SuperKEKB
入射器の現状報告
2019c(Phase3.2)～2020a(Phase3.3)

2020.4.8

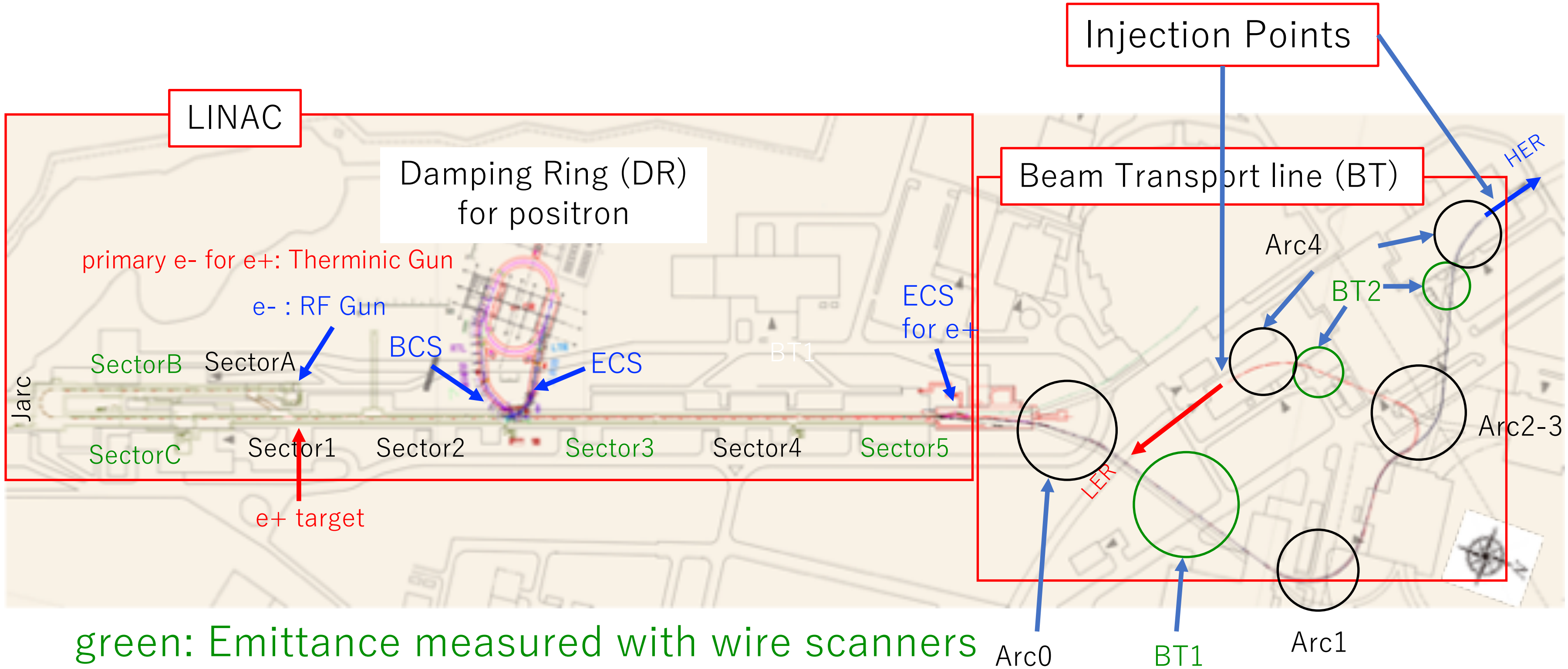
第117回 Bファクトリー計画推進委員会

加速器研究施設　飯田 直子

Layout of LINAC, BT, Injection to MR

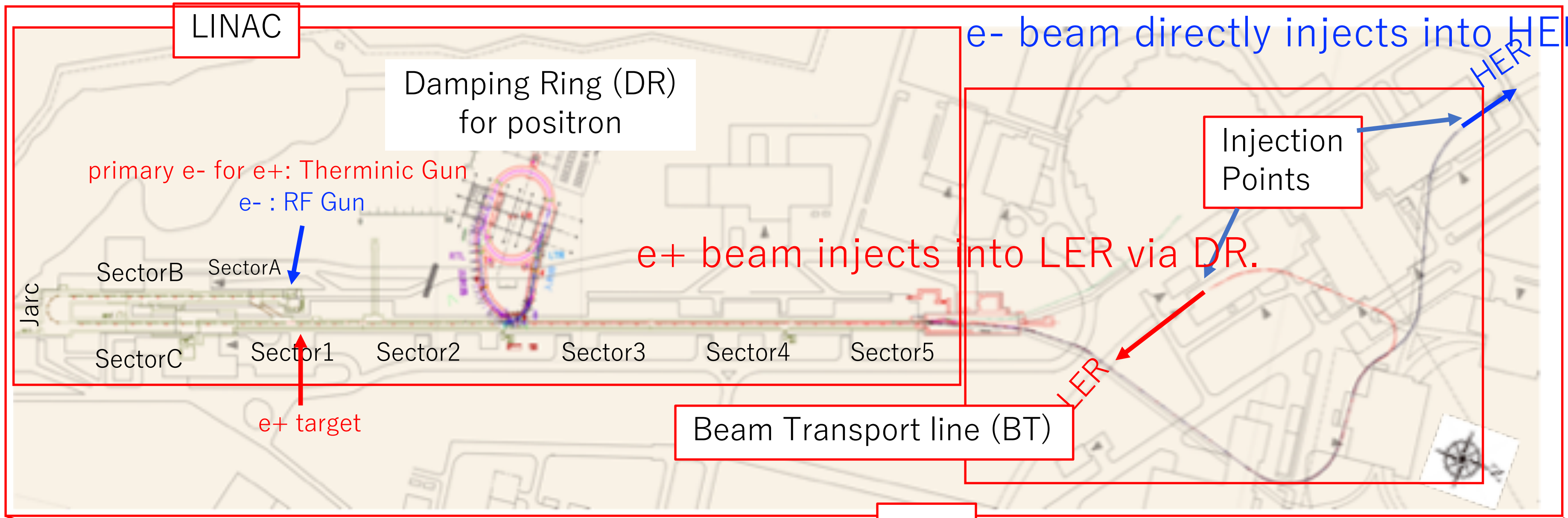
e+ beam injects into LER via DR:
The injection BG is not affected very much by the condition upstream the DR.

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



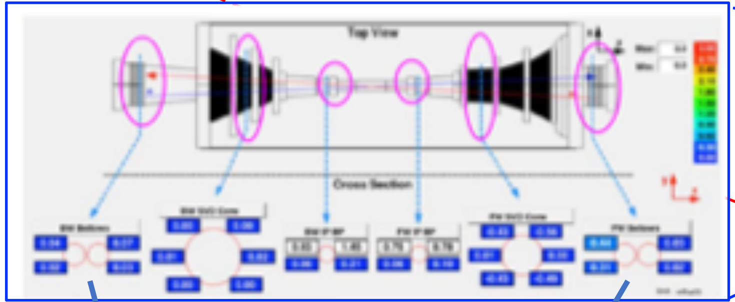
green: Emittance measured with wire scanners
BCS: Bunch Compression System
ECS: Energy Compression System

Layout of LINAC, BT, Injection to MR



MR

Diamond detectors at VXD in Phase3

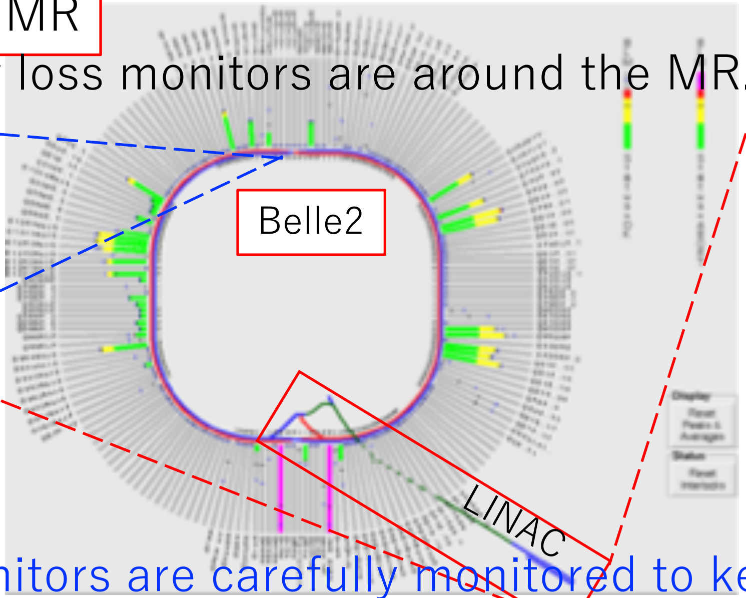


HER:
VXD(Diamond) BW135

LER:
VXD(Diamond) FW135

Most sensitive to the BG on Belle2.

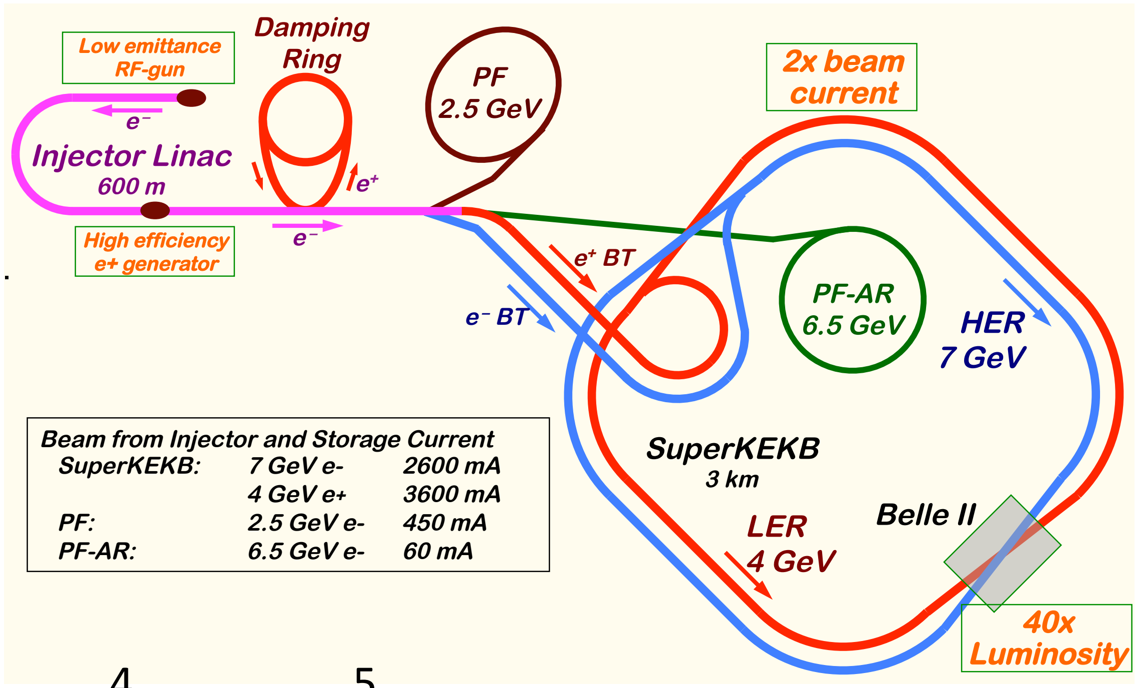
Many loss monitors are around the MR.

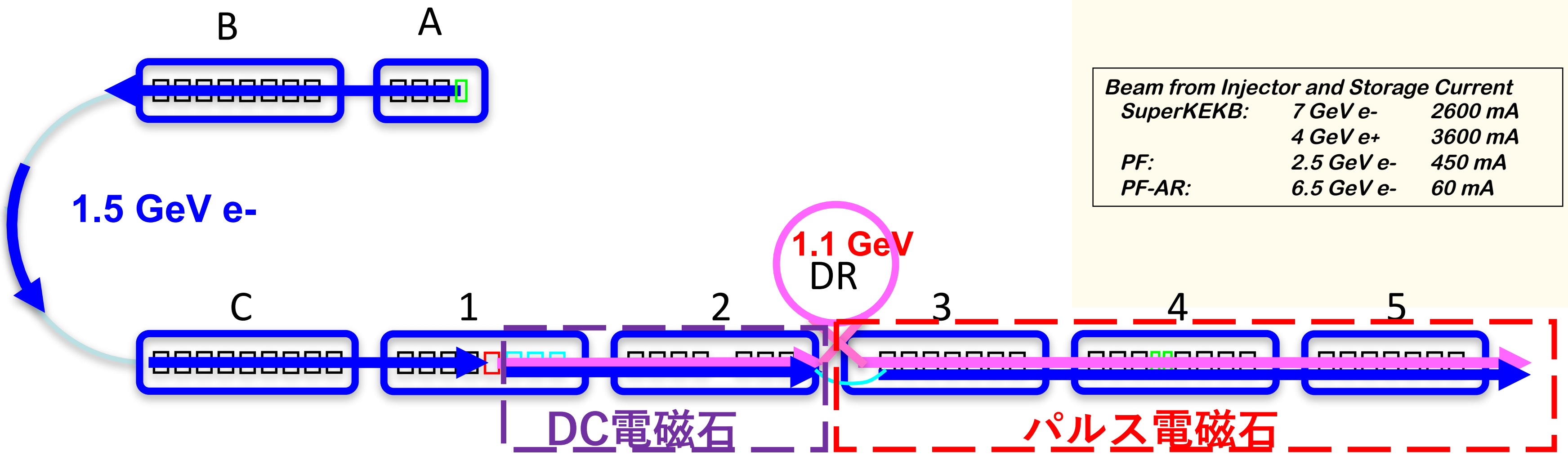


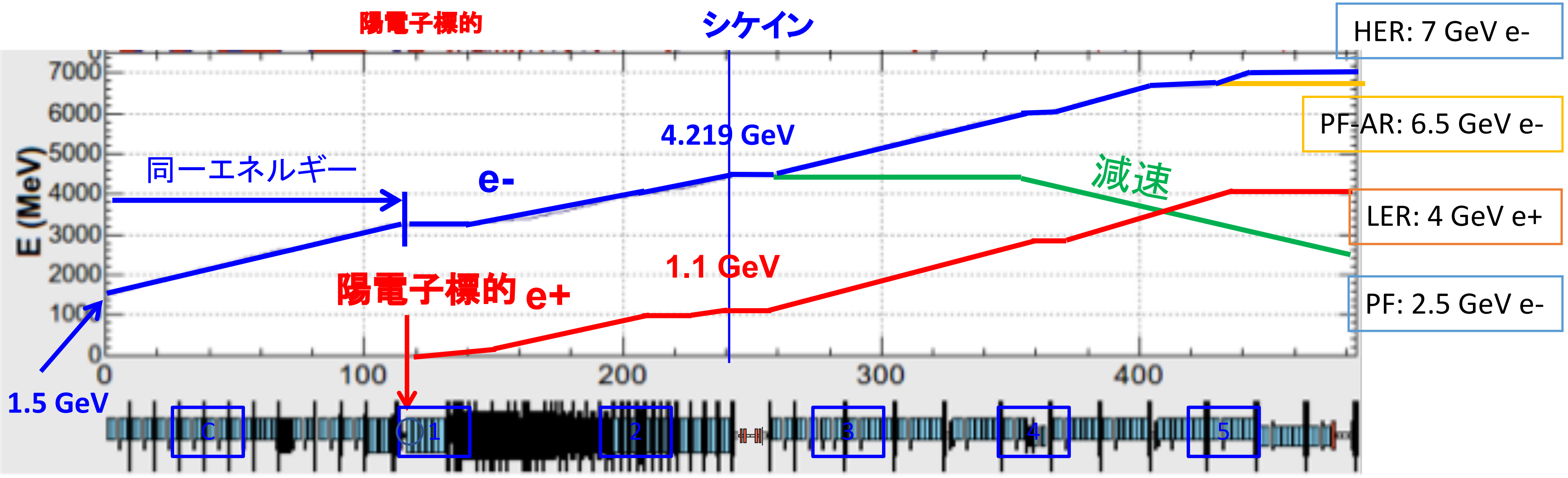
The signals from the Diamonds and the loss monitors are carefully monitored to keep the BG low.
Some aborts are avoided by stopping injection when the signals are high.

4 +1リング同時入射

- パルスごとに異なるバンチ電荷量，エネルギーのビームを加速，入射する．
- 50 Hz (20ミリ秒ごと）のパラメタ切り替えをおこなう．

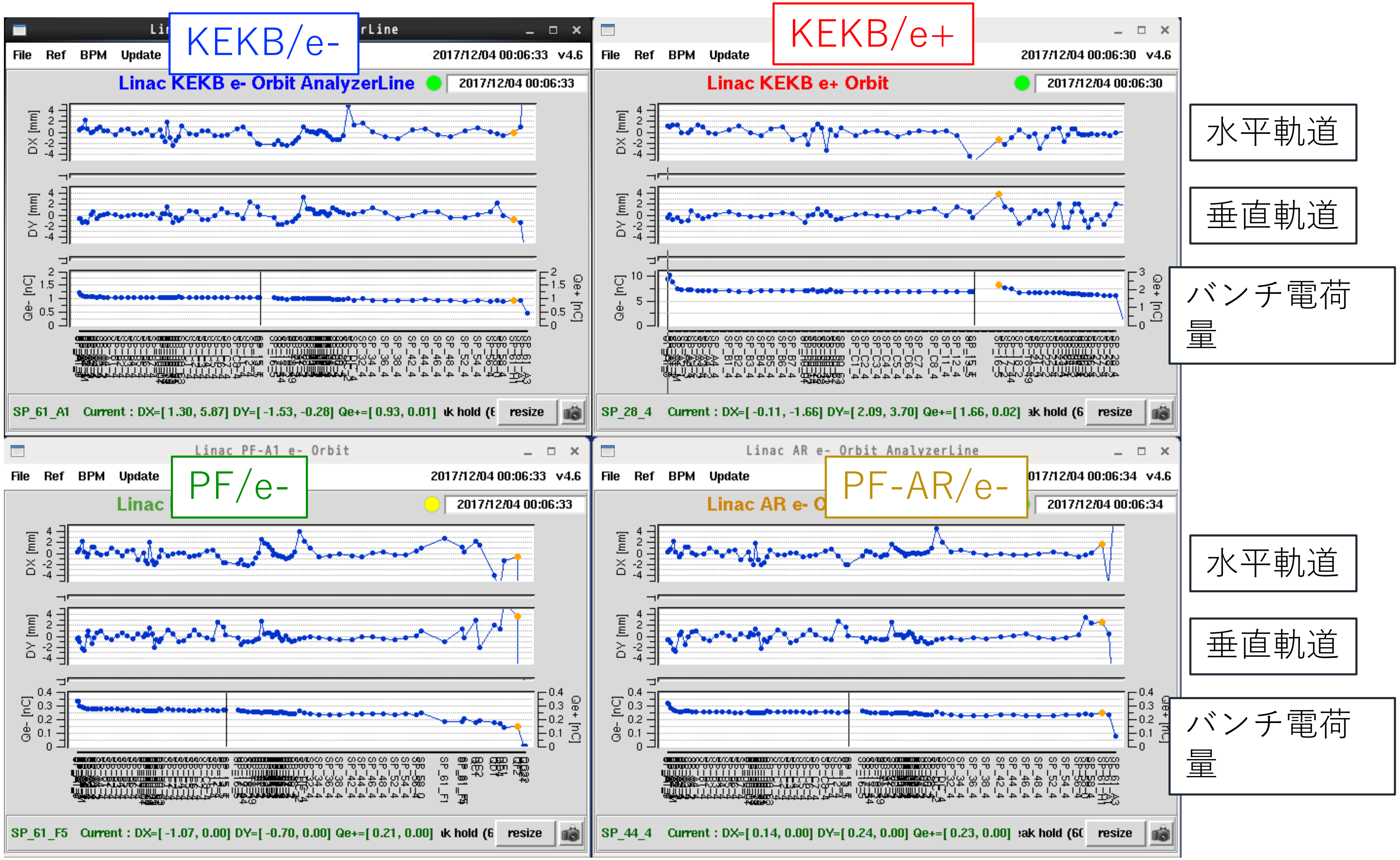






熱電子銃による同時ビーム運転(パルスごと切り替え)

