Recent status of LINAC, DR, BT, and Injection

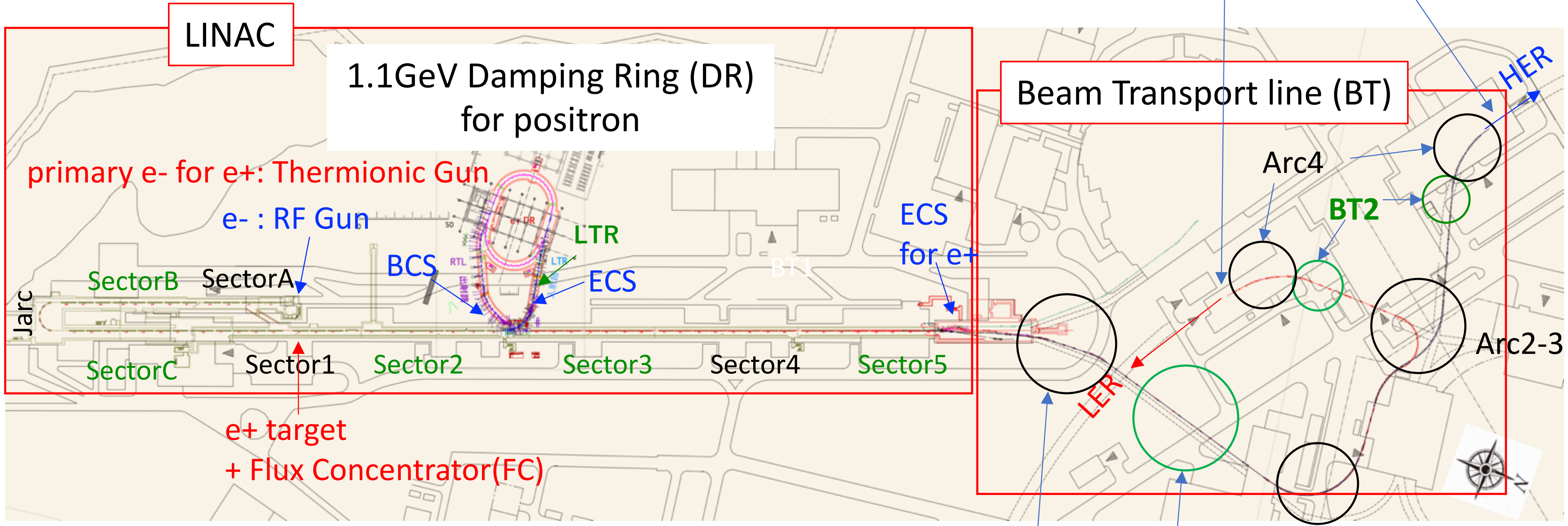
1/Mar/2021
BPAC
N. Iida
for the Beam Injection TF

LINAC: Injector for 4 rings(HER, LER, PF, PF-AR)
DR: Damping Ring for e+
BT: Beam Transport line for HER and LER

B) Layout of LINAC, BT, Injection to MR

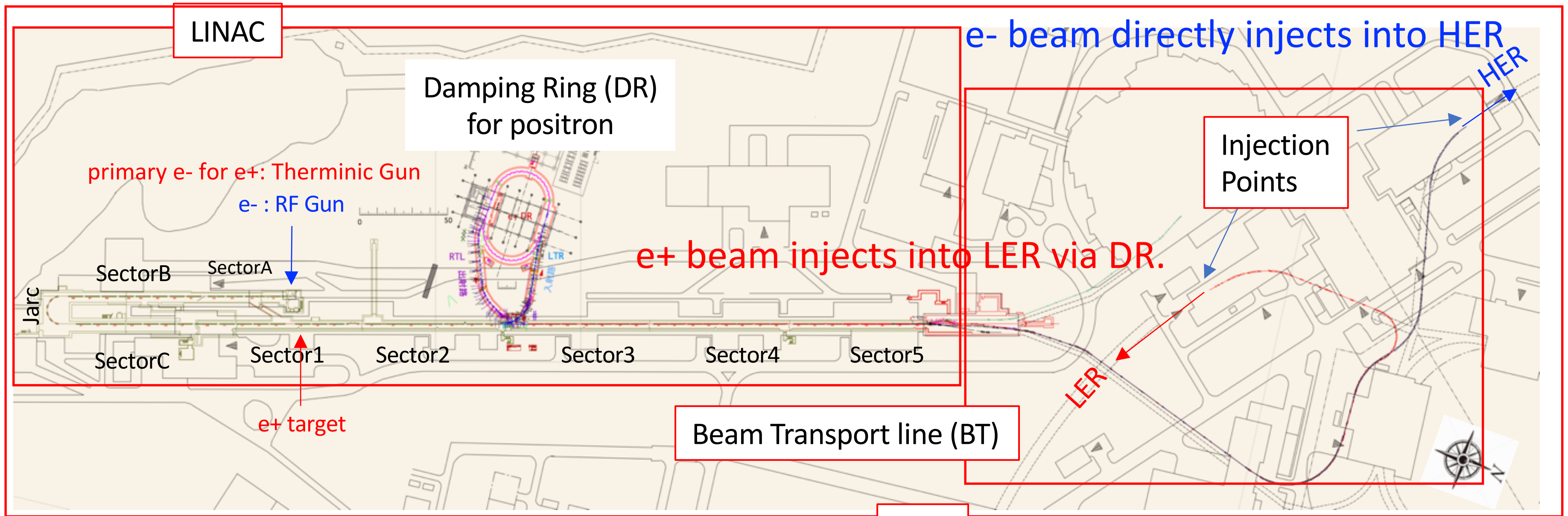
e+ beam injects into LER via DR:
The injection BG is not affected very much by the condition upstream the DR.

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

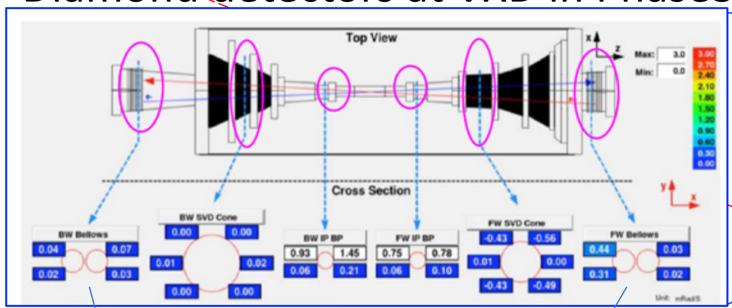


Green: Emittance measured with wire scanners(WSs)
BCS: Bunch Compression System
ECS: Energy Compression System

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



Diamond detectors at VXD in Phase3



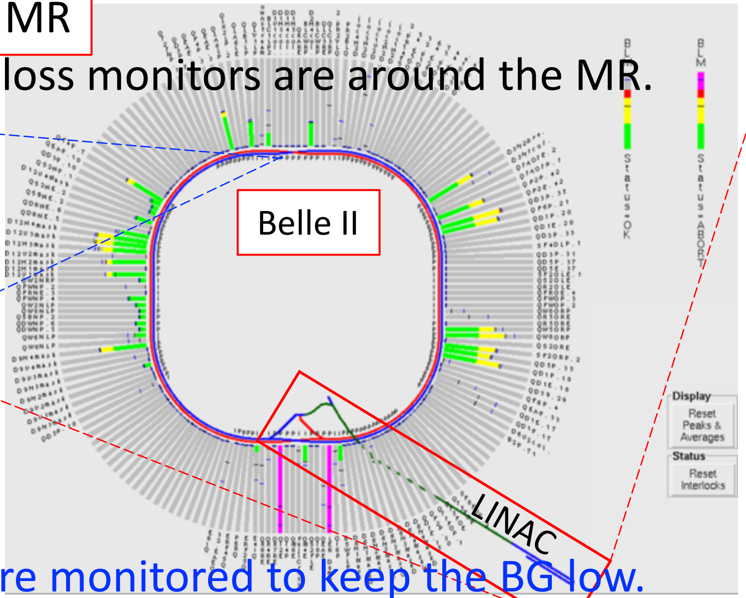
HER: VXD(Diamond) BW135

LER: VXD(Diamond) FW135

Most sensitive to the Background (BG) on Belle2.

MR

Many loss monitors are around the MR.



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

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

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1. Injection summary of 2020c
2. Beam quantity and quality in LINAC
3. Injection efficiency
4. 2-bunch injection
5. Collaboration with Belle II about injection

Injection summary of HER 2020c

Injection efficiency calculated from BCM* for the first ~100 turns is useful as it is independent on the beam lifetime.

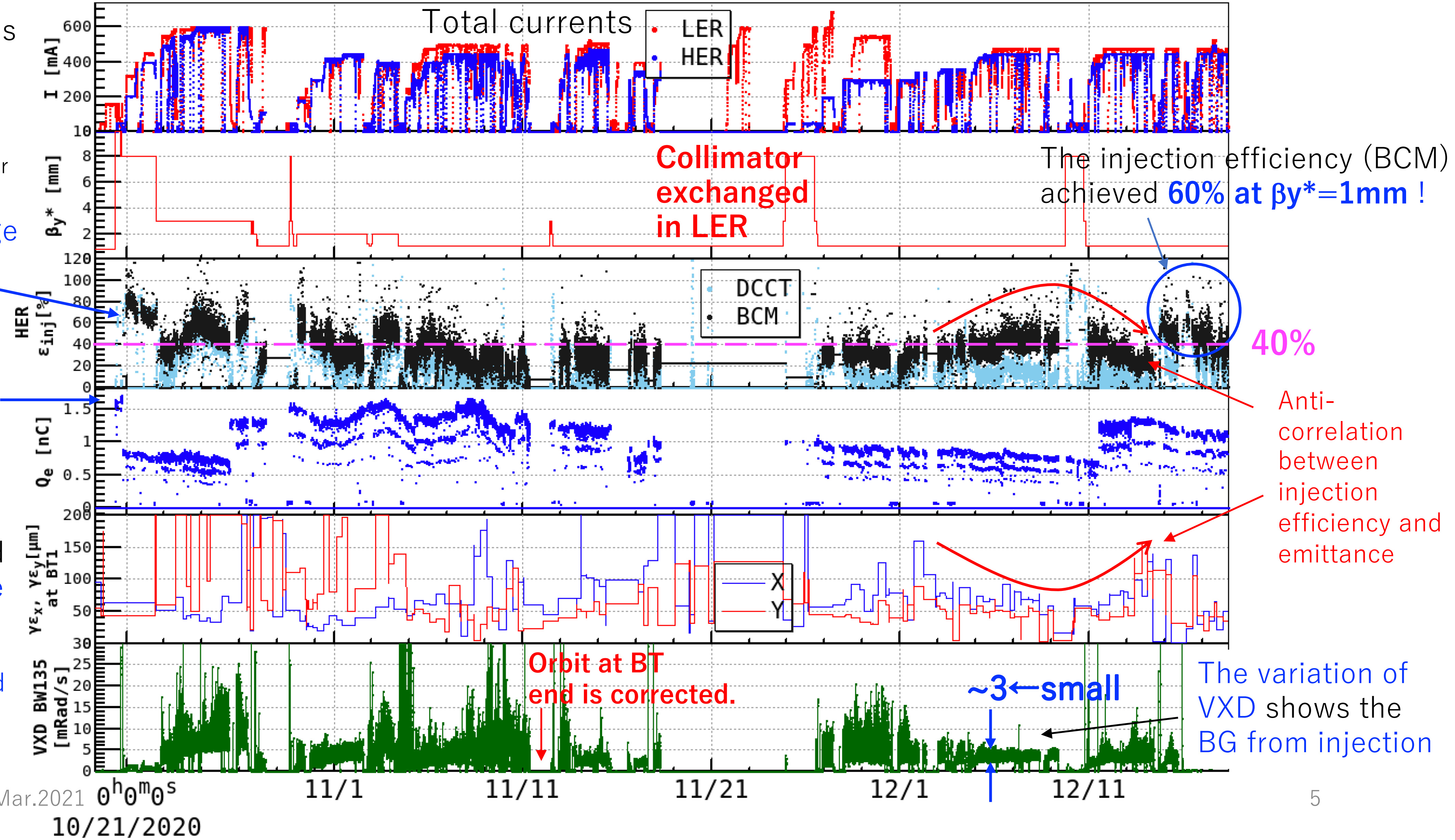
*BCM:Bunch Current Monitor

Look at the lower edge in the injection efficiency plots.

Charge achieved **1.6 nC** at BT end

Measured emittance at BT1

Background in VXD diamond



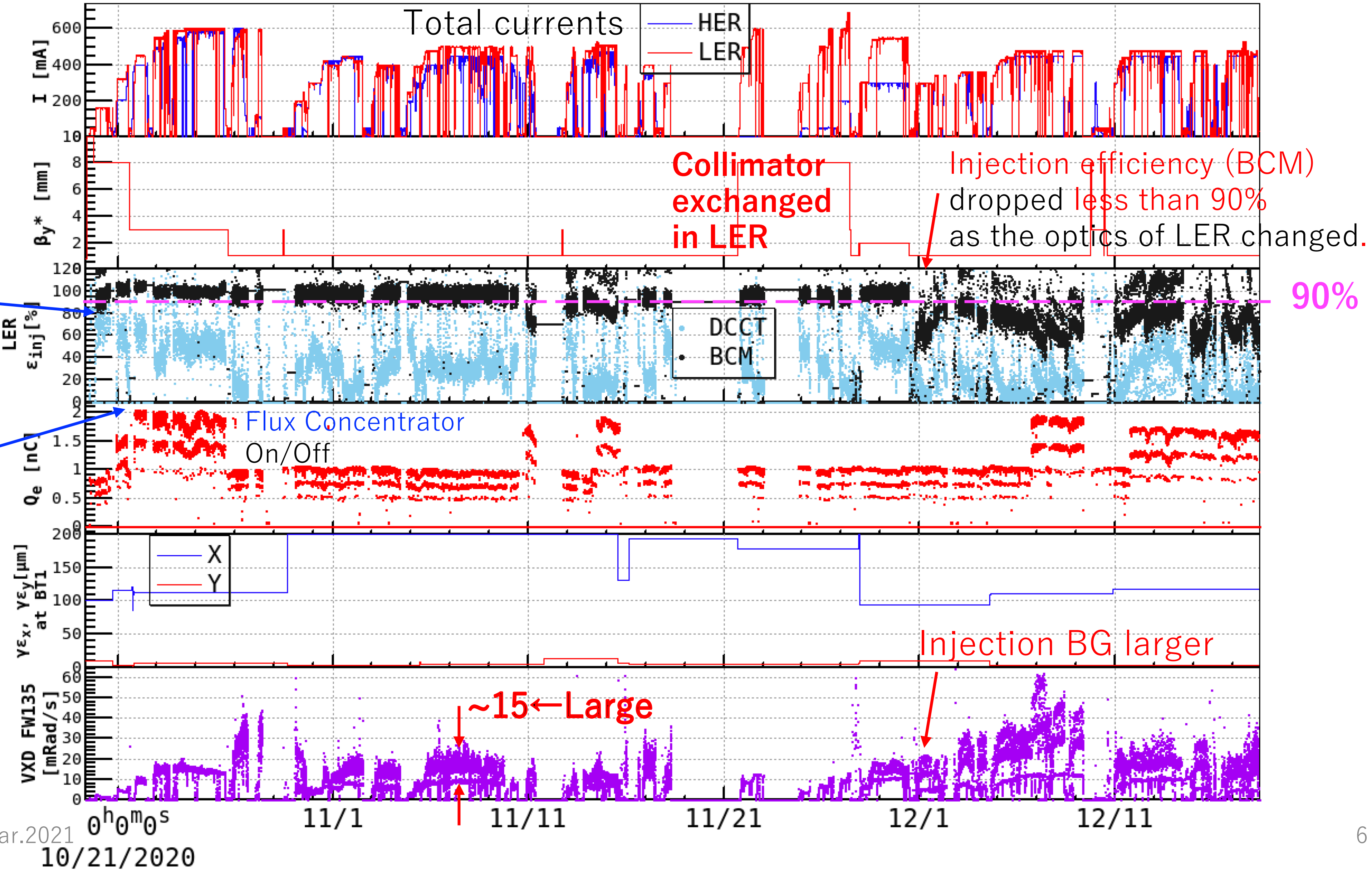
Injection summary of LER 2020c

The injection efficiency(BCM) had been more than 90% even at βy*=1mm

Look at the minimum edge in the injection efficiency plots.

Achieved **2.0 nC** at BT end

The variation of VXD shows the BG from injection



Injection summary of 2020c

- HER
  - The BCM injection efficiency had been less than 40% at $\beta y^*=1mm$. It was improved to 60% at the end of 2020c.
    - It will be discussed later.
  - The BG from injection is small, which is no problem now.
- LER
  - The BCM injection efficiency had been about 90% even at $\beta y^*=1mm$, but from December, it became 50~80%, after the change of optics for the LER.
  - The BG from injection is large, which is one of big problems.

