Injector Commissioning

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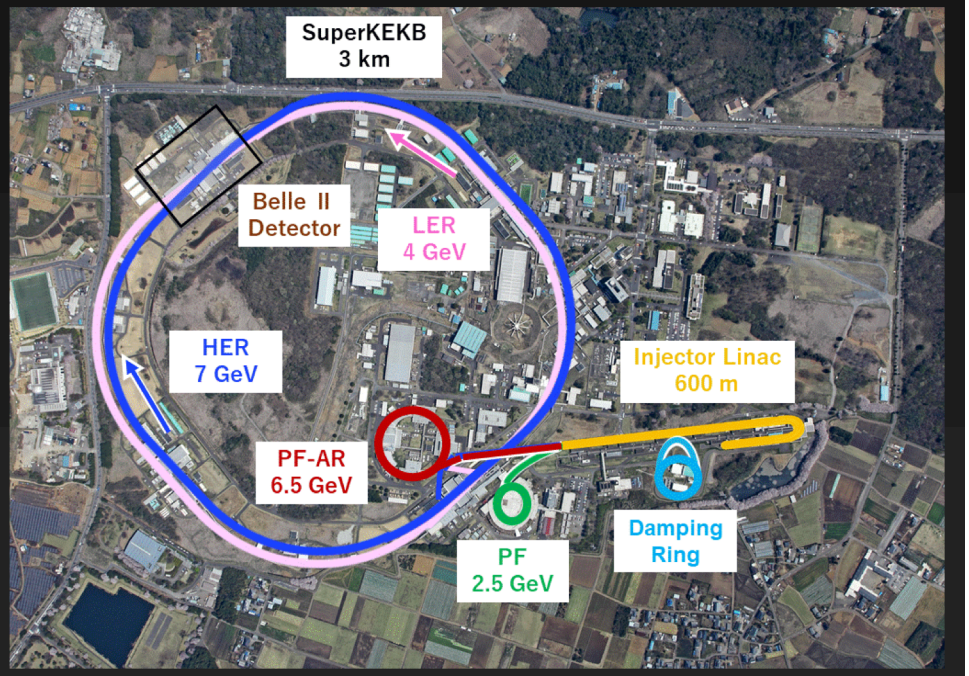
Injector Overview

- Injector linac
  - e-/e+ injector for 4 independent storage rings and e+ DR
  - 600 m, 25 Hz (up to 50 Hz)
  - Single or two bunch operation (96 ns interval) for SuperKEKB
- SuperKEKB (Phase II):
  - HER: e-, 7 GeV, 1 nC, 25 Hz
  - LER: e+, 4 GeV, 0.5 nC, 25 Hz

    Damping ring: 1.1 GeV
- Light sources:
  - PF: e-, 2.5 GeV, 0.3 nC, 5 Hz

    three times daily injection or top-up for hybrid operation
  - PF-AR: e-, 6.5 GeV, 0.3 nC, 5 Hz

    three times daily injection

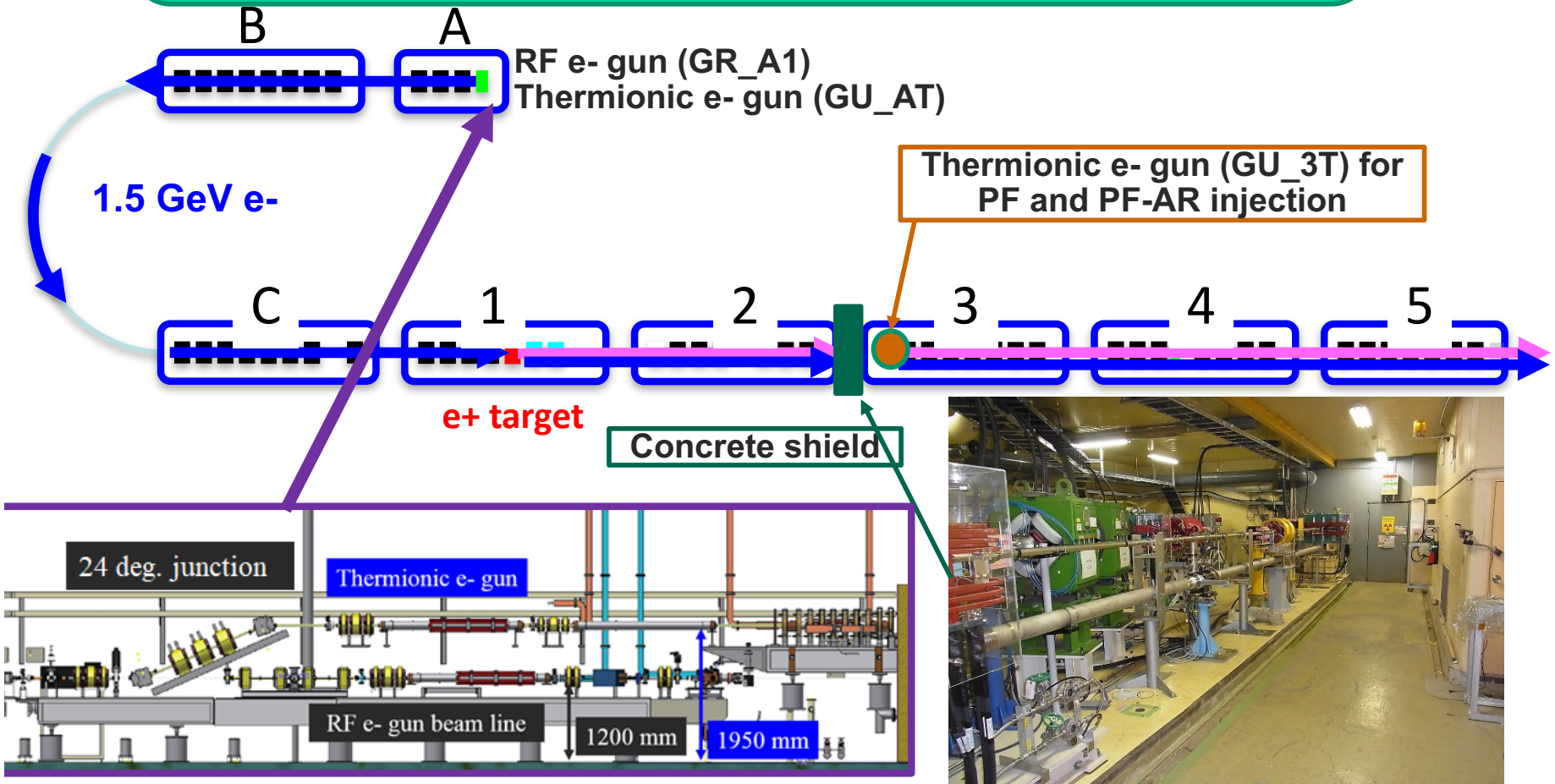


Recent Commissioning Topics

- PF, PF AR injection from GU_AT (@ SectorA) thermionic gun (previously GU_3T @ Sector3)
- PF AR injection via new beam transport line
- Monitors
  - New BPM readout (high measurement precision) and synchronized measurement
  - RF monitor. Wire scanner at Sector2 and Sector3. Streak camera at Sector3
- Simultaneous beam operation w/ thermionic e- gun
- RF e- source progress
  - M. Yoshida
- Stable operation of pulsed quad and steering (Sector3 to Sector5)
  - Y. Enomoto
- Timing system for DR injection and extraction
  - H. Sugimura
- ECS and BCS for DR are working w/o significant trouble

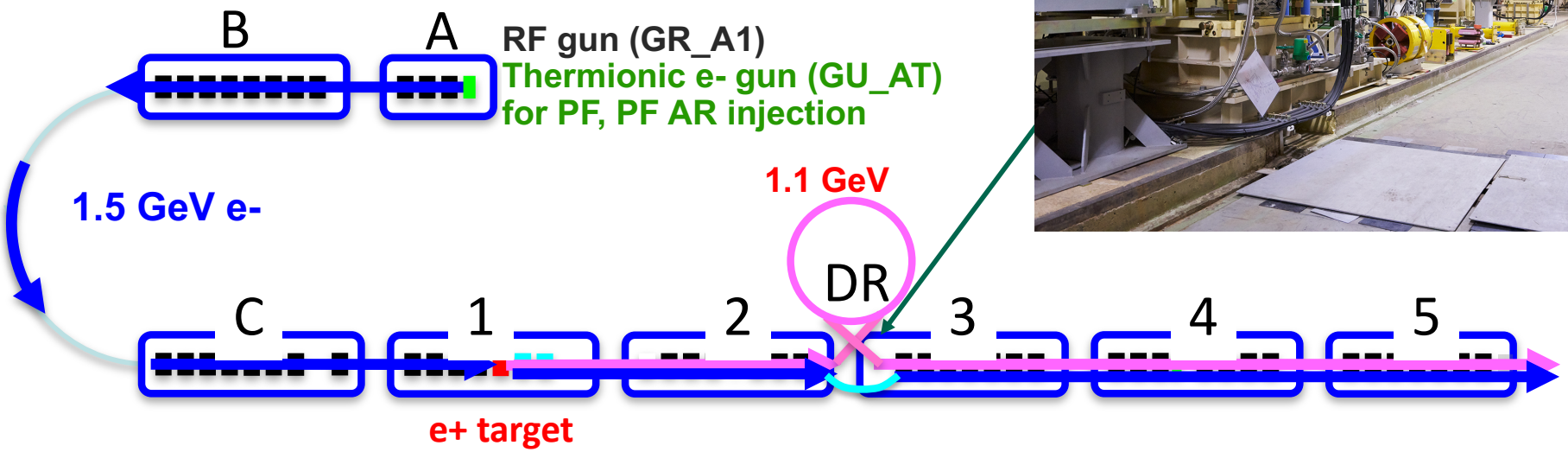
Bipartition Linac

- Summer 2010 ～ Summer 2017:
  - Concrete shield between Sector2 and Sector3.
  - Downstream: GU_3T for PF and PF-AR injection
  - Upstream: Beam line works in tunnel
    GR_A1 study @ SectorAB



