Injector Linac Status

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for Injector Linac Group

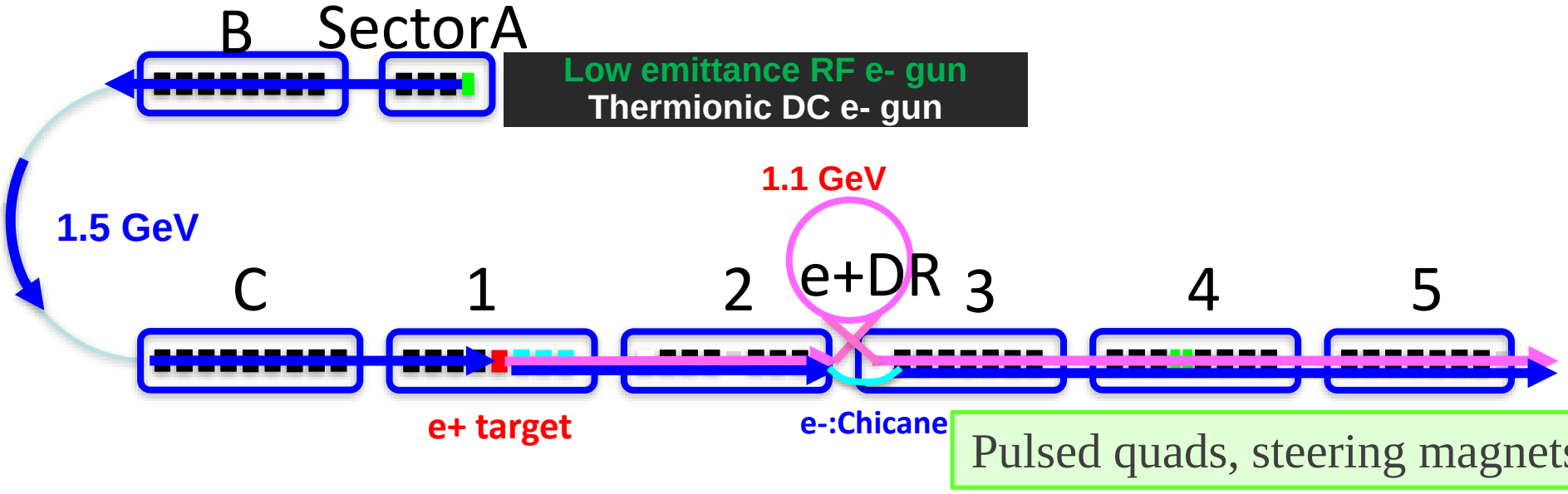
KEKB Accelerator Review Committee, July 15th, 2020

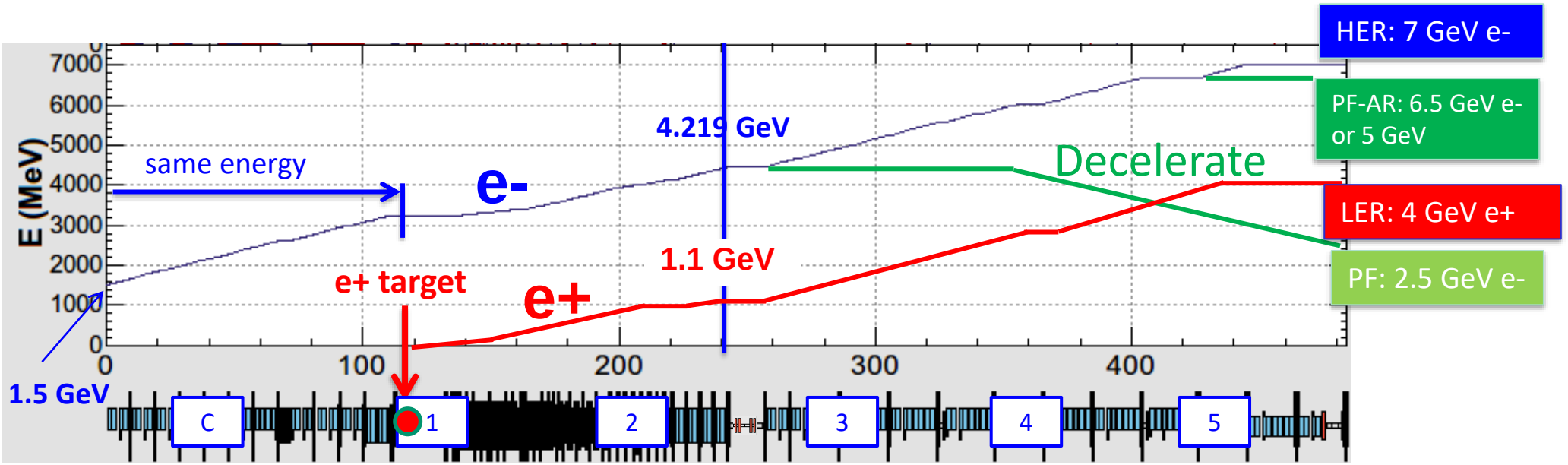
Contents

- Injector overview
- HER injection beam (rf e- gun) status
- LER injection beam (e+, FC) status
- Beam abort caused by abnormal injection beam
  - Abnormal orbit (pulsed magnet issue)
  - Abnormal energy (rf failure)
- Summary and plan

Injector: Simultaneous top-up to five rings

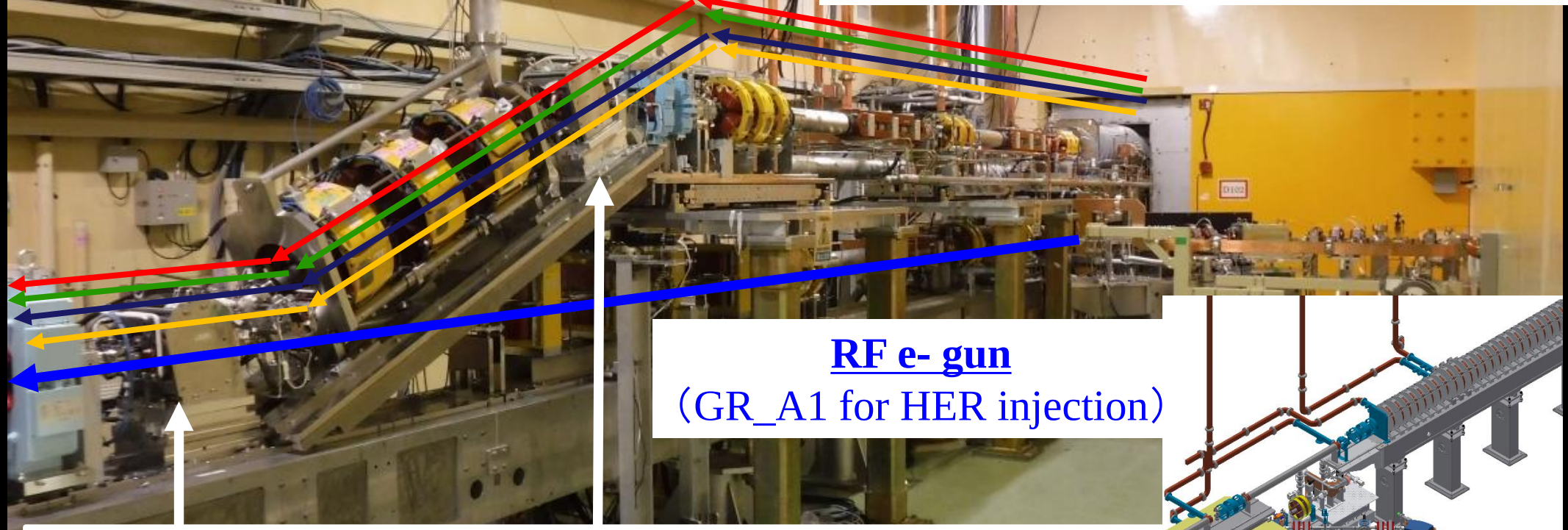
- Photocathode RF gun for HER injection
- Thermionic gun for LER (via DR), PF, PF-AR





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

Thermionic DC e- gun (GU_AT)
w/ 2 subharmonic bunchers and 2 bunchers
- 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

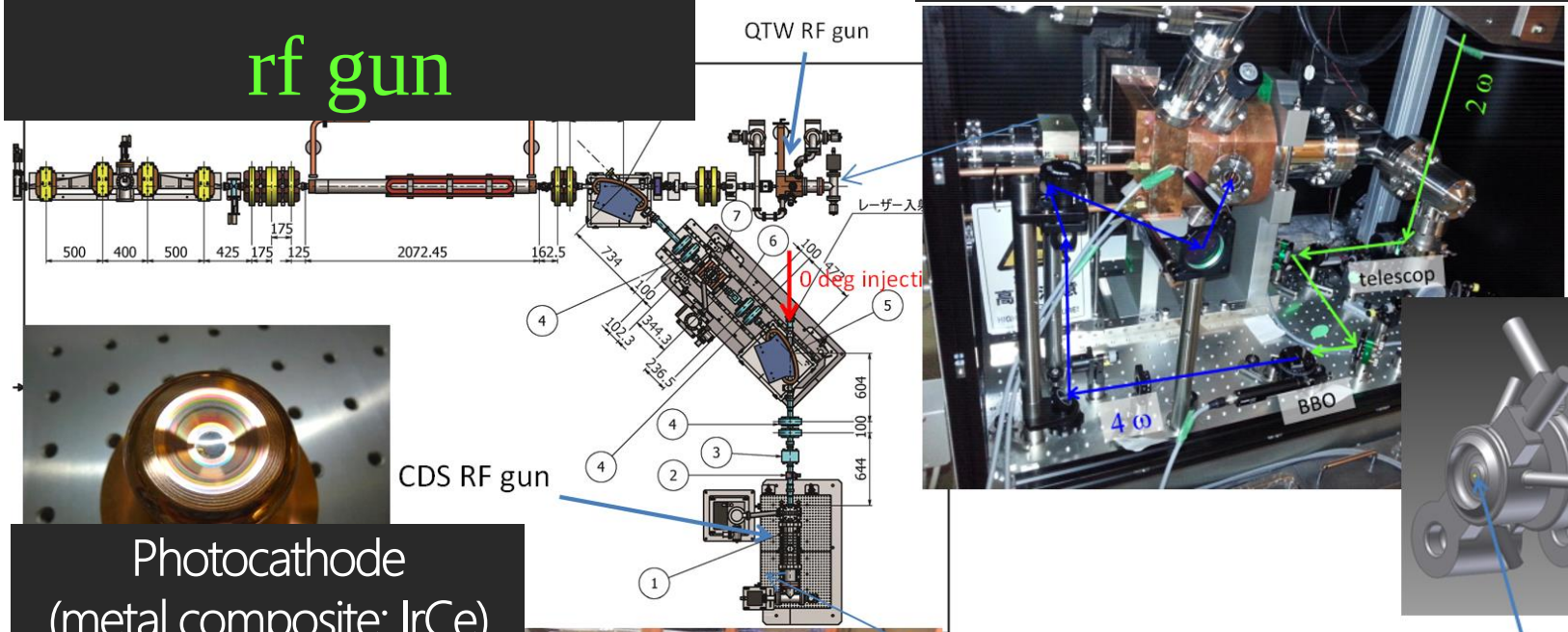


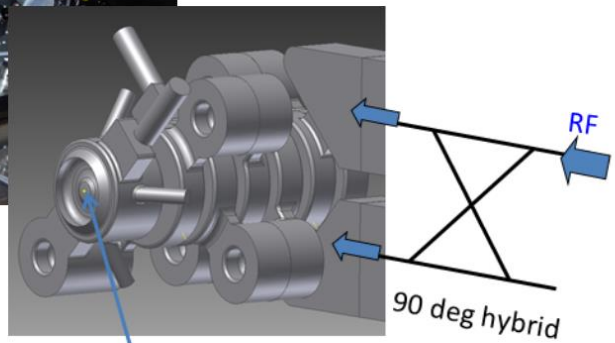
RF e- gun
（GR_A1 for HER injection）

Pulsed bend rep. up to 25 Hz (LER + PF + PF-AR)
(magnet coil and chamber heating issue)
It will be replaced by new one in summer shutdown 2020.

Low emittance rf gun

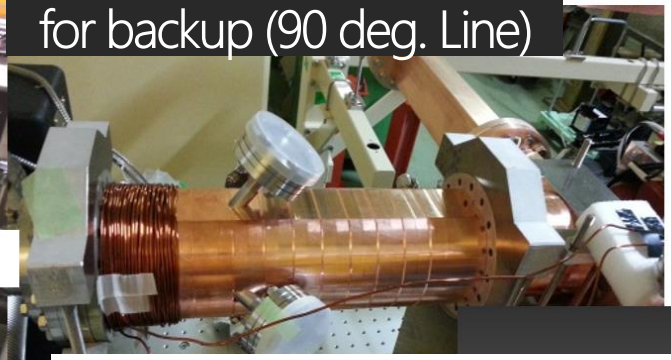
QTW RF gun or operation (0 deg. Line)

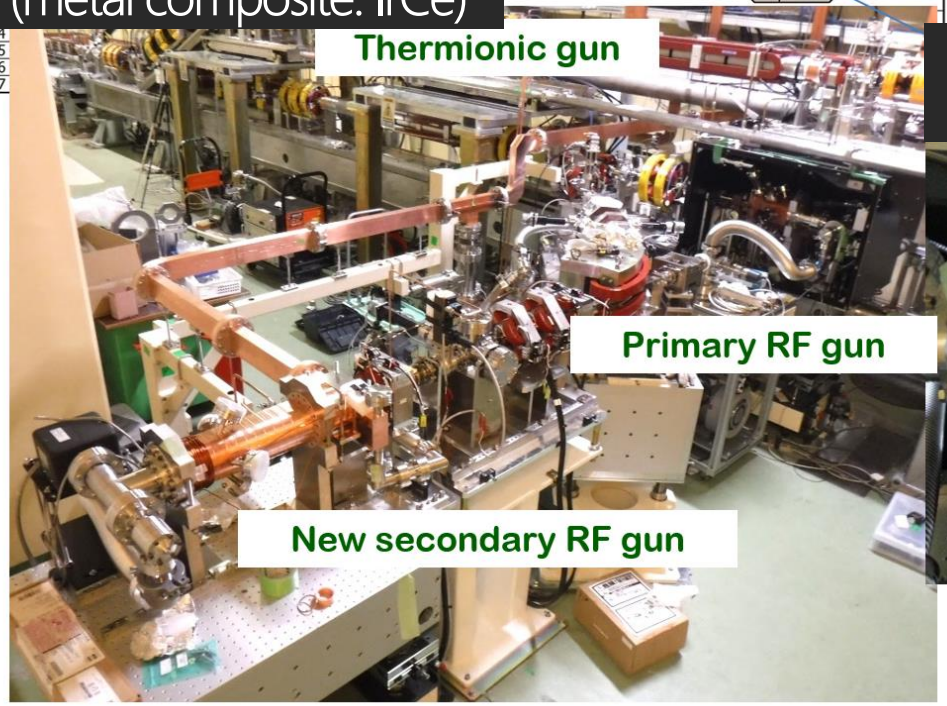




Photocathode
(metal composite: IrCe)

CDS RF gun for backup (90 deg. Line)

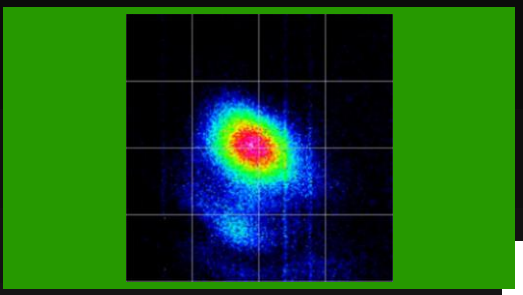




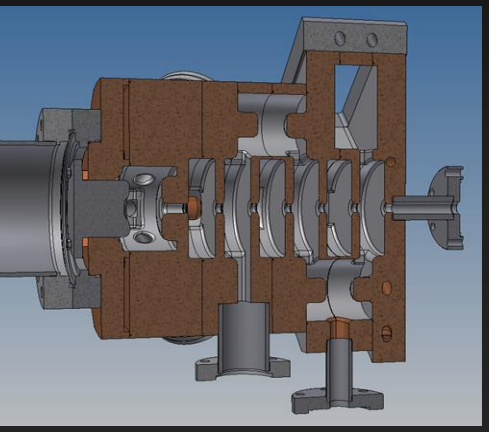
- Yb-doped-fiber and Nd/Yb:YAG laser
- IrCe cathode
- QTWSC or cut disk cavities

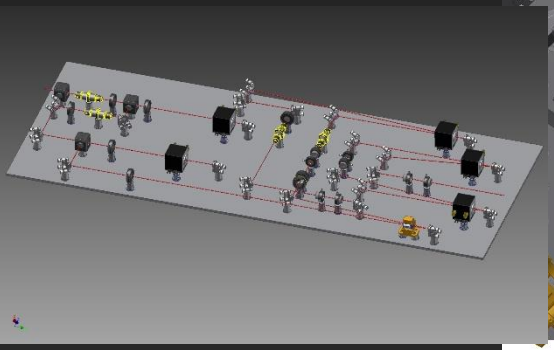
Hybrid laser system for rf gun

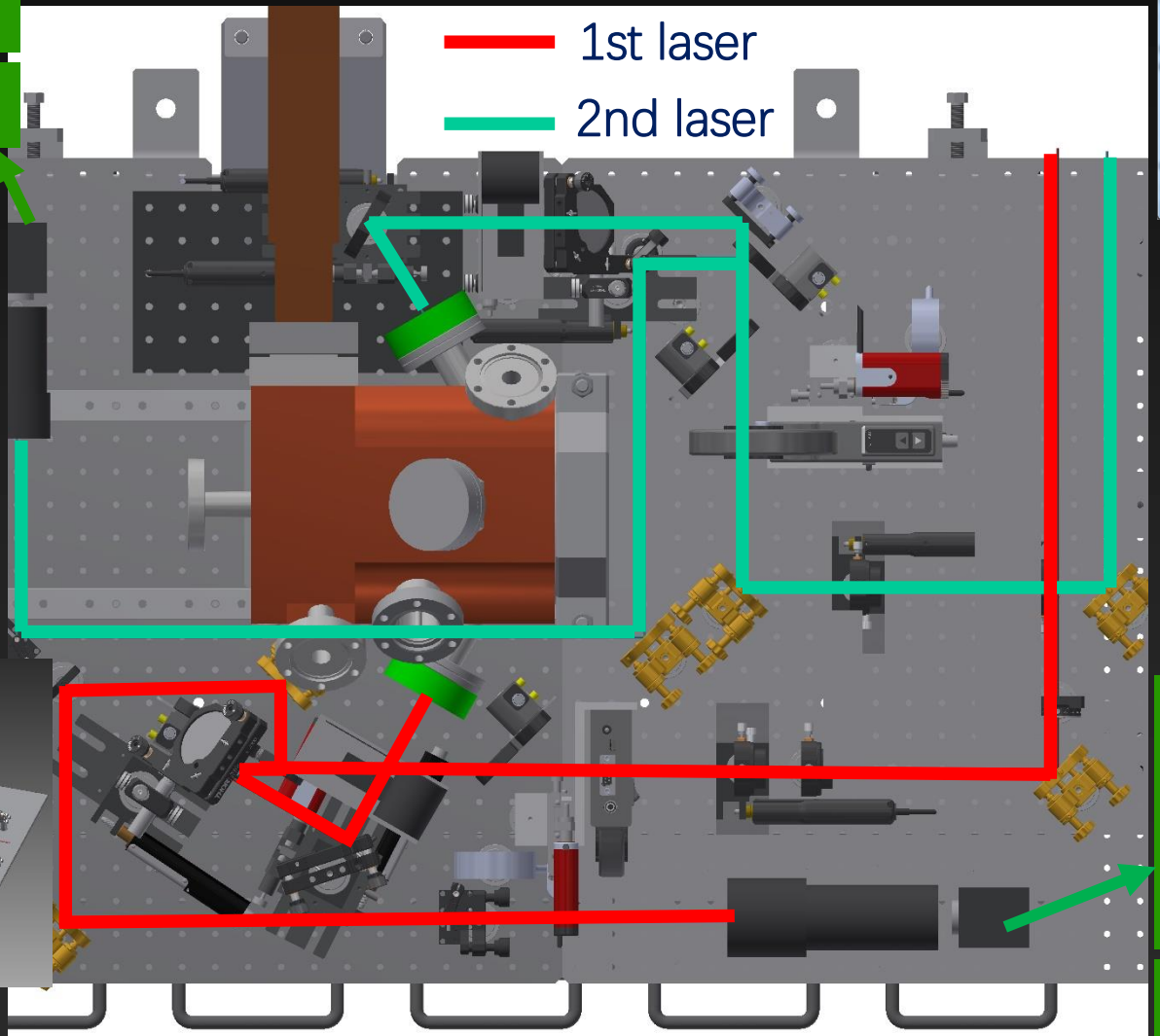
- Three Oscillators (two of them are backup)
- Yb doped fiber and Neodymium (Nd) doped laser crystal.



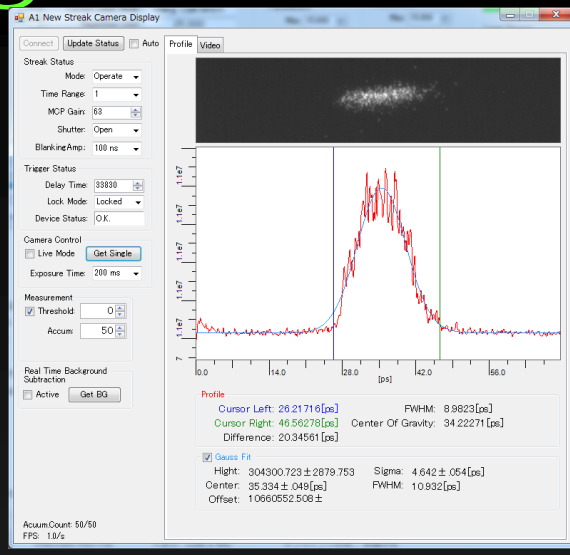
UV laser beam profile



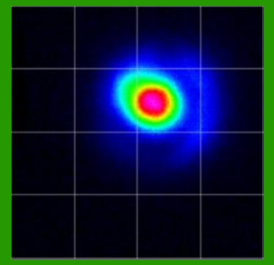




Optics layout in the tunnel



1st + 2nd laser line:
laser line:
e- beam bunch length
~ 10 ps (FWHM)



UV laser beam profile

e- source

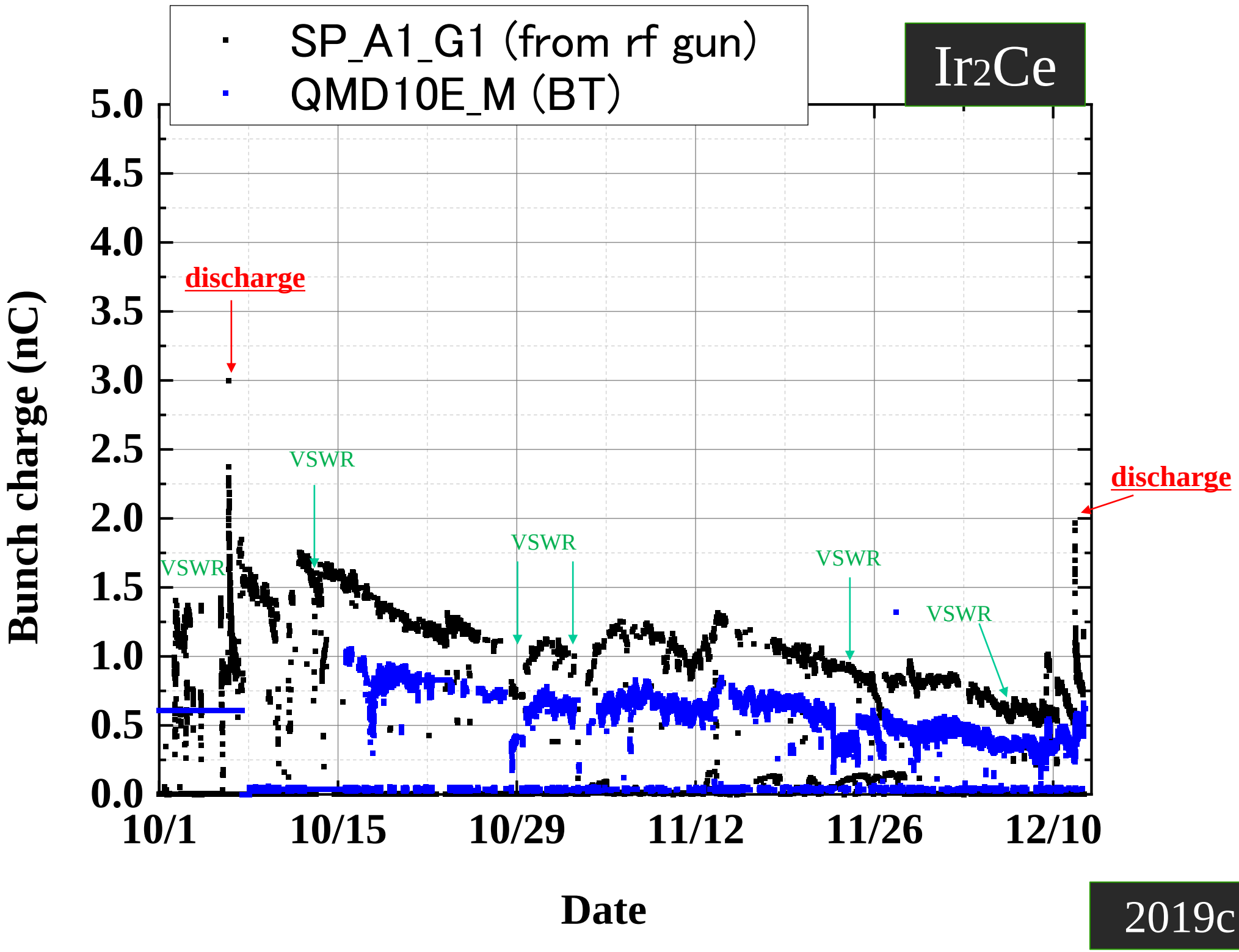
R. Zhan, SuperKEKB review, 2019

HER injection beam (rf e- gun) status

- HER injection w/ only rf gun since Mar. 11th , 2019.
- Laser system has no significant fault.

