Vacuum

The 28th KEKB Accelerator Review Committee

14th January 2025

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On behalf of KEKB Vacuum Group

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2024b

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Summer Shutdown

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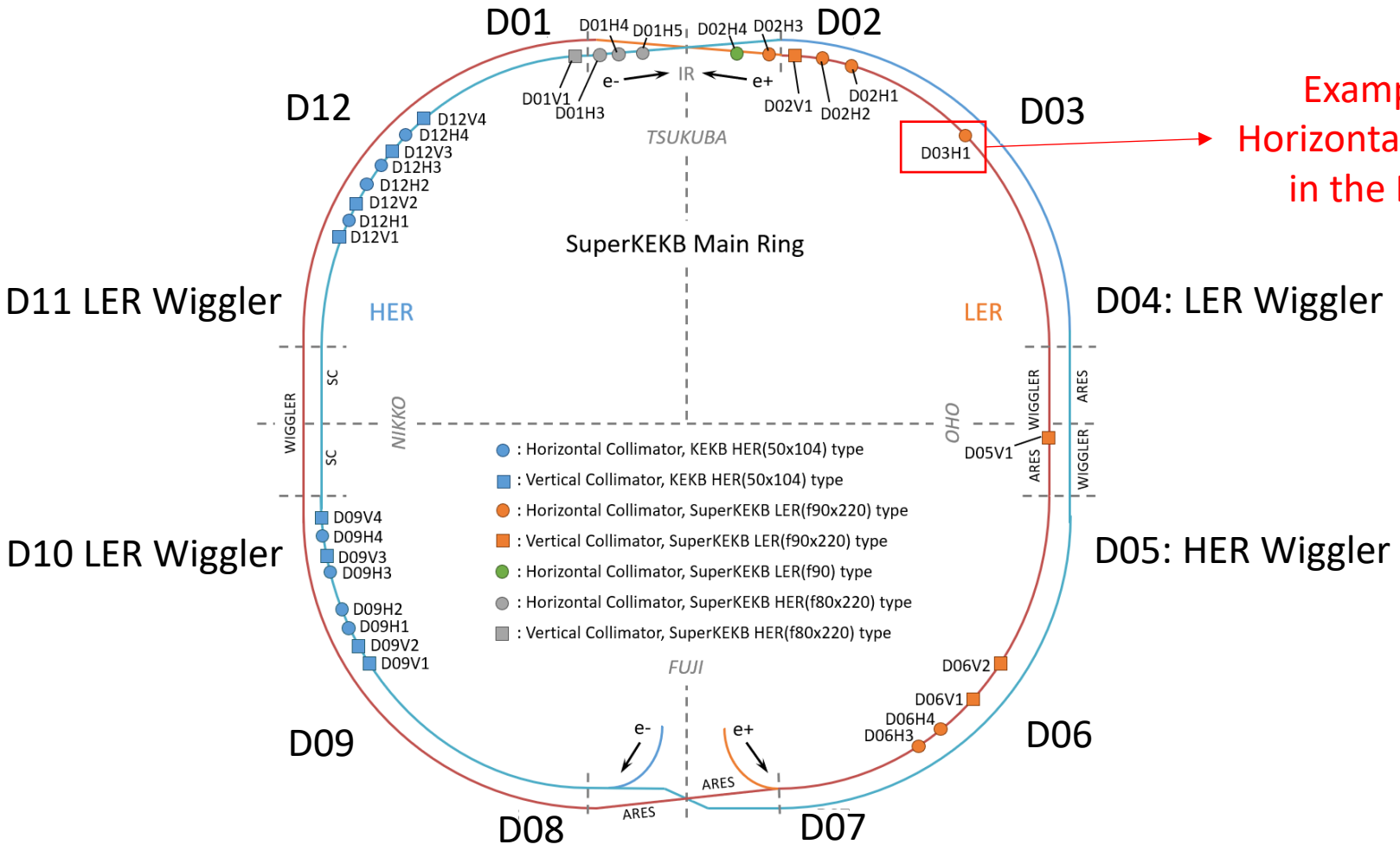
- Vacuum status
- Challenges and measures/ Vacuum works
- Answers to comments from last (27th) KEKB Review
- Plan for this long shutdown
- Summary

For Clarity: The 12 Sections of Main Ring

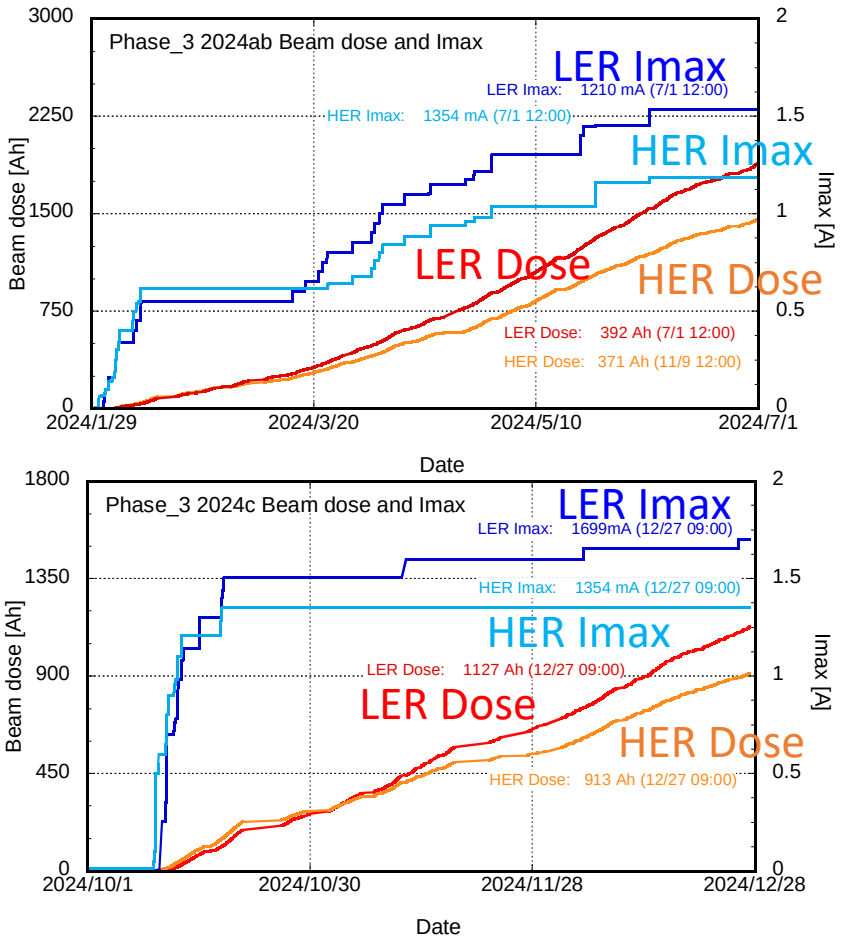
- For easier understanding of the following content, this figure is shown to help you grasp the 12 sections of the man ring
- The markers indicate the Collimators, where "V" represents vertical, and "H" represents horizontal

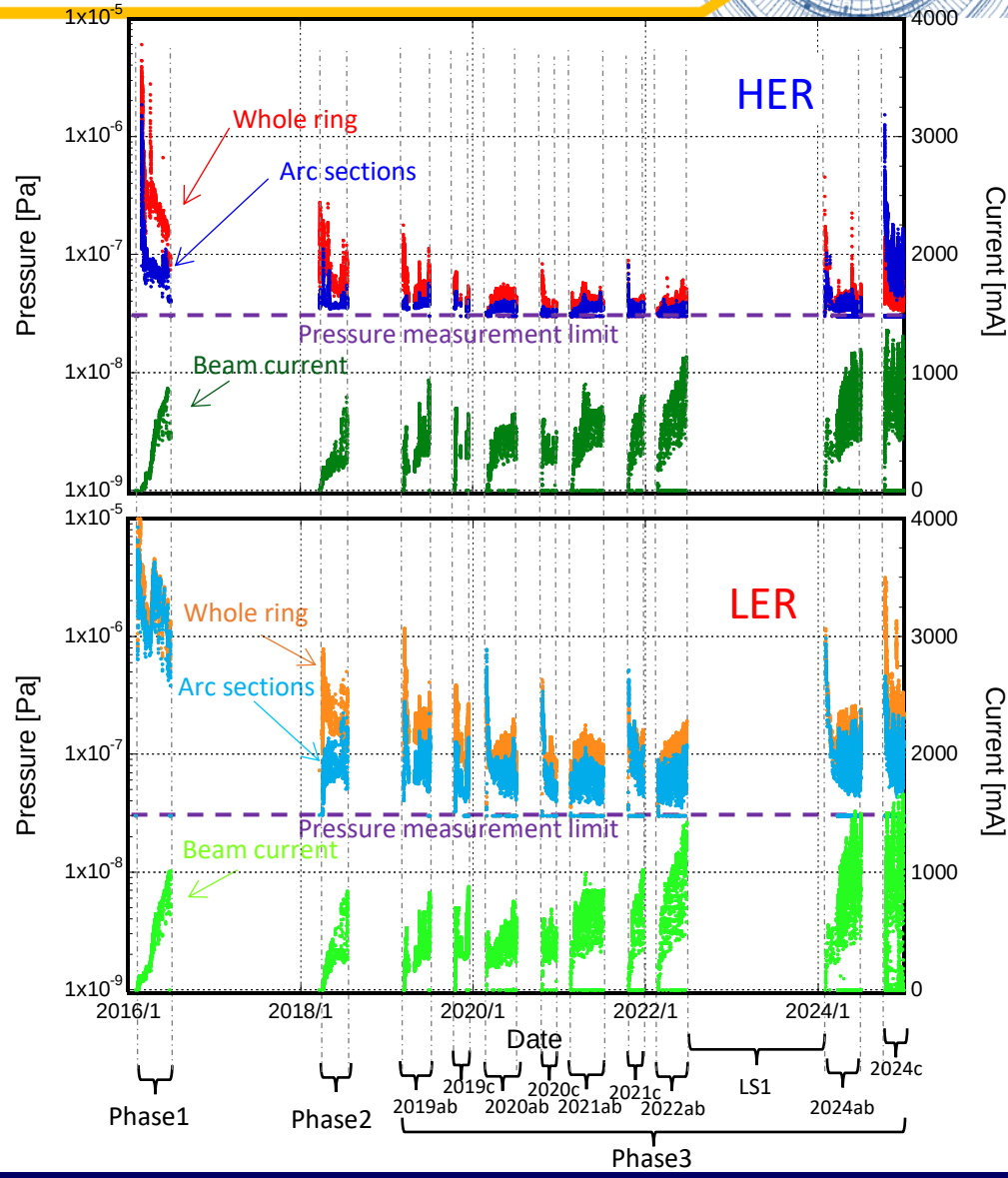


Example: D03H1
Horizontal Collimator #1
in the D03 section

Beam dose & Maximum beam currents (MR)

- Integrated Beam Dose (2024ab / 2024c)
  - HER : 1467 / 913 Ah
  - LER : 1893 / 1227 Ah
- Max. Beam Current (2024ab → 2024c)
  - HER: 1210 → 1354 mA
  - LER: 1534 → 1699 mA

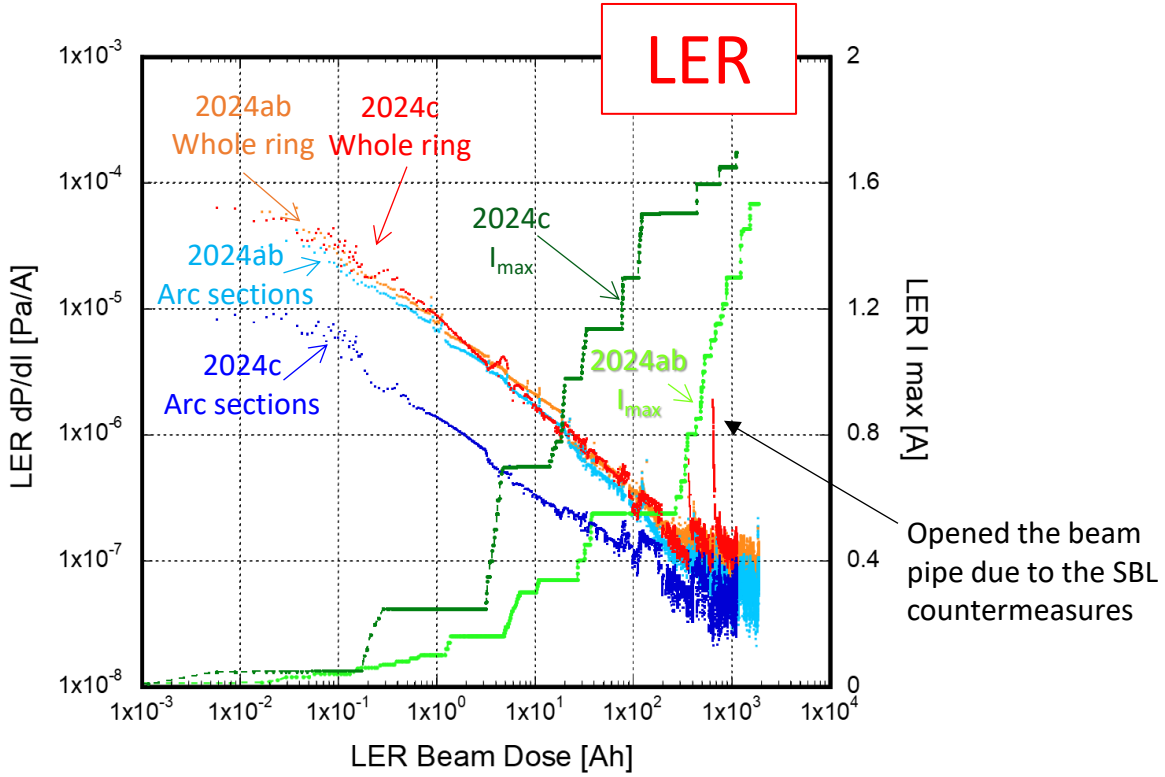


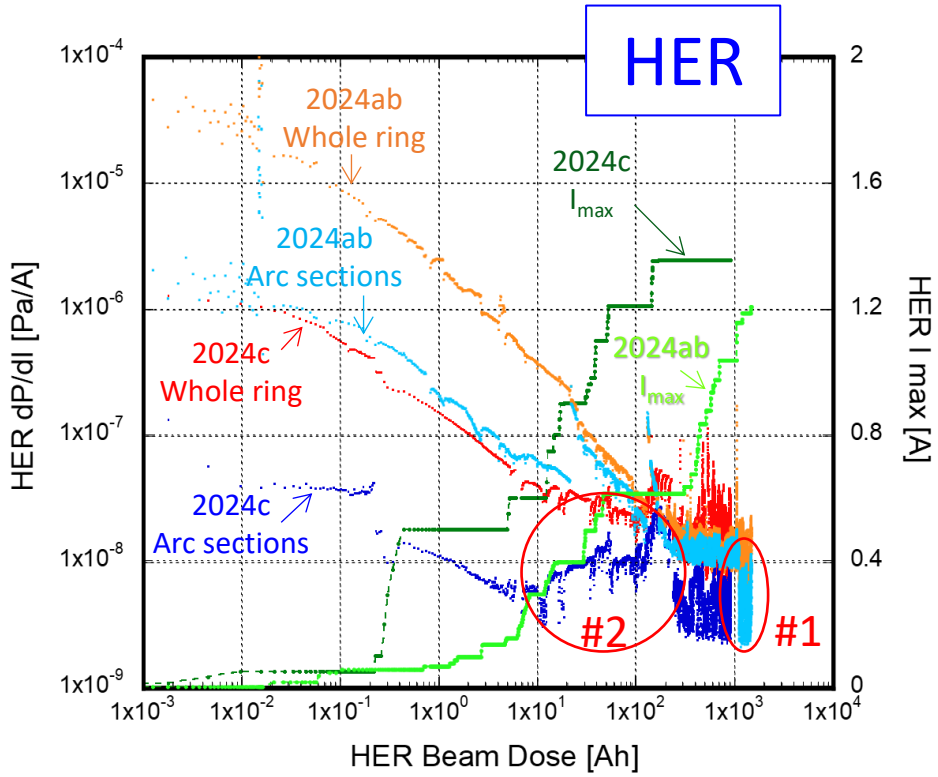


Vacuum scrubbing status (MR)

