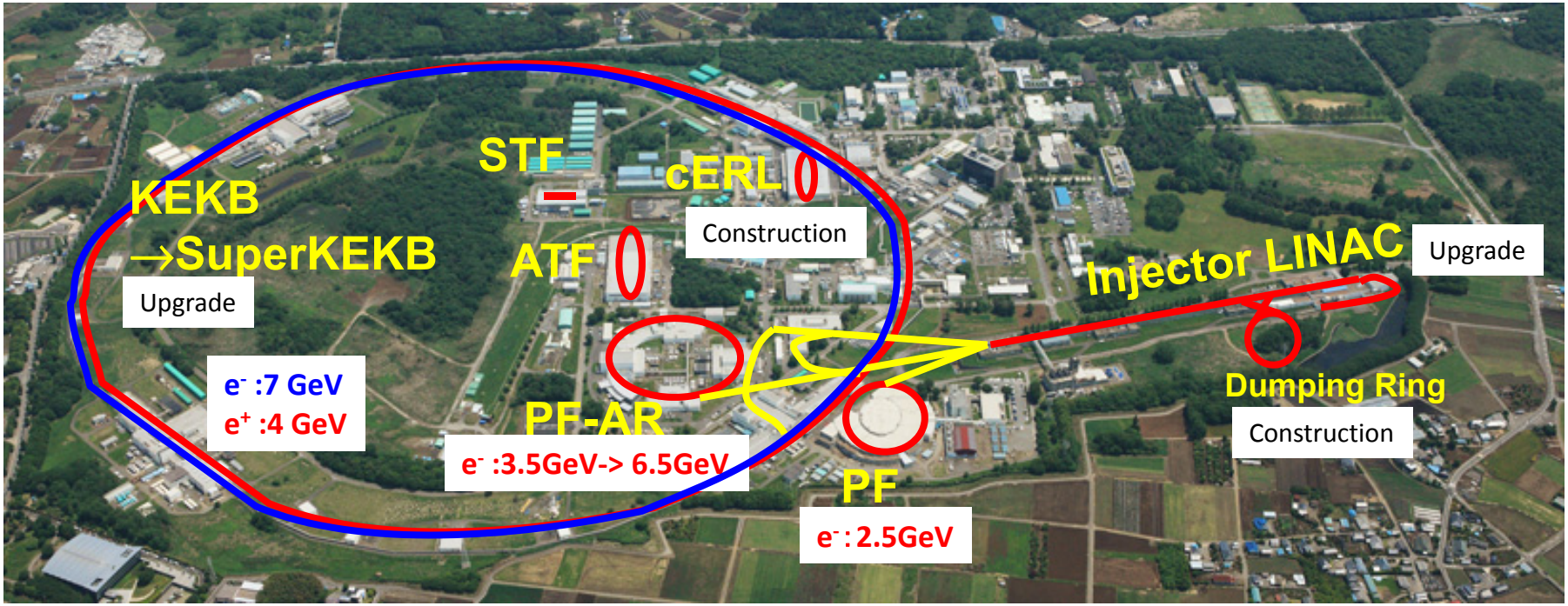
KEK LLRF SYSTEMS

Takako Miura (KEK)

Tsukuba Campus



SuperKEKB : e-,e+ collider for B-physics. Luminosity -> x40 higher than KEKB

PF (Photon Factory)

PF-AR (Photon Factory Advanced Ring for pulse X-ray) : One bunch, Pulse <100 ps

Injector LINAC : delivering e- /e+ beam to 4-Ring (e^-Ring and e^+ Ring of SuperKEKB, PF,PF-AR)

cERL (compact Energy Recovery Linac)
STF (Superconducting RF Test Facility)
ATF (Accelerator Test Facility)
} Test Facilities

Compact Energy Recovery Linac

cERL

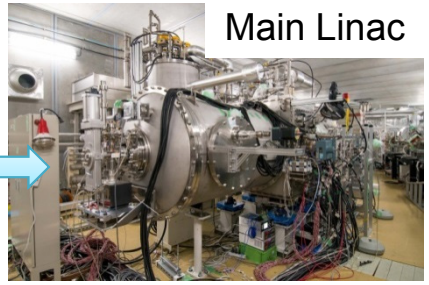
Collaboration:

Compact ERL (**cERL**) is under construction as a test facility of 3-GeV ERL future plan.

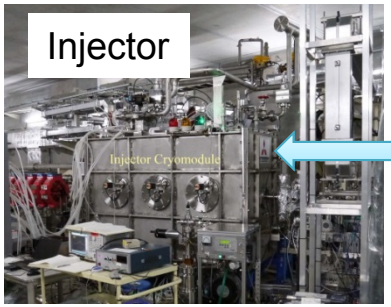
PEARL Photon Factory

9-cell SC cavity x 2

Main Linac

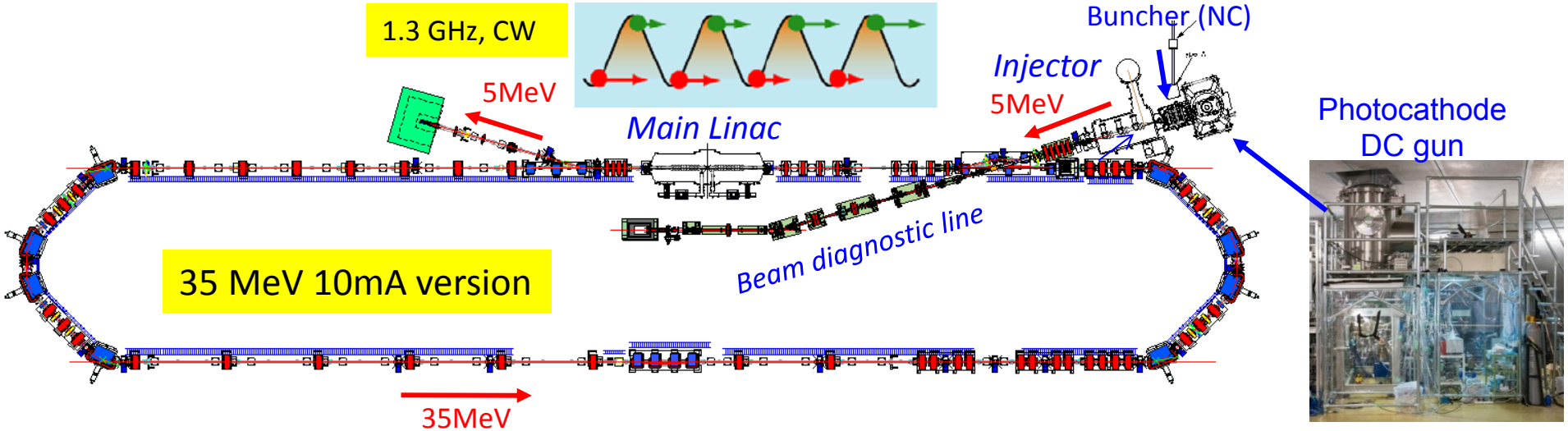


Injector



2-cell SC cavity x 3
(double feed)

