Vacuum

Collimator will be presented by Ishibashi_san (14th Dec.)

The 26th KEKB Accelerator Review Committee

13th Dec. 2022

Kyo Shibata

On behalf of KEKB Vacuum Group

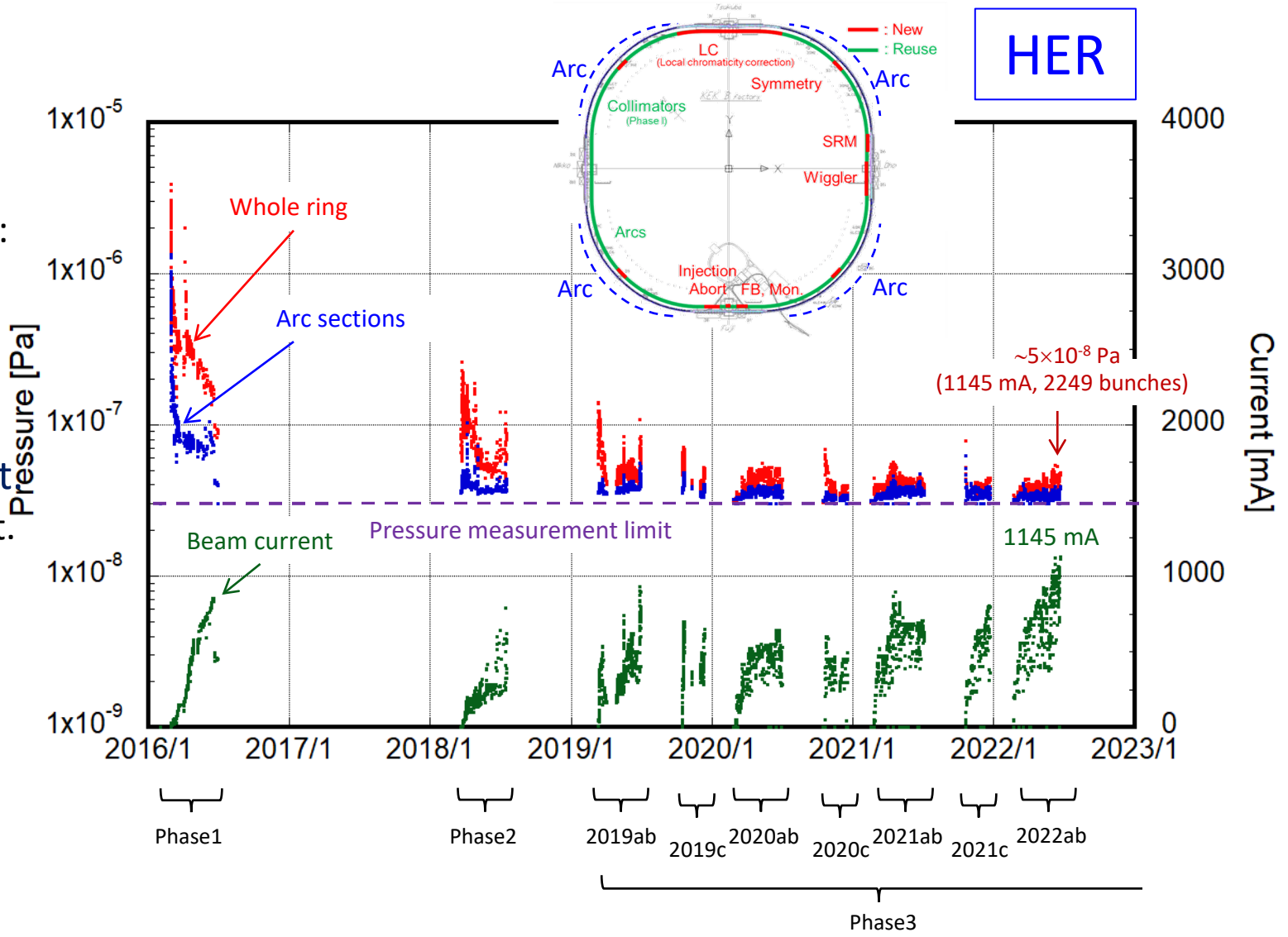
Contents

- MR
  - Vacuum System Status
  - Major troubles (from 2019c to 2022ab*)
- DR
  - DR Vacuum System Status
- Vacuum works during LS1
- Summary

* Last vacuum status report was made by Ishibashi_san at 23rd KEKB Review (immediately after 2019ab run).

MR : HER pressure and beam current

- HER pressure is decreasing steadily although beam current is increasing gradually.
  - Maximum beam current : 1145 mA
  - Pressures with beam at the end of 2022ab:
    ~5×10^{-8} Pa (1145 mA, 2249 bunches)
  - Base pressure without beam: ~3×10^{-8} Pa (Measurement limit in cold cathode gauges)
- Pressure is approaching measurement limit.
  - Accurate pressure measurement is difficult.
- HER pressure is lower than LER pressure due to memory effect.
  - See following slides.
  - ~82% of beam pipes, bellows chambers, and pumps were reused.

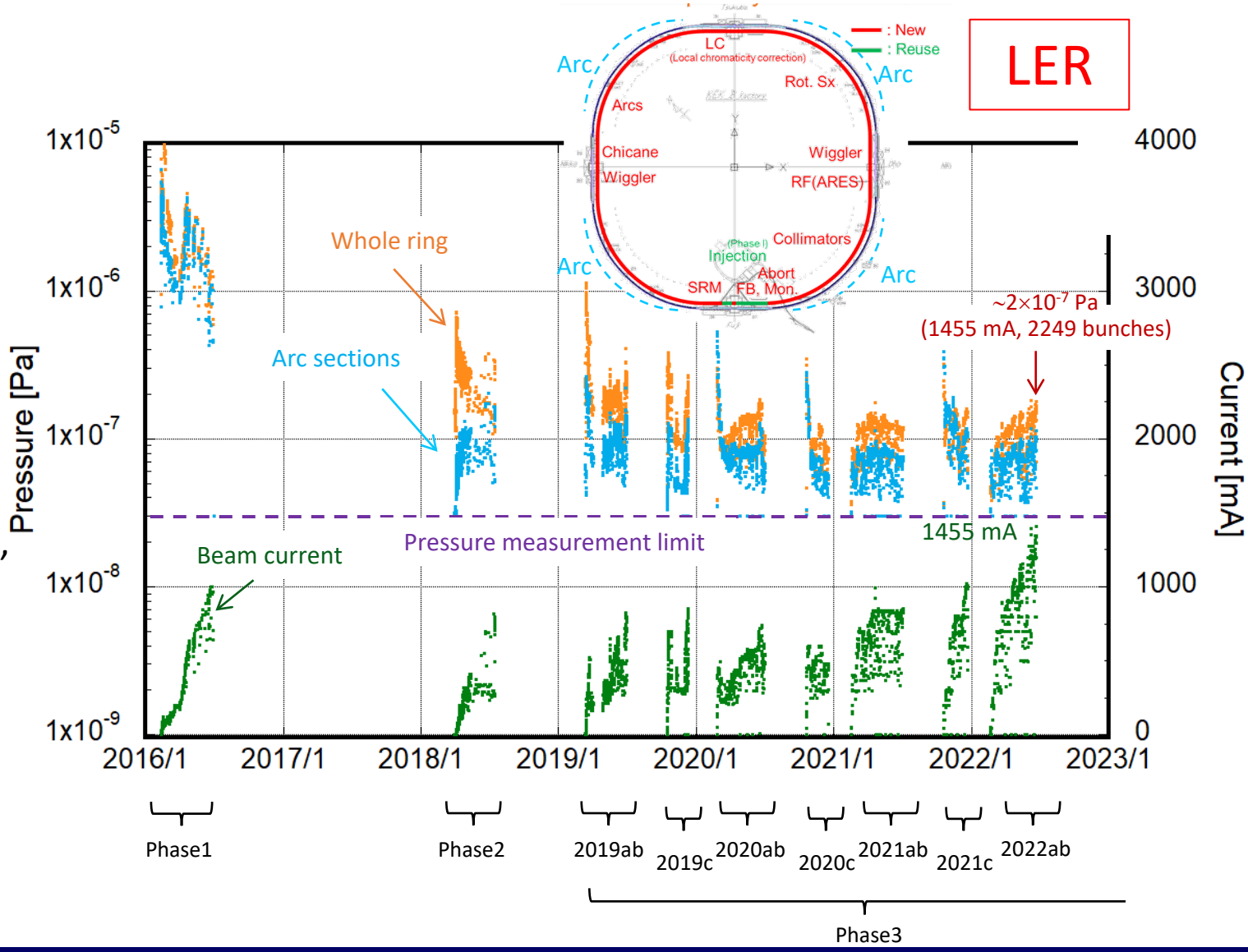


MR : LER pressure and beam current

- LER pressure is decreasing steadily although beam current is increasing gradually.
  - Maximum beam current : 1455 mA
  - Pressures with beam at the end of 2022ab:

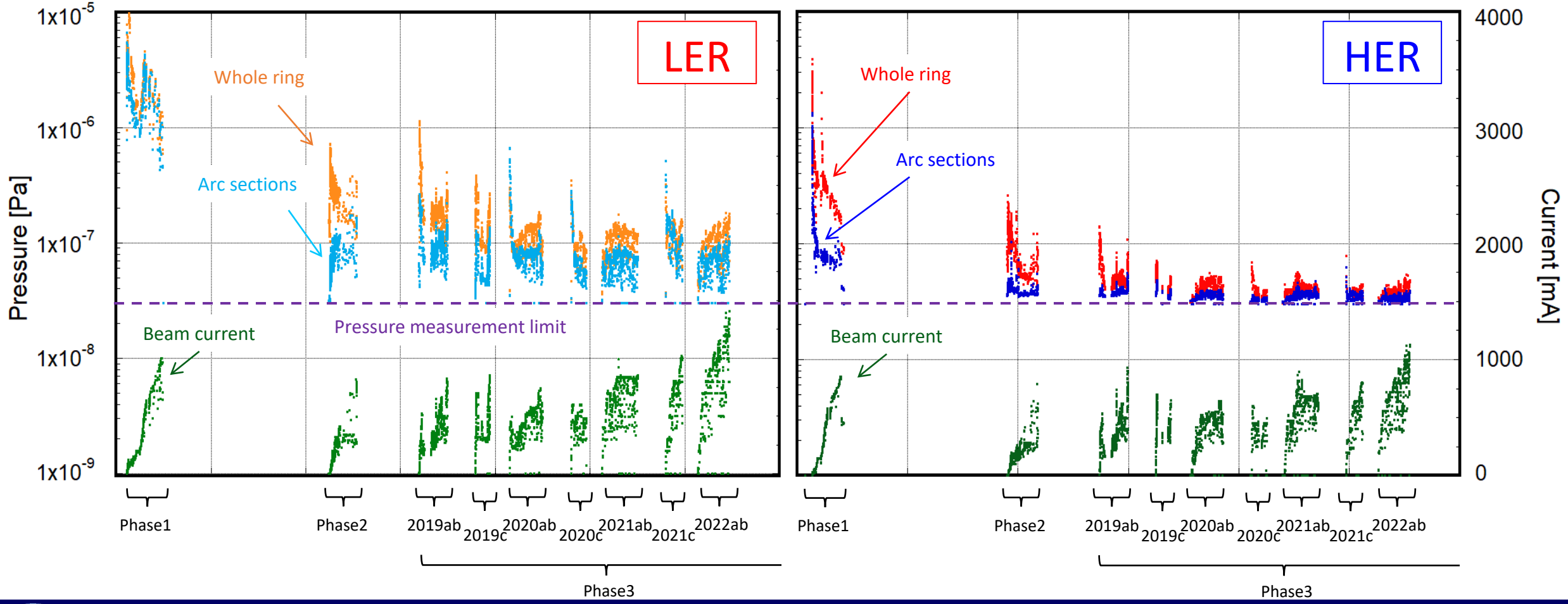
    ~2×10^{-7} Pa (1.455 mA, 2249 bunches)
  - Base pressure without beam: ~3×10^{-8} Pa (Measurement limit in cold cathode gauges)

- LER pressure is higher than HER pressure.
  - ~ 93% of beam pipes and bellows chambers, and pumps were renewed. (no memory effect)
  - More vacuum works have been done in LER than HER.



