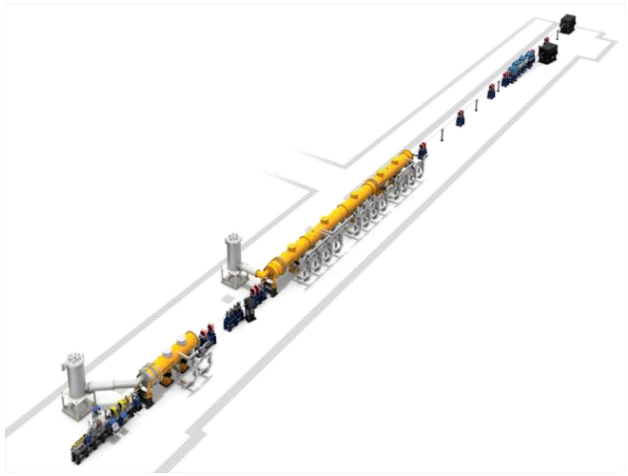
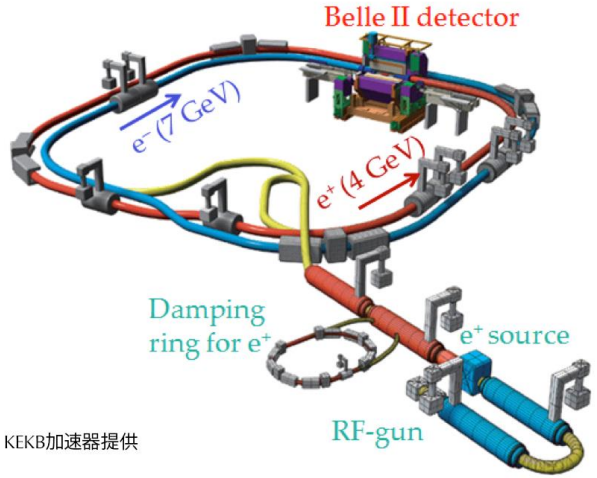
KEK Lab Talk

Low Level RF Workshop 2022

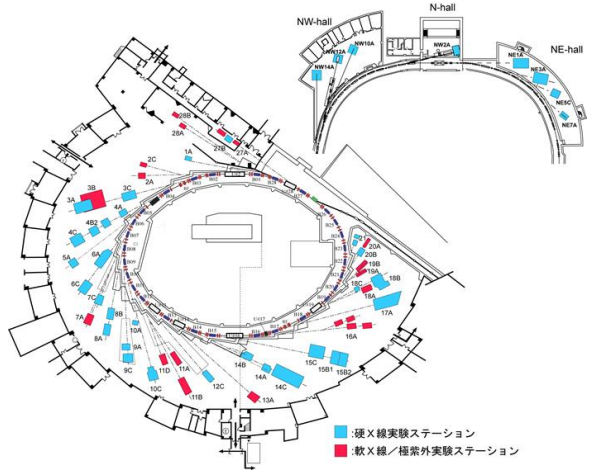
9-13 Oct 2022, Brugg-Windisch, Switzerland



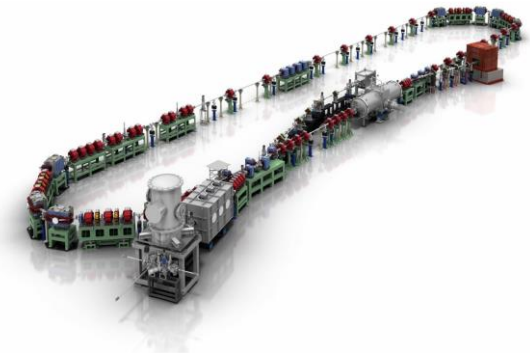
STF-2



SuperKEKB
- Injector linac
- SuperKEKB ring



Photon Factory (PF)



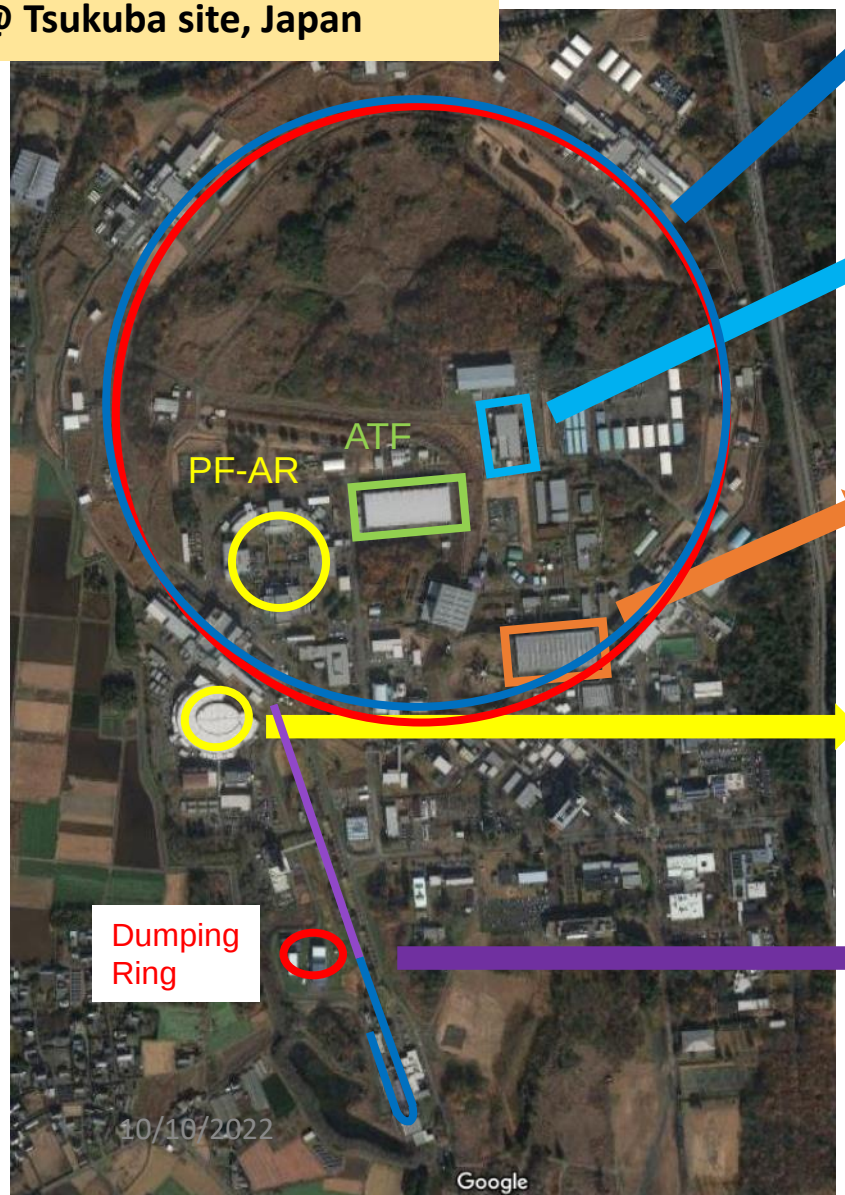
cERL

Toshihiro, MATSUMOTO

(KEK, Accel.)