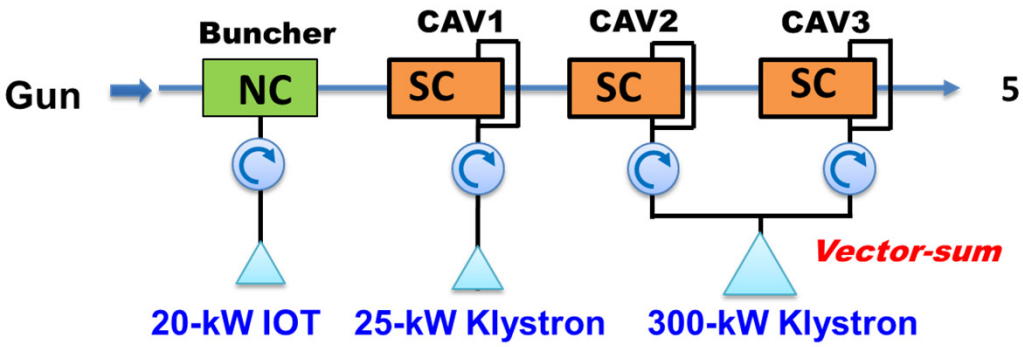
1.3 GHz, CW



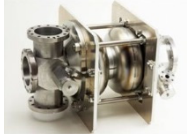
Photocathode
DC gun

Construction of the injector was completed until April 2013.
Beam commissioning has been performed for 2 month.

RF System for Injector



double-feed type



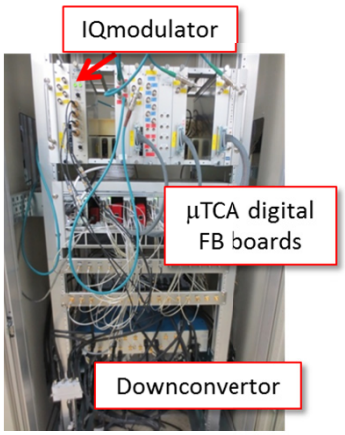
Loaded Q

CAV1: 1.2×10^6

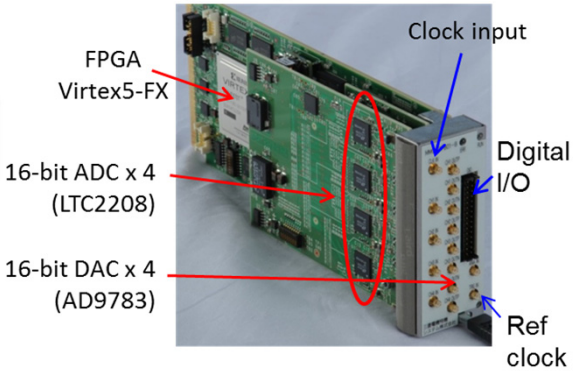
CAV2: 5.8×10^5

CAV3: 4.8×10^5

LLRF Control Room



µTCA digital FB boards



The same boards are employed in STF and SuperKEKB.
Logic is specialized each facility.

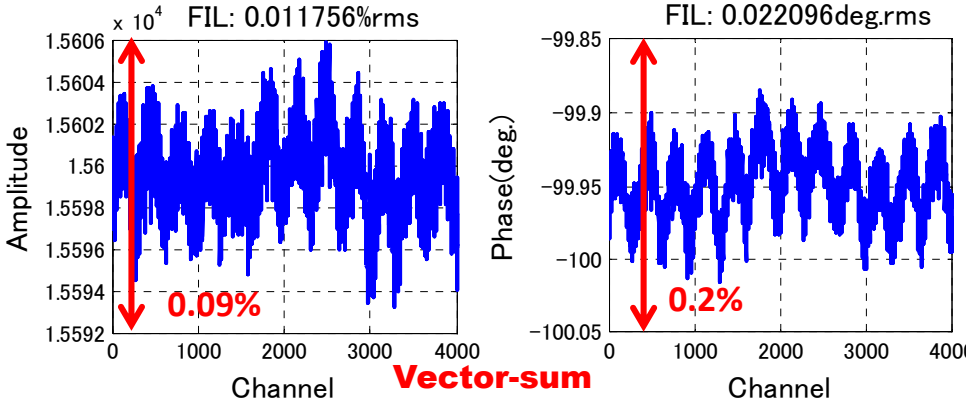
Required Stability: 0.1%rms,0.1deg.rms for cERL
0.01%rms,0.01deg.rms for 3GeV-ERL

MO: 1.3 GHz, LO:1.31 GHz, IF=10MHz
80MS/s by ADC, IQ-FB

Stabilities of Cavity Fields

	BUN	CAV1	CAV2&CAV3
w/o FB	0.5 % rms 0.7° rms	0.05% rms 1.23° rms	1.0 % rms 3.4° rms
FB	**0.05% rms** **0.06° rms**	**0.01% rms** **0.02° rms**	**0.01% rms** **0.02° rms**

Required stabilities of 0.1%rms , 0.1deg.rms

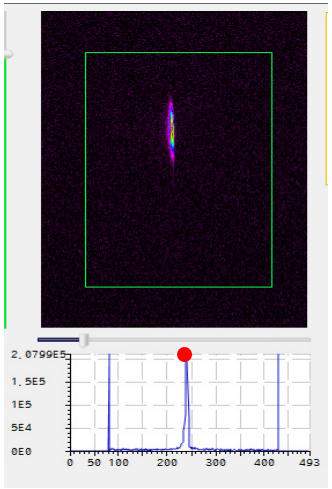


(100kS/s)

