SuperKEKB LS1 upgrade status (including injector)

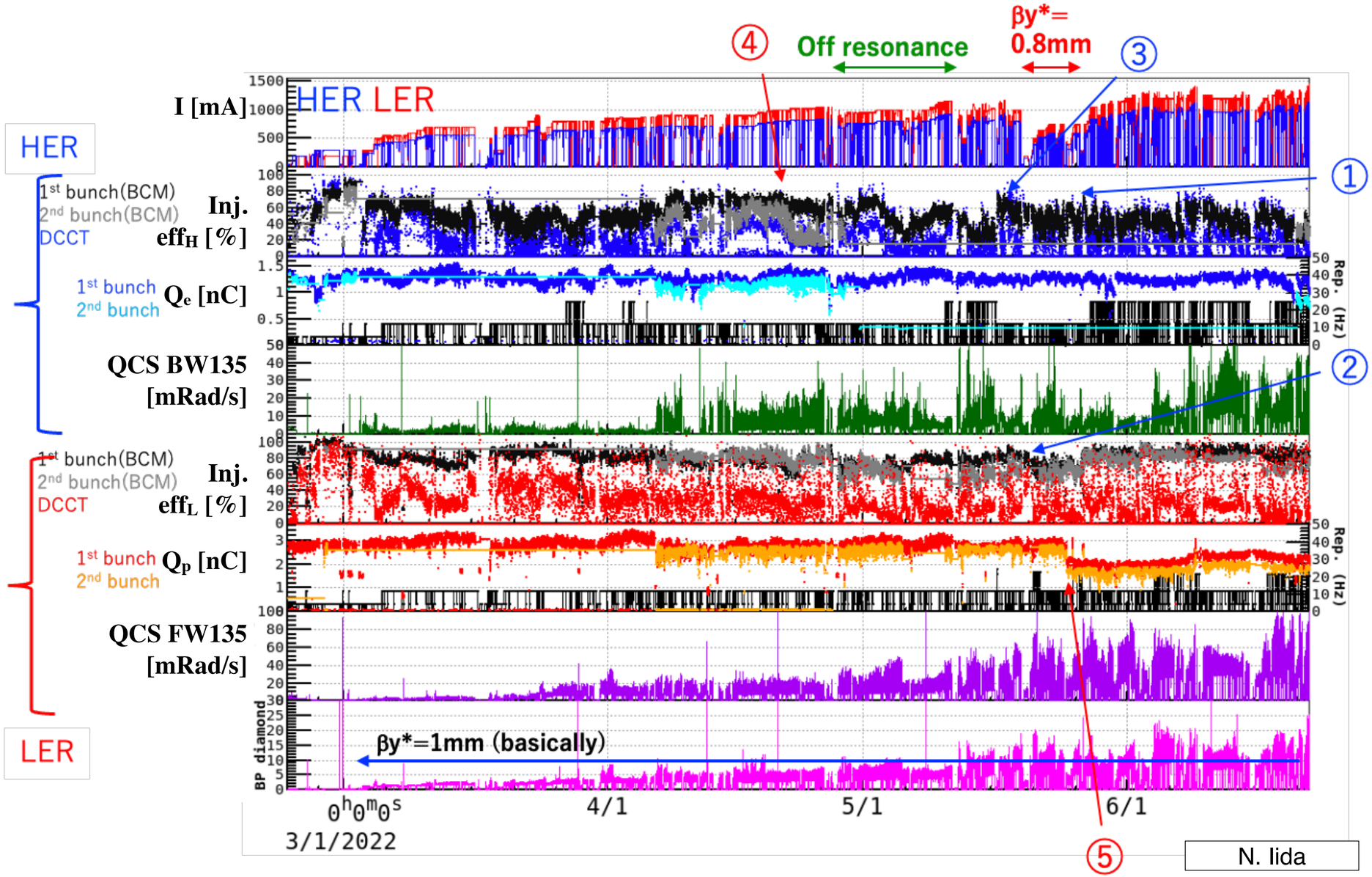
Hiroyasu EGO

KEK Injector Linac division

Contents

- Operation of SuperKEKB in 2022
- Countermeasures for high luminosity in LS1
- Upgrade works
  Main rings / Injector linac
- Summary

Operation of SuperKEKB in 2022



N. Iida

Achievements

Lp = 4.65 x 10^{34} $cm^{-1}s^{-1}$
L = 424 fb^{-1}

Ip = 1.46 A
Ie = 1.14 A

Improvements

① e-: The septa in operation at 25Hz

② e+: Fast strip-line kicker for the 2nd bunch orbit correction

③ HER: Horizontal orbit feedback system

To be improved

④ e-: Give-up of two-bunch injection due to 2nd bunch drift of the vertical orbit

⑤ e+ Decrease in charge due to the BP diamond aborts

Countermeasures for high luminosity in LS1

Planned countermeasures

- Major countermeasures discussed so far.

	Aim	Possible countermeasures
(1)	・Increase injection power (efficiency)	Linac upgrade to designed specification
		Large physical aperture at electron injection point (HER)
		Linac upgrade beyond designed specification
(2)	・Relax beam-beam effect ・Expand dynamic aperture	Utilizing rotatable sextuplole magnets (LER)
		“Perfect matching”
		QCS modification (Option#1): Move QC1RP to the far side of IP
		Larger scale QCS modification (Option #8)
(3)	・Suppress BG ・Expand physical aperture	QCS cryostat front panel modification and additional shield to IP bellows
		Optimization of collimator location
		Enlargemen of QCSR beam pipe (Option#3)
(4)	・Relax TMCI limit	“Non-linear collimator”
(5)	・Improve stability	Robust collimators
		Upgrade of beam abort system and loss monitor system
(6)	・Anti-aging measures	Preparation of standby machines and spares, repair of facilities, etc.

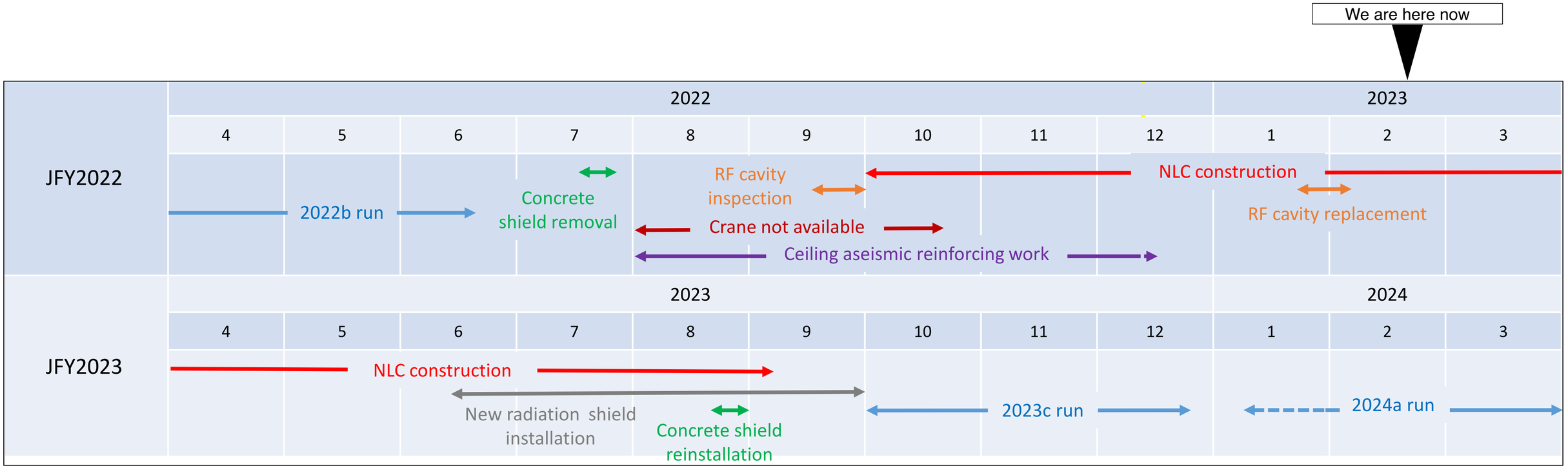
2021/9/2 7

Y. Suetsugu (2021.09.02)
The 25th KEKB Accelerator Review Committee

K. Shibata
The 26th KEKB Accelerator Review Committee

- During LS1
- Done before LS1
- Under consideration (It was found that it is not easy.)
- Under consideration
- During LS1
- Done before LS1
- Under consideration
- During LS1
- During LS1 (Partially)
- During LS1 (Partially)
- During LS1 (Partially)

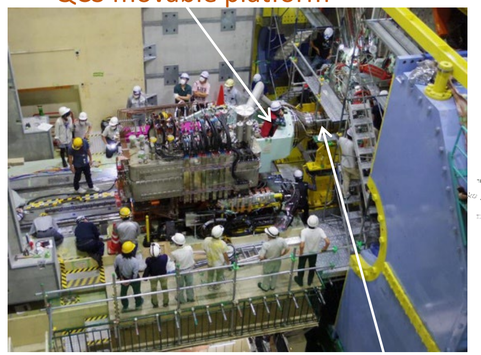
LS1 works of the main rings : Schedule

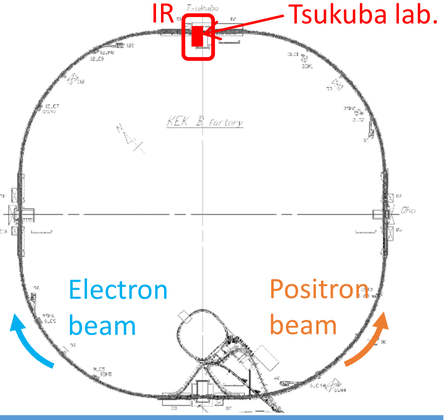


K. Shibata
The 26th KEKB Accelerator Review Committee

LS1 works of the main rings : IR

- Major work items in accelerator tunnel:
  - Disassembly and reinstallation of concrete radiation shields
  - Belle II maintenance & reinforcement work
  - Disassembly and reinstallation of magnets, beam pipes for QCS work
  - QCS extraction & reinstallation
  - QCSR cryostat leak test
  - QCS cryostat modification





IR (Tsukuba straight section)

JFY2022

2022									2023		
4	5	6	7	8	9	10	11	12	1	2	3

2022b run; Concrete shield disassembly; Belle II work; QCS extraction; QCSR cryostat leak test; We are here now; QCS cryostat modification; Belle II maintenance & reinforcement