- Vacuum scrubbing is proceeding steadily in both rings.
  - $\Delta p/\Delta I$ is decreasing steadily as beam dose increases.
  - $\Delta p/\Delta I$ is higher in LER than HER.
    - More vacuum works in LER due to the Sudden Beam Loss (SBL) countermeasures

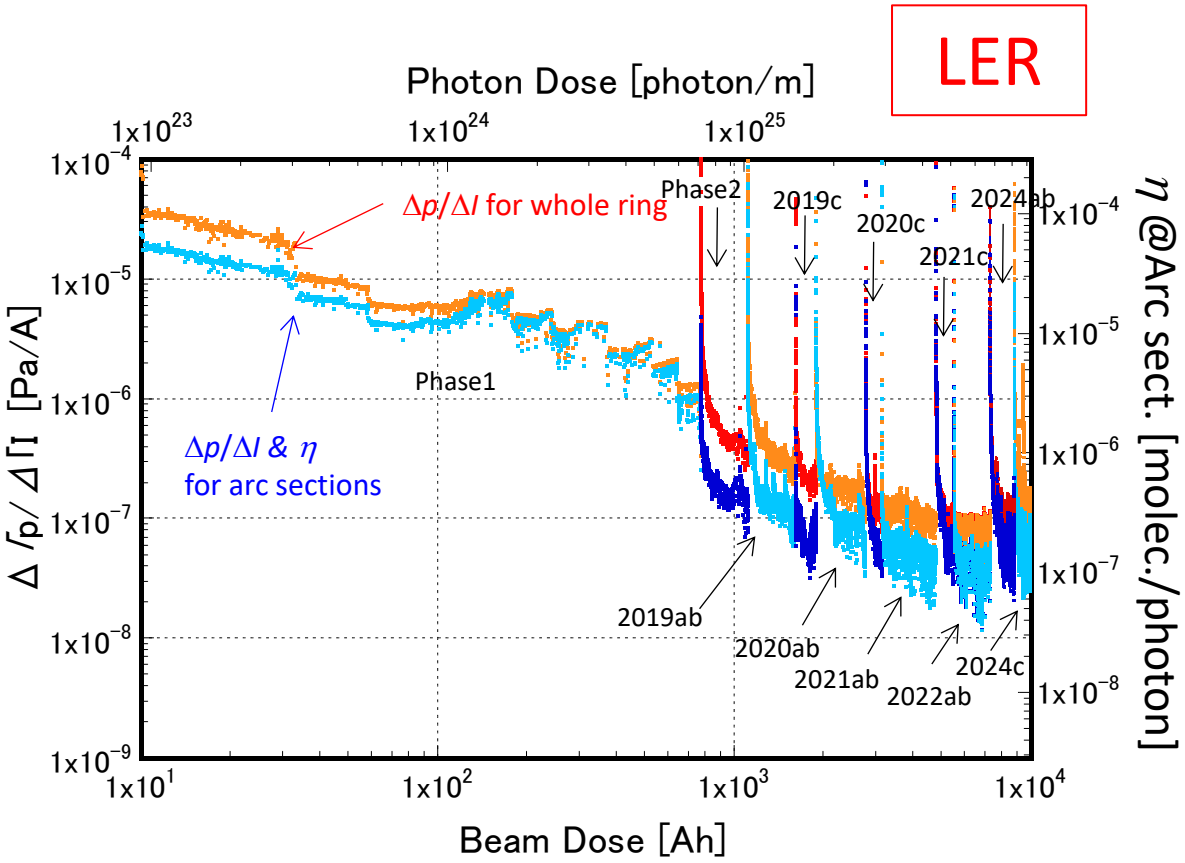
#1 Pressure of gauge D09_H25 decreased after maintenance day (5/29). The cause remains unknown
#2 Abnormal pressure rise near D09V3: The collimator was opened a little to reduce the pressure.

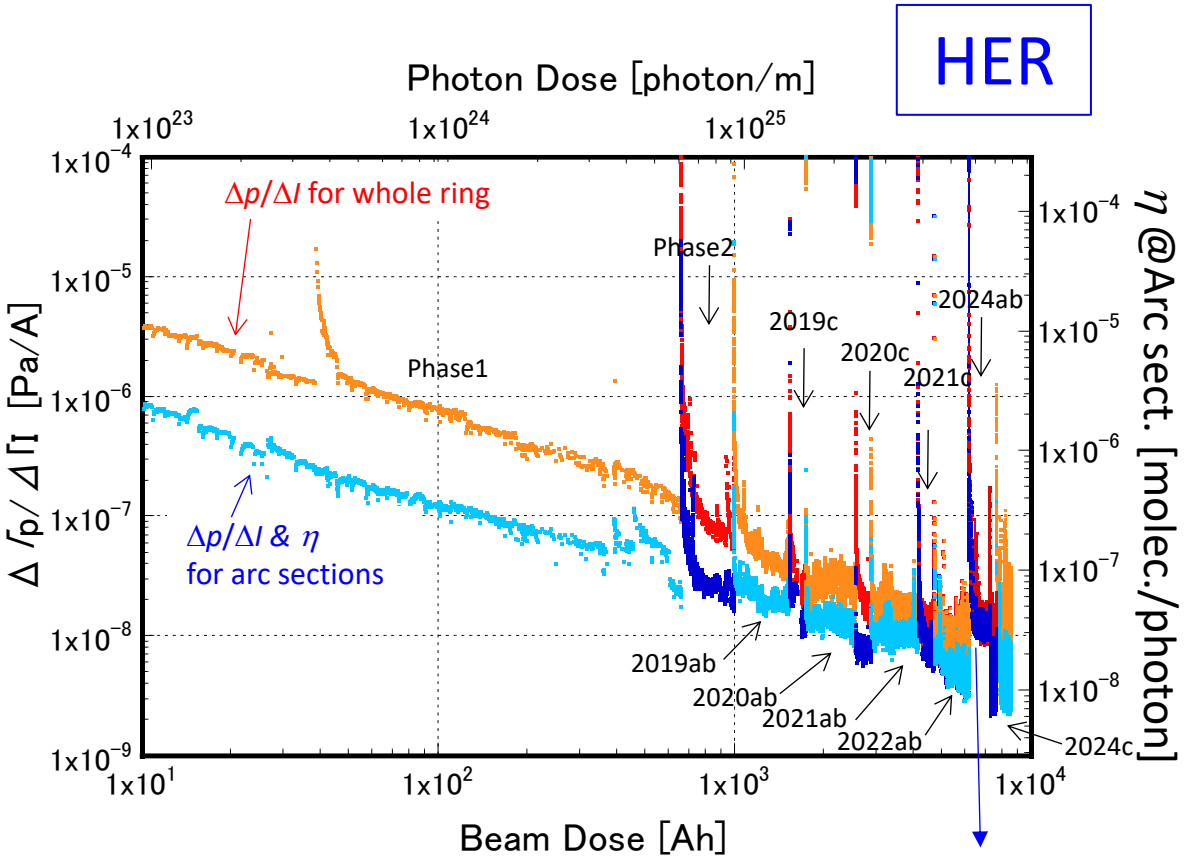




Vacuum scrubbing status (MR)

- Vacuum scrubbing status from Phase-I to Phase-III 2024c run (~12/27)
- Due to some vacuum-breaking works, the pressure in 2024 slightly increased but remains within the expected range





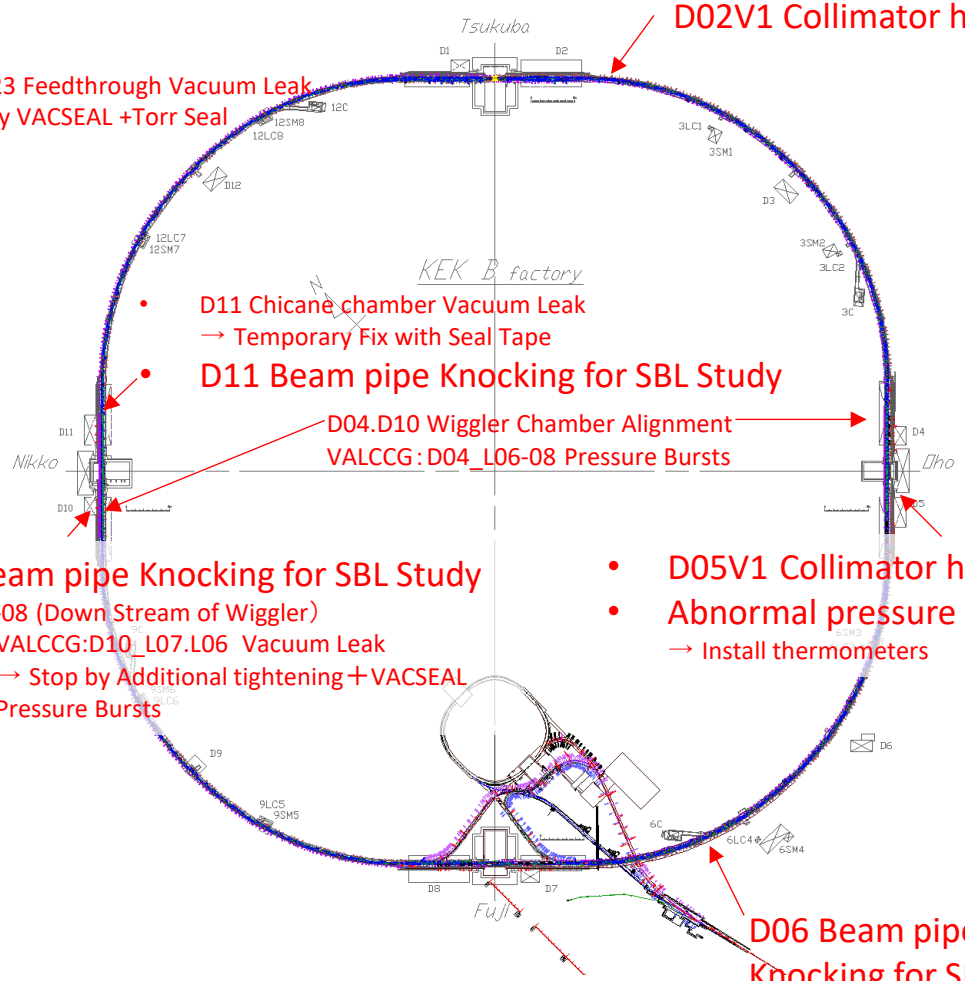
Due to a pressure increase caused by the vacuum gauge D09_H25

Challenges and measures during 2024b at a glance (MR)

LER

D12 IP_L23 Feedthrough Vacuum Leak
→ Stop by VACSEAL +Torr Seal

D02V1 Collimator head damage



- D11 Chicane chamber Vacuum Leak
  → Temporary Fix with Seal Tape
- D11 Beam pipe Knocking for SBL Study

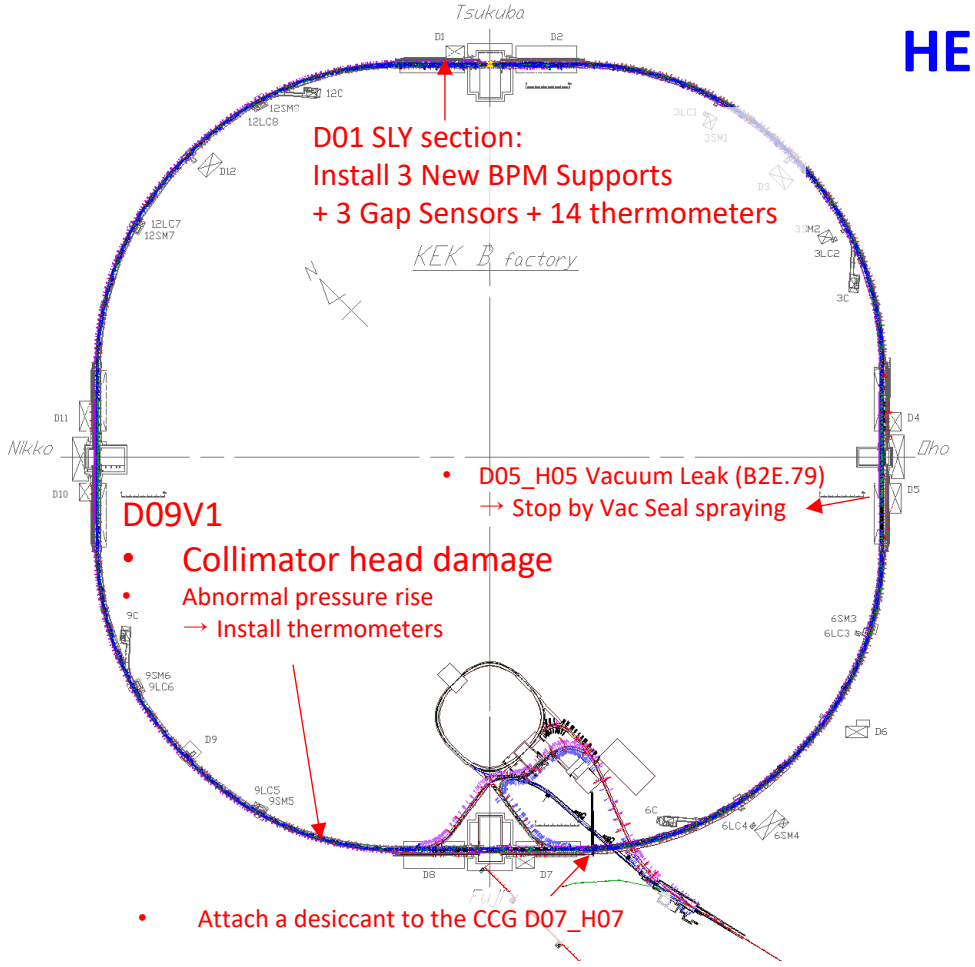
D04.D10 Wiggler Chamber Alignment
VALCCG：D04_L06-08 Pressure Bursts

