Summary of the SuperKEKB beam monitors

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on behalf of the KEKB beam monitor group

The 27th KEKB Accelerator Review Committee

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One-page summary

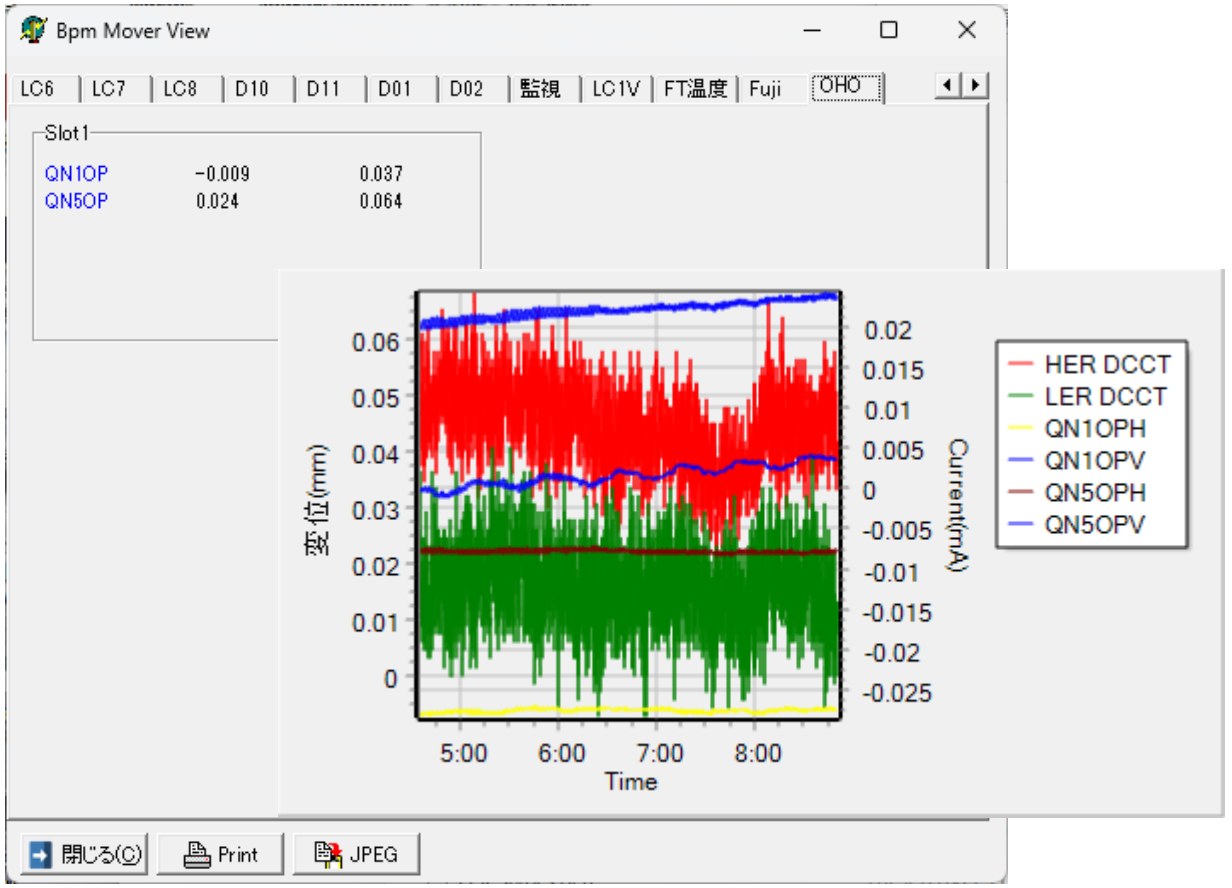
	Pre-LS1	LS1	Post-LS1
Displacement sensors	No major trouble	Installation near NLC	Spare sensors production
BPM (narrowband)	No major trouble	Maintenance	No major trouble
BPM (turn-by-turn)	Power supply failures	Power supply replacement	Some malfunctioning GTBTs
Feedback system	Concern on noise level	Detector upgrades	No major trouble
Bunch oscillation recorder	SBLs need more BORs	New BOR R&D	No major trouble
Beam profile monitors	No major trouble	Detector upgrades	No major trouble
Beam loss monitors	No major trouble	Maintenance	No major trouble
ML-assisted beam tuning		Code development Machine study at Linac	Machine study at SuperKEKB

Displacement sensors

- All displacement sensors are operating normally.
- In LS1, we newly installed the two displacement sensors near the non-linear collimator.

