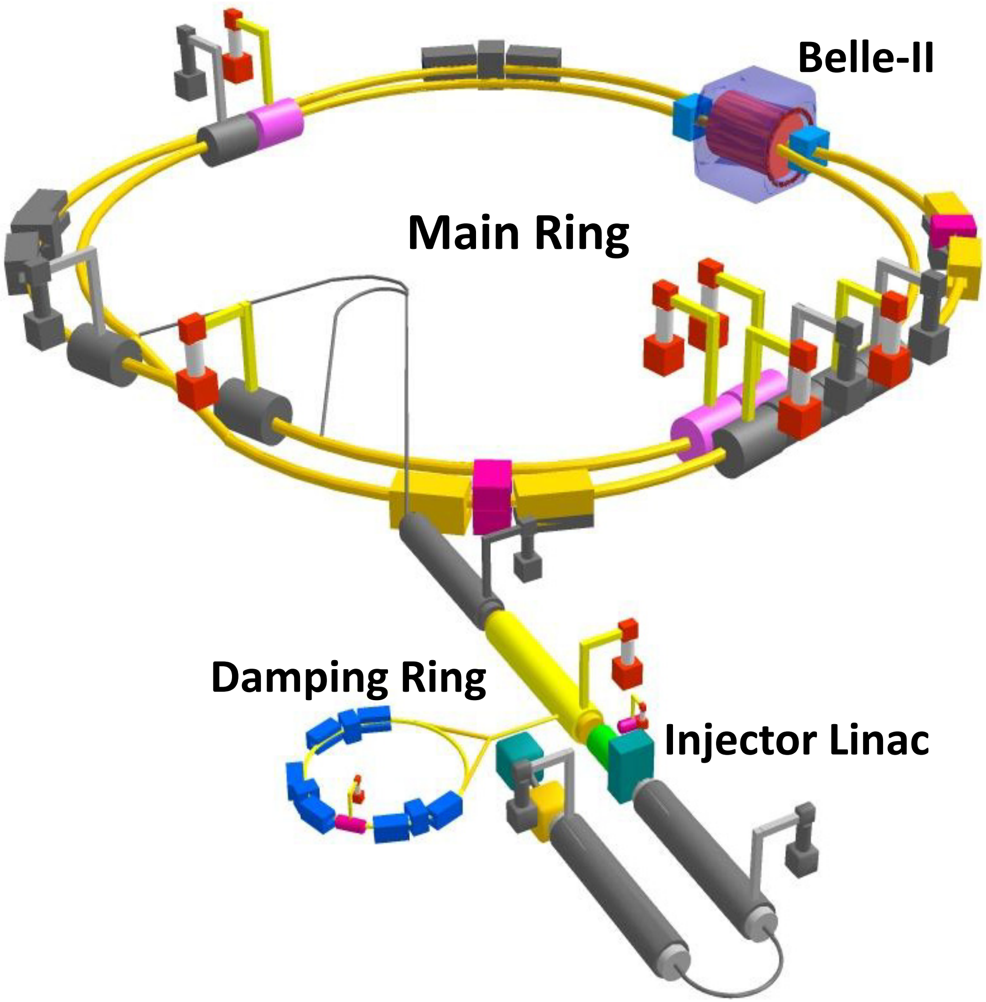
Hiroshi Kaji（KEK）
on behalf of the SuperKEKB control group

Control System of SuperKEKB

The SuperKEKB Accelerators



Electron-Positron Collider

C.M.S. Energy: $\sqrt{s}$ = 10.58 GeV
Luminosity: **L = 8 x 10^{35} $cm^{-2}s^{-1}$**
(Luminosity Frontier Machine)

	Electron	Positron
Energy (GeV)	7	4
Current (A)	3.6	2.6

This progressive project is strongly supported by the hard and sophisticated works of the control group.

