SuperKEKB MR status and upgrade during LS1

Y. Arimoto for SuperKEKB

Oct/10th/2022 B2GM

Contents

- SuperKEKB status
  - Achievements and issues
- LS1 activity
  - Non-Linear Collimator
  - The other activities
- Summary

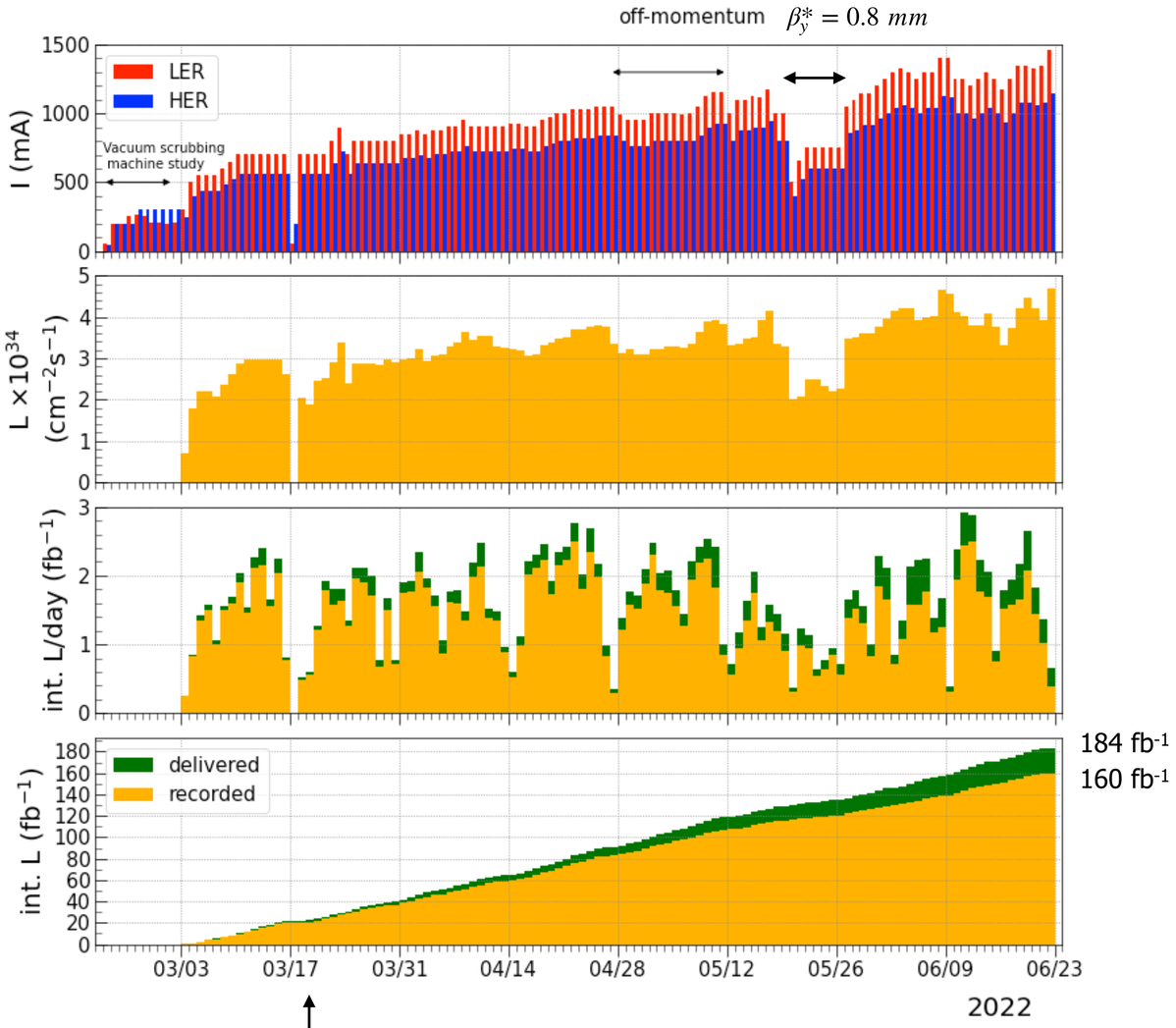
Achievement on 2022ab

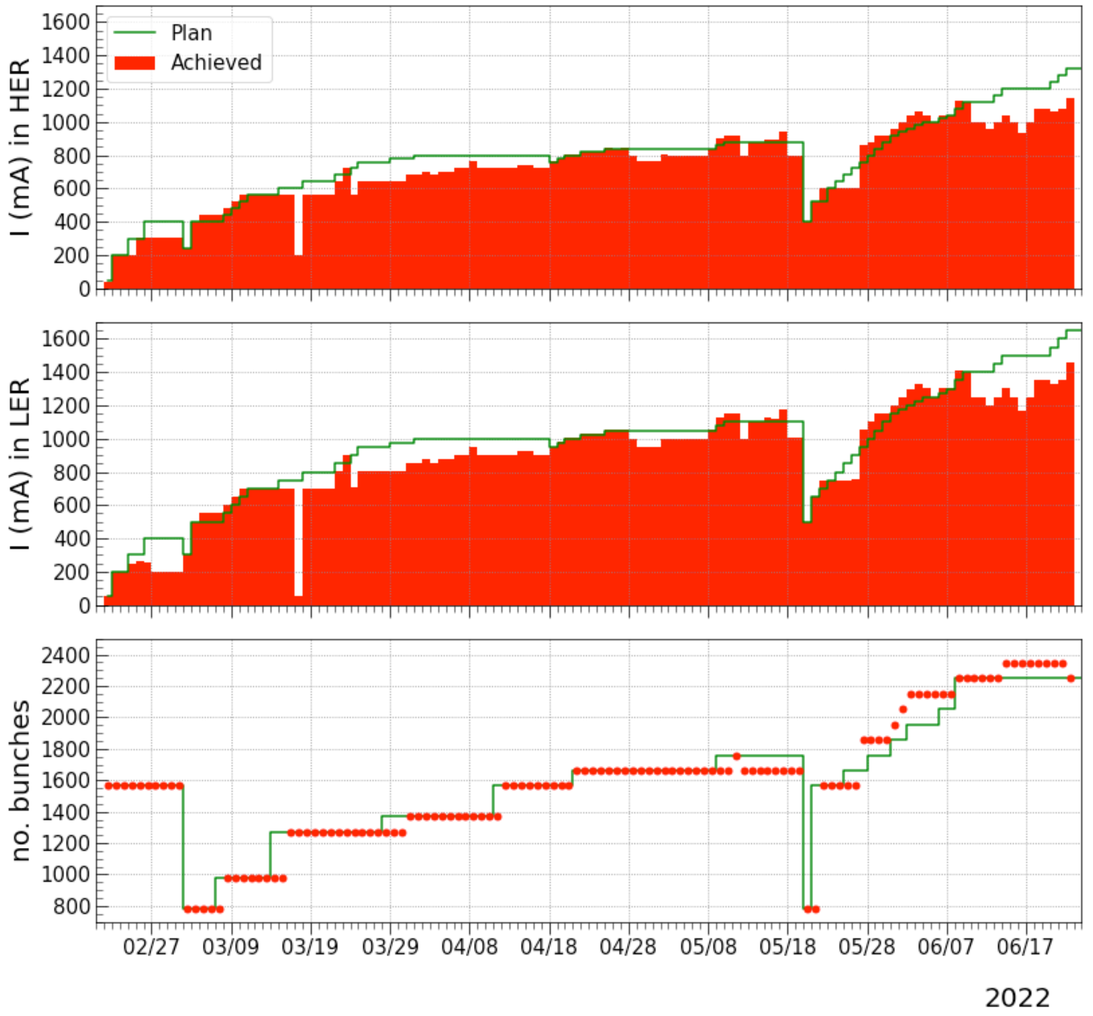
- Peak luminosity : 4.65 x 10^{34} $cm^{-2}s^{-1}$ (4.71 x 10^{34} $cm^{-2}s^{-1}$ w/o Belle II data taking)
- Integrated luminosity : 424 fb^{-1} (491 fb^{-1})
- Peak currents : 1.46 A (LER) / 1.14 A (HER), 2346 bunches (2-bucket spacing) with stable operation over 1 A in LER
- Chromatic X-Y coupling correction with the rotatable sextupoles in the LER: luminosity improvements
- A long-term drift of QCS magnetic field (beta-beat): reduced by the new QCS initialization procedure

