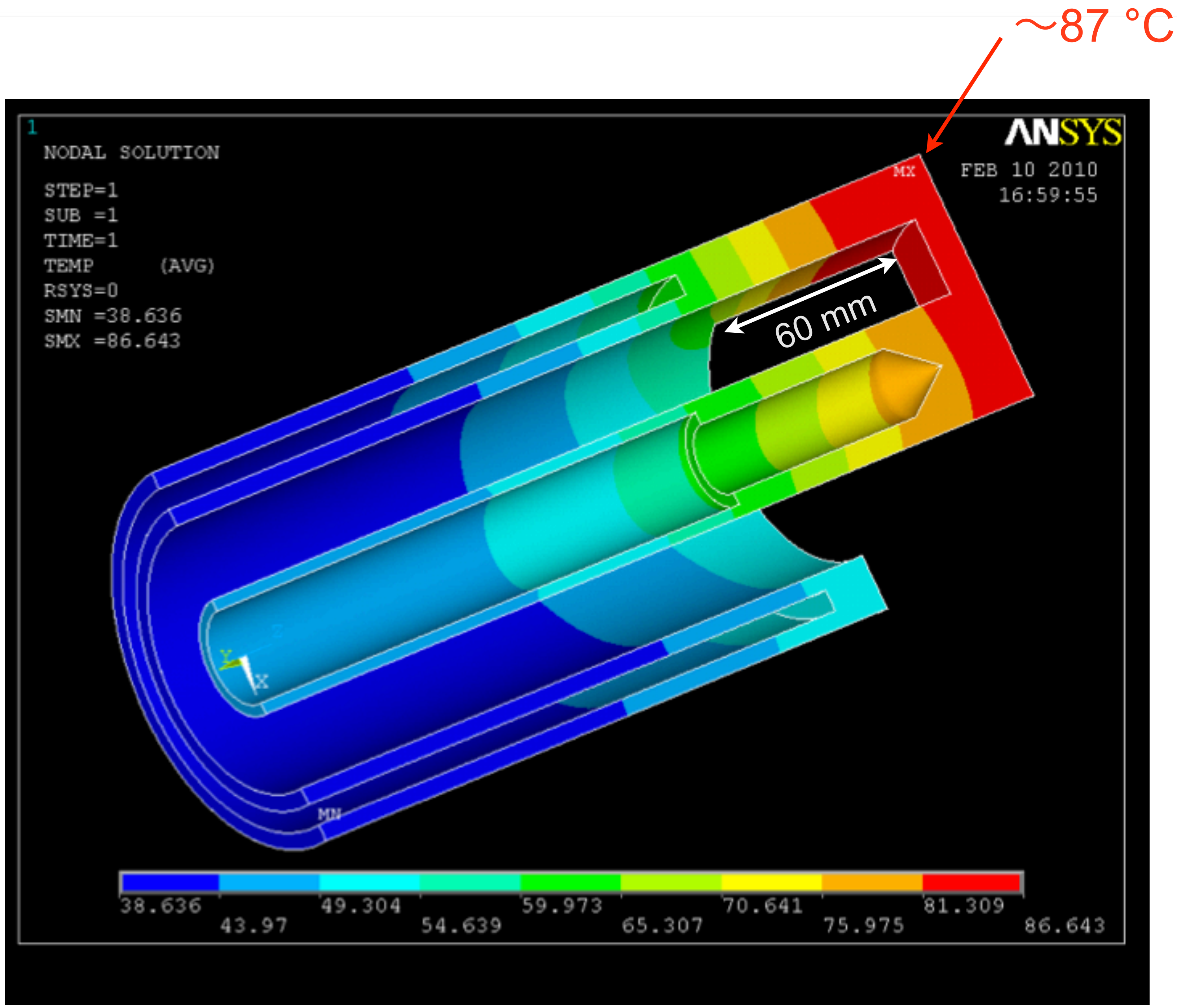




K. Yoshino, H. Sakai, T. Kageyama

A prototype coupler with a loop height of 60 mm
was fabricated in JFY 2009.

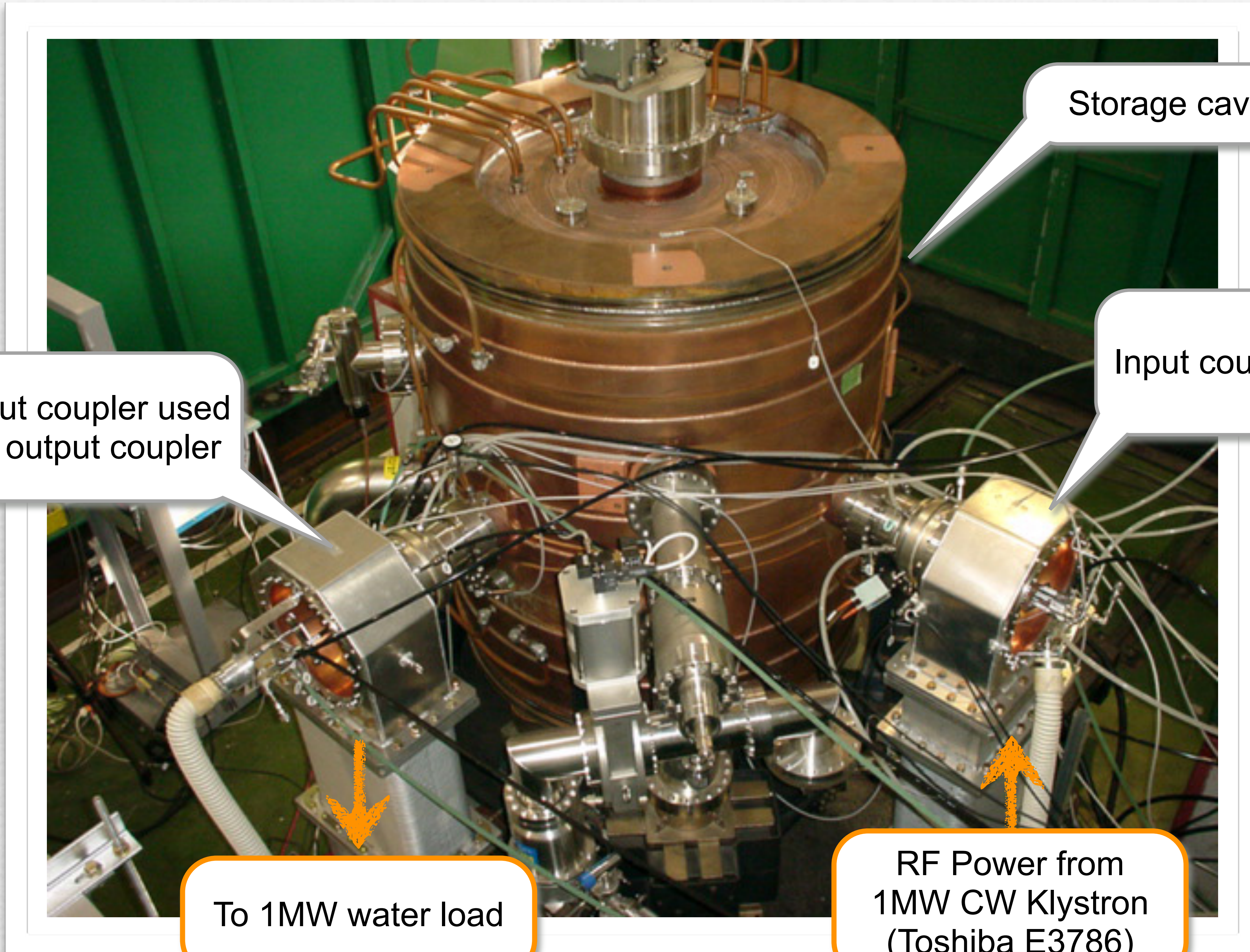
Temperature Distribution for the Coupling Loop extended to 60 mm.



Flow rate 3L/min. of cooling water (30°C) for each of the inner and outer conductor.

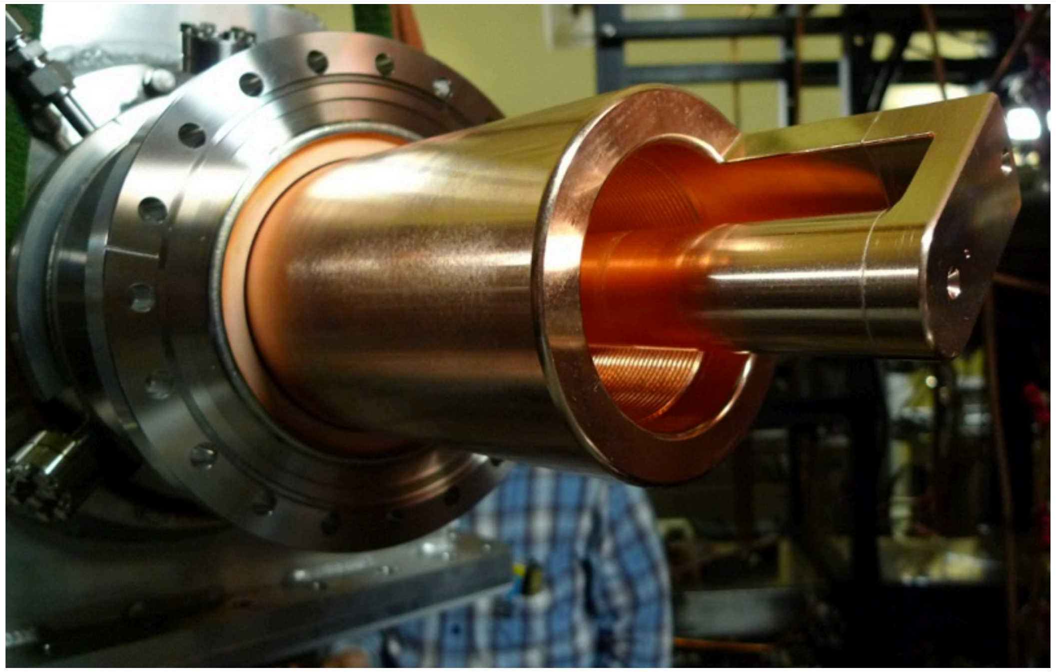
K. Yoshino

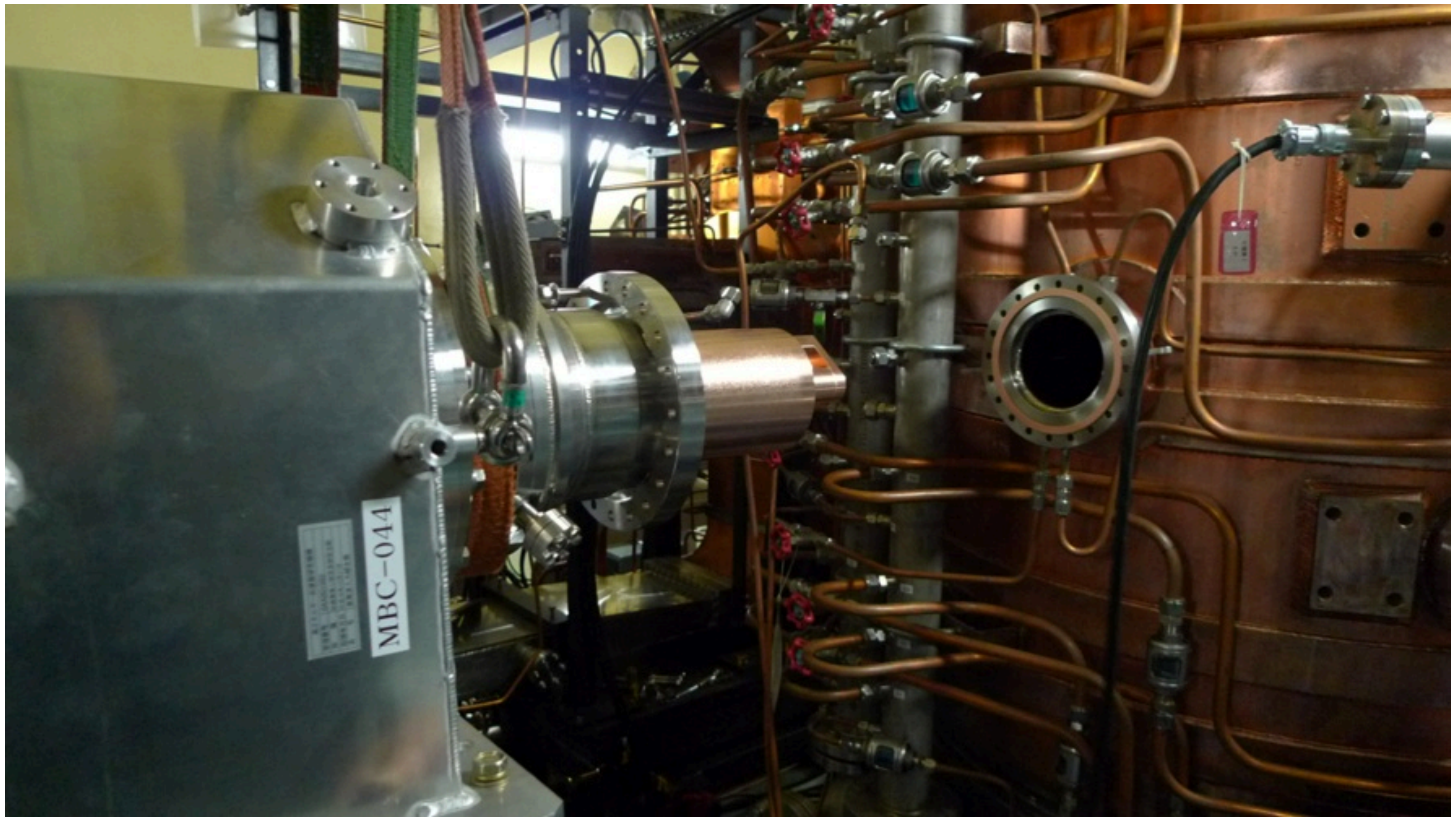
Prototype Coupler was tested up to 800 kW.
(Apr. 12~23, 2010)



High Power Test Stand D1-A

Prototype Coupler attached to the ARES Cavity at D5-C.
(Apr. 27, 2010)





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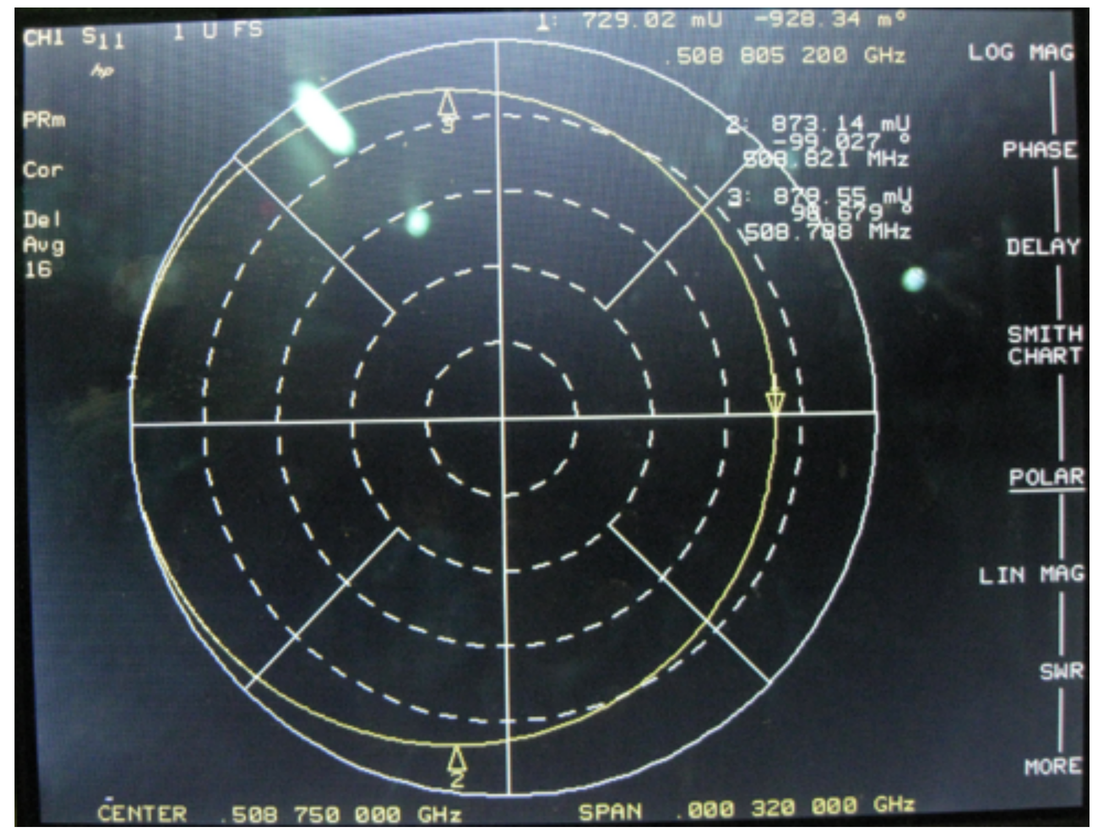
Input Coupling Factor set at β = 6.4 (cold).

2010/4/27　　MBC44号機_D5C1取り付け

※TRL校正使用

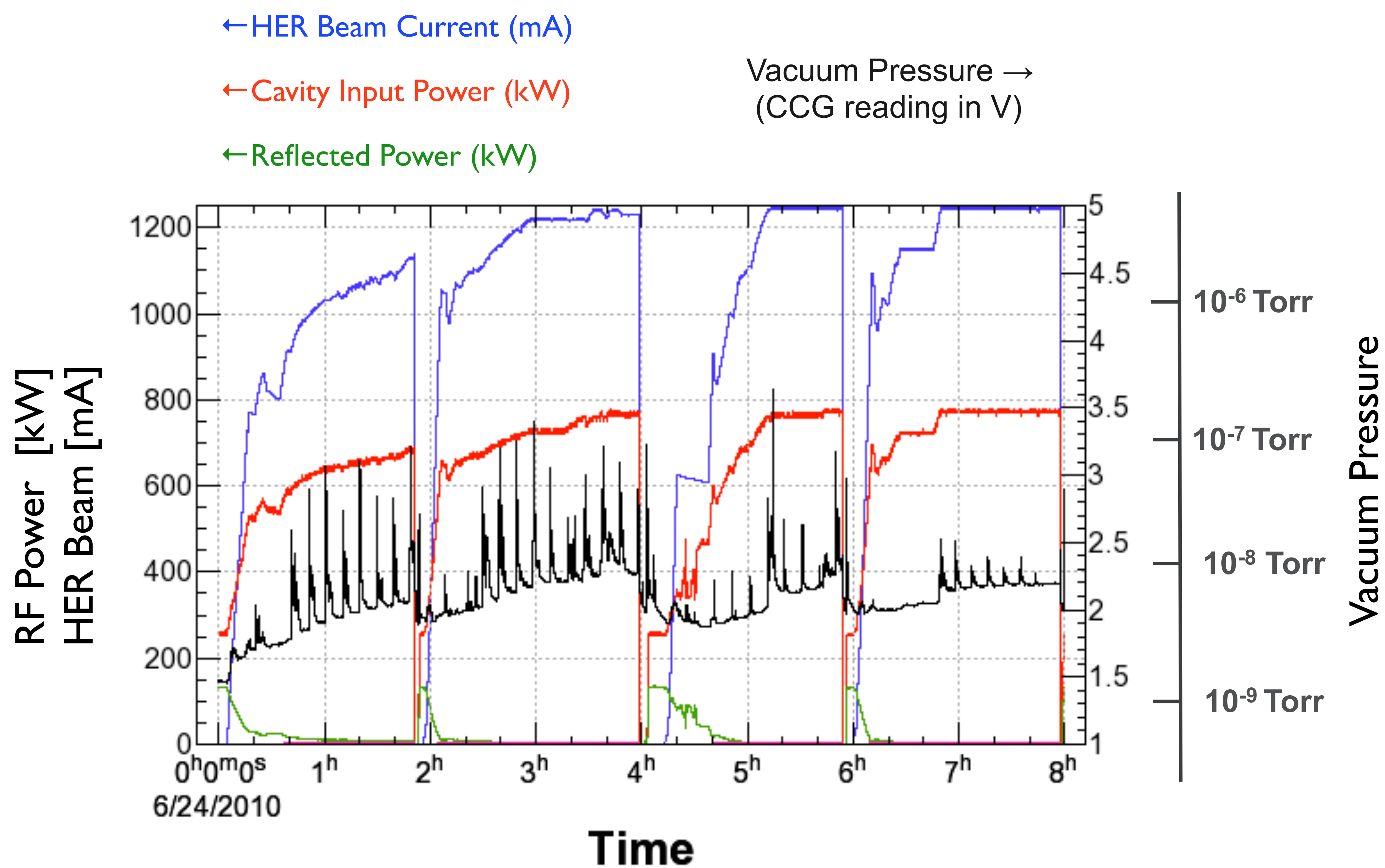
測定日	2010/4/27		
時間	10:23	10:31	
備考	入力カプラループ34度	入力カプラループ42度	
リターンロス	2.3 dB	2.76 dB	dB
Γ(極座標測定)	0.768	0.728	
Γ(リターンロス)	0.767	0.728	1.000
β =	7.597	6.347	#DIV/0!
Q_L=	13239	15528	#DIV/0!
f_1=	508.807600 MHz	508.805200 MHz	MHz
f_2=	508.826736 MHz	508.821296 MHz	MHz
f_3=	508.788304 MHz	508.788528 MHz	MHz
Q_0=	113817	114080	#DIV/0!

加速空洞チューナーポジション:17mm
貯蔵空洞チューナーポジション:29mm



K. Yoshino

Test Operation of the ARES Cavity at D5-C with the Prototype Coupler for SuperKeKB. (June 24, 2010)



Y. Yoshimoto, K. Marutsuka, T. Kageyama

ARES Cavity D5-C successfully delivered 610 kW to the beam.

Kly. Output =800kW / Cavity Input=770 kW

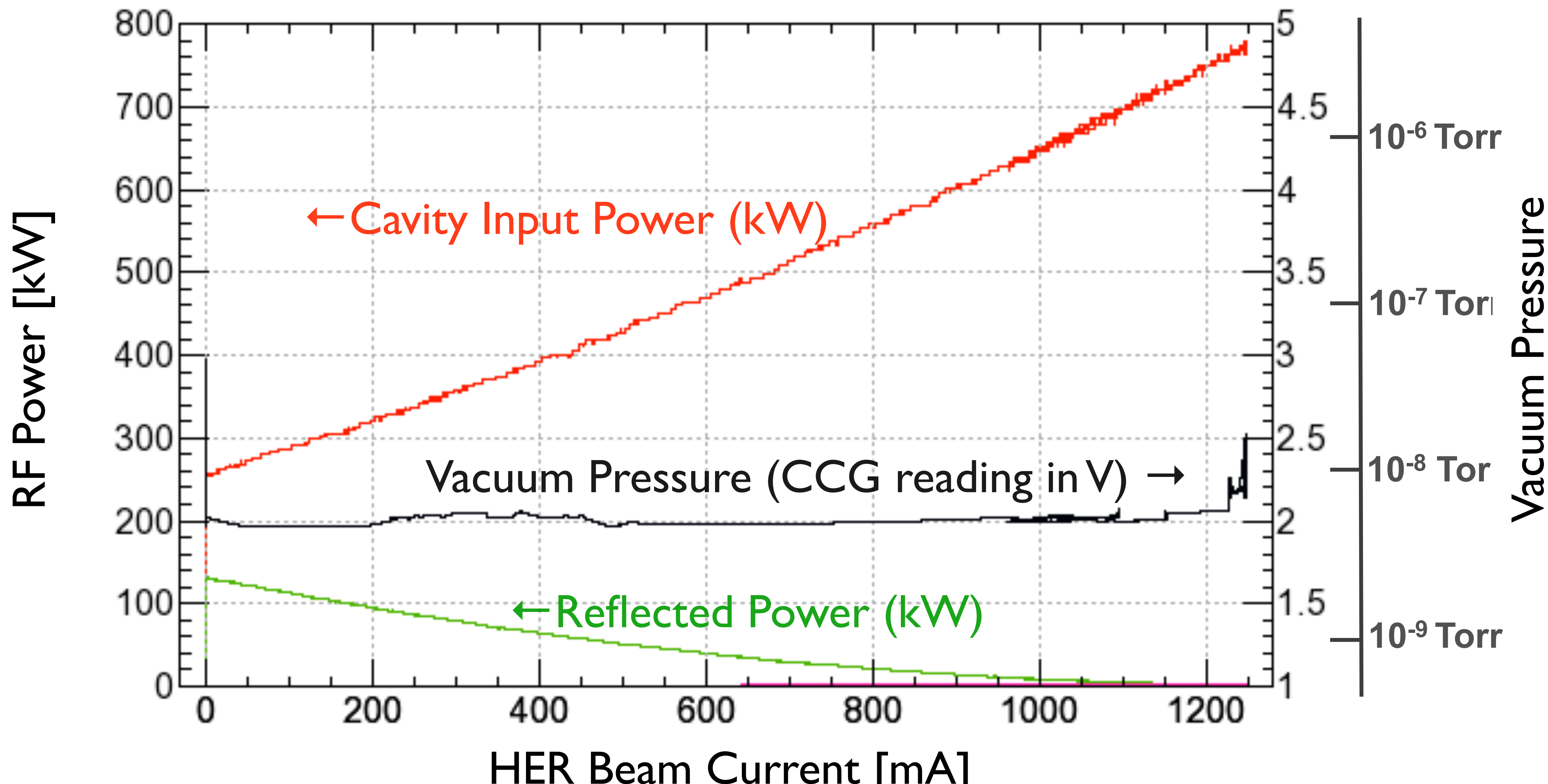
V_c = 0.47 MV

P_{wall} = 133 kW / P_{AC} = 53 kW

P_{beam} = 610 kW

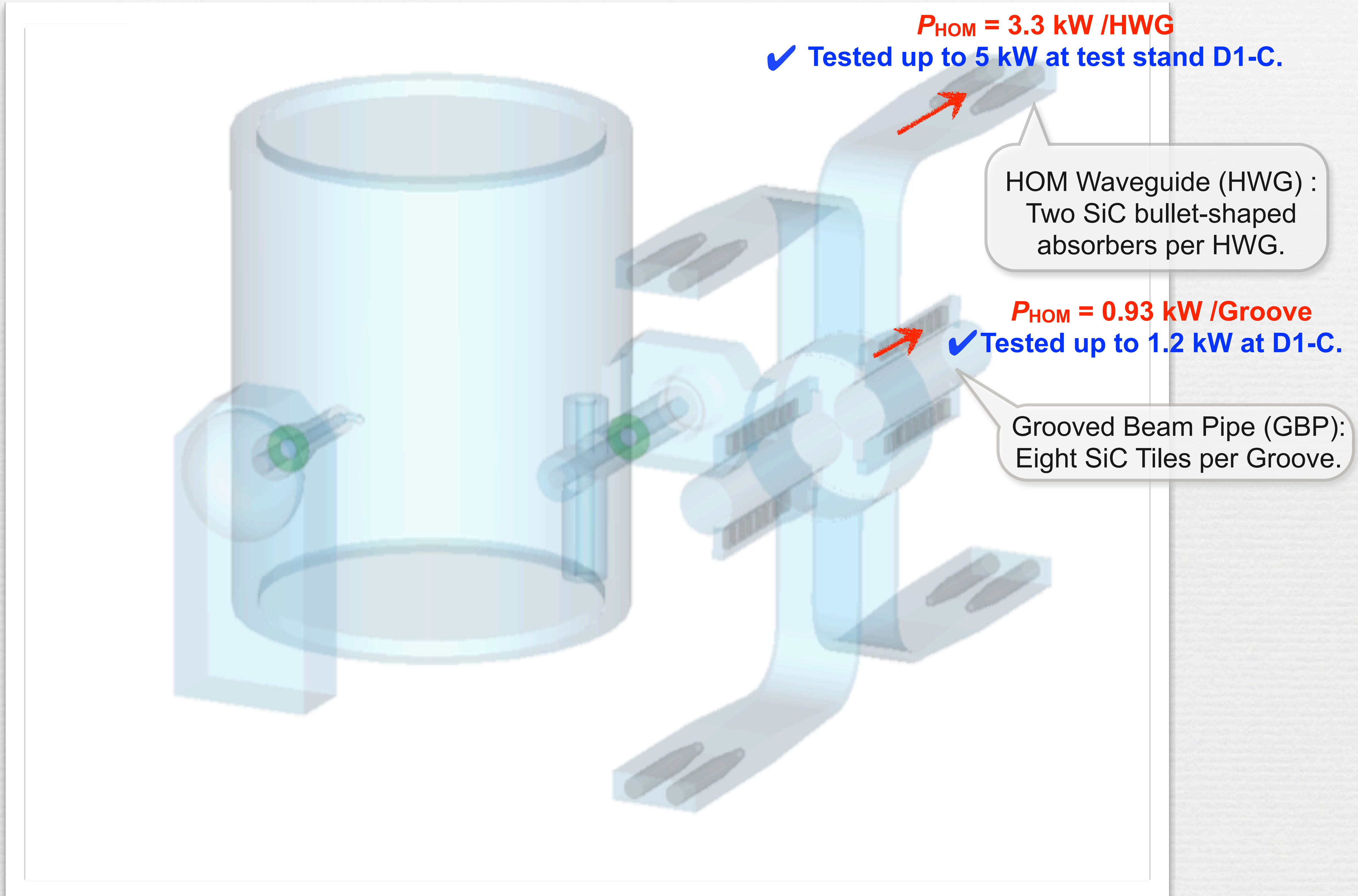
$P_{reflection}$ = ~1 kW

P_{PMD} = 24 kW (meas.) / 24 kW (predicted)

