

Summary of the SuperKEKB beam monitors

Gaku Mitsuka (KEK Acc. Lab.)
on behalf of the KEKB beam monitor group



The 28th KEKB Accelerator Review Committee

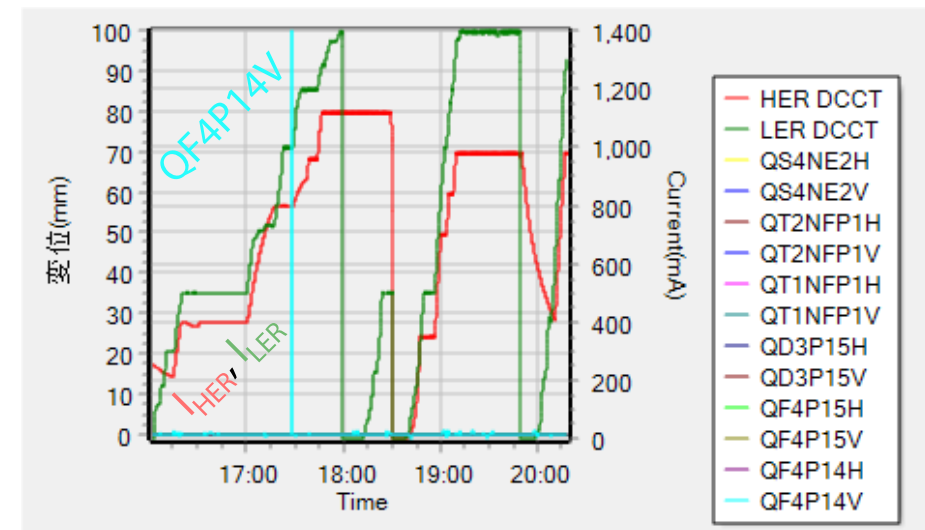
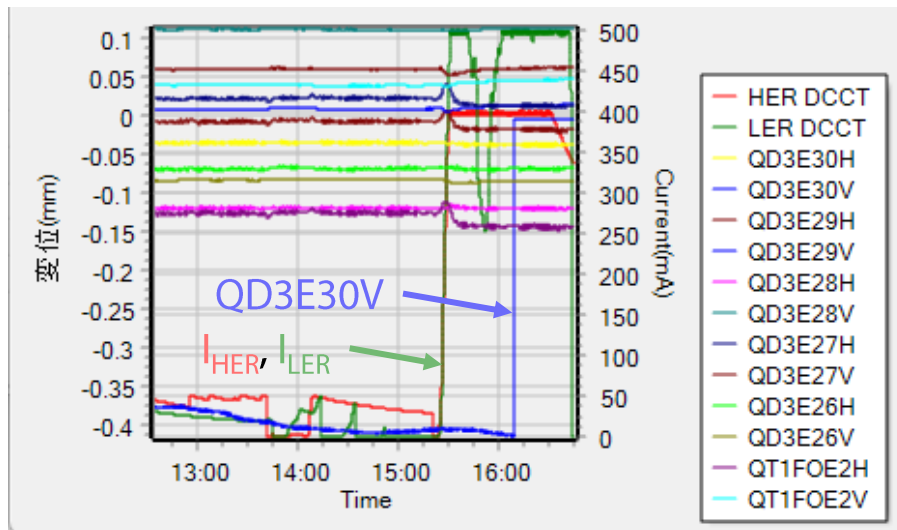
 14 Jan 2025, 08:00 → 16 Jan 2025, 17:00 Asia/Tokyo

One-page summary

	2024ab (Feb-Jun)	Summer shutdown	2024c (Oct-Dec)
1. Displacement meters	No major trouble	Maintenance	Radiation near LC4
2. BPM (narrowband, Libera)	No major trouble	All N-connectors tightened	All Liberas malfunctioning
3. BPM (turn-by-turn)	Regulator output failed	Regulator circuits modification	No major trouble
4. Bunch-by-bunch FB	iGp12 event misalignment	iGp12 firmware bug fix	No major trouble
5. Bunch oscillation recorders	Oscilloscope → RFSoc	Maintenance	18K10 BOR malfunctioning
6. Beam orbit FB at IP	No major trouble	Maintenance	No major trouble
7. X-ray beam size monitor	Three CMOS cameras died	Add Pb shielding near cameras	No major trouble
8. Beam loss monitors	No major trouble	Cable replacement, Opt. fiber LM	No major trouble
9. CT and DCCT	No major trouble	Maintenance	Fast DCCT introduced
10. ML-assisted beam tuning	Machine study at SuperKEKB	Code development	Machine study at SuperKEKB

1. Displacement meters

- Displacement meters worked well overall.
- Troubles
 - HER QD3E30V suddenly jumped and drifted. QD3E30V was temporarily disabled.
 - Re-fixing the sensor physically solved the drift.
 - LER QF4P14V suddenly jumped ~100 mm. QF4P14V was masked in the operation.
 - BNC connector seems healthy. ADC unit of the logger will be replaced.
 - The displacement meter logger (+Ras. Pi-based thermo-hygrometer) at LC4 hung up frequently.
 - Needs adding lead shielding.



2. Beam position monitors

- **Maintenances**

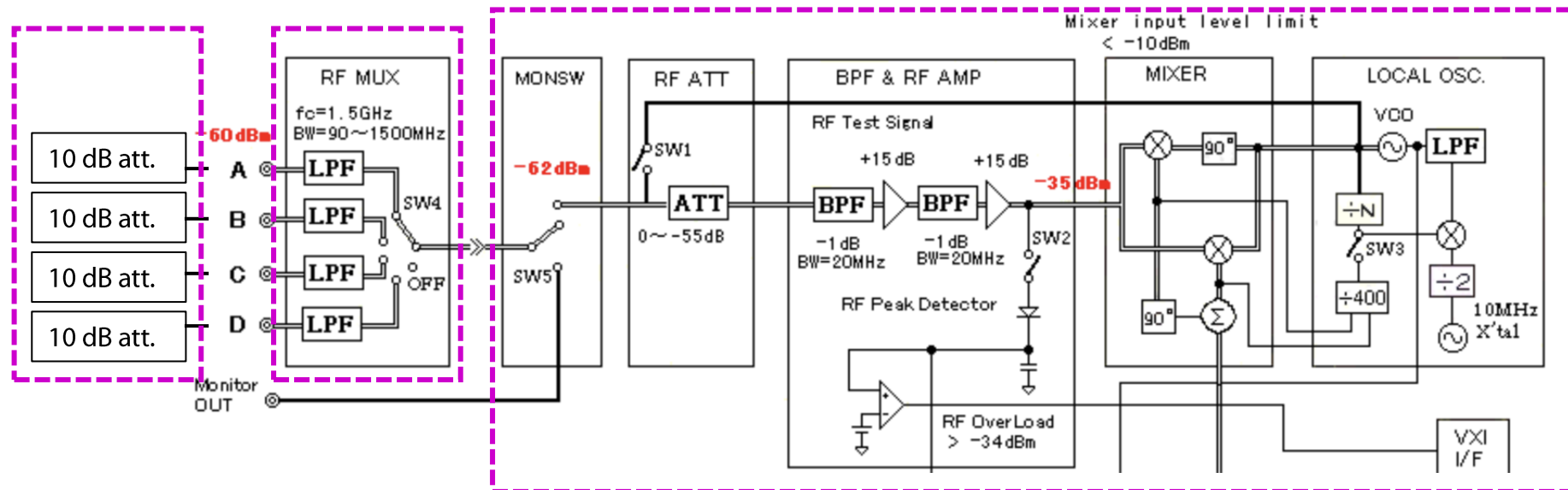
- During the 2024 summer shutdown, we found many loosely tightened N-connectors at the BPM relay panel. LER has been in this condition from the beginning of SuperKEKB??
 - LER: minor (79/445), **major (250/445)**
 - HER: minor (34/467), major (68/467)
- All connectors were re-tightened with torque wrenches.
- No significant change in the gain before/after tightening.

minor: 1 loose connector
major: 2-4 loose connectors



2. Beam position monitors (narrowband det.)

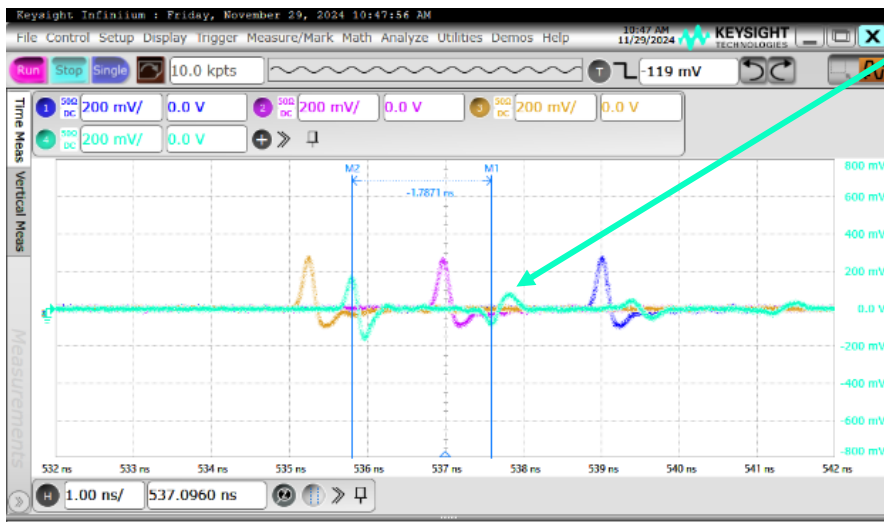
- **No major issue was found.**
- **Troubles**
 - Replacement of several HP 10 dB attenuators
 - Power-dependent unbalanced behavior. Replaced with the spare attenuator sets.
 - Replacement of two HP 4:1 MUX units and two HP 1 GHz narrowband detectors
 - We still have enough number of the spare 1 GHz detectors.



