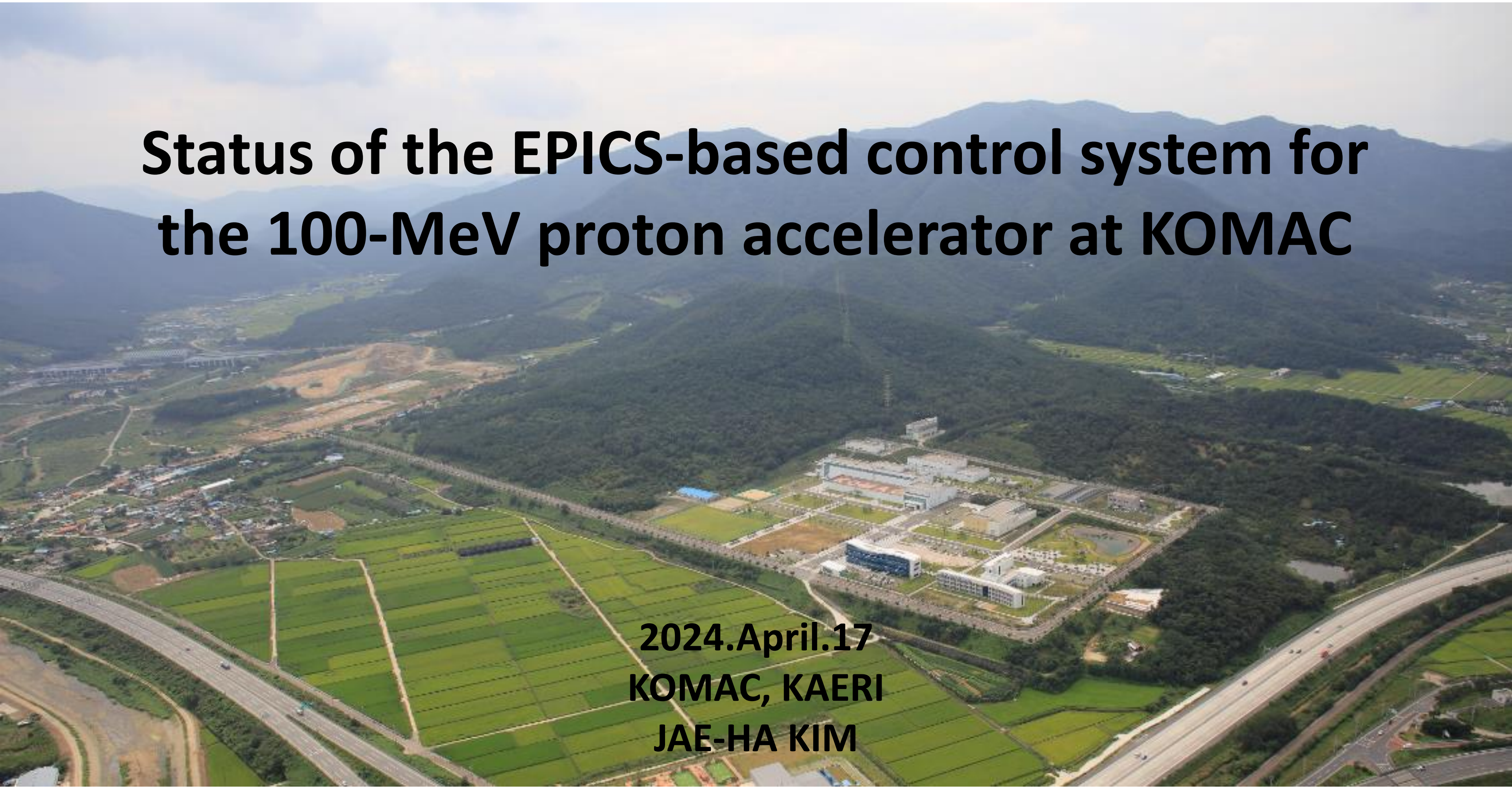
KOMAC
Korea Multi-purpose Accelerator Complex
양성자가속기연구센터



Status of the EPICS-based control system for the 100-MeV proton accelerator at KOMAC

2024.April.17
KOMAC, KAERI
JAE-HA KIM

KAERI 한국원자력연구원 Korea Atomic Energy Research Institute

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  - Local System Control
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Facility Overview

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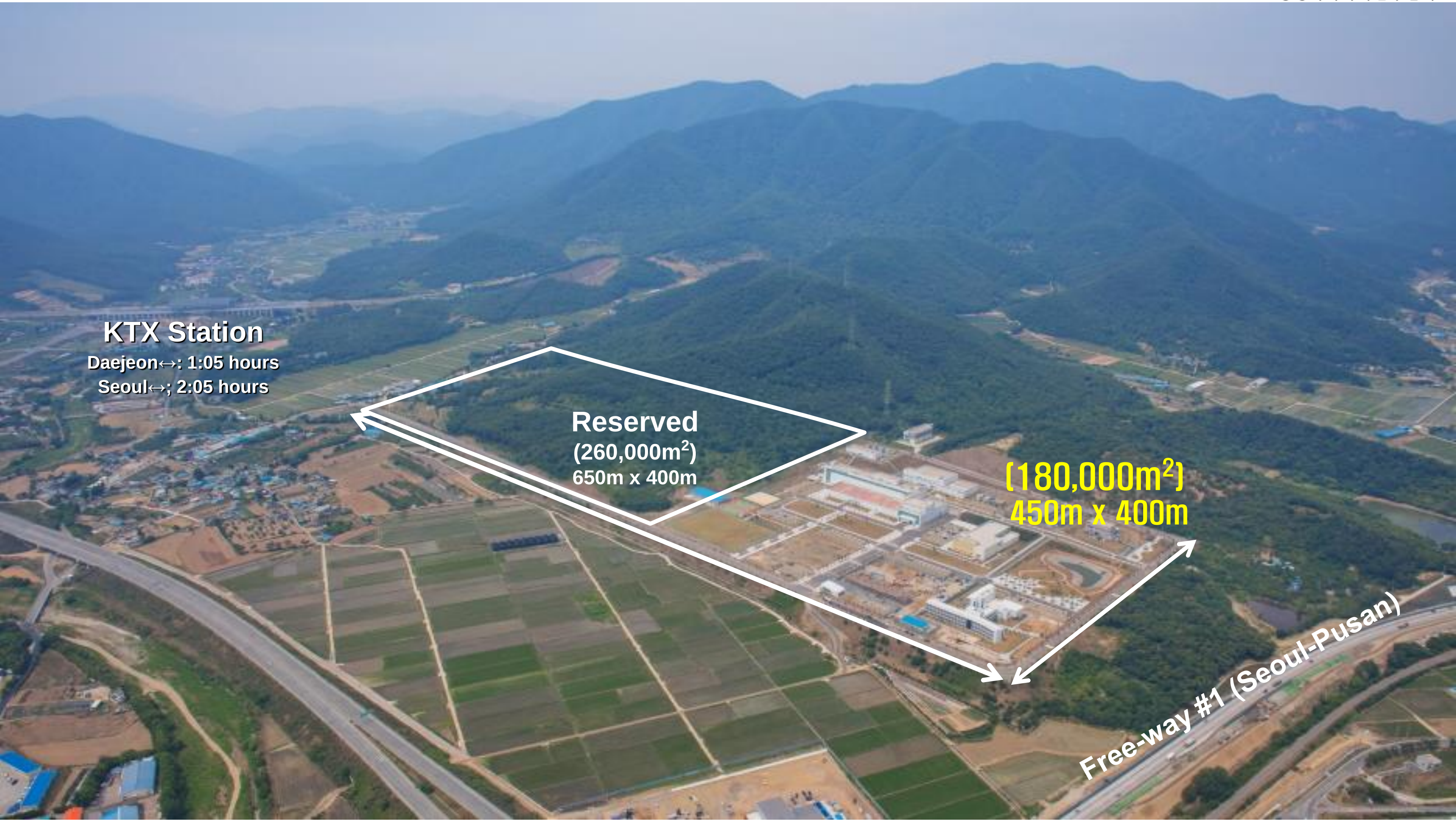

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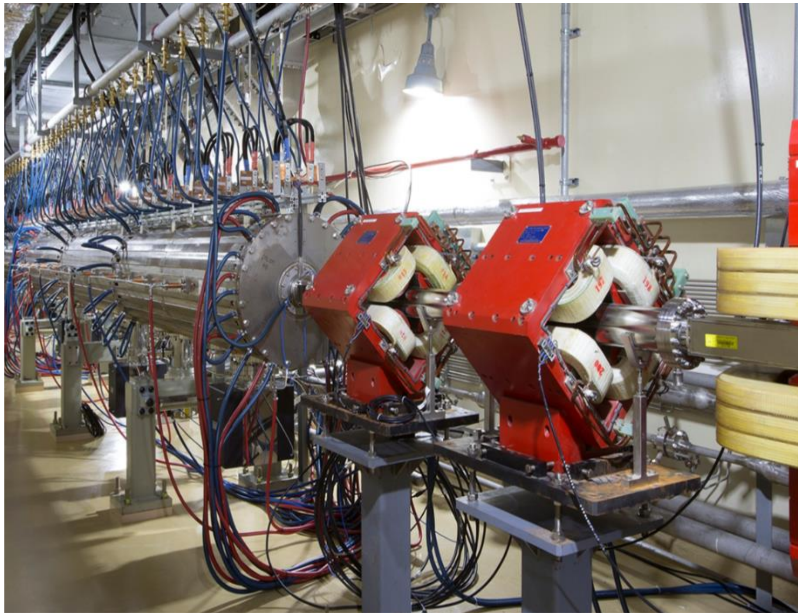
Facility Overview

- Main facilities at KOMAC
  - **100 MeV Proton Linac** in accelerator building.
  - Various small-scale accelerators and test stands in beam application building.
- Developed via Proton Engineering Frontier Project (2002 ~ 2012)
- Started user beam services from July 22, 2013.