4リング同時入射



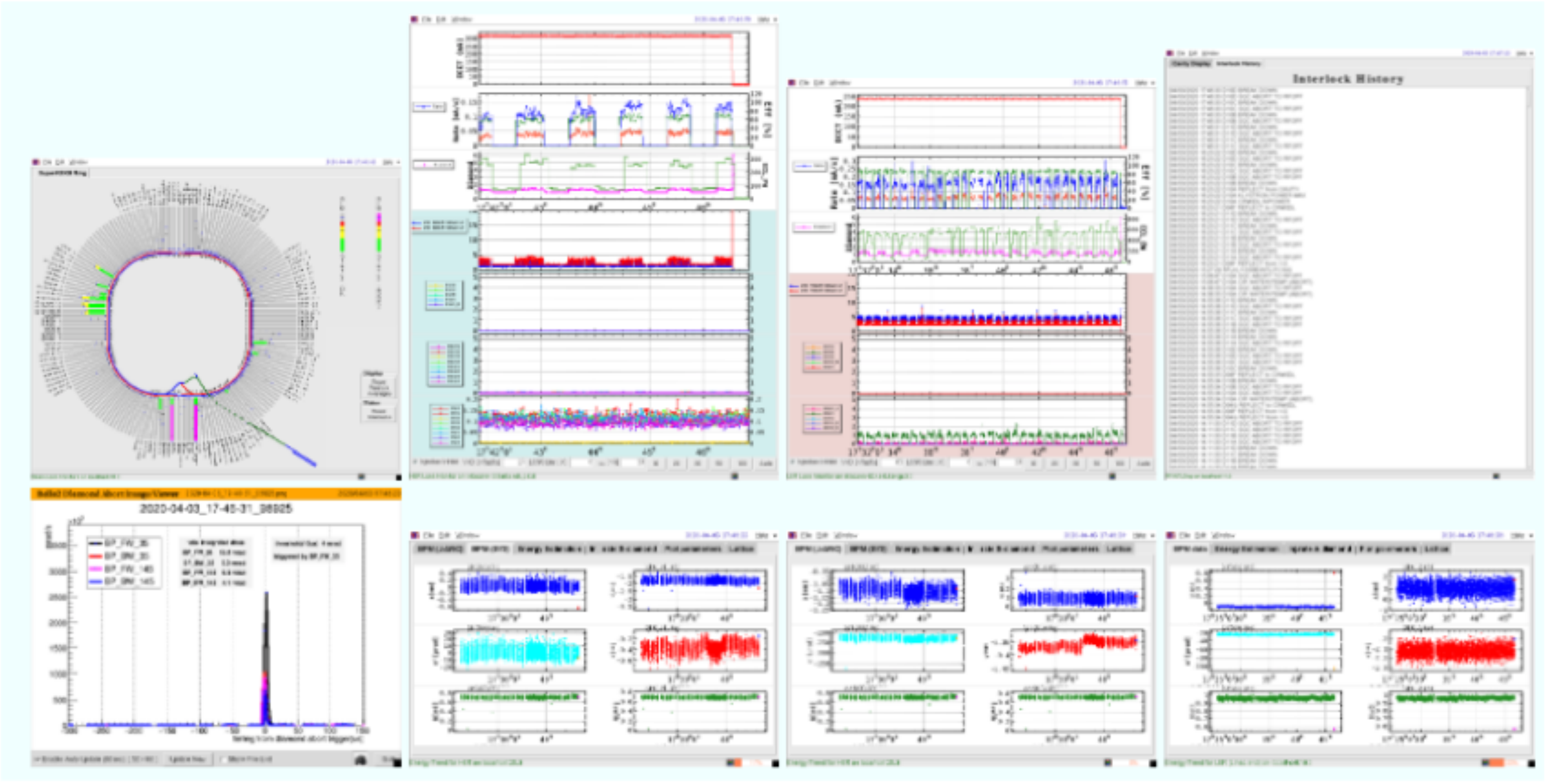
あたかも4本のビームラインを運転しているかのように見える。

前回(2019.10.3)からの大きな変更点

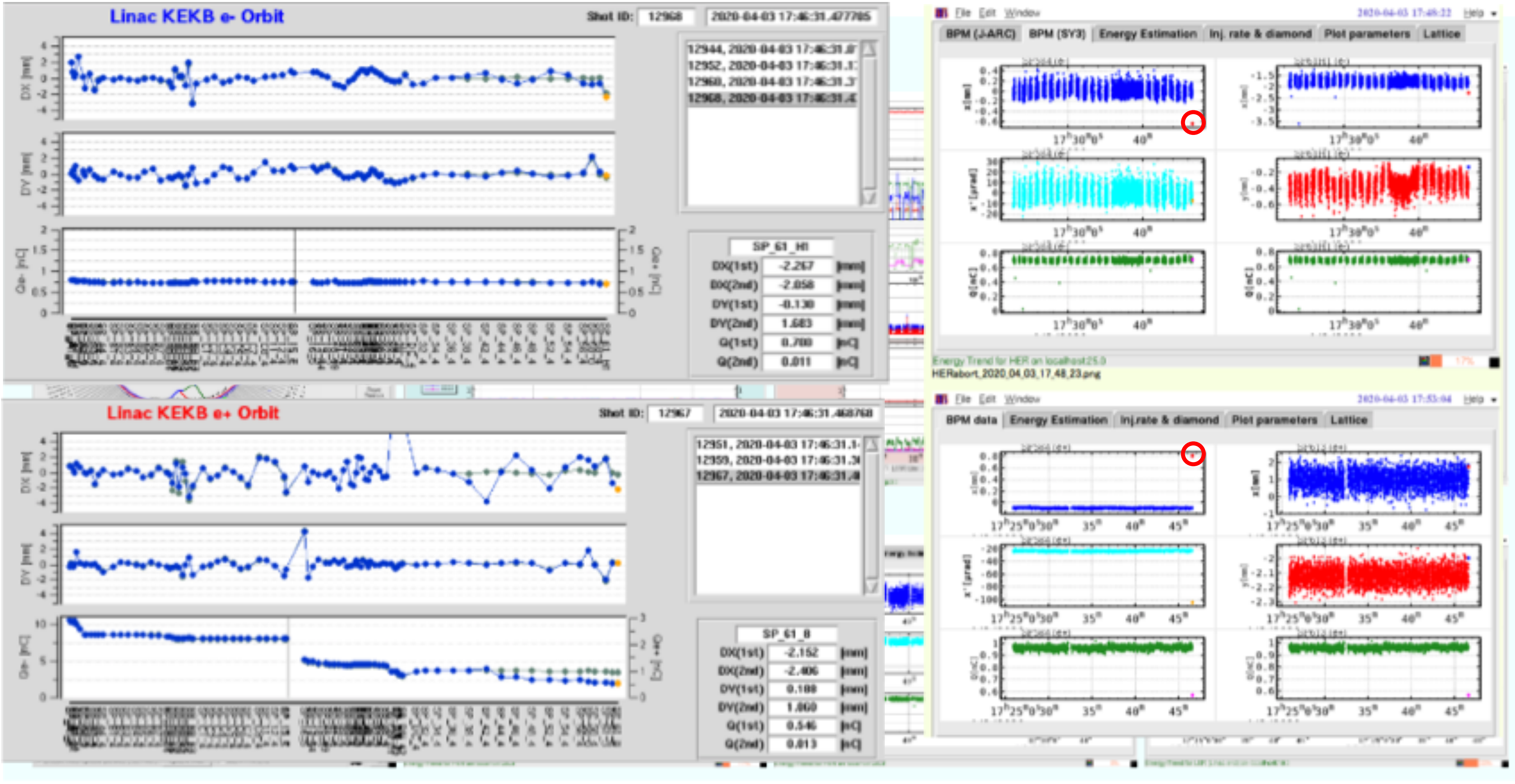
- 問題点
  - LINAC Pulsed magnetのmis-triggerにより、Abortが多発している。

- e- beam
  - Cathode 交換
- e+ beam
  - BTでのEmittance増大がある程度抑制された

LINAC Pulsed magnetのmis-triggerによるAbort、BGによる入射停止の多発

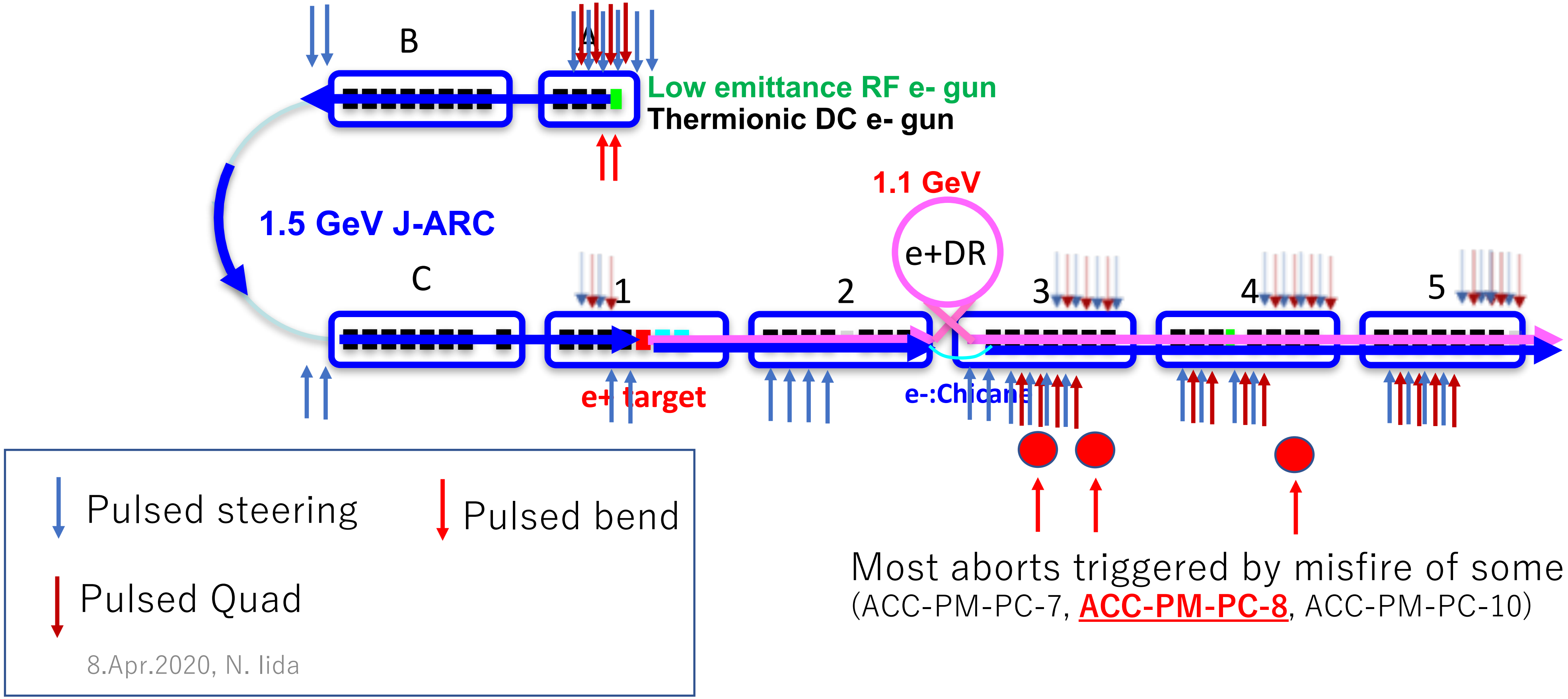


LINAC Pulsed magnetのmis-triggerによるAbort、BGによる入射停止の多発

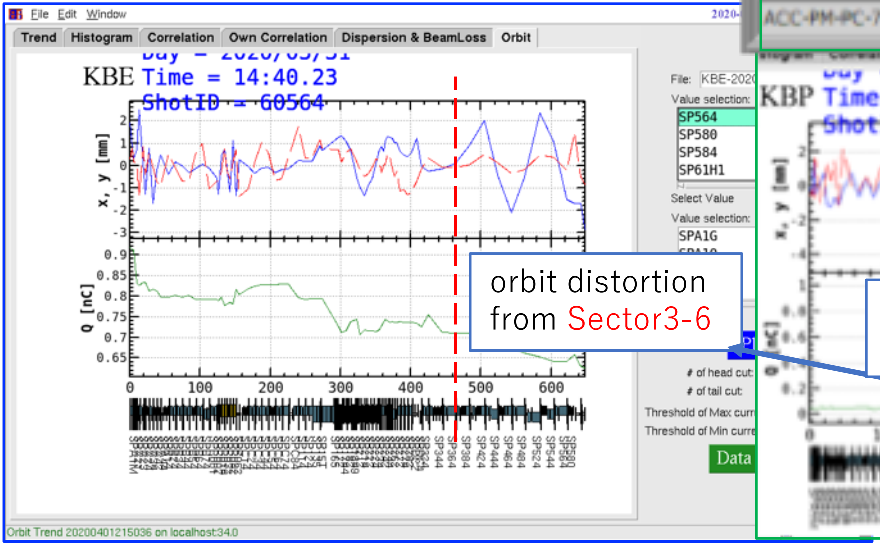


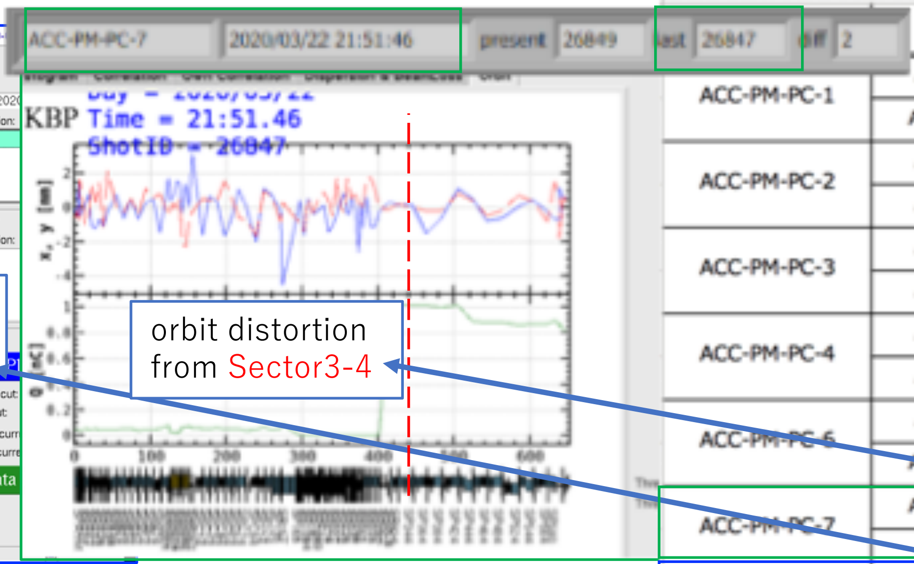
Many pulsed magnets (Oct. 2017～) (Y. Enomoto et al.)

- Pulsed Quad x46, Pulsed Steering x80 , Pulsed bend x 2
- PXIe based controller x 16
    - Windows 8.1 Pro./LabVIEW/MRF EVR230

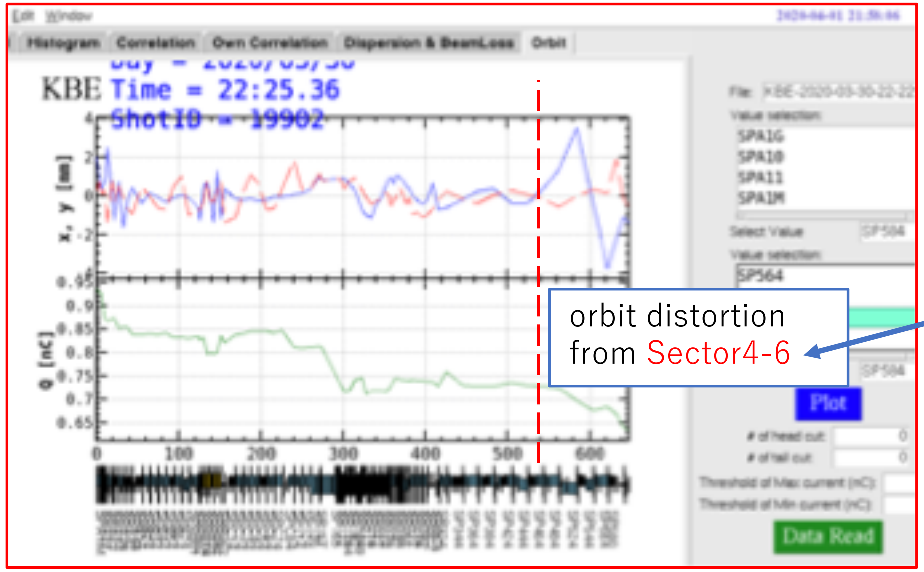


Most aborts triggered by misfire of some controllers.
(ACC-PM-PC-7, **ACC-PM-PC-8**, ACC-PM-PC-10)

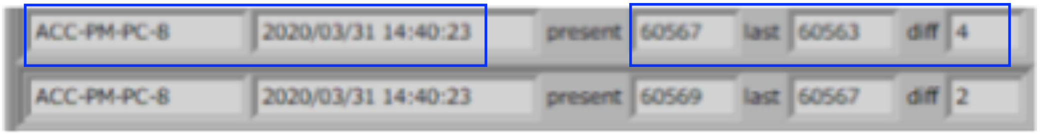


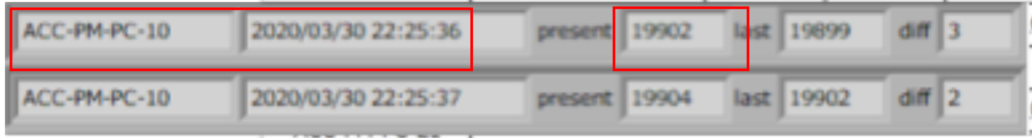


	cRIO	Pulse Magnet				セクター	場所
ACC-PM-PC-1	ACC-PM-CRIO-2	PF_13_5	PD_13_5	PX_13_5	PY_13_5	1 Sec	1-E 棟
	ACC-PM-CRIO-23			PX_13_2	PY_12_2		
ACC-PM-PC-2	ACC-PM-CRIO-3			PX_16_5	PY_16_5	1 Sec	1-D 棟
	ACC-PM-CRIO-4	PX_17_4	PY_17_4	PX_17_2	PY_17_2		
ACC-PM-PC-3	ACC-PM-CRIO-5			PX_18_2	PY_18_2	1 Sec	1-D 棟
	ACC-PM-CRIO-6			PX_18_4	PY_18_4		
ACC-PM-PC-4	ACC-PM-CRIO-7	PX_21_4	PY_21_4	PX_21_2	PY_21_2	2 Sec	2-E 棟
	ACC-PM-CRIO-8			PX_22_4	PY_22_4		
ACC-PM-PC-6	ACC-PM-CRIO-9	PF_DC_4	PD_DC_4	PX_DC_4	PY_DC_4	2 Sec	3-C 棟
	ACC-PM-CRIO-10	PF_32_4	PD_32_4	PX_32_4	PY_32_4	3 Sec	
ACC-PM-PC-7	ACC-PM-CRIO-11	PF_34_4	PD_34_4	PX_34_4	PY_34_4	3 Sec	3-A 棟
ACC-PM-PC-8	ACC-PM-CRIO-12	PF_36_4	PD_36_4	PX_36_4	PY_36_4	3 Sec	3-B 棟
	ACC-PM-CRIO-13	PF_38_4	PD_38_4	PX_38_4	PY_38_4		
ACC-PM-PC-9	ACC-PM-CRIO-14	PF_42_4	PD_42_4	PX_42_4	PY_42_4	4 Sec	4-A 棟
	ACC-PM-CRIO-15	PF_44_4	PD_44_4	PX_44_4	PY_44_4		
ACC-PM-PC-10	ACC-PM-CRIO-16	PF_46_4	PD_46_4	PX_46_4	PY_46_4	4 Sec	4-B 棟
	ACC-PM-CRIO-17	PF_48_4	PD_48_4	PX_48_4	PY_48_4		
ACC-PM-PC-11	ACC-PM-CRIO-18	PF_52_4	PD_52_4	PX_52_4	PY_52_4	5 Sec	5-A 棟
	ACC-PM-CRIO-19	PF_54_4	PD_54_4	PX_54_4	PY_54_4		
ACC-PM-PC-12	ACC-PM-CRIO-20	PF_56_4	PD_56_4	PX_56_4	PY_56_4	5 Sec	5-B 棟
	ACC-PM-CRIO-21	PF_58_4	PD_58_4	PX_58_4	PY_58_4		
ACC-PM-PC-13	ACC-PM-CRIO-1	PB_AT_J1	PB_AT_J5	PX_AT_22	PY_AT_22	A Sec	A-D 棟
	ACC-PM-CRIO-22	PF_A1_M	PD_A1_M	PX_A1_M	PY_A1_M		
ACC-PM-PC-15							1-E 棟
ACC-PM-PC-16	ACC-PM-CRIO-26	Test	Test	Test	Test		A-C 棟
	ACC-PM-CRIO-28	PF_A2_1	PD_A2_1	PX_A2_1	PY_A2_1	A Sec	
				63	PY_R0_63	R Sec	C-A 棟
				02	PY_R0_02	R Sec	B-B 棟



A mis-trigger was occurred at the time, called "Shot ID".

