Status of SuperKEKB collider

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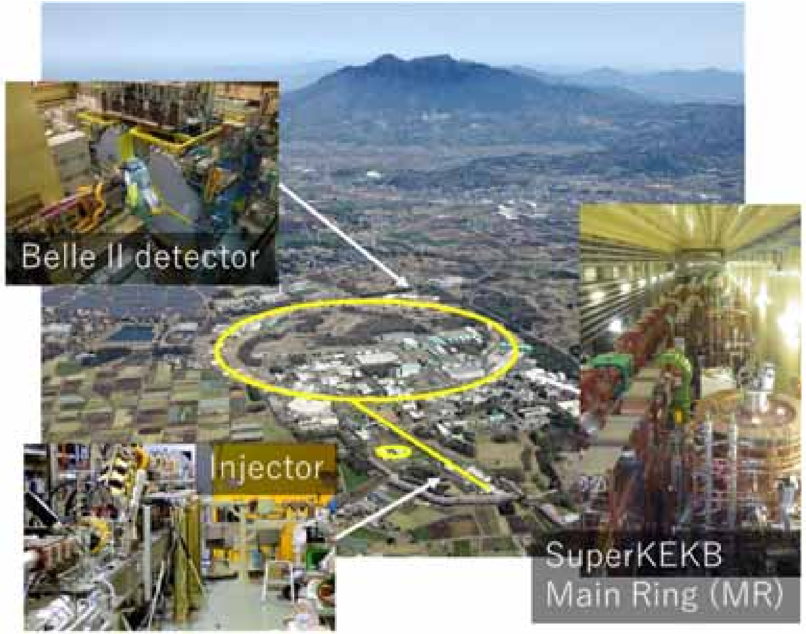
KEK Accelerator Laboratory

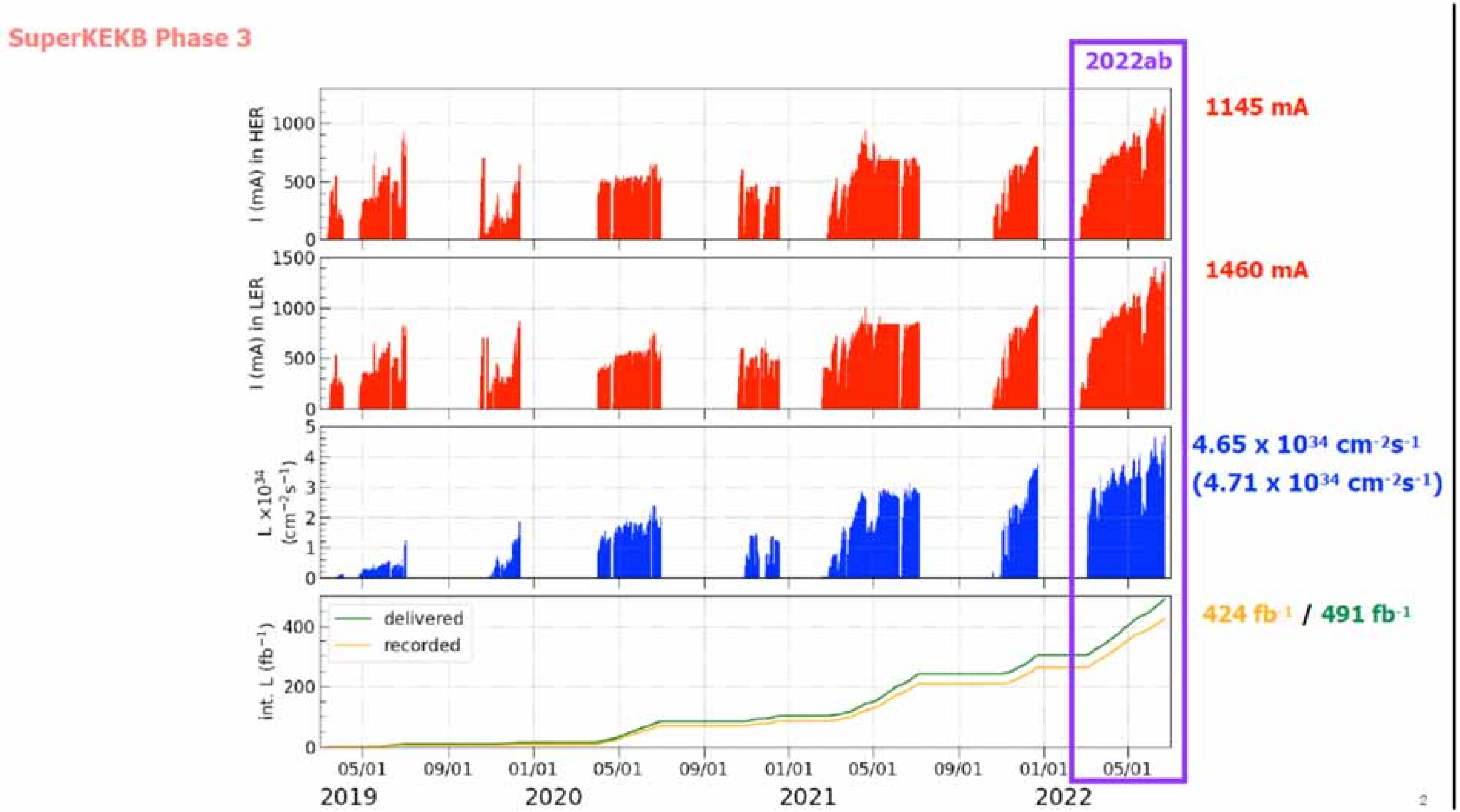
CEPC2022, Oct. 24, 2022

SuperKEKB Accelerators

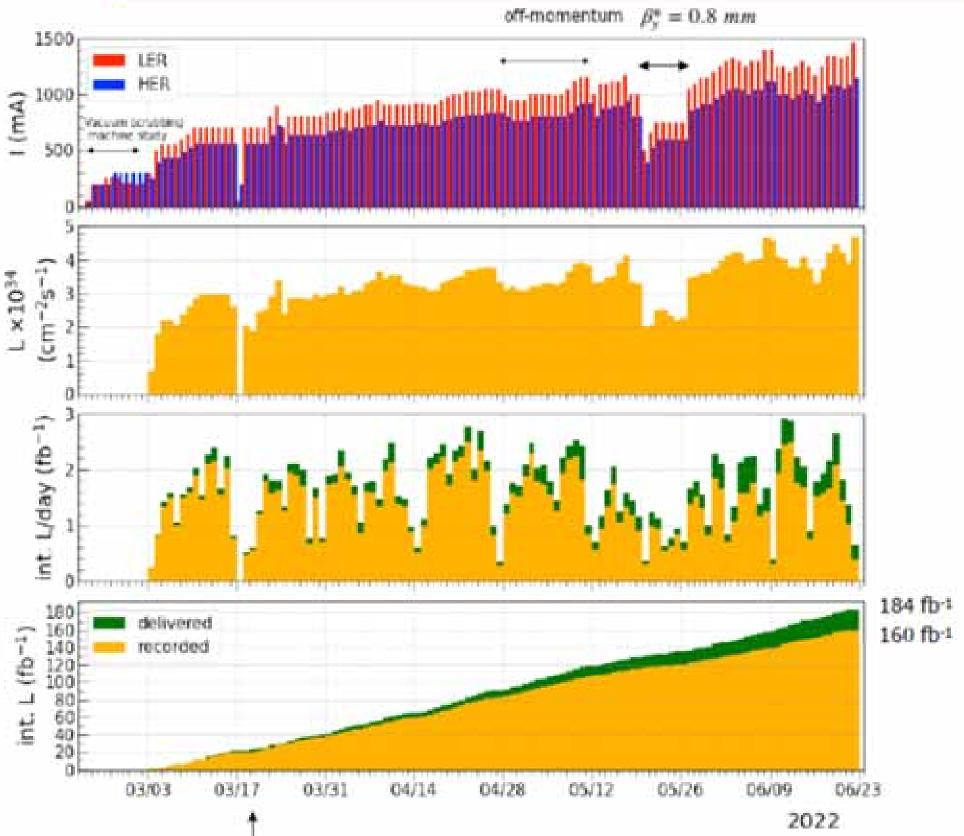


- MR Circumference : 3km
- e- 7 GeV x e+ 4 GeV
- world highest luminosity
- Full energy injector linac (600m)
  - Positron DR(e+), RF gun (e-)
- Starting construction on 2010
  - Phase 3 operation (Physics run) 2019-
- Nano-beam colliding with large crossing angle (83mrad)

Recent operation



2022ab Run



Accidental fire of LER injection kicker on March 18
The reserver voltage of thyratron was adjusted.

Integrated luminosity	Recorded	Date	Delivered	Date
Shift (pb^{-1})	958.1	April 24, swing, 2022	1035.9	April 22, swing, 2022
1 days (fb^{-1})	2.503	April 22, 2022	2.912	June 11, 2022
7 days (fb^{-1})	15.001	April 18 - April 24, 2022	16.599	April 18 - April 24, 2022

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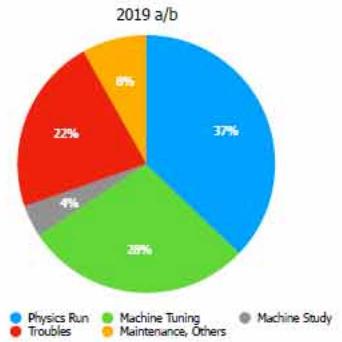
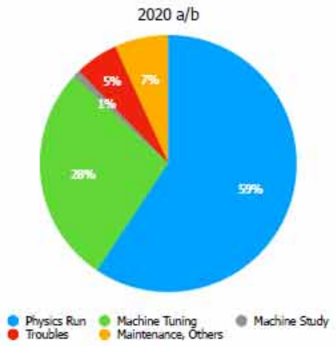
Achieved up to now..

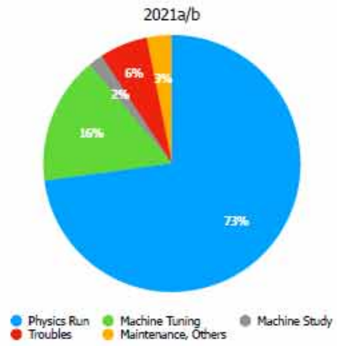
- Peak luminosity : 4.65×10^{34} $cm^{-2}s^{-1}$ (4.71×10^{34} $cm^{-2}s^{-1}$ w/o Belle II data taking)
- Integrated luminosity : 424 fb^{-1} (491 fb^{-1})
- Peak currents : 1.46 A (LER) / 1.14 A (HER), 2346 bunches (2-bucket spacing)
- β_y^*: 1 mm (0.8 mm) << bunch length ~6 mm -> proof of the nano-beam scheme
- Crab waist scheme has been applied (80 % in the LER, 40 % in the HER).
  - luminosity improvement
- Beam-Beam parameter : 0.035 at 0.7 mA (0.045 at 1.1 mA for small number of bunches)
- Bunch-by-bunch FB tuning (gain, noise reduction) in the HER ->luminosity improvements
- Bunch-by-bunch FB tuning (number of taps) in the LER ->suppress single bunch blowup, luminosity improvements
- Chromatic X-Y coupling correction with rotatable sextupoles in the LER ->luminosity improvements

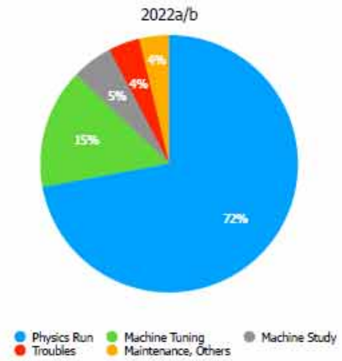
- Long-term drift of QCS magnetic field (beta-beat) <-reduced by new QCS initialization procedure
- Orbit deviation due to IP knob tuning (beta-beat) <- suppressed with QCS corrector (ZHQC2RP)
- Increase of positron charge for the LER injection : 3 nC at the end of e+ beam transport line
- 2-bunch injection for the LER and HER ->improve injection efficiency
- Adjustment of injection orbit in the HER (septum, kicker) ->improve injection efficiency (not enough)
- Reduce leakage orbit from injection kickers <- reduced by additional inductance for the coils

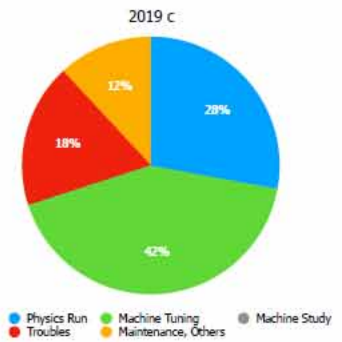
Operation statistics

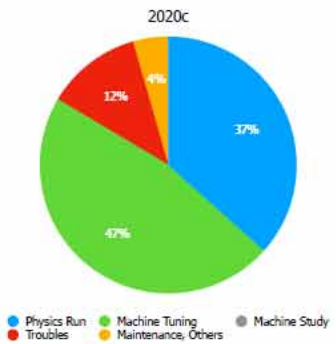


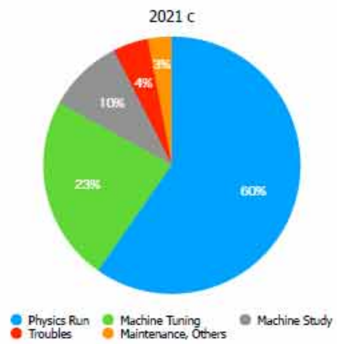












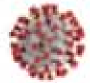
Operation statistics 2019 -2022

Machine parameters

Machine Parameters

	SuperKEKB : June 8, 2022		SuperKEKB : May 22, 2022		Unit
Ring	LER	HER	LER	HER	
Emittance	4.0	4.6	4.0	4.6	nm
Beam Current	1321	1099	744	600	mA
Number of bunches	2249		1565		
Bunch current	0.587	0.489	0.475	0.383	mA
Horizontal size σ_x^*	17.9	16.6	17.9	16.6	μm
Vertical cap sigma Σ_y^*	0.303		0.250		μm*1
Vertical size σ_y^*	0.215		0.177		μm*2
Betatron tunes ν_x / ν_y	44.525 / 46.589	45.532 / 43.573	44.525 / 46.589	45.532 / 43.574	
β_x^* / β_y^*	80 / 1.0	60 / 1.0	80 / 0.8	60 / 0.8	mm
Piwinski angle	10.7	12.7	10.7	12.7	
Crab waist ratio	80	40	80	40	%
Beam-Beam parameter ξ_y	0.0407	0.0279	0.0309	0.0219	
Specific luminosity	7.21×10^{31}		8.74×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	4.65×10^{34}		2.49×10^{34}		$cm^{-2}s^{-1}$

← twice the size of COVID-19 virus



*1) estimated by luminosity with assuming design bunch length
*2) divide *1 by √2

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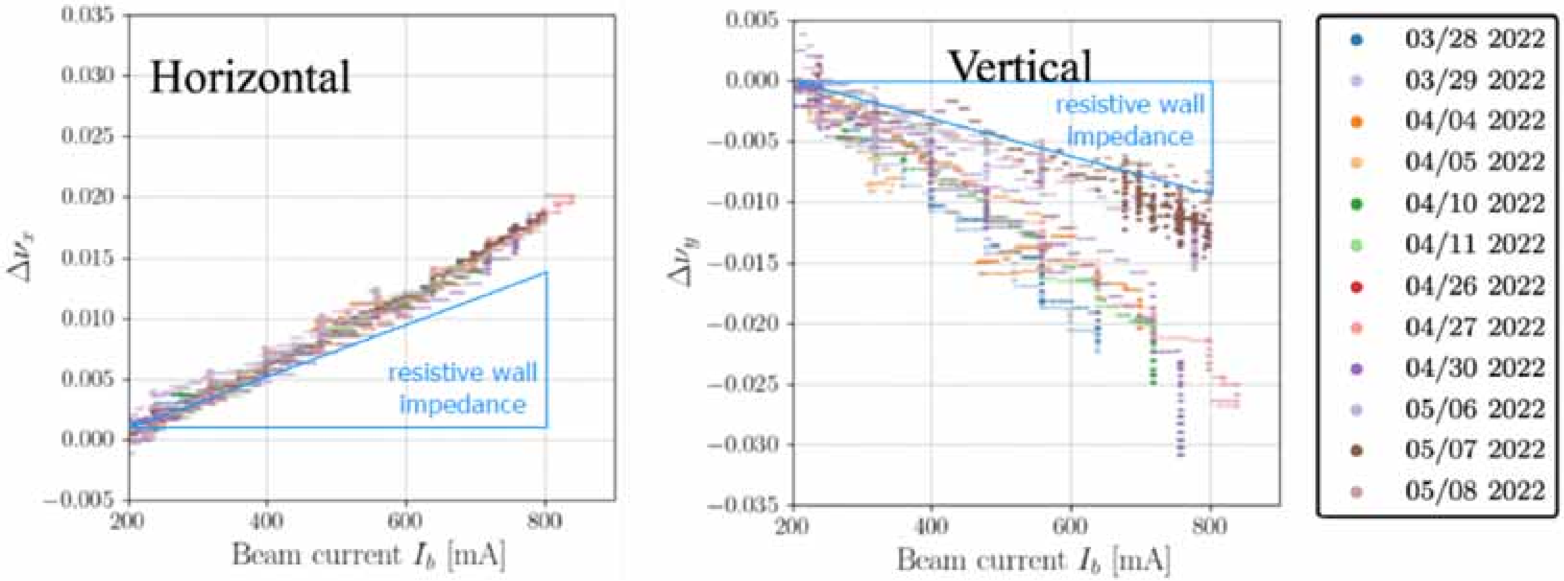
Challenges to improve luminosity(1)

- **IR Optics (by*) modulation due to stored current (HER)**
  - Betatron tune shift due to resistive wall current on racetrack vacuum chamber (HER)
  - Horizontal orbit deviation around strong sextupoles, especially around local chromaticity correction sections.

