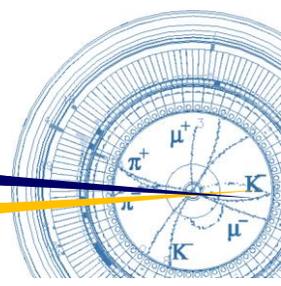


SuperKEKB Accelerator Status

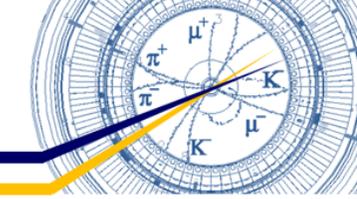
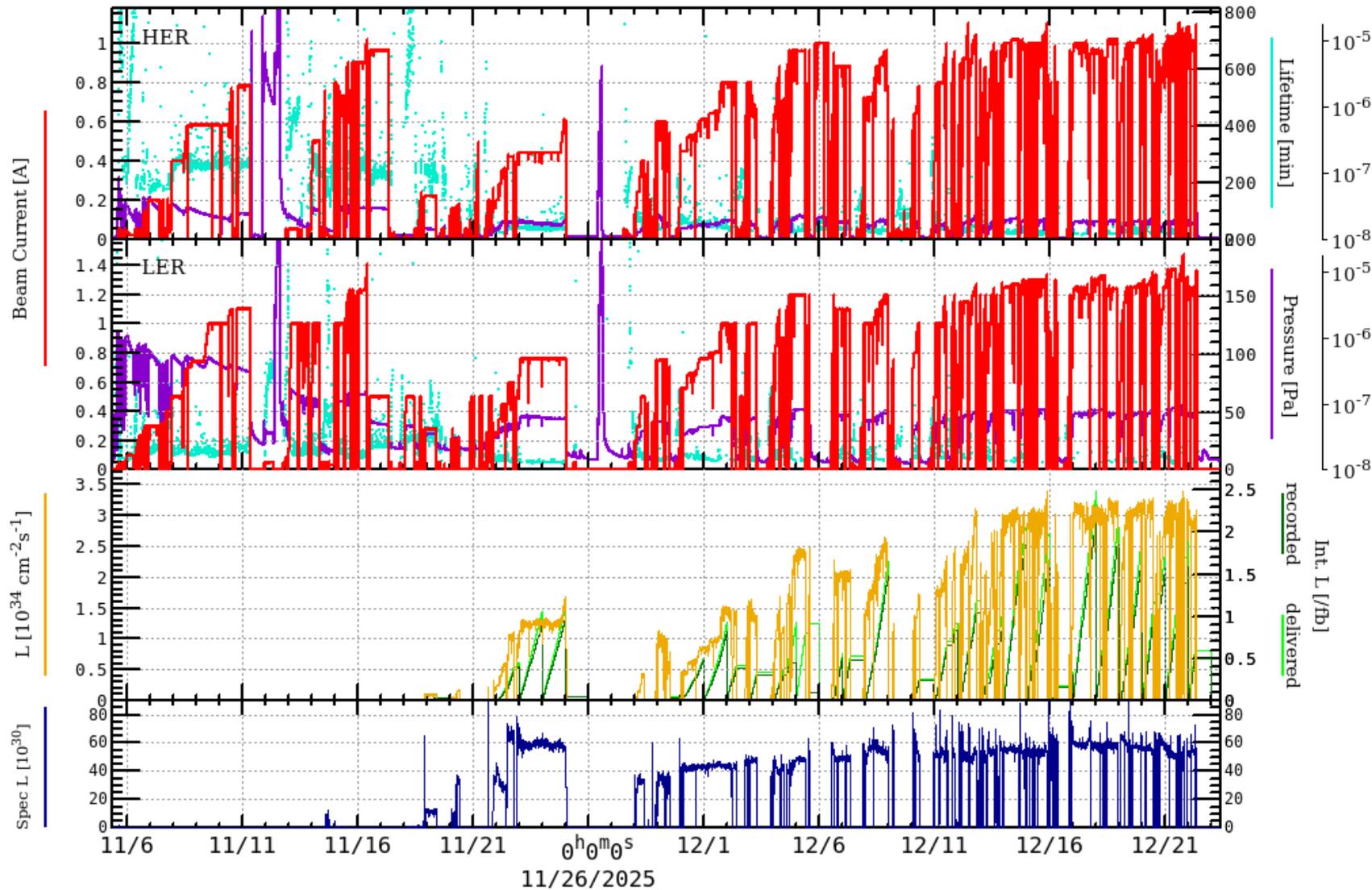


Makoto Tobiya
KEK Accelerator Laboratory
(on behalf of SuperKEKB Accelerator Team)

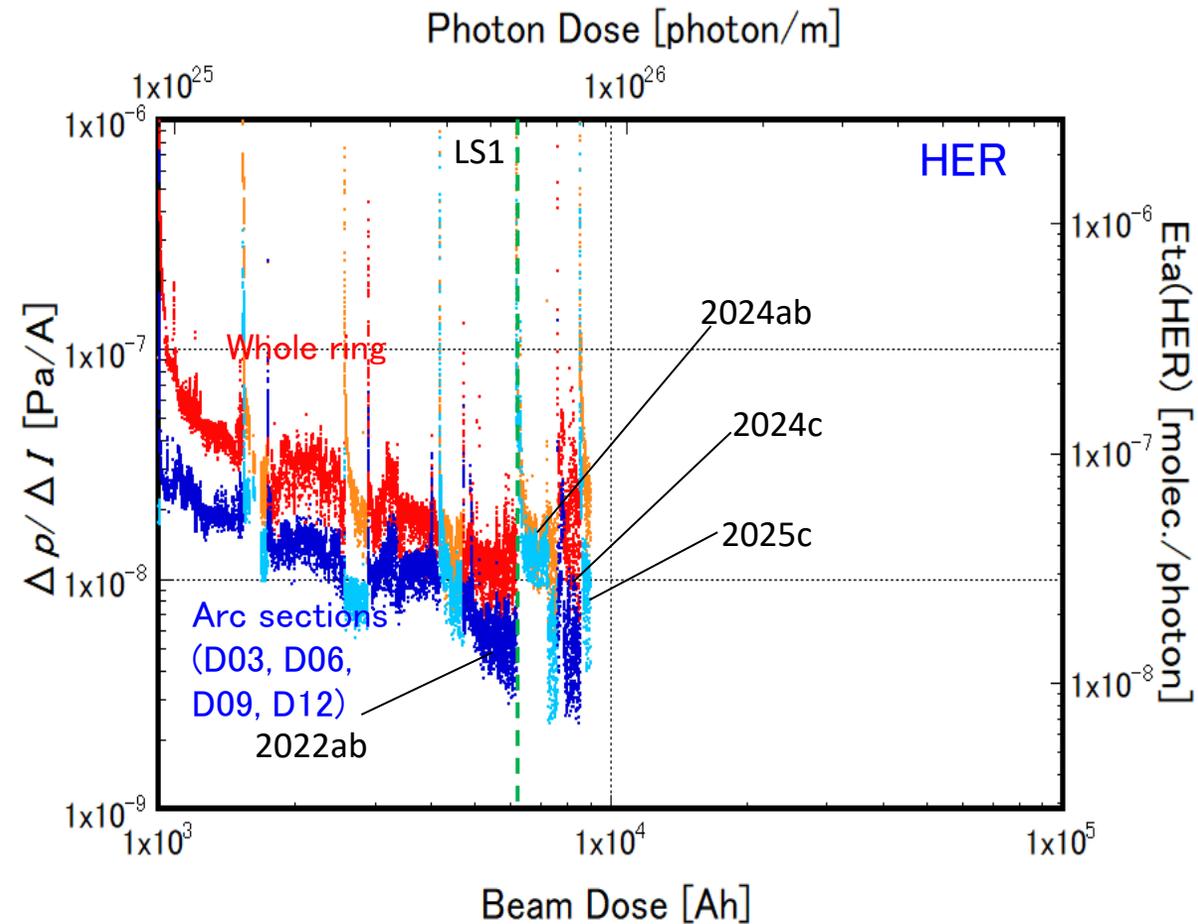
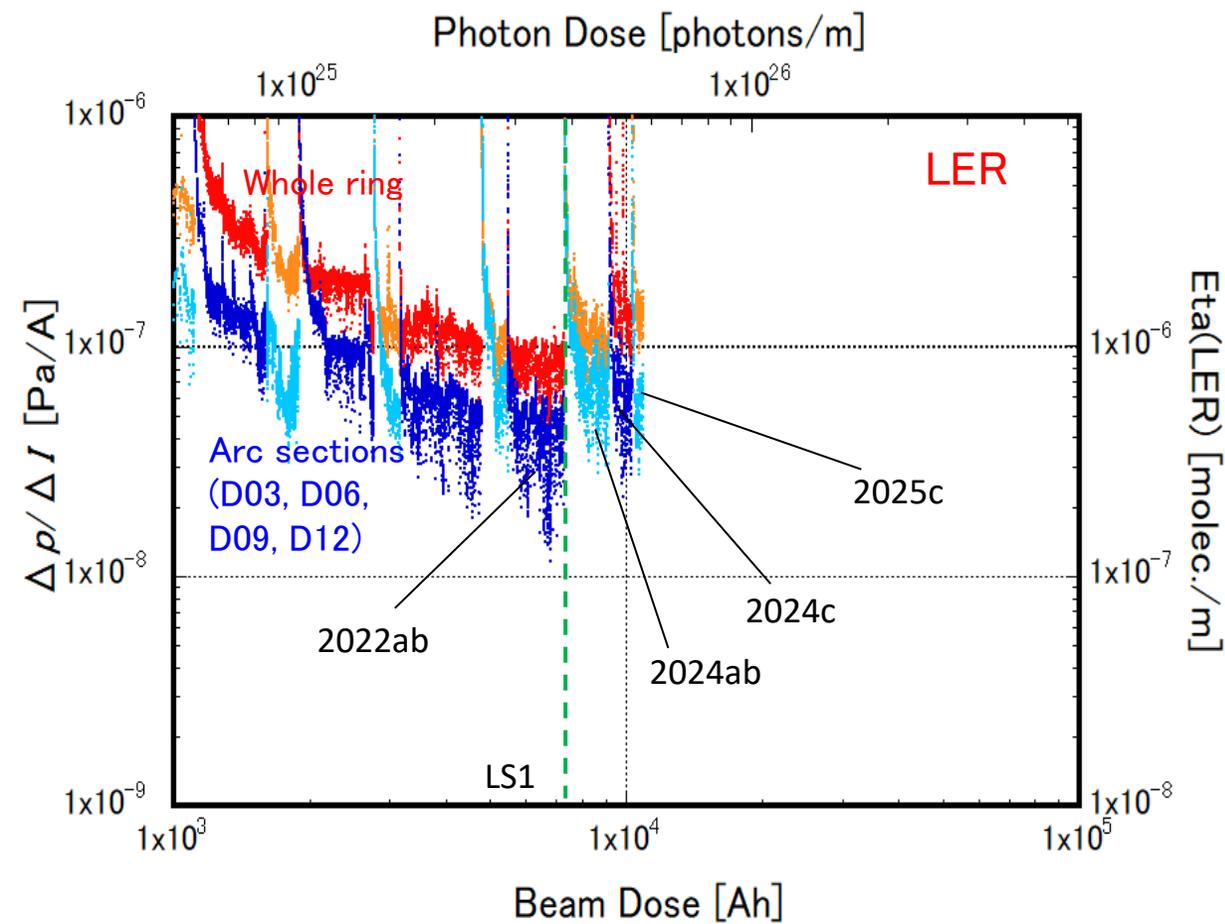
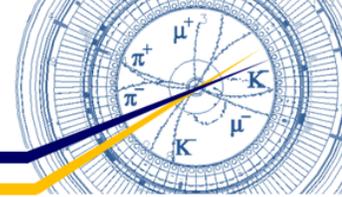




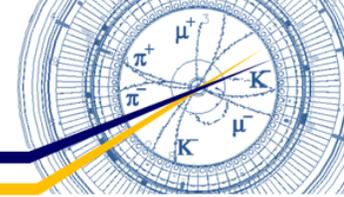
Peak L 3.424 [$10^{34}/\text{cm}^2/\text{s}$] @ 2025-12-15 20:37 HER I_{peak} : 1100.0 [mA] $\beta_{x/y}$: 60./ 1.00 [mm] n_b : 2346
Int. L/day 0.000 / 0.000 [fb] LER I_{peak} : 1477.9 [mA] $\beta_{x/y}$: 60./ 1.00 [mm] n_b : 2346



history of dp/dI during Phase-3 operation



Sudden Beam Loss



- Sudden Beam Loss (SBL)

- SBL is the most critical obstacle to achieving stable operation.
 - Part of the beam is suddenly lost within a few turns.
 - It is difficult to prevent uncontrollable beam from damaging Belle II and collimators.