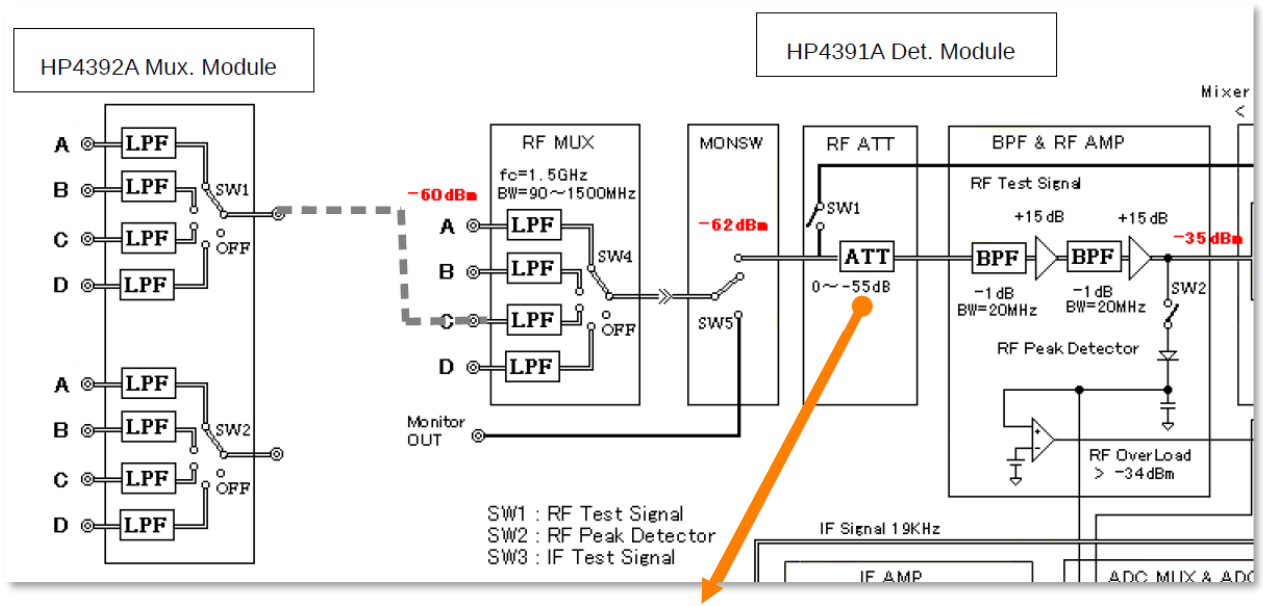
QN5OP

QN1OP

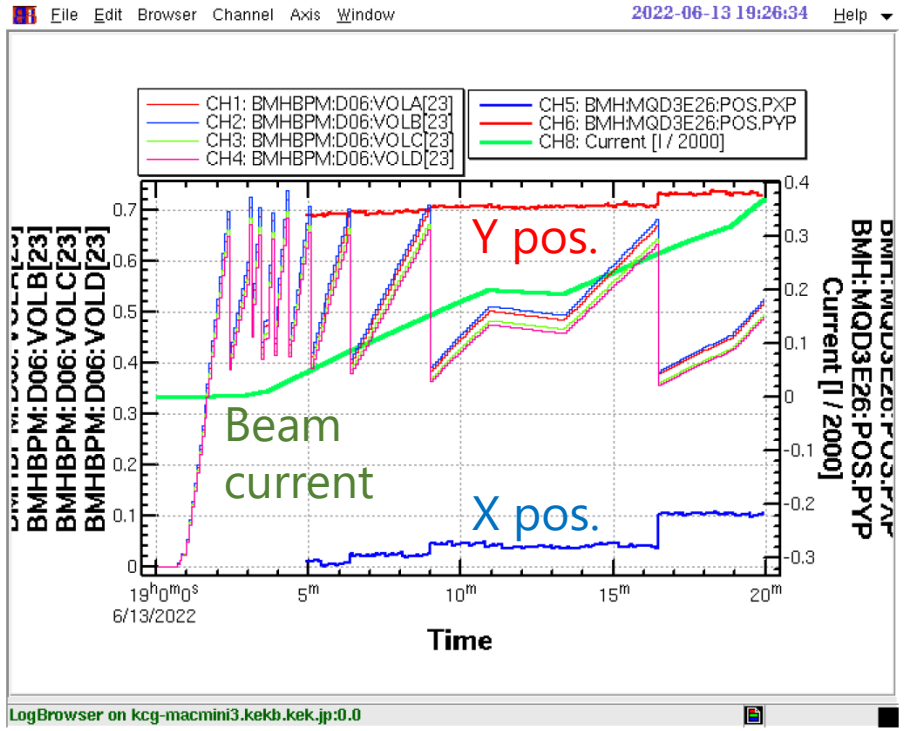


Beam position monitors (narrowband det.)

- No major issue was found.
- In HER before LS1, we observed beam position jumping when the RF attenuator switched. Then in LS1, we replaced the three 1 GHz narrowband detector boards.
  - There are enough spare boards available.



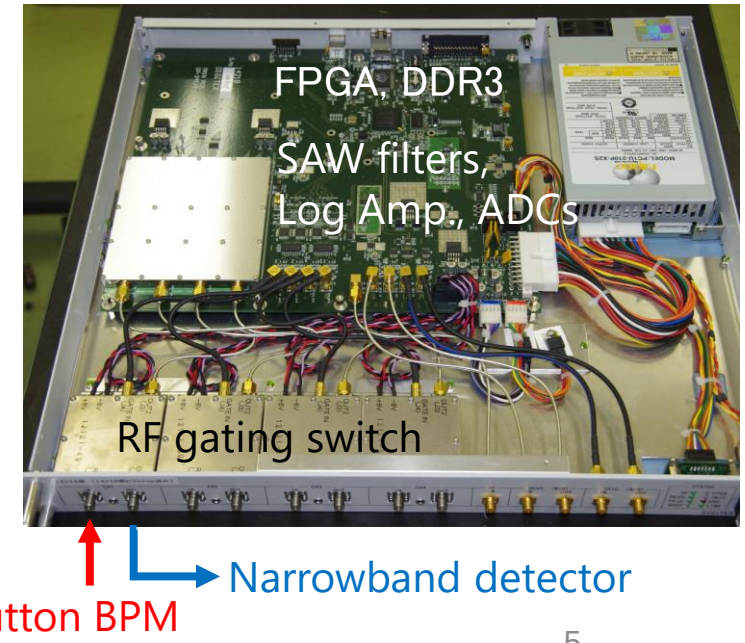
RF attenuator (0 down to -55 dB)



Gated turn-by-turn BPMs

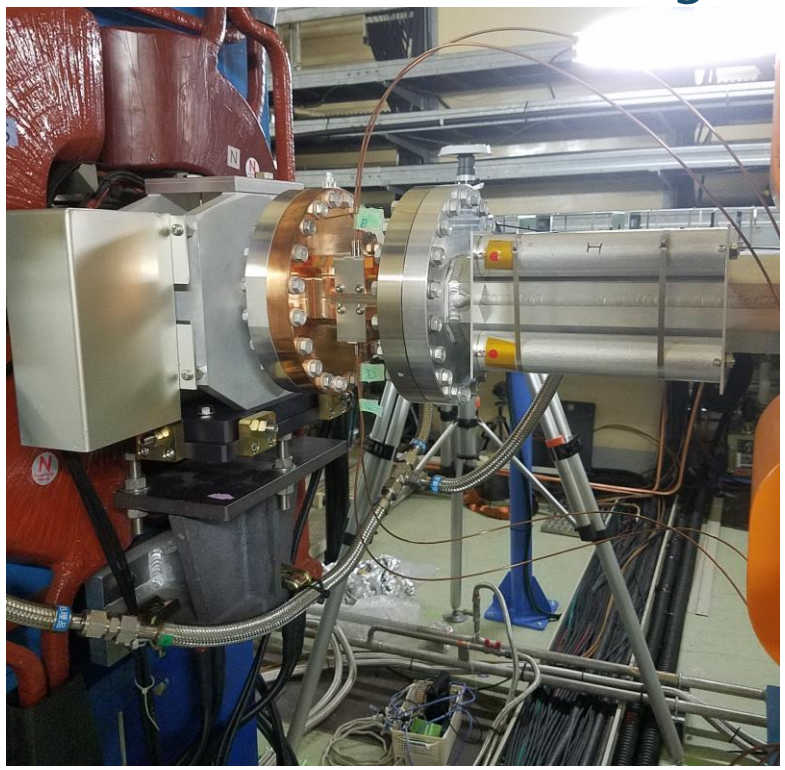
- In LS1, we have replaced an ATX power supply of all GTBT boards to manage frequent power supply failures.
  - First, the fan rotation slows down, the internal temperature rises, and the entire power supply begins to fail.

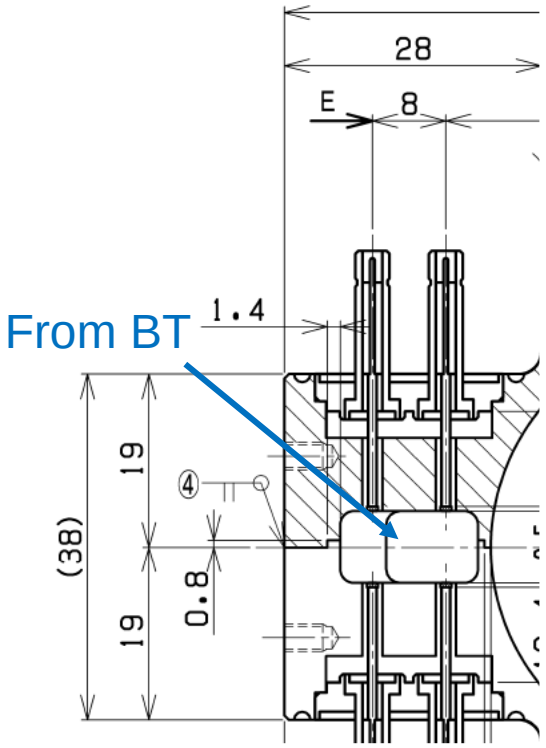
- Multiple GTBTs malfunctioning after LS1
  - Case1: No signal is sent to the narrowband detector due to RF switching failure.
  - Case2: Ch. C and D ADCs give too high or ~noise counts.
    - Regulator voltage was abnormally low (3.3 V → 1.3 V).
  - We disconnected the cables from 5 of 140 GTBTs and bypassed them to the narrowband detectors.
  - The manufacturer is investigating the cause.
- GTBTs help with beam injection tuning and measurements for physical/dynamic apertures using vertical or RF kickers.