Accelerators at KEK, Tsukuba site

High Energy Accelerator Research Organization (KEK) @ Tsukuba site, Japan



SuperKEKB

- Asymmetry double ring collider of e^- (7 GeV, HER) & e^+ (4 GeV, LER)
- 509 MHz RF, NC & SC, CW op.

STF (Superconducting RF Test Facility)

- R&D facility for ILC RF system
- 1.3 GHz RF, NC(RF-gun) & SC, Pulse op.

cERL (Compact Energy Recovery Linac)

- Test facility for ERL technology and its application for industrial use
- 1.3 GHz RF, SC, CW op.

PF (Photon Factory)

- Synchrotron Radiation Facility (3rd Generation): 2.5-3 GeV
- 500 MHz RF, NC, CW op.

LINAC

- Linear accelerator for four rings (HER, LER, PF-AR, PF)
- 114/571/2856 MHz RF, NC, Pulse op.

Recent Progress in SuperKEKB

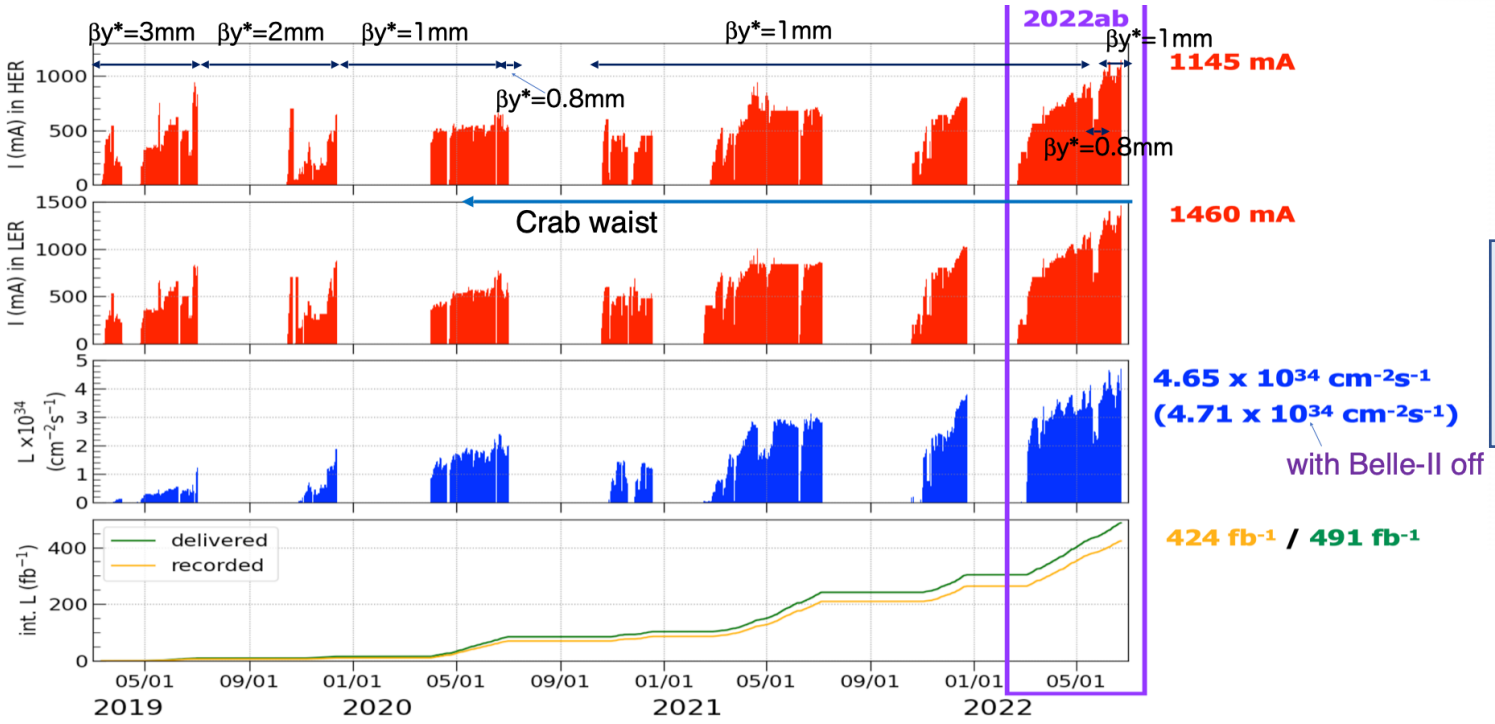
- Target Peak Luminosity

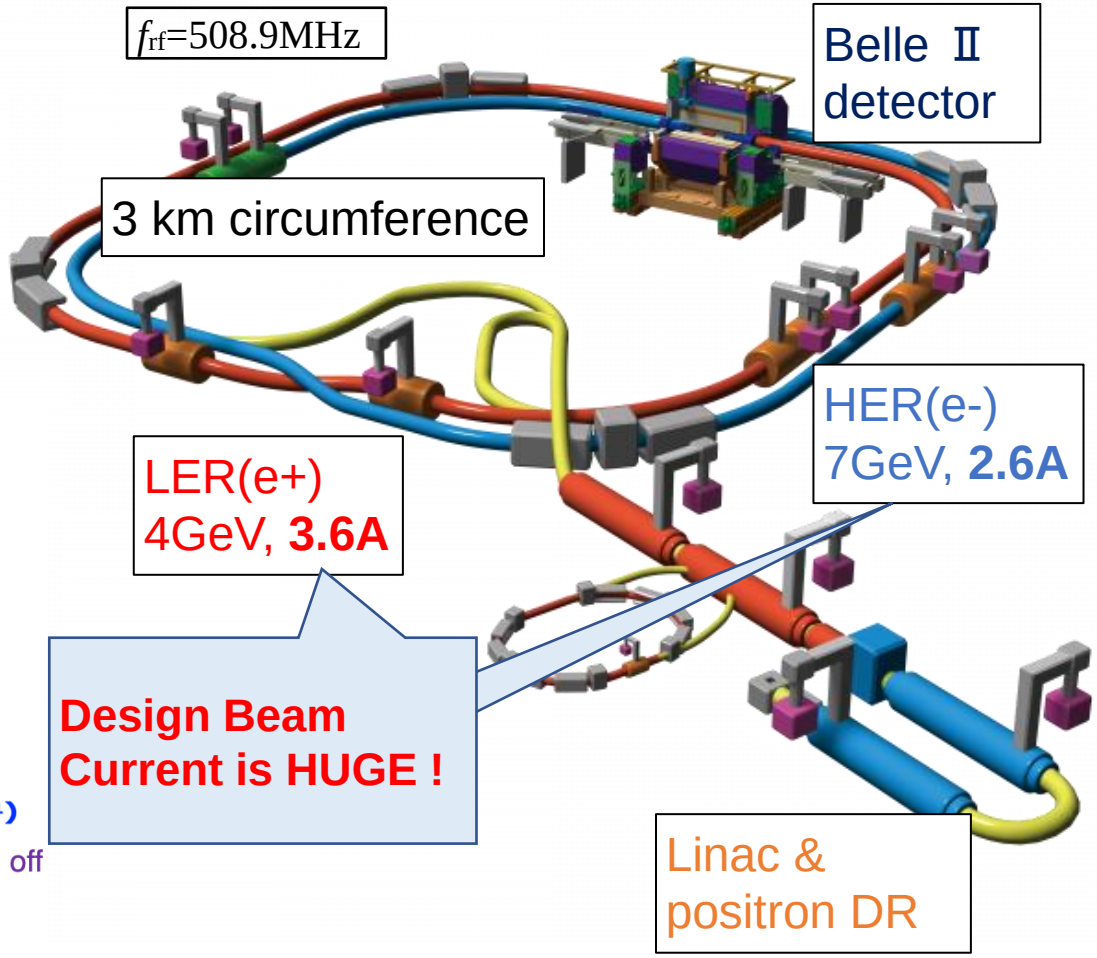
  8 x 10^{35} /cm^2/s = 800 /nb/s

  40 times of KEKB achieved

Achieved Peak luminosity of 4.65×10^{34} /cm^2/s

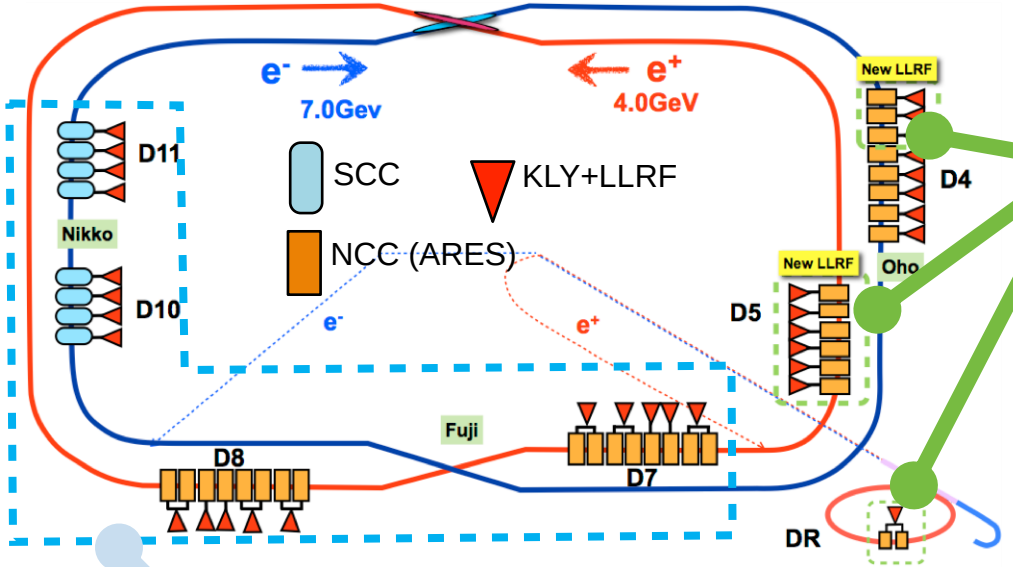
1.14 A for HER / 1.46 A for LER in June 2022





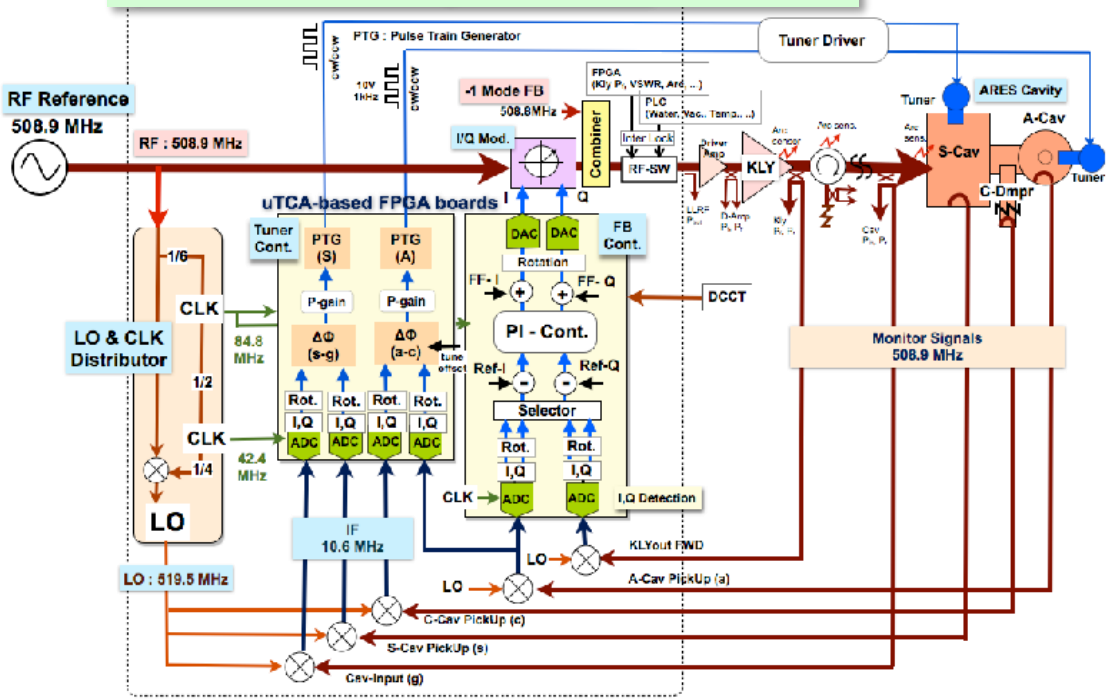
Status of LLRF Control System

- Both of Superconducting (SCC) & Normal Conducting Cavities (ARES cavity) are used.
- About 30 klystron stations are working in the two rings.



About 10 RF stations for ARES cavity are operated by MTCA.0-based digital LLRF systems.
They are successfully working in high beam current operation.