- Countermeasures

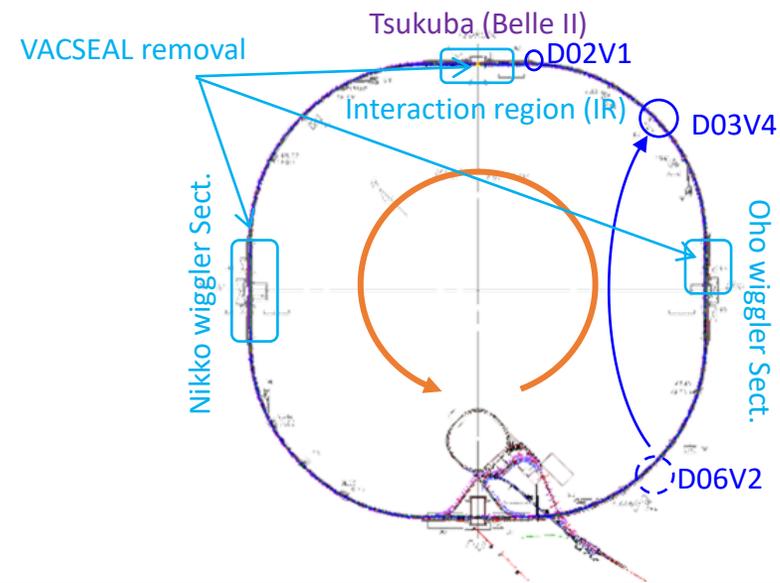
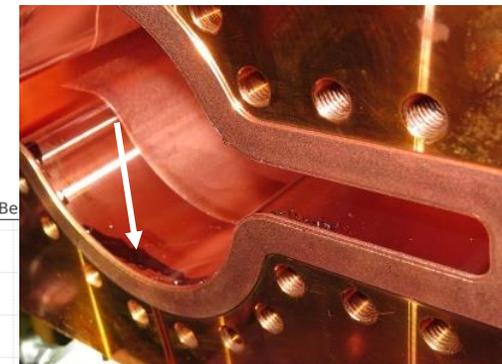
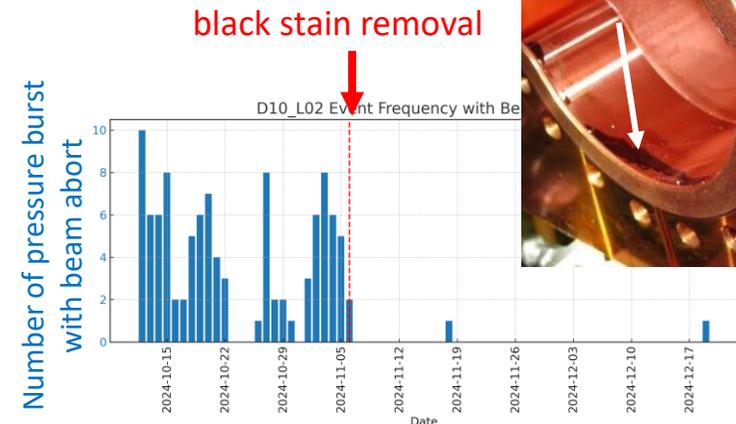
- **Removal of VASCEAL contamination** ← **Last shutdown**
 - **All MO-type flange connections likely used VACSEAL were checked and fully cleaned during the previous shutdown.**
- SBL mitigation effect of VACSEAL removal was confirmed during 2024c run.

➡ **Significant reduction in SBL events**

- Additional countermeasures

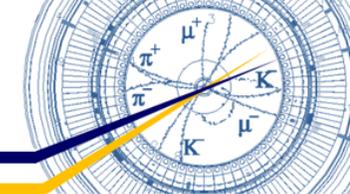
- Collimator relocation ← **Last shutdown**
 - D06V2 -> D03V4 (to protect IR (Belle II, QCS, D02V1 collimator) from uncontrollable beam)
- Additional beam loss monitors and acoustic sensors
- Faster beam abort system

T. Ishibashi





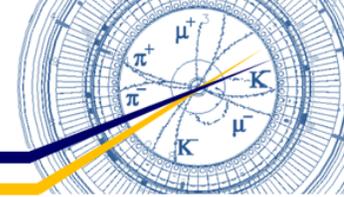
However..



- Still observed SBL-like events without vacuum bursts in both rings.
- SBL events with vacuum bursts (some of them caused the QCS quench), where we have cleaned the chamber completely inside in LER.
 - Near Nikko and Oho wiggler section
- We have investigated the inside during this shutdown.
 - No significant indication of dust (like vacseal).
 - Exchanged the bellows chambers with the spares.



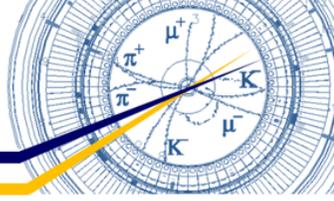
Many machine failures



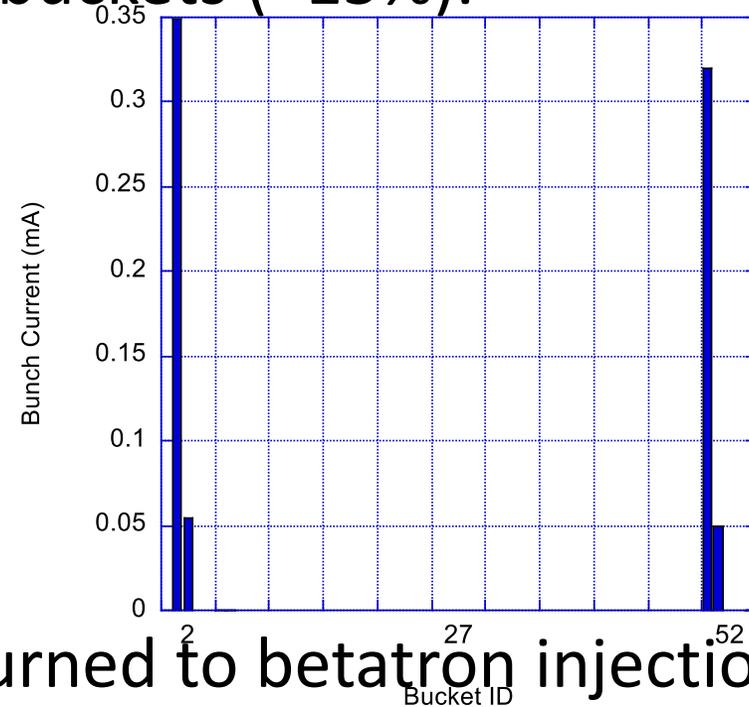
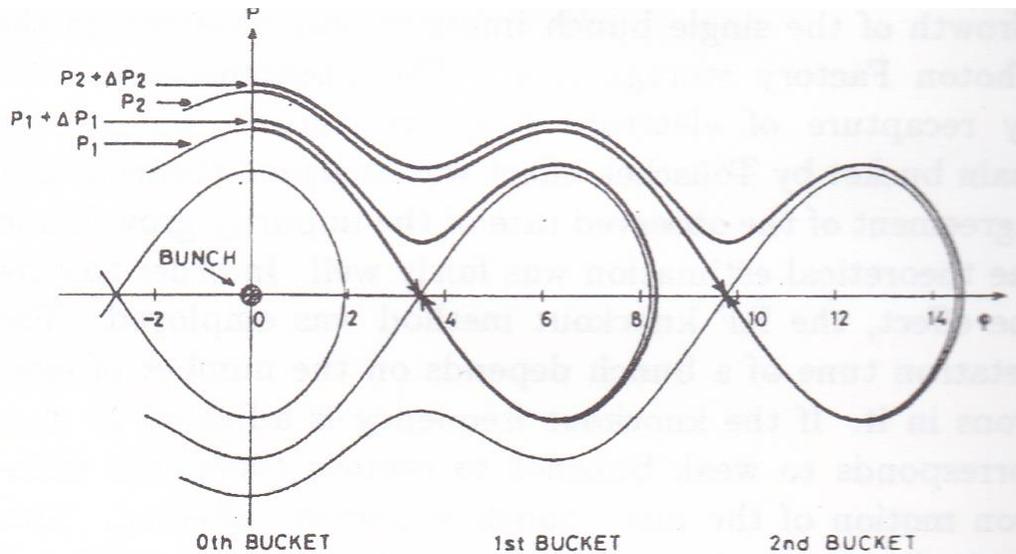
- HER synchrotron injection-related failures
 - Damage the vacuum chamber wall (and gasket) around the beam dump due to the aborted beam, which resulted in a large vacuum leak after one day of operation.
 - The issue was temporarily resolved by re-examining the trajectory of the abort beam and modifying it to maintain sufficient distance from the chamber wall.
 - Large bunch leaks to the following buckets.
- Failure of the pulsed power supply of the HER beam abort system caused the extreme beam loss by the backup system (weak bending magnet off)
 - Damaged the D1V1 collimator heads.
 - By tuning the other vertical collimators, we could turn on the Belle II detector, but with a low injection rate.
 - Suspected QCS-L vacuum leak at the vacuum insulation vessel.



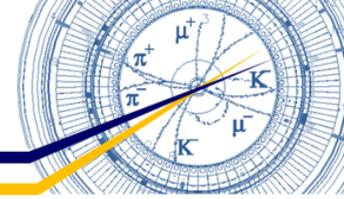
Synchrotron Injection of HER



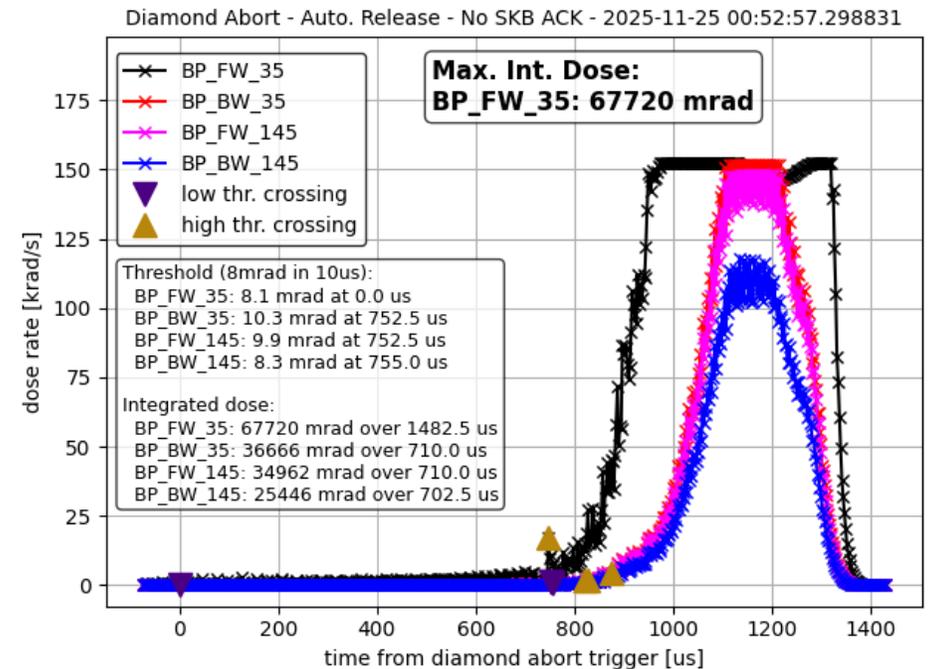
- For the collision optics with $\beta^* \sim 8$ mm to 1 mm, we have struggled to get a good injection efficiency, but it did not work out for a higher repetition rate of larger than 12.5Hz.
- Significant charge leak to the following buckets ($\sim 15\%$).



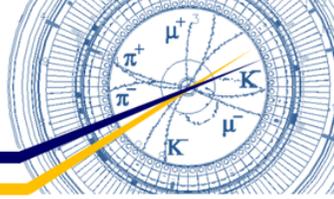
- Given up synchrotron injection and returned to betatron injection.



- Due to weak-bends cutoff, a large beam orbit primarily in the horizontal direction emerged with a time constant of 0.1 seconds, resulting in catastrophic beam loss.
- Simulation suggests more than 80% beam loss in the IR direction.
 - Large xy coupling.
 - Shrunk RF separatrix.
- The QCS on the L side caused a quench in all magnets, taking about 7 hours to restore the liquid level.

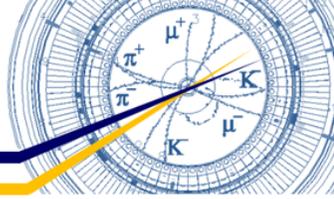


(Temporally) countermeasure for both rings



- When an abort kicker power supply malfunctions, do not issue an abort request.
 - In principle, it will not be strongly needed to abort the beam due to the malfunctioning of the abort kicker PS.
- Simultaneously with the power supply issue, we decided to send an HV shutdown request to Belle II, completed signal verification and operational confirmation at Belle II.
- During this period, we will attempt to restore the abort kicker power supply. If restored, use the abort kicker to abort the beam correctly. If restoration fails, wait until the current decays sufficiently, then drop the beam via RF off or weak-bends.
- Note: Even if the abort power supply is in an abnormal state, kicking is possible if charged. Therefore, changing the interlock logic is also under consideration.