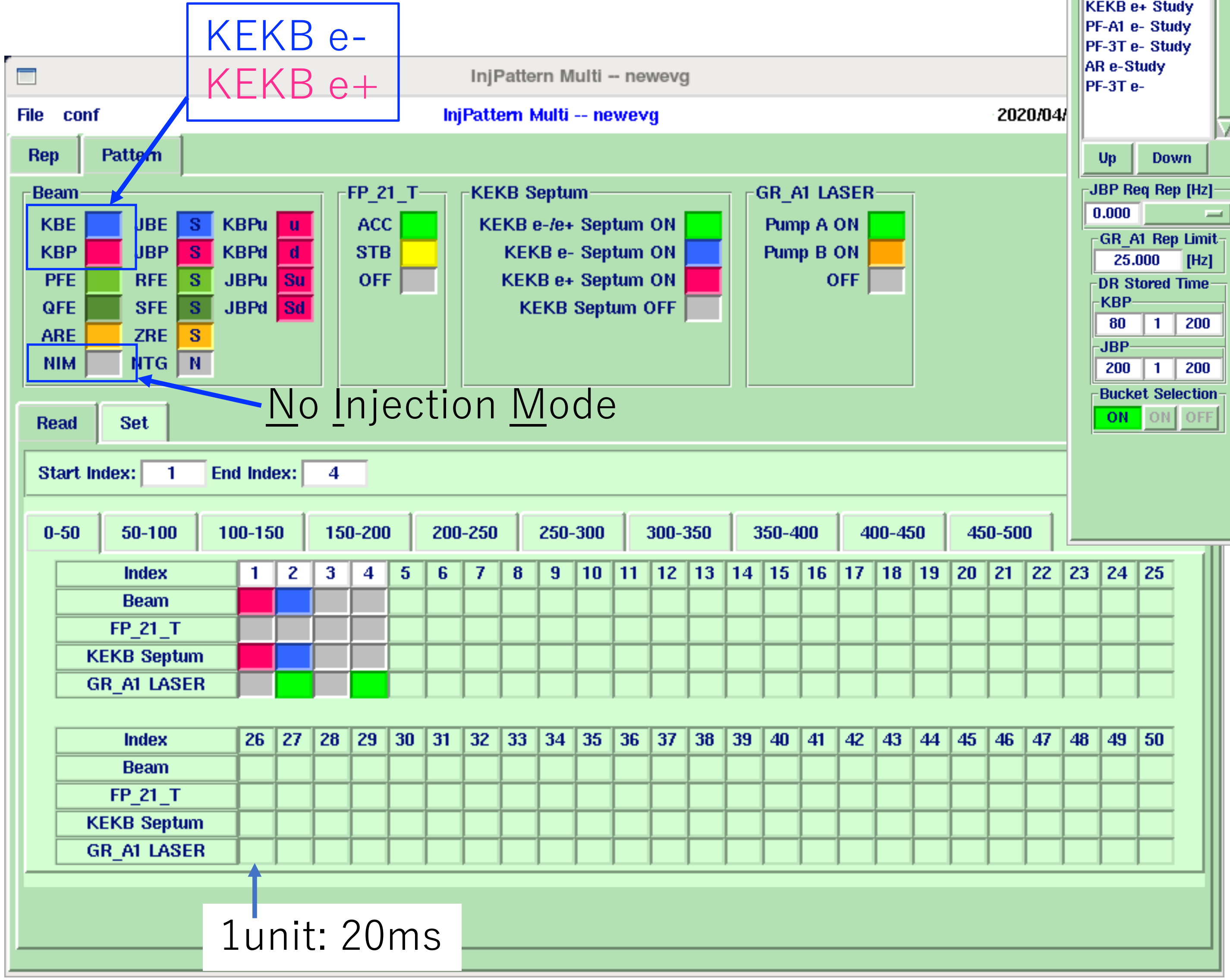


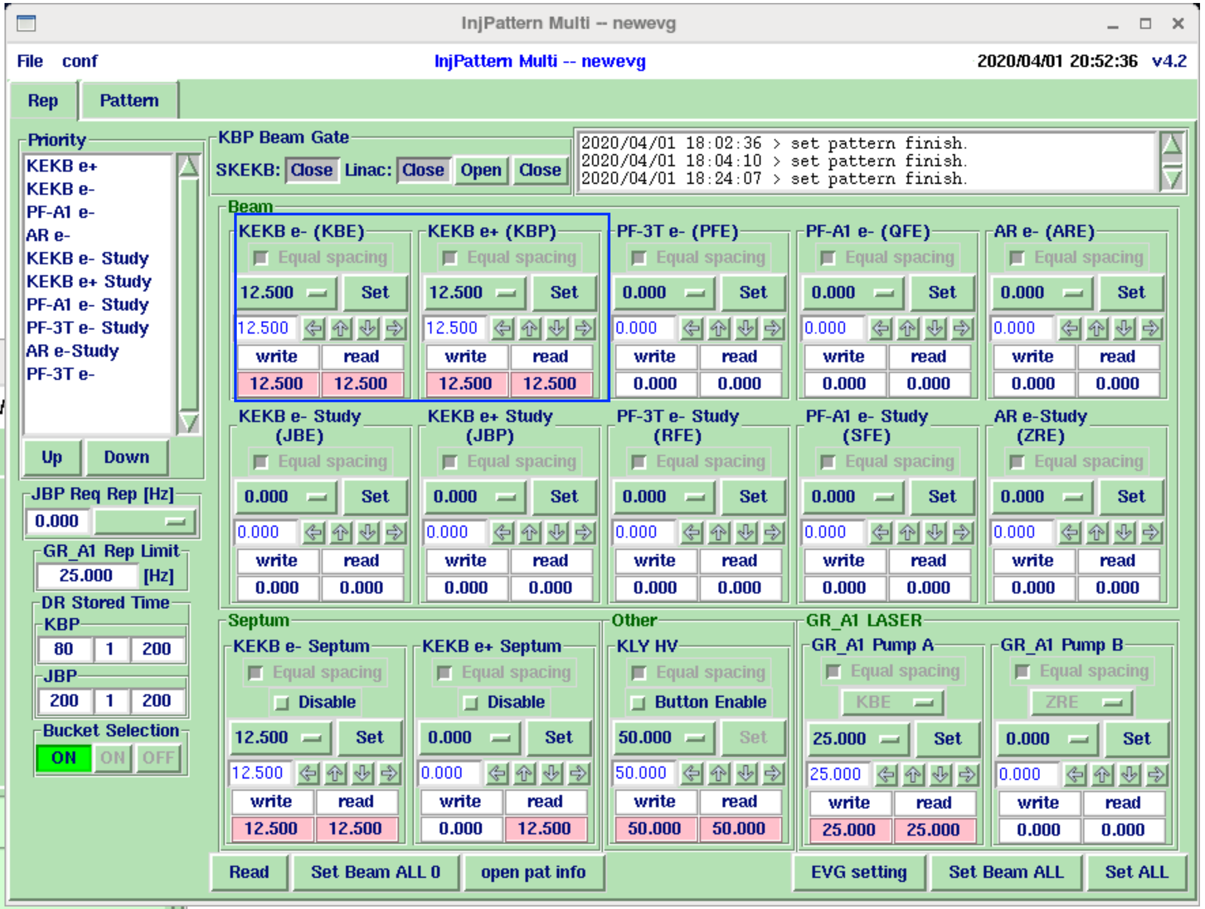


Injection pattern

Event system

example: 12.5Hz for both beam

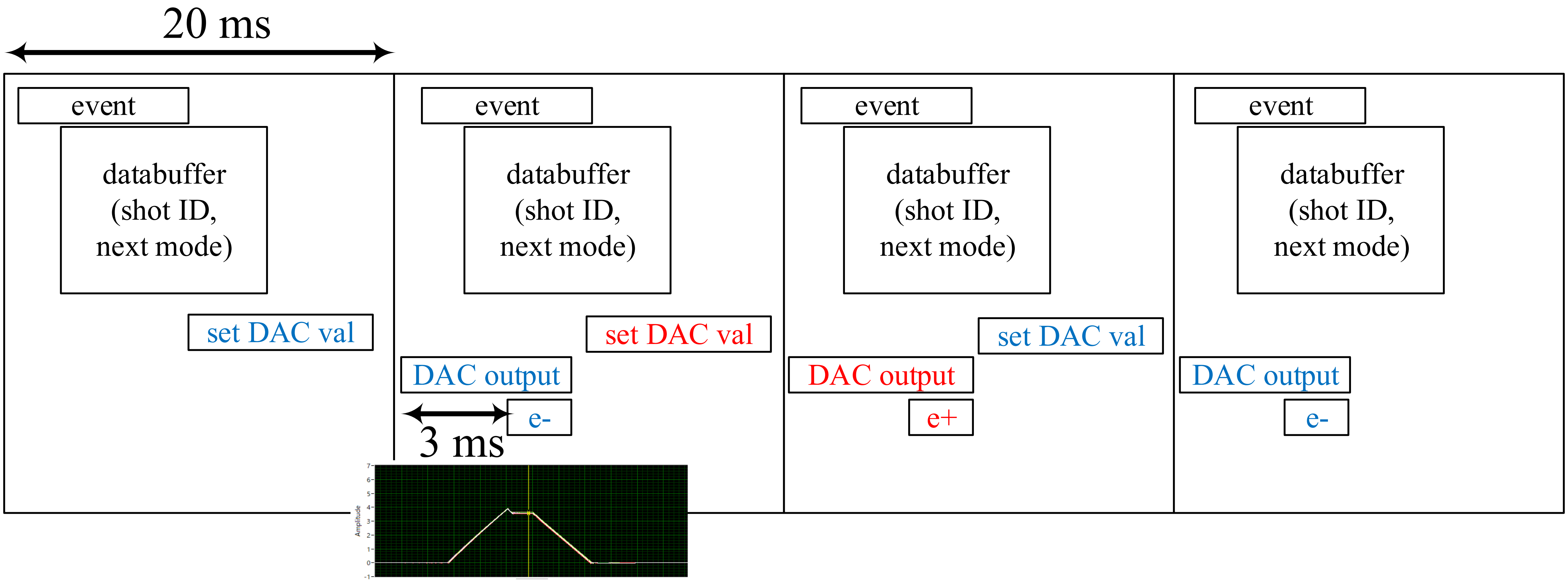




Operation sequence of pulsed magnet

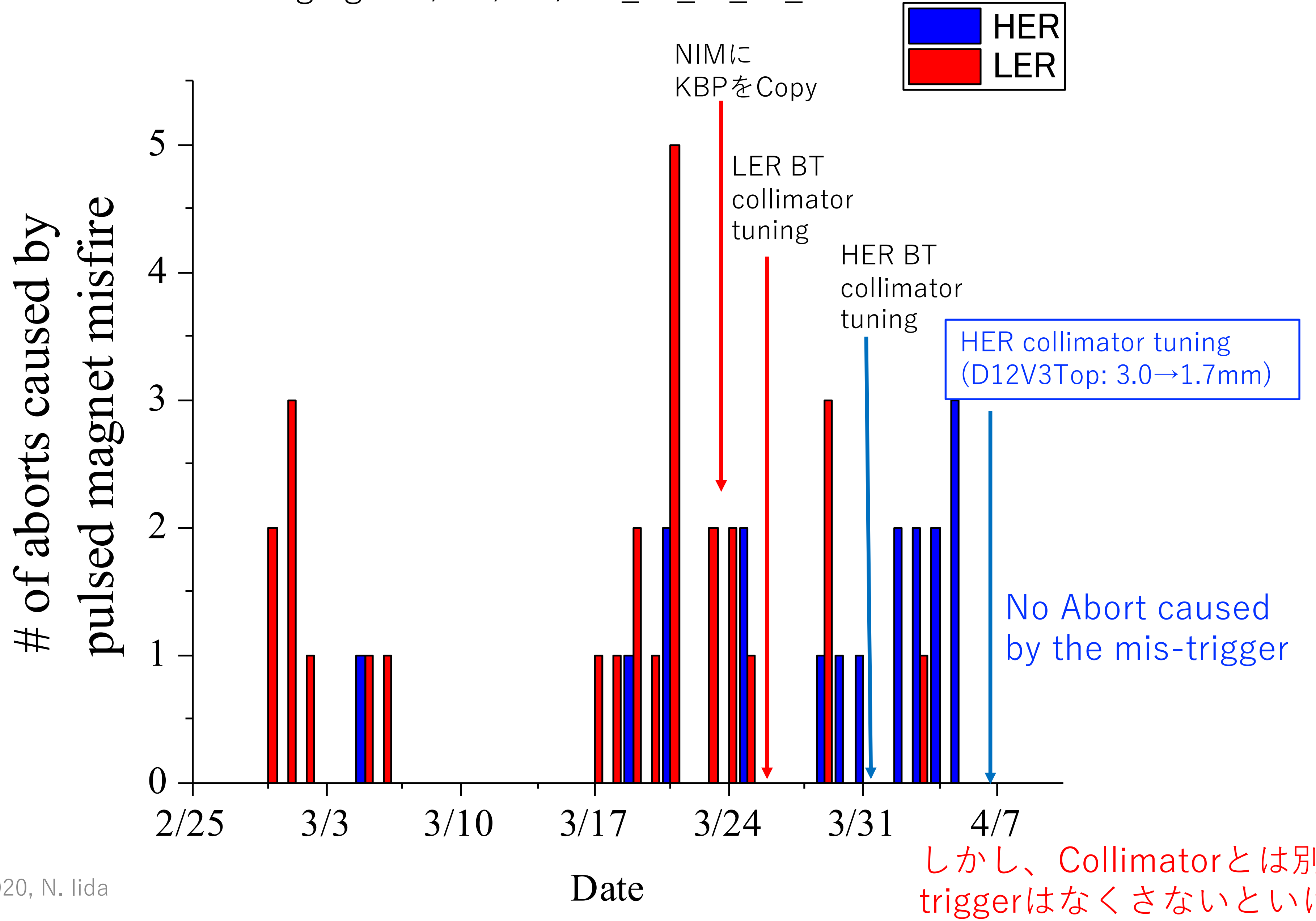
M. Satoh

- In some events, (what's happening is not clear)
  - DAC value setting is delayed or failed. DAC is not trigger waiting mode.
  - Trigger is delayed or missing.
- It could cause bad beam orbit and eventually MR beam abort.



Most cases were caused by misfire of ACC-PM-PC-8 controller managing “PF/PX/PY/PD_36_4-_38_4”.

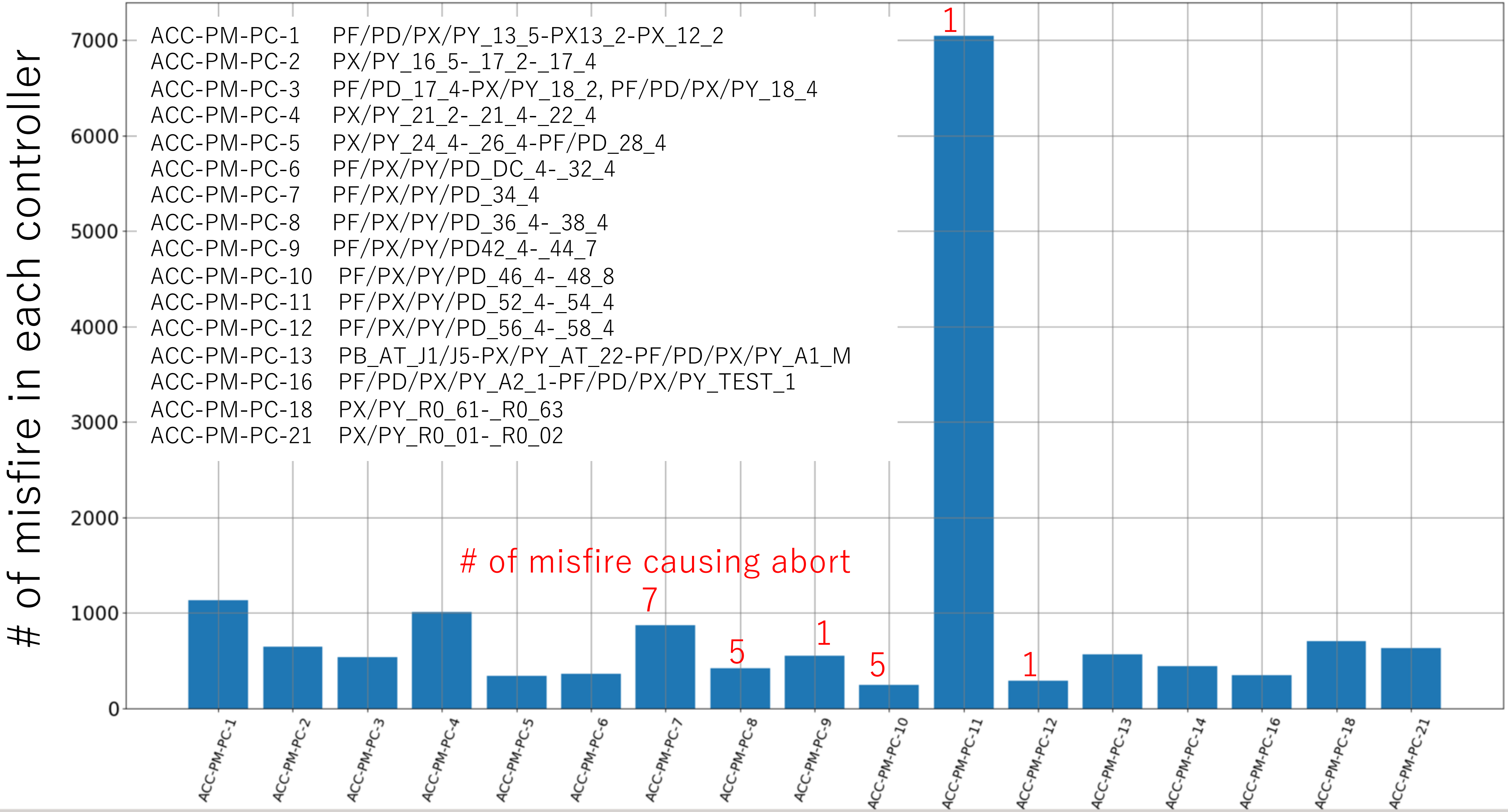
M. Satoh
2020.4.8 10:00現在



しかし、Collimatorとは別にmis-triggerはなくさないといけない。

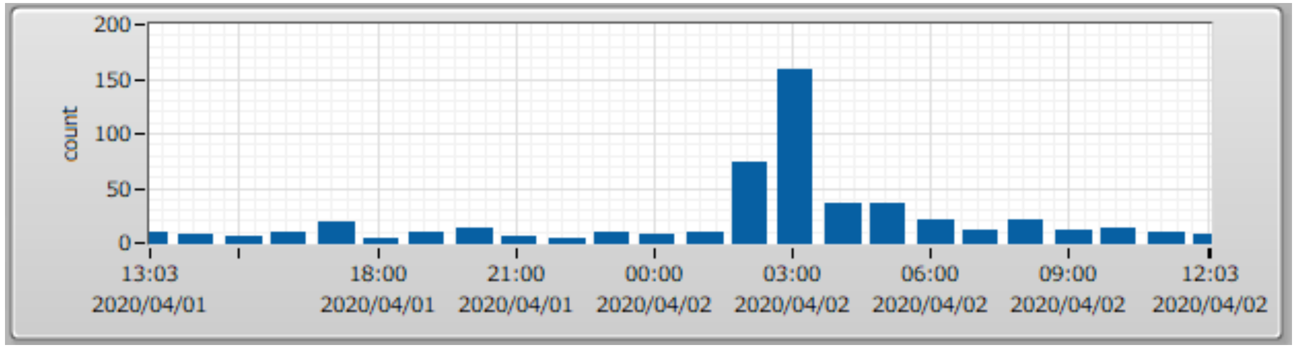
Pulsed magnet misfire events: 2/29 – 3/31
(17/day/controller in average)

