Injector LINAC Status

Kazuro Furukawa for Injector LINAC

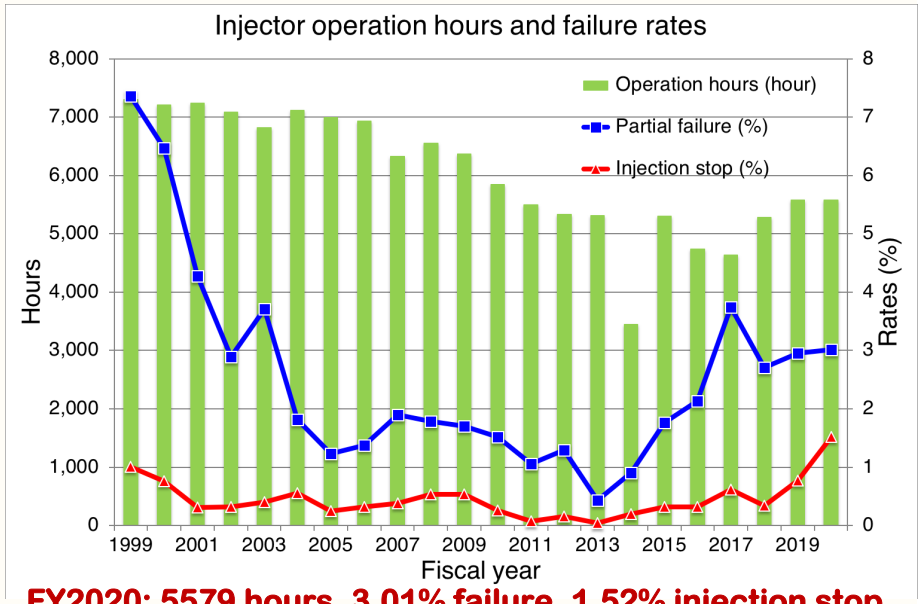
<http://www-linac.kek.jp/linac/>

Data from all injector group members,

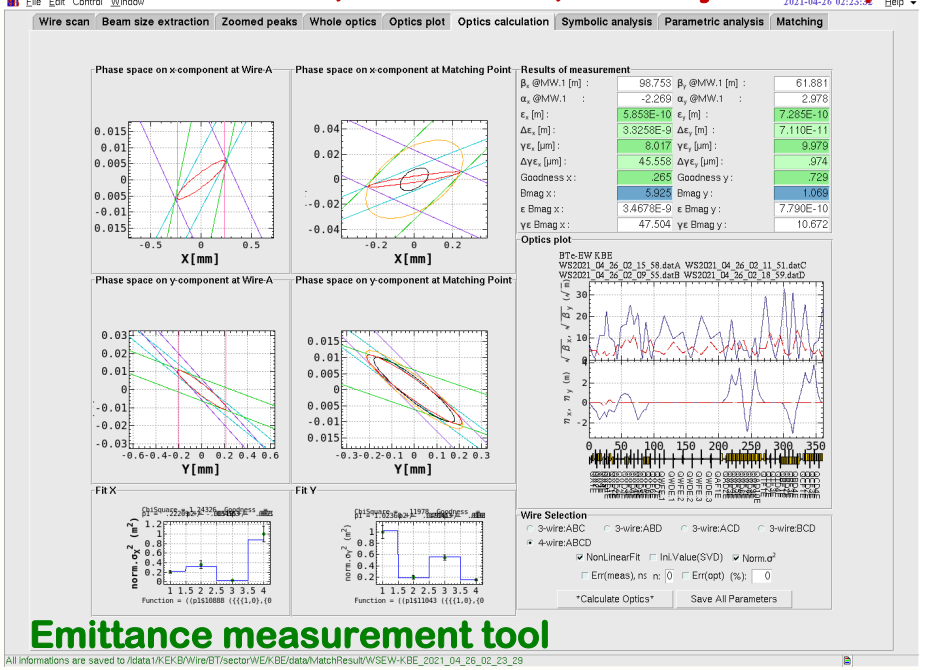
especially M.Satoh, F.Miyahara, R.Zhang, N.Iida, Y.Enomoto, M.Yoshida

Linac Operation Overview

- Operated 5579 hours in FY2020 till March, giving a higher interruption rate in order to meet the more precise SuperKEKB injection requirement
- Gave a higher pulse repetition rate or dual bunches for higher SuperKEKB storage currents
  - Lower injection efficiency with dual bunches at smaller beta-y*, needing more study time (in the future)
- Beam emittance from linac is reasonable, however several times increase in BT
- Reduction of DR emittance is ongoing, with injection/extraction optical matching
- Beam charge increase for electron and positron

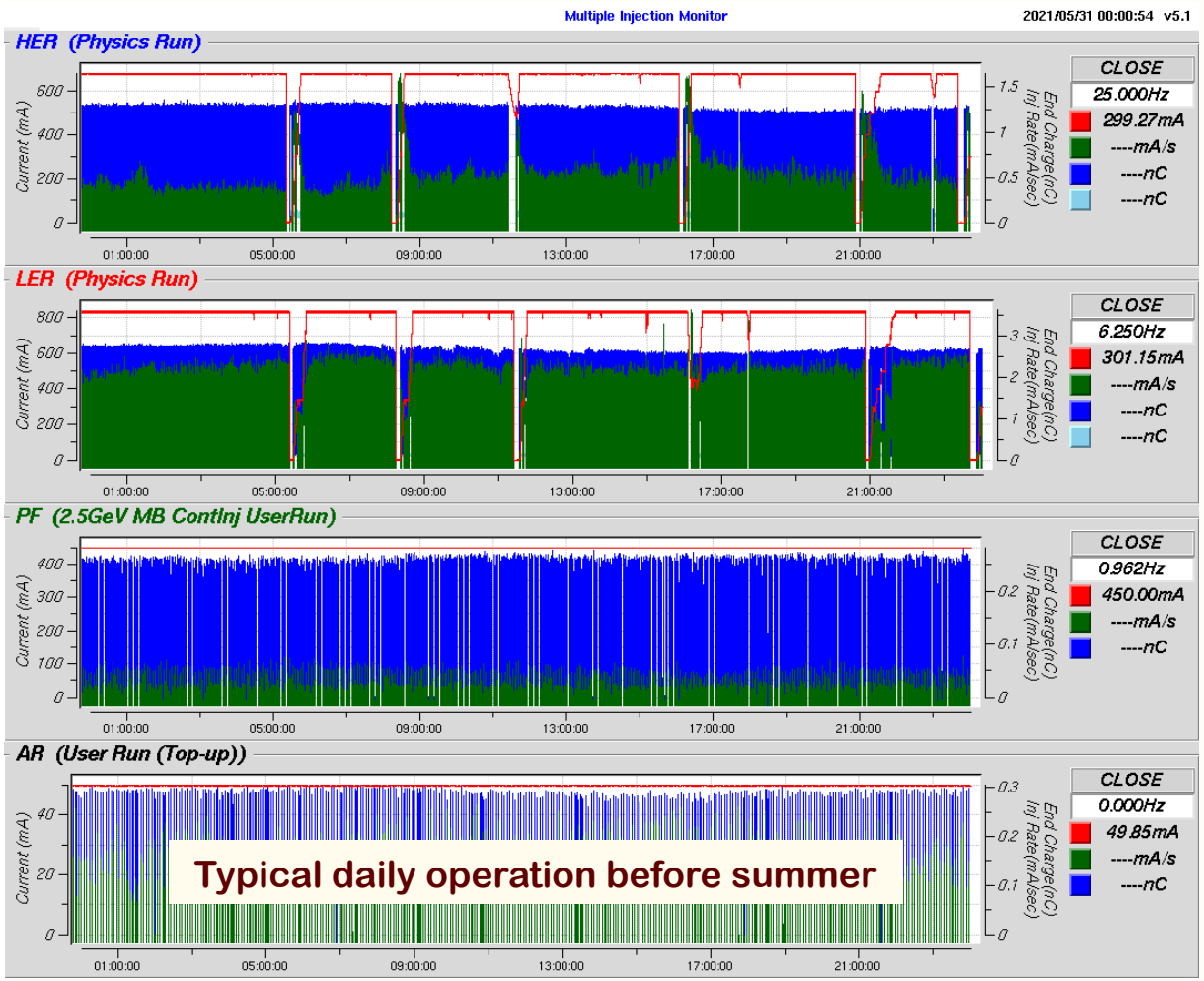


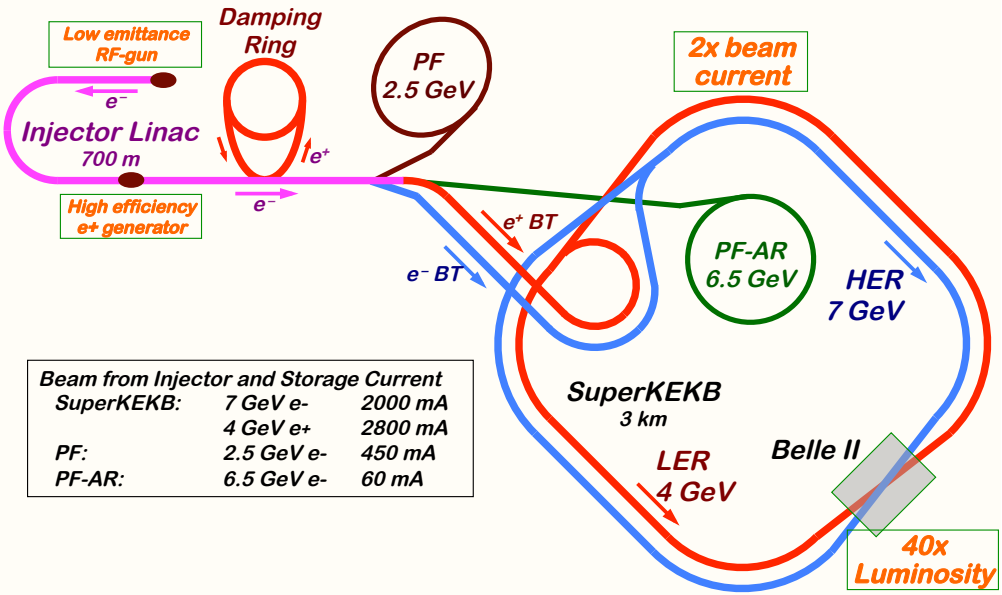
FY2020: 5579 hours, 3.01% failure, 1.52% injection stop