µTCA-based Digital LLRF for ARES



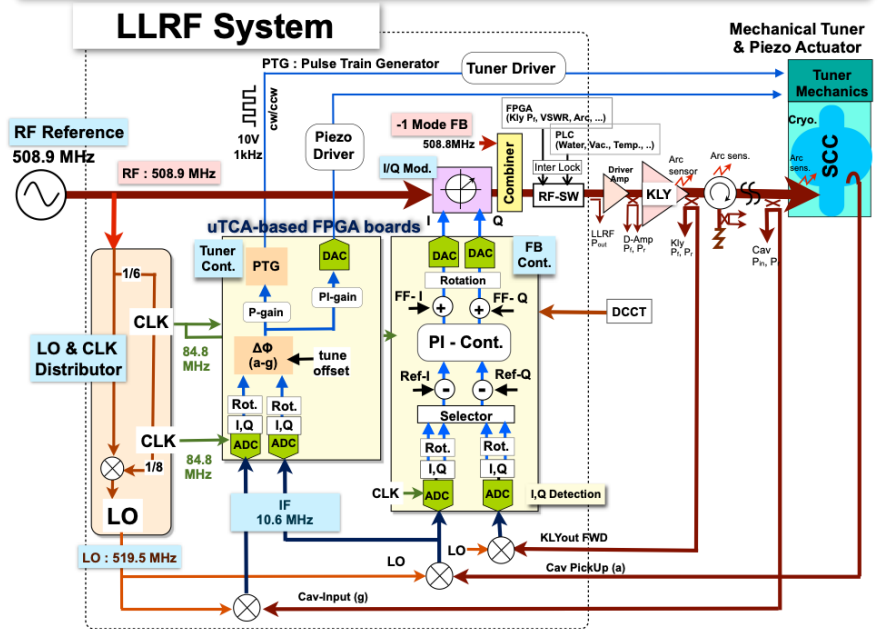
SCC stations and some ARES stations are still operated by old analog LLRF systems of KEKB (CAMAC is still used for remote control).

Prototype of Digital LLRF for SCC

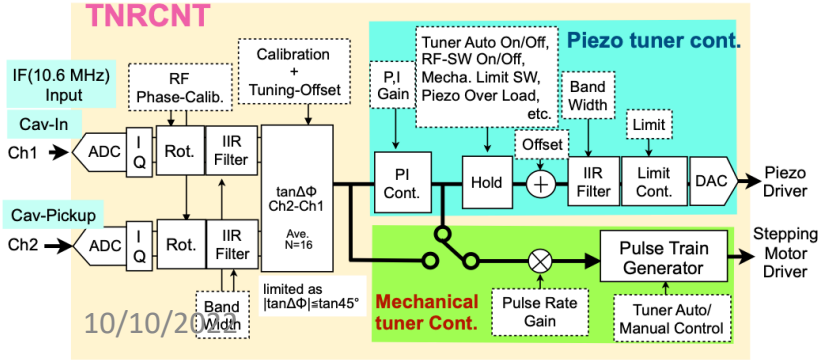
T. Kobayashi, *et al.*, Proc. of PASJ2022, WEP048.

- Prototype of MTCA.0-based digital LLRF system for SCC was newly developed.(Base hardware is the same for ARES)
- High power test was successfully demonstrated at a test station with a spare SCC in 2022.

MTCA.0-based Digital LLRF for SCC

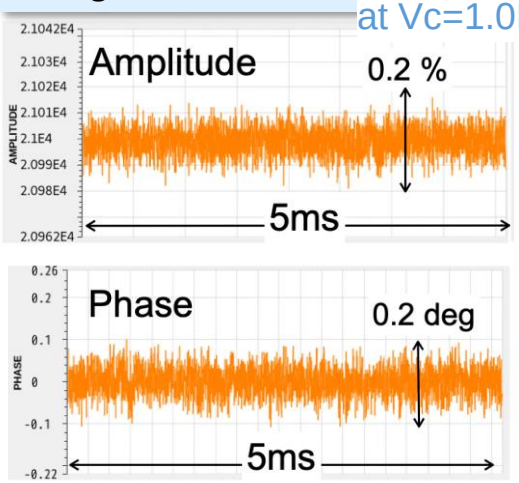


FPGA Logic of Tuner Control including Piezo Control

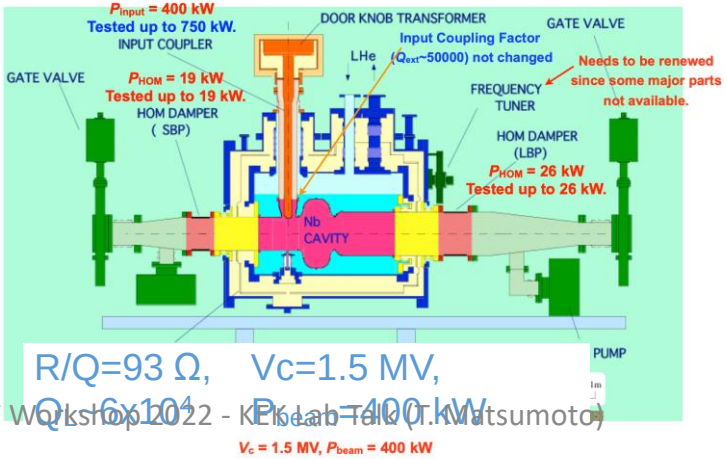


Stability of Vc-Regulation in High Power Test

at Vc=1.0MV



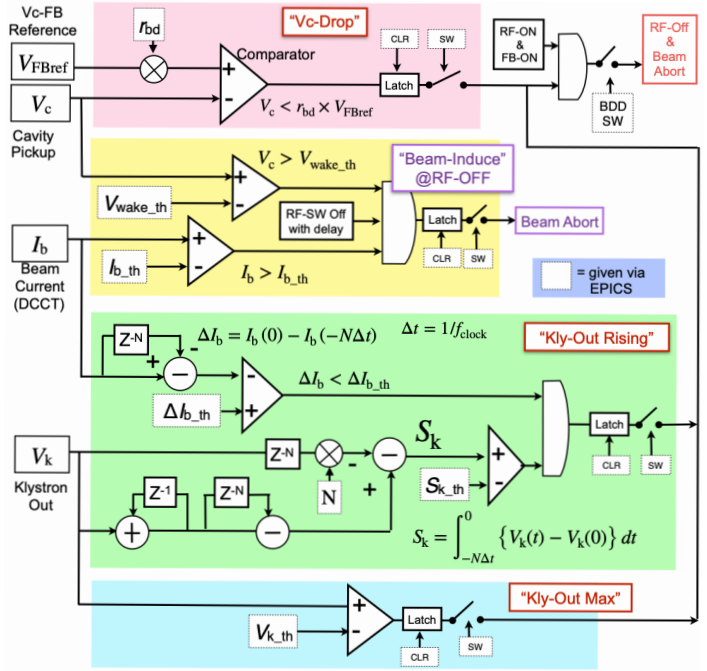
SCC for SuperKEKB



R/Q=93 Ω, Vc=1.5 MV,
Q0=6x10^9, Pb=400 kW

New Functions for SCC stations (Cavity Breakdown Detector for SCC)

