SuperKEKB Shutdown Activities and Operational Plan for 2025c Run

B2GM

June 16, 2025

T. Ishibashi

on behalf of SuperKEKB Commissioning Group

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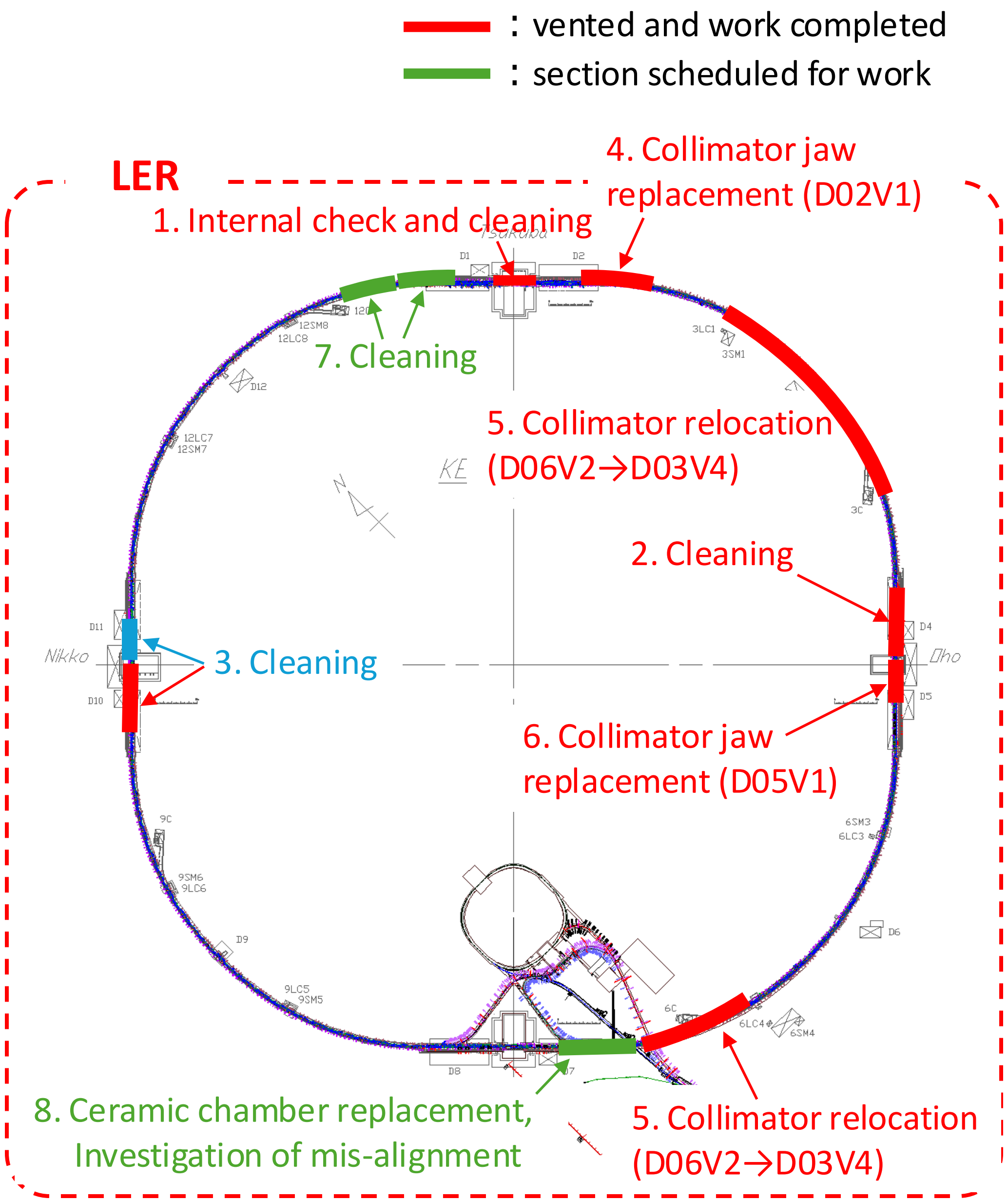
Vacuum Tasks - LER



1. Internal inspection and cleaning of beam pipes in IR → Completed
2. Cleaning of beam pipes in the Oho wiggler section → Completed
3. Cleaning of beam pipes in the Nikko wiggler section

   → Ongoing (May - July)
4. Replacement of damaged jaws in the D02V1 collimator

   → Completed
5. Relocation of the D06V2 collimator to D03V4 → Completed
6. Replacement of damaged jaws in the D05V1 collimator

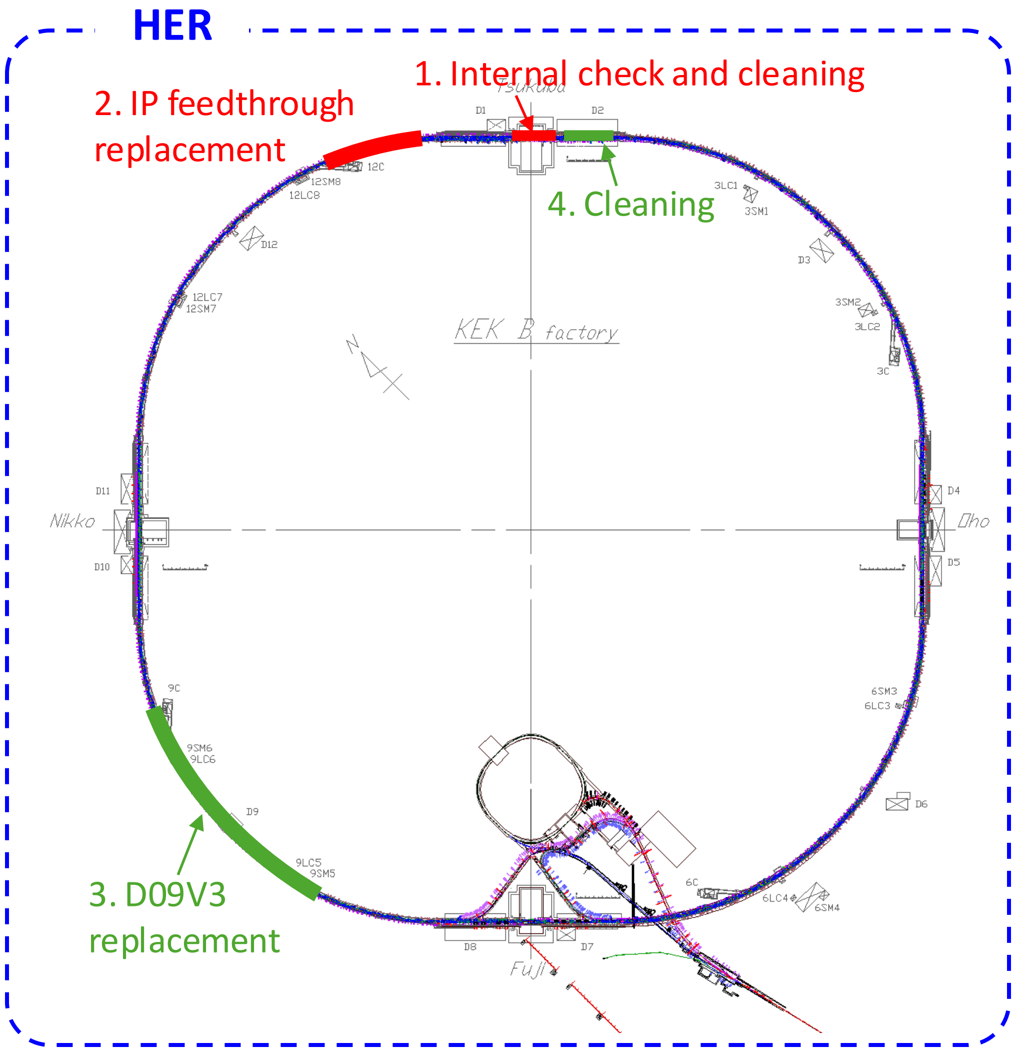
   → Completed
7. Cleaning of MO-flanges known to have used VACSEAL

   (location: around CCG D01_L10, D01_L15)
8. A) Replacement of ceramic chambers in the kicker magnets (to reduce residual kicks)

   B) Alignment check and correction of beam pipes around the injection point.

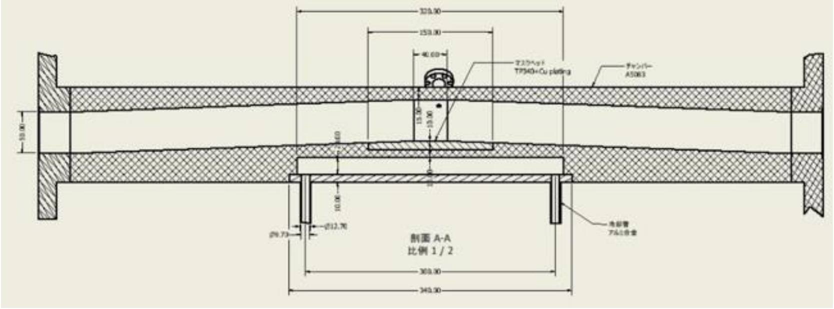
Vacuum Tasks - HER

: vented and work completed
: section scheduled for work



1. Internal inspection and cleaning of beam pipes in the IR → Completed
2. Replacement of an ion pump feedthrough → Completed
   - Vacuum leak was caused by abnormal discharge in the HV connector.
3. Replacement of the damaged jaw in the D09V3 collimator
   - A new collimator with a cooling water channel is being manufactured. Installation is scheduled for the beginning of Nov.
4. Cleaning of MO-flanges known to have used VACSEAL.
   (location: SUS flanges around CCG D02_H22)

Drawing of HER vertical collimator with water channel

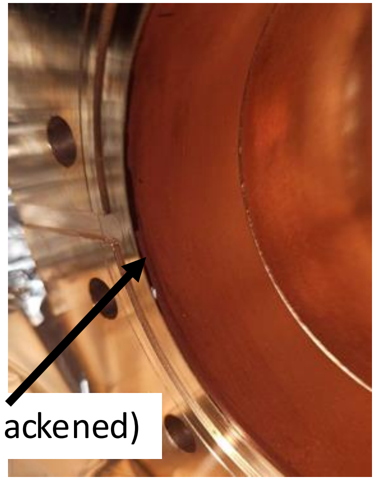


Vacuum Tasks - Internal Inspection and Cleaning in IR

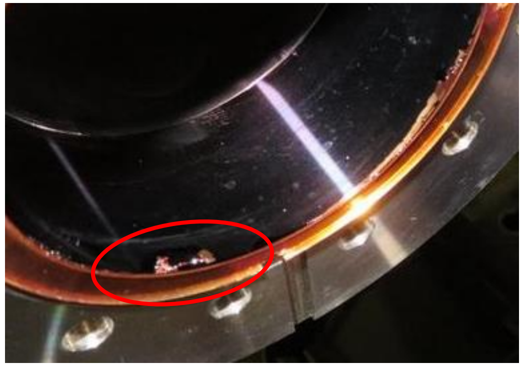
- VACSEAL was used on all flanges in the IR during construction.
- We removed the VACSEAL from all MO-flanges and reinstalled them without using it.
  - LER: 23 MO-flange connections (11 bellows chambers + 1 flange connection)
  - HER: 18 MO-flange connections (9 bellows chambers)
- The connections near the IP cannot be opened during this shutdown.
  - LER: 8 HELICOFLEX-flange connections remain uncleaned (2 bellows chambers on each side closest to the IP)
  - HER: 8 HELICOFLEX-flange connections remain uncleaned (2 bellows chambers on each side closest to the IP)
- No evidence of VACSEAL intrusion into the beam channel (e.g., black stains) has been observed so far with HELICOFLEX flanges.
  - Experimental results have also confirmed that at a leak rate on the order of 1×10^{-9} Pa·m³/s, VACSEAL does not intrude into the beam channel.

