Beam Loss and Abort Diagnostics during SuperKEKB Phase-I Operation

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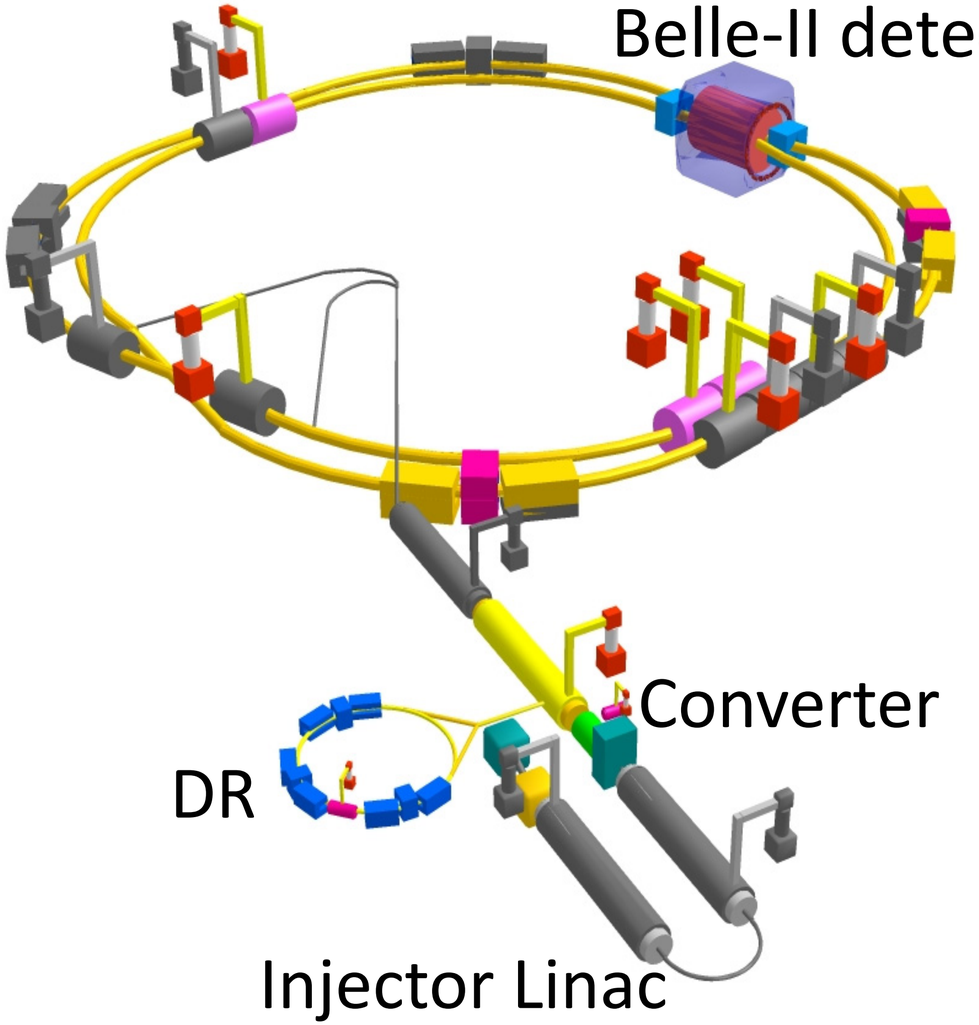
Introduction : SuperKEKB

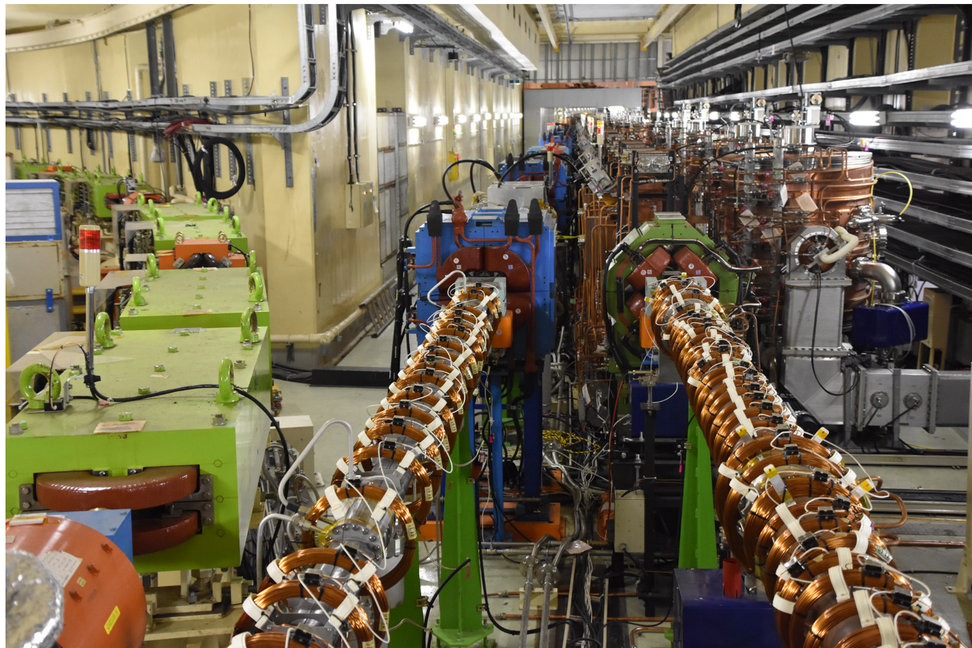


Parameter	LER(e+)	HER(e-)	DR(e+)	unit
Energy	4.0	7.0	1.1	GeV
No. of bunches	2500		4	
Circumference	3016		135.5	m
Max. stored current	3.6	2.6	0.07	A
Emittance (h)	3.2	4.6	42.5	nm
Emittance (v)	8.64	12.9	3150	pm
Bunch length	6.0	5.0	6.53	mm
βx/βy at IP	32/0.27	25/0.30		mm
Luminosity	8×10^{35}			$cm^{-2}s^{-1}$
RF frequency	509			MHz