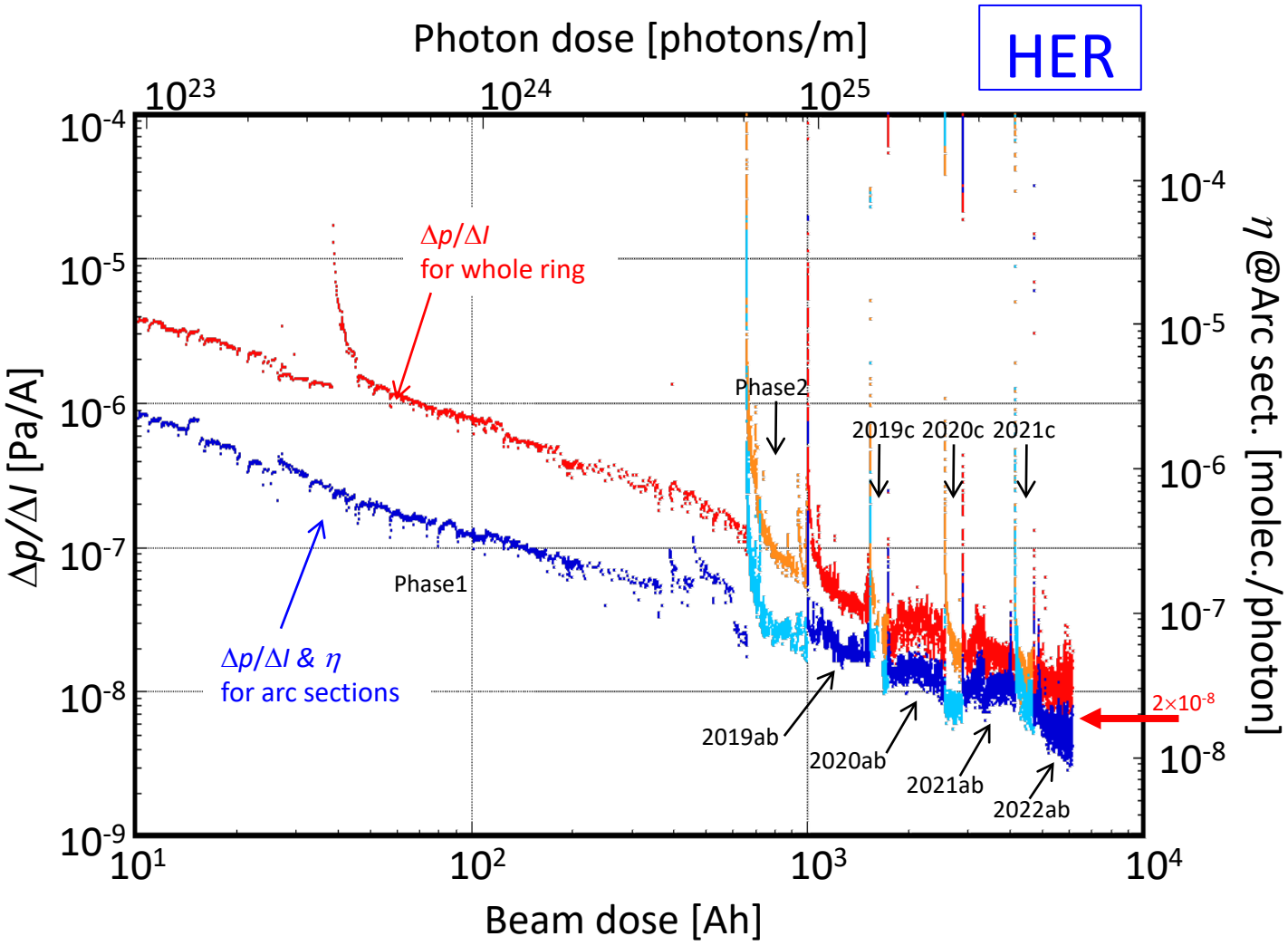
MR : pressure and beam current

- Comparison between LER and HER



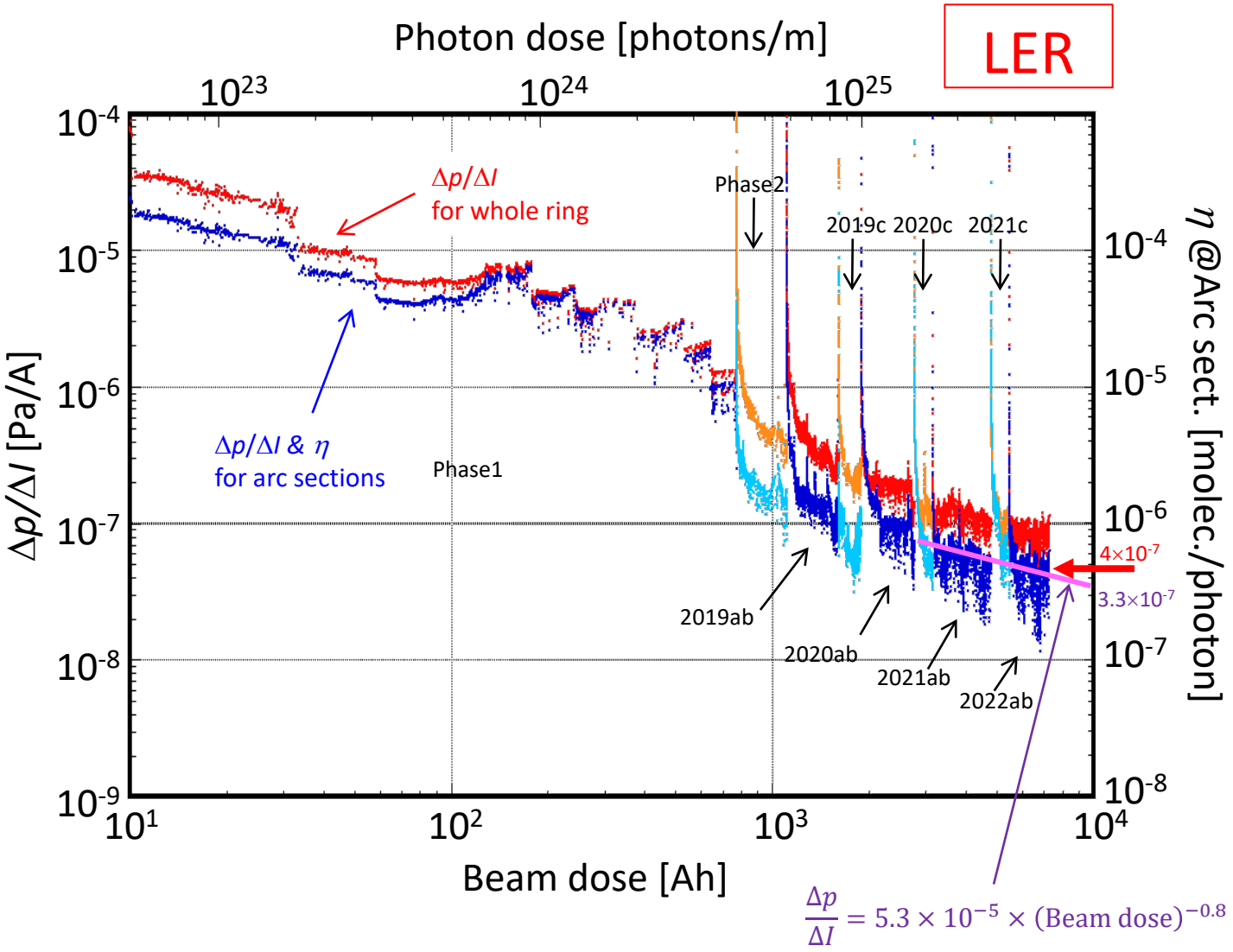
MR : HER vacuum scrubbing

- For HER, $\Delta p/\Delta I$ and η show the vacuum scrubbing is progressing steadily.
  - $\Delta p/\Delta I$ [Pa/A]: pressure rise per unit beam current as function of the beam dose
    - $\Delta p/\Delta I = (3 \times p_{measure} - p_{base})$ / beam current
      - $p_{measure}$: pressure measured by CCG at pumping port
      - $3 \times p_{measure}$: estimated pressure in beam channel (3 is conversion factor from pressure at CCG to pressure in the beam channel)
      - p_{base} : base pressure (3.0×10^{-8} Pa)
  - η [molec./photon]: photon-stimulated gas desorption rate at arc sections as a function of photon dose
    - η [molec./photon]$= 94.7 \times \Delta p/\Delta I$ [Pa/A] $\times S$ [$m^3s^{-1}m^{-1}$]
      - S [$m^3s^{-1}m^{-1}$] : Pumping speed per unit length (0.03 $m^3s^{-1}m^{-1}$ for HER)
    - At the end of 2022ab (at 5.7×10^{25} photons/m), η reached 2×10^{-8} molec./photon



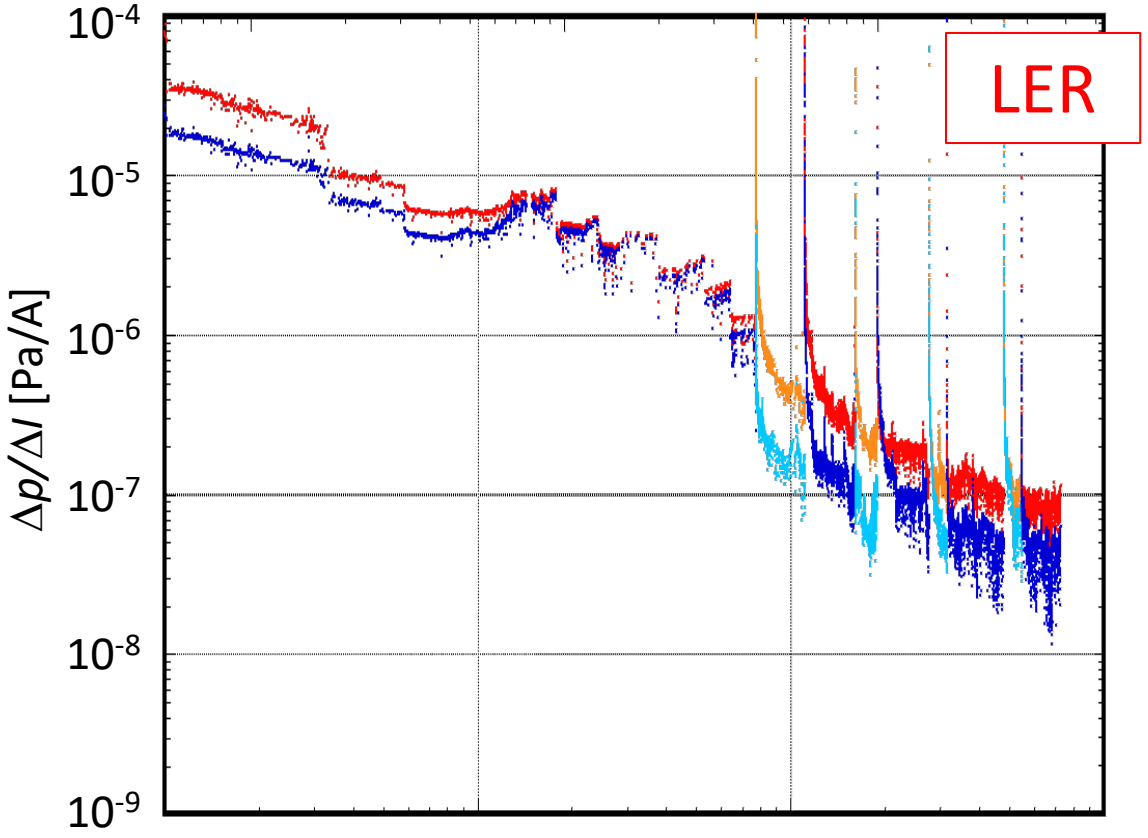
MR : LER vacuum scrubbing

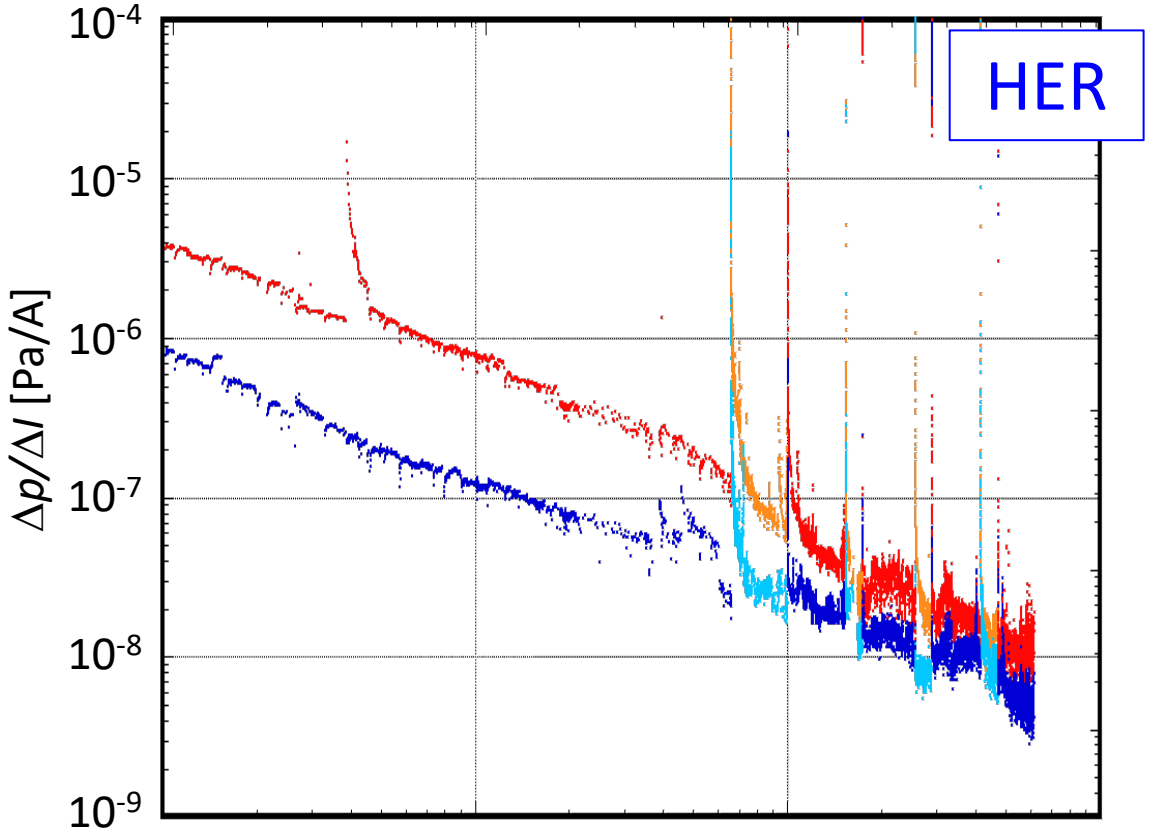
- For LER, $\Delta p/\Delta I$ and η show the vacuum scrubbing is progressing steadily, but still much larger than those for HER.
  - η [molec./photon]: photon-stimulated gas desorption rate at arc sections as a function of photon dose
    - η [molec./photon]= 166 × $\Delta p/\Delta I$ [Pa/A] × S [$m^3s^{-1}m^{-1}$]
      (S [$m^3s^{-1}m^{-1}$] : Pumping speed per unit length (0.06 $m^3s^{-1}m^{-1}$ for LER))
    - At the end of 2022ab (at 3.9×10^{25} photons/m), η reached 4×10^{-7} molec./photon
  - $\Delta p/\Delta I$ evaluation by fitting curve:
    - $\Delta p/\Delta I$ [Pa/A] = $5.3\times10^{-5}\times$(beam dose)$^{-0.8}$
    - At 1×10^4 Ah, $\Delta p/\Delta I$ [Pa/A] will reach 3.3×10^{-7} Pa/A.



