Challenging issues on timing and control of largescale colliders

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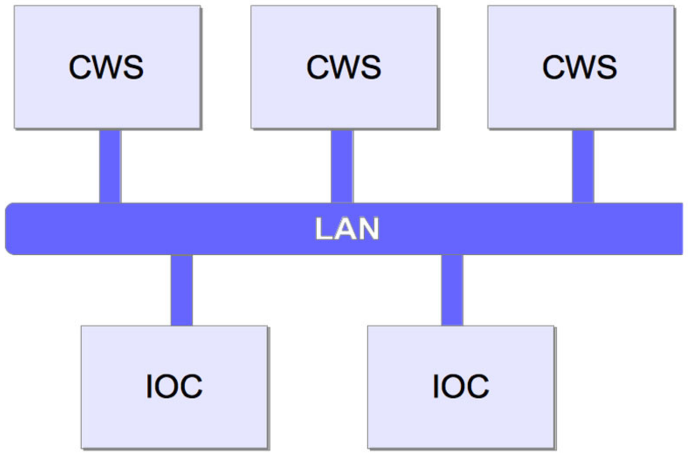
Outlook

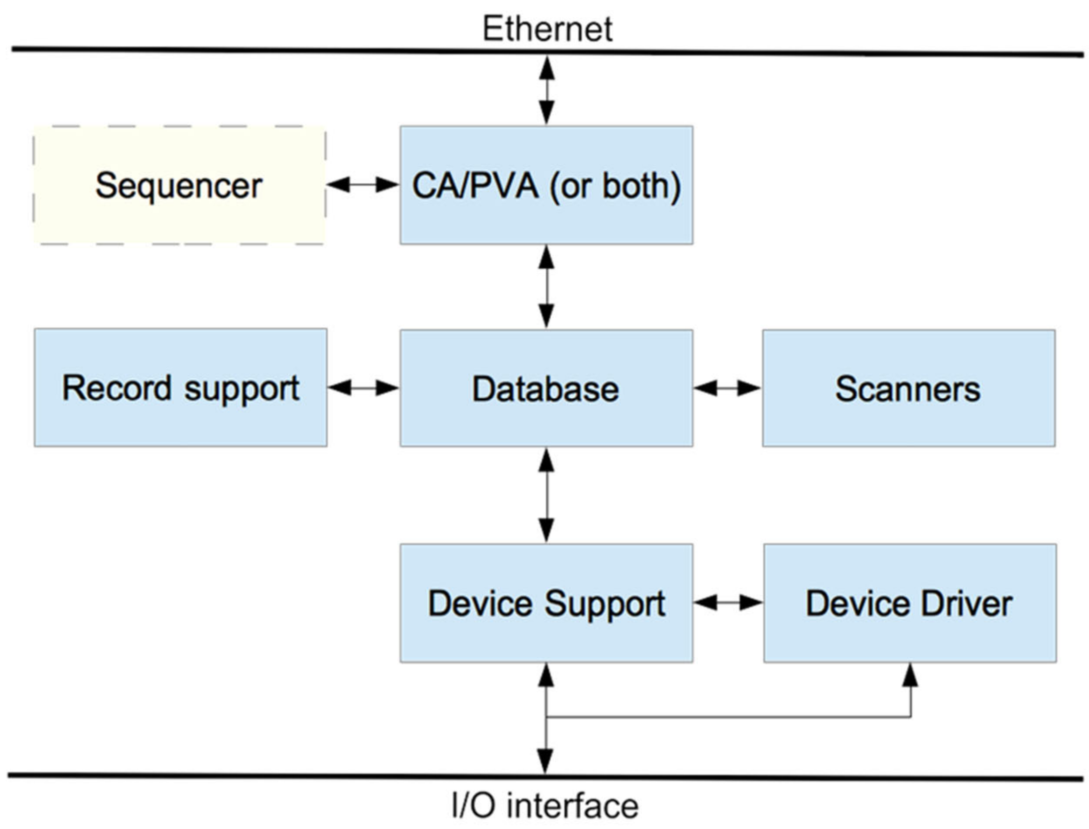
- Following is mainly based on the lessons learned from the experience of SuperKEKB/KEKB.
- Challenge on the control system using EPICS
  - Current trends of IOC/field-bus/Controlled-devices
  - Huge broadcast packets
- Challenge on the timing system
  - Requirements from Beam instrumentation, especially from the bunch feedback system
  - MPS related emergency timing, especially on the beam abort request.