Machine Parameters of SuperKEKB

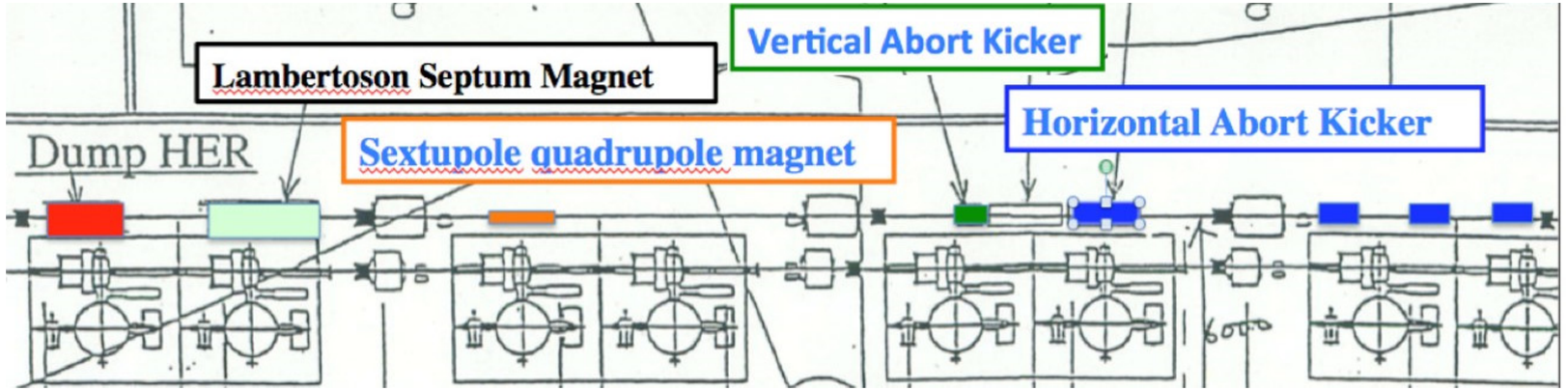
Introduction : Operation Plan

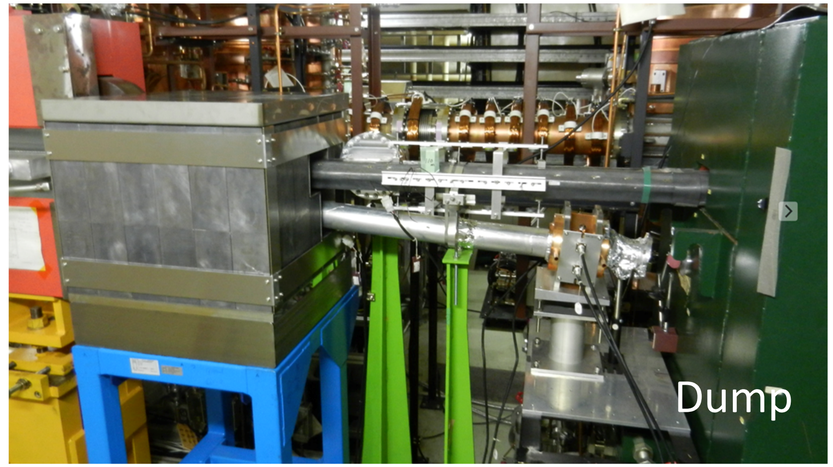
- Phase-I : Feb.- June, 2016,
  Hardware performance check w/o QCS and Belle-II.
  ↓ Installation of QCS, Belle-II, and Damping Ring.
- Phase-II : Oct.,2017 - July, 2018,
  With Belle-II (no VXD).
  ↓ VXD installation.
- Phase-III : Jan.,2019-,
  Operation of full Belle-II detector.



Abort and Abort Monitor System : Abort System

In order to protect the hardware components of the detector and the accelerator against the high beam currents, we installed the controlled abort system.



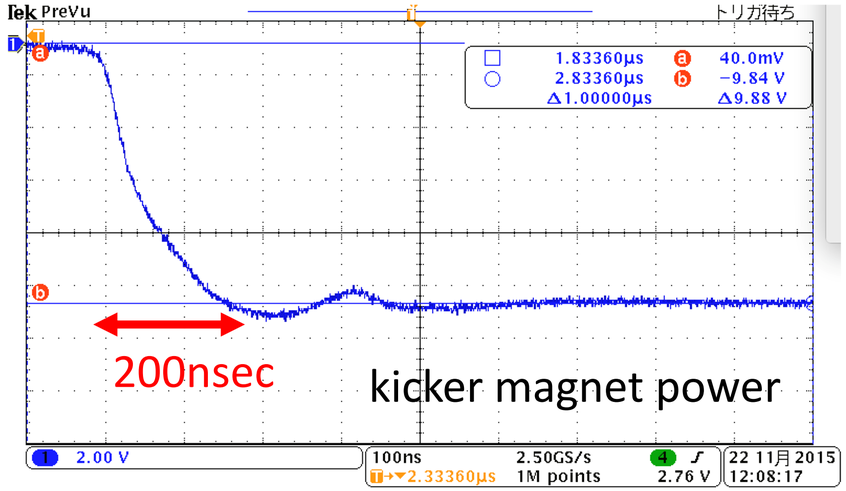


Dumped beam length : one revolution time (10 μs).