Emittance measurement tool

Simultaneous Top-up Injection





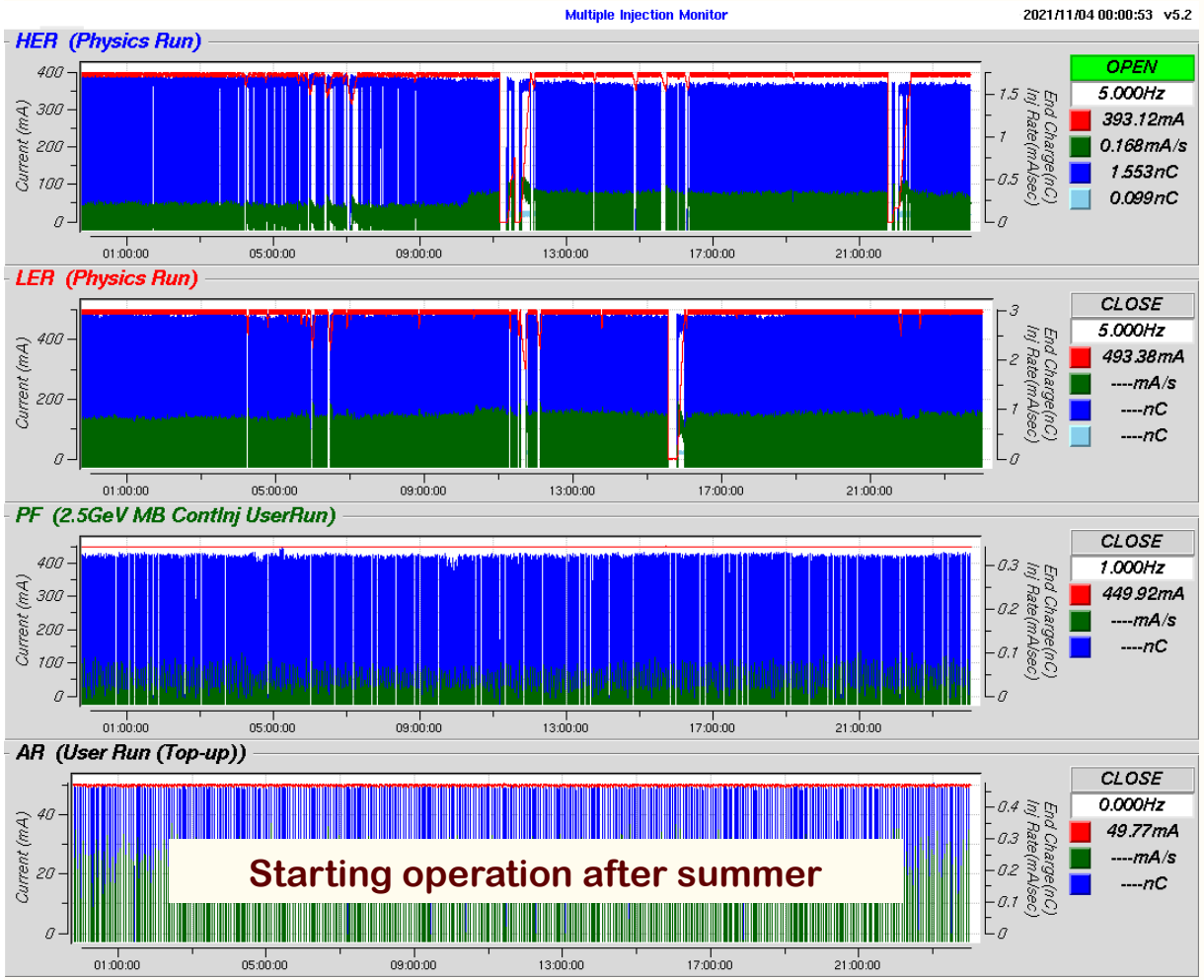
Beam from Injector and Storage Current		
SuperKEKB:	7 GeV e-	2000 mA
	4 GeV e+	2800 mA
PF:	2.5 GeV e-	450 mA
PF-AR:	6.5 GeV e-	60 mA

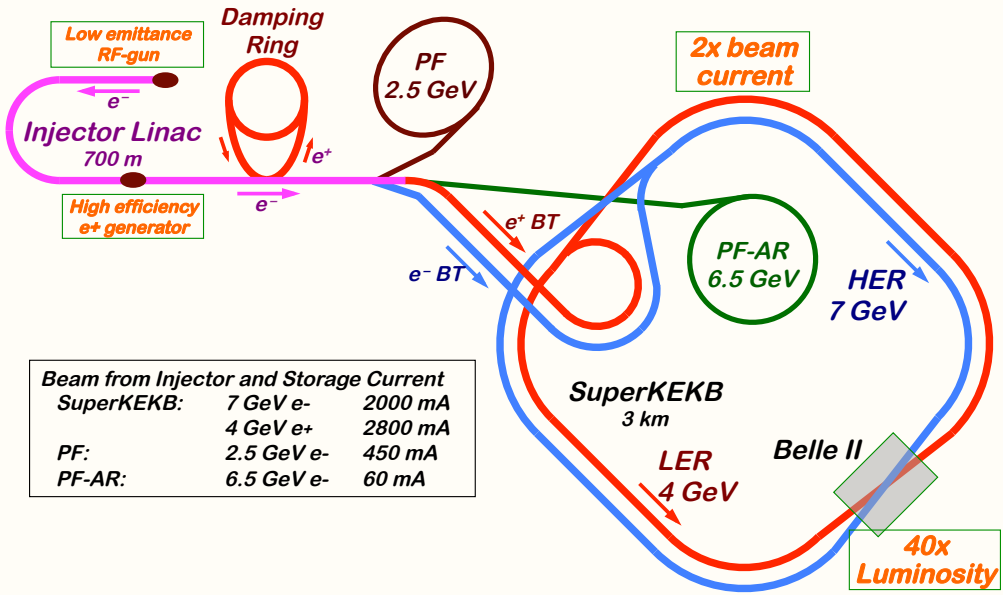
Typical 24 hour operation

- **HER:** 680mA, 12.5 – 25 Hz, 1 bunch, 1.3 nC
- **LER:** 840mA, 12.5 – 25 Hz, 1-2 bunch, 2.6 nC
- **PF ring:** 450mA, <1 Hz, 0.25 nC
- **PF-AR:** 50mA, <1 Hz, 0.3 nC

- **Red**: Storage current (mA)
- **Blue**: Injection charge (nC)
- **Green**: Injection rate (mA/s)

Simultaneous Top-up Injection





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- PF-AR: 50mA, <1 Hz, 0.3 nC

HER 1-2 bunch 2 nC

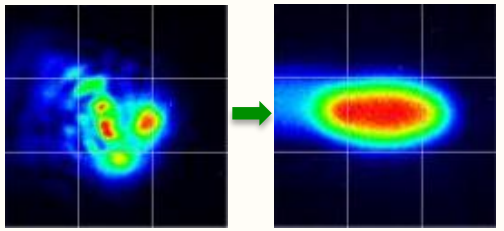
(after summer) LER 1-2 bunch 3 nC

- **Red**: Storage current (mA)
- **Blue**: Injection charge (nC)
- **Green**: Injection rate (mA/s)

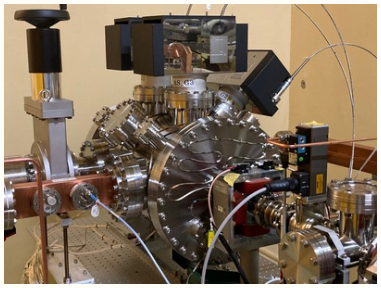
Injector Linac Improvements

Short term：Summer 2021

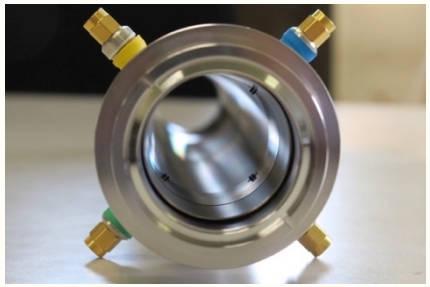
- Optical element and amplifier for 2nd Laser of Rf-gun
- Photo cathode and laser window replacement
- Core/Edge network switch upgrade
- 7 pulsed corrector magnet addition
- Solid-state amplifiers replacing mid-power klystron
- Damaged waveguide renewal
- Beam position monitor just after positron target
- Improved secondary RF-gun as backup
- Improved protection against AC 50Hz fluctuation