Removal of Concrete Shield

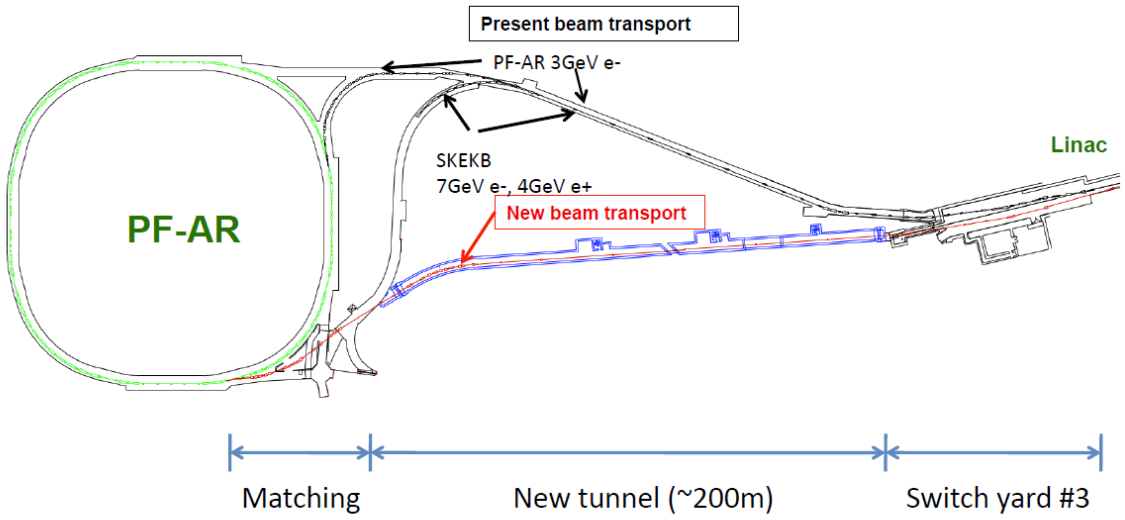
- Summer 2017
  - Construction of junction beam line between RTL and Linac
  - Removal of concreate shield and GU_3T thermionic e- gun
  - Light source injection w/ GU_AT e- gun
    - PF injection: Apr. 2017
    - PF-AR injection: Feb. 2017



New PF AR BT for Full Energy Top Up Injection

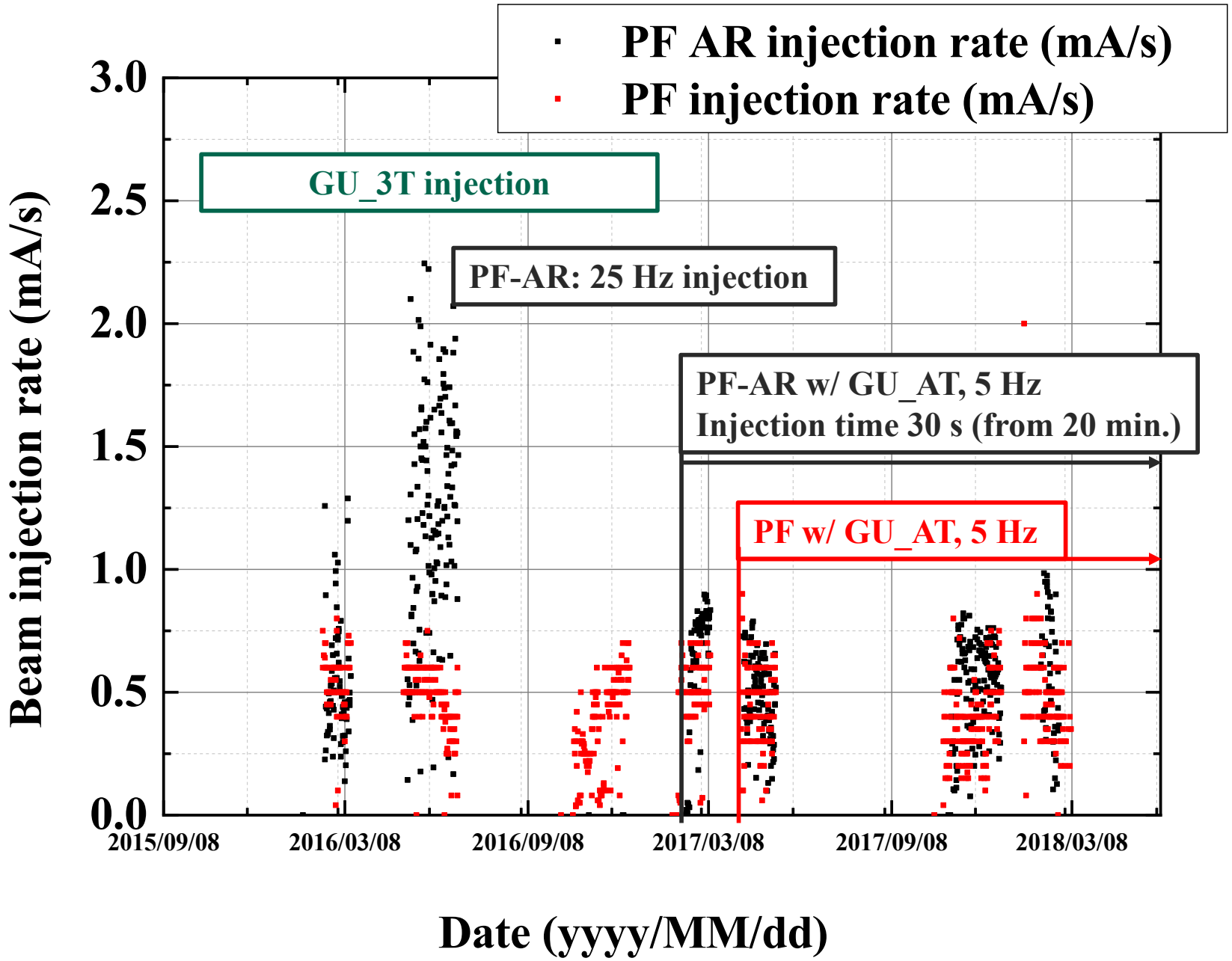
- During KEKB operation, PF-AR and KEKB share the long part of BT line. PF-AR injection interrupts KEKB injection ~ 20 min. (sometimes 1 hour)
- New PF-AR BT is required for SuperKEKB operation
  - Design work FY2012
  - New tunnel construction: FY2013 - 2014
  - Installation of full components: FY2016
  - Success of beam commissioning: Feb. 13 – Mar. 10, 2017
    - Day1: Deliver e- beam to end of new BT
    - Day2: Beam storage

New beam transport for PF-AR



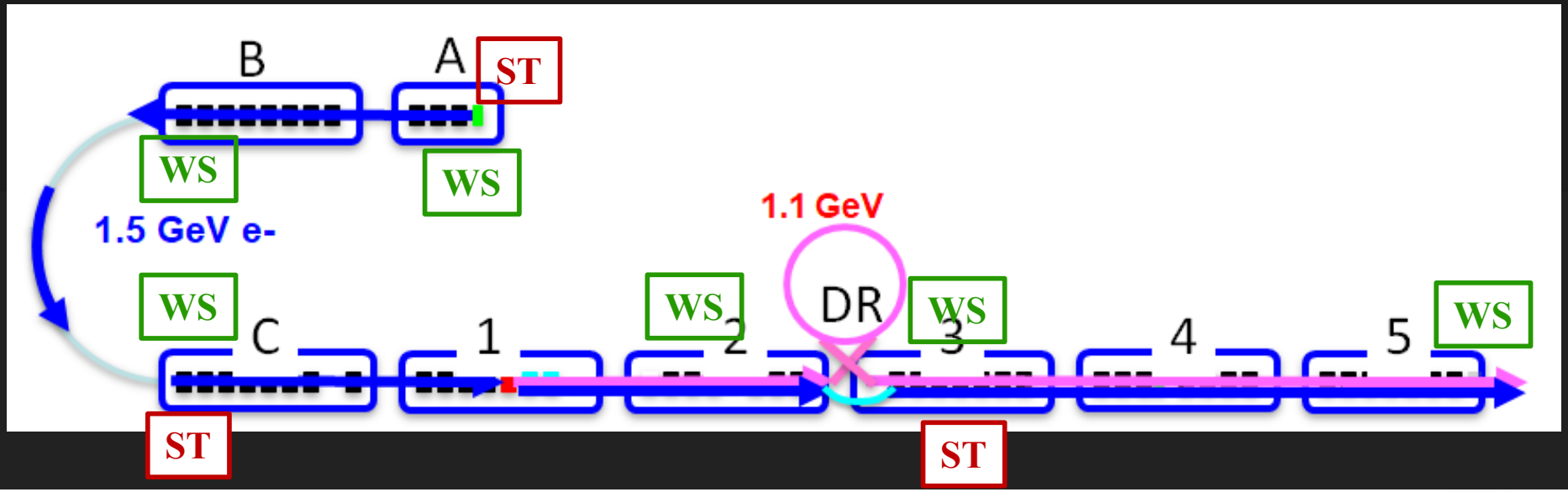
H. Takaki (KEKB review 2013)