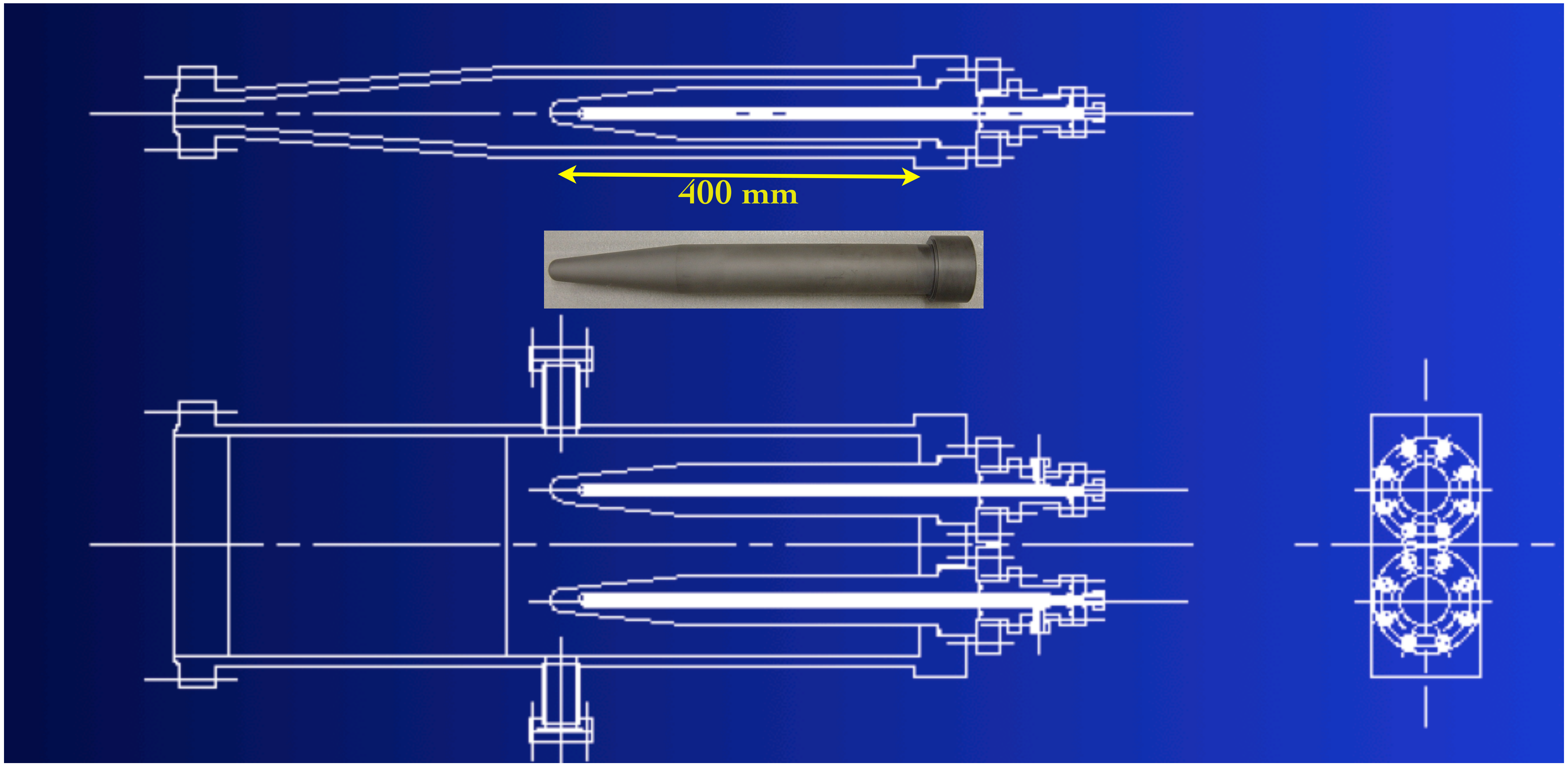


Y. Yoshimoto, K. Marutsuka, T. Kageyama

HOM Loads for the ARES Cavity



HWG Load

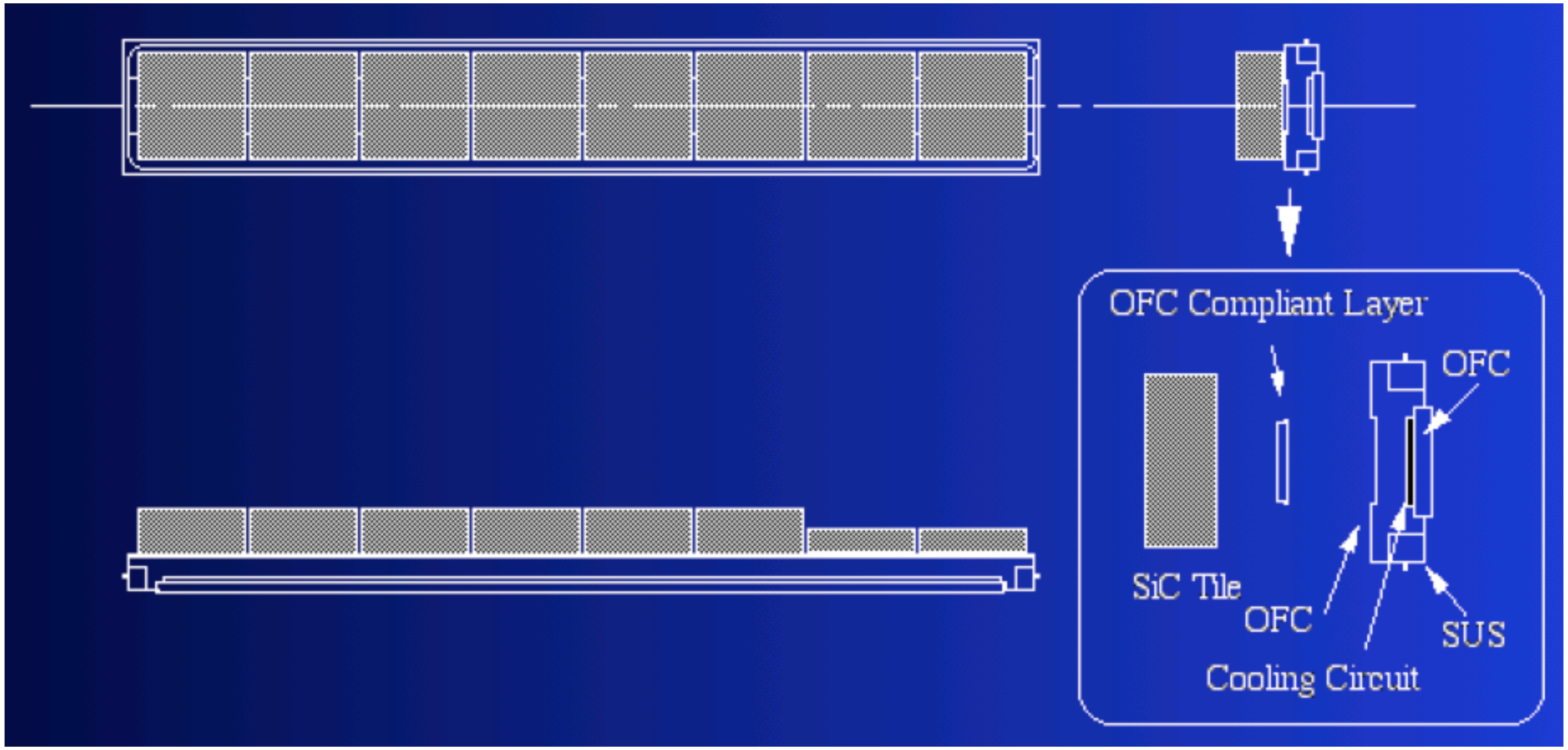


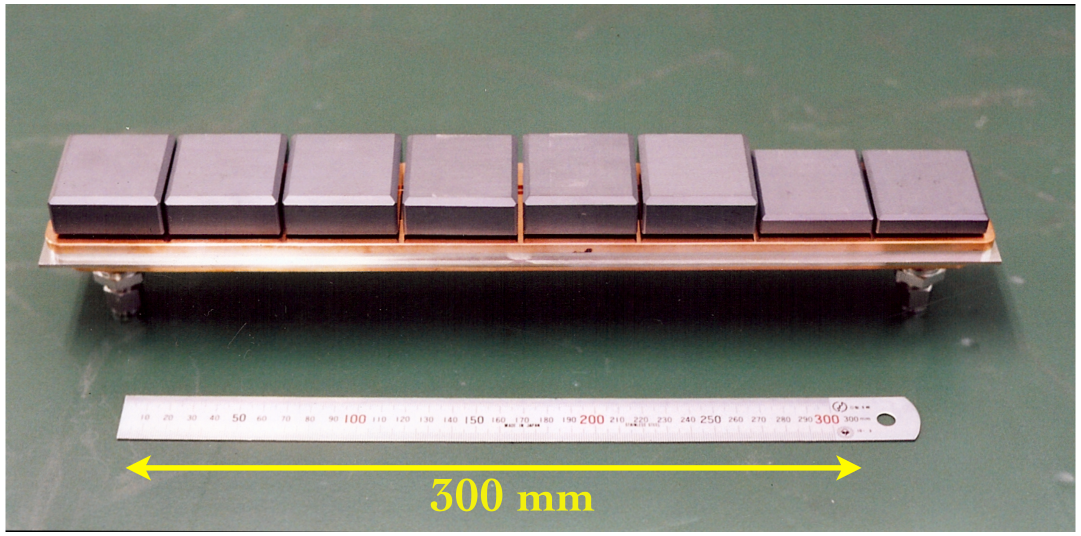
Y. Takeuchi

Each HOM WG (HWG) is terminated with two bullet-shaped SiC absorbers.

The power handling capability = 2.5 kW / bullet (5 kW/HWG, or 20 kW/cavity).

GBP Load

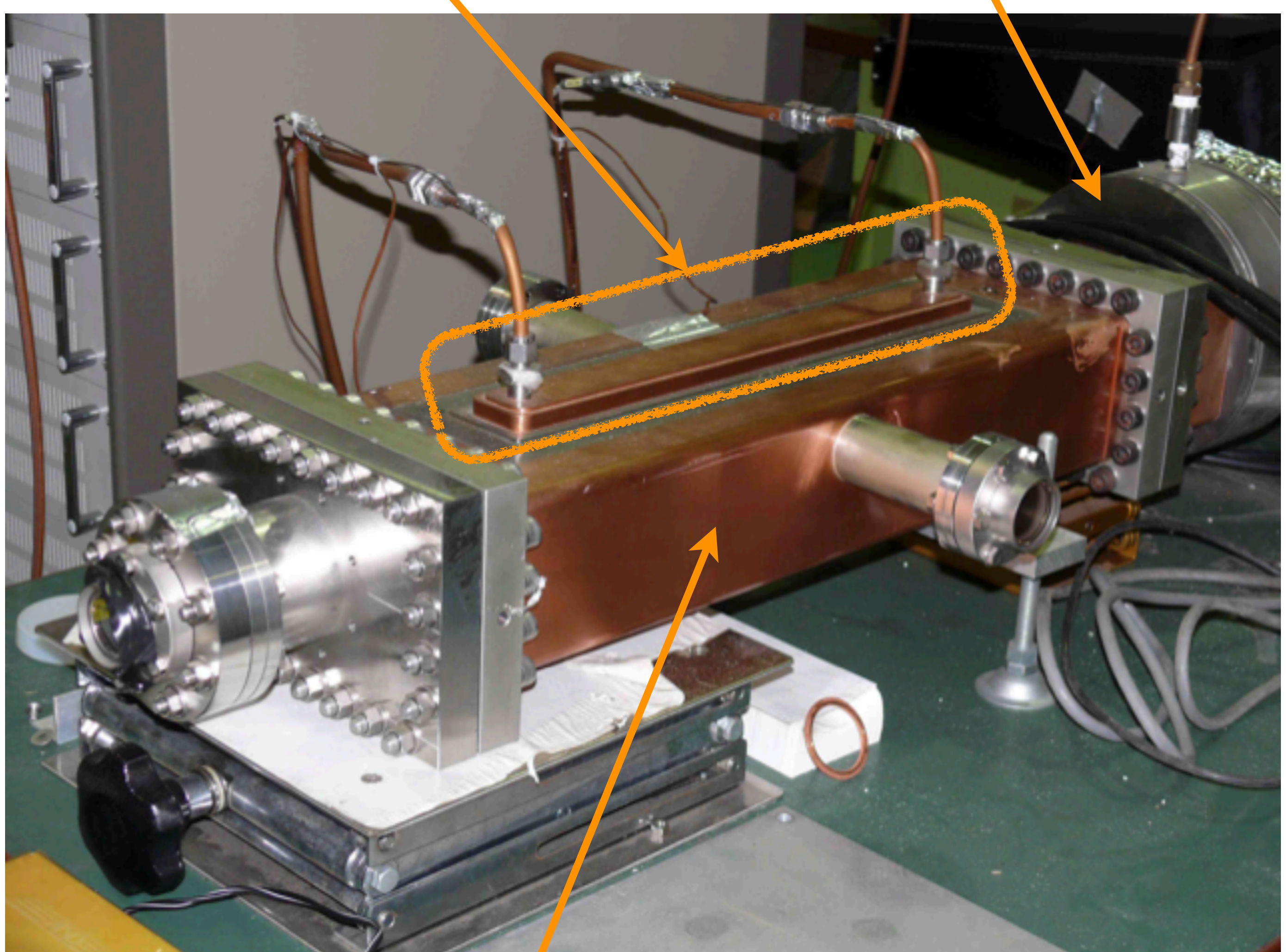


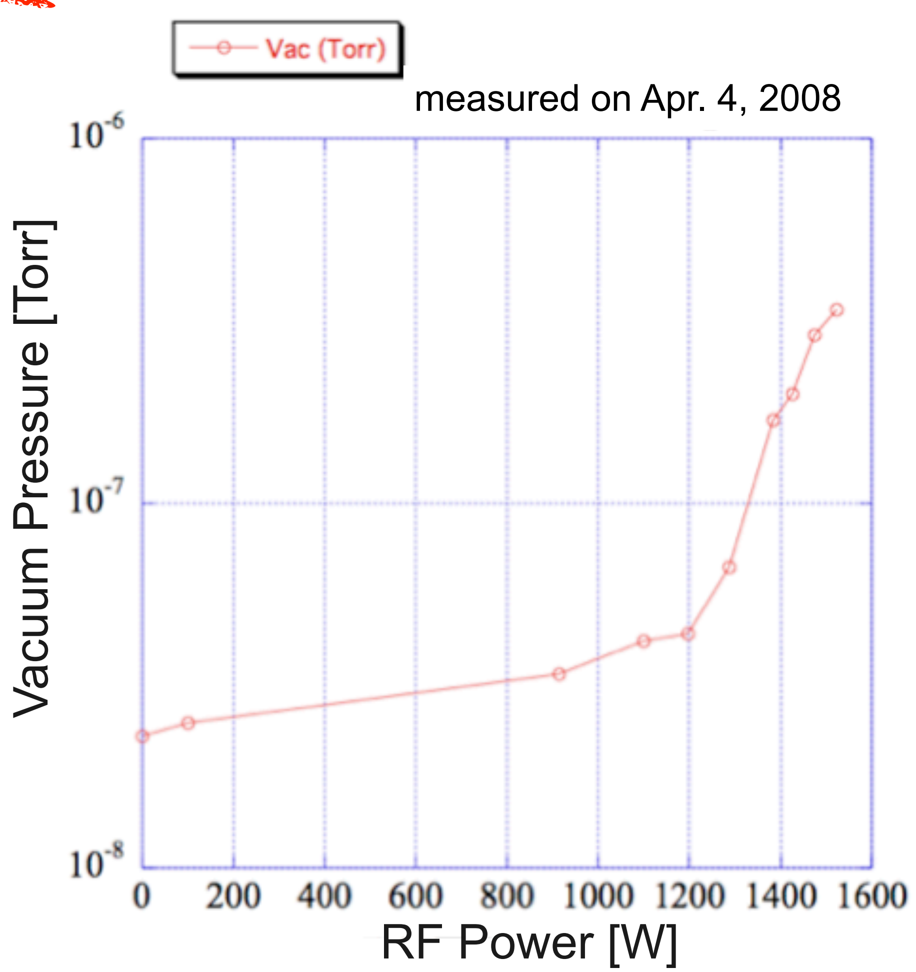


Y. Takeuchi

Each groove has eight SiC tiles in line, where every tile is brazed to a water-cooled copper plate.

High Power Test of GBP Load @D7-*yoko* (annex) in 2008

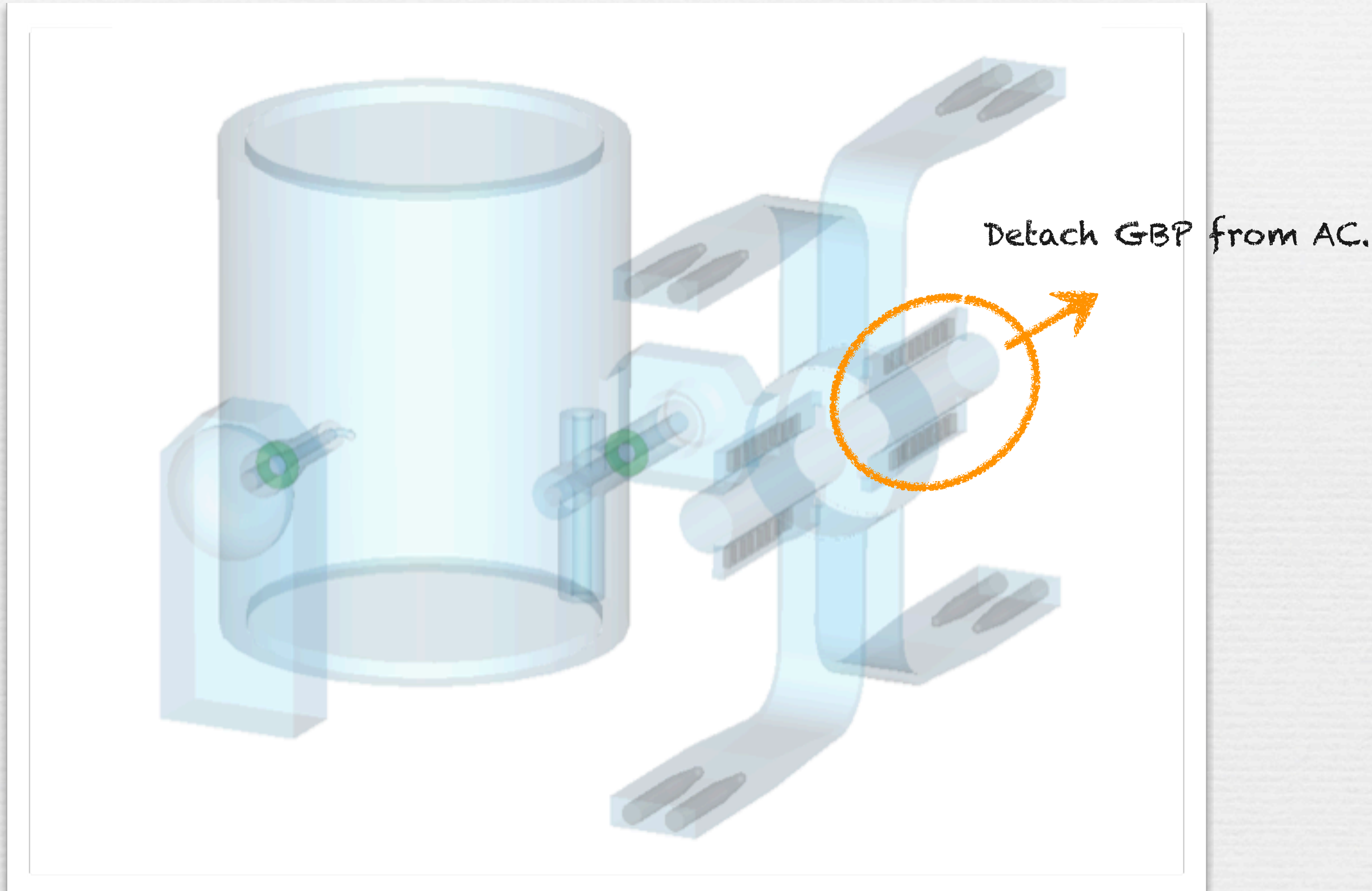




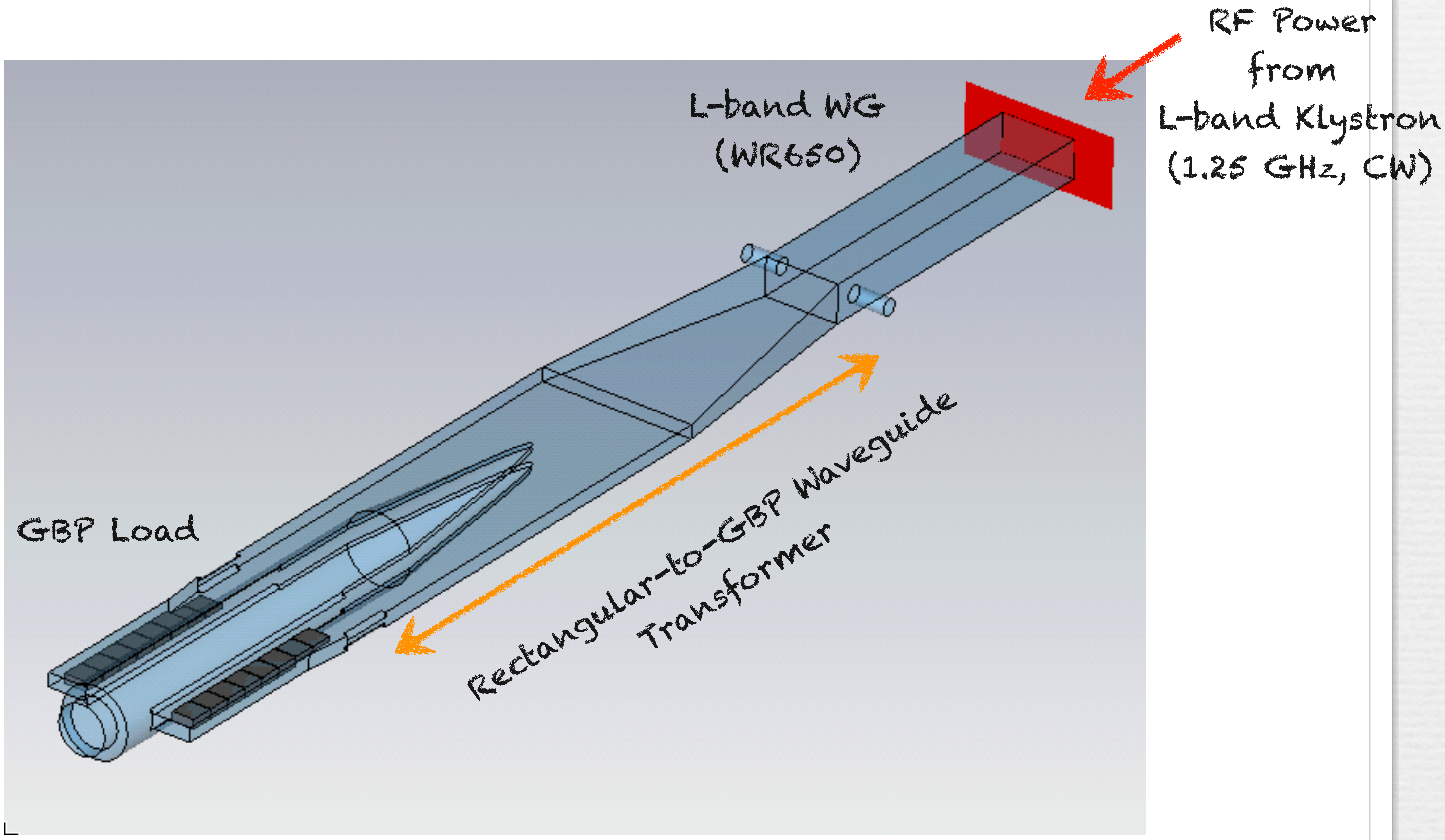
As reported last year, abnormal vacuum pressure rise observed above ~1.2 kW.

Y. Takeuchi

High Power Testing of GBP Load
more precisely reflecting the actual environment.

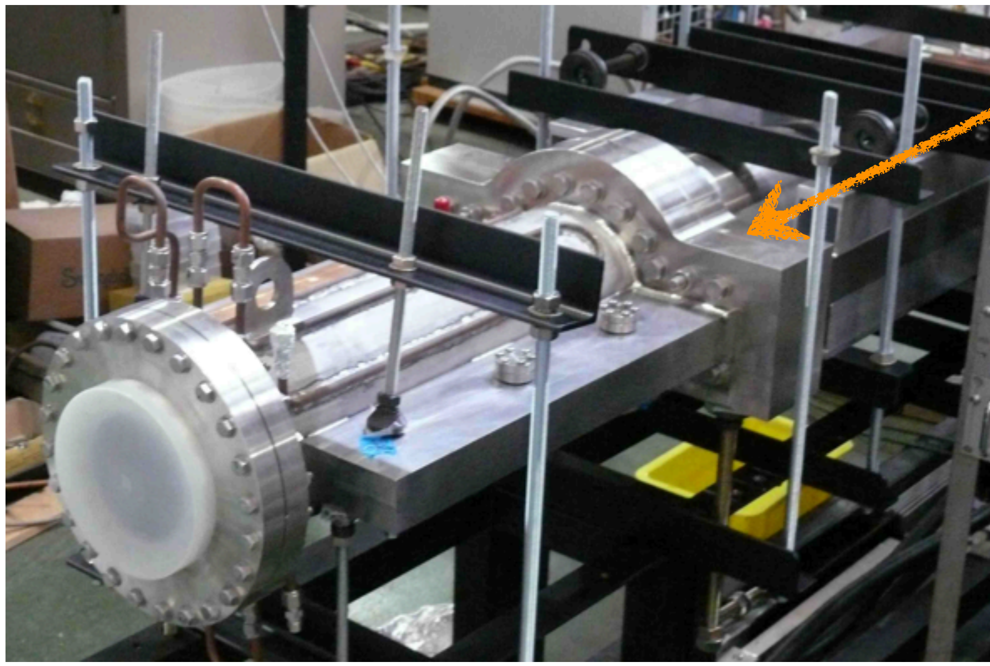


Setup for High Power Test of GBP Load
more precisely reflecting the actual environment.



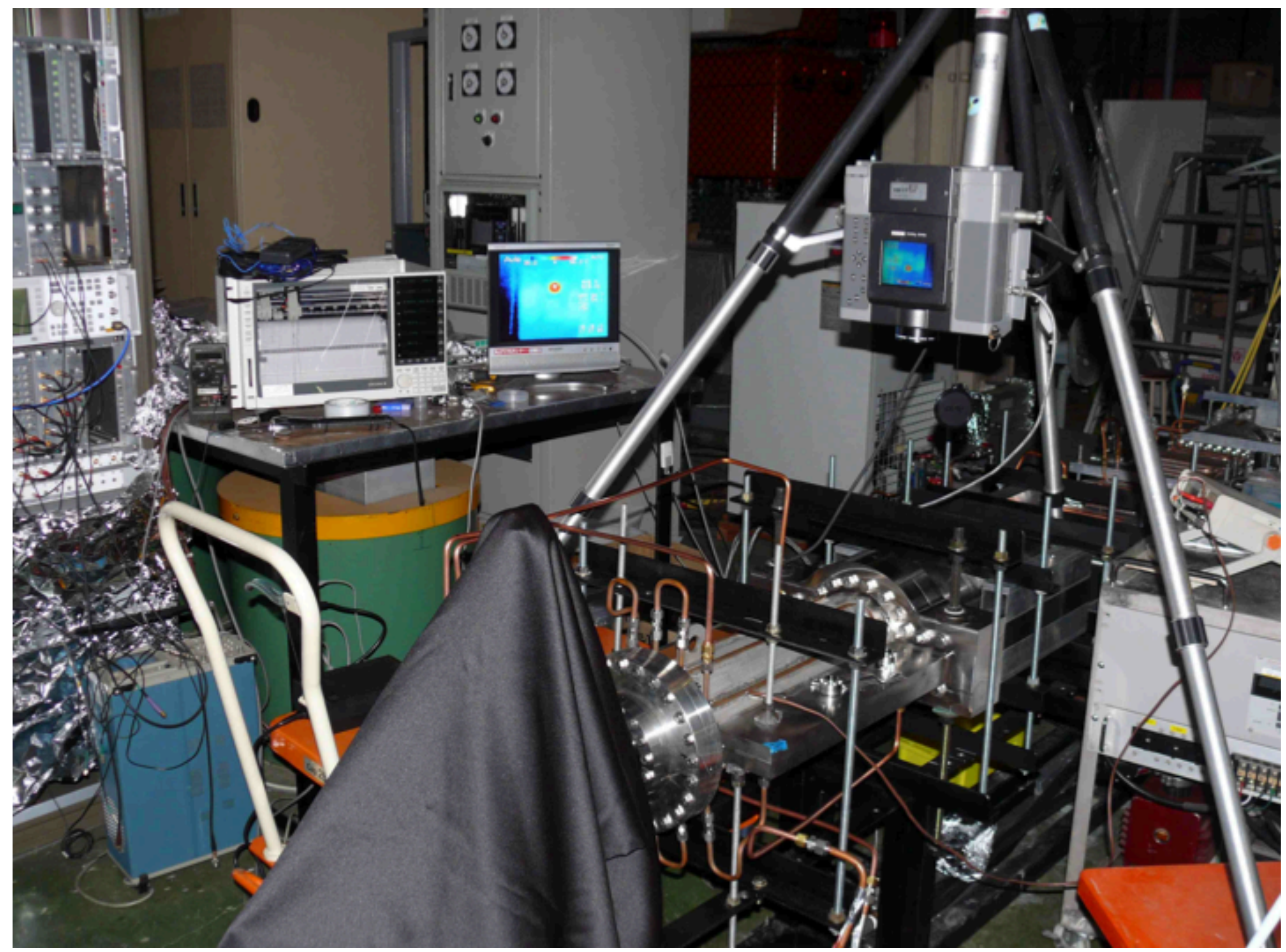
Y. Takeuchi

High Power Testing of GBP Load @ D1C (from Oct. 2010 through Feb. 2011)