EPICS control system



- IOC: Input Output Controller
  - Historically VME bus system with VxWorks, Linux, RTEMS OS
  - Might have several field bus, such as GP-IB, RS-232C, TTL I/O, etc
- CWS: Client workstation, might be mentioned as OPI: Operator Interface
  - GUI
  - Data archive sever
  - Software IOC

Inside IOC



Field bus: GP-IB, Serial, TTL I/O ARCNET, etc

"Devices with Ethernet IF" are widespread

Some basic architectures

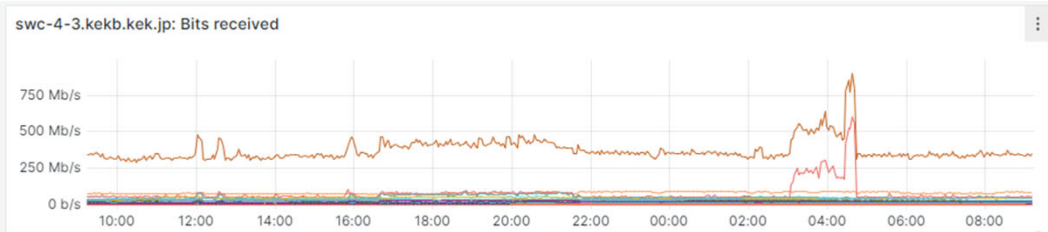
- **Distributed:**
  - An arbitrary number of IOCs and OPIs can be supported (as long as the network is not saturated).
  - As a distributed system, EPICS can scale from systems with a single IOC and a few clients to large installations with hundreds of IOCs and millions of I/O channels and process variables.
- **Event Driven**
  - The EPICS software components are all designed to be event driven to the maximum extent possible. For example, an EPICS client may, instead of having to query IOCs for changes, request to be notified of a change.
- **Robust**
  - Failure of a single components does not bring the whole system down. Components (IOCs, clients) can be added to and removed from the system without having to stop operation of the control system. The components can withstand intermittent failures of the interconnecting network and recover automatically when the network recovers from failure.

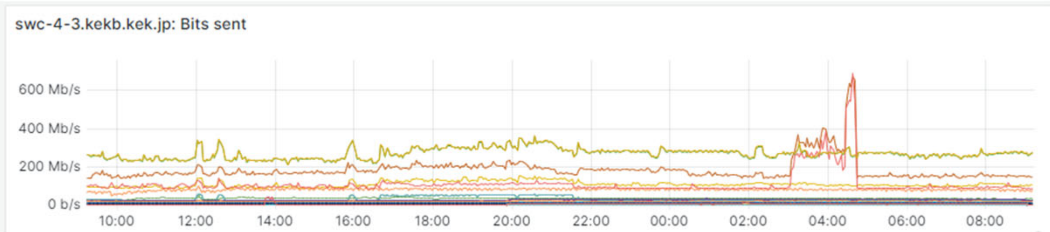
Channel Access (CA)

- **CA**
  - A network protocol and library for exchanging control data between CPUs (applications/processes).
    - The CA protocol is defined as a higher layer of TCP &UDP/IP.
  - In EPICS/CS, every control point has a unique name. Data exchange in EPICS/CA is done using this name without knowing the real place/structures, that is, user is not required to specify the IOC(CA Server).
  - Searches for actual locations are automatically performed using UDP broadcasts.
  - If the connection is lost due to network failure, etc., a similar mechanism will be used to try to reconnect.
- Enabling flat & easy access to the devices for user

Network traffic

- **Always large number of UDP packets are spread on the control network**





  - For example, during SuperKEKB ring operation, there exists 300M–400Mbps of traffic on the control network.
  - Note: During maintenance time, the traffic could increase x2–x3 due to downed (or off-lined) IOCs.
    - SuperKEKB's backbone network is 10Gbps, but the speed downstream from the edge switch remains 1Gbps (or less).