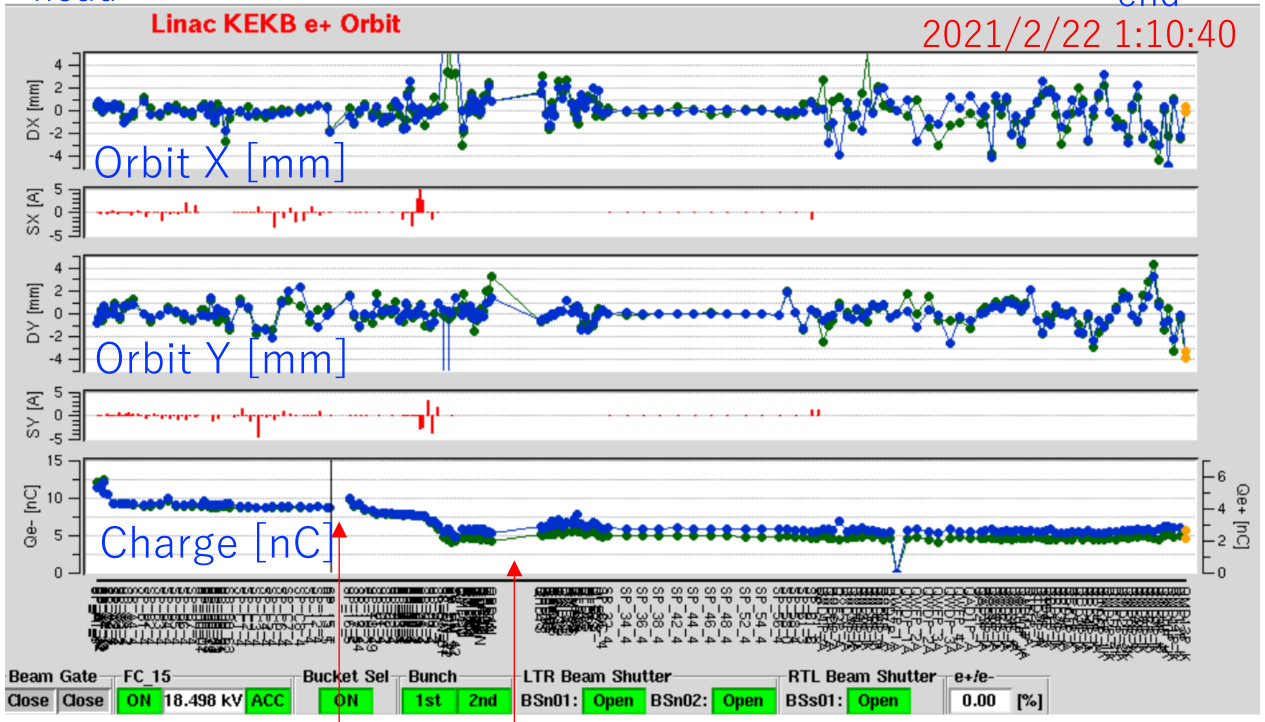
2. Beam quantity and quality in LINAC

- e-
- e+

Orbit and Charge from LINAC to MR in 2021a

LINAC head **Positron** BT end

2021/2/22 1:10:40



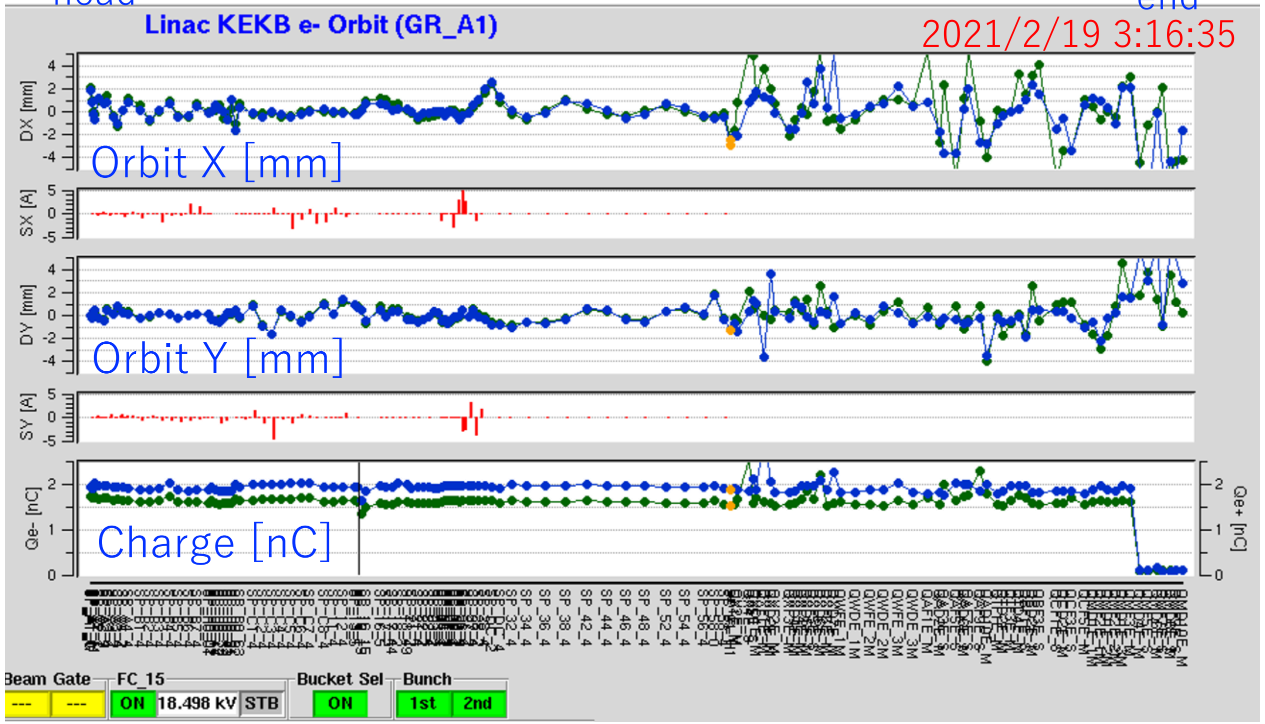
e+ Target

DR

1st: 2.6nC
2nd: 2.2nC
at BT end

LINAC head **Electron** BT end

2021/2/19 3:16:35



The charge amount is kept constant by feedback at the RF gun.

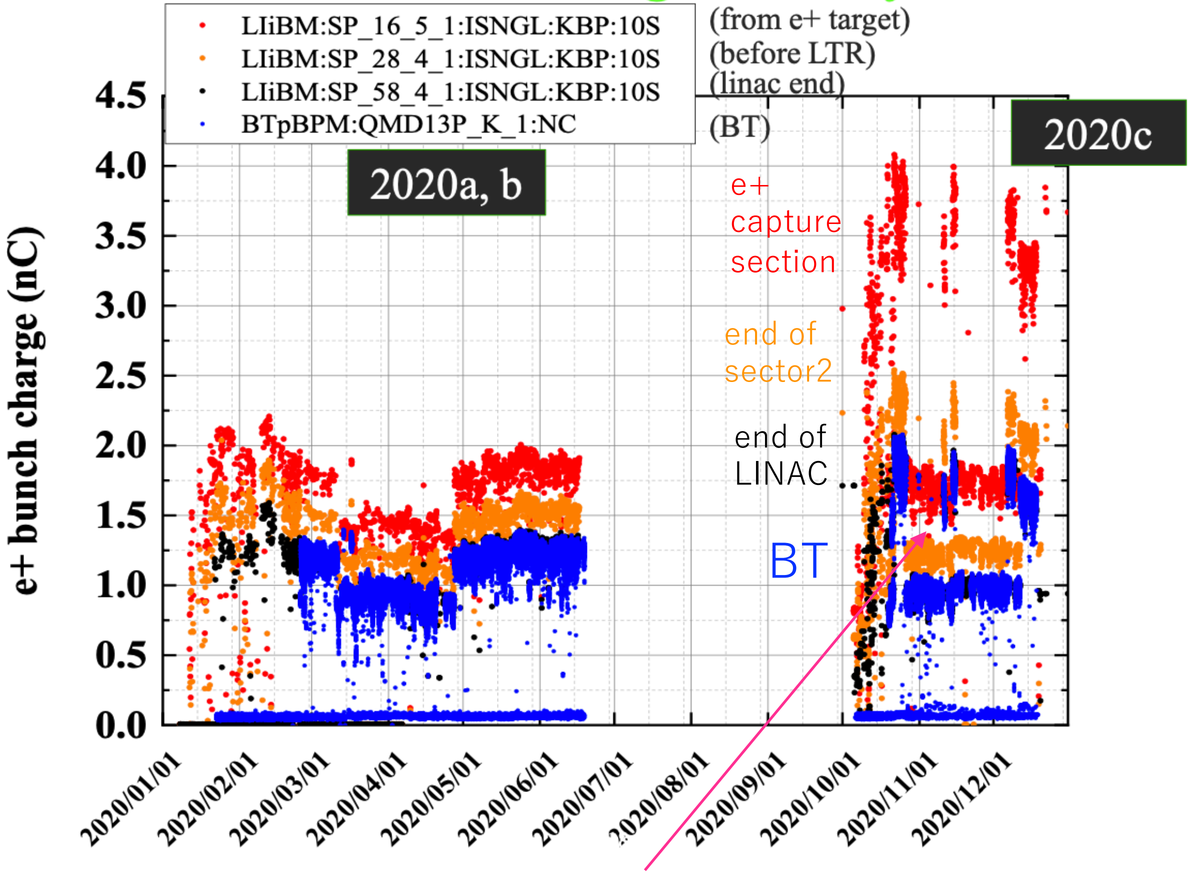
1st: 2.0nC
2nd: 1.6nC
at BT end

Bunch charge history in 2020

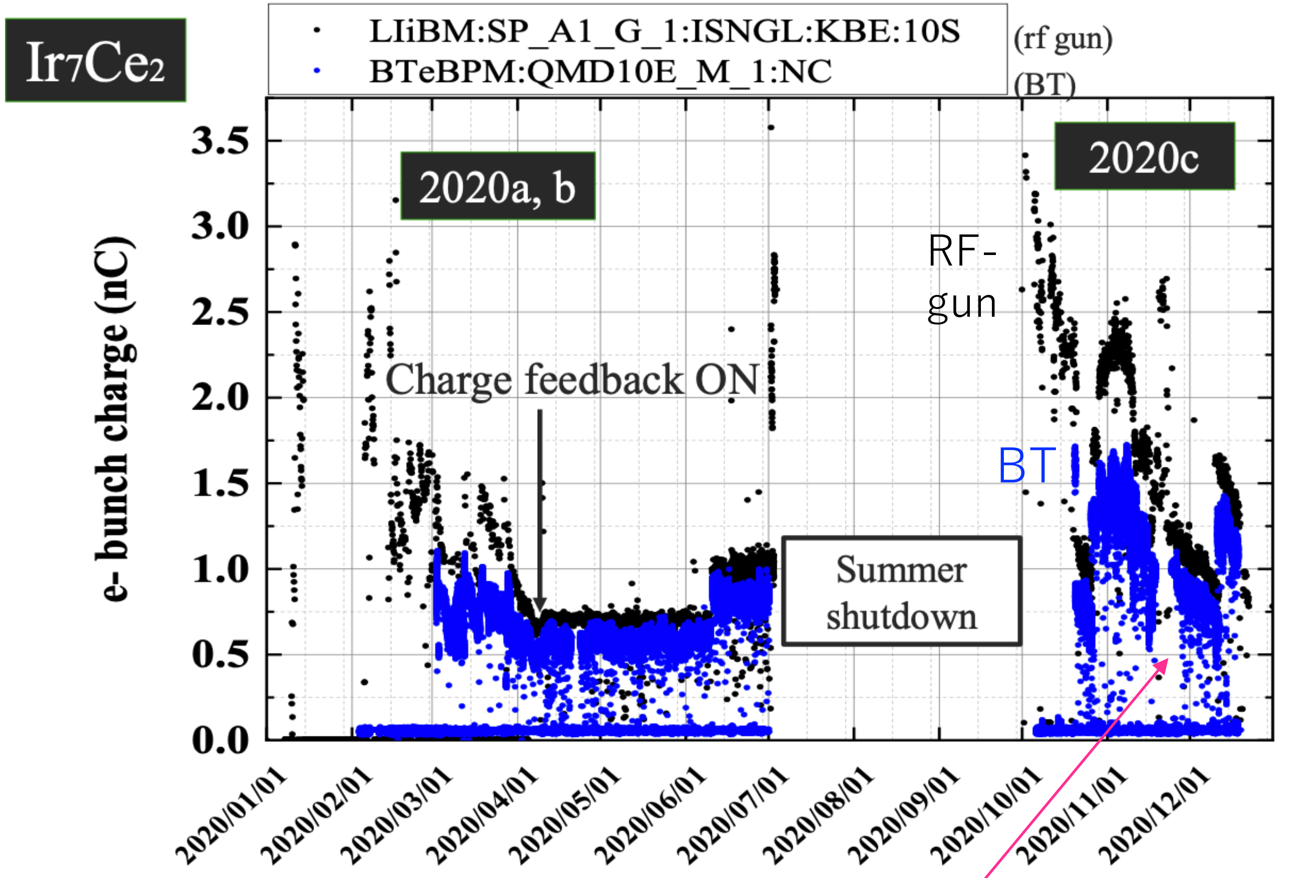
Charge amount at the sources became higher.
The transmittance is going to improve in 2021a.

M. Satoh

e+ bunch charge history



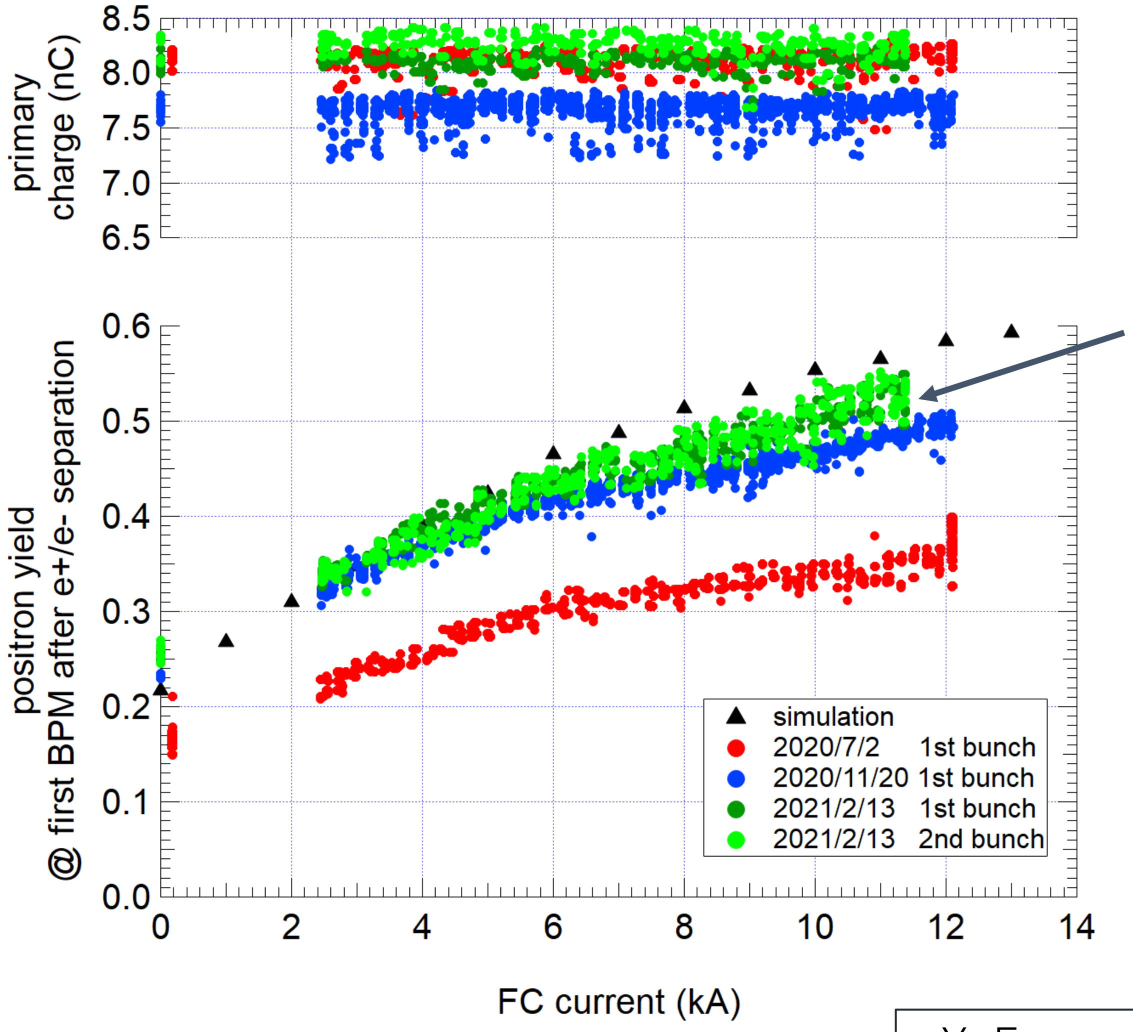
e- bunch charge histry



- Increased Loss in 16_5→28_4
- Once beams for PF, AR are tuned and their operations start, it is difficult to tune the KBP beam, due to the interference.
- Some pulsed steering magnets are added now.

The charge at BT end had been made lower by requirement from HER.

