Injector progress and Stable injection

Feb. 4, 2019
32nd B2GM
N. Iida
for SuperKEKB LINAC group

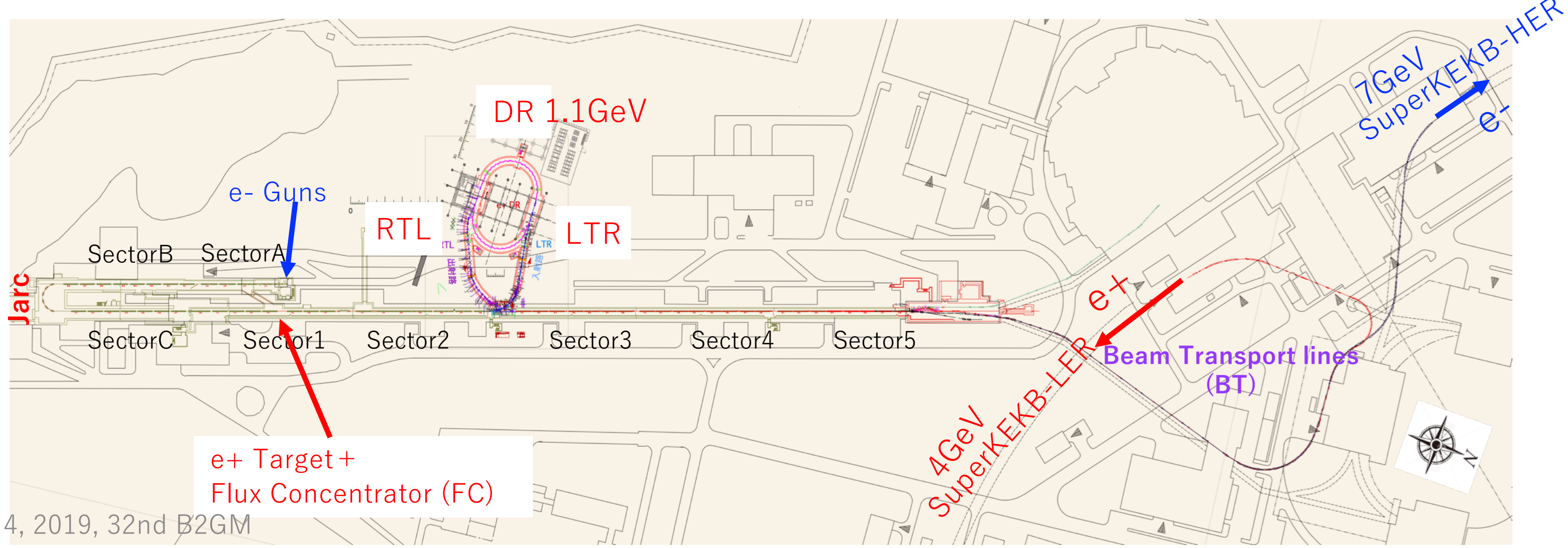
Contents

LINAC Layout

Request of injection beam from SuperKEKB			
	Phase 2	Phase3 Goal	
	2018	2019～2022?	
		e+	e-
γεx [μm]	< 200	< 100	< 40
γεy [μm]	< 40	< 15	< 20
σδ [%]	0.16	0.16	0.07
Charge [nC]	1.5	4.0	4.0

We are here

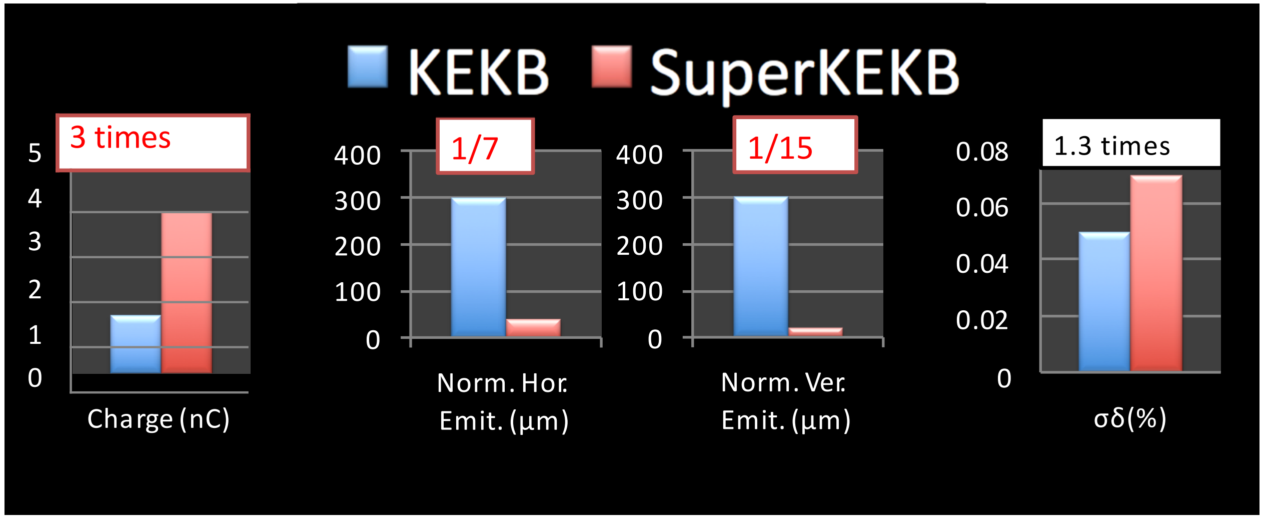
The goal emittances and charges are gradually improved as βy* is squeezed.



Injection Beam at KEKB and SuperKEKB

- Comparison between the achievement at KEKB and requirement at SuperKEKB Phase 3 goal
  - Much smaller emittance even with 3 times higher beam charge.
  - Still a big challenge that must be resolved.

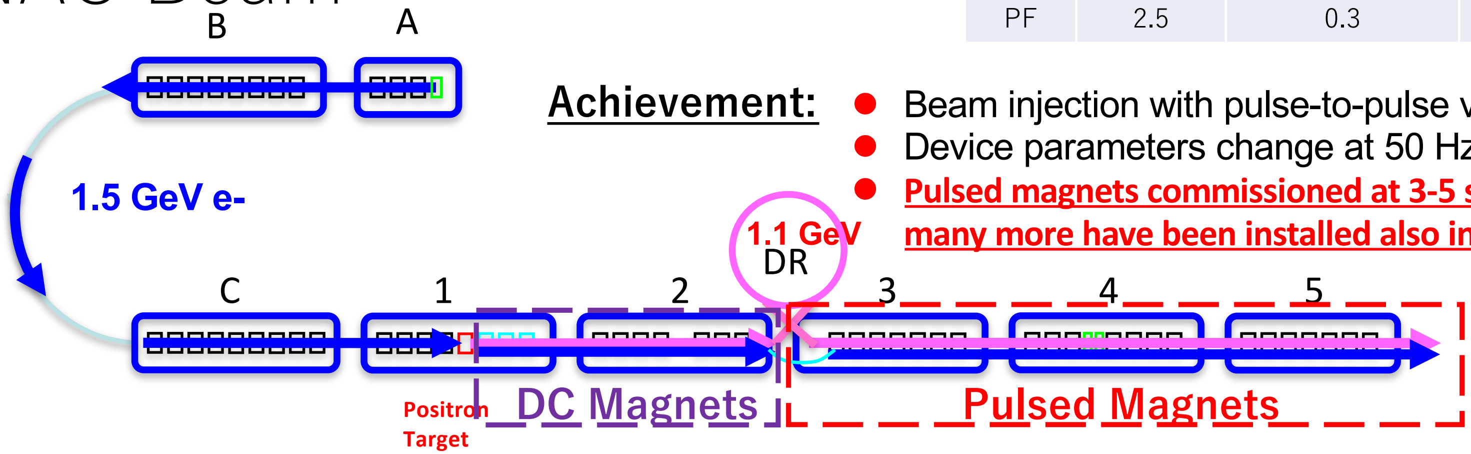
Electron beam for the HER

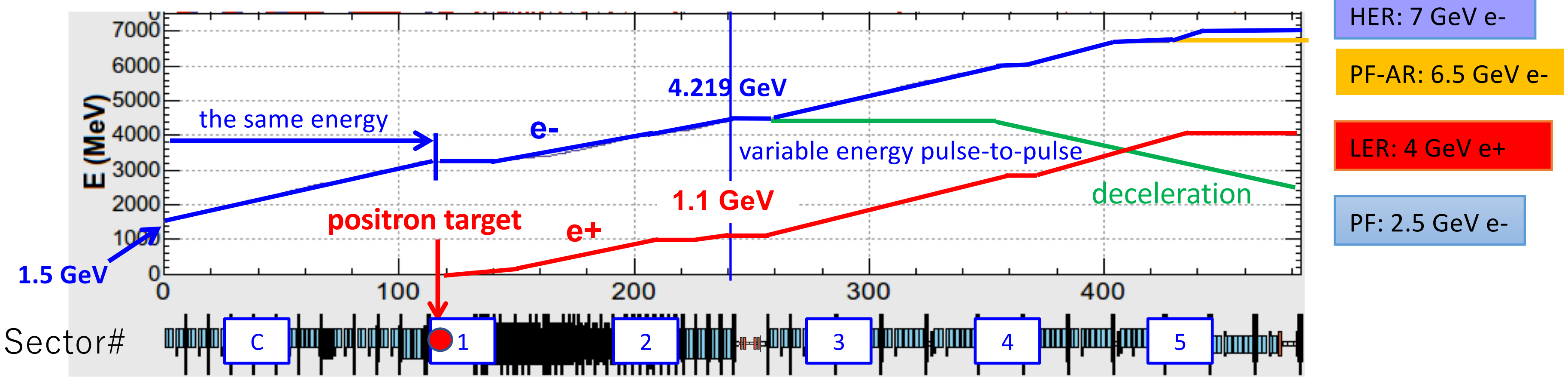


Simultaneous Injection
LINAC Beam

Ring	Energy [GeV]	Charge/bunch [nC]	# of Bunch	Rep. Rate [Hz]
LER	4	4	2	50
HER	7	4	2	50
PF-AR	6.5	0.3	1	25
PF	2.5	0.3	1	25

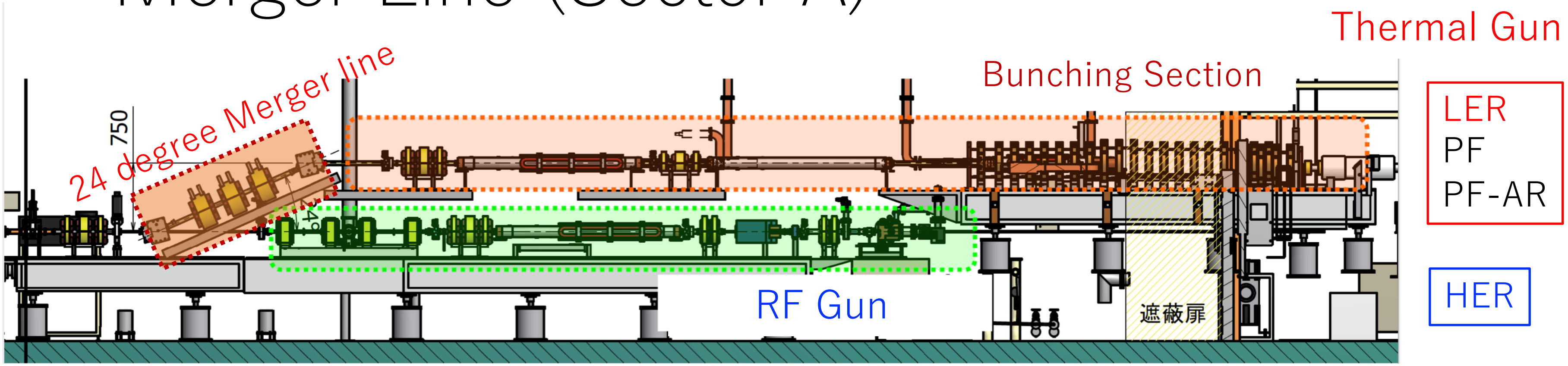
Achievement:
- Beam injection with pulse-to-pulse variable charge and energy
- Device parameters change at 50 Hz (20 ms)
- **Pulsed magnets commissioned at 3-5 sectors (2017 autumn), and many more have been installed also in this winter.**