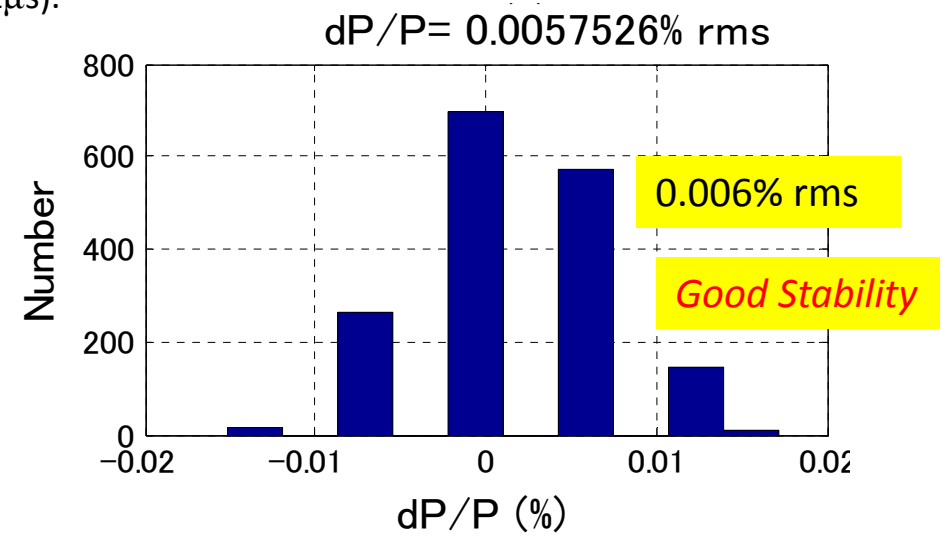
Measurement of Beam Momentum Jitter

To evaluate RF performance, beam momentum jitter was measured with small beam current.

Beam : 5nA (5Hz, 0.77pC/Bunch, 3ps rms, Macro pulse=1μs).
Buncher was not used. (turned off)



Dispersion = 0.82m
@ screen monitor
Resolution = 53.4 μm/pixel
(ΔP/P=6.5e-5)



Measure the peak point of the projection

Talk (Fri 4/10, 09:30 - 09:55) **Dr. QIU, Feng (KEK)**

STF (Superconducting RF Test Facility)

STF is a project to build and operate a test linac with high-gradient superconducting cavities, as a prototype of the main linac systems for ILC.

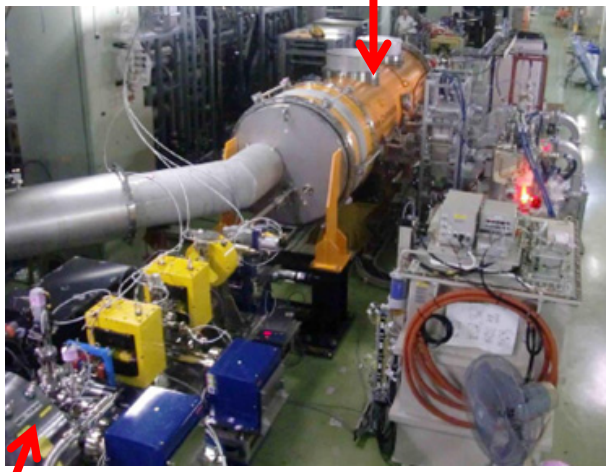
Operation for Quantum Beam Project (QBP) in STF (2011-Mach, 2013)
(Demonstration of high brightness X-ray generation by inverse laser Compton scattering.)

RF: 1.3 GHz, Pulse Operation
Beam: 10mA, 40MeV, 1ms, 5Hz

800 kW klystron in the tunnel

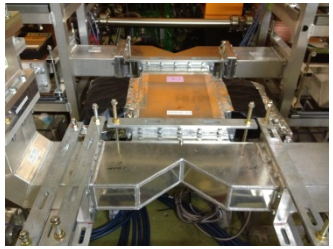
Two superconducting 9-cell cavities. (loaded Q=3e9)

Vectorsum Control



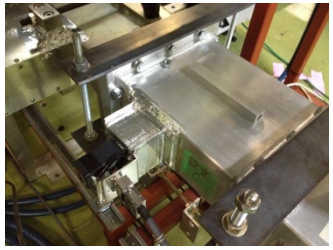
RF GUN

Flexible operation



Variable hybrid (RF power ratio)

Phase shifter (cavity phase)



Reflector just before cavity (QL adjustment)

P_kQ_L Control

P_k: Feed power
Q_L: loaded Q

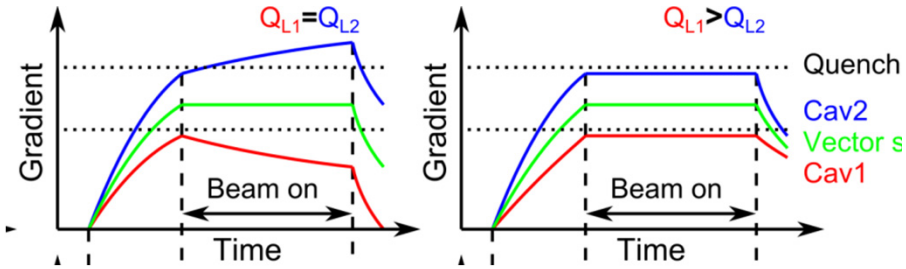
<ILC Requirement>
Vector-sum: 39 cavities
Field Gradient Tolerance: 31.5 MV/m ± 20%
Operation point: under 5% of quench limit for each cavity
Field Stability: 1% for each cavity

2-parameter:
Beam current and Quench limit
-> Pk and Q_L should be optimized

Condition of flat-flattop

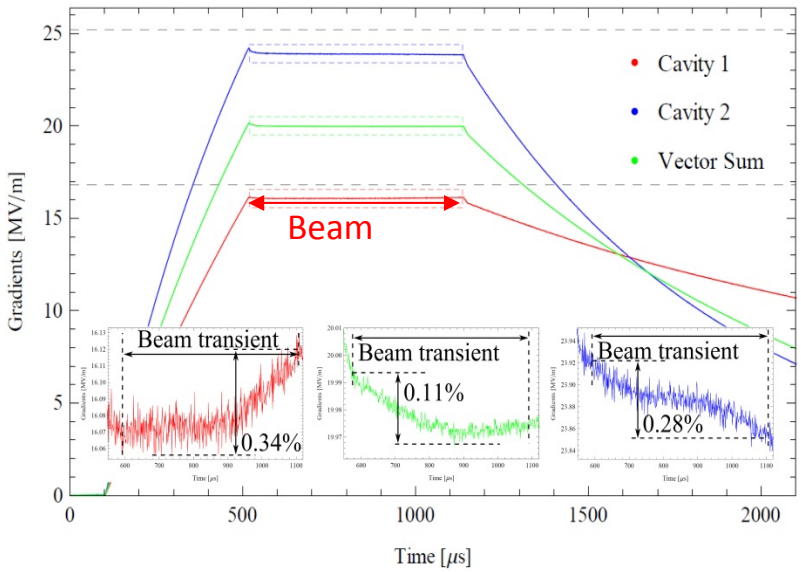
$I_g/I_b=\exp(t_{inj}/\tau)$ $\tau=2Q_L/\omega_0$

