Introduction of Linac Operation Status & Progress of Injector Group

The 120th B Factory Project Committee

Rui Zhang (ACCL 5, Injector Group)

On behalf of all the ACCL 5 members, 2021.09.22.

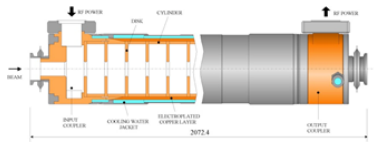
CONTENTS

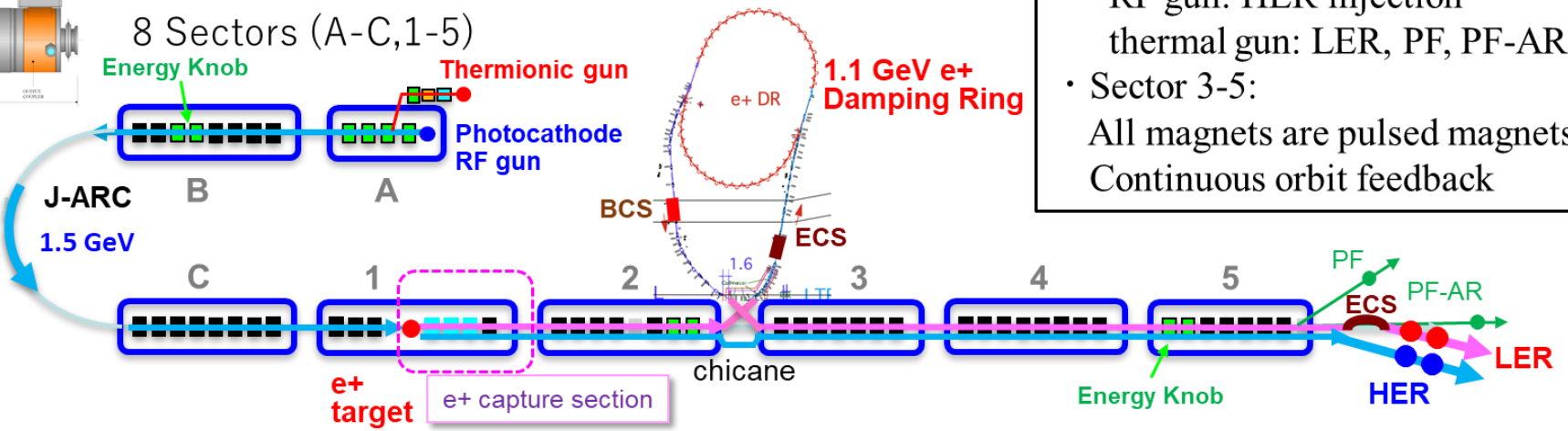
- Linac status during 2021ab commissioning
- Injector group status
  - Achievements and issues in 2021ab
  - Upgrades
- Summary

LINAC STATUS in 2021ab COMMISIONING

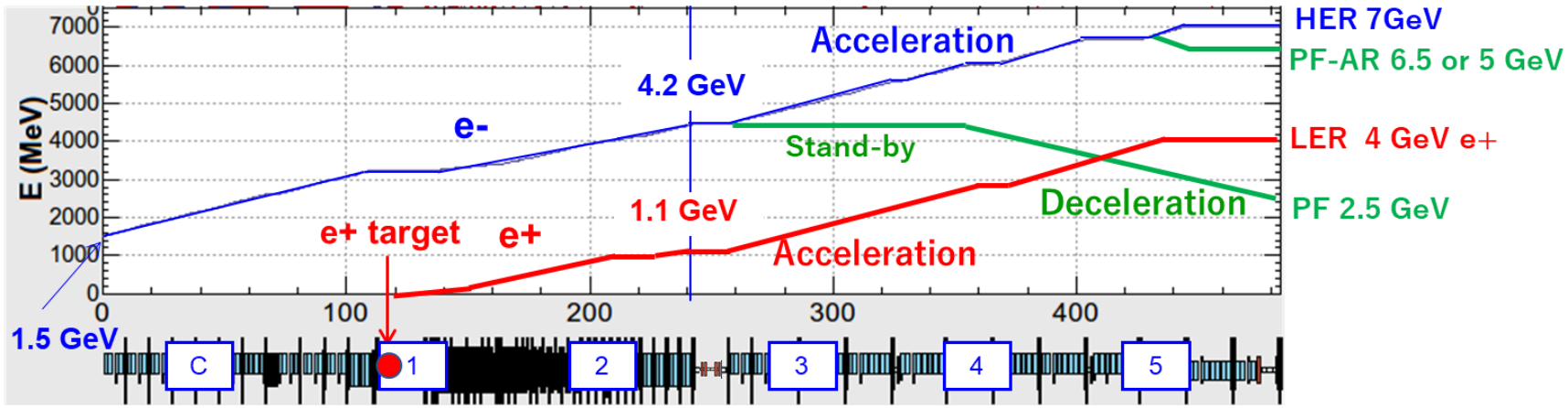
General Introduction of Linac Injector

60 klystron units
240 accelerating structures (S-band 2-m-long)





- Two electron sources:
  RF gun: HER injection
  thermal gun: LER, PF, PF-AR
- Sector 3-5:
  All magnets are pulsed magnets.
  Continuous orbit feedback



Beam energy variation for each beam mode along the beam line after the J-ARC

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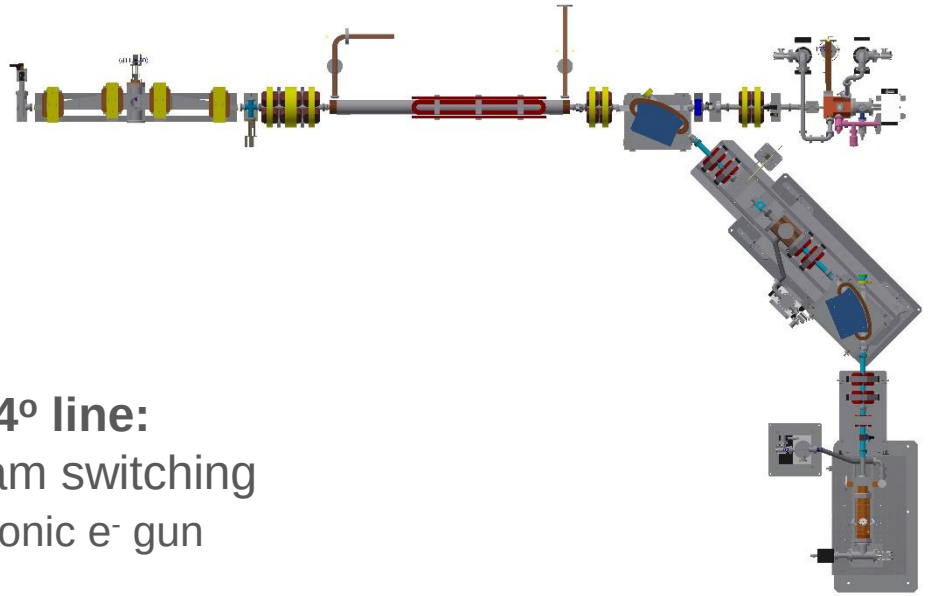
Electron Source Part

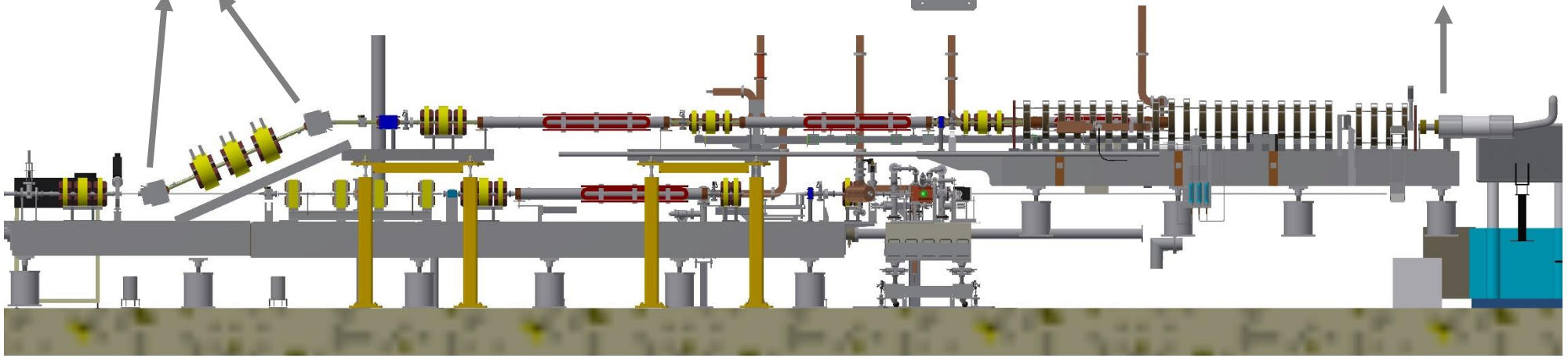
Top view



Pulse bends in 24^{o} line:
Pulse to pulse beam switching
for RF e^- gun/thermionic e^- gun

Thermionic DC e^- gun (GU_AT)
- e^+ production e^-: 10 nC (for LER injection)
- e^- study: 1 nC
- PF injection: 0.1 - 0.3 nC
- PF-AR injection: 0.1 - 0.3 nC

Side view



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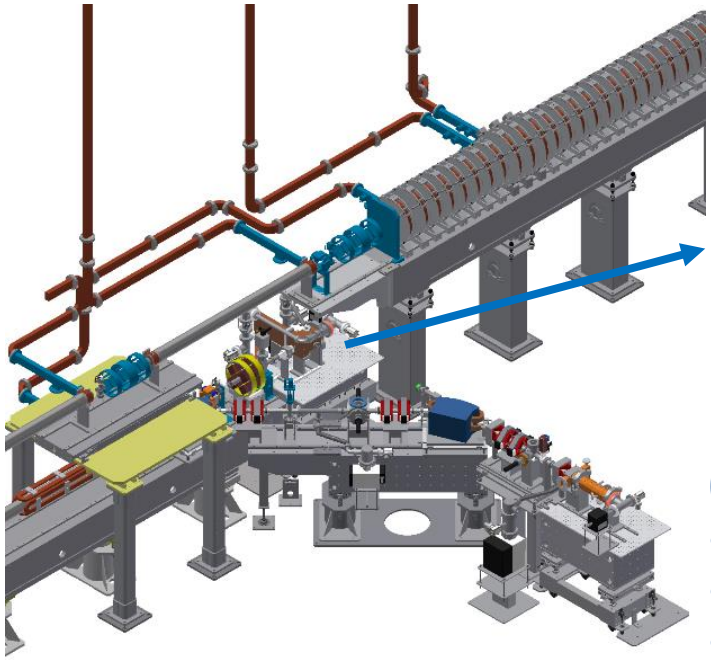
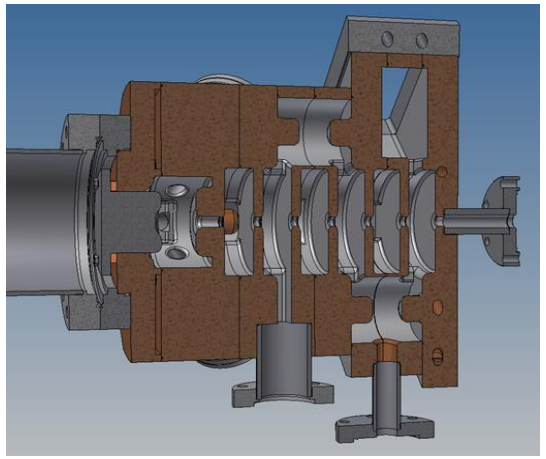
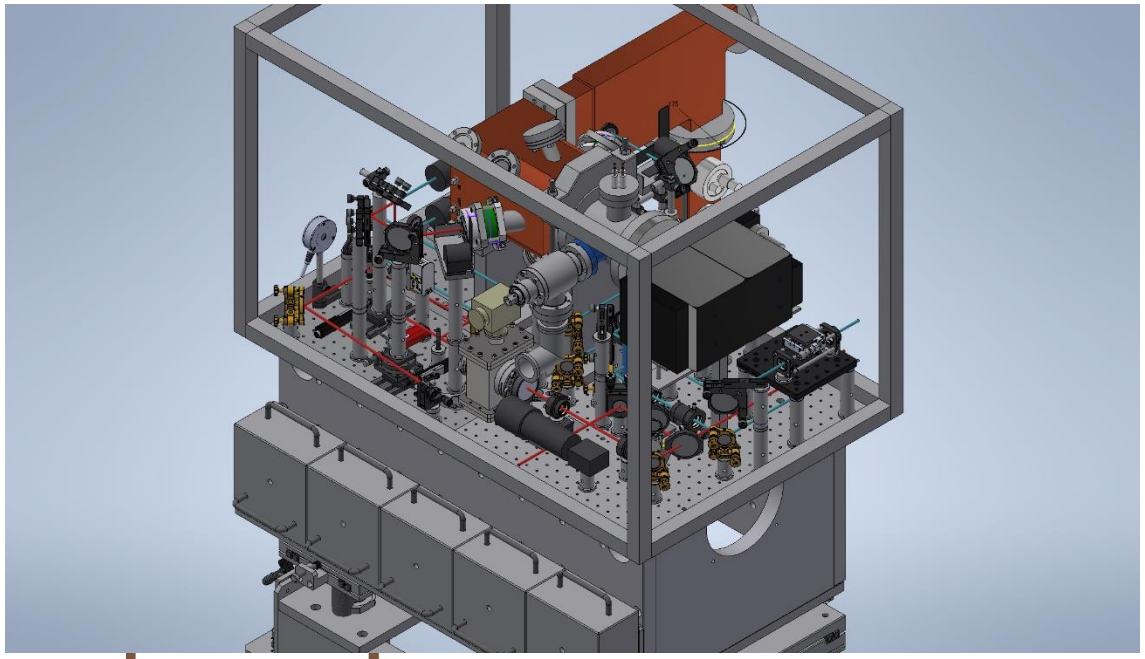
Electron Source Part



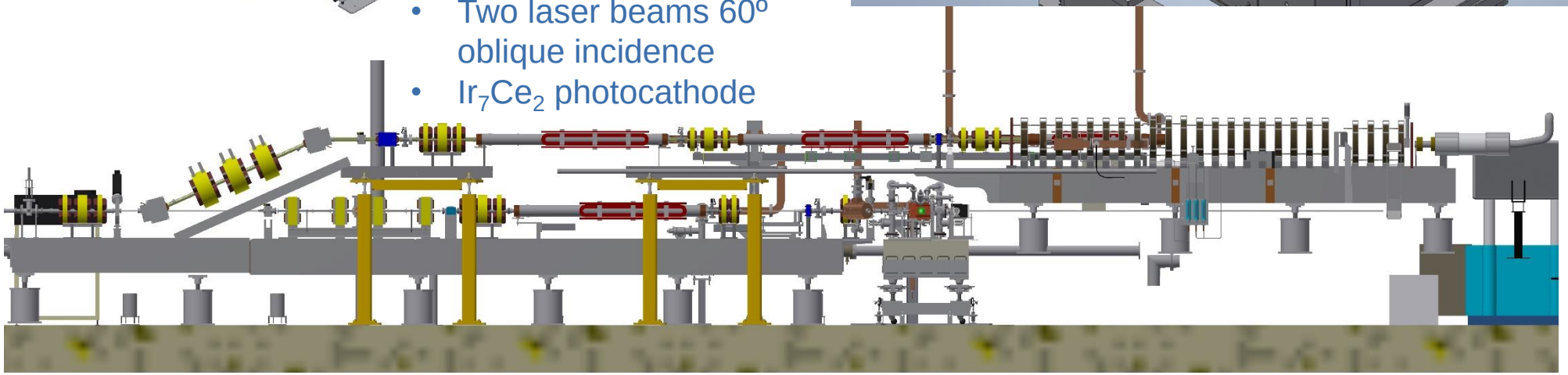




0º RF Gun

- Primary RF gun
- QTWSC cavity
- Two laser beams 60º oblique incidence
- Ir_7Ce_2 photocathode