Build-up time of the abort kicker magnet : 200 ns

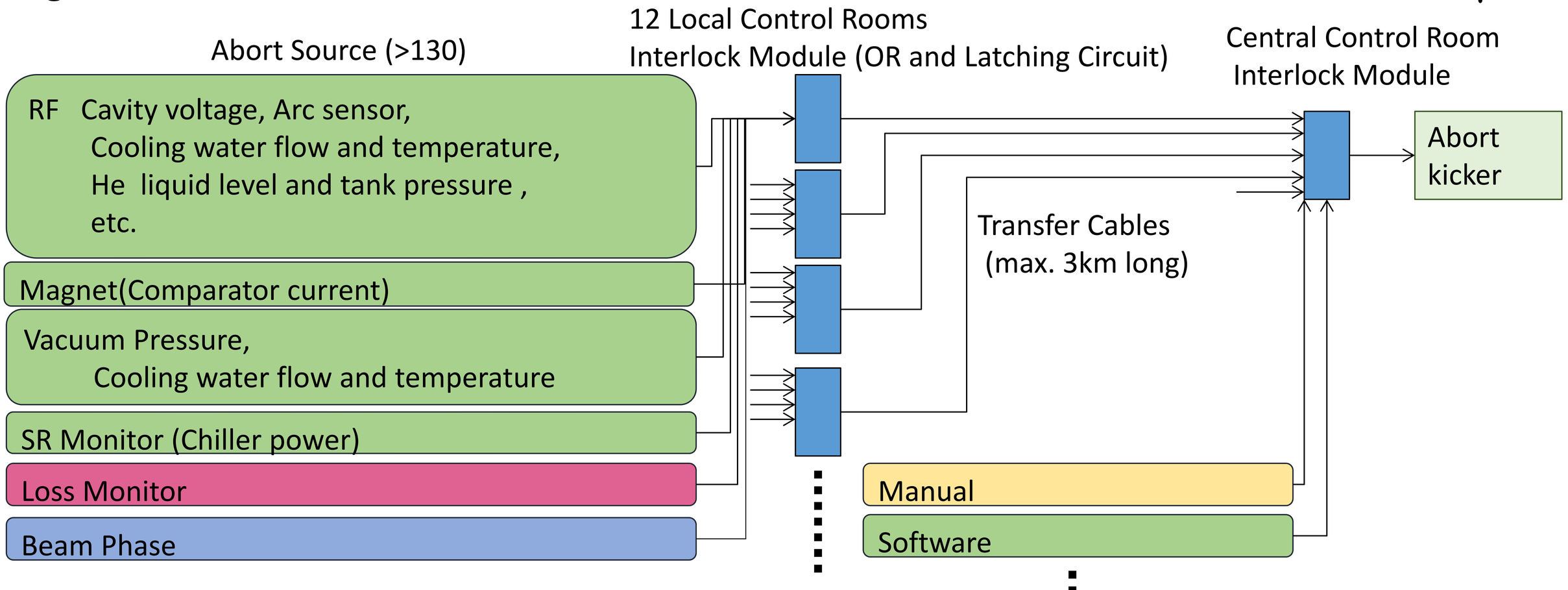
(empty bucket space).

Synchronization of the kicker timing and the abort gap is required for the protection of hardware.



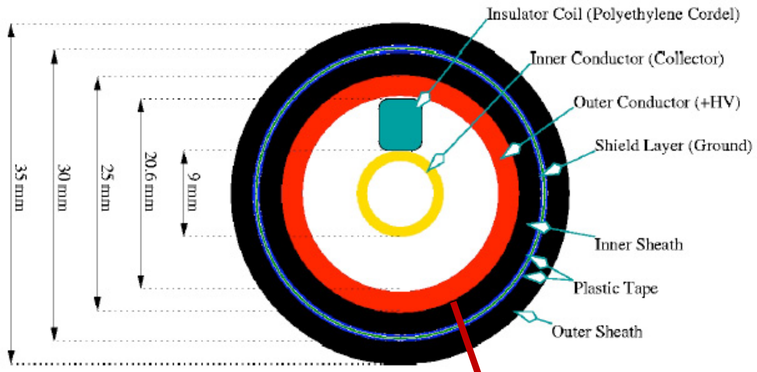
Abort and Abort Monitor System :
Three Types of Abort Trigger

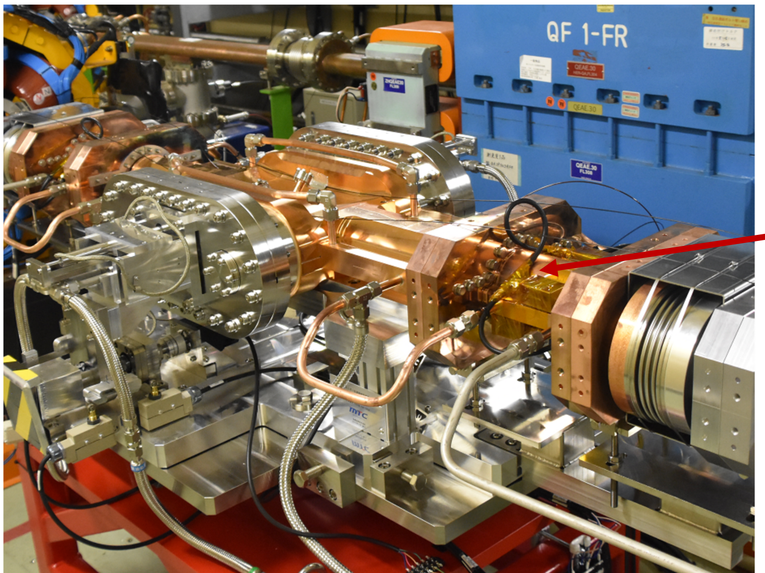
The abort request signals from each hardware component collected in 12 local control rooms. The request signals from LCRs, software abort request signals, and manual abort request signals are collected in the central control room and sent to the abort kicker within 20 μsec.

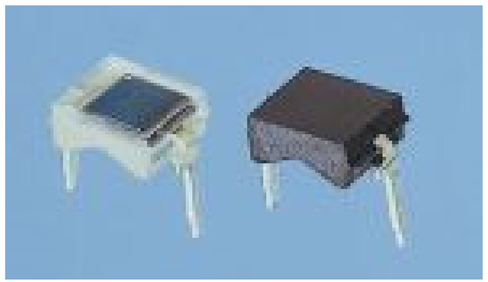


Abort and Abort Monitor System : Loss Monitor

- No. of Sensors : 200
- Ion Chamber: Free Air Ion Chamber (20D co-axial cable)
  Length: 5-8m
  Typical drift time: 1ms
  Cover a wide range in space.
- PIN photo diode: Trigger time for beam abort=A few turn
  Identify the ring in which the beam loss occurred.







2.65mm × 2.65mm

Abort and Abort Monitor System : Beam Phase Abort

There is the strong interaction between accelerated beam and RF cavities.

