# MicroTCA-based LLRF systems used at the STF at KEK

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(on behalf of the RF group and the iCASA SRF group)

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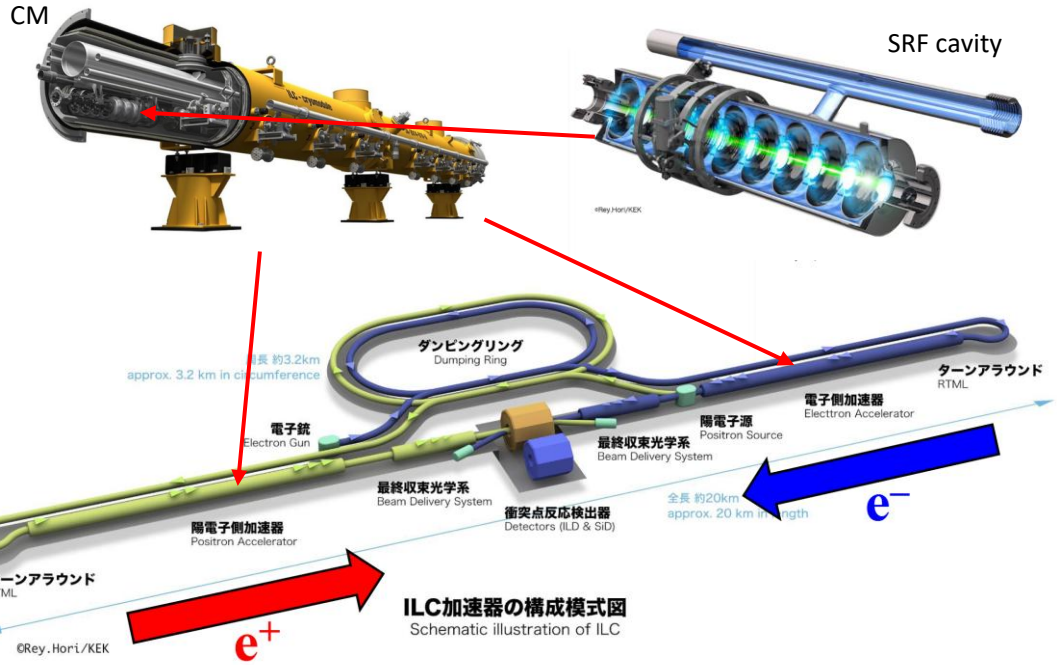
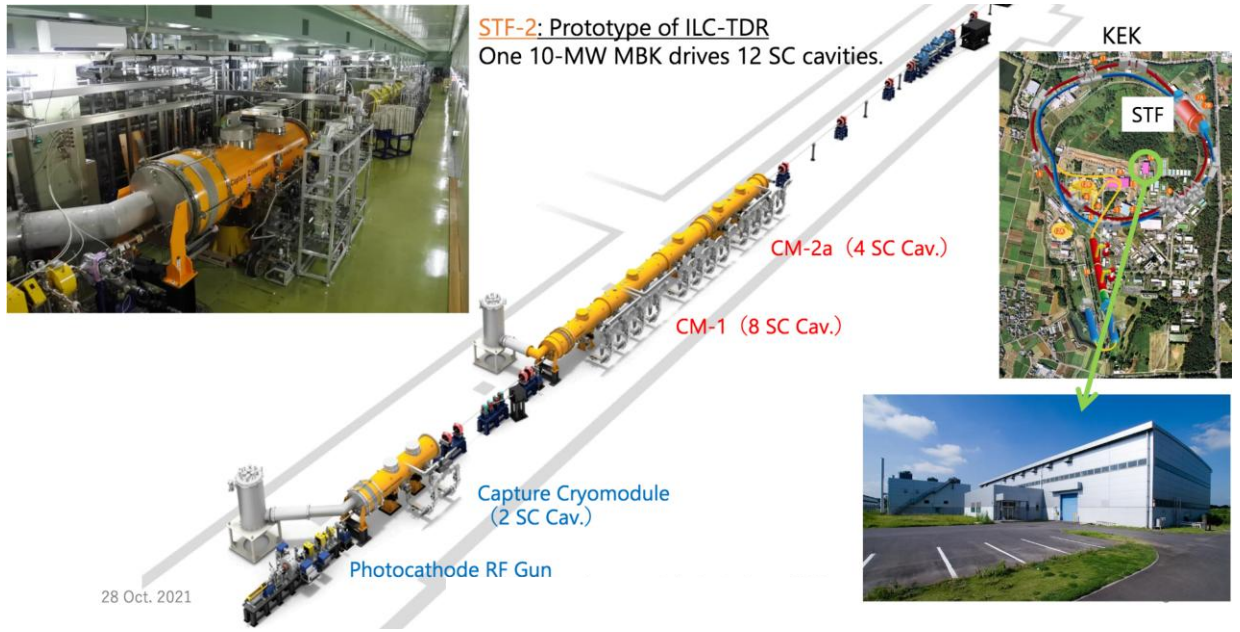
# LLRF systems at STF-II

# Introduction

- International Linear Collider (ILC)
  - Future Higgs factory machine
    - 250 GeV center of mass energy
    - Superconducting cavity / cryomodule technology
      - Based on TESLA technology
      - ~ 8,000 superconducting radio frequency (SRF) 1.3 GHz 9-cell cavities

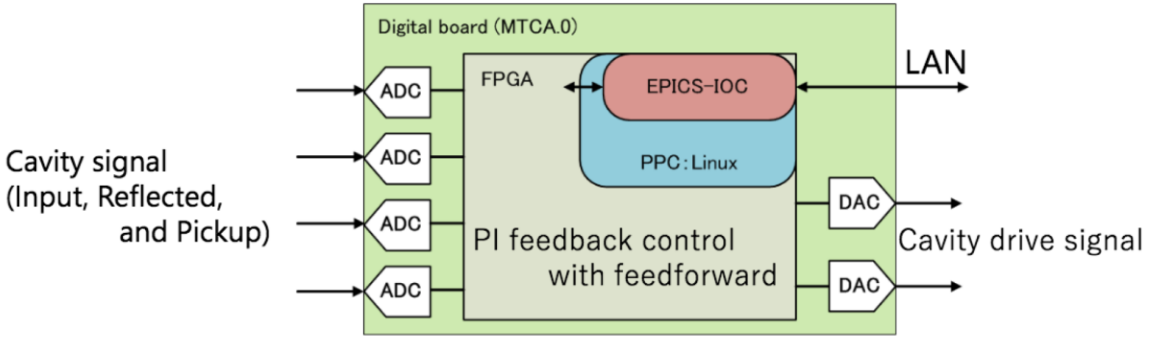



- STF-II Accelerator at KEK
  - ILC prototype / R&D accelerator
    - 1 normal conducting 1.3 GHz gun cavity
    - 2 SRF 9-cell cavities in the capture CM
    - 12 SRF 9-cell cavities in 2 main linac cryomodules
  - Operated 2015 -



# MicroTCA.0-based board developments for accelerators at KEK

- In 2008 the development MTCA.0-based LLRF hardware for the usage at SuperKEKB, cERL, and STF was conducted
- Cavity field controller/monitor
  - Multiple ADC and DAC channels
  - Virtex-5 FX FPGA
    - Wind River Linux installed on PPC 400
    - EPICS-IOC
- Was used to operate the STF-II gun and the capture CM




- FPGA (Virtex 5 FX),
- 4 x 16-bit ADCs (Max. 130MSPS)
- 4 x 16-bit DACs
- Digital I/O