Optics Change with Beam Current

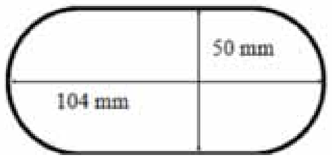
Daily variations in the vertical tune shift was observed. However, the horizontal tune shift was stable.
We assume that the vertical tune shift comes from horizontal orbit deviations at sextupoles in addition to the resistive wall.

HER



H. Sugimoto, 2022ab Summary Meeting

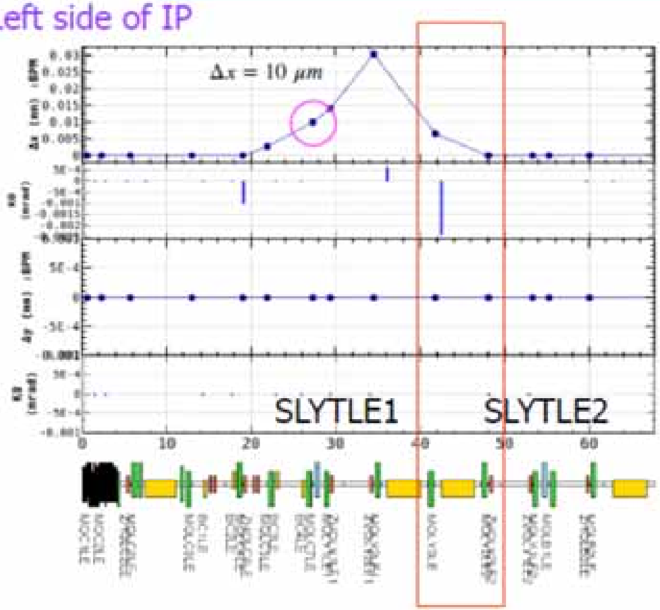
Cross section of HER chamber

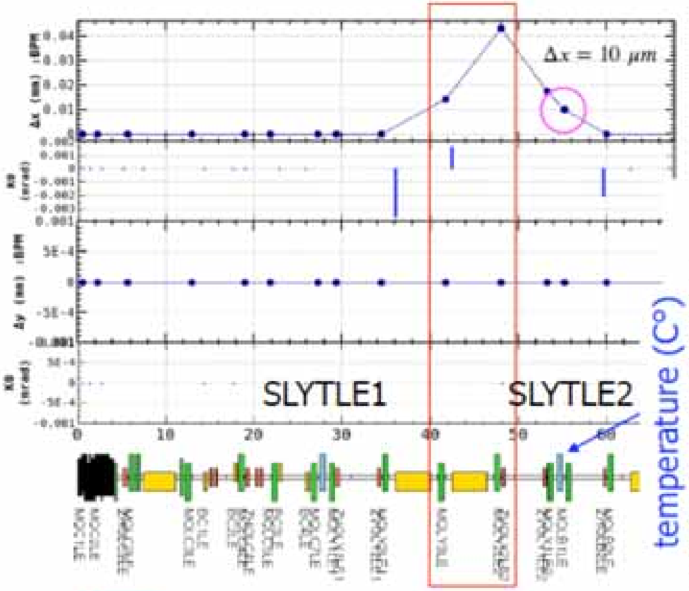


We always perform tune feedback with a pilot bunch (non collision).
Tune shift is estimated from amount of feedback.

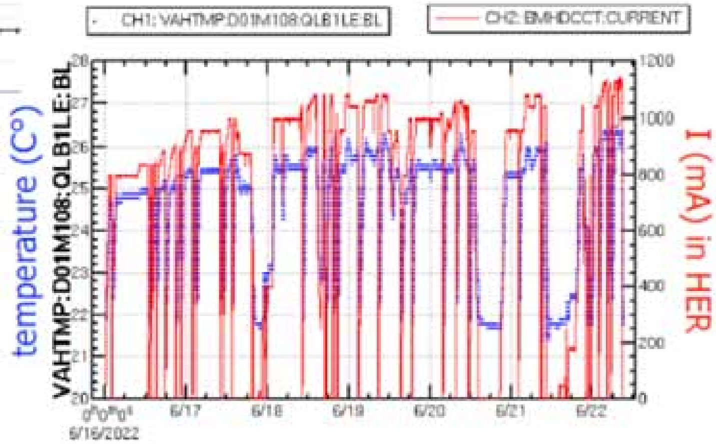
Local Orbit Correction at SLYTLE1 and SLYTLE2

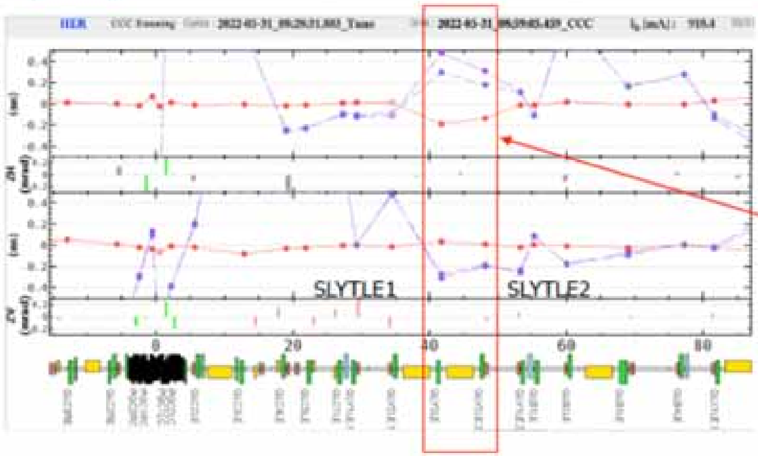
Left side of IP





The local bumps correct the orbit at SLYTLE1 and SLYTLE2 (local chromaticity region;CW sextupoles).





The horizontal orbit is distorted in the local chromaticity correction region (SLYTLE1 - SLYTLE2).

This region can not fit to the gold orbit when we correct the orbit at SLYs locally.

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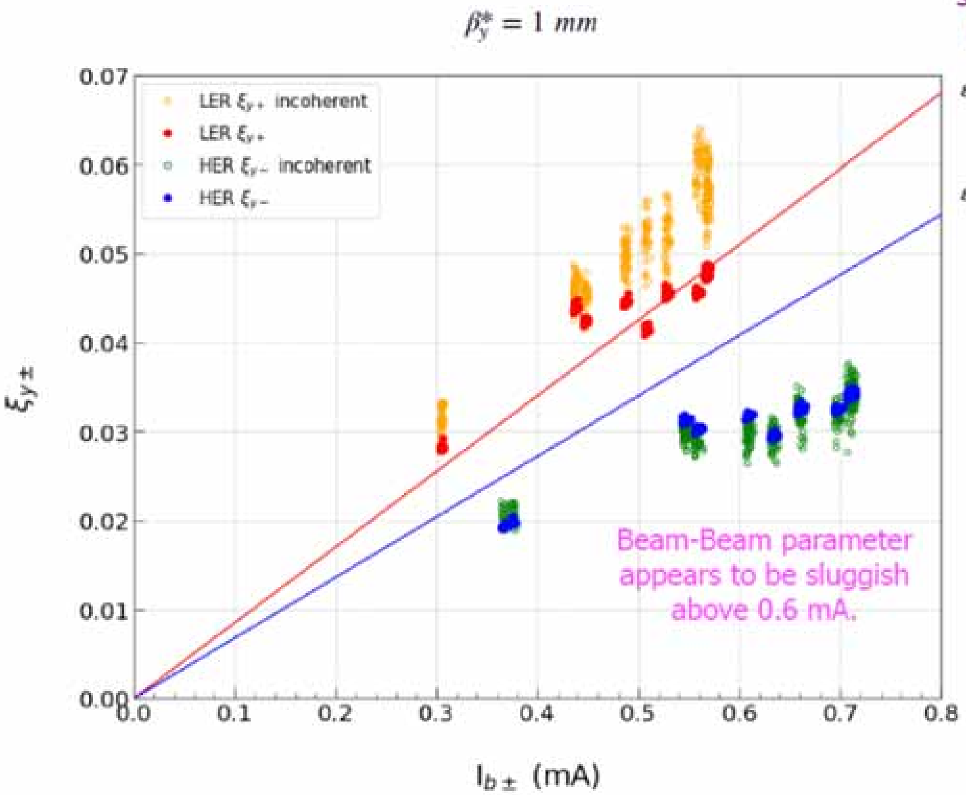
Challenges to improve luminosity(2)

- **Beam-beam interaction**
  - Lower beam current in the HER tends to cause beam blowup.
  - This means that the HER beam size is easier to blow-up when the beam current of the HER decreases.
  - Therefore, the beam current of the HER is larger than the energy ratio (4 GeV / 7 GeV).
  - The optimum ratio of LER to HER beam current is 5:4 from luminosity tuning.
  - The beam-beam parameter of the LER are larger than that of the HER.
  - The current ratio is kept constant for daily operation in principle.
  - The beam-beam parameter is sluggish with LER beam currents of around 0.6 ~ 0.8 mA.

Beam-beam parameter



single beam emittance

$\varepsilon_{y-}^0 = 40\ pm$

$\varepsilon_{y+}^0 = 25\ pm$

Vertical beam-beam parameter

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

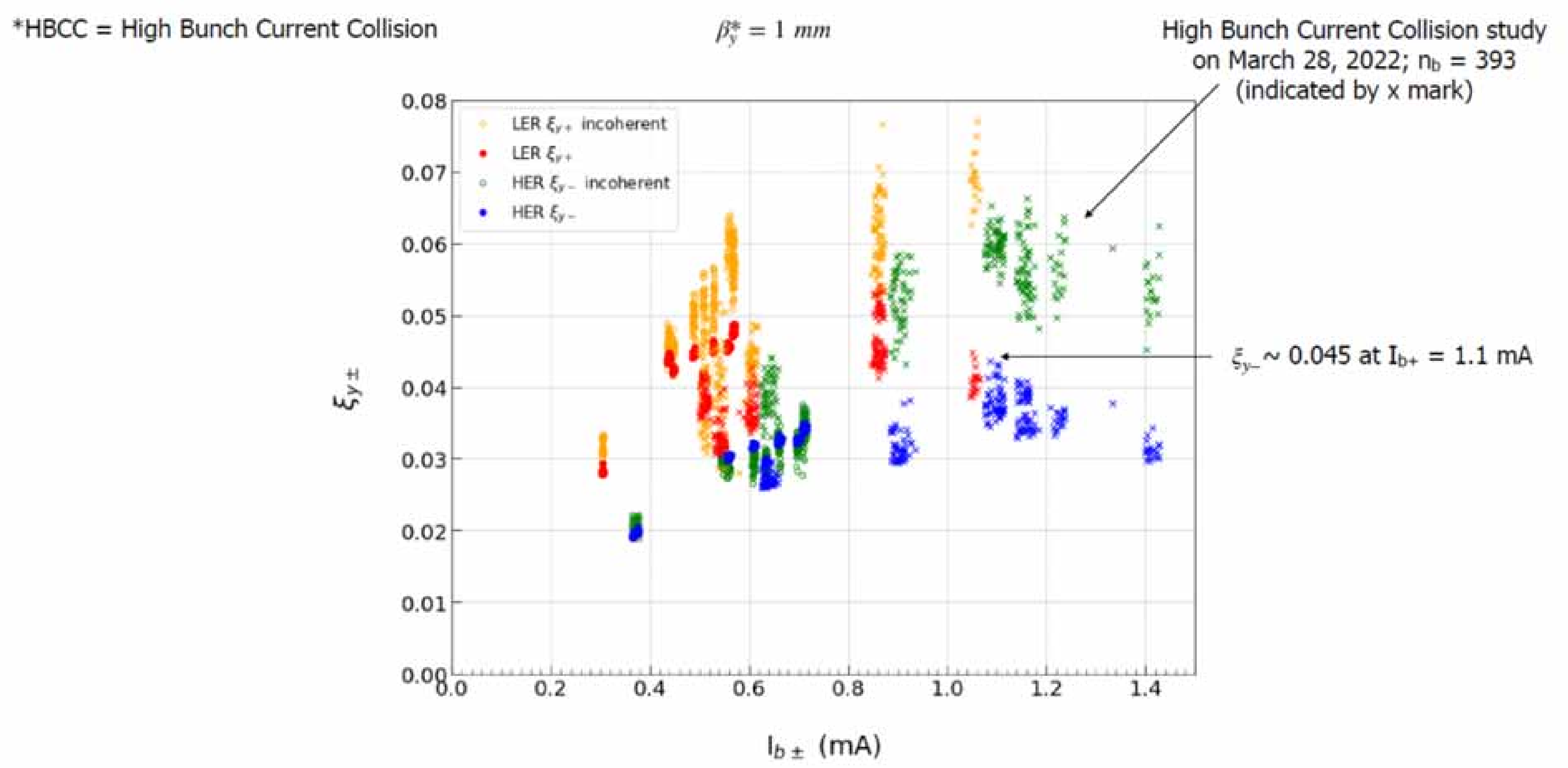
Vertical beam-beam parameter (incoherent)

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

measured by X-ray size monitor

Bunch lengthening is an important parameter.
Here, the nominal bunch length is used.