PF, PF AR injection rate



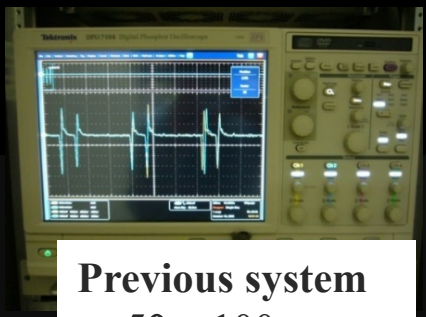
Monitors

- Beam position monitor (x 103)
  - Four strip line electrodes (x 97)
    - Measurement precision ~ 10 μm
  - Eight strip line electrodes (x 6) (J-ARC, LTR x2, PF BT, HER BT, LER BT,)
- Profile monitor (x 104)
  - Al_2O_3/CrO_3 (AF995R, Demarquest Co.). (t: 1 mm, 0.1 mm), YAG:Ce (t: 0.1 mm)
- Wire scanner (WS) (x 6)
  - SectorA, B, C, 2, 3, 5
- Streak camera (ST) (x 3)
  - SectorA, C, 3

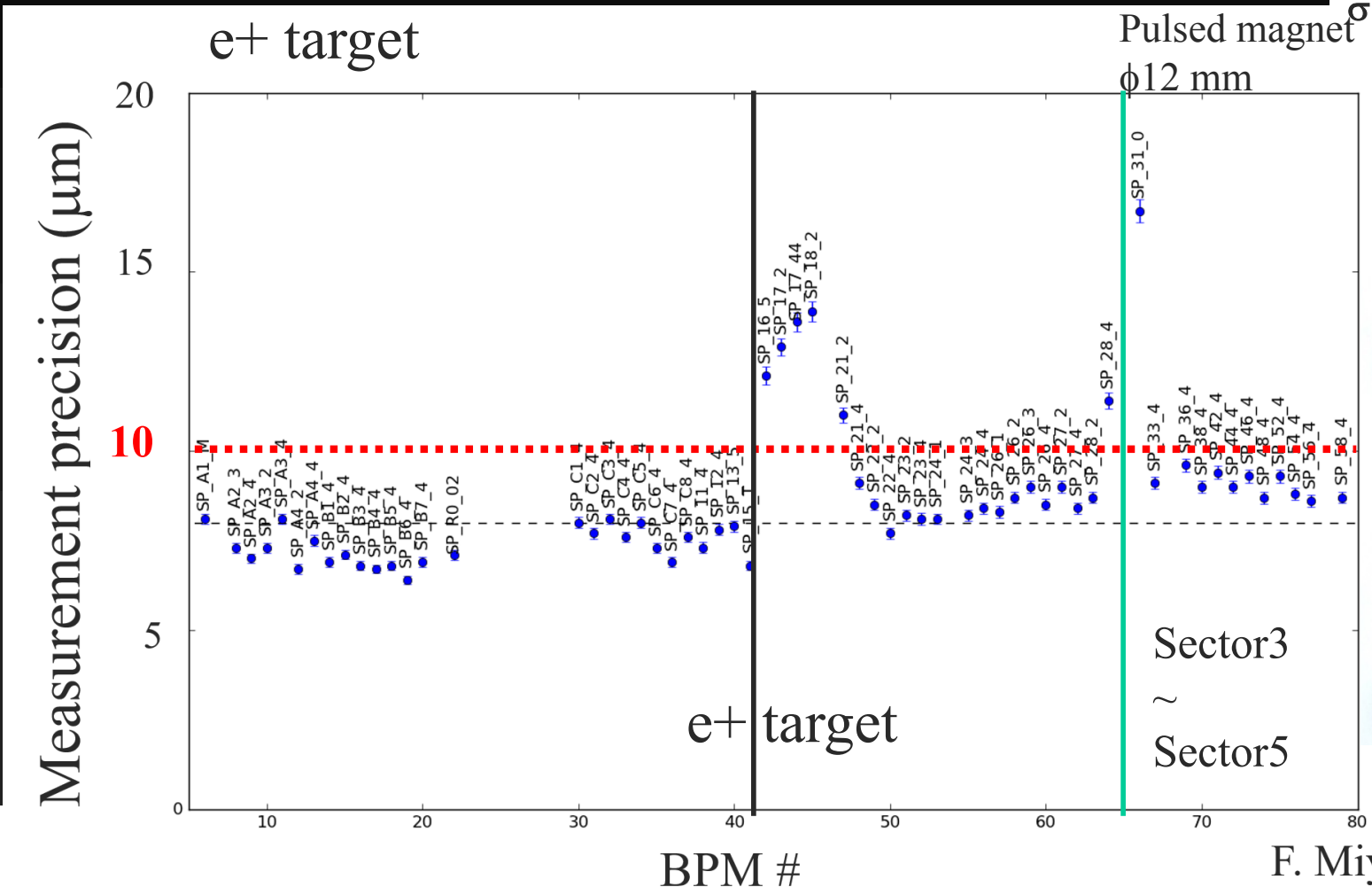


Measurement precision of BPM

- BPM readout system for 100 BPMs have been replaced by VME based card from digital oscilloscope.
- Achieve target performance ($\sigma \sim 10$ μm)



