Injector Linac Status

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on behalf of Injector Linac Group

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- Summary

Outline (I)

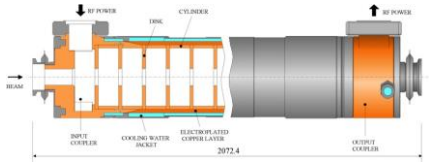
- Injector Linac [P. 5]
  - Injector linac provides positron beam to LER via DR and electron beam to HER/two light sources (PF, PF-AR).
  - Two electron guns:
    - Photocathode rf gun and thermal gun are utilized for HER and LER/two light sources injections, respectively. At the injector beam line, two different guns are situated in the double decker configuration [P. 6].
    - Maximum beam repetition is 50 Hz (sum of two guns). All klystrons are always running in 50 Hz for keeping the constant temperature of cooling water.
  - Both guns can generate two bunches in one rf pulse for HER/LER injection beam with the interval of 96 ns.
- Simultaneous top up injection
  - Simultaneous top up injection to 4 rings has been successfully conducted since May 2018. [P. 7]
  - Pulse-to-pulse beam control can be performed by changing the low level rf phase/timing (energy, energy spread), pulsed magnet settings (quad, steering, switching bend) with the event based timing system (3 event generators (EVGs) and 45 event receivers (EVRs)). [P. 8]

Outline (II)

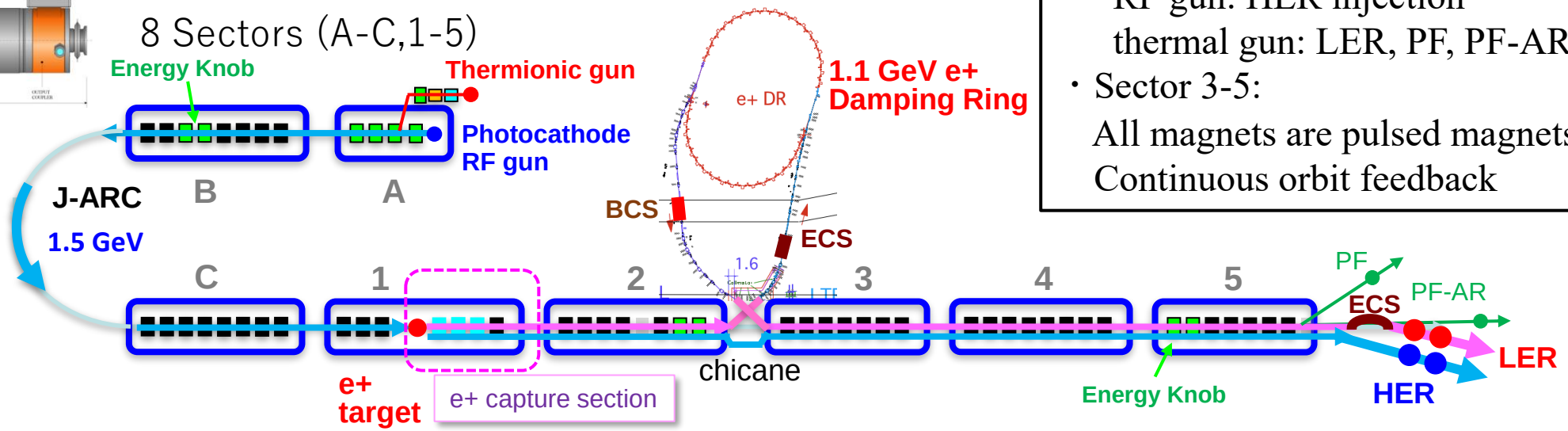
- Beam monitors
  - BPM (x103)
    - BPM can perform non destructive beam position measurement. Special module based on the VME and EVR beam position measurement precision is less than 10 μm. All beam shot data (50 Hz) can be measured and stored for the postmortem analysis.
  - Profile monitor (x104)
    - Profile monitors are utilized for the destructive beam shape measurement with the material of Al_2O_3/CrO_3 (AF995R, Demarquest Co.) (t: 1 mm, 0.1 mm) and YAG:Ce (t: 0.1 mm). Optics measurement is conducted by Q-scan method using YAG profile monitor. Linux-based PLC is used as controller.
  - Wire scanner (x2)
    - They are situated in SectorA, B, C, 2, 3, 5 for the optics measurement. The diameter of tungsten wire is 100 μm.
  - Streak camera (x2)
    - They are situated in SectorA and Sector3 for the bunch length measurement. One in SectorC was obsoleted because of the fire accident in 2019.
- RF monitors
  - RF monitors (x61) can measure rf amplitude/phase of the Klystron output, SLED output, accelerating structure output. All shots of average and peak values are stored for postmortem analysis.

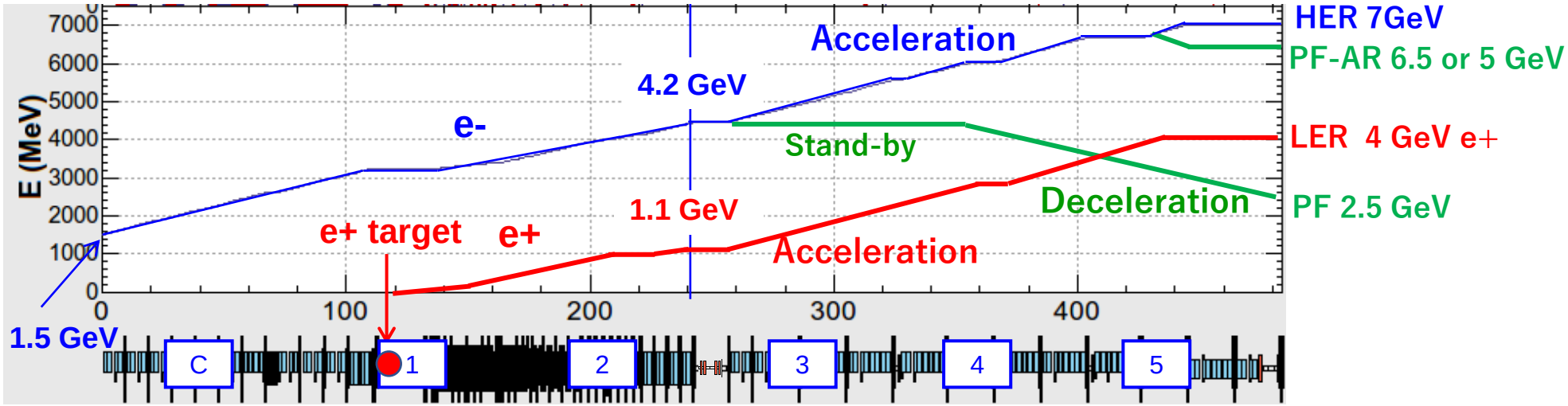
Injector Linac

60 klystron units
240 accelerating structures (S-band 2-m-long)



- Two electron sources:
  RF gun: HER injection
  thermal gun: LER, PF, PF-AR
- Sector 3-5:
  All magnets are pulsed magnets.
  Continuous orbit feedback



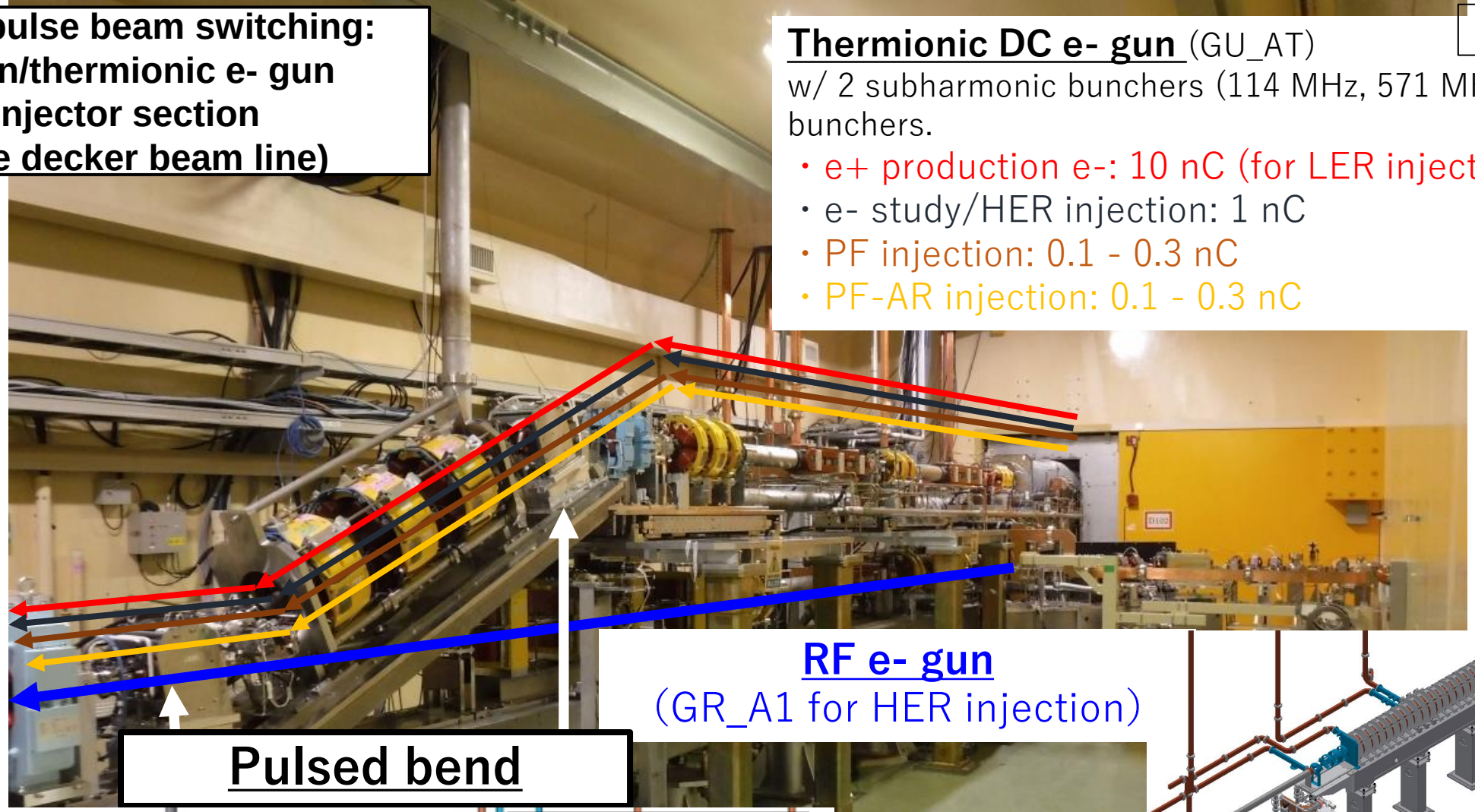


Beam energy variation for each beam mode along the beam line after the J-ARC

Pulse to pulse beam switching: rf e- gun/thermionic e- gun In injector section (double decker beam line)

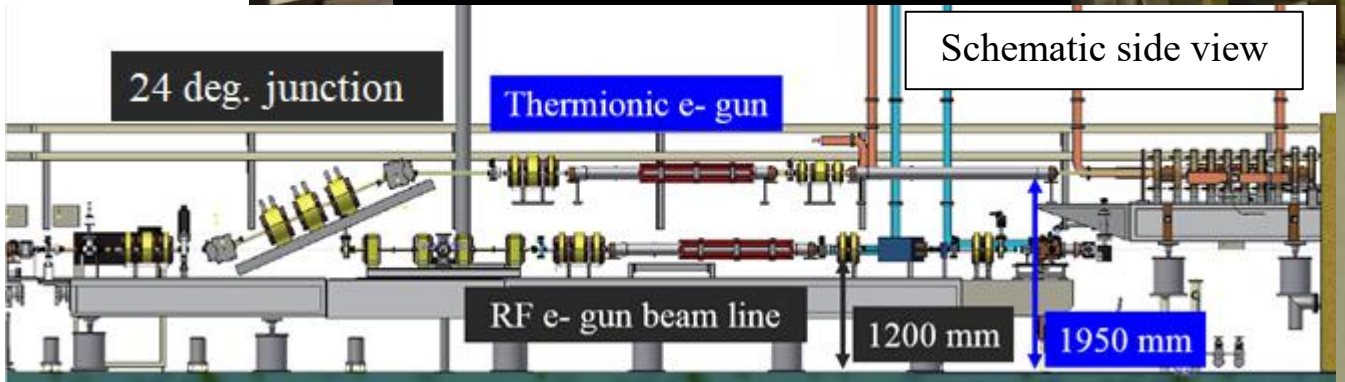
Thermionic DC e- gun (GU_AT)
w/ 2 subharmonic bunchers (114 MHz, 571 MHz) and 2 bunchers.

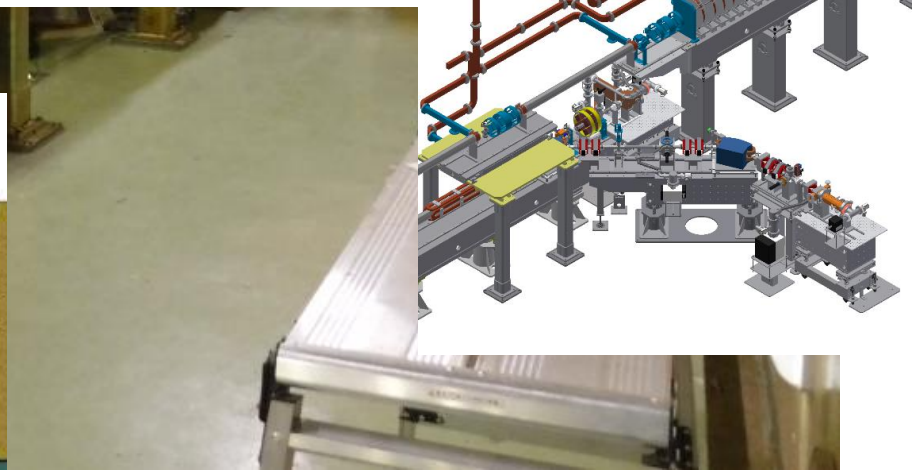
- e+ production e-: 10 nC (for LER injection)
- e- study/HER injection: 1 nC
- PF injection: 0.1 - 0.3 nC
- PF-AR injection: 0.1 - 0.3 nC



Pulsed bend

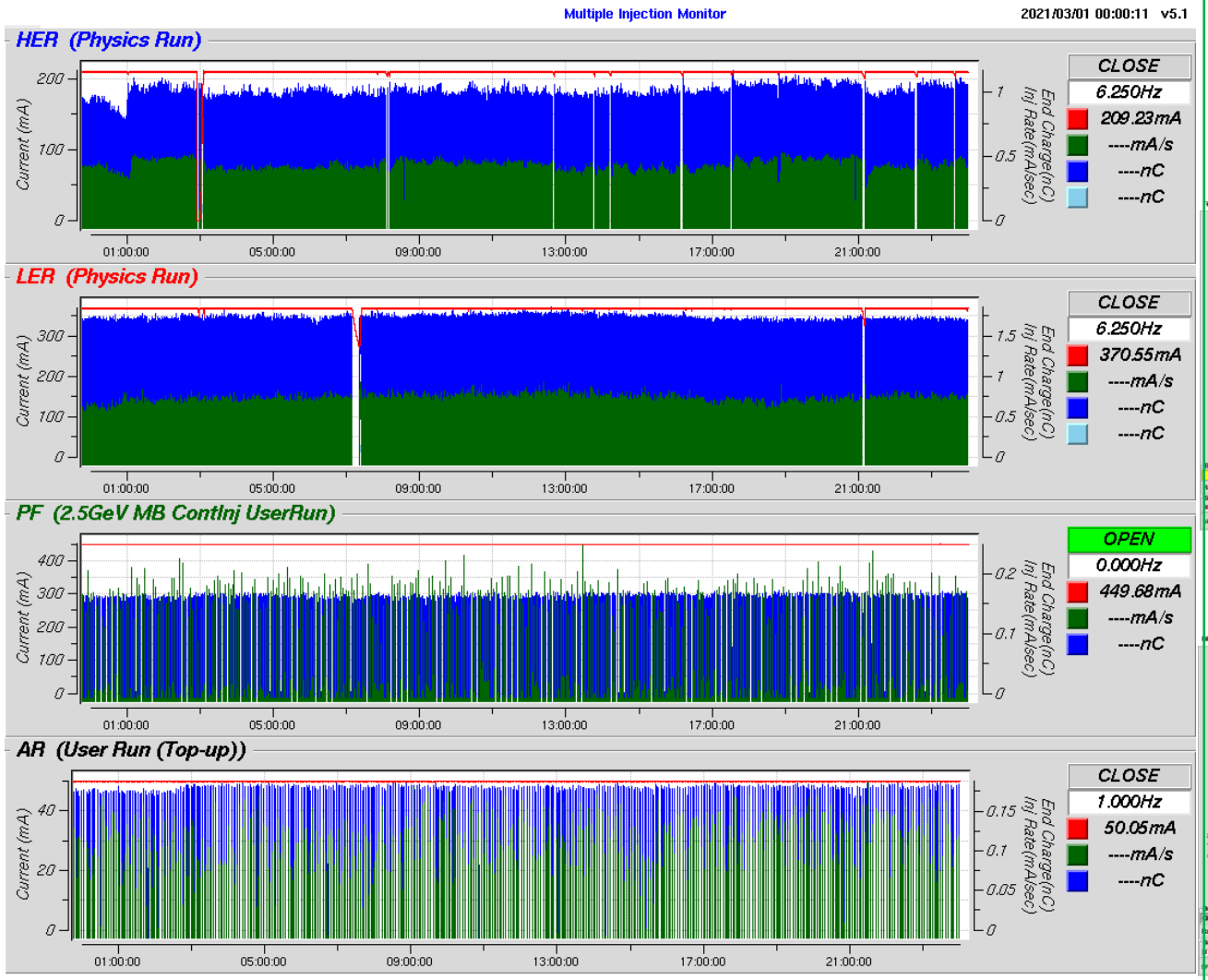
RF e- gun
(GR_A1 for HER injection)