Ref.: https://agenda.infn.it/event/21199/contributions/168882/

Y. Onishi

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

Ref. https://kds.kek.jp/event/42954/

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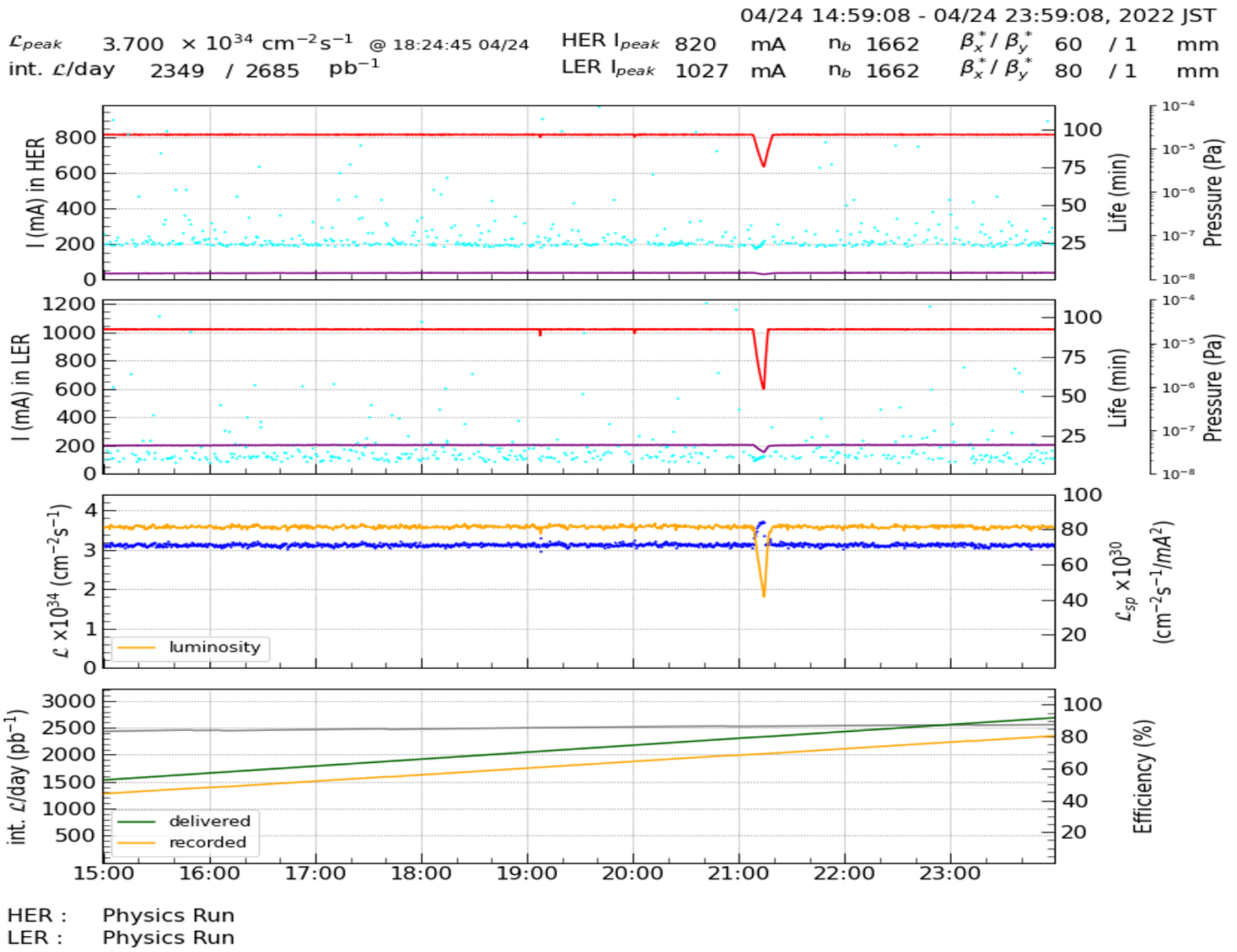
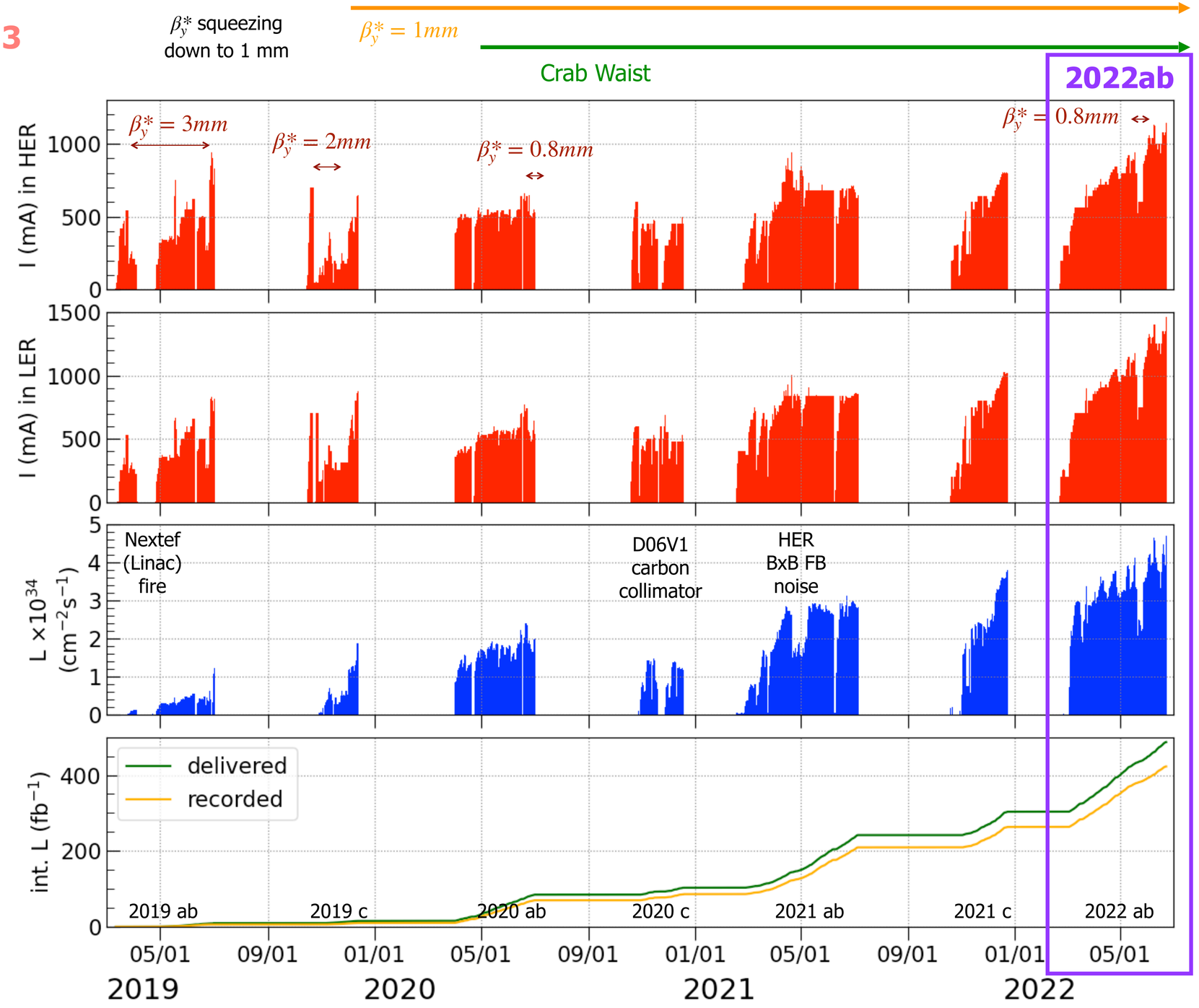
Stable operation
in 8 hours

Int. $L_{Recorded}$ = 958 fb^{-1}

Apr/24/2022



SuperKEKB Phase 3



1145 mA

1460 mA

4.65 x 10^{34} cm^{-2}s^{-1}
(4.71 x 10^{34} cm^{-2}s^{-1})

