

Upgrade status of the injector LINAC

Hiroyasu EGO

KEK Injector Linac division

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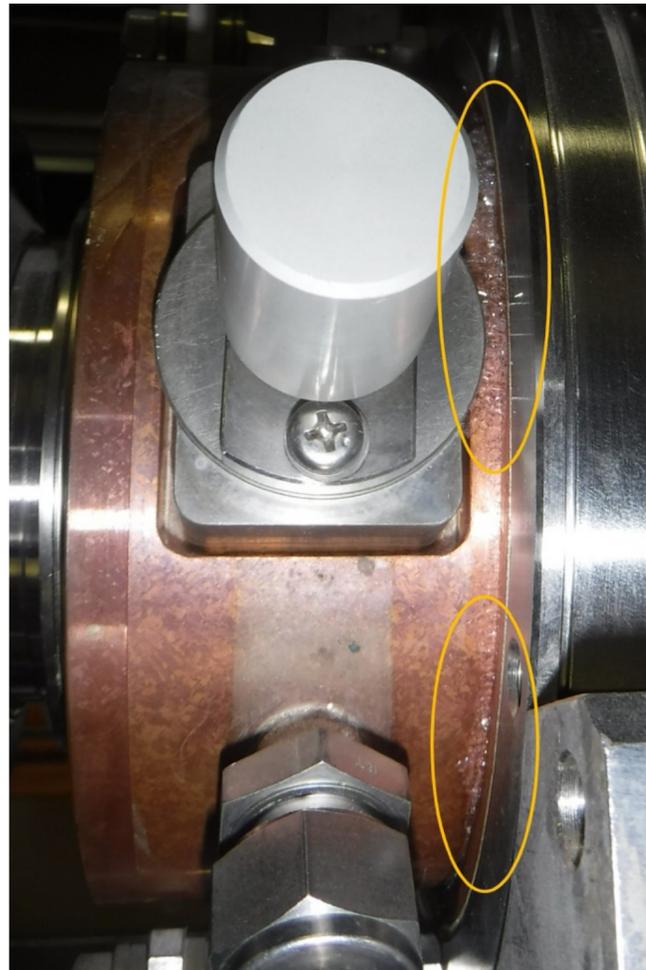
- **Issues: difficulties in stabilizing beam condition**
- **Upgrade works and countermeasures against the issues**
- **Summary**

Issue : Difficulties in stabilizing beam acceleration

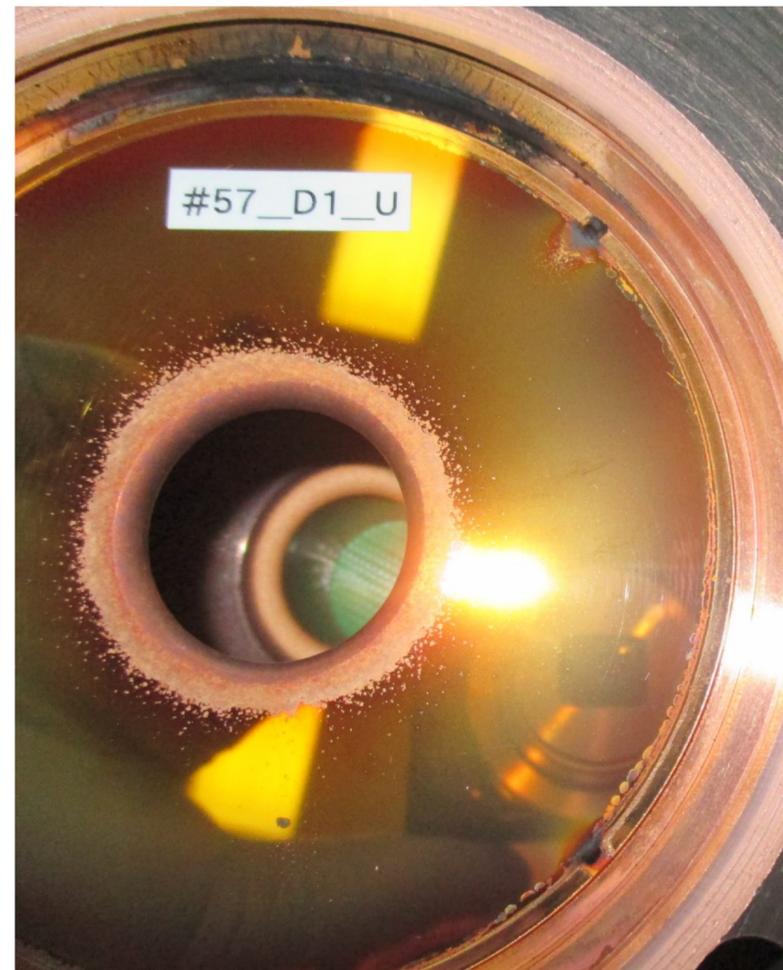
Issue : Water leaks, field emission, discharge in the structures limit the operation of the rated acceleration

Countermeasures : New high-gradient accelerating structures

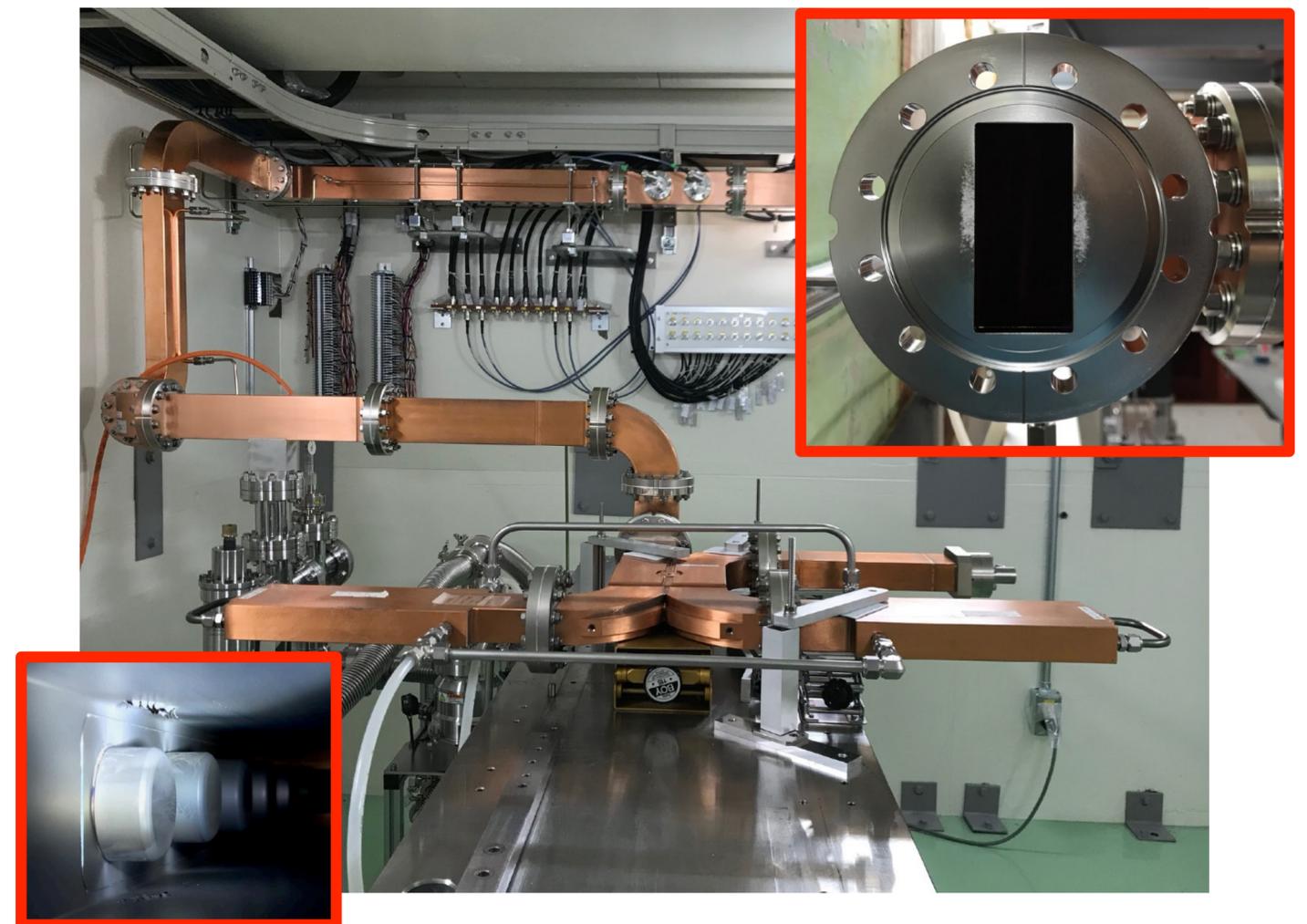
Water-leakage



Discharged damages



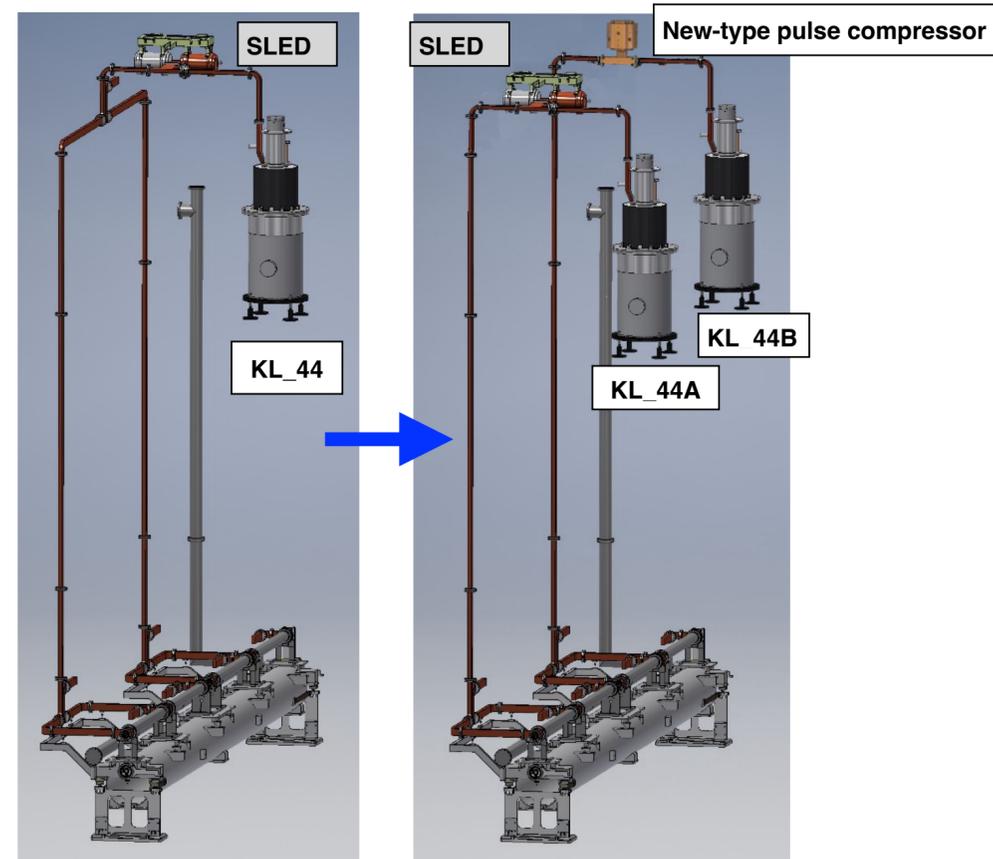
Discharged damages of waveguide circuits



Linac upgrades : Accelerating structures

UPGRADE : Successful completion of 5-year upgrade plan against deterioration of accelerating structures

- 12 water-leaked structures were replaced with the new structures in the summer of 2023
- One unit (#44) reinforces beam-acceleration from 20 MV/m to 28 MV/m