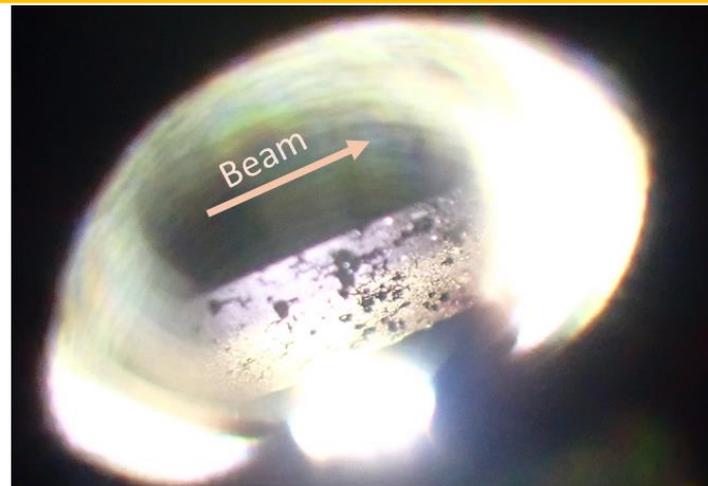
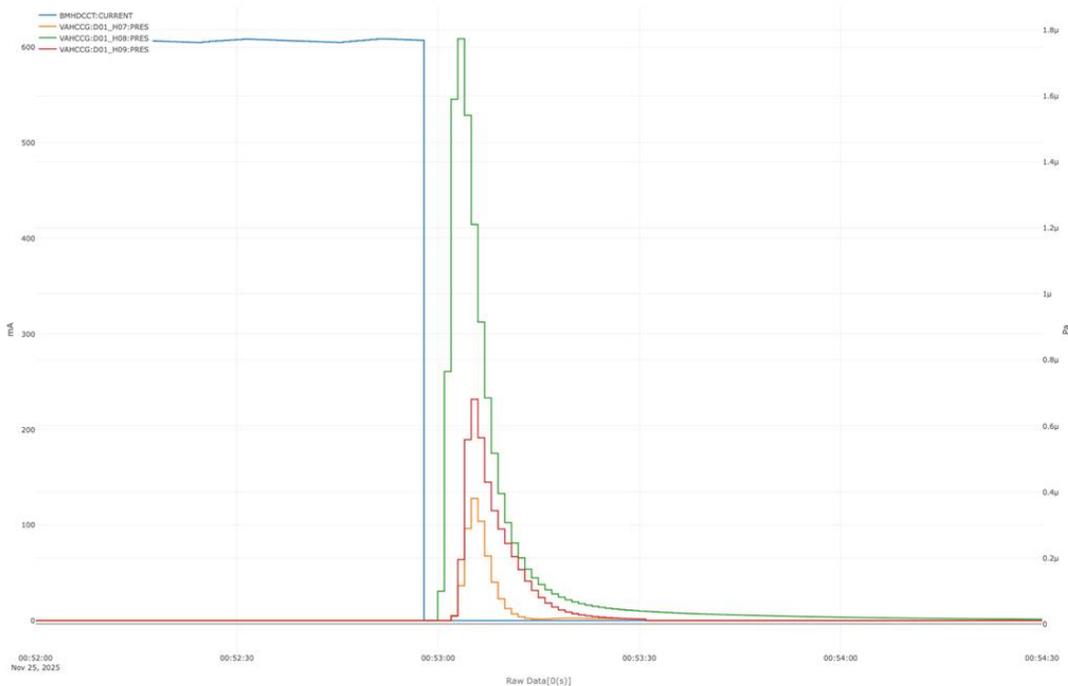
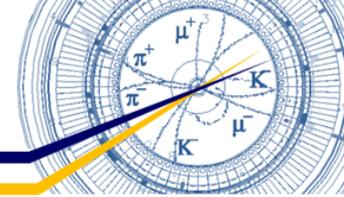




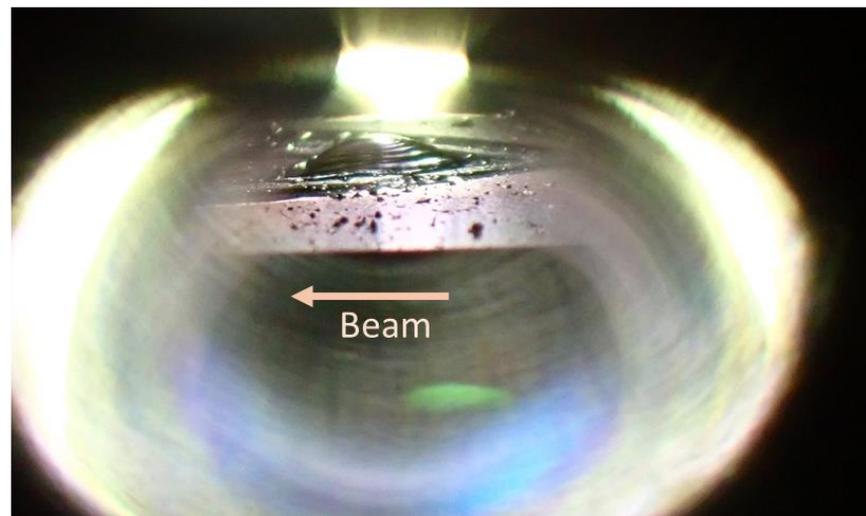
- Weak bend and RF OFF are extremely dangerous beam abort methods, so we are considering other approaches
 - (A) Control weak bend (and horizontal steering magnets) to direct the beam to a radiator that can be damaged
 - Simulation shows the beam will be crossing strong resonance lines such as 3^{rd} slowly after $B_y < 90\%$.
 - Considering preparing a horizontal bump at horizontal emergency radiators.
 - (B) With RF OFF, direct the beam to a radiator located in a safe area
- In either case, we are currently studying the beam trajectory with simulation. After confirming the orbit, we will check the orbit with the real beam (with a tiny beam current).

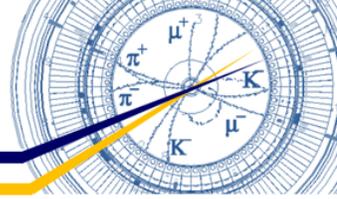


D1V1 collimator head has been damaged



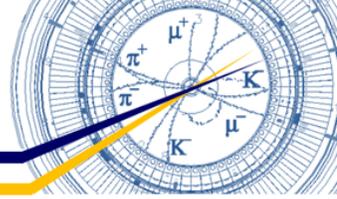
D01V1 BOTTOM



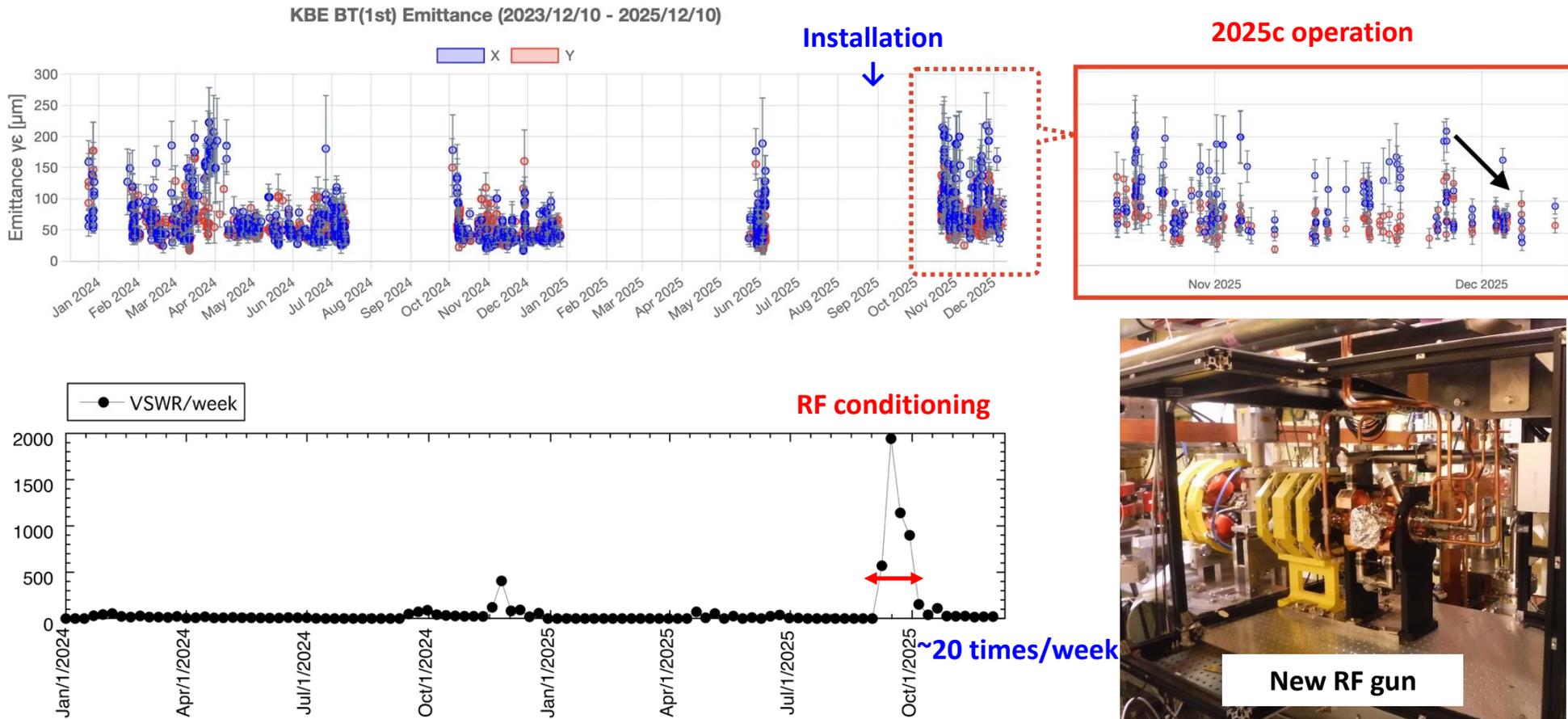


- By moving the damaged vertical collimator 1.5 mm horizontally and adjusting the other vertical collimators, we are currently able to continue operation while keeping the background to the Belle II detector within acceptable limits.
- However, this situation results in the vertical collimator being significantly narrowed, considerably reducing the HER's injection efficiency.

Injector / injection efficiency

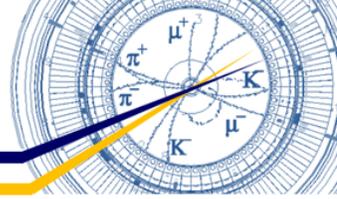


- New RF gun operation status
Emittance and frequency of VSWR at the same level as before



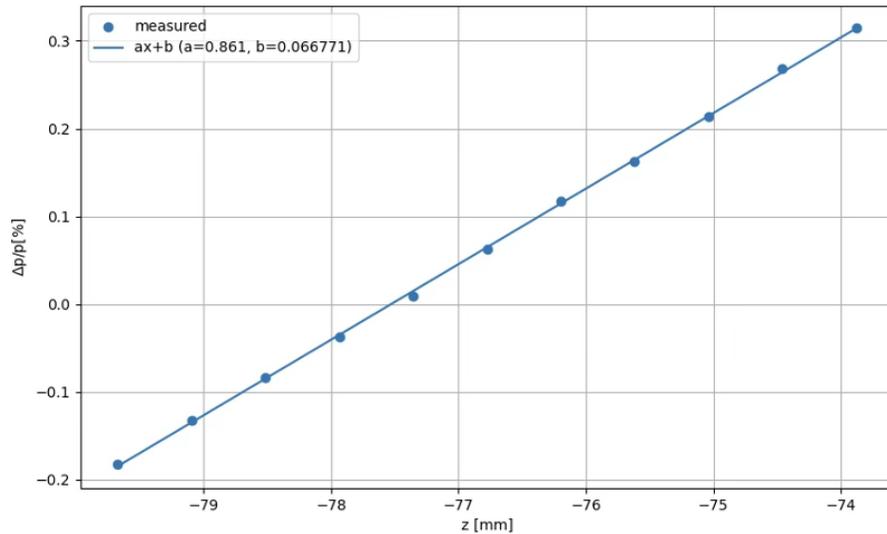
By M. Yoshida et al.

Injector / injection efficiency



- Electron ECS operation status
Design $V_c = 100$ MV and $R_{56} = -0.7$ m attained
Energy compression confirmed

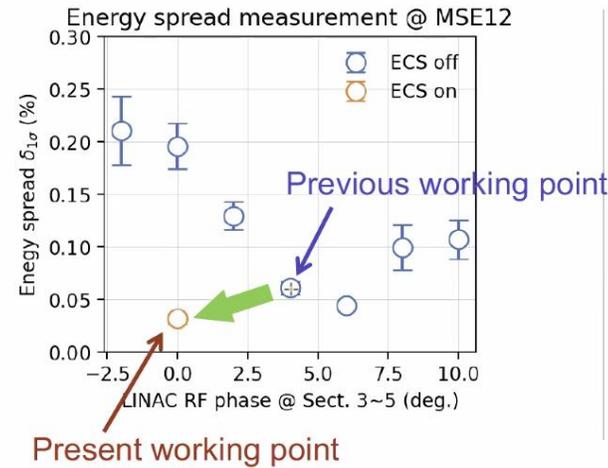
Measured voltage : 100.08 MV



By T. Natsui

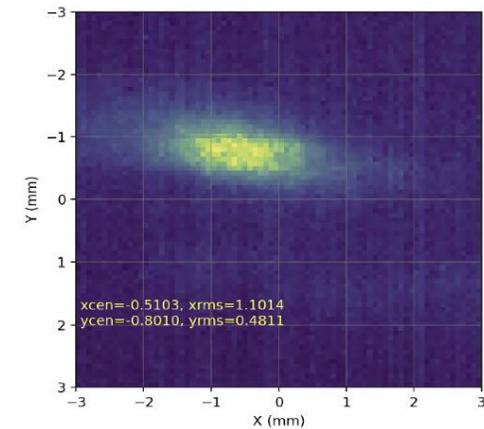
BTe-ECS Verification @ MSE12

Measurement date: 20251125



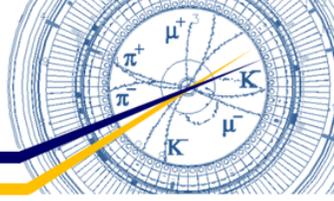
Present energy spread is $\sim 0.032\% < \sim 0.061\%$ (2024 working point).

Nominal beam profile @ MSE12



By T. Yoshimoto

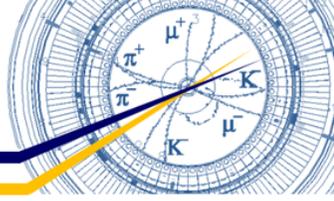




The other studies on BT and DR for injection improvement

- BT
 - Resolution improvement of BPMs for BTeV-ECS by using VME system : $72 \rightarrow 7.5 \mu\text{m}$
 - SY3 new precise beam diagnostics line for HER e^- beam commissioned
 - Tests of new ML beam-optimization and auto-phase tuning in progress
 - Test of transverse beam-size minimization by Bayesian and Down-hill optimization with BT beam profiles (Two SR monitors required)
 - BTeV new energy- and orbit-feedback
 - Disappearance of XY-coupling by revised bending magnets in BTeV
 - BTeV and BTeV dispersion correction
 - Auto phase scanning program for both eECS and pECS
- DR
 - Successful horizontal orbit correction for only 2nd e^+ bunch by using new horizontal strip-line kicker in RTL

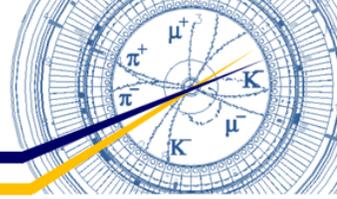
Obstacles to High beam current storage



- Vertical emittance of injection beam.
- Beam jitter of the injection beam.
- Beam-beam related injection efficiency.
 - Increase B_x at injection point, Decrease B_x at collision point
- Vacuum burst at ARES cavities
 - A cavity that periodically deteriorates the vacuum, such as argon instability(D8).
 - ARES cavity experiencing sudden vacuum deterioration, as if due to an internal leak (D5A).



