

Emittance growth in Beam transport (BT) and Injection

SuperKEKB Review

July 15th, 2020

N. Iida

for Emittance preservation task force group



Contents

1. Introduction

- A) Charge, lifetime, and luminosity
- B) Layout

2. Quality of injection beam

- A) Measured emittance and injection
- B) Improvements of e⁺ BT
- C) Emittance explosion in e⁻ BT**

3. Injection

- A) Mystery of injection tuning
- B) 2 bunch injection
- C) Correction of Injection kicker for LER
- D) Bucket selection test
- E) Future plan

4. Summary



Luminosity & lifetime



The luminosity can be written in terms of *specific luminosity* as:

$$\mathcal{L} = e^2 N_b N_+ N_- f_0^2 \mathcal{L}_{\text{sp}} , \quad (1)$$

where $N_{\pm}$, N_b , f_0 are the particles/bunch, bunches/ring, and the revolution frequency, respectively. At the equilibrium, $N_{\pm}$ must balance with the injector currents $I_{\pm\text{inj}}$ as:

$$e N_{\pm} N_b f_0 = I_{\pm\text{inj}} \varepsilon_{\pm} \tau_{\pm} , \quad (2)$$

where $\tau_{\pm}$ and $\varepsilon_{\pm}$ are the lifetimes and the injection efficiencies of $e^{\pm}$ beams. Then the luminosity is expressed as

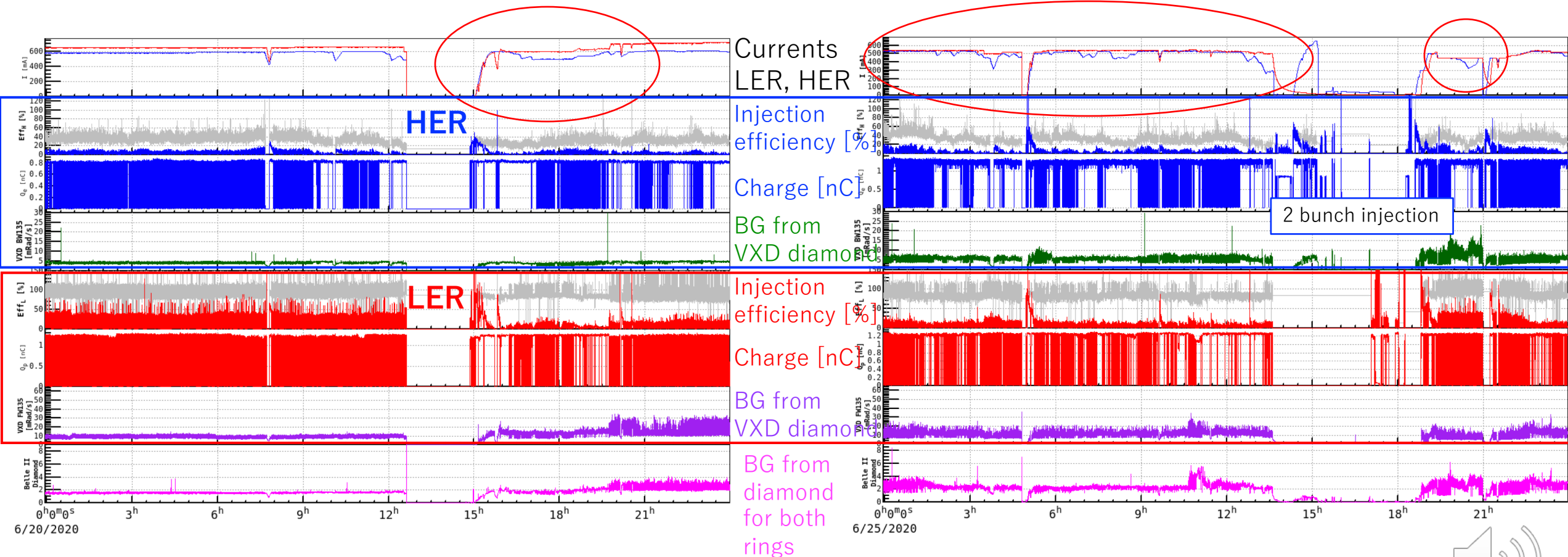
$$\mathcal{L} = \boxed{I_{+\text{inj}} \varepsilon_+ I_{-\text{inj}} \varepsilon_-} \frac{\tau_+ \tau_-}{N_b} \mathcal{L}_{\text{sp}} . \quad (3)$$

Date 2020	β_y^* mm	N_b	τ_+ sec	τ_- sec	$\mathcal{L}_{\text{sp}}$ $1/\mu\text{bs}/\text{mA}^2$	$\frac{\tau_+ \tau_-}{N_b} \mathcal{L}_{\text{sp}}$ $\text{s}/\text{nb}/\text{mA}^2$
6/21	1	978	588	1500	53.4	48.2
6/25	0.8	978	588	1122	66.8	45.1
6/29	0.8	395	588	1068	58.5	93.0
6/29	0.8	789	588	1320	65.0	63.9
6/30	0.8	1565	660	1860	76.4	53.1



Poor injection rates for the short life times

Especially for HER, once injected upto high current, the HER injection could not catch up after LER current becomes higher.



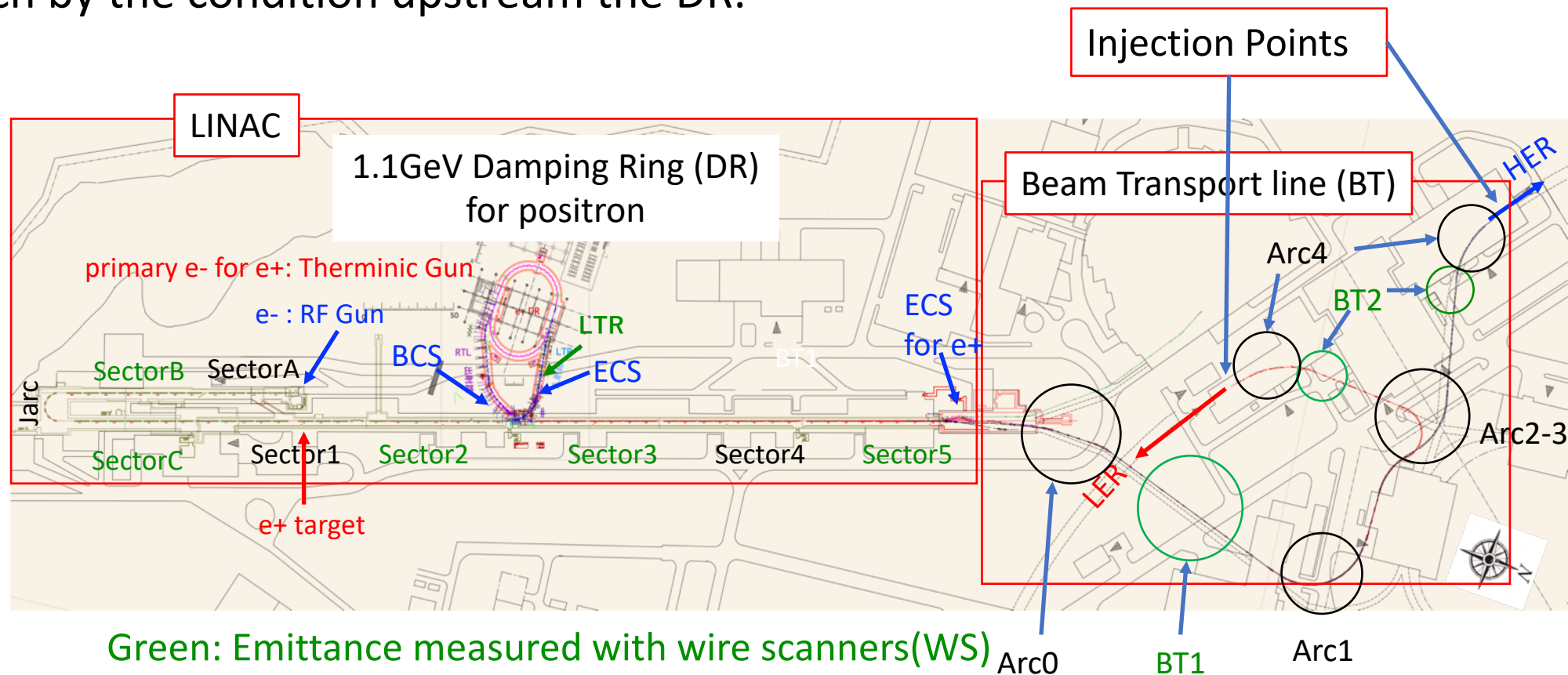
B) Layout of LINAC, BT, Injection to MR

e⁺ beam injects into LER via DR:

The injection BG is not affected very much by the condition upstream the DR.

e⁻ beam directly injects into HER:

The injection BG is directly affected by the condition of RF-gun, LINAC, and BT.



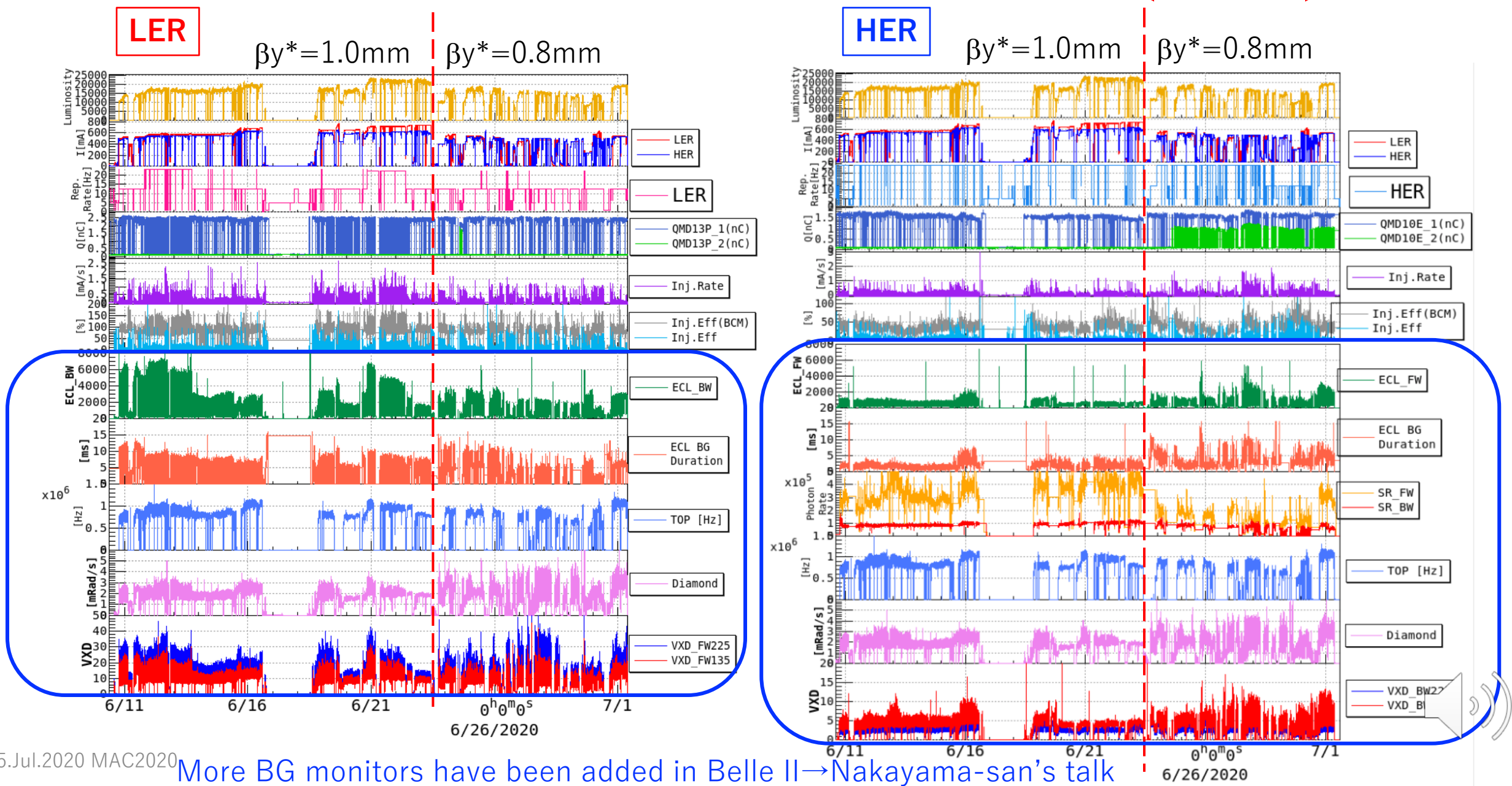
Green: Emittance measured with wire scanners(WS)

BCS: Bunch Compression System

ECS: Energy Compression System



Summary of injection (last 3 weeks)



2. Quality of Injection beam

A) Measured emittance and Injection

B) Improvements of e⁺ BT

1. Horizontal emittance
2. Vertical emittance
3. Tuning of energy spread

C) Emittance explosion in e⁻ BT



Trend graphs of measured emittance with wire scanners (e-)

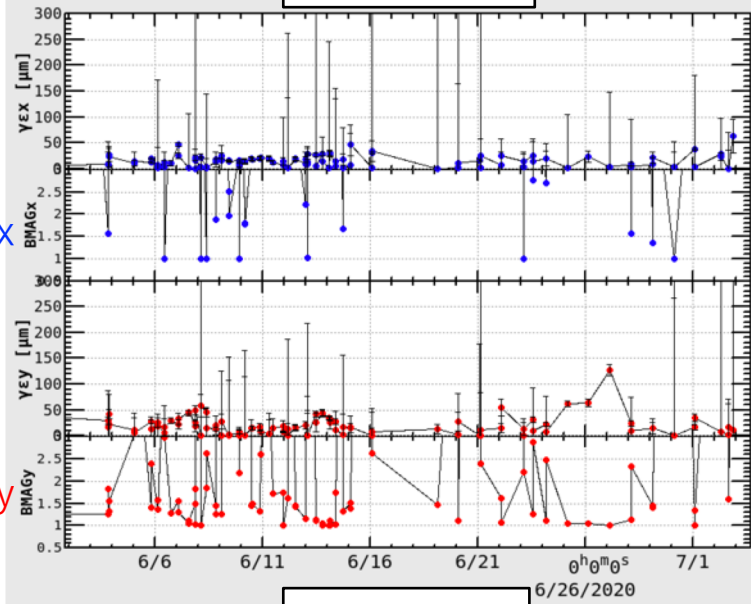
$\gamma\epsilon_x$
[μm]

BMAG_x

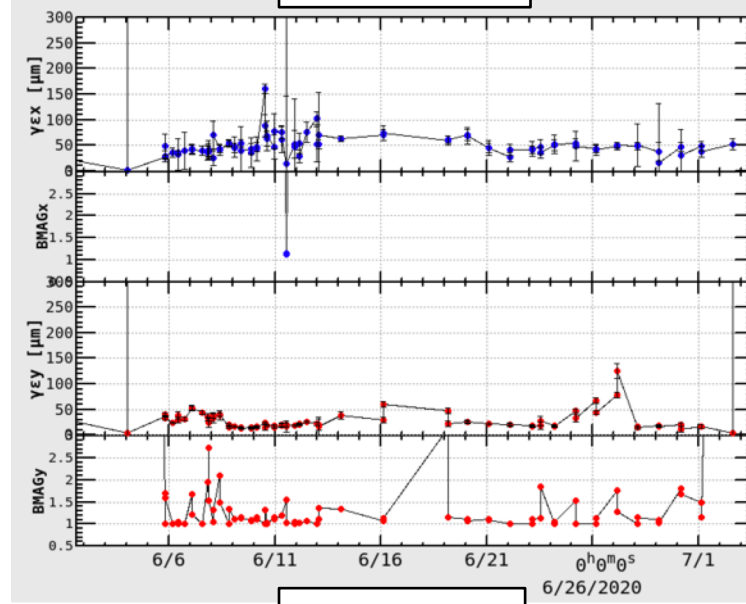
$\gamma\epsilon_y$
[μm]

BMAG_y

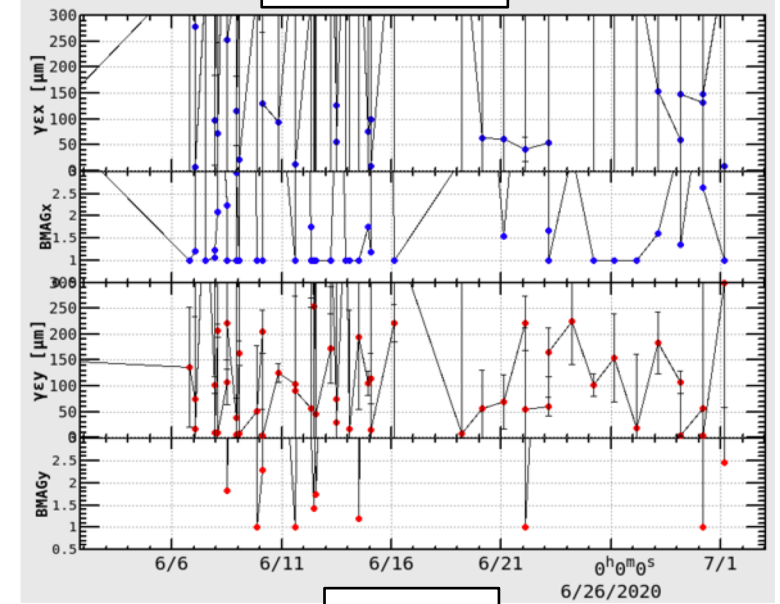
SectorB e-



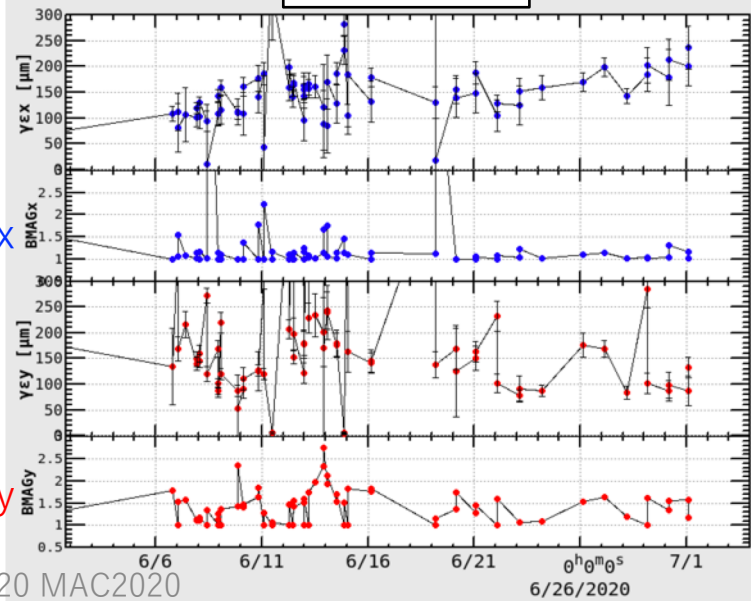
SectorC e-



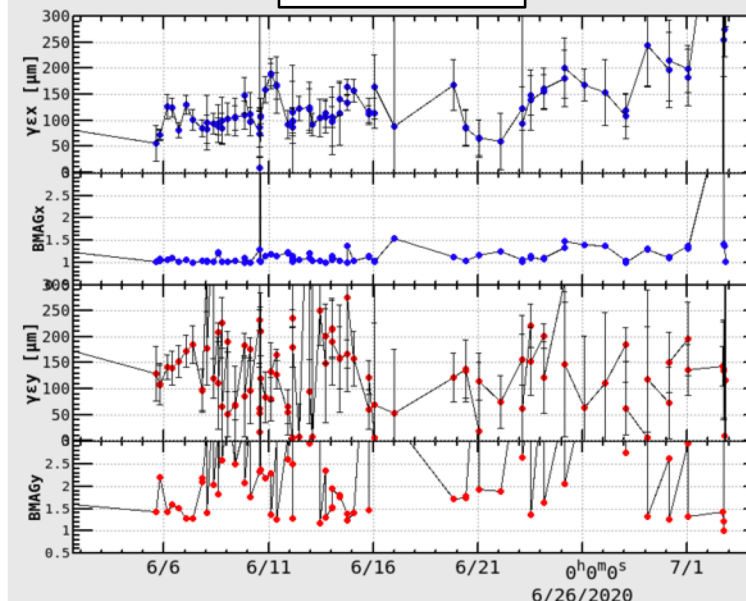
Sector2 e-



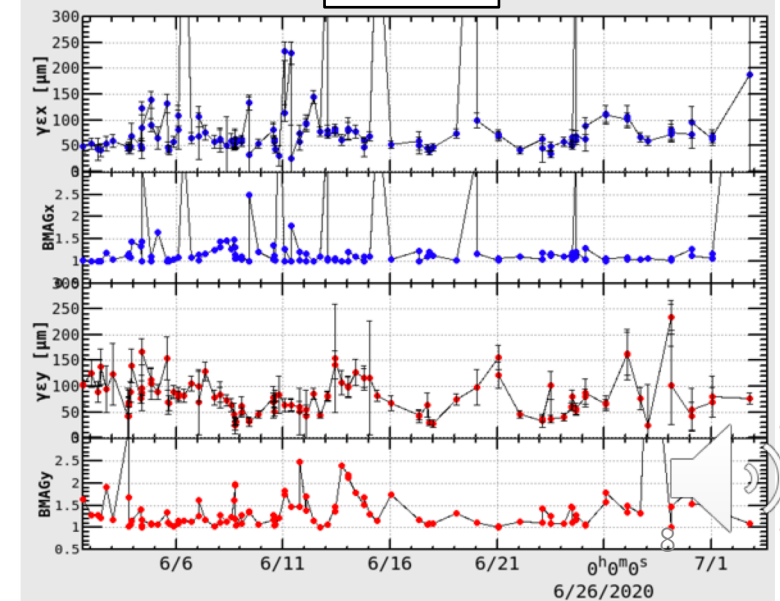
Sector3 e-



Sector5 e-



BT1 e-



Trend graphs of measured emittance with wire scanners (e+)

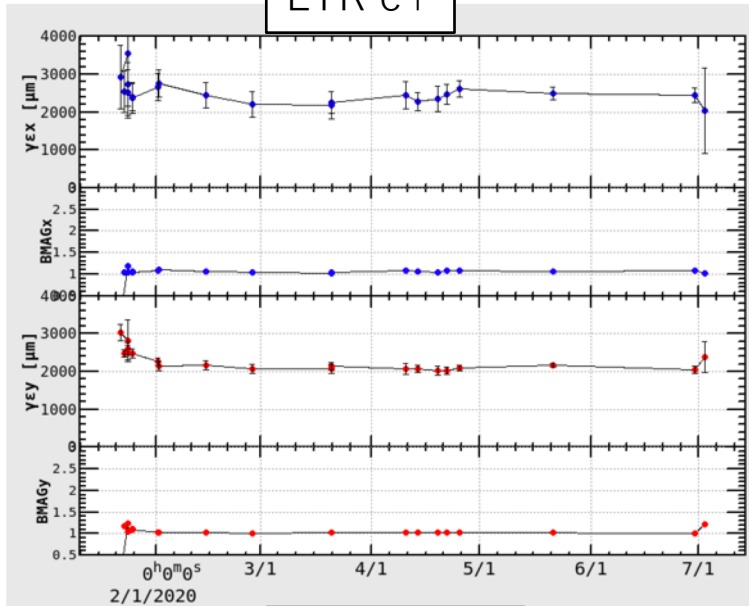
$\gamma\epsilon_x$
[μm]

B MAG_x

$\gamma\epsilon_y$
[μm]

B MAG_y

LTR e+



e+ beam is very stable thanks to the DR.

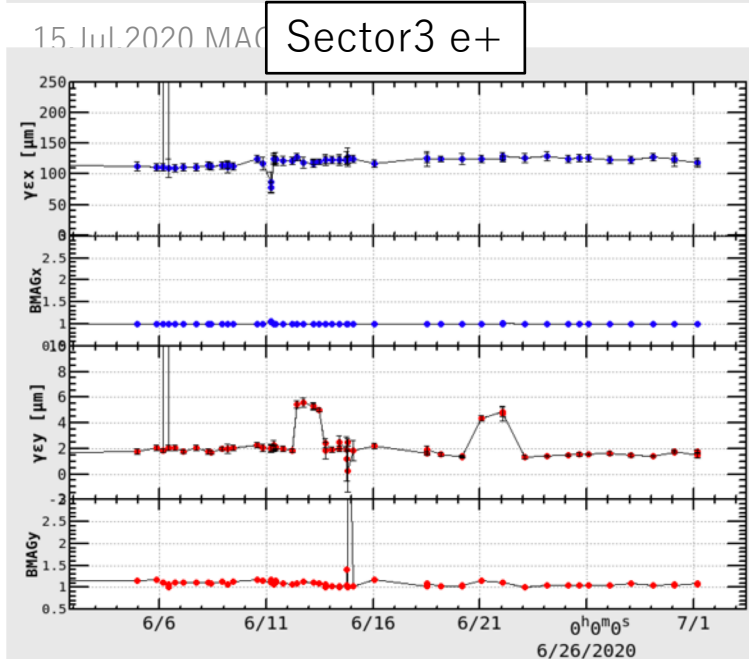
$\gamma\epsilon_x$
[μm]

B MAG_x

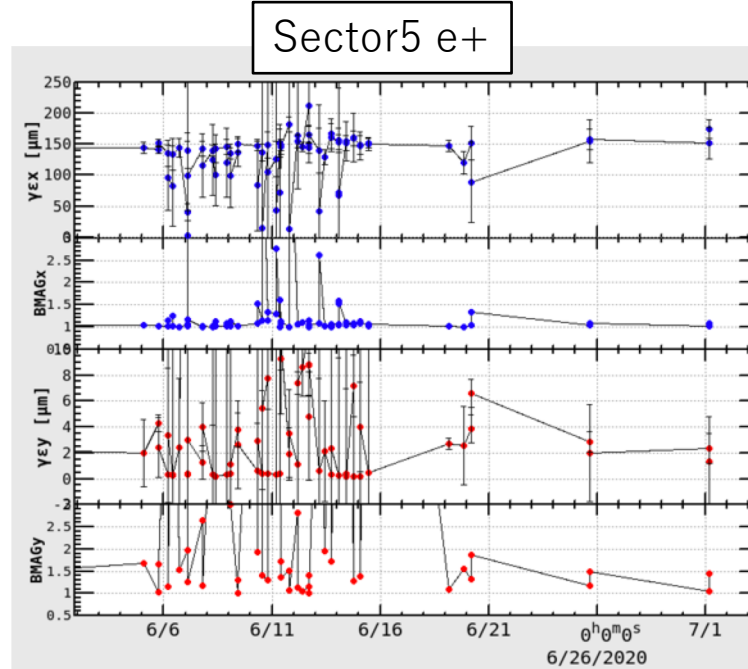
$\gamma\epsilon_y$
[μm]

B MAG_y

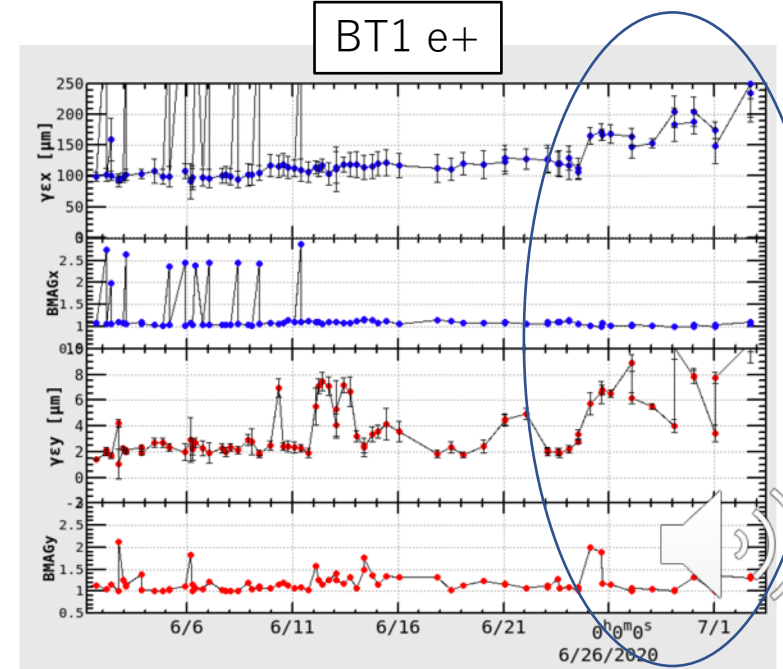
Sector3 e+



Sector5 e+



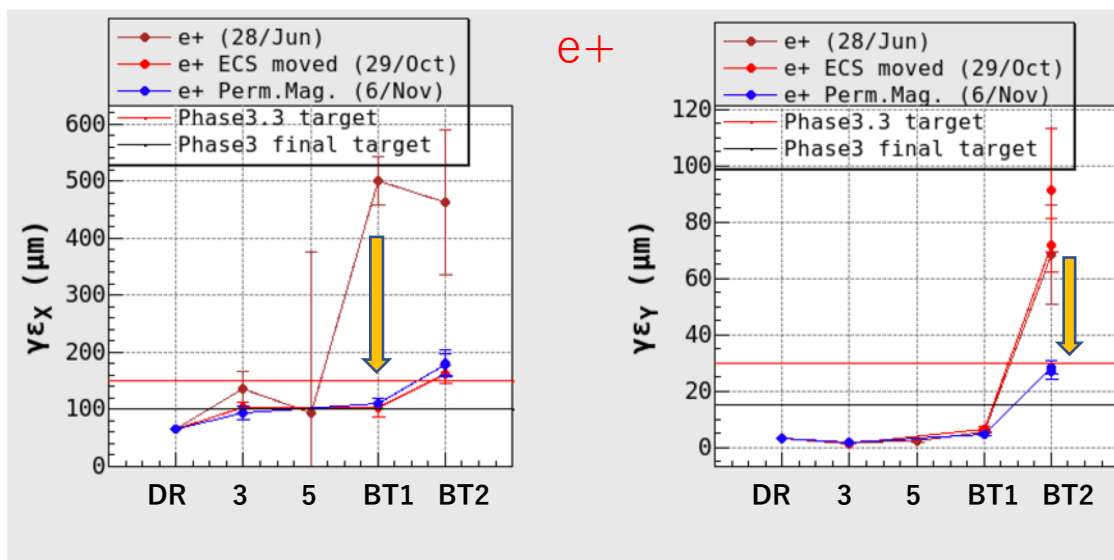
BT1 e+



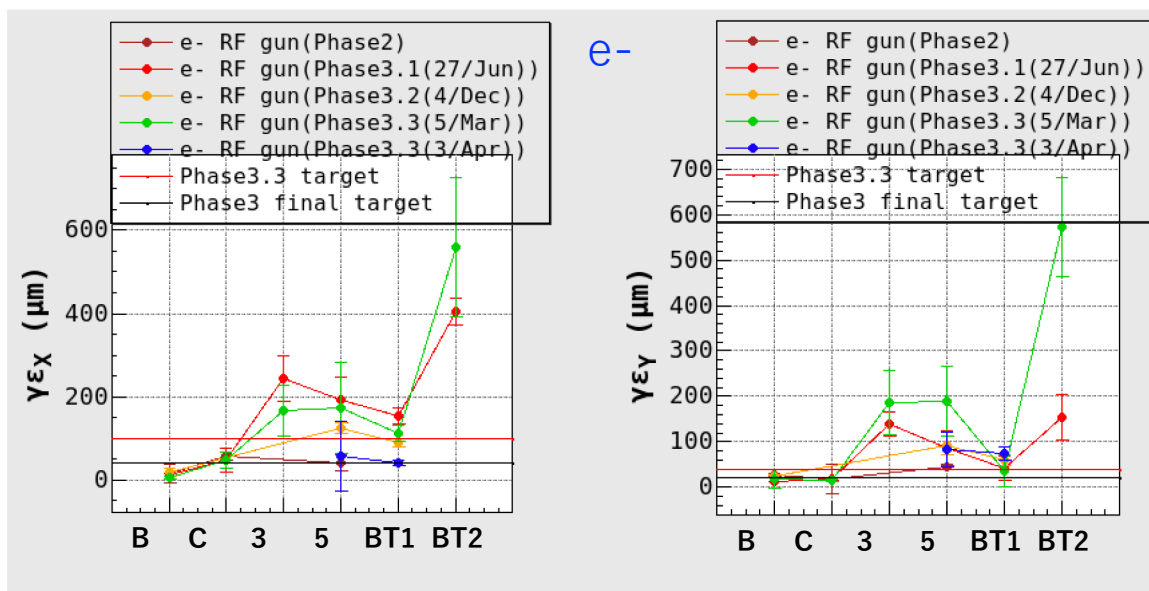
Measured Emittance

Requirements from MR

Phase3.3	e+	e-
γ_{ex} [μm]	150	100
γ_{ey} [μm]	30	40
σ_δ [%]	0.16(1 σ)	0.1(1 σ)



