# Luminosity limiting factors and the countermeasures and strategy after LS1.

B2GM 2023/10/23 H.IKEDA

# Luminosity Limiting factors

- For Luminosity↑
  - Beam Current↑
  - Beam Size↓
  - Collision Tuning

1. Beam size blowup
2. Optics & Orbit problem
3. Beam Lifetime
4. Injection
5. Sudden beam loss

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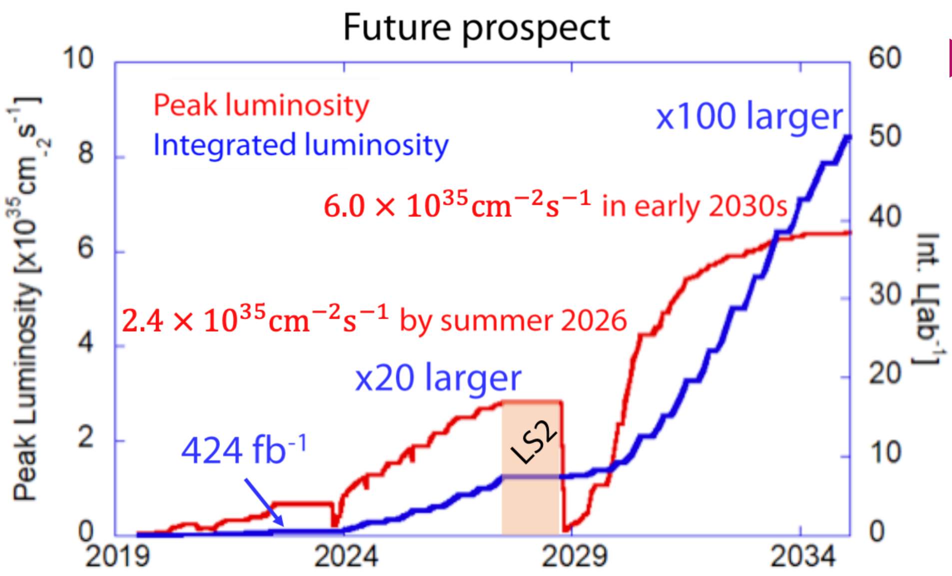
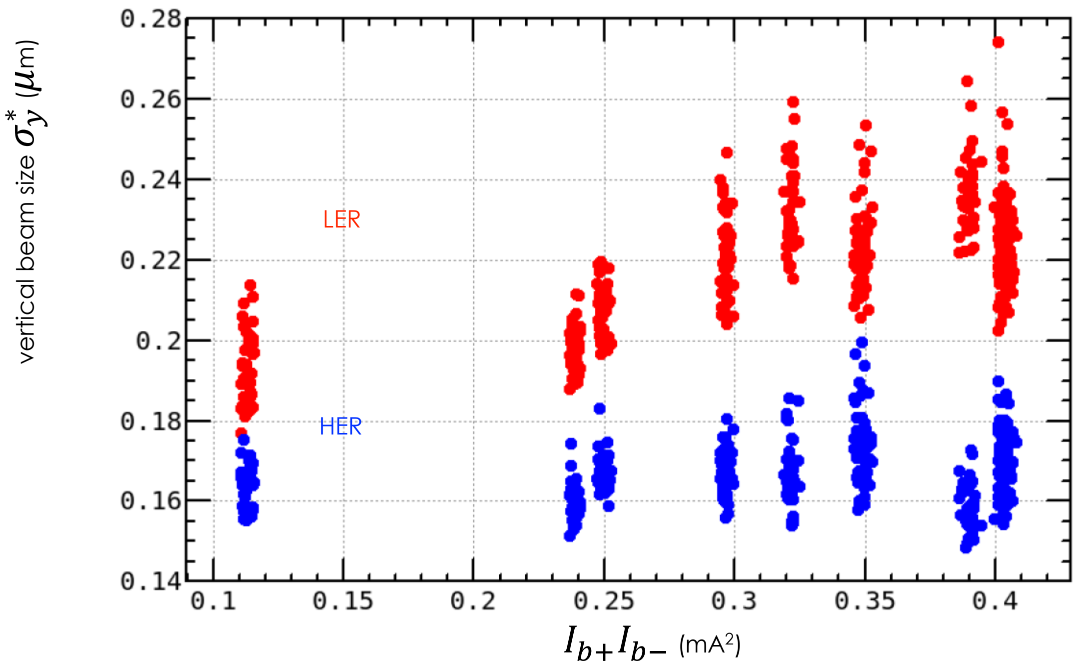
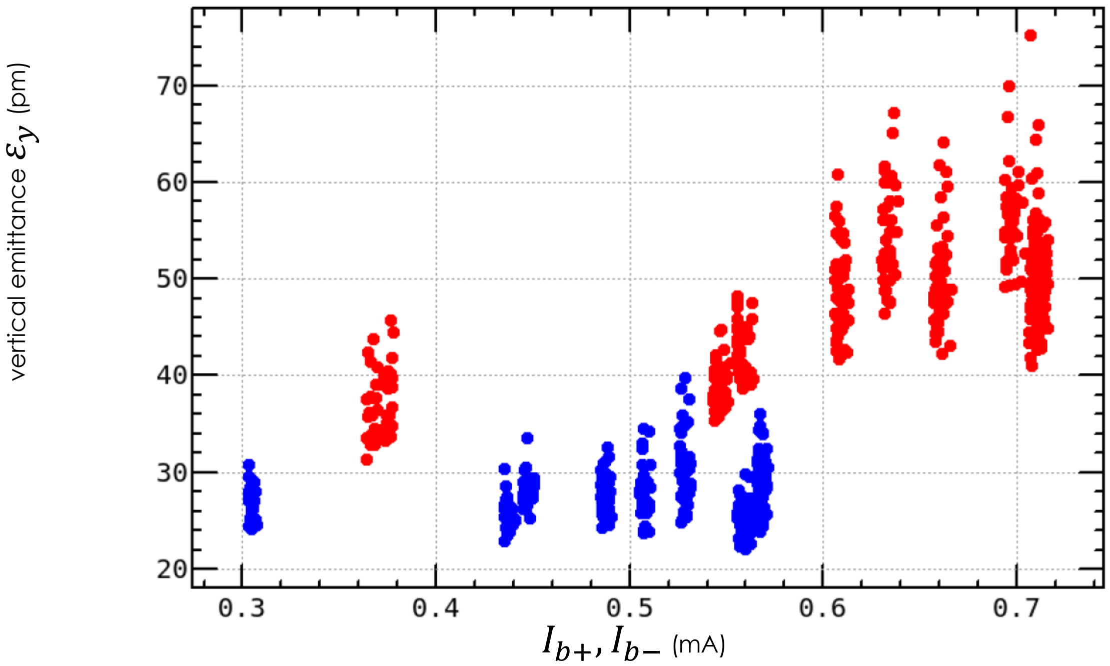


# 1. Beam size blowup

Beam size is measured by X-ray Monitor




Beam size blowup is significant in LER.

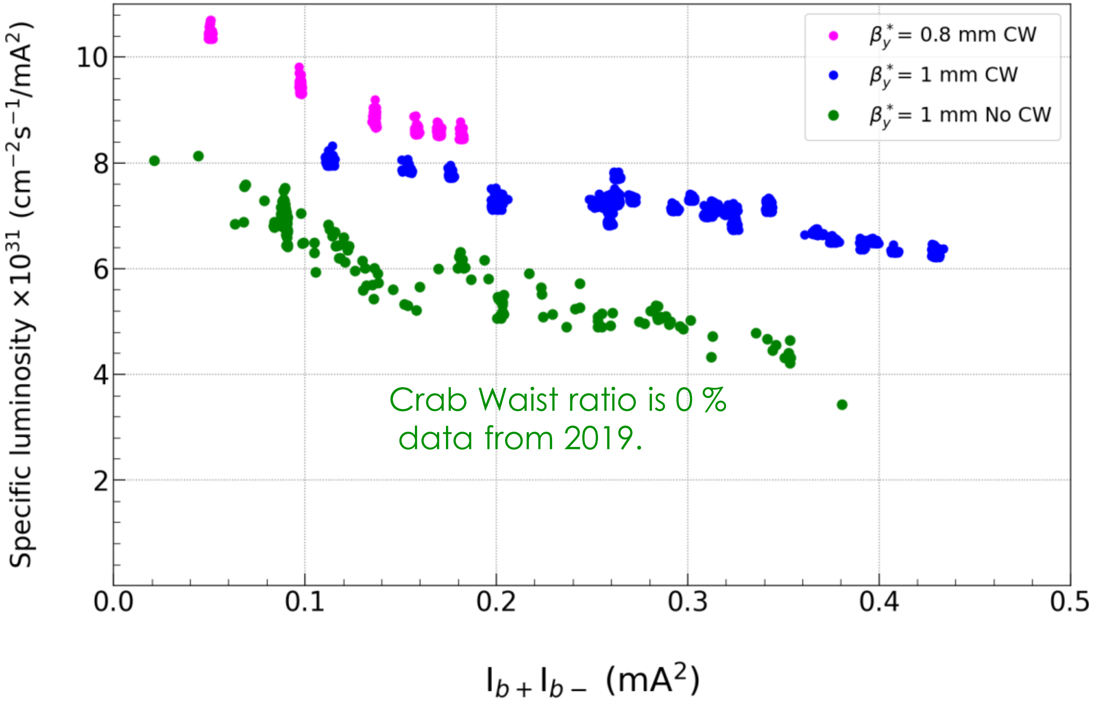
data: physics run

Y.Onishi

# Beam size blowup : Specific Luminosity

$$L_{sp} = \frac{L}{n_b I_{b+} I_{b-}} \propto \frac{1}{\Sigma_z \Sigma_y^*}$$

The CW improved luminosity.
Data without CW was not the same period as CW data.
We will confirm the luminosity gain in the next operation.
Also the CW ratio will be optimized by lifetime and luminosity gain.




$L_{sp} = 8.935 \times 10^{31}$ cm$^{-2}$s$^{-1}$/mA$^2$

$\beta_y$ = 1 mm, $\varepsilon_{y+}$ = 35 pm, $\varepsilon_{y-}$ = 25 pm, $\sigma_{z+}$ = 4.6 mm, $\sigma_{z-}$ = 5.1 mm

Y.Onishi

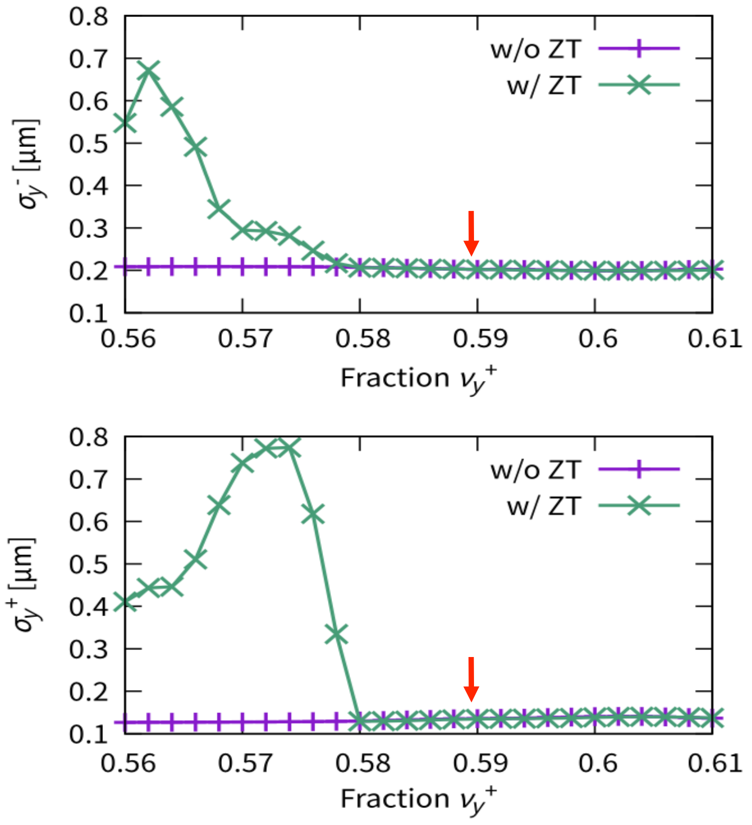
# Beam size blowup : Beam-Beam Simulations

- Simulation was done for LER with current parameters ($\beta_y^*$ =1mm) .
  - Small energy and large vertical impedance.
  - X-Z instability is well suppressed at the current working point (tune).
  - In the presence of the impedance, vertical beam blowup occurs at certain working points when beam-beam interactions are factored in.
  - This is $\sigma$-mode instability (in-phase oscillation) and is an exponential growth of the vertical dipole and quadrupole moments. It is called TMCI-like instability.
- In order to reduce this effect,
  - Increasing chromaticity, different tuning in the two rings.
  - Non-linear collimators are also useful for impedance reduction.

K.Ohmi
Y.Onishi

# Beam size blowup : Beam-Beam Simulations (cont'd)

LER




Y. Zhang et al., Phys. Rev. Accel. Beam. 26, 064401 (2023)

| | HER | LER |
|---|---|---|
| Energy (GeV) | 7 | 4 |
| Bunch population ($10^{10}$) | 5.02 | 6.28 |
| Emittance $x/y$ (nm/pm) | 4.6/35 | 4.0/20 |
| Beta at IP $x/y$ (m/mm) | 0.06/1 | 0.08/1 |
| Bunch length (mm) | 5.05 | 4.60 |
| Energy spread ($10^{-4}$) | 6.3 | 7.5 |
| Synchrotron tune | 0.0272 | 0.0233 |
| Damping time $x$ (turn) | 5760 | 4539 |
| | 0.8 mA/bunch | 1.0 mA/bunch |
| | 45.532 / 43.573 | 44.525 / 46.589 |

Measure the beam size with changing the vertical tune after LS1.

Y.Onishi

# 2. Beam Optics & Orbit

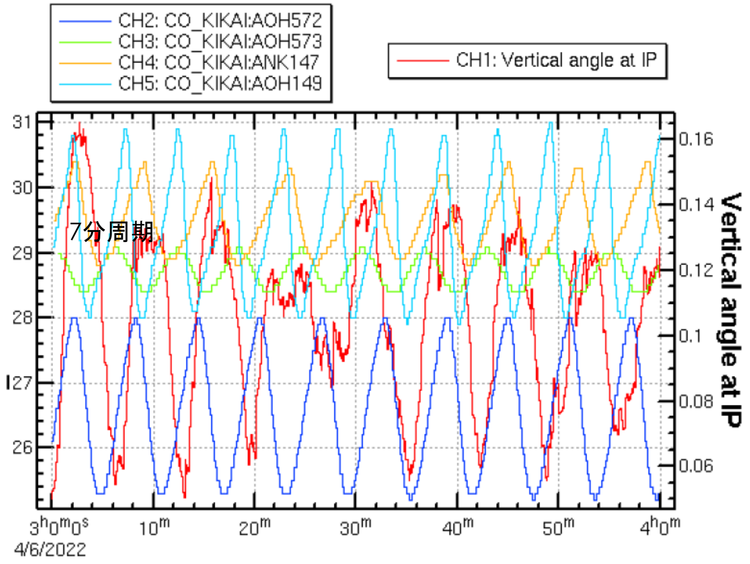
- Reproducibility and stability of the machine are important because small orbit changes can cause large optics disturbances.
- The measured orbit may not be completely corrected to the Gold orbit.
  - Cooling water effect
  - Beam current dependence
    - The beam pipe is thermally deformed where the synchrotron radiation hits it and the BPM pushes the quadrupole magnet. Reproducibility may be poor at the same current. Large discrepancies at the local chromatic aberration correction, wiggler, and injection areas.
  - Repeated aborts at high currents result in poor reproducibility.
  - Slow fluctuation of orbit over several days.
  - Effects of orbit changes due to earthquakes

↓

- Luminosity deterioration due to orbit change may be recovered by daily knob tuning.

# Beam Optics & Orbit : Cooling Water Temperature (MAG)

There is a correlation between magnet cooling water and orbit variation, but the reason is still unknown.
Under consideration of task force of Cooling Water.