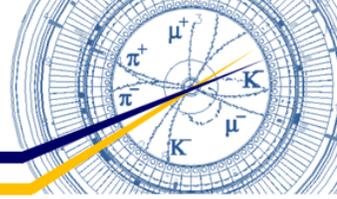
Improvement of injection efficiency



- Optical matching between the beam transport line and the ring has significantly improved the HER's injection efficiency.
 - The results do not agree well with optical calculations, and a correction method has not yet been established.
- Two-bunch injection of LER worked well to double the injection rate.
 - The equalization of injection efficiency between Bunch 1 and Bunch 2 resulted from adjusting RTL Strip Line Kicker No. 2 and matching the energy levels of both bunches.

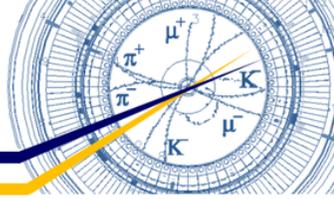


Vertical beam size



- In HER, the vertical emittance during single-beam operation has only been achieved at levels equivalent to the previous period (2024c).
 - However, there are cases where the effects of synchro-beta resonance lines can be mitigated (this depends heavily on the results of optical correction).
- In LER, a smaller vertical emittance than the previous term has been achieved.
- For the collision performance, initial concerns were raised about low specific luminosity and significant geometric deviation. However, through continued tuning, the deviation has decreased, and a specific luminosity comparable to that in the previous period has been achieved.

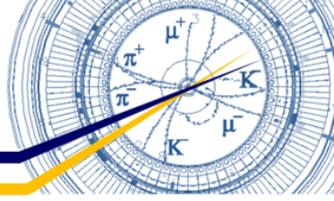
Summary



- The SuperKEKB Accelerator resumed operation as scheduled.
- We attempted synchrotron injection at HER, but due to difficulties with beam injection during collisions, we reverted to the previous betatron injection method.
- Unexpected problems have been occurring frequently, and we have not yet achieved the target performance.
 - Synchrotron injection-related troubles
 - Numerous failures associated with weak bending magnet off during HER Abort system malfunctions.
 - Large vacuum burst (internal leak?) of LER D05A ARES cavity.
 - Disruptions caused by the earthquake off the eastern coast of Aomori Prefecture
 - Difficulties to keep Liq-He level (solved)

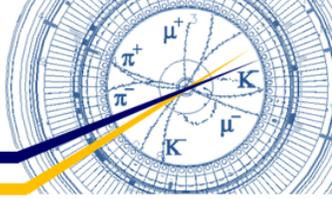


2026a/b runs

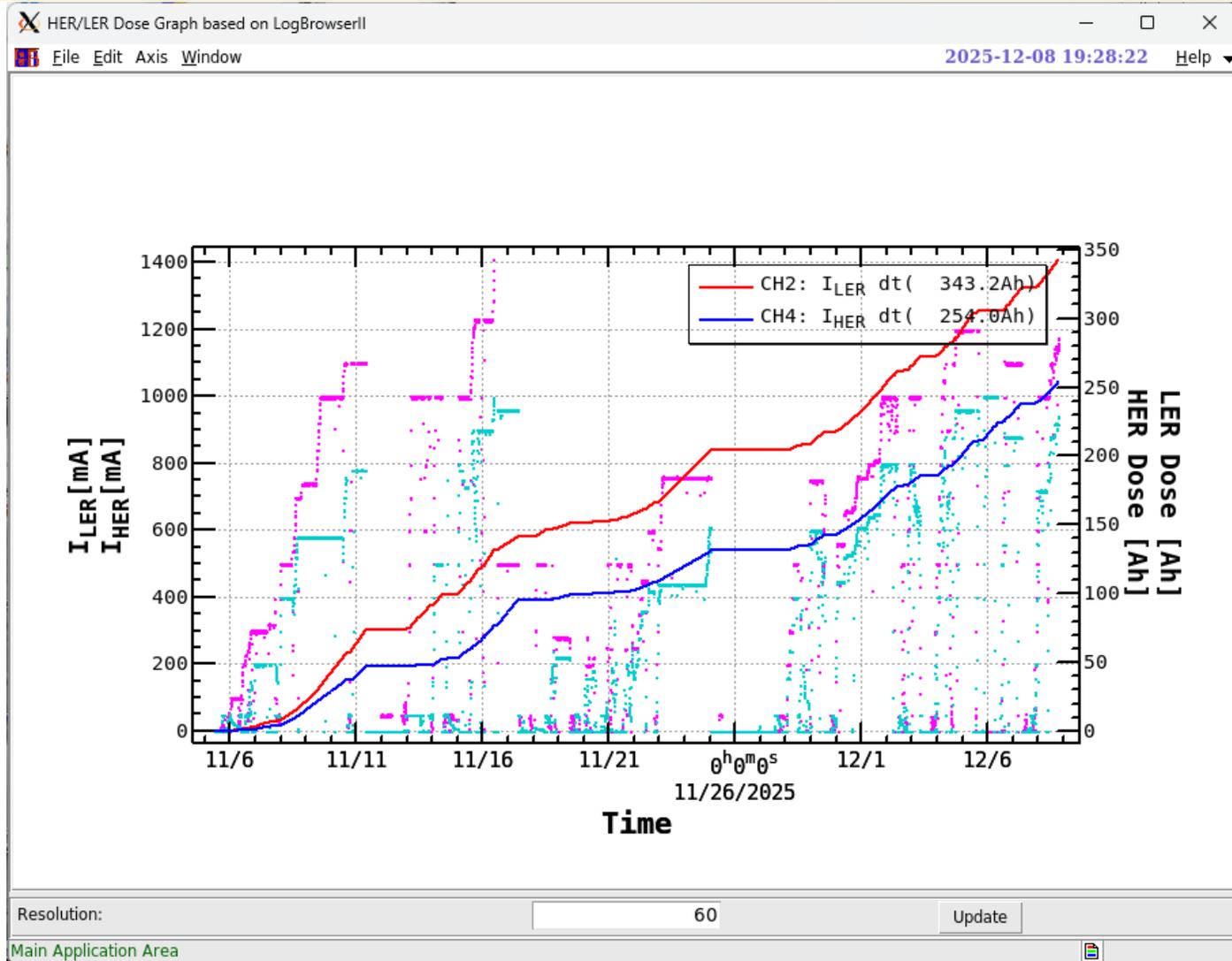
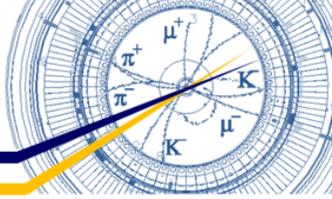


- Restart ring operation on 26/Jan/2026
- Continue operation until (at least) the end of May/2026
 - Keep $\beta y^* = 1\text{mm}$ with (trying to) increase the beam currents
 - Belle II data taking has the priority– to achieve the total integrated luminosity of 1 ab^{-1}
- Machine development time will be 3 days/month.





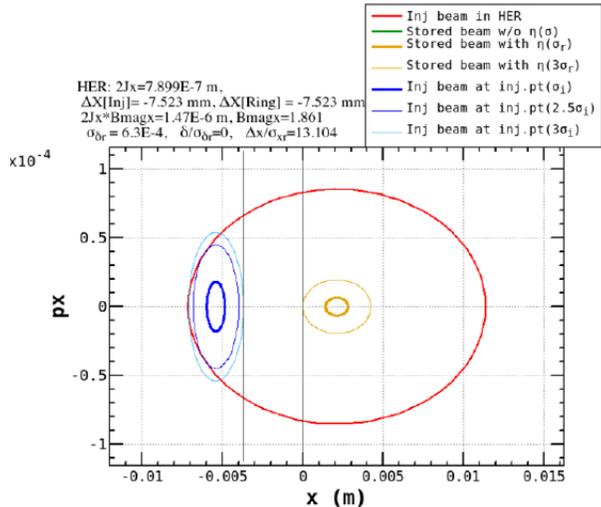
Vacuum scrubbing



HER: synchrotron injection

BI w/o cancel coil

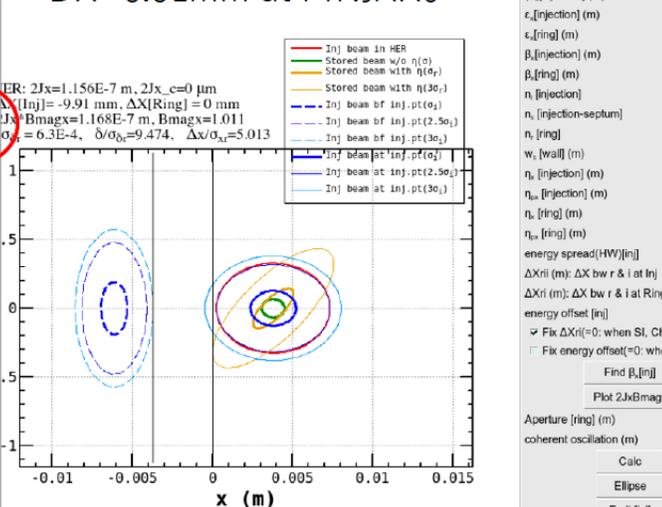
DX=7.523mm at PINJAX0



$\epsilon_x[injection]$ (m)	1.40E-4
$\epsilon_x[ring]$ (m)	1.02E-8
$\epsilon_y[injection]$ (m)	4.60E-9
$\beta_x[injection]$ (m)	31.5950
$\beta_x[ring]$ (m)	108.356
$n_x[injection]$	2.50
$n_x[injection-septum]$	3.00
$n_x[ring]$	3.00
$w_x[wall]$ (m)	0.0037
$n_x[injection]$ (m)	0.0000
$n_{tw}[injection]$ (m)	0.00000
$n_x[ring]$ (m)	0.0000
$n_{tw}[ring]$ (m)	0.00000
energy spread[HW][inj]	0.00175
ΔXri (m): ΔX bw r & i [I]	-0.00752
ΔXri (m): ΔX bw r & i at [R]	-0.00752
energy offset [inj]	.00
<input type="checkbox"/> Fix $\Delta Xri=0$: when SI, Check!	
<input checked="" type="checkbox"/> Fix energy offset(=0): when BI, Check!	
Find $\beta_x[inj]$	
Plot $2J_xBmagx$	
Aperture [ring] (m)	7.90E-7
coherent oscillation (m)	5.22E-7
Calc	
Ellipse	
Circle [inj]	

SI $\beta y^*=0.9$ mm, CW60% w/o cancel coil

DX=9.91mm at PINJAX0



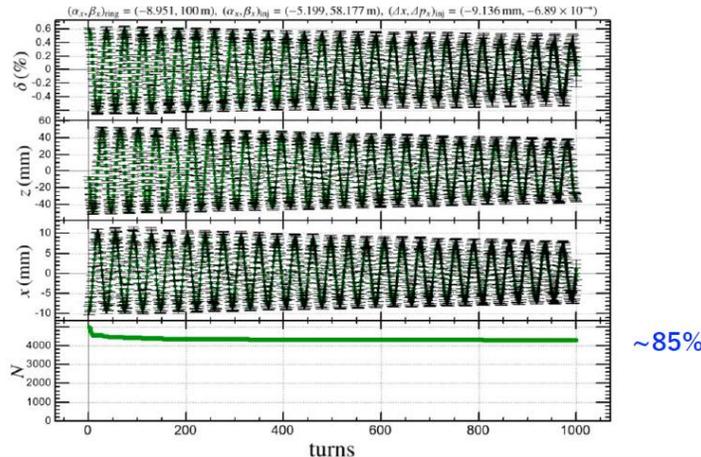
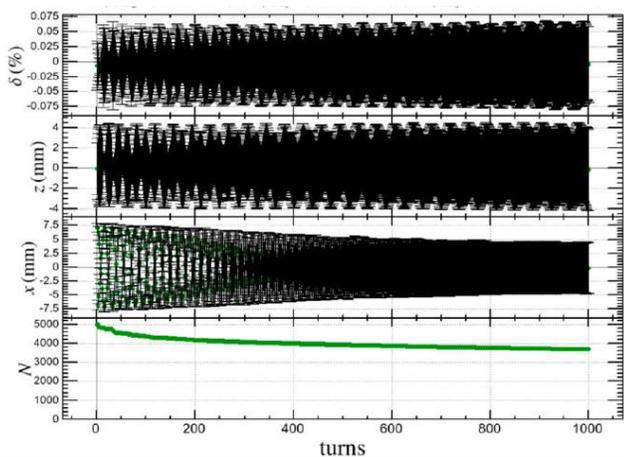
$\epsilon_x[injection]$ (m)	1.40E-4
$\epsilon_x[ring]$ (m)	1.02E-8
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$n_x[injection]$	2.50
$n_x[injection-septum]$	3.00
$n_x[ring]$	3.00
$w_x[wall]$ (m)	0.0037
$n_x[injection]$ (m)	0.0000
$n_{tw}[injection]$ (m)	0.00000
$n_x[ring]$ (m)	0.0000
$n_{tw}[ring]$ (m)	0.00000
energy spread[HW][inj]	0.00175
ΔXri (m): ΔX bw r & i [I]	-0.00752
ΔXri (m): ΔX bw r & i at [R]	-0.00752
energy offset [inj]	.00
<input checked="" type="checkbox"/> Fix $\Delta Xri=0$: when SI, Check!	
<input type="checkbox"/> Fix energy offset(=0): when BI, Check!	
Find $\beta_x[inj]$	
Plot $2J_xBmagx$	
Aperture [ring] (m)	7.90E-7
coherent oscillation (m)	5.22E-7
Calc	
Ellipse	
Circle [inj]	