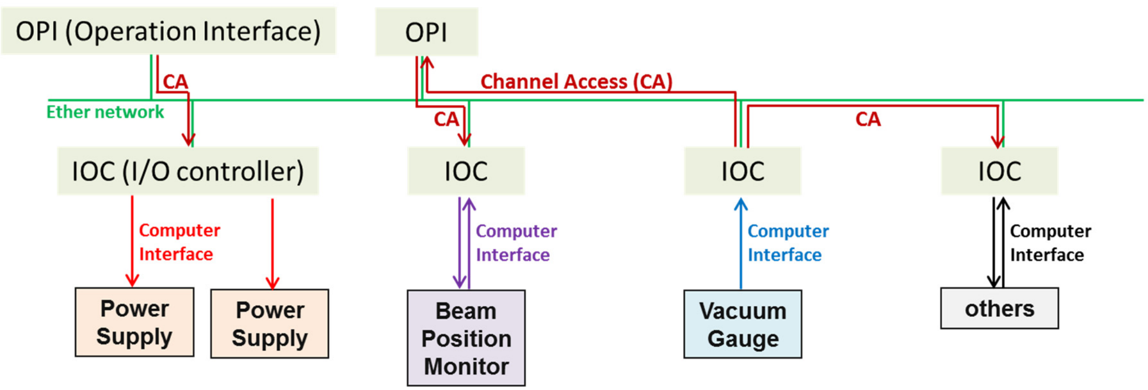
Phase-1: 2016 March - June
- Smooth start-up of accelerator
- Vacuum scrubbing

Phase-2: 2018 March - July
- Operation of positron damping ring
- Collision experiment is started.
- The world's smallest beam size at IP
  $sigma^*_y$ = 0.4um @ $beta^*_y$ = 3mm

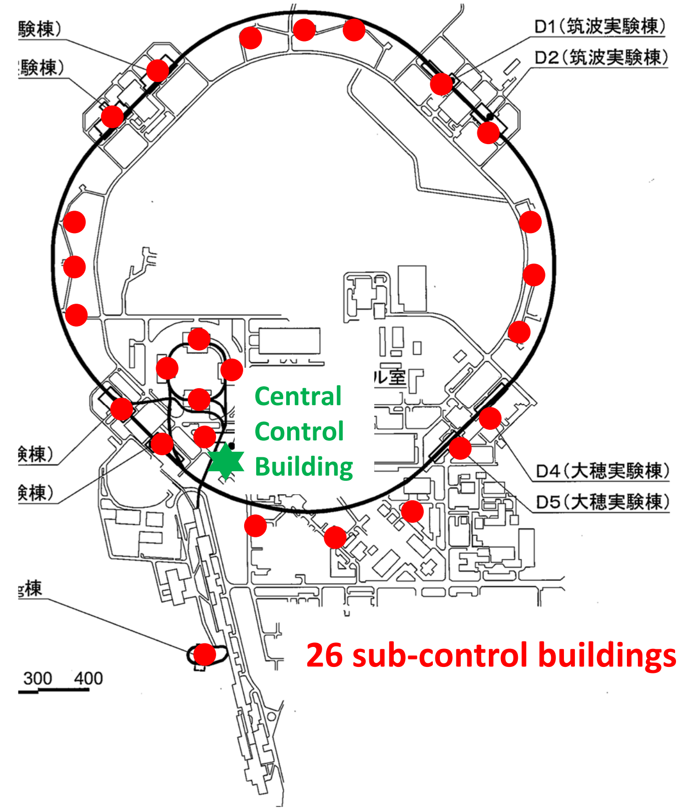
Phase-3: 2019 March -
- Physics run with top-up operation
- $beta^*_y$ = 2mm is achieved.
- The operation is resumed since this October.

Control System based on EPICS

The 10000 components installed belonging to ~3km beamline are operated with the distributed control system based on EPICS.



There are ~200 Input/Output Controllers (IOCs) installed on the **26 sub-control buildings**.
The servers and operator consoles are installed on the **Central Control Building** and most of Operator Interfaces (OPIs) are running here.
They are connected via the dedicated network system.



The control system is working properly since 2016 and we are steadily improving it with the increased requests from the operation.

IOC and OPI

IOC (Input/Output Controller)

VME form-factor 98 IOCs
- CPU: mostly MVME5500, MVME4100 and MVME6100 (EPICS v3.14.8-v3.14.12)
- OS: VxWorks (real-time OS)
- High-spec. and robust system

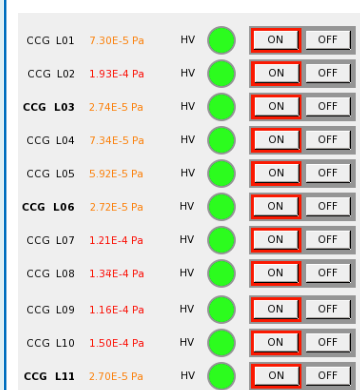
PLC form-factor 95 IOCs
- CPU: F3RP61 (EPICS v3.14.8-v3.14.12) F3RP71 (EPICS v3.15.6)
- OS: Linux
- Small size, Low price, low power consumption