**Mitsubishi Electric TOKKI System Co., Ltd.**

- FPGA (Virtex 5 FX),
- 2 x 14-bit ADCs (Max. 400MSPS)
- Digital I/O

**Mitsubishi Electric TOKKI System Co., Ltd.**

# MicroTCA.4-based board developments for ILC

- In 2013 a digital system with ILC LLRF control in mind was started
  - Required more than ten 16-bit ADCs and two 16-bit DACs as well as an optical connection
- Resulting product
  - Based on MTCA.4
  - FPGA and CPU (Zynq-7000 SoC, XC7Z045)
    - ARM-linux installed on Cortes-A9
    - EPICS-IOC
  - FPGA (Spartan 6, XC6SL150T)
    - ADC, DAC, vector-sum

Configuration of ILC LLRF system

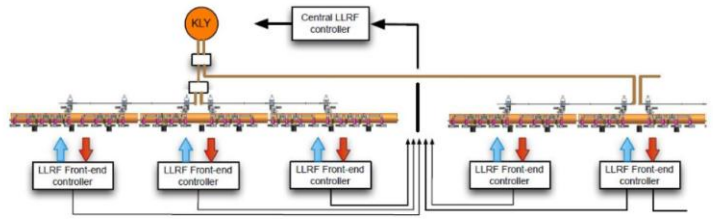
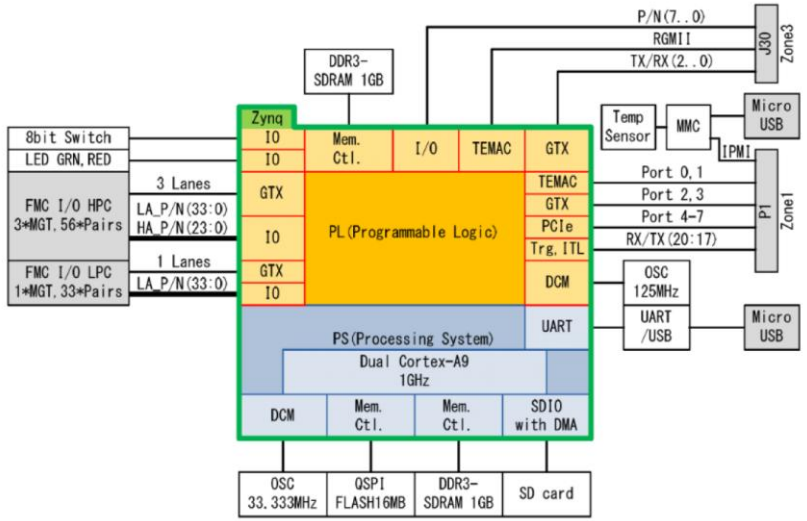



Figure 3.43. Implementation block diagram for the DKS LLRF system

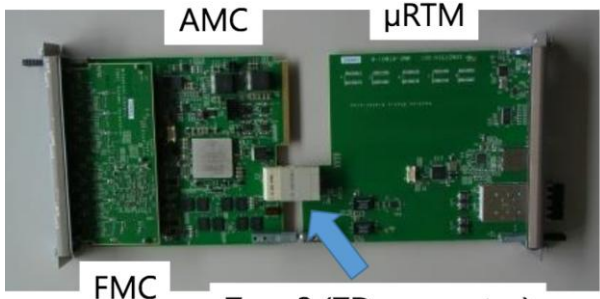
In the ILC, 39 SC cavities are operated under cavity-field vector-sum feedback control.




- Block diagram inside Zynq-7000 of newly developed board

**Newly developed board based on MTCA.4**

Mitsubishi Electric TOKKI System Co., Ltd.




○ AMC & FMC
- 2 FPGAs (Zynq-7000 SoC, Spartan 6)
- 14 x 16-bits ADCs
- 2 x 16-bits DACs

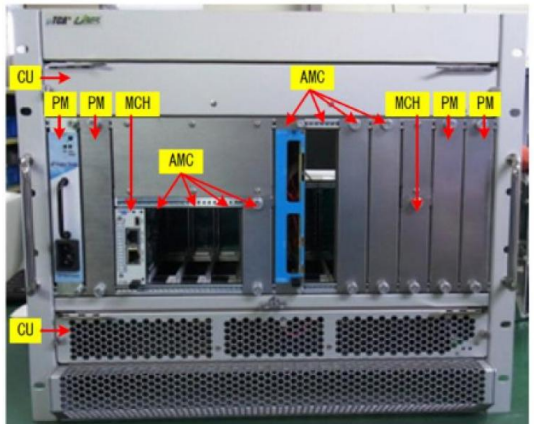
○ µRTM
- 2 x SFP
- 1 x RJ-45
- Digital I/O

# Power supply box for MTCA.4 AMC and RTM

- Boards comply with MTCA.4 standard
- Can be operated in MTCA.4 crate
- We developed and are using a custom power supply box

- Used to operate STF-II main linac (12 cavities in CM1 and CM2a)