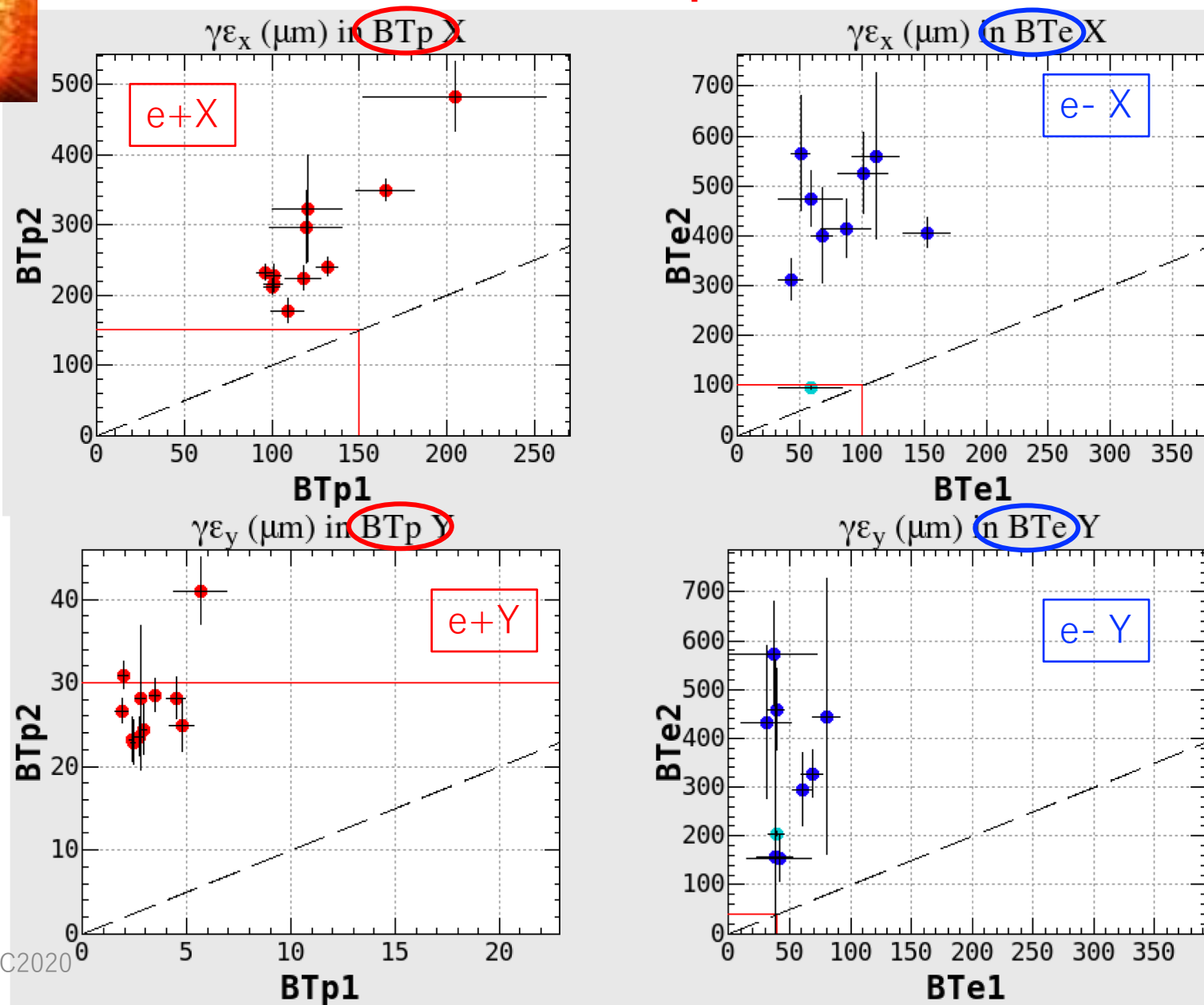
DR $\rightarrow$ Sector 3,
BT1 $\rightarrow$ BT2,
Emittances increase
 $\rightarrow$ Need study



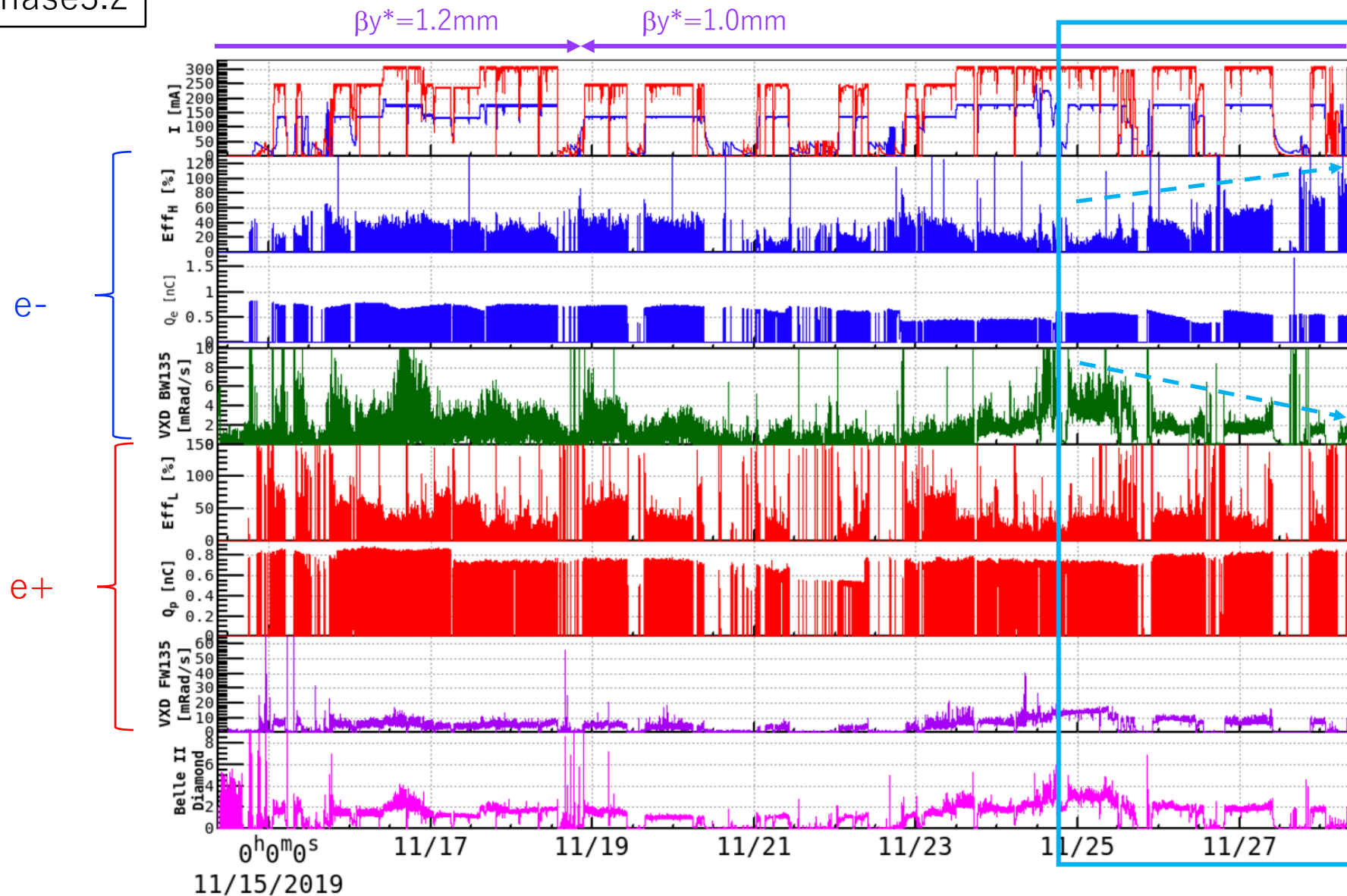
BT1 $\rightarrow$ BT2,
Emittances explosion
 $\rightarrow$ Need study



Emittance explosion in BT



Phase3.2



The injection efficiency gradually increased.

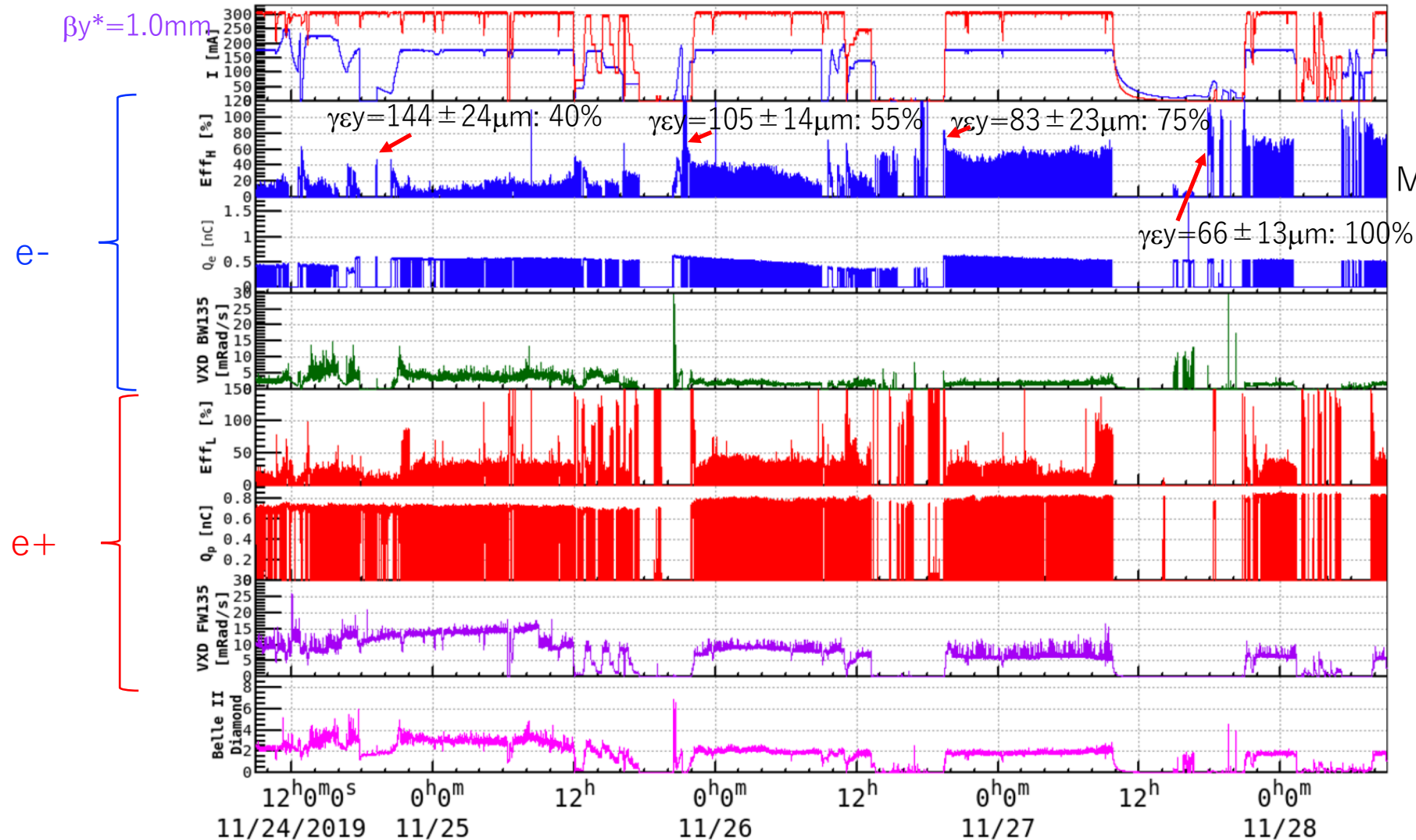
The background decreased.



The injection efficiency increased as emittance decreased by tuning.

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

Phase3.2

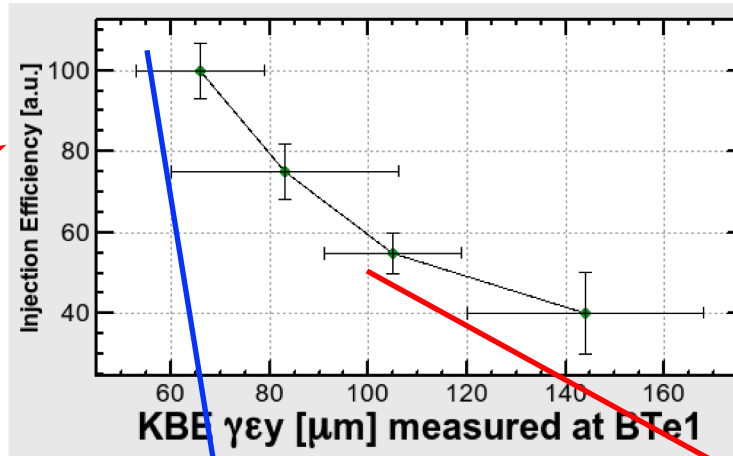


Measured emittances at BT1



Vertical emittance vs. HER Injection efficiency

This injection efficiency is an arbitrary unit.



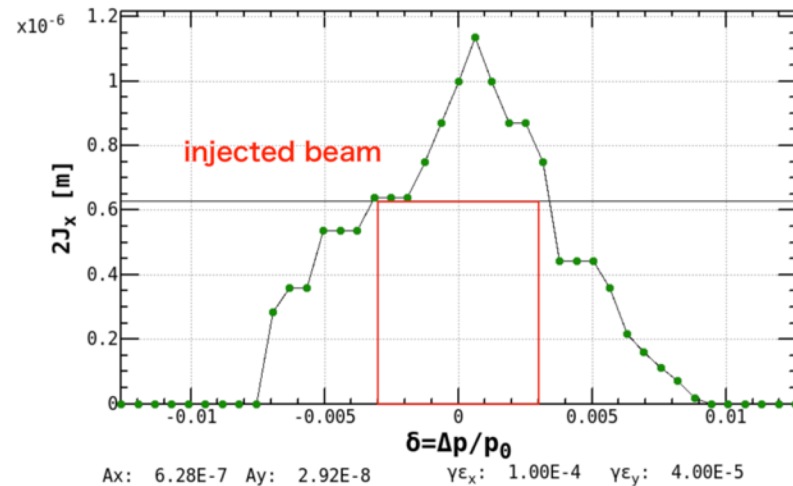
Y. Ohnishi

Dynamic Aperture for Injected Beam in HER

$\beta_x^* = 60 \text{ mm} / \beta_y^* = 1 \text{ mm}$

5780_60_1_A_Y03

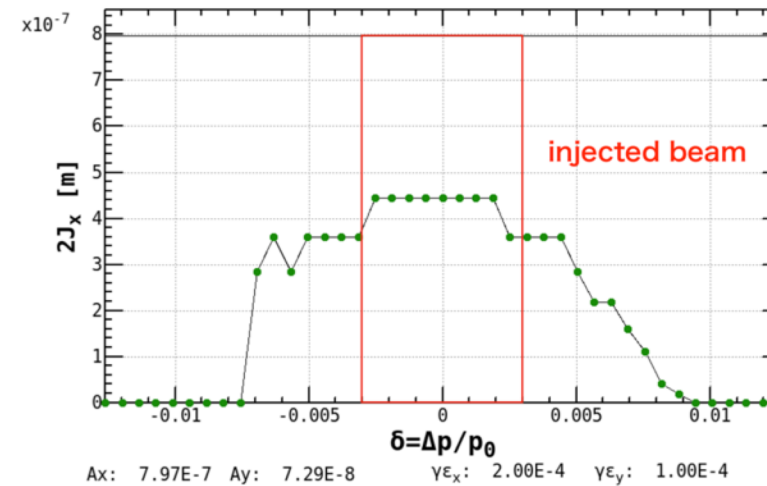
norm. emittance : $100 \mu\text{m} / 40 \mu\text{m}$



QCS aperture only with collimators

Injection efficiency = 100 % (no machine error)

norm. emittance : $200 \mu\text{m} / 100 \mu\text{m}$

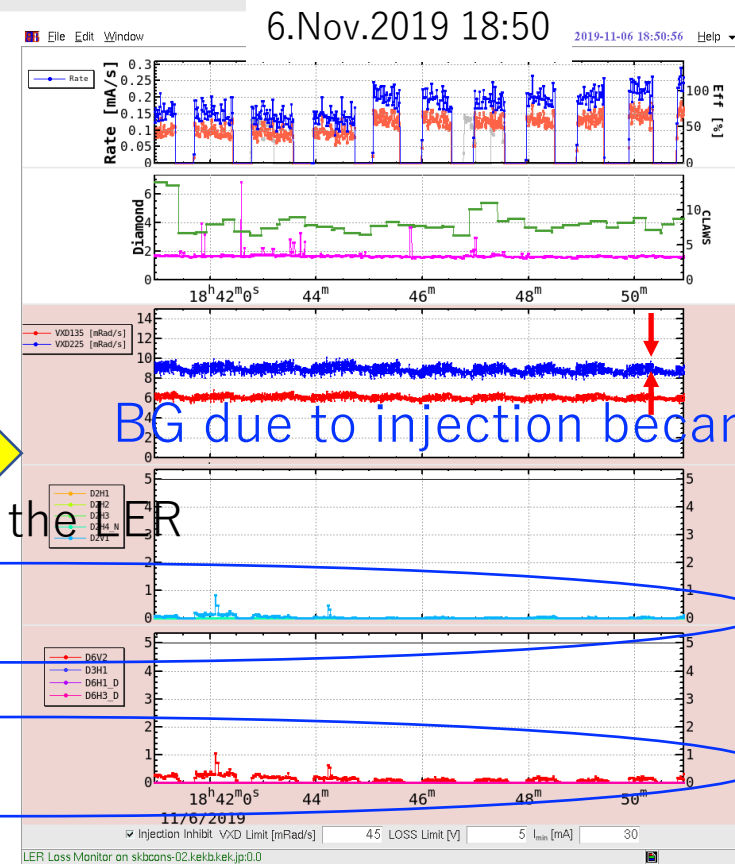
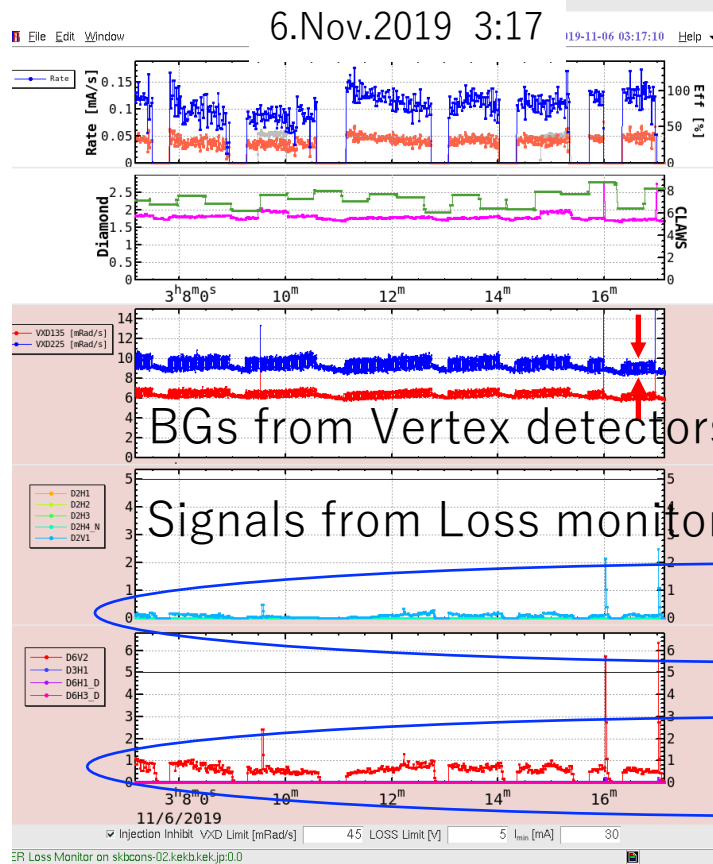
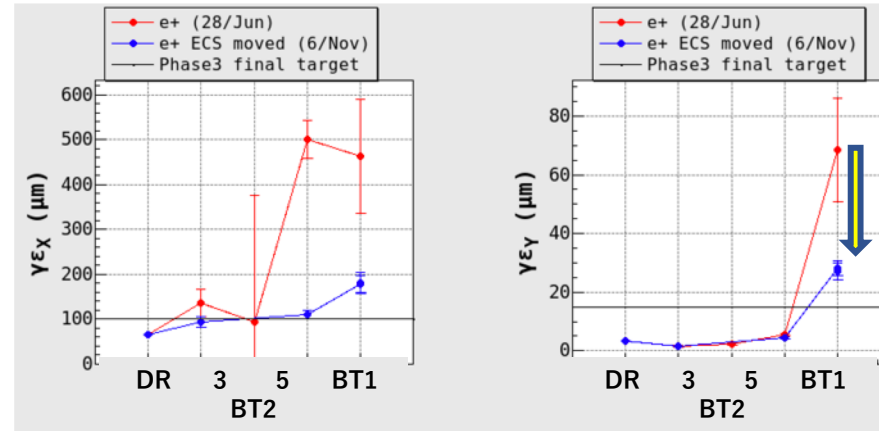


QCS aperture with collimators

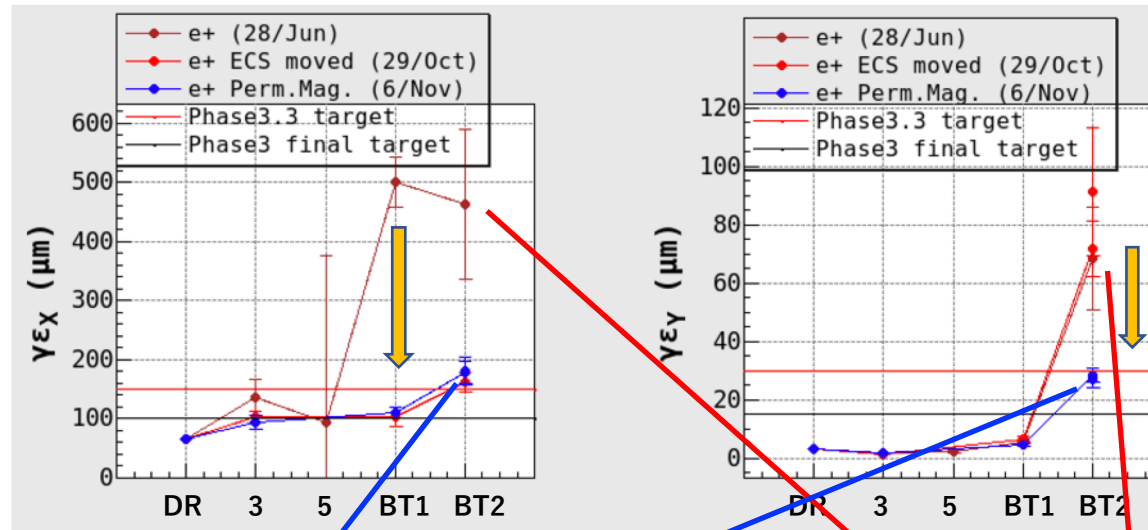
Injection efficiency = 53 %



- LER When the vertical emittance was improved,



- LER



Y. Ohnishi

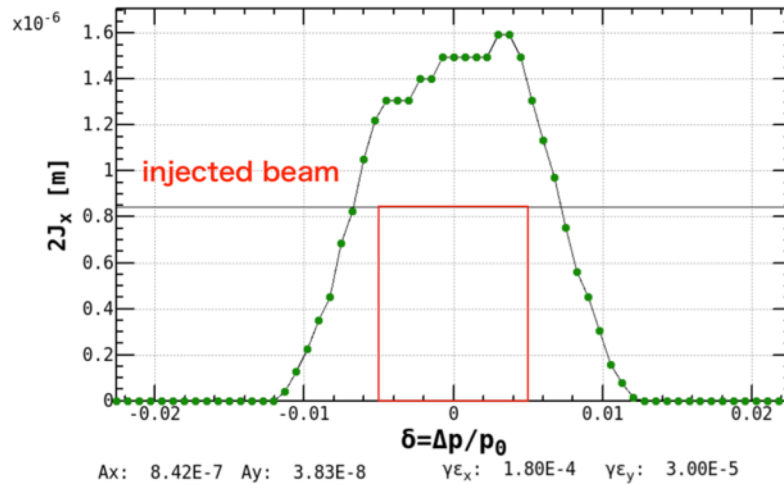
Dynamic Aperture for Injected Beam in LER

$$\beta_x^* = 80 \text{ mm} / \beta_y^* = 1 \text{ mm}$$

1704_80_1_A_Y04

norm. emittance : $180 \mu\text{m} / 30 \mu\text{m}$

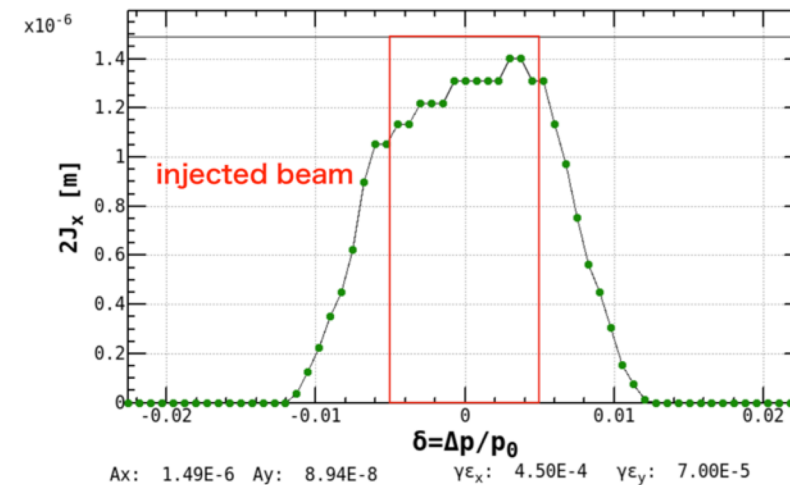
norm. emittance : $450 \mu\text{m} / 70 \mu\text{m}$



QCS aperture with collimators

Injection efficiency = 100 % (no machine error)

(6/Nov/2019)



QCS aperture with collimators

Injection efficiency = 86 %

(28/Jun/2019)

Before modification of ECS / BTP



B) Improvements of emittance growth in e+ BT

1. Horizontal emittance

- Residual dispersion at the acceleration for the ECS

2. Vertical emittance

- Abnormal skew magnetic field from bends

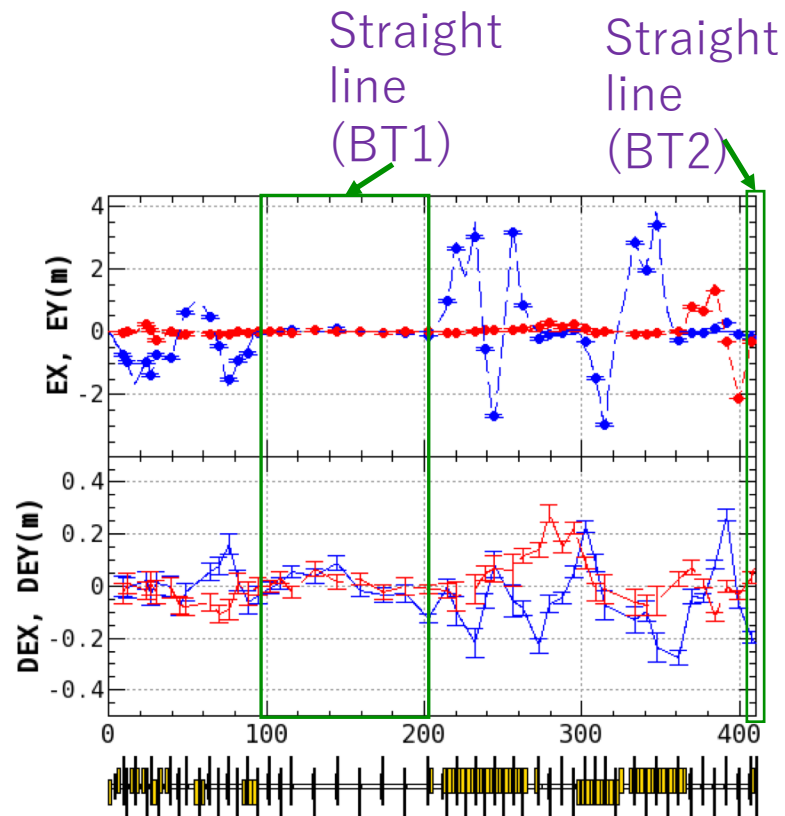
3. Tuning of energy spread



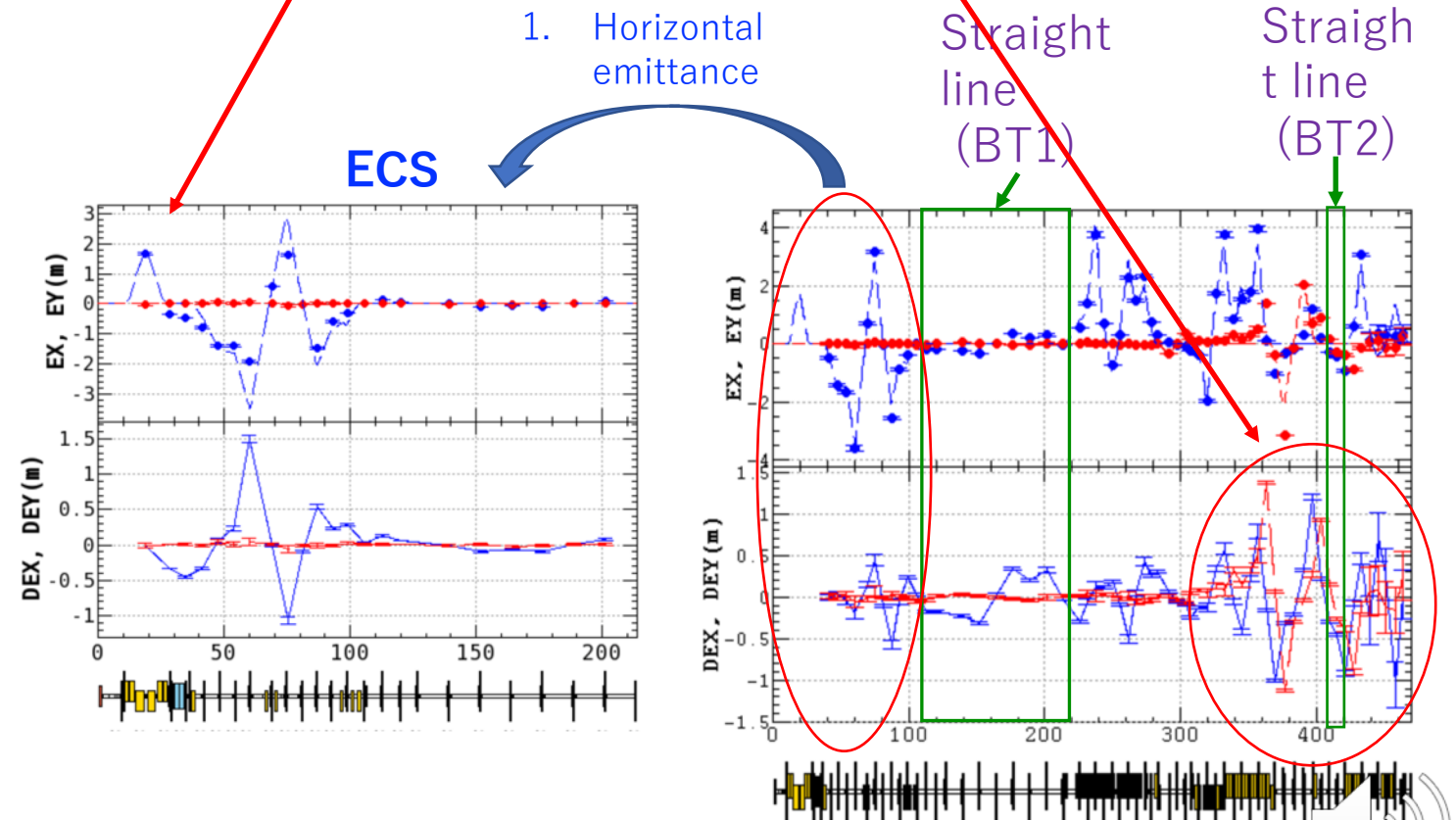
Residual Dispersion in the BT line

Y. Seimiya

- One of the causes of increased emittance is dispersion leakages.
- The dispersions have been corrected for each BT arc one by one.
- After that the dispersion of the BTs overall were measured by changing the beam energy.
- For e- line, the dispersion leak is almost good.
- Non-negligible residual dispersion is still observed especially in e+ BT.