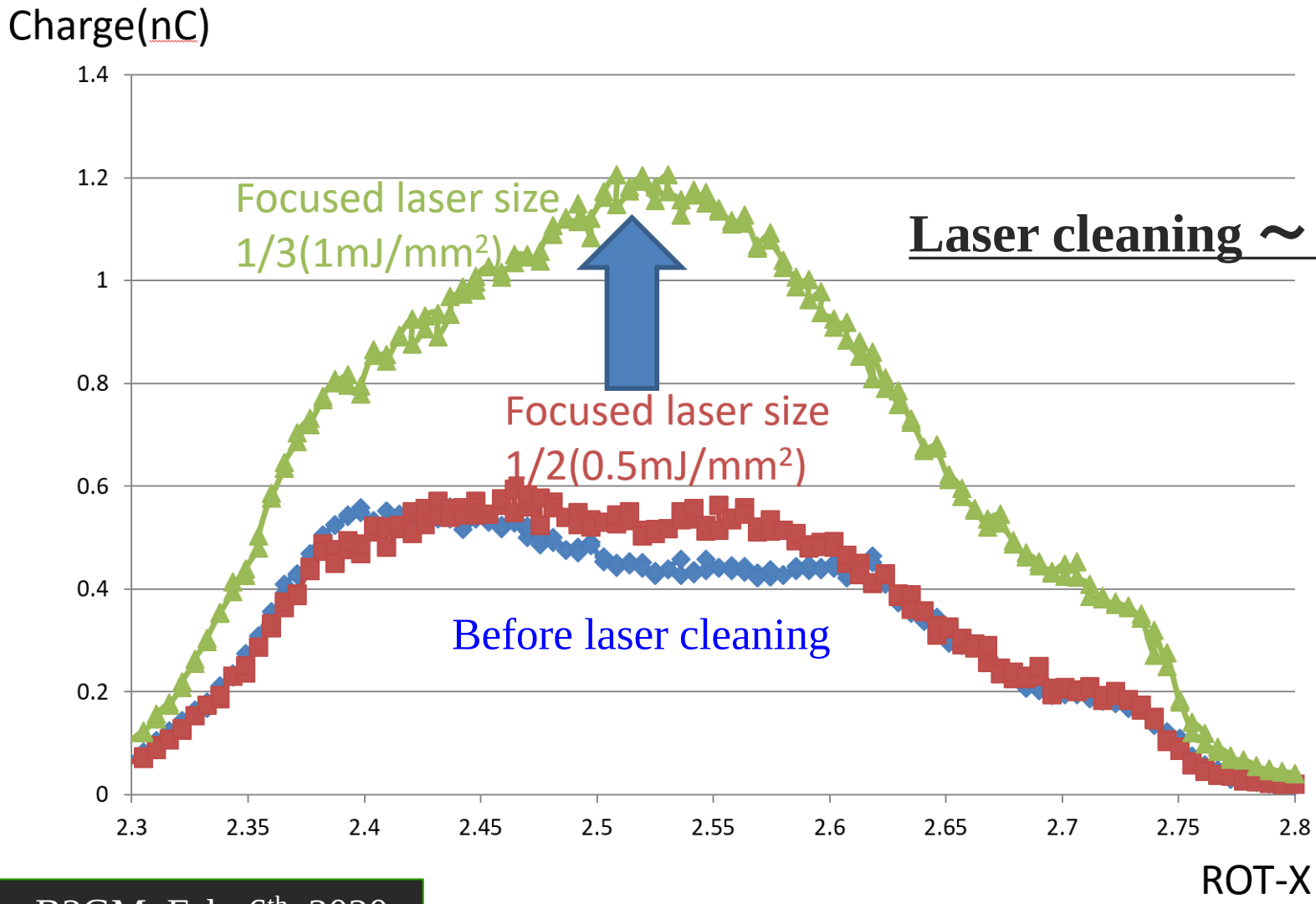
- In summer shutdown of 2019, photocathode (Ir_7Ce_2) was replaced by new one (Ir_2Ce) for aiming at better quantum efficiency (Qe).
  - Discharge, frequent VSWR, gradual decrease of bunch charge

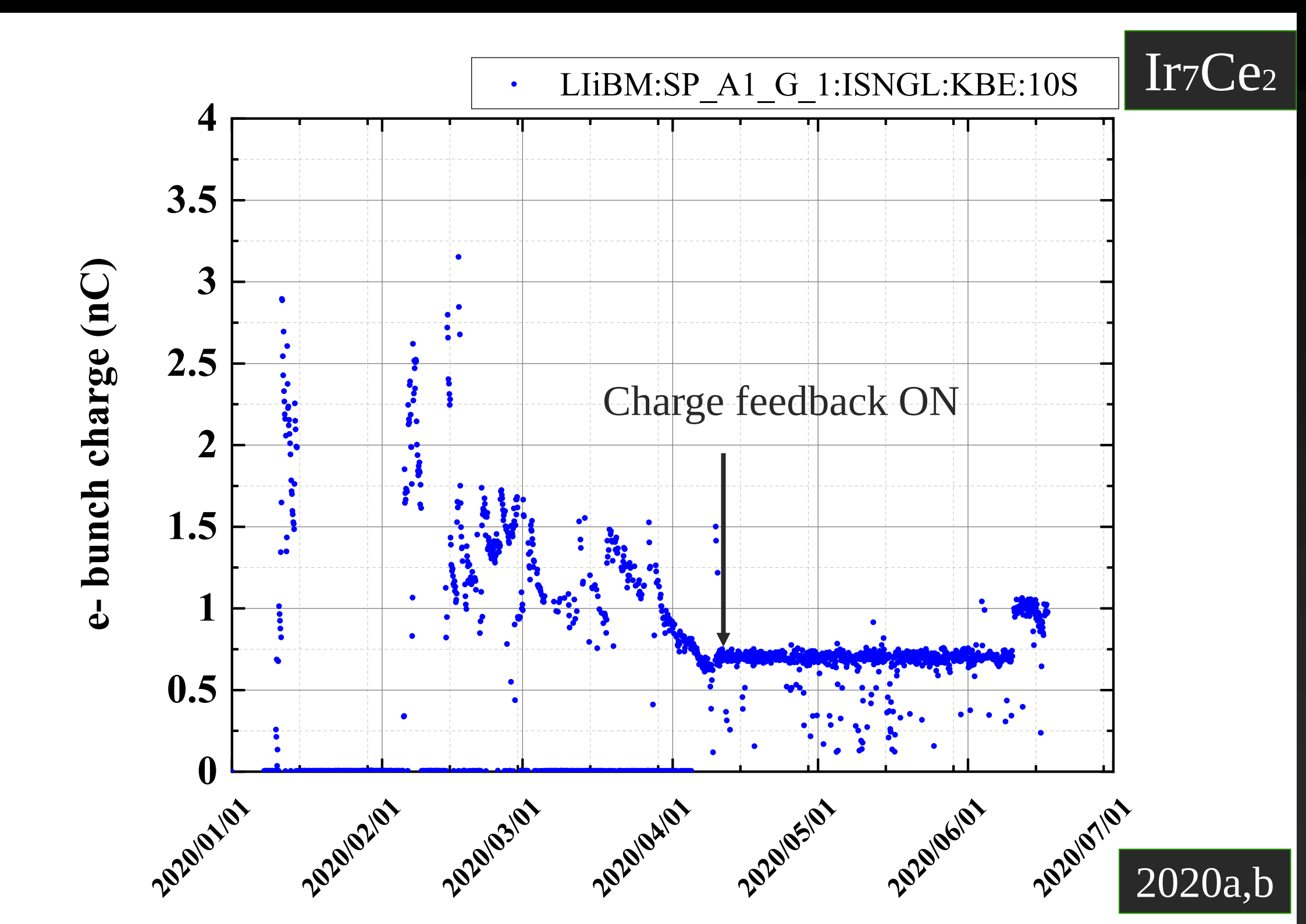
- In the last winter shutdown, photocathode was replaced (Ir_2Ce => Ir_7Ce_2). However, bunch charge decreased gradually.
  - Laser cleaning for recovering Qe
  - Bunch charge feedback


SP_A1_G1 (from rf gun)
QMD10E_M (BT)
Ir2Ce
Bunch charge (nC)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
discharge
VSWR
VSWR
VSWR
VSWR
VSWR
discharge
10/1
10/15
10/29
11/12
11/26
12/10
Date
2019c

Laser cleaning / Focused laser size

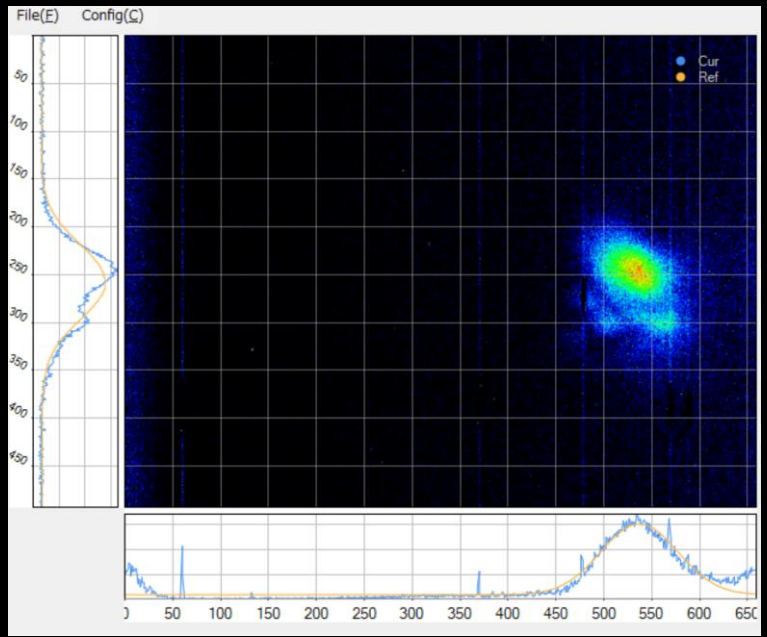
- 2nd Laser only
- Scan using focused laser beam without RF

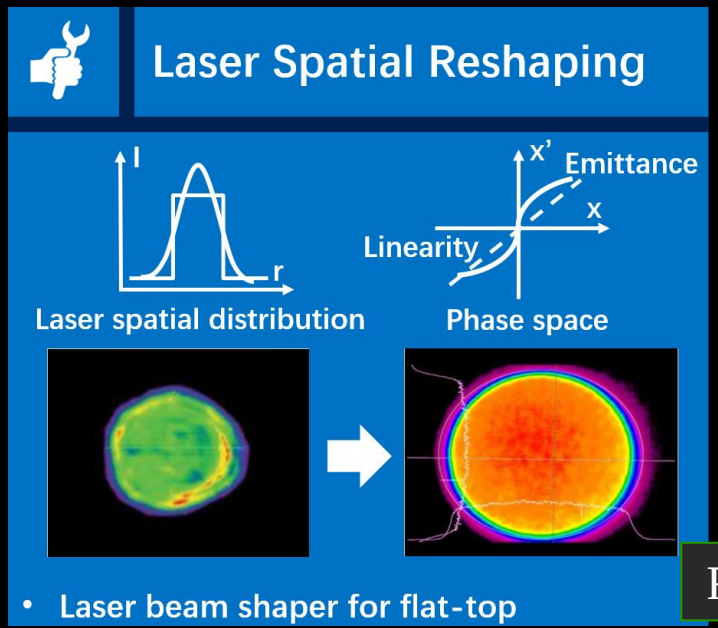



LIiBM:SP_A1_G_1:ISNGL:KBE:10S
Ir7Ce2
e- bunch charge (nC)
4
3.5
3
2.5
2
1.5
1
0.5
0
Charge feedback ON
2020/01/01
2020/02/01
2020/03/01
2020/04/01
2020/05/01
2020/06/01
2020/07/01
2020a,b

HER injection beam (rf e- gun) status

- Laser cleaning for recovering Qe works fine.
- Bunch charge feedback works fine to keep bunch charge constant.
- Diffractive optical element (DOE) was installed and tested for transverse laser beam shaping (flat top).
  - It could be help for low emittance beam w/ high bunch charge.
- Laser position feedback will be prepared in this summer shutdown.

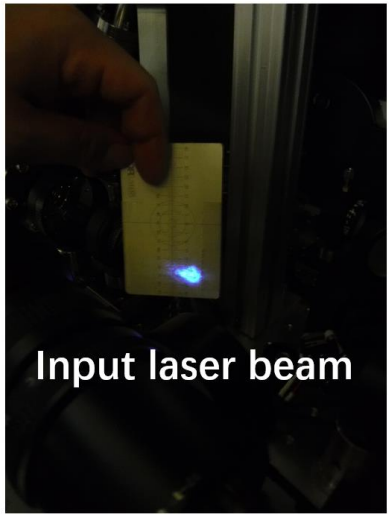


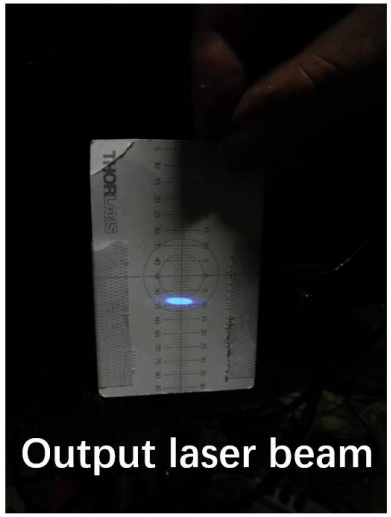


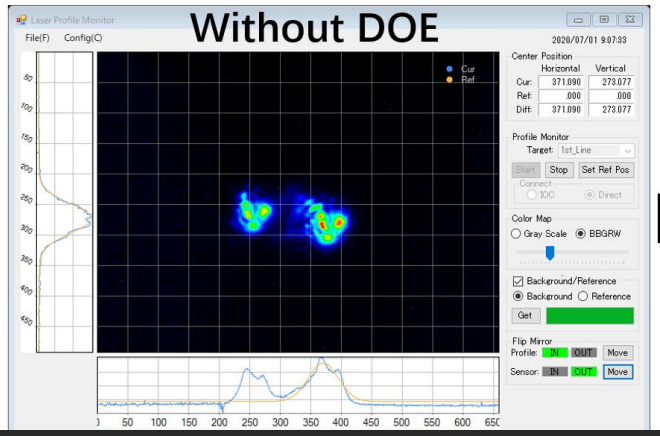
R. Zhang

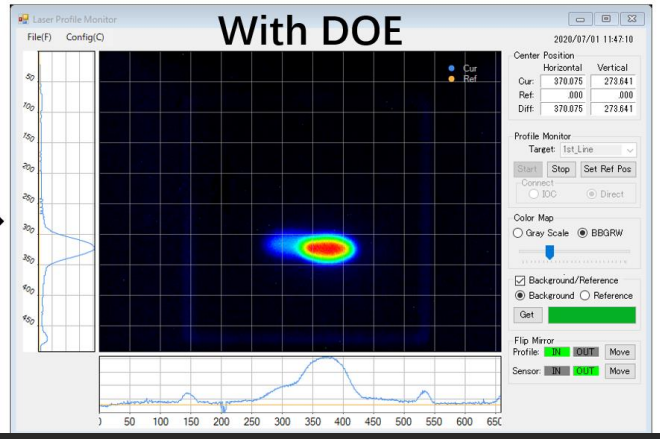
First beam test result w/ DOE (Jul. 1st)

Reshaping of RF gun laser





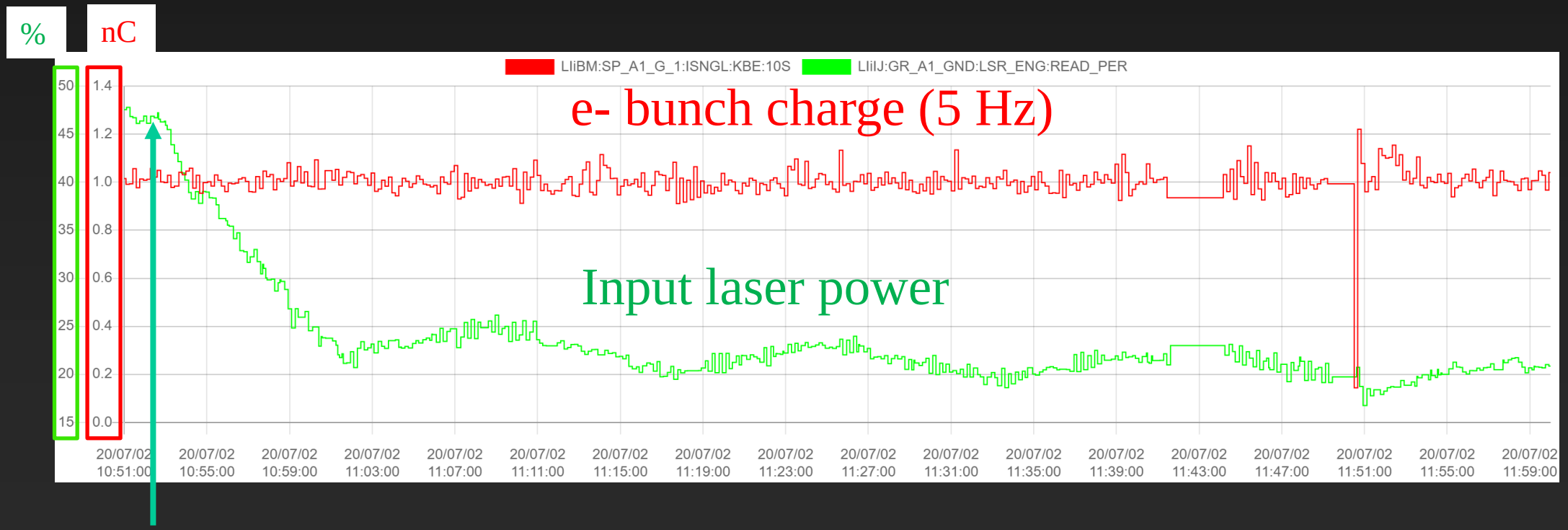




- Designed elliptical laser beam patten is realized by use of DOE
- Total loss for DOE chamber set is about 25% (acceptable)
- Laser beam stability is also improved

Inter pulse laser cleaning

- Laser cleaning works fine for recovering Qe.
- Usually, it takes 30 min. ~ 1 hour. (every two weeks).
- Fast switching scheme between beam on (rf on) and laser cleaning (rf off) was tested. (Jul. 2nd, 2020)

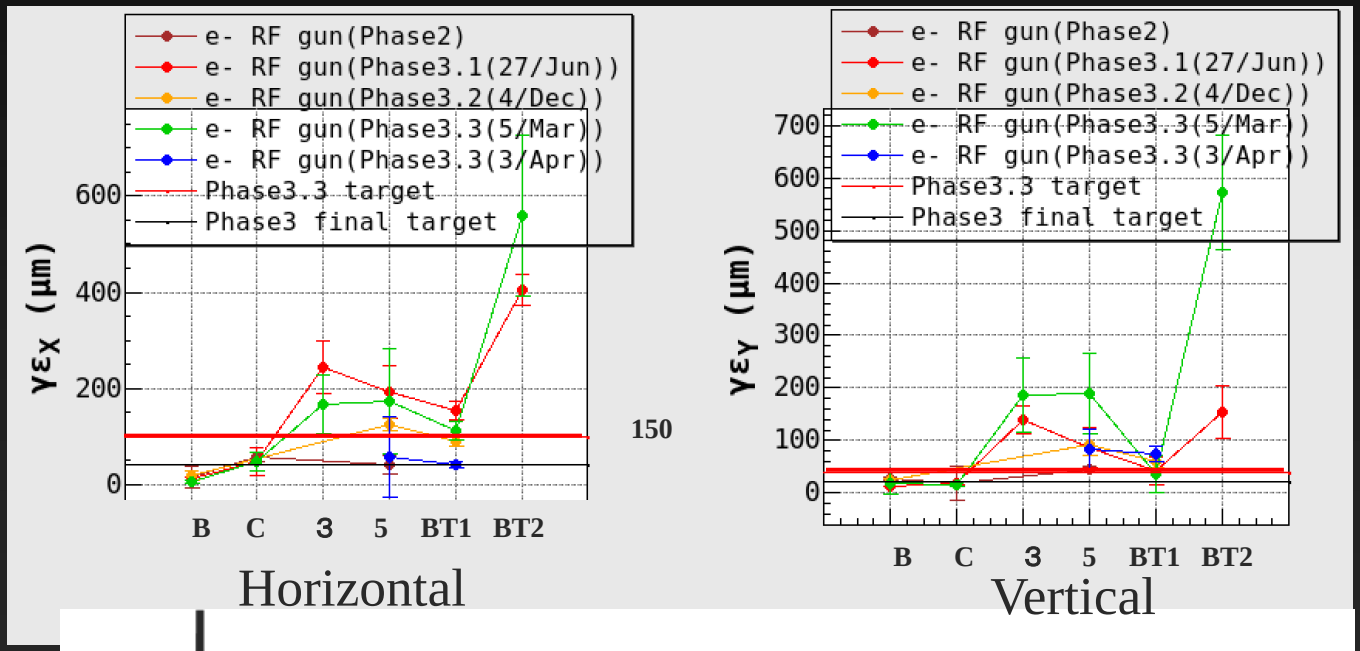


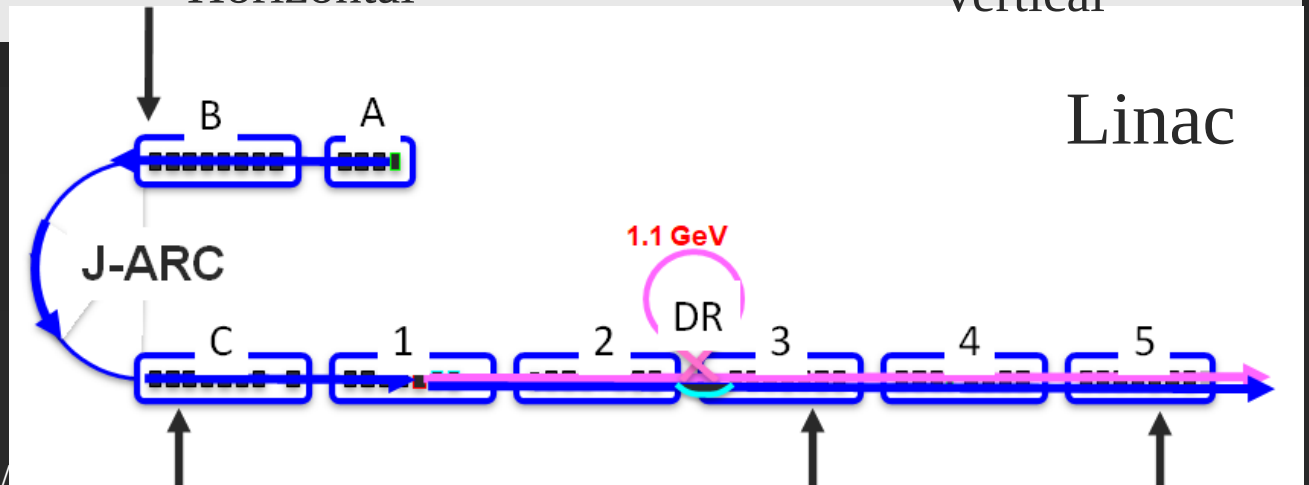
Laser cleaning on (5 Hz)

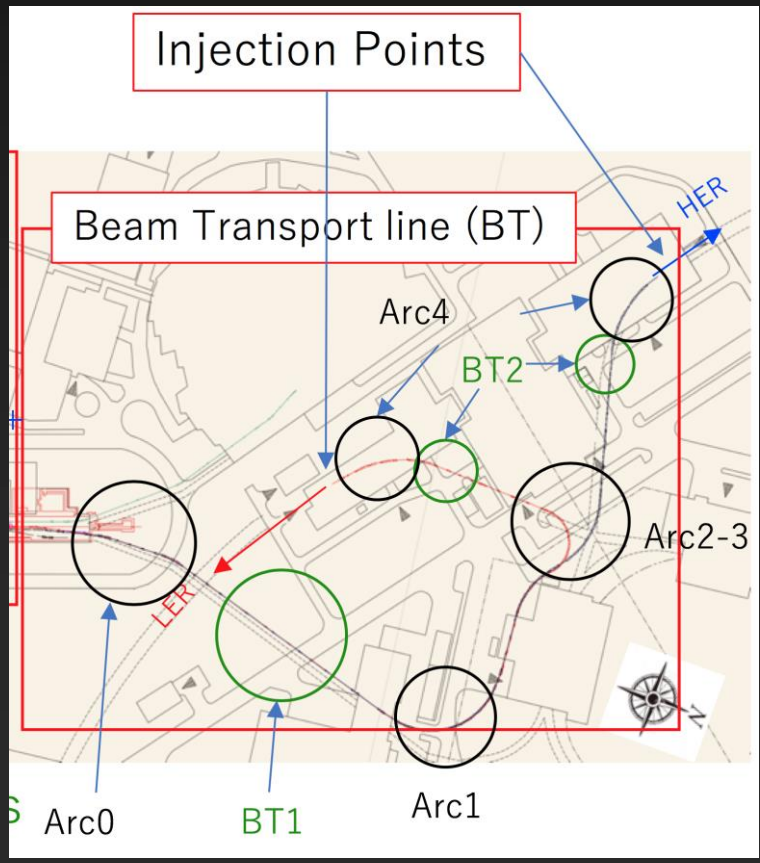
e- beam emittance (～ 1 nC)

- εx,y ～15 μm at SectorB, SectorC
- Emittance growth at BT2 in both directions.
- Emittance could be increased at around solenoid section in Sector1.

