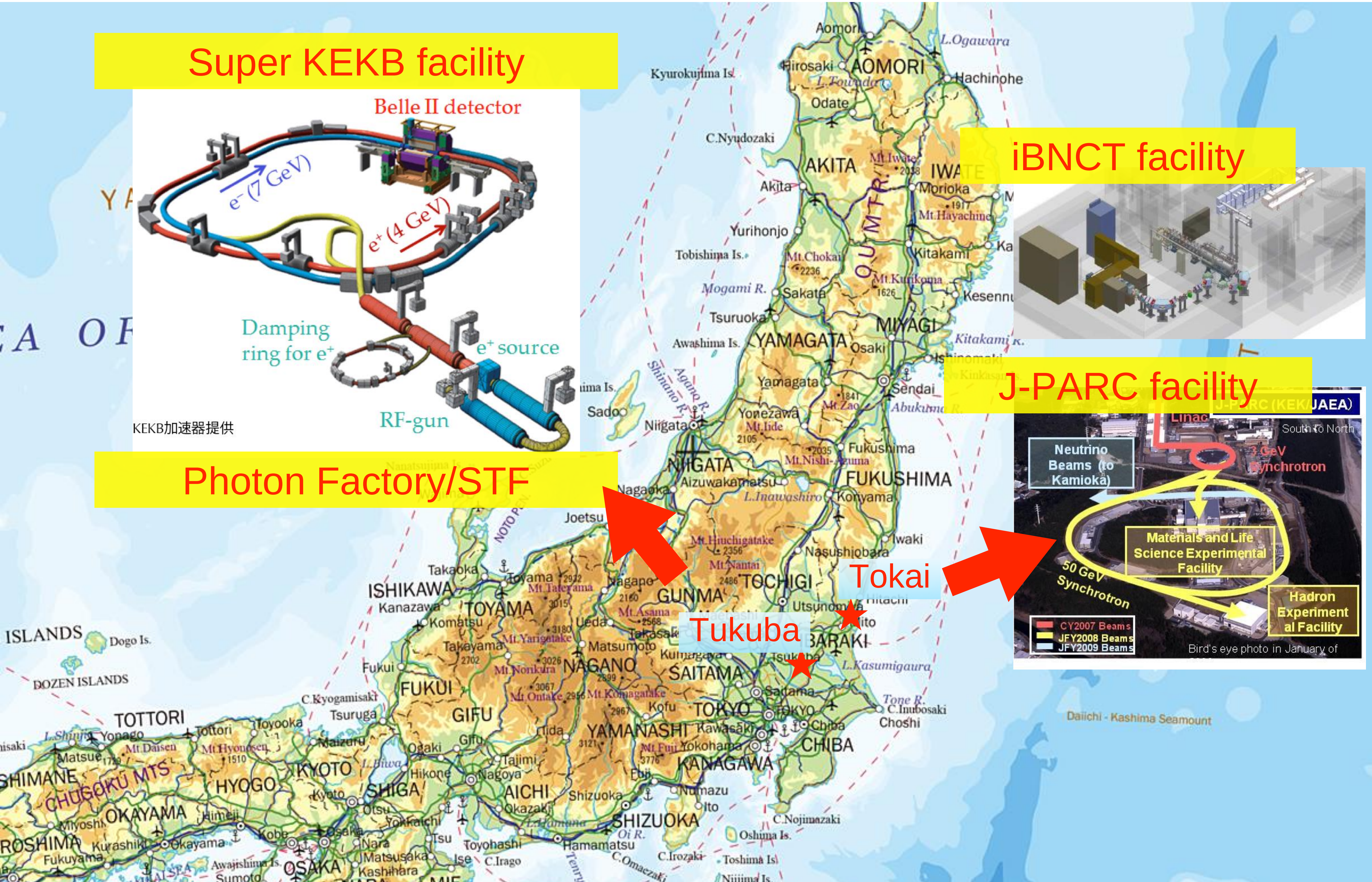
LLRF Developments at KEK and J-PARC

1 SuperKEKB (LINAC)
2 SuperKEKB
3 STF
4 J-PARC Linac RF
5 J-PARC Ring RF
6 iBNCT (ibaraki Boron Neutron Capture Terapy)

KEK/J-PARC
Masahito Yoshii

LLRF2017 Balcerona Oct.16 2017

About KEK and J-PARC



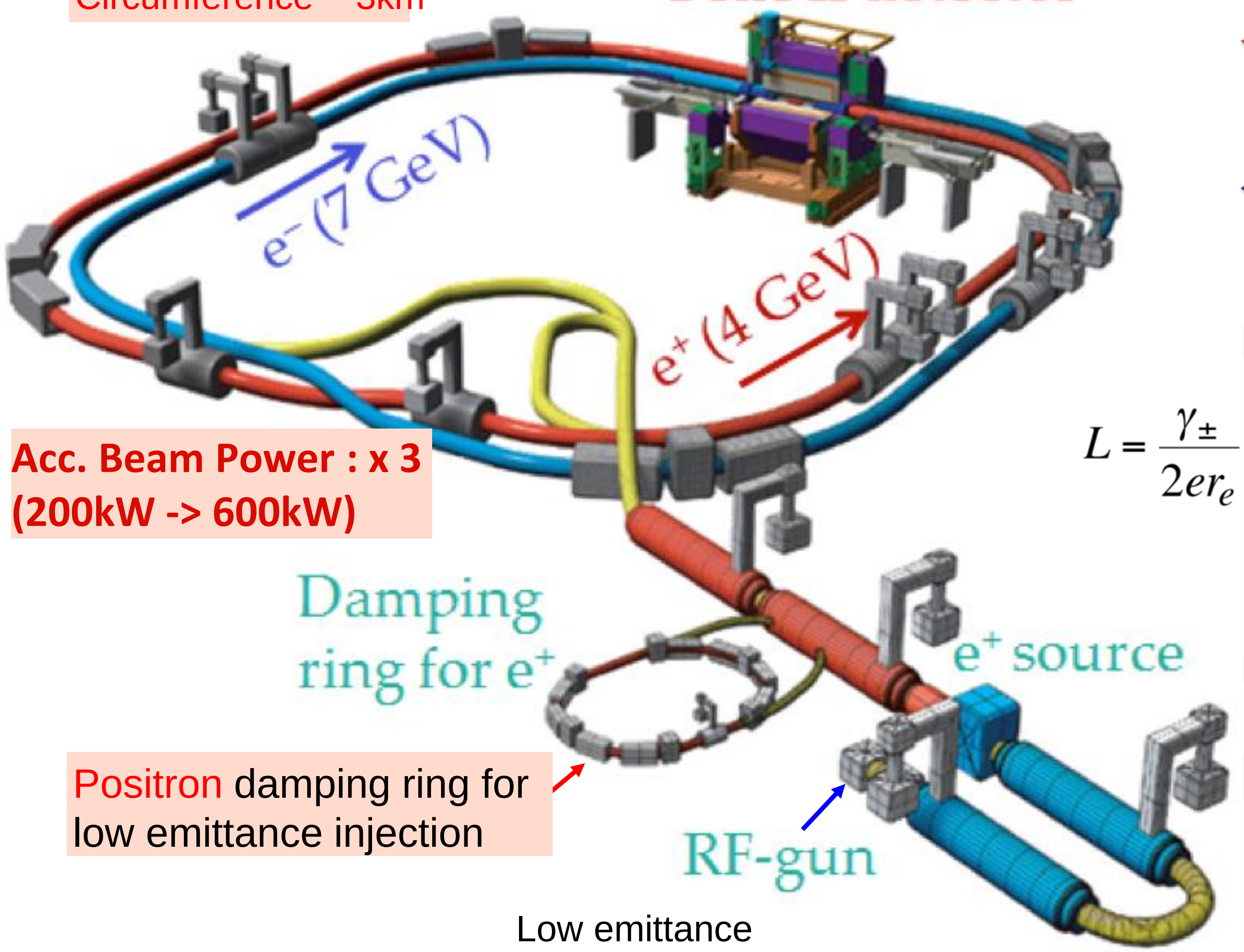
SuperKEKB Project

KEKB is being upgraded to SuperKEKB.

Luminosity : KEKB x 40 !

The first beam commissioning (Phase-1) was successfully accomplished 2016.

Circumference ~ 3km



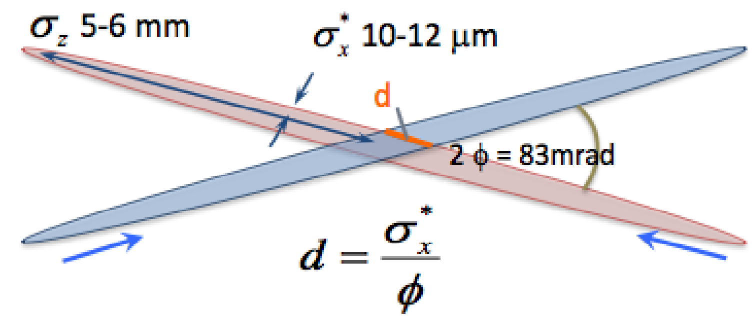
Acc. Beam Power : x 3 (200kW -> 600kW)

Positron damping ring for low emittance injection

Low emittance Photocathode electron gun

P. Raimondi

Nano-Beam Scheme SuperKEKB



Half crossing angle: φ

overlap region << bunch length

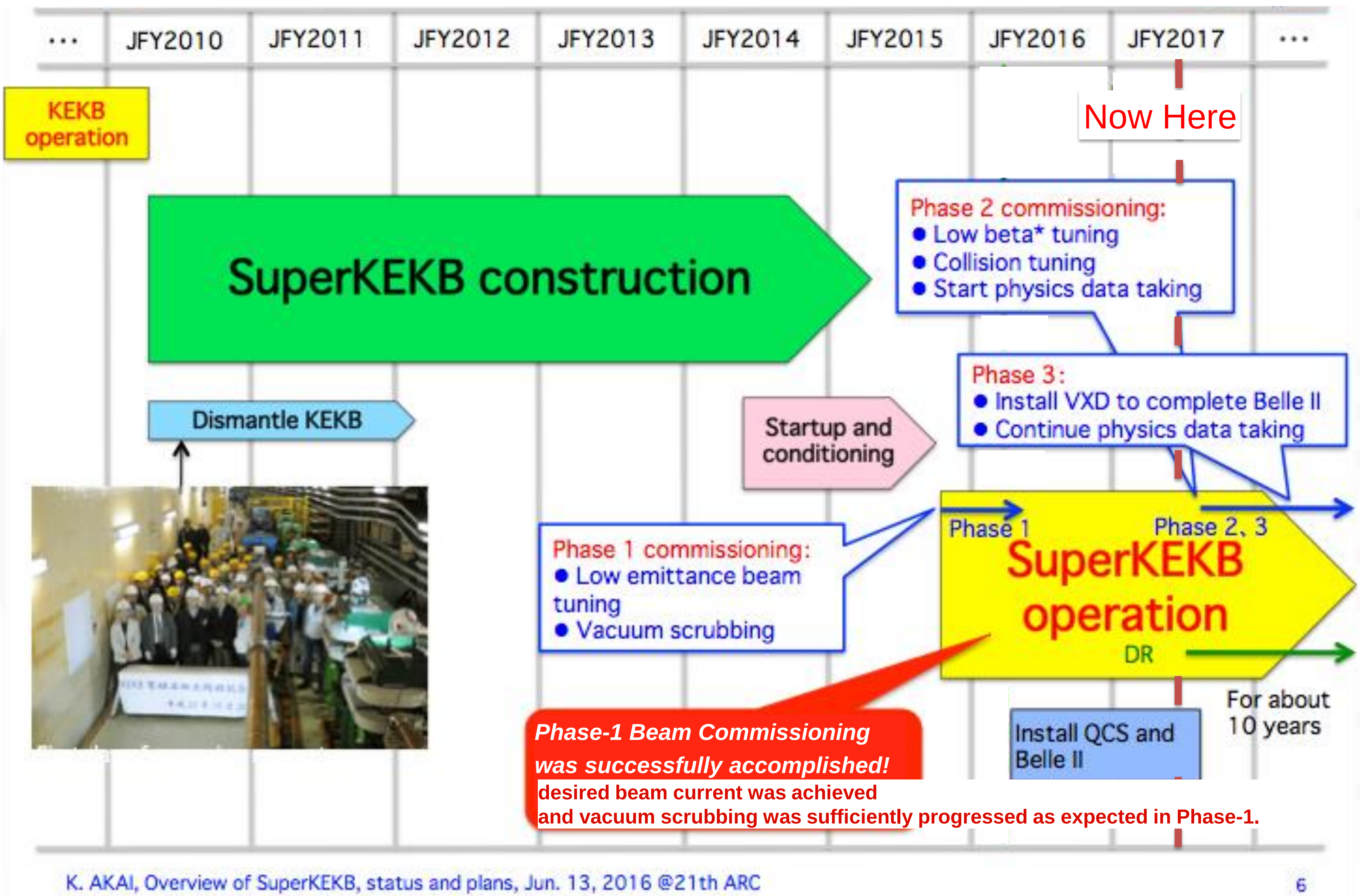
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

