Injector beam operation

Masanori Satoh
for injector linac group

KEKB Accelerator Review Committee, July 8-10, 2019

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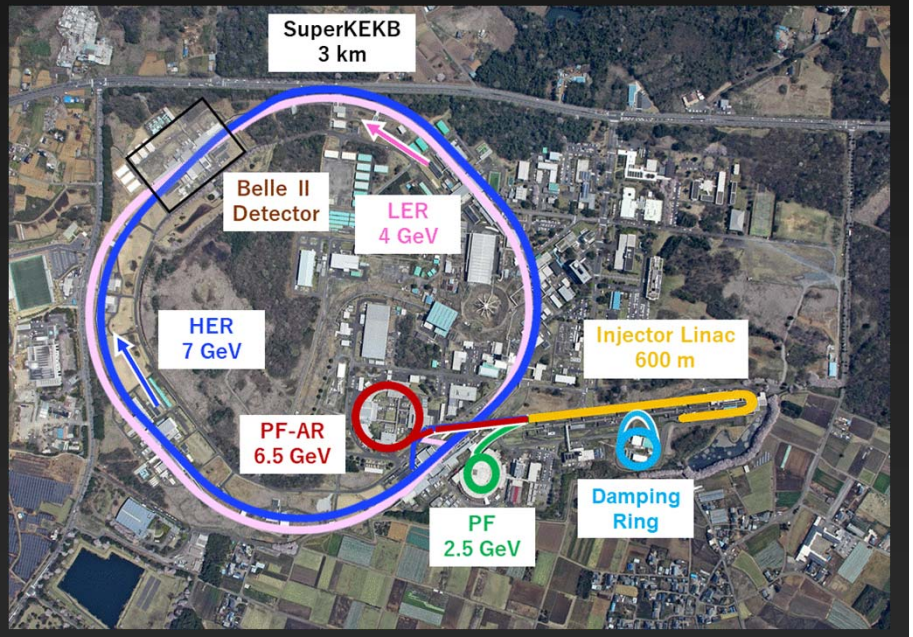
Injector linac overview

- Injector linac
  - e-/e+ injector for 4 independent storage rings, and e+ DR
  - 50 Hz, up to 2 bunches (96 ns interval)
  - Simultaneous top up injection to all rings
- SuperKEKB:
  - HER: e-, 7 GeV, 1 nC
  - LER: e+, 4 GeV, 1 nC
    (DR: 1.1 GeV)
- Light sources:
  - PF: e-, 2.5 GeV, 0.3 nC
  - PF-AR: e-, 6.5/5 GeV, 0.3 nC

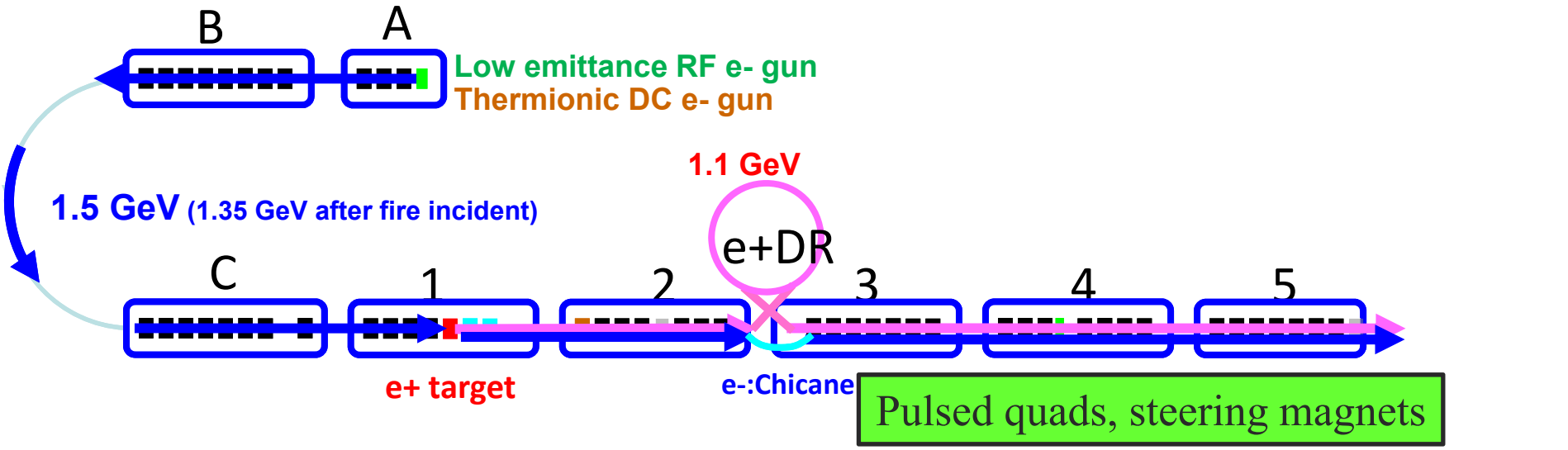


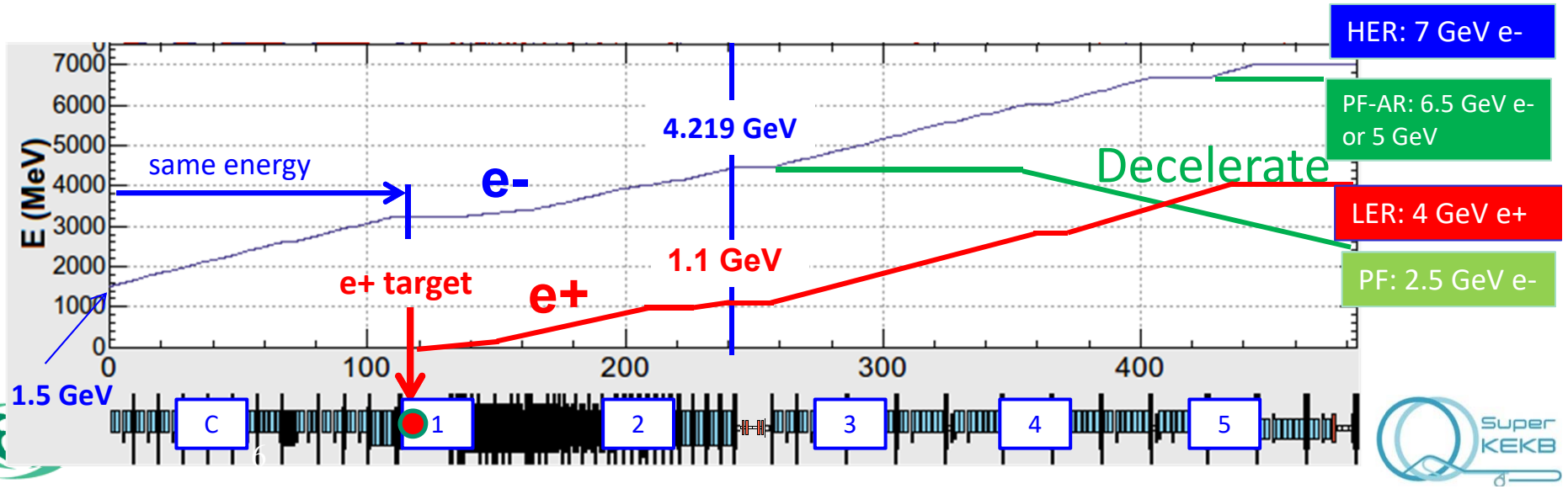
Parameters (KEKB/sKEKB)

	KEKB (final)		SuperKEKB (Phase-I)		SuperKEKB (Phase-III final)	
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 (min.)	150	200	100	100	6	6
Bunch charge (nC)	Primary e-10 → 1	1	Primary e- 8 → 0.4	1	Primary e-10 → 4	4
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	0.16	0.07
# 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)	

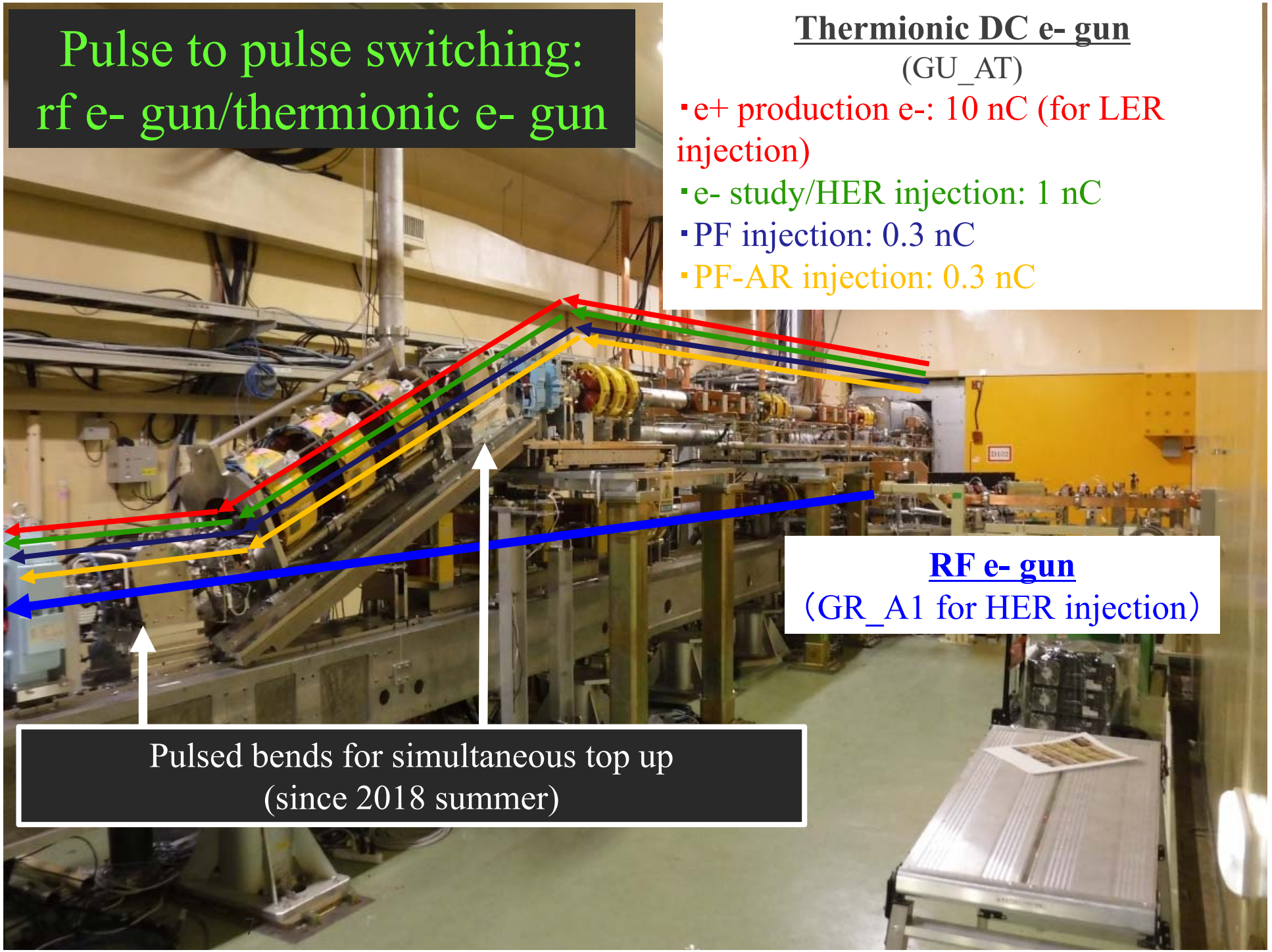
Injector linac beam operation

- Photocathode RF gun for HER injection
- Thermionic gun for LER, PF, PF-AR injection