(*) More detail will be given by Iida san.



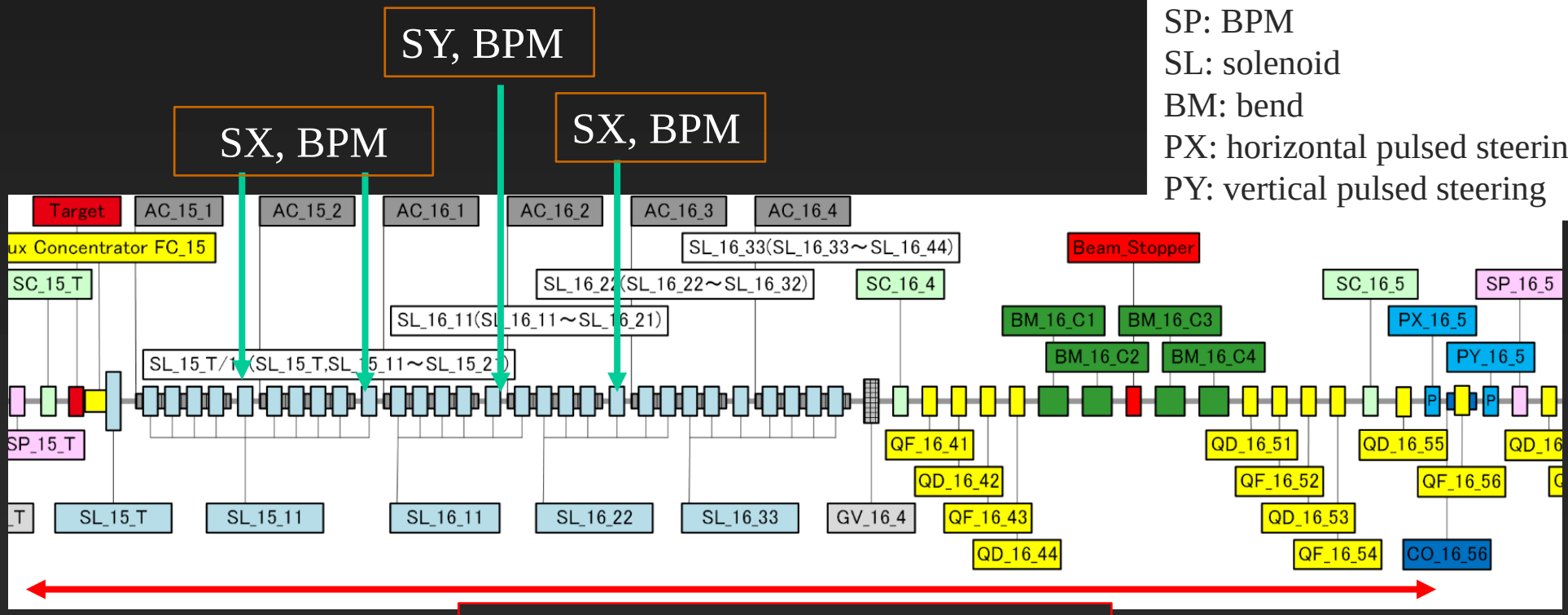




Steering magnet and BPM in solenoid section

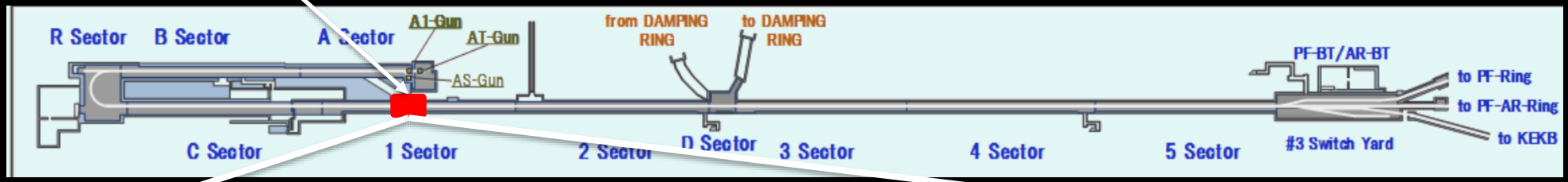
- There is no BPM and steering magnet between e+ target and 16_5 unit.
- DC steering (x4) and BPM (x4) will be installed in this summer shutdown.
- It could be help to cure e+ beam loss and e- beam emittance growth.

Target: e+ W target
FC_15: flux concentrator
SC: screen monitor
AC: accelerating structure
SP: BPM
SL: solenoid
BM: bend
PX: horizontal pulsed steering
PY: vertical pulsed steering



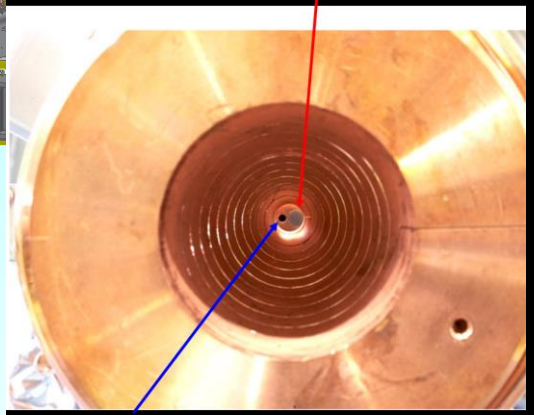
e+ source setup

Positron target and capture section



DC solenoid
Large aperture S-band acc. Structures (x10)

W target (Φ4 mm)

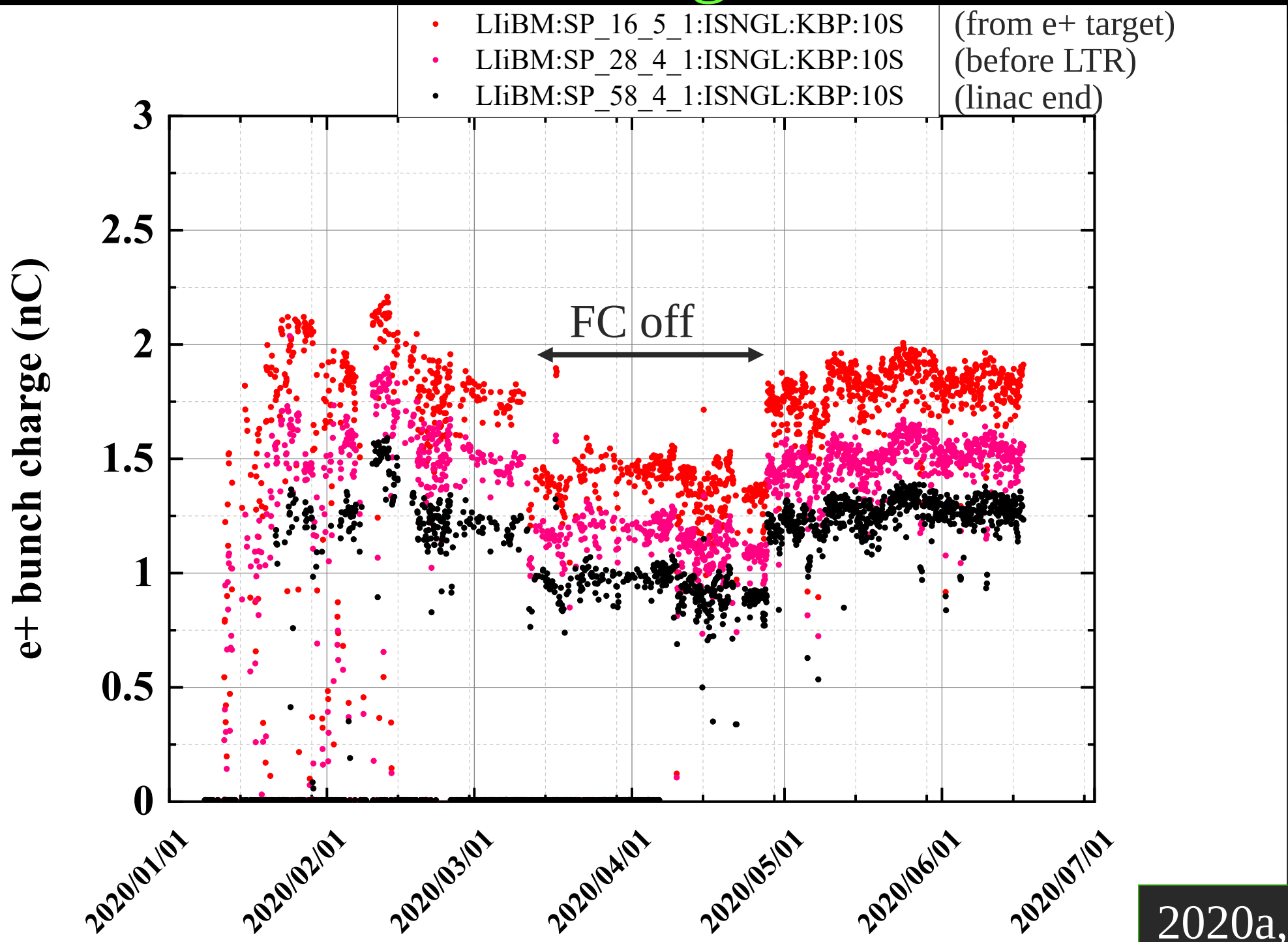


hole (Φ2 mm)
for low emittance e- beam

W target + flux concentrator (FC)

Y. Enomoto, SuperKEKB review, 2019

e+ bunch charge trend



2020a,b

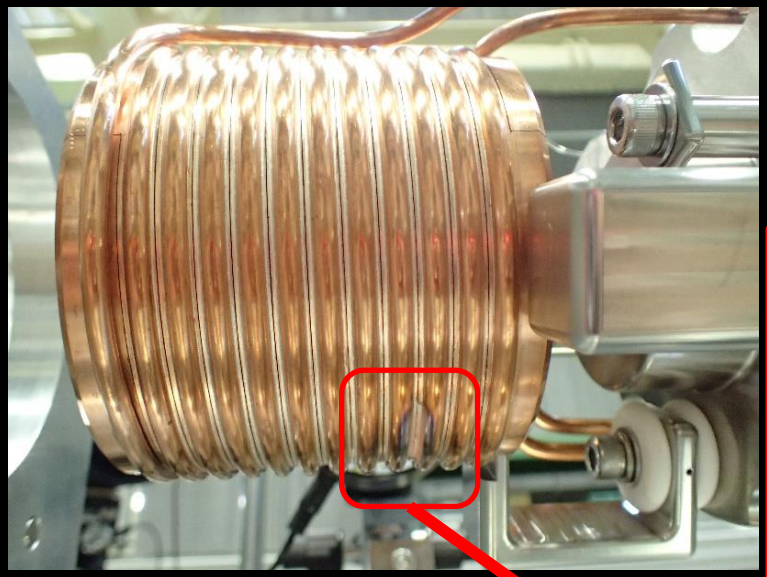
LER injection beam status

- Bunch charge
  - Stable and enough bunch charge in this stage
  - Primary e-: 11 nC (from gun), 9 nC (on W target)
  - e+ : 2 nC (after target), 1.2 nC (linac end), 1.2 nC (BT)
- Flux concentrator (FC)
  - Previous FC was damaged by large discharge during PhaseII. It was removed in Sept. 2018.
  - Current FC was installed in Jan. 2019.
  - 2 ～ 3 kA operation current (design 12 kA) for stable operation. no significant fault.

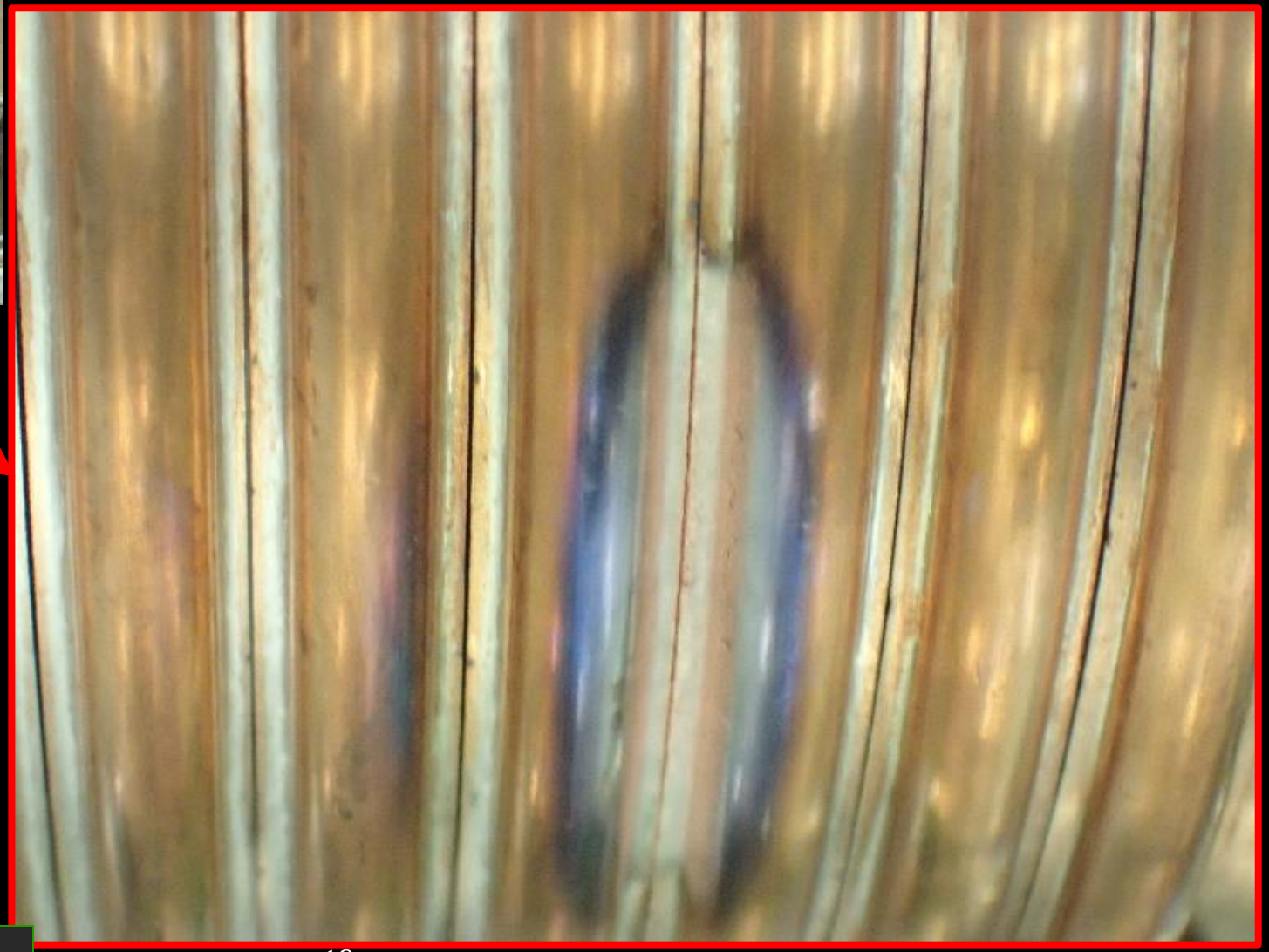
Requirements for material of the FC head are
- Good brazing characteristic
- High yield strength even after brazing
- High electric and thermal conductivity

  - New FC made of Cu-alloy (NC50: Cu-Si-Ni) has been tested w/o fault (～ 12 kA).
  - New FC will be installed in summer shutdown of 2020 for aiming at design operation current.

After large discharge…



After large discharge



Slit gap got narrow.
Not possible to apply high voltage unless the gap will be expanded.

FC assembly, base summary

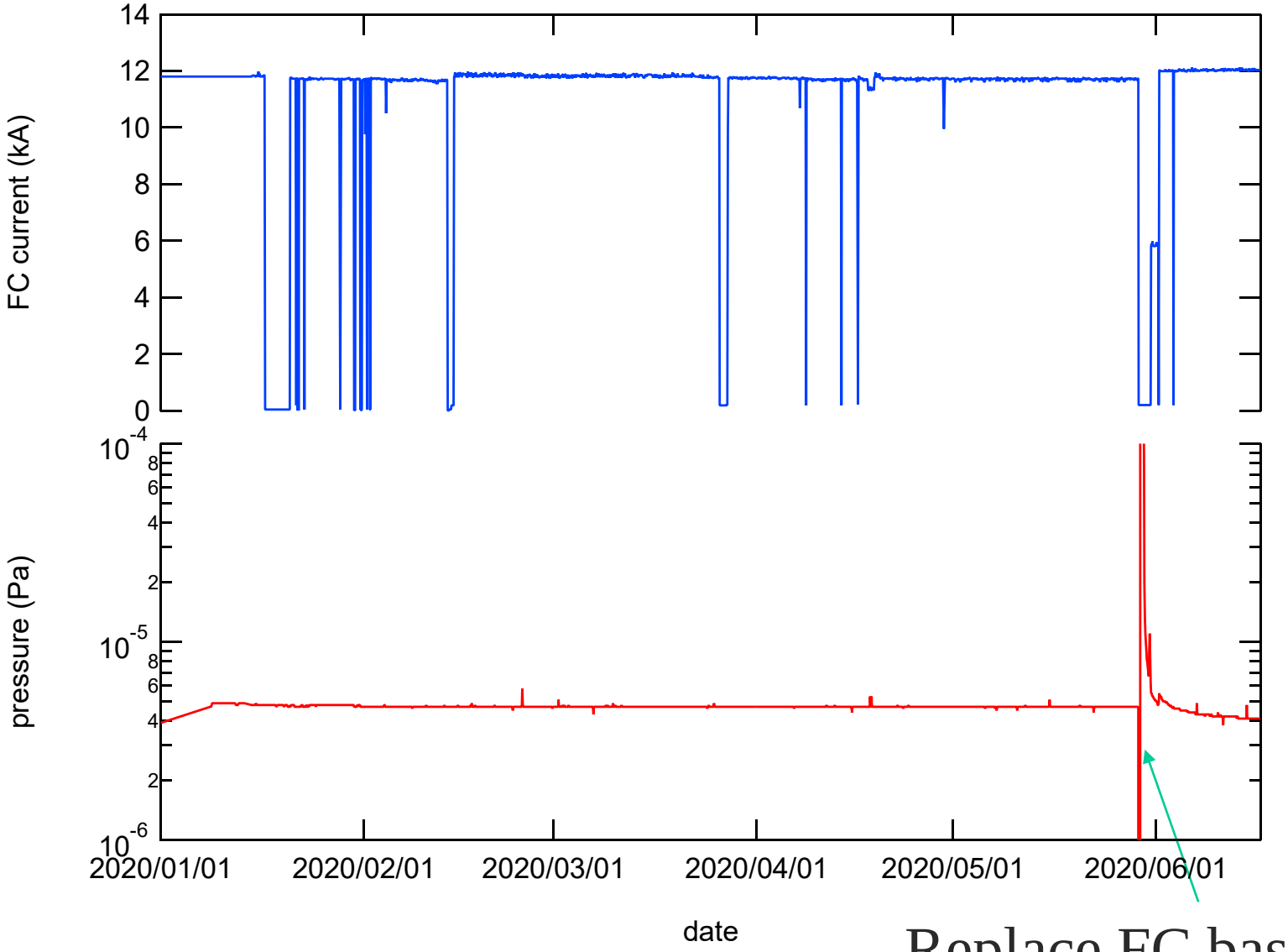
	Phase 1	Phase 2	Phase 3	2019 autumn	2020 spring	2020 autumn	2021 winter～	delivery	removal	Present status（2020/6）	remark
Assembly 1								Before 2015	2017/3	Tunnel	
Assembly 2								2016/3		Beam line	
Assembly 3								2017/11		Test bench	
FC base 1								before 2015			Trial product
FC base 2								before 2015			Trial product
FC base 3								before 2015	2017/3	Assembly 1	
FC base 4									2018/9	Tunnel	
FC base 5								2016/7	2020/9	Beam line for operation	
FC base 6								2017/11		Reserved	Hardening (Toyama)
FC base 7*								2019/10		Finished long term test	
FC base 8**								2020/5		Under test	Final version modified
FC base 9**								2021/3		Under design	Final version spare

- *Base 7, 8, 9 (head : Cu → NC50, return yoke : SS400 → permendur)
- **Base 8, 9 Shape optimization (insulation, leakage magnetic field)

red : operation
blue : spare
black : test bench

Y. Enomoto

Test result of new FC: 2020/1 – 2020/6



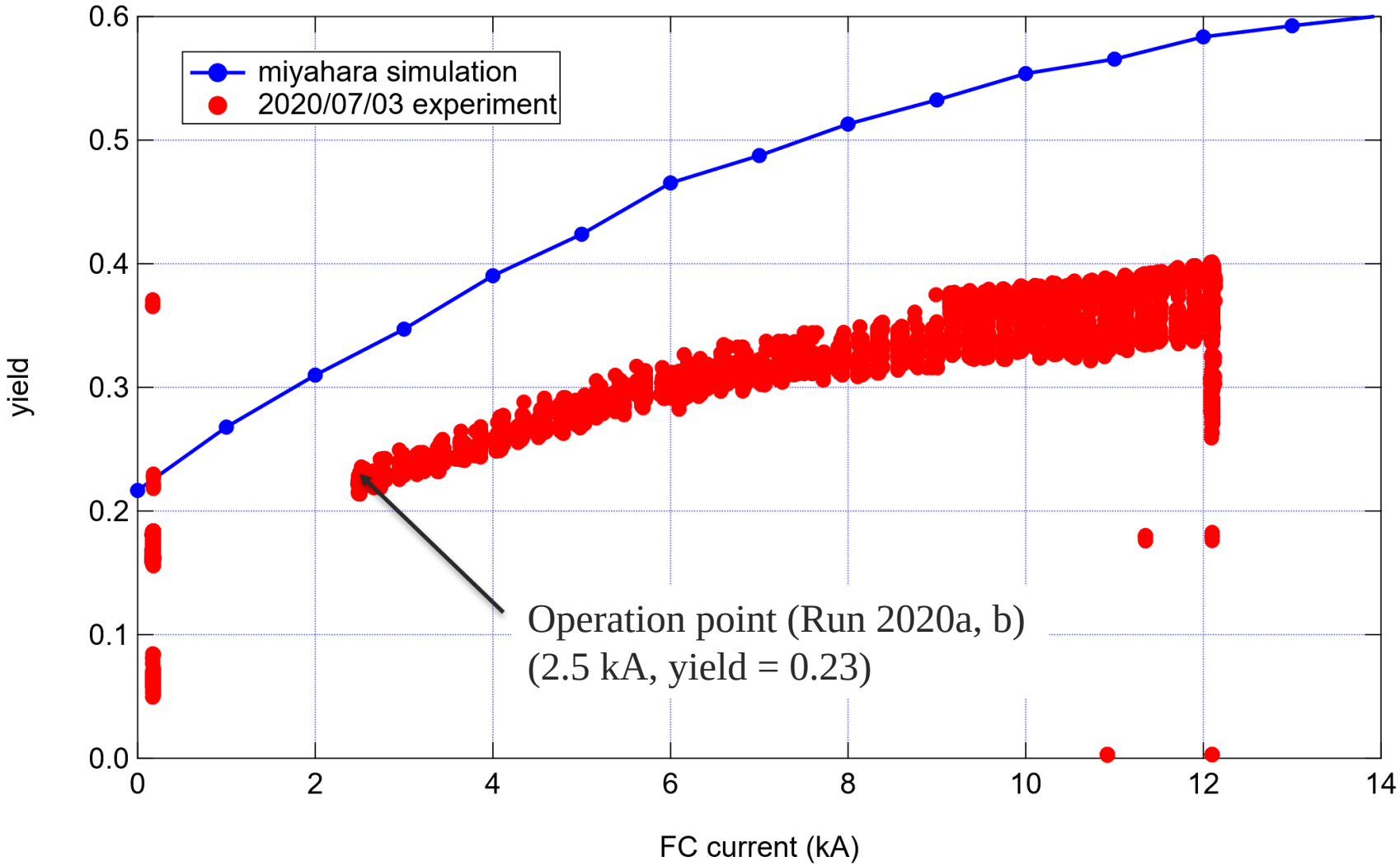
Replace FC base 7 => 8

During long term test, no trouble (discharge and vacuum pressure problem)
FC base 7 test: ~ May 2020
FC base 8 test: June 2020 ~

Y. Enomoto

FC (base 5) 12 kA beam test (Jul. 2nd, 2020)

FC current vs positron yield



Simulation condition is slightly different from experimental one.

