INTER-UNIVERSITY RESEARCH INSTITUTE CORPORATION
HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION
KEK

RF 電子銃の進展と入射器の現状

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第118回Bファクトリー計画推進委員会
2020.9.30

Linac Beam Parameters for KEKB/SuperKEKB

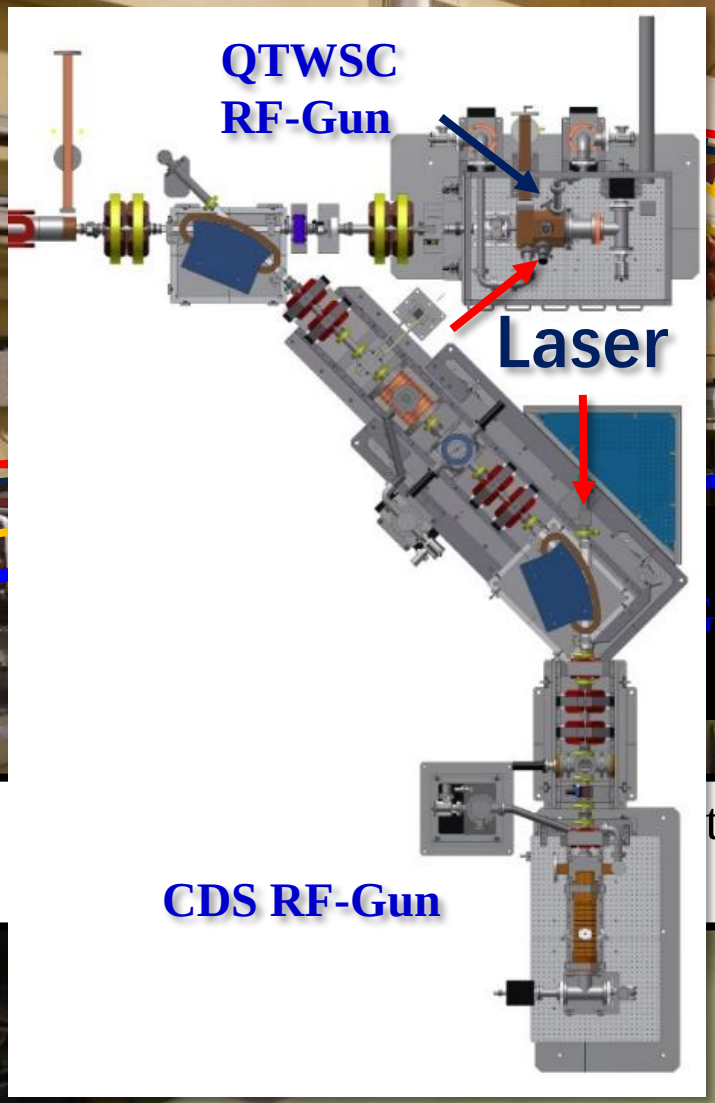
Stage	KEKB (final)		Phase-I		Phase-II		Phase-III (interim)		Phase-III (final)	
Beam	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Stored current	1.6 A	1.1 A	1.0 A	1.0 A	–	–	1.8 A	1.3 A	3.6 A	2.6 A
Life time (min.)	150	200	100	100	–	–	–	–	6	6
Bunch charge (nC)	primary e- 10 → 1	1	primary e- 8 → 0.4	1	0.5	1	2	2	primary e- 10 →**4**	**4**
Norm. Emittance (**gbe**) (mmrad)	1400	310	1000	130	200/40 (Hor./Ver.)	150	**150/30** (Hor./Ver.)	**100/40** (Hor./Ver.)	**100/15** (Hor./Ver.)	**40/20** (Hor./Ver.)
Energy spread	0.13%	0.13%	0.50%	0.50%	0.16%	0.10%	0.16%	0.10%	0.16%	0.07%
Bunch / Pulse	2	2	2	2	2	2	2	2	2	2
Repetition rate	50 Hz		25 Hz		25 Hz		50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (LER, HER, PF)		No top-up		Partially		4+1 rings (LER, HER, DR, PF, PF-AR)		4+1 rings (LER, HER, DR, PF, PF-AR)	

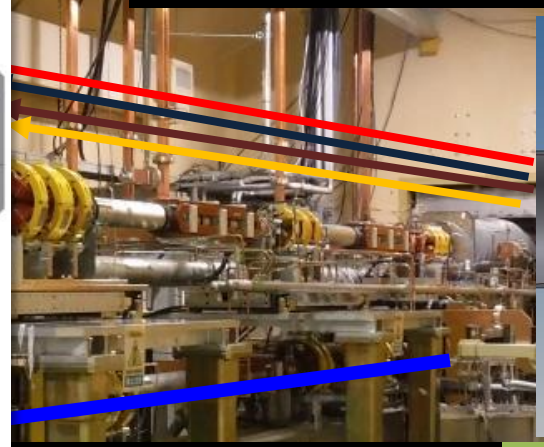
current stage

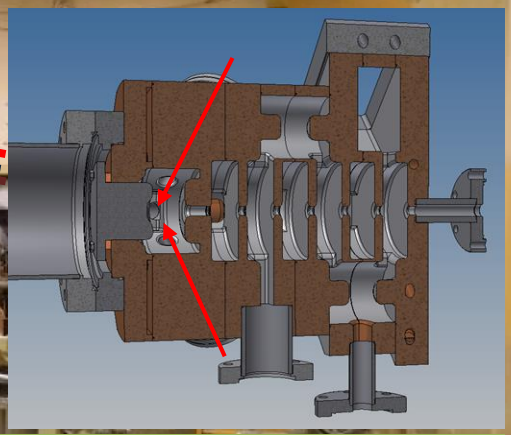
Pulse to pulse switching: rf e- gun/thermionic e- gun

Thermionic DC e- gun
(GU_AT)

- e+ production e-: 10 nC (for LER injection)
- PF injection: 0.3 nC
- PF-AR injection: 0.3 nC





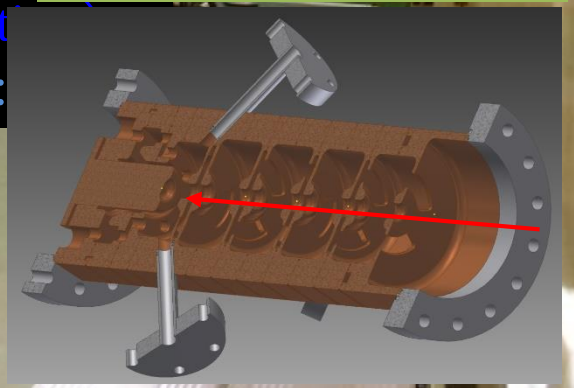


RF e- gun

R_A1 for HER inject
study/HER injection:

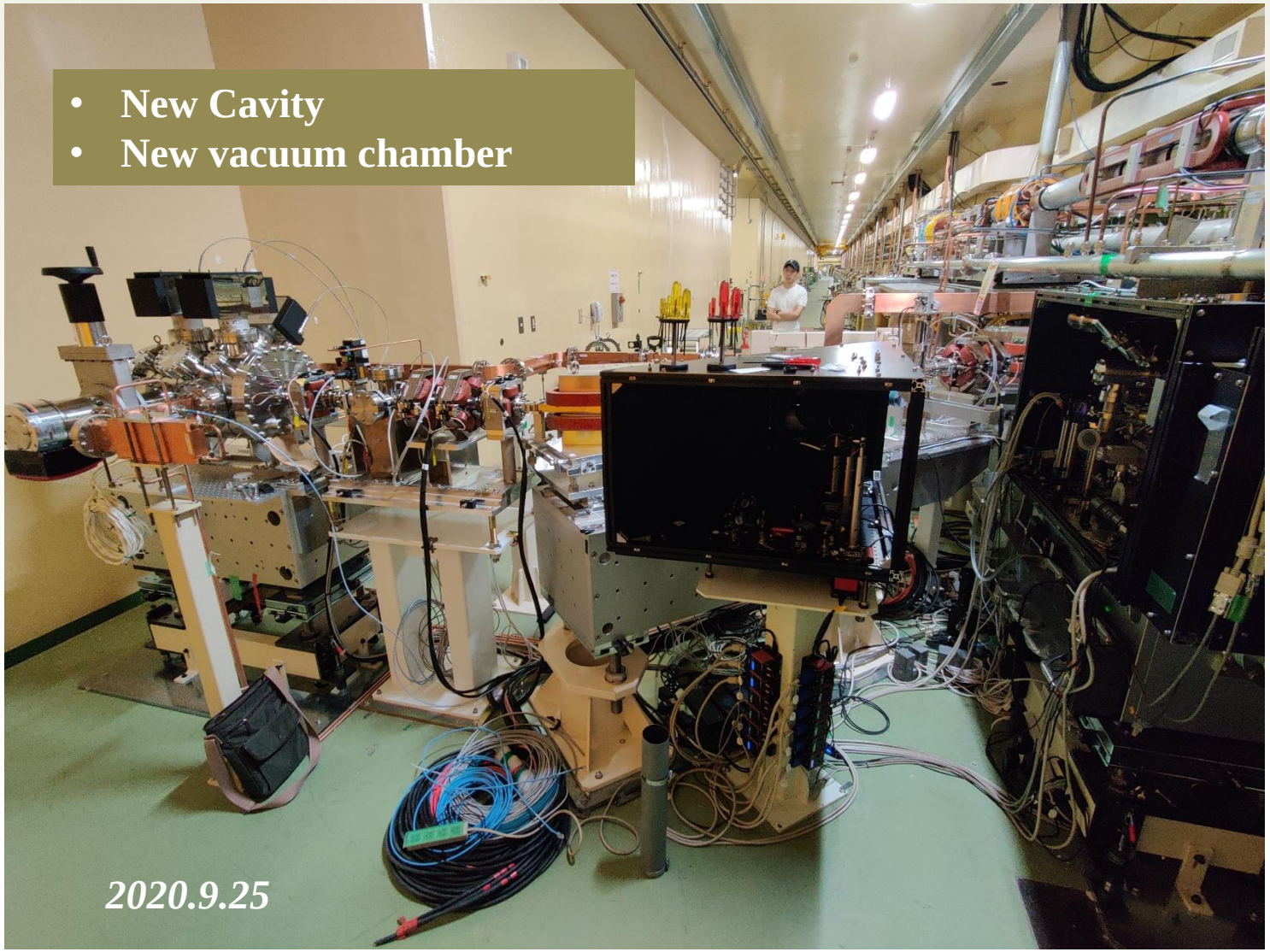
Primary RF gun

top up

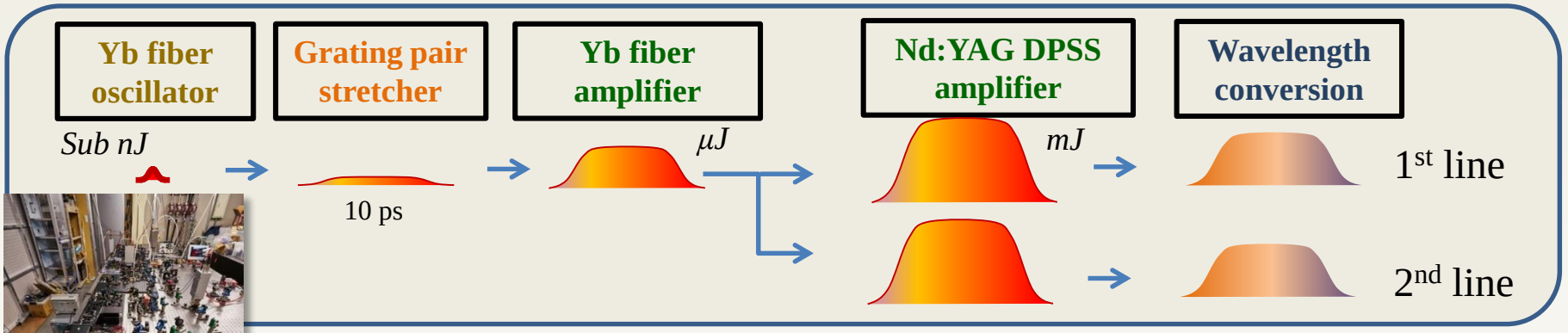


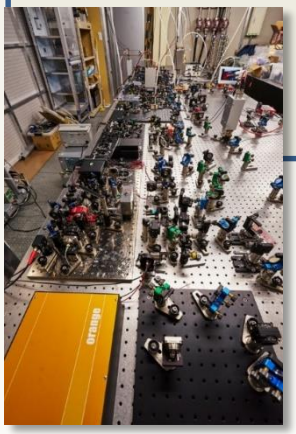
Secondary RF gun

CDS電子銃

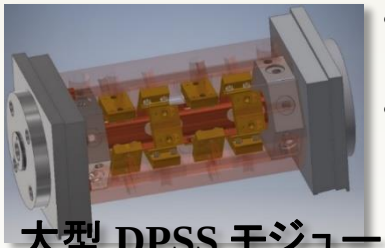


Laser system development



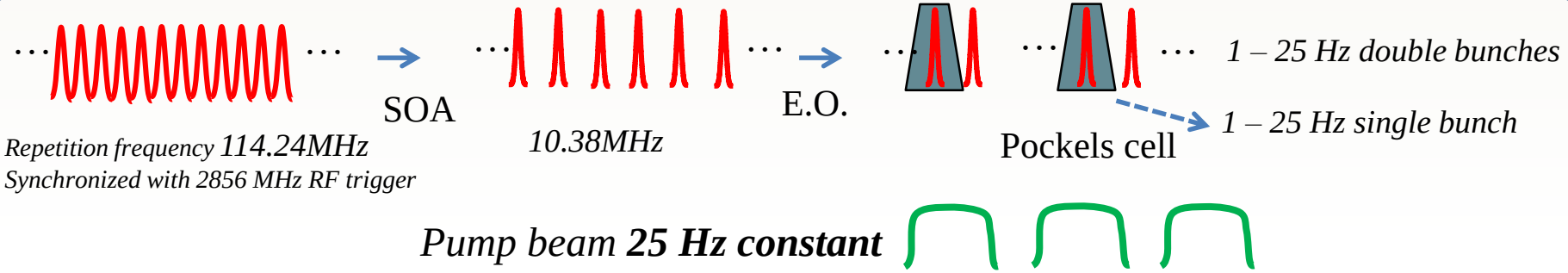


- Oscillator and pulse pickers are synchronized with the RF signal
- Fiber structures with no cooling system



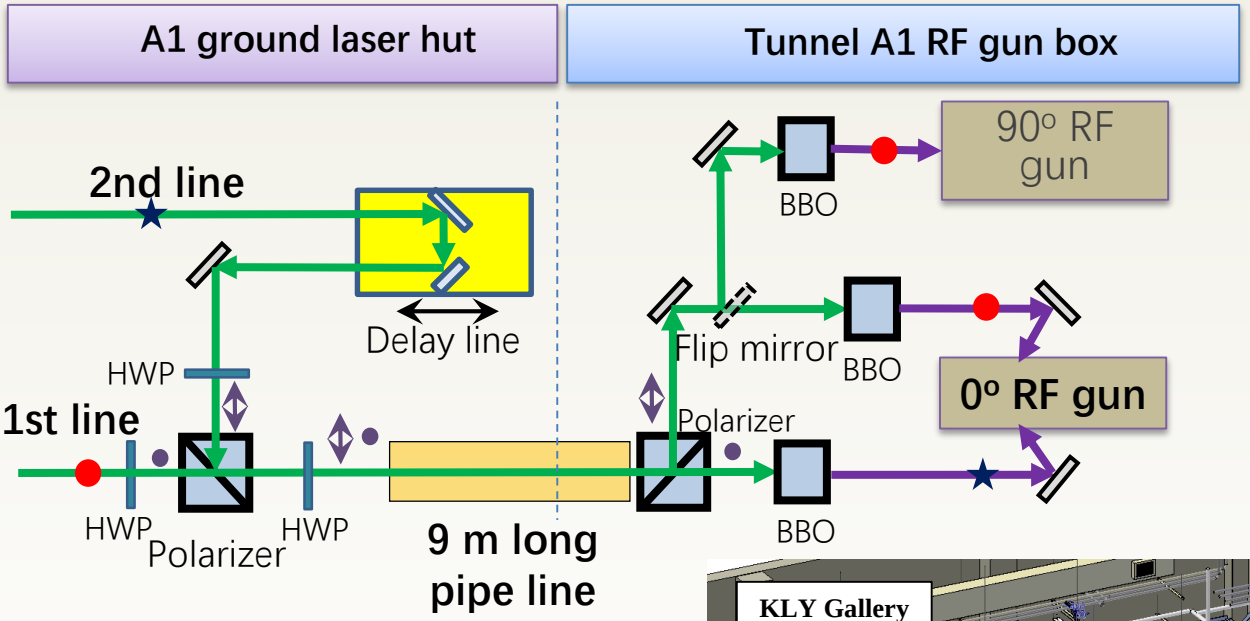
- Final state Pump @ 808 nm 1.2 kW ×12=14.4 kW=3.6 J DPSS (*2020.7*)
- Output Power: *ω(1030 nm):32 mJ, 2ω(515 nm):13 mJ, 4ω(257 nm):1.8 mJ* 1st line only

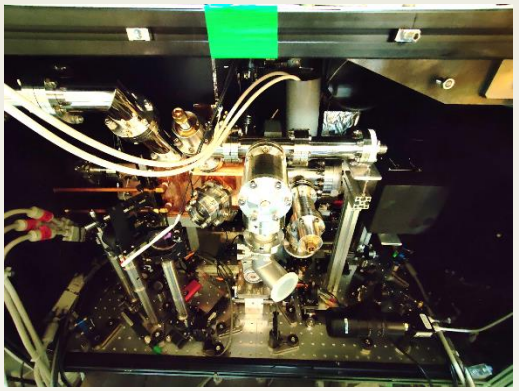
大型 DPSS モジュールへ交換 (*2020.7*)



- 2 beam sources
- 1 – 25 Hz single/double bunches selectable
- Several month 24h/day running without maintenance

Laser transport line



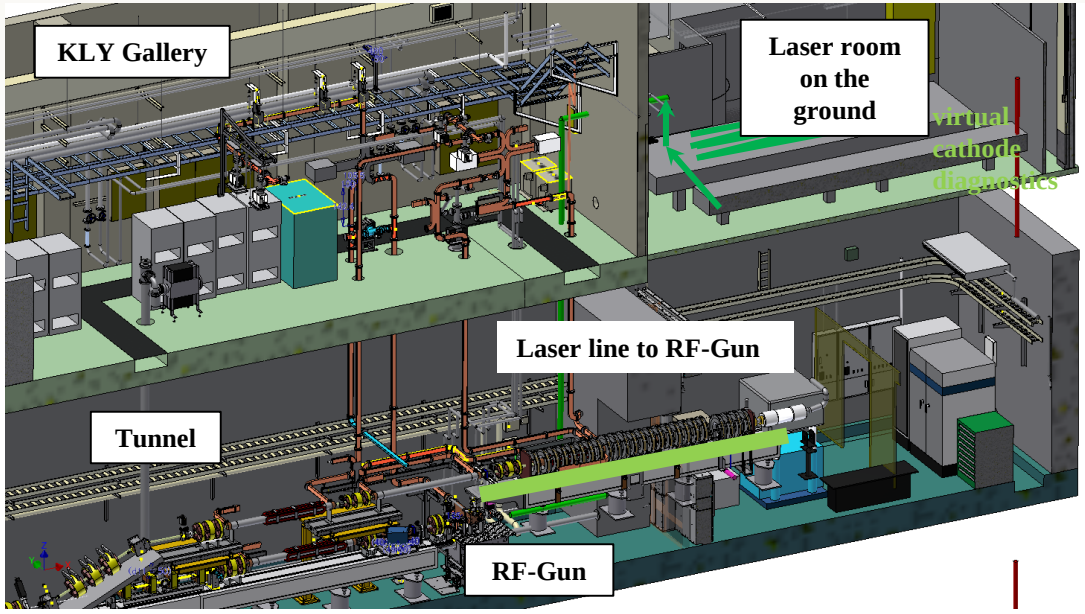


Operating mode

Single laser injection
- For both guns

Two lasers injection
- High charge
- Source(1st) + Clean(2nd)
- 25(1st) + 25(2nd) = 50 Hz