Previous system
σ: 50 ~ 100 μm

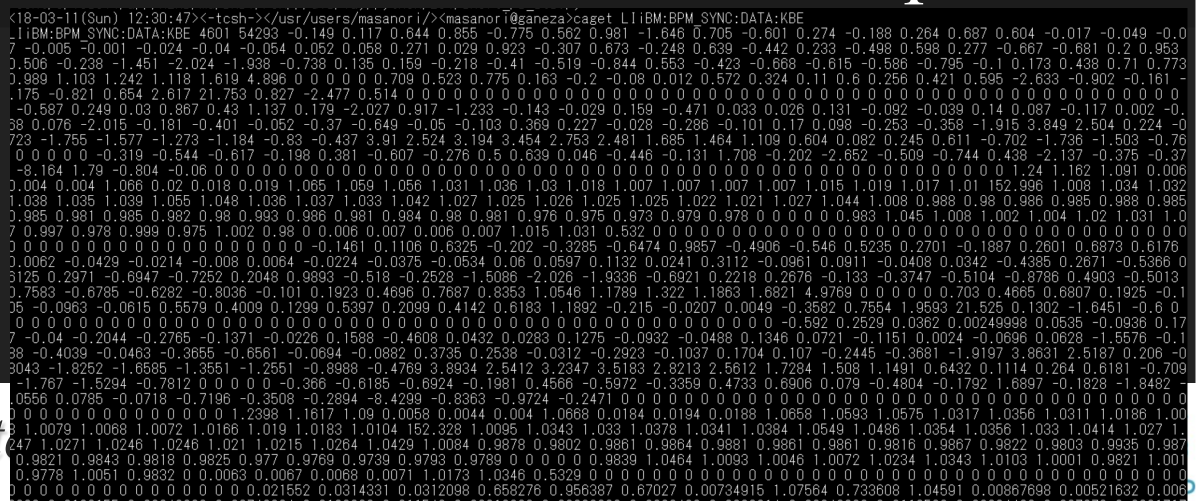


Current system

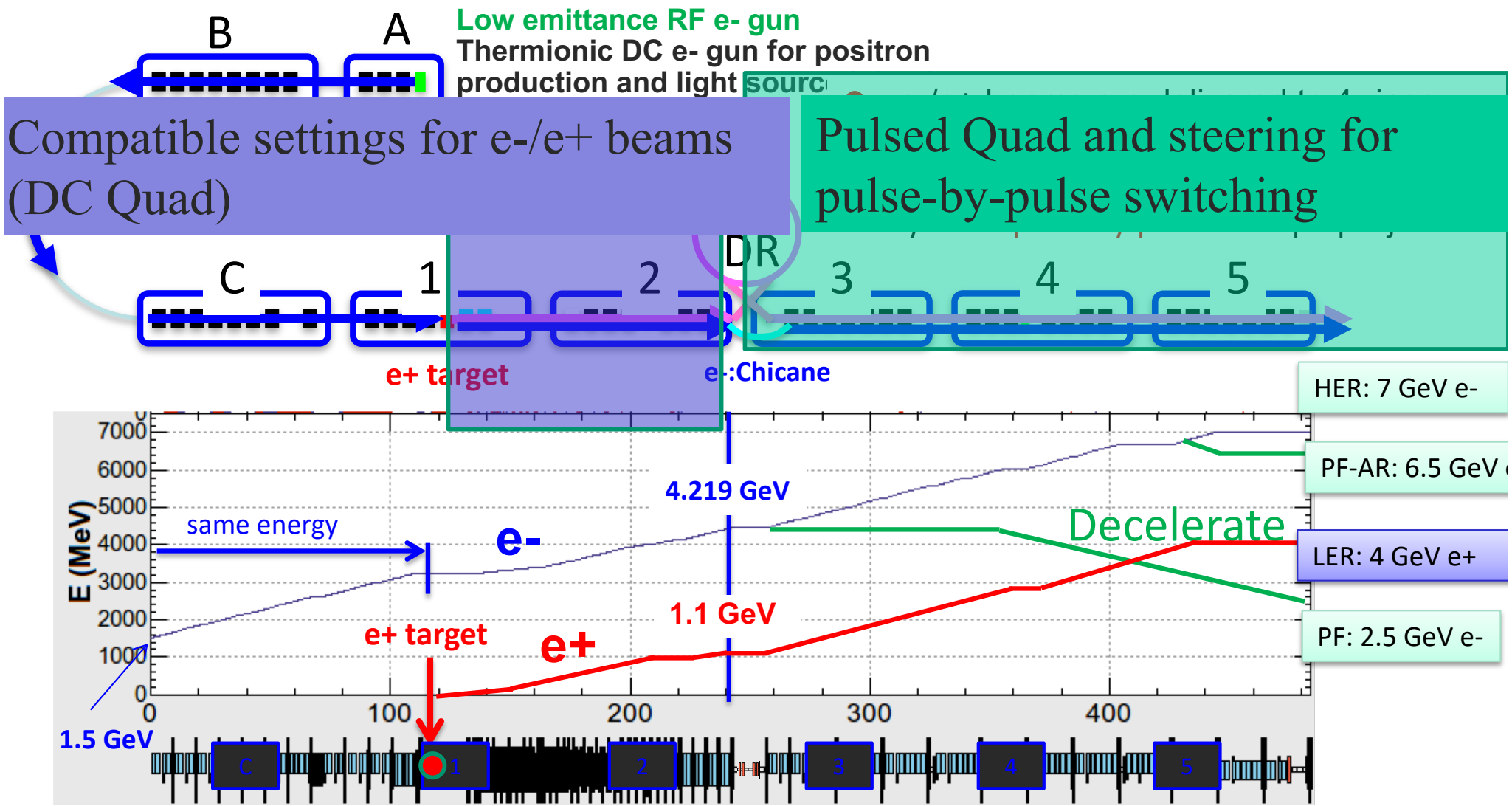
F. Miyahara

Synchronized BPM measurement

- Synchronized all BPM measurement frame work is implemented as EPICS IOC.
- Beam shot ID is delivered from event generator (EVG) to event receiver (EVR) via data buffer.
- EPICS PV contains all BPM data
  - horizontal beam position, vertical beam position, bunch charge, average value, single shot value, …
- Some application software (beam orbit display, quad BPM, ..) use this PV. Similar frame work is under development for RF monitor.



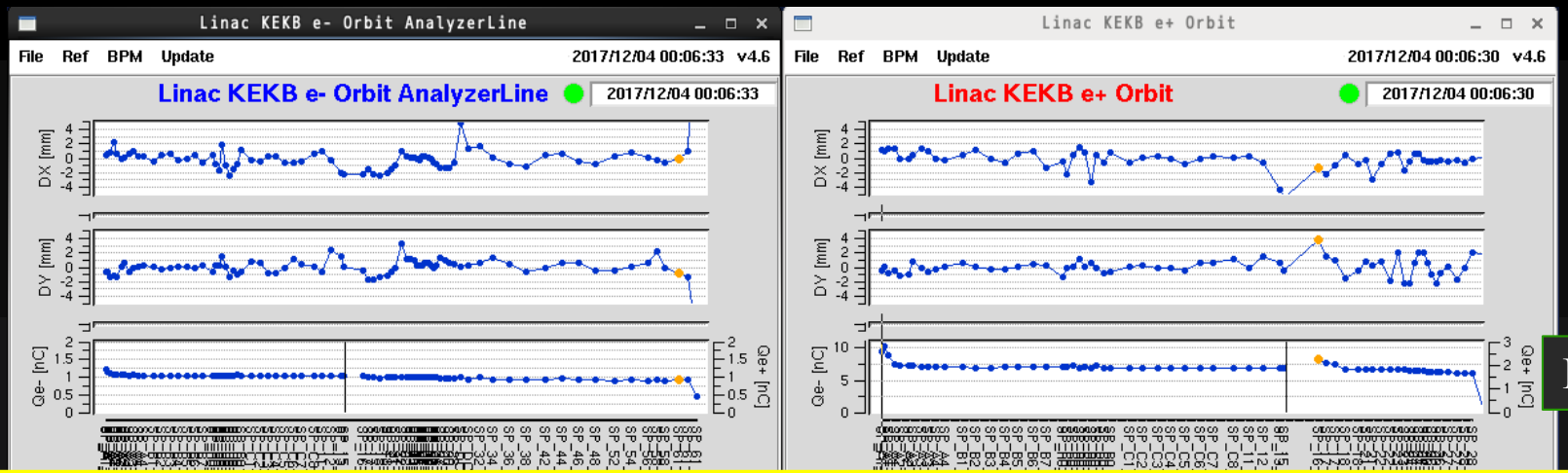
Beam Operation Scheme towards simultaneous top up injection



Pulsed Magnet Operation

- Pulsed quad (x28) (w/ ceramic duct) and steering (x 36) were installed mainly at Sector3 to Sector5 in last summer shutdown. Mounted on new girder.
- For simultaneous top up for SuperKEKB HER/LER, PF, PF-AR.
- PXI bus based local control system on Windows8.1 and LabView (Y. Enomoto).
- cPCI bus based timing system (MRF EVR-230)
- Total performance test w/o beam in Sep. 2017