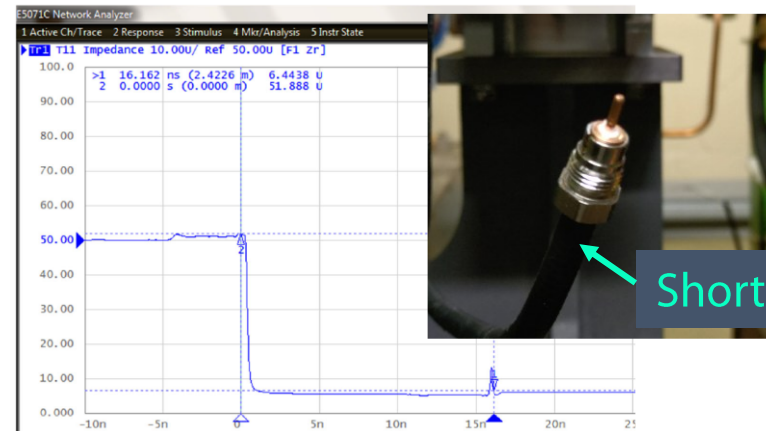
2. Beam position monitors (narrowband det.)

• Troubles

- “NaN” data contained in the BPM data
 - Restarts the VME IOC at LC6
- PLL unlock of 508 MHz detectors
 - Restarts after the power cycle of the VME (MXI) system
- QS2NP2 D channel gives low output.
 - Bypassing turn-by-turn BPM and changing the cable from FT to BPM panel did not work.
 - TDR measurement indicates a short circuit near the 5D cable and the N connector.



Small output pulse and large reflection only in D channel



Short circuit at the 5D-cable end

2. Beam position monitors (Libera detector)

• Troubles

- A total of six Libera BPMs give strange positions (bad consistency) at the lower current.
- Suspecting internal attenuator errors
- Repair (with a considerable cost and several months) or replace with narrowband detectors??

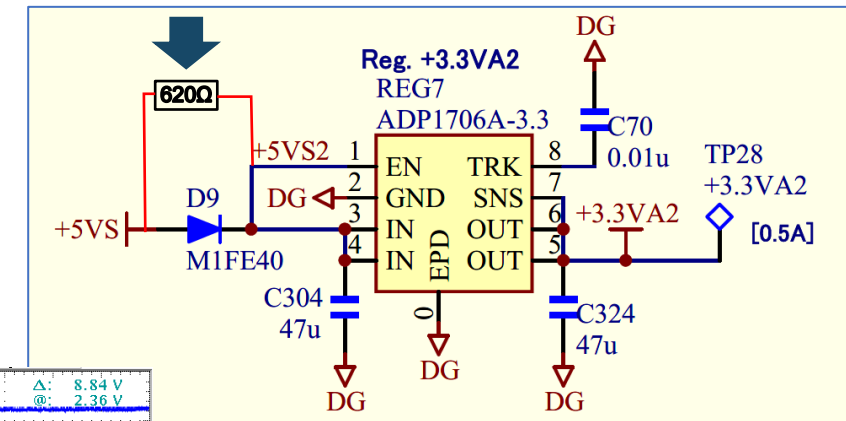
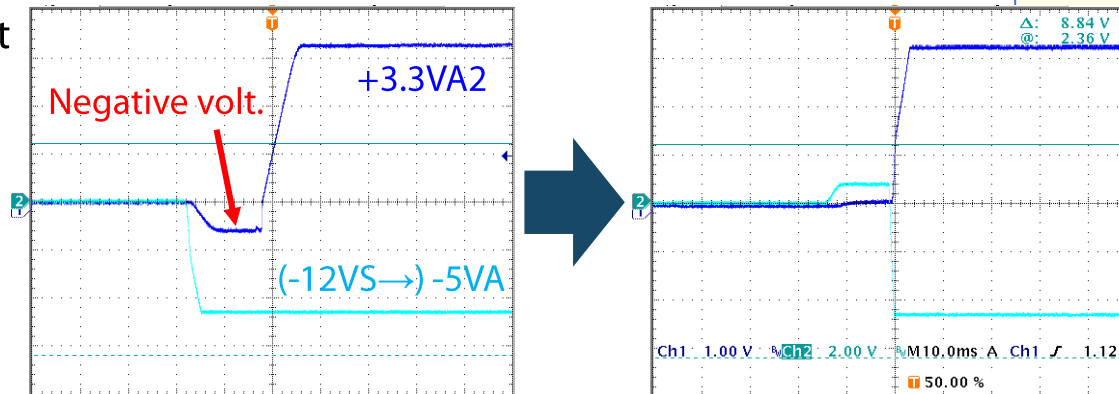


- “Consistency” is defined as the root-mean-squares of the four beam positions obtained by combinations of the three voltages.
- A large consistency suggests malfunctions in some signal channels.

3. Gated turn-by-turn BPMs

- GTBTs (~70 detectors for each ring) have worked well overall.
- **Troubles in 2024ab**
 - 3.3 V regulator gave abnormally low voltage~1.3 V. C and D-ch ADCs came too low/high counts.
 - ~10 GTBTs seemed malfunctioning. Some of the malfunctioning GTBTs somehow recovered later.
- **Maintenances**
 - Add register for discharging (D9 diode leaves charge.)
 - Enable/Disable sequence comes to work correctly.
 - Add trigger circuit to turn on -5VA by the rising edge of +5VS
 - Avoid negative voltage damage to the regulator

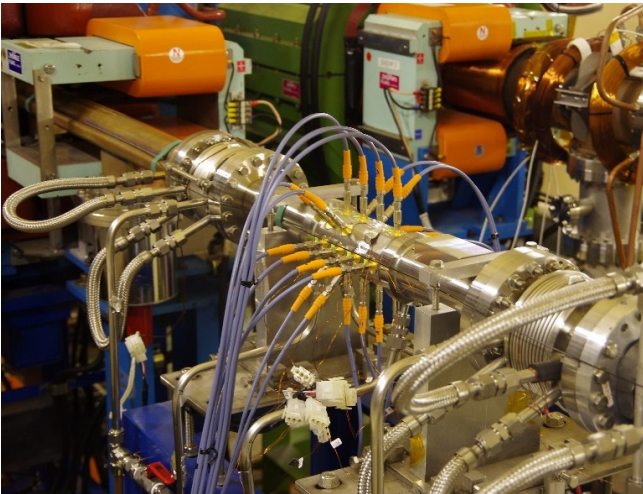
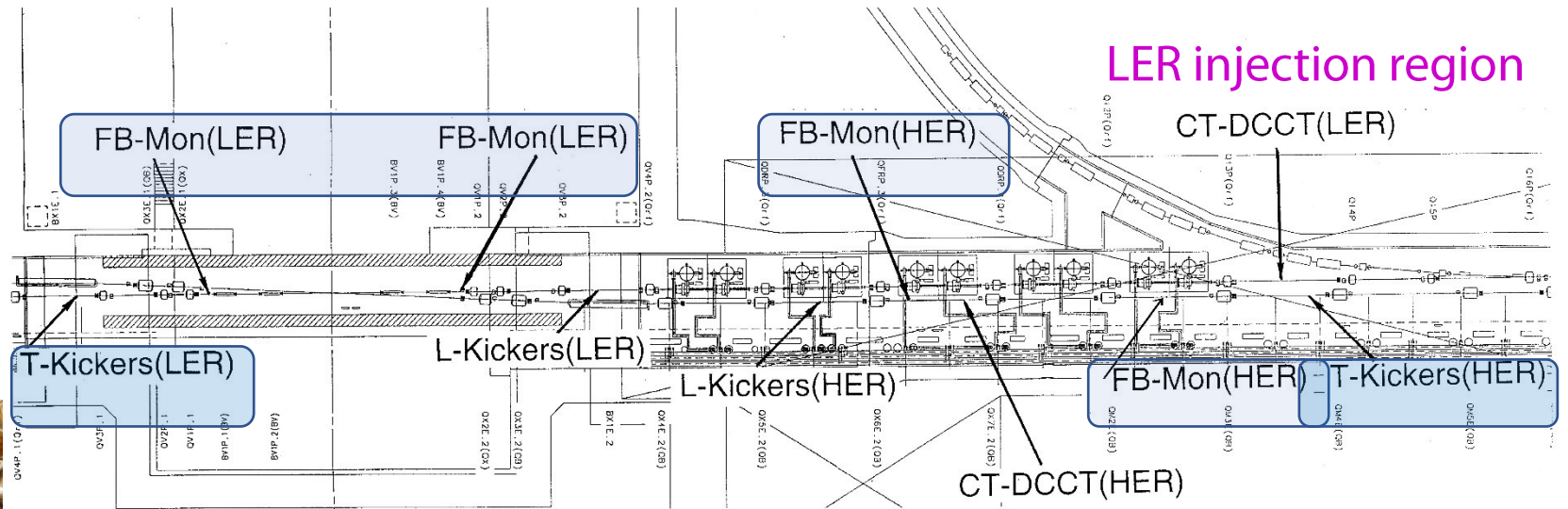
Turn-on sequence is different for each power output in new PS unit replaced in LS1.



4. Bunch-by-bunch feedback system

- **No major issue was found.**
- The FIR filter settings have often been adjusted according to changes in betatron tunes.