I_b=const., $I_{g(1)}$ not eq. $I_{g(2)}$



Target
V_{Cav1} = 16 MV/m
V_{Cav2} = 24 MV/m

Parameters
QL1 : (3e6) → 9e6
QL2 : 3e6
Filling time :410 µs
Beam: 615 µs
current:6.4 mA



Beam	6.4 mA* (60 mins)
Cav1	0.041% rms, 0.042° rms
Cav2	0.031% rms, 0.031° rms
Vector sum	0.009% rms, 0.009° rms

ILC stability requirements are satisfied.
($\Delta A/A$ = 0.07%, $\Delta\phi$ = 0.24)

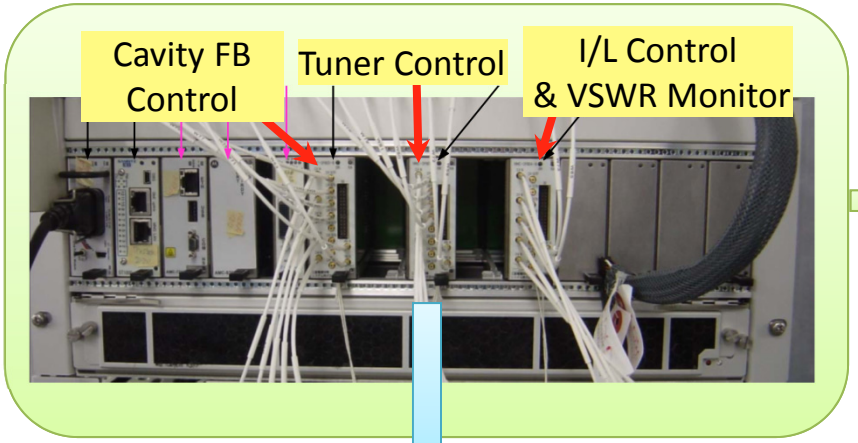
Talk (Fri 4/10 10:40 - 11:05) **Mr. OMET, Mathieu (KEK)**

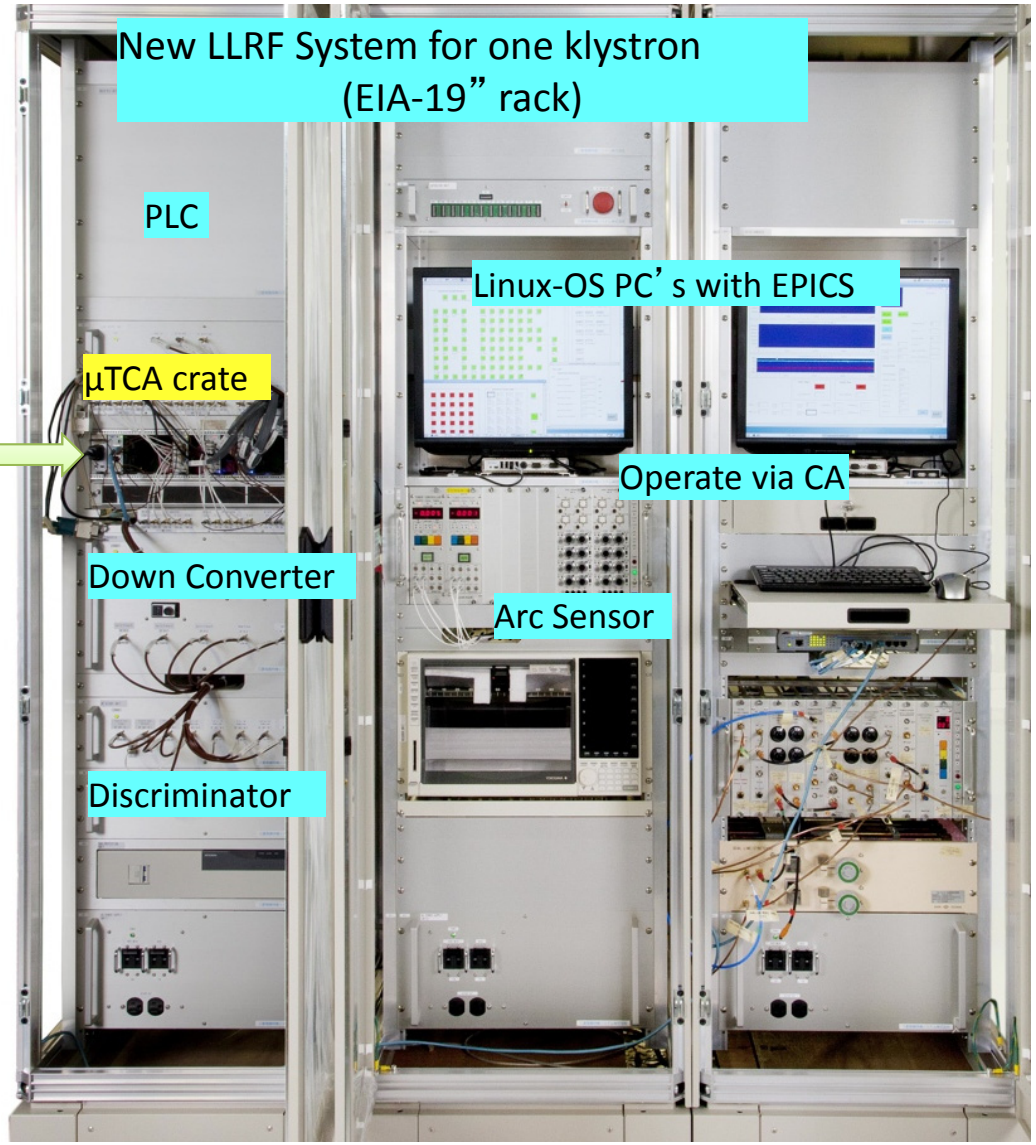
Digital LLRF System for SuperKEKB

The *construction* of the *SuperKEKB* to *upgrade* the KEKB has started from *2010.*

Old analog systems will be replaced step-by-step by new digital system.

