Beam injection issues in 2022ab

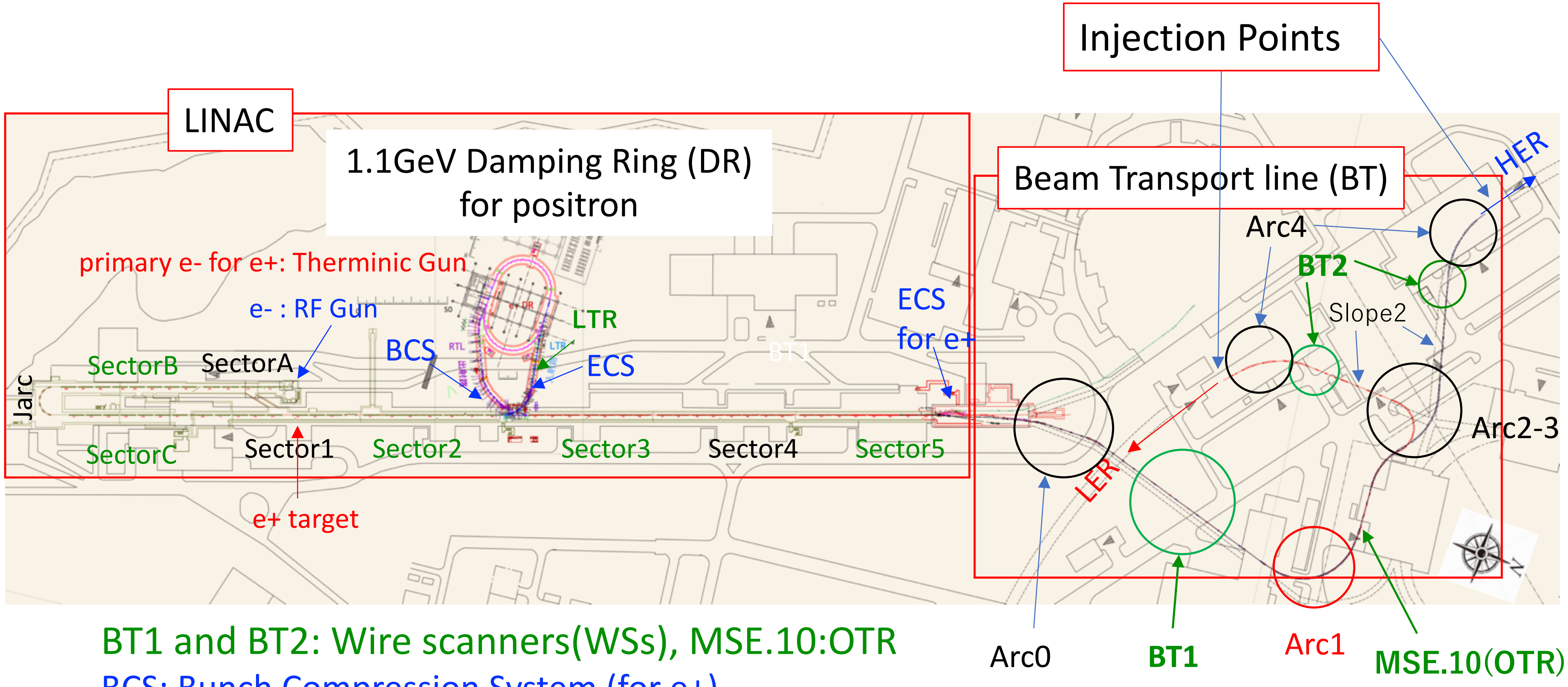
2022.Feb.21-Jun.22

2022.Dec.13
SuperKEKB Review Committee
N. Iida
on behalf of LINAC beam analysis Group
and Beam injection Task force

Layout of LINAC, BT, Injection to MR

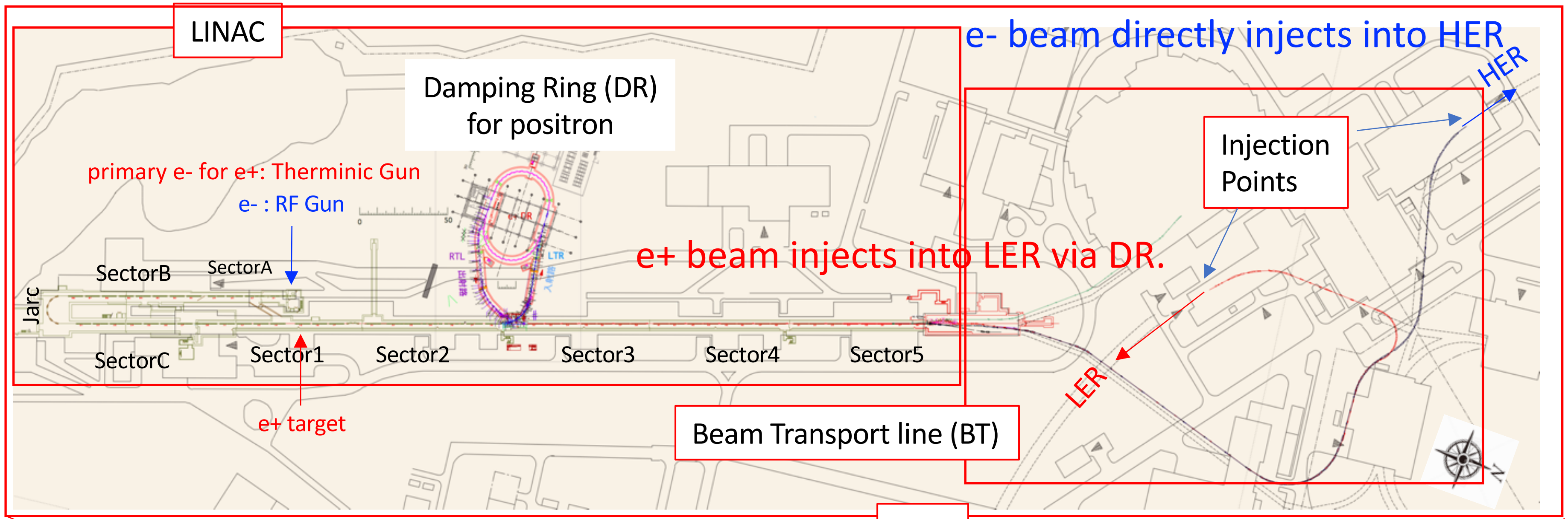
e+ beam is injected into the LER via DR:
The injection BG is not almost affected by the beam condition at upstream of the DR.

e- beam directly injects into HER:
The injeciton BG is directly affected by the condition of RF-gun, LINAC, and BT.



BT1 and BT2: Wire scanners(WSs), MSE.10:OTR
BCS: Bunch Compression System (for e+)
ECS: Energy Compression System (for e+)

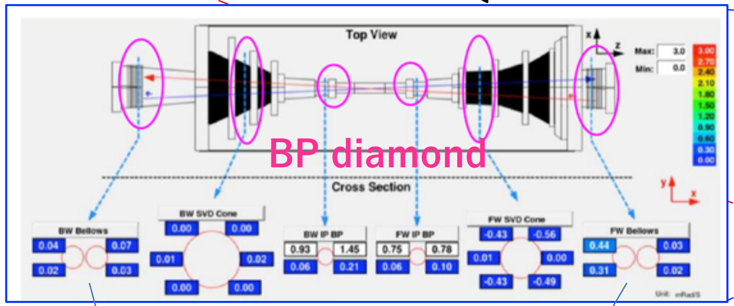
Layout of LINAC, BT, Background(BG) monitors in MR

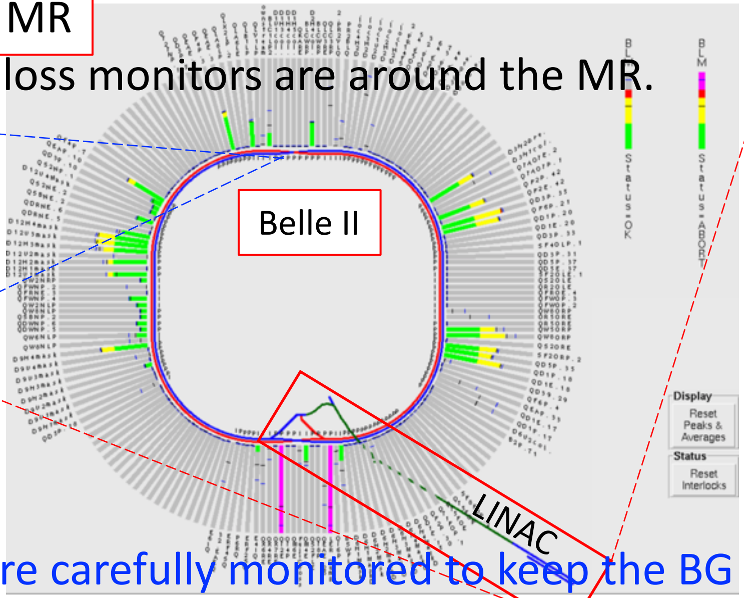


MR

Many loss monitors are around the MR.

Diamond detectors at QCS in Phase3





HER:
QCS(Diamond) BW135

LER:
QCS(Diamond) FW135

Most sensitive to the Background (BG) on Belle2.

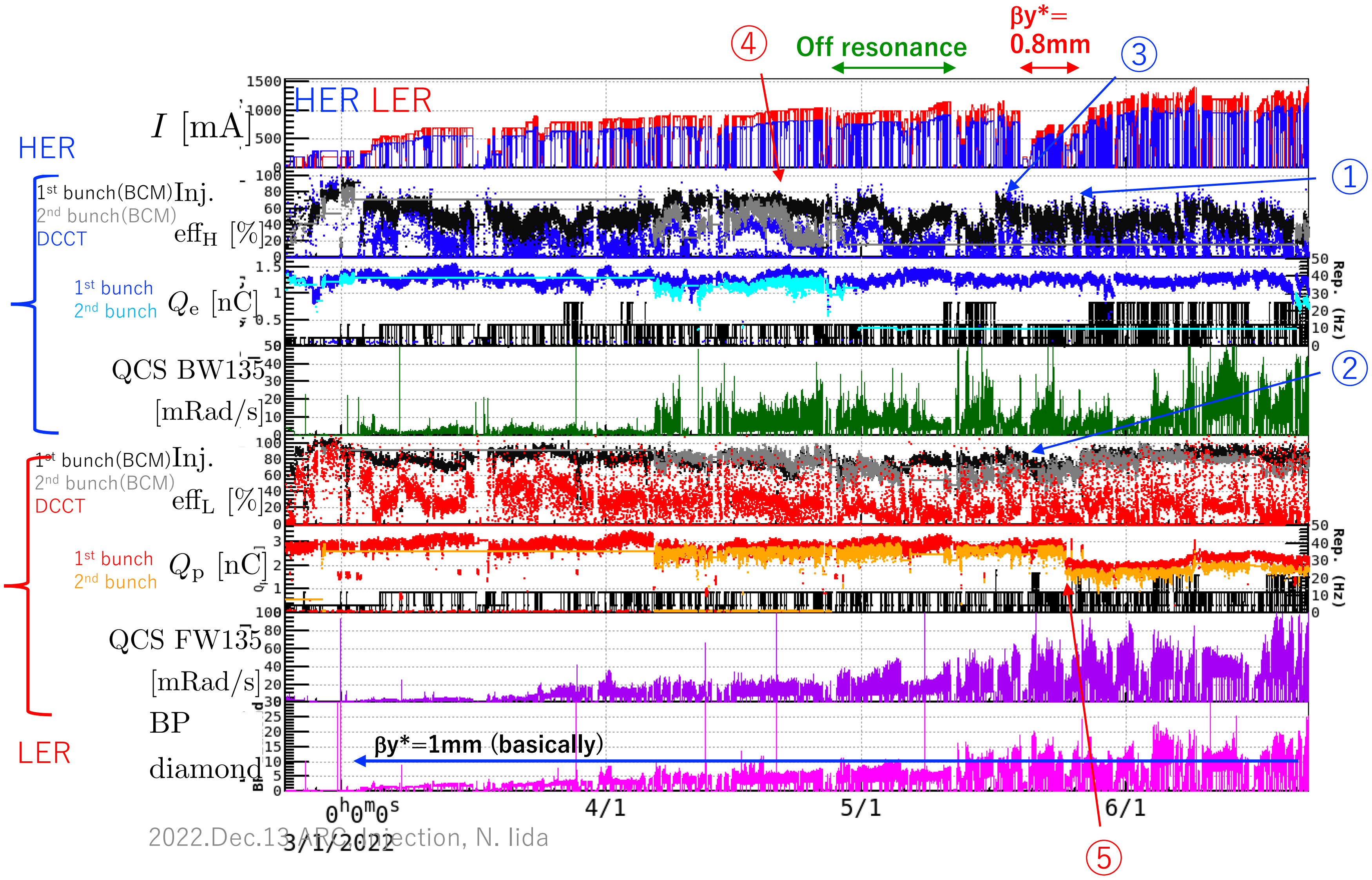
The signals from the Diamonds and the loss monitors are carefully monitored to keep the BG low.

Some aborts are avoided by stopping injection when the signals are high.

Contents

I. Injection summary of 2022ab

- e- beam needs a tuning around RF gun every a few days.
- e+ beam is rather stable thanks to the DR.



The injection efficiency depends on;

- the quality of injection beam
- injection parameters such as septum angle, vertical angle,⋯
- status of the SuperKEKB ring
- ⋯

Improvements

① e-: The septa have been operating at 25Hz.

② e+:The fast strip line kicker has been used to correct the horizontal orbit for the 2nd bunch

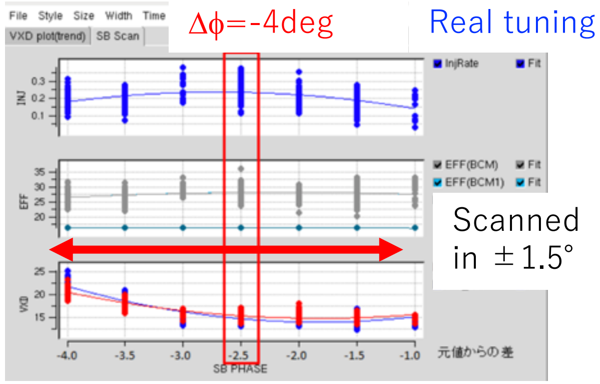
③ HER: The injection was improved by the current-dependent correction of the horizontal orbit at SLYTE* in HER. Now the orbit feedback systems are working well.

To be improved

④ e-: Since the injection efficiency of the 2nd bunch decreased due to the drift of the vertical orbit and the higher emittances of the second bunch, the two-bunch injection was temporarily given up.

⑤ e+ charge was decreased to avoid the BP diamond aborts.

Improvements of injections



1. <u>Injection tuning</u>
   - The RF phase in LINAC(SB_3-5) tunings are effective to injection efficiencies and beam backgrounds.
   - Flourecent screen monitors were replaced with OTR monitors in BT line (See talk on “BT” for detail)
     - Especially, MSE.12 is always used to check the energy spread.
     - It is expected that the measured energy spread will be quantified.
   - An SRM in BT line since the BT dump mode operation in 2022.Oct (See talk on “BT” for detail)
     - It is effective for monitoring beam size, emittances non-destructively.
     - It is expected that the measured beam size will be quantified.
   - Injection tuning by septum with 25Hz continuous operation① (See talk on “BT” for detail)
     - The angle (and position) of the septum no longer needs to be adjusted as often as before.
     - The four septum outputs depend on the temperatures of the output cables or/and the power supplies.
   - Collimator tuning in the MR is one of items for the injection tuning. (See talk on “Belle II” for detail)
2. The horizontal orbit FB at SLYTE* in HER ③ (See talk on “Optics issues” for detail)
   - It was very effective in preventing decrease in injection efficiency which is not attributed injection conditions.
3. The fast strip line kicker in RTL has been used to correct the horizontal orbit of the 2nd bunch ② (See talk on “BT” for detail)

Injection issue

1. **Emittance growth in BT line**
   - e+ BT: The charge dependence of the horizontal emittance is observed.
   - e- BT: CSR (Coherent Synchrotron Radiation) effect has been studied as a cause other than ISR (Incoherent Synchrotron Radiation) The horizontal emittance growth was observed to depends on;
     - A) The RF phases, sub-boosters in sector 3, 4, and 5 in LINAC
     - B) Beam charge
     - C) Twiss parameters of Arc1
     - D) Dispersion pattern in the Arc1 in BT
     - E) The vertical offset from median plane of the bend chambers in the Arc1
     - Vertical emittance growths for both lines are still problem
   - Comparison of the miner remodeling of current e- BT lines
     1. Make the new straight BT line along the AR-BT line
     2. Exchange the chambers in the BT Arc1~3 to narrower chambers to cancel the CSR effects.
     3. Install the e- ECS
2. **Injection efficiencies for the main rings**
   - Dynamic apertures and emittances of the injection beam
   - Injection efficiencies for both rings depend on beam-beam effect
3. Two-bunch injection in HER (See talk on “LINAC” for detail)
   - The injection efficiency of the 2nd bunch occasionally decreased due to;
     - the drift of the vertical orbit
     - the higher emittances of the second bunch
4. The aperture improvement around the injection point (See talk on “BT” for detail)
5. DR low emittance optics had been failed twice. → not resolved yet
   - There may be some discrepancy about the DR optics between design and real machine.
6. Test of “Auto-tuning” of LINAC beam (See talk on “BT” for detail)
7. The wake field cancellation with orbit bumps in the LINAC (See talk on “LINAC” for detail)

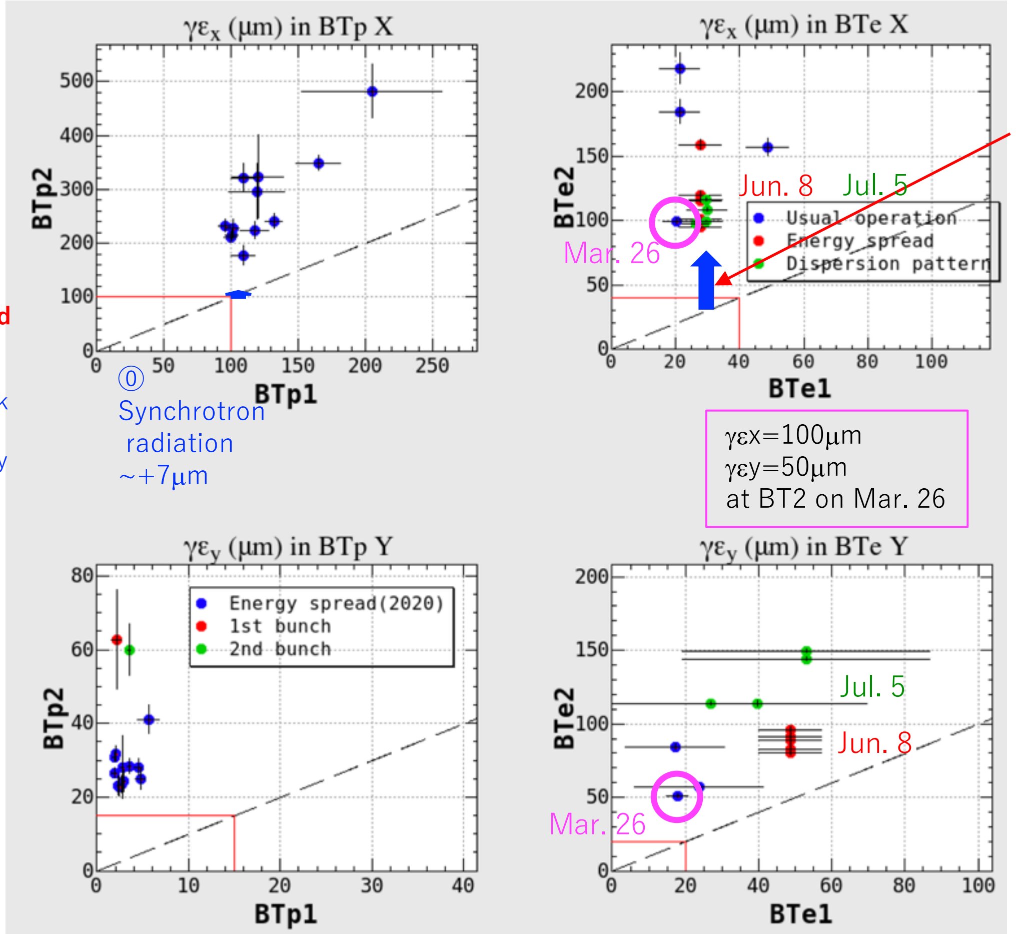
1. Emittance growth in the BT line

Previous MAC in 2021.9

1nC

③
In 2021ab,
we did not measure the horizontal emittance in BTp2.
This elementary parameter should be measured.
The reason why the horizontal emittance growth between BTp1 and BTp2 is not resolved.
The dispersion leak from ECS at SY3 will be corrected by installation of a quad at the center of chicane in the ECS in Aug. 2021.

④
The vertical emittance growth can be lower by installation of residual skew quads for the correction of skew quad components from the bends in Arc2-3.



⓪
Synchrotron radiation → Next slide (30→76μm)

①
The deviation of the horizontal emittance by changing dispersion pattern is small.
The emittance growth due to CSR effect is not confirmed yet.

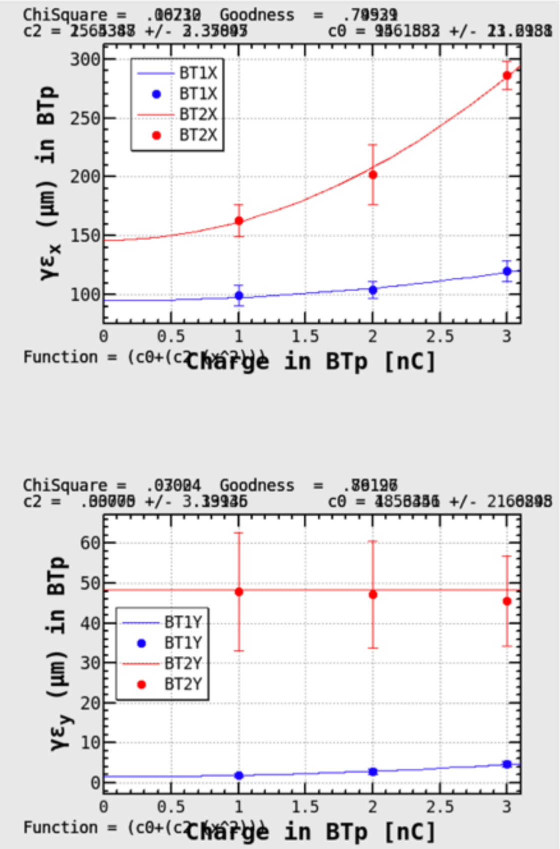
② The vertical emittance growth should be resolved.

The slit of injection channel (P.28):
height=5mm, which looks wide enough.
βy(QI4Eend)=31.85m
γεy= 50μm→6σy=2.1mm
γεy=100μm→6σy=2.9mm
γεy=150μm→6σy=3.5mm
γεy=200μm→6σy=4.1mm

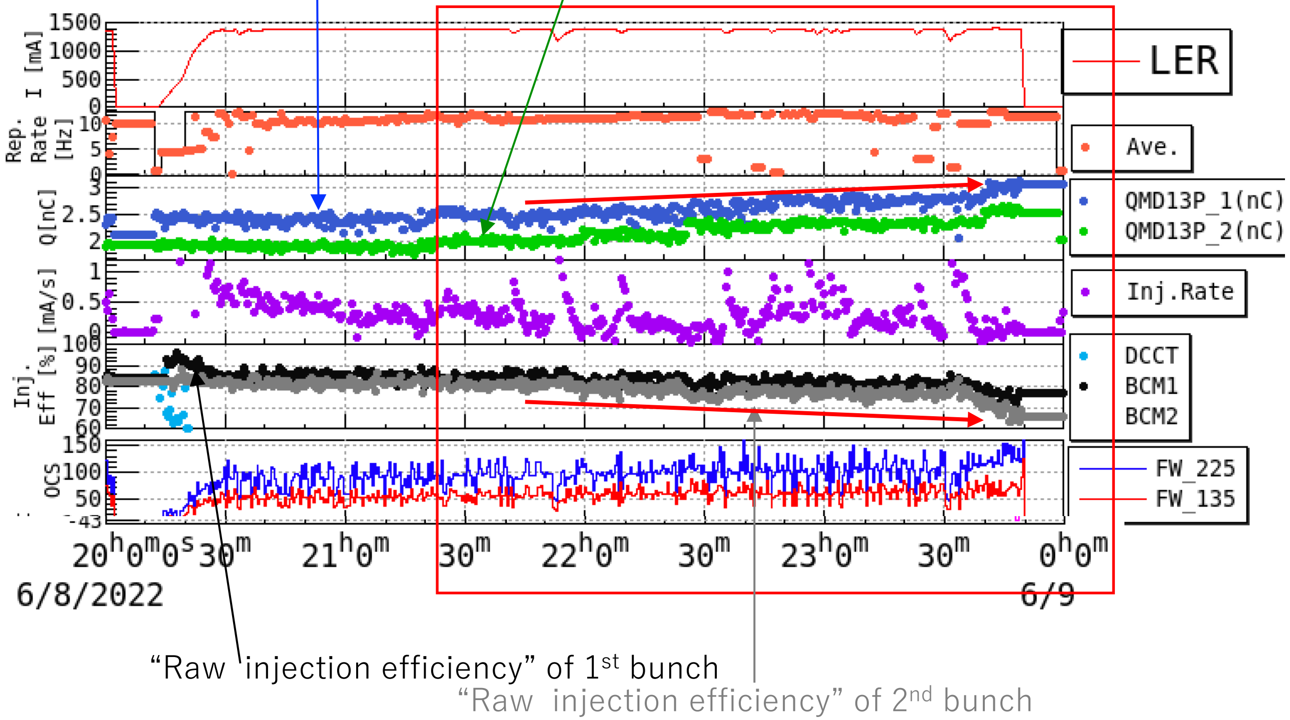
- These horizontal emittance growths are not resolved yet.
- We considered that a part of them are caused by CSR.
- For confirming it, we measured the charge dependence of emittances.

Charge dependence of emittance in BTp

Measured emittance at BT1 and BT2



- e+ horizontal emittance was increased, which is suspected due to CSR effect.

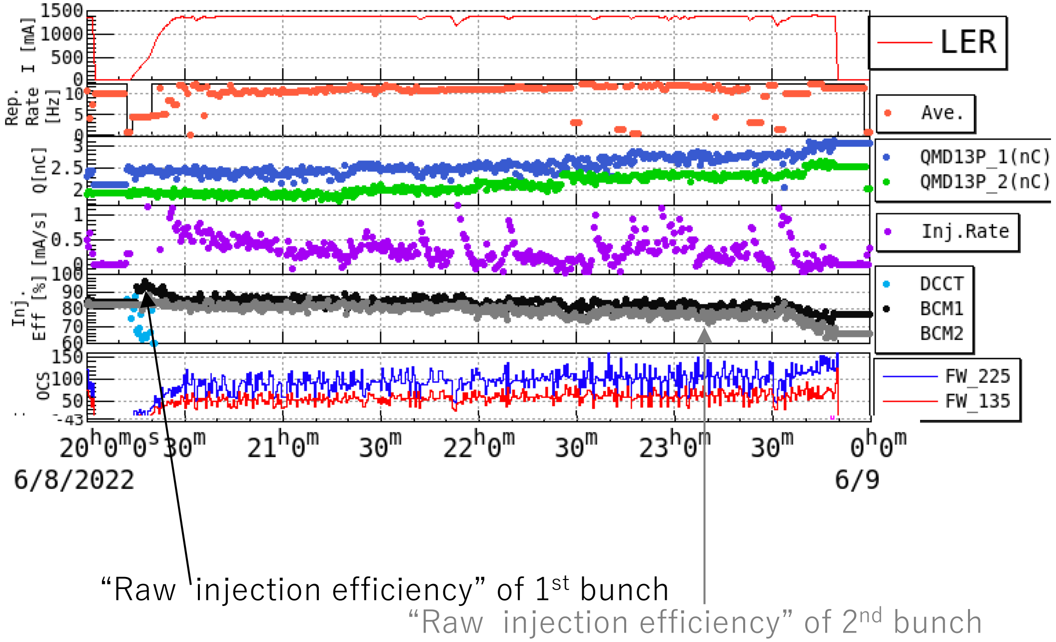


* "Raw injection efficiency" means injection efficiency corrected the beam life.