FUJ straight section

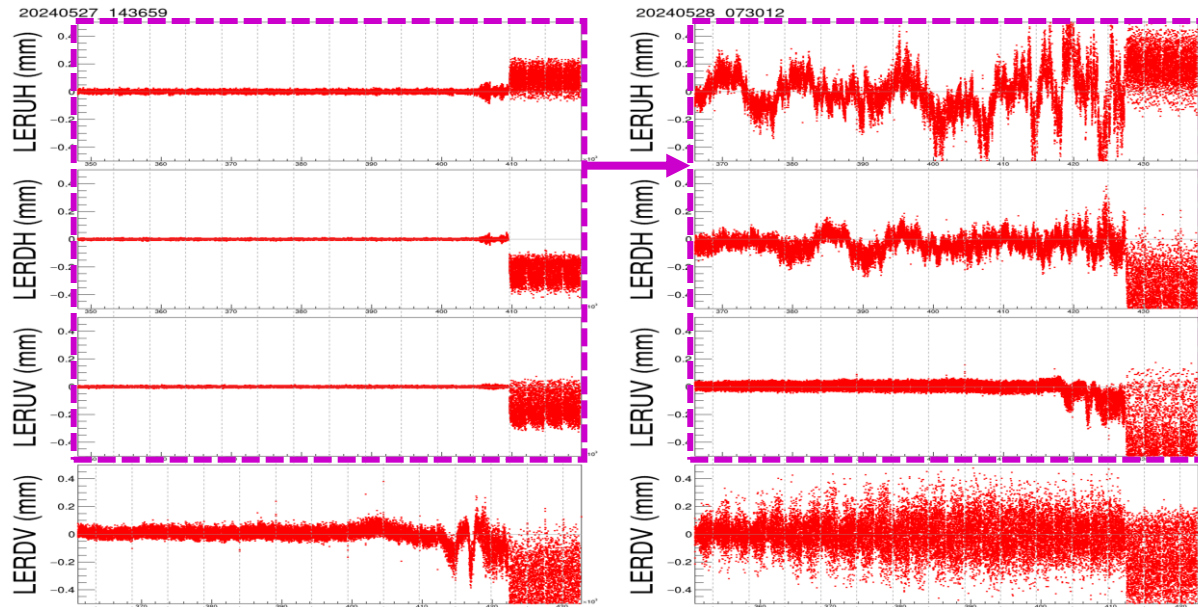


4. iGp12 firmware upgrade

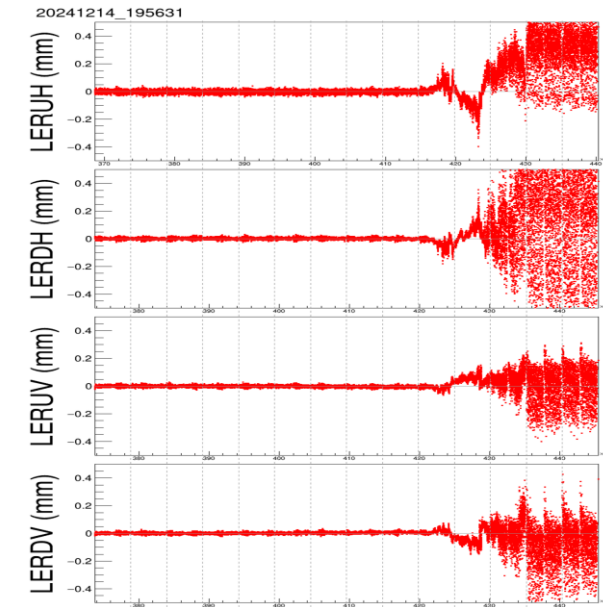
- **Maintenances**

- Bug fixed in the firmware of the iGp12 processors, applied only to the transverse FB system
 - Data acquisition/transfer at BRAM comes to working correctly.
 - Post-mortem data acquisition (i.e., bunch oscillation recorder) has been stable in 2024c.

UH, DH, and UV are delayed by 1 event in 2024ab



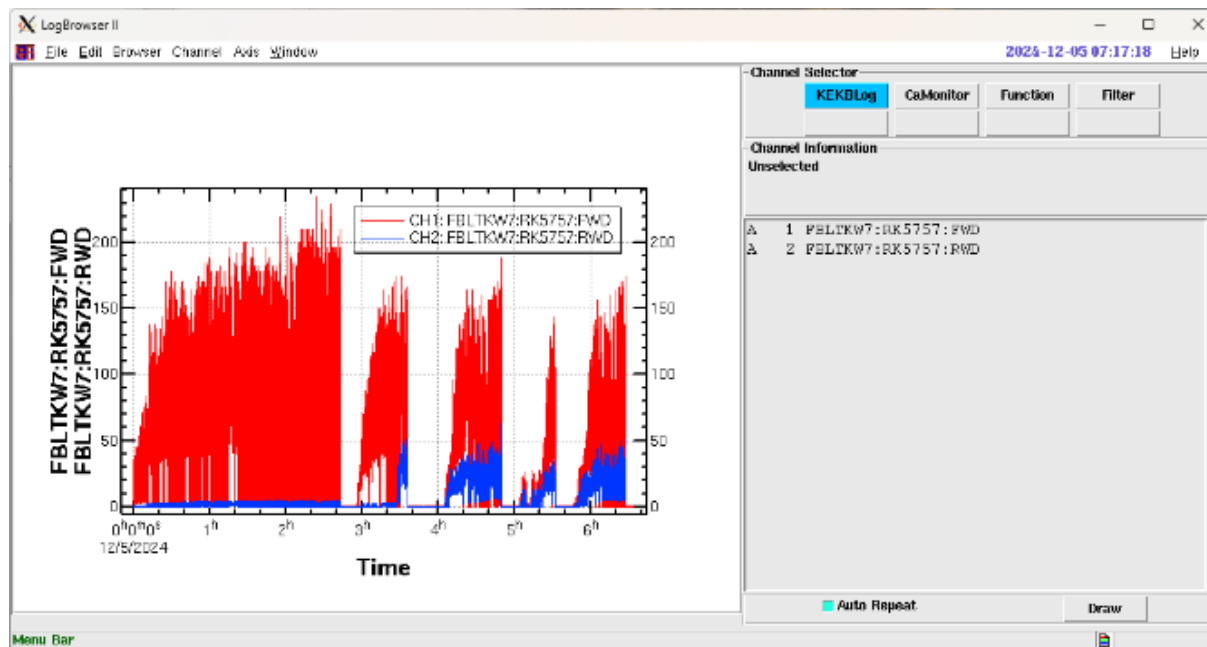
Correctly aligned in 2024c



4. Feedback system hardware troubles

- **Troubles**

- 1.5 kW attenuators for the transverse kicker broke in both HER and LER.
 - Beam aborts due to increased reflection to the final high-power amplifiers
 - Replaced with the spears. We have four spears presently.
- The temperature logger in the tunnel hung up several times due to radiation damage.
 - Power-cycled and returned to operation

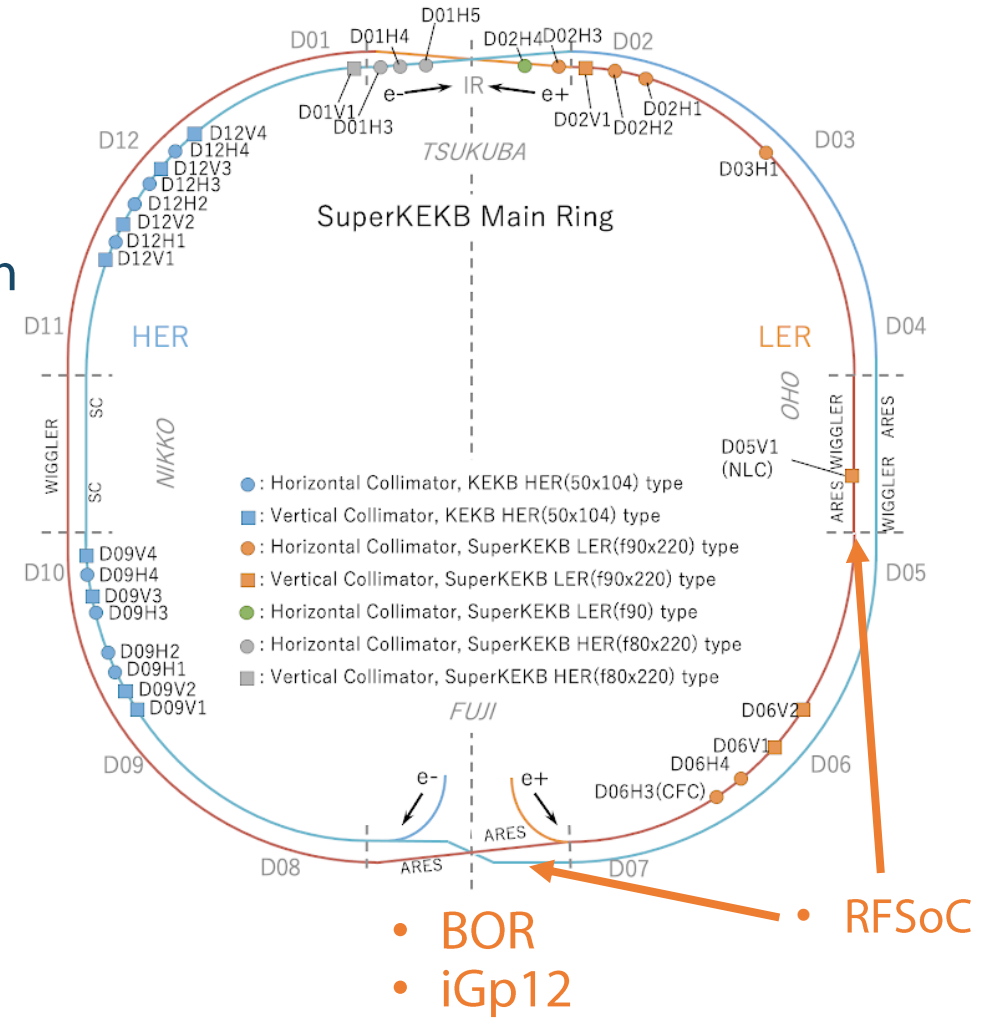


5. Bunch Oscillation Recorder (BOR)

- **BORs have worked well (except for 18K10 in LER).**
- BORs measure the bunch-by-bunch position over a few or several dozen turns just before the beam aborts.
- We added BORs more densely in LER in 2024, where Sudden Beam Loss (SBL) events had occurred severely before LS1.