JFY2023

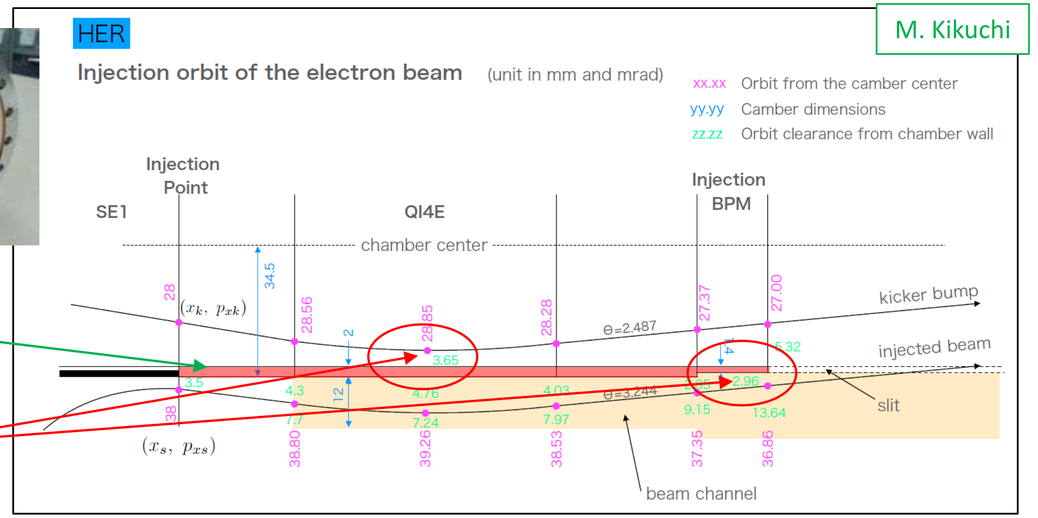
2023									2024		
4	5	6	7	8	9	10	11	12	1	2	3

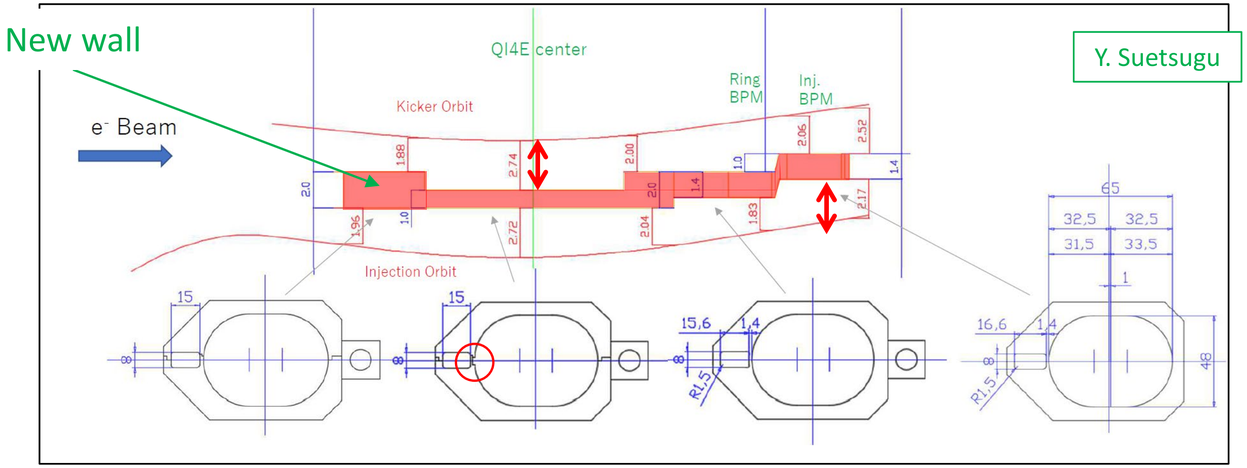
QCS reinstallation; Concrete shield reinstallation; Magnet & beam pipe disassembly; Belle II maintenance & reinforcement; Belle II work; 2023c run; 2024a run

K. Shibata
The 26th KEKB Accelerator Review Committee

LS1 works of the main rings : HER injection point

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



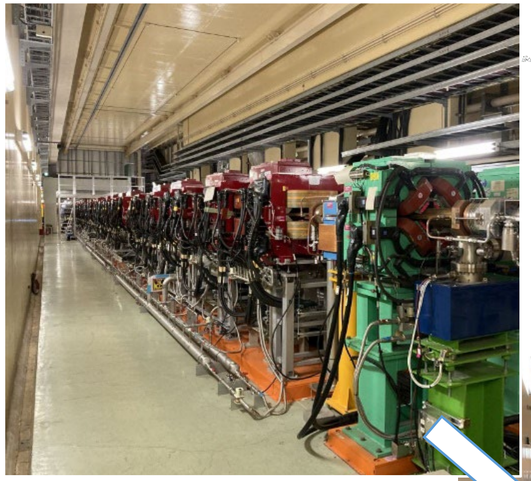


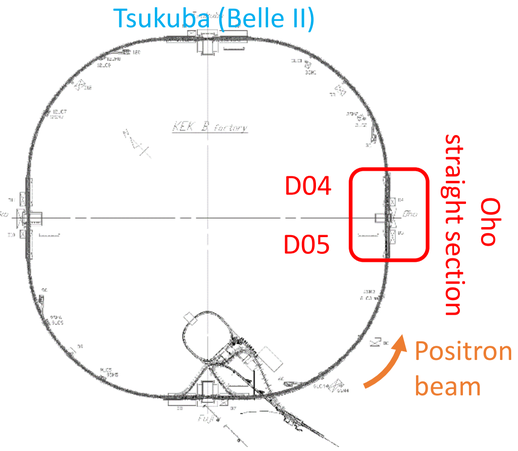
K. Shibata
The 26th KEKB Accelerator Review Committee

LS1 works of the main rings : NLC

- Wiggler magnets and beam pipe removal (already done)
  - Removed wiggler magnet and cable : 50 magnets and their cables
    - Double pole magnet (3 ton) : 20
    - Single pole magnet (2 ton) : 10
    - Half pole magnet (1.5 ton) : 20
    - Cables : 3 ton
  - Removed beam pipe for wiggler magnet : 10 beam pipes
  - Disassembly procedure
    - Removal of wiggler magnet cables
    - Upper parts of wiggler magnets disassembly
    - Beam pipes removal
    - Upper parts of wiggler magnets reassembly
    - Wiggler magnets removal