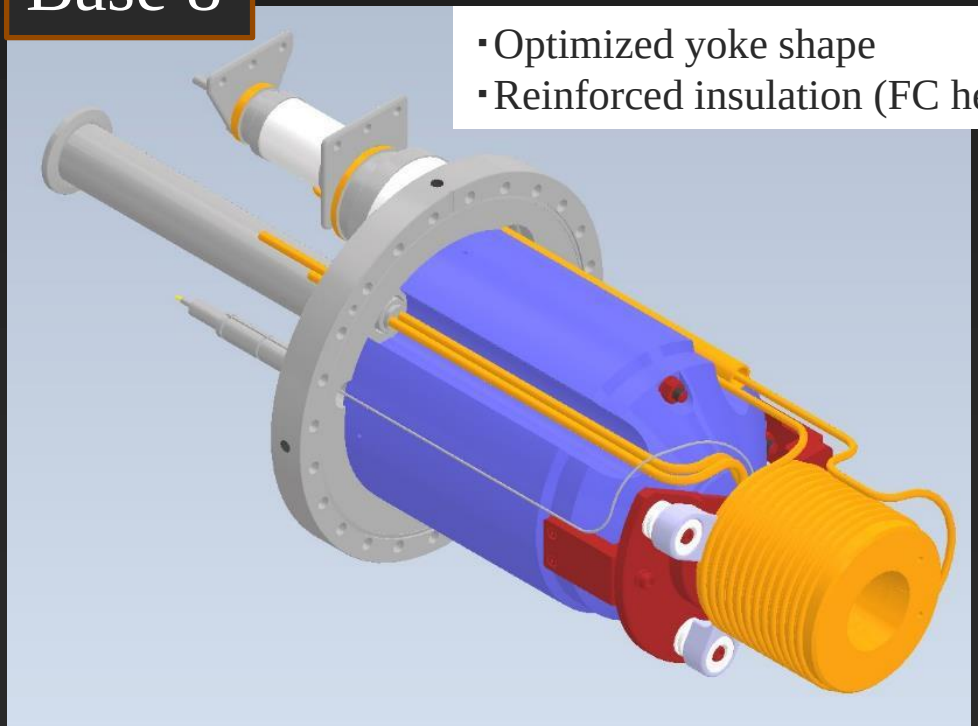
Comparison FC base

	Material	Shape	Remark	For e-	For e+
Base 5 (in operation)	OFC + SS400	Old design	12 kA in beam line large slit gap	△	○
Base 7	NC50 + permendur	Old design	4.5 months test	○	○+ *
Base 8	NC50 + permendur	New design (optimized)	Cooling water leakage was found. (already fixed and tested during 4 days)	◎	○+ *

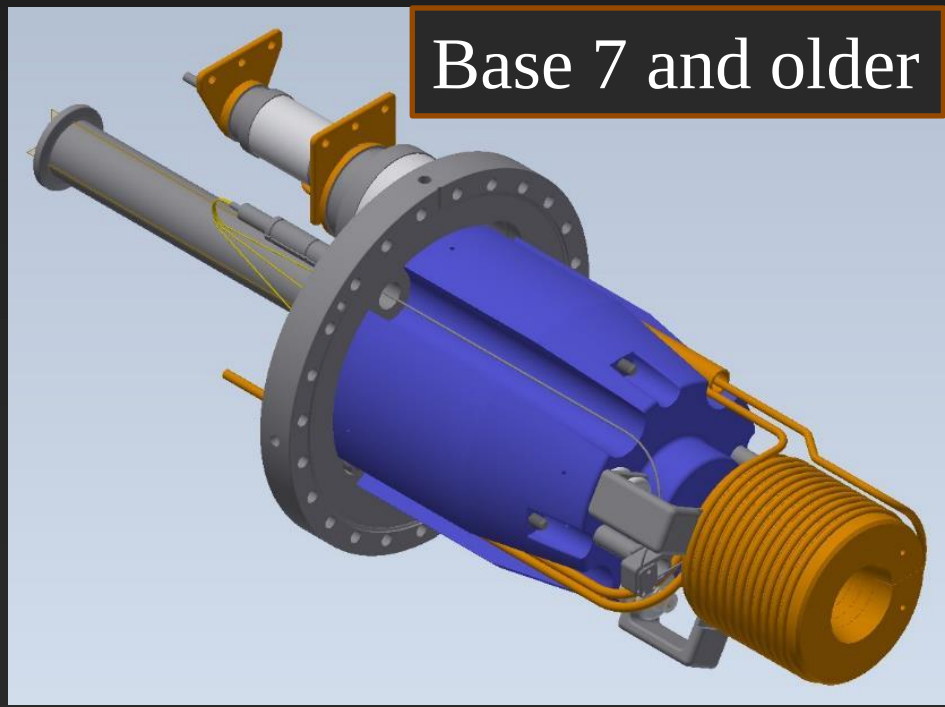
All FC bases achieve 12 kA in test stand. (*) return yoke (permendur) makes higher magnetic field.

Base 8

- Optimized yoke shape
- Reinforced insulation (FC head support)



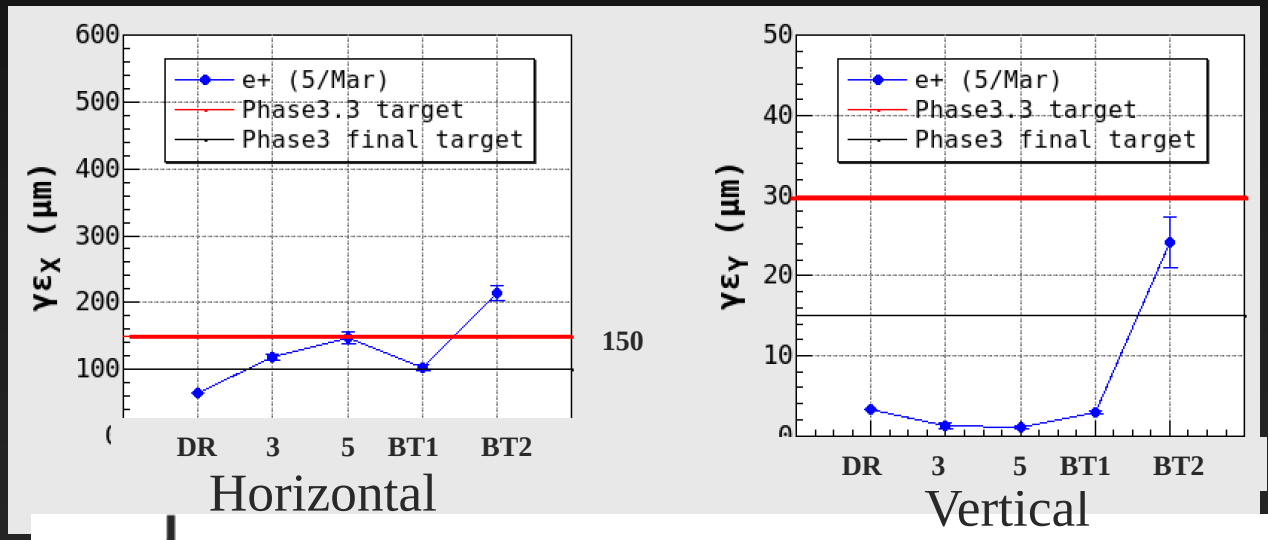
Base 7 and older

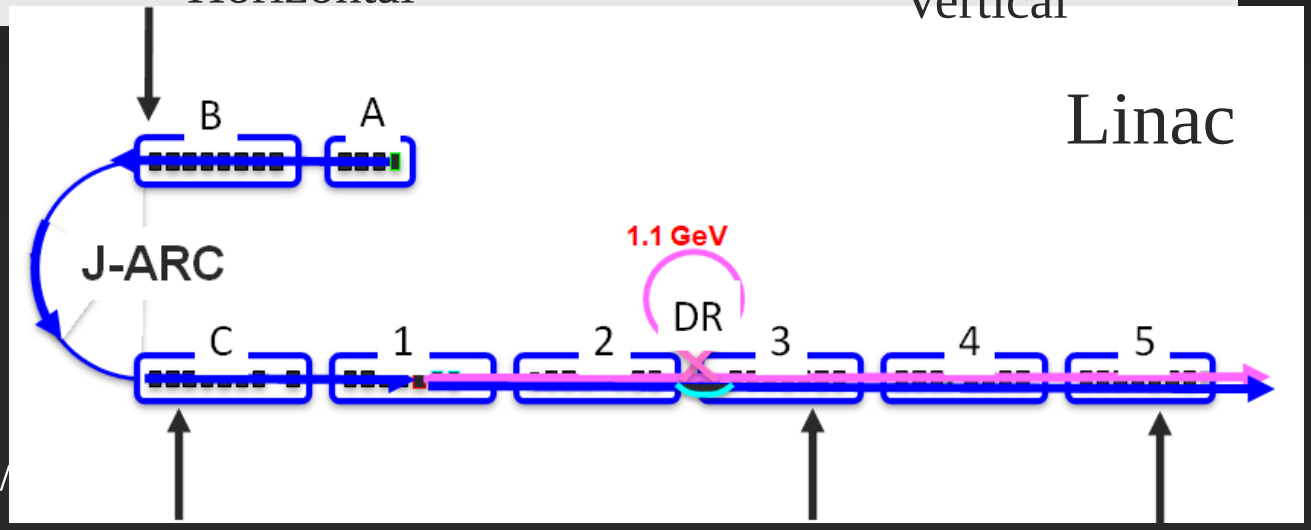


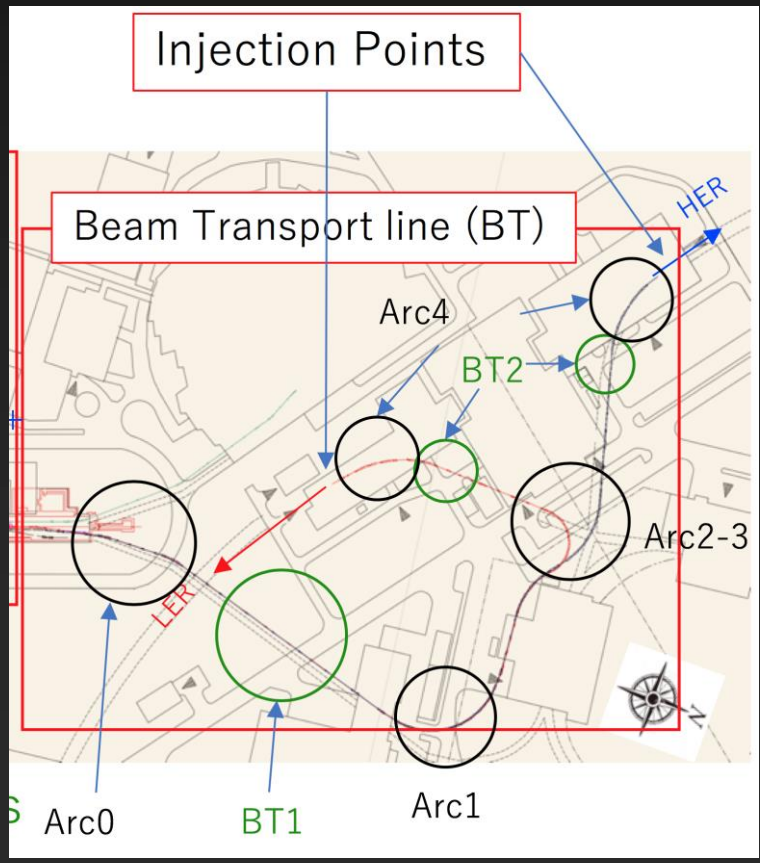
e+ beam emittance (~ 1 nC)

- e+ beam emittance in linac and BT1 are smaller than current goal.
- Emittance growth at BT2 in both directions.

(*) More detail will be given by Iida san





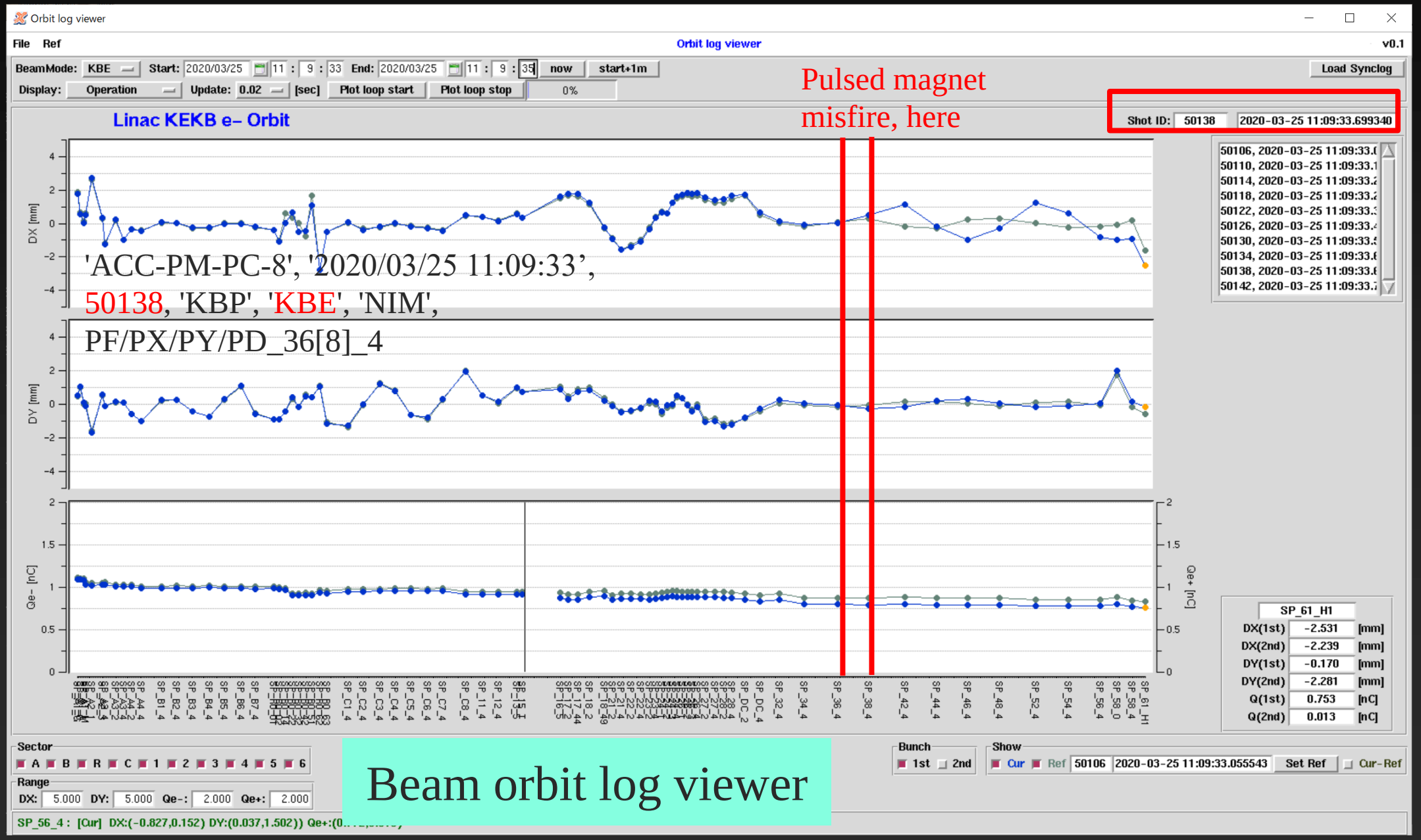


Abnormal injection beam could cause MR abort

- Abnormal beam orbit
  - Pulsed magnet misfire (Sector3-Sector5)

- Abnormal beam energy
  - Klystron down
  - RF phase trip
  - RF pulse shortening (klystron discharge)

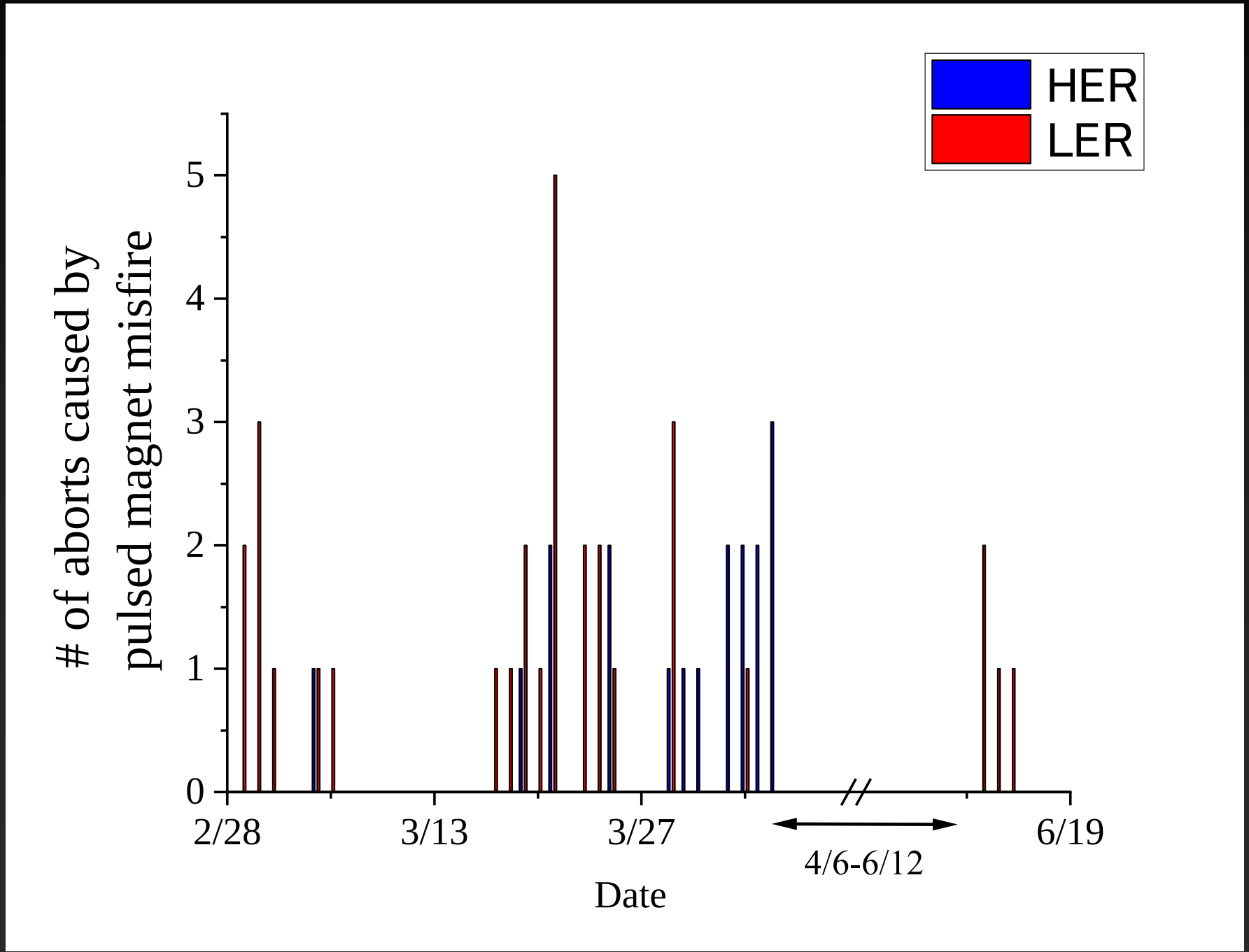
Pulsed magnet misfire events



Beam orbit log viewer

Beam abort caused by pulsed magnet misfire

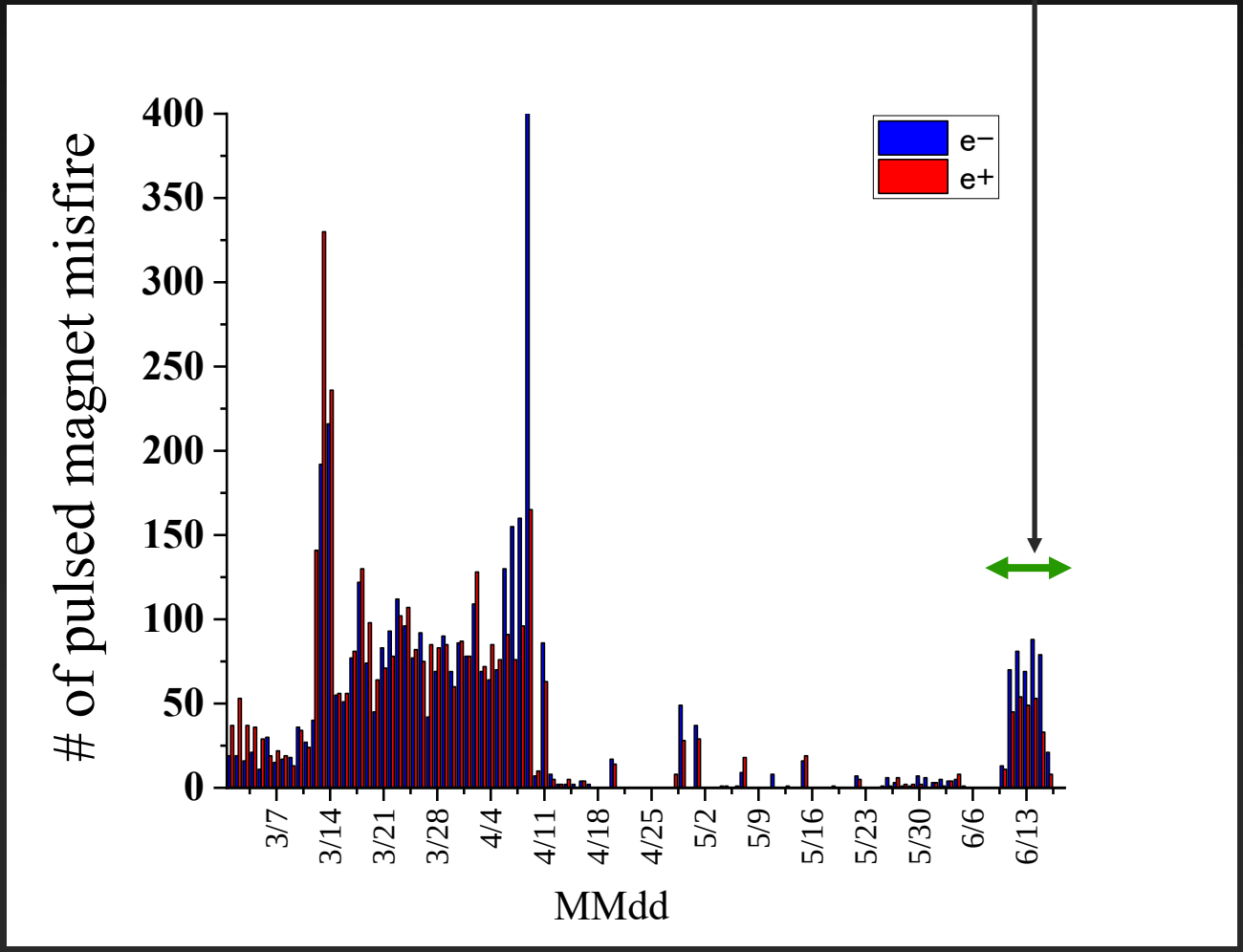
- 49 events in 2020a, 2020b.



Pulsed magnet misfire events

- ~ 100 misfire/day in Feb./Mar. (16 controllers)
- Main control software and event receiver driver were replaced by improved one (Apr. 9th~). # of misfire events decreased to almost zero.
- Misfire appears again (Jun. 10th 22:30~16th 3:23).

network trouble?