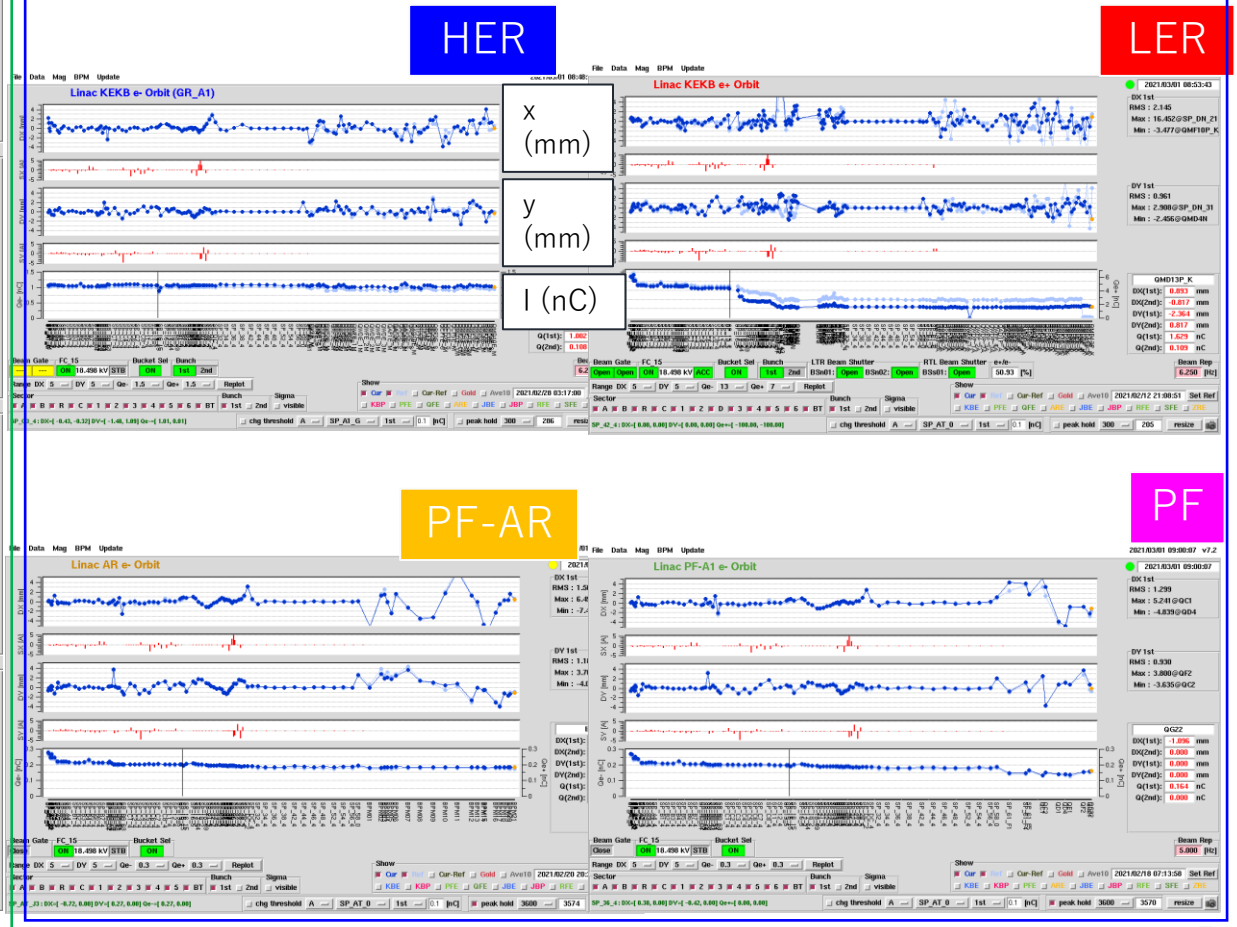


Simultaneous top up injection to 4 rings - stored current and linac beam orbit -

Stored current (1 day)

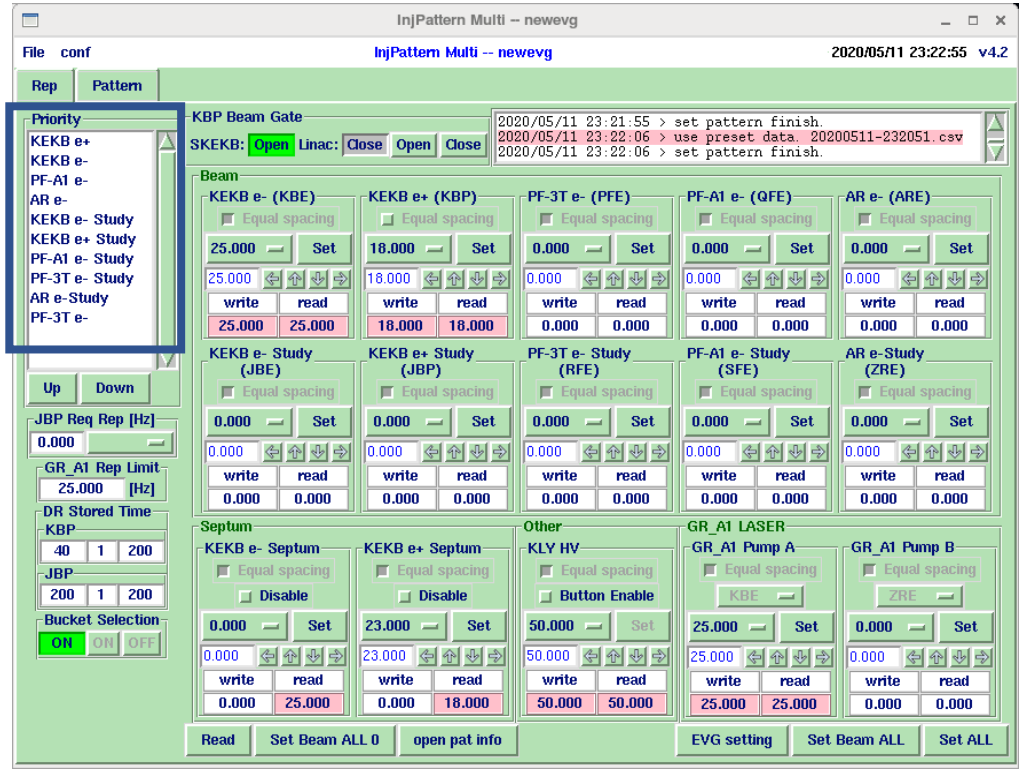


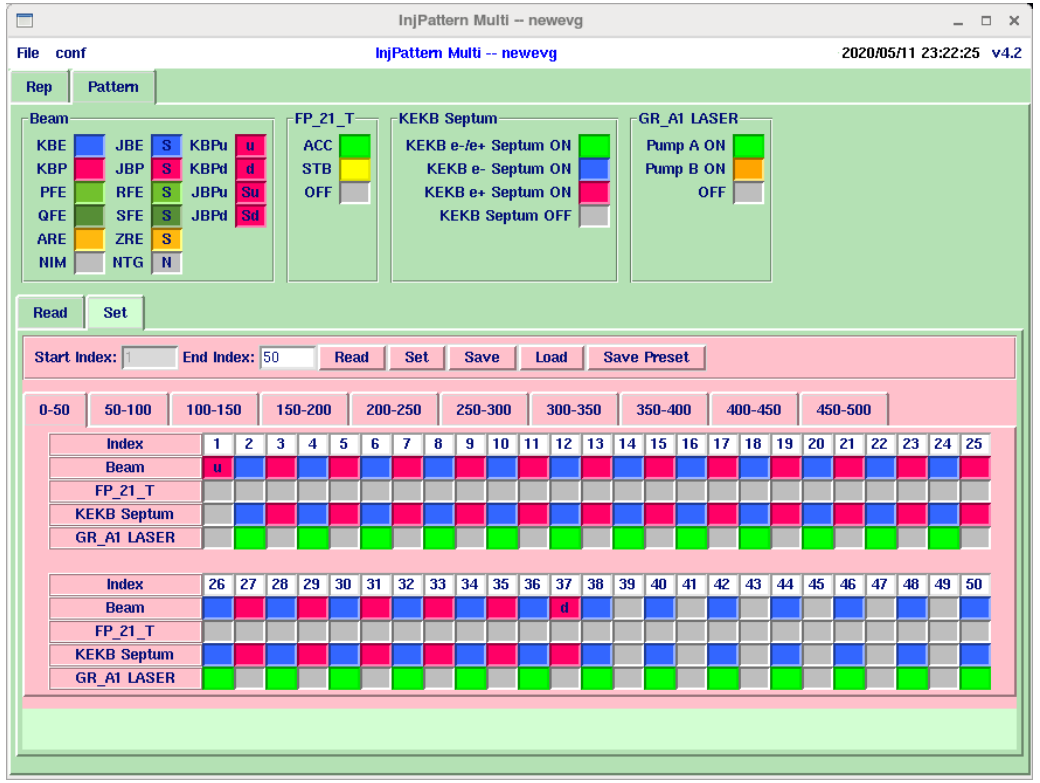
Linac/BT beam orbit



Beam Injection Pattern Generation for simultaneous top up injection

- **Beam repetition rate is determined by demand from each ring.**
- **Priority can be defined.**





Beam repetition rate management for each beam injection mode.

Beam mode

KBE: SuperKEKB e- (HER)
KBP: SuperKEKB e+ (LER)
QFE: PF
ARE: PF-AR

Parameters

Stage	KEKB (achievement)		SuperKEKB Phase-I (achievement)		Phase-II (achievement)		Phase-III Summer'19 (achievement)		Phase-III Summer'20 (achievement)		Phase-III Summer'21 (achievement)		Phase-III (final)	
Beam	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–
Energy (GeV)	3.5	8.0	4.0	7.0	4.0	7.0	4.0	7.0	4.0	7.0	4.0	7.0	4.0	7.0
Stored current (A)	1.6	1.1	1.0	1.0	1.0	1.0	0.83	0.94	0.712	0.607	0.790	0.687	3.6	2.6
Life time (min.)	150	200	100	100	50	100	20 (typ.)	70 (typ.)	12	21	9	22	6	6
Bunch charge (nC)	primary e- 10 → 1	1	primary e- 8 → 0.4	1	1.6	3.6	1.35	3.5	1.6	3	2.5	2	primary e- 10 → **4**	**4**
Norm. Emittance (γβε) (mmrad)	1400	310	1000	130	200/5 (Hor./Ver.)	200/40	120/6	54/67	100/2	41/45	**100/60**	**100/80**	**100/15** (Hor./Ver.)	**40/20** (Hor./Ver.)
Energy spread	0.13%	0.13%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.16%	0.07%
Bunch/Pulse	2	2	2	2	2	2	1	1	1	1	2	1	2	2
Repetition rate (Hz)	50		25		25		50 (LER+PF+PF-AR < 25 Hz)		50 (LER+PF+PF-AR < 25 Hz)		50 Hz		50 Hz	
Simultaneous top-up injection	3 rings (LER, HER, PF)		No top-up		Partially		4+1 rings (LER, HER, DR, PF, PF-AR)							

e- beam status

e- beam status (I)

- Thermal e- gun
  - Thermal gun provides e- beam with bunch charge of around 10 nC for positron production (LER injection) and of around 0.3 nC for light sources. Two subharmonic bunchers (114 MHz, 571 MHz), pre-buncher, and buncher can generate the single bunched e- beam with the bunch length of about 5 ps (0.3 nC)/10 ps (10 nC) in FWHM.
  - It has worked through run 2020c to 20201b without any significant troubles.
- RF e- gun
  - Photocathode rf gun is utilized for generating the low emittance e-. Electron beam from rf gun is directly delivered to HER ring without DR. The system comprises of quasi travelling wave (QTW) type cavity, Ir_7Ce_2 photocathode, and laser system. Two laser system is in operation (1st laser line and 2nd laser line). 1st laser line is utilized for daily operation, and 2nd line is backup and also cathode laser cleaning system for recovering the quantum efficiency of photocathode. Both laser lines can be simultaneously operated for obtaining higher bunch charged e- beam. [P. 14, P. 15]
  - Diffractive optical element (DOE) has been installed in 1st laser line after run 2020b for reshaping the transverse laser profile (flat-top distribution). After run 2020c, it can help obtaining the low emittance beam w/ high bunch charge by mitigating space charge effect and decreasing beam jitter. [P. 16]

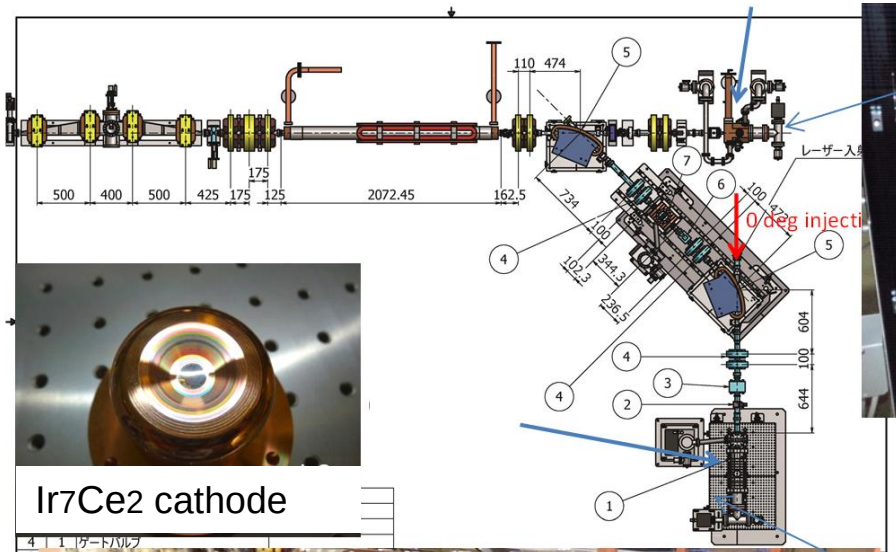
e- beam status (II)

- RF e- gun (cont'd)
  - DOE was not installed for 2nd laser line in the summer shutdown in FY2020 because of the lack of installation space. However during summer shutdown in FY2021, Another DOE will be installed also in 2nd laser line by remodeling the laser line configuration.
  - At the beginning of run 2021a, we prepared the electron beam with bunch charge of 2 nC at BT. Best normalized emittance achieve 20 μm in the both directions. Bunch charge is still smaller than the final target of 4 nC, however, emittance reaches the design value at BT1.
  - At the end of March, the output power of amplifier module #2 used in 1st laser line decreased. During investigating the amplifier module, large discharge occurred in the rf gun cavity because the module checked was done without turning off the beam and bunch charge feedback system. During checking work, 1st laser line power and bunch charge from rf gun decreased. And then, the 2nd laser (squeezed laser for photocathode cleaning) output power was increased by bunch charge feedback system for recovering the bunch charge of e- beam. In this process, discharge occurred inside the cavity and . After this event, cavity power was decreased for prevent the frequent discharge. [P. 17]

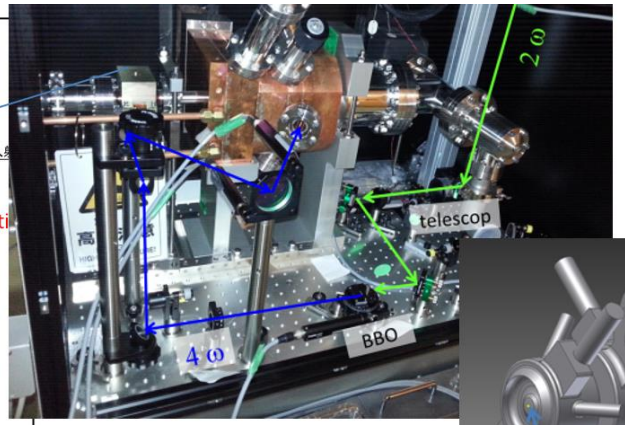
e- beam status (III)