Remaining issues

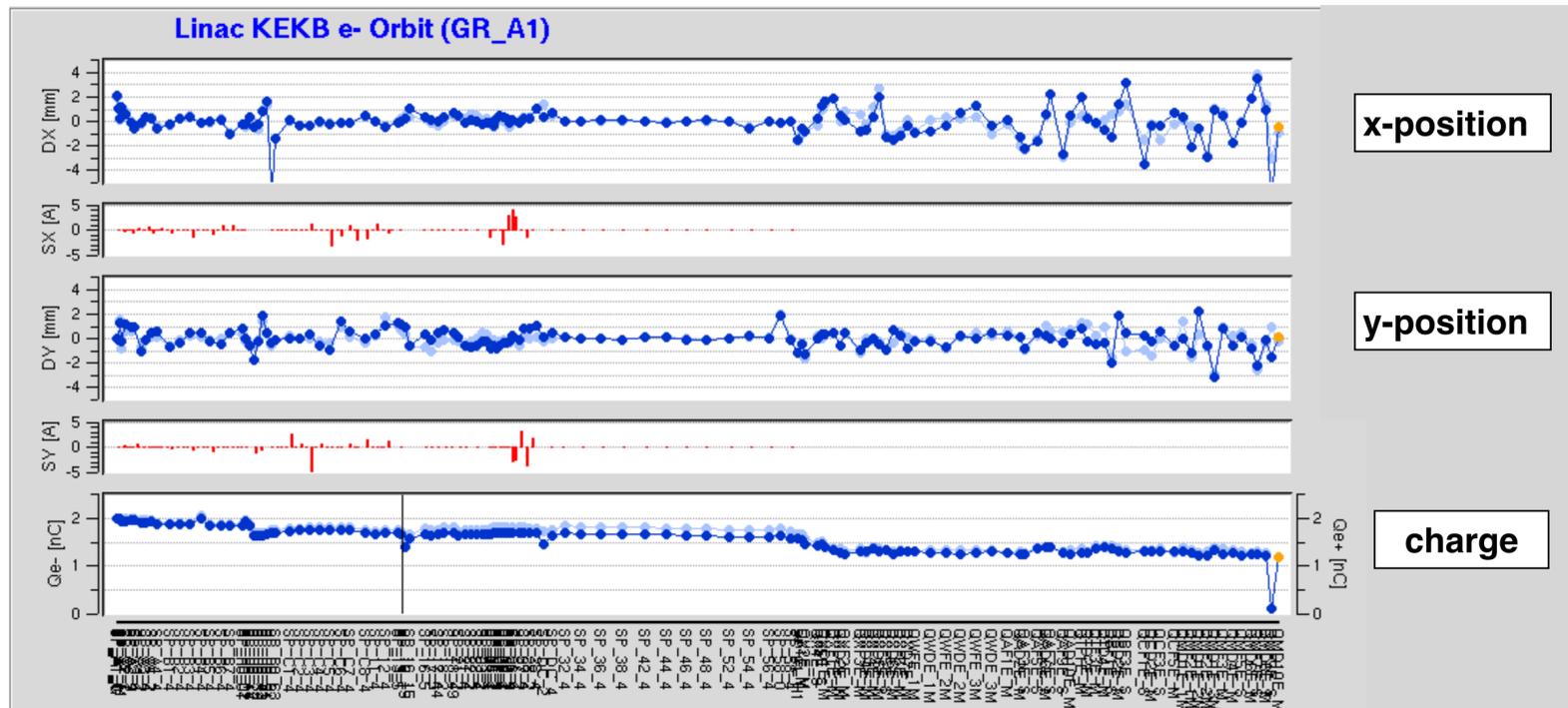
- 10 deteriorated structures are still to be replaced
- Water leakage may occur in the future (Two structures suffered from the leak in 2023)
- Production of 12 new structures start from this fiscal year (3-year plan)

H. Ego

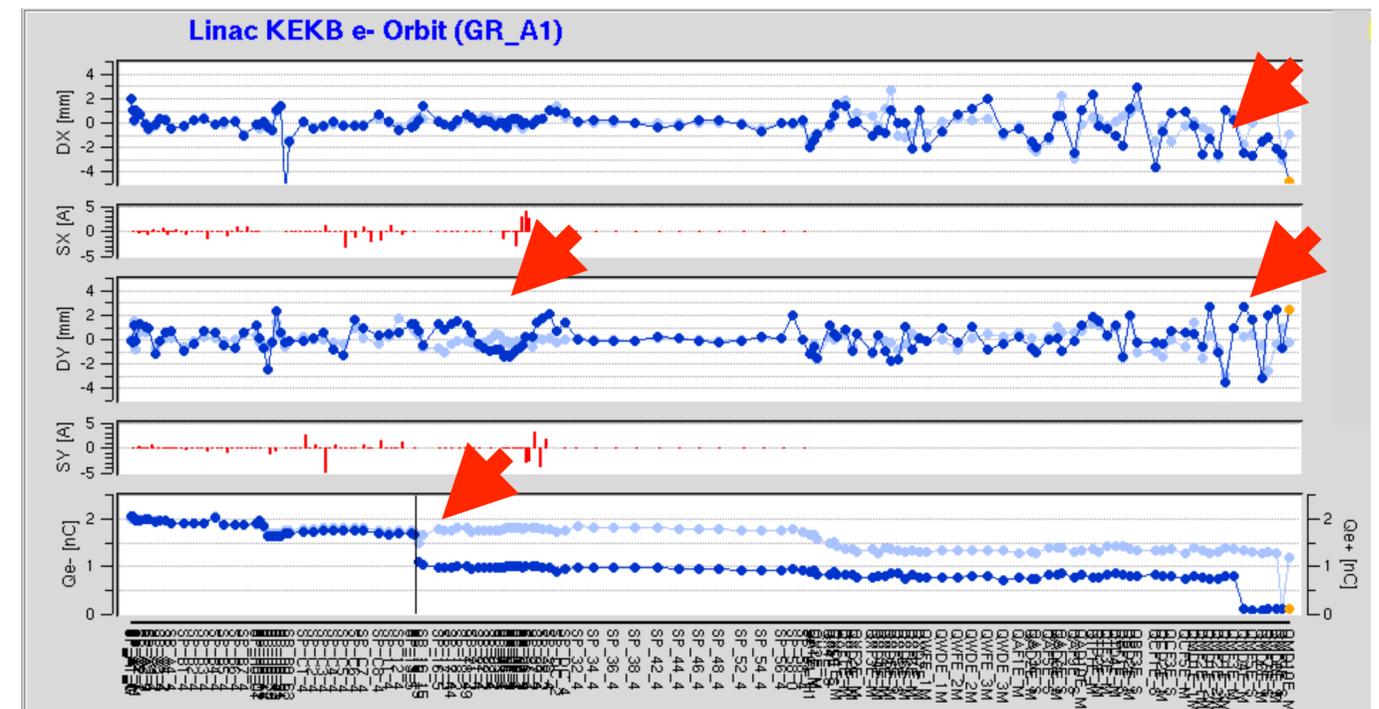
Issue : Difficulties in stabilizing beam condition

Best tuning condition is destroyed gradually in a day

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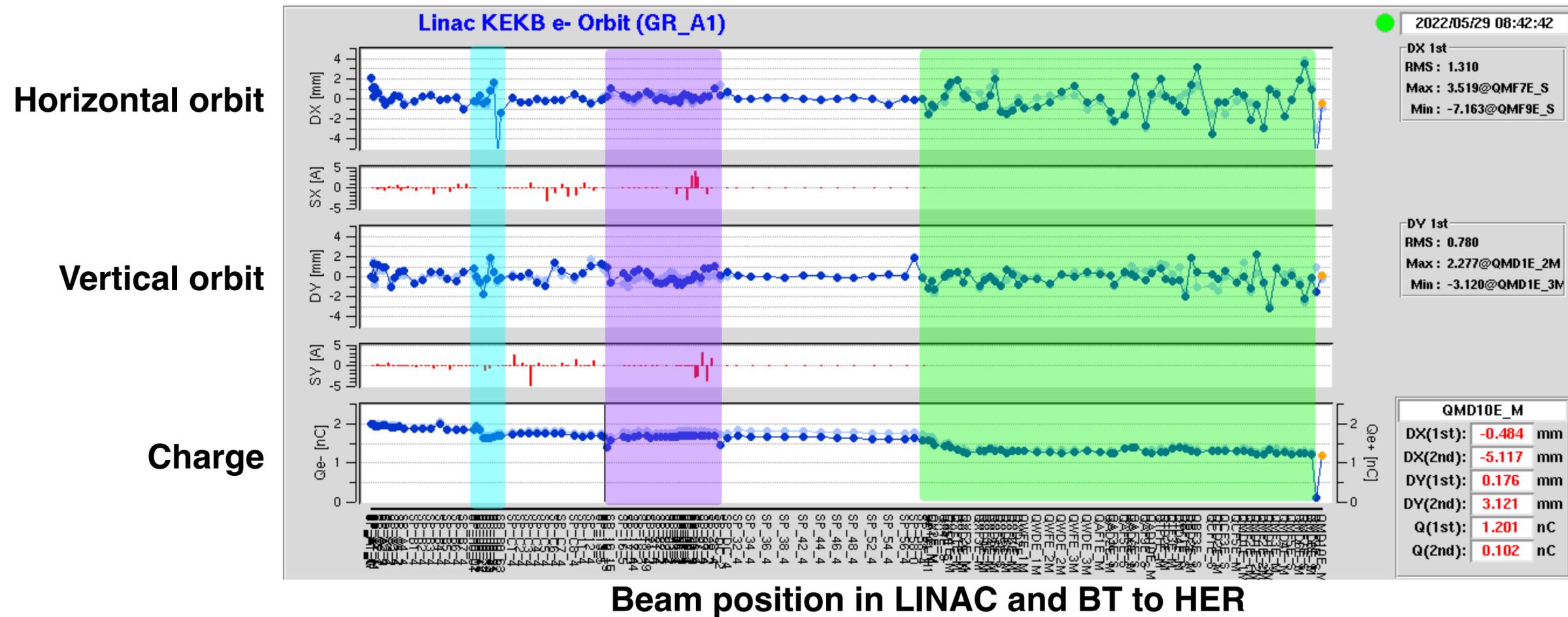
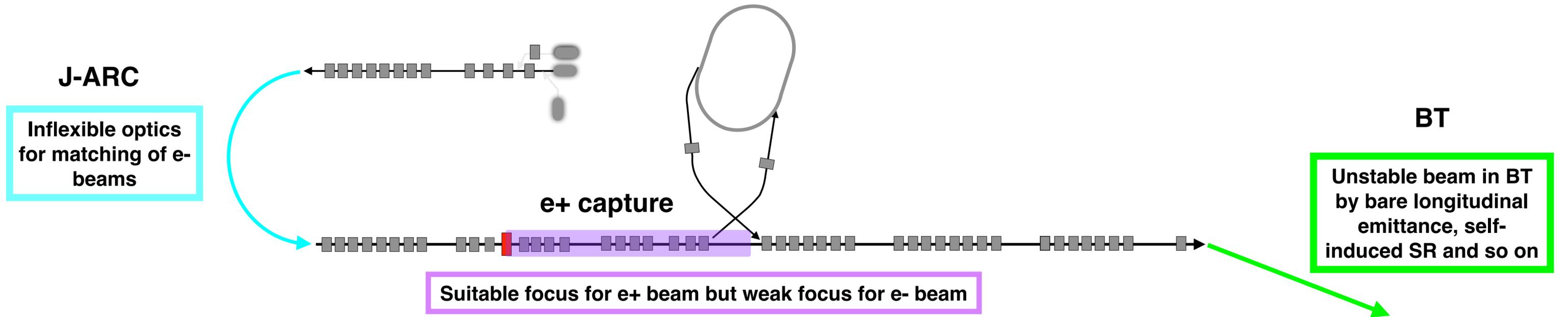
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Beam orbit and emittance of electron beam
tuned fine in the morning

