

Monitor

2026/10/26 KEKB Review

H.Ikeda

on behalf of beam monitor group

Outline

- Responses to Previous Recommendations
- BT and Injection Diagnostics
- Ring BPMs
- Bunch by Bunch Feedback
- SBL Diagnostics and Beam Protection
- Summary

Responses to Previous Recommendations

Recommendation	Current response and next step
R13.1 Libera	BPMs returned to narrowband detection. Faulty Libera confirmed beyond repair.
R13.2 Consolidation	System consolidation remains the goal. Budget and staffing constraints prevent concrete progress.
R13.3 Optics studies	Gated turn-by-turn diagnostics maintained and used. Optics studies to be verified during the next run.
R13.4 SBL diagnostics	RFSoc position readout ready. SR cameras available for SBL. X-ray sensor/RFSoc bunch-size diagnostics under development.
R13.5 Maintenance	Maintenance continues for all beam monitors.
R13.6 Vacuum checks	Vacuum Group investigation of flange contacts and discontinuities planned.
R13.7 BOR expansion	RFSocs secured, up to three BORs prepared. Timing parts have long lead times. Locations to follow MDI/Optics discussions.
R13.8 Machine learning	Emittance/luminosity estimation tools under development. AI Task Force leads analysis with Instrumentation Group support.

BT and Injection Diagnostics

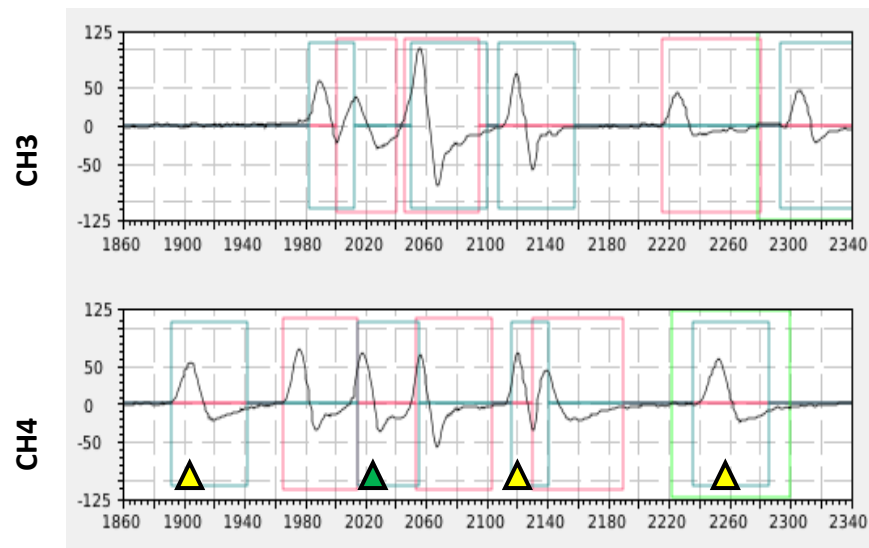
BT BPM Readout Improvements

- **Issue**

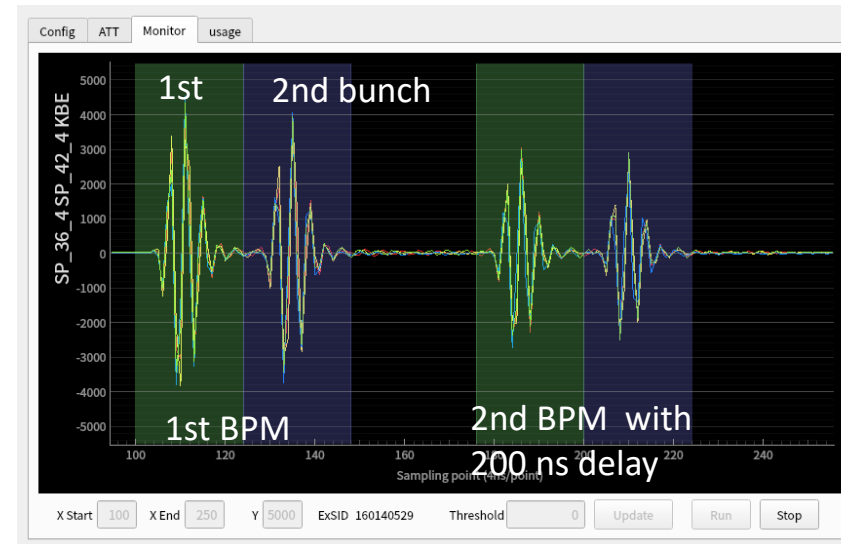
- The existing oscilloscope system combines signals from multiple BPMs using an RF combiner. It was not designed for two bunch operation, resulting in signal overlap.

- **Solution**

- Move affected BPMs to the Linac readout system. Signal delays allow multiple BPMs to share one board.
- Four BTeV ECS BPMs have already been converted. The upgrade is being extended to 25 BT BPMs.



Existing readout: overlapping signals



Linac readout: signals separated by delays

BT BPM Upgrade: Results and Status

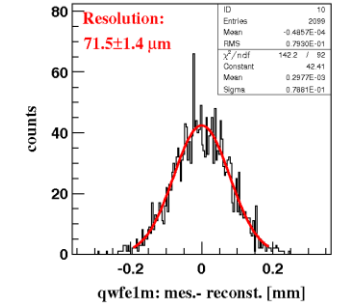
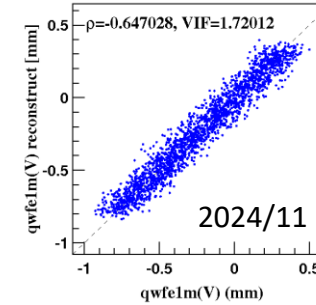
- **Demonstrated Benefits**

- Position resolution improved from approximately 66–122 μm to 7.5–15 μm in the tested BPMs.
- Measurements are integrated into the Linac event synchronized dataset.

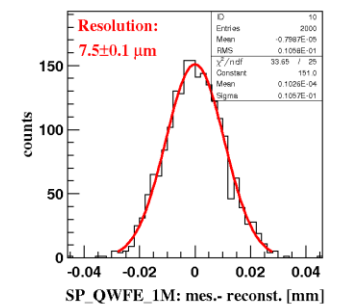
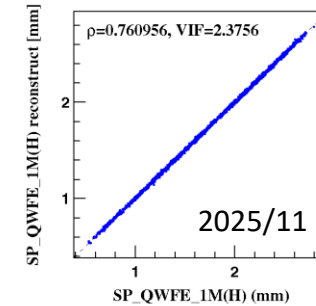
- **Status:**

- Cabling and gain calibration completed.
- Timing and charge calibration scheduled to begin on November 30.

BT Osc.
system



Linac VME
system



Measured position vs reconstructed position from the other 2 BPMs (left) and difference between measured and reconstructed position (right) using 3 BPM method.

BT Profile Monitoring and Phase-Space Diagnostics

(D. Oumbarek Espinos)

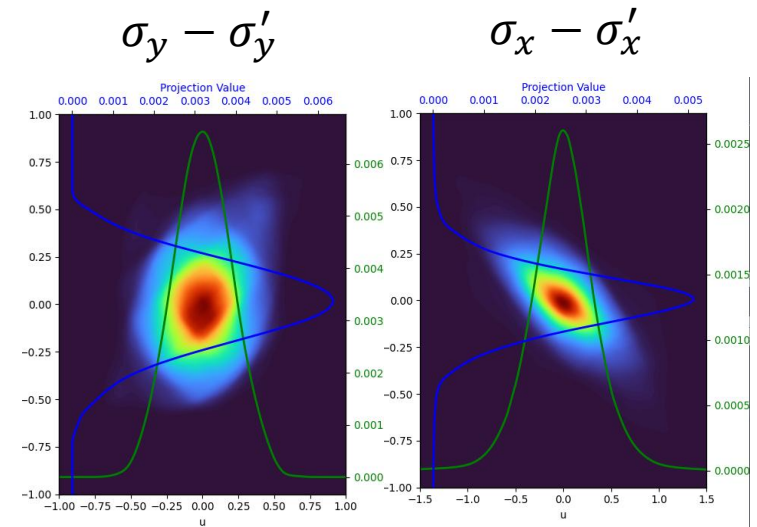
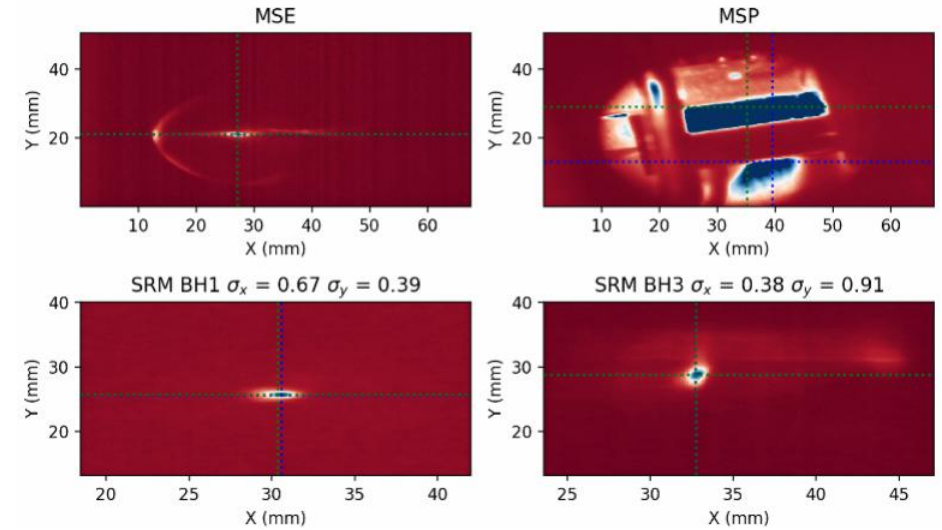
Operational Monitoring

- The system automatically saves three consecutive images from all active BT OTR/SRM screens every five minutes, together with machine settings.
- Operated reliably throughout the run, providing a database for beam-change analysis.

Phase-Space Reconstruction

- Reconstructed the transverse phase space at the entrance to LER-BT using quadrupole scans.
- Measurements at the end of LER-BT are planned for the **2027a run** to investigate changes along the transport line.

30/01/2026 - 14:05:16



QXD5P positron beam transverse phase-space at the start of LER-BT

Injection Point BPMs

(B. Urbschat)

Capability

- RFSoc-based readout independently measures both injected bunches in HER and LER, supporting injection tuning.

Operational Status

- Operated without major problems during the 2026ab runs.

Prepared for the Next Run

- New firmware supports a direct optical link to the Linac event timing system, providing timing and shot IDs.
- Updated control room interfaces.
- Channel gains were calibrated using measured signals and simulated electrode responses to improve position consistency.