KOMAC View Map

100 MeV Proton Linac



Facility Overview – Proton Linac

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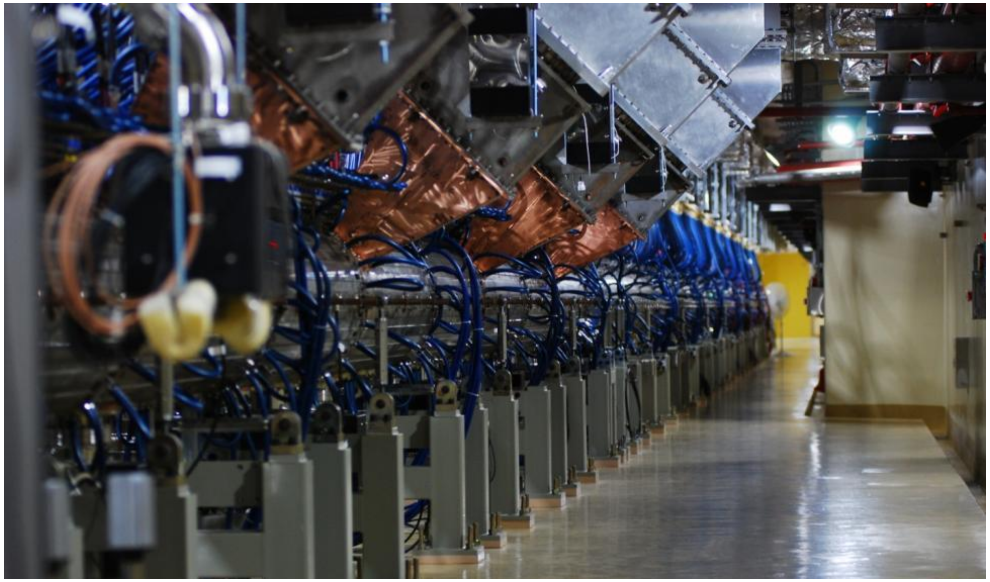
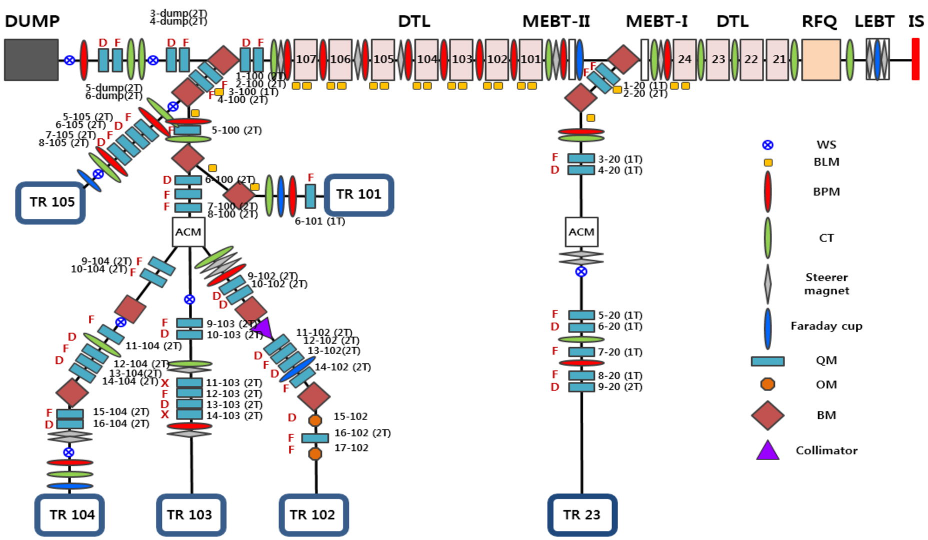


Features of KOMAC 100 MeV linac

- 50 keV Injector (Ion source + LEBT)
- 3 MeV RFQ (4-vane type)
- 20 & 100 MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV



	20 MeV	100 MeV
① Max. Peak Beam Current (mA)	1 ~ 20	1 ~ 20
② Max. Beam Duty (%)	24	8
③ Avg. Beam Current (mA)	0.1 ~ 4.8	0.1 ~ 1.6
④ Pulse Length (ms)	0.1 ~ 2.0	0.1 ~ 1.33
⑤ Max. Repetition Rate (Hz)	120	60
⑥ Max. Avg. Beam Power (kW)	96	160

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Facility Overview – Proton Beamlines

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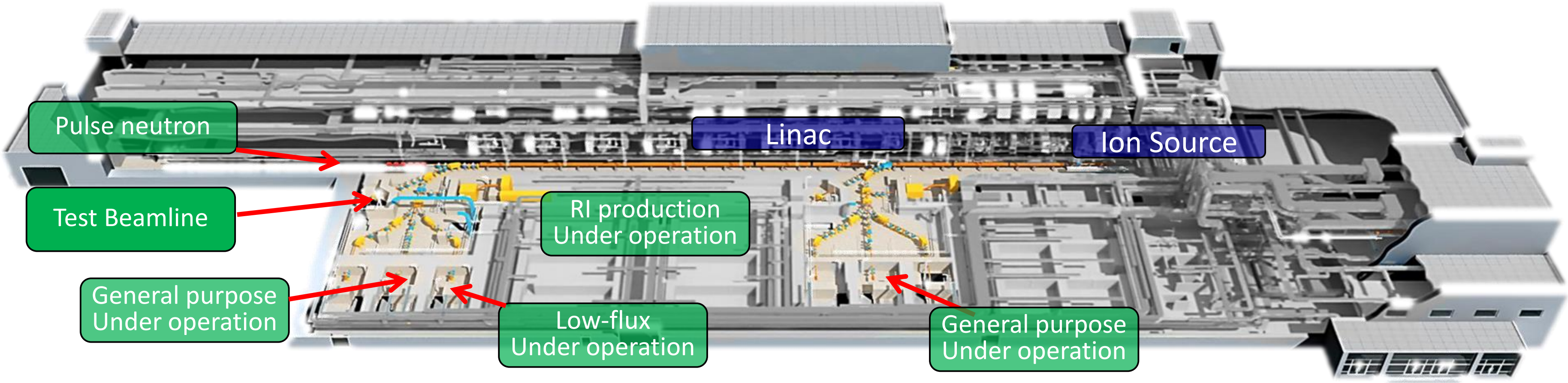

Beamlines	Features and Utilization
General purpose beamline (TR23, TR103)	• Since July 2013 • General purpose beamlines : 20/ 33~100 MeV proton beams, 10 kW @ 100 MeV • Applications : material / nano-science, nuclear physics, semiconductor etc
RI Beamline (TR101)	• RI production beamline : 33~100 MeV proton beams, 30 kW @ 100 MeV • Applications : Medical purpose RI production (Cu-67, Sr-82) • Preparing for operation
Low flux Beamline (TR102)	• Since Feb. 2018 • Low flux beamline: 33~100 MeV proton beams • Flux 1x105 ~ 1x108/cm2 per pulse • Applications : Space radiation, Detector R&D, Bio etc.
Neutron Beamline (Dump)	• Neutron beamline: Spallation neutron beam using 100 MeV proton beams • Applications : Terrestrial radiation simulation test on semiconductors • Under pilot operation