10 times



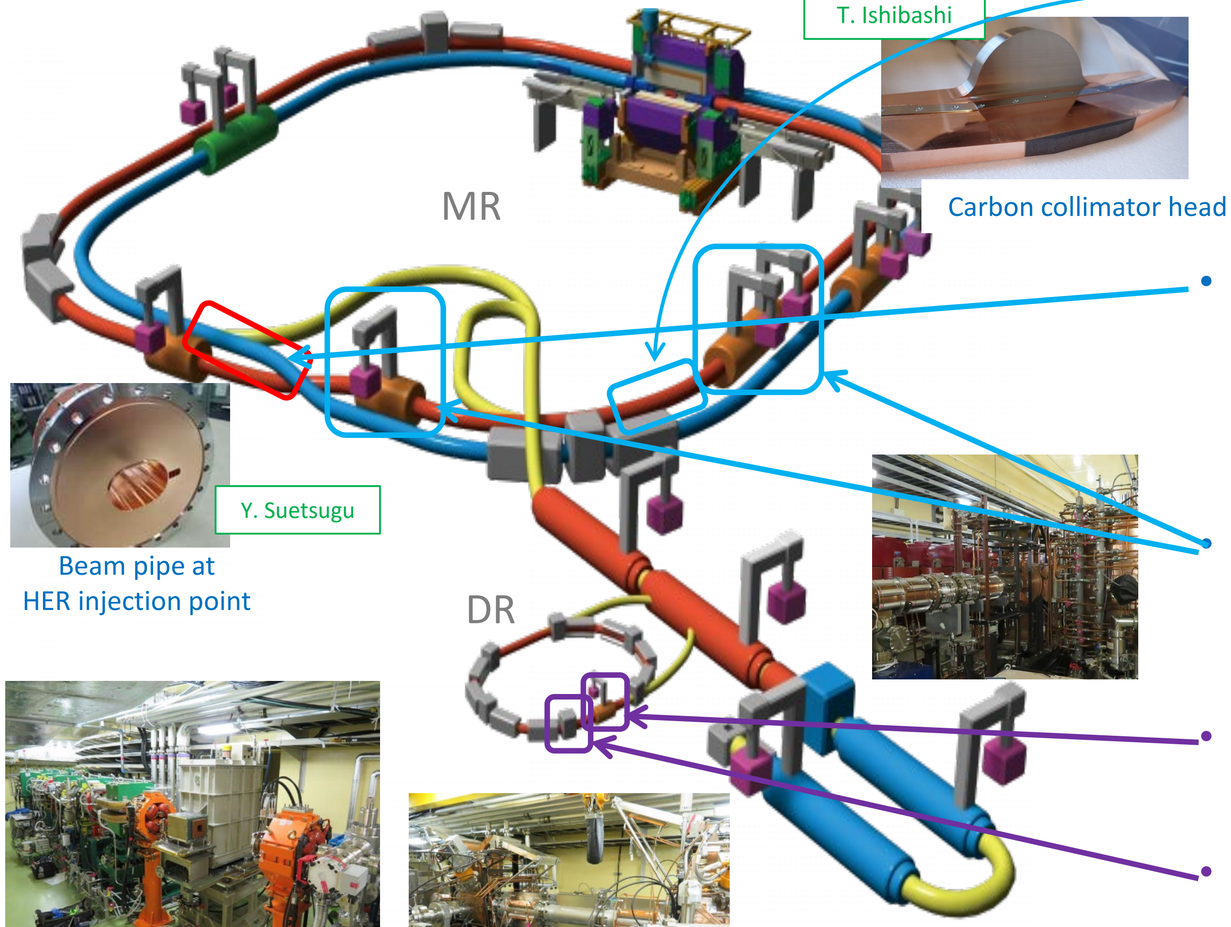


S. Nakamura

Wiggler beam pipe removal work

K. Shibata
The 26th KEKB Accelerator Review Committee

LS1 works of the main rings : Others



T. Ishibashi

Carbon collimator head

Y. Suetsugu

Beam pipe at
HER injection point

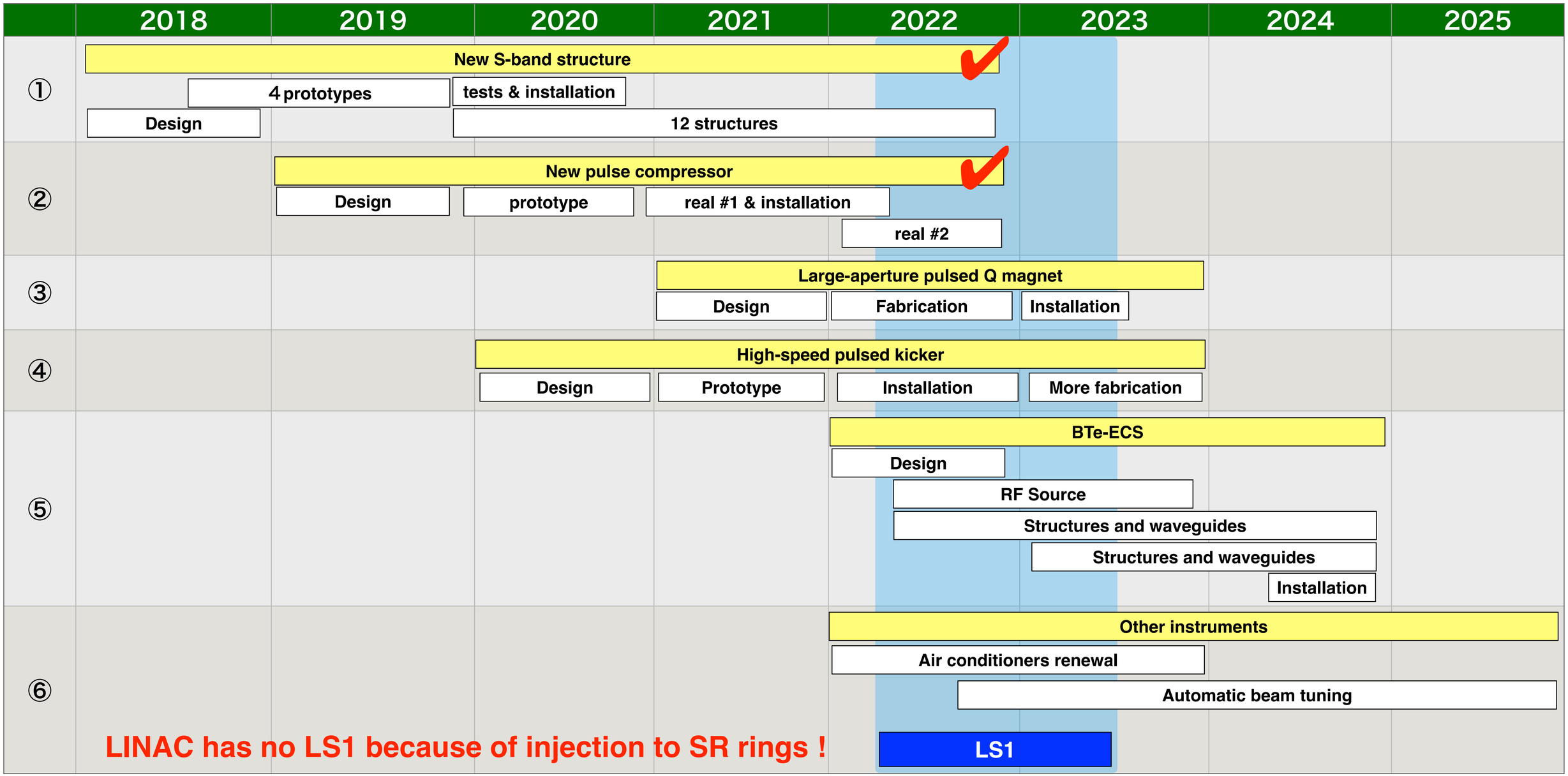
DR Ext. kicker

DR RF section

- [Robust collimator head (LER)]
  - As countermeasure against kicker-pulser misfiring and resulting destruction of collimator
    - Replacement with carbon head of horizontal collimator D06H3 and relocation from D06H1 to D06H4
    - Carbon head production : ~ March 2023
    - Head replacement : Spring ~ Summer 2023
    - Collimator relocation : Spring ~ Summer 2023
- [New beam pipes with wider aperture at HER injection point]
  - For injection efficiency improvement
    - New beam pipes with wider aperture & New BPM for precise measurement of injected beam
    - Beam pipe production : ~ March 2023
    - Beam pipe replacement : Spring ~ Summer 2023
    - Septum baking : ~ Summer 2023?
- [RF cavity modification and replacement (LER)]
  - For stable operation with larger beam current
    - Modification : Input coupler replacement, cooling power enhancement, coaxial line modification, etc. (done)
    - Cavity replacement (D05A) : January ~ February 2023
- [Vacuum seal replacement at RF section (DR)]
  - For pressure reduction
    - Replacement from elastomer gasket to metal gasket for dummy pipes (done)
- [DR Extraction kicker power supply modification and repair (DR)]
  - For stable operation
    - Modification : December 2022 ~ August 2023
- [And so on…]

K. Shibata
The 26th KEKB Accelerator Review Committee

LINAC upgrades : Schedule



LINAC has no LS1 because of injection to SR rings !

LINAC upgrades : Difficulty in stabilizing beam condition

Best tuning condition is destroyed gradually in a day

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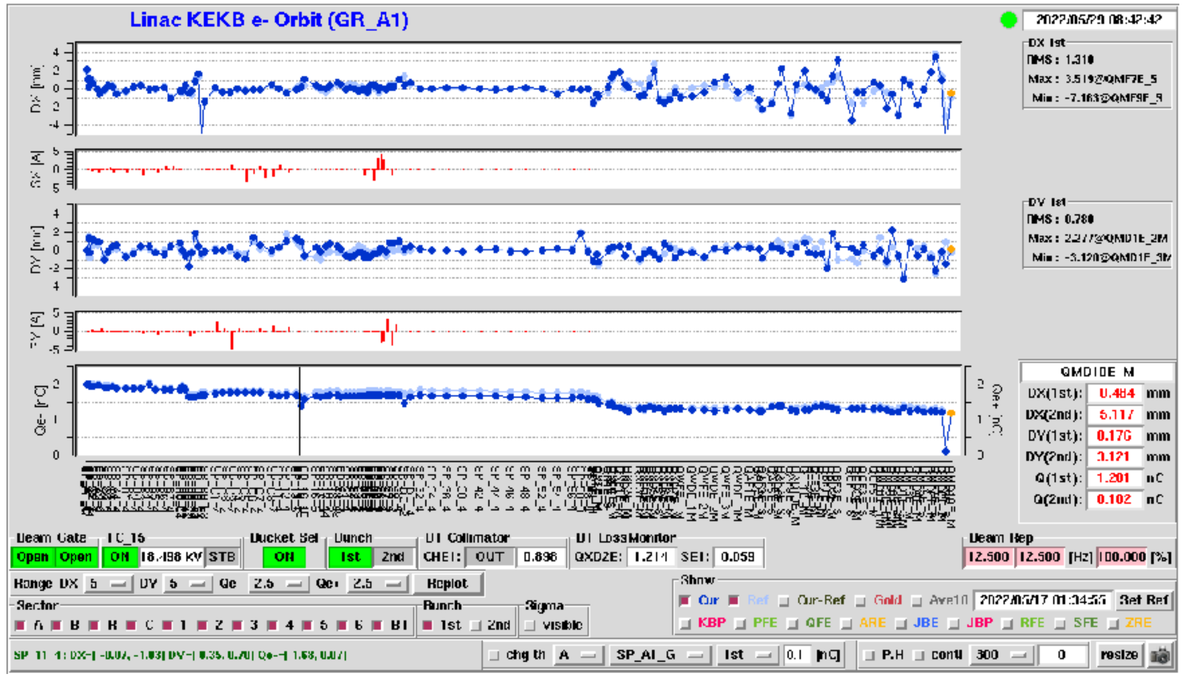

Beam orbit and emittance of e- tuned fine in the morning

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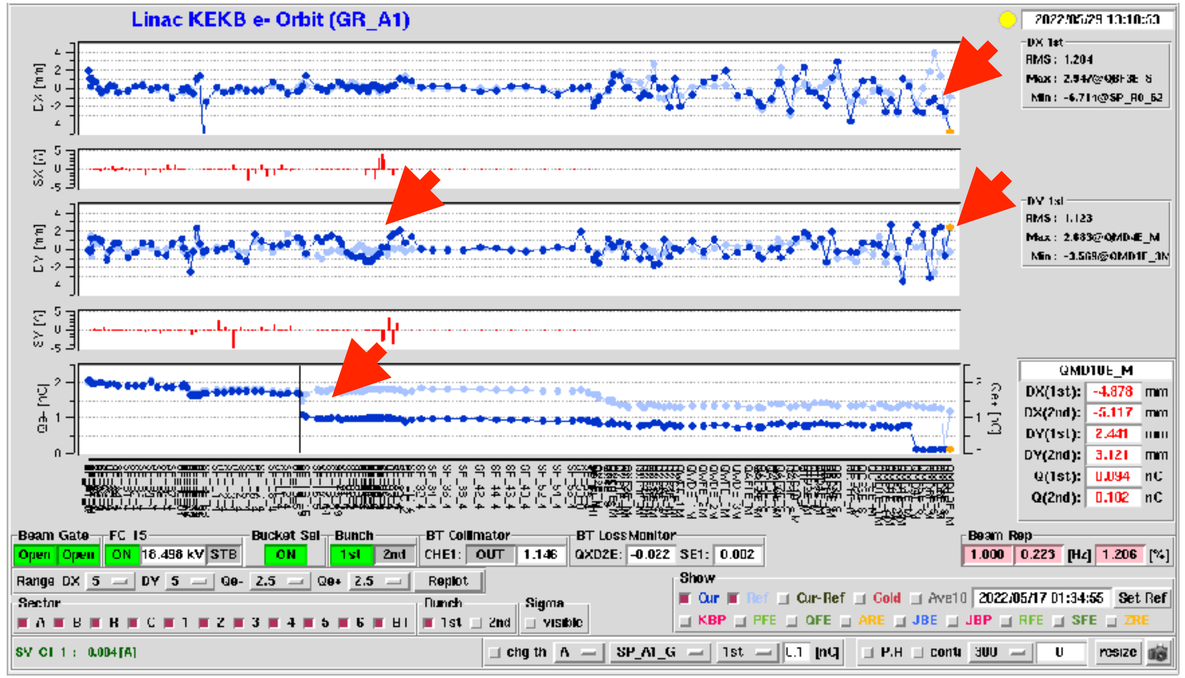
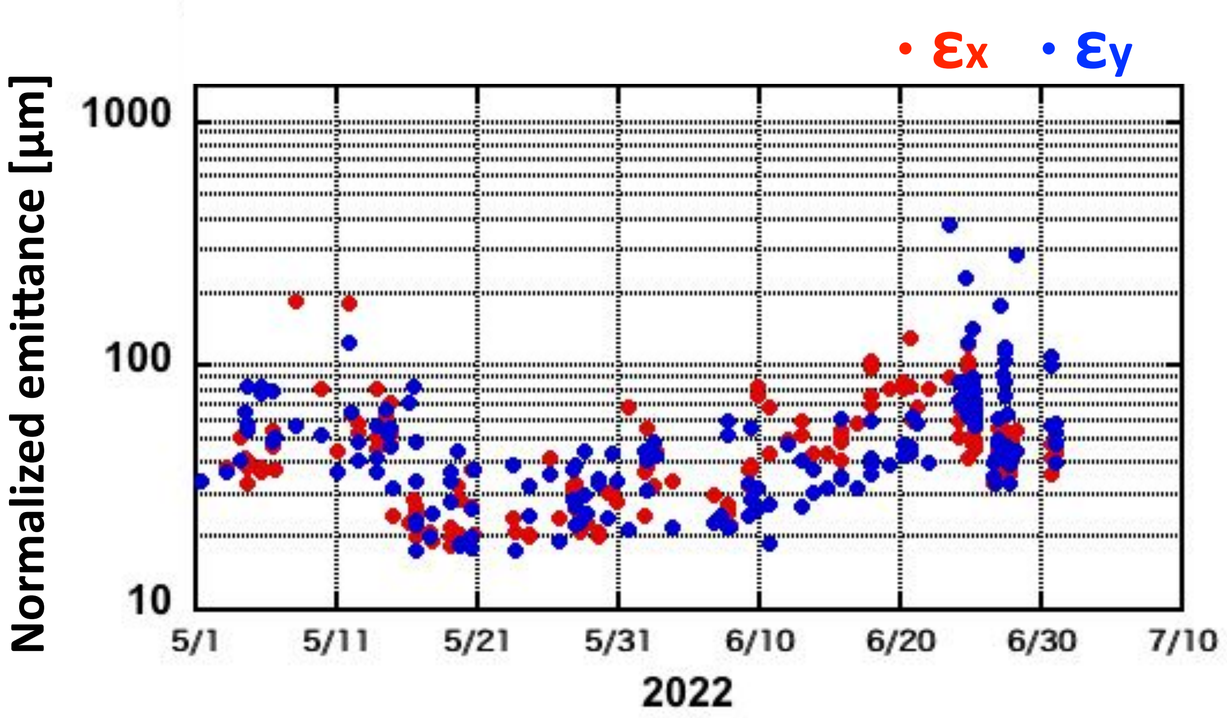