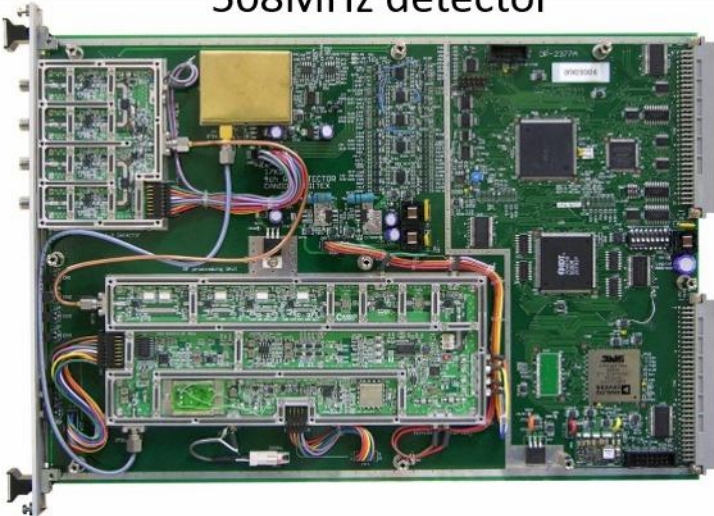
Ring BPMs

BPM

- **Operational Issues**

- Generally operated reliably, but faults appear to be increasing.
- Aging cables, MUX switches and VXI hardware have failed; VXI startup errors are also increasing.
- A poorly fixed BPM block was found, apparently dating back to the start of SuperKEKB.

508MHz detector



BPM

- **Improvement plan**
 - **Commercial system (Libera Brilliance+ or equivalent)**
 - Supports fast orbit correction and turn-by-turn measurements; gated measurements require evaluation.
 - Requires a separate GTBT system.
 - Existing Libera units show fill-pattern/current dependence and frequent failures. Further evaluation is needed.
 - **RFSoc-based system**
 - Can integrate GTBT and COD measurements.
 - High development and production costs; achievable resolution requires verification.

BPM : Displacement sensors

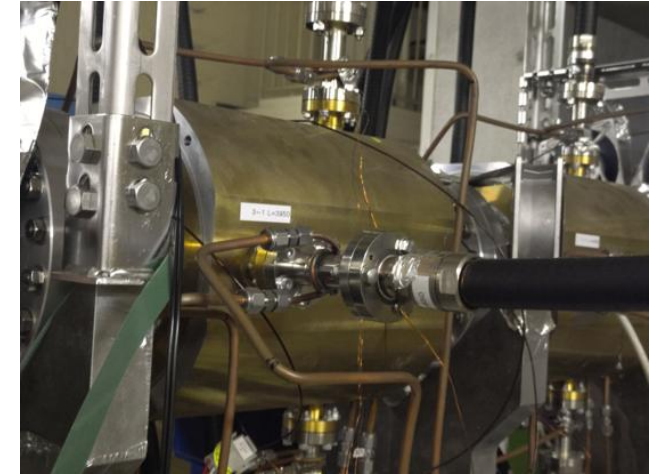
- **Function:** Capacitive sensors measure BPM block displacement relative to nearby sextupole or quadrupole magnets (range: ± 1 mm or ± 5 mm, resolution: <1 μm). Measurements are automatically incorporated into COD corrections.
- **Issue:** Sensors operate reliably, but loggers in high-radiation areas experience hang-ups and ADC failures. Lead shielding provided limited improvement.
- **Measures:** Automatic recovery, alarms, power resets and spare-module replacement.
- **Plan:** Develop EPICS support and conduct in-tunnel radiation tests for a successor logger before the current model is discontinued.



Bunch by Bunch Feedback System

Feedback System

- **Performance:** Generally operated reliably and stabilized the beam up to the maximum current under non-collision conditions.
- **Noise reduction:** Replacing the 2 GHz filter improved the noise figure by ~ 20 dB and reduced ADC RMS noise from 15 to 3 counts. Using the cleaner HER reference RF eliminated the large LER noise component.
- **Luminosity:** Feedback gain changes showed no significant effect on luminosity. Operation continued with the lowest practical transverse feedback gain.
- **Hardware issues:** Attenuator failures, amplifier trips, communication errors and logger hang-ups occurred. Two attenuators and the damaged LK2 cable were repaired, and input timing was adjusted.
- **Plans for 2027ab:** Maintain spares, monitor kicker temperature, improve power-reset recovery and consider water-cooled dummy loads. Attenuator failures and kicker temperature issues have had only a minor operational impact so far.



(M. Tobiyama)

Turn-by-Turn Measurements with RFSoc-BOR

(R. Nomaru)

Measurement

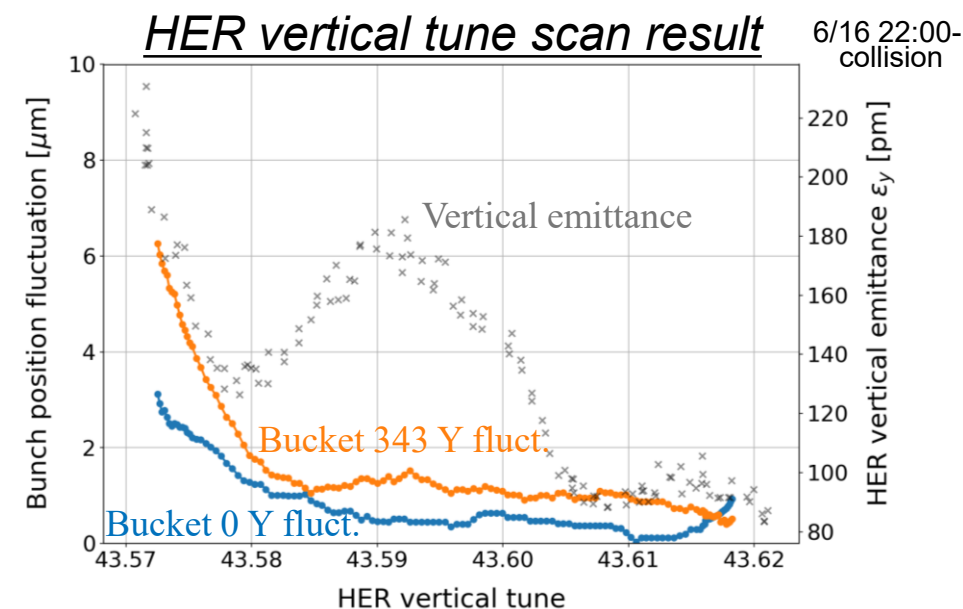
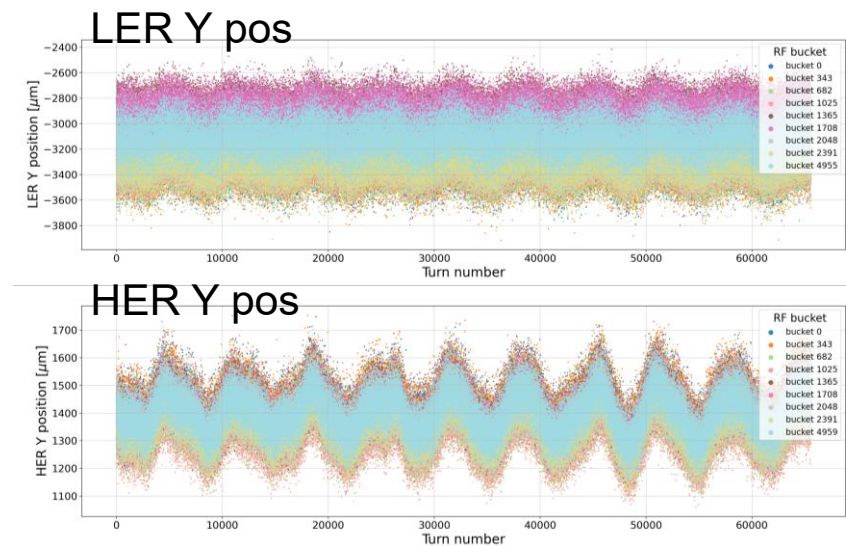
- Modified RFSoc-BOR to record 10 bunches over a long time window (~65,000 turns).
- Recorded HER/LER vertical positions every ~10 s at Fuji straight section during 2026b.

Key Findings

- Correlation of HER vertical bunch-position fluctuation(15Hz) with feedback room temperature and luminosity. ★
- Bunch position oscillations observed at low vertical tune during HER tune scan.

Plans for 2027ab

- Continue measurements during the 2027 run.
- Especially during machine studies, work with the optics and commissioning groups to ensure reliable bunch-position oscillation measurements.



Luminosity Fluctuations and Feedback Room Temperature★

(M. Tobiyyama)

Observation

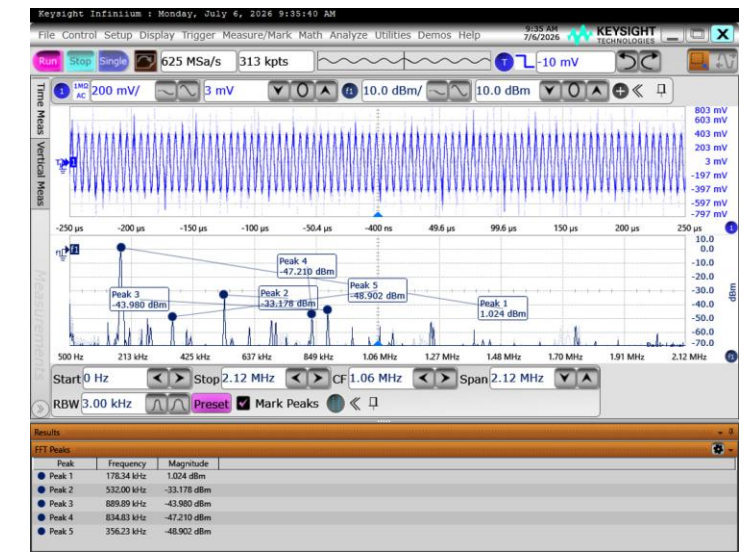
- Luminosity correlated with HER feedback room temperature. Measures to reduce air-conditioning effects had limited success.

Suspected Source

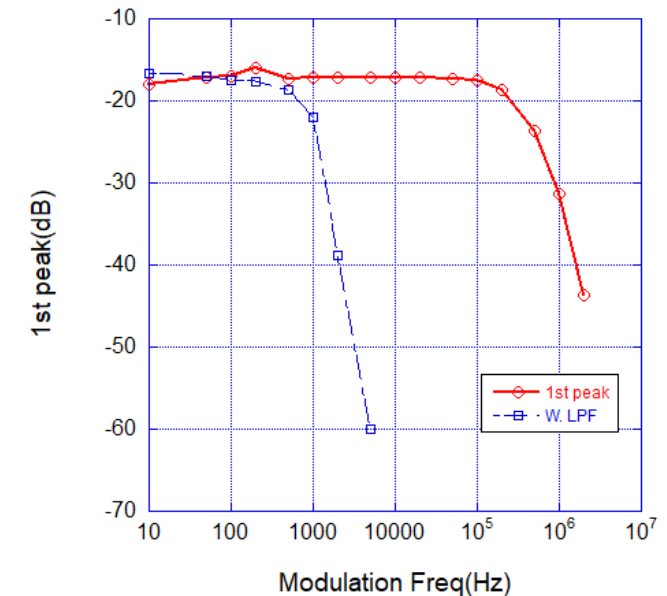
- Temperature dependent oscillations were detected on the ± 6 V NIM supply lines controlling the 2 GHz phase shifter.
- An unused NIM fan-out module is a suspected source.
- Removed the unused module and add a 1 kHz low-pass filter to the phase-shifter control line.