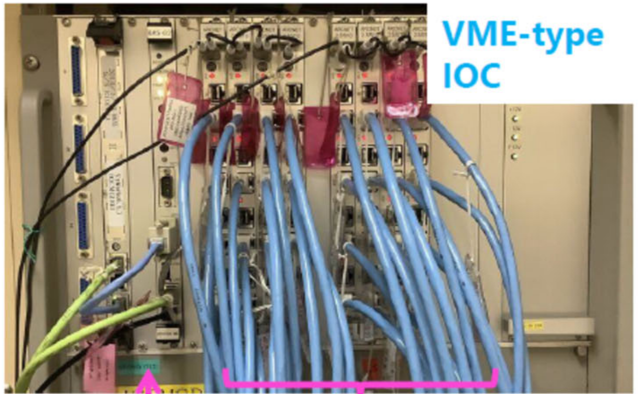
- **Will the "Device with Ethernet IF" be able to withstand that much network traffic?**

IOC at SuperKEKB

- There are more than 300 IOCs at CCR and SCRs.
  Mostly, the industrial CPUs like **VME**, **PLC**, or **μTCA**-types are utilized.
  In addition, the development of **embedded-type** and the application of **PC**

Group	VME	PLC	μTCA	PC	Embedded	Other
Magnet	9	30	0	0	0	0
RF	7	24	65	0	0	9
Monitor	48	7	0	0	0	0
BT	14	23	0	0	10	0
Control	22	0	0	19	5	0
Vacuum	2	29	0	0	0	0
Safety	0	6	0	0	0	0

Number of Control info.
- Hardware 10,000
- control info. 200,000



Devices under large network traffic

- **PC(Windows/Linux etc)**
  - Even with very old and slow PCs, I have very little experience of malfunctions due to network traffic (through I have had problems with certain Ethernet chips).
- **Device (DMM, Counters etc) with Ethernet IF**
  - Even if the device is made by a very well-known manufacturer, it may malfunction or hang up due to network traffic.
    - LAN-GPIB(Keysight), Xport, ..
    - Might be due to extremely poor CPU / miserable data buffer on the device.
    - It is better to assume in advance that manufacturers of measuring instruments, power supplies, etc. are not good at communication interfaces.
    - You could roughly check the IF with "flood ping" method. If failed with the flood ping, the device will NEVER work well under EPICS environment.

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--- 172.19.          ping statistics ---
5504 packets transmitted, 1421 received, 74% packet loss, time 85898ms
rtt min/avg/max/mdev = 64.072/645.605/864.584/130.775 ms, pipe 58, ipg/ewma 15.6
09/692.565 ms
[root@tobiyama-cv3 tobiyama]# 
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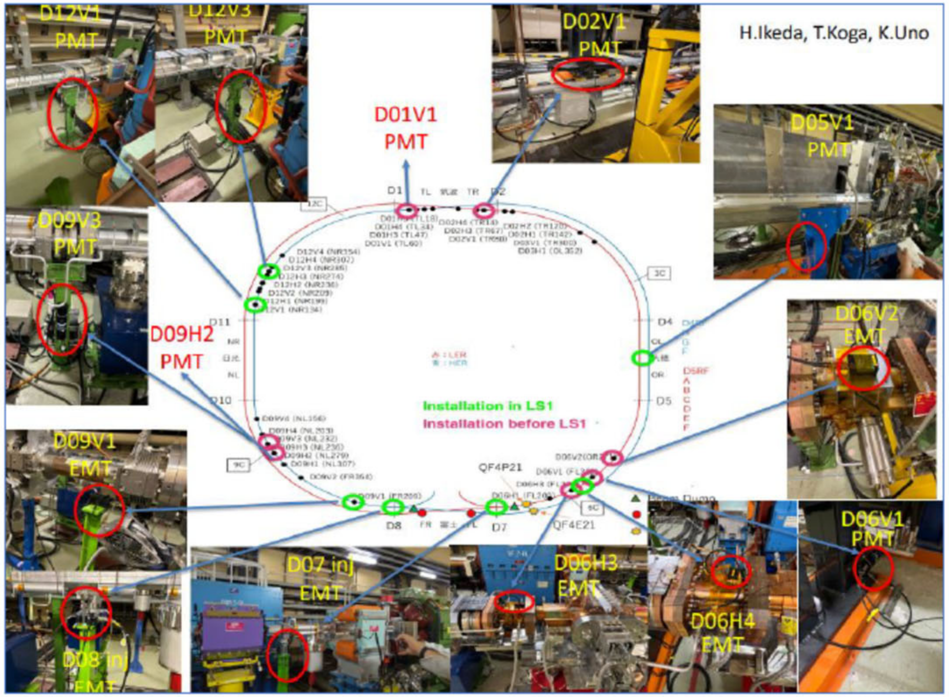
Some workarounds