LER D01 Bellows Chamber

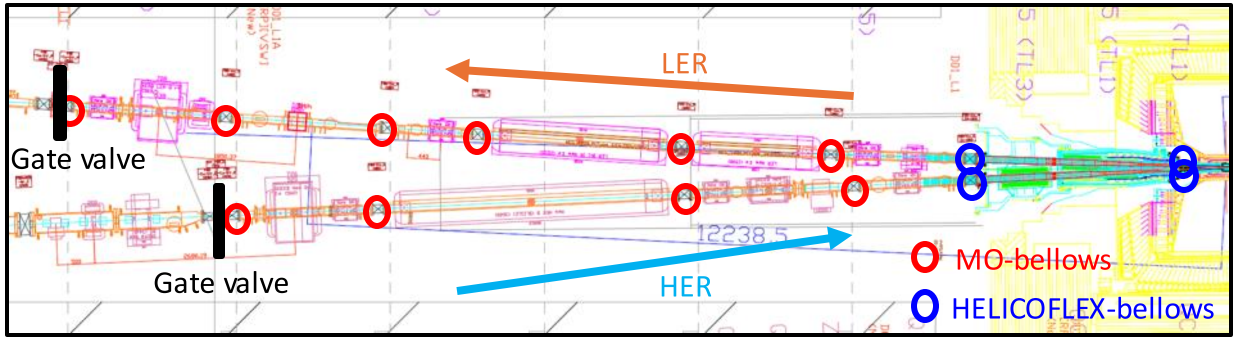
HER D01 Bellows Chamber



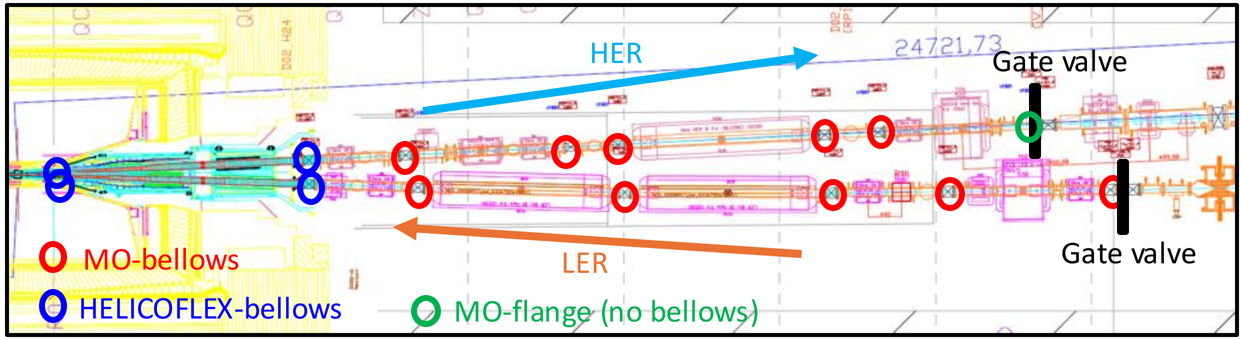
LER D02 beam pipe



HER D02 Bellows Chamber



IP



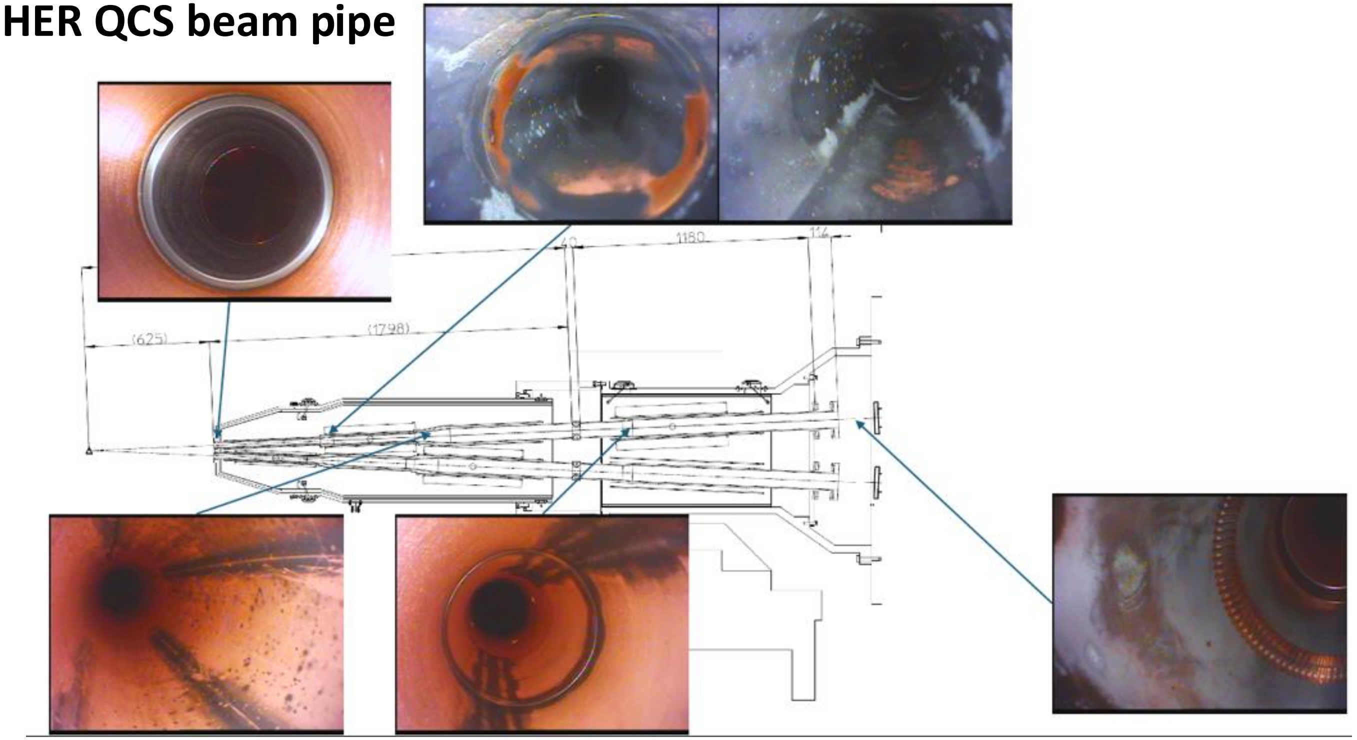
Vacuum Tasks – Internal Inspection and Cleaning in IR

- A black stain was also found near the vacuum gauge CCG D02_H23 in the HER IR, where pressure bursts associated with beam aborts had been frequently observed.
- Additionally, an inspection of the inside of the QCS beam pipes using a fiber scope were performed. In particular, the surface on the HER D02 side showed discoloration—areas that were supposed to be copper-plated had turned black.
- The vacuum gauge closest to the IP had been CCG D02_H23. To better observe where the pressure bursts occur, a new vacuum gauge, CCG D02_H24, was installed closer to the IP.

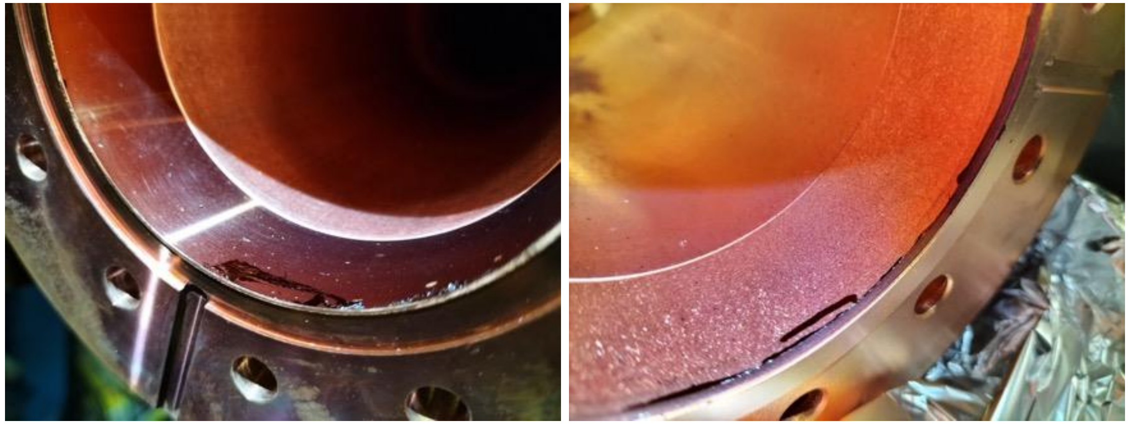
Distance from IP

- CCG D02_H23: ~11 m
- CCG D02_H24: ~7 m

D02 HER QCS beam pipe



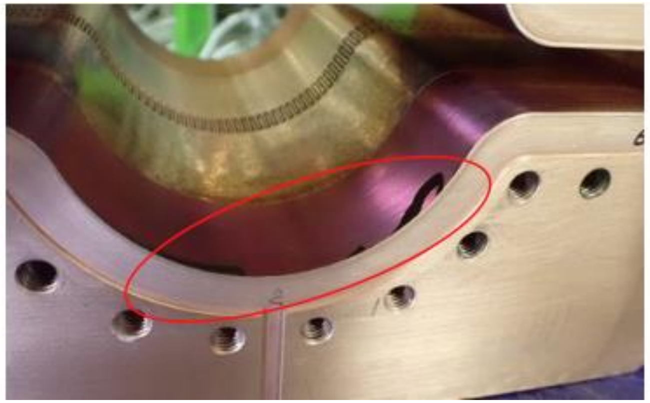
Inside of beam pipes near CCG D02_H23

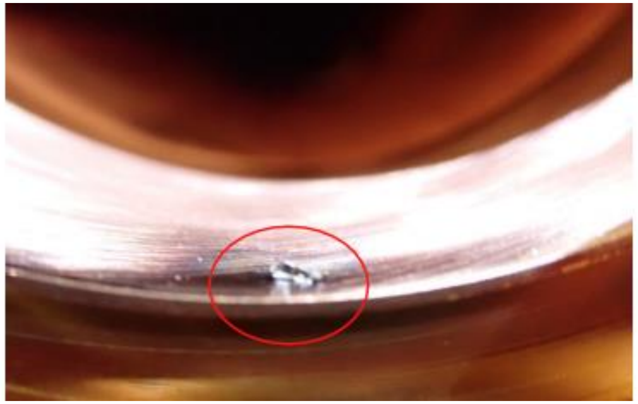


Vacuum Tasks – Cleaning in the Oho Wiggler Section

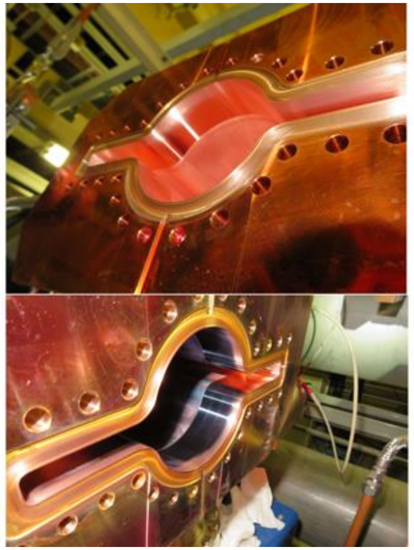
- We removed and inspected all of the bellow chambers in the Oho wiggler section.
  - 52 MO-flange connections (26 bellows chambers)
- Some bellows chambers and beam pipes showed black stains.
- We removed them and reinstalled the chambers without using VACSEAL.

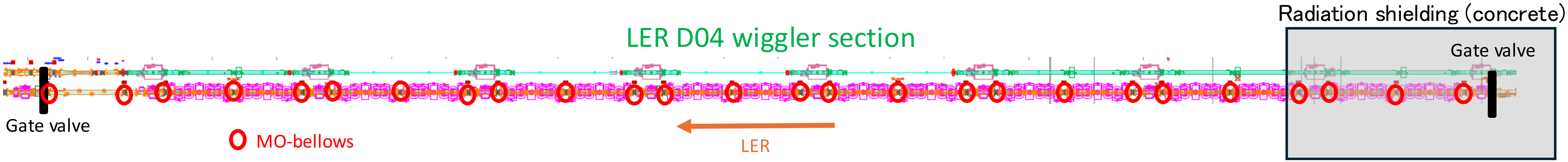
Inside of bellows chamber and beam pipe in the Oho Wiggler Section





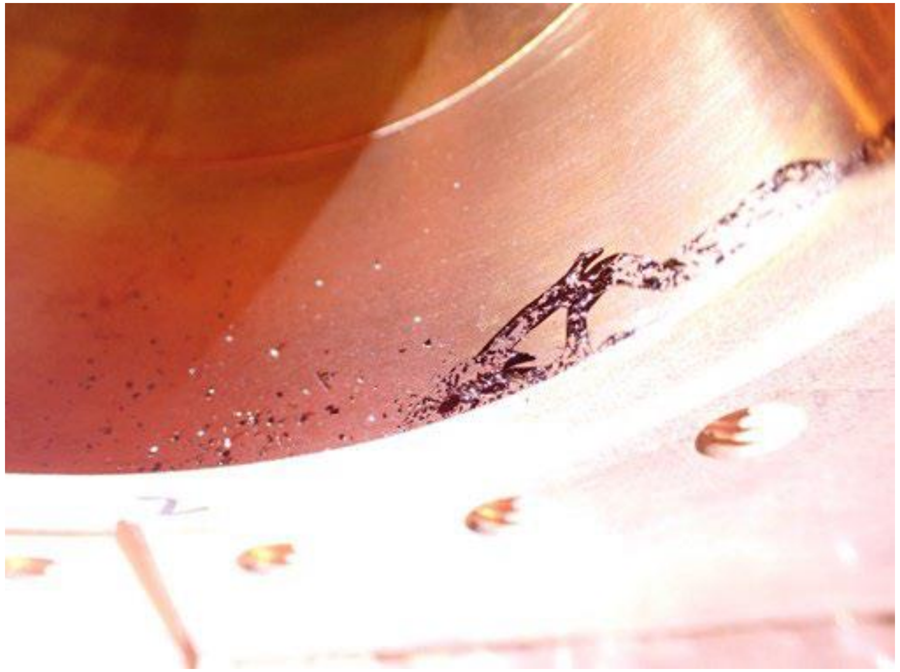
After cleaning

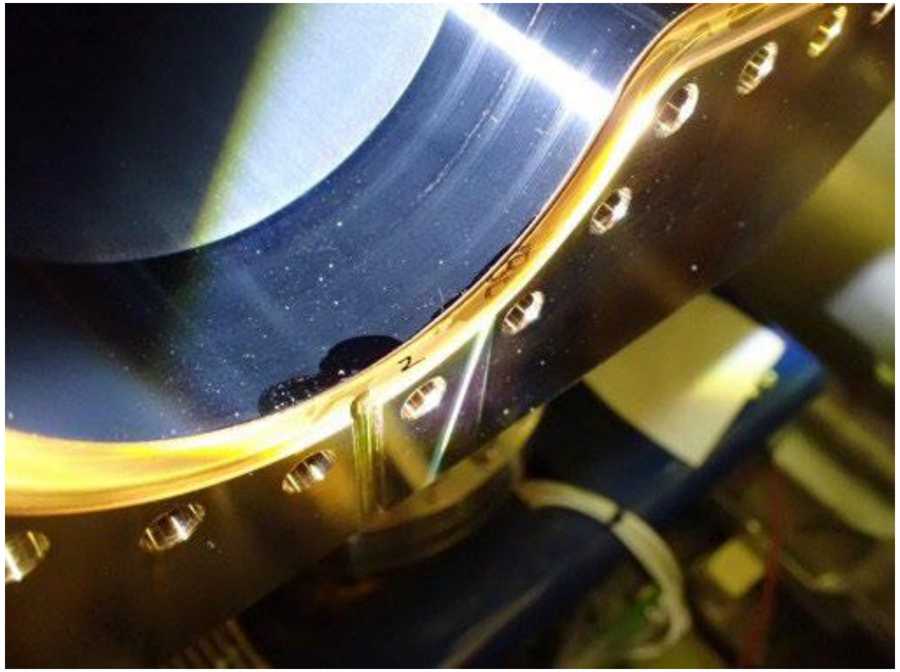




Vacuum Tasks – Cleaning in the Nikko wiggler section

- We are currently removing and inspecting all the bellow chambers in the Nikko Wiggler Section.
  - D10: 54 MO-flange connections (27 bellows chambers) → Completed
  - D11: 44 MO-flange connections (22 bellows chambers) → Ongoing
- Work is expected to be completed by mid-July.