FPGA Logic of Breakdown Detector for fast RF-Interlock

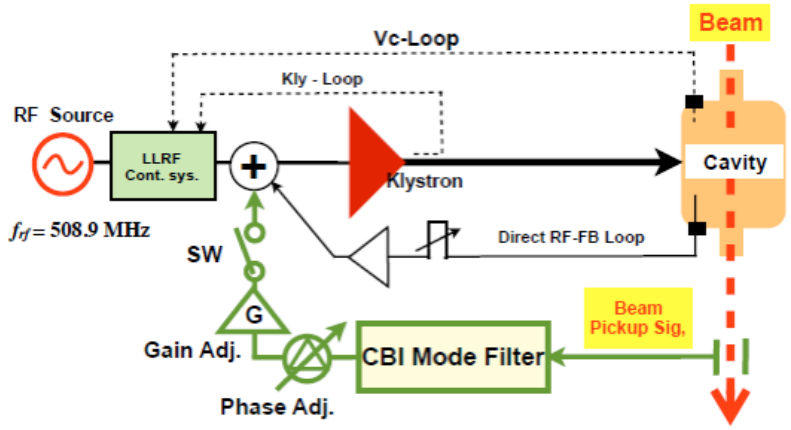


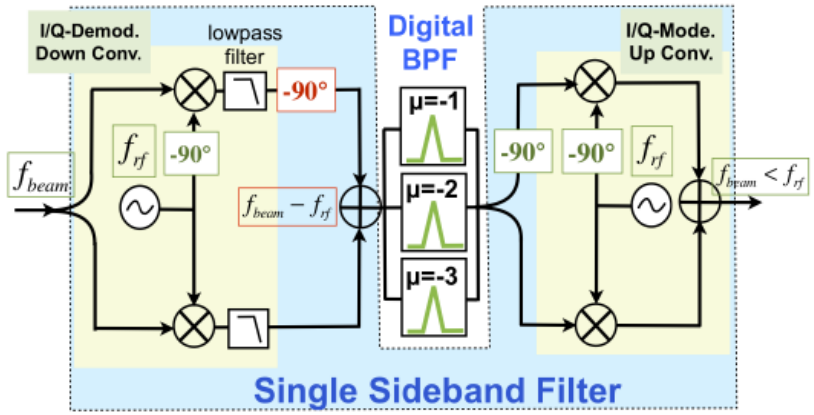
3 methods of the breakdown detection are implemented.

1) Vc-Drop, 2) Kly-Out Rising, 3) Kly-Out Max

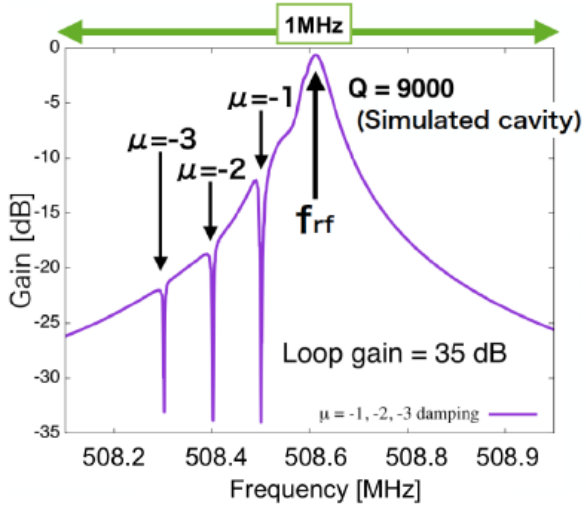
Damper System against High Current Instability

- **Damper System for Coupled Bunch Instability (CBI)**
  Threshold currents for μ=-1 mode are quite below the design current.



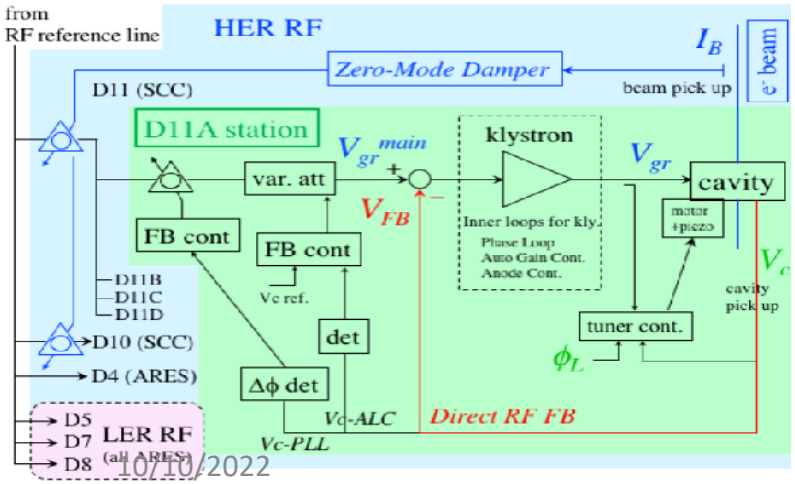


FB loop test result of the CBI mode filter for a simulant cavity



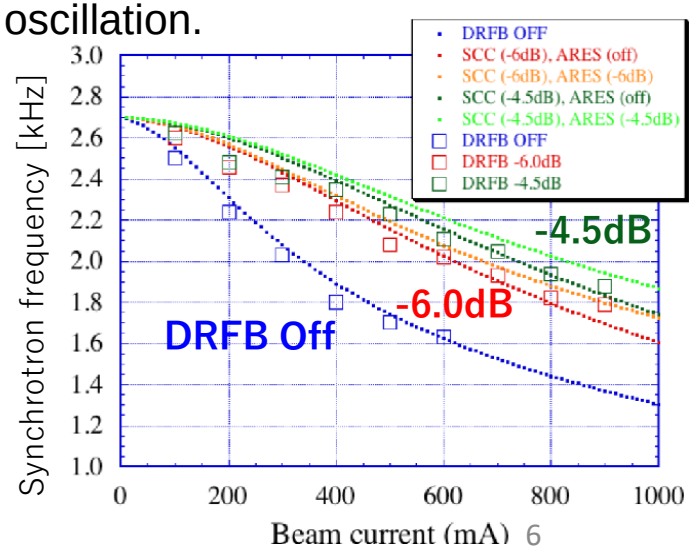
K. Hirosawa, *et al.*, NIM A 953, 163007, 2020.

- **Coherent Oscillation (zero-mode) Instability**
  In high current operation, synchrotron frequency reduction is expected due to coherent oscillation.



To mitigate the beam-loading effect, **Direct RF feedback (DRFB)** and **Zero-mode damper (ZMD)** are working.

Calculated and measured coherent oscillation frequencies in **actual HER (ARES + SCC) with DRFB Off, -6.0dB and -4.5dB**



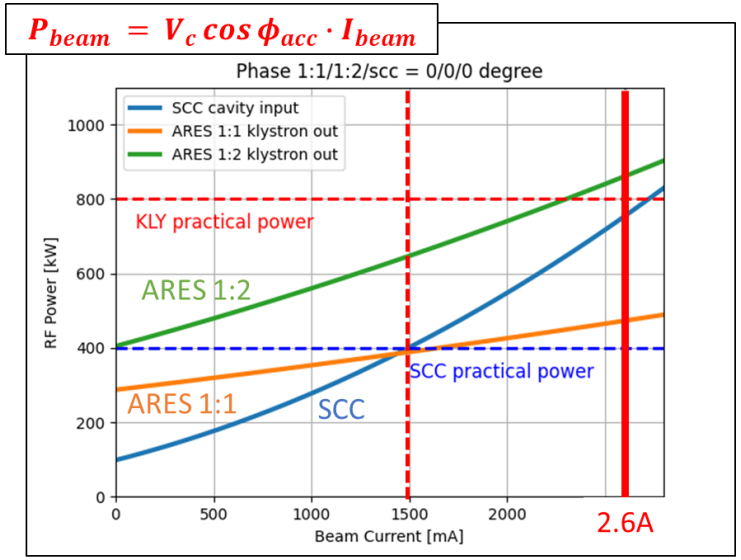
K. Akai, *et al.*, Proc. of PASJ2020, WEPP35.