M. Satoh

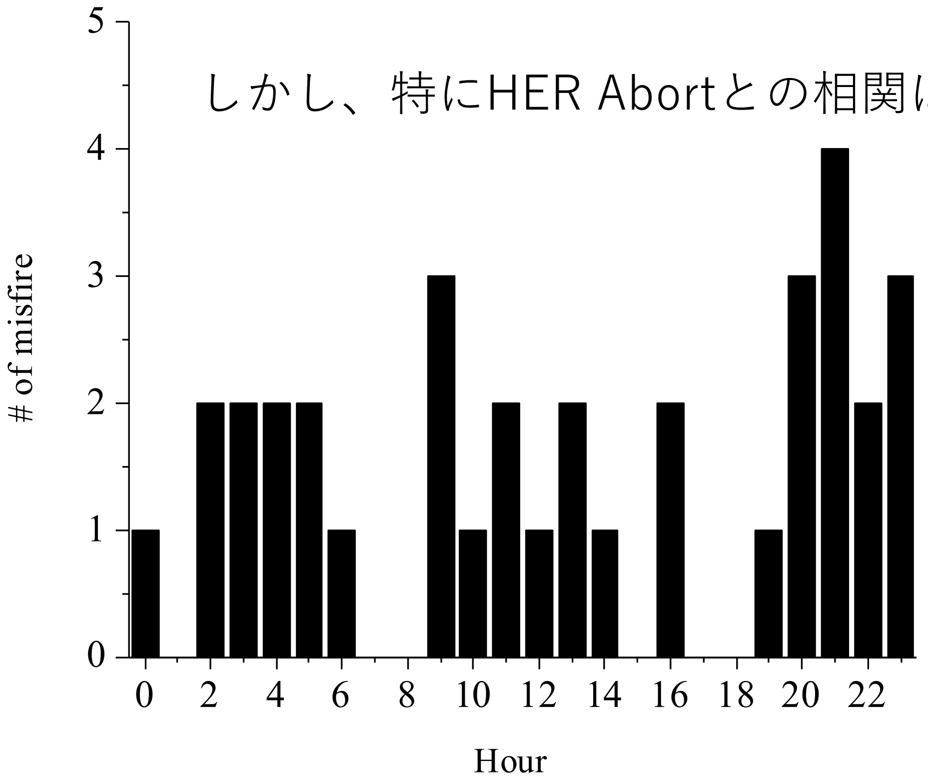


M. Satoh

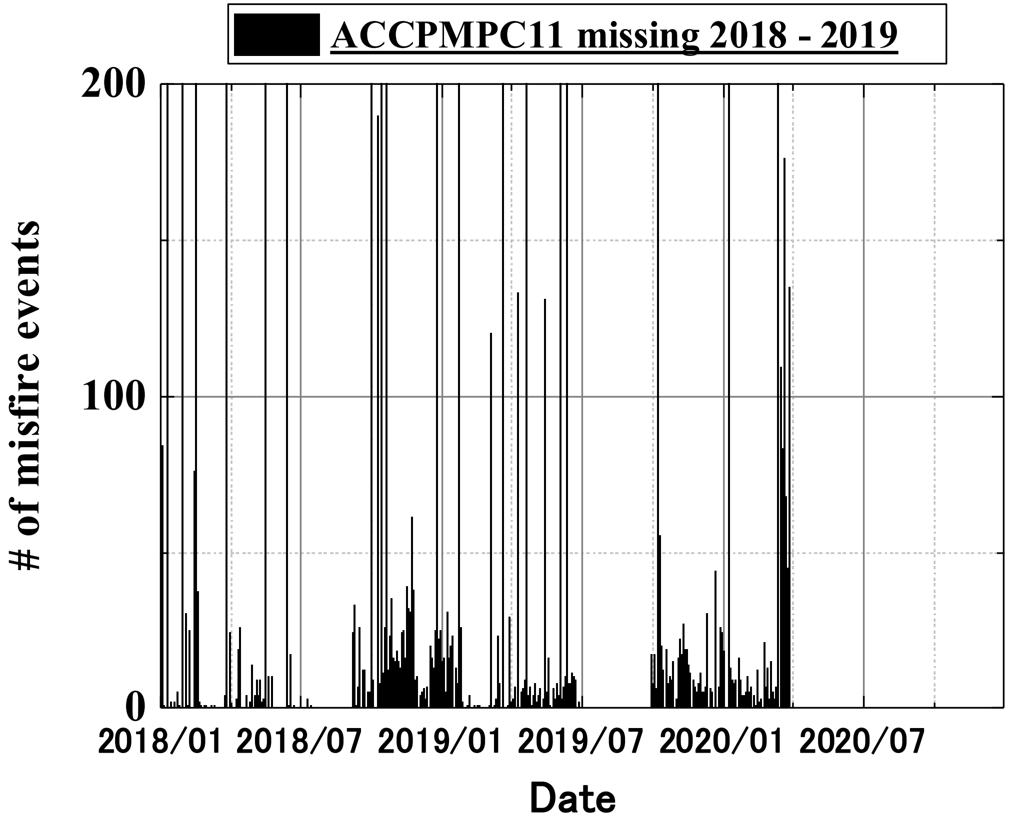
3:00頃にmis-triggerが多発している



しかし、特にHER Abortとの相関はない。

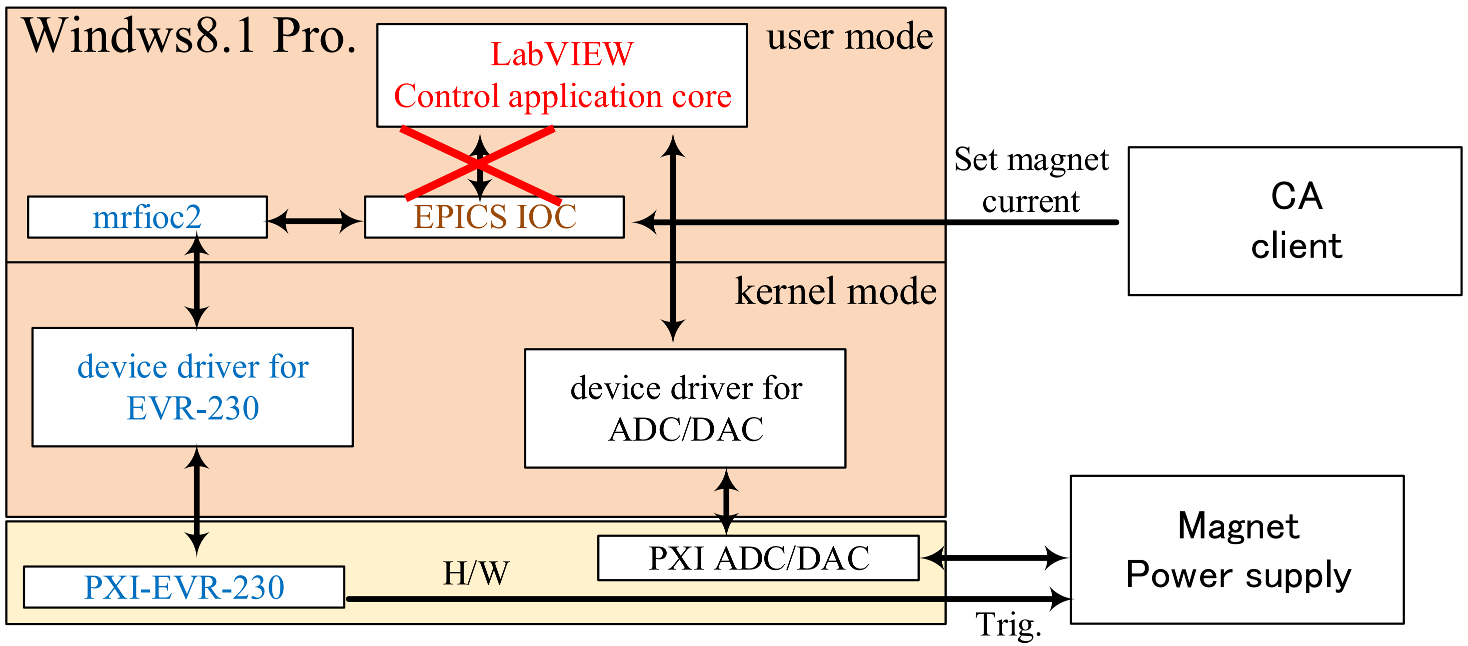


2018年には、mis-triggerはほとんどなかった。



M. Satoh

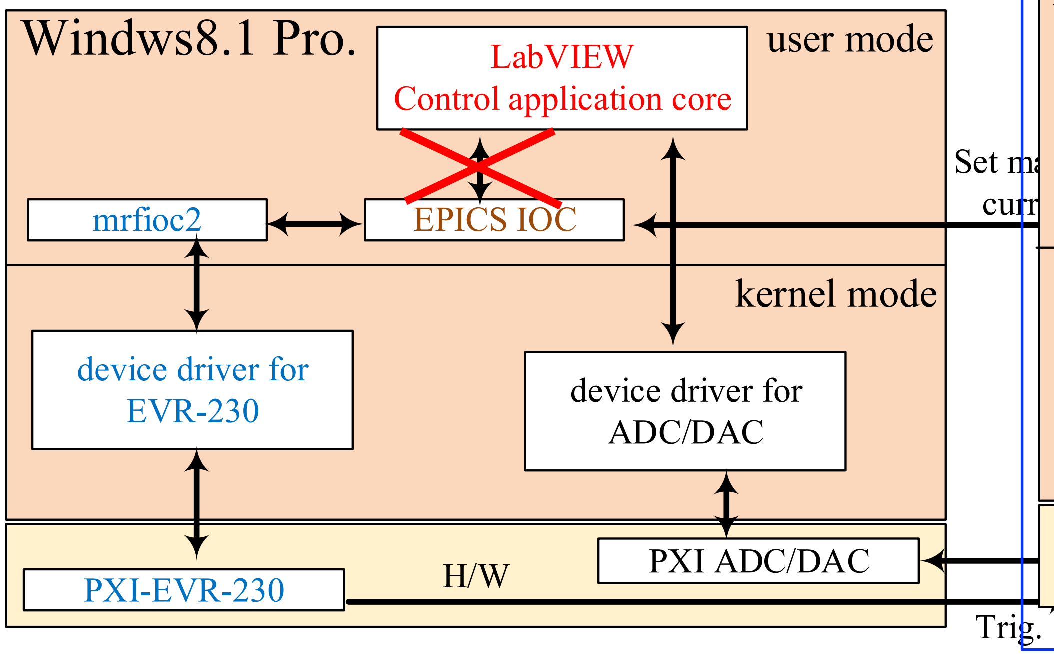
Current software structure



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

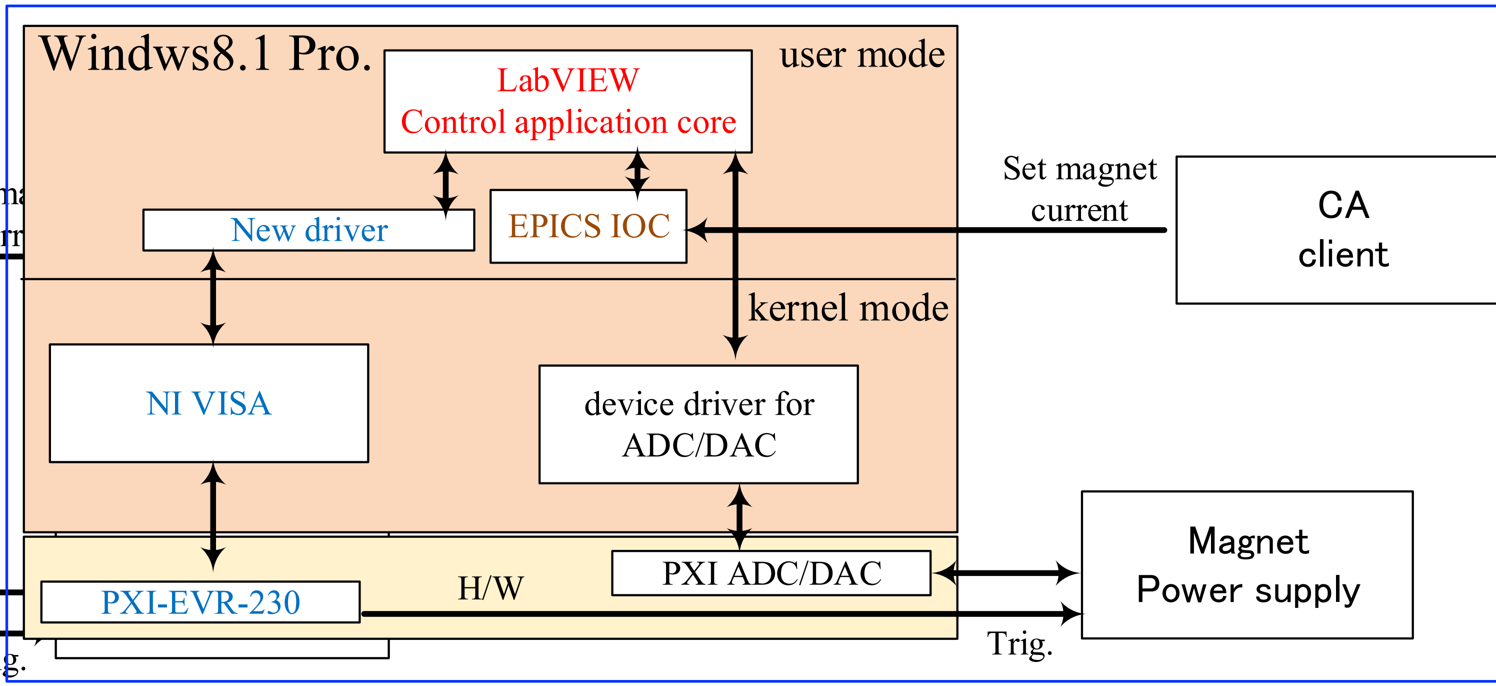
M. Satoh

Current software structure



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

New software structure under developement



NI VISA based EVR driver (under development) is currently promising candidate.
(w/o EPICS IOC for EVR control)

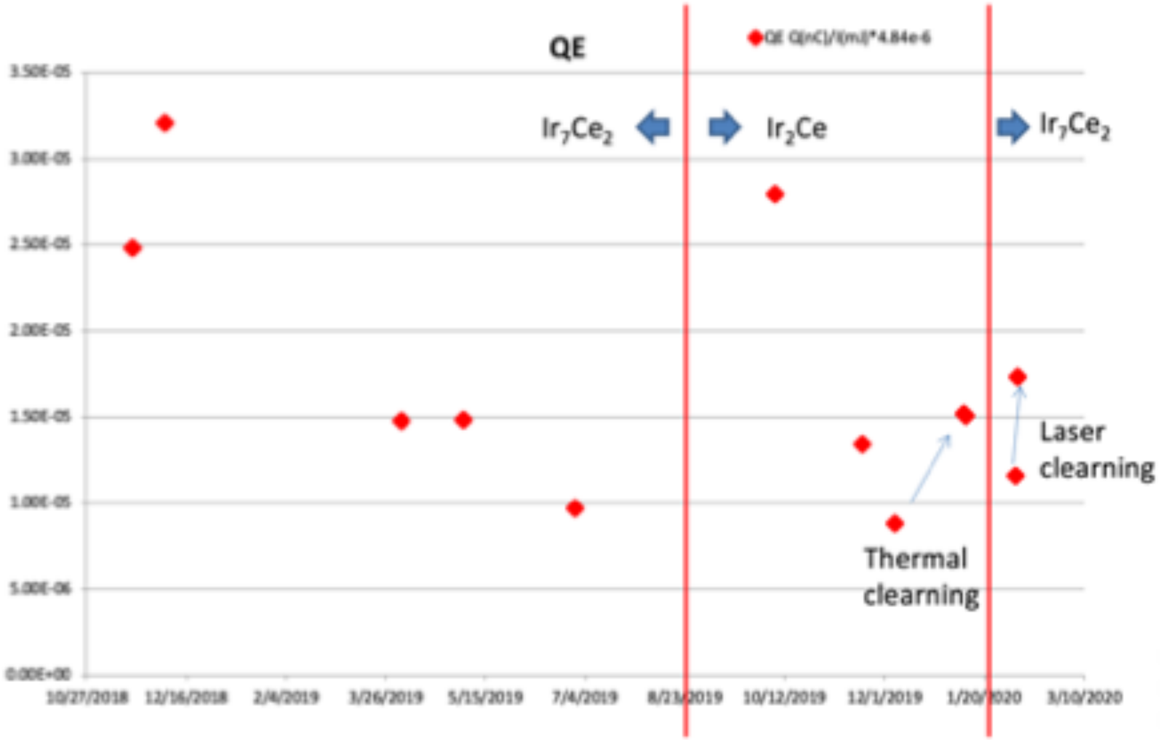
4/9(木)メンテ日、置き換え作業予定。
万が一ダメだった場合でも2時間で戻せる。

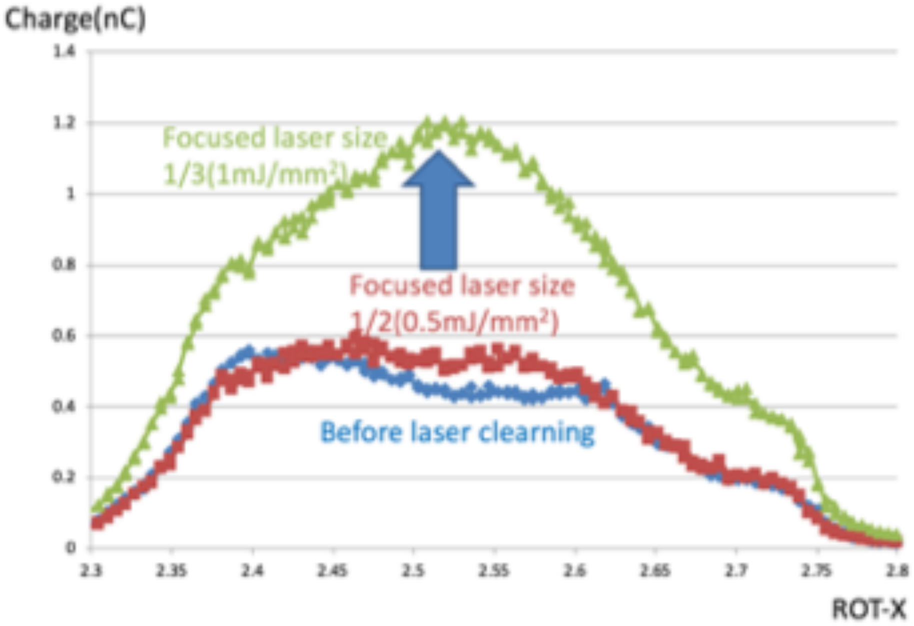
Electron beam (RF gun)