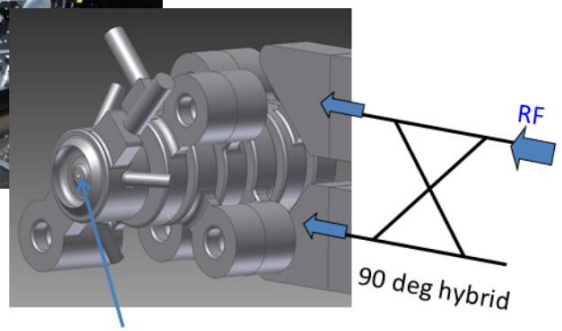
- e- beam quality
  - Emittance measurement by multiple wire scanner has been continuously conducted especially at SectorB and BT. Some measurement results show the good emittance, however, the issue is keeping the low emittance beam condition as long as possible. [P. 18]
  - In Sector3-5, orbit feedback can continuously stabilize the e- beam position with 24 pulsed steering magnets in both the horizontal and vertical planes. Emittance deterioration could be caused in the region between SectorC and Sector3. Because of this, expanding the orbit feedback is issue for keeping the low emittance. Additional pulsed steering magnets are installed at Sector2 (also SectorA, C) in summer maintenance FY2021. Moreover, some power supplies of existing pulsed steering magnets are replaced by new one (doubled maximum output current) in Sector1 and J-ARC.
  - Measured emittance of e- 2^{nd} bunch shows large value in comparison with one of 1^{st} bunch. Injection efficiency of 2^{nd} bunch is also low, and two bunch injection operation of e- beam was not established in run 2021a, b (successful in run 2020b). This reason could be the short rf pulse width (fed into rf gun cavity) since the rf pulse width was shortened from 1000 ns to 850 ns to avoid frequent discharge. In run 2021c, we will apply the nominal rf pulse width of 1000 ns after careful rf conditioning in the startup stage of autumn operation [P. 19]

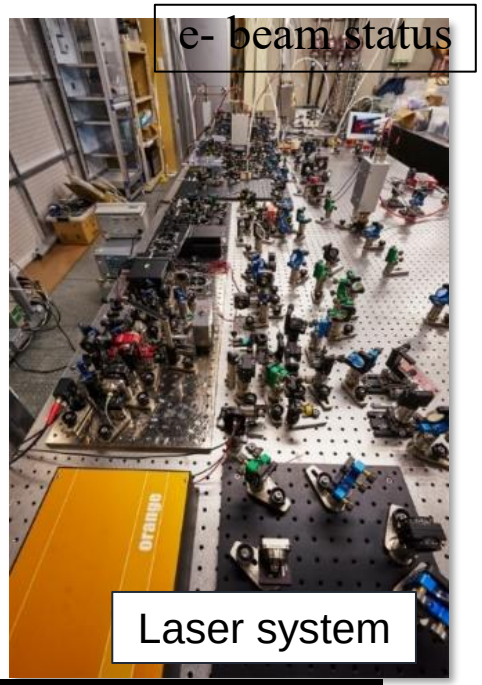
Low emittance photocathode rf e- gun

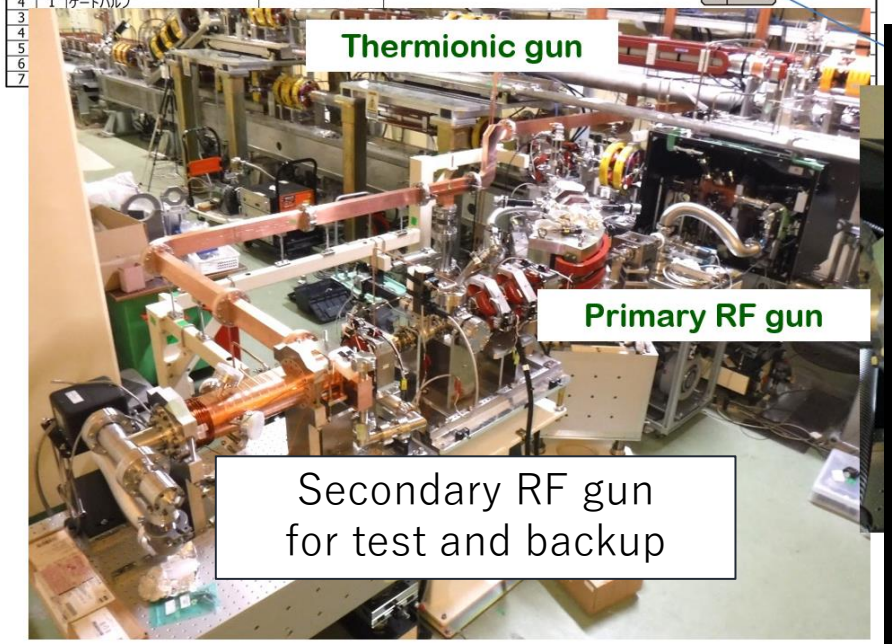


Ir7Ce2 cathode

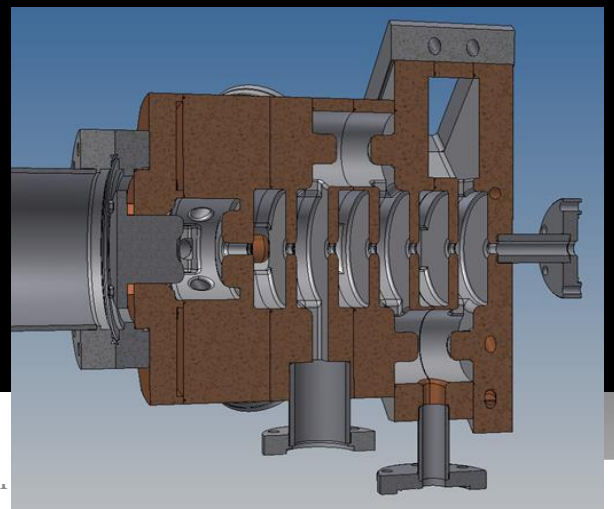


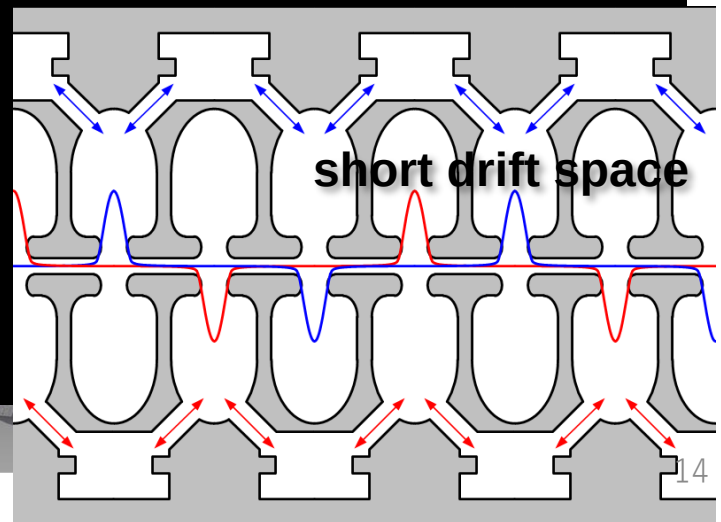






- Photocathode: Ir7Ce2
- Cavity: QTWSC (Quasi Travelling Wave Side Coupler)
  - Strong focusing electric field





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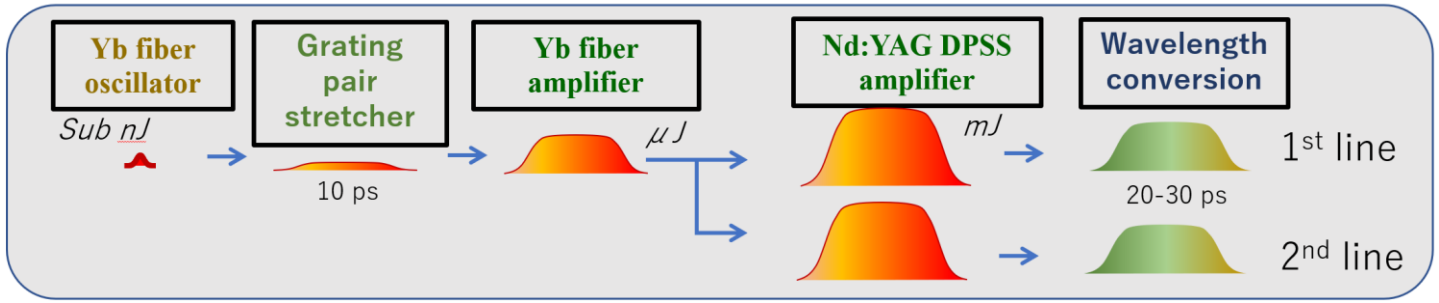
Hybrid laser system for rf e- gun

- Yb doped fiber and Nd:YAG DPSS module Amplifier



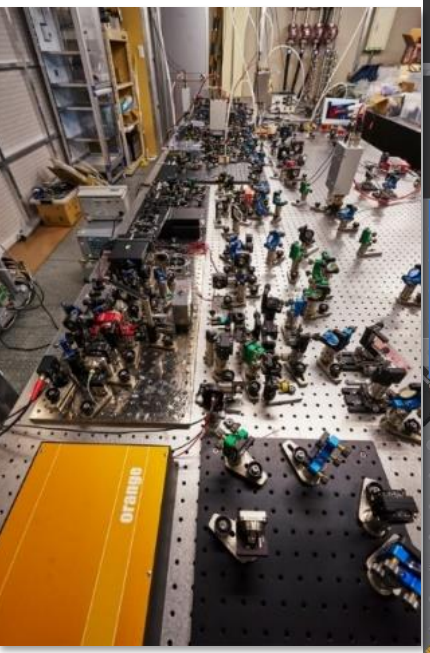
- **Output Power in 1st line:**
- *ω (1064 nm): 32 mJ*
- *2ω (532 nm): 11 mJ*
- *4ω (266 nm): 1.2 mJ*

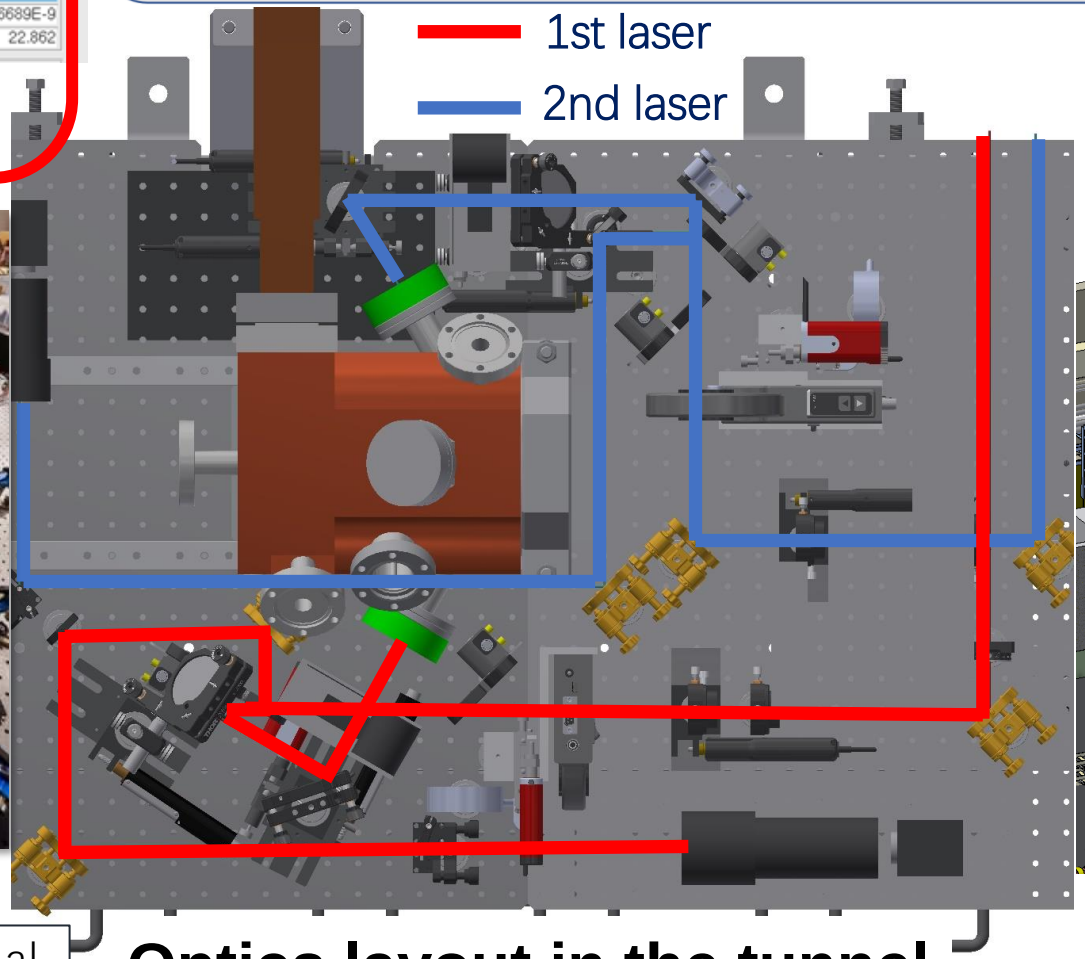
Best emittance

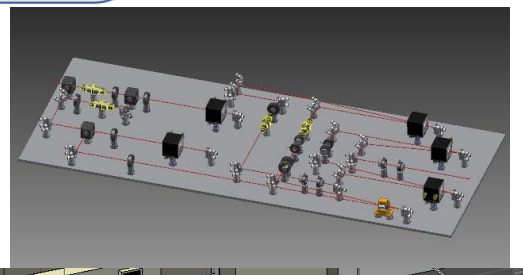
$\varepsilon_{nx,nxy}$ (2 nC)
~20 μm (BT#1)

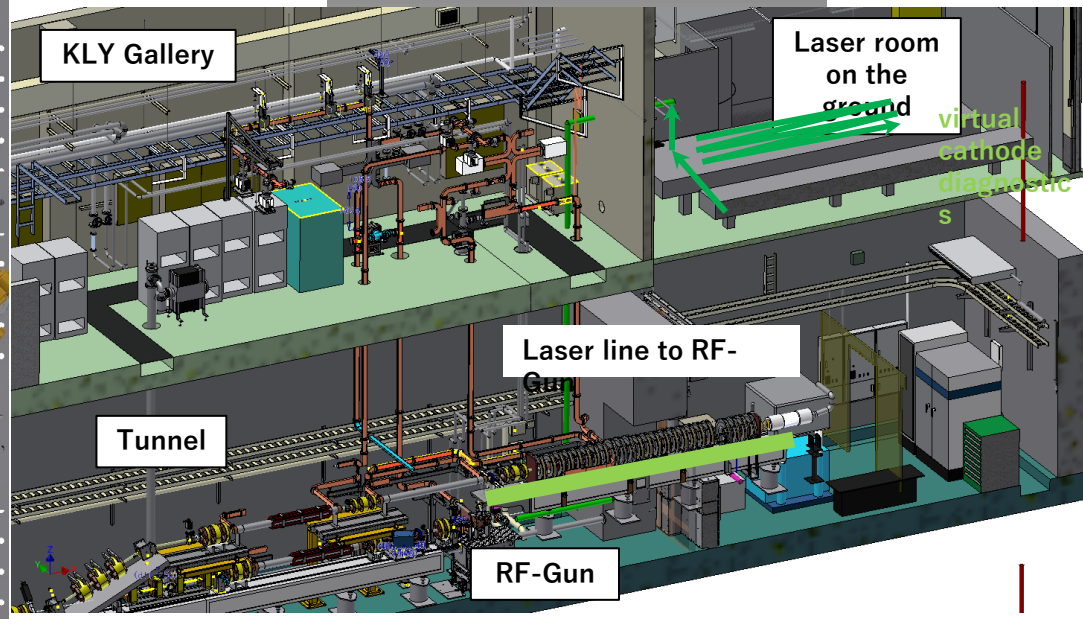
Results of measurement			
β_x @MW.1 [m] :	3.220	β_y @MW.1 [m] :	56.115
α_x @MW.1 :	.292	α_y @MW.1 :	2.507
ε_x [m] :	1.4328E-9	ε_y [m] :	1.5402E-9
$\Delta\varepsilon_x$ [m] :	3.887E-10	$\Delta\varepsilon_y$ [m] :	5.398E-10
$\gamma\varepsilon_x$ [μm] :	19.628	$\gamma\varepsilon_y$ [μm] :	21.099
$\Delta\gamma\varepsilon_x$ [μm] :	5.324	$\Delta\gamma\varepsilon_y$ [μm] :	7.395
Goodness x :	.437	Goodness y :	.256
Bmag x :	1.986	Bmag y :	1.084
ε Bmag x :	2.8450E-9	ε Bmag y :	1.6689E-9
γε Bmag x :	38.972	γε Bmag y :	22.862
Optics plot			

Goal: $\varepsilon_{nx,nxy}$ (4 nC)
~40/20 (H/V) μm)