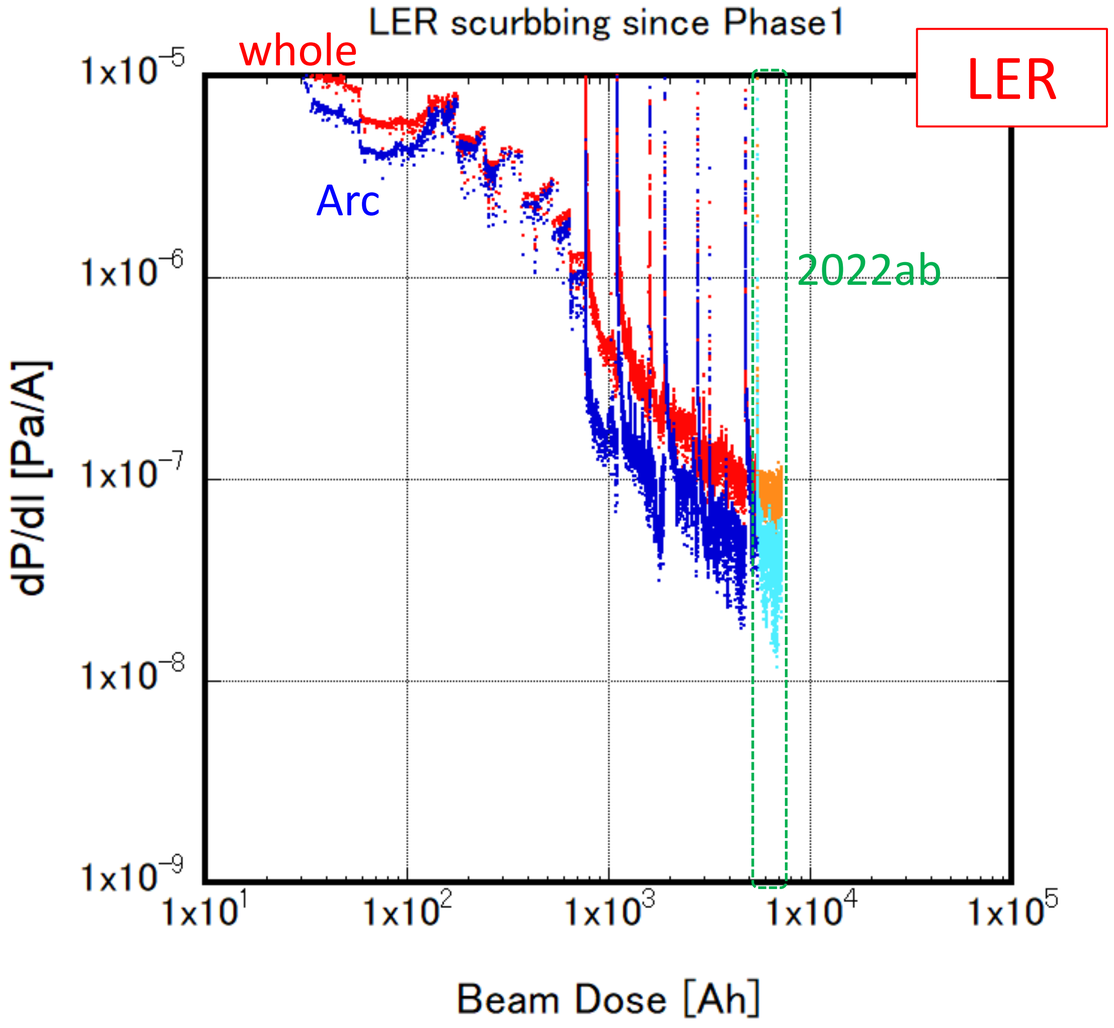
424 fb^{-1} / 491 fb^{-1}

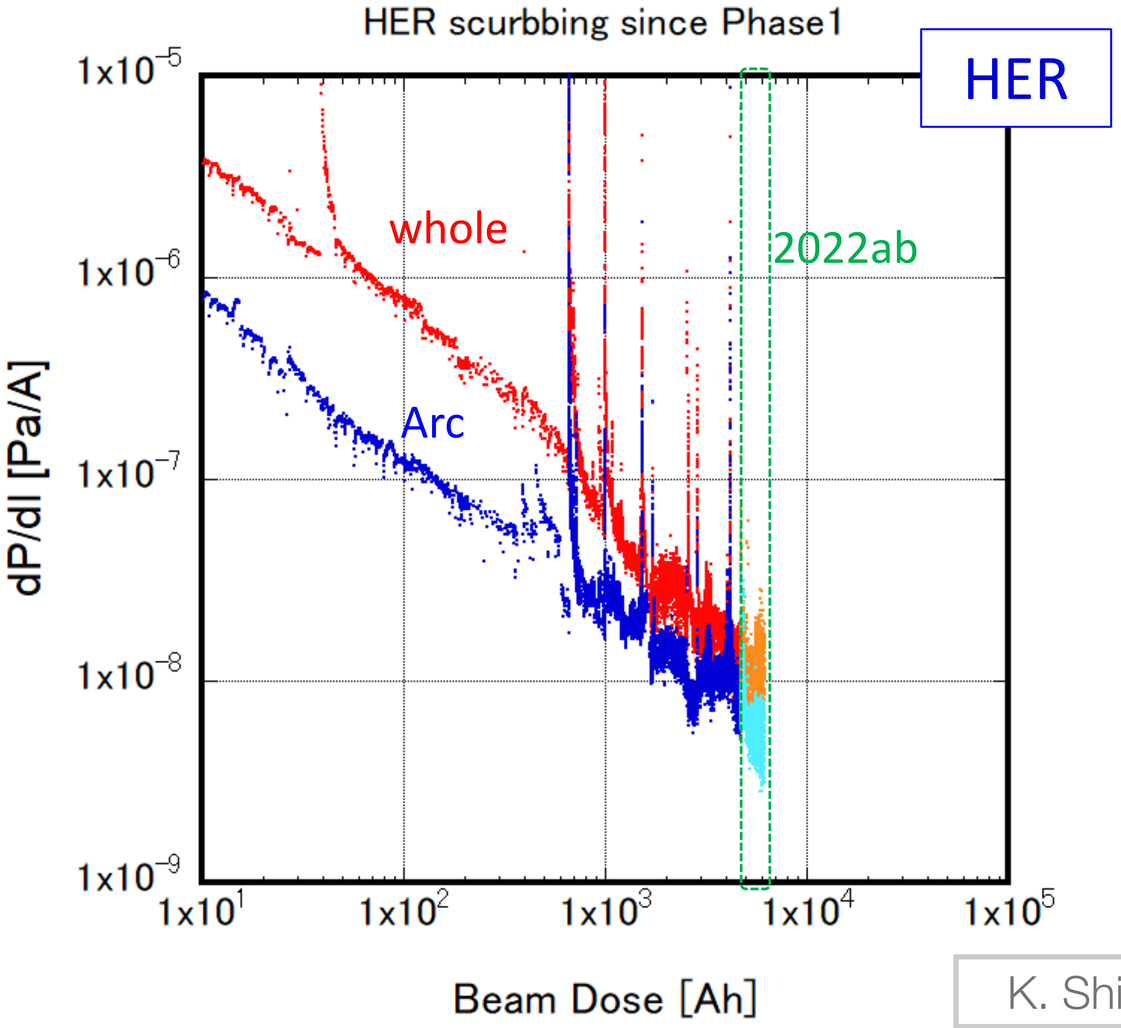
https://kds.kek.jp/event/42954/

Y. Onishi

Vacuum scrubbing since Phase1

It takes ~ 2.3 months to get 1×10^3 Ah. (LER)





K. Shibata

Issues

- Fast Beam Loss abort is a serious problem. It causes QCS quench and collimator damages if there is a large beam loss.
- Collimator damage of D06V1, D02V1, and D09V1; Impedance increases? Single beam blowup ($I_{b+} > 0.6$ mA) in LER
- Beam-line deformation due to "SR heating" or "HOM heating" (Beam position monitor depends on beam currents.)
- Optics degradation after one week of optics corrections; Earthquake also affects optics significantly in the HER.
- Injection: stability of e^- beams, 2-bunch injection (efficiency and stability)

Ref. https://kds.kek.jp/event/42954/

Y. Onishi

Machine Parameters

Y. Onishi

Ref. https://kds.kek.jp/event/42954/

	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}		$cm^{-2}s^{-1}$

*1) estimated by luminosity with assuming design bunch length

*2) divide *1 by √2

Non-linear collimator

Non-linear collimator

- We will install the non-linear collimator (NLC) during LS1.
- The NLC scrapes unwanted-beam particles even in a large aperture.
  - Reducing wake-field kick at the collimator
  - Relaxing Transverse Mode Coupling Instability
- The NLC consists of a pair of sextupole magnets and a collimator.
- A new sextupole magnet is designed and under construction.

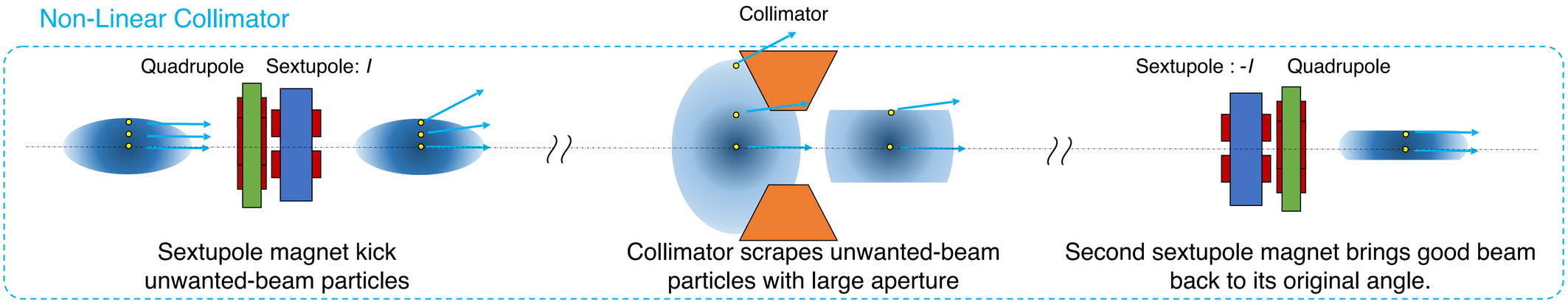
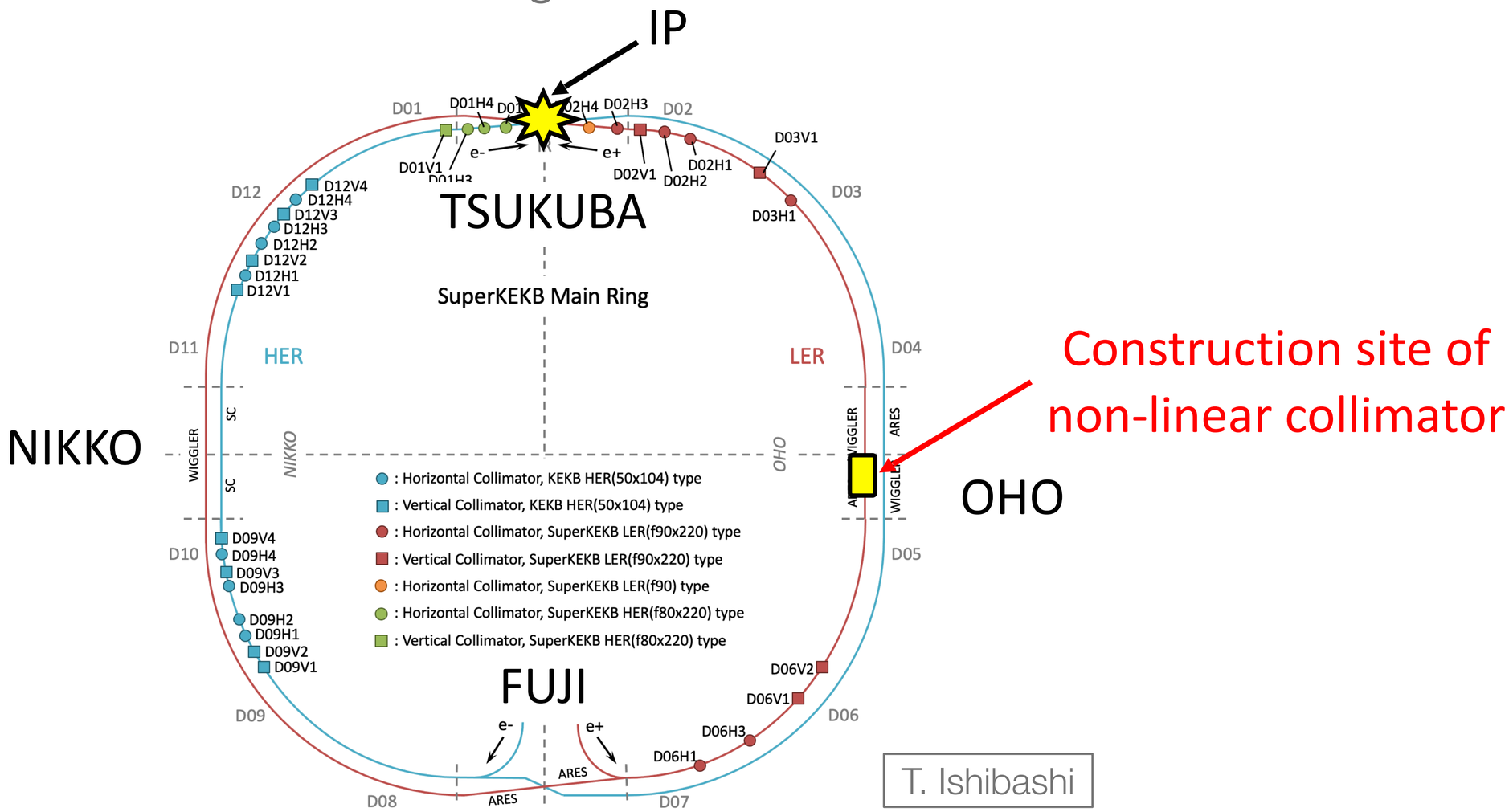


Illustration by K. Shibata

Non-linear collimator: Location

- NLC will be constructed at OHO straight section.