MO-Flange Connection

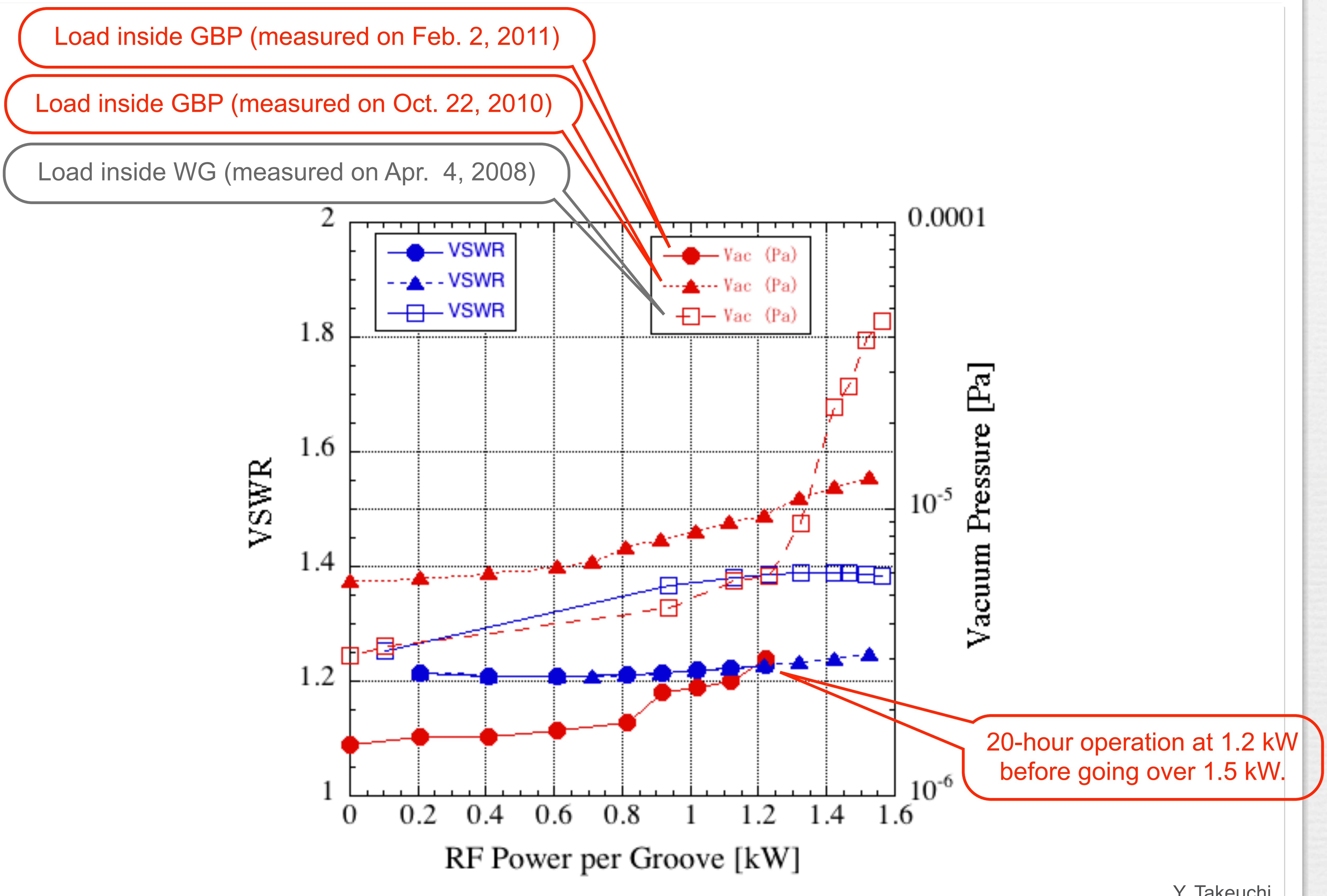
under construction



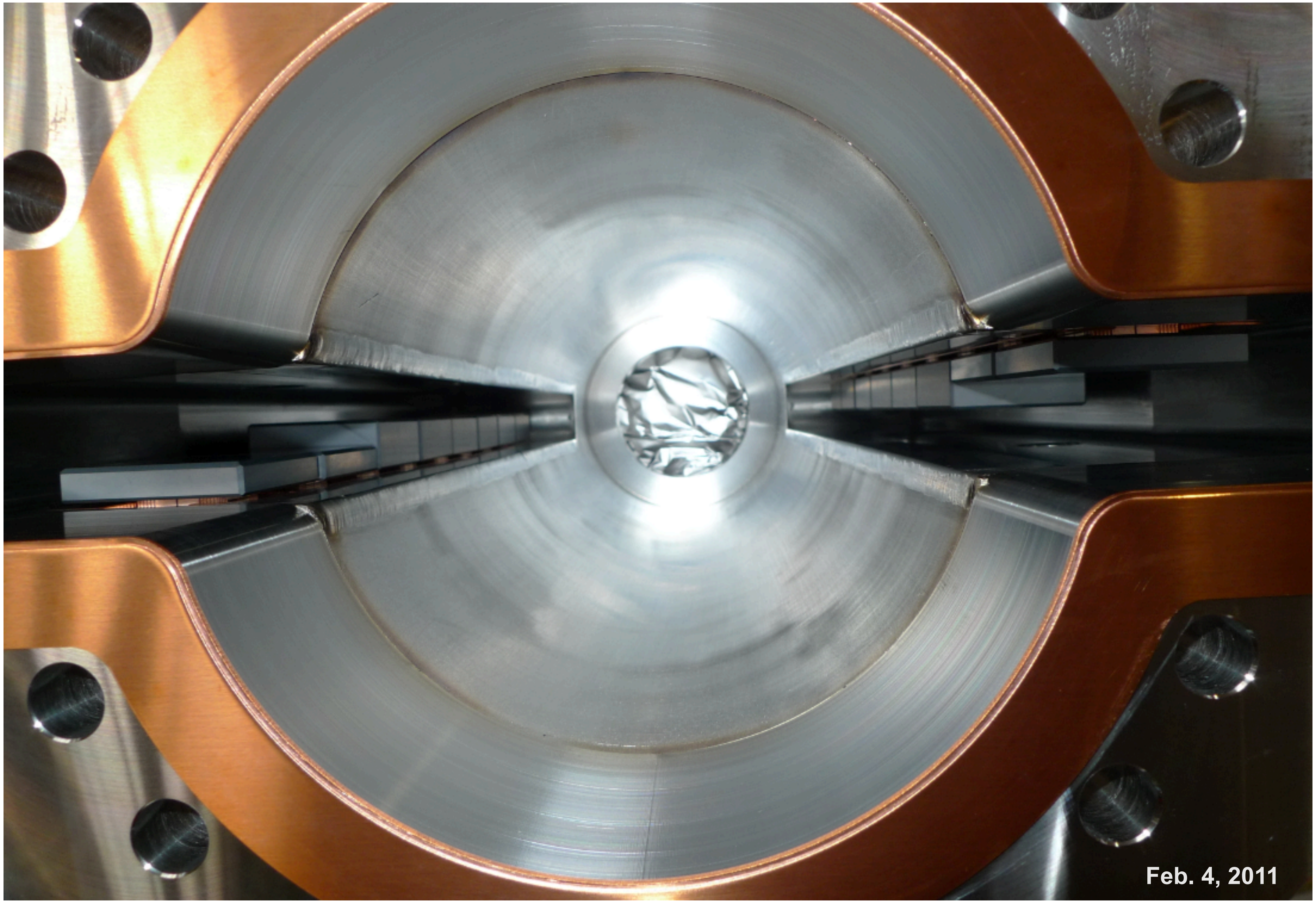
GBP Load under High-Power Test

Y. Takeuchi

Results of High Power Test of GBP Load @ D1C (from Oct. 2010 through Feb. 2011)



Results of High Power Test of GBP Load @ D1C (from Oct. 2010 through Feb. 2011)



No damage observed to the loads inside GBP
after 20-hour operation with 1.2 kW of RF power per groove.

Y. Takeuchi

HOM Power Estimation for SuperKeKB LER

	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

Summary for ARES Cavity System

★ The ARES cavities can be operated for SuperKeKB LER (3.6 A) without increasing the flywheel energy ratio (U_S/U_A = 9). Needless to say for SuperKeKB HER (2.6 A).

✔ The amount of frequency detuning for beam loading compensation: Δf_{AC} = -280kHz, that is $|\Delta f_{\pi/2}|$ = 28kHz < f_{rev} = 99 kHz.

✔ CBI (τ = 4ms for the fastest -1 mode) drivne by the accelerating mode: Cured by RF feedback.

✔ CBI (τ = 21ms, out of the klystron's bandwidth limit) due to the impedance imbalance between the 0 and π modes: Cured by longitudinal bunch-by-bunch FB.

★ Input Coupler

✔ A prototype coupler was fablicated in JFY 2009, with fine grooving on the outer conductor surface of the coaxial line to suppress multipactoring discharge, and with the coupling loop extended from 17 mm to 60 mm to obtain the input coupling factor over 6.

✔ The prototype coupler was successfully conditioned up to 800 kW at the test stand (Apr. 12~23, 2010).

✔ The prototype coupler was attached to the ARES cavity at D5-C (one-to-one configuration), and successfully delivered 610 kW to the beam (1250 mA) on June 24, 2010 (only 6 days before KEKB shutdown).

Fabrication of two pre-production couplers under way (JFY2010). Production of 6 couplers scheduled for JFY2011, followed by 8 couplers for JFY2012 and 6 couplers for JFY2013.

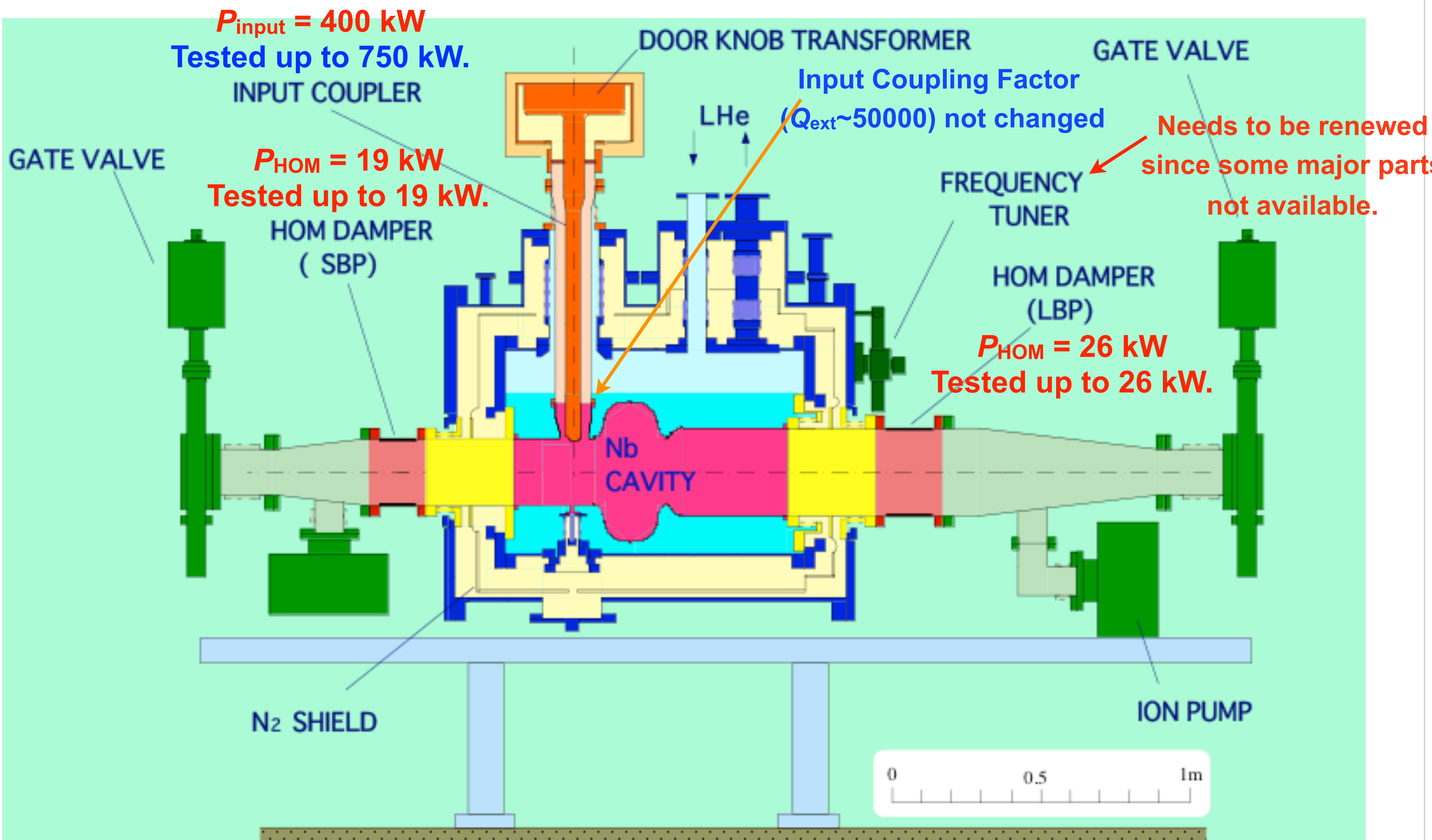
★ HOM loads

✔ The HOM waveguide loads: The power handling capability per WG verified up to 5 kW at a test stand with an L-band klystron. There will be a 50% margin left with respect to the design limit of 3.3 kW per WG for LER (3.6 A).

✔ The GBP loads: The power handling capability per groove verified up to 1.2 kW at the test stand. There will be a 30% margine left with respect to the design limit for LER (3.6 A).

Y. Morita

Superconducting Cavity System

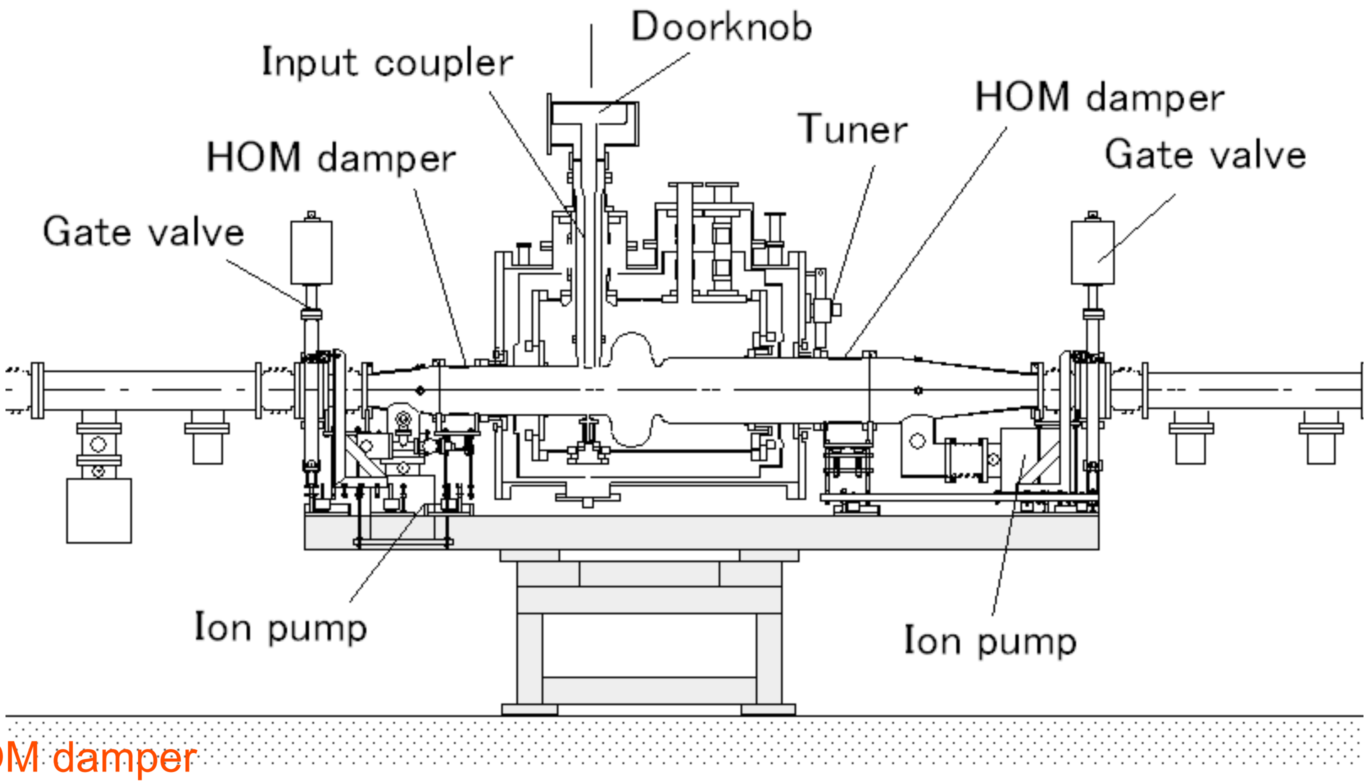


V_c = 1.5 MV, P_{beam} = 400 kW

Superconducting cavities for SuperKEKB Requirements and issues

Y. Morita

- Superconducting cavity
  - Operating voltage: 1.5MV
    - Already achieved
  - Operating current: 2.6A (SpuerKEKB HER)
    - Maximum current achieved: 1.4A (KEKB HER)
- High power input coupler
  - Beam power: 400kW
    - Already achieved
  - Optimum coupling: Qext~50000
    - Present coupling (no need to change)
- HOM damper
  - Expected HOM power:45kW @ 2.6A
    - Including self damper loss
    - SBP damper:19 kW
    - LBP damper: 26 kW
  - Ferrite temperature becomes high in the present HOM damper
    - Need to suppress temperature rise
      - to suppress outgas which trigger cavity trips
  - R&D for new dampers to suppress temperature rise underway
    - Ferrite thickness: 4 →3 mm
    - Double cooling structure
- Tuner driver system
  - Need renewal of the piezo stack because of discontinuation of product
- New electro-polishing facility
  - Renewal of the facility
- R&D for high pressure water rinsing
  - For cavity performance recovery
  - Rinsing of the cavity in the cryomodule



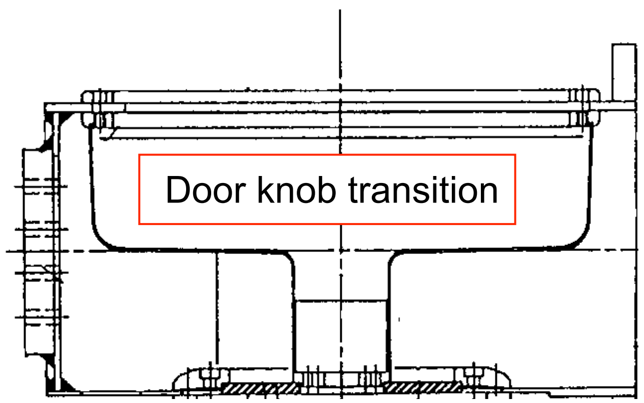
Y. Morita

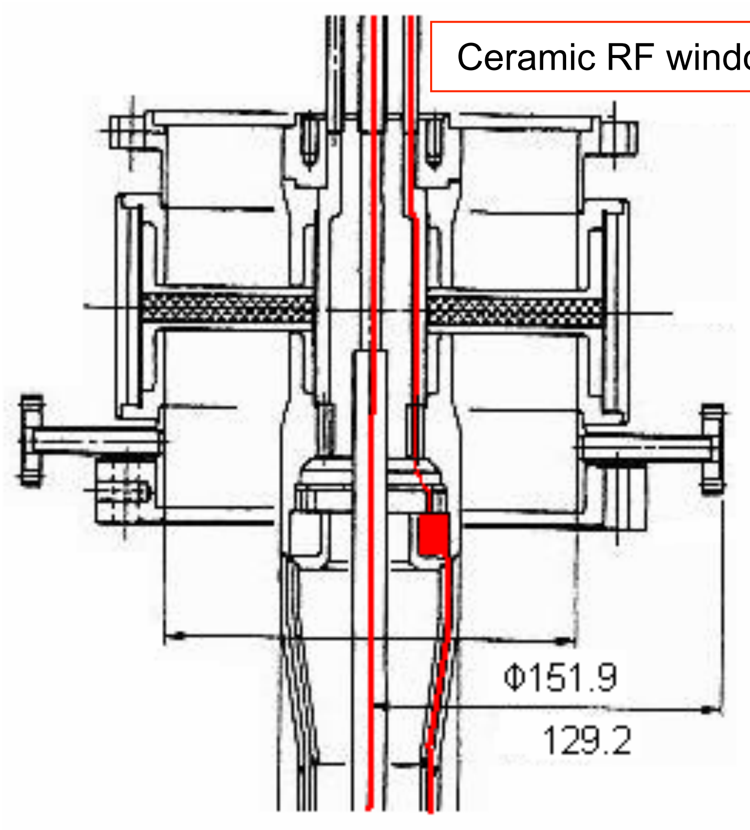
Input couplers for SCC

Beam power: 400kW (already achived)

Optimum coupling: Qext ~50000 (not changed)

Powerful cooling needed for 450kW operation

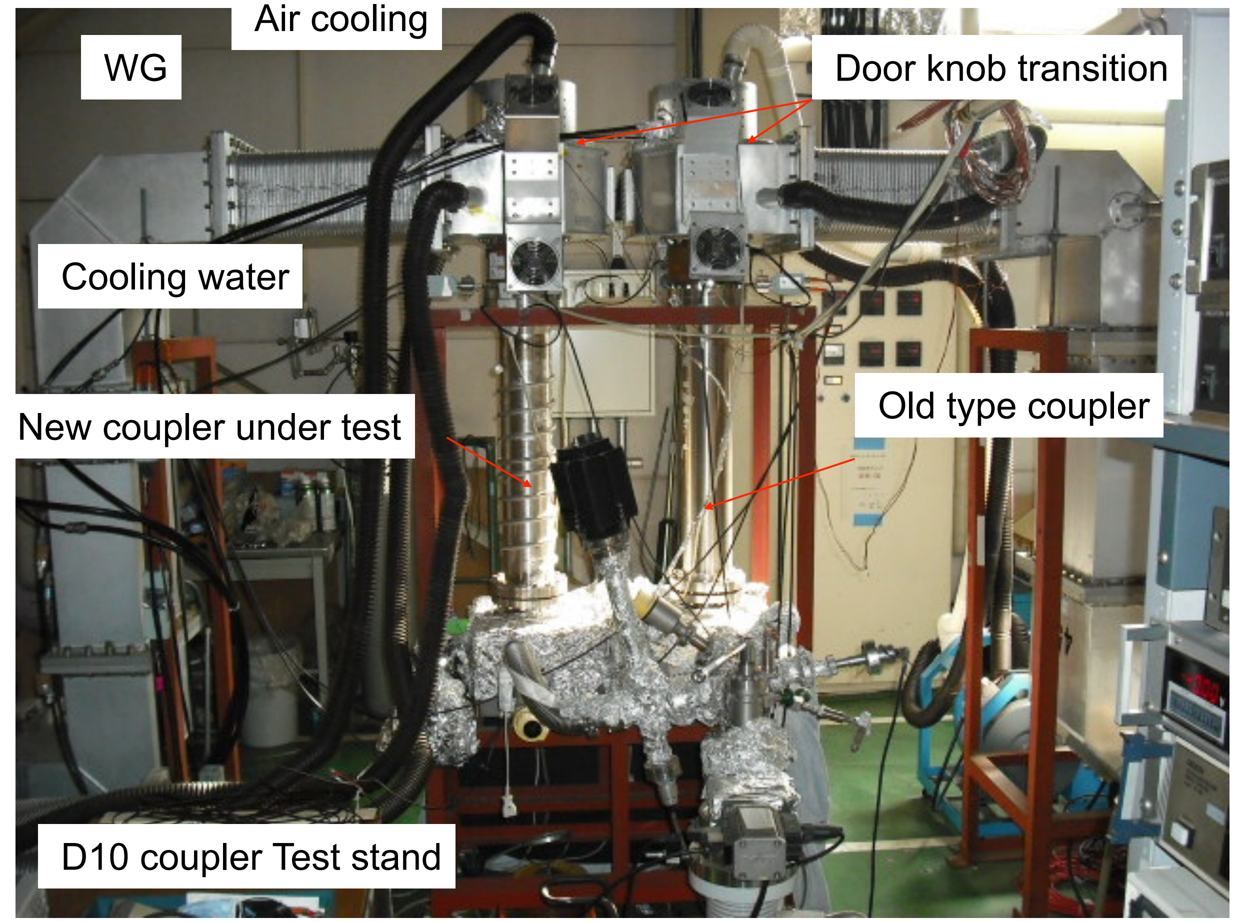


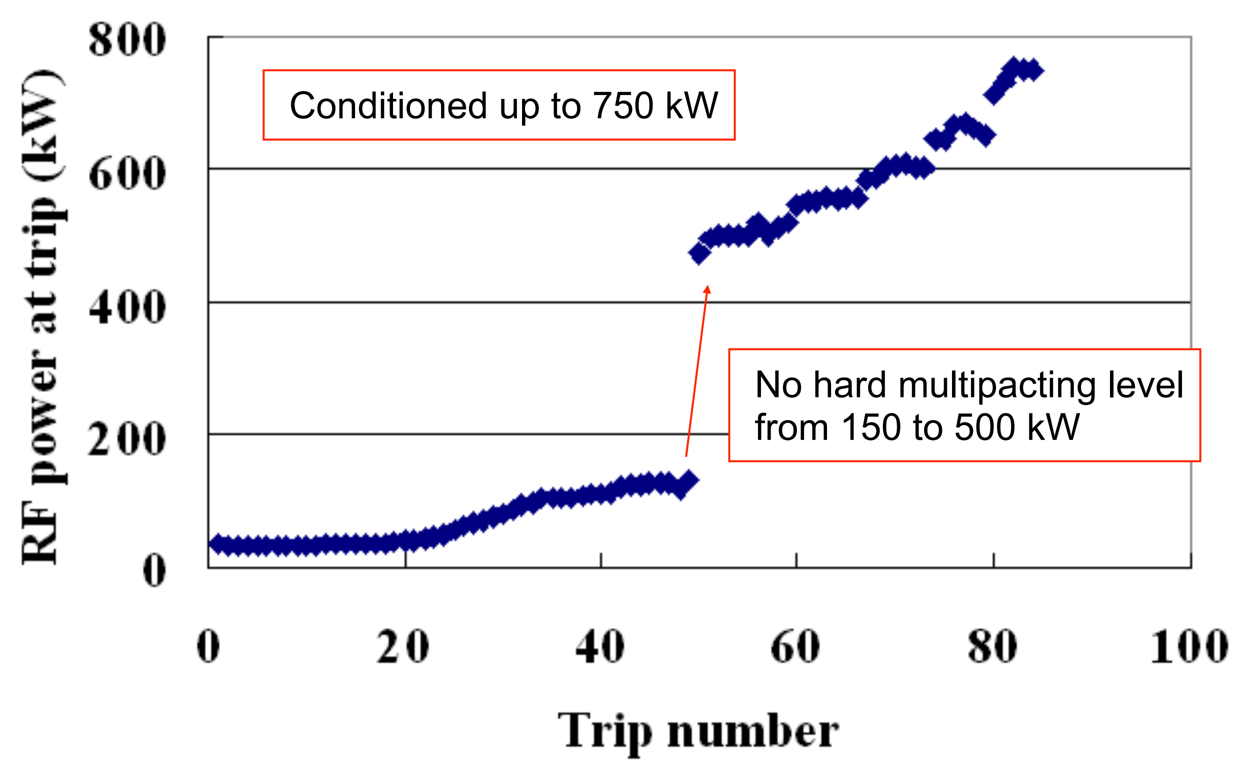


New type coupler
Simplified single cooling water path

Cooling water channel

Inner conductor at door knob





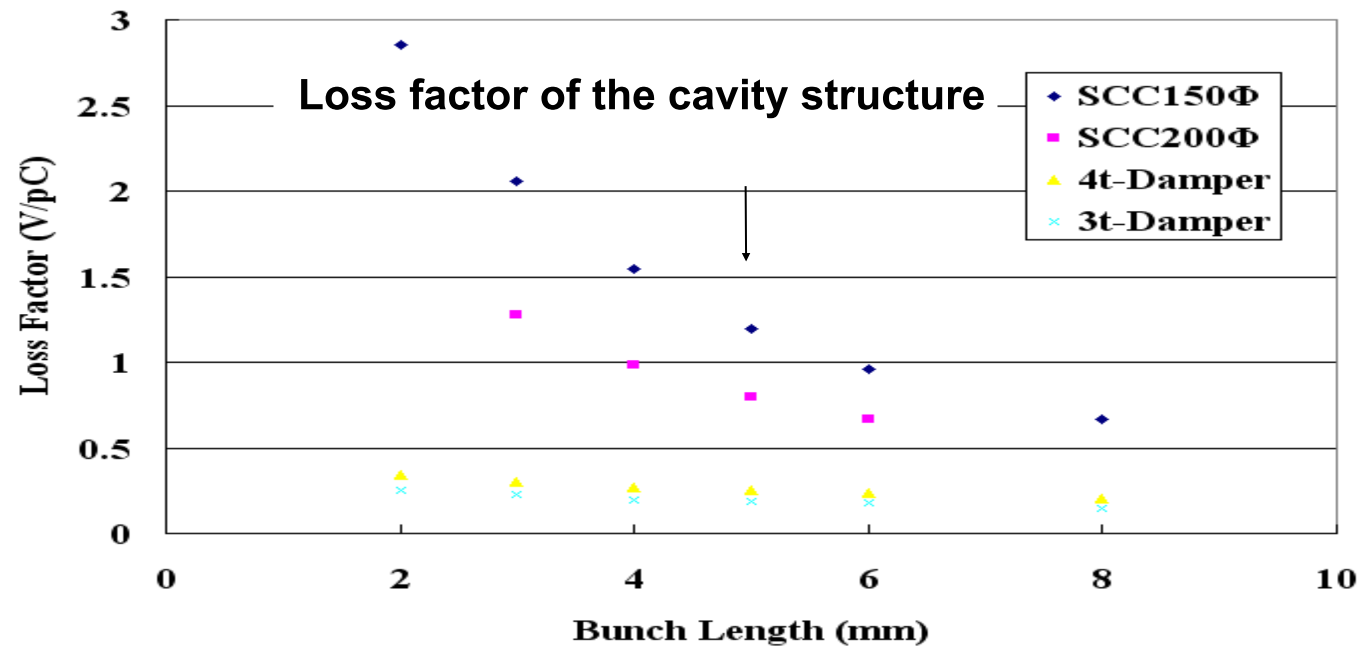
Y. Morita

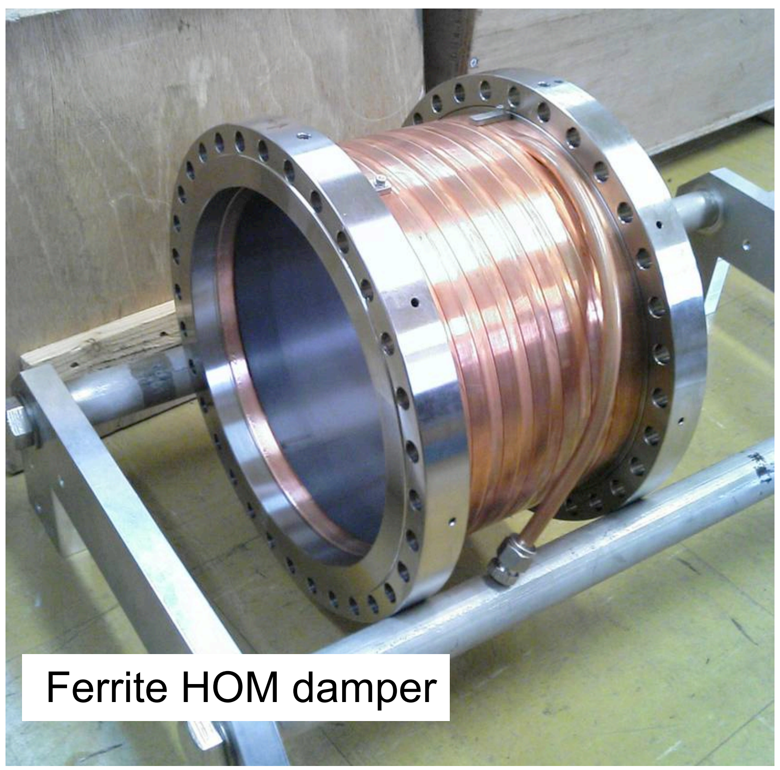
Expected HOM power for SuperKEKB-HER

- Expected HOM power
  - at 2 A, 19 kW+ damper loss (8 kW)
  - at 2.6 A, 32 kW+ damper loss (13 kW)

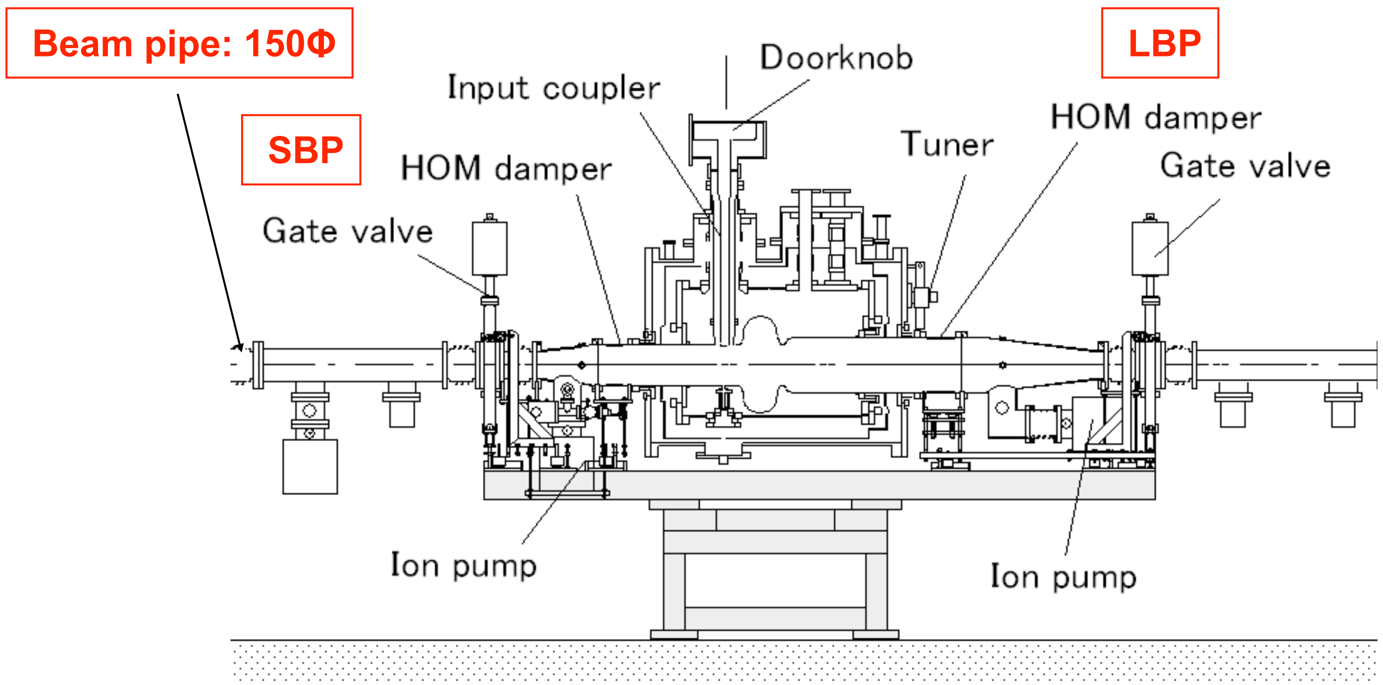
Beam current	SBP load	LBP load
(A)	(kW)	(kW)
2	12	15
2.6	19	26

Parameters of SuperKEKB HER (KEKB-HER)
Maximum current: 2.6A (1.4 A)
Bunch length: 5 mm (6-7 mm)
# of bunches: 2500 (1600)
Loss factor: 1.2 V/pC





Ferrite HOM damper

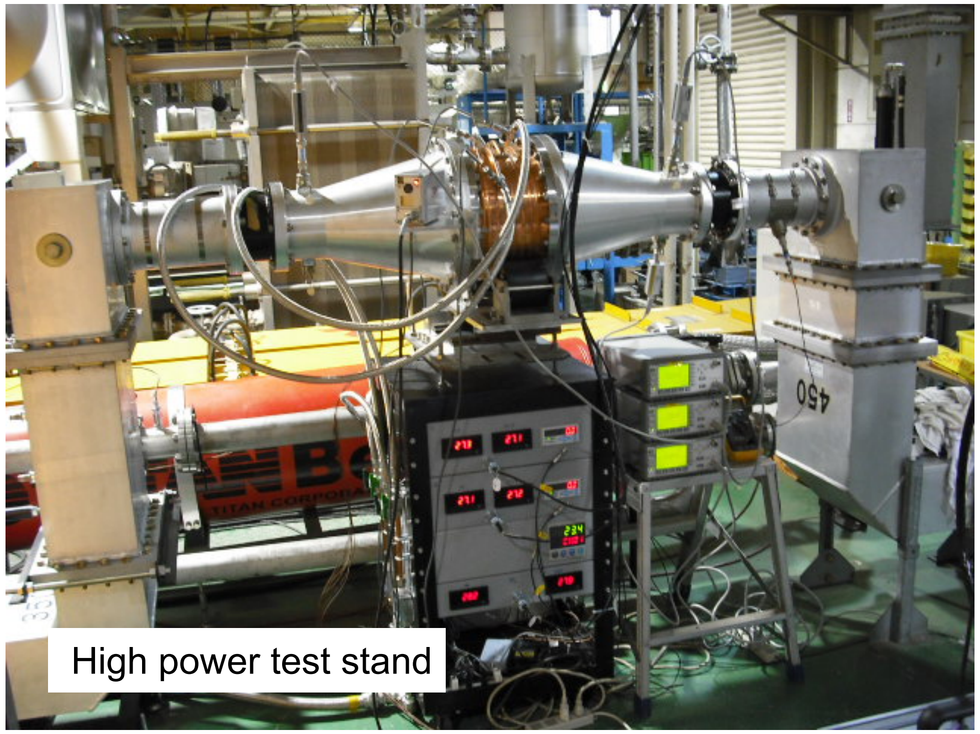


New HOM damper
Prototype #1

Improvements for higher power capacity

Surface temperature of the ferrite has to be decreased to suppress outgas. Copper base pipe temperature also has to be decreased to avoid ferrite cracking.