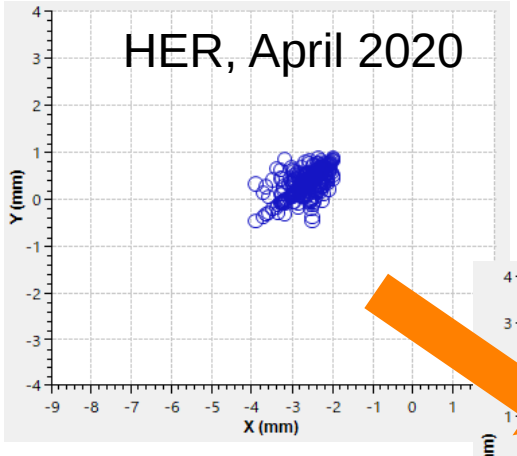


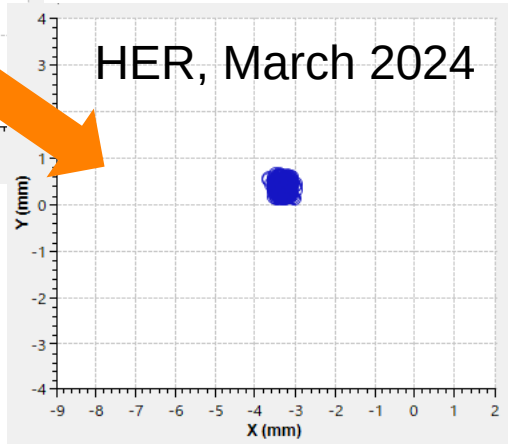
BPMs at the injection regions

- LS1 upgrade in HER; the vacuum chamber and injection septum magnet have been replaced for a wide aperture. We also installed a new-design injection BPM.
  - The electrodes are symmetrically mounted on the top and bottom, so X-Y coupling does not occur.
- The LER BPM is unchanged from the pre-LS1 system.





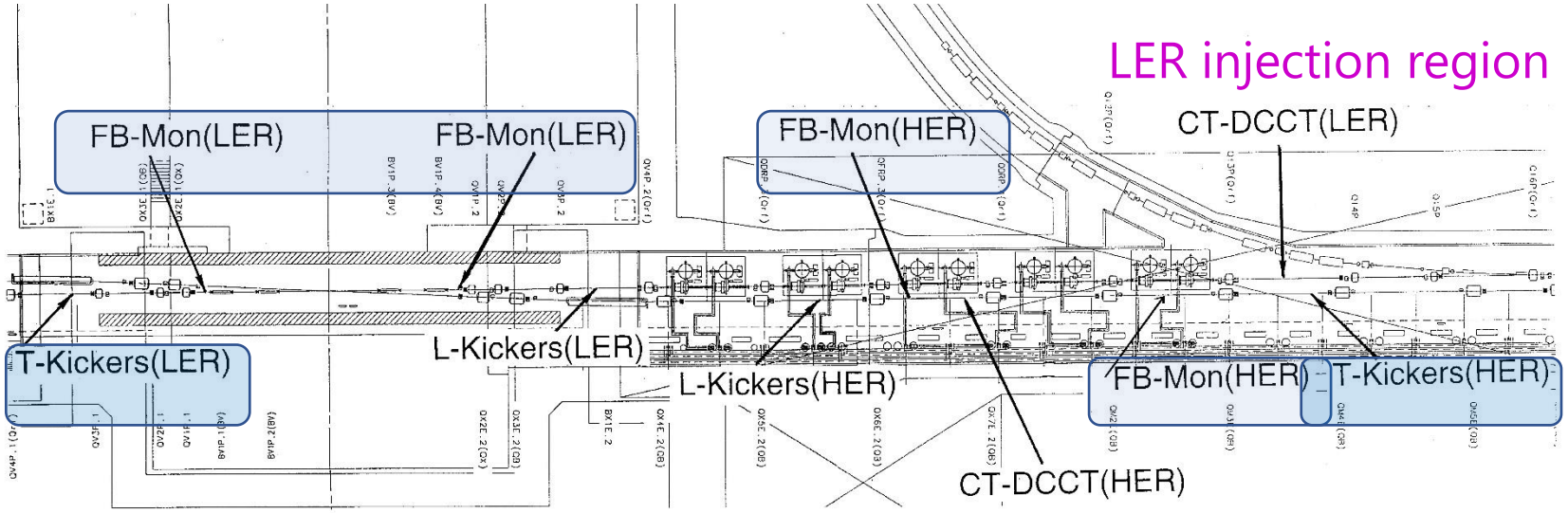


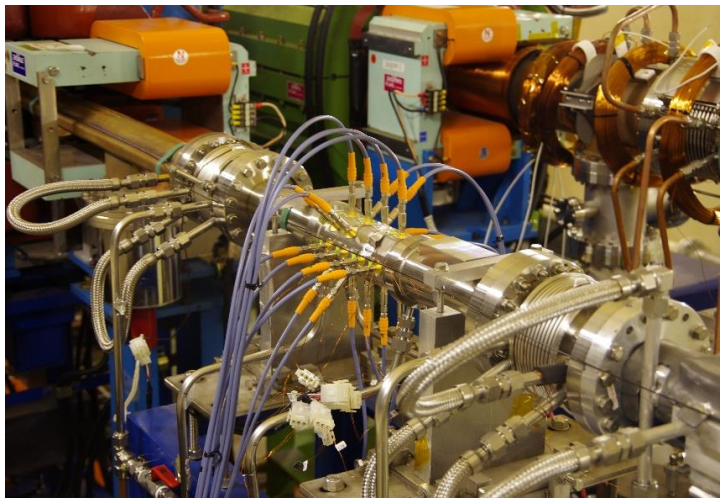


Bunch-by-bunch feedback system

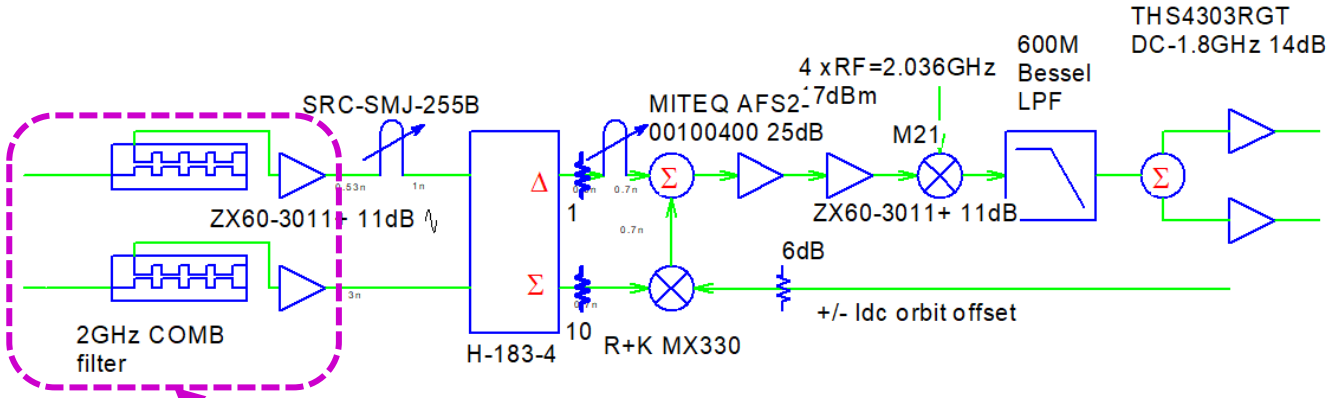
- No major issue was found. The BxB FB system is working well.