- D10 Beam pipe Knocking for SBL Study
- D10_L06-08 (Down Stream of Wiggler)
  - VALCCG:D10_L07.L06 Vacuum Leak
    → Stop by Additional tightening＋VACSEAL
  - Pressure Bursts

- D05V1 Collimator head damage
- Abnormal pressure rise
  → Install thermometers

D06 Beam pipe Knocking for SBL Study

HER



D01 SLY section:
Install 3 New BPM Supports
+ 3 Gap Sensors + 14 thermometers

- D05_H05 Vacuum Leak (B2E.79)
  → Stop by Vac Seal spraying

D09V1

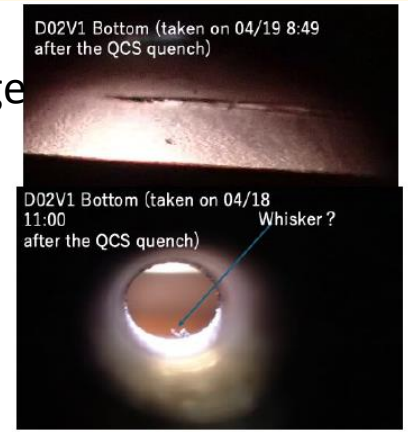
- Collimator head damage
- Abnormal pressure rise
  → Install thermometers

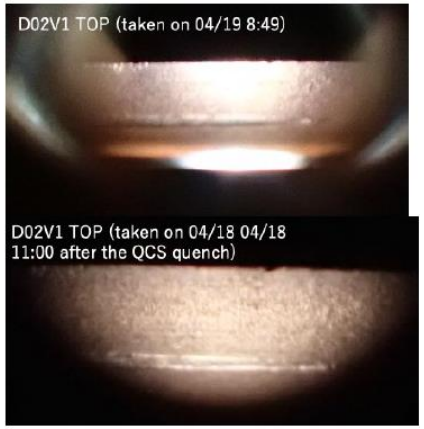
- Attach a desiccant to the CCG D07_H07

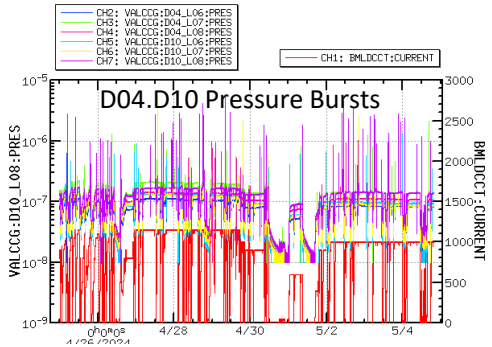
Challenges and measures during 2024b (MR) #1

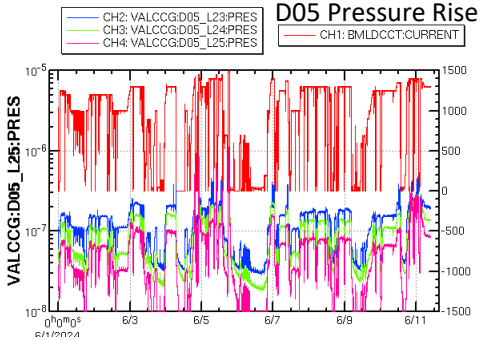
- Collimator head damage
  - LER: D02V1, D05V1(due to frequent SBL)
  - HER: D09V1(Other: LVDT malfunction)
    LVDT = Linear Variable Differential Transformer of gap sensor
- Abnormal Pressure Rise → Install thermometers for investigation
  - LER: Near D05V1
  - HER: Near D09V1
- D04. D10 Wiggler Chamber Alignment
  - Measures to prevent leak caused by excessive temperature differences between the upper and lower parts of the beam pipe
- Pressure Bursts (Down Stream of Wiggler section)
  - VALCCG:D04_L06-08
  - VALCCG:D10_L06-08
- Vacuum Leak
  - D10_L07.L06 Vacuum Leak from connection flanges
    → Stop by additional flange tightening＋VACSEAL
  - LER D11 Chicane chamber Vacuum Leak in copper-to-copper welds
    → Temporary Fix with Seal Tape
  - D12 IP_L23 Feedthrough Vacuum Leak
    → Stop by VACSEAL +Torr Seal
  - D05_H05 Vacuum Leak (B2E.79) in copper-to-copper welds
    → Sprayed VACSEAL to stop the leaks
- Attach a desiccant to the HER gauge CCG D07_H07
  - To prevent abnormal discharge in the feedthrough part due to high humidity during air-conditioning shutdown
  - To prevent vacuum leak due to the discharge

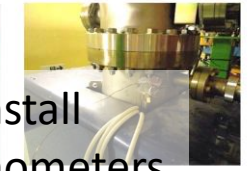
D02V1 Damage



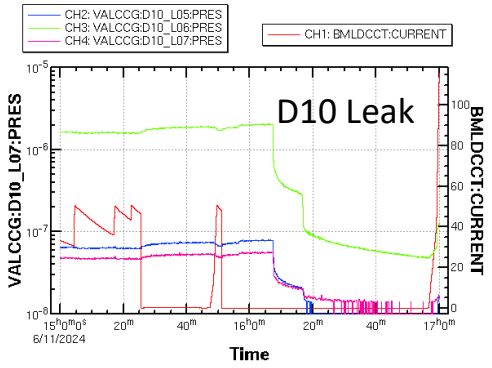


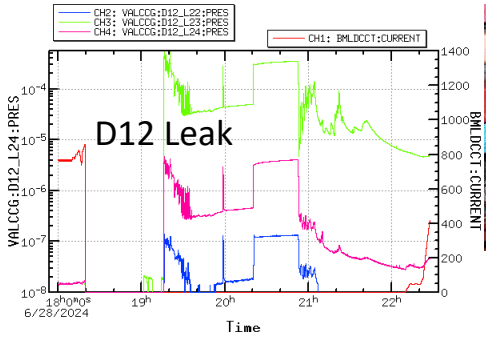






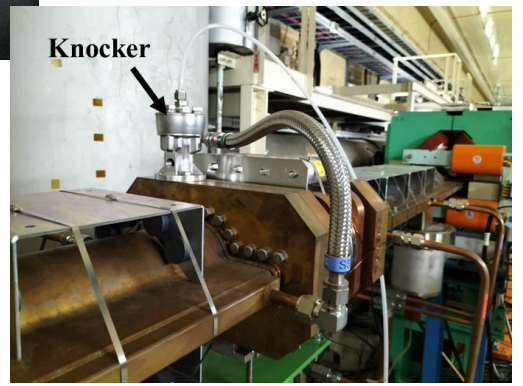
Install thermometers near D05V1





Challenges and measures during 2024b (MR) #2

- Beam pipe Knocking for SBL Study: D06, D10, D11
  - Motivation: Since pressure bursts often occurred in the Wiggler section when SBLs occurred, we suspected that the SBLs were caused by dust/beam interactions
  - Location: Grooved beam pipe and beam pipe with clearing electrode (highly suspected)
  - Result:
    1. SBL was successfully produced artificially
    2. Dust was found in the beam pipe (Summer Shutdown)
  - Measures (Summer Shutdown)
    1. Clean Clearing Electrode Beam Pipes: D04, D05, D10
    2. Flip Clearing Electrode Beam Pipes: D04, D05



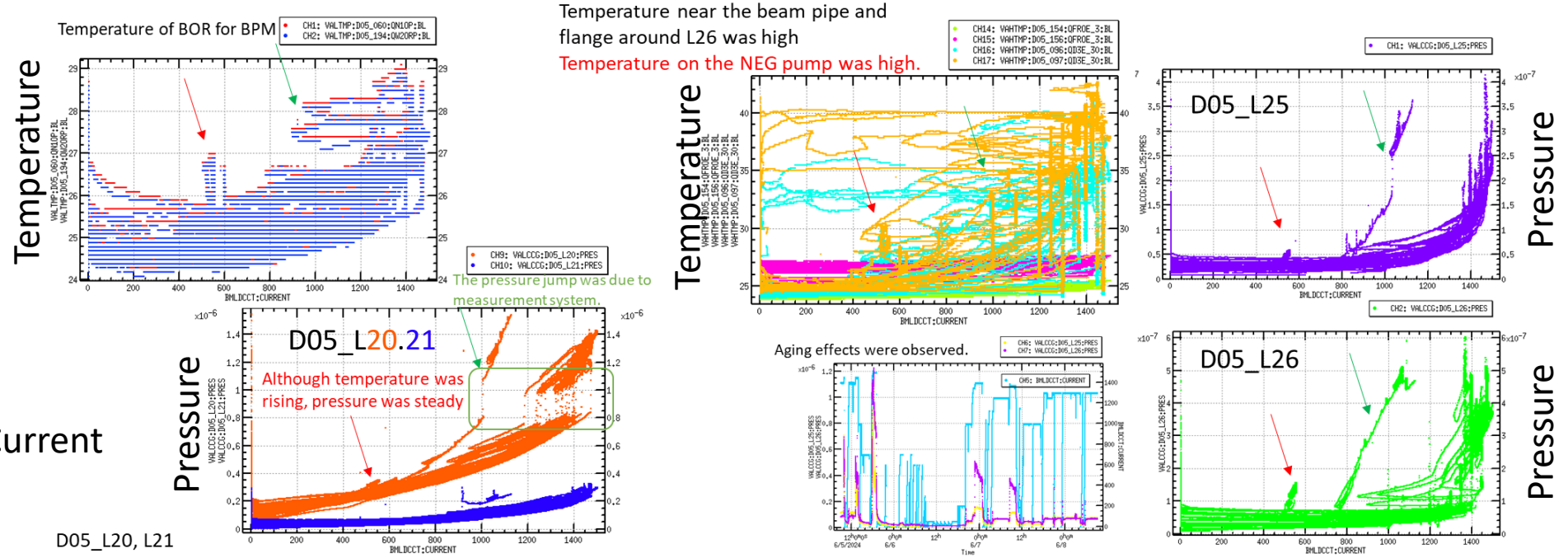
Abnormal Pressure Rise vs Temperature (LER)

Against beam current

Y. Suetsugu

D05 NLC Section

- CCG D05_L20: The vacuum gauge closest to the ARES section, located near the beam pipe with a taper structure for the skew-SX magnet of NLC. There is also a BPM electrode for BOR nearby.
  - The temperature near the BPM electrode was measured. While the temperature increase depends on the number of bunches, there seems to be no correlation between the temperature rise and the pressure increase.
  - The pressure increase is dependent on the number of bunches (HOMs or multipacting are the likely causes). A gasket with a small hole (RF shielded) was installed on a nearby ion pump (D05_L20) in the summer shutdown (for HOMs).
- CCG D05_L25, L26: Vacuum gauges near the Wiggler section, close to the beam pipe with a taper structure for the skew-SX magnet of NLC. L26 is located near the gate valve (GV) separating the Wiggler and NLC sections.
  - The temperature and pressure increases are dependent on the number of bunches. At a certain beam current, the pressure rises sharply. Occasionally, L26 exhibits pressure spikes during injection. Aging effects have been observed.
  - Gaskets with small holes (RF shielded) were installed on nearby ion pumps (D05_L25 and L26) in the summer shutdown.



X-axis: Beam Current

D05_L20, L21

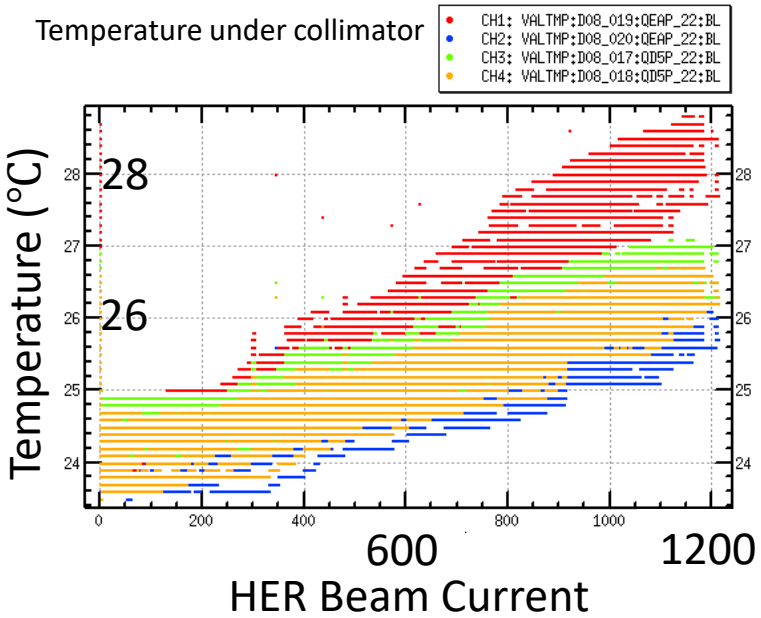
Abnormal Pressure Rise vs Temperature (HER)

Y. Suetsugu

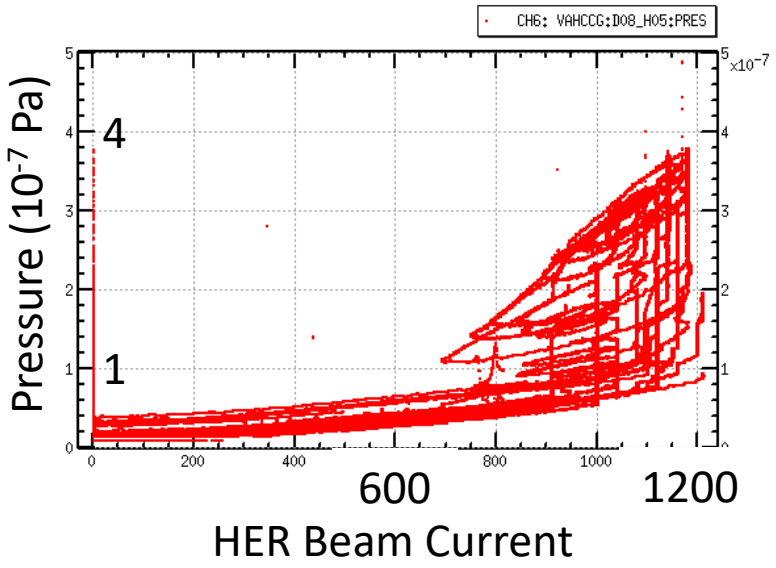
CCG D08_H05: Near the D09V1 collimator.