Facility Overview – Operational Status

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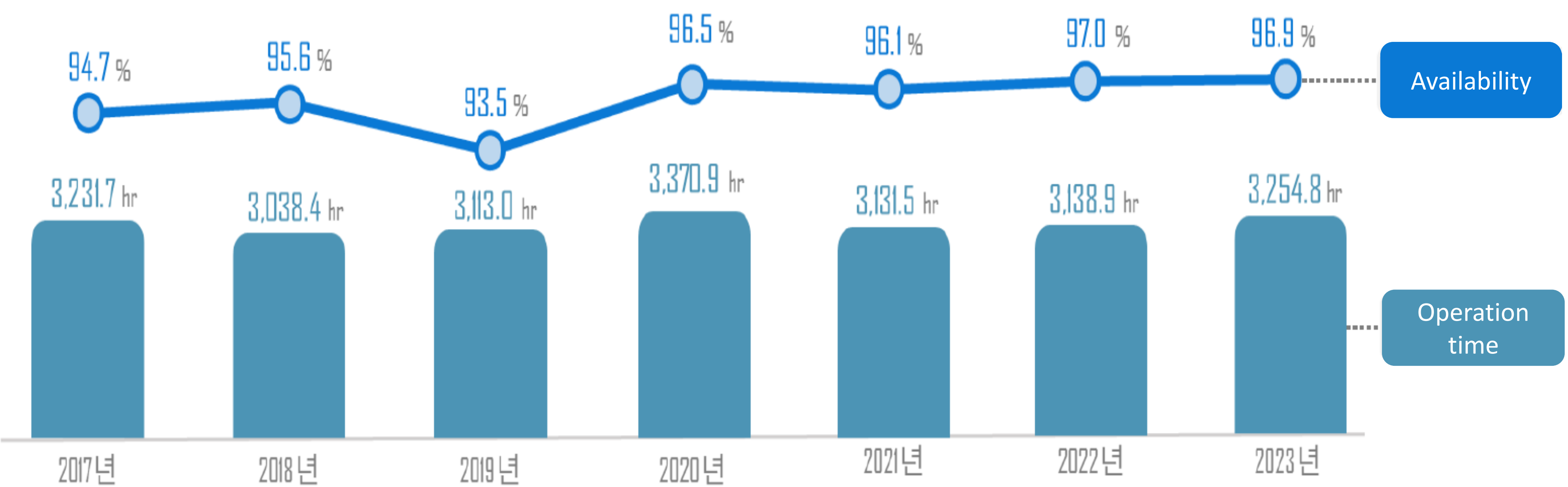
Total cumulative operation status of proton accelerators (till 2024.03.31.)

Total Operation time	Avg. Operation time in 5 yrs	Yearly Avg. Operation Rate
33,872 hr	3,202 hr	96.0 %

Yearly Operation Plan: Beam Service **22 weeks** + Beam Test **8 weeks** + Maintenance **23 weeks**



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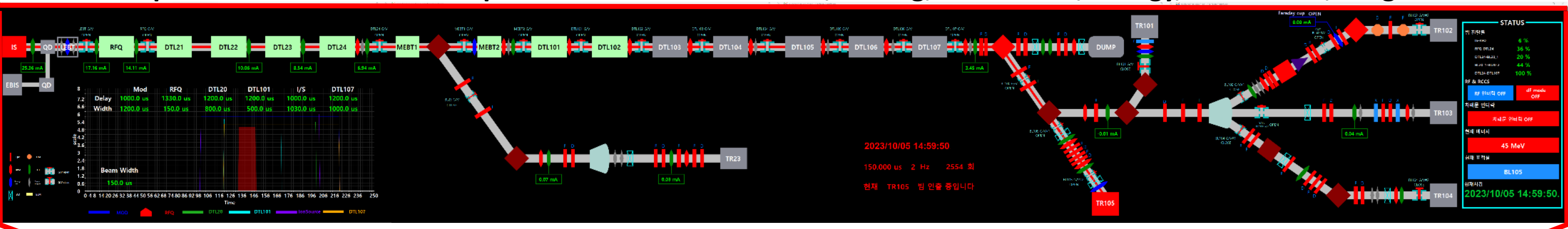
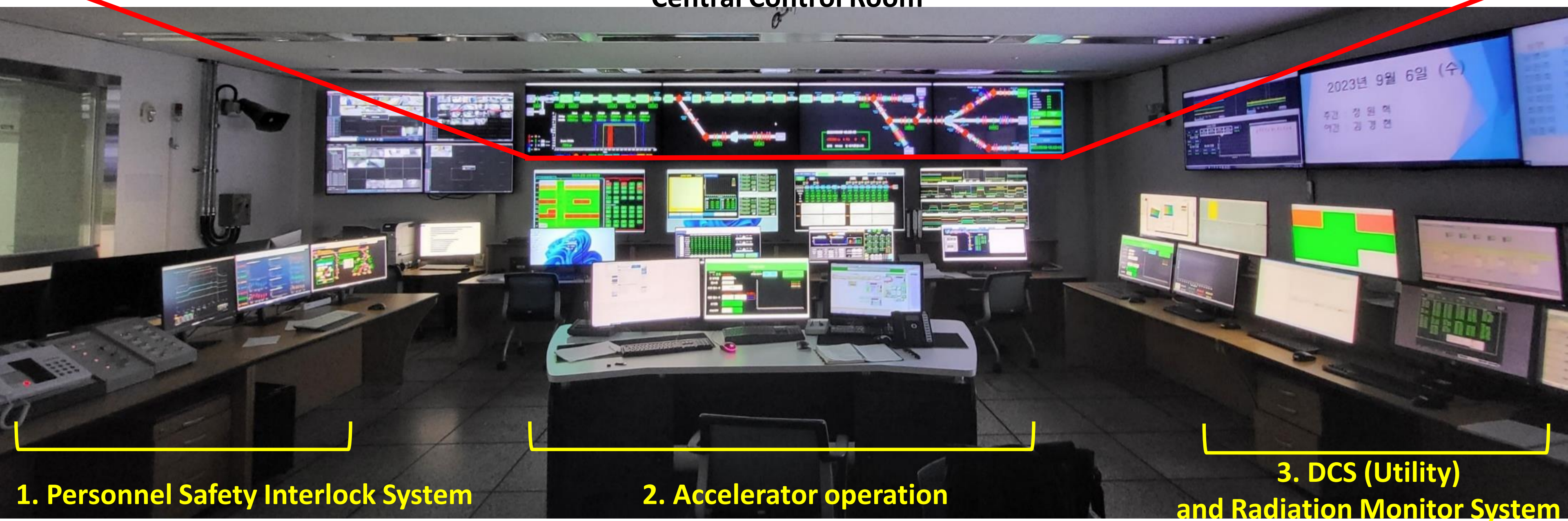
Central Control Room (CCR)

Top Screen for Accelerator Operational Status: Interlock, Timing, Beam Path, Energy, Gate Valve, Magnets

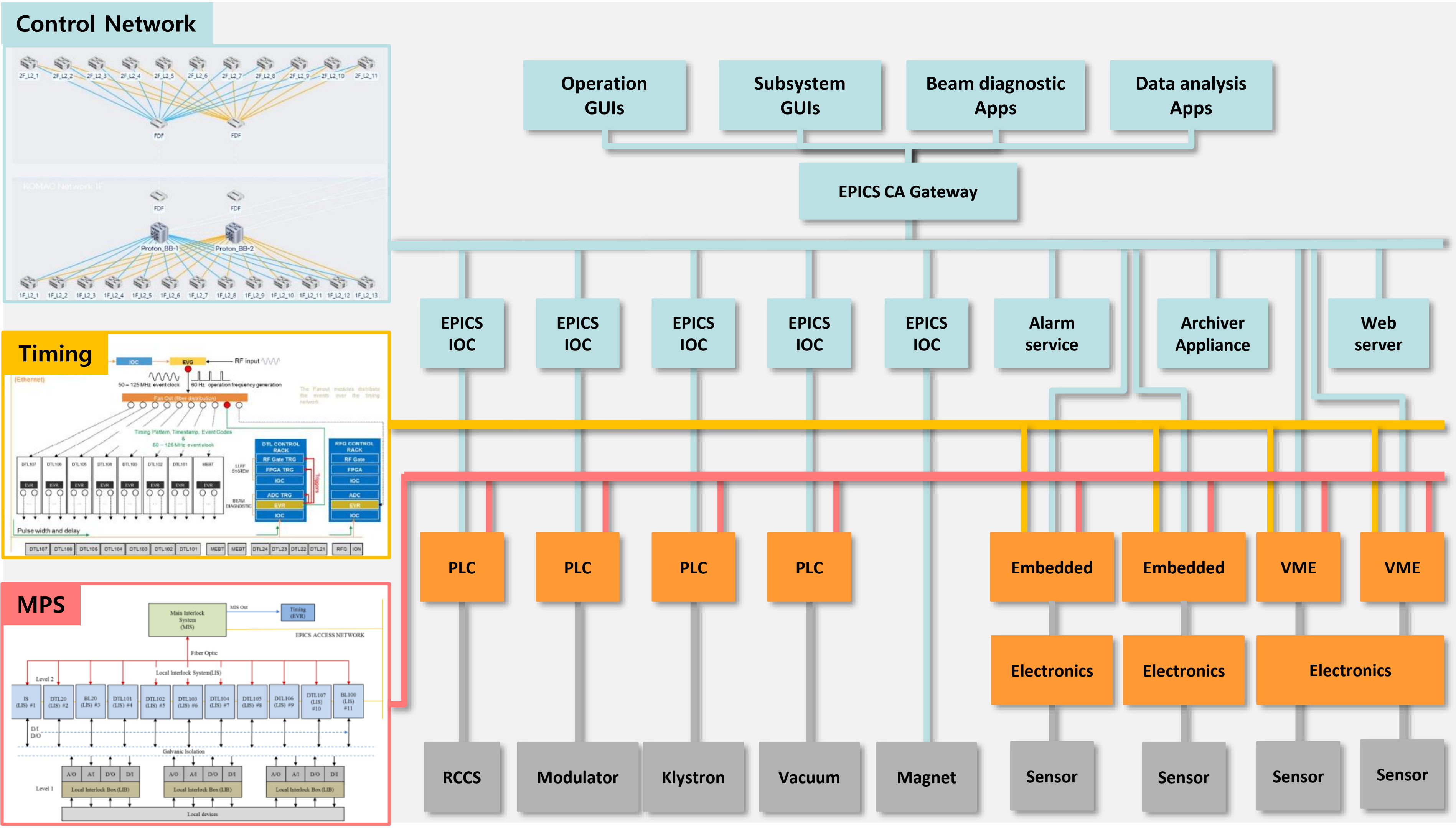


Central Control Room



1. **Personnel Safety Interlock System (PSIS)** : shielding door control, access control, interlock status, Key box for beam service
2. **Control consoles** designed with enough flexibility to allow most accelerator programs to be operated from any location in the control room
3. **DCS** for utility control system, Radiation monitoring system (RMS), Beam tuning system, Alarm monitor