FUJI straight section

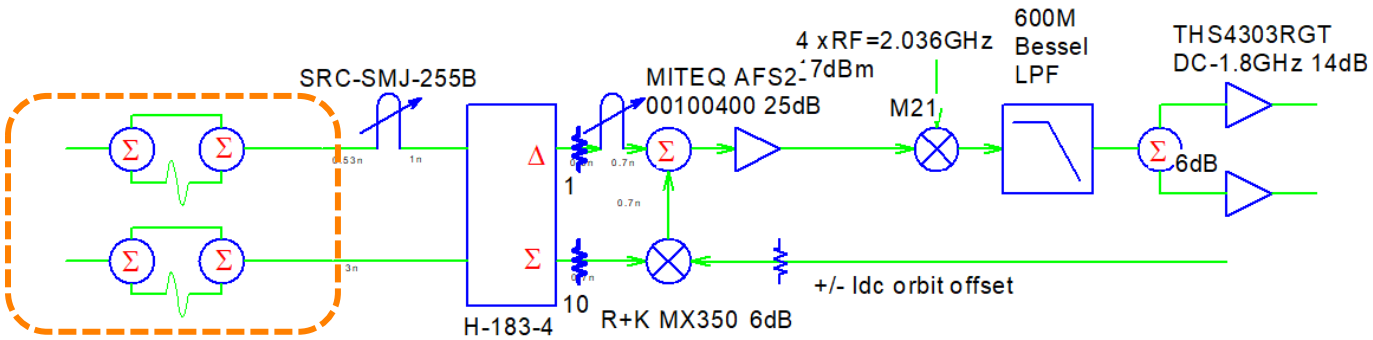


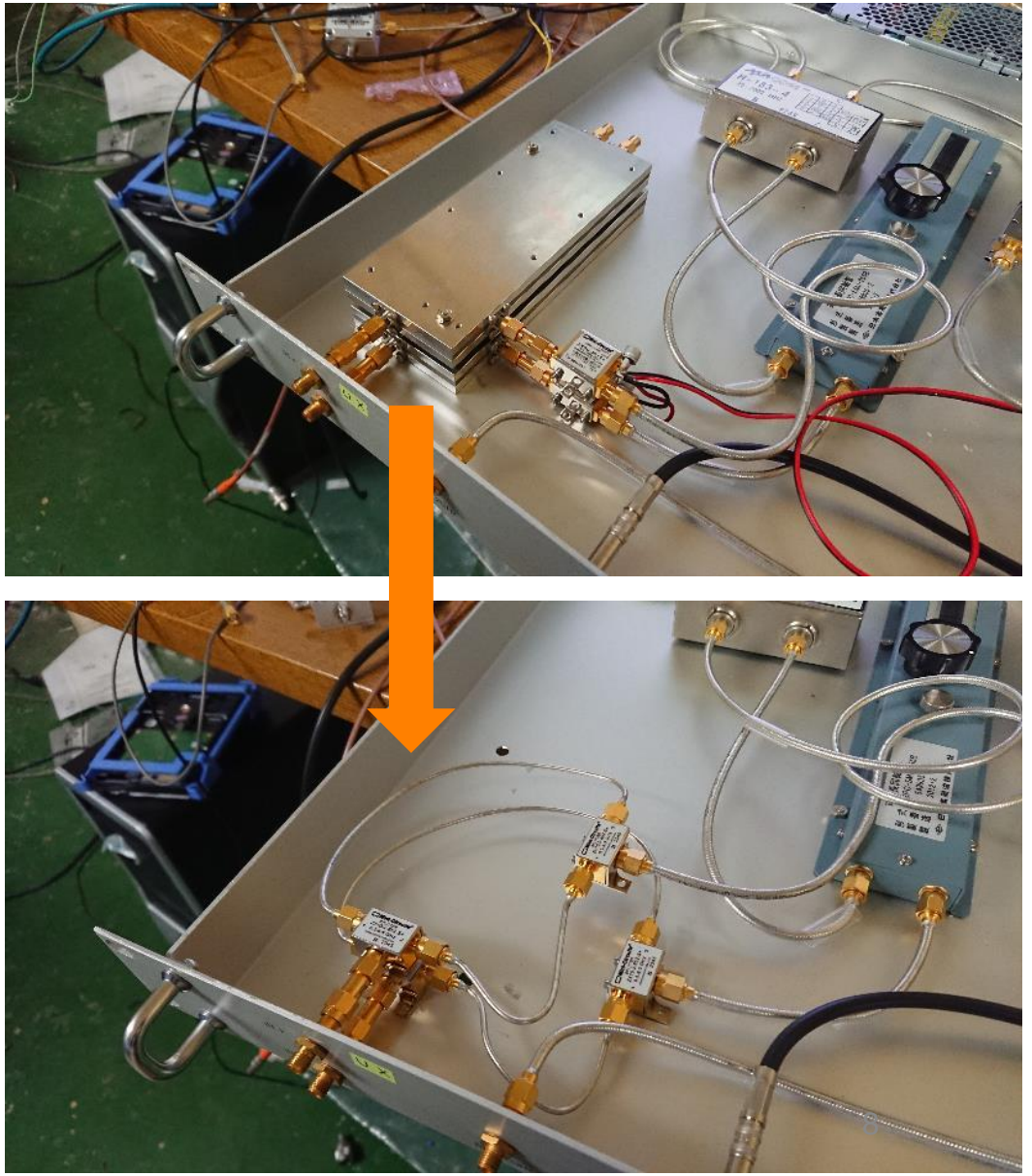


Feedback detector upgrade in the LS1

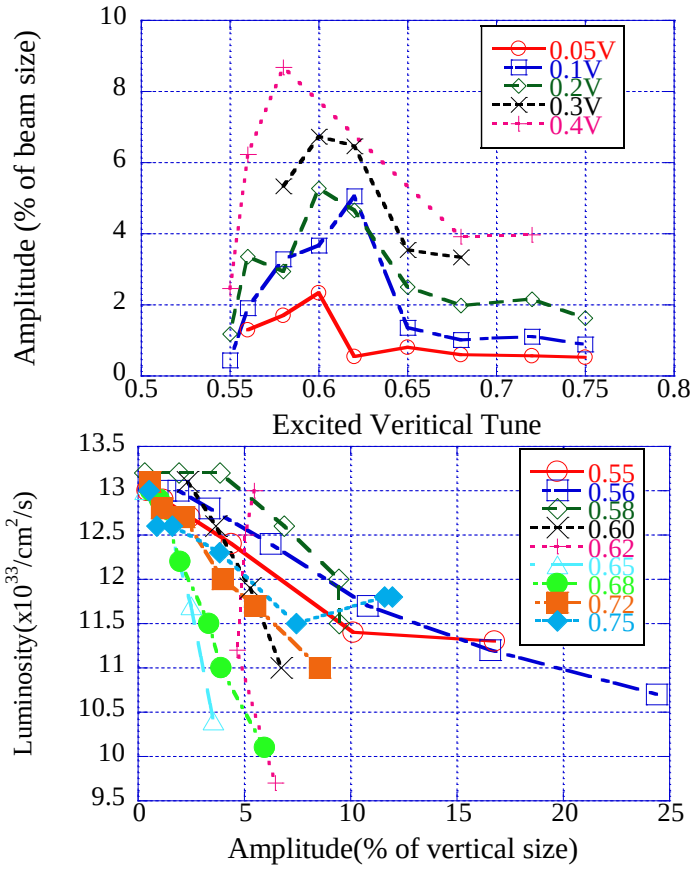


Significant insertion loss (~22 dB)
needs additional broadband amplifiers.