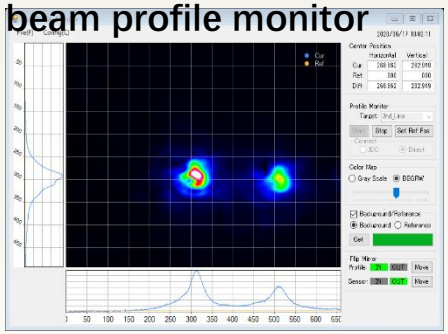
- Monitoring all the laser situation and synchronization state.
- Remote control system
- Realize real time UV laser beam profile monitor
- Improve temperature stability in the laser hut
- Beam position monitor and auto feedback program

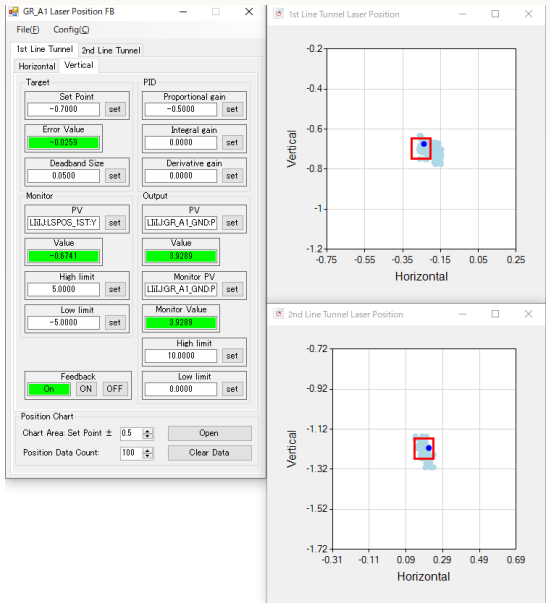


GR_A1用レーザーポジションフィードバック制御システム (*2020.9.24*)

従来のやり方：
X/Yを手動調整

beam profile monitor



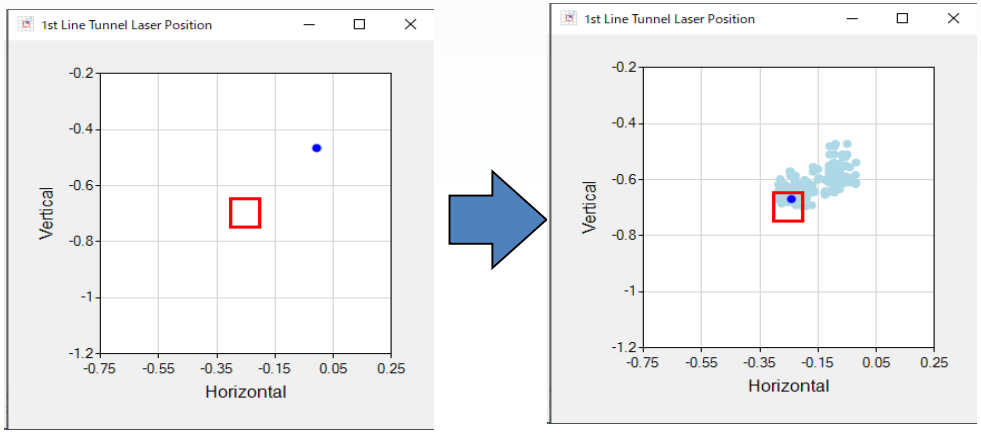


●現在のレーザーポジション
●ポジションの変化履歴
□この範囲から外れるとフィードバックが動作する。

・ポジションの調整はA1地上ハット内のピエゾアジャスタ付きミラーマウントで行っている。

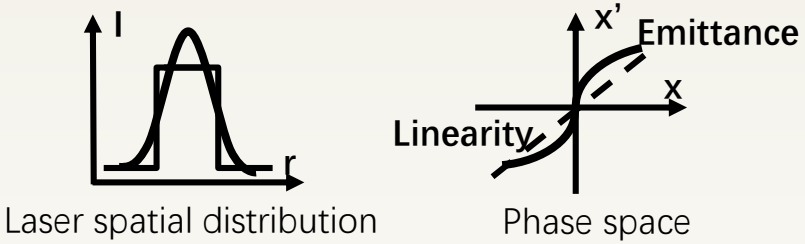
・実際のフィードバックは EPICS IOC で行っている。

フィードバック動作確認時のポジション

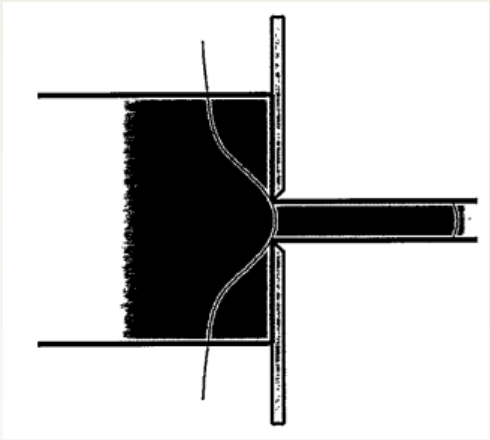


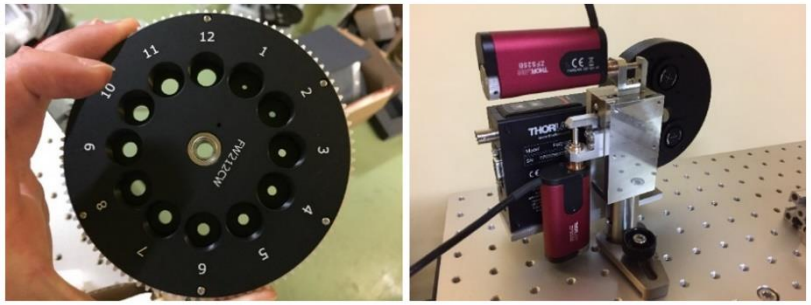
Profile reshaping (*2019*)

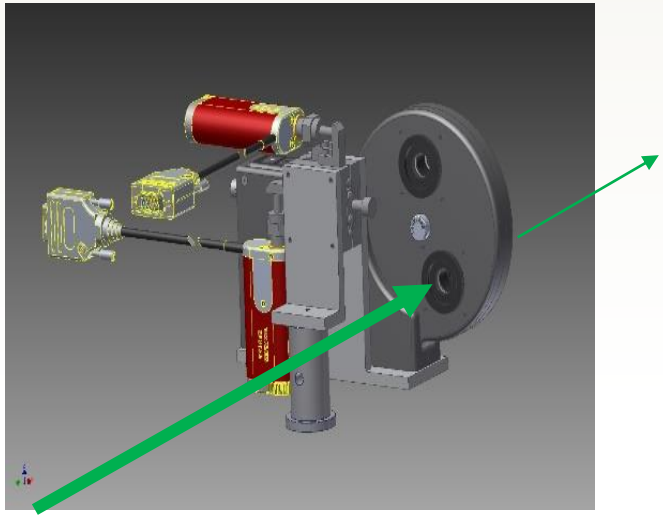
- **Aperture of the beam illustrated**



Laser spatial distribution　　Phase space





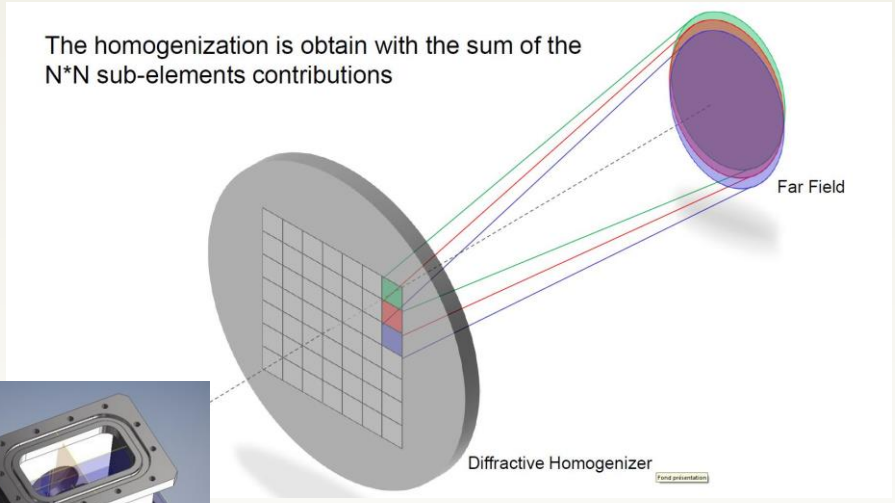


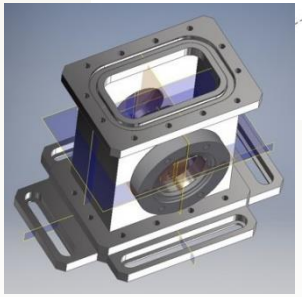
- 秋運転から、2nd ラインのみ
- ビーム径を調整

Reshaping of laser spatial distribution

1st line only (*2020.7*)

- Laser beam homogenizer: Diffractive optical element (**DOE**) for flat-top distribution
- Special compact vacuum chamber is designed, due to the micro structure is weak at dust