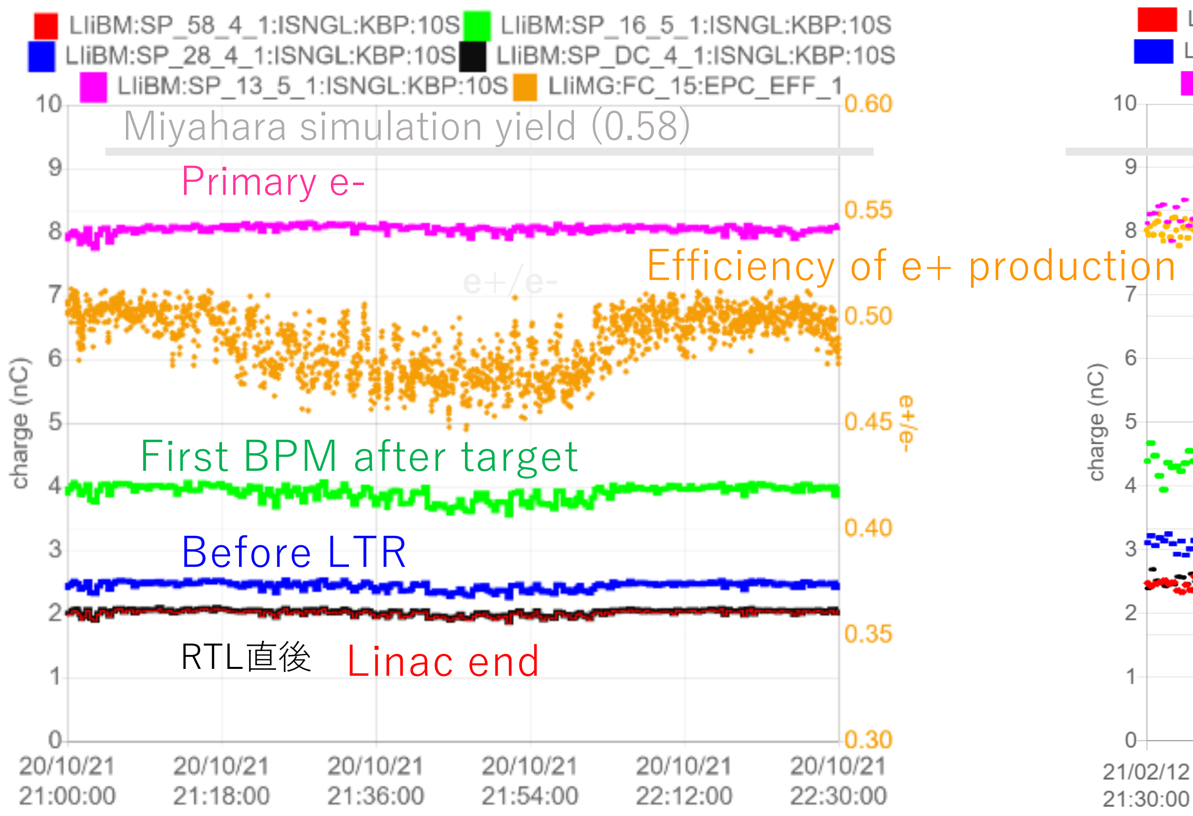
Positron yield for 2021a



FC current (2021/2/13) was raised to 11.3 kA. During winter maintenance, power supply and its surroundings were modified for noise suppression.

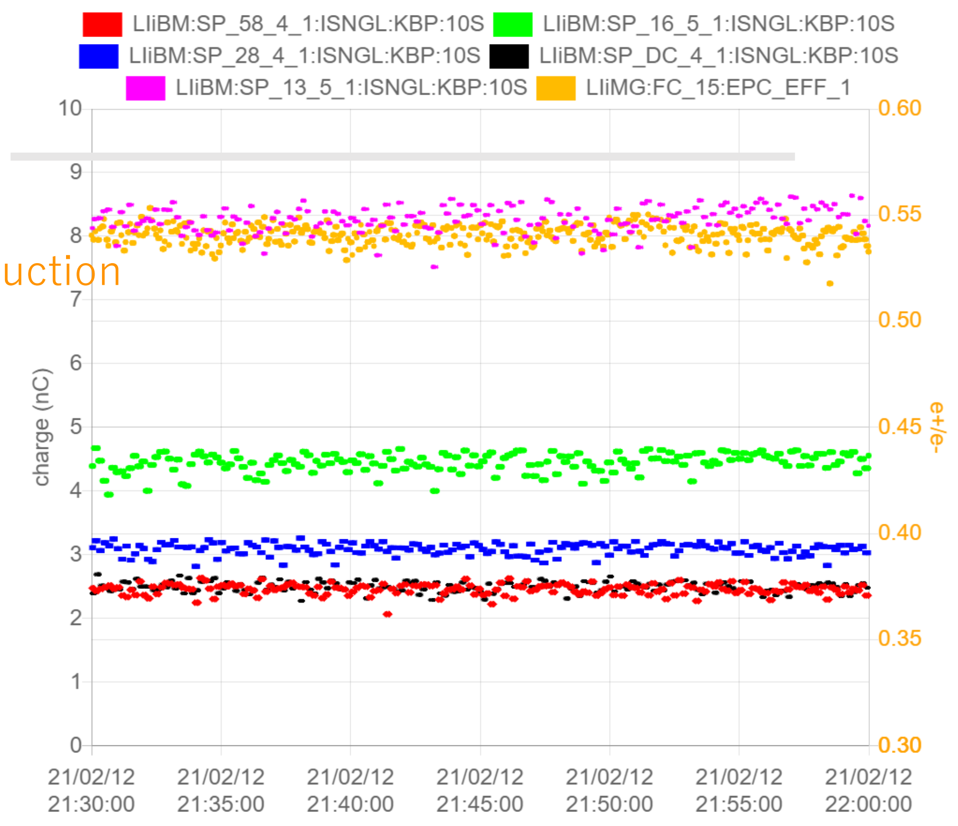
Y. Enomoto

Positron bunch charge



2020/10/21 (2020c)

(one bunch operation)



2021/2/12 (2021a)

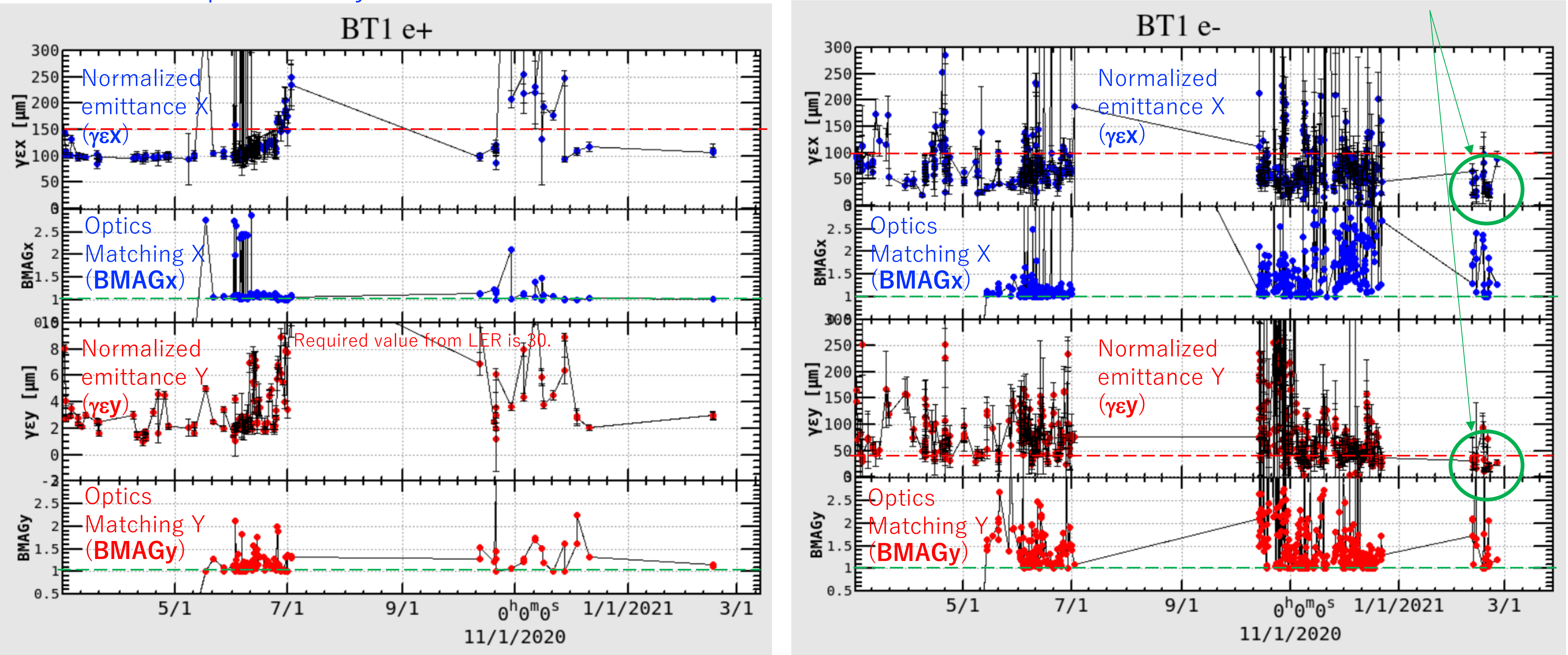
(two bunch operation)

Y. Enomoto

Measured emittance history at BT1

The e+ optics is very stable thanks to the DR.

The e- emittances have the minimum records at BT1.



------ Required emittance from the MR

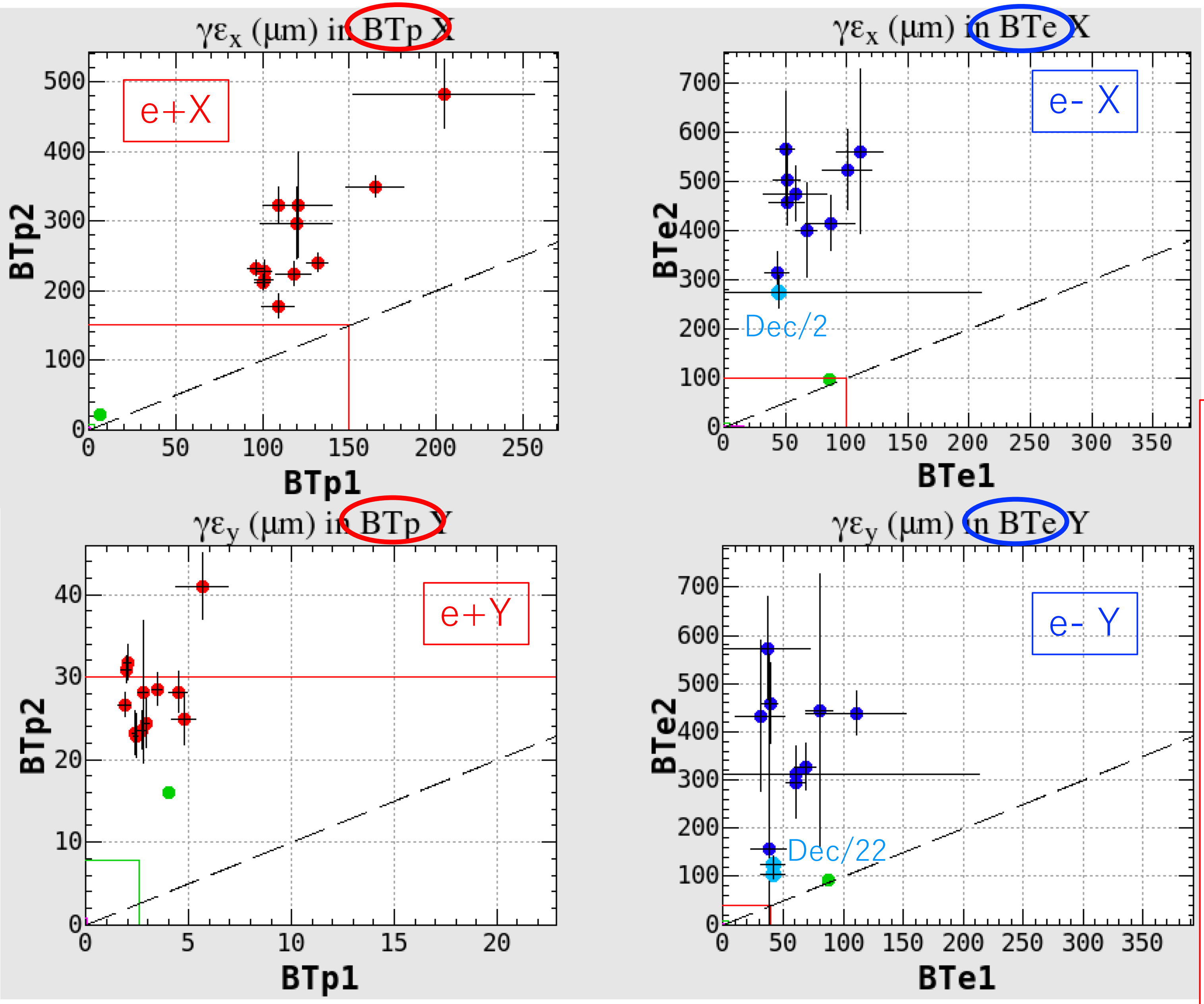
------ BMAG=1 means the optics are matched to the design values.

Summary of emittance explosion

- Achieved charges at BT ends are;
  - e-: 2.0nC(1st)+1.6nC(2nd)
  - e+: 2.6nC(1st)+2.2nC(2nd)
- The measured emittances at the entrance of BT line (BT1) are in the range of required values from the MR.

Emittance explosion in e- BT line

Emittance explosion in BT



- Measured by WS
- Newest data by WS
- Jitter emittance

Same emittance line of BT2 as BT1

Required emittance from LER/HER

<u>emittance of e+</u>

・In BT2, γεy is within the required value.

<u>emittance of e-</u>

・Close to the required value in BT1, but it is exploding in BT2.

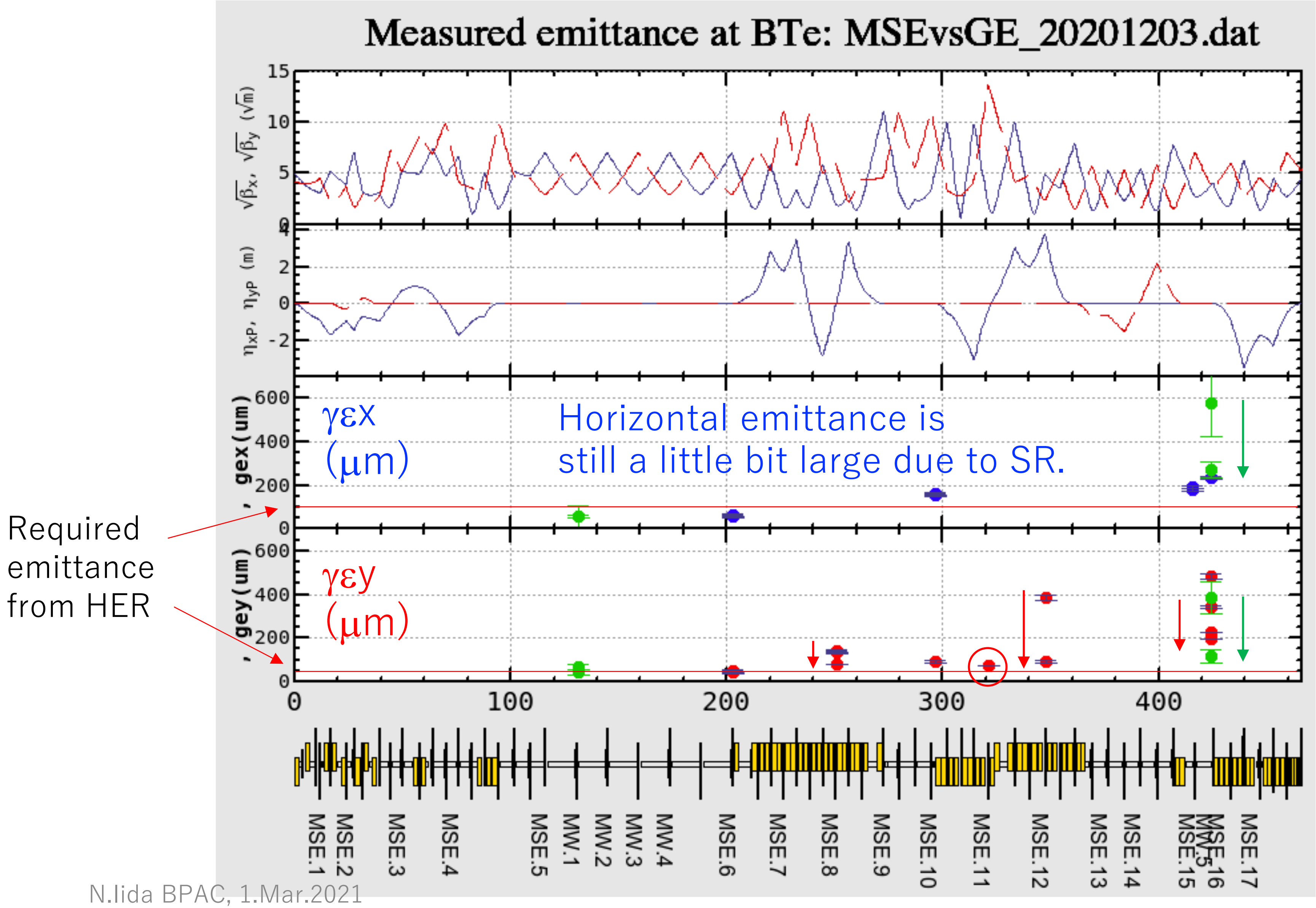
・Both X and Y are large

・BT2 has no correlation with BT1.

→ It may be blowup, not as much as an explosion.

Measured emittances with OTR and WS in BT

T. Natsui, T. Mori



WS HV: 750->450mV

OTR Quads used in q-scan are changed to upstream.