1) Thickness of ferrite was reduced from 4 mm to 3 mm.
2) The number of cooling channels was doubled.



High power test stand

High power test results
(New LBP damper)

Flow rates of the cooling water were 6, 8, 10L/min

Copper base pipe temperatures were blow 60℃

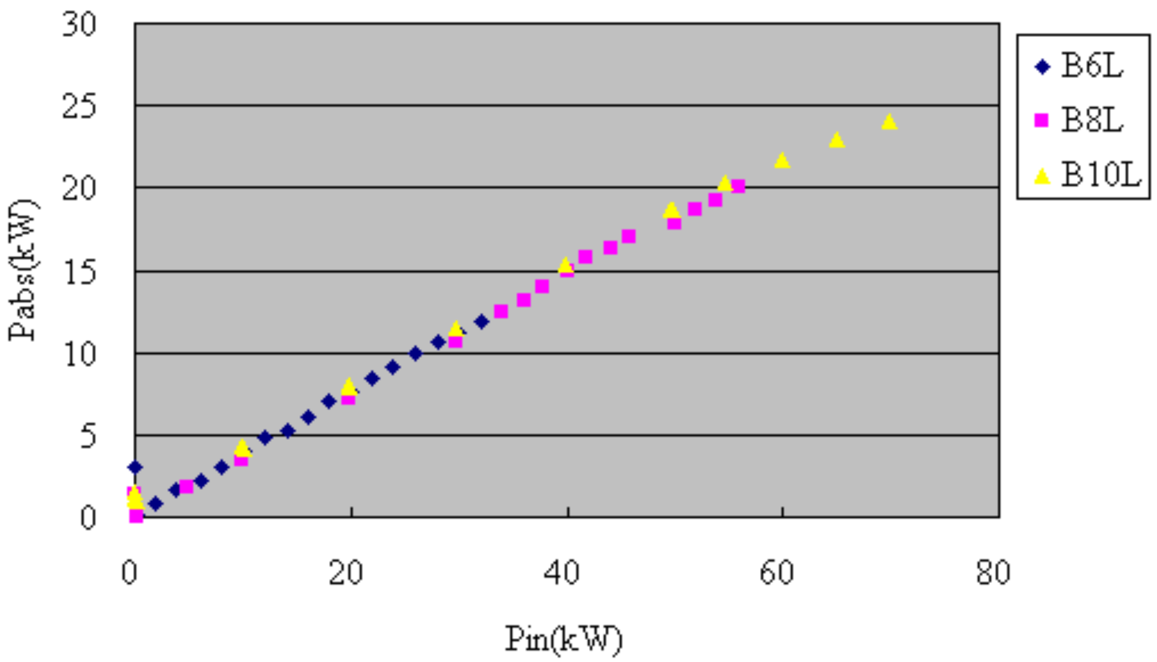
SBP damper also HP tested

up to 18kW

Tf<150℃ and TCu<60℃

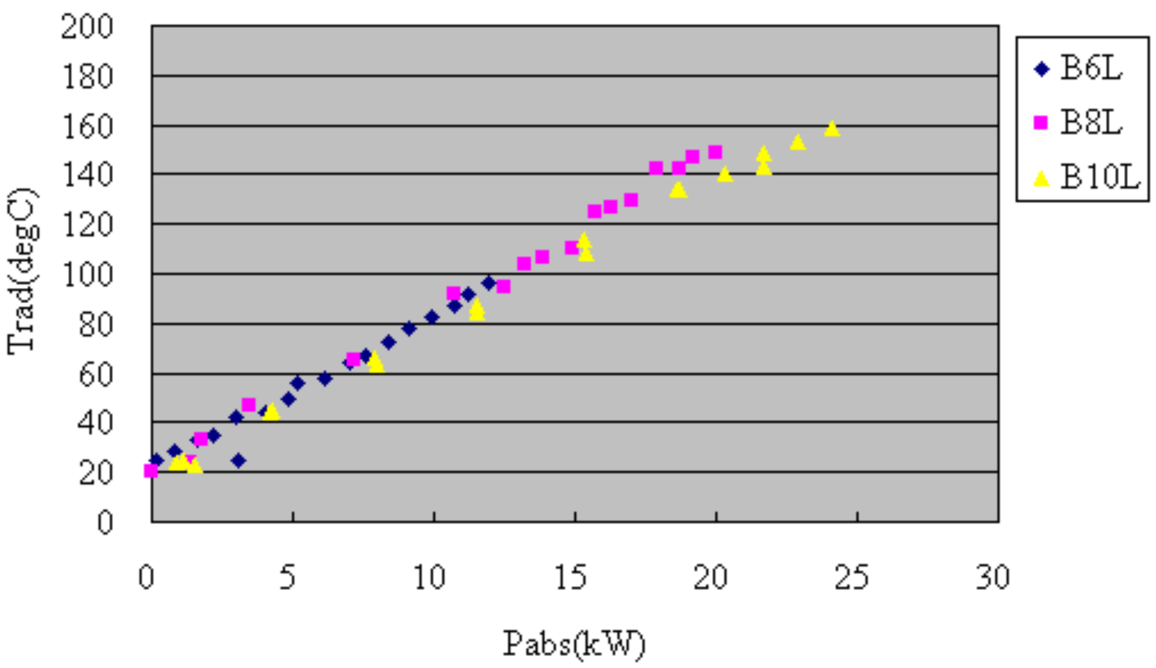
Input RF power vs absorbed power

LBP damper absorbed RF powers up to 24 kW



Absorbed power vs ferrite temperature

Temperature was 160℃ at 24kW



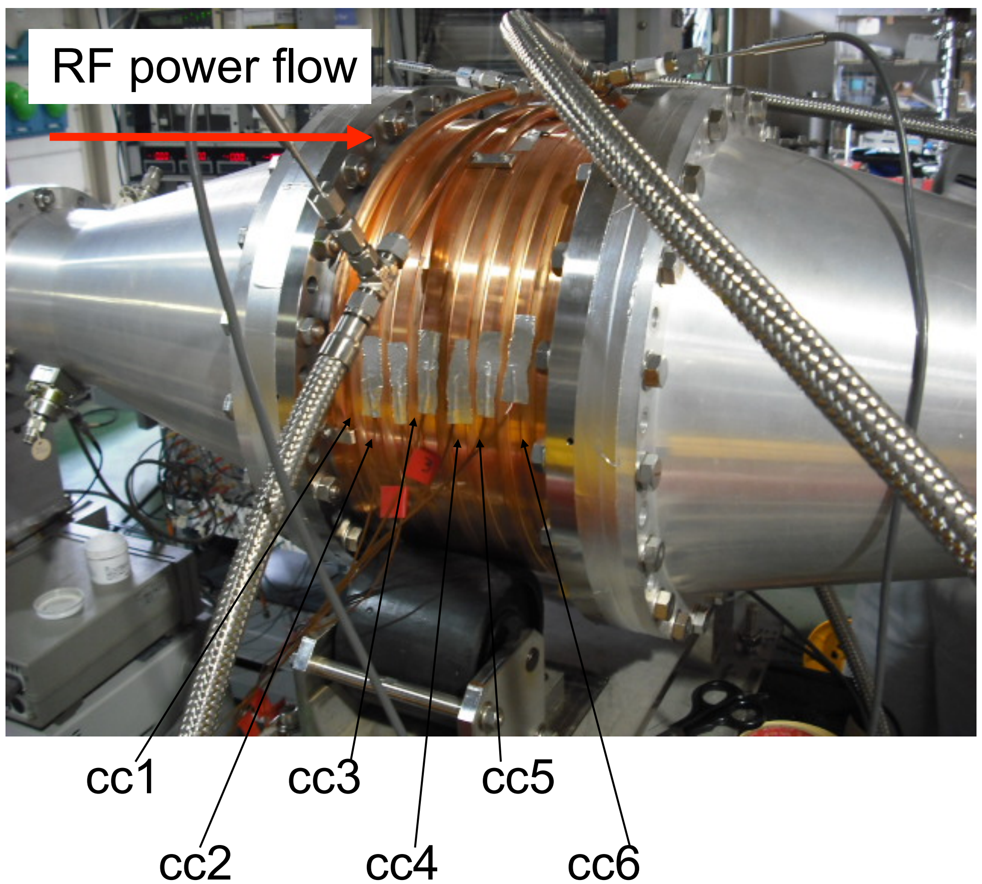
Y. Morita

Y. Morita

Temperature distribution of copper base pipe

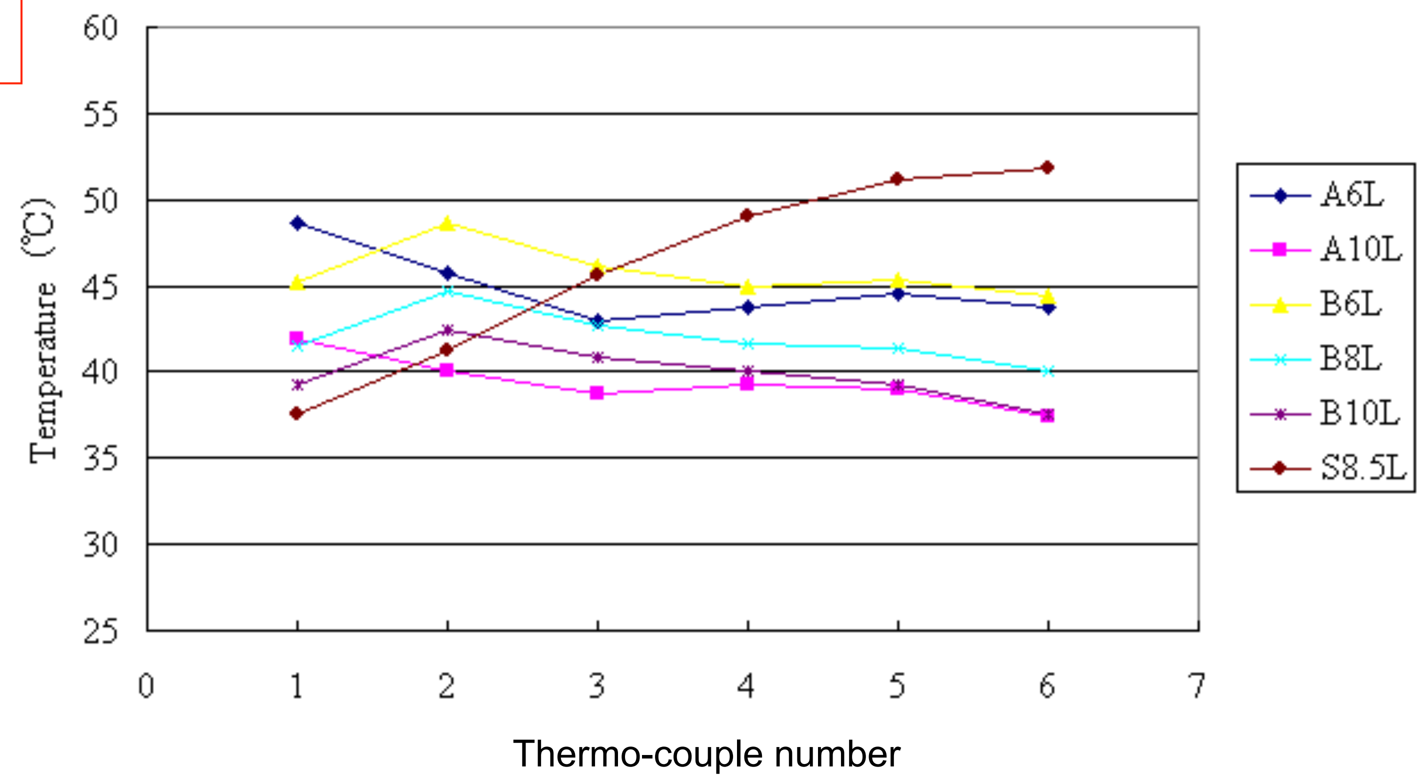
Double cooling structure can decrease temperature rise of the copper base pipe.

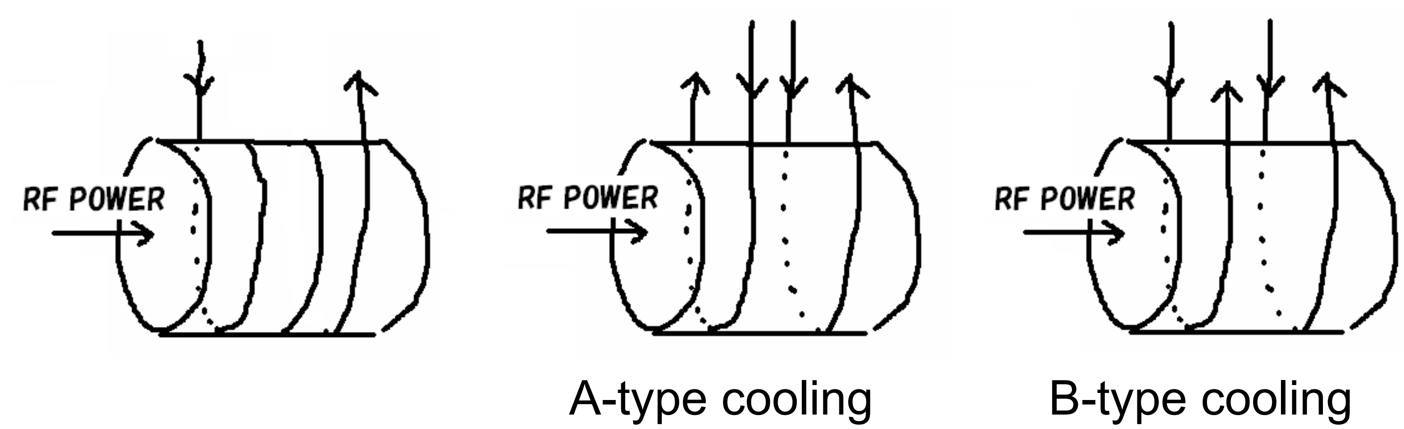
Prototype #1



Several thermo-couples were attached on the copper base pipe and temperature distribution was measured.

Temperature distribution at 14 kW





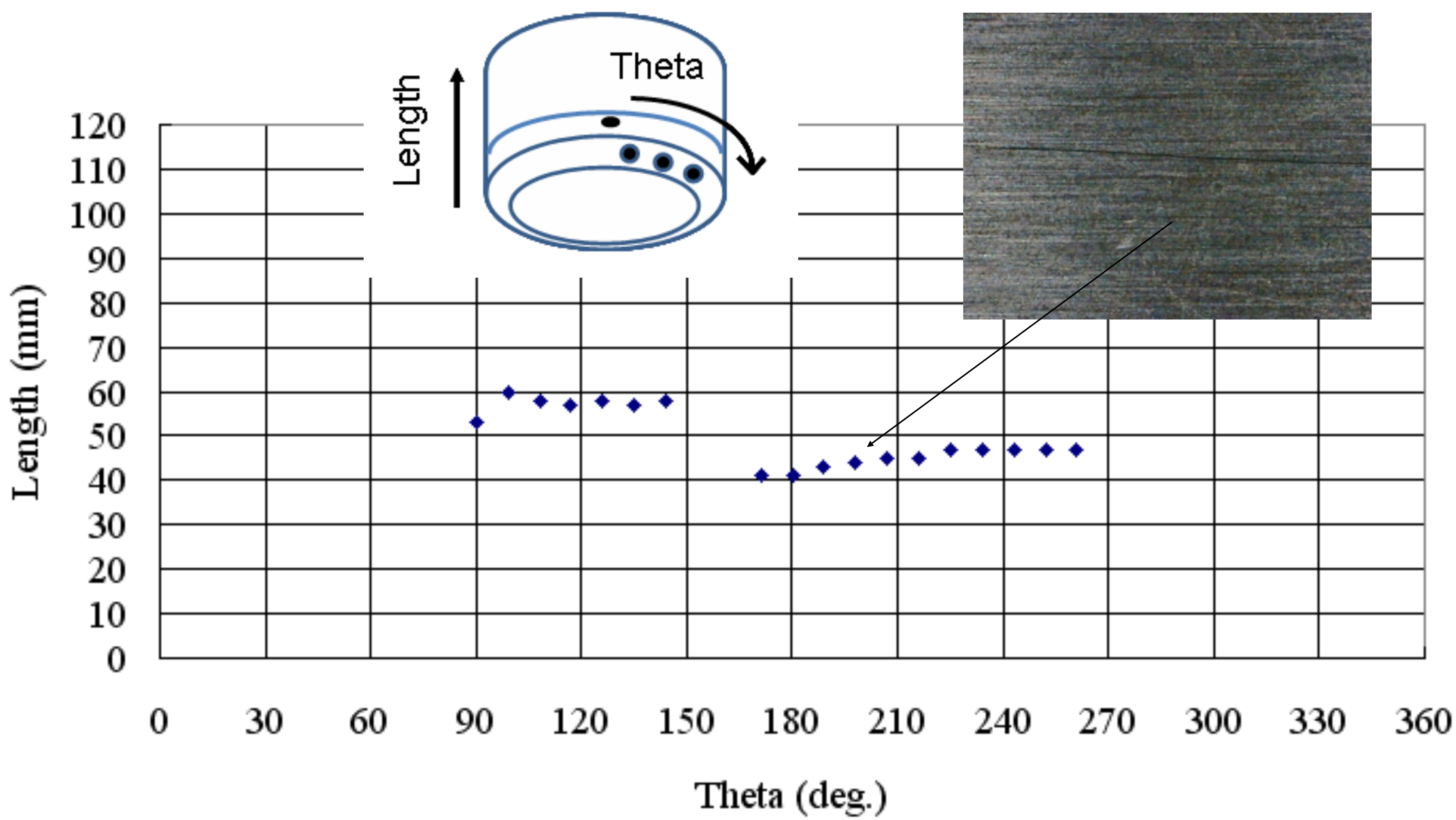
Single cooling structure

Double cooling structure

2nd prototype dampers cracked during high power test

- Dampers cracked
  - LBP: 25kW absorption
  - SBP: 15 kW absorption
- Ferrite thickness is not enough ?

Microscopic picture of the crack



Y. Morita

High power test results for HOM dampers

Damper type		Ferrite thickness (mm)	Cooling channel	Max. absorbed power (kW)	Ferrite temperature (℃)	Crack
LBP	KEKB type	4	Single	26	170	
	Prototype #1	3	Double	24	160	
	Prototype #2	3	Double	26	170	○
SBP	KEKB type	4	Single	19	190	
	Prototype #1	3	Double	18	150	
	Prototype #2	3	Double	19	170	○

New LBP and SBP dampers with the ferrite thickness of 3 mm can absorb HOM power expected for SuperKEKB HER (2.6 A).

However, the surface temperature of the ferrite was not reduced significantly as expected. If this result is true, there is no merit to replace the present 4-mm-thick ferrite dampers with new 3-mm-thick ferrite ones. In advance of the final decision, more investigation is needed.

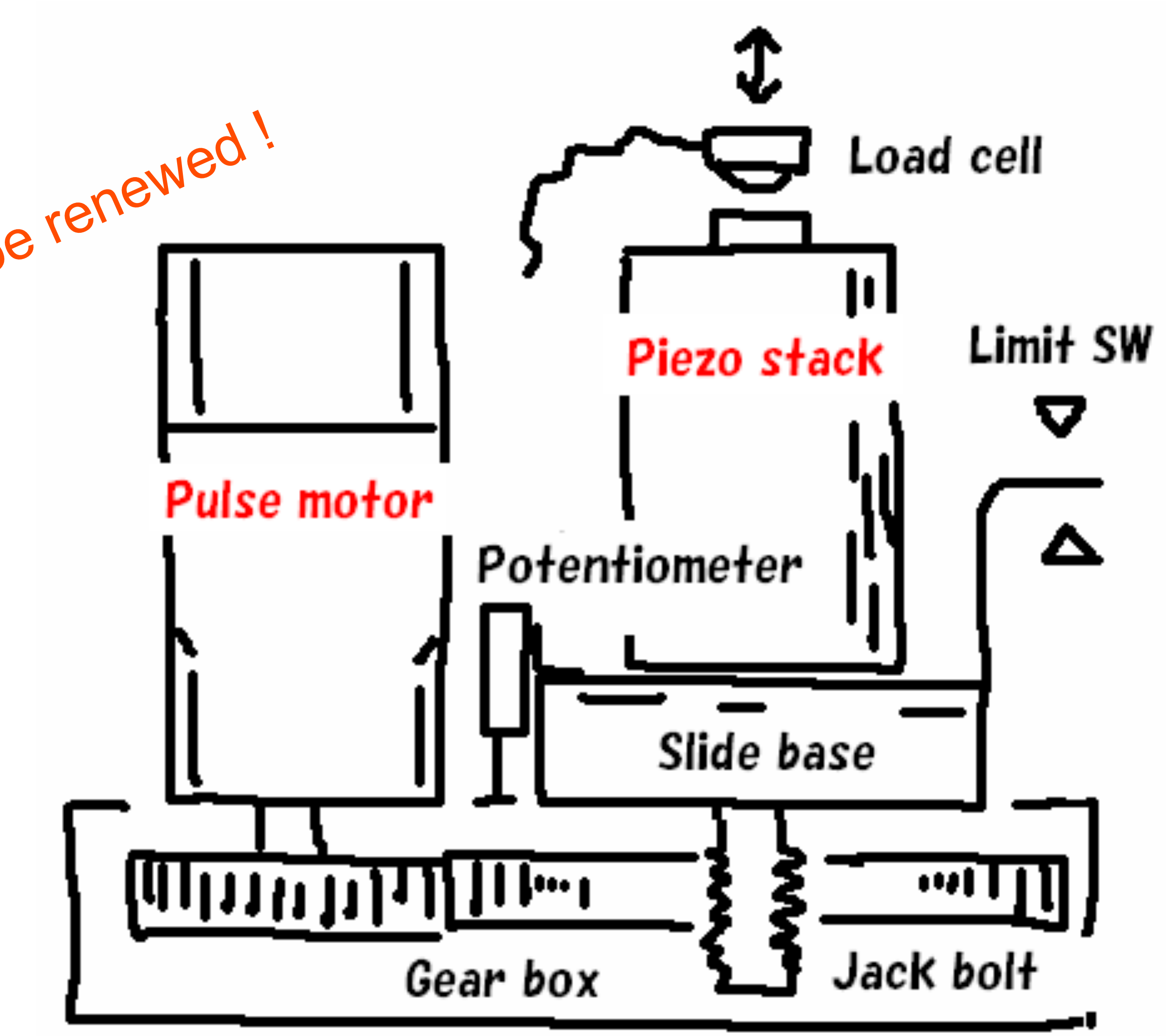
Furthermore, as for each of the 2nd prototype dampers for LBP and SBP, the ferrite layer was cracked during the high power test. The tensile strength of 3 mm-thick ferrite may not be enough.

A. Kabe

Tuner driver renewal

- Fabricated for TRISTAN SCC
- Consists of
  - Motor jack
    - Gear box
    - Jack bolt
    - Slide base
    - Limit SW
    - Potentiometer
  - Pulse motor (renewal)
  - Piezo-stack (renewal)
    - Piezomechanik
  - Load cell
  - Pulse motor driver (renewal)
  - PS for piezo-stack (renewal or revised)
  - Tuner controller
- Prototype fabrication and tests
  - A prototype tuner driver was fabricated
  - Tested at the test bench
  - Mounted on D10B cavity on 4/13, 2010
  - Operated until shutdown on 6/30, 2010
  - Successfully operated at the KEKB machine time

Those should be renewed !



Tuner driver

S. Mitsunobu

New electro-polishing system for KEKB-SCC

- 横型回転方式，連続回転方式

Horizontal and rotating system for electro-polishing developed for TRISTAN superconducting cavities.