Beam Current: x 2

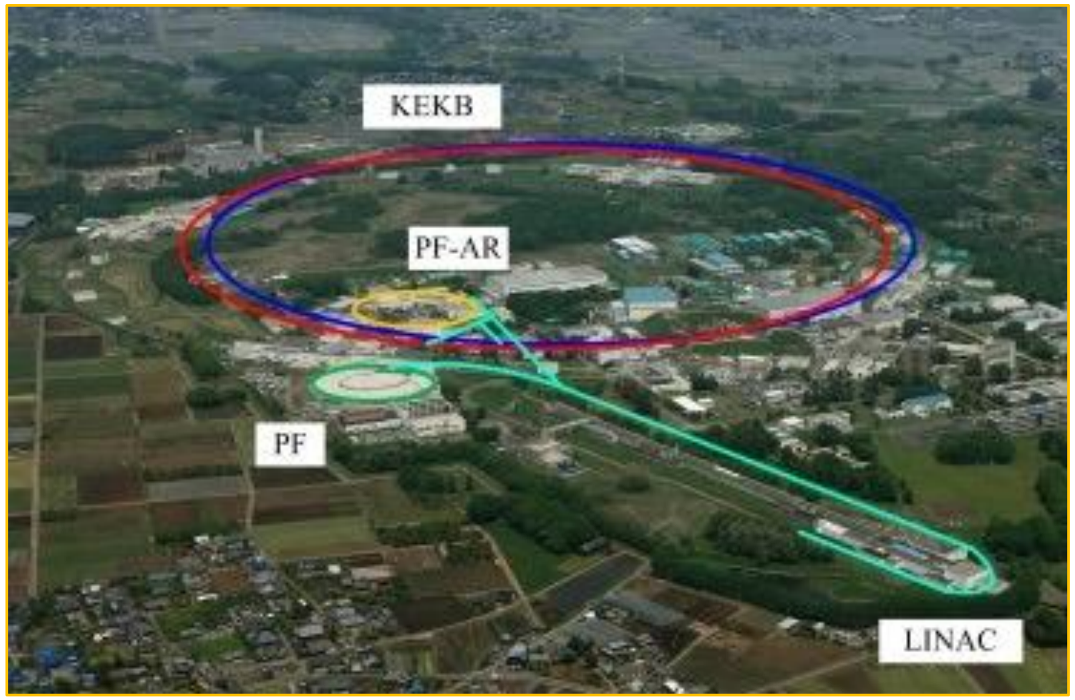
β_y @IP: 1/20

	KEKB Acieved		SuperKEKB Nano-Beam	
	LER	HER	LER	HER
I_{beam} [A]	1.6	1.2	3.6	2.6
β_y^* [mm]	5.9	5.9	0.27	0.30
ξ_y	0.09	0.12	0.088	0.081
Luminosity [cm^{-2} s^{-1}]	2.1 x 10^{34}		8.0 x 10^{35}	

Operation Schedule

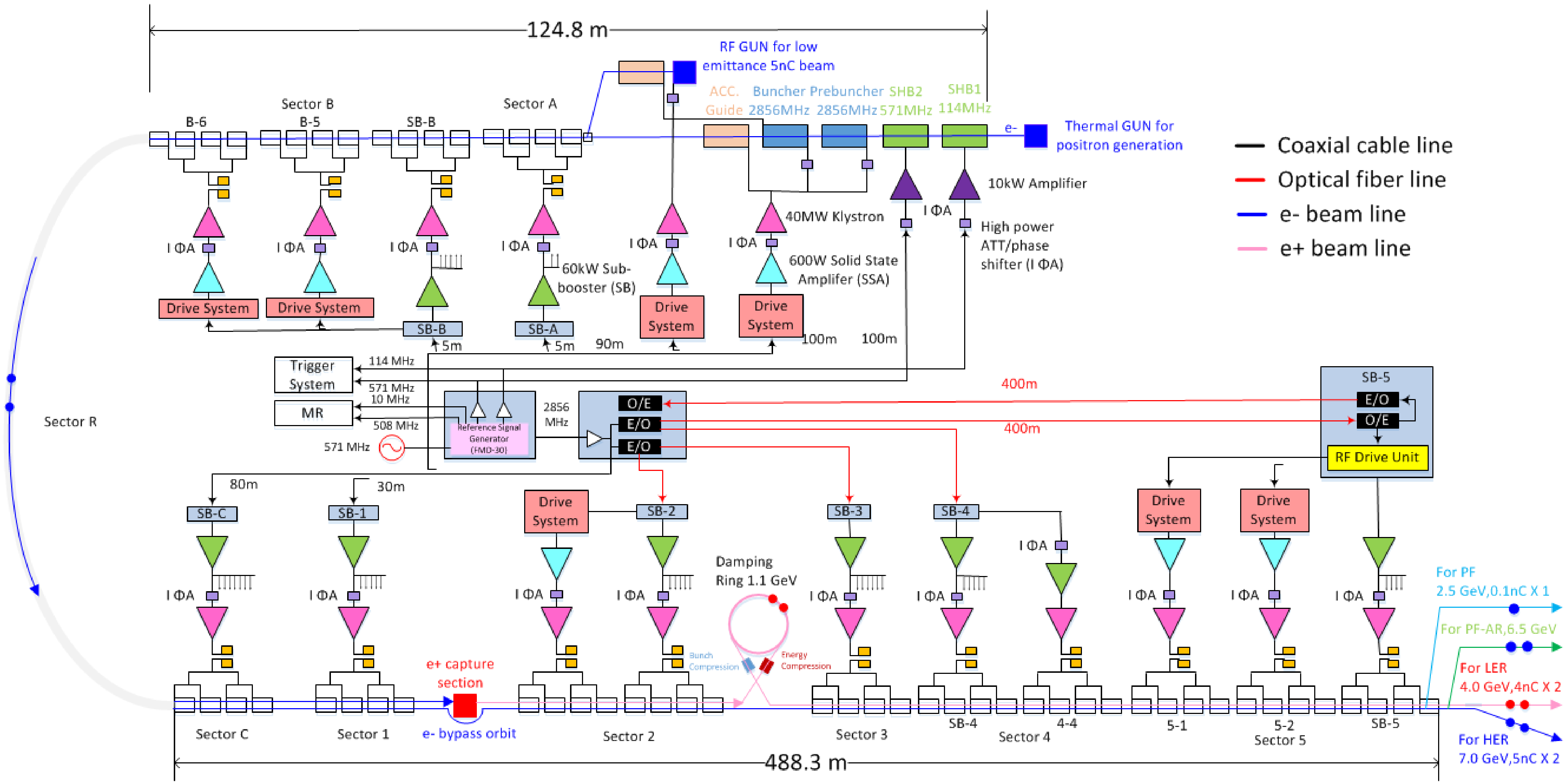


1. Status of LLRF System at KEKB-Linac



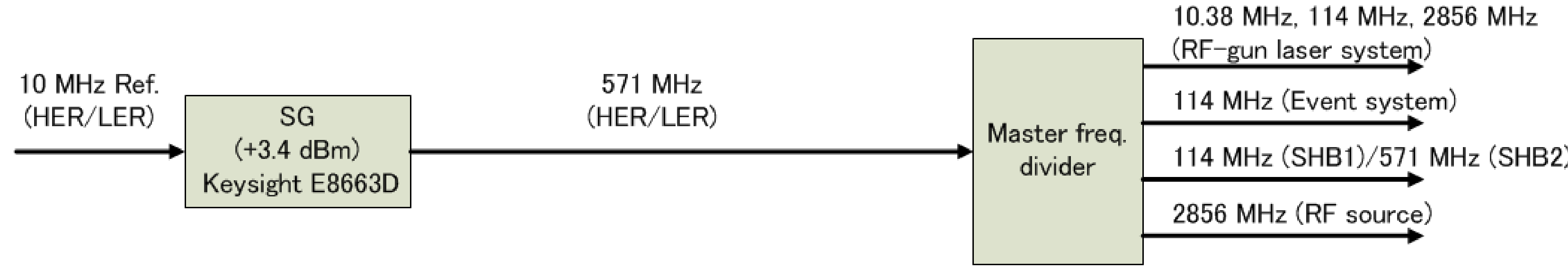
Toward the operation of Super-KEKB, improvement of LLRF system in KEKB-Linac has been promoted.

From this autumn,
1) electron emitted from RF gun is injected to HER.
2) positron generated thermal gun is injected to Damping Ring (DR).
3) positon emitted from DR is injected to LER.



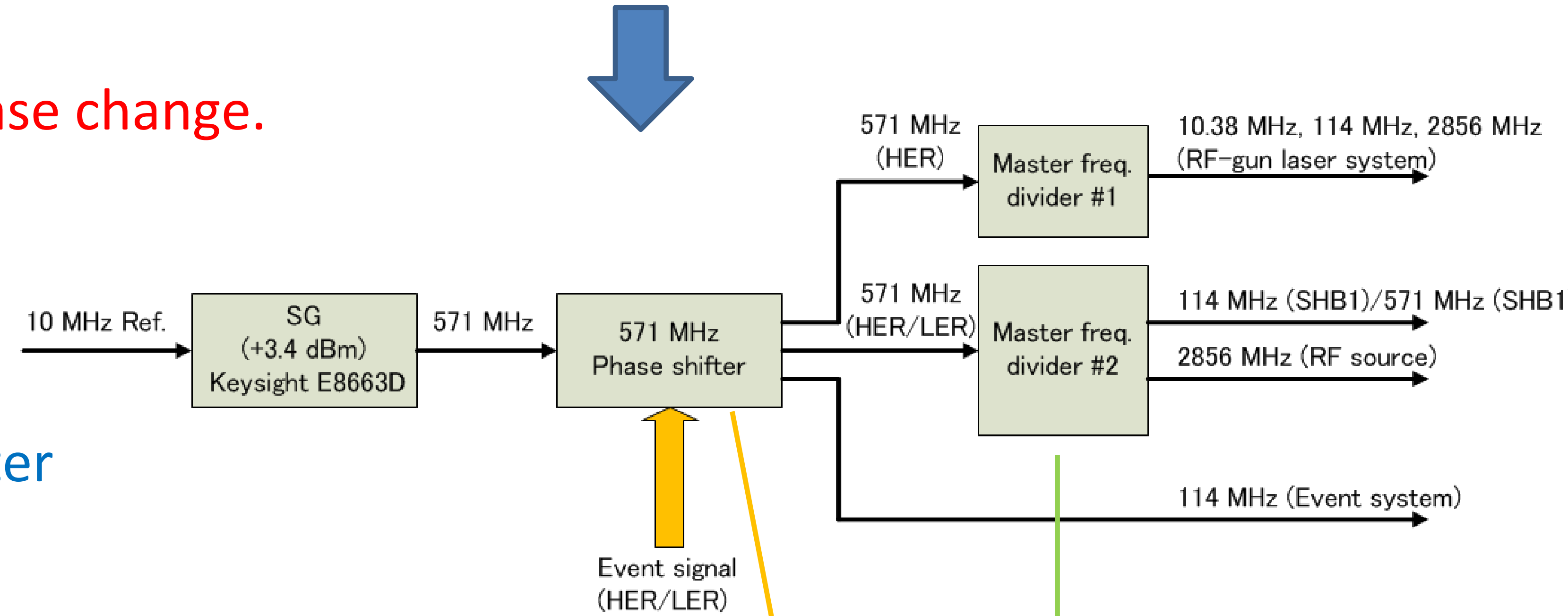
Reconfiguration of Master Oscillator System

- To change the injection phase to HER and LER, the phase of the reference RF was changed.