T. Kamitani

Merger Line (Sector A)



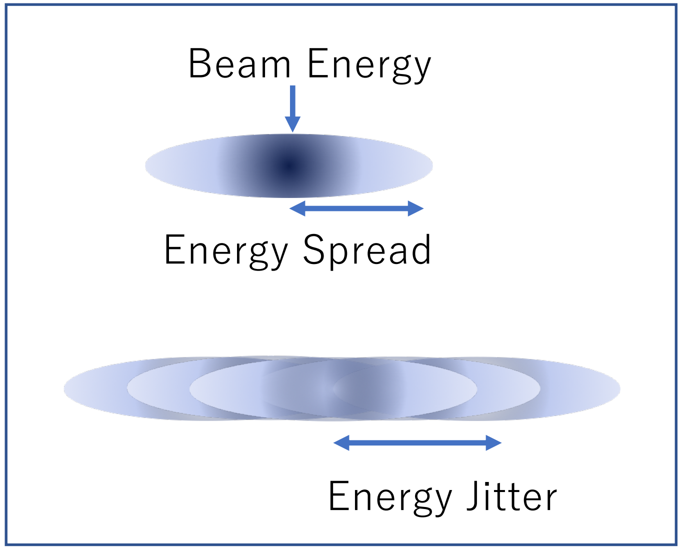
- Thermal gun
  - LER, PF, PF-AR (, HER)
  - Thermal gun
  - SHB1(114MHz)
  - SHB2(571MHz)
  - Pre-buncher
  - Buncher
  - Accelerating Structure(2mx2)
- 24 degree Merger Line
  - The beam of the thermionic gun joins at the merger line.
- RF gun
  - HER
  - 0-deg QTW RF gun
  - 90-deg CDS RF gun
  - Bunch Compress System(BCS)
  - Accelerating Structure(2mx1)

Contents

1. Injection BG in Phase 2

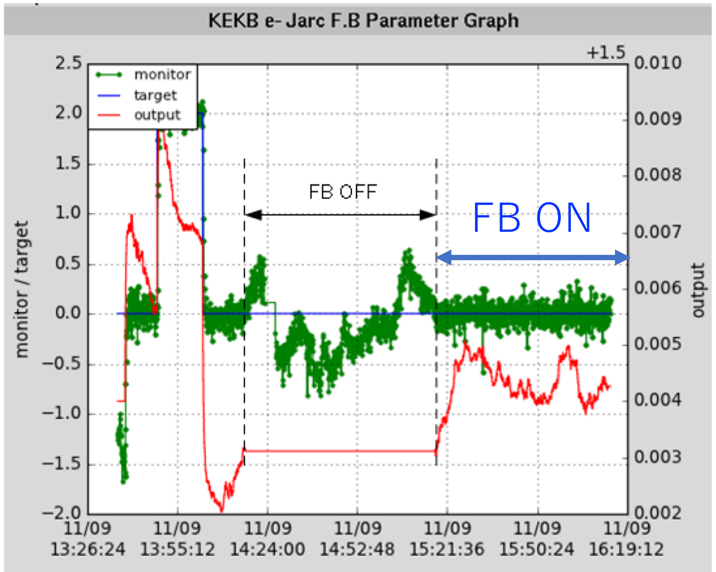
- Tuning of collimator in the MR has been very useful for suppressing the BG.
- A stable beam is very important to reduce the BG;
  A) Beam energy (Energy FB)
  B) Energy spread
  C) Energy jitter
  Orbit in LINAC, BT
  Optics, Emittance
- Tools to be prepared;
  - LINAC orbit FB (Phase 3)
    - Now preparing
  - RF phase/voltage monitor
  - Energy spread monitor

These will be talked the next topic →

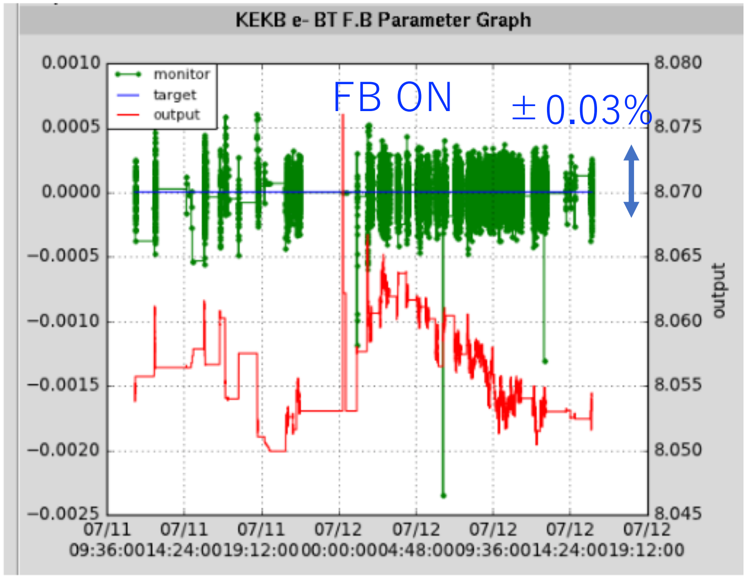


A) Energy Stabilizer (Energy FB)

Jarc



BT



Target

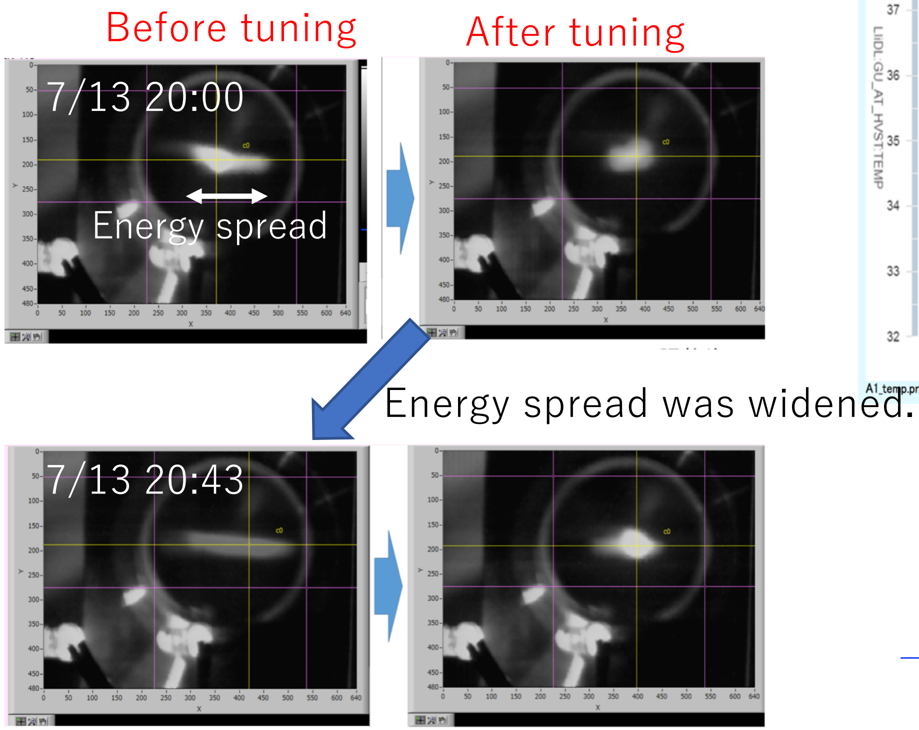
Beam energy (monitored)

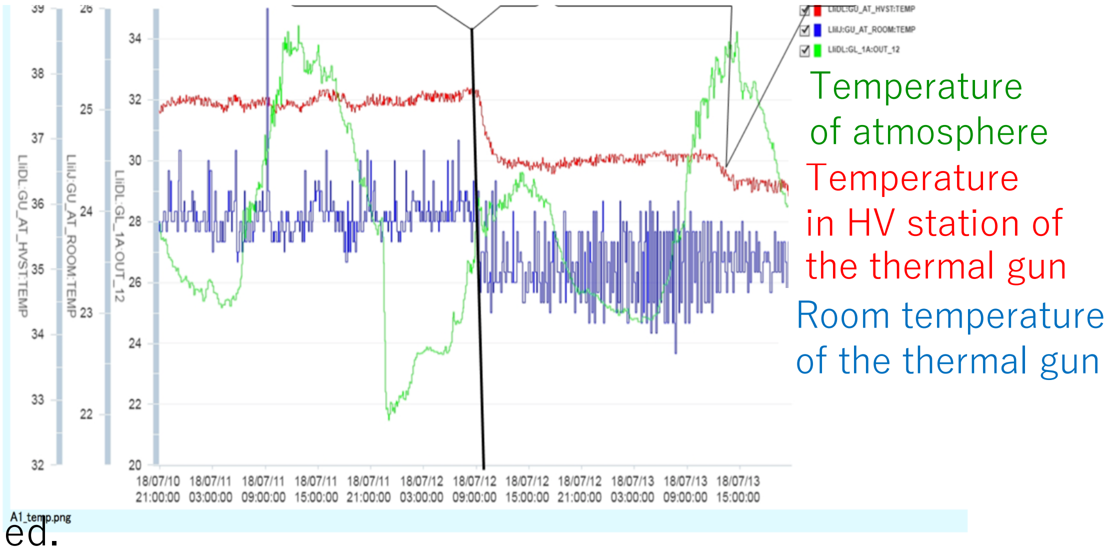
Energy knob

The injection energies have been stabilized within ±0.03% by the energy feedback.

B) Energy spread

Arc section in Beam Transport line (BT)





Energy spread is very sensitive to the RF phase.
RF Phase drifts due to temperature change.