WS HV: 750mV(11/30)
→350mV(12/2)

Measured emittance and β-mismatch(BMAG) in BT

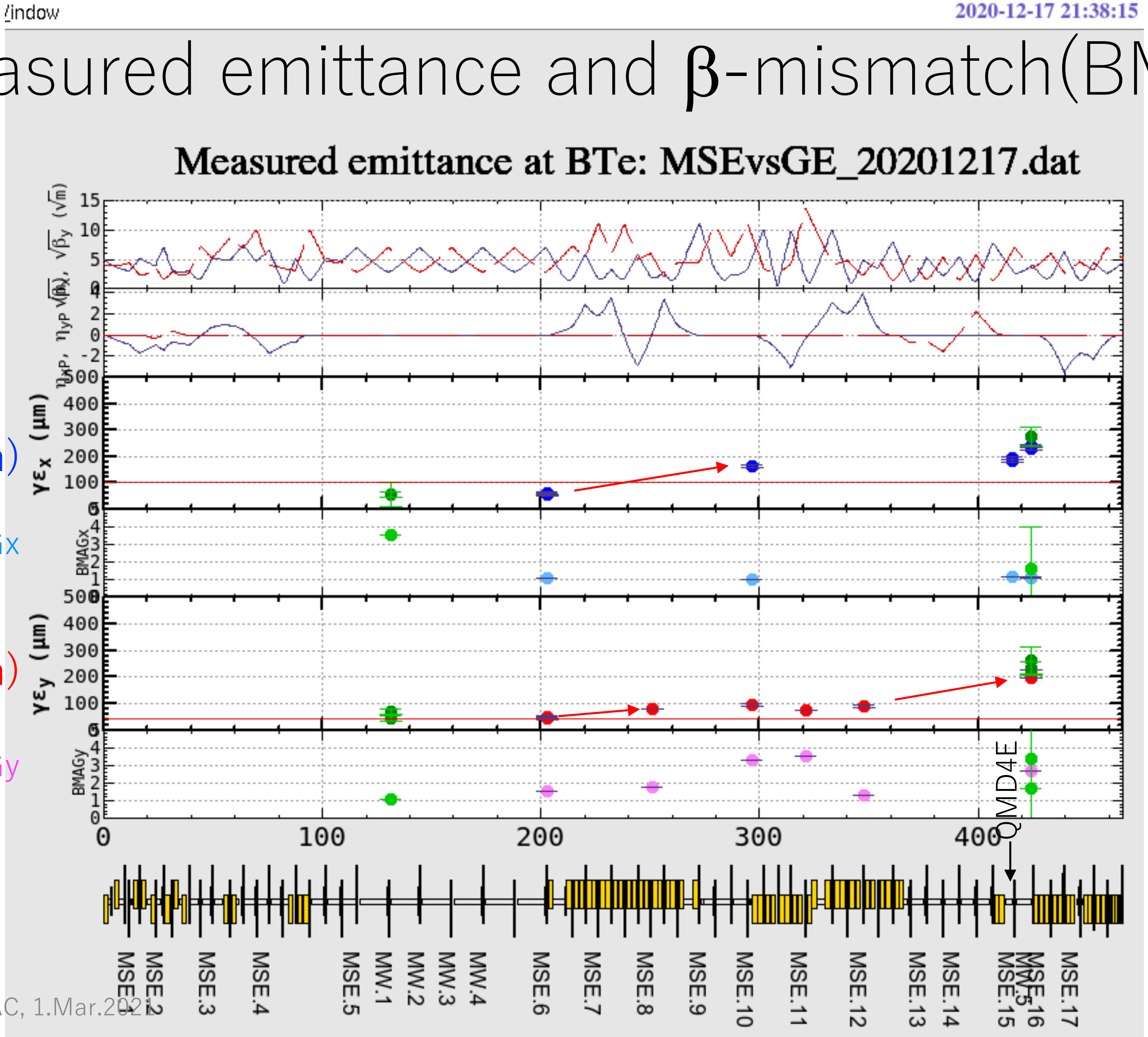
T. Natsui, T. Mori

γεx (μm)

BMAGx

γεy (μm)

BMAGy



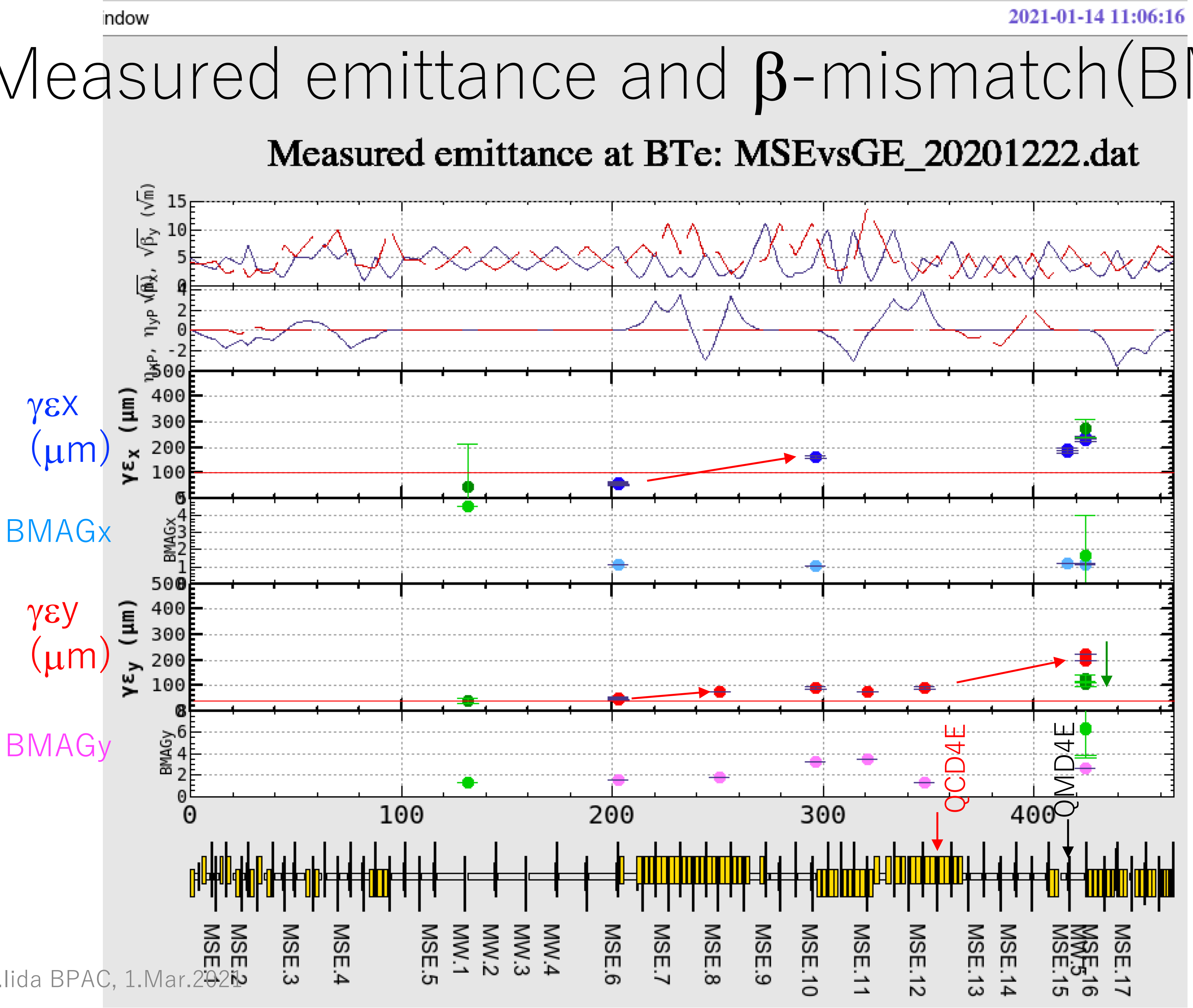
Required emittance from HER

- ● : γε with WS
- ● : γεx measured with OTR
- ● : γεy measured with OTR

WS HV: 750mV(11/30)
→350mV(12/2)
→400, 500mV(12/17)

Measured emittance and β-mismatch(BMAG) in BT

T. Natsui, T. Mori



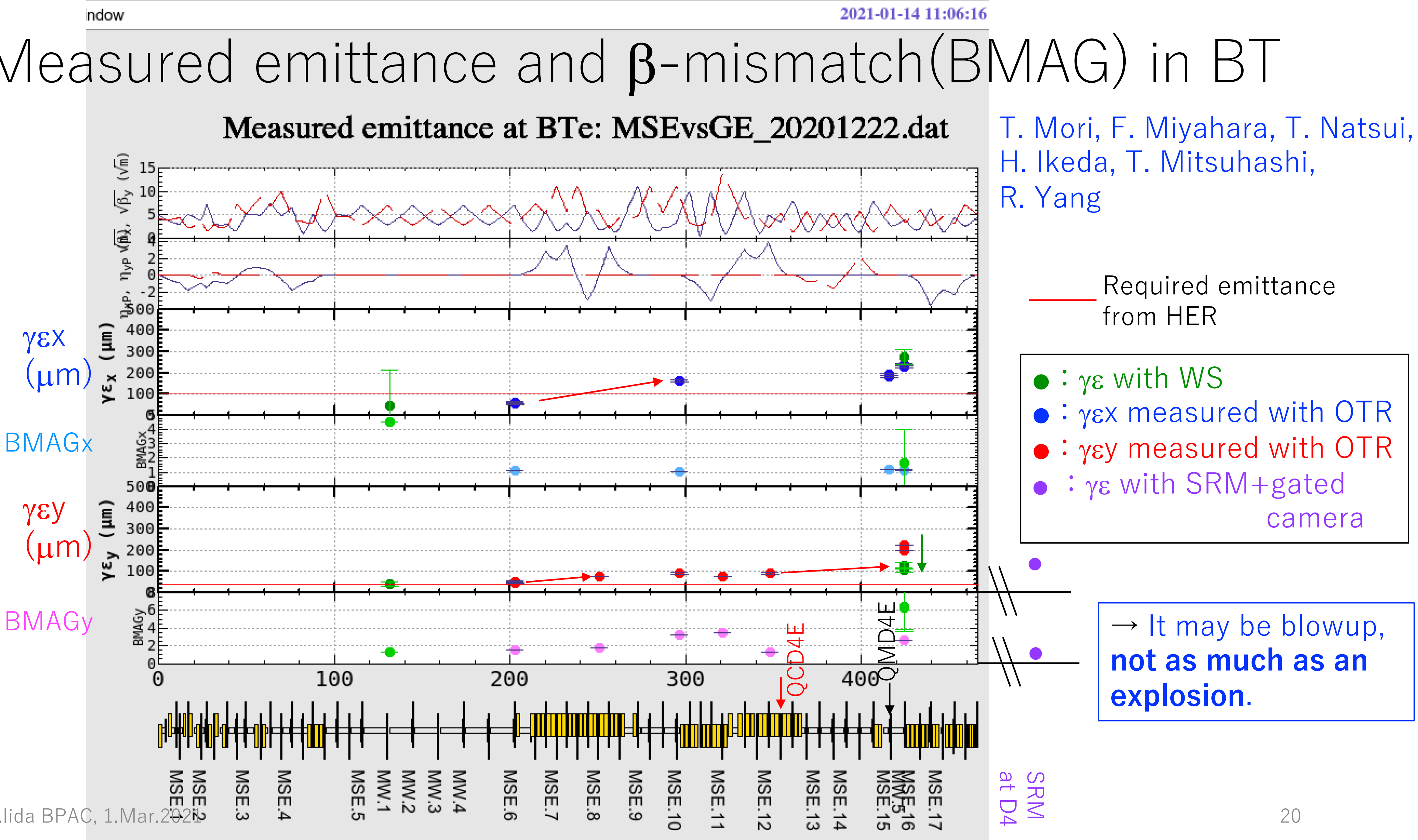
Required emittance from HER

● : γε with WS
● : γεx measured with OTR
● : γεy measured with OTR

WS:
Only vertical Q-scan were done again.
Quad of Q-Scan used far from the WS.
(Fiber: Input voltage=500mV)
(Old PMT: High voltage=950mV)

Measured emittance and β-mismatch(BMAG) in BT

T. Mori, F. Miyahara, T. Natsui, H. Ikeda, T. Mitsuhashi, R. Yang



→ It may be blowup, **not as much as an explosion**.

Summary of emittance explosion (unsolved yet)

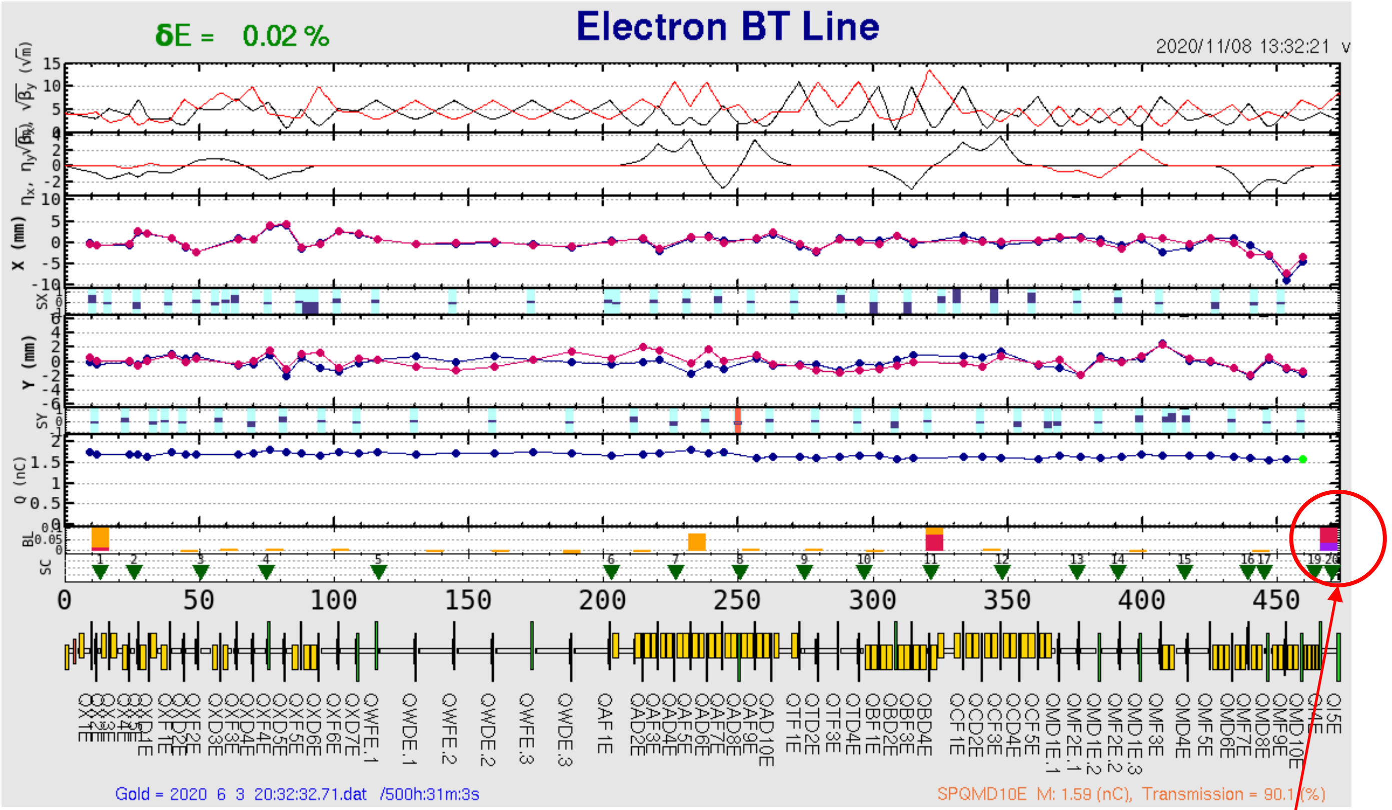
- The measured emittances at the entrance of BT line (BT1) are in the range of required values from the MR.

  However,

- the explosion of measured emittances of e- at the end of BT (BT2) has become weaker.
  - Three vertical emittance measurements were done.
    - Q-scan with OTRs
    - Q-scan with a wire scanner
    - SRM+Gated camera
    - They are consistent to each other.
  - The origin of the emittance blowup must be resolved as soon as possible.

Injection efficiency

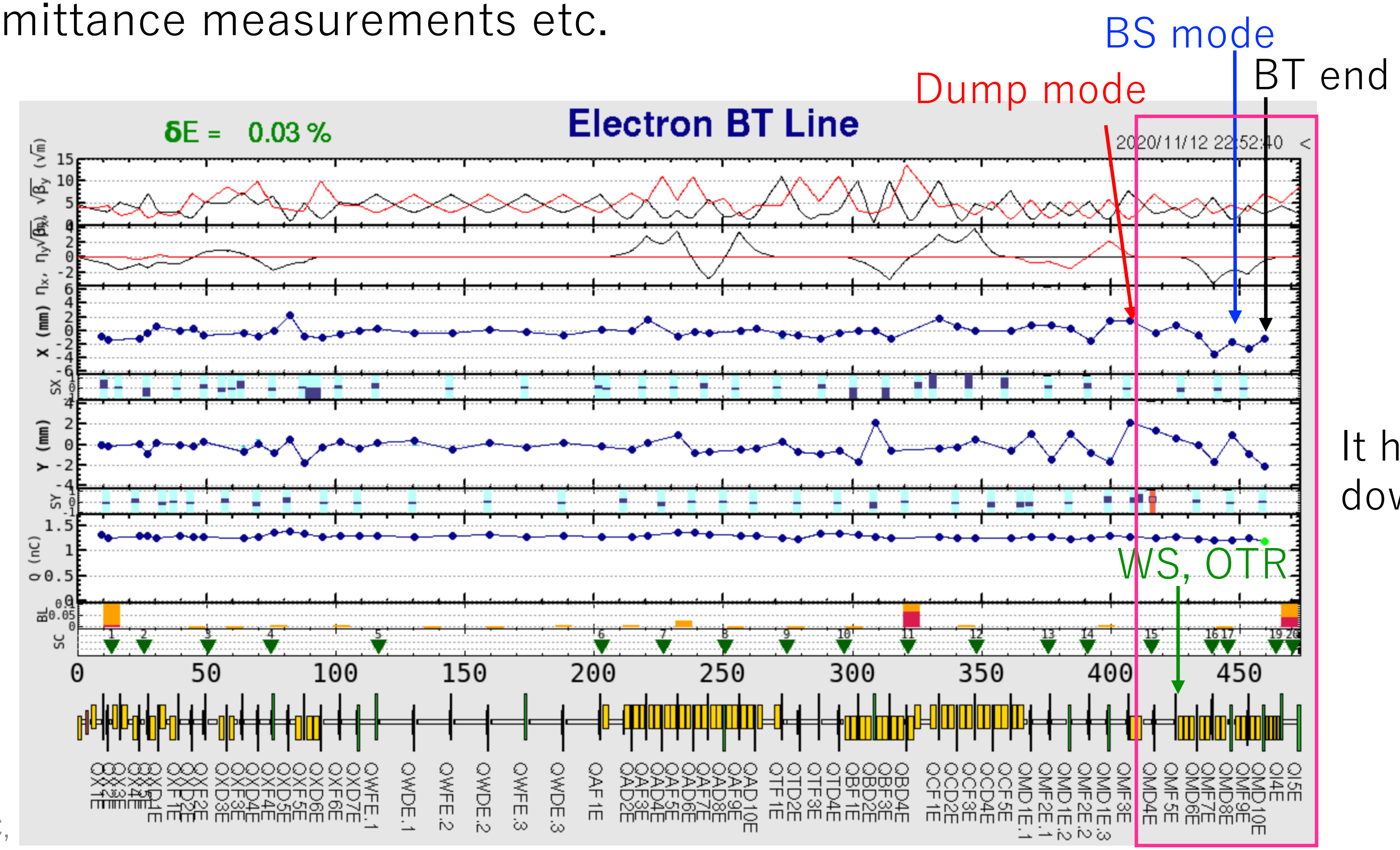
- What should we do next ?
- Does the injection orbit match to the HER ?
- The orbits at the BT end were corrected.