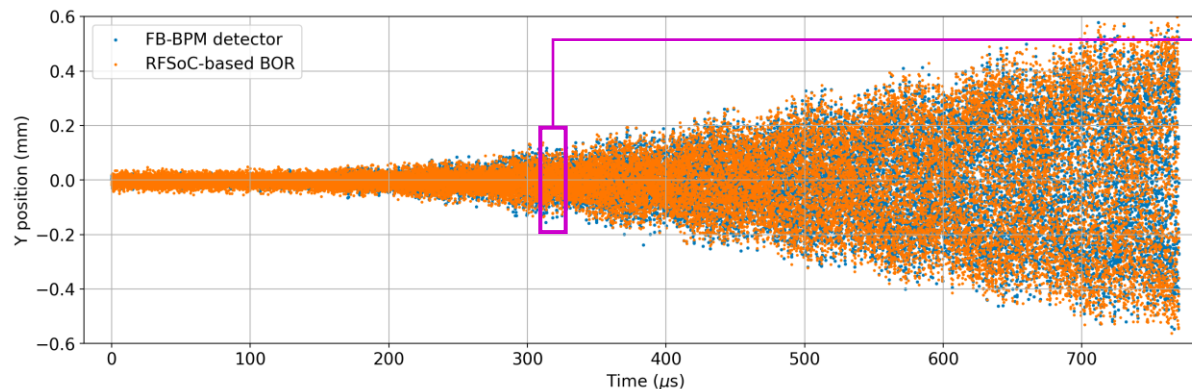
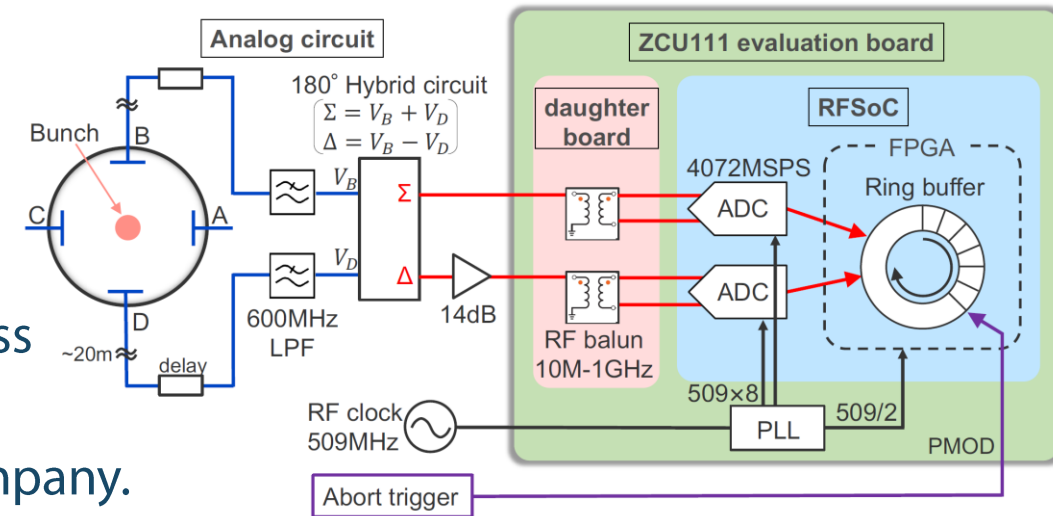
HER	Location	ADC bit	RF sync.
18K10 BOR	Fuji Upward	8	Yes
iGp12 BOR	Fuji Up & Down	12	Yes

LER	Location	ADC bit	RF sync.
18K10 BOR	Fuji Upward → malfunctioning	8	Yes
iGp12 BOR	Fuji Up & Down	12	Yes
RFSoc BOR	Fuji Down & D05	12	Yes
Simple BOR (Oscilloscope)	D05 → uninstalled	8	No (5Gsps)
	D06 → uninstalled	8	No (2.5Gsps)

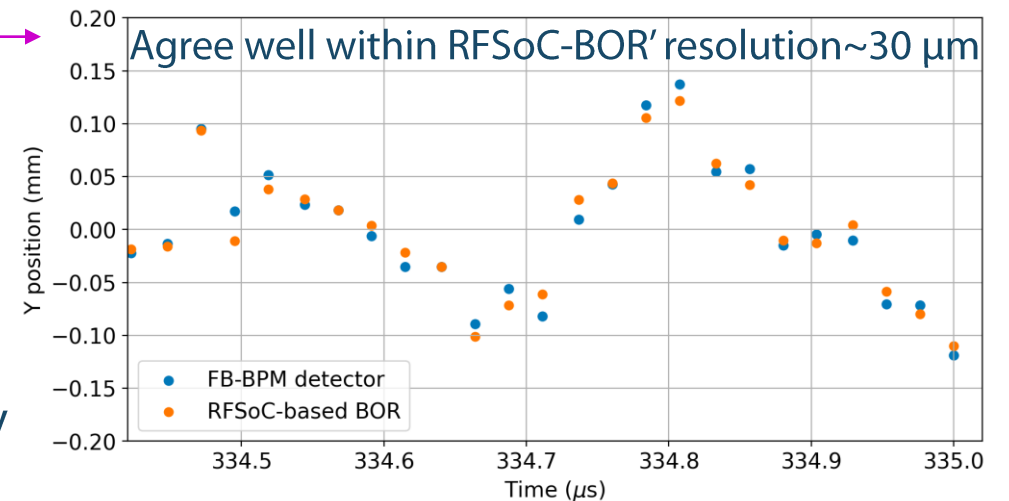


5. RFSoc BOR

- R&D of the RFSoc-based BOR is in progress with SLAC. (Xilinx/AMD RFSoc: multi-ch. ADC, DAC, FPGA, and CPU on a chip)
- Prototype BORs with the ZCU111/206 evaluation boards have been operating in 2024a-c runs.**
- Xilinx/AMD's XM500 mezzanine card was rather powerless for longer-cable BPMs (and large off-center COD)
 - A New high-gain RFMC will soon come from the company.



Agree well within RFSoc-BOR' resolution ~30 μm

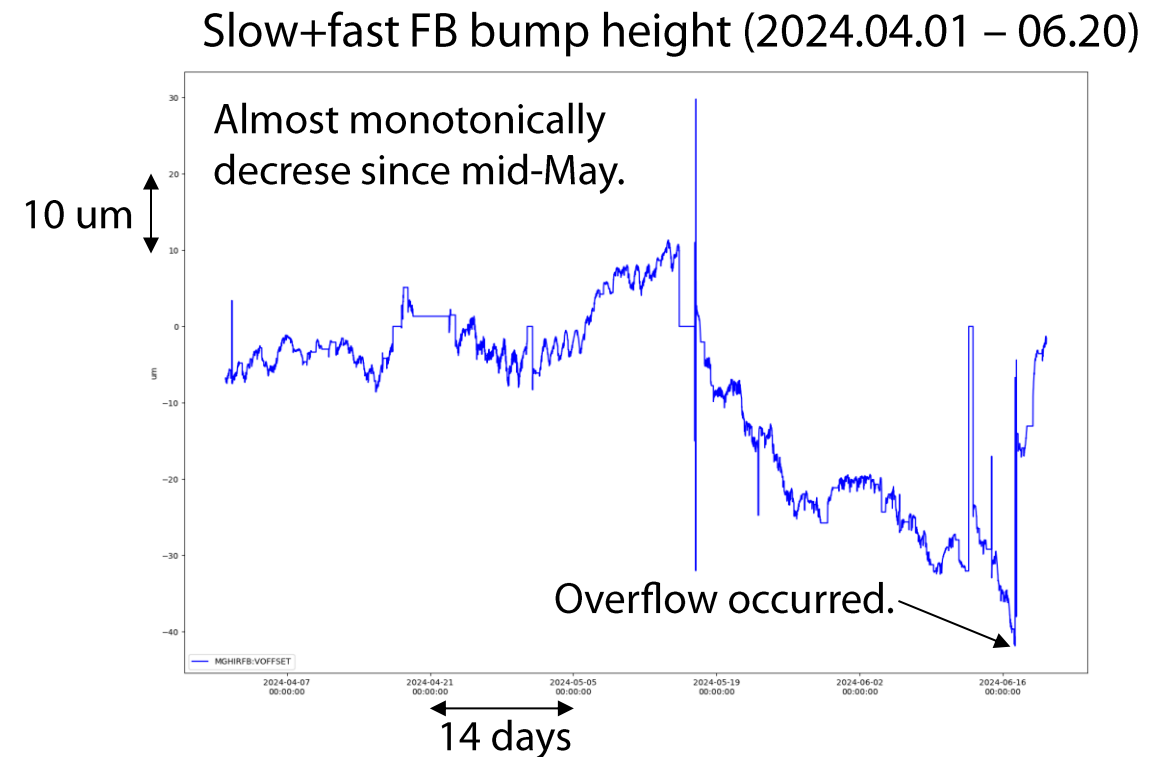


Measurements with **iGp12-BOR** and **RFSoc-BOR** for instability intentionally induced by inverting the FB kicker phase by 180°

R. Nomaru* *et al*, JINST **19** P12026 (2024)
(* Graduate student of U. Tokyo)

6. Beam orbit feedback at the IP



- **IP-FB is working well.**
- DAC value overflow (27 Jun. 2024 5:00-7:00)
 - Setting (DAC) value of the corrector ZVF2RE overflowed and jumped to positive value.
 - Beam injection in HER came to difficult and operation was interrupted for ~2 hours.
 - The overflow was eliminated by adjusting the orbit with other steering magnets.
 - “iBump damper” automatically absorbs a part of the bump height with CCC correctors. (It was OFF, while it had been ON before LS1.)