MR : vacuum scrubbing

- Comparison between LER and HER





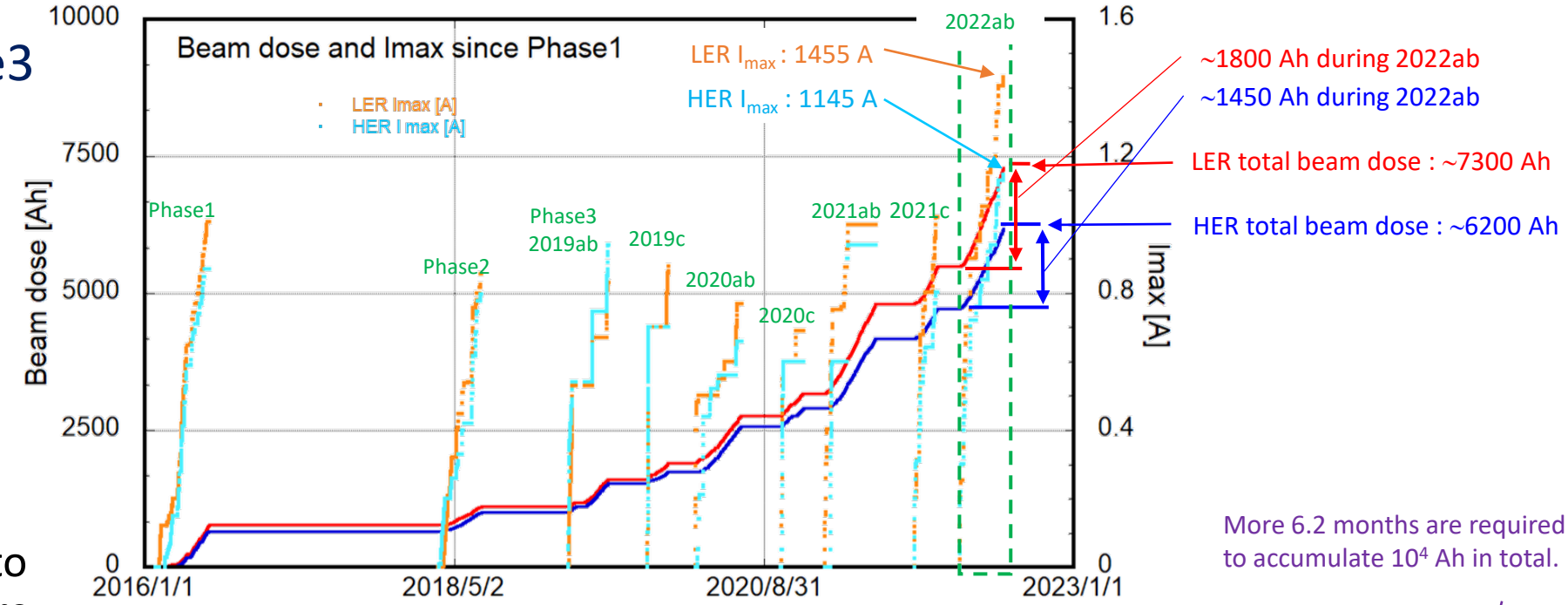
MR : maximum beam current and beam dose

- Beam dose during Phase3 2022ab
  - HER : ~1450 Ah
  - LER : ~1800 Ah
  - ~122 days

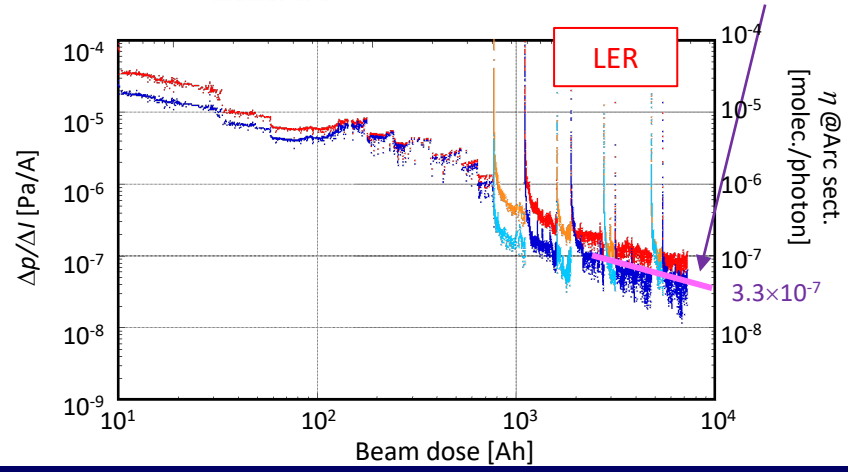
  ⇩ For LER

  - ~ 2.3×10^{-3} months/Ah
  - It will take ~2.3 months to accumulate 1000 Ah more.

  - It will take ~6.2 months more to accumulate 10^4 Ah in total and reach ~3.3×10^{-7} Pa/A.

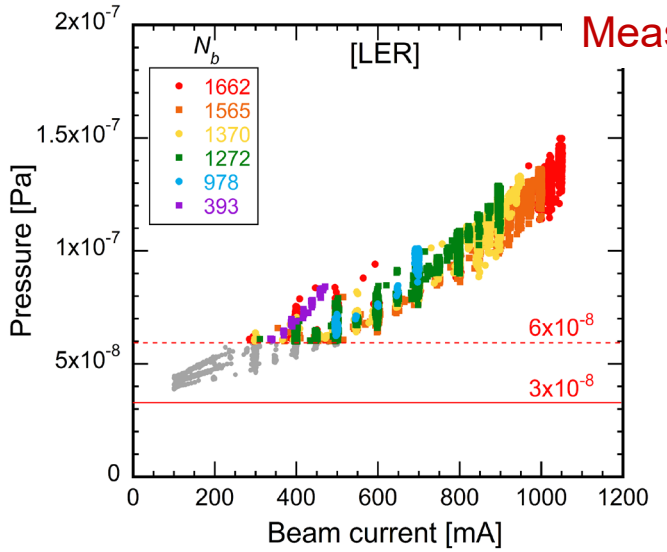


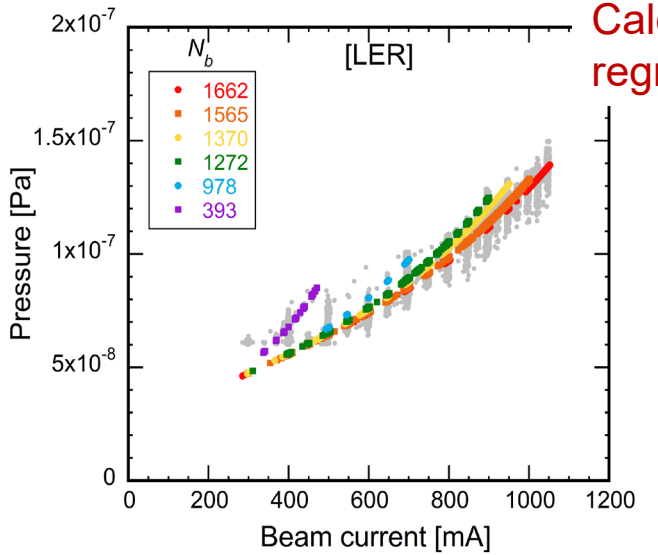
More 6.2 months are required to accumulate 10^4 Ah in total.



MR : beam current dependence of pressure

- LER Pressure rise is not in proportional to the total beam current (*I*) recently.
  - Pressure rise rate becomes larger at higher beam currents.
  - Pressure depends on the number of bunches (N_b).
- It seems that pressure is determined by thermal desorption (TD) and photon-stimulated desorption (PSD).
  - Measured pressures are well reproduced by the regression curve with following assumption and experimental result.
    - Regression curve : $p = p_0 + \Delta p_p + \Delta p_t = p_0 + C_p I + C_t (I^2/N_b)^2 = 2.42 \times 10^{-8} + 7.64 \times 10^{-11} I + 7.64 \times 10^{-11} (I^2/N_b)^2$
      - Assumption (PSD): $\Delta p_p \propto I$
      - Experimental result (TD): $\Delta p_t \propto (\Delta T)^2 \rightarrow \Delta p_t \propto (I^2/N_b)^2$
      - Constants (p_0, C_p, C_t) were determined by multi regression analysis using data for LER.
  - There may be some vacuum components heated by HOM?



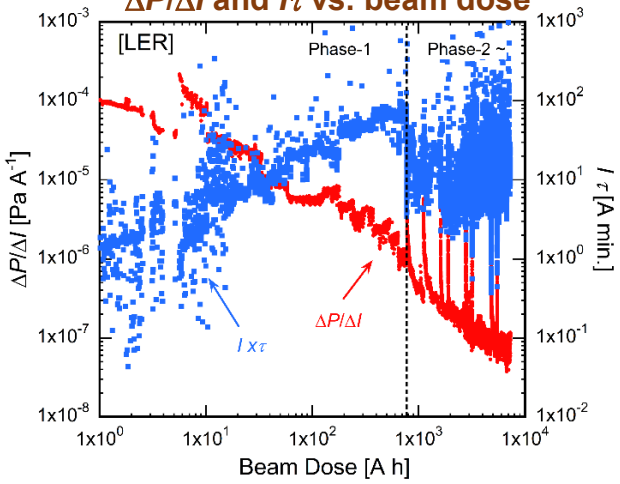


Y. Suetsugu

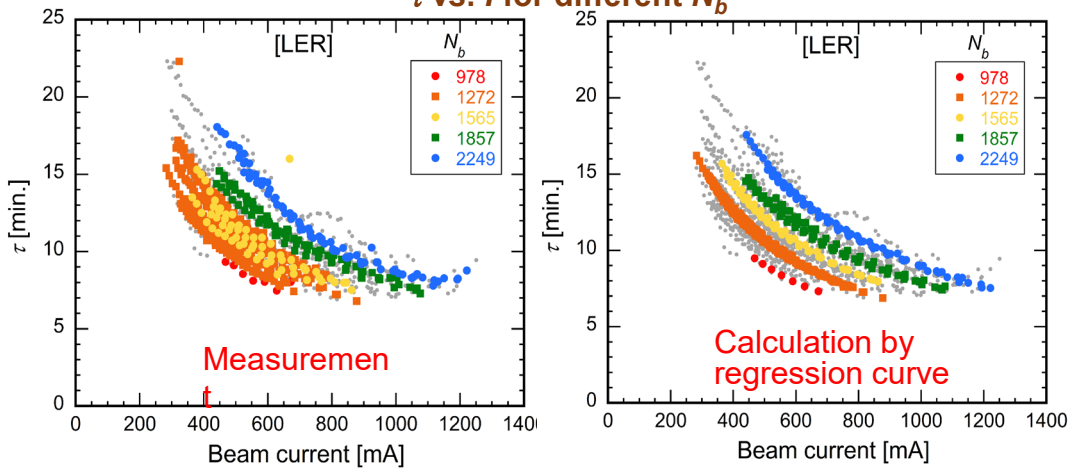
MR : contribution to beam lifetime

- Recent single beam lifetime is not limited by only pressures but also the Touschek effect (Touschek lifetime).
  - Pressures have been decreasing steadily though the apertures are strongly restricted by beam collimators.
  - Beam emittance is small (ε_y = ~20 pm) and bunch length is short (σ_z = ~6 mm).
- Contribution of the pressure to beam lifetime (τ) was estimated by multi regression analysis for LER.
  - Measured lifetime are well reproduced by the regression curve with following assumption.
    - Regression curve : $1/\tau = 1/\tau_p + 1/\tau_t = C_p p + C_t I/(N_b \sigma_z) = 2.61 \times 10^5 p + 0.979 I/(N_b \sigma_z)$
      - Assumption1 (beam lifetime due to pressure): $\tau_p \propto p$
      - Assumption2 (Touschek lifetime) : $\tau_t \propto I/(N_b \sigma_z)$
        - Dependence on the emittances was not included in the Touschek effect here, since the measured emittances were scattered.
      - Constants (C_p, C_t) were determined by multi regression analysis using data for LER.
  - For LER single beam, approximately 60-80% of the total lifetime is determined by Touschek lifetime at present.
    - For HER single beam, approximately 100% of the total lifetime is determined by Touschek effect.

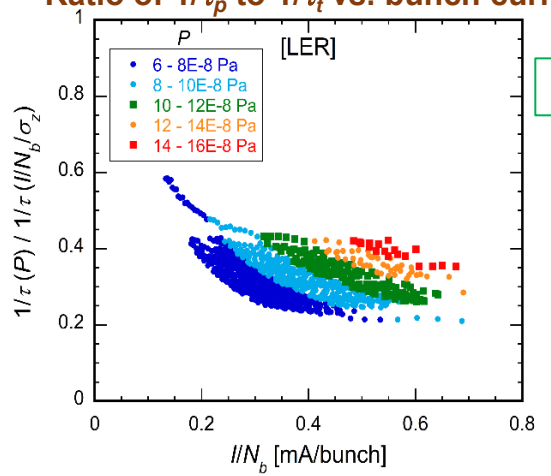
$\Delta P/\Delta I$ and $I\tau$ vs. beam dose



τ vs. I for different N_b



Ratio of $1/\tau_p$ to $1/\tau_t$ vs. bunch current

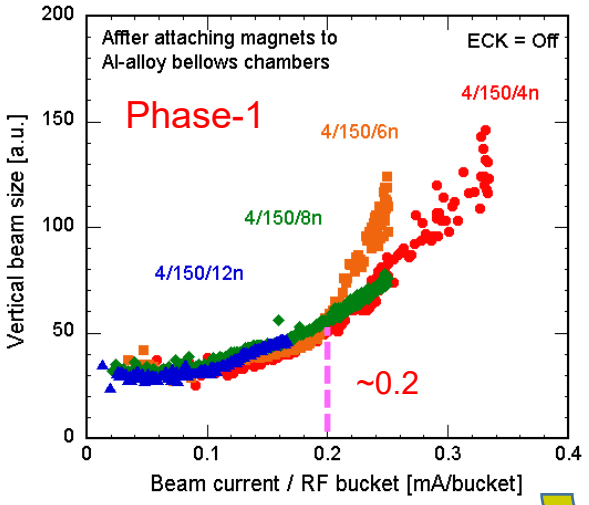


Y. Suetsugu

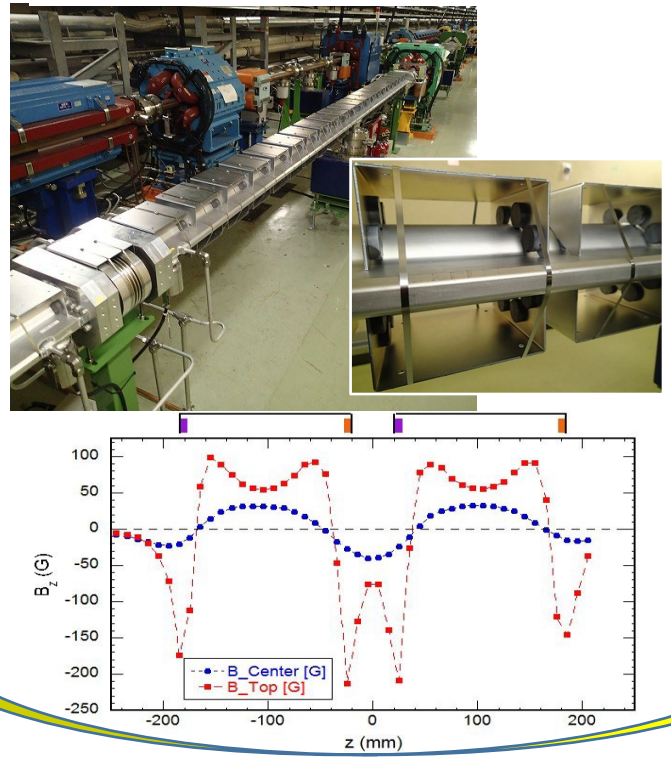
MR : electron cloud effect

- At present, any obvious signs of electron cloud effect are not observed in usual collision experiments.
  - Current linear density is now over 0.53 mA/bunch/RF-bucket