Control System Architecture



Software and Infrastructure

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- **EPICS for the distributed control system at KOMAC**
  - Accelerator and local systems, target rooms, and beamlines.
  - IOCs run on Linux except data acquisition applications
- **Network**
  - Diverse networks : machine, timing and interlock network
  - Establishing a backbone switch-based network
  - Network Management System (NMS) for optimizing network infrastructure
- **Client Software**
  - Control System Studio
    - Operations, alarm service, save & restore service
  - Applications development for data analysis
    - Python / Java / Web technology

Local System Control

- Managing process and device operations with high reliability while executing essential local control functions
- Integrated the local system : VME, PLC and embedded systems
- Application field:

VME systems

- Applications needing rapid data acquisition and custom FPGA-based processing.
- Timing system (Micro Research Finland)
- LLRF control system
- Beam profile monitor


PLC

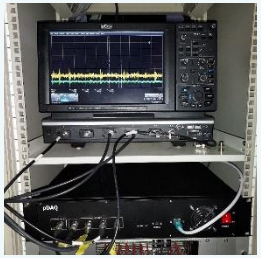
- Used to effectively control automated processes with High reliability
- Vacuum control system
- Resonance control cooling system
- Klystron control system
- Modulator control system



Embedded systems

- Employed for the collection of beam profile data and analysis
- Beam Current Monitor
- HPRF monitor

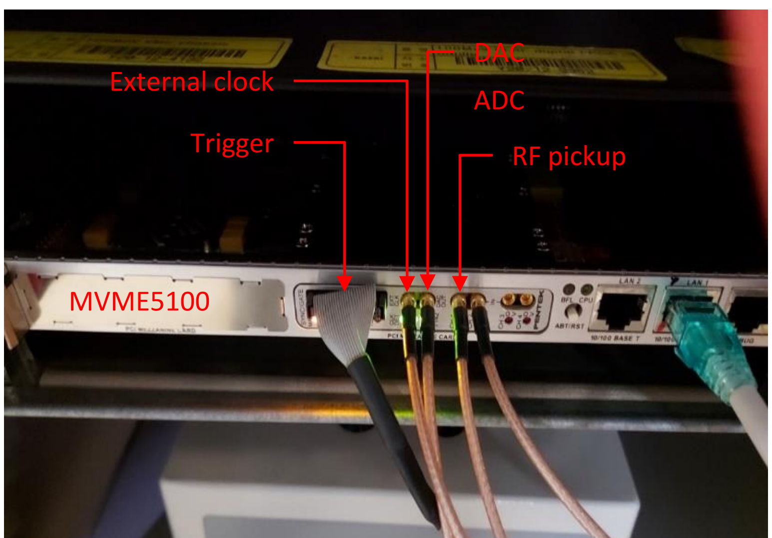




VME Systems – LLRF

- **Low Level RF (LLRF) System: Control RF amplitude/phase within 1% and 1˚**
  - RF digital feedback control system via FPGA
  - Input and monitoring RF Amplitude, phase, PI control variables, and Open/Closed loop
- **LLRF IOC**
  - PENTEK7142, PMC type, 4ch 125 MHz 14bits ADCs, 1ch 500 MHz 16bits DAQ, Xilinx Virtex-4 FPGA
  - Baseboard : MVME5100, vxWorks 6.8 OS
  - EPICS Software tool
  - EPICS IOC : pick-up signal processing, waveform viewer

LLRF Control System



VME Systems – BPM

CPU board

Channel Access | Record Support | Device Support

Driver Support

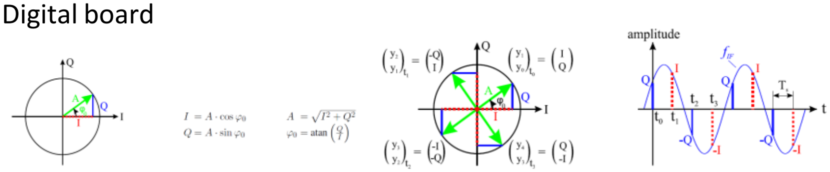
- Initialize digitizer board
- Create interrupt processing routine using semaphore
- Data transfer from digital board to CPU board
- Preprocessing for data processing and classification

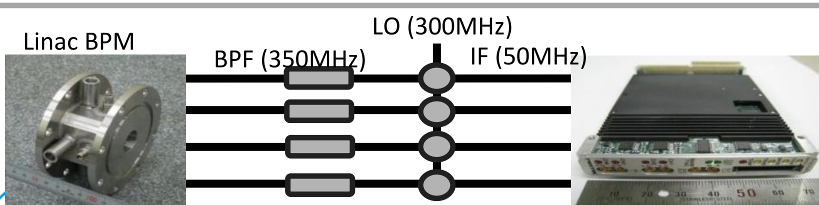
Data extracted from driver support

Beam position: difference over sum	Beam phase: vector sum of 4 ch signal	Beam current: 4 channel size measurement
$(x,y) = f(\frac{V_R - V_L}{V_R + V_L}, \frac{V_T - V_B}{V_T - V_B})$	$Beam\ phase = \text{atan}(\frac{Q_{vs}}{I_{vs}})$	$Beam\ current = \text{K}\sum_{i=1}^{4}\sqrt{I_i^2 + Q_i^2}$

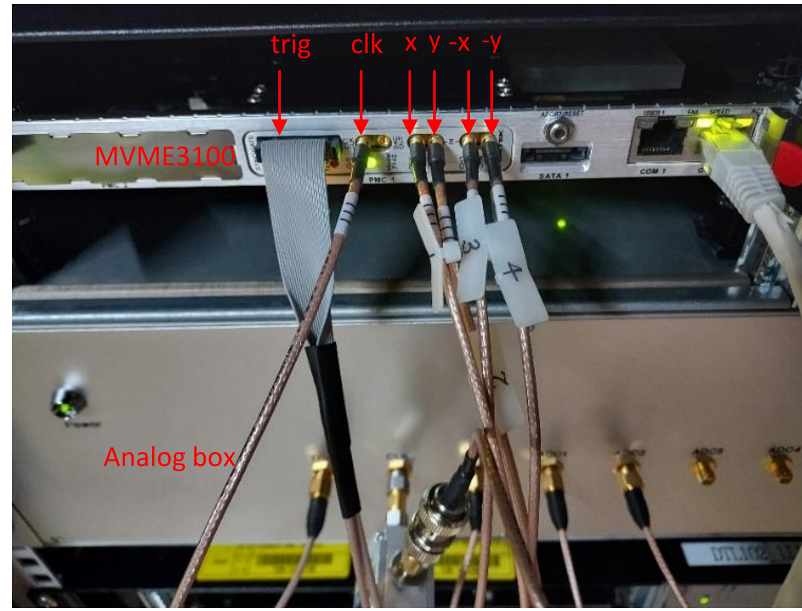
PCI bus

Digital board

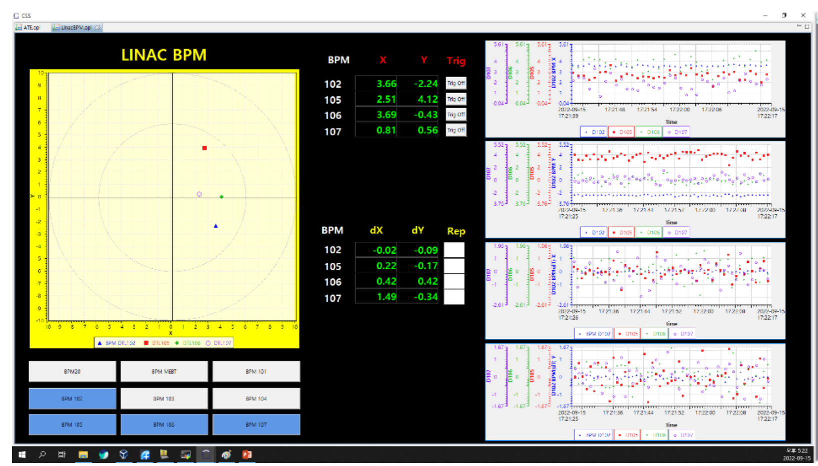




BPM IOC (MVME3100 & PENTEK7142)