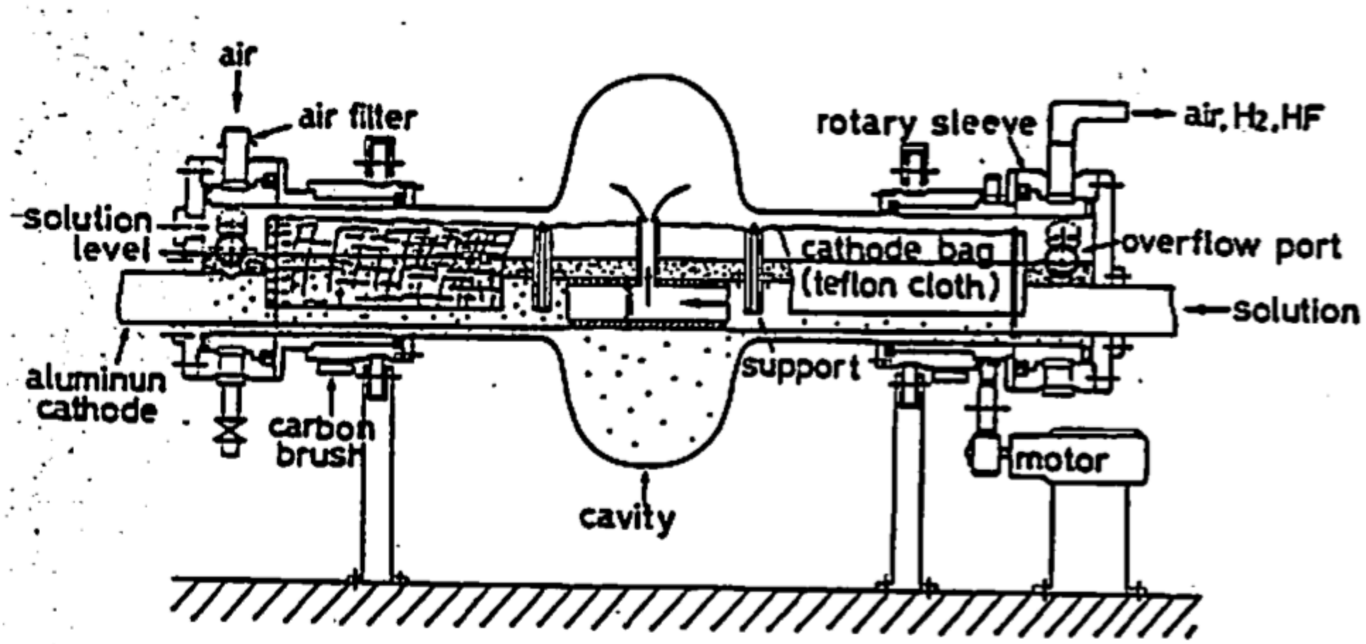
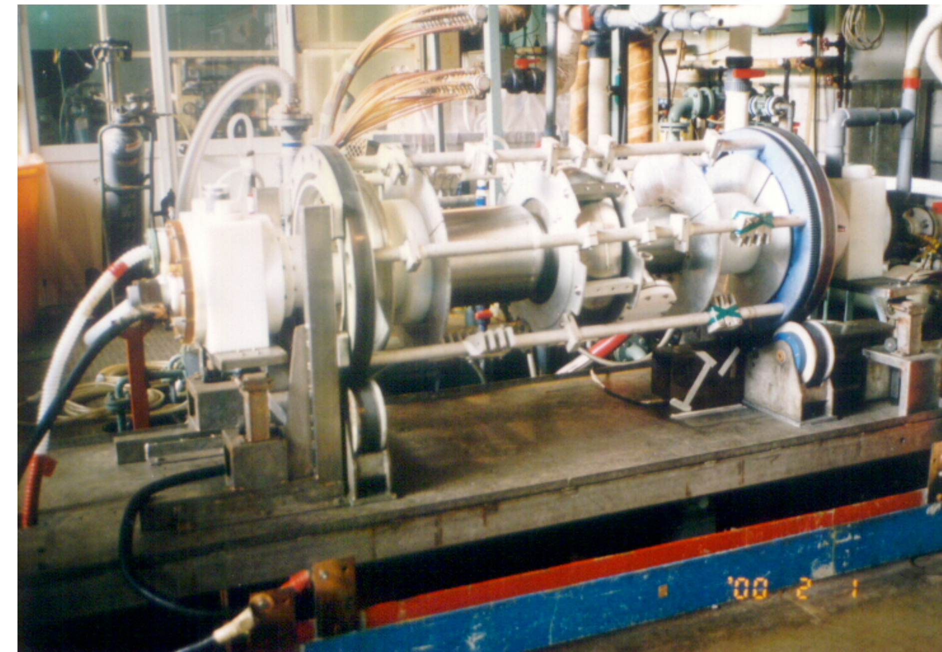
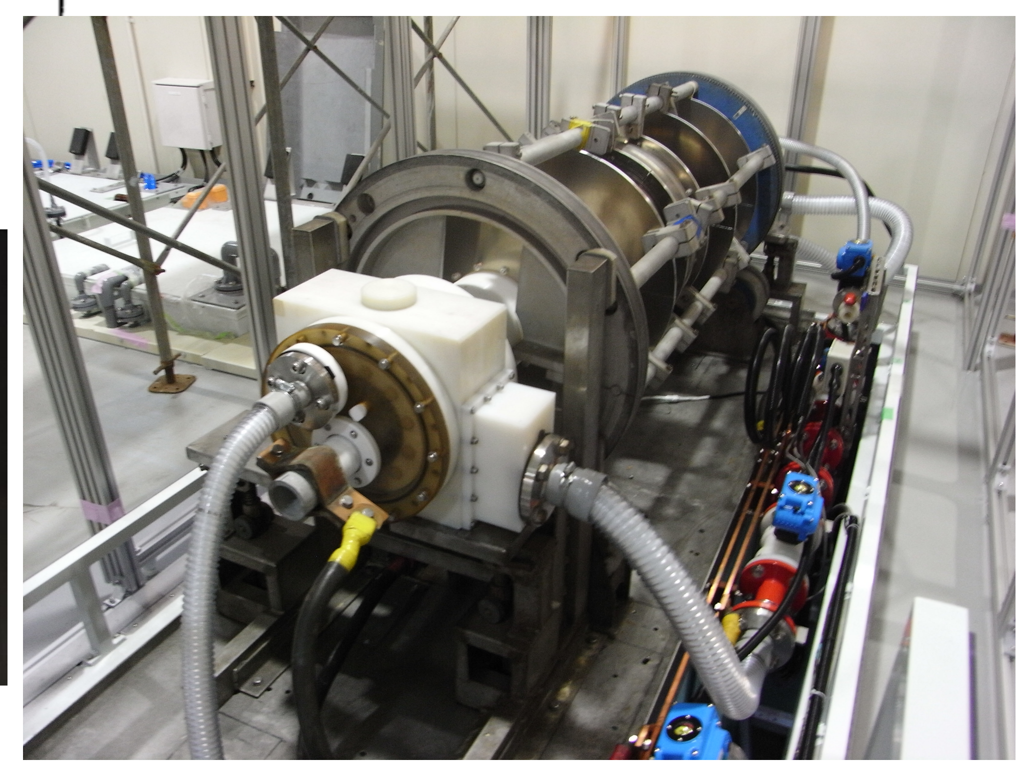


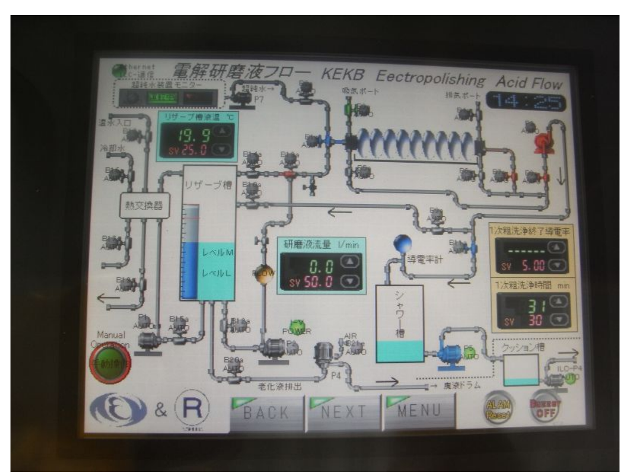
Fig.23
Horizontal rotational EP method for single cell cavities.

Old EP system at Nomura Plating Co.



Rotating equipment and EP bed were transferred to new EP facility at KEK.





Control panel

New features
Automatic controlling system
Tight sealing for HF acid

S. Mitsunobu

New EP facility for KEKB-SCC

New EP equipment for SCC on 2nd Floor

Acid gas cleaning system

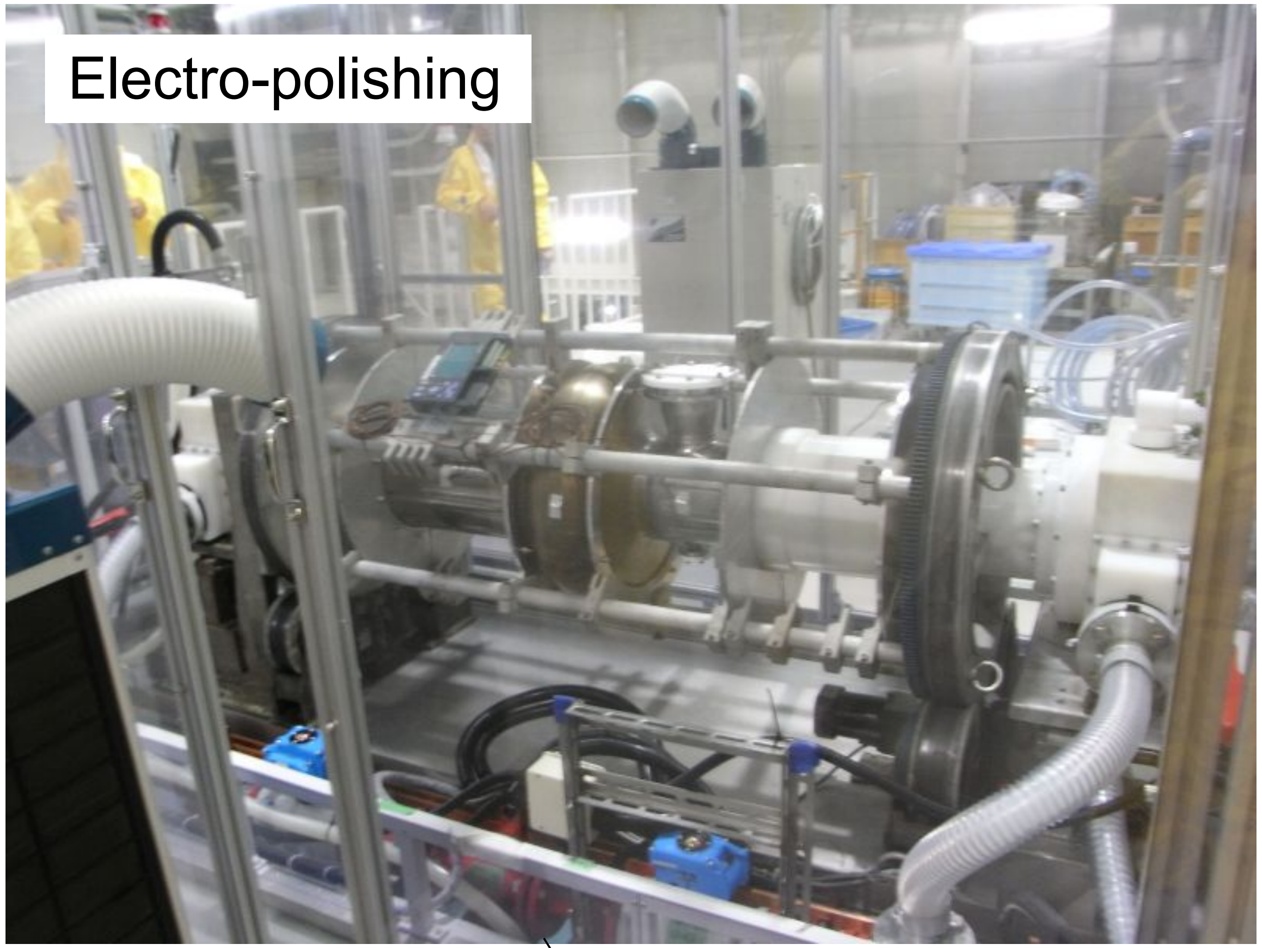
New 500 L reservoir for HF/H_2SO_4 solution

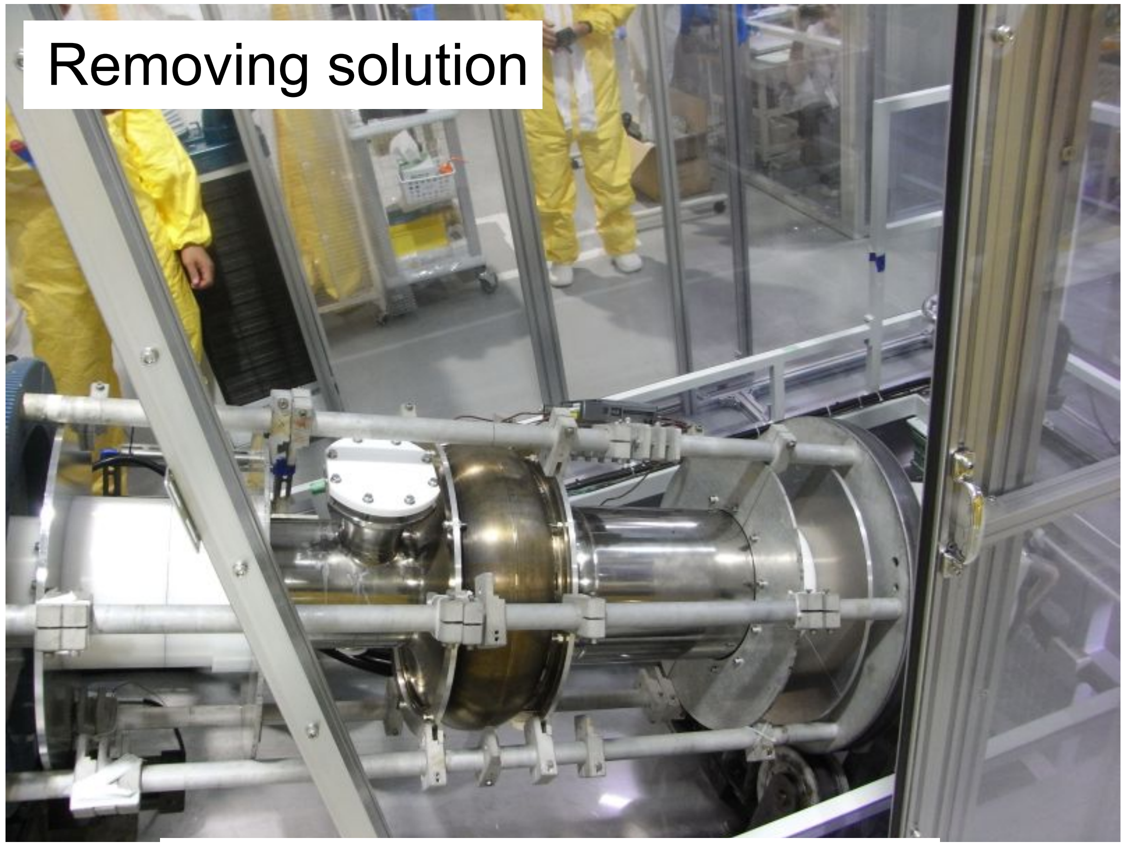
Ultra-sonic bath and shower tank

S. Mitsunobu

1st EP for a test cavity

- Electrolyte solution: HF(45%):H_2SO_4(96%)=1:9
- Acid temperature: 20~30 ℃
- Cathode voltage: -20~-30 V
- Current density: 30~50 mA (EPI>EPII)
- Acid flow rate: 40L/min



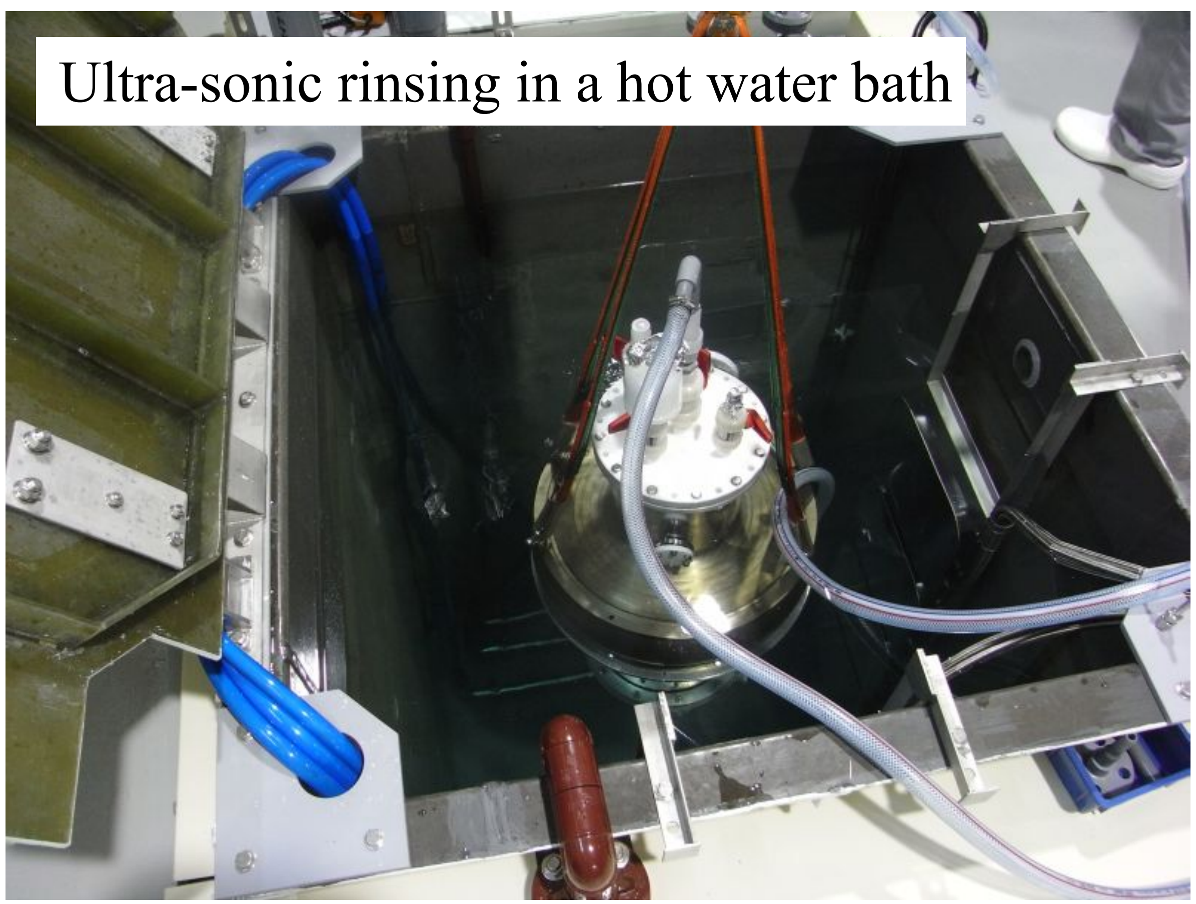


EP bed is moving to hold the cavity vertically.

Electrolyte solution is extracted while the cavity was vertically held.

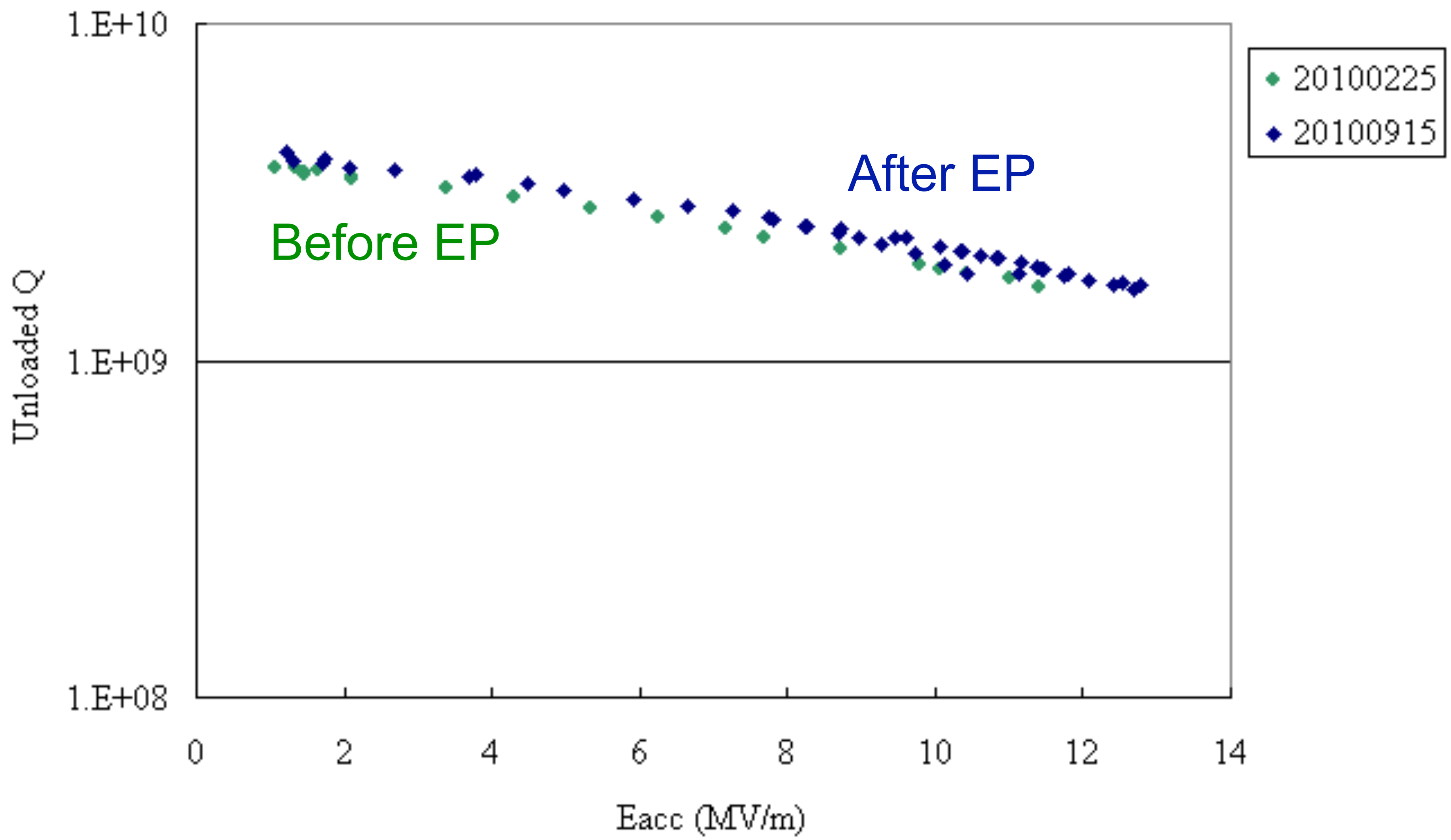

4 bar shower rinsing with pure water


O_3 rinsing


Ultra-sonic rinsing in a hot water bath

Vertical test

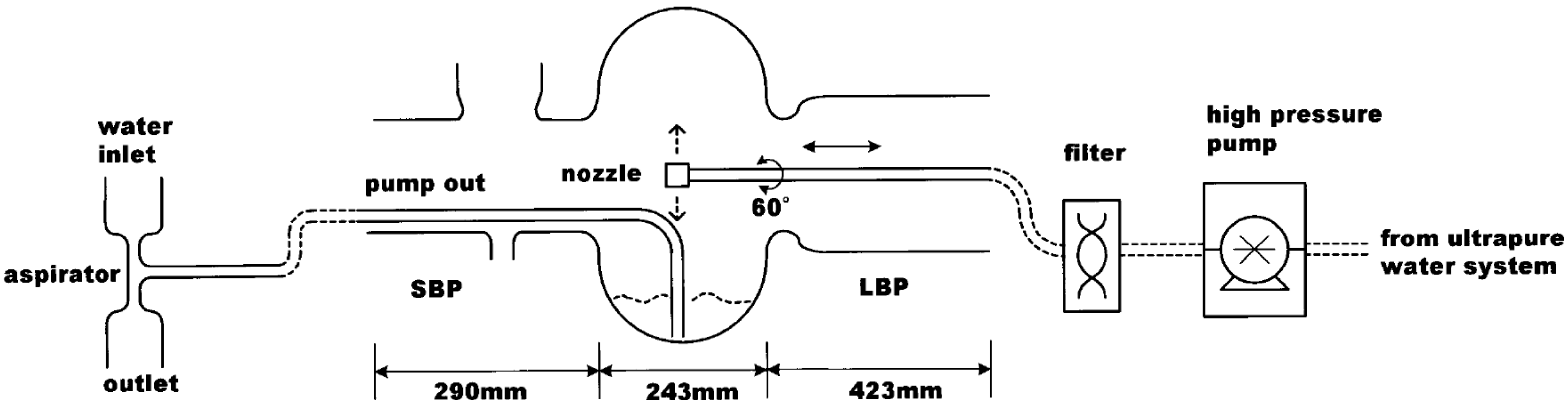
Eacc＝13MV/ｍ was achieved after EP（@KEK)
Test cavity was successfully electro-polished with new EP system



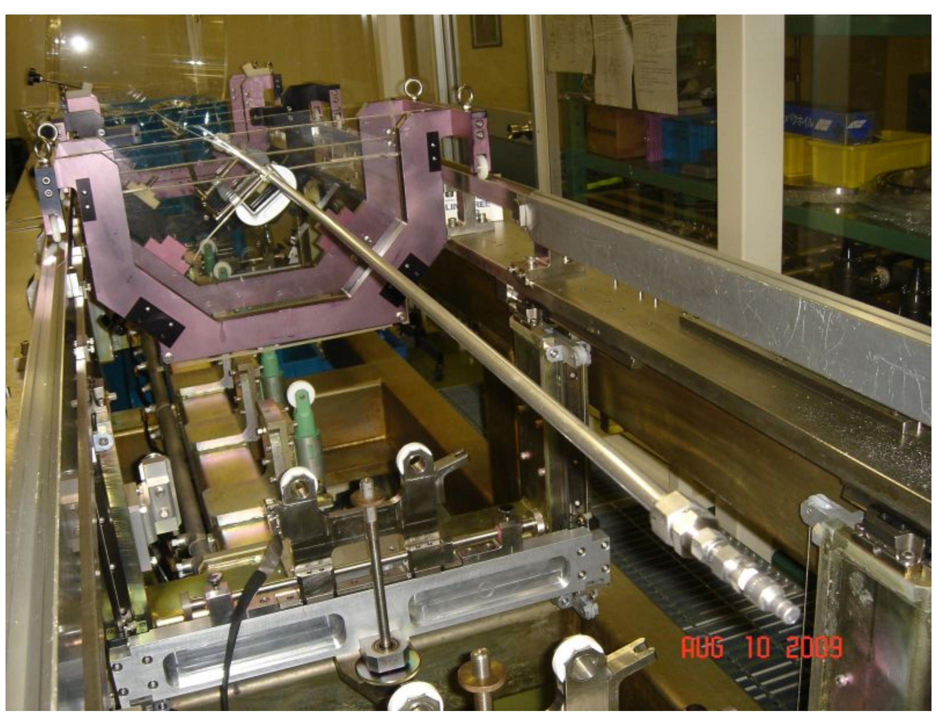
S. Takano

Horizontal High Pressure Rinsing (in situ)

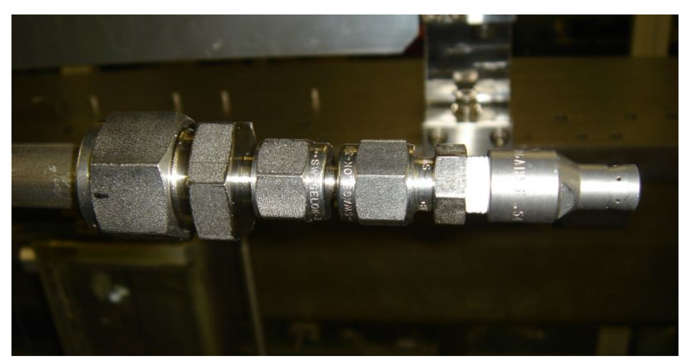
Degraded cavity might recover its performance with the high pressure ultra-pure water rinsing. In order to apply for cavities in operation, the rinsing has to be done horizontally as shown in a figure below. An aspirator removes wasted water in a cavity sell.



Nozzle head and stainless steel pipe



Nozzle head made of stainless steel (SUS410)



Ultra-pure water pressure : 60 bar
Holes : 6 holes, f0.54mm
Driving speed : 10mm /15sec for LBP & SBP
5mm /15sec for Cell
Rotation speed : 60deg. / 5sec
Total time : 20 min.
Nozzle was manipulated manually.

Rinsing a prototype cavity in a clean room

Summary for the Superconducting Cavity System

SCCs for SuperKEKB
Need
1) Input coupler for high beam powers (400kW)
2) HOM damper for high HOM powers (>40kW)
3) Renewal of infrastructures for long term operation

- Cavity
  - 1.5MV (achieved)
  - 2.6A (target)
- Input coupler
  - 400kW (achieved)
  - Need R&D for higher beam powers
- HOM damper
  - Two new damper sets fabricated and tested
    - Expected HOM powers @ 2.6A can be absorbed
    - Temperature rise not significantly reduced
    - 2nd prototype dampers cracked during high power test
  - Need to study to understand above reasons
- Tuner driver
  - Renewal
- Infrastructure
  - Electro-polishing facility
    - Construction completed
    - To be used for cavities for the Taiwan Photon Source project
  - HHPR apparatus
    - Continue R&D

p.18

23) Superconducting Cavity

The feasibility of “reversed-phase operation” of the superconducting HER cavities is critical to the RF system plan for Super KEKB. Only by using this technique can the new RF demands be supported by existing hardware without major changes. By analysis and careful test, the KEKB RF group have examined the issues and determined that none of them will prevent implementation of this concept; synchrotron tune, beam loading response,controllability, bunch length and transient trip response are all either unchanged, or if changed are acceptable and controllable. Tests included support of a luminosity run at 1200 mA delivering 300 kW/cavity to the beam. The only unusual event was a rise in cavity voltage on a reversed-phase cavity during a beam energy change. A thorough investigation demonstrated that this was to be expected, and that the range of possible excursions at the nominal operating point is well within the tolerable operating range of the superconducting cavities.

HOM dampers will have to be improved to deal with beam currents in excess of 2 A, but this should be achievable with straightforward extensions of the existing design. Design concept tests were successful and prototypes are being constructed for further proof.

Although the existing input couplers will meet the RF power requirements of SuperKEKB, further development of couplers for higher power is ongoing.

Reply from Y. Morita to the above comments in the report from the 15th KEKB Accelerator Review Committee:

<u>Reverse Phase Operation</u>

We have no need for the reverse phase operation because the operating voltage of the superconducting cavity was set sufficiently high enough to maintain normal phase operation in the new machine parameters.

<u>HOM damper</u>

The superconducting accelerating cavity has two dampers. One is a large beam pipe damper (LBP damper) with a beam pipe diameter of 300 mm, and the other is a small beam pipe damper (SBP damper) with a beam pipe diameter of 220 mm. Those dampers are required to absorb 25 kW in LBP and 18 kW in SBP, respectively, at the designed current of 2.6A.Surface temperatures of the ferrite with those power absorption becomes high and outgas may cause cavity trips. In order to reduce surface temperature, we made two modifications. The first modification is to reduce thickness of the ferrite from 4 to 3 mm for better thermal conduction. The second one is make double cooling structure for better cooling to reduce temperature rise of the copper base. We have fabricated two prototype dampers with 3mm thick ferrite and double cooling structure. Those dampers were high power tested and absorbed expected HOM powers of SuperKEKB. However, surface temperature of the ferrite was not decreased as we expected. Those test results showed that the thickness reduction of the ferrite has little merit for temperature decrease of the ferrite surface. Furthermore 2nd prototype dampers cracked during the high power test. The thickness reduction may make the tensile strength of the ferrite insufficient. We have to re-examine the HOM damper for SuperKEKB. We also have to examine to reduce the loss factor by using beam pipes with larger diameters.

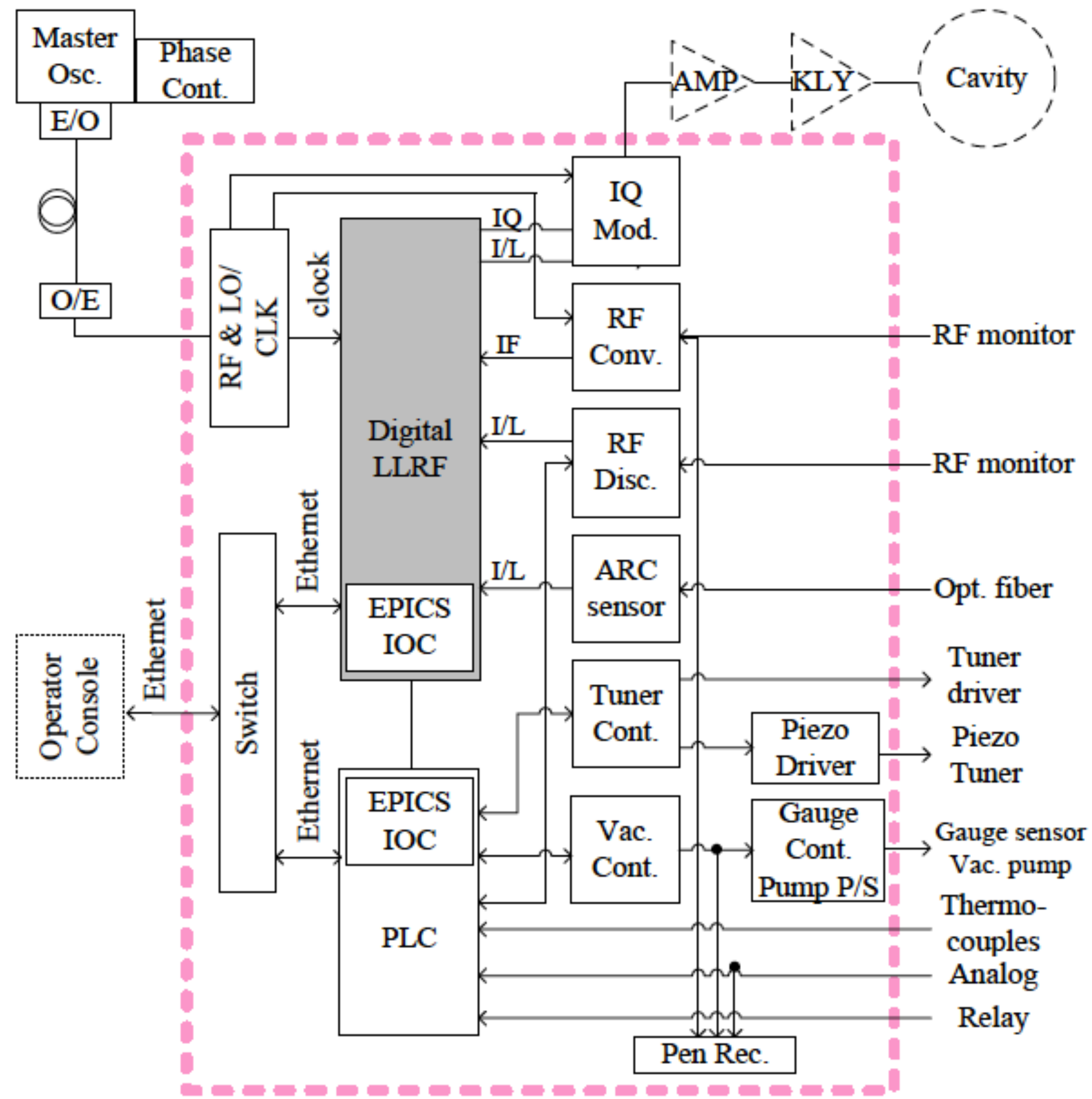
<u>High Power Input Coupler</u>

We continue R&D for higher power handling.