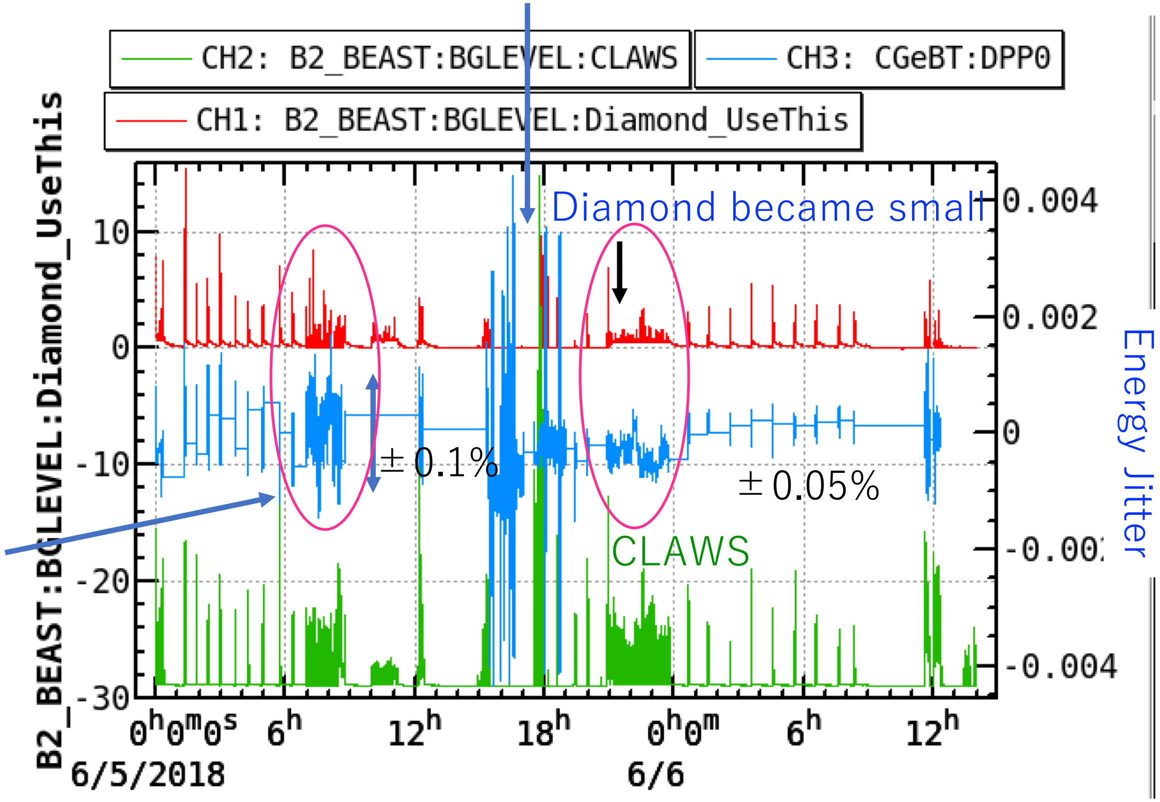
→ RF phase/voltage monitors are necessary.

The energy spread can be monitored only by destructive screen monitors. → A nondestructive monitors are necessary.

C) Energy jitter

After suppressing the energy jitter,
the signal from Diamond detector was reduced.

Energy FB did not work well.



Beam background is sensitive to the energy jitter.

Contents

0. Introduction
1. Injection background(BG) during Phase 2
2. Progress of LINAC study for autumn, 2018
    - Mainly about the study related to BG
3. Injection beam for the beginning of Phase 3
4. Summary

LINAC Beam Studies (Oct.-Dec., 2018)

- RF Gun (M. Yoshida, X. Zhou, R. Zhang)
- Thermionic Gun
  - Tuning of Buncher (T. Natsui)
  - Q-Scan、10nC（T. Natsui and Y. Seimiya）
- 24 degree Line
  - Measurement and Correction of Dispersion（Y. Seimiya）
  - Measurement of Response and Aperture (Y. Seimiya)
  - Consistency Measurement of BPM (F. Miyahara)
- Jarc
  - Measurement and Correction of Dispersion（Y. Seimiya）
  - Bunch Compress（M. Yoshida）
  - OctoPos BPM (F. Miyahara)
- Measurement of Beam Position Jitter and Fluctuation (Y. Seimiya)
  - Binarization from Pulsed Magnet (T. Natsuim Y. Enomoto, M. Satoh, I. Satake)
  - Monitors of RF Phase and RF Induced wave
- Monitors of RF Phase and RF Induced wave（T. Miura, et al.)
- Primary side power fluctuation (T. Miura, T. Natsui)
- Investigation around Dummy Target (Y. Enomoto, H. Sugimura, T. Kamitani, Y. Ohnishi, Y. Funakoshi, N. Iida)
  - Beam Based Aligment (Ballistic Orbit、QuadBPM)
- Investigation of Solenoid magnet after Positron Target (T. Kamitani, Y. Ohnishi)
- Measurement of RF Energy Gain (T. Kamitani, Y. Ohnishi, T. Natsui, Y. Seimiya, M. Satoh)
- SY2 (N. Iida, H. Koiso)
  - Measurement of Dispersion
- Sector 3-5
  - Offset Injection (Y. Seimiya, N. Iida, T. Mimashi, T. Kawamoto, K. Yokoyama)
  - Fudge Factor Measurement of Quad (Y. Seimiya, M. Satoh)
  - QuadBPM (H. Sugimura), Mover Alignment (Y. Enomoto, T. Kamitani)
- Coexistence with PF and PF-AR

… Studies especially related to the BG:
Core subjects

2. Progress of LINAC in autumn, 2018

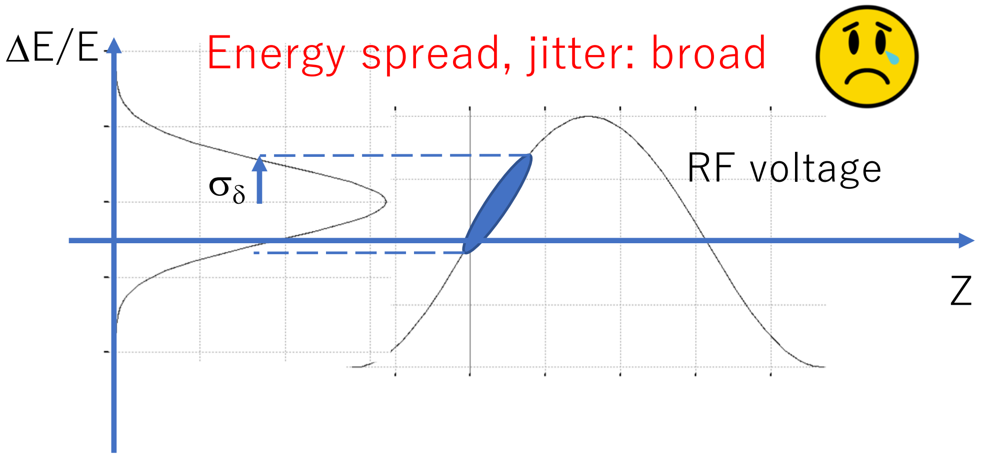
related to the BG

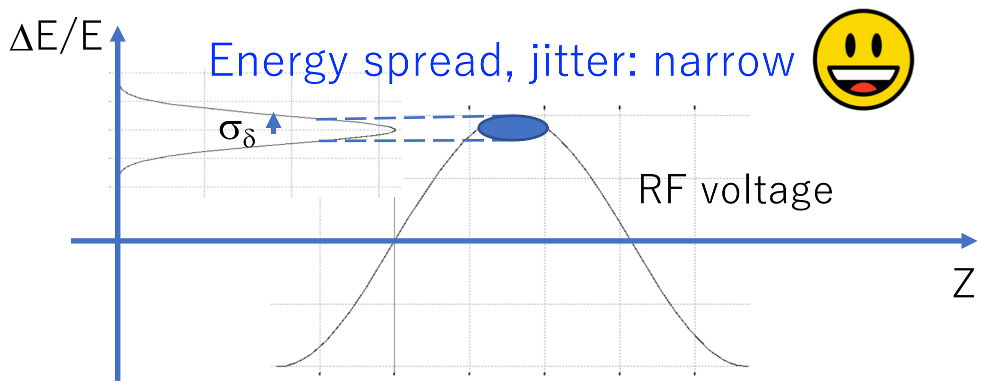
A) Jitter of beam position

B) Beam energy stabilization
- RF phase/voltage monitor
- RF Stabilization

C) Energy spread monitor
- “OctoPos”:
  Eight electrode BPM

D) Tuning of the bunching

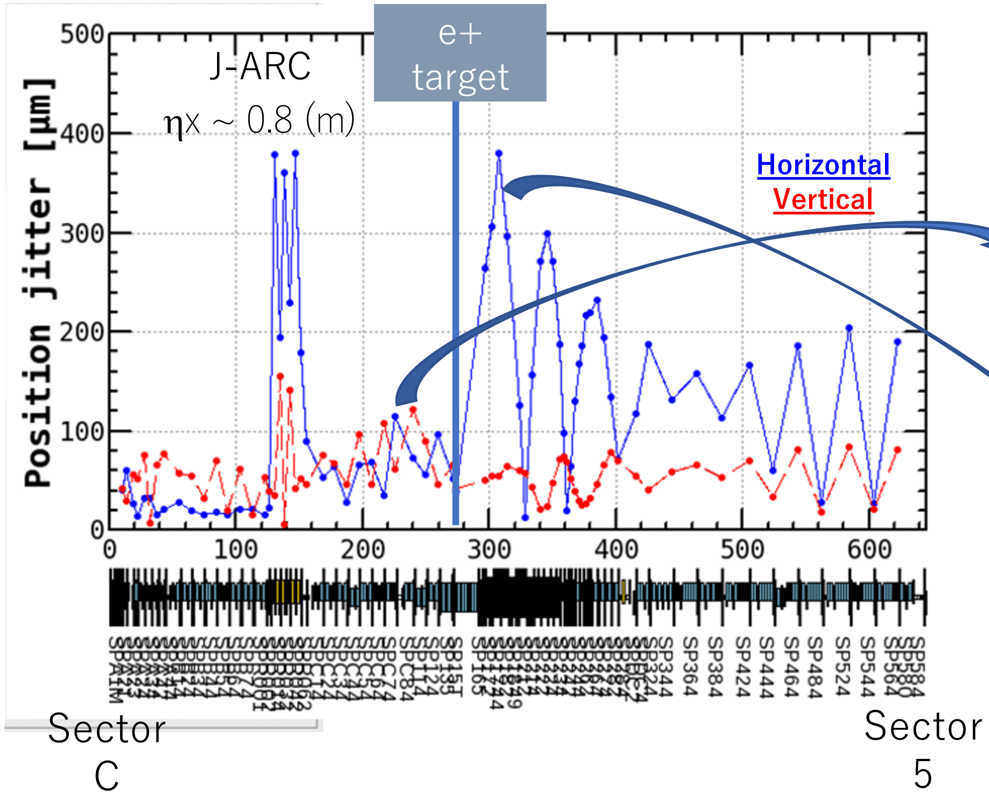




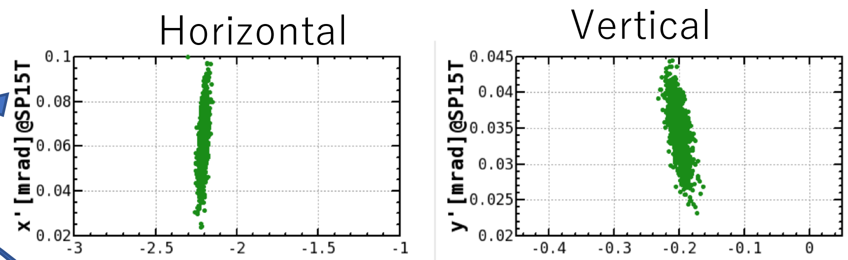
(A) Jitter of beam position

Y. Seimiya

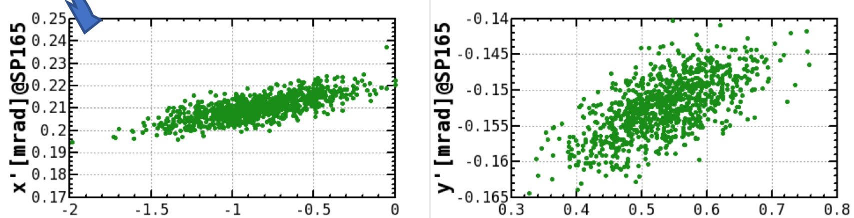
- A hole in the positron target for HER e- beam： ϕ2 mm.
  - Possibly the small hole could have caused the position jitter ?