Laser stabilization with DOE element



Secondary RF-gun



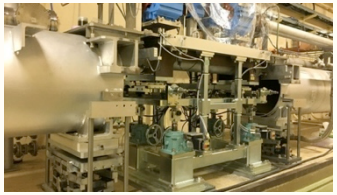
New beam position monitor

Core network switches

Mid-term：up to 2026

- Pulsed magnets & kicker
- Precision girder mover
- Energy compression system
- Improved RF-gun
- Improved positron generation
- Accelerating structure upgrade
- PCB capacitor renewal

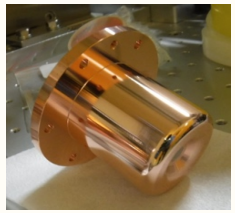
Pulsed magnets



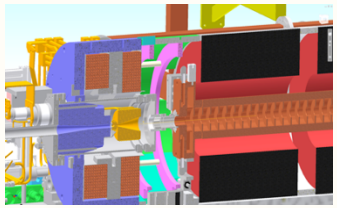
High-precision mover

PCB capacitor renewal

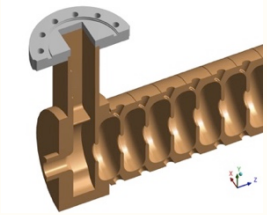
Energy compression



RF gun



Positron generation



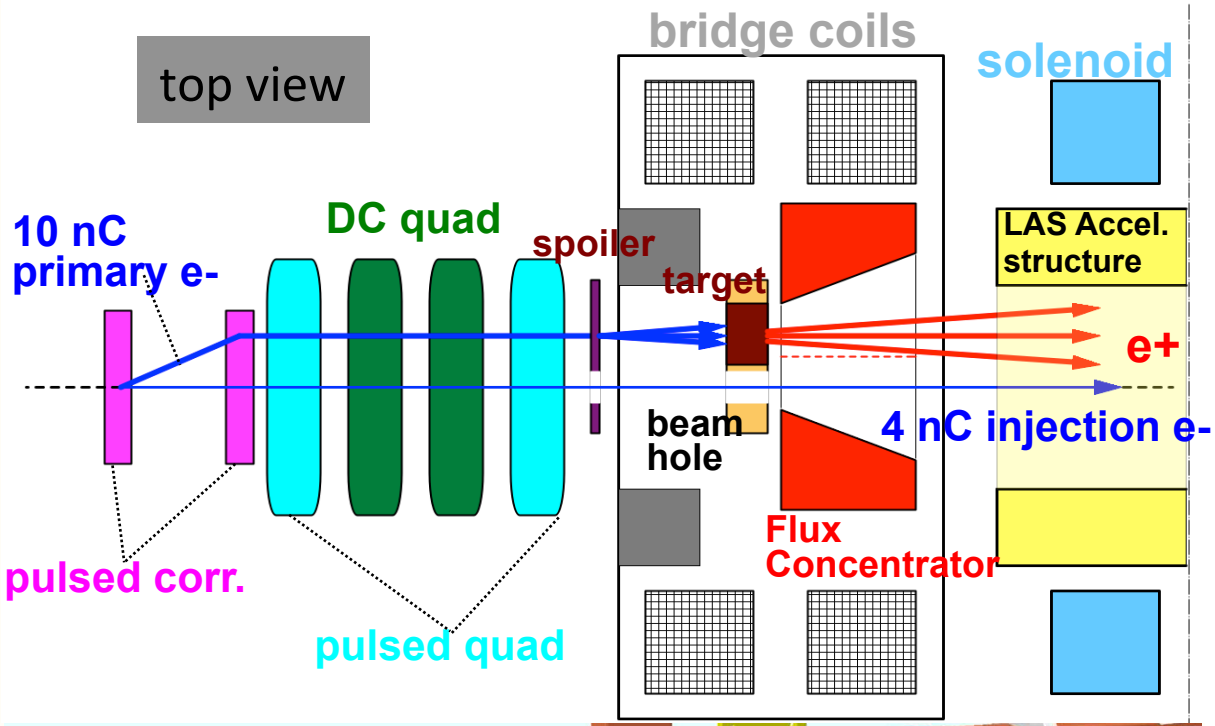
Accelerating structure

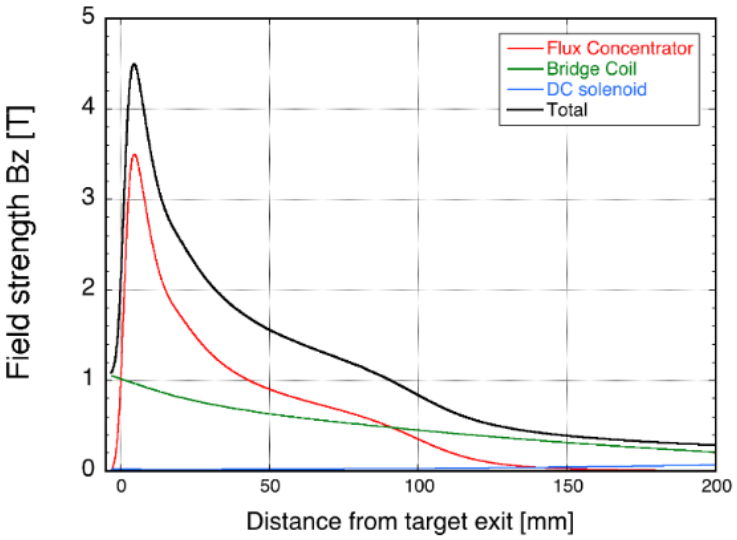
KEKB ARC Review Recommendations

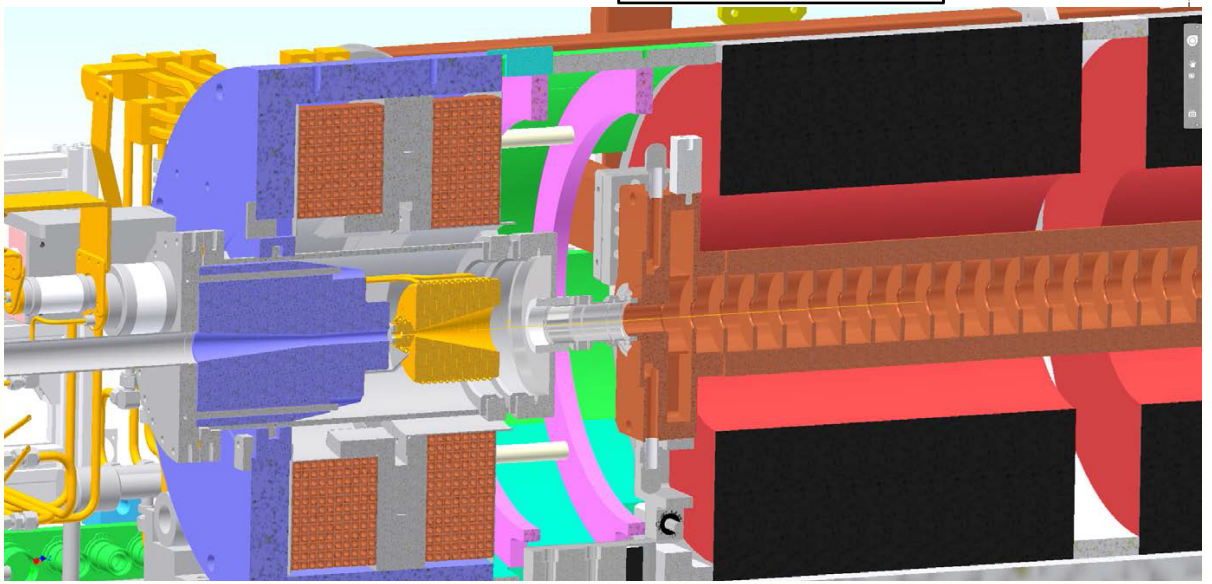
- R2.1: Check RF gun timing and perform careful RF conditioning of the QTW RF gun to recover the RF pulse width and, possibly, to improve the 2nd bunch emittance.
- R2.2: Find and eliminate the source of emittance blow up in the beam transport to improve injection efficiency and minimize radiation damage to the collimators and detector.
- R2.3: Sufficient beam time should be allocated for linac beam studies to achieve and maintain optimum injection performance.
- R2.6: The middle- or long- term upgrade plans must be reviewed by the ARC, ITF, and/or external experts.
- R4.1: Check the injection hardware for both LER and HER, ensuring that the equipment works with the design parameters under the correct circumstances. In particular, the conformity of the waveform of the kicker power supplies needs to be checked.
- R4.6: Pursue the design of the straight transport line and examine its performance.