Beam orbit **unstable** and emittance **worse**
charge **lost** in the afternoon

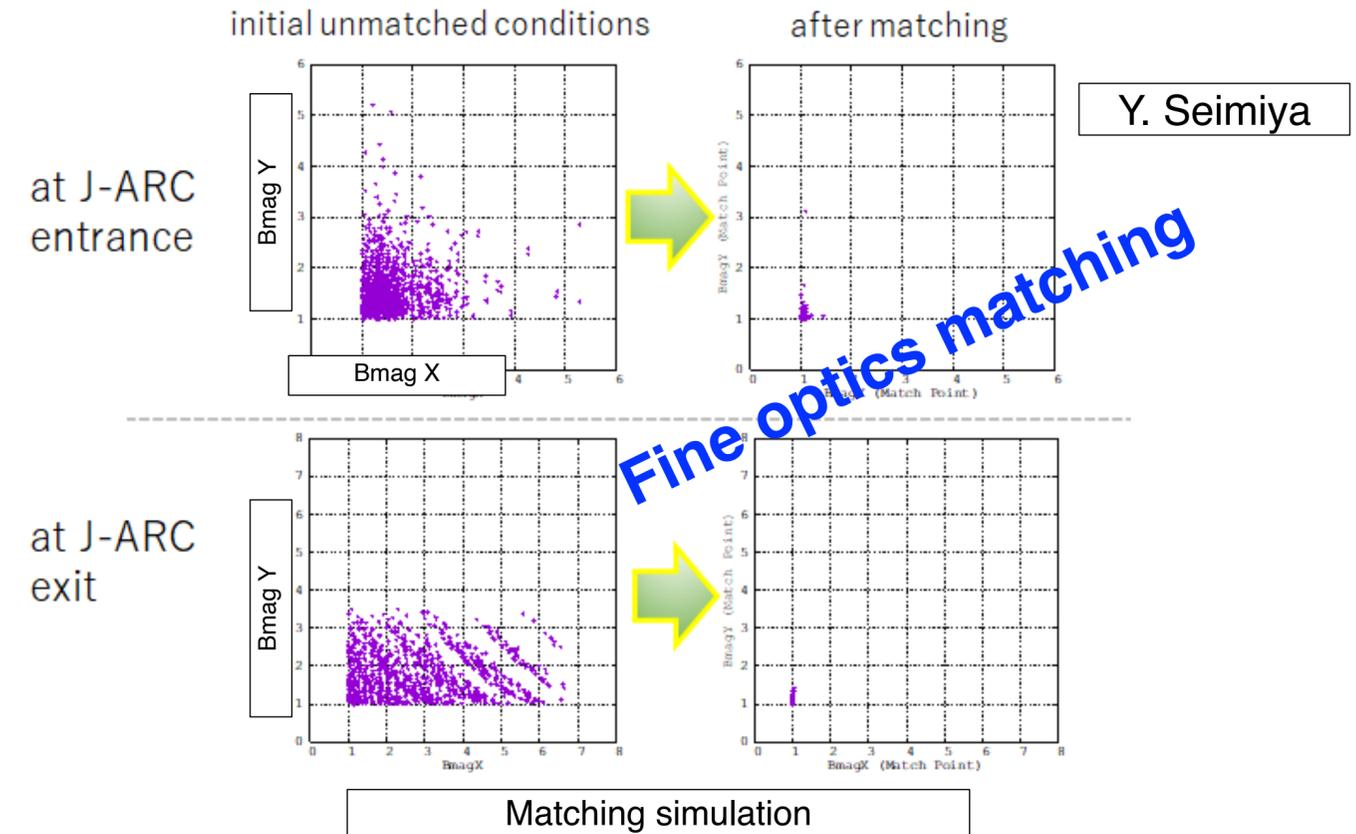
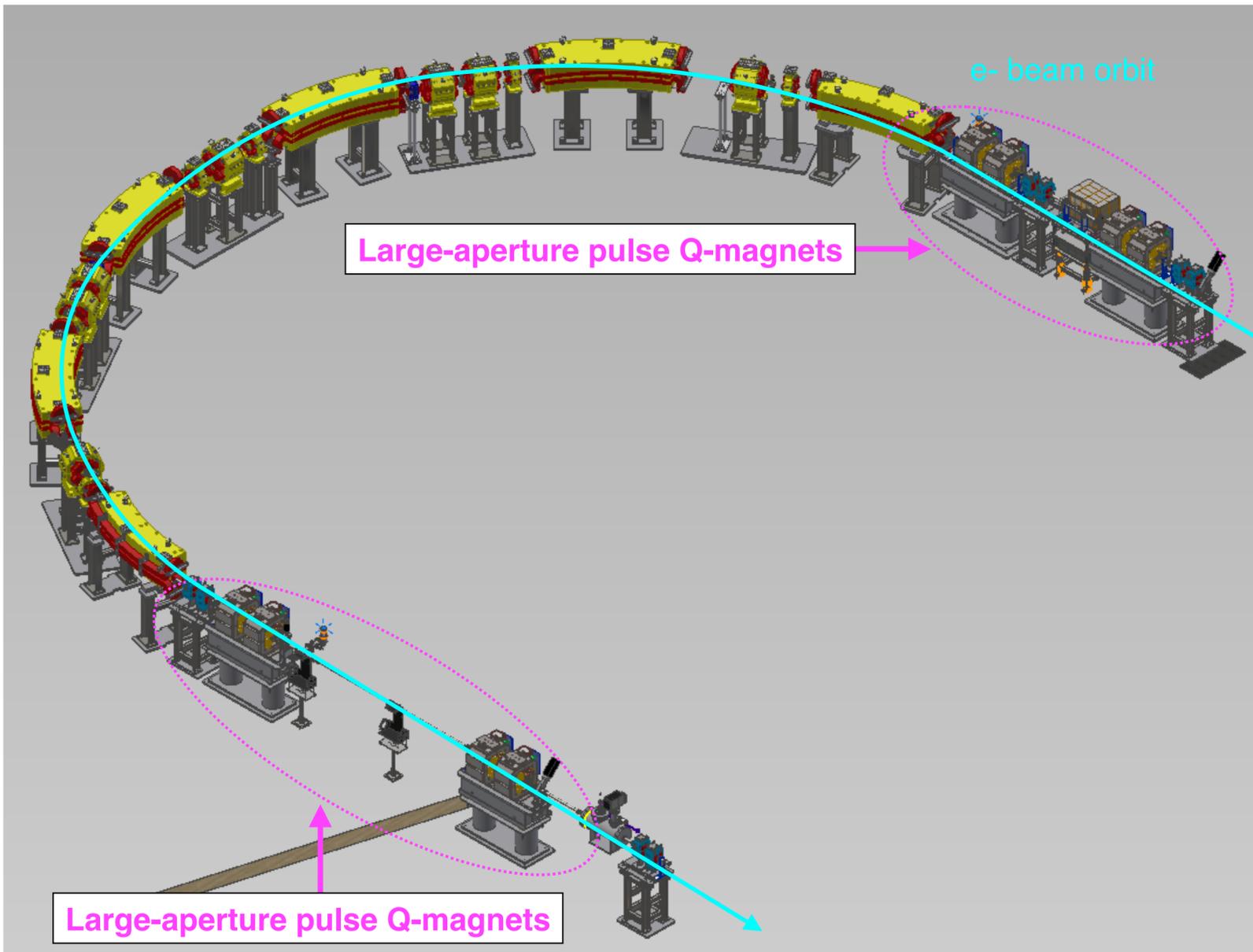
Issue : Beam-degrading areas



LINAC upgrades : Beam optics 1

Issue : Beam loss, emittance deterioration in the J-ARC

Countermeasure : Large-aperture pulsed Q magnets

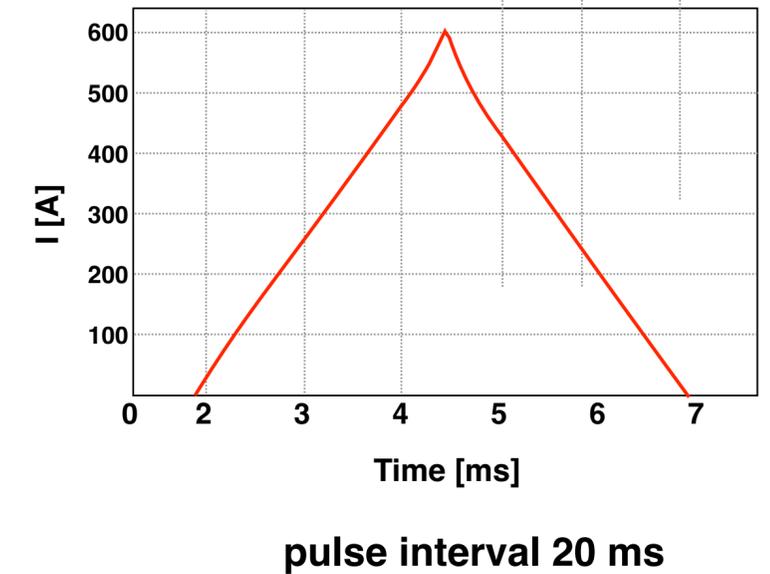
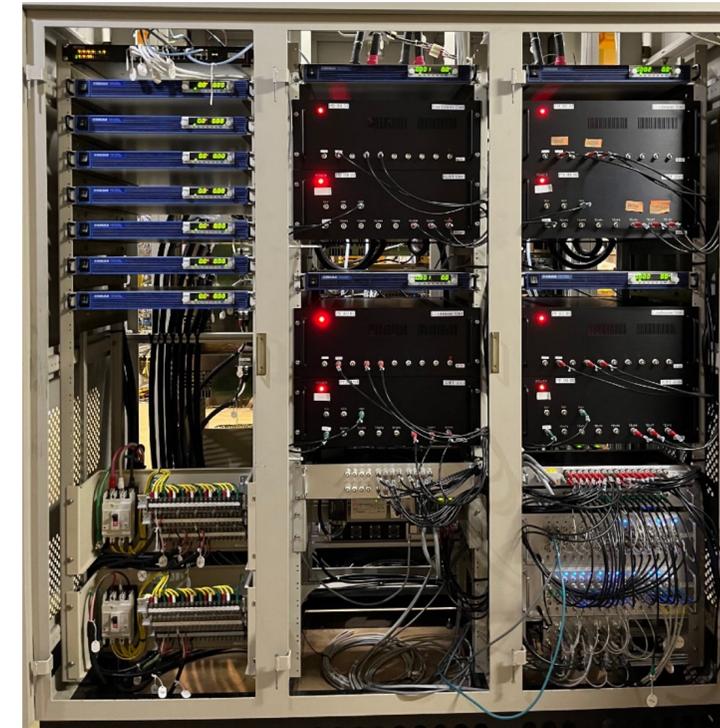
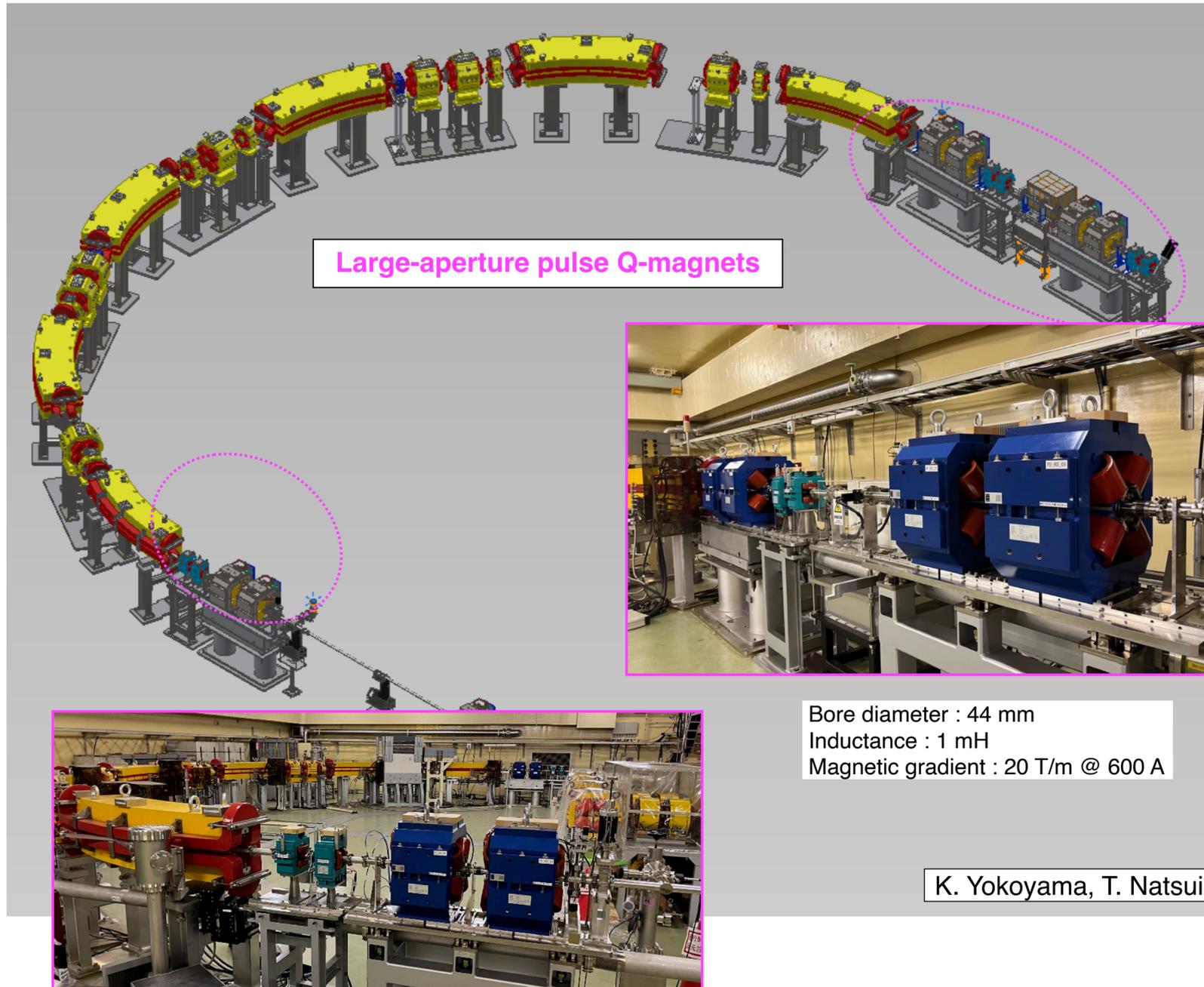


- At the entrance and exit of 180 deg. J-ARC region, a good optics matching is indispensable to mitigate beam loss and emittance growth.
- Simultaneous matching for both of HER and LER injection beams requires the pulsed Q magnets.
- From the simulation results, four pulsed Q magnets at the entrance and exit of J-ARC are required for the matching.