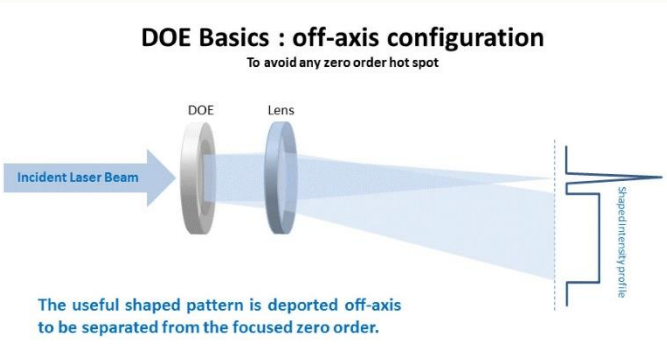


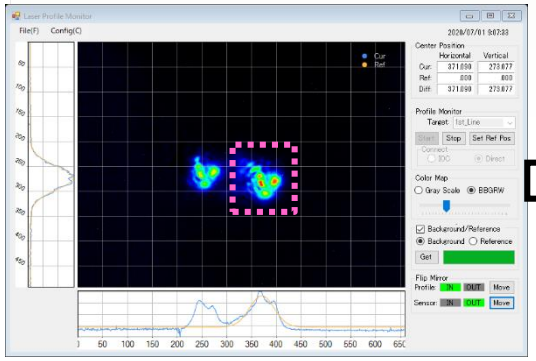
✓ No electrical discharge with high charge commissioning

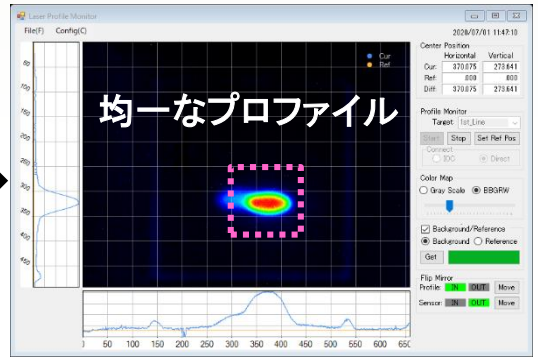
✓ Laser beam stability is also improved

☐ Low emittance effect is expected

× Beam size is fixed (For high charge)





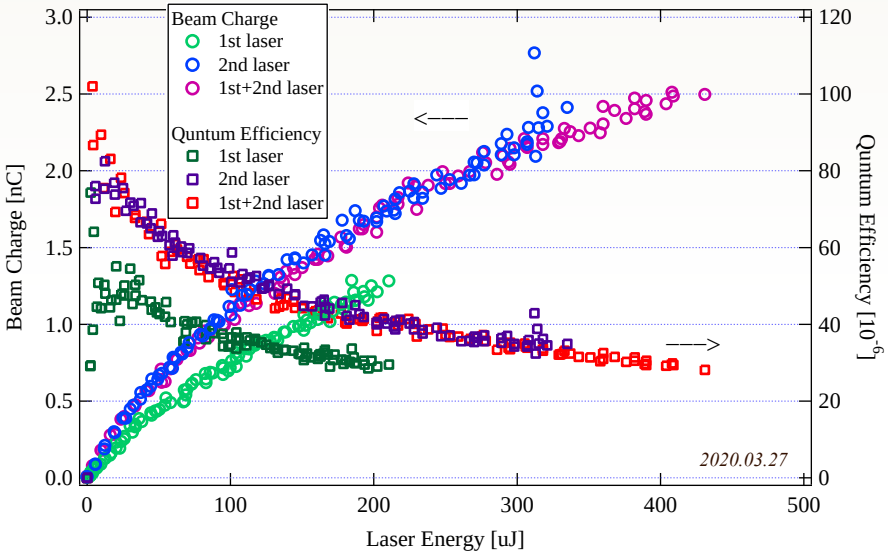


QE & Lifetime

	Off line	On line
Ir_5Ce	1.5×10^{-4}	1.5×10^{-5}（3-2）
Ir_7Ce_2 + Heating (2018)	1.0×10^{-4}	1.5×10^{-5}（A1）
Ir_2Ce + Heating +Better vacuum(2019)	5.0×10^{-4}	2.0×10^{-4}（A1）
Ir_7Ce_2+ Laser Clean (2020)	-	1.0×10^{-4}（A1）

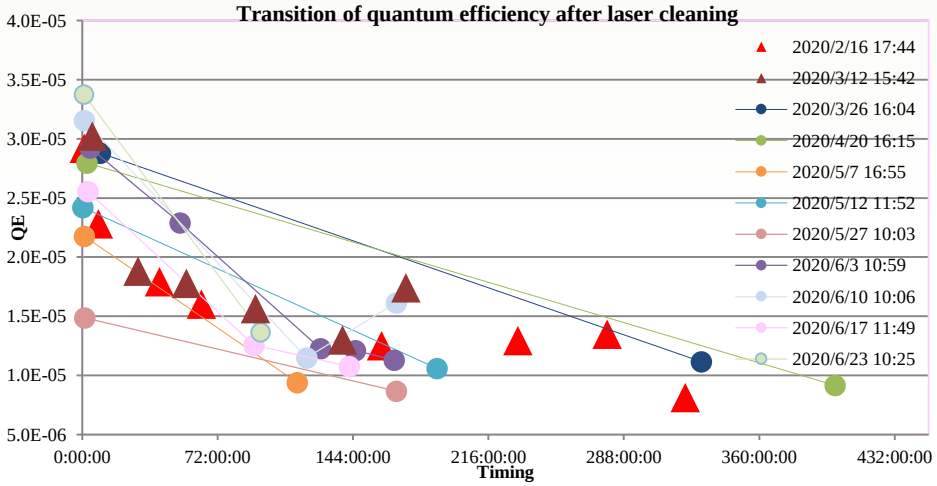
The QE dependence of the laser energy

- QE decreasing by increase the laser energy

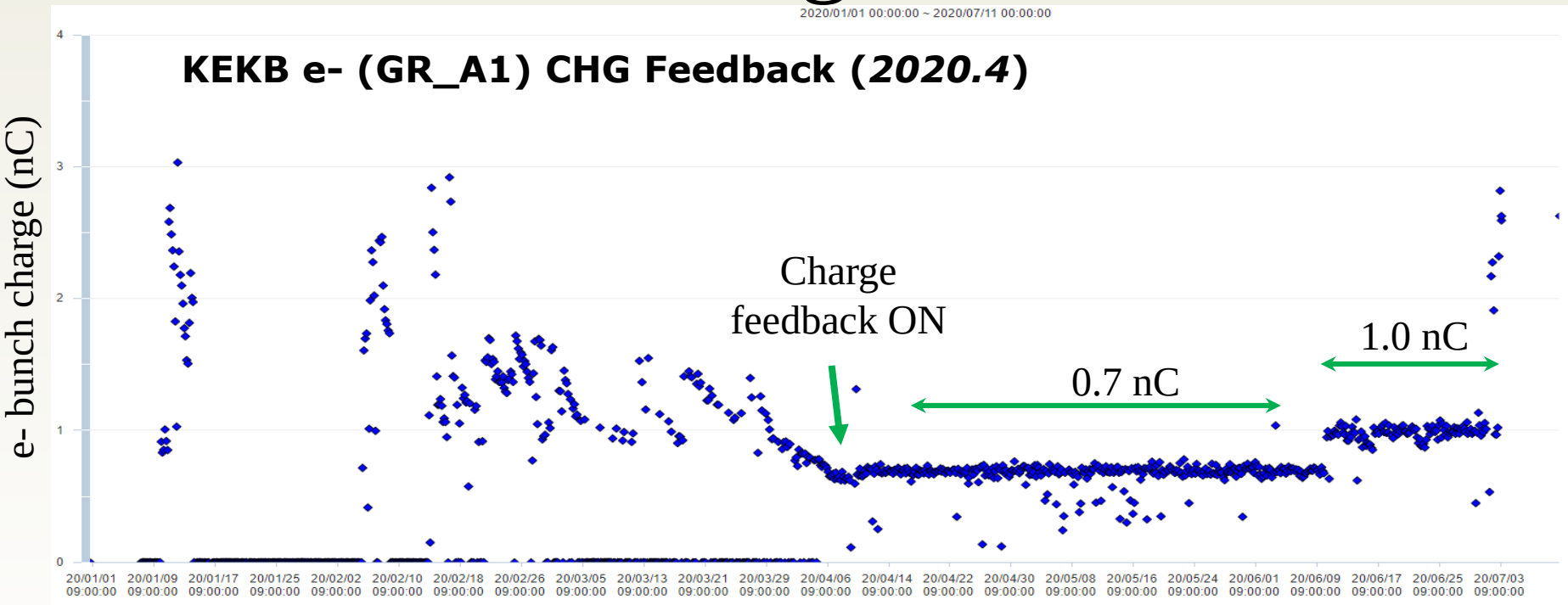


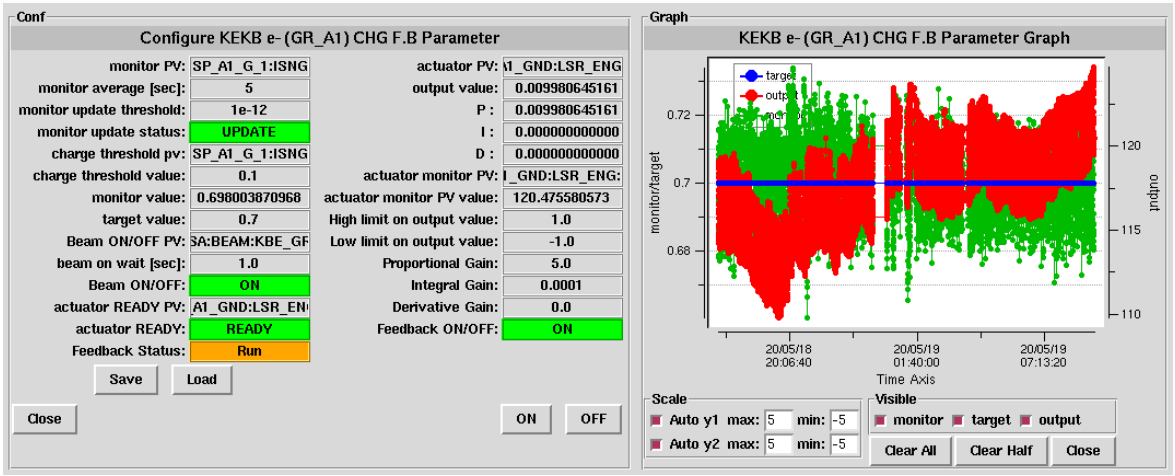
The QE transition of the time

- The QE drops rapidly, from about 50 hours after cleaning.
- After that, it appears to be gradually decreasing.