High current beam loss ⇒ Cavities trip

Cavities trip⇒ Coherent synchrotron motion of the beam

& Beam loss

↓

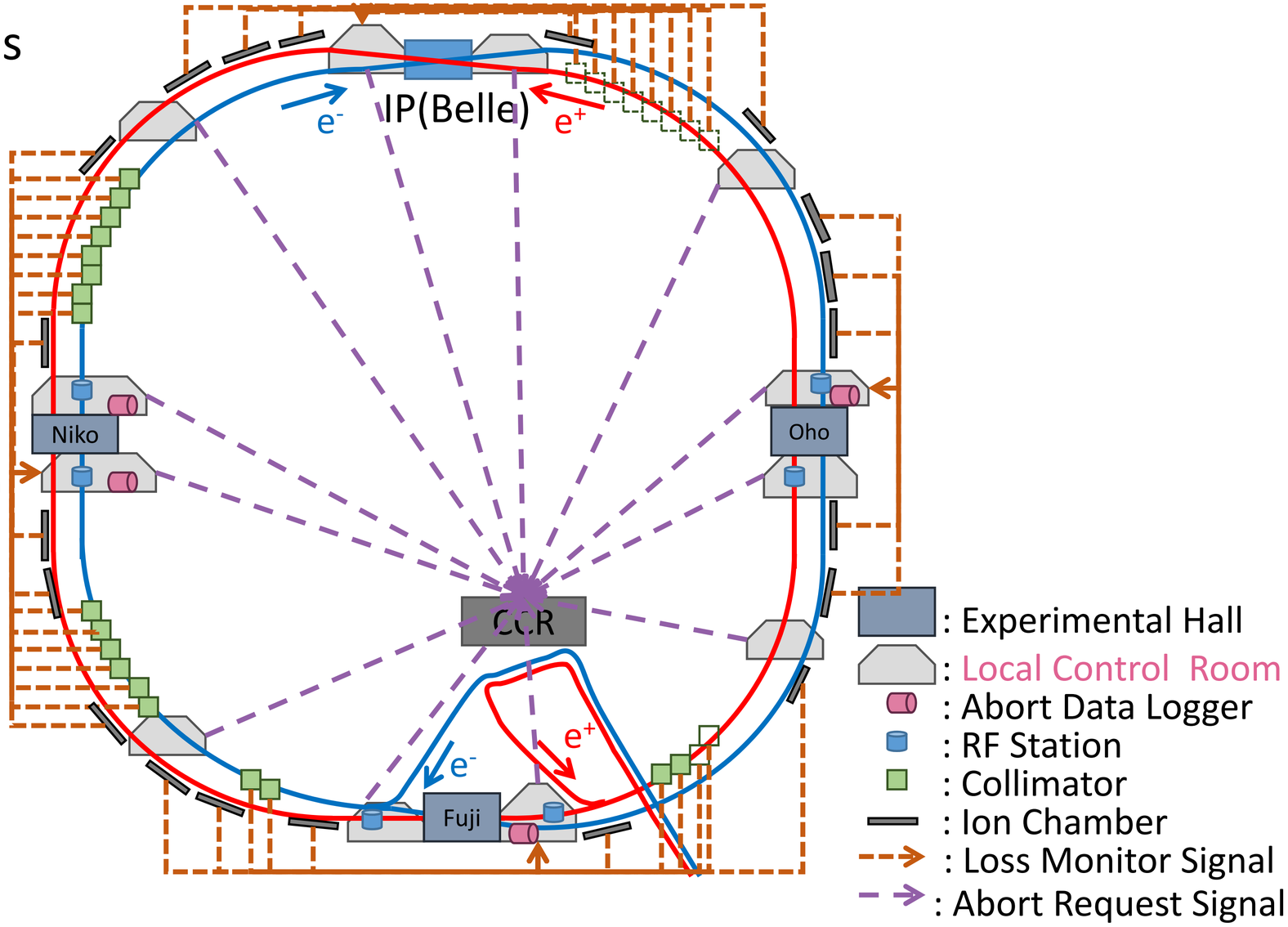
Beam phase abort trigger was introduced.

Beam Phase = Synchronous phase between the beam oscillation and the reference RF phase

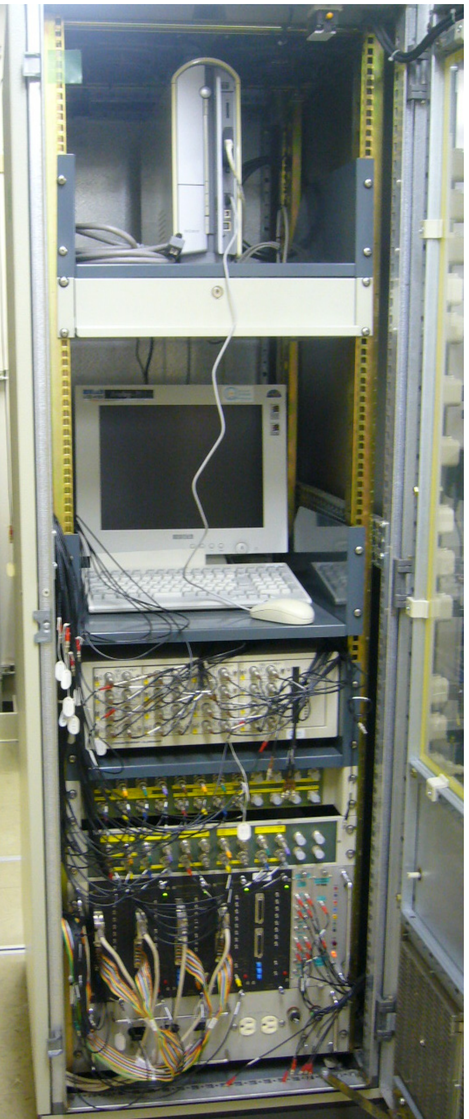
Abort and Abort Monitor System : Abort Monitor

A beam abort monitor system was prepared aiming to monitor the machine operation and to diagnose the hardware components.