Betatron injection (BI):

conventional method at SuperKEKB, horizontal distance at the injection region (ΔX) goes to betatron (horizontal) oscillation

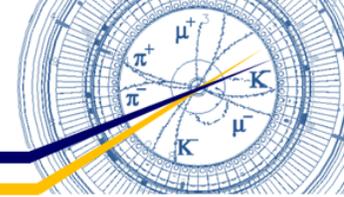
Synchrotron injection (SI):

proposed method at SuperKEKB, horizontal distance at the injection region (ΔX) goes to synchrotron oscillation

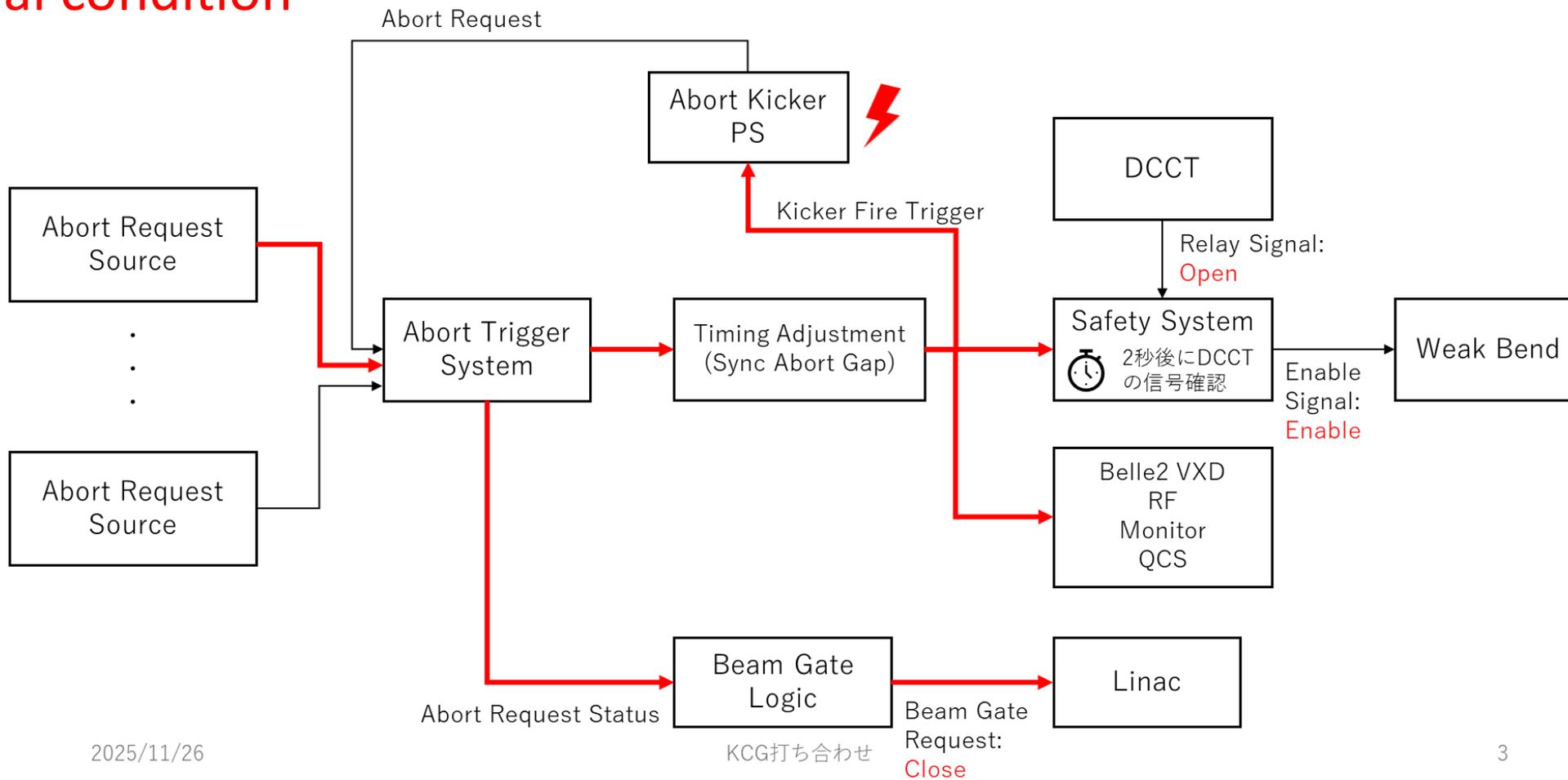


In synchrotron injection, beam-beam effects can be reduced, then the beam injection efficiency will come improved.

HER beam abort kicker malfunctioning



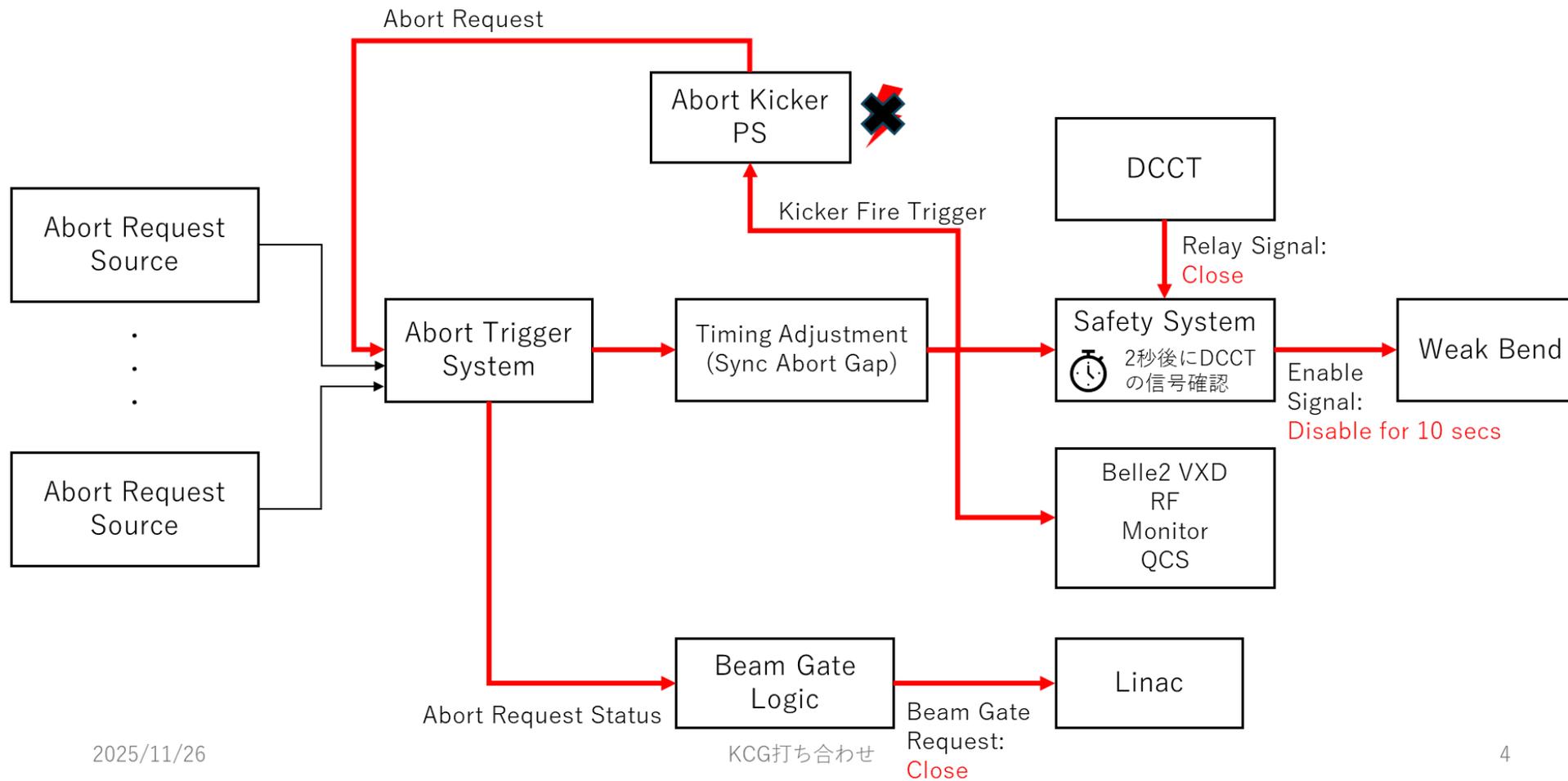
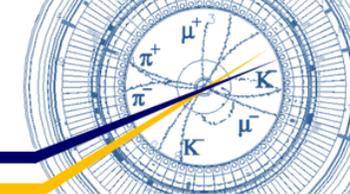
Normal condition



2025/11/26

3

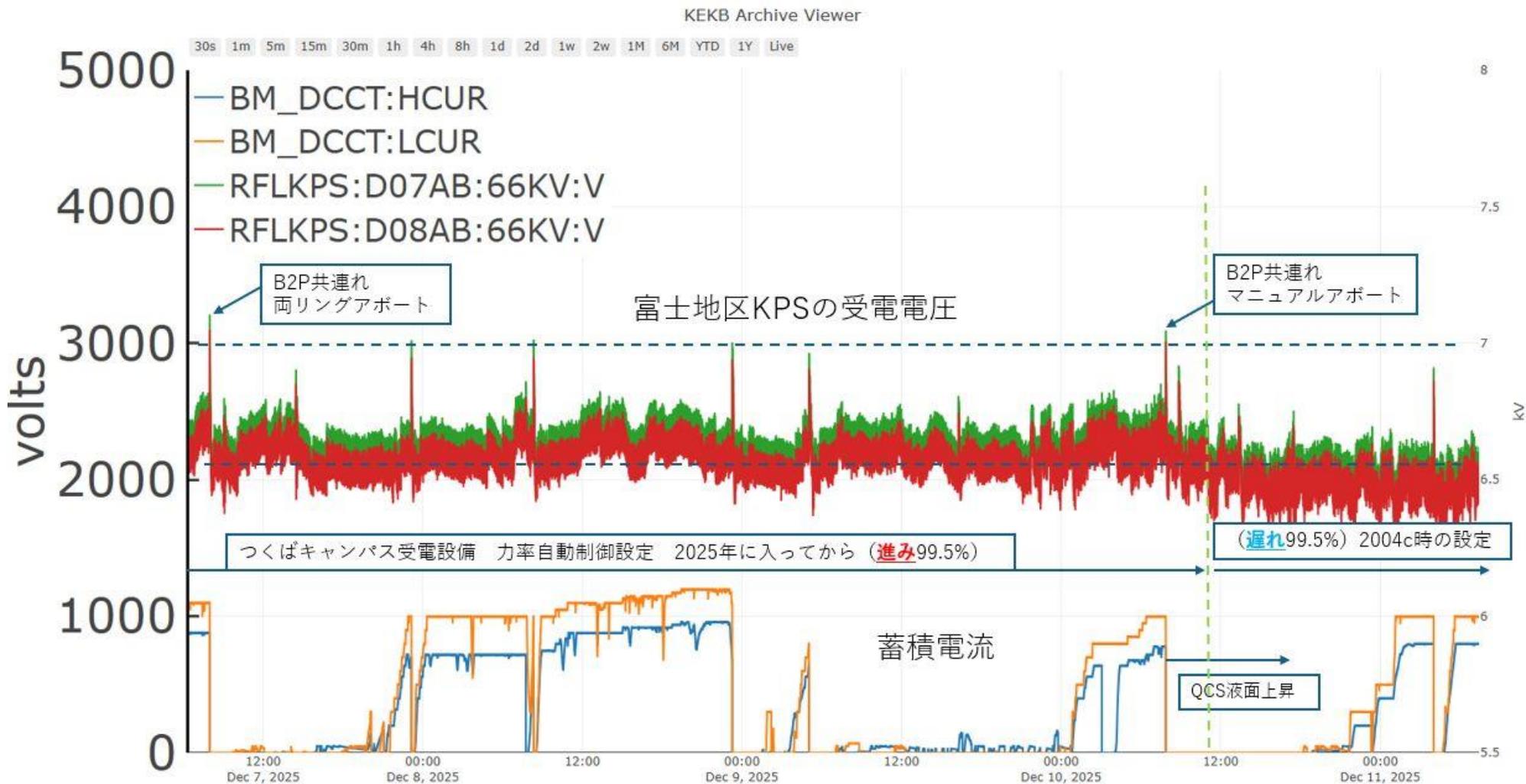
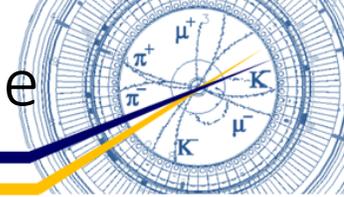
Abort kicker malfunctioning

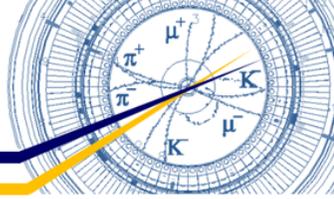


2025/11/26

4

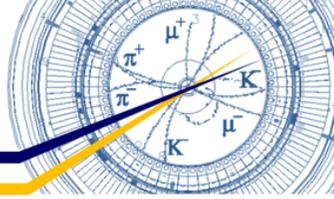
B2P power supply down due to overvoltage of the primary 6.6kV line



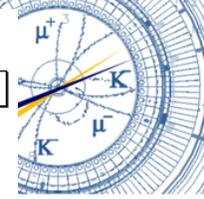


- The LER bending magnets power supply (B2P) tripped due to a primary voltage (6.6kV) overlimit interlock (occurred twice) caused by the trip of all RF sources of Fuji area due to beam abort.
- After investigating the cause with KEK's Facilities Department, it was determined that the settings for the power factor correction capacitors at KEK's power receiving section—intended to improve power efficiency—differed from those used in fiscal year 2024 (having been adjusted toward greater energy savings). These settings were reverted to their original configuration.
 - Efforts were also made on the RF side to reduce power consumption in the Fuji area.
 - After this, the B2P power supply is not interlocked.