There is a problem of the beam position jitter after the positron target.



Phase space plot at BPM before target.

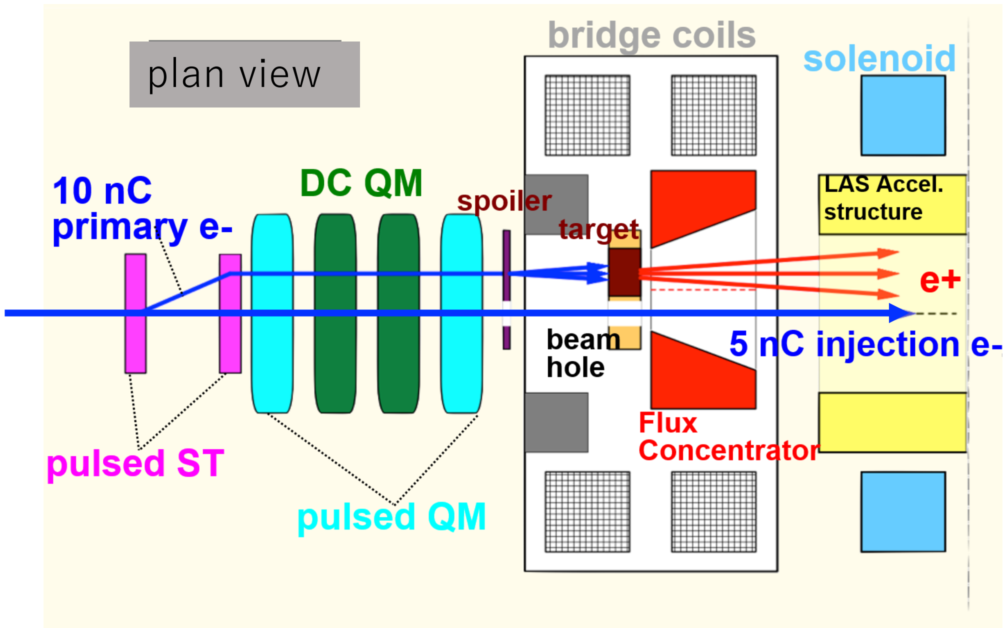


Phase space plot at BPM after target.

Jitter of Beam Position

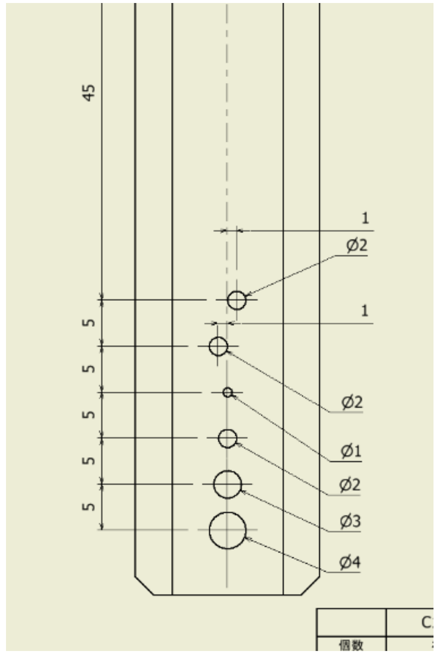
Y. Enomoto

- A hole in the positron target for HER e- beam： ϕ2 mm.
  - Possibly the small holes could have caused the position jitter ?
- LINAC Study in Autumn, 2018
  - A movable dummy target was installed instead of the positron target.
  - Beam studies were done with in/out the dummy target.
- The positron target was re-installed now.

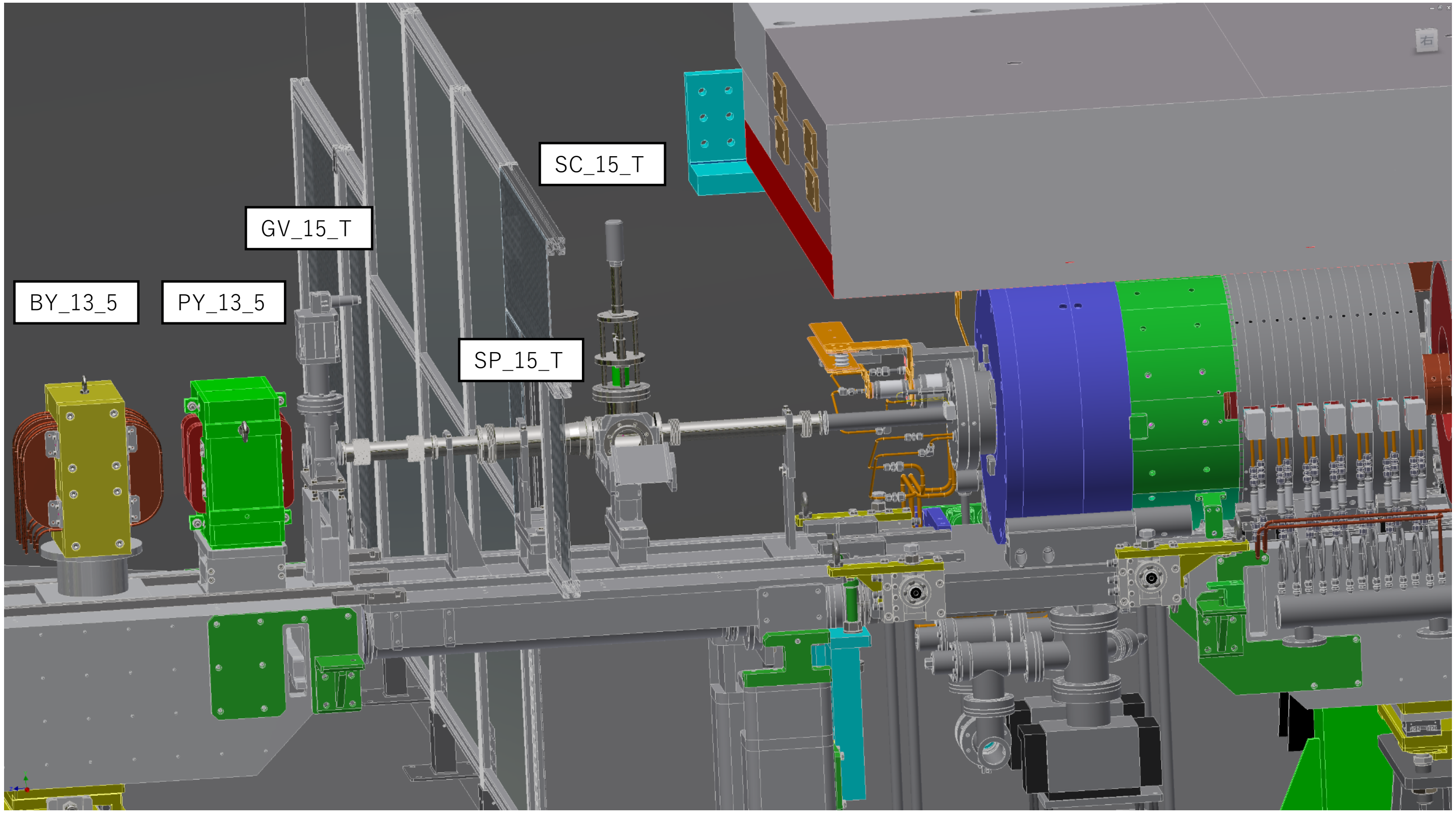


for LER

for HER

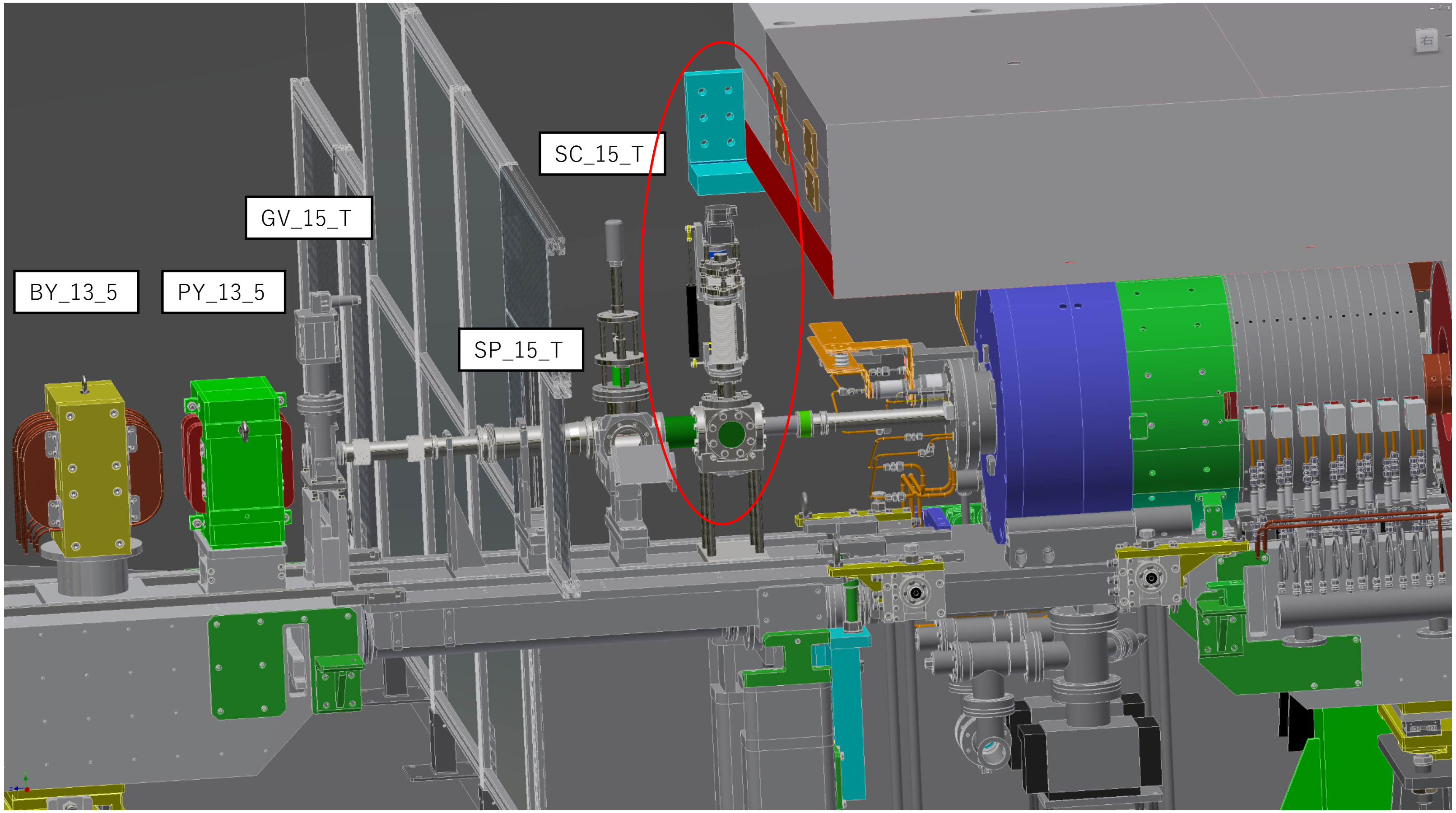


Removed the Flux Concentrator (FC)