Side view



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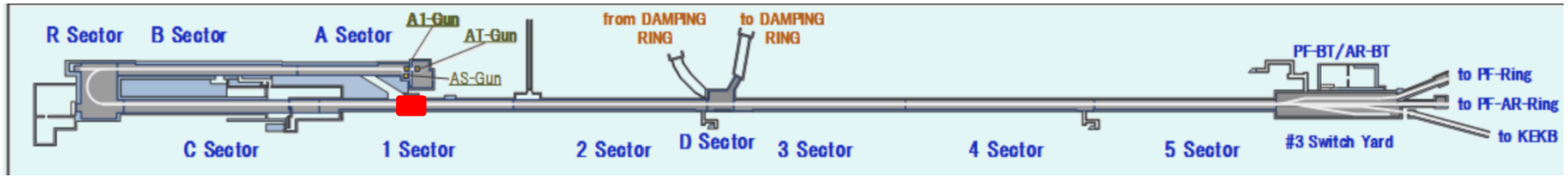
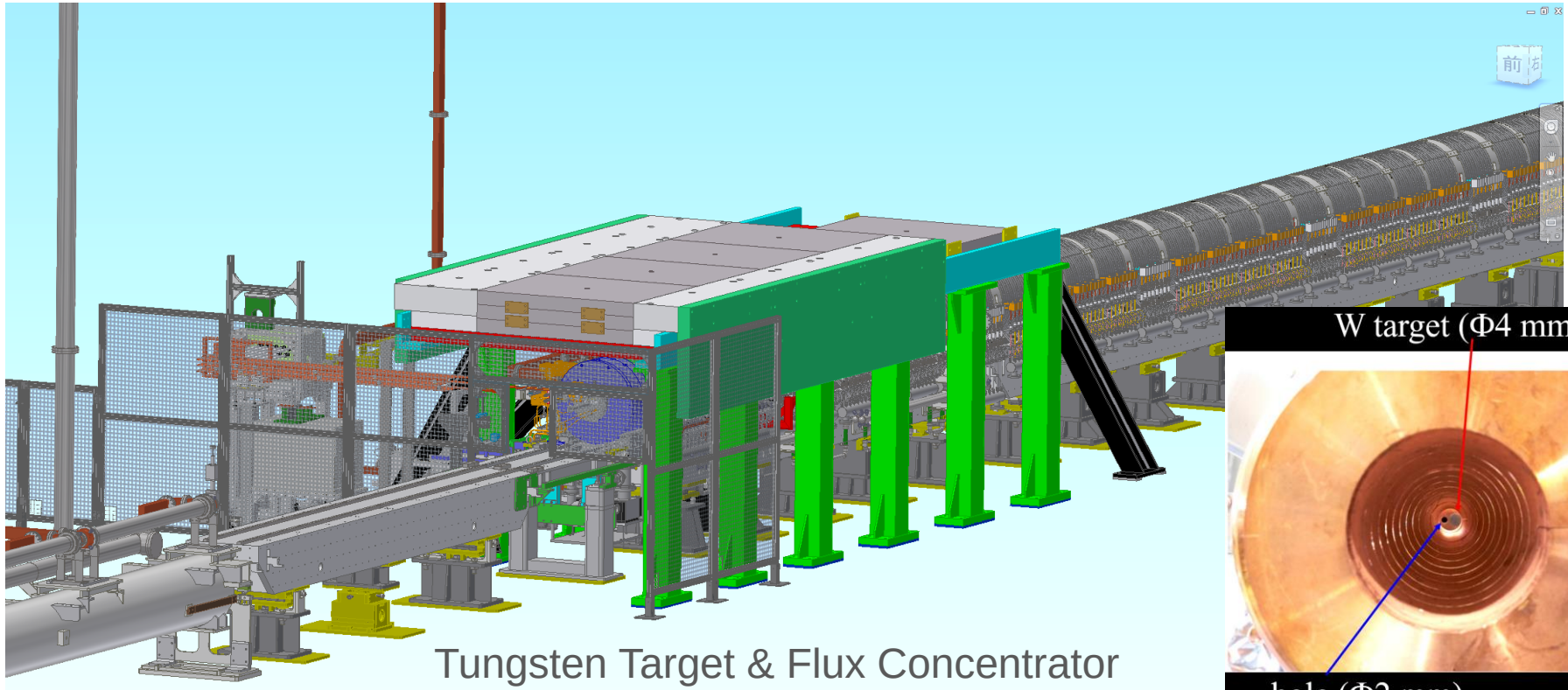
Positron Target and Capture Section



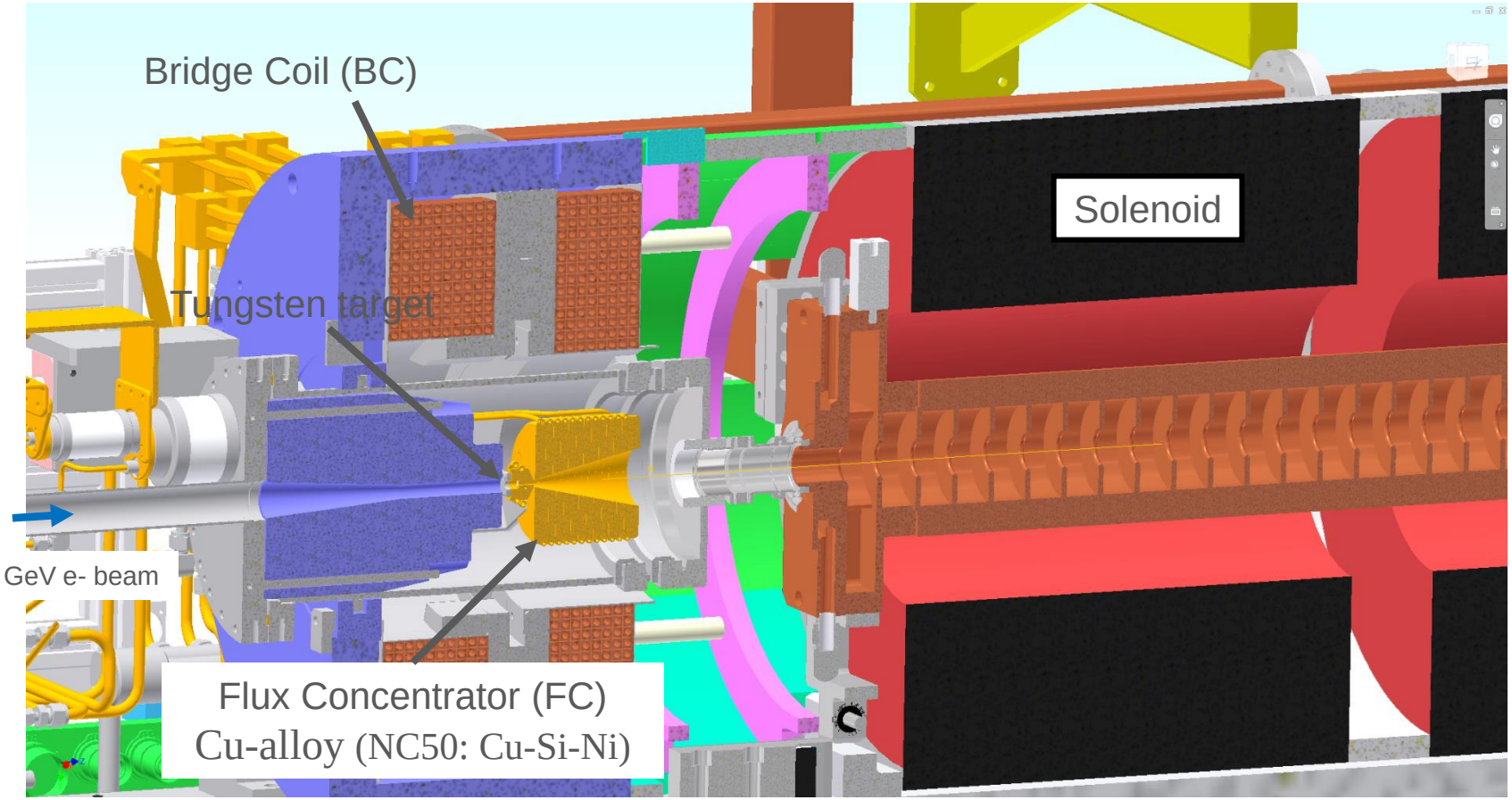


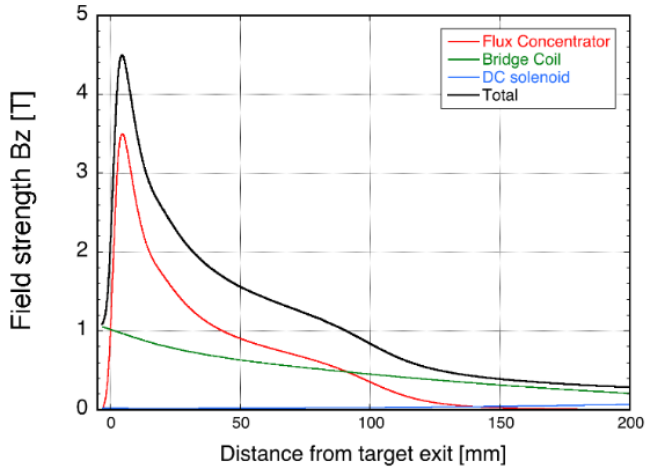
Tungsten Target & Flux Concentrator

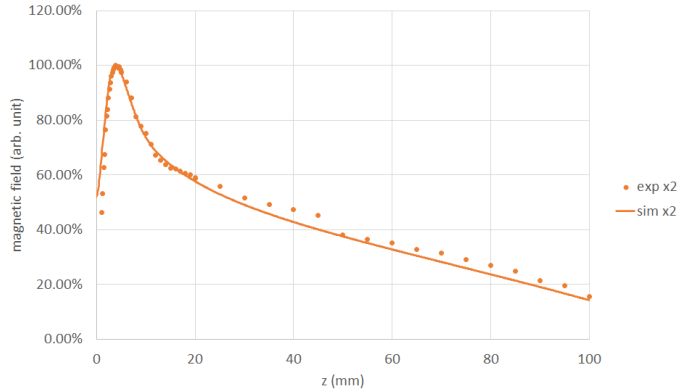
LINAC STATUS in 2021ab COMMISIONING

Positron Target and Capture Section

Large Aperture S-band acc. structure (LAS)



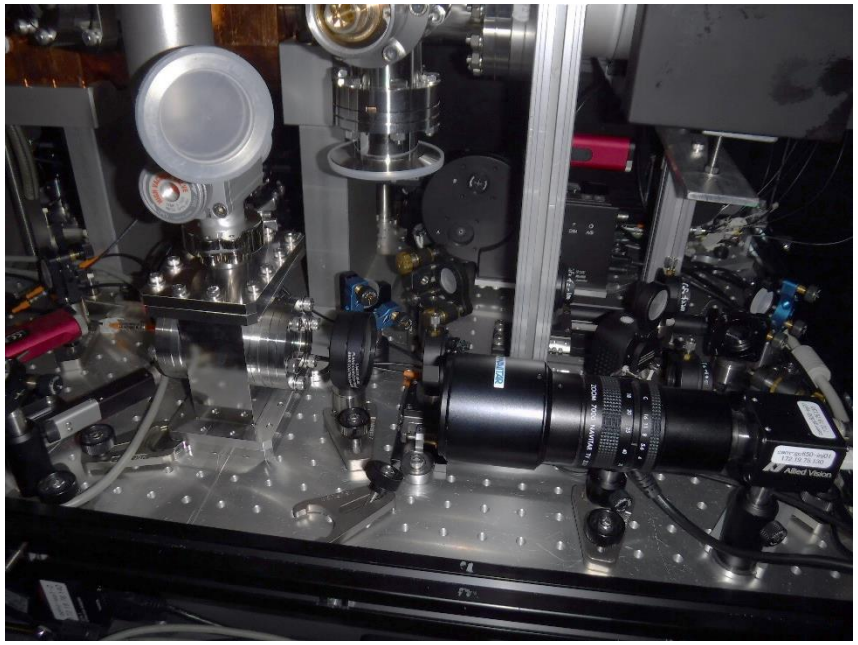


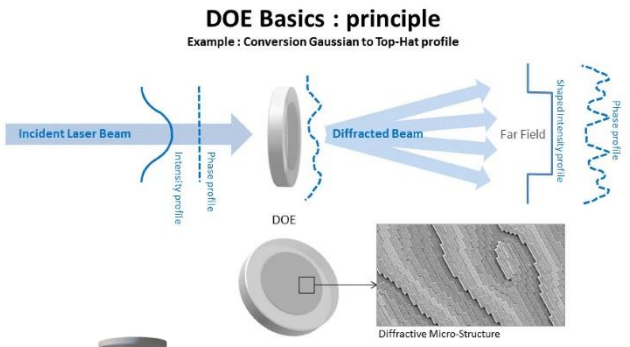


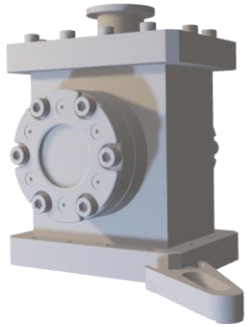
LINAC STATUS in 2021ab COMMISIONING

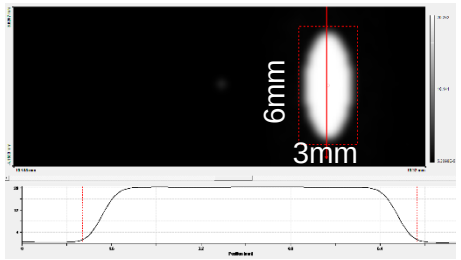
Electron Beam (HER) for SuperKEKB in 2021ab

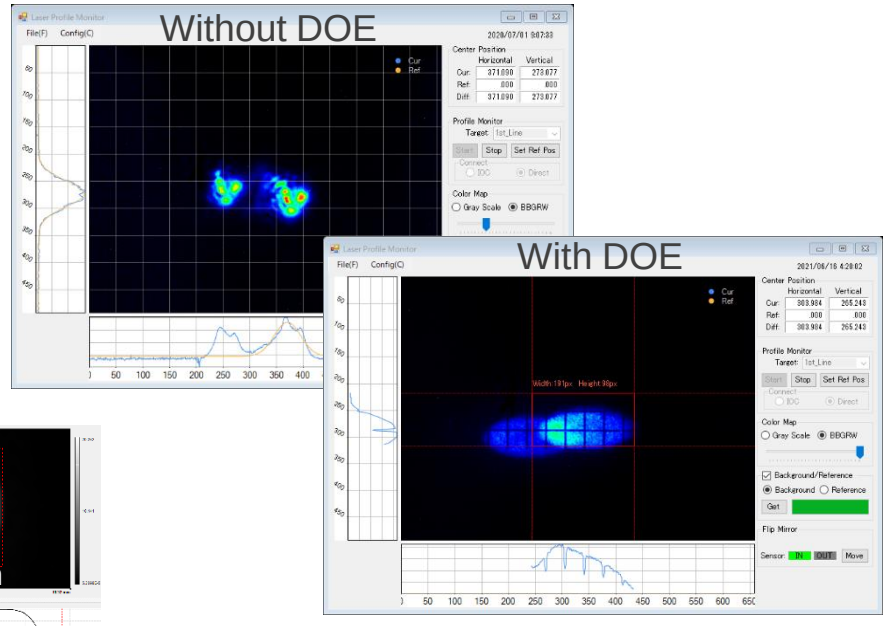
- Installed DOE (Diffractive Optical Element) in 1st laser line from 2020c
- Elliptical flat-top spatial distribution on the surface of photocathode (LA6mm SA3mm) for low emittance e^- generation and avoiding discharge
- Single laser incidence in 2020c and 2021ab (No installation space for 2nd laser)