Bunch Charge feedback

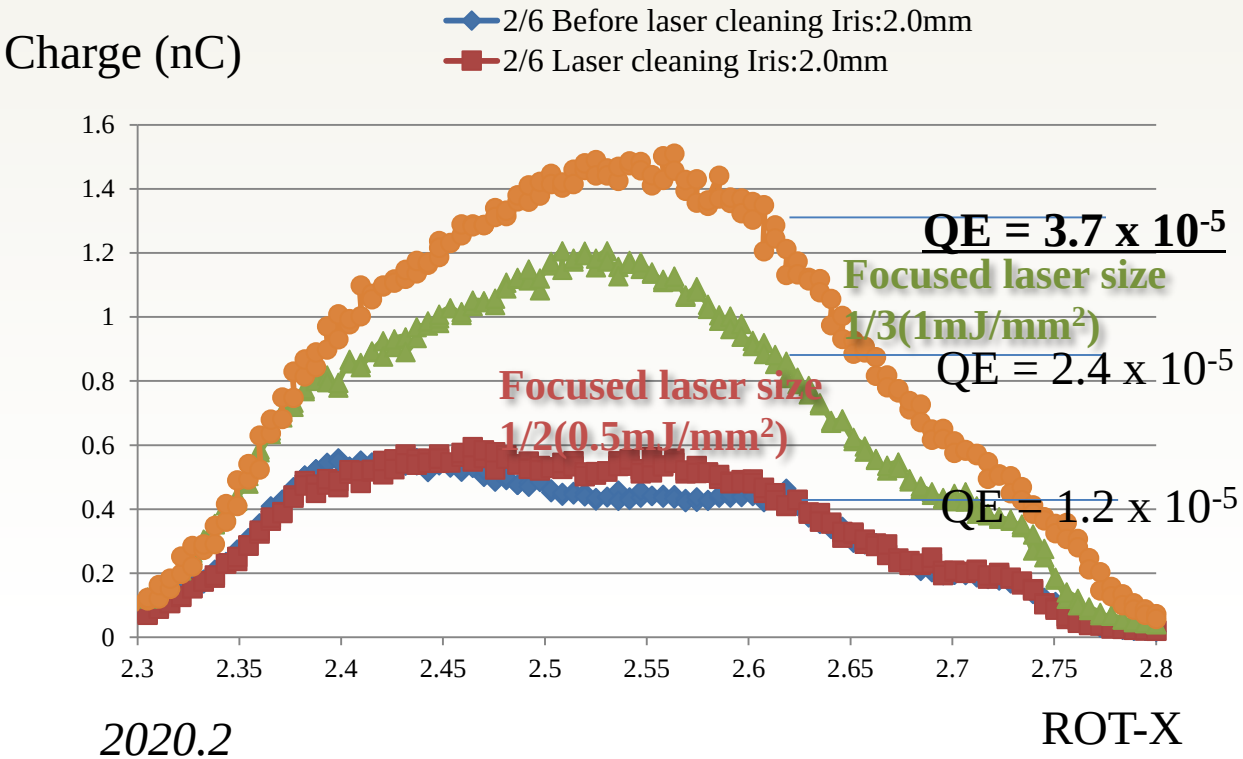


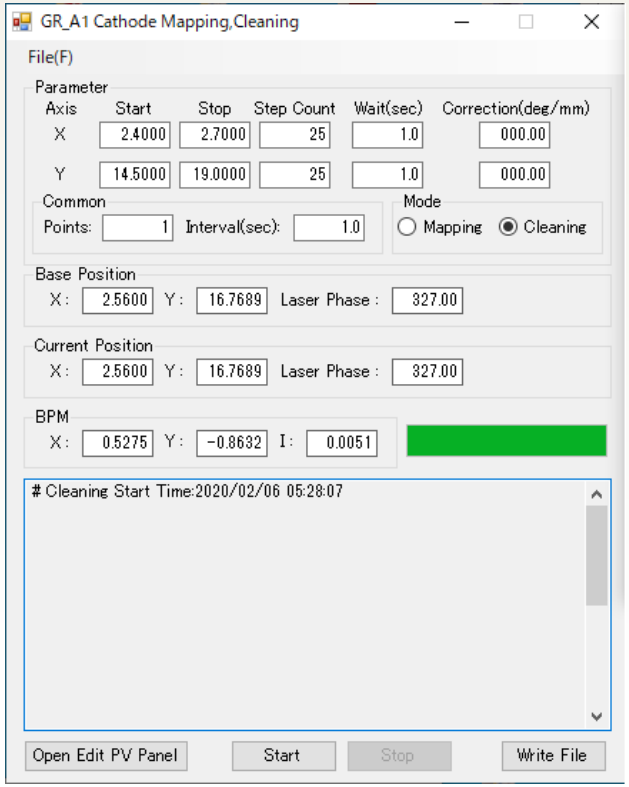


- チャージ量が指定値 となるよう、レーザーエネルギーを調整する
- 調整方法:波長板を調整する。(自動・手動)

Laser cleaning / Focused laser size

- Irradiation of shorter-wavelength laser (2nd laser line only)
- Scan using focused laser beam without RF
- Laser cleaning works for recovering QE in maintenance day (every two weeks)
- Automatically running by program

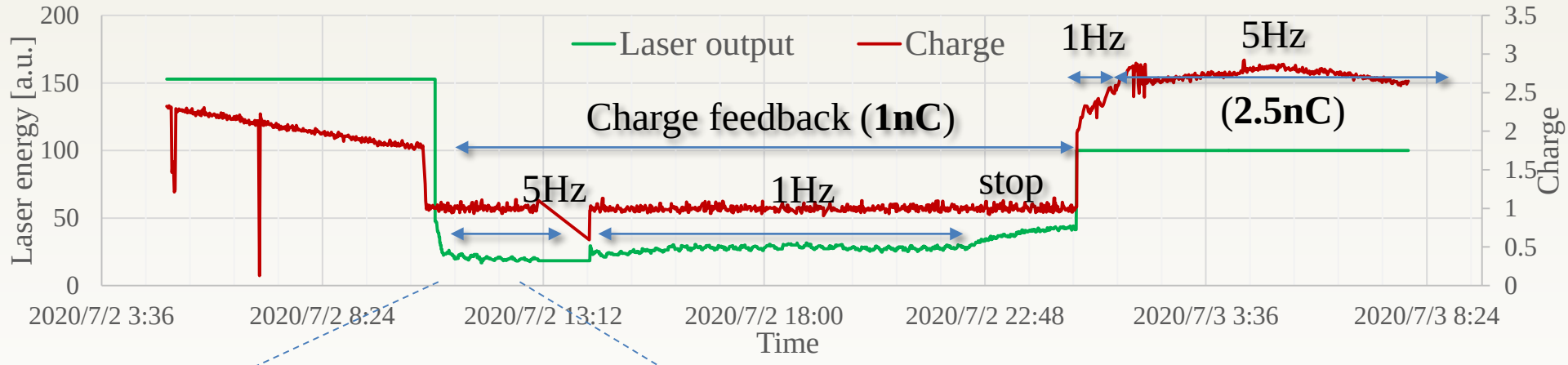


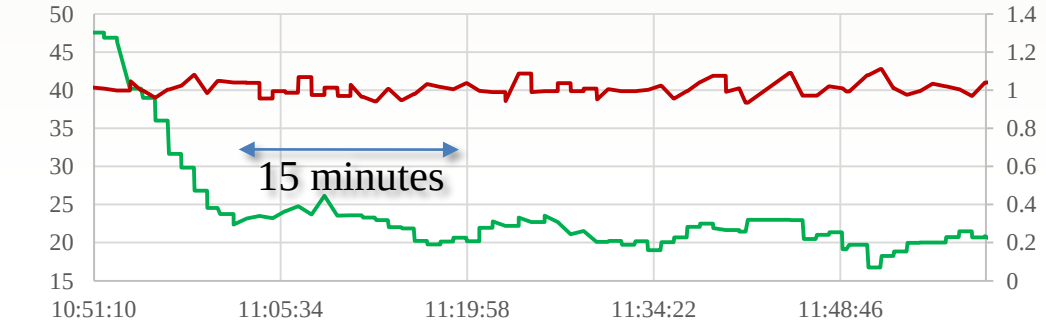


量子効率Mapping と Laser Clearningプログラムを開発した

常時Laser Cleaning On (量子効率の長寿命化)