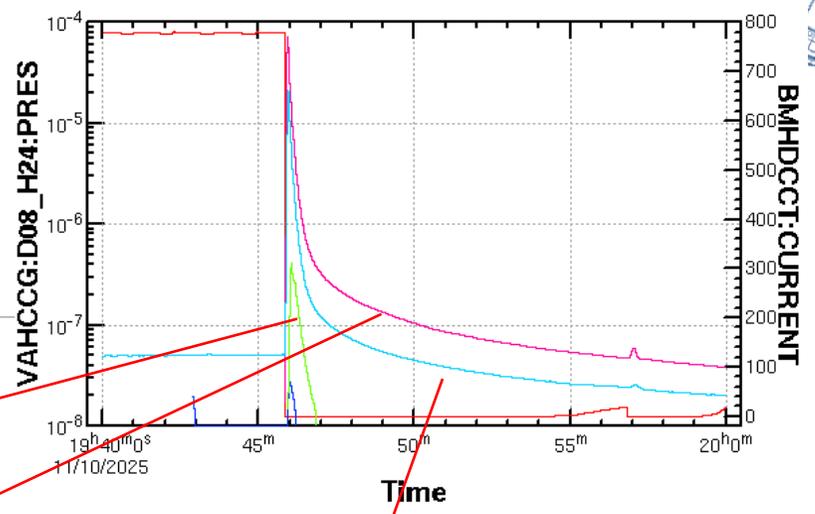
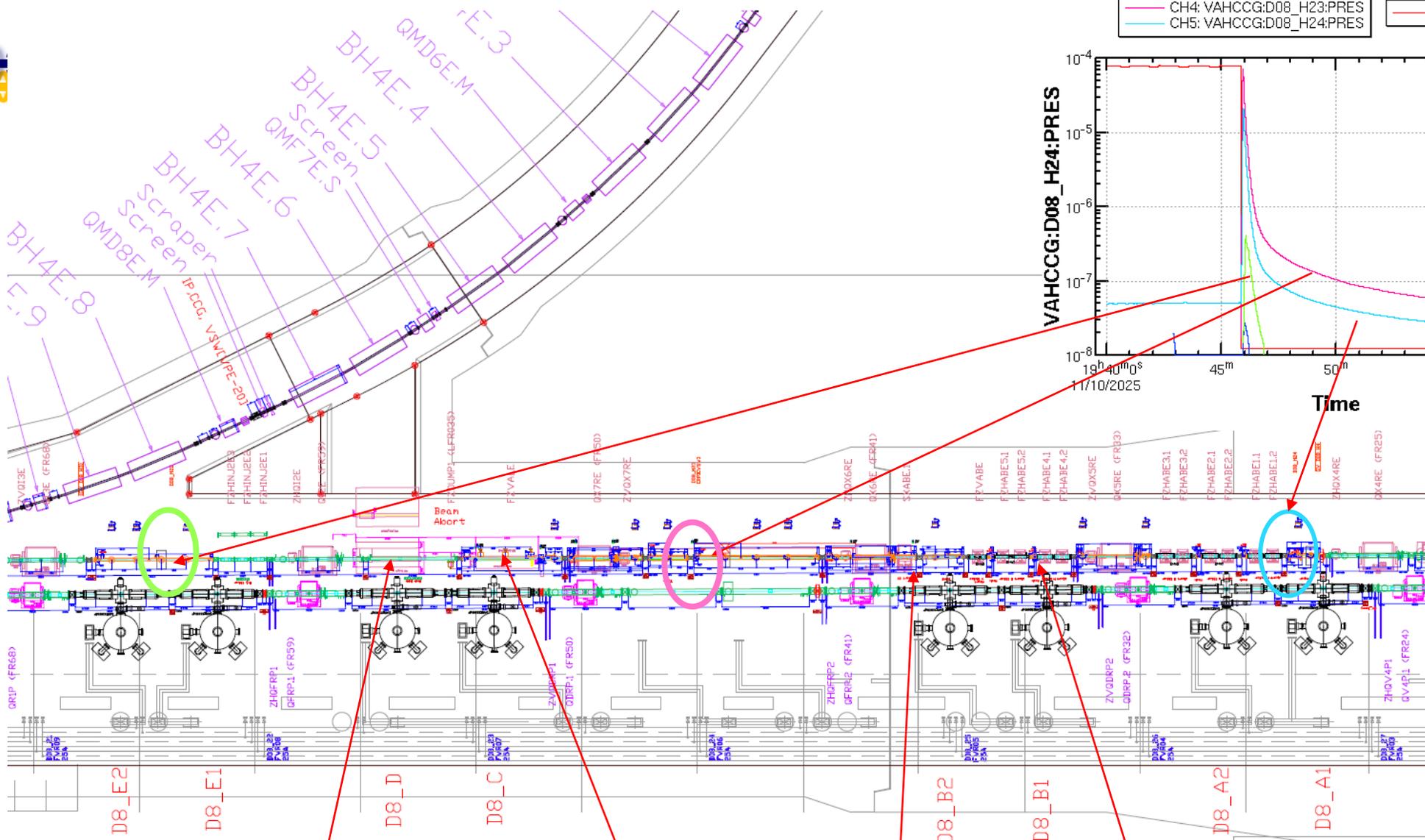
Synchrotron Injection for HER



- Successfully with the detuned optics, but
 - Damage the vacuum chamber wall (and flange) around the beam dump due to the aborted beam, which resulted in a large vacuum leak after one day of operation.
 - The issue was temporarily resolved by re-examining the trajectory of the abort beam and modifying it to maintain sufficient distance from the chamber wall.



- CH2: VAHCCG:D08_H21:PRES
- CH3: VAHCCG:D08_H22:PRES
- CH4: VAHCCG:D08_H23:PRES
- CH5: VAHCCG:D08_H24:PRES
- CH1: BMHDCCT:CURRENT



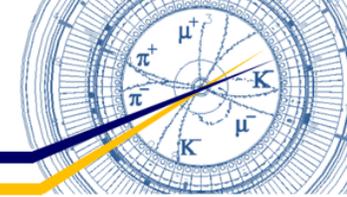
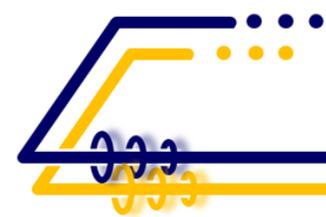
ビームダンプ