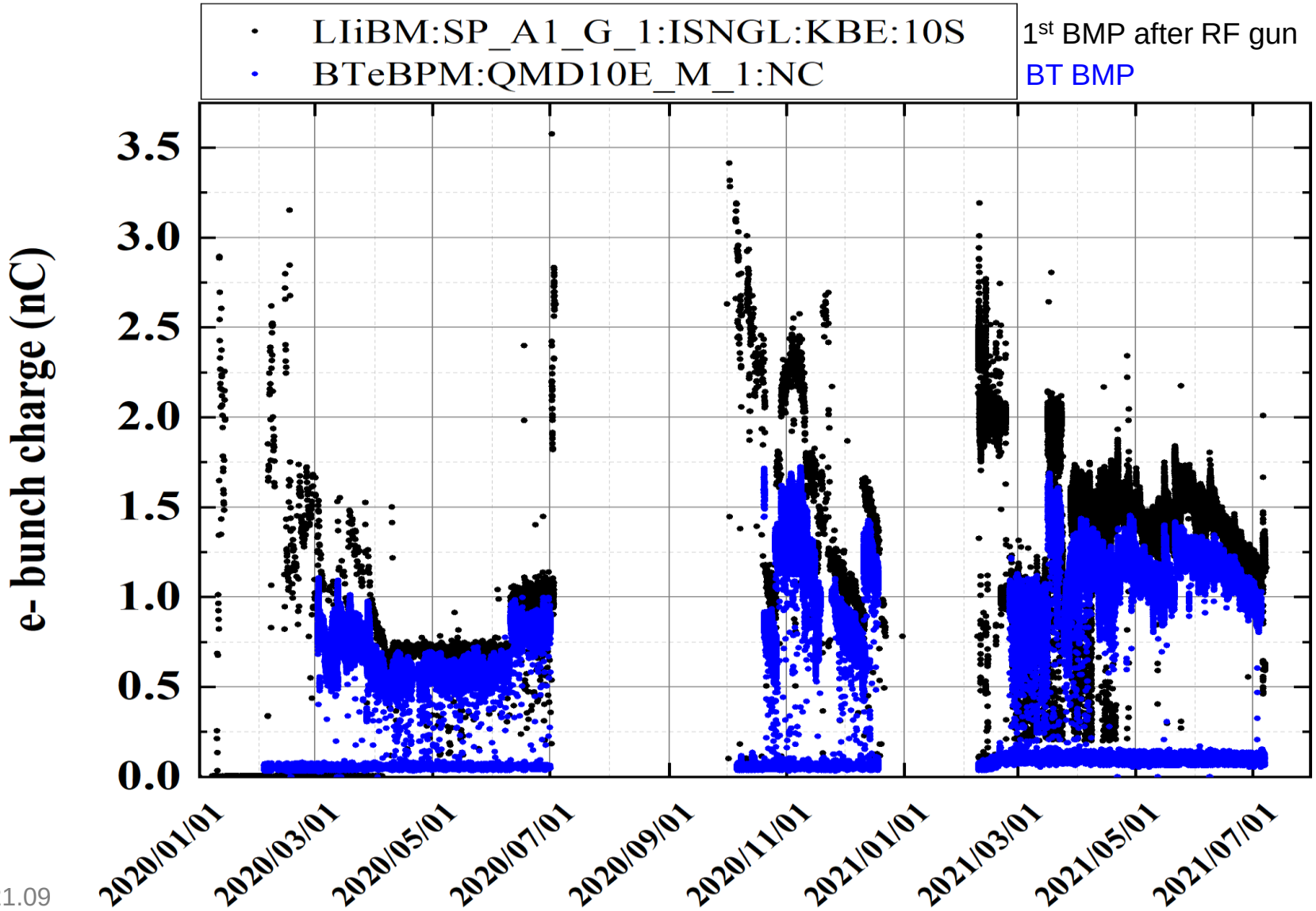




Laser beam profile monitor

LINAC STATUS in 2021ab COMMISIONING

Electron Beam (HER) for SuperKEKB in 2021ab



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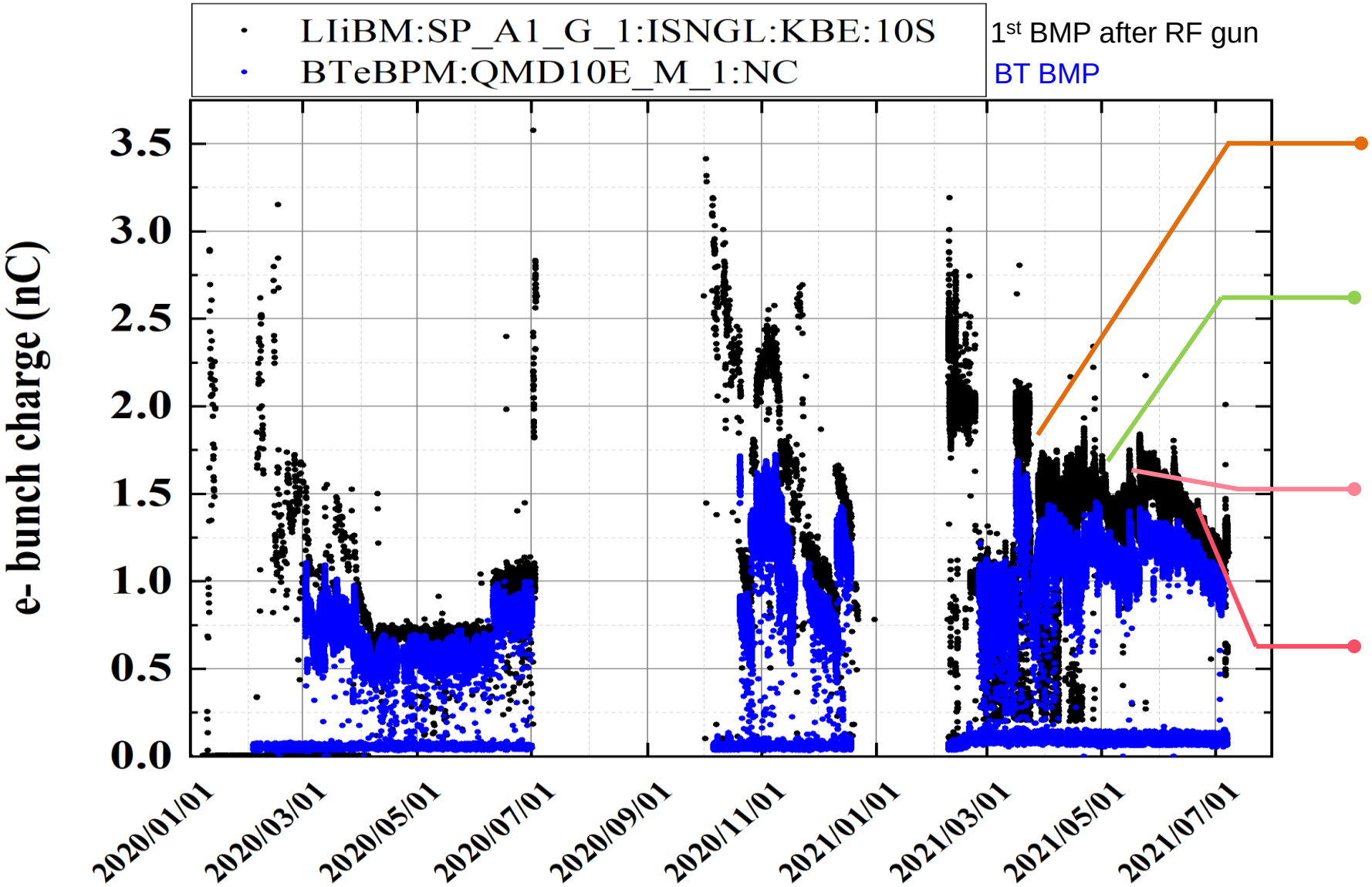


Discharge
- Mis-operation under the status of feedback on
- 2 nC → 1.5 nC

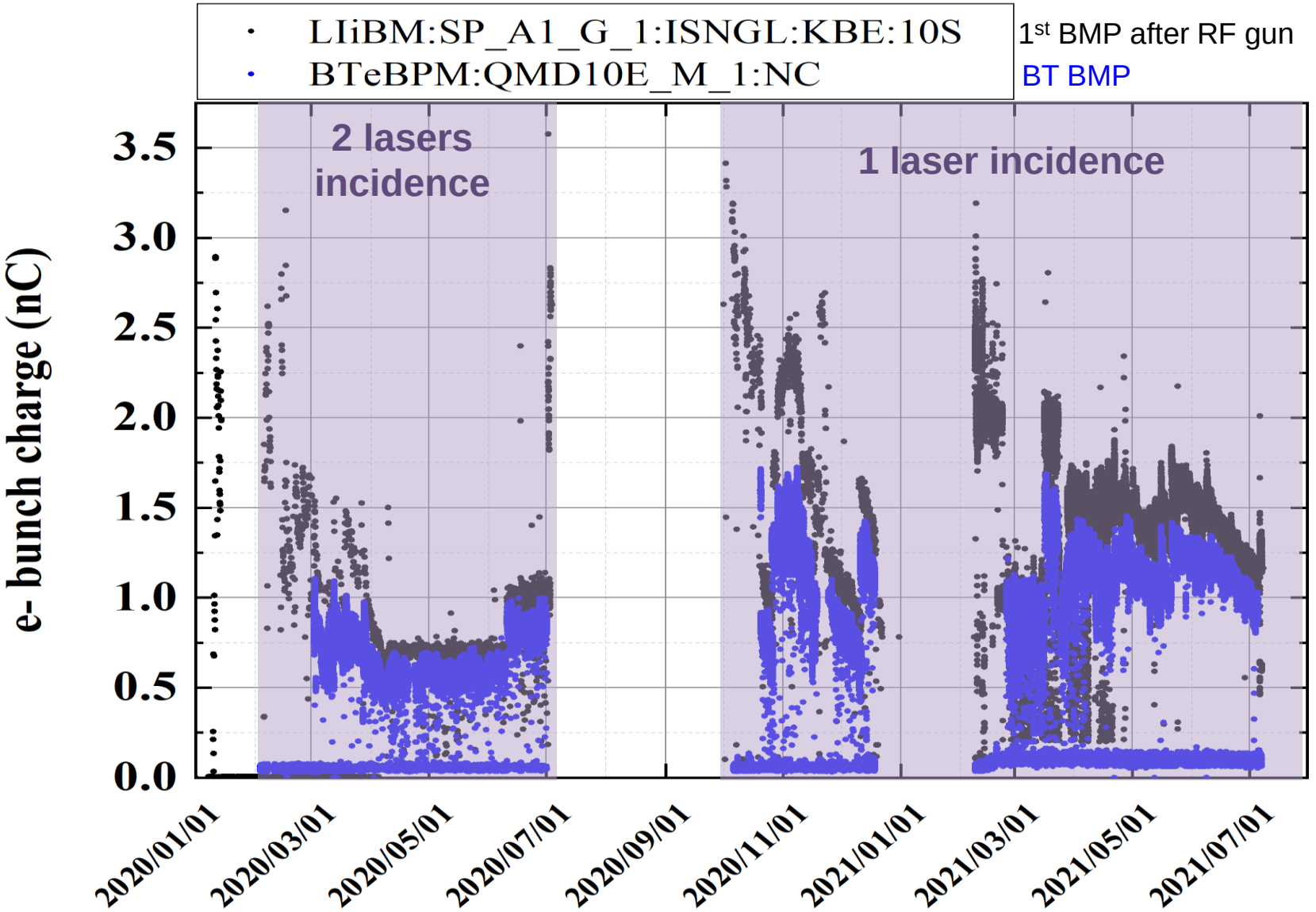
Temperature fluctuation
- Air-conditioner of A1 laser hut
- A1 Klystron gallery

Beam tuning
- Exchange of air-conditioner
- Laser phase adjustment
- Beam adjustment

Performance degradation
- Quantum efficiency of photocathode
- RF gun vacuum window for laser incidence