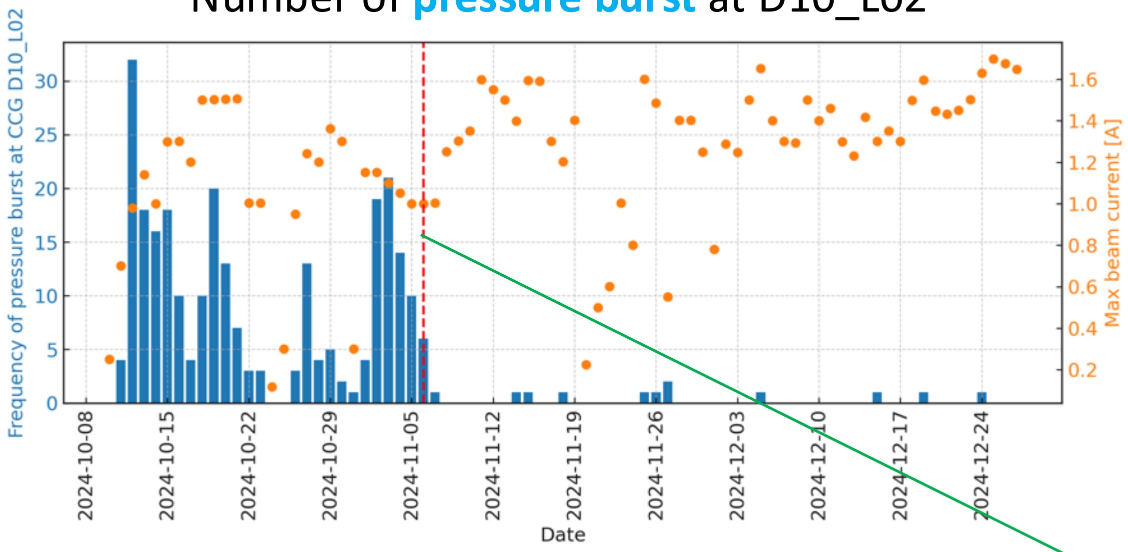




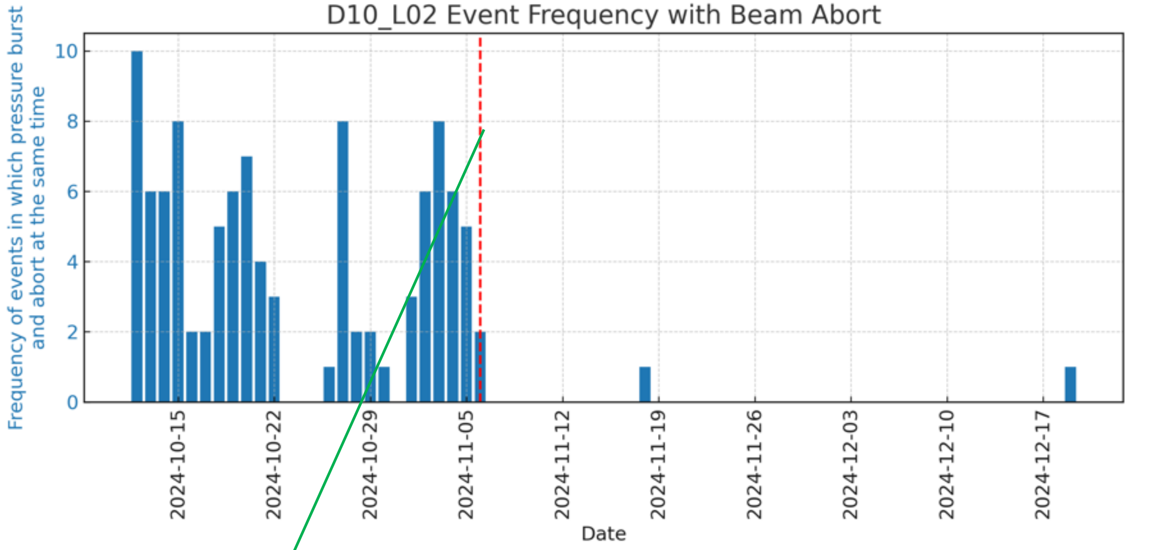
Vacuum Tasks – Cleaning Effect

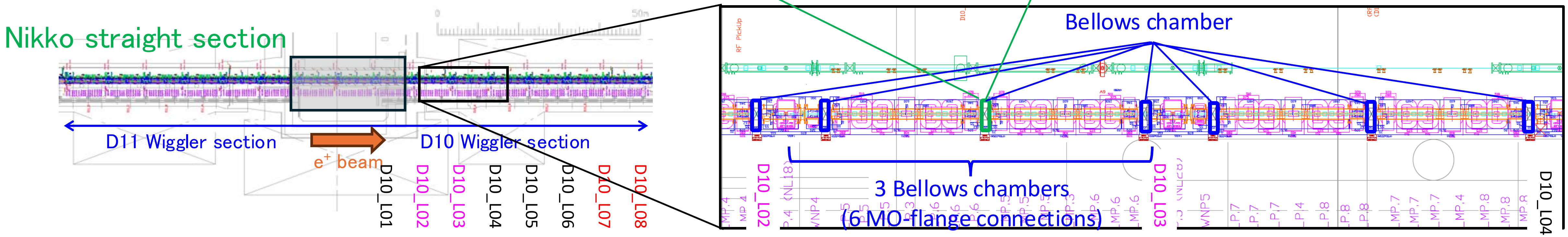
- A bellows chamber near CCG D10_L02 was replaced, and VACSEAL was removed from the adjacent beam pipes on Nov. 6 during the 2024c run, using the same cleaning method.
- After this work, the number of pressure bursts in the area has been significantly reduced.

Number of **pressure burst** at D10_L02



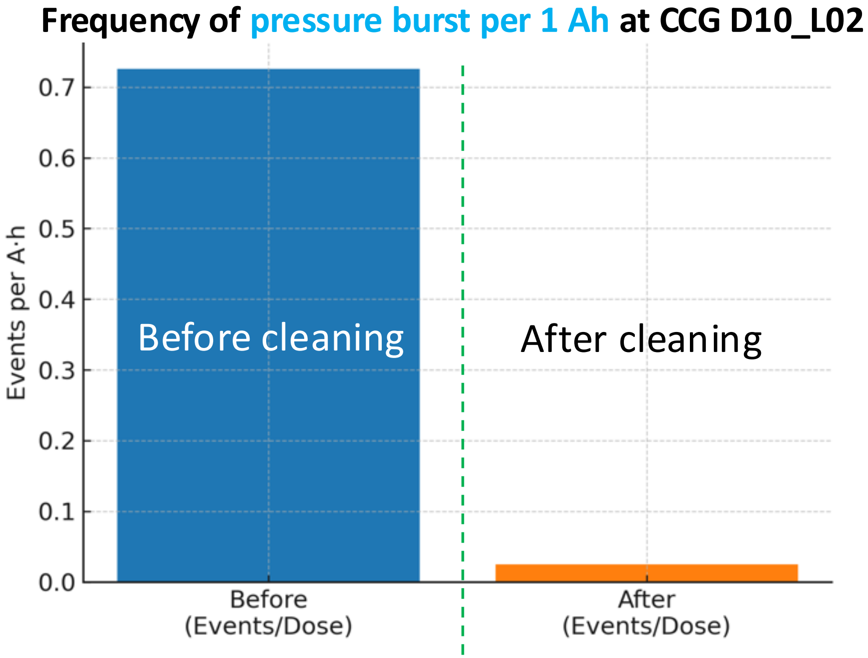
Number of **beam abort accompanied by pressure burst** at D10_L02

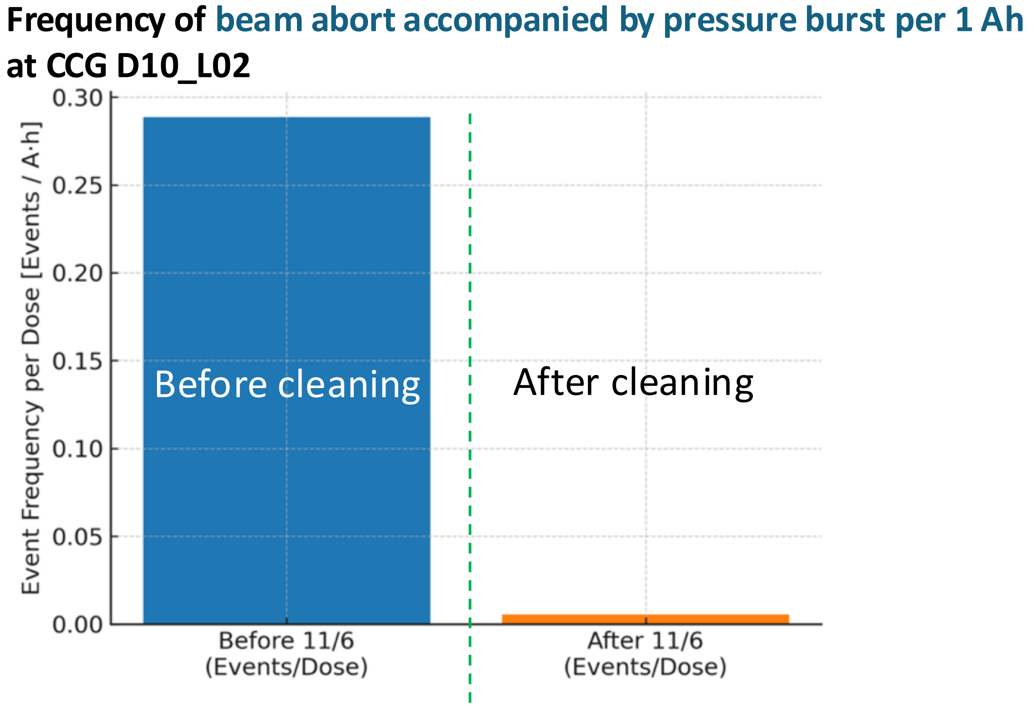


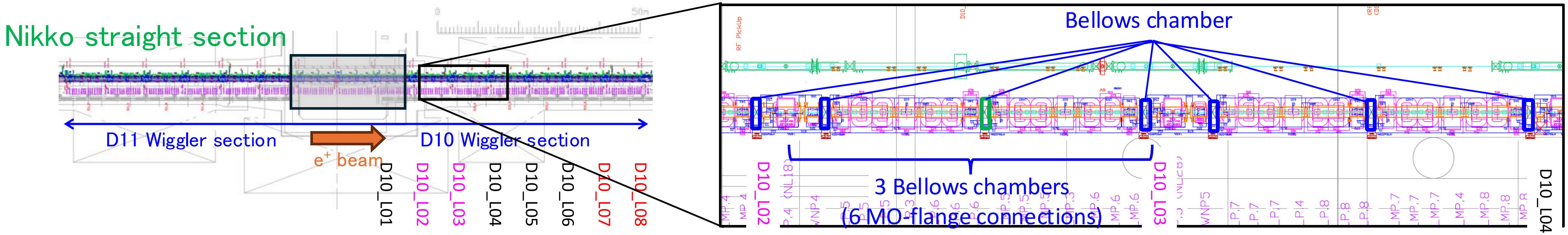


Vacuum Tasks – Cleaning effect

- A bellows chamber near CCG D10_L02 was replaced, and VACSEAL was removed from the adjacent beam pipes on Nov. 6 during the 2024c run, using the same cleaning method.
- After this work, the number of pressure bursts in the area has been significantly reduced.







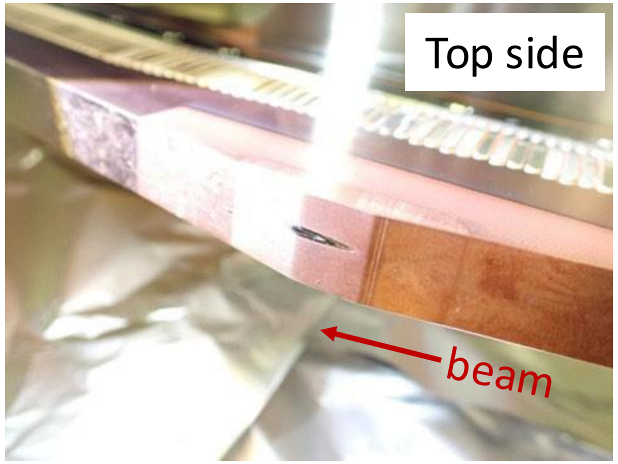
Vacuum Tasks – LER Collimators (Jaw Replacement)

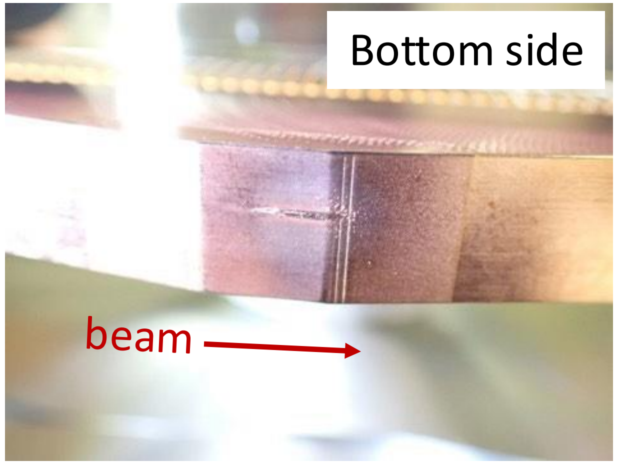
- Damaged jaws in D02V1 and D05V1 were replaced with new ones.
- The top jaw removed from D05V1 was replaced, although its flat area at the tip appeared undamaged and still usable.
- We installed a Ti jaw on the top side of D05V1 to test its durability and evaluate its background reduction performance.

Installed jaws

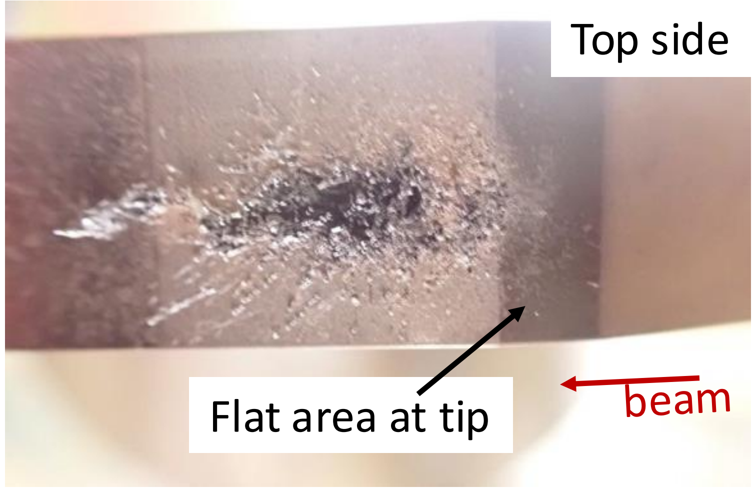
- D02V1: Ta, 10 mm (both side)
- D05V1: Ti, 10 mm (top side)
  Ta, 10 mm (bottom side)

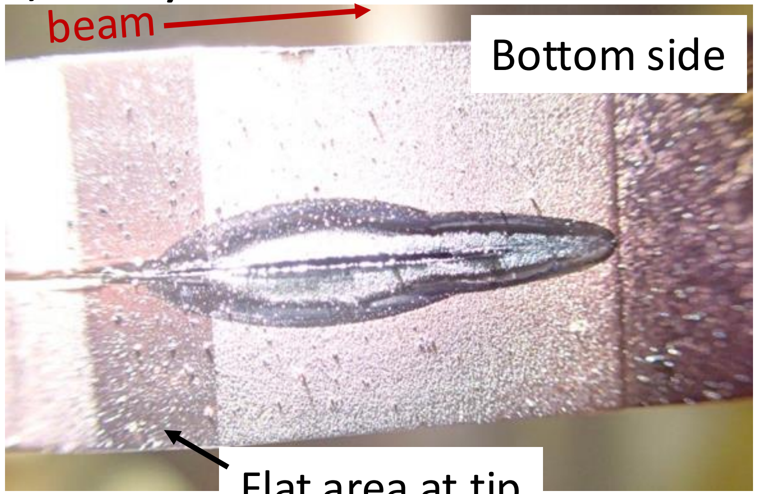
Damaged jaws removed from D02V1 (Ta, 10 mm)





Damaged jaws removed from D05V1 (Ta, 4 mm)

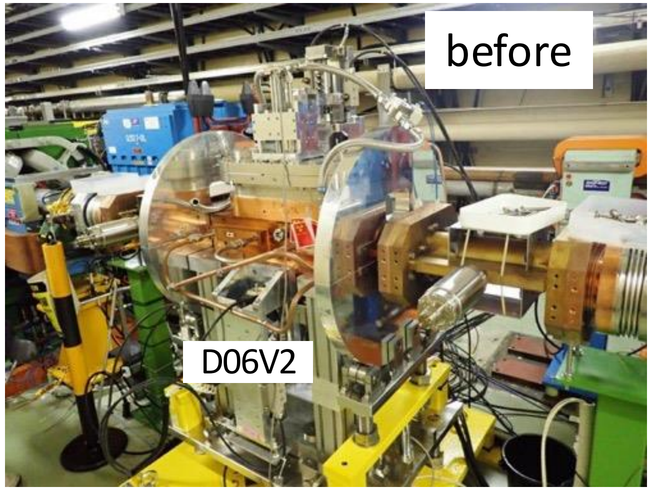


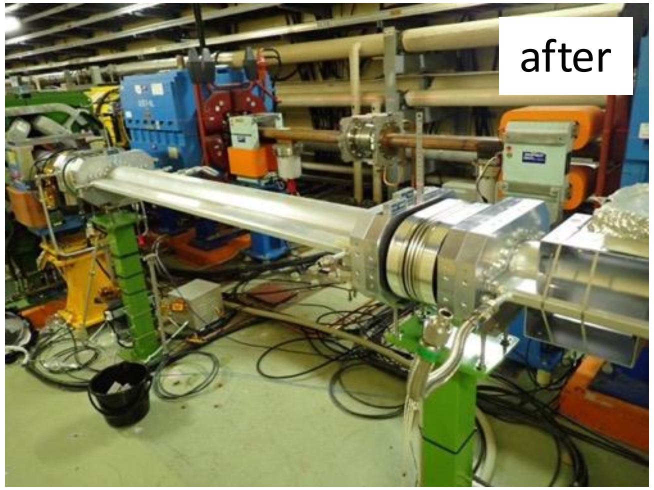


Vacuum Tasks – LER Collimators (D03V4 Relocation)

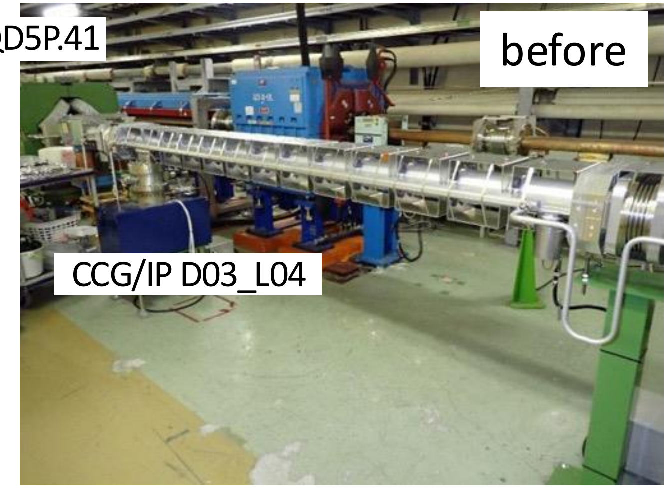
- The D06V2 collimator was relocated to D03V4 as a countermeasure against SBLs to reduce losses at the IR and D02V1 regions.