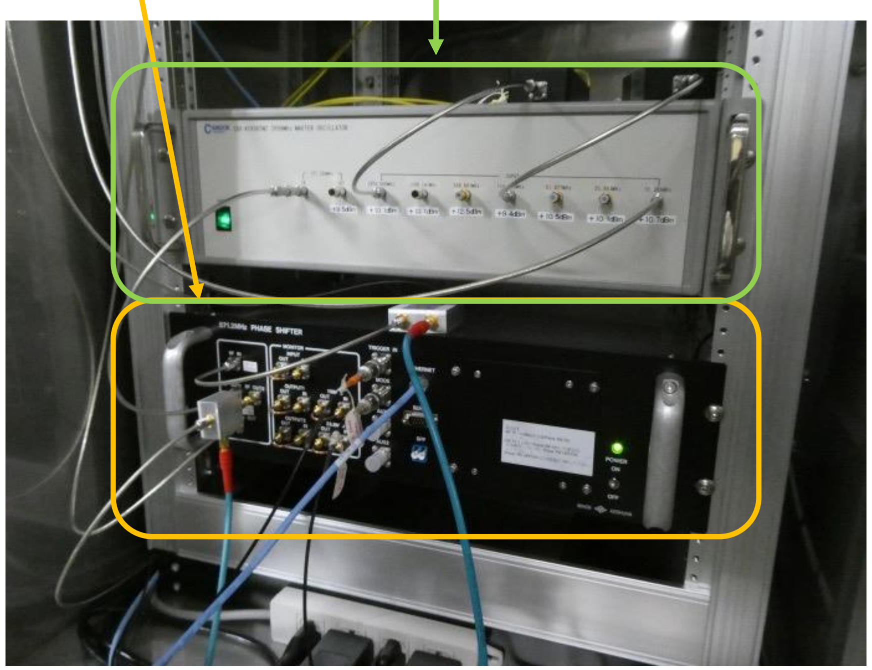
→ Laser resonance for RF-gun can not be maintained by HER/LER phase change.

- The configuration of the master oscillator system was changed.



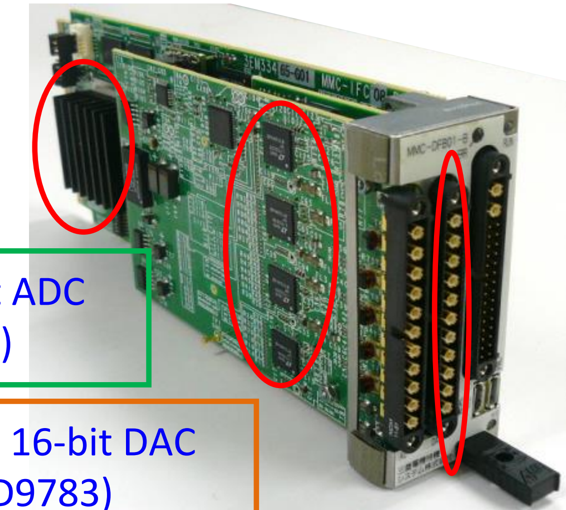
Installation of 571 MHz phase shifter

Thermostat chambers



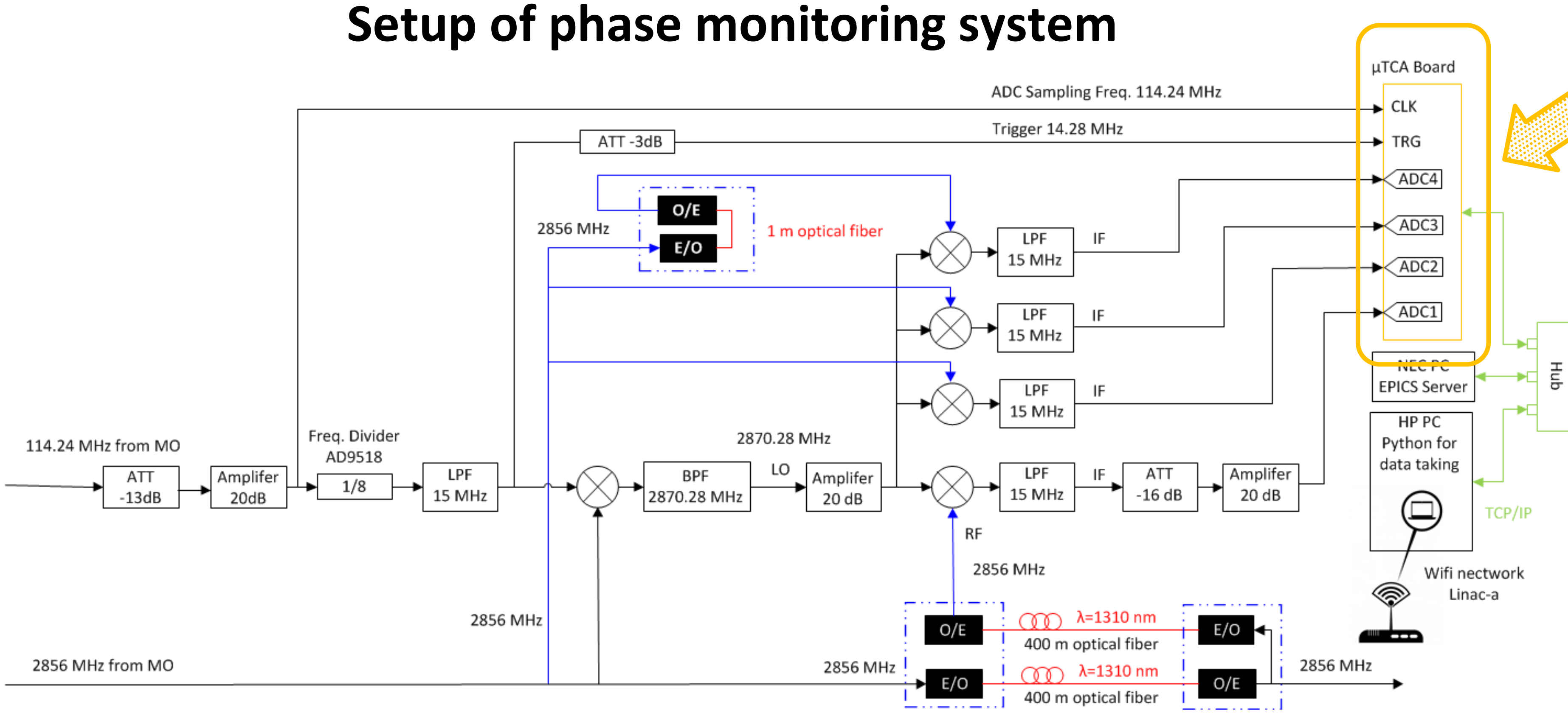
Construction of Phase Monitoring System

- In order to measure the phase stability of RF reference system, the monitoring system that uses the digital board developed by cERL and SuperKEKB was constructed.



Mitsubishi Electric TOKKI

Setup of phase monitoring system



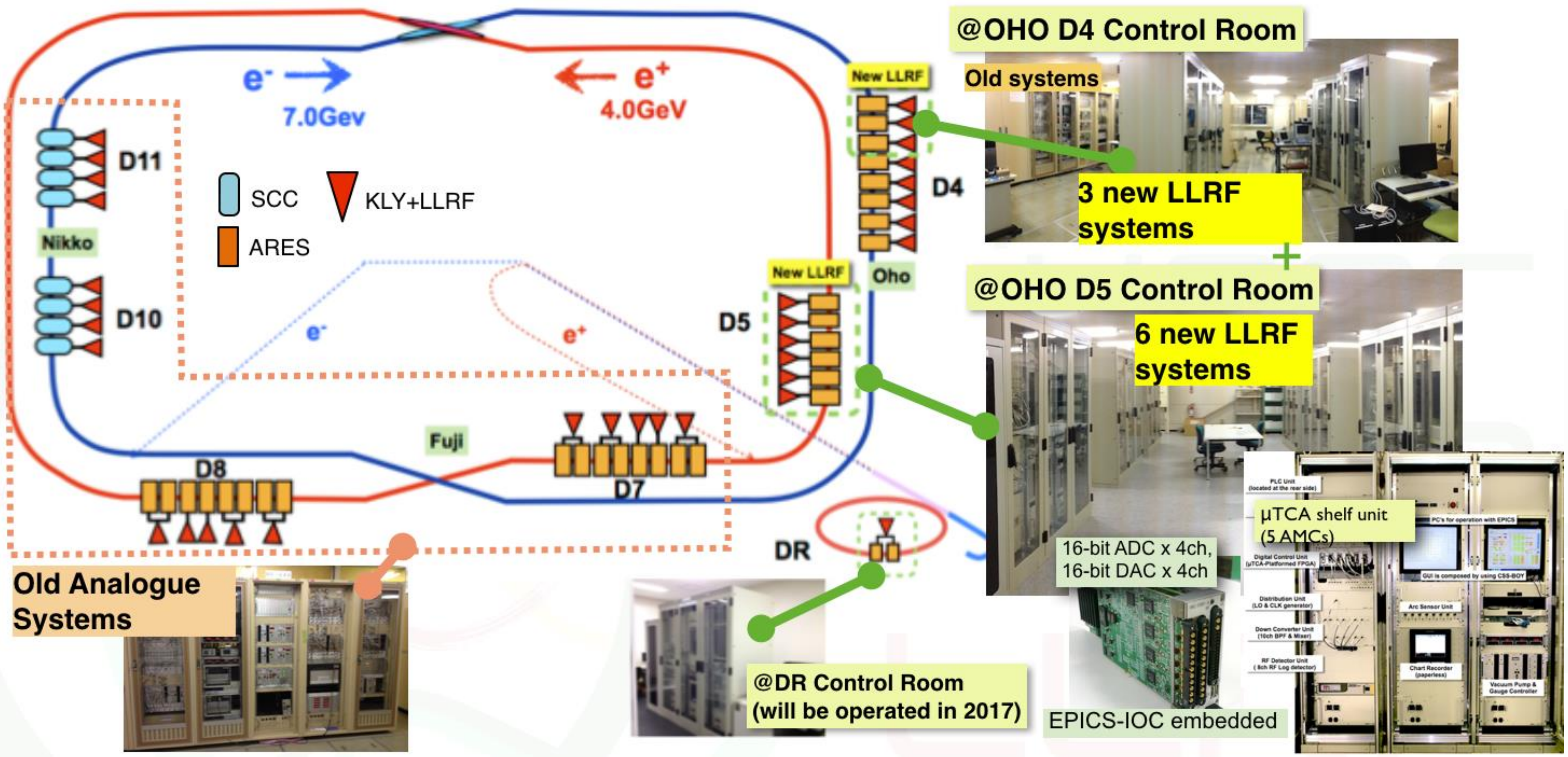
10/17 P-81: “The Consideration of RF Reference Phase Stabilization for the SuperKEKB Injector LINAC” Liu Na

- In order to stabilize RF reference system, we proceed with …

  1) Evaluation of phase variation caused by temperature and humidity

  2) Installation of feedback system (if it is required)

2. Installation of new LLRF System



- About 30 klystron stations are operated for SuperKEKB Acceleration. SC is used at 8 stations in Nikko.
- New LLRF control systems were applied to 9 stations for NC's at OHO section for Phase-1.
- Exiting old systems, which had been used in KEKB operation, are still reused for the others stations.
- All of them successfully worked well without problem.
- The DR-LLRF control system has already installed in DR control room.