Vertical beam size vs. current density in Phase-1



Magnet units attached to beam pipes



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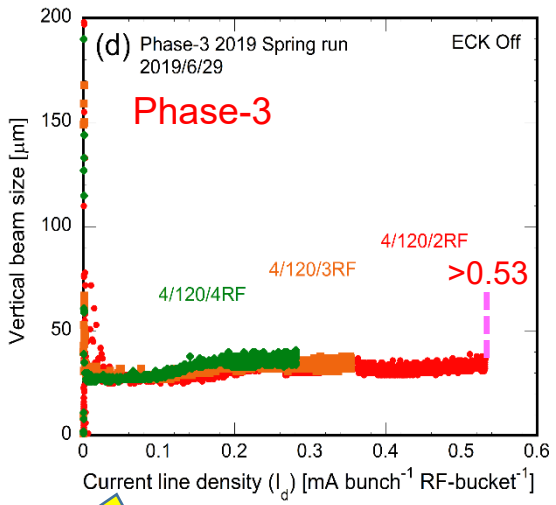
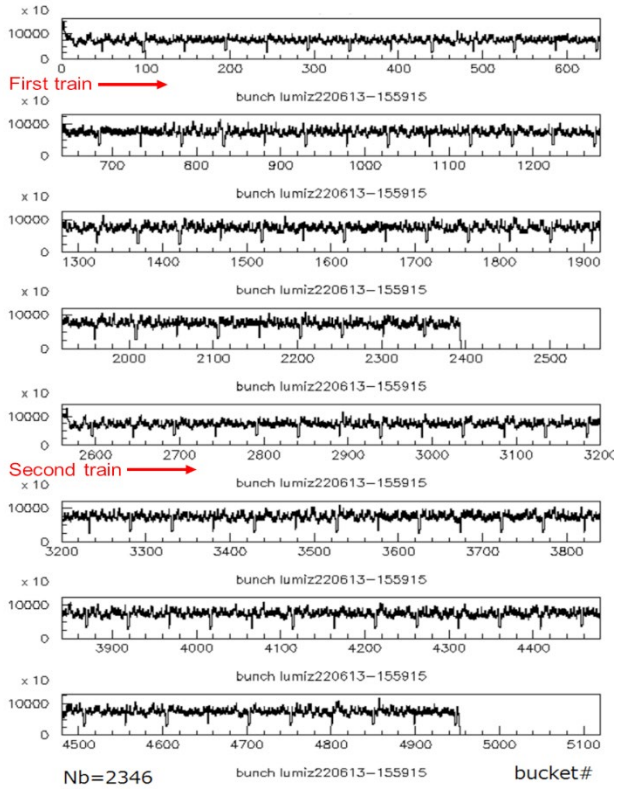
Vertical beam size vs. current density in Phase-3

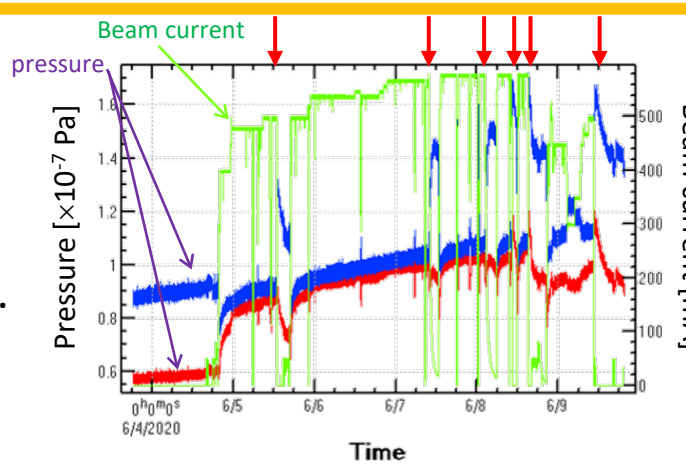


Bunch by bunch luminosity along a train by ADLM (S. Uehara)

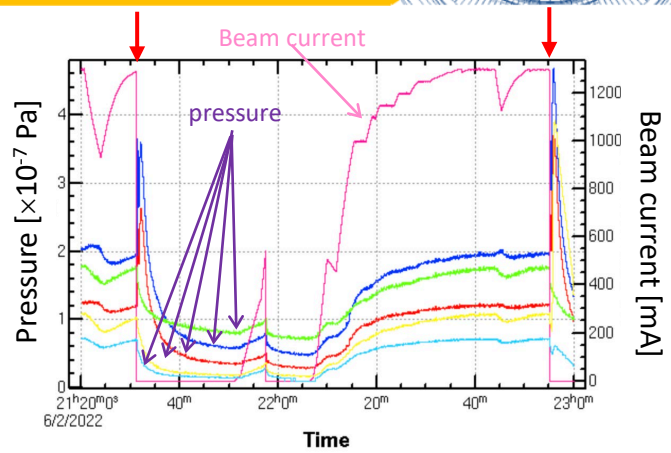


MR : major troubles #1

- Vacuum leak (from 2019c) #1&2:
  - Vacuum leaks at LER D04 wiggler sections (2020ab, 2022ab)
    - Abnormal pressure rises due to vacuum leak were observed immediately after beam abort.
      - Possible cause was thermal expansion due to strong SR irradiation.
      - Pressure was still low enough to continue beam operation.
    - Vacuum leak was stopped by “flange refastening” and “Vac seal injection”.
      - We tried refastening the suspect flanges without identifying the leak location on maintenance day.
      - It was confirmed that vacuum leakage had occurred at flange connection.
      - Vac seal was injected into the flange connection.
    - Countermeasure
      - Bellows chambers were replaced to new ones with SR masks.
      - Air and water cooling were reinforced.
      - See page 24.

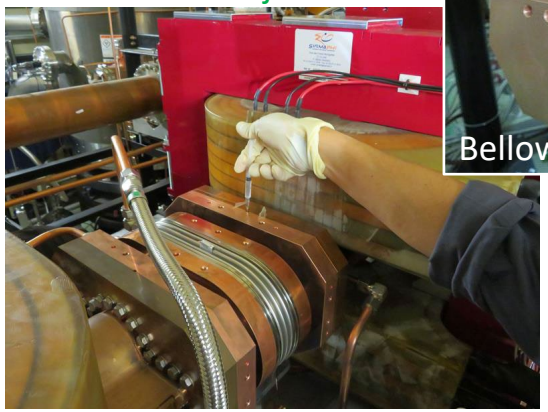


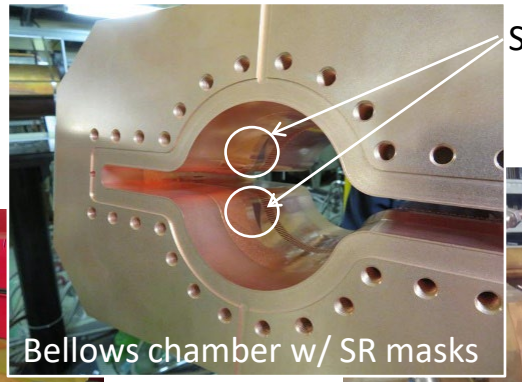
Vacuum leak during 2020ab

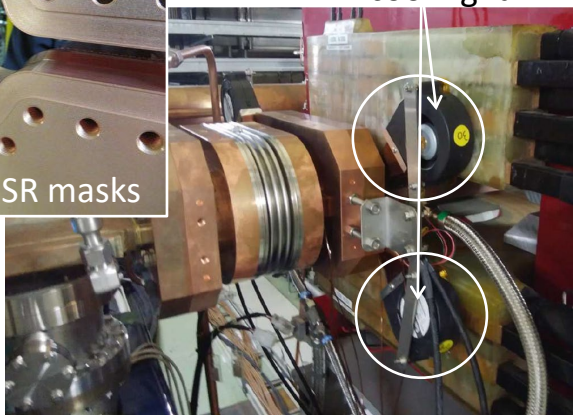


Vacuum leak during 2022ab

Vac seal injection



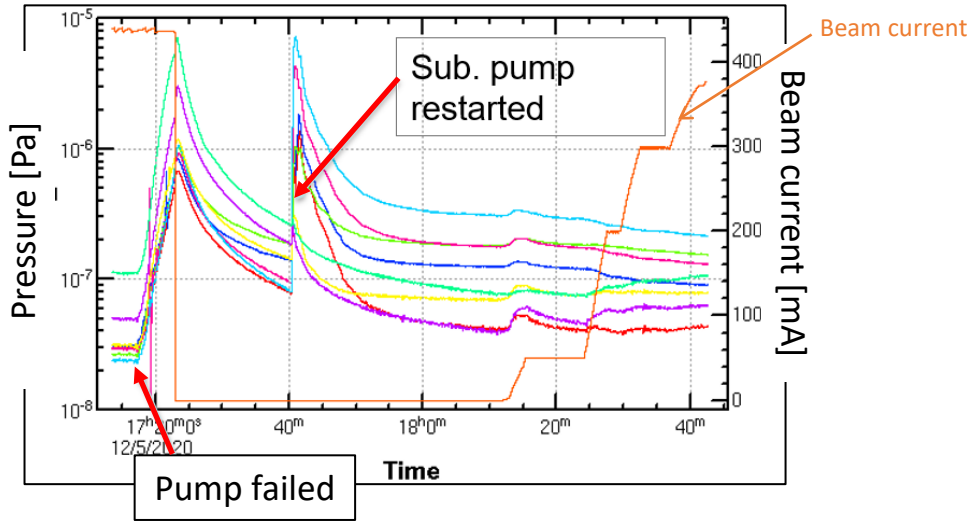


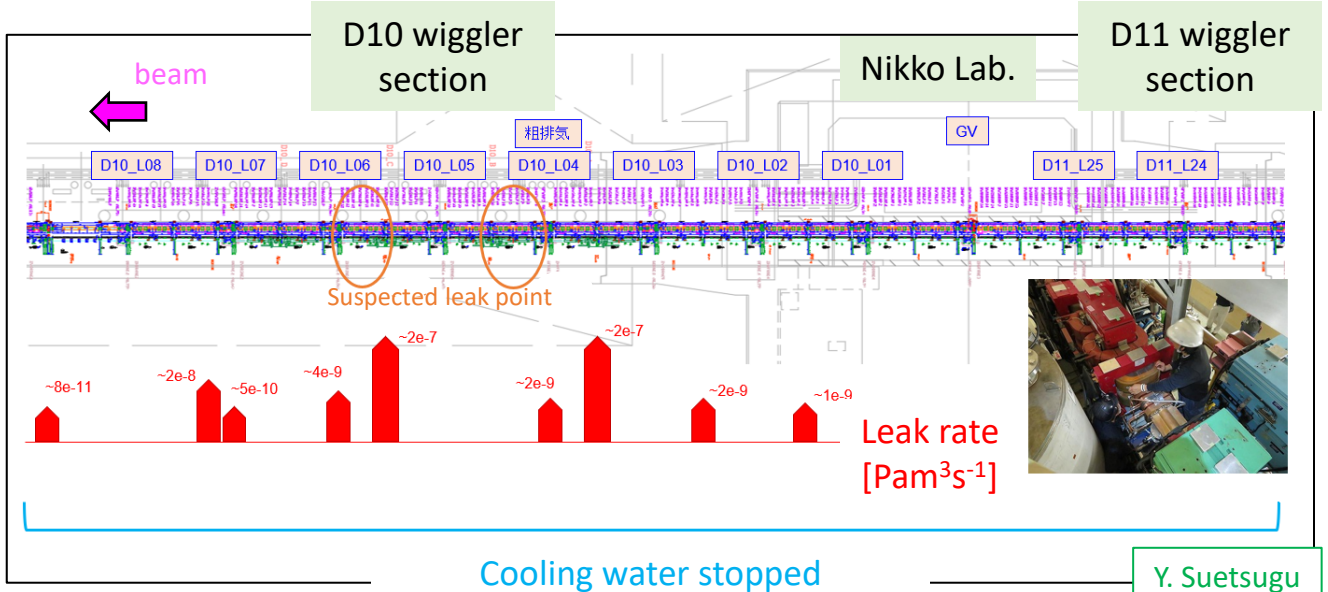


Air cooling reinforcement

MR : major troubles #2

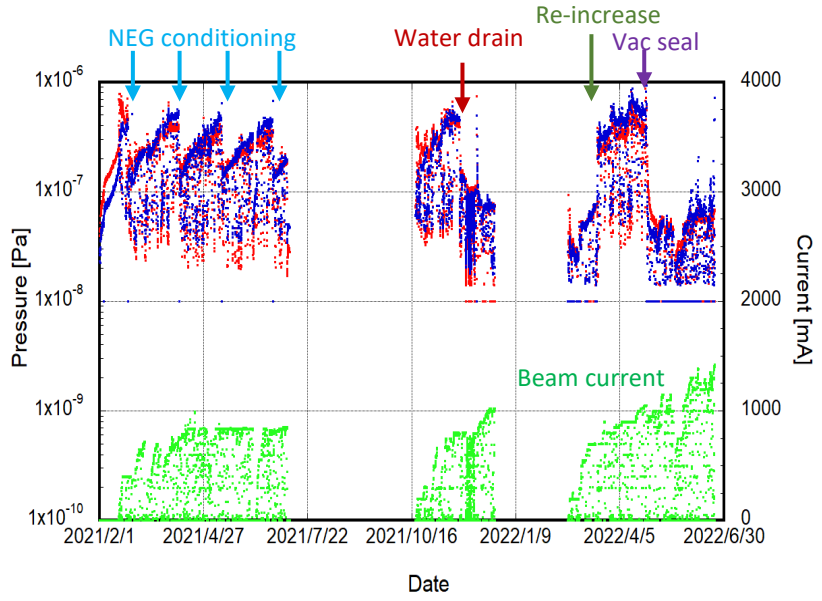
- Vacuum leak (from 2019c) #3:
  - Vacuum leaks at LER D10 wiggler section (2020c)
    - Cooling water stopped due to pump failure, but beam operation was continued for a few minutes.
      - "Low water flow" alarm did not issue beam abort request because flow meters often failed.
      - At final, beam abort was requested by "high temperature & low water flow" alarm.
    - After cooling water flow was made by sub pump, beam operation was resumed.
    - Some vacuum gauges at D10 wiggler section showed higher pressures than usual.
      - Pressures were still low enough to continue beam operation.
    - Leak test was performed on the next maintenance day.
      - It was found that vacuum leaks occurred at 9 flange connections.
    - Vacuum leaks were stopped by "flange refastening" and "Vac seal injection".
  - Countermeasure
    - Interlock modification
      - When several "Low water flow" alarms are issued simultaneously, beam abort is requested.
      - Water flow rate of main pipe was newly monitored by vacuum group.
      - When cooling water flow rate of main pipe drops, beam abort is requested.