Proposed Measures for 2027ab

- Verify noise suppression and its impact on luminosity.



The oscillation frequency strongly depends on the environment temperature.



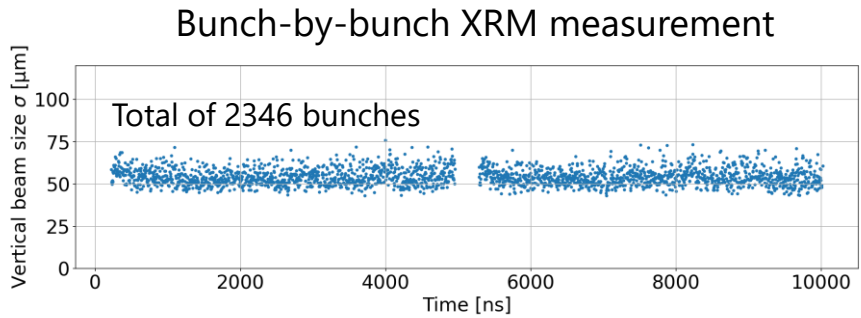
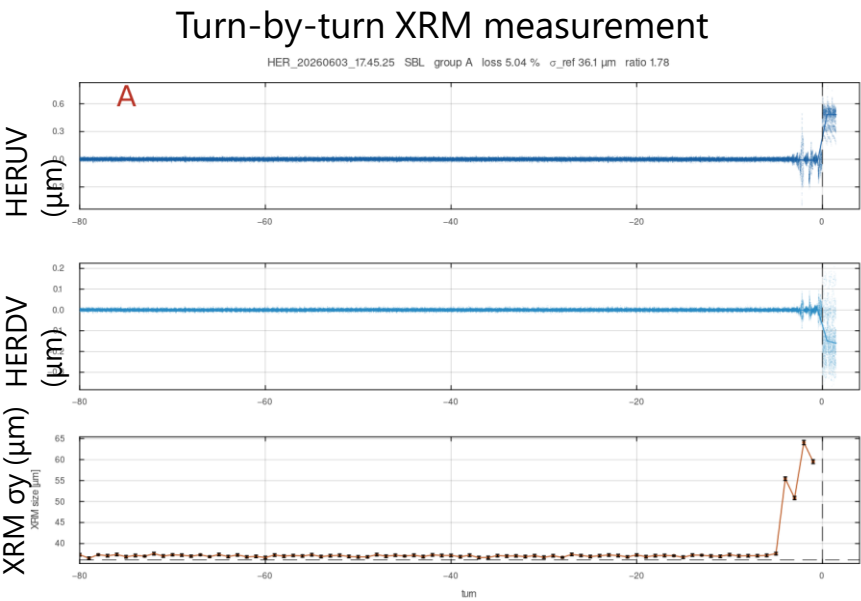
Frequency response of the control line of 2GHz phase shifter. 1 kHz low-pass filter should suppress noise.

SBL Diagnostics and Beam Protection

Beam Size Monitors: Status

Operational Status

- X-ray and visible-light monitors operated reliably in 2025–2026. No XRM-related beam-current limitation has been identified.
- The HER turn-by-turn XRM CMOS camera recorded approximately 290 events.
- SiXRM measured HER bunch-by-bunch vertical beam sizes.
- Visible-light gated and streak cameras are available for SBL studies.



(submitted to NIM-A, M. Andrew et al. arXiv:2607.08205)

Visible light beam size monitor	HER	LER
Interferometer	OK	OK
Turn-by-turn CMOS camera	Will be installed in 27 if not installed to HER X-ray line	Will be installed in 27 if not installed to LER X-ray line

X-ray beam size monitor	HER	LER
Low-speed CMOS camera	OK	OK
Turn-by-turn CMOS camera	OK (since April 2026)	Uninstalled in 25-26 Will be installed in 27
 Si-sensor XRM NATIONAL ACCELERATOR LABORATORY  1st gen. detector operated in HER 2nd gen. under R&D will be ready in 27 spring		

SBL Beam Profiles Measured with Visible Light

Measurement

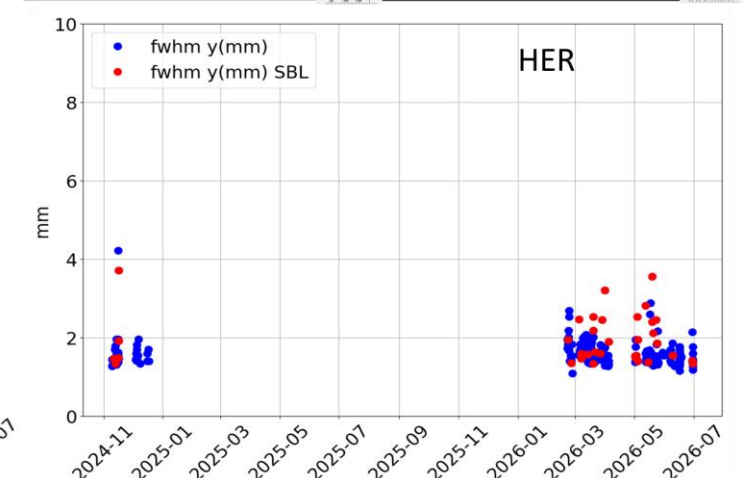
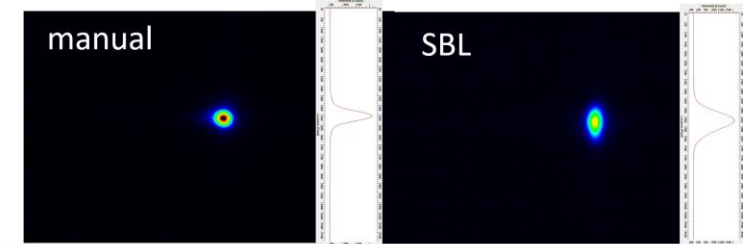
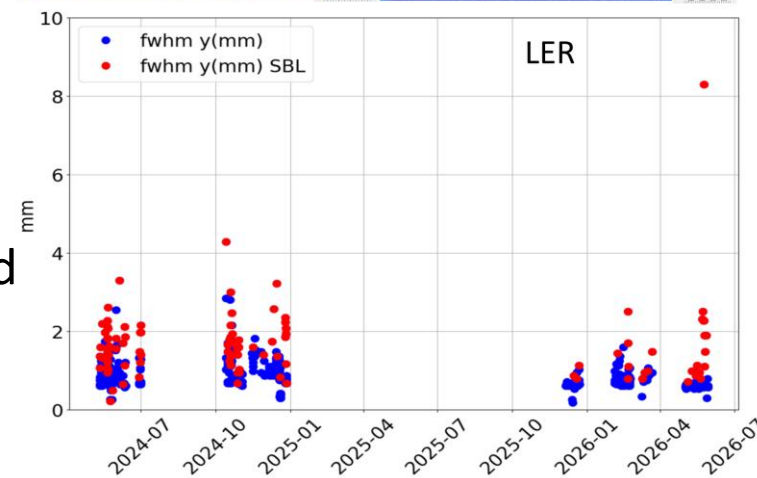
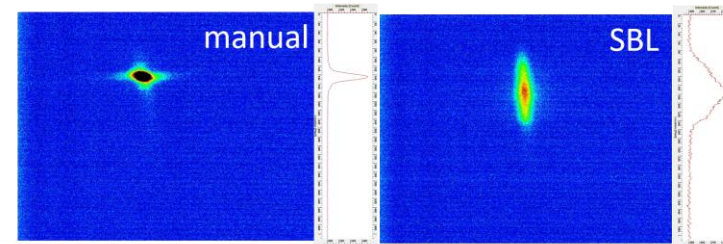
- A visible-light gated camera captures transverse beam profiles on the final turn before an abort, using a 100 ns gate.
- Compare SBL events with manual and other aborts in HER and LER at beam currents ≥ 1 A.

Findings

- SBL-related vertical broadening is more pronounced in LER than in HER.
- The different responses suggest that HER SBL may involve mechanisms beyond the VACSEAL-derived dust previously observed in LER.

Next Step

- Continue complementary position and beam-size measurements to investigate the mechanisms.



Vertical beam size @ abort moment

HER SBL may involve mechanisms other than the VACSEAL-derived dust observed in LER.

Beam Size Monitors : Plans for 2027ab

Diagnostic Upgrades

- **LER XRM:** Install a turn-by-turn CMOS camera in 2027.
- **SiXRM:** Develop the second-generation detector, targeting readiness in spring 2027.
- **Visible-light CMOS:** Installation depends on camera allocation between the X-ray and visible-light lines.

SBL Studies

- Continue complementary X-ray and visible-light measurements to investigate beam-size changes during SBL events.

Operation and Resources

- Prepare for more frequent scintillator replacement at higher beam currents.
- Secure a consumables budget: approximately JPY 200,000 per scintillator, with prices increasing annually.

Loss Monitors

2026 operation

- Loss monitors generally operated reliably and detected beam losses as intended. Some PIN abort settings required adjustment to support injection tuning and beam operation.
 - D1V1: Frequent loss-triggered aborts after PIN replacement; abort input disconnected on Mar 26. HER SBL damaged the collimator head on Apr 4; monitoring-only readout restored on Apr 15.
 - Injection-related PIN aborts hindered tuning; some triggers were disabled.
 - Downstream of the LER dump, LER aborts also triggered HER PIN aborts; input disconnected.

Plans for 2027ab

- Install injection vetoes for all collimator PINs to suppress injection related aborts.
- Restore D1V1 abort protection; Adjust the setup to reduce the PIN signal amplitude, as the gain is already at minimum and the threshold at maximum.

Implementation of iGp12-BRAM BOR

- **Measurement**

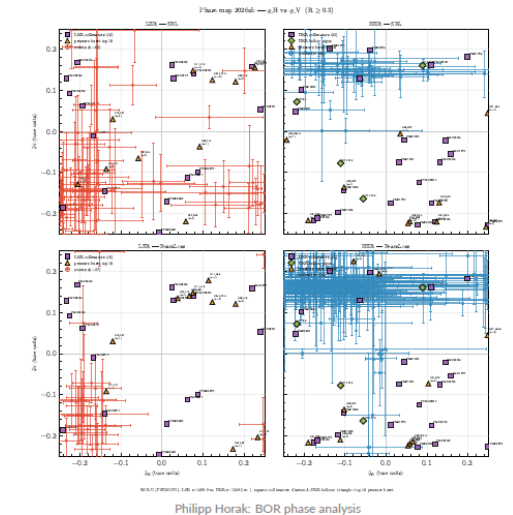
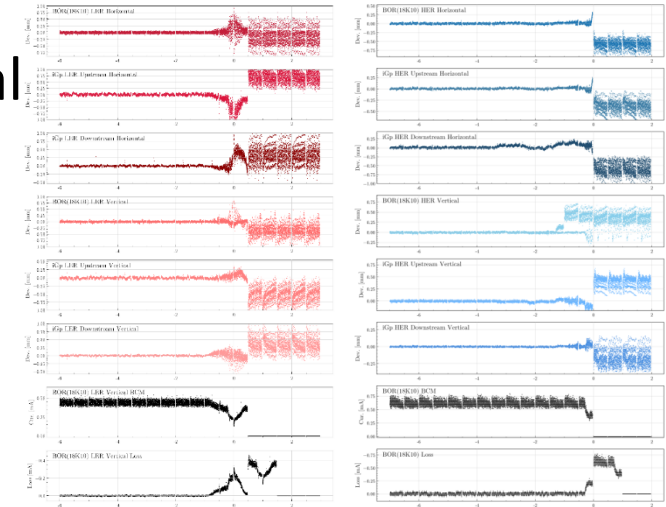
- Uses bunch feedback signals to measure horizontal and vertical bunch positions at two locations separated by approximately 90° in betatron phase.