Y. Enomoto
(LCG meeting, '18/7/2)

Installed a dummy target block

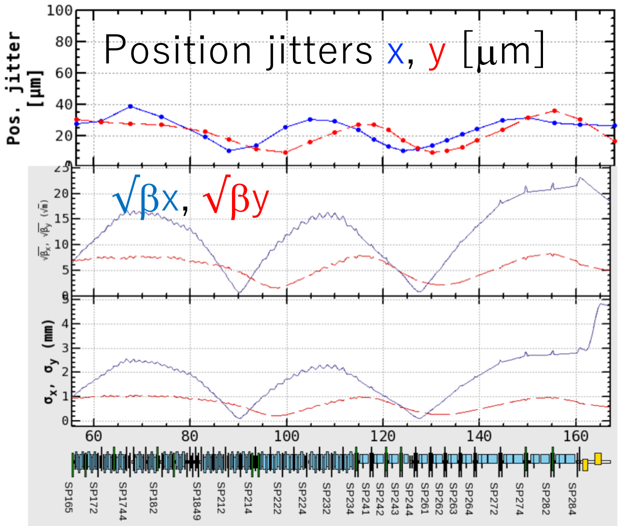


Y. Enomoto
(LCG meeting, '18/7/2)

Jitter Emittance

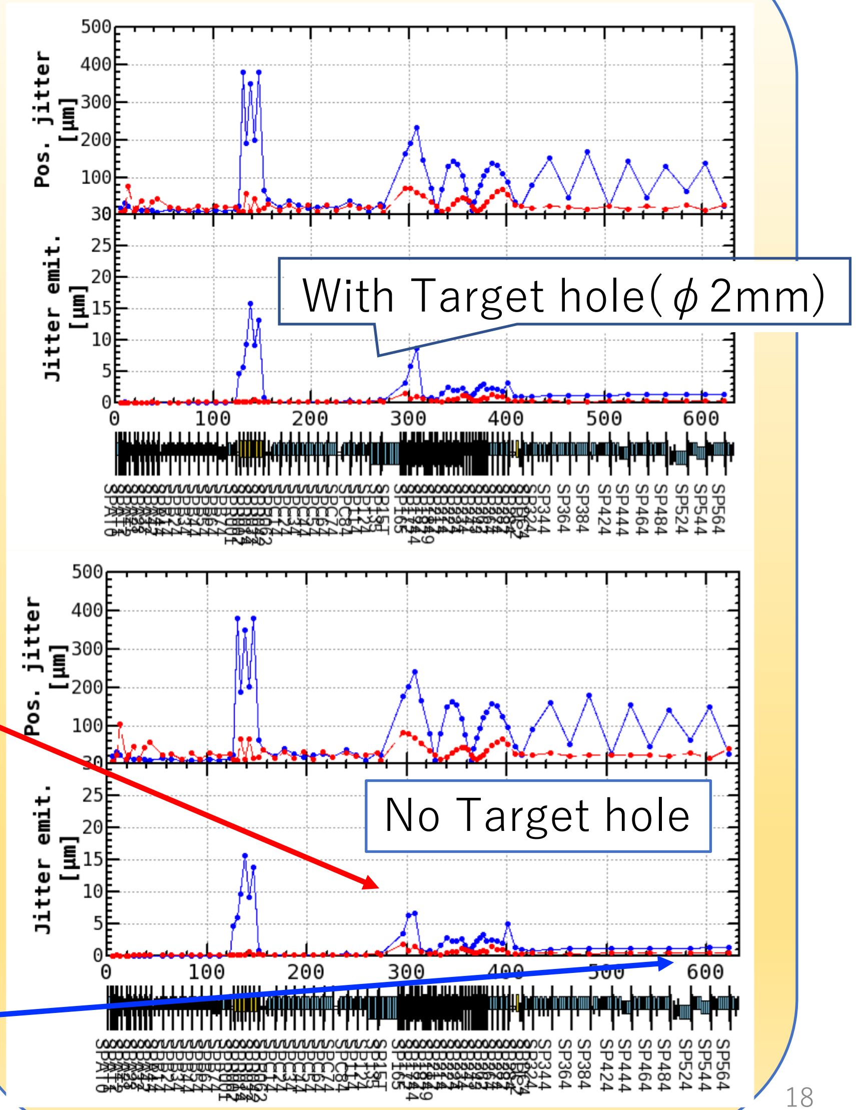
The result is;

- The growth of the jitter emittance has been nothing to do with the small hole.
- Strong correlation between orbit jitter and beta function.
- The beta function after the target is large to squeeze the beam sizes to pass through the hole, which causes the large orbit jitter.



Although the jitter emittances are still increased as shown in the jitter emittance plots, it is known that this jitter becomes smaller when Jarc's dispersion leakage is reduced.

They are small enough at the end of LINAC.

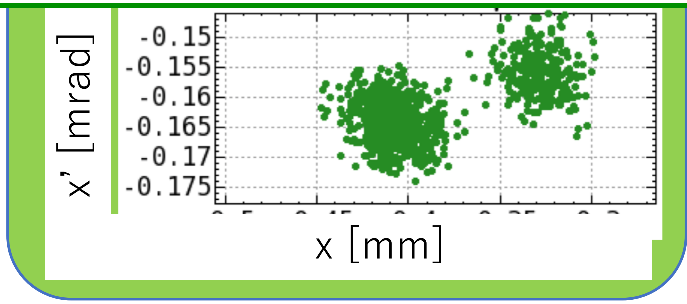


Y. Seimiya

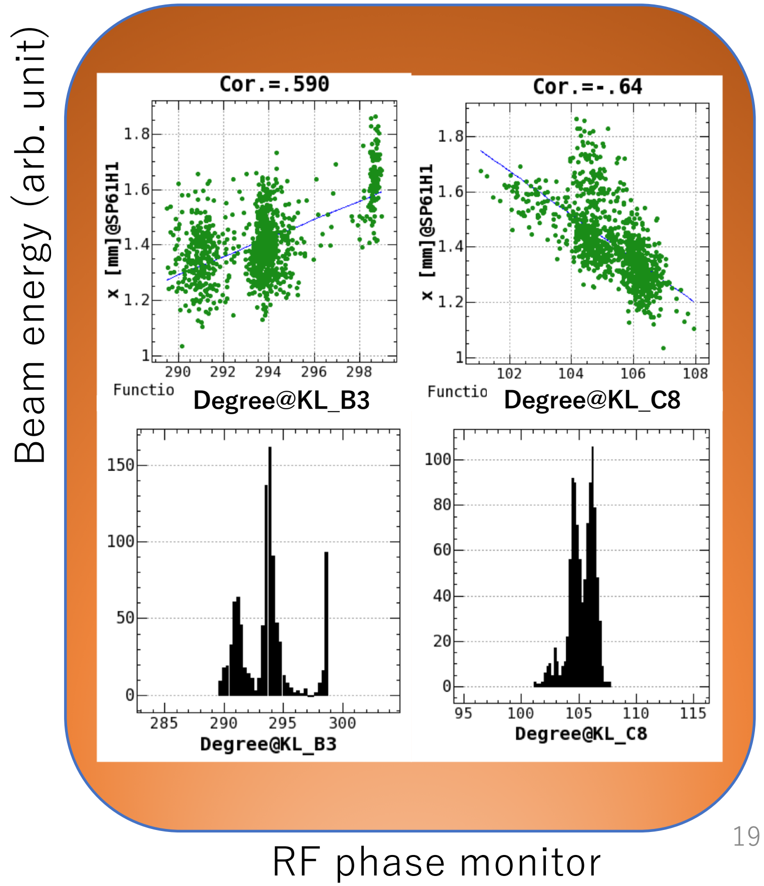
Beam Jitter Sources

Causes of several beam fluctuations were revealed by BPMs and the new RF monitors.

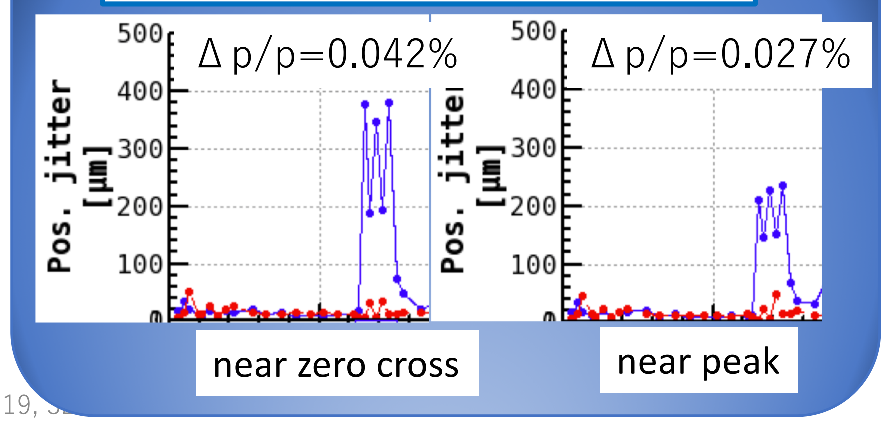
① Binarization from the Pulsed Magnets (at the straight section)



② Binarization from the RF Phase (at the dispersive section)



③ Large variation of Energy gain near zero cross of RF phase



Beam jitter (cause and remedy)

① Binarization from the Pulsed Magnets
- Currently under investigation

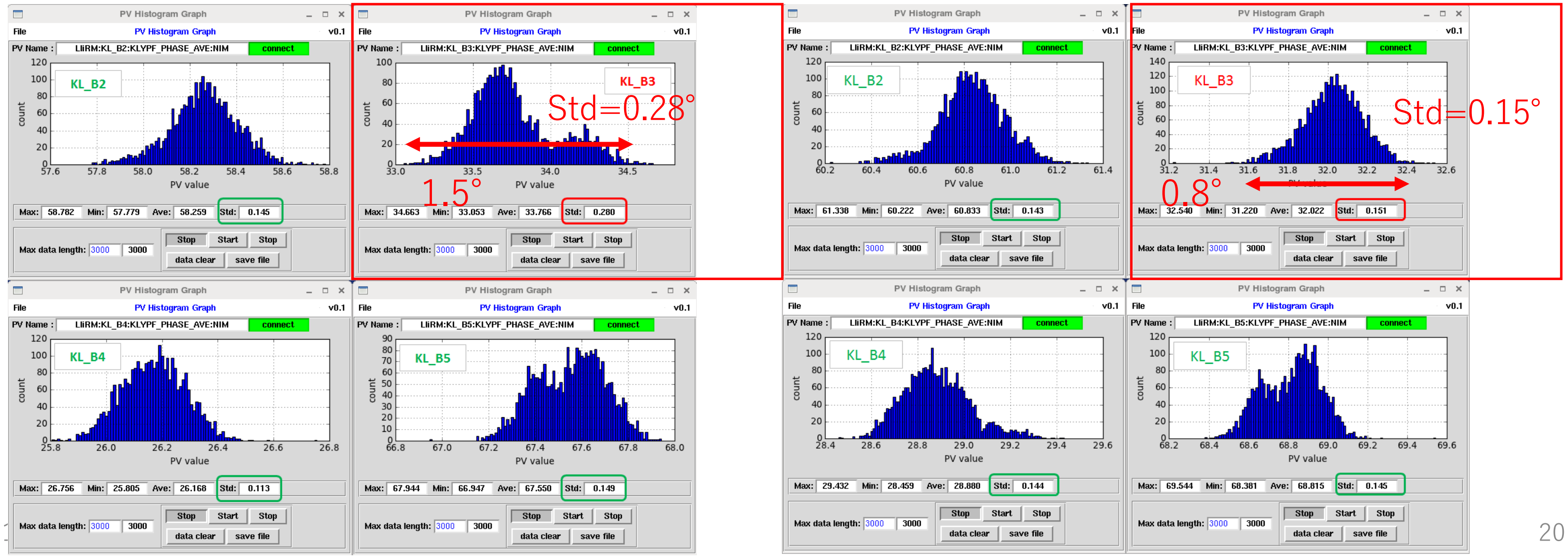
② Binarization from the RF Phase
- Connector or Cable Problems