Simultaneous beam operation w/ thermionic e- source

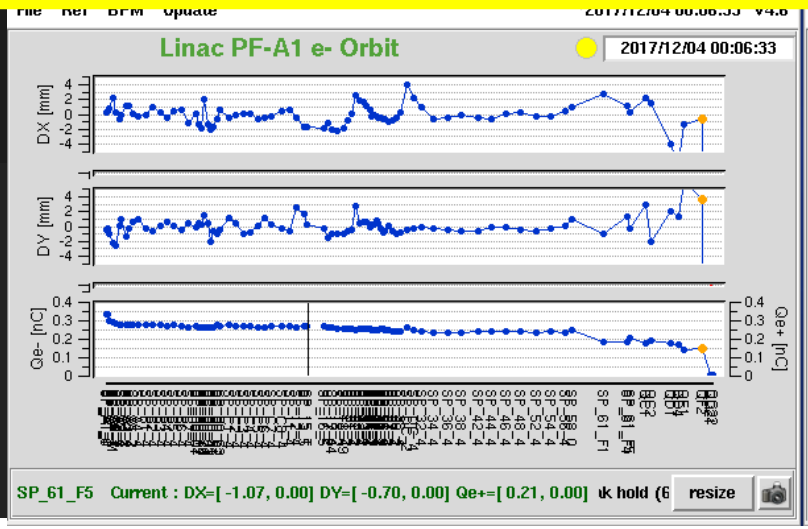


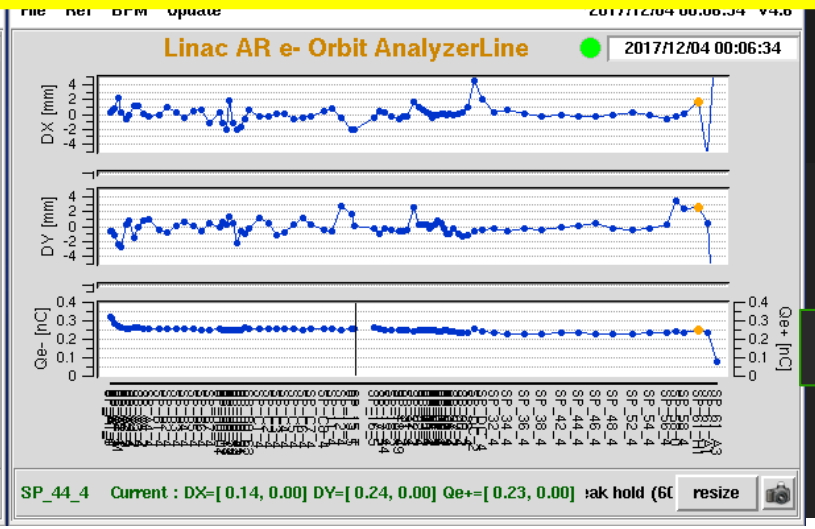
Hor. orbit

Ver. orbit

Bunch charge

Stable operation w/o significant trouble





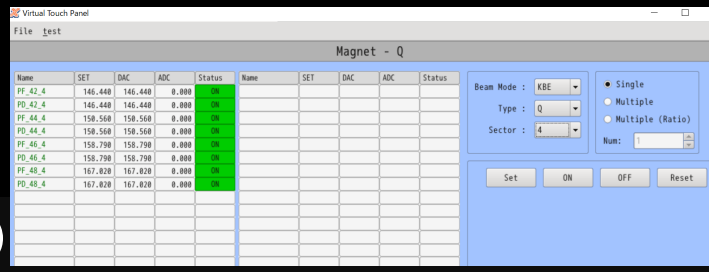
Hor. orbit

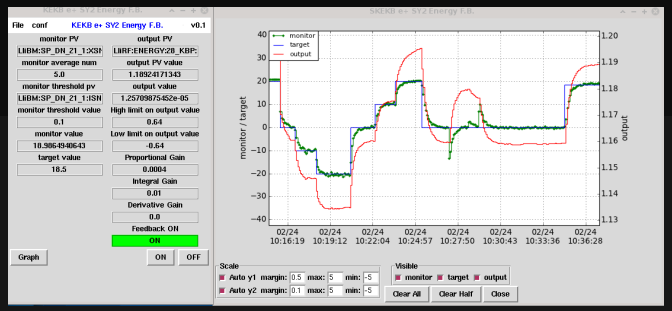
Ver. orbit

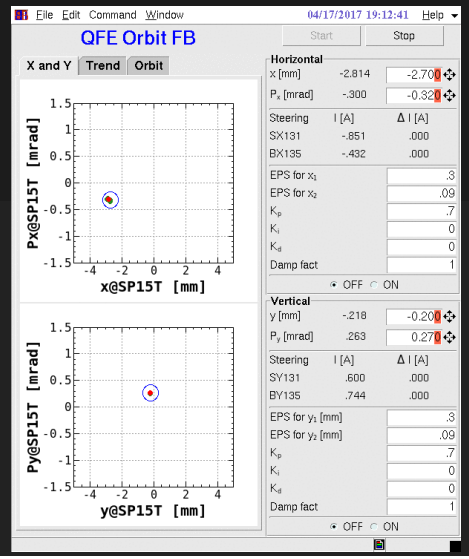
Bunch charge

Operation Software

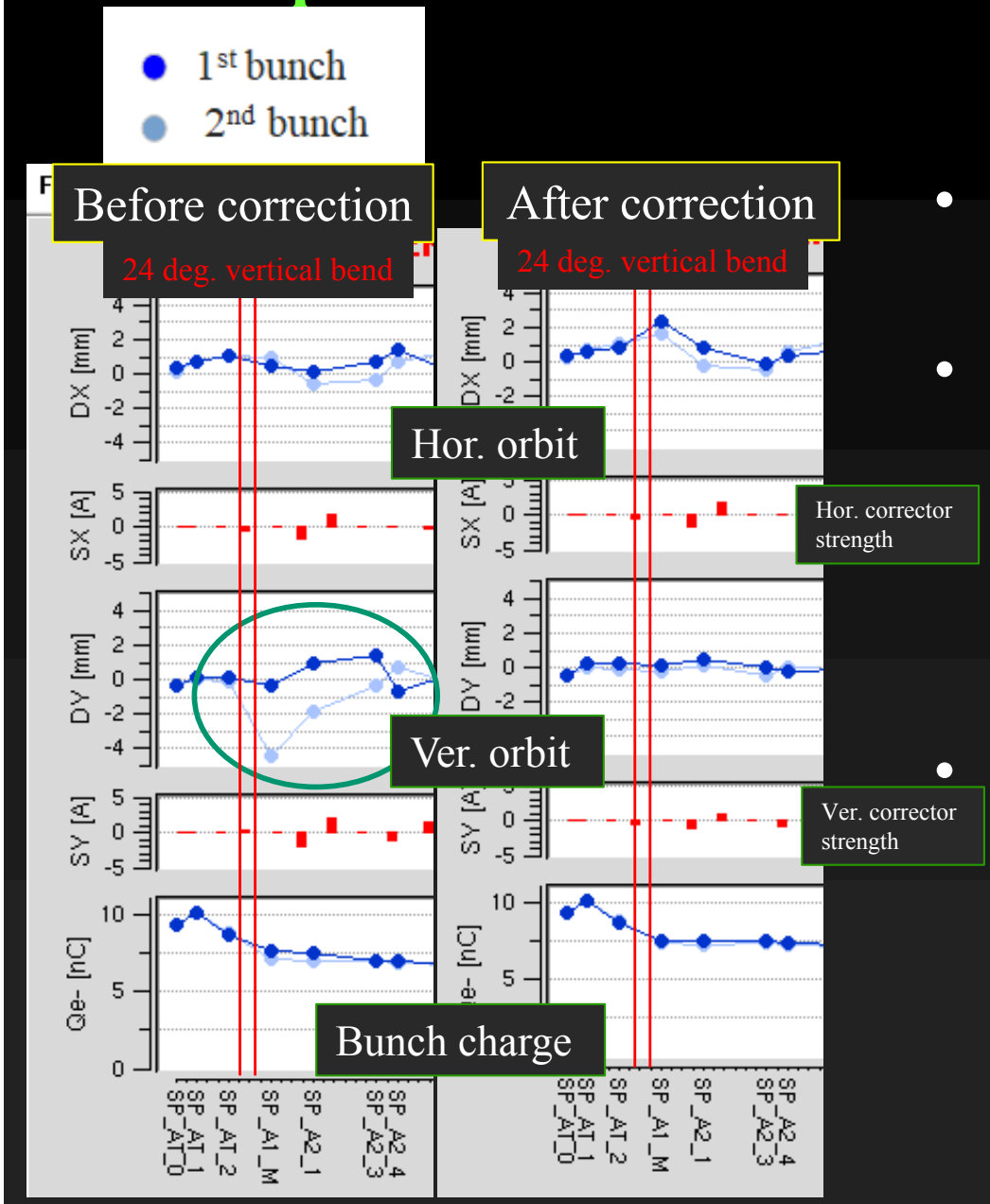
- Key application: Virtual Touch Panel
  - Control GUI for any parameters
  - Rewritten by Python (previous one by Tcl/Tk) for adding pulsed magnet control.
- Energy feedback
  - At J-ARC, Sector2, LTR, ECS (LTR), Sector5
  - Implemented as EPICS IOC
- Target Feedback at e+ target hole
  - Can be applied for any locations







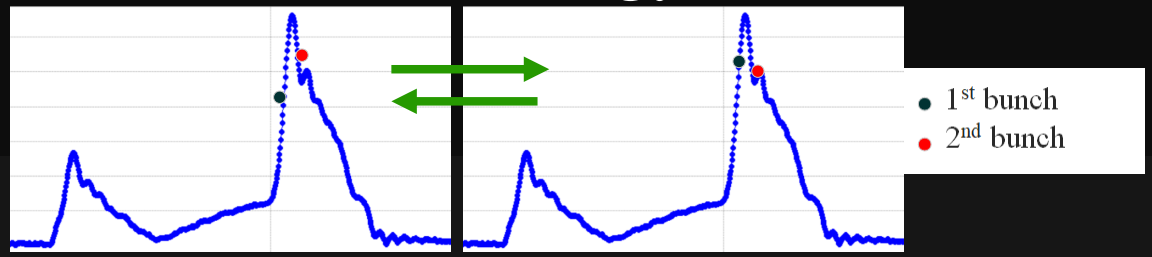
Dispersion correction at 24 deg. line



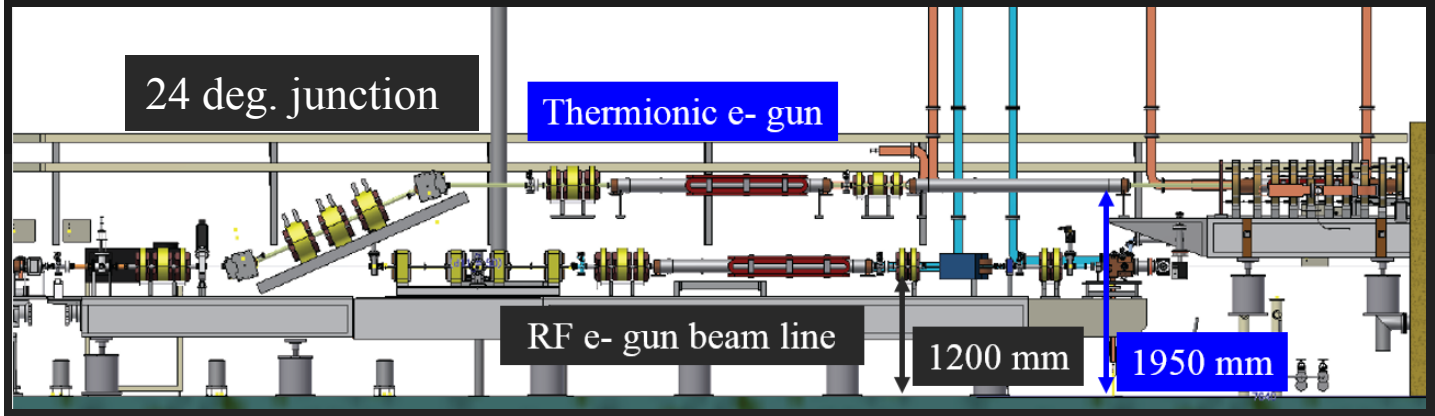
- Beam energy of 1st and 2nd bunch are different before fine tuning.
- At BPM (SP_A1_M) downstream the 24 deg. junction beam line (two vertical bends), the vertical beam orbit of 1st and 2nd bunch is much different.
- After correction, 1st and 2nd bunch vertical orbits are almost the same.