- **Recording and Automated Analysis**

- Records up to 96 turns before an abort and automatically transfers the data to a NAS.
- Uses automated analysis software developed by Belle II MDI collaborators.

- **Source Localization**

- Assuming a single localized kick, the oscillations at two locations determine the betatron phase of the source.
- Assuming simultaneous horizontal and vertical kicks at the same location further narrows down the candidate locations.



Summary

Summary: Operation and 2027ab Priorities

BT and injection diagnostics

BT BPM readout has been improved, and tests have confirmed an enhancement in resolution.

RFSoc injection BPMs **operated reliably**.

2027ab: complete BT calibration and integrate injection BPMs with Linac timing and shot IDs.

Feedback and luminosity stability

FB **operated reliably**. ADC RMS noise has decreased. Attenuator/kicker impact was minor. Removal of unnecessary NIM modules and insertion of a 1 kHz filter

2027ab: maintain spares parts, monitor temperature, and verify the impact on luminosity.

Beam-size monitors

X-ray and visible-light monitors **operated reliably**. No XRM-related current limitation is identified.

2027ab: install LER XRM CMOS and target second-generation SiXRM readiness in spring 2027.

Loss monitoring and SBL studies

Loss monitors **operated reliably**.

Planned: Injection vetoes for all collimator PIN and D1V1 protection restoration and continue complementary position/size measurements for SBL.

Summary: Long-Term Renewal and Support Needs

Ring BPM renewal

Aging cables, MUX and VXI electronics are the main renewal concern.
Compare commercial readout and RFSoc for performance, reliability, integration and cost.

GTBT replacement

Failures affect 1–2 units per year, likely due to aging.
Improved units cost JPY 1.5–2.0 million each. Procurement depends on available funding.

Readout systems and instruments

Develop successor logger EPICS support and perform radiation tests. Develop an ADC/Zynq BOR.
VME18K10 boards have no spares. Instrument replacement prices have roughly doubled.

Support requested and decisions for review

Secure renewal/development funding, maintenance budgets and additional personnel.
Agree on BPM/GTBT replacement priorities and a feasible development scope and schedule.

backup

Response for the recommendations

R13.1: The ARC supports maintaining and expanding diagnostics capabilities at a high level. In this context, the faulty LIBERA modules can be replaced by updated devices, if their performance cannot be recovered by the procedure sketched in the following R13.6.

- The BPM that was connected to the malfunctioning Libera Brilliance+ was reconnected to the narrowband detector. Additionally, we reconnected the BPM connected to the Libera near the OHO NLC—which was not malfunctioning—to the narrowband detector at the strong request of the optics group. Regarding the malfunctioning Libera, the manufacturer's investigation found the issues lie with the attenuator and crossbar switch; however, we have already been informed it is beyond repair.

R13.2: Strive to minimize the number of different systems to maintain and to develop.

- We surely agree with your point. The current system is burdened by many legacy systems, and we believe we should eventually consolidate it into a simpler system with sufficient performance; we intend to work toward that goal. Unfortunately, we have not yet achieved any concrete results, either in budget or staffing.

R13.3: Maintain, expand and strive to improve turn-by-turn BPM diagnostics for advanced optics studies, including coupling and nonlinear topics.

- The gated turn-by-turn monitoring system is being adequately maintained and is being fully utilized for tasks such as beam alignment. Regarding the optical study, we have several ideas, but we have not yet been able to validate them due to limited experimental time. We plan to conduct verification during the next operation.

R13.4: Develop and expand turn-by-turn bunch-by-bunch diagnostics to diagnose SBL events (e.g. from FBCK system, RFSoc, SR monitors, ...)

- Development of the RFSoc-based bunch-by-bunch position detection system has progressed, and it is now ready for practical use. Regarding the SR monitoring system, the gated camera and streak camera are now available for SBL observations, and development of a detection system using X-ray sensors and RFSoc for individual bunch size measurements is underway as part of a U.S.-Japan collaboration.

R13.5: Continue the maintenance work of all kinds of beam monitors during the upcoming shutdown time.

- We continue to perform maintenance on all monitors to ensure they operate at peak performance.

R13.6: For the LIBERA systems, check the contact of the flanges of the vacuum chambers close to the BPM buttons, or other possible disconnections and discontinuities, which may impact the adjacent BPMs.

- We plan to commission the Vacuum Group to conduct an investigation.

R13.7: The ARC supports installing more BORs to localize the SBLs, if the budget and human resources are available.

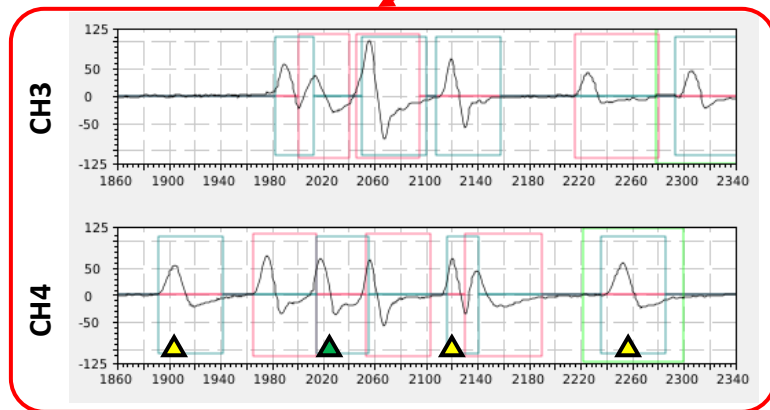
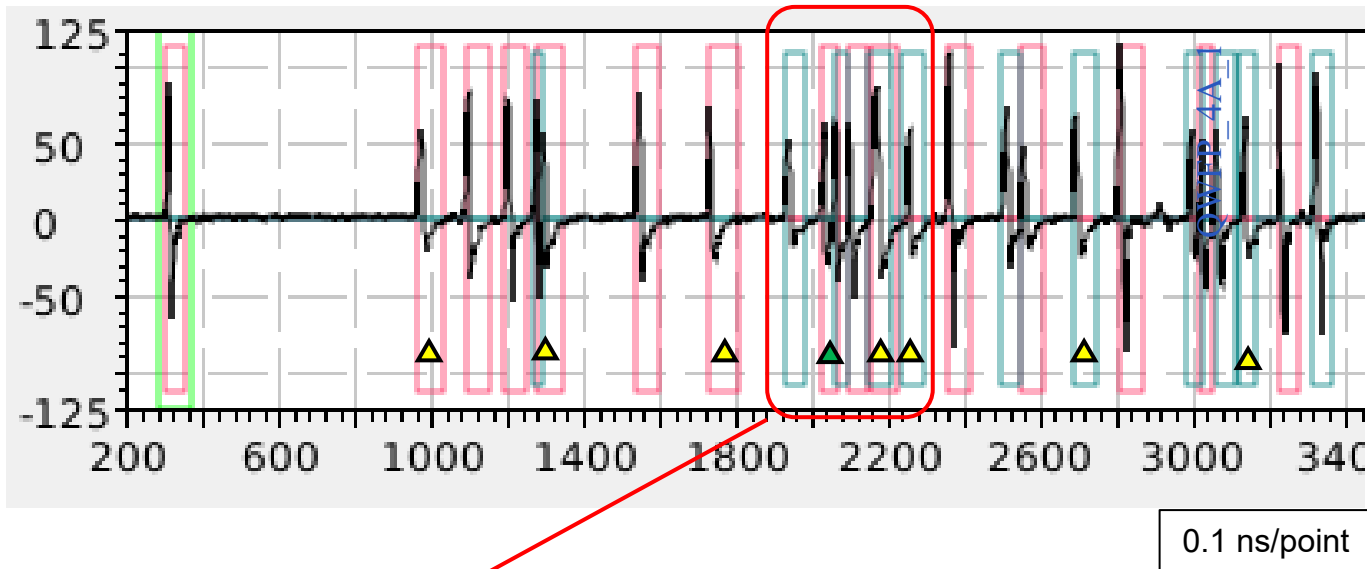
- Thanks to the cooperation of the Belle II Group, we have secured a sufficient number of RFSocs; however, delivery times for other timing components—particularly variable-length coaxial delay lines—are extremely long, and as of now, we have been able to prepare only up to three units. Regarding the installation location, we plan to follow the results of discussions between the MDI Group and the Optics Group.

R13.8: Continue developing Machine-Learning applications for the on-line analysis of data from different monitors.

- We are developing a machine learning tool that estimates beam emittance and luminosity based on settings of IP knobs and the data from ring monitors.
- The AI task force is leading the analysis of Beam instrumentation data using machine learning, and the Instrumentation Group is fully cooperating with this effort.

BT BPM Readout Improvements

Signal Overlap in BT BPMs



A single oscilloscope measures signals from multiple BT BPMs combined using RF combiners. The original design did not account for two-bunch operation, resulting in overlapping signals from multiple BPMs.

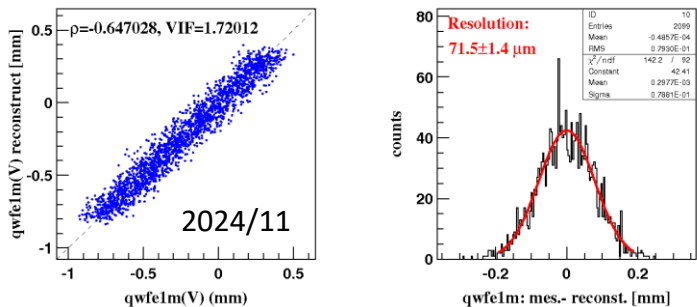
Elimination of Signal Overlap and Readout Improvements in BT BPMs

To eliminate signal overlap, the affected BPMs need to be moved to a separate readout system. The Linac BPM readout board was designed for one BPM per board. By adding delays to additional BPM signals, multiple BPMs can be read out using a single board.