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

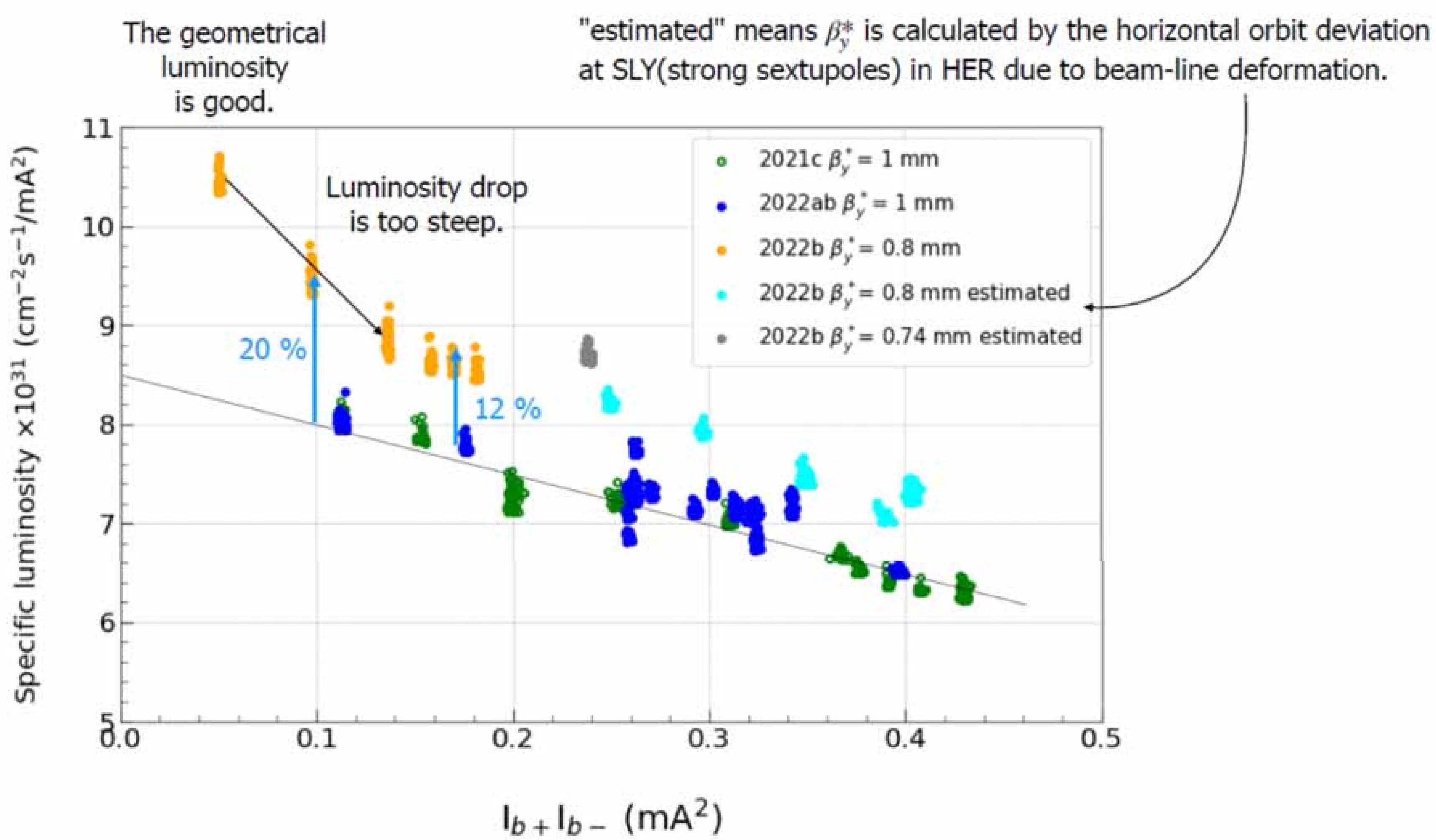

*HBCC = High Bunch Current Collision
$\beta_y^* = 1\ mm$
High Bunch Current Collision study
on March 28, 2022; n_b = 393
(indicated by x mark)
LER ξ_{y+} incoherent
LER ξ_{y+}
HER ξ_{y-} incoherent
HER ξ_{y-}
ξ_{y-} ~ 0.045 at I_{b+} = 1.1 mA
$\xi_{y\pm}$
$I_{b\pm}$ (mA)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Specific luminosity

- The definition of specific luminosity:

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

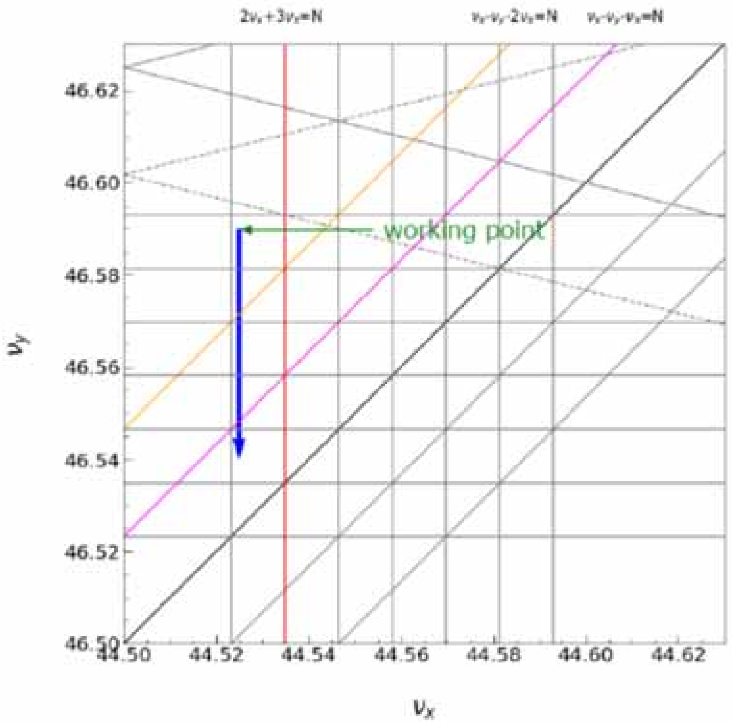
- It was found that even if the setting is 1 mm, β_y^* can be shifted due to beta-beat caused by a deviation of the horizontal beam orbit at the strong sextupoles in the local chromaticity correction.
  - The orbit deviation is caused by beam line deformation due to intense SR heating.
  - This effect is more significant for the HER rather than the LER.
- Higher specific luminosity for β_y^* = 0.8 mm is obtained at a bunch current product of 0.05 mA^2, but the specific luminosity rapidly decreases around 0.1 mA^2.
  - L_{sp} for β_y^* = 0.8 mm is about 20 % higher than 1 mm at 0.05 mA^2 and decreases to about 12 % at 0.1 mA^2 and above.
- This implies that the corrections of the chromatic X-Y coupling and other parameters are not optimized yet for β_y^* = 0.8 mm which affect beam-beam blowup.

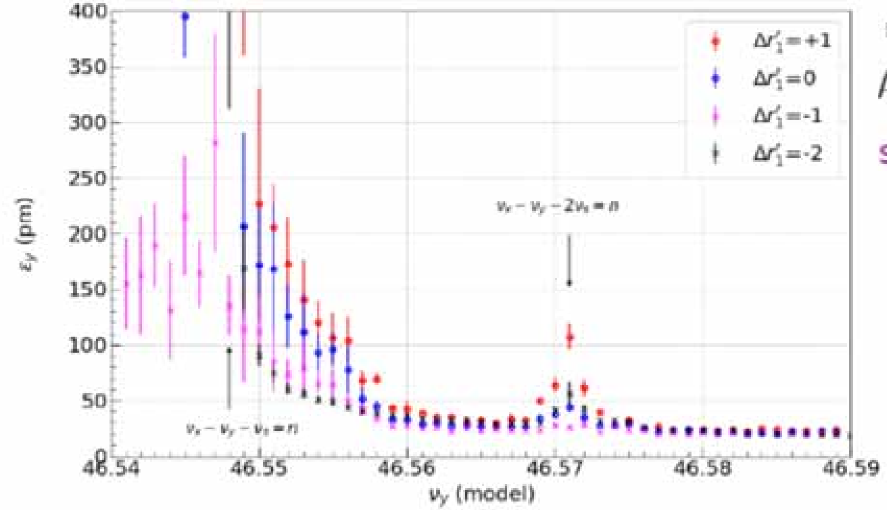

The geometrical luminosity is good.
"estimated" means β_y^* is calculated by the horizontal orbit deviation at SLY(strong sextupoles) in HER due to beam-line deformation.
Luminosity drop is too steep.
20 %
12 %
2021c β_y^* = 1 mm
2022ab β_y^* = 1 mm
2022b β_y^* = 0.8 mm
2022b β_y^* = 0.8 mm estimated
2022b β_y^* = 0.74 mm estimated
Specific luminosity ×10^{31} ($cm^{-2}s^{-1}/mA^2$)
$I_{b+}I_{b-}$ (mA^2)
11
10
9
8
7
6
5
0.0
0.1
0.2
0.3
0.4
0.5

Challenges to improve luminosity(3)

- **Chromatic X-Y coupling**
  - QC1s of LER have no magnetic shields nor anti-solenoid to cancel strong solenoidal field from Belle II detector.
  - Beam-beam simulations suggest the induced chromatic X-Y coupling could introduce large vertical beam blowup
  - Rotatable sextupole magnets around IR to correct chromatic coupling.

Chromatic X-Y Coupling Correction with Rotatable Sextupoles in LER

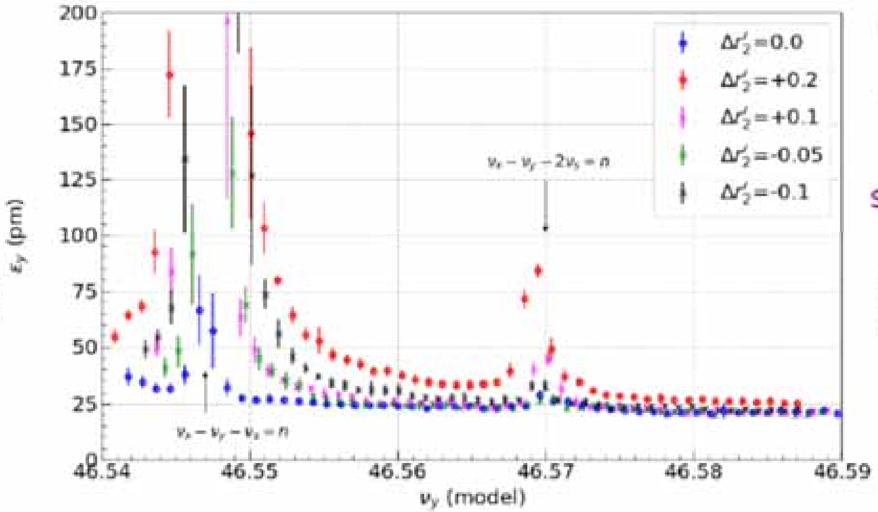




Dec. 20, 2021

$\beta_y^* = 1\ mm$

single beam



March 14, 2022

$\beta_y^* = 1\ mm$

$\Delta r_1' = -1$

single beam

$\Delta r_2' = 0$
is optimal.

The rotatable sextupoles (6 families for right and left side of IP) are used to make the first synchro-beta coupling resonance weak together with the second resonance.

SLYTLPs and SLYTRPs were not used here.

Rotatable sextupoles:
M. Masuzawa, T. Kawamoto et al.

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Rotatable Sextupole in LER

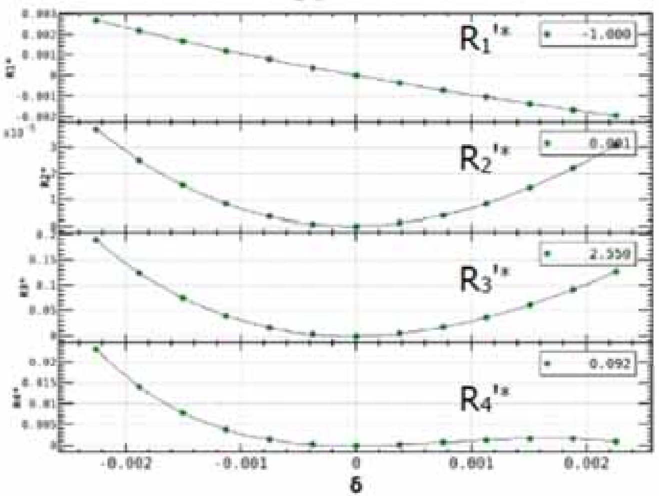
There are 24 sextupole magnet (12 families) supporting tables in the LER and make them roll to induce skew sextupole field.

The 12 sextupoles (6 families) are located at each side of the IP among 54 sextupoles in total.

Those sextupoles are used to make chromatic X-Y couplings at the IP by matching procedure with chromaticity correction.
The X-Y couplings, R_1^* and R_2^* are effective for luminosity.

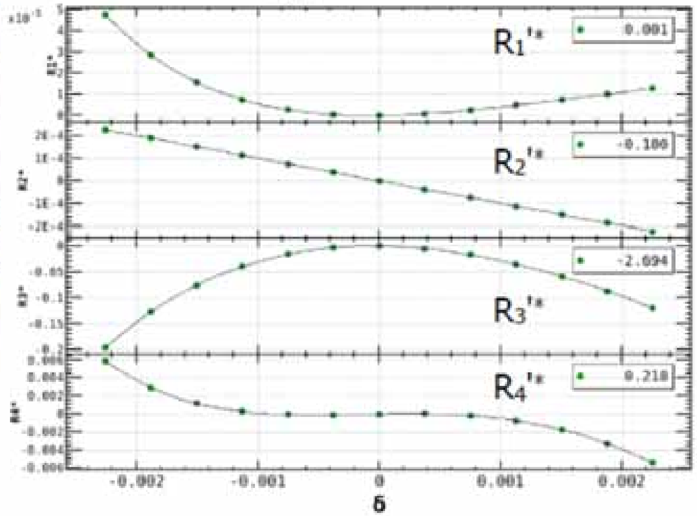
Roughly θ to make $R_1'^* = -1$ or $R_2'^* = -0.1$ m is smaller than 0.1 rad.

$$\frac{\partial R_1^*}{\partial \delta} = -1$$



$$\frac{\Delta p}{p_0}$$

$$\frac{\partial R_2^*}{\partial \delta} = -0.1\ m$$



$$\frac{\Delta p}{p_0}$$

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* Lattice model and matching at IP is performed by SAD.

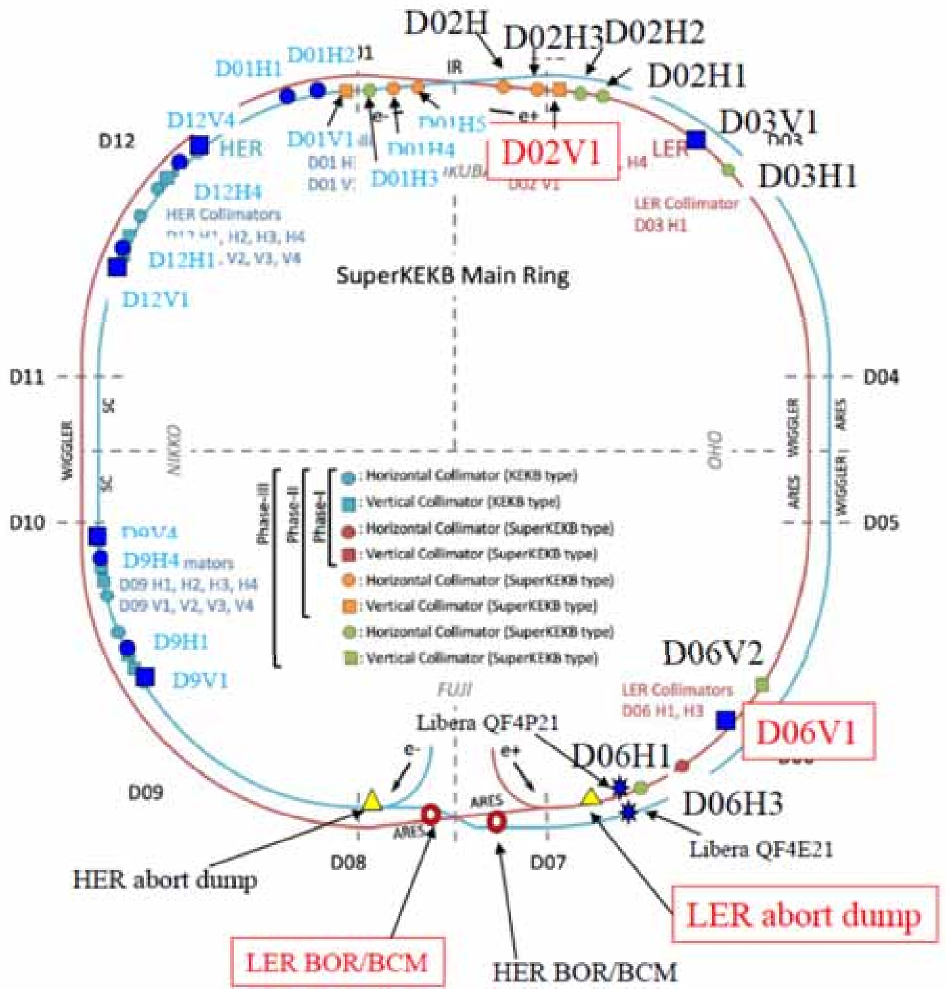
Challenges to improve luminosity (4)

- **Sudden beam loss (within 1-2 turns), damage of vertical collimator heads.**
  - Might cause QCS (superconducting final quads and correctors) quench and/or severe damage to the detector.
  - After damage of collimator heads, many unwanted side-effects might happen.
    - Much larger injection (and stored-beam) background.
    - Much larger transverse beam impedance due to damaged heads, reduce threshold of transverse mode coupling instability : Vertical beam size blowup with higher bunch current.
  - International Task Force for SuperKEKB upgrade Sudden beam loss subgroup (H.Ikeda)
  - https://kds.kek.jp/category/2423/