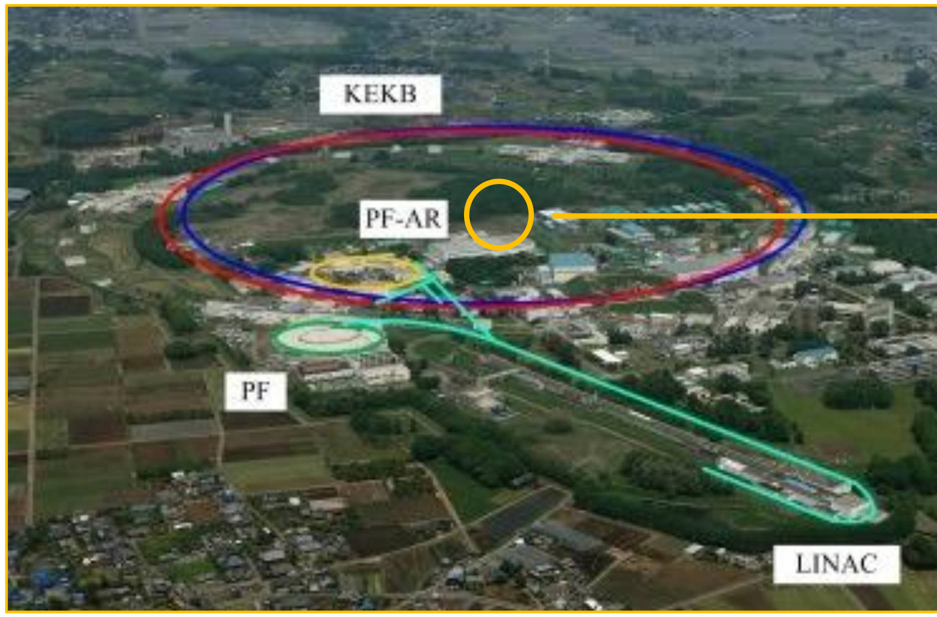
10/17 O-21: "A New Damper for Coupled-Bunch Instabilities caused by the accelerating mode at SuperKEKB" K. Hirosawa

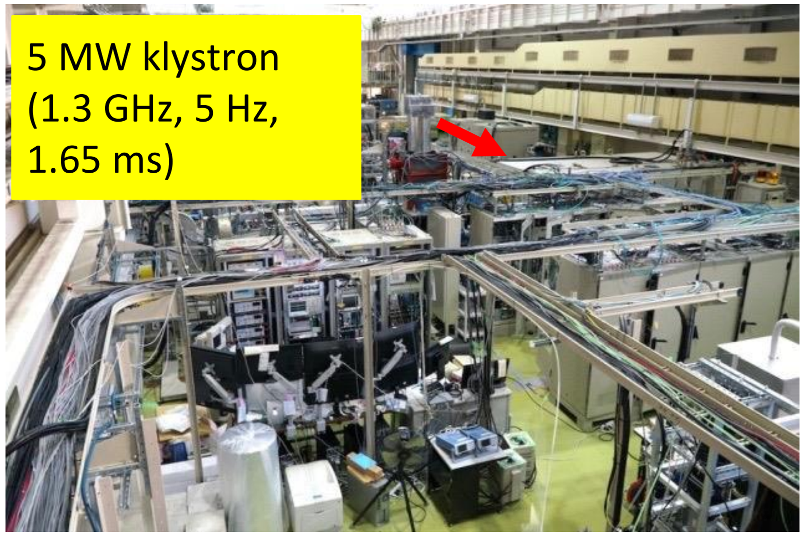
10/17 P-60: "LLRF controls in SuperKEKB Phase-1 comissioning" T. Kobayashi

3. Status of LLRF System at STF

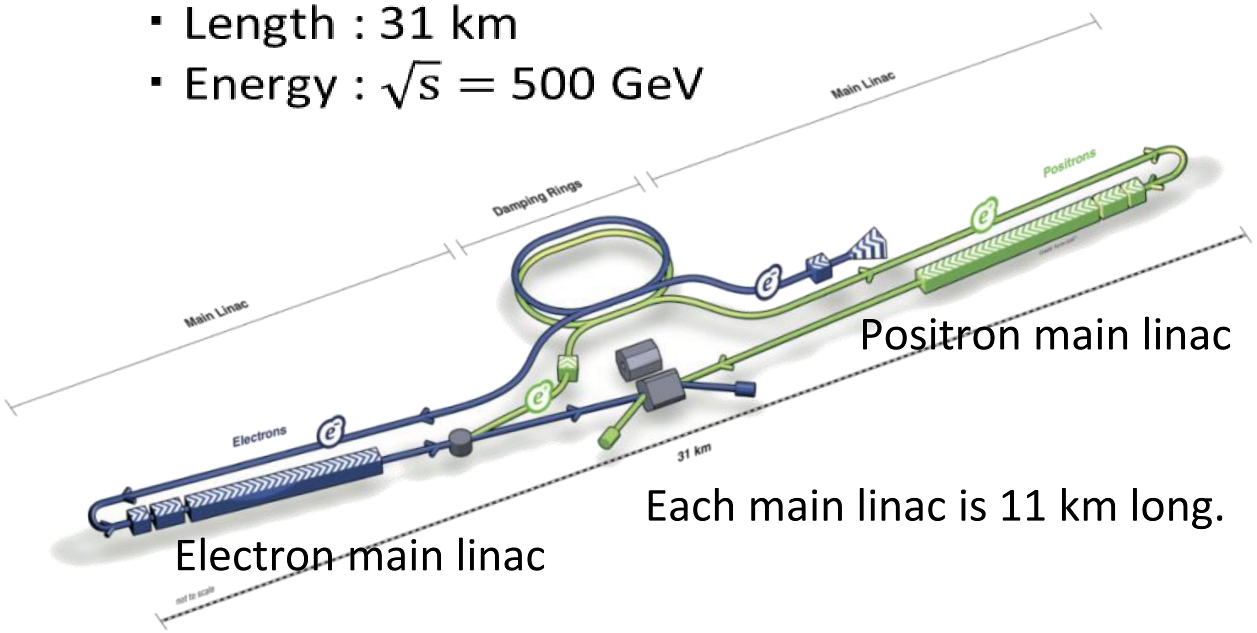
Purpose: Research and development for the realization of International Linear Collider (ILC)

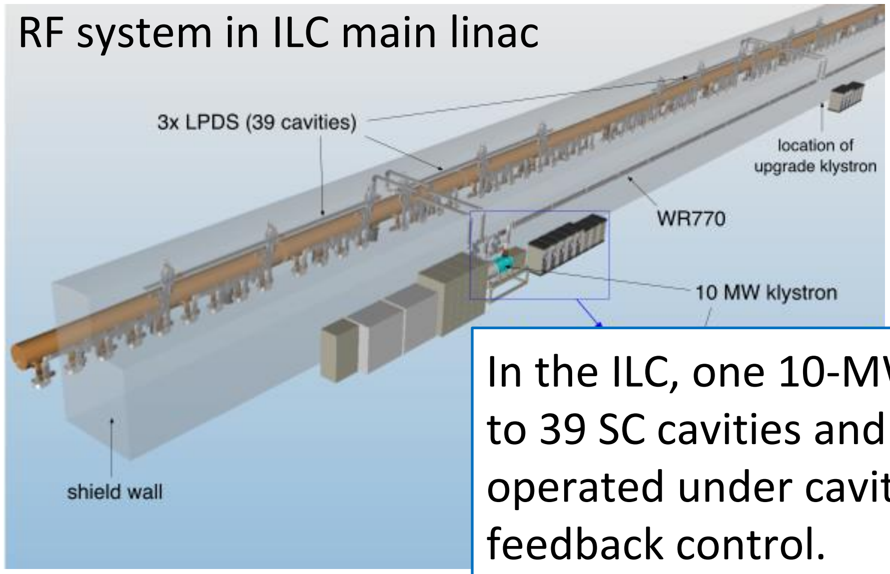
- **Superconducting RF Test Facility (STF)**





- **International Linear Collider (ILC)**
  - Planned electron-positron linear accelerator
  - Length : 31 km
  - Energy : $\sqrt{s} = 500$ GeV





In the ILC, one 10-MW klystron feeds its power to 39 SC cavities and these cavities are operated under cavity-field vector-sum feedback control.

Configuration of ILC LLRF system

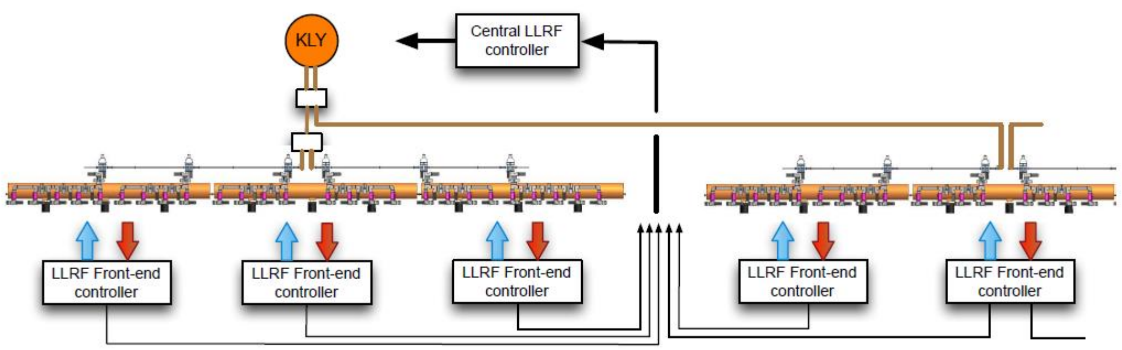
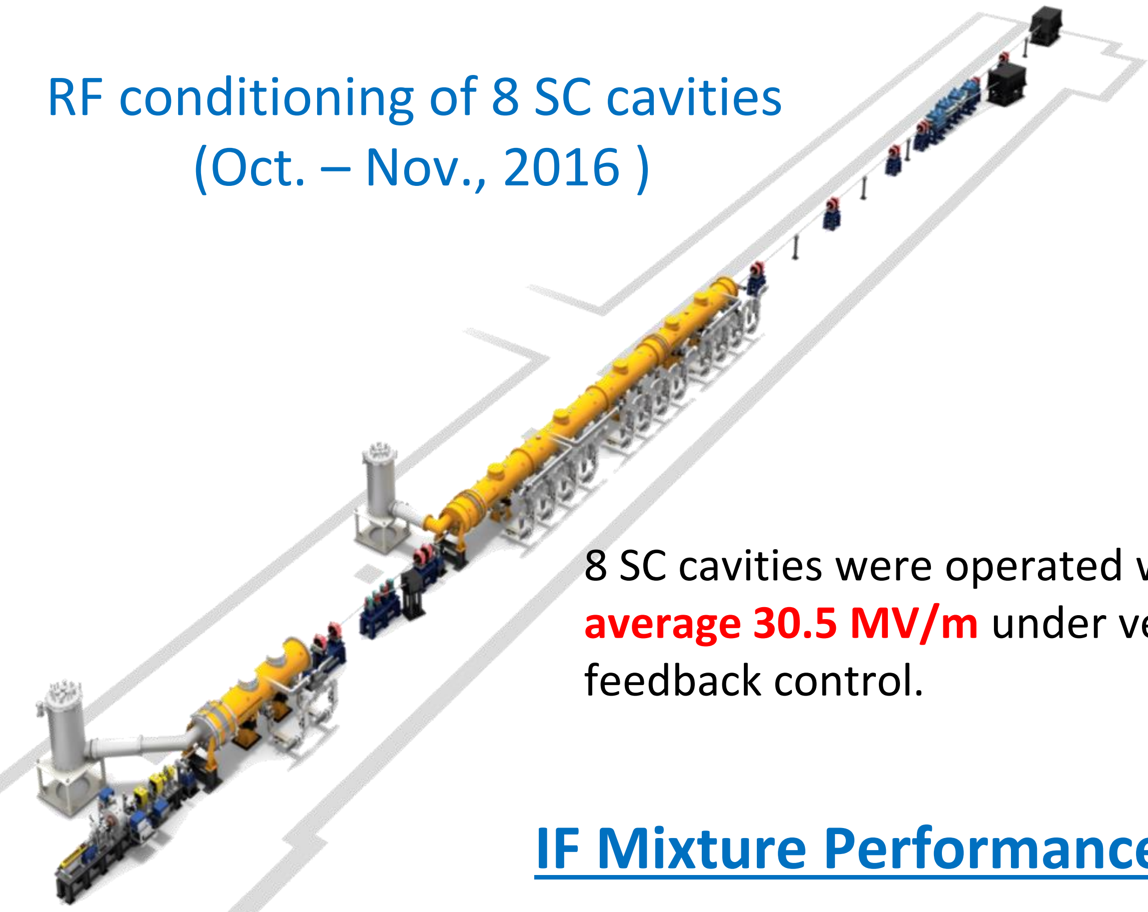


Figure 3.43. Implementation block diagram for the DKS LLRF system

STF-2 : Prototype of ILC-TDR (2015-)

STF-2: Prototype of ILC-TDR
One 10-MW MBK drives 12 SC cavities.