BPM User interface



Embedded System – BCM

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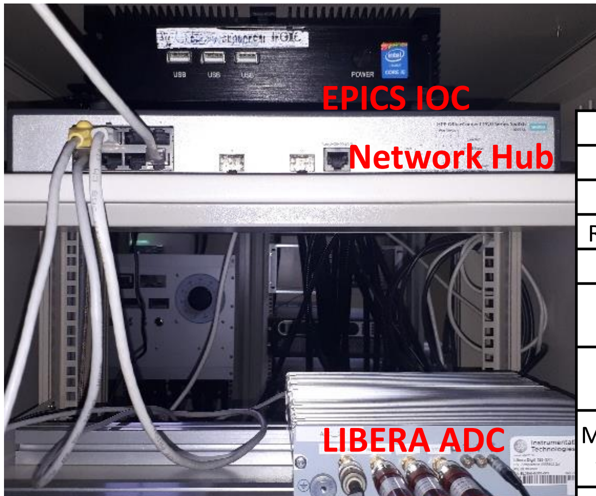
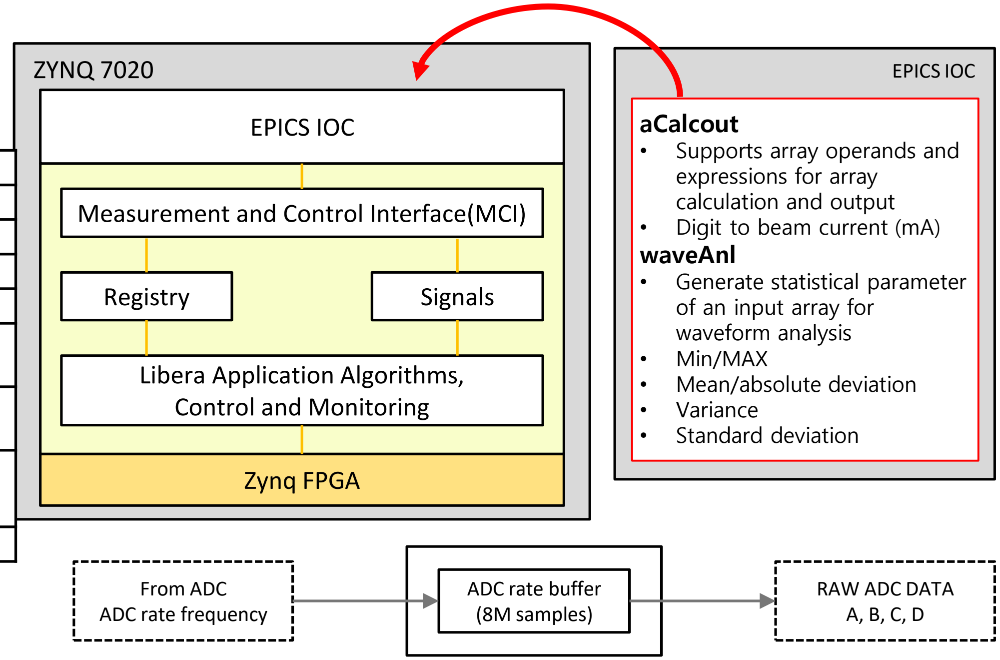
Beam Current Monitor(BCM)



Feature	Specification
Model	Libera Digit 125
ADC	125 MS/s
Resolution	14 bit
Trigger	External
Network Interface	Yes
Channel Memory	2 ~ 8 MB/ch
Max. Repetition Rate	5 Hz
SoC Chip	Zynq 7020



- Requested the compiler from I-tech and Received a **VM (LINUX)** with the **compiler configuration completed** from the vendor(DEC. 2023)
- With a **software upgrade**, the electronics can directly process ADC sample data internally, allowing for advanced data processing and waveform analysis.

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Embedded System – pDAQ Development

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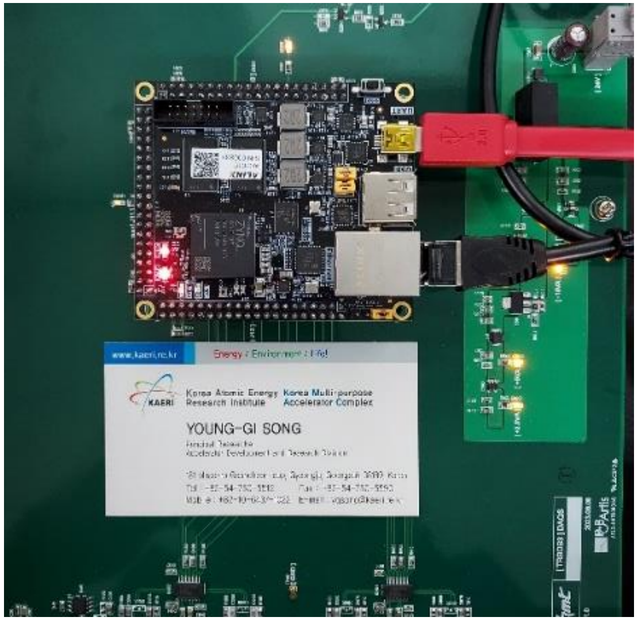

Feature	Specification
FPGA chip	XC7Z010-1CLG400L
Processor	Dual-core ARM Cortex-A9
Memory	DDR3, 512MB
ADC	AD7903
ADC Specifications	Differential ended, 16-bit, 1MSps, 0 ~ 10 V
External Trigger	1.3ms data acquisition
Data Storage	BRAM
Channels Sampled	4
External Trigger I/O Channels	1
Relay Output Channels	1
Operating Frequency	20Hz or higher
Pulse Width	1.5ms width

1. **PL** reads the **ADC** periodically.
2. When **trigger** occurs, **ADC** data is sequentially read and stored in the **BRAM**.
3. Interrupt occurs when the count of the data stored in the BRAM is the count required.
4. Interrupt is input to the **PS** and delivered to the **kernel**.
5. When the **kernel** module catches interrupt, it generates a signal through a specific process (**EPICS IOC**).
6. When an **EPICS IOC** receives a signal, it reads the data of the BRAM and generates the waveform data.

Embedded System – pDAQ Performance

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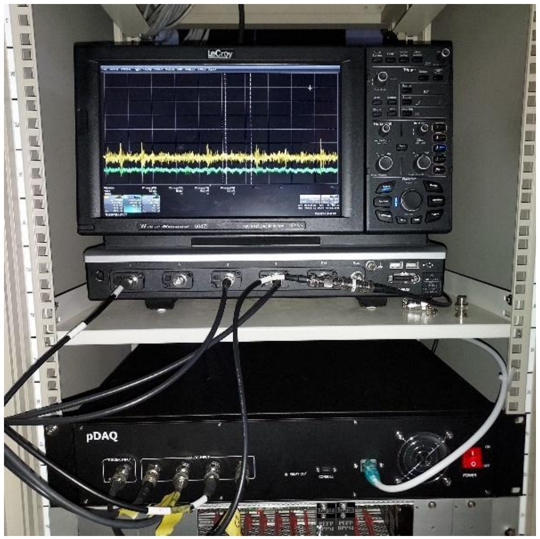
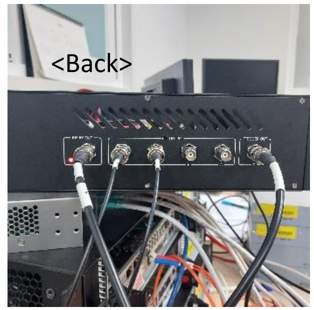
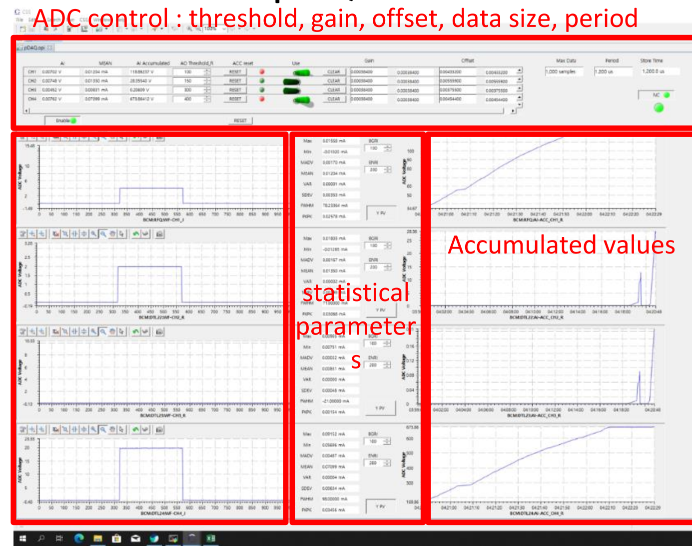
pDAQ Installation for Beam Monitoring