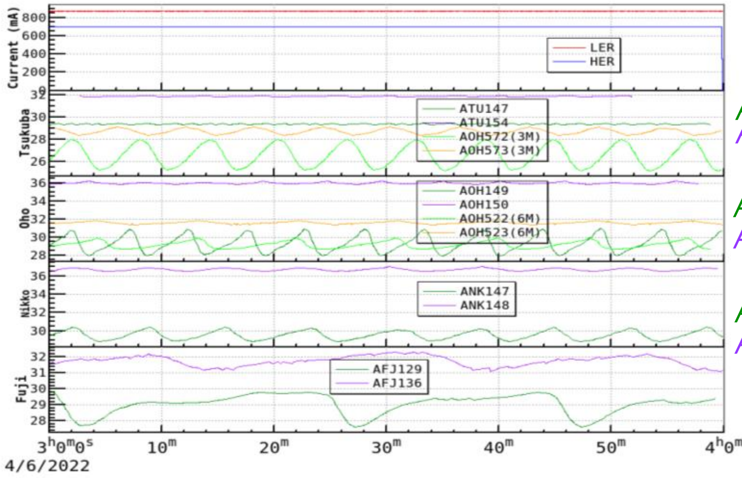

AOH572: マグネットTN内純水冷却水往温度（大穂3M機械棟）

AOH573: マグネットTN内純水冷却水環温度（大穂3M機械棟）

ANK147: 日光冷却マグネット往温度

AOH149: 大穂冷却マグネット往温度

AOH572: マグネットTN内純水冷却水往温度（大穂3M機械棟
AOH573: マグネットTN内純水冷却水環温度（大穂3M機械棟
AOH522: マグネットTN内純水冷却水往温度（大穂6M機械棟
AOH523: マグネットTN内純水冷却水環温度（大穂6M機械棟




ATU147: 筑波冷却マグネット往温度
ATU154: 筑波冷却マグネット環温度

AOH149: 大穂冷却マグネット往温度
AOH150: 大穂冷却マグネット環温度

ANK147: 日光冷却マグネット往温度
ANK148: 日光冷却マグネット環温度

AFJ129: 富士冷却マグネット往温度
AFJ136: 富士冷却マグネット環温度

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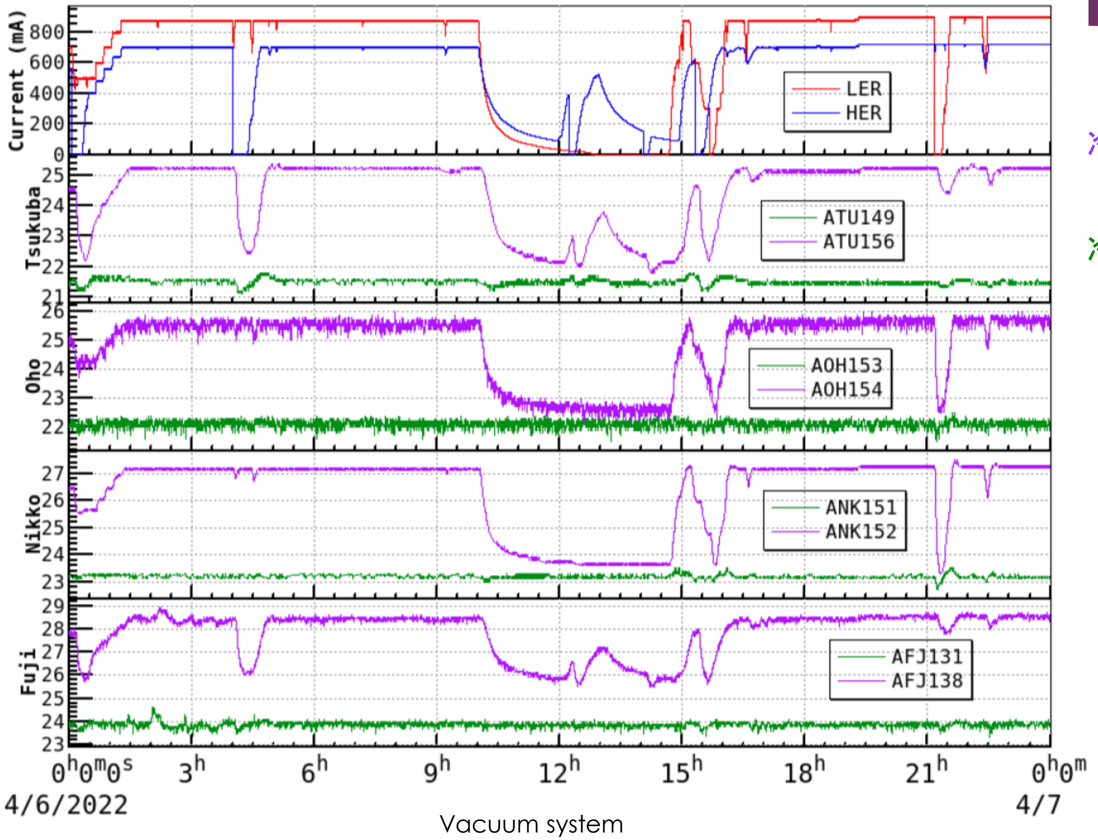
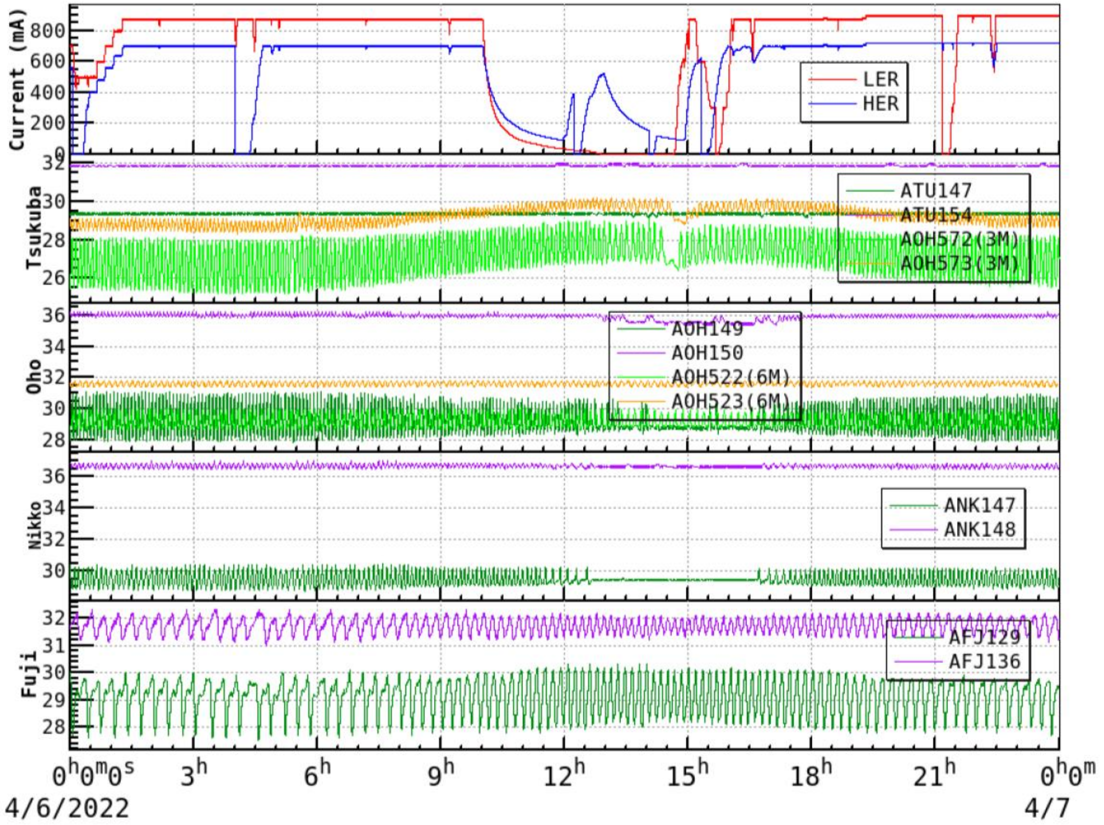
# Beam Optics & Orbit : Cooling Water Temperature (MAG)




Vacuum system

冷却環

冷却往




Magnet system

Temperature of vacuum cooling system is very stable.

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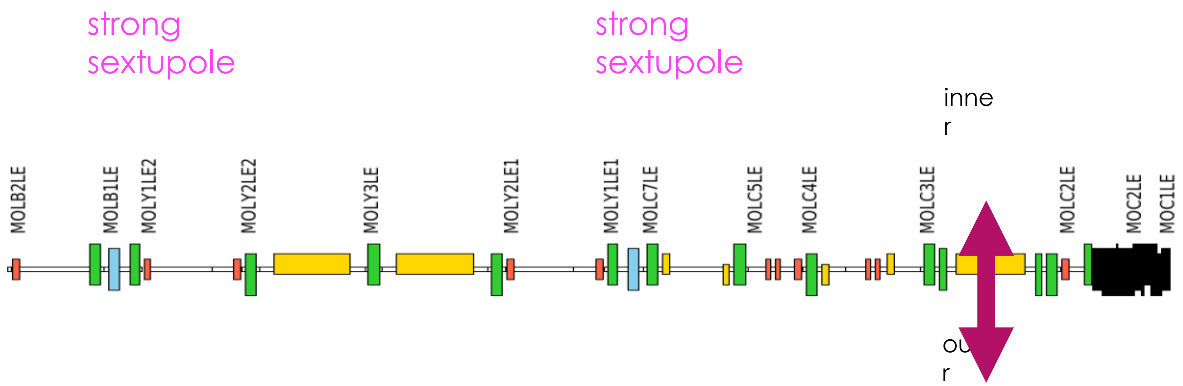
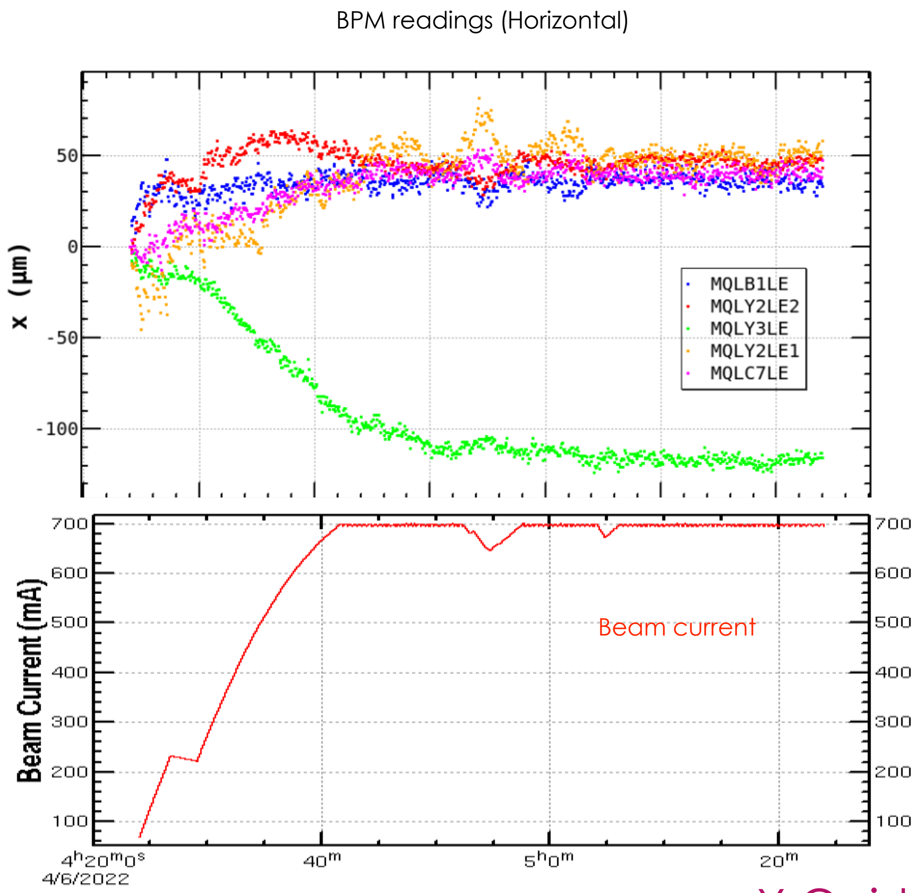
# Beam Optics & Orbit : Current Dependence at Strong Sextupole Region in HER

- The orbit at the SLY (sextupole for local aberration correction) near the IP has the largest impact on OPTICS.
  - A change in orbit of about 20 microns can change the beta function of the colliding point by as much as 20%.
- The horizontal orbit at SLY depends on the beam current.

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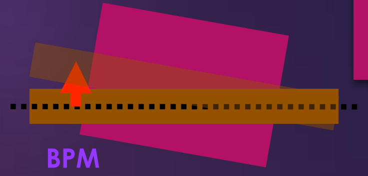
# Beam Optics & Orbit :Hypothesis of why orbit depend on beam current




Quad. moves like yaw and horizontal shift if BPM pushes quad.

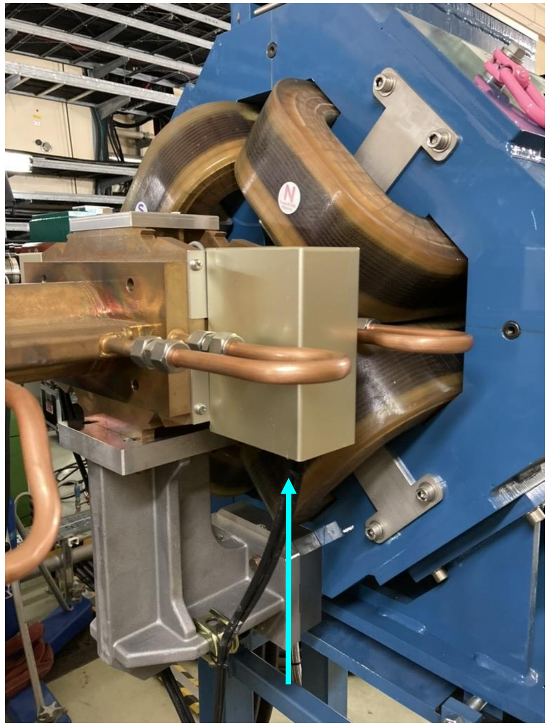
Radiation from the bending magnet thermally deforms the beam pipe.

- BPM and quadrupole magnet (Q) are connected by supports.
- When the beam pipe moves due to heat generation, BPM and Q move.
- Beam receives a dipole kick.

The fact that BPM is connected to Q complicates matters.

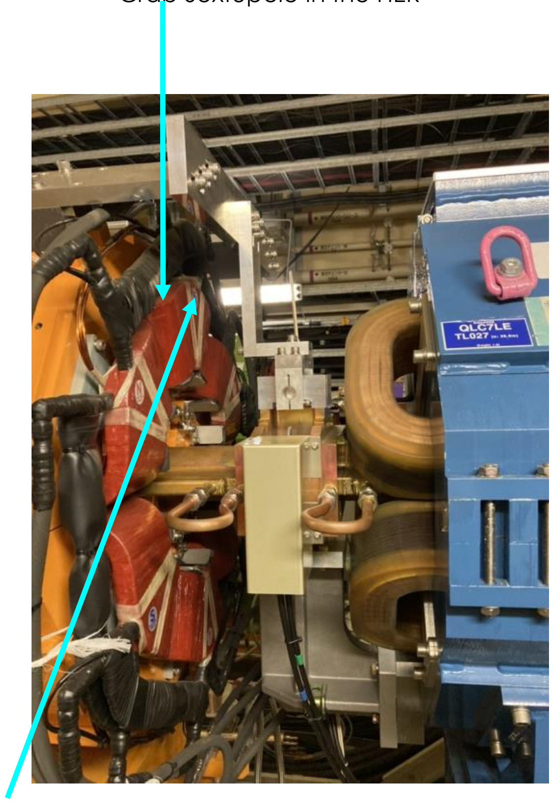
- If BPM and Q are disconnected, the problem becomes simpler.
- If the connection is severed, Q will not move even if the beam pipe is deformed and no orbit will be generated.
- Beam test scheduled for next operation

BPM and Quadrupole Magnet



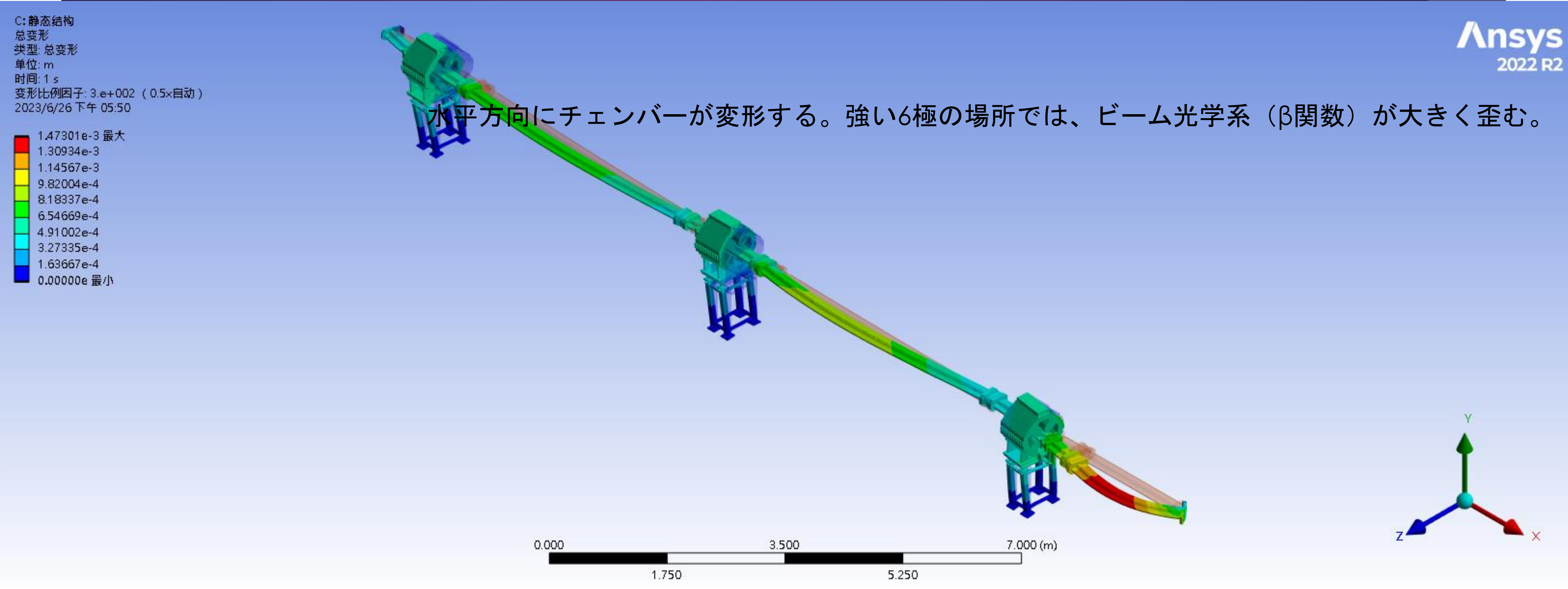
The beam pipe (BPM) is fixed to the quadrupole magnet.