LINAC STATUS in 2021ab COMMISIONING

Electron Beam (HER) for SuperKEKB in 2021ab

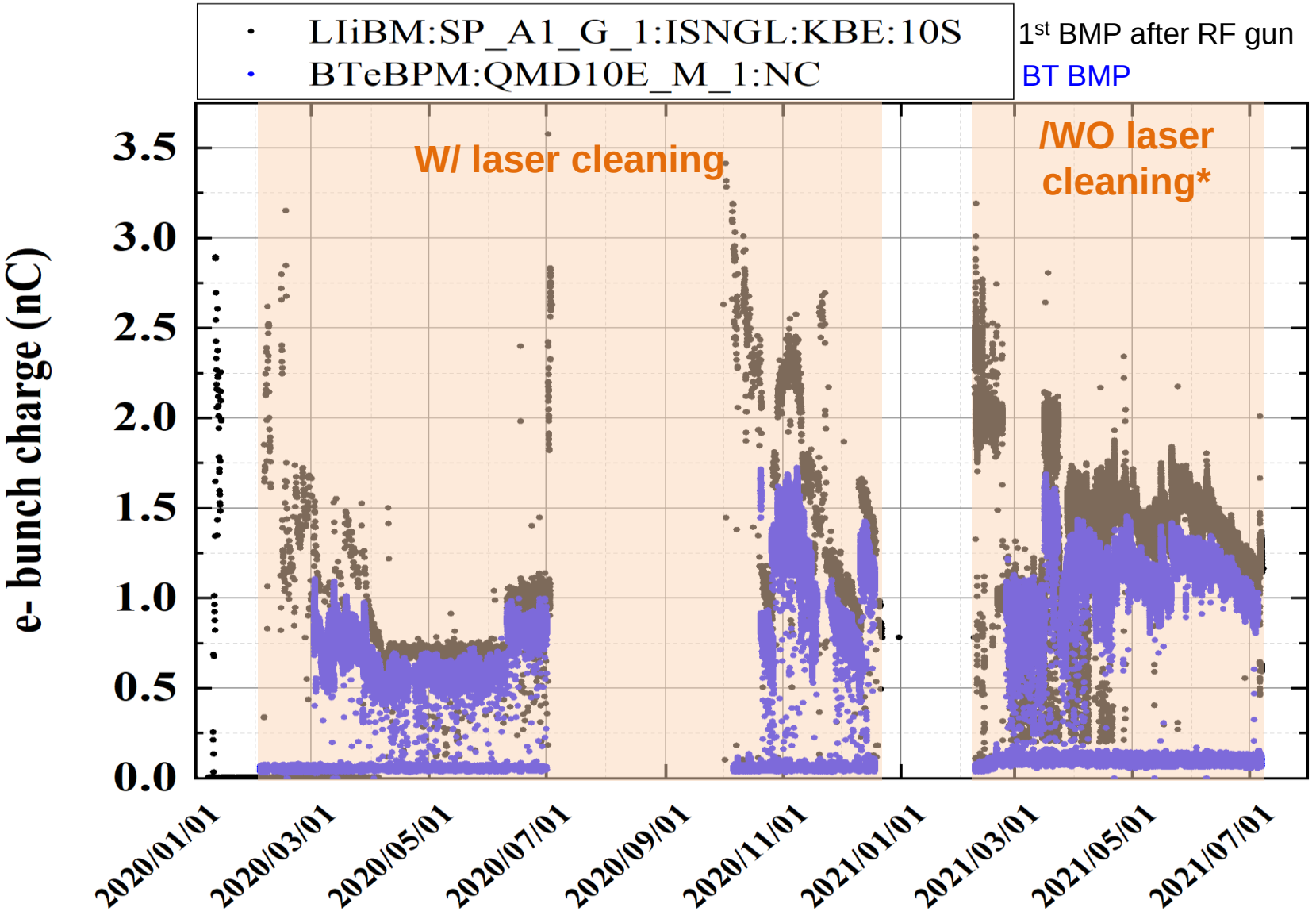


2/1 laser incidence

- DOE in 1st laser line
- No DOE in 2nd laser line
- Photocathode QE increased

LINAC STATUS in 2021ab COMMISIONING

Electron Beam (HER) for SuperKEKB in 2021ab



2/1 laser incidence

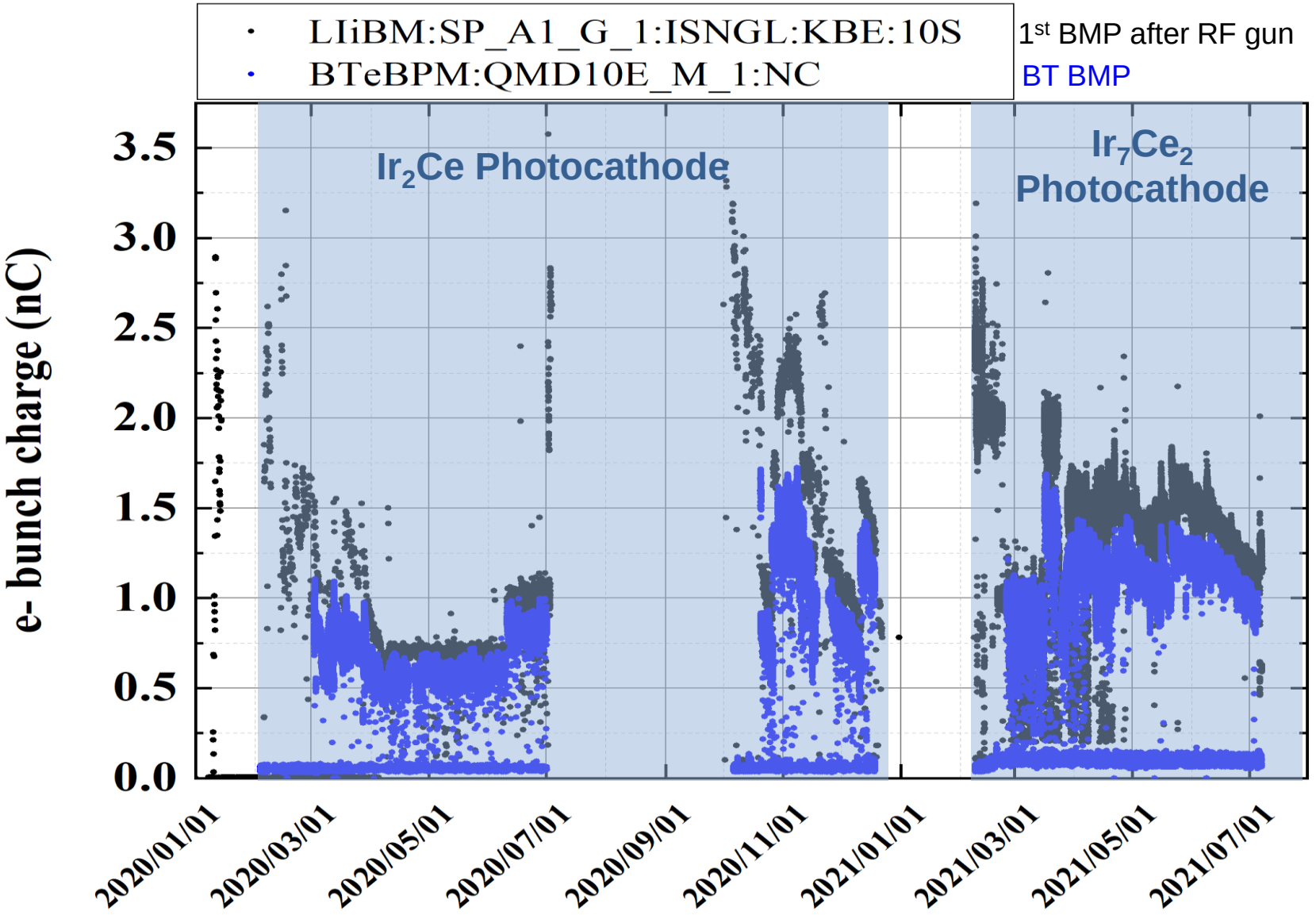
- DOE in 1st laser line
- No DOE in 2nd laser line
- Photocathode QE increased

W/WO laser cleaning

- Essential to keep QE
- *Laser cleaning tested in 2021ab but inefficient

LINAC STATUS in 2021ab COMMISIONING

Electron Beam (HER) for SuperKEKB in 2021ab



2/1 laser incidence

- DOE in 1st laser line
- No DOE in 2nd laser line
- Photocathode QE increased

W/WO laser cleaning

- Essential to keep QE
- *Laser cleaning tested in 2021ab but inefficient

Ir_2Ce / Ir_7Ce_2

- QE: Ir_2Ce < Ir_7Ce_2
- Lifetime: to be estimated
- Laser cleaning: Ir_2Ce >> Ir_7Ce_2

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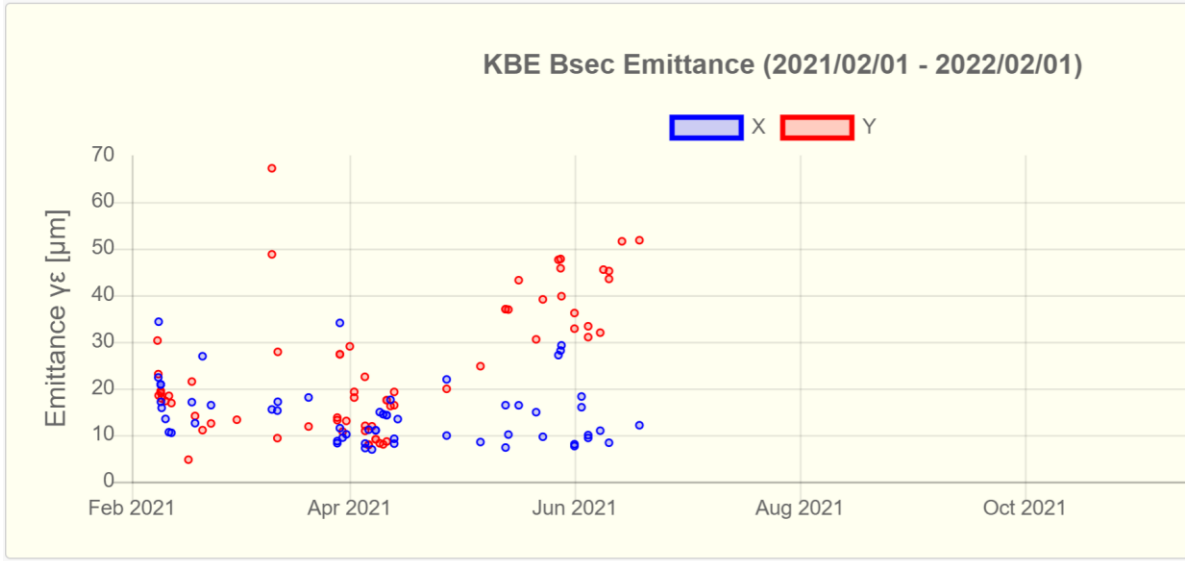
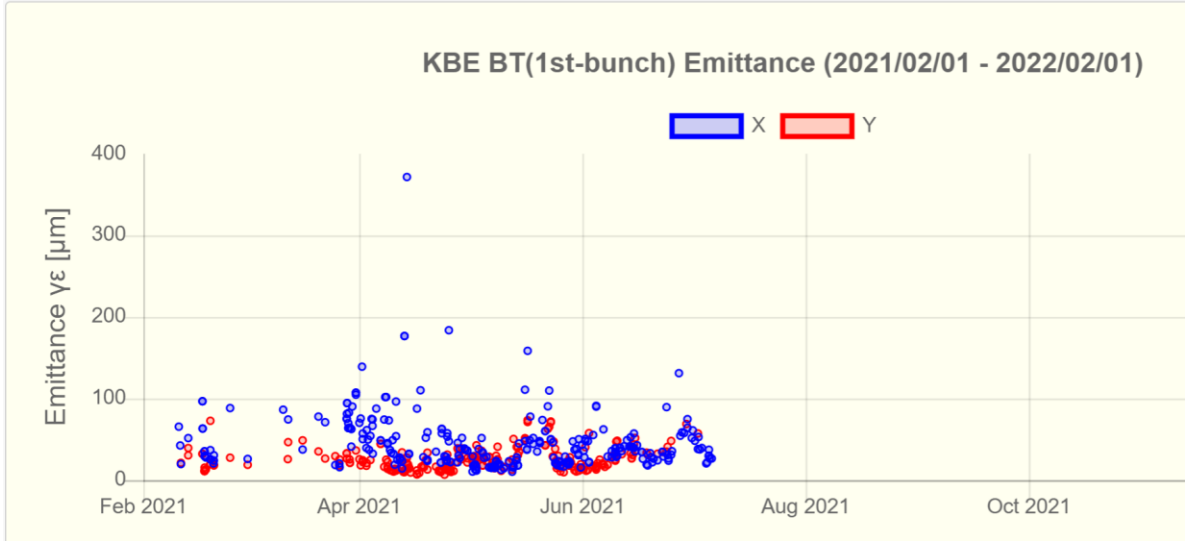
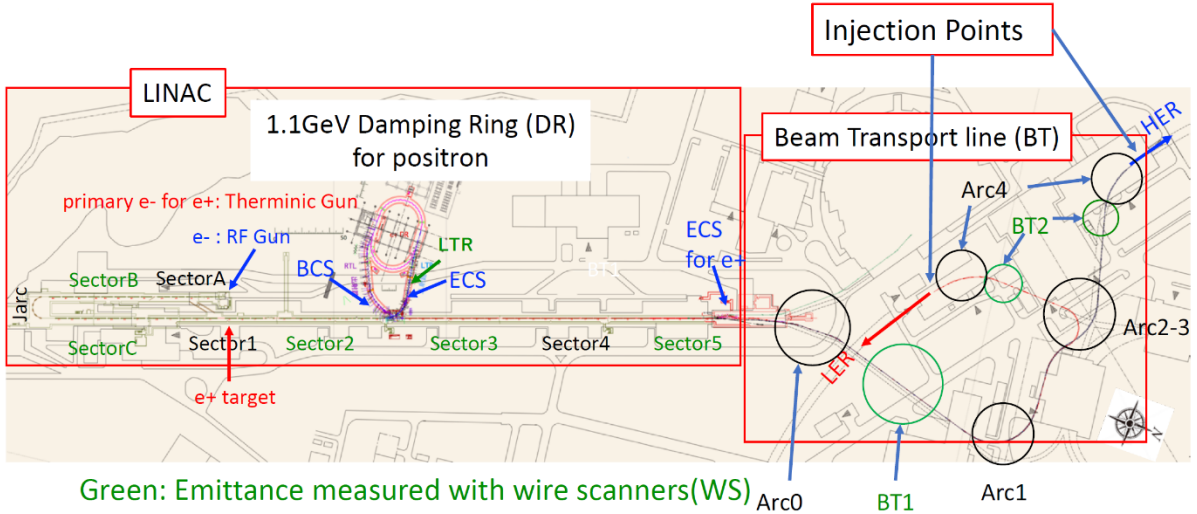
Electron Beam (HER) Emittance History in 2021ab







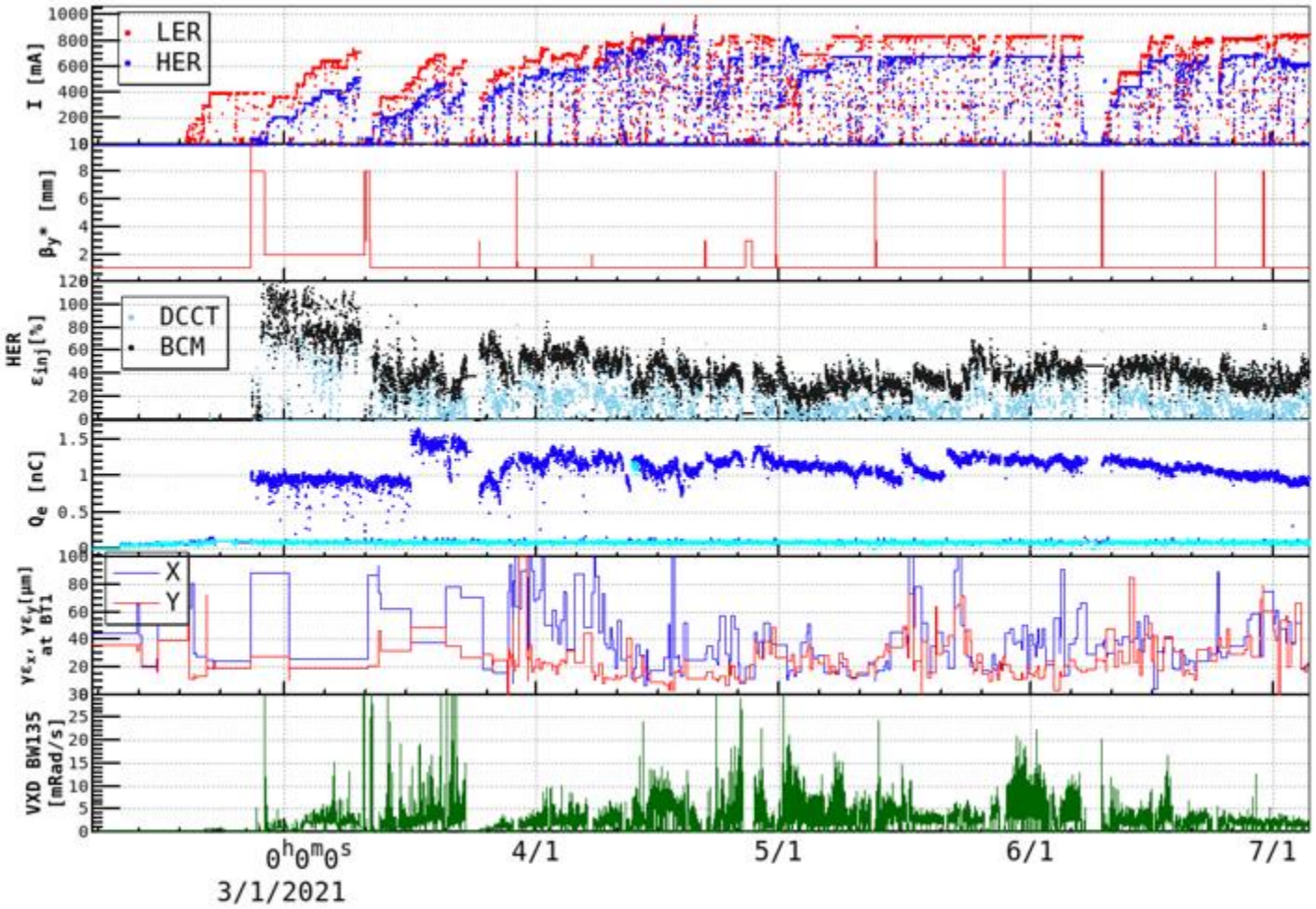
Green: Emittance measured with wire scanners(WS)
BCS: Bunch Compression System
ECS: Energy Compression System

Emittance of electron beam

- Unstable $\gamma\varepsilon_y$@Sector B (e^- charge 1.5~2.0 nC)
- → Newly added pulse steering magnets in upstream and orbit feedback system (2021c)
- Reason unknow on blowup of vertical emittance
- → Under investigating
- Horizontal emittance increased by synchrotron radiation
- → Under simulation

LINAC STATUS in 2021ab COMMISIONING

Electron Beam (HER) Injection History in 2021ab



Injection of electron beam

- High injection efficiency under β_y*=2 mm
- Poor injection efficiency for β_y*=1 mm case
- Reason unknow on poor efficiency (Simulation result: ~70% under the same emittance level)
- →Under simulation
- Frequent setting adjustment for injection septum
- →Please consult other experts
- Unachievable 2-bunch injection (Injection efficiency of the 2nd bunch is almost 0)
- →To do sufficient RF conditioning and adjust the RF pulse width, improve the emittance of the 2nd bunch beam