K. Akai

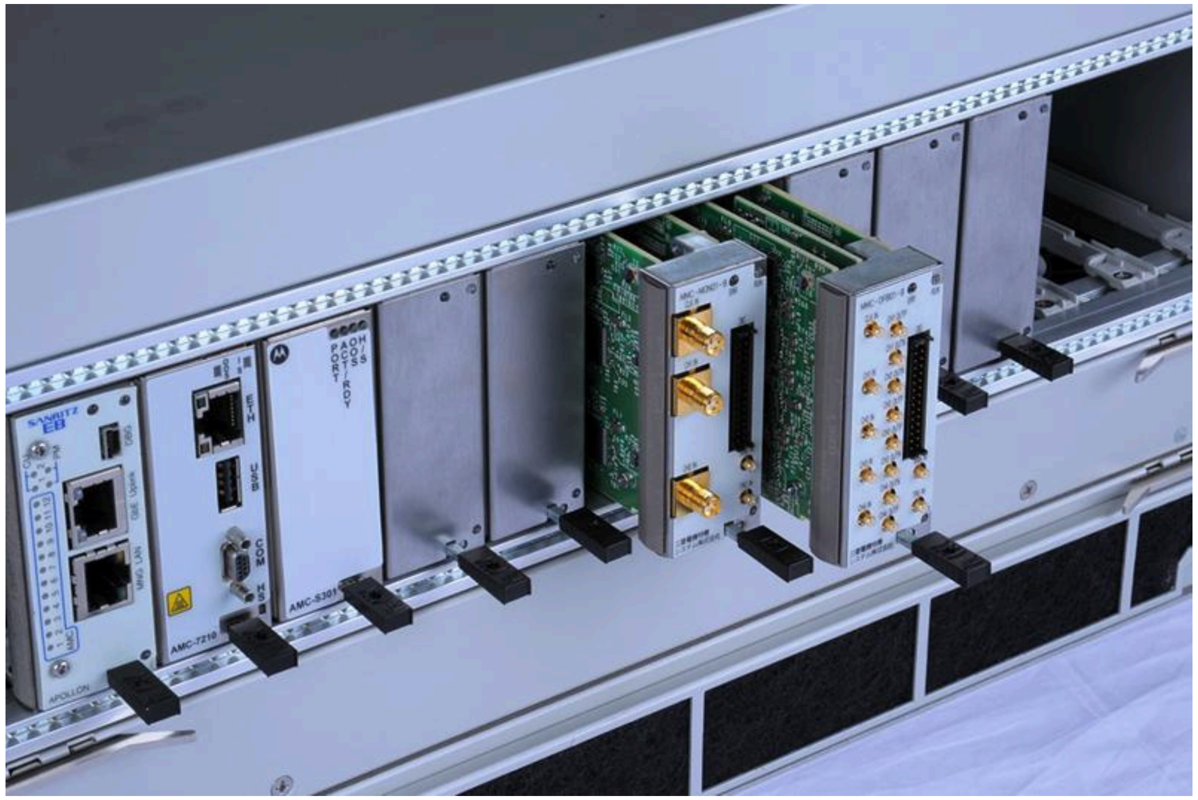
New digital LLRF for SuperKEKB

- System
  - Replace old analog circuits with digital control
  - Replace CAMAC with PLC
  - Measures for heavy beam-loading
  - Compatibility between the old and new systems (Commissioning will start with both systems existing.)
- Digital control board
  - Digital LLRF board is being developed, common to SuperKEKB and cERL projects. The board is also planned to be used for collision feedback system.
  - EPICS IOC on FPGA and EPICS IOC on PLC is adopted, under collaboration with KEKB control group.
- Prototype
  - Will be installed at D8-D station next month, and tested with klystron and ARES cavity this year.
- Construction
  - Install new LLRF for new stations where one klystron drives one ARES cavity.
  - The old system will be kept for stations where one klystron drives two ARES cavities. They may be replaced with new LLRF in future, depending on budget.

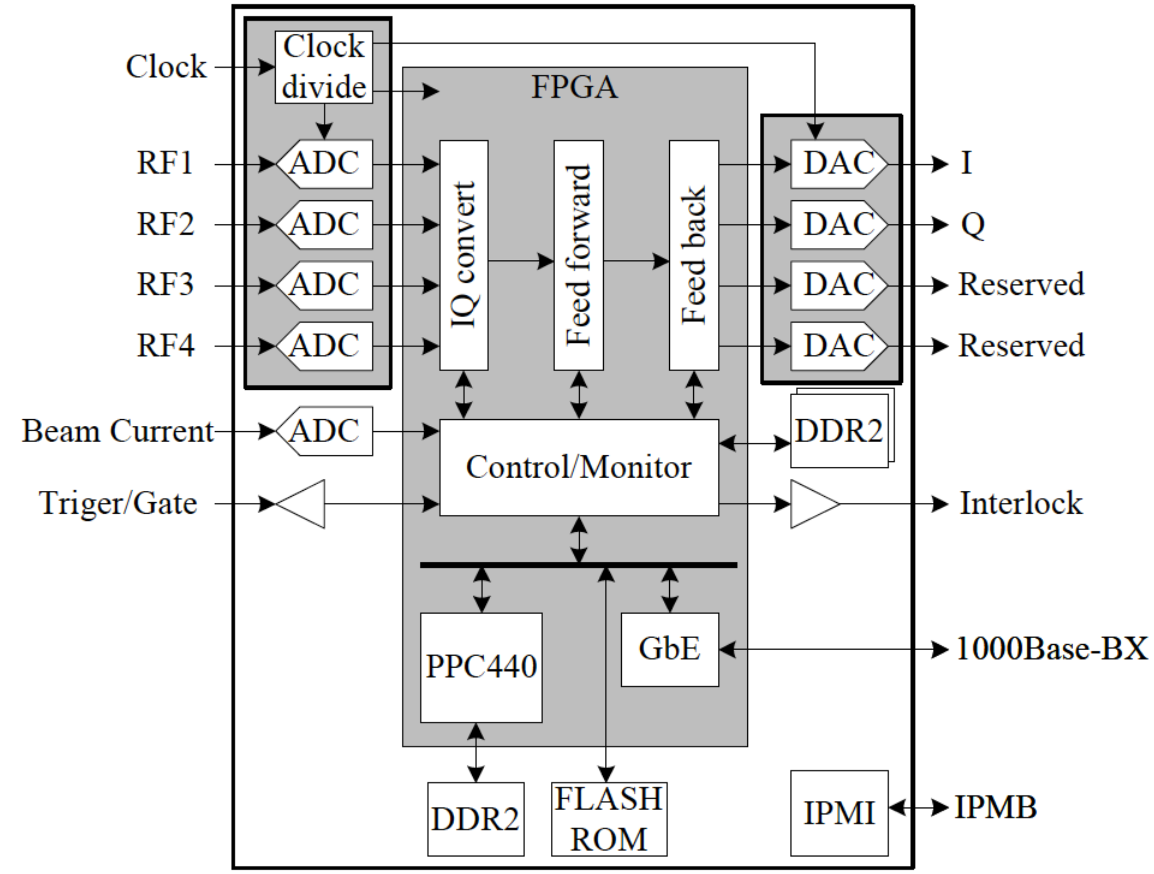


Block diagram of new LLRF for SuperKEKB

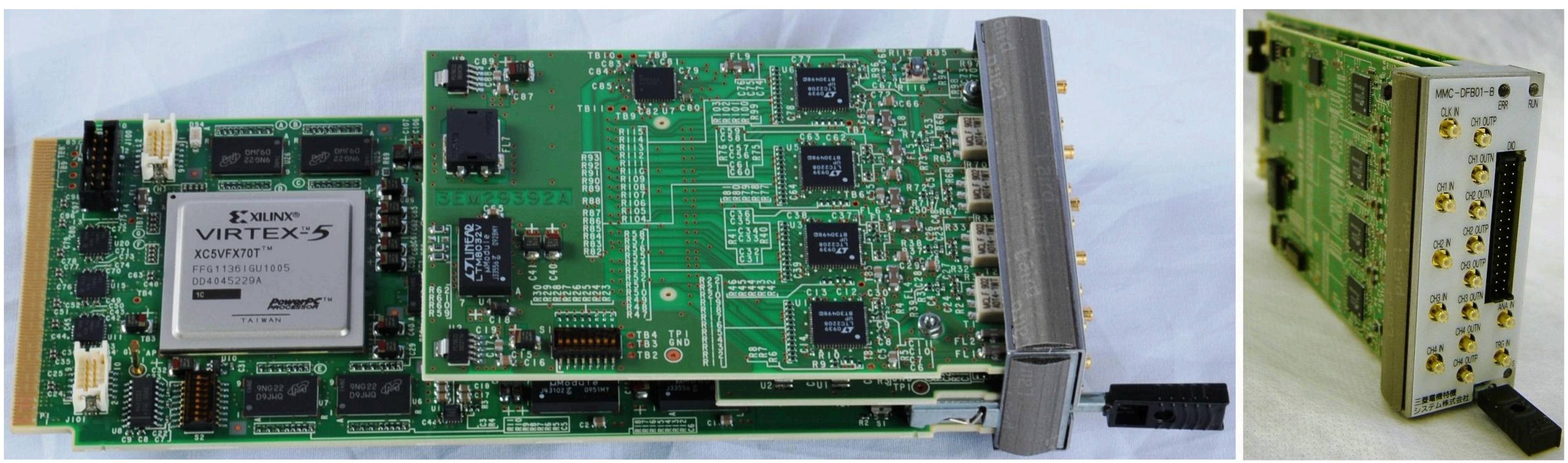
K. Akai



μTCA shelf

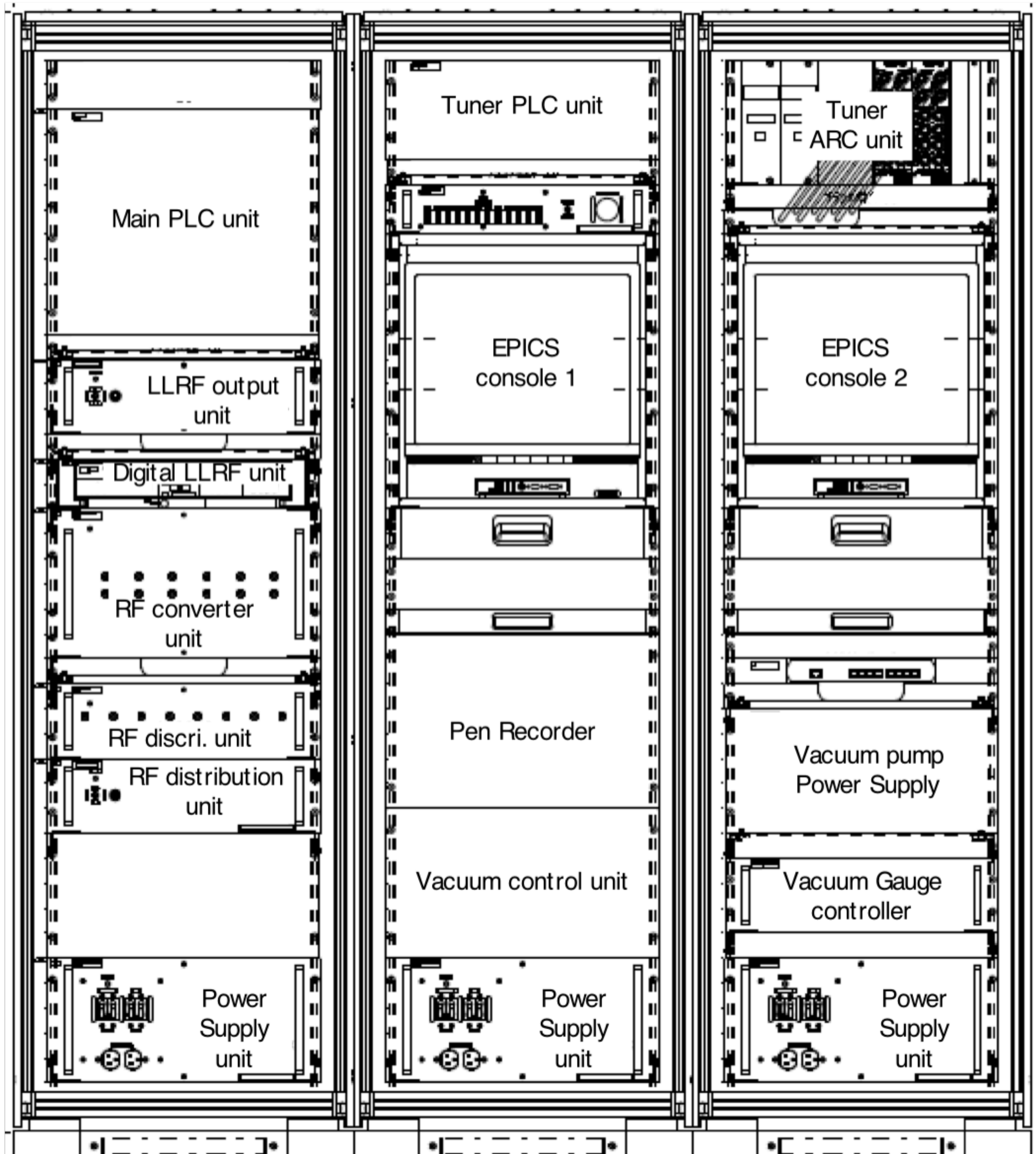


Block diagram of digital LLRF



Digital LLRF board

K. Akai



New LLRF for one station

p. 3
7) The continued use of the older analog RF low level controls on the existing stations should be evaluated for compatibility with the new digital systems, which are currently only proposed for the new stations.

p. 17
While this plan meets operational requirements, reliable implementation will require the deployment of the advanced digital Low Level RF control circuitry being developed by KEK and its industrial partners, in parallel with most other accelerator laboratories around the world. Hardware design is nearly done and the first system will be installed and tested later this year. The only proposal that is of some concern to the committee is the suggestion that some of the RF systems would continue to be operated with the old analog LLRF control. The reliability and simplicity of operation achieved by a having a common system seem worth the additional 10 Oku-yen.

Reply from K. Akai to the above comments in the report from the 15th KEKB Accelerator Review Committee:

(Compatibility)
The present LLRF system has been operated successfully up to 2.0A in KEKB. Since the longitudinal parameters such as RF voltage, bunch length and phase stability are not very much different between KEKB and SuperKEKB, the present system could be used without problems, at least up to about the same beam current. For the one-to-one stations (one klystron drives one ARES cavity), where beam-loading becomes heavier, new digital LLRF will be used. The old system will be kept at one-to-two stations where the beam-loading is lower. In addition, compatibility on signal connections between the LLRF and outer system and relevant EPICS records will be kept as much as possible between the old and new LLRF systems.

(Additional budget?)
Considering the budget and schedule for whole SuperKEKB construction, replacement of all old LLRF stations with new digital ones by T=0 does not seem to have higher priority than fabricating and installing those components that are absolutely necessary at T=0. Our plan is to install new LLRF to new one-to-one stations where no LLRF is existing, and to keep the present old systems for one-to-two stations until when additional budget would allow us to implement new systems to replace old ones.

In my personal view,
the new digital and the old analog LLRF systems
will function in harmony as below.

The New York Times

The iPod and the Vacuum Tube Sing a Warm Duet

By ANNE EISENBERG
Published: April 15, 2007

IPODS are fine for listening to music on the go, but sometimes people want to cast headsets aside and hear their playlists piped through the living room by a sound system.

http://www.nytimes.com/2007/04/15/business/yourmoney/15novel.html

Kageyama, T.

THANK YOU SO MUCH

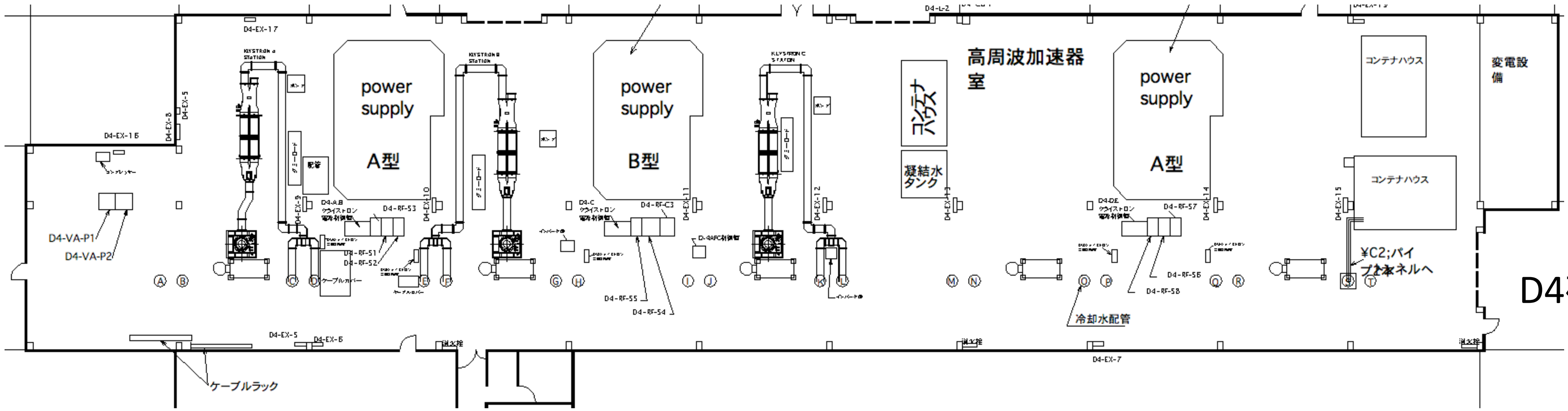
FOR

YOUR ATTENTION.

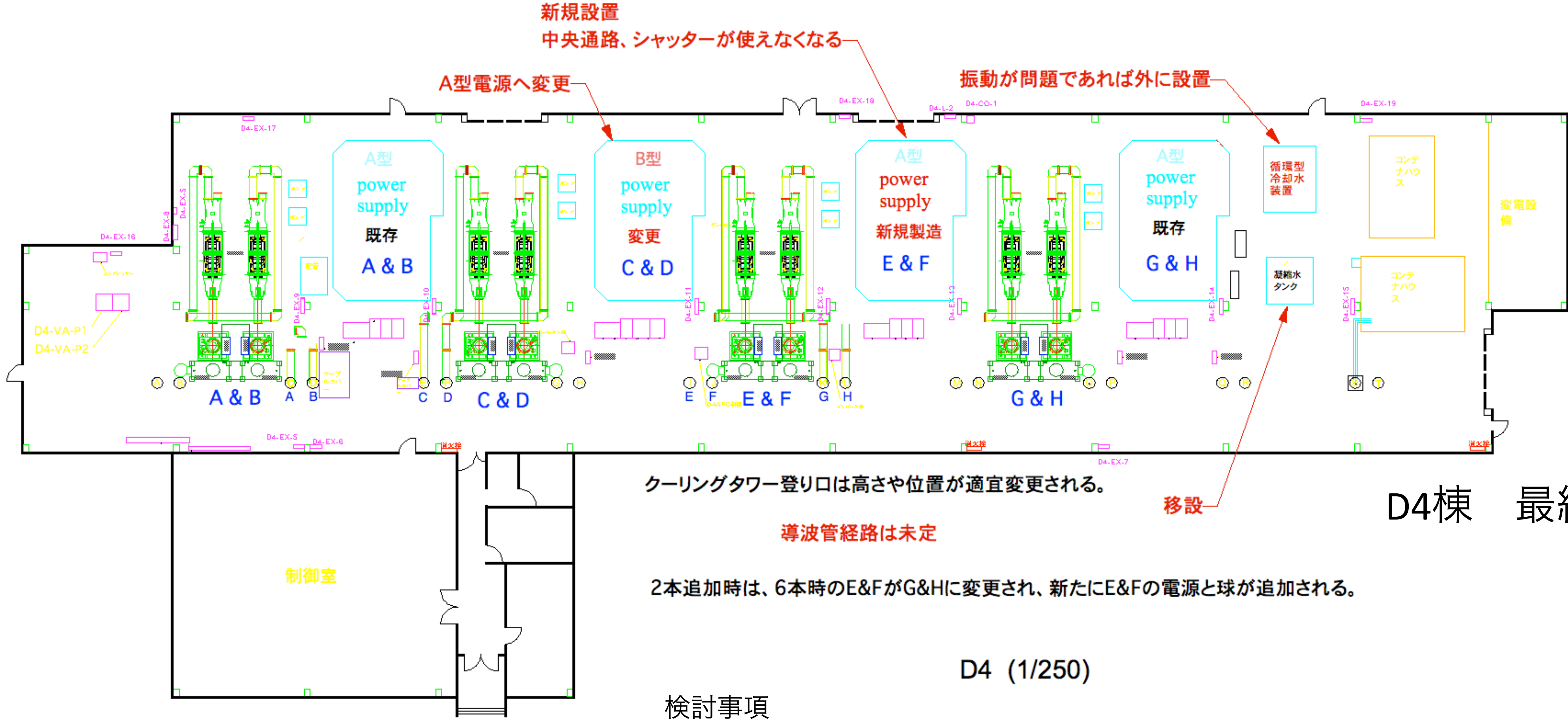
FOLLOWED BY BACKUP SLIDES

D4 のKlystron を3本→8本に増設するための電源棟内配置変更

M. Yoshida



D4棟　現状図



D4棟　最終8本増設案

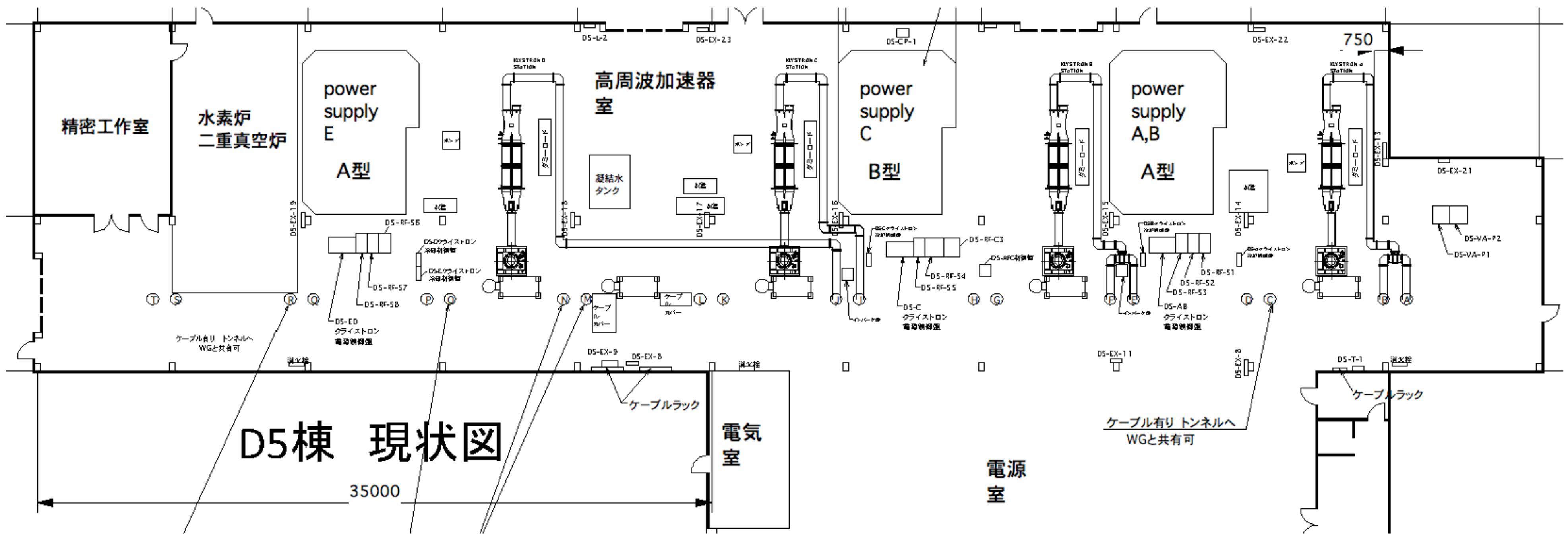
D4 (1/250)

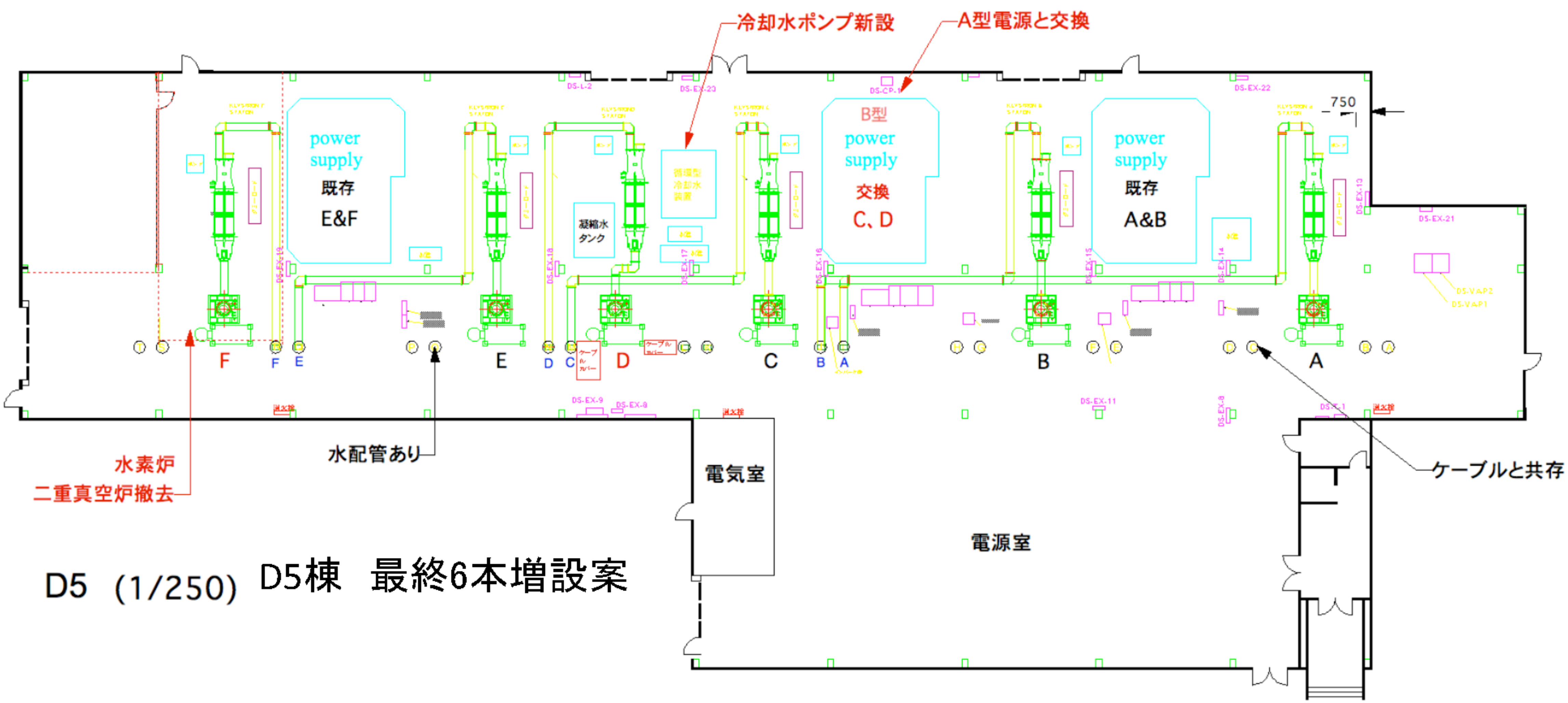
検討事項

1) 循環型冷却水装置（1MW DL用）の振動はSRモニタに影響はないか？
2) 凝縮水タンクの振動はSRモニタに影響はないか？
3) 蒸気装置は中央設置ではないが問題（圧力、給水能力）ないか？