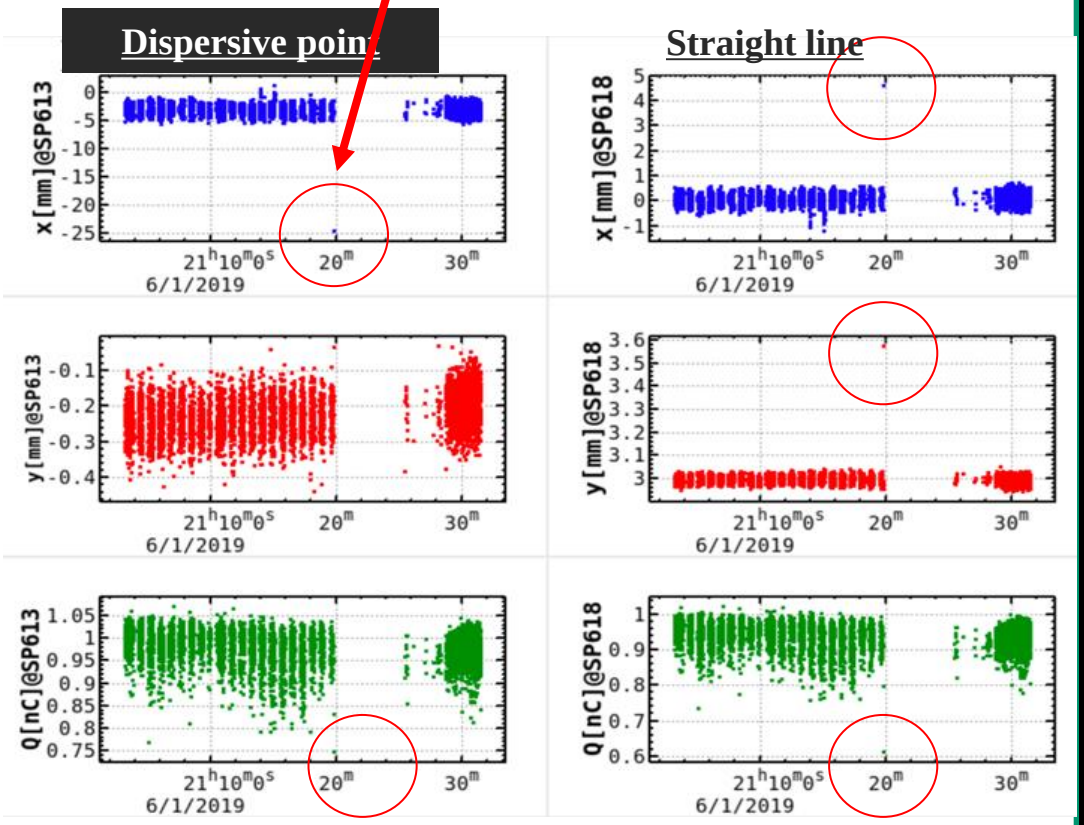


(*) including all misfire events (even no beam)

Beam abort caused by injection beam w/ abnormal energy

Jun., 2019 21:19 LER D6V2 LM abort

Beam energy was 50 MeV lower than nominal condition



Horizontal position (mm)

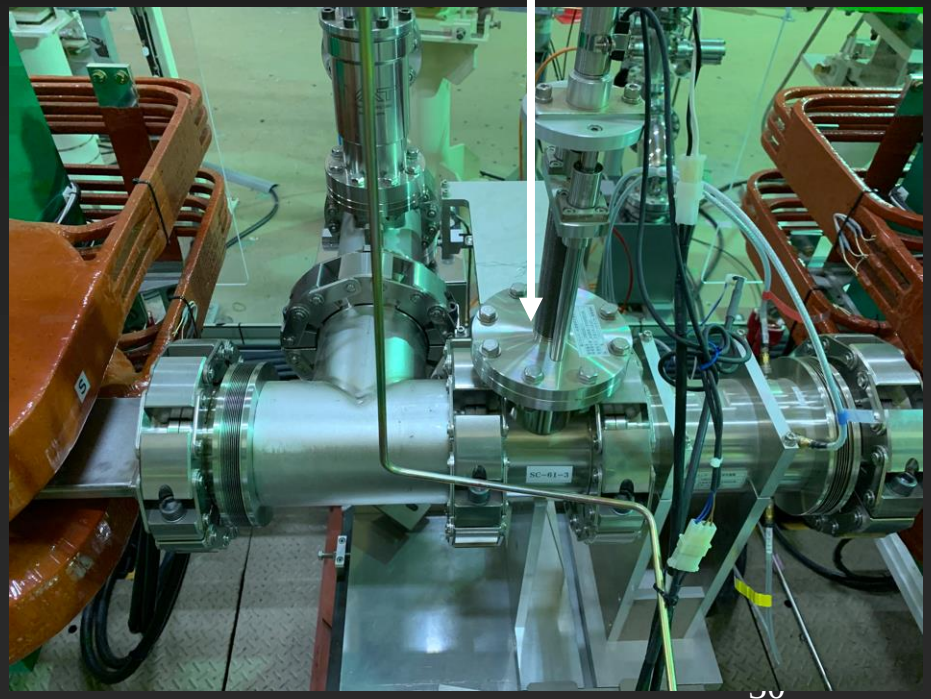
Vertical position (mm)

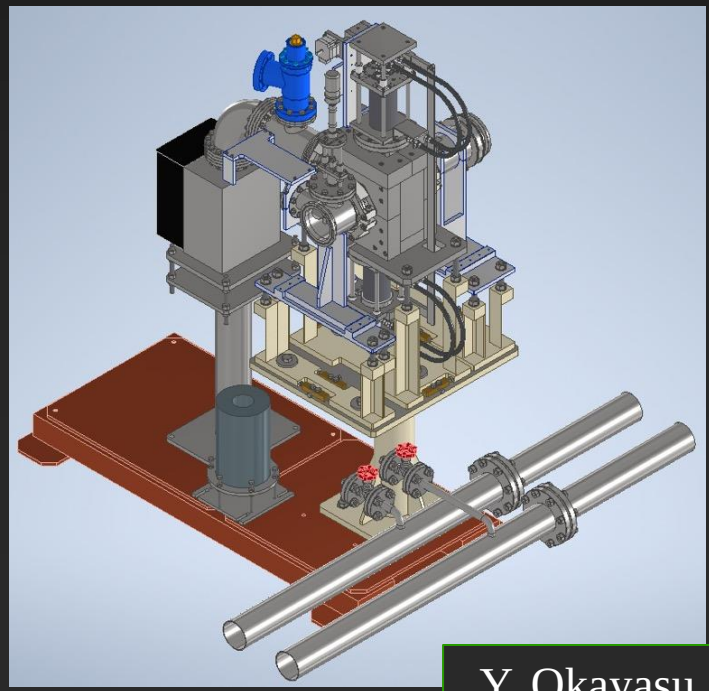
Bunch charge (nC)

The klystron 51 was down at the time.
The estimation was -46.5 MeV which is consistent with the beam position.

Abnormal energy beam
- Collimator at ECS of linac end -

- Klystron down or rf phase trip could cause energy change.
- In the case of e+ beam, ECS (in linac end) can correct it to a certain extent. Beam can go through BT and into MR.
- To prevent such beam, collimator will be installed in this summer maintenance.





Y. Okayasu

Summary and plan

- RF gun (e- beam)
  - no significant fault
  - Bunch charge feedback works fine.
  - Laser cleaning can cure degradation of Qe. Laser cleaning during beam operation was tested.
  - Diffractive optical element (DOE) was installed and tested for transverse laser beam shaping (flat top).
  - Laser position feedback will be implemented in this summer shutdown.
- Flux concentrator (e+ beam)
  - no significant fault
  - New flux concentrator will be installed for higher e+ bunch charge in this summer shutdown.
  - Steering magnet and BPM will be installed inside solenoid section in this summer shutdown.

Summary and plan (cont'd)

- Beam abort caused by bad quality beam (orbit, energy)
  - Pulsed magnet misfire (orbit)
    - Control software have been improved.
  - Install collimator at ECS (linac end) in this summer shutdown.

- Vertical pulsed bends and chambers will be replaced new one for 50 Hz operation of thermionic e- gun (LER, PF, PF-AR) in this summer shutdown.

- Beam quality issues
  - Emittance growth at BT2
  - Reproducibility
  - Low emittance w/ high bunch charge (～ 2 nC)

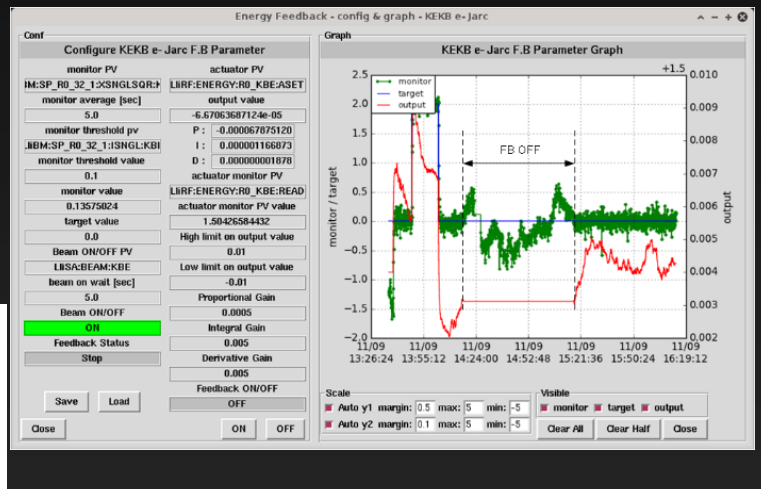
Backup

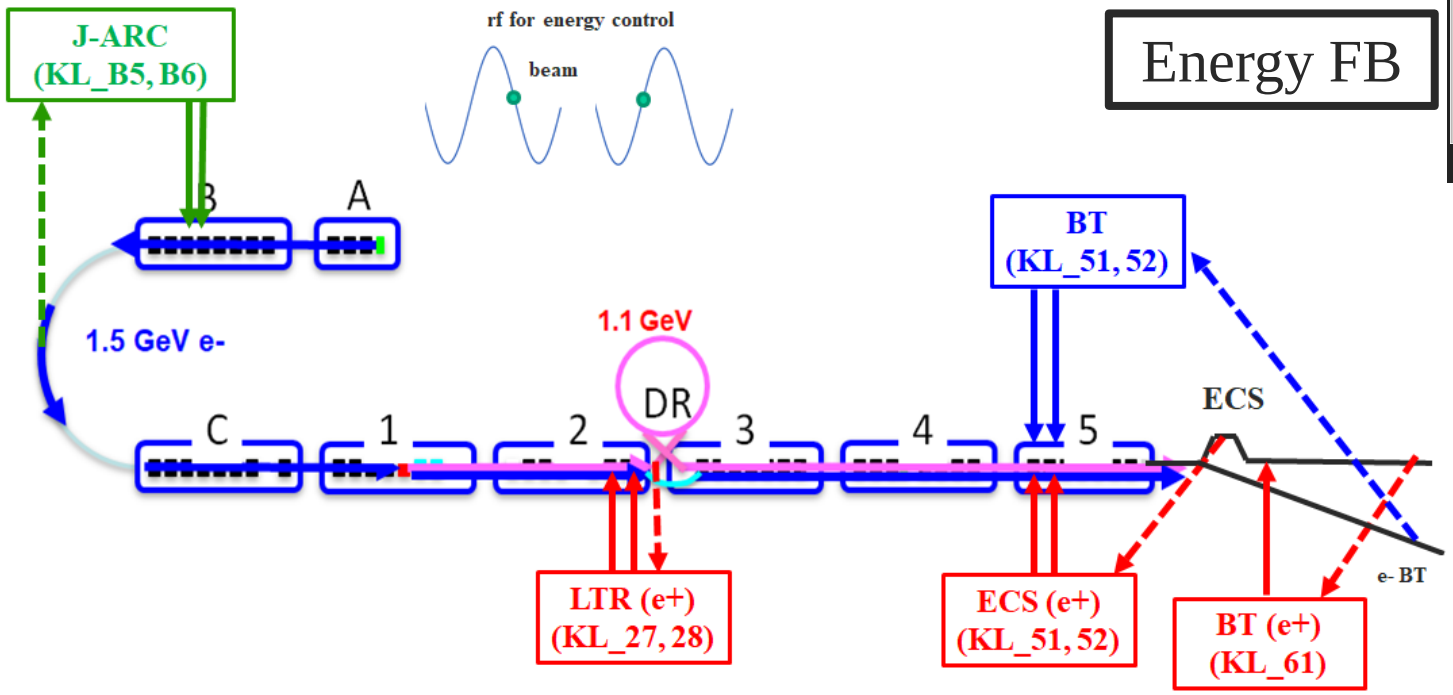
Linac Beam Parameters for KEKB/SuperKEKB

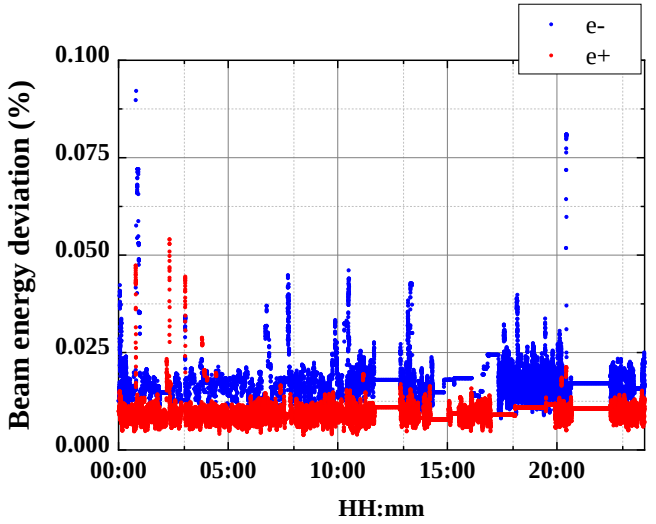
Stage	KEKB (final)		Phase-I		Phase-II		Phase-III (interim)		Phase-III (final)	
Beam	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Stored current	1.6 A	1.1 A	1.0 A	1.0 A	–	–	1.8 A	1.3 A	3.6 A	2.6 A
Life time (min.)	150	200	100	100	–	–	–	–	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) (μmrad)	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)	

Feedback loops (1)

- Beam energy feedback (J-ARC, LTR, ECS, BT)
  - J-ARC (e-, e+)
  - DR (e+)
  - Linac end
  - BT (e-, e+)
- Energy stability at BT line < 0.025%

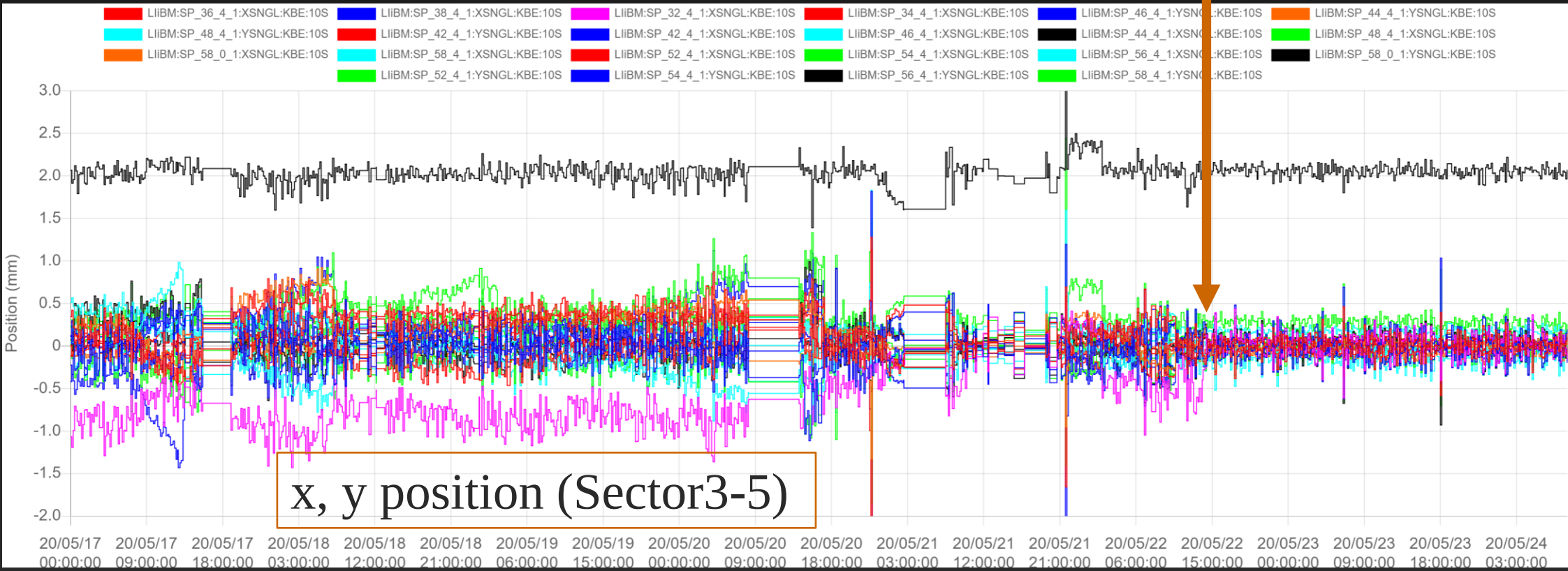






Feedback loops (2)

- Beam orbit feedback
  - J-ARC (e-, e+)
  - e+ target upstream (e-, e+)
  - Sector2 (e-)
  - Sector3-5 (e-)
  - Linac end, BT end (e-, e+)

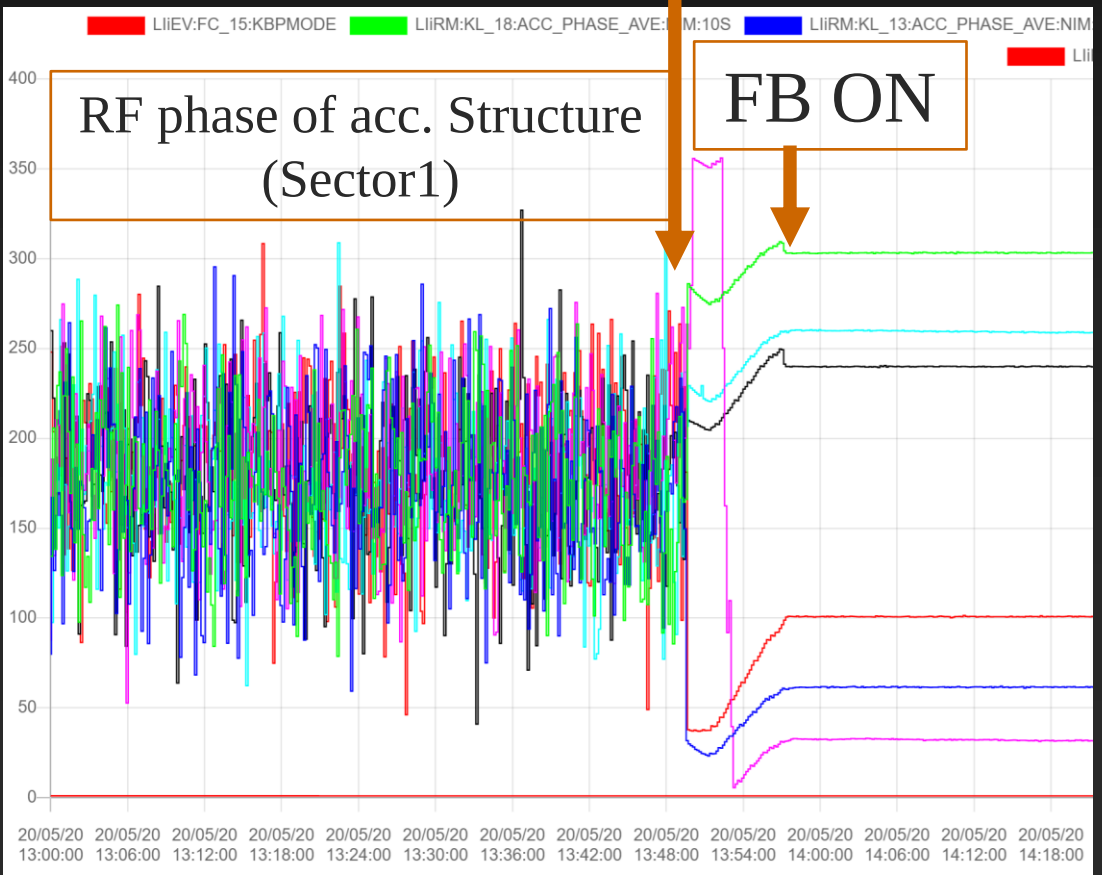


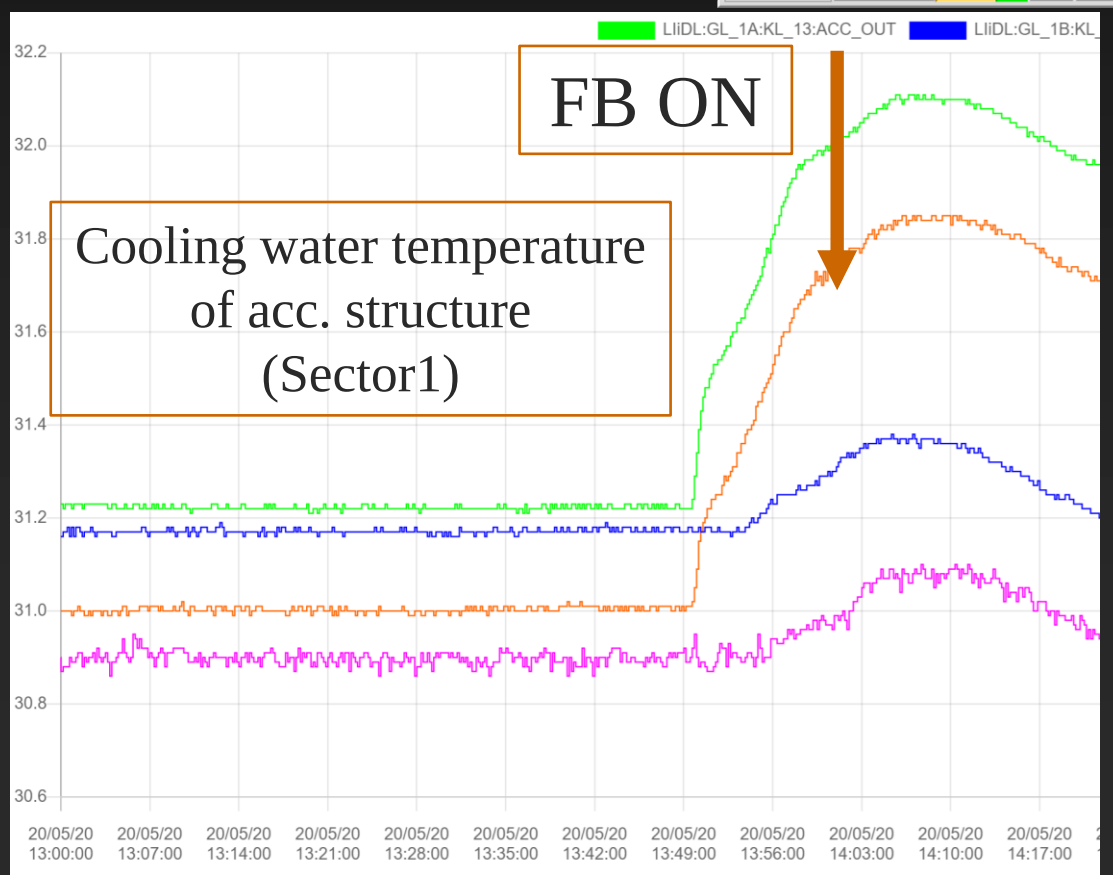
Feedback loops (3)

- RF phase feedback has been newly implemented.
- Quick recover from tunnel work (after maintenance or trouble recovery)