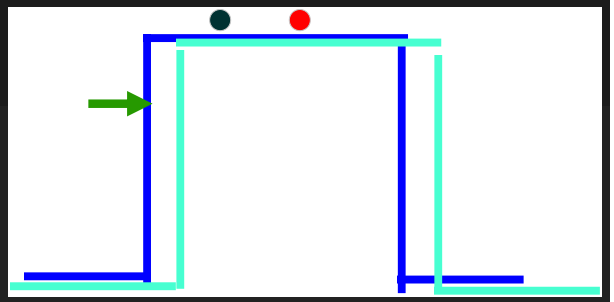
Energy correction for two bunch operation

- 1st and 2nd bunch timing interval ~ 96 ns
- For regular accelerator unit using SLED, rf timing is adjusted to equalize the beam energy of 1st and 2nd bunch.

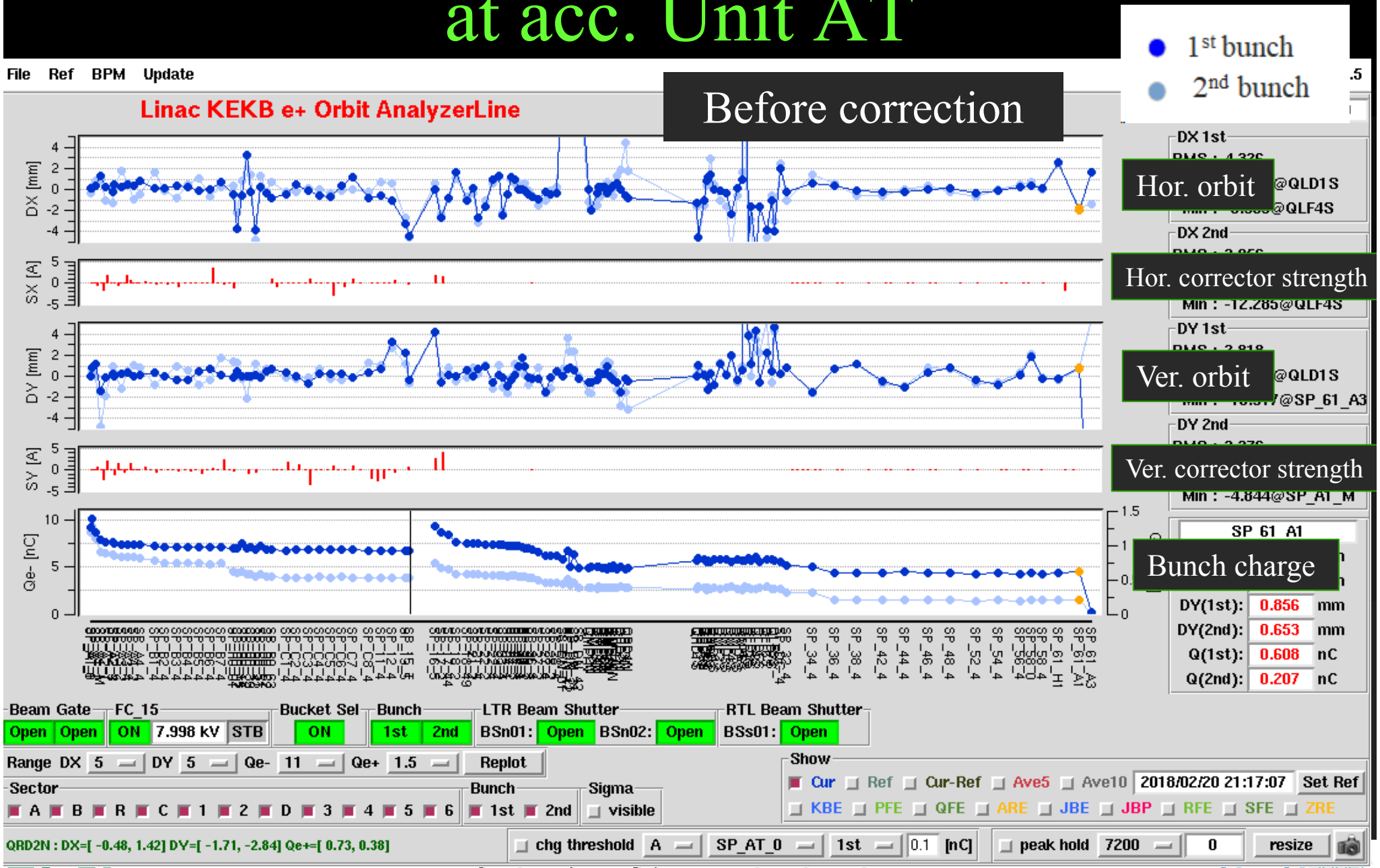


- For rectangular RF output (w/o SLED), prefilling timing injection for 1st bunch is applied for energy correction.