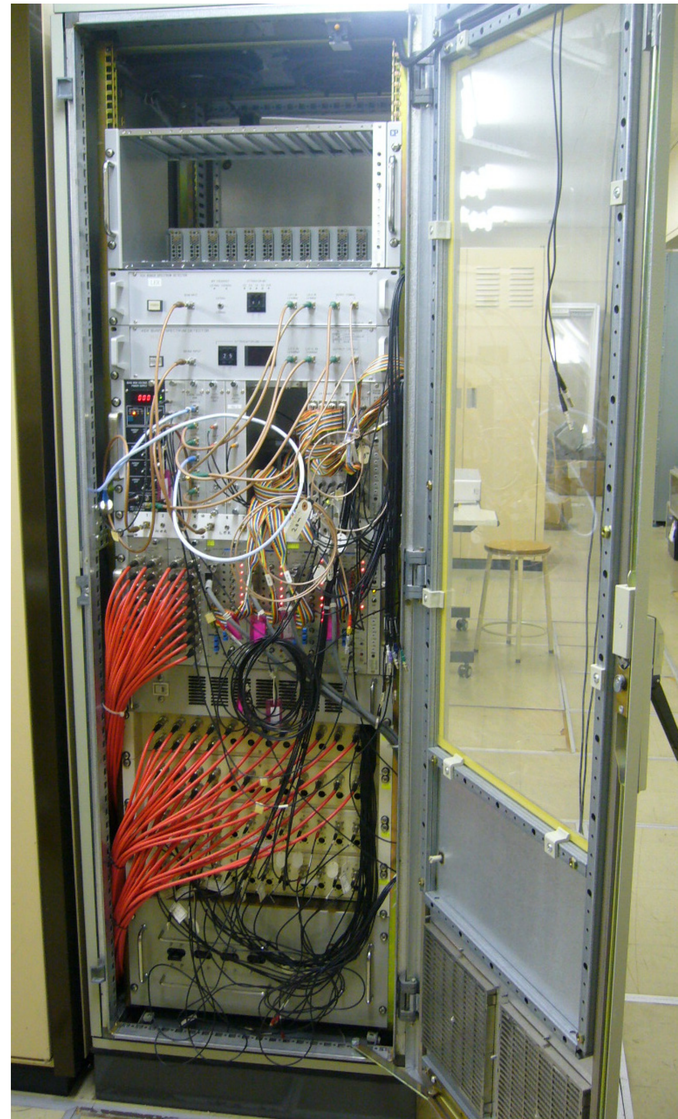
Ring circumference : 3 km,
12 Local Control Rooms (LCRs)
Loss monitor signals
⇒4 LCRs,
RF signals
⇒6 LCRs
Abort Monitor Location
⇒4 LCRs.



Abort and Abort Monitor System : Abort Monitor

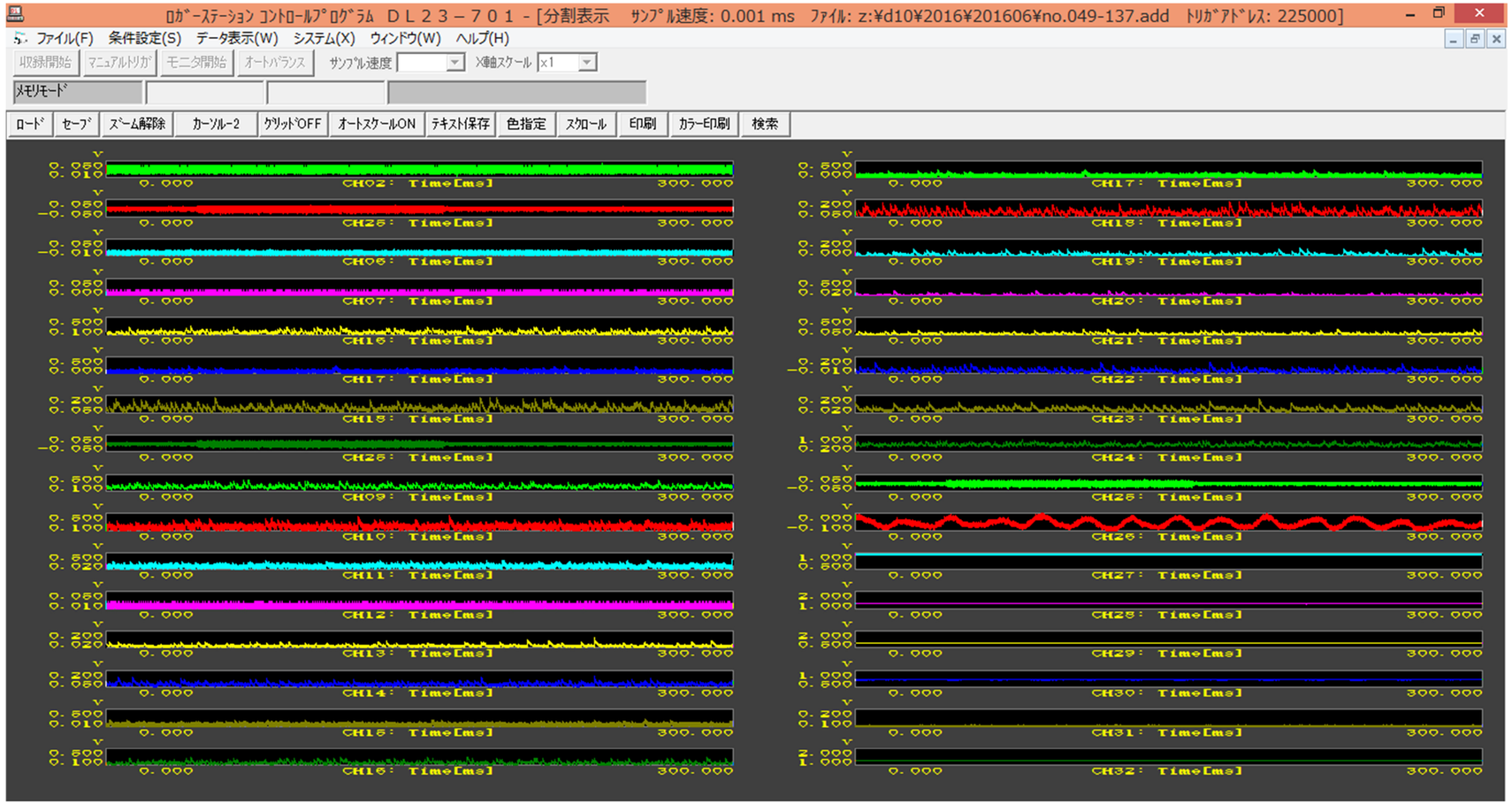


- High-sampling-rate Data Logger
- Logging Time : 300～600 ms
- Sampling Time : 1 ～5 μs
- Input Signal : 24～32channels/LCR
  - Beam Current (DCCT)
  - Injection Trigger Timing
  - Abort Trigger Timing
  - Loss Monitor Signal (PIN photo-diodes, Ion Chambers)
  - RF signals (Cavity Voltages, Out-put Power of Klystrons etc.)
  - Beam Phase