Pulse to pulse switching: rf e- gun/thermionic e- gun



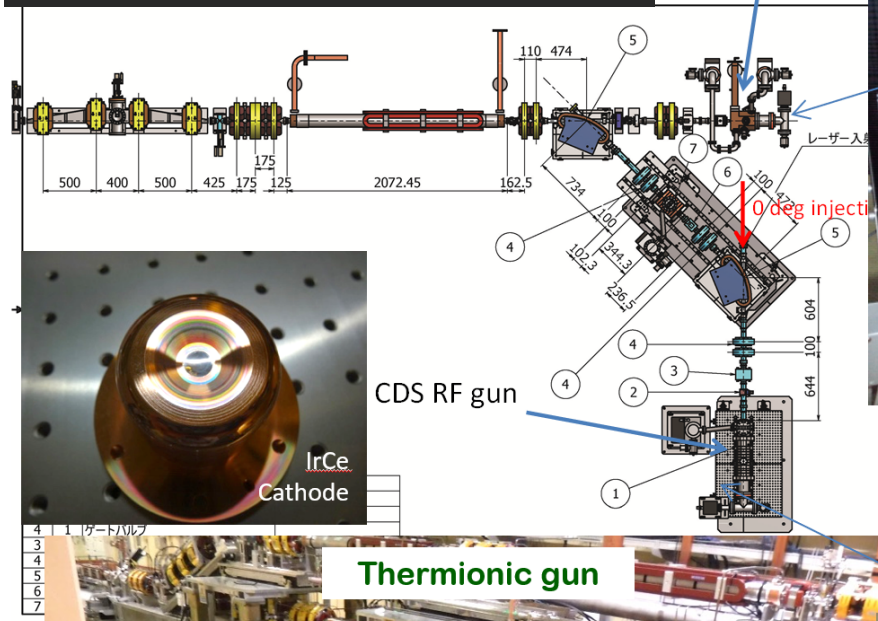
Thermionic DC e- gun
(GU_AT)

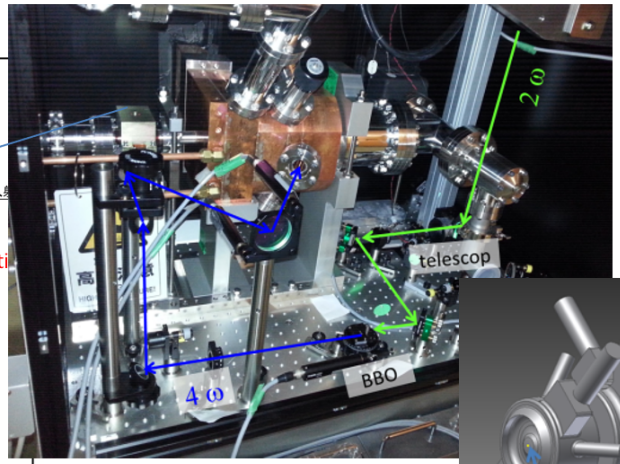
- e+ production e-: 10 nC (for LER injection)
- e- study/HER injection: 1 nC
- PF injection: 0.3 nC
- PF-AR injection: 0.3 nC

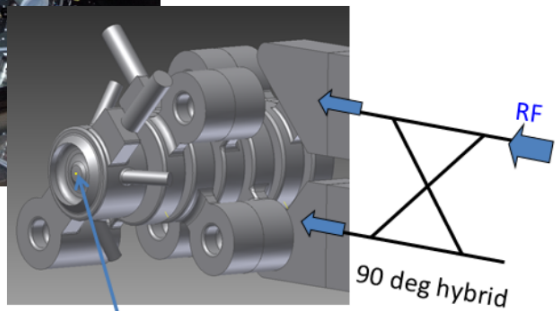
RF e- gun
(GR_A1 for HER injection)

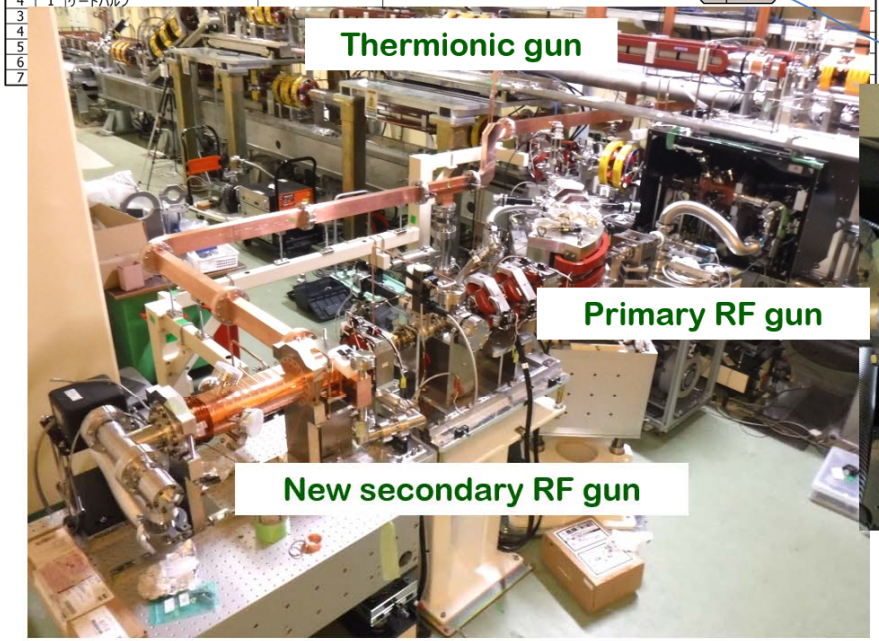
Pulsed bends for simultaneous top up
(since 2018 summer)