µTCA Digital boards

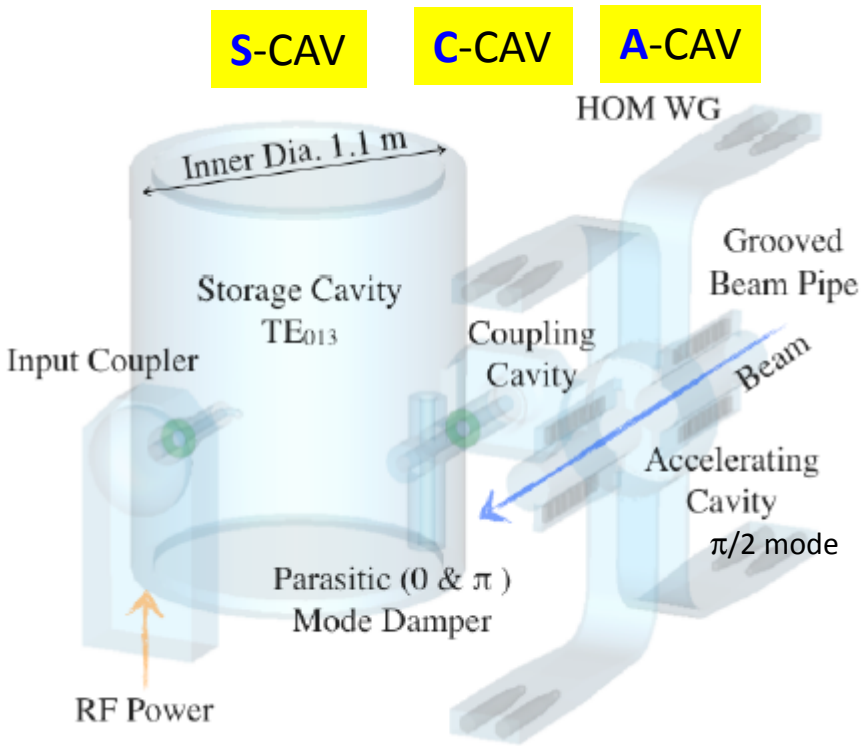




Mitsubishi Electric TOKKI System Corp.

ARES Cavity

(ARES: Accelerator Resonantly Coupled with Energy Storage)



f_{RF}	=	508.887 MHz
$Ua : Us$	=	1 : 9
R / Q	=	15 Ω
Q	=	1.1×10^5 †

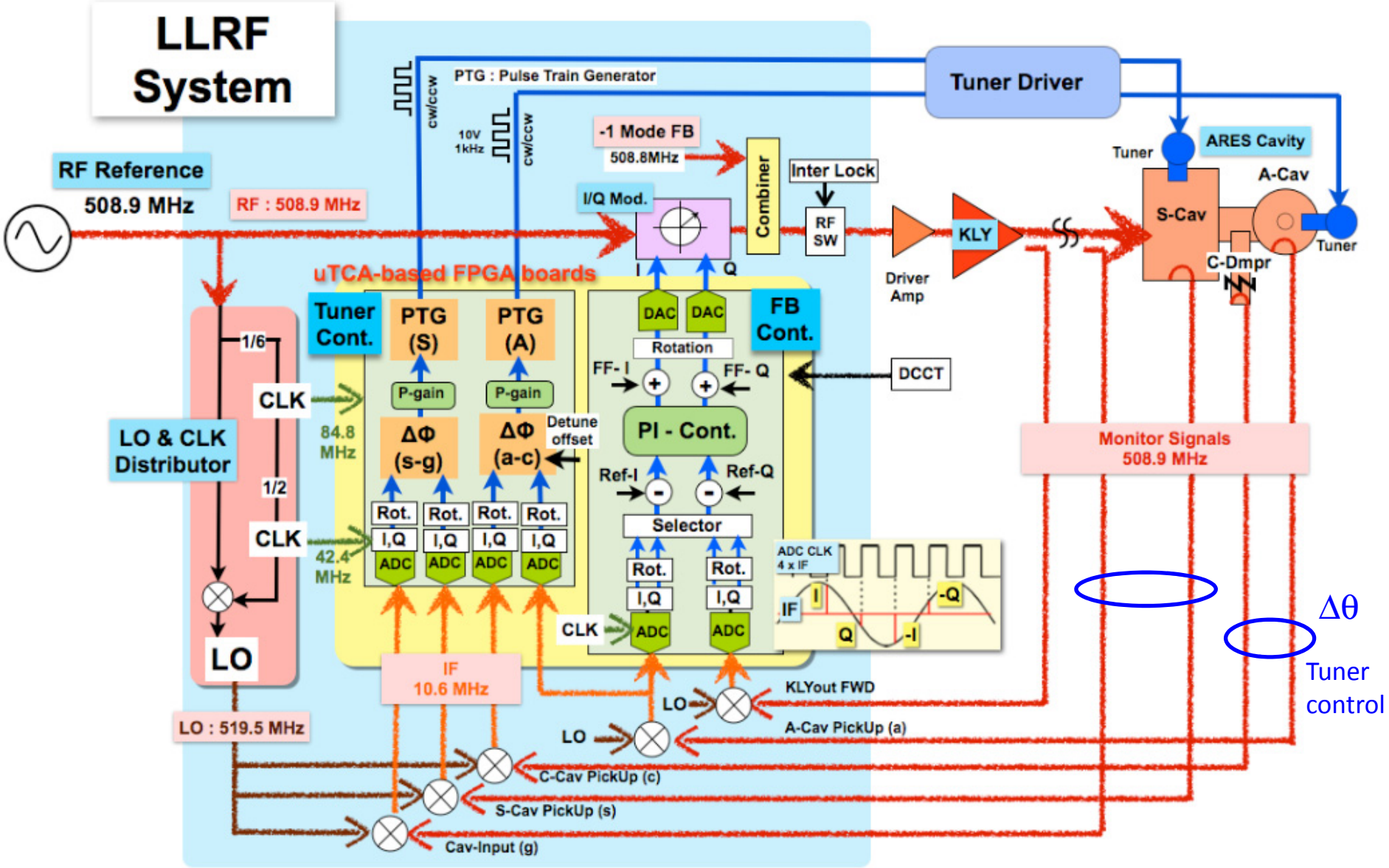
Pc = 150 kW per ARES Cavity generating
Vc = 0.5 MV (KEKB Design)

Stored energy: $U_S = 9\ U_A$ U_A

Effect of beam loading is reduced by an order of magnitude.