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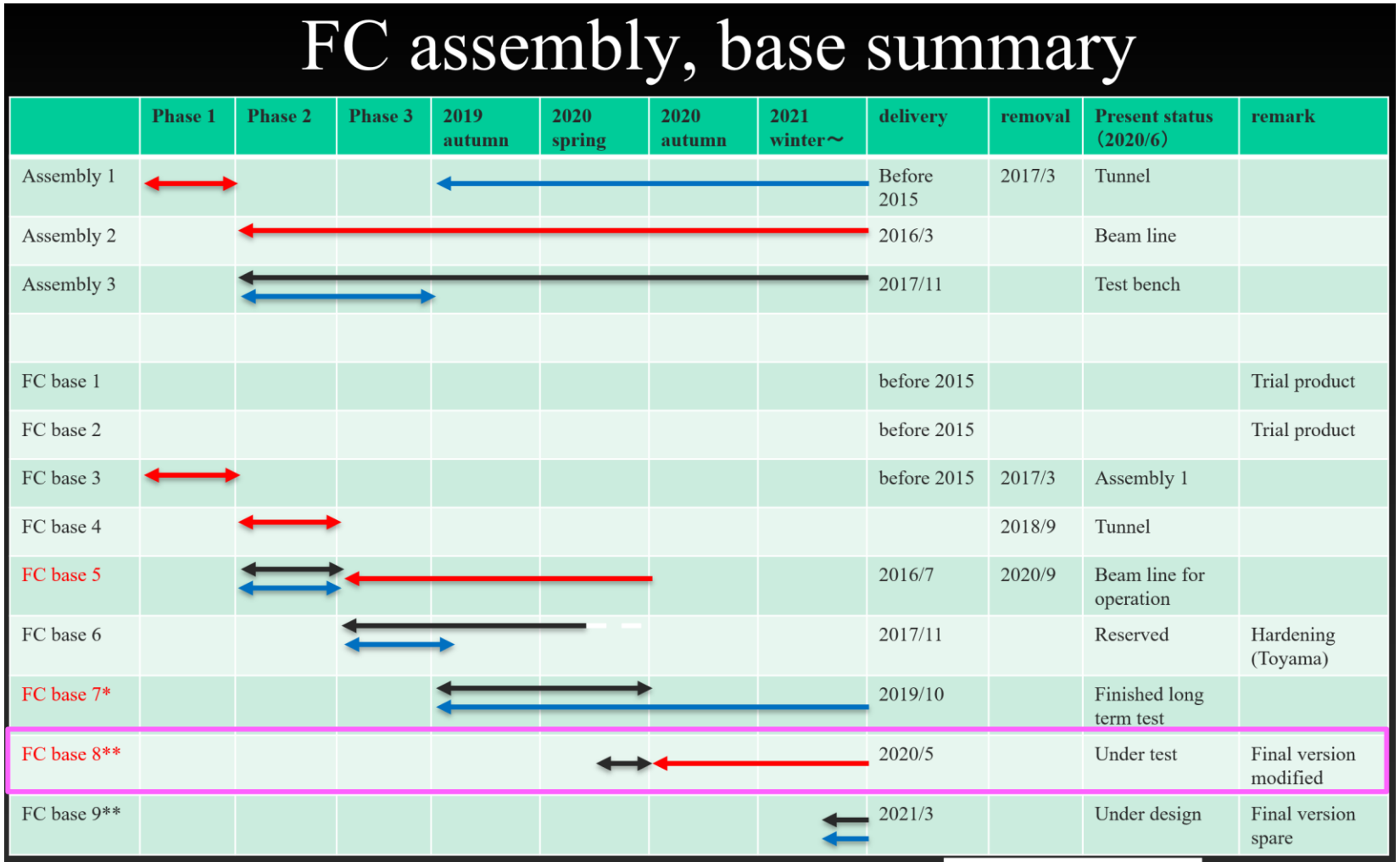
Positron Beam (LER) for SuperKEKB 2021ab

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

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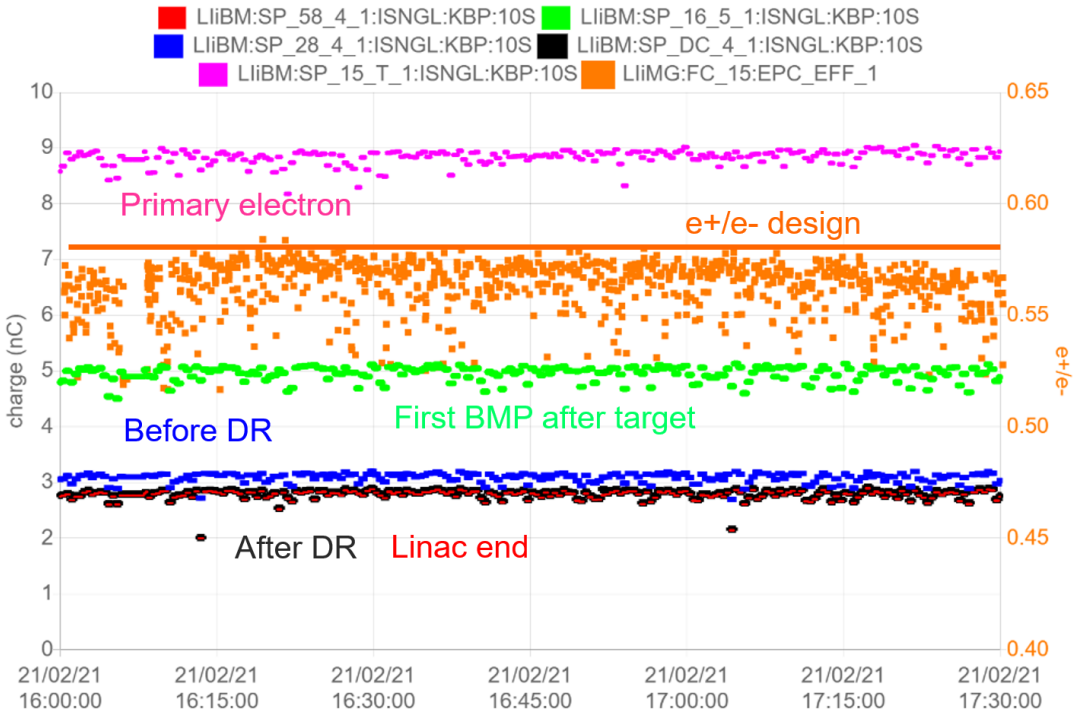
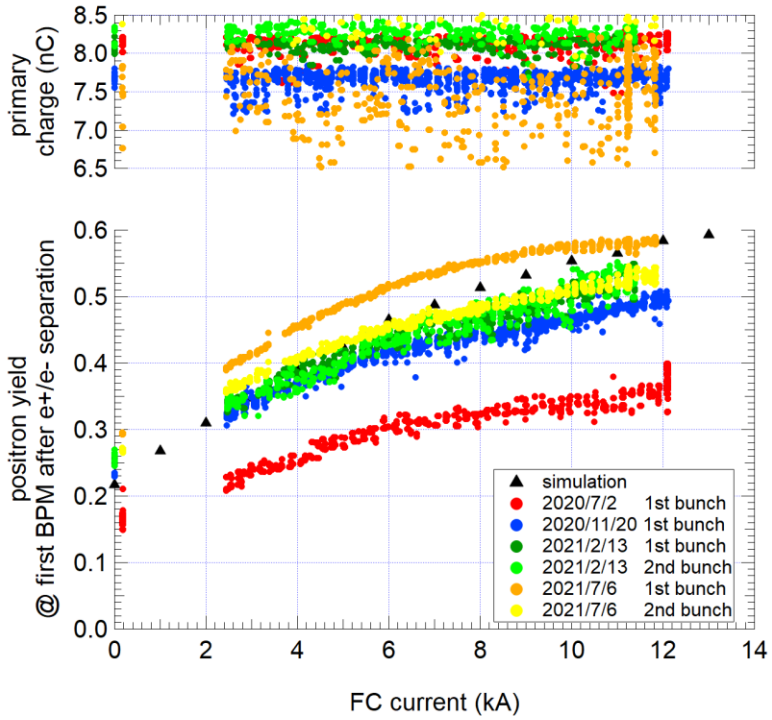
Positron Beam (LER) for SuperKEKB 2021ab





Results of measurement			
β_x @MWP.1 [m] :	9.504	β_y @MWP.1 [m] :	20.183
α_x @MWP.1 :	-.251	α_y @MWP.1 :	1.737
ε_x [m] :	1.3258E-8	ε_y [m] :	4.193E-10
$\Delta\varepsilon_x$ [m] :	3.5336E-9	$\Delta\varepsilon_y$ [m] :	1.498E-10
$\gamma\varepsilon_x$ [μm] :	99.667	$\gamma\varepsilon_y$ [μm] :	3.152
$\Delta\gamma\varepsilon_x$ [μm] :	26.563	$\Delta\gamma\varepsilon_y$ [μm] :	1.126
Goodness x :	.827	Goodness y :	.982
Bmag x :	1.089	Bmag y :	1.458
ε Bmag x :	1.4436E-8	ε Bmag y :	6.112E-10
γε Bmag x :	108.522	γε Bmag y :	4.594

$\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ (2.3 nC)
99.7/3.2 μm @BT

Positron beam

- 5 nC positron beam achieved after the positron target
- 3 nC is realized after DR and linac end
- High positron yield closes to the simulation result
- Qualified emittance at BT

Y. Enomoto, LCG, 2021.07

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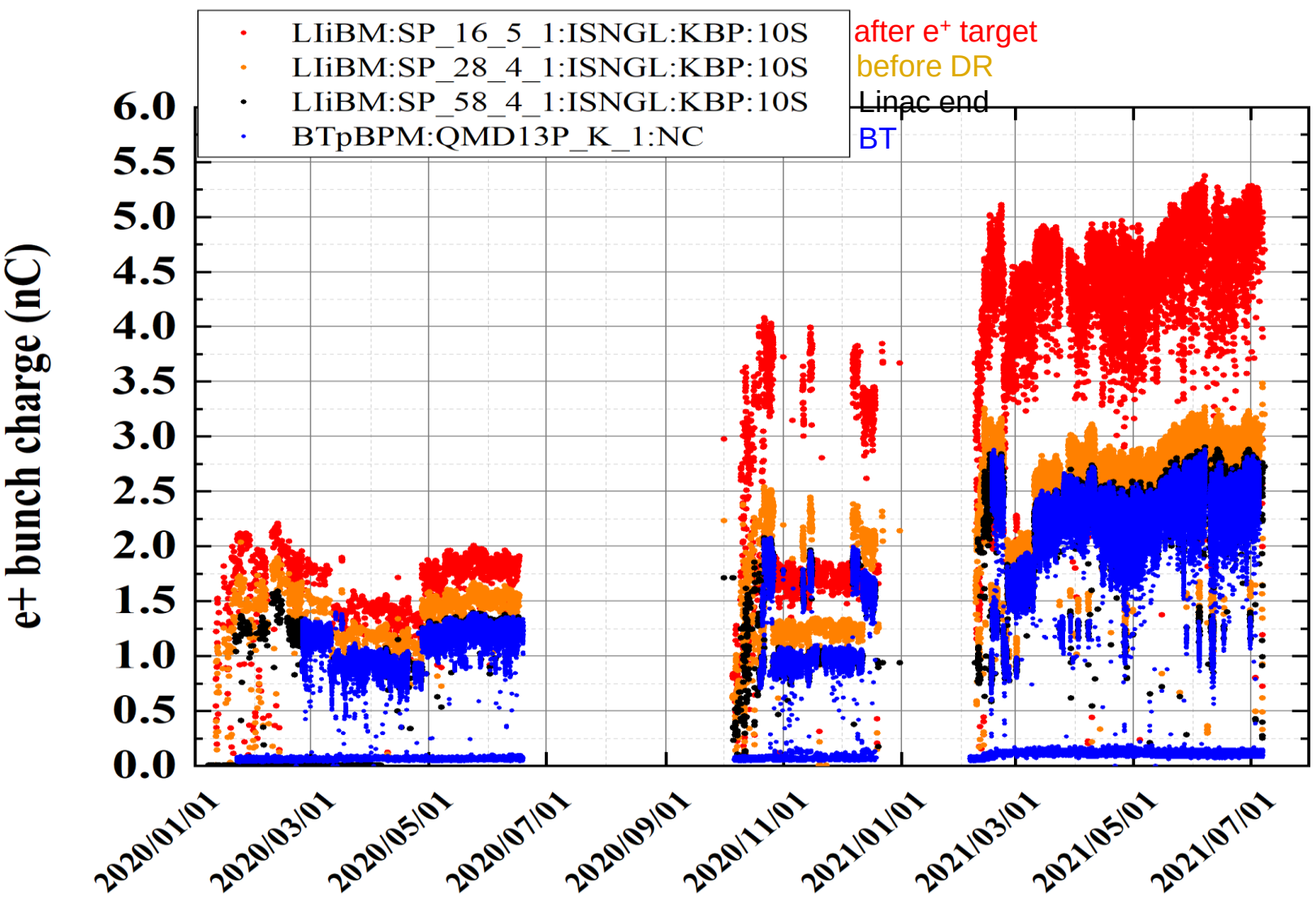
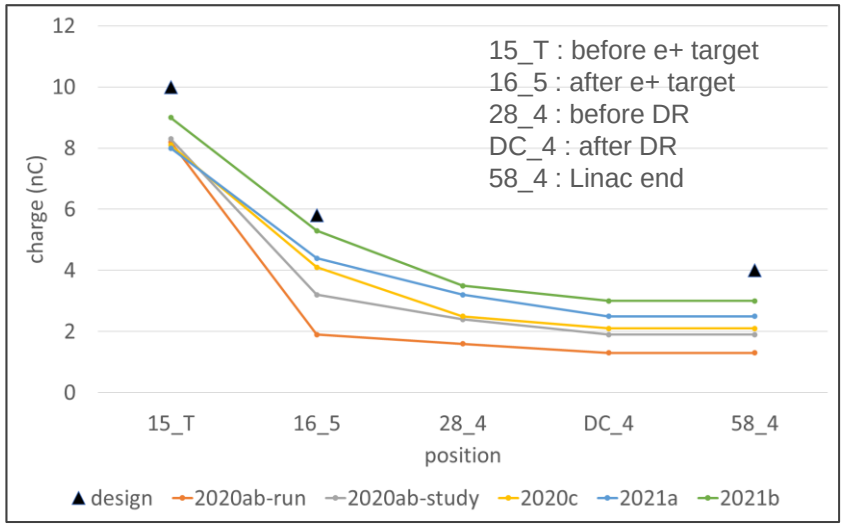
Positron Beam (LER) Beam Charge History in 2021ab





Positron beam charge history

- Stable charge operation
- Tiny loss between Linac end and BT
- Charge increased efficiently and closes to the 4 nC design value
- →Newly installed Q & steering magnets
- →Increase the gradient of AC_15_1[2]
- →Increase FC and DC solenoid field

Y. Enomoto, LCG, 2021.07

M. Satoh, KEKB ARC, 2021.09

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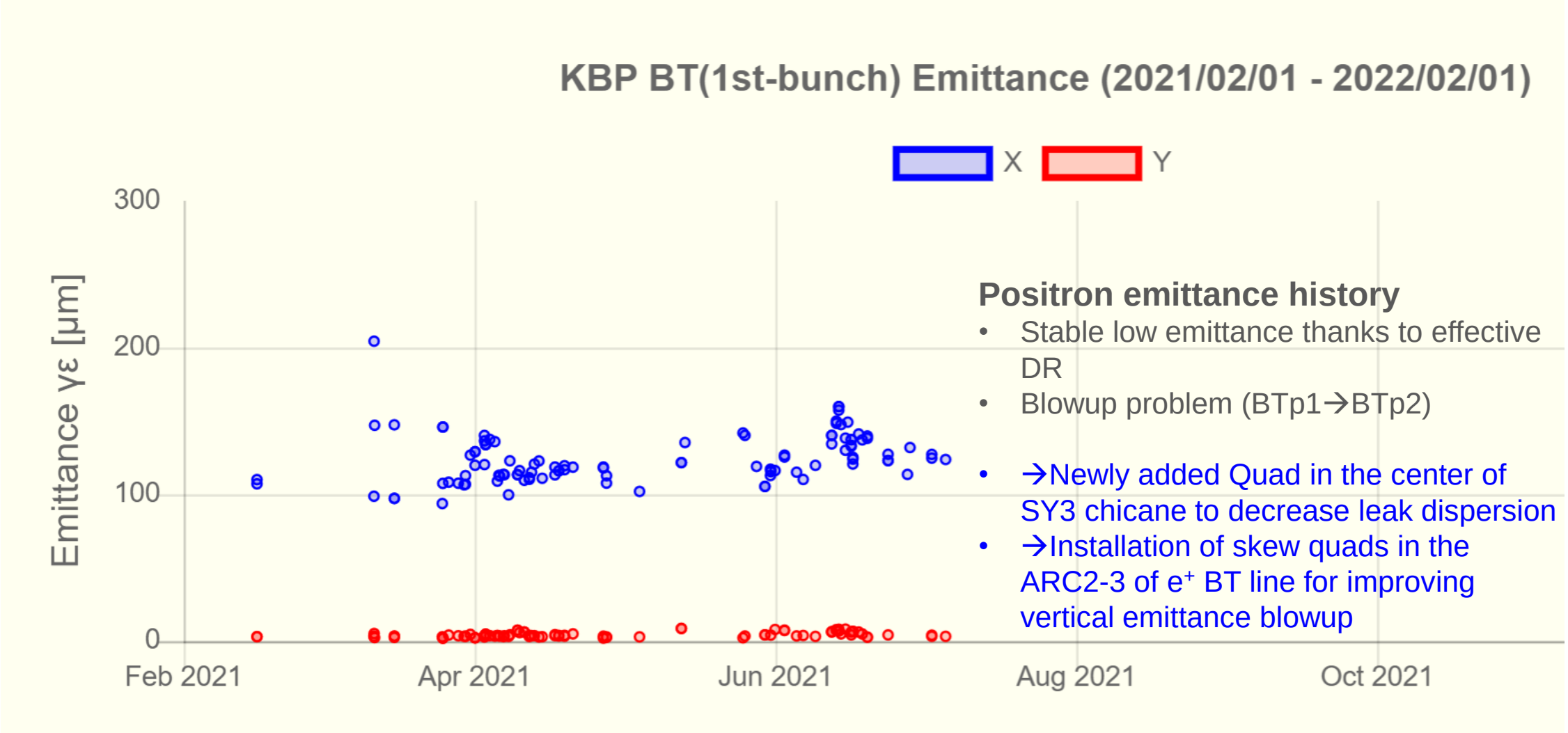
Positron Beam (LER) Beam Emittance History in 2021ab