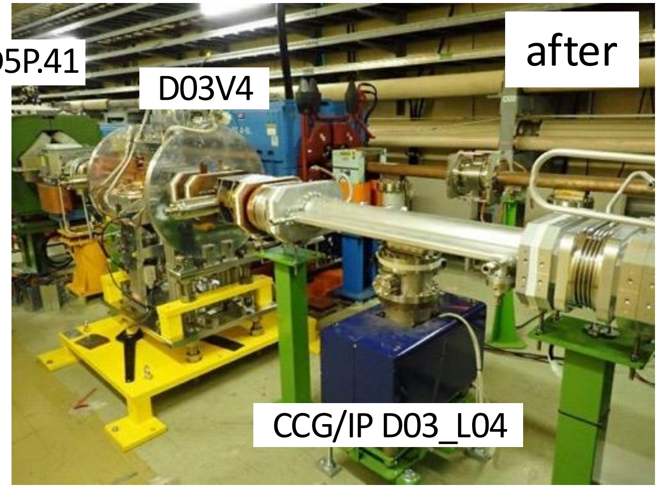
Location of D06V2



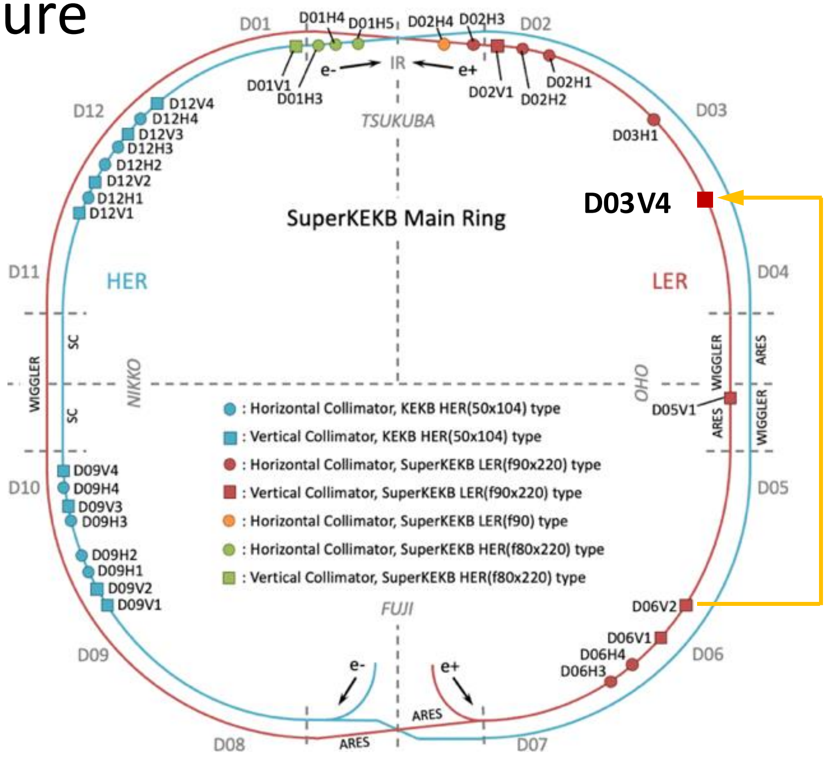


Location of D03V4





Location of collimators

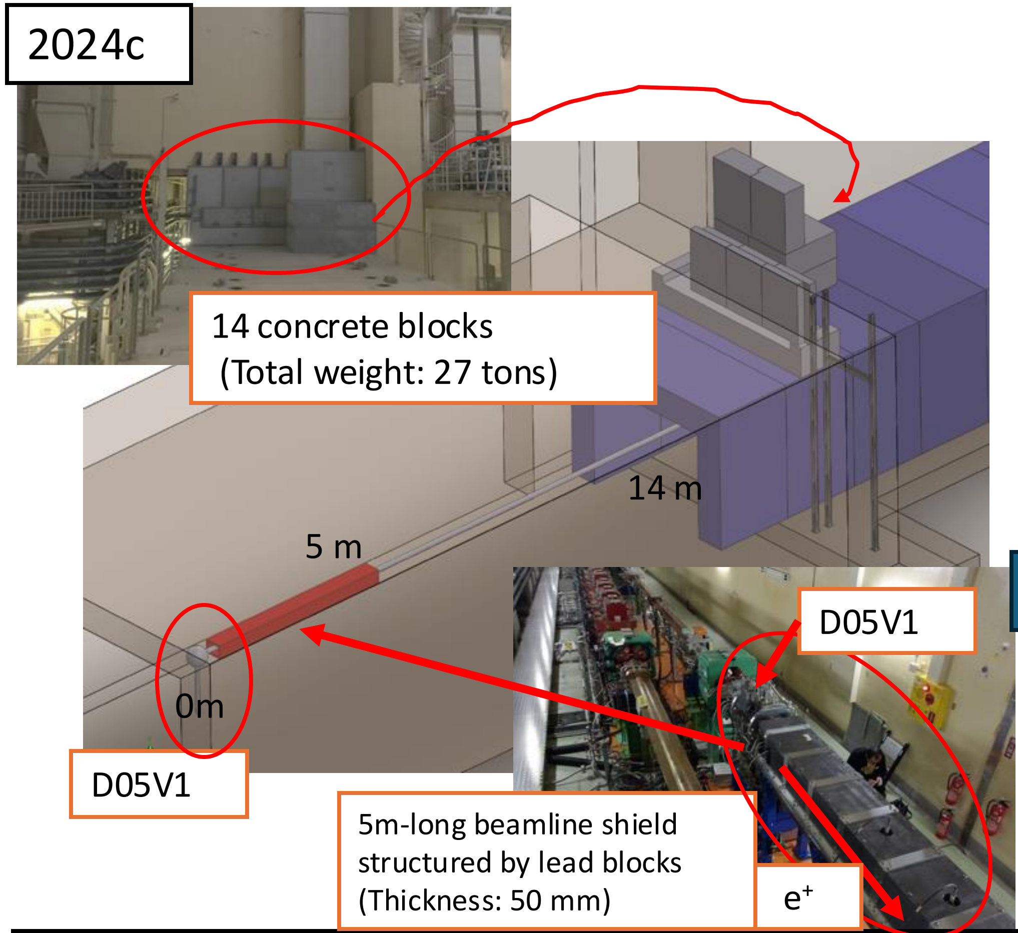


LER vertical collimators and jaws

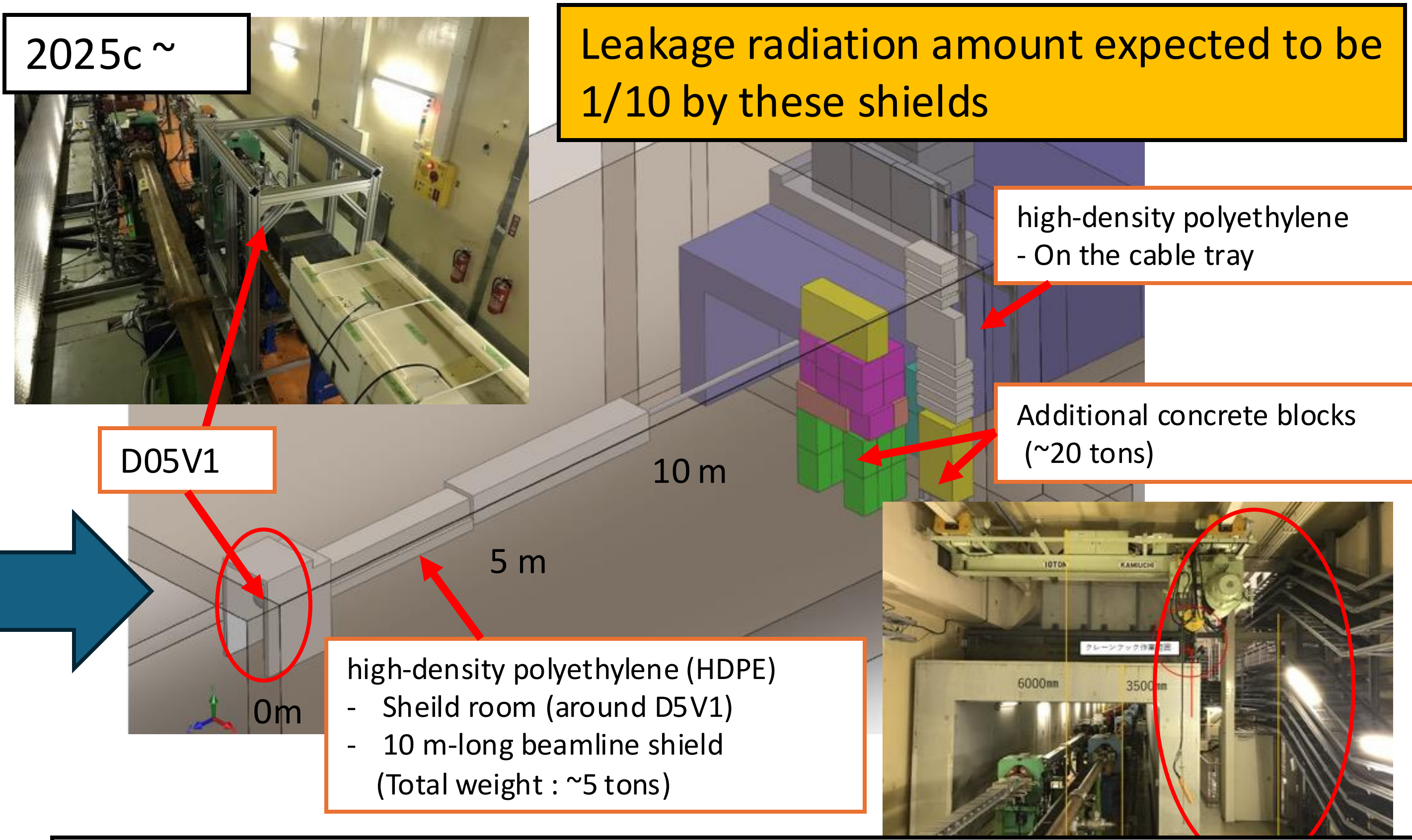
Name	Tip Material (): longitudinal length in mm	Tip Condition
D06V1	Ti (10)	Healthy
D05V1	Top: Ti (10) Bottom: Ta (10)	Healthy
D03V4	Hybrid: Ta (3) + C (7)	Healthy
D02V1	Ta (10)	Healthy

Radiation Shielding around D05V1

[K. Watanabe]



Leakage radiation amount expected to be 1/10 by these shields



* Radiation shields were installed at two locations.

- A beamline shield covering ~5 m from D05V1
- A concrete shield added onto the existing shield for the straight section

-> The dose limit within the radiation control area was reached, making additional shielding necessary.

* Plan for installation of additional shields before the start of 2025c

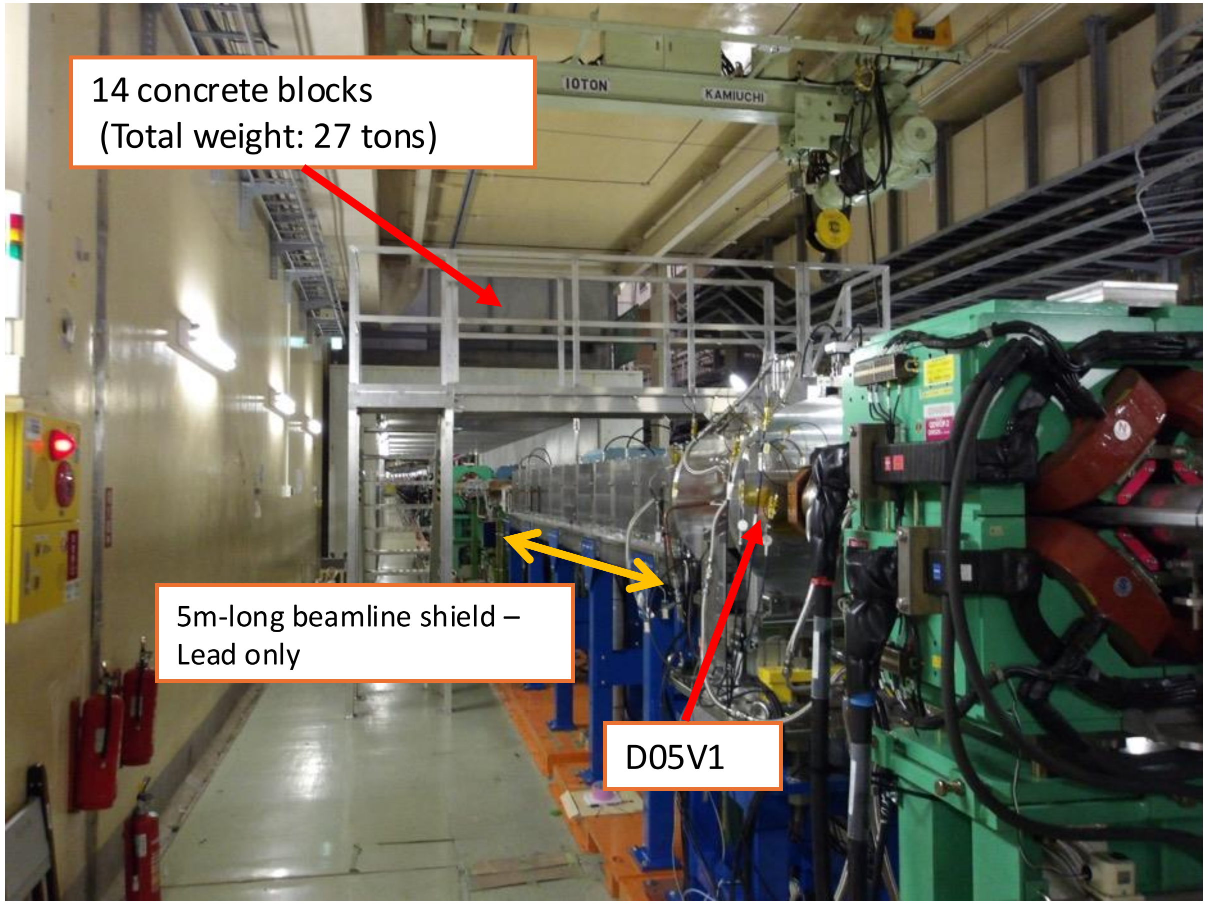
- For the beam line,
  - Sheild room around D5V1 (HDPE, thickness: 100-200mm)
  - 10 m-long beamline shield (HDPE, thickness: 150-200mm)
  - Additional lead beamline shield (5-10m section, thickness: 50 mm)
- For the inside of the accelerator tunnel,
  - Additional concrete shield (max. 4.5 m height, thickness: 0.6-1.2m)
  - Additional shield on the cable tray (HDPE)