**MTCA.4 crate**





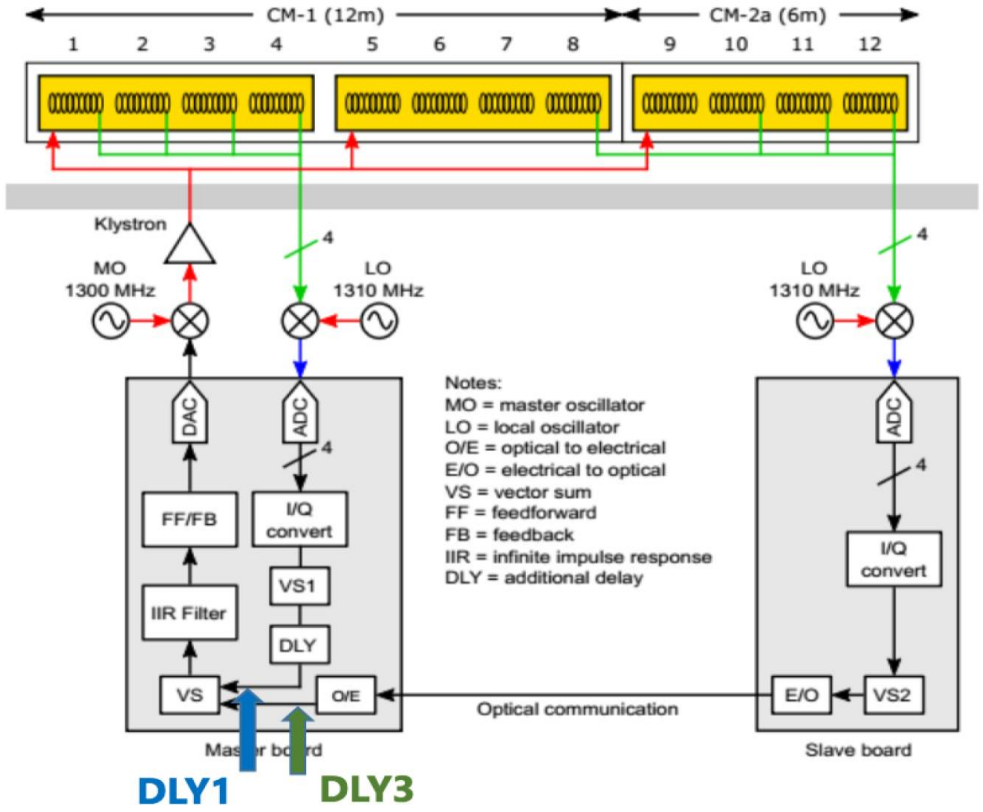
**Power supply box**

- Front side

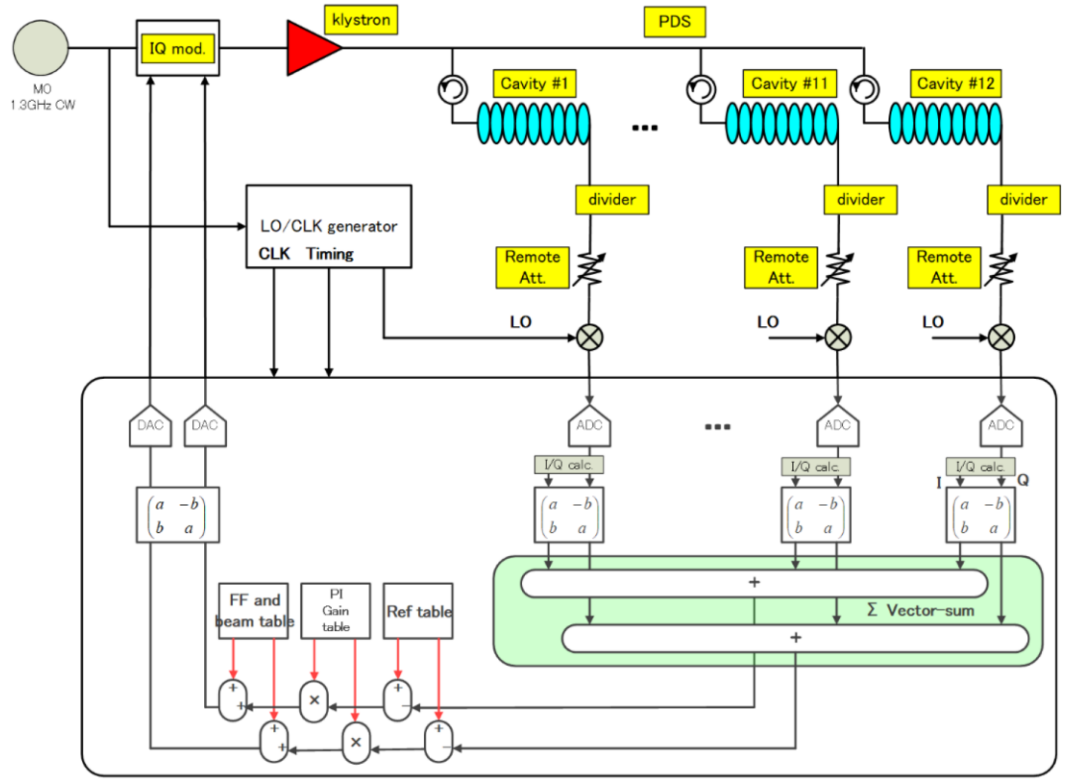
- Rear side

# STF-II main linac LLRF system overview

- Two systems were connected via an optical link in a master-slave configuration

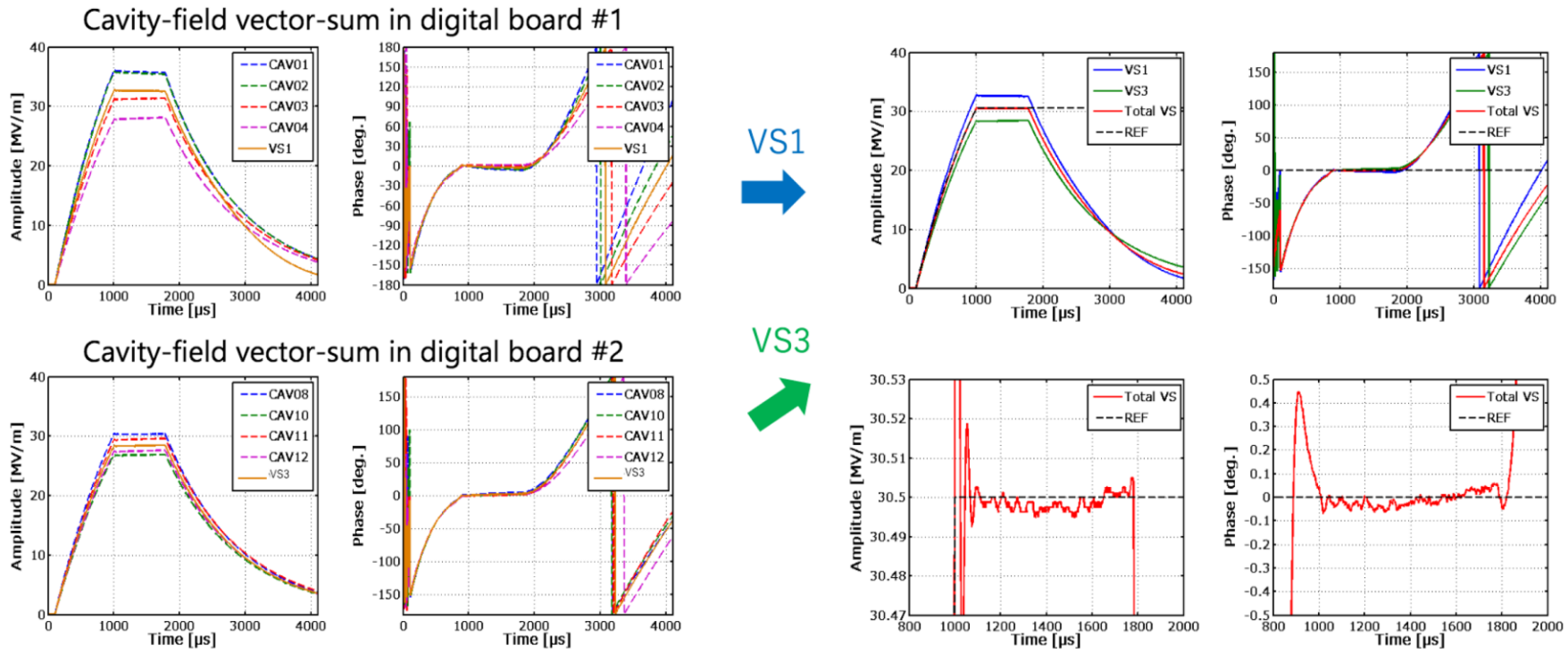



- On the master board feedforward (FF) and the vector-sum PI feedback (FB) are implemented



# Achievements of STF-II LLRF system operation

- Amplitude and phase stabilities




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

**ΔA/A =0.006%rms (0.07%@ILC)**

**Δφ = 0.03deg.rms (0.35deg.@ILC)**

- Maximum beam energy gained in CM1/2a with 12 cavities: 343.7 MeV
- Maximum average accelerating gradient with 9 cavities: 32.9 MV/m

# Outlook for LLRF system for the ILC CM prototype

# ILC Prototype Cryomodule

- From 2023 to 2027 we are building and testing an ILC prototype cryomodule at KEK
  - In scope of MEXT ATD and the ILC Technology Network
- Currently developing all necessary infrastructure
- Plan to develop and implement a MicroTCA.4-based LLRF system very similar of the STF-II LLRF system
  - New feature: better integration with the cavity frequency tuner piezo driver
- Dedicated keynote talk:

**8 1.3 GHz TESLA-type 9-cell SRF cavities**

| ILC spec. | $E_{acc}$ | $Q_0$ |
|---|---|---|
| Vertical test | 35 MV/m | 0.8 x 10E10 |
| **Cryomodule** | **31.5 MV/m** | **1.0 x 10E10** |