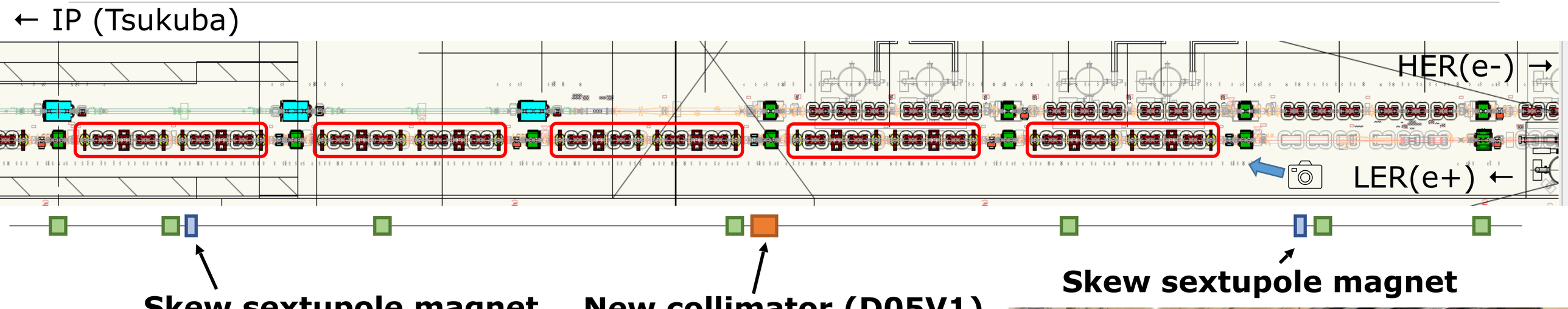


Construction site of non-linear collimator

T. Ishibashi

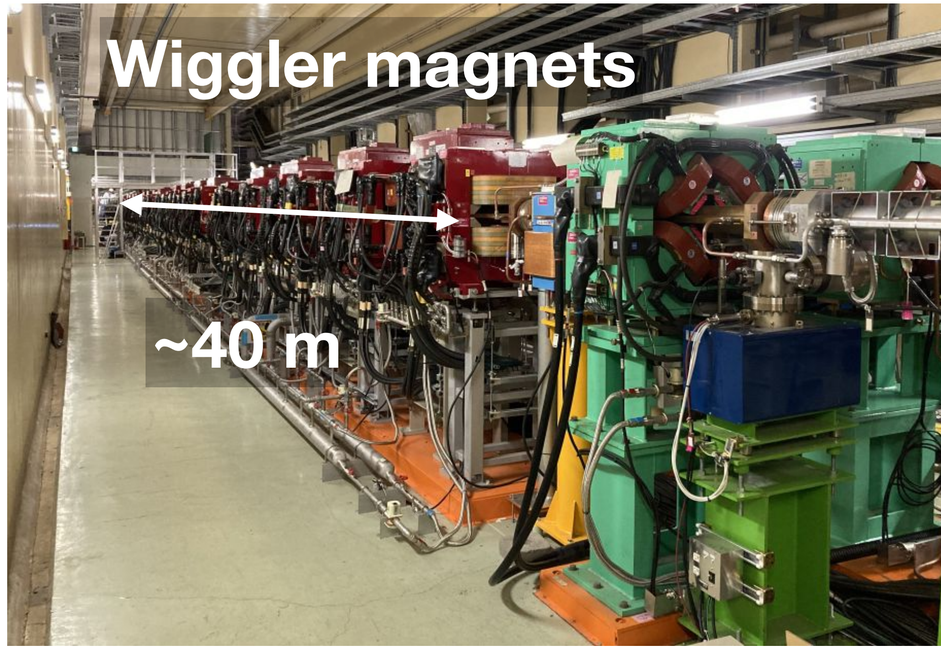
Non-linear collimator: Construction

S. Nakamura



- Take away these wiggler magnets.
  Twenty double pole magnets, ten single pole magnets, ten half pole magnets.
  The weight of the power cable, which is removed together with magnets, is about 3000 kg.
- Relocation quadrupole magnets.
- Install a pair of new skew sextupole magnet.
- Install new vertical collimator (D05V1).

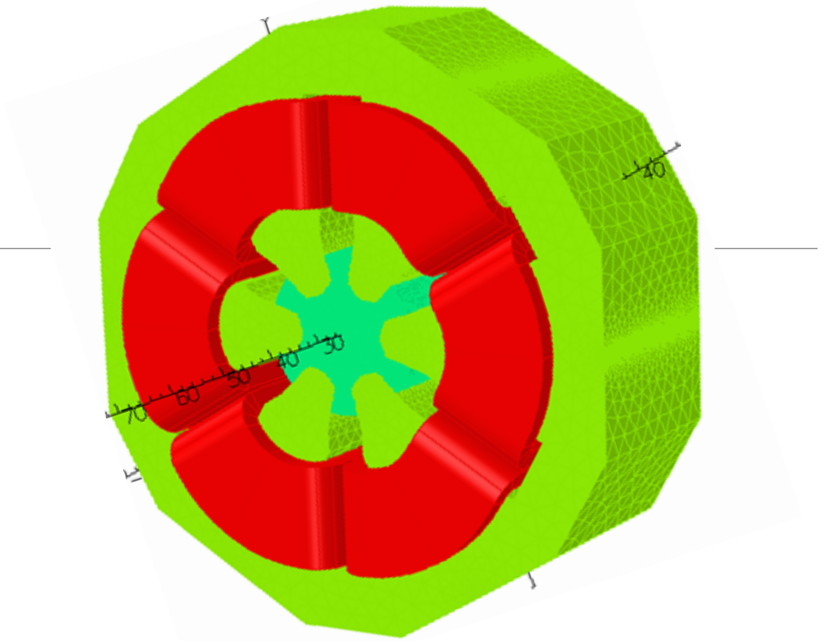
Now we start to remove the wiggler magnets.



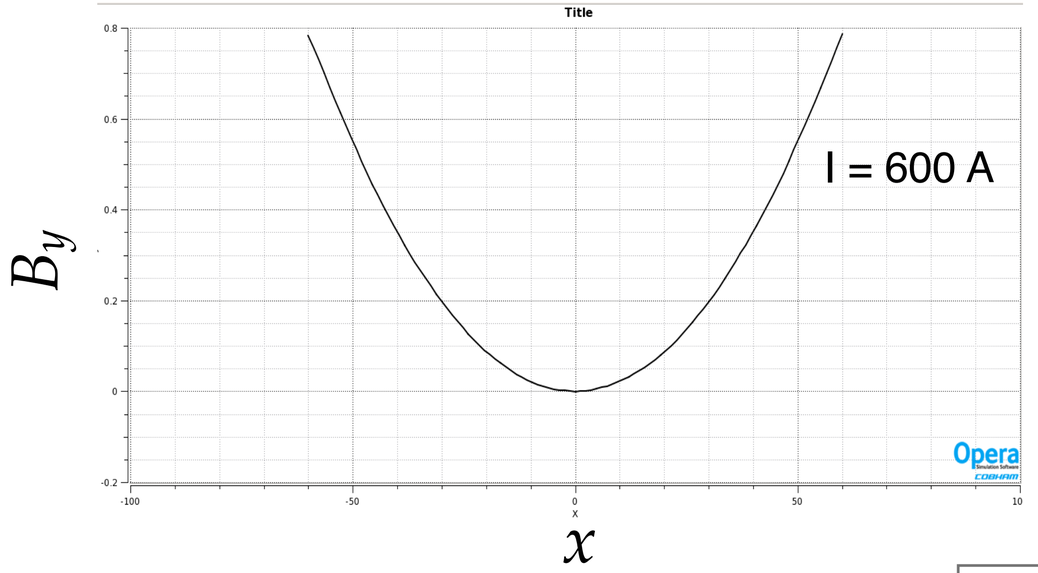
Sextupole magnet for Non-linear colliemator

Parameters of sextupole magnet for NCL

Mechanical parameters	
Bore radius [mm]	56.0
Lamination length [mm]	300
Electromagnetic parameters	
Maximum current [A]	600
Number of turns in a coil [Turns/pole]	21
B”[T/m^2]	400-500
Resistance at 30+ΔT°C [mΩ]	33.4
Inductance [mH]	11.8
Voltage [V]	20
Power consumption [kW]	12.0
Thermal parameters	
Flow rate of cooling water [L/min/mag]	16.5
Temperature rise [°C]	10.4
Maximum pressure[kg/cm^2]	15
Working pressure [kg/cm^2]	10
Pressure drop [kg/cm^2]	5



3D Model of sextupole magnet



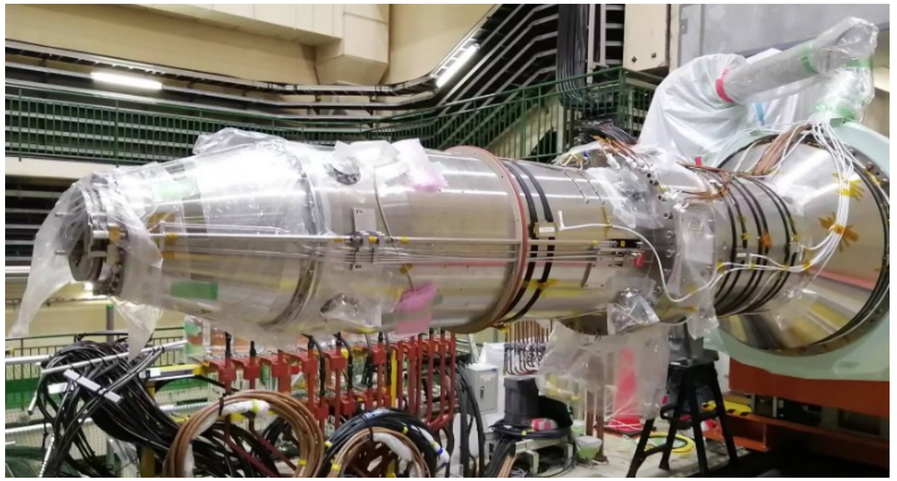
B vs x (Simulated by OPERA)

R. Ueki

The other activity during LS1

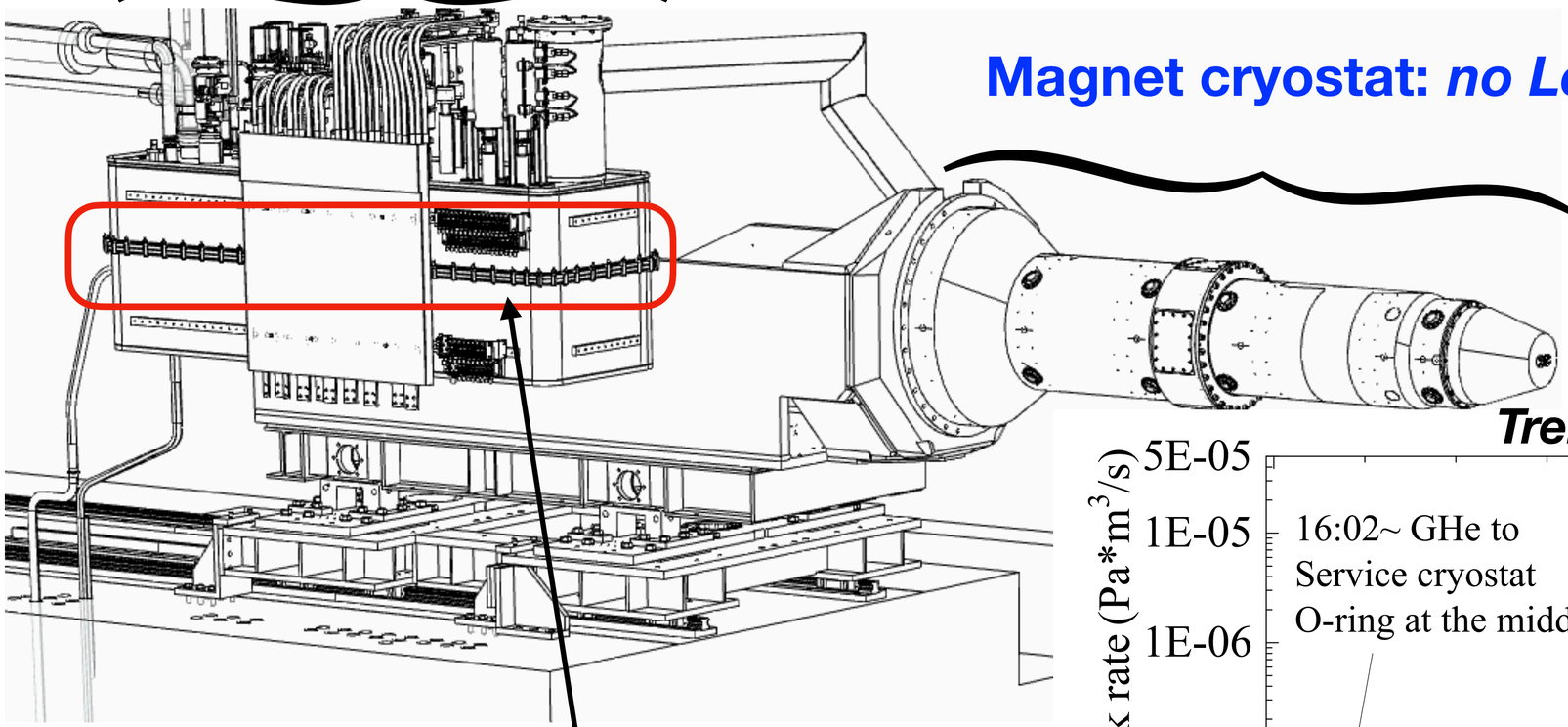
QCS-R Vacuum-Leak Check

- QCS-R vacuum-leak incident:
  - We found a large leak in the vacuum chamber (Reported by Ohuchi-san at MDI meeting on Sep. 2021)
- Helium leak check on Sep/2022:
  - by Vacuum group and QCS group
  - We found a vacuum leak at the service vessel, not the cryostat.
- Repairing the vacuum leak
  - We will repair at IR during LS1.