RF gun

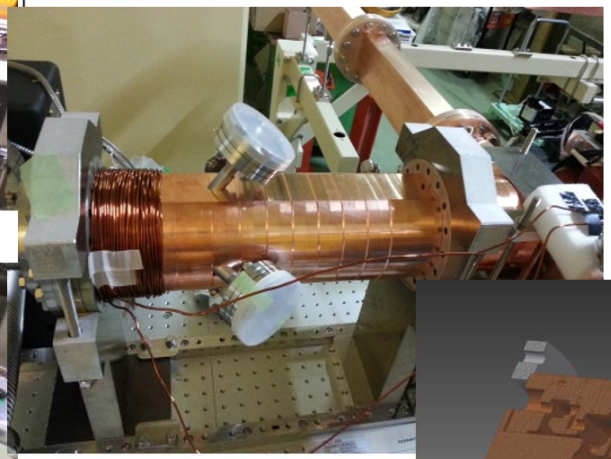


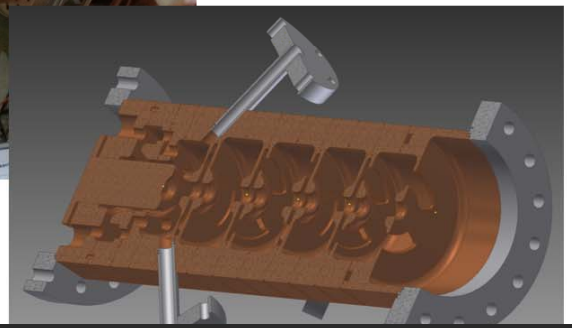






90-deg CDS RF gun

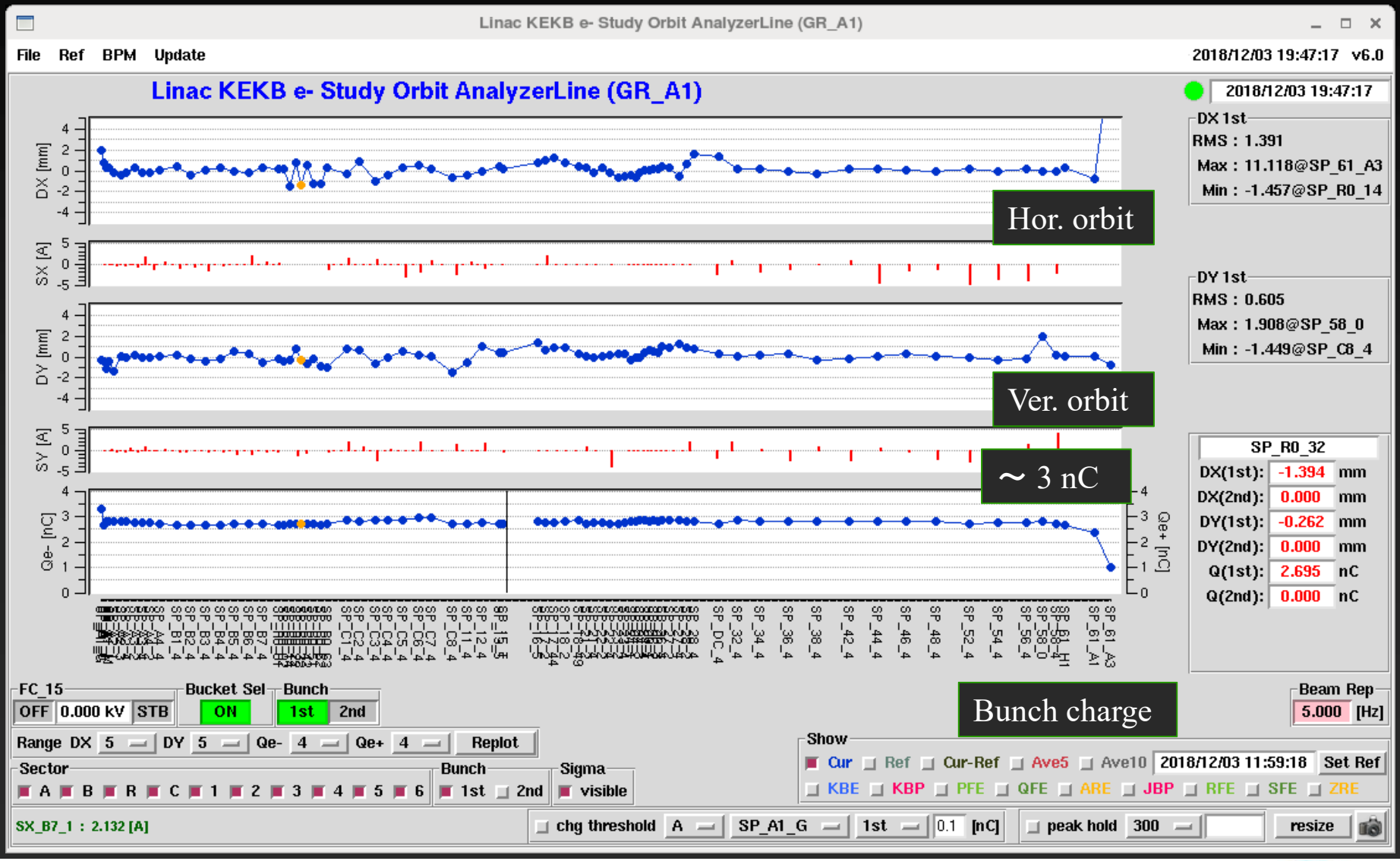




M. Yoshida, SuperKEKB review, Mar. 14th, 2018

M. Yoshida, R. Zhang, X. Zhou

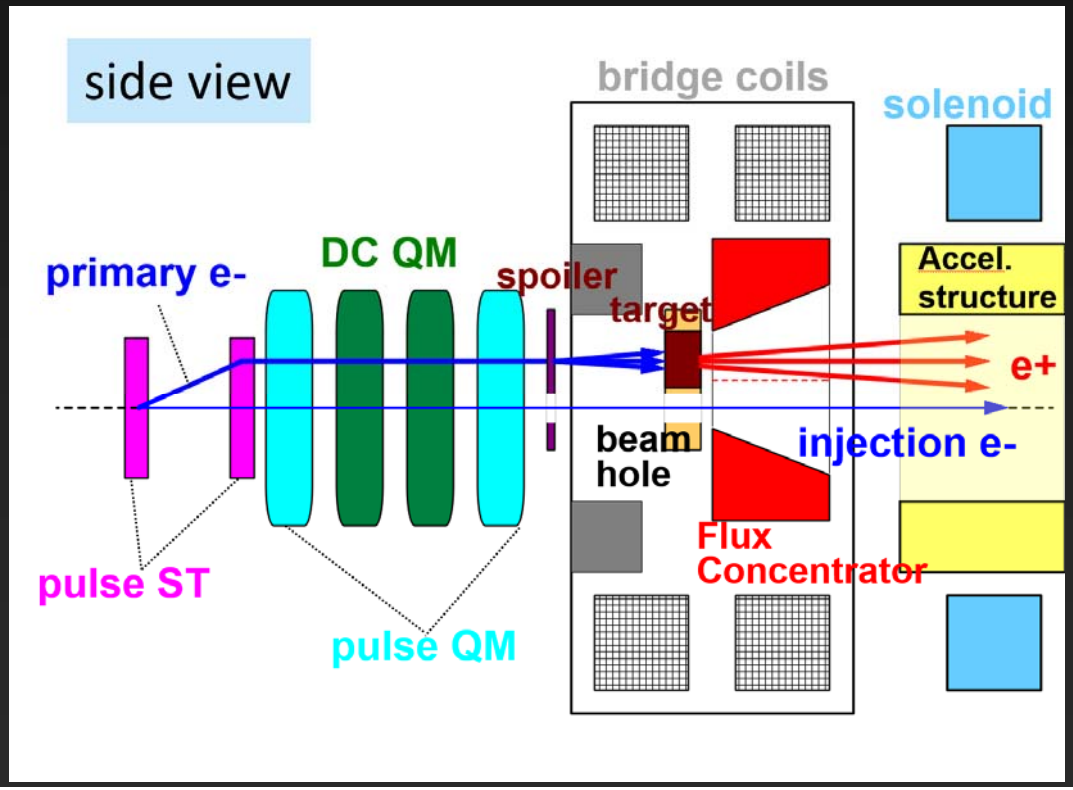
High bunch charge e- from rf gun



Injector beam operation

Pulse to pulse e-/e+ beam switching

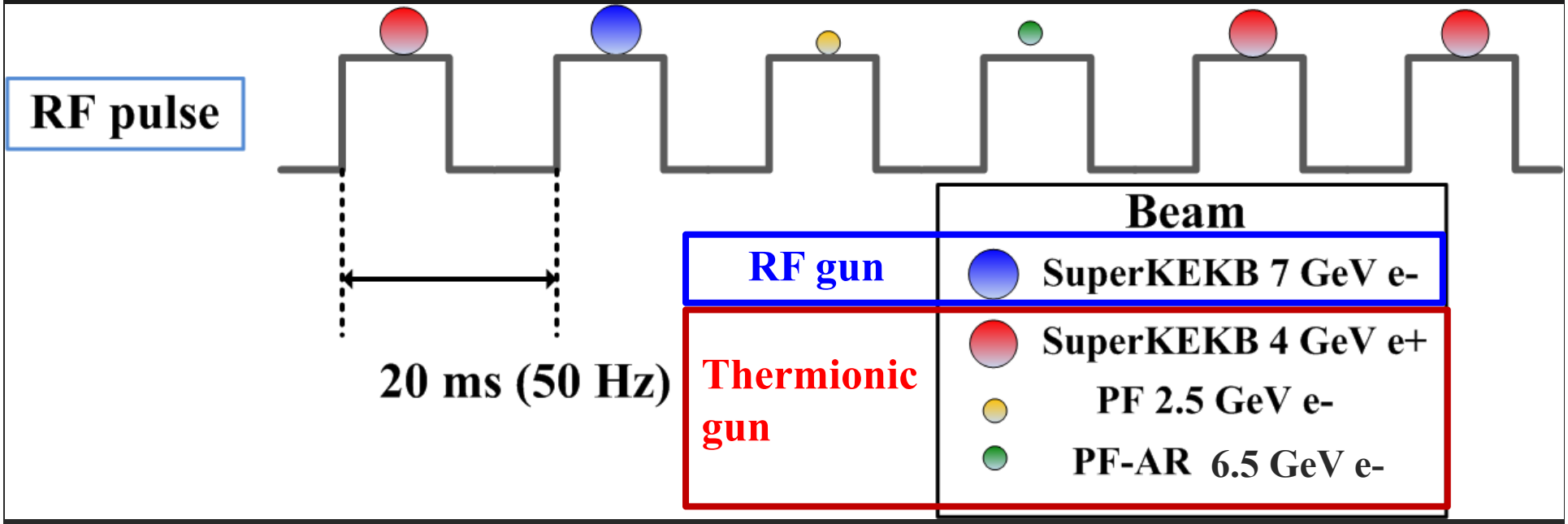
- Pulsed steering magnet control e- beam orbit.
- Low emittance e- beam goes through a hole at center of beam line.



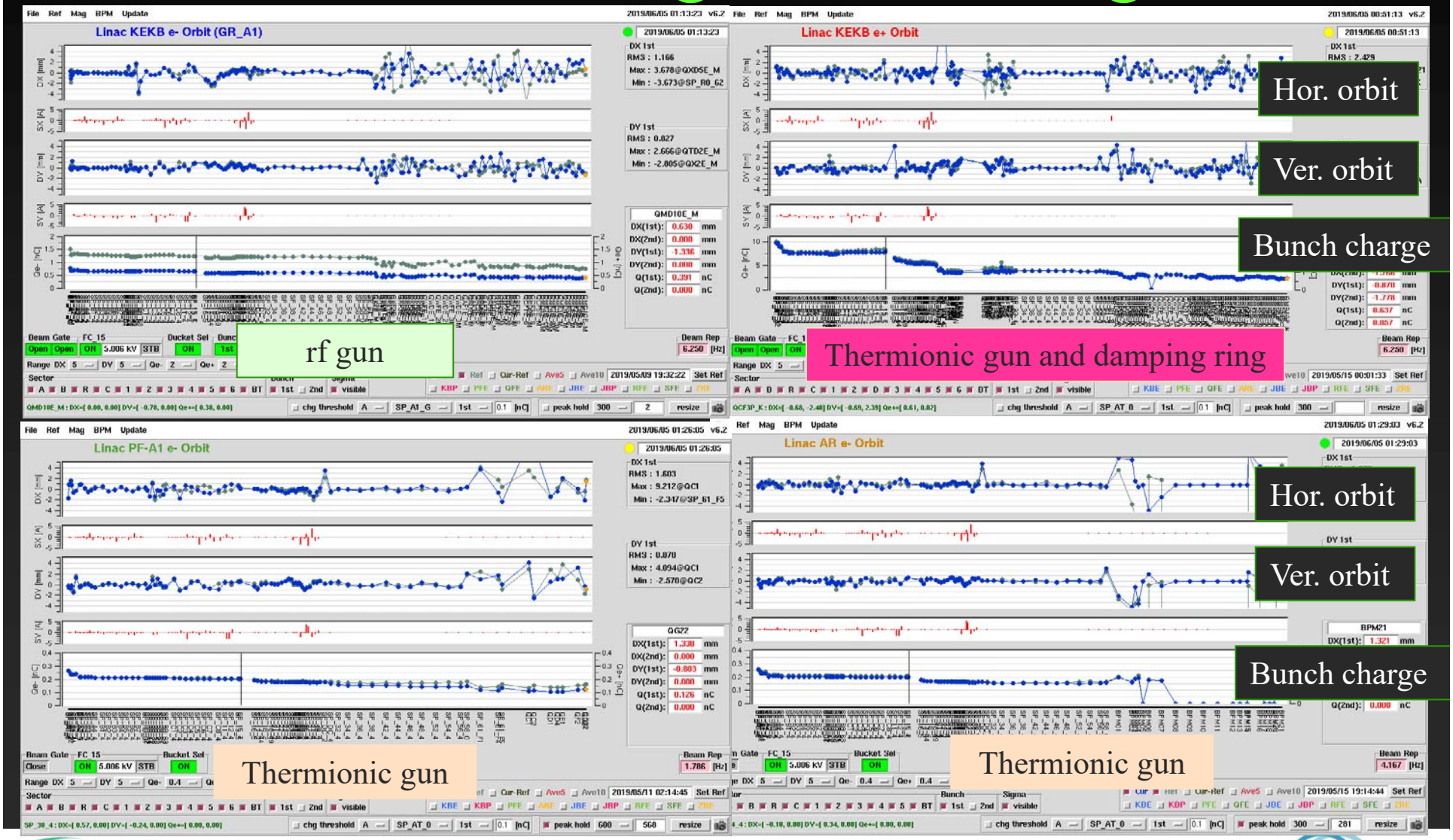
W target (Φ4 mm)
w/ hole (Φ2 mm) for e- beam

Pulse to pulse beam switching for simultaneous top up

- Maximum repetition of e- beam w/ thermionic gun is limited up to 25 Hz.
  - Heating issue of pulsed bend coil and chamber
  - New bend and vacuum chamber will be installed in summer 2020.