BT for e- → almost good



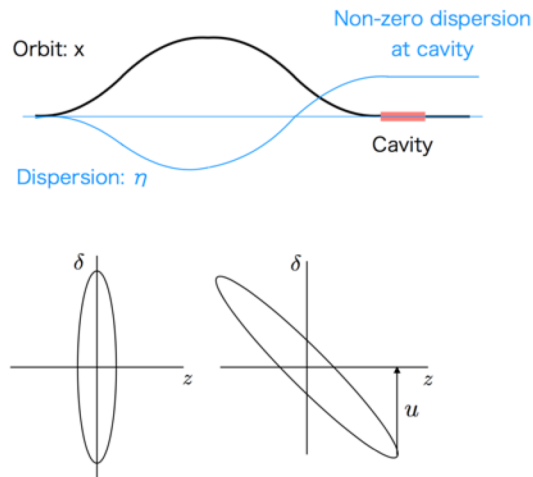
BT for e+

2. Vertical emittance

Residual dispersion at the acceleration structure for a compression system induces emittance growth

- When the beam with dispersion is accelerated by RF cavity, $\eta\delta$ converts to betatron oscillation and causes emittance growth.

M. Kikuchi



If the cavity has non-zero dispersion, a beam, gaining its energy depending on z , has net growth in the projected-emittance.

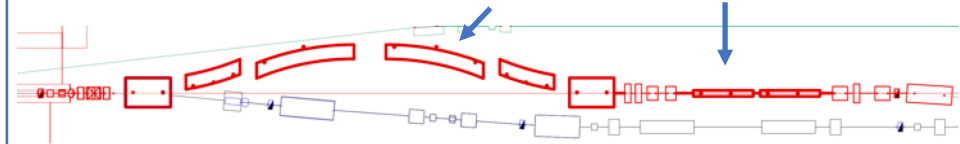
This is an analogue of the synchro-beta excitation at the cavity with non-zero dispersion in the ring.

$$\bar{\epsilon}^2 = \epsilon_0^2 + \epsilon_0 (\beta\eta'^2 + 2\alpha\eta\eta' + \gamma\eta^2) \langle u^2 \rangle$$

$$u = -vz \quad v = \frac{eV}{E_0} \frac{\omega_{rf}}{c}$$

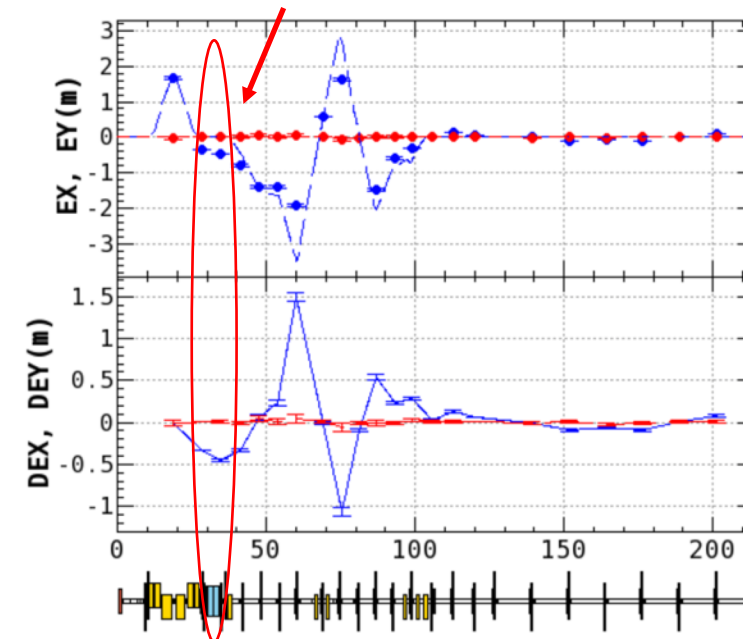
Simulation result: $\frac{\epsilon}{\epsilon_0} \sim 2$

ECS: chicane + acceleration tube



Measured dispersion at the end of LINAC

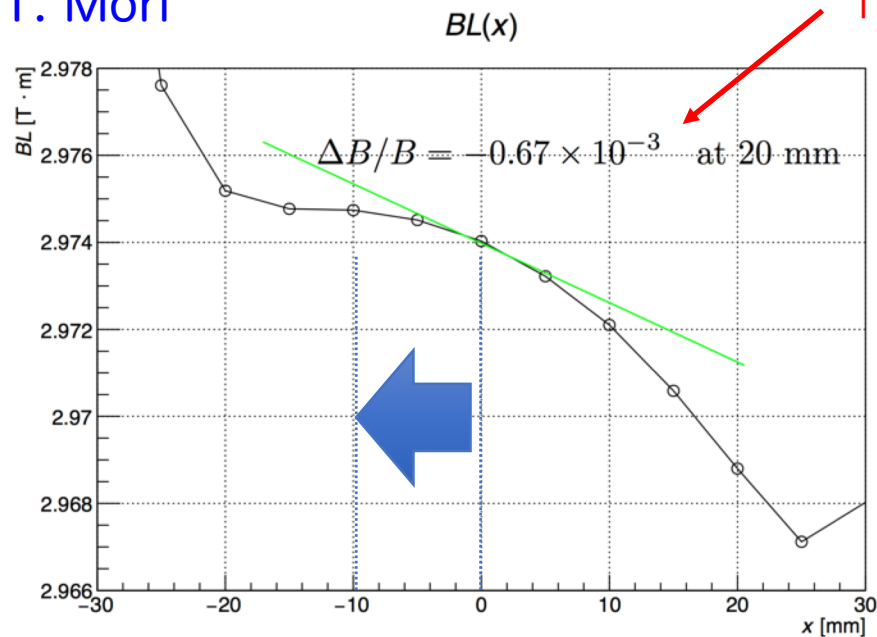
The dispersion leaks at the ECS cavity.



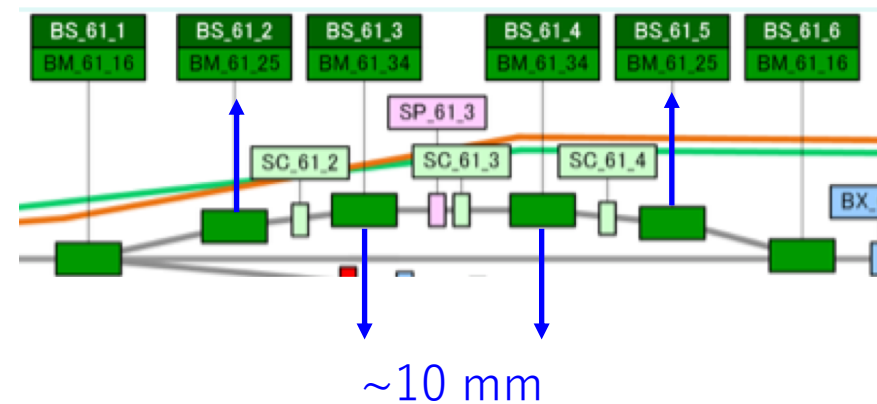
Residual dispersion at the acceleration structure for a compression system induces emittance growth

- The bending magnets used in the ECS have multipole components by the measurements in the figure below.
 - Passing through the design orbit in the bends, the beam feels B' field, which results in dispersion leakage.
 - By moving the bends about 10mm, the small area of B' can be passed.

T. Mori

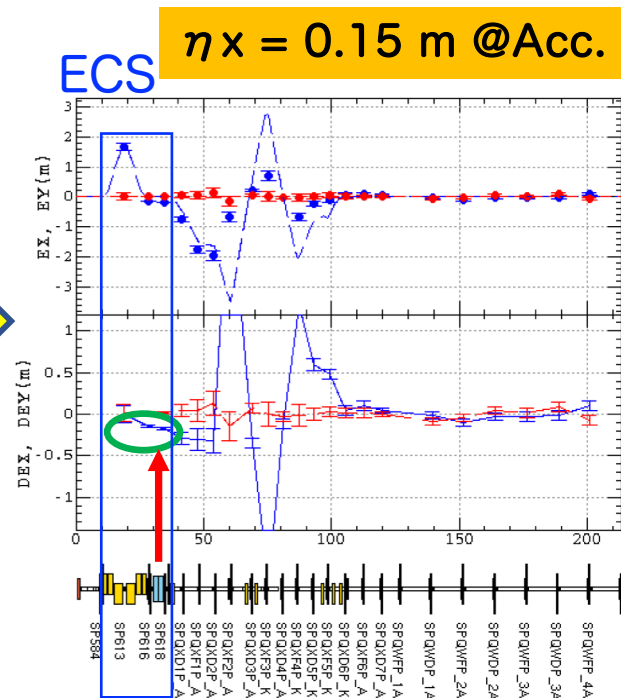
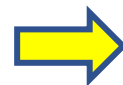
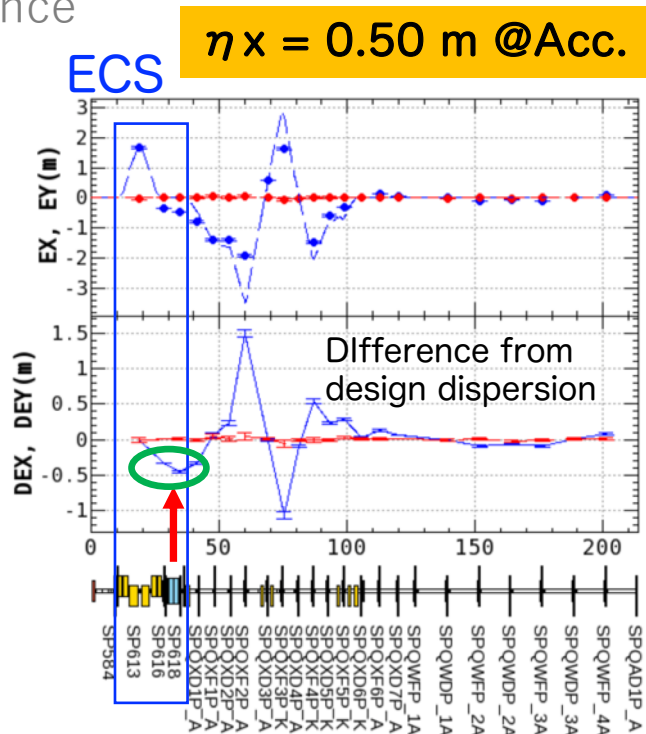


This can explain the measured dispersion leak.



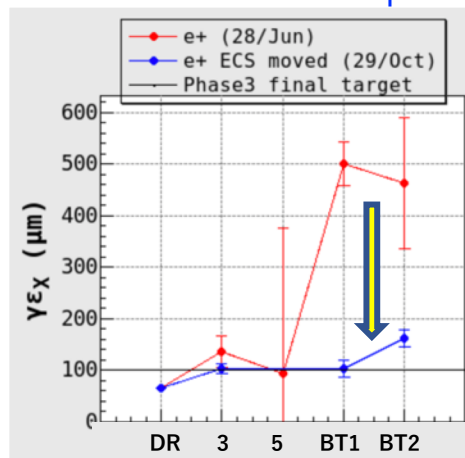
BL along the horizontal direction

1. Horizontal emittance

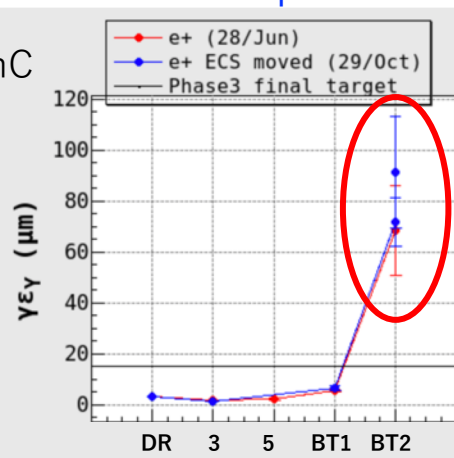


Y. Seimiya

The horizontal dispersion has been improved by moving ECS bends.



1nC

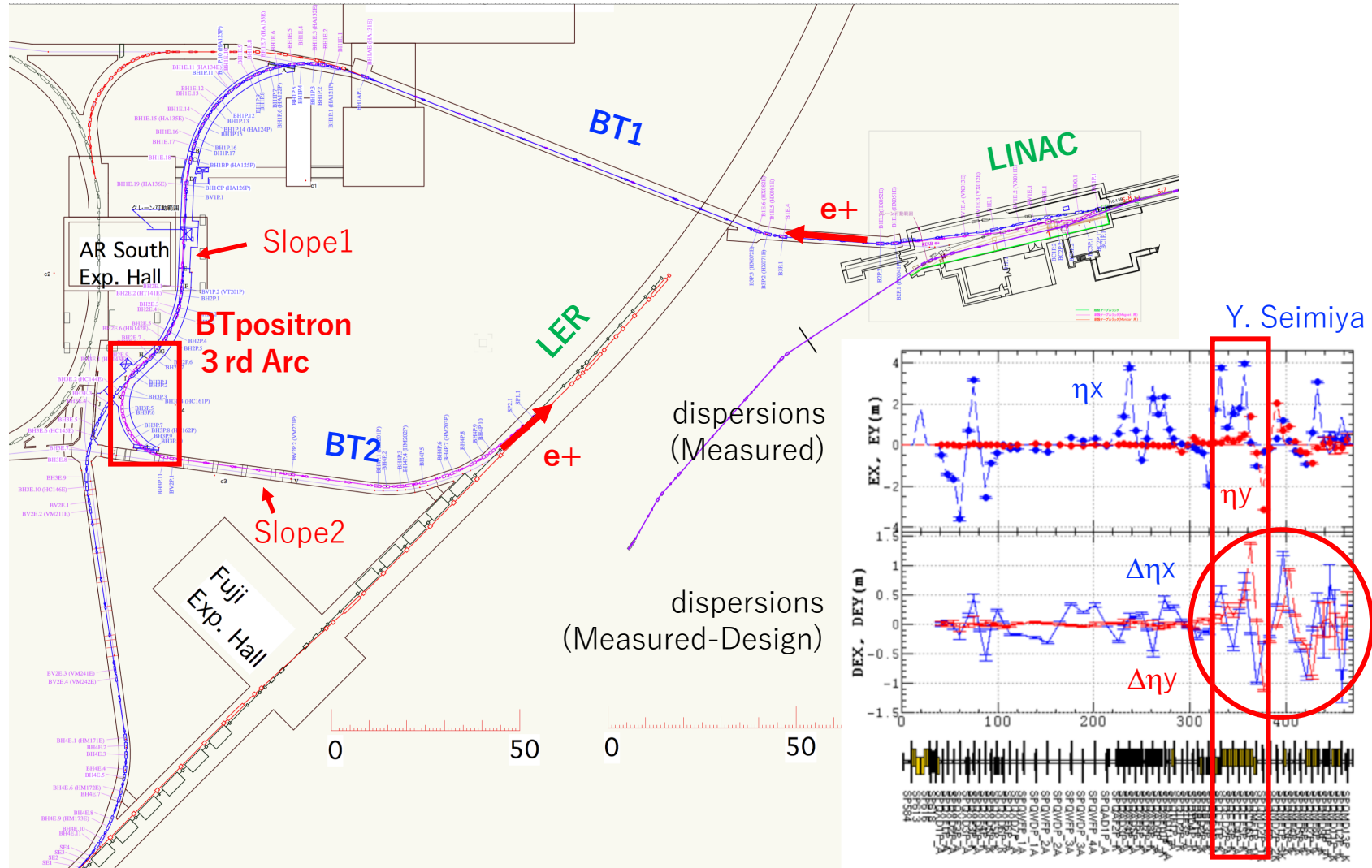


Remained big problem is a large vertical emittance.

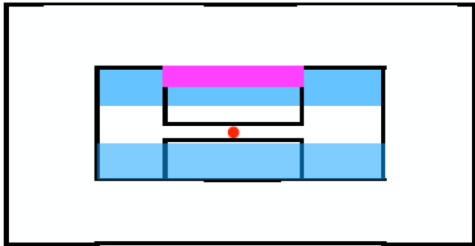
This is considered to come from abnormal vertical dispersions.(by M. Kikuchi)



Abnormal skew magnetic field from bends



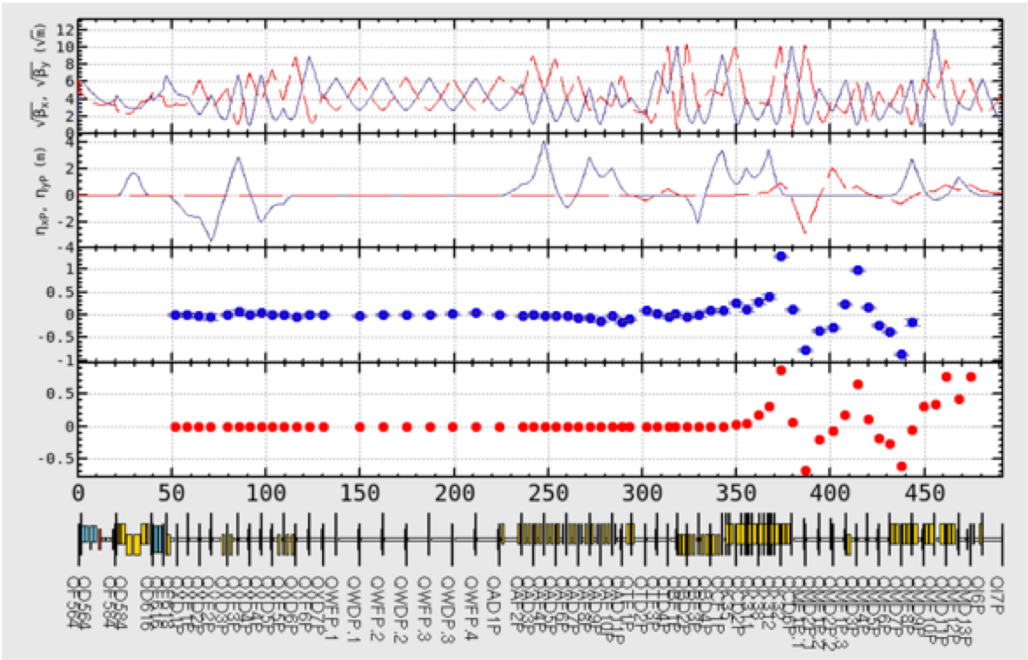
Simulation



The energy of the e+ beam has increased to 4 GeV.
The gap of bends in the Arc3 had been narrowed asymmetrically.
This created an unusual skew component in bends.
However, this can only explain about one-third of the measured skew quad components.
Anyway, tried to correct it.

M. Kikuchi

e+ beam



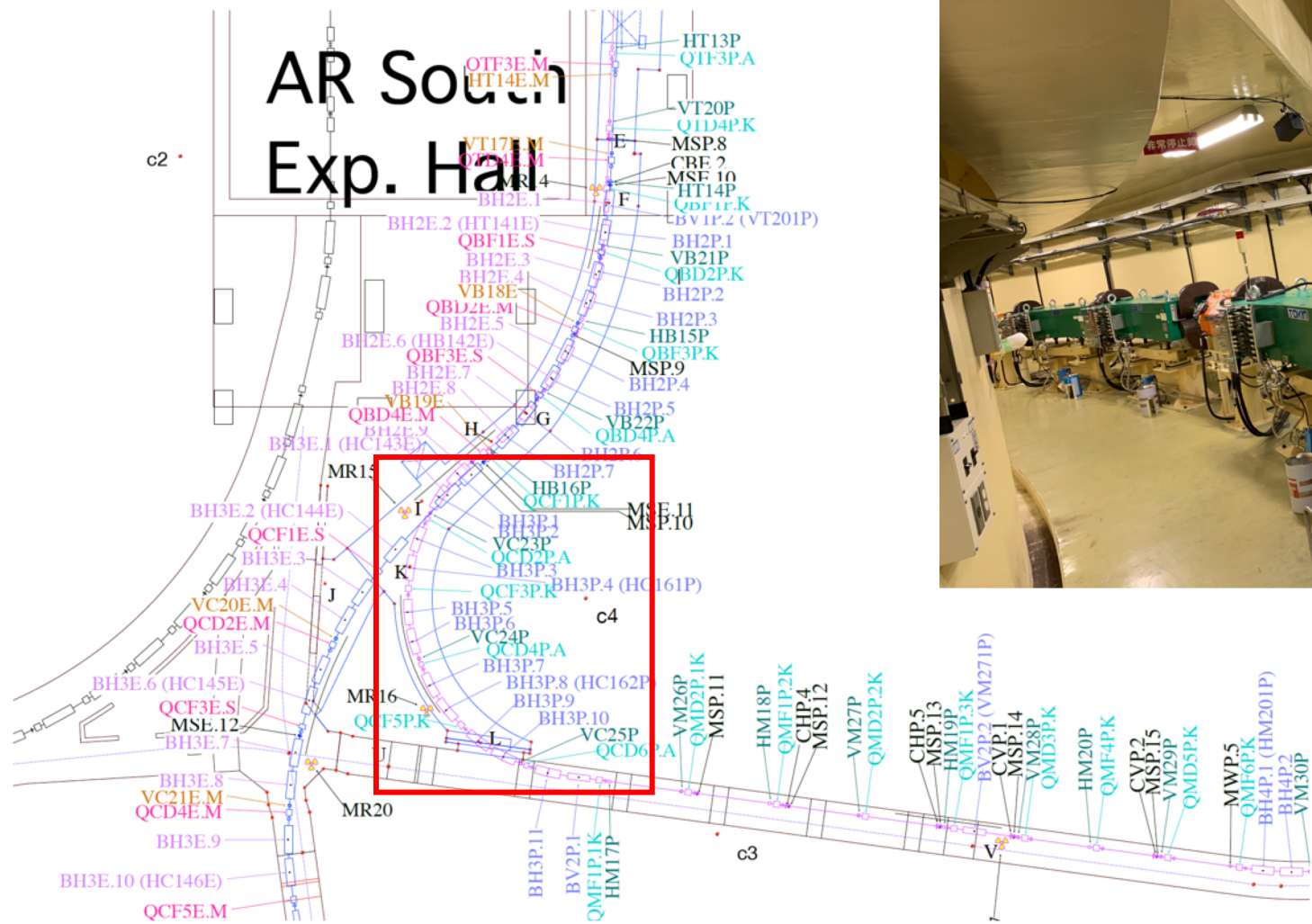
Measured vertical dispersion

Calculated vertical dispersion by the skew quads

The measurement and calculation are good agreement !

The vertical dispersion could be corrected with the skew quads with permanent magnets.

2. Vertical emittance

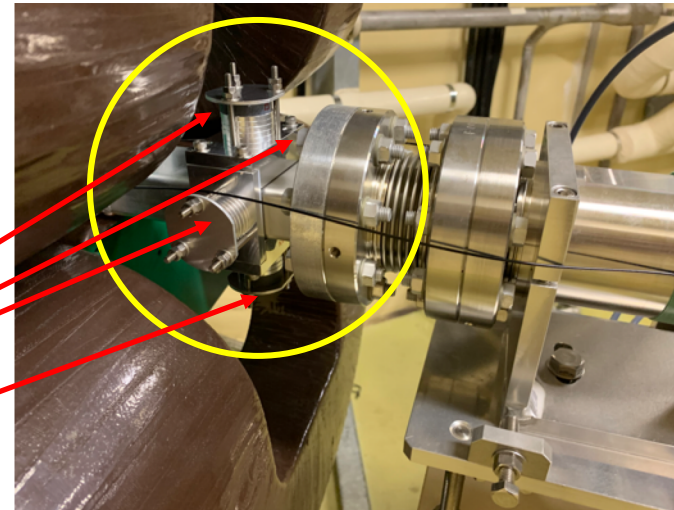
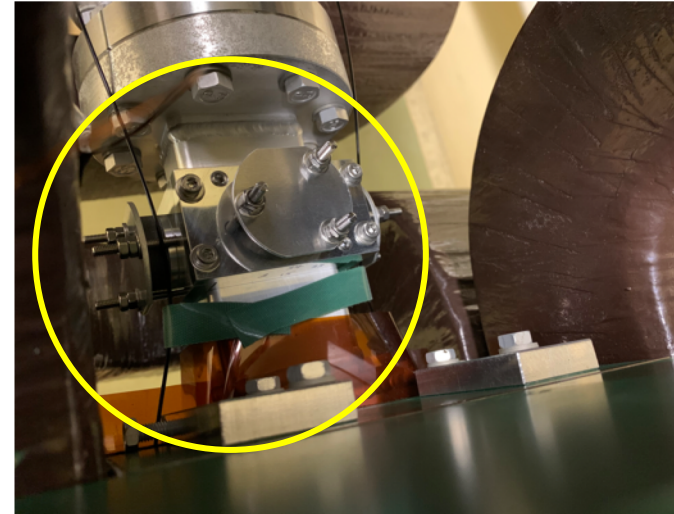


2. Vertical emittance



11 of 16 skew quads were installed.

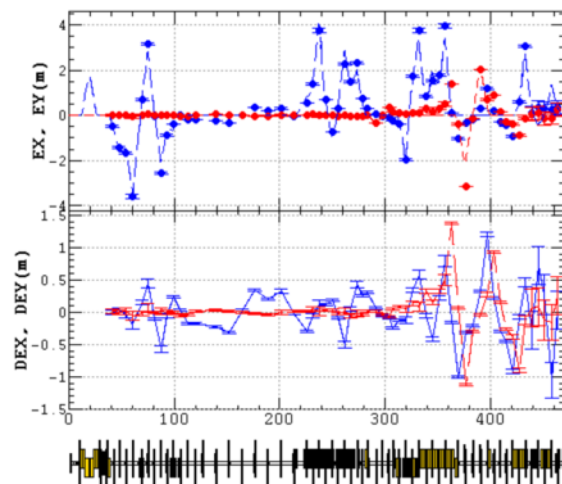
permanent magnets
(Black blocks)



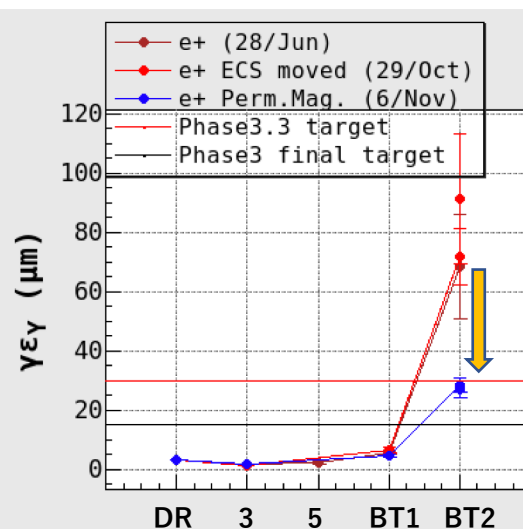
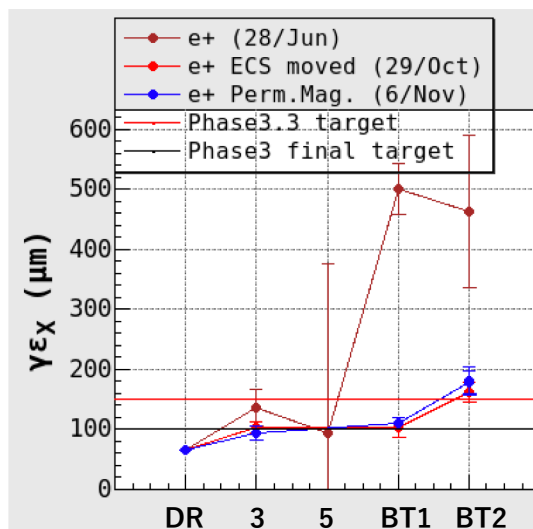
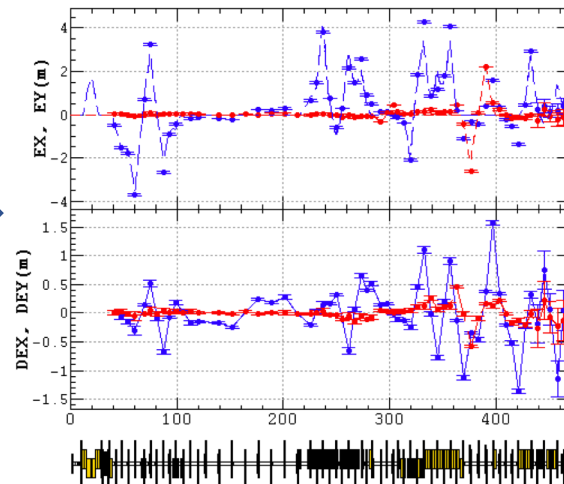
Measured Dispersion

Y. Seimiya

① Before installation of skew quads



② After installation of skew quads



3. Tuning of energy spread



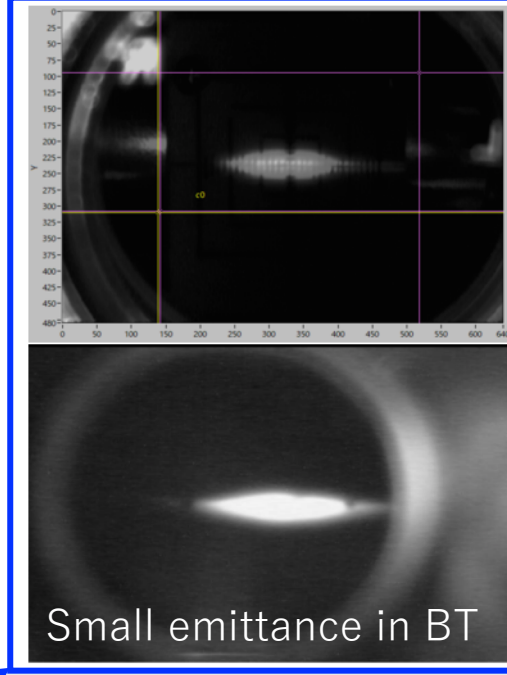
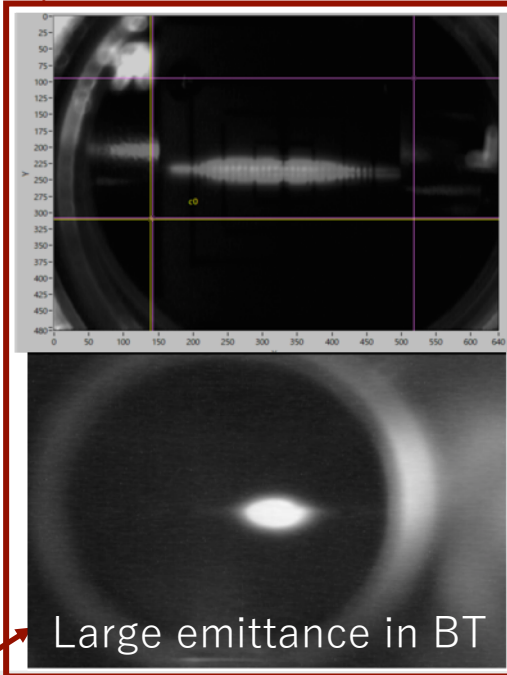
3. Tuning of energy spread $\Delta\phi$ of Sector3-5: +9deg

$\Delta\phi$ of Sector3-5: 0deg

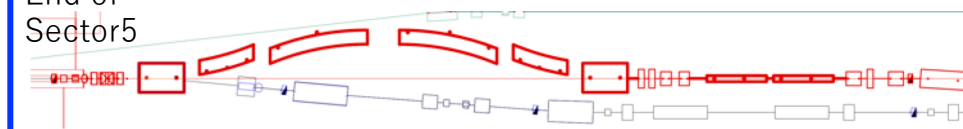
ECS: Chicane+Acc

Screen monitor
Center of Chicane

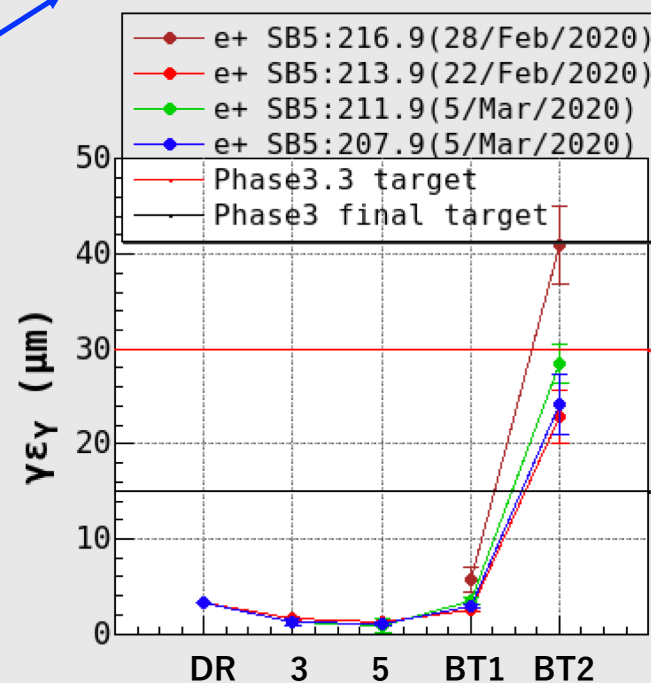
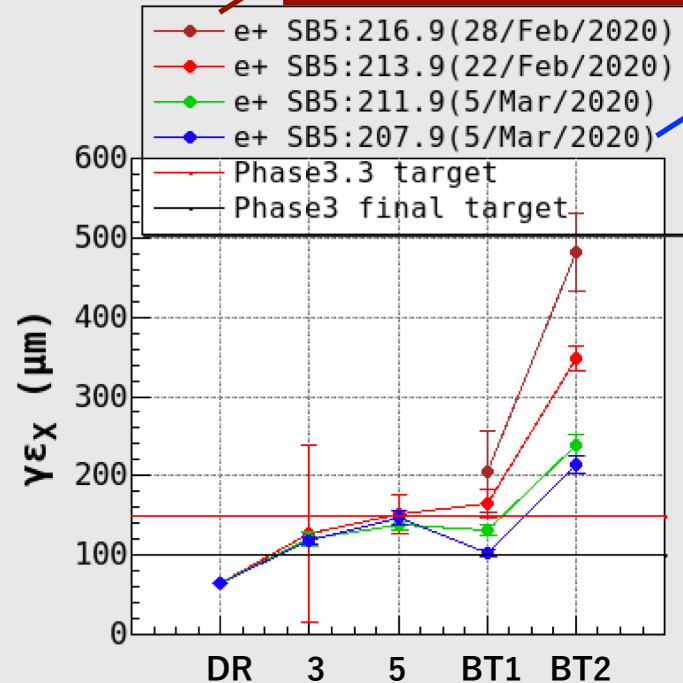
e+ BT



End of
Sector5



The emittances in the BT becomes large when the energy spread is large in the ECS.
It may be caused by the residual dispersion leak from the chicane which should be closed.