Crab Sextupole in the HER



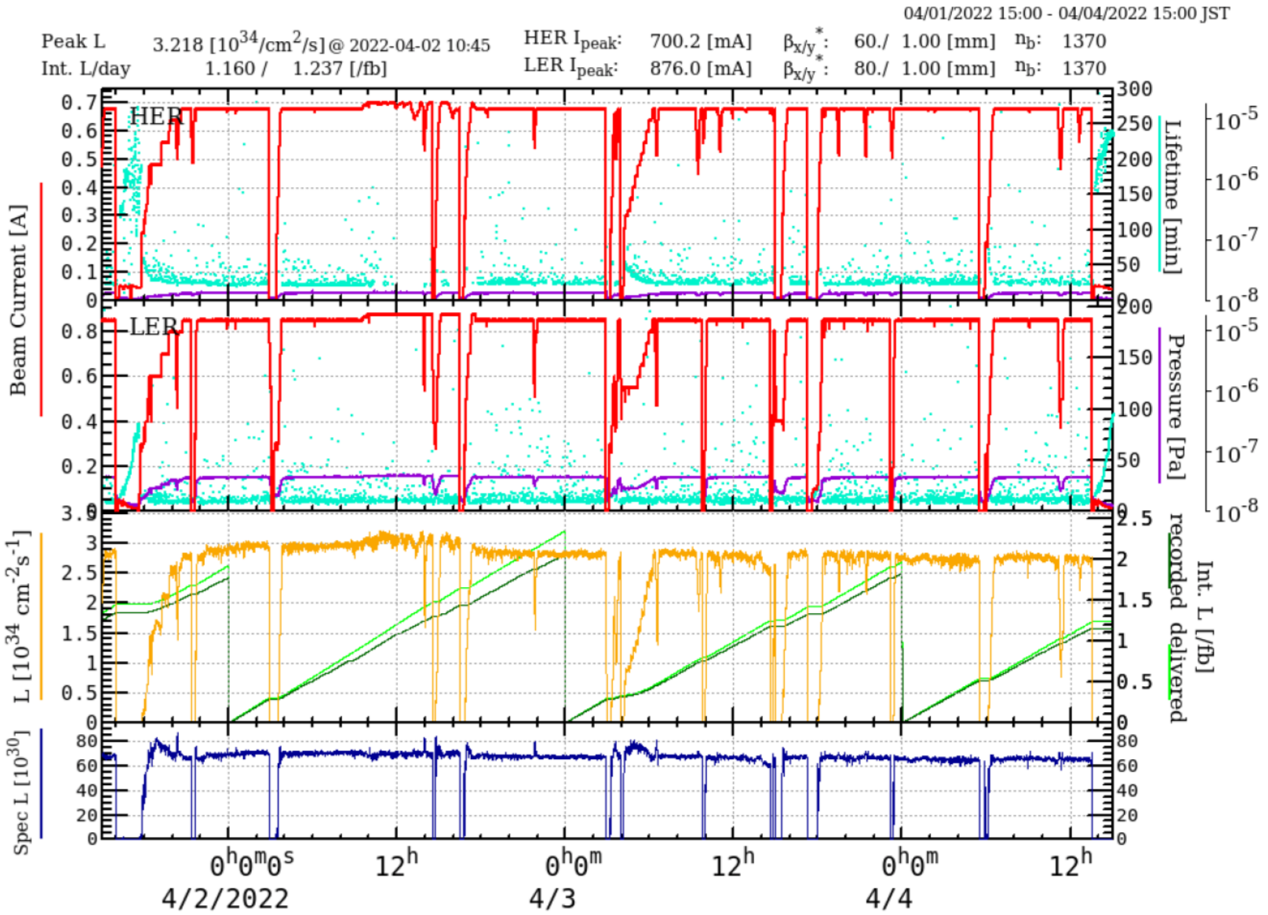
Gap sensor measures $(\Delta x, \Delta y)$ between BPM and sextupole.
Relation between BPM and quad. does not change. (see left fig.)

水平方向にチェンバーが変形する。強い6極の場所では、ビーム光学系（β関数）が大きく歪む。



# Beam Optics & Orbit : Beam optics degradation of unknown cause

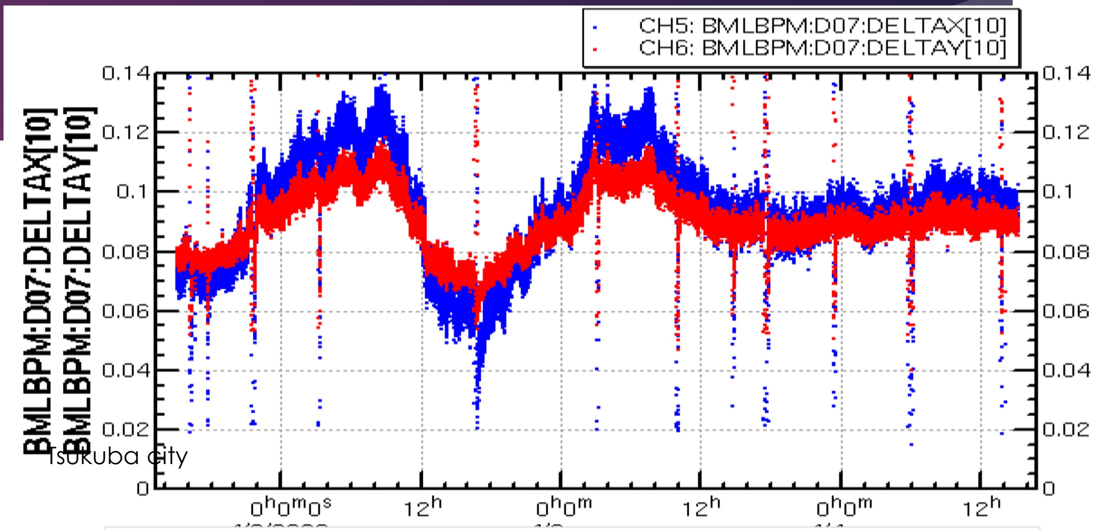
- Optics correction was performed every two weeks.
  - HER beam performance deteriorates in a few days under high current operation.
  - Frequent beam adjustments reduce operating efficiency.

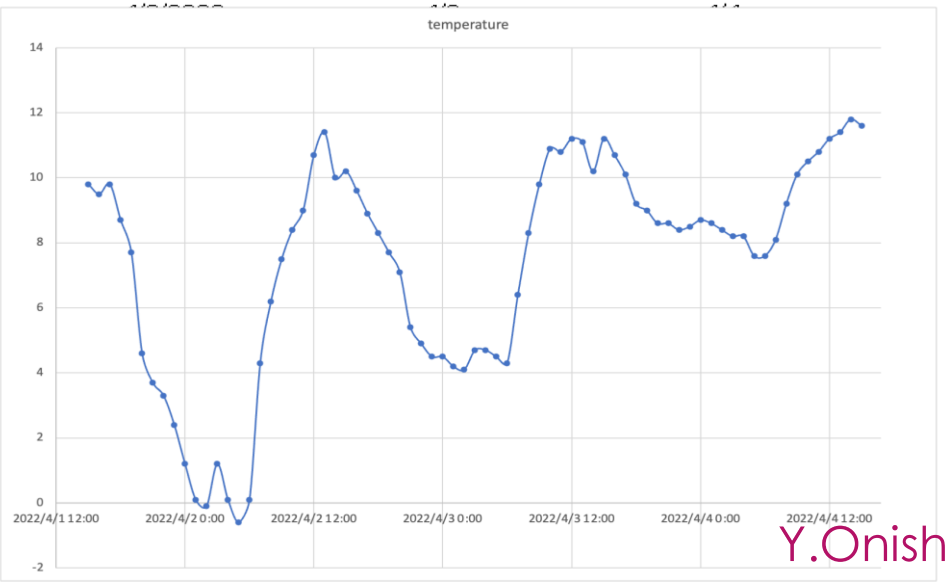


# Residuals (measured orbit - gold orbit)

- Residual does not appear to deteriorate in one direction in about 3 days. However, there is a correlation between residual and consistency, and daily differences are visible.
- Temperature dependence?
  →Measure the temperature dependence of the coaxial cable characteristics of BPM using the existing cable and SG.

*consistency=RMS of x and y positions obtained with 3 electrodes of BPM

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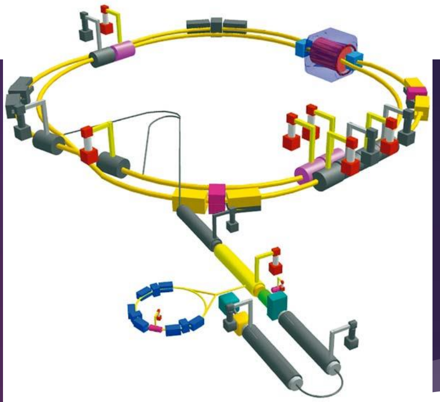
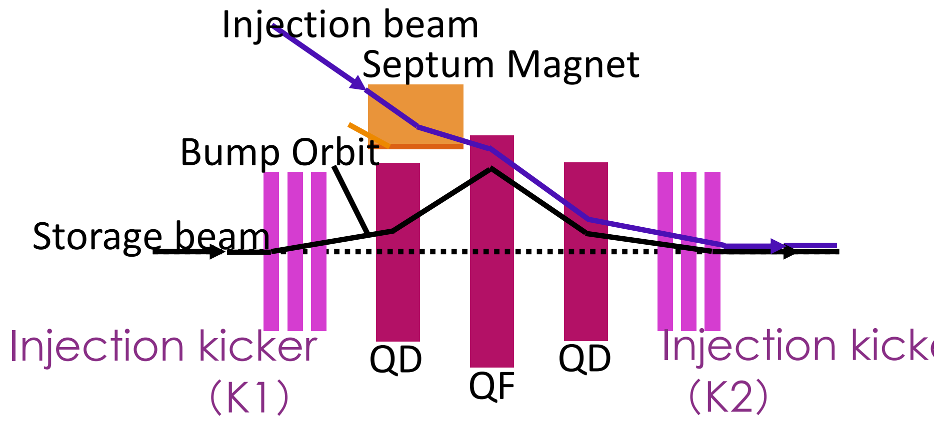
# 4. Injection



- The beam created at the linac injected to the MR via the DR(e+) and BT.
- The amount of beam current that can be accumulated is limited by the injection beam and the beam lifetime.
- The injection system consists of special equipment such as kickers and septum magnet, and ceramic beam pipes.
- A low emittance beam is required for the nanobeam scheme (focusing the beam into a small size), and stable injection efficiency is essential to compensate for the short beam life of the main ring.



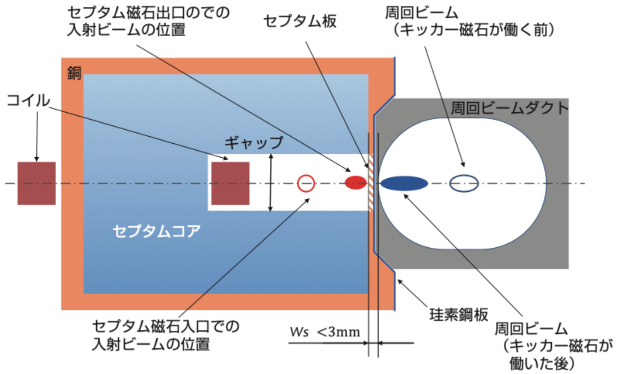




Table 1: Beam Parameters for a Luminosity of $1\times10^{35}$/cm$^2$s; * denotes the values at the interaction point.

| Parameters | LER | HER | LER | HER |
|---|---|---|---|---|
| bunches/ring | 2345+1 | | 2345+1 | |
| Luminosity [/cm$^2$s] | $1\times10^{35}$ | | $1\times10^{35}$ | |
| $I_{\text{total}}$ [A] | 2.08 | 1.48 | 2.78 | 1.65 |
| $\beta_y^*$ [mm] | 0.8 | 0.8 | 1 | 1 |
| $\sigma_z$ [mm] | 6.49 | 6.35 | 7.26 | 6.51 |
| $\tau_{\text{beam}}$ [min.] | 3.4 | 14.8 | 4.7 | 16.9 |
| $\epsilon_{\text{inj}}$ [a] [%] | 68 | 17 | 66 | 16 |
| $Q_e^{\text{inj}} \times n_{bi}$ [a] [nC] | 3×2 | 2×2 | 3×2 | 2×2 |
| $r_{\text{inj}}$ [a] [nC/pulse] | 4.1 | 0.68 | 4.0 | 0.64 |
| $r_{\text{inj}}$ [b] [nC/pulse] | | | 2.3 | 0.34-0.65 |

[a] Requirement for injection for 25 Hz, $r_{\text{inj}} \equiv \epsilon_{\text{inj}} Q_e n_{bi}$.
[b] Parameters when maximum luminosity was achieved in 2022.

**50% less than required !!**

# Injection : Possible causes of low injection efficiency



- HER
  - Emittance blowup in the beam transport line (BT)
  - Drift of the emittance of injection beam
  - The orbit and emittance drift of $2^{nd}$ bunch of the injection beam
  - We could not put the injection beam close to the septum plate because of the magnetic field drop → The horizonal oscillation becomes larger.
  - Misalignment in the injection region
  - Shorter lifetime than the design
- LER
  - Emittance blowup in the beam transport line (BT)
  - We could not put the injection beam close to the septum plate because of the magnetic field drop → The horizonal oscillation becomes larger.
  - Misalignment in the injection region
  - Short lifetime

# Injection : LINAC and BT Upgrades done in LS1

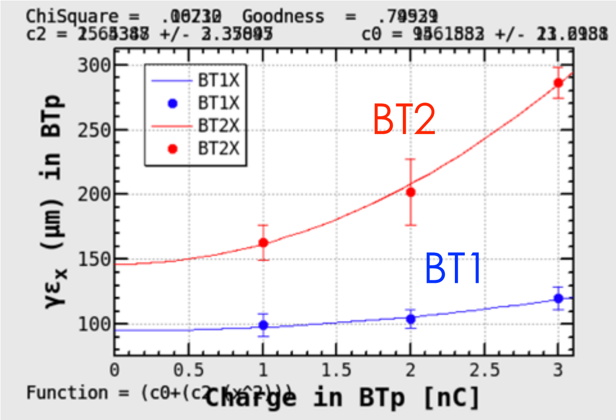
- Many pulsed magnets and fast kickers(for the 2nd bunch) were installed in LINAC
  - Tuning for each beam (HER, LER, PF, and PF/AR) becomes better.
- New accelerator structure installation
  - Decreased down frequency, and high-energy beam can be supplied.
- Auto-tuning gives LINAC fast beam rise and beam stabilization.
- Improved the septum magnetic field for HER and enlarging the aperture near the injection point
  - This contributes to injection recovery that is degraded by canceling coil errors.
- DR kicker modification will speed up the DR injection/extraction tuning.
- OTR (Optical Transition Radiation) conversions of the screen monitor
  - make the investigation of the cause of the emittance blowup in BT more sophisticated.
- **The chambers at bending magnets in the e+ BT 1st arc was vertically shifted.**
- A CSR monitor is installed in the e+ BT 1st arc.