Laser transport line

Optics layout in the tunnel

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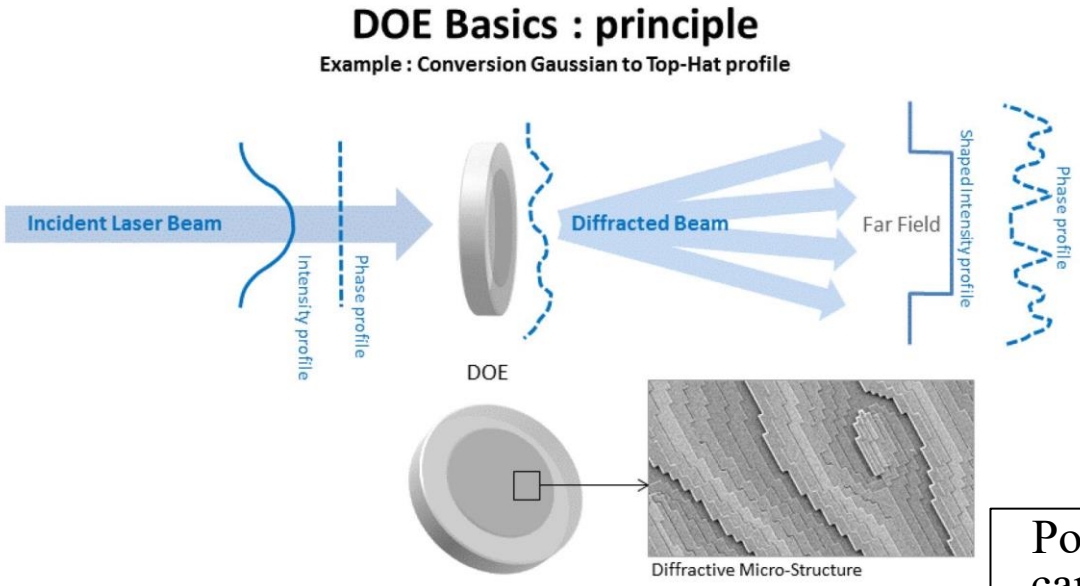
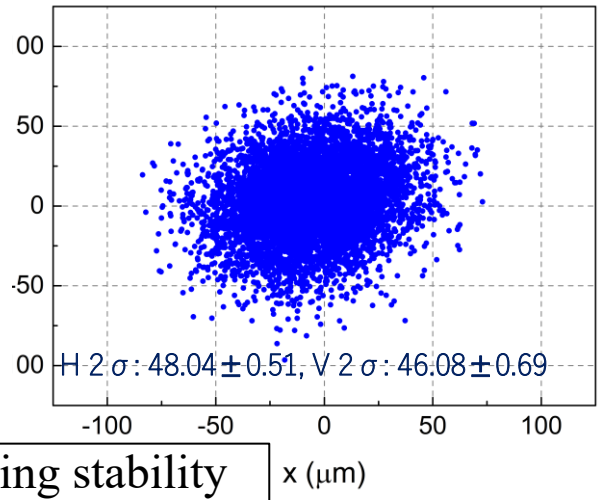
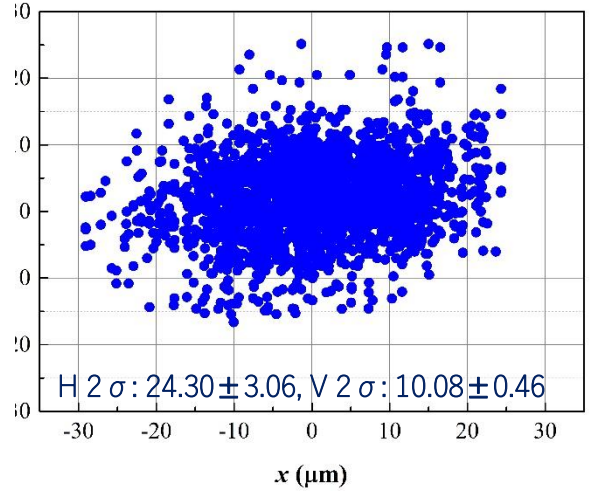
DOE for reshaping of laser spatial distribution



2019.06 without DOE & beam position sensor

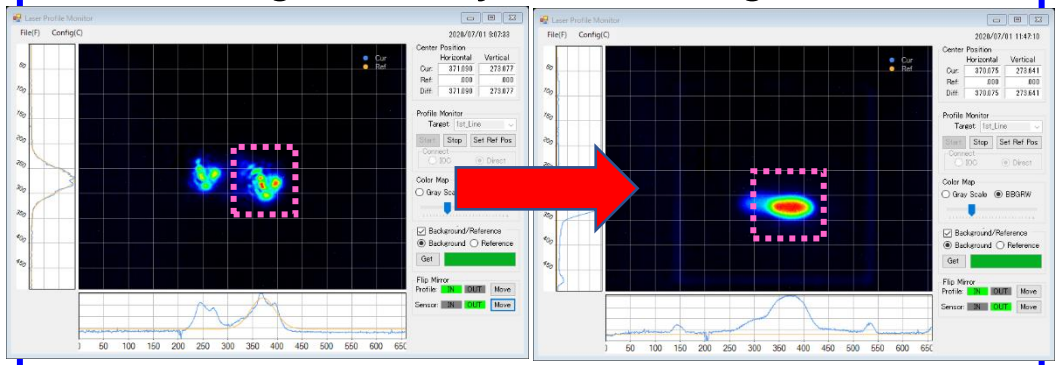


2021.06 with DOE & beam position sensor

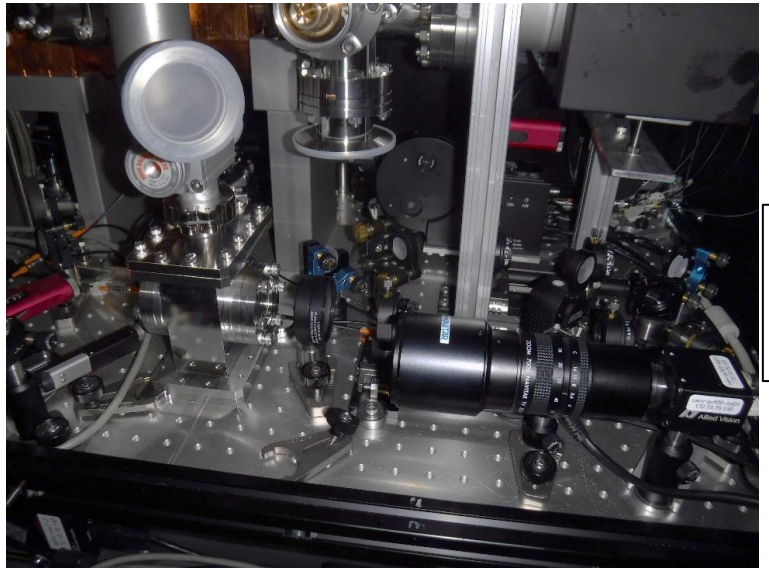


Pointing stability can be improved.

DOE (diffractive optical element) in 1st laser line: Laser beam homogenizer for low emittance beam w/ high intensity bunch charge.

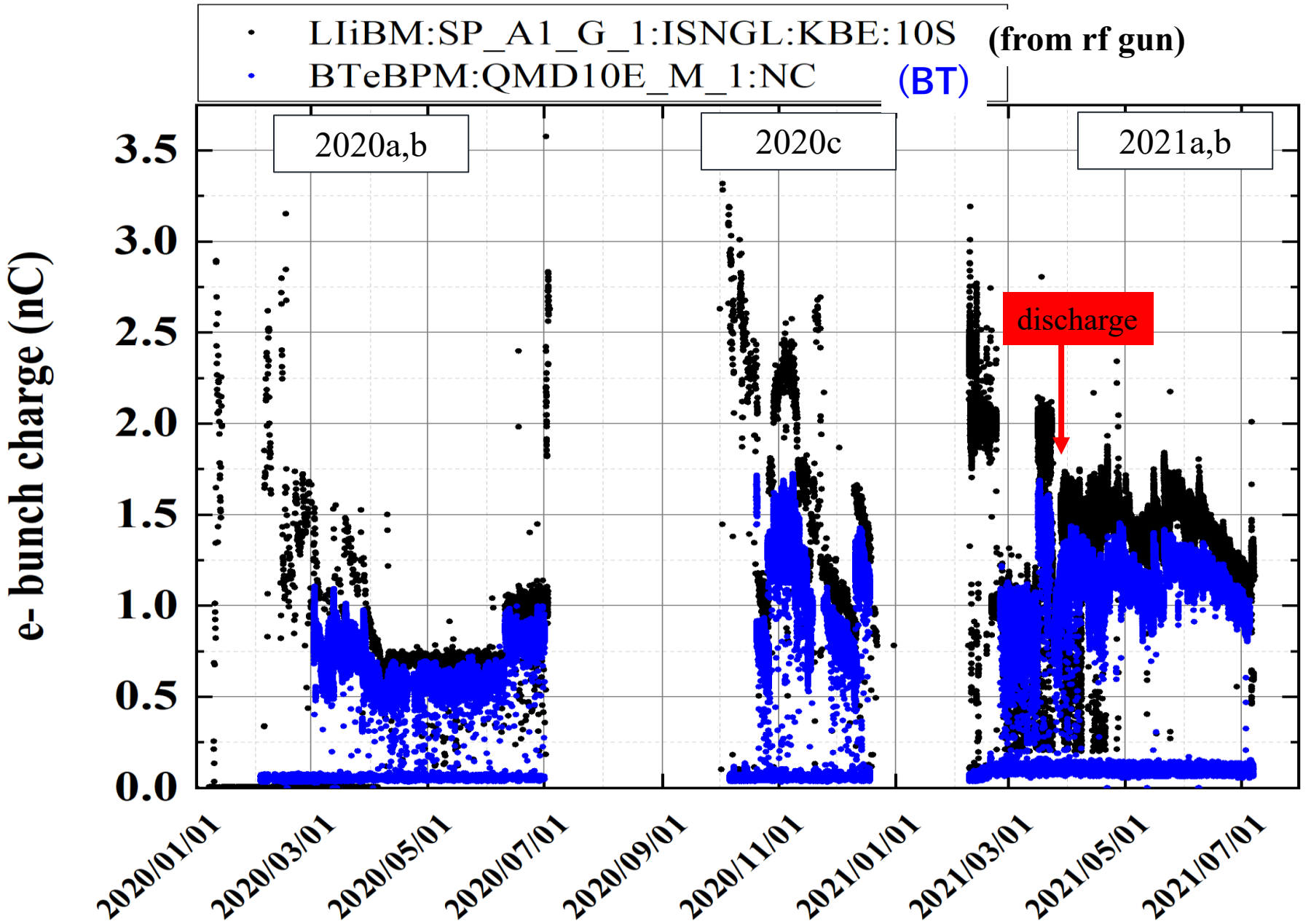


world first DOE application in UV laser

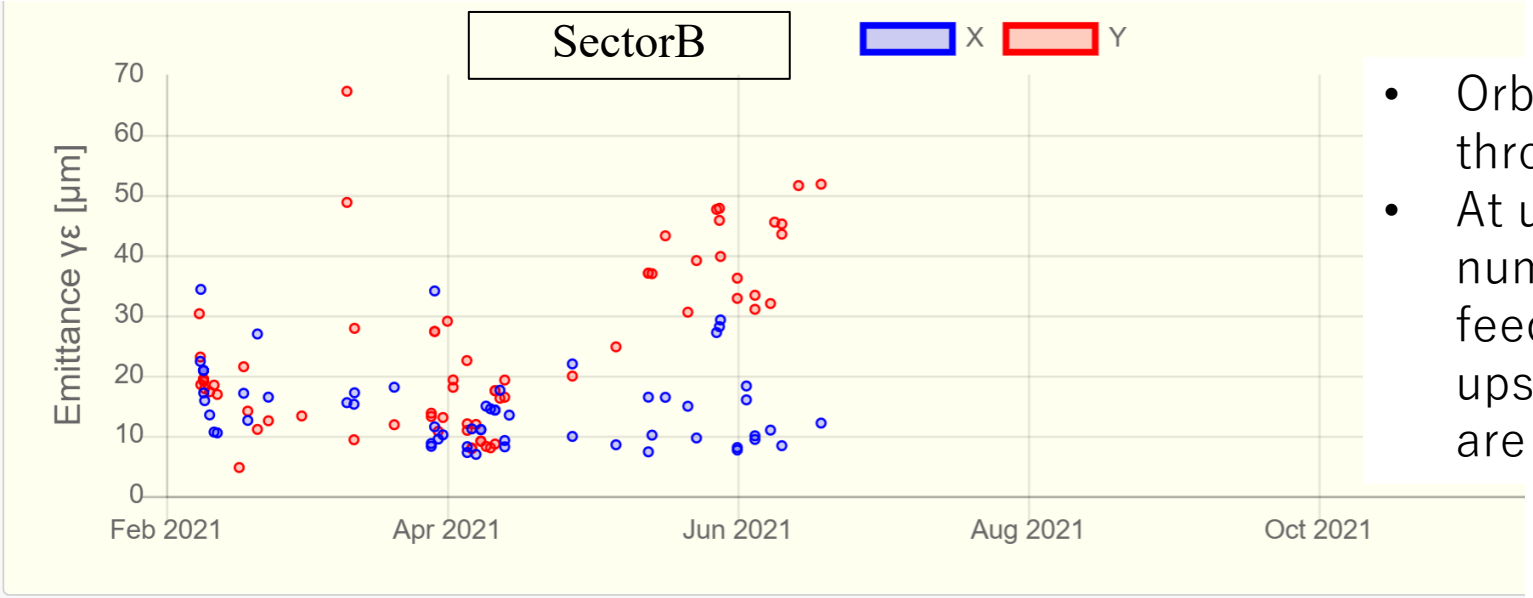


DOE is installed in vacuum chamber filled with Argon gas.

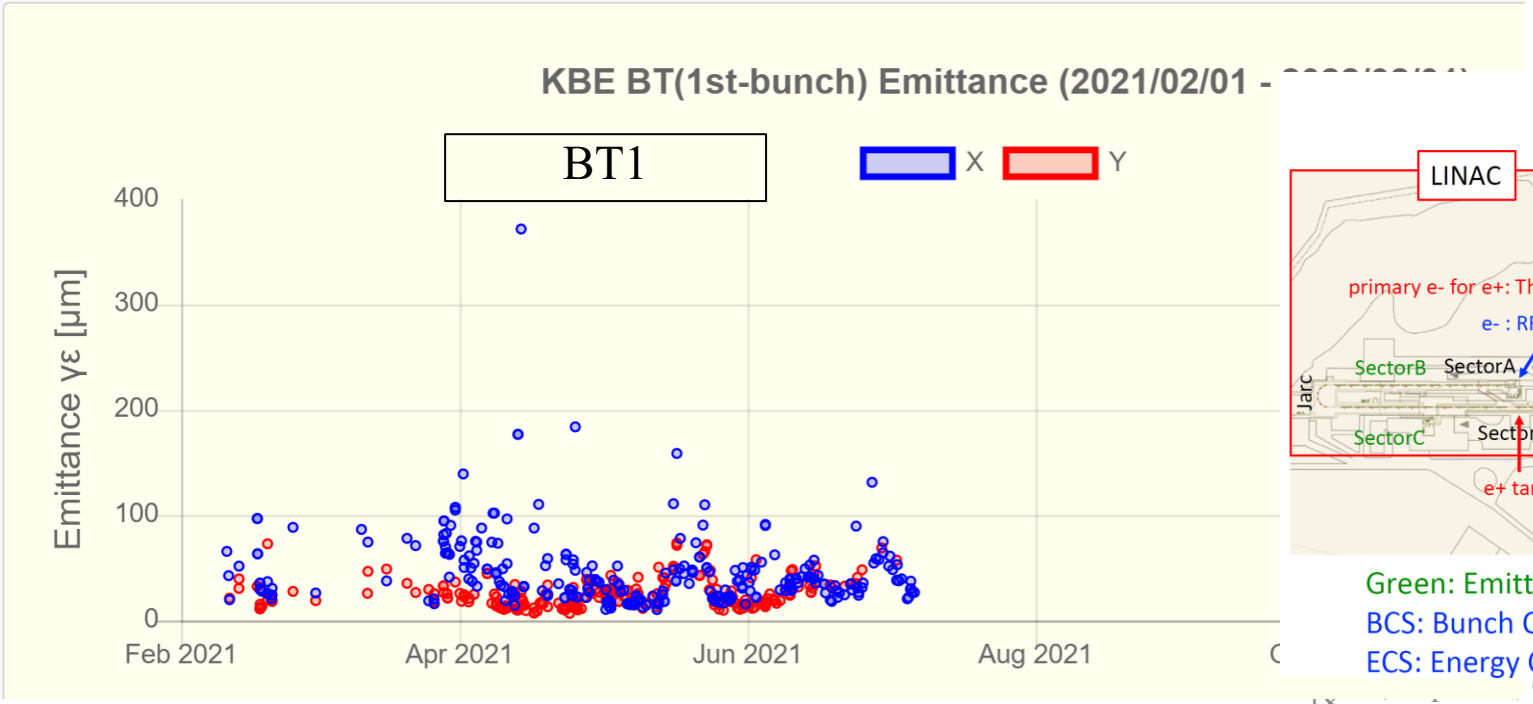
e- bunch charge history (2020a to 2021b)