D5 のKlystron を4本→6本に増設するための電源棟内配置変更

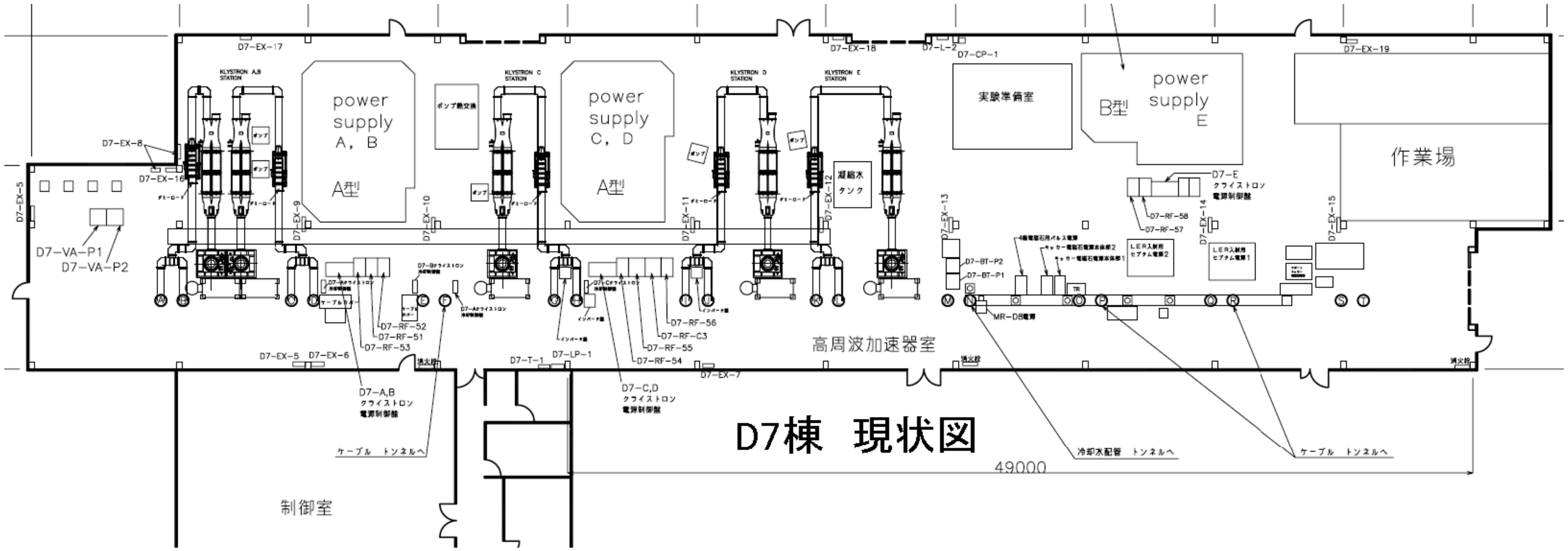
M. Yoshida

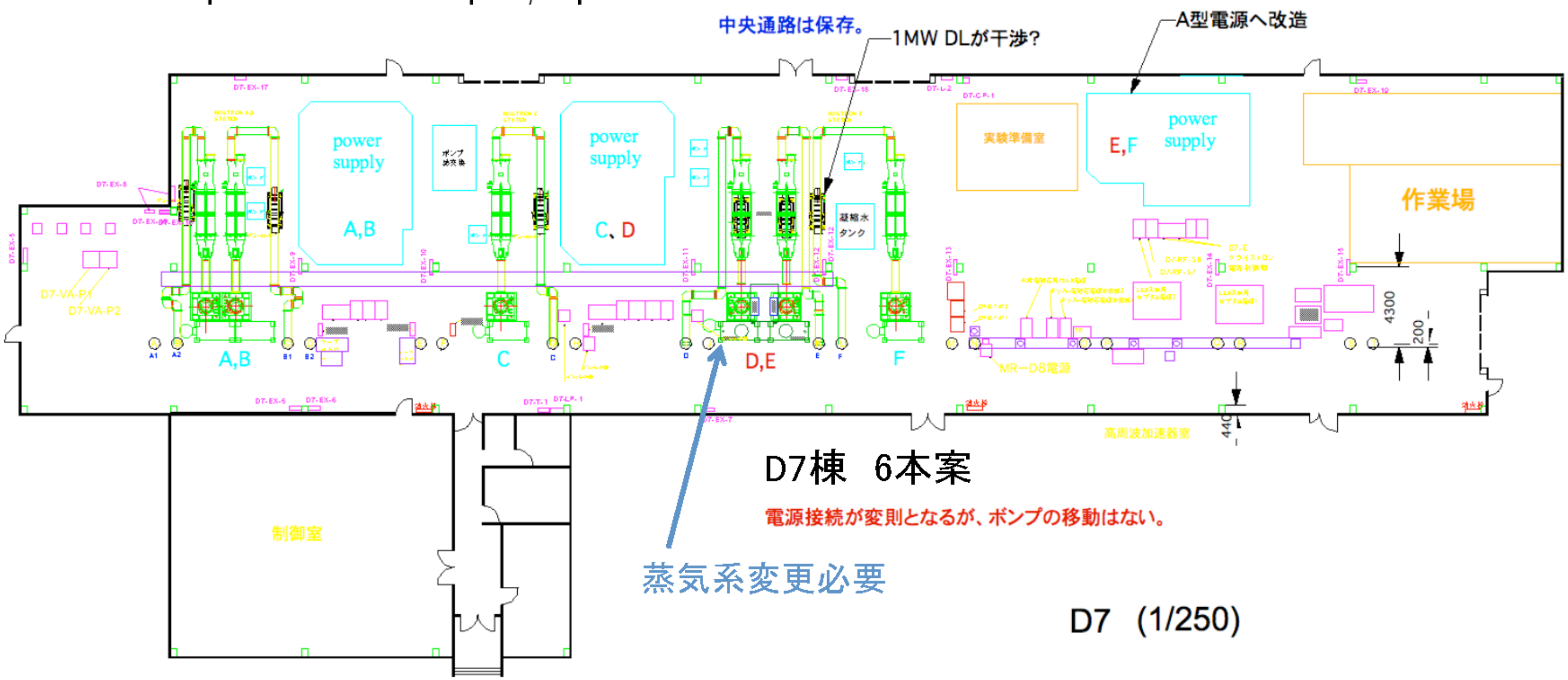




D7 のKlystron を5本→6本に増設するための電源棟内配置変更

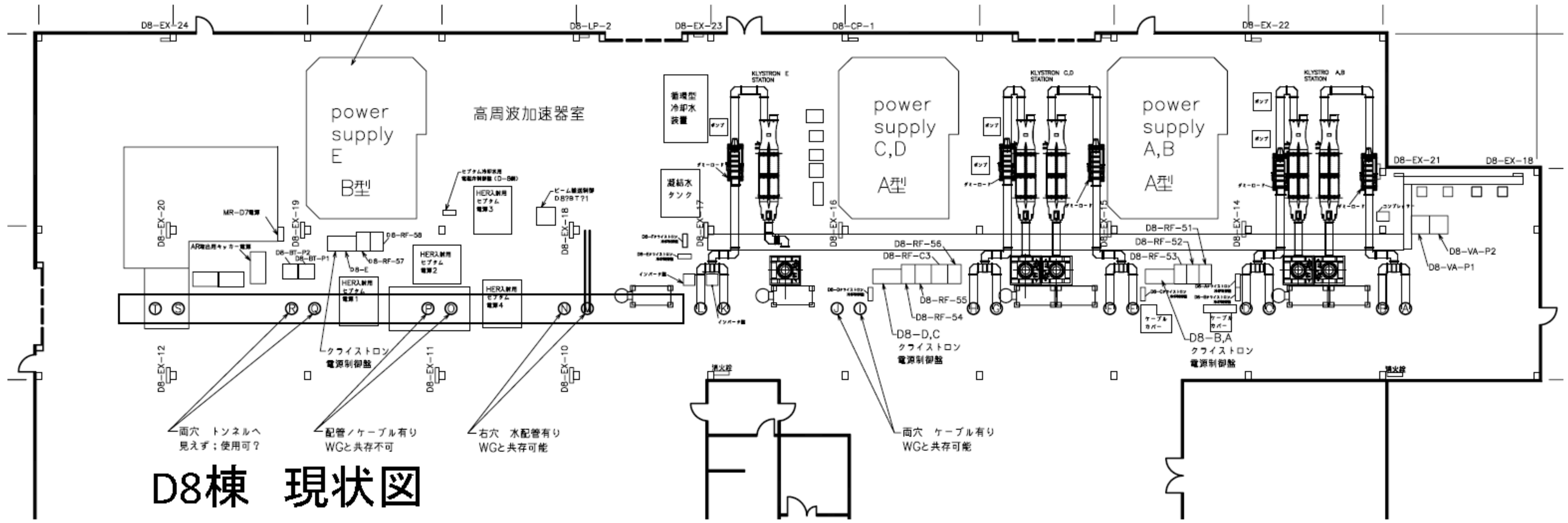
M. Yoshida



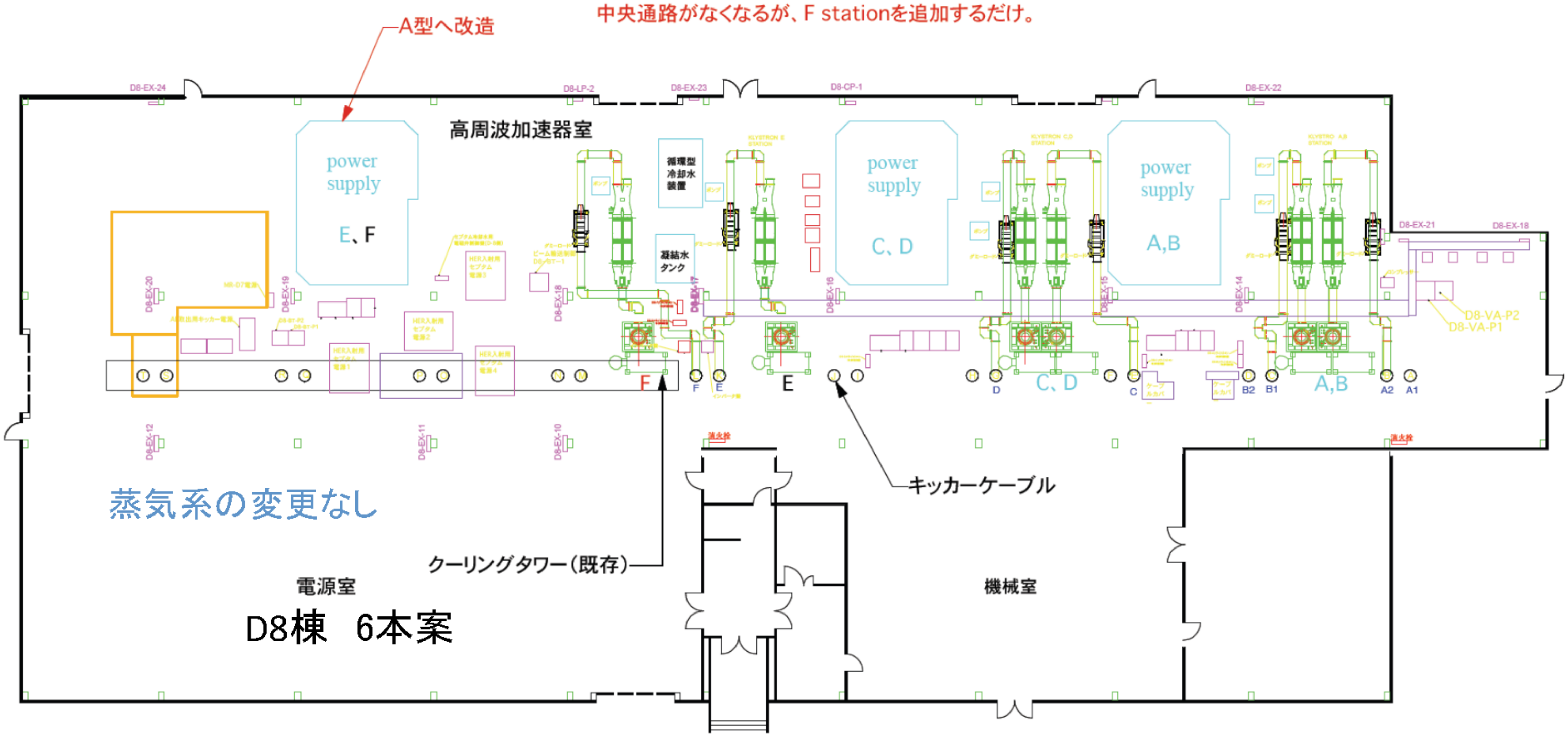


D8 のKlystron を5本→6本に増設するための電源棟内配置変更

M. Yoshida



中央通路がなくなるが、F stationを追加するだけ。



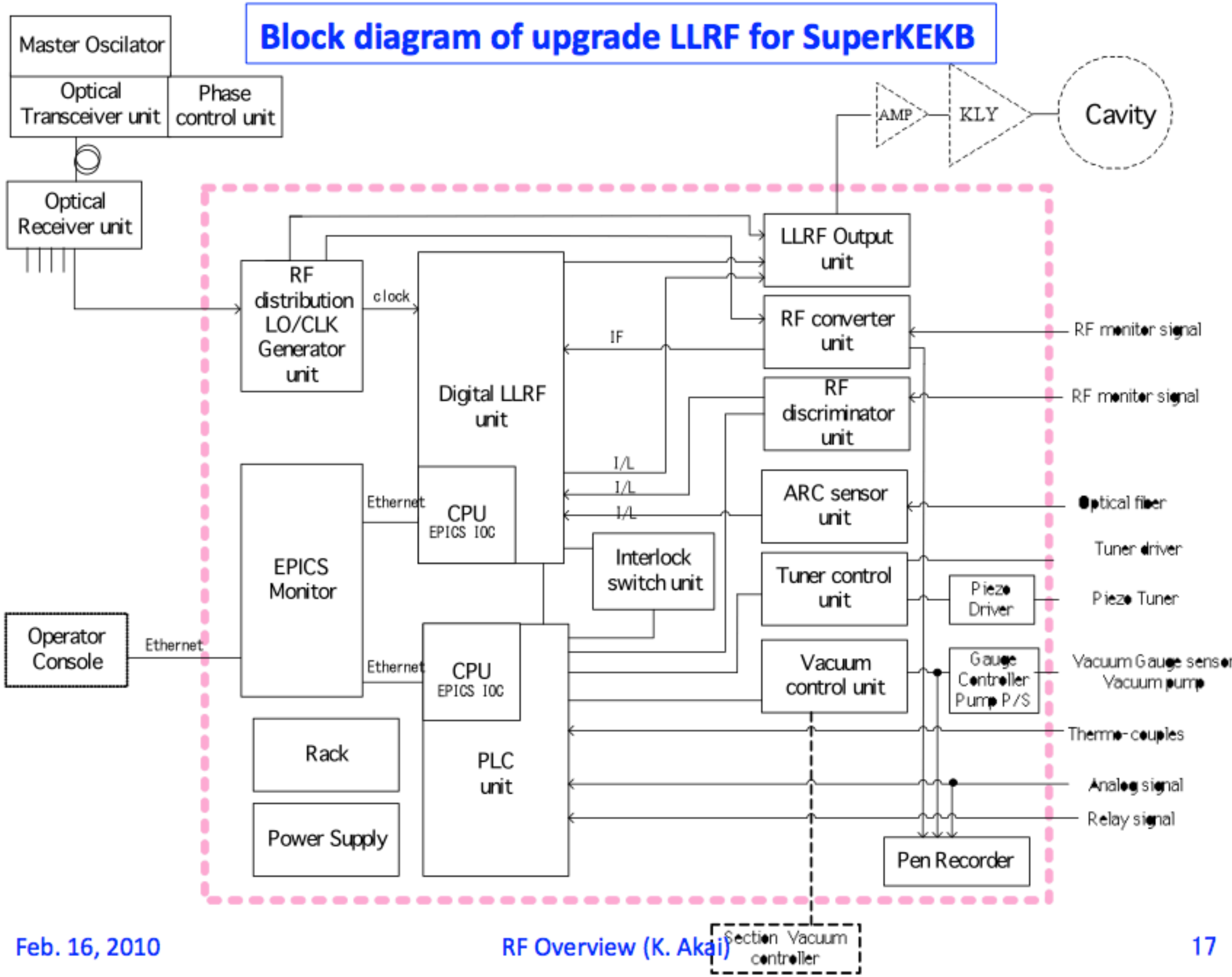
Bunch gap transient

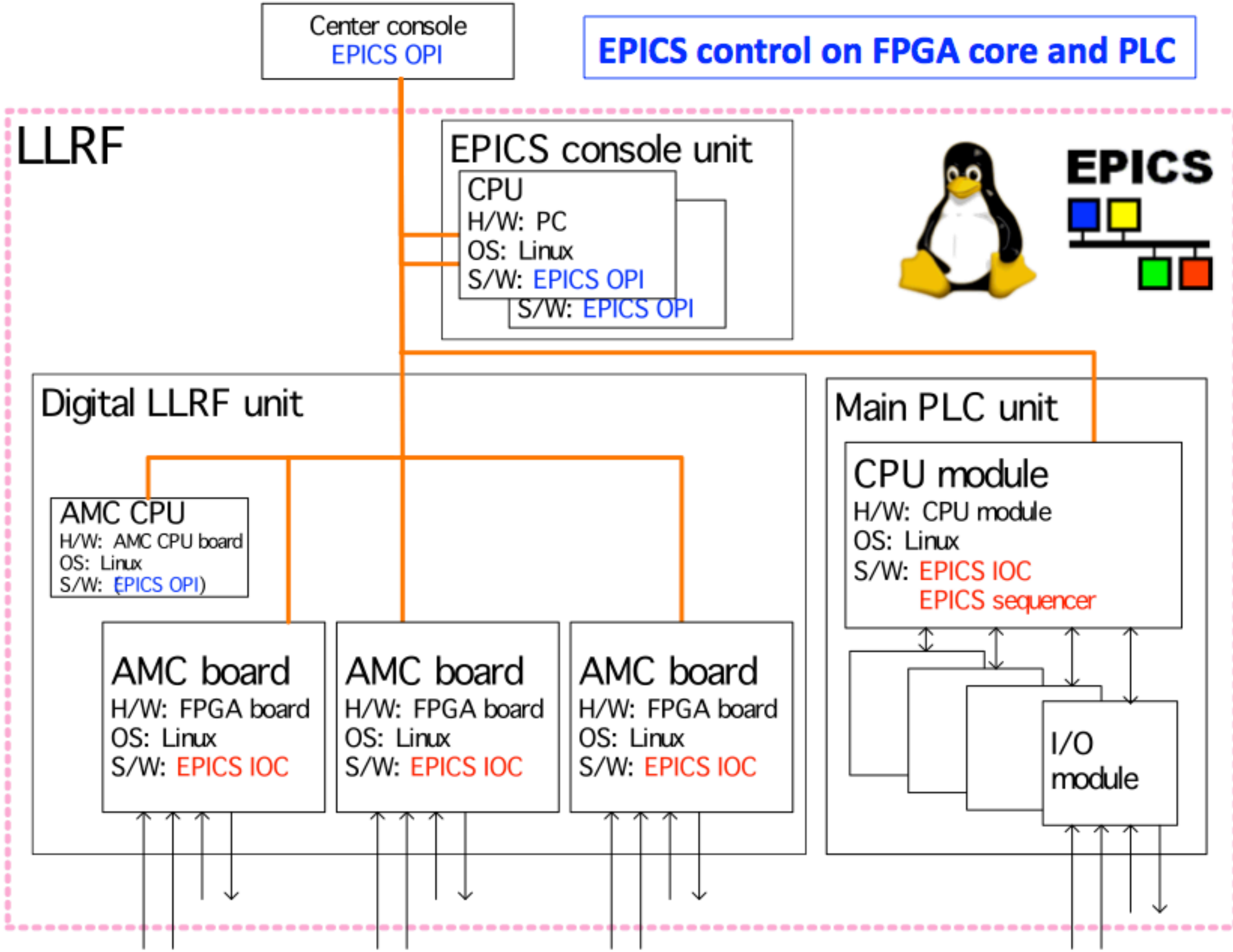
- Phase modulation along a bunch train caused by an abort gap

$$\Delta\phi = \frac{\omega_{rf}}{2V_c}\left(\frac{R}{Q}\right) \times I_b \Delta t = \frac{P_b \Delta t}{2\cos\phi_s U}$$

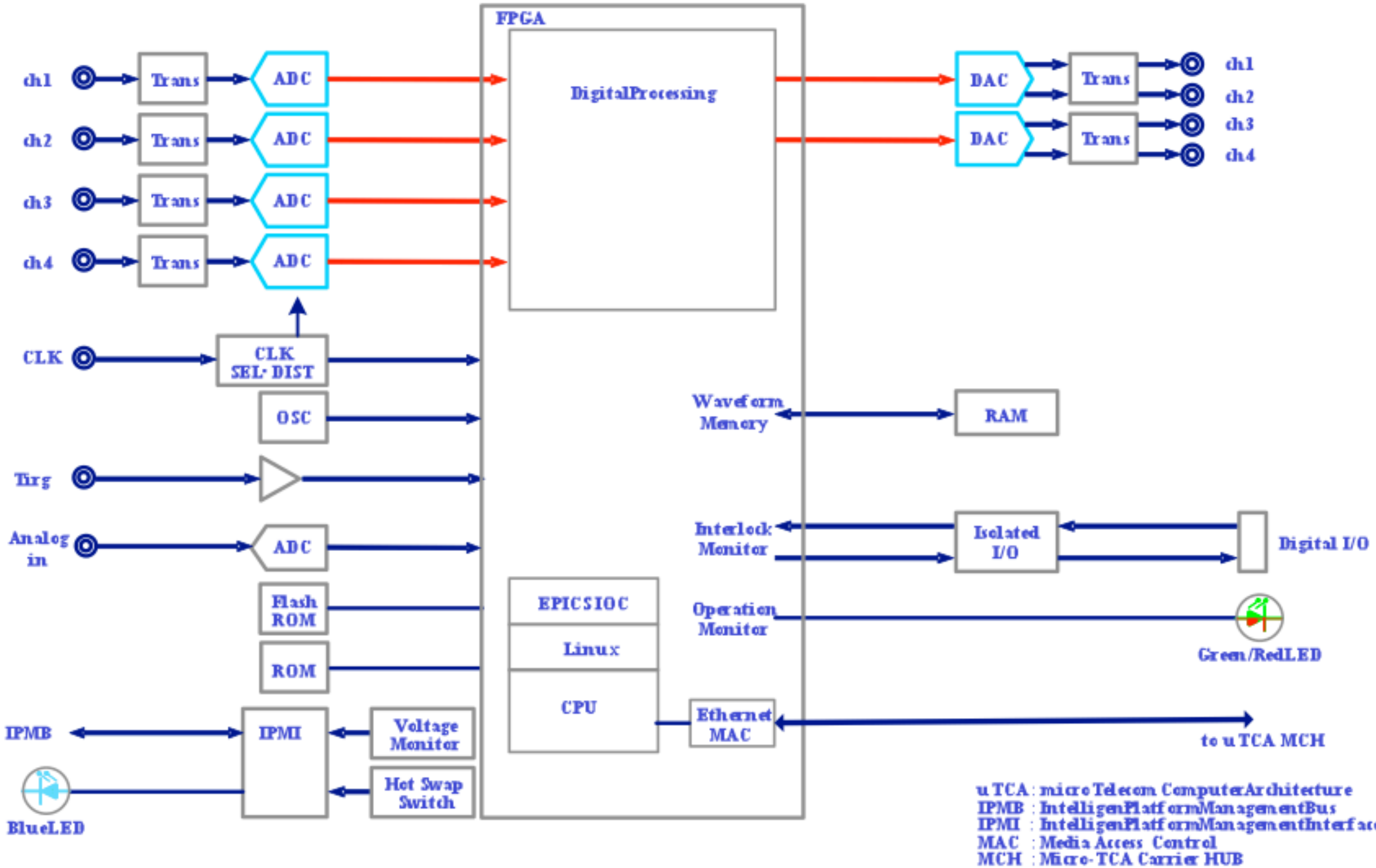
- KEKB
  - Owing to high stored energy of the ARES and SCC, transient phase modulation (also longitudinal position change of beam) is small, about 3 to 5 degrees. No luminosity degradation along a train is observed.
  - Calculation and measurements agree well.
- SuperKEKB
  - Since the beam current is twice, the gap length should be reduced less than half (500ns --> 200ns). Rise time of the abort kicker will be improved.

Block diagram of upgrade LLRF for SuperKEKB

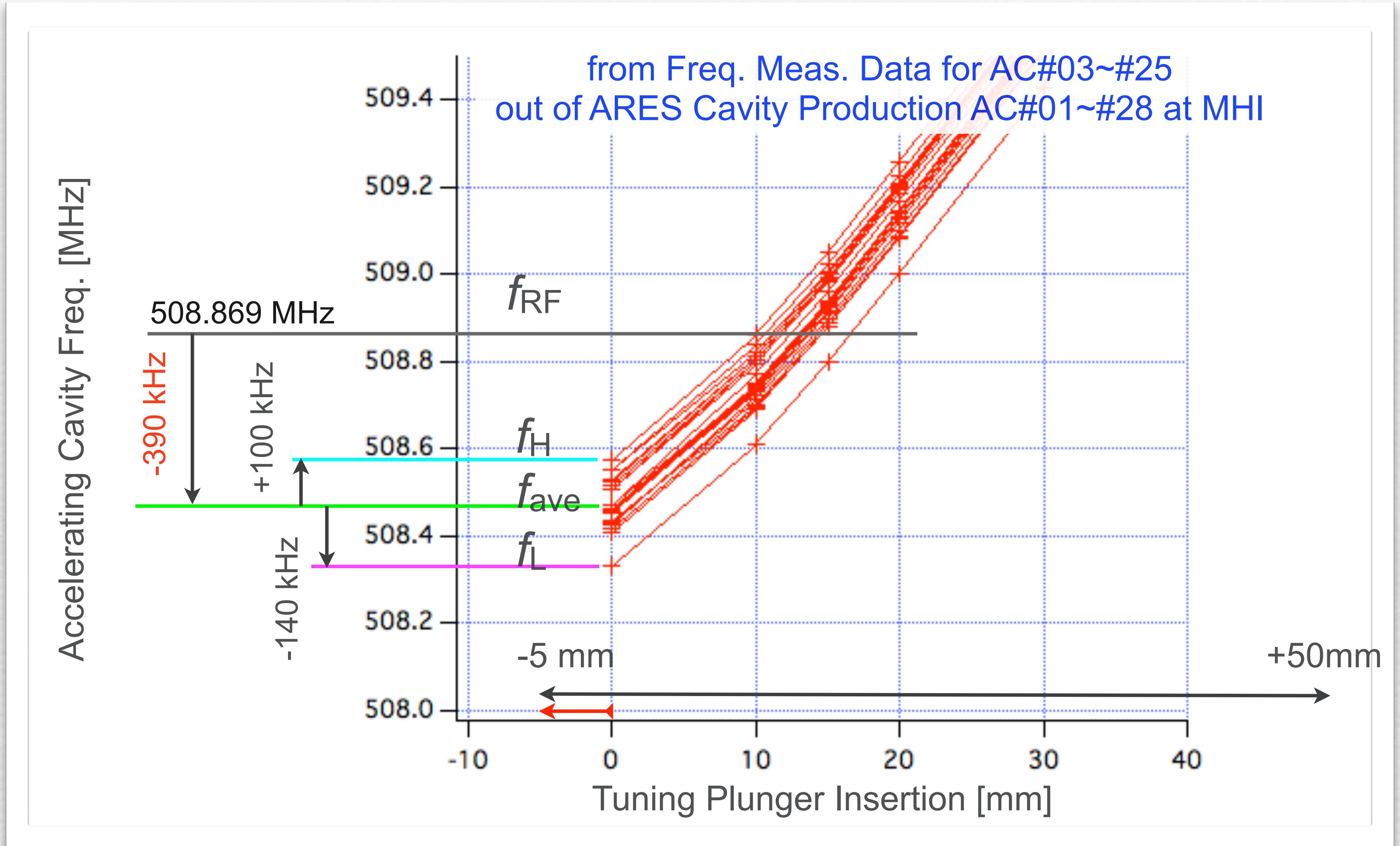



EPICS control on FPGA core and PLC
Center console
EPICS OPI
LLRF
EPICS console unit
CPU
H/W: PC
OS: Linux
S/W: EPICS OPI
S/W: EPICS OPI
EPICS
Digital LLRF unit
AMC CPU
H/W: AMC CPU board
OS: Linux
S/W: (EPICS OPI)
AMC board
H/W: FPGA board
OS: Linux
S/W: EPICS IOC
AMC board
H/W: FPGA board
OS: Linux
S/W: EPICS IOC
AMC board
H/W: FPGA board
OS: Linux
S/W: EPICS IOC
Main PLC unit
CPU module
H/W: CPU module
OS: Linux
S/W: EPICS IOC
EPICS sequencer
I/O
module

Block diagram of digital LLRF board



Tuning Range for the Resonance Frequency of the Accelerating Cavity when f_{RF} = 508.869 MHz

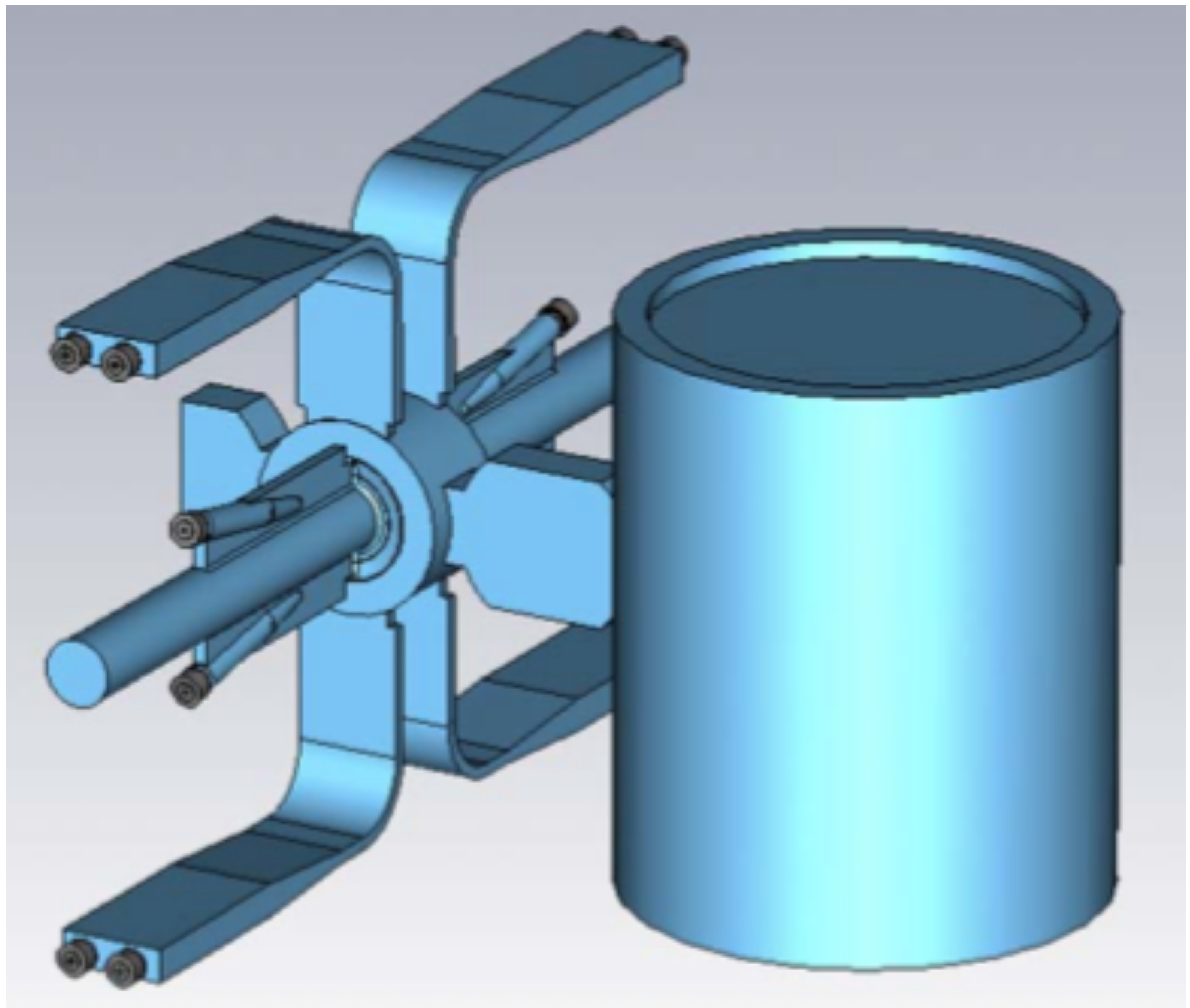


Min | $\Delta f_{\text{tuner}} + \Delta f_{\text{thermal}}$ | = 370 kHz > | Δf_{AC} | = 280 kHz

Δf_{tuner} = -290 kHz ~ -530 kHz
$\Delta f_{\text{thermal}}$ = -80 kHz for ΔT = +10 K
not include Δf (tuner travel from 0 mm to -5 mm) = ~ -100 kHz

R&D being continued.