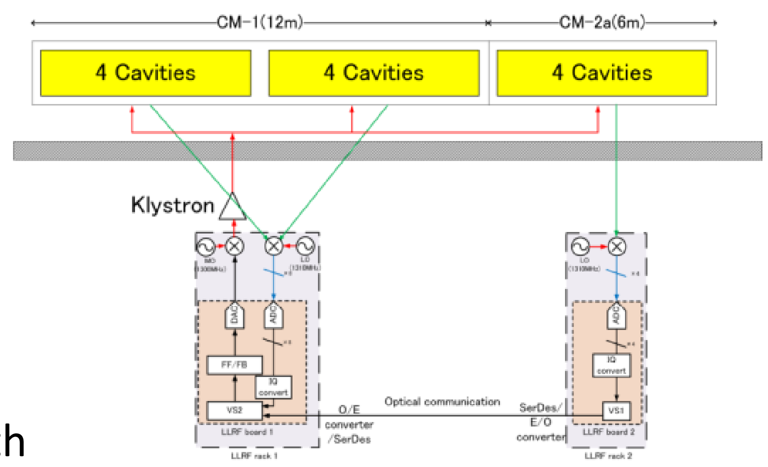
RF conditioning of 8 SC cavities
(Oct. – Nov., 2016)



8 SC cavities were operated with **average 30.5 MV/m** under vector-sum feedback control.

- In STF-2, two digital LLRF boards connected with optical communication are configured for operation.

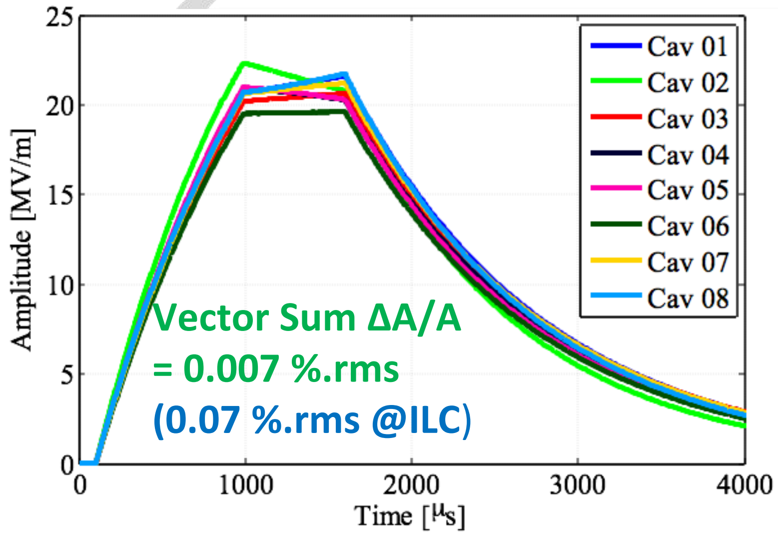
→ minimal combination of ILC LLRF system.

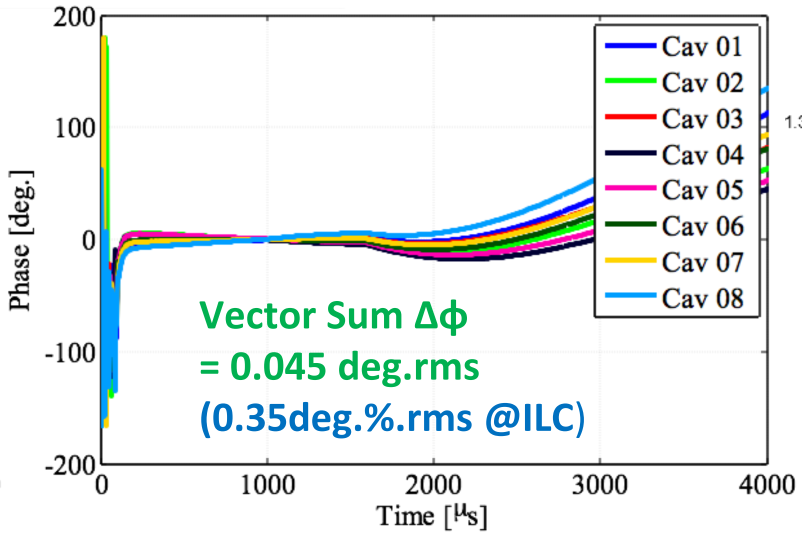


MTCA.4 standard board
2ch SFP connectors

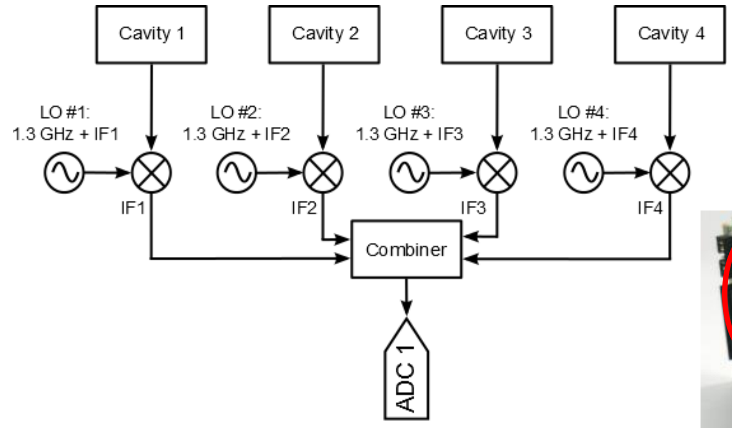
Zynq-7000(XC7Z045):
ARM (Cortex-A9) → EPICS-IOC

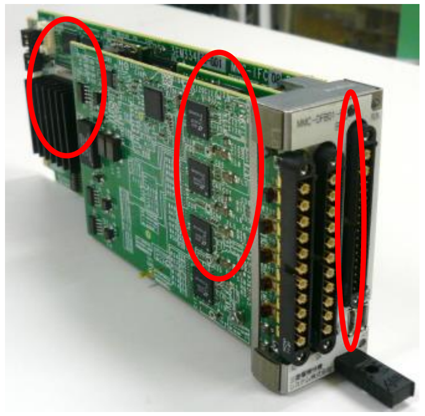
IF Mixture Performance





IF-mixture Technique





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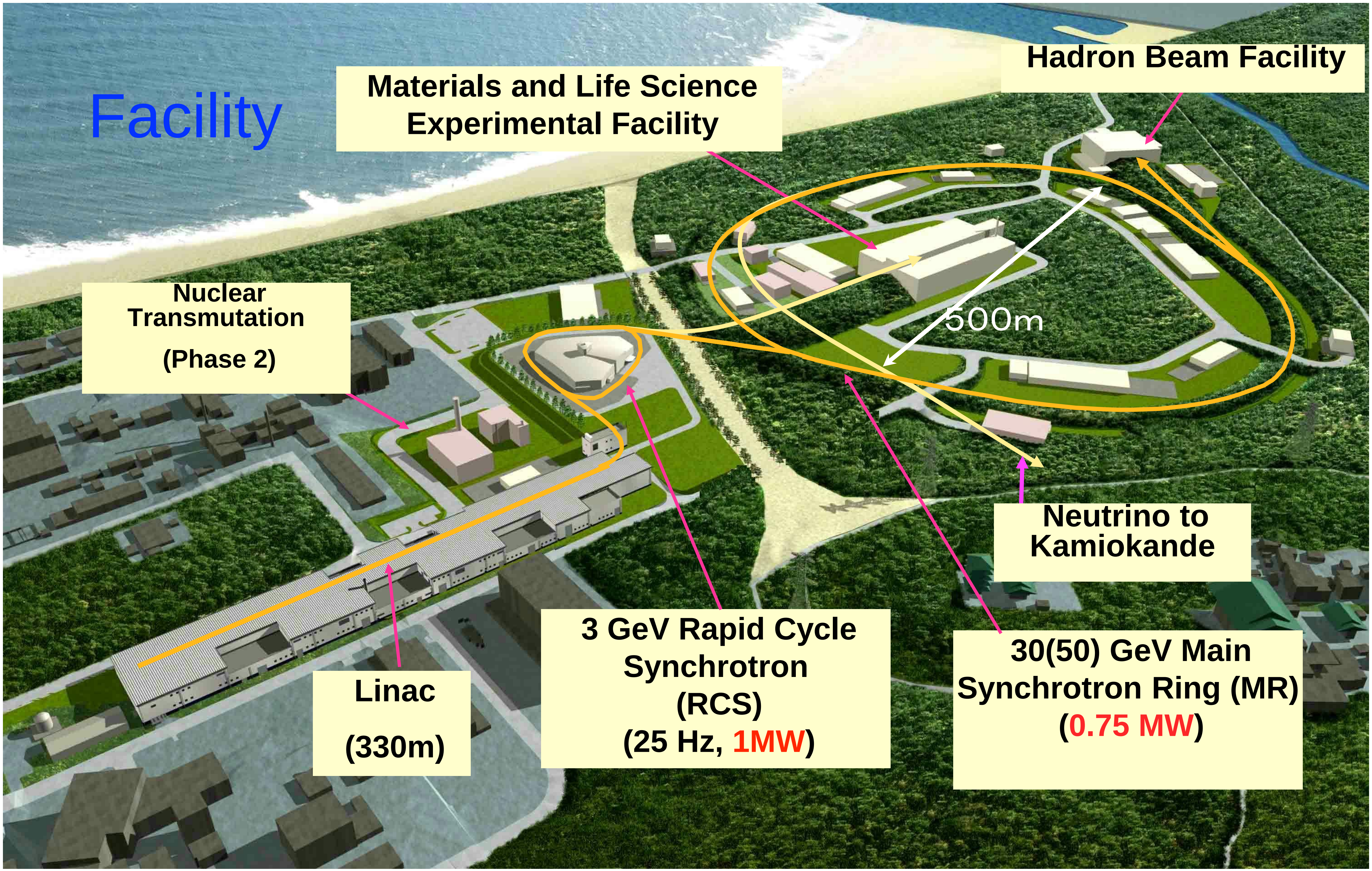
By using IF signal with different frequencies, 8 SC cavities are operated with 2 ADCs.