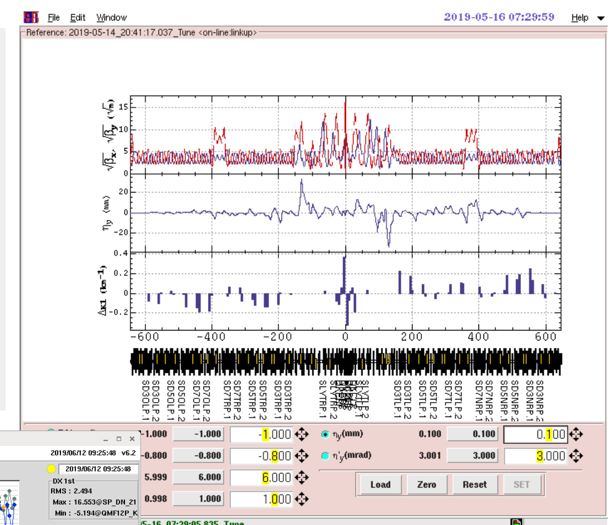
Others
- cPCI Event Receiver IOC
- microTCA for LLRF
- Software IOC as the middle layer system

OPI (Operator Interface)

SAD and Python scripts
- Tk toolkit for GUI
- Channel Access functions
- Optics calculation, tracking, ...

Control System Studio (CSS)
- All-in-one application for accelerator control





Server and Console

Control Server
- OS: Linux (and one HP-UX)
- 14 blade servers
- 10 rack-mount servers
- software IOC
- Monitoring system
- Alarm System
- Archive System
- Electronic Log system
- OPI based on Python

Middle Layer Services (software IOC, Monitoring system, Alarm System, Archive System, Electronic Log system)

Operation Server (SAD cluster)
- OS: FreeBSD
- 8 servers for operation and offline
- SAD script services
- OPI based on SAD
- tracking/simulation

Operation Console on CCB
- on Central Control Building
- Linux as X-terminal
- OPI based on CSS

Mac mini
- on each Sub-Control Building
- for maintenance works at the local site
- network boot

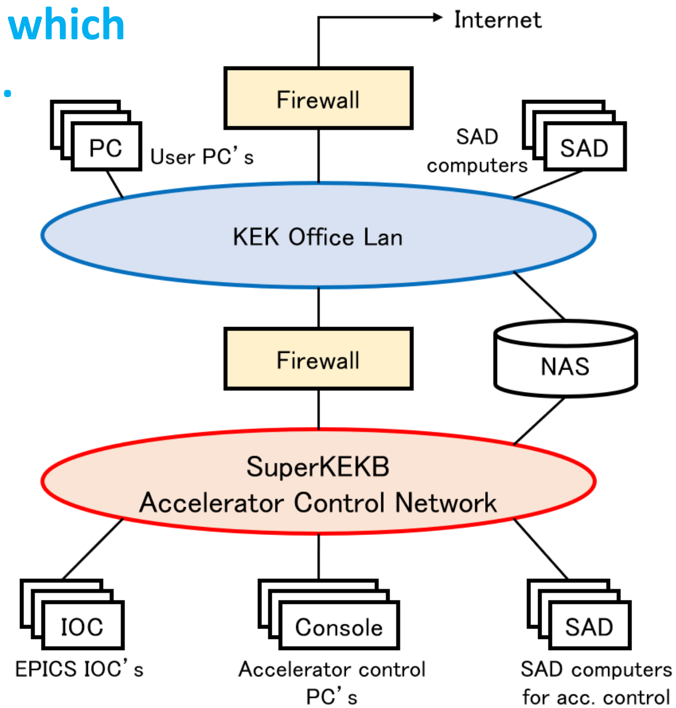
Network

The control system is developed on the dedicated network which is separated from the KEK office network with the fire-wall.