Positron Generation Improvements

- **Improvement at summer 2020**
  - Cu-Ni alloy for flux concentrator
  - Routine 12 kA operation
  - Correctors inside of 15-m solenoid section
  - Accelerating structure & load
  - Stable 3 nC positron delivery

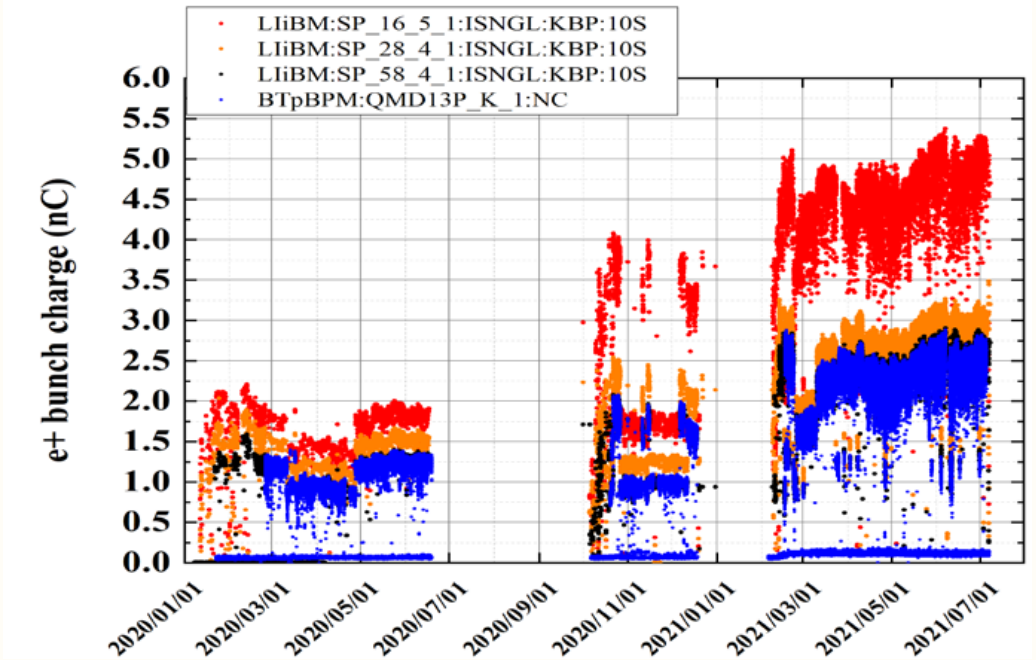


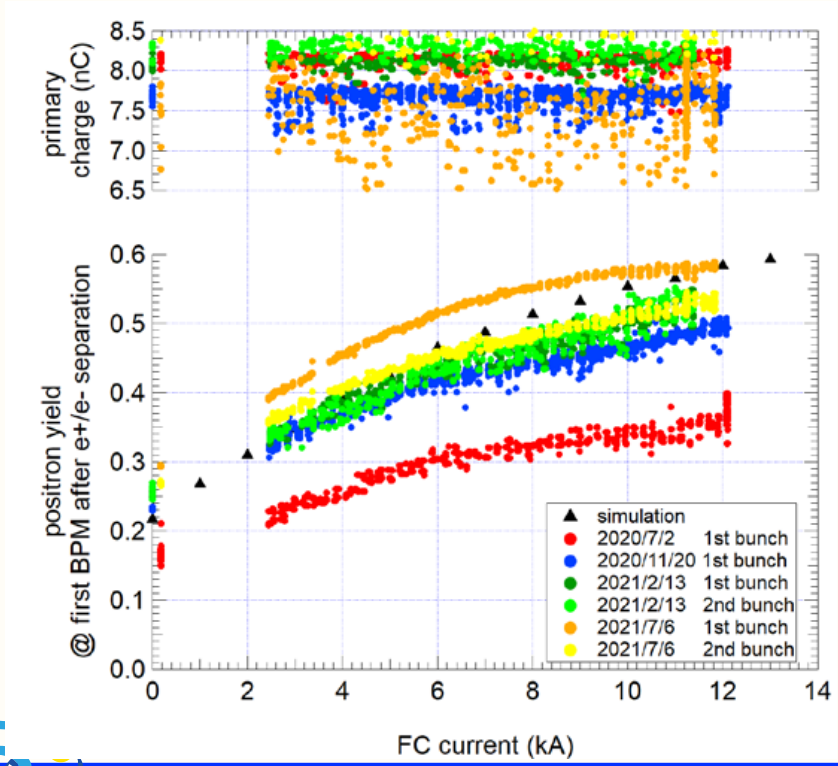




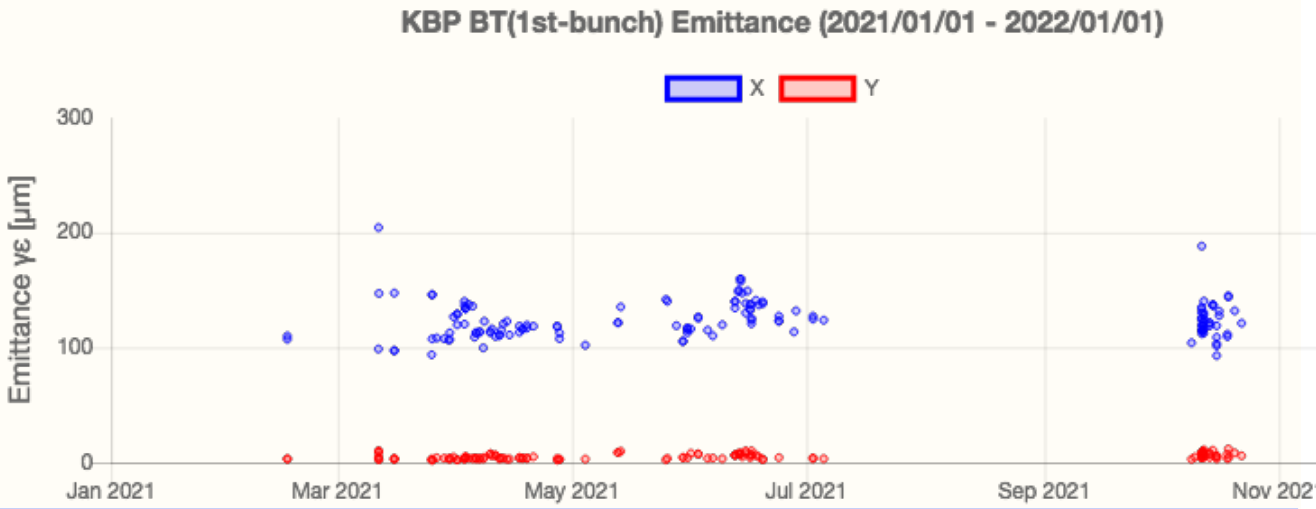
Positron Reaching Designed Charge

- Positron beam tuning
  after hardware improvements
- Solenoid field and accelerating field
  are not optimal yet
- Needs further tuning for the future
  - Often operated at lower beam current
    depending on the stored beam





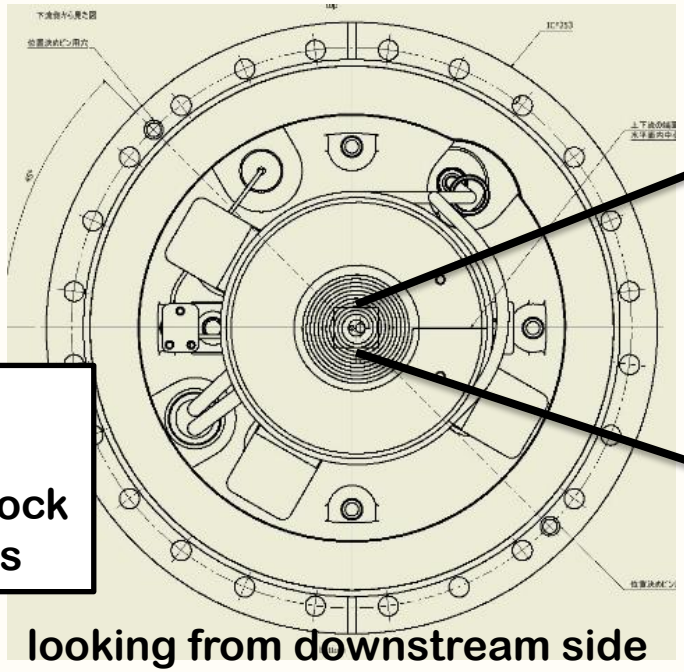
Present emittance requirement: γεx 100 μm, γεy 30 μm



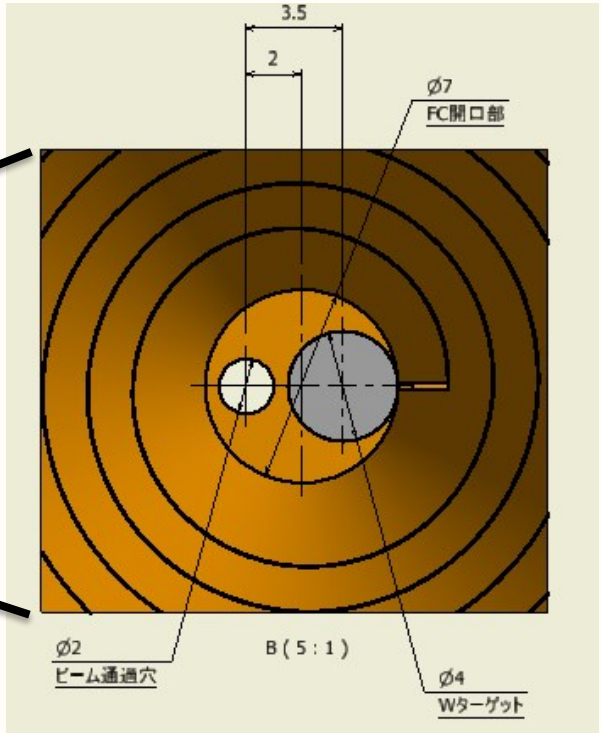
Future Improvement

- **Further optimization is considered**
  - Positron LER storage current is higher and the lifetime is shorter
  - We may need more positron charge
    - Such as 6 nC / bunch
  - Closer target placement
  - Beam instrumentations
  - Correctors
  - etc.