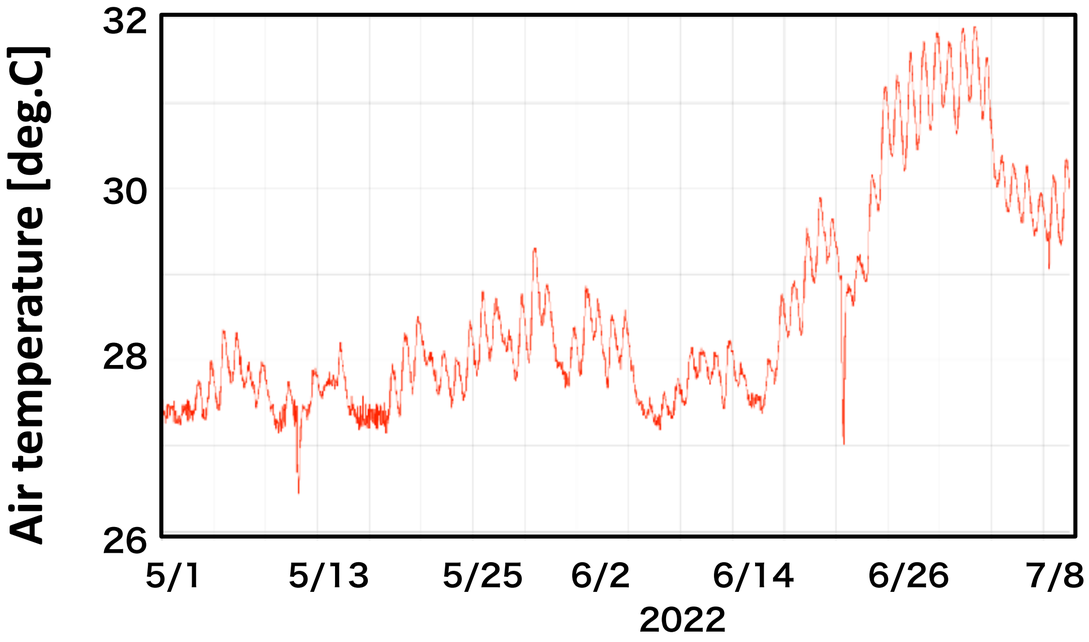
Beam orbit unstable and emittance worse charge lost in the afternoon

Upgrade works : Difficulty in stabilizing beam condition

Best tuning condition destroyed by change in air temperature arising from seasonal and daily conditions

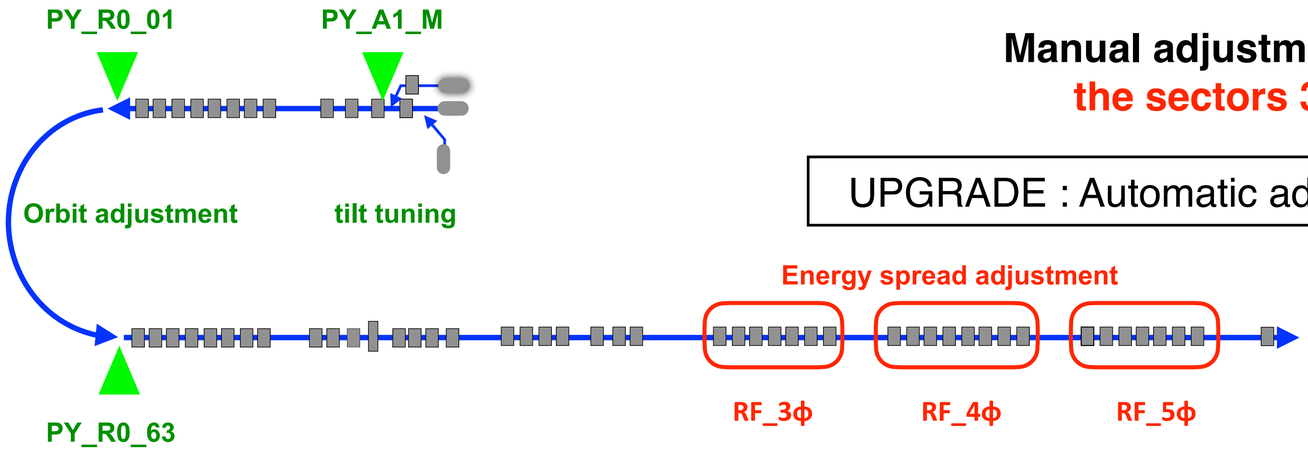
UPGRADE : Renewal of air conditioners for the klystron gallery and linac tunnel（2022 - 2023）





Y. Shimosaki

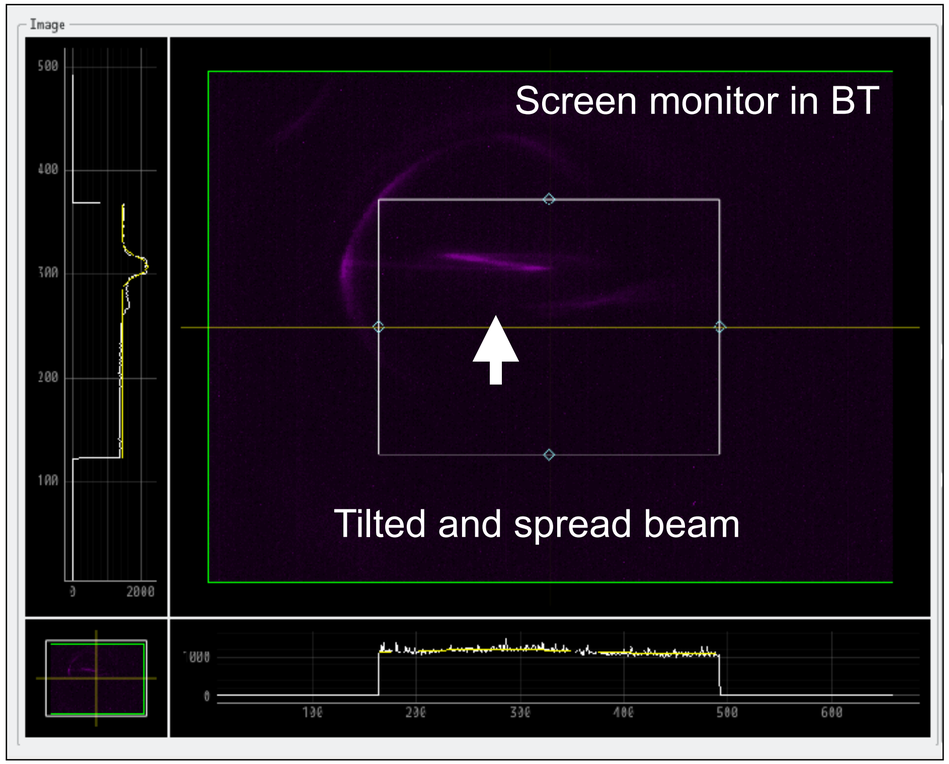
LINAC upgrades : Beam tuning

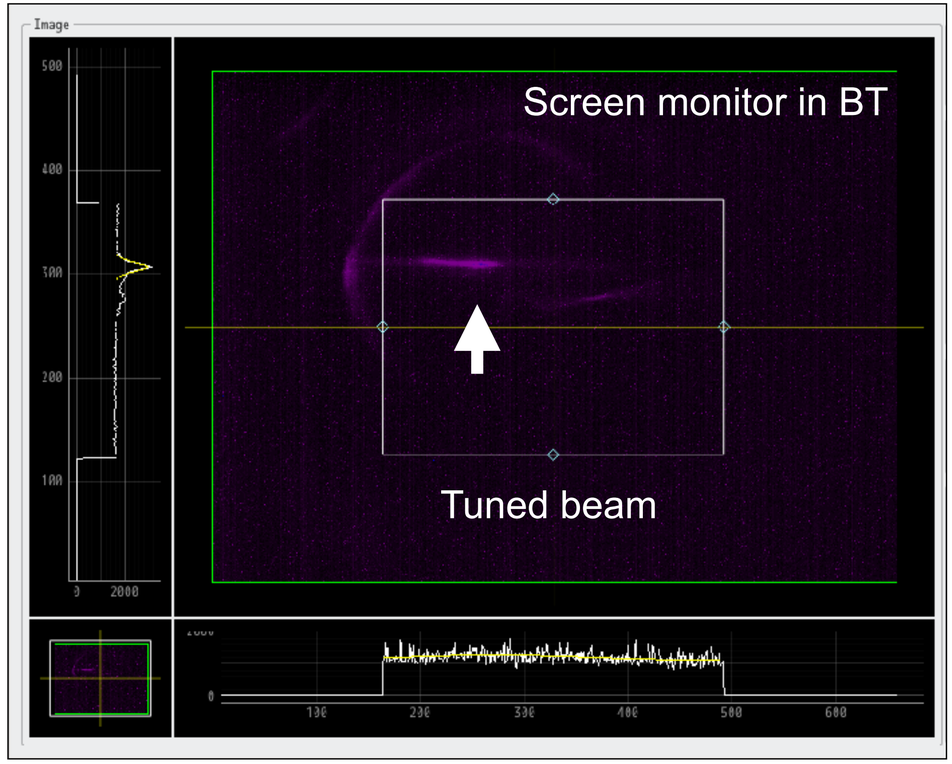


Manual adjustment of magnets upstream and accelerating phase of the sectors 3 to 5 by using beam-destructive profile monitor

UPGRADE : Automatic adjustment by using none-destructive monitor (2022-2025)