Location of BOR/BCM

BOR = Beam Orbit Recorder
BCM = Bunch Current Monitor

https://www.pasj.jp/web_publish/pasj2016/proceedings/PDF/TUOM/TUOM06.pdf

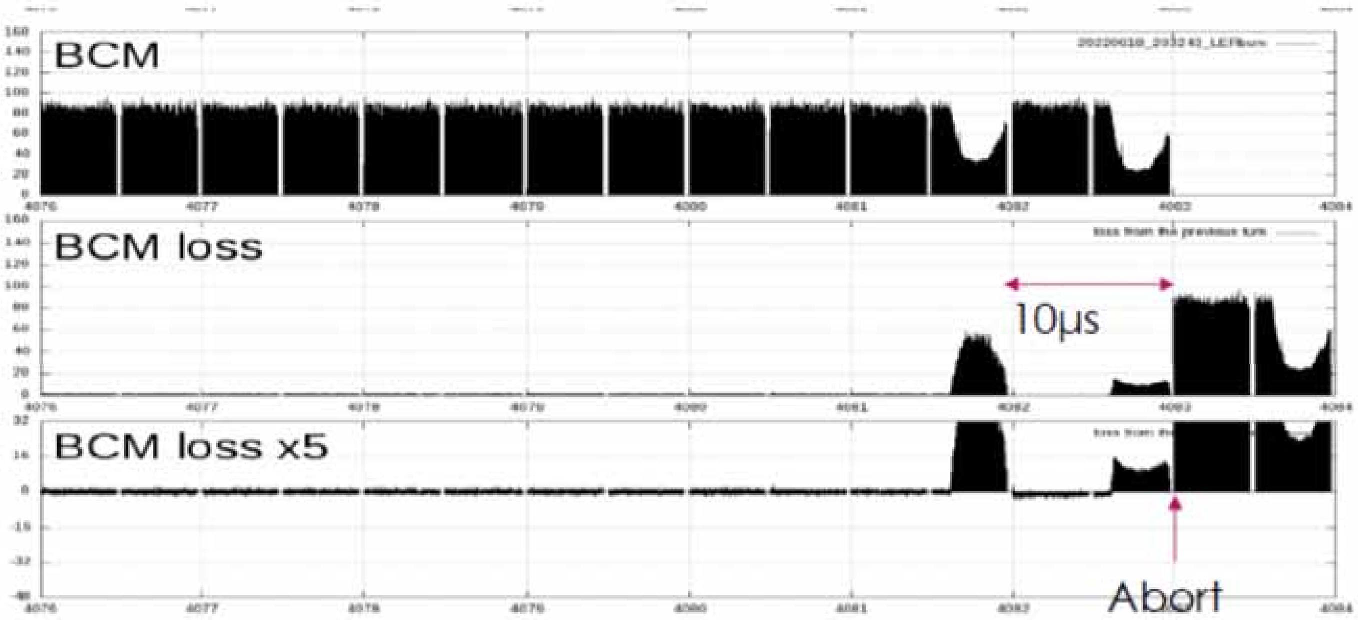


Two fast beam monitors in the ring

- VXD diamond at IP
- BOR/BCM at Fuji

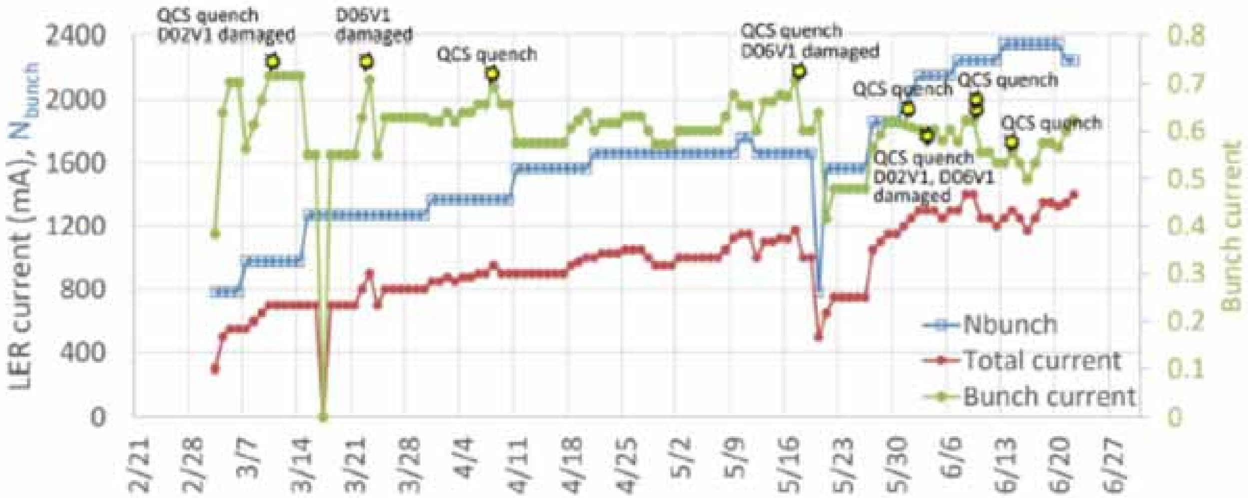
Sudden beam loss

- Beam loss has been measured by bunch current monitor (BCM) to occur suddenly on a certain turn.



Beam(bunch) current

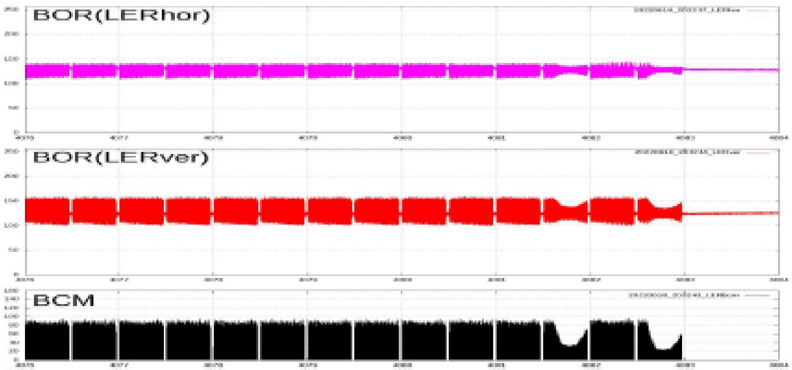
- Beam loss occurs in both HER and LER, but the damage to the hardware is particularly large when loss occurs in LER.
- It is likely to occur when a certain bunch current is exceeded.
- We don't know if it will happen even with a single beam operation, low current beam because we haven't operated for a long time.

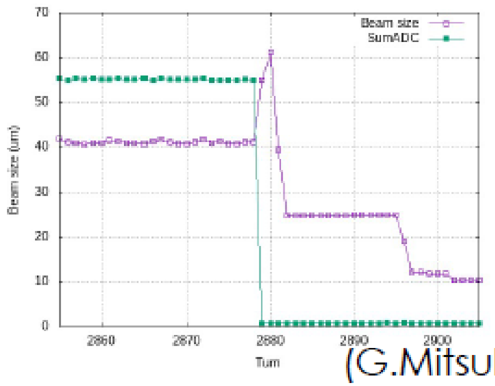


(K.Matsuoka)

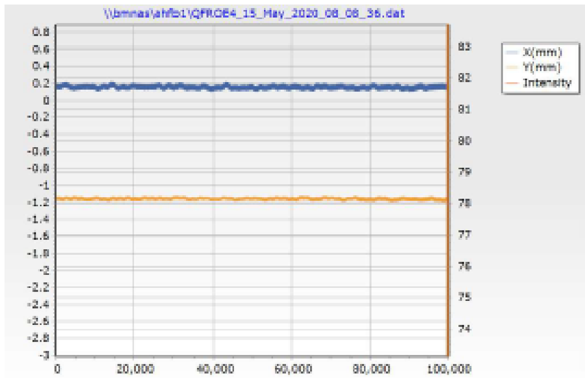
Before beam loss

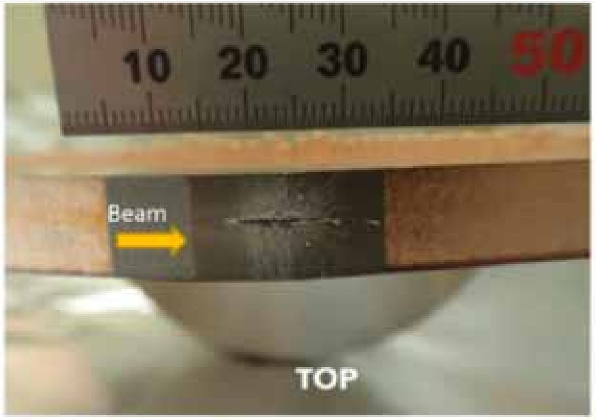
- There are no signs before beam loss.
  - No small beam loss (beam loss monitor, BCM)
  - No oscillation (Bunch Oscillation Recorder (BOR))
  - No beam size change (X-ray monitor (XRM))
  - It is not clear if the orbit changed significantly.(Libera)

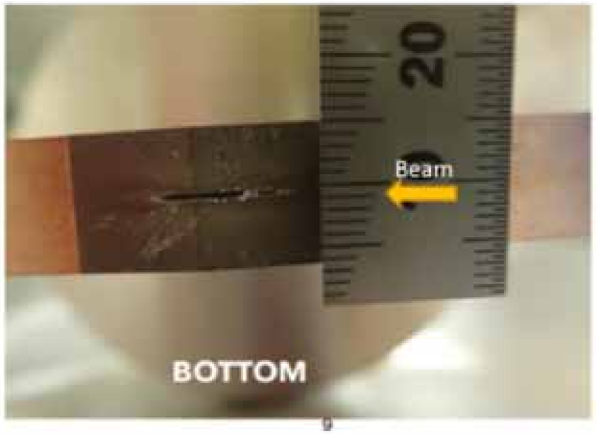




(G.Mitsuka)



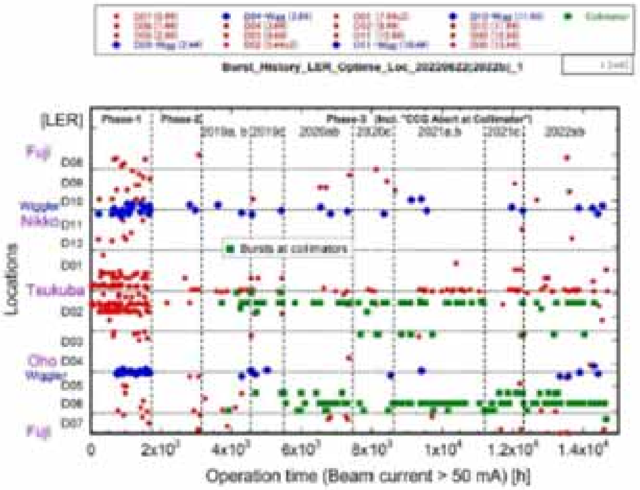


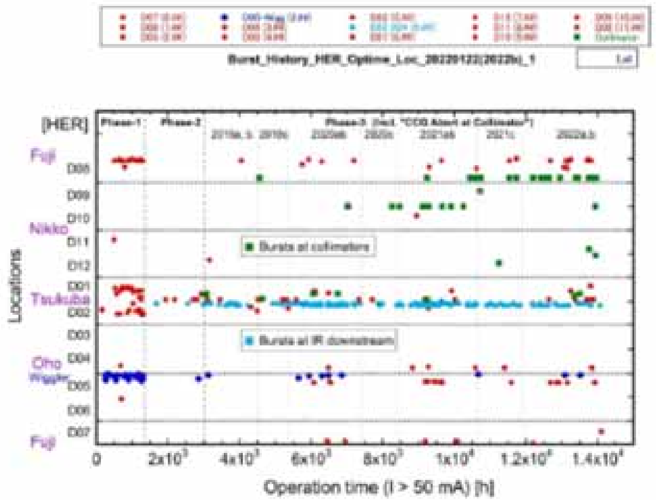


- After a huge beam loss event on June 6th in 2021, LER BG increase significantly.
- D02V1 collimator jaws were severely damaged (deep scar on the bottom jaw).
- Typically, collimator replacement work and the baking runs take 3~4 days.

Vacuum pressure

- Pressure bursts have been observed here and there, and it rarely occurs in the same place except in the collimator section. It may be the result, not the reason.

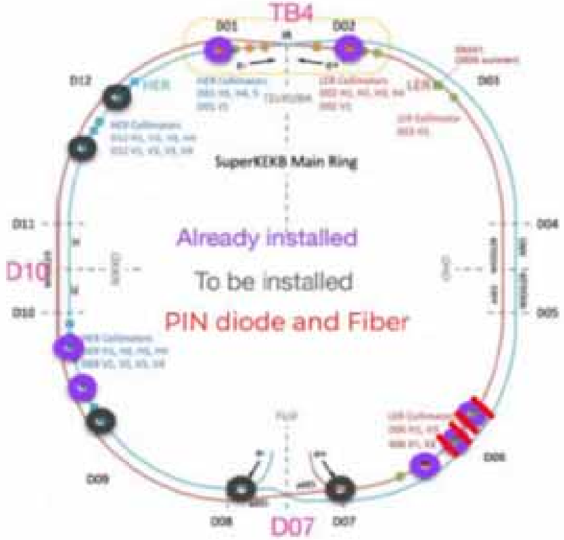


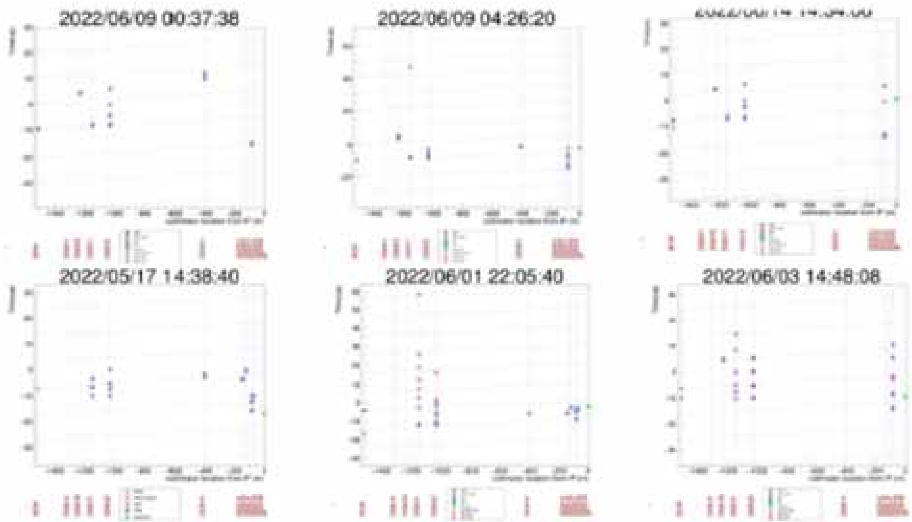


(Y.Suetsugu)

Start position of beam loss

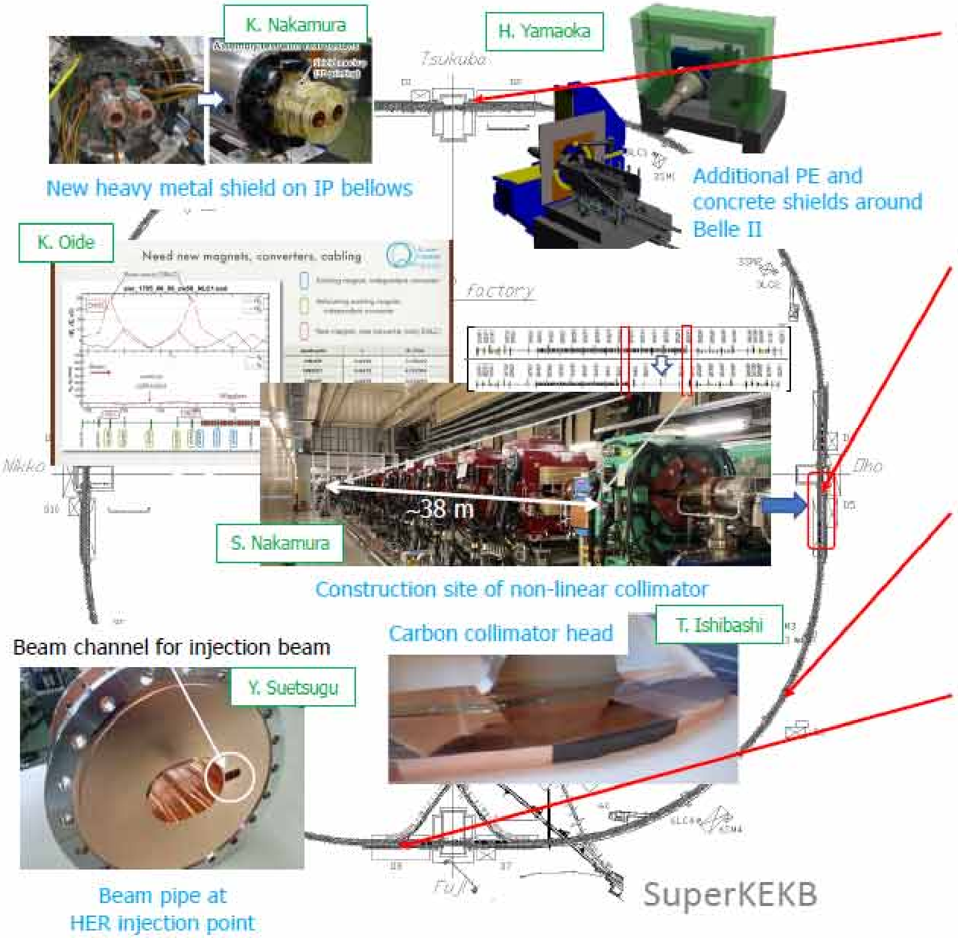
- Beam loss occurs in collimator & IR, and where it occurs first depends on collimator tuning (Loss Monitor timing analysis).