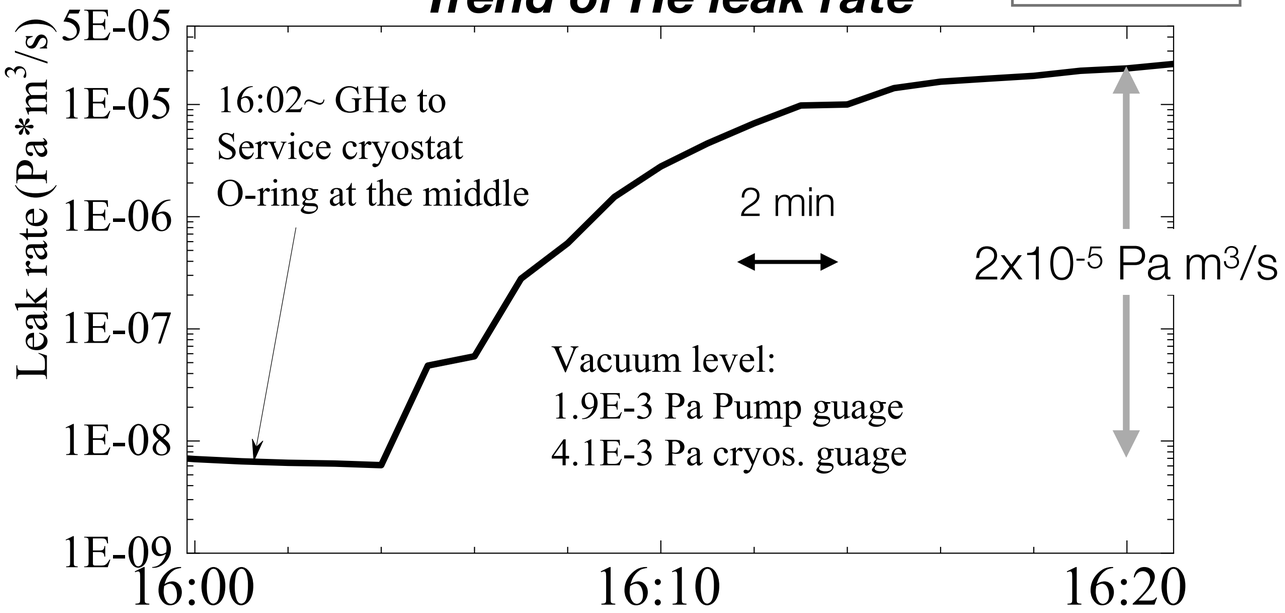
Photos by Z. Zong

Leak area of QCS-R



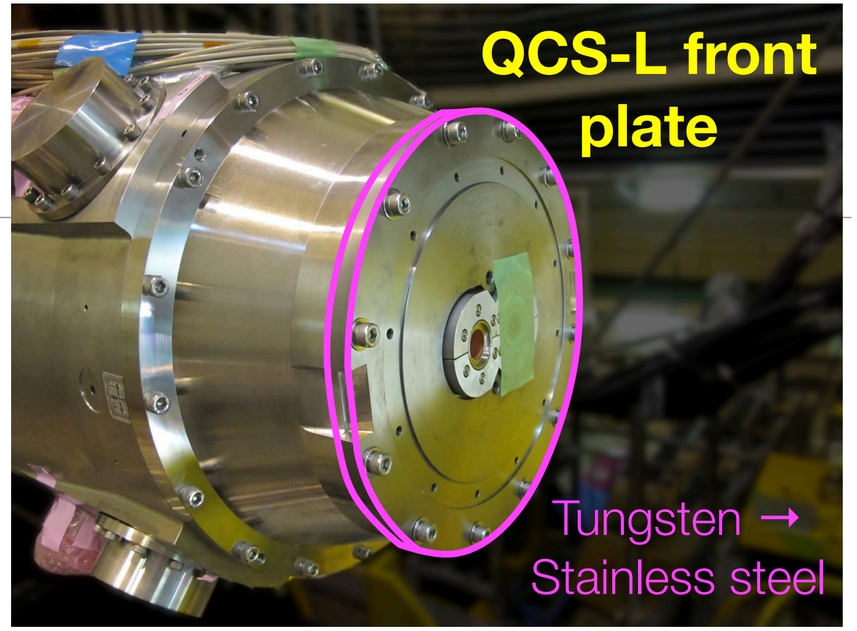
by Z. Zong

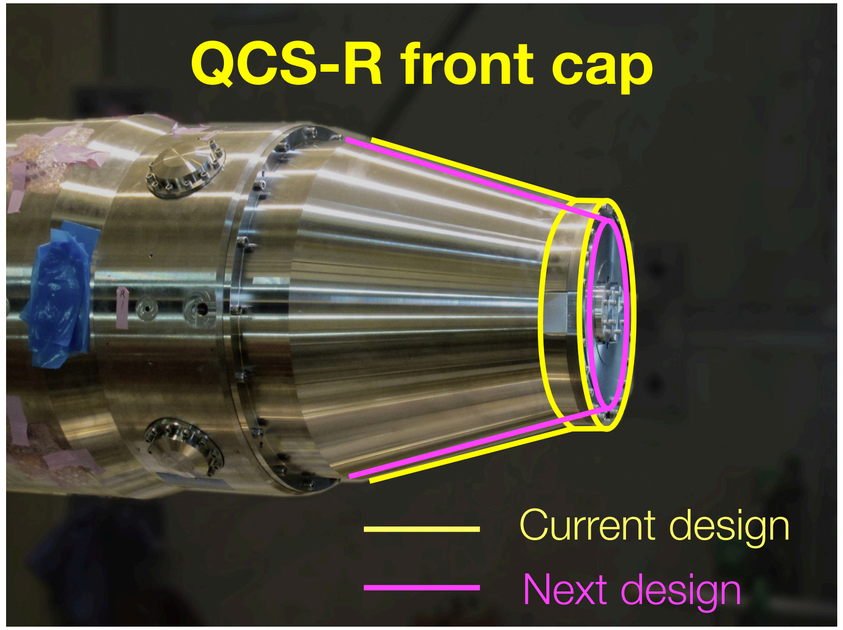
Trend of He leak rate



Modification of QCS front cap

- Motivation
  - Making space for cables of Belle II
  - Reducing background produced at QCS front surface.
- QCS-L
  - Changing front plate material from tungsten to stainless steel
- QCS-R
  - Making the front cap smaller
  - Changing material to all stainless steel

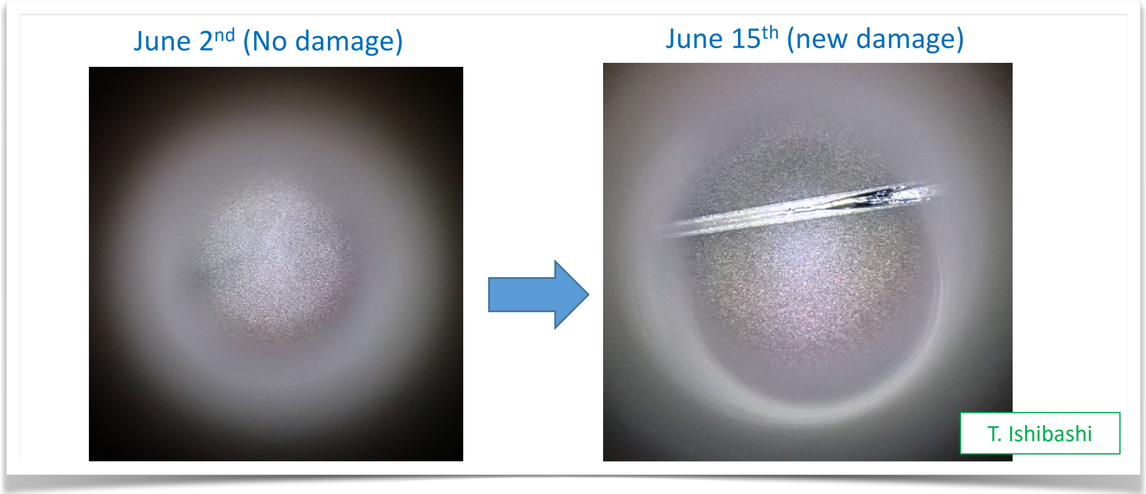




Collimators

- Replacement of damaged collimator
  - LER: D02V1, D06V1
  - HER: D09V1
  - Damaged by sudden beam loss
- Replacement to Low-Z (Carbon) collimator
  - D06H3
  - Damaged by the accidental fire of the kicker magnet
  - Expected to be robust against beam loss
- Relocation for NLC
  - D03V1 → D05V1
  - Set at the NLC section

HER: D09V1 collimator damage



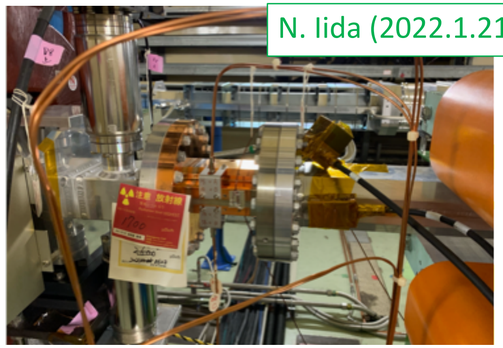
Carbon collimator head

T. Ishibashi

Aperture enlargement of HER injection channel

- Problem of HER injection
  - Wall can be an obstacle to injection.
    - A wall should be placed between beam channels for stored beam and injected beam.
    - Injected beam orbit is too close to the wall.
    - High levels of radiation detected at the injection BPM chamber indicates that the injected beam hits the wall.
    - It is hard to modify the injection beam orbit.