	+9deg	0deg
$\sigma\delta$ in Chicane	Large	Small
$\sigma\delta$ in BT	Small	Large
Emittances	Large	Small

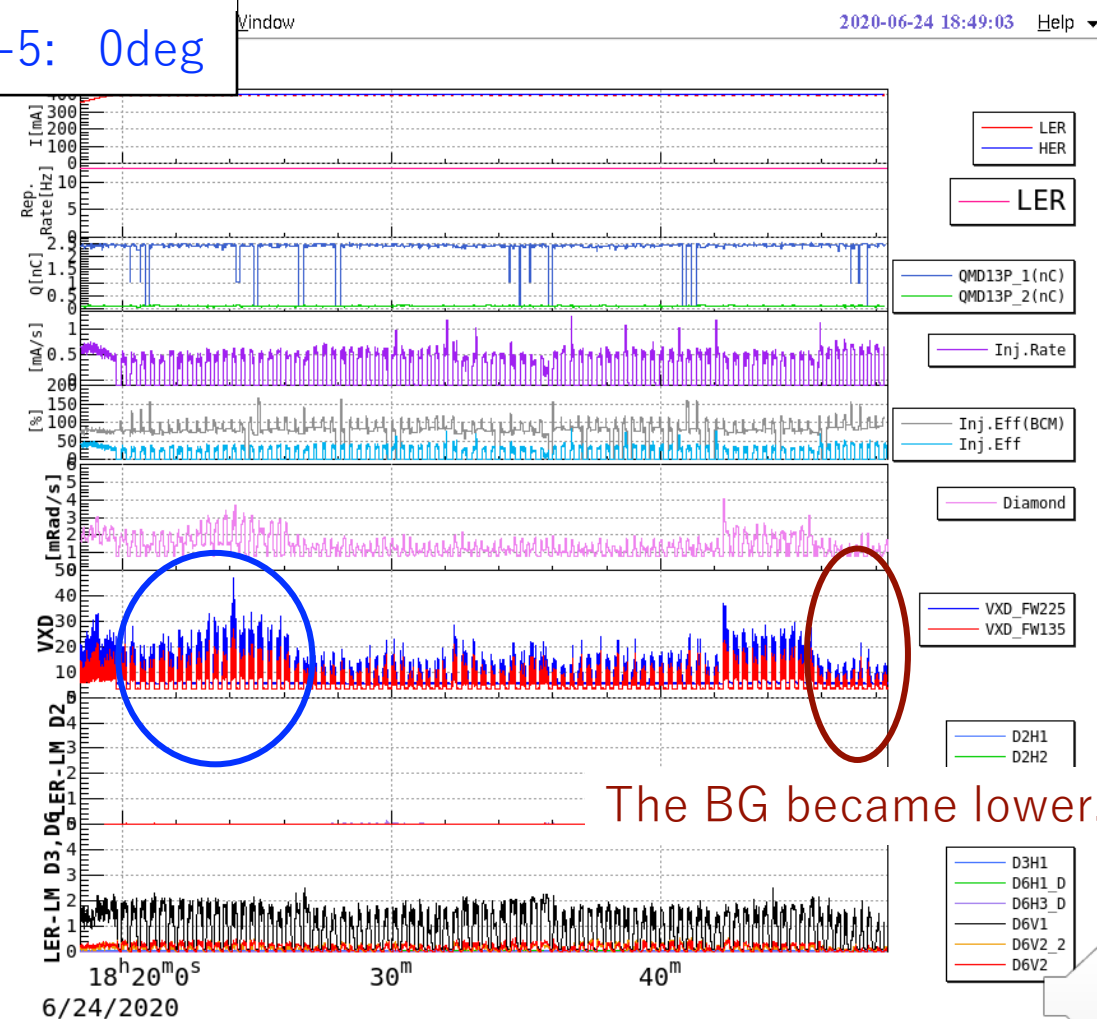
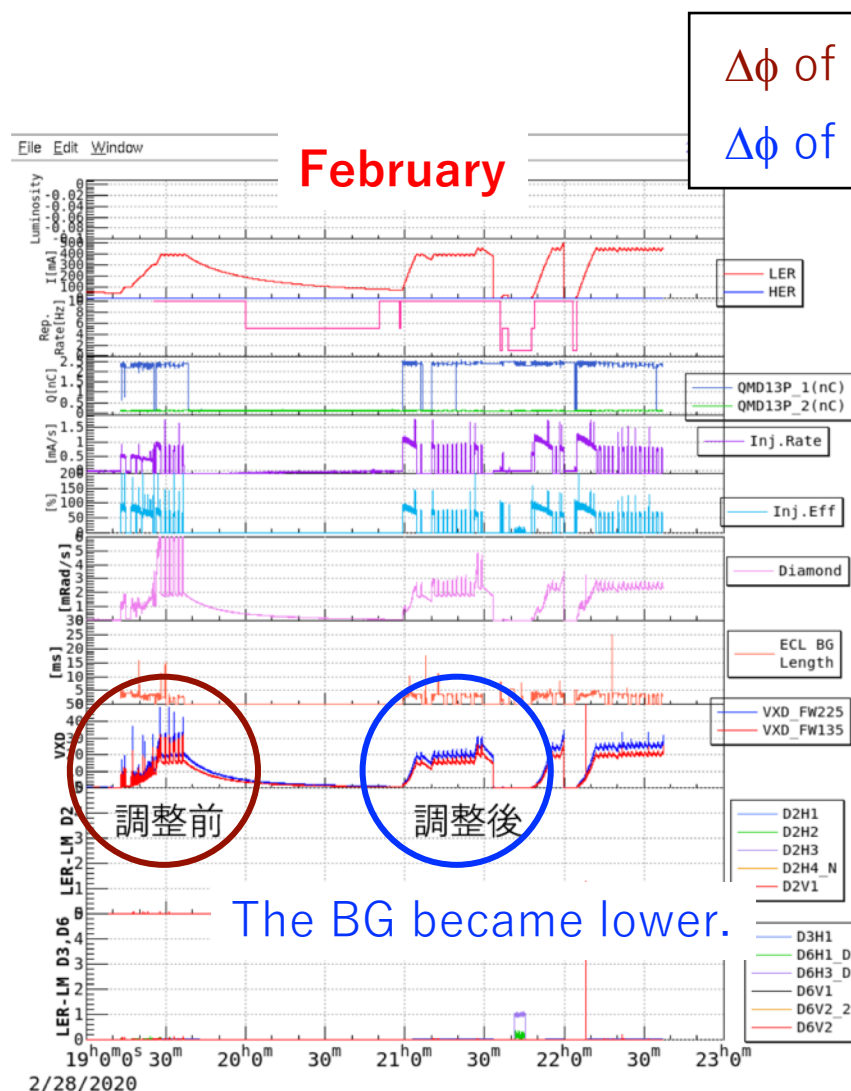
This should be small !



3. Tuning of energy spread

Belle BG depends on the situation of the LER.

Belle BG monitor



C) Emittance explosion in e- BT line

1. Dispersion and orbit jitter emittance:

- Measurements have been performed.
- Jitter of power supplies ?

2. Intensity dependence:

- Not yet done.
- Small for e+ (10% for 0.9/1.2nC, T. Mori).

3. Multipole components of bends:

- Not yet done.
- For e+ changing orbit in the bends did not affect the emittance.

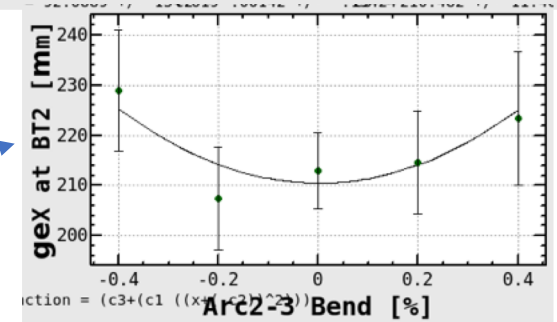
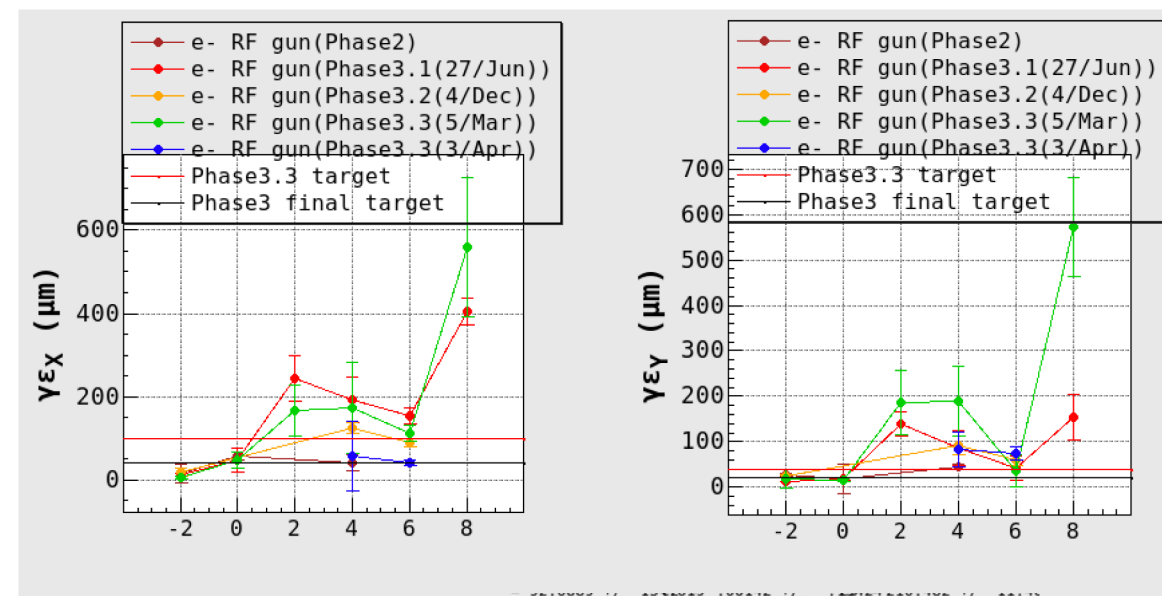
4. Multipole components of quads ?

- A simulation with multipole components tells that the horizontal emittance is doubled with energy spread of 0.3%. However only 15% increase in vertical.
- Measurements are to be done.

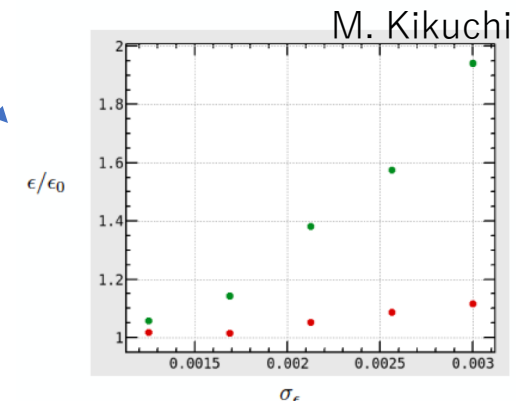
5. Abnormal quads in the line ?

- Making bumps to find out the quads.

6. The source of emittance explosion is still mystery.

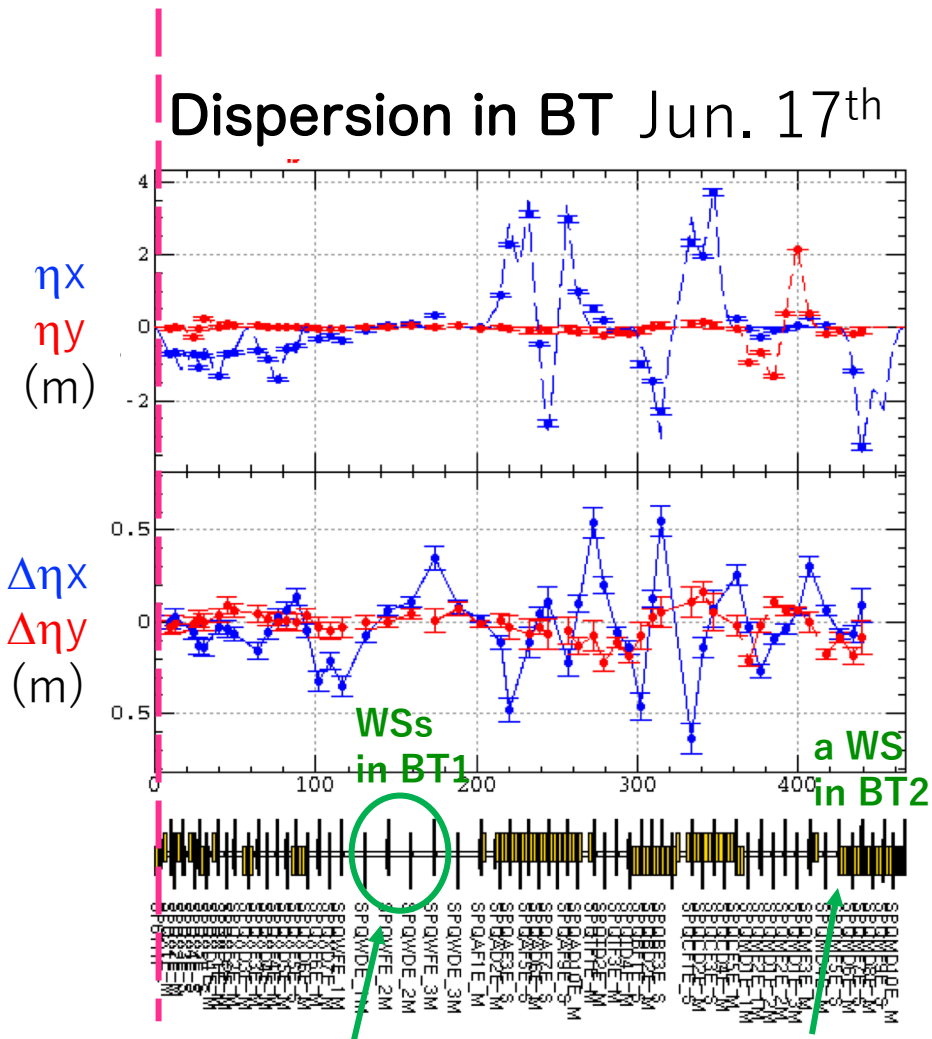


• Emittance v.s. energy spread



Measurements in e- line

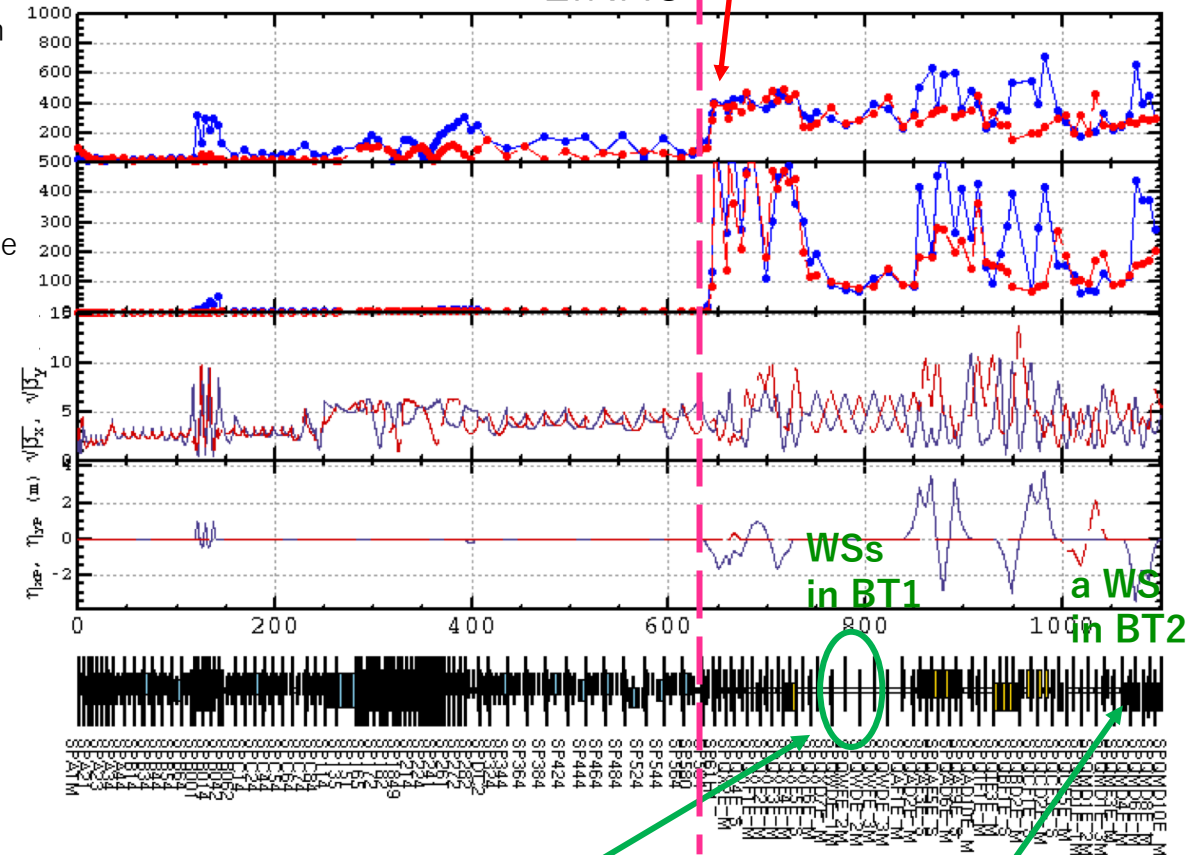
Jitter in e- BT is already large in both X and Y at the entrance of BT, which is also mystery.



$\text{RMS } \eta_x @ \text{BT1} = 0.19 \text{ m}$ $\eta_x @ \text{BT2} = -0.07 \text{ m}$
 $\text{RMS } \eta_y @ \text{BT1} = 0.02 \text{ m}$ $\eta_y @ \text{BT2} = -0.09 \text{ m}$

Position
 jitter
 x, y
 (μm)
 Jitter
 emittance
 x, y
 (μm)

Orbit jitter

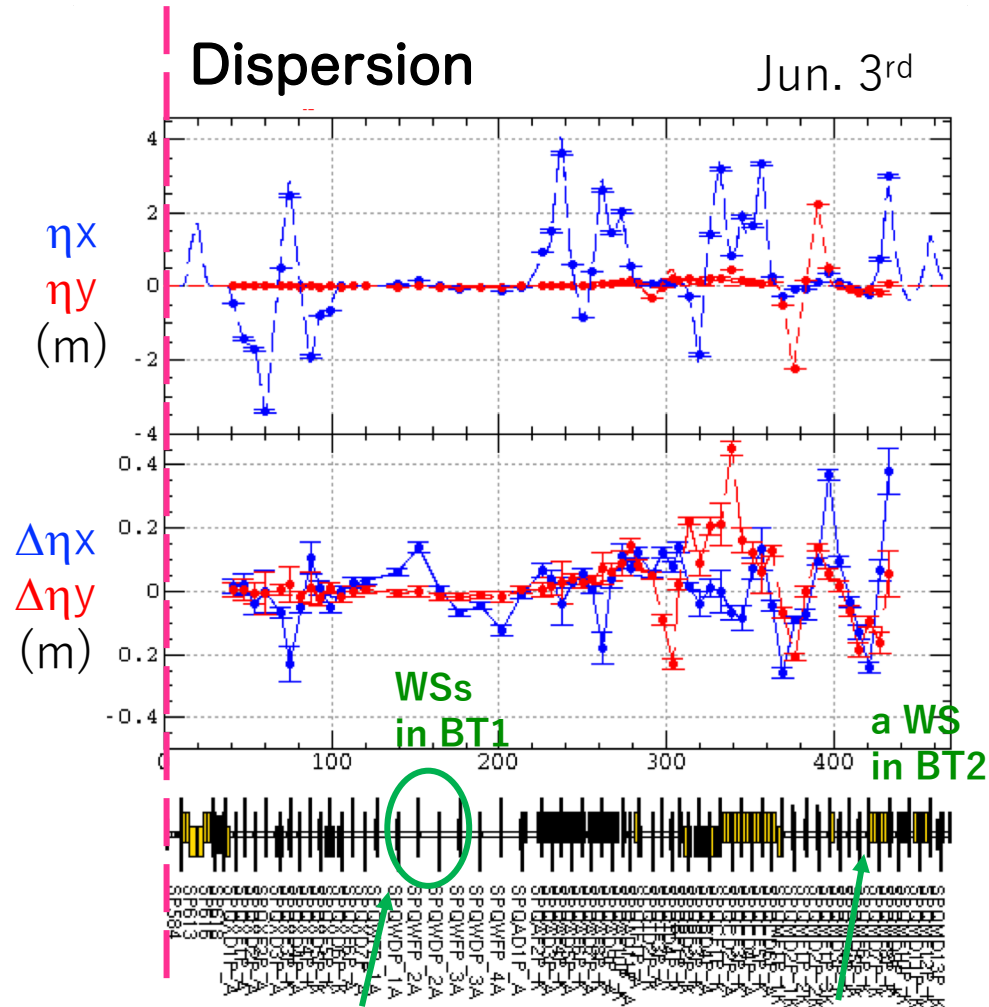


$\epsilon_{jx} @ \text{BT1} = 86 \mu\text{m}$ $\epsilon_{jx} @ \text{BT2} = 97 \mu\text{m}$
 $\epsilon_{jy} @ \text{BT1} = 88 \mu\text{m}$ $\epsilon_{jy} @ \text{BT2} = 93 \mu\text{m}$

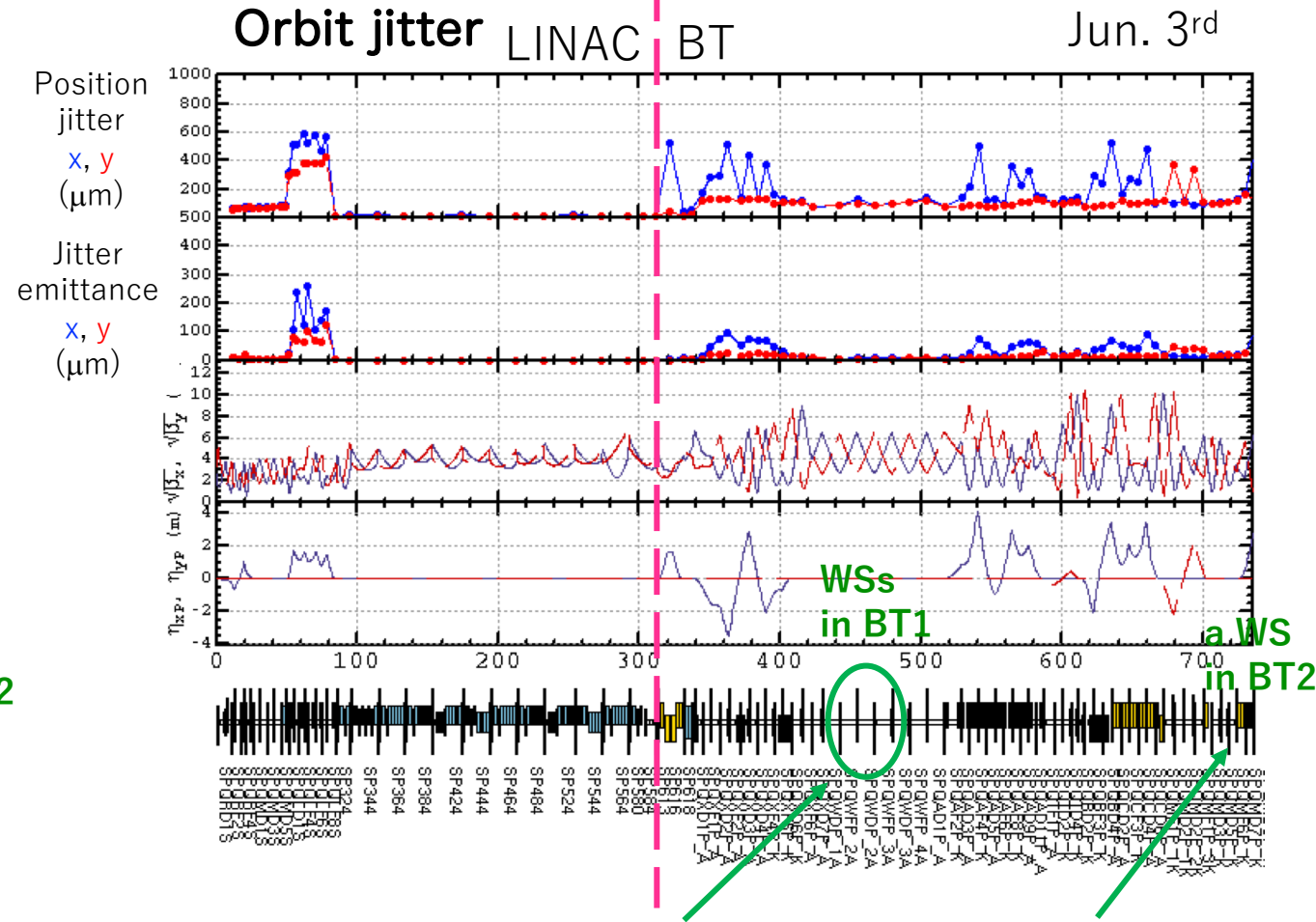
Measurements in e^+ line

Y. Seimiya

Jitter in e^+ BT is small thanks to the DR.



RMS η_x @BT1 = 0.05 m η_x @WS2 = -0.09 m
RMS η_y @BT1 = 0.01 m η_y @WS2 = -0.07 m

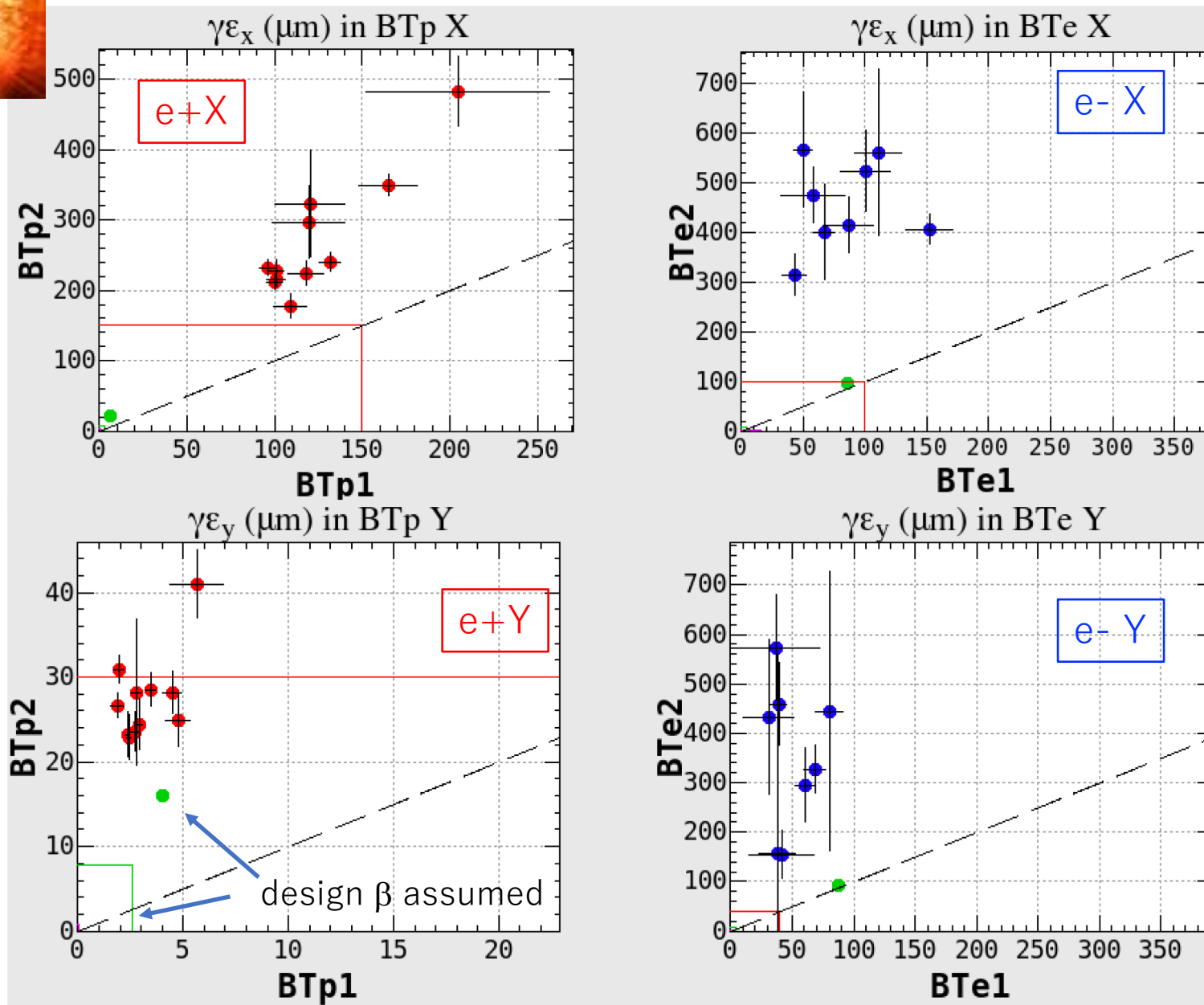


ϵ_{jx} @BT1 = 6 μm
 ϵ_{jy} @BT1 = 4 μm

ϵ_{jx} @BT2 = 22 μm
 ϵ_{jy} @BT2 = 16 μm



Emittance explosion in BT



- Measured by WS
- Emittance due to Jitter
- Emittance due to BPM res.
- Emittance due to σ_δ (invisibly small)

--- Same emittance line of BT2 as BT1

— Required emittance from LER/HER

- The horizontal orbit jitter in the e+ is negligibly small.
- The other jitter emittances at BT1 is comparable as measured emittance.
- But in BT2, all measured emittances are larger than the jitter emittances.



Jitter of power supplies

- Bends in the BT line
 - The jitter generates only the orbit jitter emittance, which does not explain the explosion.
 - e-: $\pm 350\text{ppm(p-p)}$ in max → [See backup slides.](#)
 - e+: $\pm 100\text{ppm(p-p)}$ in max
 - The chamber is made of aluminum.
- Quads in the BT line
 - e-/e+ : $\Delta K=1\text{e-}4$ (p-p) in max, but low frequency components are large.
→ [See backup slides.](#)
 - → $\Delta\beta/\beta \sim 1\%$
 $\epsilon_{\text{jitter}} \sim 10\mu\text{m}$, assuming 2 mm orbit distortion → [small for e-](#)
- Bends in the Jarc
 - A large fluctuation of $\pm 190\text{ppm(p-p)}$ has been observed.
 - Chamber is made of SUS.
 - This produces $\pm 2(\text{H})/\pm 1(\text{V})$ mm orbits in BT.
 - Plan to replace with high-performance power supply (Y. Enomoto).
 - Dispersions may be leaked from Jarc through BT.



C) Emittance explosion in e- BT line

1. Dispersion and orbit jitter emittance:

- Measurements have been performed.
- Jitter of power supplies ?

2. Intensity dependence:

- Not yet done.
- Small for e+ (10% for 0.9/1.2nC, T. Mori).

3. Multipole components of bends:

- Not yet done.
- For e+ changing orbit in the bends did not affect the emittance.