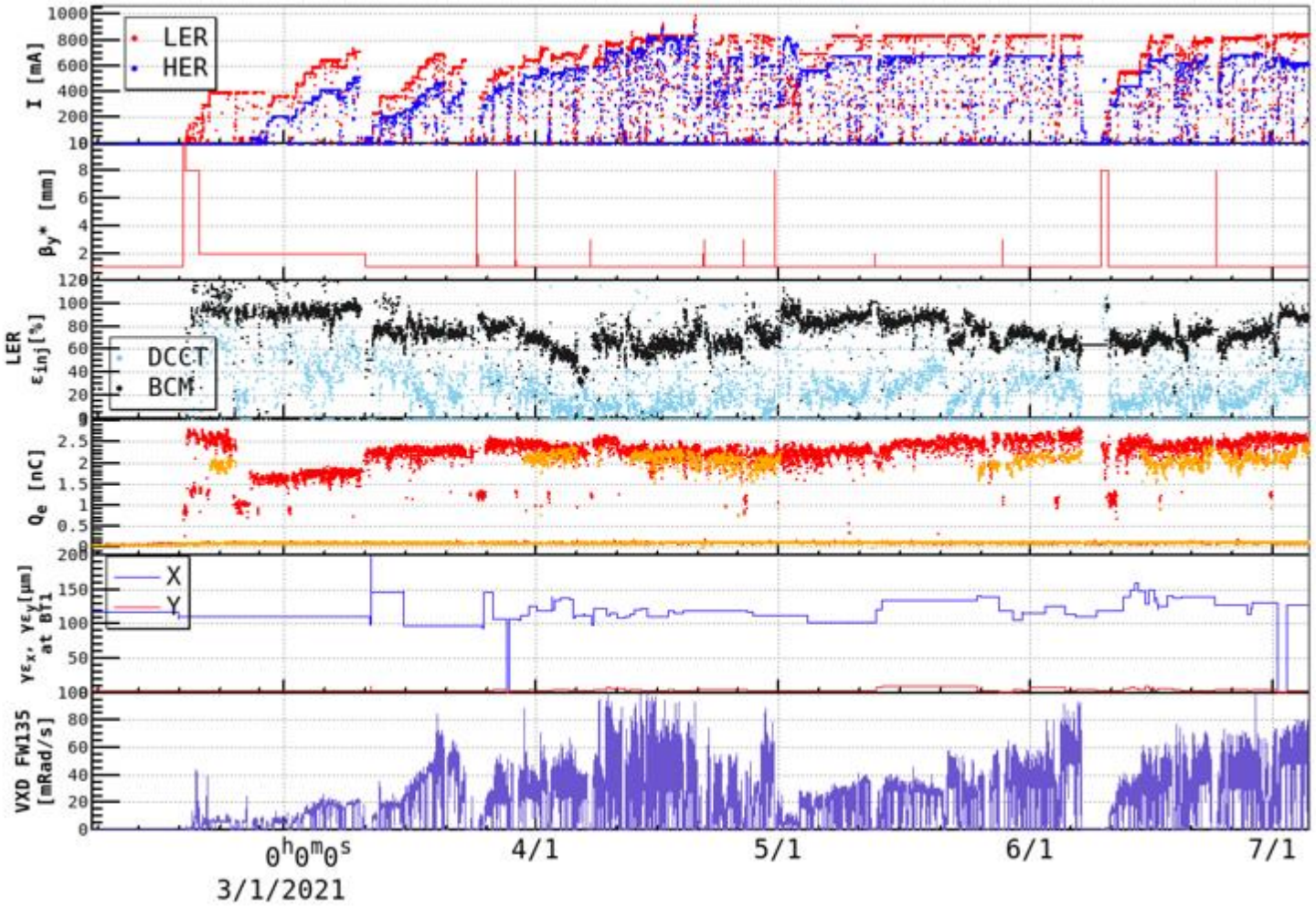


Positron emittance history

- Stable low emittance thanks to effective DR
- Blowup problem (BTp1→BTp2)
- →Newly added Quad in the center of SY3 chicane to decrease leak dispersion
- →Installation of skew quads in the ARC2-3 of e^+ BT line for improving vertical emittance blowup

LINAC STATUS in 2021ab COMMISIONING

Positron Beam (LER) Injection History in 2021ab

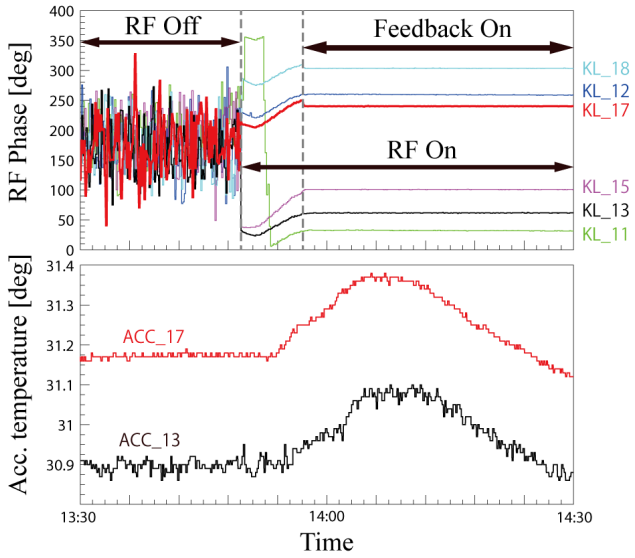


Injection of Positron beam

- High injection efficiency
- Successful double bunch injection
- Injection status of the 2nd bunch is worse
- Large beam background of Belle II

LINAC STATUS in 2021ab COMMISIONING

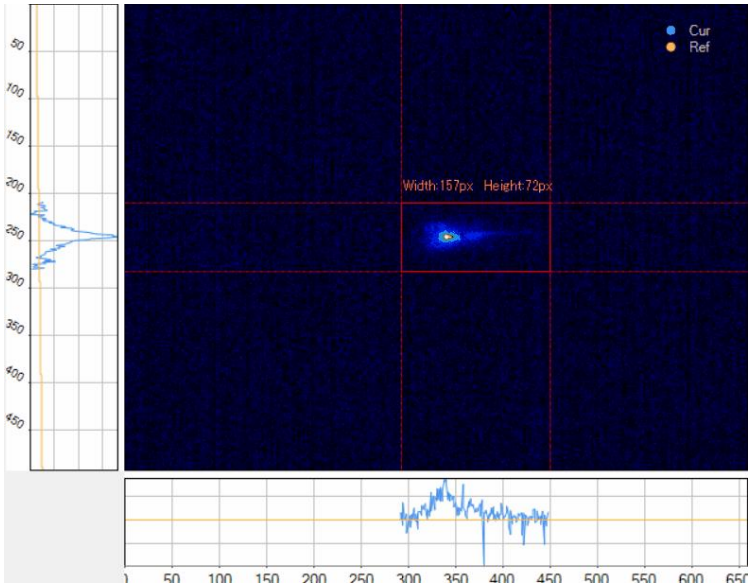
Other Improvement of Linac in 2021ab

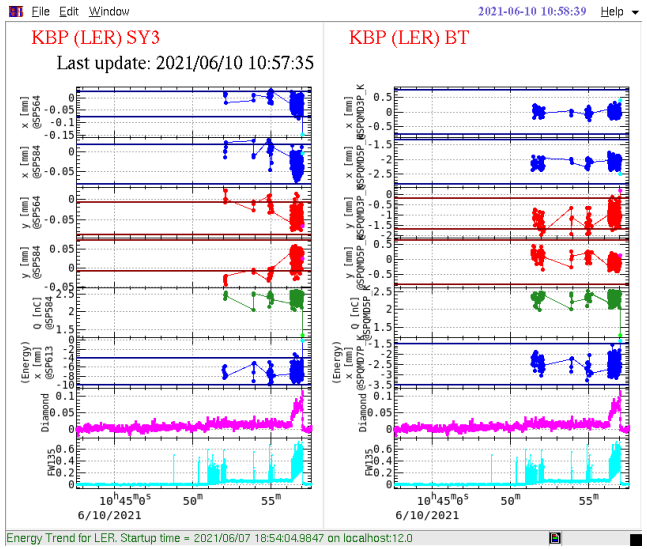


RF phase feedback
-T. Miura

- Application in many locations
- Fast recovery from maintenance status

T. Miura, LCG, 2021.03





Synchronized measurement
-F. Miyahara

- Available to BPM, RF, pulsed magnet
- Large data storage (ASCII→gzip)
- Abnormal event analysis for MR abort

F. Miyahara, LCG, 2021.04

J-arc synchrotron radiation Monitor
-R. Zhang

- RF phase correction
- Measurement of transverse beam size
- For orbit feedback in the future

R. Zhang, Linac Technology Meeting, 2021.04.20

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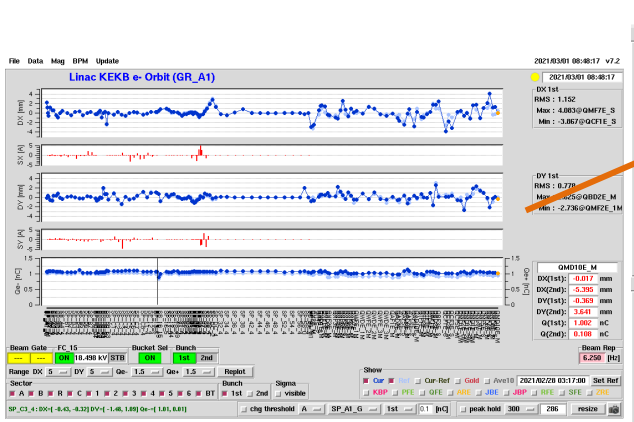
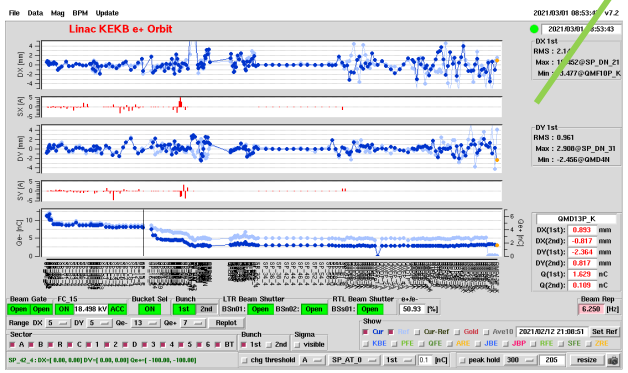
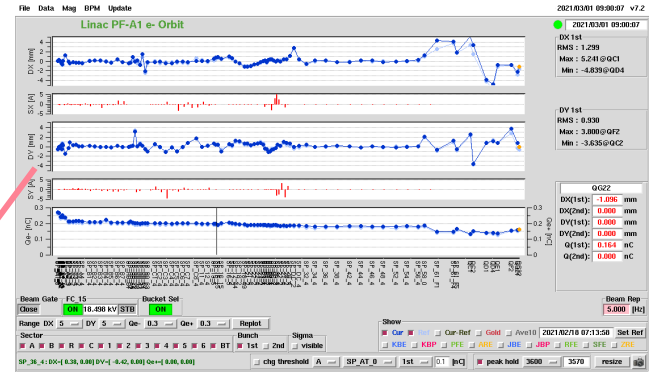
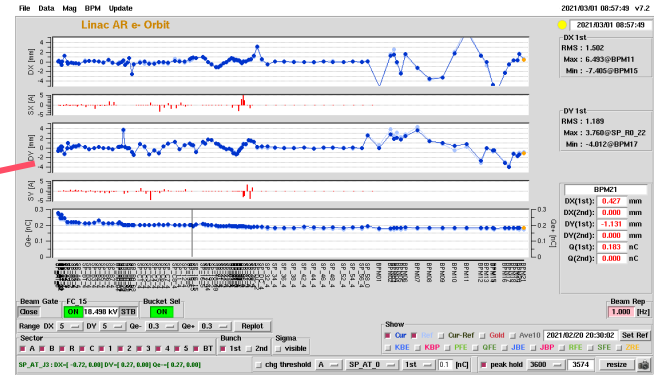
Smooth 4-Ring Simultaneous Top-up Injection