Manipulation for High Beam Current

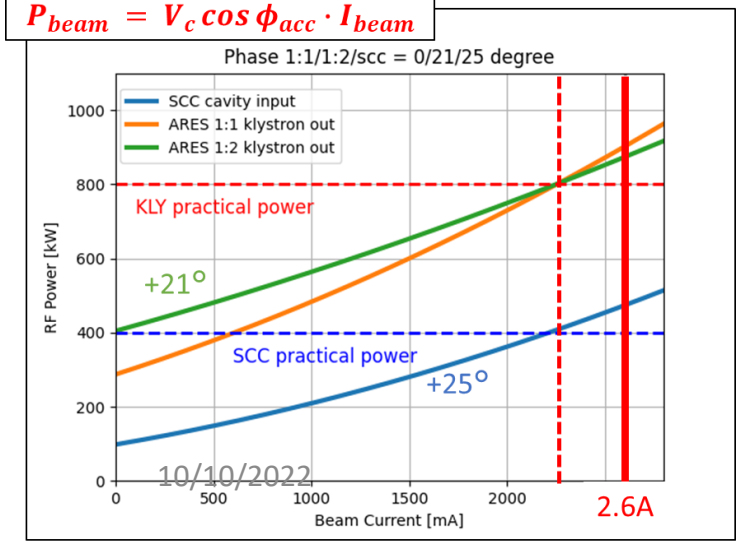
Optimization of RF phase and beam loading distribution among RF stations in SuperKEKB

⇒ Talk S. Ogasawara; Th

$P_{beam} = V_c \cos\phi_{acc} \cdot I_{beam}$

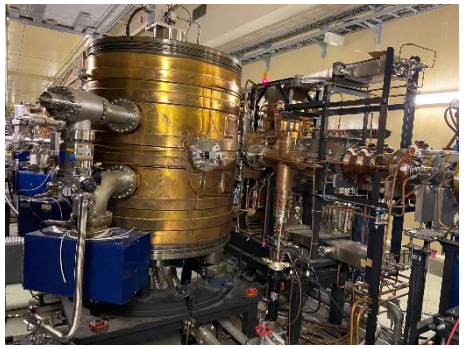


$P_{beam} = V_c \cos\phi_{acc} \cdot I_{beam}$

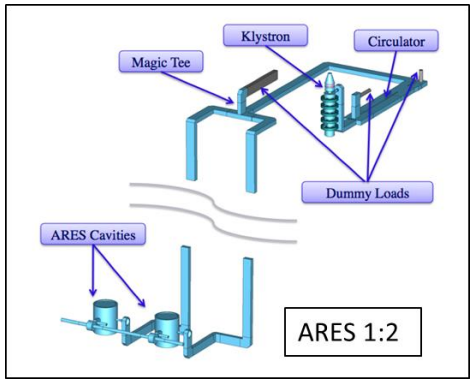


In SuperKEKB, there are three types of RF sources for beam acceleration.
(SCC / ARES 1:1 / ARES 1:2)

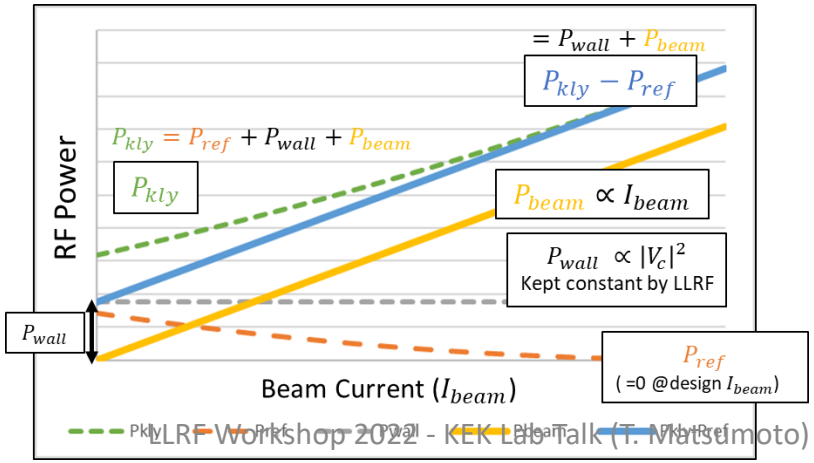
SCC (Only HER)



ARES (HER,LER)



RF power exceeds the limit @ I_{beam} << design with equal ϕ_{acc} condition.
For high beam current operation, ϕ_{acc} of each cavity should be optimized without changing beam collision timing.