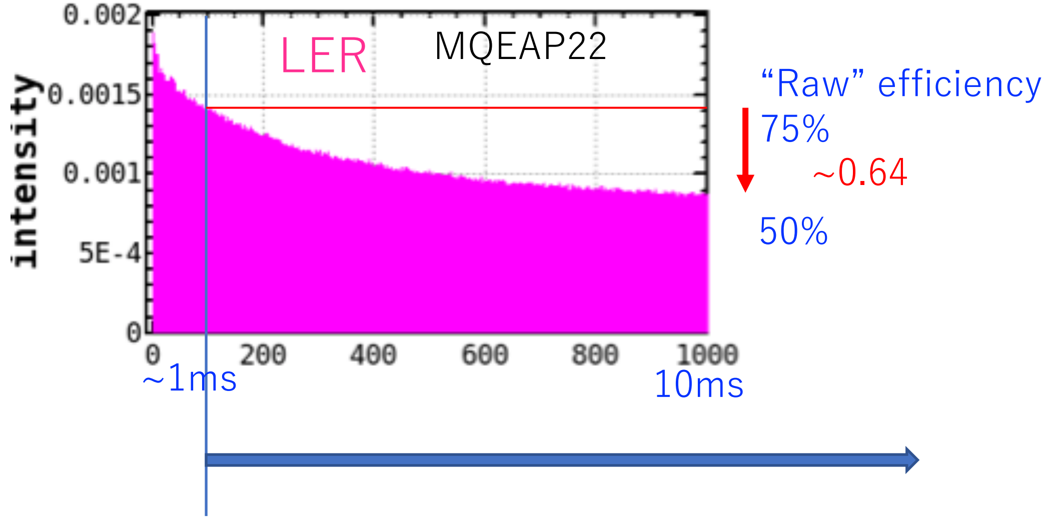
- The injection efficiencies decreased as the beam charges of the injection beam increased.
- The e+ charges had been reduced to less than 2.6nC to avoid beam aborts.

By the way,

"Raw injection efficiency"



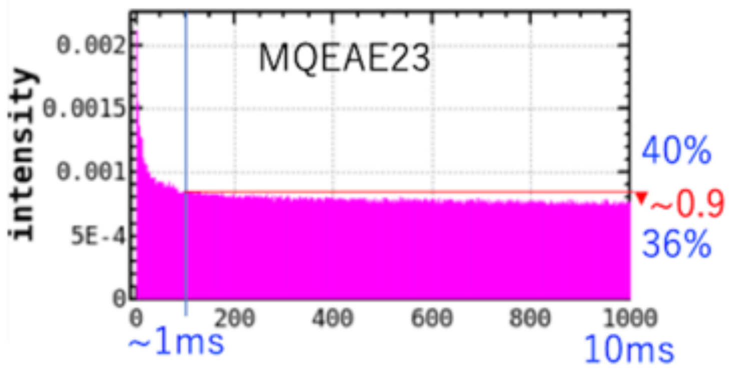
Current of the injected bunch measured by a turn-by-turn BPM in the LER



"Raw injection efficiency" had been measured too early (~100turns).
It will be changed just before the next injection after LS1.

We have calculated the "raw injection efficiency" using the BCM(Bunch current monitor) that measures the increment of the bunch charge before and after the injection. It should, however, be noted that this may overestimate the injection efficiency because the BCM takes data at 100 turns after the injection while the injected beam decays in longer period.

HER



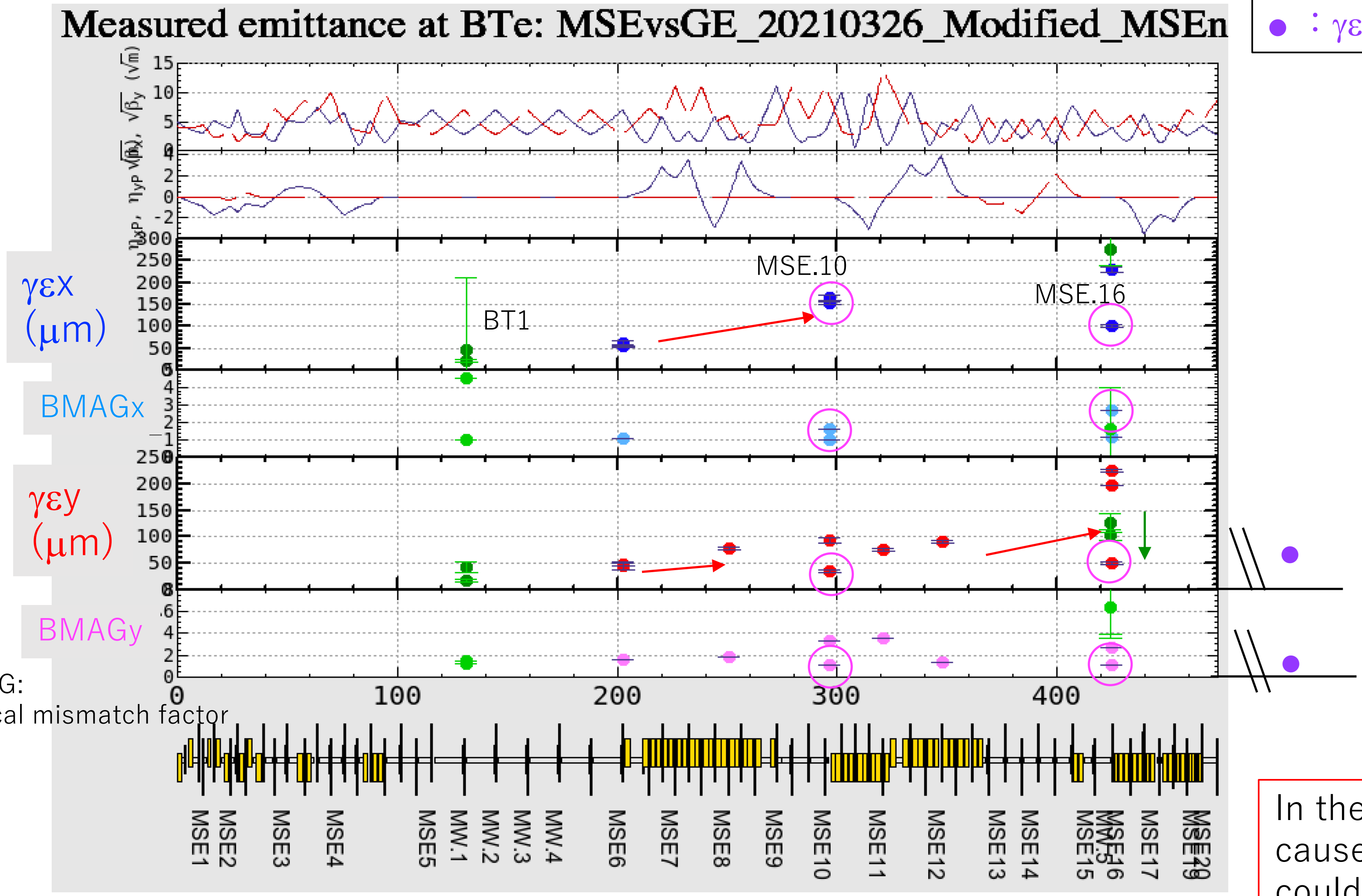
Emittance measurements in e- BT line at BT dump mode

- We had a study time for e- BT for one week from Oct.31 to Nov.7
  - It was done in “Fuji mode” in which the tunnel work in the half north area of the ring can be done.
  - Electron charge of 0.9~2.2 nC was available while the positron beam was not available because of works in the DR and power saving.

Summary of the previous measurements of emittance and β-mismatch(BMAG) in e- BT

1.0~1.1nC

● : γε with WS
● : γεx measured with OTR
● : γεy measured with OTR
● : γε with SRM+gated camera



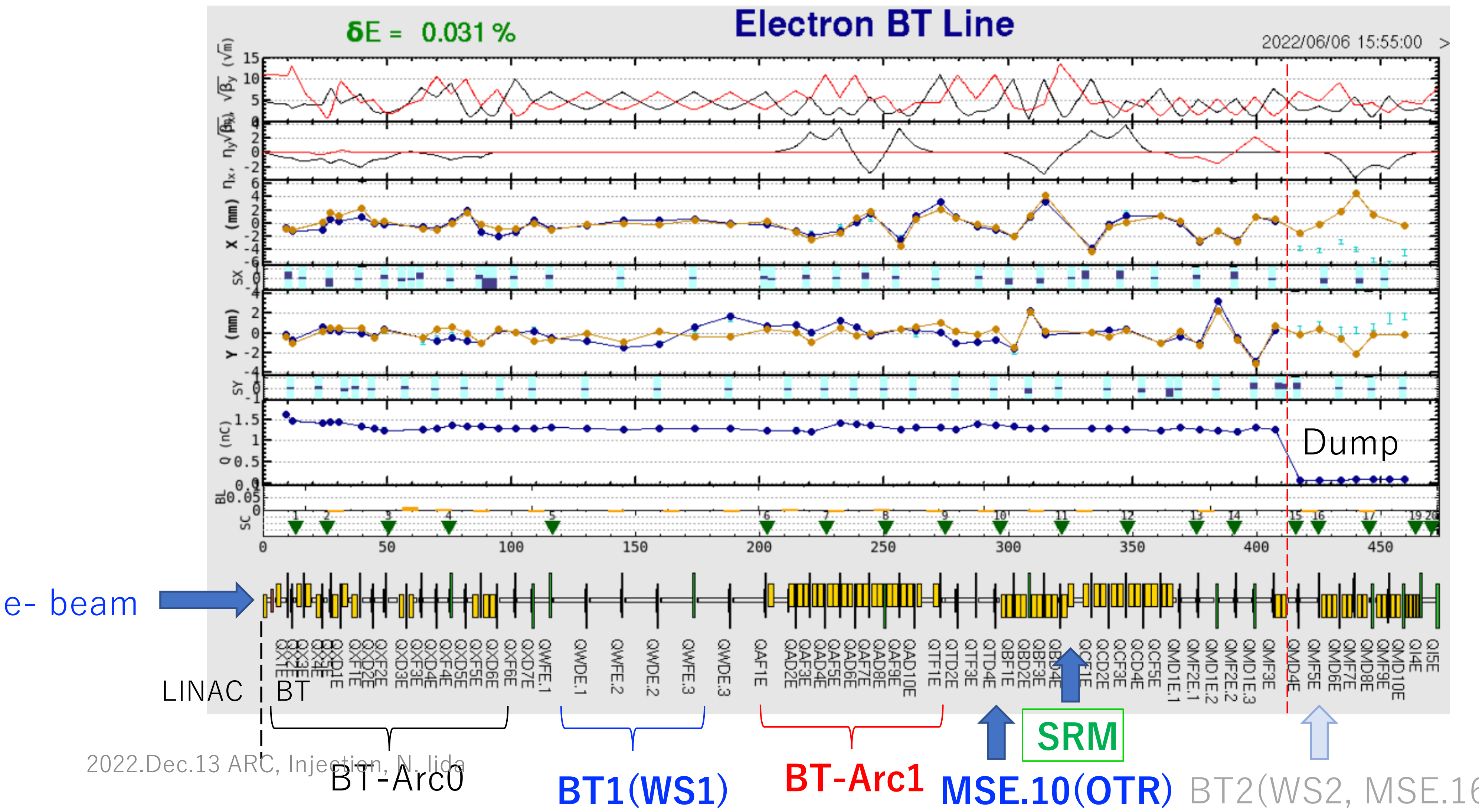
BMAG: Optical mismatch factor

- The others are measured in 2020.Dec.22.
- ◯ are measured in 2021.Mar.26.
- There are still uncertainties in absolute values because an error of the quadrupole strength used in the Q-scan turned out to give a sizable effect to the measured values in the study. We plant to precisely measure the quadrupole errors using the beam.
- Anyway, it is considered that;
- The horizontal emittance growth occurs in the Arc1.
- The vertical emittance growth occurs in the Arc1 and Slope2.

In the study we mainly focused whether the cause of the horizontal emittance growth could be attributed to CSR or not.

Study of CSR in BT-Arc1 in Nov.2022

- Emittance growth between BT1 and MSE.10



Unfortunately, the beam dump in BT is in front of the BT2 monitors.
So, we measured the emittance at MSE.10 (OTR).

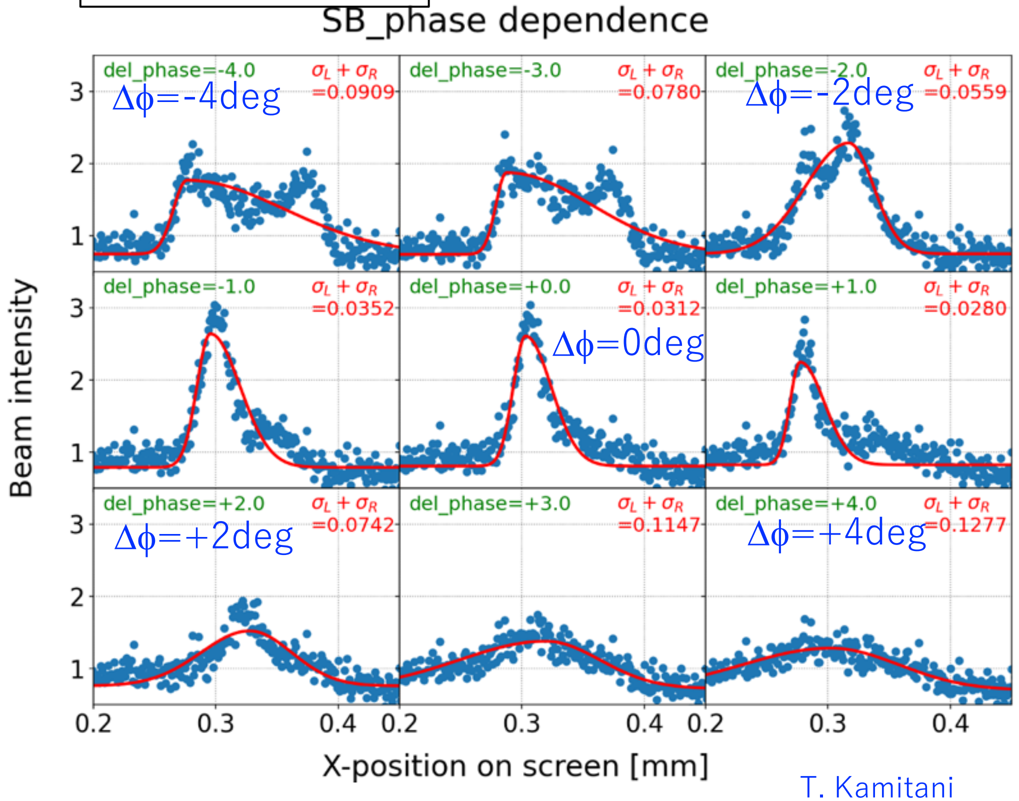
Study of CSR in BT-Arc1

1. Emittance growth dependence
   A) RF phase of SB_3~5
   B) Charge
      - 0.9, 1.6, **2.2** nC
   C) Twiss parameter of Arc1 using,
      - QAF1E, QXD6E
   D) Dispersion pattern
      - 2 patterns in the Arc1
   E) Vertical beam offset from the median plane of the chamber
      - Making vertical bump in the Arc1

Energy distribution dependence on the RF phase in SB_3~5

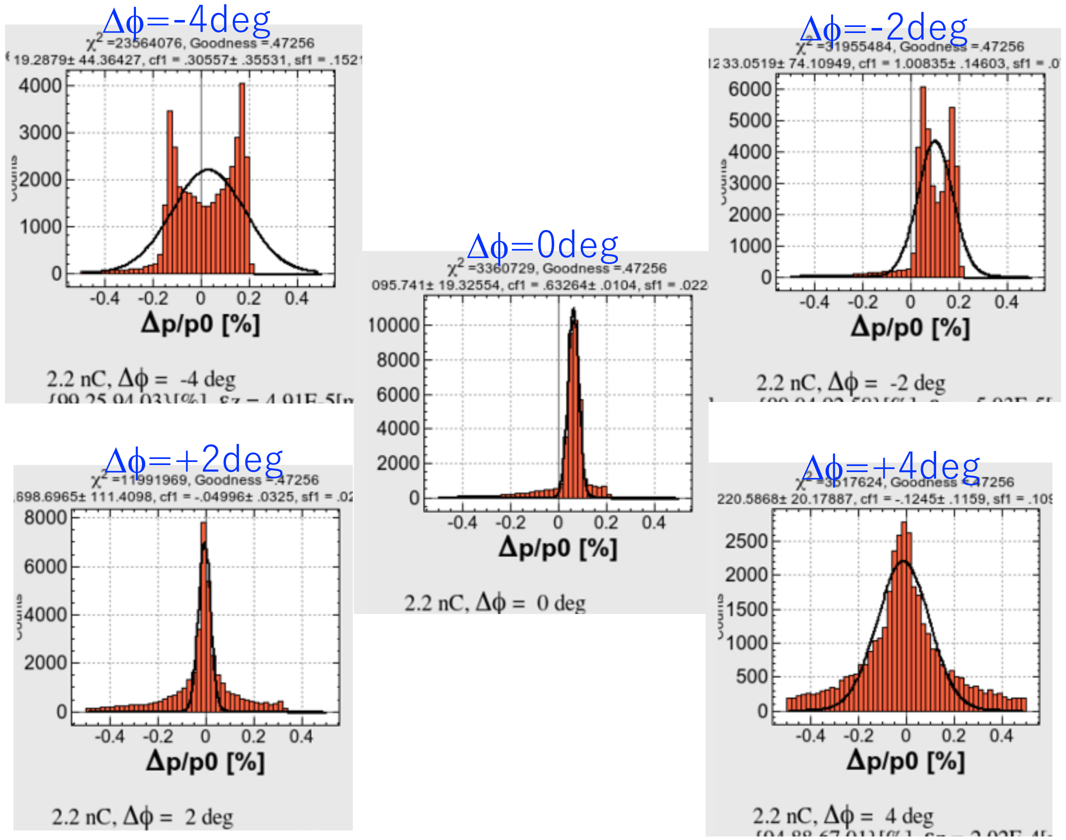
2.2nC

Measurement
MSE.12



T. Kamitani

Simulation



A) PF phase and B) charge dependence on transverse emittances (measurement)

Emittance measurement:

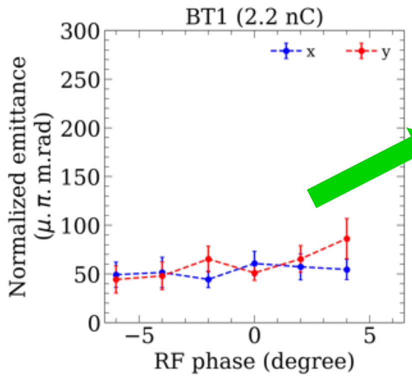
Simulations (ELEGANT)

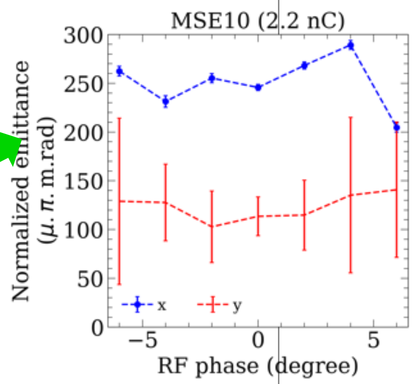
* zero RF phase gives the minimum energy spread of a beam.

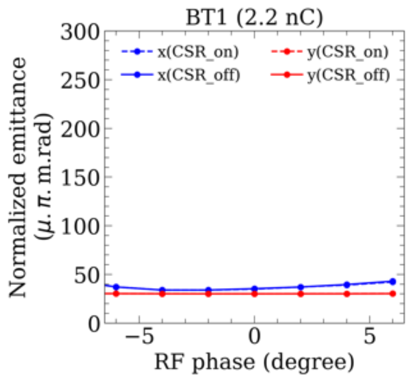
T. Yoshimoto

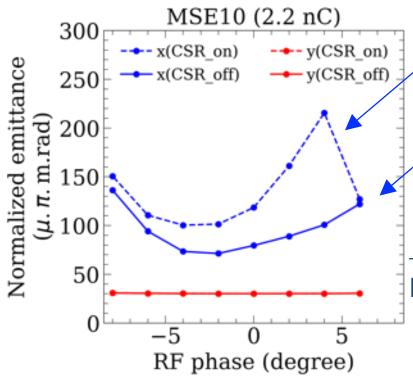
	BT1	MSE10	BT1	MSE10

2.2 nC



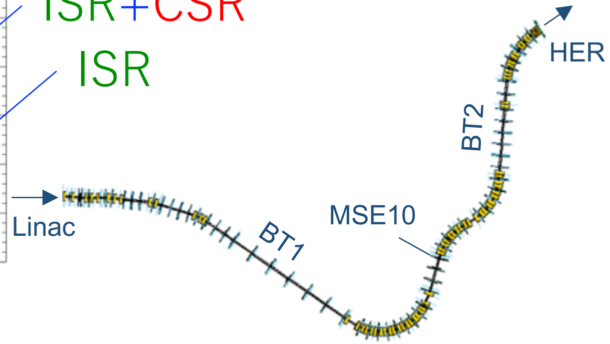




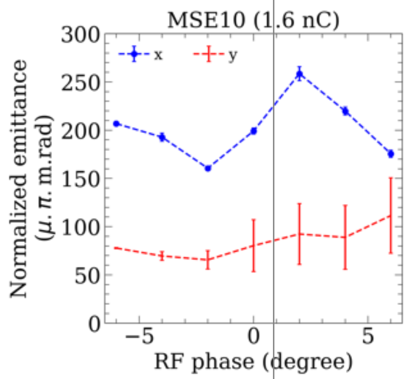


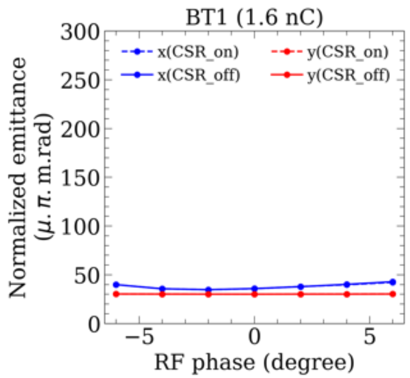
ISR+CSR

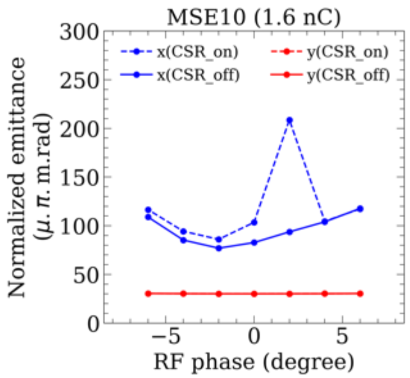
ISR



1.6 nC





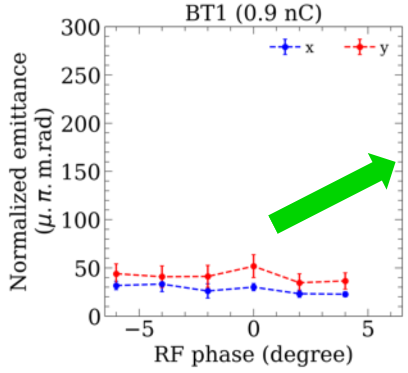


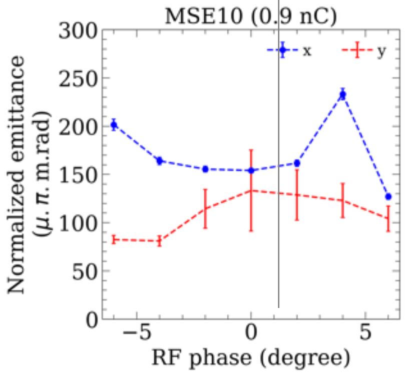
Dependence on RF phase and bunch charge (0.9, 1.6, 2.2 nC), was measured in this study.

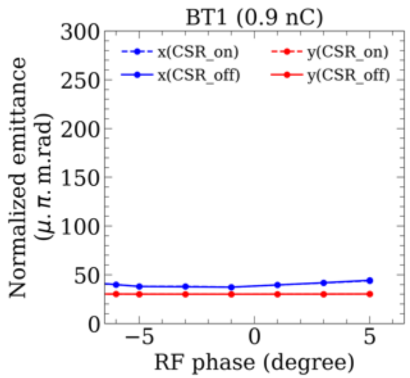
=>

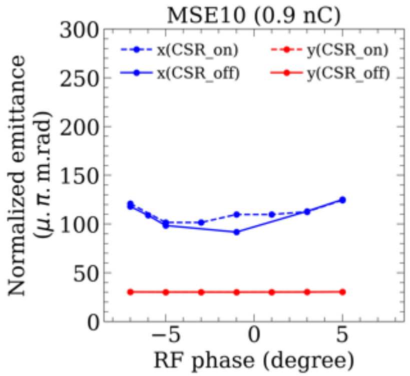
For each bunch charge, large emittance growths between BT1 and MSE10 were observed.

0.9 nC









- CSR effect explains large emittance growth at a phase of ~2 deg, except the 0.9 nC case.

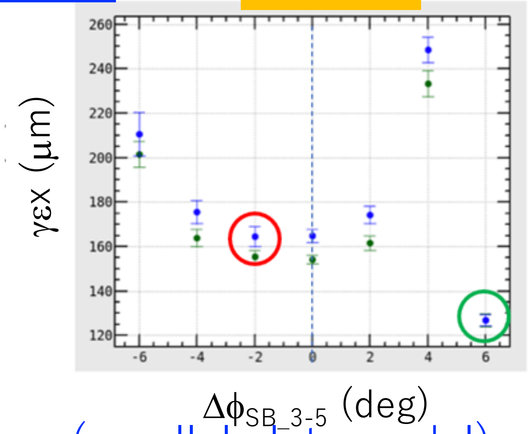
B) Bunch charge dependence

MSE.10

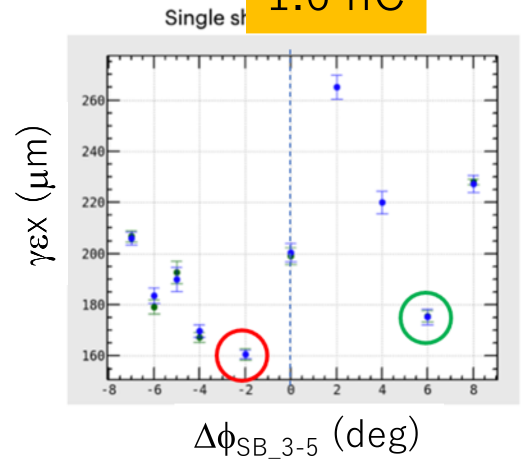
The measured horizontal emittances clearly show charge dependency.