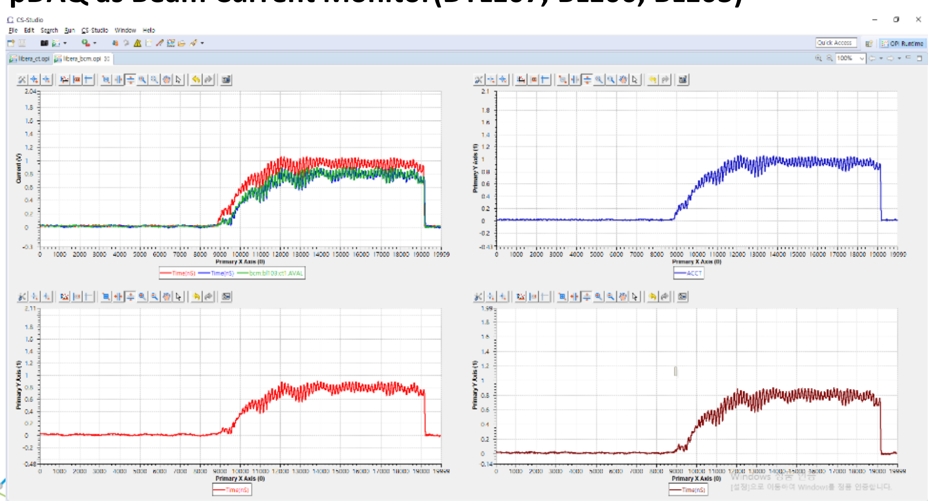




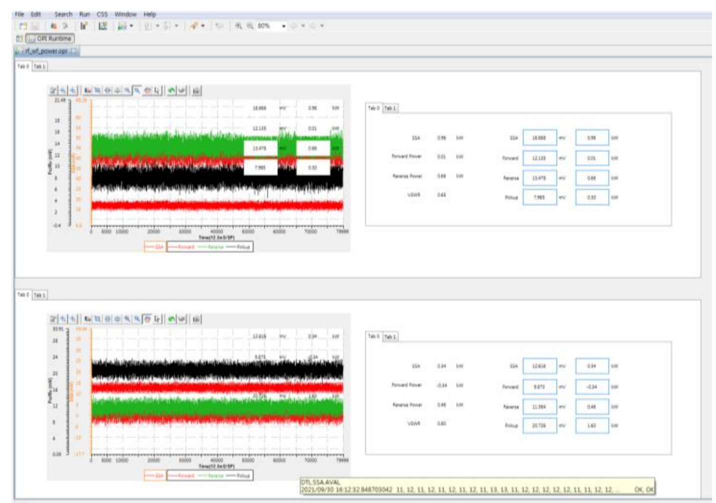
User Interface for pDAQ



pDAQ as Beam Current Monitor(DTL107, BL100, BL103)



pDAQ as RF Monitor



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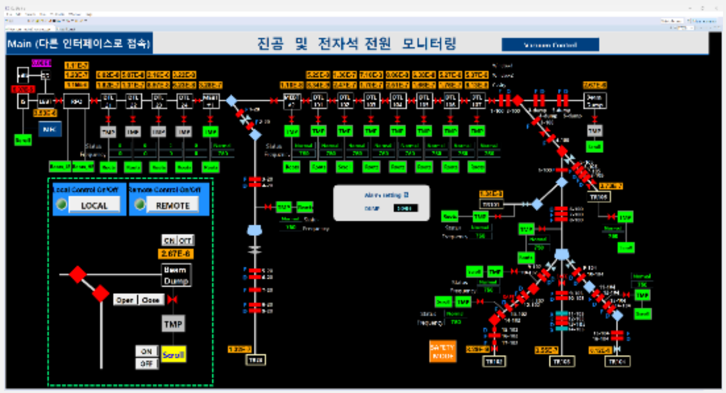
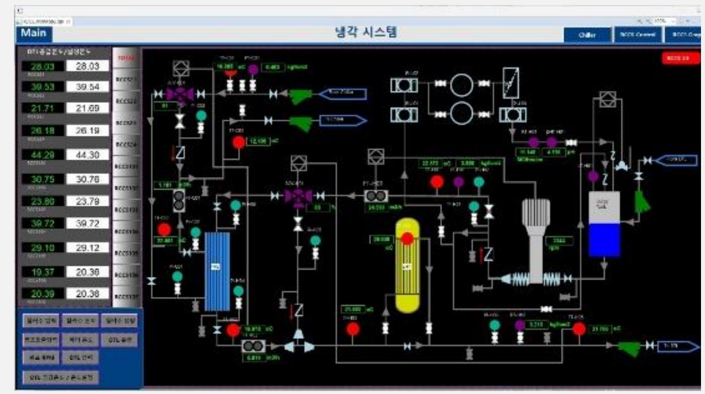
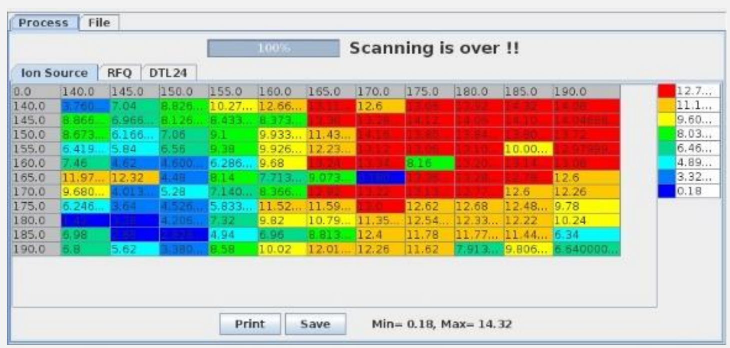
Client Software