- The temperature rise appears to be nearly linear with respect to the beam current.
- The pressure value is nonlinear with respect to the beam current.
- Even at the same beam current, the pressure gradually increases over time.
- It seems that above a certain current, the pressure rises significantly.
- The behavior depends on the number of bunches.
- A gasket with a small hole (RF shielded) was installed on the nearby NEG pump in the summer shutdown.

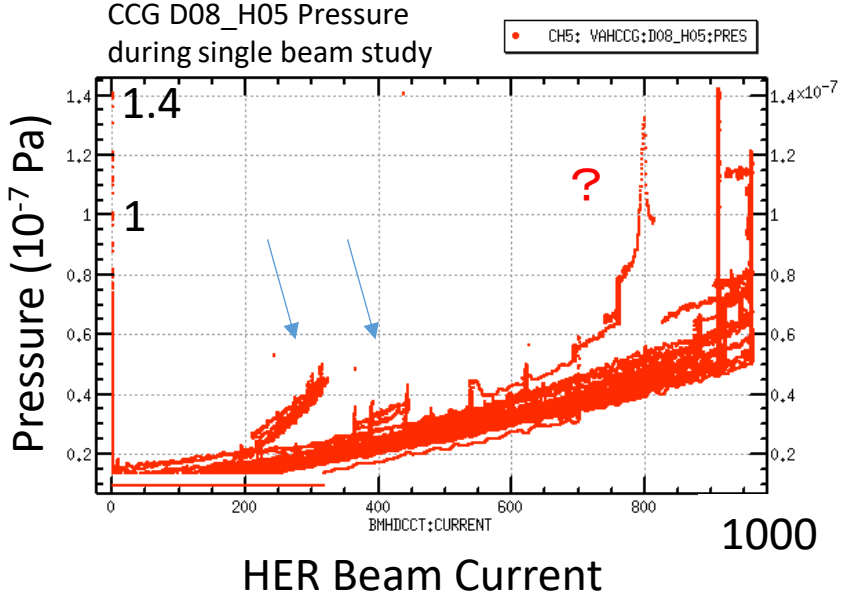
Temperature under collimator



CCG D08_H05 Pressure



CCG D08_H05 Pressure during single beam study



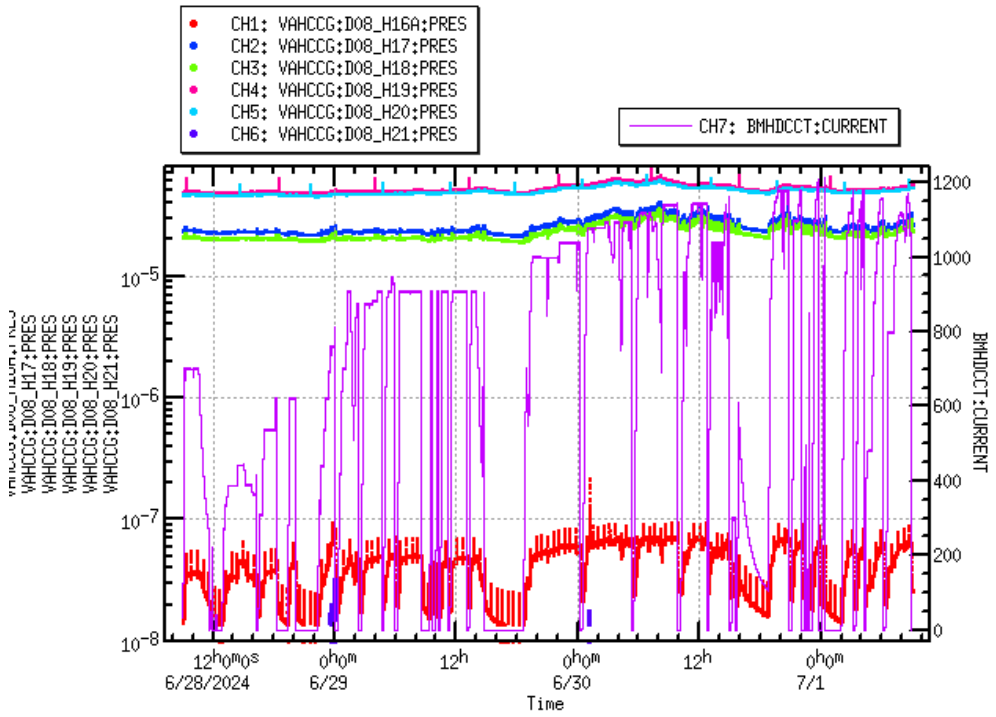
Abnormal Pressure Rise (HER)

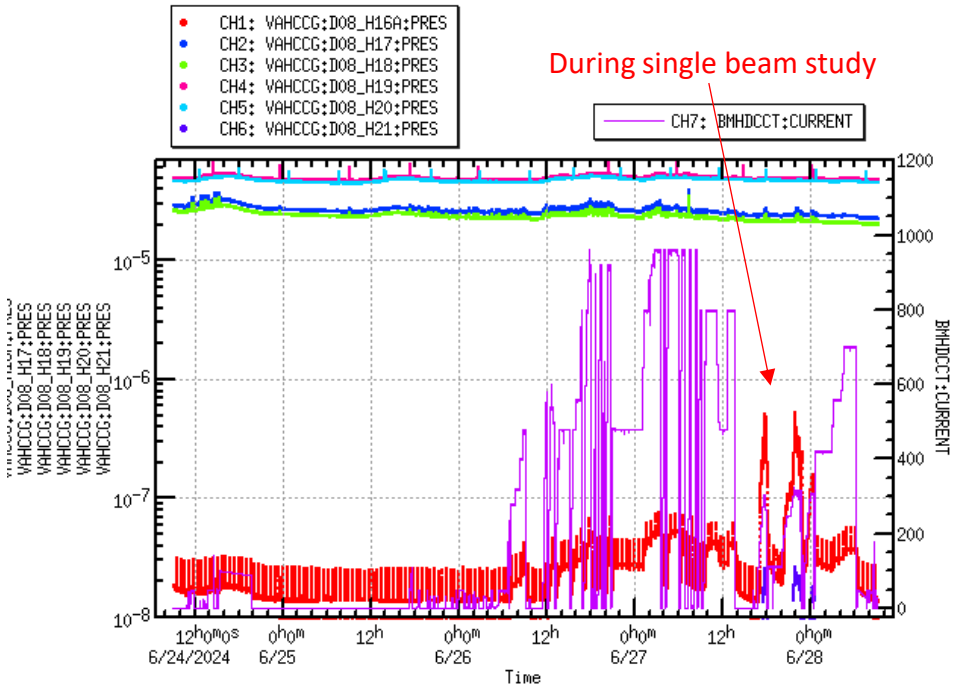
Y. Suetsugu

CCG D08_H16A, H21: Vacuum gauges near the septum in the MR section.

- During single-beam studies with a small number of bunches and high bunch current, the pressure rises sharply.
- The behavior depends on the number of bunches.

(CCG D08_H17, H18, H19, H20: Pressure in the septum vacuum chamber)





Vacuum works during Summer Shutdown at a glance (MR)

: Area open to dry nitrogen or atmosphere

LER

D01 SLY section:
Install 1 New BPM Support
+ 3 Gap Sensors

Collimator head replacement (D02V1)

IP feedthrough replacement

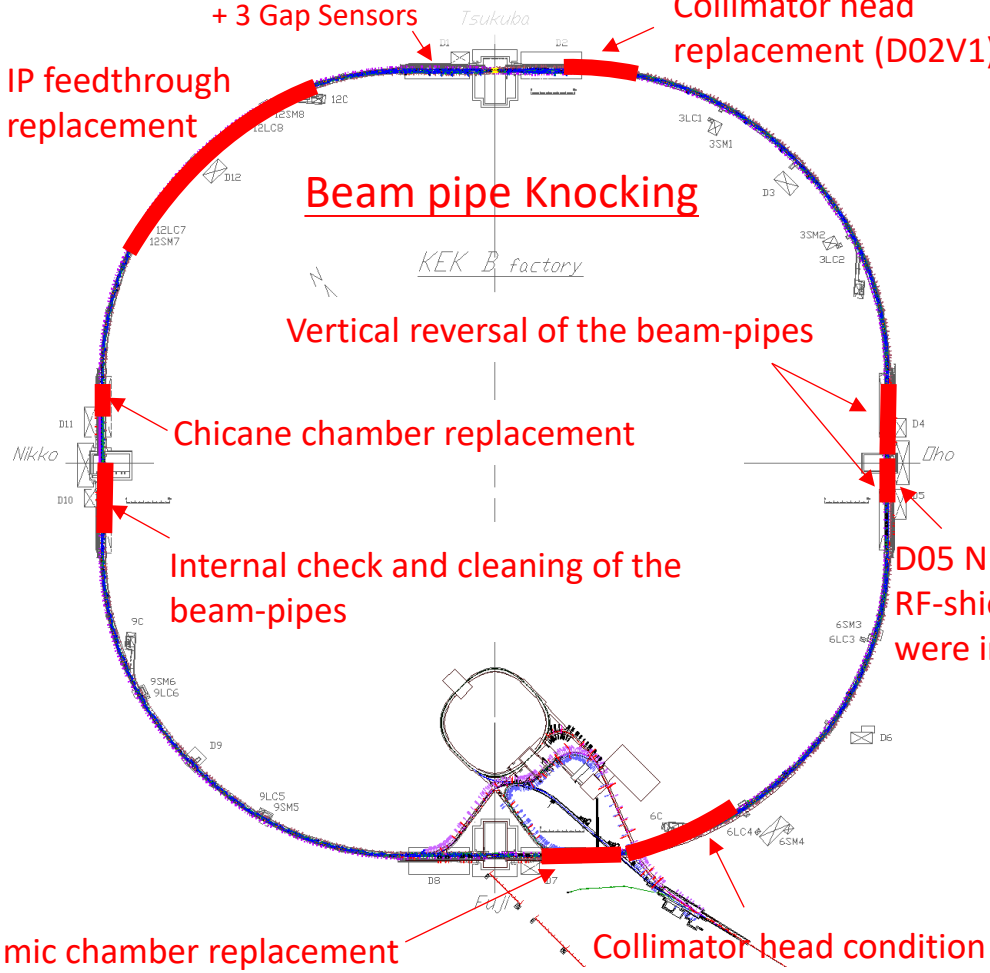
Beam pipe Knocking

Vertical reversal of the beam-pipes

Chicane chamber replacement

Internal check and cleaning of the beam-pipes

D05 NLC Section:
RF-shielded gaskets were installed

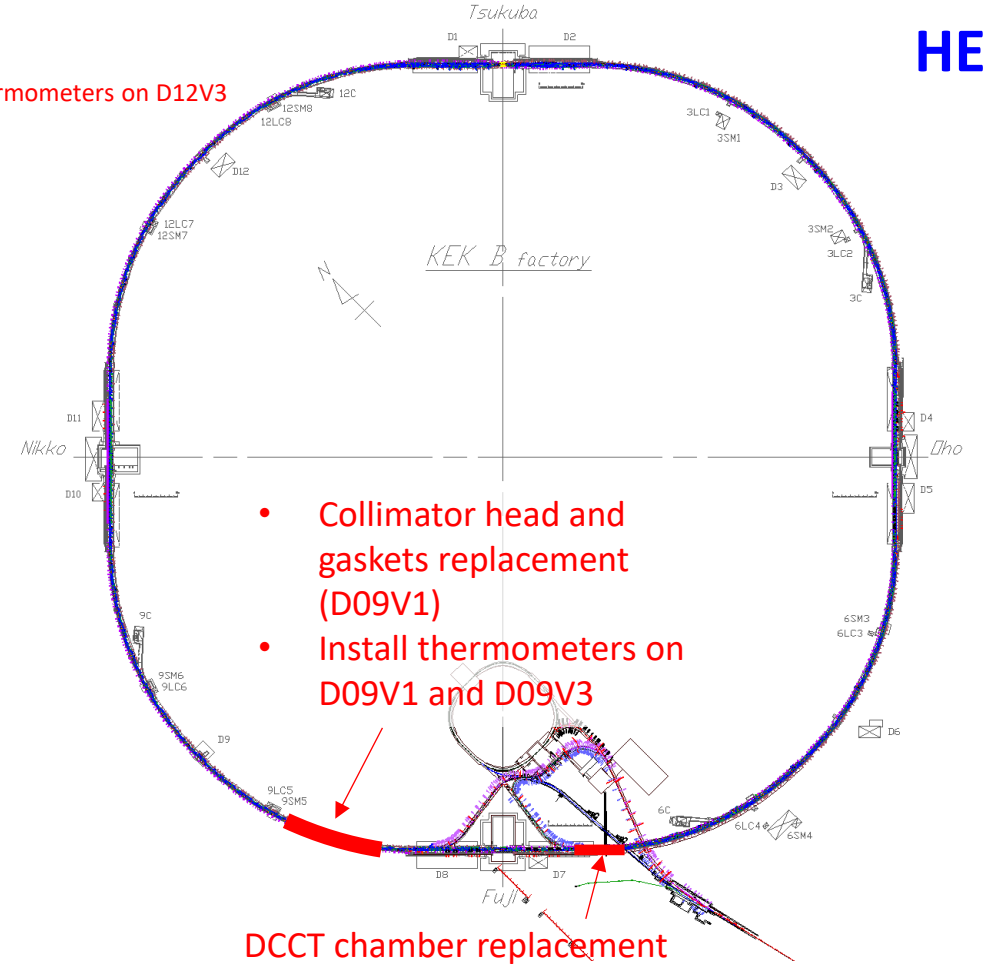


Ceramic chamber replacement

Collimator head condition check
(D06H3, D06H4)