Shield Installation Progress

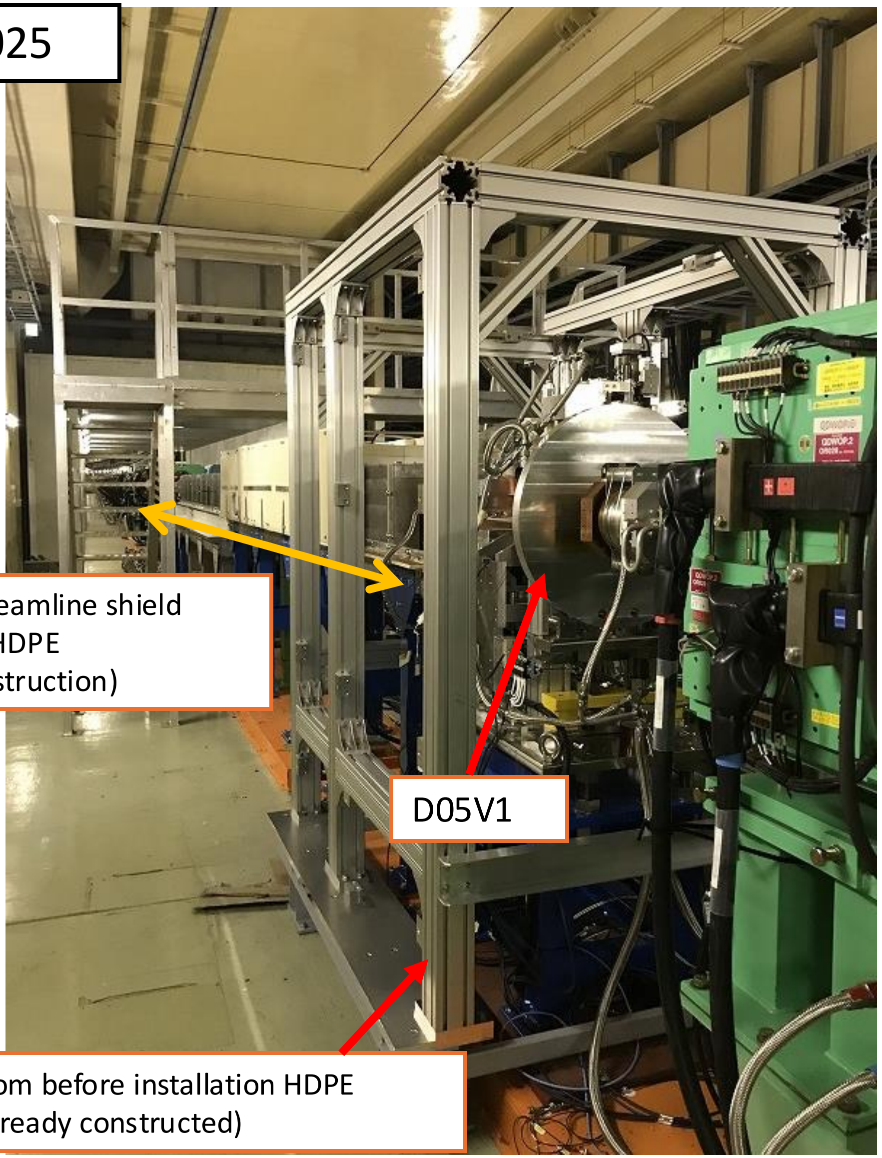
[K. Watanabe]

Photos show the installation status of:
- ① Concrete shields
- ② HDPE (High-Density Polyethylene) shields
- ③ Lead shields

Oct 2024



June 2025

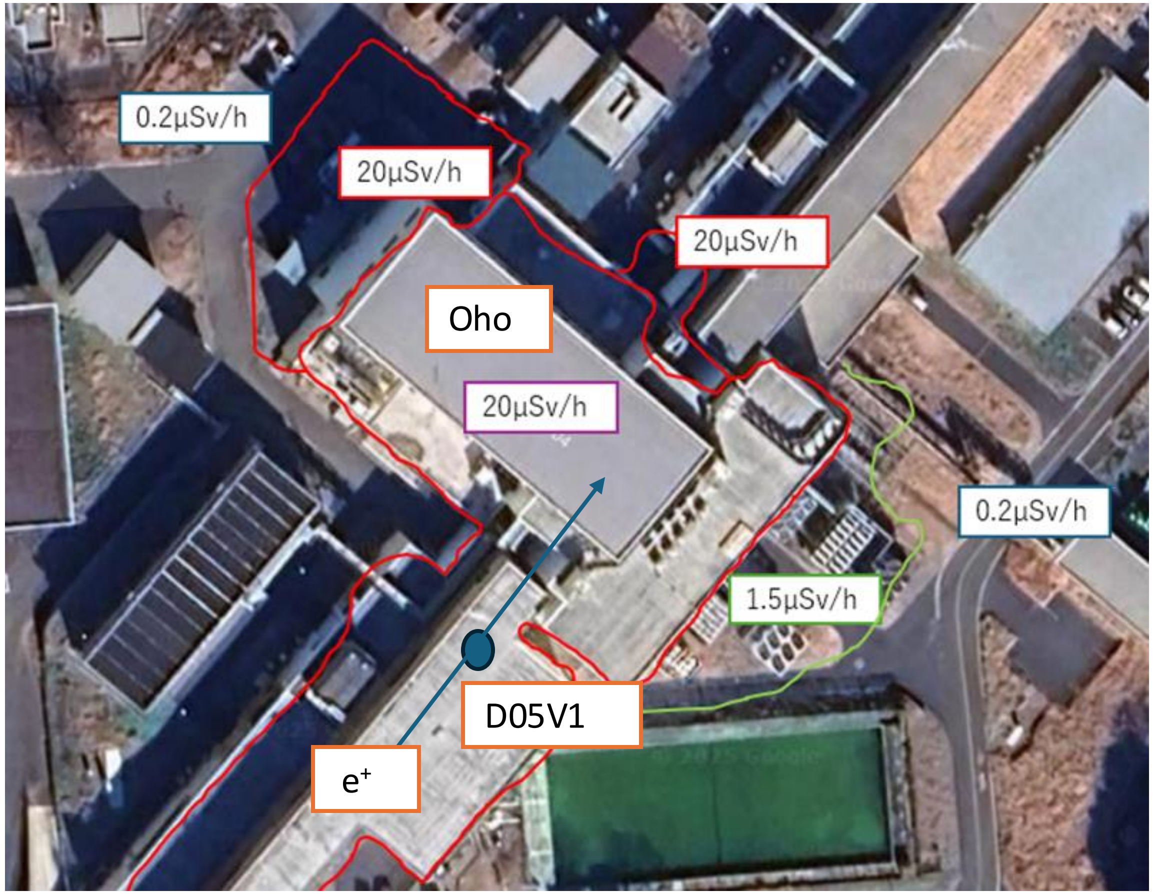


Expansion of Radiation Control Area around Oho

[K. Watanabe]

Oct 2024

June 2025



Radiation control area (< 20μSv/h)

A fence is being constructed to establish the boundary of the radiation control area until Sep 2025.

Other Upgrade Tasks

- Energy Compression System (ECS) installation at BTe [M. Yoshida *et al.*]
  → Suppress the energy spread of high-charge bunches.
  - This system will be available for the 2025c run.

- Reinforcement of a Q-magnet mount in SLY [R. Ueki *et al.*]
  → Suppress Q-magnet displacement at high beam current to stabilize the orbit.
  - The specific Q-magnet to be worked on is still under consideration.

- Installation of gap sensors for vertical collimators [T. Ishibashi]
  → Measure jaw displacement with higher precision and cross-check with the existing displacement sensors.

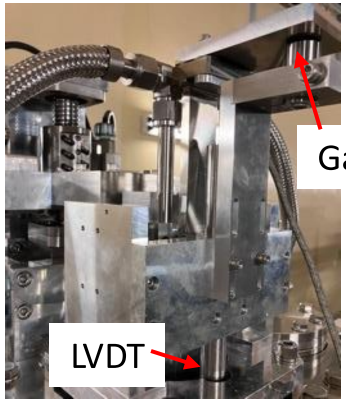
- Replacement of bending magnet poles (BH3P) at BTp [M. Tawada *et al.*]
  → Mitigate emittance growth in BTp.
  - To improve magnetic field quality, poles for 11 bending magnets will be replaced by Oct.

- Investigation and realignment of the LER injection point beam pipes [VA, BT Gr. *et al.*]
  → Ensure that the injection point configuration is consistent with the model.
  - Correcting this misalignment may improve the injection efficiency.

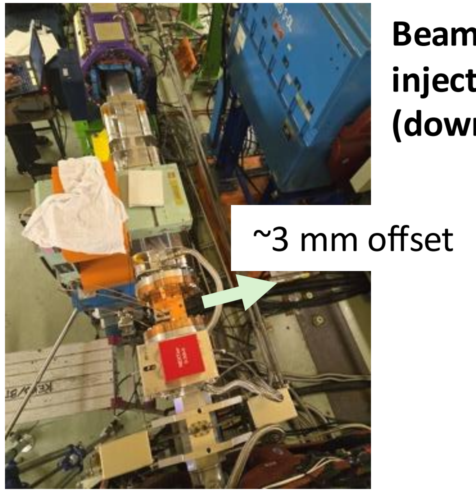
etc.

ECS at BT1

Q-magnet in HER SLY



Drive mechanism of D02V1



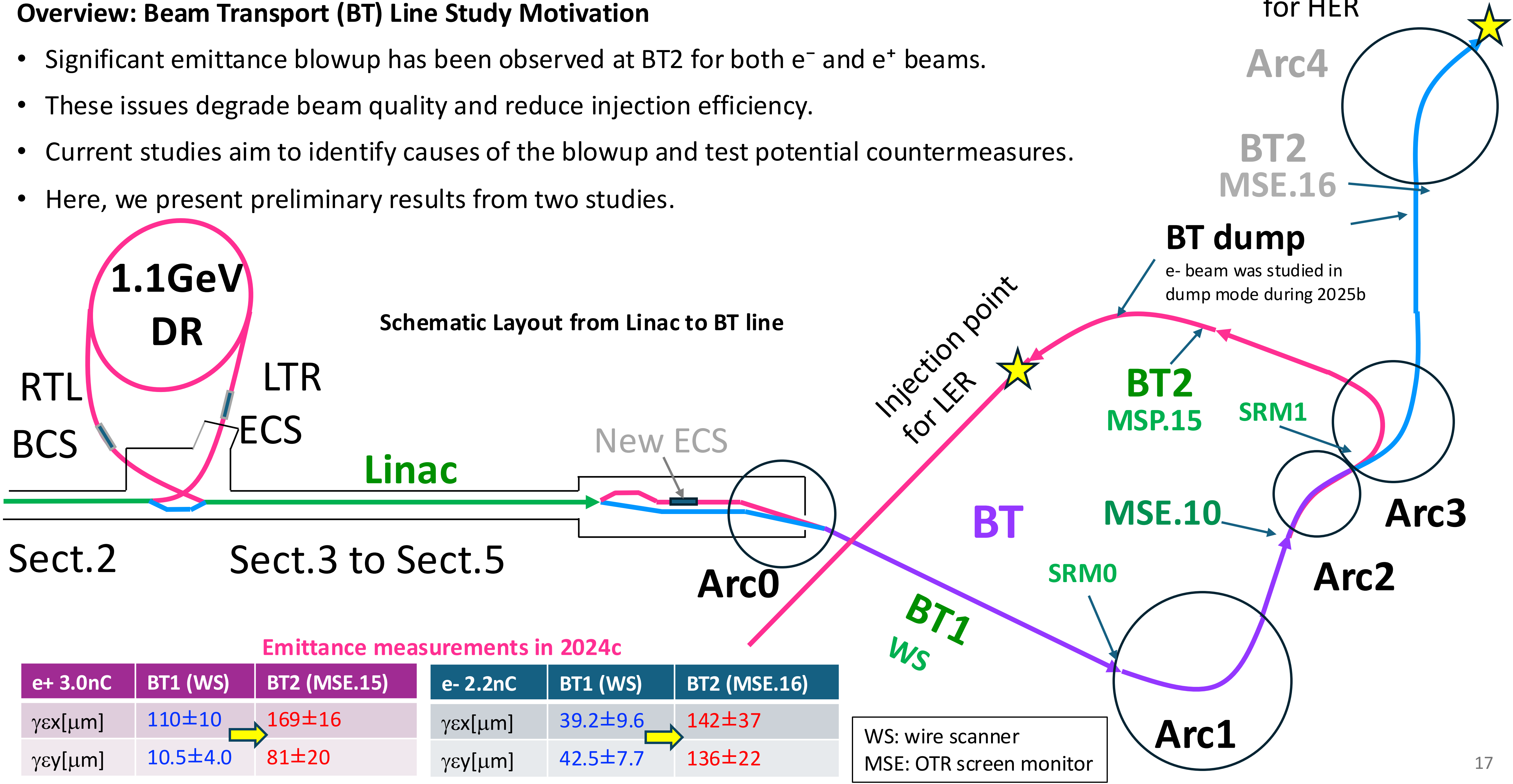
Beam pipes around the injection point (downstream of QI6P).

Preliminary Report of BT Study

[N. Iida]

Overview: Beam Transport (BT) Line Study Motivation

- Significant emittance blowup has been observed at BT2 for both e^- and e^+ beams.
- These issues degrade beam quality and reduce injection efficiency.
- Current studies aim to identify causes of the blowup and test potential countermeasures.
- Here, we present preliminary results from two studies.



Emittance measurements in 2024c

e+ 3.0nC	BT1 (WS)	BT2 (MSE.15)
γεx[μm]	110±10	169±16
γεy[μm]	10.5±4.0	81±20

e- 2.2nC	BT1 (WS)	BT2 (MSE.16)
γεx[μm]	39.2±9.6	142±37
γεy[μm]	42.5±7.7	136±22

WS: wire scanner
MSE: OTR screen monitor

Preliminary Report of BT Study – e^- Beam

[N. Iida]

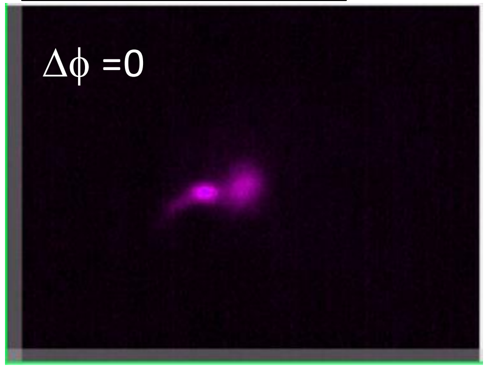
Emittance Blowup Due to Large R56 Optics for ECS and 3 nC Beams

- 3 nC electron beams were successfully transported through the BT line using the Quasi Traveling Wave Side Coupled (QTWSC) RF gun (same RF gun as 2024c), with small emittance up to BT1. However, the emittance increased significantly at BT-Arc1 (MSE.10).
  - No data was obtained at BT2 since the beam was studied in dump mode.
- A double-peak structure was observed at the OTR screen in the large R56 optics or 3 nC; attributed to wakefields and energy spread tuning.
  - R56 changed from -0.11 m to -0.7 m for ECS, which was not powered during this study.
  - This is a newly observed phenomenon discovered during this study.
  - The presence of a double peak effectively results in emittance blowup.
- Linac-mode studies are ongoing to find orbit settings that suppress this blowup.