Configuration

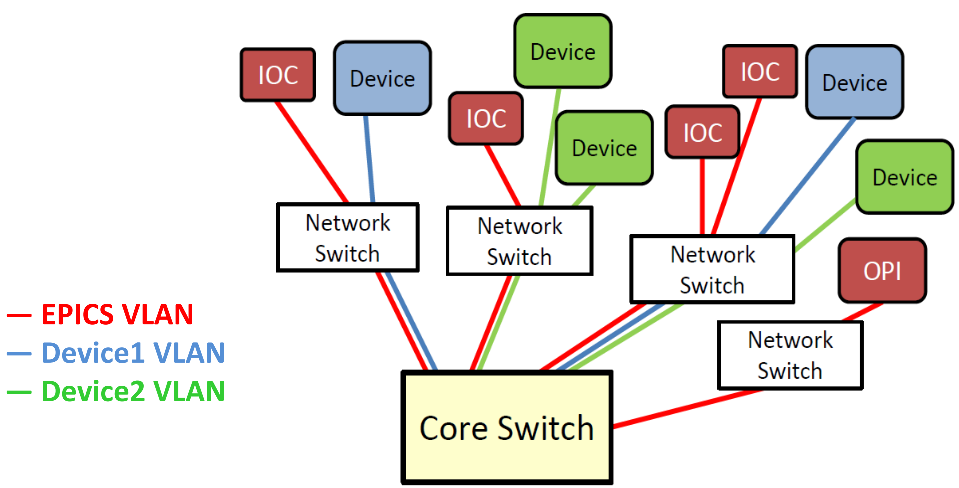
2 core switch at Central Control Building
40 edge switch at every Sub-Control Building
Redundant network based on Virtual Switching System
- Set of 10GbE and 1GbE-backup
- Partially, 1GbE and 1GbE, link aggregation

Leaky Coaxial cables in the entire accelerator tunnel



VLAN segmentation

EPICS VLAN + three Hardware VLAN
(for protecting the hardware from the large EPICS broadcast)

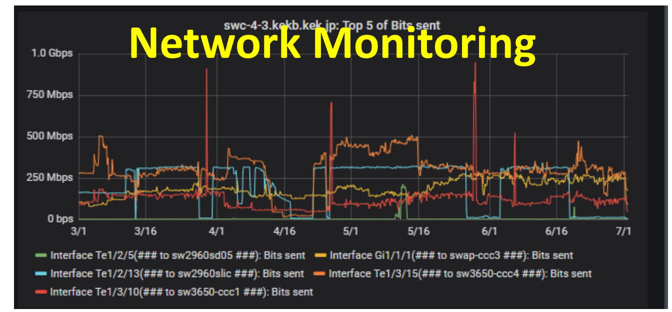


Monitoring System

The monitoring system is economically developed with open-source software.
The status of the control system can be checked from everywhere via web-browser.

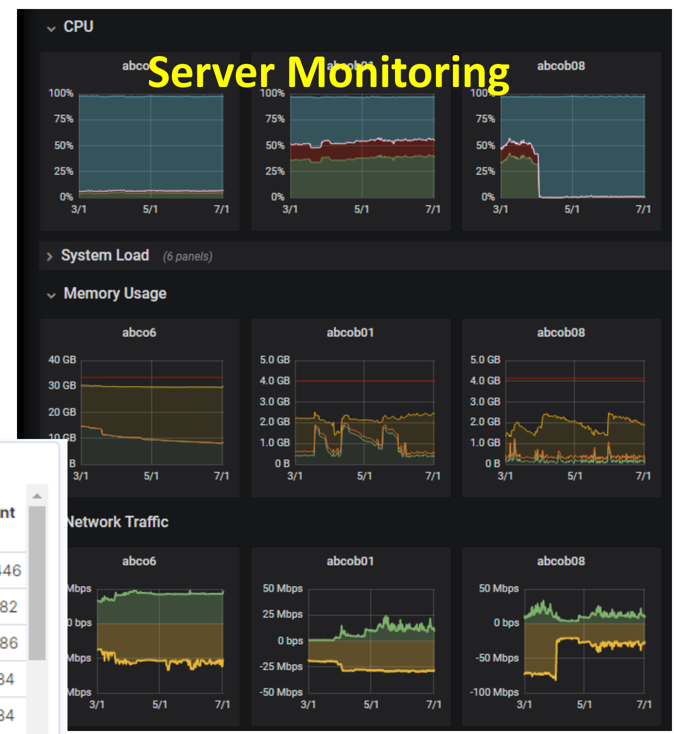
Followings are visualized with Grafana.