Improved injection efficiency

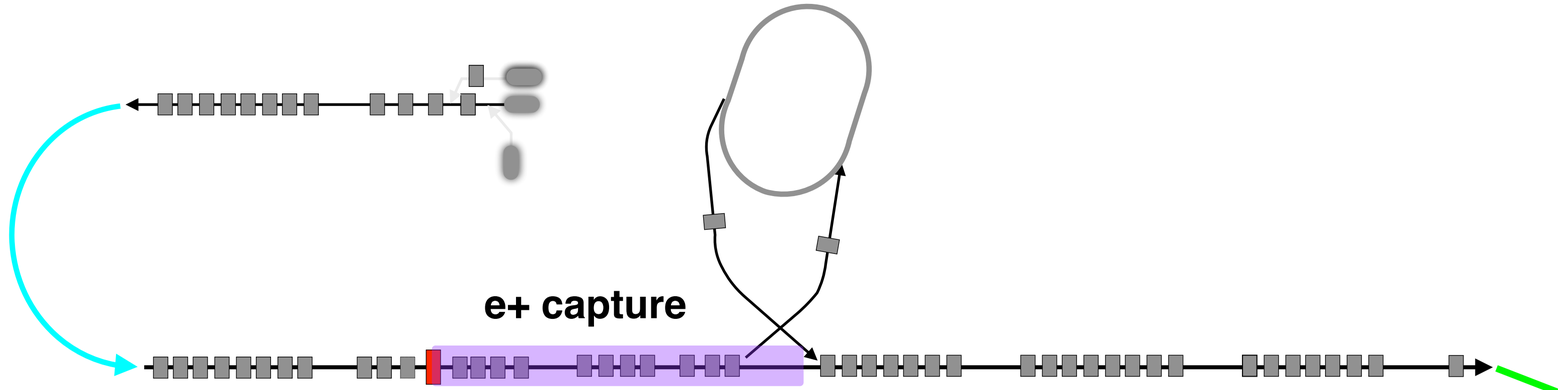




LINAC Upgrades : Beam-degrading areas

J-arc

Inflexible optics for matching of e- beams



e+ capture

Suitable focus for e+ beam but weak focus for e- beam

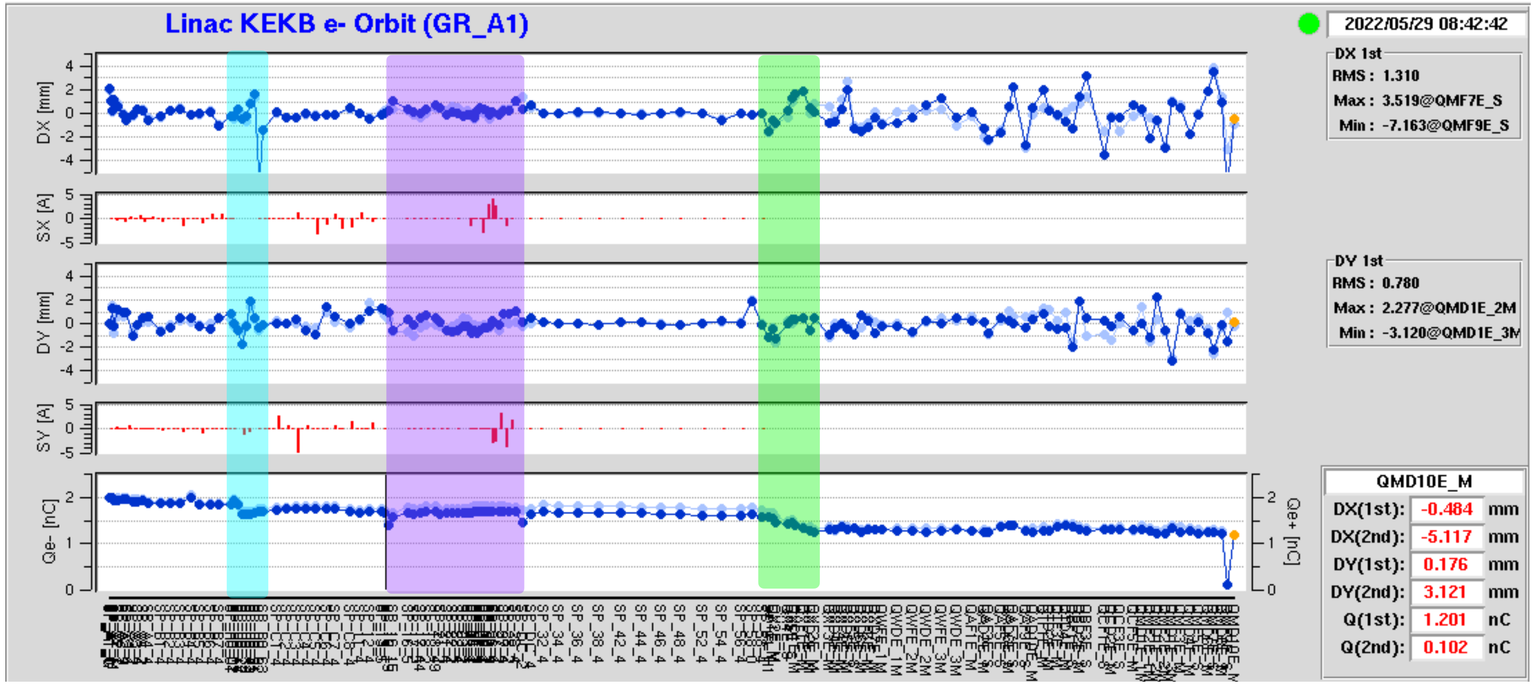
BT

Unstable beam in BT by bare longitudinal emittance, self-induced SR and so on

Horizontal orbit

Vertical orbit

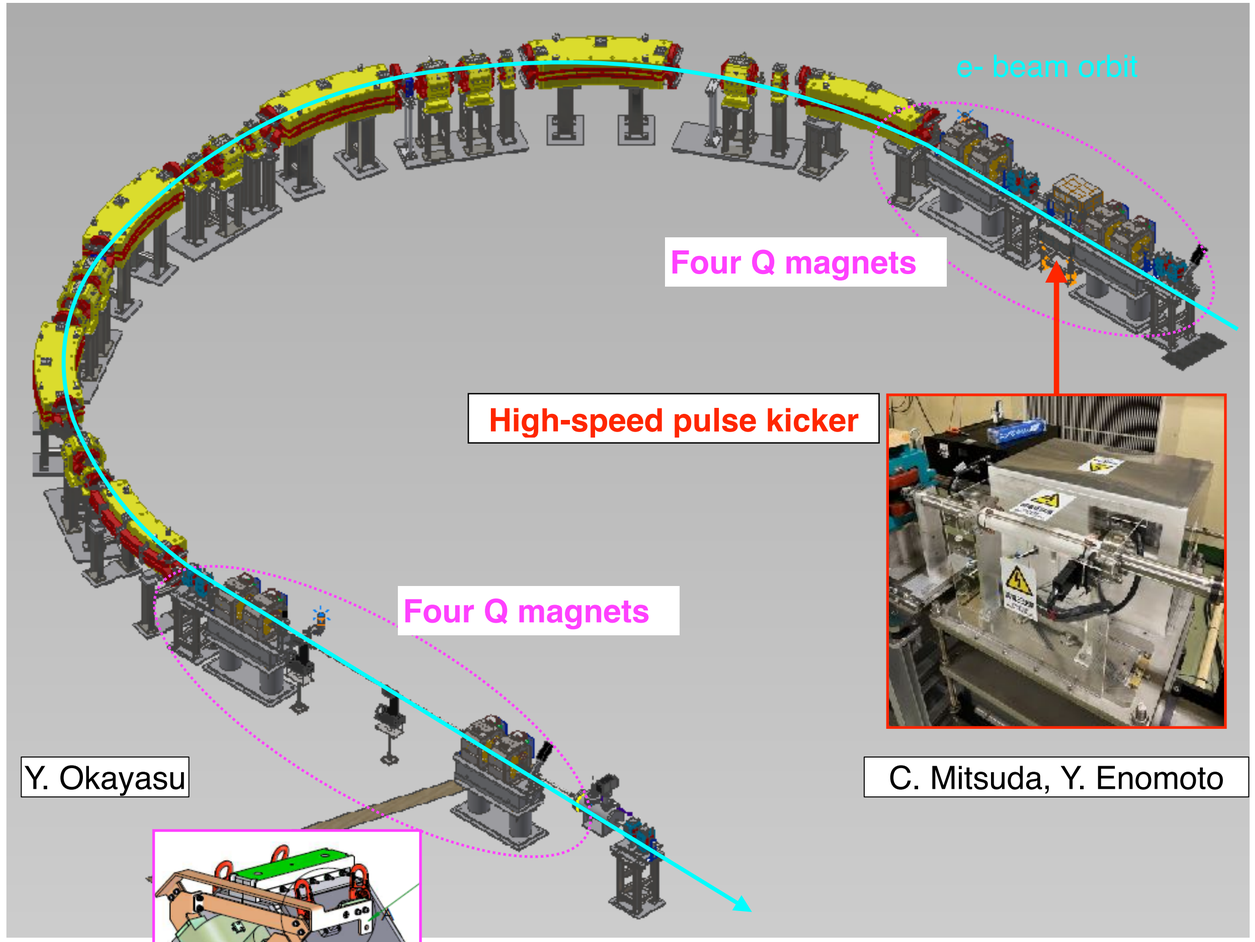
Charge



Beam position in LINAC and BT to HER

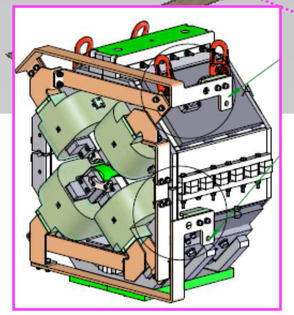
LINAC upgrades : Beam optics 1

Large-aperture pulsed Q magnet & High-speed pulse kicker



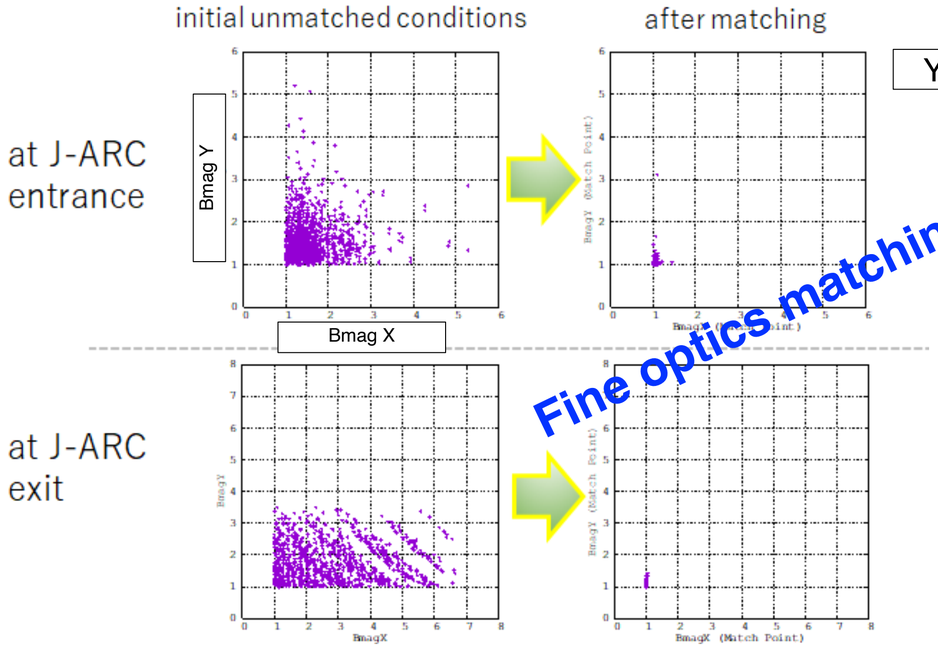
Y. Okayasu

C. Mitsuda, Y. Enomoto



K. Yokoyama, T. Natsui

Large-aperture pulse Q-magnet

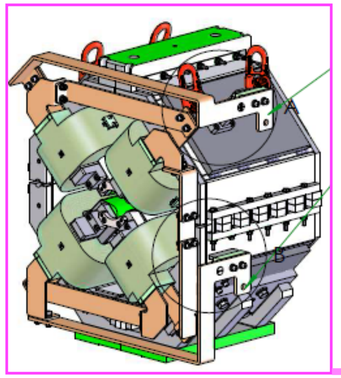


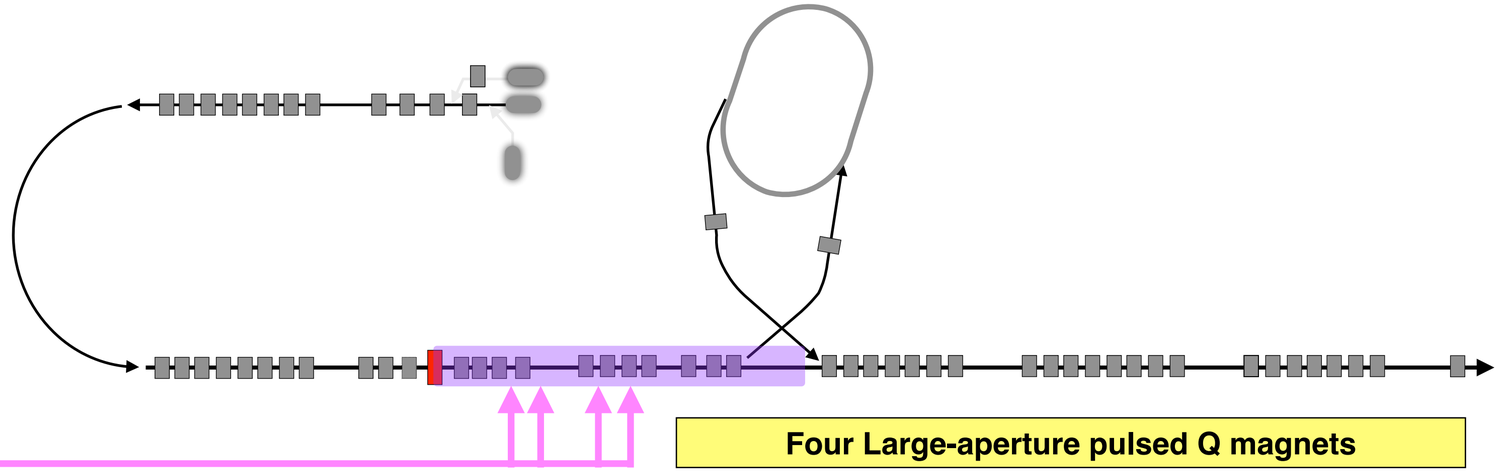
Y. Seimiya

Matching simulation

- At the entrance and exit of 180 deg. J-ARC region, a good optics matching is very important to mitigate beam loss and emittance growth.
- Simultaneous matching for both of HER and LER injection beams requires the pulsed Q magnets.