# Studies regarding the offset of the first arc in e+ BT

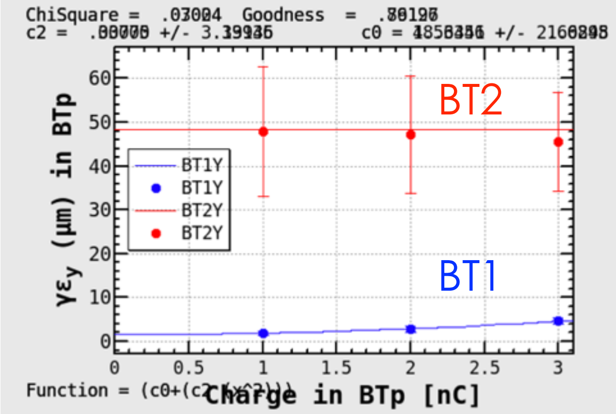


Measured emittance

Horizontal emittance



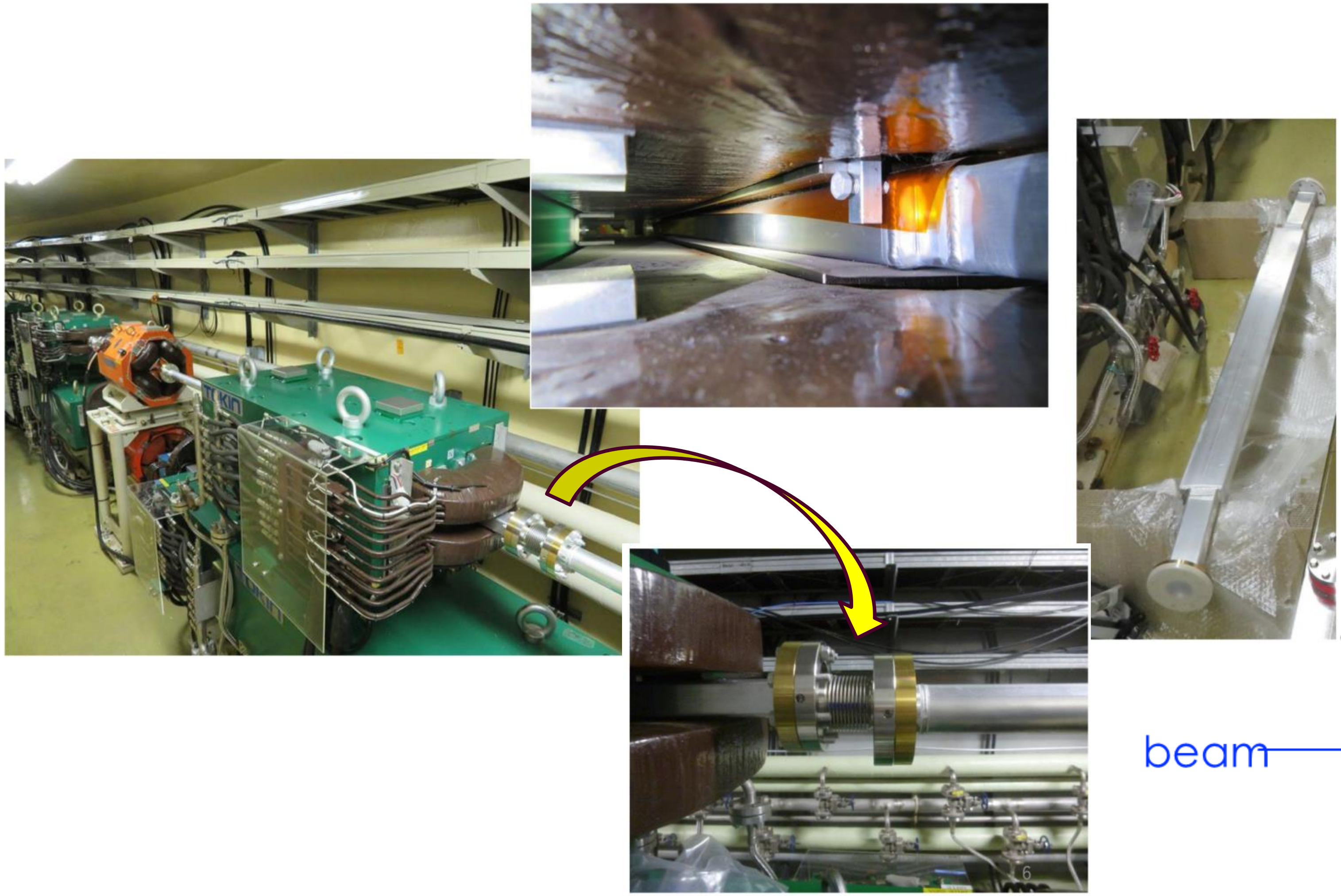

Vertical emittance

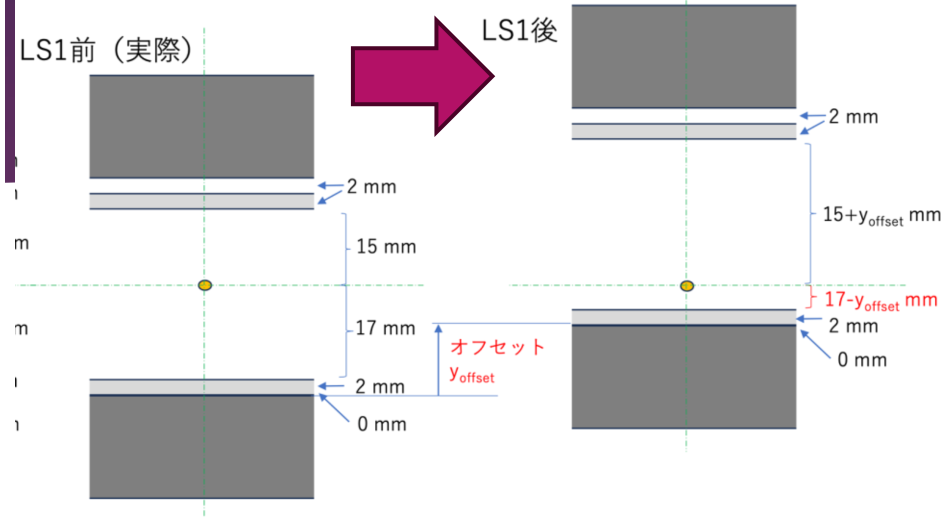


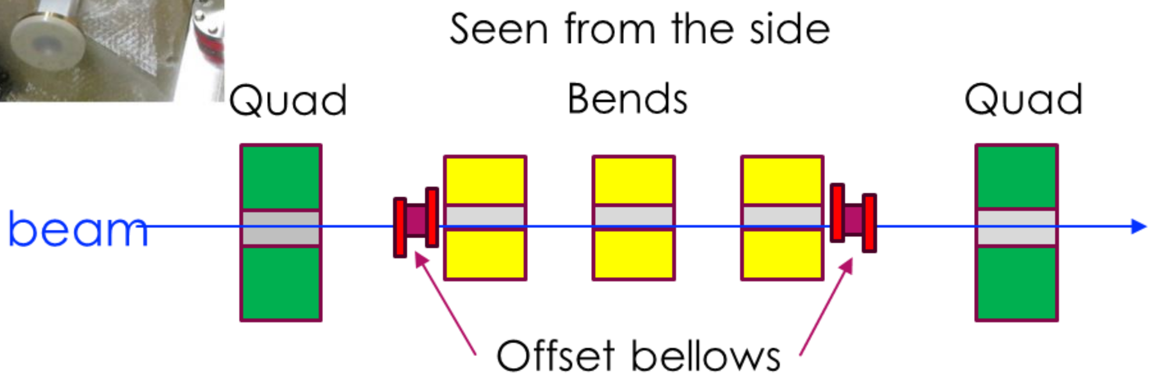

1. Since the horizontal emittance blowup seems to depend on the amount of charge, we suspected the influence of CSR and decided to move the e+ beam closer to the chamber inner wall of the first arc bend (BH1P) to see if the blowup would be reduced.
2. However, there was no large gap between the chamber and bend, so it was decided to offset the chamber and bend upwards.
3. In normal operation, the beam is designed to pass near the vertical center of the bend, but if the offset is set to 14 mm, there is a concern that the unexpected vertical dispersion generates due to the influence of the fringe magnetic field of the bend. We confirmed it using tracking simulation to find that the beam tuning will take a longer time than before.

# Bending magnet chamber








The bellows were replaced with ones with a 13mm offset on the left and right sides.

K. Shibata

- The cause of injection emittance blowup in BTs are still mystery.
- In the next BT dump mode operation in December
  - In the e+ BT, we will study if the horizontal emittance blowup in the e+ BT is suppressed or not.
    - If YES, we know that CSR is the cause, or if NO, we need to consider other causes.
  - We also plan to conduct a study to improve the accuracy of emittance measurement for investigating the emittance blowup.

# 5. SBL : What is "Sudden Beam Loss"

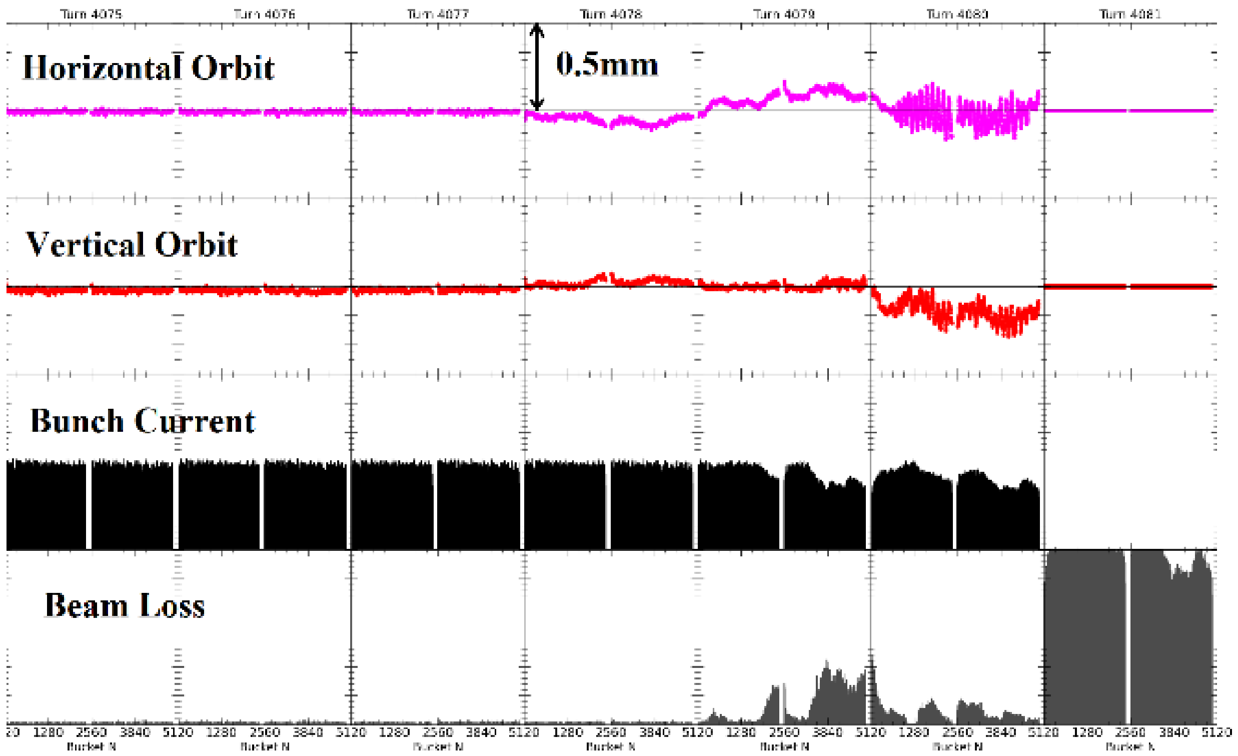
**Beam loss that occurs suddenly within 1 turn (10μs) without precursory phenomena. = Sudden Beam Loss (SBL)**

- The cause of SBL is unknown.
- A significant percentage of the beam is lost before the abort trigger is applied.

→ Harmful effects of SBL;

- Damage to collimators and other accelerator components,
- Quench of the final focusing superconducting magnets (QCS),
- Large backgrounds to the Belle-II detector,
- **Inability to store high current due to beam abort.**

Beam signal measured by
Beam Oscillation Recorder(BOR) & Bunch Current Monitor(BCM)



# Beam Abort Categorization

After the categorization:

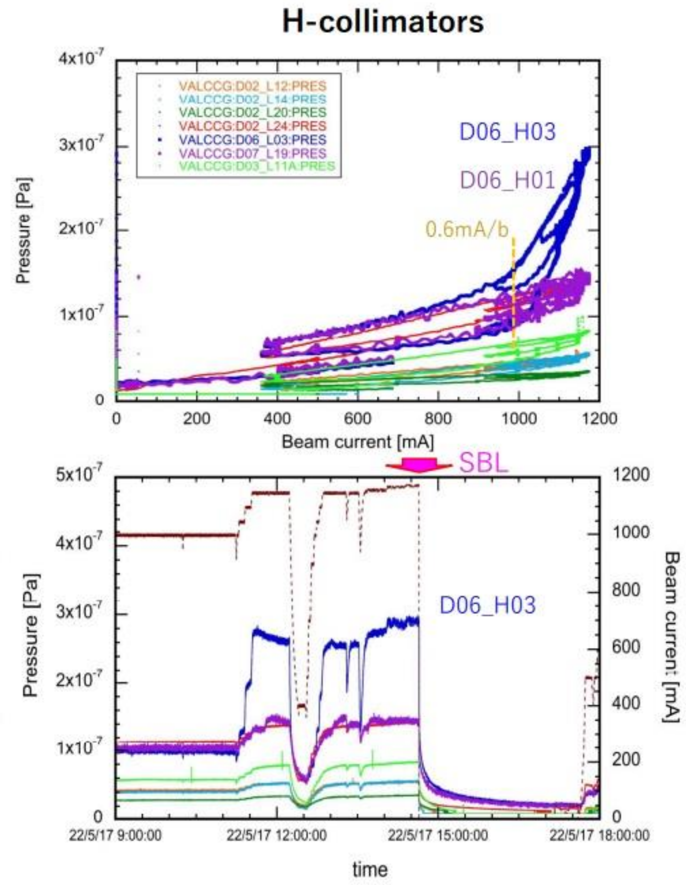
| Aborts N. | 2022/02 | 2022/03 | 2022/04 | 2022/05 | 2022/06 | 2022 |
|---|---|---|---|---|---|---|
| **HER** | 1 | 62 | 87 | 101 | 76 | 323 |
| **LER** | 10 | 29 | 66 | 88 | 65 | 258 |
| **Machine** | 0 | 2 | 1 | 1 | 0 | 4 |
| **Unknown** | 0 | 0 | 2 | 1 | 0 | 3 |
| **Total** | 11 | 93 | 156 | 191 | 141 | 592 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **SBL HER** | 0 | 6 | 9 | 10 | 9 | 34 |
| **SBL LER** | 2 | 8 | 10 | 12 | 21 | 56 |
| **Injection Related** | 4 | 16 | 48 | 81 | 24 | 173 |
| **RF/magnet/vacuum /earthquake** | 7 | 42 | 39 | 43 | 31 | 162 |

No particular correlation was found

# Sudden Beam Loss (SBL) : Observation

- The beam suddenly disappears just before the abort.
- Beam loss occurs in both HER and LER, but the damage to the hardware is particularly large when loss occurs in LER.
- We don't know if it will happen even with a single beam or low current beam because we haven't operated for a long time.
- The starting point of beam loss depends on the tuning of the collimator and is not limited to a specific location.
- Just before the beam loss begins, the orbit appears to move, but its value is small∼O(0.1 mm).
- The orbit is changing < O(1mm) after the beam loss.
- No oscillations that could be precursors to beam loss are observed.
- Pressure bursts have been observed all over the place and rarely occur in the same place except at the collimator section.
- Regarding the pressure of D06H3 and H1 collimators there are rapid or nonlinear increase of pressure depending on the beam current.



# SBL : Candidate Reasons for SBL

- Damage of vacuum component (RF Finger) @KEKB & PEP-II
  - Beam phase changes (beam energy losses) observed ms to several hundred μs before aborts. → The time scale differs from that of SBL.
  - Abnormal temperature rise at bellows chambers had been observed and the catastrophic damages in the RF-finger had been confirmed. → We could not find that damage.
- Dust : Early stage @ SuperKEKB
  - Vacuum chambers were cleaned or tapped to remove as much dust as possible.
- Electron Cloud
  - SBL should be measured only in LER.→ SBL is also measured in the HER beam.
  - Curious behavior of the pressure in D06H3 collimator may suggest the formation of a discharge or electron cloud.
  - Simulations show that the electron density distribution changes with time and a maximum electron density is on the order of 1E13/m3 to 1E14/m3 → How this relates to SBL?
- Fireball : Measured @ RF cavity
  - The vacuum chamber is made of copper with low sublimation point and collimator head is made of tungsten or tantalum with high sublimation point.

  → The situation has the potential for a fireball to be formed.
  - This fireball hypothesis could explain SBL (~μs) due to the fast plasma evolution (~100 ns at the fastest).