LINAC upgrades : Beam optics 1

UPGRADE : Installation of the new pulsed Q magnets in J-ARC

- Large-aperture pulsed Q magnets installed in the summer of 2023
- New high-power pulsed power supply of energy-recovery type driving the pulsed Q magnet up to 600 A - 400 V

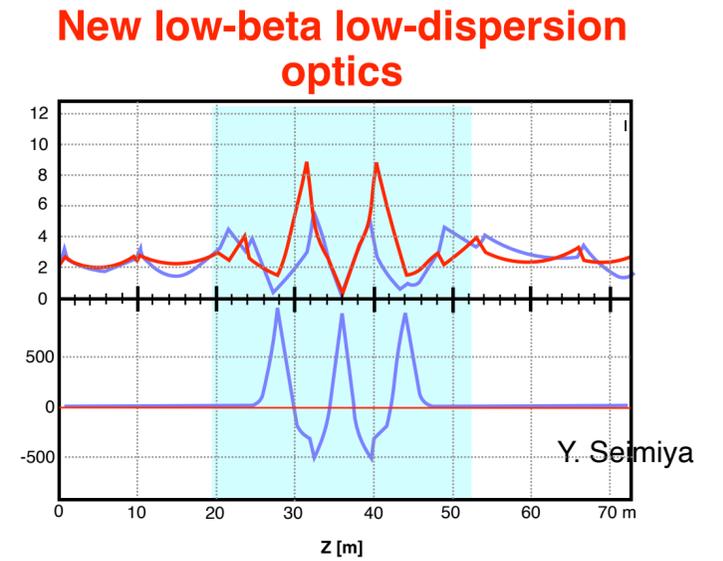
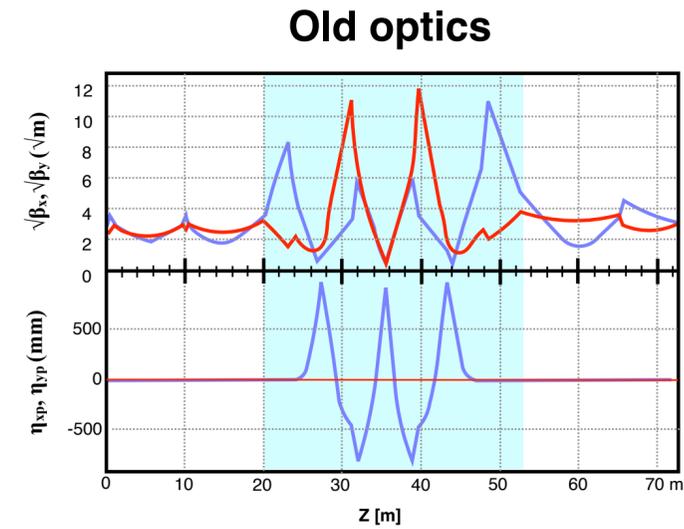
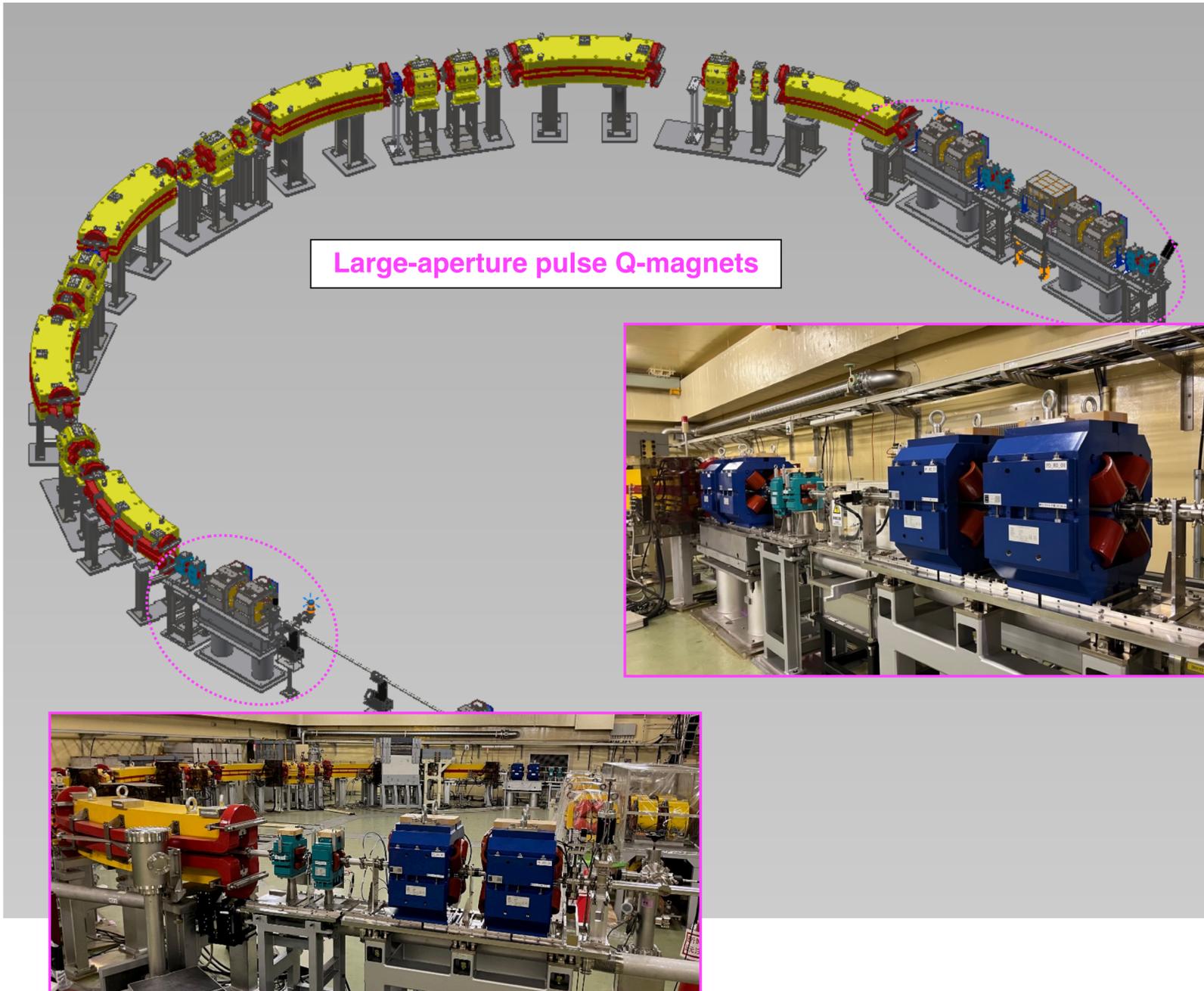


- Energy recovery low-loss, compact, high power supply
- Drives the large-aperture pulsed quadrupole magnet up to 600 A
- Rise and fall speed 2.5 ms supporting pulse-to-pulse current change
- **Energy recovery efficiency > 83%**

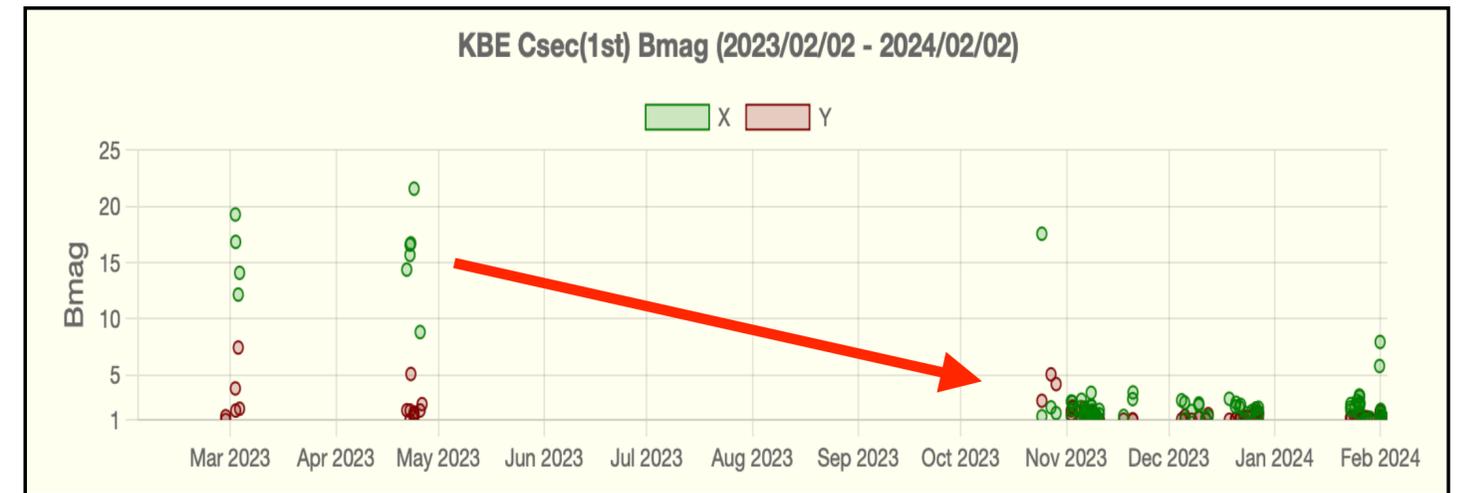
LINAC upgrades : Beam optics 1

UPGRADE : Installation of the new pulsed Q magnets in J-ARC

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Optics matching results of HER beam



Markedly improved

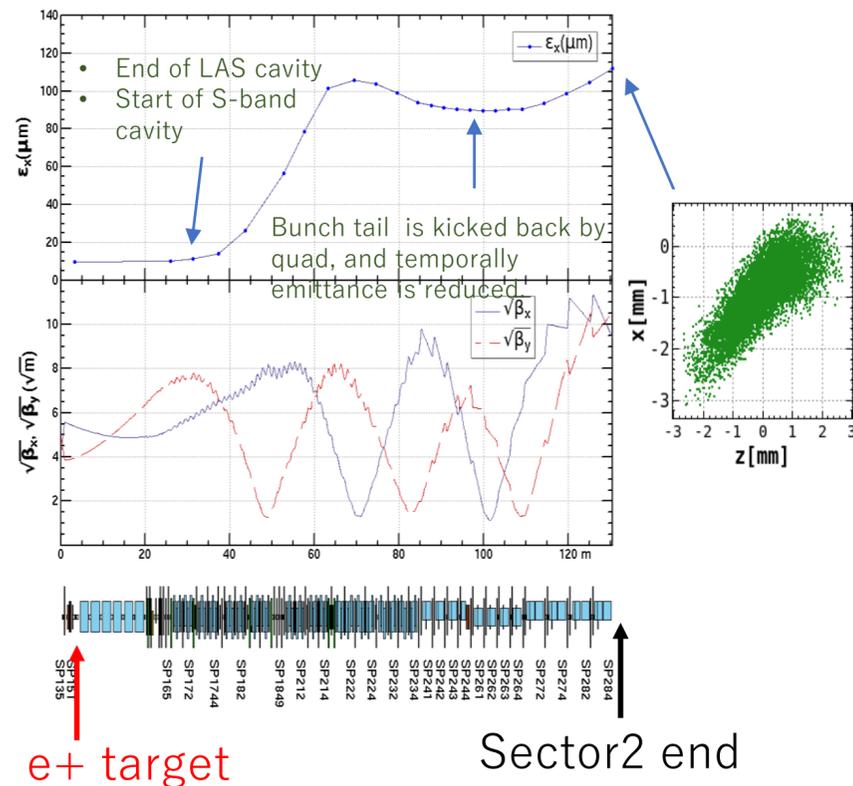
Linac upgrades : Beam optics 2

Issue : Weak focus for HER electron beam in 1-2 sector (positron-capture section)

Countermeasure : Large-aperture pulsed Q magnets

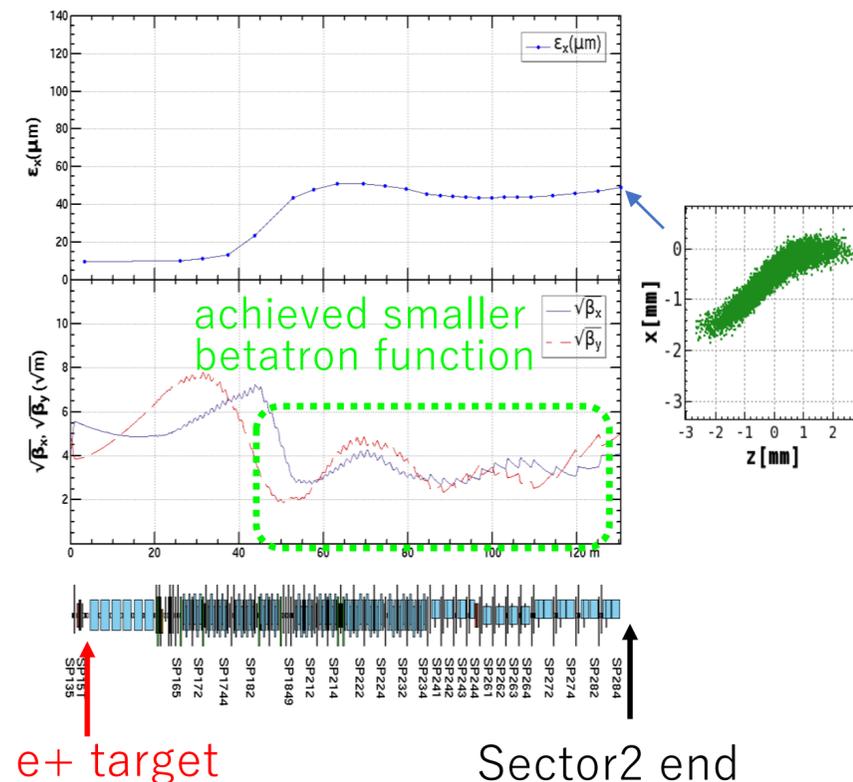
Old optics

$\Delta\gamma\epsilon_x \sim 100 \text{ } \mu\text{m}$, $\overline{\beta_x} = 45.2 \text{ m}$