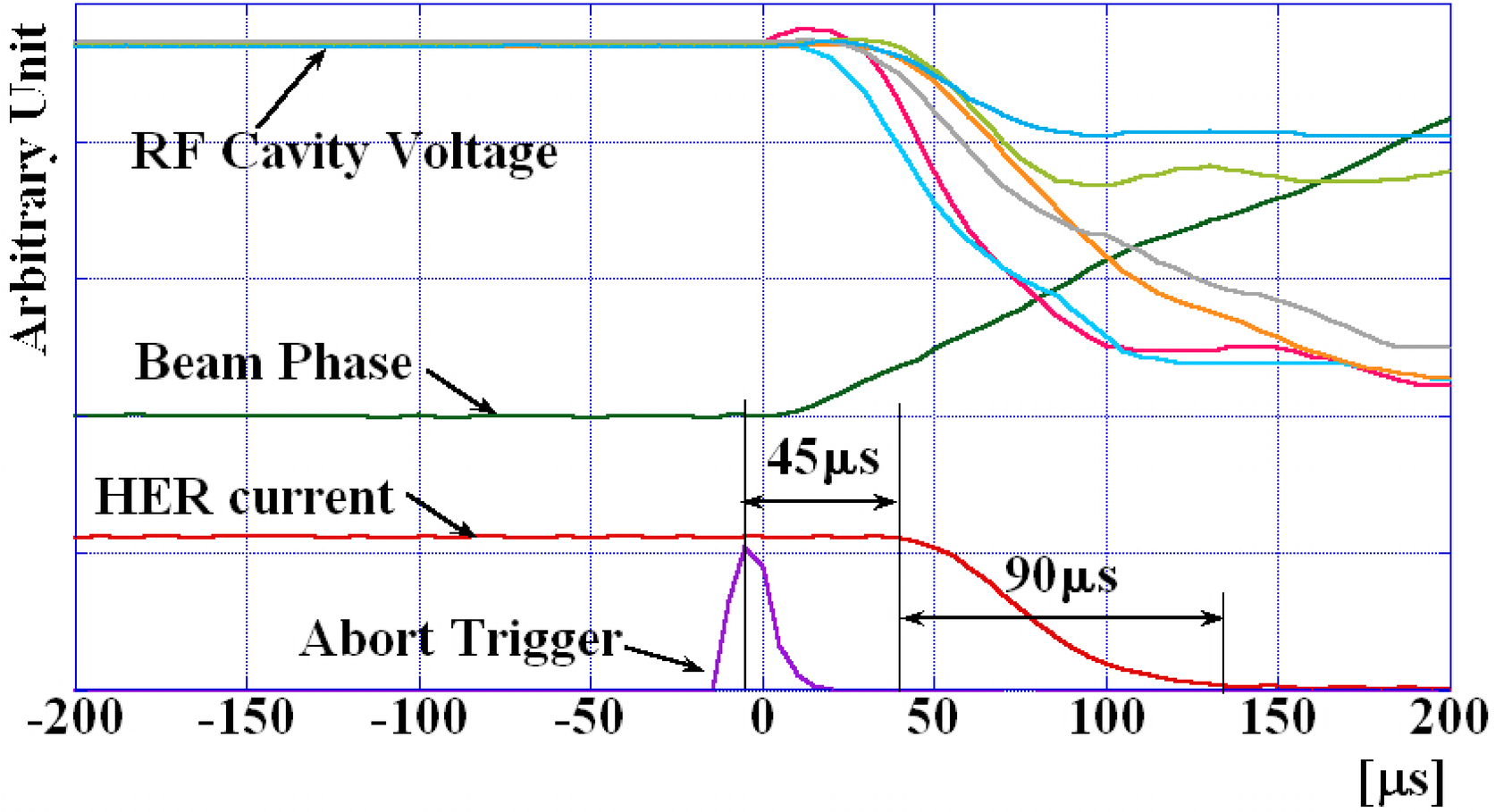
Abort and Abort Monitor System : Abort Monitor

The total number of events collected by four data loggers after March was more than 5000.
We diagnosed more than 1500 aborts during Phase-I operation and classified.



Data Analysis : Manual Abort

Manual abort : Reference of each signal response time.
Beam current (DCCT):
delay of 45 μs ,
decay slope of 90 μs.
↓
If the decay time and the slope differ from this, we consider the abort abnormal.



Data Analysis : Loss Monitor Abort (Vacuum)

・Beam phase oscillation & beam loss occurs.

・Vacuum pressure spikes took place somewhere.