Under present configuration:
Magnetic field is lower
and asymmetric
Positron would be spirally
transferred



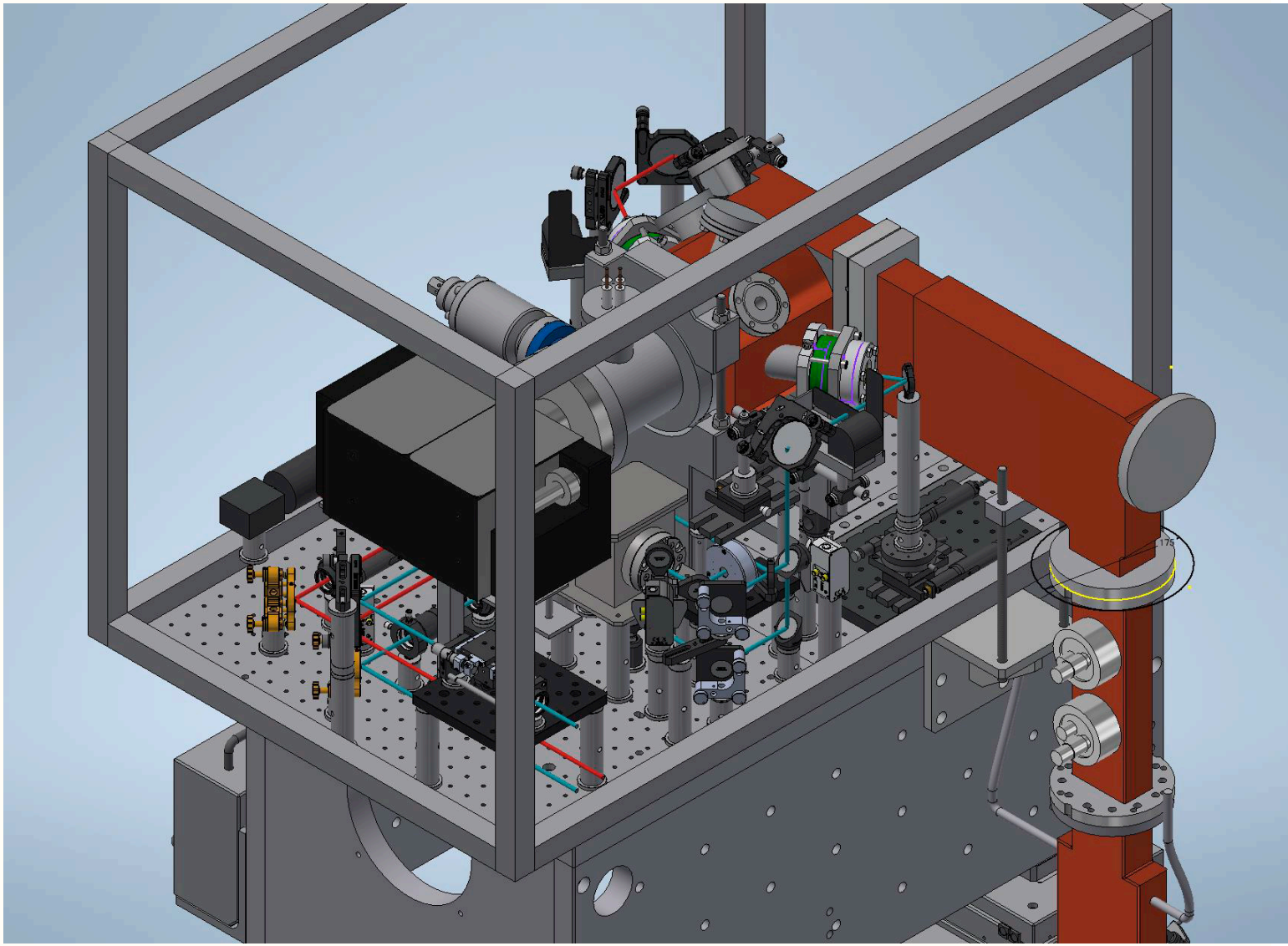
looking from downstream side



Target material : W
Target size : Φ4 x 14
Inserted in the pure Cu block
Connected by HIP process

Electron Beam from RF gun

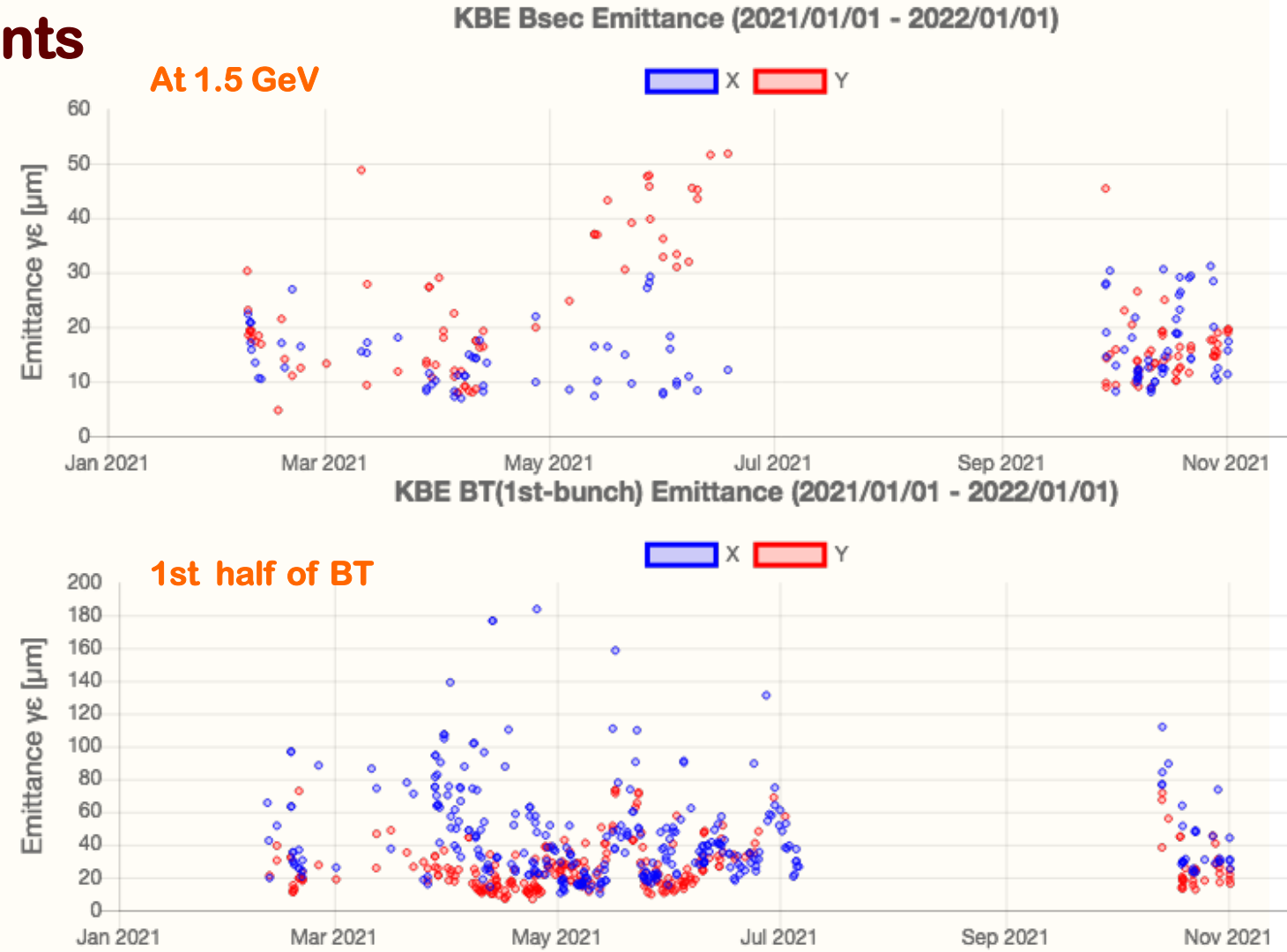
- **Tight configuration for cavity and optical elements**
  - **Dual laser introduction with 1st and 2nd laser for photocathode**
    - **Flat laser beam with DOE**
  - **As well as laser application for laser cleaning**
    - **Focused laser beam**



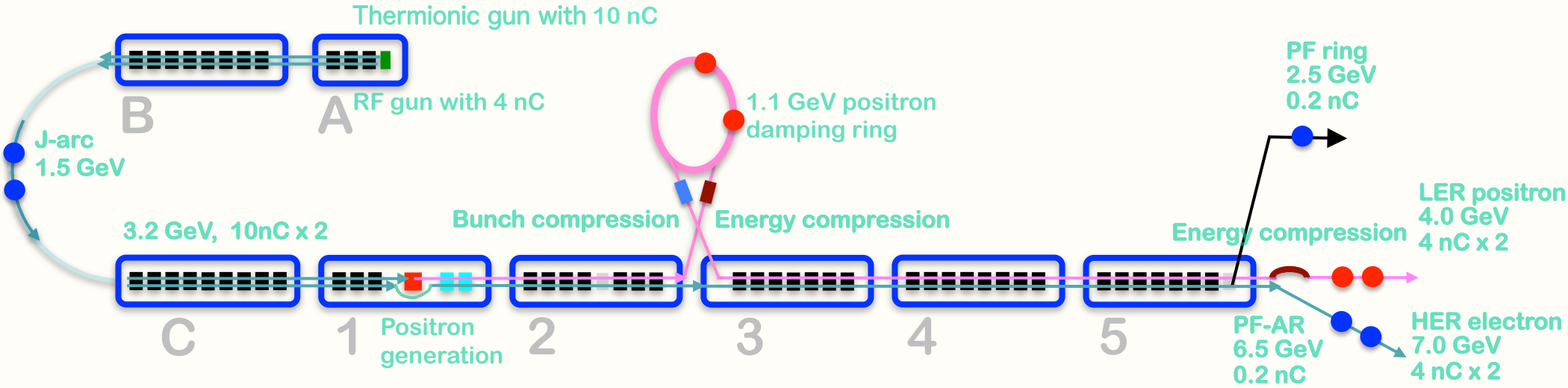
Electron Beam from RF gun

Beam emittance

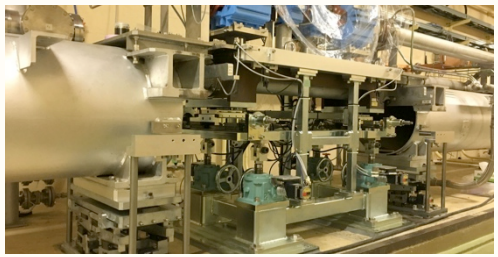
- Present requirement γεx 100 μm, γεy 40 μm
- Stability improvements
  - DOE for 2nd laser
  - Stabilization loops
  - 7 pulsed correctors
- Emittance blow-up in later part of BT
  - Needs further studies