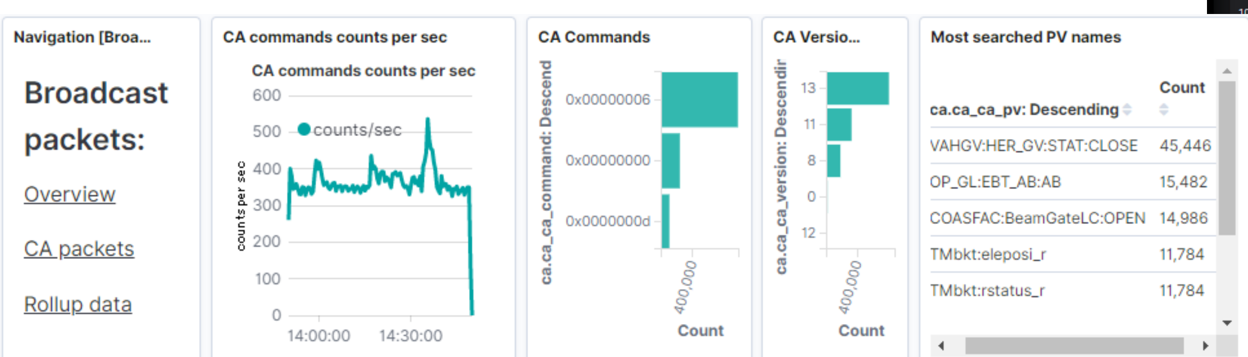
The status of network switches, servers, and IOCs are collected with Zabbix.
We originally developed and integrated the functions to collect the pvAccess of EPICS7. It enables us to collect the various fields information of PV such as the ***severity***, ***time***, ***…***



Elastic stack is utilized to monitor the following log messages. The results are shown with Kibana.

The "ps", "caSnooper", "casw" commands are periodically implemented and their logs are recorded with Elastic search.
The broadcast of the EPICS system is monitored with Wireshark which includes the cashark plugin.





Archive System

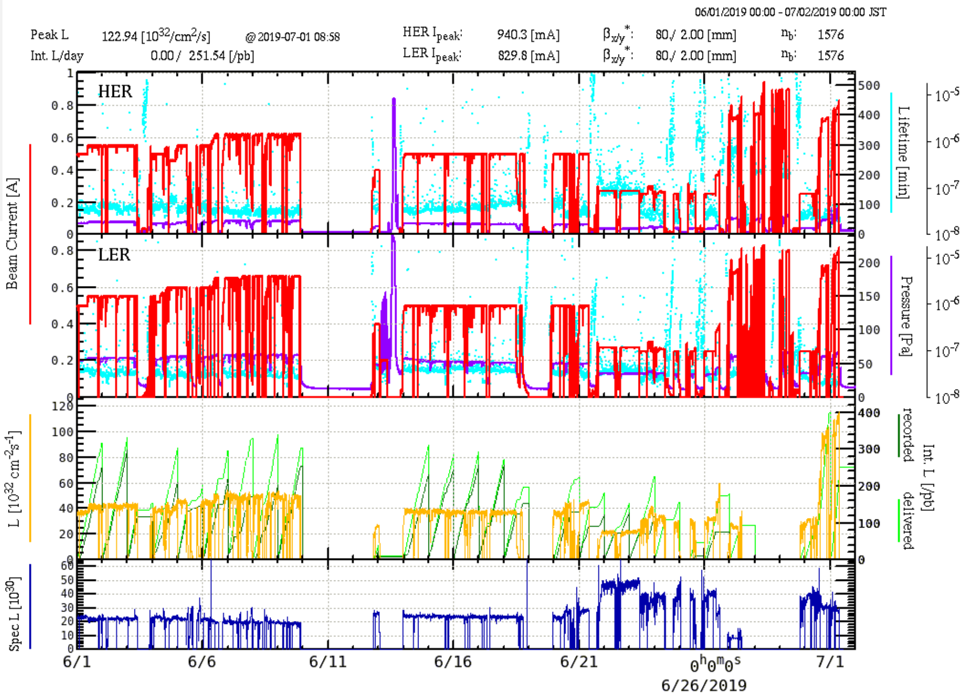
Our archive system collects and records the information of the EPICS PV.

KEKBLog: *maintained by the control group*

- Home-made archive system since the KEKB project
- All necessary information (130,000PVs) for accelerator operation is recorded.
- NAS is increased as needed.
- CASH server based on SSD