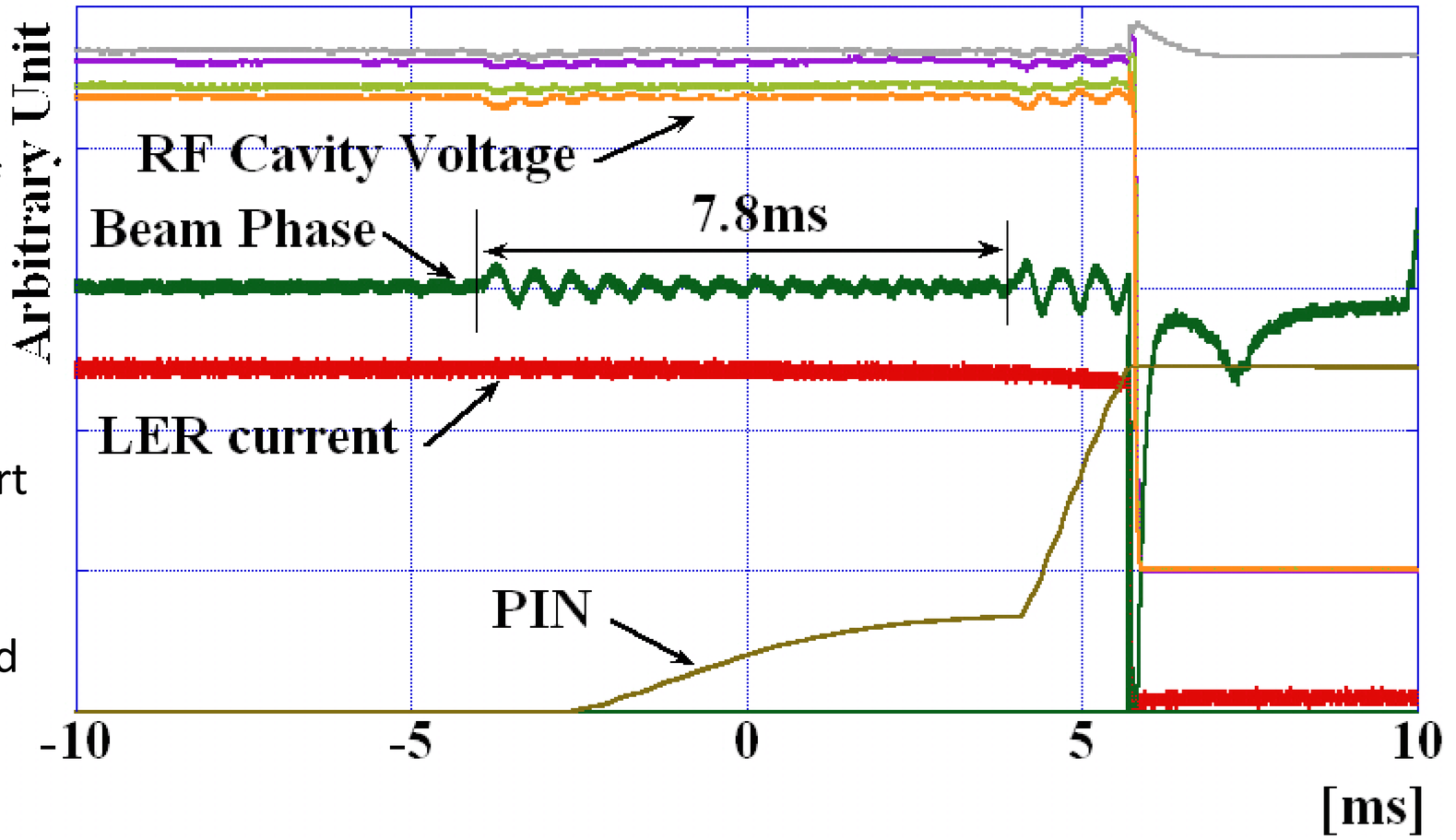
⇒Beam was lost at a narrow aperture of the ring.

↓

Adjustment of collimators to protect the beam pipes .

⇒PINs located on collimators make abort requests.

This type abort is expected to be reduced after further vacuum scrubbing.



Data Analysis : Beam Phase Abort (RF Quench)

BP abort was requested.

↓Checked whether RF signals were normal or not.

RF cavity voltage jumped up during a quench.

Klystron power increased gradually over 75 ms.

The power reached to the interlock level, and turned off.