HER

Install thermometers on D12V3



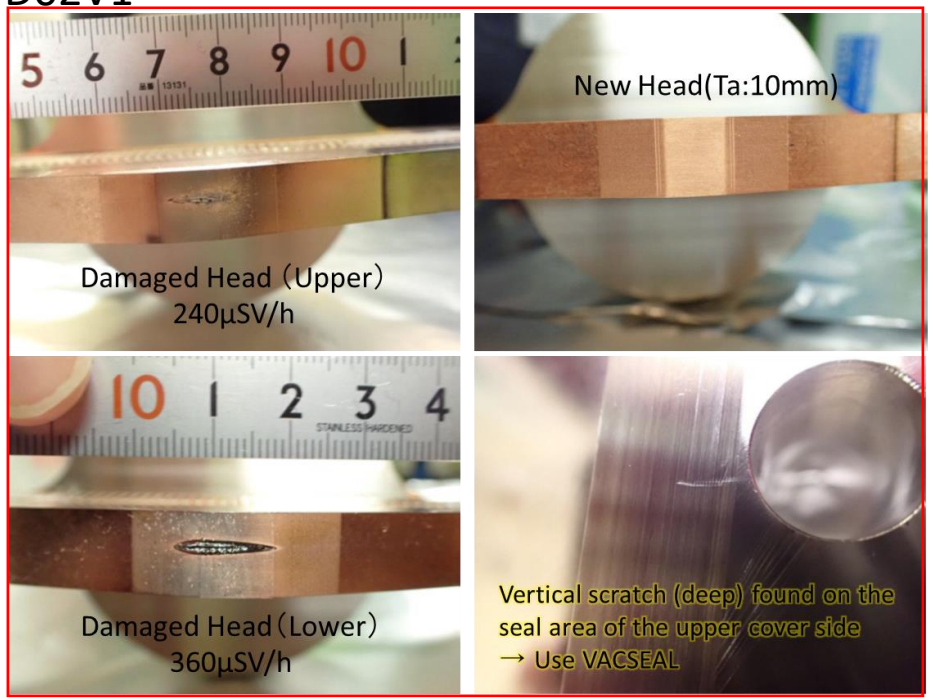
- Collimator head and gaskets replacement (D09V1)
- Install thermometers on D09V1 and D09V3

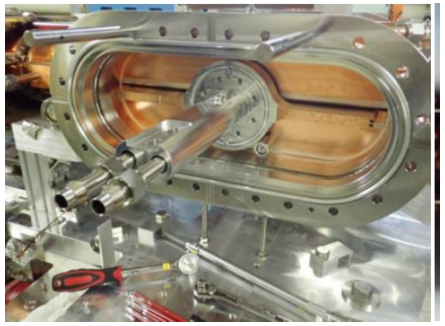
DCCT chamber replacement

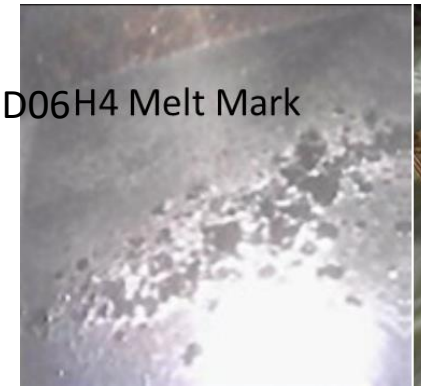
Vacuum works during Summer Shutdown (LER) #1

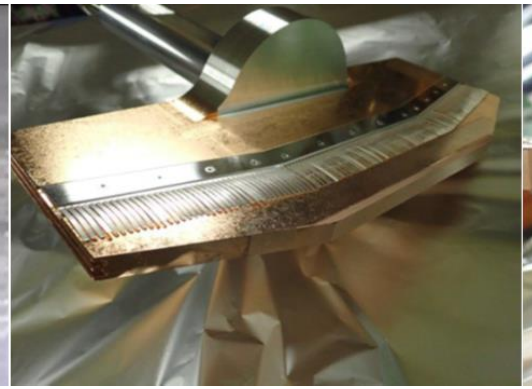
- Collimator Head Replacement: D02V1
- Collimator Head Status Check:
  - D05V1: The lower head was damaged.
  - D06H4: The inner head was damaged slightly.
  - D06H3 (Graphite head):
    1. Movement mechanism has become difficult to operate (due to the copper shavings)
    2. But the graphite head, which has been used since 2024a, remains healthy even after several accidental firings of the injection kicker

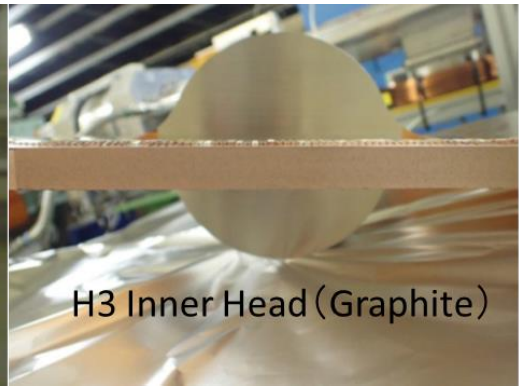
D02V1











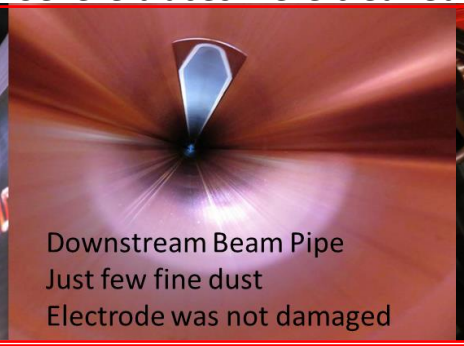
Vacuum works during Summer Shutdown (LER) #2

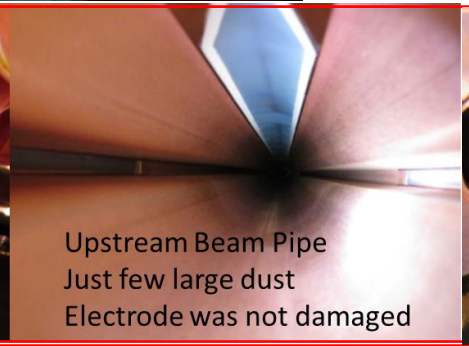
- D05 NLC Section Work:
  - Clearing Electrode Beam Pipes: 2/4 pipes were flipped upside down and cleaned.
    ※Beam pipe inside lead shield cannot be flipped
    - To reduce the SBLs that were believed to be caused by dust in the clearing electrode beam beampipe at the time
  - RF-shielded gaskets were installed on Ion Pumps D05_L20, L25, L26.
    - Try to reduce the abnormal pressure rises (if they originate from HOMs)
- The feedthrough of Ion Pump D12_L23 was replaced (∵leak), and desiccants were added to the connector area.
  - To prevent abnormal discharge in the feedthrough part due to high humidity during air-conditioning shutdown
  - To prevent vacuum leak due to the discharge

Vacuum works during Summer Shutdown (LER) #3

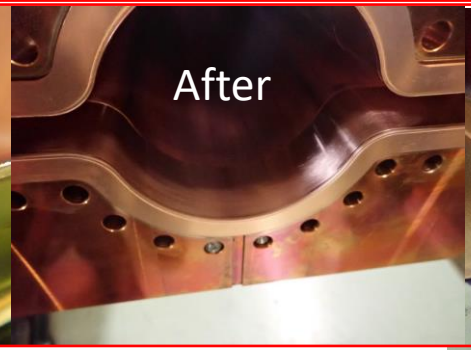
- LER D11 Chicane Q Chamber (QW5NRP) was replaced with new one.
- Beam Pipe Inspection and Cleaning:
  - D10 Clearing Electrode Beam Pipe: Interior was inspected and cleaned.
  - D04 Clearing Electrode Beam Pipe: Flipped upside down and cleaned.
    13/16 beam pipes outside the Oho concrete shield were flipped.
- Result of inspection:
  - D10: No obvious damage to the electrode. Some dusts at the bottom of beam pipes.
  - D04: No obvious damage to the electrode. Black traces of (probably) burnt VACSEAL were found inside near most of flanges . Severe traces were cleaned before restoring.

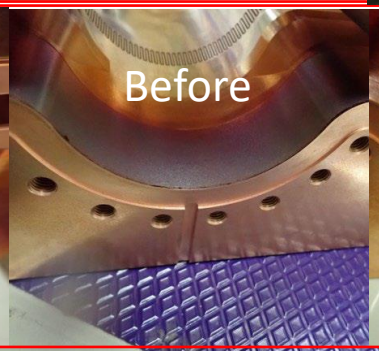
D10: VACSEAL was used for sealing flange as before.

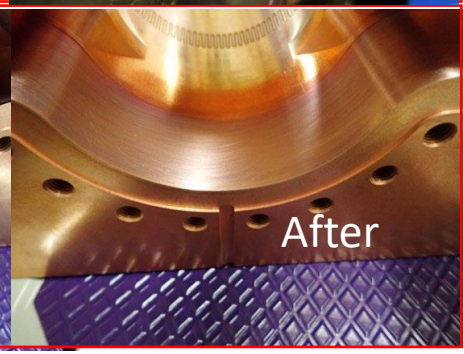




D04: VACSEAL was NOT used for sealing flanges, but the black stain of them were not COMPLETELY removed to preserve the TiN coating.

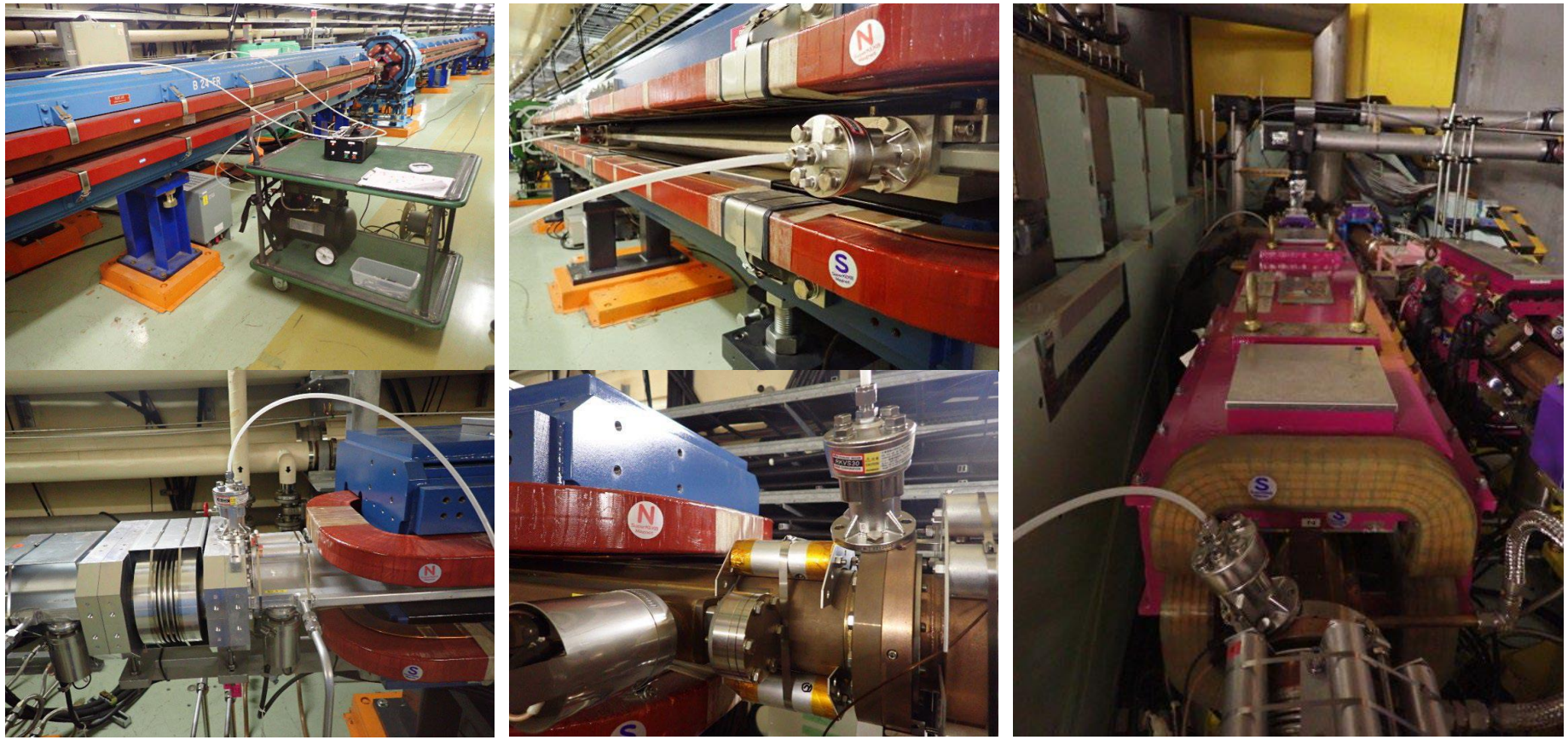






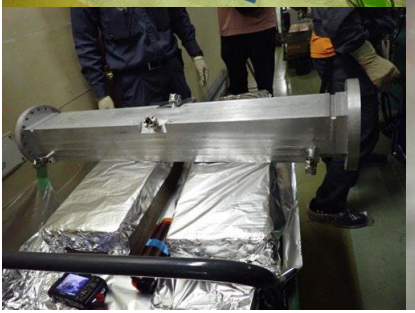
Vacuum works during Summer Shutdown (LER) #4

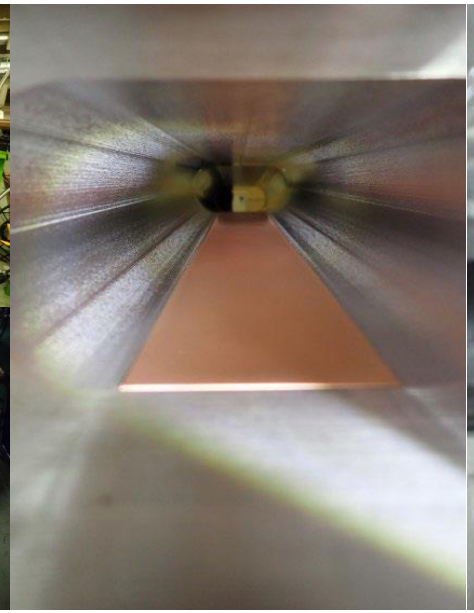
- Beam pipe Knocking: try to reduce the dust/beam interactions
  - Beam pipes were struck using the knocker, including all groove-type beam pipes and clearing-electrode beam pipes around the ring.