Injector Linac Upgrade Items 2022 - 2026



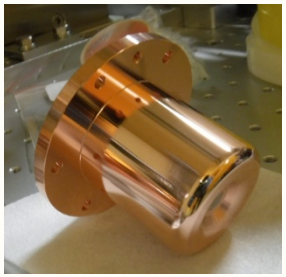

Pulsed magnets/kickers



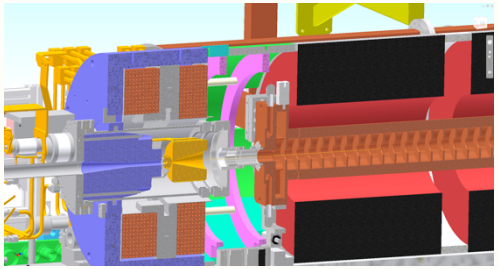
High precision movers

PCB capacitor renewal

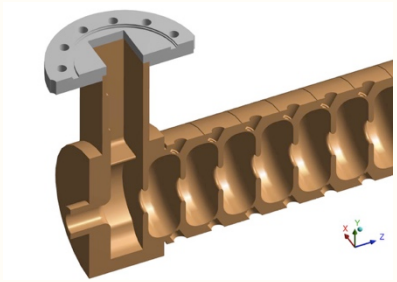
New energy compressor



RF gun



Positron capture section



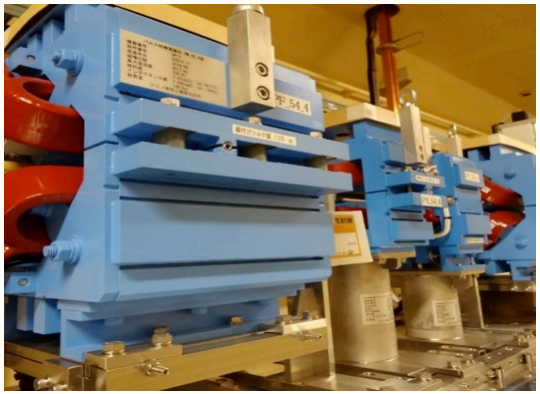
Accelerating structure

Pulsed Magnet, Kicker and Mover

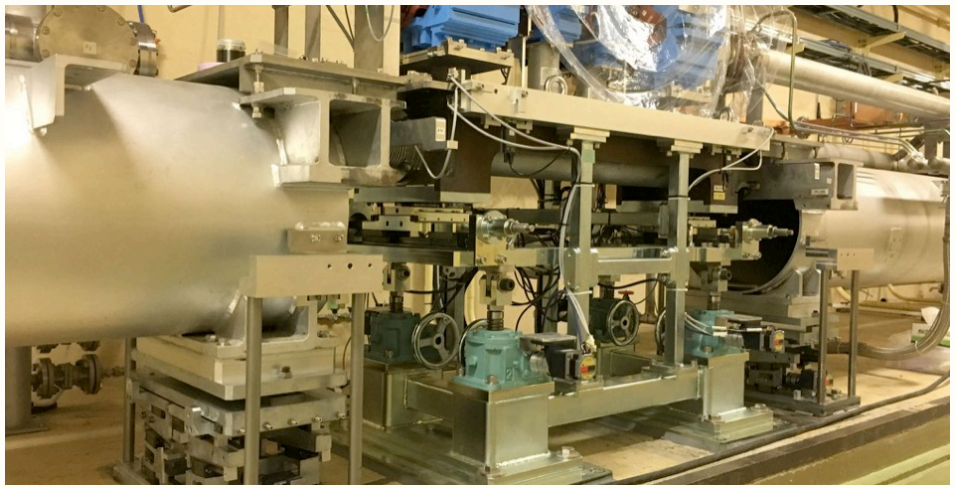
Injector linac injects beams into SuperKEKB HER, LER as well as light sources PF, PF-AR with adequate beam properties at 50 Hz maximum in simultaneous top-up injection scheme. Pulsed magnets, kicker magnets and girder movers will be installed in order to suppress emittance blow-up caused by wakefield in accelerator structure with 4 nC per bunch. Kicker magnets may correct beam orbits separated by only 96 ns. Girders may adjust girders at less than 10 microns.