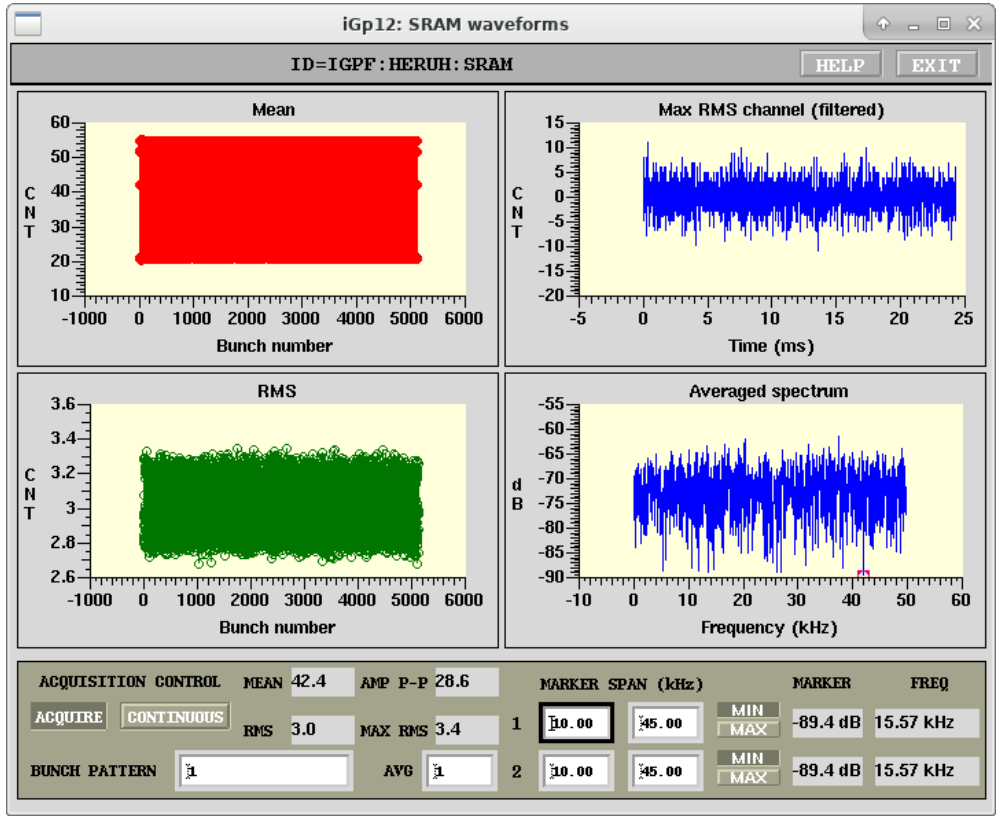


Reduction of noise level



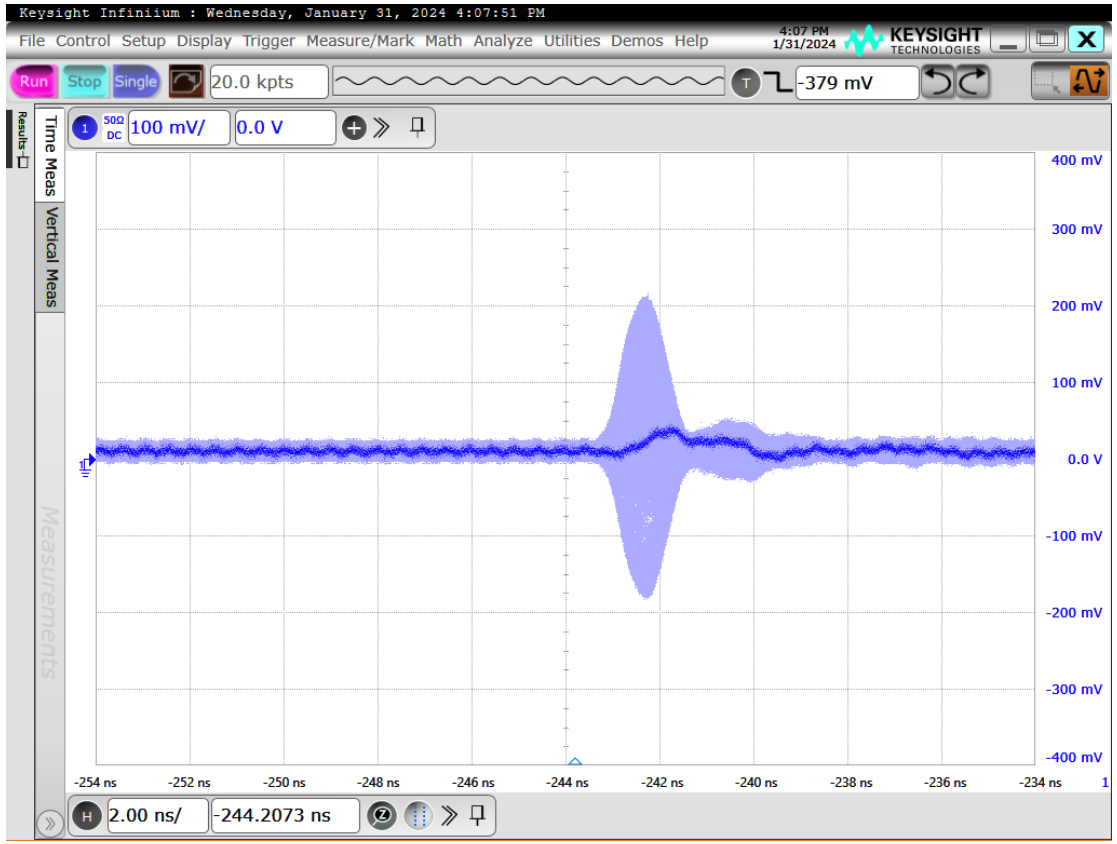
Lessons from KEKB:
Sinusoidal noise signal increases the beam size and degrades luminosity.
(Tobiyama & Ohmi, MOPD73, DIPAC2011)

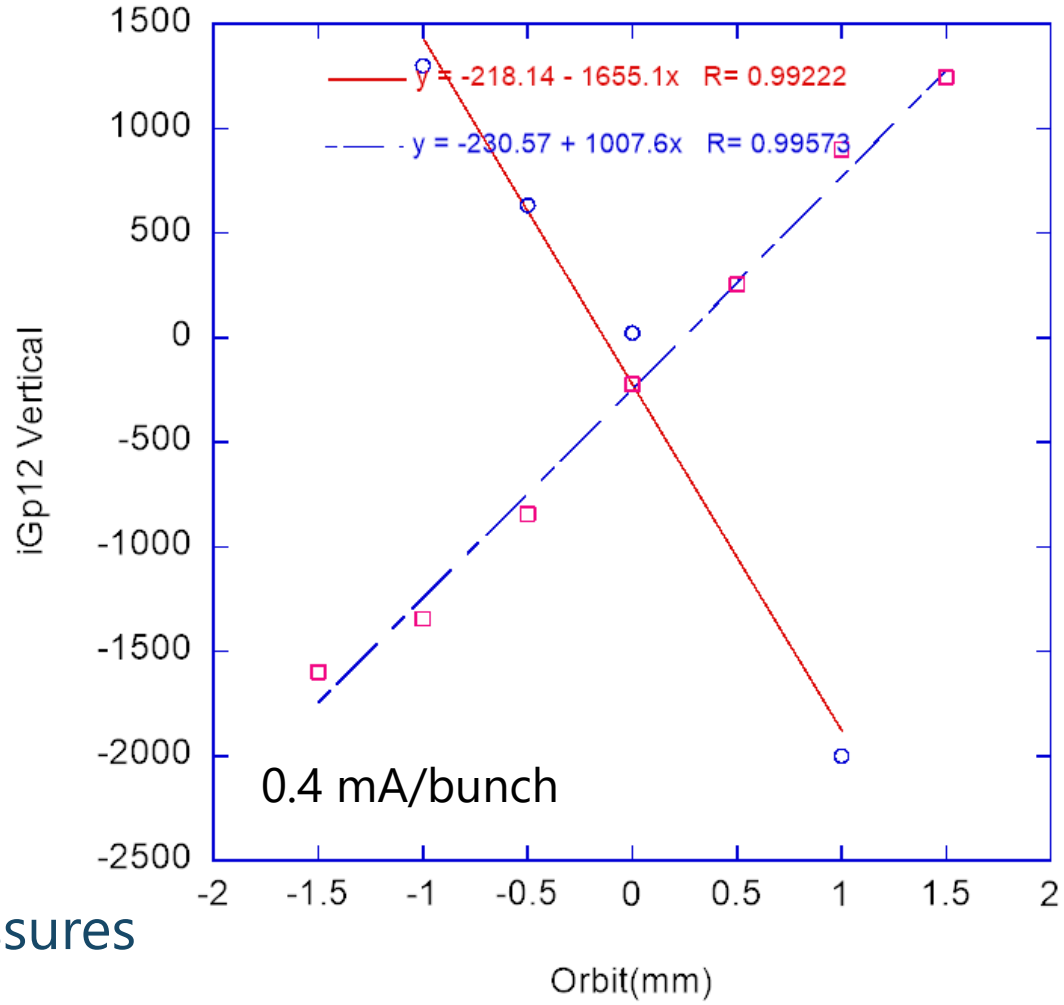
ADC counts with no beam



- RMS (noise level) was successfully reduced from 13 (pre-LS1) to 3.