Measurements

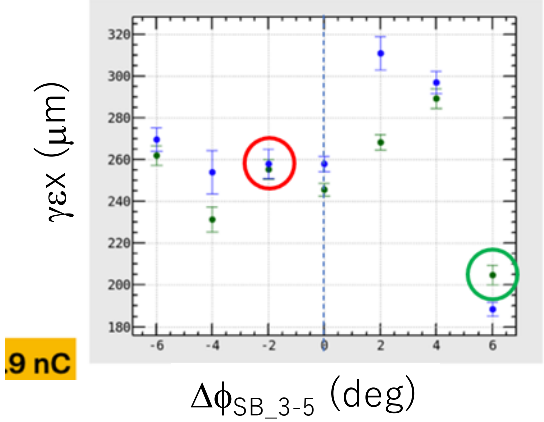
0.9 nC



1.6 nC

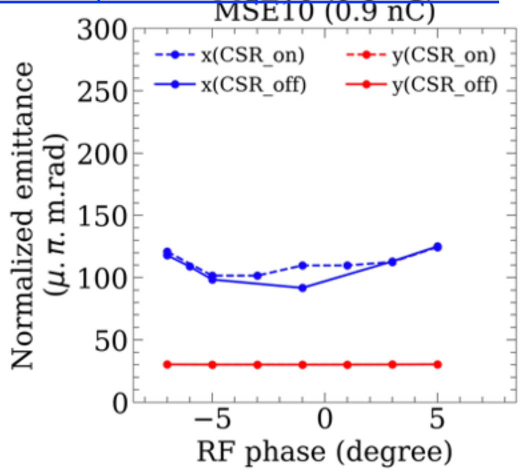


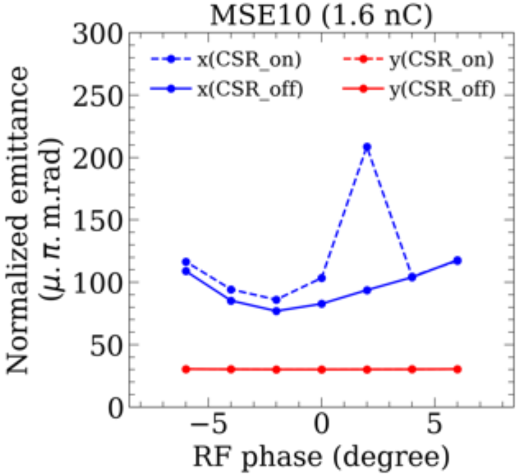
2.2 nC

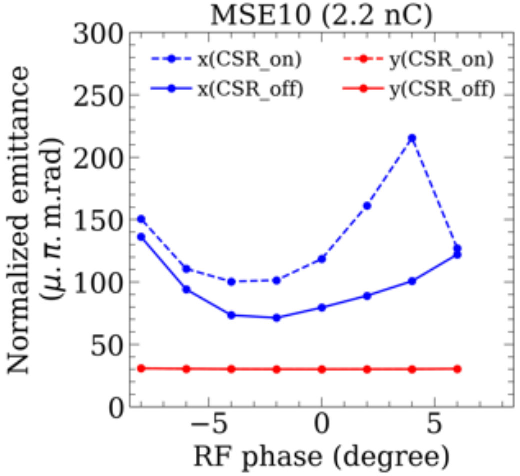


Simulations(parallel plate model)

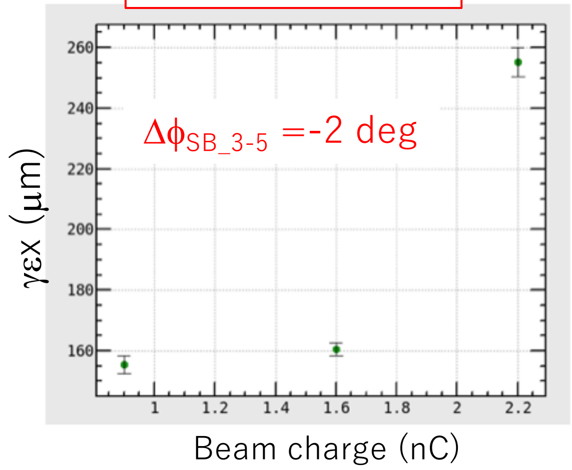
ISR + CSR

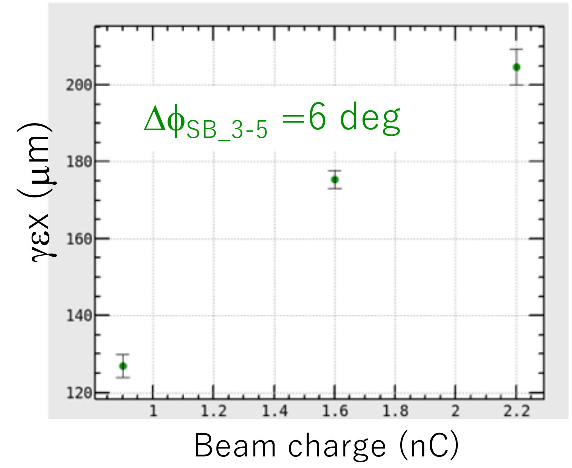






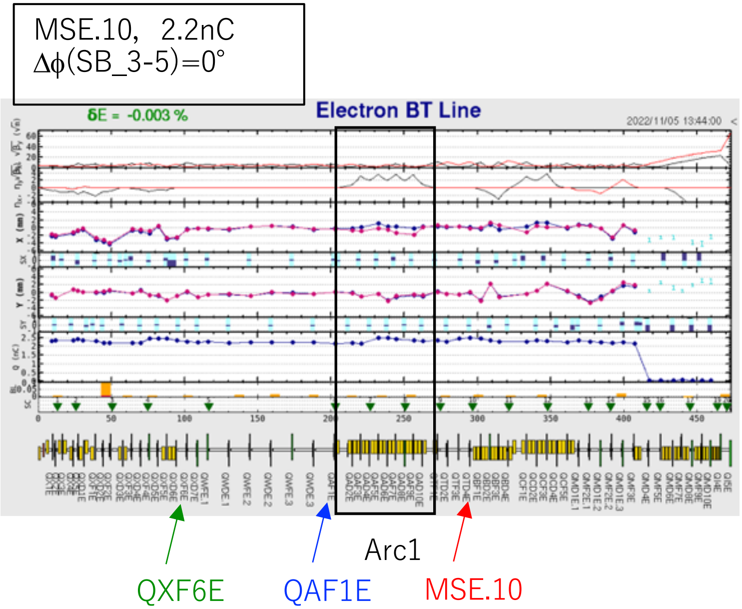
Measurements

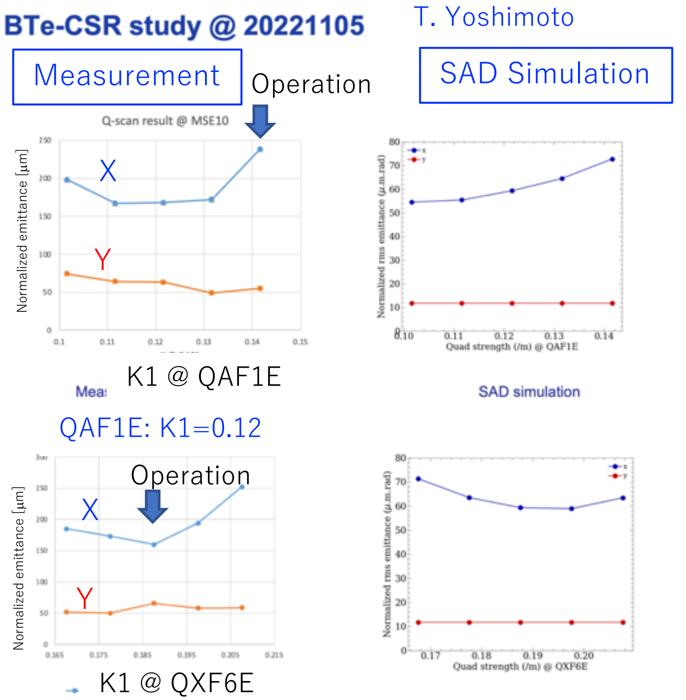




Observed emittance growth is consistent with the CSR effect, but the measured blowup is still larger than that of the simulation.

C) Changing Twiss parameters of Arc1

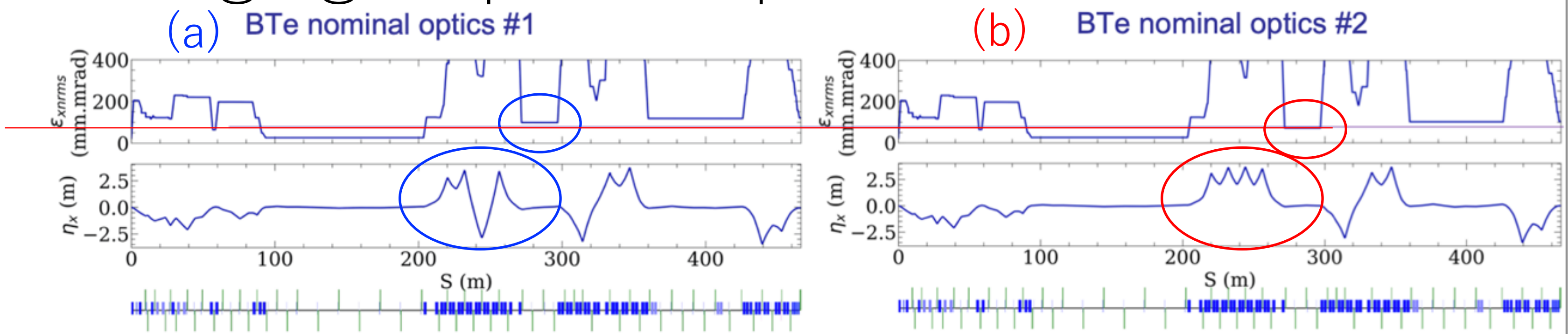




- The horizontal emittance measured after the Arc1 depends on the Twiss parameters in the Arc1.
- The tendency is reproduced with simulation.

D) Changing dispersion pattern in the Arc1

T. Yoshimoto



- **BTe nominal optics #2 is better in hor. Emittance.**

The lower dispersion optics will be simulated.

γεx [μm]	Meas. BT1	Meas. MSE.10	Sim.
(a)	34±9	246±6	100
(b)	34±6	240±5	75

- The measured horizontal emittances were almost same for the two dispersion patterns.
- In simulation, (b) gives a smaller emittance.

E) Vertical bump orbit

T. Mori, M. Kikuchi

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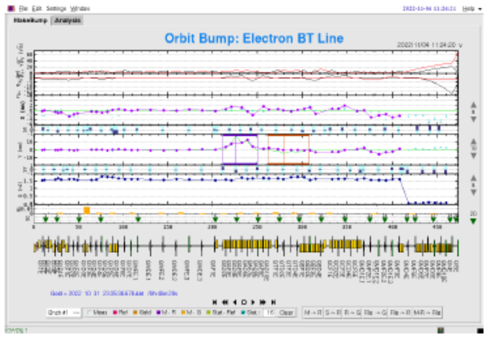

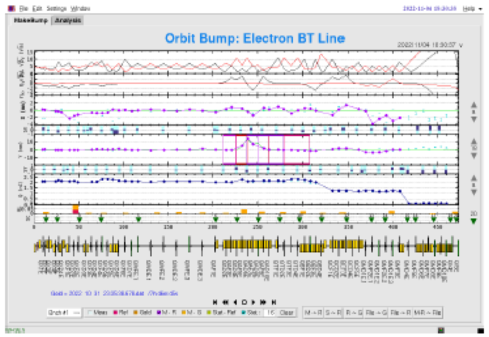

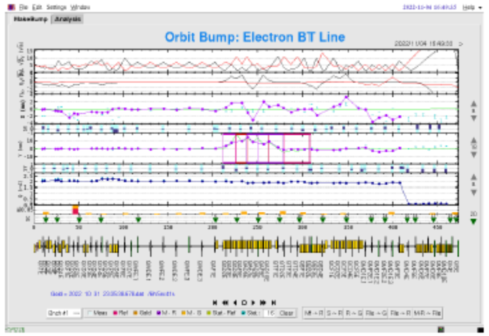

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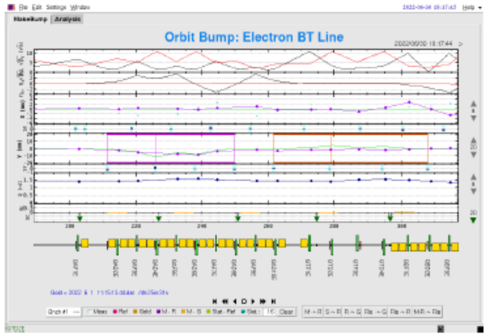
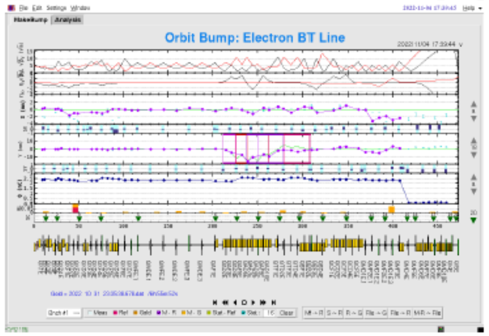
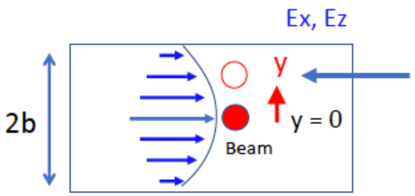


NA
Taking screen shot had been forgotten.



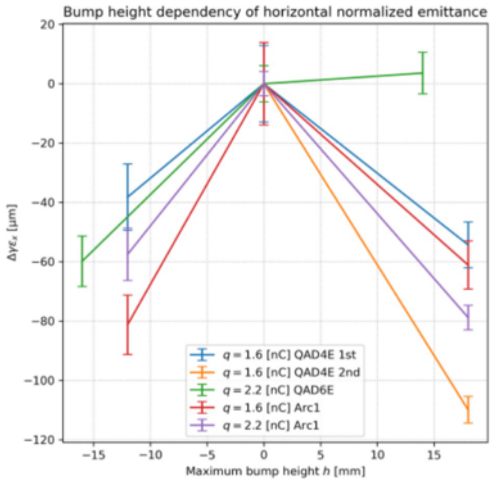
T. Nakamura (J-PARC)

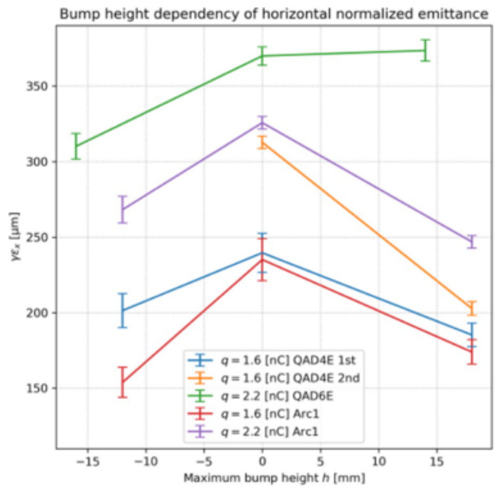


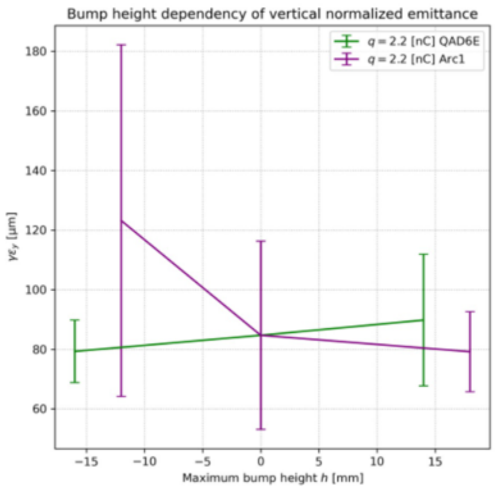
the excitation of the mode and the kick by the mode, both, are proportional to

$$\cos\left(n\frac{\pi}{2b}y\right)$$

- According to the parallel conducting plates model, CSR wake fields are reduced when the beam passes through the offset position from the median plane of the plates.
- It has been observed that the horizontal emittance has significantly reduced when the vertical bump orbit gets closer to the top or bottom wall of the beam chamber.
- Quantitative explanation using the model is in progress.



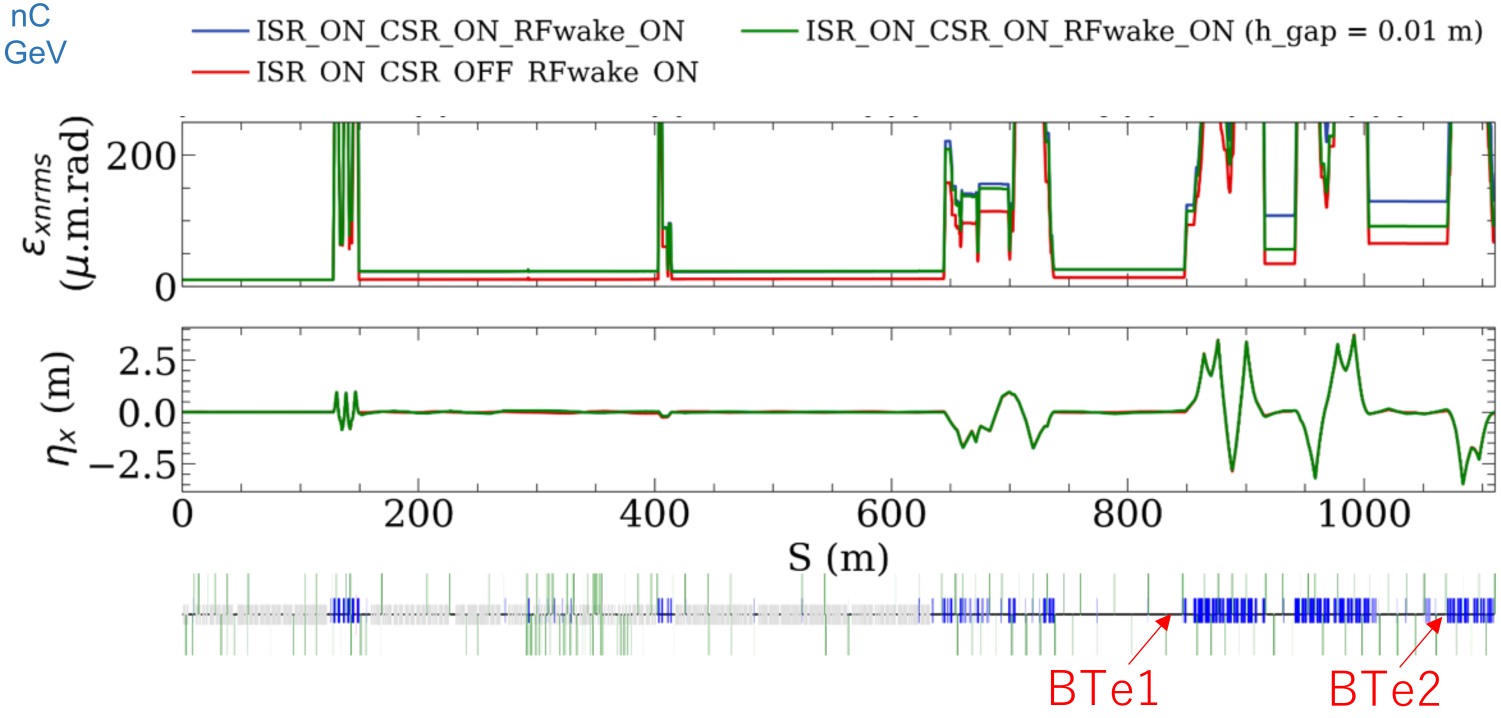




E) CSR shielding with narrower ducts

T. Yoshimoto

Conditions in simulations:
- Linac RF phase: 86 deg (for minimum energy spread)
- CSR model: steady-state parallel-plate CSR model
- Bunch charge: 2 nC
- Beam energy: 7 GeV
- Jarc R56: 0.3



Narrow gap is good.

Model	x/y nemit (pi.um.rad) @ BTe1	x/y nemit (pi.um.rad) @ BTe2
ISR + CSR + RFWAKE (h=32 mm)	**26/12**	**129/12**
ISR + RFWAKE	14/10	65/11
ISR + CSR + RFWAKE (h = 10 mm)	25/11	91/11

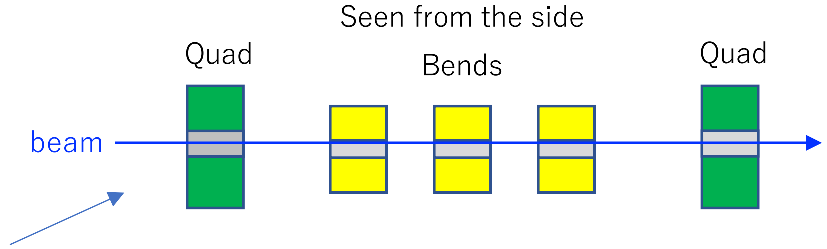
- In the BTe, lower duct heights (h = 10 mm) partially mitigate CSR effects.

Possible solution to avoid the emittance growth

The Horizontal emittance growth

There is a high possibility that CSR is one of the causes in addition to ISR.

- Current e- BT line
  1. Operate with the vertical orbit near the chamber wall
  2. Optimize the Twiss parameters in the Arc1
  3. Optimize the dispersion pattern of the Arcs.



- Miner modification of current e- BT line

  0. Realign the bending magnet of the Arc to pass the beam near the top or the bottom wall of the chamber.
     It is necessary to remake the bellows chamber at both ends of the bend

  1. Exchange the chambers in the BT Arc1~3 to narrower chambers to cancel the CSR effects.
  2. Install the e- ECS
  3. Make the new straight BT line along the AR-BT line

  →The beam emittances about the above 1.~3. patterns were estimated;
  - Horizontal emittance
  - Longitudinal emittance

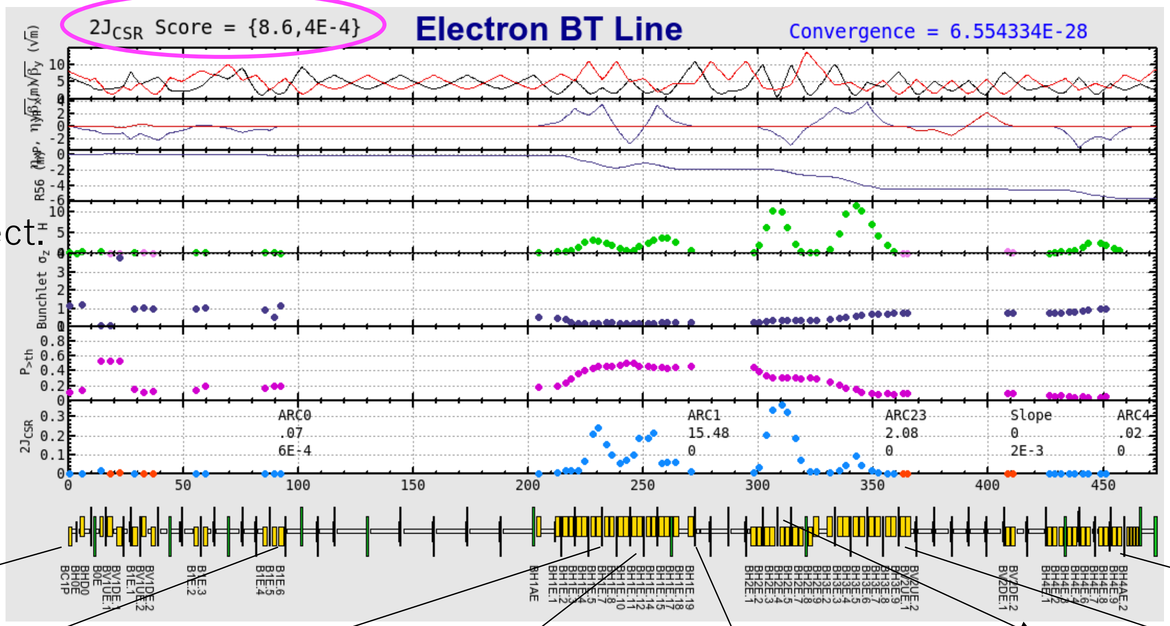
- e+ BT line
  - CSR measurement is planned. → "BT" talk

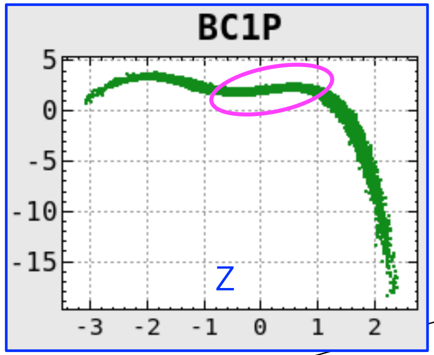
Horizontal emittance

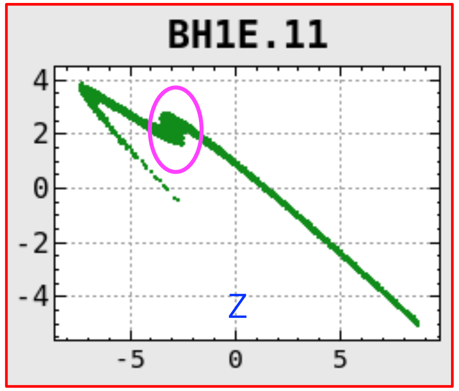
Microbunching in e- BT

M. Kikuchi

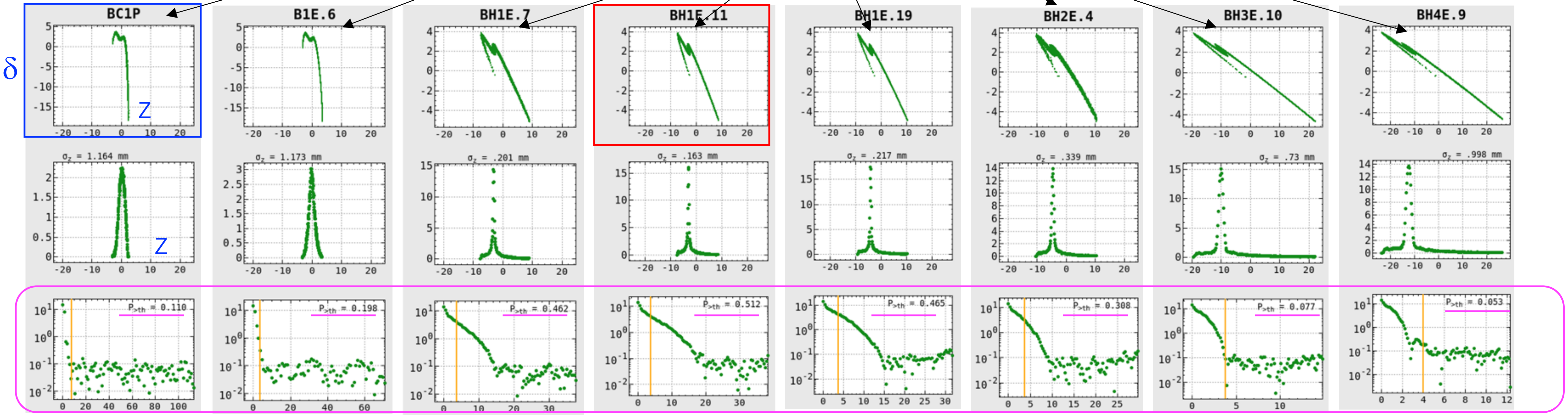
Rough estimations were done to study parameter dependence of the CSR effect.







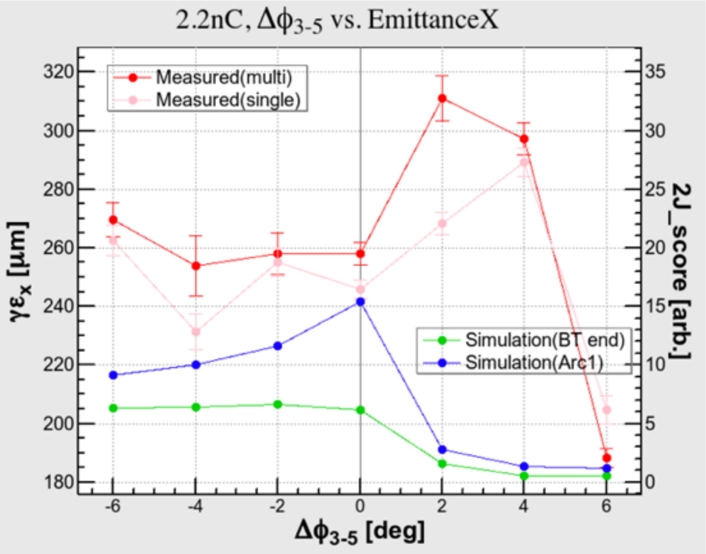
Microbunching is caused by **this part** standing in the phase space.



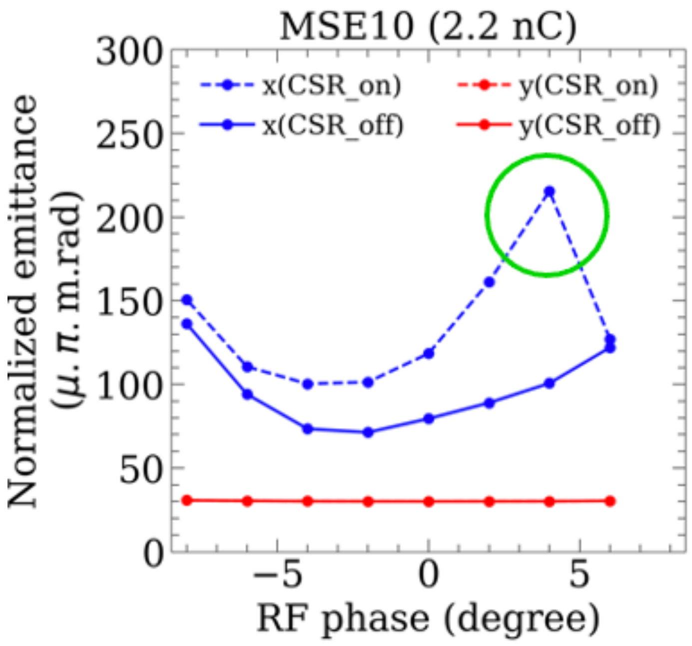
This model assumes CSR can be represented by an integration of the spectra exceeding the threshold($P_{>th}$).
Betatron oscillation caused by CSR at bends can be estimated by taking into account the betatron phase and its action is defined as "$2J_{CSR}$ Score". $P_{>th}$ is very large in Arc1.→CSR effect is expected to be large at Atc1.

Horizontal emittance

- Both of the measurement and $2J_{CSR}$score has the same tendency;
  the emittance increases in the region where $\Delta\phi_{3\text{-}5}$ is negative while decreases for positive $\Delta\phi_{3\text{-}5}$.