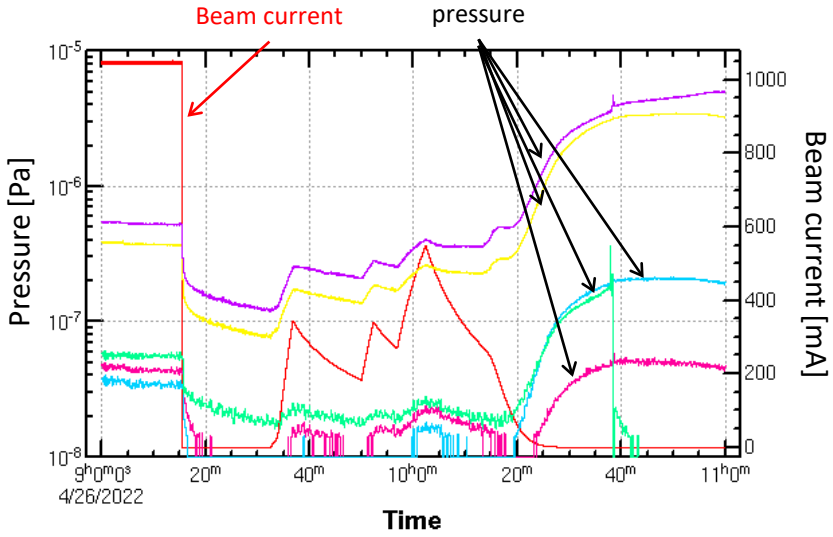




MR : major troubles #3

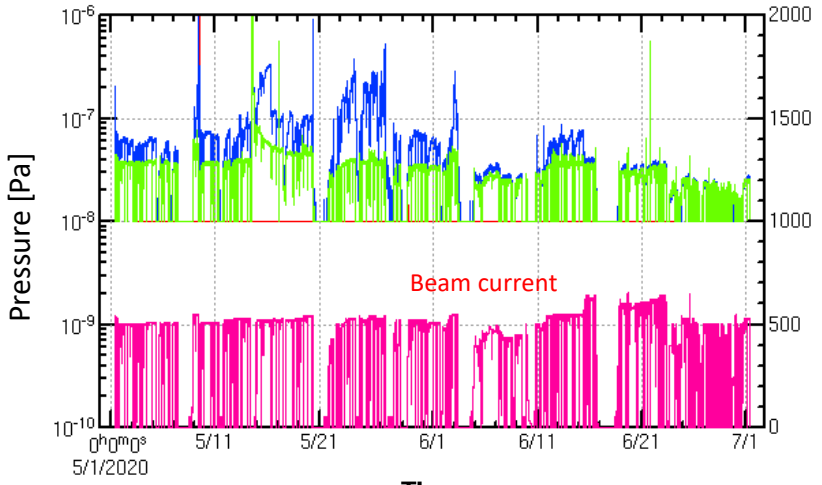
- Vacuum leak (from 2019c) #4:
  - Gradual pressure increase at LER D04 weak bend section
    - Pressure increase had been observed since the start of 2021 run.
    - NEG pump conditioning was effective to temporarily reduce pressure, but pressure gradually increased again.
    - Vacuum leak test had been carried out several times, but no vacuum leak had been detected.
    - Pressure dropped when cooling water was drained from cooling channel for leak test.
      - Leak test showed no vacuum leaks from the cooling channel.
      - Abnormal pressure increase stopped after that.
    - Abnormal pressure re-increased during 2022ab.
  - Vacuum leak from cooling channel at LER D04 weak bend section
    - Large pressure increase was observed with low beam current during 2022ab.
    - At final, vacuum leak from the cooling channel was detected.
    - “Vac seal” was injected into the cooling channel by an injector.

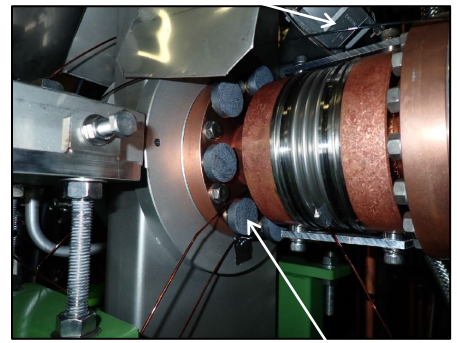


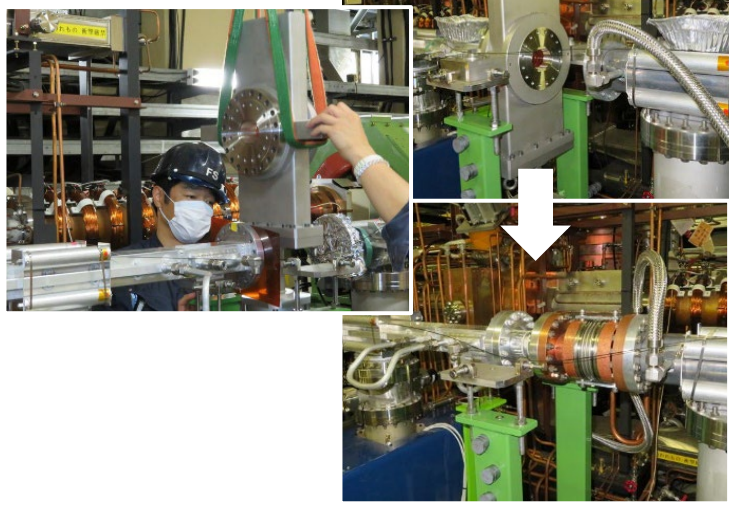


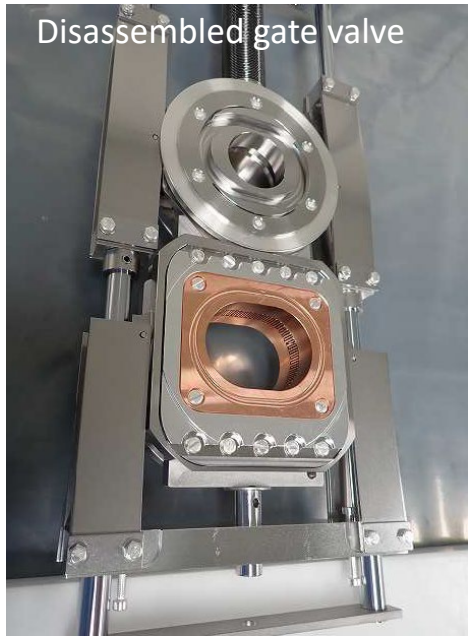
MR : major troubles #4

- Abnormal pressure rise #1
  - Abnormal pressure rise near gate valve was observed at HER inj. section (2020ab).
    - Pressure did not depend on beam current.
    - Abnormal pressure rise seemed to have improved.
      - Cause of improvement is still unknown.
      - Countermeasures were taken, but their effects were not clear.
        - Permanent magnets to suppress multipactor effect.
        - Air cooling reinforcement
  - Possible cause of abnormal pressure rise is abnormal heating of gate valve.
    - During summer shutdown after 2020ab run, the suspected gate valve was replacement with dummy pipe.
    - No abnormal pressure rise has been observed after that.
    - Removed gate valve was disassembled and checked, but no obvious abnormality was found.
      - Is there small gap at opening and closing mechanism of gate valve? (See next slide)



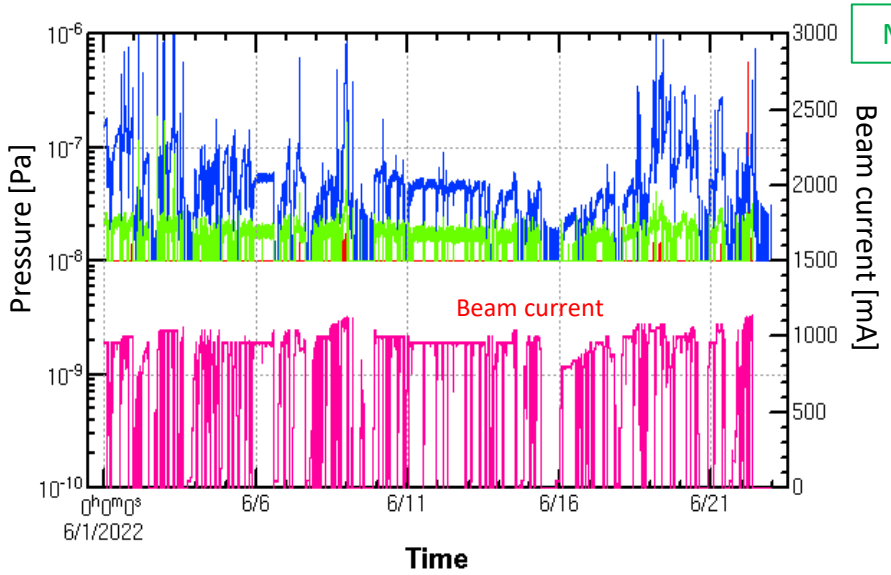




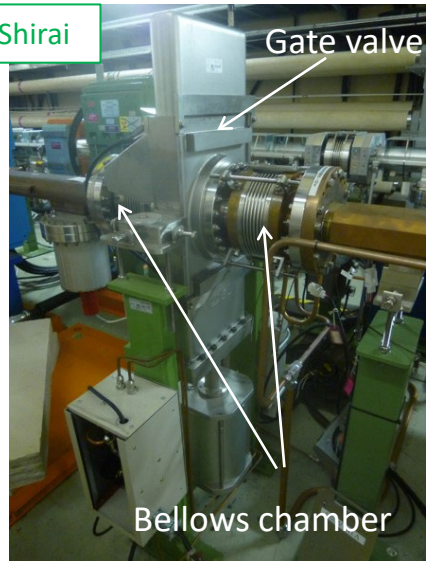


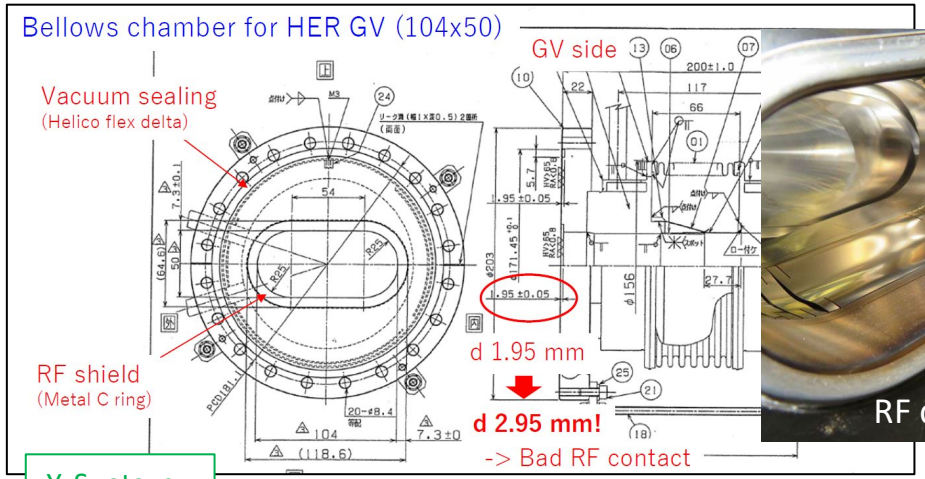
MR : major troubles #5

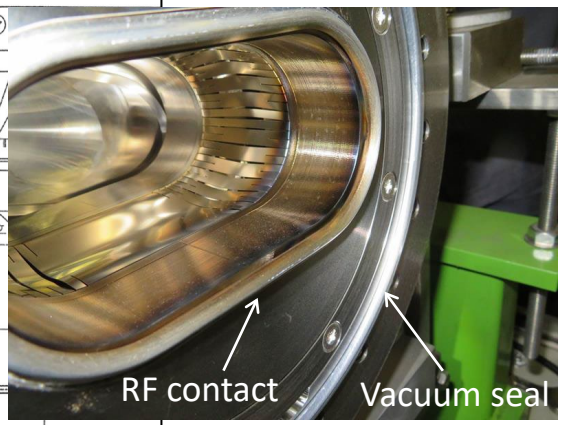
- Abnormal pressure rise #2:
  - Abnormal pressure rise near gate valve was observed at HER D12 arc section (2022ab).
    - Abnormal temperature rise of gate valve was also observed.
  - During LS1, bellows chambers connected to the gate valve were disassembled for internal check.
    - It was found that some parts were discolored probably due to heating and/or discharge.
      - RF shield of the gate valve
      - RF contact installed between the gate valve and bellows chamber
    - It was also found that groove for the RF contact on the bellows chamber was 1 mm deeper than design.
    - Possible cause is small gap due to poor contact between gate valve and bellows chamber.
  - Gate valve and bellows chamber were replaced with new ones.
    - It was confirmed that the groove for the RF contact on the bellows chamber is correct.
    - It was confirmed that the pressure and temperature of other HER gate valves are normal.
      - Pressure at this gate valve was a little similar to pressure at the gate valve at HER inj. section. (see previous page)
      - Gate valve at HER inj. Section had a similar problem?