7. X-ray beam size monitor (XRM)

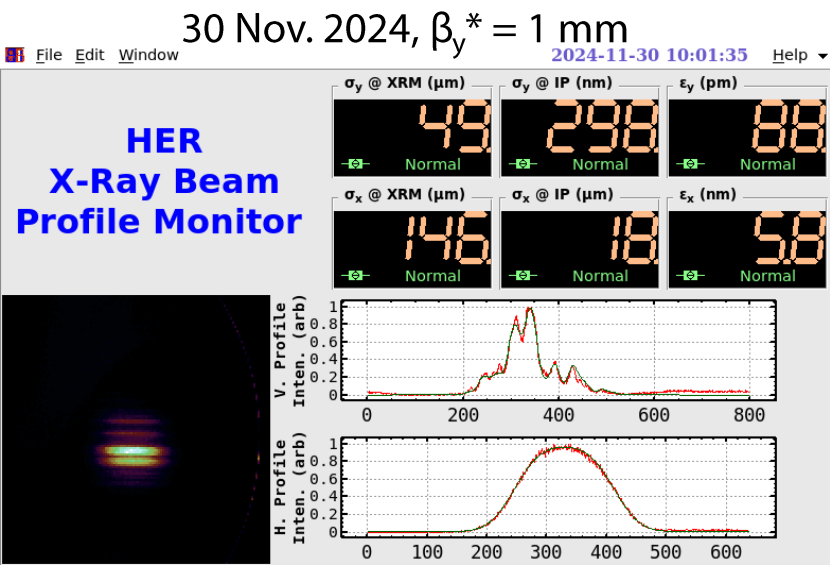
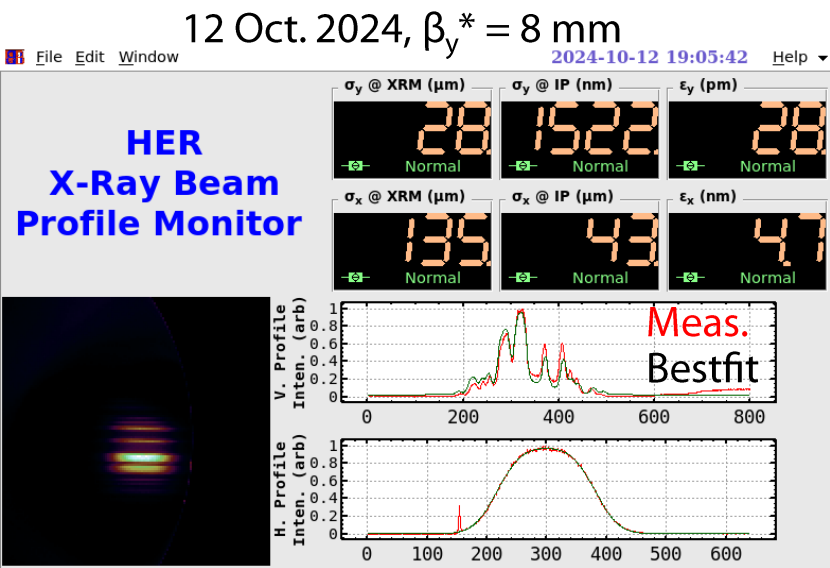
- **No significant issue was found in 2024c.**
 - Pb shielding was added in the 2024 summer shutdown.
- Fast turn-by-turn CMOS cameras (expensive) were usually on standby at the ground floor hut.
 - Only one camera installed in LER for a month in 2024b
- Wire bonding of a new silicon sensor is in progress.

	HER	LER
Low-speed CMOS camera	OK	OK
Turn-by-turn CMOS camera	Parking at ground floor	
Si-sensor XRM	<div>One detector damaged by radiation</div> <div>Wire bonding, new DAQ (RFSoc?)</div>	

NATIONAL
ACCELERATOR
LABORATORY

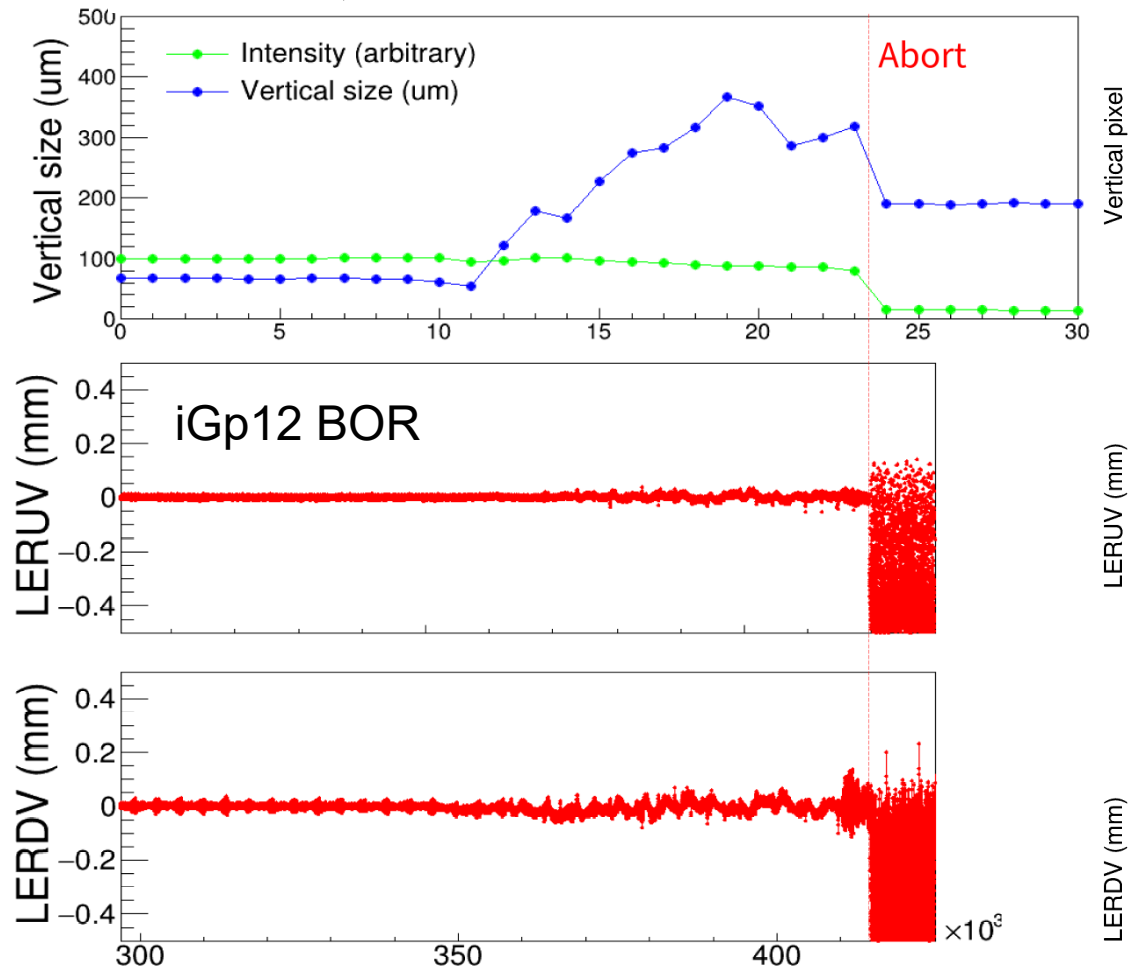




7. Beam size blowup in SBL-like events

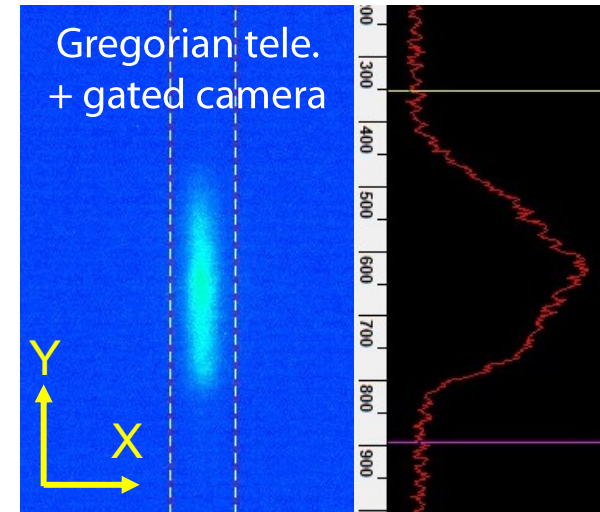
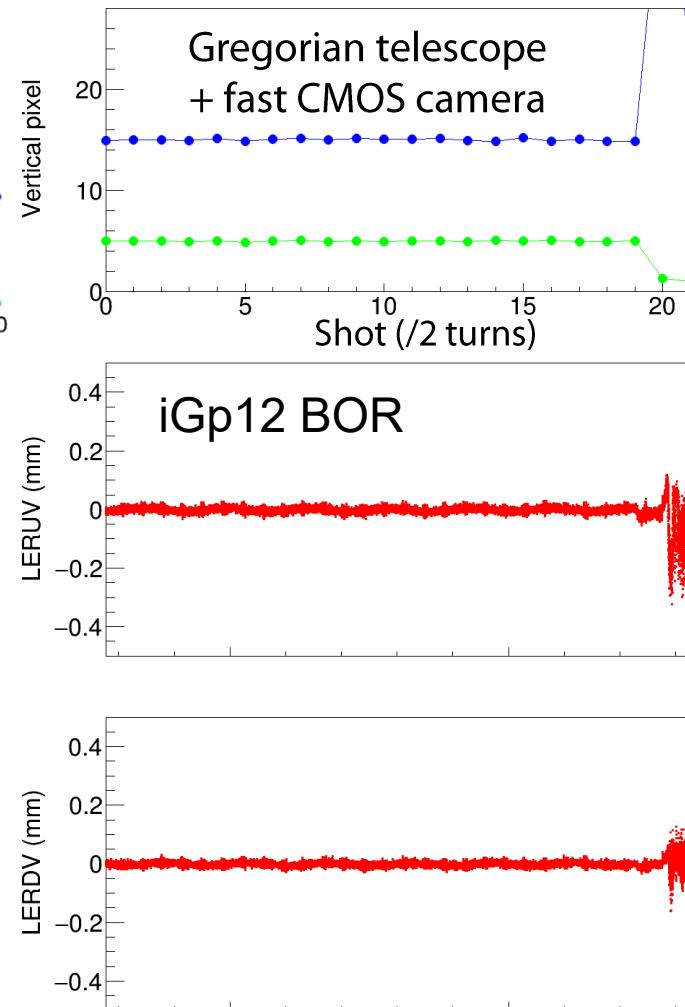
XRM measurement ($\beta_y = 69$ m)