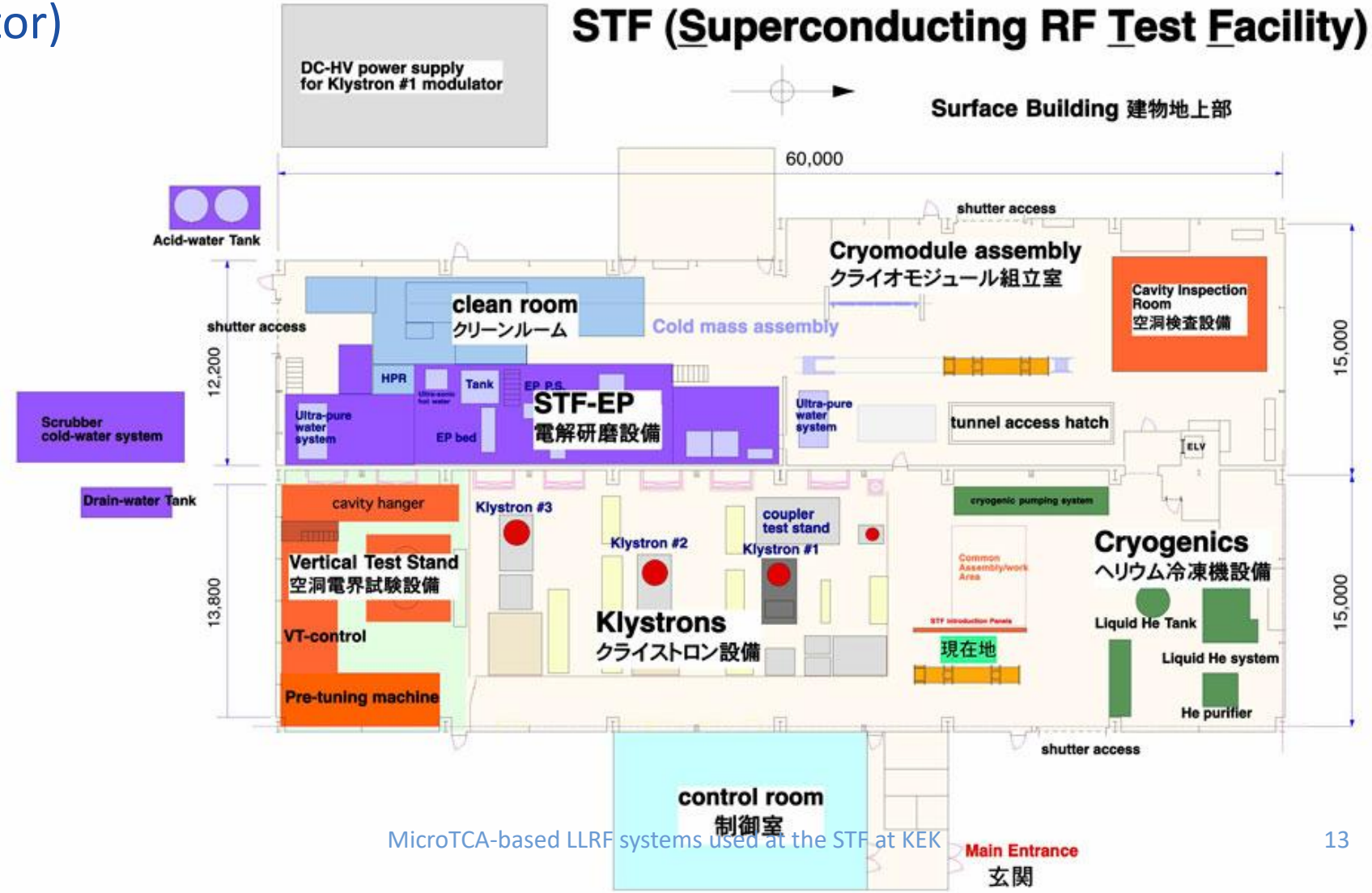
**Keynote Talk: Future Linear Collider and its LLRF system** *Shinichiro MICHIZONO*

*Bldg. #3 Seminar Hall, High Energy Accelerator Research Organization (KEK), Tsukuba Campus*

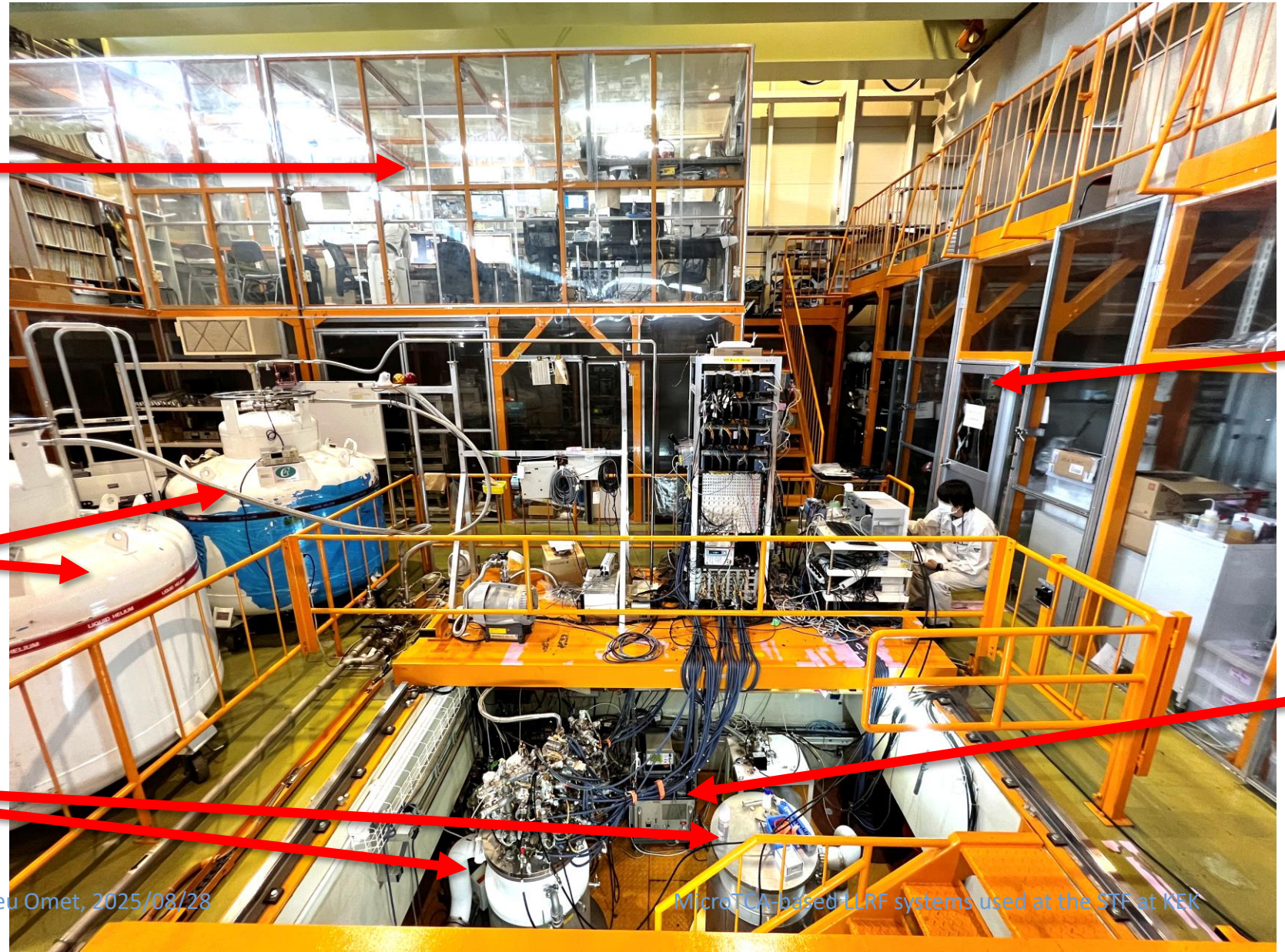
# LLRF system at the STF vertical test stand

# Introduction

- Superconducting RF test Facility (STF)
  - STF-2 (ILC R&D accelerator)
  - SRF facilities
    - Inspection
    - Pre-tuning
    - Electro polishing
    - Clean room
    - Vertical test stand