Always the loss signal here is high.
And residual radiation is high here and around the collimator D09V1.

HER Injection

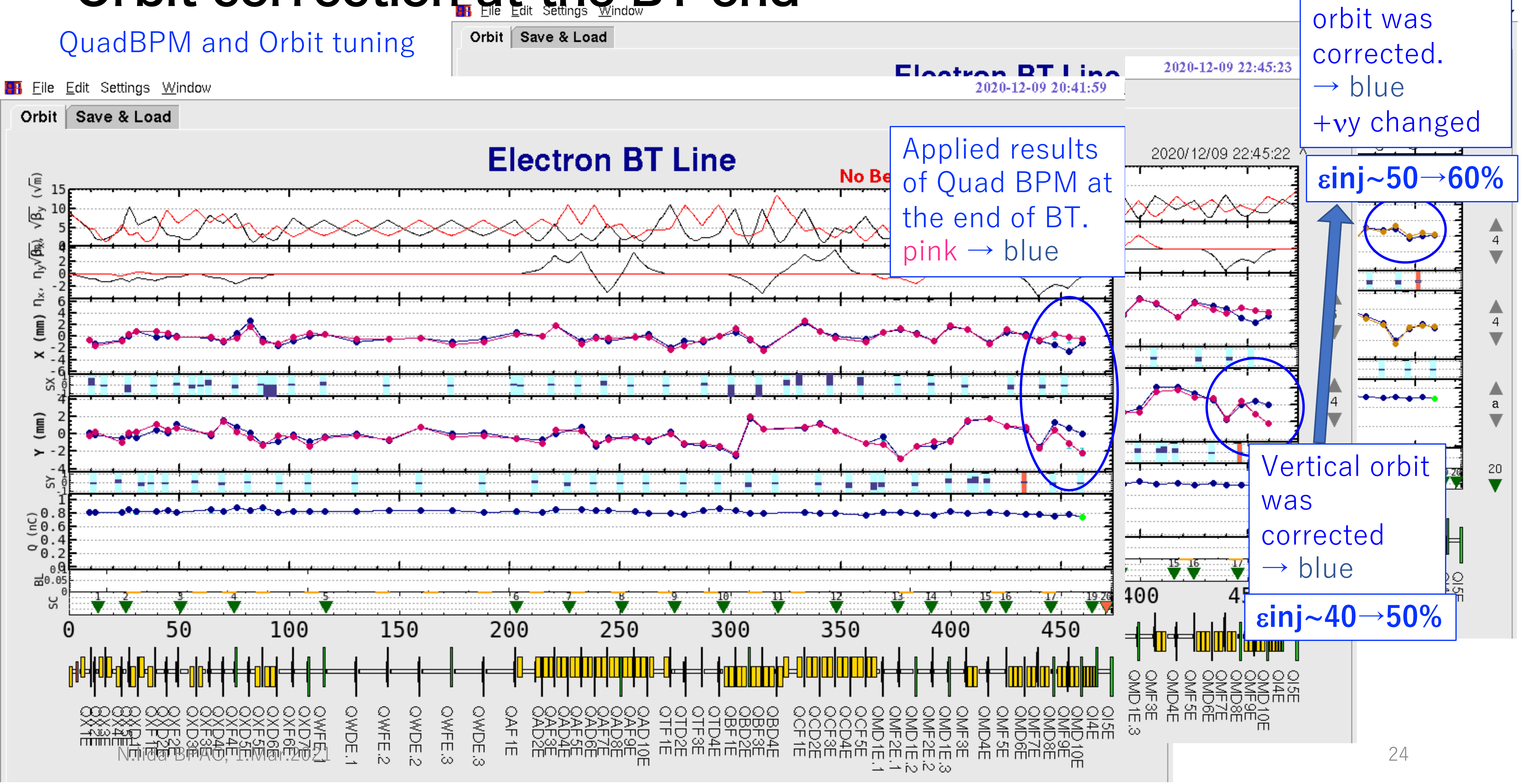
- The beam shutter mode at the end of BT has been available from 2020c.
- It is very powerful to study the BT end.
  - Emittance measurements etc.



It had been difficult to study downstream the Dump

Orbit correction at the BT end

QuadBPM and Orbit tuning



Applied results of Quad BPM at the end of BT.
pink → blue

Horizontal orbit was corrected.
→ blue
+νy changed

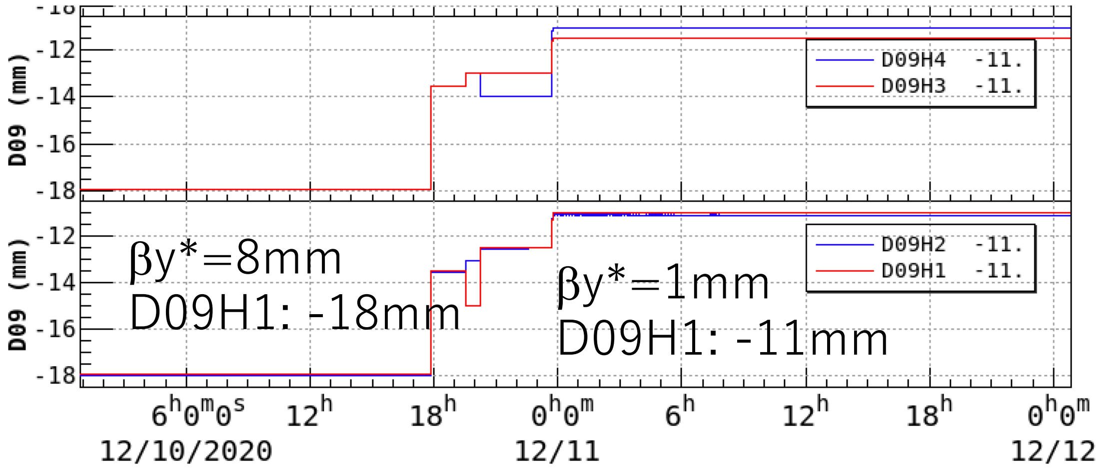
εinj~50→60%

Vertical orbit was corrected
→ blue

εinj~40→50%

HER injection -Horizontal-

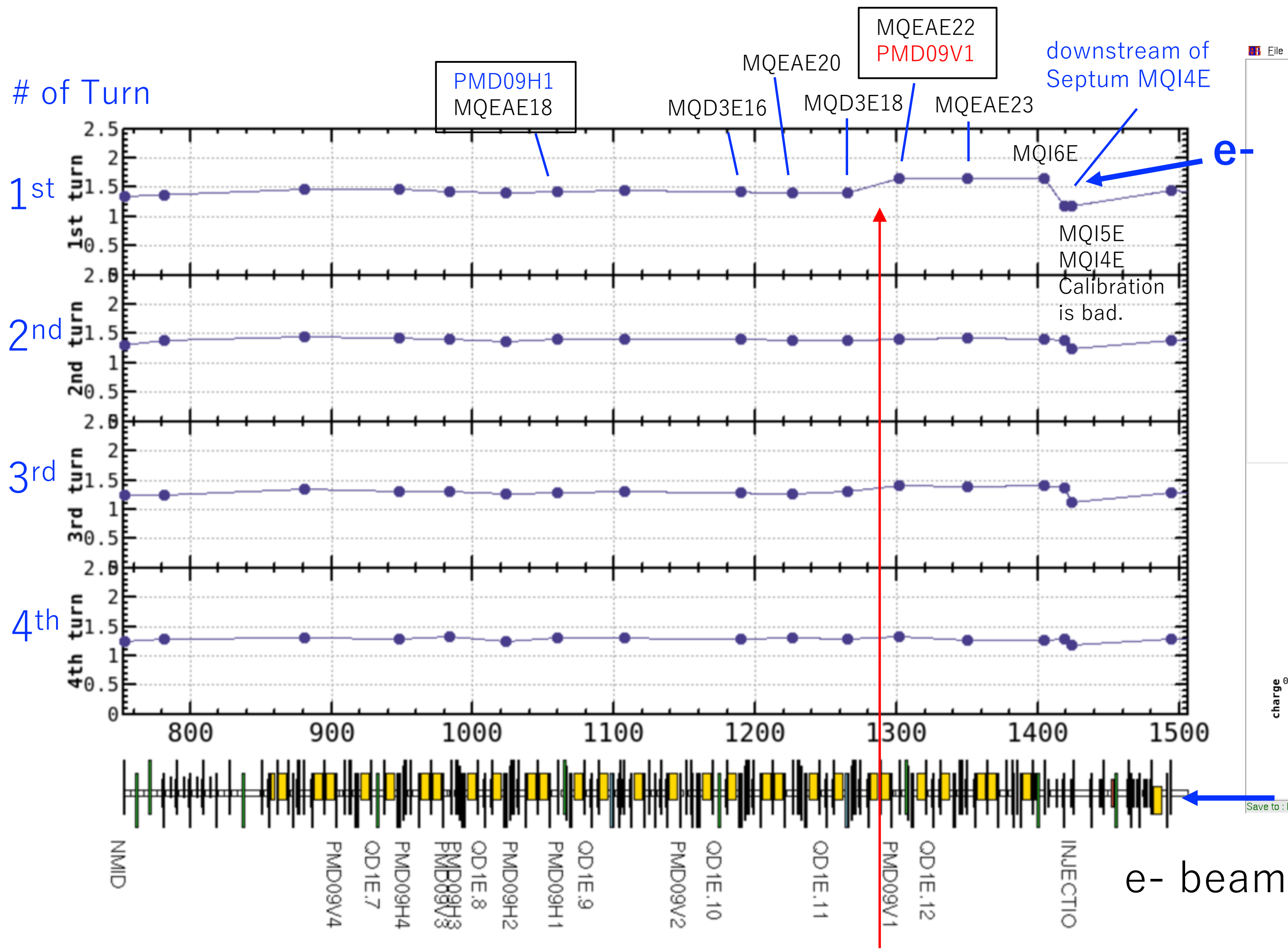
- Horizontal emittance
  - The aperture for the injection is $5x10^{-7}$ m, corresponding to 4.4 mm at D09H1(βx=39.7m).
  - The collimator(D09H1) was not closed very much(18mm to 11mm, far from 4.4mm) when optics changing βy^*=8mm to 1mm, however the beam was lost with optics change.
  - It is considered that the problem is mainly from the vertical emittance or/and orbit.

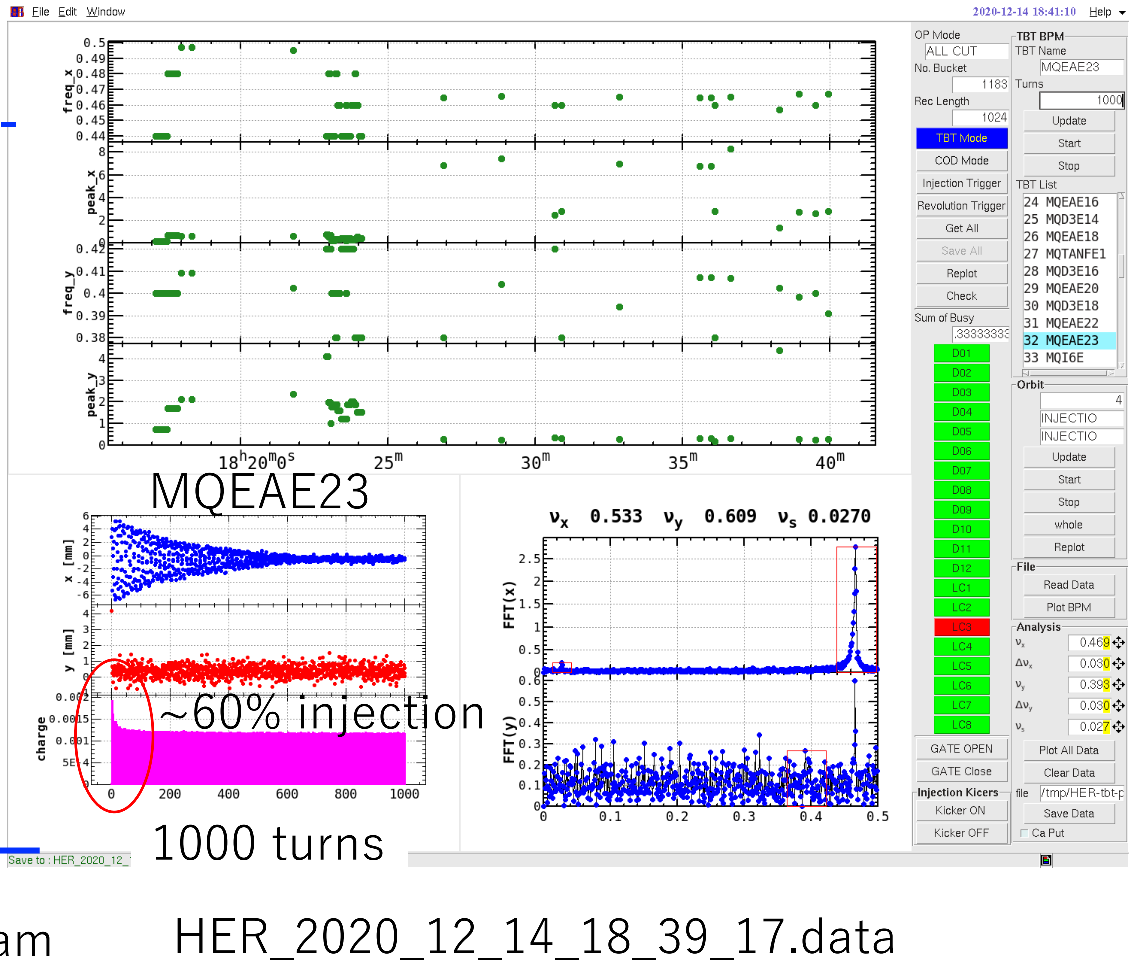


1-shot injection

The charges of injection beam were monitored by Turn-by-turn BPM with 1-shot injection

Y. Ohnishi

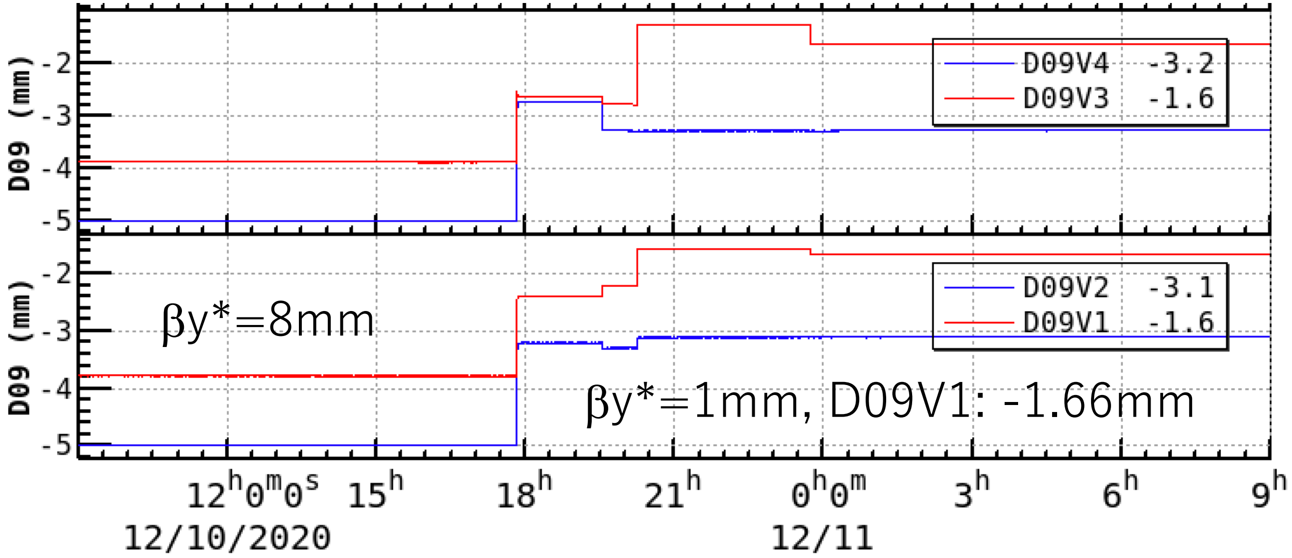




The injected beam losses at Collimator D09V1 for every 2 turn due to the half integer vertical tune