LER, 20 May 2024, 00:41:11 (burst at D10_L03)

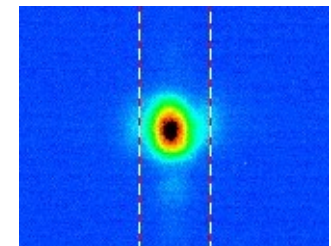


SRM measurement ($\beta_y = 60$ m)

LER, 14 Dec. 2024, 10:06:03 (no clear burst)

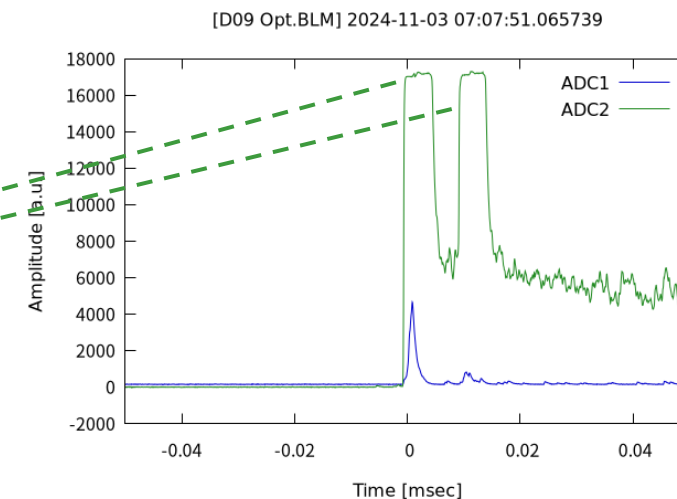
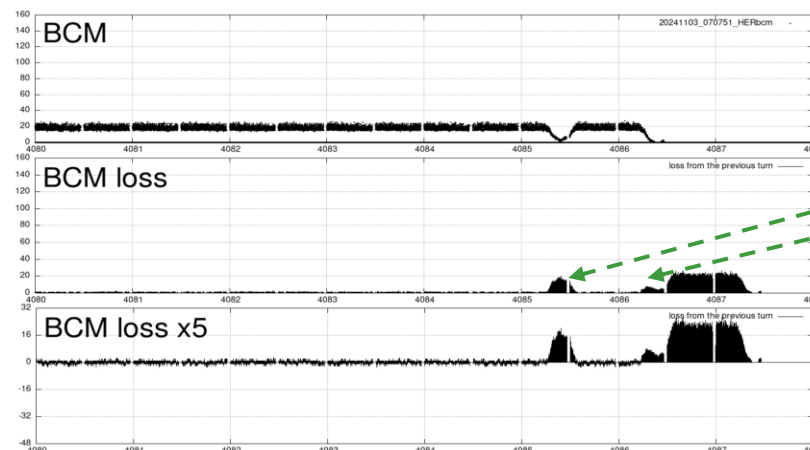


cf. non-SBL abort



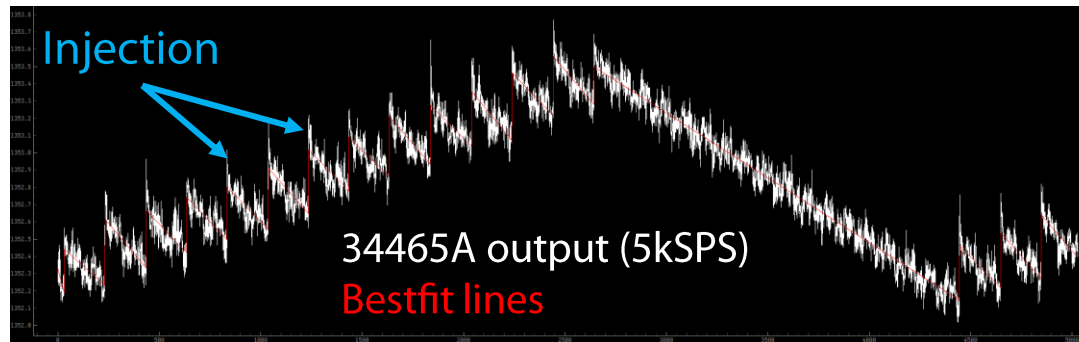
8. Beam loss monitors (PIN/IC/Optical Fiber)

- **The system overall worked well.**
- **Maintenances**
 - The 5D signal cable of the PIN near the D12V4 collimator was replaced with an 8D cable.
 - Signal was noisy (owing to the long cable~450 m) and sometimes issued unintended beam-abort triggers at high beam current.
 - Replacement solved the problem, which no longer happens after the replacement.
 - Optical fiber LM was placed near the D9V1 collimator (close to the HER abort kicker).
 - Out of 18 SBLs in HER, 13 were also triggered by the optical fiber LM; of the 13, 6 received the fastest abort-trigger signal from the optical fiber LM.

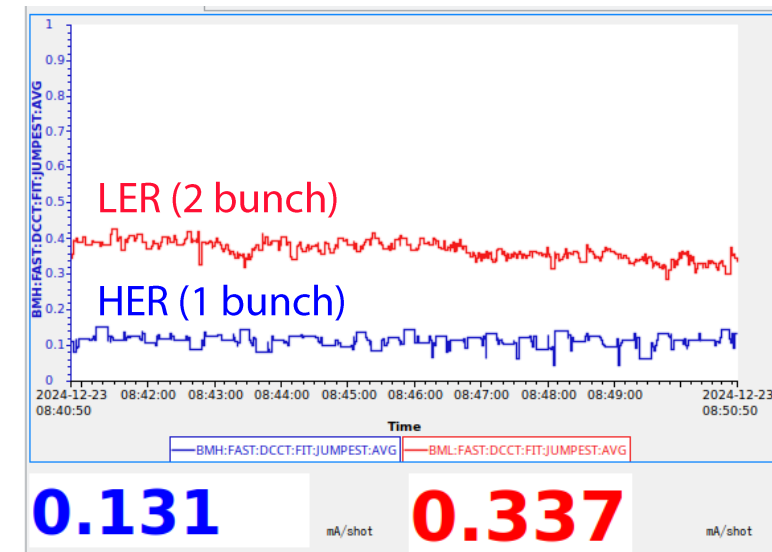


9. CT and DCCT

- **CT and DCCT worked well.**
- **Maintenances**
 - The test DCCT chambers were replaced with straight pipes.
- **Fast analysis of DCCT**
 - The DCCT chamber has two analog outputs:
 - One is connected to high-precision DMM (so-called DCCT)
 - Another is to Keysight 34465A DMM (5kSPS)



- Fitting codes were prepared/maintained by Bela Urbschat (graduate student of Nagoya U.)
- Quick “mA/shot” information will be helpful in beam injection tuning.



10. Machine-learning assisted beam tuning

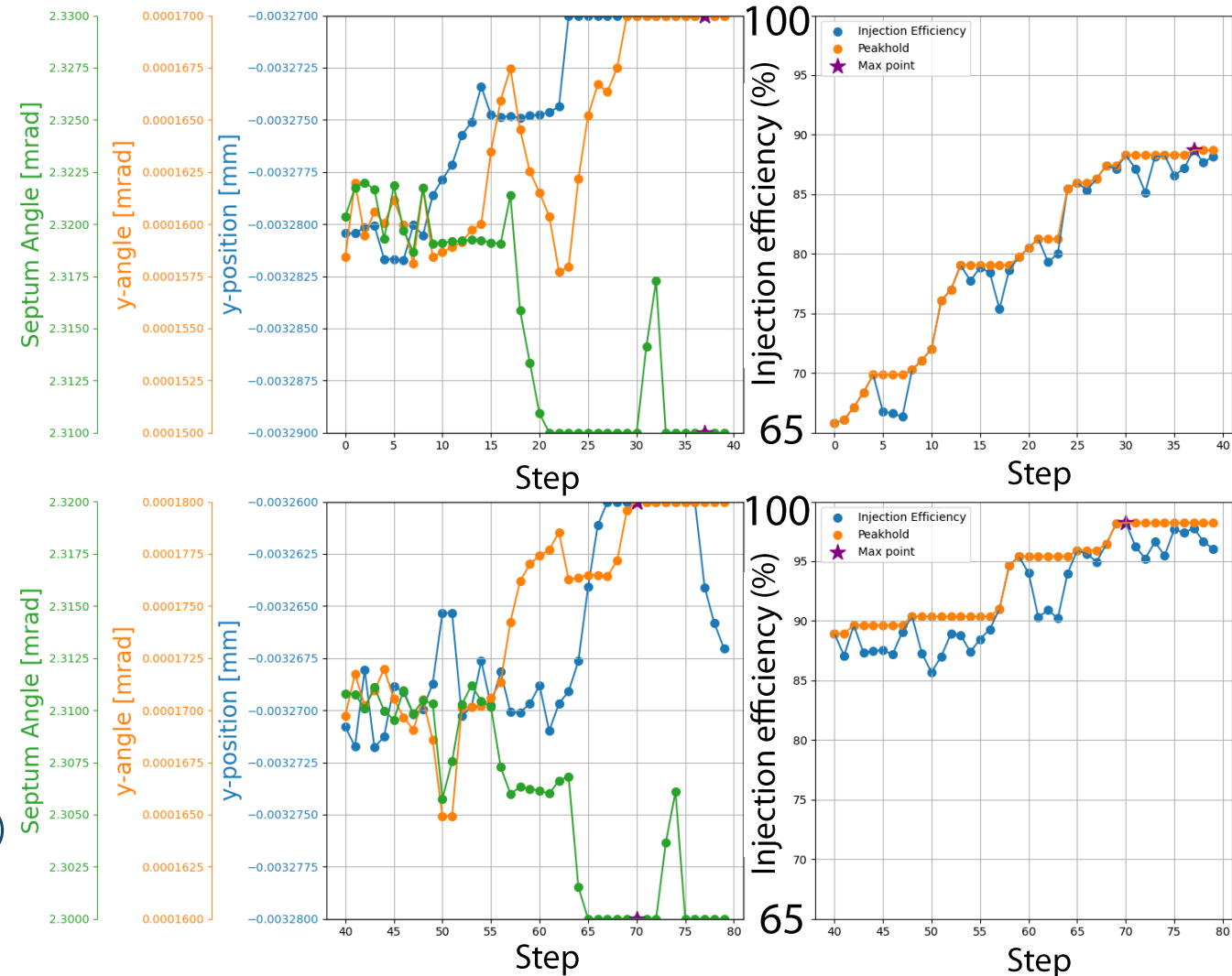
PHYSICAL REVIEW ACCELERATORS AND BEAMS 27, 084601 (2024)