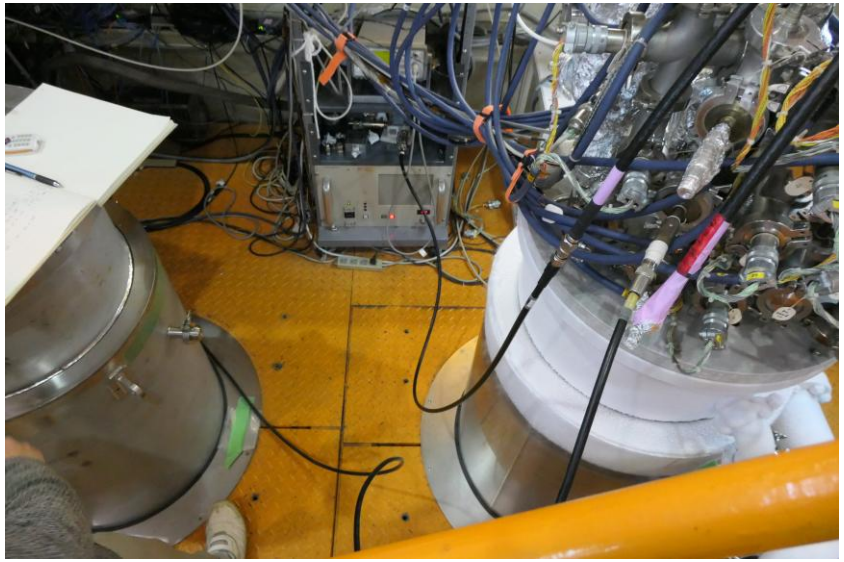


# STF vertical test stand for SRF cavity R&D



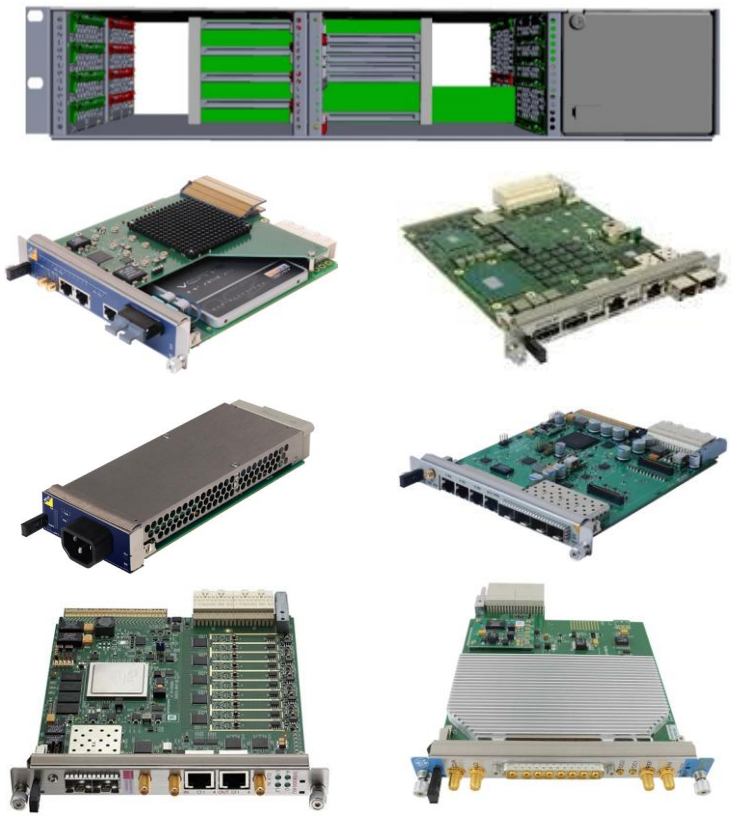
# Current RF system for STF VT stand

- >20 years old
- All analog
- Important channels are monitored in EPICS
- No automation

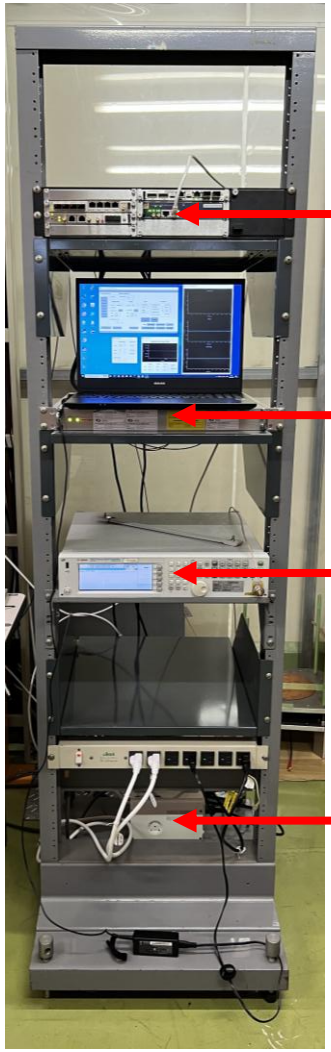


# Component overview of new MTCA.4-based LLRF system

- Decided to buy “of-the-shelf system” → MTCA.4
- Collaboration with DESY
- Component list
  - RackPak/M5-1, 2HE 6-Slot MTCA.4 Crate
  - NAT-MCH-PHYS80
  - AM G64/471-41, AMC CPU with Xeon E3-1505M, 16GB RAM and onboard 256GB SDD
  - NAT-PM-AC600D (Single Full-Size AC PSU)
  - NAMC-psTimer
  - SIS8300-KU MTCA.4 Digitizer FPIO 8AC2DC DZ3 125 MS/s 16-bit 10 Kanal 4 x 4 Gbit
  - DWC8VM1 R13 1.3 GHz RF FP 11 MTCA.4 Downconverter/Vektor Modulator RTM