New optics

$\Delta\gamma\epsilon_x \sim 40 \text{ } \mu\text{m}$, $\overline{\beta_x} = 16.3 \text{ m}$

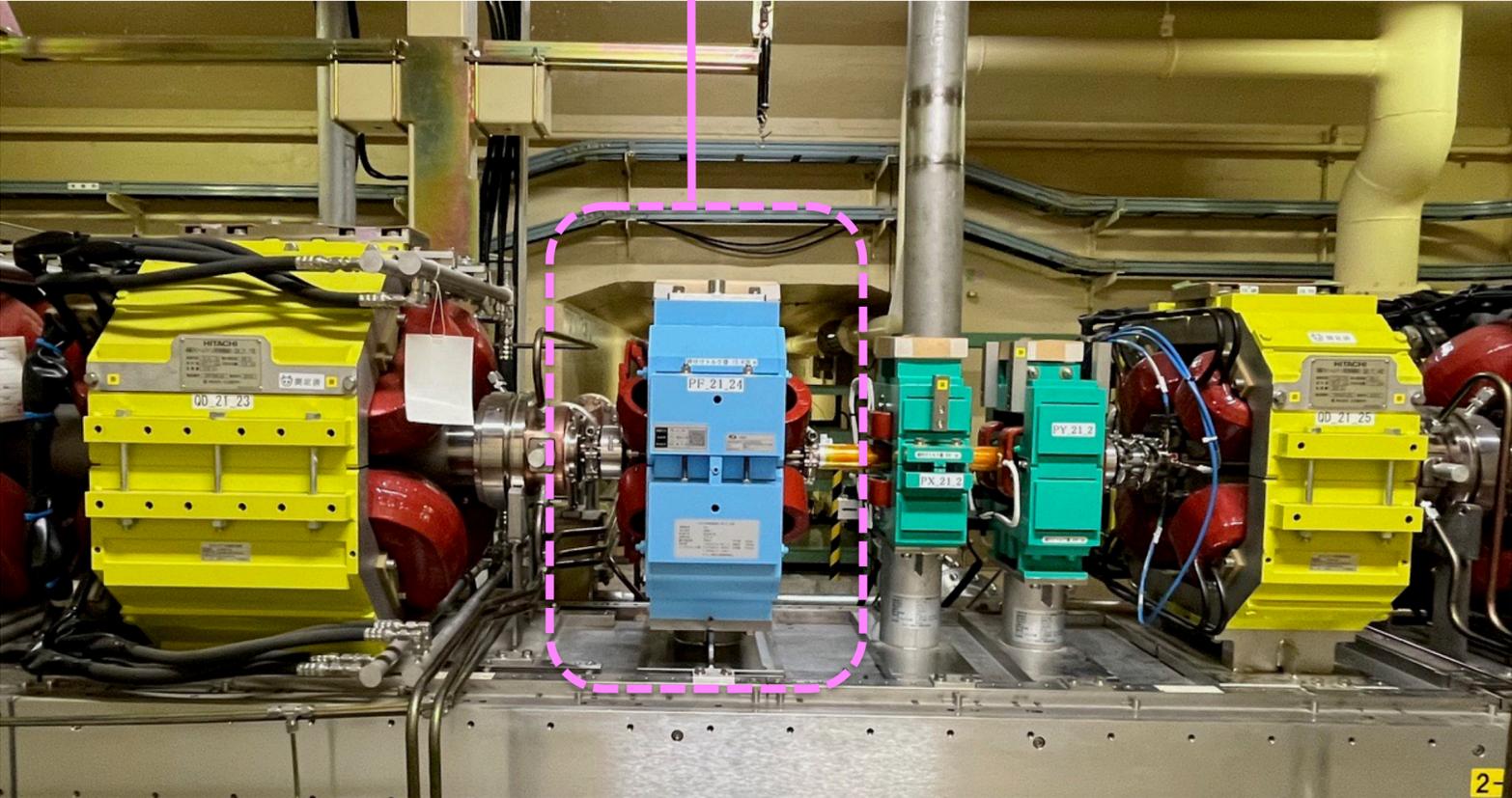
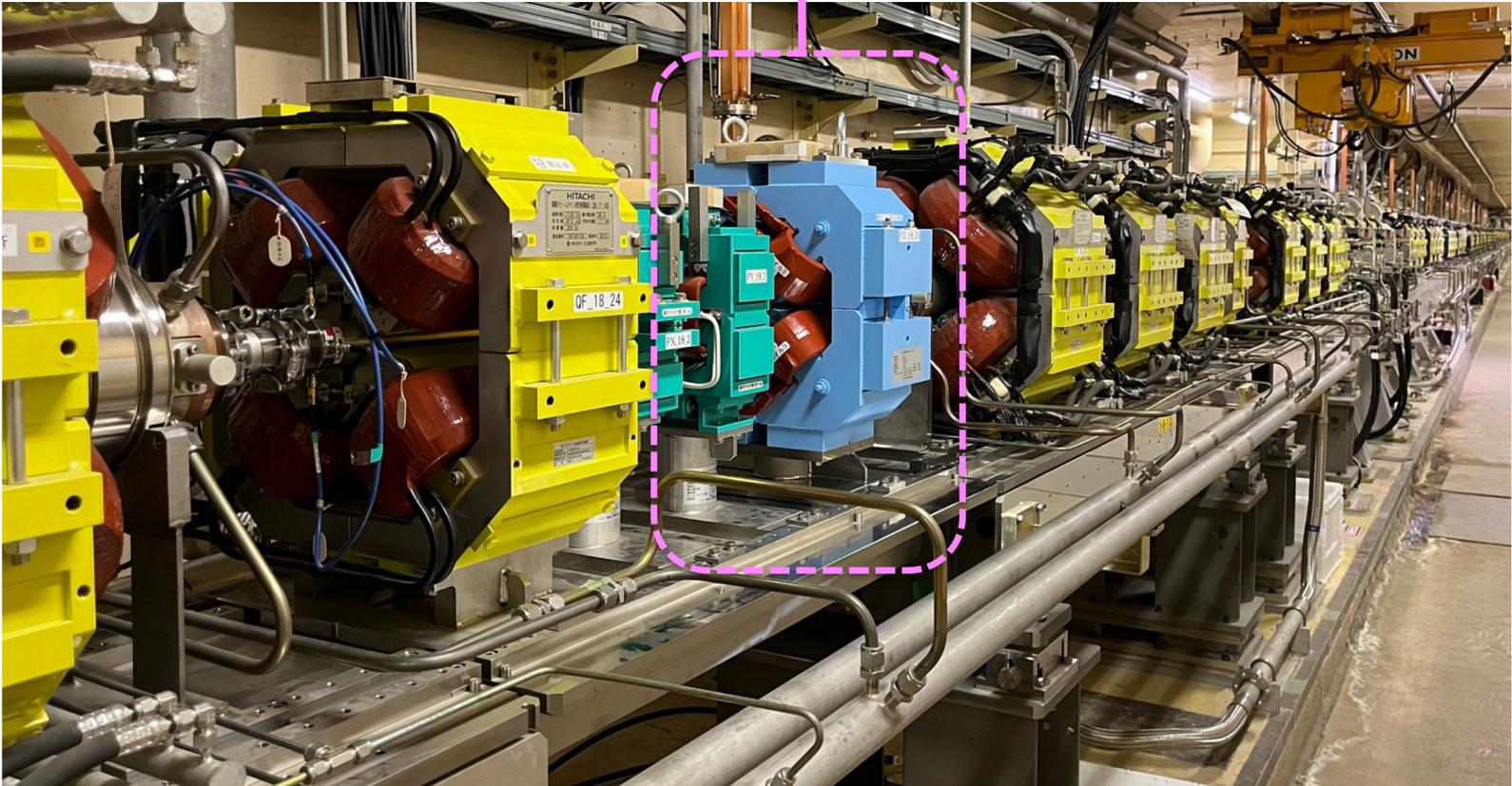
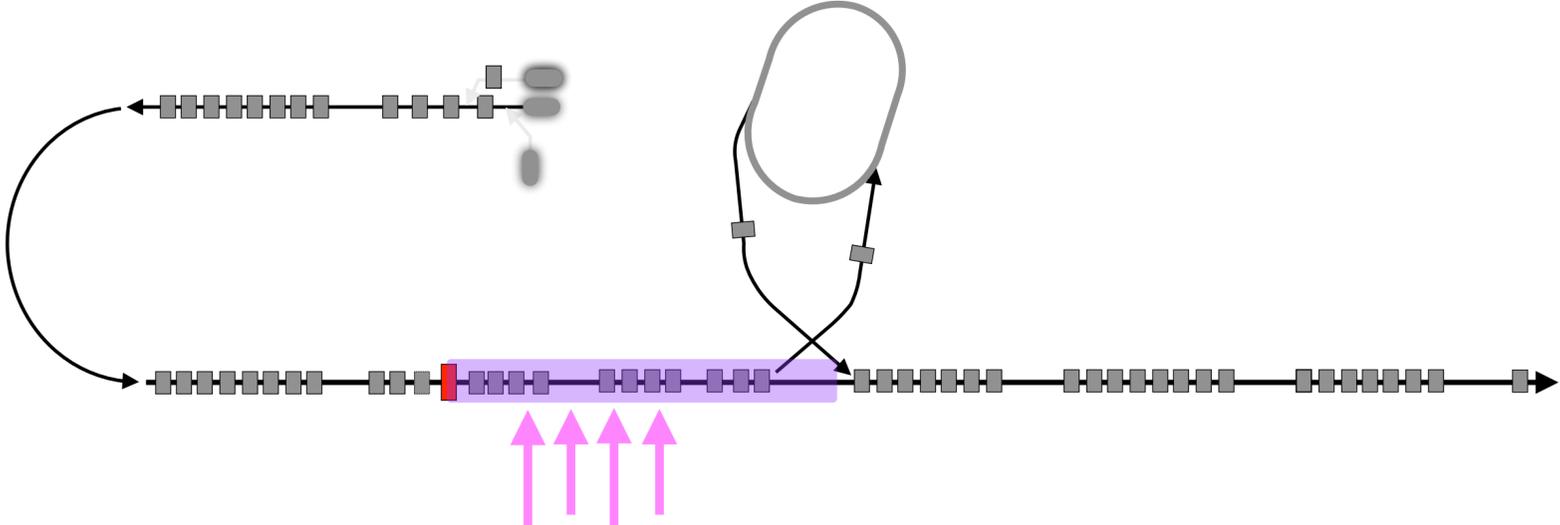


- Large emittance e+ beam is accelerated from 0.1 GeV to 1.1 GeV for DR injection.
- Operation of DC Q-magnets is optimized for e+ beam.
- For e- beam (3 to 4 GeV), the focusing force is so weak as to cause its emittance growth.