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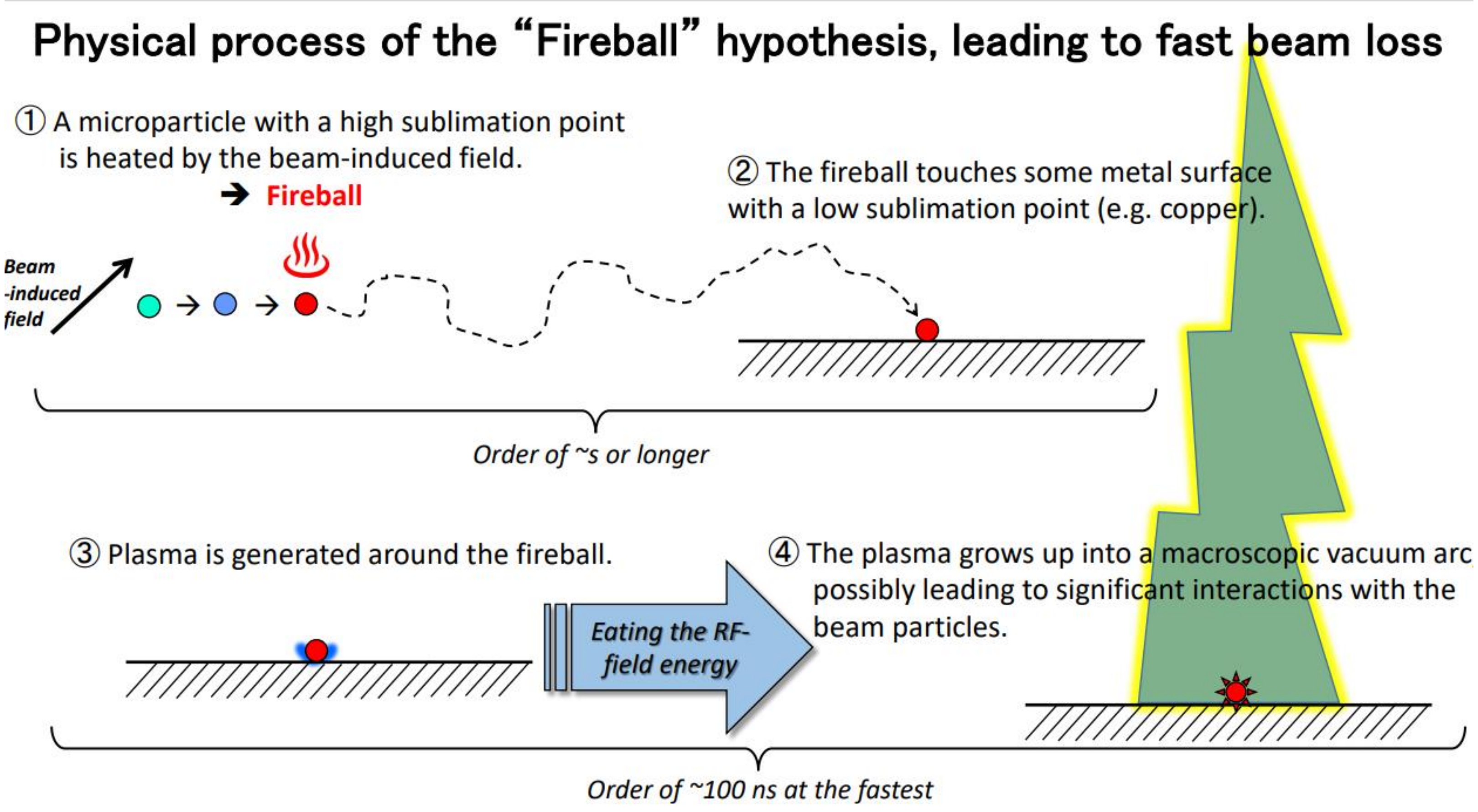


# SBL : Work during LS1

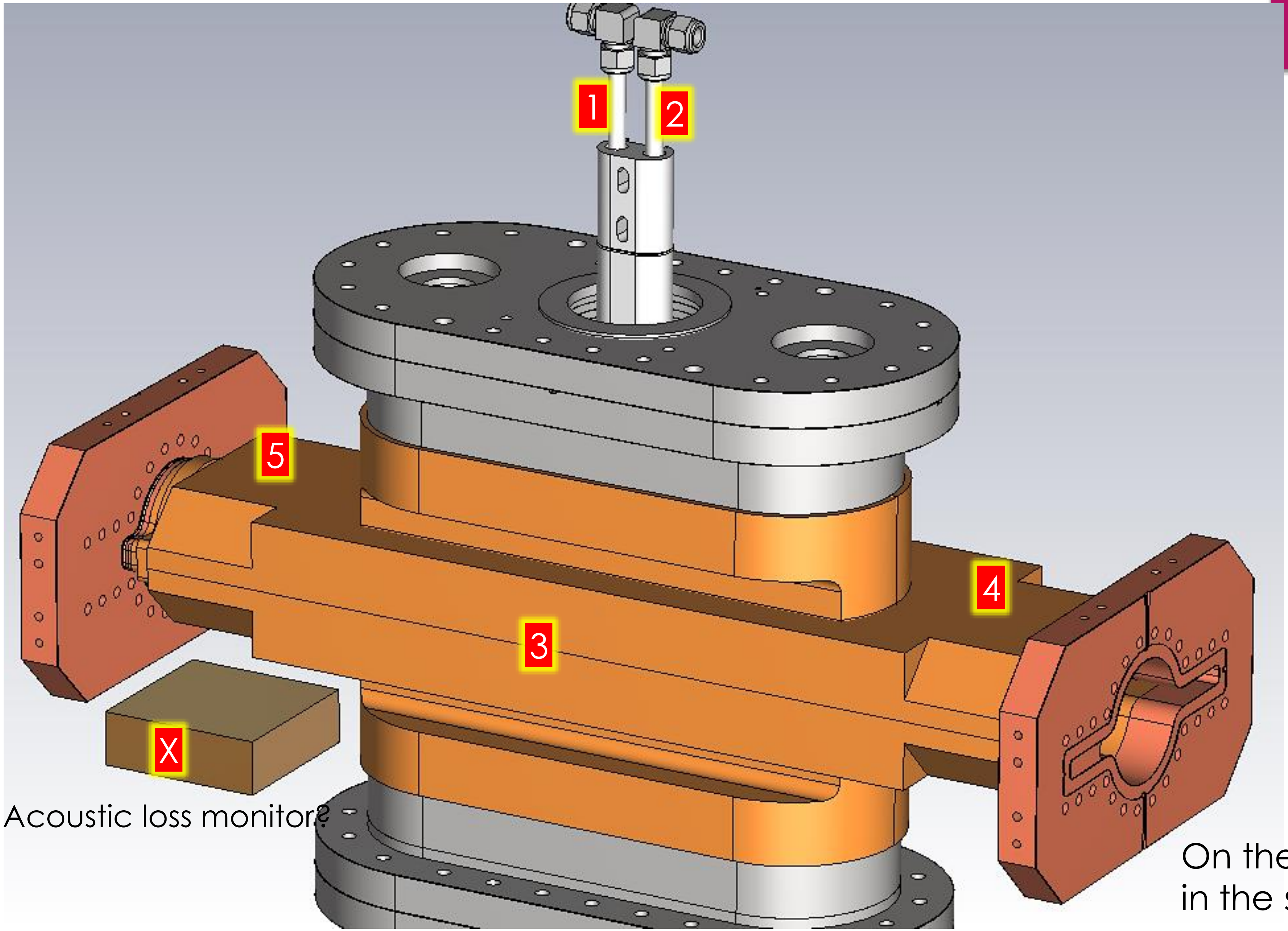
**For preventing SBL**

- Replacing damaged collimator head.
- Copper coating of collimator heads (D6H3, D6V1, D5V1, D2V1). (Cover material with a high sublimation point, which could be the seed of a fireball, with material with a low sublimation point.)
- Installation of permanent magnets in all SuperKEKB-type horizontal collimators. (In order to reduce the electron cloud effect...)
  - LER D02H4, D02H3, D02H2, D02H1, D03H1, D06H3, D06H4
  - HER D01H3, D01H4, D01H5

**For investigation the cause of SBL**

- Add BOR to investigate beam orbit change in locations that may be the cause of SBL.
  - Measure the orbit at two different locations with phase differences.
  - Add a simplified version to measure in phase with the collimator, although with less accuracy.
- Install acoustic sensors to observe the sound when the Fire-ball occurs.(D2V1:minimum physical aperture, D5V1:new collimator)
- Add loss monitor for timing measurement

: Acoustic sensor




On the underside
in the same manner

# Summary

- There are many factors of limiting luminosity.
  - Beam size blowup
  - Optics & Orbit
  - Beam Lifetime
  - Injection
  - Sudden beam loss
- Hardware that could be addressed in LS1 was addressed.
- In addition, monitors were prepared for a better understanding of each problem and to prepare for future operations.

# International Task Force

- collective effects
- injection
- beam tuning
- SBL

- IR Upgrade

# backup

# Beam-Beam Parameter

Vertical beam-beam parameter

$$\xi_{y\pm} = 2er_e \frac{\beta^*_{y\pm} L}{\gamma_\pm I_\pm}$$

Vertical beam-beam parameter (incoherent)

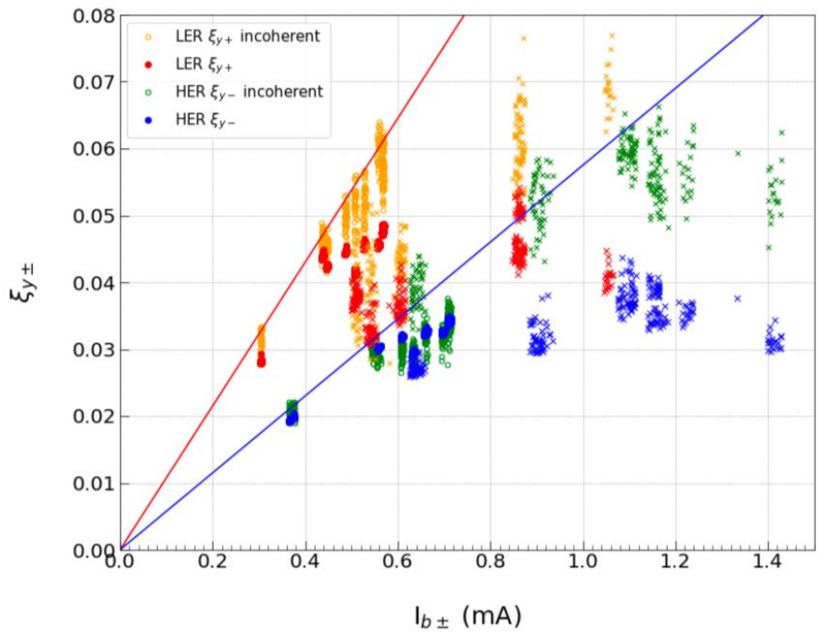
$$\xi_{y\pm} = \frac{r_e}{2\pi\gamma_\pm} \left(\frac{I_{b\mp}}{ef_0}\right) \frac{\beta^*_{y\pm}}{\phi_x \sigma_{z\mp} \sigma^*_{y\mp}} \propto I_{b\mp} \sqrt{\frac{\beta^*_{y\pm}}{\varepsilon_{y\mp}}}$$

Bunch lengthening is an important parameter.

Here, the nominal bunch length is used.

$$\sigma_{z+} = 4.6\ mm$$
$$\sigma_{z-} = 5.1\ mm$$

$\varepsilon_{y-} = 25pm$ $\varepsilon_{y+} = 35pm$




physics run and HBC - High Bunch Current Study (393 bunches)

Beam-Beam parameter in the LER is already large at 0.8 mA.
Especially, incoherent tune-shift is $\xi_y$ ~ 0.065. (-15% due to bunch lengthening)

Y.Onishi

# Progress and outlook for emittance blowups of the injection beam

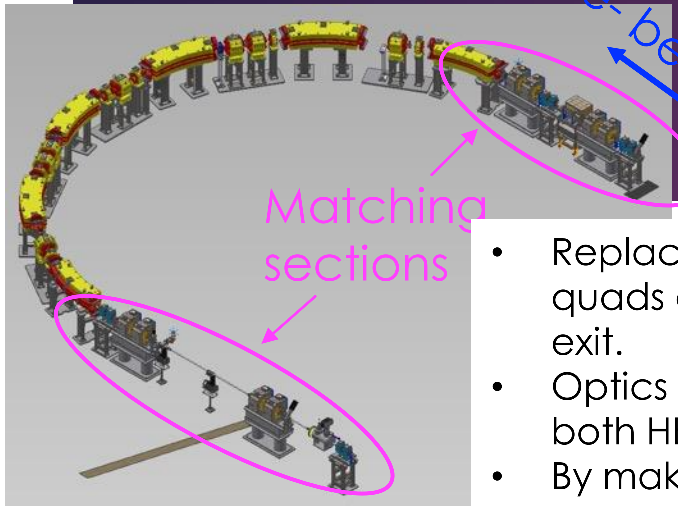
| e- beam | Issue | Solution | LS1 | Sometime after LS1 |
|---|---|---|---|---|
| Horizontal emittance $\gamma\varepsilon x$ growth (Charge dependent) | Cancellation of CSR | Exchanging to the narrower chambers | No | balance with budget |
| | | Low dispersion optics | if good | under consideration |
| Horizontal emittance $\gamma\varepsilon x$ growth (Charge independent) | ISR | New straight BT line | No | balance with budget |
| **Vertical emittance $\gamma\varepsilon y$ growth** | **Still mystery** | | | |
| Longitudinal acceptance | Just barely in HER acceptance | ECS installation (already decided) | No | to be completed in BT1 by 2024 |

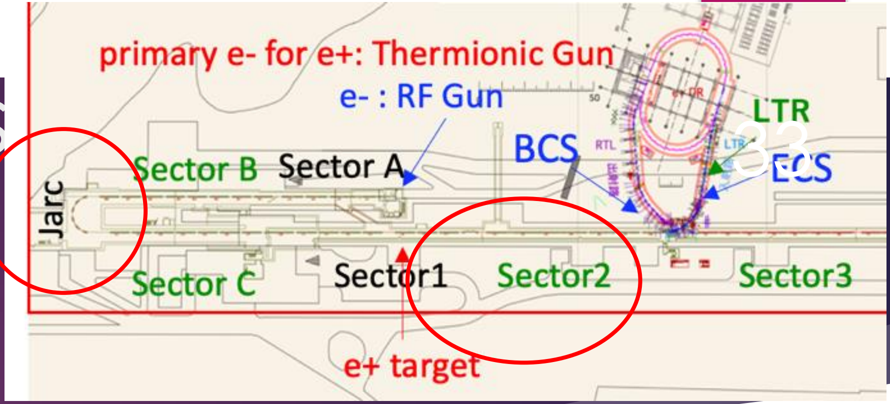
| e+ beam | Issue | Solution | LS1 | Sometime after LS1 |
|---|---|---|---|---|
| Horizontal emittance $\gamma\varepsilon x$ growth (Charge dependent) | CSR | **V. Offset of bending in e+BT Arc1** | Yes | **will be studied in December** |
| | | Low dispersion optics | If good | under consideration |
| Horizontal emittance $\gamma\varepsilon x$ growth (Charge independent) | Blowup somewhere from DR to BT1 | Low emittance optics in the DR | | under consideration |
| **Vertical emittance $\gamma\varepsilon y$ growth** | **Still mystery** | | | |
| Longitudinal acceptance | no problem | | | |

# 1. Pulsing quadrupole magnets

Y. Okayasu

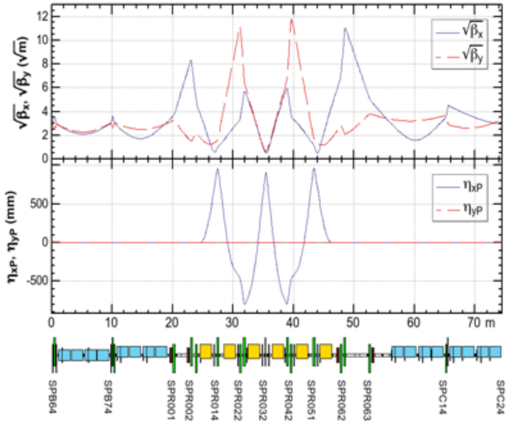
J-ARC



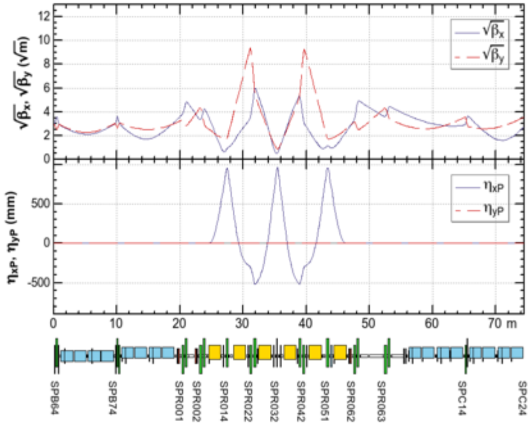




- Replace 3 DC quads with 4 pulse quads at both of entrance and exit.
- Optics matching can be done for both HER and LER beams.
- By making beta functions in J-ARC become small, the beam loss there will be suppressed.

Current optics at J-ARC

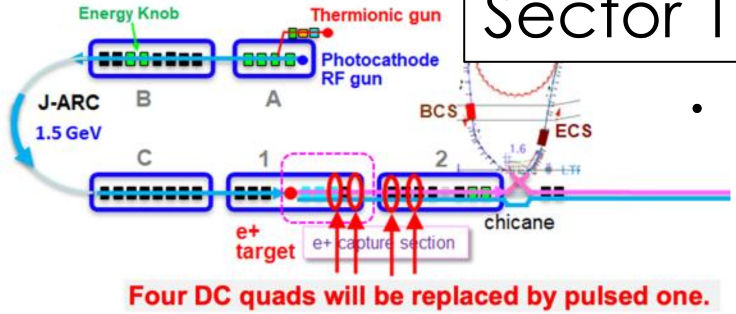


New optics at J-ARC with pulsed quads



Y. Seimiya

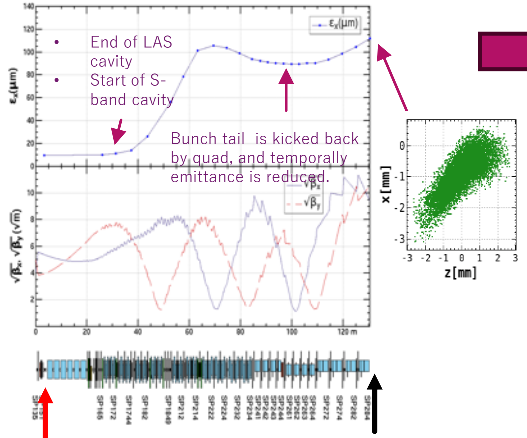
Sector 1-2




- Emittance growth due to the transverse wake field of e- beam will be suppressed by the smaller beta functions with the new pulsed quads.