Machine-learning approach for operating electron beam at KEK electron/positron injector linac

Gaku Mitsuka,^{1,2,*} Shinnosuke Kato³, Naoko Iida,^{1,2} Takuya Natsui,^{1,2} and Masanori Satoh^{1,2}

- **Bayesian optimization successfully maximized the injection efficiency.**
 - The injection beam orbit is optimized (changing 3 parameters: septum magnets and vertical steerings).
- Of the ~40 trials conducted in LER and HER at 2024c, over half had 10% or more improvements in injection efficiency.
- Developing ML tools is in progress:
 - Anomaly detection (vacuum group)
 - Causal discovery (R. Arima*, K. Matsuoka, GM)
 - Injection tuning, etc.

(* Graduate student of U. Tokyo)



(Courtesy of S. Kato*)

Responses to Recommendations

- **R12.1:** ..., further improve the SBL diagnostics such as by additional beam oscillation monitors, bunch-by-bunch beam-size monitors, and even more beam-loss monitors around the ring.
 - Added new BORs, turn-by-turn & bunch-by-bunch beam size monitors, and loss monitors
- **R12.4:** Continue the development for the acquisition of a set of experimental data with systematic analysis and categorize the different beam loss observations.
 - SBL events can be categorized into several patterns with a help of the BOR and vacuum burst information.
- Gated T-B-T monitors and beam loss monitors need further maintenance, and a machine learning assisted beam tuning tool is being developed to optimize the beam injection efficiency and lifetime, etc. The system shall come into operation by 2024.
 - Done.
- R13.1: Continue the effort of adjusting the threshold of the beam loss monitors to avoid unnecessary beam abortion due to small beam losses.
 - The 5D signal cable was replaced with an 8D corrugated cable for the PIN near the D12V4 collimator.
- R13.2: Start maximization of injection efficiency with machine-learning (ML) from a random or a lower value than the human-optimized one, to develop the tool of ML.
 - Of the ~40 trials in 2024c operation, over half had 10% or more improvements in injection efficiency.

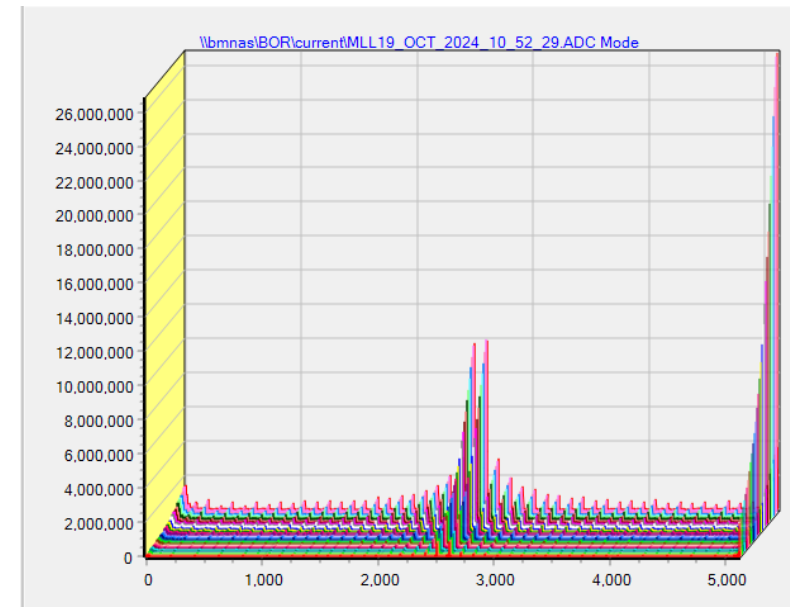
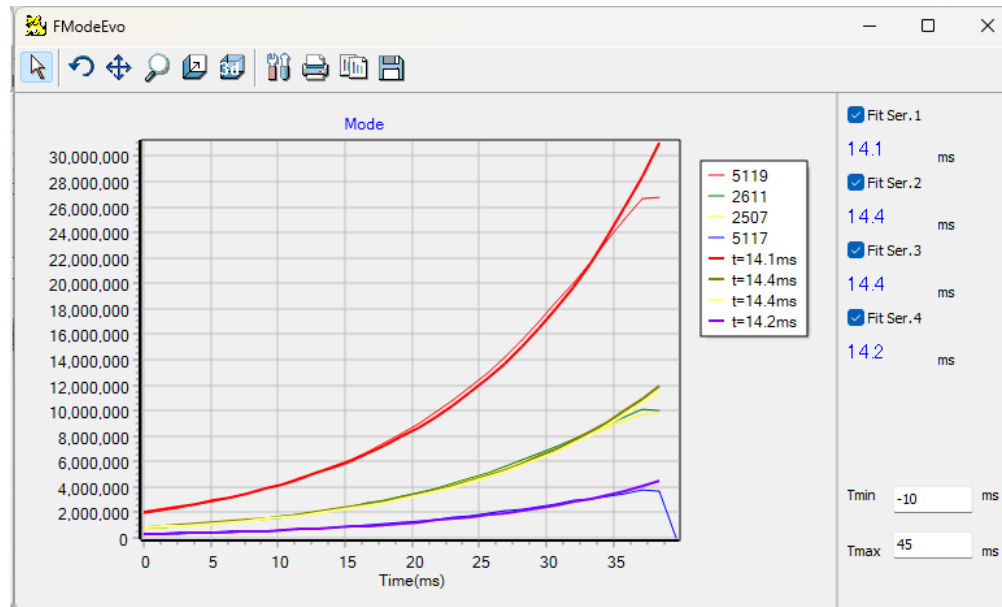
Summary

- **Beam monitors and feedback systems have worked well overall.**
- Some monitors need continuous maintenance (or replacement):
 - Displacement meters
 - Libera BPMs
- New R&D projects started cooperating with graduate students, MDI group, and international collaborators.
 - BPM and BOR
 - Beam size monitor

Backup

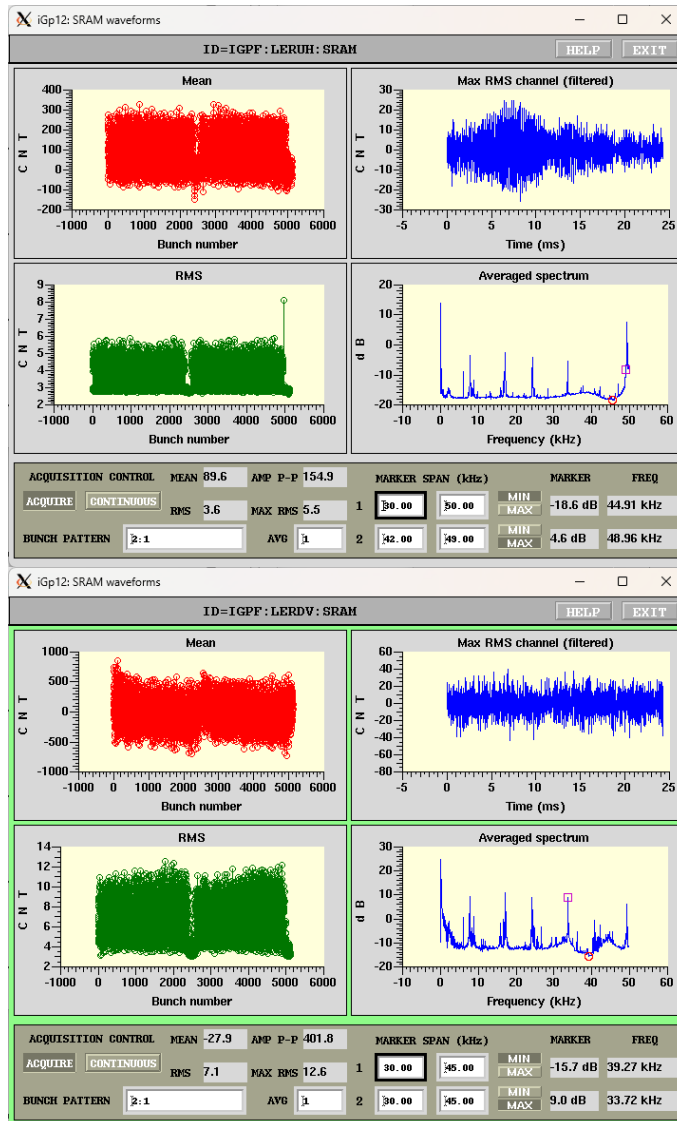
LER longitudinal FB

- During scrubbing run (non-collision, LER~1500mA, by 2 pattern) when the L-BxBFB happened to be turned off, the beam was aborted due to longitudinal instability (mode=-1, growth time~14.1ms).
- After this, RF group has tuned the mode FB to suppress fundamental mode instabilities.