M. Shirai





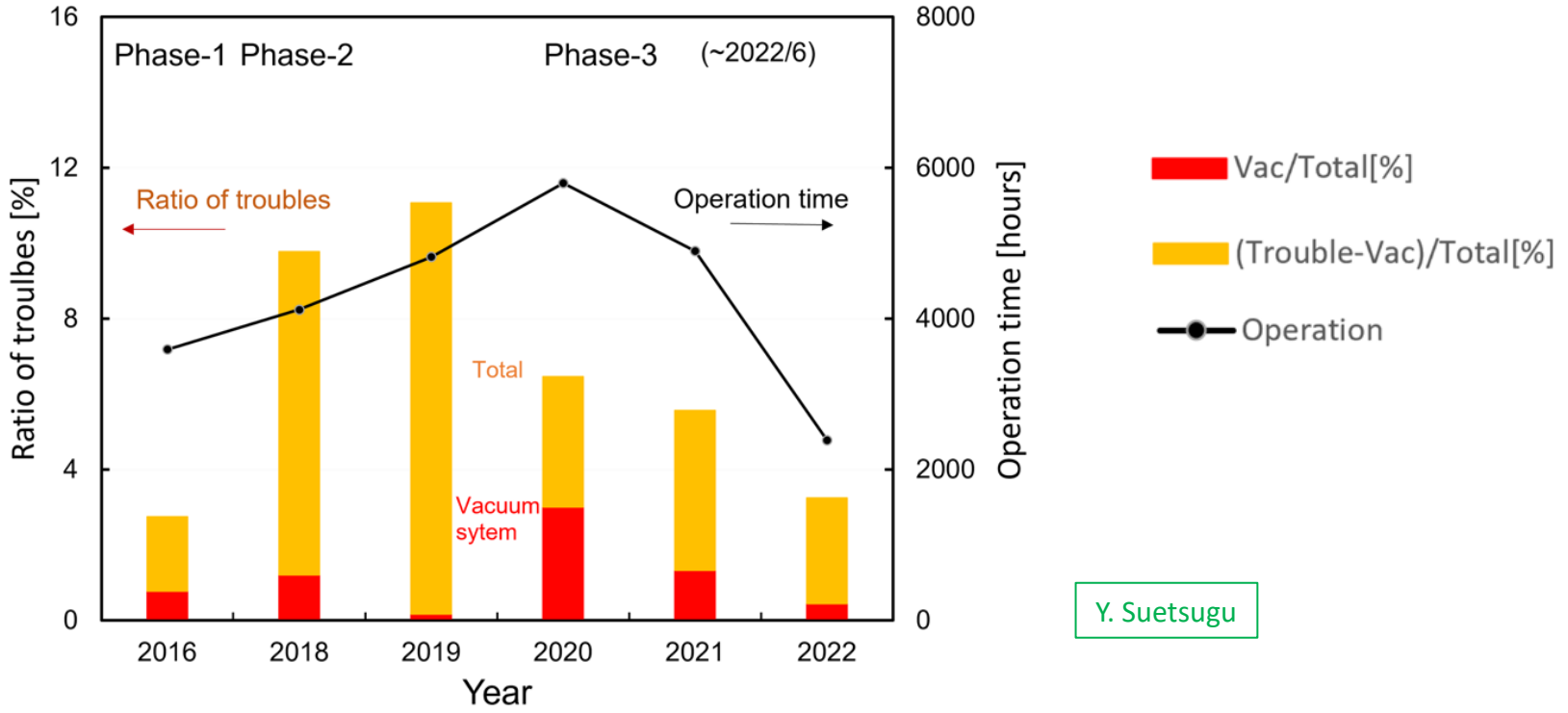


Y. Suetsugu

MR : major troubles #6

- Troubles of vacuum system are decreasing:
  - The ratio of troubles of vacuum system was less than 4%.
  - Main troubles are repairs of vacuum leaks and exchanges of damaged vacuum components.

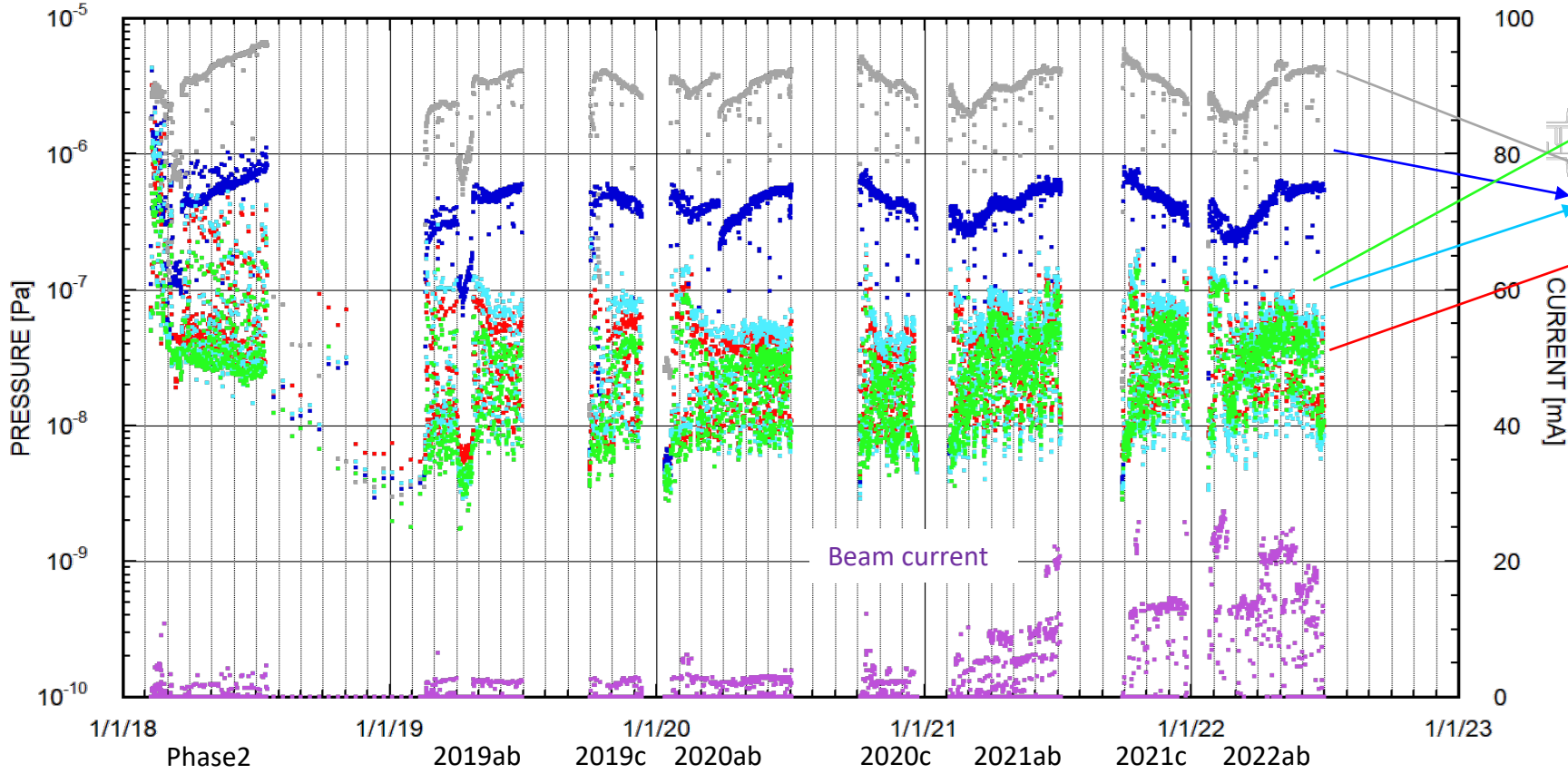
Total operation time, the ratio of no-operation time resulted from troubles to the total operation time, and those related to vacuum system

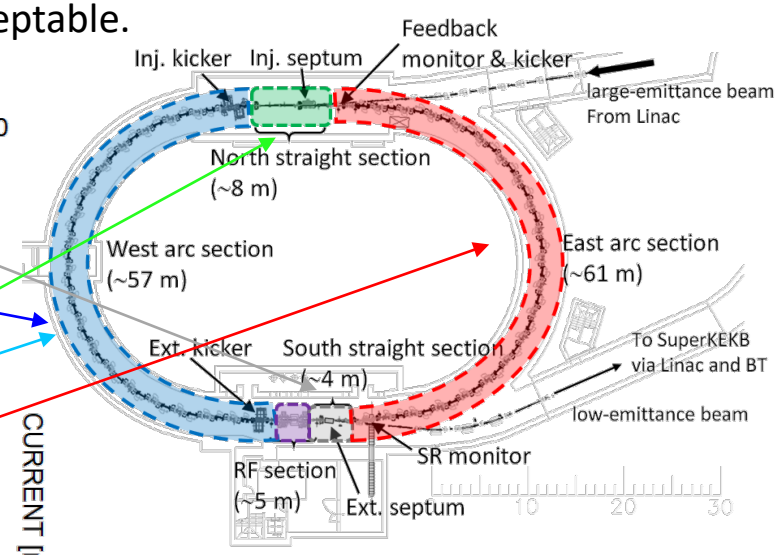


Y. Suetsugu

DR : vacuum status

- Average pressure of the two arc sections and two straight sections since Phase2(excluding RF section).
  - The pressures in the arc sections are sufficiently low.
    - In the west arc section, 2 beam pipes are temporarily disassembled for Ext. kicker works during LS1.
  - High pressures near the RF section indicate higher pressure in the RF section, but it is still acceptable.
    - Elastomer gaskets in the RF section were replaced with metal gaskets during LS1 by RF group.





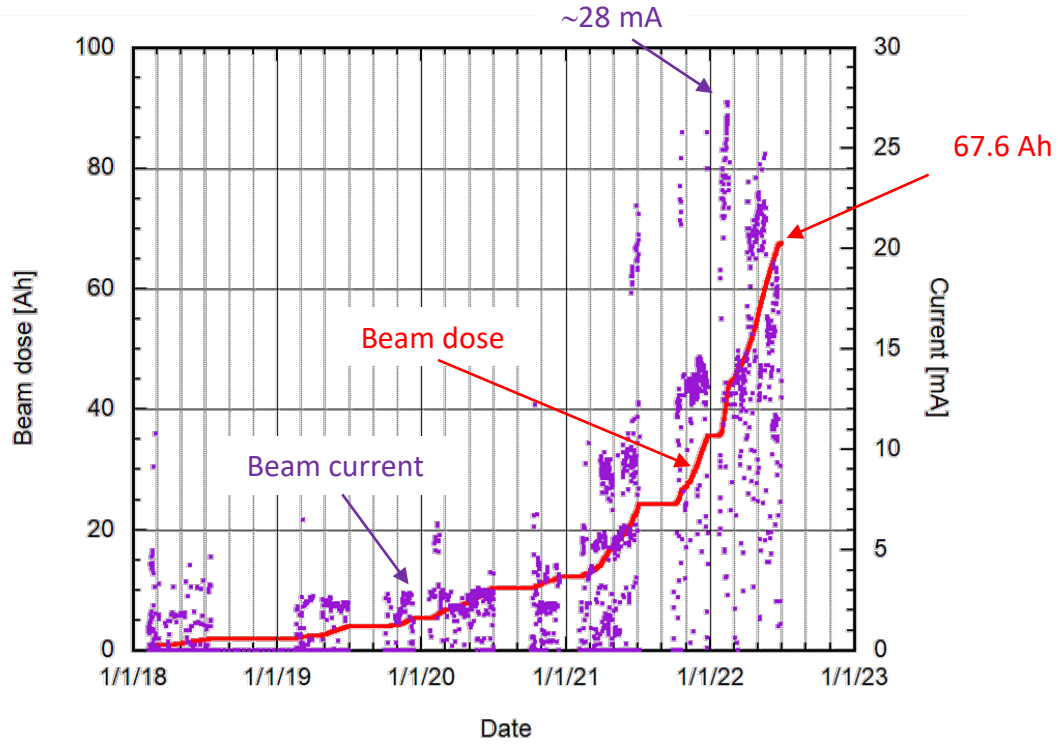
- East arc section
- West arc section 1 *
- West arc section 2 **
- North straight section
- Sough straight section

* Average over all IPs

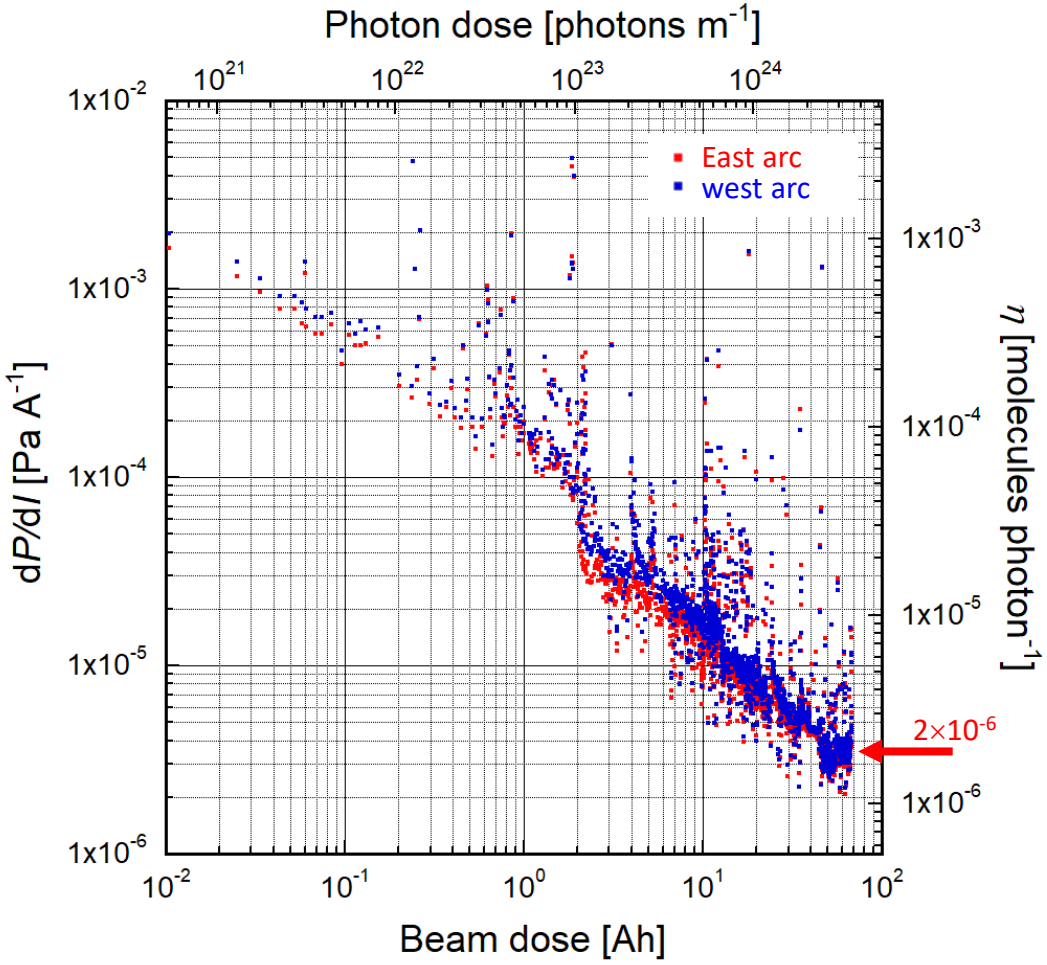
** Average over IPs excluding one near RF sect.