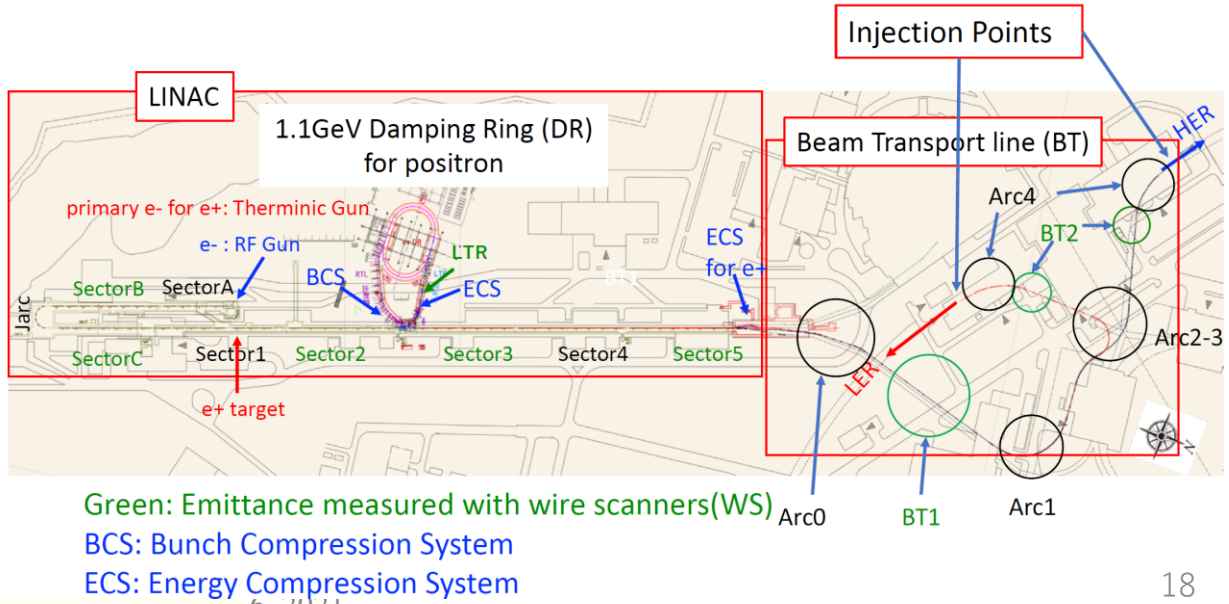


e- emittance history in run 2021a, b at SectorB and BT1



- Orbit feedback can stabilize the e- beam orbit through Sector3-5.
- At upstream Sector, there are not enough number of pulsed steering magnets for orbit feedback. For keeping the beam orbit upstream, additional pulsed steering magnets are installed in summer shutdown FY2021.



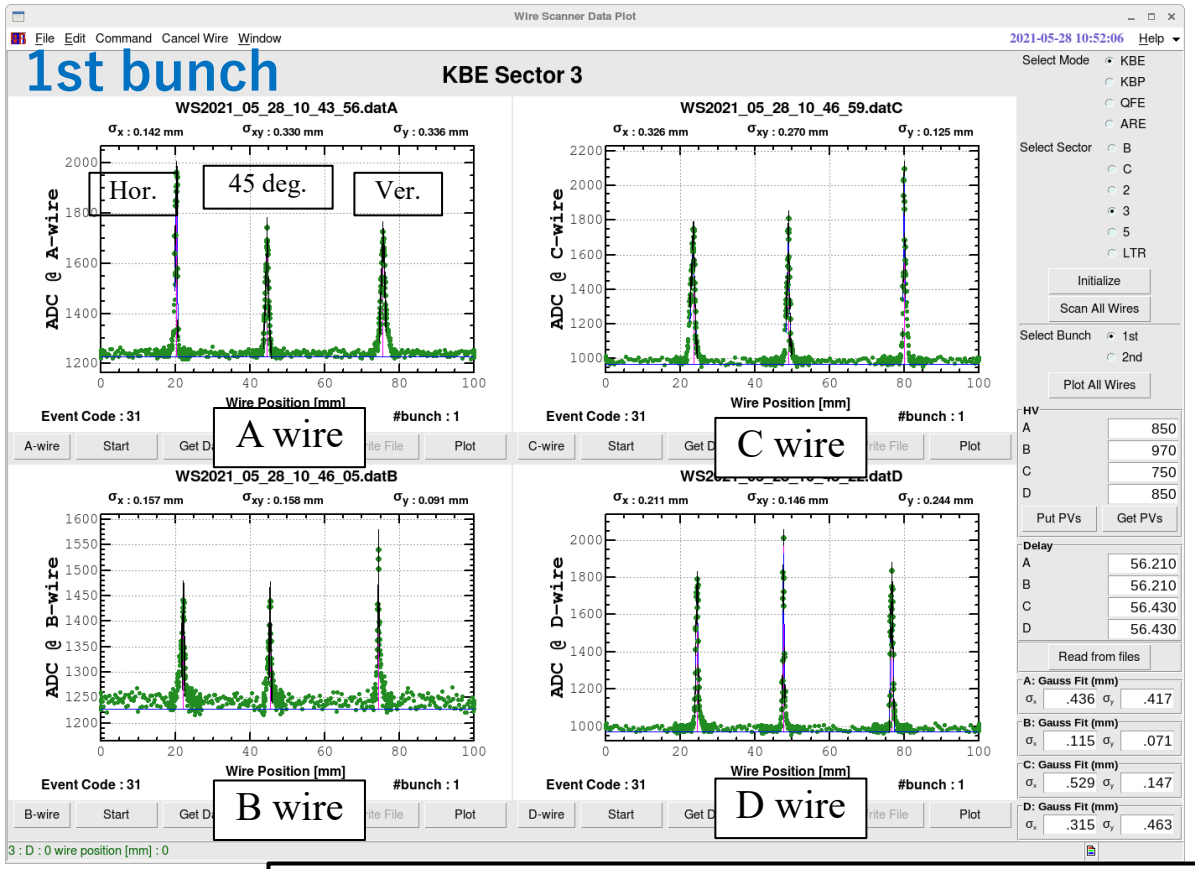


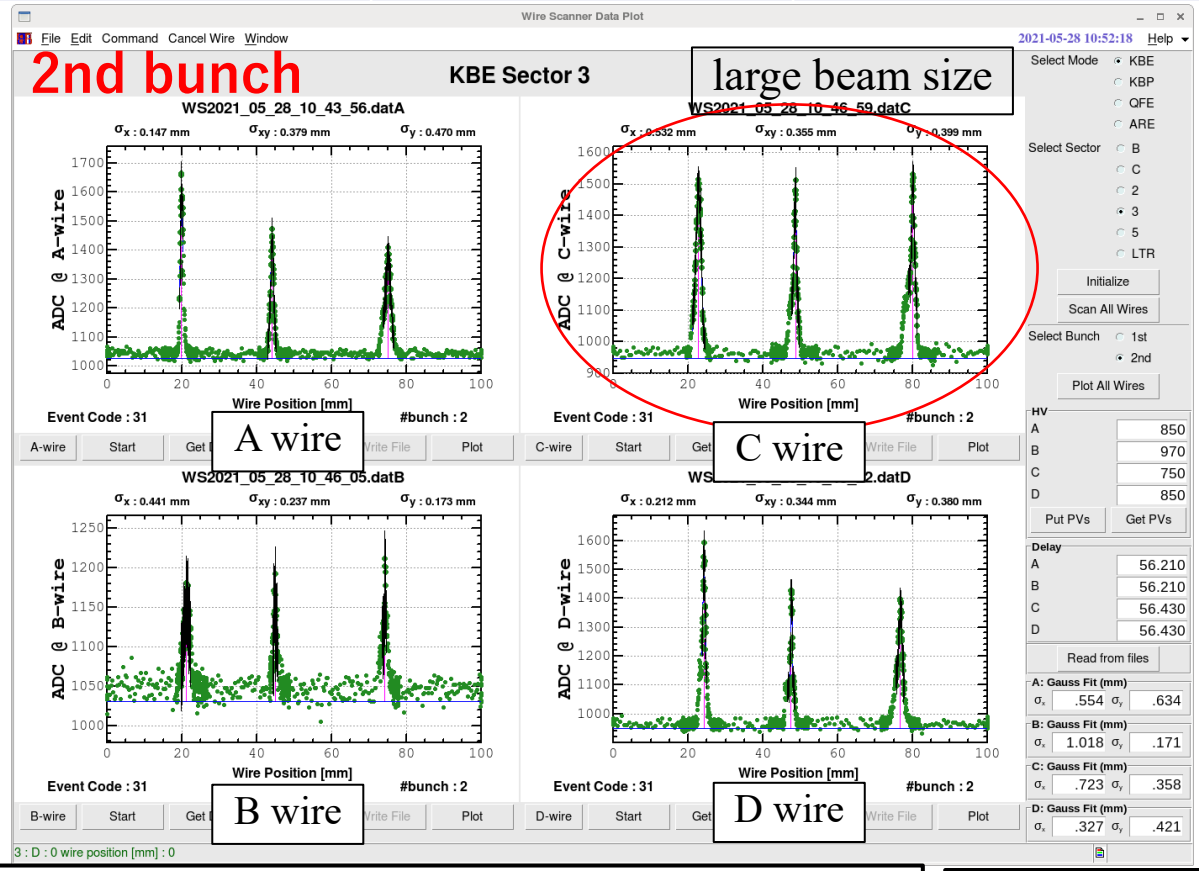
2nd bunch of e- beam: deteriorated emittance

・2nd bunch emittance of e- beam is large in comparison with one of 1st bunch. It shows the low injection efficiency.

Emittance measured at BT1

	1st bunch	2nd bunch
Horizontal: $\gamma\varepsilon_x$ [μm]	16.4 ± 2.0	45.9 ± 3.6
Vertical: $\gamma\varepsilon_y$ [μm]	9.6 ± 1.8	67.7 ± 6.5





e- beam profile measured by wire scanner at Sector3

(A, B, C, D wires mean the different wire scanner monitors (multiple wire scanner) situated in the different locations of Sector3)

M. Yoshida

e+ beam status

e+ beam status (I)

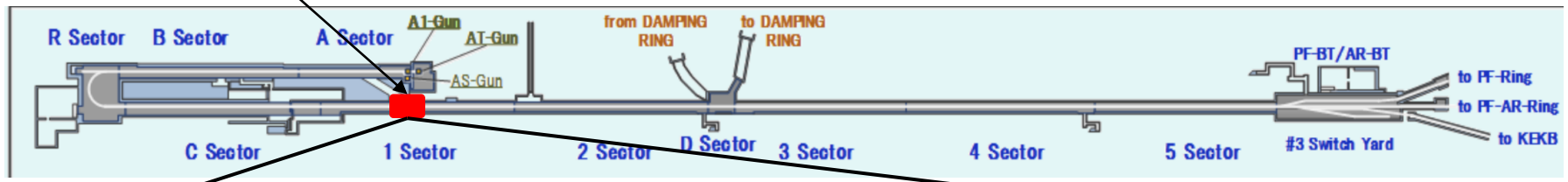
- e+ production system
  - e+ generation and capture system is situated in the middle of Sector1. The system comprises of tungsten target inside flux concentrator (FC), bridge coil, DC solenoid, 10 large aperture S-band accelerating structures. The tungsten target has a small hole with diameter of 2 mm. e- beam for HER/light source injection traverses inside the hole. [P. 23, P. 24]
  - For e+ beam generation mode, primary electron beam with bunch charge of around10 nC, energy of around 3 GeV is impinging on the tungsten target with diameter of 4 mm.
- FC
  - FC made by oxygen free cupper was damaged by large discharge in Phase2. After this discharge, it is difficult to apply the high voltage because of shortening of slit gap distance. [P. 25]
  - To improve FC head performance, Cu-alloy (NC50: Cu-Si-Ni) was adopted as FC head material. In addition, FC design was also optimized. A new FC (current version) was manufactured, tested and finally installed into beam line in summer shutdown FY2020. Since run2020c, the new FC has been successfully in operation without any significant problem. [P. 26]
  - Sometimes FC operation was interrupted for a short time since the thyratron for FC has some noise problem. Some countermeasure was already applied (modification of cabling inside thyratron, adjustment of reservoir voltage).

e+ beam status (II)

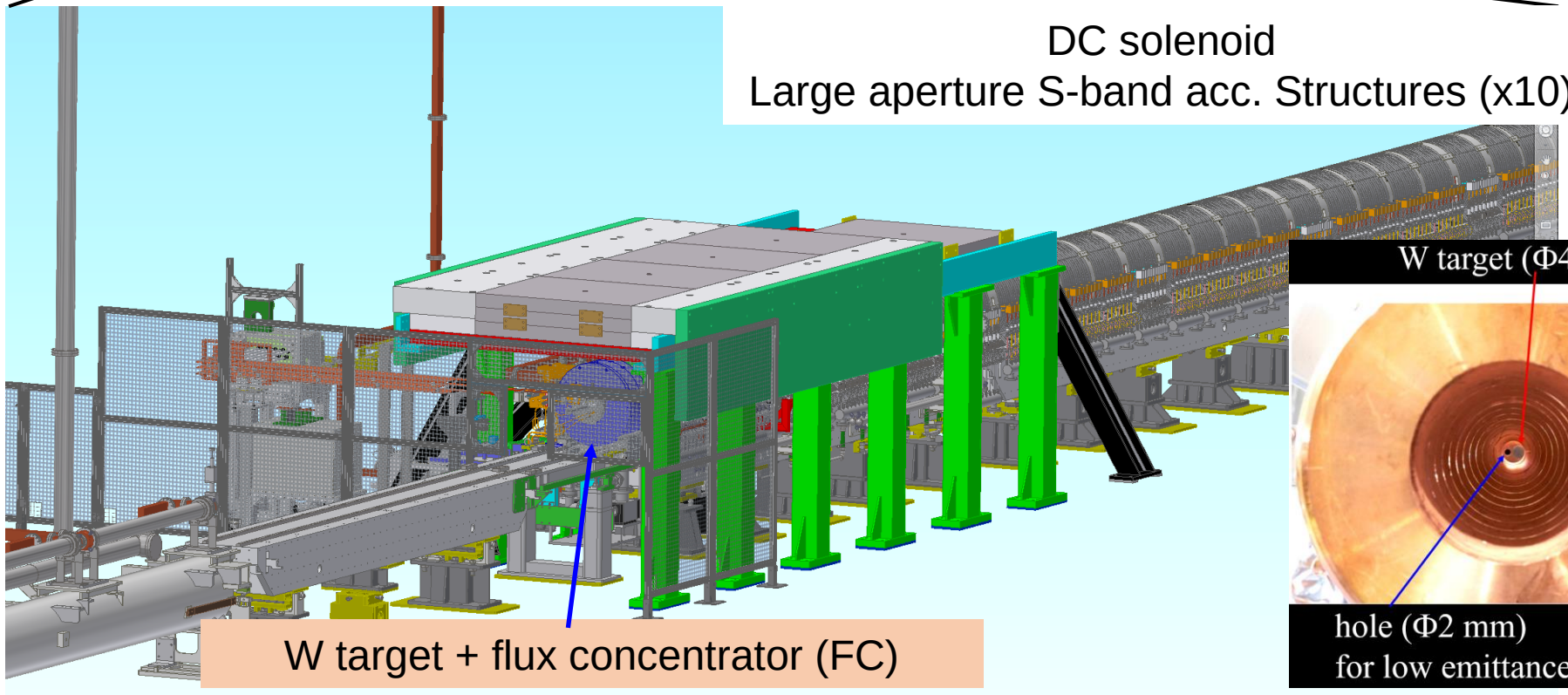
- e+ beam quality
  - Nominal e+ bunch charge has been improved from 1 nC to 2.5 nC at BT since the new FC has worked in stable trough run 2020c to 2021b. [P. 27]
  - In summer shutdown FY2020, several BPMs and steering magnets in Sector1 after e+ target. They can help to reduce the beam loss in Sector1 (after target) and Sector2. [P. 28]
  - e+ bunch charge after tungsten target already reaches 5 nC, and the best positron production efficiency is 0.59 which already beyond the design value of 0.58. In the linac machine study day (July 6th, 2021), the e+ bunch charge of 3 nC was obtained at linac end and BT (final target 4 nC). Remaining challenge is to reduce beam loss at the beam line between e+ capture section and DR injection point (Sector1, 2, and LTR). Additional pulsed steering magnets in Sector2 could be helpful for this issue. Pulsed steering in Sector1 is also helpful for this issue since the maximum output current of these power supplies will be doubled. [P. 29, P.30]
  - Best emittance already satisfies the design value at BT1 with the bunch charge of 2.3 nC (final target is 4 nC). For the emittance variation of e+ seems be stable in comparison with one of e- beam because of DR. However, horizontal emittance (larger than 100 μm) is slightly worse than expected value (65 μm). In the autumn run, low emittance optics of DR will be tested to examine the origin of large horizontal emittance. [P. 31]