- 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 : Beam optics 2

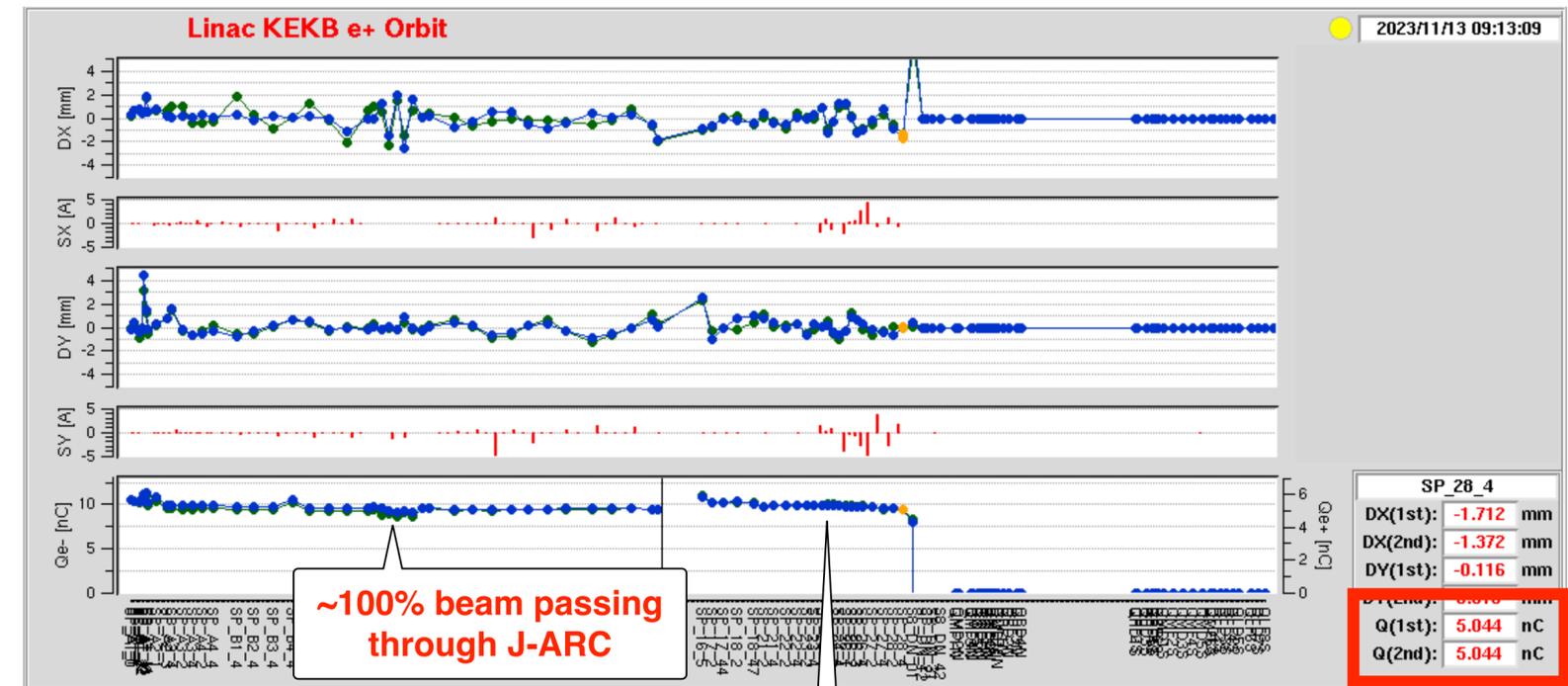
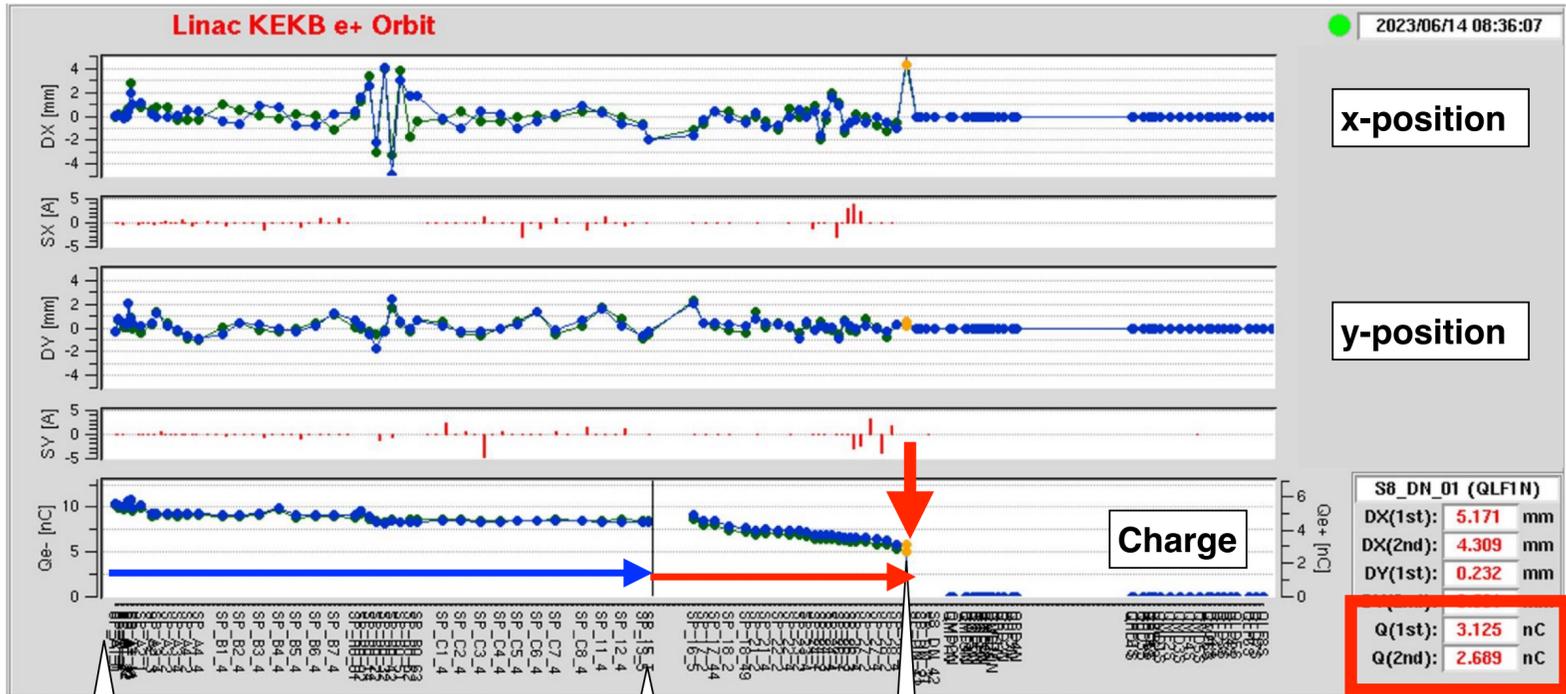
UPGRADE : Installation of four large-aperture pulsed Q magnets



Linac upgrades : Beam Control - Machine learning

Issue : Loss of positron charge

UPGRADE countermeasure : Machine-learning control + Large-aperture pulsed Q magnets

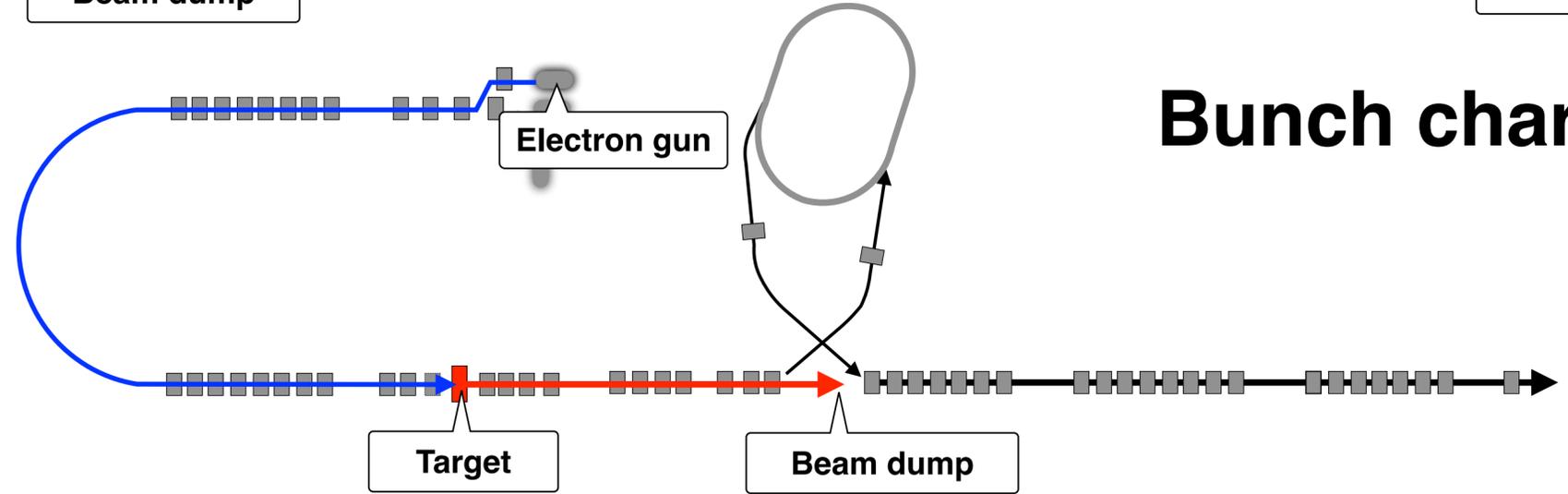


Markedly reduction in beam loss

Electron gun
10 nC

Target

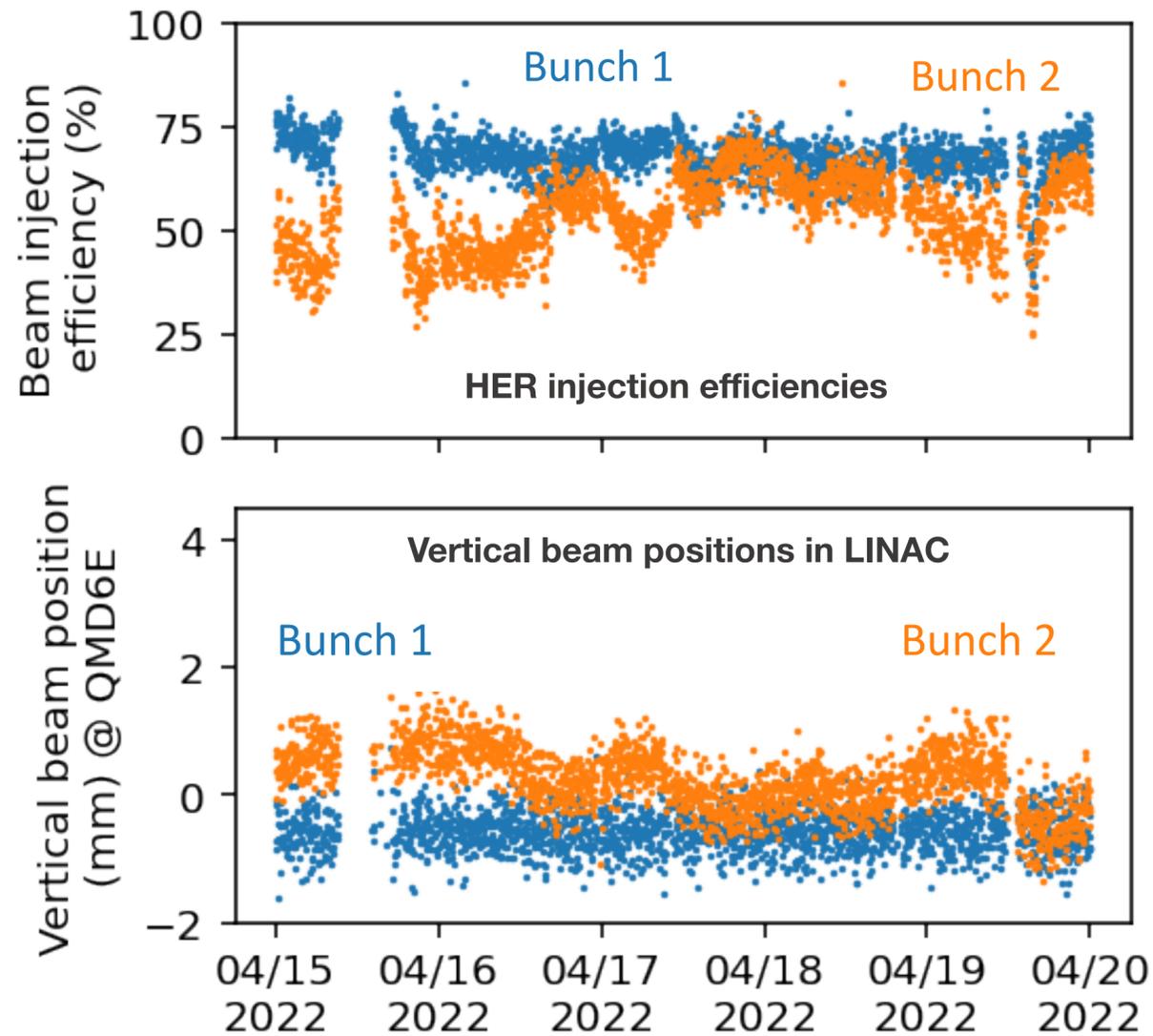
Beam dump



LINAC upgrades : Beam optics 3

Issue : Low injection efficiency of 2nd bunch in double-bunch operation

Countermeasure : High-speed pulsed kicker

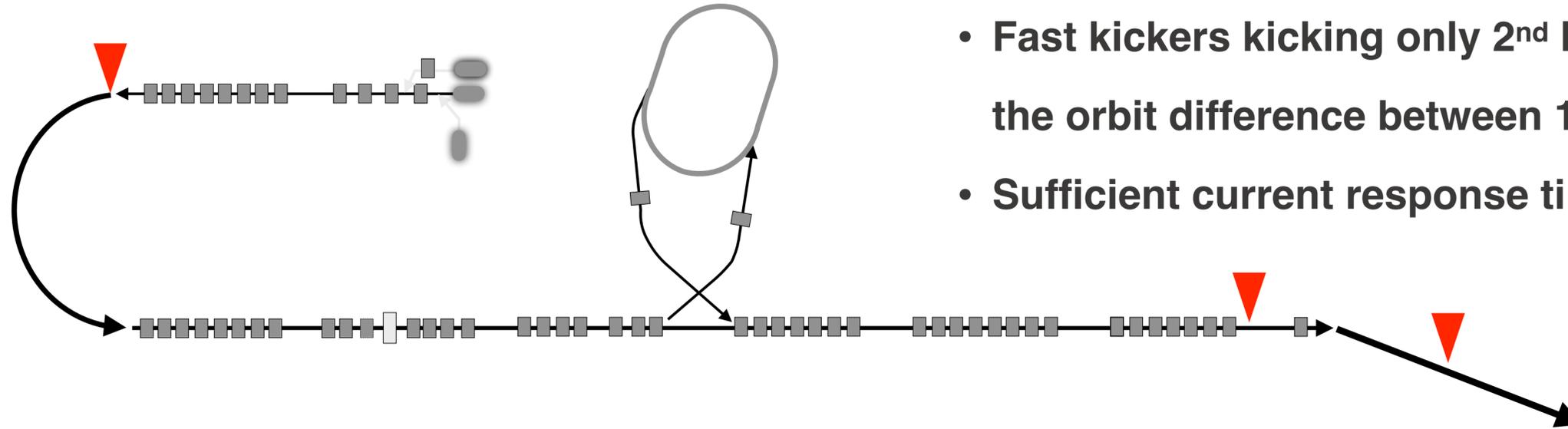


- Double-bunch acceleration (spacing: 96 ns) is employed for both e⁻ and e⁺ beam deliveries at an injection frequency (< 25 Hz).
- Injection efficiency of the 2nd bunch is usually lower than that of the 1st bunch in both e⁻ and e⁺ beam operations.
- One of the reasons is the beam orbit difference between 1st and 2nd bunches.