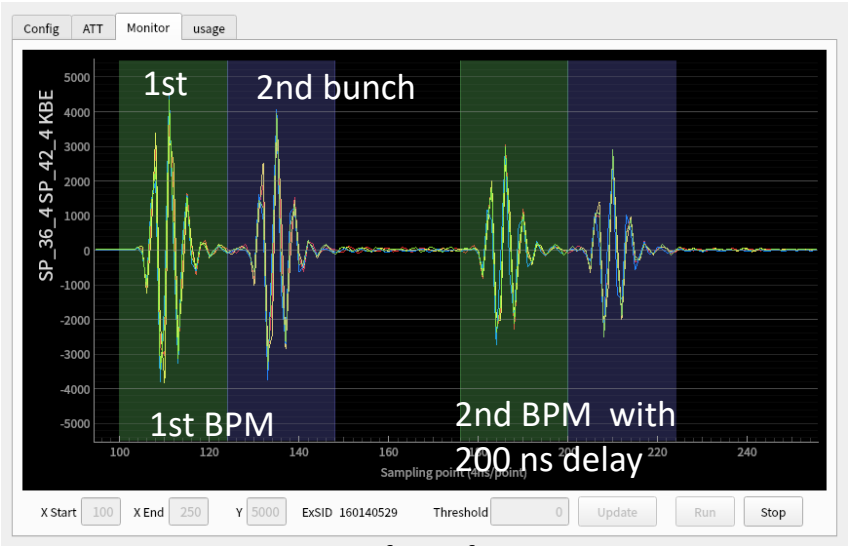
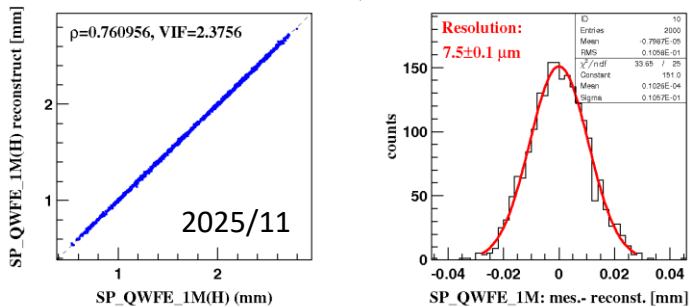
Four BTeV ECS BPMs have already been converted. The same scheme was applied to eight Linac BPMs to free up boards. It will be extended to the affected BPMs to improve position resolution and enable synchronization with the Linac event system.

F. Miyahara

BT Osc.
system



Linac VME
system



ADC Waveforms from two BPMs

Comparison of position resolution of BT BPM[μm]

	Oscilloscope	Linac VME
QXF6E_M	66.2±1.2	15.4±0.3
QXD7E_M	71.6±1.3	12.6±0.2
QWFE_1M	71.5±1.4	7.5±0.1
QWDE_1M	121.9±2.4	7.5±0.1

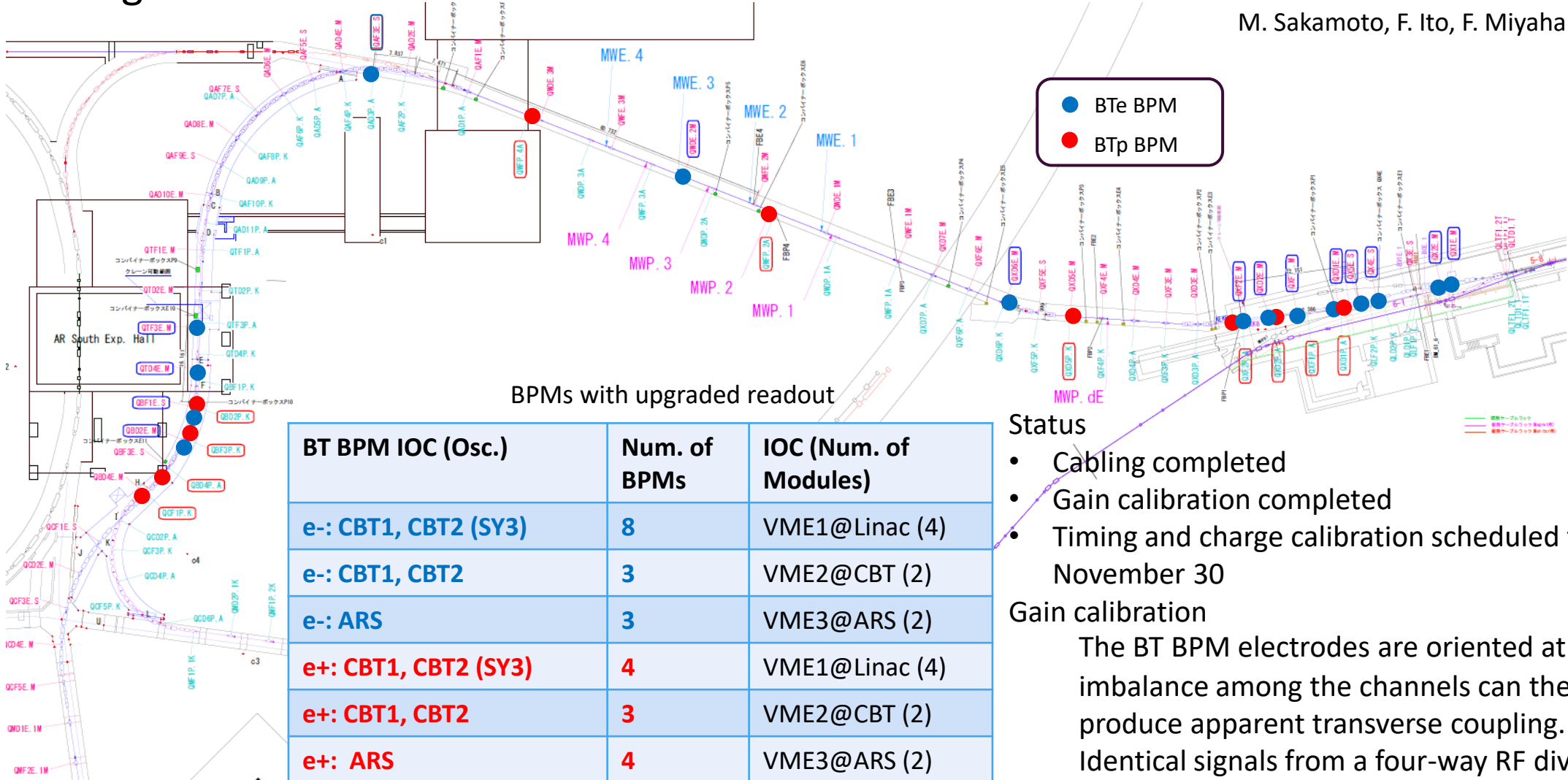
Significantly improved position resolution
Integration into the Linac event-synchronized dataset

Measured position vs reconstructed position from the other 2 BPMs (left) and difference between measured and reconstructed position (right) using 3 BPM method.

BT BPM Readout Upgrade

Readout of 25 BPMs using the injector's event-synchronized, high-resolution BPM signal-processing boards

M. Sakamoto, F. Ito, F. Miyahara



BT BPM IOC (Osc.)	Num. of BPMs	IOC (Num. of Modules)
e-: CBT1, CBT2 (SY3)	8	VME1@Linac (4)
e-: CBT1, CBT2	3	VME2@CBT (2)
e-: ARS	3	VME3@ARS (2)
e+: CBT1, CBT2 (SY3)	4	VME1@Linac (4)
e+: CBT1, CBT2	3	VME2@CBT (2)
e+: ARS	4	VME3@ARS (2)
e-/e+ : The others of ARS	11/12	New digitizer

Status

- Cabling completed
- Gain calibration completed
- Timing and charge calibration scheduled to begin on November 30

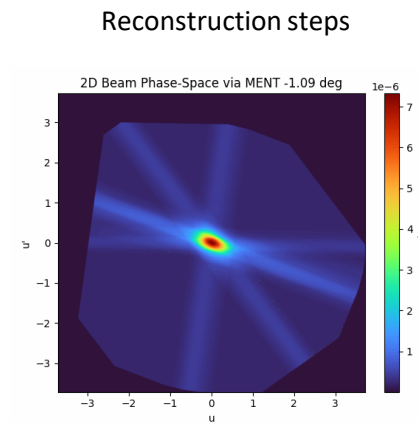
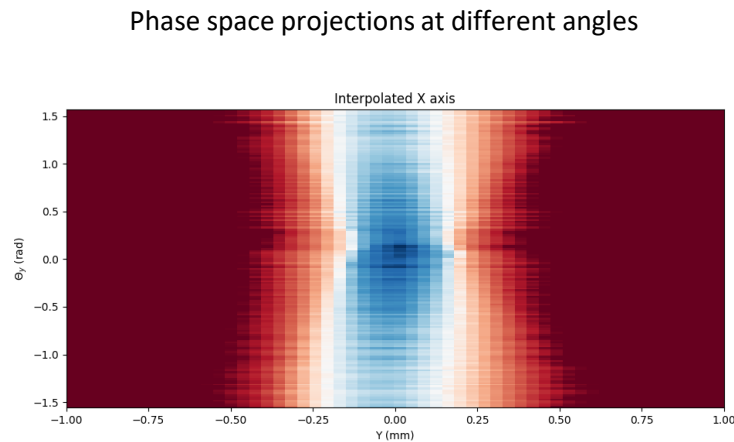
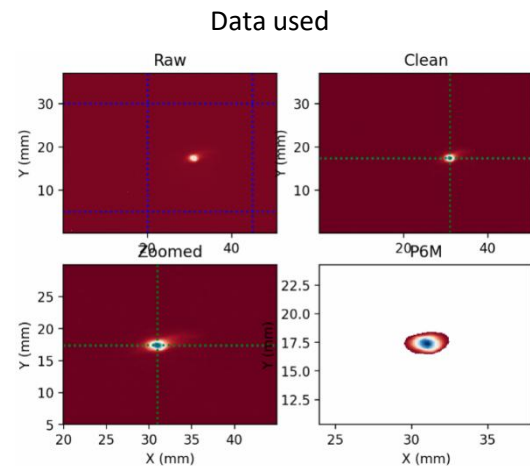
Gain calibration

The BT BPM electrodes are oriented at 45° . Gain imbalance among the channels can therefore produce apparent transverse coupling. Identical signals from a four-way RF divider are measured to calibrate the channel gains.



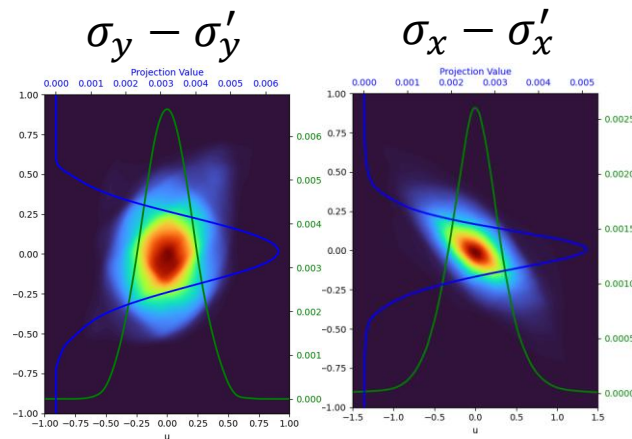
Transverse BT Beam Phase-Space Reconstruction

- The reconstruction of the phase-space is based on a lot of measured projections of the phase-space at different angles.
- The beam phase-space rotation θ is done by changing the quadrupole magnet field. From the transport matrix 'M', one can calculate the rotation.
- However, the projection of the rotations come with an elongation/contraction of the distribution (represented by the α parameter).