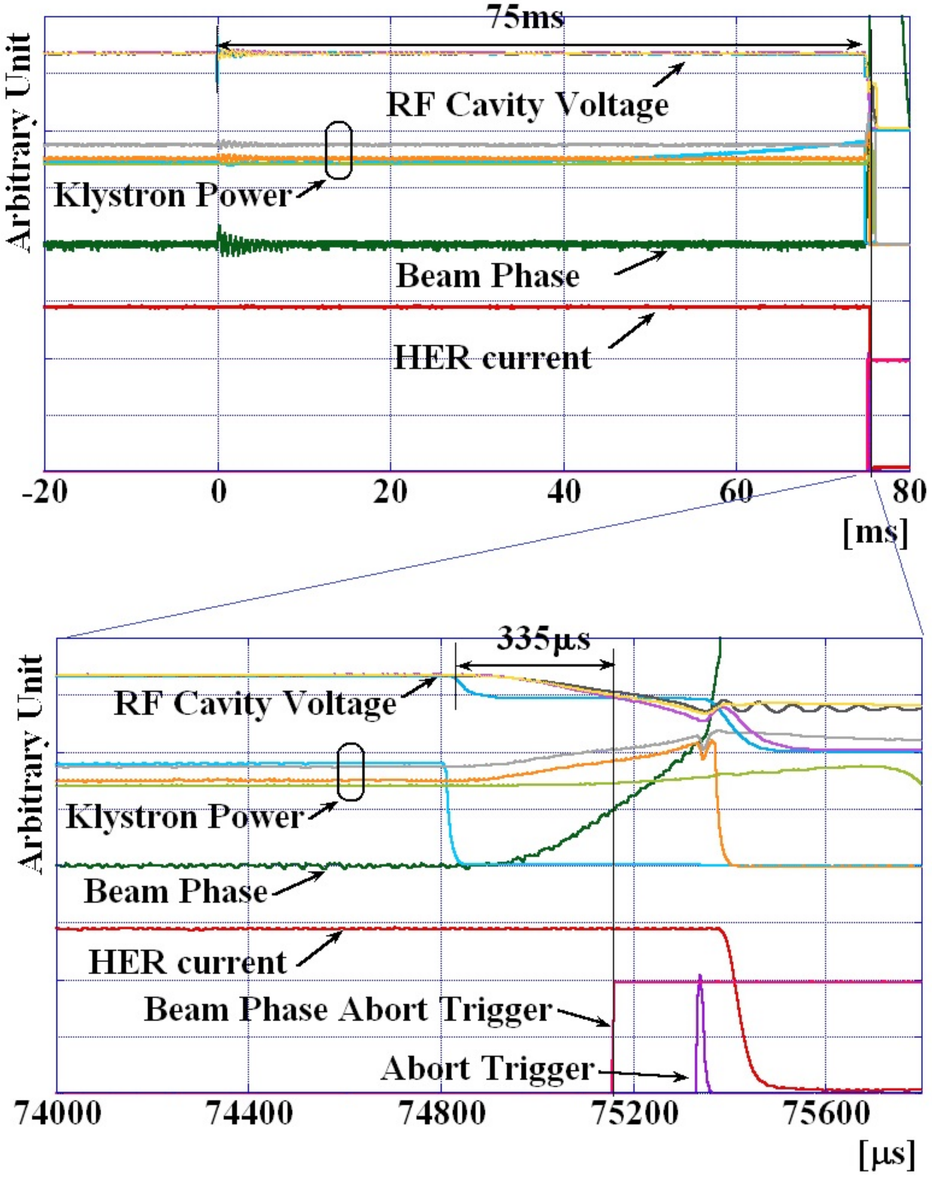
↓

Beam Phase rose up since the RF cavity voltage changed.

↓

Beam phase abort was requested.

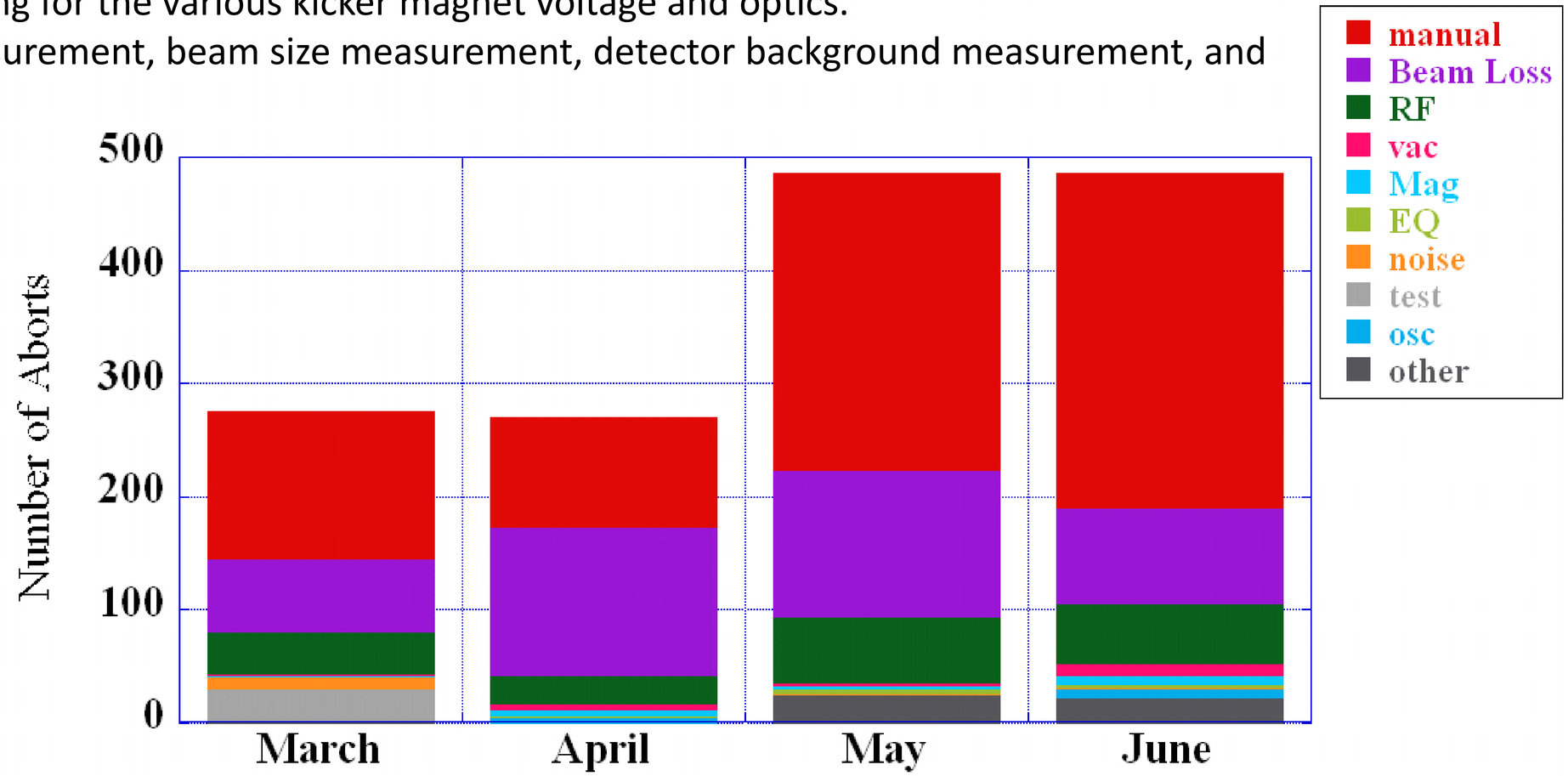
It is fast enough to protect the RF cavity.



Statistics

The number of beam aborts was about 1500 and about 95% of the aborts were recorded. The other 5% were missed due to too-short intervals of successive manual aborts in the kicker timing studies.

- Manual Aborts :
  Optimizing kicker timing for the various kicker magnet voltage and optics.
  Beam instability measurement, beam size measurement, detector background measurement, and others.
- Beam Loss Aborts :
  Problem of Injection trigger system software.
  Vacuum spike which occurred at higher current operation.
- RF Aborts : Troubles of frequency tuner and insufficient HOM dumping.



Conclusion

- We installed the controlled beam abort system to protect the hardware components of the detector and the accelerator against the high beam currents. And prepared the loss monitor and beam phase abort trigger in addition to hardware interlock.
- An abort monitor system was prepared aiming to monitor the machine operation and to diagnose the hardware components.
- We diagnosed more than 1500 aborts during phase-I operation, and classified them by using the abort monitor.
- The beams were correctly dumped by the abort system after optimizing the abort trigger timing.
- The abort system of LER will be improved by adding a pulsed quadrupole magnet to increase the beam size at the extraction window before the phase-II commissioning.