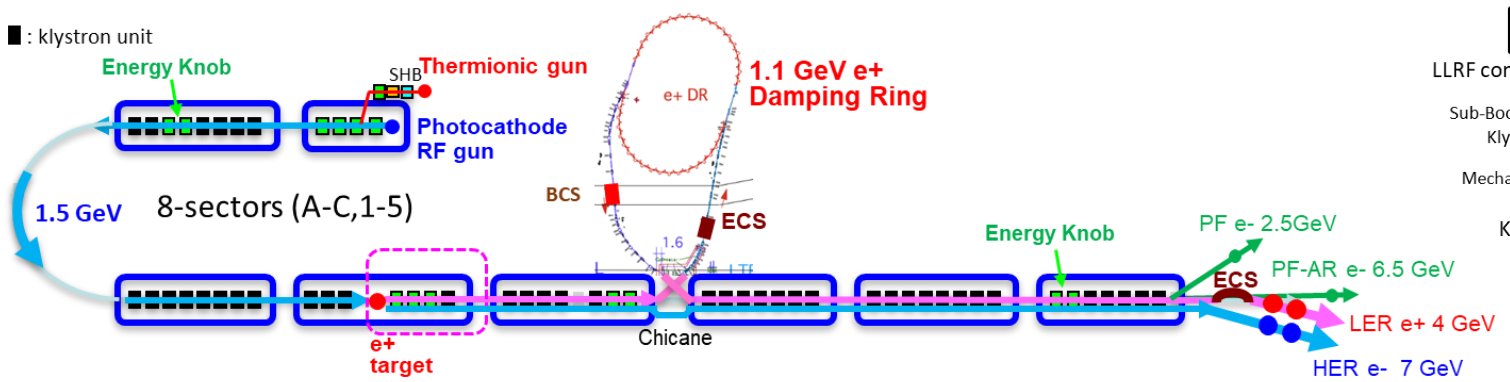


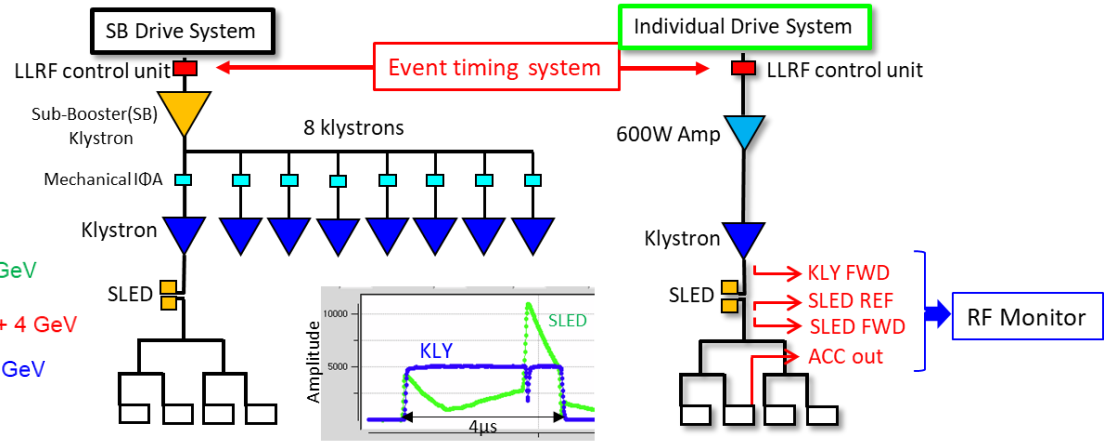
ϕ_{acc} for each cavity is evaluated by use of linear fit of $P_{beam} - I_{beam}$ with sufficient accuracy.

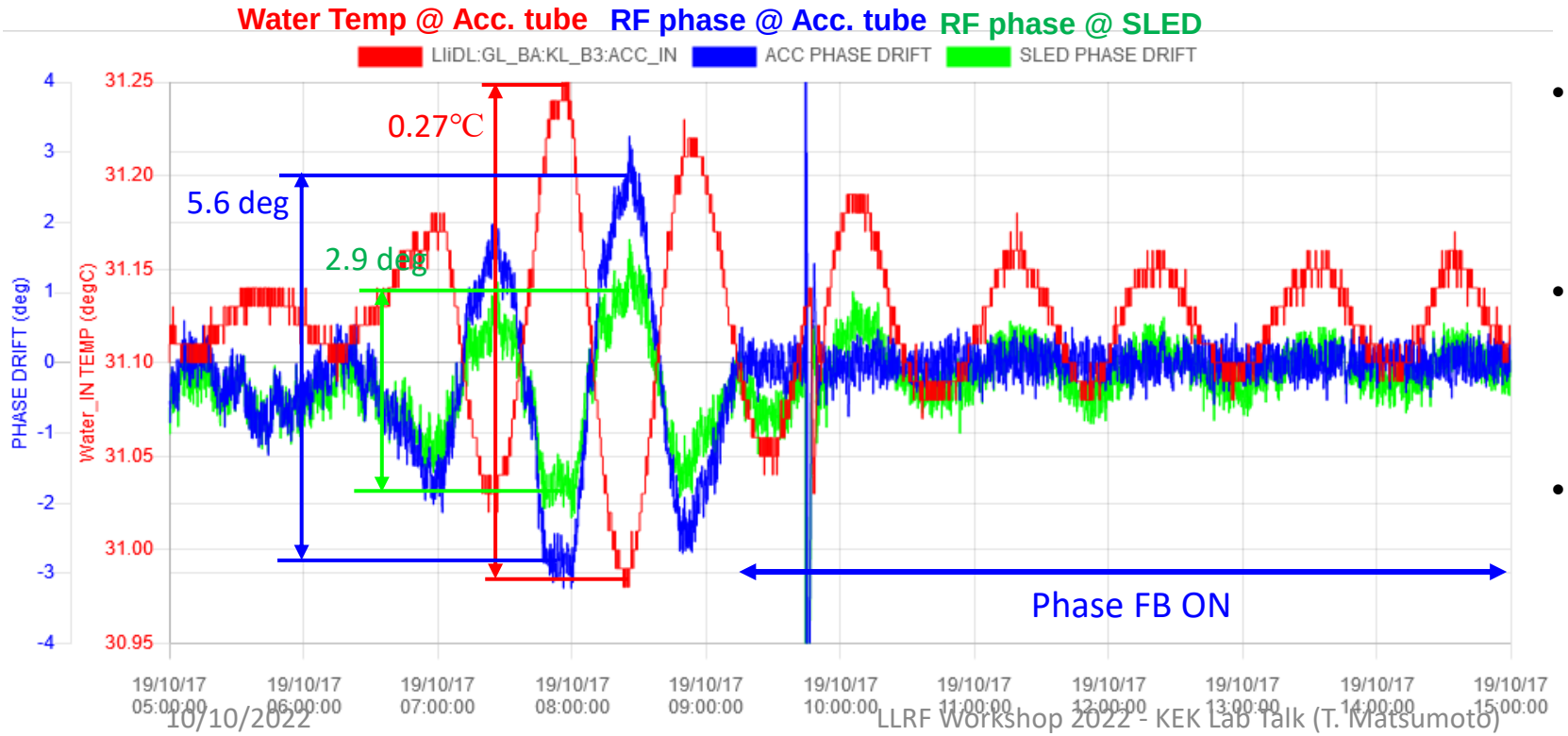
The procedure of optimum RF beam phase and beam loading adjustment for each RF station will be shown in his presentation.

RF Phase Feedback at KEK LINAC

T. Miura, *et al.*, Proc. of PASJ2021, MOP046.







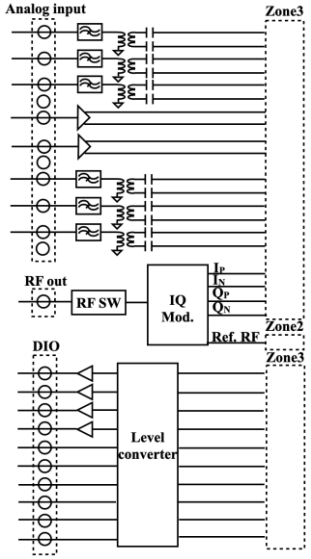
- During recovery from HV down, the cooling water temperature to the accelerator tube becomes unstable, causing the beam phase to fluctuate.
- RF phase feedback to keep RF phase of NIM (Non-Injection-Mode) mode at the exit of the accelerator tube (ACC out) as constant is installed.
- This shortens the recovery time after HV down interlock action and contributes to stable operation of SuperKEKB.

Prototype of Digital LLRF for PF

D. Naito, *et al.*, Proc. of PASJ2022, WEP044.

Plan to replace analog LLRF system with digital LLRF system based MTCA.4 standard.