DR : vacuum scrubbing

- $\Delta p/\Delta I$ and η for arc sections show the vacuum scrubbing is progressing steadily.
  - At the end of 2022ab:
    - Total beam dose : 67.6 Ah (photon dose : 3.5×10^{24} photons/m)
    - η : 2×10^{-6} molec./photon



DR Vacuum scrubbing status

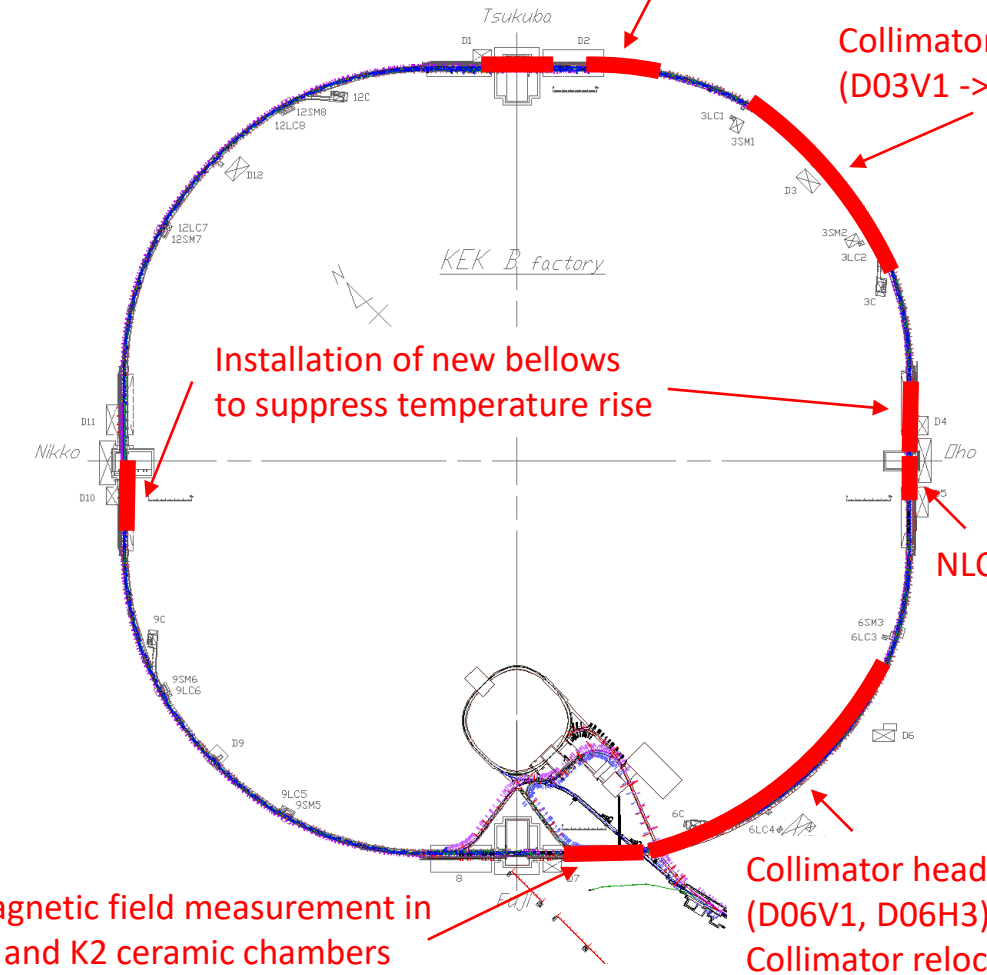


Vacuum works during LS1

LER

Collimator head replacement (D02V1)

Collimator relocation (D03V1 -> D05V1)



Installation of new bellows to suppress temperature rise

NLC (D05V1)

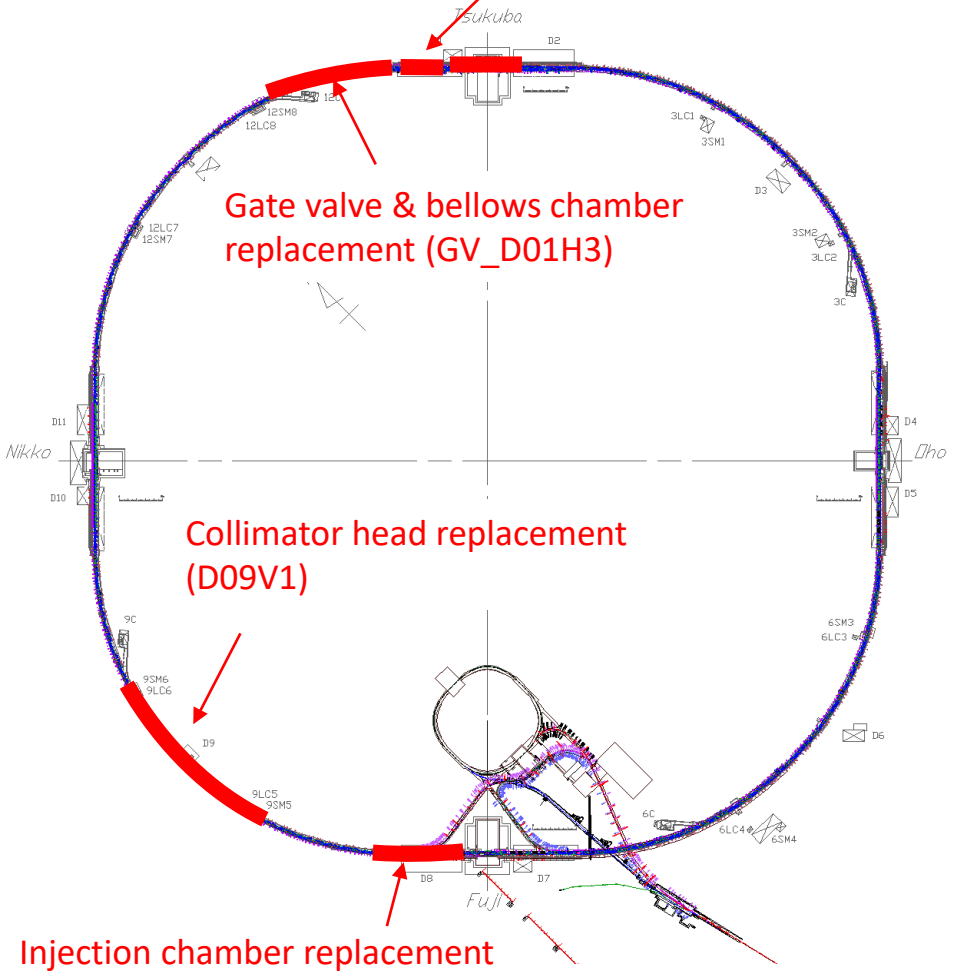
Magnetic field measurement in K1 and K2 ceramic chambers

Collimator head replacement (D06V1, D06H3)

Collimator relocation (D06H1 -> D06H4)

HER

Collimator head replacement (D01V1)



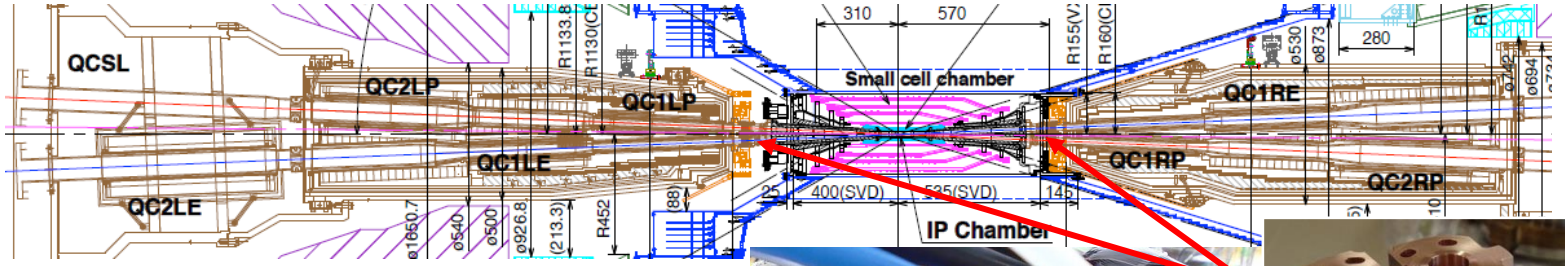
Gate valve & bellows chamber replacement (GV_D01H3)

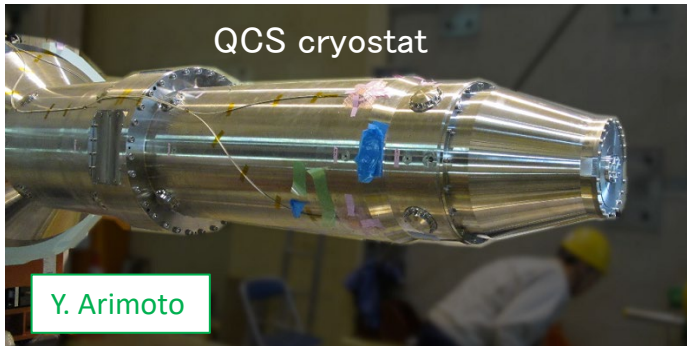
Collimator head replacement (D09V1)

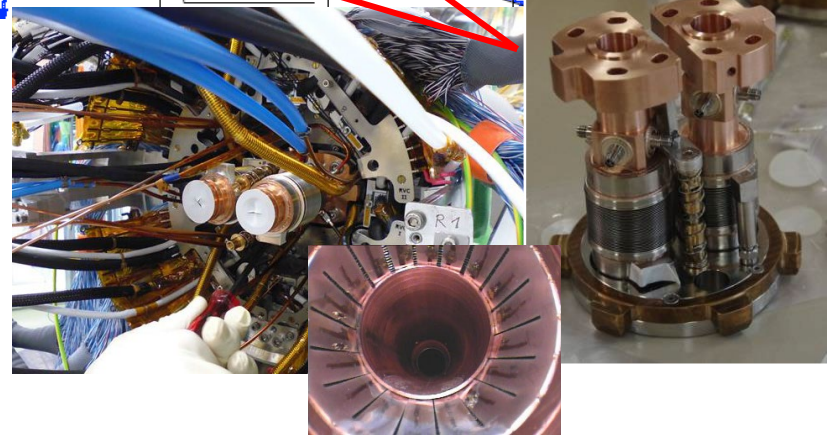
Injection chamber replacement

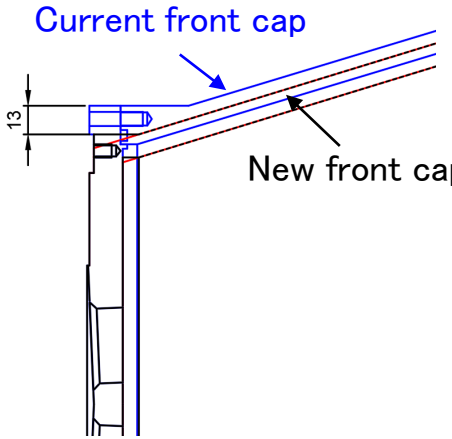
Major vacuum works during LS1 #1

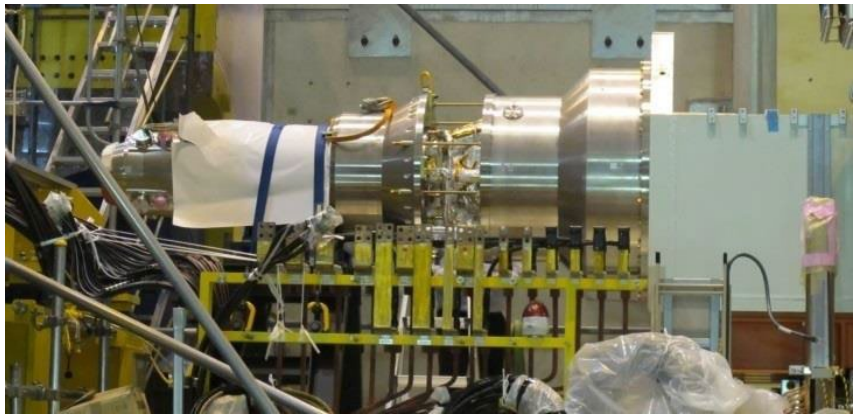
- Vacuum work at IR:
  - IP bellows chambers will be replaced with new ones of the same design.
    - Fiberscope observations show that RF shield fingers are discolored but appear to be healthy.
    - More detailed check will be done after removing IP chamber. (March 2023?)
  - Front cap (R-side) and front plate (L-side) of QCS cryostat will be replaced with new one with a different material.
    - For background noise reduction, material will be changed from W to SUS.
    - Tip of QCS-R cryostat will be smaller to allow more space for Belle II cables.
    - For this work, it is necessary to disassemble QCS cryostat and QCS beam pipes.