- Talk to the manufacture and ask them to modify it to work under high traffic conditions (by showing flood ping data).
- Separate the network with "with CA (EPICS)" and "without CA—instruments only" using VLAN technique.
  - In SuperKEKB, we have (1) EPICS_CA (2) Device (3)Device for Beam instrumentation (4) Vacuum group VLANs.
  - For example, number of devices on (3) are ~270.
  - Still under "silent" network condition, some devices may malfunction or hang up– prepare remote-reboot ways.
- Prepare CA-search server to suppress broadcast.
- Anyway, devices with Ethernet IF should be tested under large UDP broadcast environment.

Timing system

- **On the viewpoint of beam instrumentation, we need following GOOD timing signal in all the distributed local control rooms:**
  - RF signal (with phase stabilized)
    - We usually use frequency multiplier (such as x4, x6 etc) for the bunch feedback system. As the phase jitter of the multiplied RF should be larger than the multiplied phase jitter of the original one, we strongly request small phase jitter.
    - Temperature drift of the signal (due to day-night, seasonal change) is also worrisome.
  - Fiducial (revolution)/Injection/Extraction timing with the jitter much less than the RF period.
    - It is easy to re-synchronize the signal using D-FF
  - Event timings (both incoming and outgoing)
    - Trigger the data acquisition, evet etc.
    - Abort request
  - Fine timing stamps (using White Rabbit?)

More loss monitors installed during LS1



- **Beam loss monitors** equipped with GPS-synchronized fast readout are installed along the main ring
- We can track the **chronological sequence of beam loss** at loss monitors and identify the ring location where initial beam loss occurred during SBL events
- During LS1, we installed **more loss monitors** at HER/LER collimators, which provides more precise position analysis and better understanding of SBL events
- We also installed loss monitors at **HER/LER injection points**, which allows injection loss timing analysis and useful for **injection /collimator tuning to minimize injection BG.**
- **GUI panel** is in preparation to provide read-time feedback to machine operator