: contact details : "MATSUMOTO, Toshihiro" <toshihiro.matsumoto@kek.jp>

J-PARC

(Japan Proton Accelerator Research Complex)

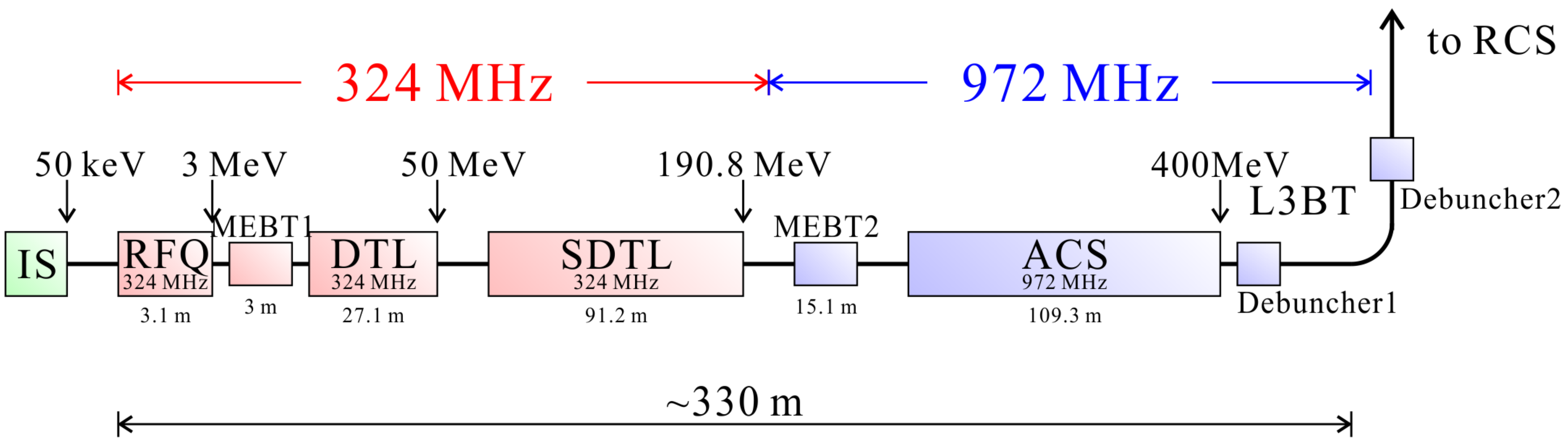
Joint Project between KEK and JAEA



J-PARC Proton Linac

Features

- p Accelerated particles: H- (negative hydrogen)
- p Output energy: 400 MeV
- p Peak current: 40 mA (in operation) & 50 mA (1 MW at 3 GeV)
- p Repetition: 25 Hz
- p Pulse width: 0.5 msec (beam pulse), 0.65 msec (RF pulse)



RF system

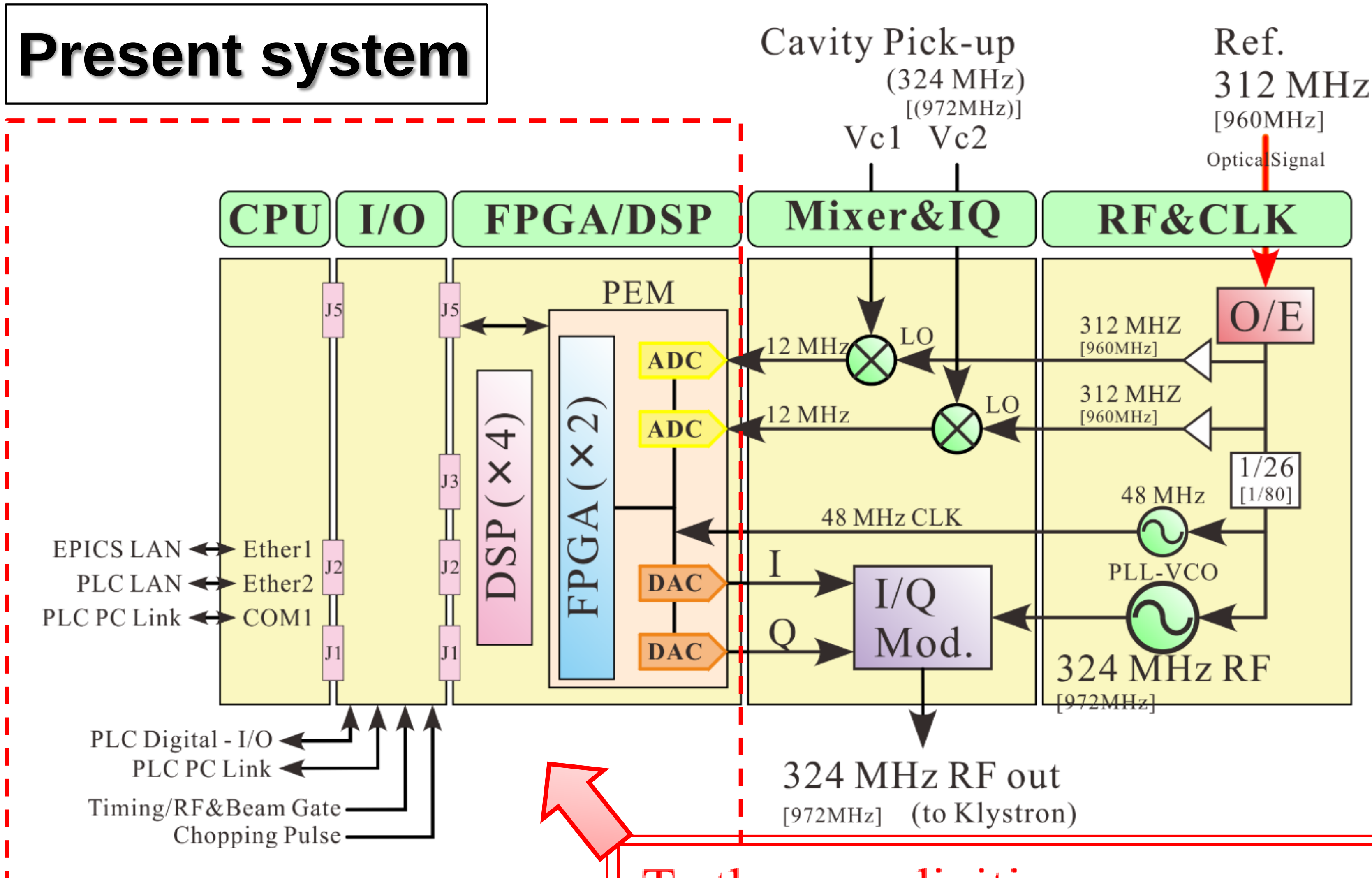
- # LLRF: 24 (324MHz), 25 (972MHz)
- # Klystrons: 20 (324MHz), 25 (972MHz)
- # Solid State Amplifiers: 4 (324MHz)

4. Next Plan of J-PARC Linac RF

Next plan:

Development of the new digitizer

Present system



Present system

- Production stoppage
- Difficulty of developing environment

To the new digitizer

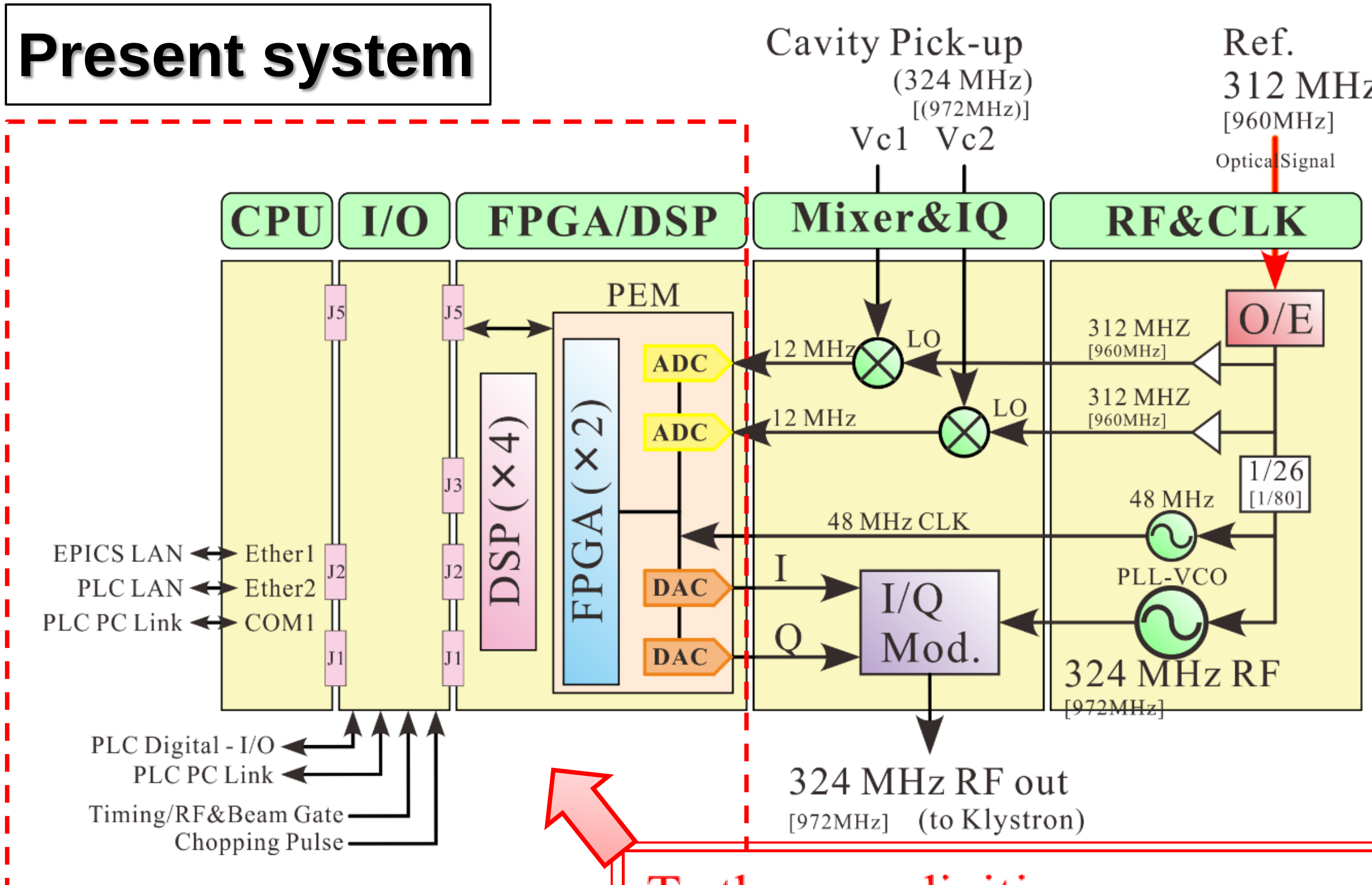
- 8ch 16bit-ADCs, 2ch 16bit-DACs
- Zynq(XC7Z045-1FFG900C), EPICS-IOC on linux
- DDR3-SDRAM 1Gib × 2
- SFP 2 ports

4. Next Plan of J-PARC Linac RF

Next plan:

Development of the new digitizer

Present system



Present system

- Production stoppage
- Difficulty of developing environment

To the new digitizer

10/17 P-24: “Overview of Improvements for the J-PARC Linac LLRF System” K. Futatsukawa