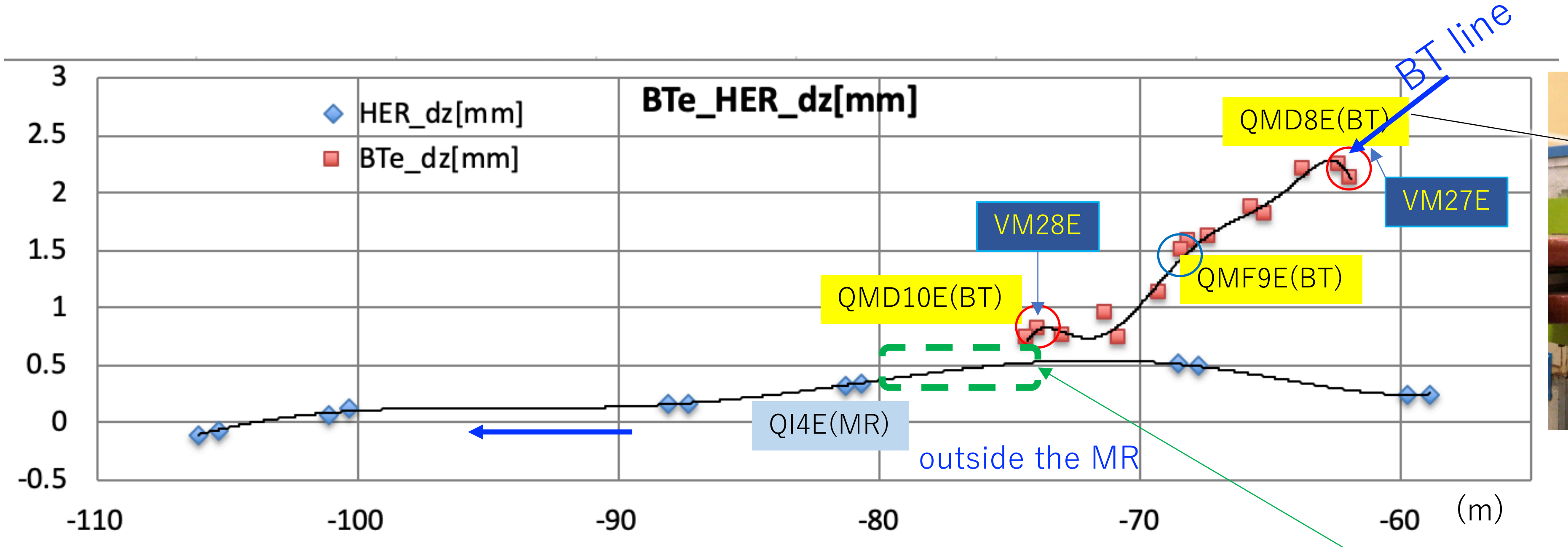
HER injection –Vertical-

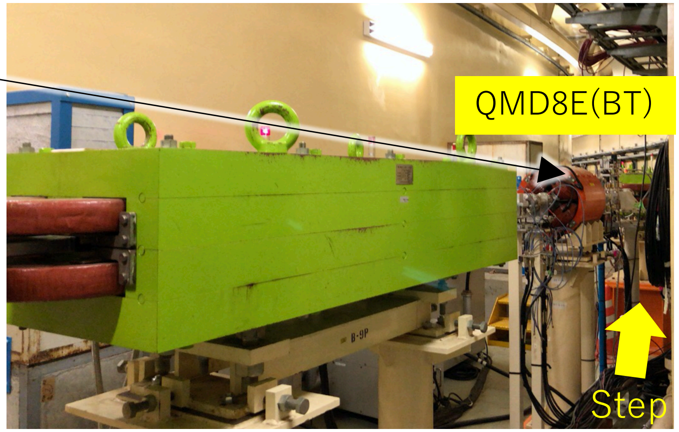
- Vertical emittance
  - D09V1: -1.66mm, DY(the vertical orbit of beam)=-0.2mm
    - → Distance between the center of beam and the D09V1 head(A) is -1.46mm
    - βy=15.5m → $\varepsilon y = A^2/\beta y (1.46 \times 10^{-3})^2/15.5 = 1.38 \times 10^{-7}$m, $\gamma\varepsilon y$=1.9mm
  - Assuming 3σy, more than $\gamma\varepsilon y$= 1.9mm/9=210μm beam will loss here.
  - Since the measured vertical emittance is about 130μm, if the beam passes the design vertical orbit, the injection beam should not be lost.



The vertical orbit in the injection region

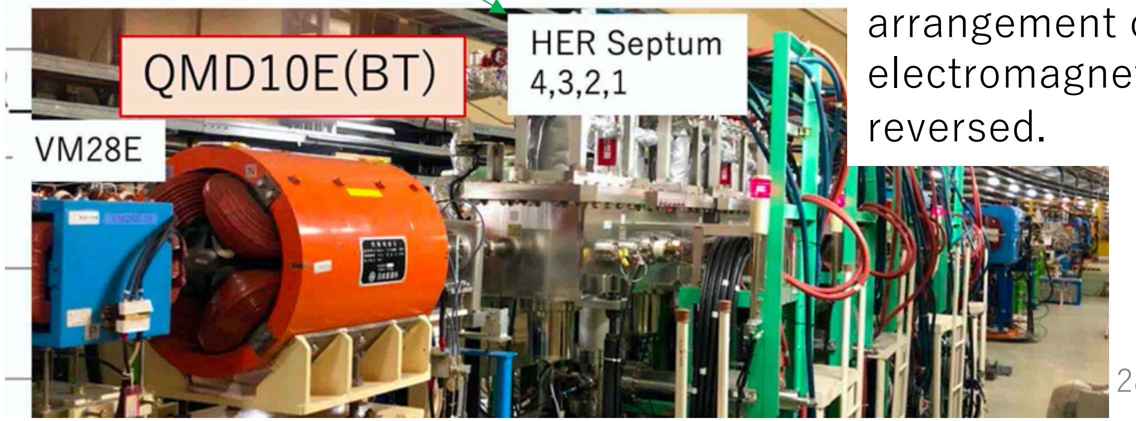
T. Oki



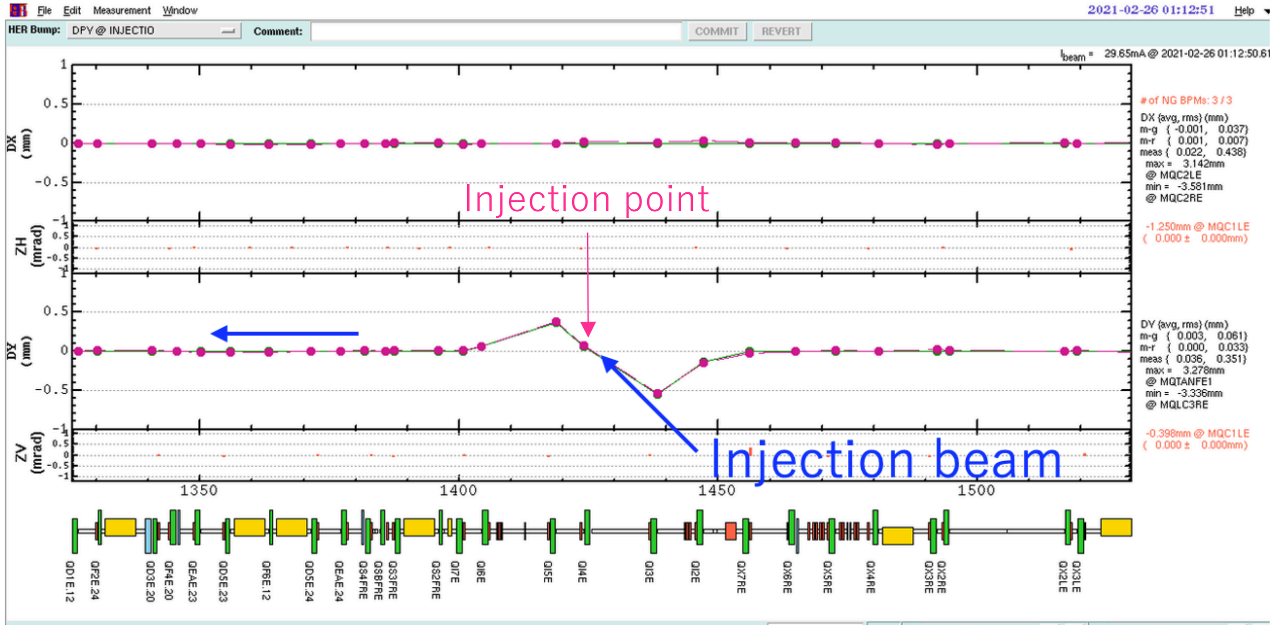


The photo was taken from the inside of the ring, so the arrangement of the electromagnets was reversed.

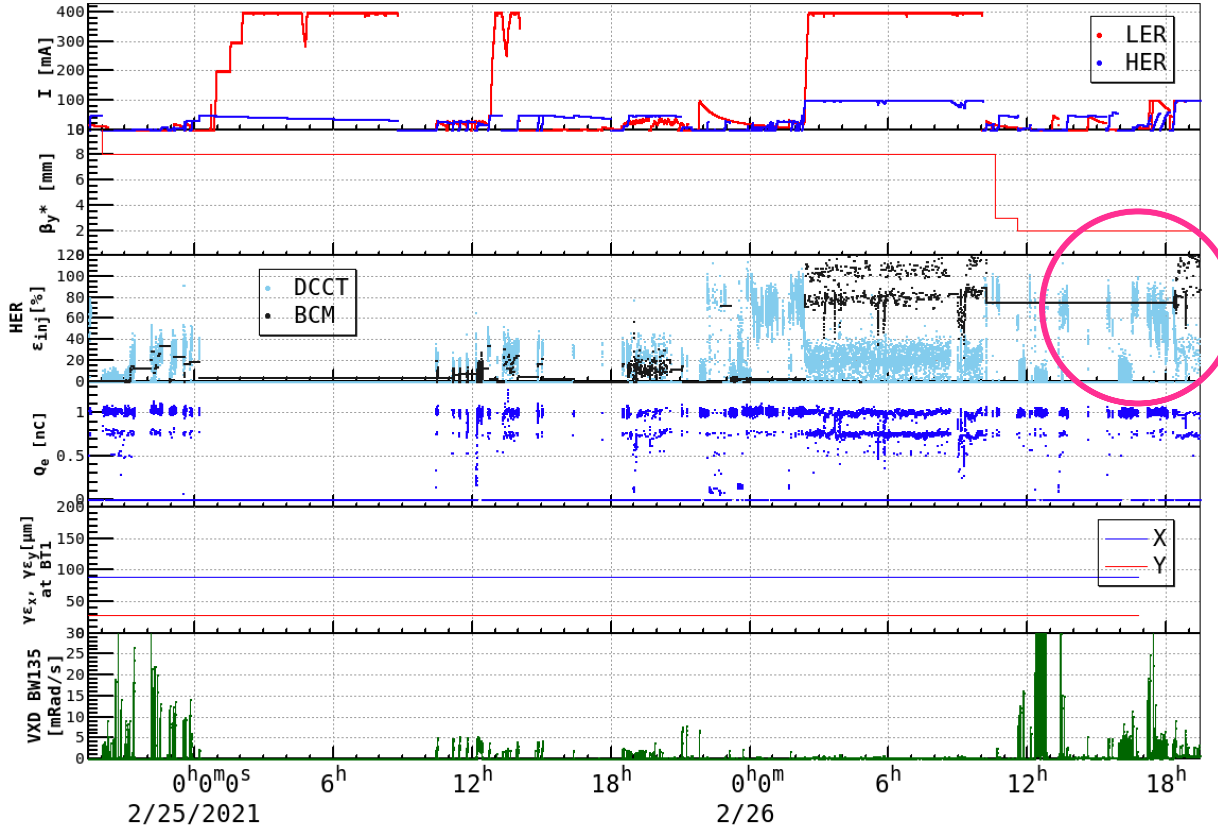
It is considered that the angle between the BT line and the MR comes from the Geoid. ~80μm.



The vertical bump in HER along to the injected beam



A vertical bump orbit of the accumulated beam was made at the injection point so that the accumulated beam would follow the injection beam.



The injection efficiency reached ~80% at βy*=2mm !

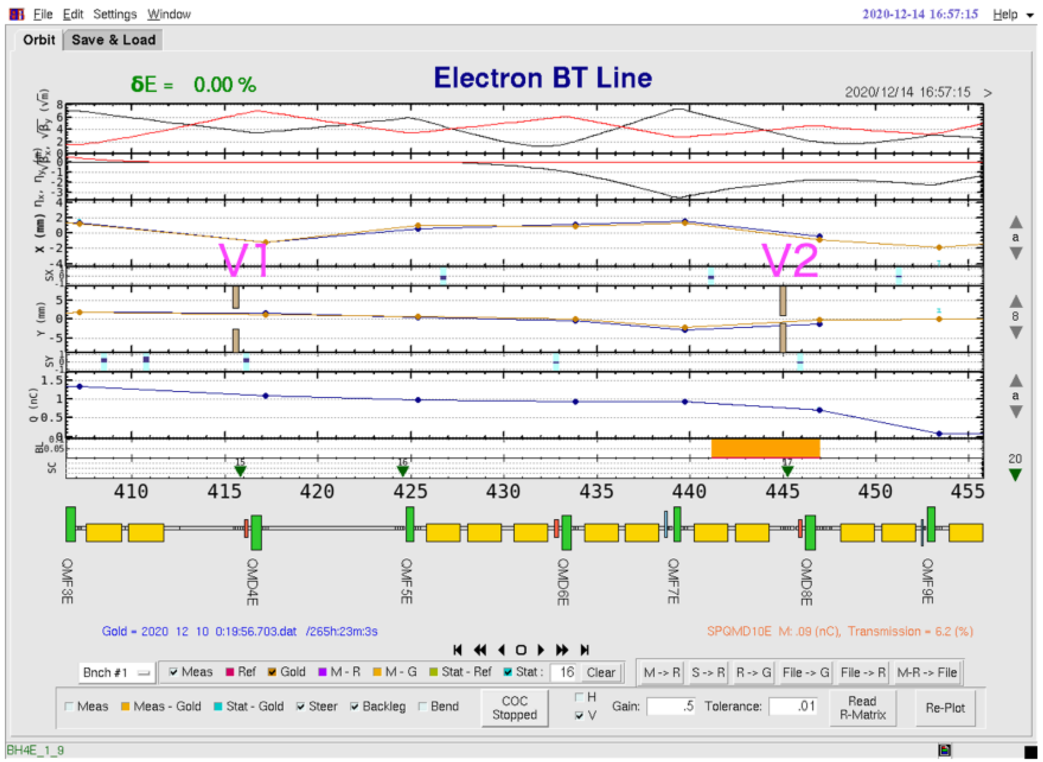
Injection efficiency of low emittance beam

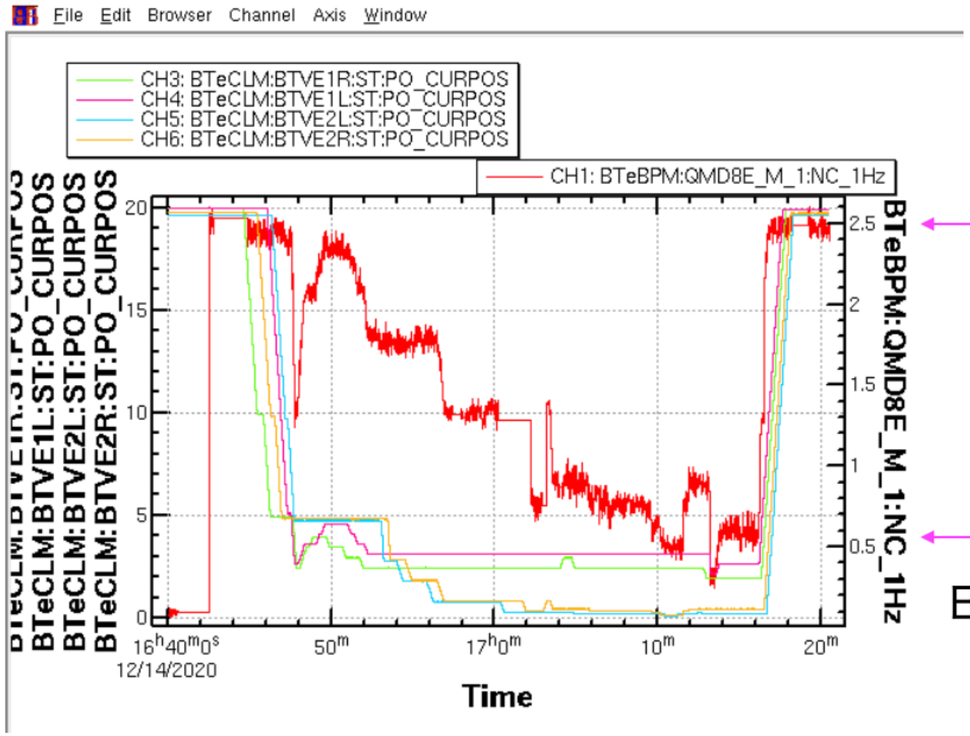
The low emittance beam was made by artificially by cut with collimators in the BT.

V1T 2.5 mm, V1B 2 mm,

V2T 0.4 mm, V2B 0.6 mm

M. Kikuchi





1.4 nC

.35 nC

Efficiency ~70%

The injection efficiency increased from 50% to 70% at the time.
The lower emittance increases the injection rate to some extent.
But it didn't reach 100%.
→ We want to try again with measurement of the vertical collimator offset.

Plan of improvements for injection

	Effect to injection eff.[%]	Inj. eff. [%]
before December		40
V. orbit at BT end	+10	50
νy in HER, H. and V. orbit at BT end	+10	60
Vertical bump of HER at the injection region	+15	75
Low emittance with collimator	+15	90
Optics matching at Arc-4 ?	+10 ?	100 ?

Very rough estimation

Summary of injection efficiency

- One of the reason why a bad injection efficiency is from the vertical orbit mismatch between BT end and the vertical collimator in HER.
- The injection efficiency was improved by correcting the orbit at the BT end and choosing the tunes.
- The injected beam mainly losses at the vertical collimator, D09V1 and injection region, which are considered from the high residual radiation around them.
- The charge losses at the D09V1 are also monitored by Turn-by-turn-BPM(TbT-BPM).
- The vertical alignments between BT and MR have some discrepancy due to a different coordinate system about a geoid.