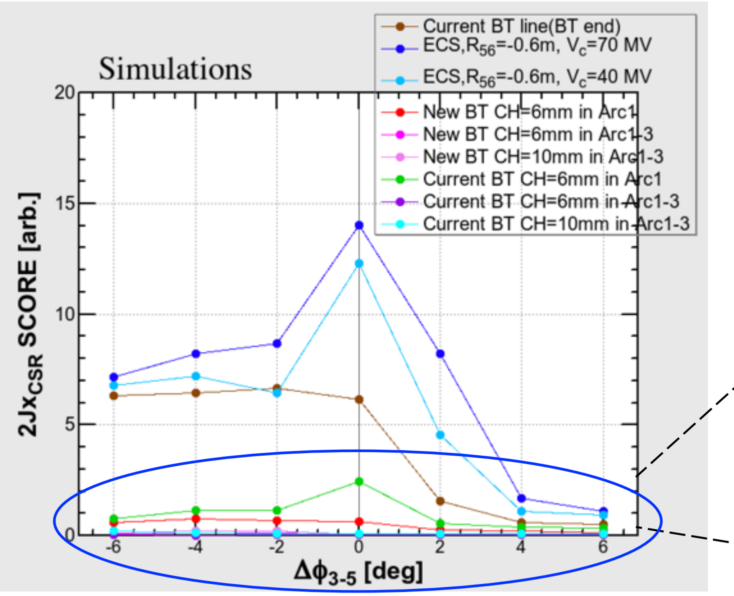
Tracking simulation



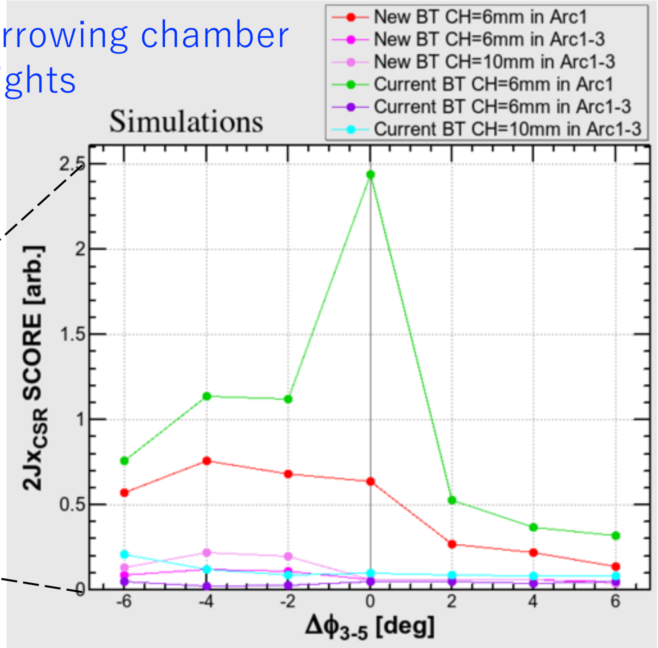
- Narrowing chamber heights is very effective to suppress the CSR for both of current and the new BTs.

ε(6 mm in Arc1~3)
< ε (10 mm in Arc1~3)
< ε (6 mm in Arc1 only)

<< ε (32 mm in all Arcs (Now))



Narrowing chamber heights

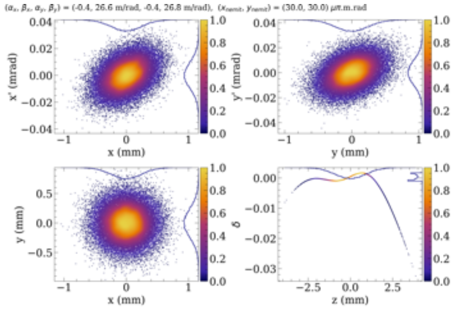


New beam transport line (1)

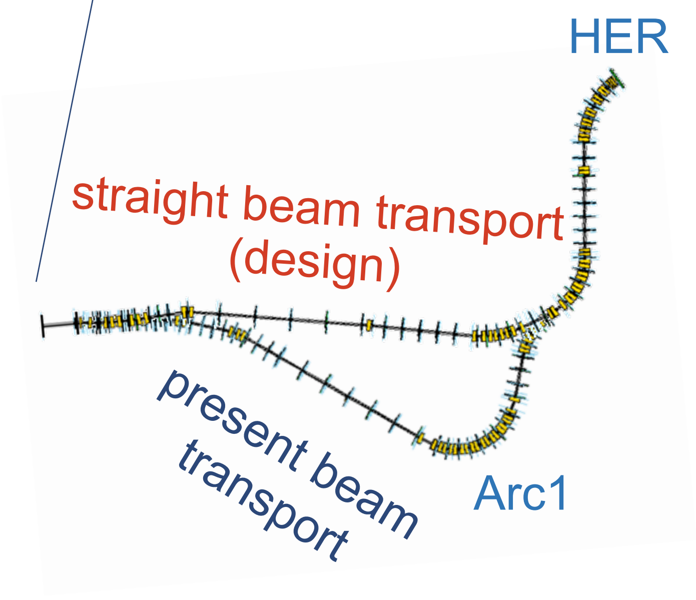
T. Yoshimoto

- Purpose: ISR & CSR suppression at Arc1 => A new straight line is introduced instead of current Arc1.
- Simulation with ISR & CSR is essential to evaluate the emittance improvements.

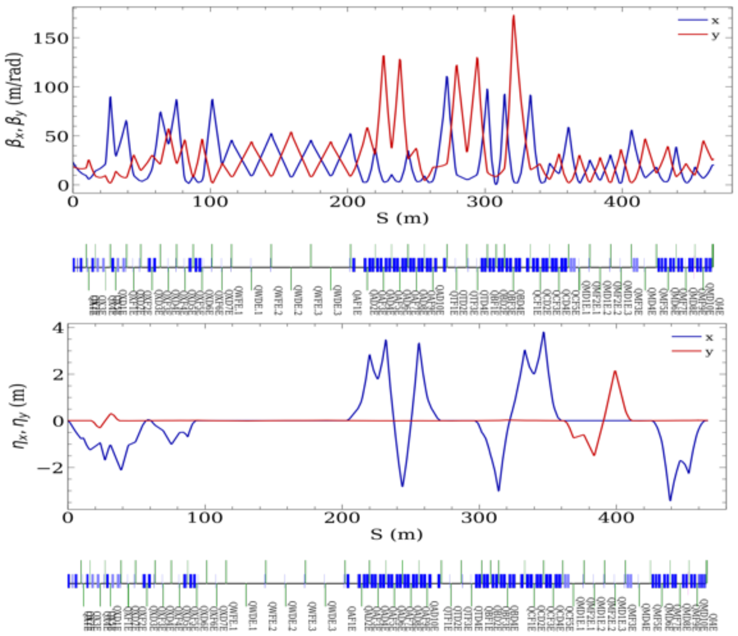
Initial distribution



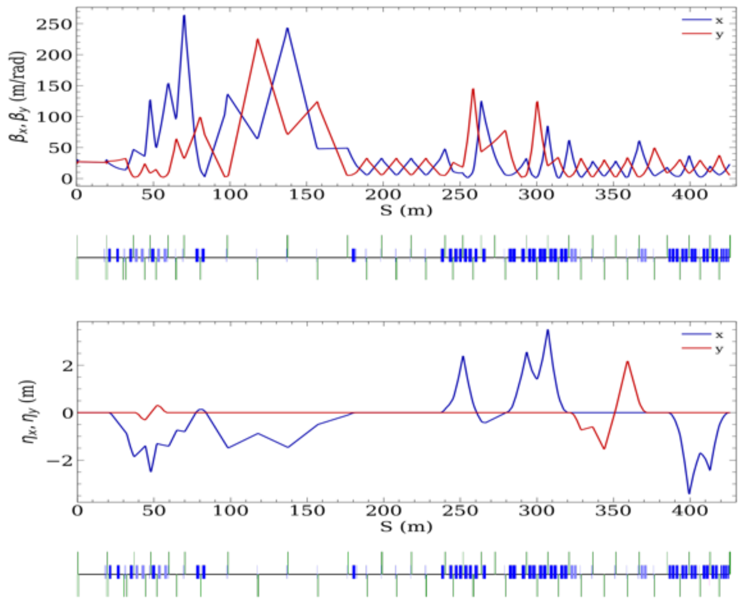
Conditions in simulations:
- x/y nemit: 30 um.rad
- Bunch charge: 2.2 nC
- Beam energy: 7 GeV
- Linac RF phase: 86 deg (for minimum energy spread)
- CSR model: steady-state parallel-plate CSR model* *New optics is calculated with a full gap of 3 cm for all bending magnets.
- Full *x*/*y* aperture: 4 cm



Current beam transport



straight beam transport



Preliminary

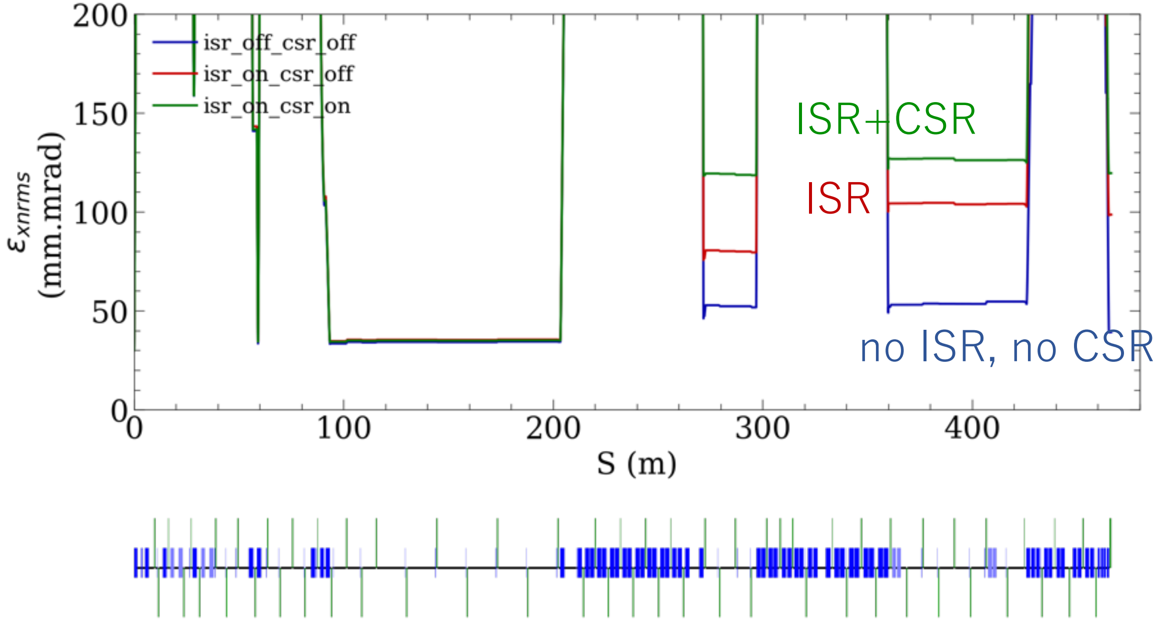
Curtesy: M. Kikuchi

New beam transport line (2)

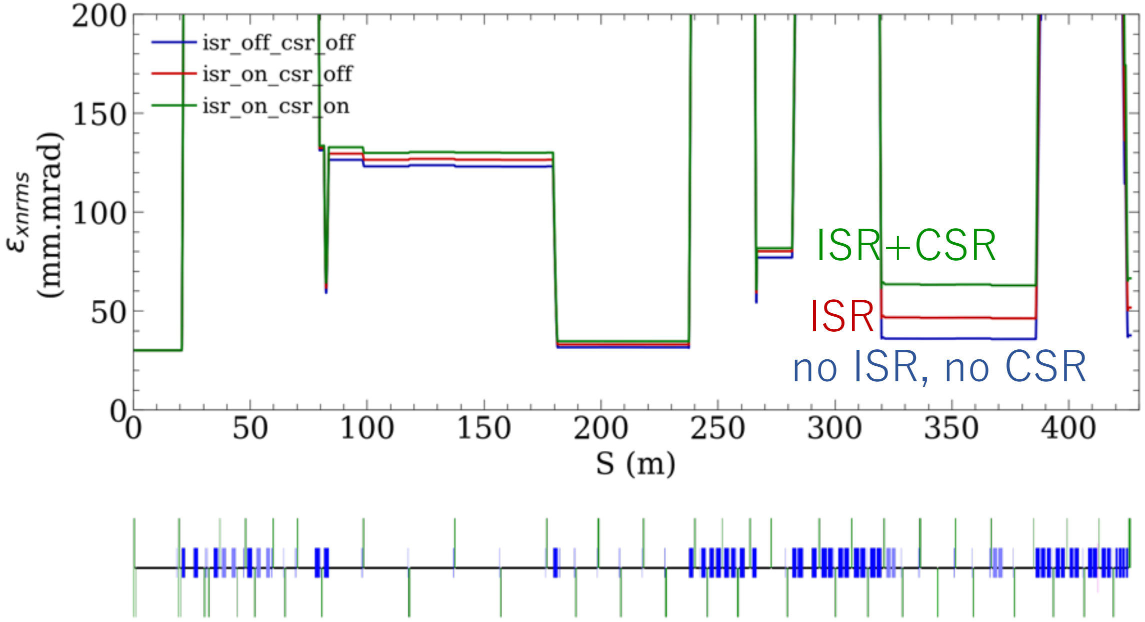
- x/y nemit: 30 um.rad
- Bunch charge: 2.2 nC

T. Yoshimoto

Current beam transport



straight beam transport (design)



- New straight beam transport line can <u>effectively suppress CSR and ISR effects</u> thanks to fewer and weaker bending magnets, as expected.
- Bending ducts with a full height of 30 mm cannot completely suppreess CSR.

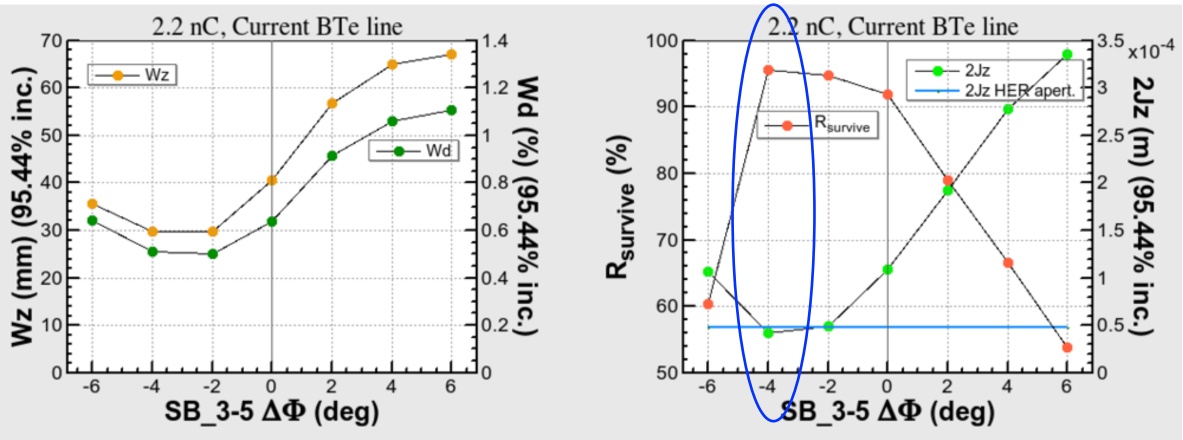
Simulation		γεx [μm] at the end of BT	
ISR	CSR	present BT	new BT
Off	Off	53	36
On	Off	104	46
On	On	126	63

Longitudinal emittance

1. Current BT, no ECS SB_3-5 Δϕ scan

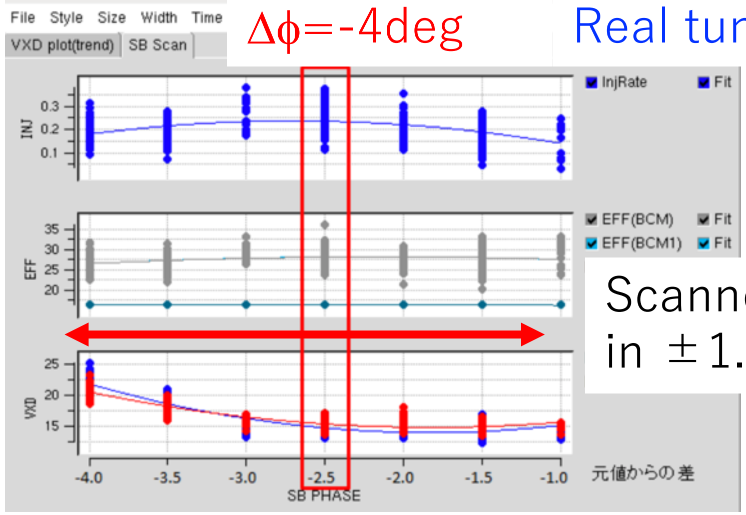
The simulation is consistent with the usual operation tuning that Δϕ=-4 deg is the best injection.

Simulation

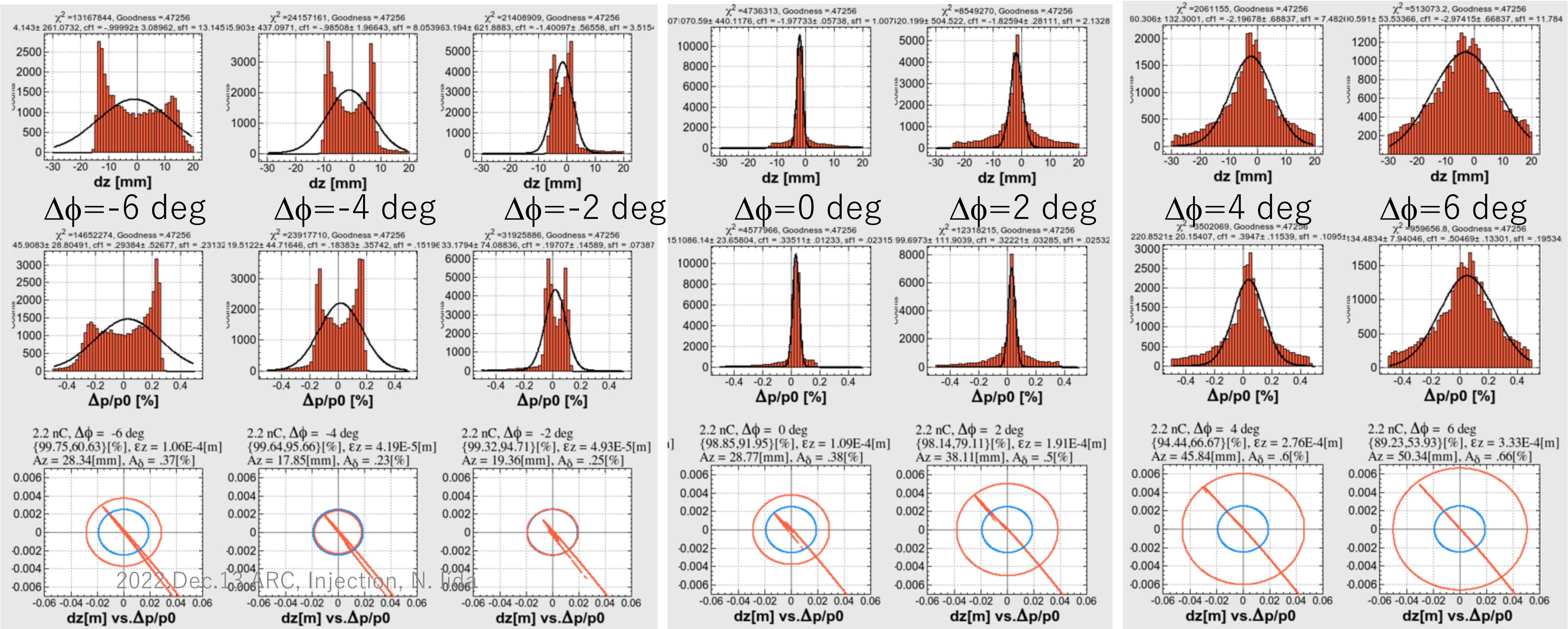


Δϕ=-4deg

Real tuning



Scanned in ±1.5°



Simulation of Injection

Y. Ohnishi

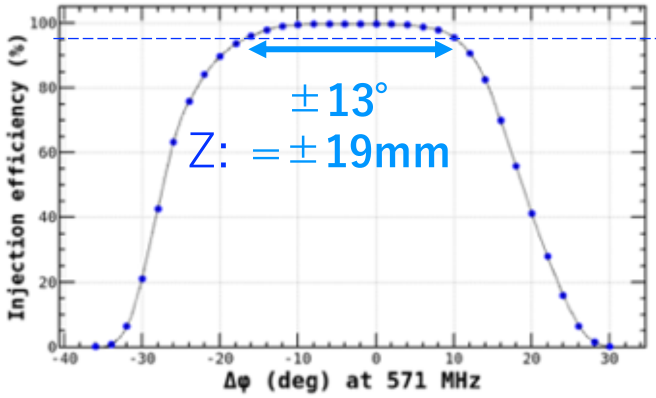
The tolerance of injection tunings to the HER(βy*=1mm) are simulated.

βy*=1mm Tolerance of Injection in HER

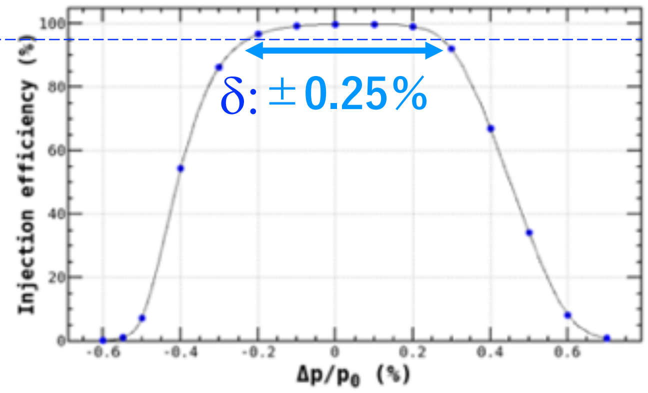
Injection efficiency : QCS aperture + collimators

$$\Delta z = \lambda \frac{\Delta\phi}{360^\circ} = \frac{c}{f}\frac{\Delta\phi}{360^\circ}$$

$$\Delta z[\mathrm{mm}] = 1.46\Delta\phi^\circ$$

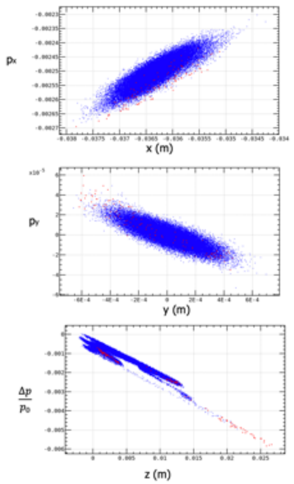


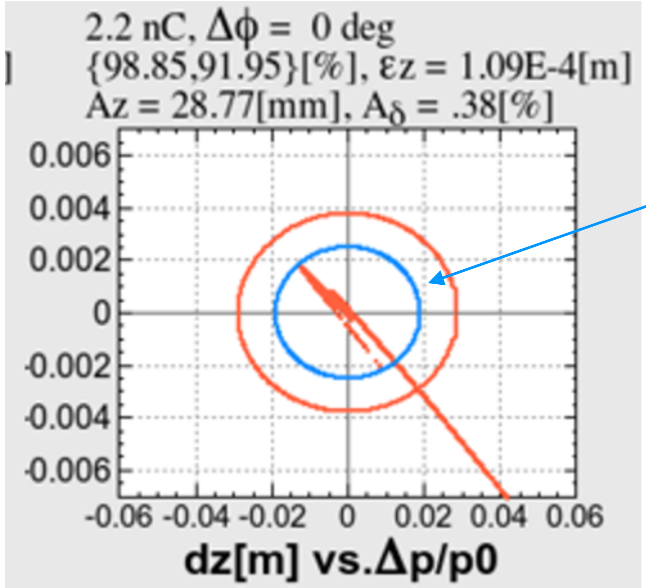
95%



Initial particles which are tracked from LINAC via the BT line.

γεx=118μm
γεy=12μm





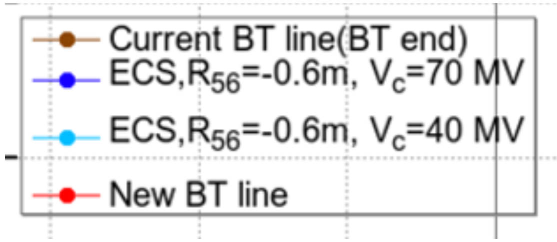
Aperture of HER is drawn using the width where the injection efficiency is more than 95%.

Design values of HER are assumed.

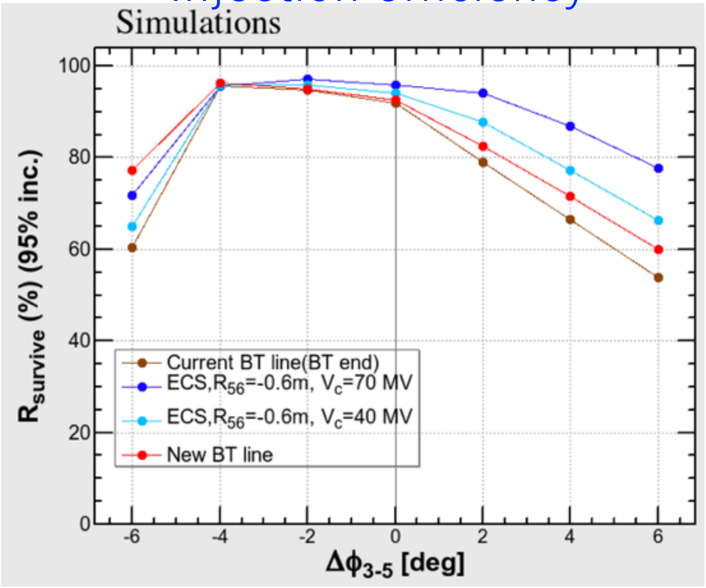
σz=4.9 mm
σδ=6.3e-4

Longitudinal emittance

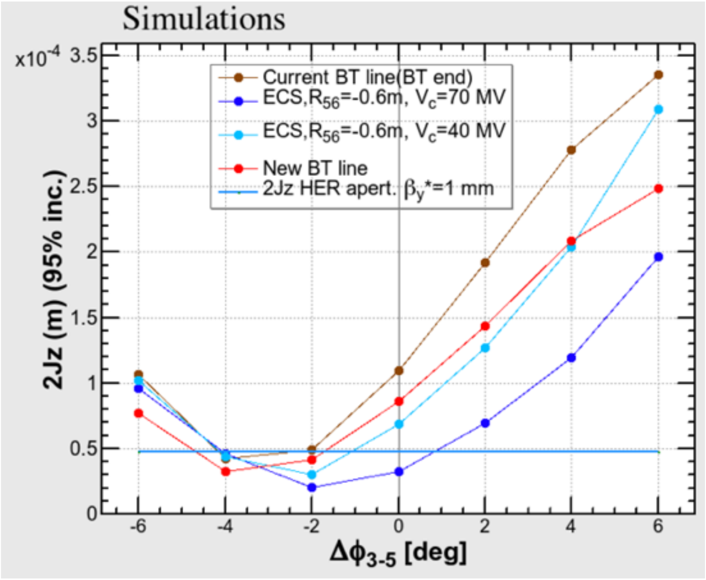
Preliminary



Injection efficiency



2Jz of injection beam



Result:

e- ECS

- Even with R56=-0.6m Vc=70MV, the effect of lowering 2Jz can be seen.
- Investigation with a parameter of R56 = -1.0m will be done soon.

New straight BT line

- For this longitudinal emittance study, it is better than the current BT a little.

Preliminary

Comparison of proposed improvement schemes

	ISR	CSR	Longitudinal emittance	Cost	Construction period
Current BT, no ECS	Large	Large	Just in	0	0
Current BT, ECS R56=-0.6m, MV=70MV	Large	Larger	**Small**	?	?
Current BT, ECS R56=-1.0m, MV~100MV ?					
New BT, no ECS	**Small**	Small	just in	?	?
New BT, with ECS					
with narrow chambers in Bends	no effect	**very small**	no effect ?	?	?

- More simulation studies are on going.
- We should also study about $\beta y^* < 1mm$

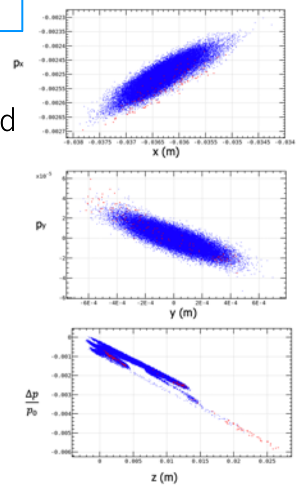
2. Injection efficiencies

Y. Ohnishi

Assume:
γεx=250μm
γεy=45μm

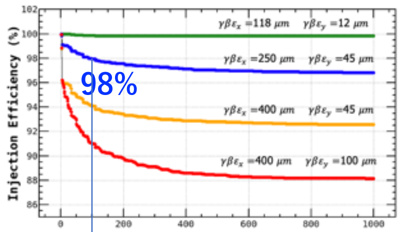
HER

Initial particles



Initial particles which are tracked from LINAC via the BT line.