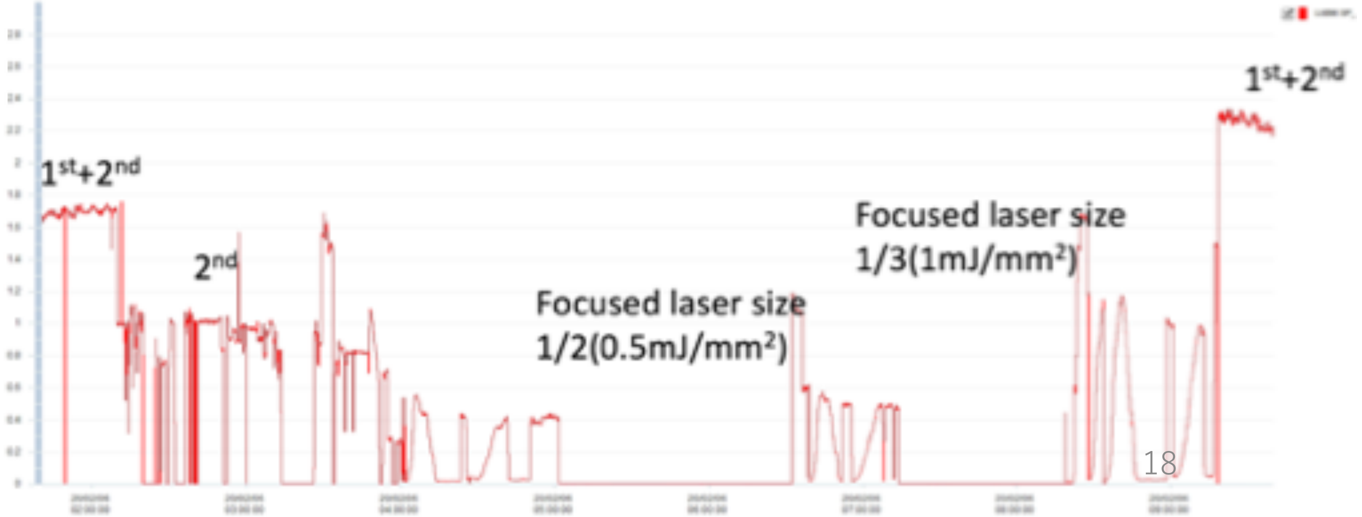
M .Yoshida

RF gun Cathodeの交換前後の量子効率

Laser cleaningの効果

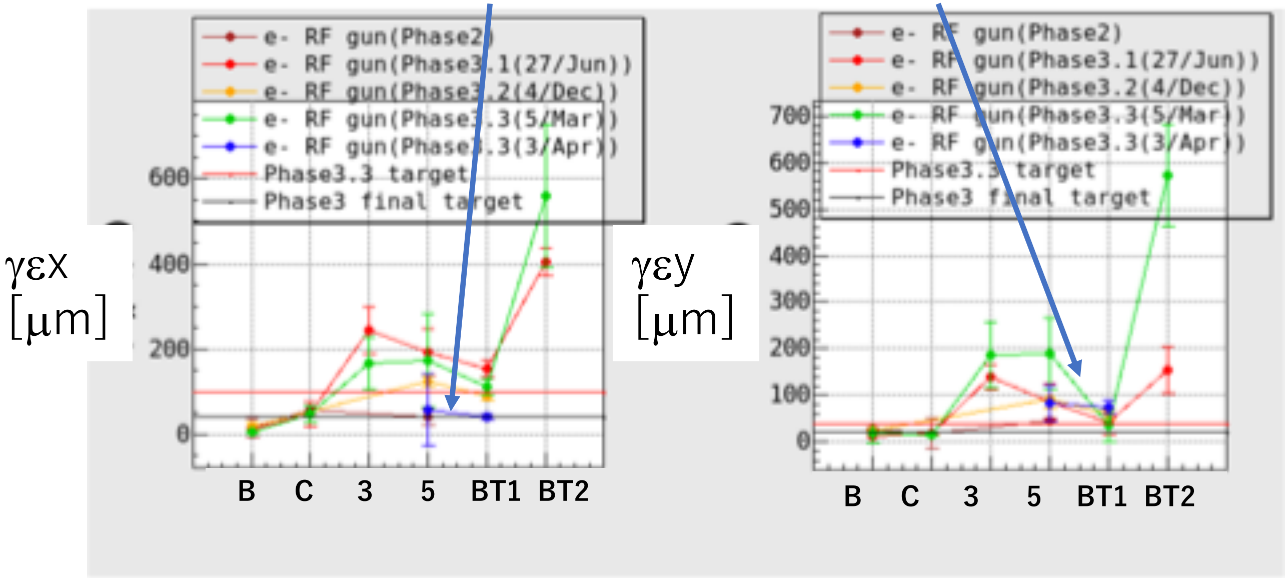






Measured Emittance

e- beam (Phase3.3(2020/4.3))



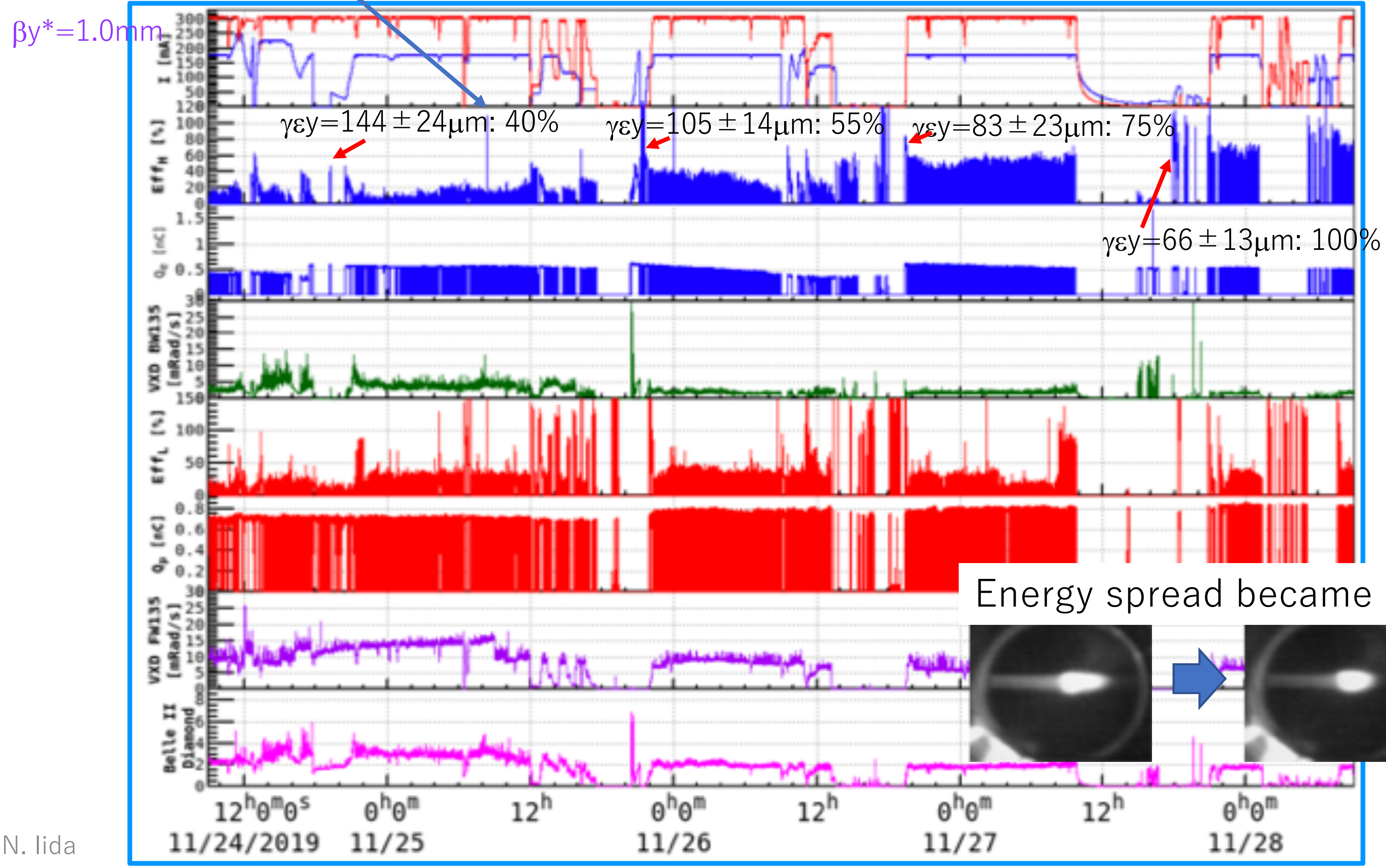
Phase3.3	e+	e-
$\gamma\varepsilon_x$ [μm]	150	100
$\gamma\varepsilon_y$ [μm]	30	40
σ_δ [%]	0.16(1σ)	0.1(1σ)

1. Injection efficiency and background

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

Phase3.2
2019c(Autumn)

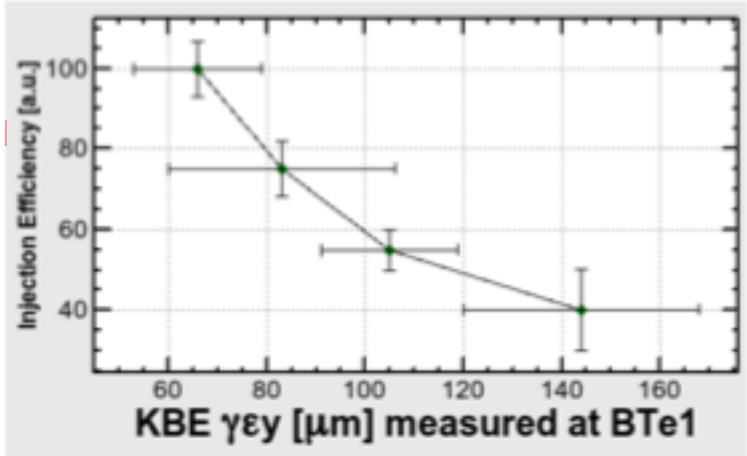
These efficiencies are calculated at the low current beam in the HER.
→ The effect of Touschek lifetime can be neglected.

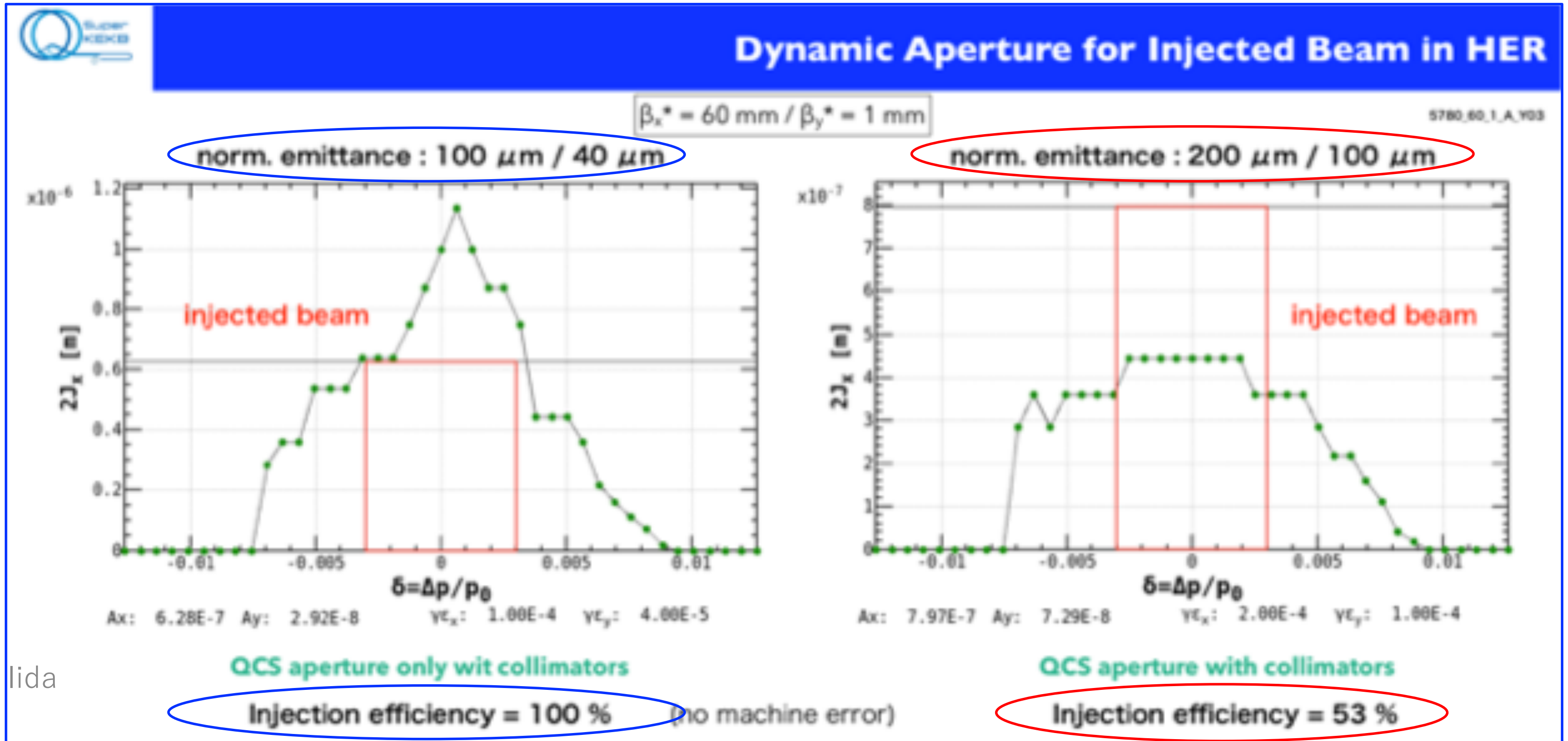


Energy spread became better

Vertical emittance vs. HER Injection efficiency

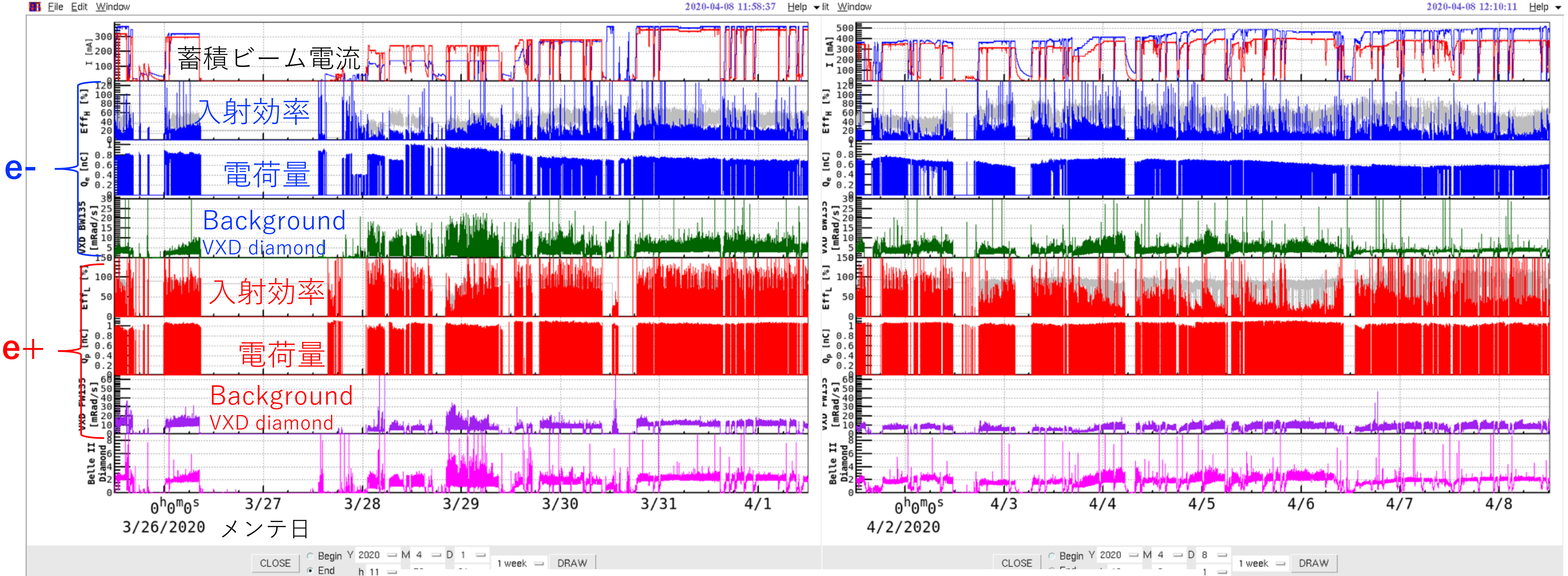
How keep ?
How to stablize laser





Y. Ohnishi

入射まとめ（二週間）

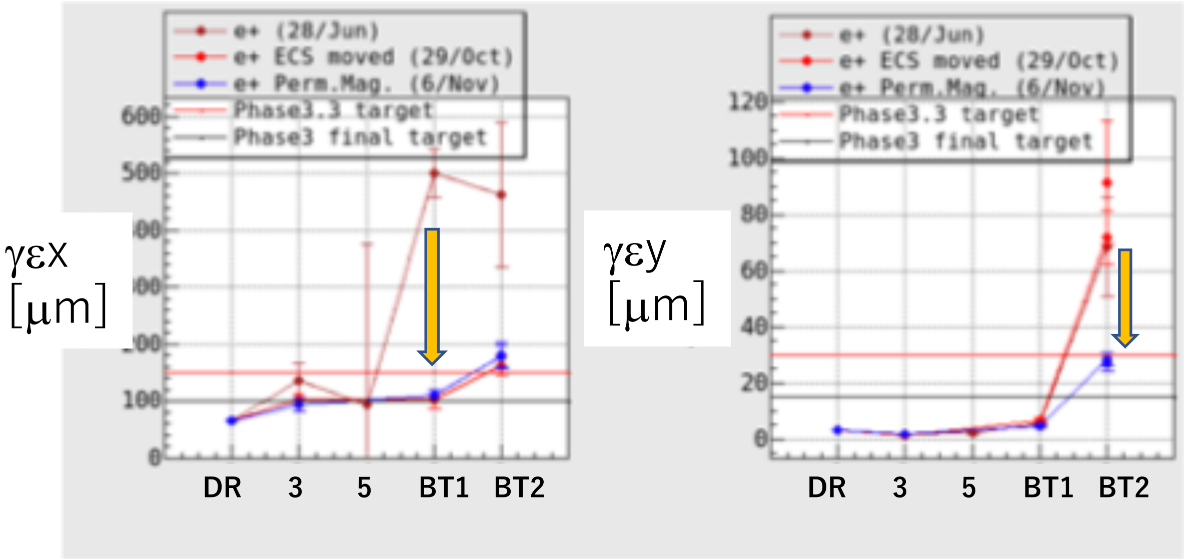


e- 電荷量が徐々に減っている。
蓄積ビーム電流が高くなるにつれて、入射効率が下がる。
今のBackgroundは比較的良好。

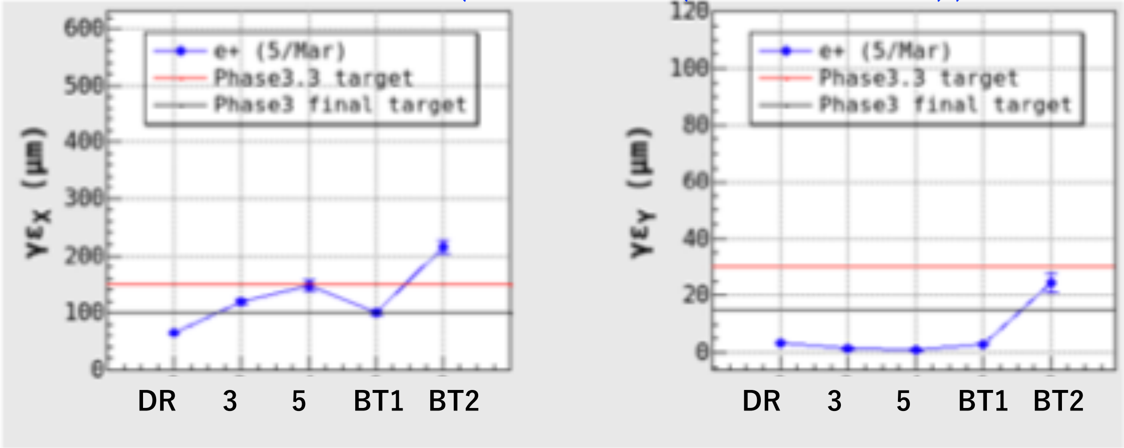
Positron beam

Measured Emittance

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



e+ beam (Phase3.3(5.Mar.2020))