CSS Archiver: *freely maintained by all users*

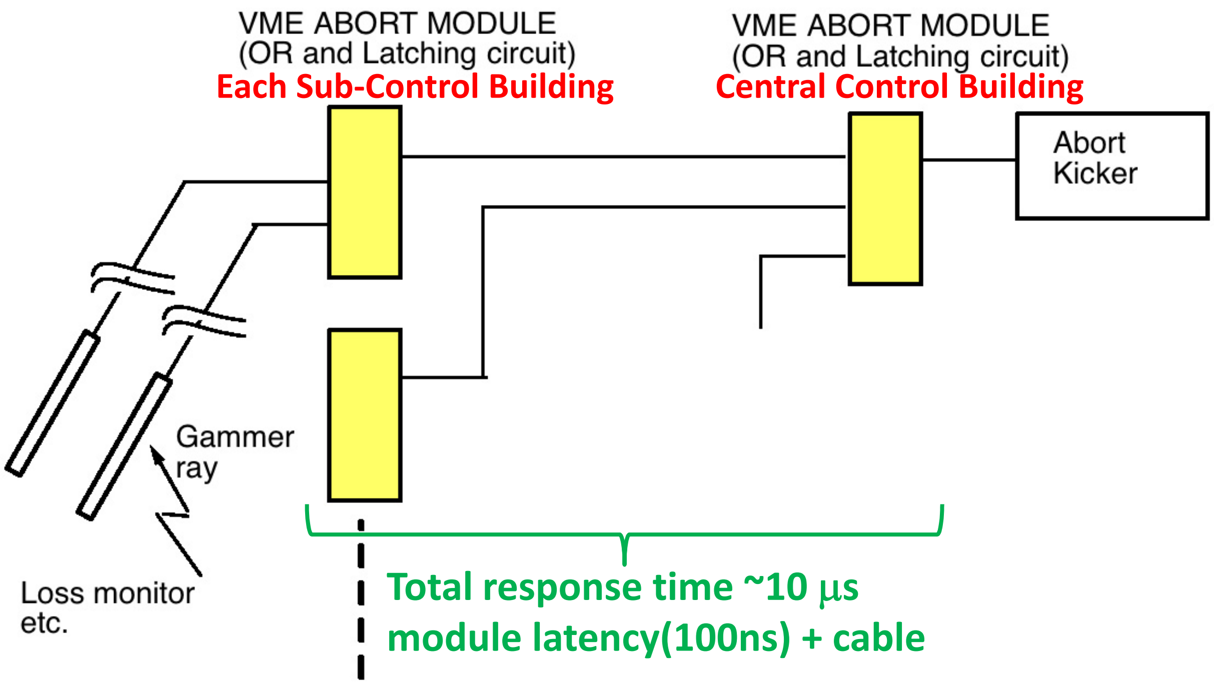
- Archiver for the particular usages



We plan to integrate the above two systems by Archiver Appliance.
The full service will be available since this Autumn run.
The new retrieve functions are developed with ROOT.

Abort Trigger System

Abort Trigger System collects and transfers ~260 inputs as the abort request signals.
Then it implements the abort kicker magnet to throw the beam from MR.
There is the timestamp function to distinguish the order of inputs.
The system is working without any serious problem since 2016.



The following upgrades are carried out in this summer shutdown.
- Increase the abort request signals from the IP hardware.
- Rewired from the CCB module to the abort kicker for reducing the response time.
- We decide to operate SuperKEKB with two abort gaps filling pattern.