[T. Kamitani, F. Miyahara, Y. Seimiya, M. Yoshida *et al.*]

Results	BT1 (2025b)	BT2 (2024c, Ref)	MSE.10 (2025b)	MSE.10 (2025b)	MSE.10 (2025b)	MSE.10 (2025b)
	2-3 nC	2 nC	2nC	3nC	3nC	
R56 [m]	-0.11, -0.7	-0.11	-0.7	-0.11	-0.7 w bump	-0.7 w/o bump
$\gamma\varepsilon x$ [μm]	30-40	140	**300**	**337**	**342**	**333**
$\gamma\varepsilon y$ [μm]	30-40	140	107	106	**158**	**170**

MSE.10(η_x~0 m)



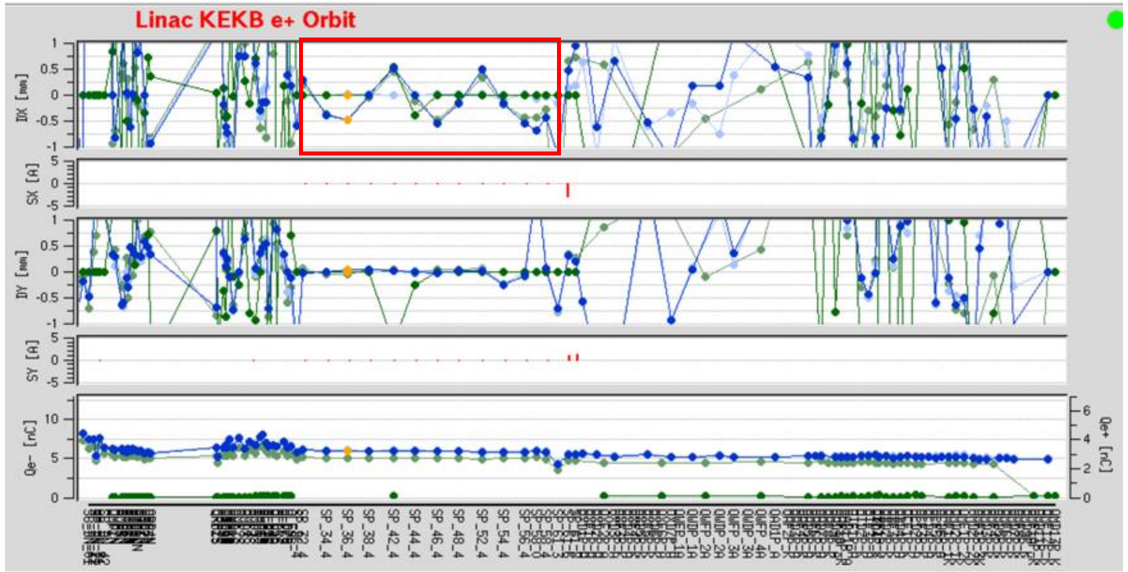
Preliminary Report of BT Study – e^+ Beam

[N. Iida]

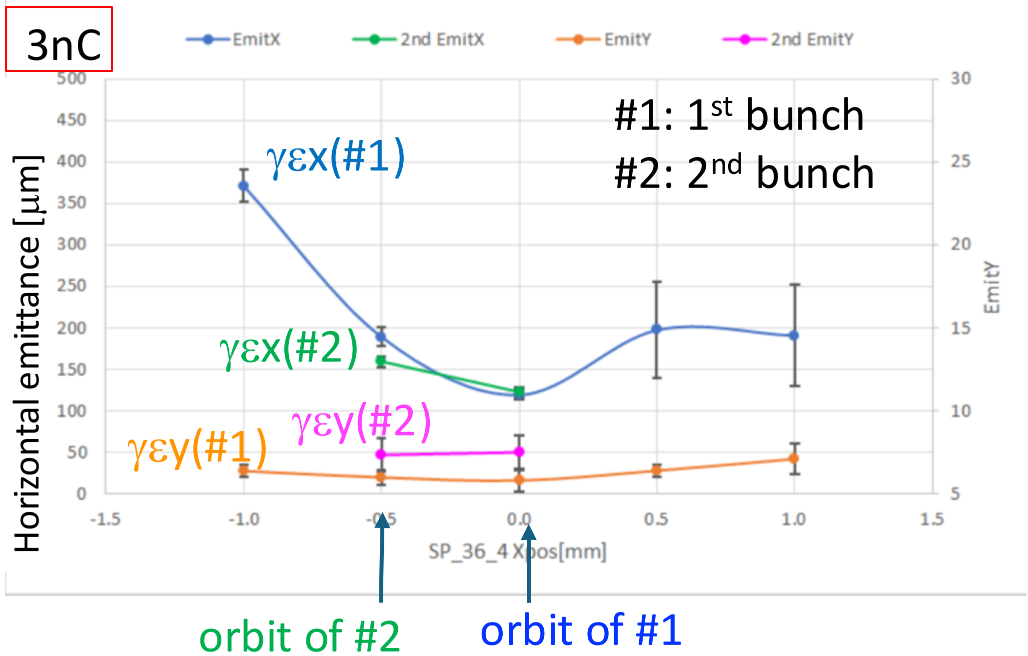
Horizontal orbit of the 2nd bunch

- A consistent horizontal orbit offset (~0.5 mm) is observed in the 2nd bunch only.
- This is considered to be caused by a pre-pulse from the DR extraction kicker acting one turn early.
  - In the model, the resulting kick angle can explain the orbit shift in the Linac.
- This orbit deviation increases the bunch's horizontal emittance.
- It may be responsible for the reduced injection efficiency of the 2nd bunch compared to the 1st .
- A countermeasure for the 2nd bunch is being considered.

e^+ orbit



Horizontal orbit and emittance for each bunch (meas.)



Preliminary Report of BT Study – Items

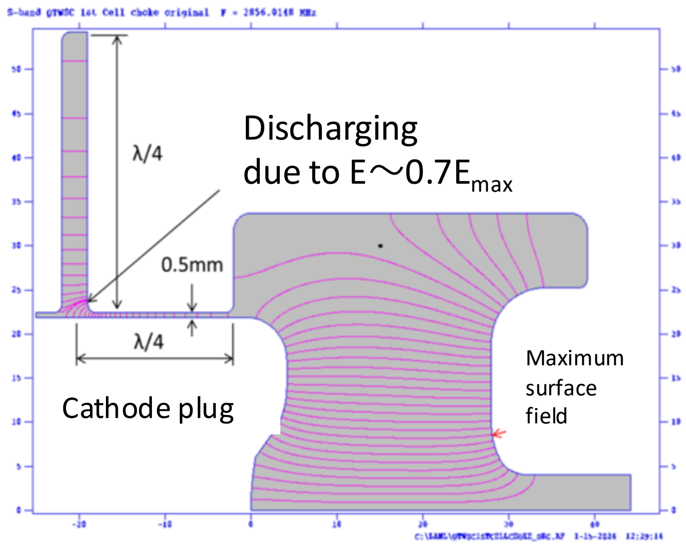
- Summary meeting https://kds.kek.jp/event/55934/
- e- beam(KBE)
  - Response measurement, Linear optics of BTe(Y. Shimosaki, Y. Shoji)
  - Emittance measurement and its charge dependence(T. Yoshimoto)
  - Emittance measurement by q-scan(D. Oumbarek)
  - Q-scan program check(K. Oide)
  - Linac new diagnosis system to the east-dump(T. Kamitani)
  - **Emittance blowup of the large R56 in BT-Arc0 optics for ECS, and 3nC (N. Iida)**
  - Dispersion measurement(Y. Seimiya)
  - Two-pieces observation and investigation(F. Miyahara, M. Yoshida, ...)
- e+ beam(KBP)
  - Emittance tuning at RTL(T. Yoshimoto)
  - **Horizontal orbit of the 2nd bunch (N. Iida)**
  - Energy tuning of the 1st and 2nd bunches(T. Miura)
- Both beams
  - Radiation measurements(T. Mimashi, Y. Okayasu, H. Iwase)
  - Pulse-to-pulse data taking and orbit analysis(K. Oide, H. Kaji)

Status of RF Gun (Linac) – Updated QTWSC RF Gun

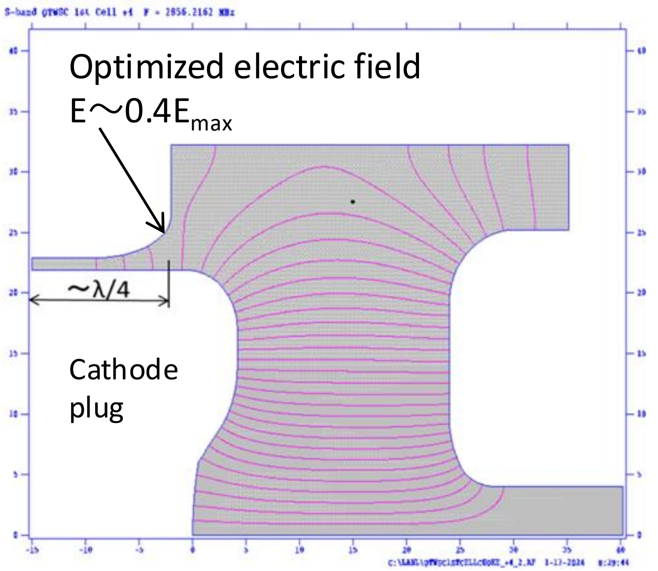
[M. Yoshida *et al.*]

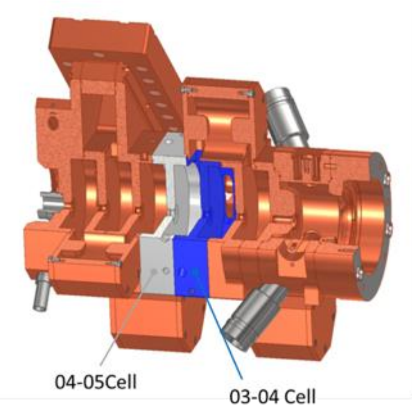
- The current RF gun cathode cell includes a choke structure for thermal cleaning of the cathode.
- The updated cathode cell is designed with:
  - Optimized surface field
  - Additional vacuum pumping
  - A new triplet downstream of the gun
- During brazing, the wrong cavity cell was assembled, resulting in a 10 MHz frequency offset (No tuning required for cathode side cavity chain).
- Tuning of the RF cavity is scheduled this week. RF conditioning will be performed until July.

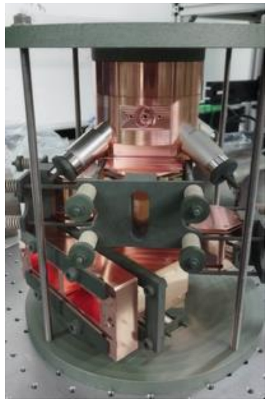
Current



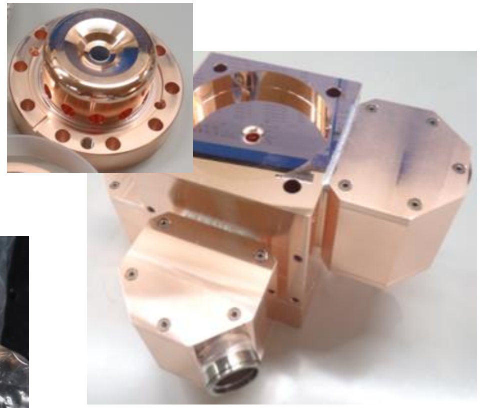
Updated

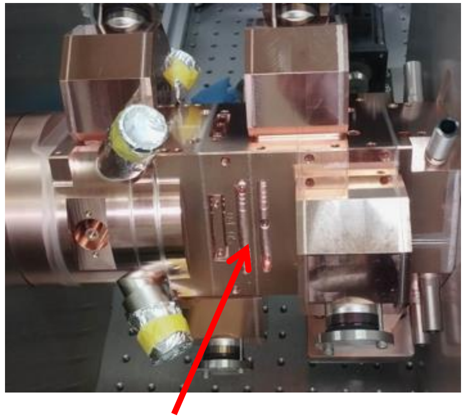






Brazing assembly



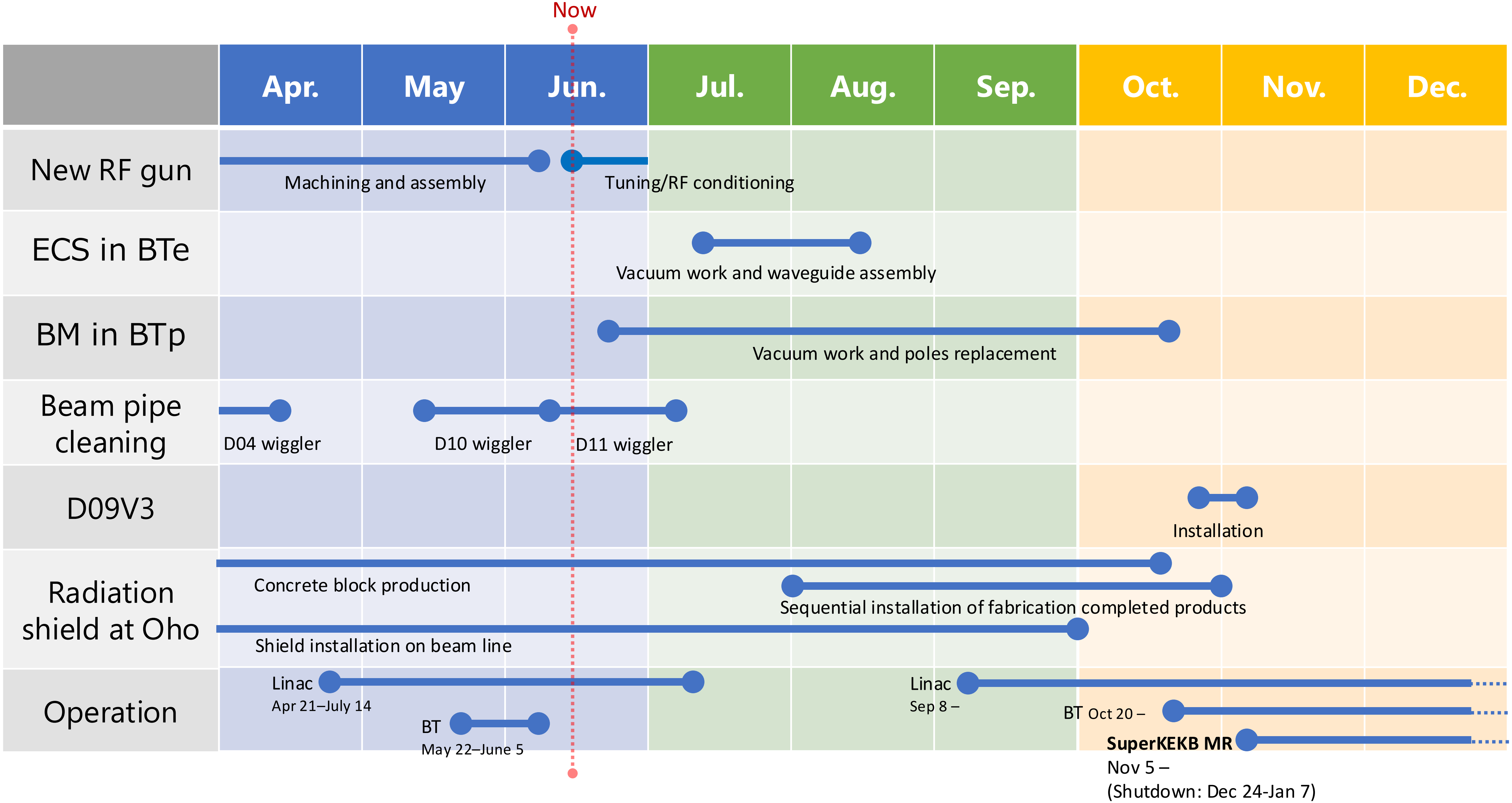


Additional machining for tuning

- If tuning cannot sufficiently correct the frequency offset and the schedule is delayed, a new IrCe cathode plug will be installed in the current RF gun.