2-bunch injection

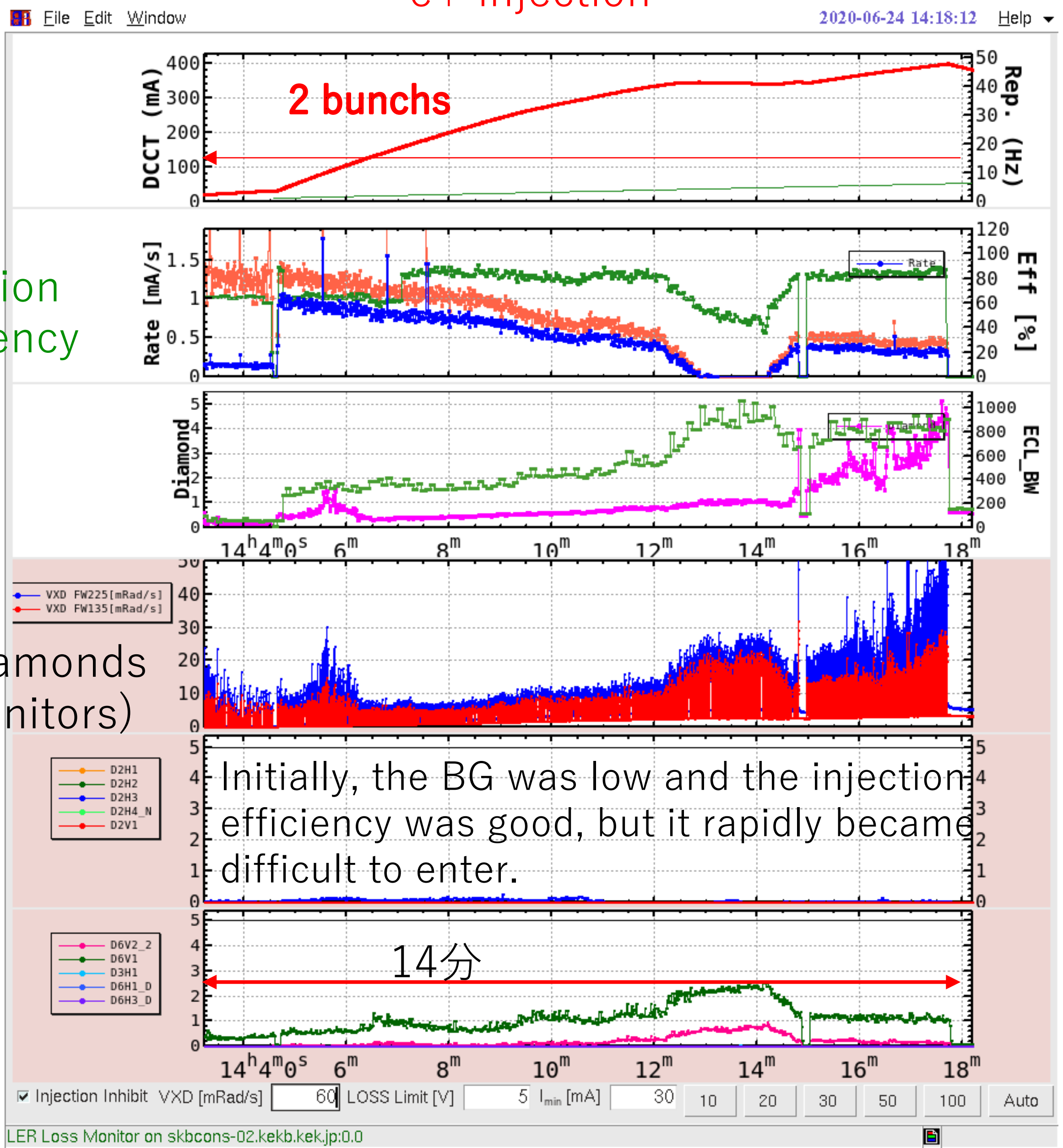
- Until 2020c, 2-bunch injection was successful only for HER.
- At the begining of 2021a, it has been succeeded also for LER !

2-bunch injection and BG

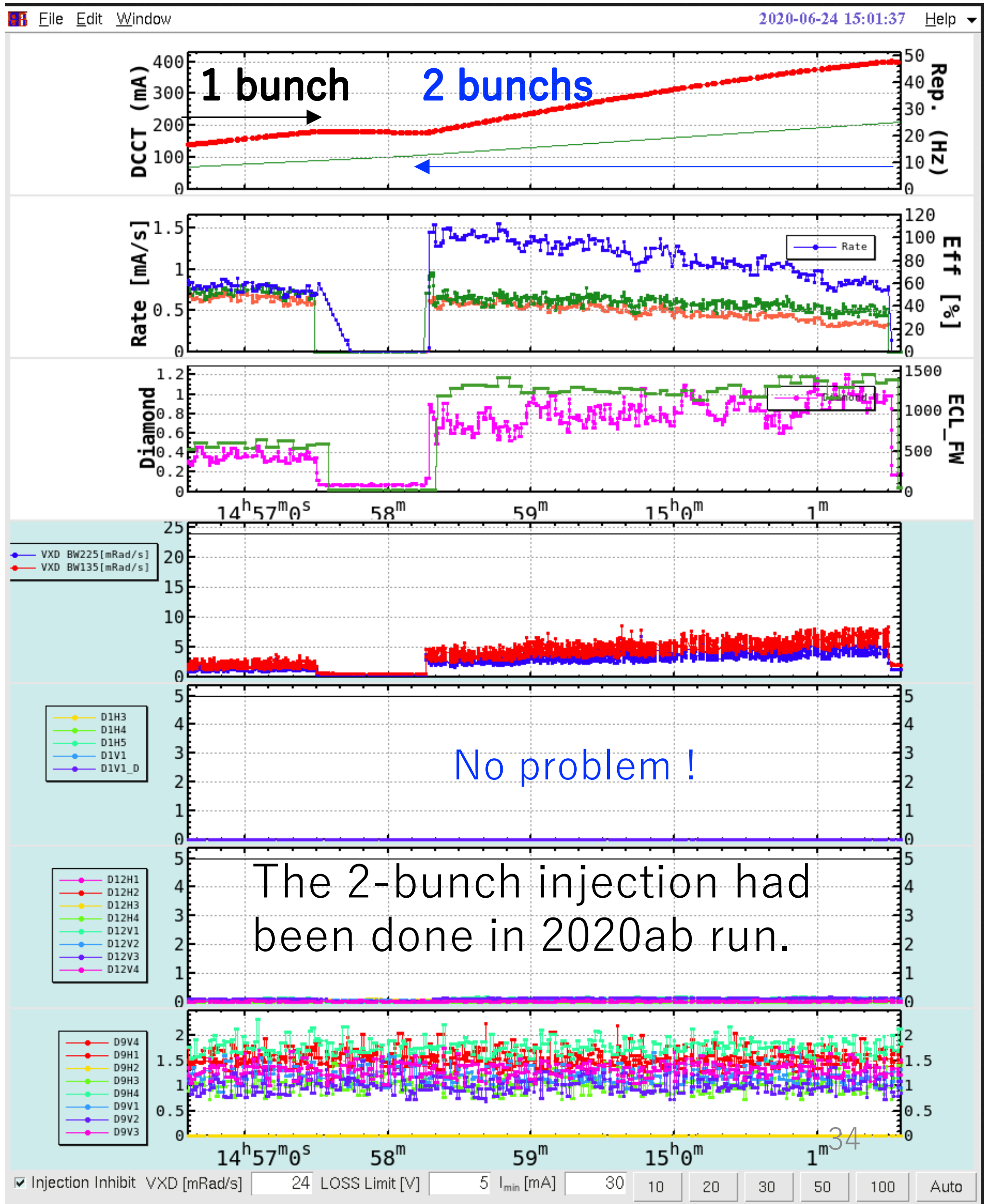
e+ injection

Injection efficiency

VXD diamonds (BG monitors)

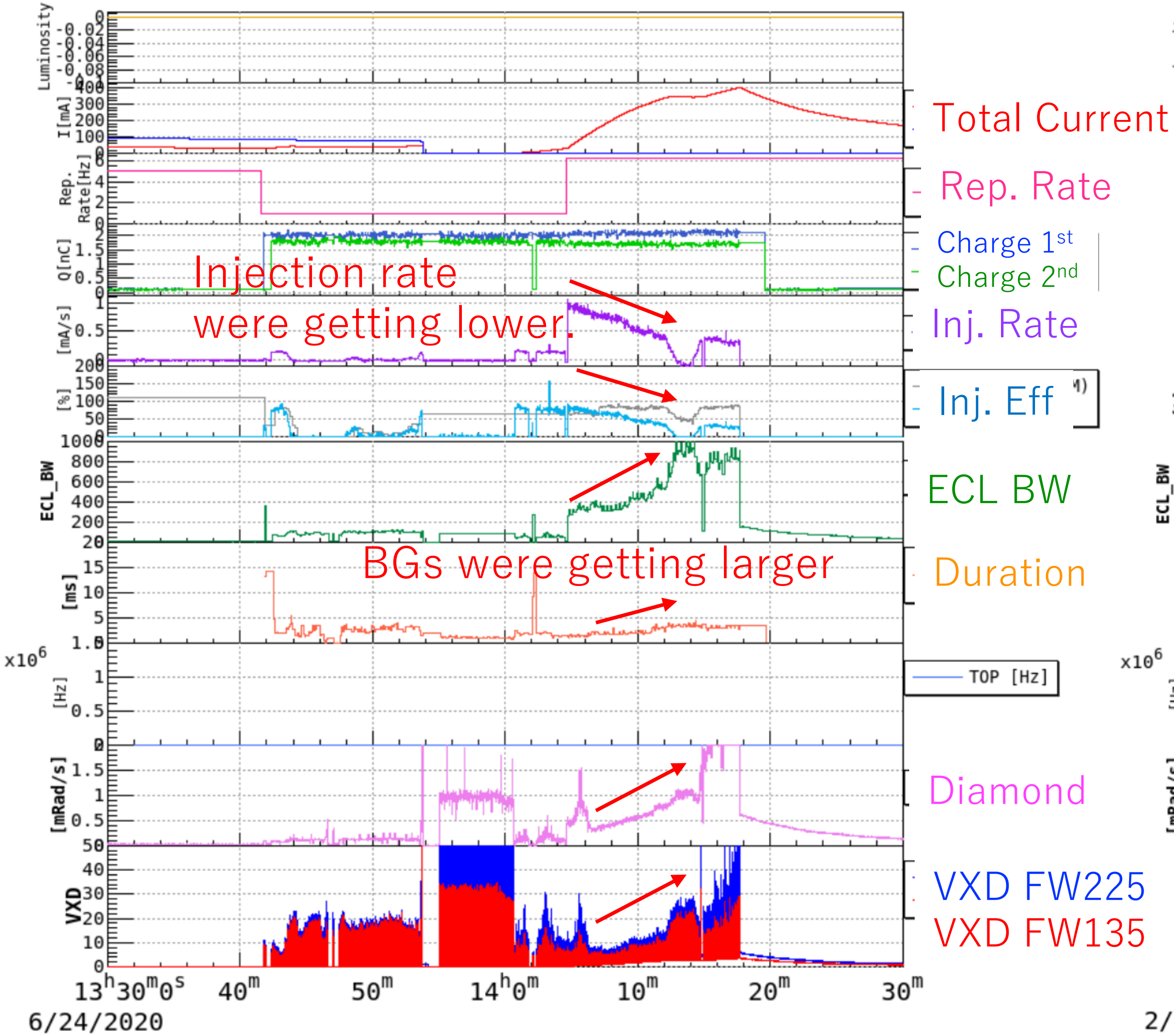


e- injection

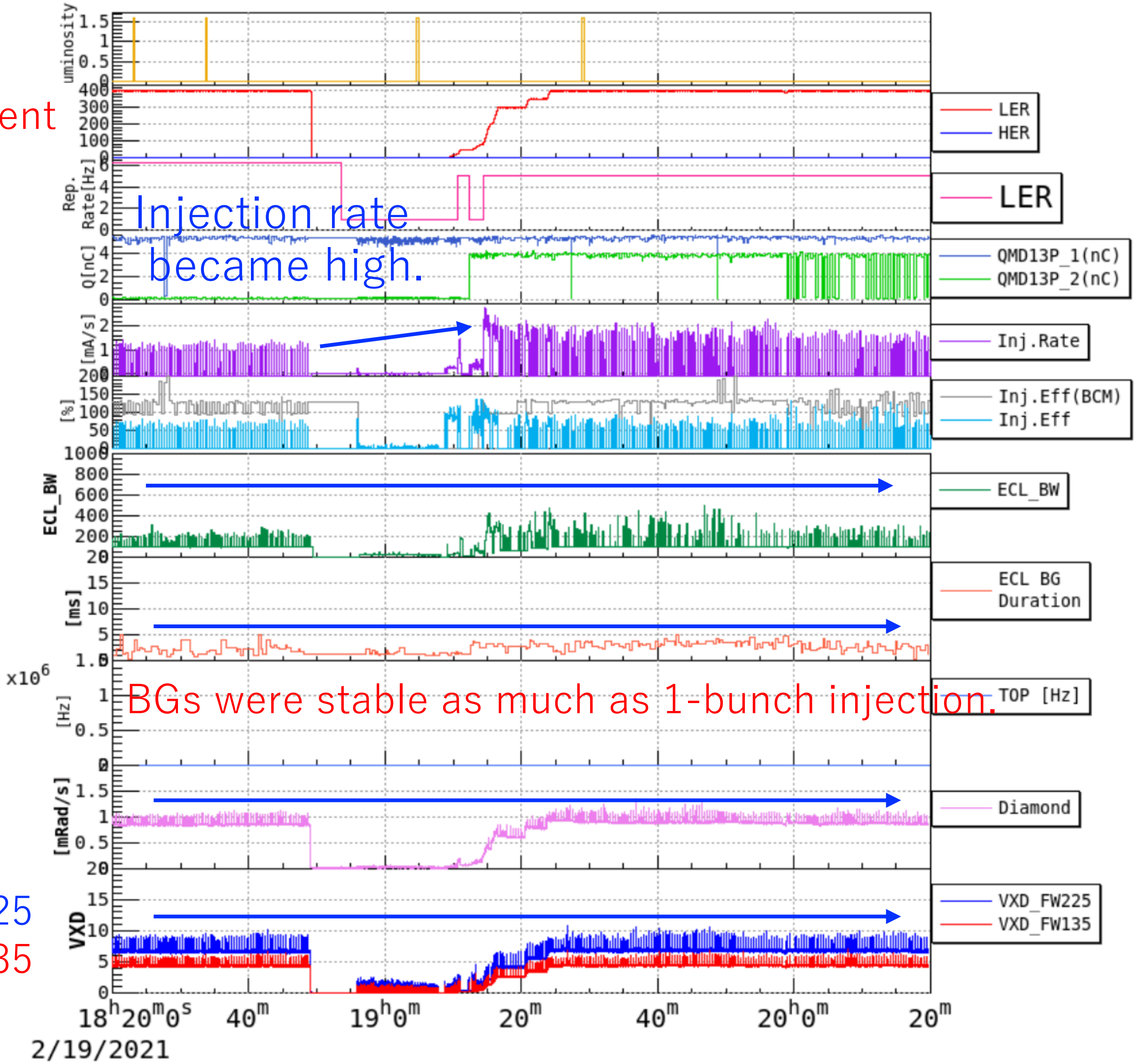


2-bunch injection to LER

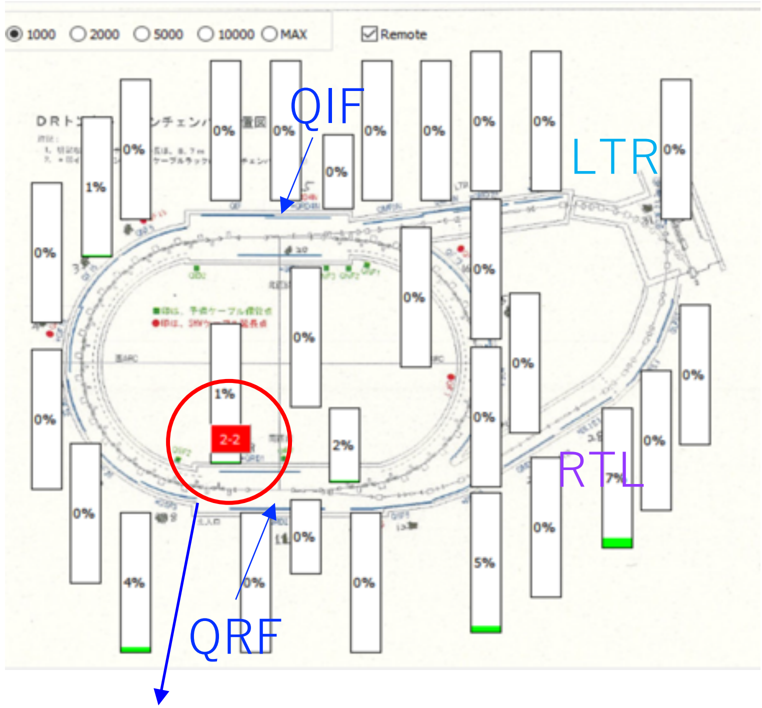
24/Jun/2020, 2-bunch injection failed….



19/Feb/2021, 2-bunch injection succeeded !