ARES-*KAI*
(originally designed for SuperKEKB)



アレス改 T. Abe and Y. Takeuchi

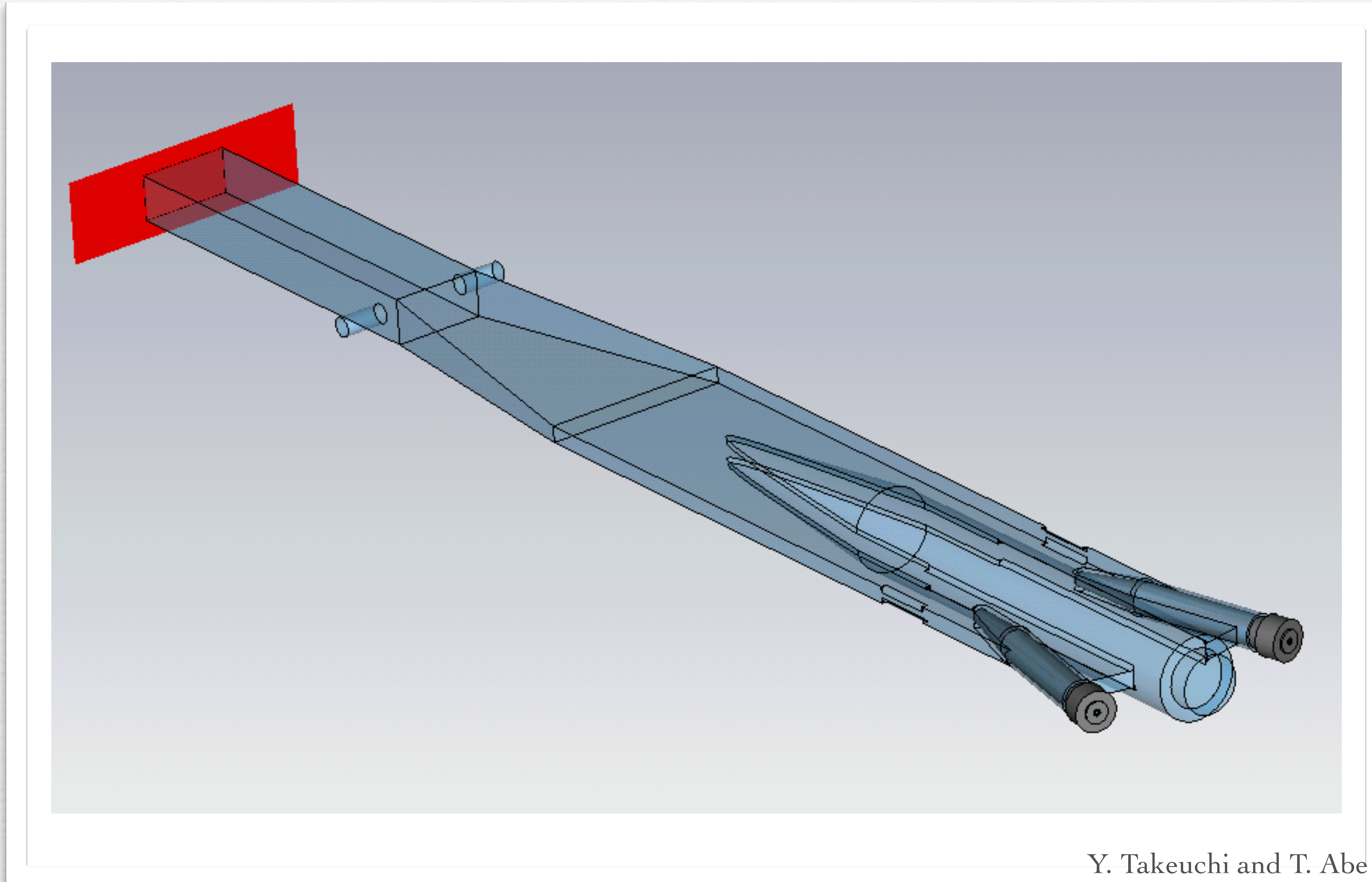
Replace the grooved beam pipes with winged chambers.
Each wing equipped with a bullet-shaped SiC absorber.

Winged Chamber loaded with two bullet-shaped SiC Absorbers under High Power Test @ D1C. (Aug. 2010)

Y. Takeuchi and T. Abe

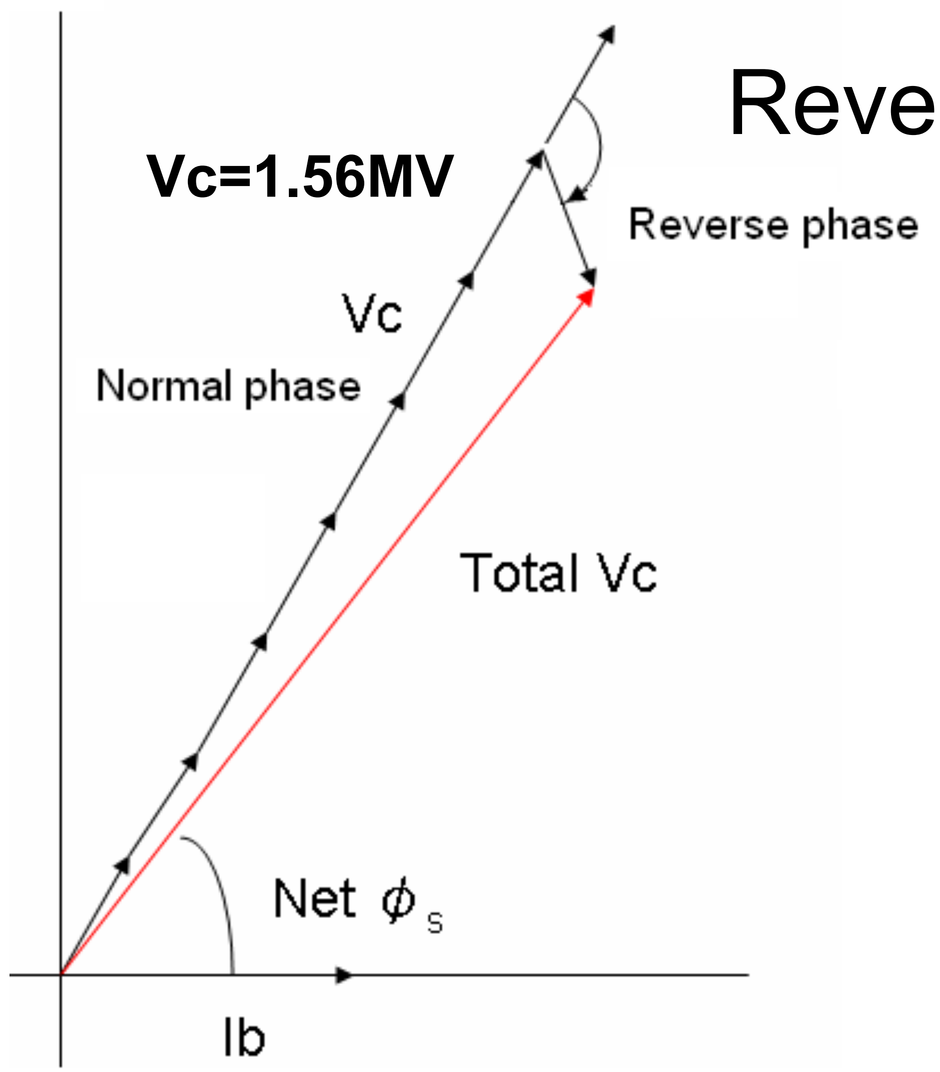
Successfully tested up to 10 kW per chamber / 5 kW per wing.

Setup for High Power Test of Winged Chamber



3D Schematic View

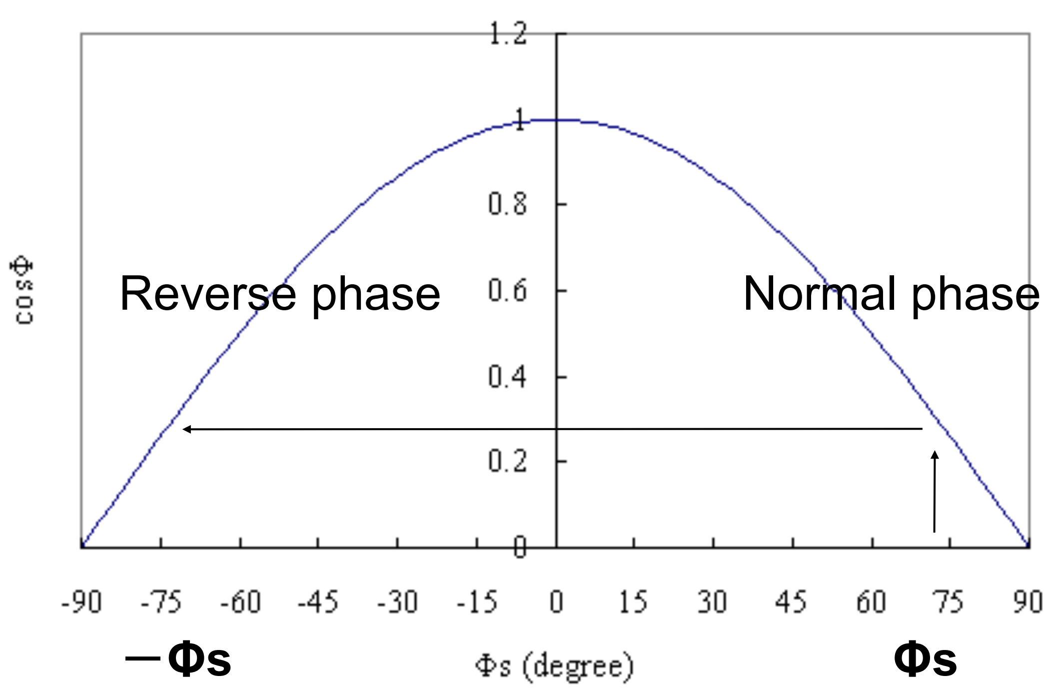
Reverse phase operation

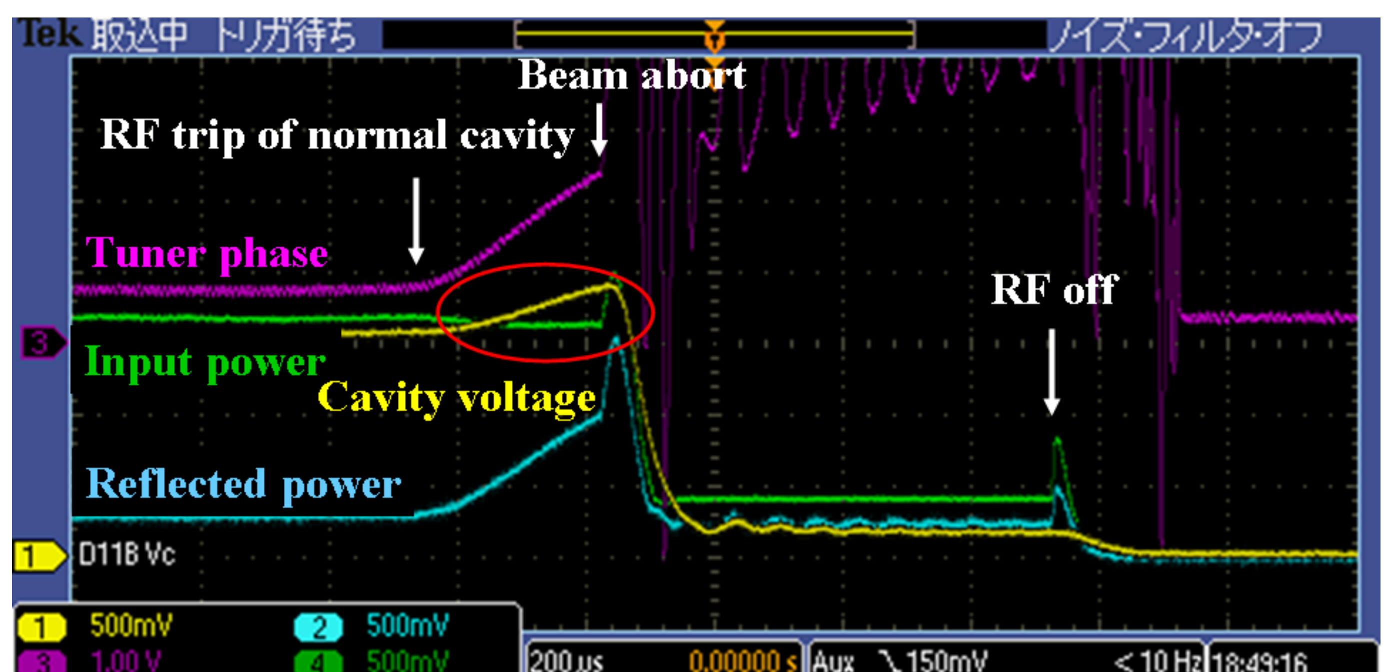


Phasor presentation of cavity voltage

Merit of reverse phase operation
1）Low total voltage while each cavity voltage is high
No need to change coupling constant
Small detuning
2）Reverse phase cavity also gives beam power

Beam study
Low current study（150mA）
Measured bunch length, synchrotron tune, beam loading when the beam phase of single cavity was reversed.
High current study（1A)
Measured voltage variation of the reversed cavity when the normal phase cavity trips.

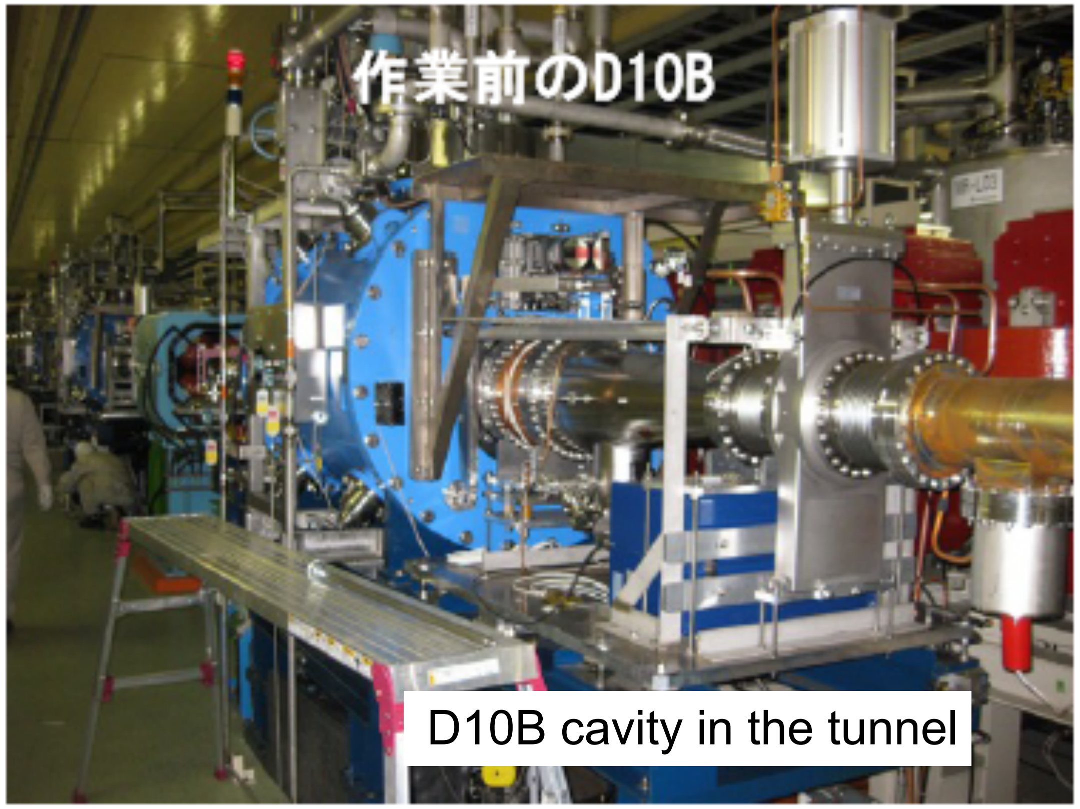




0.3MV increased at the trip (acceptable)

A. Kabe

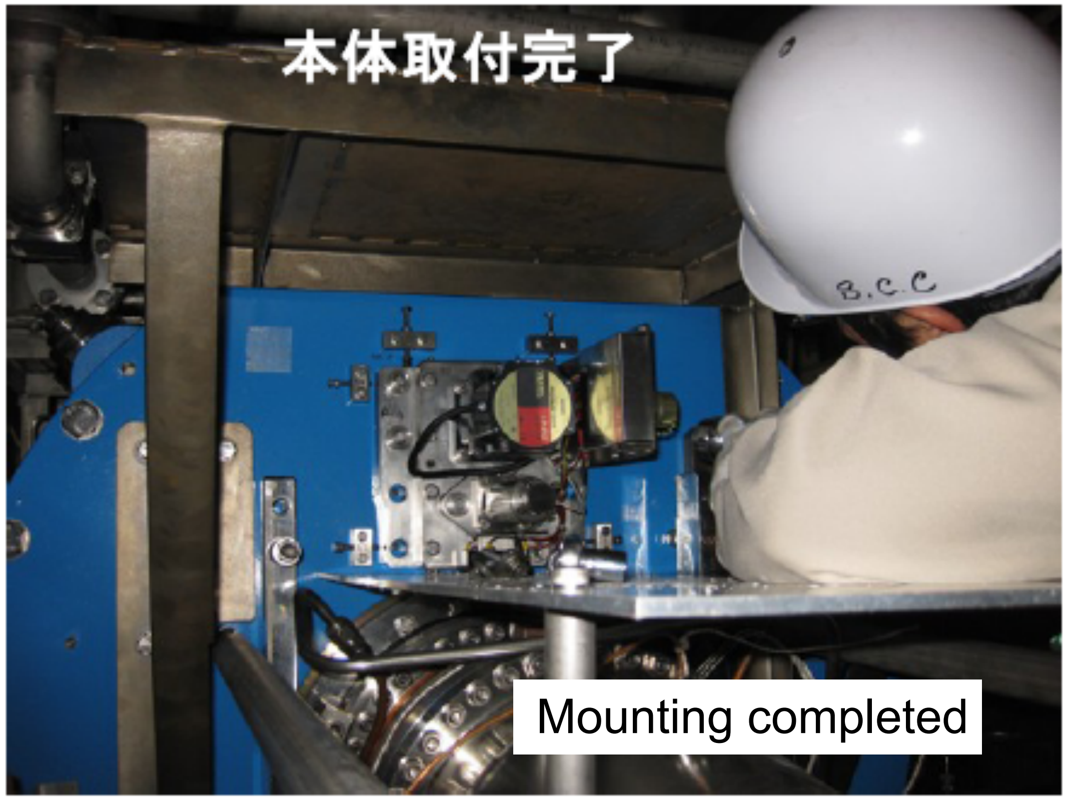
作業写真集（１）

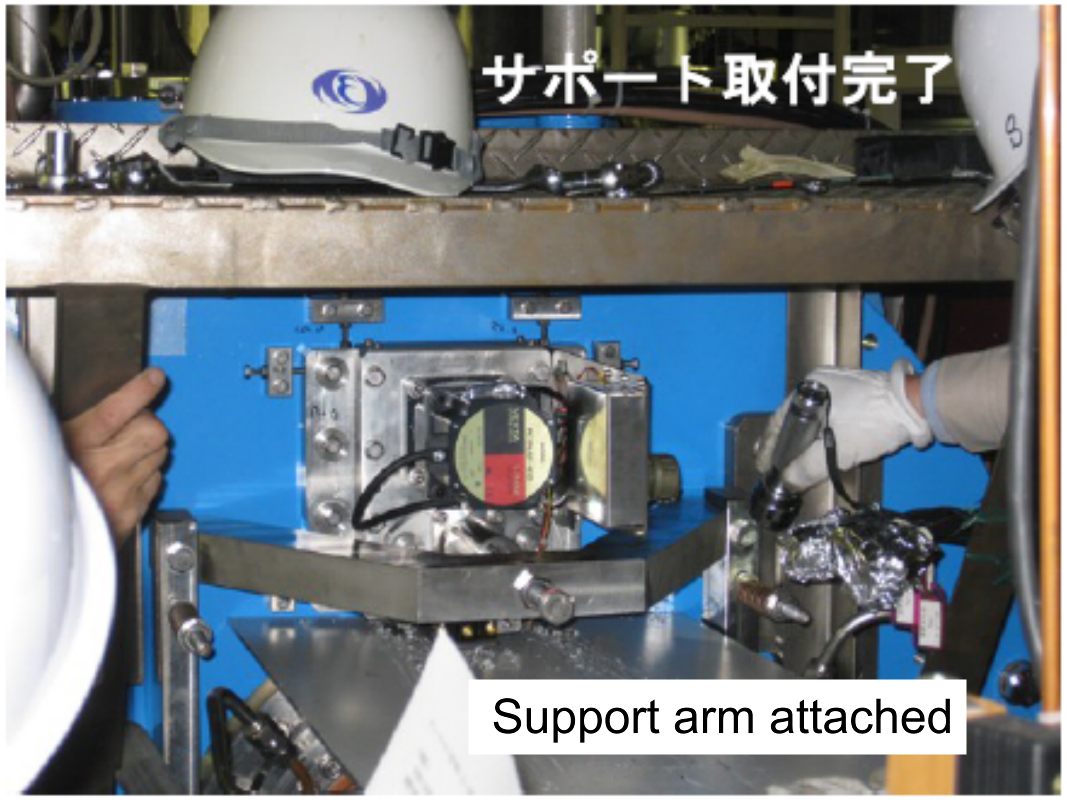


作業写真集（2）

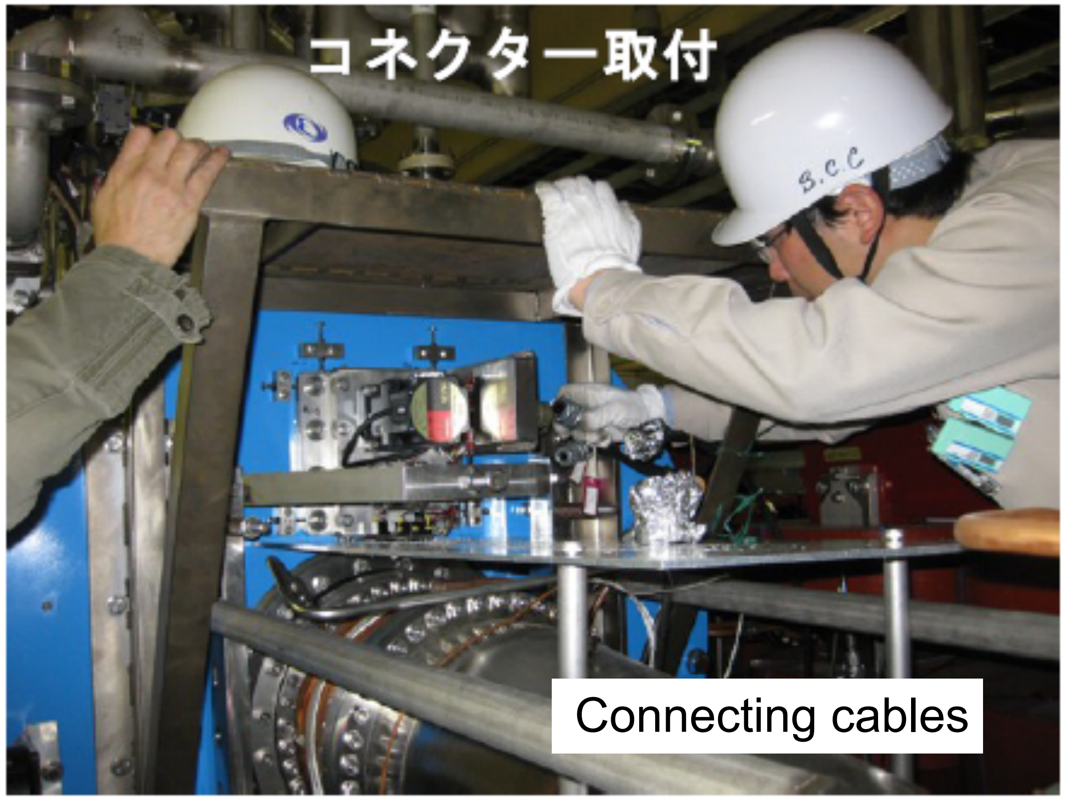

新型TUNER取付作業
Mounting new tuner driver

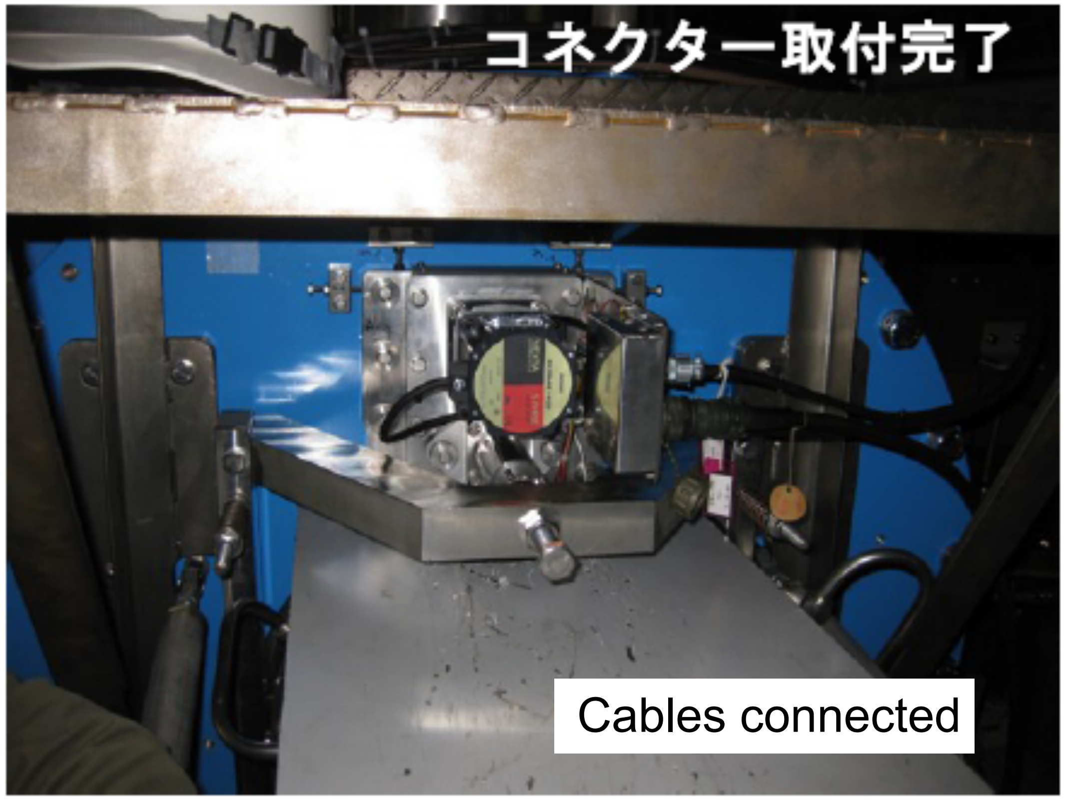

新型TUNER取付作業
B.C.C
Mounting new tuner driver

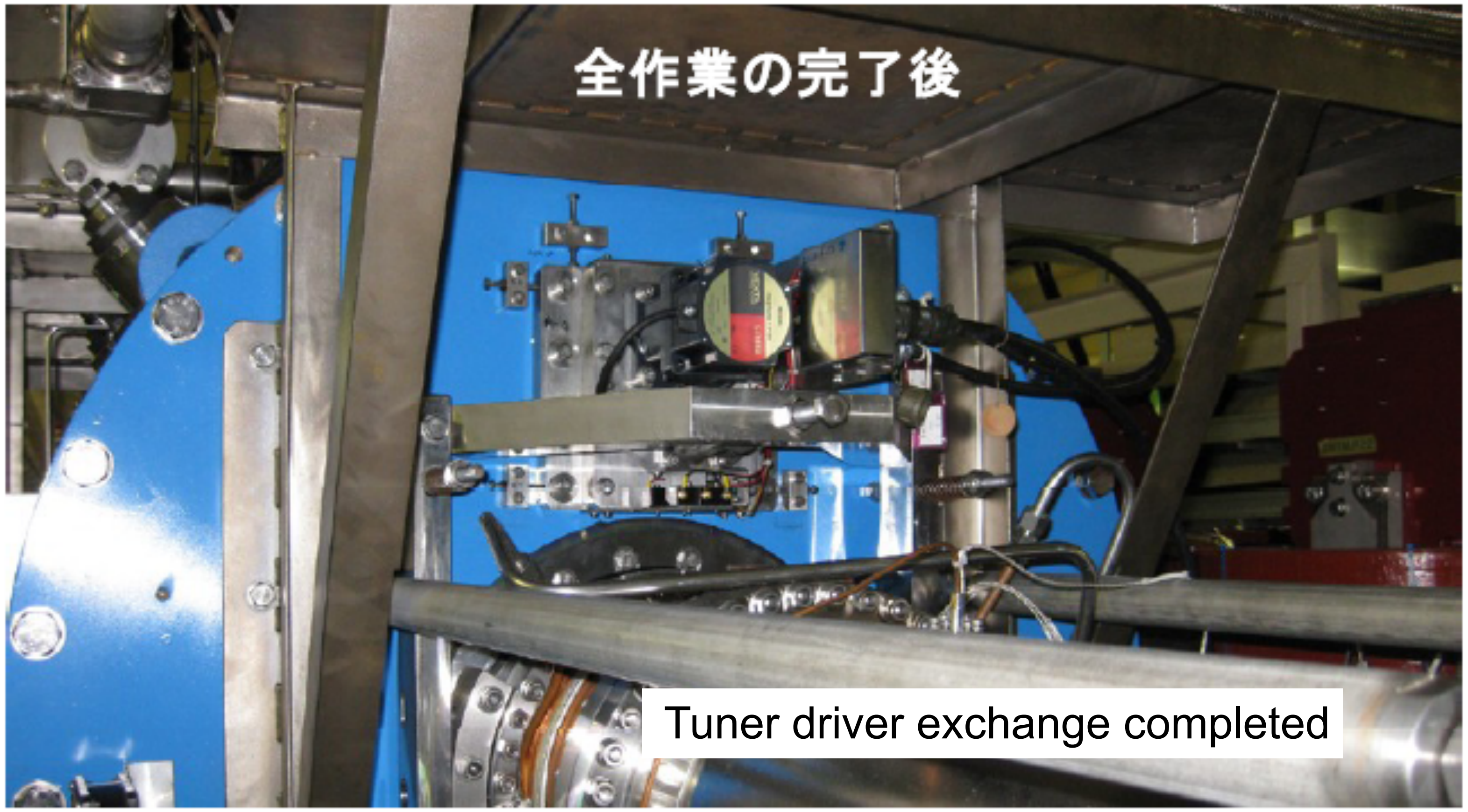

本体取付完了
B.C.C
Mounting completed


サポート取付完了
Support arm attached

作業写真集（３）


コネクター取付
Connecting cables


コネクター取付完了
Cables connected


全作業の完了後
Tuner driver exchange completed

TERMINATOR