(Y.Liu)

Upgrade Items during Long Shutdown (LS1)



- IR radiation shield modification
  - For BG reduction
    - New heavy metal shields around IP bellows
    - Additional concrete & polyethylene shields around Belle II
    - Material change from W to SUS of QCS cryostat front plate
- Nonlinear collimator (LER)
  - For impedance and BG reduction
    - New collimation scheme less likely to cause TMCI
    - Removal of 50 wiggler magnets
    - Installation of 2 skew sextupole and 5 quadrupole magnets
    - Installation of new vertical collimator with wider aperture
- Robust collimator head (LER)
  - As countermeasure against kicker-pulser misfiring and resulting destruction of collimator
    - Replacement with carbon head of horizontal collimator D06H3
- New beam pipes with wider aperture at HER injection point
  - For improvement of injection efficiency
    - New beam pipes with wider aperture
    - New BPM for precise measurement of injected beam.

Reference: Y. Funakoshi, IPAC 2022

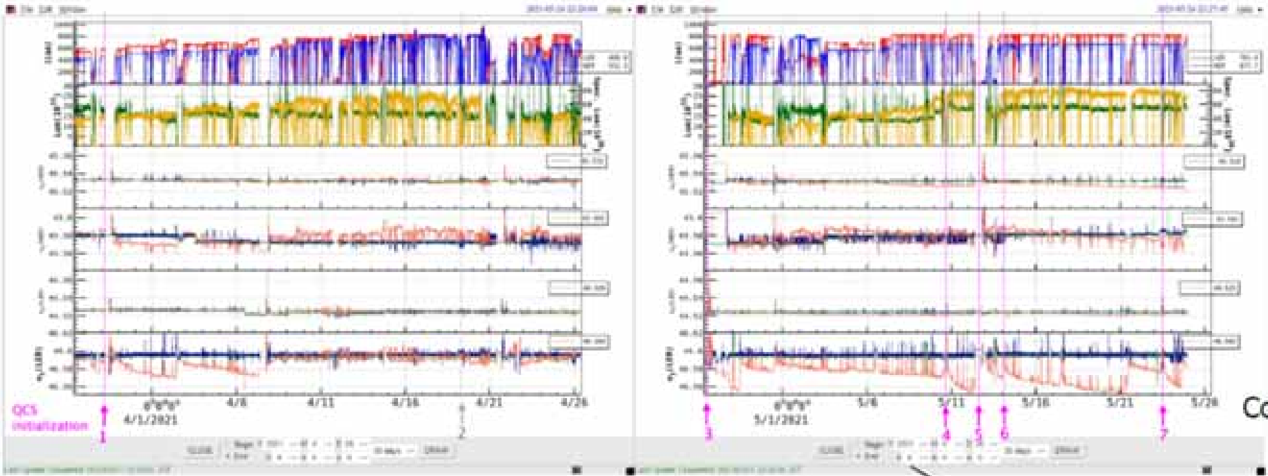
Summary

- Peak luminosity of $4.7x10^{34}cm^{-2}s^{-1}$ has been achieved
- Demonstrated stable operation over 1A in the LER (with smaller bunch current less than 0.7mA/bunch)
- Sudden beam loss is one of the most serious challenge to increase luminosity and beam current, up to now.
- Many other challenges:
  - Beam blowup in LER
  - Beam line deformation with HER beam current
  - Shorter beam lifetime; both dynamic aperture and physical aperture (beam collimators), need to clarify the effect of crab waist.
  - Injection efficiency, long-term stability of the injector.
- Several upgrade items during long shutdown 1.

Backup

QCS hysteresis

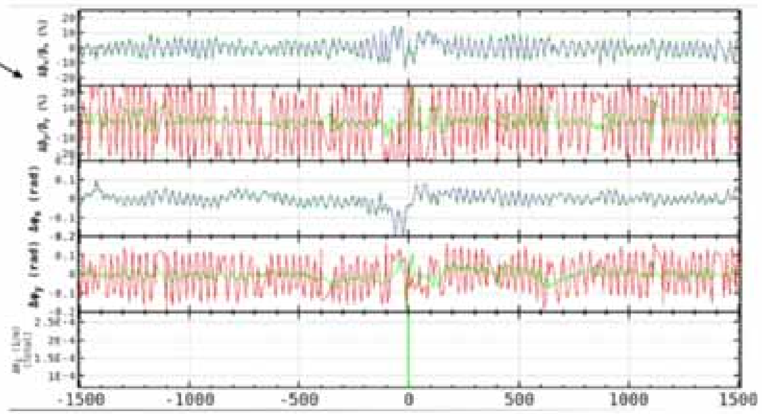
H. Koiso and H. Sugimoto



1. 3/28 Magnet PS QC1LE Charging Volt I/L Trouble
2. 4/19 QC1LE quench
   (4/21 On -> Off-resonance)
3. 4/26 Off -> On-resonance
4. 5/10 QC1RP & QC1LP quench
5. 5/12 Maintenance
6. 5/14 QC1RP quench
7. 5/23 QC1RP & QC1LP quench

Correction of beta-beat by only QCS

$\Delta K1$ = a few x 10^{-4} (1/m)

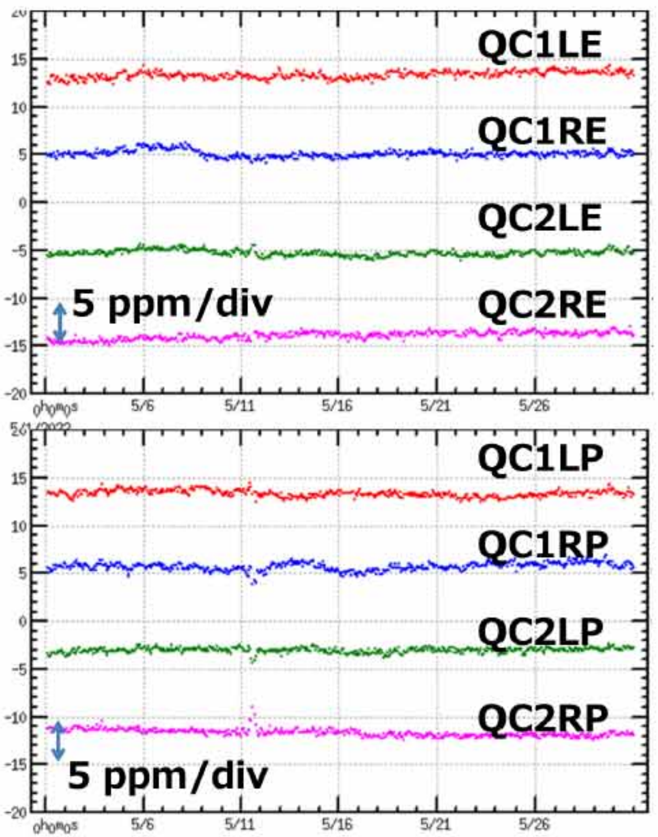


Drift of QCS magnetic field can be estimated by estimated tune shift.

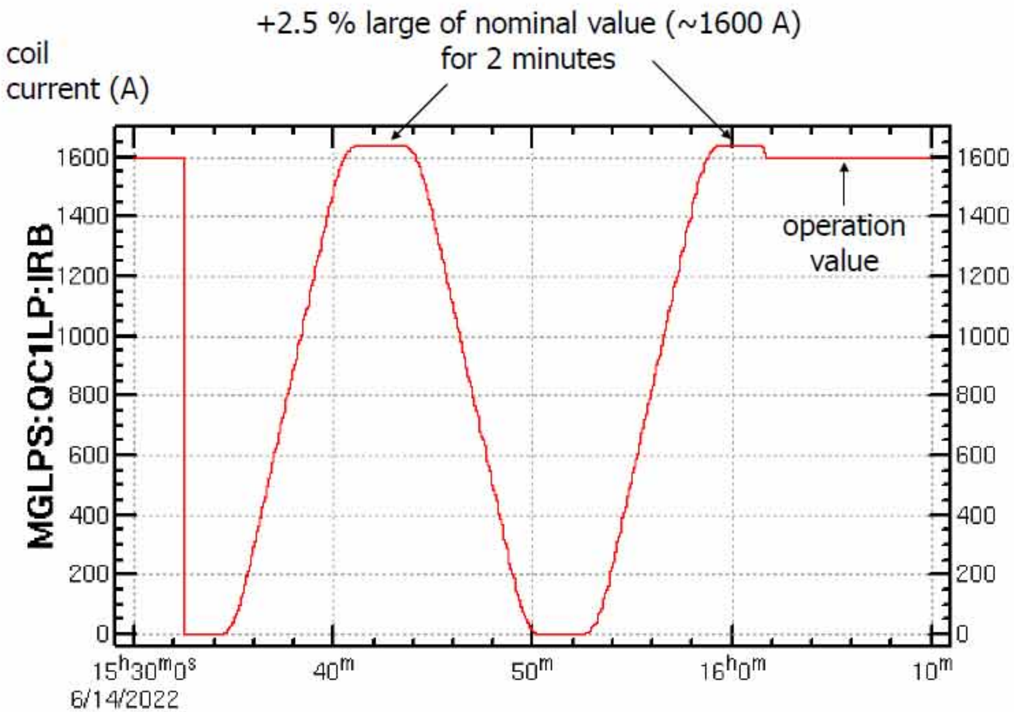
Betatron tune (vertical) changes gradually after optics correction.
QCS initialization is performed before optics correction.
QCS initialization and optics correction is also performed after QCS quench.

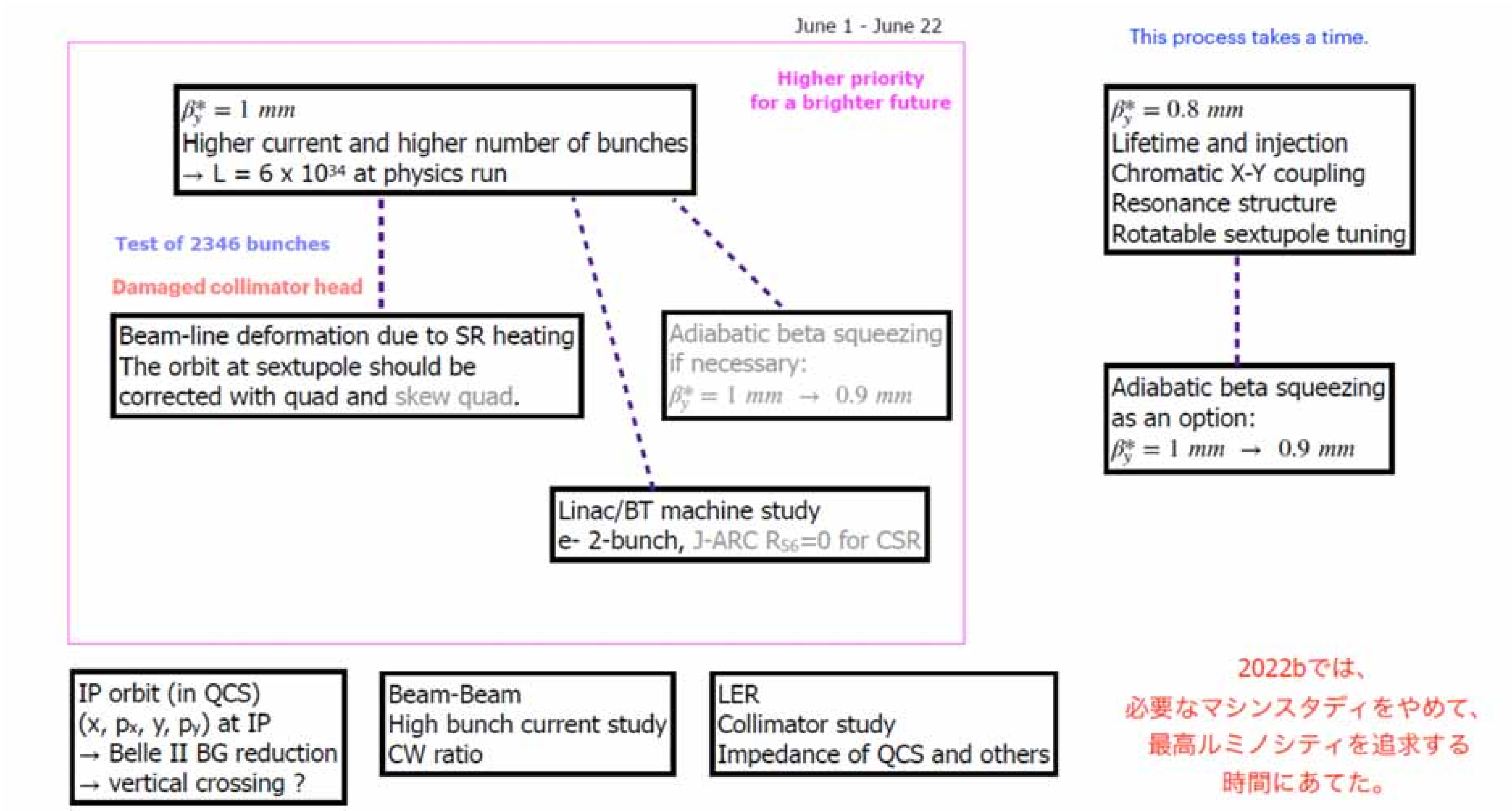
Recently we modified the way of QCS initialization.
The drift of magnetic field is much reduced.

Modified QCS initialization method



Main QCS coils: 2 ppm / 8 hours

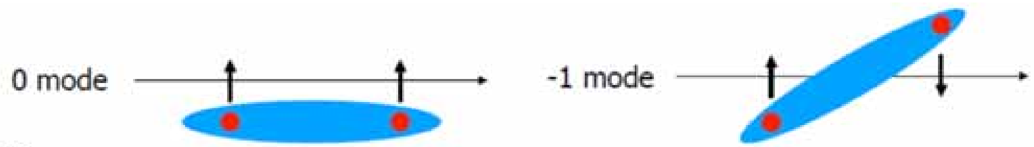



June 1 - June 22
This process takes a time.
Higher priority
for a brighter future
$\beta_y^* = 1\ mm$
Higher current and higher number of bunches
→ L = 6 x 10^{34} at physics run
$\beta_y^* = 0.8\ mm$
Lifetime and injection
Chromatic X-Y coupling
Resonance structure
Rotatable sextupole tuning
Test of 2346 bunches
Damaged collimator head
Beam-line deformation due to SR heating
The orbit at sextupole should be
corrected with quad and skew quad.
Adiabatic beta squeezing
if necessary:
$\beta_y^* = 1\ mm \rightarrow 0.9\ mm$
Adiabatic beta squeezing
as an option:
$\beta_y^* = 1\ mm \rightarrow 0.9\ mm$
Linac/BT machine study
e- 2-bunch, J-ARC R_{56}=0 for CSR
IP orbit (in QCS)
(x, p_x, y, p_y) at IP
→ Belle II BG reduction
→ vertical crossing ?
Beam-Beam
High bunch current study
CW ratio
LER
Collimator study
Impedance of QCS and others
2022bでは、
必要なマシンスタディをやめて、
最高ルミノシティを追求する
時間にあてた。

To improve luminosity..