- From the simulation results, four pulsed Q magnets at both of entrance and exit of J-ARC are sufficient for the matching.
- Pulsed kicker with a speed of about 100 ns has been demonstrated to control the vertical orbit of 2nd bunch independently.

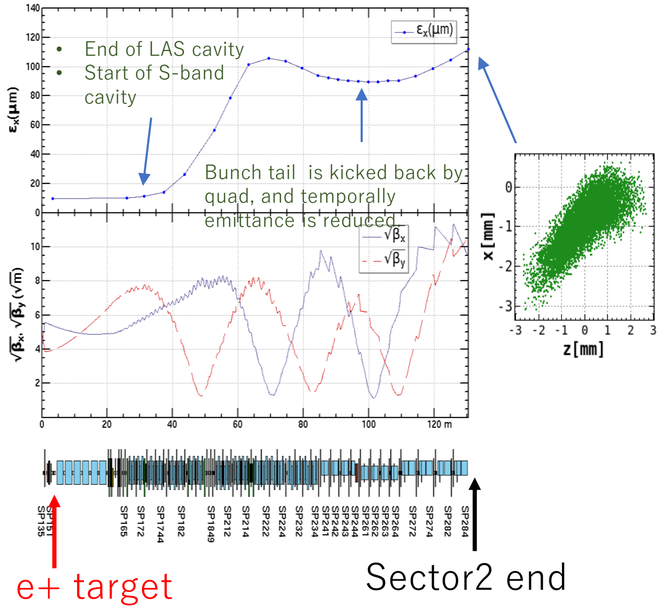
Linac upgrades : Beam optics 2





Current optics

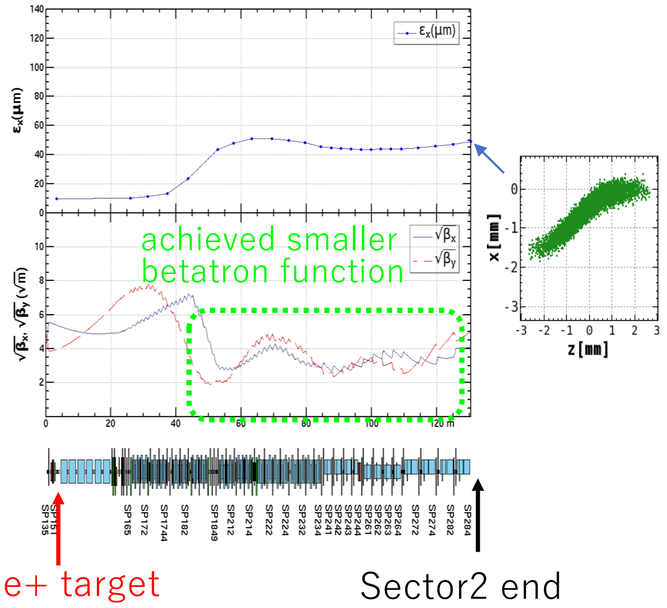
$\Delta\gamma\varepsilon x \sim 100$ um, $\overline{\beta x} = 45.2$ m



- Large emittance e+ beam is accelerated from 0.1 GeV to 1.1 GeV for DR injection.
- Operation of DC Q -magnets is optimized for e+ beam.
- For e- beam (3 to 4 GeV), the focusing force is so weak as to cause its emittance growth.

New optics

$\Delta\gamma\varepsilon x \sim 40$ um, $\overline{\beta x} = 16.3$ m



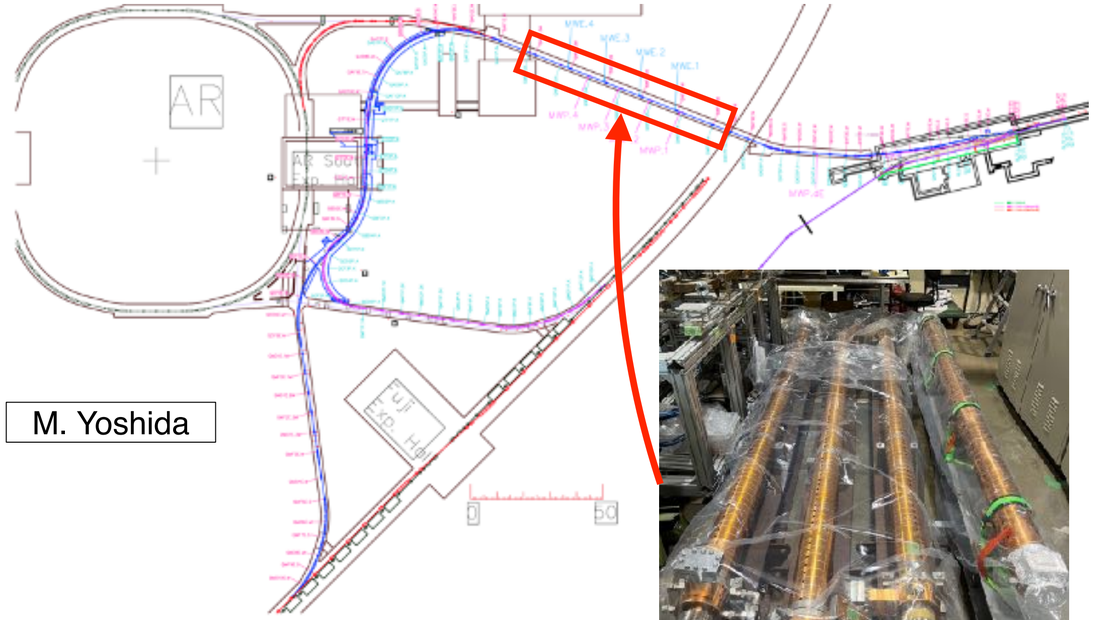
- The four pulsed Q magnets can optimize both the e- and e+ beams, the betatron functions can be decreased.
- Simulations shows that they can help to decrease the emittance growth to less than half.