1st line: ~700μJ　　2nd line (clean laser) : 300μJ

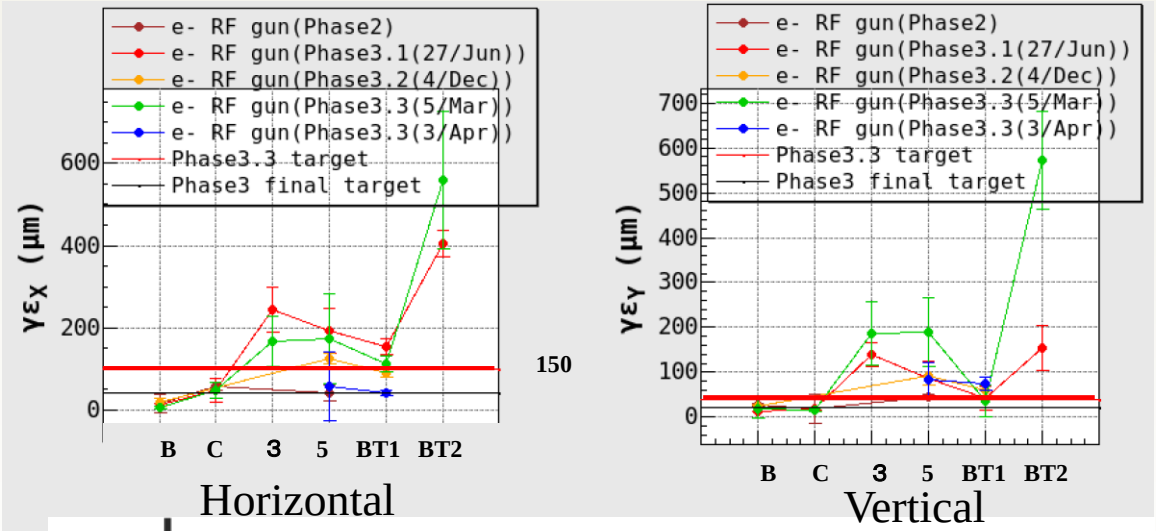


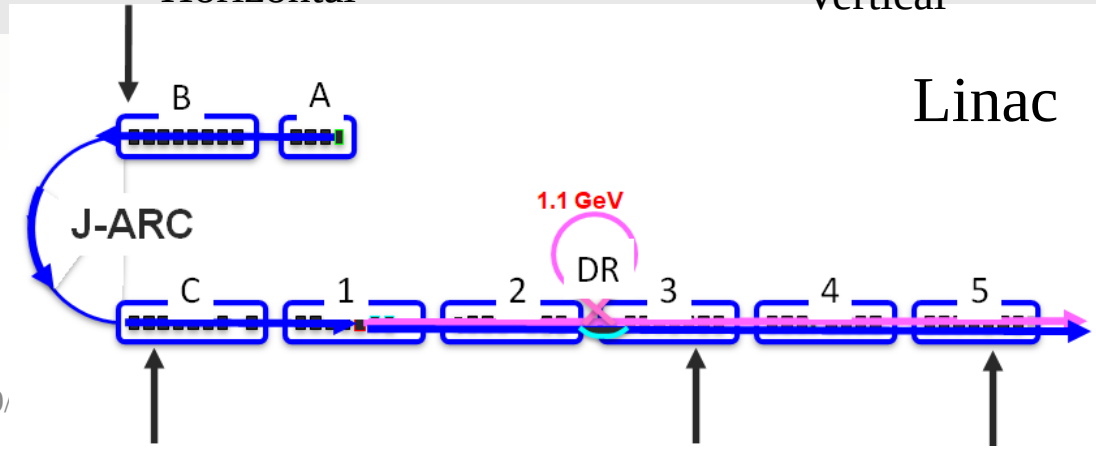


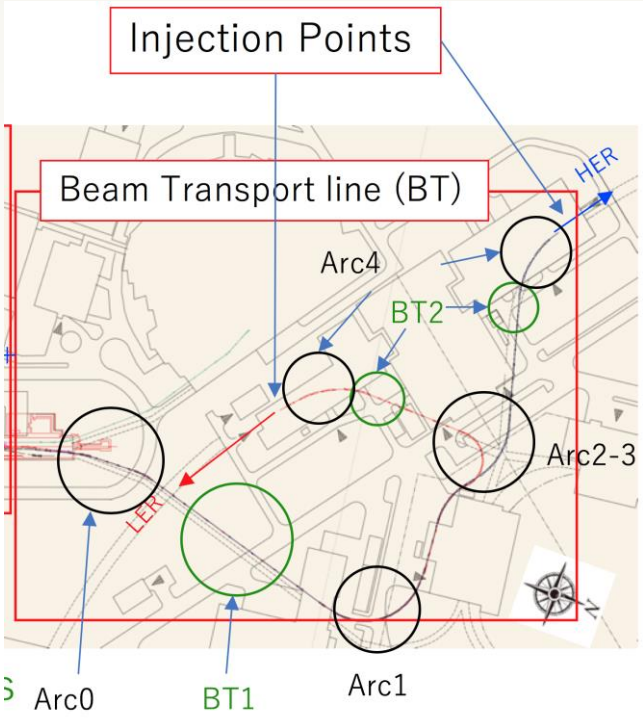
- Adjust the laser output energy to stabilize the charge
- Continuous laser cleaning between pulses
- No discharge (maybe due to DOE)
- Maintains at 2.5 nC

e- beam emittance (～ 1 nC)

- εx,y ～15 μm at Sector-B, Sector-C
- Emittance growth at BT2 in both directions.
- Emittance could be increased at around solenoid section in Sector1.

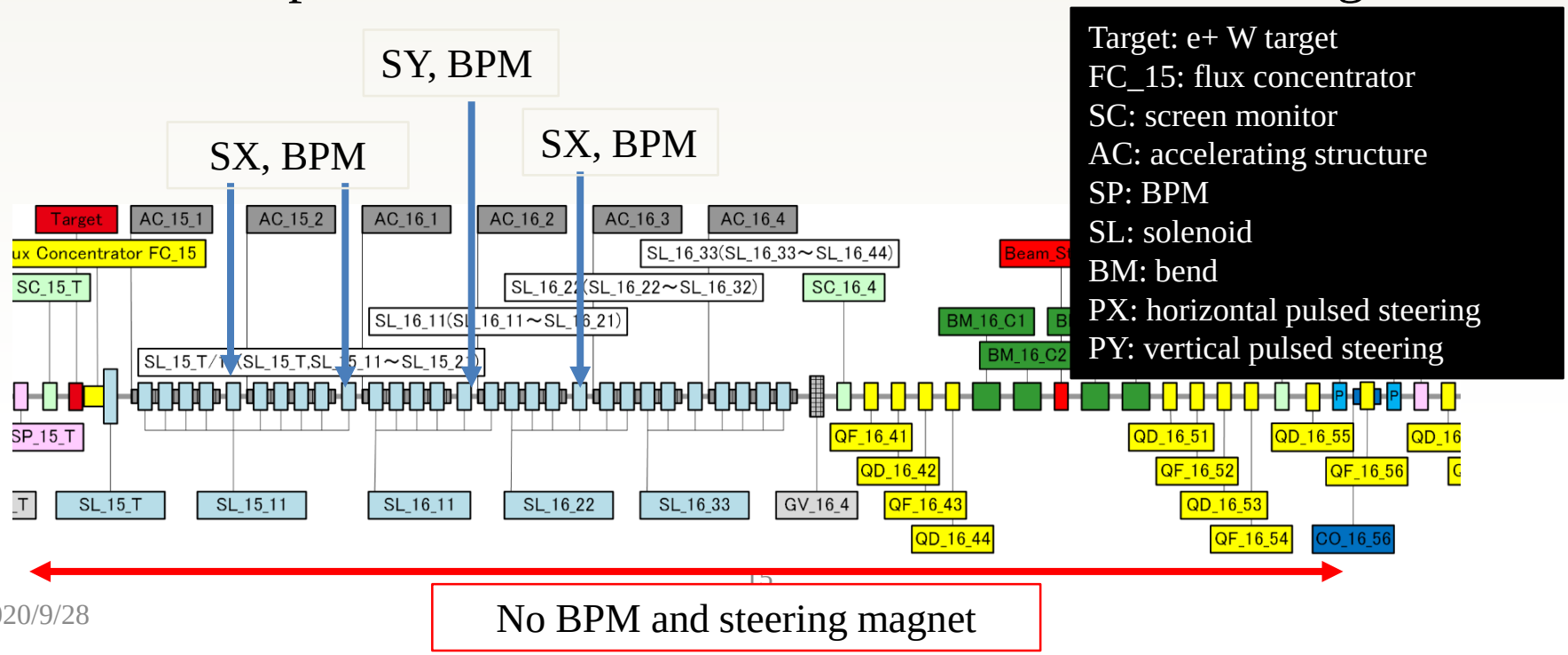






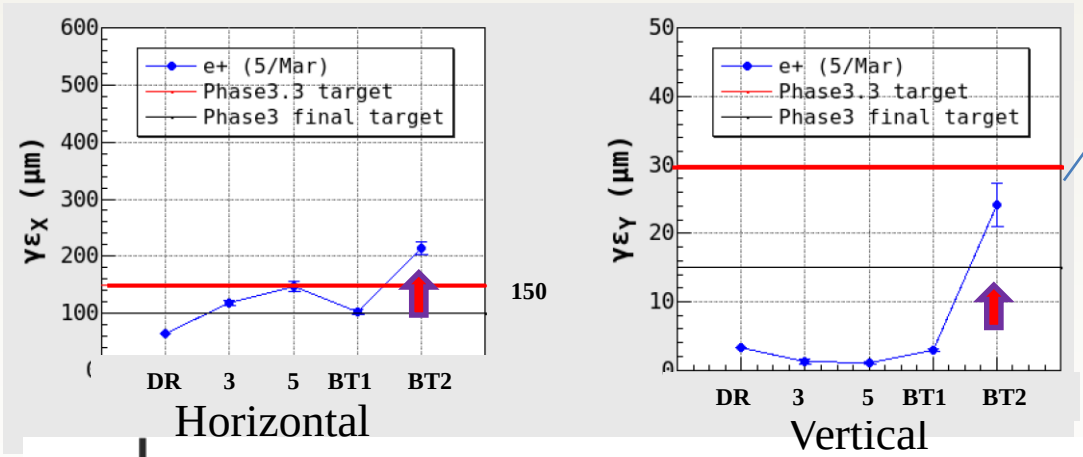
Steering magnet and BPM in solenoid section

- There is no BPM and steering magnet between e+ target and 16_5 unit.
- DC steering (x4) and BPM (x4) will be installed in this summer shutdown.
- It could be help to cure e+ beam loss and e- beam emittance growth.