Tuning transverse FB

- Tune FIR filters to be resistive, but not excite unwanted unstable modes such as coming mode coupling (not so visible this time), strange near half tune mode (imaginary tune split mode??)
- Tune the feedback gain to increase luminosity
 - Exceed vertical feedback gain usually increases vertical beam size and reduce luminosity
 - Too low feedback gain also increase beam size and reduce luminosity

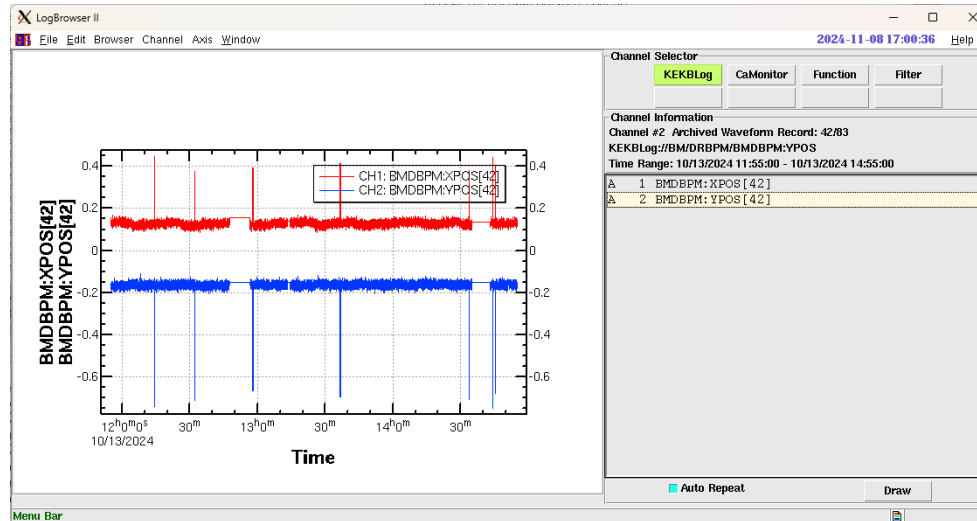


- Noise related lines (8kHz) appears in all the FB detectors. RMS noise level has greatly reduced from 30 to 5 counts
- Sharp horizontal spectrum near half integer?? (LERUX) which greatly restricts the tuning range of FIR filter
- Mode coupling related instabilities were not so obvious.

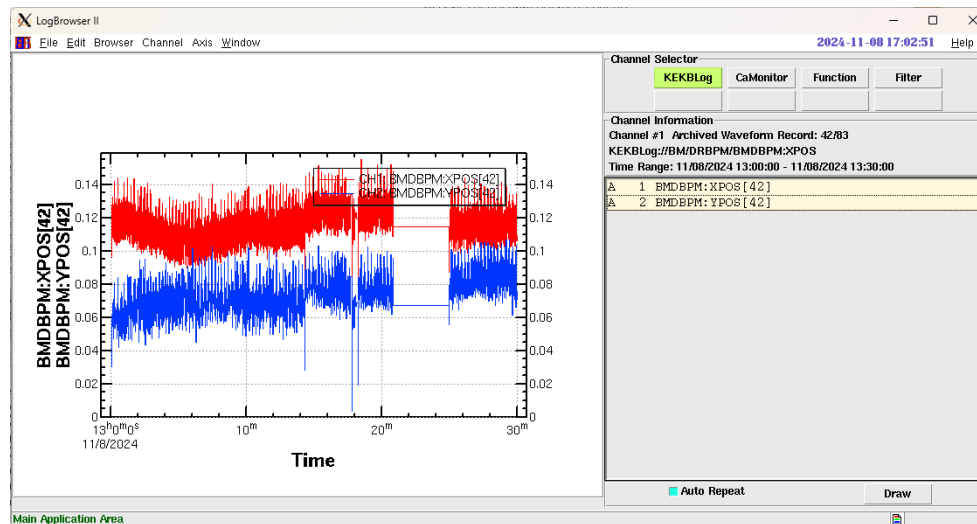
- LAN-GPIB to control the FB final amplifiers in the tunnel (almost no radiation) had hanged-up several times. Need the tunnel access to power-cycle LAN-GPIB and all the FB amplifiers.
 - LAN-GPIBs with GbE interface (current version) seems much weaker than old LAN-GPIB
 - Suspecting large network load
- FB components temperature sensor (3-wire Pt100) failure caused beam aborts. Repaired in the tunnel.
- Failed final power amplifiers due to forward power limit
 - Could be restarted by the remote-reset, without beam abort.
 - From the power log, it did not show the exceed power??
 - Suspecting failure in the power amplifier control unit.

DR

- It was reported that only the vertical orbit of the 1s bunch of the DR extracted beam shifted from shot to shot. When we checked the COD near the DR FB detector, we found that it had shifted significantly in the vertical direction, causing the ADC of iGp12 to become saturated.
 - Charge of 1st bunch was higher than 2nd bunch- larger vertical offset in the FB detection circuit.
- Though this offset has been corrected by DC offset cancel circuit in the FB detector and the shot-by-shot orbit change has suppressed, we hope to stabilize the COD of DR in some degree (<0.1 mm in long term).



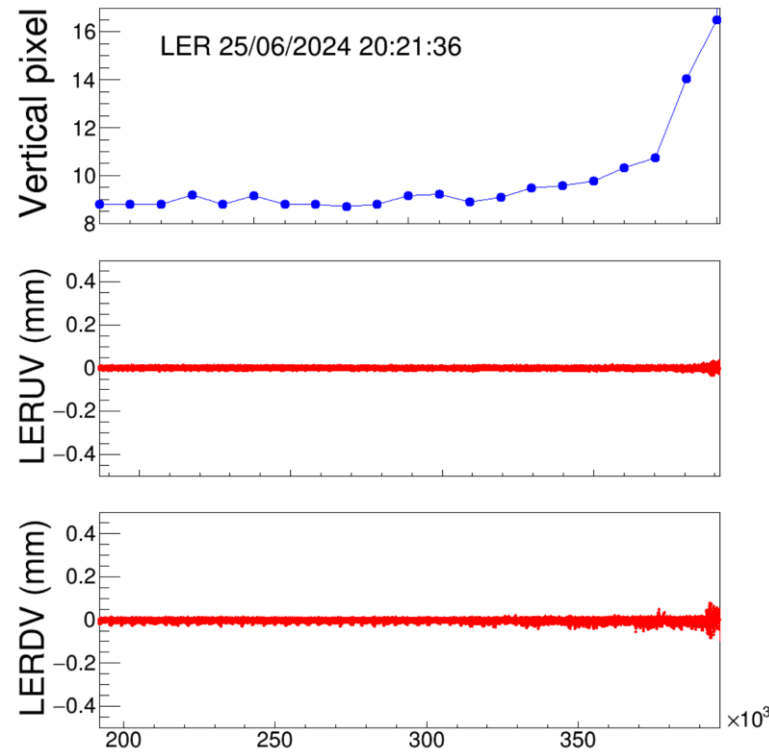
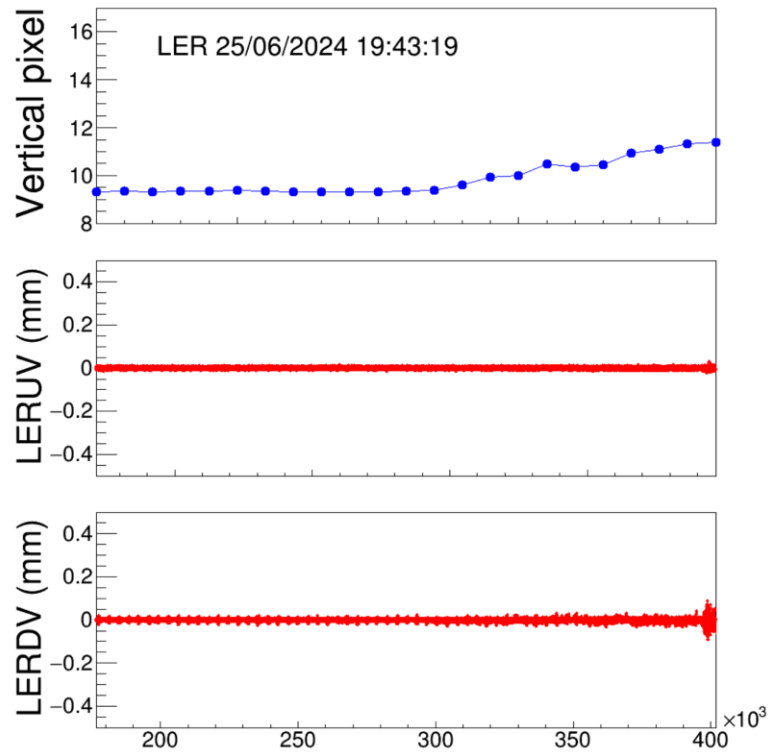
Early Oct, 2024
V orbit $\sim -0.2\text{mm}$



Early Nov.
V orbit $\sim 0.1\text{mm}$
V orbit has changed $\sim 0.3\text{mm}$

Beam size blowup in LER

“Knocker” events (D1 Cu pipe with groove)



SBL (burst at CCG D10_L04)