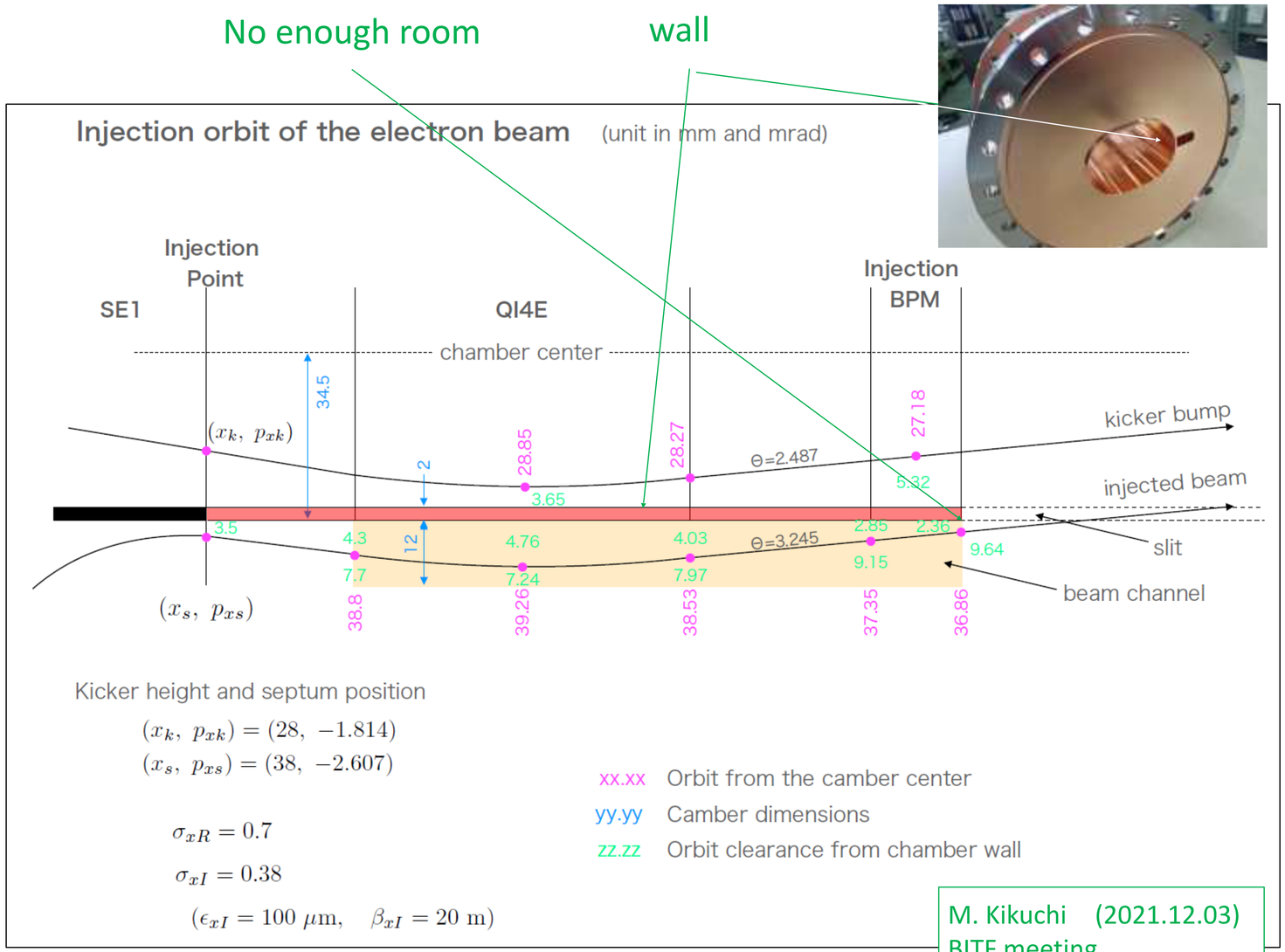
    ⇒ it is necessary to enlarge the horizontal aperture of the injection channel.



N. Iida (2022.1.21) BITF meeting

  - What is planned during LS1
    - Replacement of three beam chambers with new ones.
    - Update of injection BPM

    ⇒ More precise injection tuning



M. Kikuchi (2021.12.03) BITF meeting

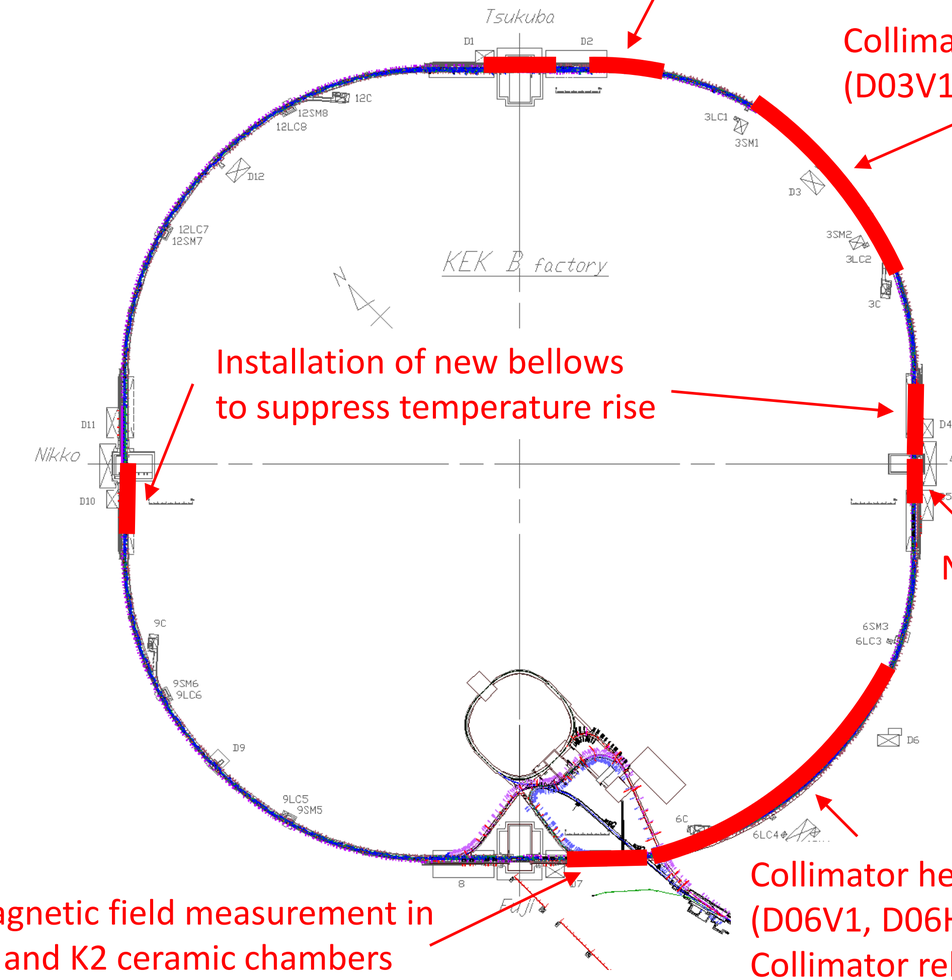
K. Shibata

Vacuum work locations during LS1

LER

Collimator head replacement
(D02V1)

Collimator relocation
(D03V1 -> D05V1)



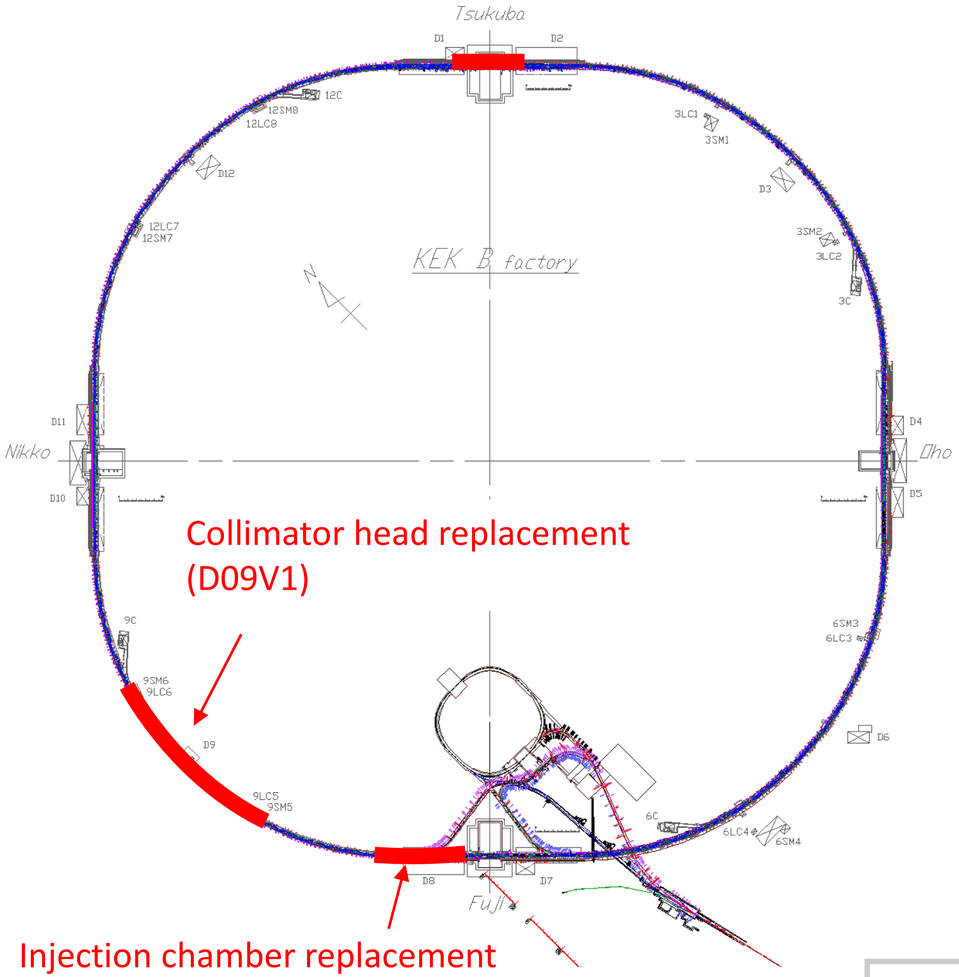
Installation of new bellows
to suppress temperature rise

NLC (D05V1)

Collimator head replacement
(D06V1, D06H3)
Collimator relocation
(D06H1 -> D06H4)

Magnetic field measurement in
K1 and K2 ceramic chambers

HER



Collimator head replacement
(D09V1)

Injection chamber replacement

K. Shibata

Upgrade items during LS1 (BT)

- MR
  - Replacement of HER injection chamber.
  - Replacement of HER septum magnet (SE1) and modification of the power supply to improve field quality
  - Re-alignment of HER 4th arc quadrupole magnets
  - Install OTR screen monitors as many as possible
  - Modification of voltage divider circuits of LER kickers to increase reliability
  - Replacement of ceramic chambers for LER kicker K1 to make the same pulse shape between K1 and K2 kickers
  - Modification of thyratron's trigger circuit of HER/LER abort kickers for faster triggering
- DR
  - Replacement of main capacitors of DR ext. kickers to improve stability

M. Tawada

Update items during LS1 (Control group)

- Apply “Bunch Current Equalizing” system for two-bunches injection
- Revise the algorithm of the injection efficiency determination
  - Bunch current after injection is monitored one pulse later.
- Improve the timestamp synchronization for Abort Trigger modules
  - utilize White Rabbit module
  - need discussion of the software development for the abort analysis.
- Upgrade the Beam Gate system for HER
  - delayed control signal based on White Rabbit to synchronize the control of the gun and septum/kicker magnet triggers.
  - that for LER is followed in 2024.