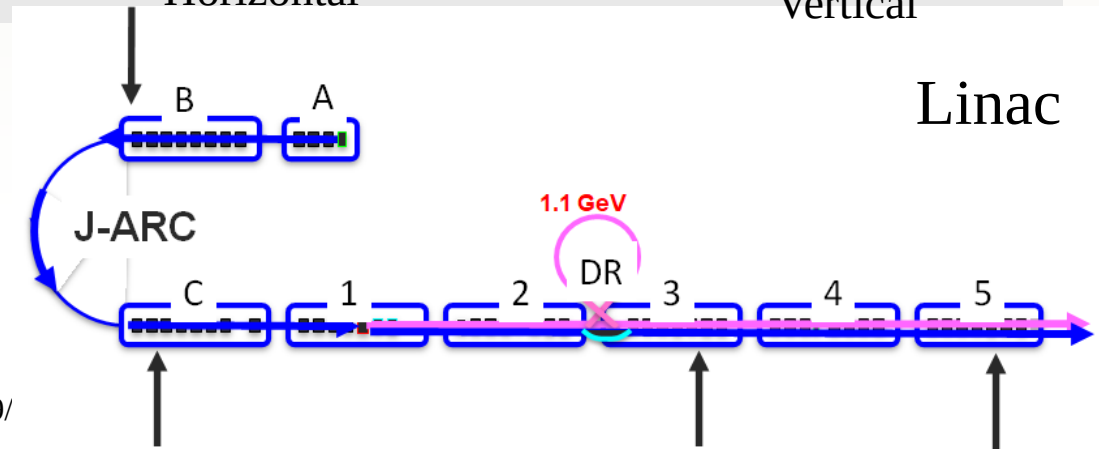
e+ beam emittance (～ 1 nC)

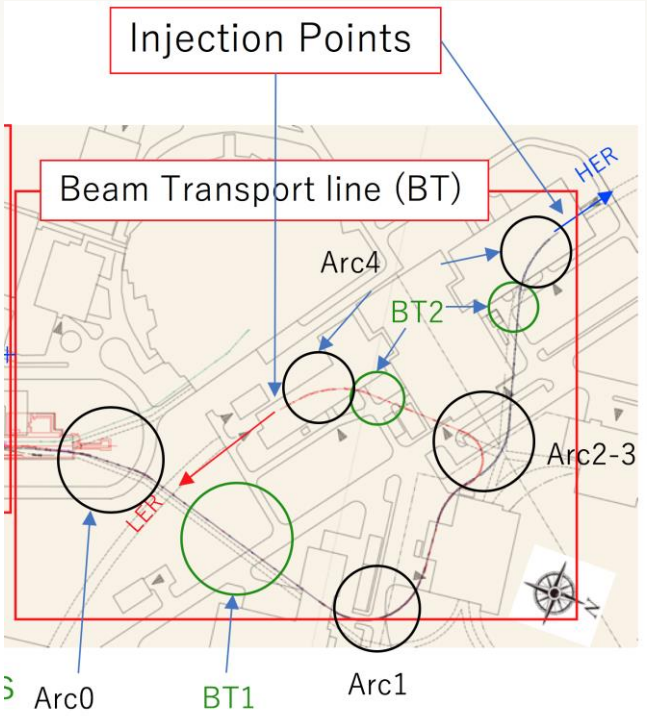
- e+ beam emittance in linac and BT1 are smaller than current goal.
- Emittance growth at BT2 in both directions.



The reason for the emittance growth from BT2 is not clear.

More studies are needed.





FC assembly, base summary

	Phase 1	Phase 2	Phase 3	2019 autumn	2020 spring	2020 autumn	2021 winter～	delivery	removal	Present status（2020/6）	remark
Assembly 1								Before 2015	2017/3	Tunnel	
Assembly 2								2016/3		Beam line	
Assembly 3								2017/11		Test bench	
FC base 1								before 2015			Trial product
FC base 2								before 2015			Trial product
FC base 3								before 2015	2017/3	Assembly 1	
FC base 4									2018/9	Tunnel	
FC base 5								2016/7	2020/9	Beam line for operation	
FC base 6								2017/11		Reserved	Hardening (Toyama)
FC base 7*								2019/10		Finished long term test	
FC base 8**								2020/5		Under test	Final version modified
FC base 9**								2021/3		Under design	Final version spare

- *Base 7, 8, 9 (head : Cu → NC50, return yoke : SS400 → permendur)
- **Base 8, 9 Shape optimization (insulation, leakage magnetic field)

red : operation
blue : spare
black : test bench

Y. Enomoto

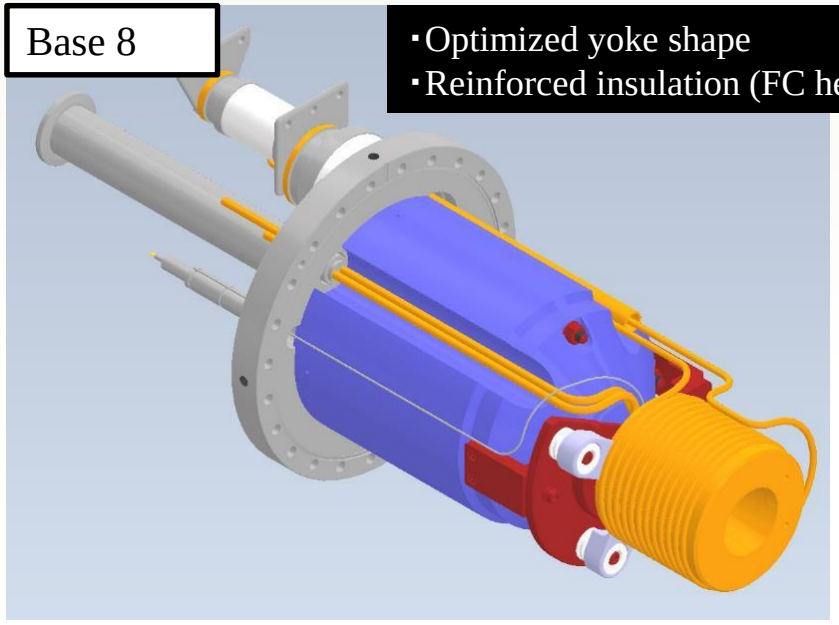
Comparison FC base

	Material	Shape	Remark	For e-	For e+
Base 5 (in operation)	OFC + SS400	Old design	12 kA in beam line large slit gap	△	○
Base 7	NC50 + permendur	Old design	4.5 months test	○	○+ *
Base 8	NC50 + permendur	New design (optimized)	Cooling water leakage was found. (already fixed and tested during 4 days)	◎	○+ *

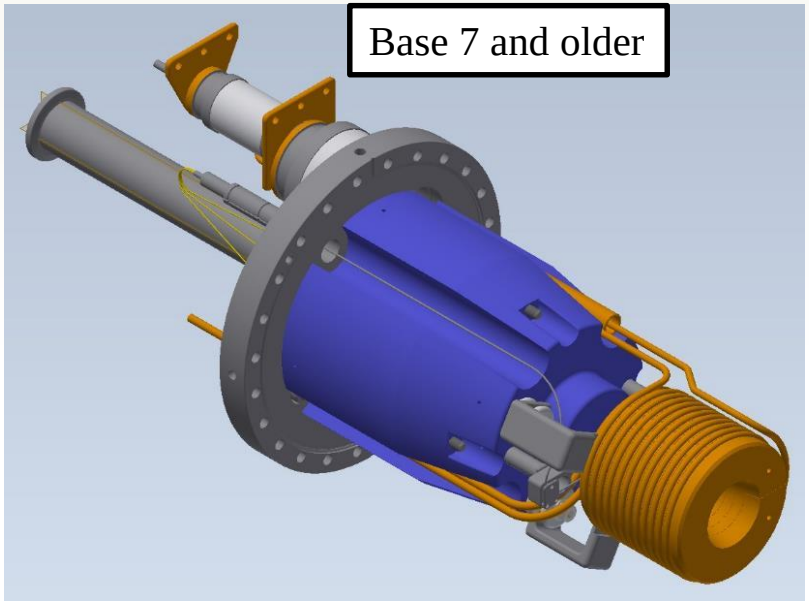
All FC bases achieve 12 kA in test stand. (*) return yoke (permendur) makes higher magnetic field.

Base 8

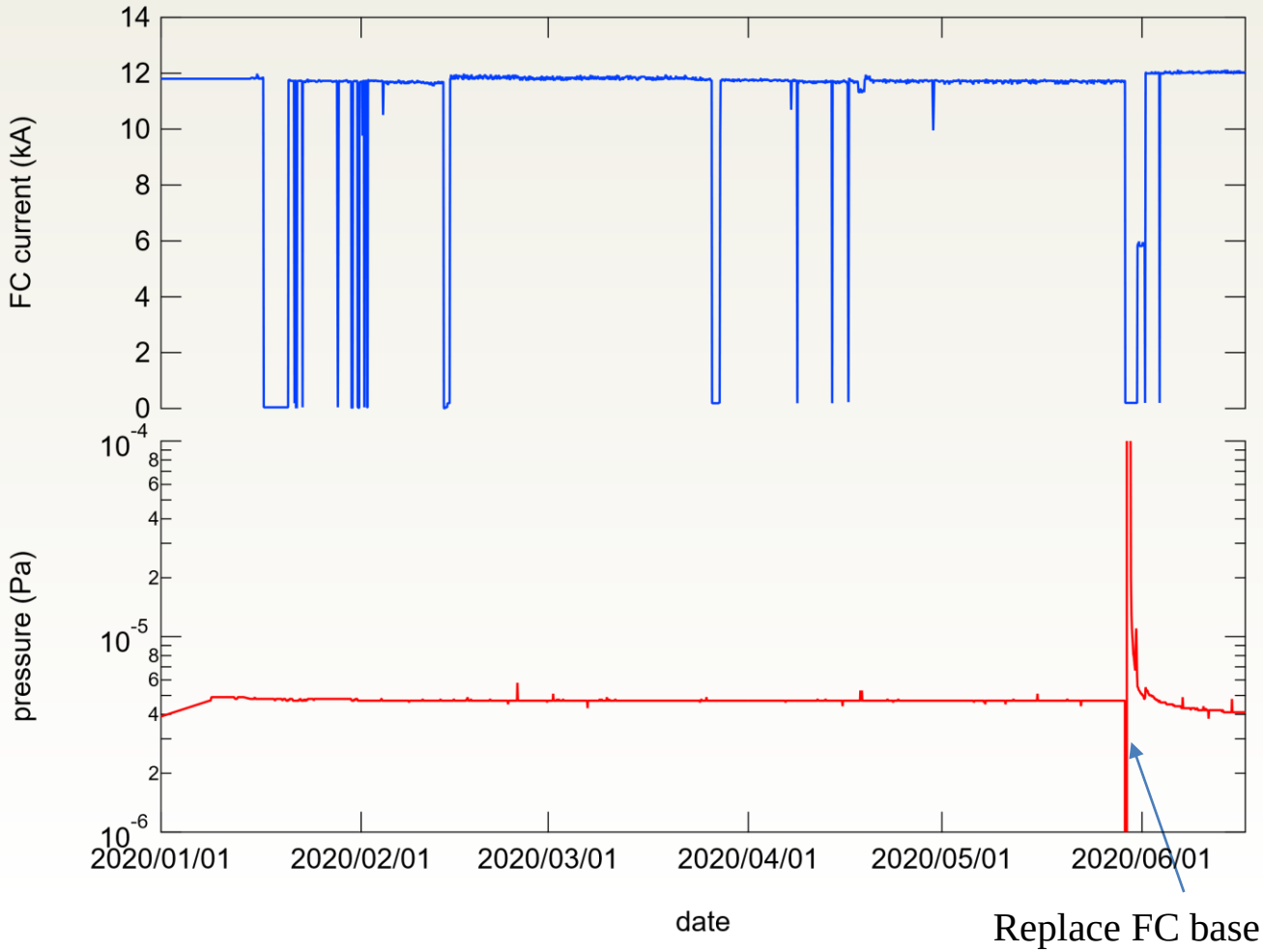
- Optimized yoke shape
- Reinforced insulation (FC head support)