New IrCe Cathode Plug

Main tasks schedule leading up to 2025c



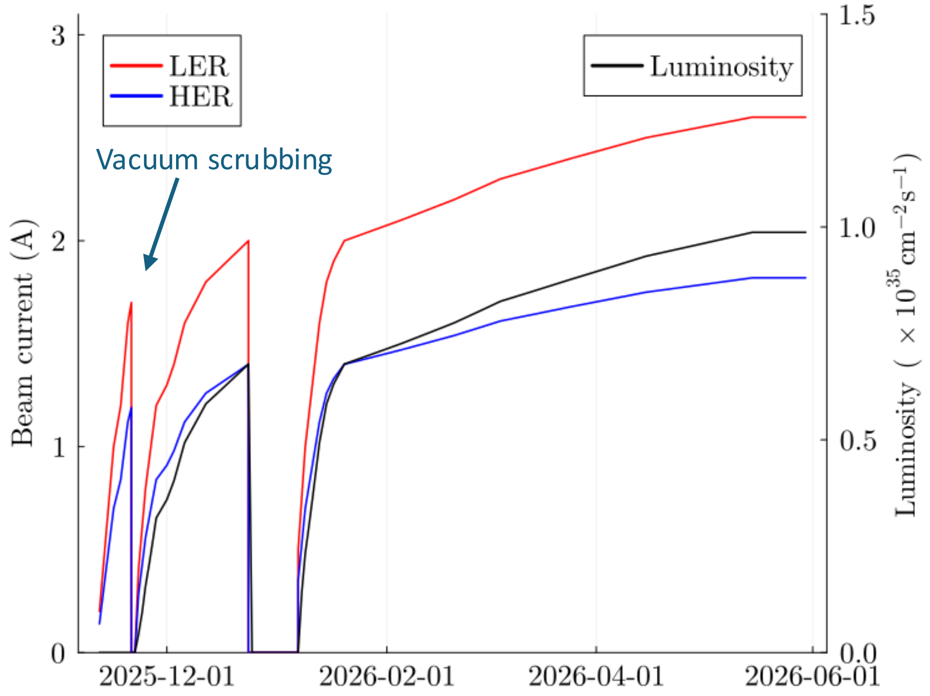
Operational Plan for 2025c-2026b

Accelerator efficiency
= (Actual daily ∫Ldt) / (Ideal ∫Ldt at peak L for 24 hours)

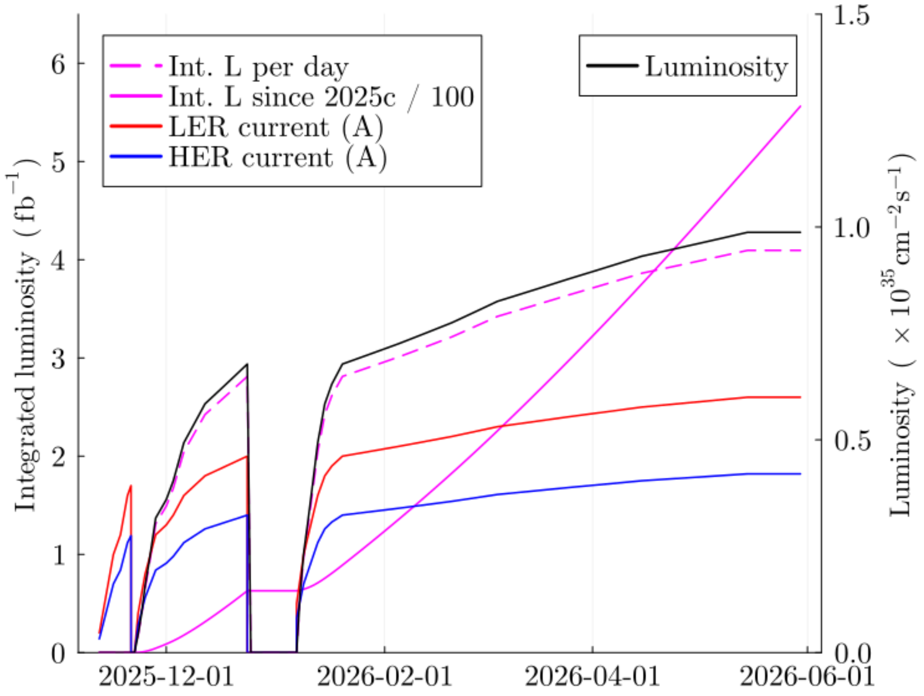
- 180 days of collision operation during the 2025c–2026b run
- Plan A (Base Plan): Target peak luminosity: 1×10^{35} cm^{-2}s^{-1}, Target integrated luminosity: ≥ 425 fb^{-1}
  - 1×10^{35} cm^{-2}s^{-1} can be achieved with β_y^*=1 mm if we can increase the beam current as shown in this plot.
  - 556 fb^{-1} (delivered) is estimated with 0.60 efficiency.
- For the integrated luminosity estimation:
  - Physics runs account for 80% of the full collision operation period (with 4 days per 3-week cycle allocated to studies).
  - The accelerator efficiency is assumed to be 0.60, lower than the ~67% achieved during the 2024c run due to high current conditions.
  - The estimated integrated luminosity (delivered) is 556 fb^{-1}.

[G. Mitsuka *et al.*]

Beam current and peak luminosity



Luminosity and integrated luminosity



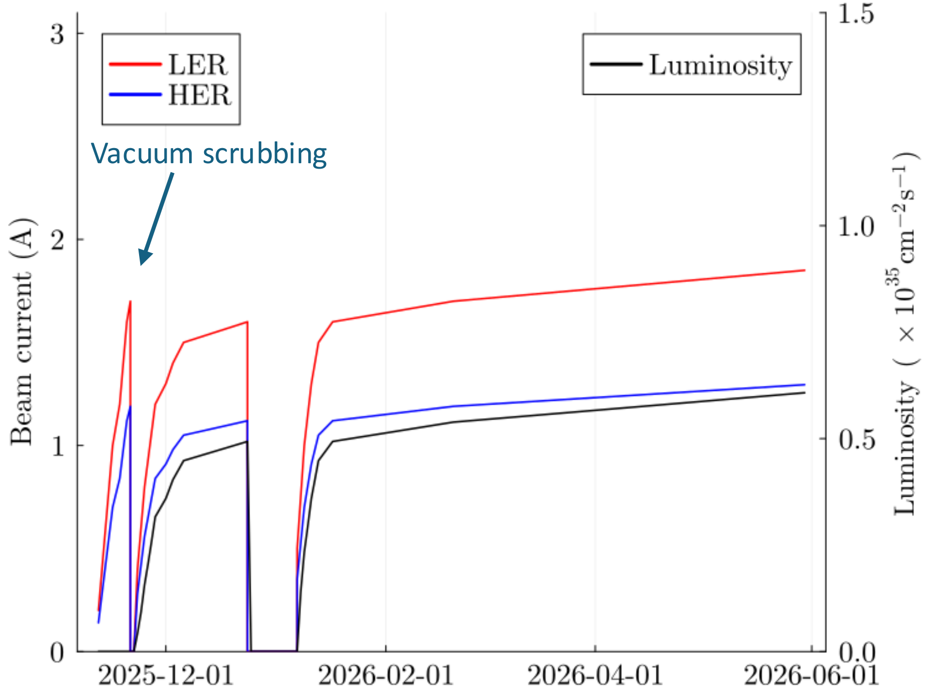
Operational Plan for 2025c-2026b

Accelerator efficiency
= (Actual daily ∫Ldt) / (Ideal ∫Ldt at peak L for 24 hours)

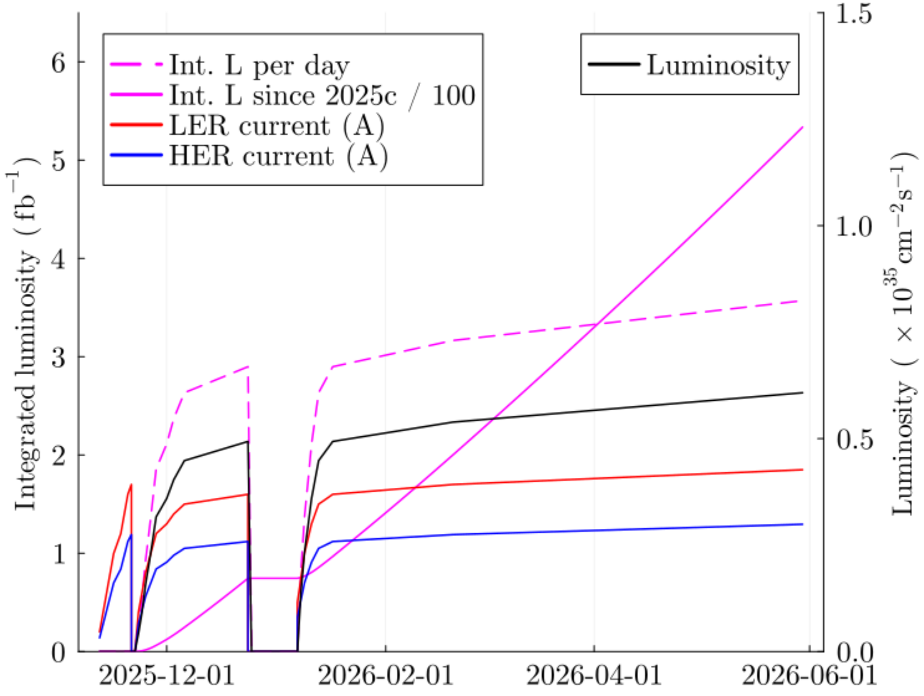
- Plan B (Optional Plan): Target peak luminosity: 6×10^{34} cm^{-2}s^{-1}, Target integrated luminosity: ≥ 425 fb^{-1}
  - If we cannot increase the beam current much, 6×10^{34} cm^{-2}s^{-1} and 0.85 efficiency are required to achieve 534 fb^{-1}
- For the integrated luminosity estimation:
  - Physics runs account for 80% of the full collision operation period (with 4 days per 3-week cycle allocated to studies).
  - The accelerator efficiency is assumed to be 0.85 (highest efficiency level achieved during 2022b)
  - The estimated integrated luminosity (delivered) is 534 fb^{-1}.

[G. Mitsuka *et al.*]

Beam current and peak luminosity



Luminosity and integrated luminosity



Operational Plan for 2025c-2026b – Challenges and Countermeasures

Black: both
Blue: HER
Red: LER

- Increasing Beam Current
  - Installation of the updated RF gun
    - Enables stable two-bunch injection
    (HER two-bunch injection had not been possible since a discharge in late Nov. 2024)
  - Installation of BT e^- ECS
    - Reduces energy spread → improves injection efficiency
  - Radiation shielding at Oho
    - Open the D06V1 aperture and make more effective use of D05V1 → reduce the detector background and vertical impedance
  - Replacement of BT e^+ bending magnet poles
    - Suppress vertical emittance growth → improves injection efficiency
  - Investigation and realignment of the LER injection point beam pipes
    - Better alignment near the injection point may improve injection efficiency by reducing model mismatch
- Improving Accelerator Efficiency
  - Cleaning of beam pipes (VACSEAL removal)
  - Installation of the updated RF gun
    - Discharges in the cavity intermittently interrupted HER injection.
  - Relocation of the D06V2 to the D03V4 collimator
    - Protect D02V1 and detectors from SBLs.
- Enhancing Specific Luminosity
  - Suppression of horizontal beam size blow-up in LER
    - Lowering β_x^* from 80 mm to 60 mm suppresses beam size growth at high-current
  - Measures against manufacturing error in leak-field cancellation coils (HER QCS)
    - May be degrading luminosity; countermeasures are under consideration
  - Unsolved large emittance in HER (cause under investigation)
  - Upgrading beam-beam simulations

Summary

Shutdown Works

- Beam pipe cleaning (LER, HER, IR, wigglers) → to be complete by July
- Radiation shielding at D05V1 ongoing → expected to reduce leakage by 90%, allowing a wider D06V1 aperture and more effective use of the D05V1.
- Other upgrade tasks: ECS installation, RF-gun replacement, Q-magnet support reinforcement, etc.

Operational Plan (2025c-2026b)

- 180 collision operation days: 146 for physics runs, 34 for tuning/studies
- Target peak luminosity: 1×10^{35} $cm^{-2}s^{-1}$
- Target integrated luminosity: ≥ 425 fb^{-1}

  → estimated delivered (Plan A): ~556 fb^{-1}

Key Challenges and Countermeasures

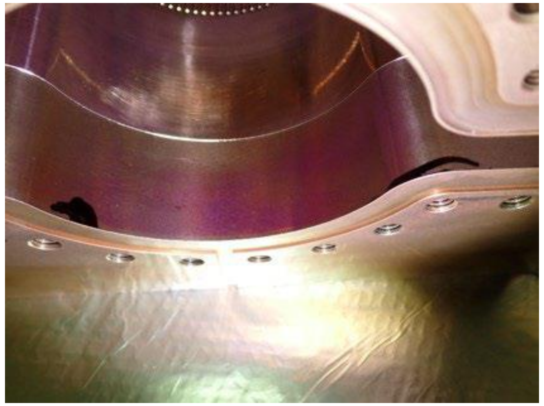
- Beam current: BTe ECS, new RF-gun, BTp magnet pole replacement, radiation shielding at Oho etc.
- Accelerator efficiency: VACSEAL removal, HER injection recovery (RF-gun discharge), D03V4
- Specific luminosity: LER β_x^*↓, HER QCS manufacturing error, HER emittance issue, beam-beam sim

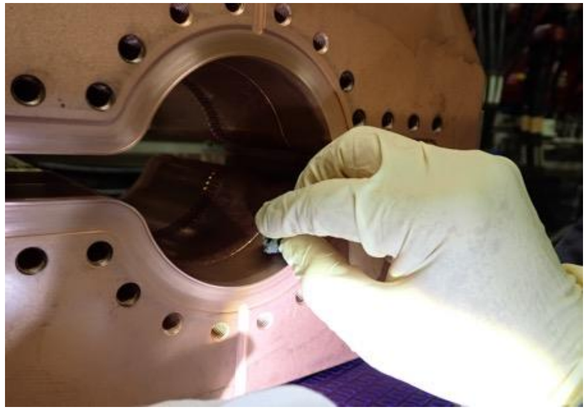
Back-up

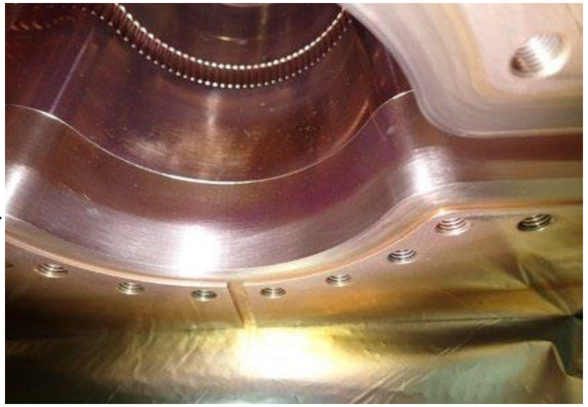
Vacuum Tasks – Cleaning Work

- The black stains caused by VACSEAL cannot be removed ethanol-soaked wipes alone.
  - Some black stains have a flaky structure and tend to detach easily.
- The inside surfaces are polished with Scotch-Brite, then cleaned with ethanol-soaked wipes.
  - Beam pipes in the Q-magnets are coated with TiN, and part of this coating is also removed during polishing.
- This cleaning process is also applied to areas without visible black stains, since VACSEAL residues may be present in less visible forms.
- Powdery dust is found throughout the beam pipes, regardless of the presence of black stains. It is removed from accessible areas via the removed bellows chamber openings.
- All flanges are labeled, and work records including photos are documented.