N. Iida

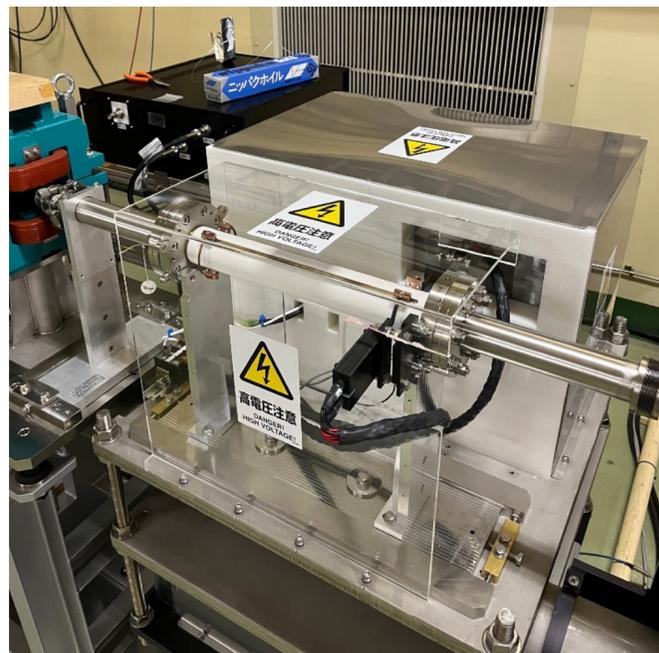
LINAC upgrades : Beam optics 3

UPGADE : High-speed pulsed kickers

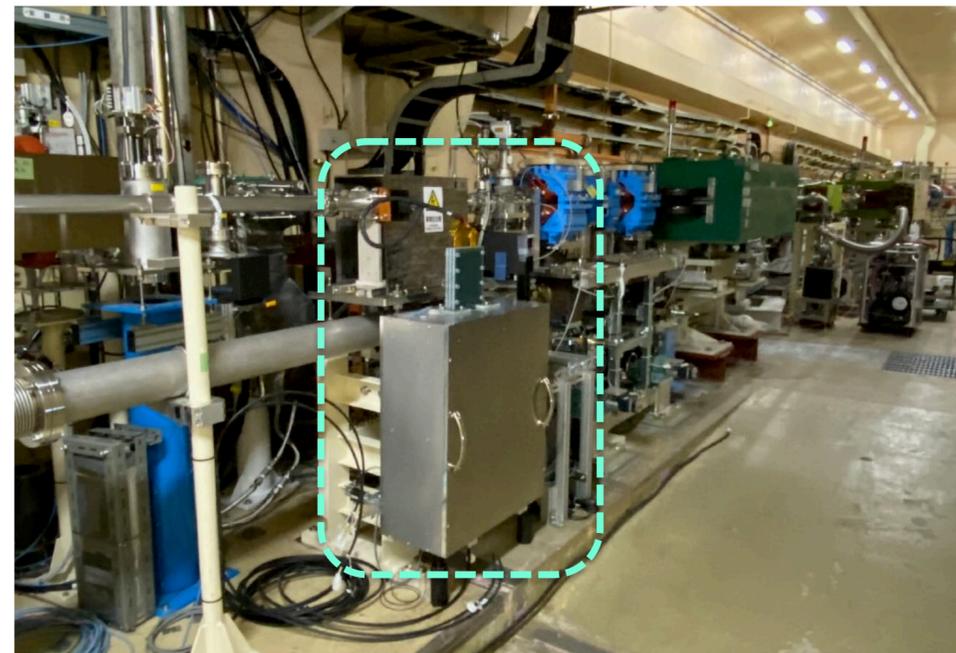


- Fast kickers kicking only 2nd bunch transversely to correct the orbit difference between 1st and 2nd bunches
- Sufficient current response time (< 96 ns)