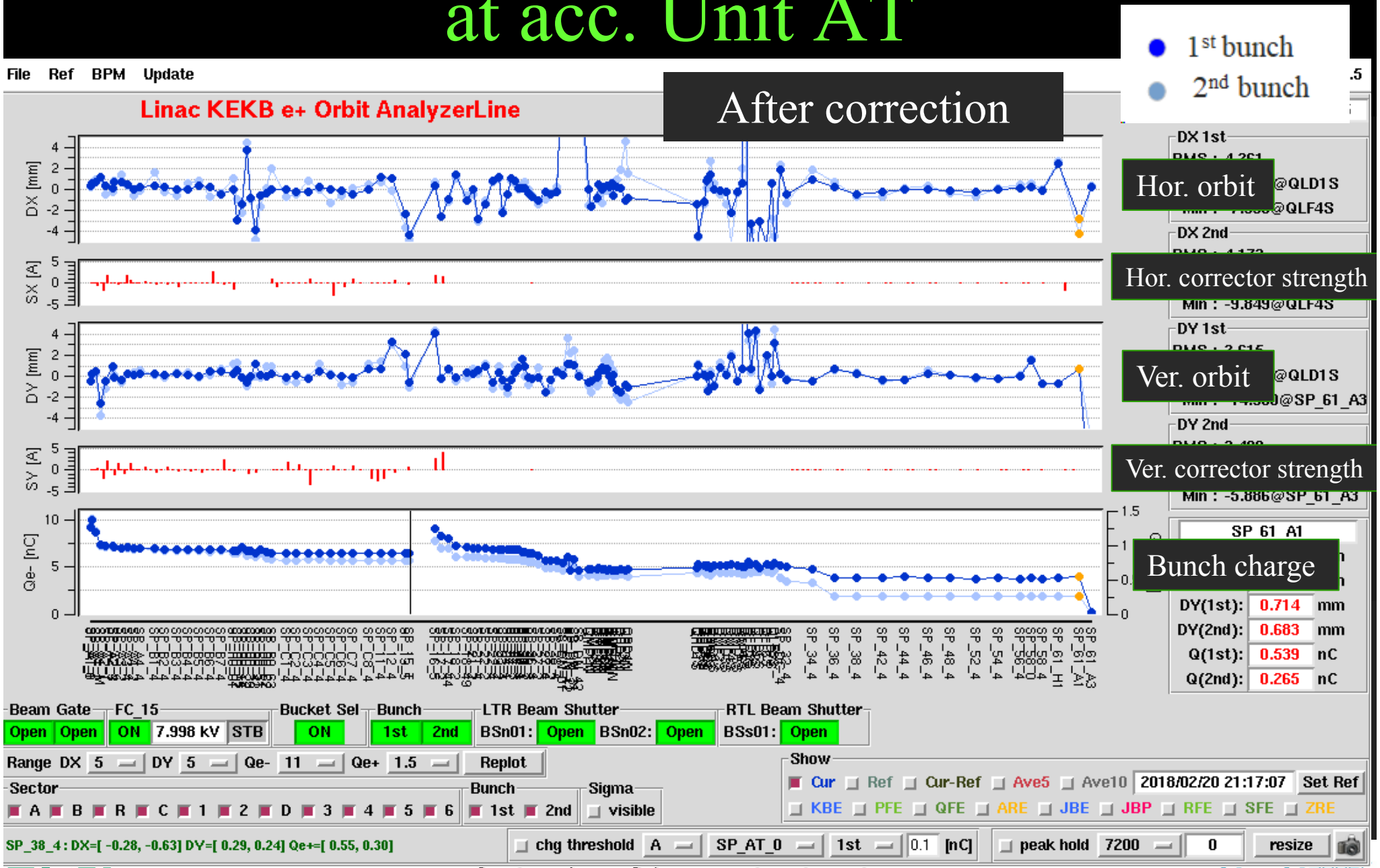




Energy equalization of 1st and 2nd bunch at acc. Unit AT



Energy equalization of 1st and 2nd bunch at acc. Unit AT



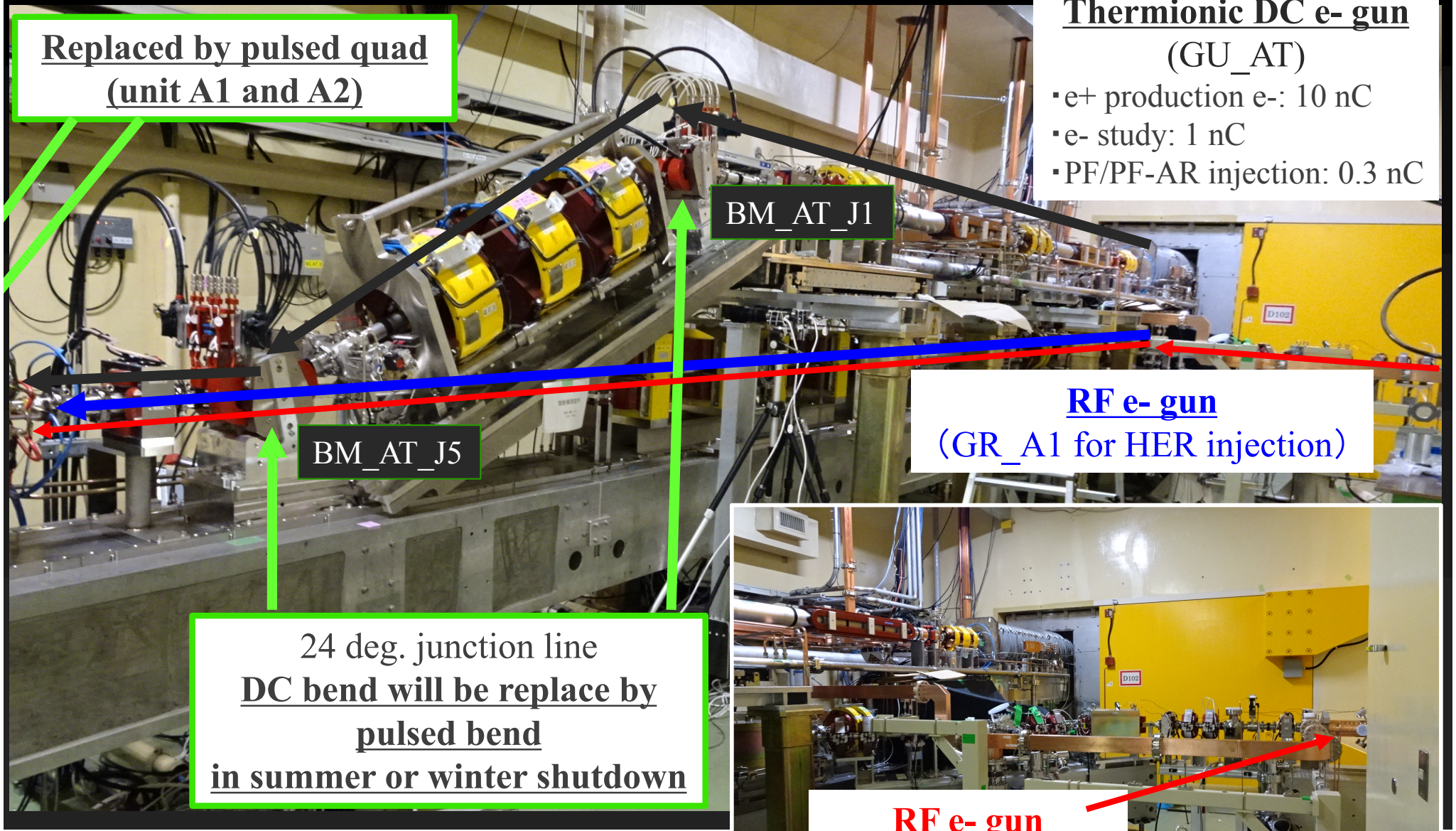
Towards Phase II

- PF top up (hybrid operation) is planned in June.
- Frequent switch operation (rf/thermionic e- gun) is necessary.
  - HER injection (rf gun) 1 min. => switch (10 s) => LER and PF injection (1 min.) => switch,……

	LER injection beam		HER injection beam	
	Goal	Current status	Goal	Current status
Normalized emittance (Hor./Ver.) (mm·mrad) (wire scanner measurement)	200/40 (w/ DR)	192 ± 22.4 / 2.01 ± 0.363 @ Sector3 185 ± 28.4 / 1.72 ± 0.704 @ Sector5	150/150	~ 20 @ SectorB (rf e- gun) ~ 100 @ Sector5 (rf e- gun: Phase I) ~ 160 / 300 @ Sector5 (thermionic e- gun: Phase I)
Bunch charge (nC)	0.5	1.4 (w/ flux concentrator) @ Sector5	1.0	1.0 (thermionic e- gun) 1.0 ~ 3.0 (rf e- gun) @ Sector5

Towards Phase III

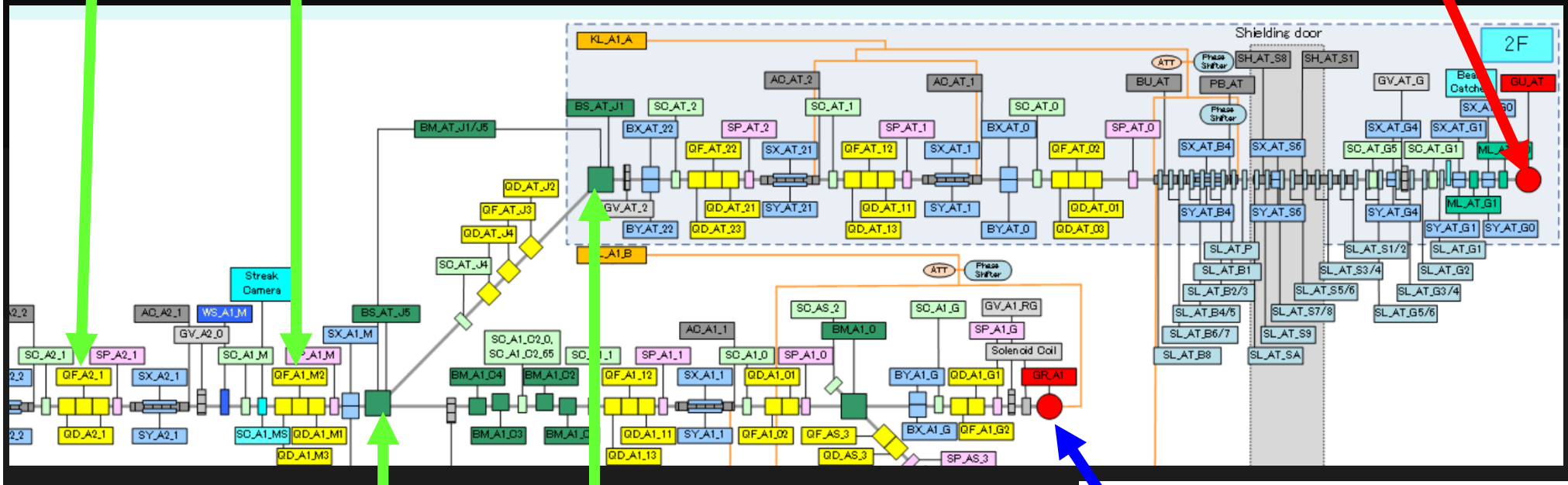
- Simultaneous top up w/ thermionic and RF e- gun is necessary.



Towards Phase III

Replaced by pulsed quad (unit A1 and A2)

Thermionic DC e- gun (GU_AT)