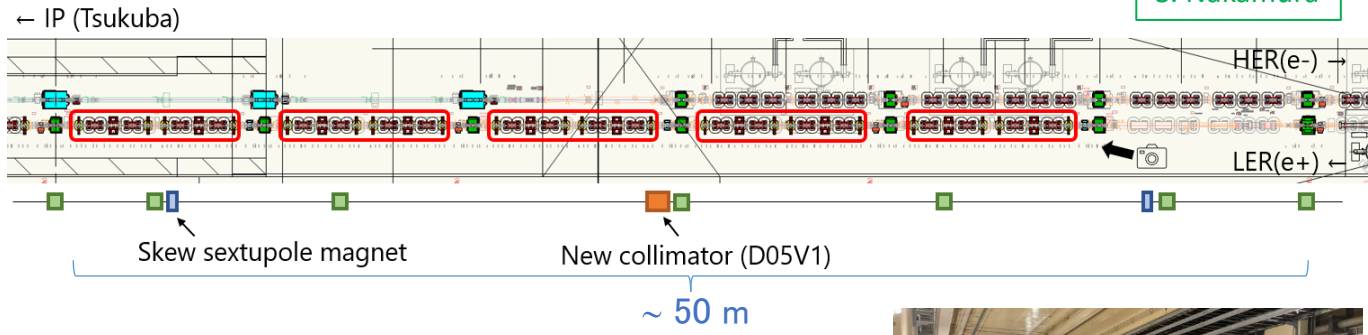


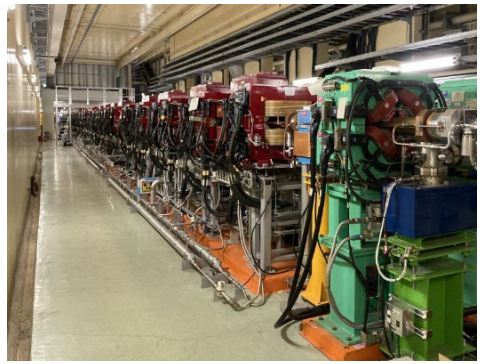


Major vacuum works during LS1 #2

S. Nakamura

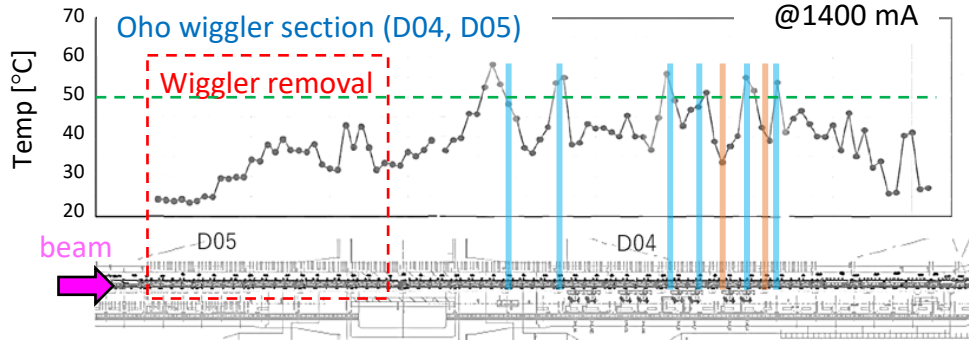
- Vacuum works for NLC:
  - Beam pipe replacement are required within a range of ~50 m.
    - Removal : 16 beam pipes & 18 bellows chambers
      - 10 Wiggler-mag. beam pipes with electron clearing electrode, 5 Q-mag. beam pipes, 1 taper pipe, 1 straight pipe, 18 bellows chambers
    - Installation : 1 collimator, 13 beam pipes, 22 bellows chambers
      - 1 Collimator (relocation from D03V1), 2 new beam pipes, 2 modified beam pipes, 4 reused beam pipes, 15 spare beam pipes, 22 bellows chambers
    - TiN coating & baking at laboratory:
      - TiN coating: 2 new beam pipes, 2 modified beam pipes
      - Baking : 19 beam pipes excluding 4 reused beam pipes
    - Others:
      - New chamber support, Cooling water piping, Pb radiation shield, concrete shield removal and installation, etc.
  - Schedule
    - Production & modification : ~ March/2023
    - Wiggler-Mag beam pipes removal : done
    - Collimator installation : ~ March/2023
    - Beam pipe baking and TiN coating at laboratory : Nov./2022~ May/2023
    - Beam pipe installation : May/2023 ~ July/2023?

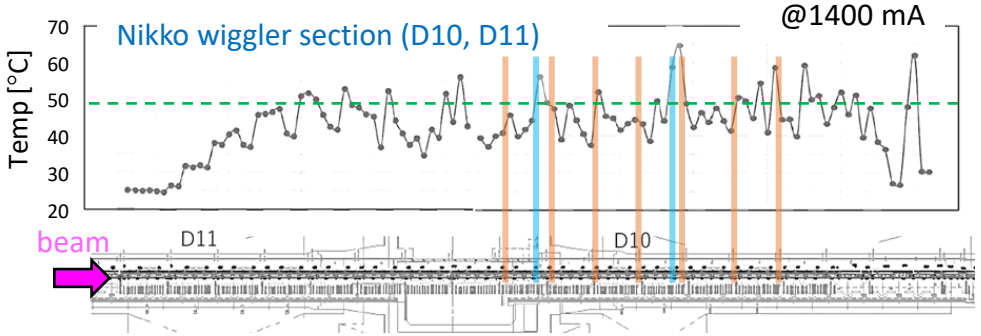




Major vacuum works during LS1 #3

- Vacuum work at LER wiggler sections:
  - Replacement of bellows chambers
    - From bellows chamber w/o SR masks to w/ SR masks : 9 chambers
    - From bellows chamber w/ SR masks to w/o SR masks : 8 chambers
  - As a countermeasure against temperature rise of beam pipes downstream of the wiggler sections
    - Beam current will be increased after LS1.
    - Magnetic field of wiggler magnets will be increased by the amount of decreased wiggler magnets.
    - Strong SR should be absorbed by SR masks in the bellows chambers.
    - Bellows chambers w/ SR masks installed in locations where strong SR would not be irradiated were replaced with bellows chambers w/o SR masks
  - Air and water cooling of the bellows chamber with SR masks were also enforced.



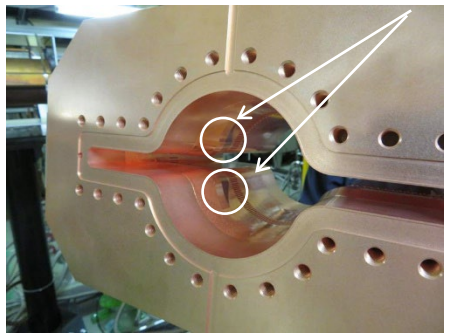


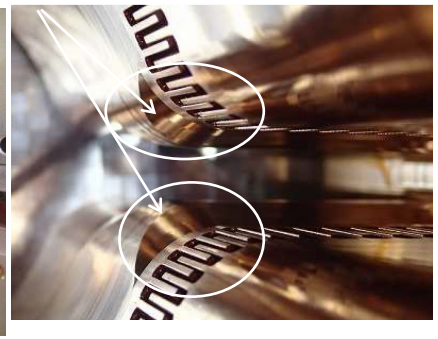
Bellows chamber replacement

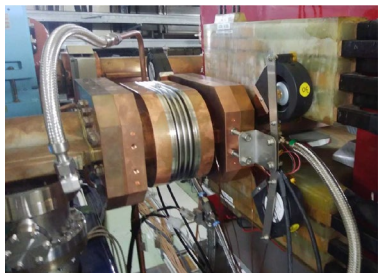
w/o → w/ SR masks

w/ → w/o SR masks

SR mask





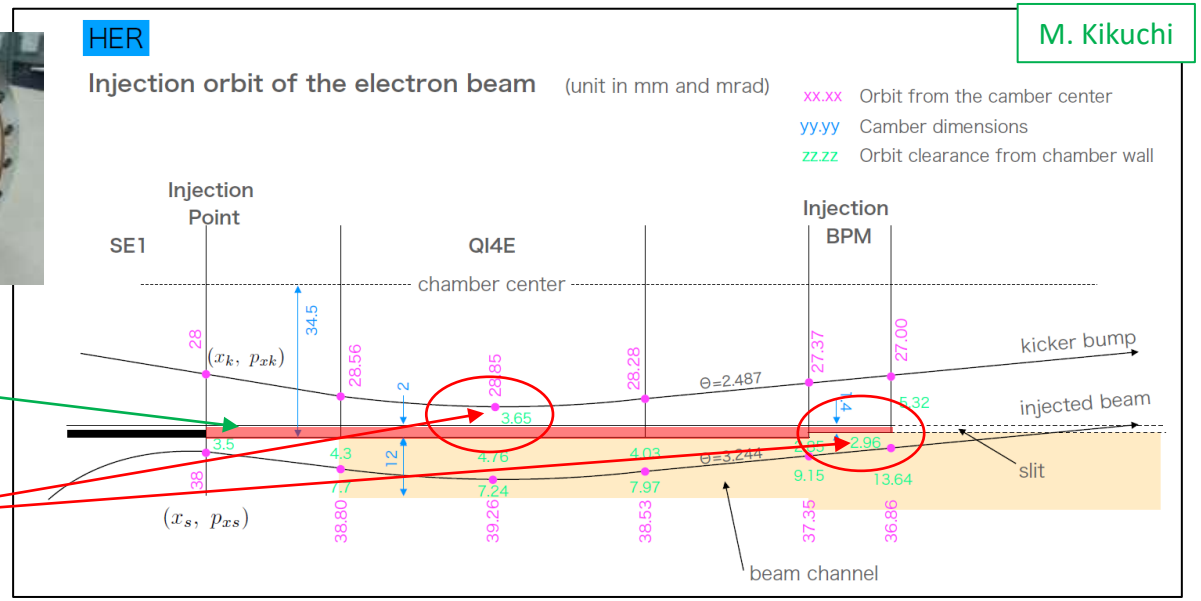


Major vacuum works during LS1 #4

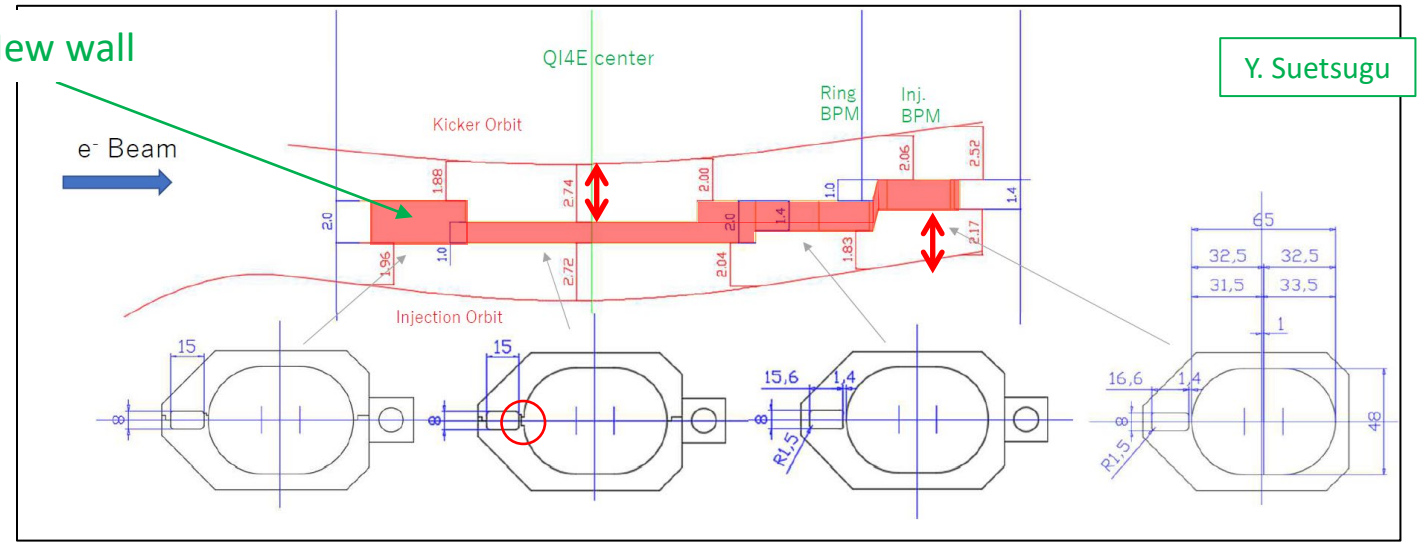
- Vacuum work at HER injection section:
  - 3 beam pipes are replaced with new ones to increase injection rate.
    - Orbit clearance from chamber wall is enlarged by changing wall position along beam axis.
    - Wall length along the beam axis is shorten as much as possible.
      - Pumping port will be removed to shorten wall length if possible.
    - New BPM for injected beam is installed for precise injection tuning.
  - Schedule
    - Production : JFY2022 (~ March/2023)
    - Beam pipe replacement : JFY2023 (April/2023 ~)

wall

too small clearance



New wall



Summary

- MR and DR vacuum systems have been working mostly well.
  - Vacuum scrubbing progressed steadily.
  - Troubles of vacuum system are decreasing.
  - No clear indication of ECE has been observed.
- Recent behaviors of pressure against beam current are explained including thermal desorption (heating by wall current and HOM) as well as PSD.
- Recent single beam lifetime is mostly limited by the Touschek effect rather than pressure (the Rutherford scattering).
- Large vacuum works are ongoing during LS1.
  - NLC construction at LER D05
  - IR vacuum works for modification of Belle II detector and QCS cryostat.
  - Installation of bellows with SR masks at LER D04 and D10
  - Replacement of HER injection chambers
  - Many collimator works (not mentioned in this talk)
  - Etc.

Fin.

Thank you for your attention.

Backup