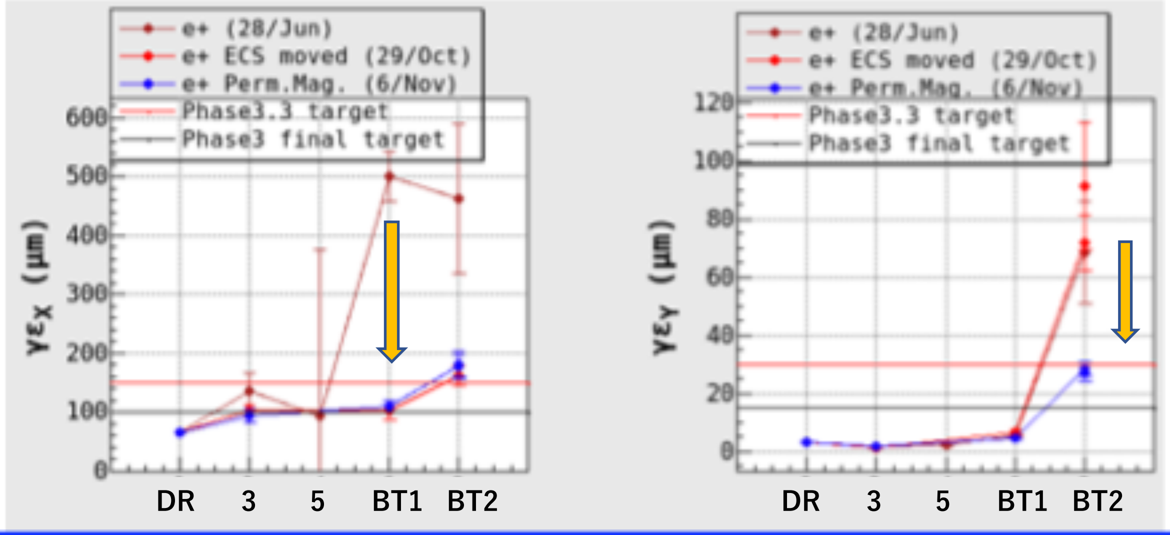


SuperKEKBからの要求値

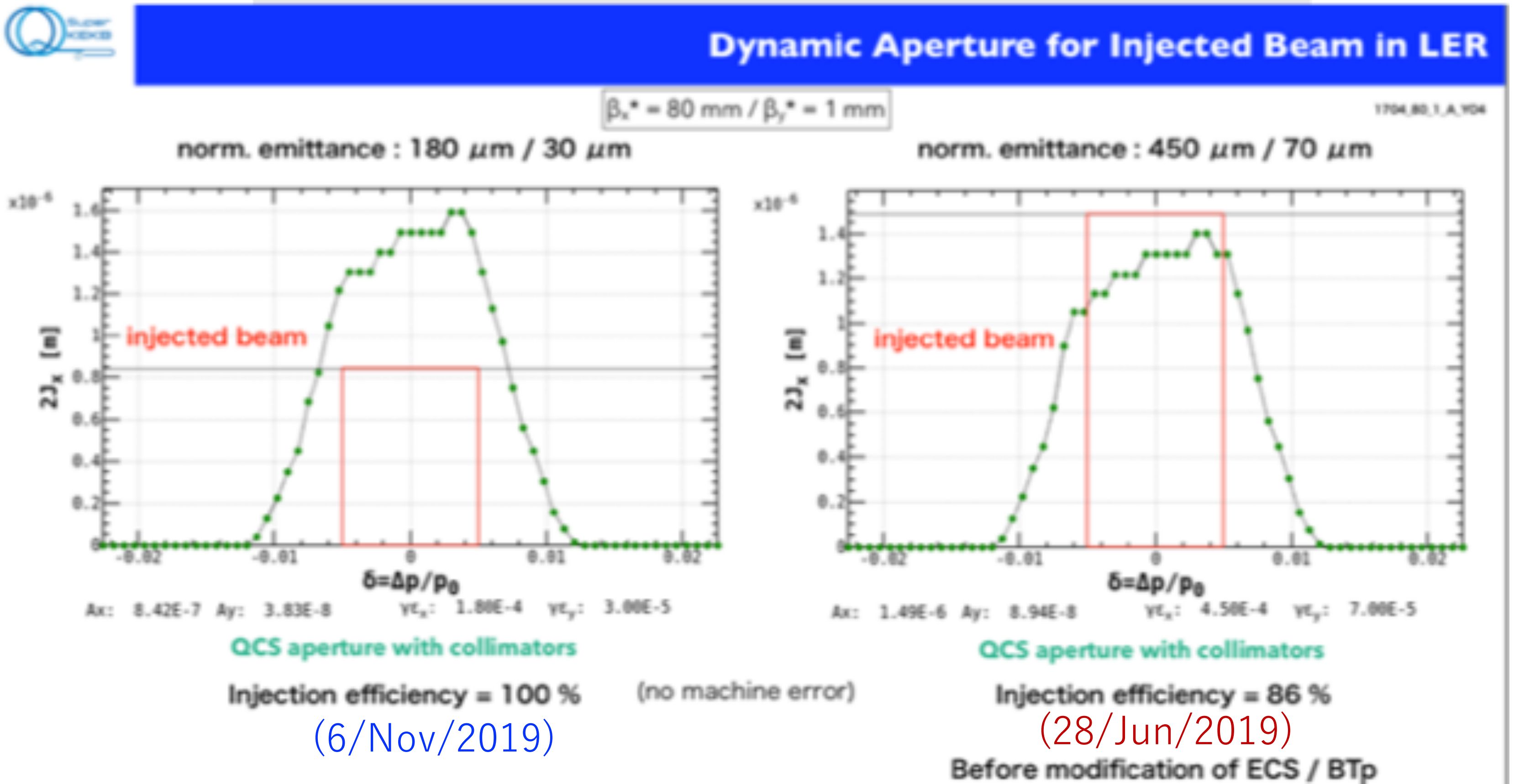
Phase3.3	e+	e-
γεx [μm]	150	100
γεy [μm]	30	40
σδ [%]	0.16(1σ)	0.1(1σ)

LER入射

ECS/SY3 Bendの磁場一様性の良い場所を、ビームが通過するようにBendを移動させた。（約10mm）

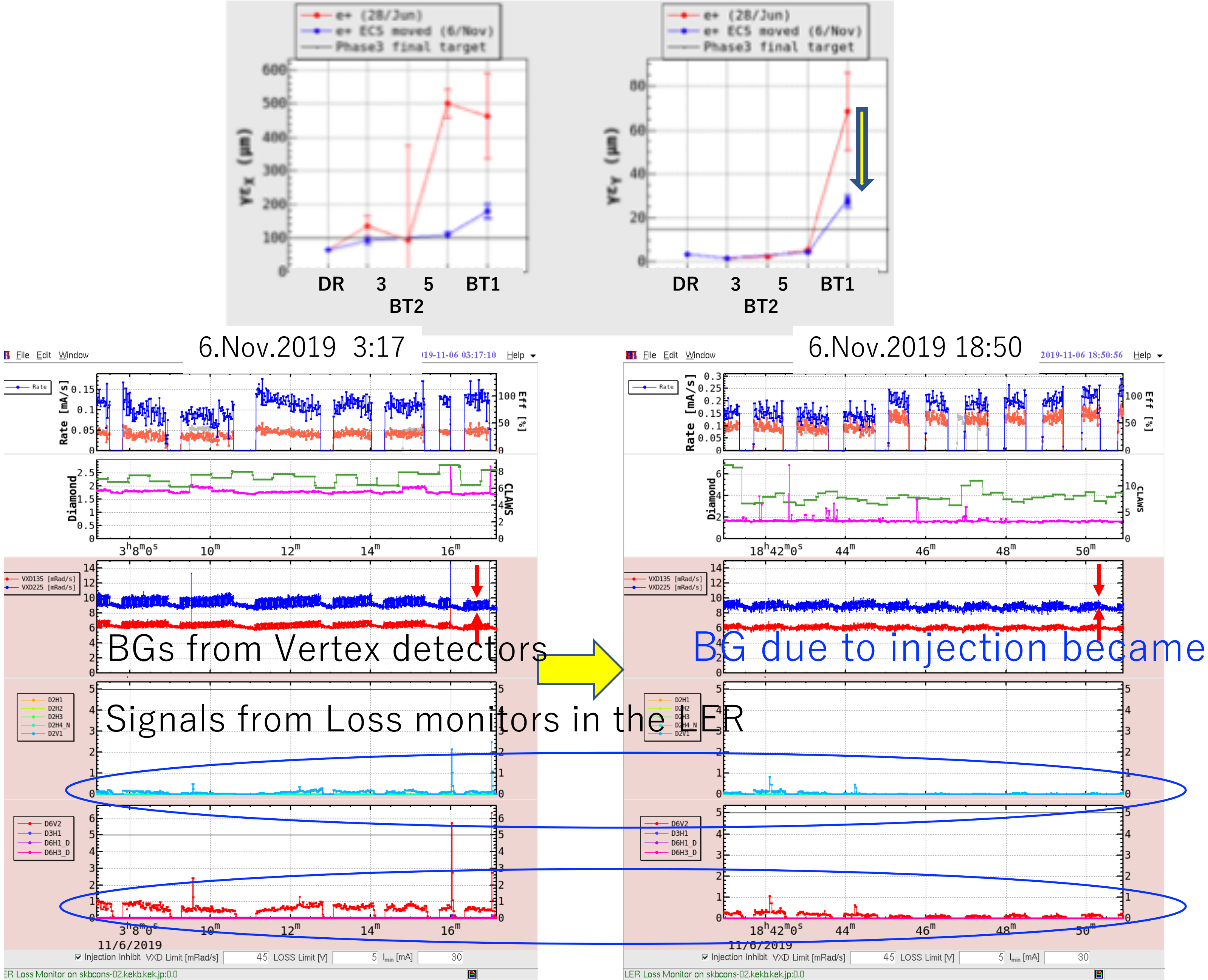


BT 第2-3アークのBendのSkew Quad成分をキャンセルする永久磁石を取り付けた。



Y. Ohnishi

・LER When the vertical emittance was improved,



BGs from Vertex detectors

Signals from Loss monitors in the LER

BG due to injection became smaller.

その他も含めたまとめ

- 改良点
  - e+入射ビームのエミッタンス改善（SY3/ECS Bend移動、永久磁石のSkew quadを、BTアーク部にInstallation）
  - e- 量子効率の電荷量依存性（レーザークリーニングが有効）
  - ２バンチ入射最適化（ECS、BCSの加速管HV Timing調整）
  - RF位相変動の緩和
    - Es下げた
    - DeQing trigger unit
  - Operationで、生の入射効率表示
- 問題点
  - パルスマグネットのmis-trigerによるAbort
  - さらなるEmittance増大の解消

Pulse shortening

T. Miura

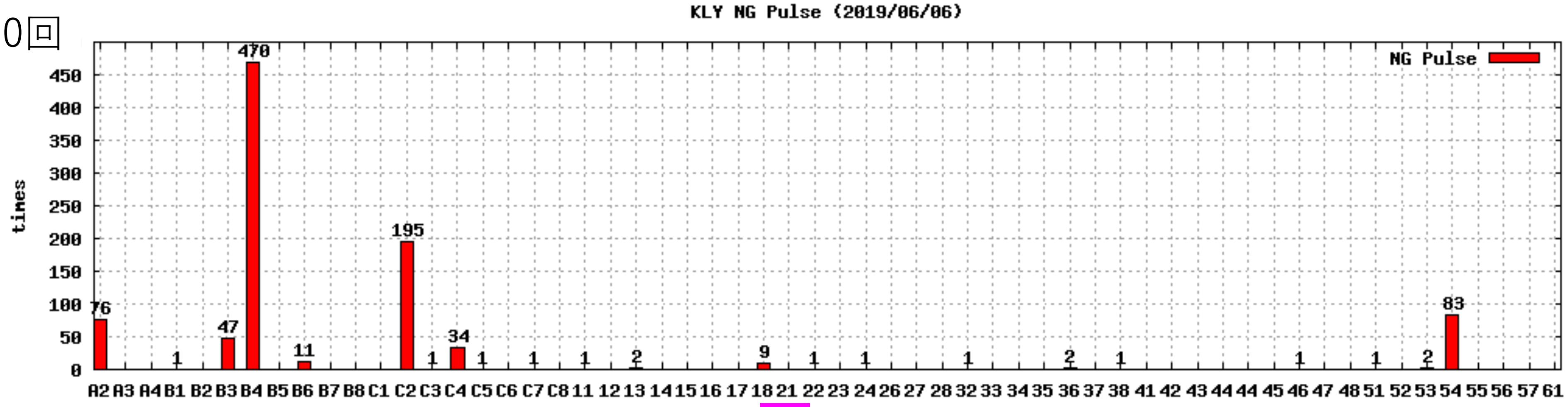
@2020,Jan

- KL_A2 Es: 42→40kV
- KL_B3 Es: 42→40kV
- KL_B4 Es: 42→38kV
- KL_C2 Es: 42→40kV
- KL_C4 Es: 42→40kV
- KL_54 Es:42kV → 38 kV

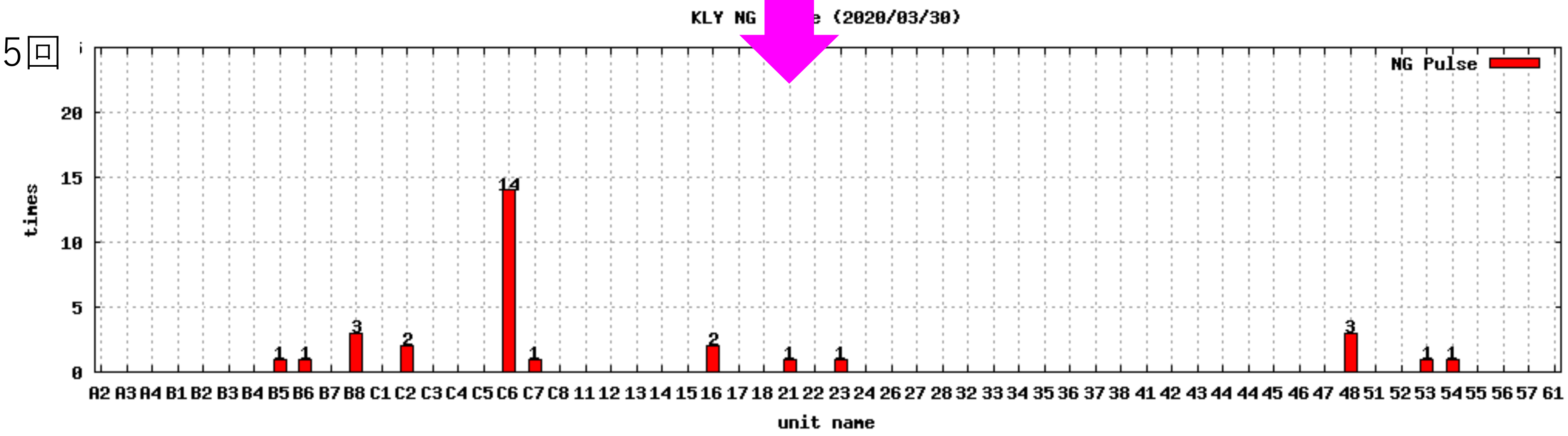
頻度の高い箇所の高圧を下げた。

1 Day Summary

500回



25回

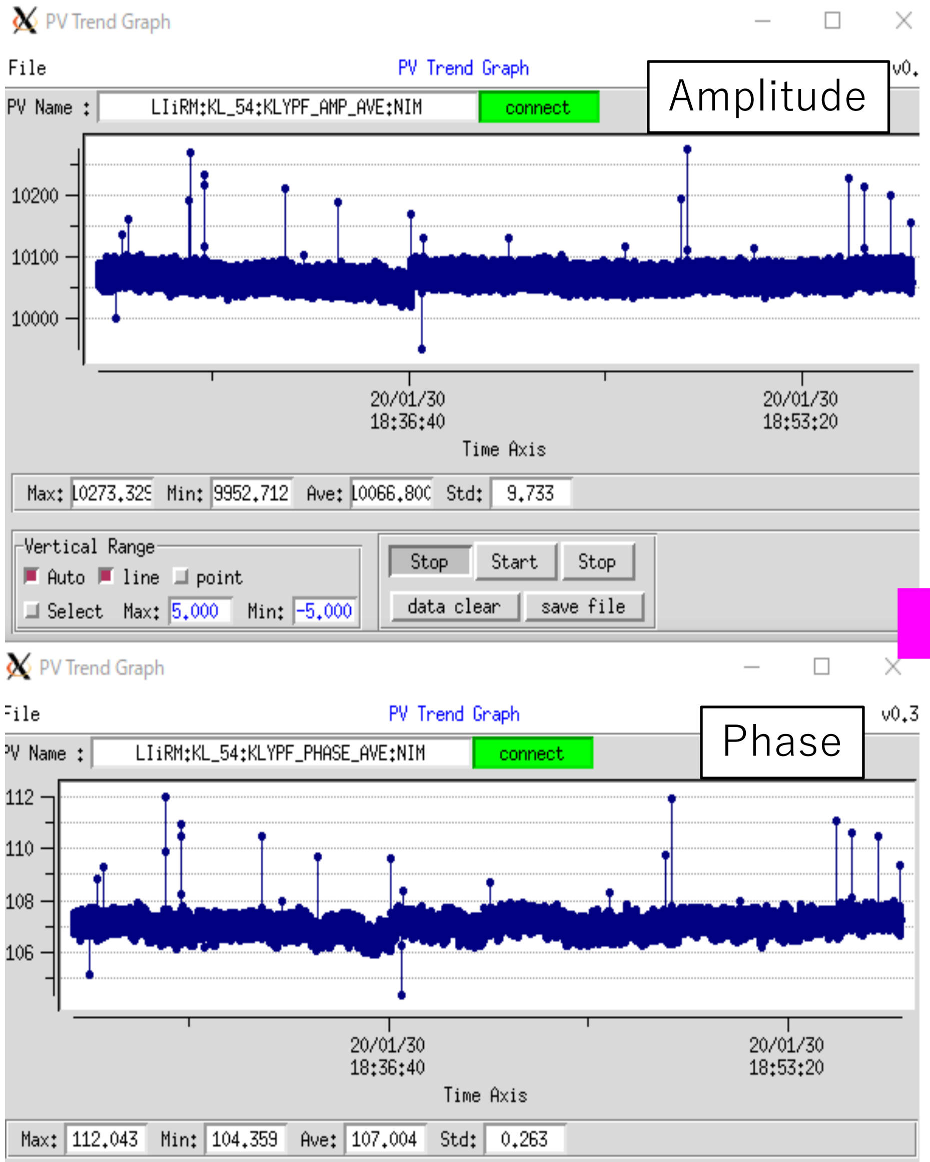


Improvement of DeQing Trigger Unit

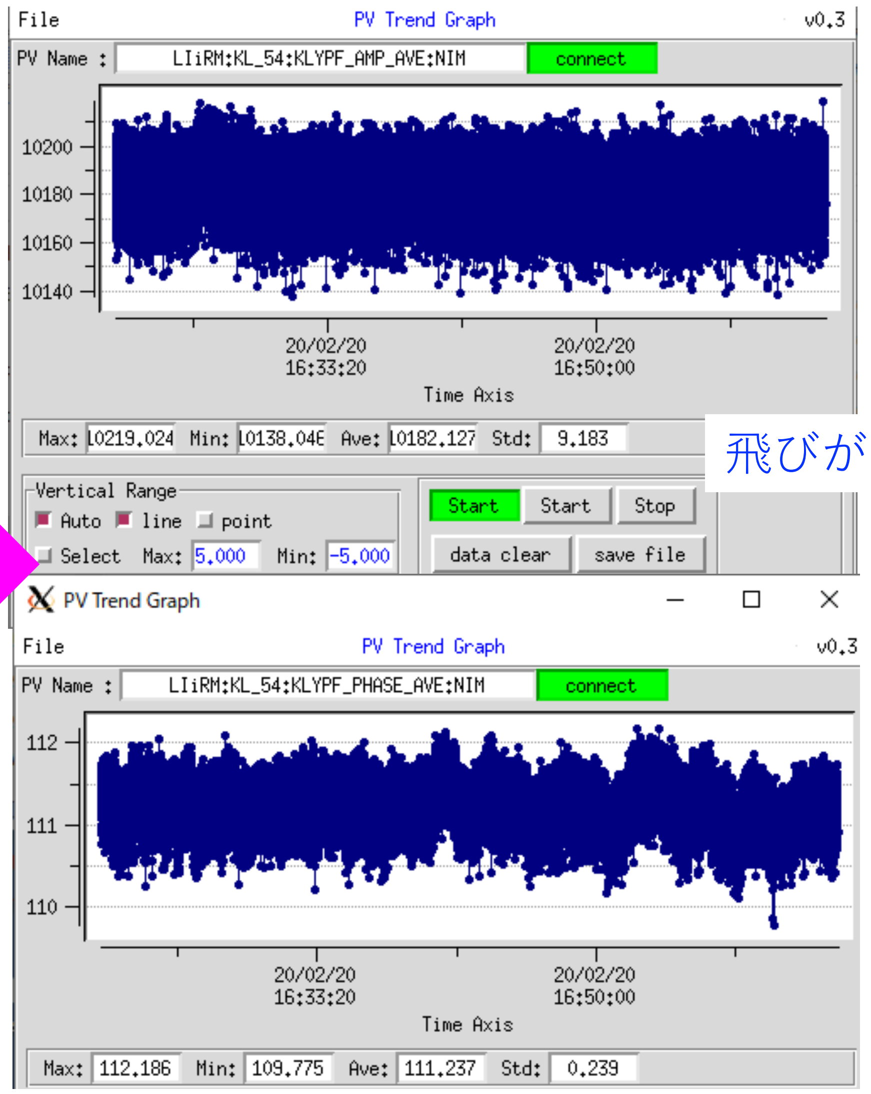
T. Miura

Esの設定値をアナログレベル信号で受信しているが、受信タイミングをノイズの影響がないところに同期させることで改善

共振充電電源の箇所で振幅・位相にトビが見られた



21ヶ所対応@3/12
A2,A3,B5,B6,B7,35,41,42,43,45,46,
47,48,51,52,53,54,55,56,57,61



飛びがなくなった！

LINAC、BT改造

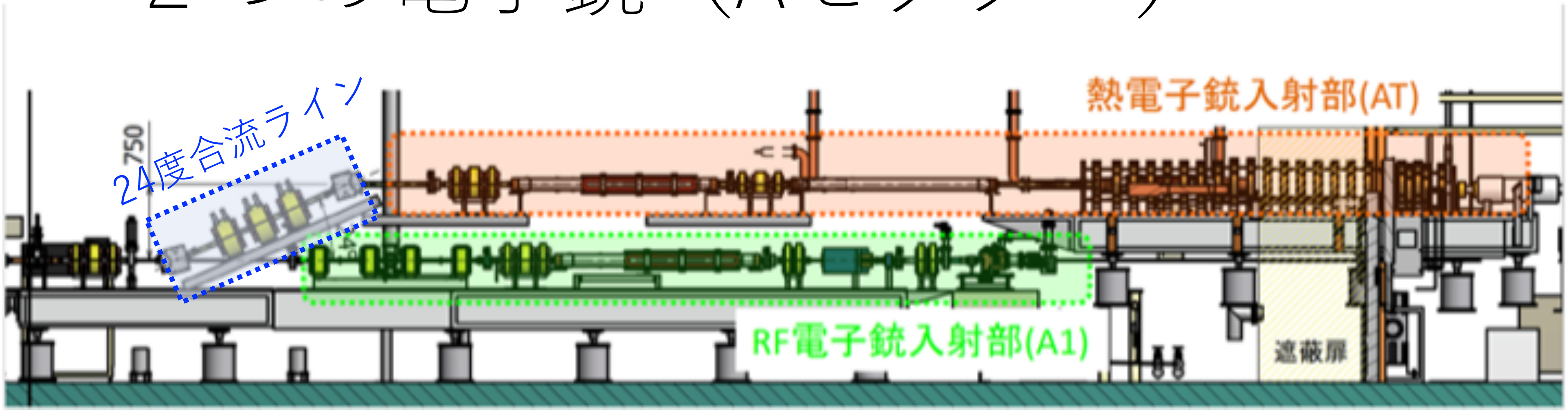
- 2020年夏の作業
  - 熱電子銃とRF電子銃のMerger lineのPulsed bendの50Hz化
  - 加速管４本(4_4)/12本(3年計画)/230本
  - FC入れ替え（放電しにくくなる）
  - Positron capture section改造（BPM, Steeringのインストール）