10/17 P-58: “The upgrade of J-PARC LINAC LLRF system” Song LI

- SFP 2 ports

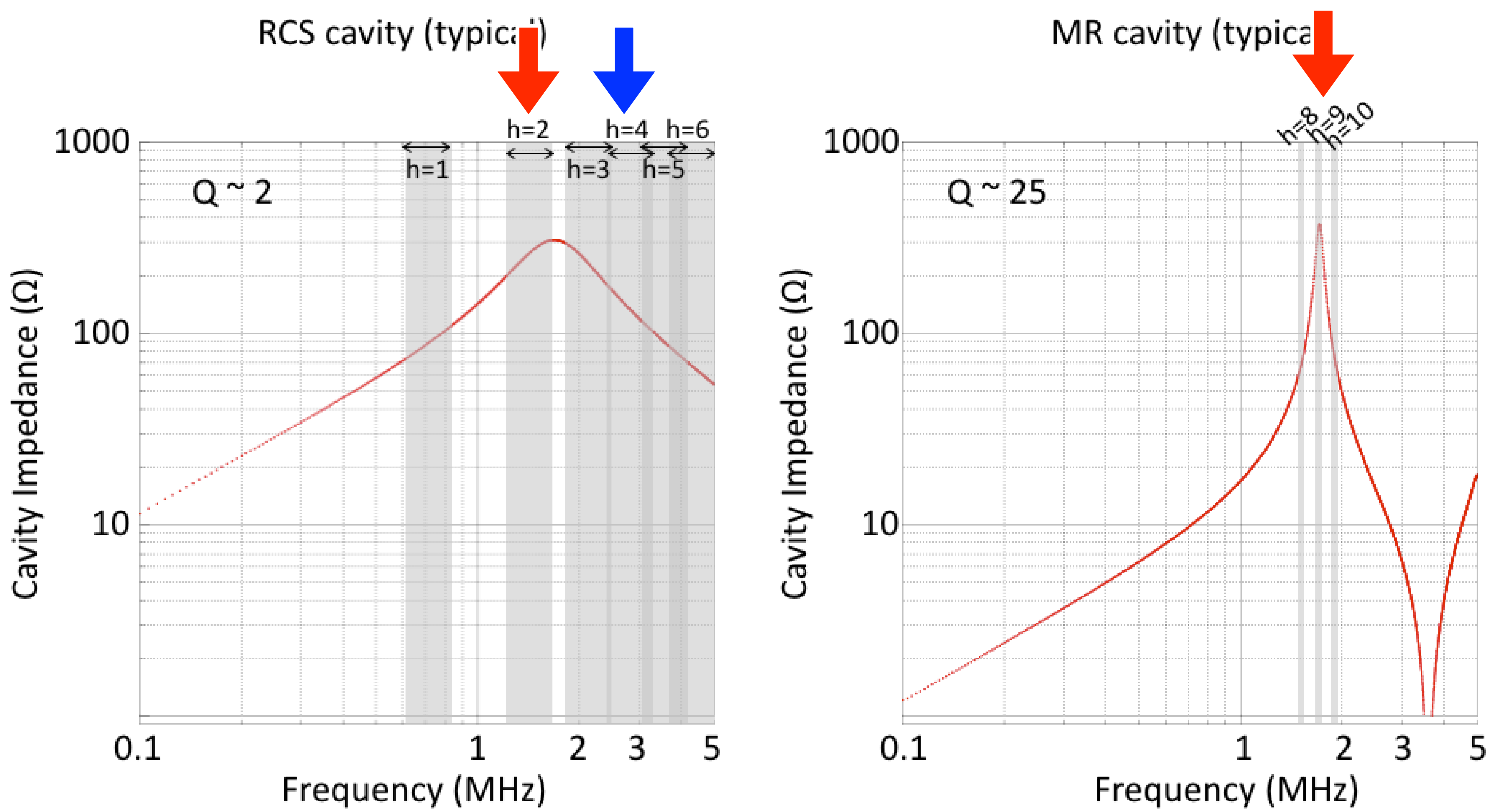
J-PARC proton synchrotorns

Parameters	RCS	MR
1. Circumference	348.333 m	1567.5m
2. Energy	400MeV - 3GeV	3GeV - 30GeV
3. Beam intensity	8.3 x 10^{13}ppp	2.4 x 10^{14} ppp
4. Repetition freq/period	25Hz	2.48s (FX) 5.52s (SX)
5. Accelerating frequency	1.227 - 1.671MHz	1.671 - 1.721MHz (h=9)
6. Accelerating harmonics	h = 2	h = 9
7. Number of cavities	12 (h = 2)	7 (h=9) 2 (h = 18)
8. Q-value	2	24 (h=9) 15 (h=18)
9. Peak accelerating voltages	400 kV	300 kV

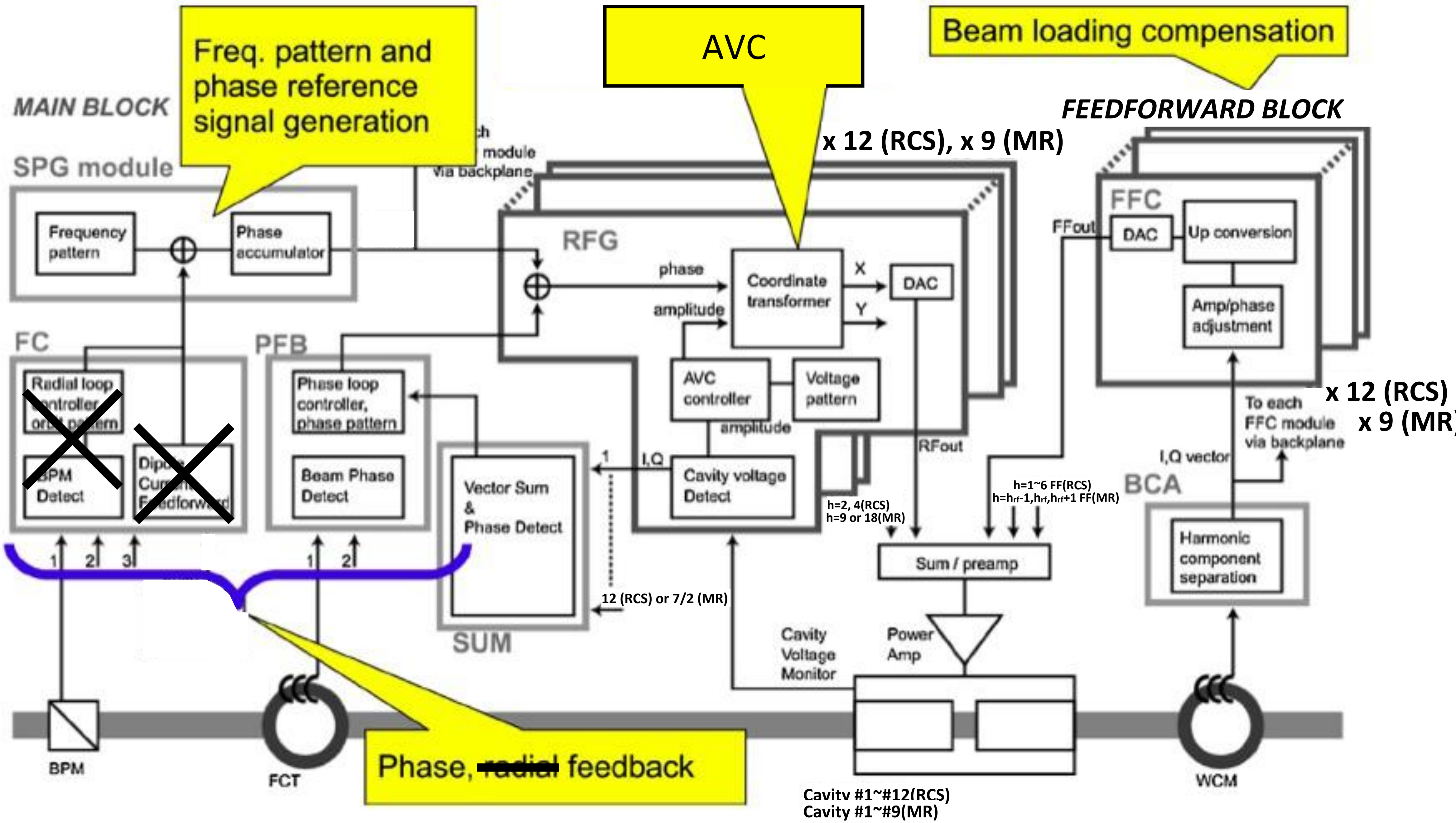
4. J-PARC Ring RF

J-PARC synchrotrons use the MA loaded cavity systems.

- high accelerating field gradient >20kV/m achieved
- The system is a wide-band, especially, RCS cavity impedance covers an accelerating frequency and second harmonic frequency for bunch shaping to inclease a bunching factor
- the MA cavity is a “passive load”, no tuning loop provided.



First genaration of LLRF controls system for RCS and MR



Thanks of stable Linac operations and good reproducible magnet fields in RCS and MR, the radial feedbacks are not used in RCS and MR.

DDS based full digital LLRF control system is used,
- the best match with a passive MA loaded cavity system.
- realize stable/reproducible acceleration under an extreme heavy beam loading.

Feedforward beam loading compensation is one of the distinctive features of our RF sys
- Multi-harmonic Feedforward system was developed

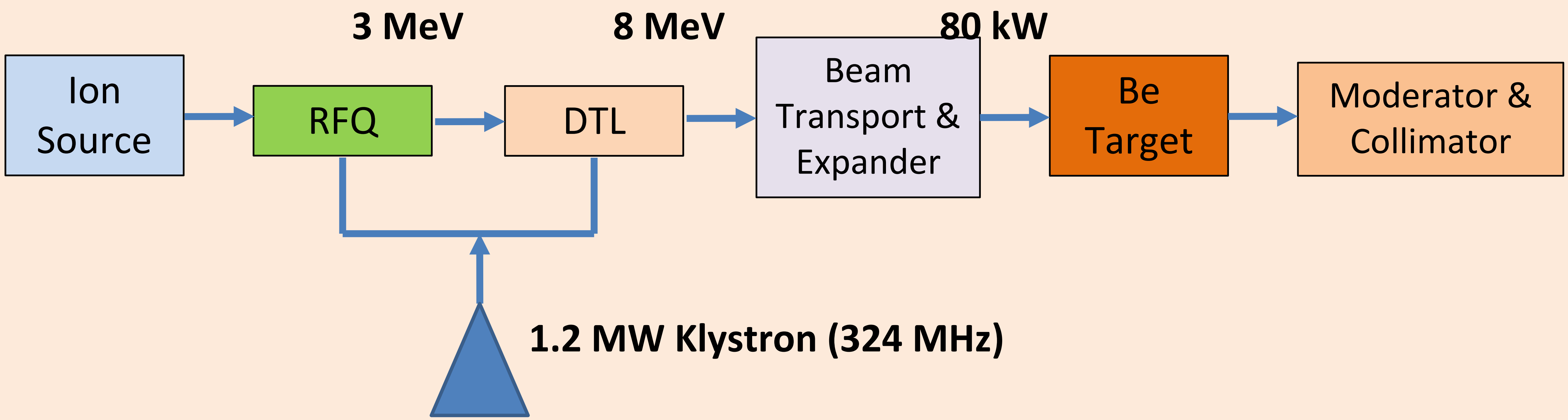
Thanks to a good matching with the passive magnetic alloy loaded RF cavity systems, the LLRF control systems are enable to realize stable proton beam acceleration since 2007. 1 MW proton beam was accelerated at RCS in 2015.