4. Multipole components of quads:

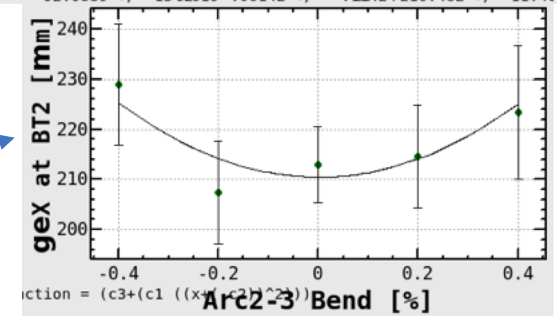
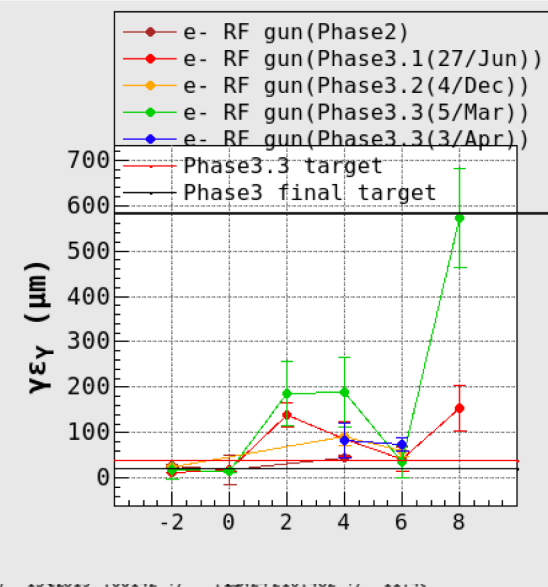
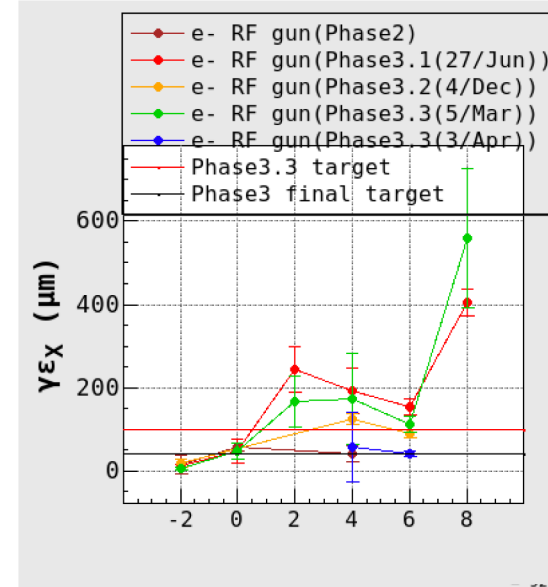
- A simulation with multipole components tells that the horizontal emittance is doubled with energy spread of 0.3%. However only 15% increase in vertical.
- Measurements are to be done.

5. Abnormal quads in the line:

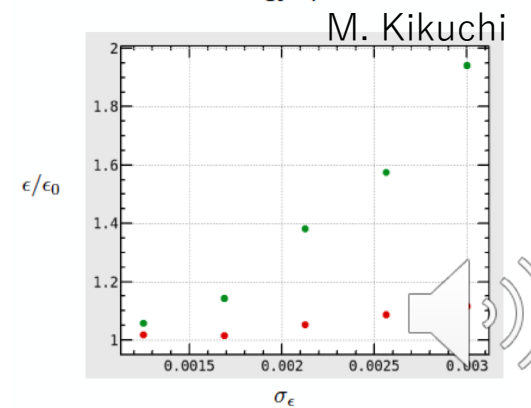
- Making bumps to find out the quads.

6. The source of emittance explosion is still mystery.

7. A new candidate of the source has been proposed by Kikuchi-san.



• Emittance v.s. energy spread



Emittance Explosion in Electron BT :

A possible explanation

M. Kikuchi, EPTF-meeting, July 17, 2020.

- Emittance at BT2 is roughly the same for horizontal and vertical plane.
 - Independent on the emittance at BT1.
- ➡ • Obstructive material may exist in the beam pipe.

-
- Induced emittance due to multiple scattering,

$\beta\sigma_\theta^2$, where

$$\sigma_\theta = \frac{13.6 \text{ MeV}}{cp} \sqrt{\frac{x}{X_0}} \left(1 + 0.0382 \ln \frac{x}{X_0} \right) \quad (1)$$

X_0 : radiation length

- Observed emittance,

$$\gamma\epsilon = 450 \text{ } \mu\text{m} \quad \epsilon = 32.8 \text{ nm}$$

- From $\beta\sigma_\theta^2 = \epsilon$ and Eq. (1),

$$x/X_0 = (1.9 \sim 6.7) \times 10^{-4}$$

for $\beta = 25 \sim 100 \text{ m}$

Note: this is beyond validity of Eq.(1), $10^{-3} \leq x/X_0 \leq 100$

For Al, $X_0 = 89 \text{ mm}$

$$x = (17 \sim 60) \text{ } \mu\text{m}$$

For Polyethylene, $X_0 = 480 \text{ mm}$

$$x = (92 \sim 320) \text{ } \mu\text{m}$$



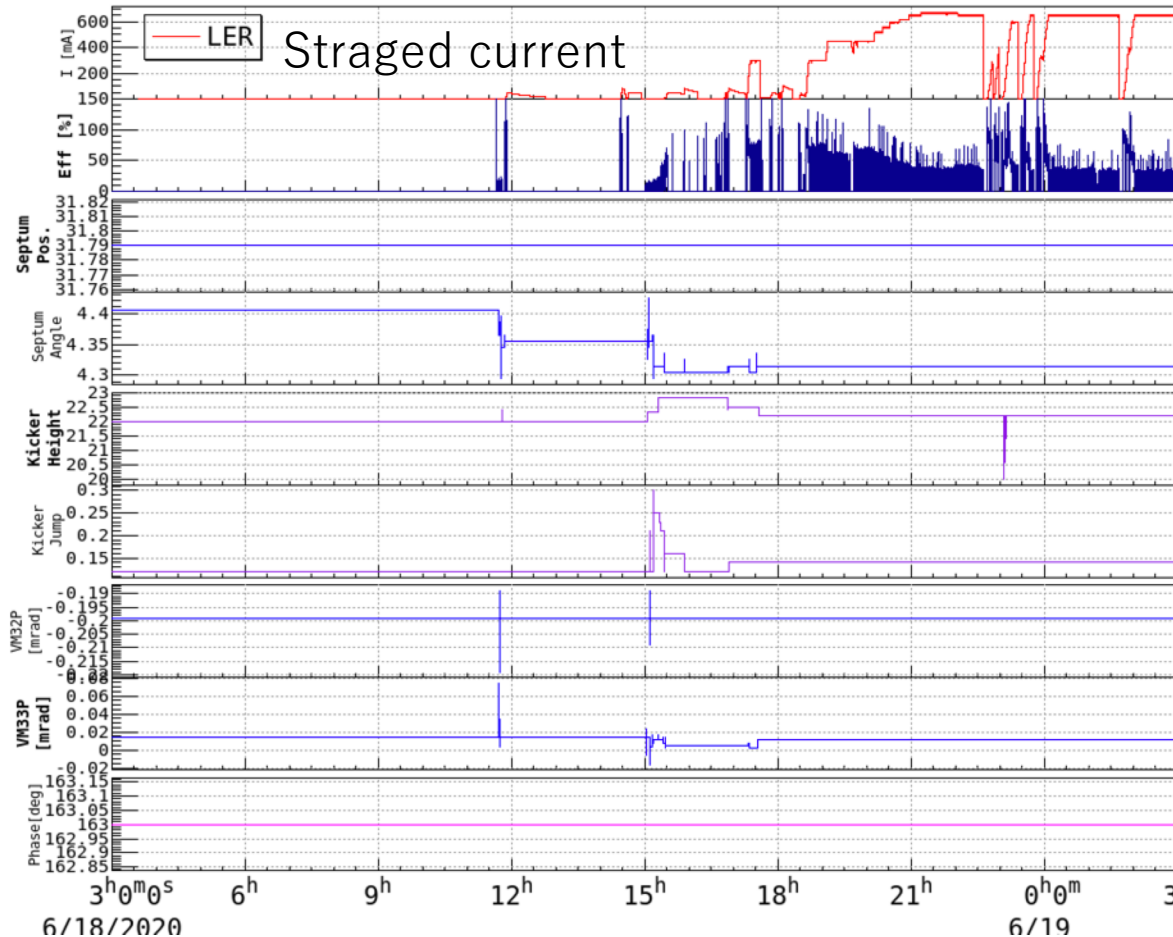
3. Injection

- A) Mystery of injection tuning
- B) 2 bunch injection
- C) Correction of Injection kicker for LER
- D) Bucket selection test
- E) Future plan
 - New BT dump mode
 - Collimator, Screen monitor
 - Synchrotron injection
 - Fast kicker for 2 bunch injection



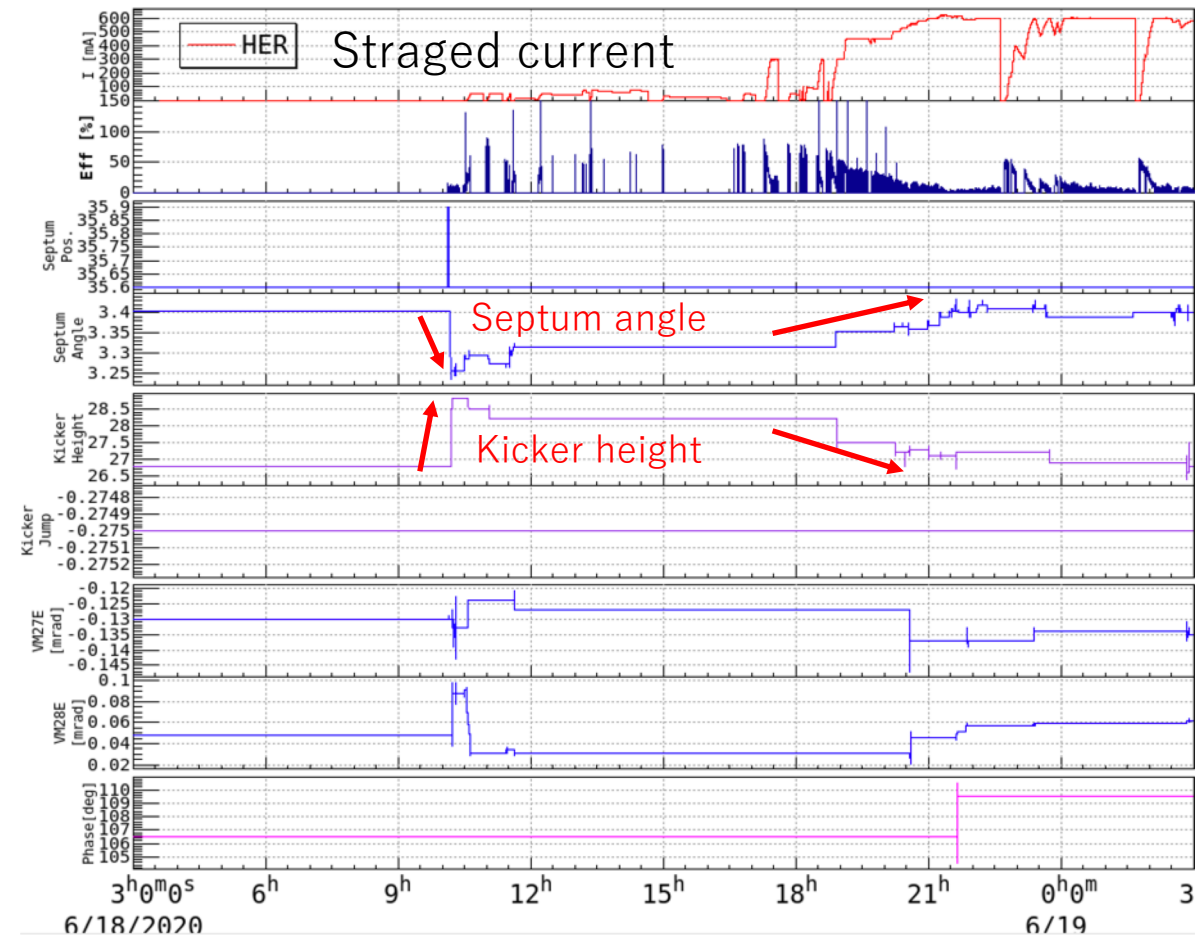
A) Mystery of injection tuning

LER



For LER, the tuning are not so large.

HER

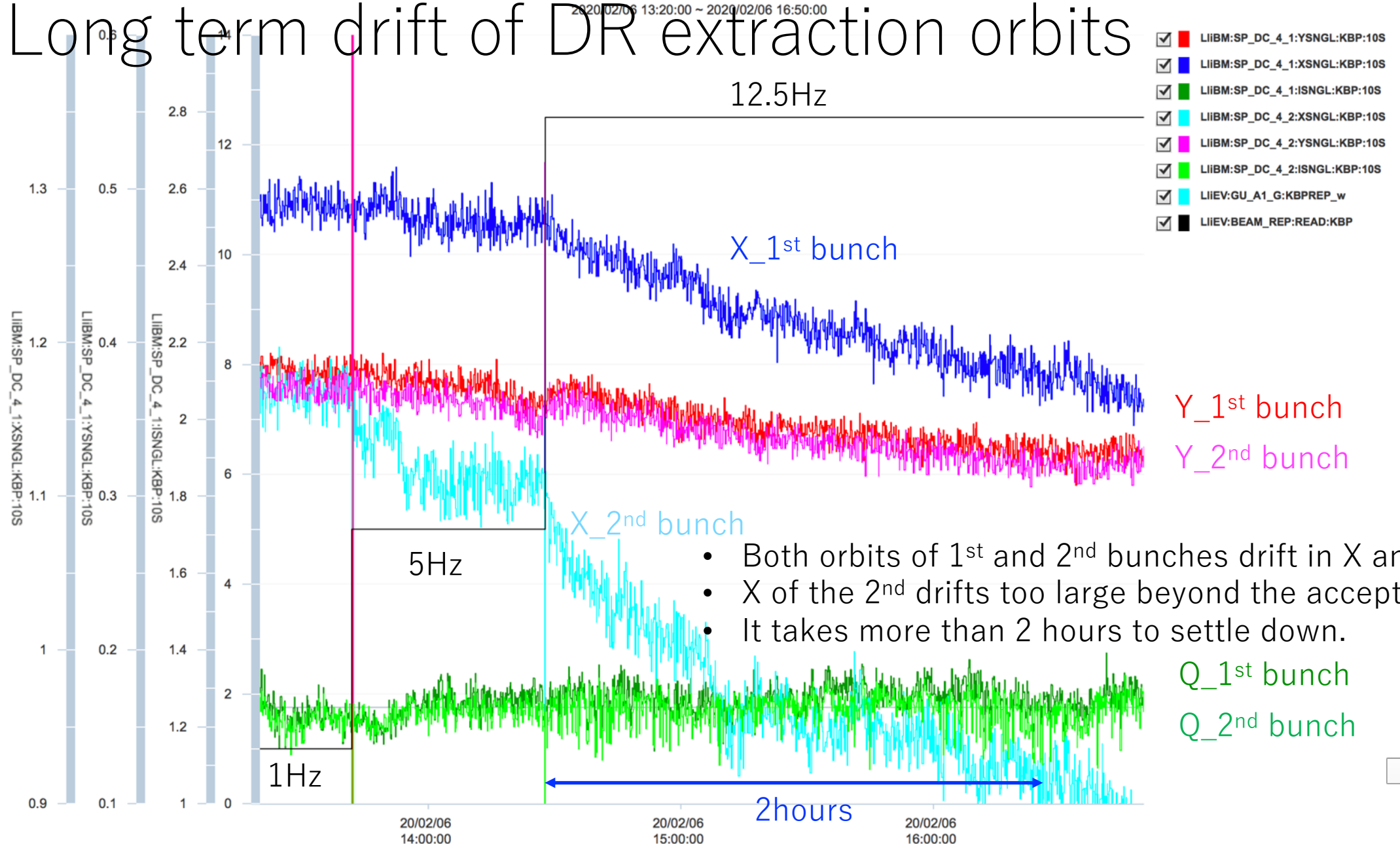


After longer absence than 2-3 hours,
the orbit tuning for HER are always needed.
If the absence is shorter than 30min., the
tuning is not needed so much.



B) 2 bunch injection

Long term drift of DR extraction orbits



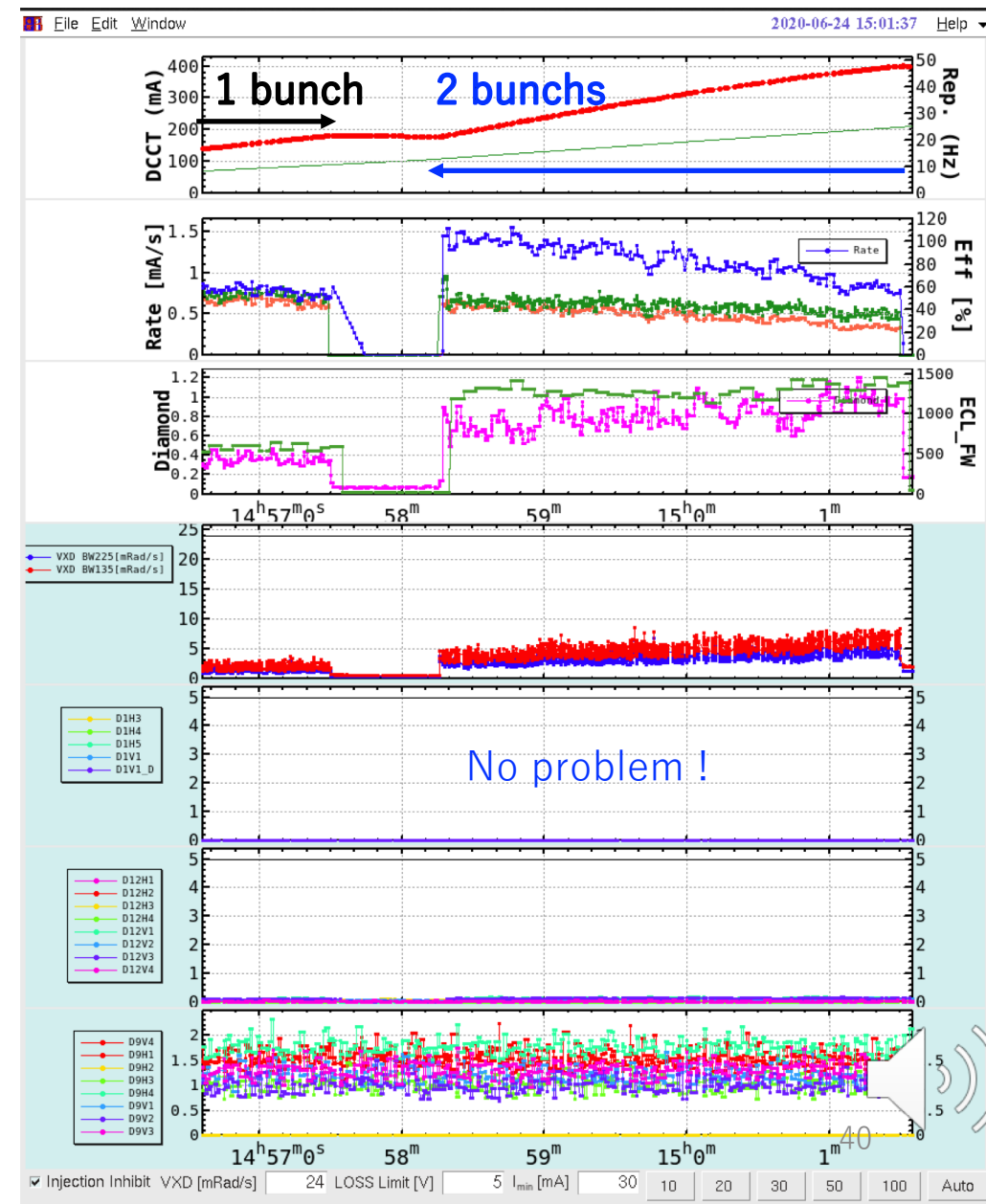
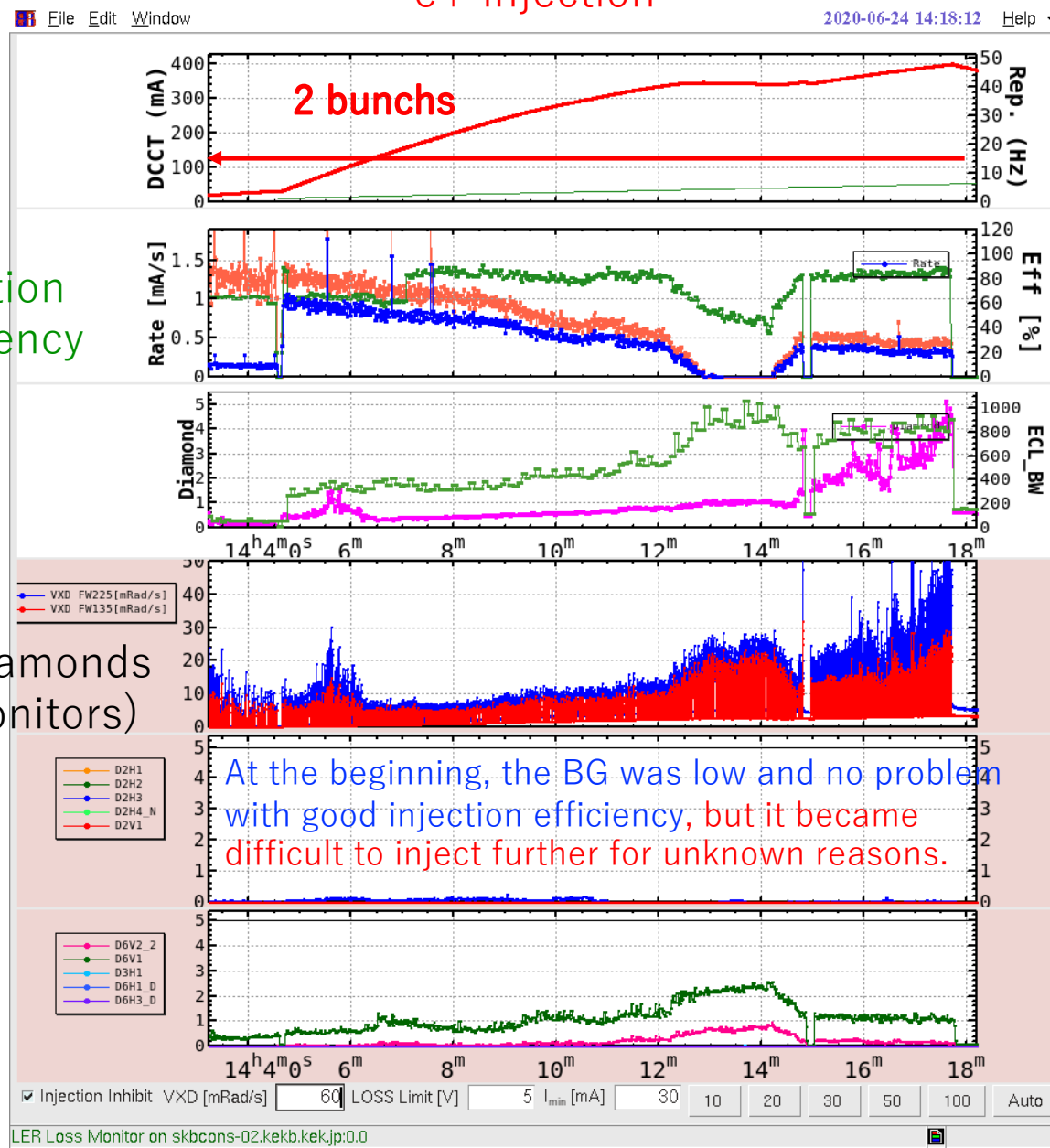
2 bunch injection and BG

e+ injection

e- injection

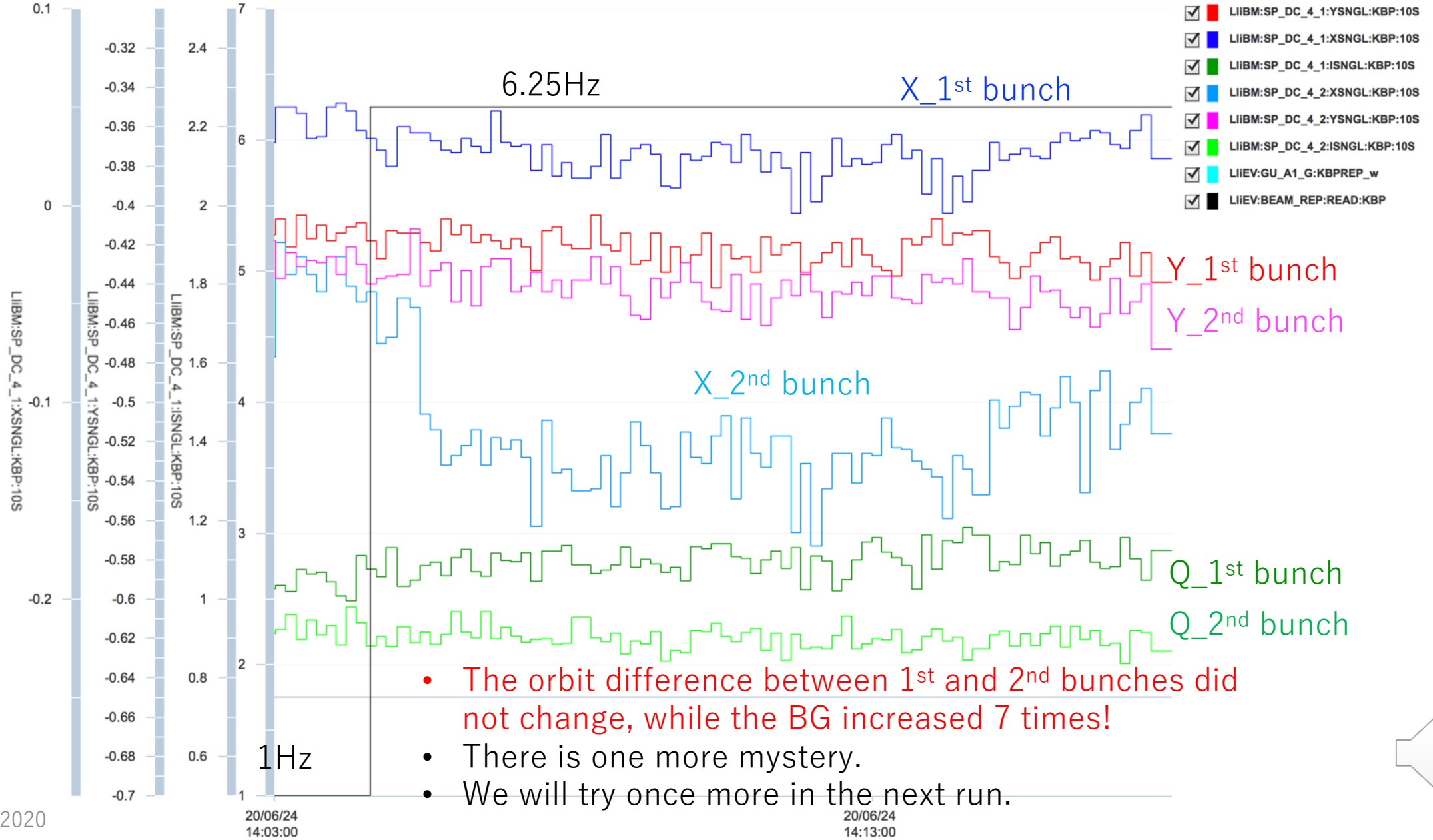
Injection efficiency

VXD diamonds (BG monitors)



DR extraction orbits

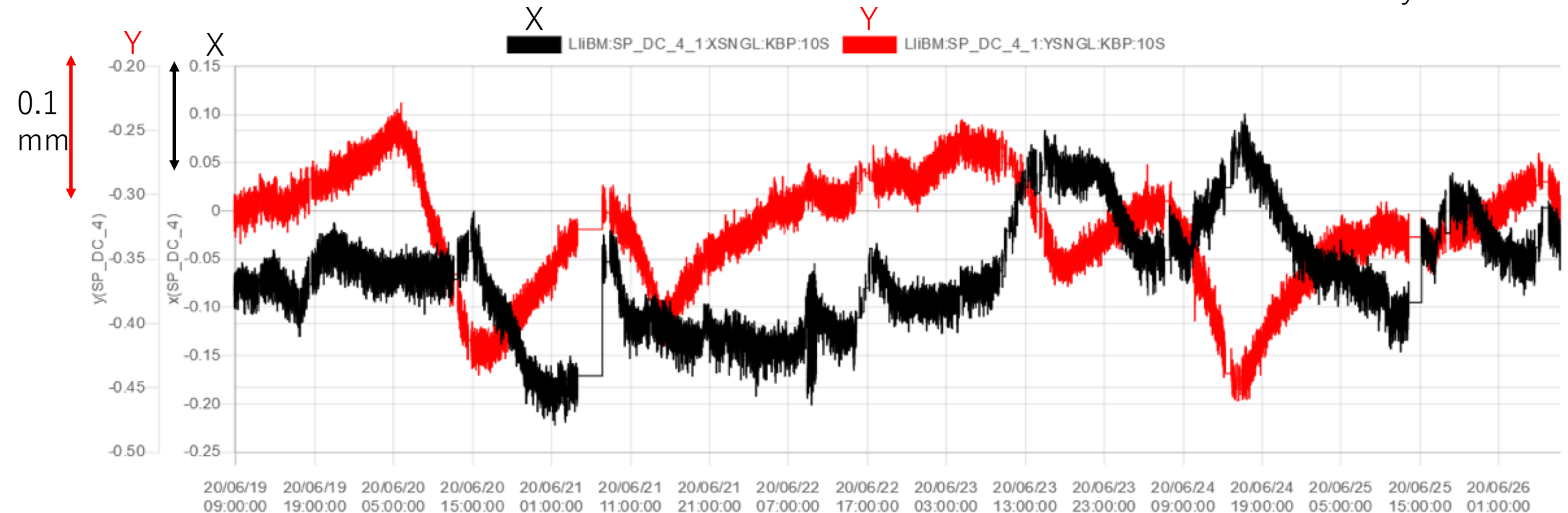
2020/06/24 14:03:00 ~ 2020/06/24 14:18:00



Orbit drift for 1 week

The 1st BPM of LINAC after the DR

F. Miyahara



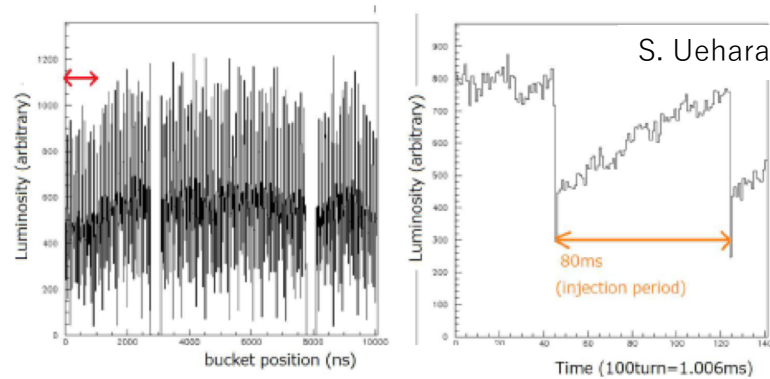
An anticorrelation between X and Y is observed.
The source has not been identified.

We have a plan to work the continuous orbit correction in DR as well as MR.

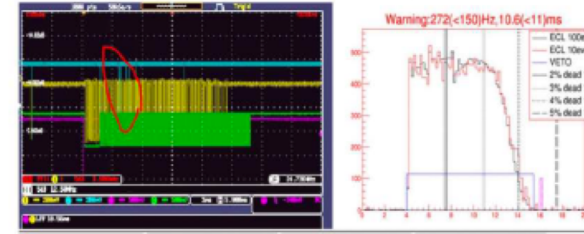


C) Correction of X-Y coupling between injection kickers in the LER

There was a vertical oscillation in the LER just after injection, causing luminosity reduction and the BG.



-June 2nd: BG timing is changed. Outside of injection veto.
It happened ~30 minutes after change 12.5Hz->23hz.



S. Terui,
T. Mimashi, et al.

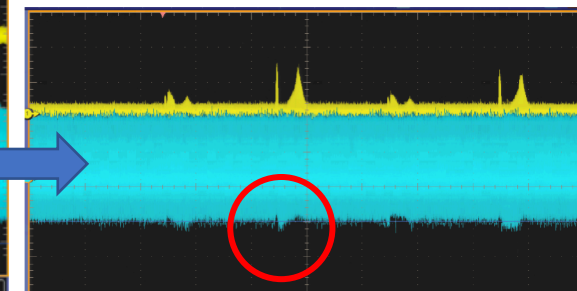
The detail will be talked
by Morita-san.