Investigation of detector performance

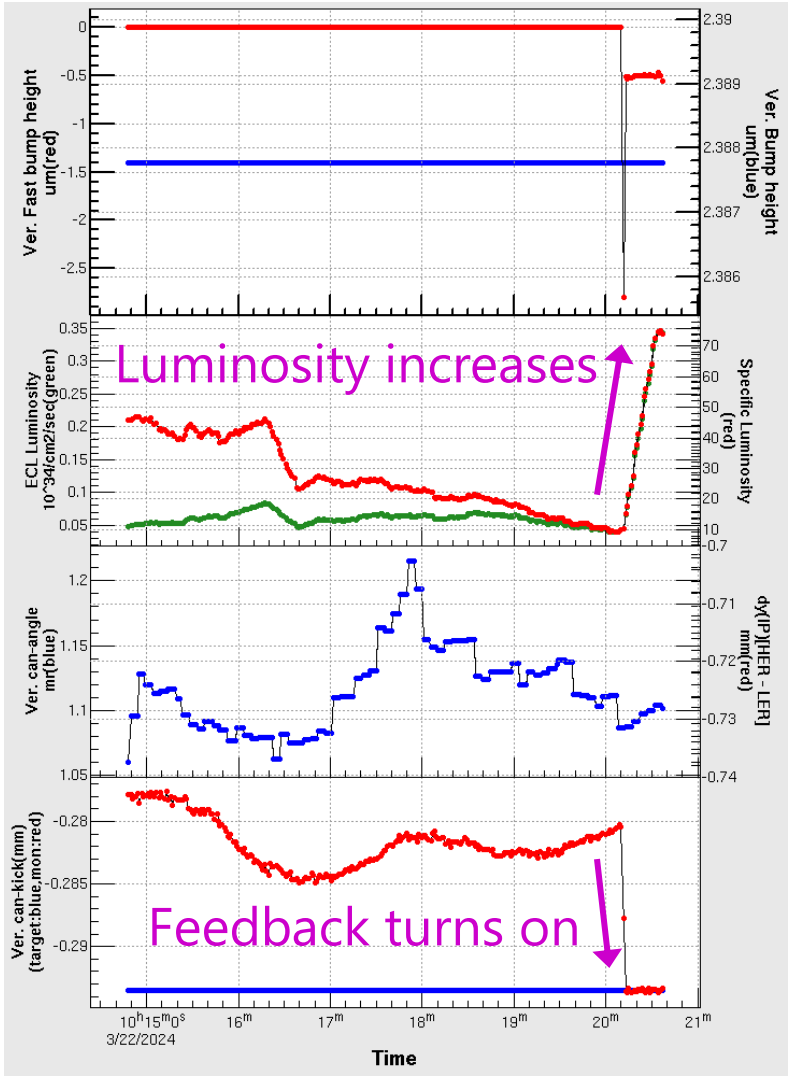




- Gain calibration with local beam bump assures the dynamic range of +/-1.5 mm.
- Their contribution to improving luminosity will be visible shortly.

Beam orbit feedback at the IP

- IP-FB are working well.

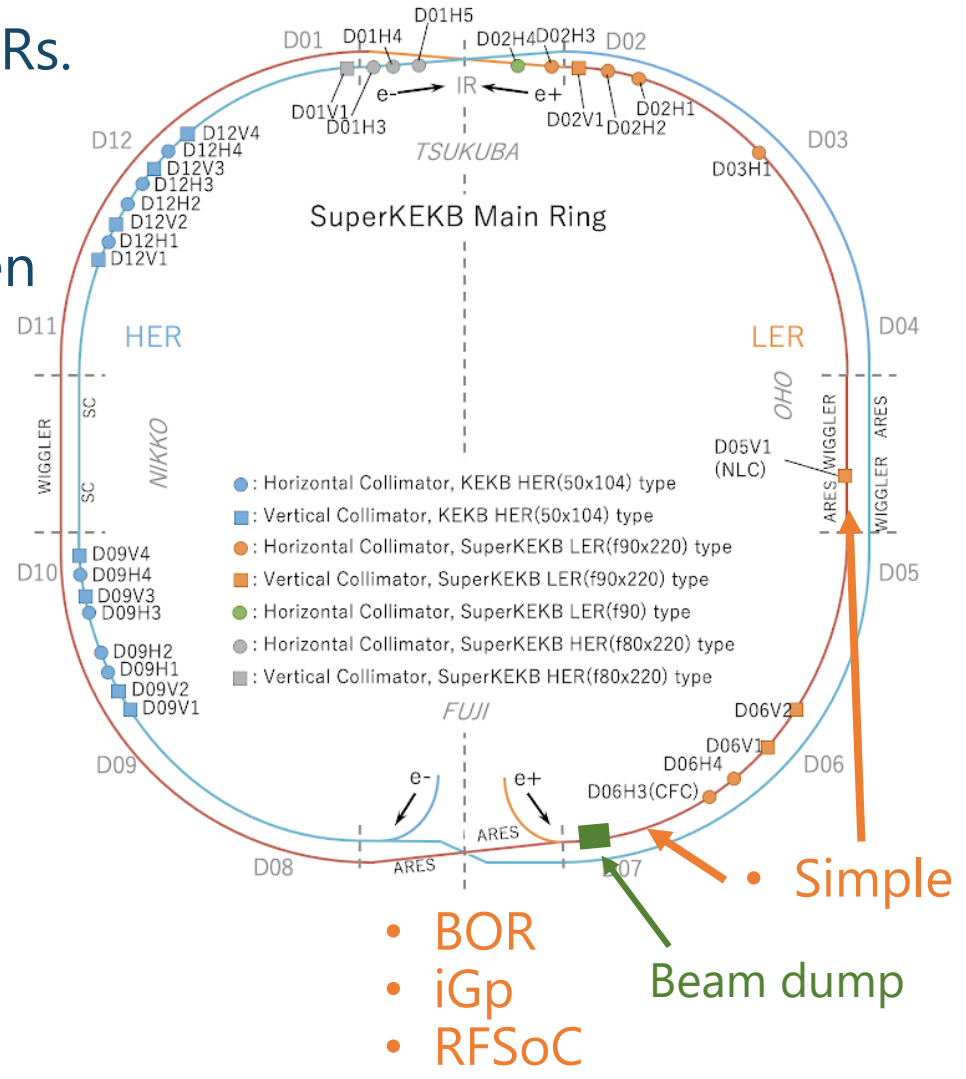


Bunch Oscillation Recorder (BOR)

- Since 2022, we have developed several types of BORs. BORs measure the bunch position just before the beam aborts over a few or more turns.
- We added BORs more densely in LER, where Sudden Beam Loss (SBL) events were severe in before LS1, especially across the D06 collimators.