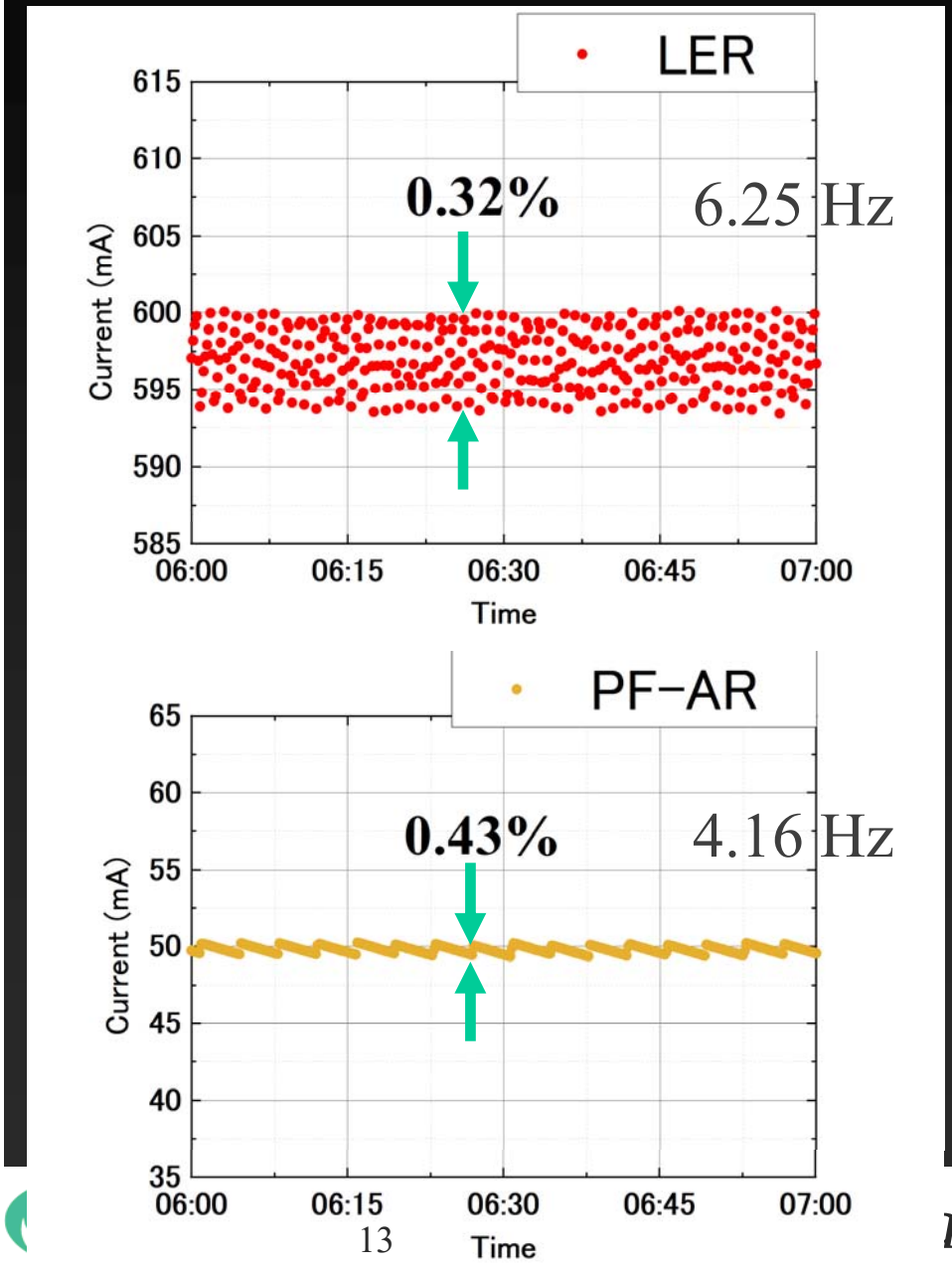


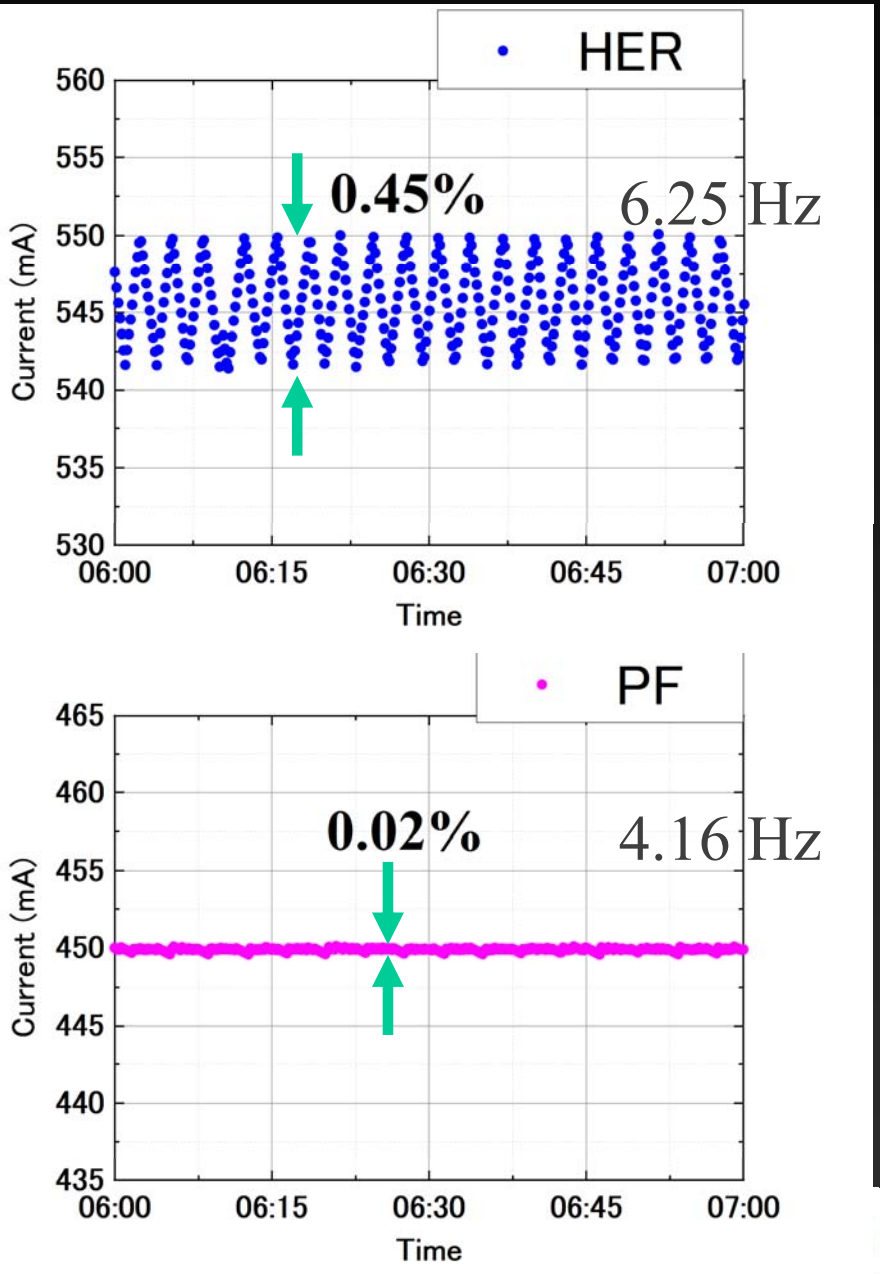
Simultaneous beam operation w/ thermionic e- gun and rf e- gun



Injector beam operation

Stored current stability during simultaneous top up

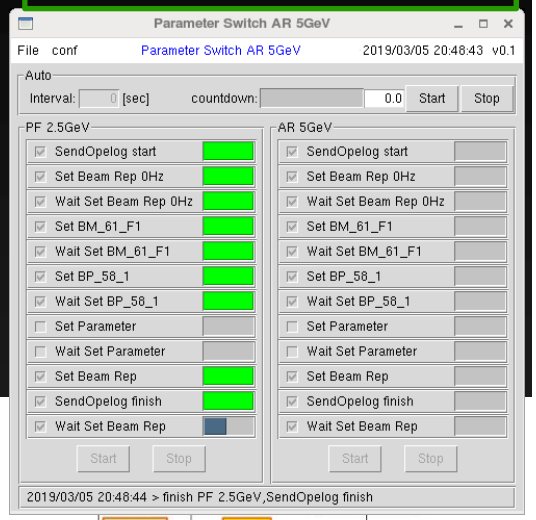


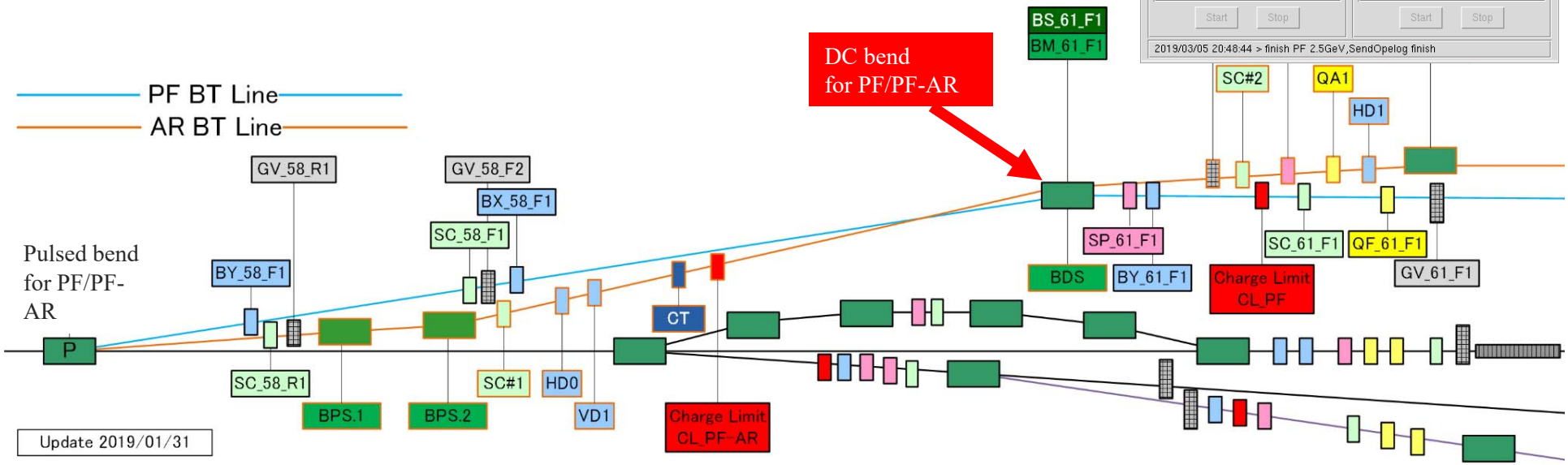


PF-AR 5 GeV injection (1)

- PF-AR 5 GeV operation to save operation cost
- Common DC bend for PF/PF-AR beam transport line
- Frequent parameter switching for quasi top up
  for both of PF and PF-AR

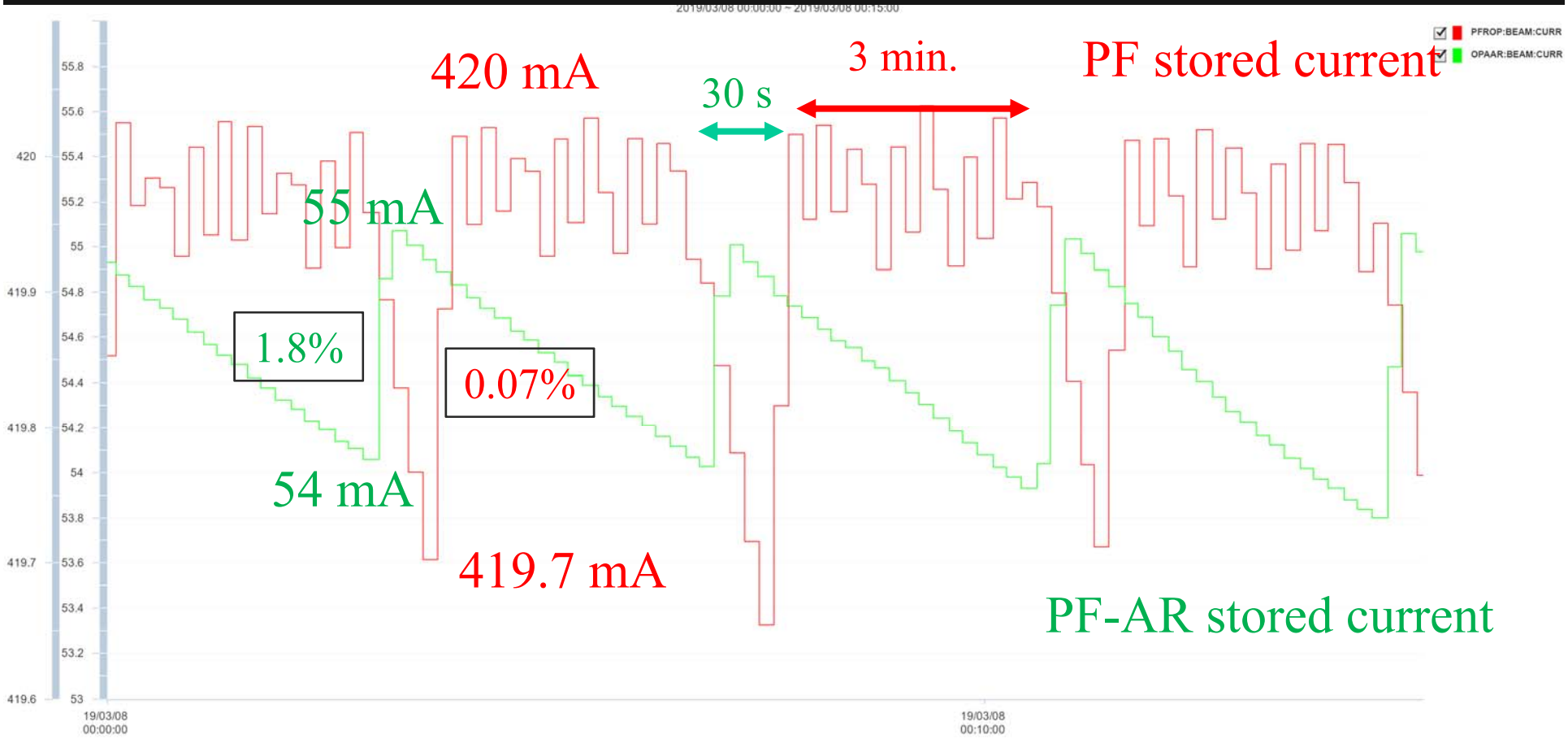
Auto parameter switch



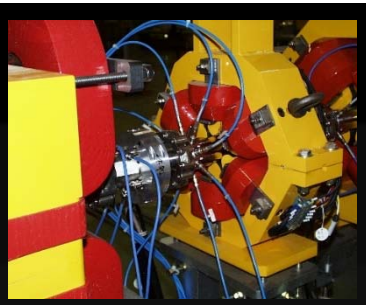


PF-AR 5 GeV injection (2)