Ceramics chamber integrated kicker development

Pulsed magnets and power supplies

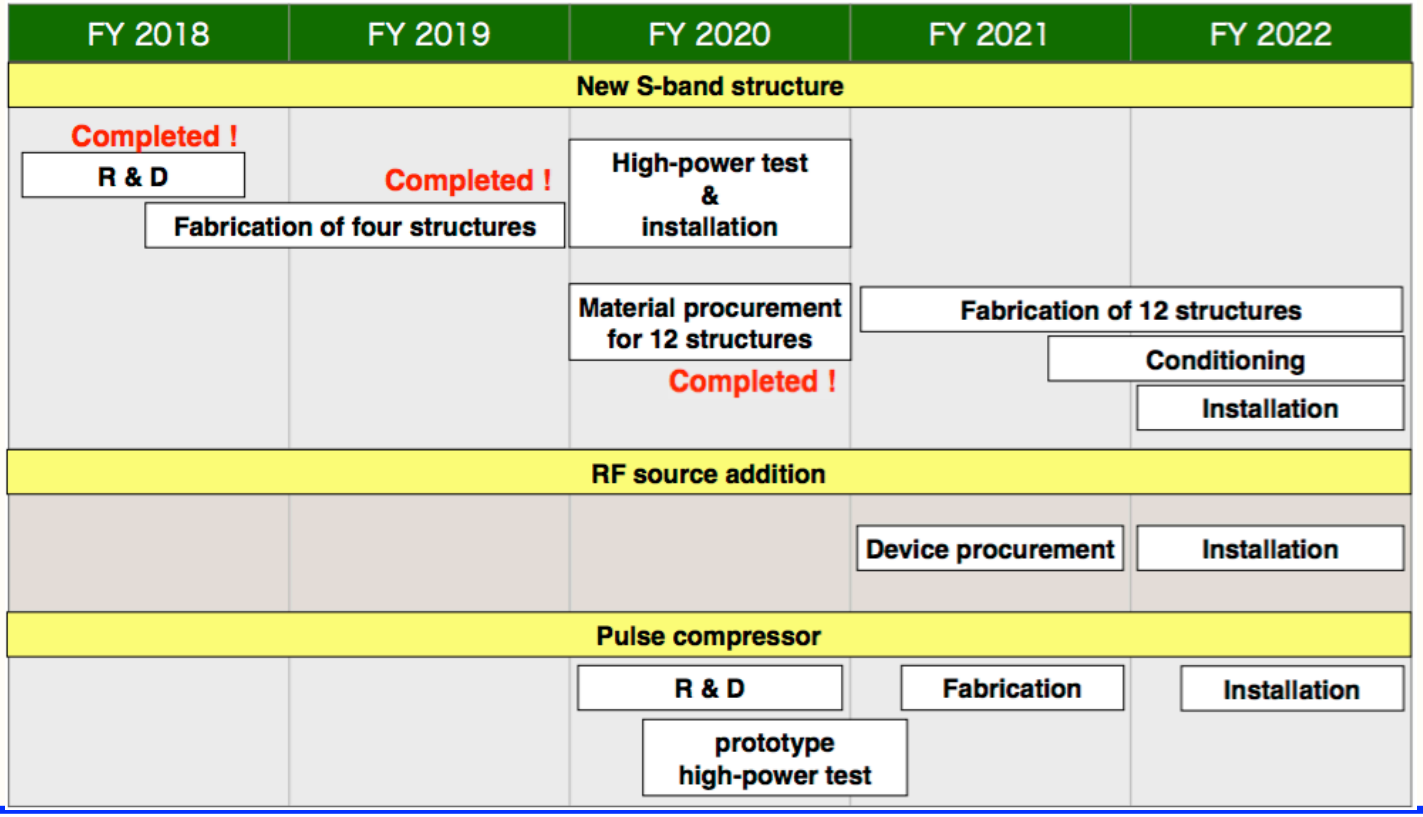


High-precision girder movers



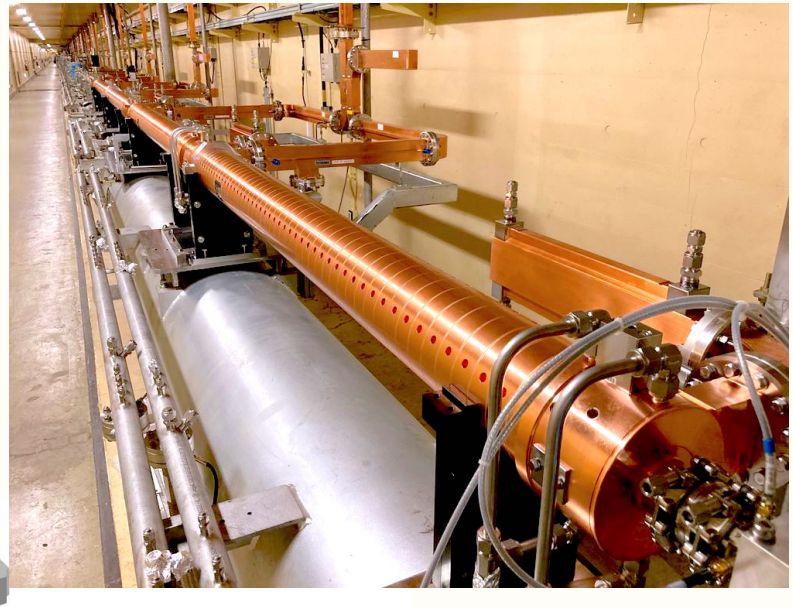
Higher Energy Injection and Collision

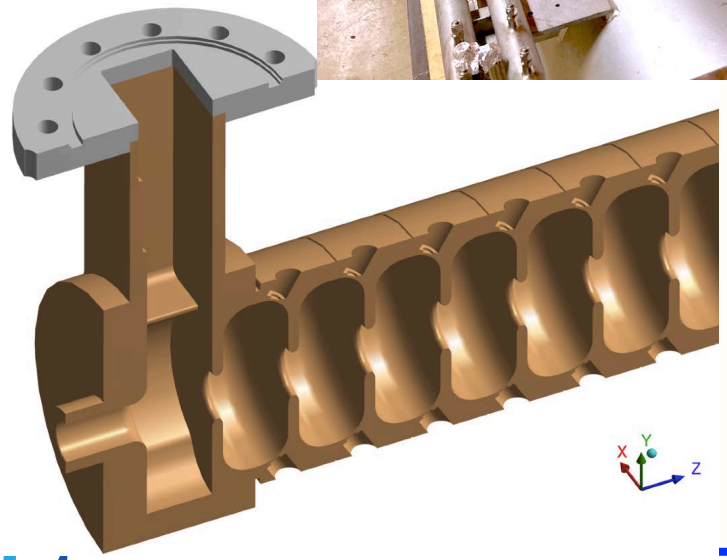
- **Mitigation of accelerator structure issues**
  - Originally designed for 8 MeV/m, but has been used at 20 MeV/m
  - Degradation that lead to high field emission rate and discharges
  - Water leaks
  - Not only Y(6S) but even Y(4S) could be suffered
- **4-year plan to fabricate and install new accelerator structures**



New Accelerating Structures and ECS for Electron Beam

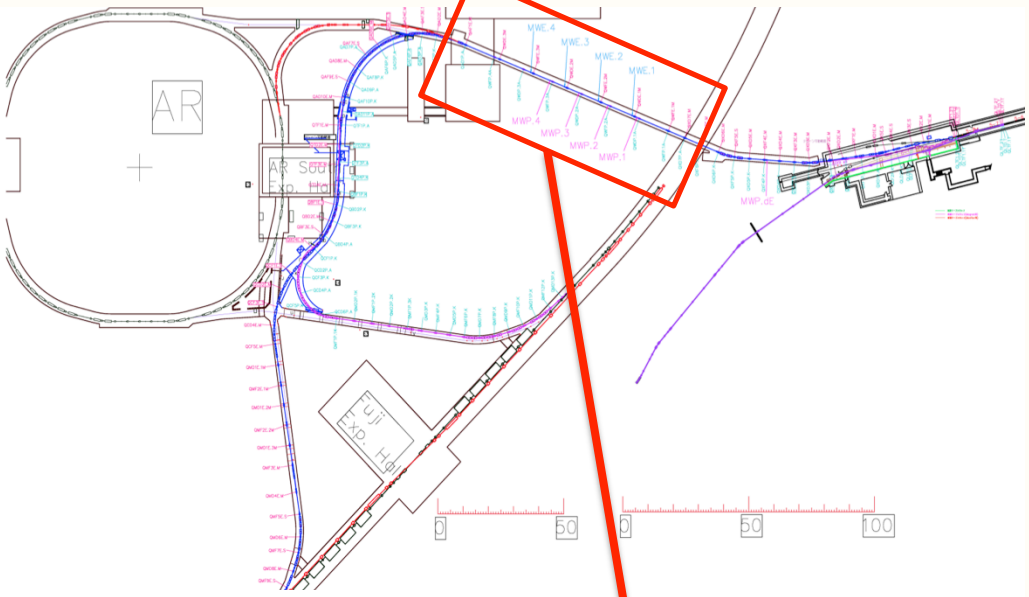
7% of 230 accelerating structures will be replaced for mitigation of 40-years of degradation by discharges and water leaks.

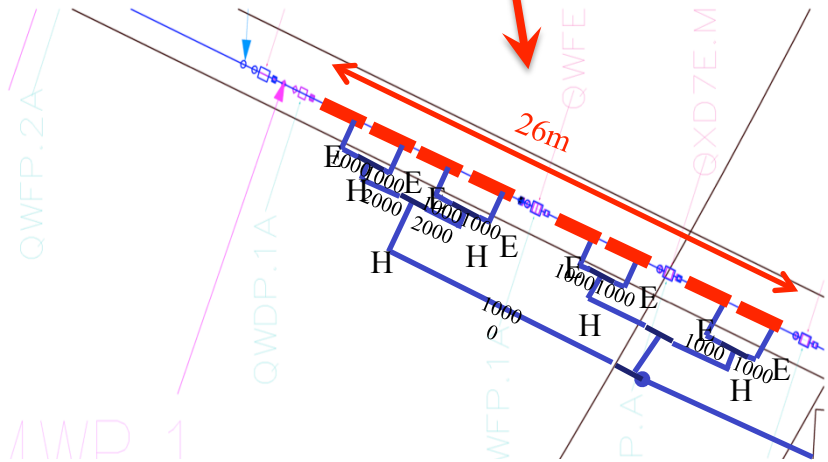




Additional replace-ment will be necessary in near future.

Energy compression system (ECS) for electron beam will be installed at the beginning of the beam transport line.

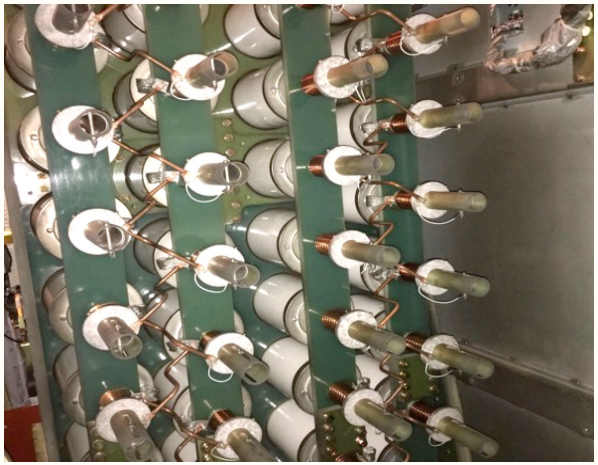




Capacitors with PCB contamination

Capacitors (up to 1200) in power modulators with low-level PCB produced before 1991 will be replaced following the law.

Capacitors in high-power klystron modulators



Summary:

Injector linac continues to improve with hardware upgrade in above 7 category regions from 2022 to 2026.

Summary

- Injector LINAC continues reasonable injections in simultaneous top-up injection mode.
- Emittance blow-up at the 2nd half of beam transport line is still a mystery, but partially relaxed recently with finer parameter tuning to make injection and storage beams match.
- The injector upgrade implementation is discussed in 7 categories for the final beam parameters with higher bunch charges and lower transverse and longitudinal emittances.