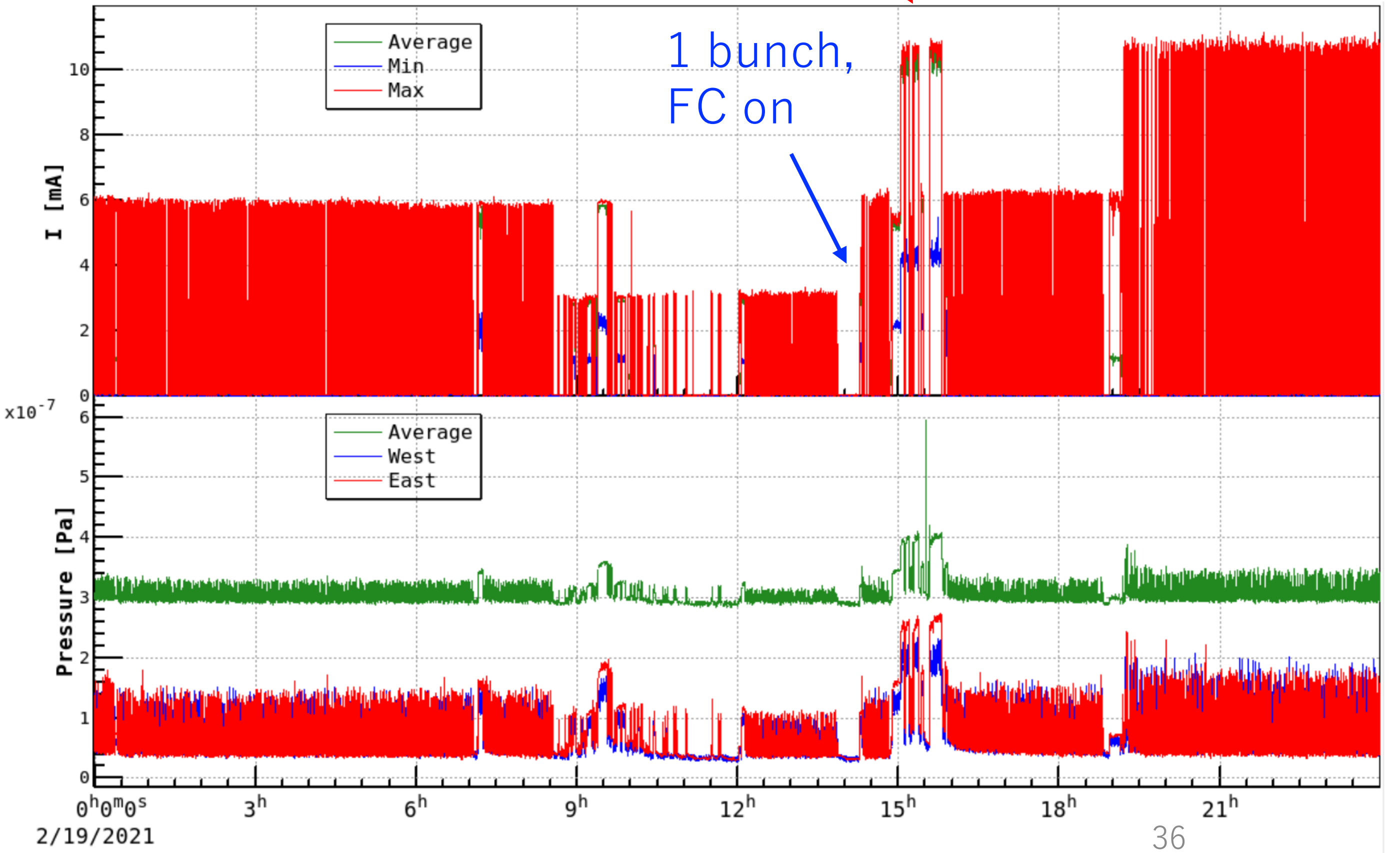
Damping Ring (DR)



The injection to the DR had been stopped by the loss monitor near a RF cavity.
This interlock occurred when the FC works and 2-bunch injection (The total current in the DR was more than)

2 bunch, FC on
Injection stopped by I/L at DR

2 bunch, FC on
Continuous injections can be done by tuning RF feedback system.
→See the next slide.

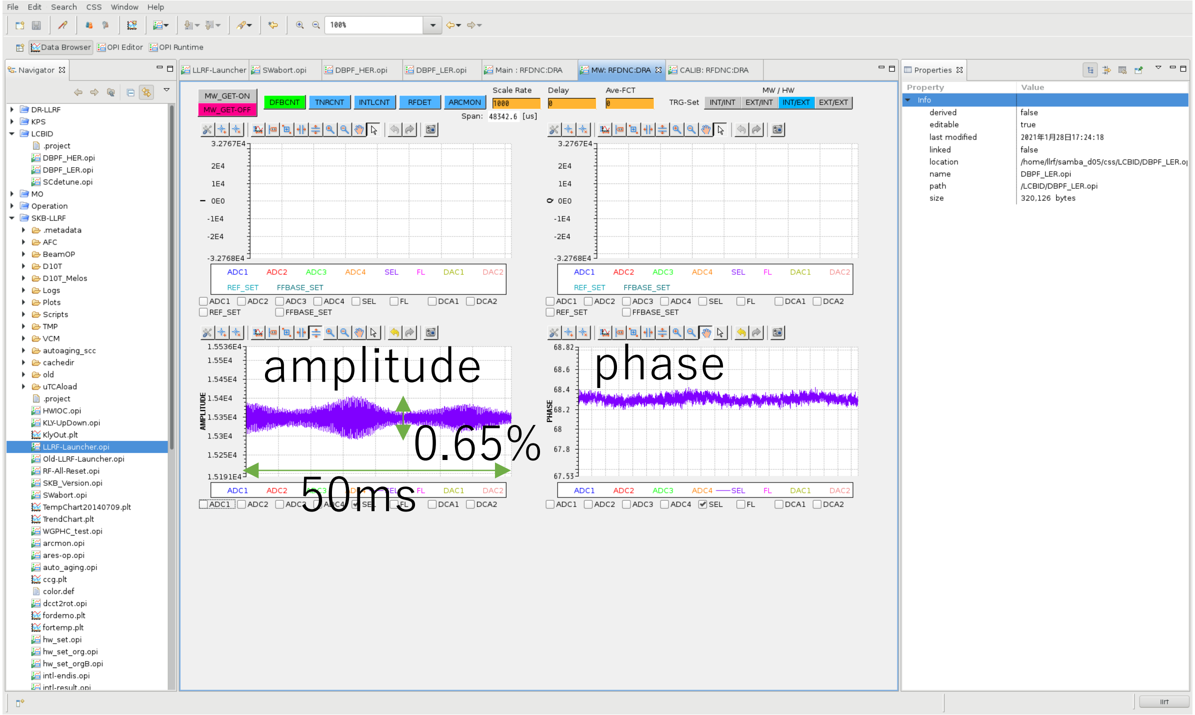


15:20 - DR operation with 2 bunch and FC on (T. Kobayashi, M. Nishiwaki, H. Ikeda)

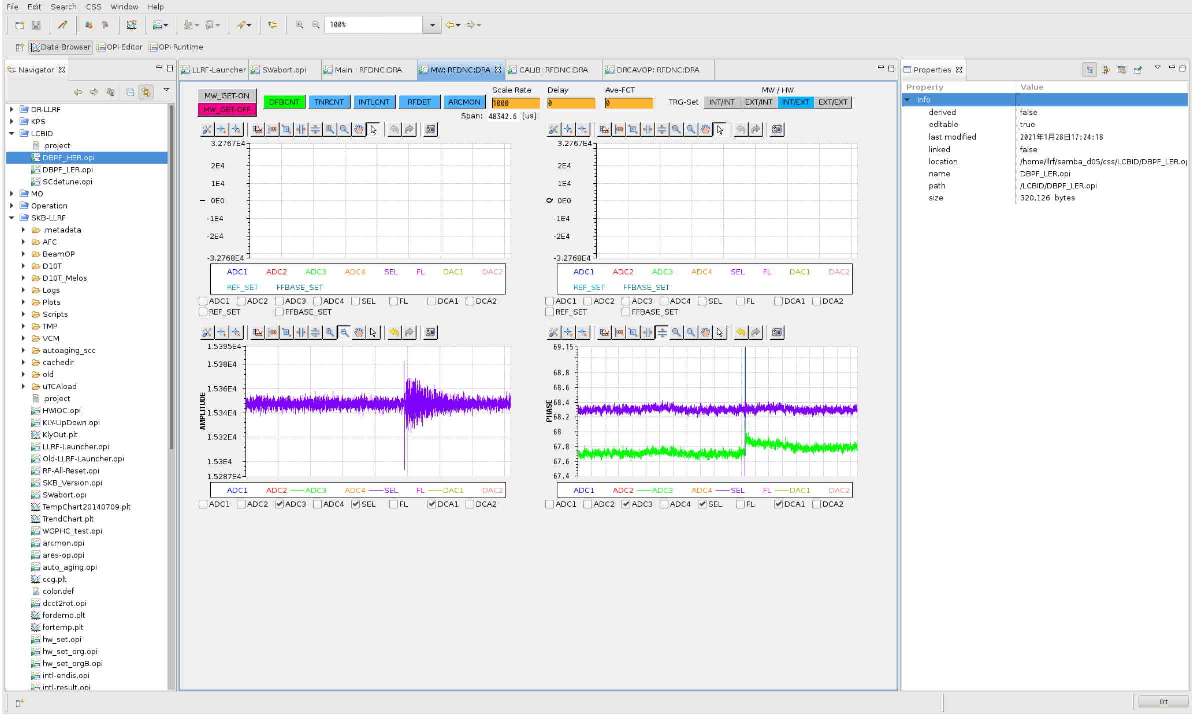
Observation of RF behavior(response of RF voltage and cavity phase to beam)

->Tuning of LLRF feedback loop

before tuning(DAC-IIR Filter OFF)



after tuning(IIR(BW 5kHz) ON)



"Inhibit injection" by the loss monitor seems cured by this tuning.
More detail investigation about the instability will be done.

Summary of 2-bunch injection

- HER
  - The 2-bunch injection had been done in 2020ab.
  - It had not been done in 2020c because the pulse width of the RF was made narrower than the optimum value, 1 μsec due to the often klystron down.
  - In 2021a, the pulse width will be wider than 0.95μsec under the lower Es voltage of the klystron, for stability.
- LER
  - The 2-bunch injection had not been able to done until 2020c.
  - An instability in the longitudinal plane was occurred, which was improved by tuning the RF feedback.
  - It is considered that the reason why enable to the LER with 2-bunch was due to the unstable beam from the DR.
  - Now the 2-bunch injection to the LER is on going without any trouble.

Collaboration with Belle II for an injection

- BT-PS file control system (See the next slide)
  - Matsuoka-san suggested that Hara-san's group helps the file save system for the PS of BT.
- Injection support team
  - Funakoshi-san made a special support team for the injection.
  - The team aims to make an injection manual for the operators.
  - At first, H. Nakayama, K. Nakamura, S. Tanaka, and I. Adachi joined it.
  - They will help making an injection manual to take care of the background monitors of Belle II.
  - Of course, we welcome to join the injection tuning, or making the injection beam.

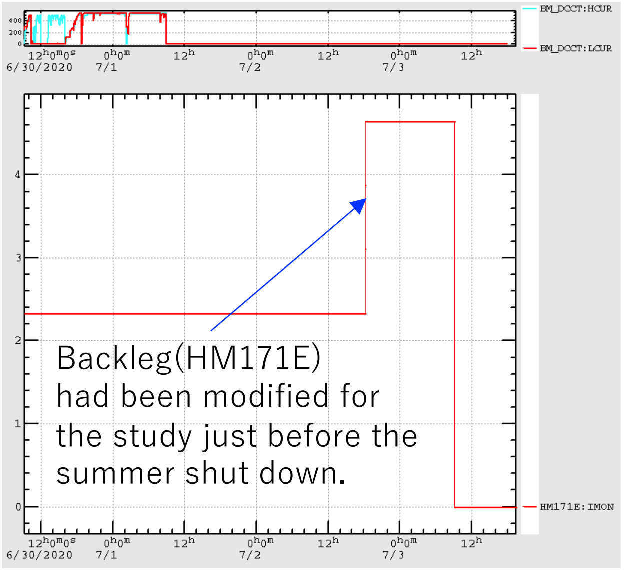
BTe Orbit

At the end of 2020b, I saved the setting of a backleg at the BE end changed for a measurement of WS for a study, and accidentally loaded the file at the beginning of 2020c.

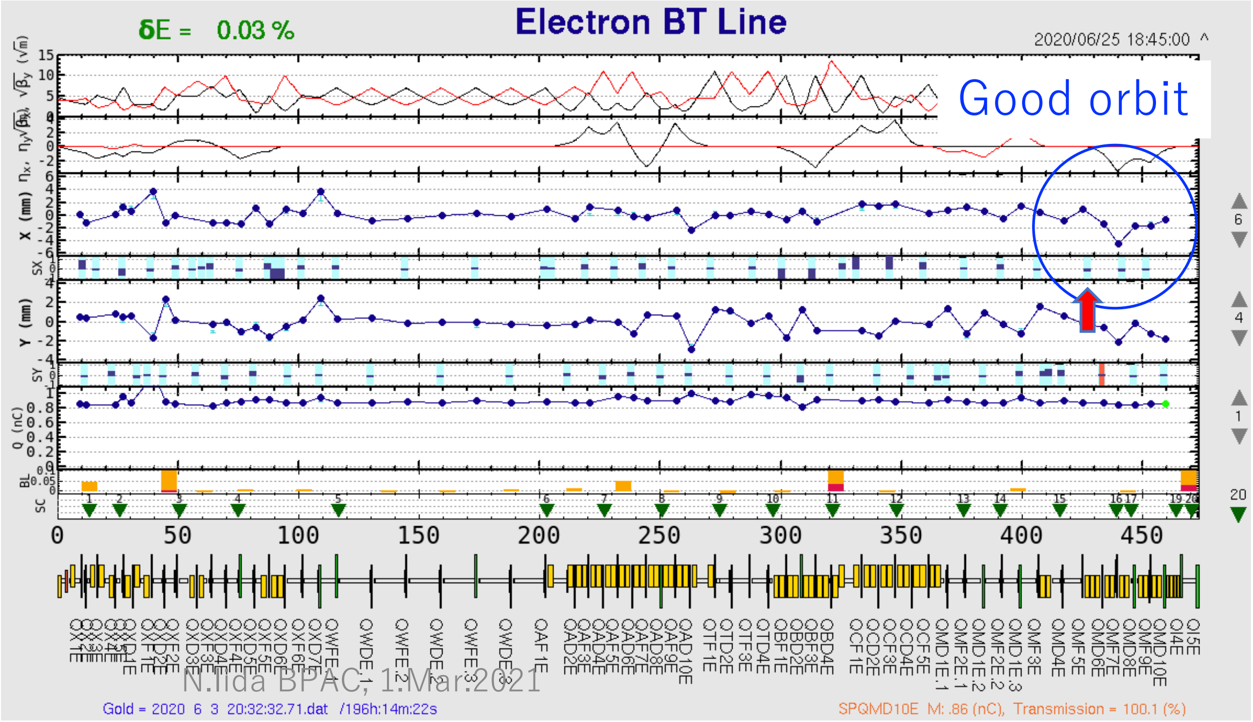
I am VERY sorry.

Future plan：

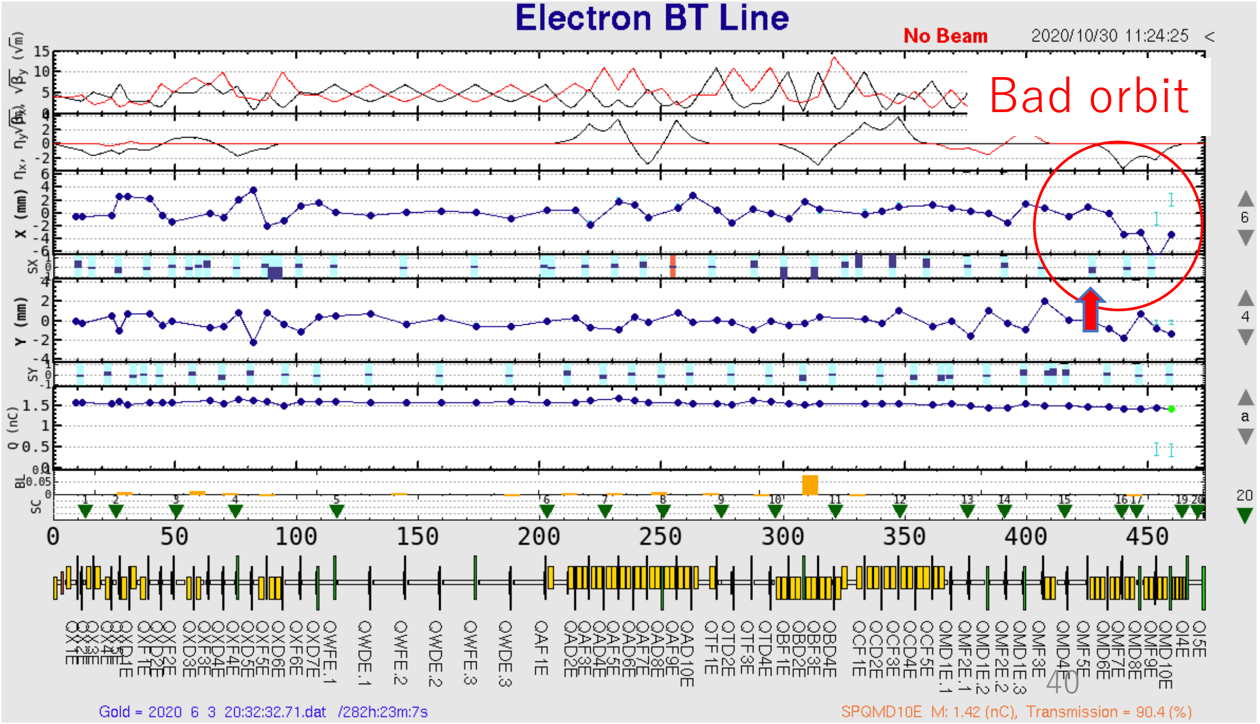
- Be careful of File Save and Load
- Save GOLD Orbit at the time of injection.
- Display GOLD Orbit.
- Belle II people help us for the PS control system.



2020b(2020.6.25)



2020c(2020.10.30)



Summary

	LER	HER
Injection efficiency at βy^*=1mm	Usually more than 80%, but in the end of 2020c, it became lower because of LER optics changing.	Raised up to 60% from 40% by correcting the BT end orbit in 2020c.
Injection efficiency at βy^*=2mm	80~90%	Up to 80% in 26/Feb/2021a !
Charge [nC] (1^{st} + 2^{nd})	2.6+2.2	2.0+1.6
($\gamma\varepsilon x$, $\gamma\varepsilon y$) at BT2 [μm]	200, 30	300, 100
Required emittance [μm]	150, 30	100, 40
2-bunch injection	Ready	Ready
Collaboration with Belle II for Injection	• PS control system of BT line • Injection support team	