$$U_A / (U_A + U_s) = 1/10$$

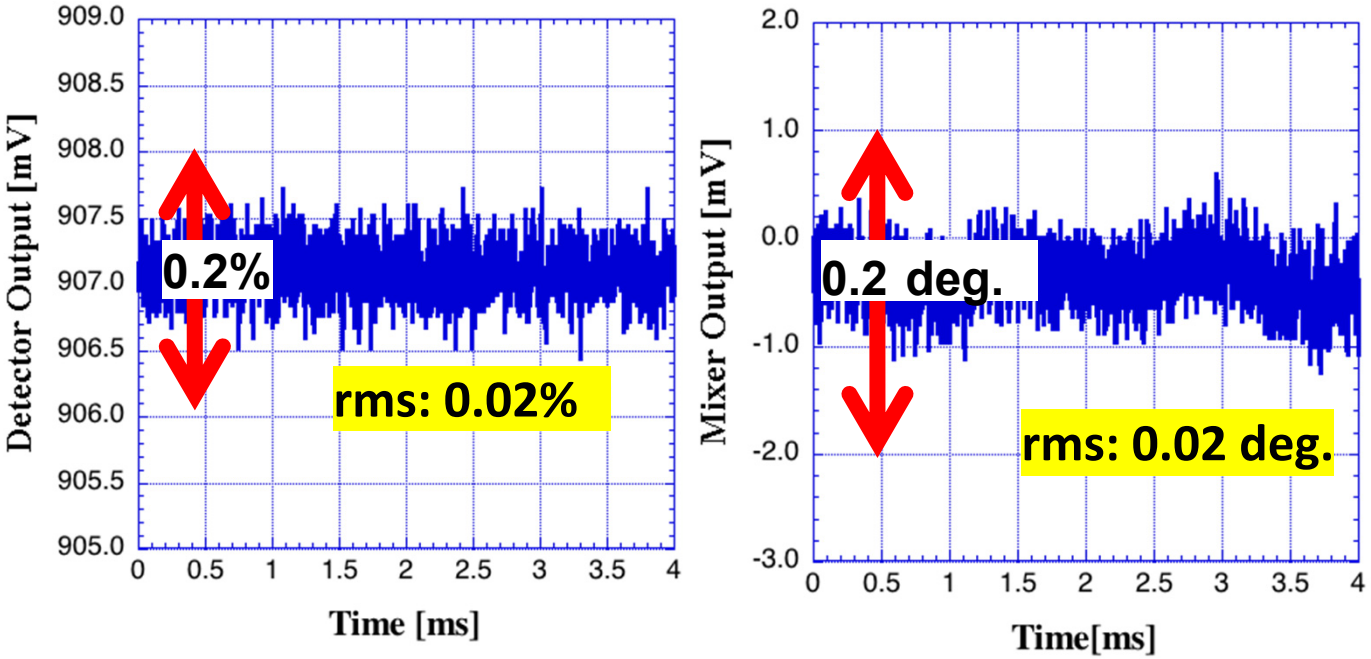
Block Diagram of LLRF System



High Power Test using Digital LLRF System

ARES Cavity :100kW driving with FB control.

Required Stability : 0.2% in amplitude, 0.2deg. in phase.



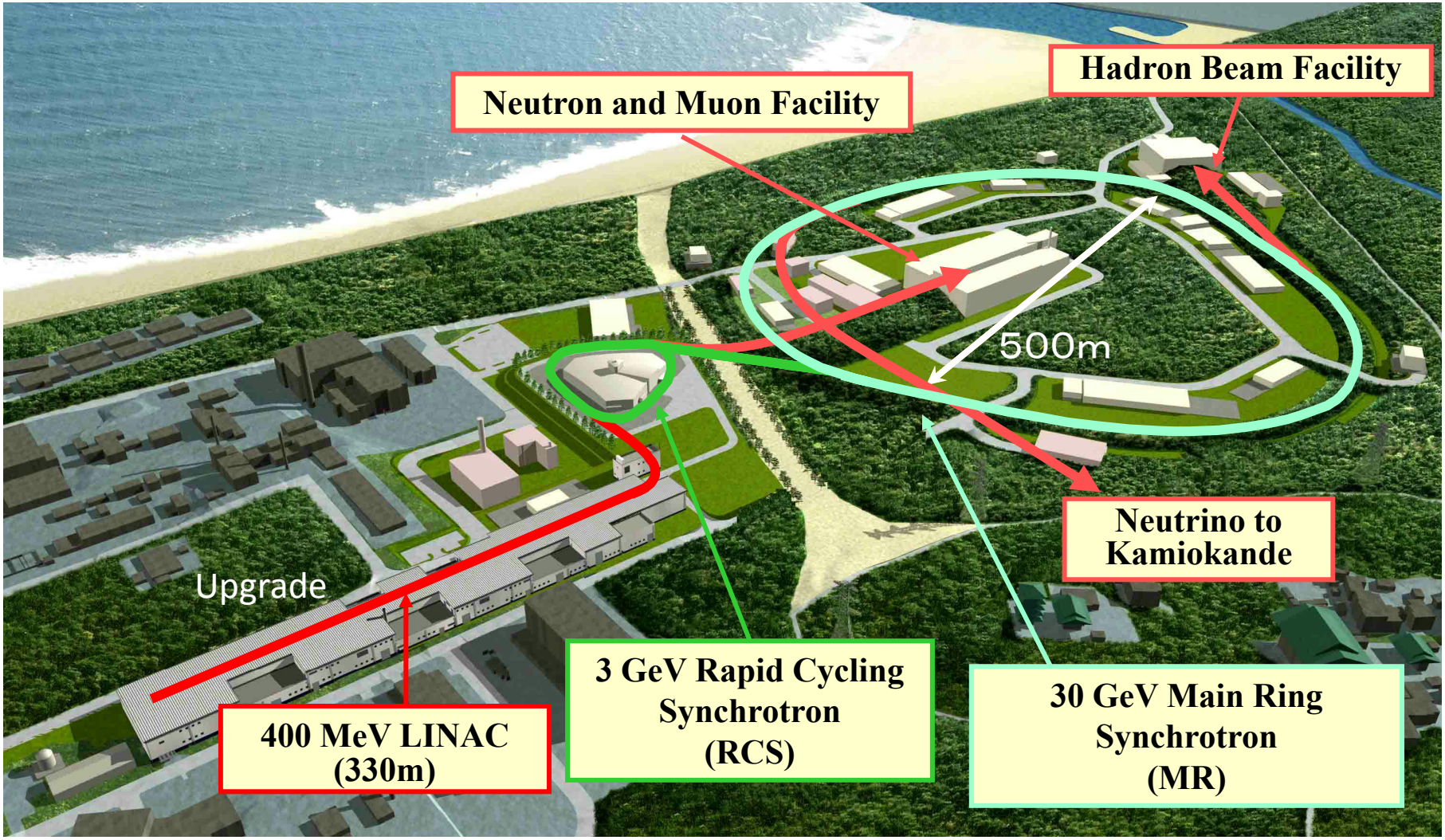
Commissioning of Super KEKB will start from FY 2014

Poster (ID:10) **Dr. KOBAYASHI, Tetsuya (KEK)**

Tokai Campus

J-PARC (Japan Proton Accelerator Research Complex)

*Joint project of KEK and JAEA(Japan Atomic Energy Agency)