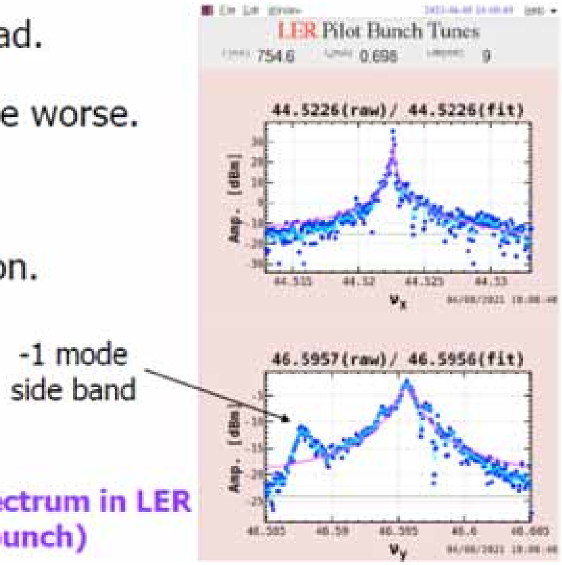
- Beam blowup in the LER (single beam, non-collision) : "-1 mode instability"
- Sudden beam loss (fast beam loss, especially in the LER)
  - Damage of collimator head due to large beam loss
- Lower beam-beam parameter: ~0.035 at 0.7 mA
- Beam current dependence of beam orbit
  - Orbit deviation at strong sextupoles is caused by beam line deformation due to intense SR heating.
- Short beam lifetime (dynamic aperture, physical aperture) : LER 8 min(1.25 A) / HER 25 min(1 A) nb=2346
- Beam related background (optimization of collimator, QCS aperture, IR orbit)
- Beam injection (small physical aperture of injection region, emittance growth in the beam transport line)
- Earthquake : The beam aborts invariably. The becomes large in the HER. The optics ε y correction is needed.

Beam blowup in LER



- Non-collision and single-bunch phenomenon
- As the bunch current increases, the blowup appears with the side band ($\nu_y + \nu_s$) observable. This is called **"-1 mode (head-tail) instability".**
- The threshold of -1 mode instability is quite low (about **0.8 mA**). It appears much smaller than TMCI.
- **Fine-tuning bunch-by-bunch FB** and **opening collimators** can relax the instability.
- TMCI: When 0 mode and -1 mode are fully coupled, the tune becomes imaginary and unstable.
  - Tune shift measurement shows that TMCI occurs at a bunch current of 2.3 mA (> 1.4 mA design value).
- -1 mode instability can appear due to the interplay of bunch-by-bunch FB and transverse wake field (under investigation). FB gain and multi taps seem to be fundamental. FB noise also induces the instability.
- To increase the threshold of -1 mode instability, **optimization of the bunch-by-bunch FB**, **reduction of collimator impedance** are needed. Also **higher vertical tune** is helpful.

- It is important to reduce collimator impedance. (Collimators account for about 75 % of the total.)
  - Coating of the collimator head with copper helps. (It evaporates in case of damage.)
  - Adopting of the nonlinear collimator may reduce the vertical impedance after LS1.
  - If the collimator is damaged, the impedance increases. Avoid damage as far as possible.
- When we set the vertical tune too high, injection efficiency becomes bad.
- One option is to increase the chromaticity, but as the injection would be worse.
  - It is not considered at the moment.
- -1 mode instability can be relaxed by beam-beam effects during collision.

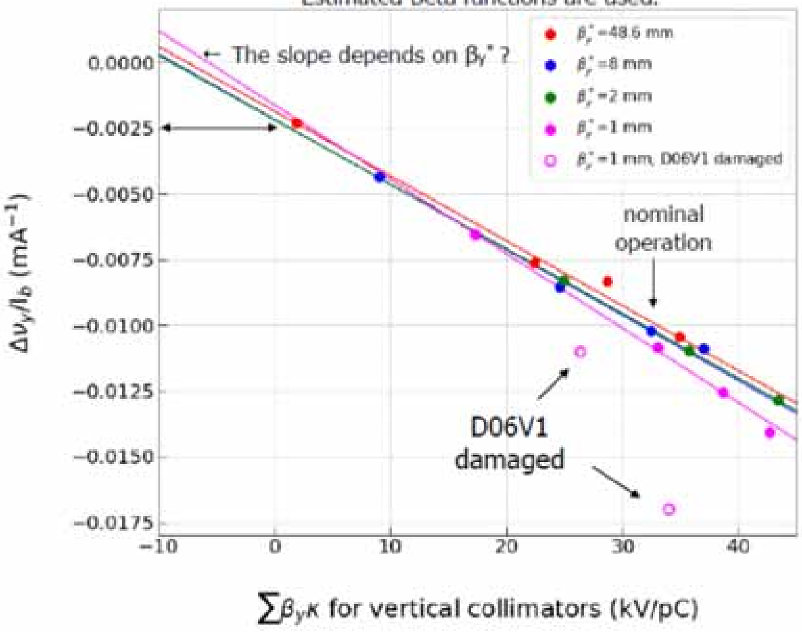


Pilot Bunch Tune Spectrum in LER
(no collision bunch)

tune shift due to bunch current

Tune shift as a function of $\sum \beta_y \kappa$. $\frac{\Delta\nu_y}{I_b} = -\frac{T_0}{4\pi(E/e)} \sum_i \beta_{yi}\kappa_i(d)$ → $\frac{T_0}{4\pi(E/e)} = 0.2\ (ps/kV)$

Estimated Beta functions are used.



The others are about 10 kV/pC.
β_y^* 1 mm is slightly deferent from those of 2 mm, 8 mm, and 48.6 mm.

Approximately 75 % of the vertical impedance is contributed by the collimators.

estimation of loss factor :

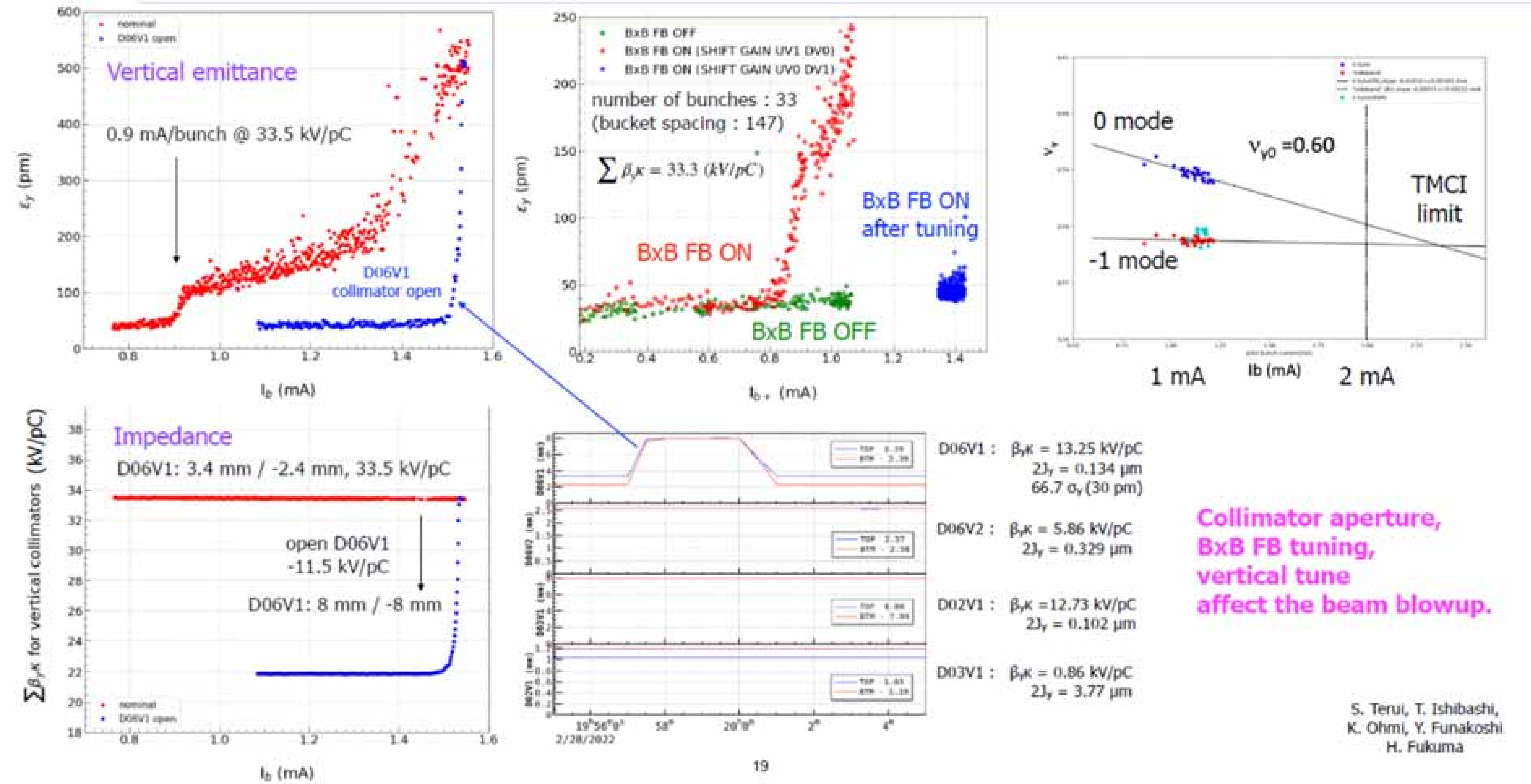
$$\kappa(d) = ad^b$$ d: aperture (mm)

Feb. 24 and Feb. 28, 2022

collimator	D06V1	D06V2	D03V1	D02V1	Remarks
a	1.26	1.24	1.24	1.24	
b	-1.69	-1.54	-1.54	-1.54	
β_y (m) model	67.35	20.57	16.96	11.89	β_y^* =1 mm
	↑	↑	↑	10.26	β_y^* =2 mm
	↑	↑	↑	9.93	β_y^* =8 mm
	↑	↑	↑	8.25	β_y^* =48.6 mm

18

Y. Ohnishi, K. Ohmi, S. Terui, T. Ishibashi



Collimator aperture, BxB FB tuning, vertical tune affect the beam blowup.

S. Terui, T. Ishibashi, K. Ohmi, Y. Funakoshi, H. Fukuma

beam monitors

- Bunch oscillation recorder (Fuji)
- Bunch current monitor (Fuji)
  - 2GHz detector (same as FB detector).
  - 4096 turns x 5120 bunches (whole ring) before beam abort
  - MAX108 ADC (8bit)
  - Triggered by beam loss signal
- X-ray beam size monitor (100kHz rep.)
- beam loss monitor (PIN-diode, scintillator, optical fiber, etc).
- (500MHz) bunch current/oscillation detector

kekb-co-web.kek.jp/doc/image/BELLE/abort_summary/web/json/index.php

[Abort manual by Ikeda-san] [Diamond plots (1) (2) (3)] [BOR/BCM plots] [BTorbit plots] [AbortBPM plots] [RF abort verification] [CLAWS abort (plots) (list) (daily) (hourly)] [LossMon plots (1) (2) (3)] [Earthquakes (1) (2) (3) (4) (5)] [Pressure burst events] [Linac pulse missing]
[Machine Learning Daily Reports] [LINAC orbit of injection aborts]