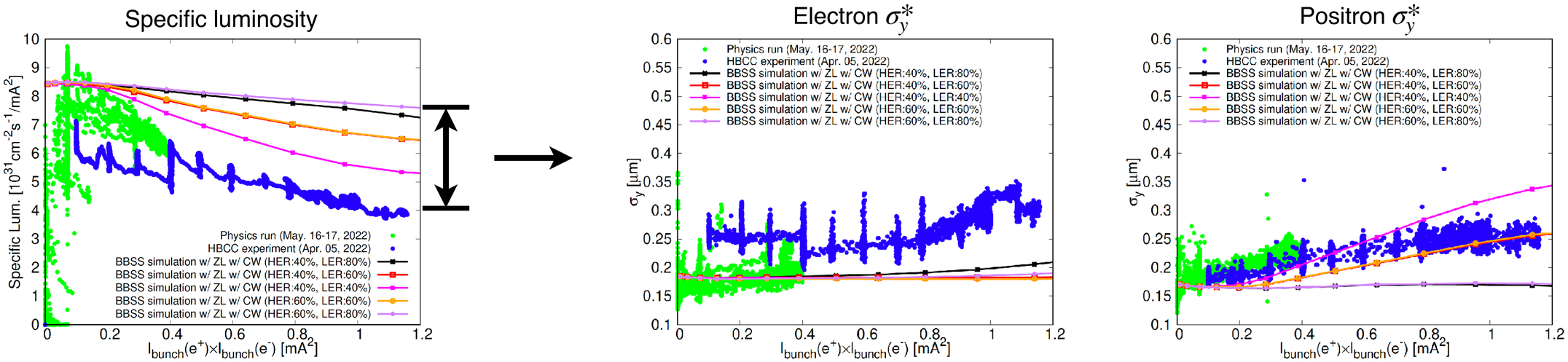
H. Kaji

Beam dynamics issues

Ref. D. Zhou, eeFACT2022 workshop, Frascati, Rome, Italy, and references therein

- Many sources of luminosity degradation were better understood during 2022b run, leading to better agreements in simulated and measured luminosity
- Known sources of luminosity degradation
  - Bunch lengthening; Chromatic couplings; Single-beam blowup in LER caused by an interplay of impedance and feedback system; Optics distortion due to synchrotron radiation heating; Luminosity loss correlated with injection; …
- Sources of luminosity degradation to be investigated via simulations and experiments
  - Imperfect crab waist; Beam-beam driven synchro-betatron resonances; Interplay of beam-beam, longitudinal and transverse impedances, and feedback system; Global couplings; Interplay of beam-beam and nonlinear lattices; Coupled bunch instabilities; …

2022b run: Luminosity degradation corresponds to an extra blowup of vertical beam sizes



Beam dynamics issues (cont'd)

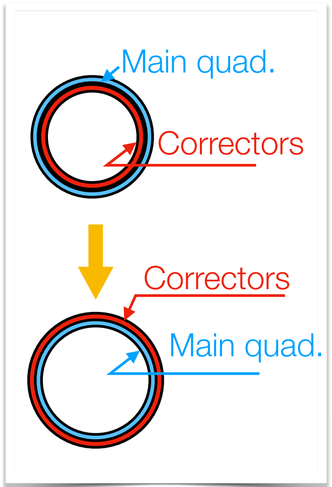
- TO-DO list of investigations during LS1
  - Impedance budgeting (T. Ishibashi): Impedance models are ready for both LER and HER. Benchmarks and further refinements are ongoing.
  - Strong-strong beam-beam simulations with impedances: Use the latest impedance models as input.
  - Strong-strong beam-beam simulations with impedances and complete lattices: Codes are under development considering GPU-boosting (K. Ohmi, Joint SuperKEKB-CEPC team)
  - Strong-strong beam-beam simulations with impedances and other factors (such as space charge, realistic feedback, etc.): Code development, benchmark, and investigations
  - Impact of the nonlinear collimator (NLC) on machine performance
- International collaboration on accelerator physics challenges at SuperKEKB
  - Joint efforts on simulation codes for reliable predictions of luminosity: Teams of SuperKEKB, CEPC, and FCC-ee
    - An international workshop on "Luminosity of colliders: Predictions, experiments, and machine tunings" (Tentative title) is under preparation
  - Joint efforts on theories/simulations of impedance modeling and impedance effects in colliders
    - The first international workshop on "Impedance modeling and impedance effects at SuperKEKB and future colliders" (Tentative title) is under the organization
- From the viewpoint of beam dynamics, during LS1, we must develop an executable strategy/ plan of luminosity tuning/optimization, and machine studies, together with the Belle II team

Toward LS2

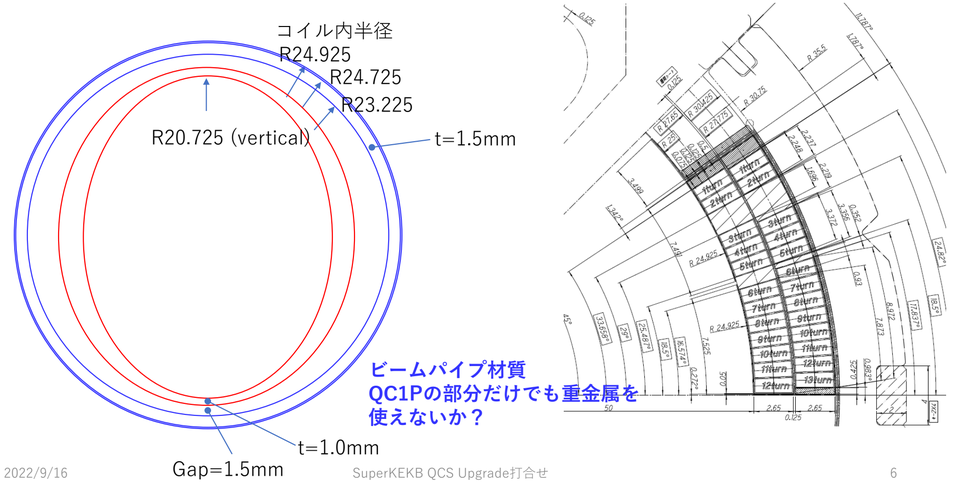
- We are revisiting the investigation of IR section to achieve integrated luminosity of 50 ab^{-1} around 2030.
- Beam optics investigate IR optics
- QCS group considers magnet design.
- Vacuum group and QCS group investigate the mechanical design.

Option-3

QC1P cross section



QC1Pとビームパイプ



Summary

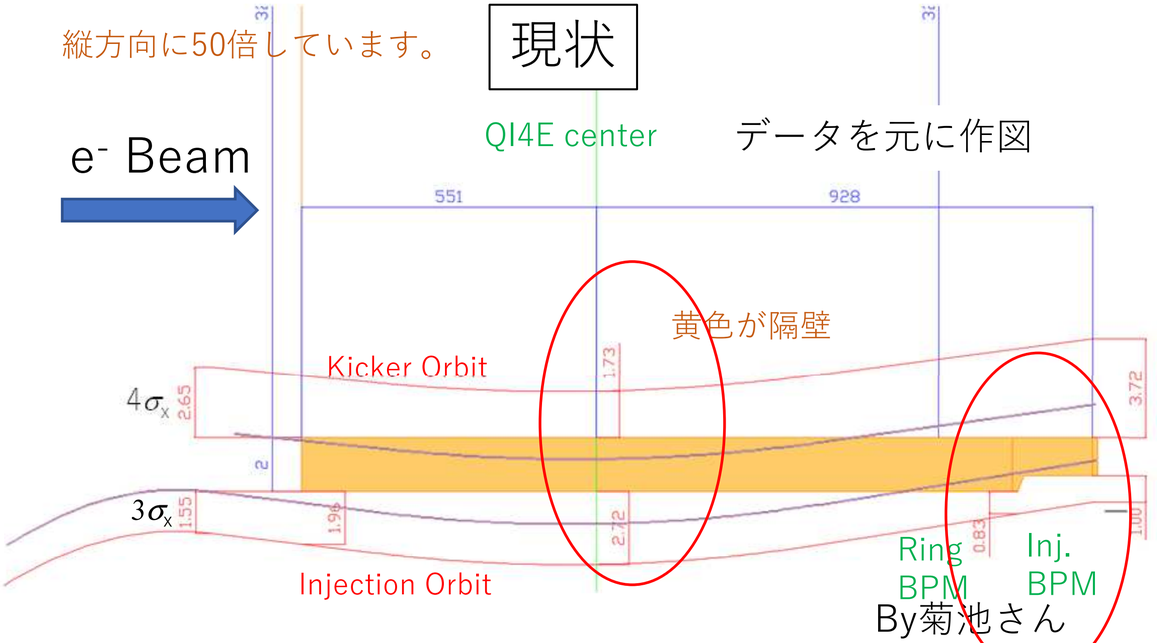
- Main ring status
  - Achievement: peak luminosity: 4.65 x 10^{34} $cm^{-2}s^{-1}$, integrated luminosity : 424 fb^{-1} (491 fb^{-1})
  - Issues: Fast beam loss, Injection efficiency, current dependence of beam position.
- NLC
  - We decided to install NLC during LS1, now in construction.
- Works during LS1
  - We found a vacuum leak at QCS-R
  - Installation the low-z collimator at D06H3
  - Replacement of HER injection chamber.
  - The control system will be updated
  - The optics group investigate beam-beam simulation
- Toward LS2
  - We are revisiting the investigation of IR section.