- ❖ The process analyzes each angle projection measured and modifies an initially uniform phase-space to match the projections observed, reconstructing step by step the real distribution. .

QXD5P positron beam
transverse phase-space at the
start of LER-BT
[4Quadrupoles used for phase-
space rotation]



Measurements at the end of LER-BT
to be performed next RUN.

(B. Urbschat)

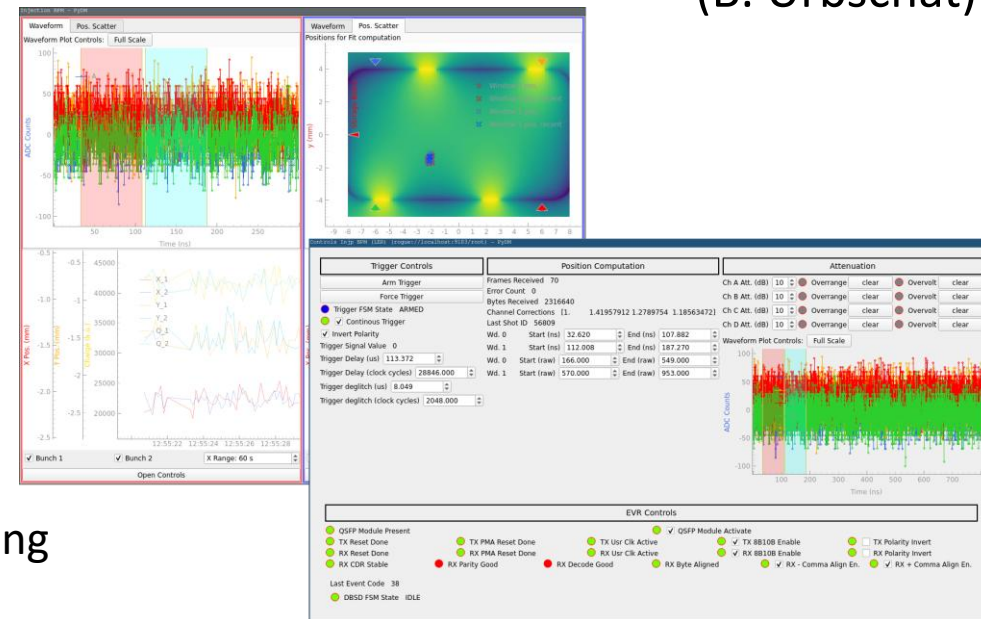
Based on AMD RFSoc platform

Operated without major problems in 2026ab runs

Added functionality for direct integration with injector linac's event timing system (optical fiber link)

Obtain timing as well as metadata information (e.g. shot ID)

Updated operator interfaces for the control room

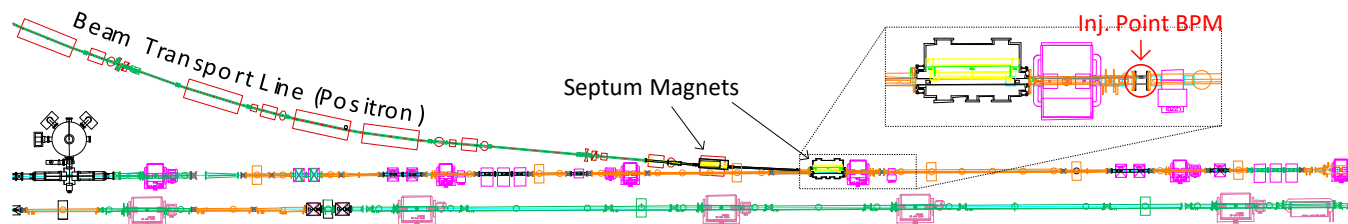


B. Urbschat, G. Mitsuka, L. Ruckman. Application of RFSoc technology for beam position monitors at the SuperKEKB storage rings injection points. *Journal of Instrumentation*, 21(03):P03035, Mar 2026

Injection Point BPMs – Calibration

(B. Urbschat)

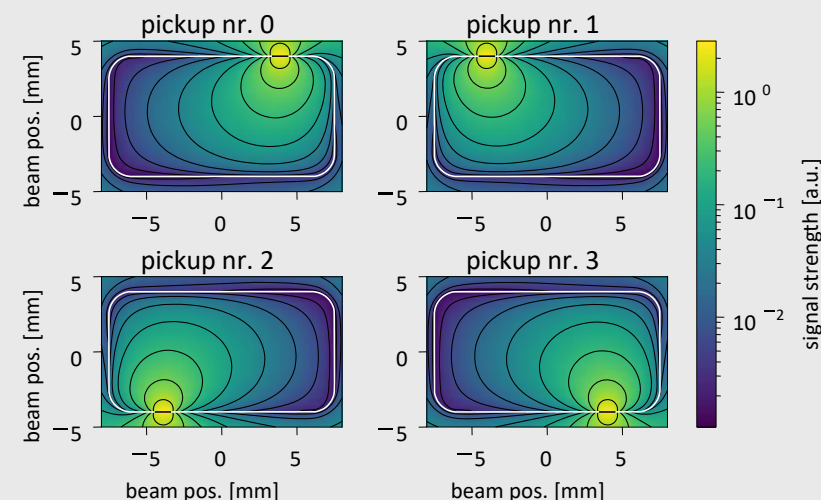
- Extrapolation from adjacent BPMs difficult as septum magnets on upstream side and only ring BPMs downstream



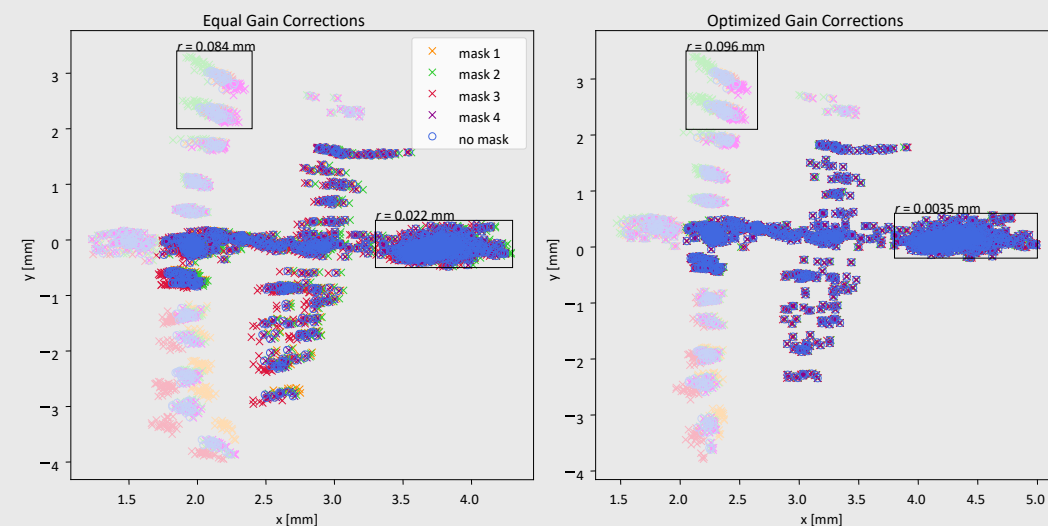
- Applied a **calibration method possible due to position computation algorithm able to operate with only three out of four signals**
 - Position computed by fit determining the most likely position, comparing the measured signals against simulation (possible at 25 Hz injection rate)
 - Determine channel corrections by optimization over a dataset, *minimizing average spread amongst four positions computed with one signal excluded each*
 - Some regions excluded due to inherent lack of consistency (related to simulation accuracy in that region)

Obtained Parameters:	Beam	g_0	g_1	g_2	g_3
	Electron	1.00	1.42	1.28	1.19
	Positron	1.00	0.714	0.759	0.792

Simulated Electrode Response (HER)

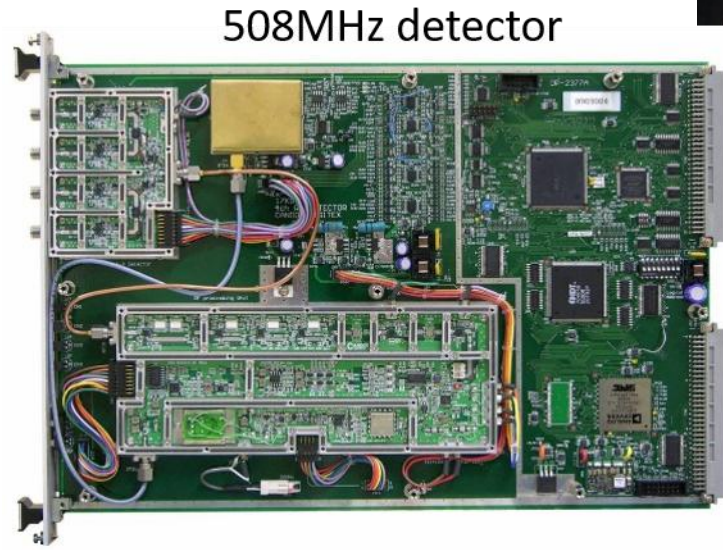


Calibration Result (HER)



BPM

- They worked properly, but the frequency of glitches seems to be increasing slightly.
 - FT-panel cables (used KEKB time)
 - Panel to 4 in one coax cables
 - VXI 1GHz narrowband detector (4:1 MUX switch failure)
 - 4:1 MUX unit failure
 - VXI main frame (Fan failure)
 - Also, an increasing number of units are displaying errors when VXI starts up.
- Found a BPM block with poor fixation
 - It appears this has been the case since SuperKEKB began.