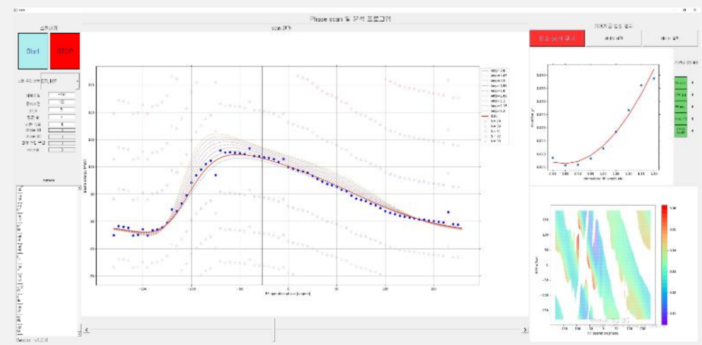
CSS



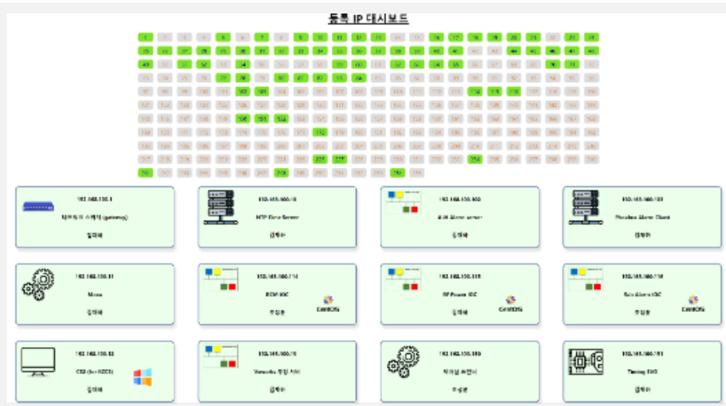


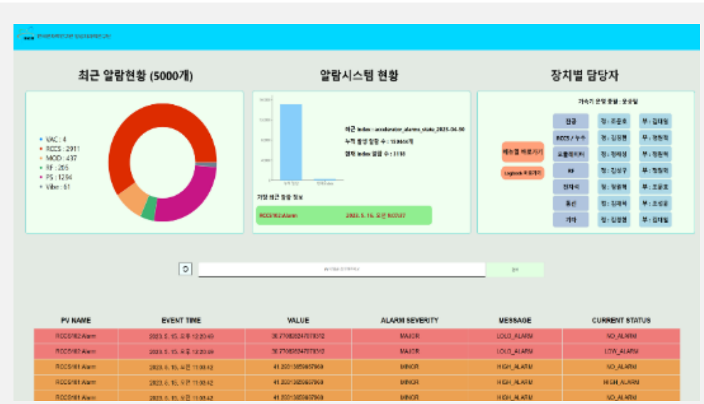
Python + Java





Web



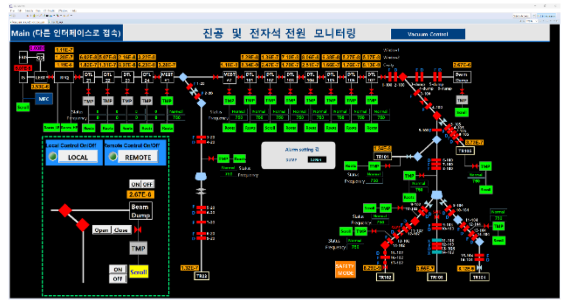


Client Software – CSS

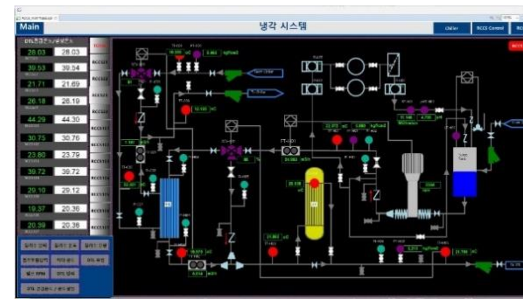
GUIs for LINAC

Magnet Power Supply GUI

Vacuum GUI



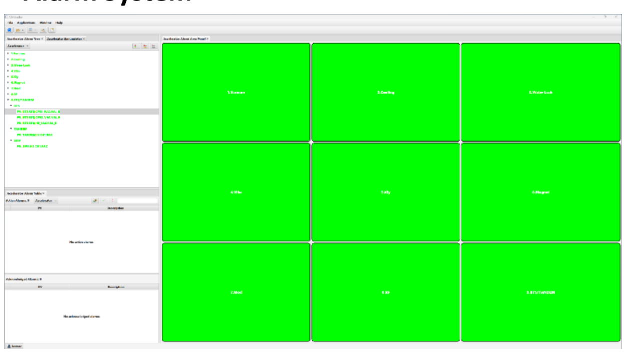
RCCS GUI



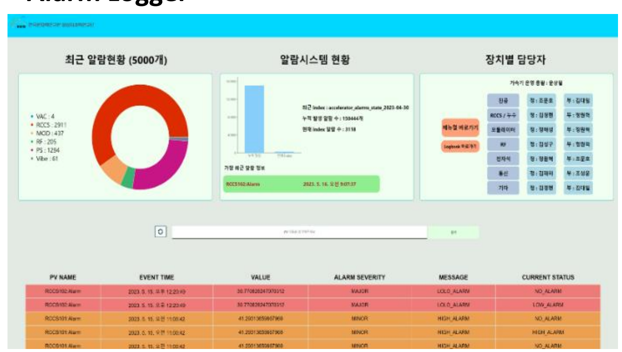
- The main user interface for the KOMAC control system
- Comprehensive set of tools for monitoring and controlling various aspects of the system

CSS Services

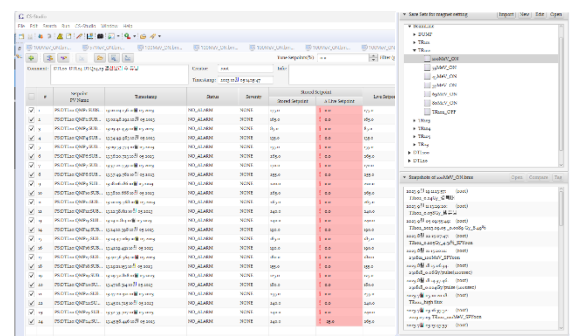
Alarm System



Alarm Logger



Save and Restore



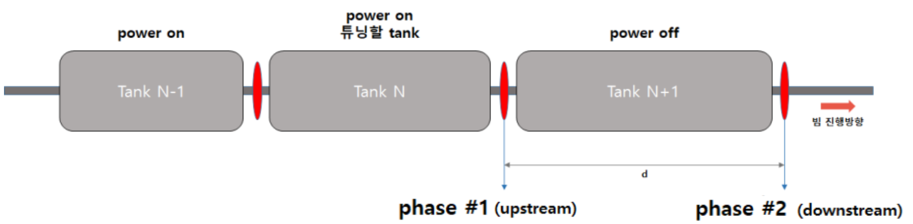
- Alarm system : **Phoebus** based alarm server, Alarm logger with **ELK stack**
- Save and Restore : Timing & Magnet operating information, Integration with **GitLab**

Client Software – Python/Java

Beam Tuning and Diagnostics Applications

Phase scan

RF Phase scan application find phases accelerated by design energy using beam phase monitor diagnostic equipment



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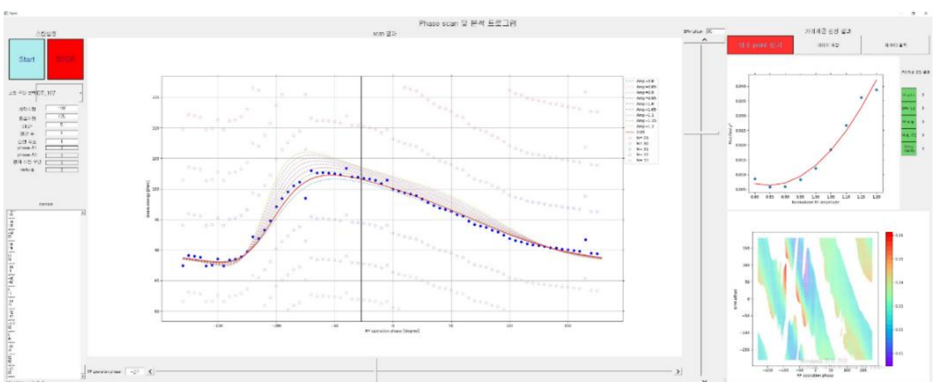
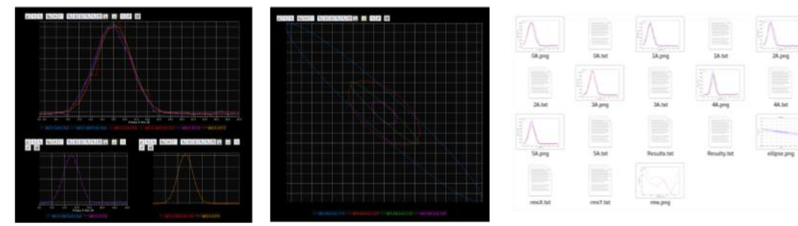
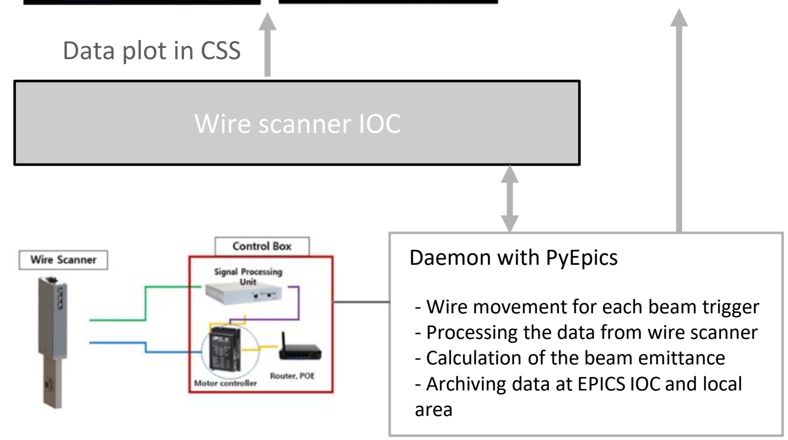


Quad scan

Efficiency of beam emittance measurement by improving wire scanner control and data processing system



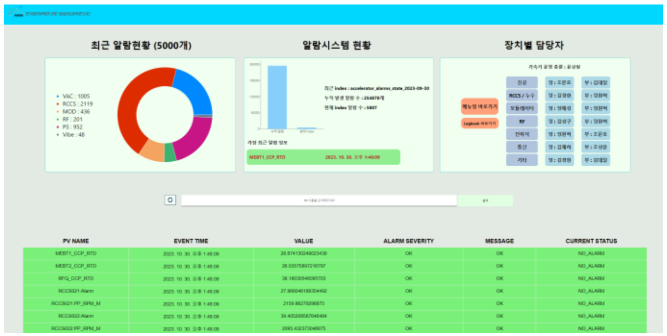


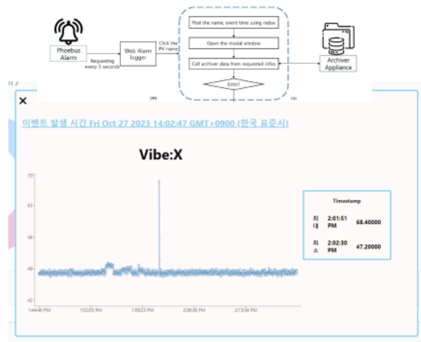
- **Python and Java binding** for powerful user interface in beam diagnostics applications:

  Modelling simulation, machine learning, enterprise database and experiment DAQ

Client Software – Web

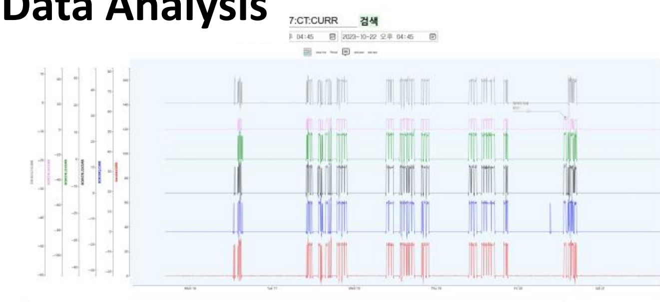
Alarm Log Analysis





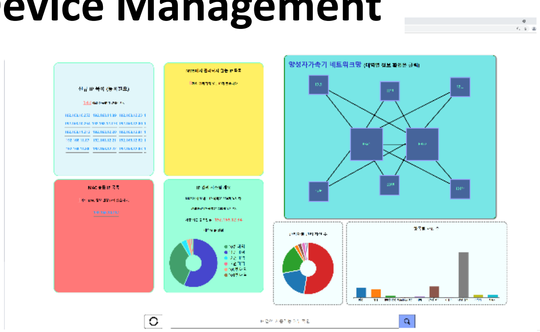
- Collecting alarm information from phoebus-based alarm system via **ELK stack** and Visualizing alarm status using **Reat**
- Every time an alarm occurs, update the most recent alarm
- Selecting a PV from the alarm table allows immediate access to data for the one-hour period before and after the event occurrence.