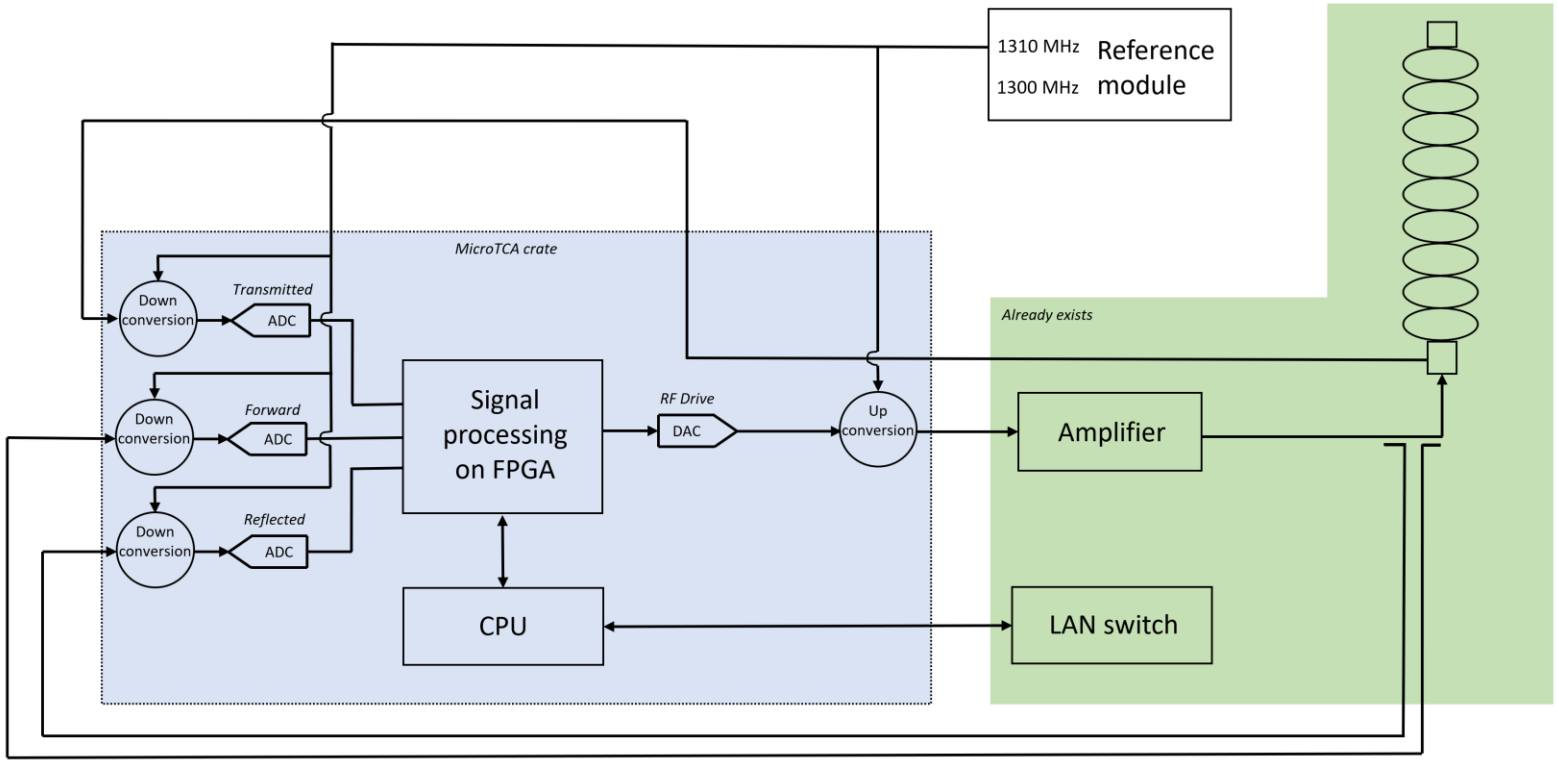


**LLRF system at STF VT area**

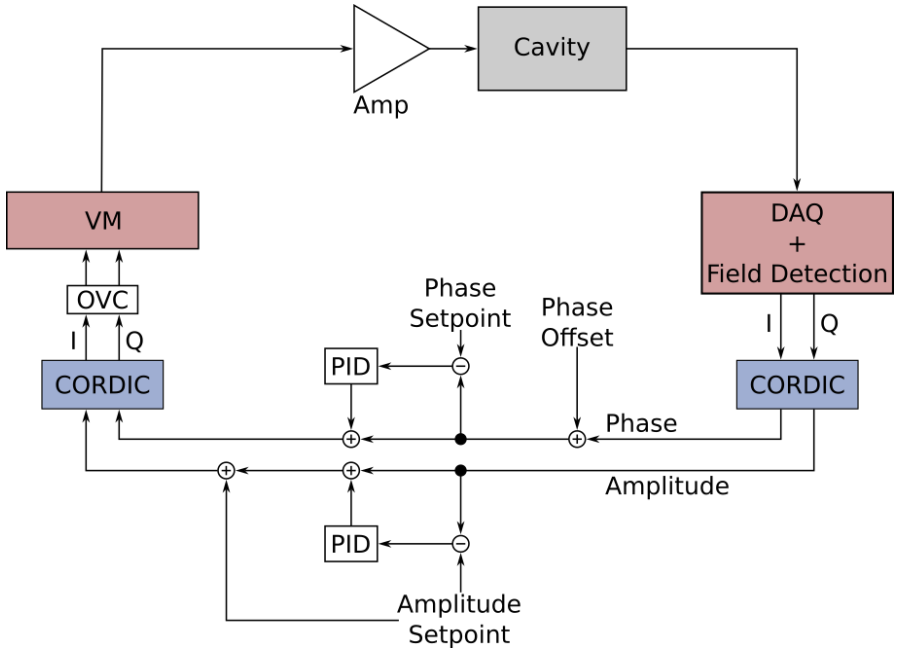


# Schematic of LLRF system

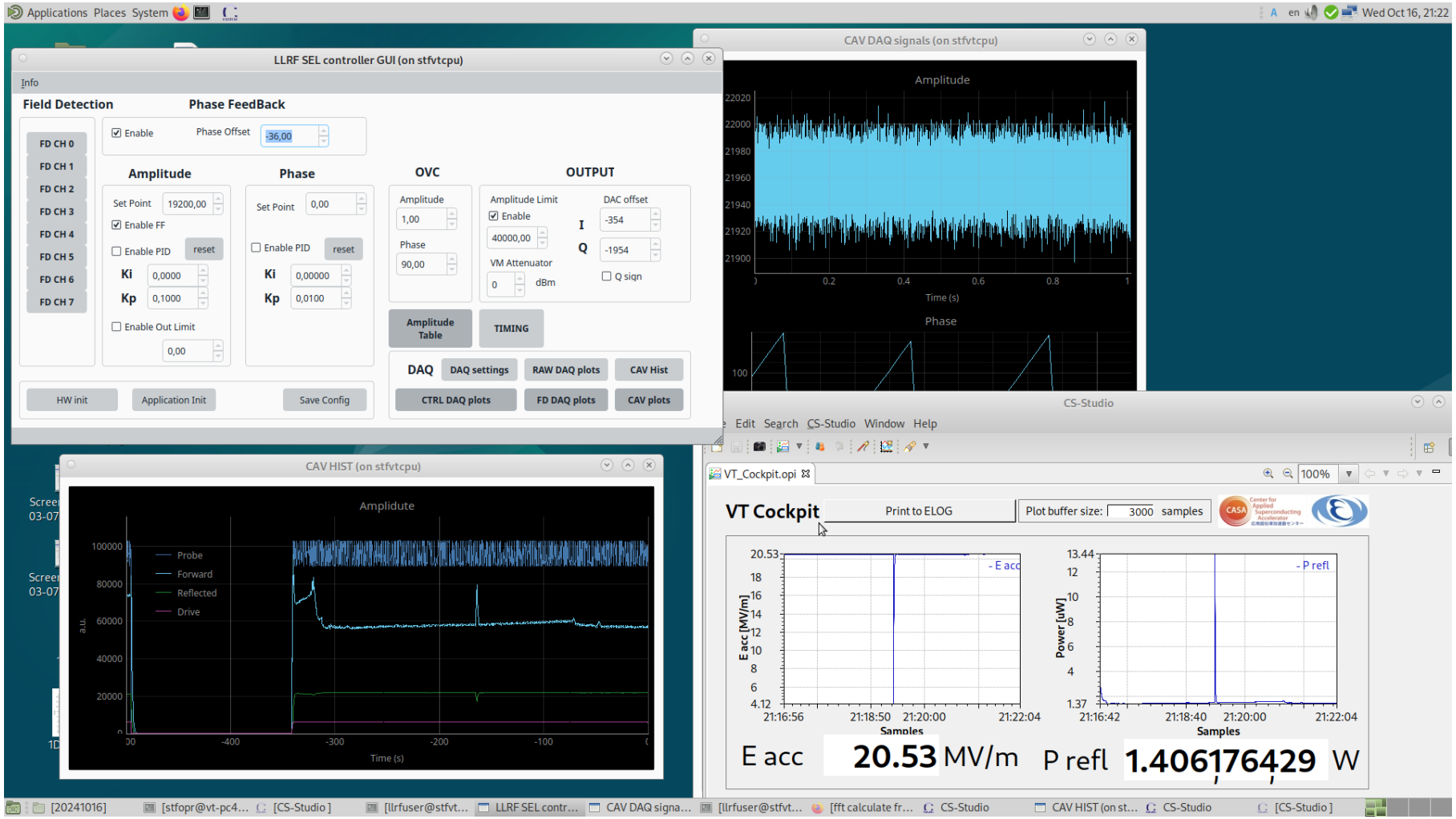
## Schematic of the LLRF system for the KEK STF VT stand