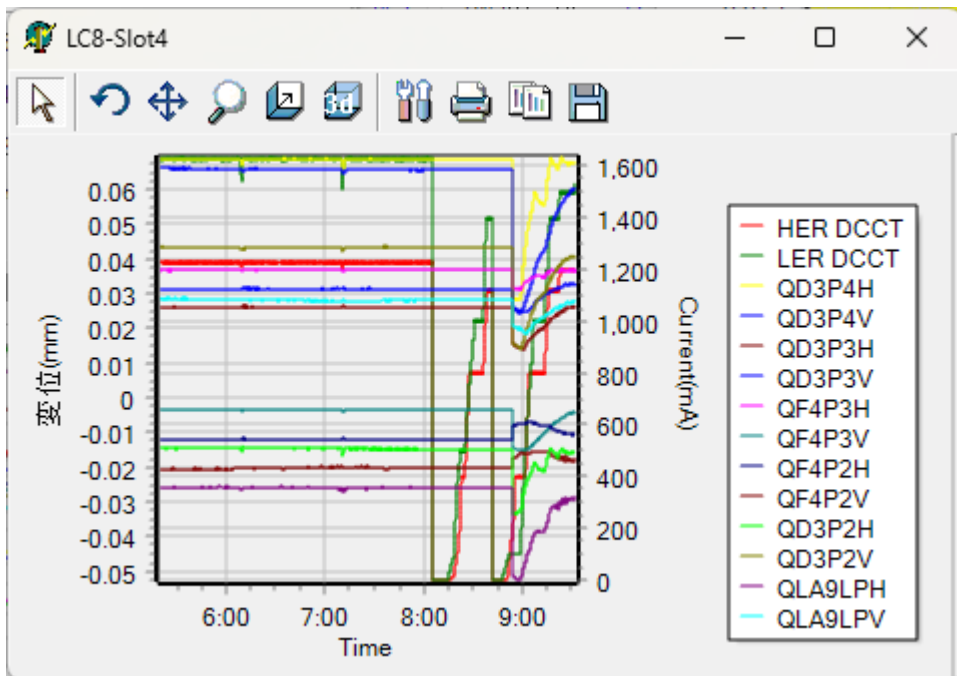
508MHz detector



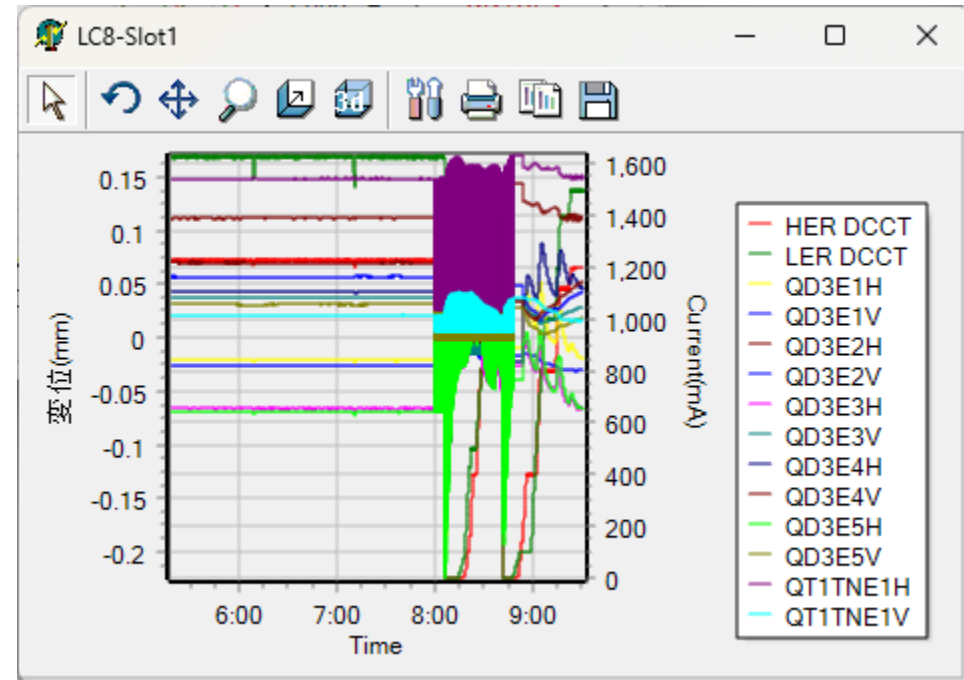
1GHz detector



- Some data acquisition slots (ADC module) that frequently hung up experienced a failure that could not be resolved by a power-on reset, so they were replaced with spares. All the failed modules had high residual radiation levels and could not be removed from the tunnel.
 - Even when enclosed in a 5-cm-thick lead block, the hang-up rate did not decrease significantly.
- The logger used will be discontinued within a year. We plan to develop EPICS device support for the successor system and conduct radiation resistance tests inside the tunnel.



Hanged up slot(slot 4)

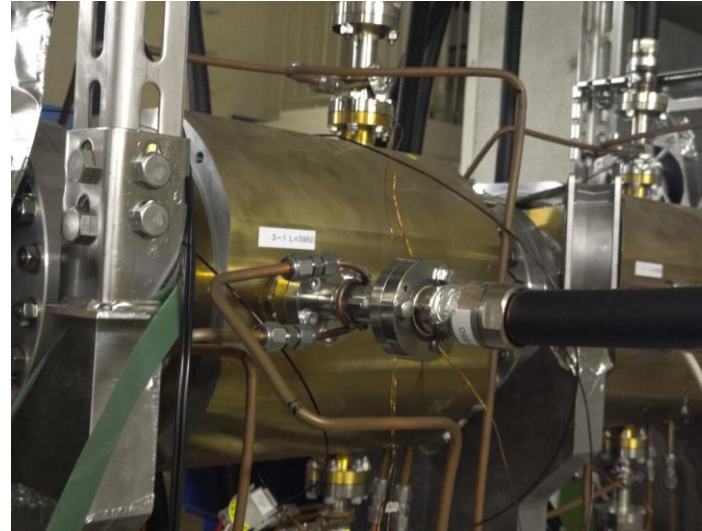
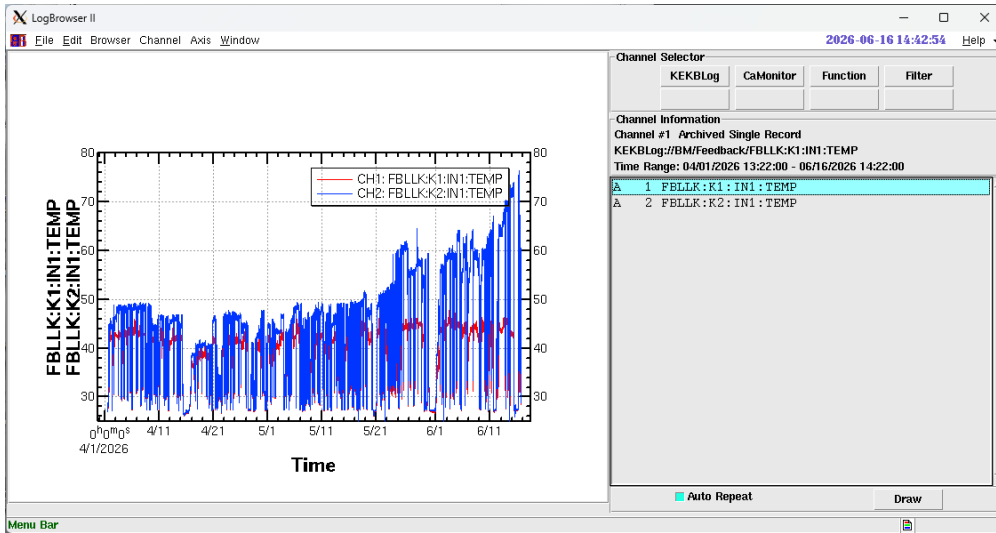


Because the faulty slot continues to occupy the logger's bus line, data from the normal slot fluctuates wildly.

Bunch by bunch feedback systems

- Operated generally smoothly and contributed to the stable operation of the collider.
 - Could keep the beam stable even at the maximum beam current under non-collision conditions.
- Several failures
 - High-power attenuators for transverse feedback kickers
 - 5 units failed; all due to input section malfunctions (burnout of the first resistor).
 - 2 units were repaired. Other repairs are in progress.
 - Several spares are available and can be made operational by adding cooling fans.
 - Communication failures between the LAN-GPIB and the FB final amplifiers
 - Examine the possibility of recovery by the power-on reset of the LAN-GPIB
 - Frequent down of DR No.1 feedback amplifier (suspecting aging of the amplifier).
 - Hang up the data logger (same as for the deformation sensor) at the feedback section.
 - Cabling the AC line that enables power-on reset without stopping the beam.

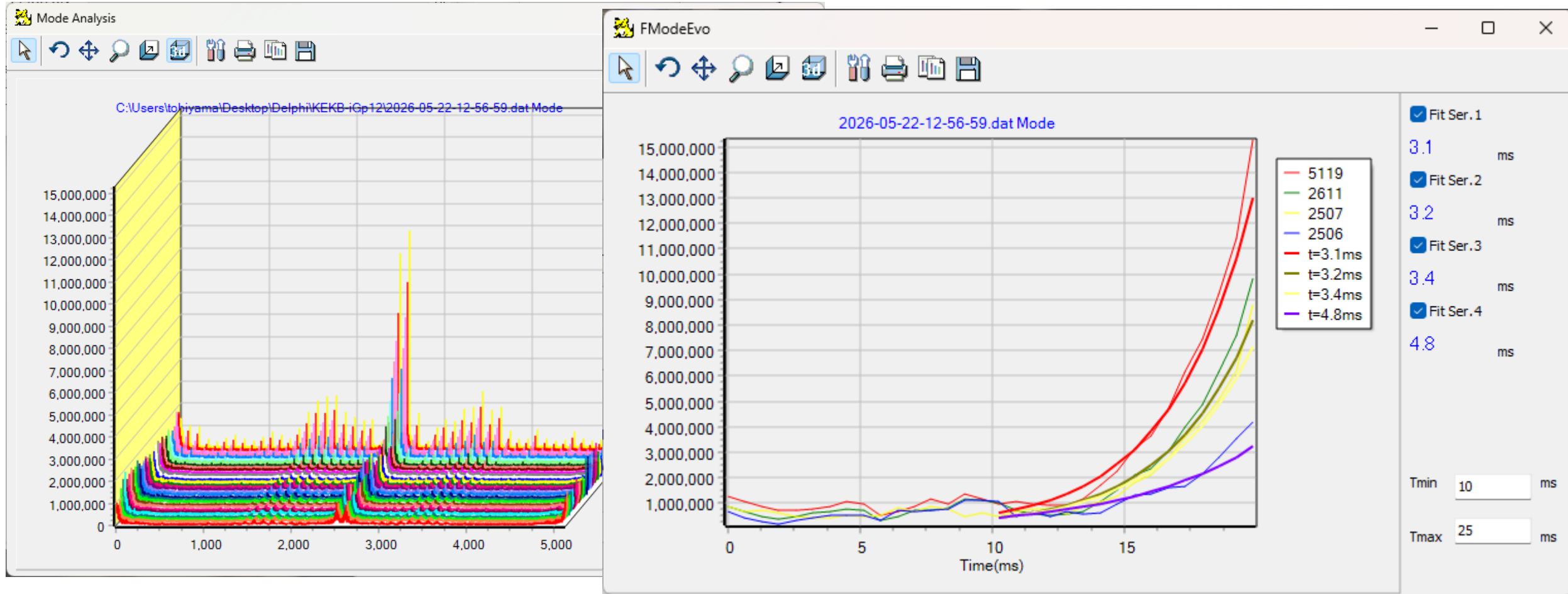
- Inspection following a gradual temperature rise at the No. 1 input feedthrough of LK2 revealed damage to the 7/8-inch EIA anchor contact.



- The cable was also damaged, so the entire cable from the absorptive LPF to the feedthrough was repaired, and the signal timing between the two inputs was adjusted.