LINAC Energy Upgrade

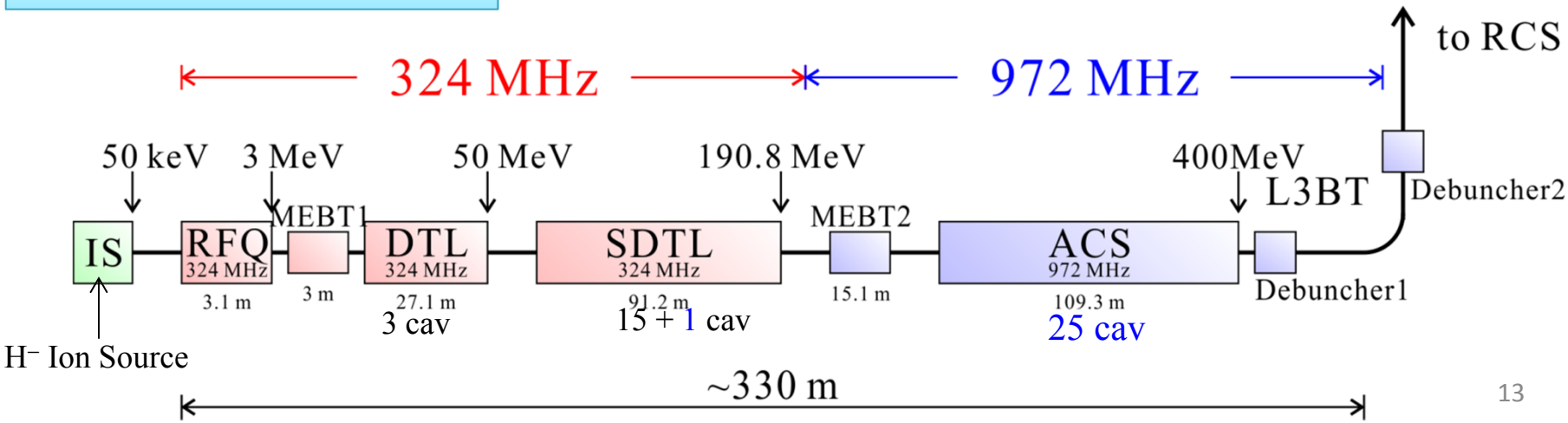
Energy changed to 400 MeV to increase beam intensity.
The new ACS cavities are installed and operated at a frequency of three times higher than the current one.

- Kinetic Energy : **181 MeV → 400 MeV**
- Peak Current : **30 mA → 50 mA**
- Acc Freq. : **324 MHz + 972 MHz**
- Pulse Width : 500 μs (Beam)
  650 μs (RF)
- Repetition : 25 Hz

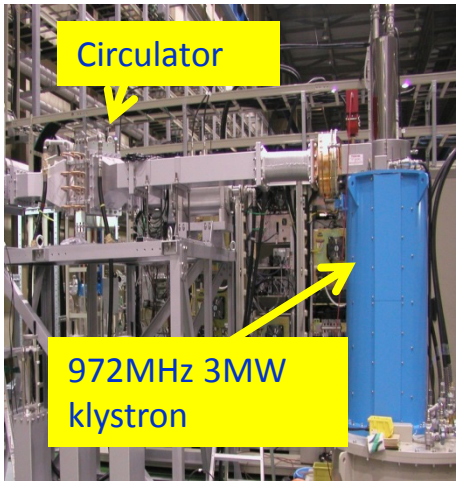
Installation of ACS started from May 2013