ランバートソン

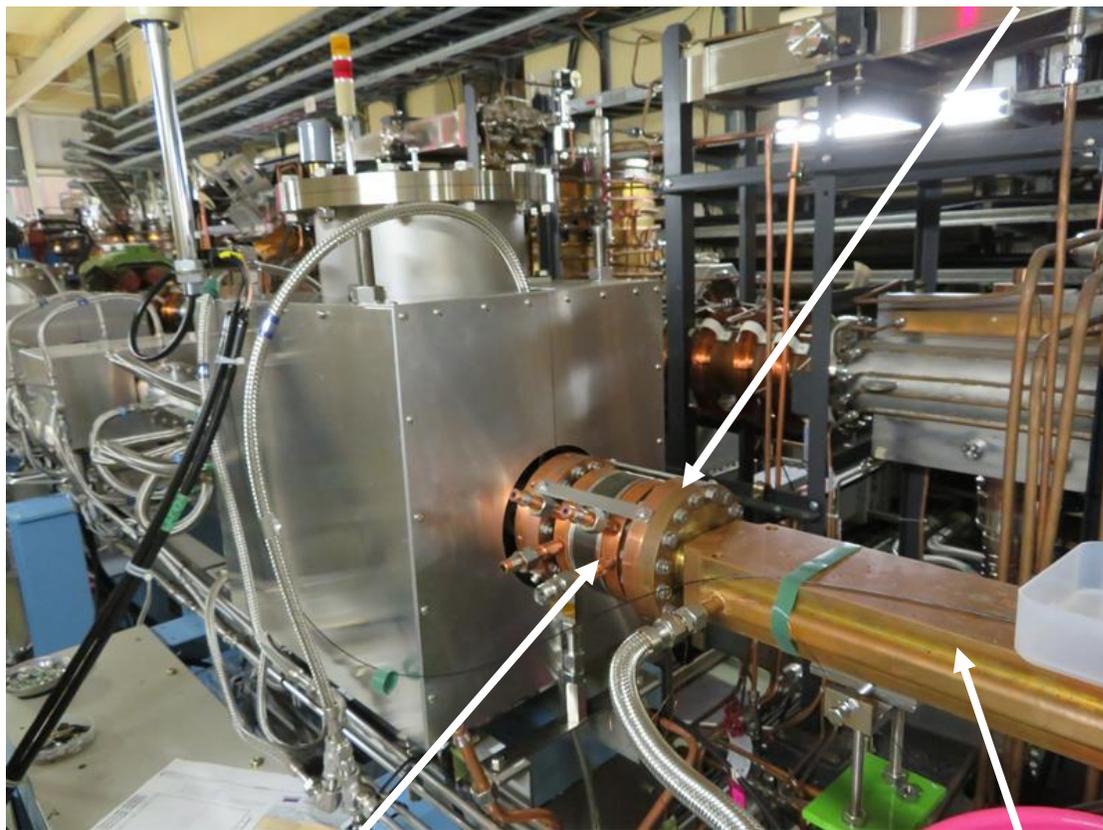
アボートキッカー

リーク箇所

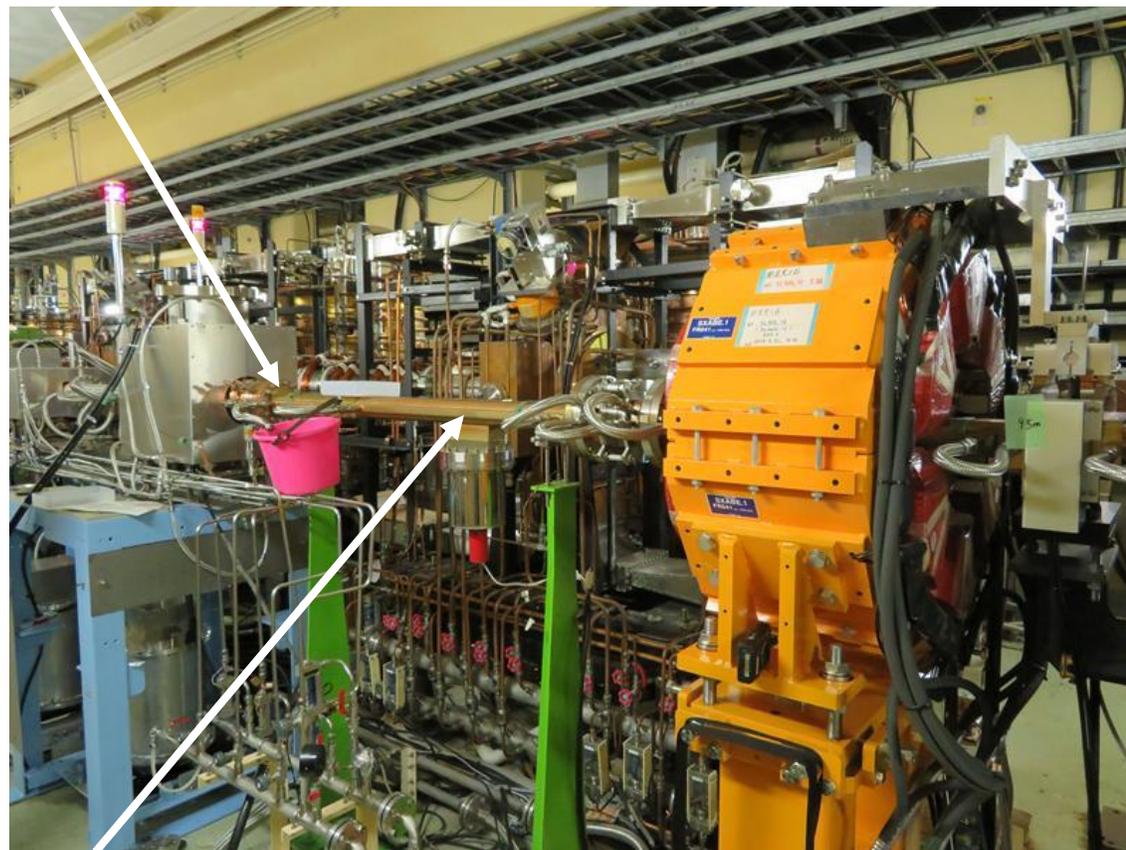




リーク箇所



ベローズ

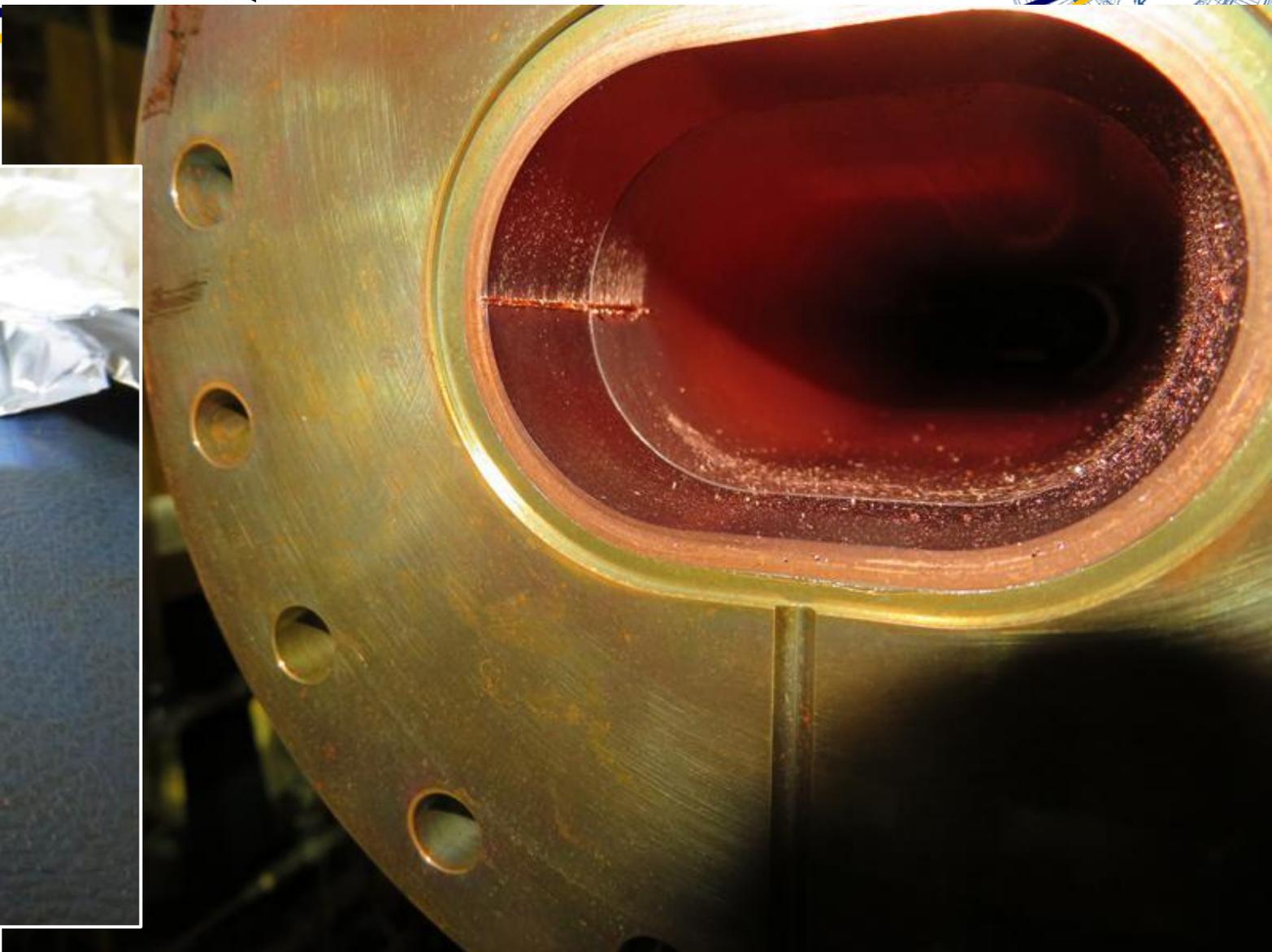


テーパ chambers

この chambers で H60 x V40 から H104 x V50 に変換



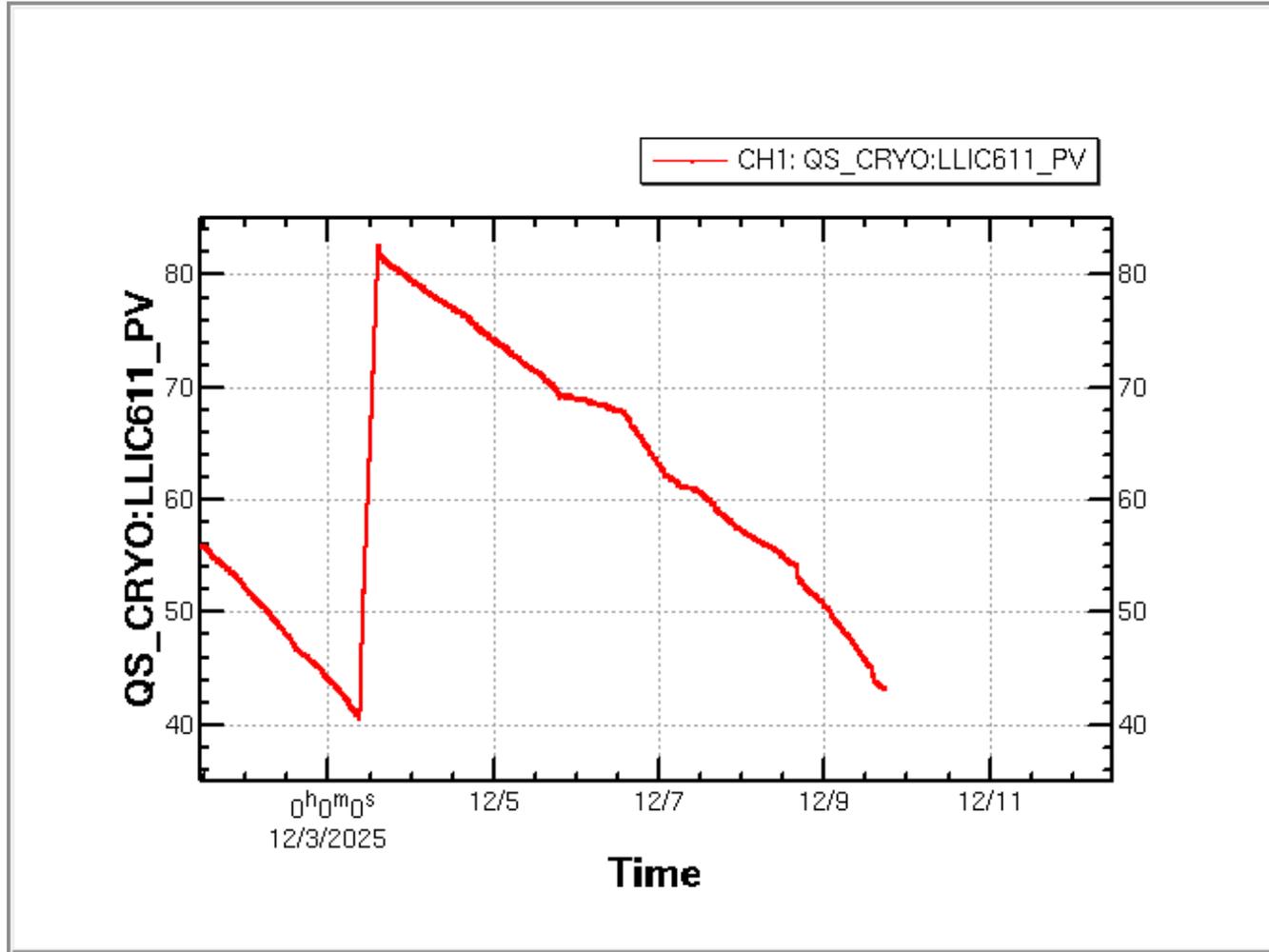
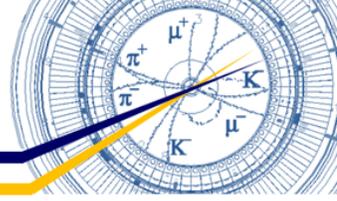
リング外側



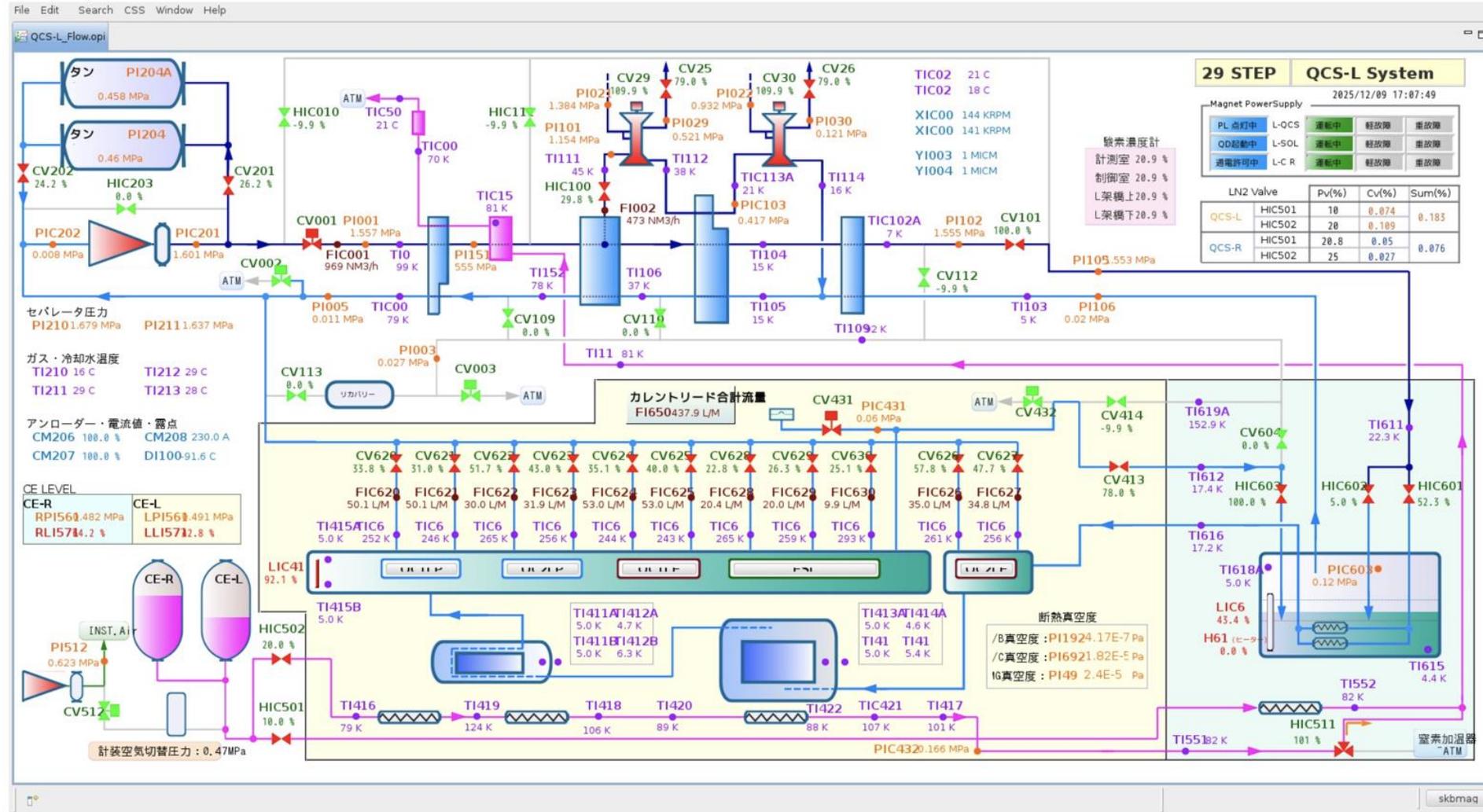
リークしたフランジの
ヘリコフレックスガスケット

リークしたフランジ側から見たテーパードレンジャー

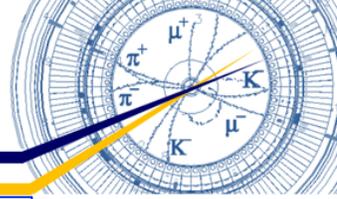




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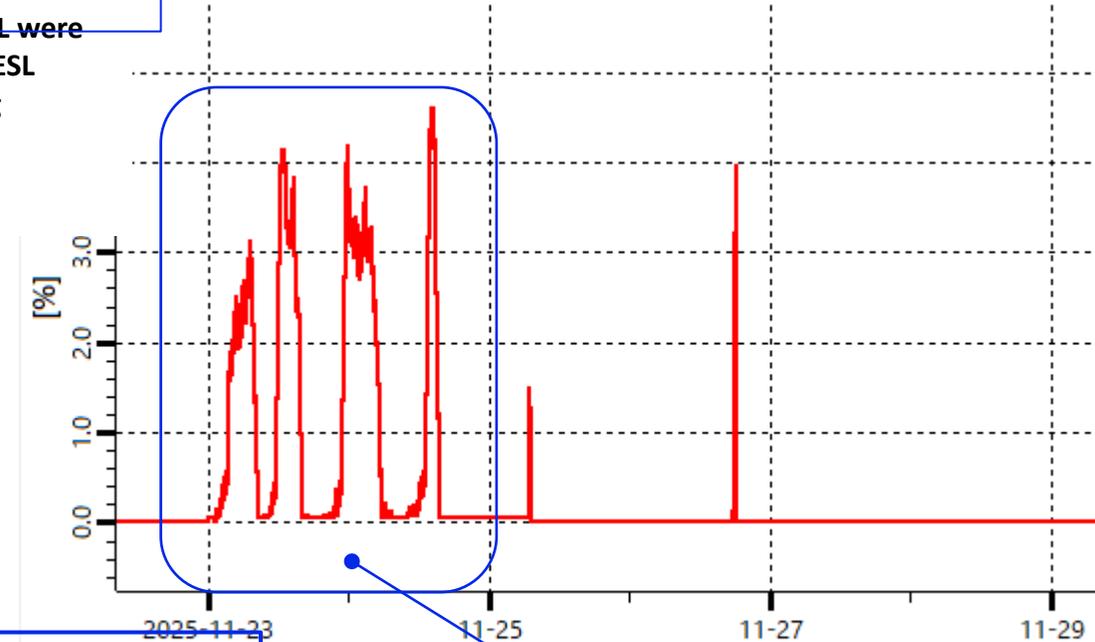
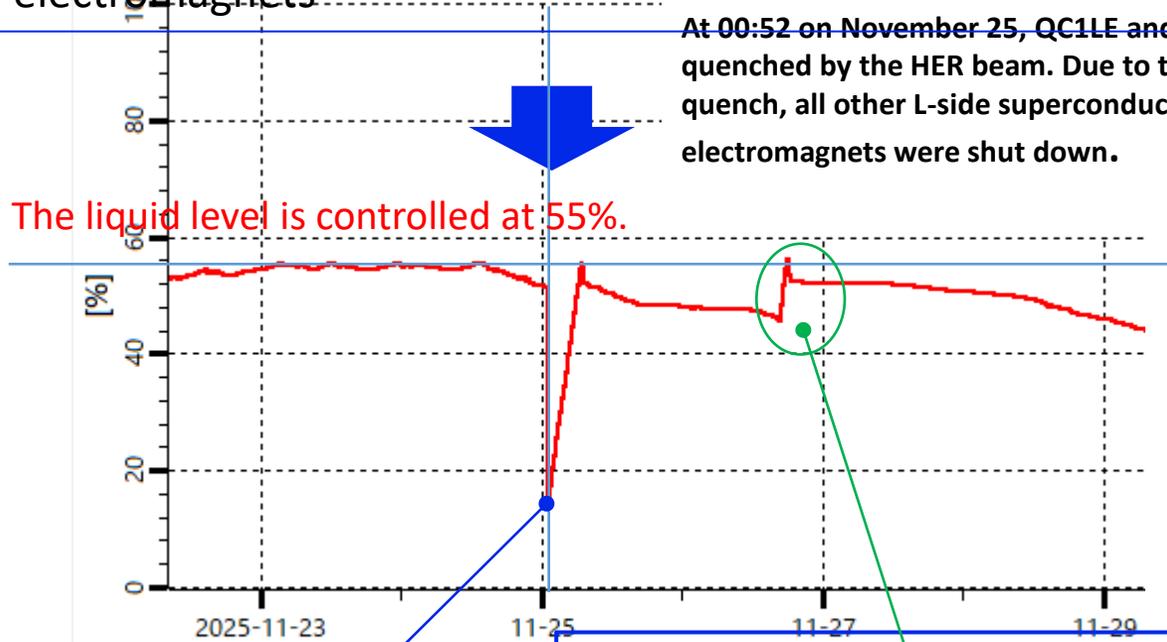