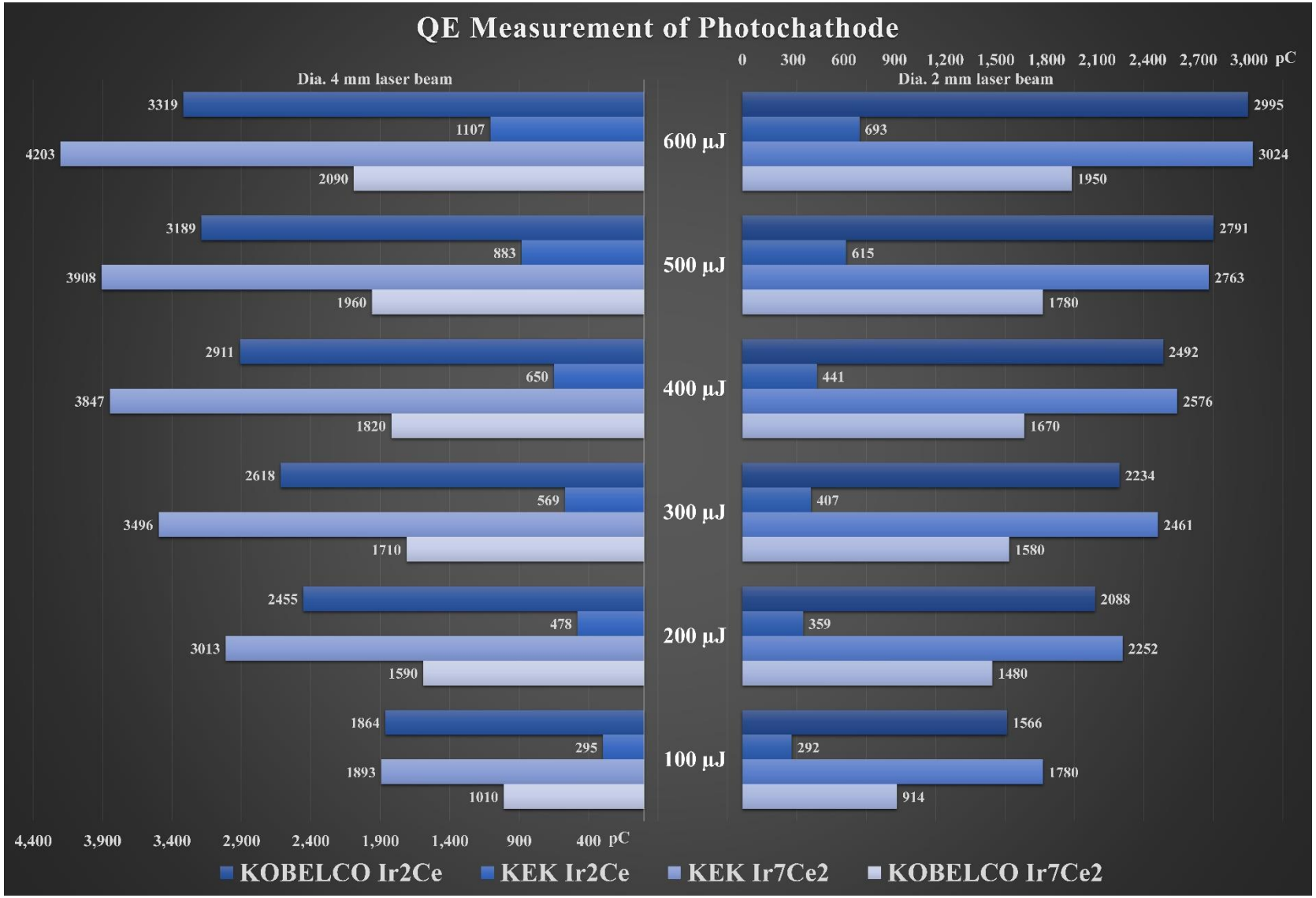




M. Satoh, KEKB ARC, 2021.09

INJECTOR GROUP STATUS

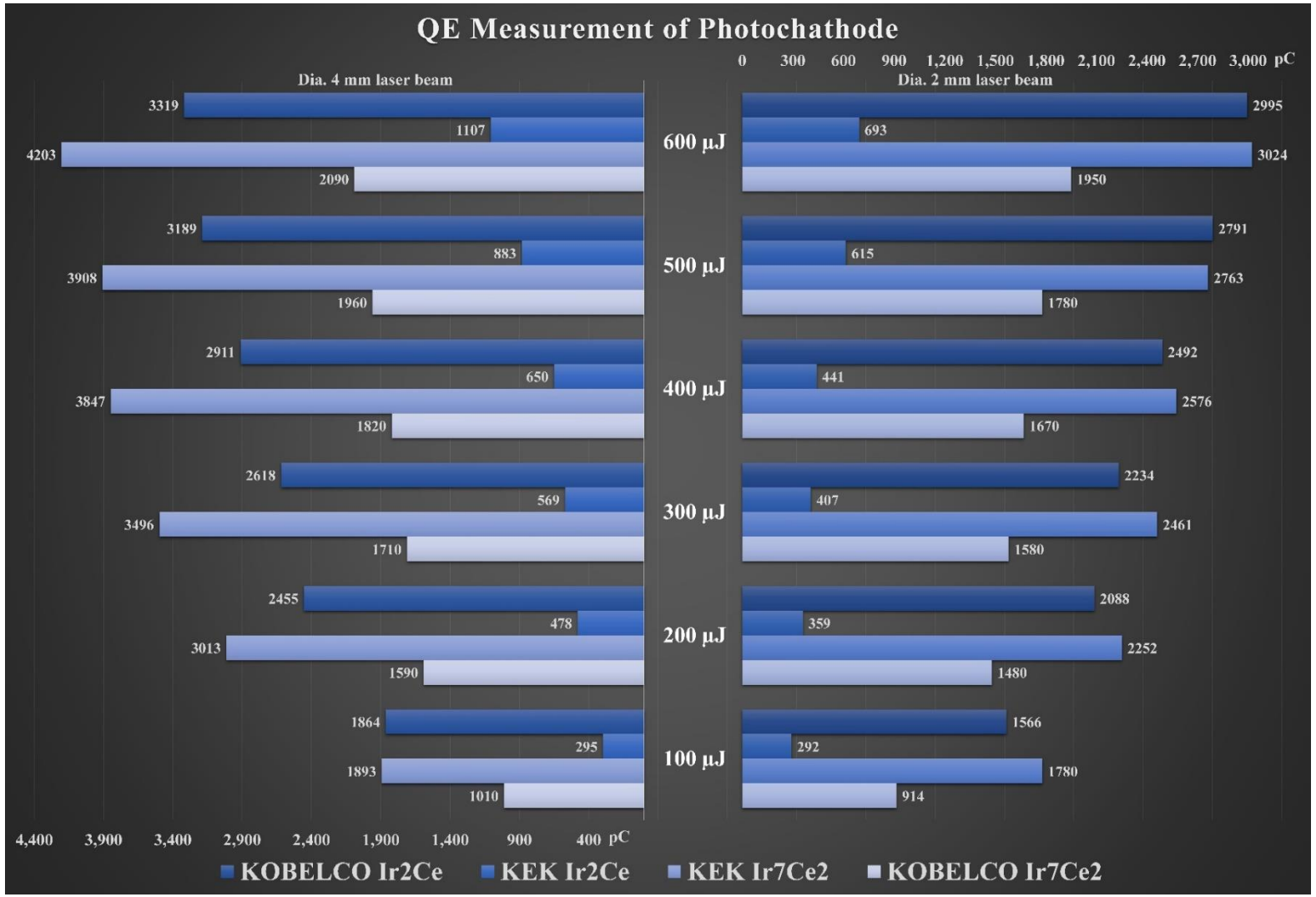
Achievements and Issues in 2021ab



R. Zhang, Linac Technology Meeting, 2020.12.22

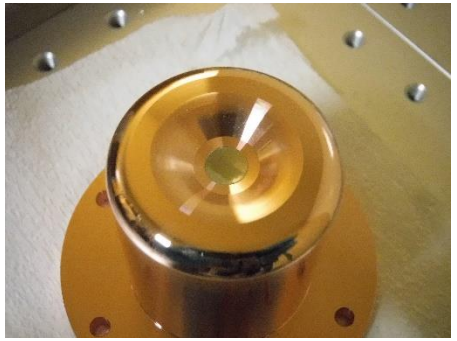
INJECTOR GROUP STATUS

Achievements and Issues in 2021ab



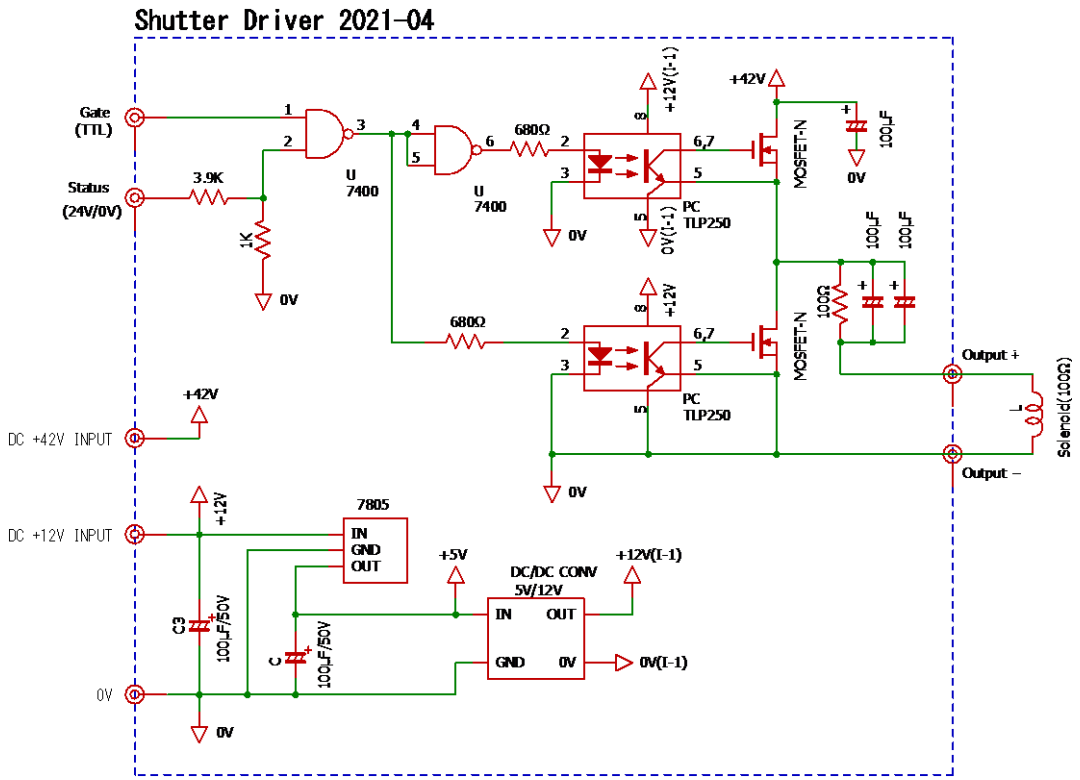
QE of Photocathode

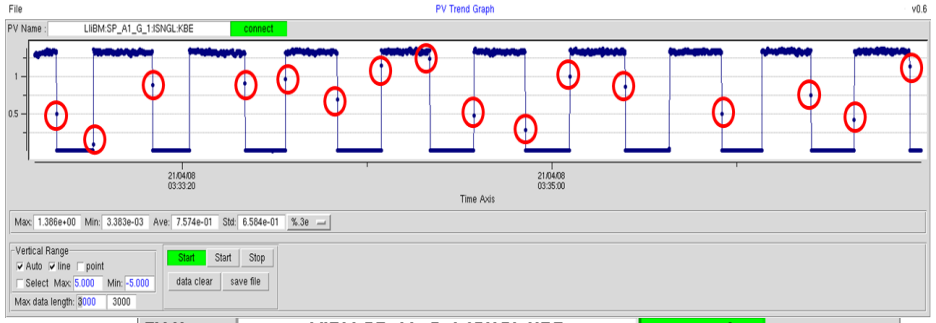
- QE Ranking:
  KEK Ir_7Ce_2 >
  KOBELCO Ir_2Ce >
  KOBELCO Ir_7Ce_2 >
  KEK Ir_2Ce
- Discharge Probability
  KEK Ir_7Ce_2 <
  KOBELCO Ir_2Ce
- Adoption of KEK Ir_7Ce_2 from 2021ab
- Achievable bigger size

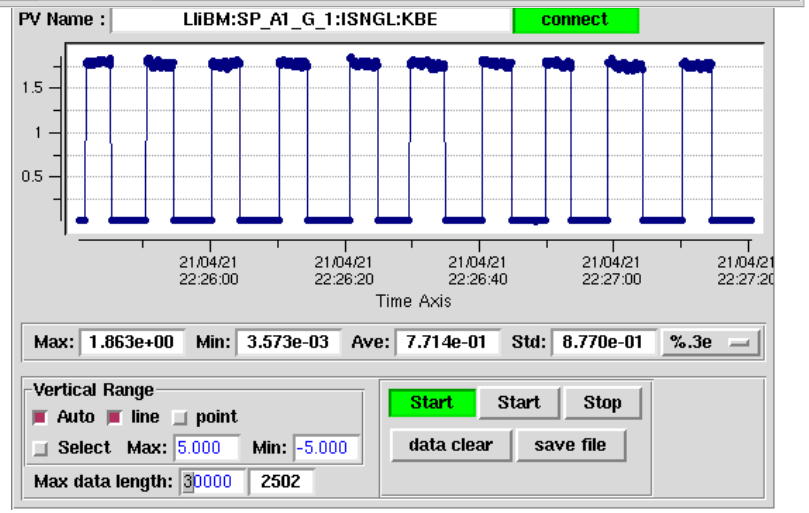


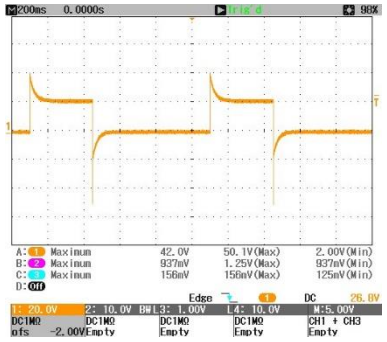
INJECTOR GROUP STATUS

Achievements and Issues in 2021ab









Improvement of Laser Shutter for HER Gate

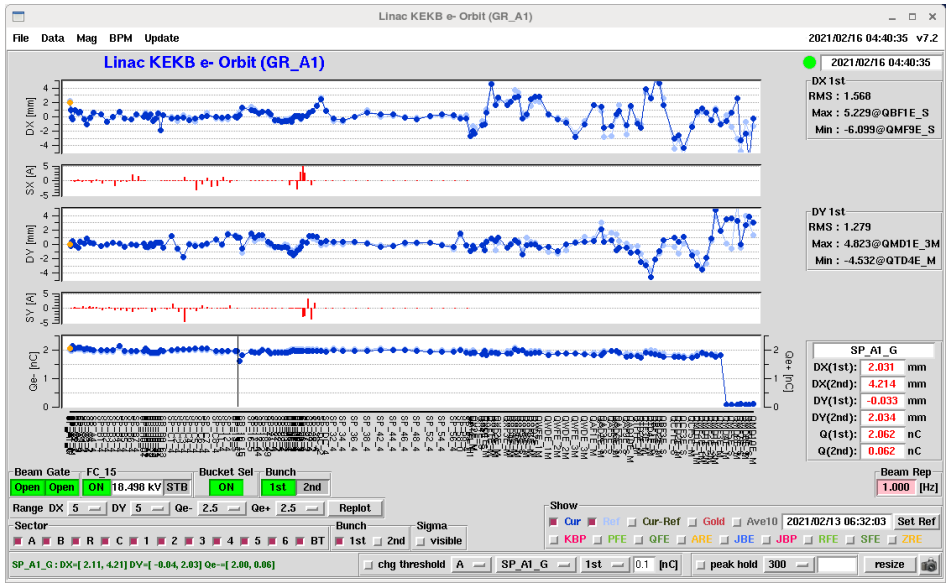
- Application of new synchronization circuit
- Light weighting of physical shutter
- Removal of ambiguous injection beam which is potential cause of HER beam abort

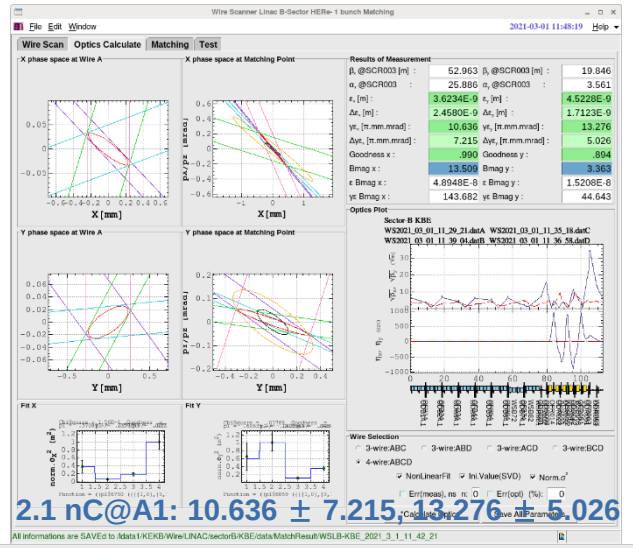
INJECTOR GROUP STATUS

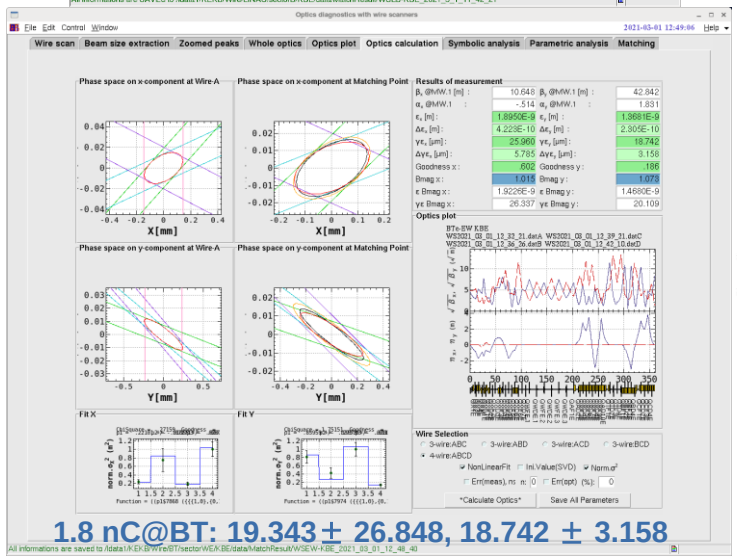
Achievements and Issues in 2021ab

Laser System for RF gun

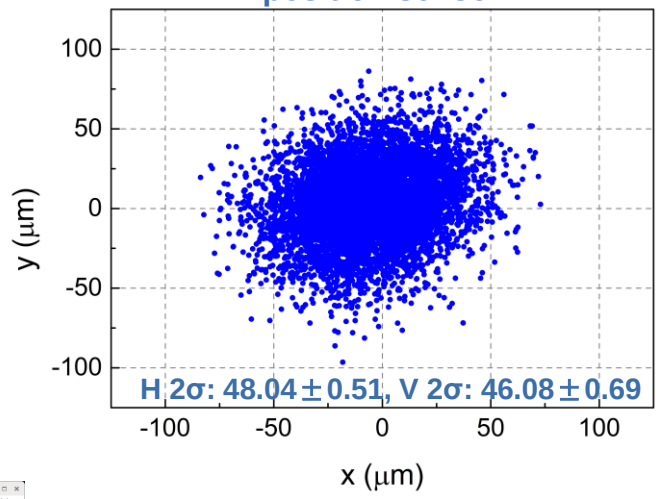
- Application of DOE in 1st laser line
- Energy upgrade of 1st laser line
- Laser beam position sensor for point stability feedback
- Trouble-free continuous laser operation