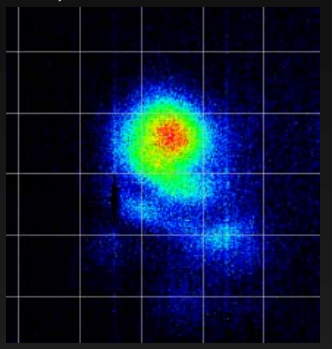
- Typical operation mode
  - PF injection: 3 min.
  - Parameter switching: 10 s
  - PF-AR injection: 30 s



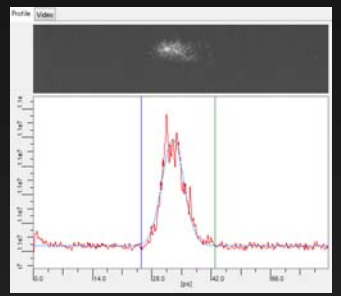
Monitors (1)



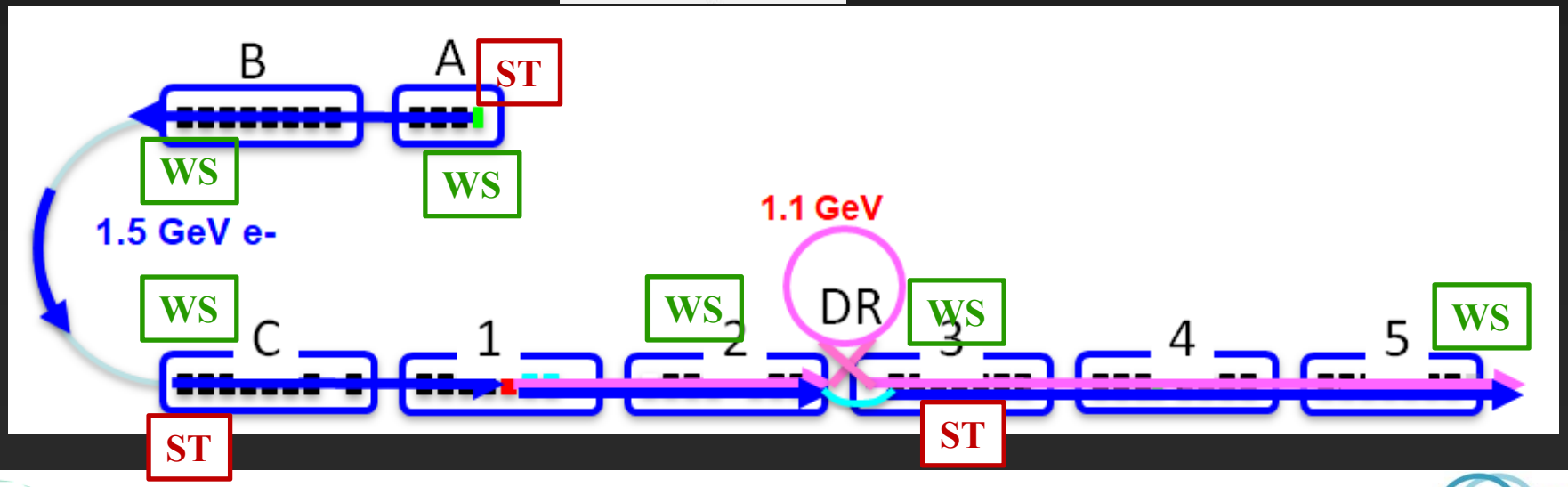
- Beam position monitor (x 103)
  - Four strip line electrodes (x 97)
    - Measurement precision ~ 10 μm
  - Eight strip line electrodes (x 6) (J-ARC, LTR x2, PF BT, HER BT, LER BT)
- Profile monitor (x 104)
  - Al_2O_3/CrO_3 (AF995R, Demarquest Co.). (t: 1 mm, 0.1 mm), YAG:Ce (t: 0.1 mm)



- Wire scanner (WS) (x 6)
  - SectorA, B, C, 2, 3, 5



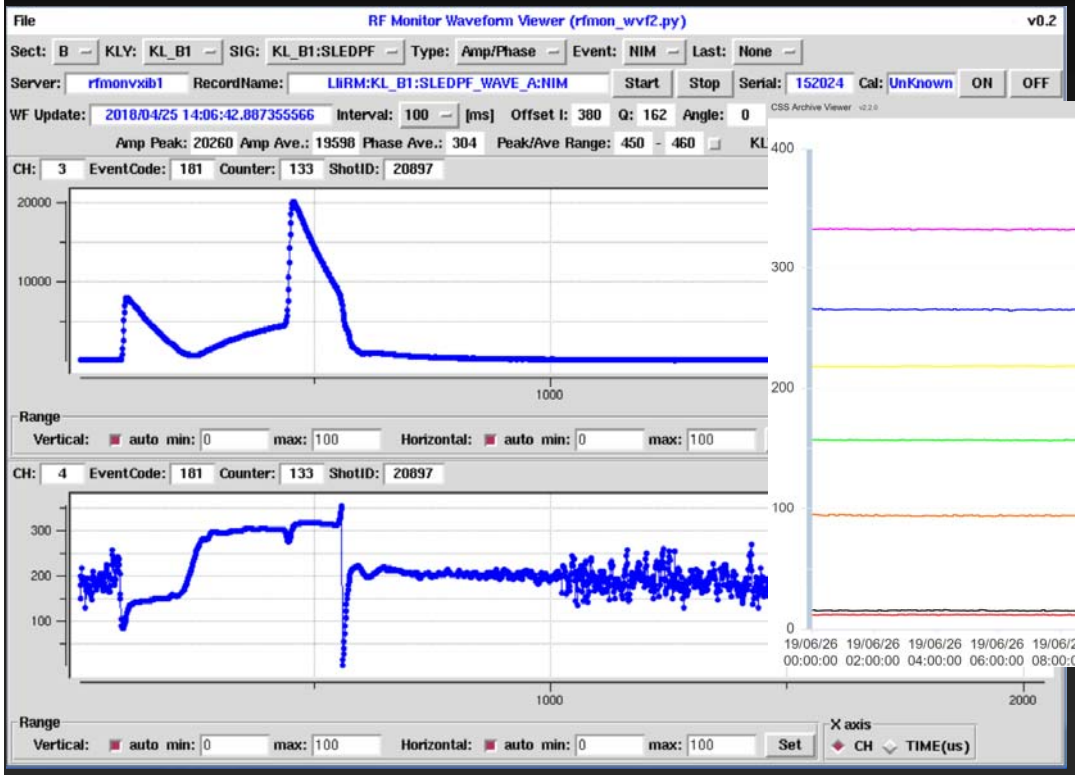
- Streak camera (ST) (x 3)
  - SectorA, C, 3

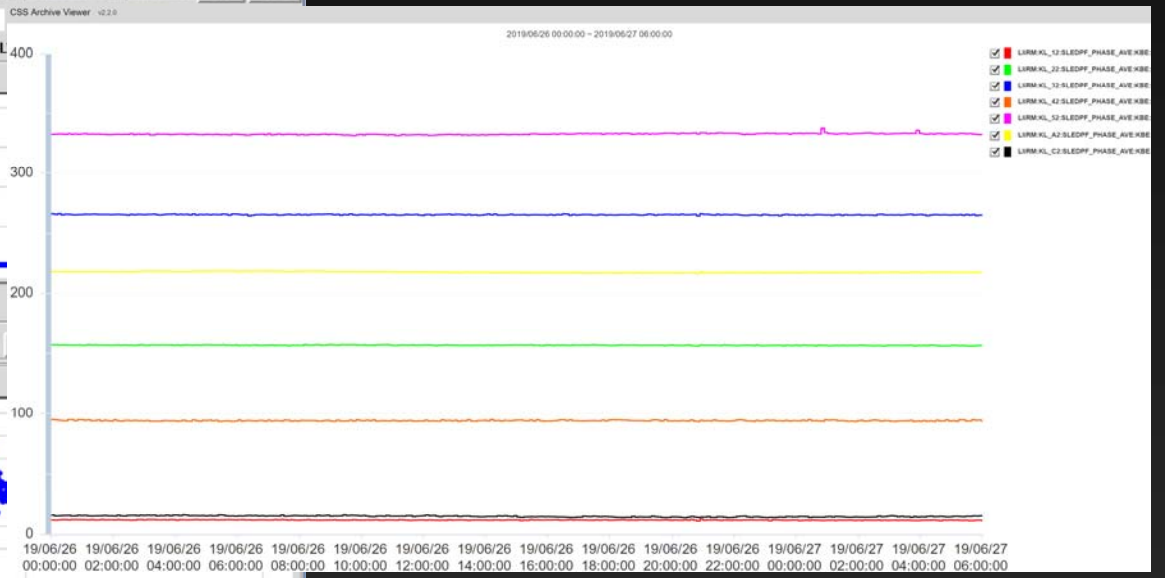


Injector beam operation

Monitors (2)

- RF (amplitude, phase) monitor (x 61)
  - Klystron output, SLED output, accelerating structure output (beam induced field), reference signal
  - average, peak, rms values