Positron source setup at Sector1

Positron target and capture section



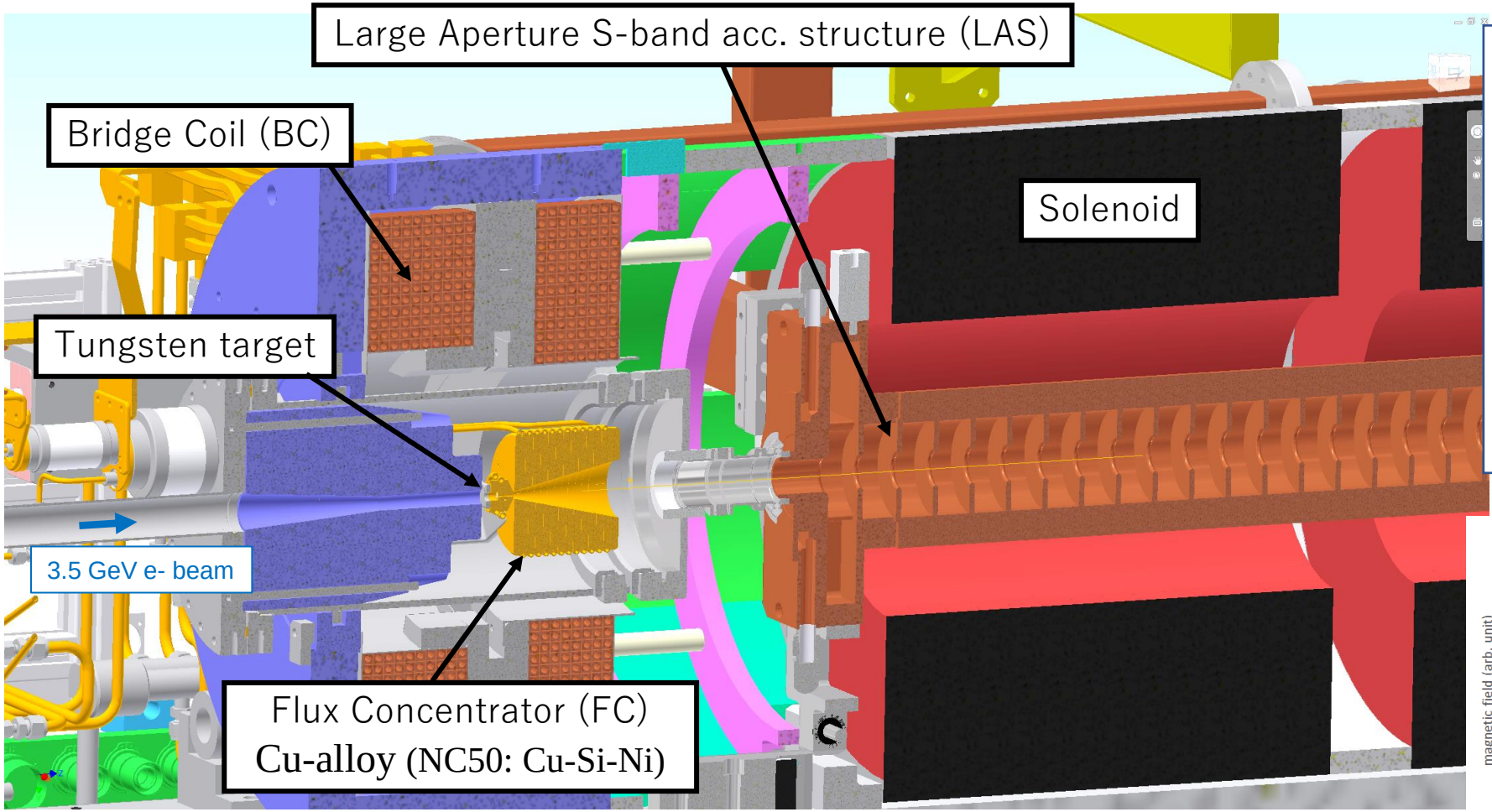
DC solenoid
Large aperture S-band acc. Structures (x10)

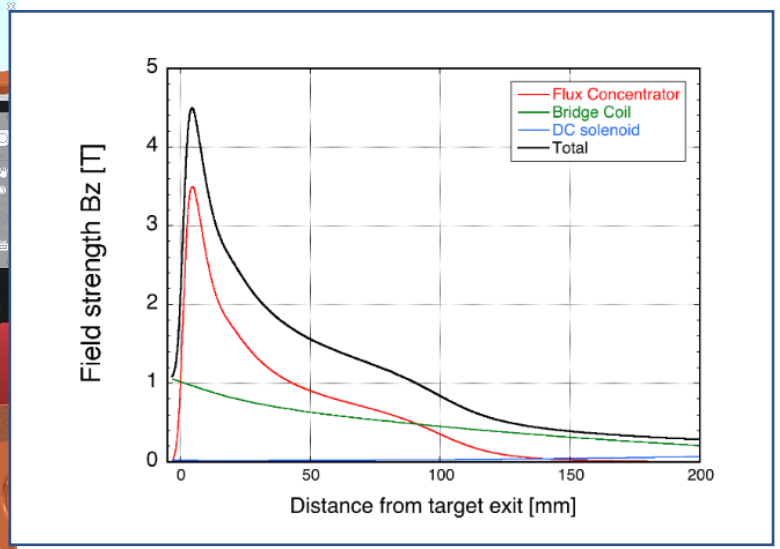


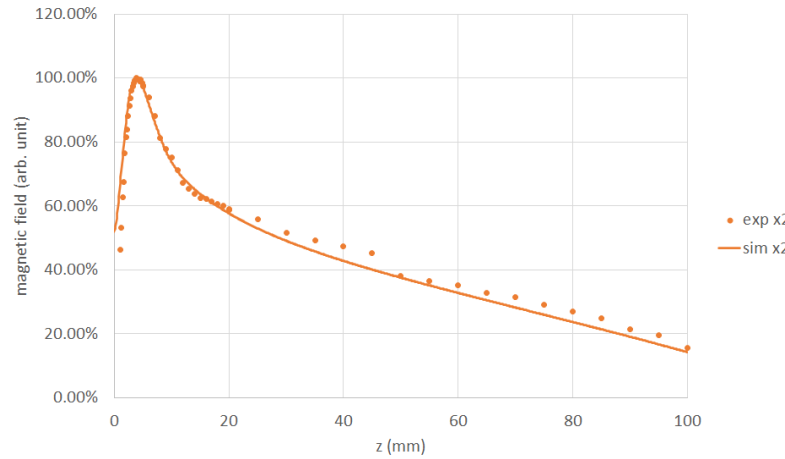
W target + flux concentrator (FC)

Y. Enomoto et al.

Positron Capture Section: Flux concentrator, bridge coil, solenoid







I_{FC}= 12 kA

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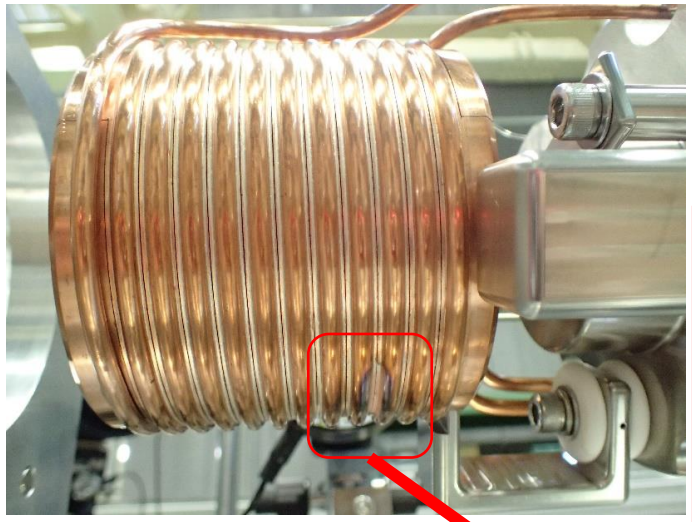
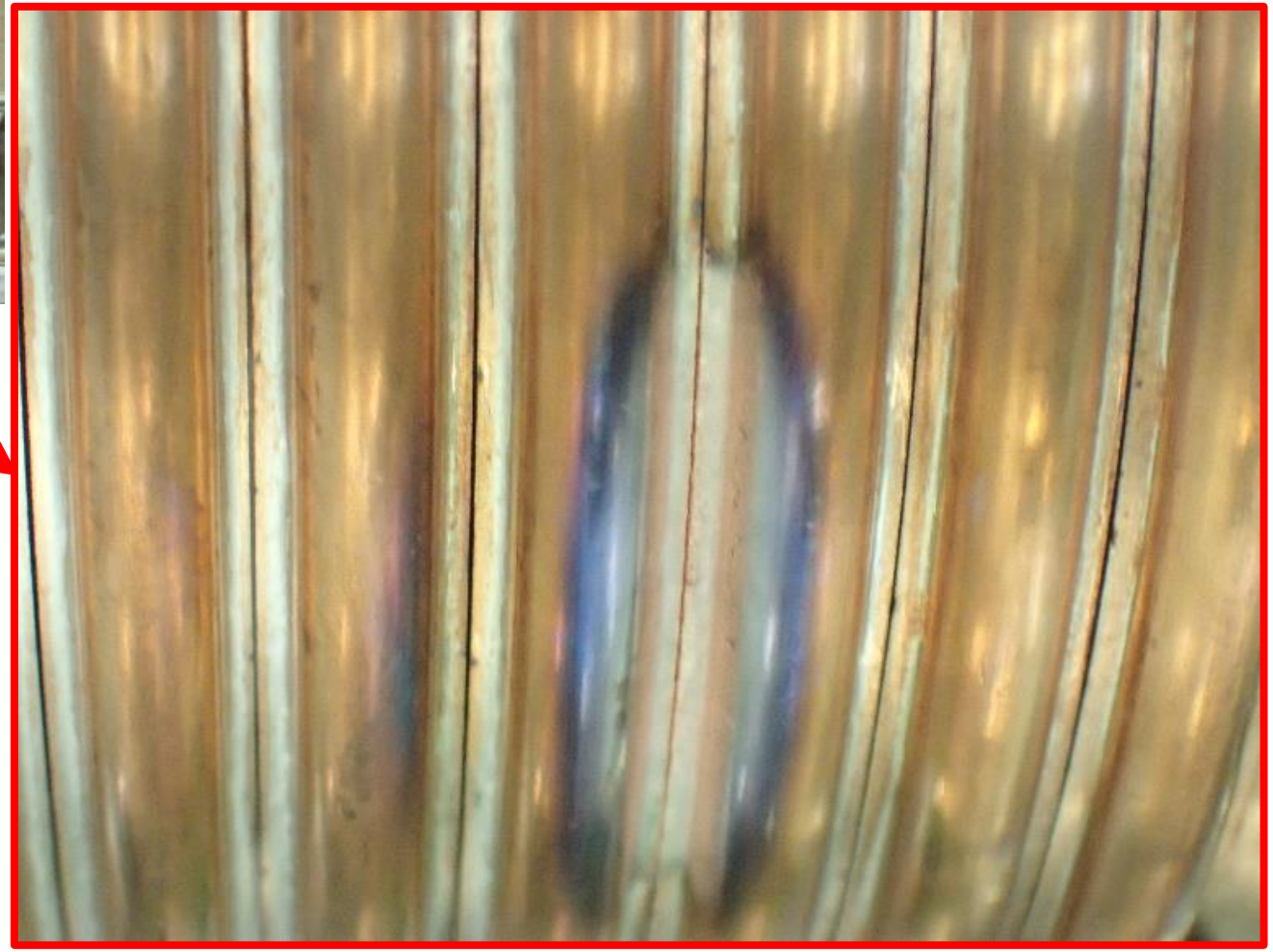
After large discharge…



After large discharge



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

Y. Enomoto
SuperKEKB review, 2019

FC assembly, base summary

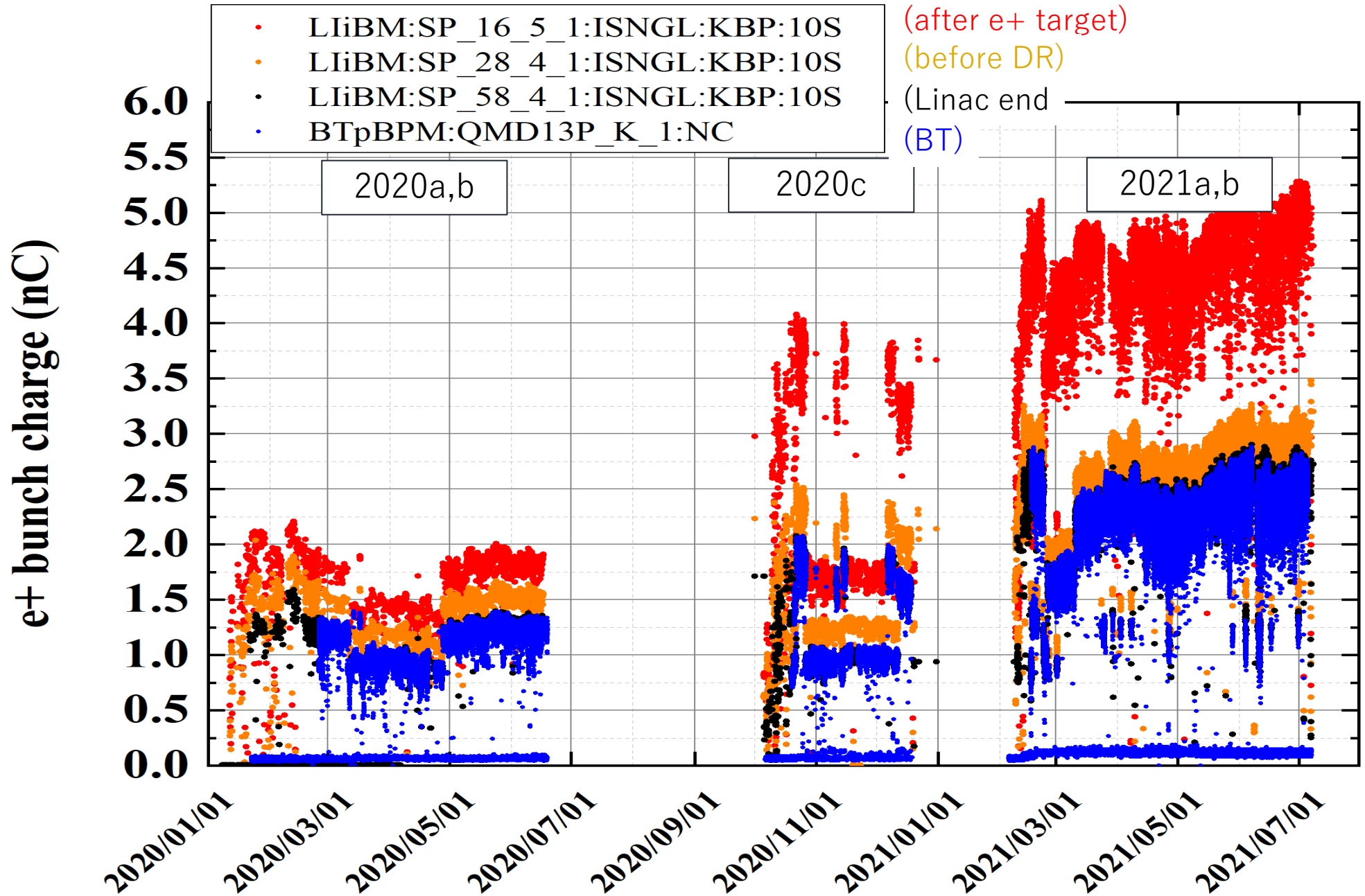
	Phase 1	Phase 2	Phase 3	2019 autumn	2020 spring	2020 autumn	2021 winter～	delivery	removal	Present status (2020/6)	remark
Assembly 1								Before 2015	2017/3	Tunnel	
Assembly 2								2016/3		Beam line	
Assembly 3								2017/11		Test bench	
FC base 1								before 2015			Trial product
FC base 2								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

e+ bunch charge history (2020a to 2021b)