Y. Seimiya

$\Delta\gamma\epsilon x$ ~ 100 um, $\overline{\beta x}$ = 45.2 m

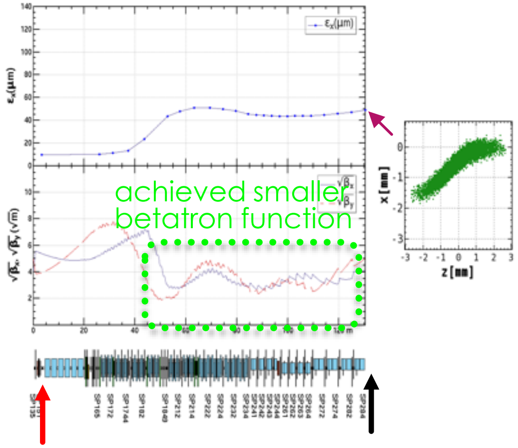



e+ target

Sector2 end

Before optimization

$\Delta\gamma\epsilon x$ ~ 40 um, $\overline{\beta x}$ = 16.3 m




e+ target

Sector2 end

After optimization

e- beam

# 2. New accelerator structure



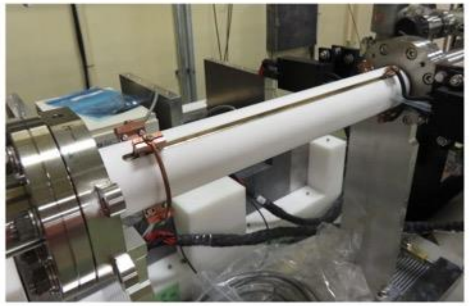
- Mitigation of accelerating structure failures
  - Originally designed for 8 MeV/m (PF injector), but used at 20 MeV/m (KEKB upgrade)
  - Degradation that lead to high field emission rate and discharges
  - Water leaks, field emission , discharge in waveguide, and so on (29 of 60 units have some problems)
  - Not only future Υ(6S) but even Υ(4S) could be suffered
- 5-year upgrade plan to fabricate and install new accelerator structures (FY2018 – FY2022)
  - 4 units (16 acc. structures) will be replaced by new one. (Unit44 in sector 4 was already replaced in the summer of 2022)
  - New acc. structure: acc. gain ↑7%, surface field ↓20% (reduce breakdown)
  - New pulse compressor (SCPC) was also developed and installed in Unit44.

New S-band 2-m-long TW acc. structure

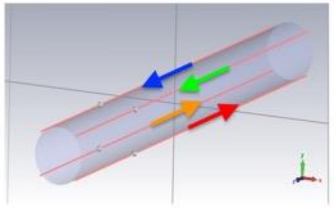
H. Ego

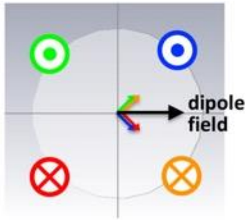
# 3. Fast kicker for 2nd bunch orbit correction

- Ceramics Chamber with integrated Pulsed Magnet
- Magnetic field type kicker with four parallel coil wires
- The current configuration described above
  - Parallel and anti-parallel currents generate horizontal dipole magnetic field (vertical beam kick)
- Two fast kickers will be installed at the LINAC end and the electron BT line in this summer.
  - Prototype one was already installed at J-ARC in summer 2022.



C. Mitsuda





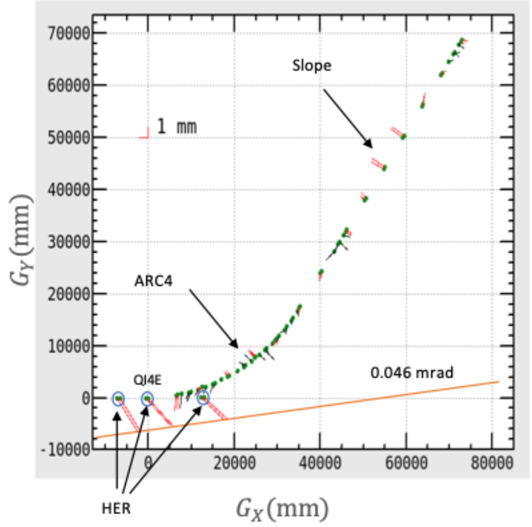

T. Kamitani, T. Natsui

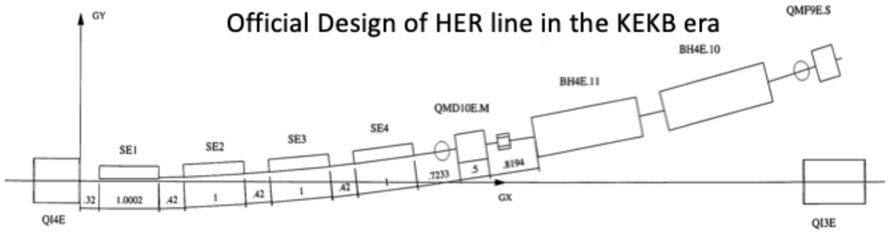
# 1. BT ARC4 alignment



HER

M. Tawada, M. Kikuchi




| Element | GX(in) | GY(in) | CHI1(in) | GX(out) | GY(out) | CHI1(out) |
|---|---|---|---|---|---|---|
| BH4E.11 | 9.333249 | 1.04257 | -0.217947 | 7.582857 | 0.719259 | -0.147351 |
| QMD10E | 6.772384 | 0.598962 | -0.147351 | 6.277802 | 0.525553 | -0.147351 |
| SE4 | 5.56232 | 0.419356 | -0.147351 | 4.570578 | 0.291108 | -0.109851 |
| SE3 | 4.153109 | 0.245064 | -0.109851 | 3.157256 | 0.154088 | -0.072351 |
| SE2 | 2.738355 | 0.123727 | -0.072351 | 1.739791 | 0.070151 | -0.034851 |
| SE1 | 1.320046 | 0.055517 | -0.034851 | 0.32 | 0.039413 | 0.002649 |
| QI4E | 0 | 0 | 0 | -0.8 | 0 | 0 |
| QI3E | 13.0807 | 0 | 0 | 12.0427 | 0 | 0 |

注1：(GX,GY)座標系の原点はQI4Eの端板の外側とリングビームラインの交点である。
注2：CHI1は(-GX)軸から(+GY)軸方向に時計方向に測った角度である。
注3：QI4E,QI3Eは端板(t=19mm)を含めてかいてある。その他の電磁石はコアを示している。

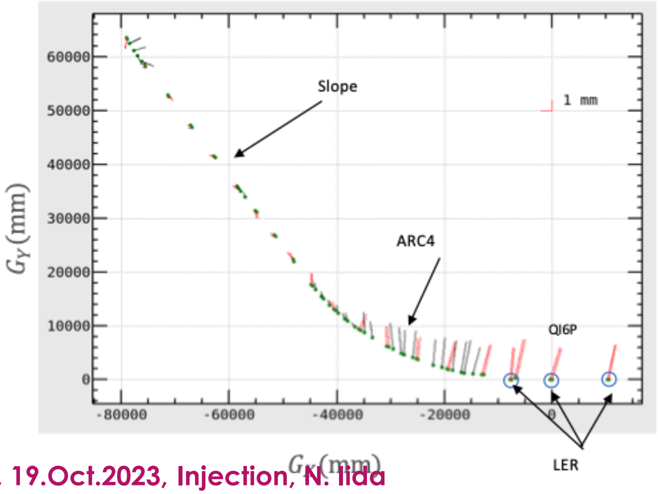
- Example of septum angle adjustment

$X_{ini} = 36\text{mm} \quad Px_{ini} = 2.44\text{mrad}$

The surveyed electromagnet position (2018) was analyzed.
- The HER was tilted 46 µrad relative to the BT coordinate system
- The QI4E position was offset by (2.9mm,-2.73mm) from the BT coordinate system.
- The position of the electromagnets in the 4th arc was different from the "Official Design" Optics.

Using the straight part of the ramp as a reference, align the last four Q magnets and the BPM (about 1 mm). All four Septum magnets need adjustment.

LER




Analysis of measured electromagnet positions (2018)
- Both BT and LER electromagnet positions are misaligned by about ΔGy ~2.5mm relative to design
- Relative relationship between BT and LER electromagnets is almost correct.

Using the straight section of the ramp as a reference, change the bend angle of the 4th arc Bend design Align the B and Q magnets with the BPM for the changed Bend. Septum needs to be readjusted.

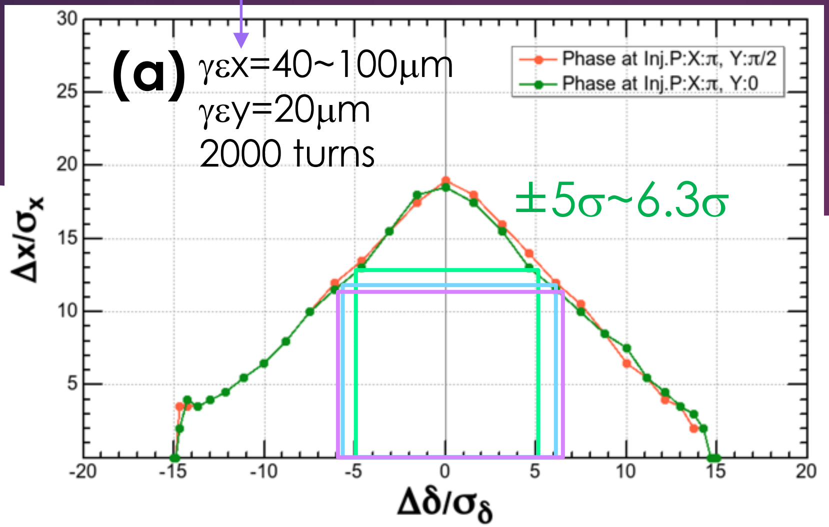
# Dynamic aperture (DA) of HER for injection

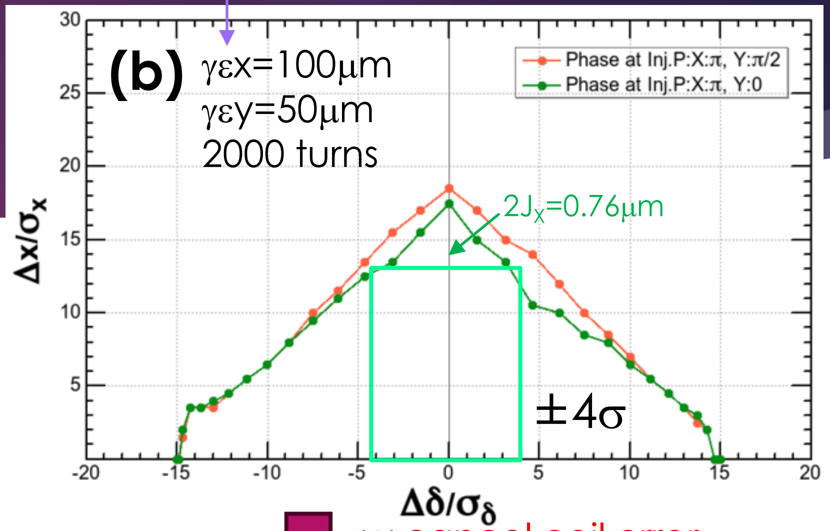


Simulation

Designed vertical emittance of injected beam

Measured best emittance of injected beam

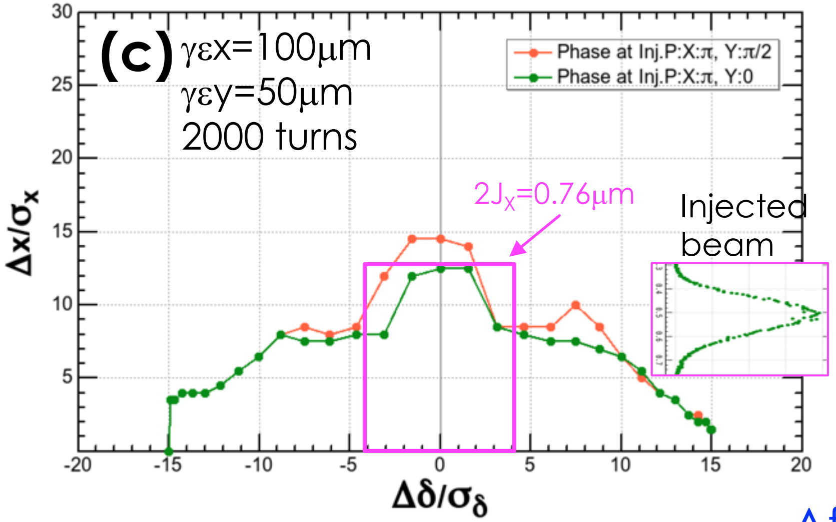


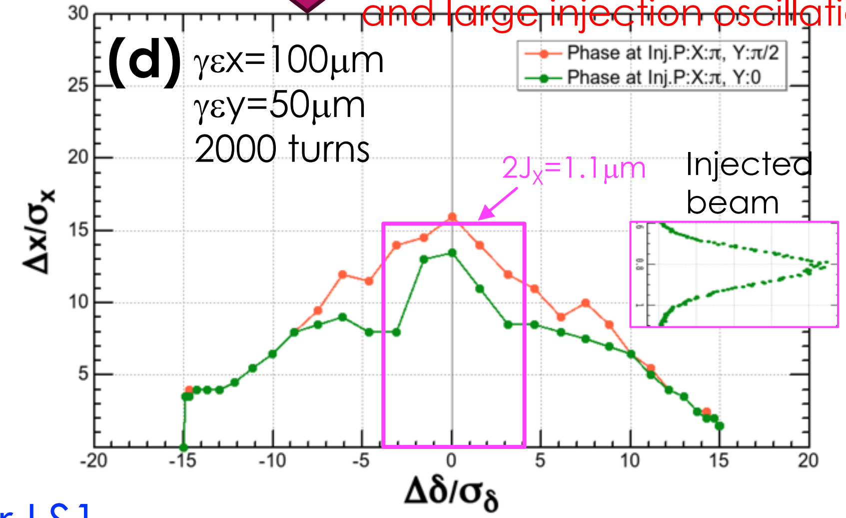




Recently, a wrong fabrication in canceling coil has been noticed.
Reflecting this effect, all injected particles no longer entered in the DA as shown in (d).

However, by widening the aperture near the injection point and by an improvement of the magnetic field of the septum magnet in LS1, it was found that the situation recovers to some extent as shown in (c).

w cancel coil error
and large injection oscillation




After LS1

In the future

Tracking simulation of HER injection under the conditions below to obtain the injection efficiency.

# 5. Convert screen monitor to OTR

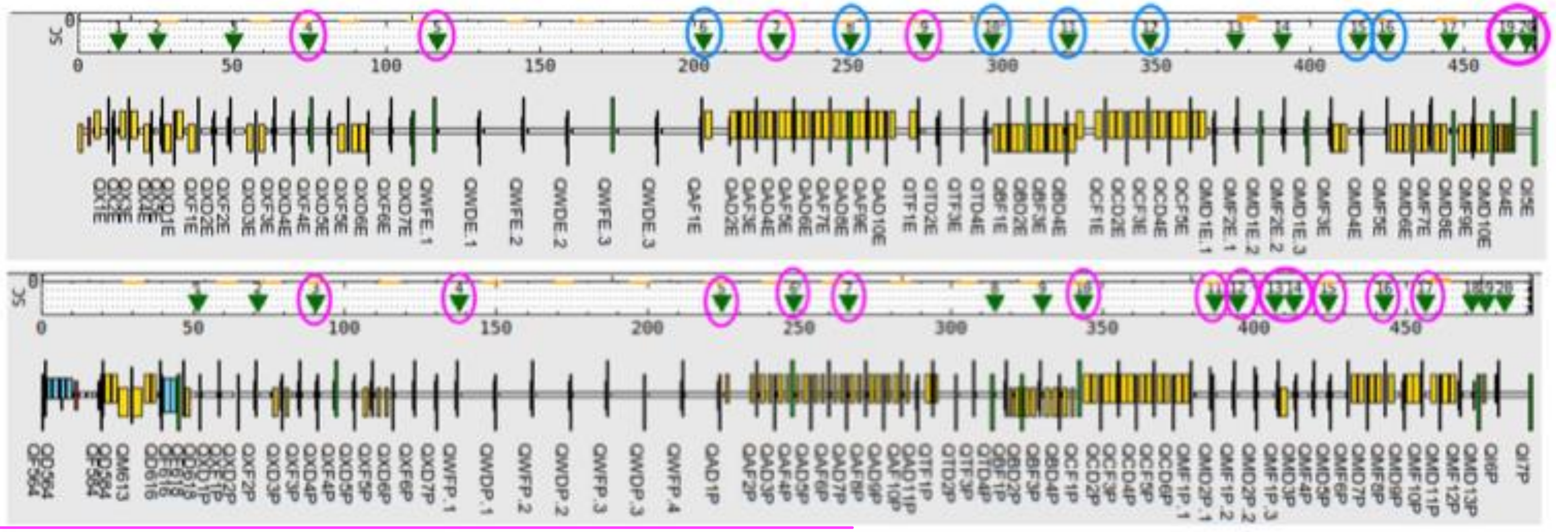
Locations of OTR monitor at BT line

e- for HER

Linac END

BT End

e-




e+ for LER

$e^+$

○: OTR monitors already in use.