Linac upgrades : Injection efficiency

BTe-ECS (Energy Compression System)

ECS reduces the longitudinal emittance of electron beams for HER

Installation plan in BTe



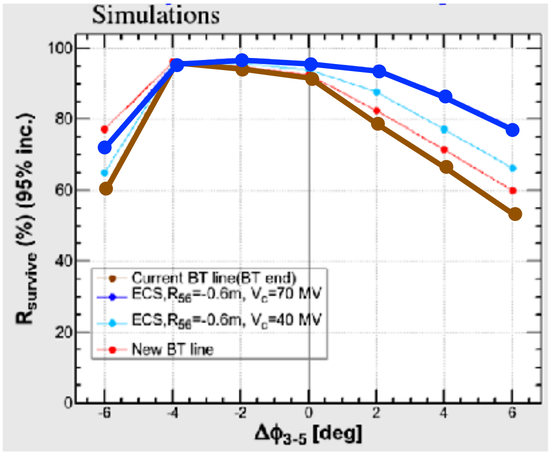
M. Yoshida

S-band 3m-long TW structures

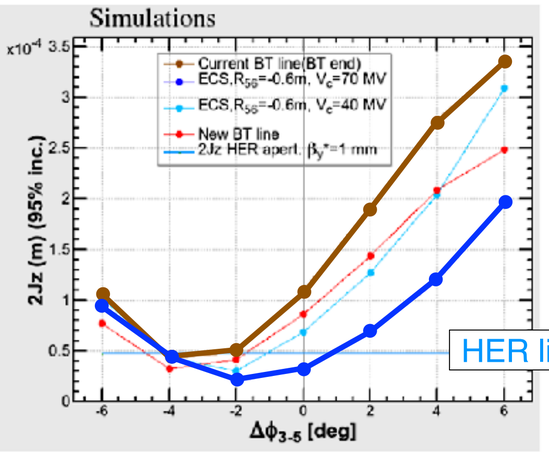
Simulations for best operating parameters

by the beam-analysis group

Injection efficiency



2Jz of injection beam



N. Iida, T. Yoshimoto

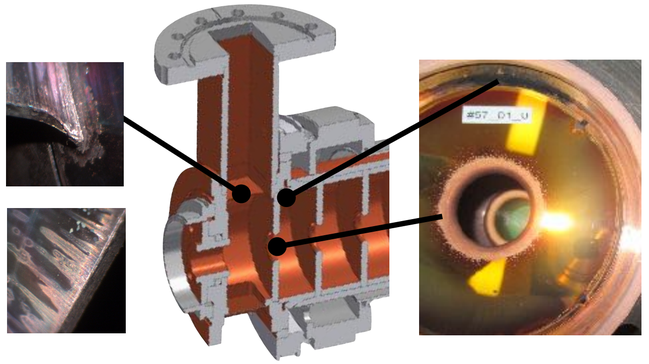
- **Design of the components have finished.**
- **High-power RF sources are under construction.**
- **Component layout are in the process of design.**
- **3m-long TW accelerating structures ready for high-power conditioning**

Results:

- **Longitudinal emittance, 2Jz, becomes small by ECS.**
- **Even with R_{56} = - 0.6 m Vc = 70 MV, 2Jz can be lower than the energy acceptance of HER.**
- **Investigation with a parameter of R_{56} = -1.0 m will be done soon.**

Linac upgrades : Accelerating structures

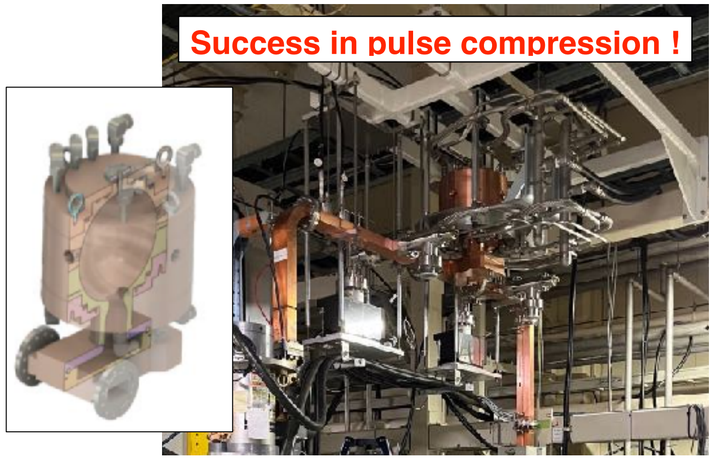
New S-band structure



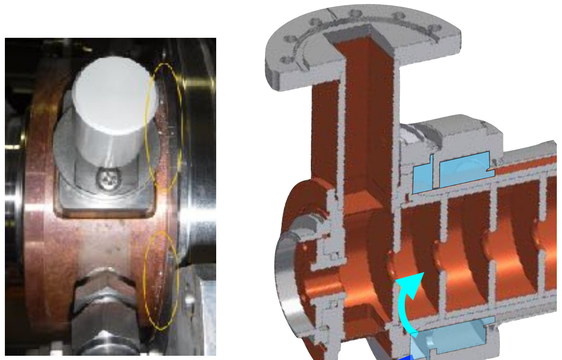
Discharged damages

New S-band 2m-long TW accelerating structure

New pulse compressor



Super-compact pulse compressor



Water leakages

- **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 Y(6S) but even Y(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 was replaced in this summer)
  - New acc. structure: acc. **gain up 7%**, **surface field down 20%** (reduce breakdown)
  - **Suppression of instabilities** arising from long-range wakefields
  - **New pulse compressor (SCPC)** was also developed and installed in Unit44.

H. Ego

Summary

- **Achievements; Ie = 1.14 A, Ip = 1.46 A, Lp = 4.65 x 10^{34} $cm^{-1}s^{-1}$ and recorded int. L = 424 fb^{-1}**
- **Fatal shortage of operation time due to incredible increase in electricity costs**

- **Main ring upgrades in LS1**
  - **IR works**
  - **Non Linear Collimator (NLC) installation**
  - **Beam pipe replacement at the injection point of HER for large physical aperture**
  - **Etc**

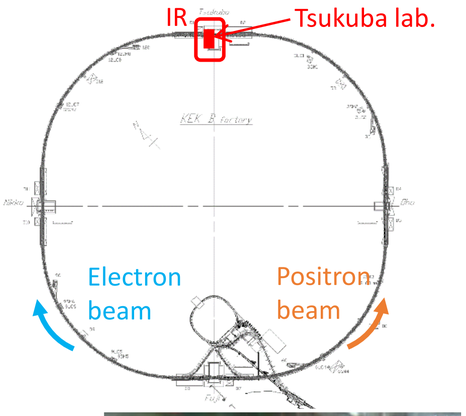
- **LINAC Upgrades**
  - **No LS1 because of beam injection for not only SuperKEKB but also the SR rings**
  - **Beam optics improvements by installing new large-aperture pulsed Quads at J-arc and positron capture section**
  - **Fast kicker for 2nd bunch orbit correction**
  - **New accelerating structures against deterioration over time**
  - **Replacement of air conditioners**
  - **ECS in the electron BT**

- **Severe difficulties in procurement for electric devices, materials and so on**

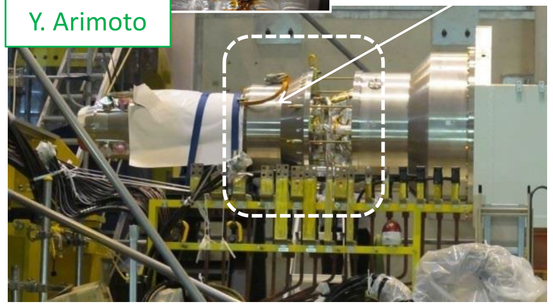
Appendix

IR (Tsukuba straight section) #4

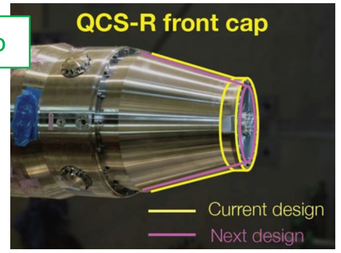
- Future works
  - QCS cryostat modification
    - To reduce Belle II background noise, the material at the tip of QCS cryostat will be changed from W to SUS.
      - QCSR front cap replacement
      - QCSL front plate replacement
    - To make more space for Belle II cables, the tip of QCSR cryostat will be thinner.
      - QCSR cryostat modification including front cap replacement
    - QCS cryostats will be disassembled for these works.
      - It is necessary to shift QCS beam pipes in longitudinal direction.