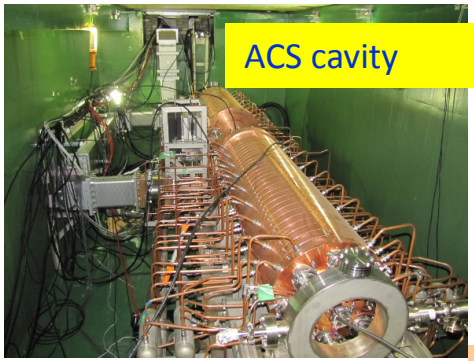
2014~ : Start 400 MeV Operation

3 GeV RCS-ring aims 1 MW

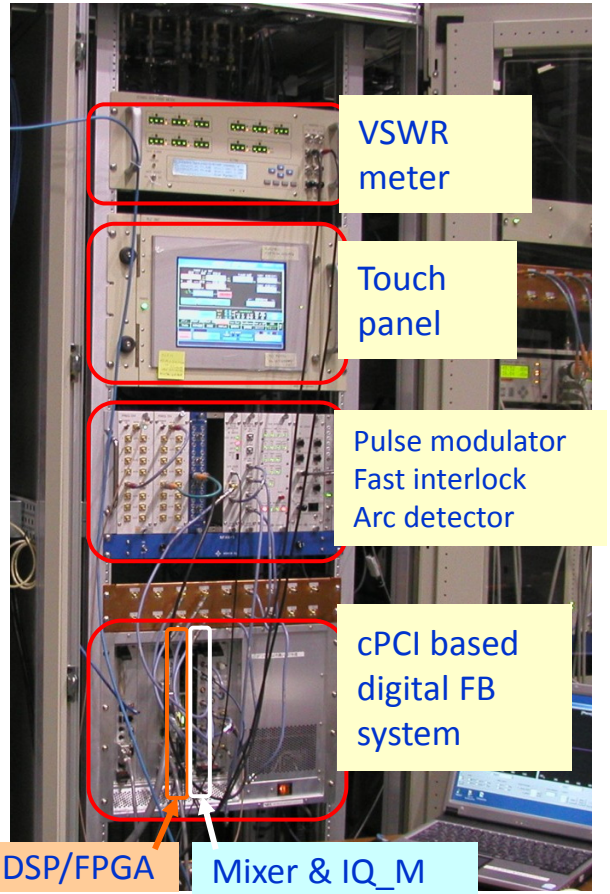


High power test of ACS cavities using 972MHz LLRF systems

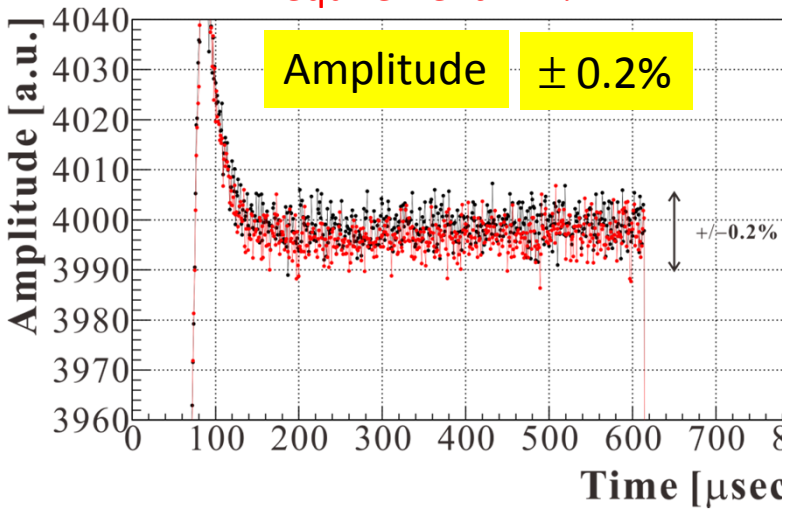




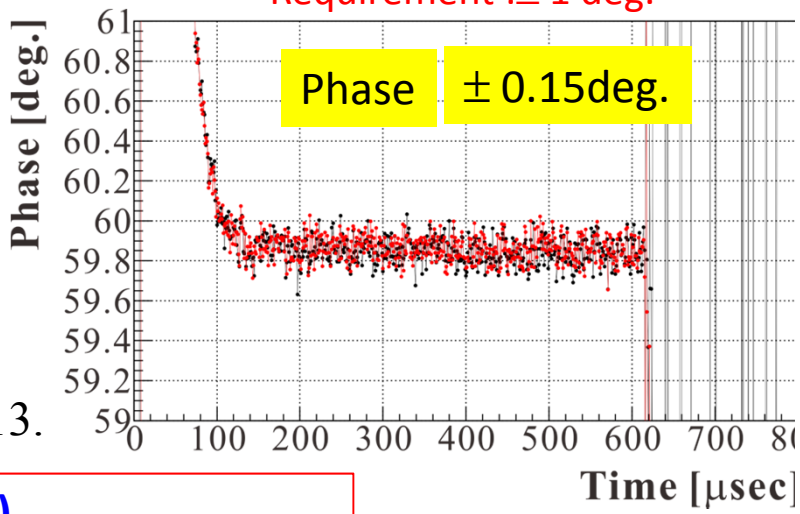
Digital feedback system



Requirement :± 1%



Requirement :± 1 deg.



High power conditioning will be started in November 2013.

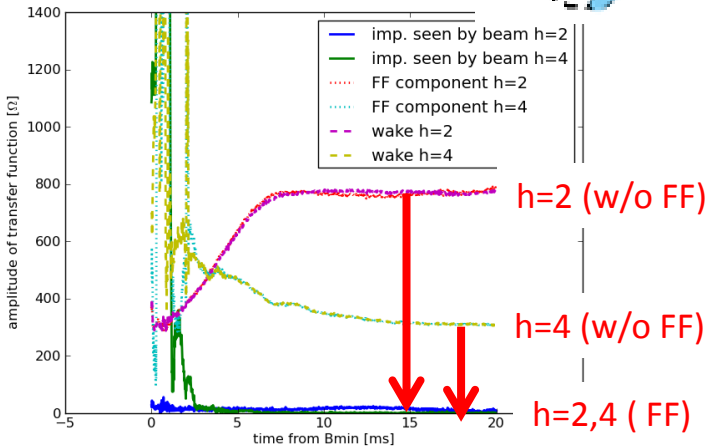
Poster (ID:12) **Dr. FANG, Zhigao (KEK)**
Poster (ID:75) **Dr. FUTATSUKAWA, Kenta (KEK)**

Multi-harmonic Beam Loading Compensation by Feedforward

Harmonic number = (RF freq.) / (Revolution freq.)

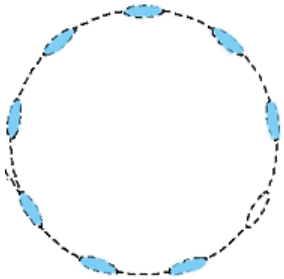
3-GeV RCS: Rapid cycling Synchrotron

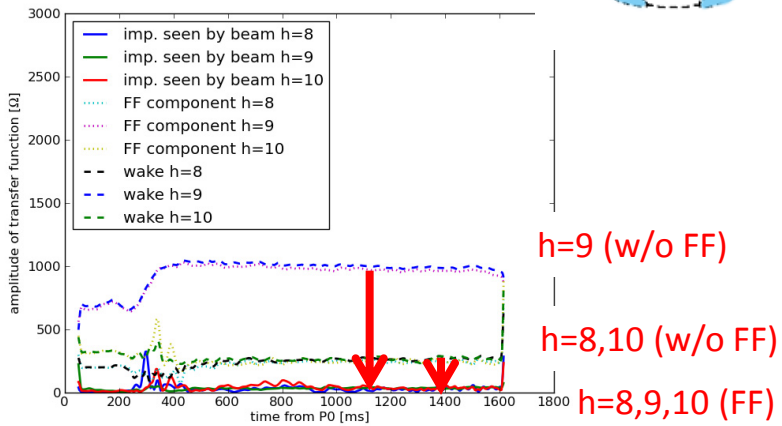
***h* =2** Beam: 2 bunch

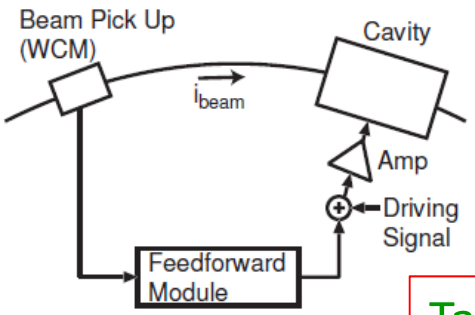


30-GeV MR: Main Ring

***h* =9** Beam: 8 bunch







Multi-harmonic beam loading in wide-band cavities are compensated well by "multi-harmonic feedforward system".

Talk (Thu 3/10, 11:25 - 11:50) **Dr. TAMURA, Fumihiko (JAEA)**

Presentation List

Oral Presentation

Thu 3/10, 11:25 - 11:50 **Dr. TAMURA, Fumihiko (JAEA)**
"Multiharmonic beam loading compensation in the **J-PARC synchrotrons**"

Fri 4/10, 09:30 - 09:55 **Dr. QIU, Feng (KEK)**
"Performance of CW superconducting cavity at **ERL** test facility"

Fri 4/10 10:40 - 11:05 **Mr. OMET, Mathieu (KEK)**
"Development and Test of Digital LLRF Control Procedures and Techniques in Scope of **ILC**"

Poster

ID:10 **Dr. KOBAYASHI, Tetsuya (KEK)**
"Progress in development of new LLRF Control and RF Reference System for **SuperKEKB**"

ID:11 **Dr. KOBAYASHI, Tetsuya (KEK)**
"Development of ARES Cavity Simulator"

ID:12 **Dr. FANG, Zhigao (KEK)**
"Present Status and Improvement Plan of **J-PARC Linac** RF Control Systems"

ID:75 **Dr. FUTATSUKAWA, Kenta (KEK)**
"LLRF Parameters Tuning for the 972 MHz System at **the J-PARC Linac**"