③ Large variation of RF phase near the zero cross
- Use the energy knob closer to the top of the RF wave

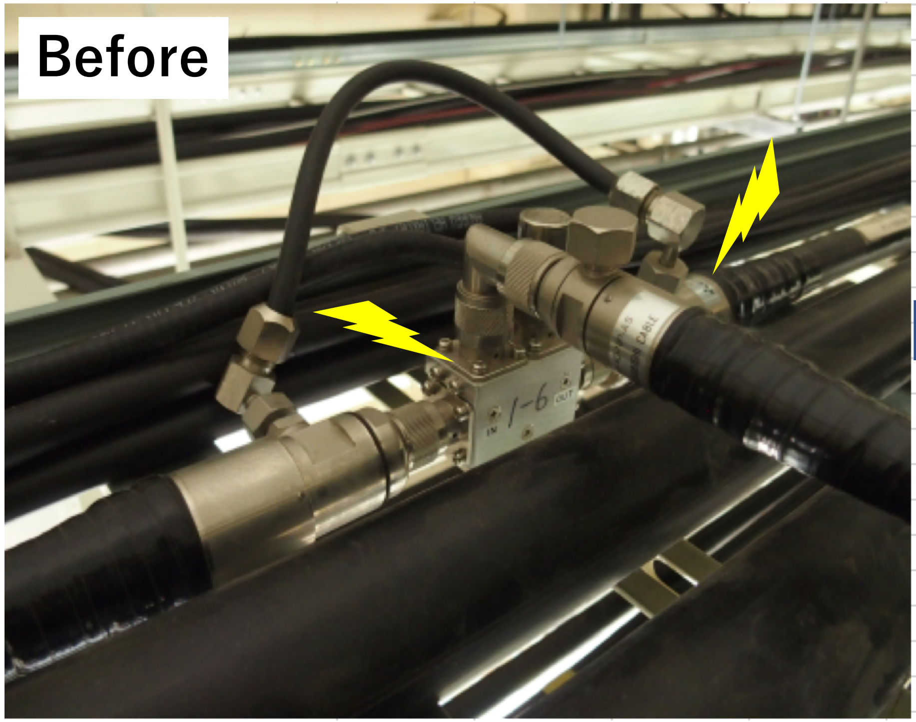
(B) Beam energy stabilization

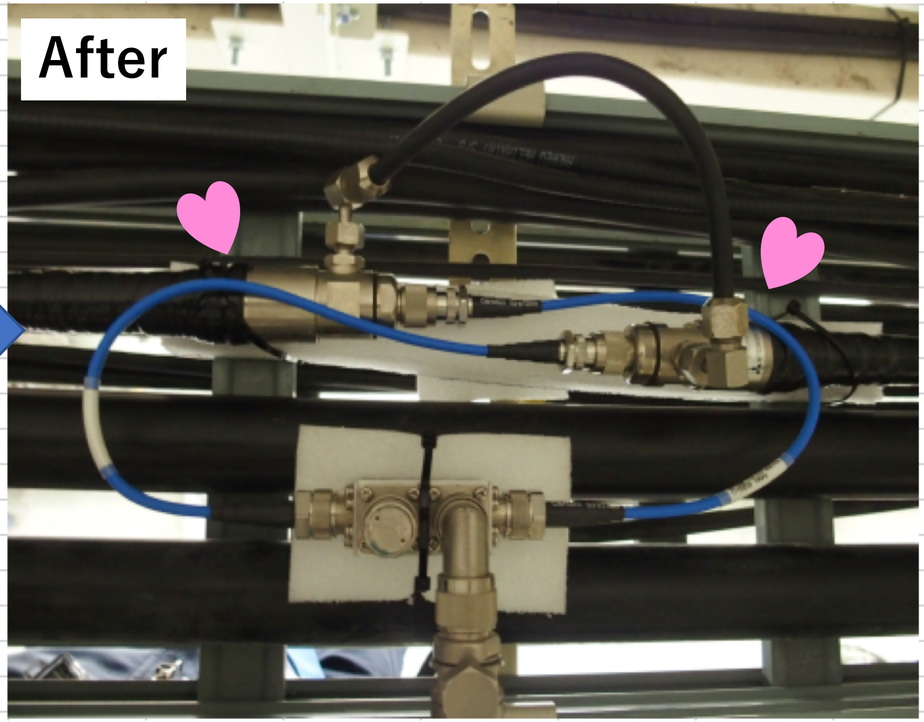
T. Miura, T. Matsumoto

18:00 Before tightening the cable 20:00 After



Cable re-connection



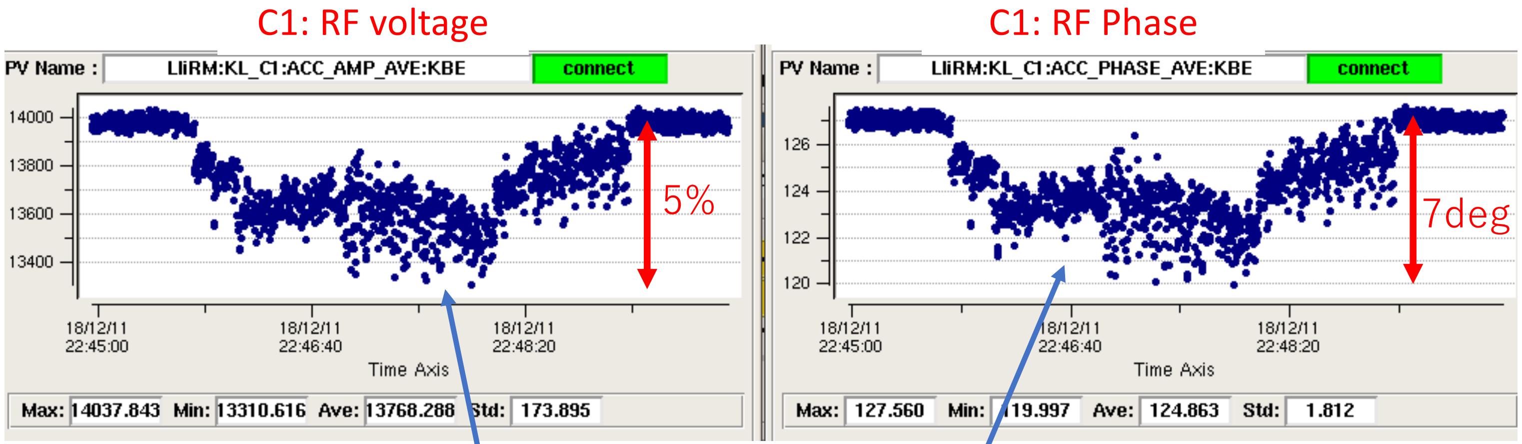


In the cable connection before work, since the cable was hard and thick, a force was applied to the connecting part, causing poor contact between the cables.

By holding a soft cable in between, the cables felt less stress any more.
In this winter shut down, some other connectors were re-connected.

(B) Beam energy stabilization

Other voltage fluctuation of klystron power supply



RF voltage / phase variation

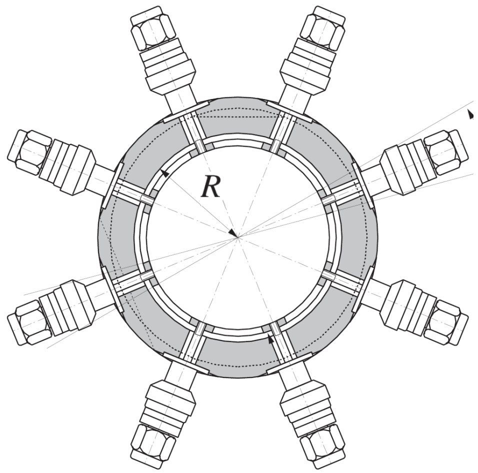
Sometimes the AC line voltage for klystron power supply drops.

Klystron output power is stabilized by
Induced Voltage Regulator (IVR) at the sudden change of AC line voltage.
In Phase 2, IVR stabilization had been done once an hour.

It is planed to establish the IVR feedback in Phase 3.

F. Miyahara

(C) Nondestructive Energy Spread Monitor : "OctoPos", eight electrode BPM in Jarc

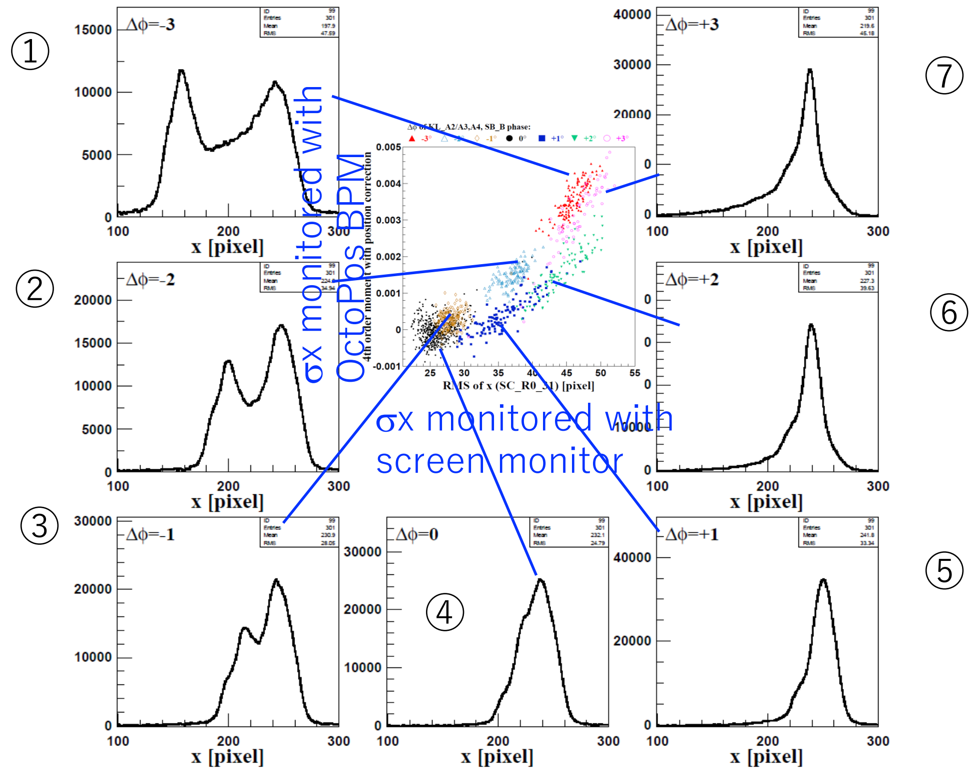


$$J_q = \frac{1}{R^2}(\langle x^2\rangle - \langle y^2\rangle + \langle x\rangle^2 - \langle y\rangle^2)$$

$$J_q = \frac{\sum_{i=1}^{N} V_i \cos 2\theta}{\sum_{i=1}^{N} V_i}.$$

The beam spread can be measured from the second moment.