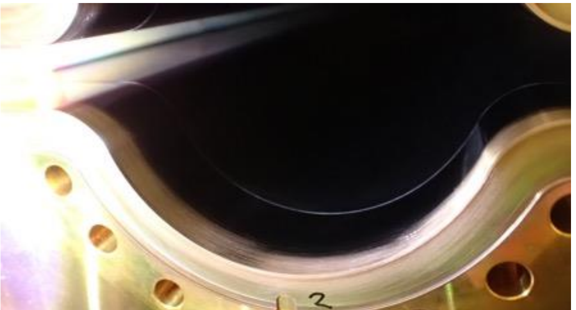
Bellows chamber



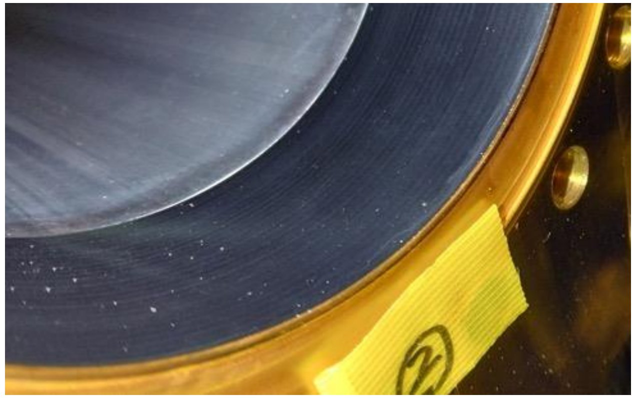


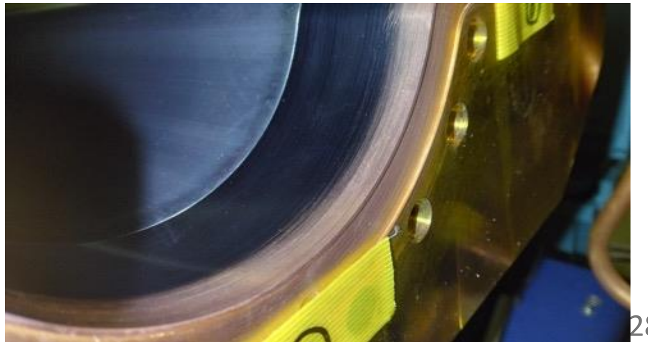


Q chamber (TiN coated)



Powdered dusts

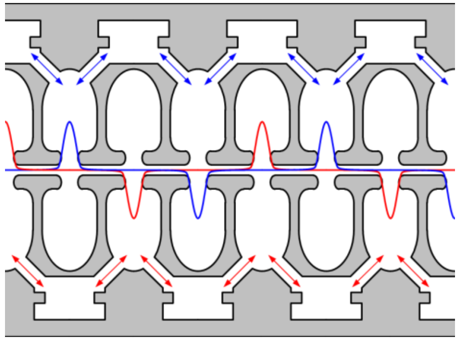


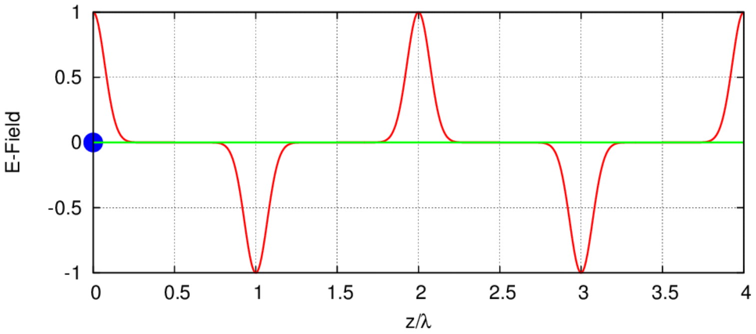


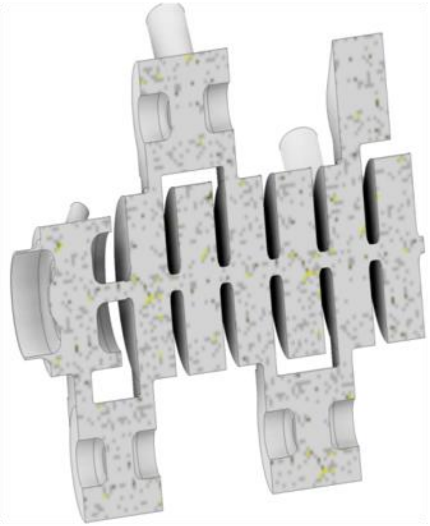
Status of RF Gun (Linac)

[M. Yoshida *et al.*]

- The Quasi Traveling Wave Side Coupled (QTWSC) RF gun can generate high charge, low emittance electron beams

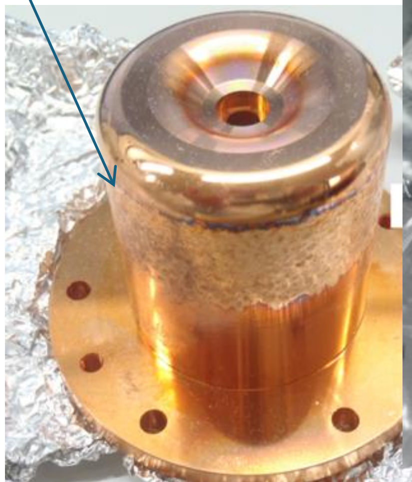






- **New IrCe cathode plugs are ready for use, regardless of the progress on the next RF gun.**

Discharge was observed due to the choke structure



IrCe Cathode Plug

- **A bunch charge 6nC has been demonstrated using the QTWSC gun.**
- **At BT1, a charge of 3nC was achieved with a normalized emittance of 27 x 30 μm at BT1**

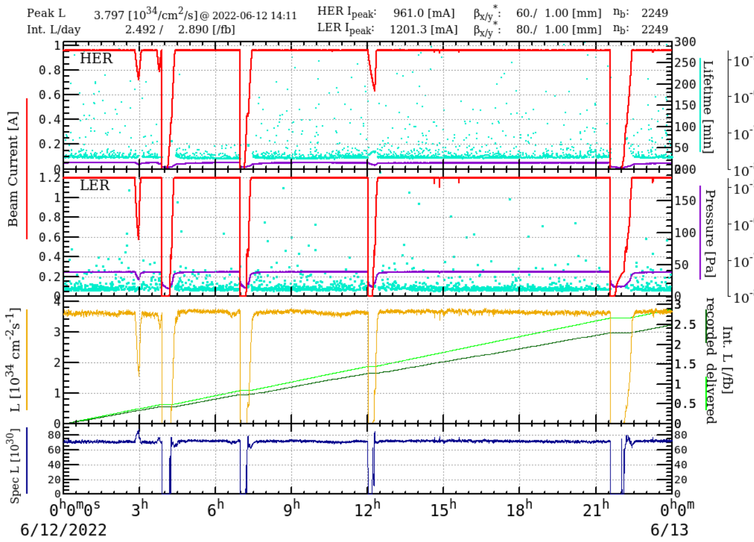
Results of measurement

β_x @MW.1 m :	6.998	β_y @MW.1 m :	39.014
α_x @MW.1 :	.364	α_y @MW.1 :	2.979
ε_x m :	1.9735E-9	ε_y m :	2.1811E-9
$\Delta\varepsilon_x$ m :	4.974E-10	$\Delta\varepsilon_y$ m :	1.0465E-9
$\gamma\varepsilon_x$ μm :	27.034	$\gamma\varepsilon_y$ μm :	29.879
$\Delta\gamma\varepsilon_x$ μm :	6.814	$\Delta\gamma\varepsilon_y$ μm :	14.335
Goodness x :	.109	Goodness y :	.439
Bmag x :	1.464	Bmag y :	1.550
ε Bmag x :	2.8893E-9	ε Bmag y :	3.3803E-9
γ ε Bmag x :	39.580	γ ε Bmag y :	46.305

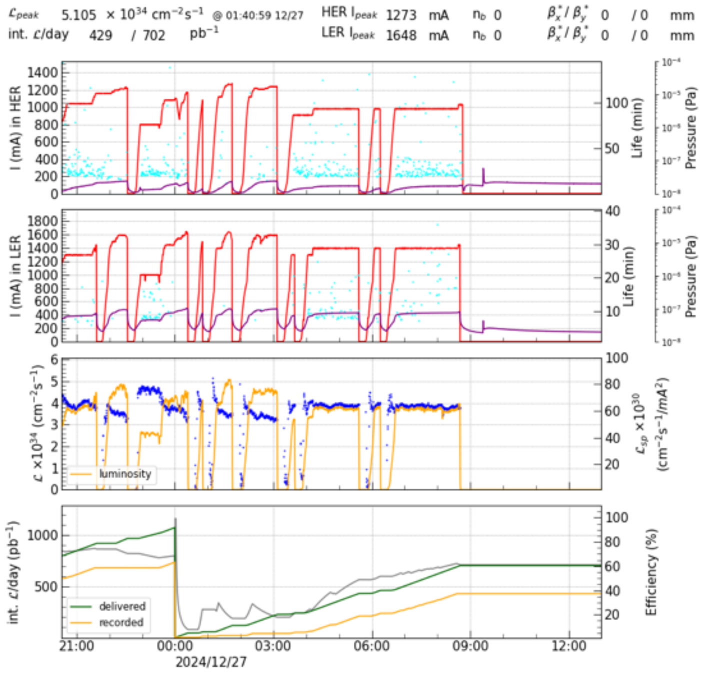
Recent achievement (June 2025)

Operational Plan for 2025c-2026b

- Example of a day with high integrated luminosity
  - Date: 2022-06-12, with β_y^*=1 mm
  - Beam currents: I_{LER}=1200 mA, I_{HER}=960 mA (# of bunches=2249)
  - Peak luminosity: ~ 3.8×10^{34} cm^{-2}s^{-1}
  - Int. luminosity: 2.49 fb^{-1} (recorded)/2.89 fb^{-1} (delivered)
  - DAQ efficiency: ~86%
  - If operated at this luminosity for 24 hours:
    → Delivered integrated luminosity = 3.28 fb^{-1}/day
    → Accelerator efficiency: (2.89/ 3.28) × 100 ≈ 88%



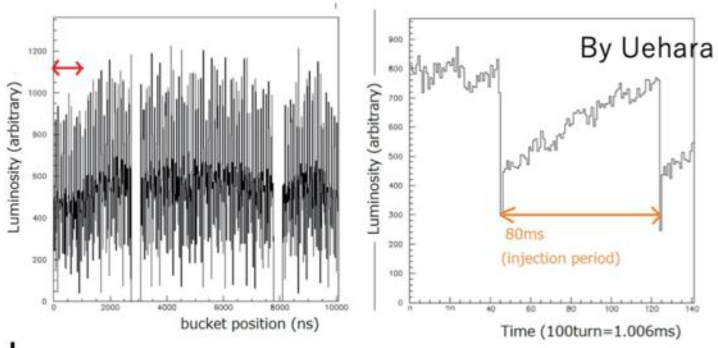
- Luminosity during 2024c with Belle II HV ON
  - Peak luminosity: 4.4×10^{34} cm^{-2}s^{-1}
  - Beam currents: I_{LER}=1600 mA, I_{HER}=1280 mA (# of bunches=2346)



- The highest priority is to establish machine conditions that allow stable operation at high luminosity.

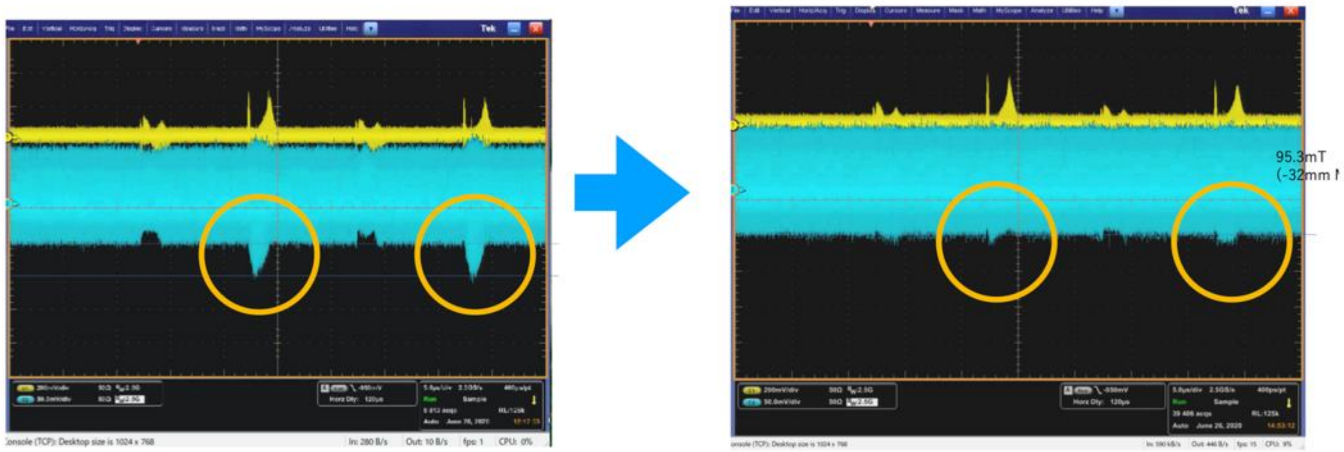
Transverse injection oscillation in the LER

Beams are oscillated due to the horizontal injection error.
If there is X-Y coupling at the injection kicker region, the vertical orbit oscillation can be induced. Then, luminosity degradation occurs for the injection intervals.

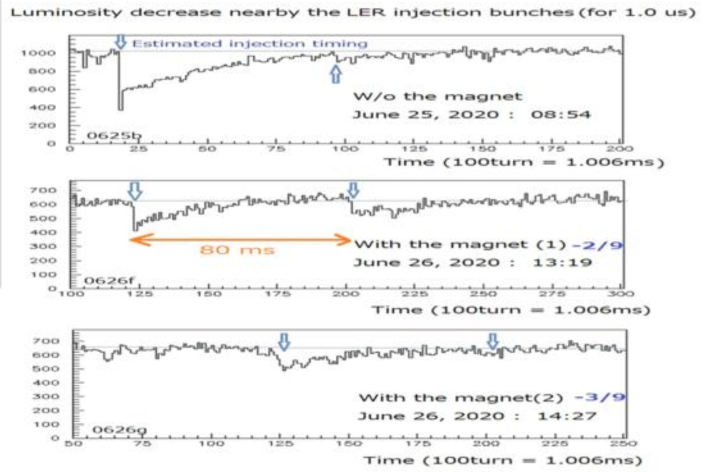


injection repetion rate : 12.5 Hz
80 msec interval

We installed skew quadrupole (permanent magnet) to correct local X-Y coupling in the vicinity of injection kickers.



By Uehara



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