Klystron ON

After linac maintenance

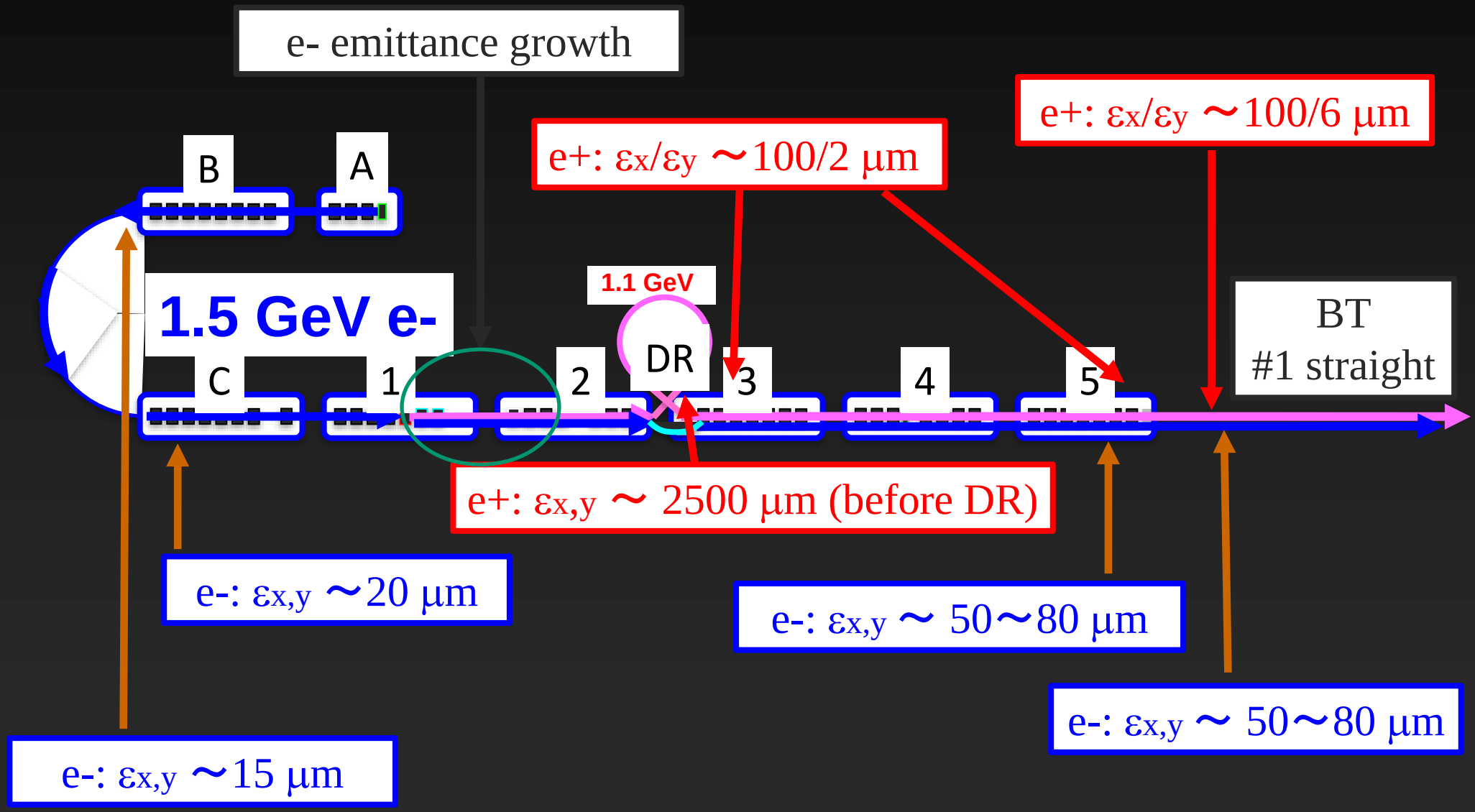




常時レーザークリーニング

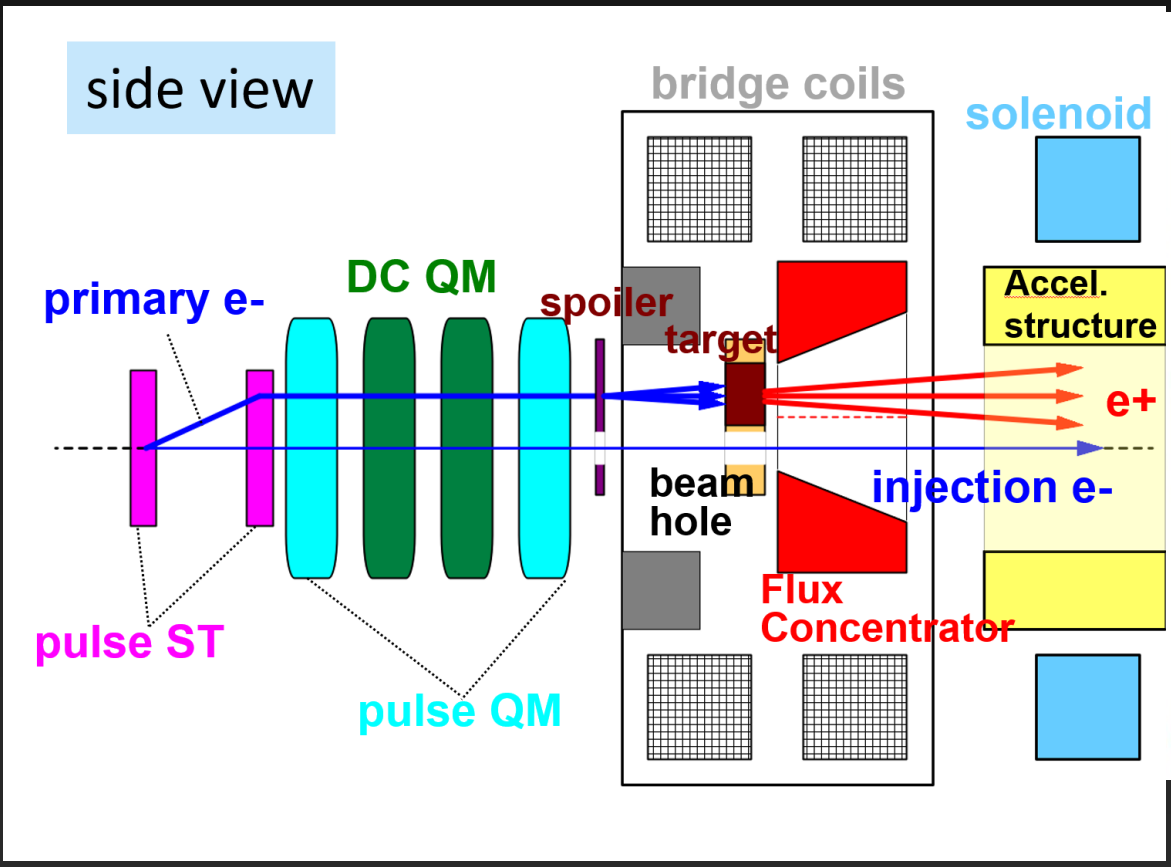
- 1st-PumA, 2nd-PumpB

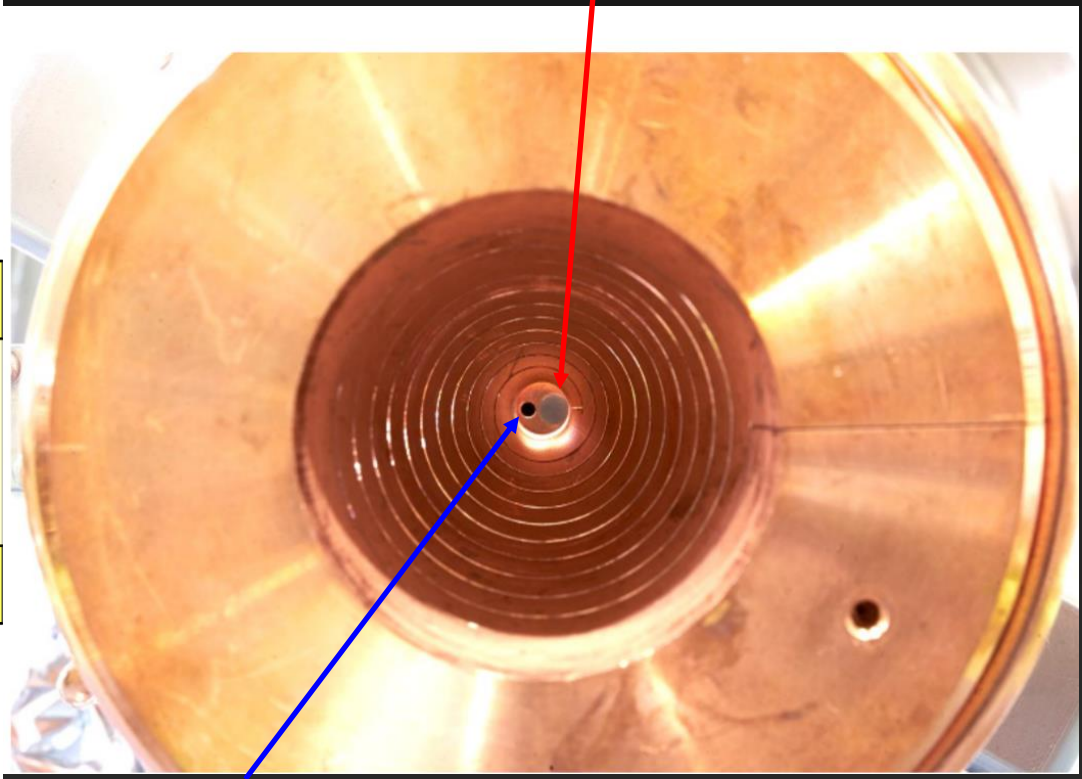
Beam emittance example (~1 nC) w/ multiple wire scanners



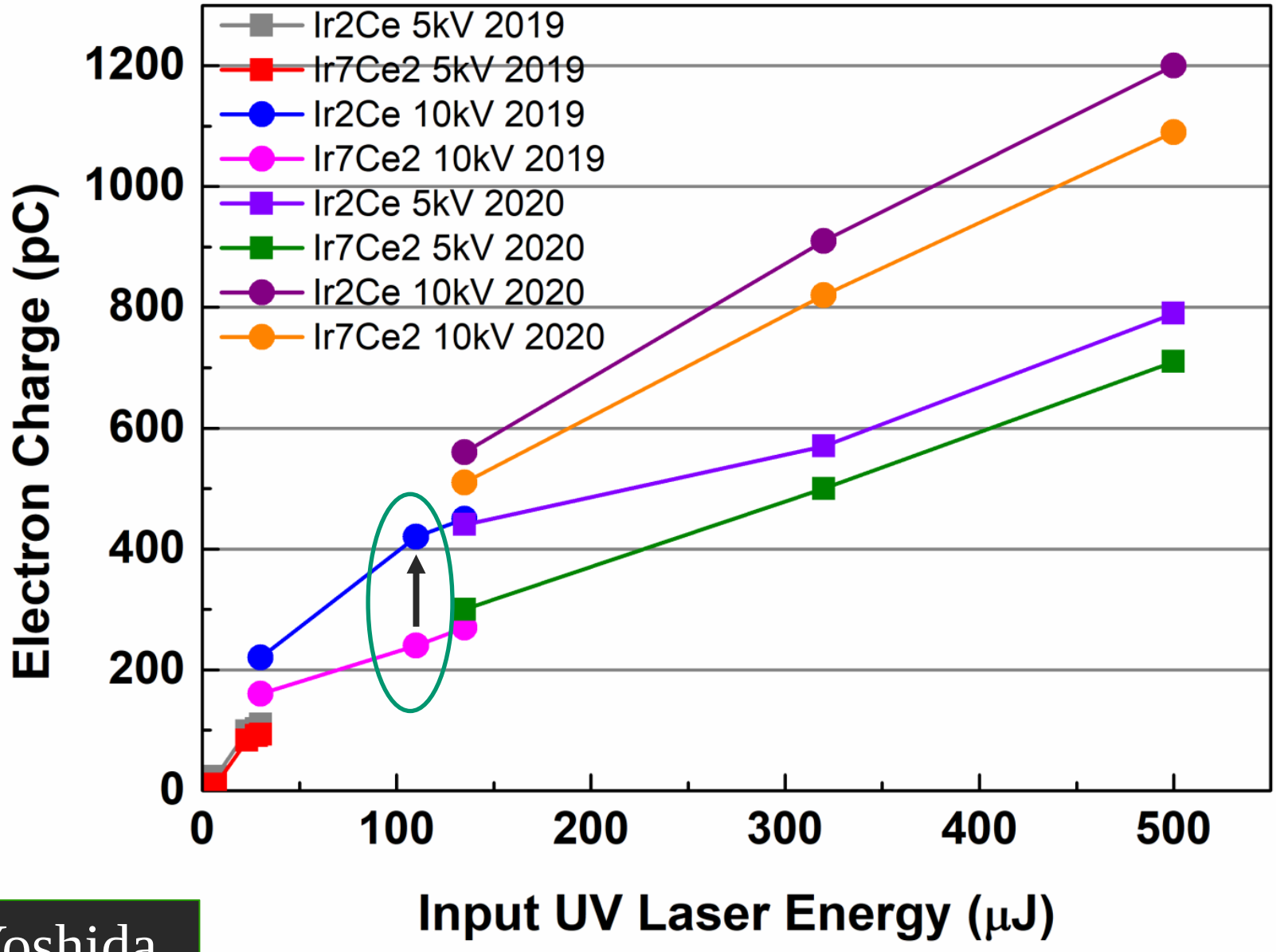
Pulse to pulse e-/e+ beam switching

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





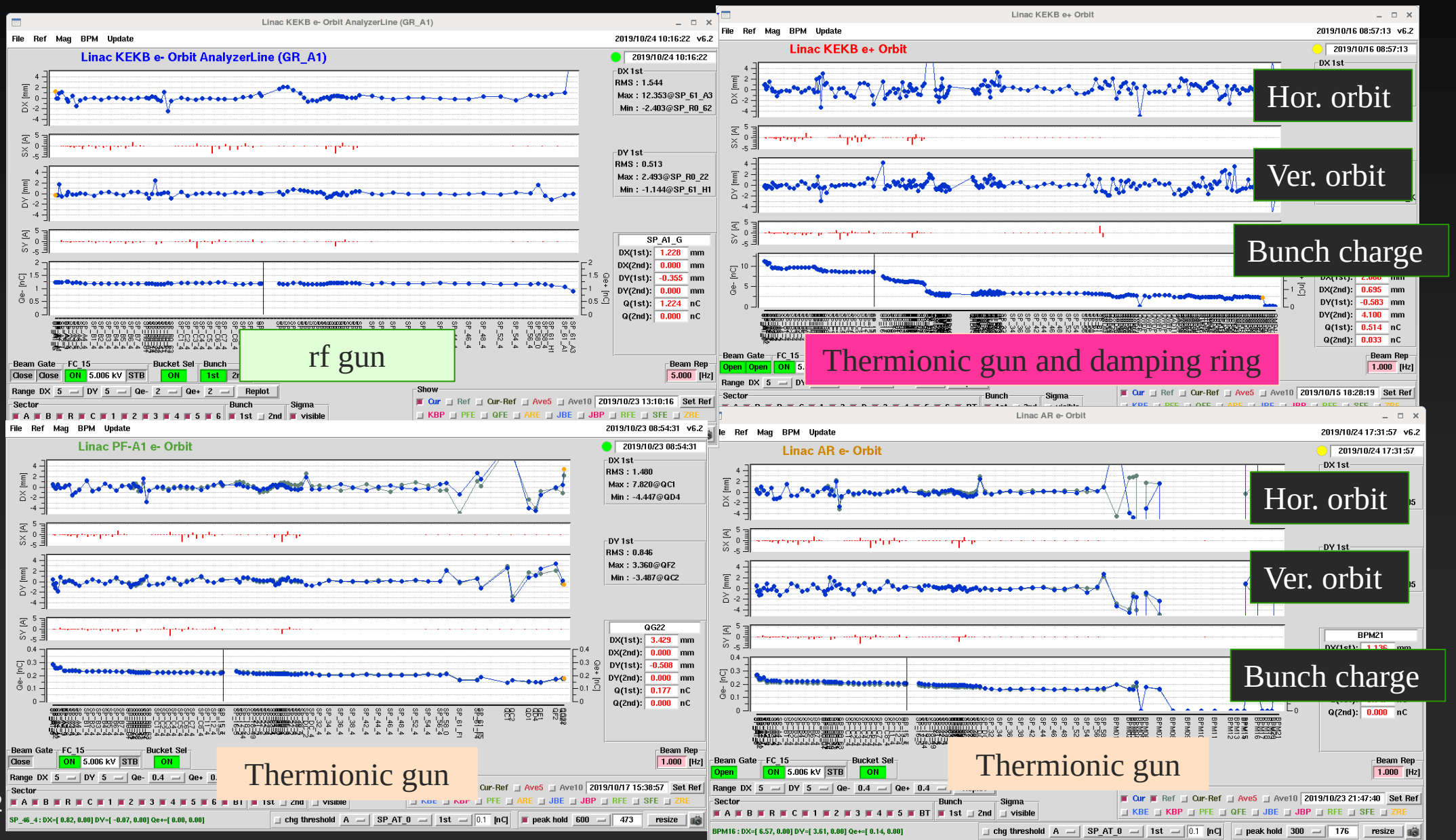
Qe of photocathode (Ir_7Ce_2, Ir_2Ce)



M. Yoshida

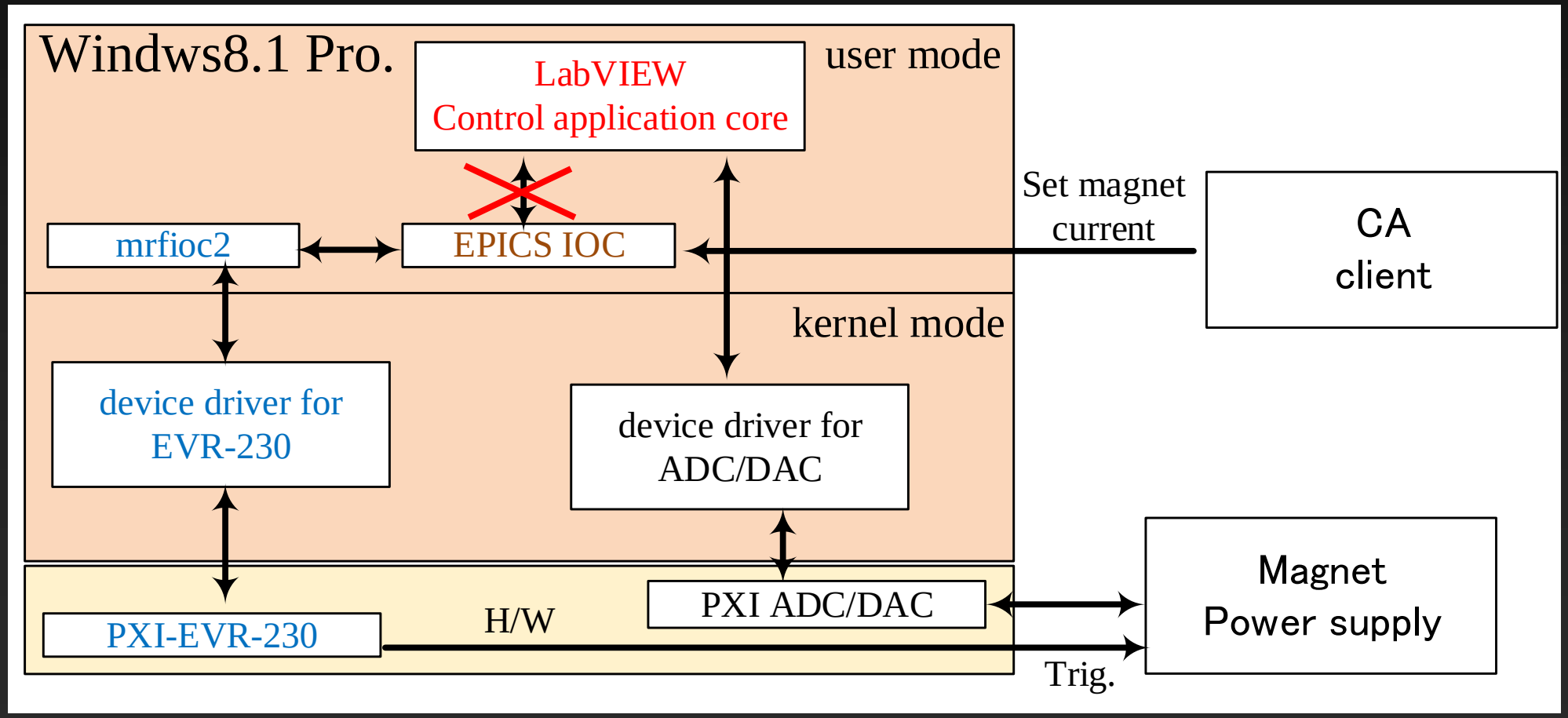
Simultaneous beam operation (w/ thermionic and rf e- gun)

- Stable simultaneous top up injection to 4 storage rings (HER, LER, PF, and PF-AR) w/ thermionic gun, rf gun, pulsed magnets.



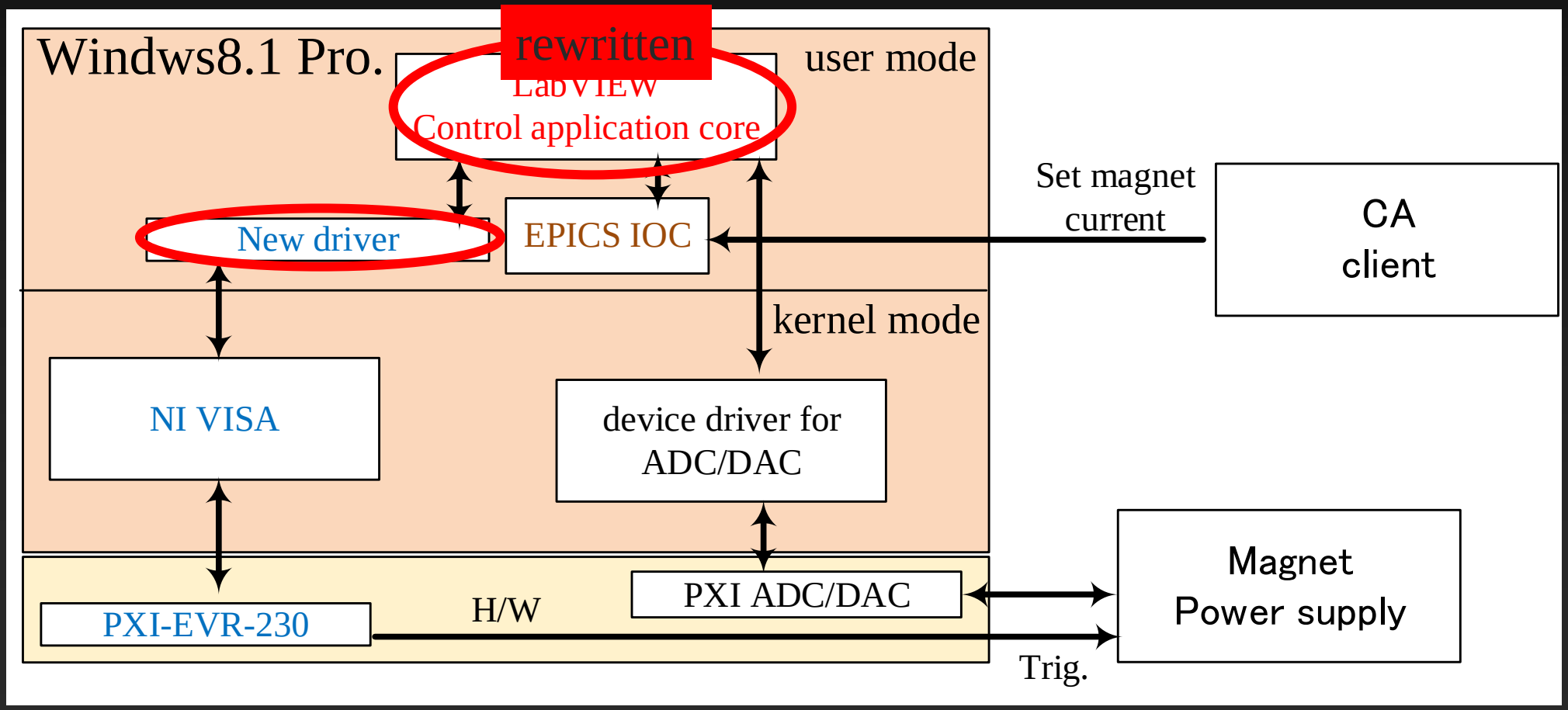
Previous software structure

In some events, LabVIEW/EPICS IOC communication is delayed or failed.