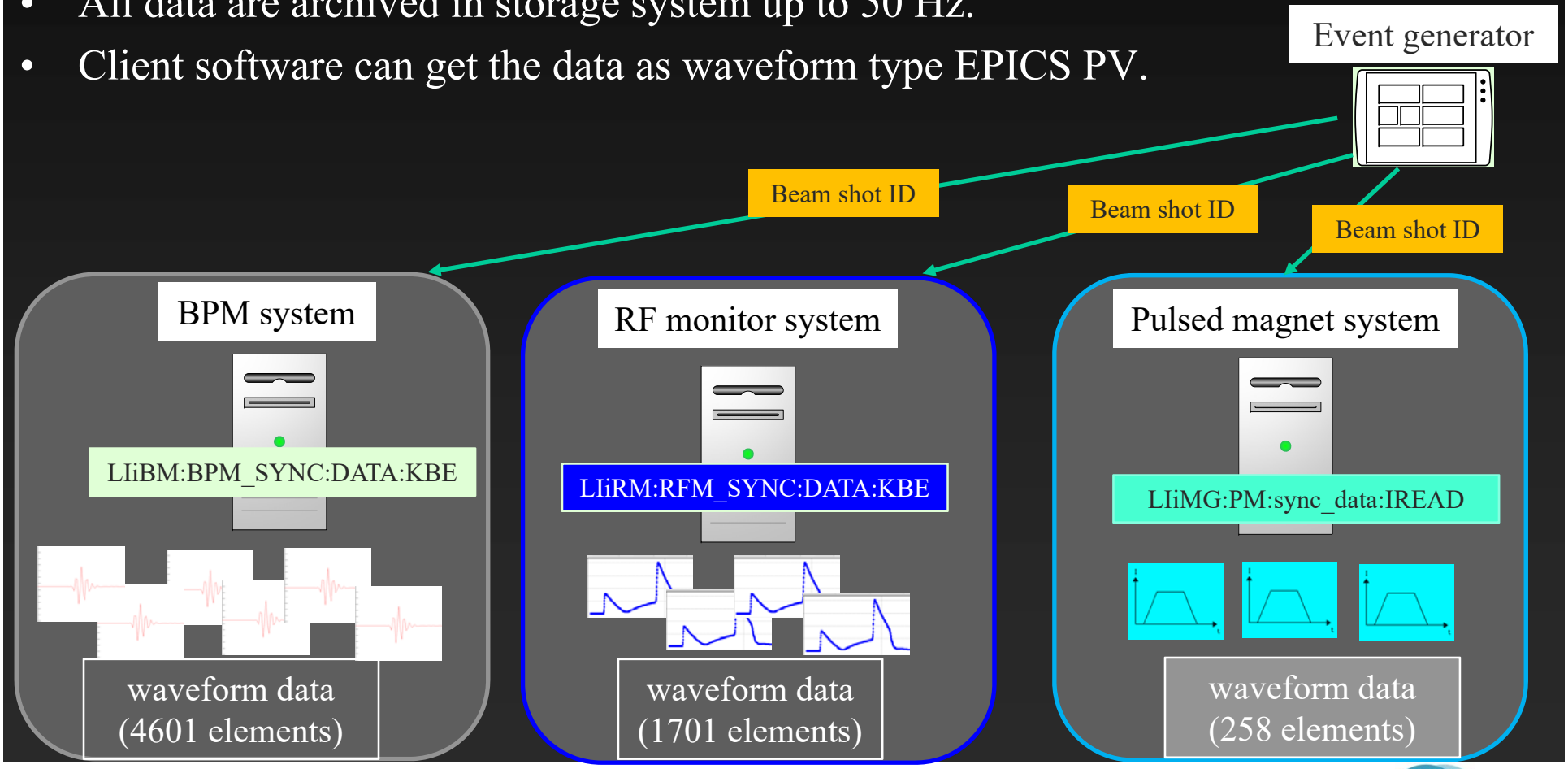
RF monitor
Waveform viewer

Archiver viewer

T. Miura, H. Katagiri

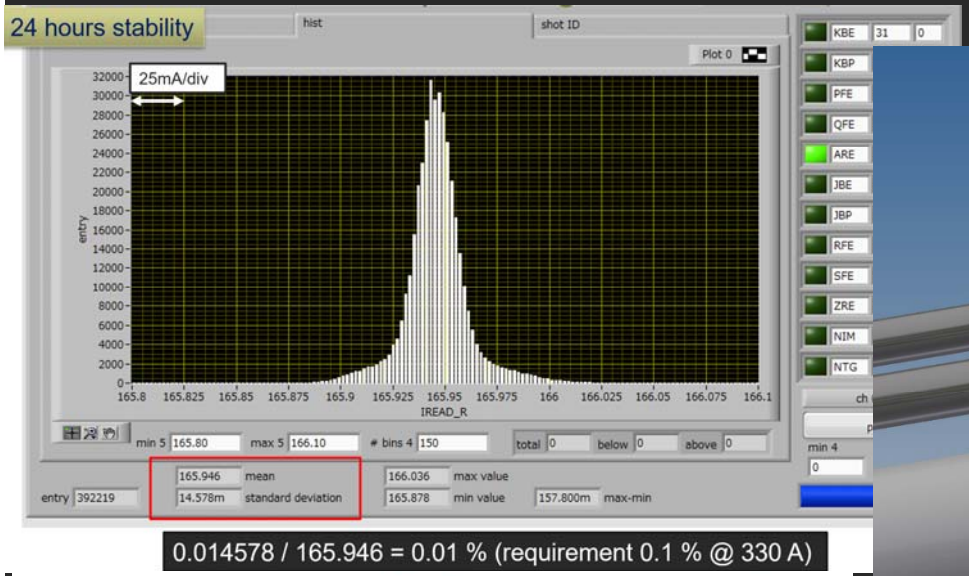
Synchronized data acquisition

- Shot by shot information of all BPM, RF monitor, Pulsed magnet data are available.
- Waveform type data including beam shot ID
  - Beam shot ID is delivered from event generator to event receiver via data buffer.
- All data are archived in storage system up to 50 Hz.
- Client software can get the data as waveform type EPICS PV.

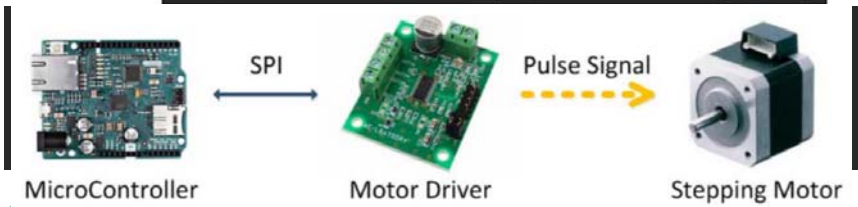


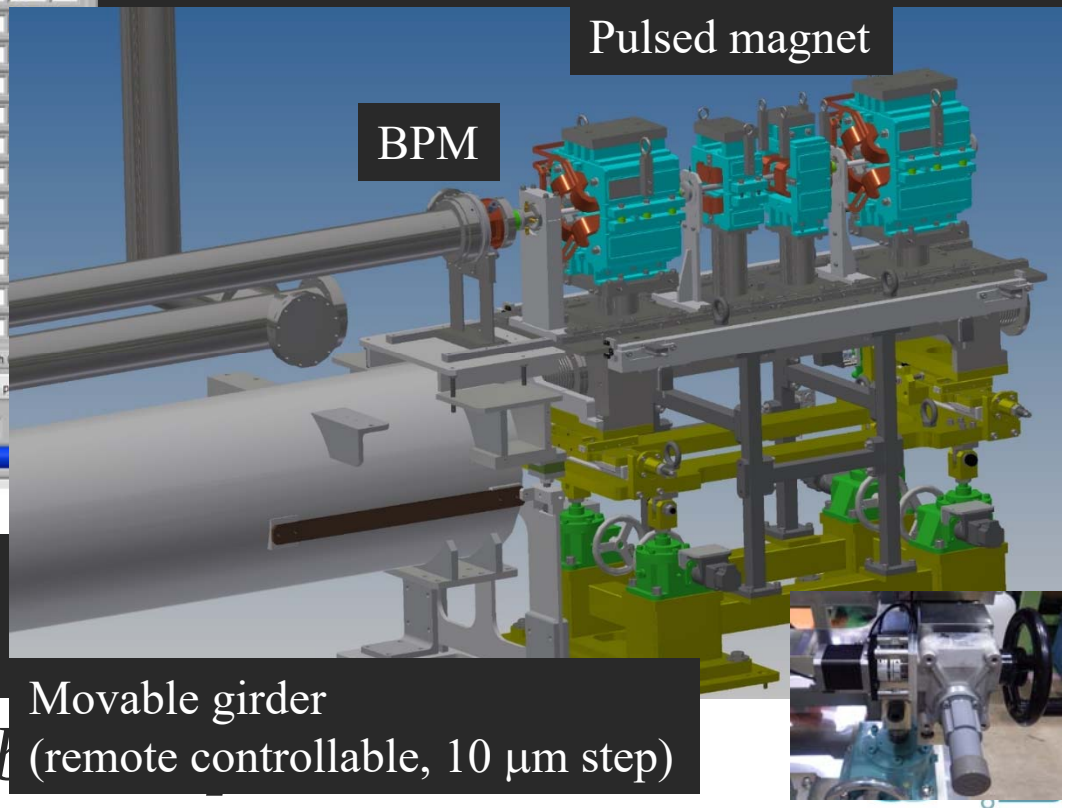
Pulsed magnet system

- Pulsed quads (x 28) (w/ ceramic duct) and steering (x 36) were installed at Sector3 to Sector5 in 2017 (on movable girder).
- Pulsed bend, additional quad and steering were installed in 2018 summer and winter shutdown.
- PXIe based control system (Windows 8.1, LabVIEW, EPICS) have worked fine w/o any serious trouble.
- Power supply stability: 0.01% (24 hours)



0.014578 / 165.946 = 0.01 % (requirement 0.1 % @ 330 A)

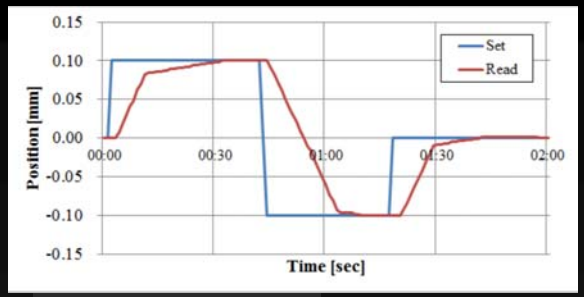




Movable girder
(remote controllable, 10 μm step)

Movable girder

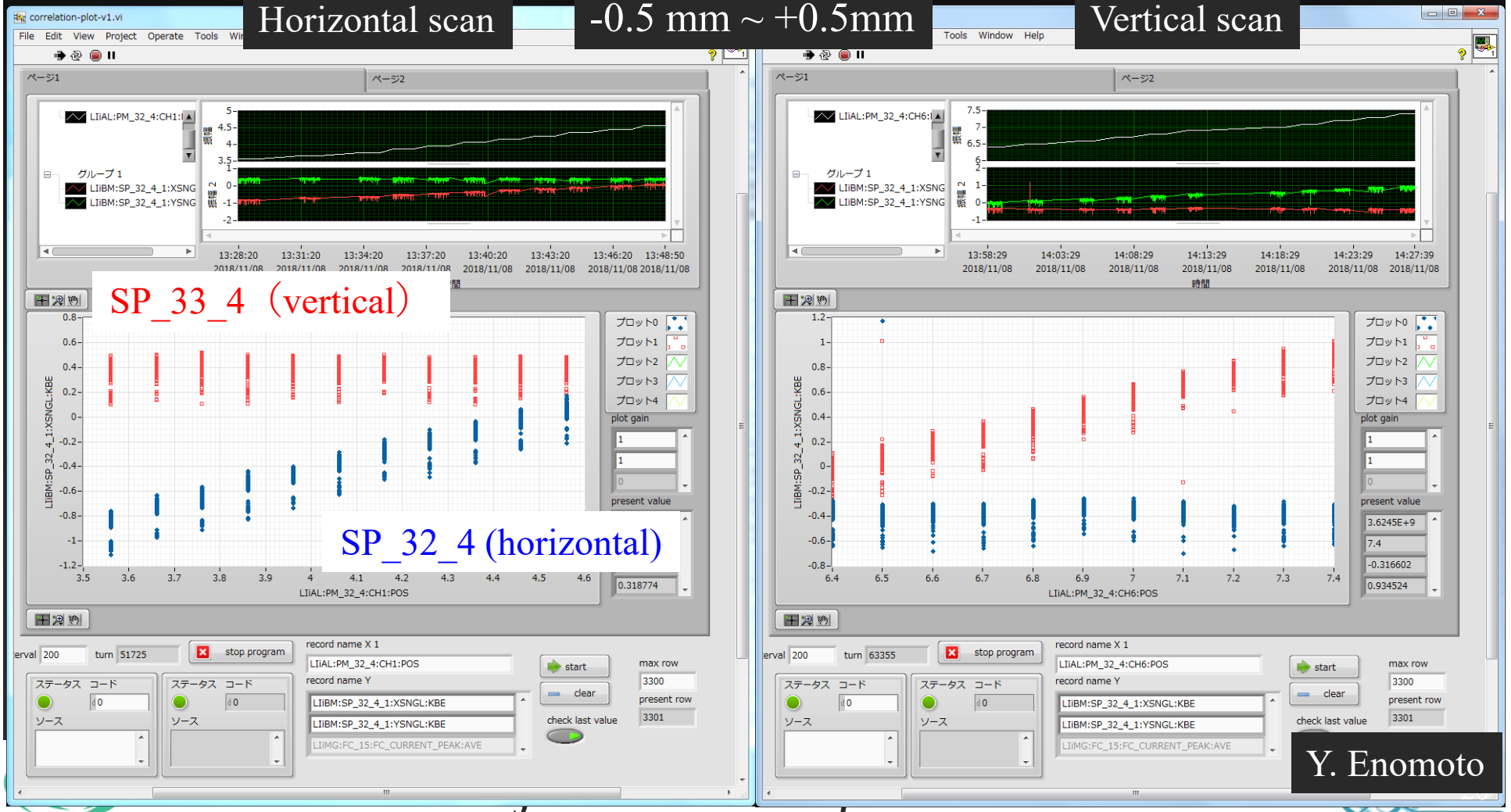
- Movable girder was tested in the beam line.
- Beam position was measured by BPM.