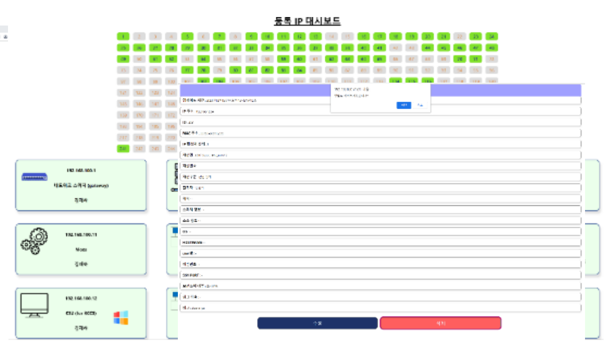
Data Analysis



- developing a data analysis web tool using the **D3 library**
- Adjusts sampling size dynamically for swift rendering during zoom events.
- Computes stability statistics with each zoom event for real-time analysis.

Device Management





- Developing a device management application using **Django** and **React**
- Utilizing IP activation connection information from NMS
- Management through DB enables real-time interworking and identifies network status, MAC changes, etc.

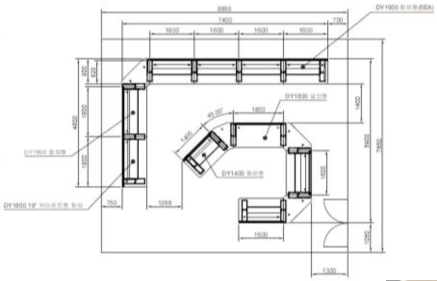
Summary

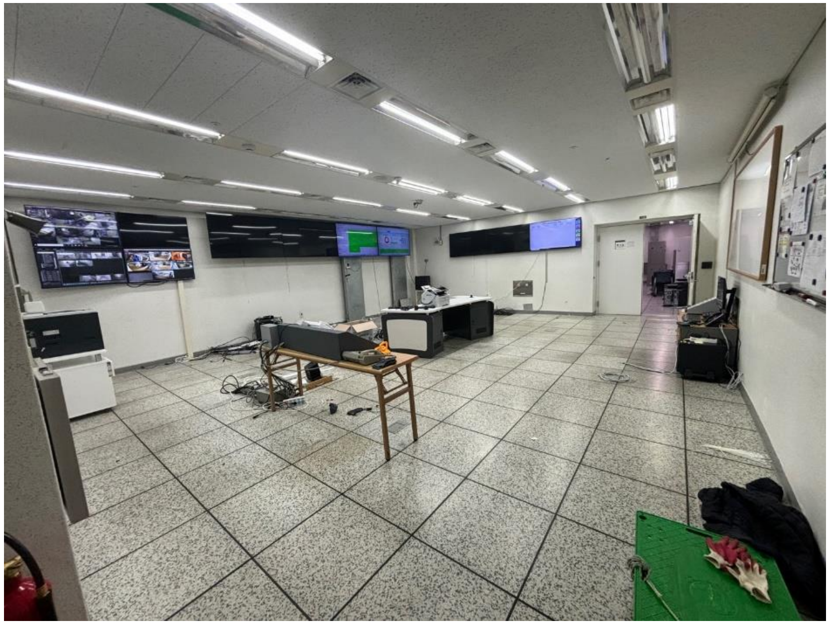
- Development and stable operation of an integrated control system Using EPICS software.
- Implementation of a user-friendly interface tailored to optimize operation of the KOMAC
- Continuous enhancement of the KOMAC accelerator control system through in-house technology development
- Establishing an environment for data acquisition system (DAQ) application, synchronized data collection, storage, and analysis.
- Advancement in application development skills for machine study and beam diagnostics.
- Planning for modernizing the framework :

  Ubuntu or Rocky Linux(Centos7), Phoebus (CSS), EPICS7(EPICS3)

Thank you

Renewal of Central Control Room



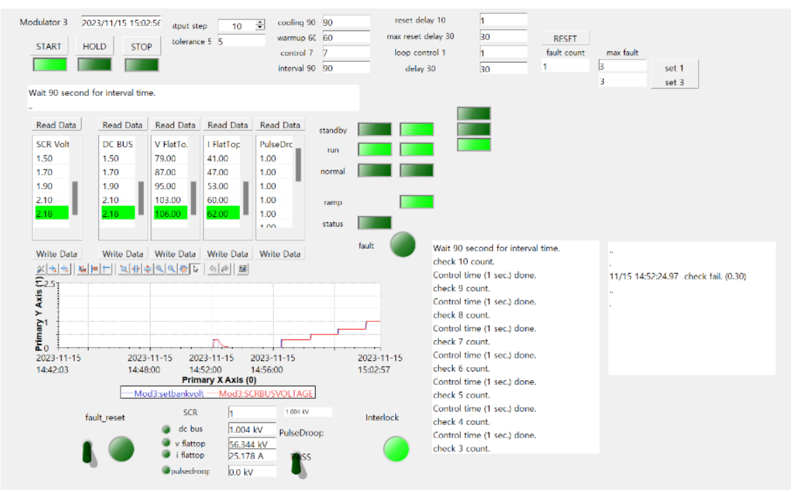


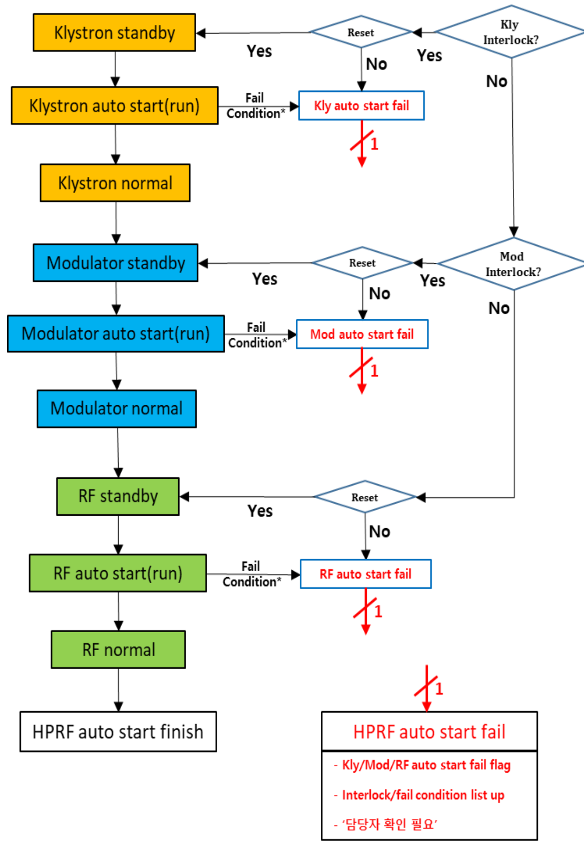
Automation

- Reducing the burden on operators by simplifying tasks and automating processes

Implemented automatic driving logic for the moderator (2023)

Developing automatic driving logic for the klystron and high-frequency (2024~)





Interlock condition

1. Klystron interlock
   1) Heater
   2) Ion pump
   3) Magnet
   4) Flow
   5) Kly temperature
2. Modulator interlock
   1) Gate width
   2) Modulator output width
   3) Gate repetition
   4) Gate duty
   5) DSP fault
   6) Cap Bank voltage
   7) SCR voltage
   8) IGBT OV/OI
   9) Mod out OV/OI
3. RF interlock
   1) Vacuum interlock
   2) RCCS interlock
   3) RF stabilization interlock
   4) dF

Fail condition*

1. Klystron fail condition

2. Modulator fail condition

   1) DC bus voltage > ±5% (Ref. LUT)
   2) V&I flat-top Avg. > ±5% (Ref. LUT)
   3) V&I pulse droop > ±5% (Ref. LUT)
   4) |Read SCR voltage - Target SCR voltage| > 5%

3. RF interlock

   1) | Read_Temp-Set temp| >0.5°C
   2) | Read dF cold side valve rate -Read Temp cold side valve rate| > 5 %
   3) |Read_dF-Target_dF| > 5kHz
   4) RF stability counts > 3 counts
   5) |Read_dF-Target_dF| > 0.5kHz

Embedded System – pDAQ Development

1. **PL** reads the **ADC** periodically.
2. When **trigger** occurs, **ADC** data is sequentially read and stored in the **BRAM**.
3. Interrupt occurs when the count of the data stored in the BRAM is the count required.
4. Interrupt is input to the **PS** and delivered to the **kernel**.
5. When the **kernel** module catches interrupt, it generates a signal through a specific process (**EPICS IOC**).
6. When an **EPICS IOC** receives a signal, it reads the data of the BRAM and generates the waveform data.