Second moment and horizontal profile



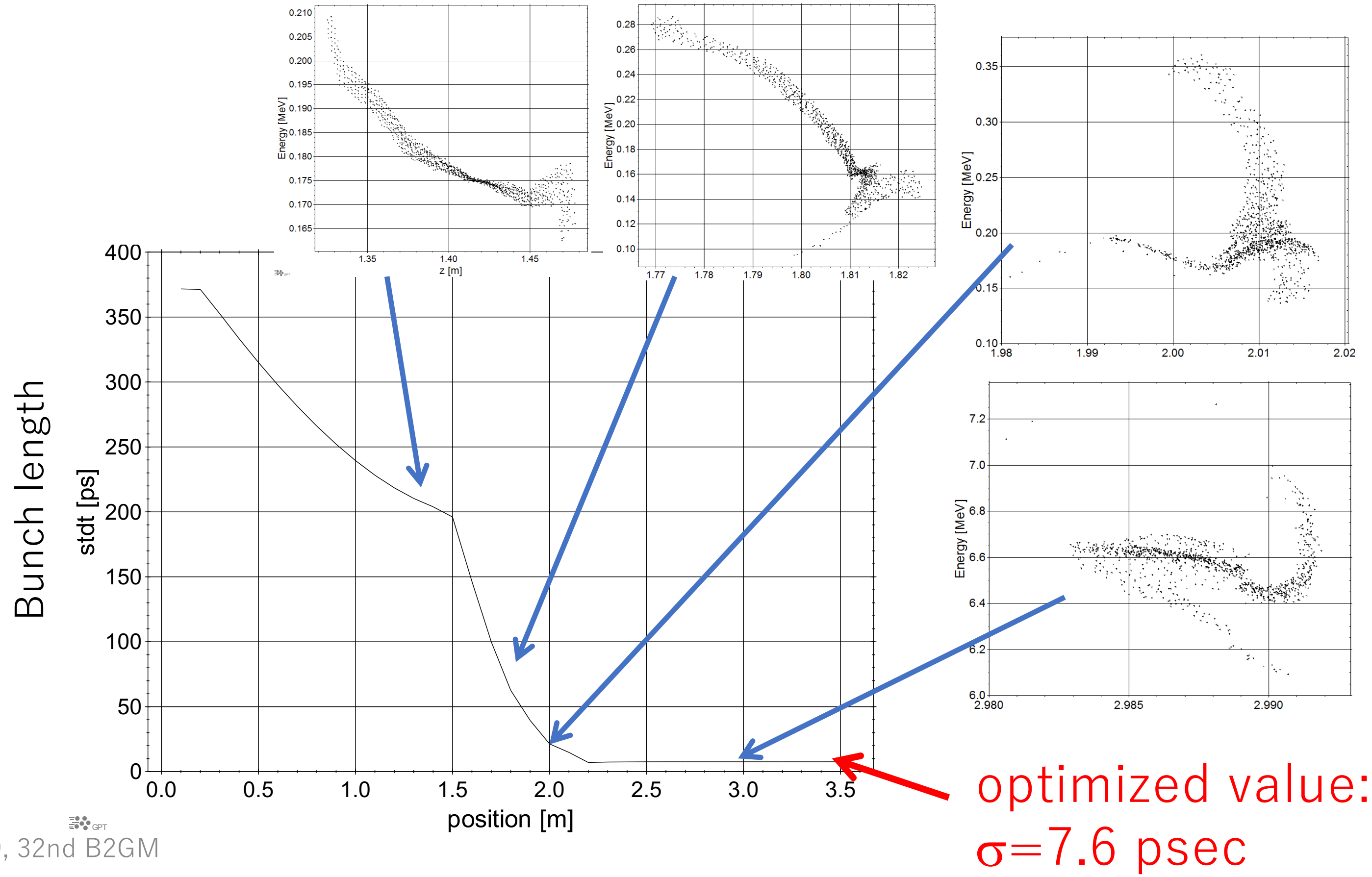
Although the profile with two peaks ② can not be recognized from ⑥ only with the second moment, it is important to keep the energy spread to ③ or ④.

There are two more OctoPos in the BT. We would like to use this monitor in Phase 3.

T. Natsui

(D) Bunching after the thermal gun (Simulation)

The beam dynamics in the bunching section is simulated with the GPT code.



T. Natsui

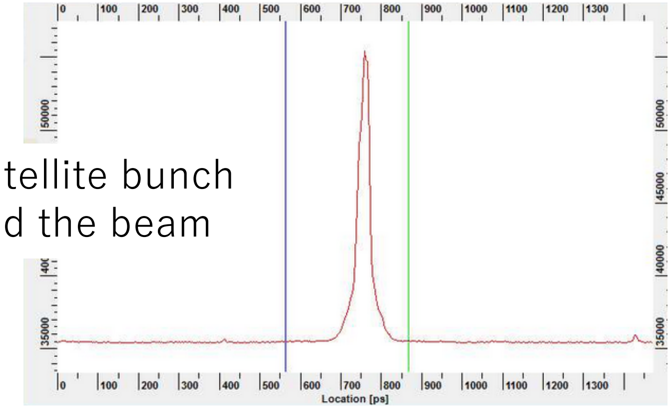
(D) Bunching after the thermal gun (Beam study)

- Oct. 29 Tuning with 10 nC-beam

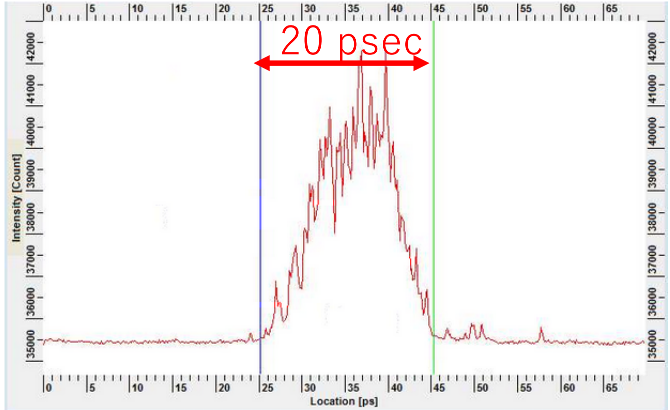
SHB1 : 9.4 kW, SHB2 : 3.2 kW

Monitored bunch length with a streak camera

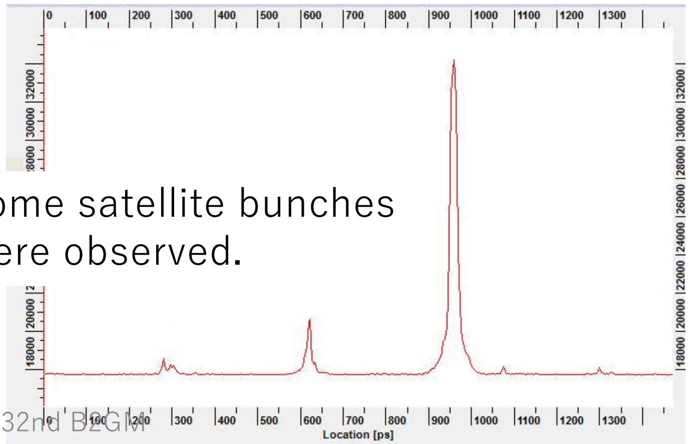
The bunch length is short enough.



No satellite bunch around the beam



- Nov. 22



Some satellite bunches were observed.

After 3weeks

The satellite bunches appeared, while the phases of the bunchers were not changed.
By the RF phase drift ?

We would like to monitor the phase drift of the SHB which can affect the BG due to the satellite.

Contents

3. Injection Beam for the beginning of Phase 3

1. Charge and Repetition Rate (Max.)

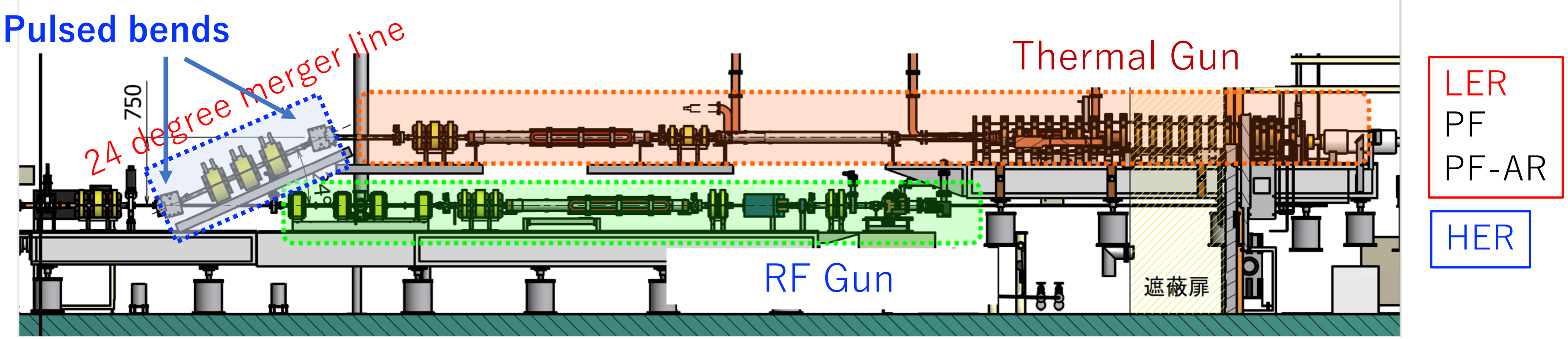
- LINAC RF: 50Hz
- HER : 2nC, 25Hz, 2 bunches
- LER : 2nC, 23Hz=25Hz-2Hz(PF+AR), 2 bunches
- They are enough for the top-up injection.

2. Emittance Preservation

- The big issue for the BG.

T. Kamitani

Merger Line (Sector A)



- Thermal gun
  - LER, PF, PF-AR (, HER)
  - Thermal gun
  - SHB1(114MHz)
  - SHB2(571MHz)
  - Pre-buncher
  - Buncher
  - Accelerating Structure(2mx2)
- RF gun
  - HER
  - 0-deg QTW RF gun
  - 90-deg CDS RF gun
  - Bunch Compress System(BCS)
  - Accelerating Structure(2mx1)
- 24 degree Merger Line
  - The pulsed bends for 25 Hz are available now.
  - 50 Hz operation will be ready in 2020 summer.