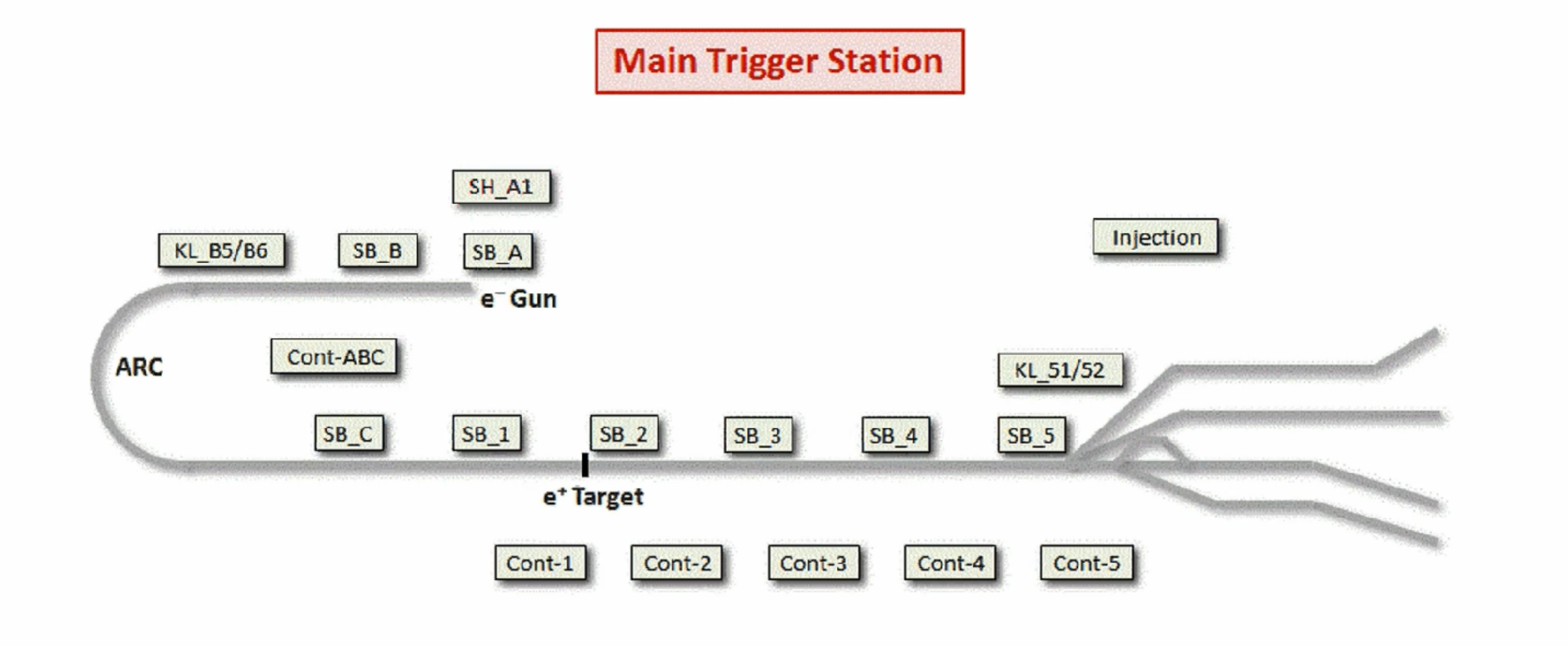
Timing System

Timing System based on the Event Timing System
- launches timing-triggers to the accelerator hardware
- launches interruptions at remote IOCs to change the operation parameters.

Pulse-to-pulse modulation

more than 150 LINAC parameters are switched in 50 Hz for the simultaneous top-up operations at 4 rings.

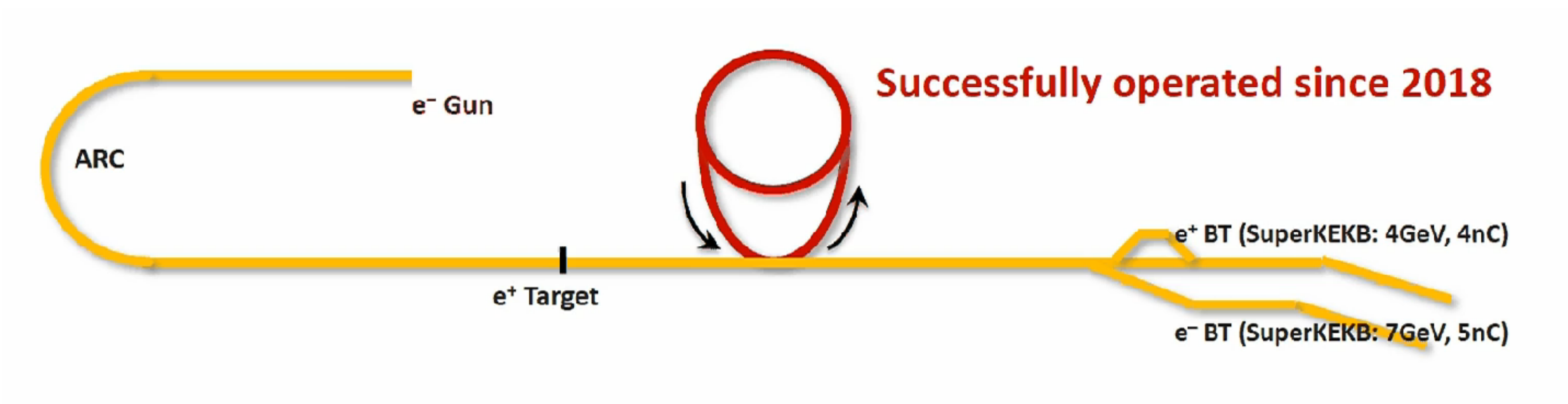
Ring	Particle	Energy (GeV)	Charge (nC)
HER	e^-	7.0	5.0
LER	e^+	4.0	4.0
PF	e^-	2.5	0.2
PF-AR	e^-	6.5	5.0



Injection with Damping Ring

The damping ring (DR) operation for the positron injection is started since 2018.
Injection scheme becomes heavily complicated.