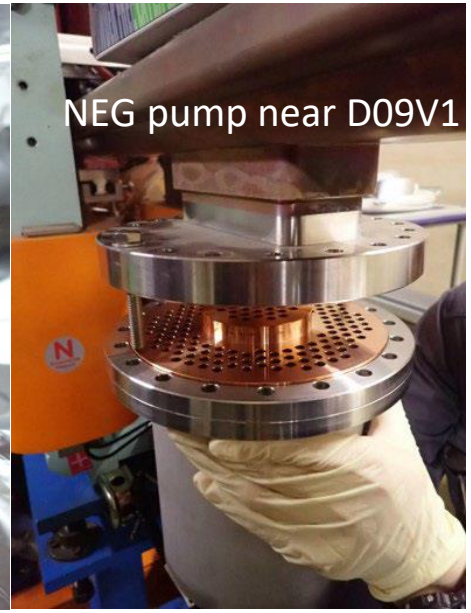
Vacuum works during Summer Shutdown (HER)

- Collimator Head Replacement: D09V1 (14.4 mSv/h)
- Installed RF-shielded gaskets on Ion Pump D08_H05 and the NEG pump near D09V1.
- Install thermometers on D09V1, D09V3, D12V3 (for nonlinear pressure rise study)
- Note: No knocker work was performed in HER





D09V1 Head
Color of Cu coating changed
SR? HOMs?

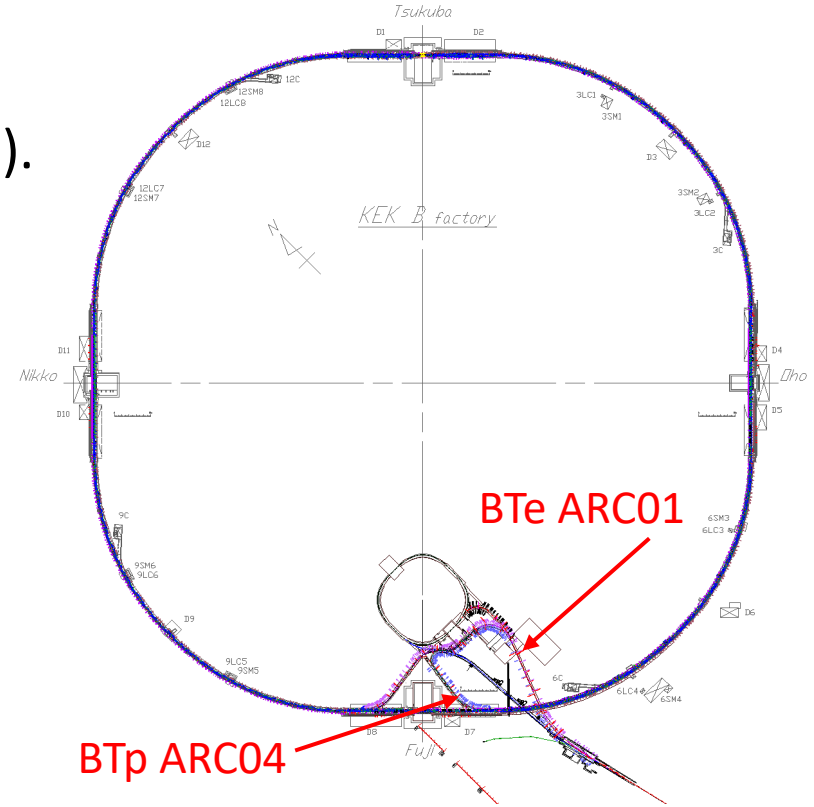


NEG pump near D09V1

Install thermometers on D09V3

Other works during Summer Shutdown (MR)

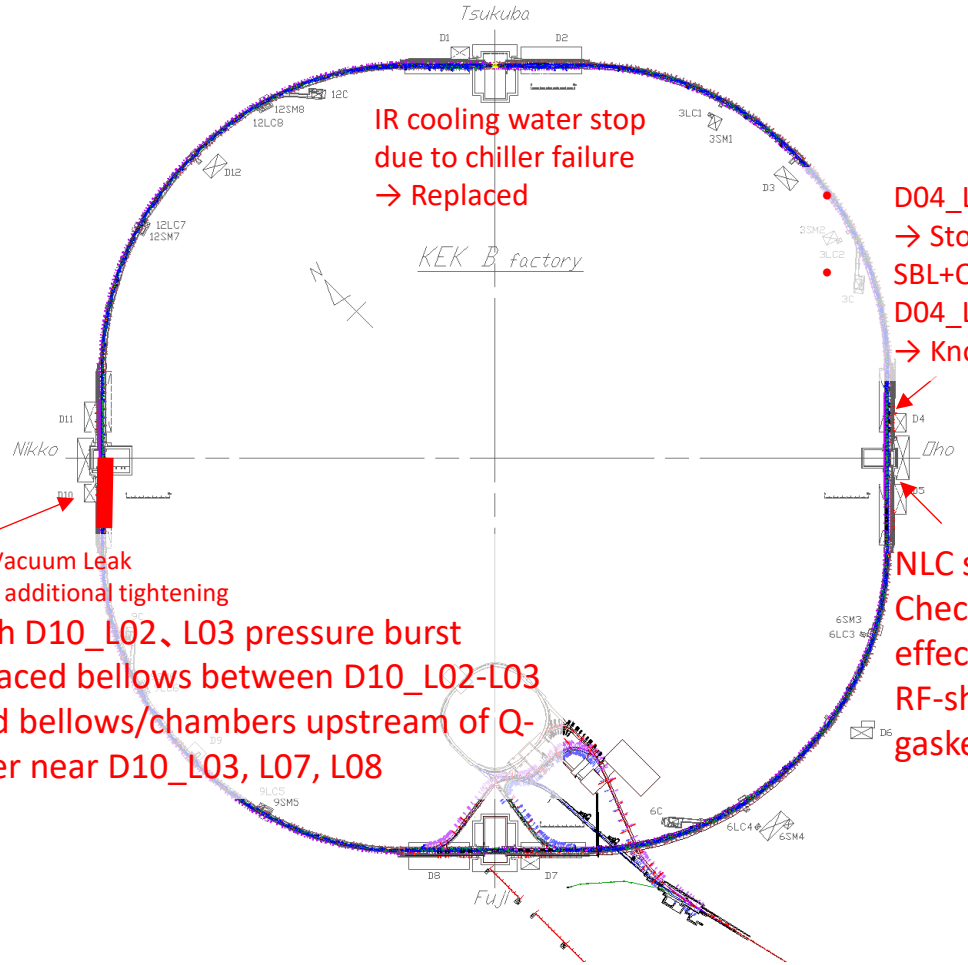
- LER Vacuum Leak Repairment (from connection flanges)
  - Addressed by tightening bolts and applying VACSEAL.
  - CCG D01_L15: Upstream flange of the beam pipe inside B2P.3.
  - CCG D01_L10: Upstream flange of the beam pipe inside BLA2LP.
  - Both leaks are presumed to have been caused by knocker work.
- BTe ARC01: SRM installation (by BT group).
- BTp ARC04: Screen Monitor: Position adjustment (by BT Group).



Challenges and measures during 2024c at a glance (MR)

: Area open to dry nitrogen or atmosphere

LER



IR cooling water stop due to chiller failure
→ Replaced

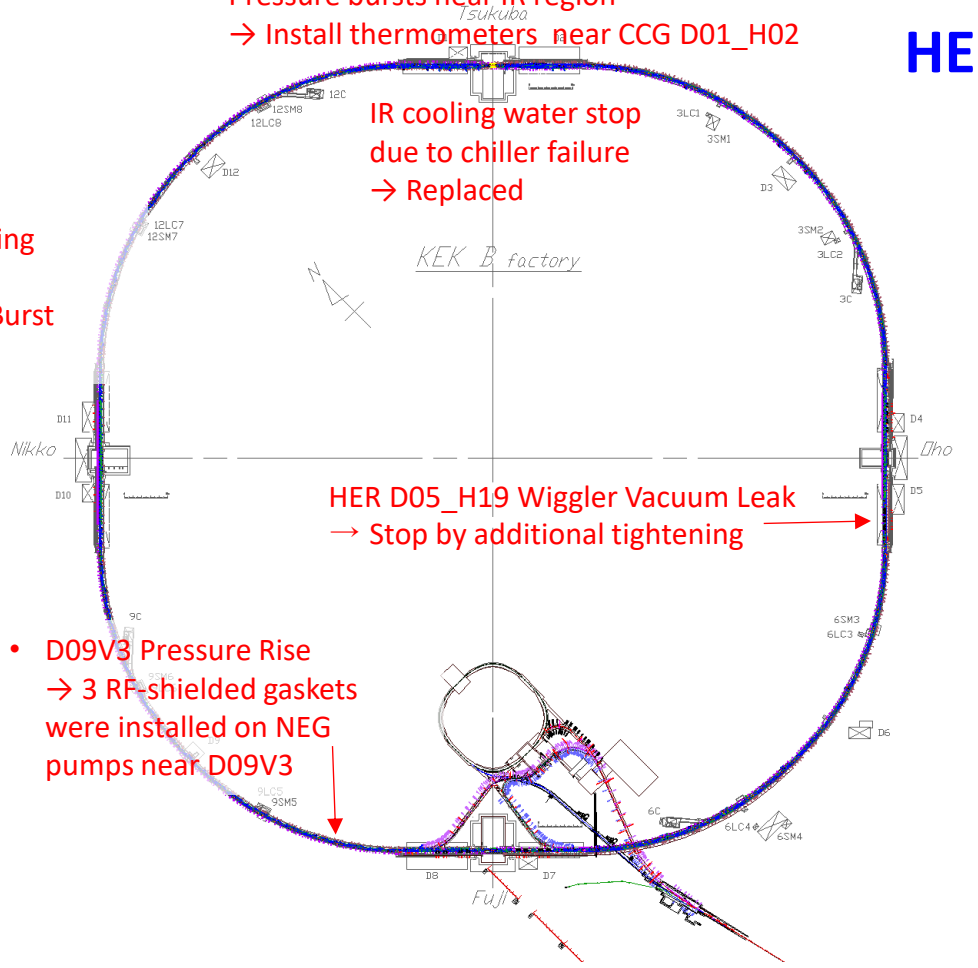
D04_L08 Vacuum Leak
→ Stop by additional tightening
SBL+QCS quench with D04_L02,03,07,08 Pressure Burst
→ Knocker

NLC section: Check the effectiveness of RF-shielded gaskets

- D10_L05 Vacuum Leak
  → Stop by additional tightening
- SBL with D10_L02、L03 pressure burst
  → Replaced bellows between D10_L02-L03
- Cleaned bellows/chambers upstream of Q-chamber near D10_L03, L07, L08

HER

Pressure bursts near IR region
→ Install thermometers near CCG D01_H02



IR cooling water stop due to chiller failure
→ Replaced

HER D05_H19 Wiggler Vacuum Leak
→ Stop by additional tightening

- D09V3 Pressure Rise
  → 3 RF-shielded gaskets were installed on NEG pumps near D09V3

Challenges and measures during 2024c (LER)

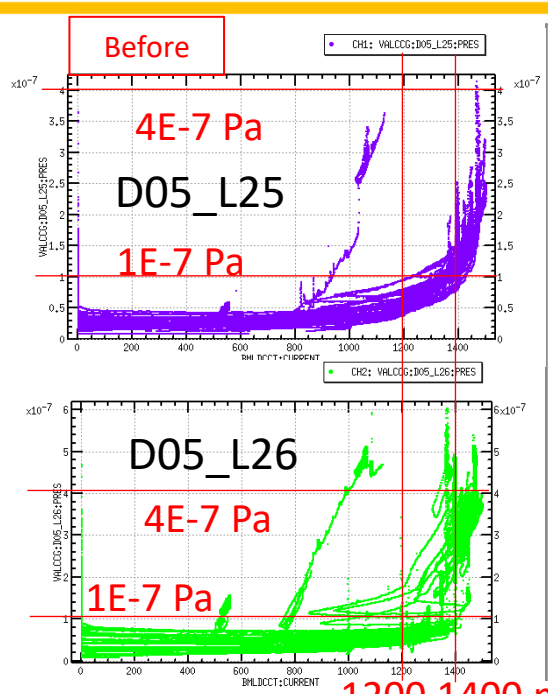
- NLC section: Check the effectiveness of RF-shielded gaskets
  - After installing the RF-shielded gaskets, the pressure is relatively high (possibly due to insufficient aging).
  - However, the behaviors of pressures has significantly changed → Continuous monitoring is required.