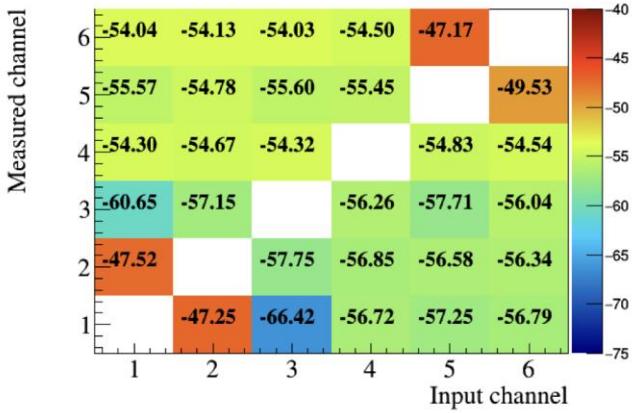
Evaluation of dedicated µRTM boards



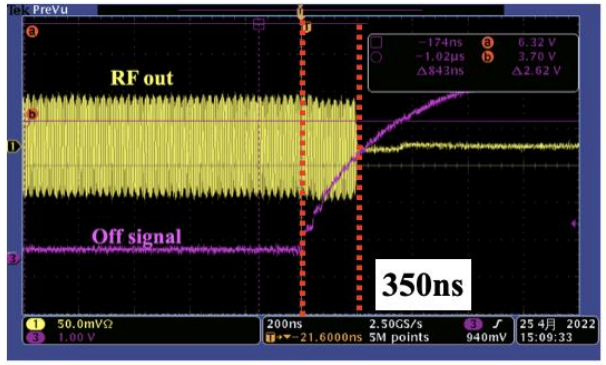
<Cavity parameters>

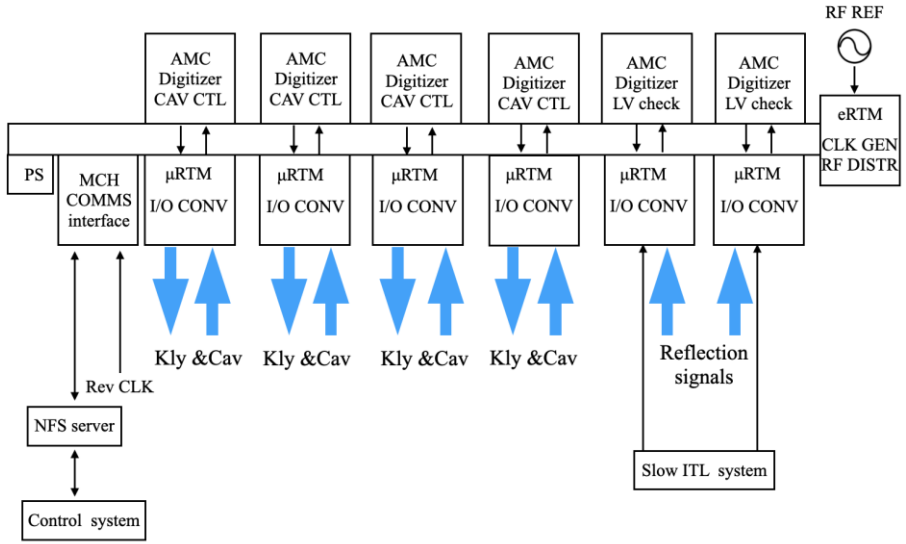
Number of cavities	4
Radio frequency	500.1 MHz
Harmonic number	312
Cavity voltage per cavity	0.425 MV
Beam current	450 mA
Klystron power per cavity	72 kW

Inter-channel crosstalk



Evaluation of interlock response





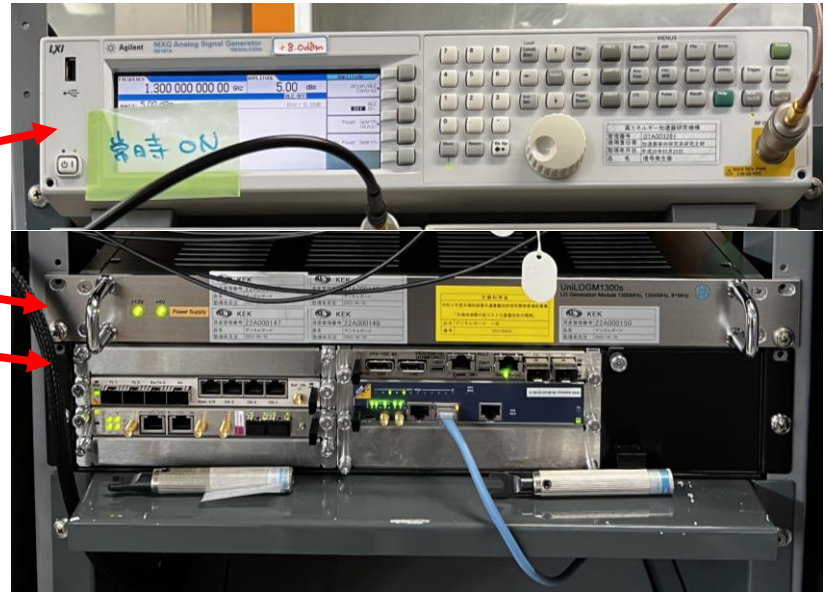
Schematic view of the new LLRF system

High power test using klystron is planned for the second half of FY2022.

Upgrade of Vertical Test (VT) Stand RF System in STF

By courtesy of M. Omet (KEK, iCASA)

- iCASA performs VTs in the scope of SRF cavity R&D
- Replacement of current >20-year-old all analog RF system
- Modern digital LLRF system
- Single cavity control (CW, self-excited loop (SEL))
- Collaboration between DESY MSK & DESY MSL and KEK iCASA
- Installation of system at the STF VT stand after passing initial tests
- Upgrade to self-excited loop (SEL) firmware
  - Direct loop-back operation with amplitude and phase feedback activated successfully tested
- First VT of 9-cell cavity at 2 K
  - Measurement of π-mode until quench at 38.3 MV/m
  - Some issues found, which need to be addressed
- Next steps
  - Development and commissioning of high-level automation software
  - Start of production use planned for January 2023



2U 6-Slot MicroTCA.4 crate

Summary

- In SuperKEKB, the peak luminosity of 4.65×10^{34} /cm^2/s with 1.14 A for HER and 1.46A for LER was achieved. Damper system was included in LLRF system and was effective to stabilize the operation under high beam current.
- The optimum procedure of RF phase and beam loading was developed for further high beam current operation.
- In LINAC, feedback control of the accelerating phase for each RF station is employed, contributing to the operation of SuperKEKB.

- In SuperKEKB, prototype of MTCA.0-based digital LLRF system for SCC is demonstrated successfully by use of spare SCC.
- In PF and STF VT stand, their analog LLRF system is planed to upgrade to the digial LLRF system based with MTCA.4 standard.

Thank you for your attention!