Base 7 and older



Test result of new FC: 2020/1 – 2020/6

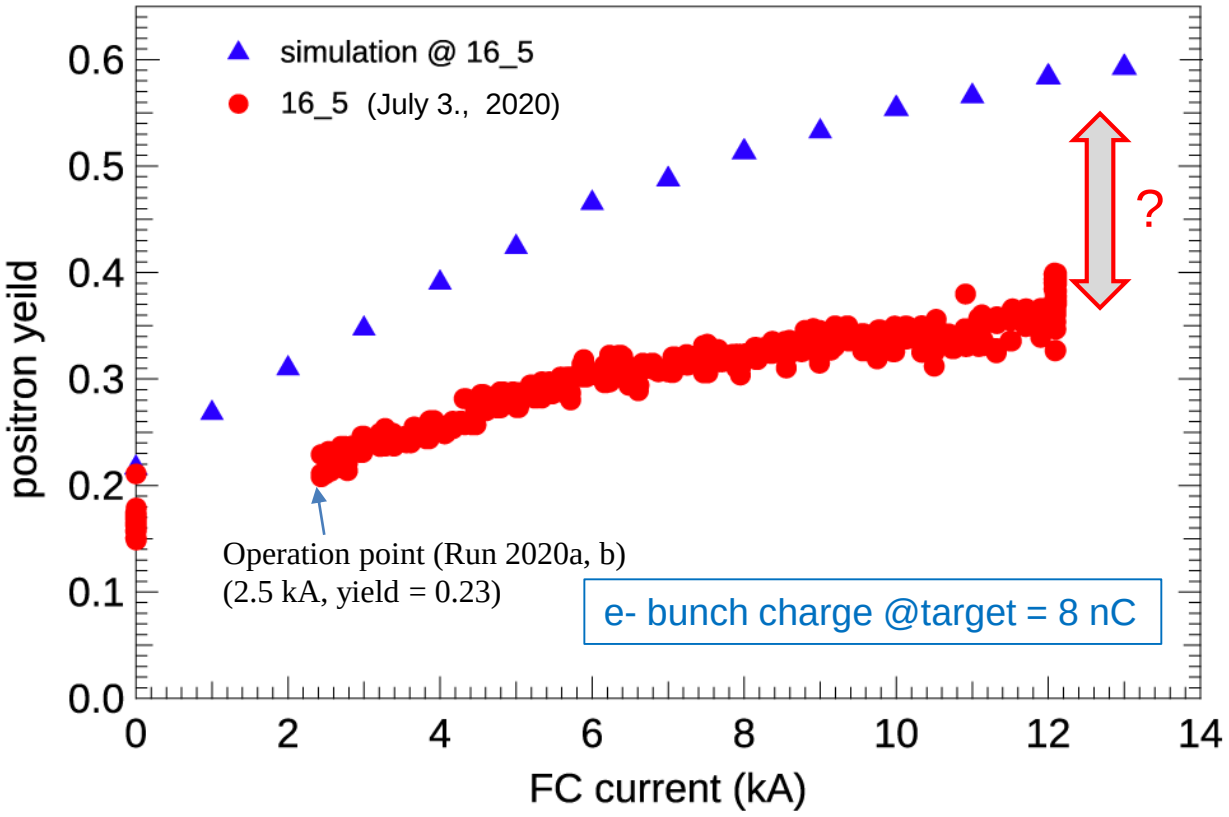


During long term test, no trouble (discharge and vacuum pressure problem)
FC base 7 test: ～ May 2020
FC base 8 test: June 2020 ～

Y. Enomoto

Positron yield by FC (base 5) beam test

Y. Enomoto



Ratio of bunch charge of positron at capture section exit to primary electron vs FC current.

Positron yield is 35% lower than the simulation.

- Differences between exp. and sim. conditions. (E/B field, primary beam direction/position, em shower sim. etc.)

The cause of the difference is not clear.

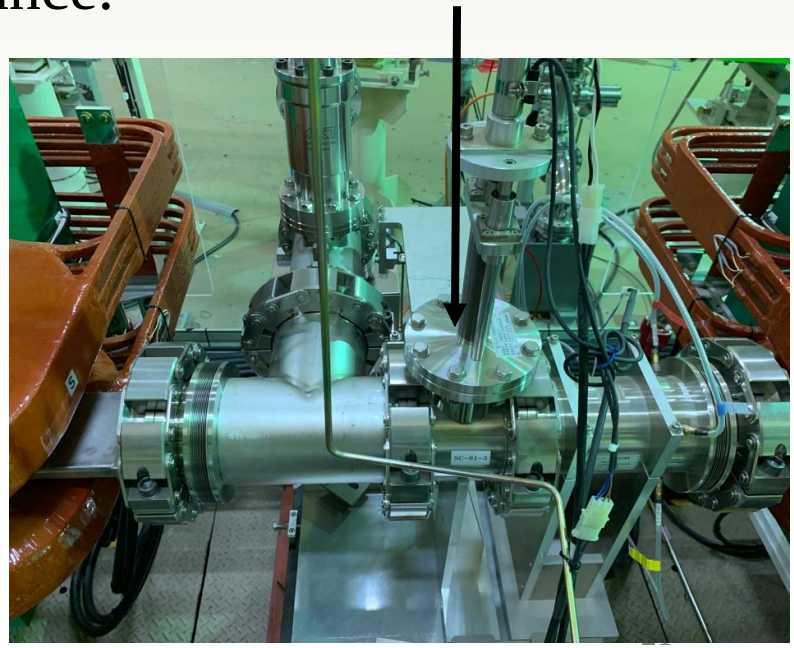
We've started a detailed investigation.

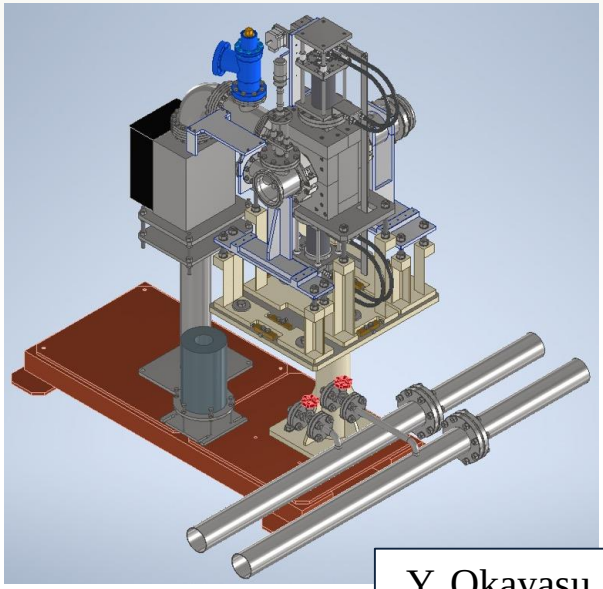
There are no BPM and steering magnet until 17 m downstream of the target. (Only 6 acc. structures and solenoids)

2 stripline BPMs and 2 BPMs for e+ and 4 steering magnets will be installed in this summer.

Abnormal energy beam
- Collimator at ECS of linac end -

- Klystron down or rf phase trip could cause energy change.
- In the case of e+ beam, ECS (in linac end) can correct it to a certain extent. Beam can go through BT and into MR.
- To prevent such beam, collimator will be installed in this summer maintenance.





Summary

- Bunch charge
  - Stable and enough bunch charge in this stage
  - e-: 1.3 nC (from gun), 1.0 nC (linac end)
  - e+: Primary e-: 11 nC (from gun), 9 nC (on W target), e+ : 2 nC (after target), 1.2 nC (linac end), 1.2 nC (BT)

- RF電子銃の進展
  - 90° CDS銃を準備した
  - DOE 導入 / 1st レーザー増強
    - ジッターは全く無くなった
    - カソード寿命が長寿命化
  - 常時Laser Cleaning On （2nd専用レーザー）
    - 1, 5 Hz で Inter Pulse Laser Cleaning 実施 (300μJ)
    - 2.5nC で維持でき
    - Trigger システムを改造
  - Position monitorを設置

- e+の進展
  - FC入り替え（High bunch charge）
  - SolenoidにSteering magnet と BPMを追加
    - e +ビームの損失とe-ビームのエミッタンスの増加を解消する

Summary 2

- Beam abort 問題の改善
  - Pulsed magnet misfire (orbit)
    - Control software have been improved.
  - Install collimator at ECS (Linac end) in this summer shutdown.
- 50 Hz operationの対応
  - Vertical pulsed bends and chambers will be replaced new one for 50 Hz operation of thermionic e- gun (LER, PF, PF-AR) in this summer shutdown.

- 問題点
  - Emittance growth at BT2
  - Reproducibility
  - Low emittance w/ high bunch charge (～ 2 nC)