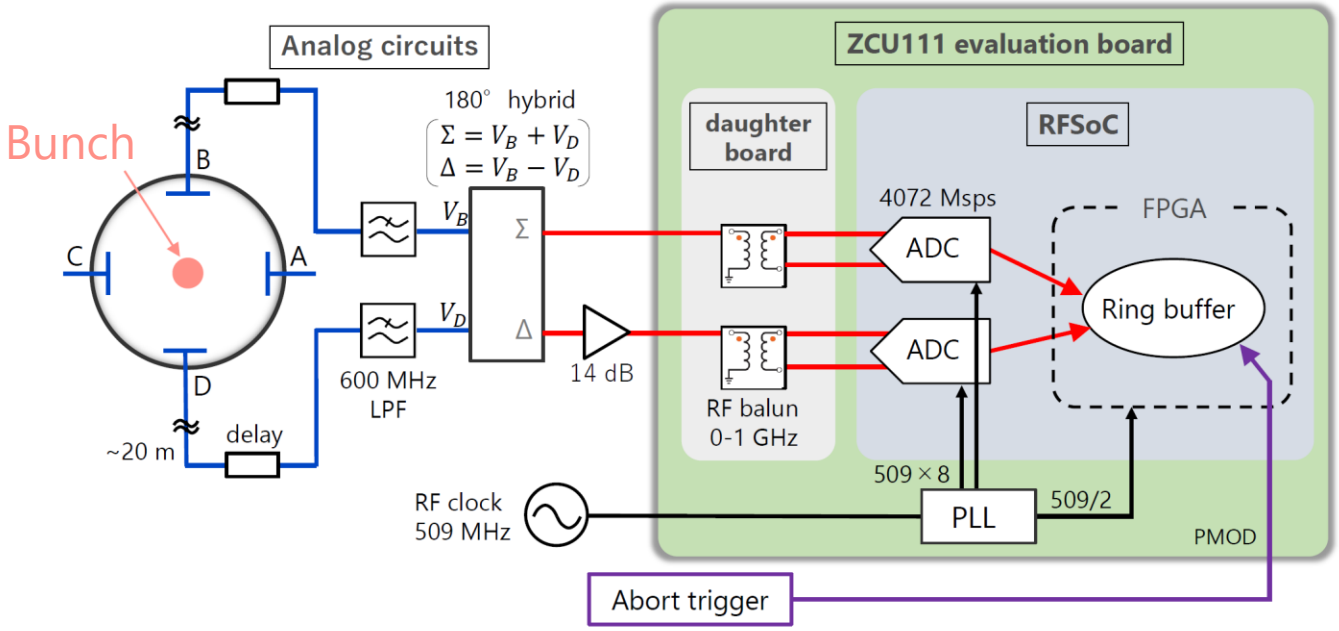
HER	Location	ADC bit	RF sync.
BOR	Fuji Upstream	8	Yes
iGp BOR	Fuji Up & Down	12	Yes

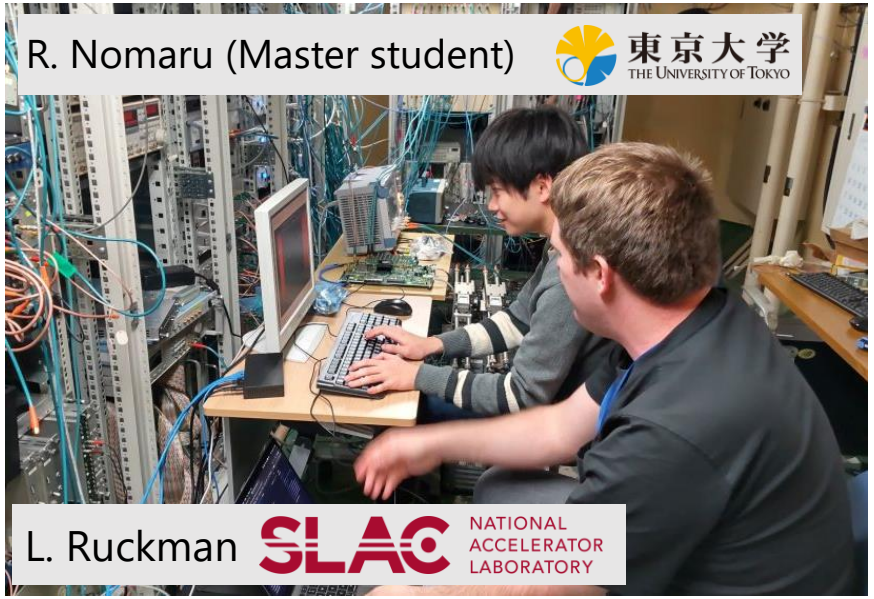
LER	Location	ADC bit	RF sync.
BOR	Fuji Upstream	8	Yes
iGp BOR	Fuji Up & Down	12	Yes
RFSoC BOR	Fuji Downstream	12	Yes
Simple BOR (Oscilloscope)	D05	8	No (5Gsps)
	D06	8	No (2.5Gsps)

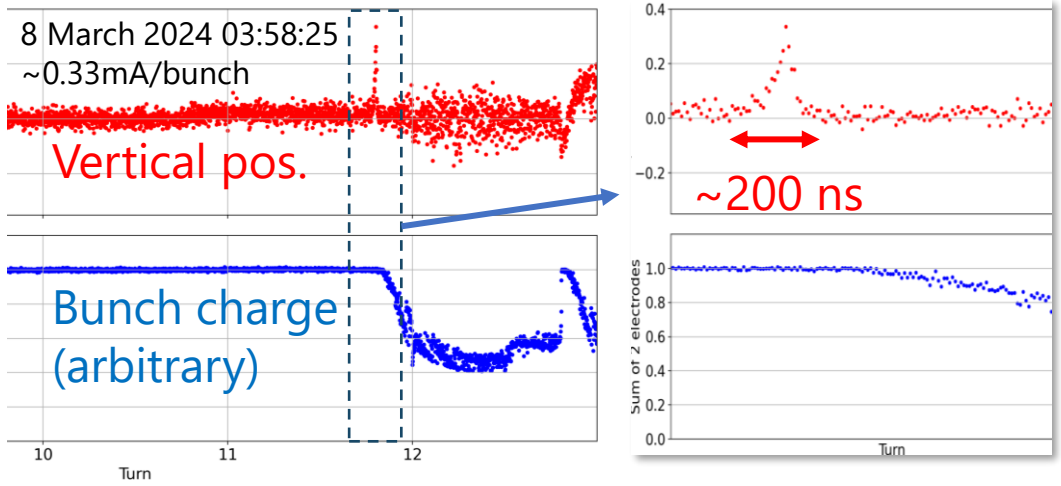


RFSoC BOR

- We started R&D in the fiscal year 2023 to apply a new architecture, Xilinx/AMD RFSoC, to BOR.
  RFSoC: multi-ch. ADC, DAC, FPGA, and CPU on a chip
- The 1st prototype detector with the ZCU111 evaluation board has been operating since February 2024.
- More details at IPAC2024 TUBD3 (cont. oral)