Thanks

Linac Beam Parameters for KEKB/SuperKEKB

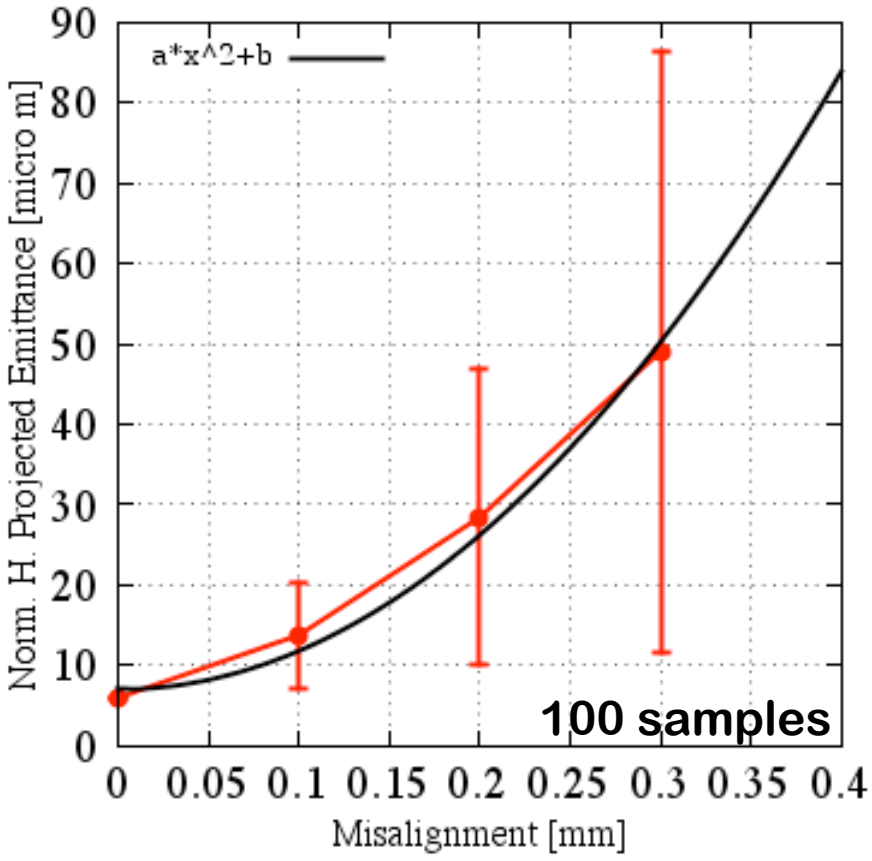
Stage	KEKB (final)		Phase-I (achieved)		Phase-II (achieved)		Phase-III (interim)		Phase-III (final)	
Beam	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Stored current	1.6 A	1.1 A	1.0 A	1.0 A	–	–	1.8 A	1.3 A	3.6 A	2.6 A
Life time (min.)	150	200	100	100	–	–	–	–	6	6
Bunch charge (nC)	primary e- 10 → 1	1	primary e- 8 → 0.4	1	0.5	1	2	2	primary e- 10 → 4	4
Norm. Emittance (γβε) (mrad)	1400	310	1000	130	200/40 (Hor./Ver.)	150	150/30 (Hor./Ver.)	100/40 (Hor./Ver.)	100/15 (Hor./Ver.)	40/20 (Hor./Ver.)
Energy spread	0.13%	0.13%	0.50%	0.50%	0.16%	0.10%	0.16%	0.10%	0.16%	0.07%
Bunch / Pulse	2	2	2	2	2	2	2	2	2	2
Repetition rate	50 Hz		25 Hz		25 Hz		50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (LER, HER, PF)		No top-up		Partially		4+1 rings (LER, HER, DR, PF, PF-AR)		4+1 rings (LER, HER, DR, PF, PF-AR)	

Gradual improvements keeping light source injections

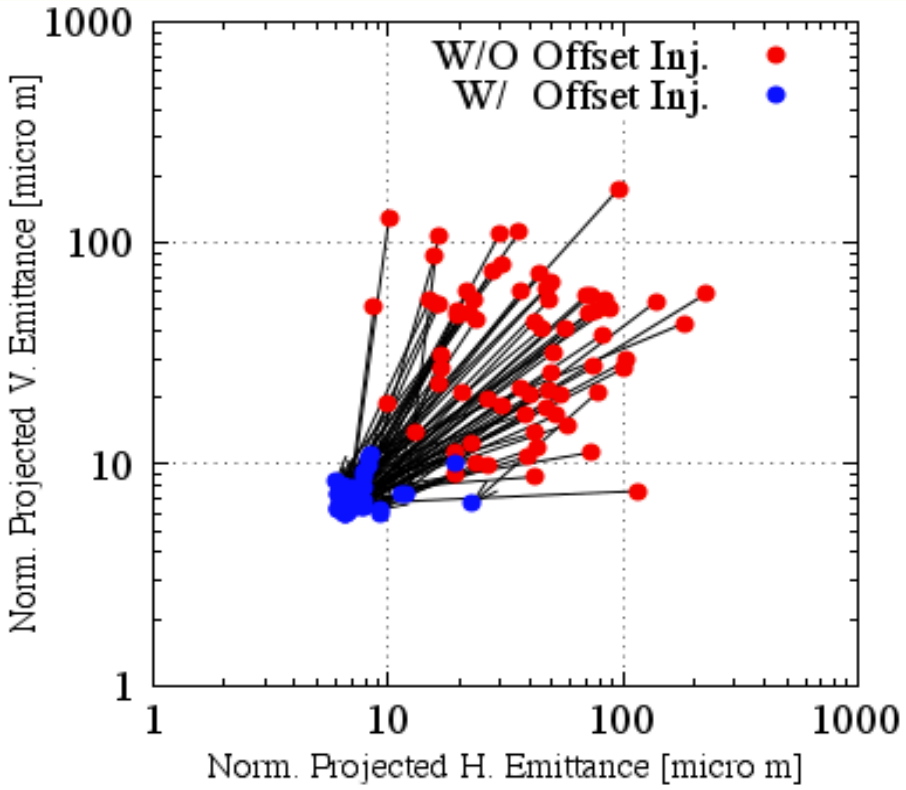
Emittance Preservation

- Offset injection may solve the issue
- Orbit have to be maintained precisely
- Mis-alignment should be <0.1mm locally, <0.3mm globally

Mis-alignment leads to Emittance blow-up



Orbit manipulation compensates it

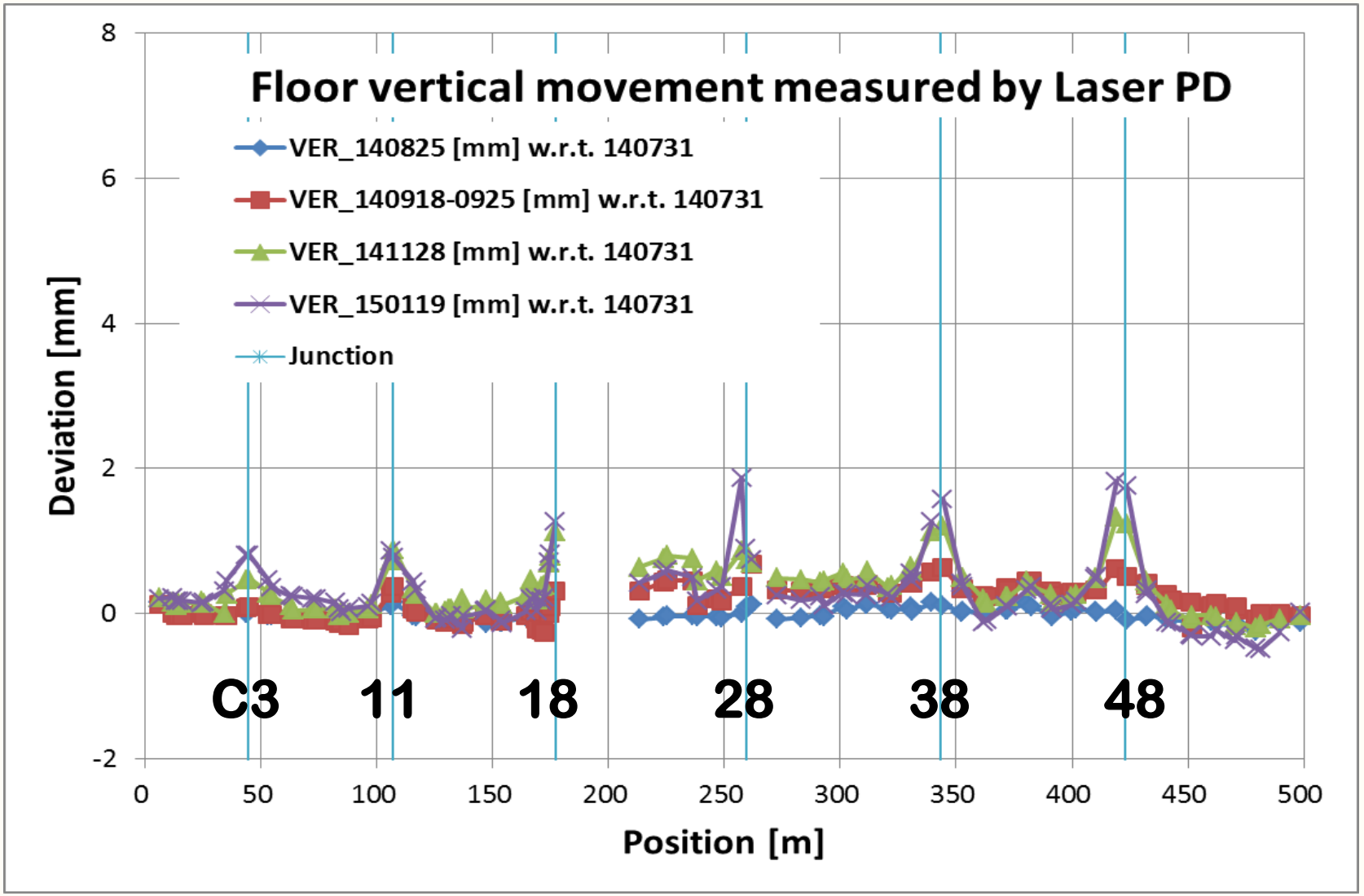


Sugimoto et al.

Floor vertical movement

in a half year from summer to winter

Higo et al.



Injector Linac and AC Power Frequency

- Injector linac selects a proper timing depending on the storage ring and injects beams at a precision less than 10 ps
- It should synchronize with AC power 50 Hz within 2 ms considering the stability of 40 year-old devices
- It is required for the bucket selection mechanism through the damping ring that the AC line frequency should stay within 49.9 Hz to 50.1 Hz
- Such an event occurred a few time a month. However, it increased up to several times a day since April. It prevented the injection, and triggered RF discharges.
- Additional software and hardware were introduced.

Figure by Di Wang