Horizontal scan

-0.5 mm ~ +0.5mm

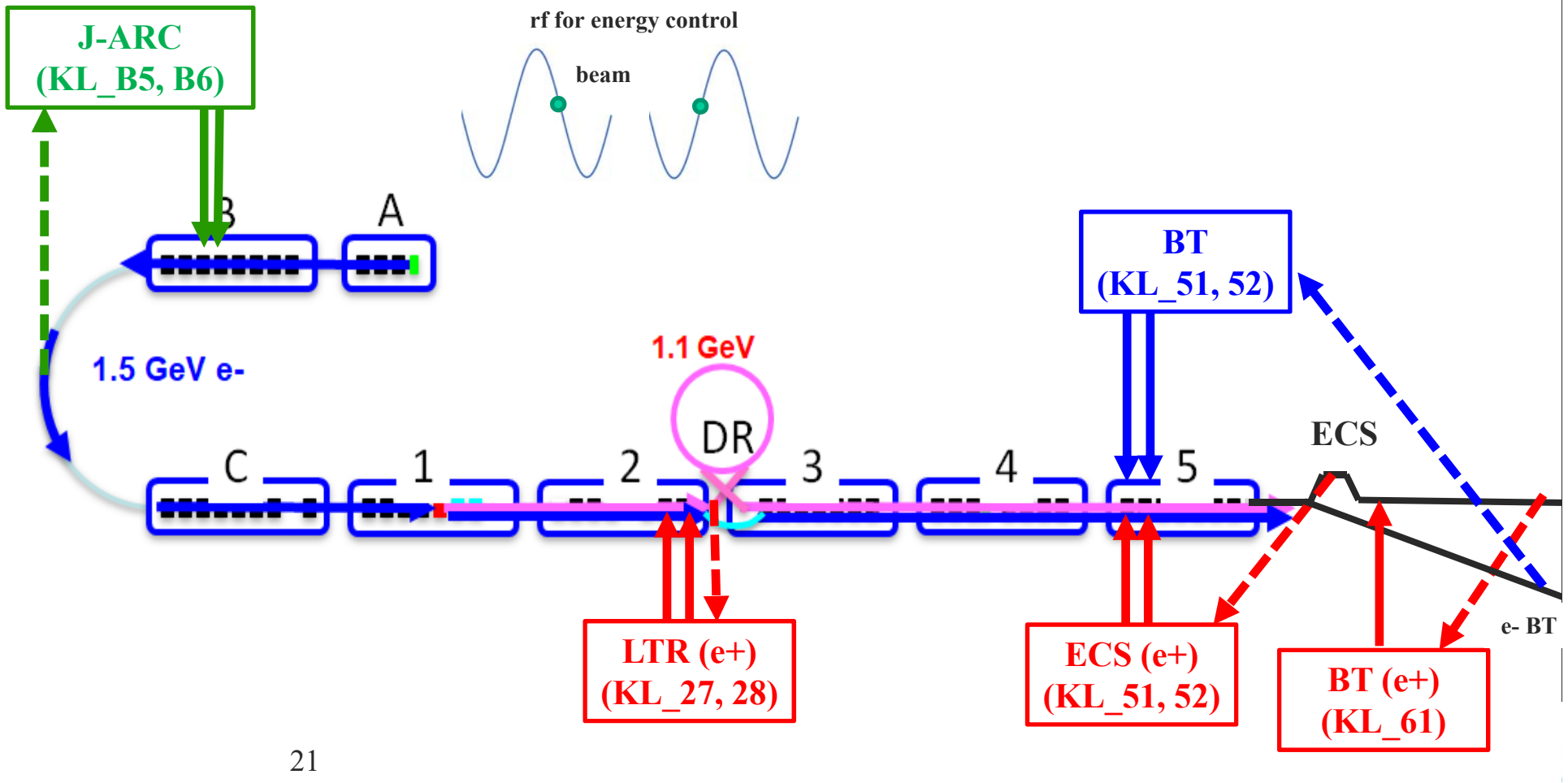
Vertical scan



Y. Enomoto

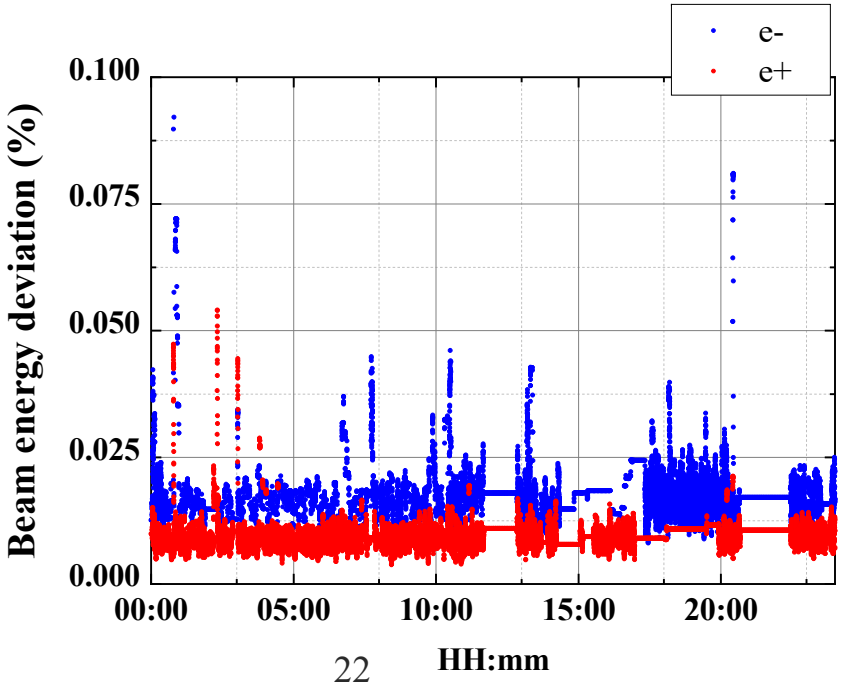
Energy feedback loops (1)

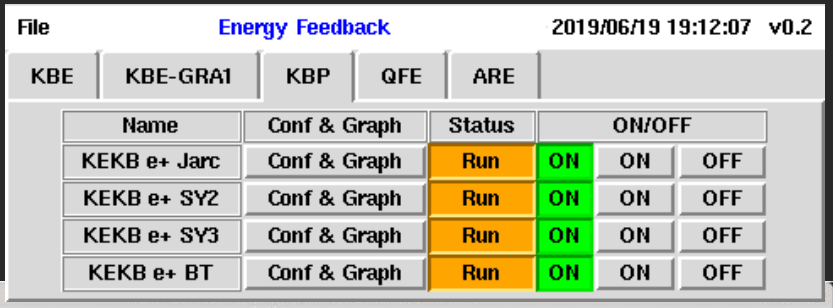
- SuperKEKB
  - e- (HER injection beam): J-ARC, BT
  - e+ (LER injection beam): J-ARC, LTR, ECS, BT
- PF and PF-AR
  - J-ARC, BT

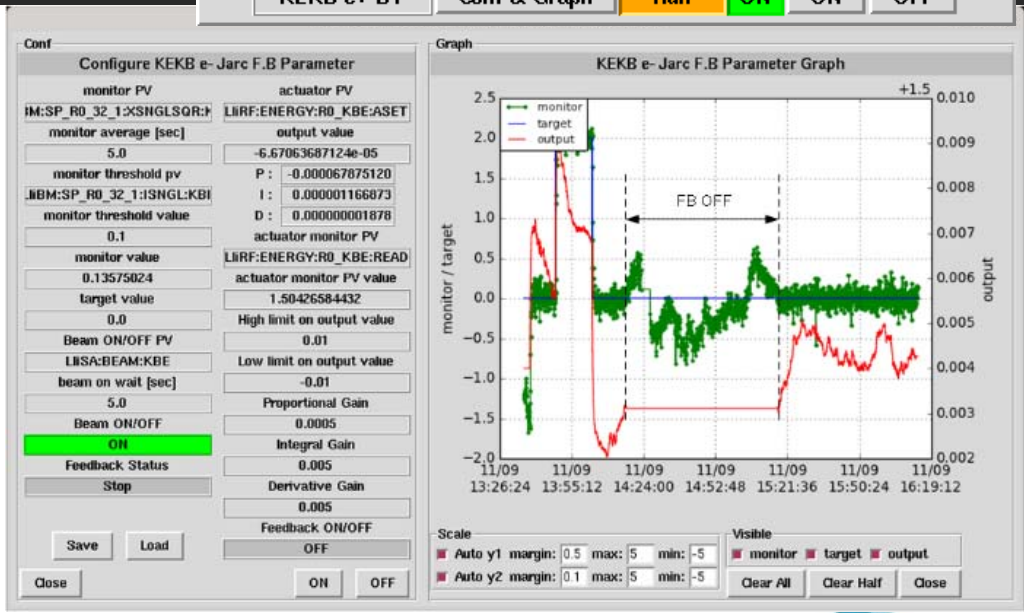


Energy feedback loops (2)

- Energy feedback core
  - work as EPICS IOC for PID control
- Control GUI
  - Set/Read feedback parameter, monitor location, actuator device (klystron)
- Energy stability at BT line
  - < 0.025%