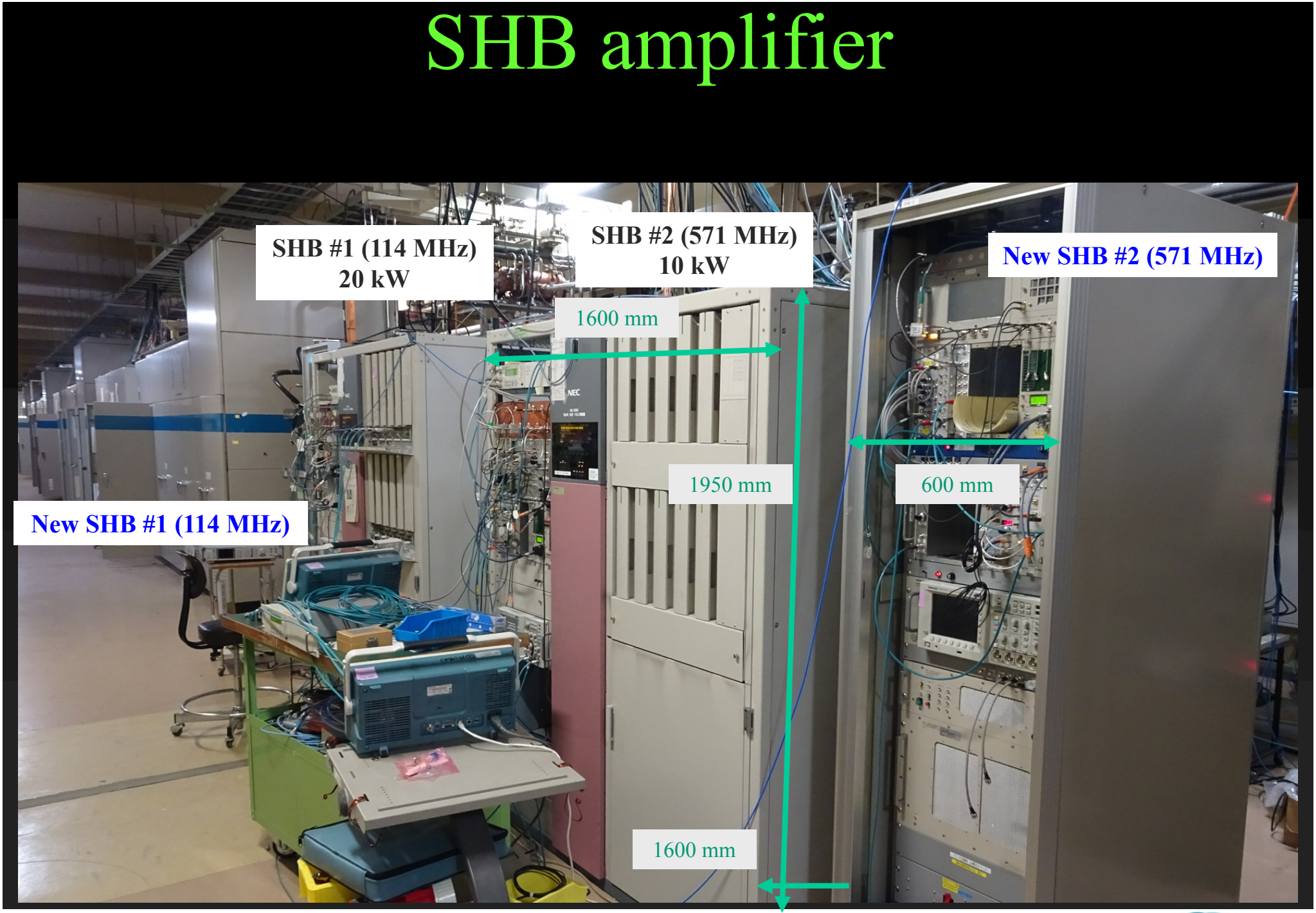
RF e- gun
（GR_A1 for HER injection）

24 deg. junction line
DC bend will be replace by pulsed bend in summer or winter shutdown

Operational Concerns

- RF breakdown problem of LAS unit (ACC17)
  - Sometimes, one or more shift is required for recovery.
  - Stable e+ operation is difficult.
- At the thermionic e- gun station
  - Unstable temperature control at thermionic e- gun station
    - New air conditioner will be installed in the near future.
  - EVR for thermionic e- gun timing sometimes stops. Several min. is required for recovery.
- Unstable SHB#1 (114 MHz) amplifier
  - New amplifiers (also SHB#2 (571 MHz)) are now under test.
- Remote control of BM_AT_J1/J5 is unstable.
  - New power supply is now under test.

SHB amplifier



Summary and Plan

- Success of light sources injection (PF and PF-AR) via GU_AT e- gun, and PF-AR full energy injection w/ new BT line.
- New BPM readout and synchronized measurement framework work well.
- Simultaneous top up injection is ready by using thermionic e- gun.
- Success and stable operation of pulsed quad and steering magnets, and timing control of DR injection and extraction.
- Safety system and beam gate signal handling for DR work well.

Summary and Plan (cont'd)

- Towards Phase II:
  - Almost required parameters have been achieved
  - Operational concerns should be solved.
  - PF top-up operation (one week) is planed in June. Frequent switch between thermionic and rf e- gun should be tested.
- Towards Phase III:
  - Simultaneous top up injection by using both of thermionic and rf e- gun.
    - Pulsed bend and quad will be installed at SectorA in this summer or winter shutdown.
  - Low emittance preservation operation
    - Jitter (Y. Seimiya)
    - Alignment

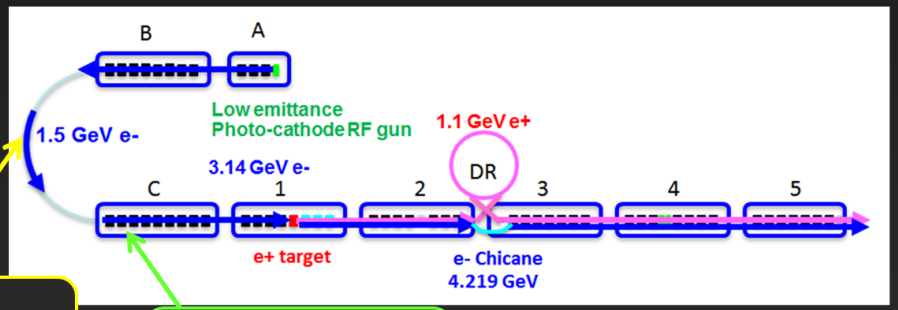
Backup

Parameters (KEKB/SKEKB)

	KEKB (final)		SuperKEKB (Phase-I)		SuperKEKB (Phase-III)	
Beam	e+	e–	e+	e–	e+	e–
Energy (GeV)	3.5	8.0	4.0	7.0	4.0	7.0
Stored current (A)	1.6	1.1	1	1	3.6	2.6
Beam lifetime (分)	150	200	100	100	6	6
Bunch charge (nC)	Primary e-10 → 1	1	Primary e- 8 → 0.4	1	Primary e-10 → 4	5
Normalized emittance (mm·mrad)	1400	310	1000/1200	200/130	**100/15 (Hor./Ver.)**	**40/20 (Hor./Ver.)**
Energy spread (%)	0.125	0.125	0.5	0.5	0.1	0.1
# of bunch	2	2	2	2	2	2
Beam rep. (Hz)	50		25		50	
Simultaneous top up	3 rings (KEKB e–/e+, PF)		n/a		4+1 rings (SuperKEKB e–/e+, DR, PF, PF-AR)	

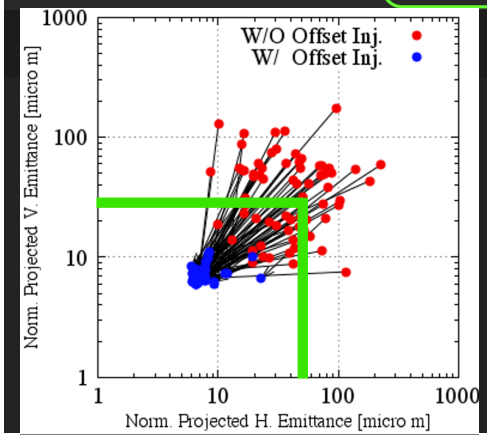
Low emittance preservation

- Low emittance e- beam transport w/o damping ring
- Emittance preservation w/ precise beam orbit control is key issue for e- beam.
- Simulation results show the feasibility of emittance preservation w/ bunch compression and offset injection. Beam study was also conducted.
- Beam study was also conducted at Sector A and B (125 m straight section)

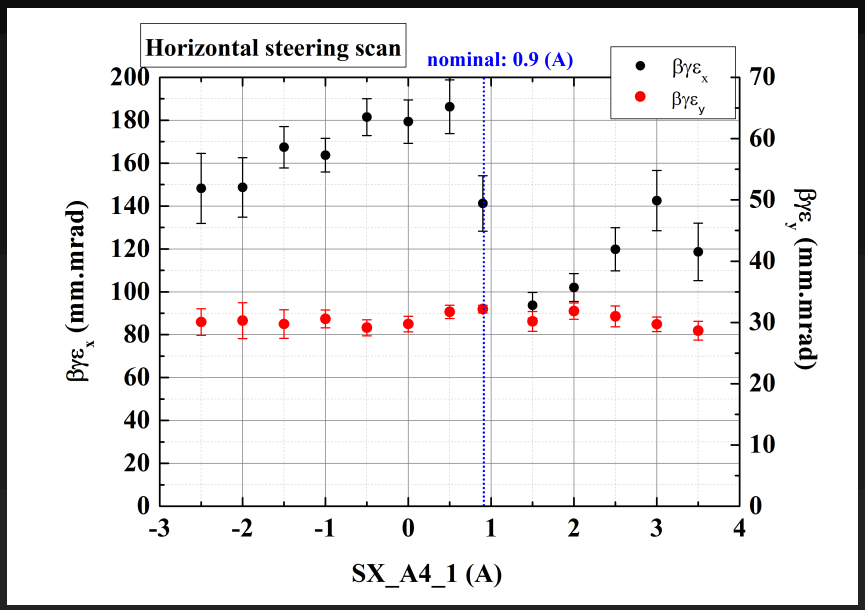


Bunch compression

Offset injection



- Simulation -
- Quads and acc. w/ misalignment of 0.3 mm (σ)
- 50 different error seeds
- All seeds can be corrected.



- Experiment -
- Control steering at Sector A
- Emittance was changed at Sector B