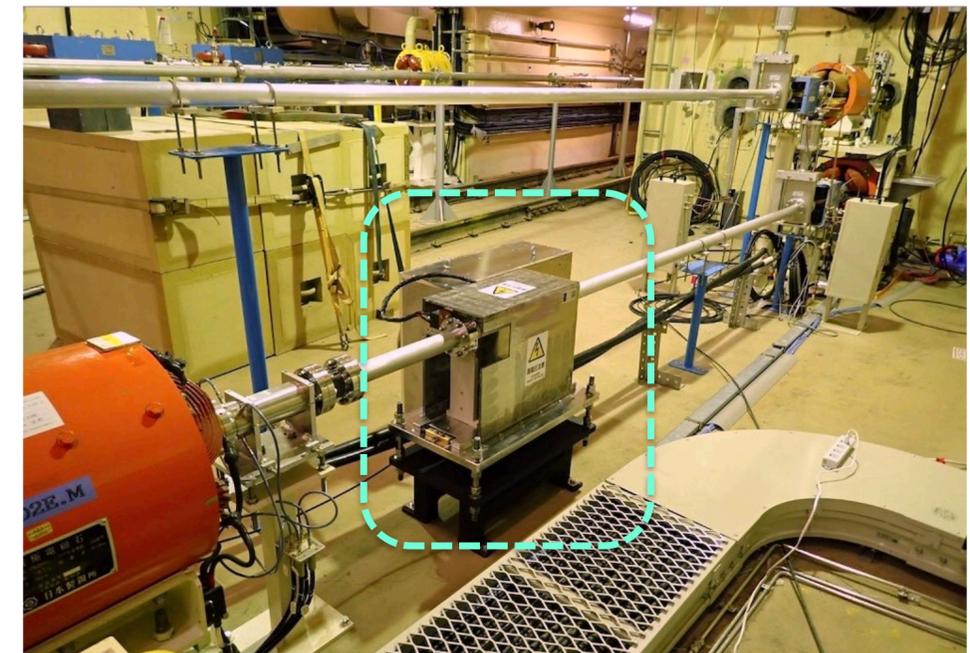
C. Mitsuda, T. Natsui,
Y. Okayasu



HSPK at the entrance of J-ARC



HSPK at the exit of LINAC



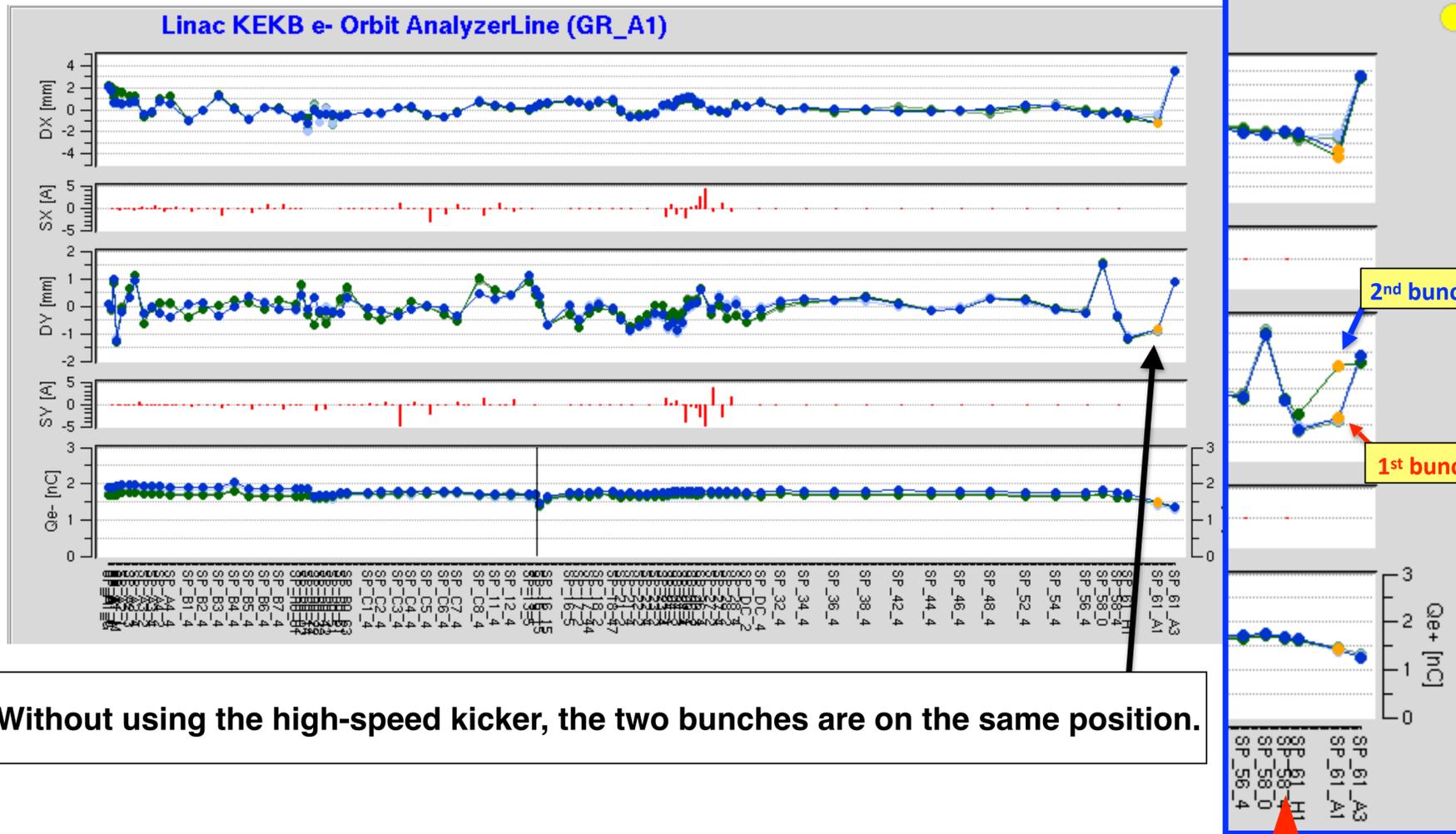
HSPK at SY3 in HER-BT

LINAC upgrades : Beam optics 3

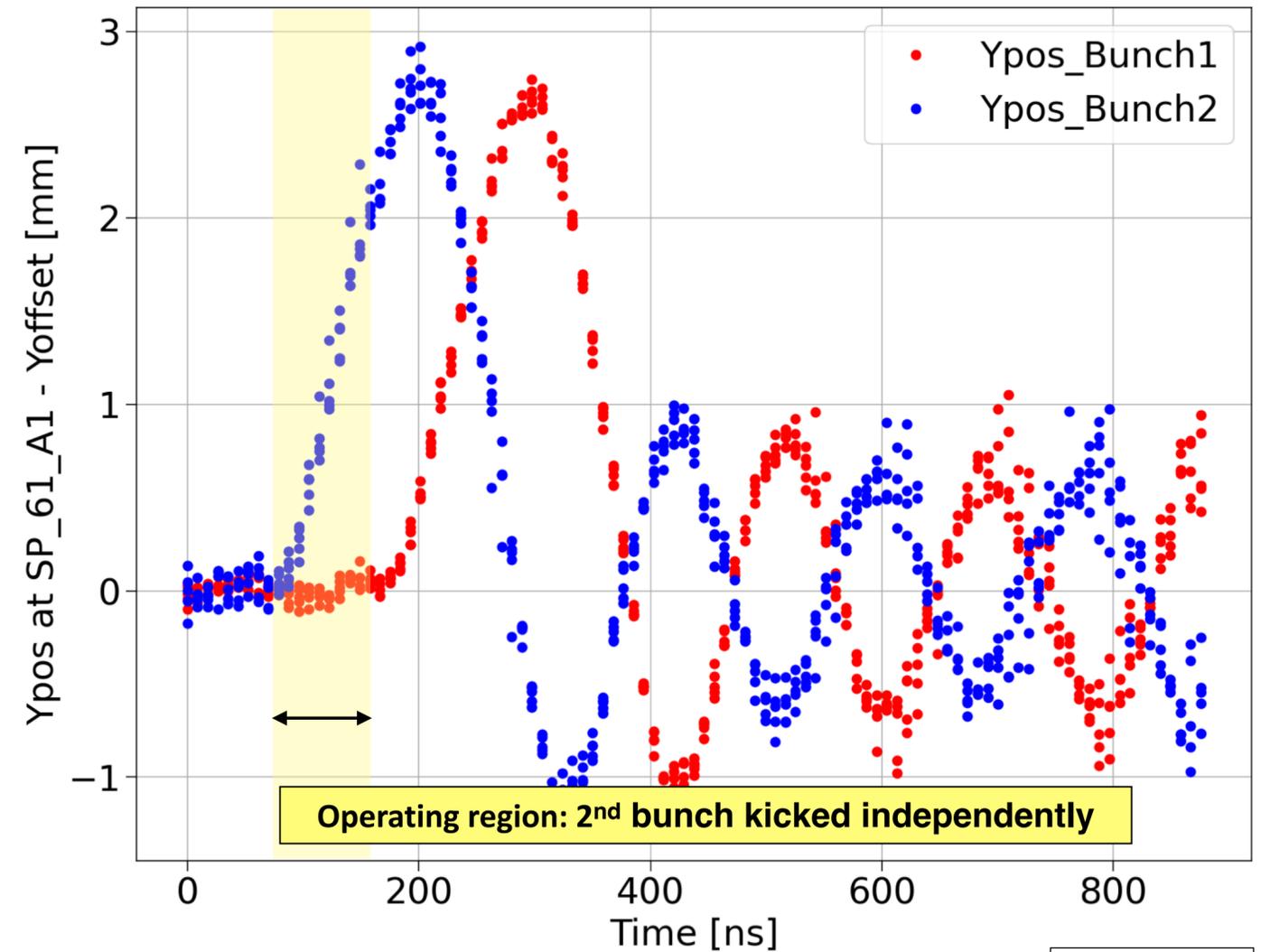
UPGRADE : High-speed pulsed kickers

Success in independent beam-orbit control of 2nd bunch only

Only the 2nd bunch is controlled by using the high-speed kicker



Without using the high-speed kicker, the two bunches are on the same position.

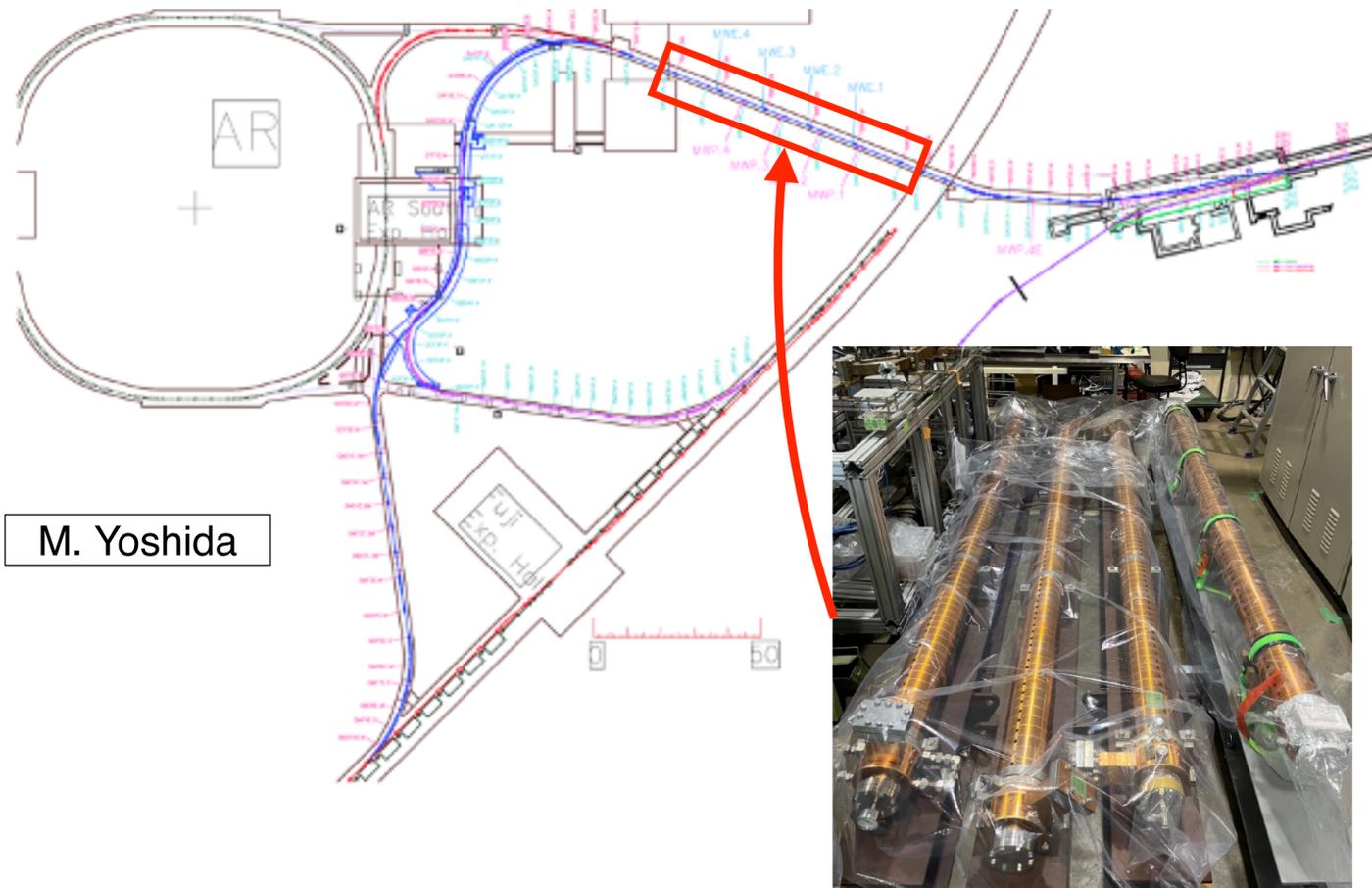


T. Kamitani

Linac upgrades : Injection efficiency

ECS reduces the longitudinal emittance of electron beams for HER

UPGRADE : Installation of BTe in 2024



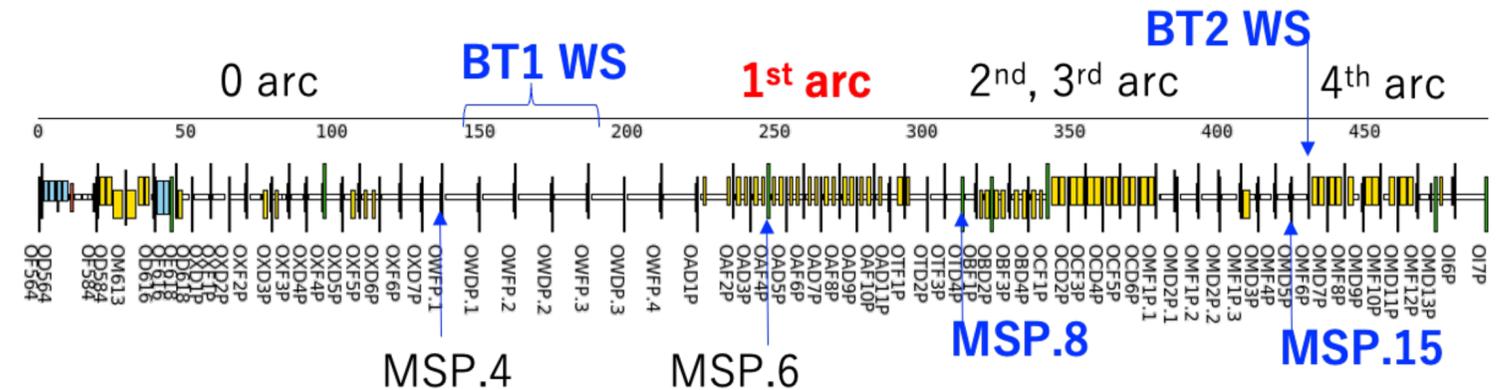
M. Yoshida

S-band 3m-long TW structures

- High-power RF sources prepared
- Successful operation of 3 m-long TW accelerating structures up to a rated power of 55 MW in the test bench
- **Waveguide system under fabrication**

We are exploring what causes the degradation of beam quality in BT

UPGRADE : To be shown in the next BPAC



N. Iida, Y. Seimiya, T. Yoshimoto

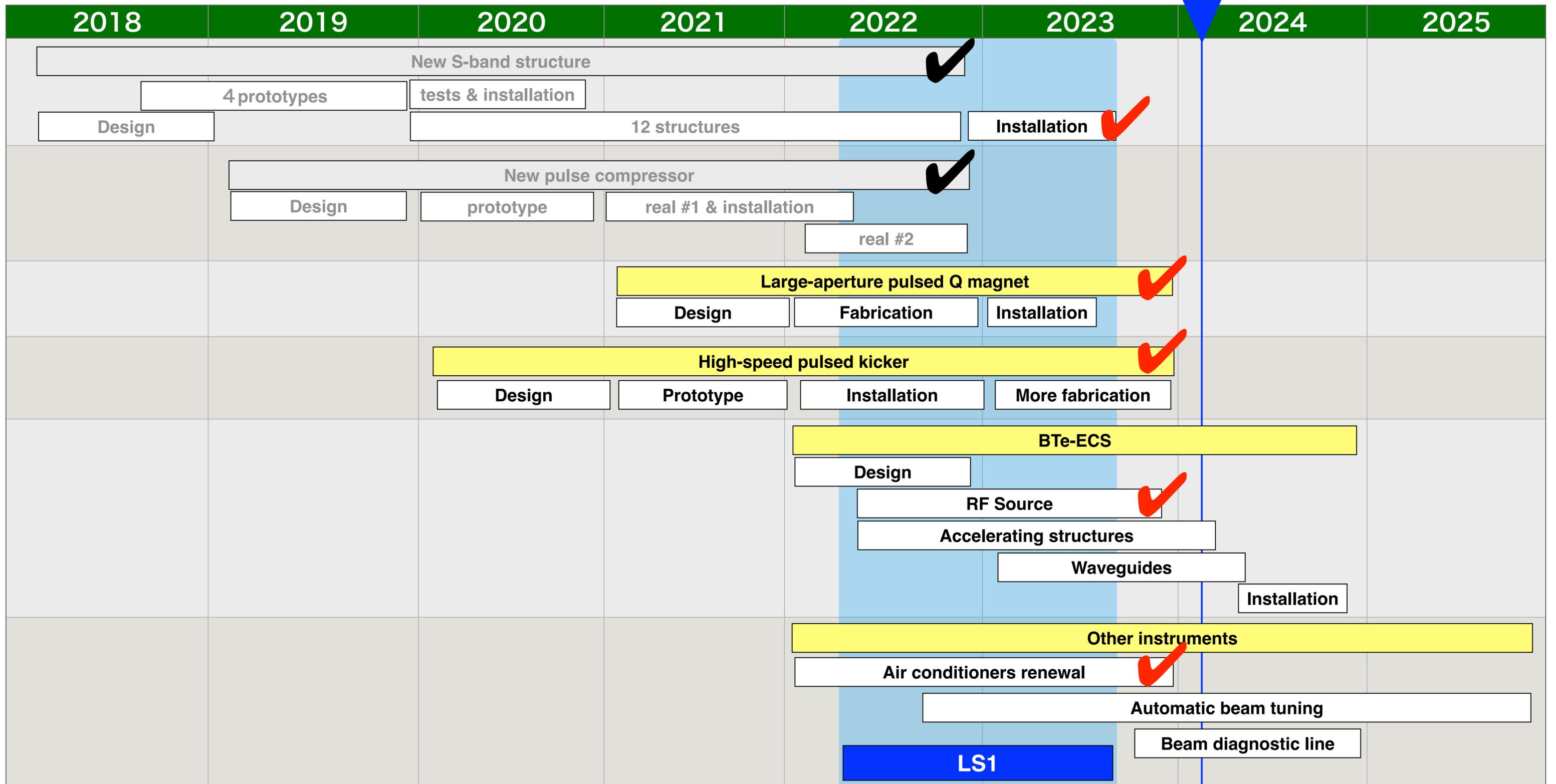
Findings:

- No bunch-charge dependence of beam emittance in BTp arcs 2 and 3 was observed.
=> No wakes, No CSR wakes.
- There would be magnetic errors to explain the horizontal emittance growth.

Summary

- **Upgrades in this year carried out as planned**
- **New accelerating structures against deterioration smoothly installed and operated**
- **Beam optics improvements by installing new large-aperture pulsed Quads at J-ARC and positron capture section**
- **Demonstrated high-speed kickers for 2nd bunch orbit correction**
- **Arrangements of RF sources and accelerating structures for ECS in the electron BT Waveguide system under fabrication and ECS installation to be carried out in this FY**
- **Beam degradation in the BT lines to the MR rings under exploration**

Summary



Thank you