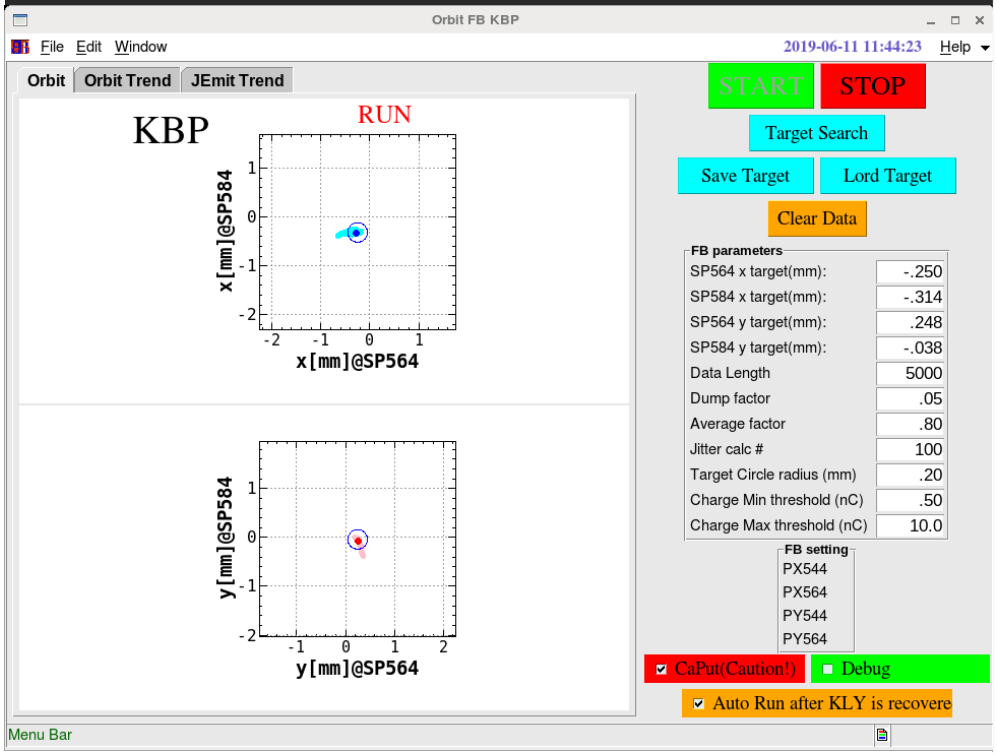


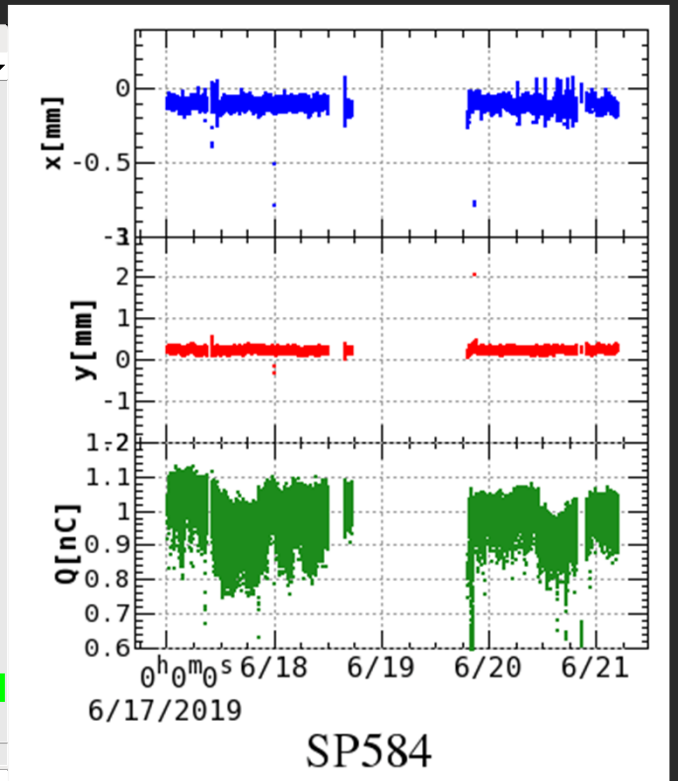


1 operation

Beam orbit feedback

- Orbit feedback tool is ready.
- It can be deployed in any point.
  - J-ARC, end of linac, …
- Large orbit drift (~ 1 mm) can be corrected within ~ 0.1 mm w/ feedback.

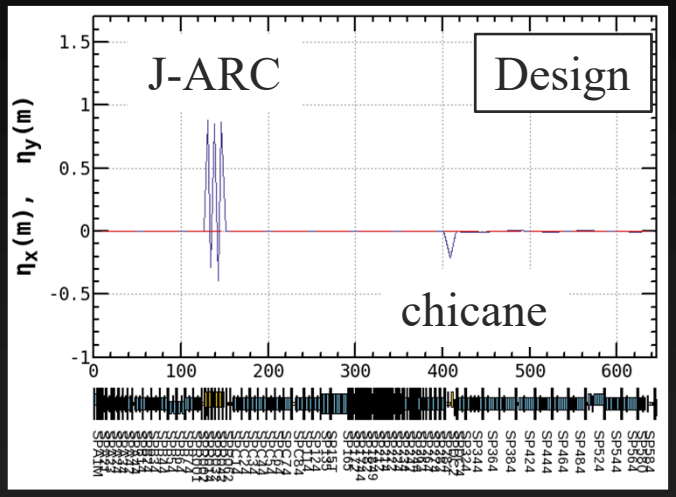




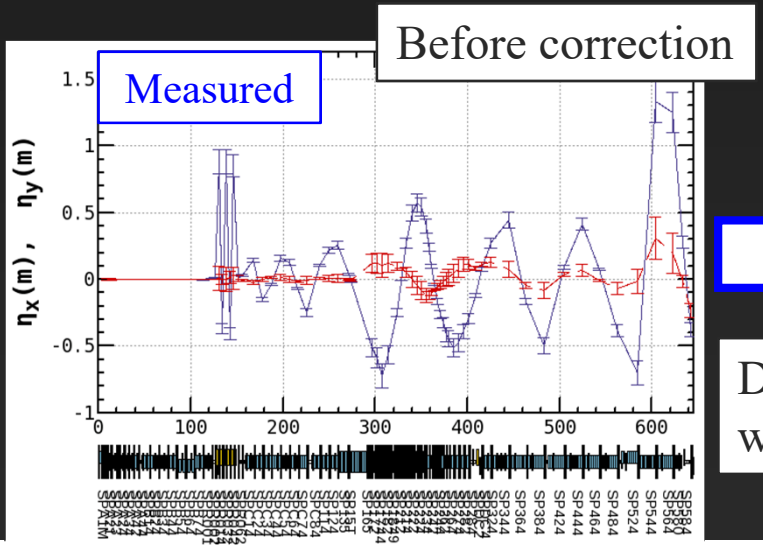
Injector beam operation

Y. Seimiya

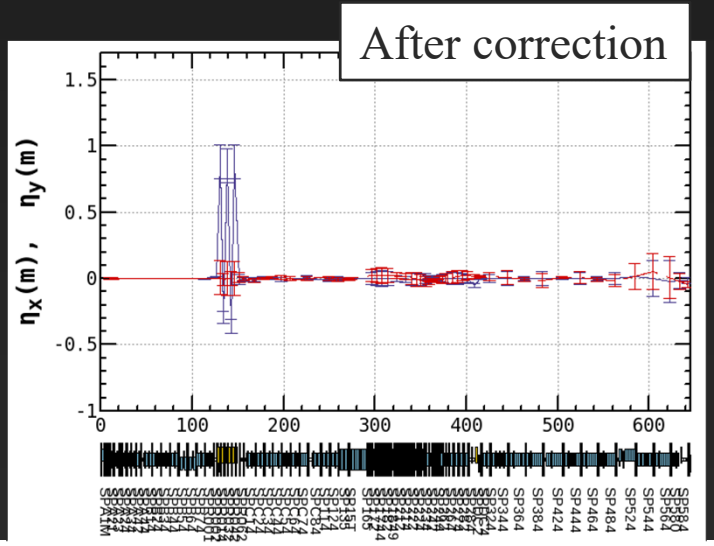
Dispersion measurement and correction



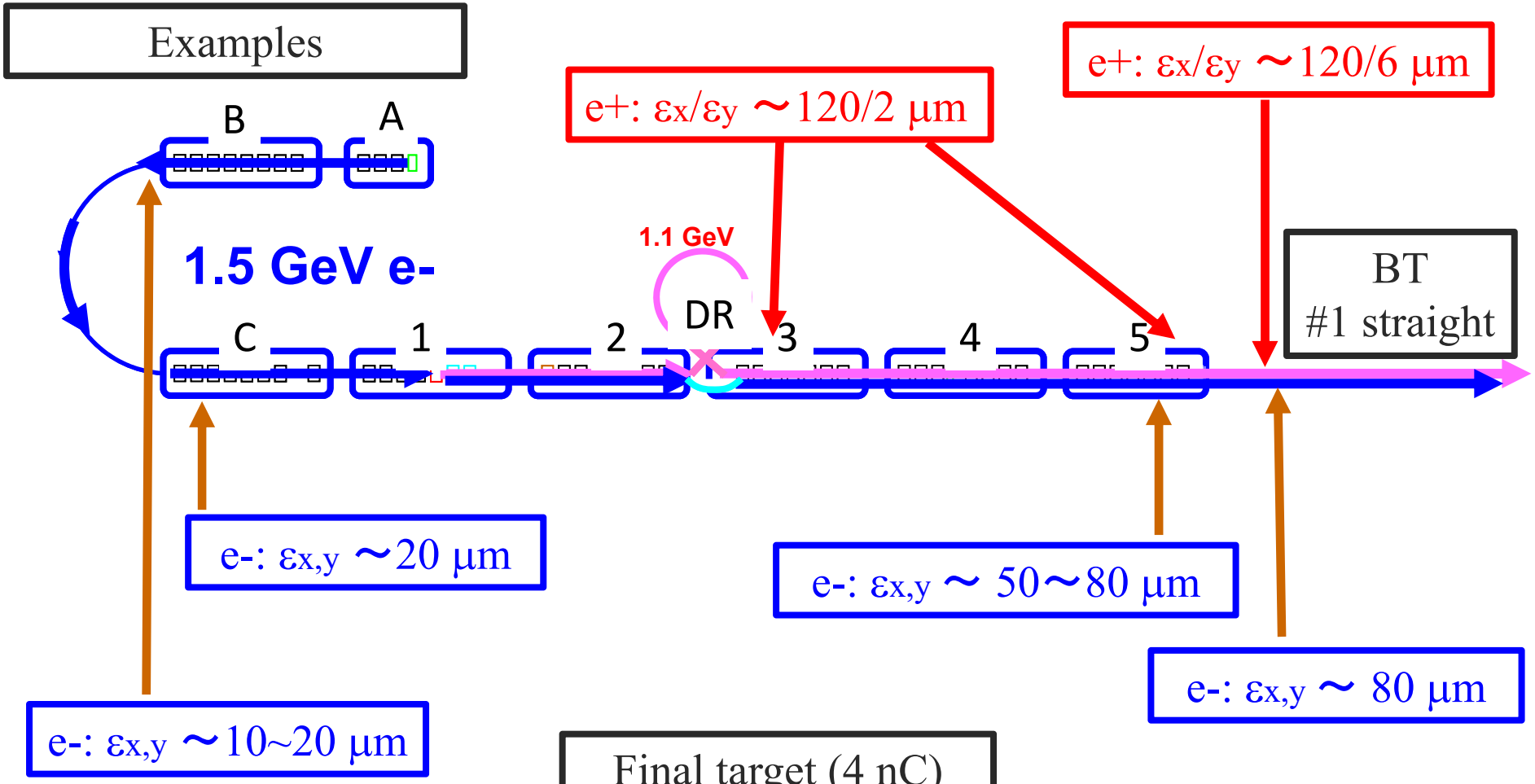
- Horizontal dispersion leakage from J-ARC causes the beam position jitter.
- Applying fudge factors to quads in J-ARC, dispersion is well corrected.



Disp. correction w/ quads



Emittance measurement (~1 nC) w/ multiple wire scanners



Final target (4 nC)

e-: εx/εy 40/20 μm

e+: εx/εy 100/15 μm

Recommendations of the 22nd Review

R24.1: Measure the energy spread and energy jitter at the end of the linac and demonstrate that the required goals are met.

- Energy jitter @ BT < ~ 0.025%
- Energy spread: High precision profile monitor will be installed at BT

R24.2: Develop with priority automatic correction algorithms for critical procedures like the dispersion correction.

- Dispersion measurement and correction software is ready.
- Orbit and energy feedback tools are also working.

R24.3: Define a backup strategy for Phase III in case that the primary RF gun cannot be used, e.g. by preparing a scenario of using the second RF gun.

- In the future, second rf gun will work as backup.
- Thermionic gun is a backup for a while.

Summary

- Achievement of stable simultaneous top up injection to HER, LER, PF, and PF-AR w/ thermionic gun, rf gun, pulsed magnets
- HER injection has been done w/ rf gun from PhaseIII day 1 to run end w/o any significant problem.
- Establish of PF (2.5 GeV)/PF-AR (5 GeV) injection scheme (quasi top up)
- Quick recover from fire incident (one night rf conditioning, two days beam tuning)
- Energy feedback, orbit feedback loops, and other operation tools

Future plan

- Increase e+ bunch charge (Y. Enomoto)
  - New flux concentrator in 2020
- RF gun improvement (R. Zhang)
  - Temperature stability in laser hat, laser profile monitor during top up in 2019
  - Better vacuum and higher rf power, higher Q_E photocathode in 2020
- Pulsed bend (heating issue)
  - New bend will be installed in summer shutdown 2020.
- Low emittance preservation w/ high bunch charge (Y. Seimiya)
  - Alignment, movable girder of acc. structure (x7) will be tested w/ beam soon.
  - Precise orbit control, wake field free steering
- Synchronized data acquisition and analysis
  - All data (BPM, rf, pulsed magnet) are already archived.
  - Integrated data analysis tool is under development.