- The vertical oscillation around the injected bunch has been observed with a bunch oscillation recorder(BOR) (S. Terui, M. Tobiya).
- If there is a vertical offset at the interaction point due to X-Y coupling in the injection π bump,
- the skew quadrupole component k_1 is 1.41×10^{-4} ($2\sigma_y$, M. Kikuchi).
- A skew quadrupole made of permanent magnets is installed near the injection point.(S. Terui, et al.)
- The skew quadrupole consists of doublet quads whose strength is adjusted by rotating opposite direction to change the skew quad component but not to affect the quad.(K. Oide)

Doublet
quads



T. Mimashi

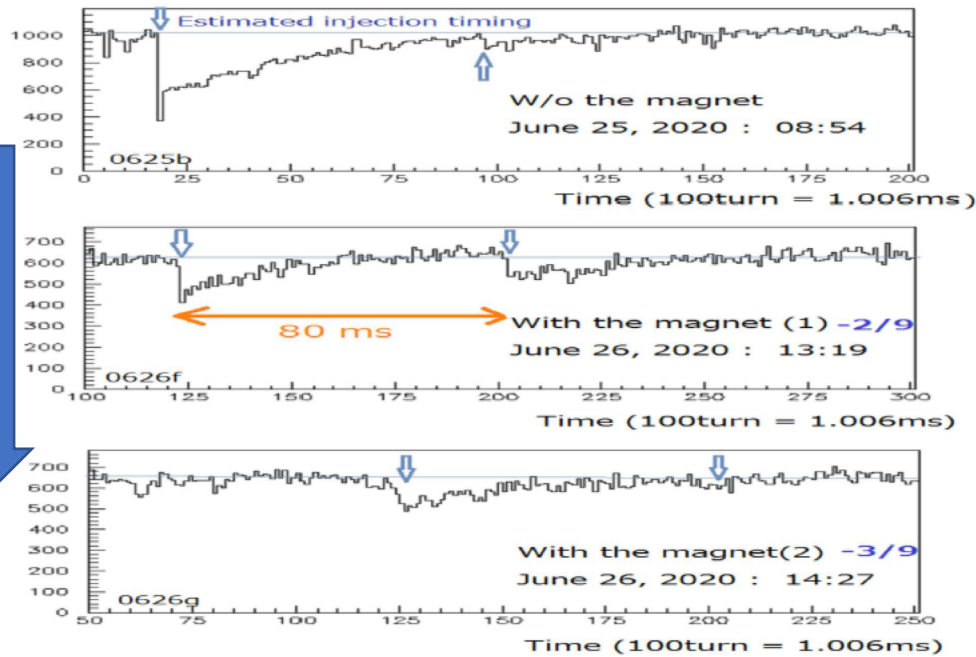


9.53mT

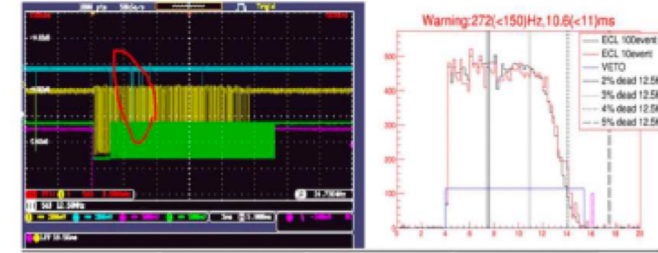


Luminosity decrease nearby the LER injection bunches (for 1.0 us)

S. Uehara

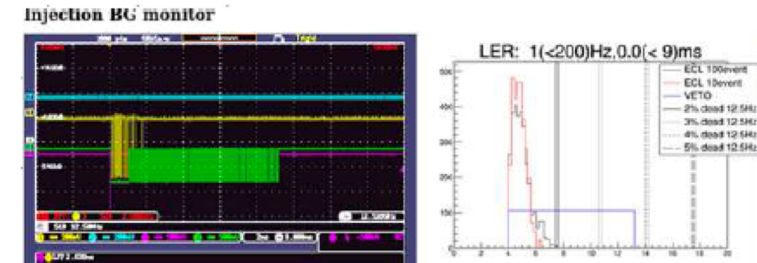


-June 2nd: BG timing is changed. Outside of injection veto.
It happened ~30 minutes after change 12.5Hz->23hz.



T. Koga

skewQ -32mm



$B'L=0.043T(max)$
(The permanent magnet:
 $B'L=0.021T$)



- The vertical oscillation became smaller.
- The dead time of luminosity can be shorter.
(LER: 3.5→2.0%, HER: 1.5%)
- The residue is suspected to be an electric field of the kicker.(K. Oide)

In this summer shutdown, an electromagnetic skew quad will be installed instead of the permanent magnet.
(M. Masuzawa, et al.)



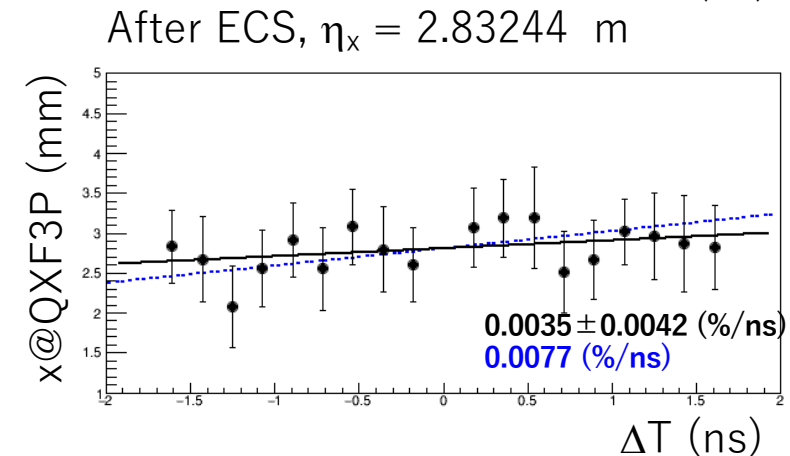
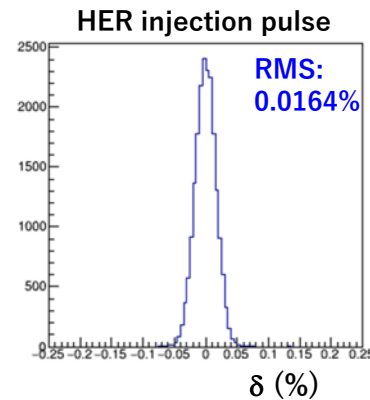
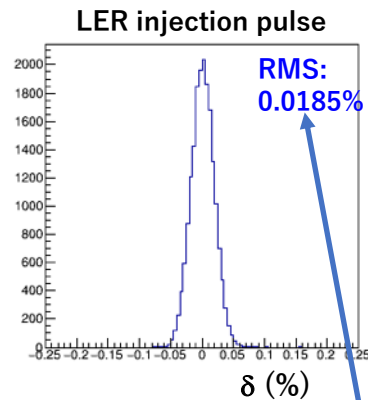
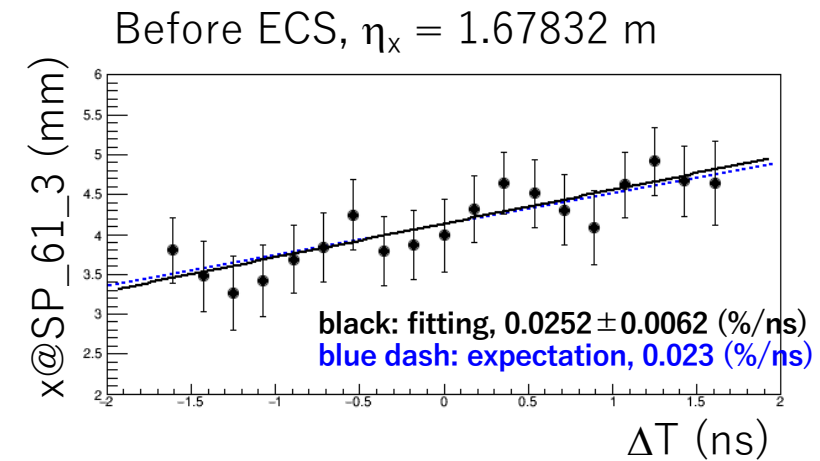
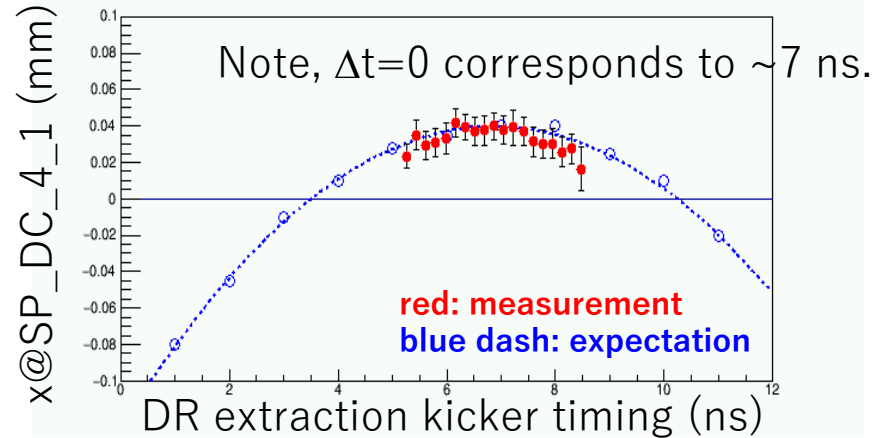
D) Study of a new bucket selection scheme

H. Kaji

The new bucket selection scheme implements the RF phase-shifting in the LINAC 3-5 sectors to suppress the waiting time for the bucket-matching.

The RF phase-shifting causes the timing difference between the timing-trigger and the beam pulse, Δt . It becomes at most $\pm 1.6\text{ ns}$.

Its influences could be certainly confirmed in the LINAC/BT study on Feb 7th.



The energy fluctuation induced by the new bucket selection is smaller than the existing fluctuation shown above.



E) Future plan

- New BT dump mode → by winter
 - Since now the e- BT dump block is located downstream of the wire scanner(WS) at BT2, emittance measurement cannot be done in the BT dump mode.
 - It is planned that a beam shutter is installed downstream of the WS for another dump. (T. Mori, et al.)
- Screen monitor improvement → this summer
 - Replace some screen monitors with OTR to digitize beam sizes. (T. Mori, et al.)
 - To measure emittances between Arc1 to Arc4 is very important to explore the emittance explosion.
- Collimator installation → by winter
 - It will cut the long tail of energy spread of e- beam, which reduces the injection BG of HER and protects to inject beams with abnormal energy. (T. Mori)
- Closing ECS dispersioin
 - Install quads with permanent magnets. There is a space issue.
- Synchrotron injection → in this autumn run ?
- Fast pulsed steering magnets in Jarc and BT for 2 bunch injection
 - → 2-3 years later (T. Kamitani, Y. Enomoto, et al.)



4. Summary

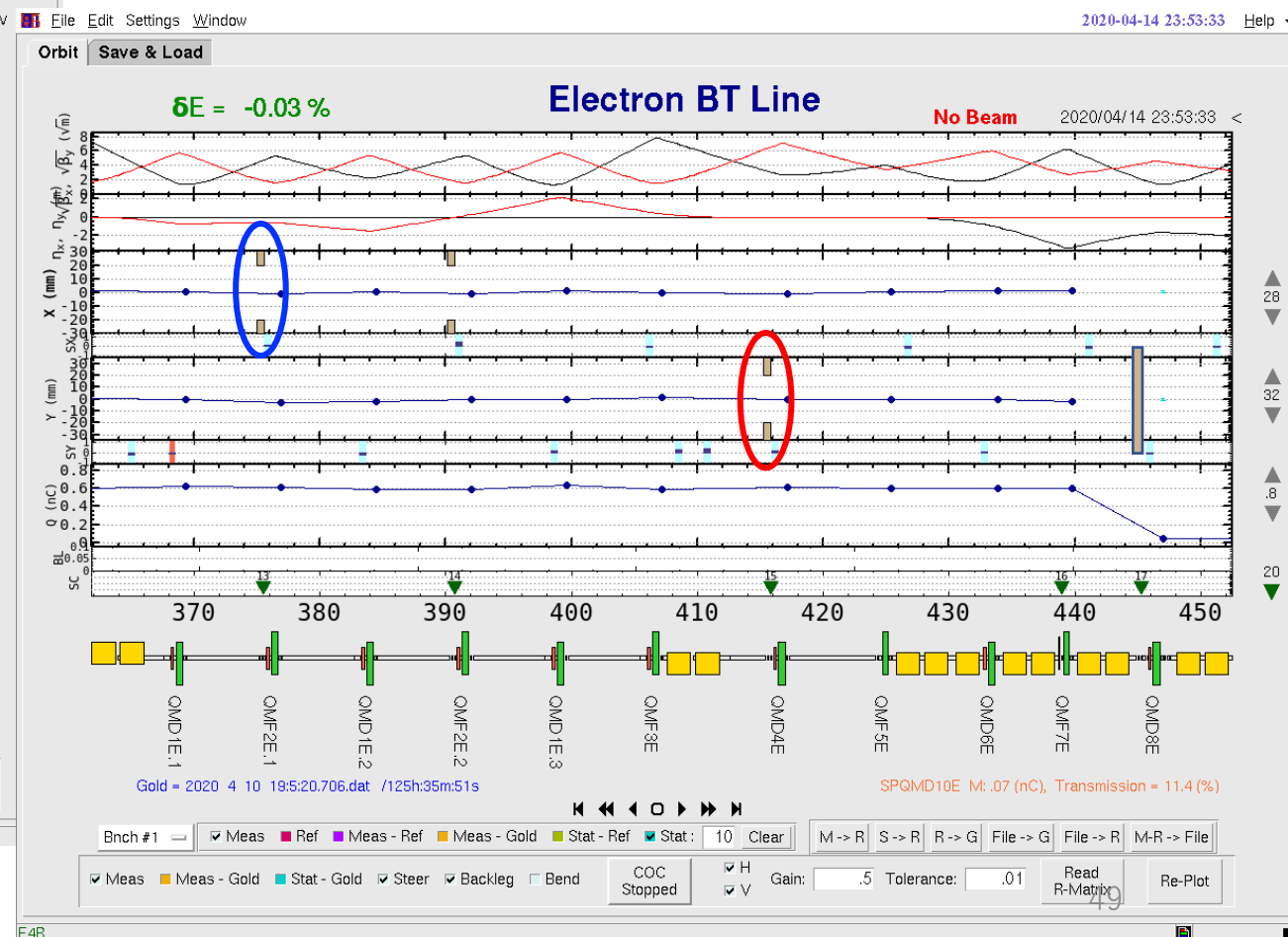
- The injection beam with lower emittance and higher charge is essential for higher luminosity.
- The **explosion of e- emittance** is the biggest problem.
 - Orbit jitters do not explain the explosion.
 - The new candidate from Kikuchi-san is so plausible.
- The e+ emittance has a room to improve.
 - Close the dispersion at the exit of the ECS chicane
- 2 bunch injection of e+ will be indispensable in the next run.



Backup slides

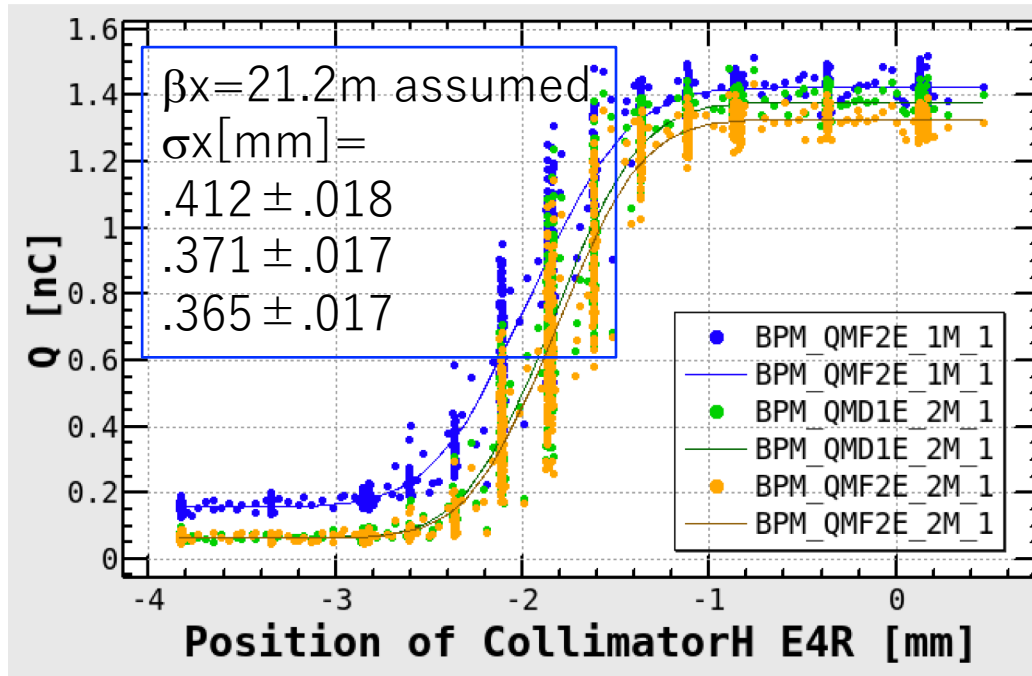
Horizontal Collimator
Vertical Collimator

15.Jul.2020 MAC2020



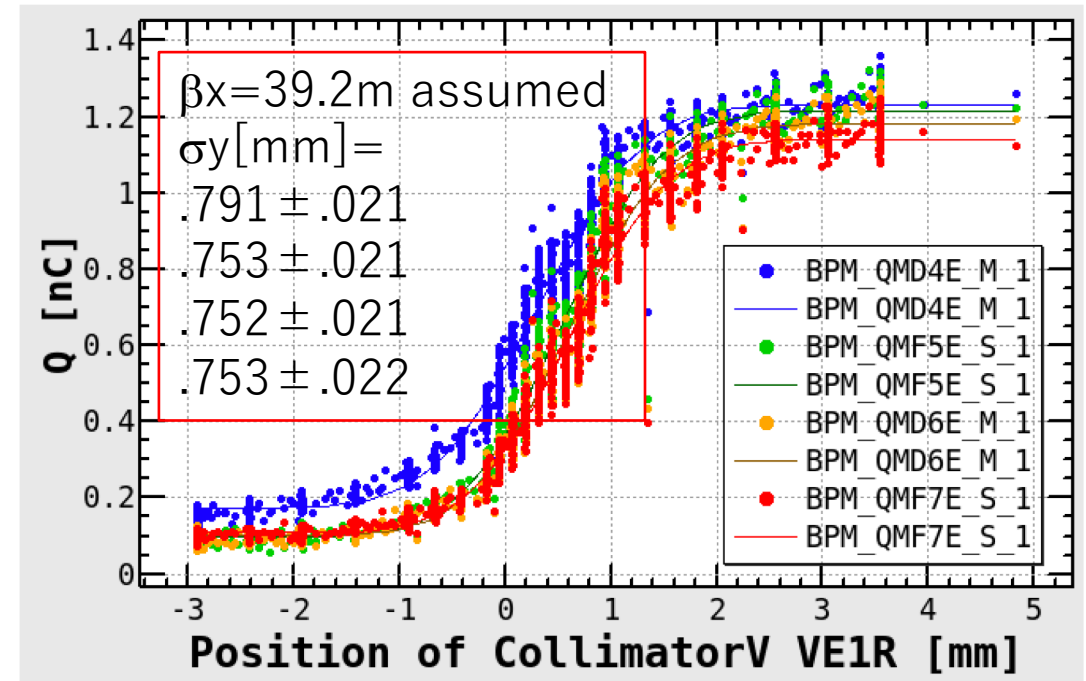
Beam size measured with BT Collimator and BPM

Collimator H



$$\gamma\epsilon_x = 94.8 \pm 5.1 \mu\text{m}$$

Collimator V



$$\gamma\epsilon_y = 203.3 \pm 5.6 \mu\text{m}$$

Measurements with WS@BT2 :

$$\gamma\beta\epsilon_x = 472.82 \pm 55.808 [\mu\text{m}], \quad \gamma\beta\epsilon_y = 457.5 \pm 83.811 [\mu\text{m}]$$

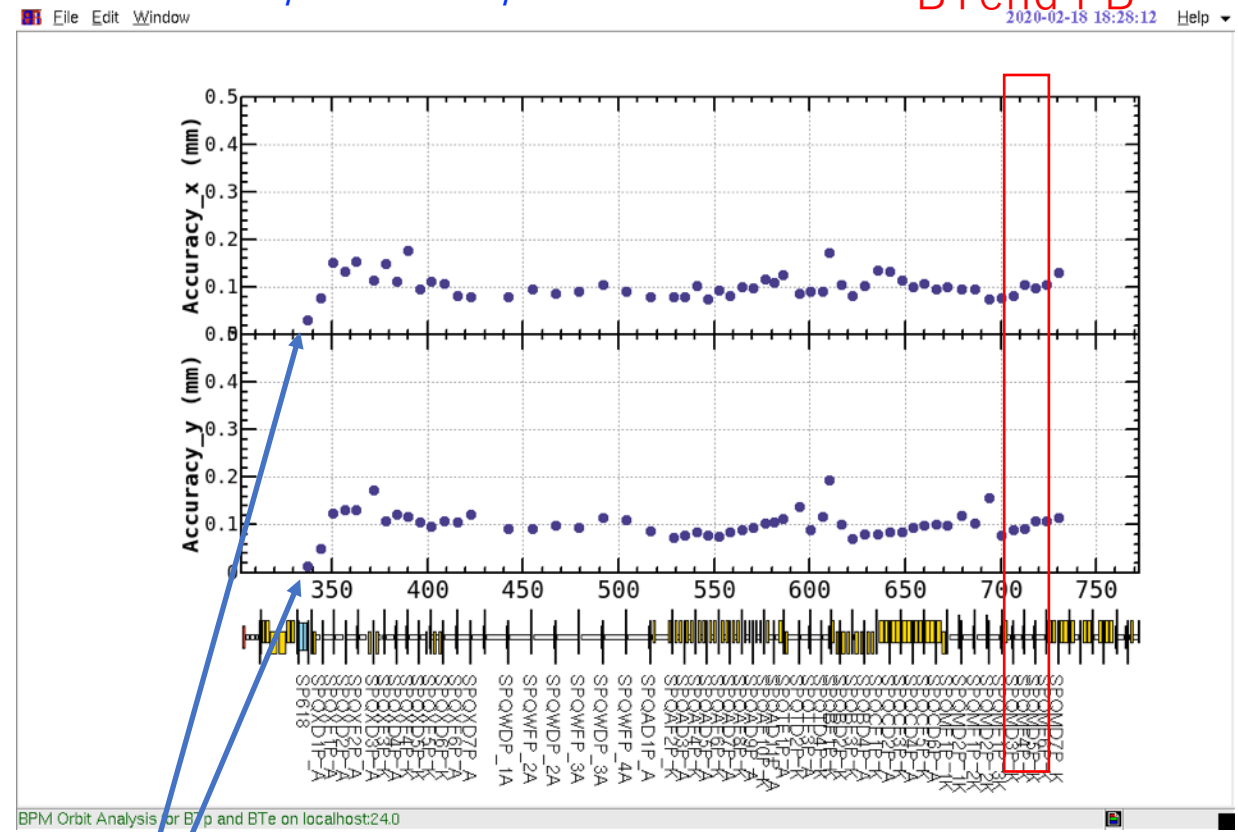
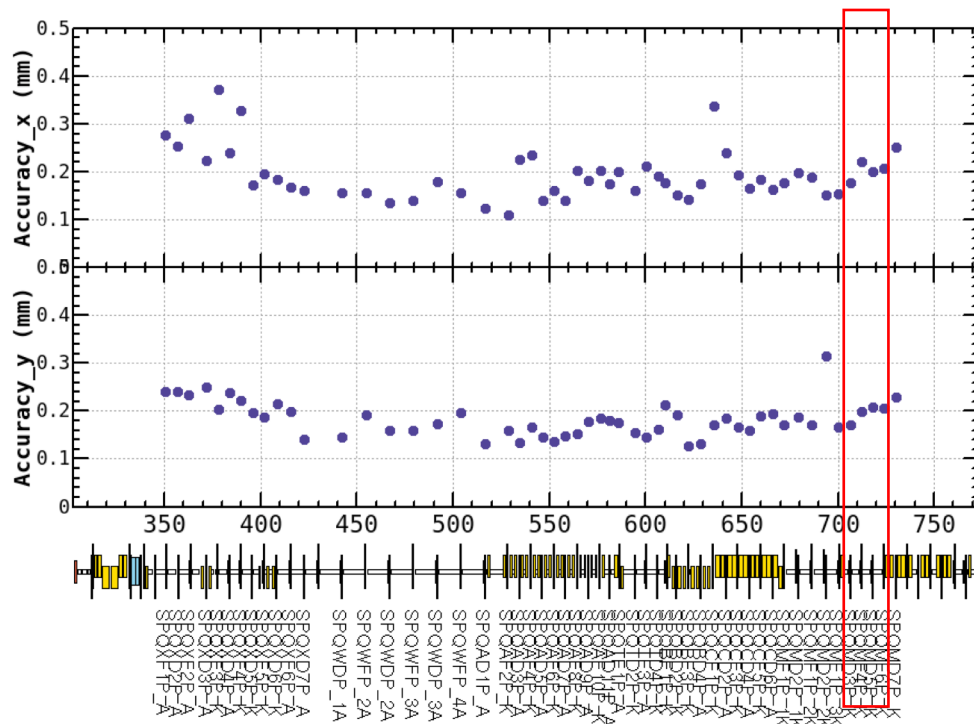
Why are the results of Wire scanner and Collimator different ?

3-BPM before and after BPM improvements

T. Mori, M. Kikuchi

Accuracy at BTendFB :
200 μ m $\rightarrow$ 100 μ m

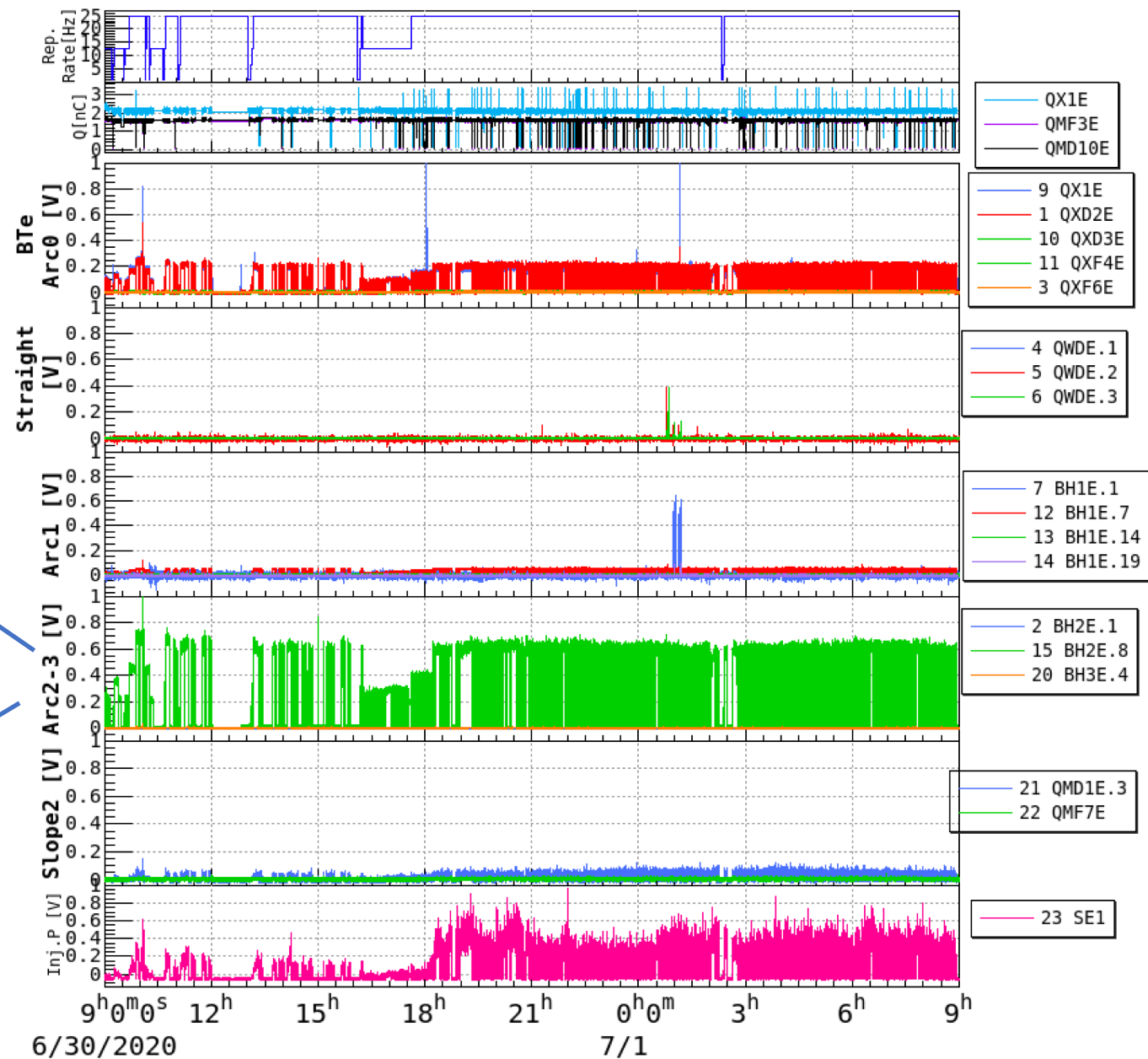
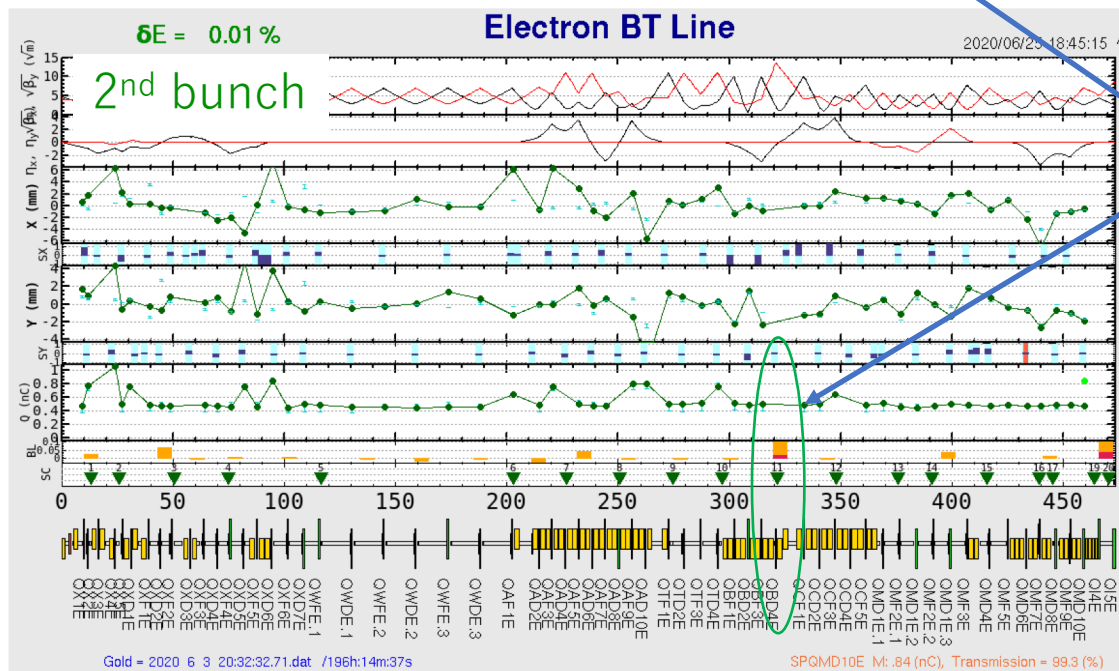
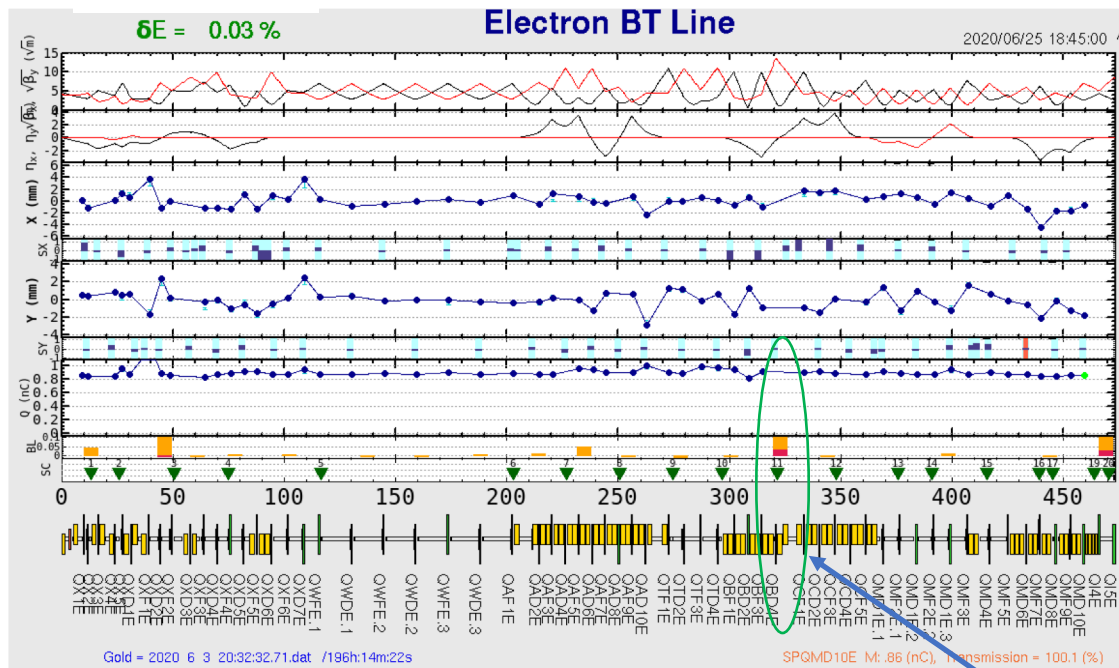
BTend FB