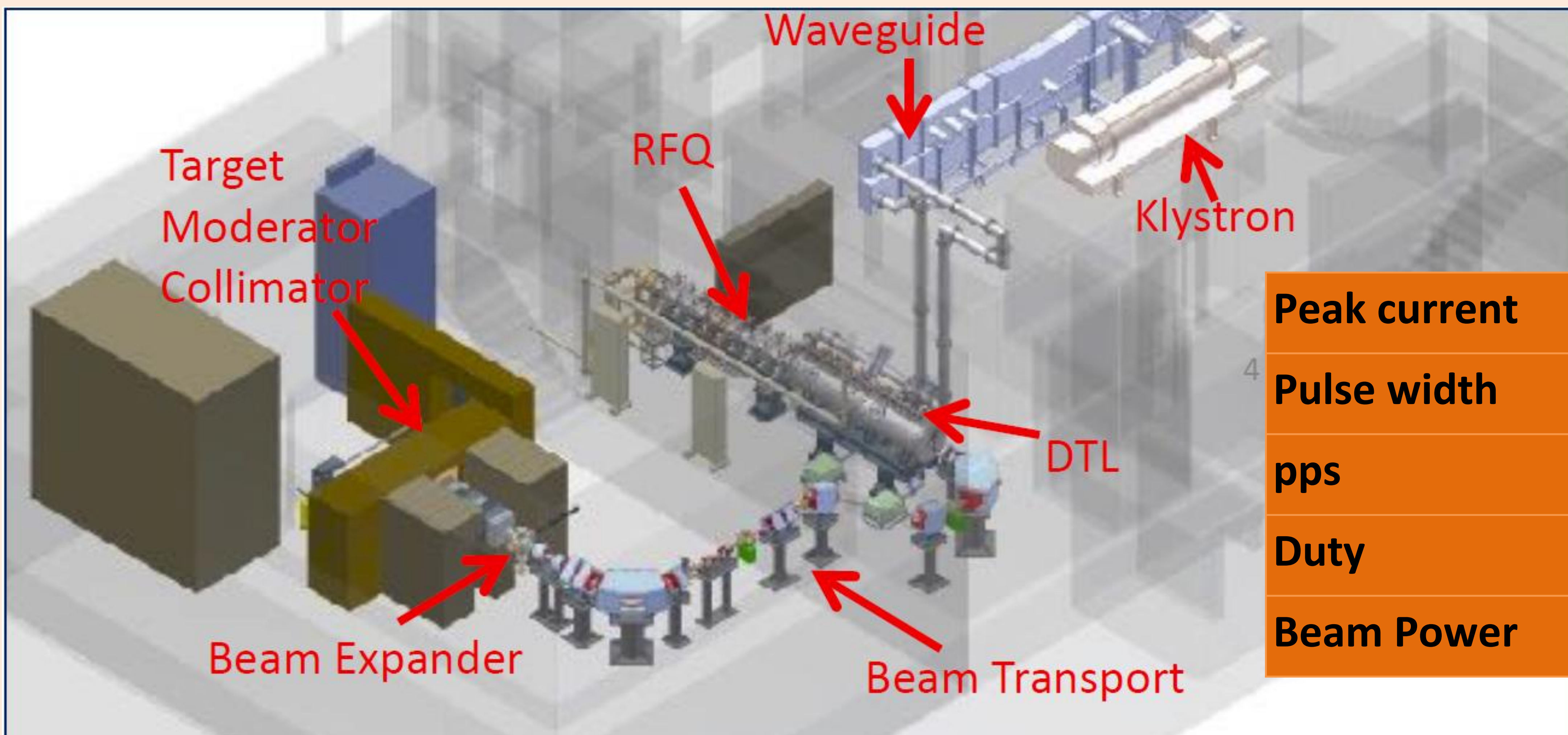
However, it is the time that we must consider the next generation!
We choose a micro-TCA standard, which is similar to the boards designed for the LLRFs of SuperKEKB and J-PARC LINAC. By using a common architecture will be minimize engineering development and costs for a new LLRF system. We target to improve functionality and downsizing in a new design.

10/17 O-20: "A prototype system of multiharmonic vector voltage control for the J-PARC rapid cycling synchrotron" F. Tamura

10/17 P-2: "Upgrading the J-PARC Ring LLRF systems" M. Yoshii

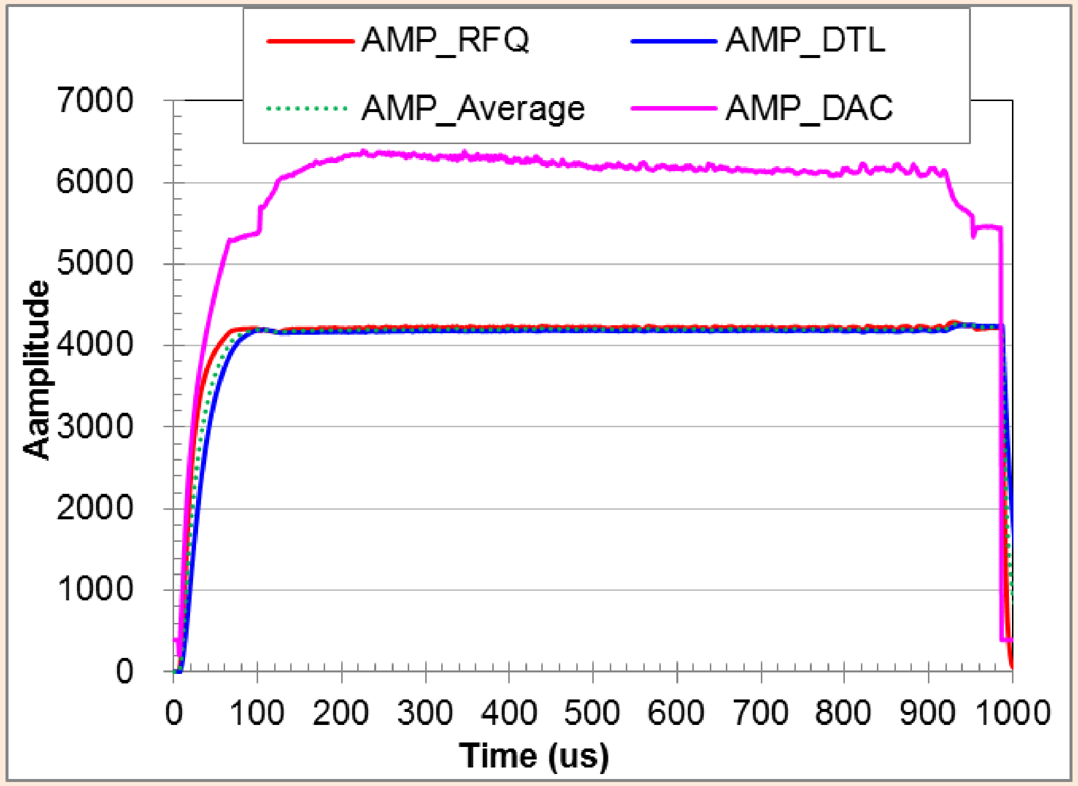
5. iBNCT



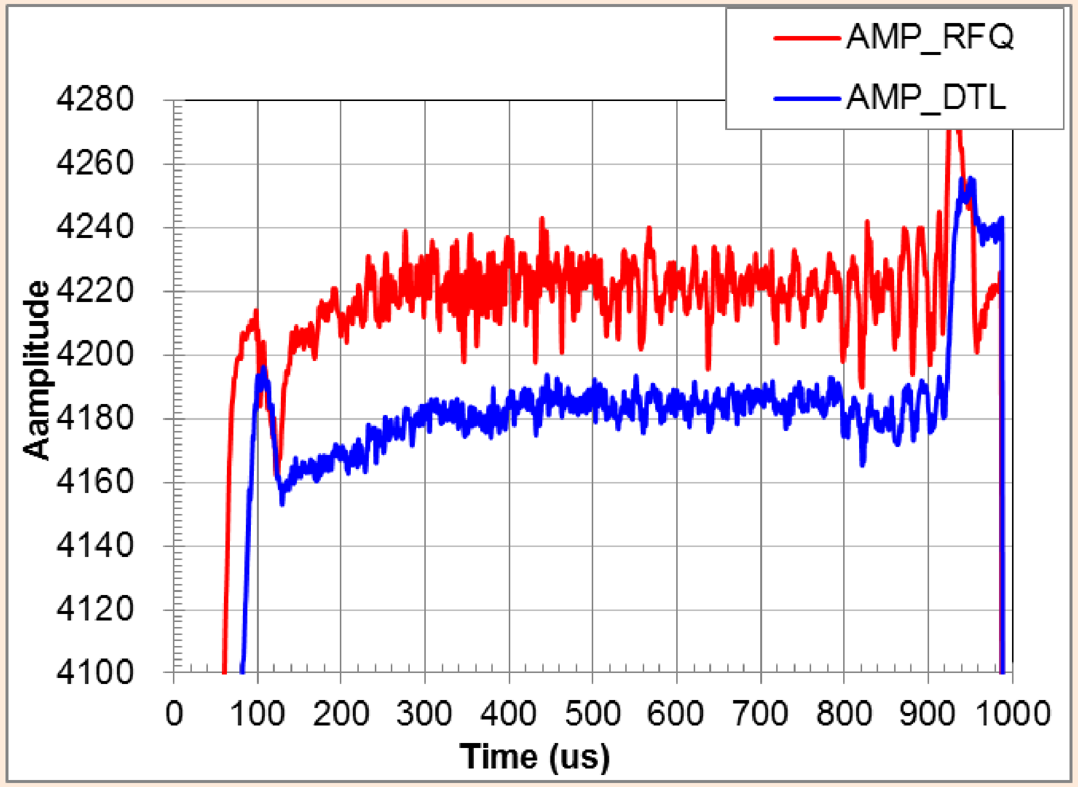


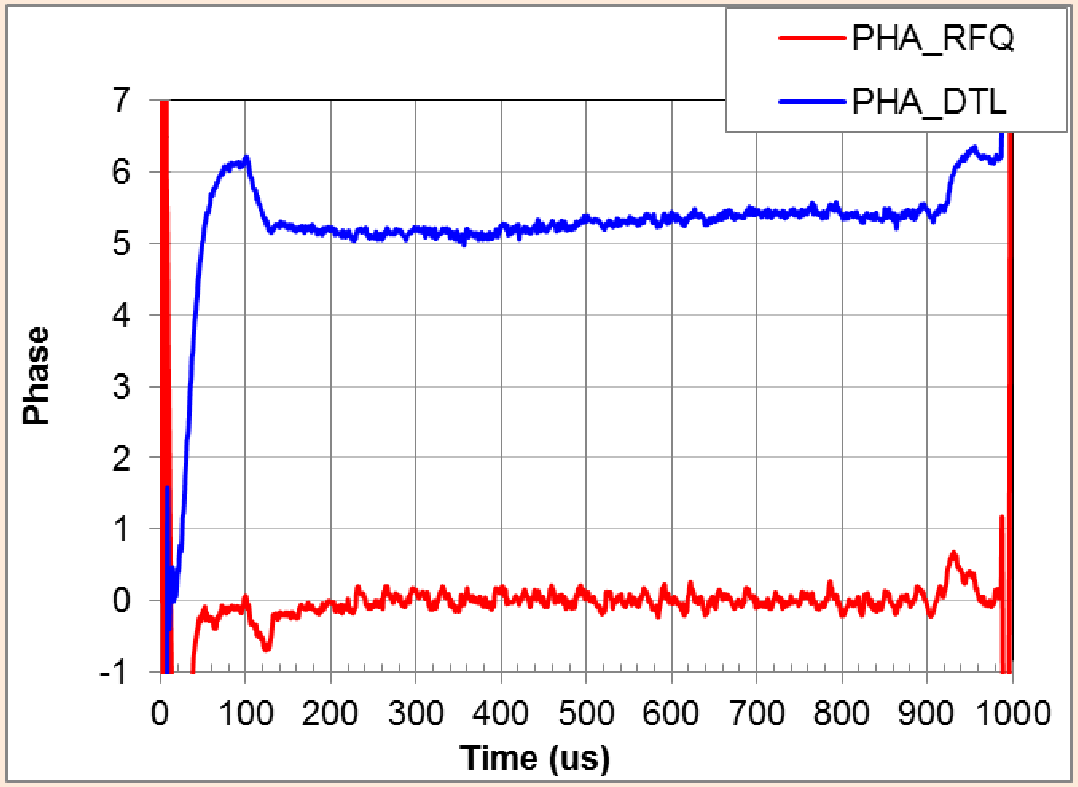
Peak current	Max. 50 mA
Pulse width	Max. 1 ms
pps	Max. 200 Hz
Duty	Max. 20%
Beam Power	80 kW

Stabilities (with beam: 20 mA, 850 μs)



Stabilities	Amplitude	Phase
RFQ	±1.00 %	±0.40°
DTL	±0.40 %	±0.30°





10/17 P-10: "Overview of LLRF System for iBNCT Accelerator" Zhigao Fang

SUMMARY

TUESDAY 17 OCTOBER 2017

O-20: “A prototype system of multiharmonic vector voltage control for the J-PARC rapid cycling synchrotron”
Fumihiko Tamura, J-PARC

O-21: “A New Damper for Coupled-Bunch Instabilities caused by the accelerating mode at SuperKEKB”
Kouki Hirosawa, KEK

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SONG LI, KEK/J-PARC

P-60: “LLRF controls in SuperKEKB Phase-1 commissioning"
T.Kobayashi

P-81: “The Consideration of RF Reference Phase Stabilization for the SuperKEKB Injector LINAC” Liu Na