New software structure (Apr. 9 ~)

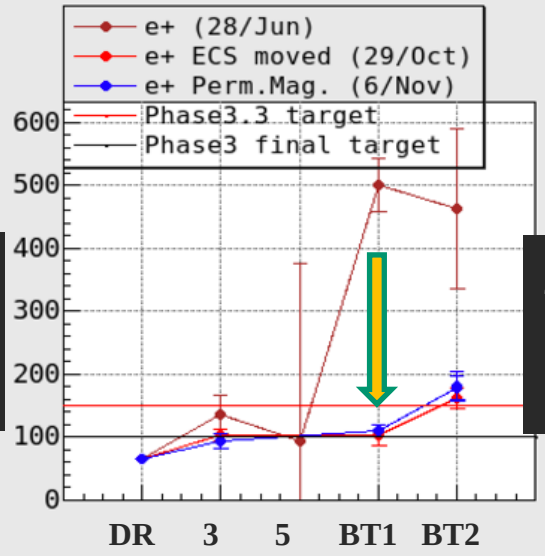
- NI VISA based EVR driver (w/o EPICS IOC for EVR control) (H. Saotome)
- Most part of control core (LabVIEW) was rewritten (Y. Enomoto)



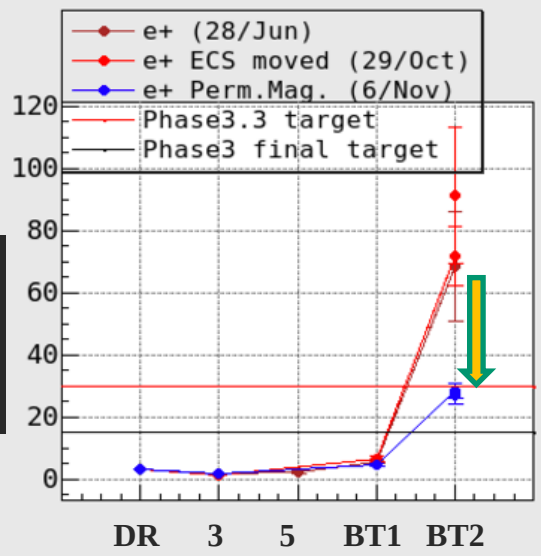
Measured emittance

e+ beam (Phase3.2(6.Nov.2019))

γεx [μm]



γεy [μm]



Phase3.3	e+	e-
γεx [μm]	150	100
γεy [μm]	30	40
σδ [%]	0.16(1σ)	0.1(1σ)

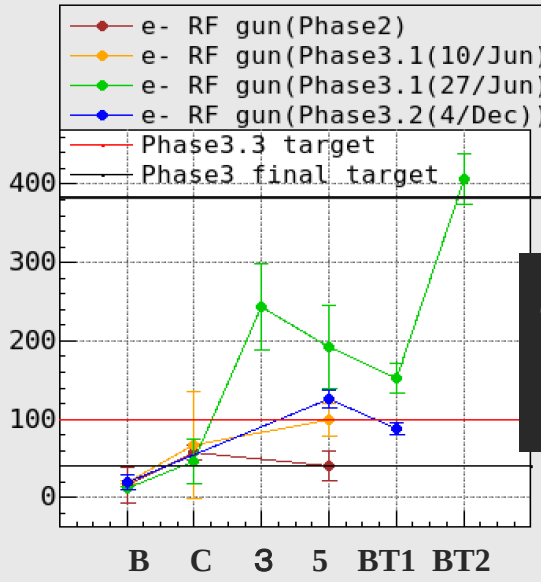
Emittances increase

- DR → Sector3
- BT1 → BT2

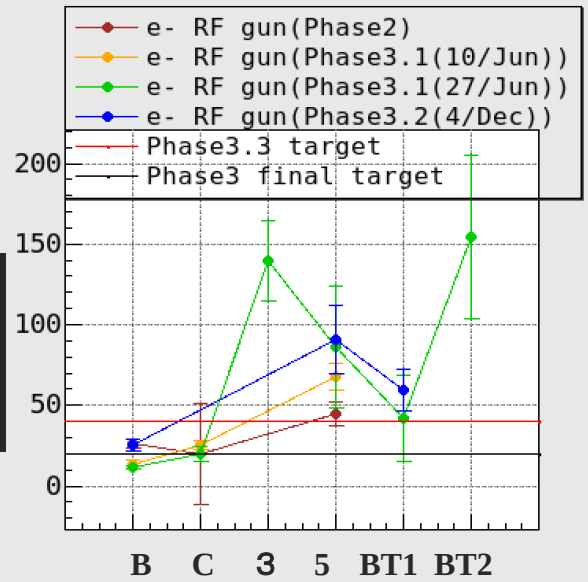
Beam study will be continued

e- beam (Phase3.2(4.Dec.2019))

γεx [μm]



γεy [μm]



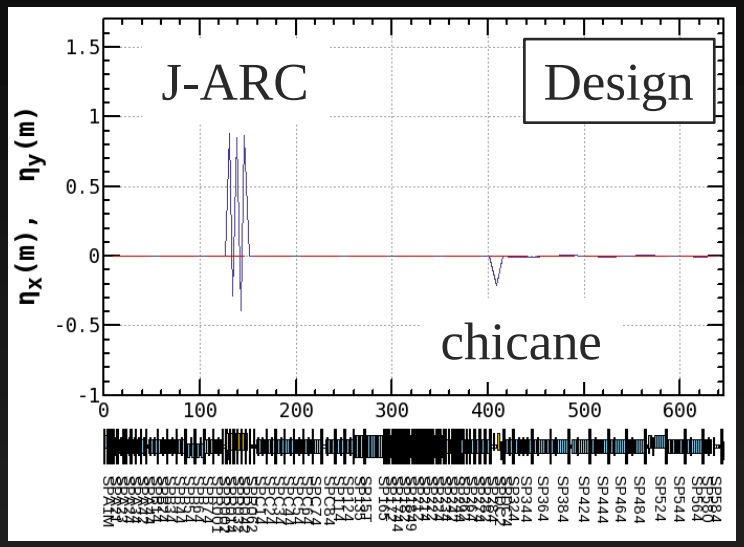
Emittances increase

- C→Sector3
- BT1→BT2

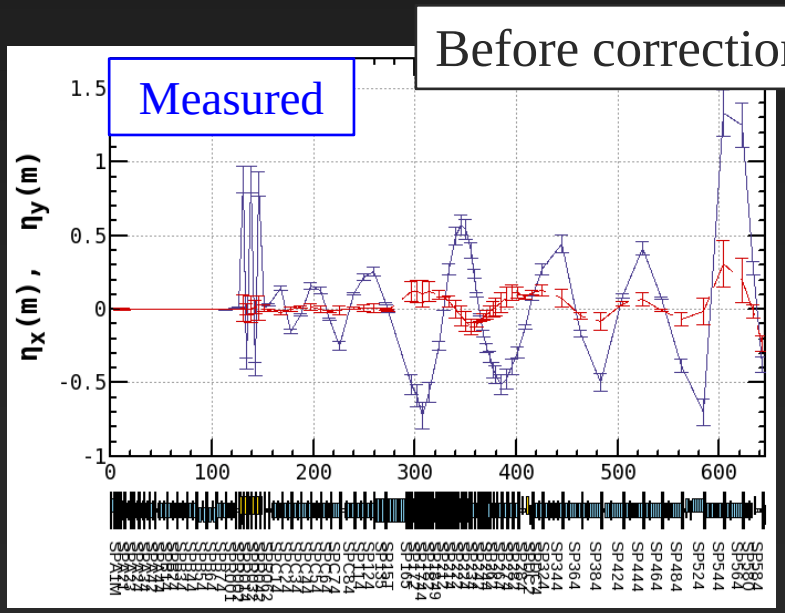
Beam study will be continued

N. Iida, 31. Jan., 2020

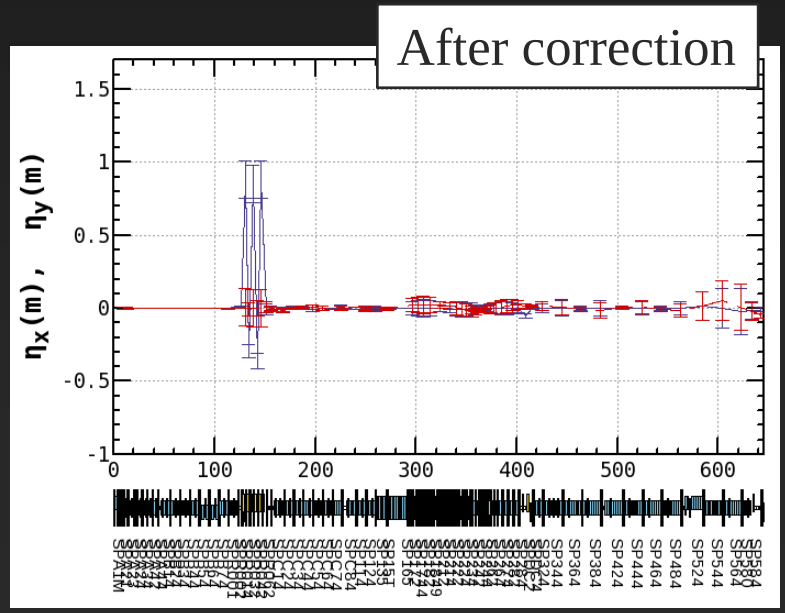
Dispersion measurement and correction



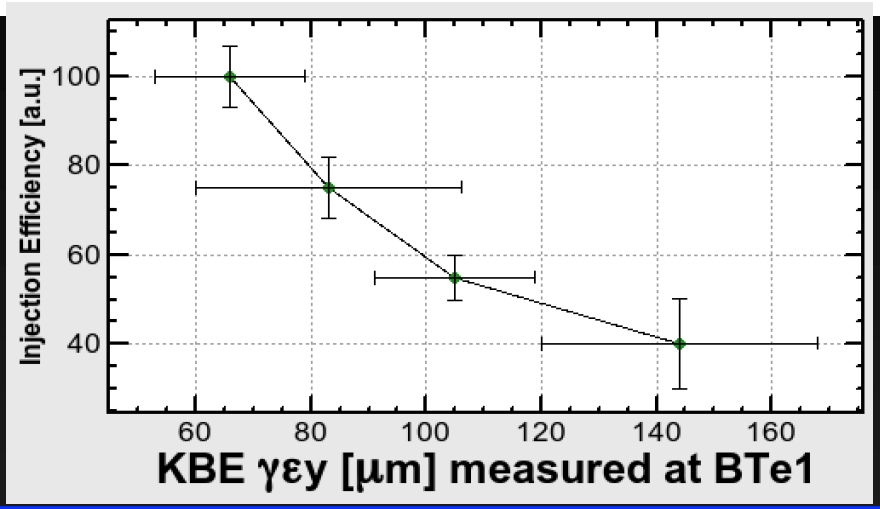
- Horizontal dispersion leakage from J-ARC causes the beam position jitter.
- Applying fudge factors to quads in J-ARC, dispersion is well corrected.



Disp. correction w/ quads



Vertical emittance vs. HER Injection efficiency



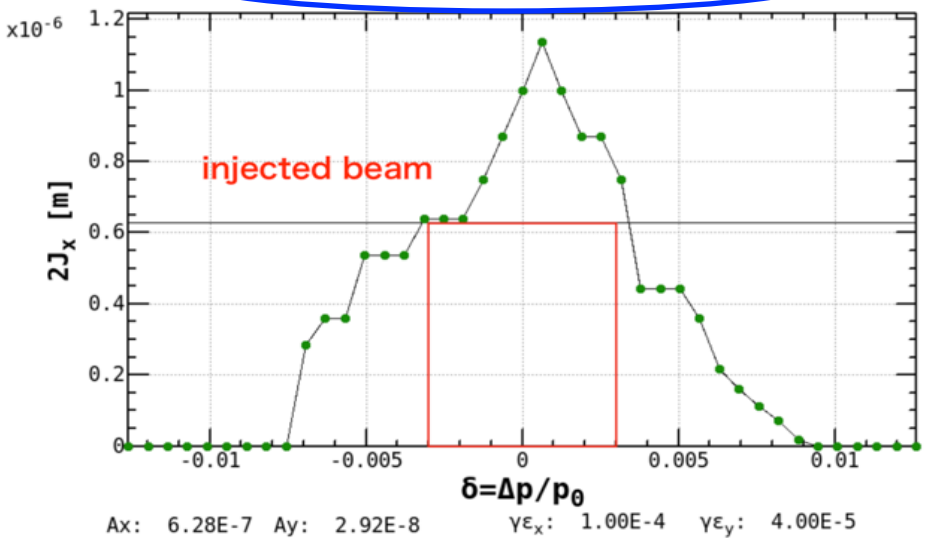
Y. Ohnishi

Dynamic Aperture for Injected Beam in HER

$\beta_x^* = 60$ mm / $\beta_y^* = 1$ mm

5780_60_1_A_YO3

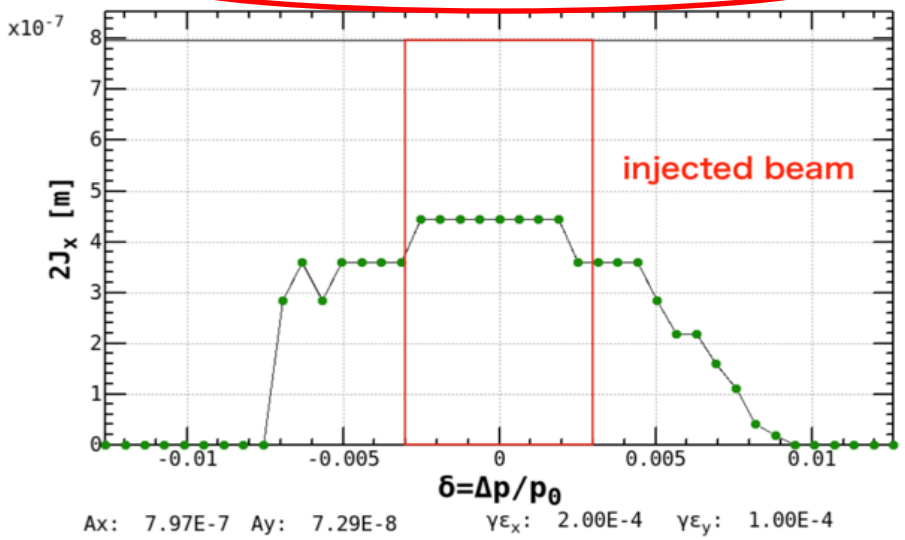
norm. emittance : 100 μm / 40 μm



QCS aperture only wit collimators

Injection efficiency = 100 % (no machine error)

norm. emittance : 200 μm / 100 μm

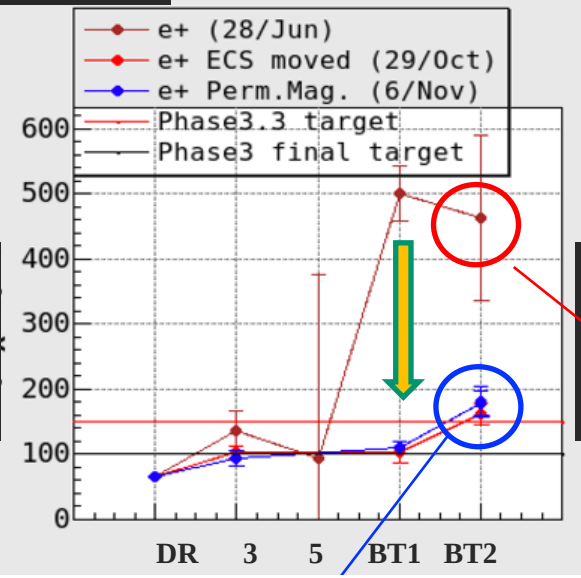


QCS aperture with collimators

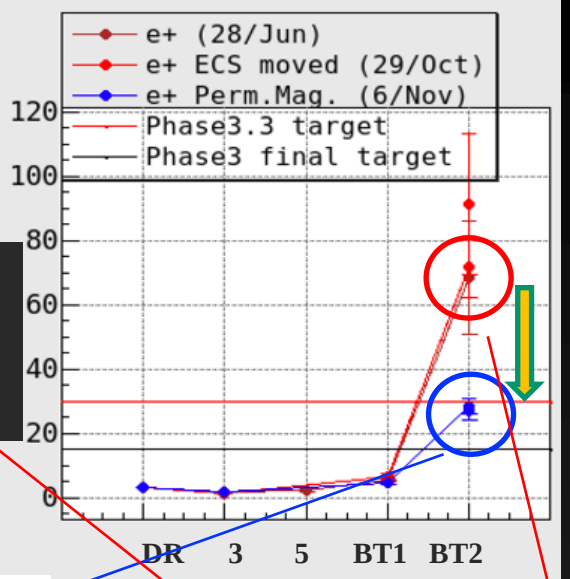
Injection efficiency = 53 %

LER

γεx [μm]



γεy [μm]



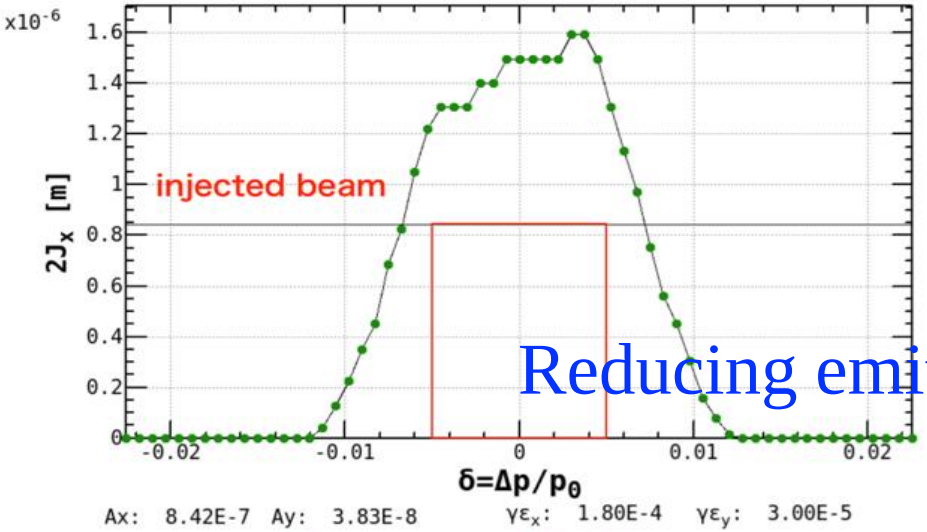
e+ horizontal emittance has been improved after ECS bend alignment.

erture for Injected Beam in LER

1704_80_1_A_YO4

$\beta_x^* = 80$ mm / $\beta_y^* = 1$ mm

norm. emittance : 180 μm / 30 μm



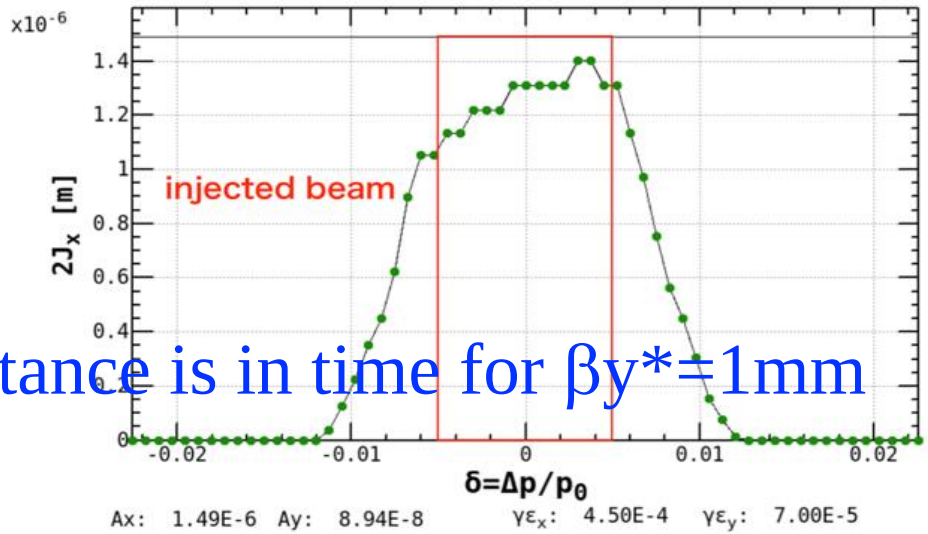
QCS aperture with collimators

Injection efficiency = 100 %

(no machine error)

(6/Nov/2019)

norm. emittance : 450 μm / 70 μm



QCS aperture with collimators

Injection efficiency = 86 %

(28/Jun/2019)

Before modification of ECS / BTp

Reducing emittance is in time for βy*=1mm

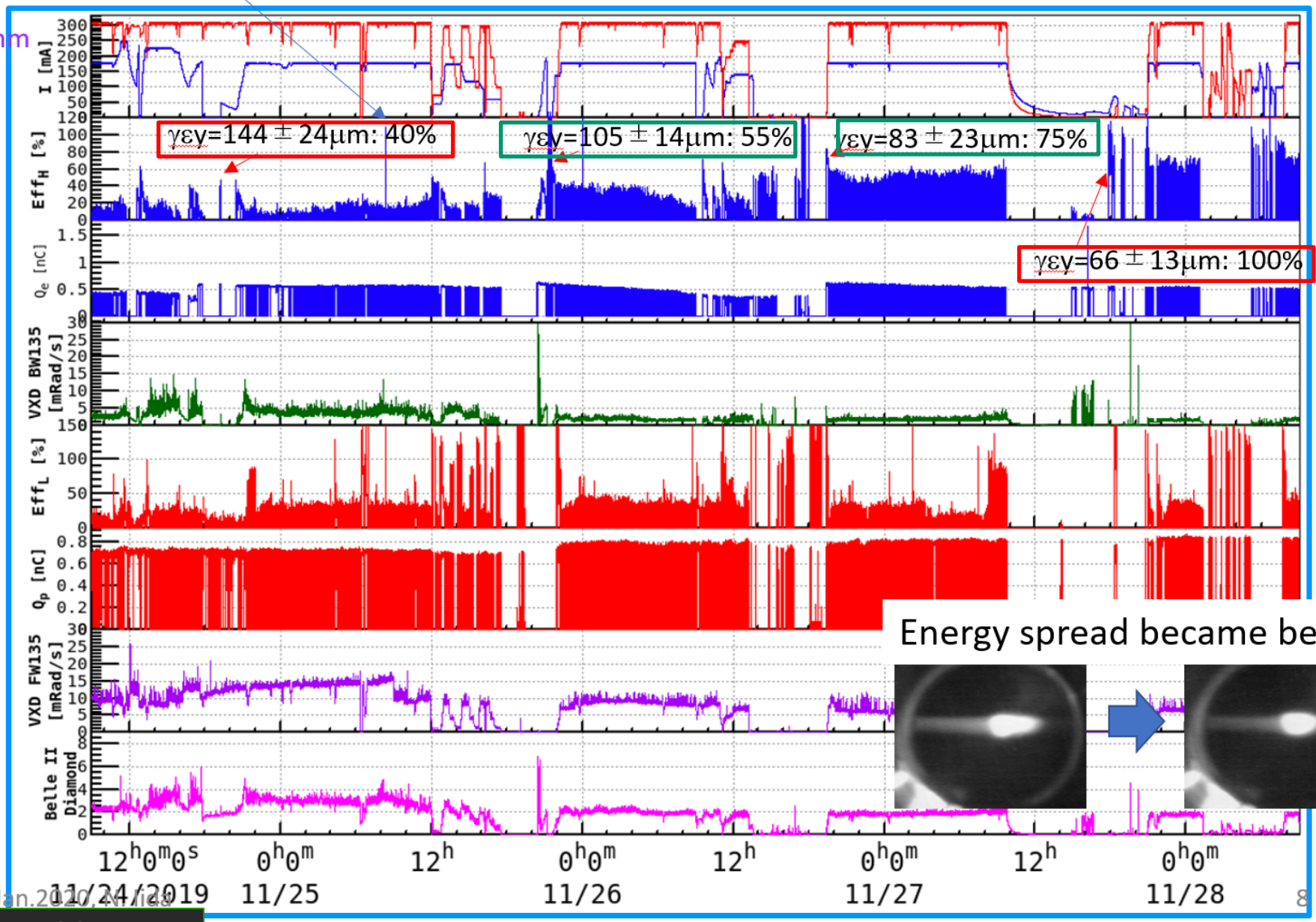
1. Injection efficiency and background

The injection efficiency increased as emittance decreased by tuning day by day.