Lifetime and injection rate

Example : Phase 3-3ex Parameter

Assumed from the lifetime of Phase 2

	LER	
Life time [sec.]	600	N_b=1578, I_{tot}=2.0A
Loss Rate [mA/sec]	3.0	

$$-\left.\frac{dI}{dt}\right|_{Loss} = 3.0\mathrm{mA/s} \qquad \text{for } \mathrm{I} = 2000\mathrm{mA}, \quad \tau = 600\mathrm{sec}$$

$$\left.\frac{dI}{dt}\right|_{Inj} = \mathrm{N_e}\ \mathrm{f_{rev}} \qquad \mathrm{N_e} = \mathrm{Q_{BTend}} \cdot \mathrm{f_{rep}} \cdot \mathrm{n_{bunch}} \cdot \mathrm{eff_{inj}}$$

$$= 3.5\mathrm{mA/s}$$

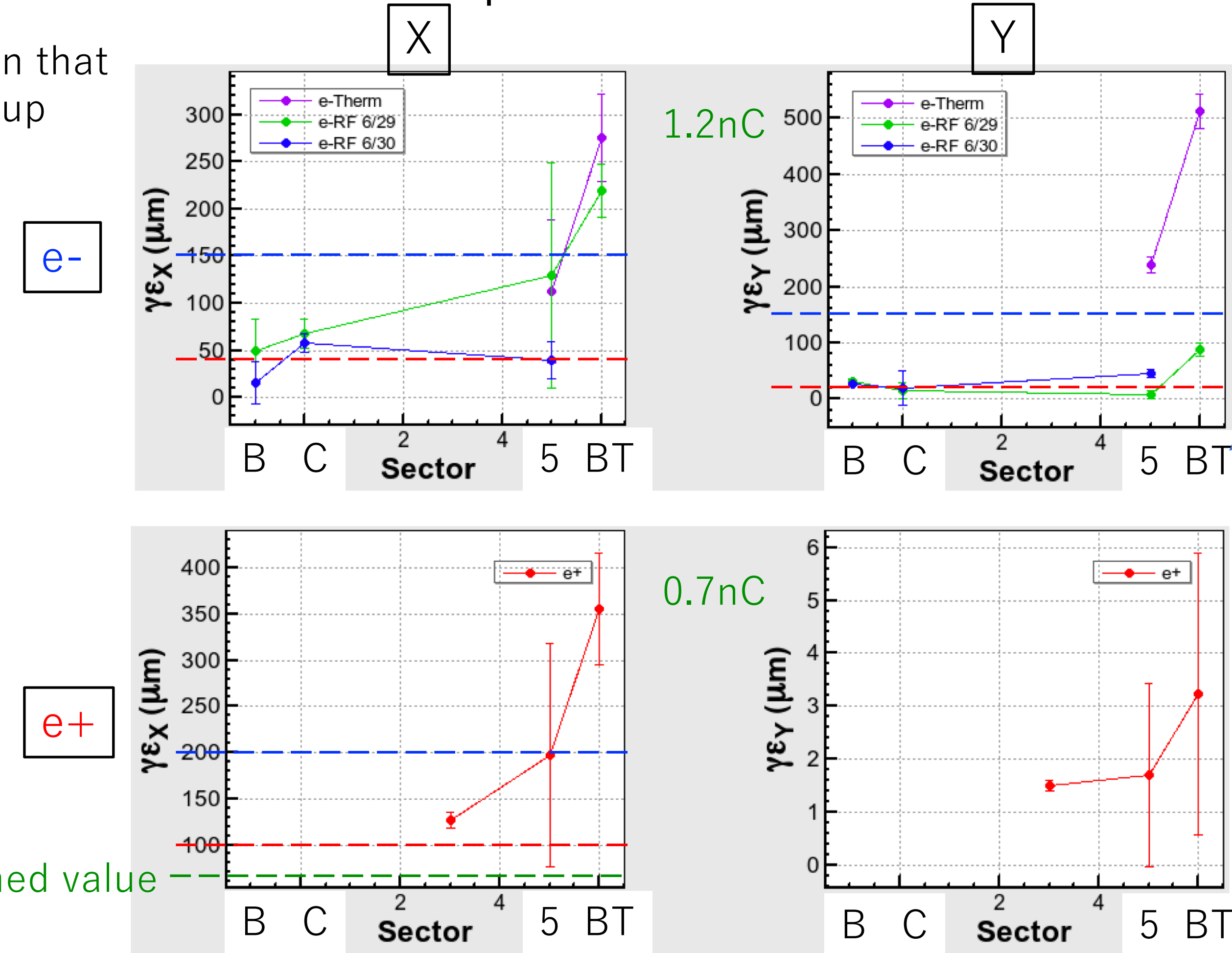
frev=100kHz
Q_{BTend}=1.0nC
f_{rep}=25Hz
n_{bunch}=2
eff_{inj}=70%

Even if such a low charge injection, the total beam current can be kept with 25Hz injection.

Emittance blowup in Phase 2

Final Request from MR
Phase2 ----------
Phase3 ----------

There is no question that the emittance blowup affects the BG.



Measurement at the upstream of BT

40 ----
15 ----

DR designed value ---

More beam studies at BT will be needed.

Schedule

There is no future schedule for a big modification now.

Linac Schedule Overview as of Jun.2018

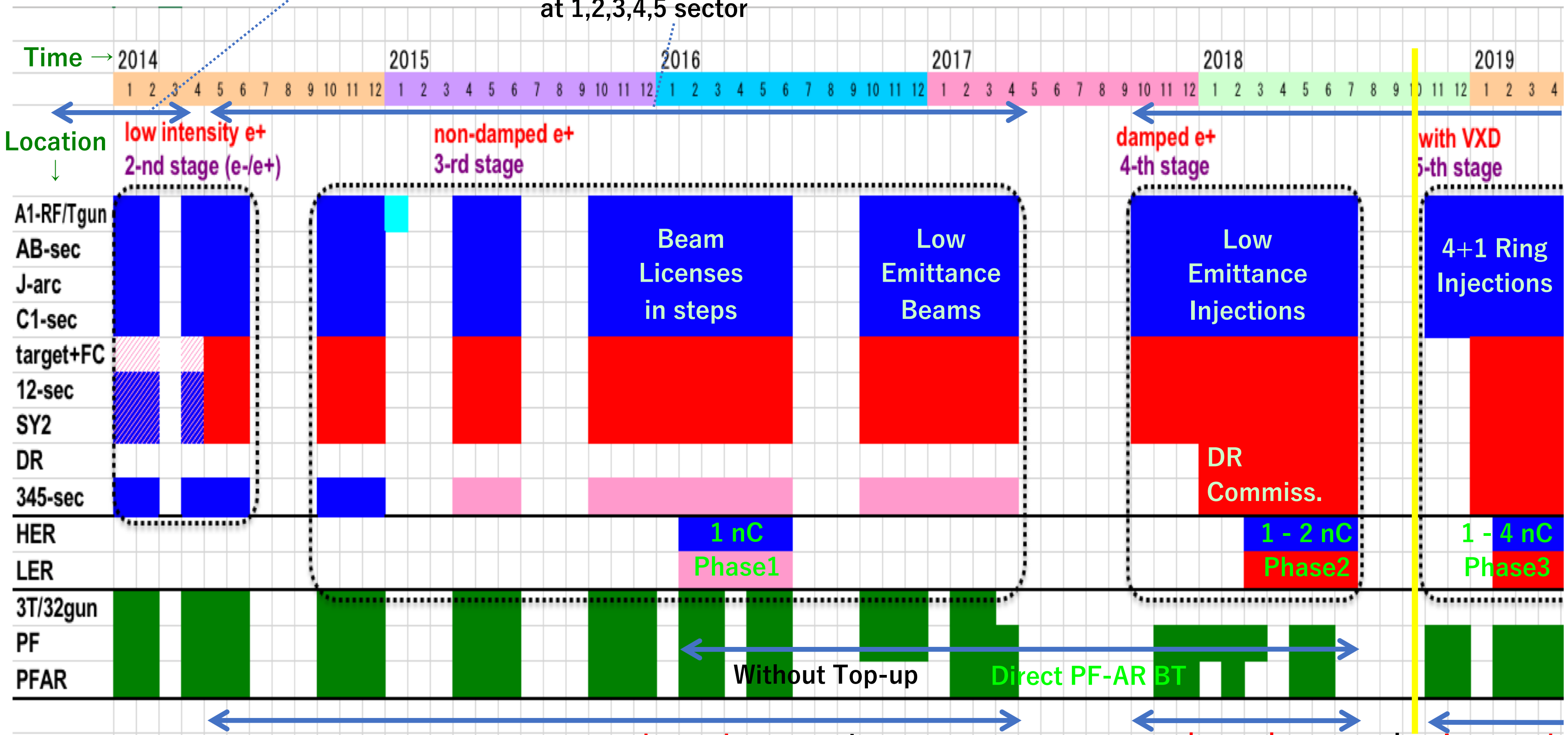
RF-Gun e- beam commissioning at A,B-sector

e- commiss. at A,B,R,C,1

e+ commiss. at 1,2 sector (FC, DCS, Qe- 50%)
e- commiss. at 1,2,3,4,5 sector

Phase1: high emittance beam for vacuum scrub
Phase2,3: low emittance beam for collision

Summer 2020



24 degree line ready for 50Hz operation

■ : Electron
■ : Positron
■ : Low current electron

non damped e+ commiss.
at 1,2, 3,4,5 sectors
e- commiss. at A→5 sectors

damped e+ commiss.
at 1→5 Qe+ = 1~4nC
e- commiss.
at A→5 Qe- = 1~4nC

Improved RF gun

4. Summary

1. Injection background(BG) during Phase 2
    - The deviations of the injection beam mainly related beam energy could be the BG source.
2. Progress of LINAC study for autumn, 2018
    - The voltage and phase monitors of RF, OctoPos BPM are powerful tools.
    - In Phase 3, we would like to use them to test and operate feedback tools.
3. Injection beam for the beginning of Phase 3
    - The charge and repetition rate are enough for Phase 3-3ex.
    - The studies for the emittance preservation are needed in LINAC and the BT.
    - More studies for LINAC including BT are indispensable !

Backup

Life and minimum injection

Example 1:

	LER	
Life time [sec.]	1200	N_b=1578, I_{tot}=1A
Loss Rate [mA/sec]	0.83	

$$-\left.\frac{dI}{dt}\right|_{Loss} = 0.83\mathrm{mA/s} \qquad \text{for } \mathrm{I} = 1000\mathrm{mA},\quad \tau = 1200\mathrm{sec}$$

$$\left.\frac{dI}{dt}\right|_{Inj} = \mathrm{N_e\, f_{rev}} \qquad \mathrm{N_e = Q_{BTend} \cdot f_{rep} \cdot n_{bunch} \cdot eff_{inj}}$$

$$= 1.8\mathrm{mA/s}$$

frev=100k
Q_{BTend}=1.0nC
f_{rep}=25Hz
n_{bunch}=1
eff_{inj}=70%

Even if such a low charge injection, the total beam current can be kept with 25Hz injection.

Lifetime and injection rate

Example : Phase 3-3 Parameter

	LER	
Life time [sec.]	670	N_b=1578, I_{tot}=1.8A
Loss Rate [mA/sec]	2.6	

$$-\left.\frac{dI}{dt}\right|_{Loss} = 2.6\mathrm{mA/s} \qquad \text{for } \mathrm{I} = 1800\mathrm{mA}, \quad \tau = 670\mathrm{sec}$$

$$\left.\frac{dI}{dt}\right|_{Inj} = \mathrm{N_e}\ \mathrm{f_{rev}} \qquad \mathrm{N_e} = \mathrm{Q_{BTend}} \cdot \mathrm{f_{rep}} \cdot \mathrm{n_{bunch}} \cdot \mathrm{eff_{inj}}$$

$$= 3.5\mathrm{mA/s}$$

frev=100k
Q_{BTend}=1.0nC
f_{rep}=25Hz
n_{bunch}=2
eff_{inj}=70%

Even if such a low charge injection, the total beam current can be kept with 25Hz injection.