  - Collimator増設（Energy cut用：SY3/ECS Chicane、e-BT）
  - BT BPM（一部）を、リベラへの置き換えによるLINACとの同期、高速化
  - BT Screen monitor（一部）高性能化
- 長期的な改造
  - パルスマグネット増設
  - ２バンチ目だけキックする高速Pulsed steering

Backup slides

T. Kamitani

２つの電子銃（Aセクター）

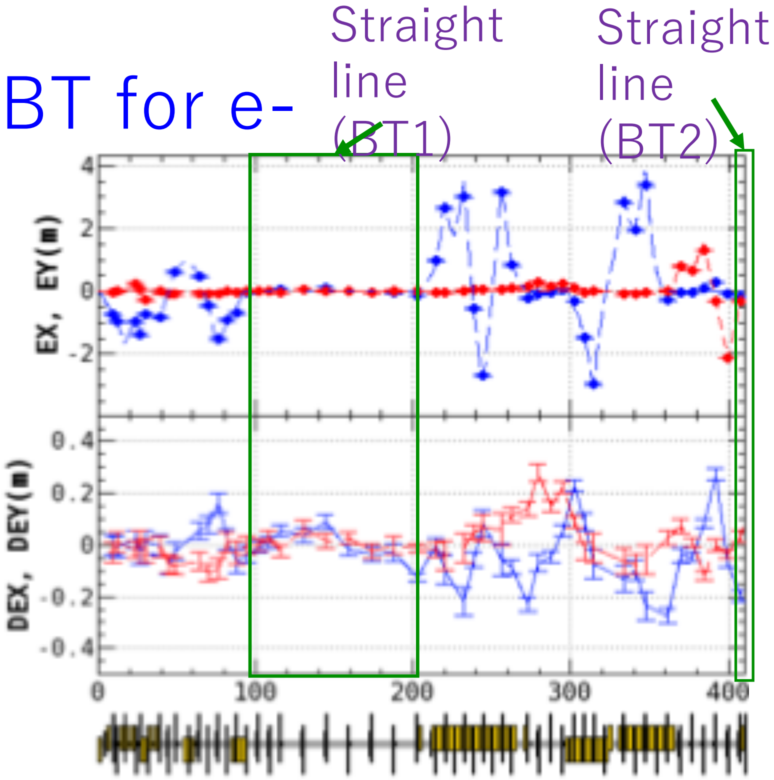


- 熱電子銃
  - LER, PF, PF-AR (, HER)
  - 熱電子銃
  - SHB1(114MHz)
  - SHB2(571MHz)
  - Pre-buncher
  - Buncher
  - 加速管(2mx2本)
- RF電子銃
  - HER
  - 0-deg QTW RF gun
  - 90-deg CDS RF gun
  - Bunch Compress System(BCS)
  - 加速管(2mx1本)
- 24度合流ライン
  - BendのChamber発熱により、DC Bend（5~10秒切り替え）に戻した。30秒切替で運転（安全システムによる30秒待ち）。
  - Phase3からPulse-to-pulse運転予定

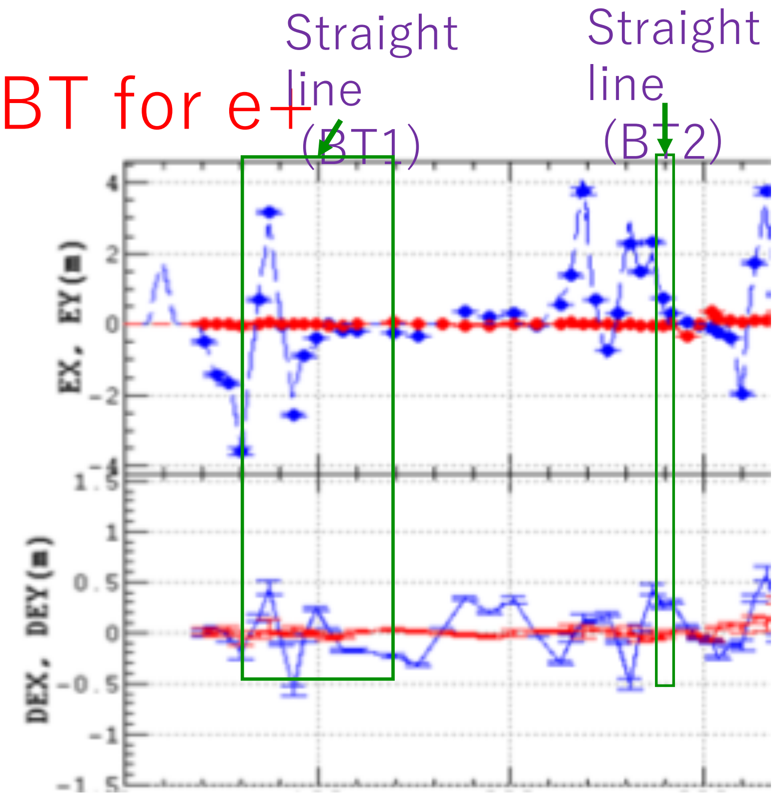
A) Residual Dispersion in the BT line

- The dispersions have been corrected for each BT ARC one by one.
- After that dispersion of the BT overall was measured changing the beam energy.
- Non-negligible residual dispersion is still observed.
- We should minimize Δη and Δη’ at the end of BT.

BT for e-



BT for e+

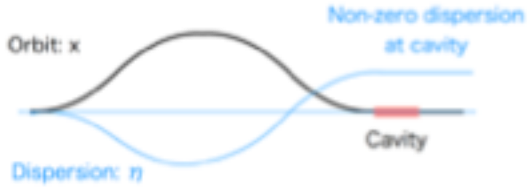


Y. Seimiya

b. Residual dispersion at the acceleration structure for a compression system

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

M. Kikuchi



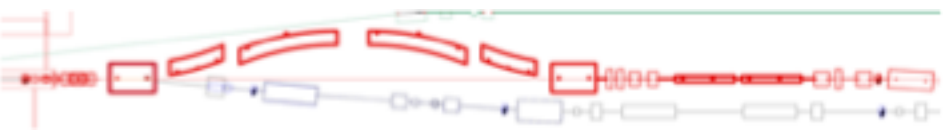
If the cavity has non-zero dispersion, a beam, gaining its energy depending on z, has net growth in the projected-emittance.
This is an analogue of the synchro-beta excitation at the cavity with non-zero dispersion in the ring.

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

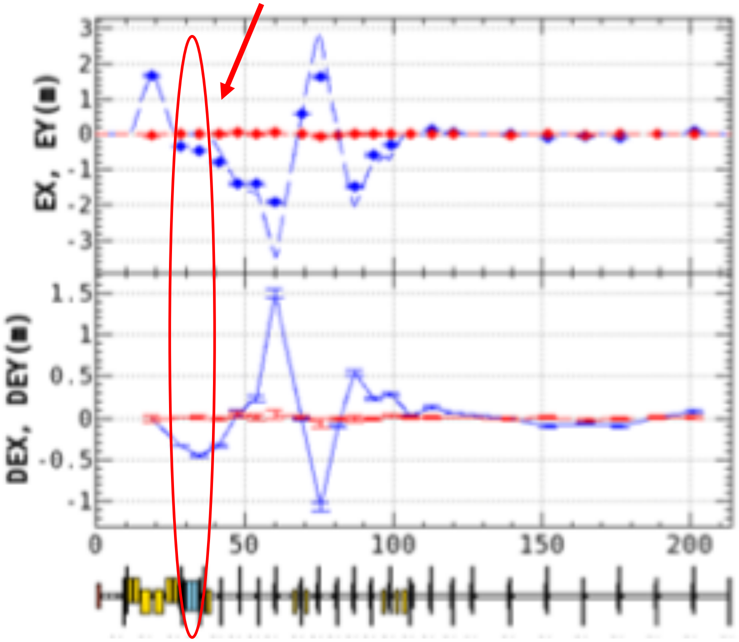
$$u = -vz \qquad v = \frac{eV}{E_0}\frac{\omega_{rf}}{c}$$

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

ECS: Chicane+Acc



Measured dispersion from ECS at the end of LINAC.
The dispersion is leak at the ECS cavity.



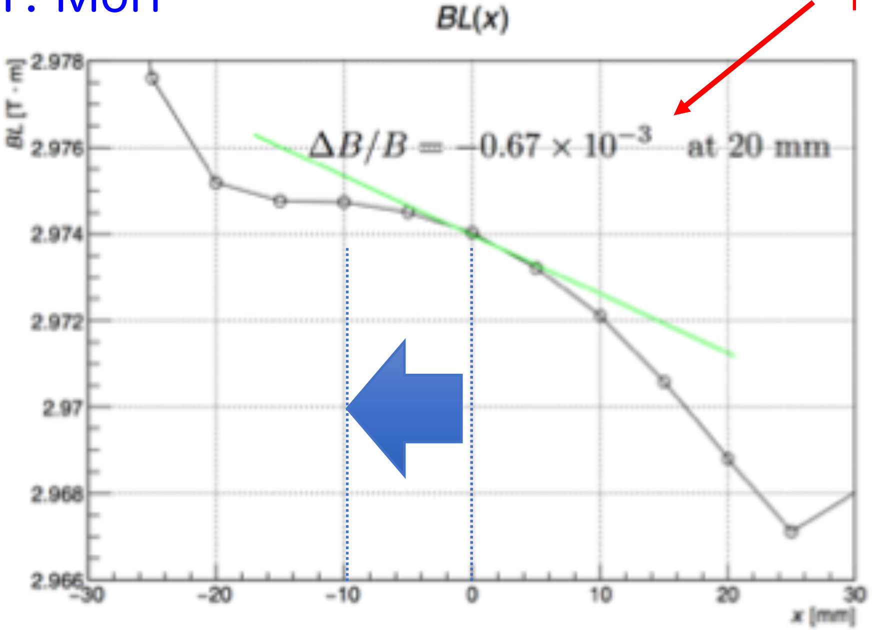
2. Improvements of emittance growth

b. Residual dispersion at the acceleration structure for a compression system

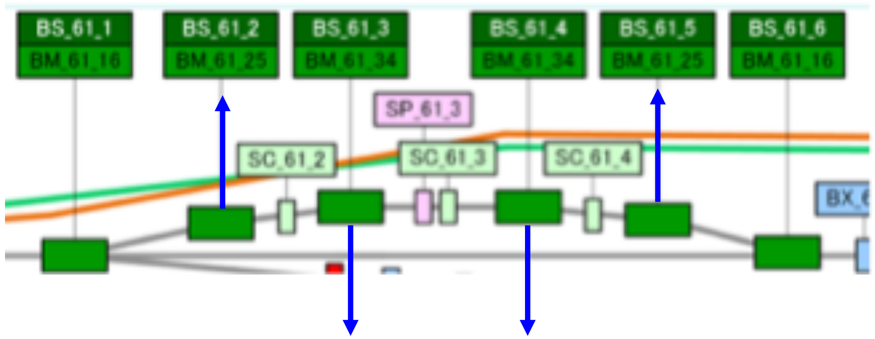
- The bending magnets used in ECS/SY3 have quadrupole component.
  - Passing through the design orbit in the bends, the beam feels B' field, which results in dispersion leakage.
- By moving the bends about 10mm, the small area of B' can be passed.

T. Mori

This can explaine the measured dispersion leak.

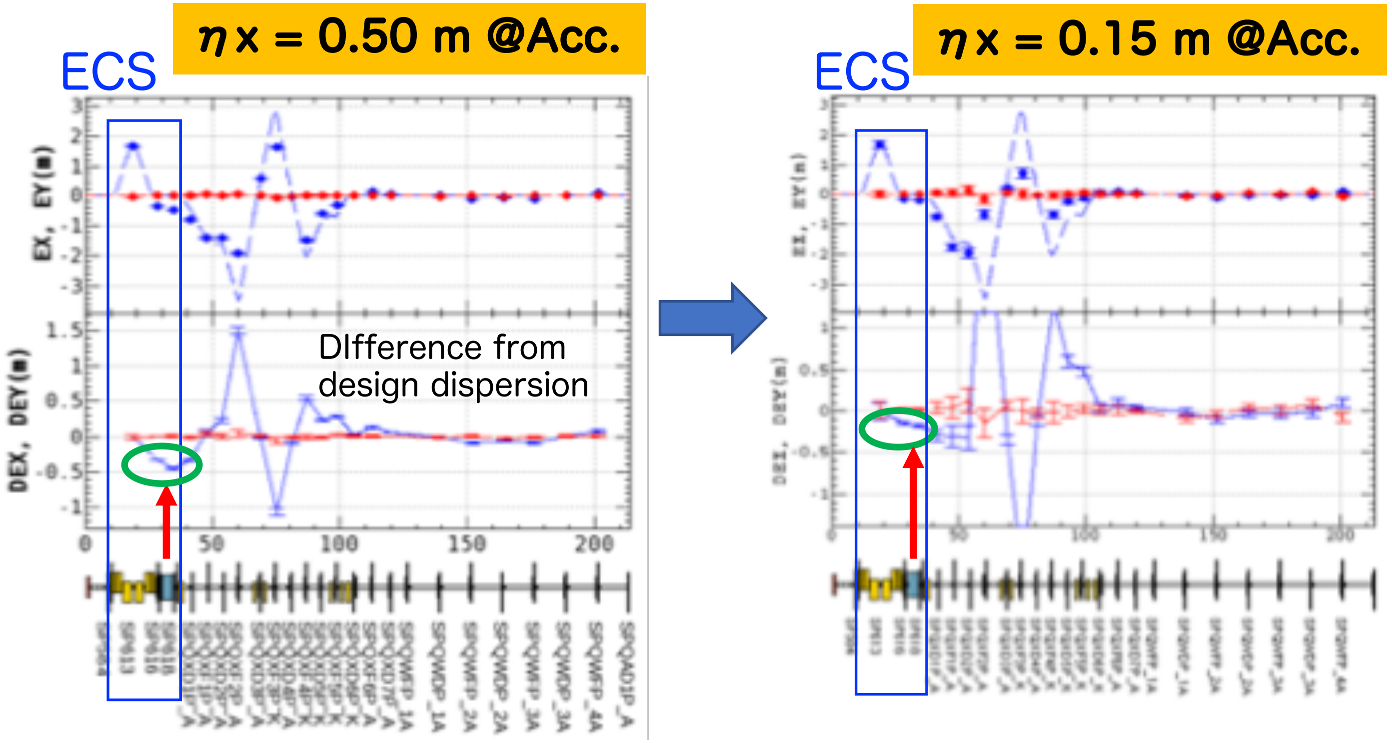


BL along the horizontal direction



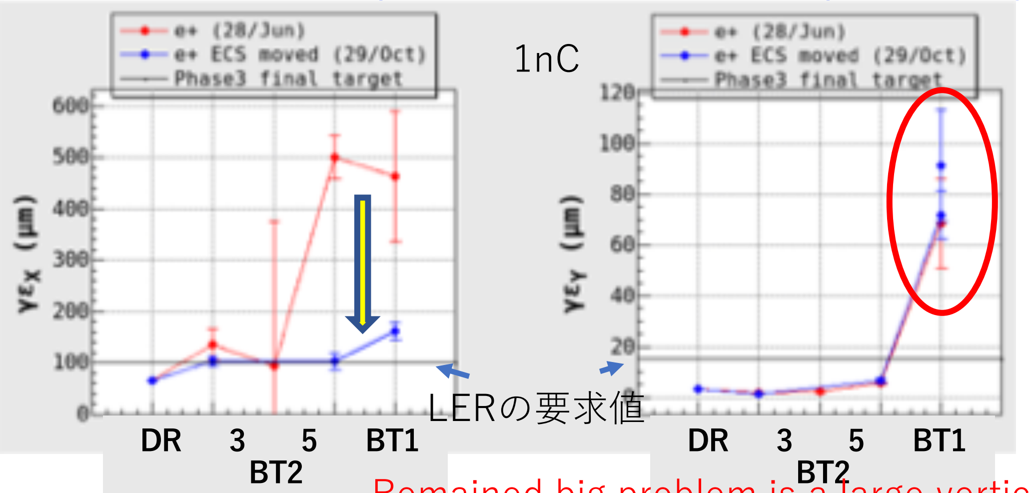
~10 mm

2. Improvements of emittance growth



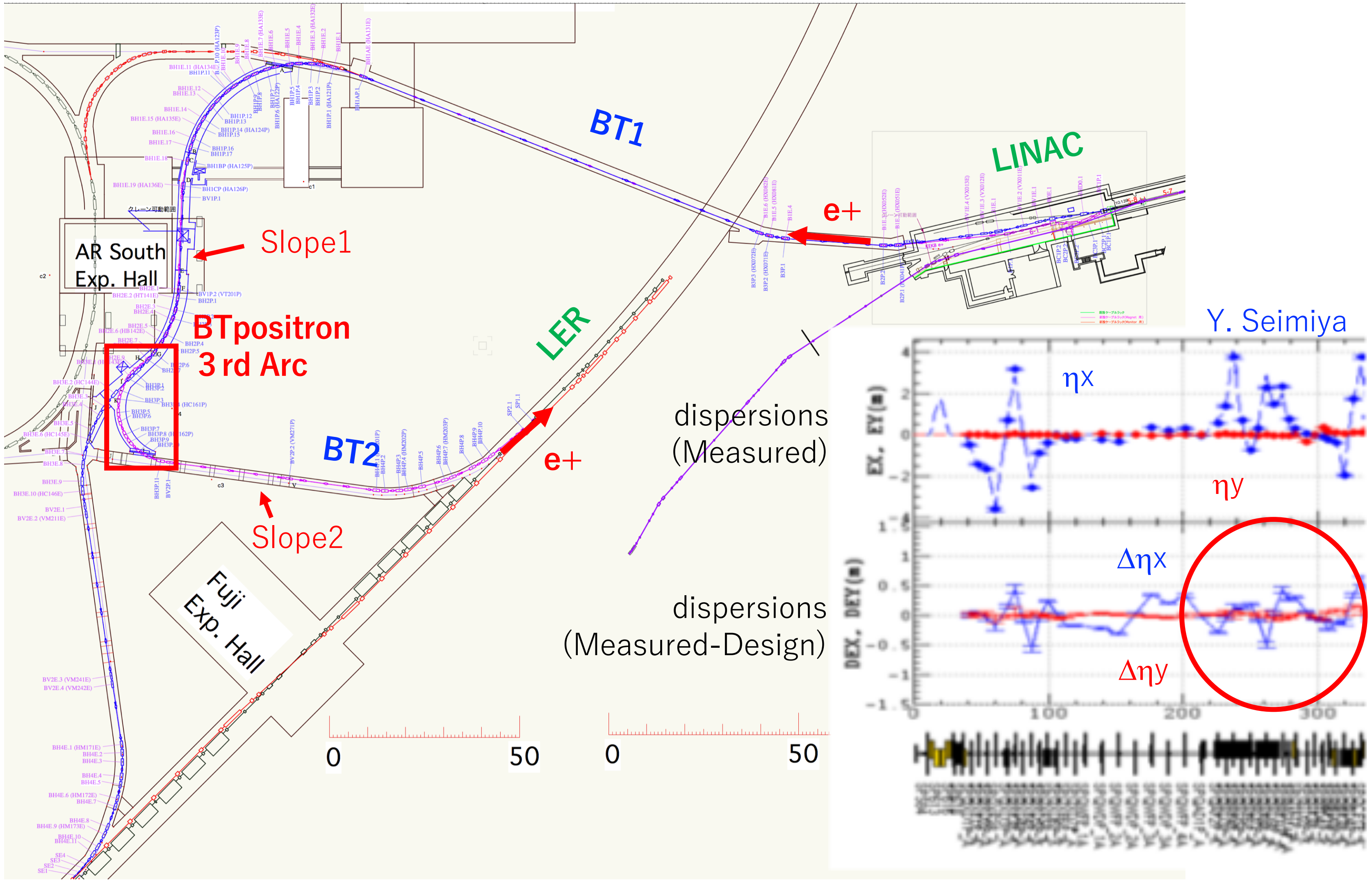
Y. Seimiya

The horizontal dispersion has been improved by moving ECS bends.