Beam abort request

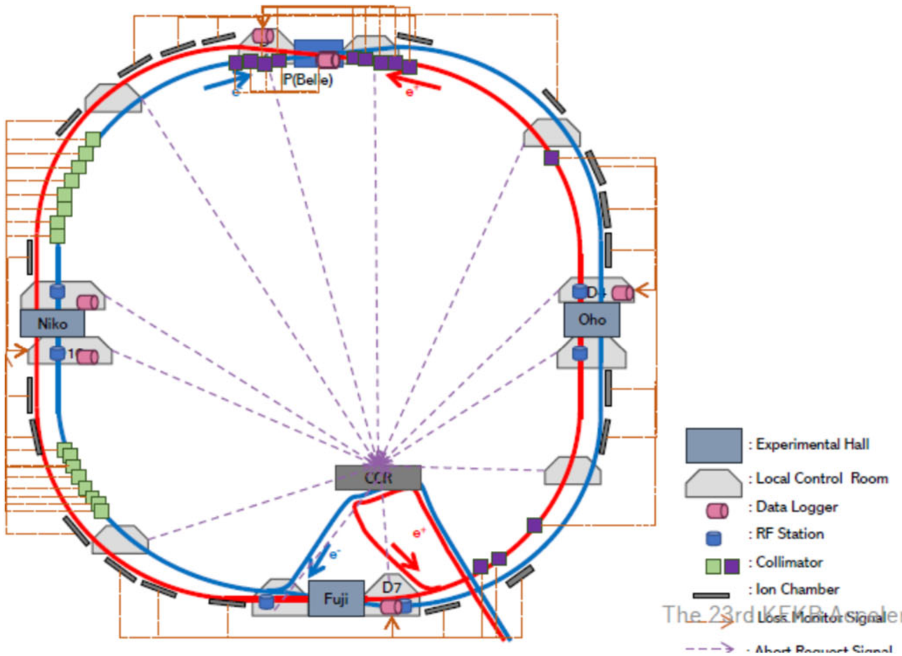
- **Beam abort request might be initiated with the following events as:**
  - Large beam loss signal from beam loss monitors (ICs, PINs, scintillator with PMTs, Diamond loss monitors..) or Experimental group.
  - Faire of the hardware devices (such as power supplies, arc discharge detectors, etc)
  - Safety system (PPS, MPS)
- **To protect vacuum components and experimental detector, prompt response (as quick as possible) is strongly required.**
  - Otherwise, "Crazy" beam could pass the experimental detector several times before beam abort!.

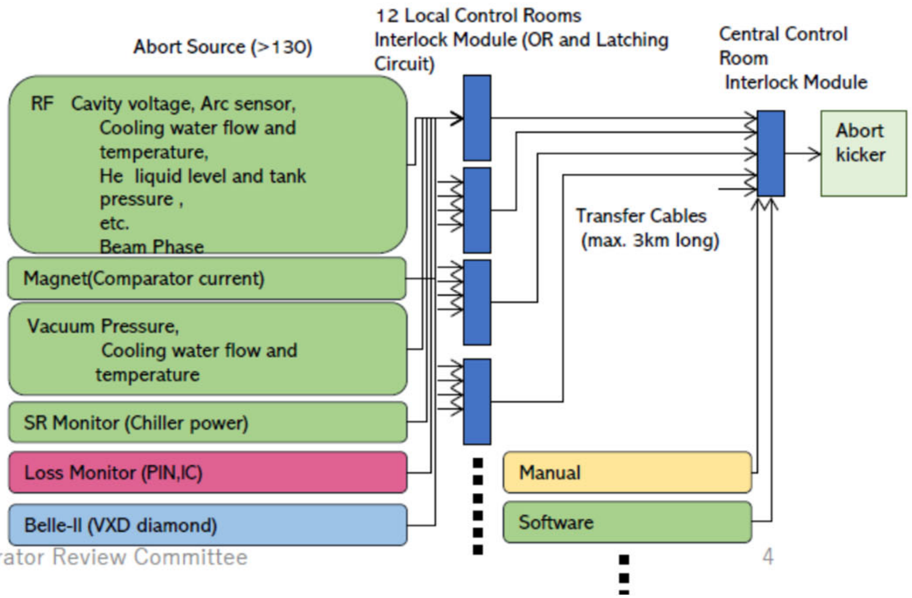
SuperKEKB case

Abort Trigger

The abort request signals from each hardware component are collected in 12 local control rooms (LCRs).