Simulation

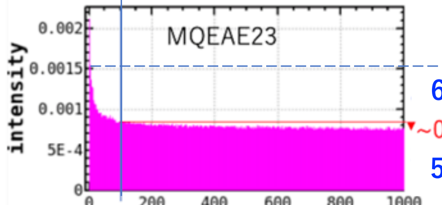


97%

88%

Measurement

HER TbT-BPM



~1ms

10ms

100%

60%

~0.9

55%

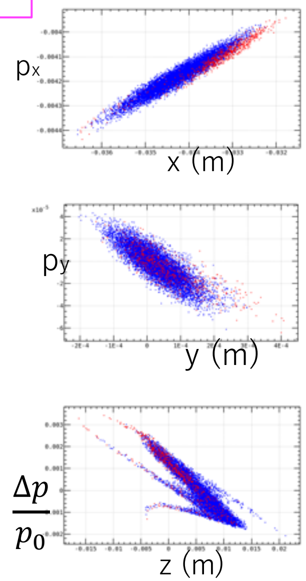
Real injection efficiency is much worse than these simulation.

- The injection beam are worse ?
  - Emittances, narrower aperture of the injection region, …

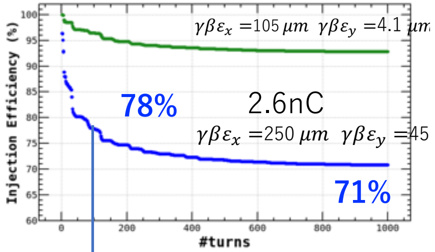
  AND
- The dynamic aperture of HER is worse ?

LER

Initial particles

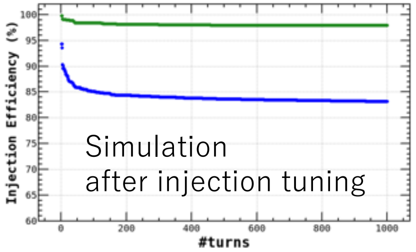


Simulation



Injection tunings $\Delta x_{sp} = -0.2mm$

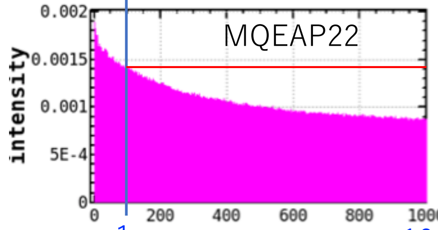
injection phase: $\Delta\phi = +8°$ $\Delta\theta_{sp} = 0.04mrad$



Measurement at BT2, 2.6nC :
γεx=250μm
γεy=45μm

Measurement

LER TbT-BPM



~1ms

10ms

"Raw" efficiency

75%

~0.64

50%

- Beam loss in the simulation after 1000 turns does not reproduce the actual injection efficiency.
- The beam loss after the injection is a serious problem to accumulate higher current.

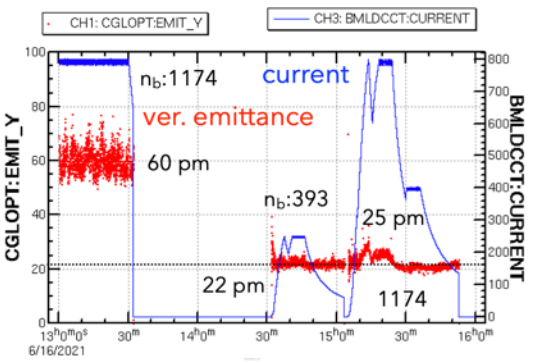
Dynamic apertures

Y. Ohnishi

Simulation

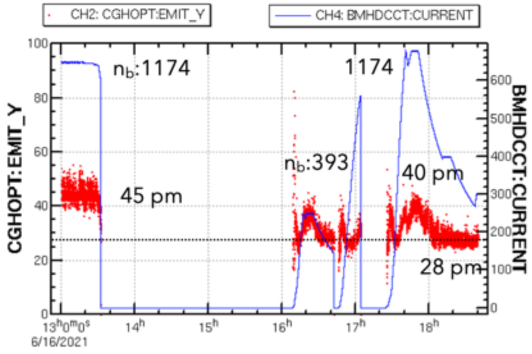
QCS Aperture + Collimators + CW On
no machine error

LER



collision **single beam**

HER



collision **single beam**

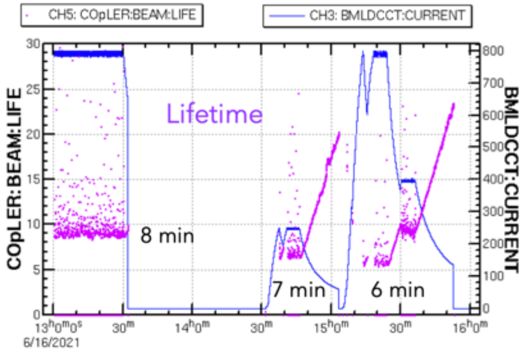
ε_y depends on bunch current.

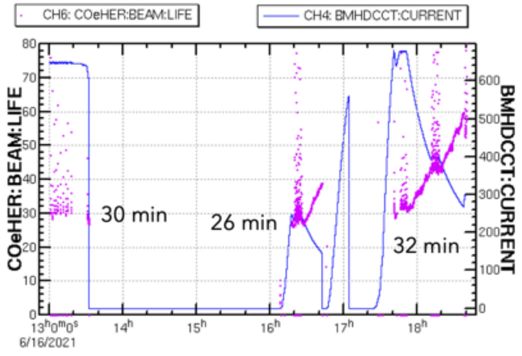
Beam Lifetime and Vertical Emittance

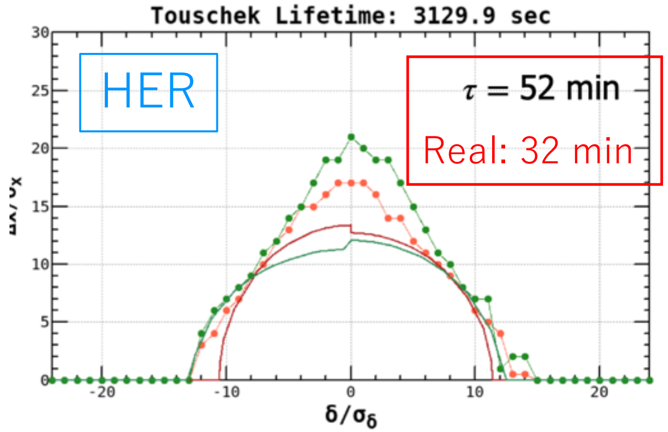
2021b

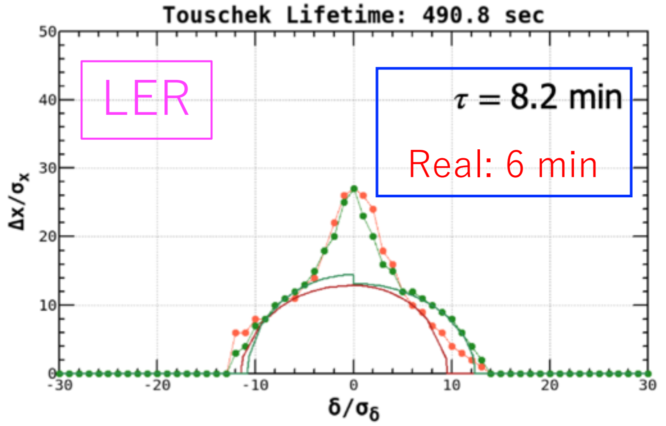
	LER	HER
β_x^*	80 mm	60 mm
β_y^*	1 mm	1 mm
I	800 mA	650 mA
n_b	1174	1174
I_b	0.681 mA	0.545 mA
ε_y collision	60 pm	45 pm
ε_y single	25 pm	40 pm
life collision	8 min	30 min
life single	6 min	32 min

e^+_{inj}: 2.3 nC x 2 x 12.5 Hz x 80 %
I_{max}= 1.5 A for lifetime: 8 min



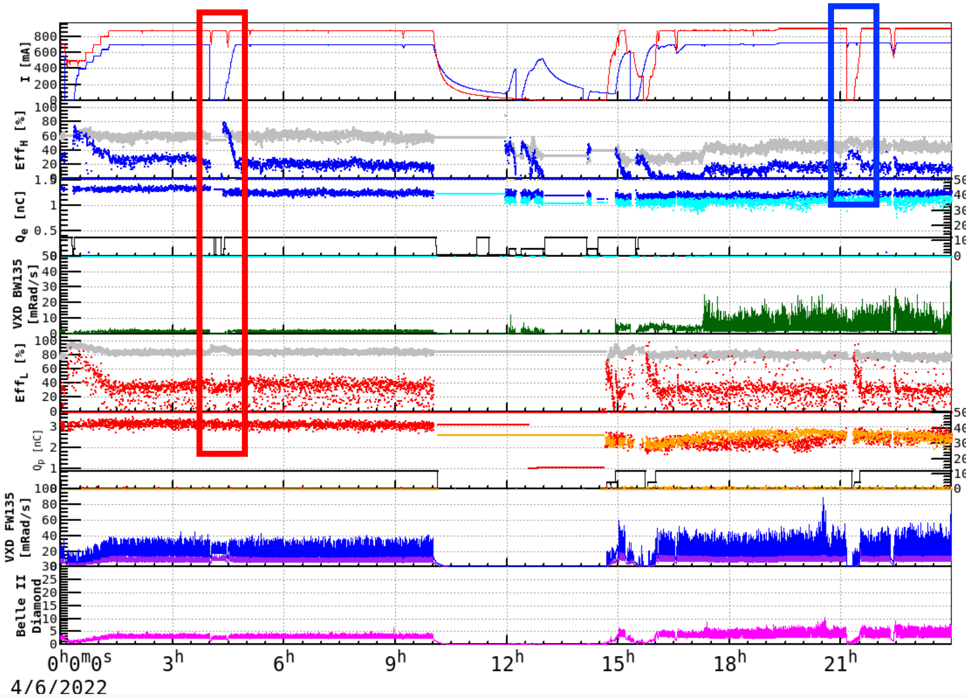


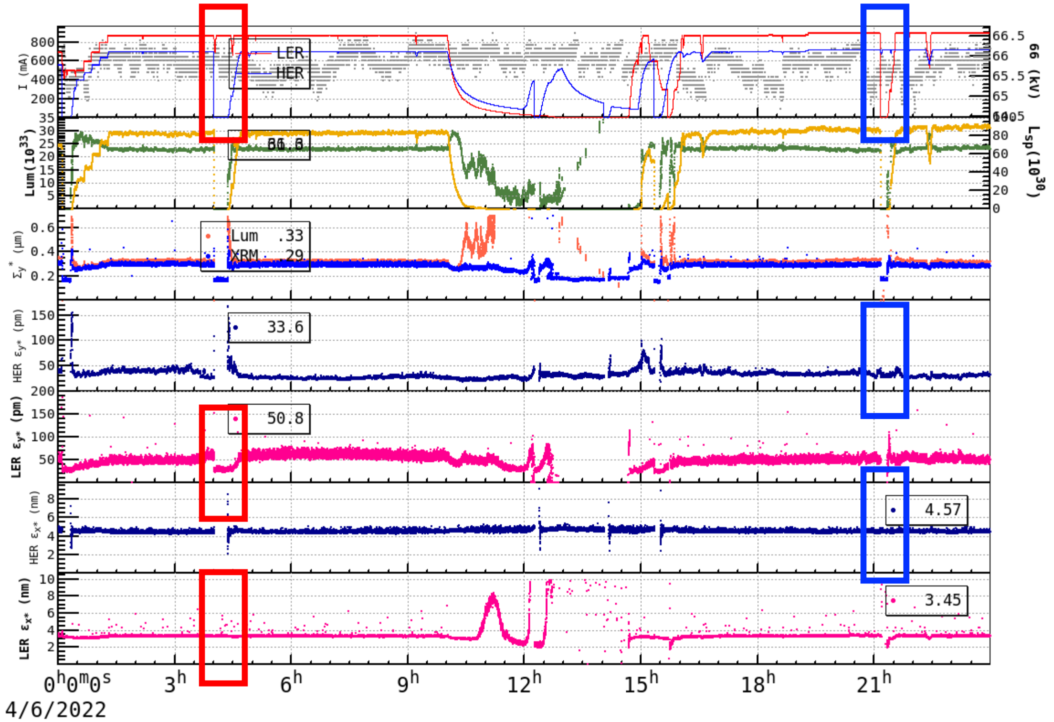


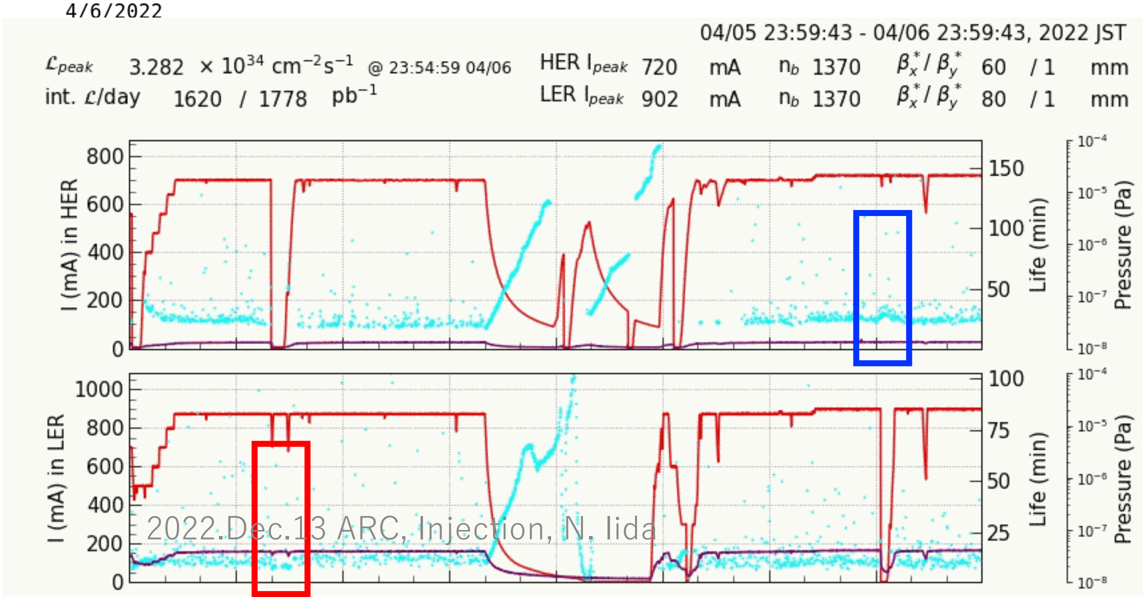


The lifetimes of simulations don't reproduce the real, especially for HER.

Injection efficiency depends on beam-beam effect





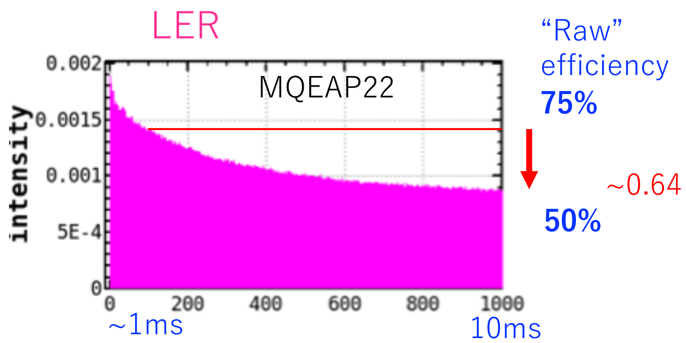


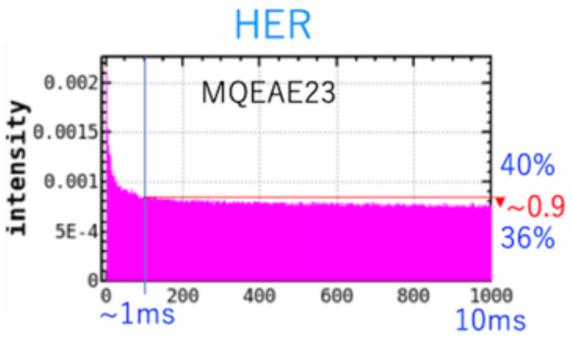
Inj. single→collision	LER	HER
"Raw" inj. efficiency [%]	↓ 90→80	↓ 50→40
Inj. efficiency [%]	↑ 30→40	↓ 40→15
εy [pm]	↑ 25→60	40→45
εx [nm]	3.5	4.6
lifetime [min]	↑ 6→8	↓ 32→30

The quantitative evaluation should be done.

II. Prospects for the future injections

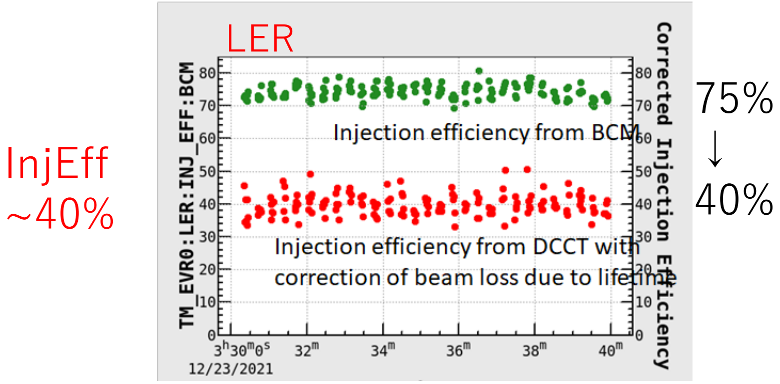
It is said this pattern is similar to the shape of one of the Belle II background, duration.

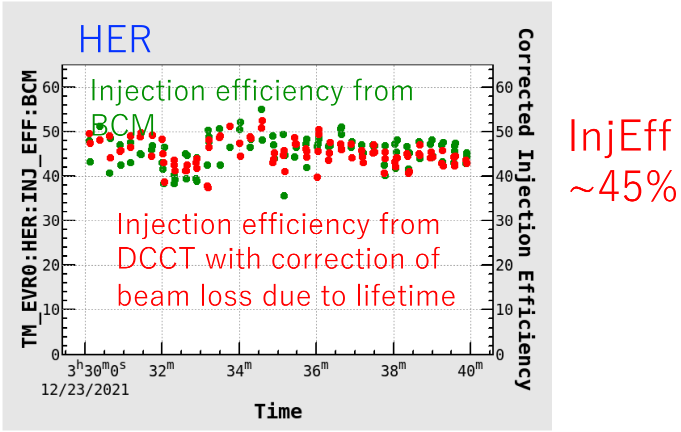




2021.Dec.23, βy*=1mm

Y. Funakoshi





The injection efficiency from DCCT with correction of beam loss lifetime is lower than "Raw injection efficiency". We used injection efficiencies which are corrected the lifetimes.

Example of parameters for L= 1 x10^{35}cm^{-2}s^{-1}

Y. Funakoshi

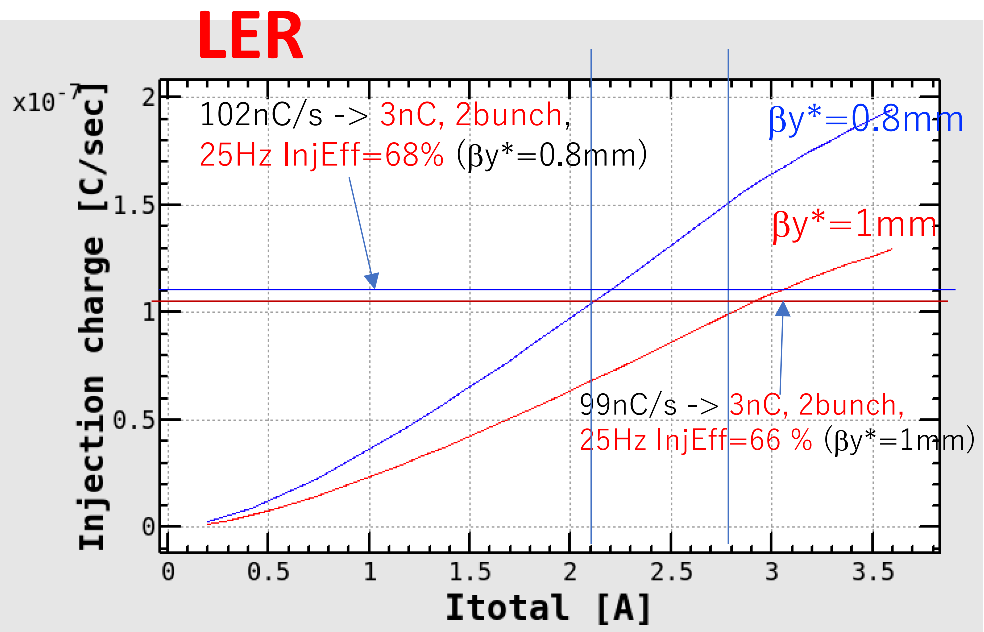
	LER	HER	LER	HER
# of bunches	2345+1		2345+1	
Luminosity	**1.0 x 10^{35} cm^{-2}s^{-1}**		**1.0 x 10^{35} cm^{-2}s^{-1}**	
I_{total}	2.08A	1.48 A	2.78 A	1.65 A
I_{bunch}	0.89mA	0.63mA	1.18mA	0.70mA
βy^*	0.8mm	0.8mm	1mm	1mm
σ_y^*	0.154μm	0.154μm	0.211μm	0.211μm
σ_z	6.49mm	6.35mm	7.26mm	6.51mm
Beam lifetime	3.4min.	14.8min.	4.7min.	16.9min.

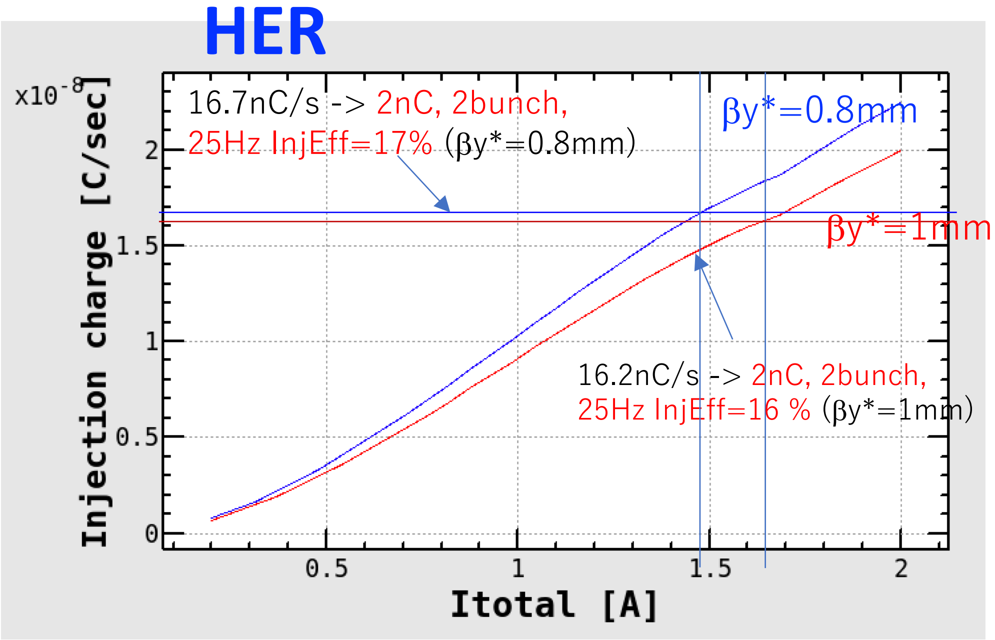
- This parameter list was made based on a high bunch current collision study.
- We will aim to achieve the parameter list.
- In the process of aiming at the parameter set, we will need to study various issues and aim at the luminosity with solving issues found and with modifying the parameter set.

Required injection charge

Many parameters assumed and see the backup slide for detail.

Y. Funakoshi

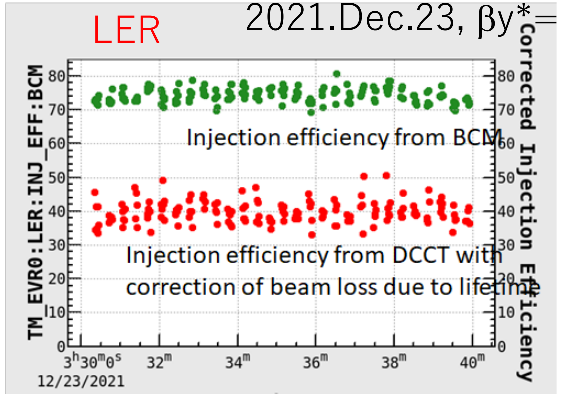


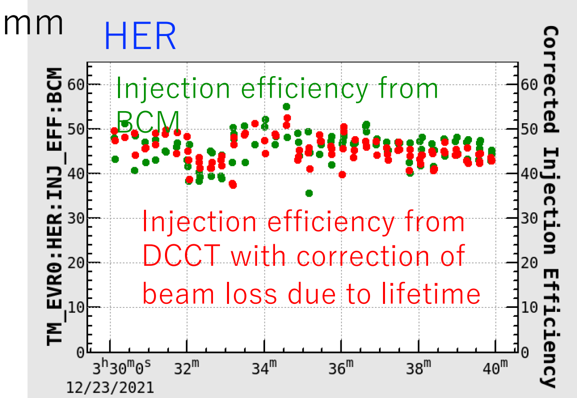


- To achieve the luminosity of **$1\text{x}10^{35}$ $cm^{-2}s^{-1}$**, the injection efficiencies should be **more than** 68% for LER and 17% for HER.
- It is difficult to achieve the injection efficiency of 68% for LER without improving the **emittance of injection beams** and **extending MR lifetimes**

2021.Dec.23, βy*=1mm

InjEff
~40%<<68% !!





InjEff
~45% >17%
for both bunches !

III. Summary

- Injection improvements
  - Some improvements and efforts were effective to realize higher injection efficiency.
  - The new beam monitors, OTRs and SRM in the BT are very useful for studies as well as operations.

- Issues
  - Observed horizontal emittance growth is consistently explained by ISR and CSR effects.
  - The source of vertical emittance growth is not understood yet.
  - Extensive simulation study as well as beam study is necessary to make decision of remodeling the BT lines or not.
    - Narrow chambers, e- ECS, New straight BT line

  - The bad injection efficiency may come from the emittance growth of the injection beam and/or the larger dynamic aperture of the HER.
  - The investigation of the beam loss during 1,000 turn in the LER is urgent. Improvement of injections are vitally importance to achieve the luminosity of $1 \times 10^{35} cm^{-2} s^{-1}$.