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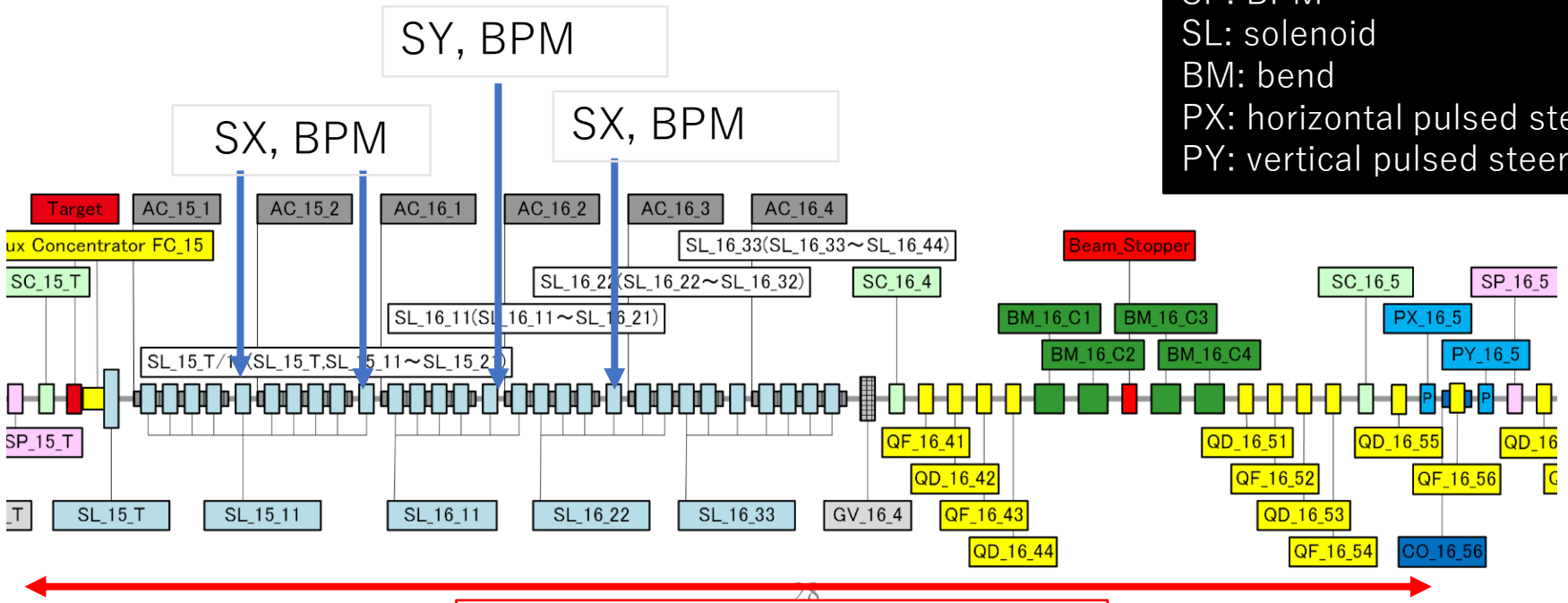
Steering magnet and BPM in solenoid section

- 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



Positron yield

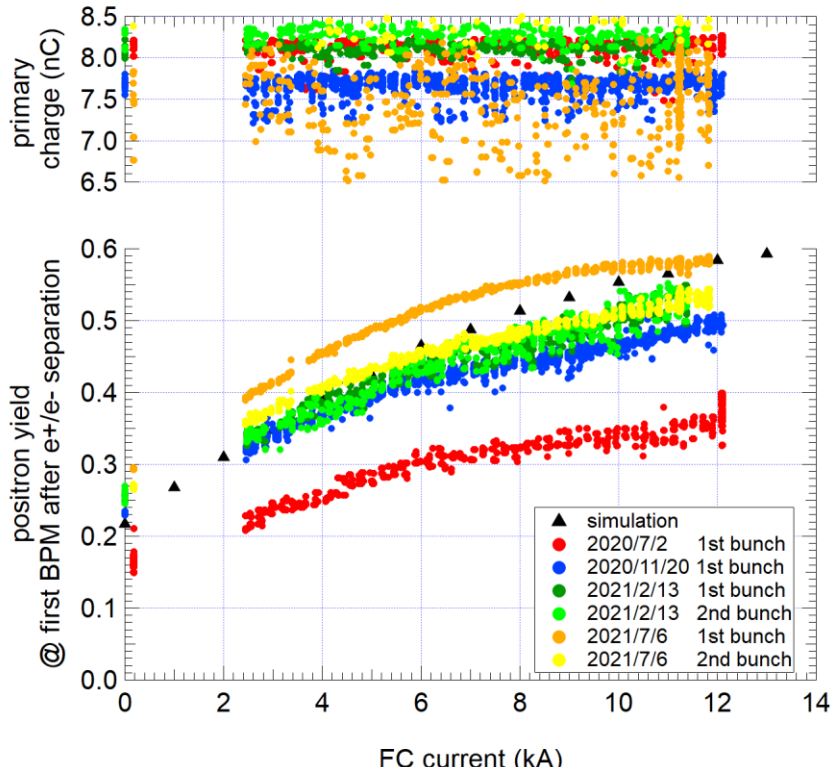
emittance

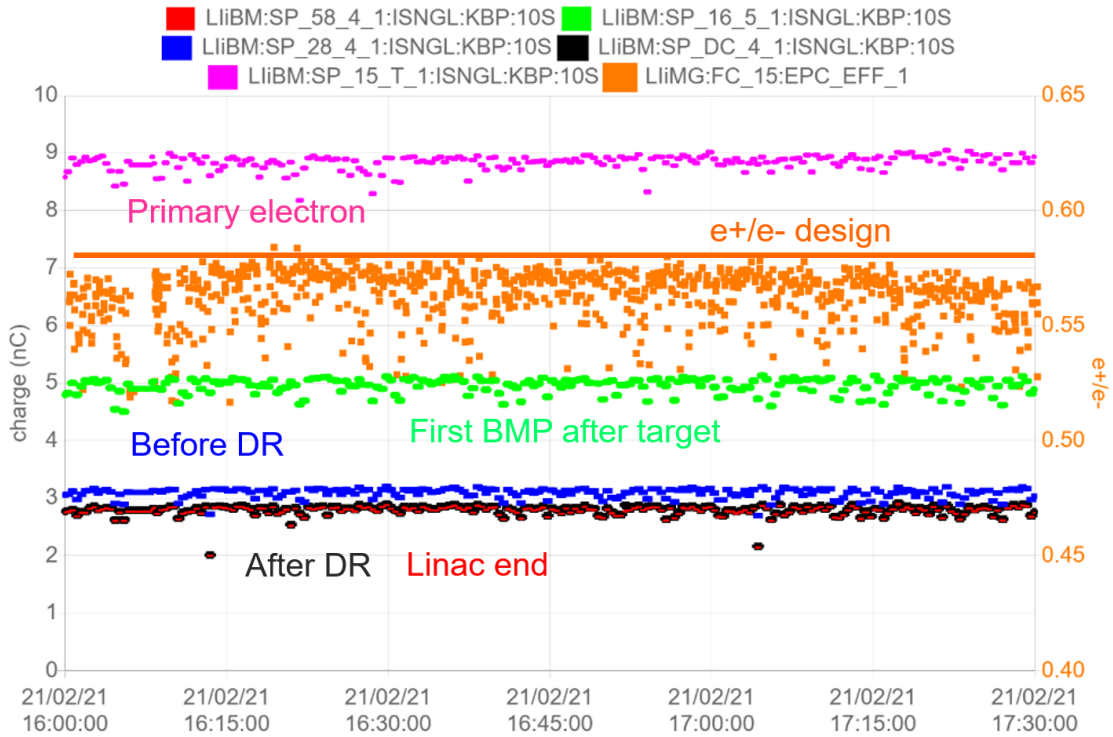
$\varepsilon_{nx,nxy}$ (2.3 nC)
～99.7/3.2 μm (BT)

Results of measurement			
β_x @MWP.1 [m] :	9.504	β_y @MWP.1 [m] :	20.183
α_x @MWP.1 :	-.251	α_y @MWP.1 :	1.737
ε_x [m] :	1.3258E-8	ε_y [m] :	4.193E-10
$\Delta\varepsilon_x$ [m] :	3.5336E-9	$\Delta\varepsilon_y$ [m] :	1.498E-10
$\gamma\varepsilon_x$ [μm] :	99.667	$\gamma\varepsilon_y$ [μm] :	3.152
$\Delta\gamma\varepsilon_x$ [μm] :	26.563	$\Delta\gamma\varepsilon_y$ [μm] :	1.126
Goodness x :	.827	Goodness y :	.982
Bmag x :	1.089	Bmag y :	1.458
ε Bmag x :	1.4436E-8	ε Bmag y :	6.112E-10
γε Bmag x :	108.522	γε Bmag y :	4.594

Goal: $\varepsilon_{nx,nxy}$ (4 nC)
～100/15 (H/V) μm)

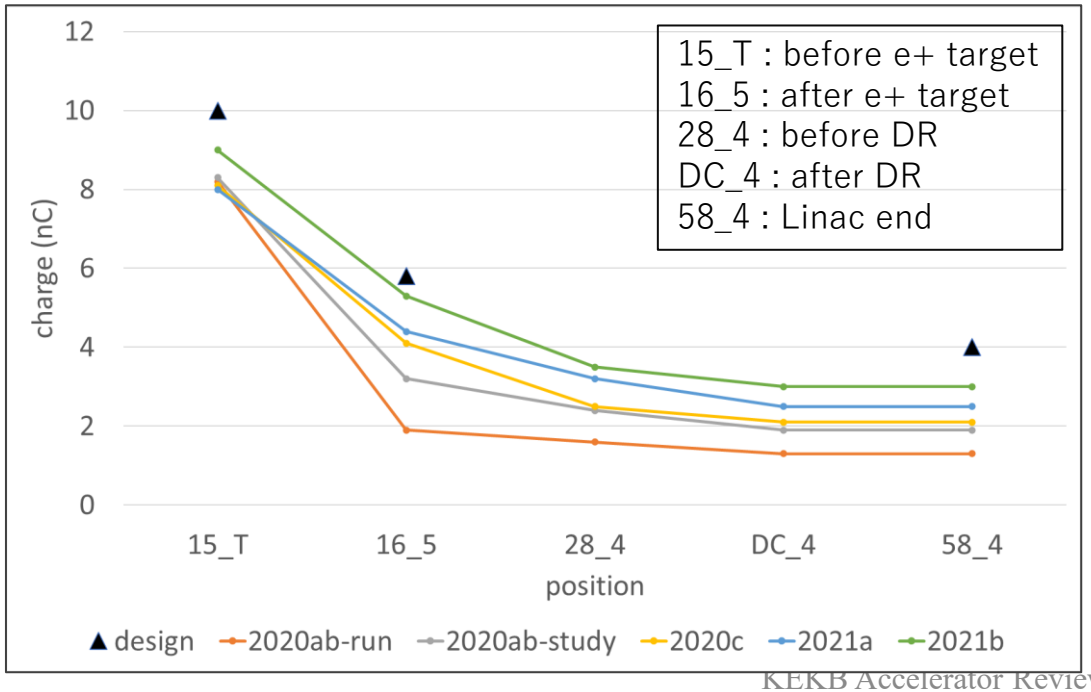
- 5 nC at BPM<SP_16_5> (1st BPM after e+ target)
- ～ 3 nC LTR (Linac To damping Ring) and downstream
- For obtaining 4 nC at BT:
  - Some more steering/Q magnets will be installed after target in 2021 (this summer).
  - Increase gradient: 7.3 MV/m to 14.0 MV/m (design) for two structures (AC_15_1[2] situated at downstream e+ target)
  - Increase FC field and DC solenoid field. (power supply should be improved)





Recent e+ yield history (run 2020a ~ 2021b)

	design	2020ab (operation)	2020ab(study)	2020c (operation)	2021a (operation)	2021b (study)
		2020/7/1	2020/7/2	2020/10/12	2021/2/12	**2021/7/6**
Energy (e-)*	3.46 GeV	3.01 GeV	3.01 GeV	2.87 GeV	2.89 GeV	**2.92 GeV**
Bunch charge (e-)	10 nC	8.2 nC	8.3 nC	8.1 nC	8 nC	**9.0 nC**
e+/e- @ SP_16_5	0.58	0.23	0.38	0.51	0.55	**0.59**
e+ @ SP_16_5	5.8 nC	1.9 nC	3.2 nC	4.1 nC	4.4 nC	**5.3 nC**
e+ @ SP_28_4	-	1.6 nC	2.4 nC	2.5 nC	3.2 nC	**3.5 nC**
e+ @ SP_DC_4	-	1.3 nC	1.9 nC	2.1 nC	2.5 nC	**3.0 nC**
e+ @ SP_58_4	4 nC	1.3 nC	1.9 nC	2.1 nC	2.5 nC	**3.0 nC**
e+ @ QMF8P_K**	4 nC				2.77 nC	**2.95 nC**

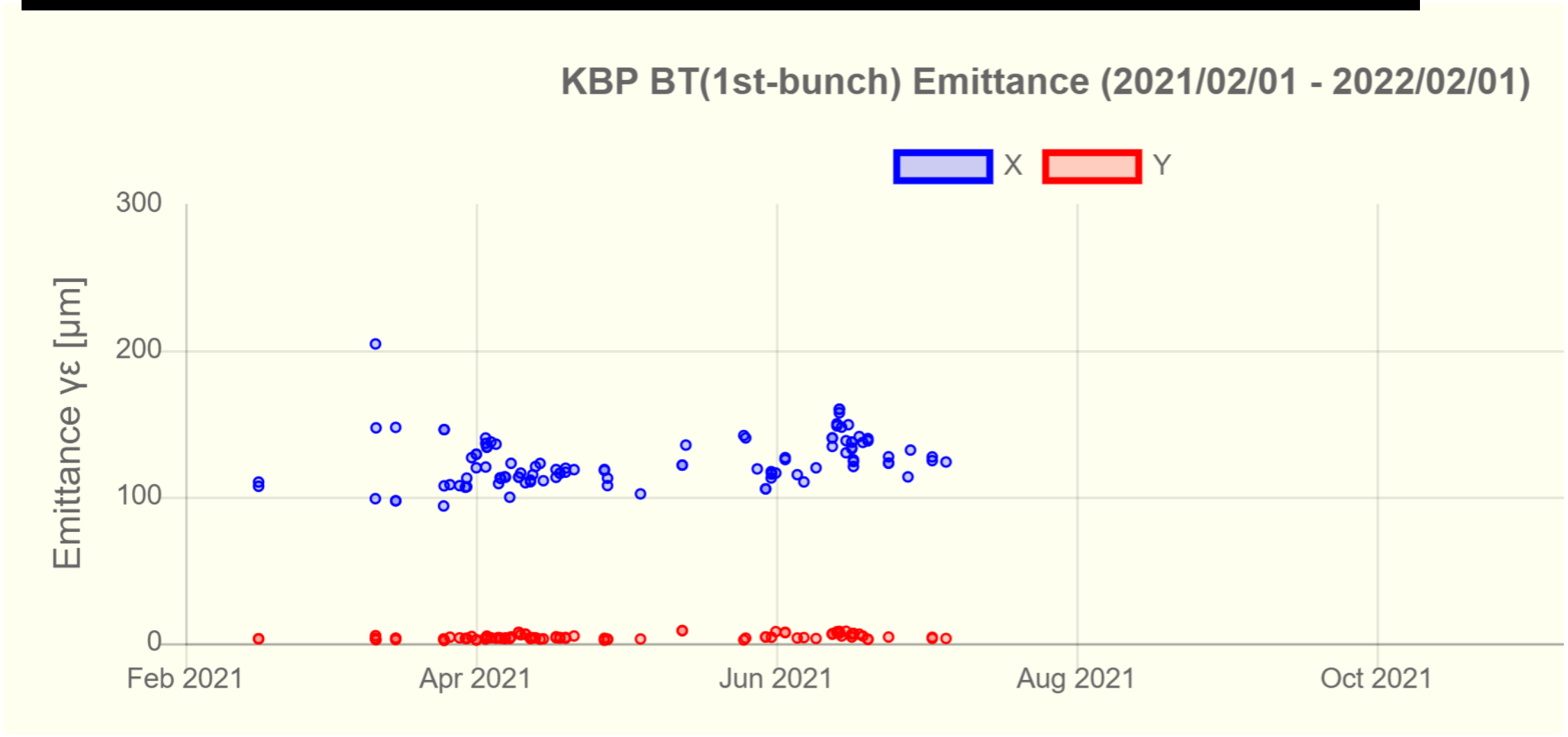


*LIiOP:AC_13_4:GAINSUM:KBP
**BTpBPM:QMF8P_K_1:NC_1Hz × CGpBPM:QMF8P_K:FQ (0.475575)

Y. Enomoto, LCG (2021/7/6)

e+ emittance history in run 2021a, b at BT1

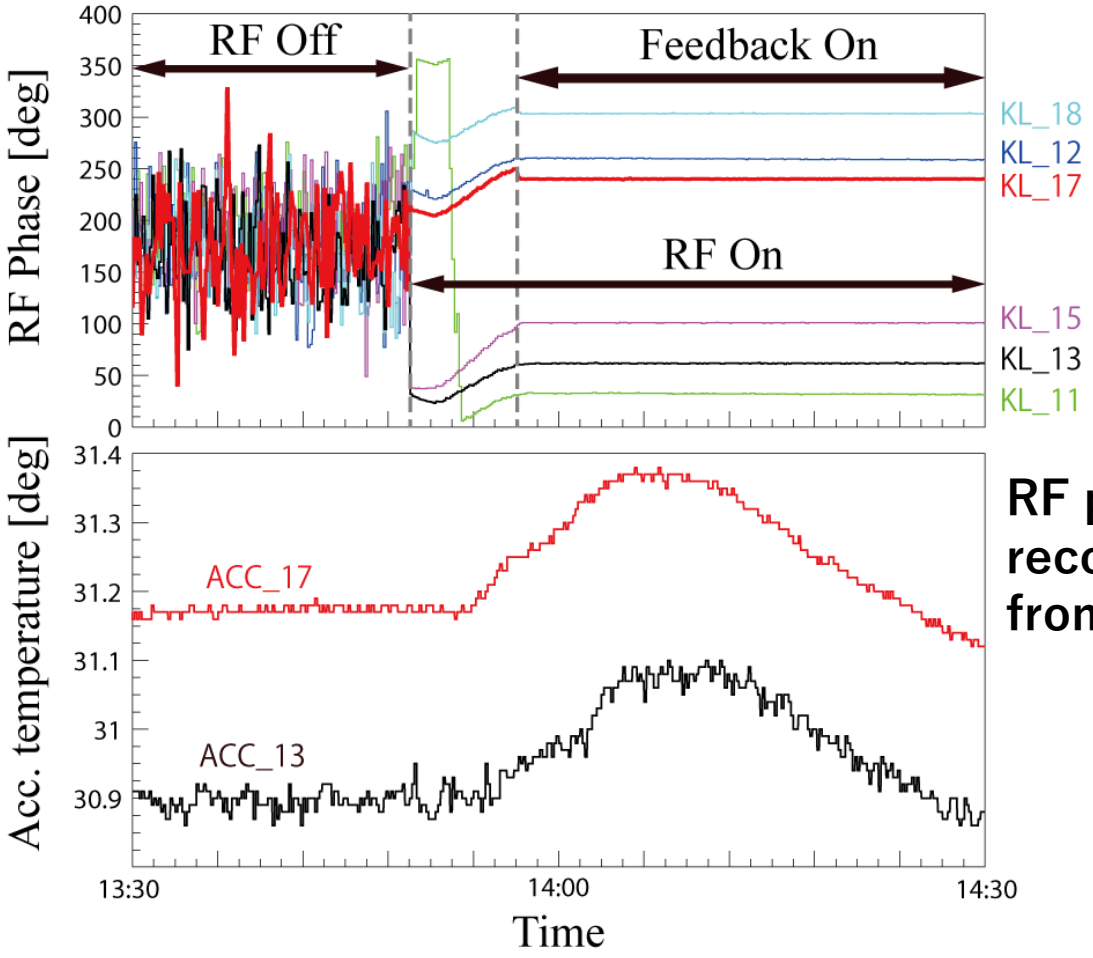
- DR is effective for obtaining the stable low emittance positron beam.
- Machine study of low emittance DR optics is planned in this autumn.