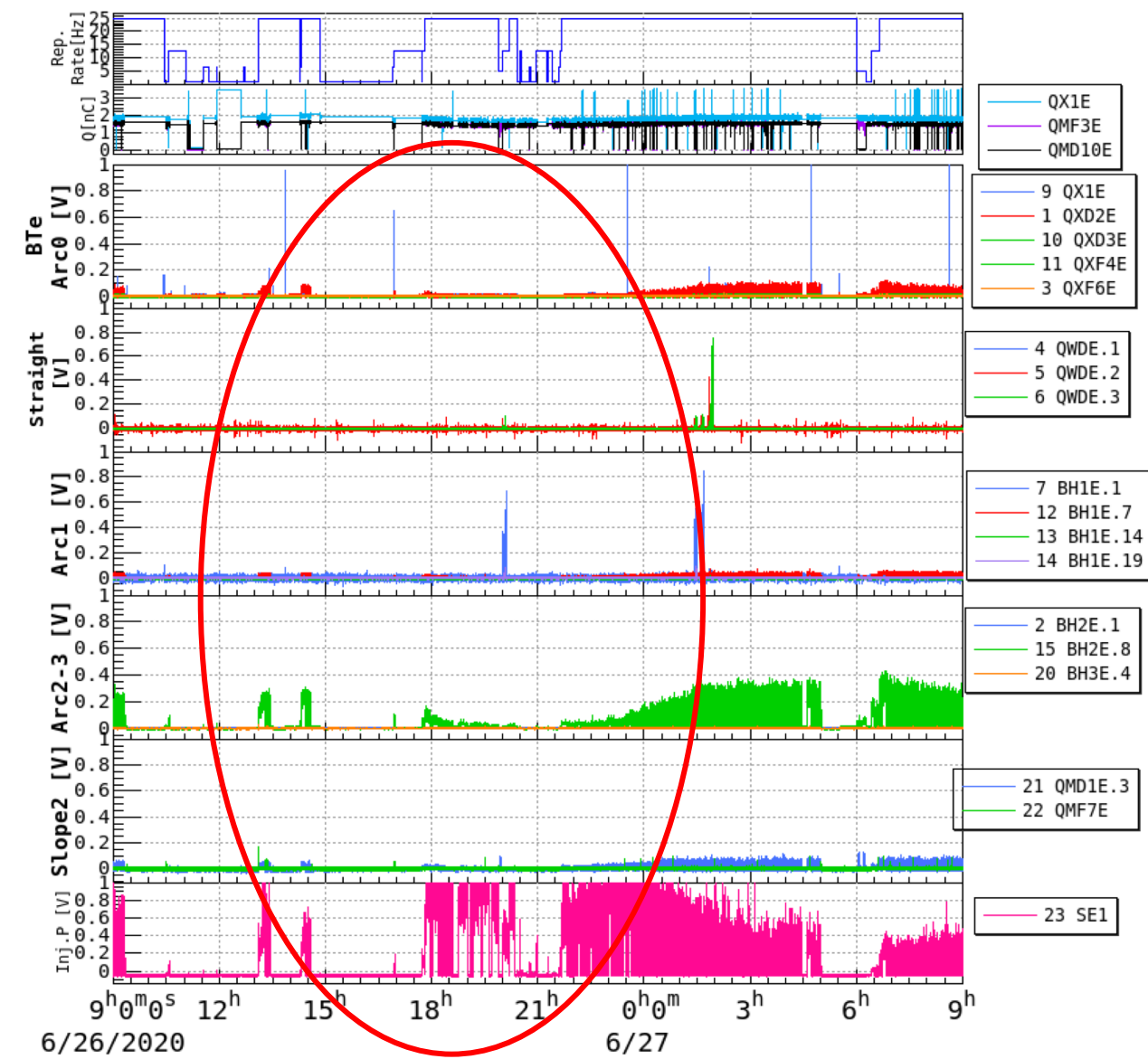


BPM of LINAC

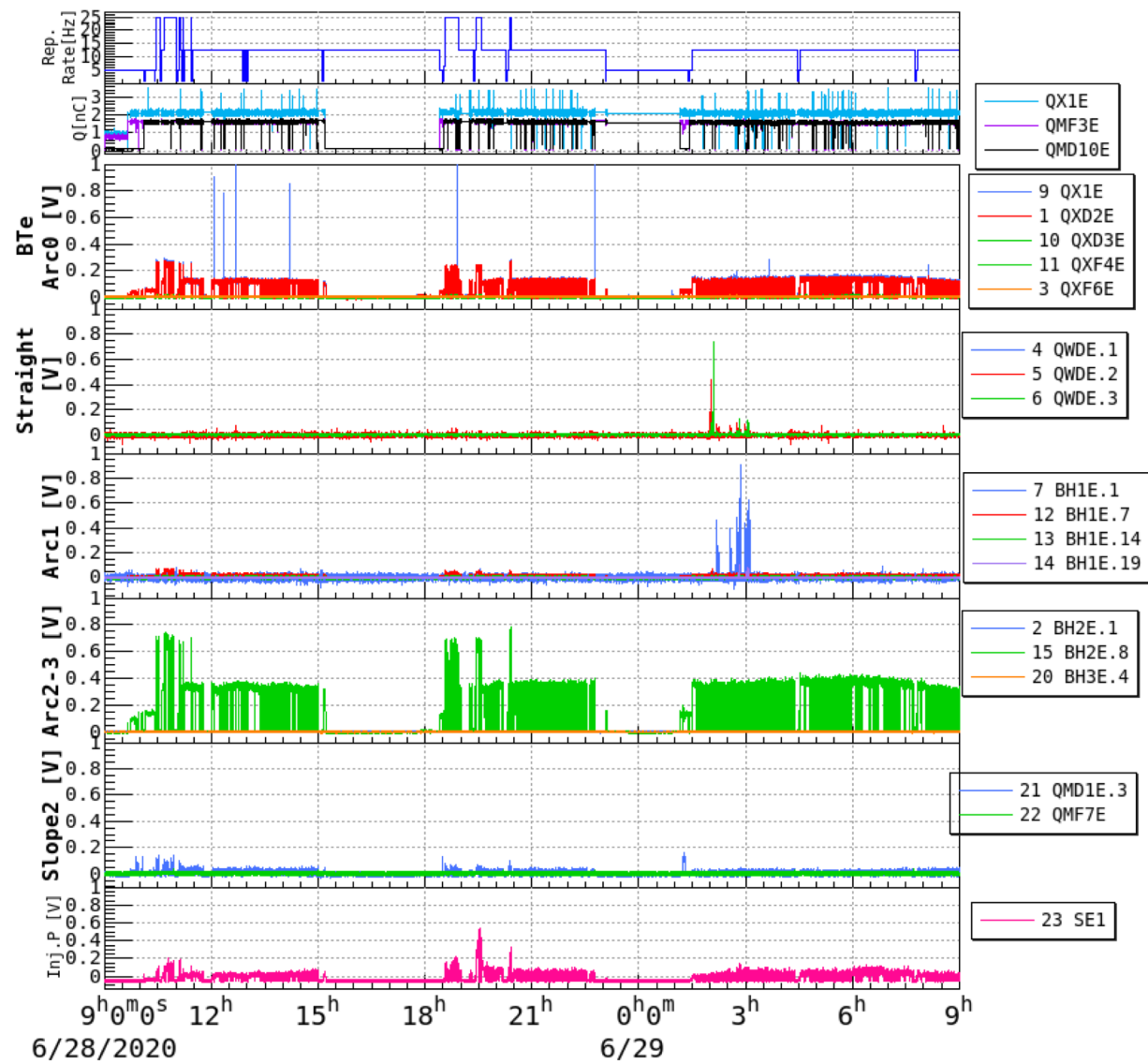
Measured by Y. Ohnishi

1st bunch

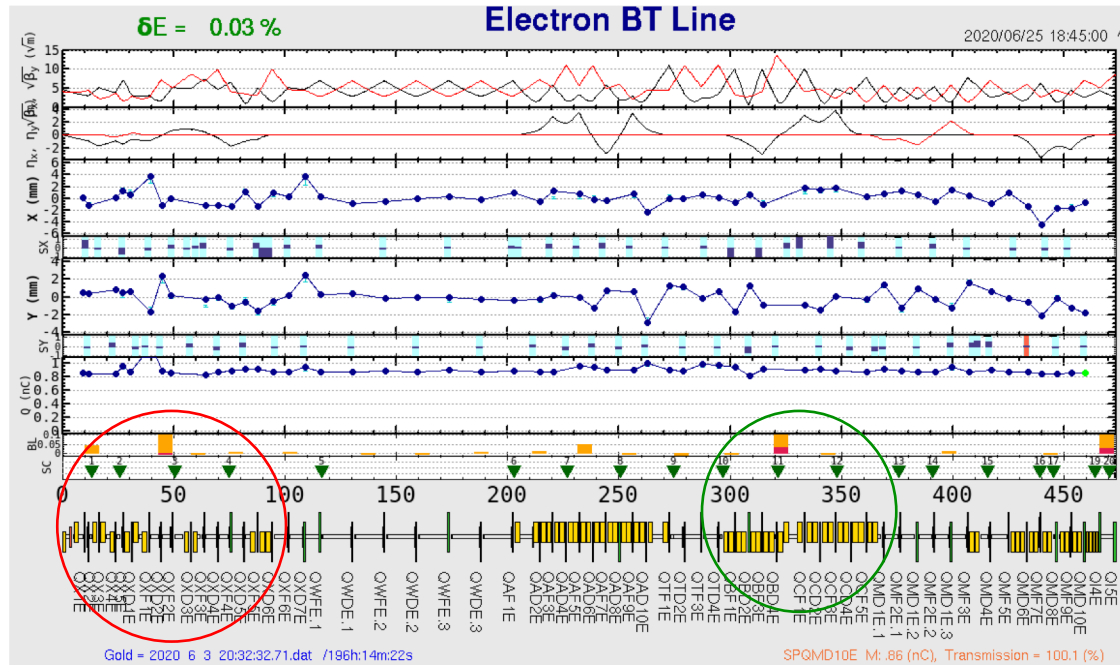




15.Jul.2020 MAC2020



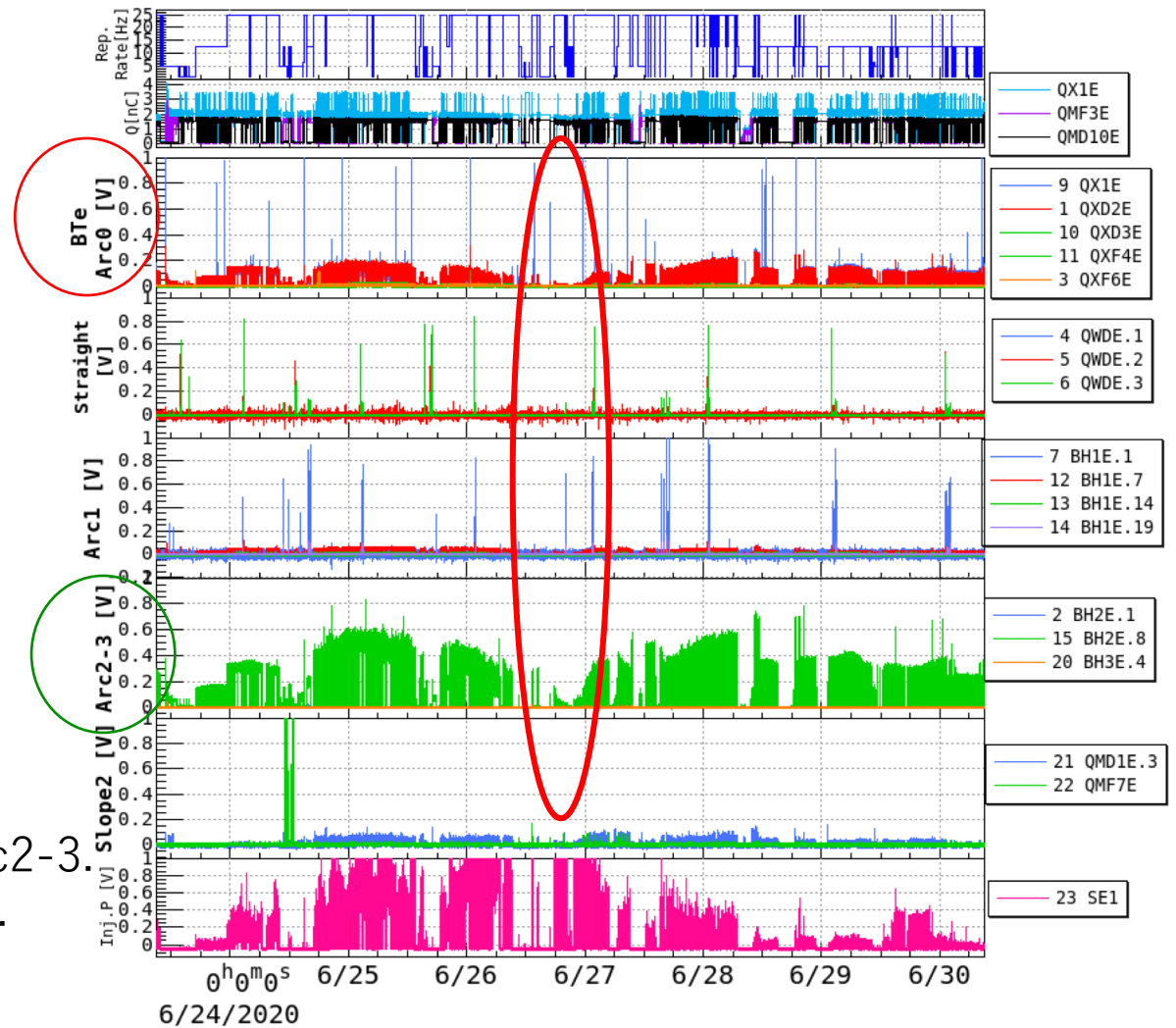
53



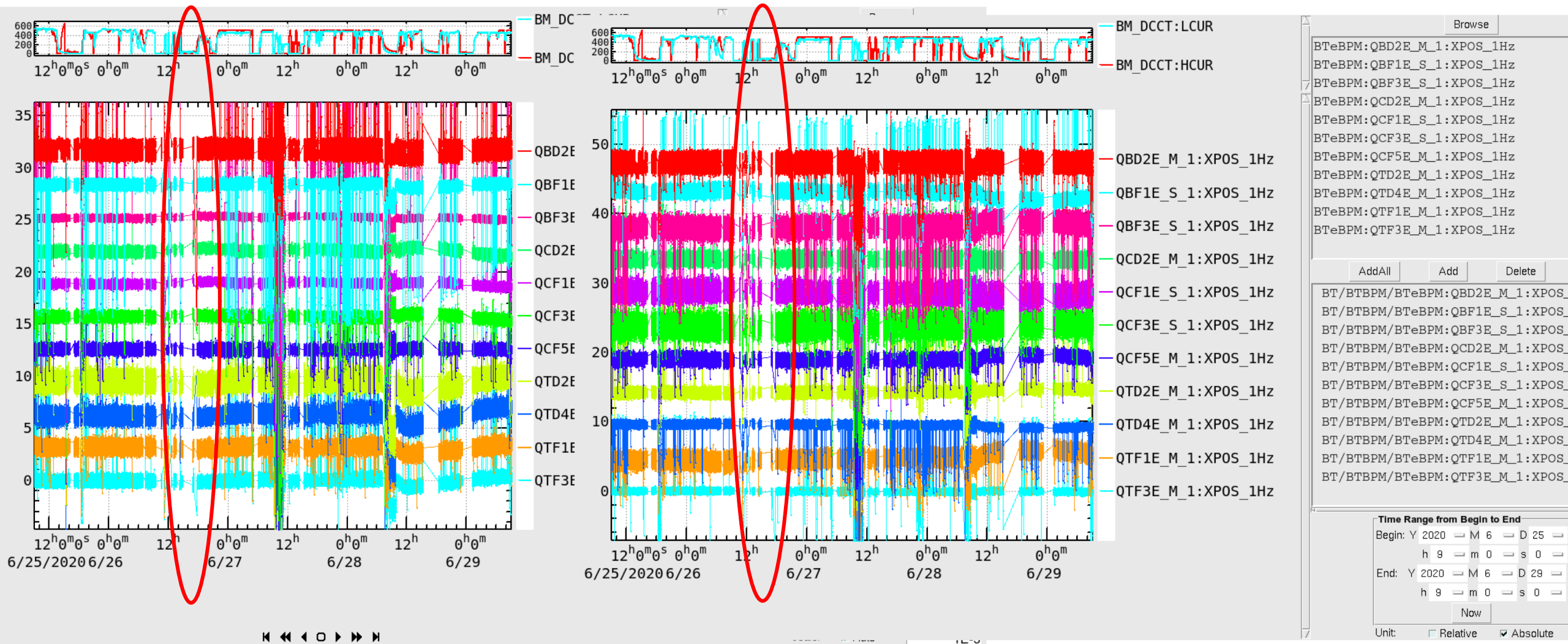
Arc0

Arc2-3

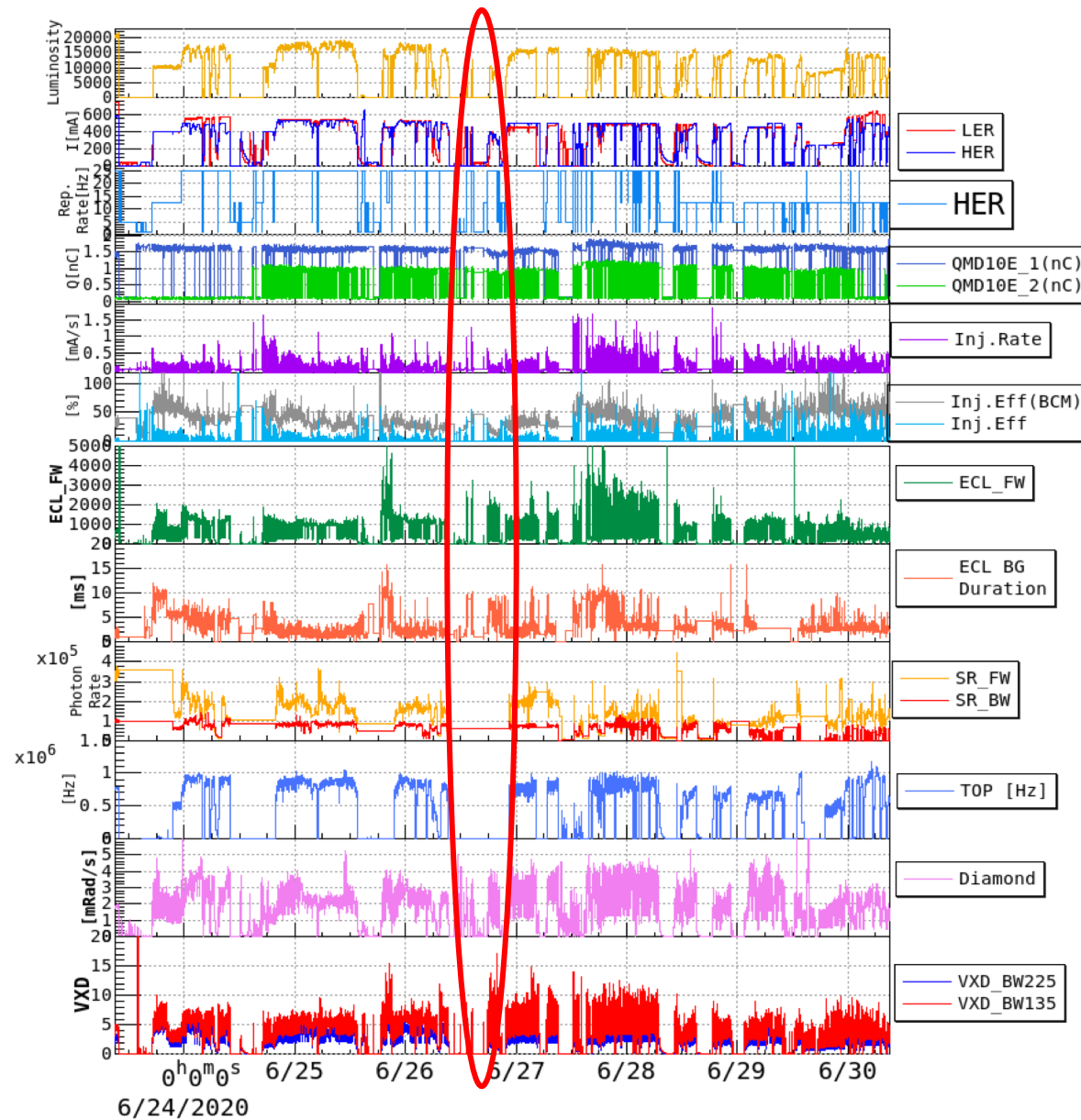
The LM signal has correlation between Arc0 and Arc2-3.
So, the Loss is considered due to the energy spread.



No big orbit distortion around the June 26.



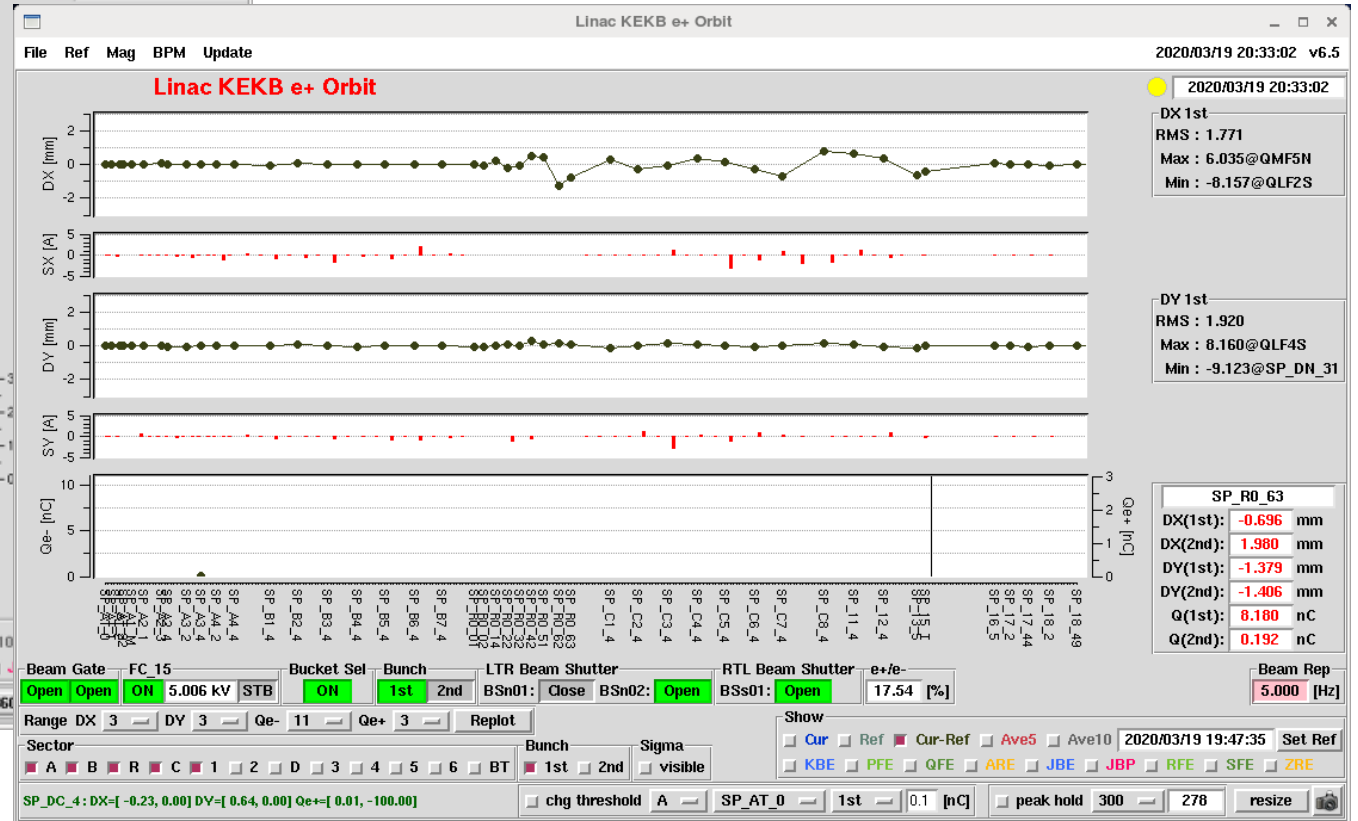
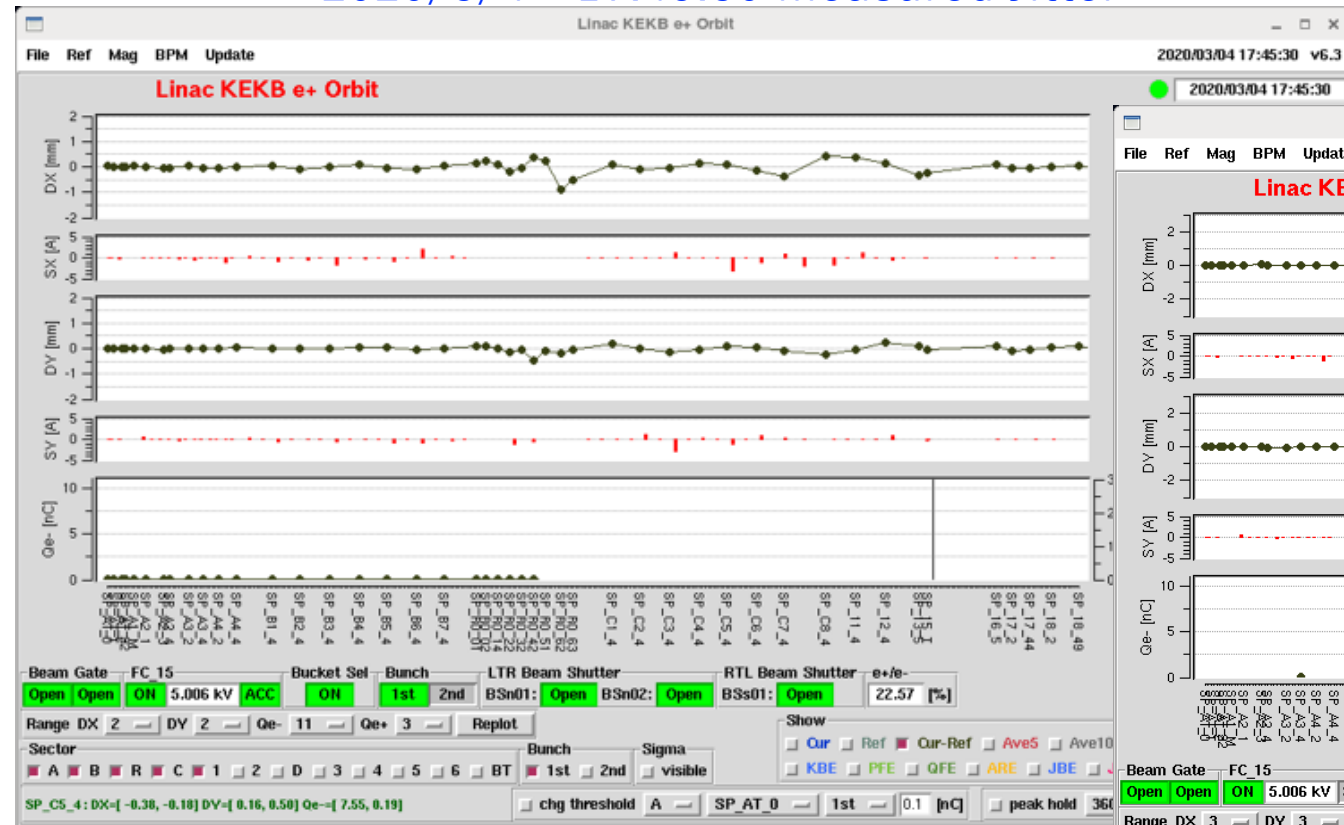
The BG is not so low.