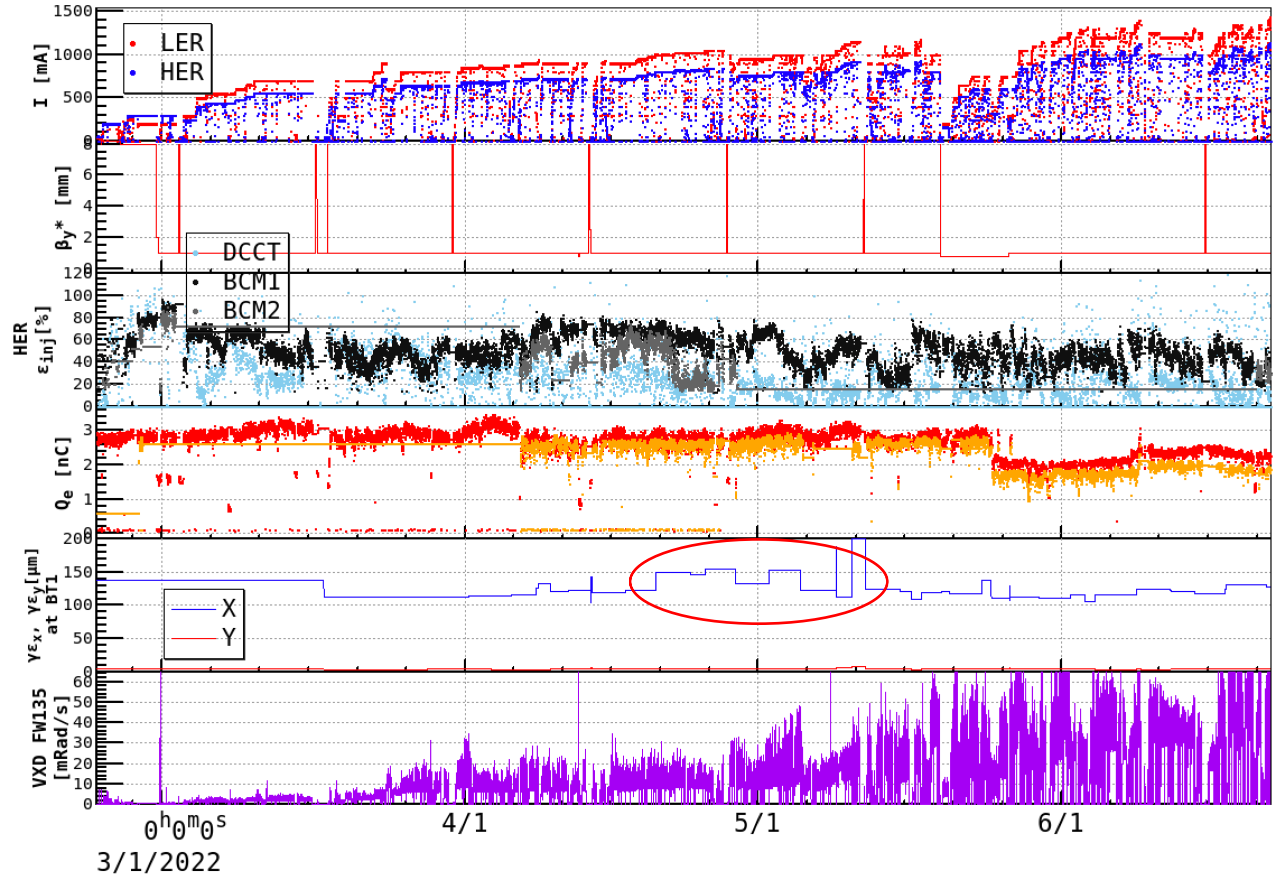
- To be continued to the new international task force for injection….

Backup slides

Emittances of injection beams

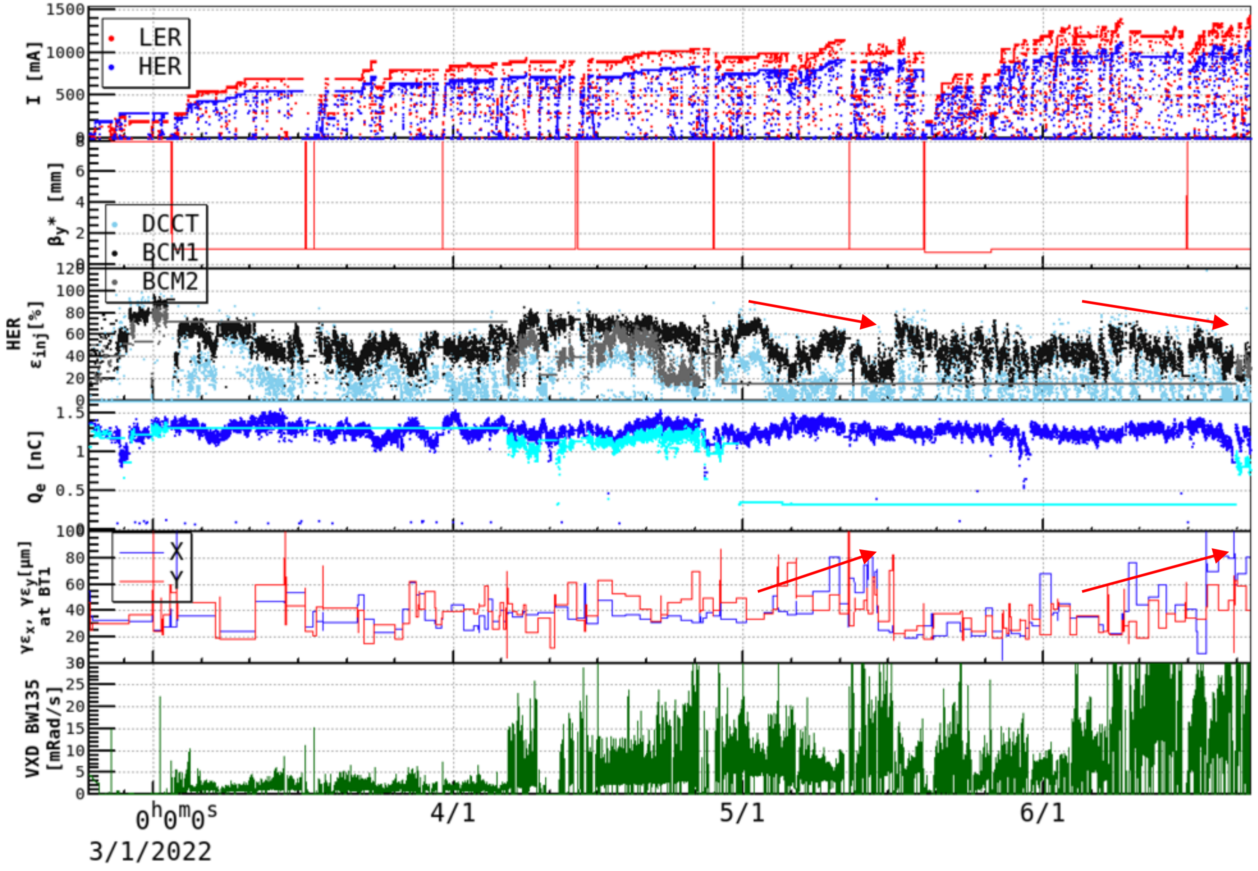
Sometimes the horizontal emittance($\gamma\varepsilon x$) became ~150mm, but it recovered after a few days. It's still a mystery.

LER

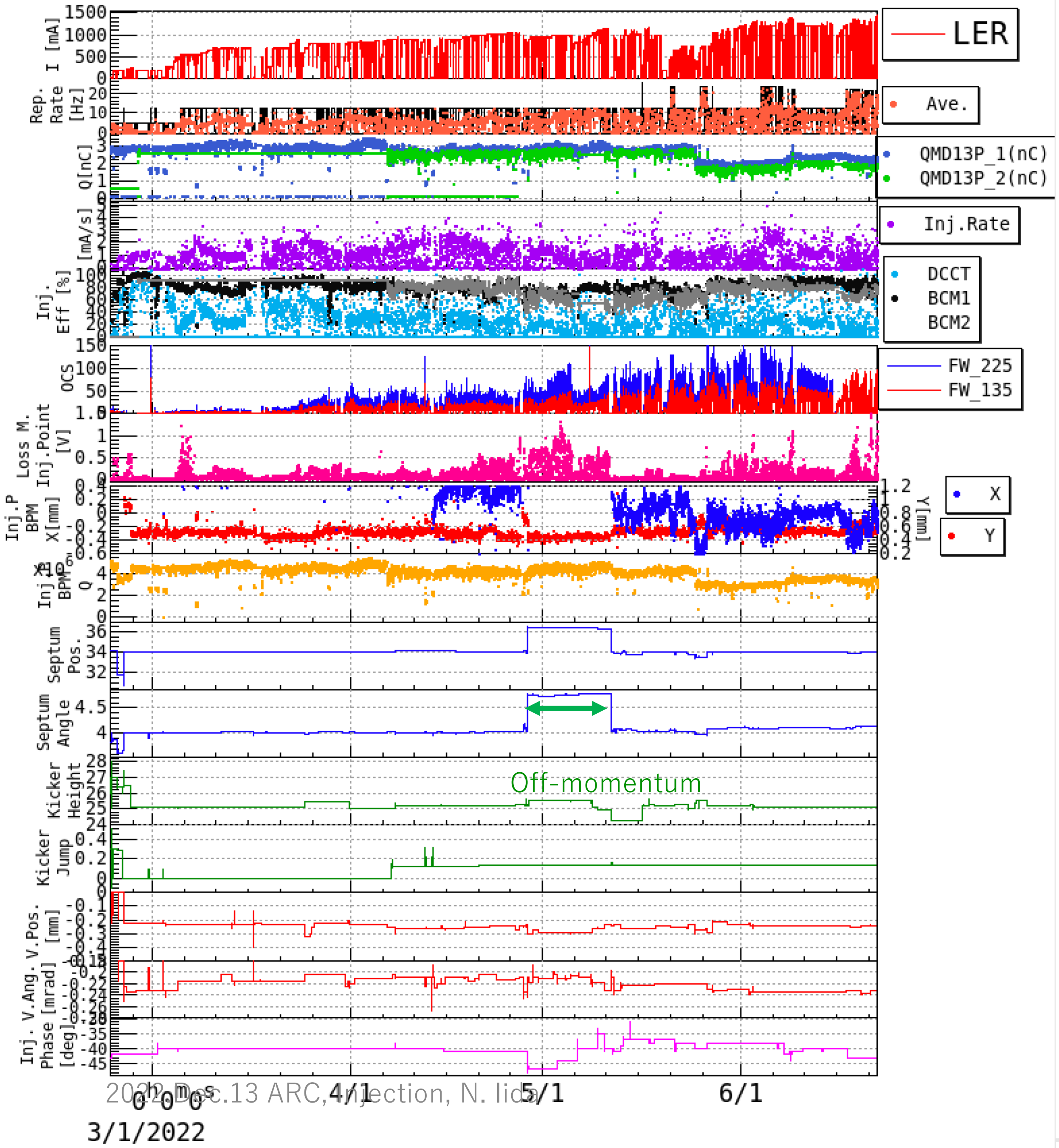


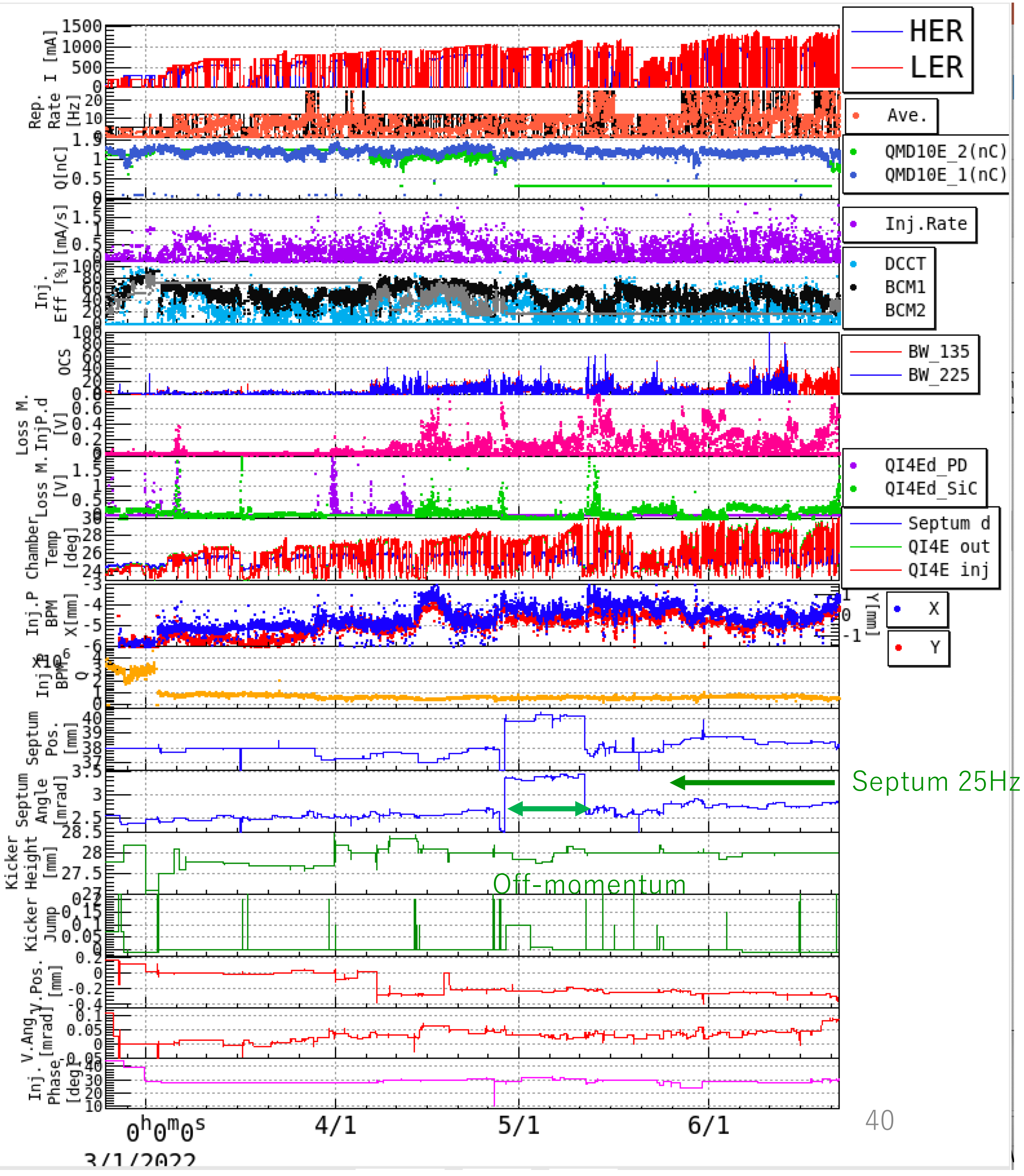
The emittances of e- beam had been gradually larger at the last 2 weeks, which caused the lower injection efficiency.

HER



1. Injection summary

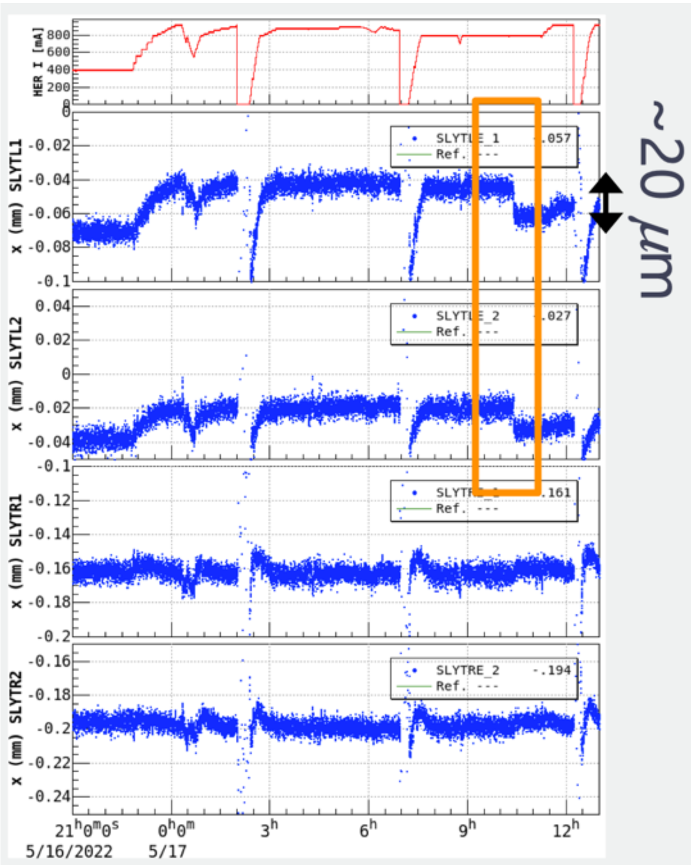




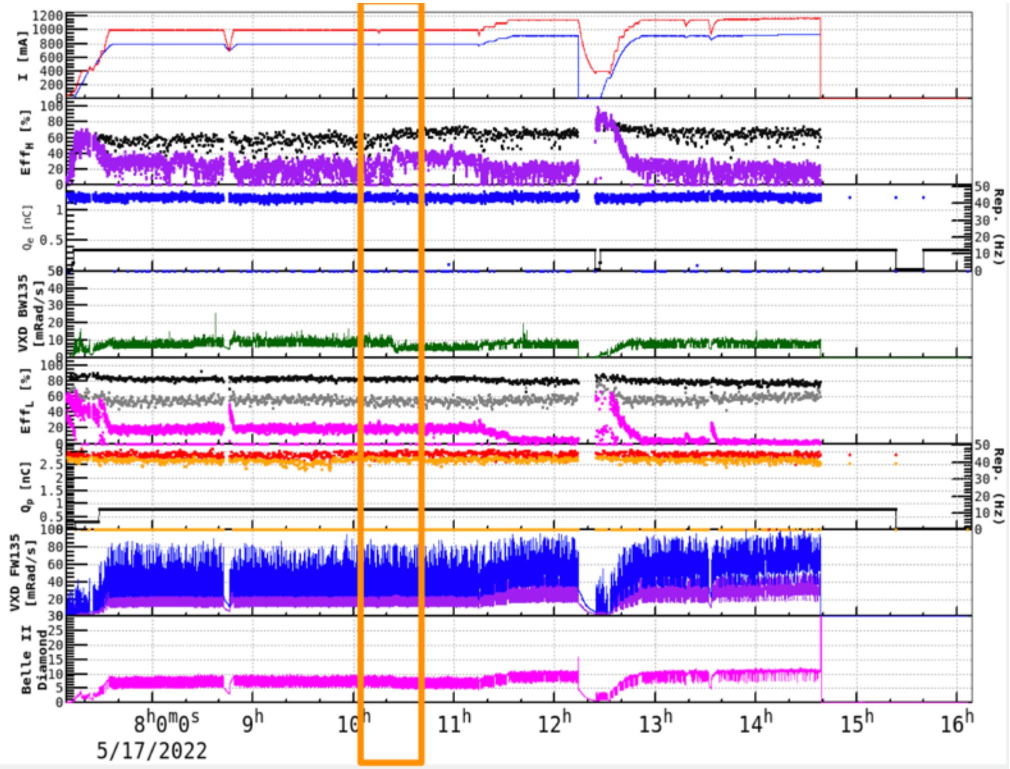
The orbit FB at SLY* in HER

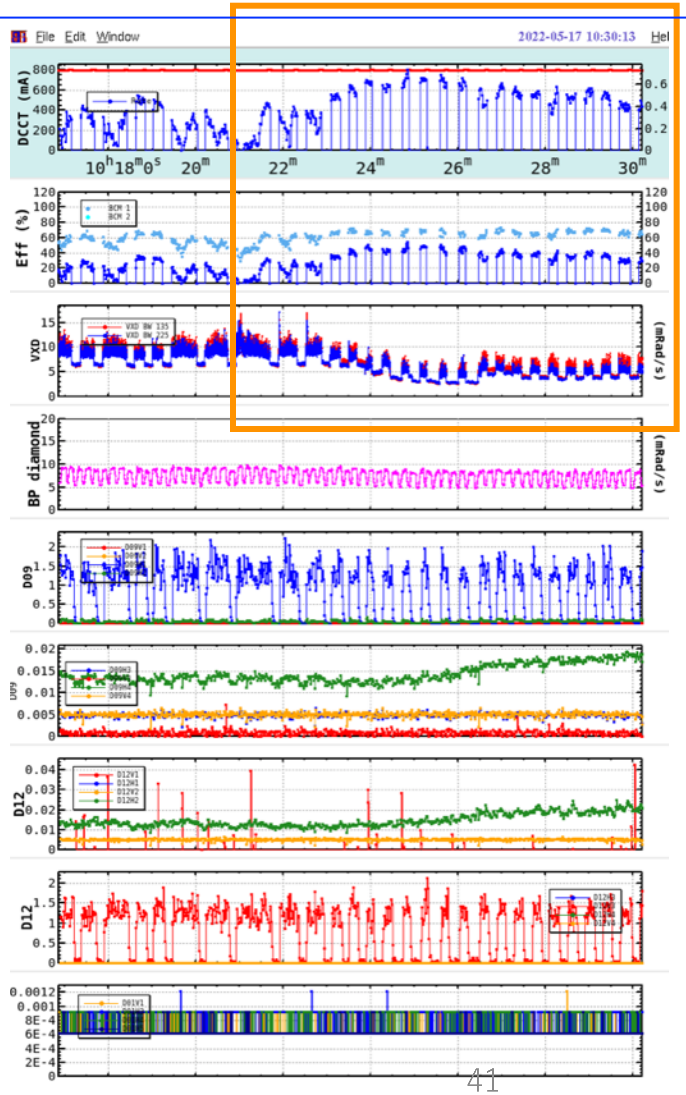
The horizontal orbits at SLY* in the KEKB rings affects to the injection.
Not only the injection efficiency and BG were improved, but the fluctuations were also reduced.

Orbit correction was performed using Local bump to compensate for the current dependence of the horizontal orbit in SLY.
Now the orbit feedback system was working.



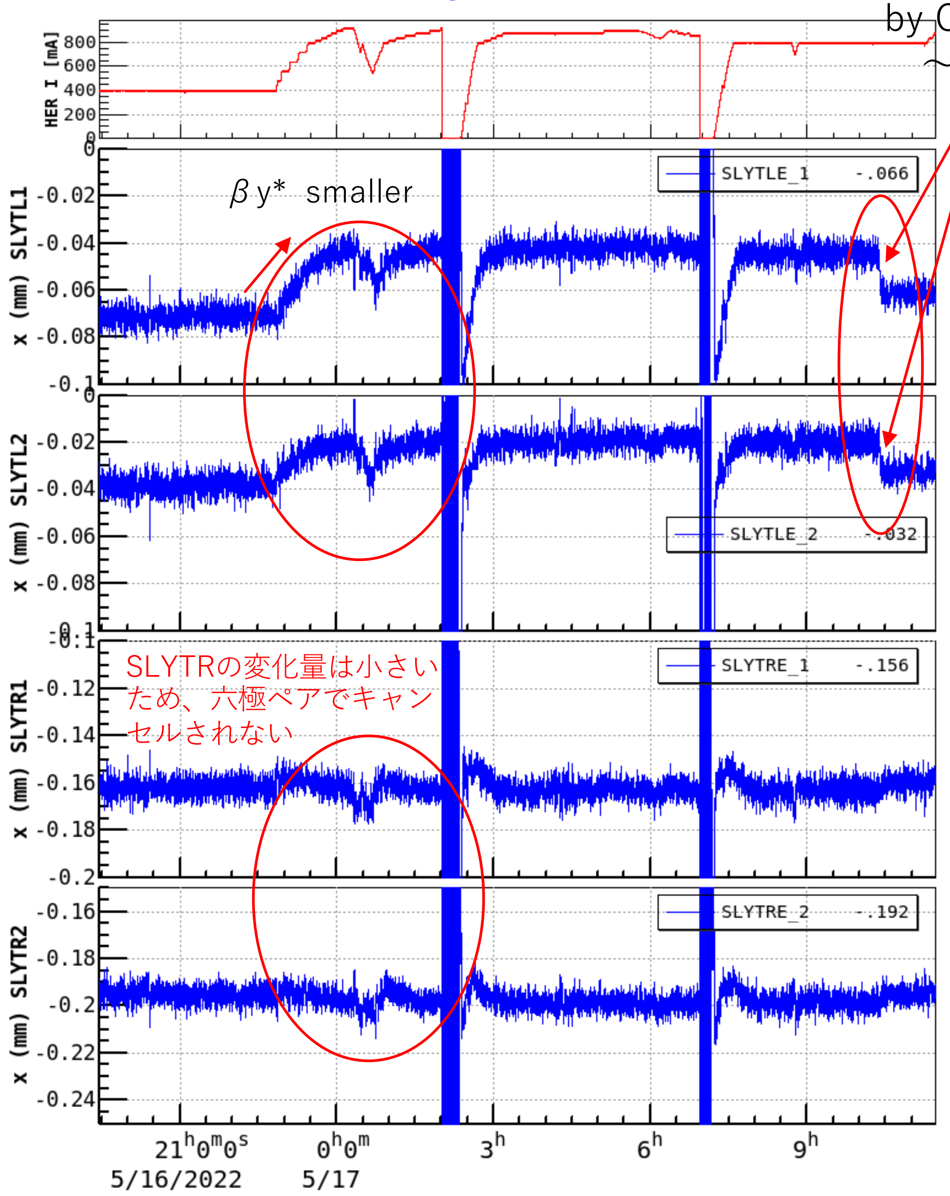
H. Sugimoto, Y. Ohnishi





Current dependent orbit offset @ SLYT**E

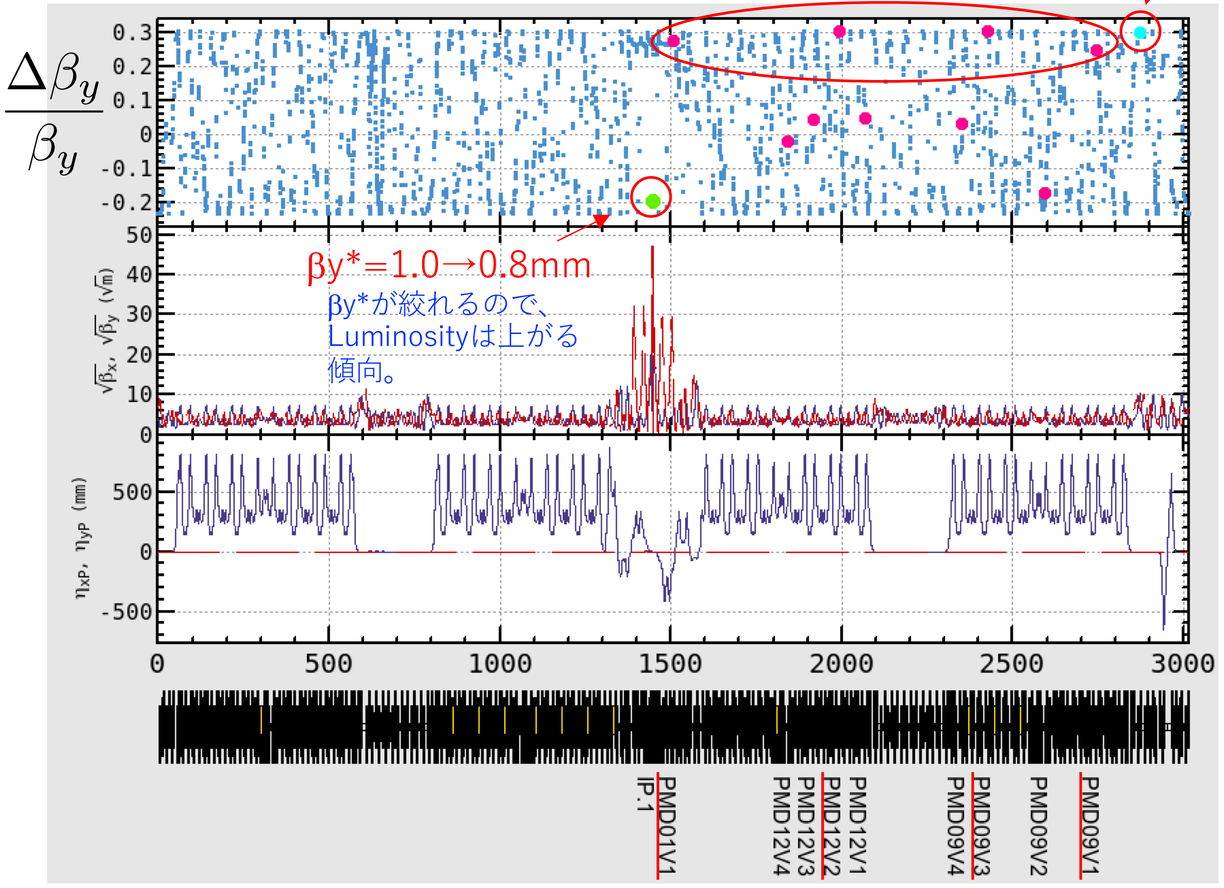
KCG: 2022_05_17_0900_Yoshino_Egawa



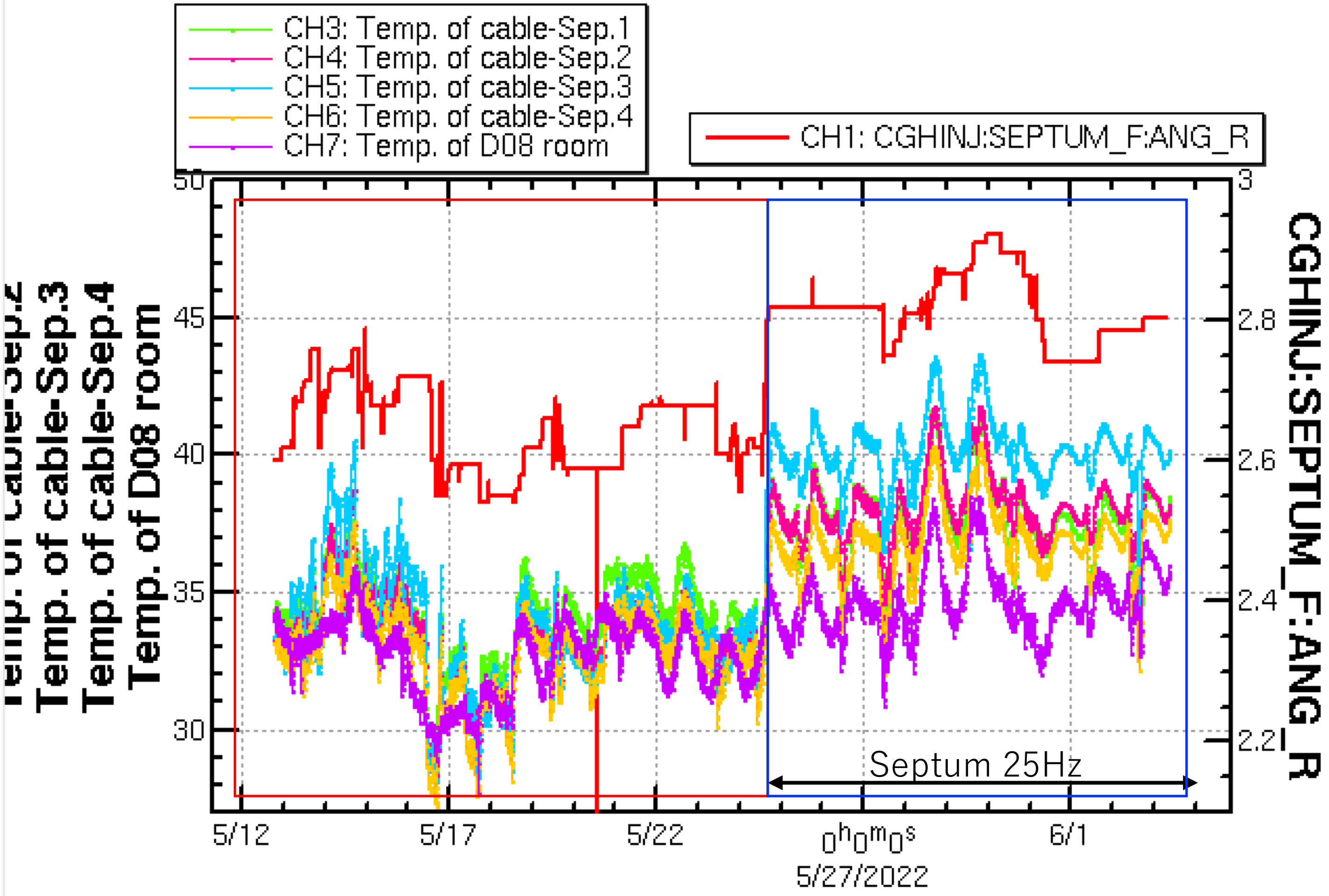
Corrected by Ohnishi-san ～20μm

Simulation:

DX(SLYTLE1)=DX(SLYTLE2) = -20μm の場合のβ beat

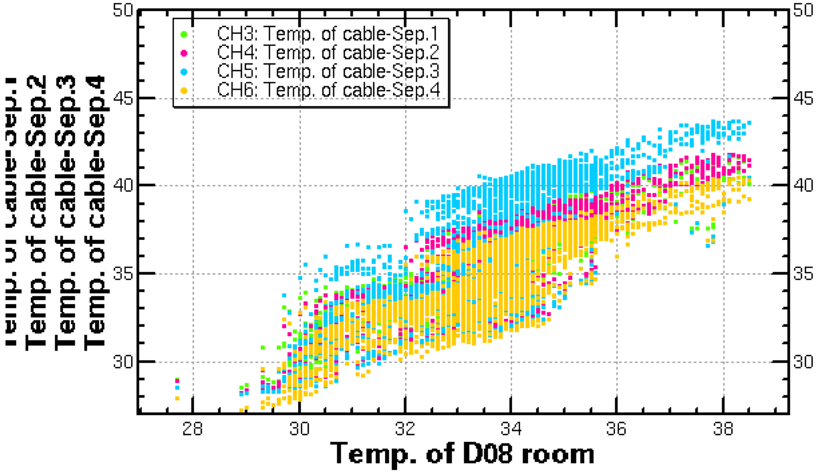


・入射点でのβyが設計値の1.3倍(BMAG=1.035)になる
・コリメータでのビームサイズが14%増大する
・HER内のβ関数が乱れる
等より、入射効率が悪化していた。実際には70%→60%であった。(前頁)



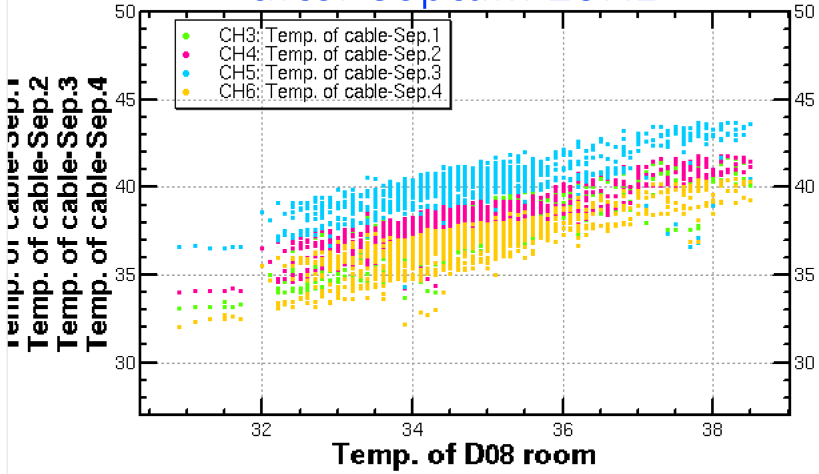
By the septum operation with keeping 25 Hz, the injection tuning was easier.

before septum 25Hz



The D08 room temperature dependence of the cable temperature had various coefficients due to the repetition of septum.

after septum 25Hz



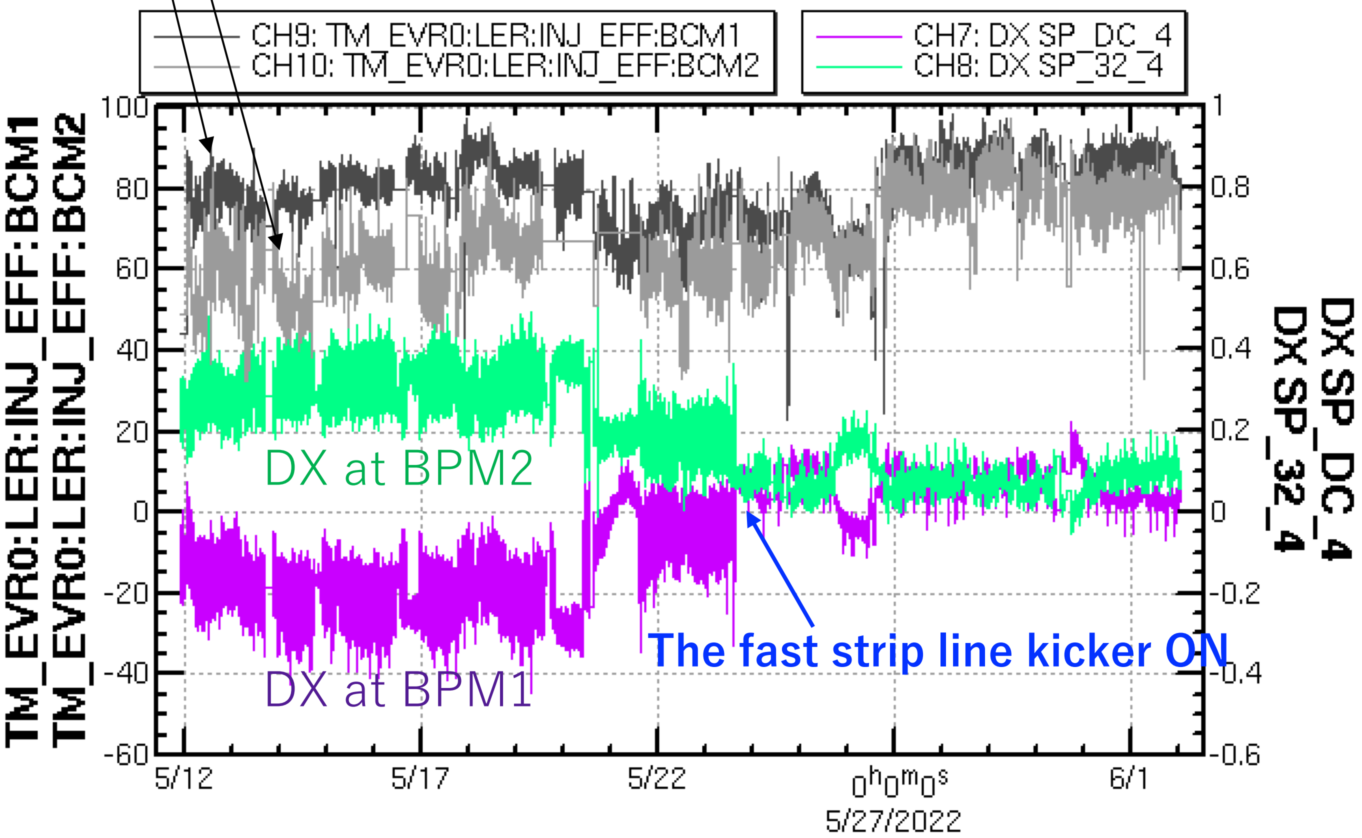
The cable temperatures which affects to the septum outputs now has a simple dependency on room temperature.

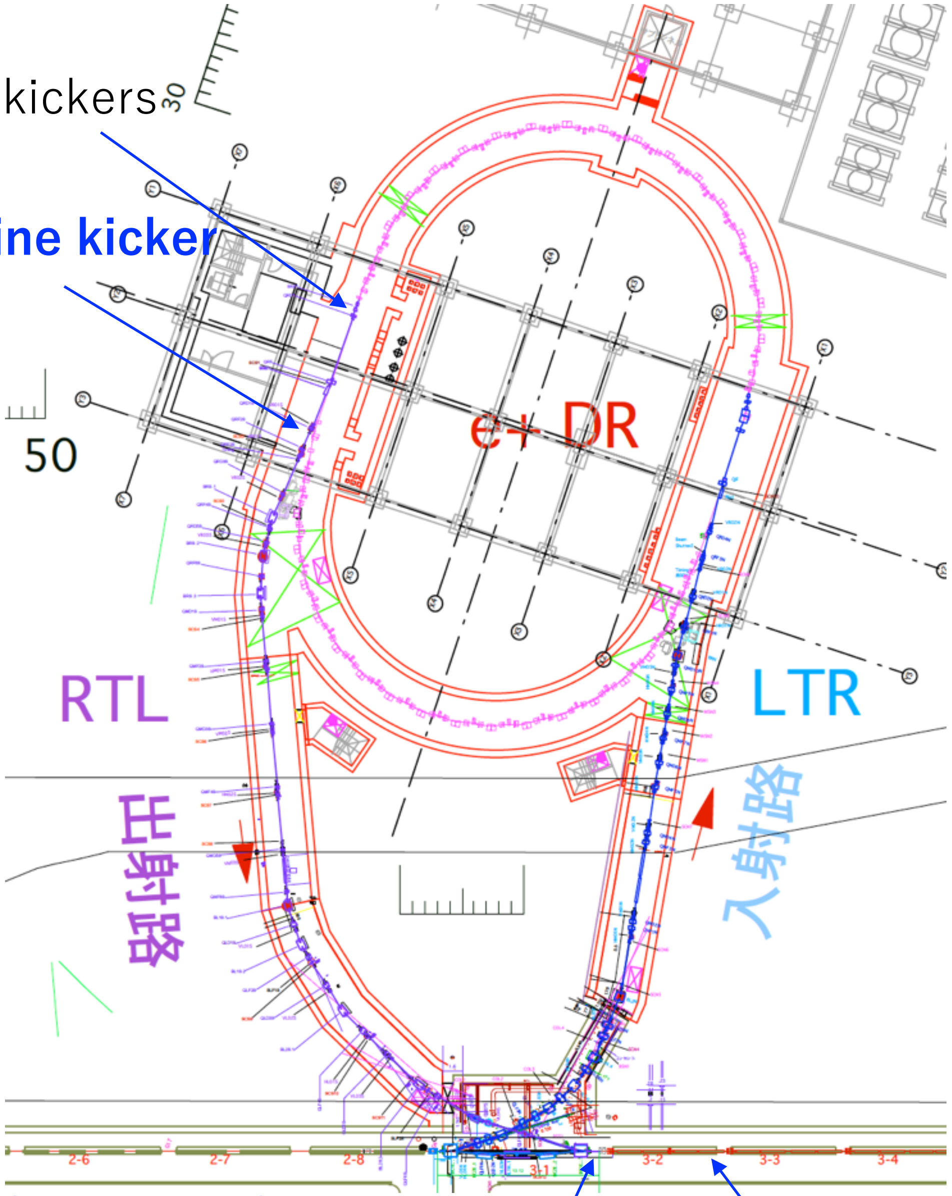
3. Fast strip line kicker for the e+ 2nd bunch in RTL

“Raw” injection efficiency of #1

“Raw” injection efficiency of #2

The efficiencies have been almost same since the kicker worked.



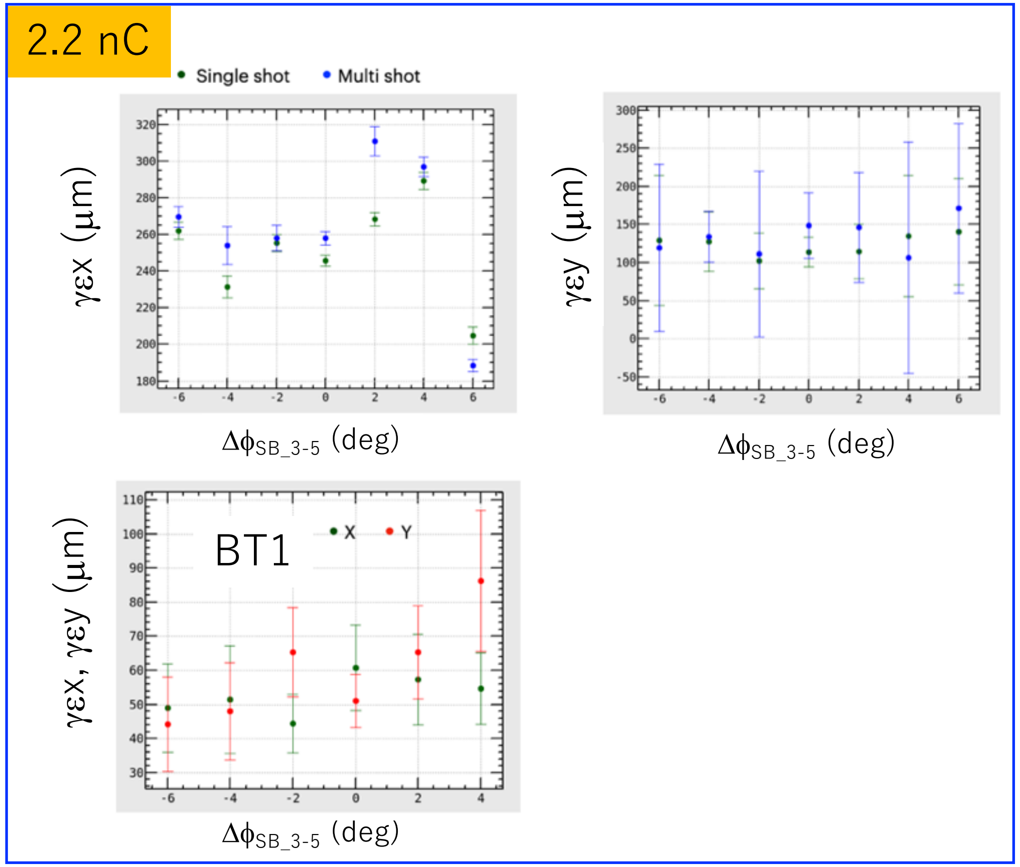


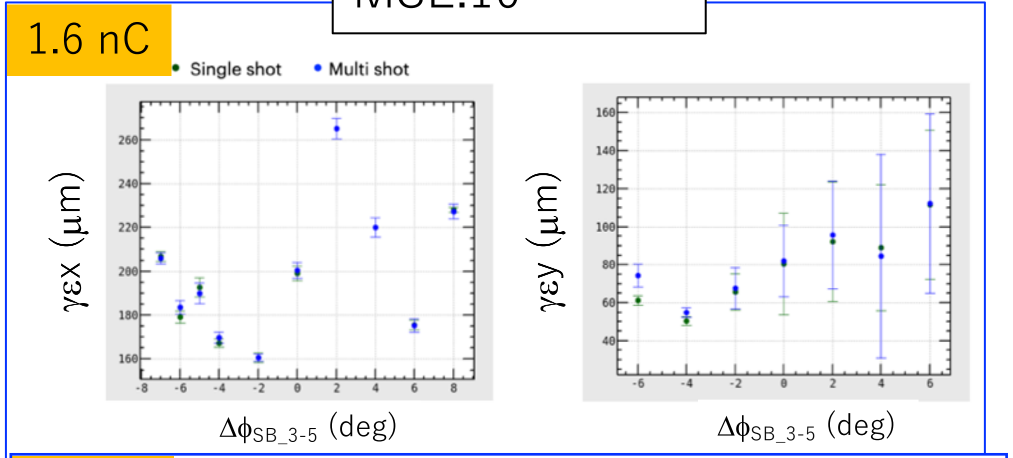
DX: Horizontal orbit difference (X_2-X_1)

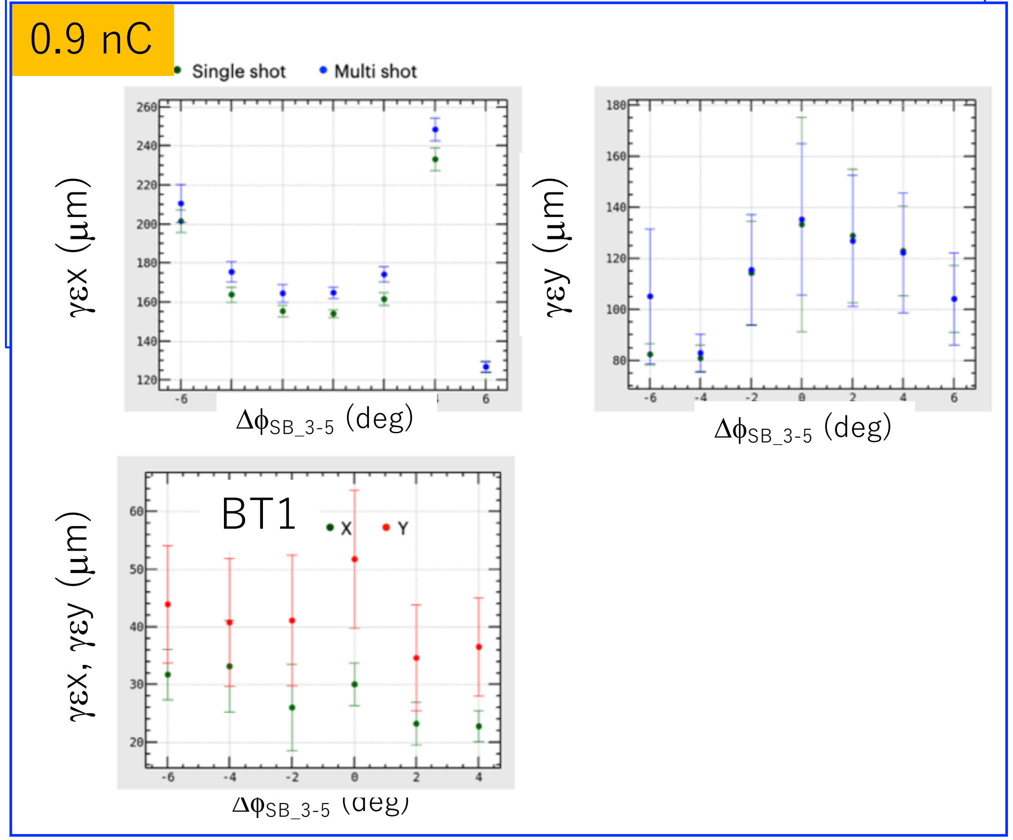
By improving the timing system, the fluctuation of the horizontal orbits became very small.

A) RF phase in SB_3~5

Measurements
MSE.10







- In the (–) region, γεx has a parabolic dependence.
- In the (+) direction, there is a region with smaller emittance.
- The correlation with RF phase is small between γεx and γεy at BT1 and gey at MSE.10.

A) PF phase and B) charge dependence on transverse emittances (measurement)

T. Yoshimoto

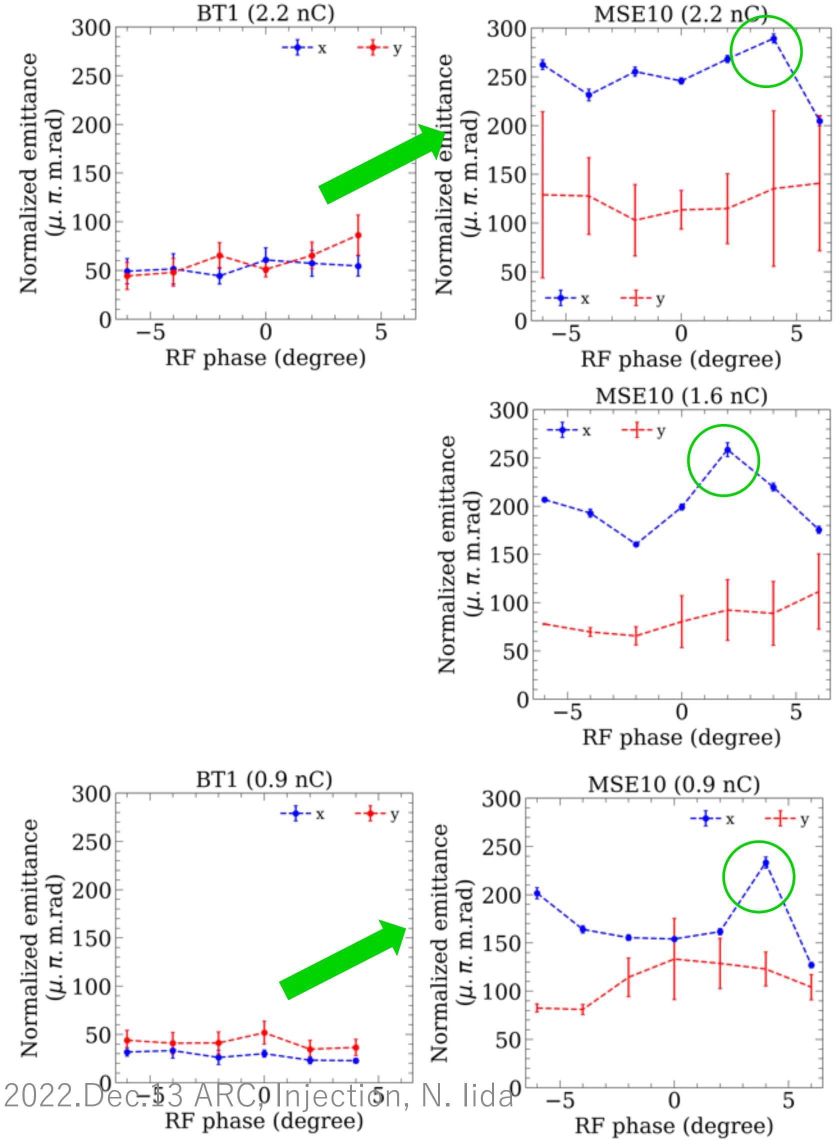
Emittance measurement:

BT1 MSE10

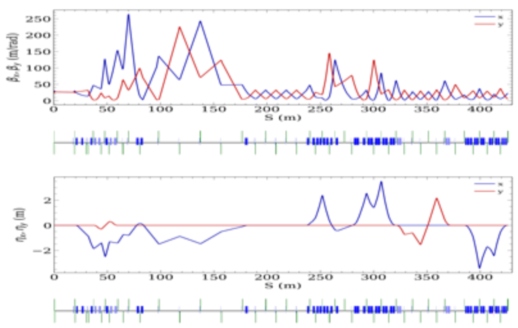
2.2 nC

1.6 nC

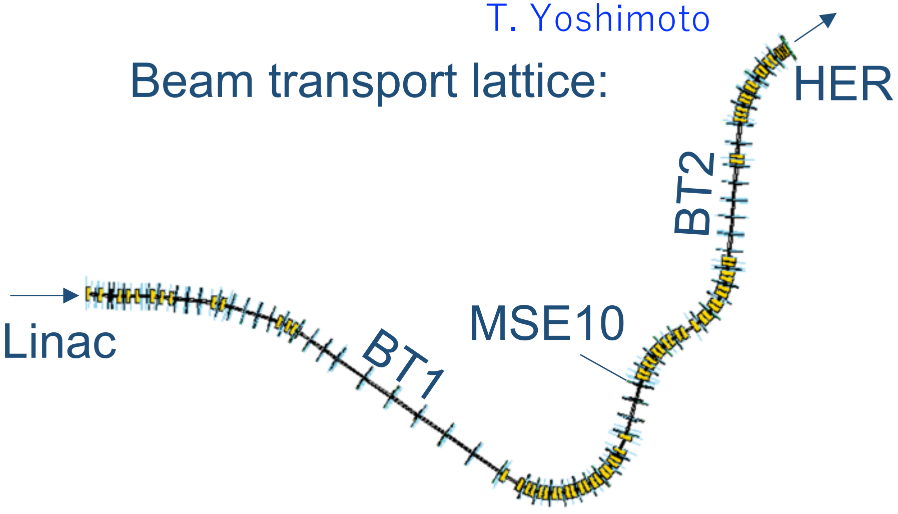
0.9 nC



Beam optics:



Beam transport lattice:



Sec. 3-5 RF phase and bunch charge (0.9, 1.6, 2.2 nC) were changed in this study.

=>

For each bunch charge,

- large x/y emittance growths between BT1 and MSE10 were observed.
- RF phase of max. horizontal emittance was ~ +4 deg.

=> Is this CSR effect?

* zero RF phase gives the minimum energy spread of a beam.