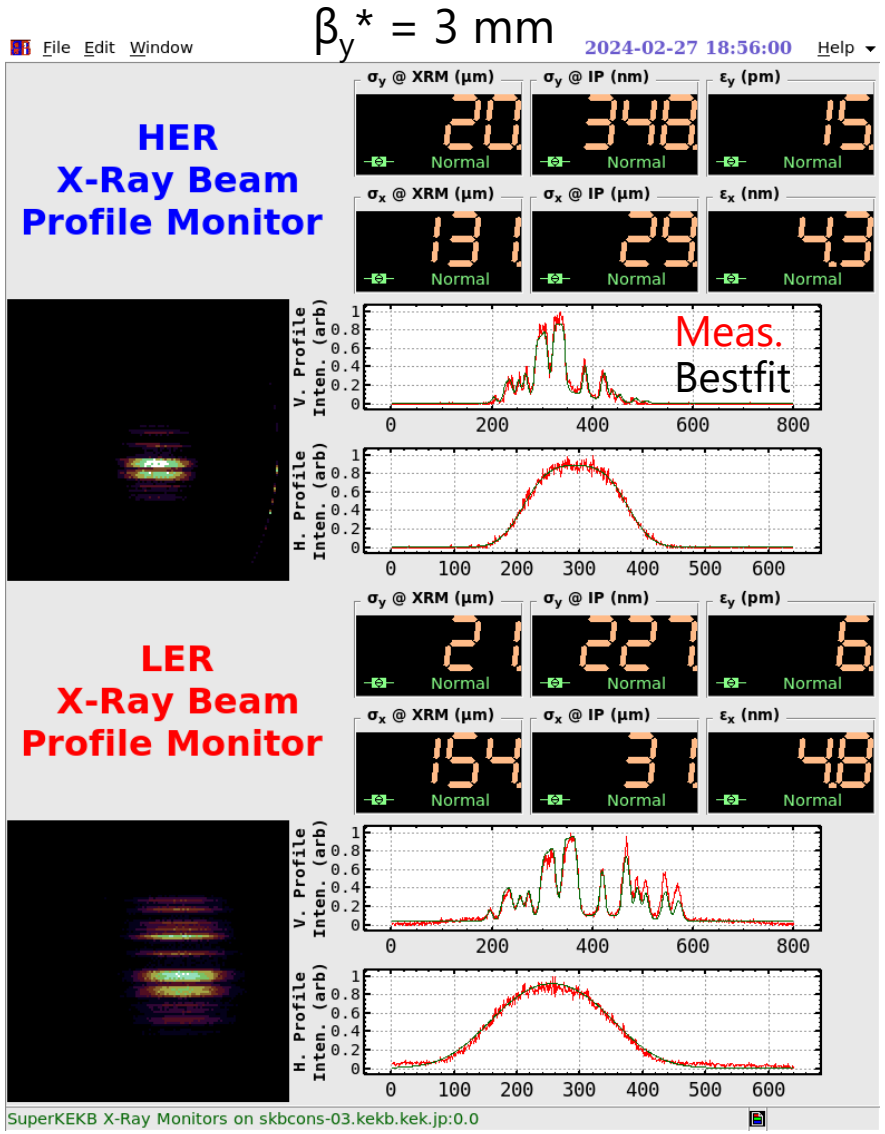




X-ray beam size monitor

- No significant issue is found in 2024.
  The X-ray beam size monitors are working well.
- On the HER side, a new and large detector chamber (filled with He/N2 gas) was installed in LS1.
- On the LER side, there are no significant changes from the pre-LS1 system. The YAG:Ce scintillator screen was changed to a new one.

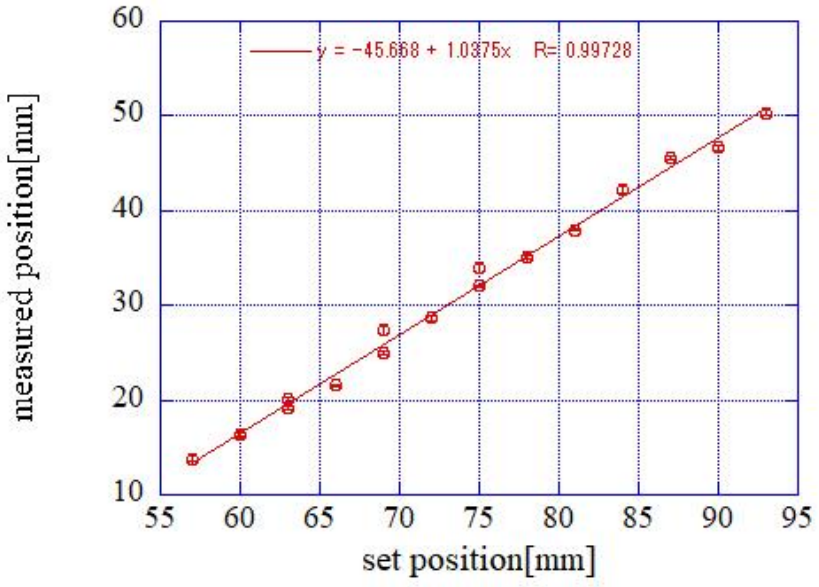
	HER	LER
Low speed CMOS cam.	OK	OK
Turn-by-turn CMOS cam.	Parking at ground floor	Parking at ground floor
Si-sensor XRM	Installed without Silicon sensor	Damaged by radiation



Visible-light beam profile monitors

		HER	LER
Visible-light interferometer	Horizontal beam size	OK	New in 2024
Gated camera	Bunch-by-bunch transverse	OK	OK
Streak camera	Bunch-by-bunch longitudinal	OK	OK
Intensity interferometer	Longitudinal	No	New in 2024
Coronagraph (gated camera)	Beam halo	OK	OK

- Since the optical line is healthy, we can measure once the detectors are ready.
  - For example, we checked the time axis calibration of the streak camera in LER and found no significant deviations.
- We added the visible-light interferometer and intensity interferometer in LER.

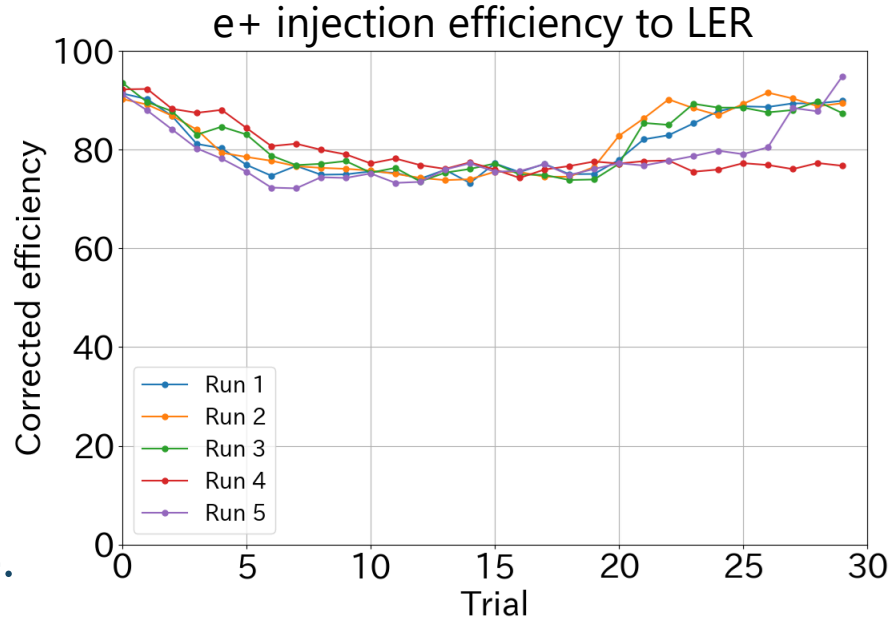


Beam loss Monitors

- The system is overall unchanged from pre-LS1 and is working well.
- We reinstalled the PINs that were once removed to install a non-linear collimator and replace the collimator heads.
- After the operation started, we investigated some PINs with low signal output. We found the (oldest) cable connectors badly damaged by radiation and replaced them.
- More connectors and cables will need to be replaced in the future. During long-term maintenance, the entire system will be inspected.
- Operating speed is fast enough as a source for an abort trigger.
- We are adjusting the threshold to avoid unnecessary aborts caused by small beam losses.

Machine-learning assisted beam tuning

- We started developing a machine-learning tool to facilitate beam injection in the fall of 2022, and a graduate student joined the project in the spring of 2023.
- We conducted machine studies using Linac e+ beams in LS1;
  Bayesian optimization successfully optimized the beam orbit, reduced dispersion, and maximized e+ yield.
  [arXiv:2401.14739 and talk at IBIC2023 TH2C02]
- After the resumption of SuperKEKB operation, a machine study is underway to maximize the beam injection efficiency from BT to LER/HER.
- We are implementing the functions necessary for ring operation, e.g., beam lifetime and care for the Belle II detector.
- The goal is to put the system into practical use by 2024.



Summary

- Beam monitors and feedback systems are generally working well.
- Upgraded performances have already been seen or will be visible soon.
- Some monitors need continuous maintenance, especially
  - Gated turn-by-turn monitors
  - Beam loss monitor cables
- New R&D projects started cooperating with grad. students and international collaborators.