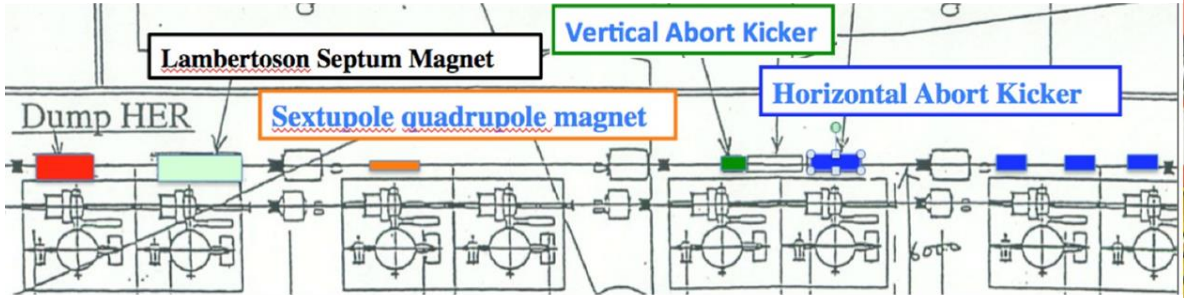
○: OTR monitors which will be ready until the end of LS1.

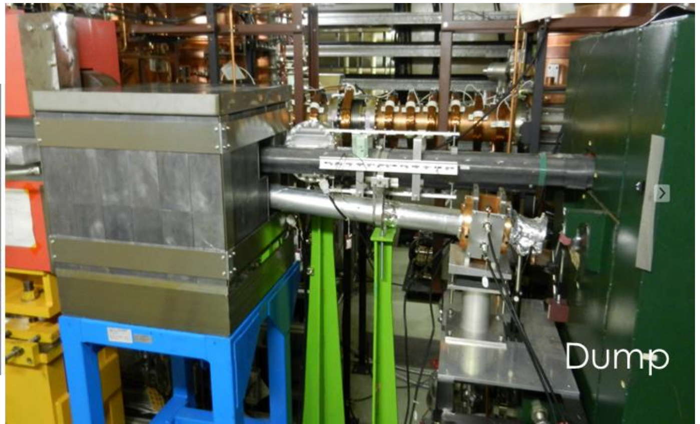
Beam size can be quantified by converting the screen to OTR, which enables more precise emittance and energy spread measurement.

T. Mori

# Beam Abort System

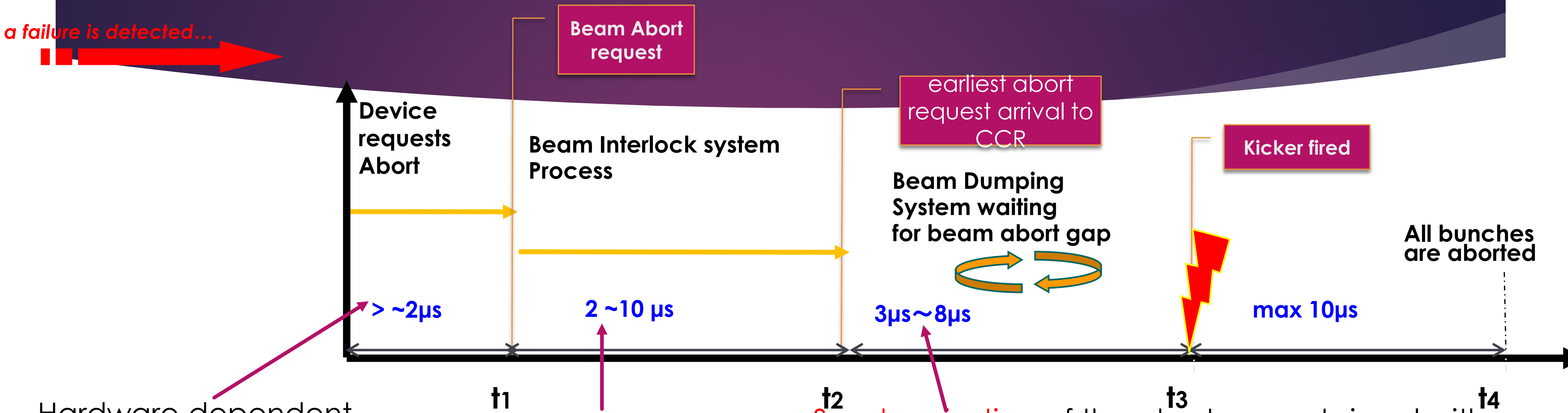
- In order to protect the hardware components against the high beam currents, we installed the controlled abort system.
- The beam is kicked by an abort kicker, taken out of the vacuum chamber through an abort window made of Ti, and throwed into a beam dump.
- Dumped beam length : one revolution time (**10 μs**).
- Build-up time of the abort kicker magnet : 200 ns (empty bucket space).
- Synchronization of the kicker timing and the abort gap is required for the protection of hardware.
- We minimized abort trigger time to protect the hardware damage.



# Abort Trigger Delays






Hardware dependent

To summarize the abort request on the beam abort system.

Depends on the optical cable length from the local control room to CCR.

Synchronization of the abort request signal with revolution/2 in FPGA. : Max delay=5μs

Delay to synchronize to the abort gap(fixed delay) : ～0μs

Delay from CCR to kicker (400m) : 2μs

Thyratron ON :1μs

Rise time for the kicker : 200ns

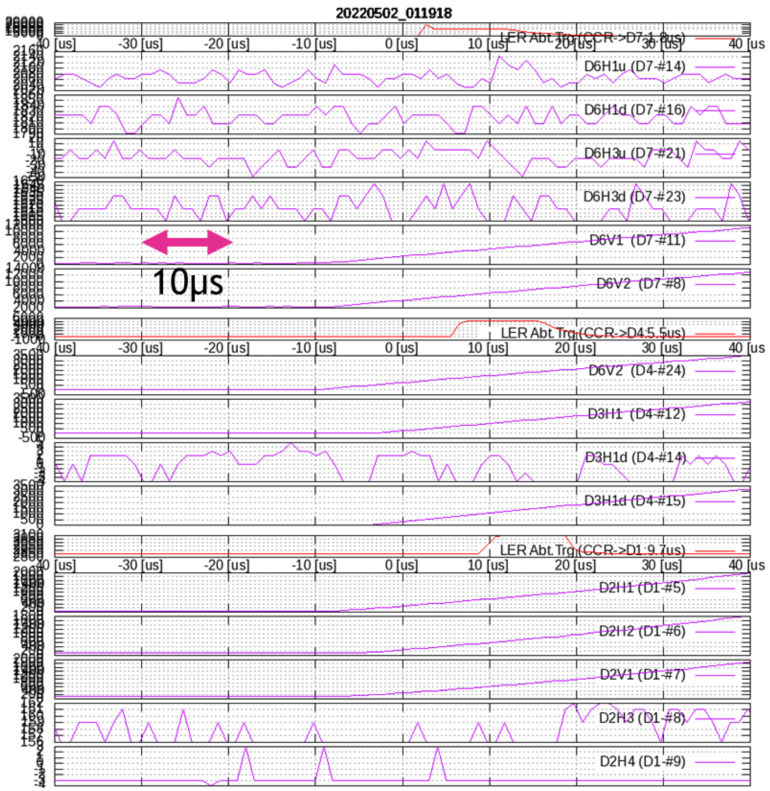
**Minimum Abort Delay = 17～30μs**

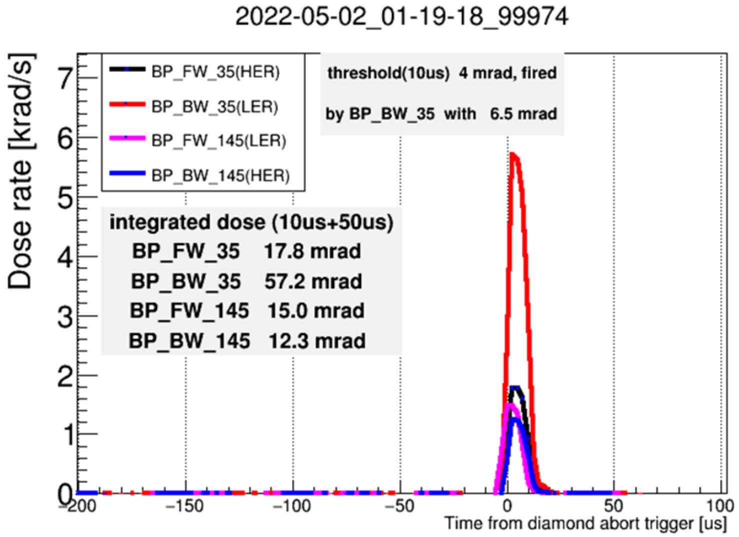
# Observation : Beam Loss Monitor

- Checked the loss monitor at the time of abort occurrence which was probably due to beam loss.

↓

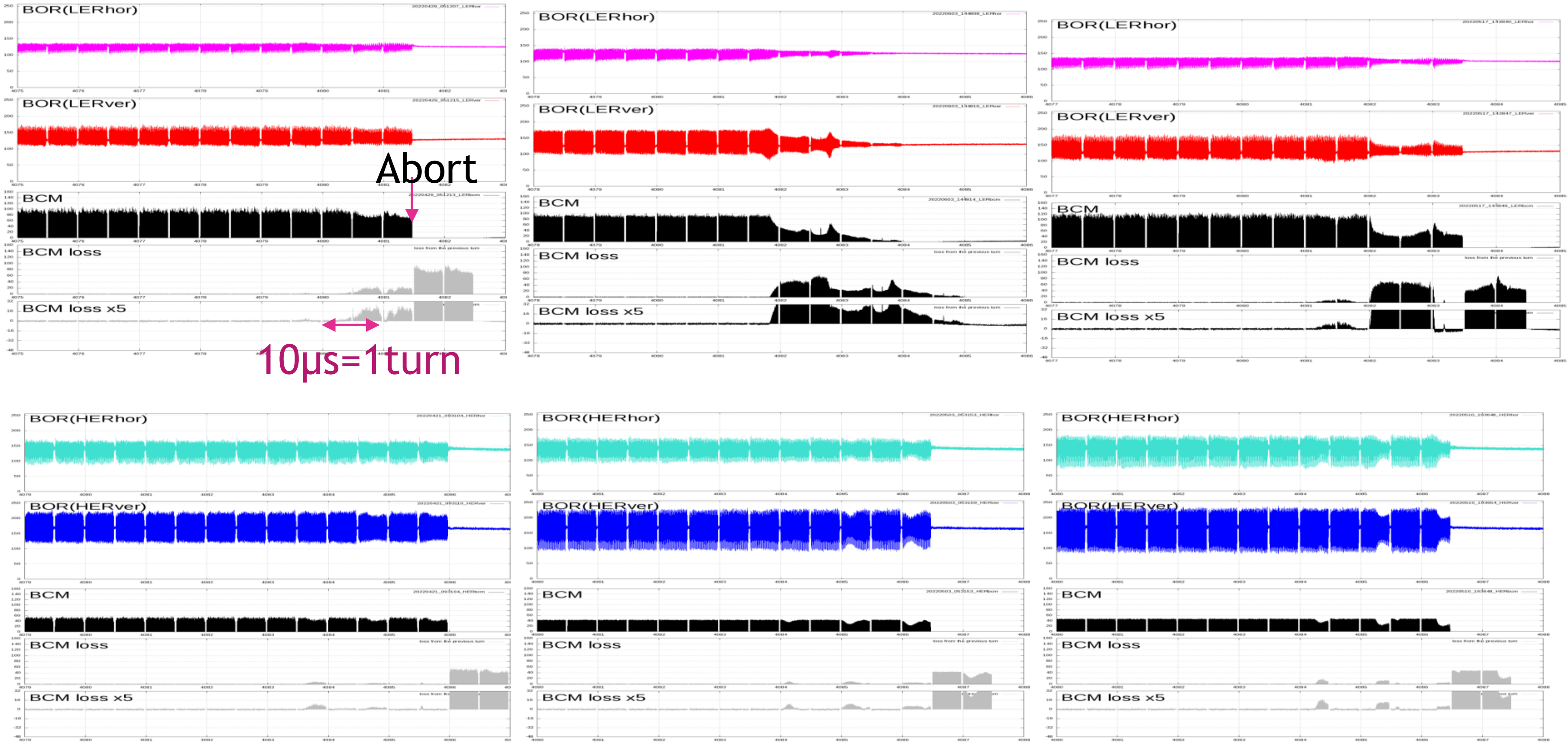
- There were many instances of sudden beam loss occurring simultaneously in the entire ring collimator section and in the Belle-II detector.



# Observation :
# Bunch Current monitor & Bunch Oscillation Recorder

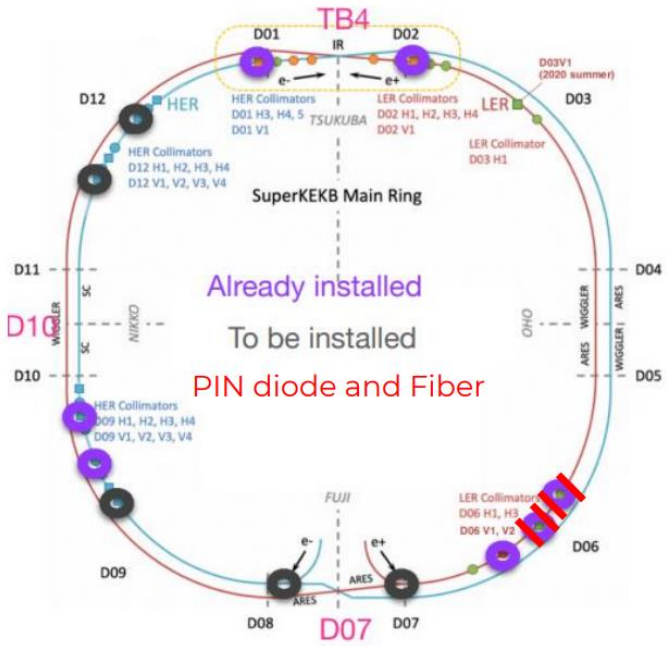
- The beam suddenly disappears just before the abort.
- Beam loss occurs in both HER and LER, but the damage to the hardware is particularly large when loss occurs in LER.

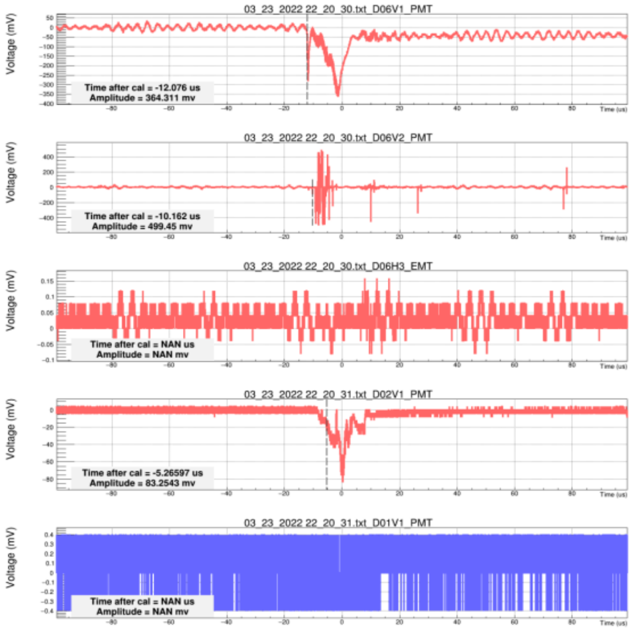


# Observation : Loss Monitor Specialized for Timing Measurements

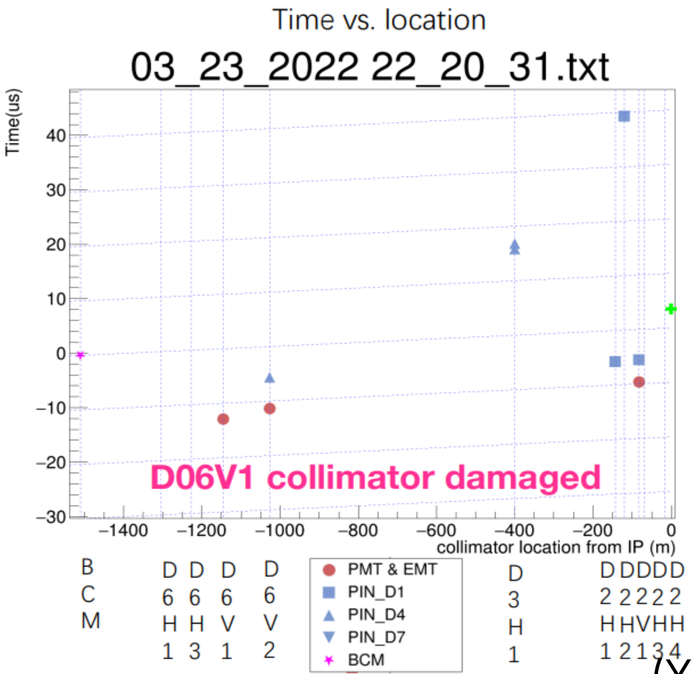
- We checked the starting point of SBL in the ring by using loss monitors specialized for position identification
- The beam loss mainly started at the D06V1 collimator (a narrow aperture to suppress background to Belle-II detector).
- When the D6 collimator was damaged and the aperture was widened, beam loss began in the D2 collimator section near the IR.