Other subsystems

RF phase feedback

Subsystem



Variation of rf phase and cooling water temperature (accelerating structure)

RF phase feedback can quicky recover the beam operation mode from maintenance mode.

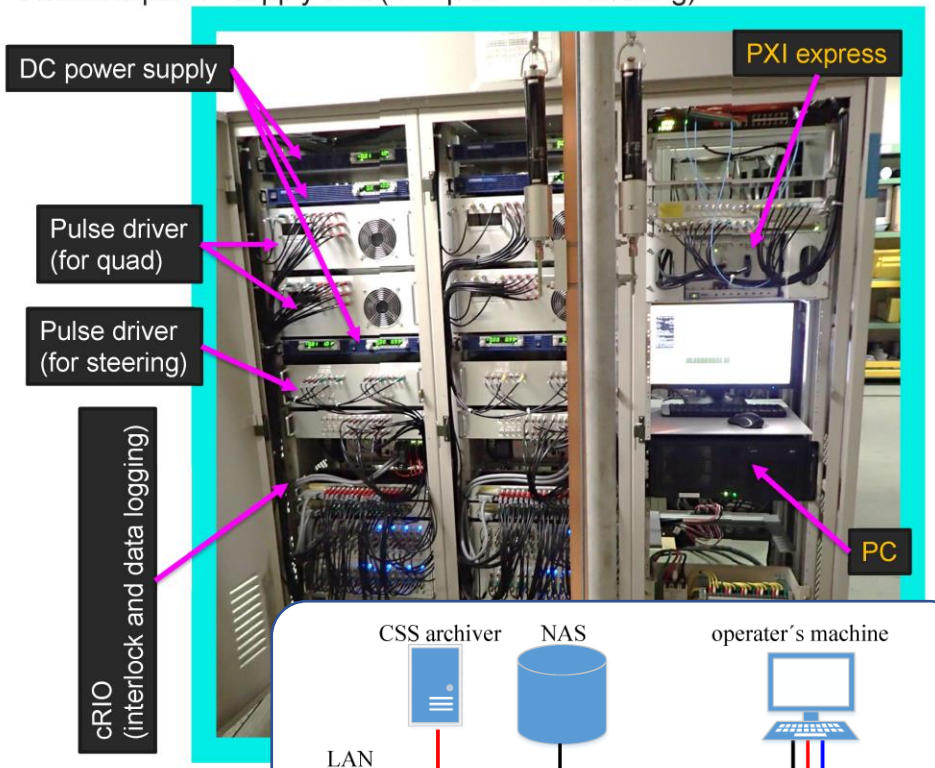
RF phase feedback:
already deployed to many locations

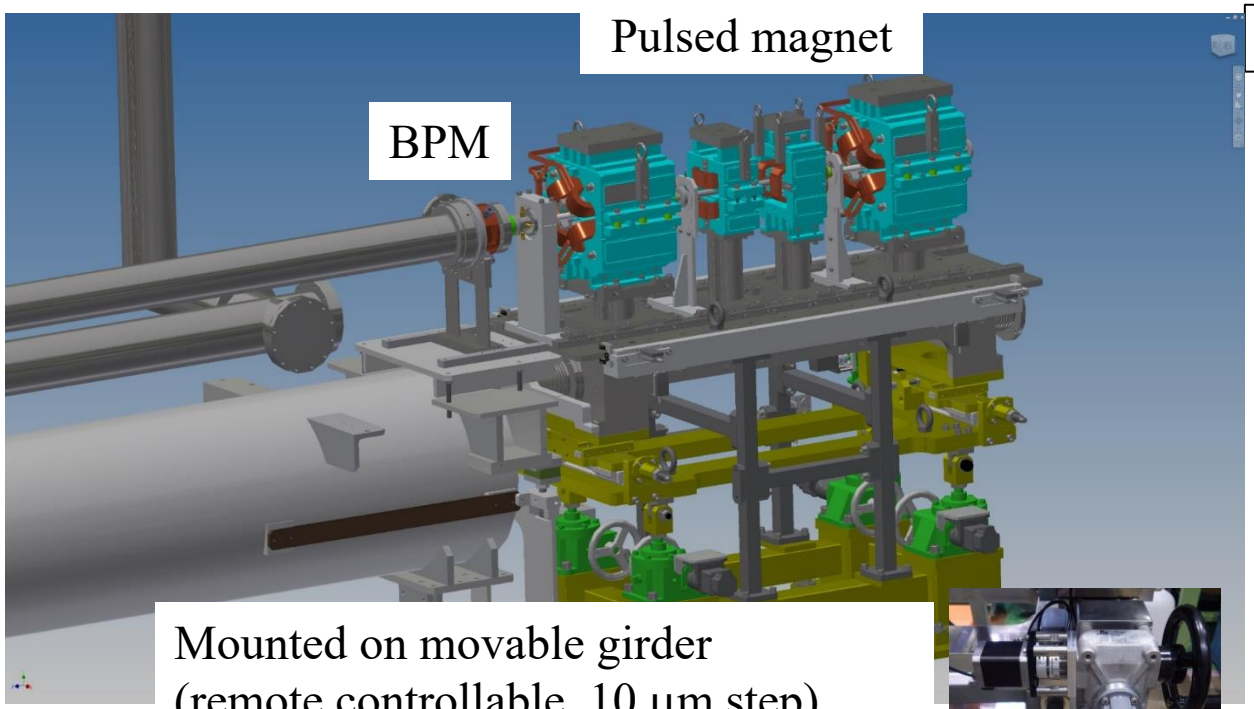
T. Miura

Pulsed magnet

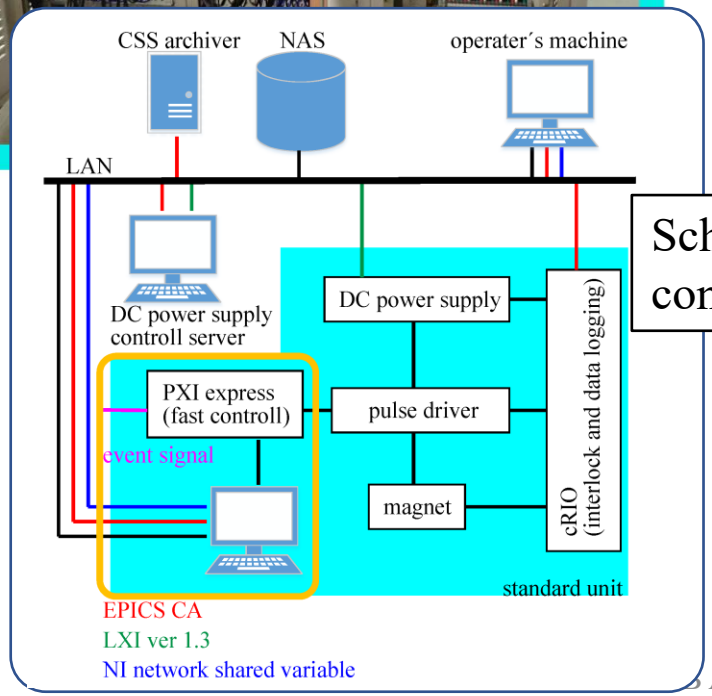
Subsystem

Standard power supply unit (4 x quad + 4 x steering)





Mounted on movable girder
(remote controllable, 10 μm step)



Schematic diagram of control system

High stability of PS output

	Design	Measured
Quad	0.1%	< ~0.006%
Steering	0.01%	< ~0.003%

Future plan

- Fast steering magnet is under development (kick only the 1st bunch or only the 2nd bunch for reducing the orbit difference between 1st and 2nd bunch).
- This work is in progress as collaboration between PF and injector linac.

Y. Enomoto

Pulsed steering magnet PS upgrade

	～ run 2021b	New (FY'21 summer)
Voltage	±50 V	±100V
Current	±10 A	±20 A　(5A x4)
Voltage drop in PS	20 V*	1 V**
Output voltage	±20 V	±90 V
Inductance	3 mH	12 mH (7.5 mH for PX_A4_4)
Amp	PA12	PA04
# of production	35 (70 ch)	19 (38 ch) + 2ch
Installation location Black：in operation Red：new Blue：replacement	**SectorA** PX/PY_AT_22, PX/PY_A1_M PX/PY_A2_1, **Sector1, 2** PX/PY_16_5, PX/PY_17_2 PX/PY_18_2, PX/PY_21_2 PX/PY_22_4, **SectorD, 1-5** PX/PY_DC_2 ～ PX/PY_58_4 (26 ch) **Total: 42 ch**	**SectorA** PX/PY_A4_4 PX/PY_C7_4, **SectorJ-ARC** PX/PY_R0_01, PX/PY_R0_02, PX/PY_R0_61, PX/PY_R0_63 **Sector1, 2** PY_12_2, PX_13_2, PX/PY_13_5, PX/PY_13_52, PX/PY_17_4, PX/PY_18_4, PX/PY_21_4, PX/PY_24_4 PX_23_4, PY_24_1, PX_26_1, PY_26_4, PX_27_2, PY_28_2 **Total: 32 ch**

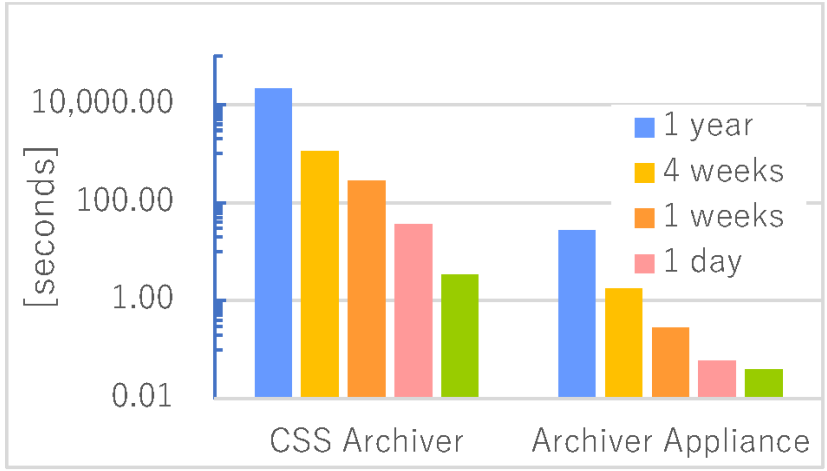
Data archiving

- **Archiver appliance**

Linac archiver: ~ 110,000 data

In addition CSS archiver,
2019/11～ Archiver Appliance in operation

- Data retrieving speed performance x800
- Easy management
- Load balance with clustering technology



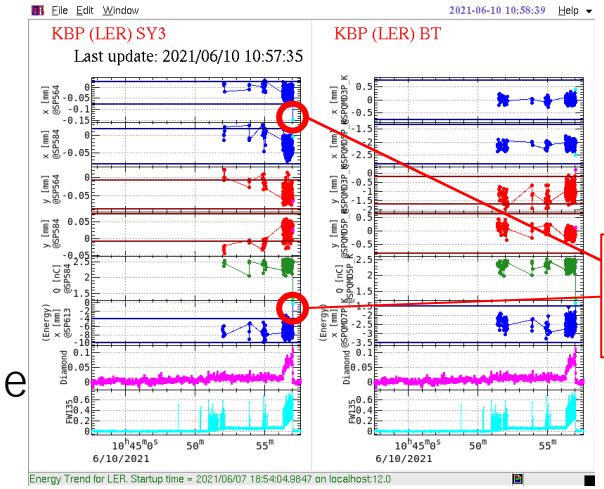
Data retrieving speed performance between CSS archiver and archiver appliance

- **Synchronized measurement (BPM, RF, pulsed magnet)**

All data are stored （ASCII → gzip）

- Postmortem analysis of event related to MR abort
  - Abnormal beam orbit
  - Abnormal rf phase/amplitude
  - Abnormal pulsed magnet current
- Binarization of data with HDF5 format in progress

F. Miyahara



Beam orbit display
(HER/LER Abort event)

I. Satake

Issue

Archiving data:
・mutual easy access and usage of linac/ring data

Synchronization of linac and ring data:
・Development of easy analysis tool
・Automation of data processing

Upgrade work
during FY2021 summer shutdown

Upgrade work during summer shutdown FY2021 (1)

Upgrade

- RF gun/laser system
  - 1st line laser: recovery of laser power (replacement of 2nd amplification)
  - 2nd line laser: increase laser power, DOE installation
  - Photocathode and laser window replacement
  - Backup rf gun line (AS line): New cavity will be tested.
- RF work
  - Sub-booster klystron
    - Sub booster of Sector2 was replaced by 600 W amplifier.
  - Firmware of all control units will be replaced for noise proof
- Accelerating structure
  - AC_44 waveguide replacement
  - AC_55, 61 waveguide examination

Upgrade work during summer shutdown FY2021 (2)

- Magnet
  - Pulsed magnet
    - New pulsed steering: PX[Y]_A4_4, PX[Y]_C7_4, PX_23_4, PY_24_1, PX_26_1
    - Pulsed steering power supply upgrade: x21 in Sector J-ARC, Sector1, and Sector2
    - Quad: high precision DCCT
  - DC magnet
    - New Quad will be installed (QF_61_3) for the dispersion correction of ECS.
    - New steering magnet PS (in-house development) in Sector1-2, and Sector6

- Control system
  - New server computers will be in operation.
  - Control network update (core switch, part of edge switches)
    - 1 Gbps to 10 Gbps connection
  - Event generator operation sequence length is changed from 16/18 to 8/9 (improve the proofness of TEPCO 50 Hz interval variation)

Summary

- Simultaneous top up injection operation of 4 storage rings (SuperKEKB HER/LER, PF, PF-AR) has been successfully conducted.
- Synchronized pulse-to-pulse monitoring system (BPM, rf phase/amplitude, pulsed magnet power supply) and analysis tool work fine, and is helpful for the postmortem analysis of beam abort event.
- e- beam
  - Laser system works fine without any significant trouble.
  - Bunch charge of 2 nC was ready at the beginning of run 2021a. However, bunch charge was decreased to around 1.5 nC after discharge in the end of March since the cavity power and rf pulse width were decreased to avoid the discharge.
  - 2nd line laser power will be upgraded, and DOE will be installed for 2nd line in this summer.
  - 2 bunch injection is key challenge in the autumn run. Careful rf conditioning will be carried out for expanding the rf pulse width. It could help to improve the 2nd bunch emittance.
- e+ beam
  - The new FC is working fine .
  - Reached bunch charge of 3 nC at BT end.
- Issues
  - Emittance reproducibility of e- beam is not stable. Additional orbit feedback by using new pulsed steering magnets could be helpful.
  - Emittance growth at BT#2 is also issue.
  - Deteriorated subsystem replacement is also issues for the future operation. (damaged acc. Structures, old magnet power supply and controller, and so on)