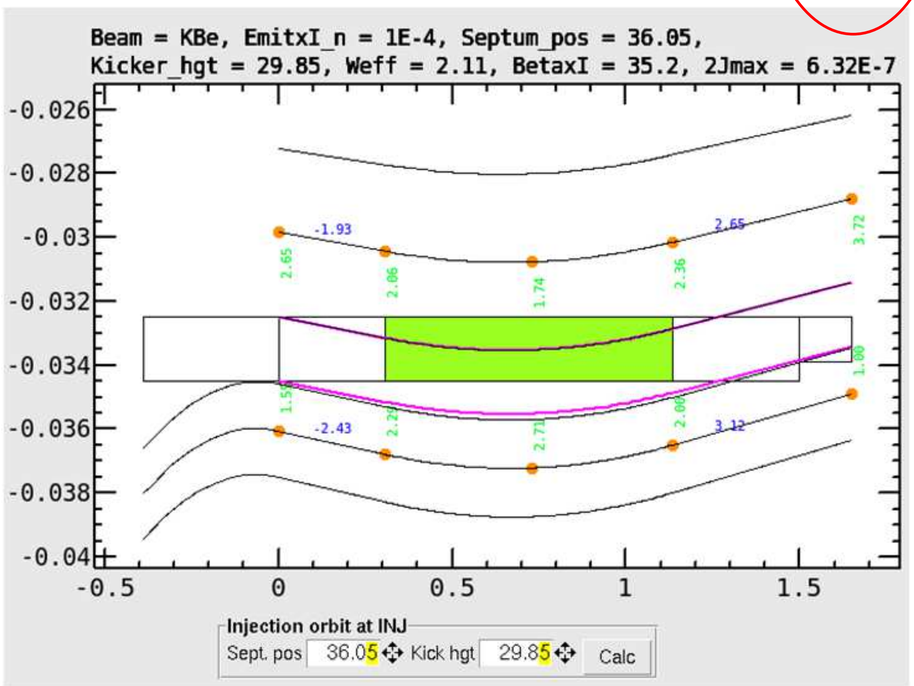
Backup

QI4E用ビームパイプ:隔壁の変更

縦方向に50倍しています。

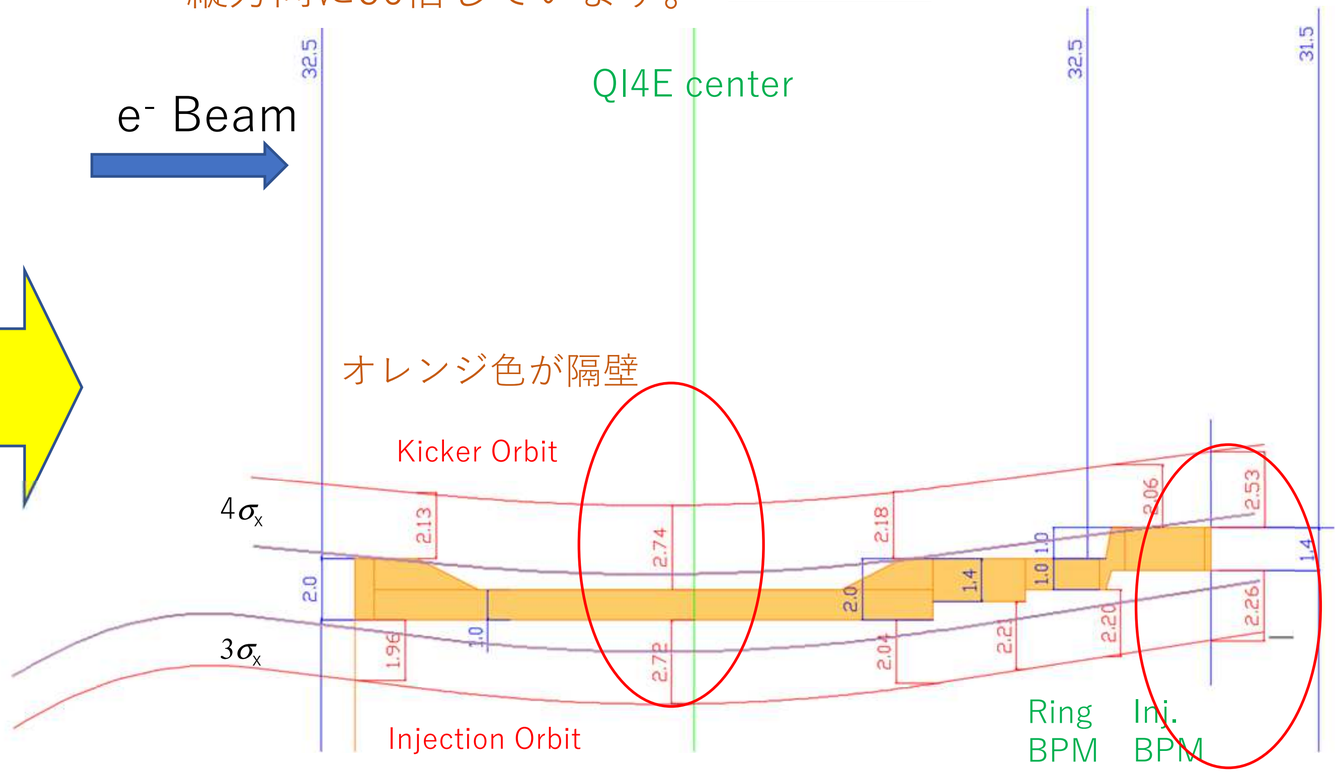
現状





変更案

縦方向に50倍しています。

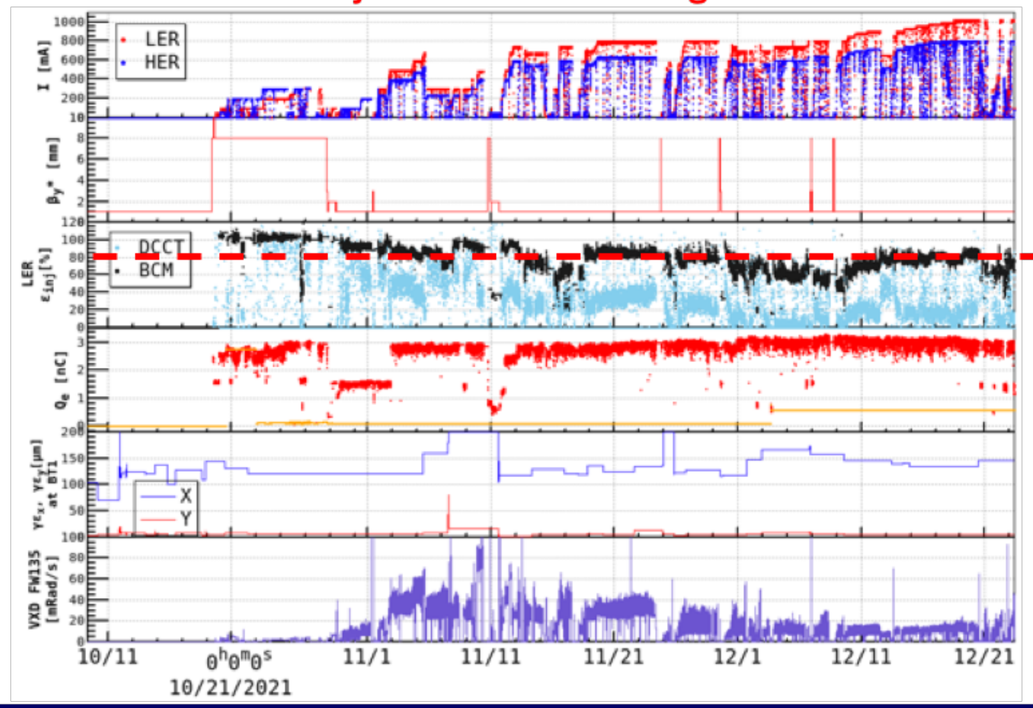


- 方針：蓄積ビーム側と入射ビーム側を隔てている壁(隔壁)を薄くしたり、オフセットしたりして、クリアランスをできるだけ確保する。
- 壁を曲げたりはしない。製作が難しい(精度がでない)。

Aperture enlargement of HER injection channel 1

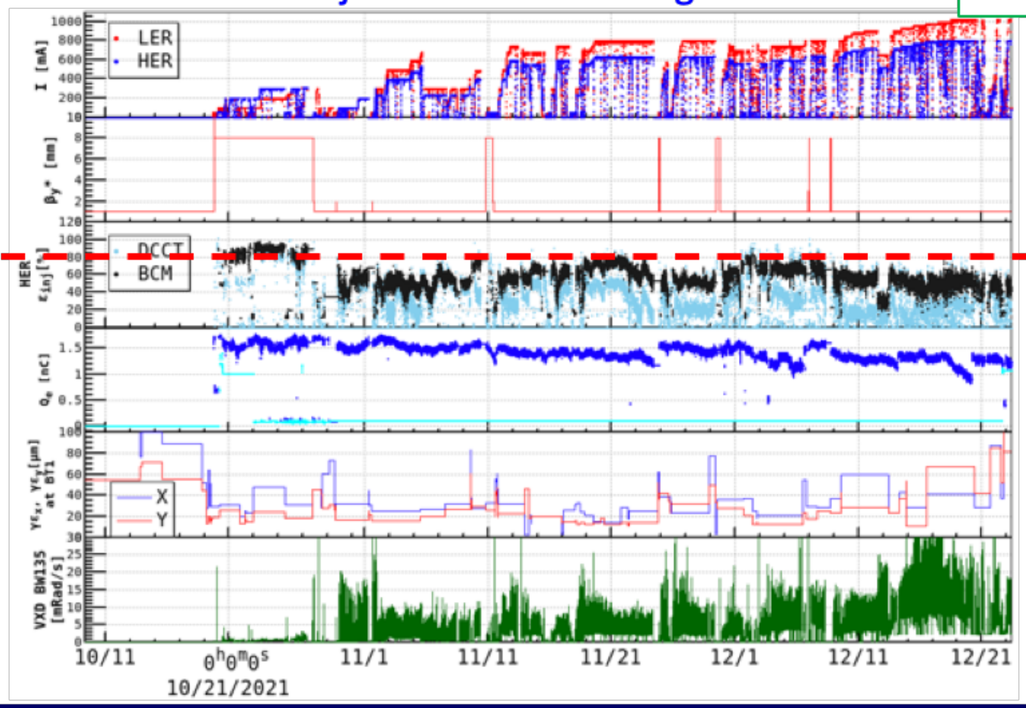
- HER injection efficiency should be improved.
  - Injection of HER beam is unstable.
    - Stable physics run requires stable injection.
    - Low injection efficiency can limit the maximum beam current.
  - Understanding of injection became deeper during 2021c.
    - It was turned out that horizontal aperture of injection channel should be enlarged to improve injection efficiency.
    - To enlarge aperture of injection channel, beam pipes around HER injection point will be replaced new ones during LS1.

LER injection status during 2021c



HER injection status during 2021c

N. Iida (2022.1.21) BITF meeting



Our target is 80%.

K. Shibata