## Schematic of the SEL controller

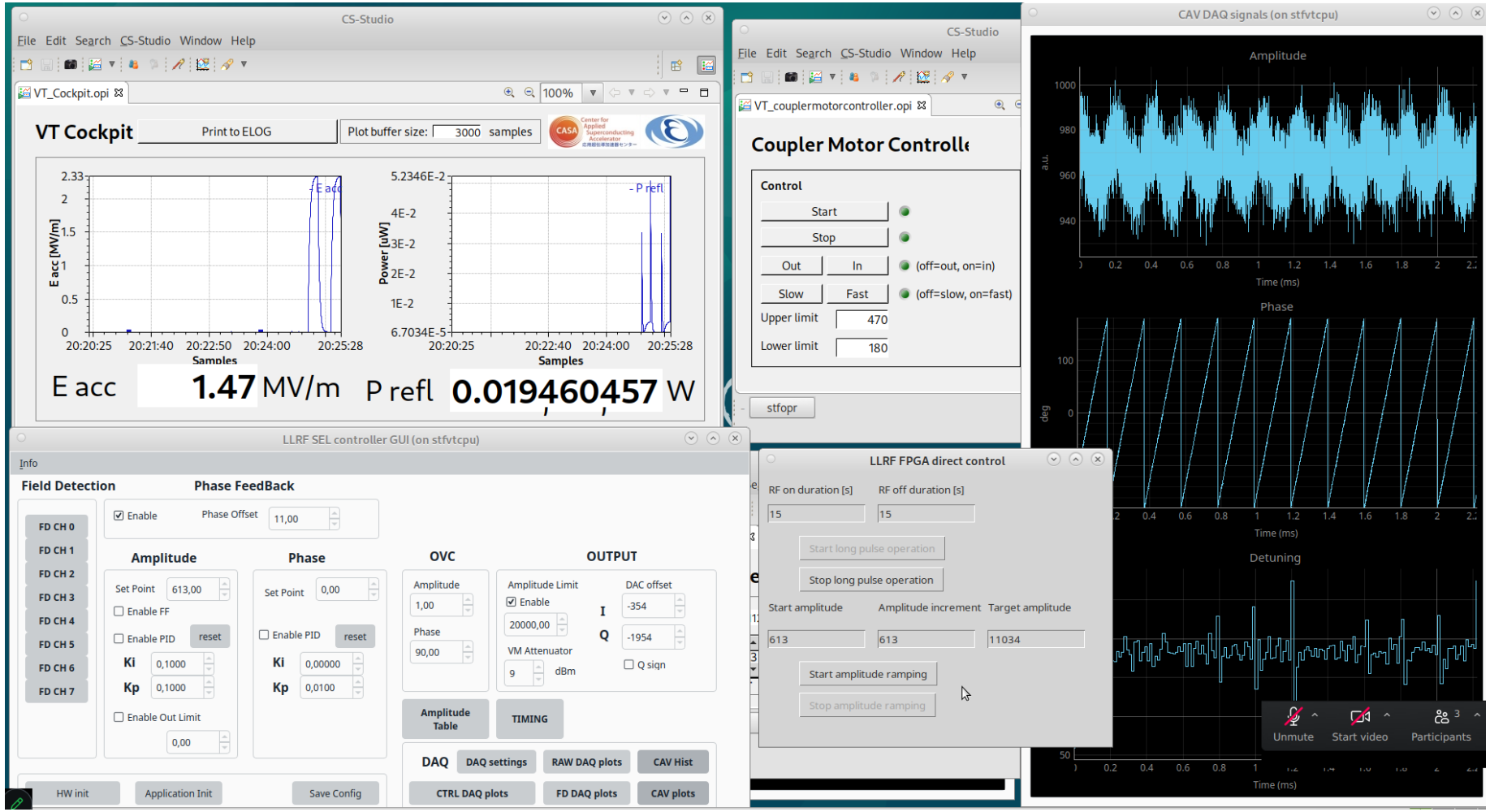


# SEL CW drive of single-cell cavity

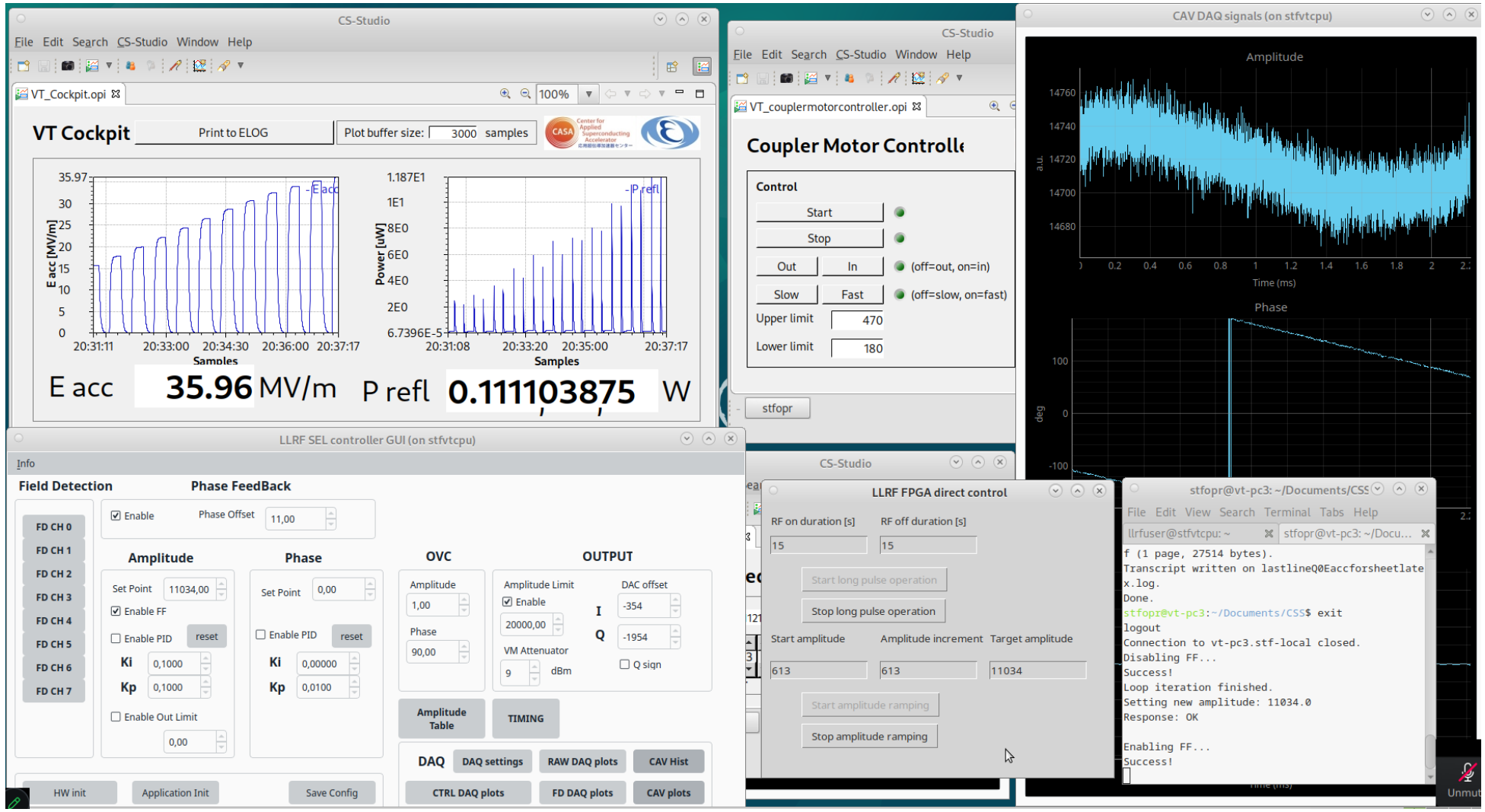


# Test of long pulse operation

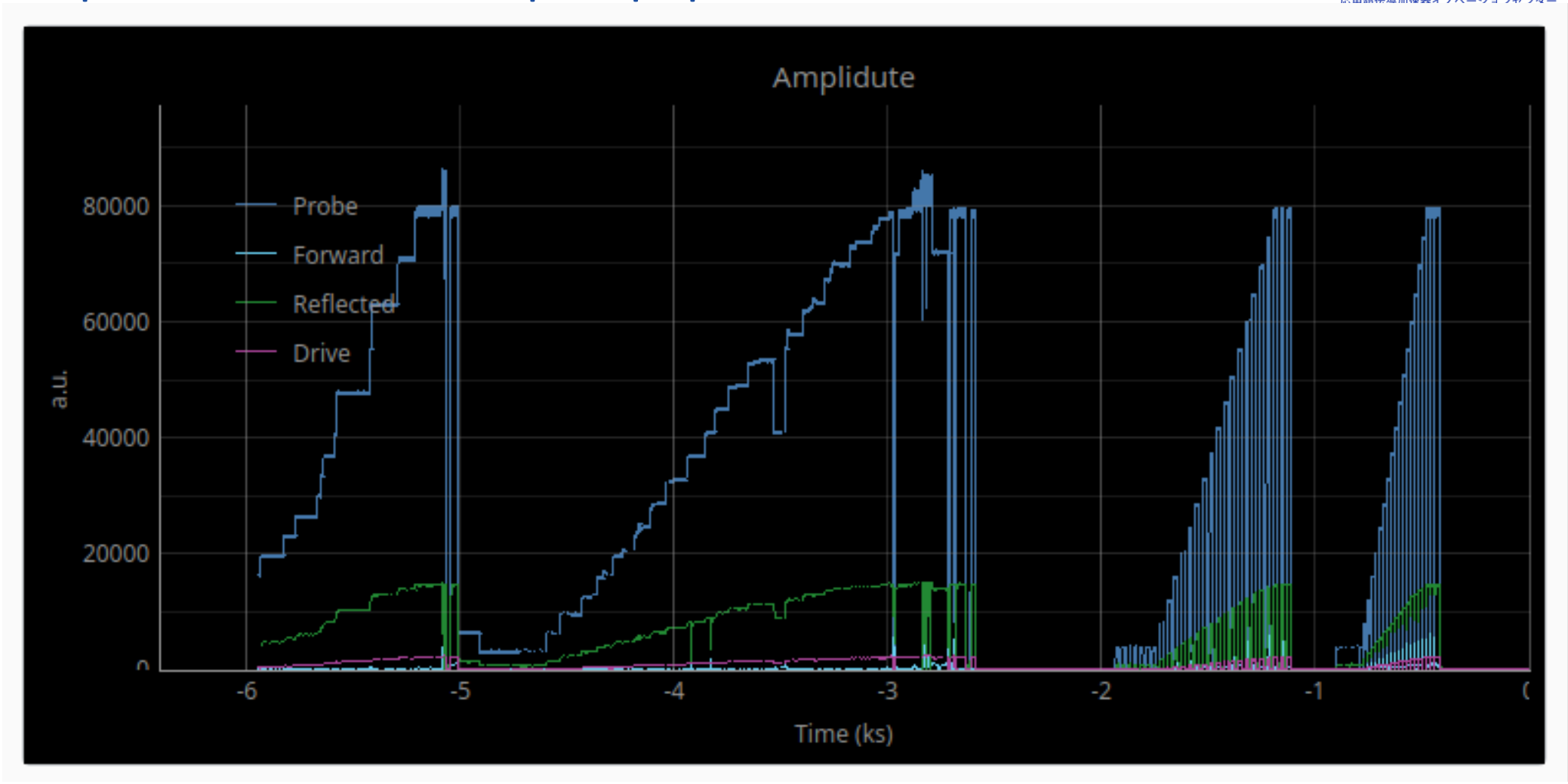
- Certain 9-cell cavities to be tested in scope of the ILC prototype CM production might need long pulse operation
- High-level software script was implemented, which allows arbitrary pulse lengths



# Automated long-pulse ramp-up and automated data taking



# Comparison of ramp-up procedures



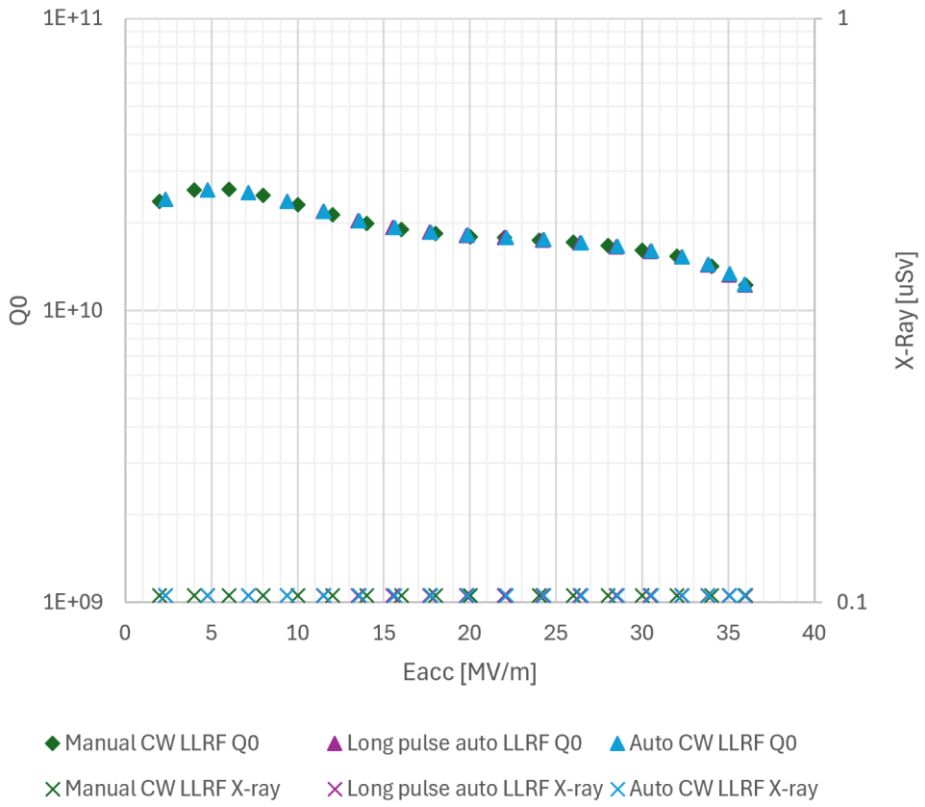

Manual ramp-up (30 mins.)

Automated long-pulse ramp-up (10 mins.)

Automated CW ramp-up (5 mins.)

# Automated CW ramp-up and automated data taking

- Identical curve as manually ramped up
- Identical to long pulse automatic ramping




- Further automation R&D will be presented in this talk:

**Automated Passband Mode Resonance Peak Finding Algorithm Using MicroTCA.4-Based Digital LLRF System**
*Eric Viklund*

# Summary

# Summary

- MTCA.0 and MTCA.4-based LLRF systems were developed at KEK
  - Together with Mitsubishi Electri TOKKI System Co., Ltd.
  - Successful operation at the SRF-II accelerator
- For the test of the currently being built ILC prototype CM a MTCA.4-based LLRF system will be developed
- A MTCA.4-based LLRF system is currently being commissioned at the STF VT stand
  - Goal is a highly automated VT procedure
  - Collaboration with DESY

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