→The starting point of beam loss depends on the tuning of the collimator and is not limited to a specific location.



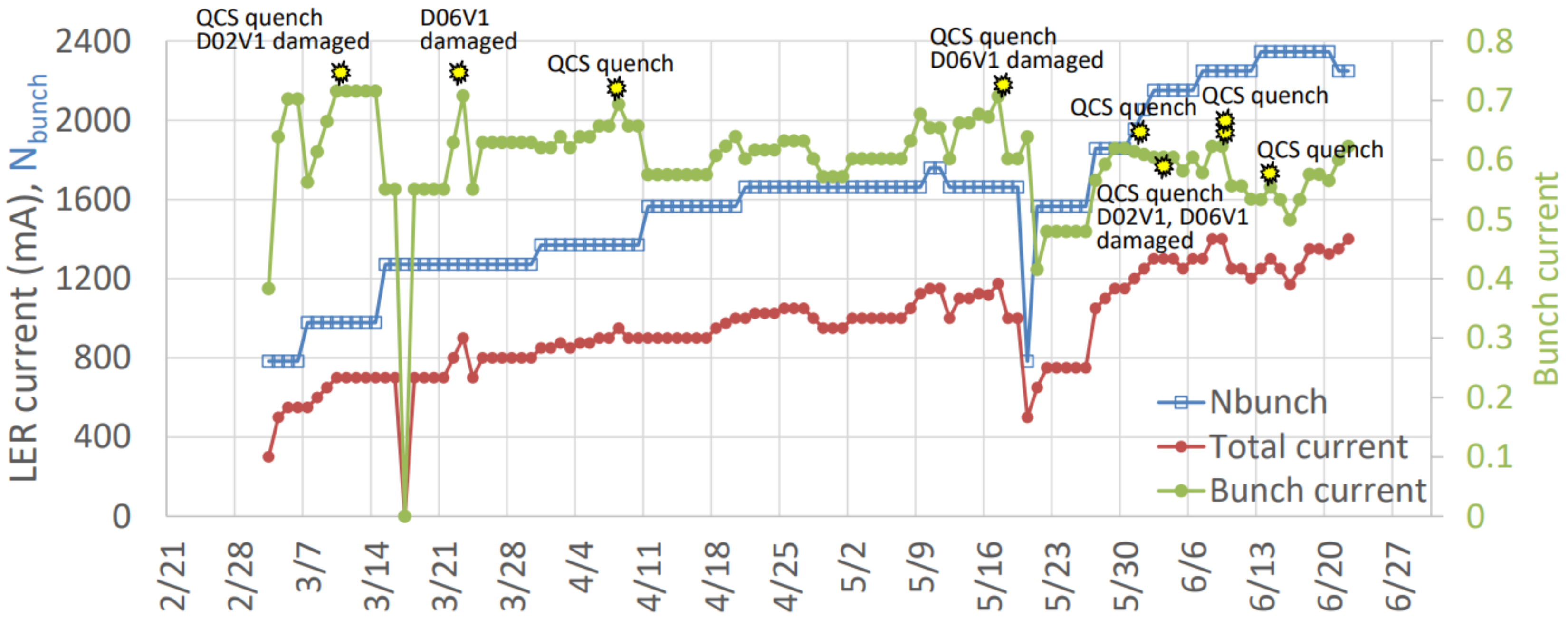
PMT & EMT




(Y.Liu)

# Observation : Beam/Bunch Current Dependence

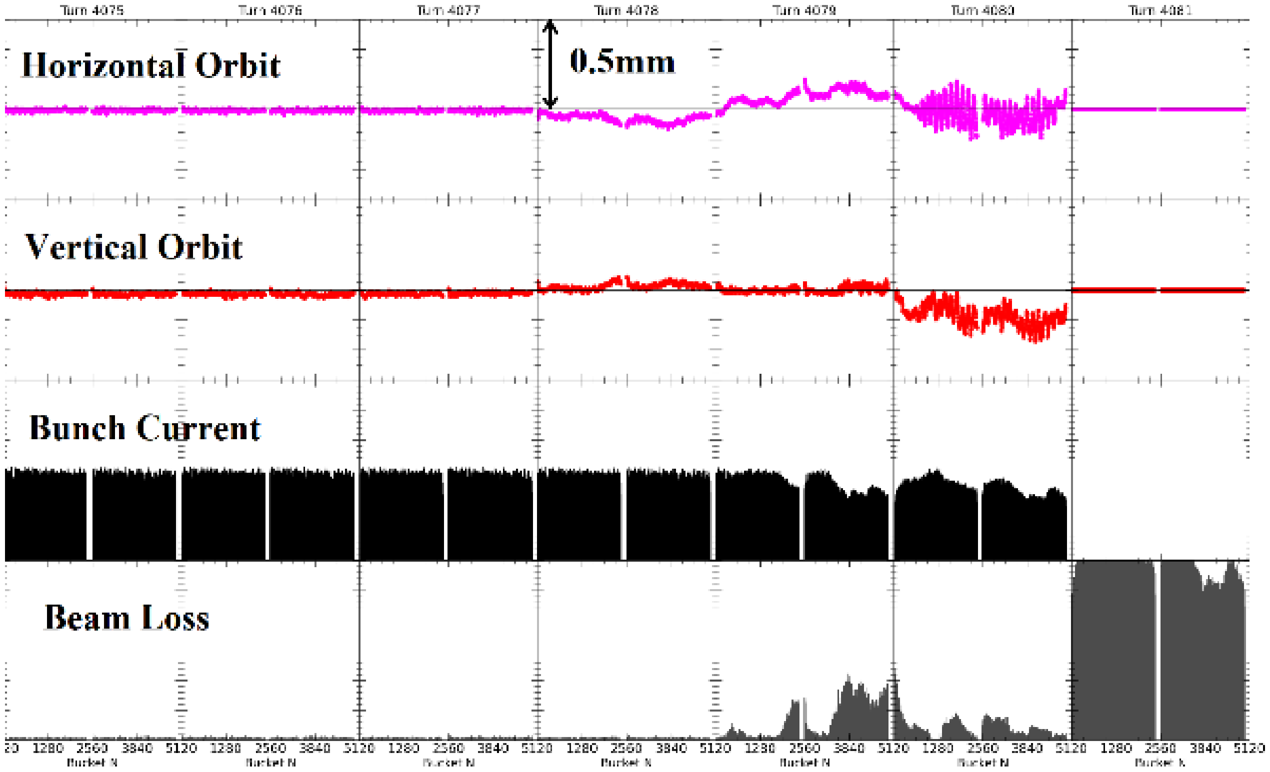
- It is likely to occur when a certain bunch current is exceeded.
- We don't know if it will happen even with a single beam or low current beam because we haven't operated for a long time.




(K.Matsuoka)

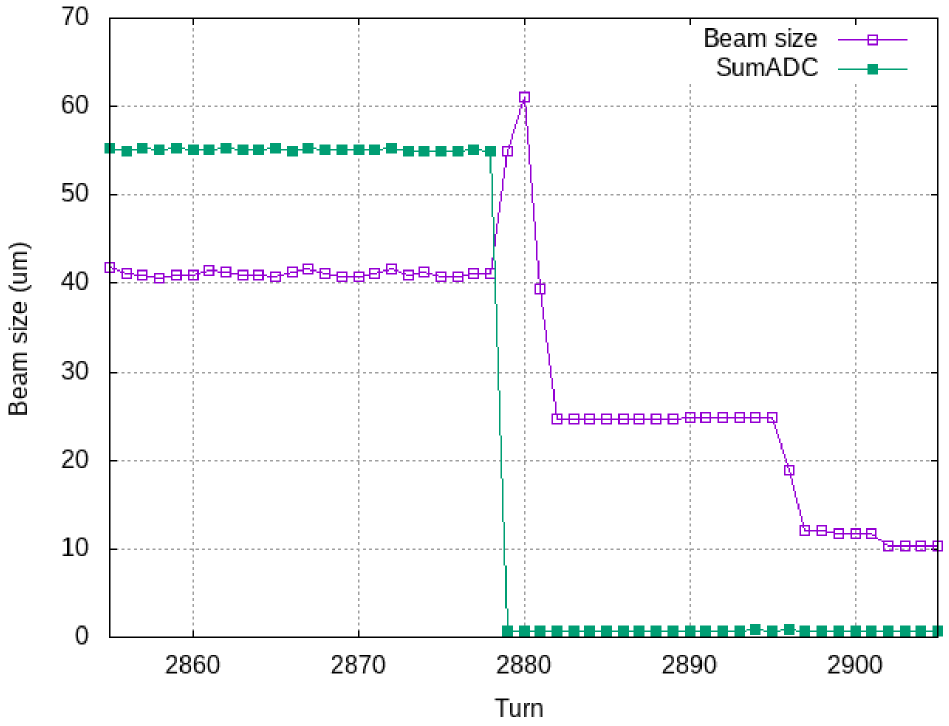
# Observation : Beam Orbit

- Just before the beam loss begins, the orbit appears to move, but its value is small∼O(0.1 mm).
- The orbit is changing < O(1mm) after the beam loss.
- No oscillations that could be precursors to beam loss are observed.



# Observation : Beam Size

- We checked for beam size fluctuations by installing an ultra-high speed CMOS camera in the X-ray monitor to take 1μs data at 100kHz when the abort is triggered.
- There was no sign of a significant change in beam size before the SBL.



# Status of LER collimator



| Name | Type | Tip Material<br>(): longitudinal length in mm | Tip Condition | Remarks |
|---|---|---|---|---|
| D06H3 | SuperKEKB | Cu coated C (160) | healthy | spoiler against inj. kickers' accidental firings |
| D06H4 | SuperKEKB | Ta (10) | healthy | absorber against inj. kickers' accidental firings |
| D03H1 | SuperKEKB | W (10) | healthy | |
| D02H1 | SuperKEKB | W (10) | healthy | |
| D02H2 | SuperKEKB | W (10) | healthy | |
| D02H3 | SuperKEKB | W (10) | healthy | |
| D02H4 | SuperKEKB | W (10) | healthy | |
| | | | | |
| D06V1 | SuperKEKB | Cu coated Ti (10) | healthy | |
| D06V2 | SuperKEKB | hybrid (3) | healthy | |
| D05V1 | SuperKEKB | Cu coated Ta (4) | healthy | |
| D02V1 | SuperKEKB | Cu coated Ta (10) | healthy | |

(T. Ishibashi)

# Status of HER collimator

| Name | Type | Tip Material<br>(): longitudinal length in mm | Tip Condition | Drive Mechanism | Remarks |
|---|---|---|---|---|---|
| D09H1 | KEKB | Cu coated Ti (40) | damaged | | |
| D09H2 | KEKB | Cu coated Ti (40) | damaged | | |
| D09H3 | KEKB | Cu coated Ti (40) | damaged | | |
| D09H4 | KEKB | Cu coated Ti (40) | damaged | | |
| D12H1 | KEKB | Ti (40) | healthy | | |
| D12H2 | KEKB | Cu coated Ti (40) | damaged | | |
| D12H3 | KEKB | Ti (40) | healthy | | |
| D12H4 | KEKB | Cu coated Ti (40) | healthy | | |
| D01H3 | SuperKEKB | W (10) | healthy | - | |
| D01H4 | SuperKEKB | W (10) | healthy | - | |
| D01H5 | SuperKEKB | W (10) | healthy | - | |
| | | | | | |
| D09V1 | KEKB | Cu coated Ti (40) | damaged | upgraded | Plan to replace with new jaw (Cu coated Ti (40)) |
| D09V2 | KEKB | Cu coated Ti (40) | healthy | | |
| D09V3 | KEKB | Cu coated Ti (40) | healthy | | |
| D09V4 | KEKB | Cu coated Ti (40) | healthy | | |
| D12V1 | KEKB | Cu coated Ti (40) | damaged | upgraded | |
| D12V2 | KEKB | Cu coated Ti (40) | damaged | | |
| D12V3 | KEKB | Cu coated Ti (40) | healthy | upgraded | |
| D12V4 | KEKB | Cu coated Ti (40) | healthy | upgraded | |
| D01V1 | SuperKEKB | Cu coated Ta (10) | healthy | - | |

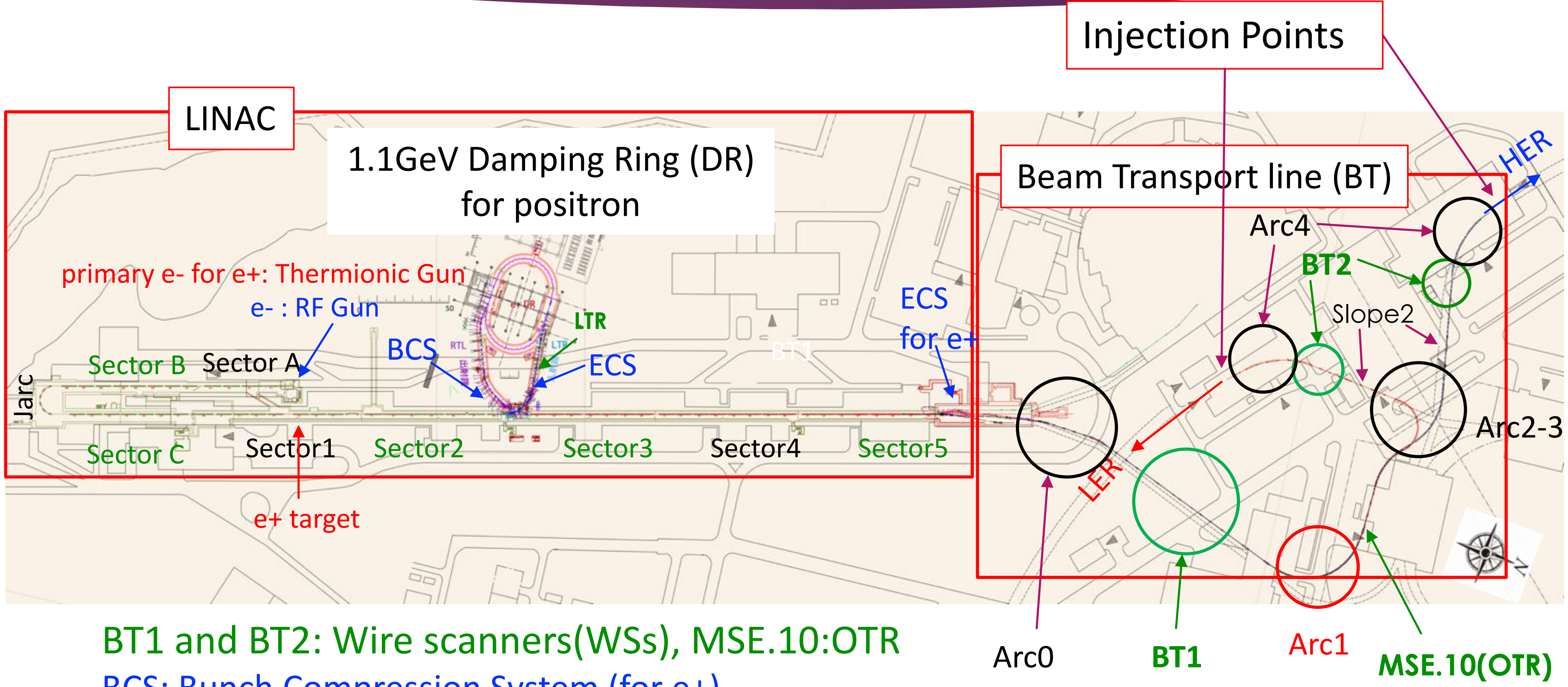
(T. Ishibashi)

# Layout of LINAC, BT, Injection to MR



e+ beam is injected into the LER via DR:
The injection BG is not almost affected by the beam condition at upstream of the DR.

e- beam directly injects into HER:
The injeciton BG is directly affected by the condition of RF-gun, LINAC, and BT.




BT1 and BT2: Wire scanners(WSs), MSE.10:OTR

BCS: Bunch Compression System (for e+)

ECS: Energy Compression System (for e+)

# RF System

- RF system is operating stable.
- For more stable and long-term operation, we will continue to conduct regular inspections and update equipment of RF system.
- Beam current limit by the present RF system is evaluated.
  - RF power delivered to beam : LER 3.6 A (design), HER 2.2 A
  - HOM power absorbed by dampers : LER 2.6 A, HER 2.0 A
  - For HER, **the adding two RF stations** and **the reinforcement of the cooling capacity for HOM damper cooling** are necessary.
- Stability analysis of RF accelerating mode (zero mode) was performed in SuperKEKB operation conditions.
  - The results showed effective measures without requiring big budget to improve the stability. And the results could be used as guidelines for future beam operation by increasing the beam current step by step.