Remained big problem is a large vertical emittance.
This is considered to come from abnormal vertical dispersions.(M.

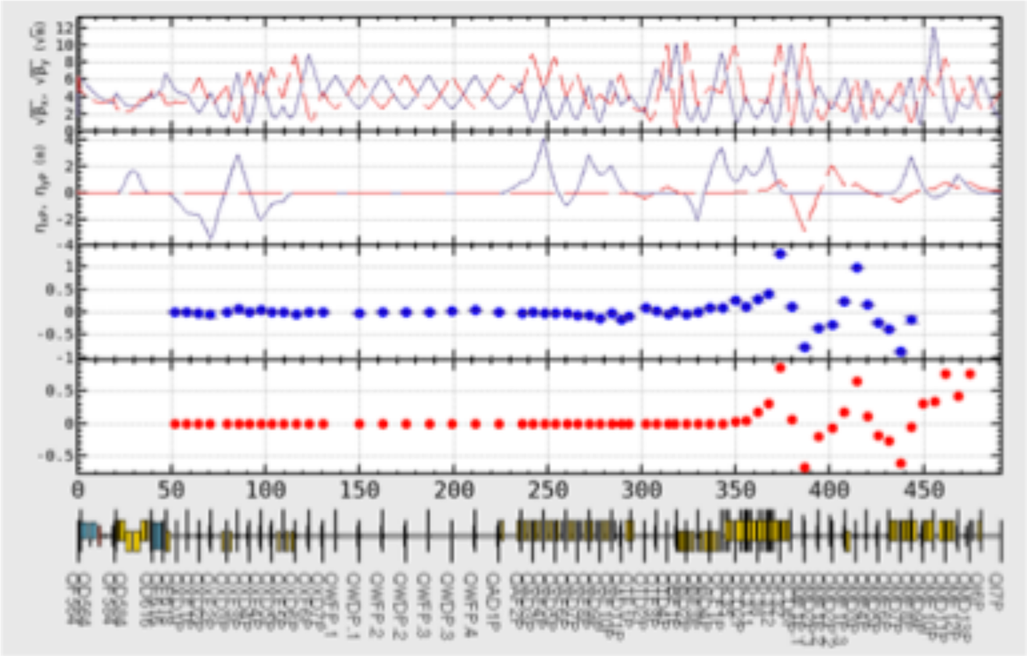
B) Abnormal skew magnetic field from bends



Simulation

M. Kikuchi

Kikuchi-san considered that the vertical dispersion could be corrected with the skew quads with permanent magnets.

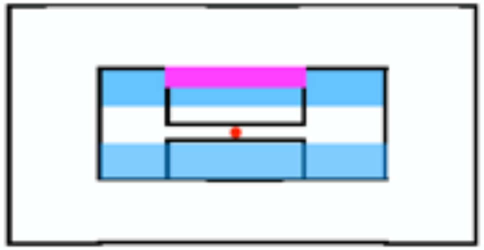


e+ beam

Measured vertical dispersion before SkewQ

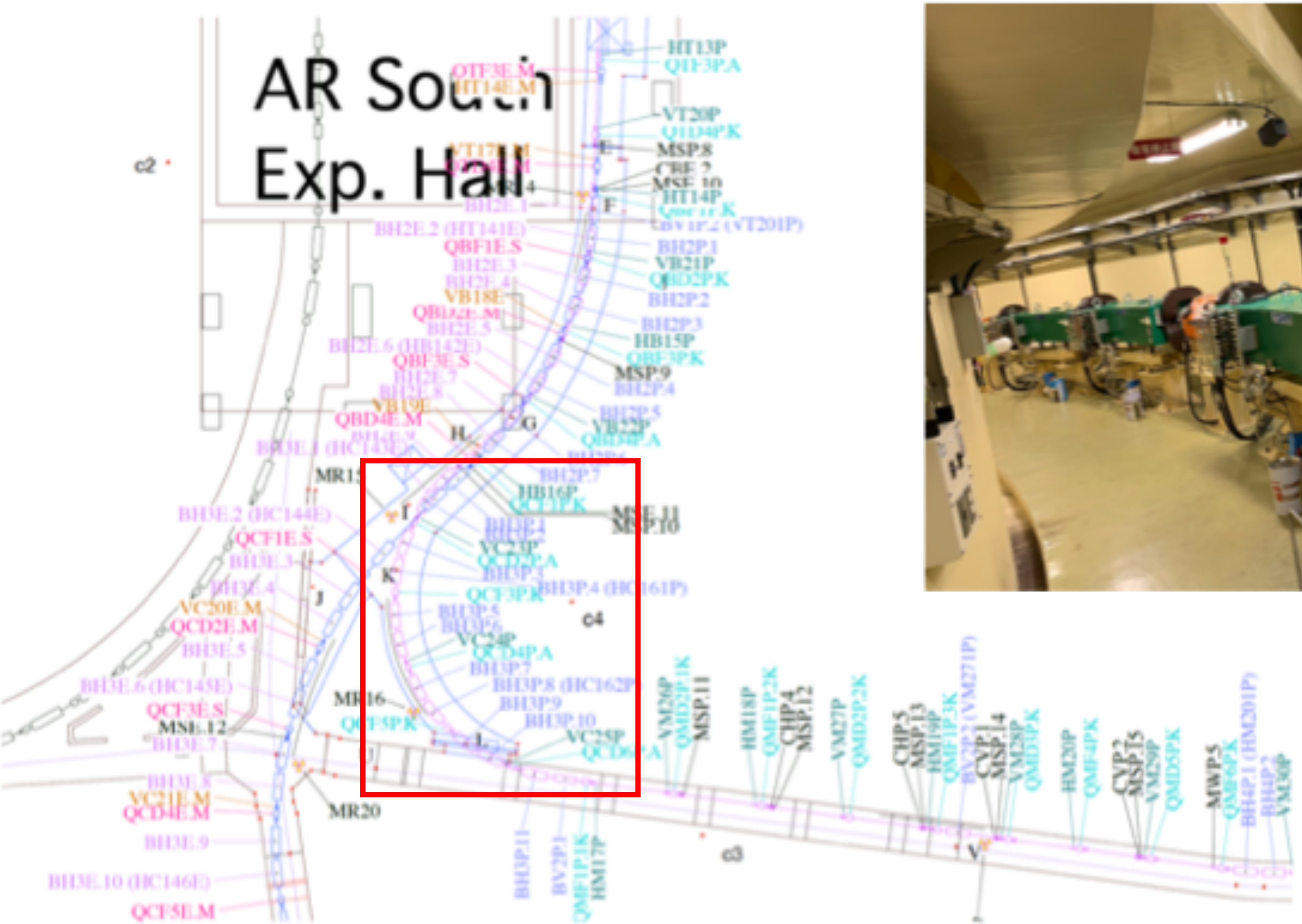
Calculated vertical dispersion by the SkewQ which are installed.

Good agreement !

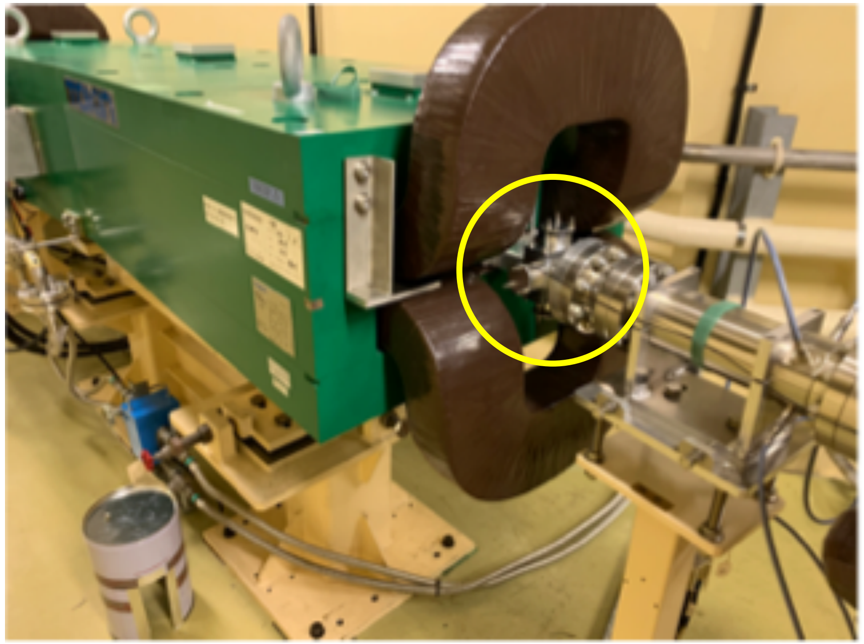


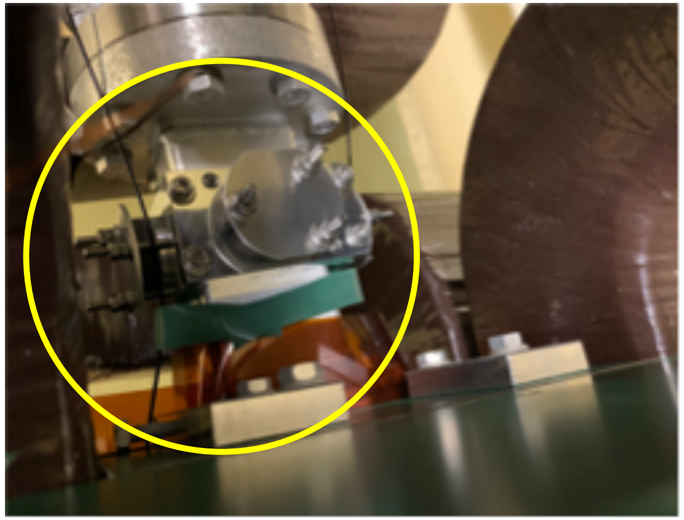
e+ビームのエネルギーが4 GeVに上がったことにより、BendのGapを狭くした。このことがBendに異常なSkew成分を作った。しかし、このことは測定されたSkewQuad成分の約３分の一しか説明できない。とにかく、補正してみる。

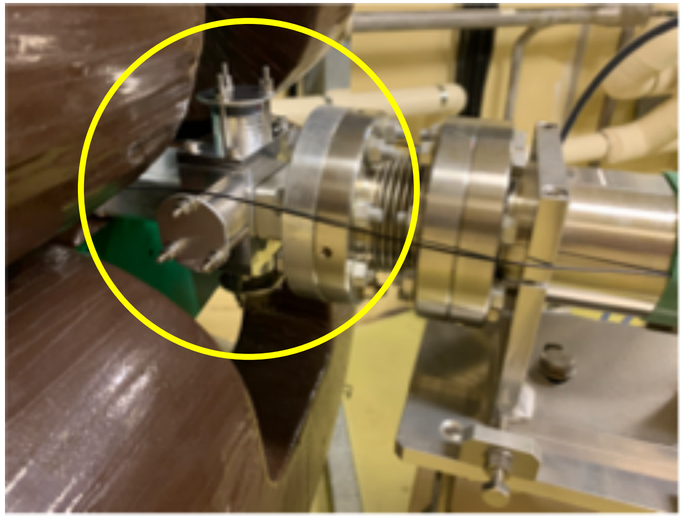
2. Improvements of emittance growth



2. Improvements of emittance growth





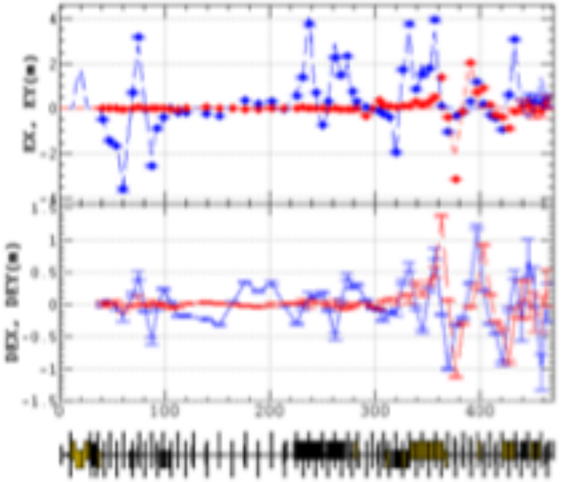


11 of 16 Skew Quads were installed.

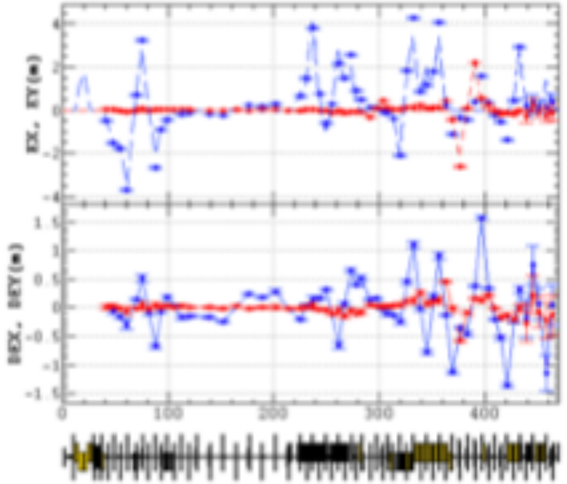
Measured Dispersion

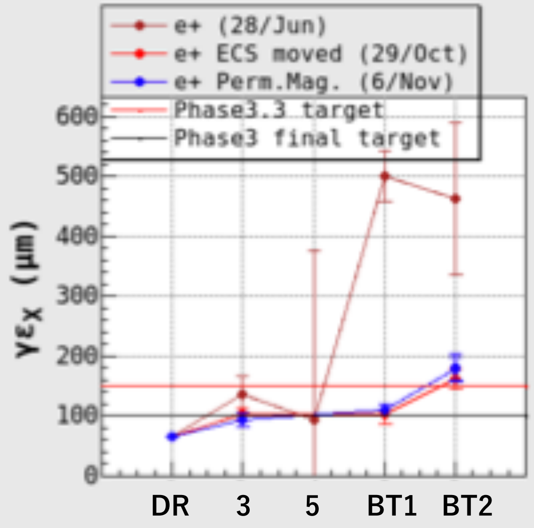
Y. Seimiya

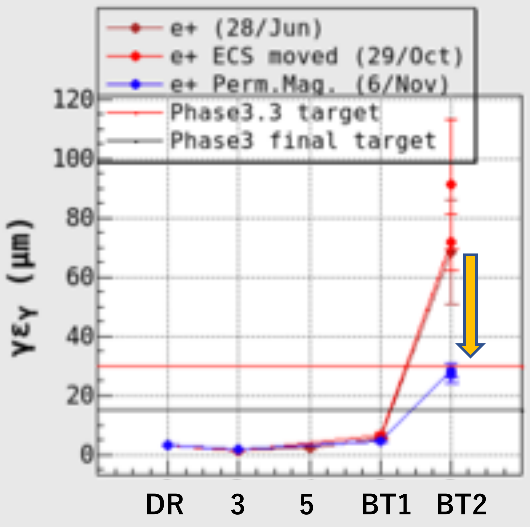
① Before installation of skew quads



② After installation of skew quads

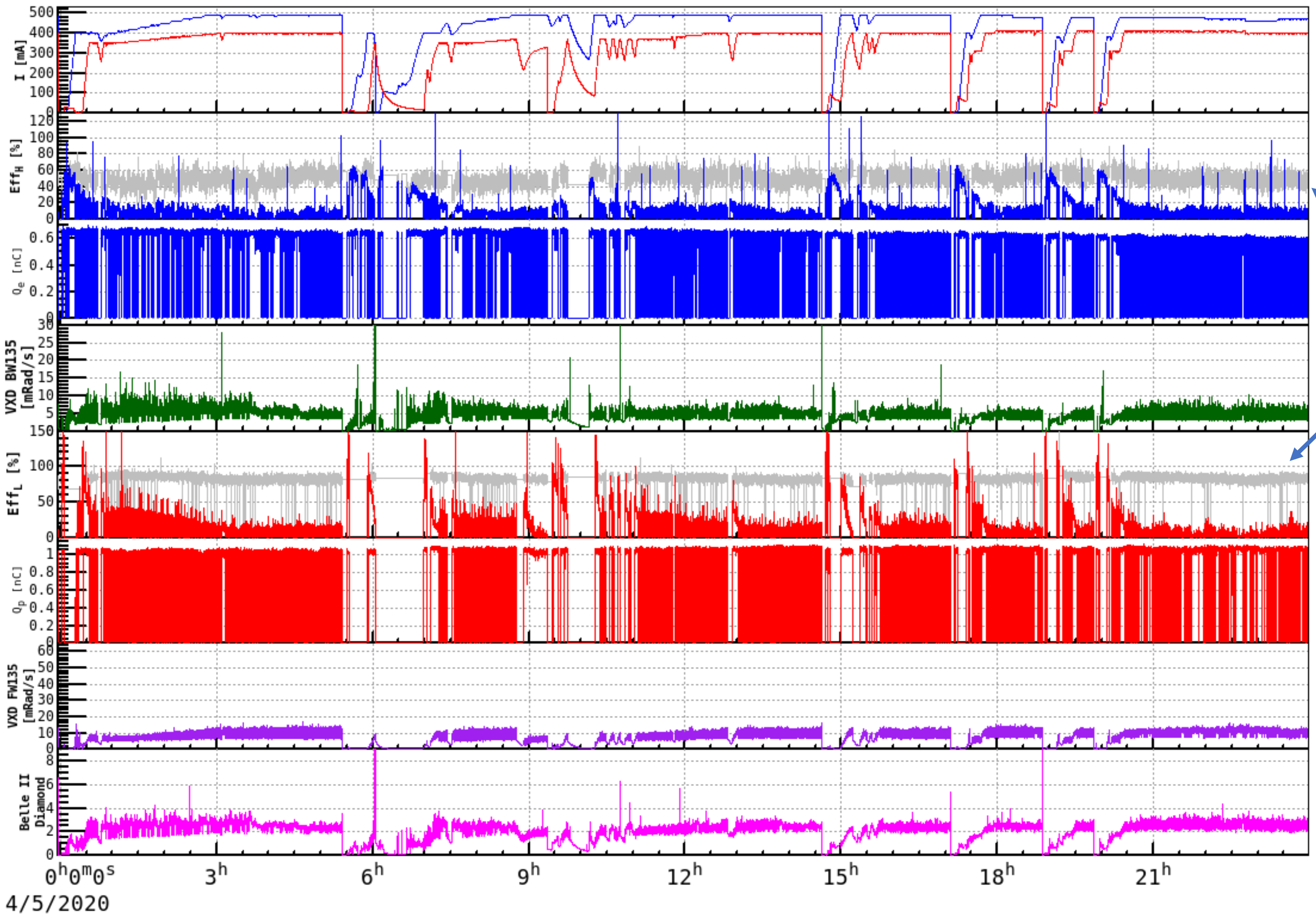






Remaining SkewQuads will further improve the vertical emittance.

生の入射効率（MRのビーム寿命によらない）



Bunch current monitorから計算した入射後数ms後の入射効率