Beam Abort Database

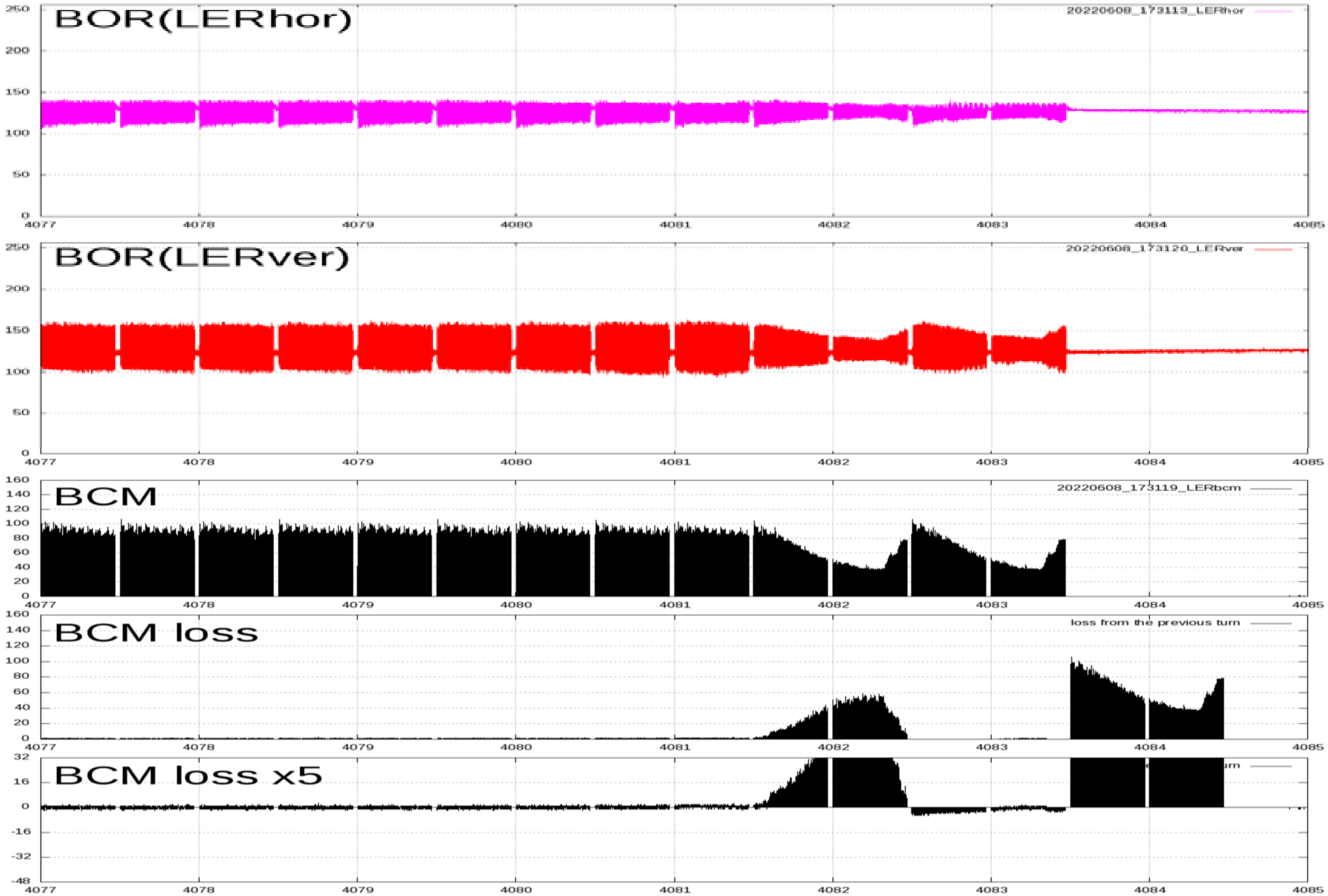
Search conditions

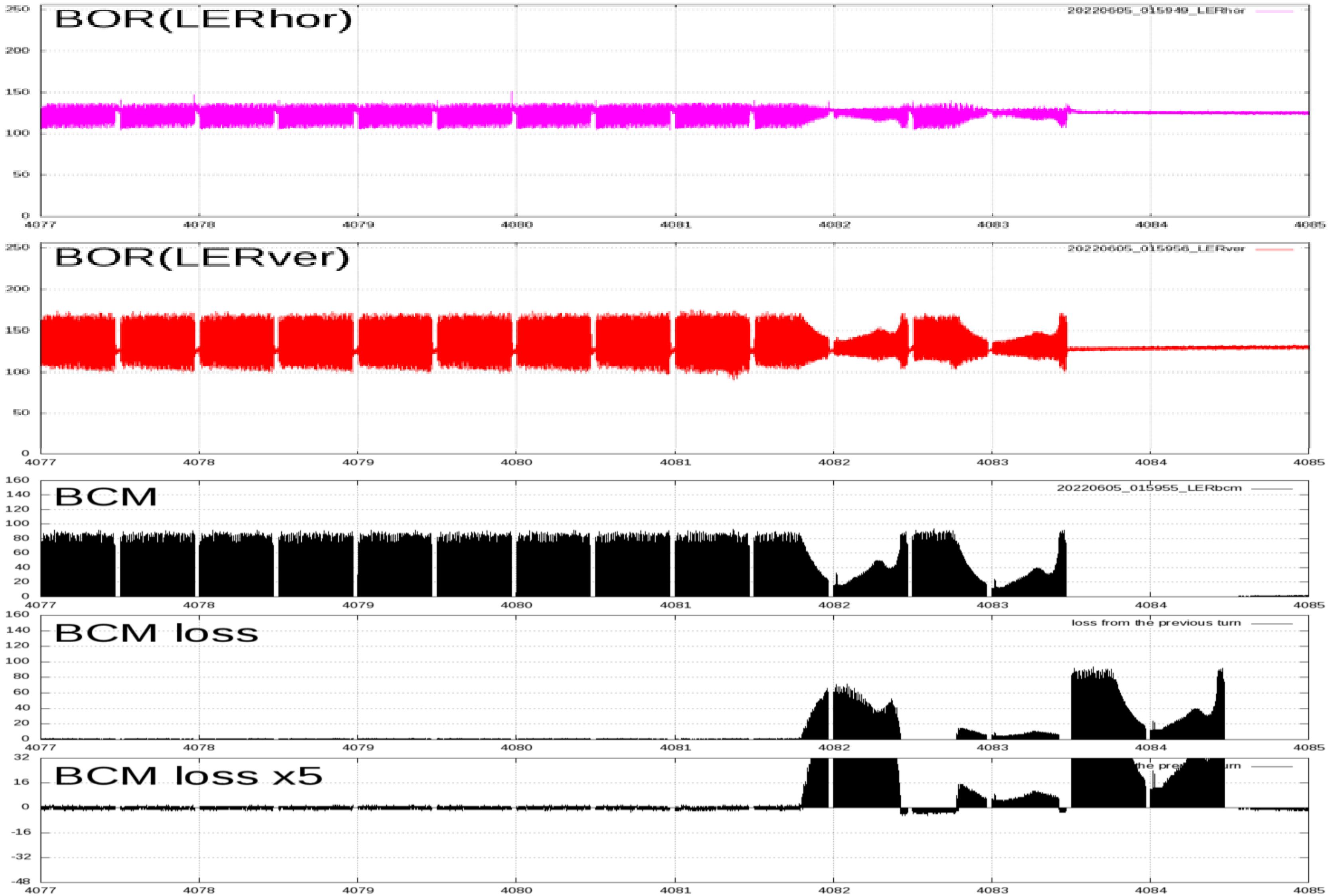
☐ Show more AbortBPM plots ☐ Show all aborts (incl. <60mA) ☐ Hide LER aborts ☐ Hide HER aborts
☐ Injection-related aborts only ☐ Non-injection aborts only ☐ Diamond aborts only ☐ >100mRad diamond aborts only ☐ Earthquake aborts only ☐ BCM loss only ☐ QCS quench only ☐ edit mode
Time period: 2021-06-01 ~ 2022-08-31 Show last 50 aborts send

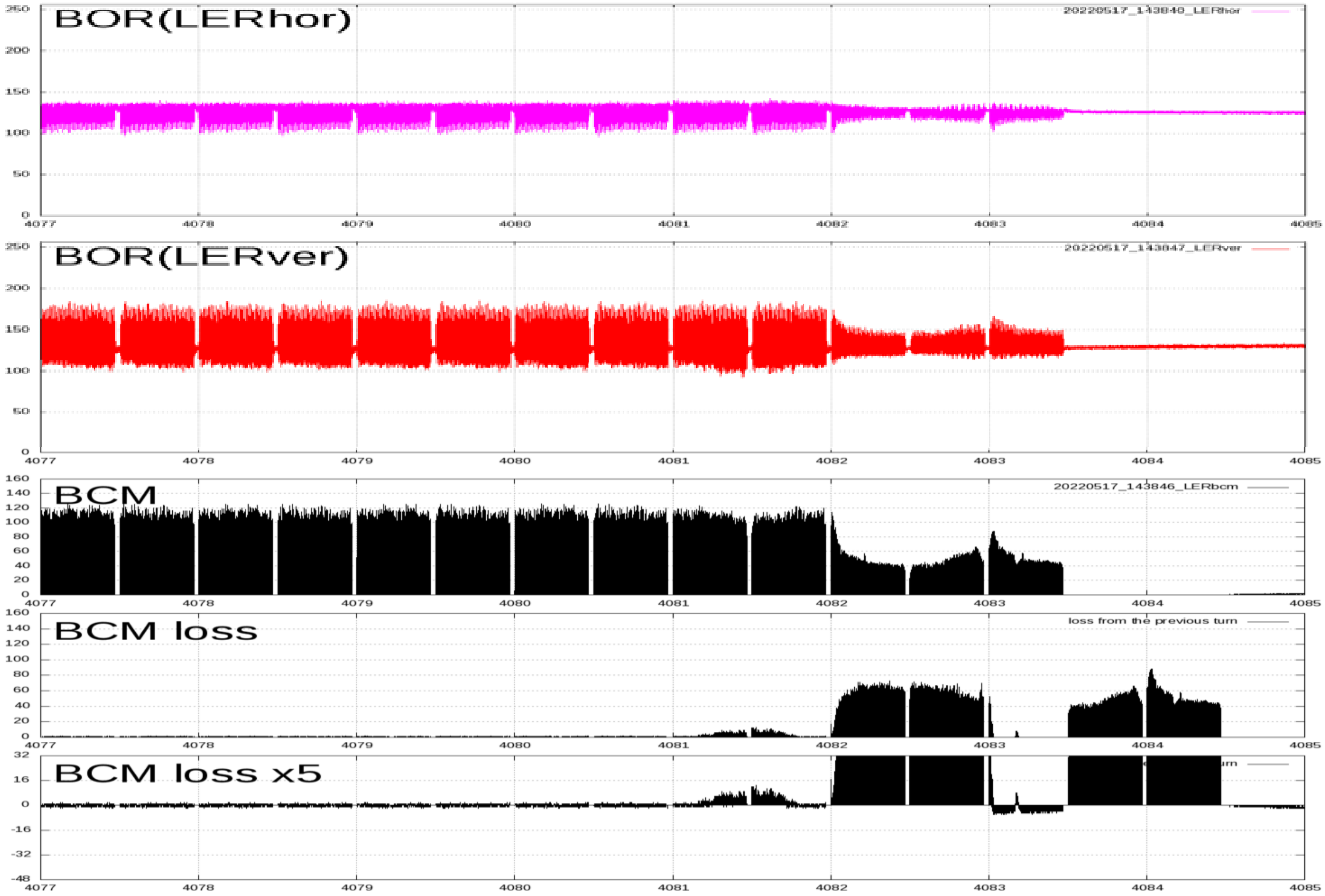
LER abort | HER abort | Both ring abort | Diamond >300mRad | QCS quench

original json file on abort database

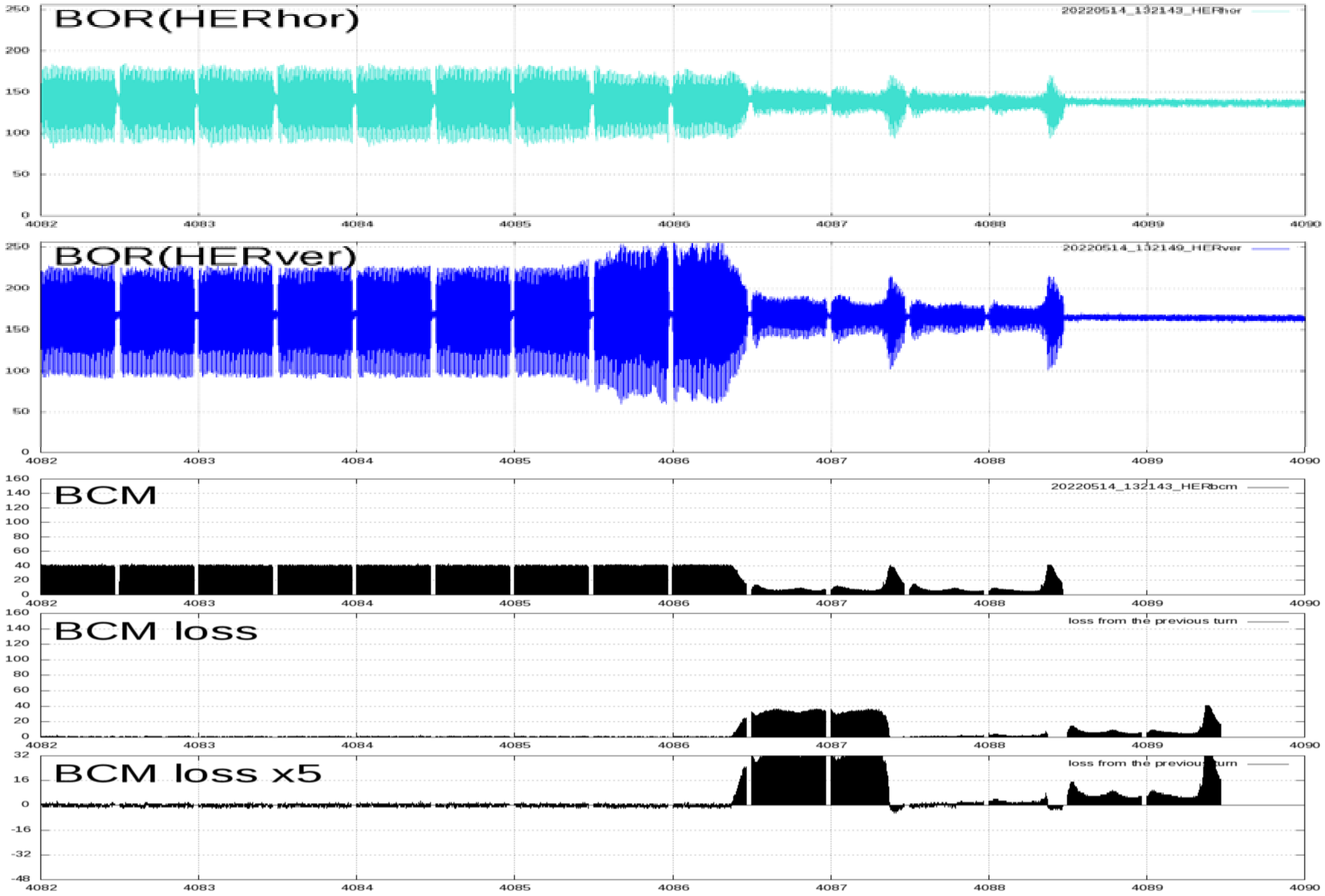
Time	Ring	Source	I_LER [mA]	I_HER [mA]	Nb	Dia(L) [mRad/s]	Dia(H) [mRad/s]	Diamond abort	LossMon (L)	LossMon (H)	BOR/BCM (L)	BOR/BCM (H)	Inj(L) [us]	Inj(H) [us]	BT orbit	AbtBPM (L)	AbtBPM (H)	Earth quake	Pressure burst	Comment
2022-06-22 08:39:42 Zlog TimeStamp	Both	Belle2 CLAWS + Belle2 VXD diamond	1457	1133	2249	178	46	306 mRad							not in-sync with inj.			[tkb]	D02_L25 QKBRP /BLC1RP /GV(D02_L04)	LER BCM loss
2022-06-22 05:38:27 Zlog TimeStamp	LER	RF D8-C	320	80	2249	6	16								not in-sync with inj.			[tkb]		
2022-06-22 05:24:23 Zlog TimeStamp	HER	Belle2 CLAWS	0	1116	2249	0	198								not in-sync with inj.			[tkb]		
2022-06-22 05:15:30 Zlog TimeStamp	LER	RF D8-C	1396	1115	2249	111	45							-88	not in-sync with inj.			[tkb]	D04_L02 QFWOP.4	
2022-06-22 04:13:32 Zlog TimeStamp	Both	Belle2 CLAWS	1413	1134	2249	116	42								not in-sync with inj.			[tkb]	D01_H02 QKALE	
2022-06-22 01:48:41	Both	Belle2	1345	1077	2249	96	182								not in-sync					


BOR(LERhor)
20220608_173113_LERhor
BOR(LERver)
20220608_173120_LERver
BCM
20220608_173119_LERbcm
BCM loss
loss from the previous turn
BCM loss x5

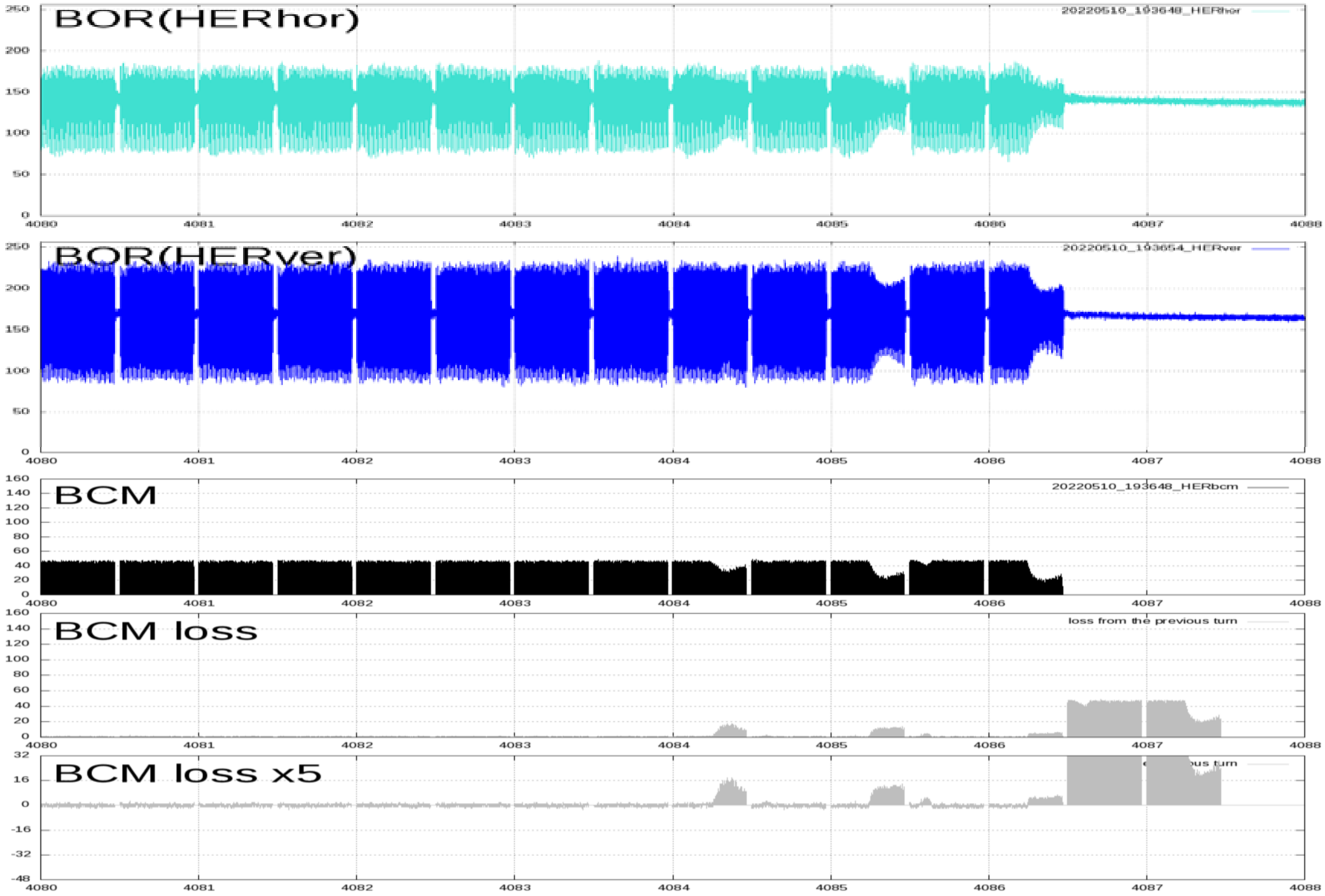

BOR(LERhor)
20220605_015949_LERhor
BOR(LERver)
20220605_015956_LERver
BCM
20220605_015955_LERbcm
BCM loss
loss from the previous turn
BCM loss x5
4077
4078
4079
4080
4081
4082
4083
4084
4085