The required damping time, “at least 40 ms”, is longer than the LINAC pulse period of 20 ms.
The difference of RF frequencies, like 2856MHz (LINAC) and 509MHz (MR/DR), requires extremely complicated timing management.



Further upgrade is required for the two pulses operation at DR.
⇒ Event Timing System controls the RF phase at LINAC in 50Hz.

EVR Development Project

The standalone EVR is developed with open source.

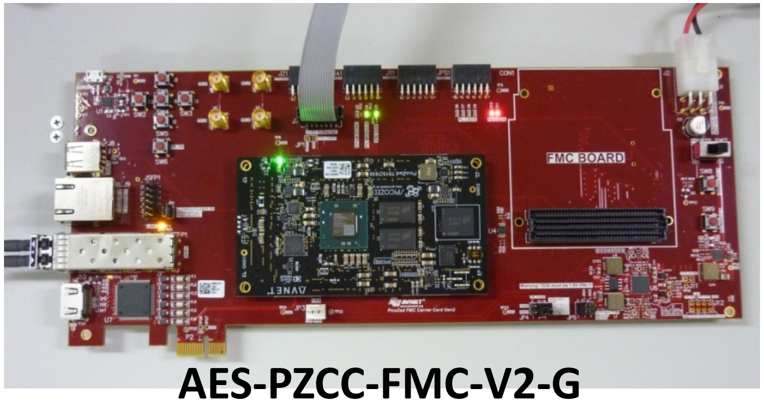
The SINAP-type standalone module is upgraded.

The Data Buffer (DB) and Distributed Bus Bit (Dbus) functions are integrated.
Individual outputs can be controlled with them.
- enable/disable by Dbus
- delay setting by DB

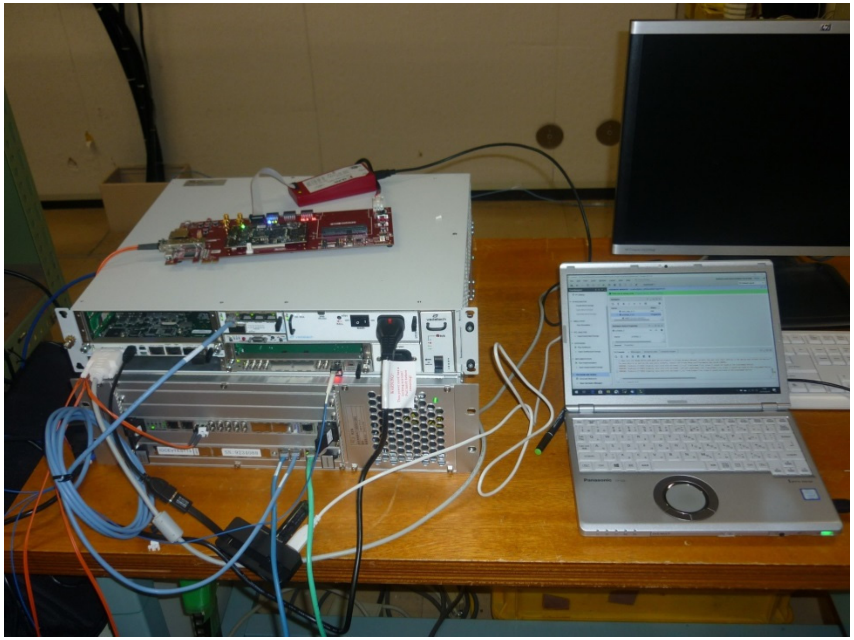
Three modules are installed and operated in our timing system.

Standalone EVR IOC with Zynq

plan to run EPICS on embedded CPU
More complicated operations become possible via the EPICS process.



AES-PZCC-FMC-V2-G



Conclusion

SuperKEKB has been operated since 2016 and smoothly attained its milestones. We developed a sophisticated control system to support this project.

The distributed control system is constructed based on EPICS.
- **There are ~200 IOCs, mostly built with VME or PLC.**
- **OPI is developed with SAD/Python script and CSS BOY.**

Several useful middle-layer services are developed/provided with open-source.

- **Monitoring system:**	**Grafana, Zabbix, Elastic search**
- **Alarm system:**	**CSS alarm**
- **Archiver:**	**CSS archiver, Achiver Appliance**
- **Electronic log:**	**Zope**

Dedicated optical network is configured for followings:
- **Timing system**
- **Abort Trigger System**
- **Beam Permission System**

The future prospect of the SuperKEKB project is promising since we are steadily upgrading the control system for the increased requests from the operations.