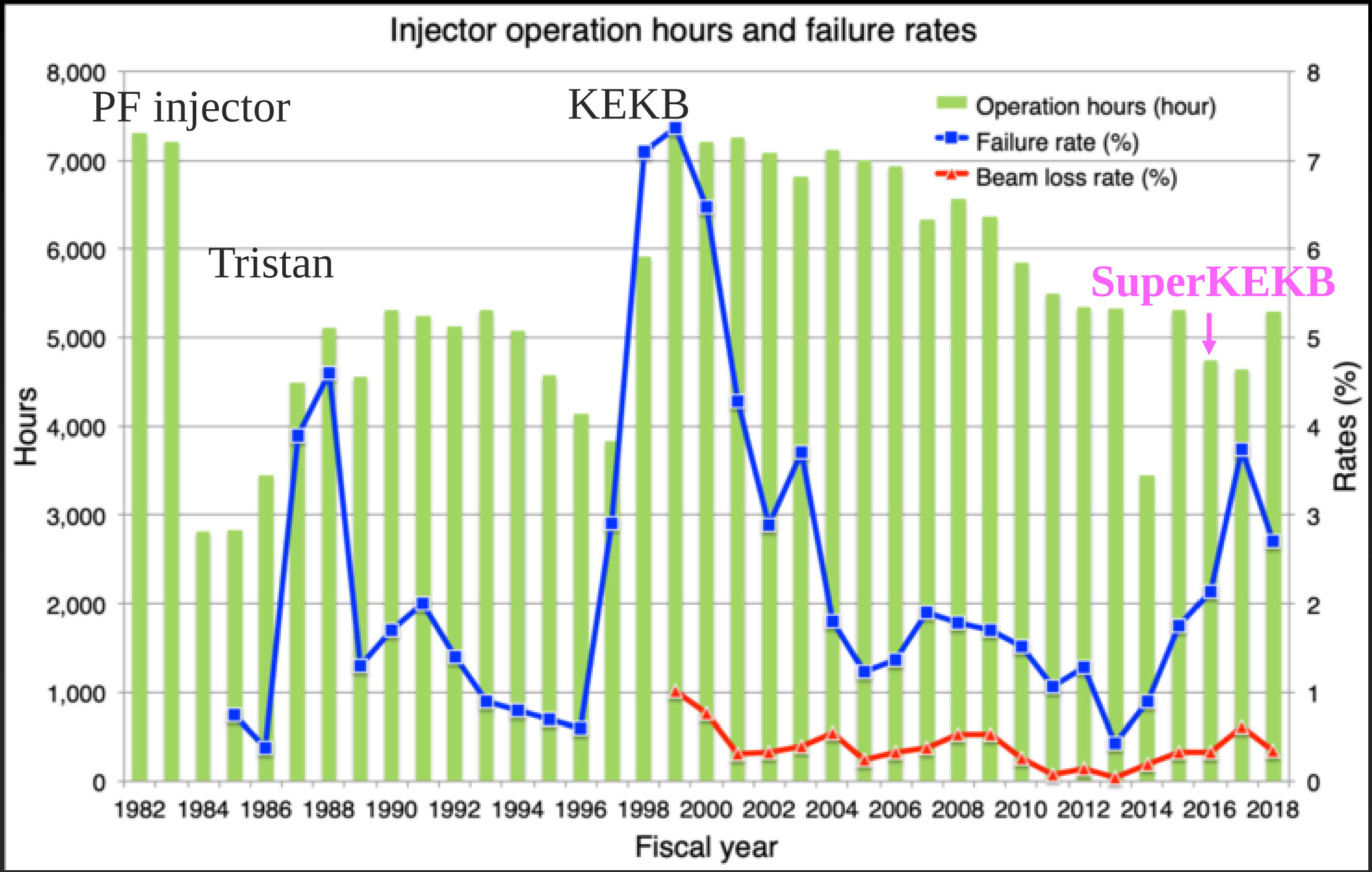
Phase3.2
2019c(Autumn)

These efficiencies are calculated at the low current beam in the HER.
→ The effect of Touschek lifetime can be neglected.

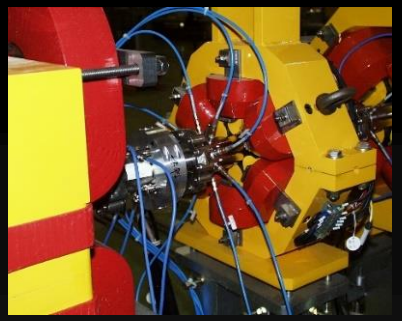
βy*=1.0mm



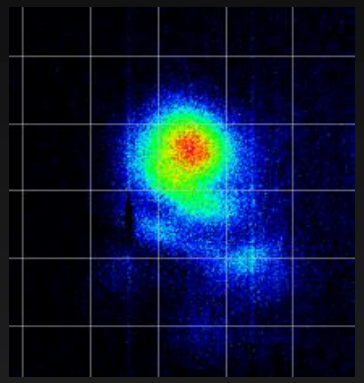
Energy spread became better


Injector operation hours and failure rates
PF injector
KEKB
Tristan
SuperKEKB
Operation hours (hour)
Failure rate (%)
Beam loss rate (%)
Hours
Rates (%)
Fiscal year
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
8
7
6
5
4
3
2
1
0
1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018

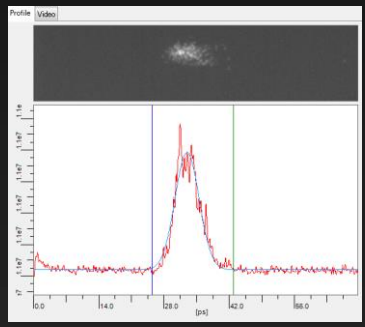
Monitors

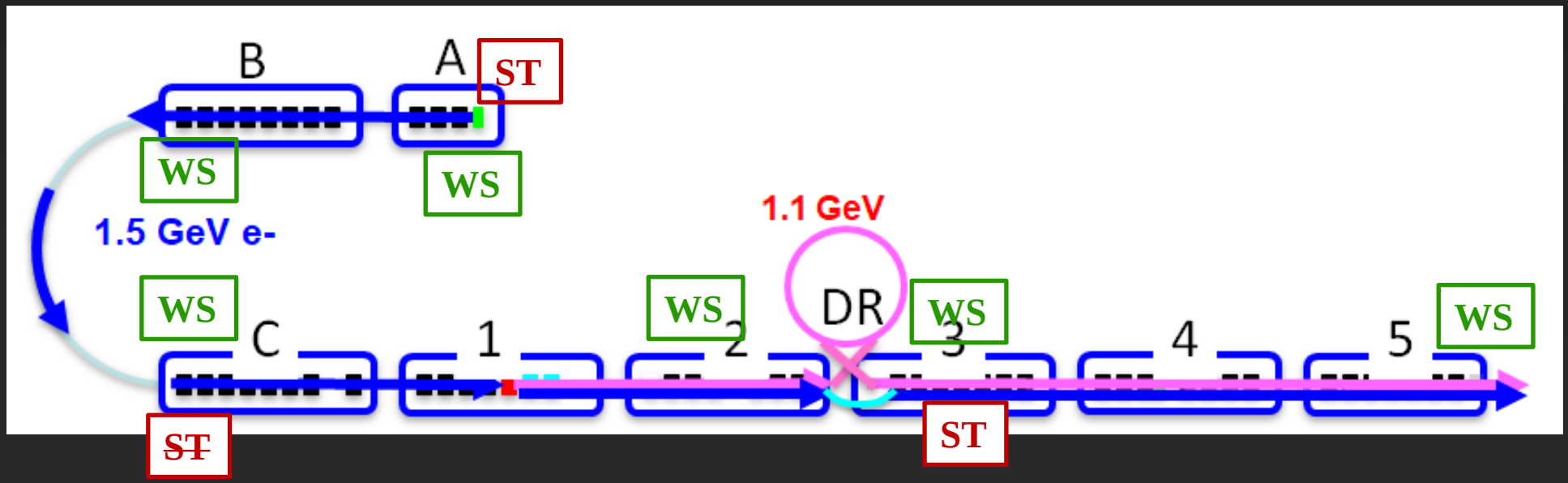


- Beam position monitor (x 103)
  - Four strip line electrodes (x 97)
    - **Measurement precision ~ 10 μm**
  - Eight strip line electrodes (x 6) (J-ARC, LTR x2, PF BT, HER BT, LER BT)
- Profile monitor (x 104)
  - Al_2O_3/CrO_3 (AF995R, Demarquest Co.). (t: 1 mm, 0.1 mm), YAG:Ce (t: 0.1 mm)



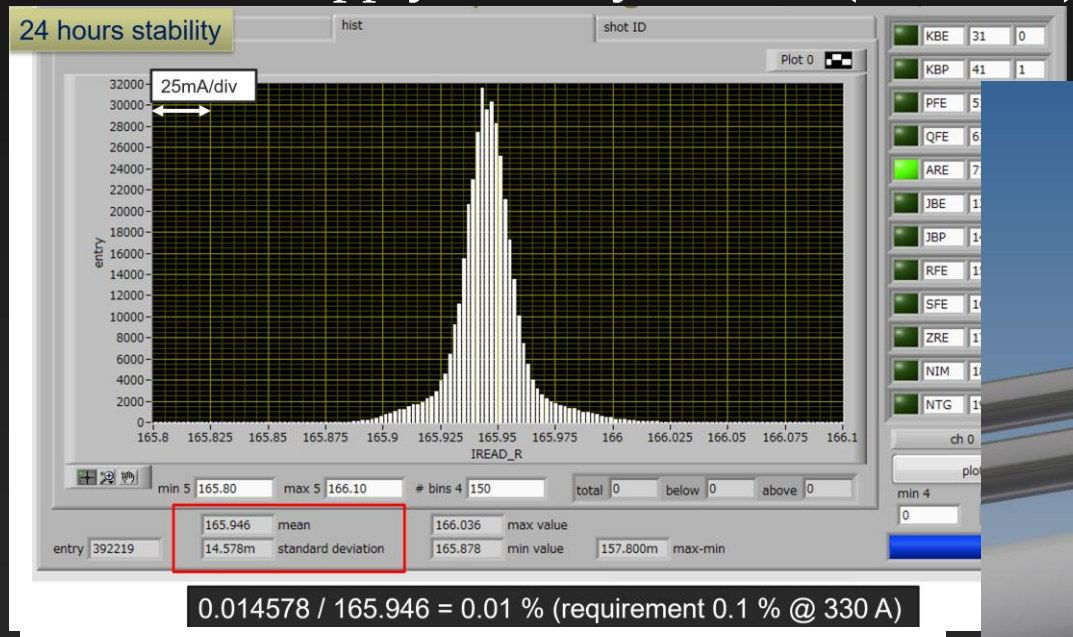
- Wire scanner (WS) (x 6)
  - SectorA, B, C, 2, 3, 5
- Streak camera (ST) (x 2)
  - SectorA, ~~C~~, 3
- RF monitors for klystron, SLED, acc. structure

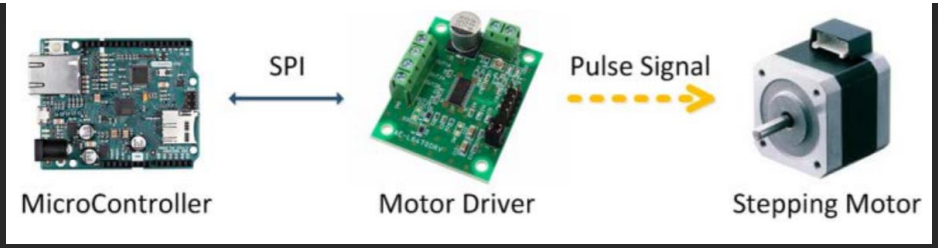


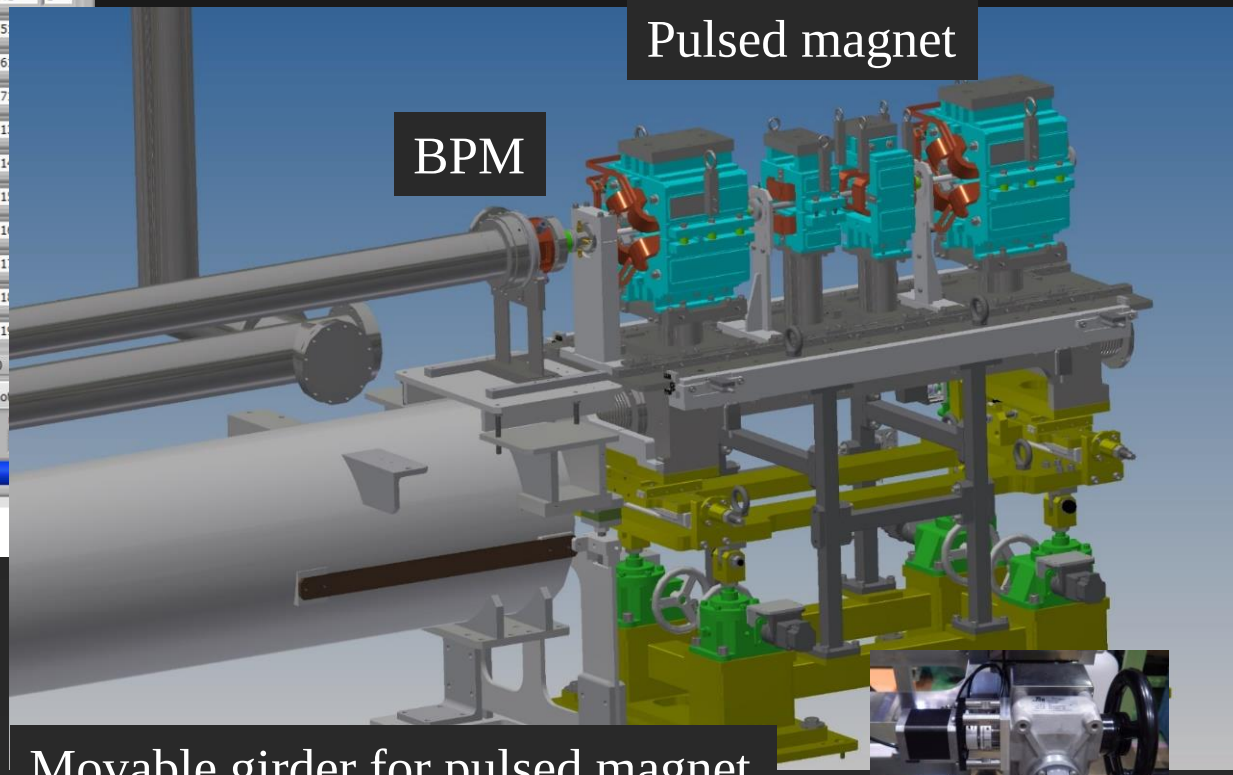


Pulsed magnet system

- 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)



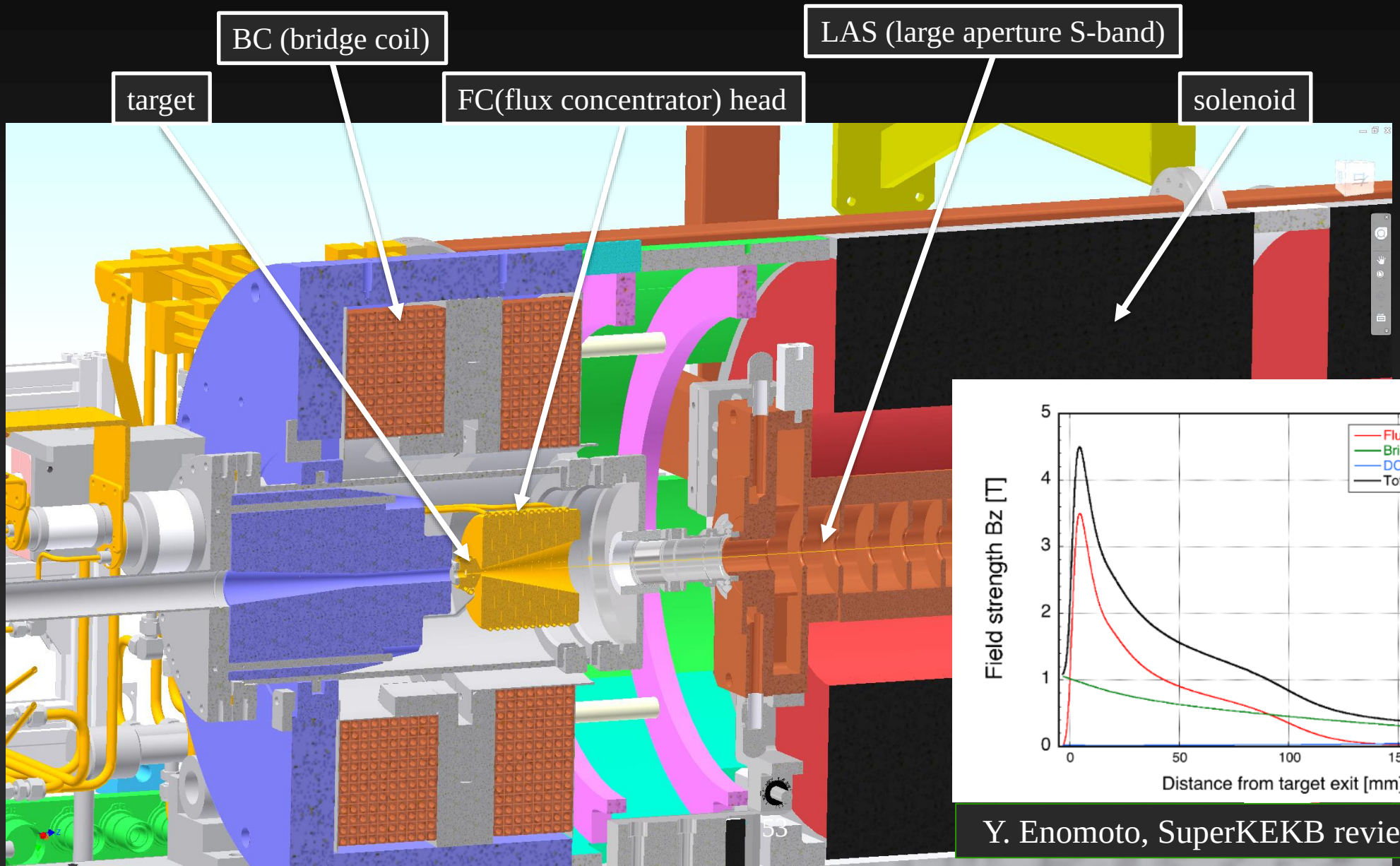




Movable girder for pulsed magnet
(remote controllable, 10 μm step)

e+ source setup 2

FC head + BC + target = FC assembly



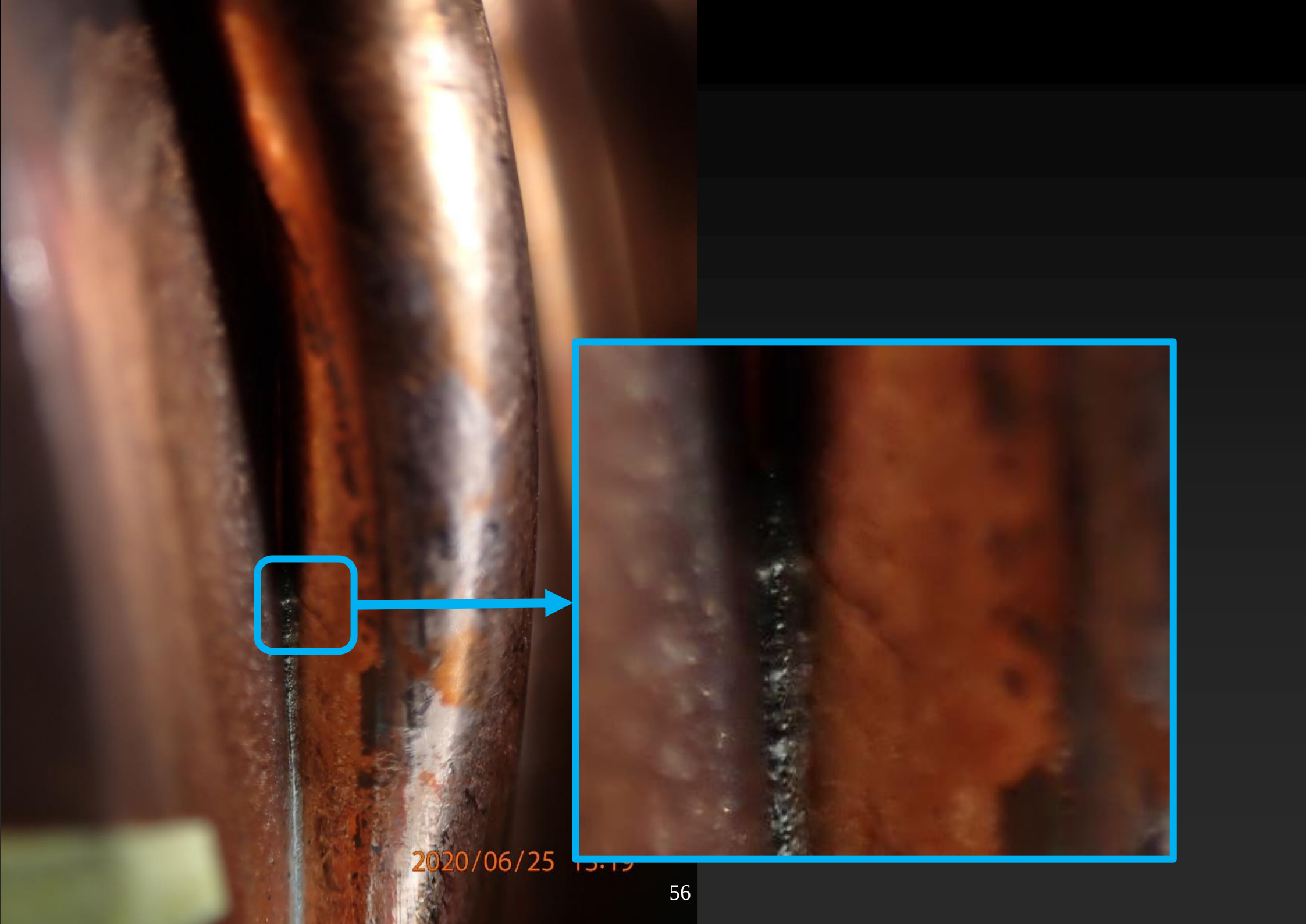
Y. Enomoto, SuperKEKB review, 2019

Movable girder for accelerating structure

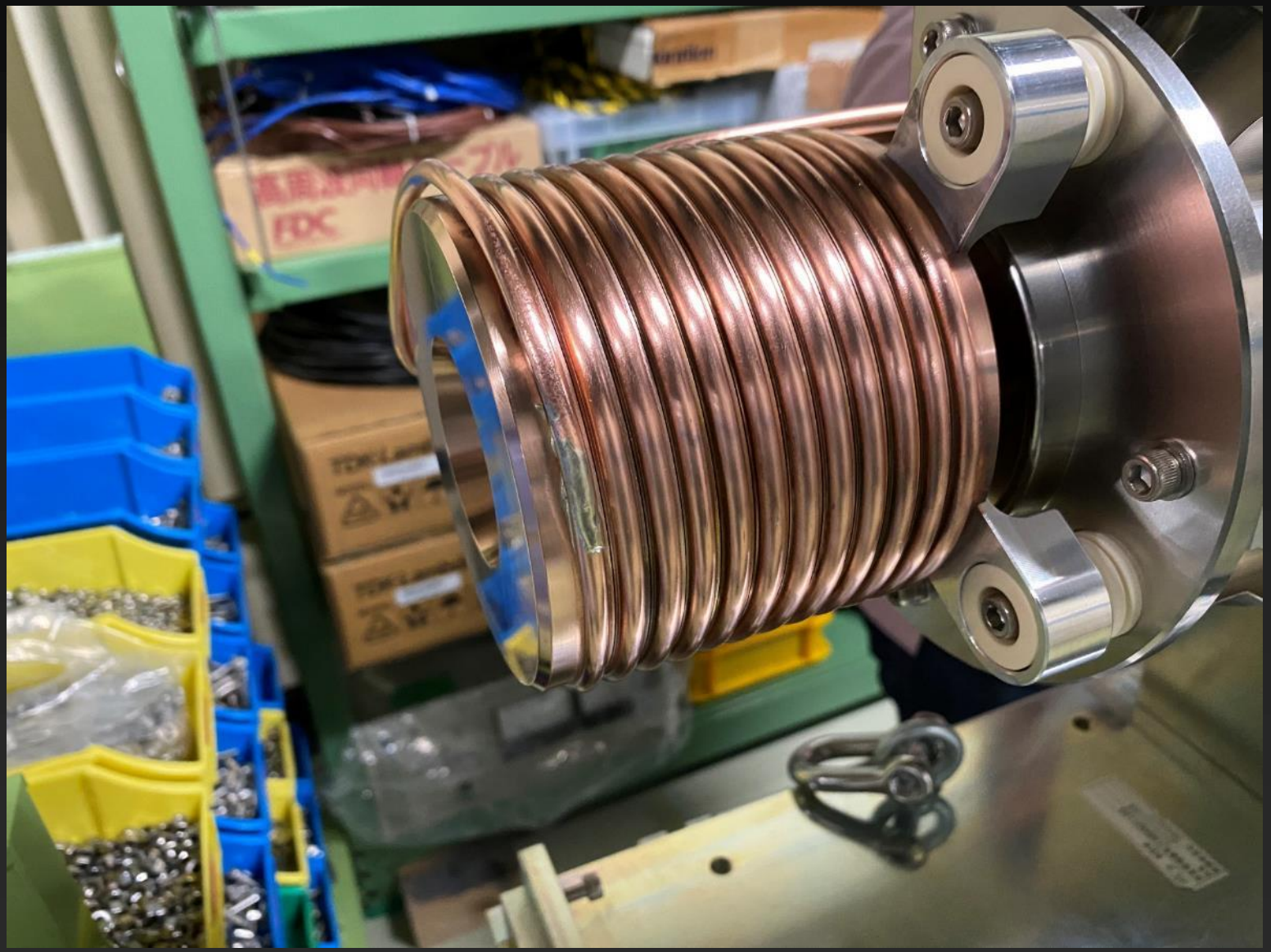
- Six movable girders have been installed in Sector3 (in summer shutdown of 2019).
  - Four 2-m-long accelerating structures are mounted on one girder.
- It could help to suppress emittance growth due to misalignment.

リーク箇所

リークテストでは水色の枠
部がピンポイントで反応する
目視では亀裂や穴は判別できない


2020/06/25

FC Base8 after repair



Pressure and FC (base8) current after repair