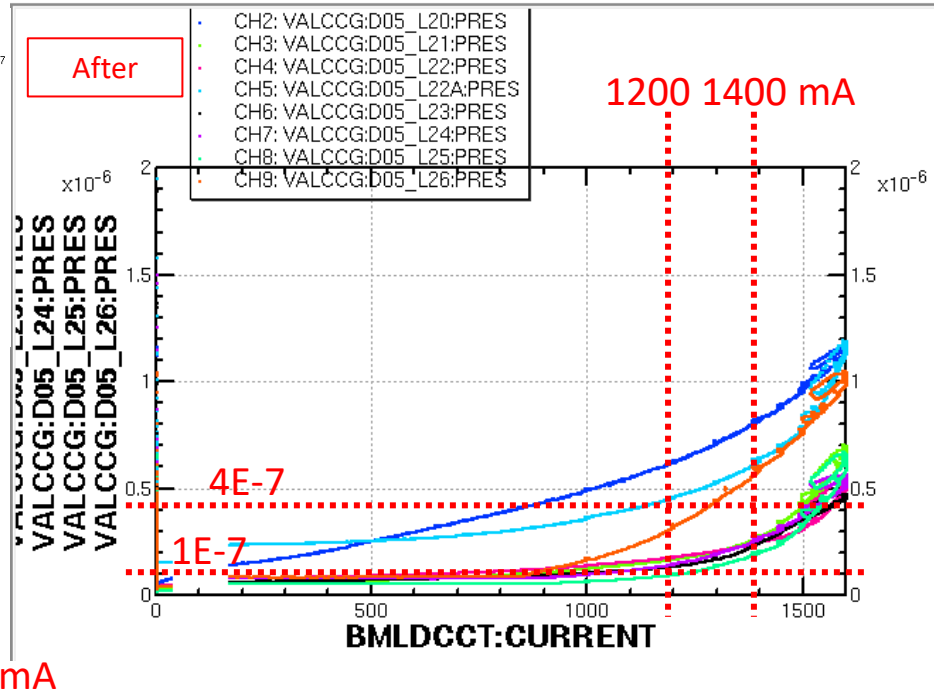
D10 Wiggler Section

- D10_L05 Vacuum Leak
  → Stop by additional tightening
- SBL with D10_L02、L03 pressure burst
  → Replaced bellows between D10_L02-L03
- Cleaned bellows/chambers upstream of Q-chamber near D10_L03, L07, L08

D04 Wiggler Section

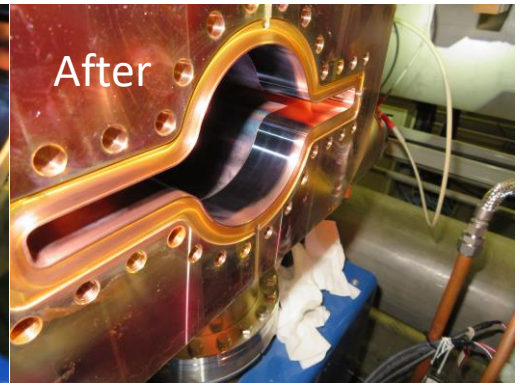
- D04_L08 Vacuum Leak
  → Stop by additional flange tightening
- SBL+QCS quench with D04_L02,03,07,08 Pressure Burst (December)
  → Knocker
- Removal of VACSEAL (including the TiN-coated parts) in the section D10 has significantly reduced the frequency of pressure bursts and SBLs.
- Now the VACSEAL is considered to be the most suspicious cause of pressure burst (SBL)





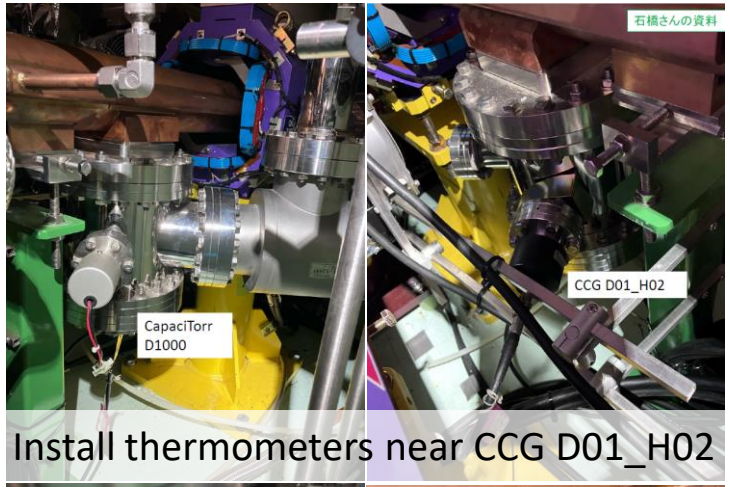
1200 1400 mA

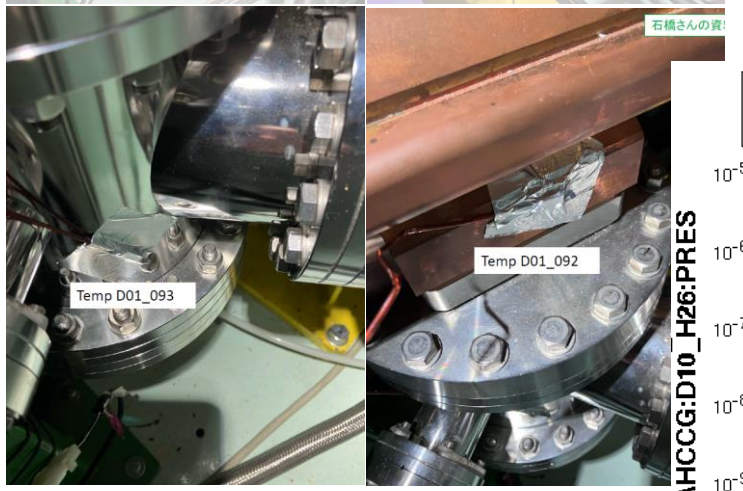
Cleaned bellows/chambers between D10_L02-L03

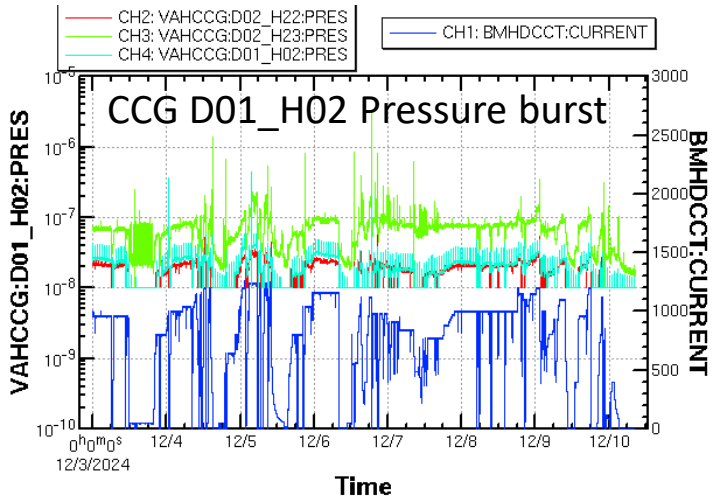


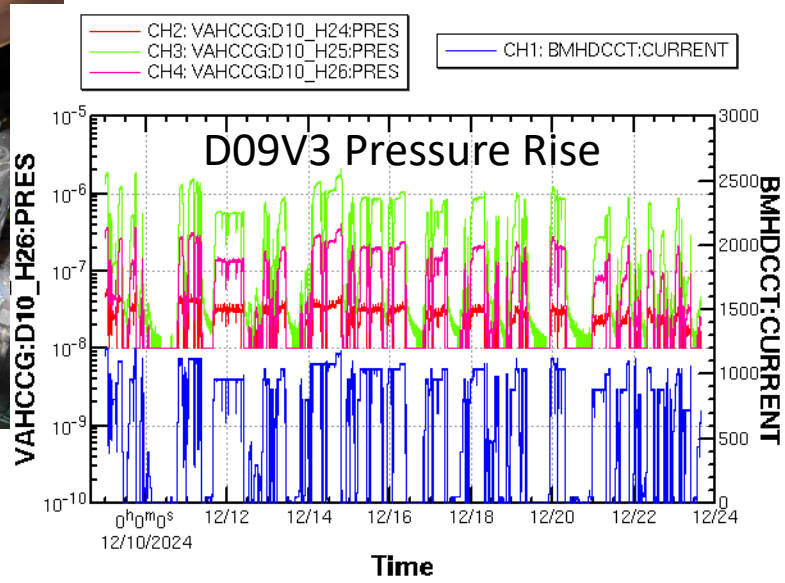
Challenges and measures during 2024c (HER)

- Pressure bursts near IR region
  → Install thermometers near CCG D01_H02
  → No suspicious findings
- HER D05_H19 Wiggler Vacuum Leak (from connection flange)
  → Stop by additional flange tightening
- D09V3 Pressure Rise
  3 RF-shielded gaskets were installed on NEG pumps near D09V3
  → Not so effective

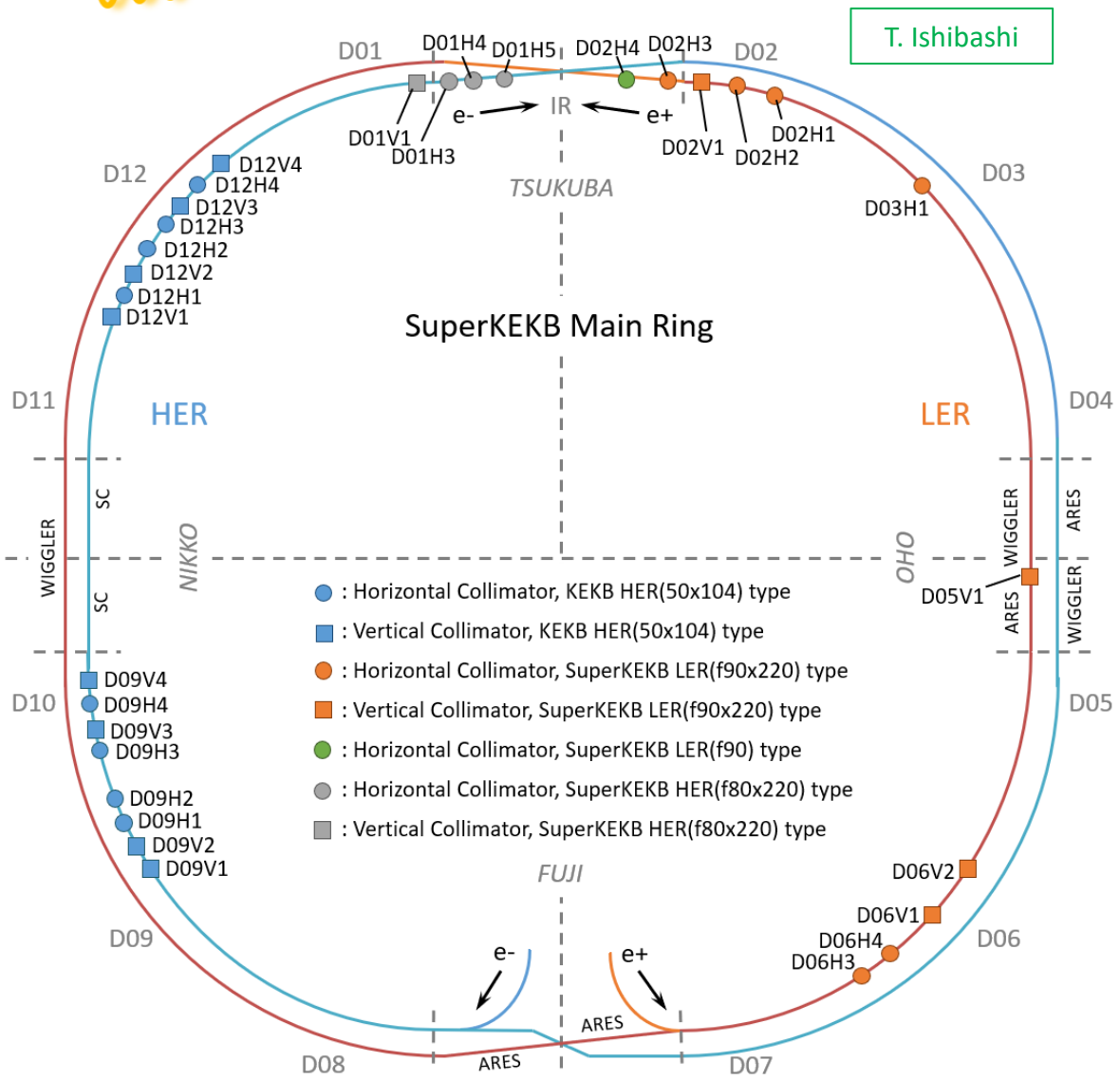








Status of LER collimator after 2024c



- Vertical collimator

× = damaged/ ○ = healthy

Name	Type	Tip Material	Cu coating	Tip condition
D02V1	SuperKEKB	Ta (10 mm)	○	×
D05V1	SuperKEKB	Ta (4 mm)	○	×
D06V1	SuperKEKB	Ti (10 mm)	○	○
D06V2	SuperKEKB	Hybrid (3 mm)	○	○

- Horizontal collimator

Name	Type	Tip Material	Cu coating	Tip condition
D02H1-H4	SuperKEKB	W (10 mm)	×	○
D03H1	SuperKEKB	W (10 mm)	×	○
D06H3	SuperKEKB	C (160 mm)	○	○
D06H4	SuperKEKB	Ta (10 mm)	×	○

- Remarks
  - D06H3 and D06H4 work as spoiler and absorber against inj. kicker accidental firings.
  - D05V1 was damage.
  - All vertical collimator heads are coated with Cu.
  - D06V1 was change from Ta (damaged) to Ti (still healthy).
  - D06H3. H4: Movement mechanism has become difficult to operate