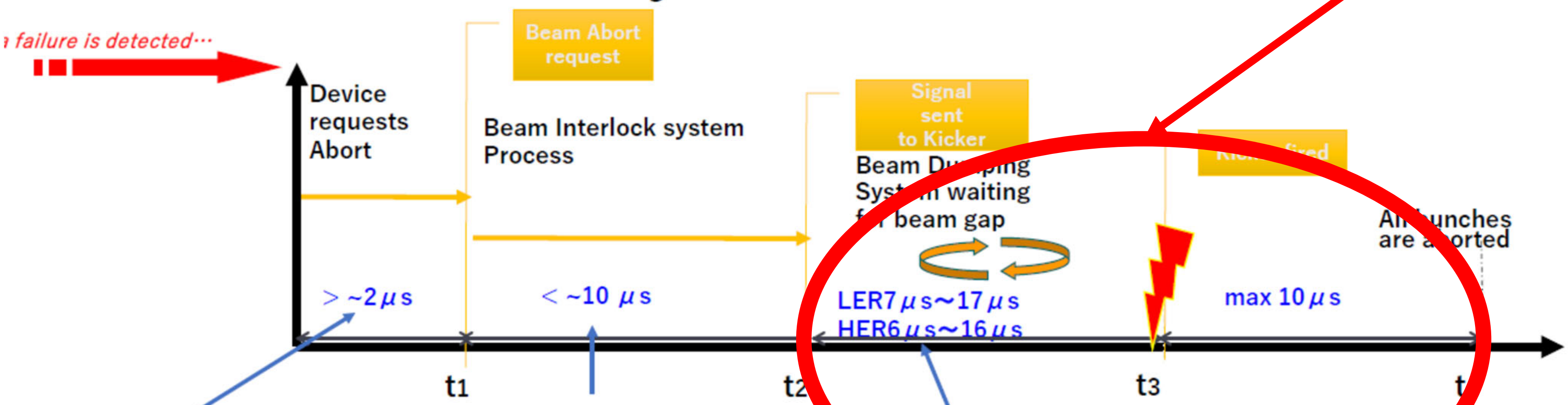
The request signals from LCRs, software abort request signals, and manual abort request signals are collected in the central control room and the abort kicker trigger is sent to the abort kicker.





Remove unnecessary delays around here (waiting time)

Beam Abort Delays



Hardware dependent

To summarize the abort request on the beam abort system.

Depends on the optical cable length from the local control room to CCR.

10μs for D1, D2(near Belle-II),

2μs for D7 or D8

Sy...chronization of the abort request signal wi... revolution in FP... : Max delay=10μs
Delay to sy...hronize to the abort ga...(fixed delay) : 4.2μs for LER, 2.8μs for HER
Delay from CCR to kicker (400m) : 2μs
Thyratron ON :1μs
Rise time for the kicker : 200ns

What could we do?

- **Beam abort gap**
  - In order to avoid giving an unnecessary kick when the abort kicker starts up, a place without a beam of a certain length is required (=Abort gap).
  - The fire timing of the abort kicker should be synchronized to the abort gap; if there are only one abort gap in the ring, we need to wait the abort with revolution time, in the worst case.
    - By preparing the several abort gap in the ring, the maximum waiting time could be 1/(number of abort gap) x Revolution time.
  - Another idea: Prepare very strong beam collimator downstream of the beam abort kicker to stop the beam that is kicked by the rising edge of the beam abort kicker.

- **Beam abort kicker**
  - It is extremely difficult to shorten the signal transmission time from the source point of abort request (loss monitor) to the abort kicker (signal speed ~2/3 c).
  - It is not realistic to transmit the beam abort signal so that it overtakes the beam.
  - By increasing the number of abort kicker (abort kicker near your loss monitor), your abort request could arrive much faster.

Suggestions to CEPC collider

- **Several beam abort system, at lest same or larger number as the number of collision detectors.**
- **Several beam abort gaps that could use for the beam abort.**
  - Or, you could prepare extremely tough beam collimators which could accept the crazy beam which is kicked at the rising edge of the abort kicker.

Summary

- **Several topics of challenges to the control system and the timing system for the largescale collider are shown.**
  - Network capacity with large broadcast packets from EPICS.
  - Sustainability of the devices with Ethernet IF under EPICS.
  - Good timing distribution.
  - Beam abort timing.