A) PF phase and B) charge dependence on transverse emittances (measurement)

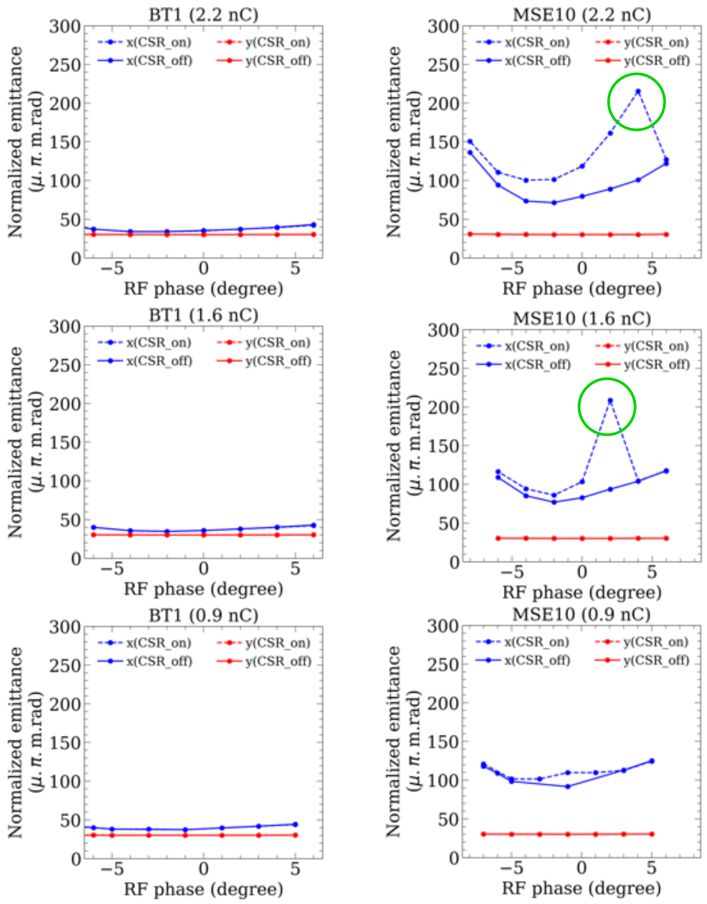
Emittances at BT1 and MSE10 (downstream)

BT1 MSE10

2.2 nC

1.6 nC

0.9 nC

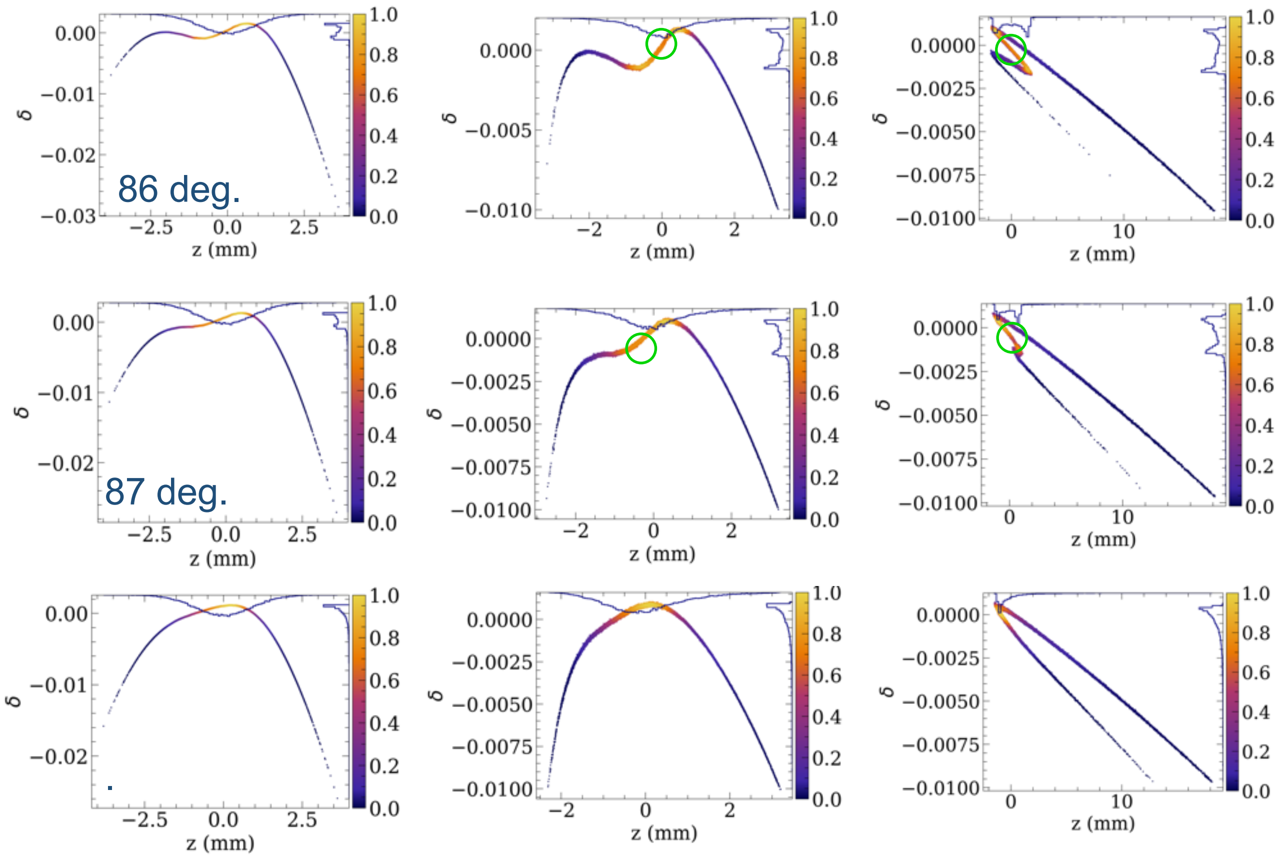


Lon. phase space dist. at BT1 and MSE10 at zero RF phase

T. Yoshimoto

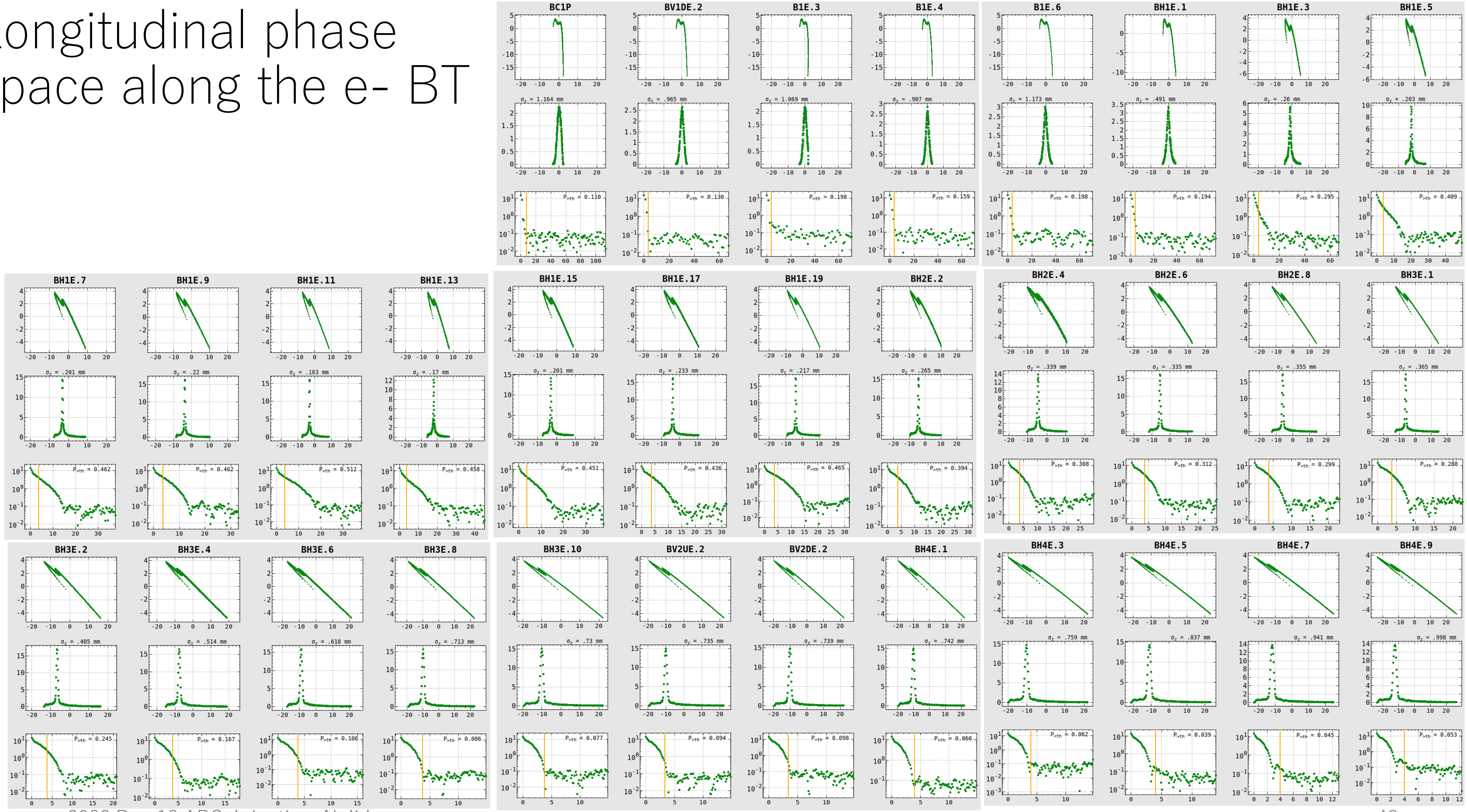
Secs.3-5 RF Phase:

PBTE (Before BT1) MSE6 (in BT1) MSE10



- Linac RF phase changes longitudinal phase distribution.
- A specific phase gives steep longitudinal histogram inside strong bending magnet. => large emittance growth
- In the simulation for a 0.9-nC bunch, there is no double peak structure in longitudinal phase before BT1, although it depends on bunch length. => it would give less CSR effect. However, the measured results shows a large emittance growth. This discrepancy is under investigation.

Longitudinal phase space along the e- BT



Optimization of the BT optics to minimize the CSR induced emittance growth

M. Kikuchi

- Betatron oscillation excited by an energy-kick due to CSR wake

$$\begin{cases} dx(z,s) = -\eta_x(s) W_{\mathrm{CSR}}(z,s) ds \\ dx'(z,s) = -\eta'_x(s) W_{\mathrm{CSR}}(z,s) ds \end{cases} \quad (1)$$

Where, W_{CSR} is the CSR wake normalized to the beam energy. If the CSR wake is constant in a single bend, we can analytically integrate Eq (1),

$$\begin{cases} x(z,s_1) = -W_{\mathrm{CSR}}(z,s_1) \int_{s_0}^{s_1} (m_{11}(s,s_1)\eta_x(s) + m_{12}(s,s_1)\eta'_x(s))\, ds \equiv W_{\mathrm{CSR}}(z,s_1) I(s_1) \\ x'(z,s_1) = -W_{\mathrm{CSR}}(z,s_1) \int_{s_0}^{s_1} (m_{21}(s,s_1)\eta_x(s) + m_{22}(s,s_1)\eta'_x(s))\, ds \equiv W_{\mathrm{CSR}}(z,s_1) I'(s_1) \end{cases} \quad (2)$$

where, s_0 and s_1 are entrance and exit of the bend, and $m(s, s_1)$ is a transfer matrix from s to s_1. In a beam line that has many bends, betatron oscillation due to multiple bends can be obtained by a summation,

$$\begin{cases} x(z,\delta,s^*) = \sum_j W_{\mathrm{CSR}} \left(z - m_{56}(s_j,s^*)\delta, s_j\right) [I(s_j) m_{11}(s_j,s^*) + I'(s_j) m_{12}(s_j,s^*)] \\ x'(z,\delta,s^*) = \sum_j W_{\mathrm{CSR}} \left(z - m_{56}(s_j,s^*)\delta, s_j\right) [I(s_j) m_{21}(s_j,s^*) + I'(s_j) m_{22}(s_j,s^*)] \end{cases} \quad (3)$$

where, $s*$ is the observation point and s_j stands for the exit of j-th bend.

Due to different phases between bends, partial cancellation is expected in the summation, which provides a possibility of optimization using the optics.

Eq. (3) can be rewritten with the normalized coordinate in the form of

$$\begin{pmatrix} X \\ P_X \end{pmatrix} = \sum_j W_j R(\Delta\phi_j) \begin{pmatrix} H_X \\ H_{P_X} \end{pmatrix}_j \quad (4)$$

where, $W_j = W_{\mathrm{CSR}}(z - m_{56}(s_j, s^*))$, $\Delta\phi_j = \phi(s^*) - \phi(s_j)$, and $R(\phi) = \begin{pmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{pmatrix}$.

$$\begin{pmatrix} H_X \\ H_{P_X} \end{pmatrix}_j = \begin{pmatrix} I(s_j)/\sqrt{\beta_j} \\ I(s_j)\alpha_j/\sqrt{\beta_j} + I'(s_j)\sqrt{\beta_j} \end{pmatrix} \quad (5)$$

- In the following example, we have replaced the CSR wake with P_j, an integral of the bunch spectrum whose frequency is higher than the threshold given by the parallel plate model. We have defined $2J\_score$ as

$$2J\_score = X^2 + P_X^2 \equiv \left\| \sum_j \left(\frac{P_j}{E_0}\right) R(\Delta\phi_j) \begin{pmatrix} H_X \\ H_{P_X} \end{pmatrix}_j \right\|^2 \quad (6)$$

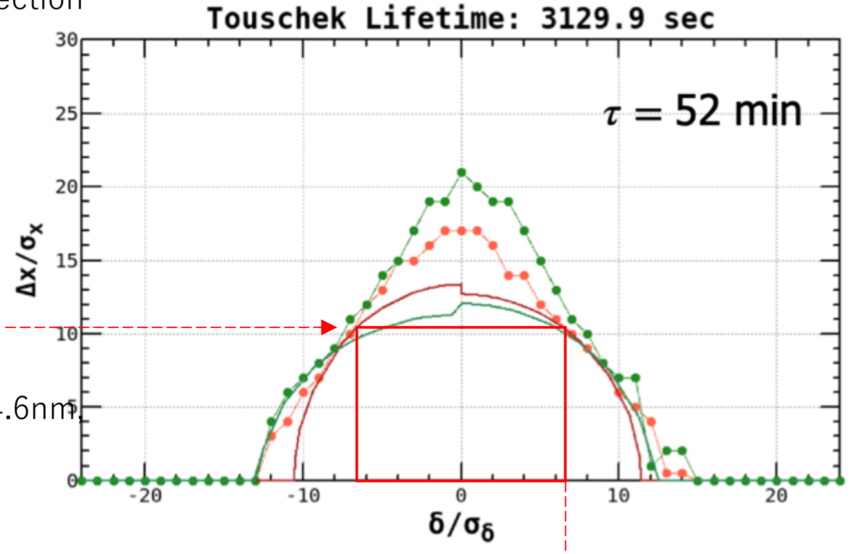
Eq. (6) is considered to be a crude measure of the CSR induced emittance growth.

Longitudinal acceptance in HER

This DA plot should be used the injection distribution.

βy*=1mm
Crab Waist=40%
QCS Aperture + Collimators
No machine error

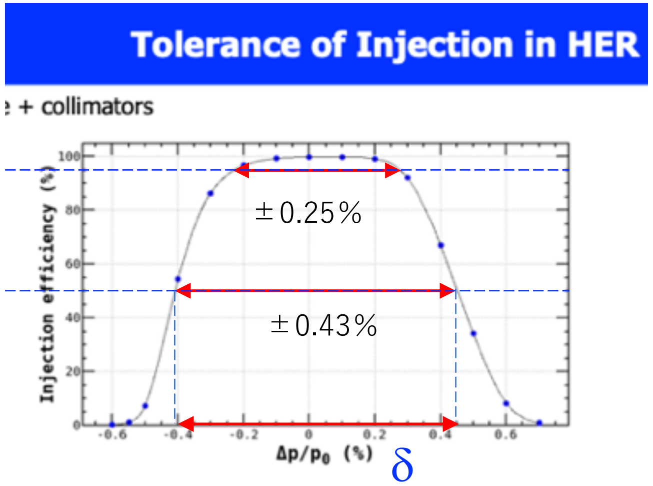
Y. Ohnishi



① $2J_x=5\times10^{-7}$、
When $\varepsilon_{xHER}=4.6$nm,
$\Delta X/\sigma_x<10.4$

② $\delta/\sigma_\delta=6.7$, $\sigma\delta=6.3\times10^{-4}$
より、δ<0.42%

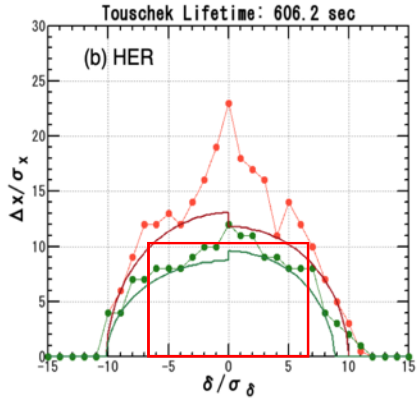
Y. Ohnishi



③
In the injection simulation,
The beam energy where the injection efficiency becomes 50% is δ=±0.43%, which is consistent to the left figure.

βy*=0.3mm
Crab Waist=0%
QCS Aperture
No machine error

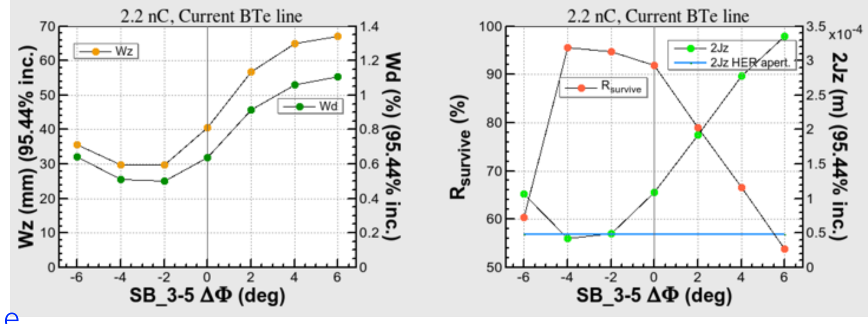
TDR



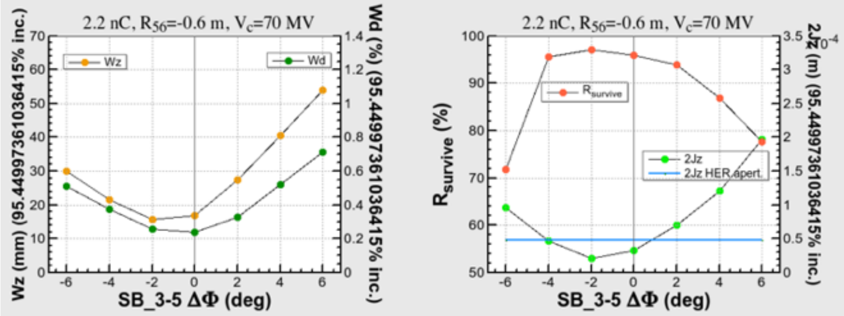
The DA of TDR is the value at βy*=0.3mm, which is smaller than $\Delta X/\sigma_x$= 10.4 and the incidence efficiency is low.
So we decided to use synchrotron injection scheme for HER at the time.

Longitudinal emittance

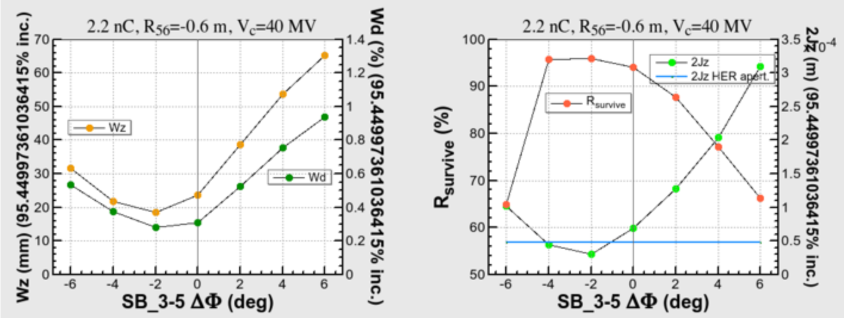
1. Current BTe line



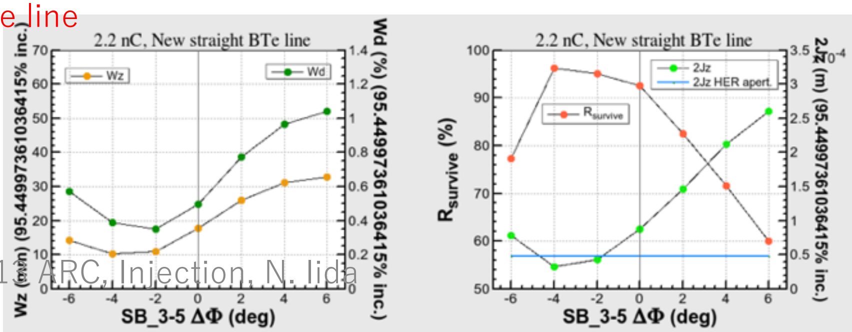
2. Current BTe line +ECS(R_{56}=-0.6, Vc=70MV)



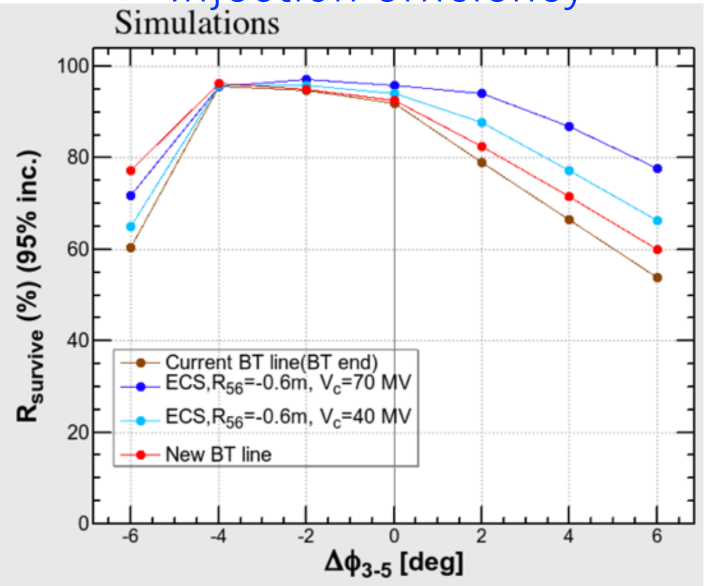
3. Current BTe line +ECS(R_{56}=-0.6, Vc=40MV)



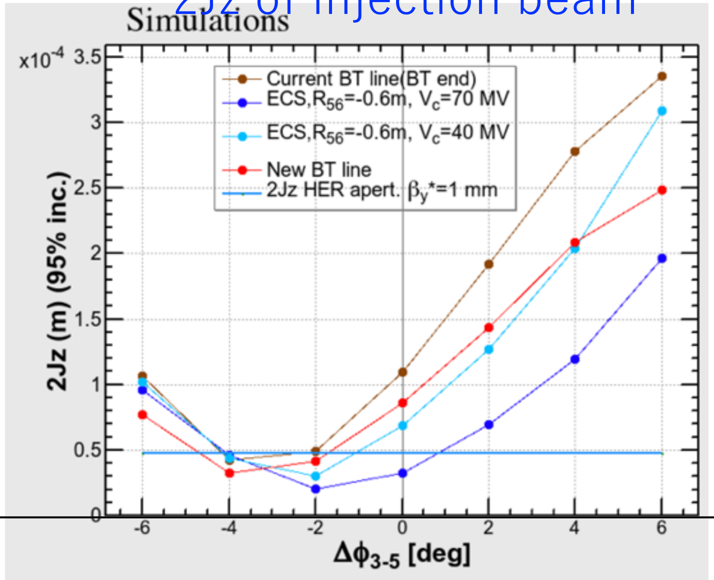
4. New straight BTe line



Injection efficiency



2Jz of injection beam



Result:

e- ECS

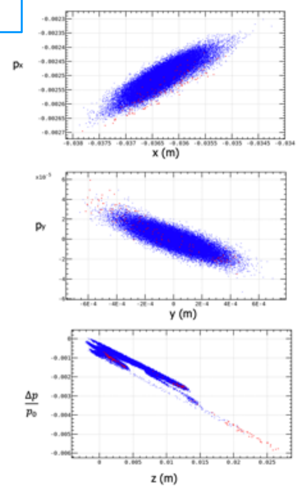
- Even with R56=-0.6m Vc=70MV, the effect of lowering 2Jz can be seen
- Investigation with a parameter of R56 = -1.0m is planed.

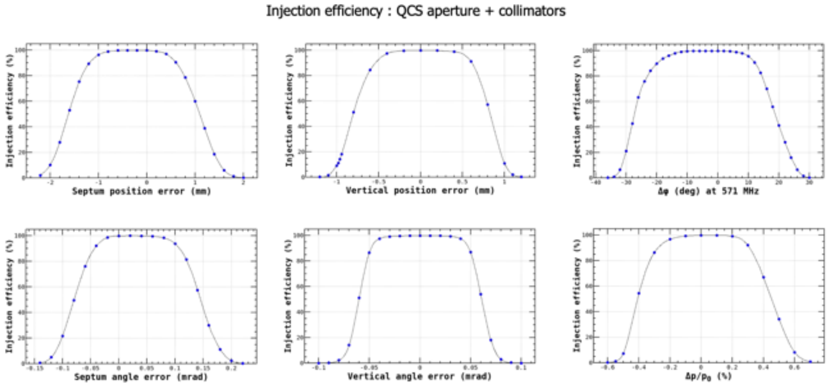
Simulation of injections

Y. Ohnishi

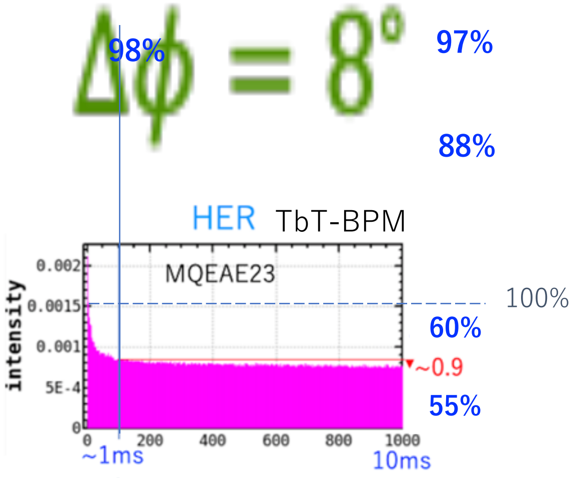
HER

Initial particles





Simulation

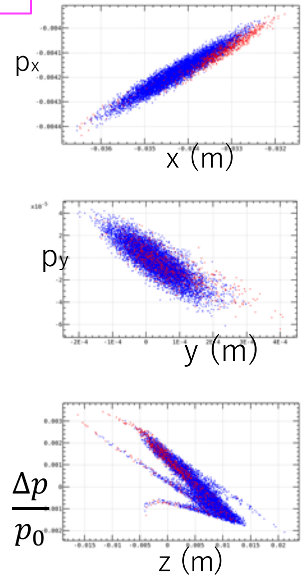


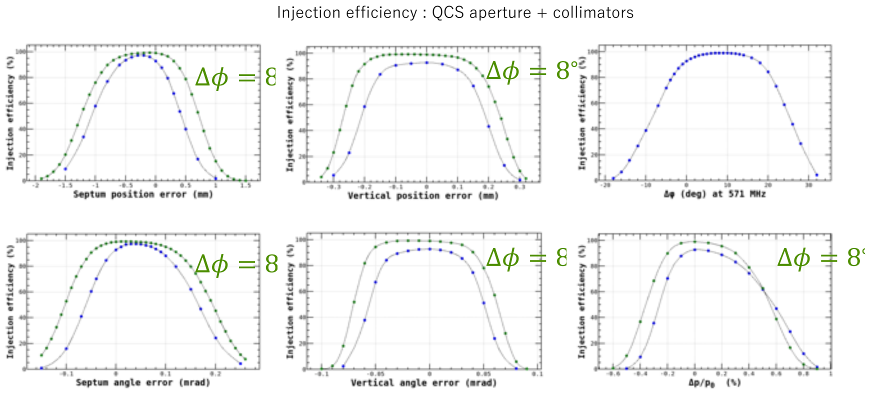
Real injection efficiency is much worse than these simulation.

- The emittances of injection beam are worse ?
  OR/AND
- The dynamic aperture of HER is worse ?

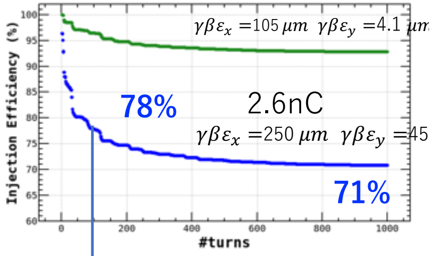
LER

Initial particles



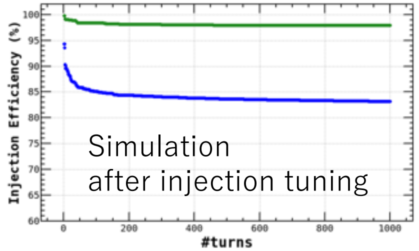


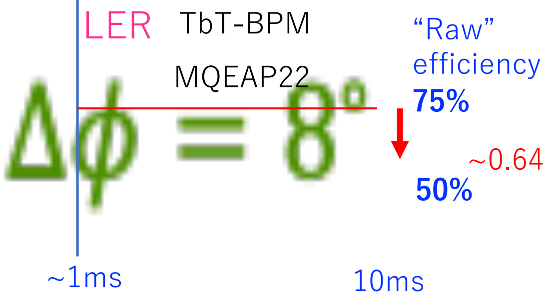
Simulation



Injection tunings

injection phase: $\Delta\phi = +8^\circ$ $\Delta x_{sp} = -0.2mm$ $\Delta\theta_{sp} = 0.04mrad$





- The simulation can not reproduce the real injection.
- It is serious problem where the beam loss after the injection comes from.

Assumption in calculation of required injection charge

Y. Funakoshi

- Required injection charge ($I_{inj}Inj_{eff}$[C/sec])

$$I_{inj}Inj_{eff} = \frac{1}{f_{rev}}\frac{I_t}{Life}$$

- Specific luminosity
  - We assume relatively high values achieved in the high bunch current study.
- Number of bunches
  - 2345 + 1 (pilot bunch) (2 bucket spacing)
- Beam current ratio
  - Assume that the ratio is dependent on bunch current product
- Required total beam currents
  - Use the above parameters and calculate required total beam current to achieve luminosity of 1 x 10^{35}/cm^2/s
    - Two cases: βy*= 1mm and 0.8mm (In case of βy*=0.8mm, specific luminosity is assumed to increase by 25%.)
- Beam lifetime
  - Touschek and vacuum lifetimes are considered. Touschek is don
  - C_T and C_V was determined experimentally. Luminosity lifetime is

$$\tau_{Touschek} = C_T \frac{n_b}{I_{beam}} \sqrt{\varepsilon_x \varepsilon_y \sigma_z}$$

$$\tau_{Vacuum} = C_V \frac{1}{I_{beam}}$$

Values in physics run

from streak camer

from specific luminosity w/ assumption of σy*(LER) = σy*(HER)