Jitter due to the PS of Jarc bend is suspicious

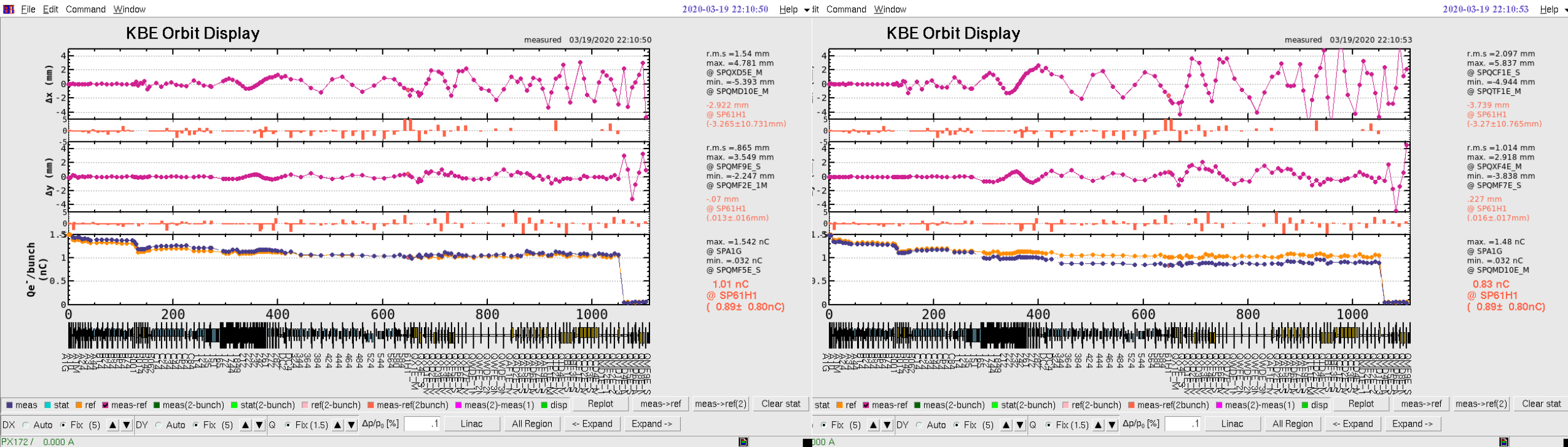
2020/3/4 17:45:30 measured Jitter

2020/3/19 Changed BMR0 and BMR06 setting for 50mA (=190ppm)



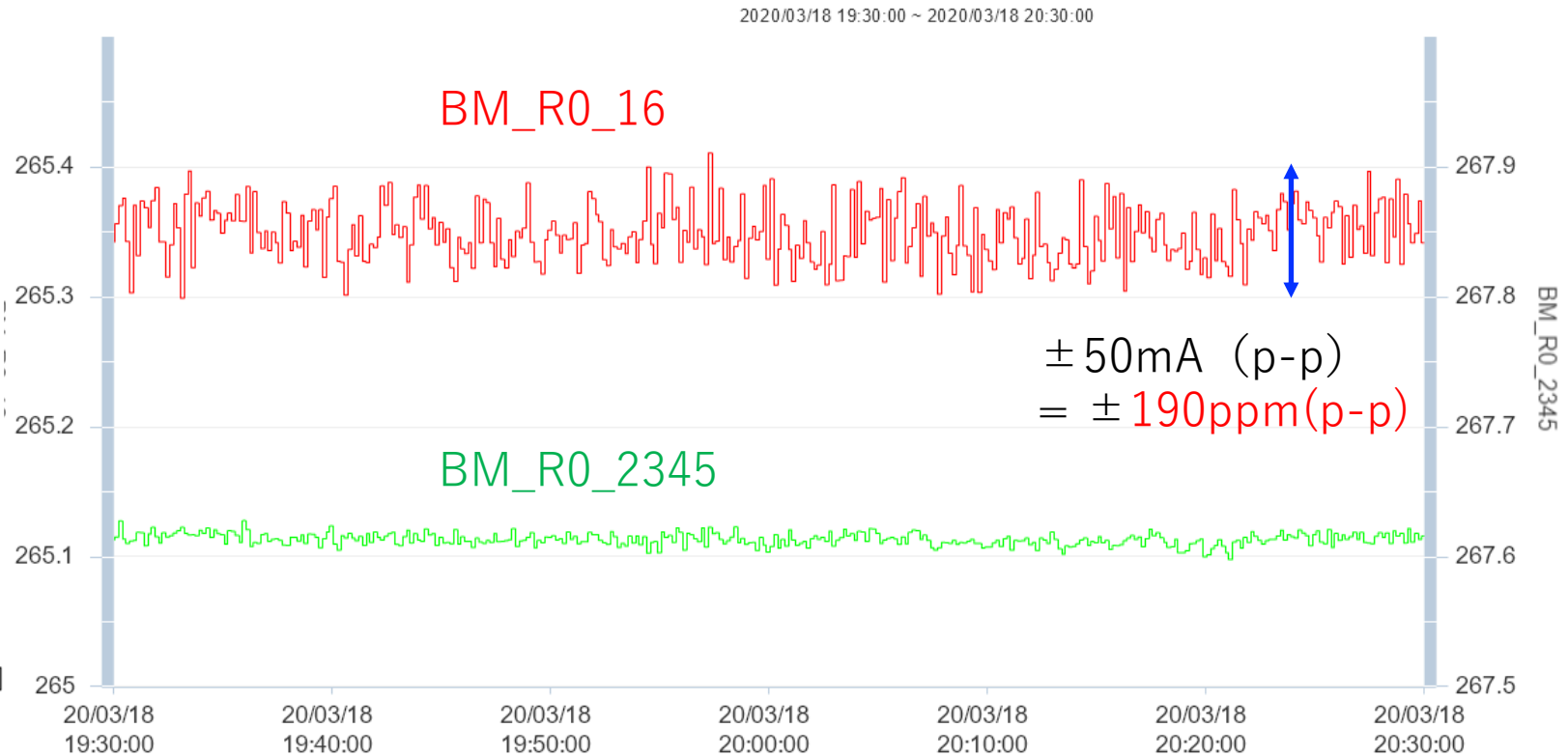
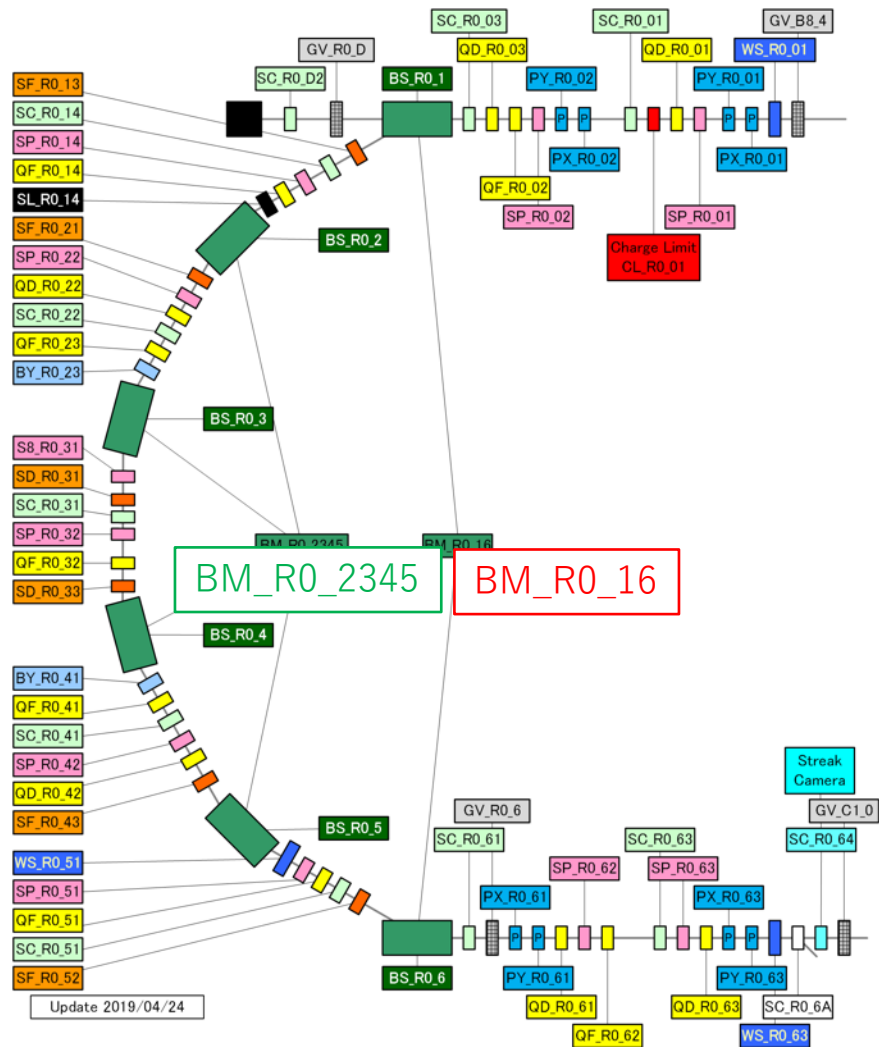
↑ reproducing the measured orbit jitter

Orbit distortion to the end of BT

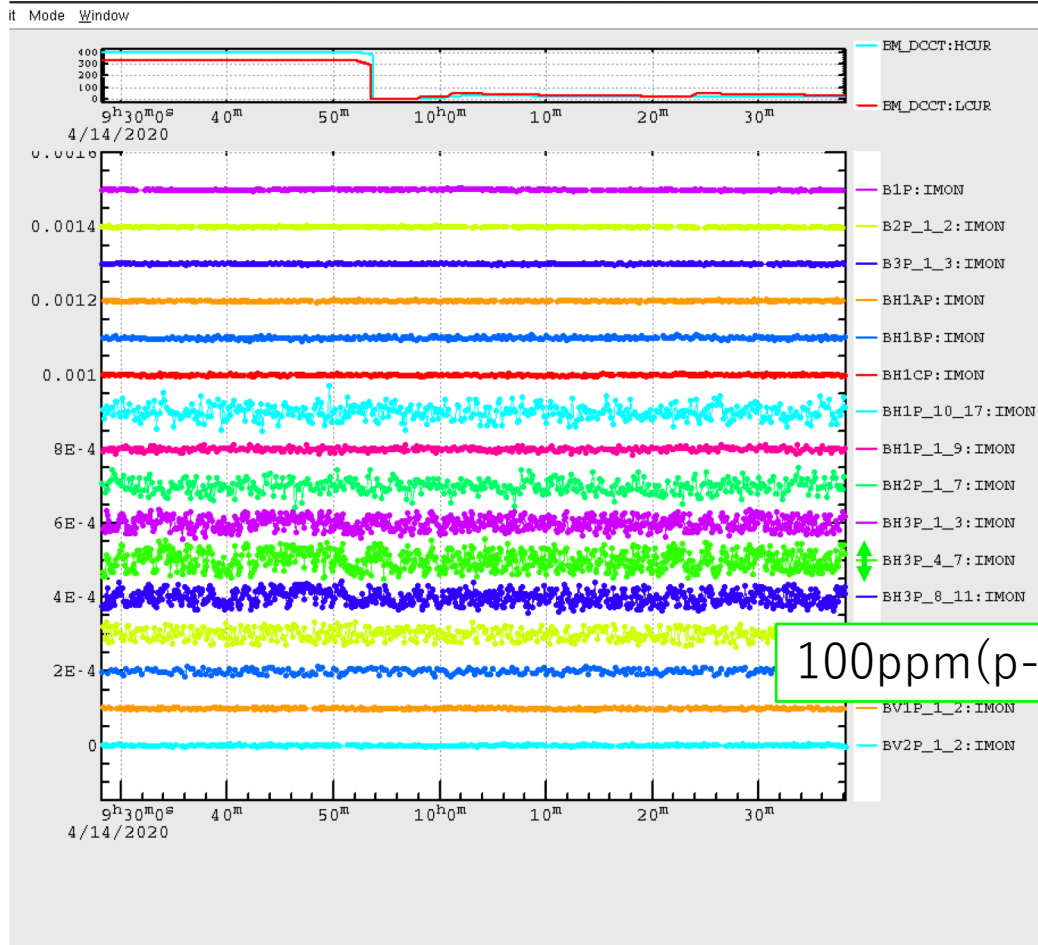


The orbit is getting larger, which is more than 2mm in horizontal in the BT.

Jitter of PS of BM_R0_16 in Jarc

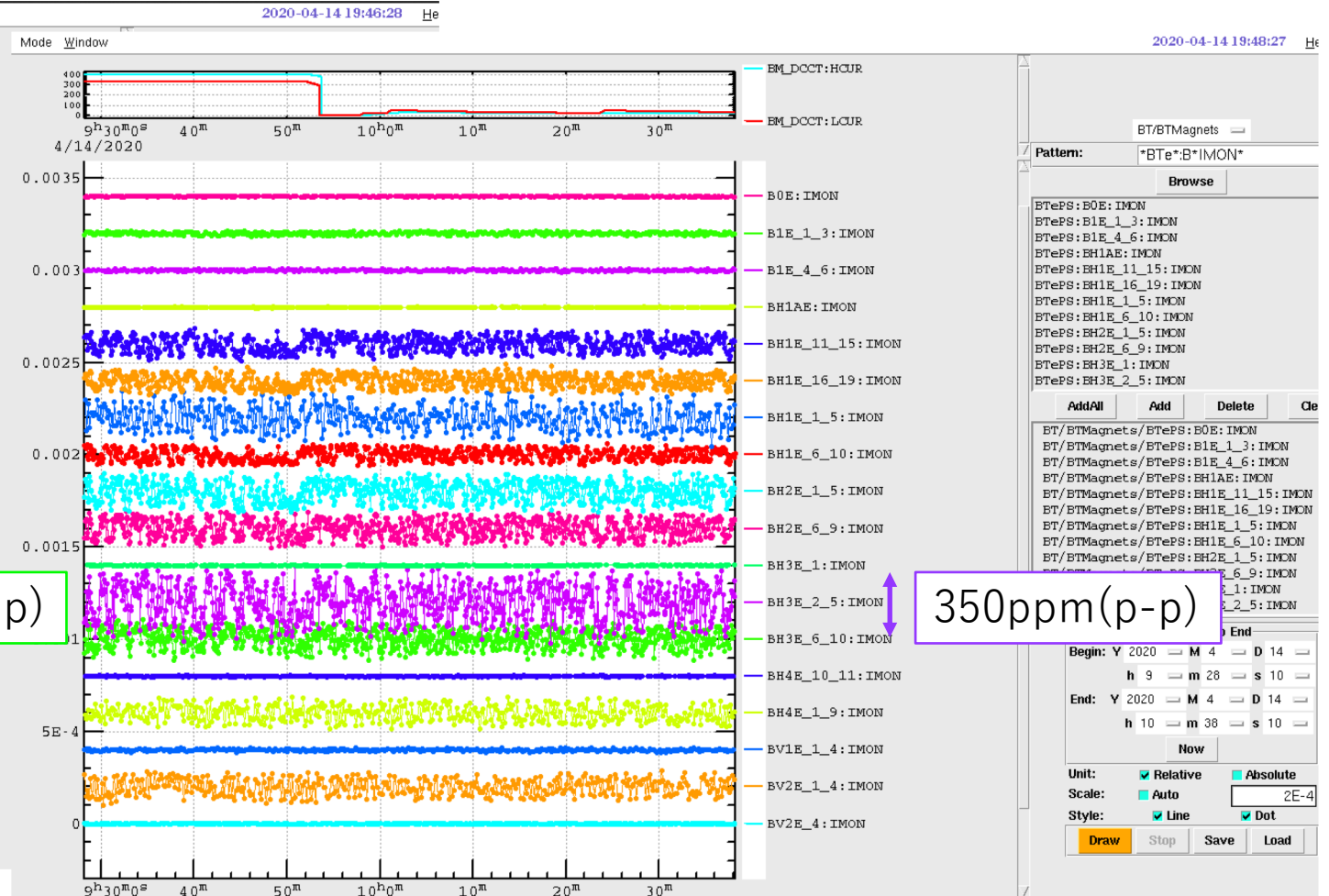


Jitter of PS of quad in e+/e- BT



e+ BT

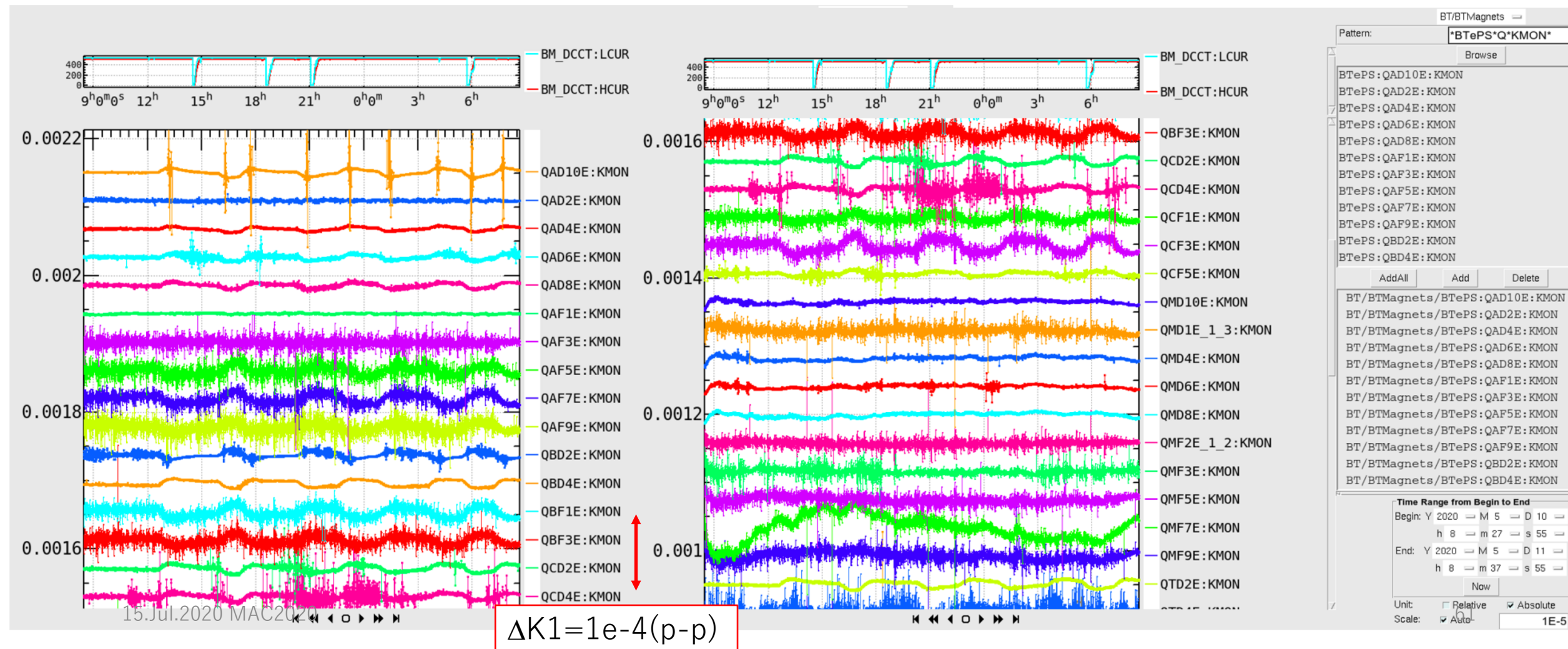
15.Jul.2020 MAC2020



e- BT

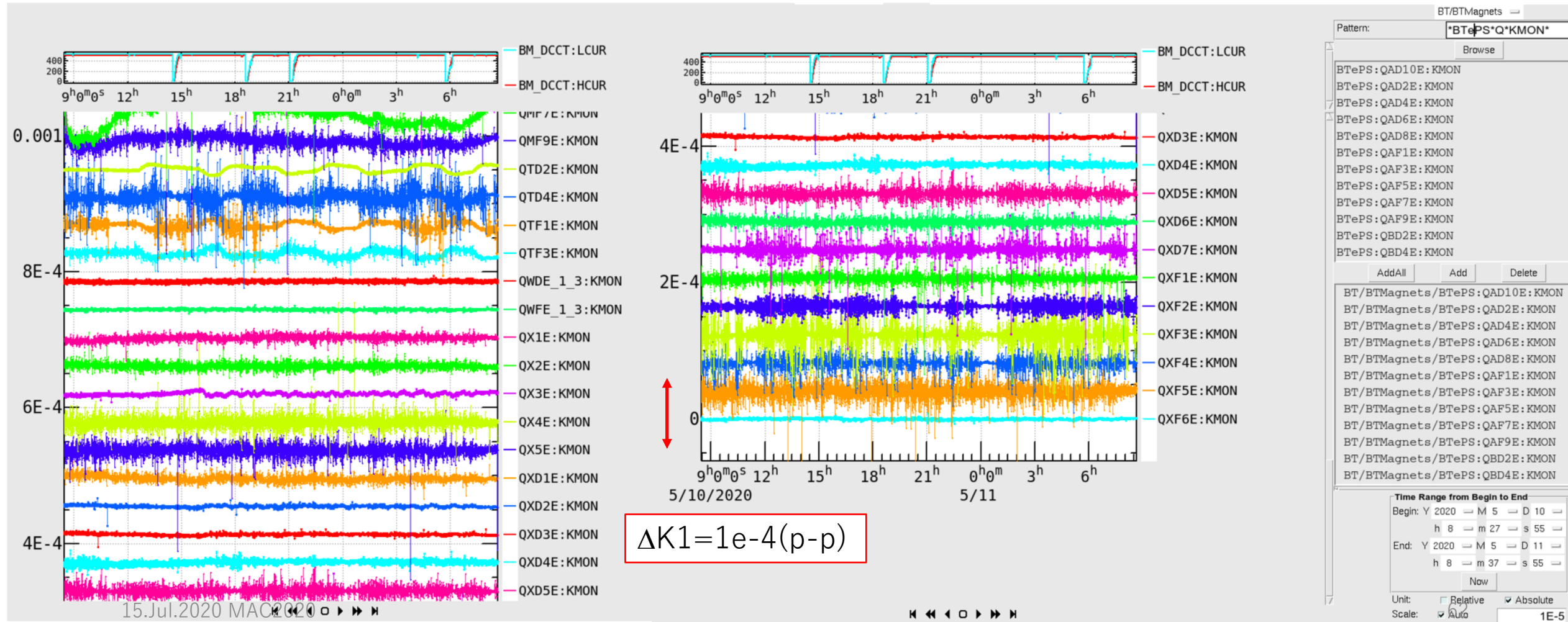
Jitter of PS of quad in e- BT

Some PS have slow drifts.



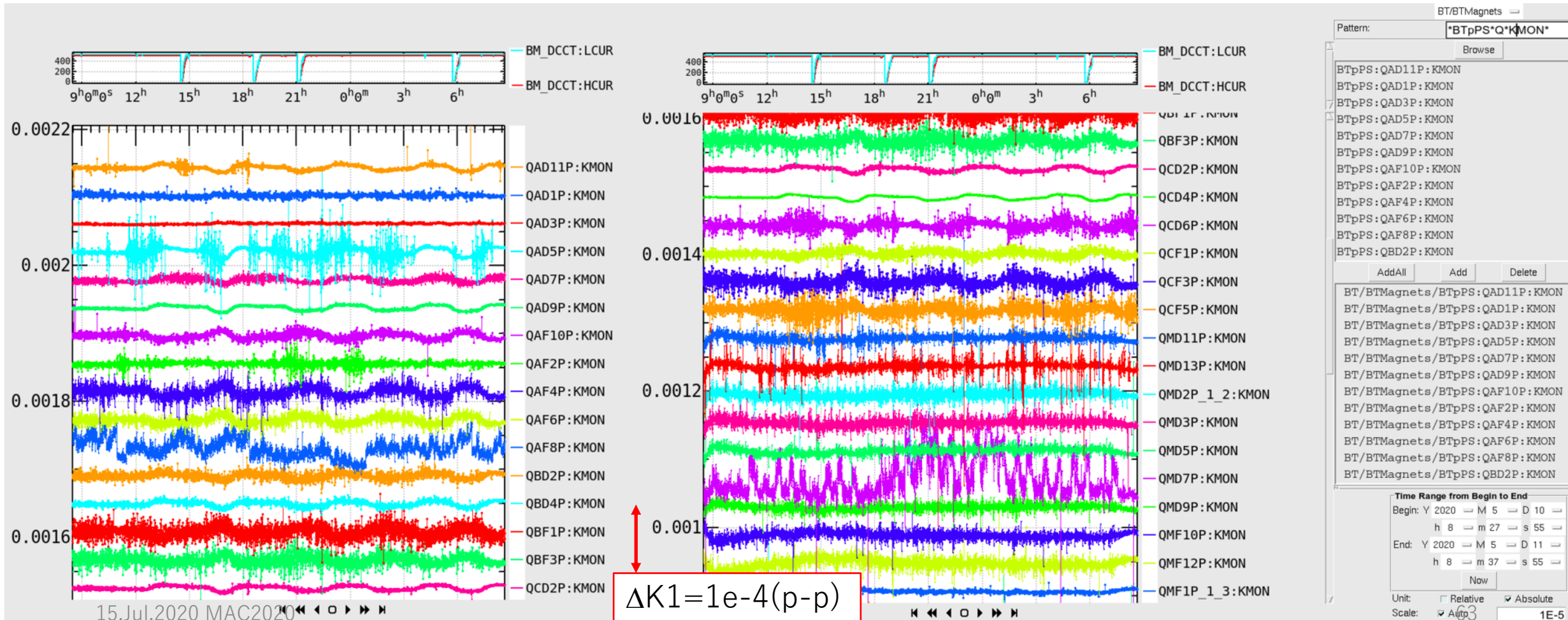
Jitter of PS of quad in e- BT

Some PS have slow drifts.



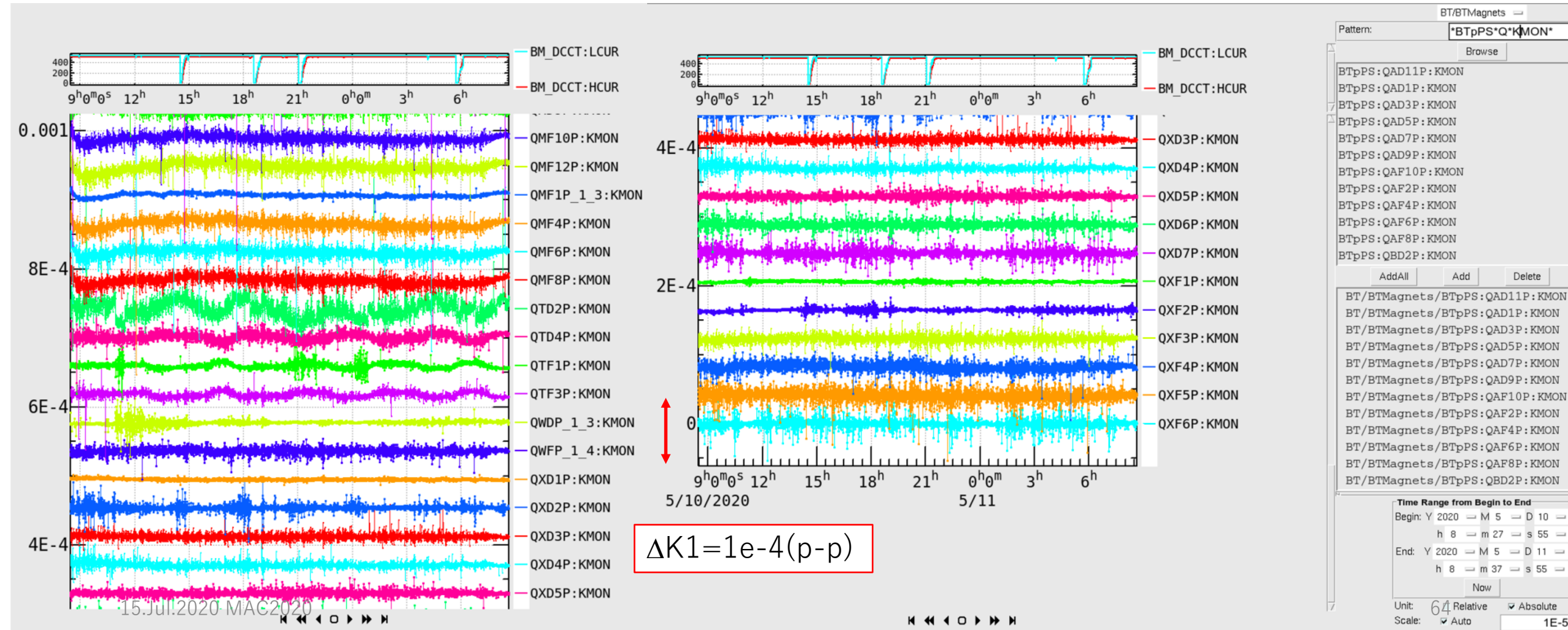
Jitter of PS of quad in e+ BT

Some PS have slow drifts.



Jitter of PS of quad in e+ BT

Some PS have slow drifts.



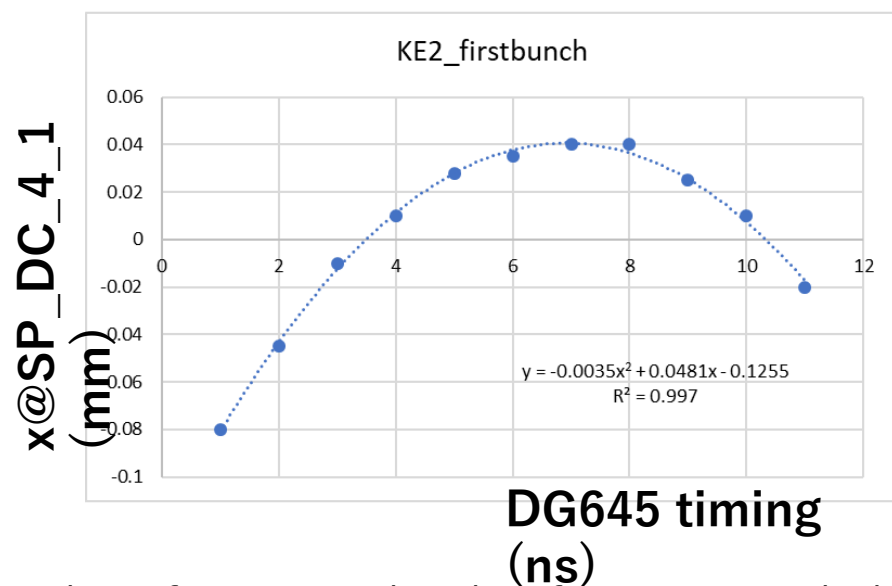
Estimation of Bucket Selection behavior

The timing difference, Δt , affects the pulse components at LINAC.

Following two influences are considerable.

- The x orbit shift is caused by the shifted DR extraction kicker timing.
- The energy shift is caused by the shifted SLED amplifier timing in 3-5 sectors.

Measured by M. Tawada and H. Sugimura

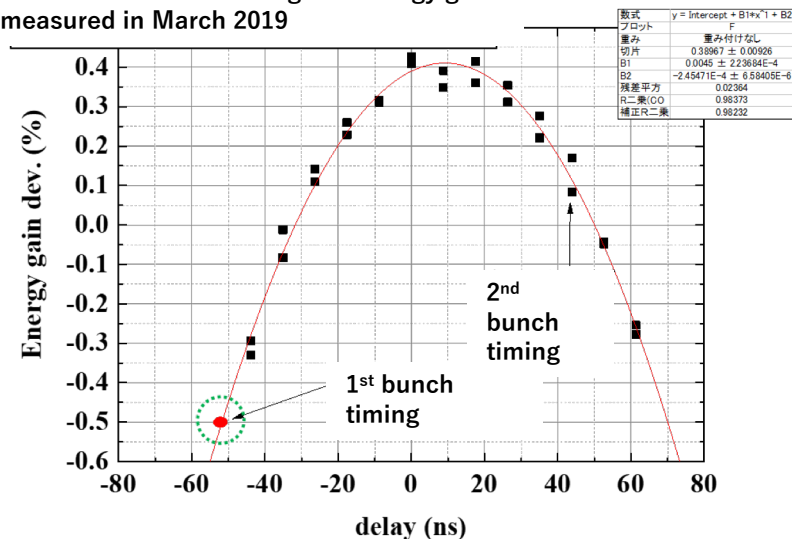


The x orbit of extracted pulse from DR is slightly shifted since the kicker angle is changed.

This data are taken when the experts optimize the kicker timing to the pulse peak.

Measured by M. Satoh and T.

Relation bet. SLED timing and energy gain measured in March 2019

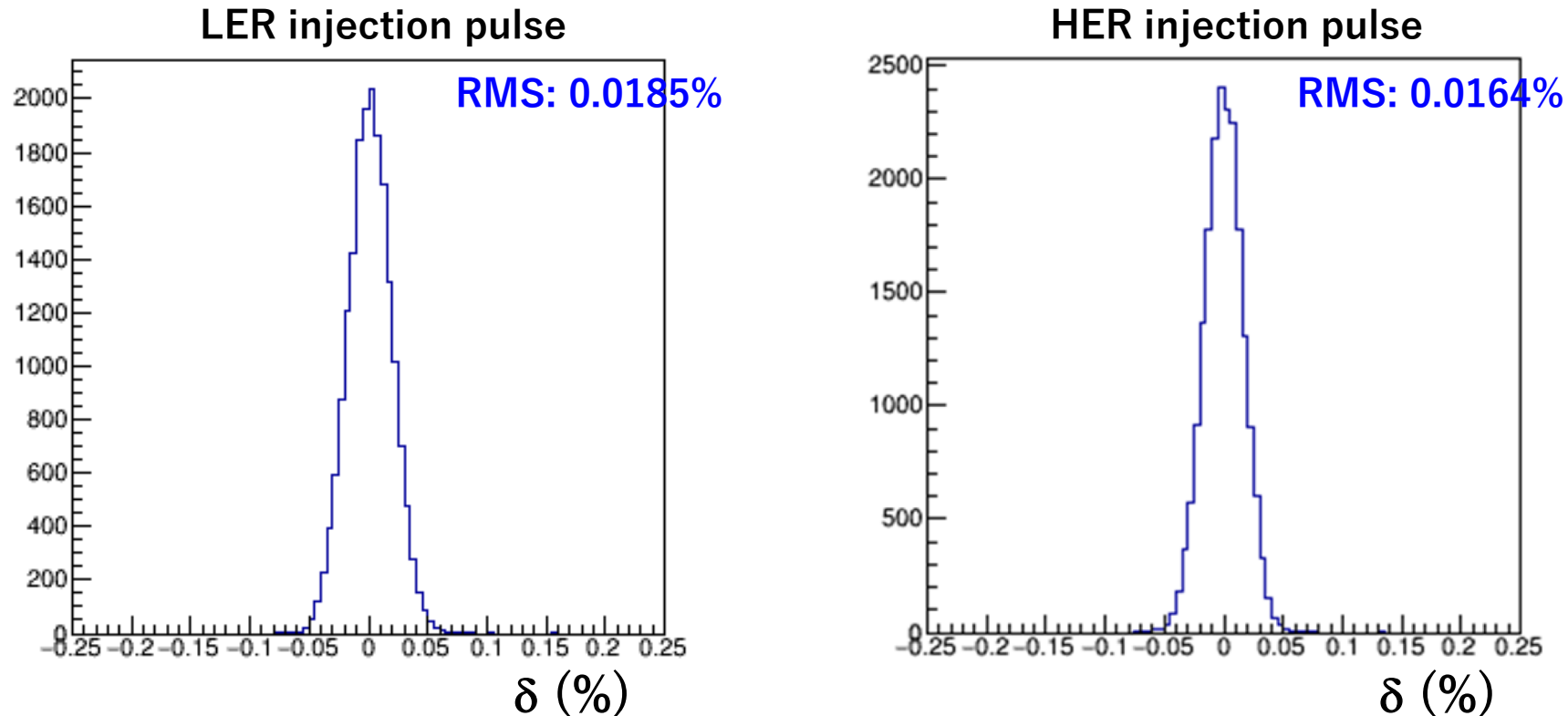


Beam energy at the LINAC-end is shifted.

Expectation in the linear approximation around 1st bunch timing is $\sim 0.023\%/ns$

Energy fluctuation in the injection operations

The injection data in Apr28 – May 6, 2020 are used to determined the energy fluctuation.



The energy fluctuation induced by the new Bucket Selection is smaller than usual fluctuation.