L-Side QCS Li-He reserve level



Liquid helium surface level near atmospheric pressure for producing supercooled liquid helium to cool QCSL superconducting electromagnets

Heater operation status to maintain liquid helium level at 55%



QCSL electromagnet quench reduced to 15%.

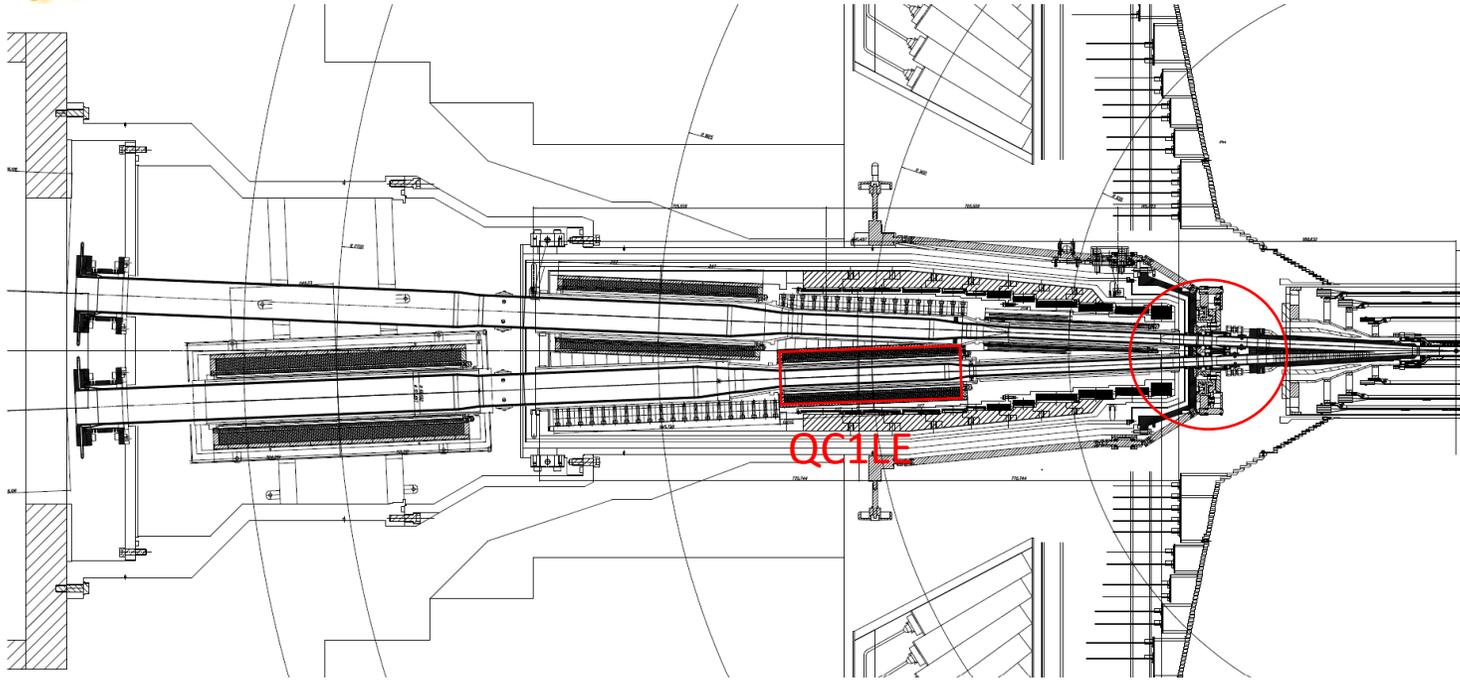
After system recovery from quench, the liquid level dropped to 46%. **Set all QCSL electromagnets to 0A and reduce the helium gas flow for current lead cooling to raise the liquid level.** (Reduce the heat load on the cryostat)

During normal operation, when the liquid helium level reaches 55% or higher, the heater inside the liquid helium container activates to maintain the level at 55%.

Why can't we keep the Li-He level?

- The heat load of the QCS cryostat has increased.
 - Air leak in the thermal vacuum chamber.
 - Air leakage may have occurred due to deterioration of the O-ring at the cryostat tip, potentially causing air to condense on the surface of the liquid helium container.

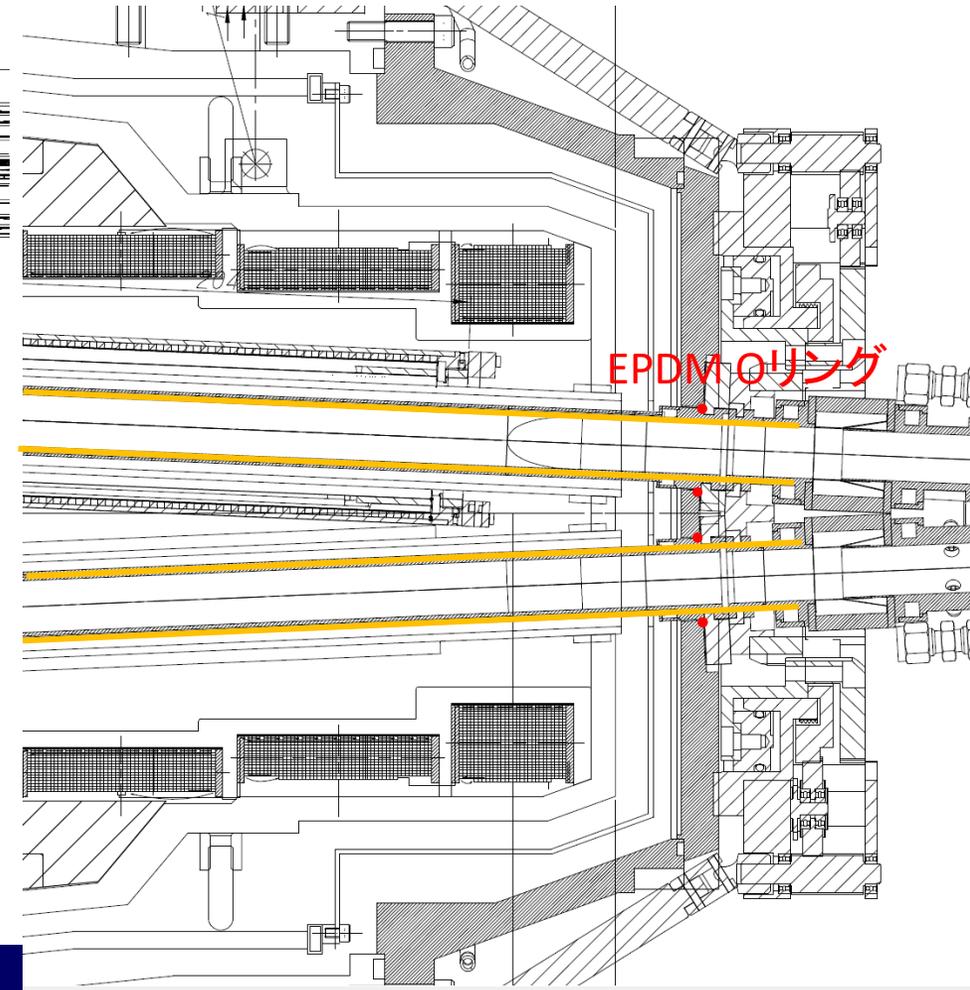
O-ring at the tip of cryostat



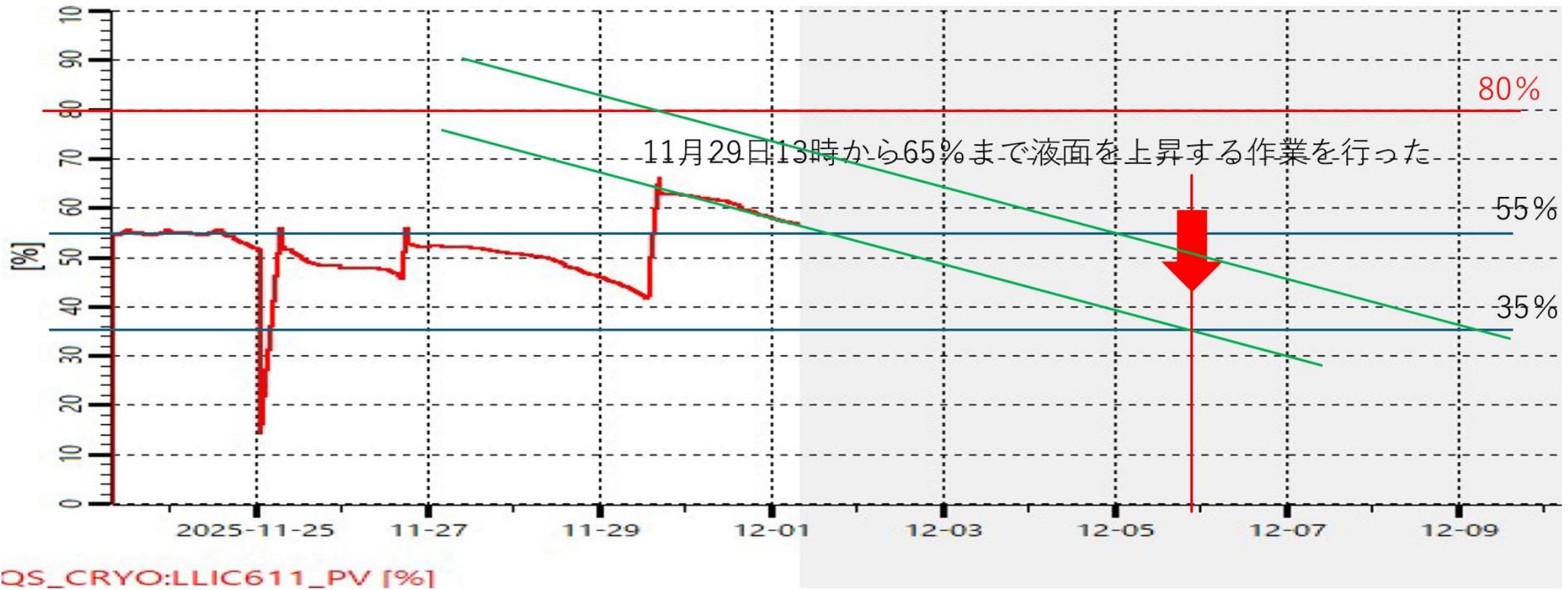
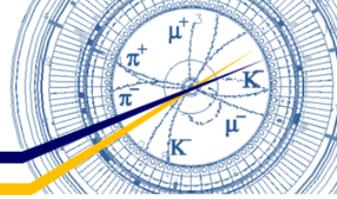
QCS-L side cryostat

EPDM O-ring

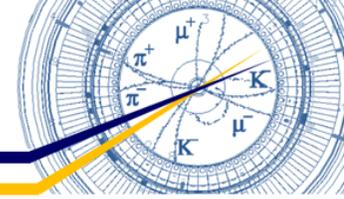
The vacuum vessel (vacuum layer) of the QCS cryostat is sealed from the atmosphere using the end face of the vacuum vessel and the outer circumference of the beam pipe.



Power off the QCS magnets and raise the liquid He level



Needs roughly 8 hours to increase the Li-He level. After the process, we need to re-do the optics correction (8h)



- Following the liquid He level rise operation on December 16, we were able to keep the liquid He Level constant (82%) by tuning the Liquid He refrigerator. Consequently, the nearly weekly shutdowns of operations and the rise in liquid He level operations conducted since early December were no longer necessary.
- By the inspection of residual molecular components in the thermal insulation vessel after heating the cryostat, we have confirmed that there were no (additional) vacuum leaks in the thermal vessel.
- We will restart the operation as early as possible, starting 26/Jan