Status of HER collimator after 2024c

- Vertical collimator

× = damaged/ ○ = healthy

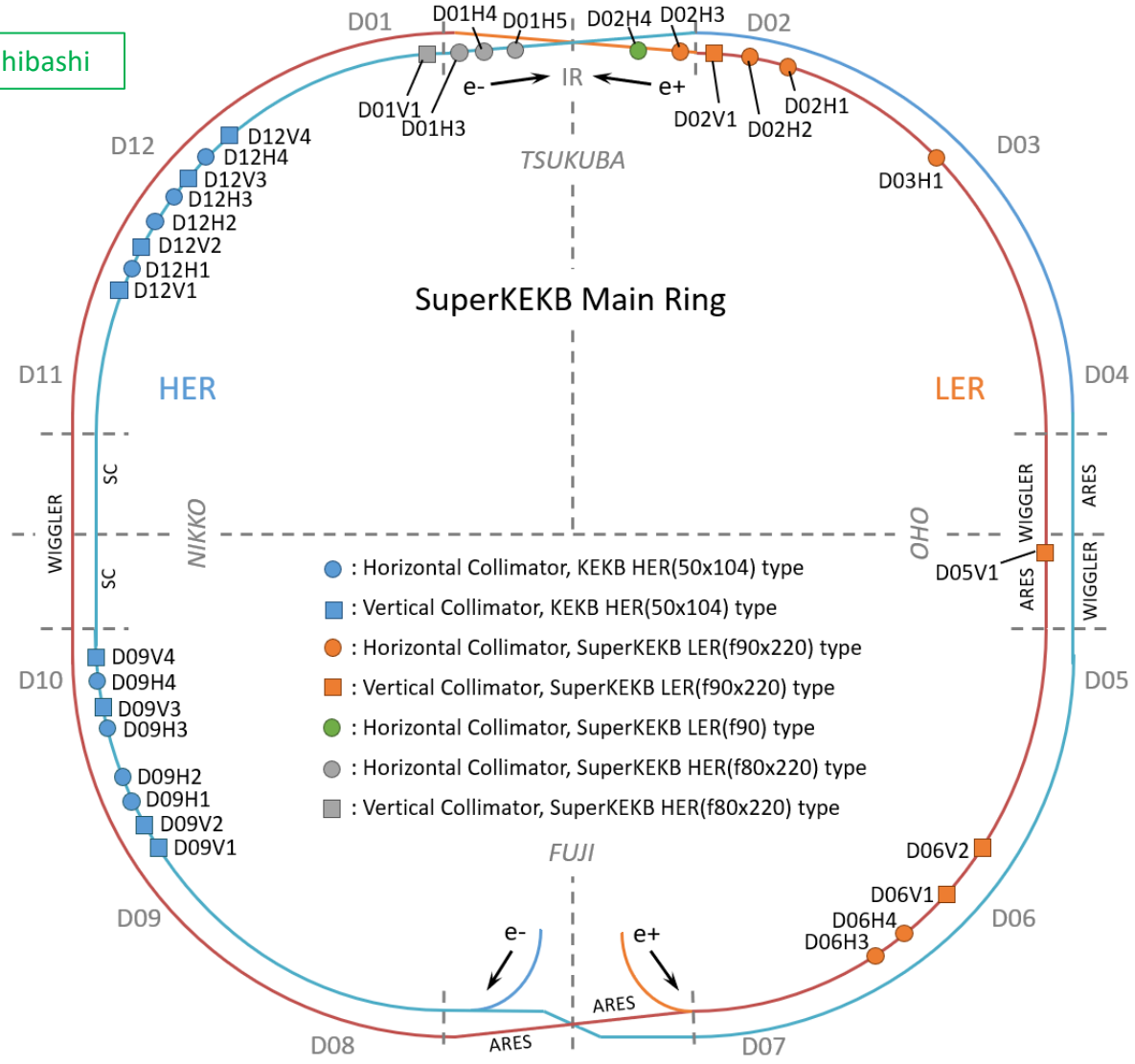
Name	Type	Tip Material	Cu coating	Tip condition
D01V1	SuperKEKB	Ta (10 mm)	○	○
D12V1, V2	KEKB	Ti (40 mm)	○	×
D12V3, V4	KEKB	Ti (40 mm)	○	○
D09V1-V4	KEKB	Ti (40 mm)	○	○

- Horizontal collimator

Name	Type	Tip Material	Cu coating	Tip condition
D01H3-H5	SuperKEKB	W (10 mm)	×	○
D12H1, H3	KEKB	Ti (40 mm)	×	○
D12H2	KEKB	Ti (40 mm)	○	×
D12H4	KEKB	Ti (40 mm)	○	○
D09H1-H4	KEKB	Ti (40 mm)	○	×

- Remarks
  - Drive mechanism of some KEKB-type collimators has been upgraded for precise and stable adjustment.
    - D09V1, D12V1, D12V3, D12V4

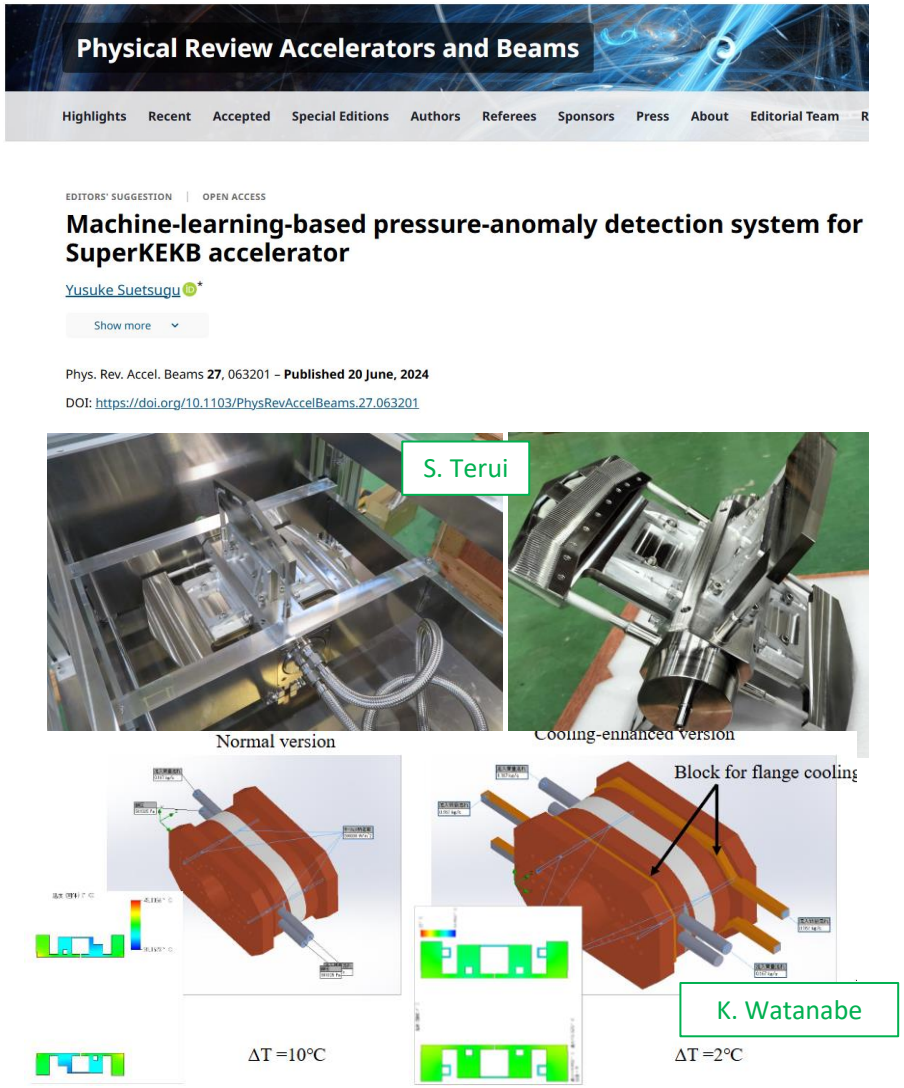
T. Ishibashi



- Remarks
  - Drive mechanism of some KEKB-type collimators has been upgraded for precise and stable adjustment.
    - D09V1, D12V1, D12V3, D12V4

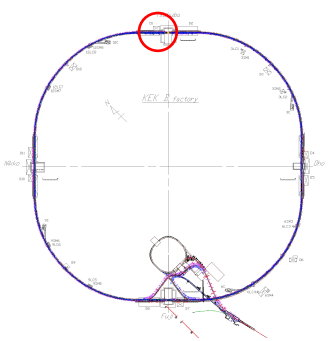
Other activities #1

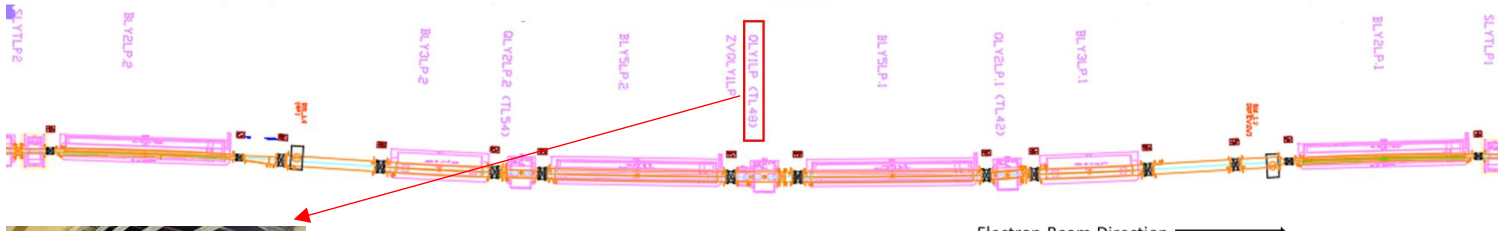
- Development of pressure anomaly detection method applying machine learning Y. Suetsugu
  - Trial operation of pressure anomaly detection program from March 2024.
  - **“Machine-learning-based pressure-anomaly detection system for SuperKEKB accelerator”** https://doi.org/10.1103/PhysRevAccelBeams.27.063201
- Collimator R&D
  - R&D of more robust head material such as MoGr
  - R&D of collimator with revolver heads
- Investigation of properties of VAC seal under high SR, temperature, electron bombardment
- Development of a bellow with enhanced cooling in the Wiggler section
  - To reduce the likelihood of leak caused by thermal deformation

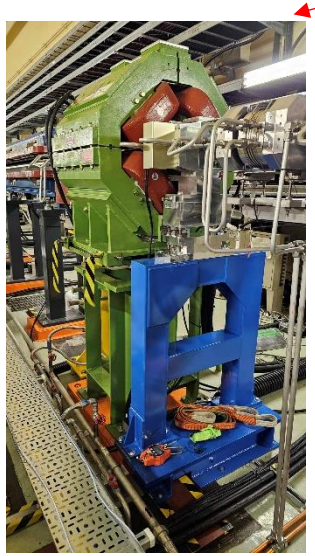


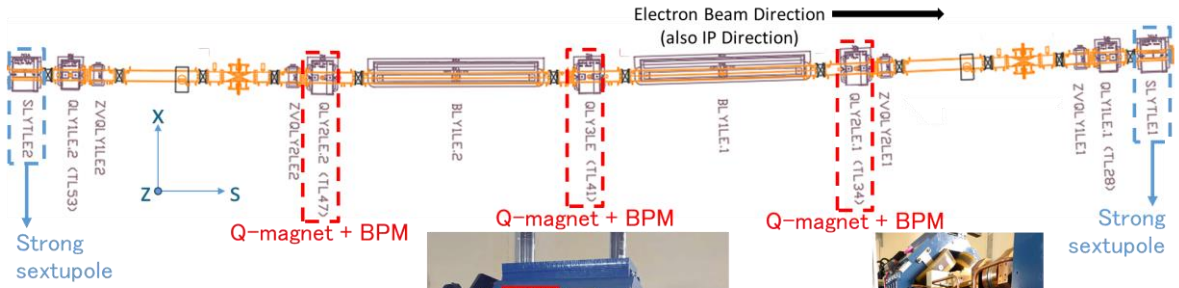
Other activities #2

- Investigation on beam pipe deformation due to SR heating in SLY section. M.L. Yao
  - Measurement of deformation of beam pipes due and displacement of BPM and Q-magnet in SLY section
  - Fabrication of new BPM supports to isolate BPM block from Q-mag.
    - HER: 3 new BPM supports were installed and improved the stability of the Q-magnets and BPMs.
    - LER: 1 new BPM supports were installed. However, the original support of Q-mag was already strong enough, so it was not so effective.









Separate

Q-magnet & Beam pipe

LER:
- 1 BPM support
- 3 contact-type gap sensors

HER:
- 3 BPM supports
- 3 capacitive gap sensors
- 14 thermometers

Comments from last (27th) KEKB Review

1. Based on the PEP-II experience with NEG pump heating from HOM power, monitor a few NEG strips feedthroughs with thermocouples for temperature increases with stored currents. Select NEG pumps that are near collimators or other HOM generating structures.
   Install thermometers → The pressure increase is dependent on the number of bunches (or bunch current) → Install RF Shield gaskets at ion pump and NEG pump ports → Maybe effective
2. In view of maintaining the robustness and availability of the vacuum system, promote the early implementation for the detection of pressure anomaly in the daily pressure follow-up and set-up a consolidation program of the vacuum system when required.
   Suetsugu-san's program
3. In connection with the sudden beam loss investigation, look for the eventual presence of debris inside the vacuum components dismounted during LS1 (or later), and routinely inspect the vacuum chambers for particulates.
   Many dust were found in the beam pipes with electrodes dismounted during the LS1 (also in other beam pipes). Later, after the knocker study at the Nikko Wiggler section during the last summer shutdown, we recognized there might be more dusts in the beam pipes in the Wiggler sections than beam pipes in the other sections. That's why we decided to flip the beam pipes with electrodes during the last summer shutdown.

   We found that the primary dust causing SBL is mainly composed of silicon, originating from VACSEAL. However, other dust particles, such as copper, iron, and aluminum, are also present, possibly originating from the beam pipe or environmental contamination.

Plan for this long shutdown

- Clean inside of Wiggler chamber and bellows, i.e., completely remove VACSEAL on the inner surface
- Check inside of IR beam pipe (HER) to investigate the cause of pressure bursts
- Install additional vacuum gauges near IR region
  - To investigate the causes of pressure bursts
- Check/Change Collimator Heads, and relocate a collimator at arc section
- Promote the R&D of new KEKB-type collimator with water cooling
  - To reduce the nonlinear pressure increases
- Investigation on Mysterious Abort
  - D02 x 1, D05 x 1, D06 x 1, D07 x 3
  - Due to abnormal abort signals (related to PLC)

Summary

- Vacuum scrubbing is proceeding steadily
- Collimator Head Damage
  - LER D02V1, D05V1
- Several leaks (mostly in the Wiggler section): Most of them were successfully stopped
  - Development of a bellow with enhanced cooling
- Attached desiccant to the CCG D07_H07 and feedthrough of IP D12_L23
  - Working well so far
- Localized nonlinear pressure increases
  - Some thermometers were installed
  - Results suggest that HOMs might be the cause
  - RF gaskets were installed at several Ips and NEG pumps. The results are still under observation. Further investigation is ongoing
  - Special attention is required for HER D09V3
  - Promote the R&D of new KEKB-type collimator with water cooling
- SBL Study: After conducting knocker studies, flipping and cleaning chambers, we suspected that the main cause of the SBL is the dusts from VACSEAL in the Wiggler section. The details are still under investigation
- Although there are concerns about localized pressure increases, the vacuum system still has room for further beam current increases

Fin.

Thank you for your attention.

Backup

- VACSEAL: https://www.vacseal.net/

Features:

- The main component is silicone resin.
- The usable temperature range is from -200° C to 450° C.
- Adheres to most solid materials.
- Stable against liquid nitrogen.
- Can be used in environments such as high vacuum and ultra-high vacuum.
- Can be removed using organic solvents.
- Curing time:
  - At 260° C: 1 hour.
  - At 300° C: 30–40 minutes.
  - At room temperature: 5–6 days.

Applications:

- Sealing leaks at the junctions of glass, ceramics, and metal.
  - (Examples: viewports, electrical feedthroughs, pressure gauges).
- Sealing leaks in metal gasket parts of UHV equipment.
  - (Examples: flanges, flange welds, bellows welds).
- Sealing leaks and adhering to glass vacuum containers.
  - (Examples: Braun tubes, blister windows).
- Linear leaks in welds.
- Leaks in dewars.