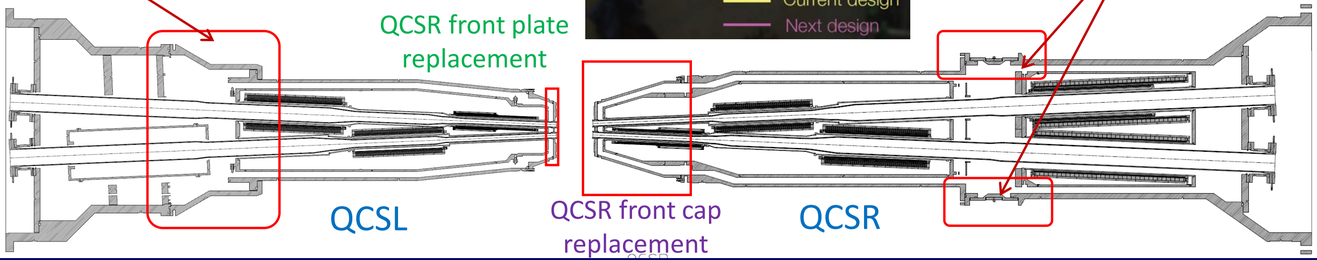


Y. Arimoto



Y. Arimoto



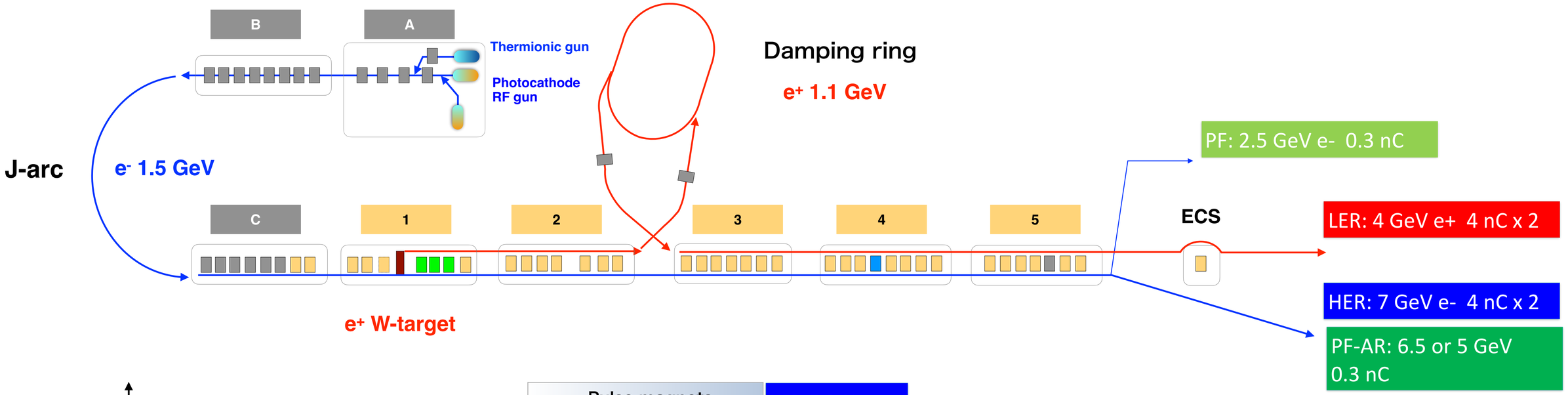


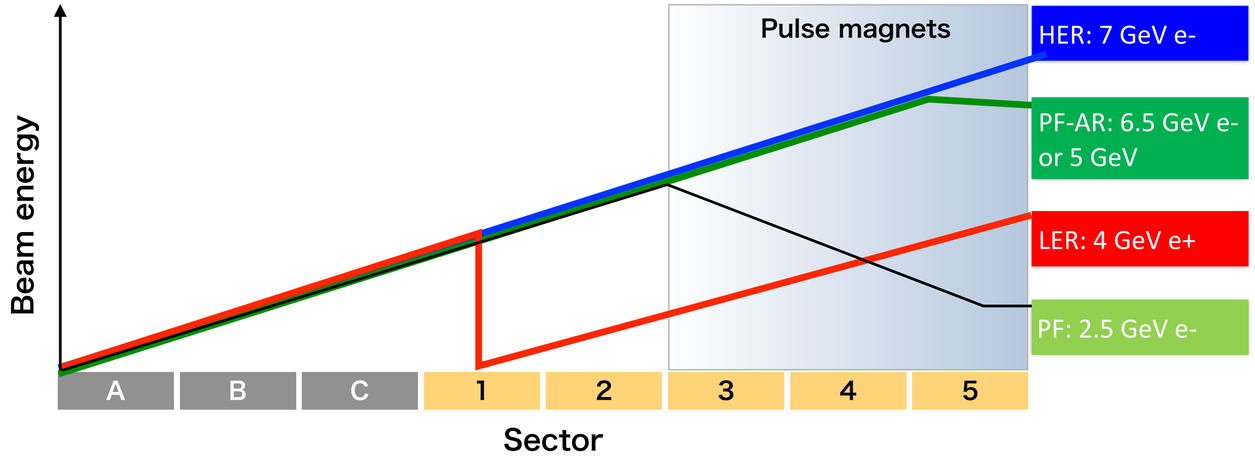
T. Oki

LINAC status : S-band Linac Layout & Energy Scheme

Simultaneous top-up beam Injector for four storage rings

60 klystron-units and 226 accelerating structures





- **Two electron sources:**

  RF gun: HER injection
  Thermionic DC gun: LER, PF, PF-AR

- **Sector 3-5: All magnets are pulsed magnets.**

  Continuous orbit feedback

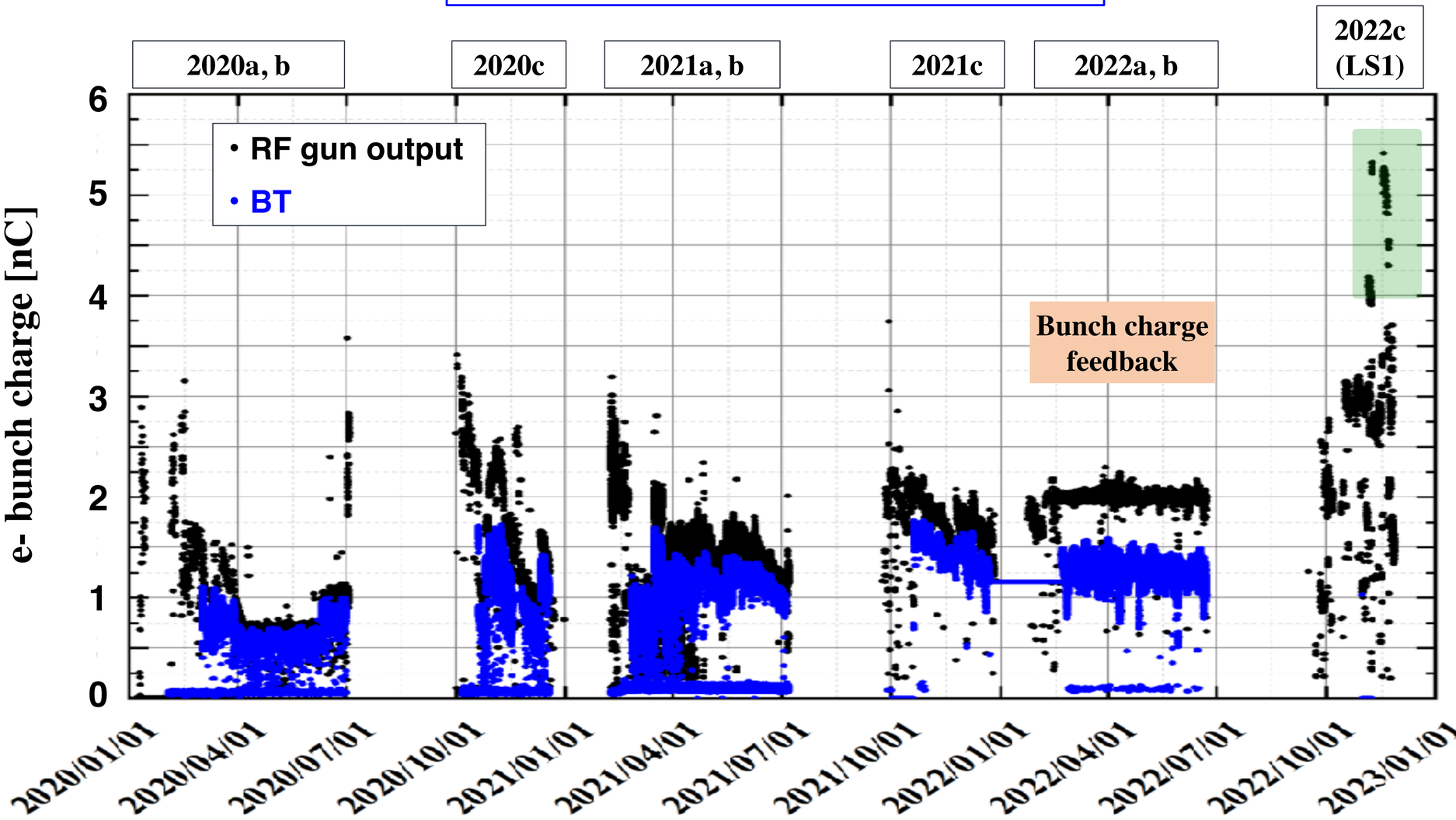
- **DC magnet settings are same for different beam mode**

LINAC status : Electron Charge History 2020a to 2022c for HER

e- emittance

Measured εnx,ny (2 nC) : 20/20 μm (at BT1)

Goal : εnx,ny (4 nC) : 40/20 (H/V) μm



High bunch charge study

test beam reached to the design charge of 4 nC !

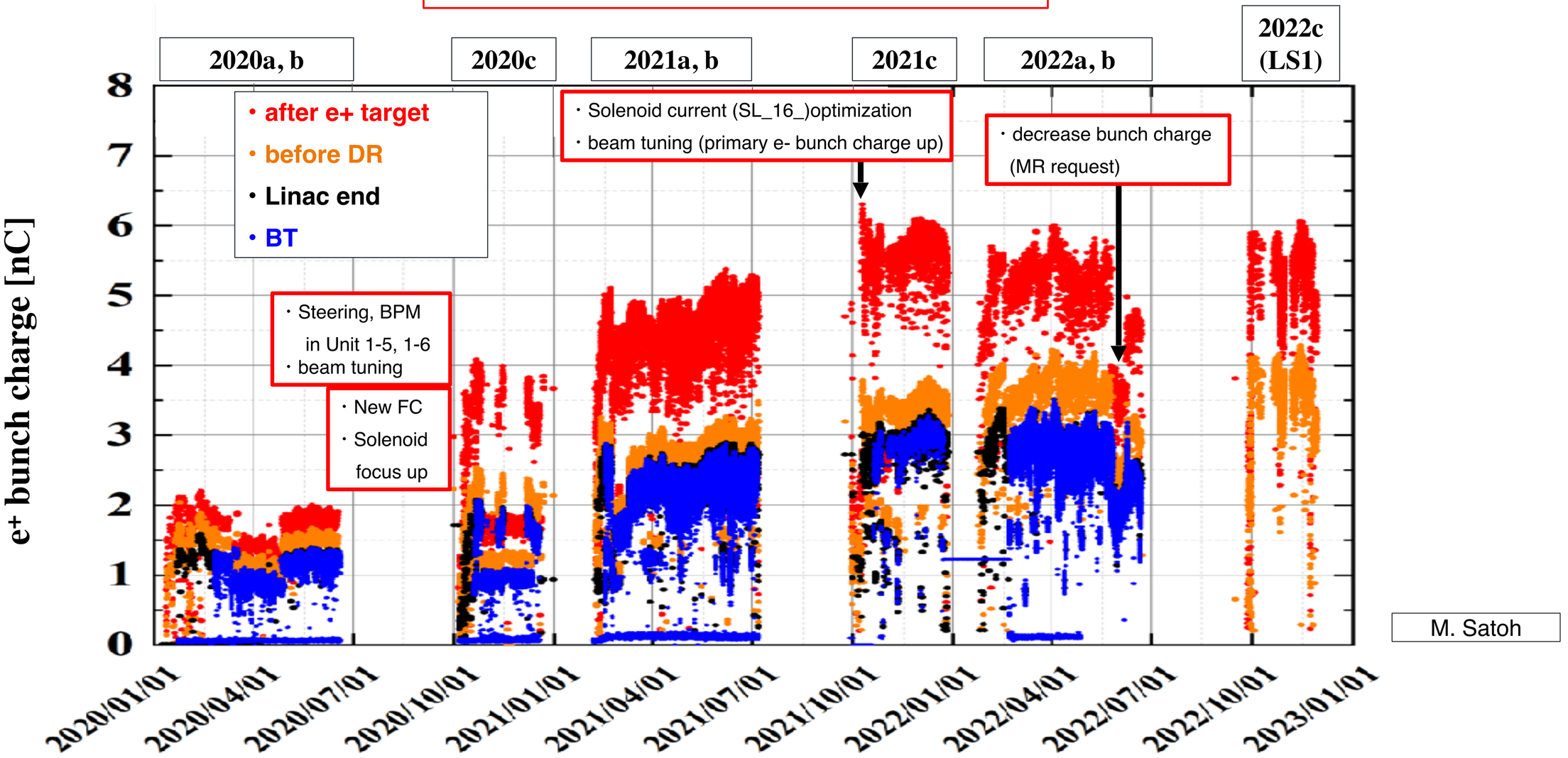
M. Satoh

LINAC status : Positron Charge History 2020a to 2022c for LER

e+ emittance

Measured εnx,ny (3 nC) : 103.5/4.7 μm (at BT1)

Goal εnx,ny (4 nC) : 100/15 (H/V) μm



M. Satoh

ARC Recommendations

- **R7.1: Perform systematic measurements of the orbit jitter of the two electron bunches and correlations with possible sources. Advance the synchronous data acquisition between Linac and BT.**
- **R7.2: More generally, perform a feasibility study for the implementation of synchronous beam data acquisition, which will be extremely useful for studying drift and instability.**
  Improve the analysis tools using the synchronous beam, rf monitor, pulsed magnet data

- **R7.3: Implementation of an orbit feedback if the use of pulsed magnets allows for this.**
  Orbit FB with pulsed magnet is already in operation (Sectors 3-5).

- **R7.4: Continue with the upgrade plan as presented in the summary slide.**
  In progress

- **R7.5: Concerning the emittance growth of the second electron bunch, study the effect of long range-wakes in the linac.**
  Fast kicker for 2nd bunch orbit correction could mitigate the 2nd bunch emittance growth.

- **R7.6: Identify the causes limiting the charge of the electron bunch along the injector.**
  Simulation work and beam study are being conducted.

- **R7.7: Discover the loss locations and causes for the positron transport in the linac.**
  Simulation work is now in progress. Beam matching after e+ target will be tested soon to reduce the beam loss.