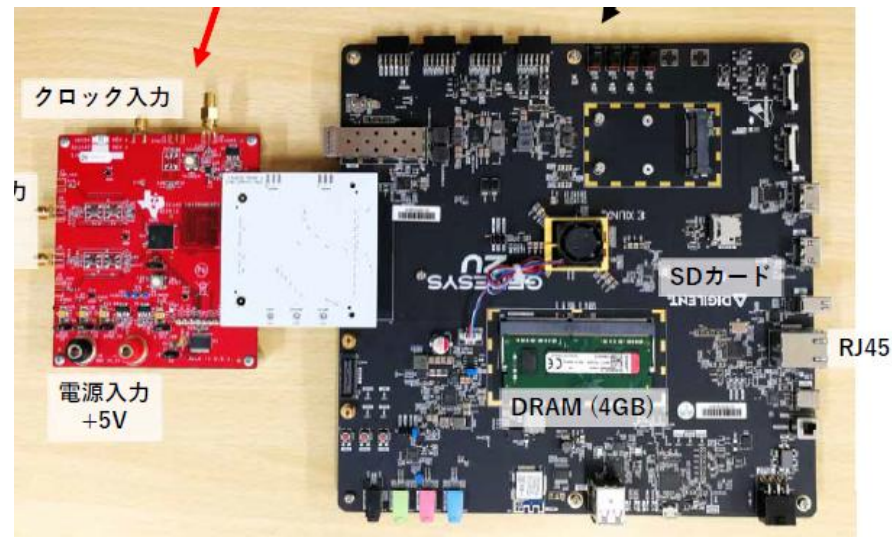
LER LFB transient-domain measurement



Growth time~9.3ms Unstable mode = -1

VME 18K10 board for BCM/BOR/BCML

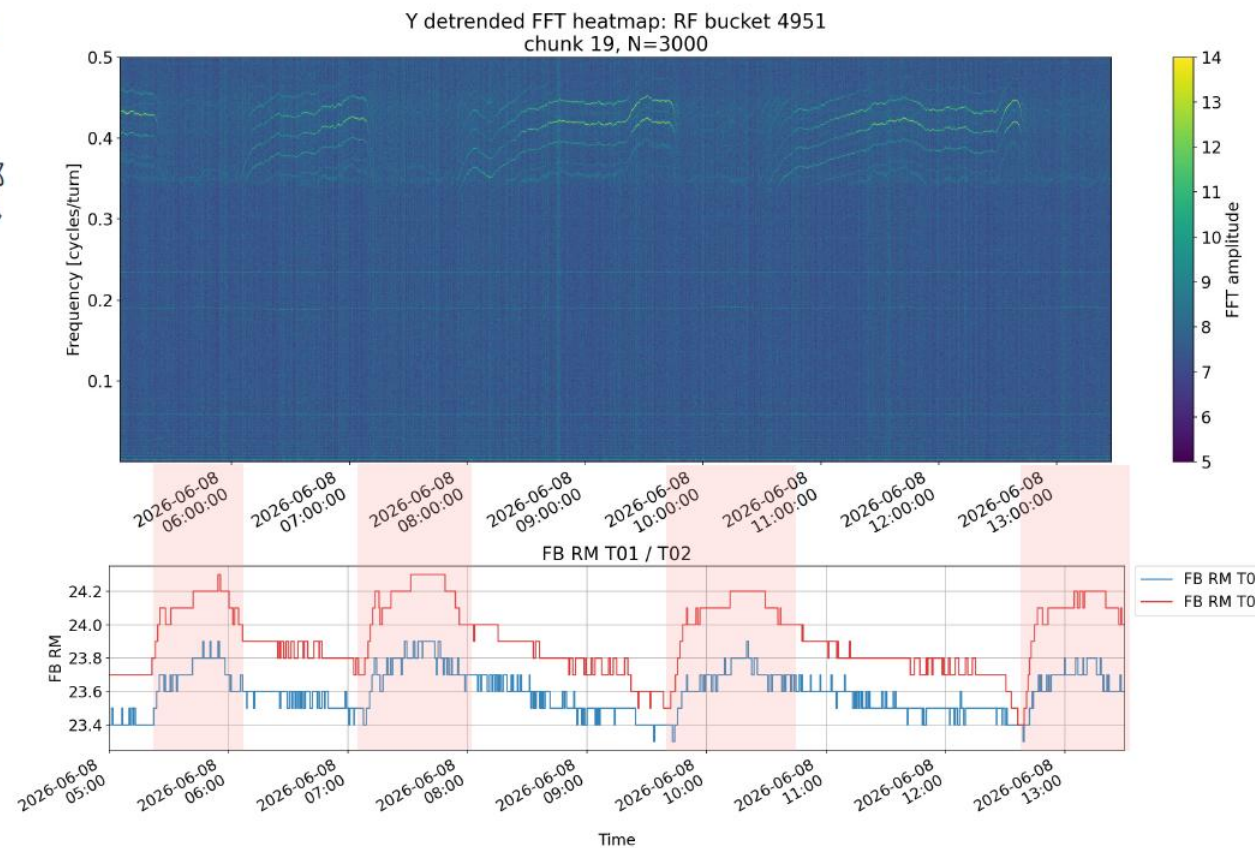
- 18K10 boards for BOR have failed.
 - 8-bit MAX108 ADC + SRAM (5102 bunch x 4096 turns)
 - Wrong VME-bus line driver? Spartan6 failed? Failed data transfer from 18K10 board to IOC.
 - No spares available.
 - R&D (TI ADS5402EVM (12bit 2ch 800MSPS) + ZU-5EV(Zynq MPSoC)



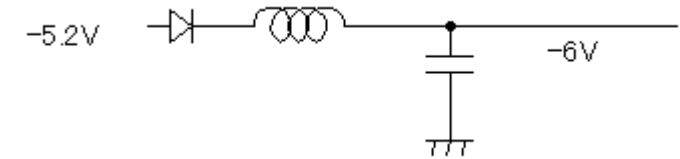
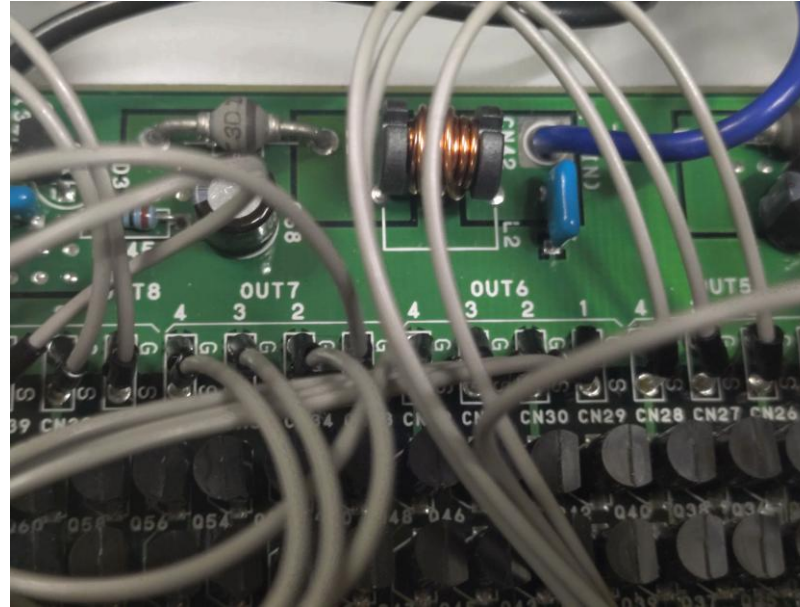
Measurement by RFSoC long-data

周波数解析

collisionバンチは全部
同じようなスペクトル



Suspected source of the unstable voltage of NIM PS



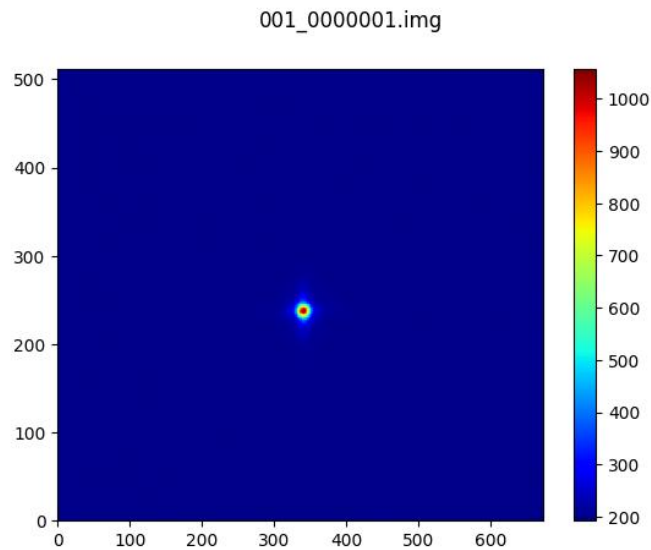
- NIM fan-out module (old technology, not used for current operation).
- Removing unused NIM module from the NIM PS
- Checked all the NIM power supplies using the oscilloscope. No other suspicious power supply has been found up to now.

LER Beam Halo Measurements

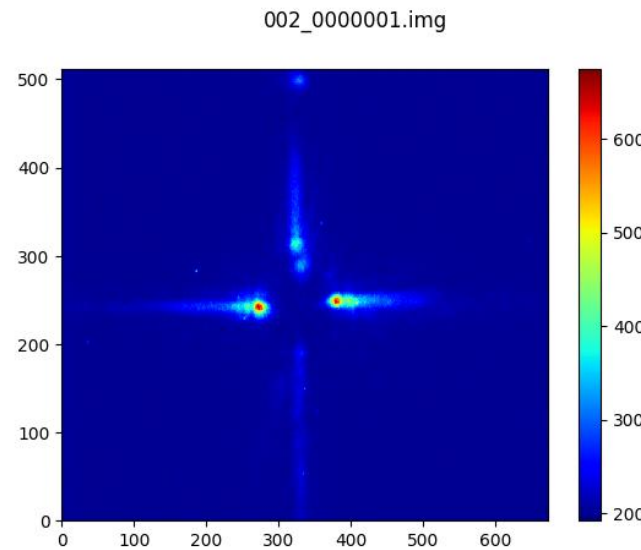
Coronagraph measurements during the 2026 physics run

Collision conditions: 1,990 bunches at 0.78 mA per bunch.

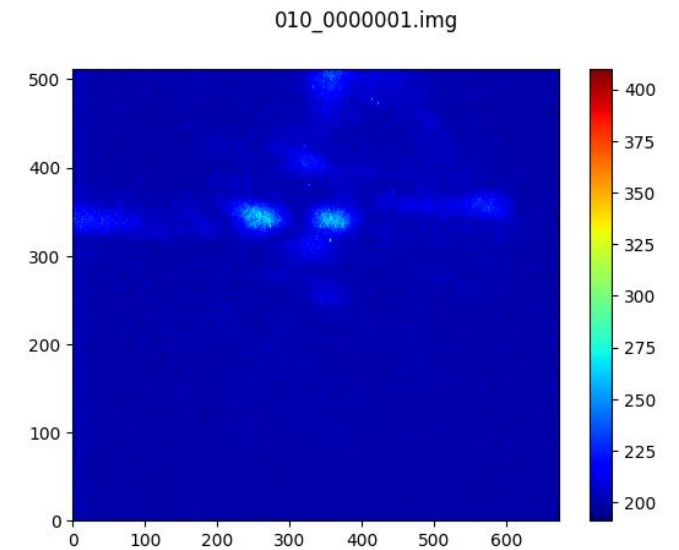
A three-stage optical system suppresses the core and re-diffraction fringes to observe the halo.



Beam core
100 ns gate



Core masked (3 mm)
100 ns gate



Re-diffraction fringes blocked
2 μ s gate

Gate-corrected peak tail/core intensity ratio: 2.7×10^{-3} .

No distinctive halo was observed. Longer gates could probe weaker structures.