BOR(LERhor)
20220517_143840_LERhor
BOR(LERver)
20220517_143847_LERver
BCM
20220517_143846_LERbcm
BCM loss
loss from the previous turn
BCM loss x5
4077
4078
4079
4080
4081
4082
4083
4084
4085

Also in HER



BOR(HERhor)
20220514_132143_HERhor
BOR(HERver)
20220514_132149_HERver
BCM
20220514_132143_HERbcm
BCM loss
loss from the previous turn
BCM loss x5
loss from the previous turn
4082
4083
4084
4085
4086
4087
4088
4089
4090


BOR(HERhor)
20220510_193648_HERhor
BOR(HERver)
20220510_193654_HERver
BCM
20220510_193648_HERbcm
BCM loss
loss from the previous turn
BCM loss x5
4080
4081
4082
4083
4084
4085
4086
4087
4088

Summary

Summary

- Peak luminosity of 4.65 (4.71) x 10^{34} $cm^{-2}s^{-1}$ was achieved in 2022.
- Stable operation over 1 A in the LER is possible if the bunch current is smaller than 0.7 mA.
- "Sudden beam loss" is the most serious problem to increase beam current so far.
- Beam blowup in the LER is still unclear. Lower impedance of collimators, BxB FB tuning, and higher vertical tune help to suppress the beam blowup above I_b = 0.8 mA. (single bunch issue)
- Beam line deformation as a function of beam current induces the large beta-beat (change of β_y^*) and global X-Y couplings. The deformation is due to SR heating. The orbit deviation at the strong sextupoles affects optics.
- BPM accuracy for all beam current region is required since the optics correction is performed at 50 mA and physics run is over 1 A.
- High current operation over 1 A is quit different from a few hundreds of mA. The 2022 run was the dawn of a new window for SuperKEKB.
- Short beam lifetime; both of dynamic aperture and physical aperture, need to check crab waist ON and OFF.
- Injection efficiency becomes poor as squeezing β_y^*. It is important to achieve 10^{35} $cm^{-2}s^{-1}$ to solve issues such as emittance growth of injection beams (CSR), injection backgrounds, and so on.

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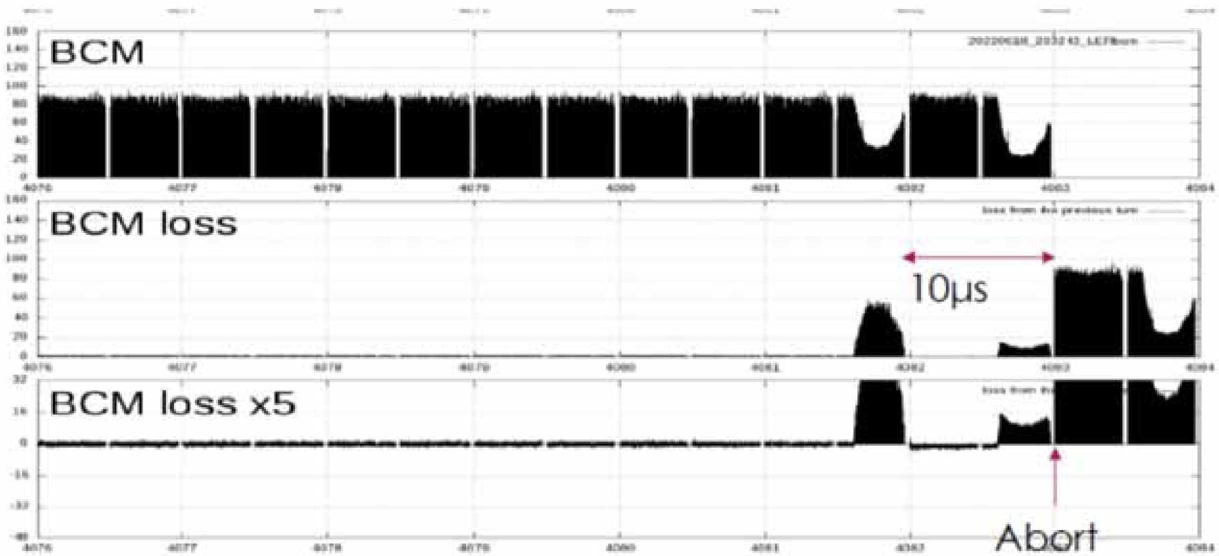
Sudden beam loss

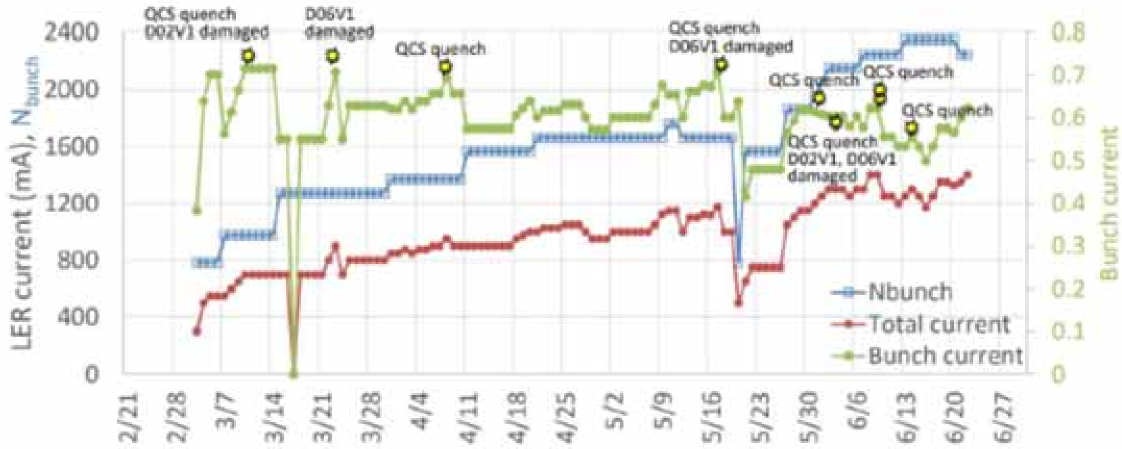
International Task Force for SuperKEKB upgrade
Sudden beam loss subgroup (H.Ikeda)
https://kds.kek.jp/category/2242/

- Beam loss has been measured by bunch current monitor (BCM) to occur suddenly on a certain turn.



Beam(bunch) current

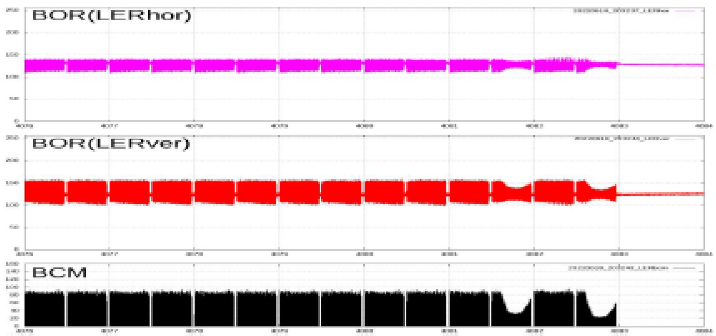
- Beam loss occurs in both HER and LER, but the damage to the hardware is particularly large when loss occurs in LER.
- It is likely to occur when a certain bunch current is exceeded.
- We don't know if it will happen even with a single beam operation, low current beam because we haven't operated for a long time.

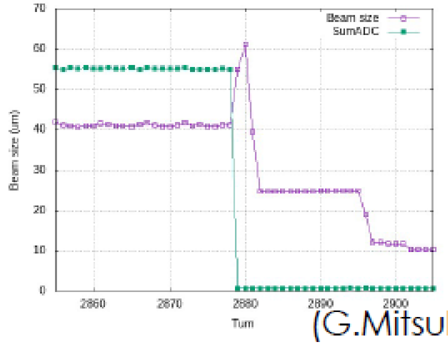


(K.Matsuoka)

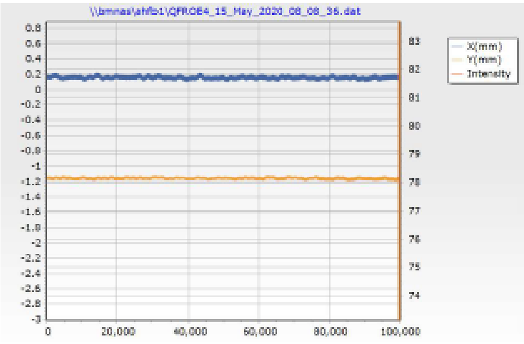
Before beam loss

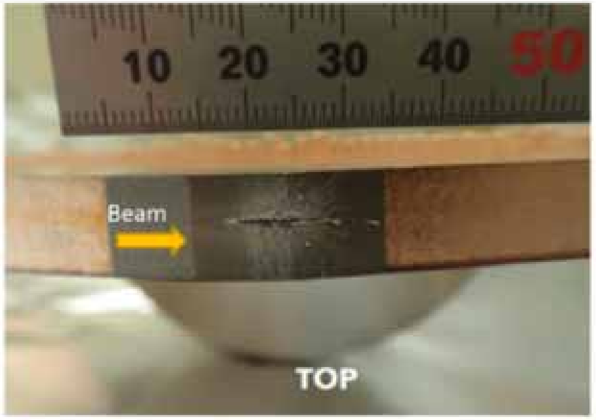
- There are no signs before beam loss.
  - No small beam loss (beam loss monitor, BCM)
  - No oscillation (Bunch Oscillation Recorder (BOR))
  - No beam size change (X-ray monitor (XRM))
  - It is not clear if the orbit changed significantly.(Libera)

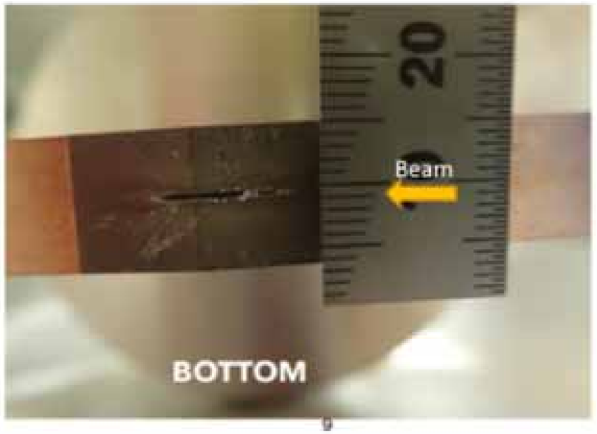




(G.Mitsuka)



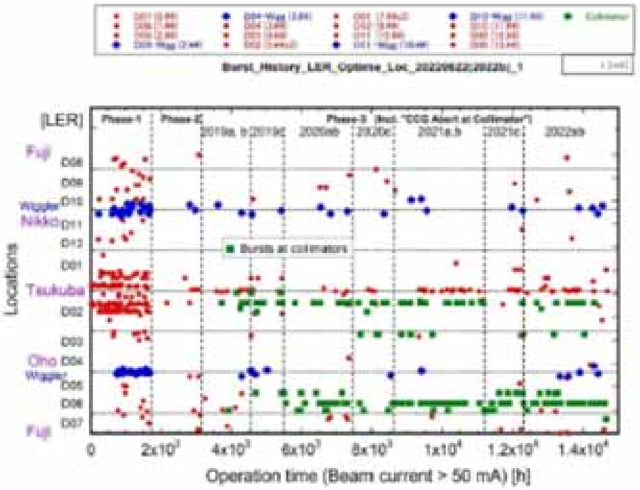


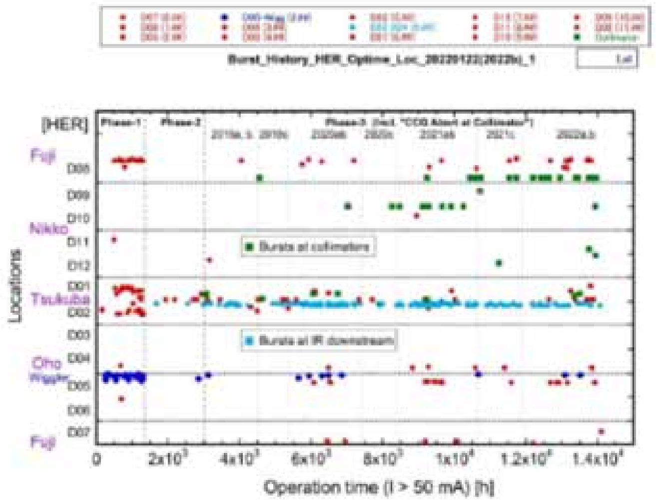


- After a huge beam loss event on June 6th in 2021, LER BG increase significantly.
- D02V1 collimator jaws were severely damaged (deep scar on the bottom jaw).
- Typically, collimator replacement work and the baking runs take 3~4 days.

Vacuum pressure

- Pressure bursts have been observed here and there, and it rarely occurs in the same place except in the collimator section. It may be the result, not the reason.

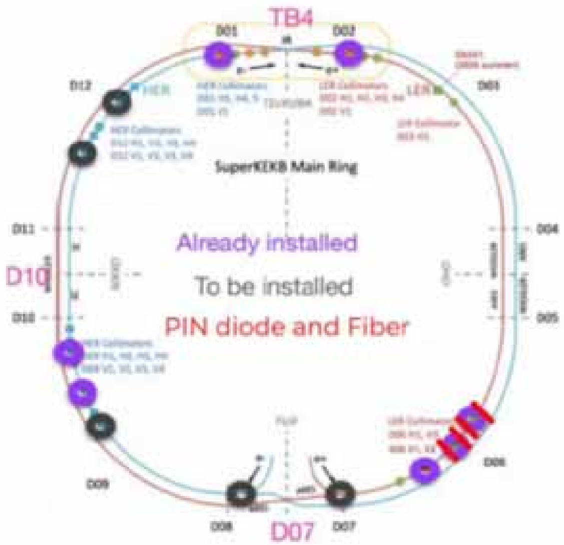


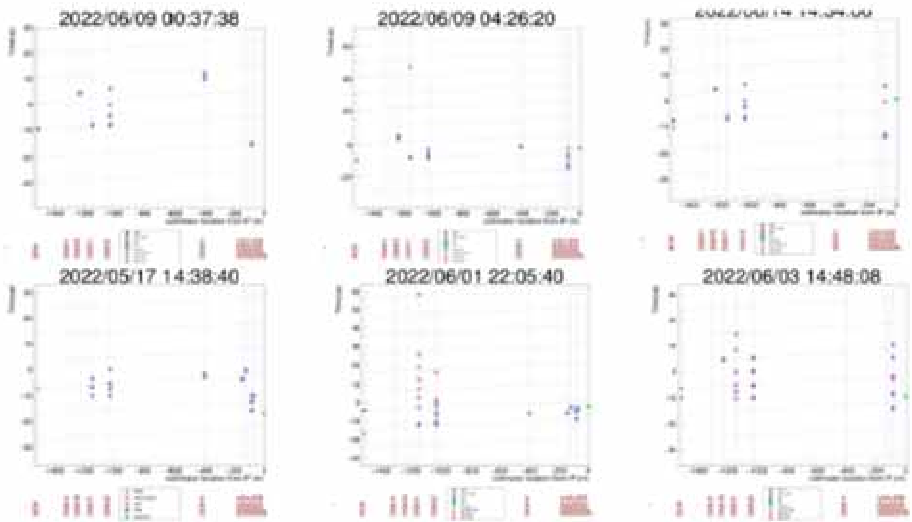


(Y.Suetsugu)

Start position of beam loss

- Beam loss occurs in collimator & IR, and where it occurs first depends on collimator tuning (Loss Monitor timing analysis).





(Y.Liu)