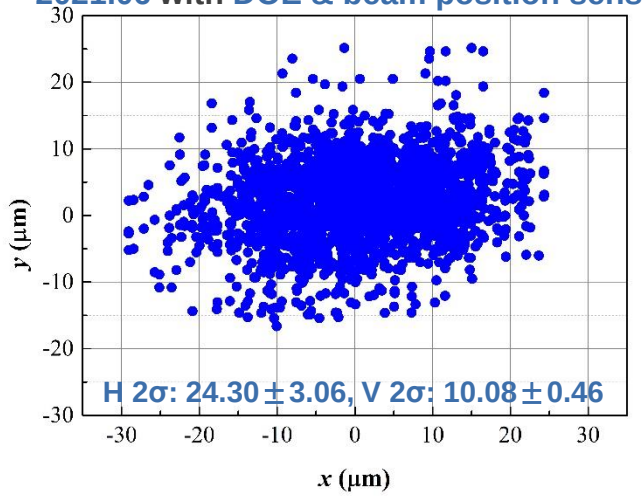




2019.06 without DOE & beam position sensor



2021.06 with DOE & beam position sensor

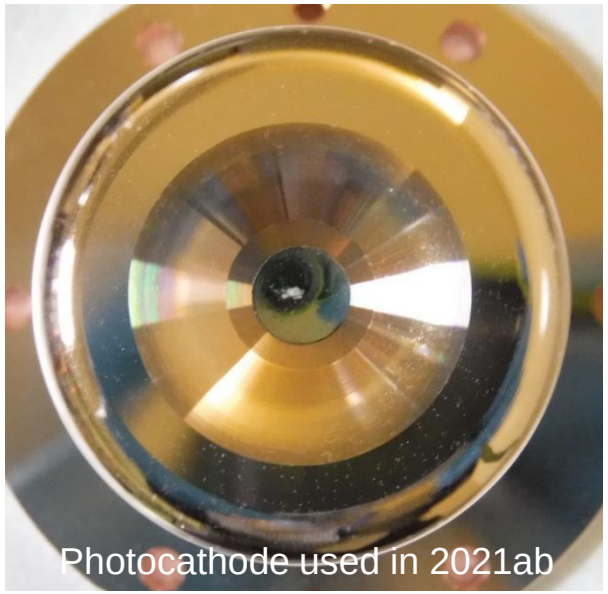


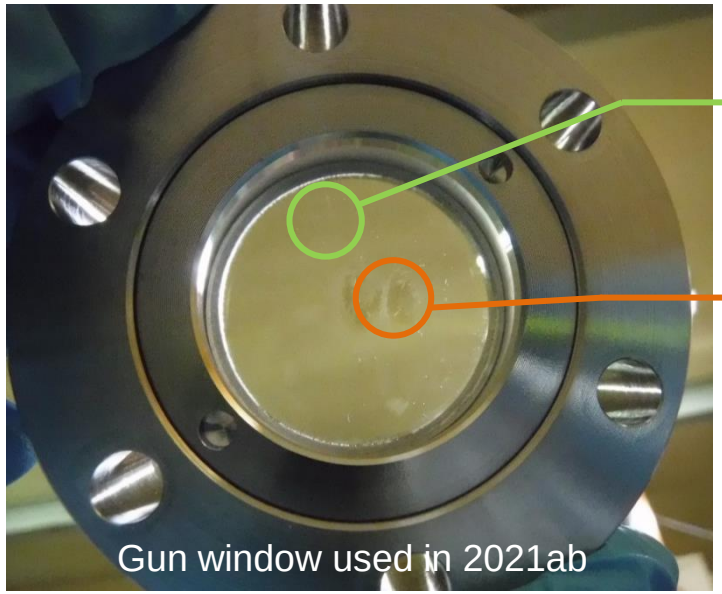
INJECTOR GROUP STATUS

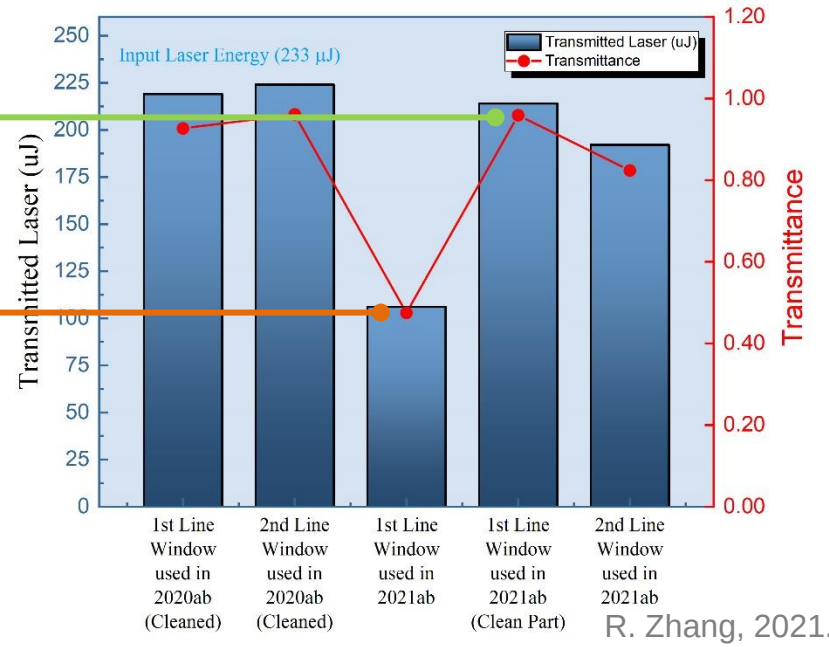
Achievements and Issues in 2021ab

Arisen issues in 2021ab

- Serous discharge → Uniform laser intensity distribution and smooth RF conditioning
- Performance deterioration of RF-gun window → Component analysis of deposits
- Unavailable 2-bunch injection → Sufficient RF conditioning and adjust the RF pulse width, improve the emittance of the 2nd bunch beam
- Not achieved charge at BT end > **2 nC** → Next page

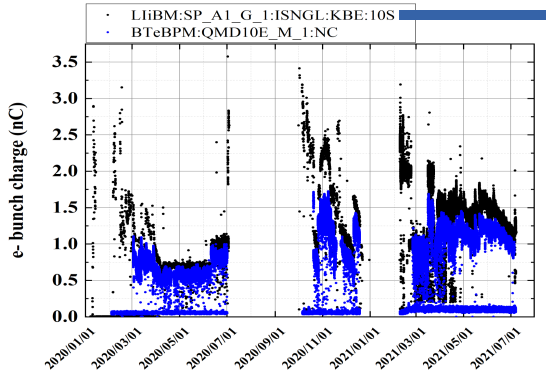

Photocathode used in 2021ab


Gun window used in 2021ab



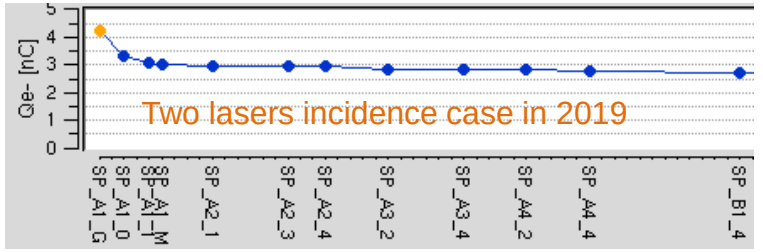
INJECTOR GROUP STATUS

Upgrade for Higher Charge from 2021c



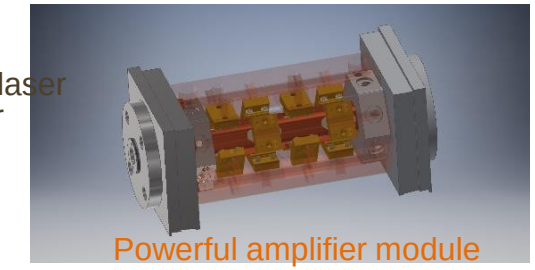
Higher Charge

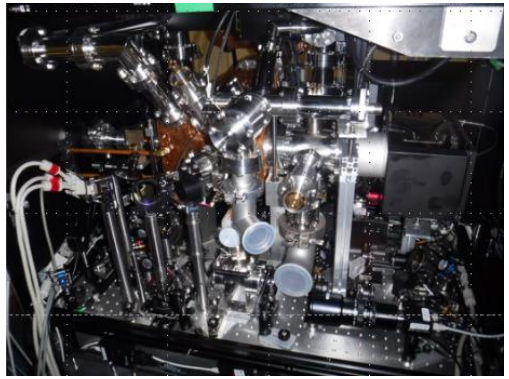
Electron charge @BT-end > **2 nC and for higher HER injection efficiency**



Higher Laser Energy

A. Two lasers incidence
B. Upgrade of 2nd laser line 5th amplifier module





Space in RF Gun Box

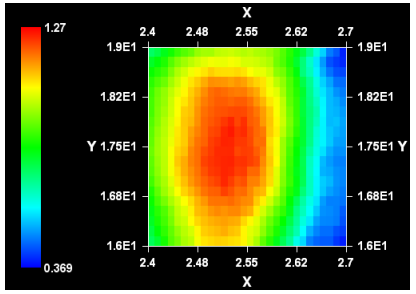
Extremely overcrowded

Two Tier Laser Configuration

01 02 03 04 05 06

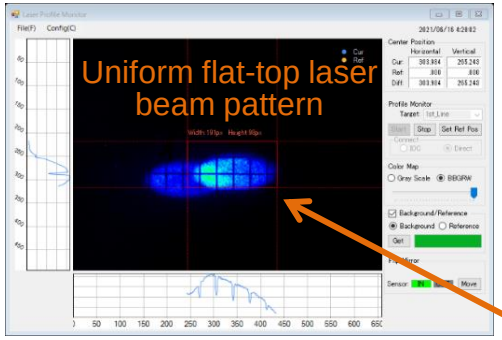
Higher Photocathode QE

Available laser cleaning mode during commissioning



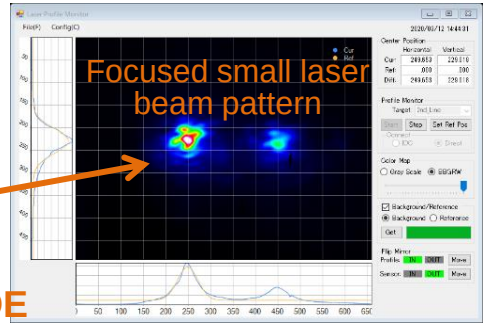
DOE for 2nd laser line

A. For uniform laser intensity distribution after laser energy upgrade of 2nd laser line
B. Keeping laser cleaning function



Discharge Problem

Non-uniform powerful laser beam induces discharge easily

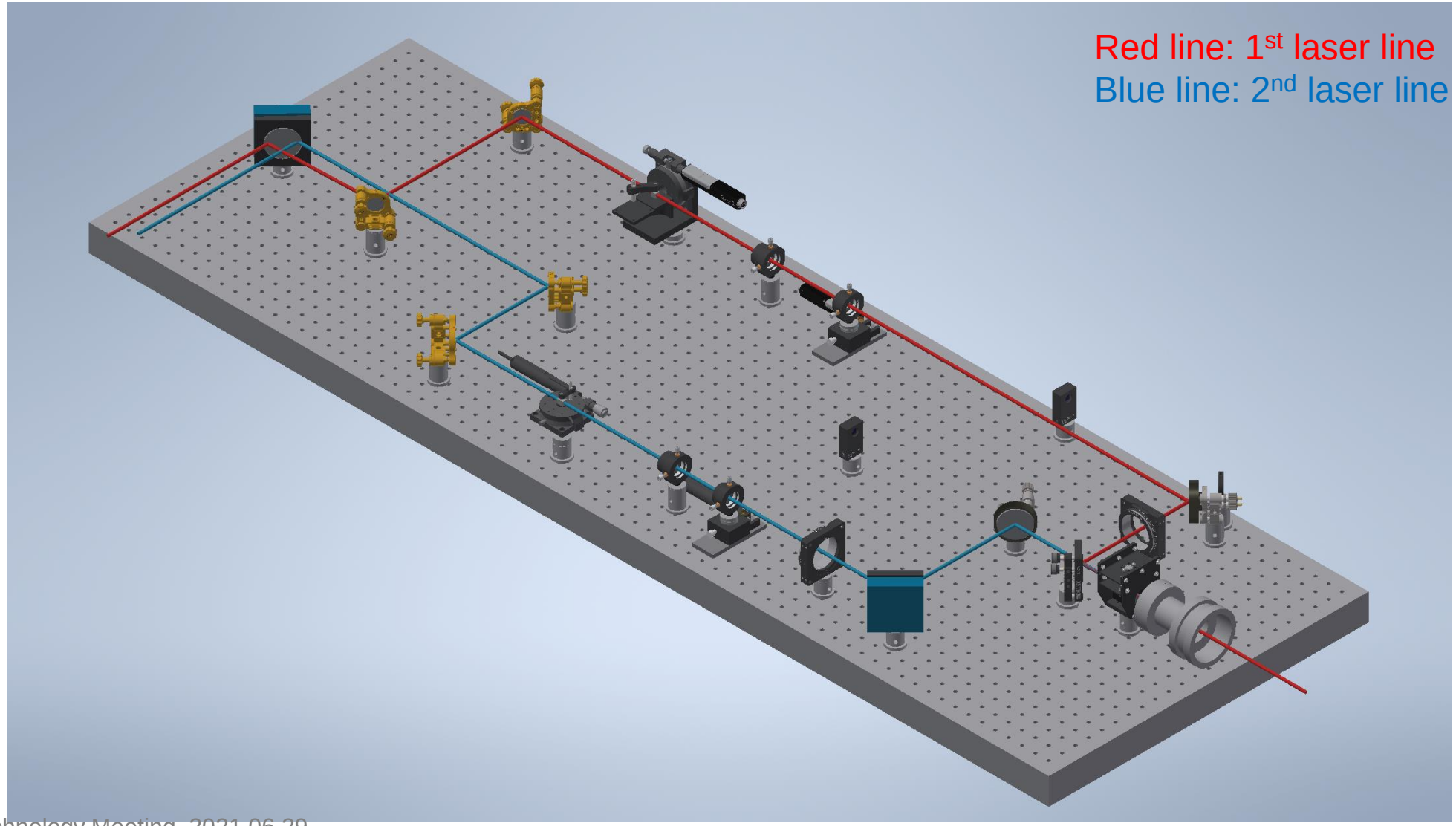


Laser cleaning needs small laser beam spot wo DOE

KBE operation requires big and uniform laser beam with DOE

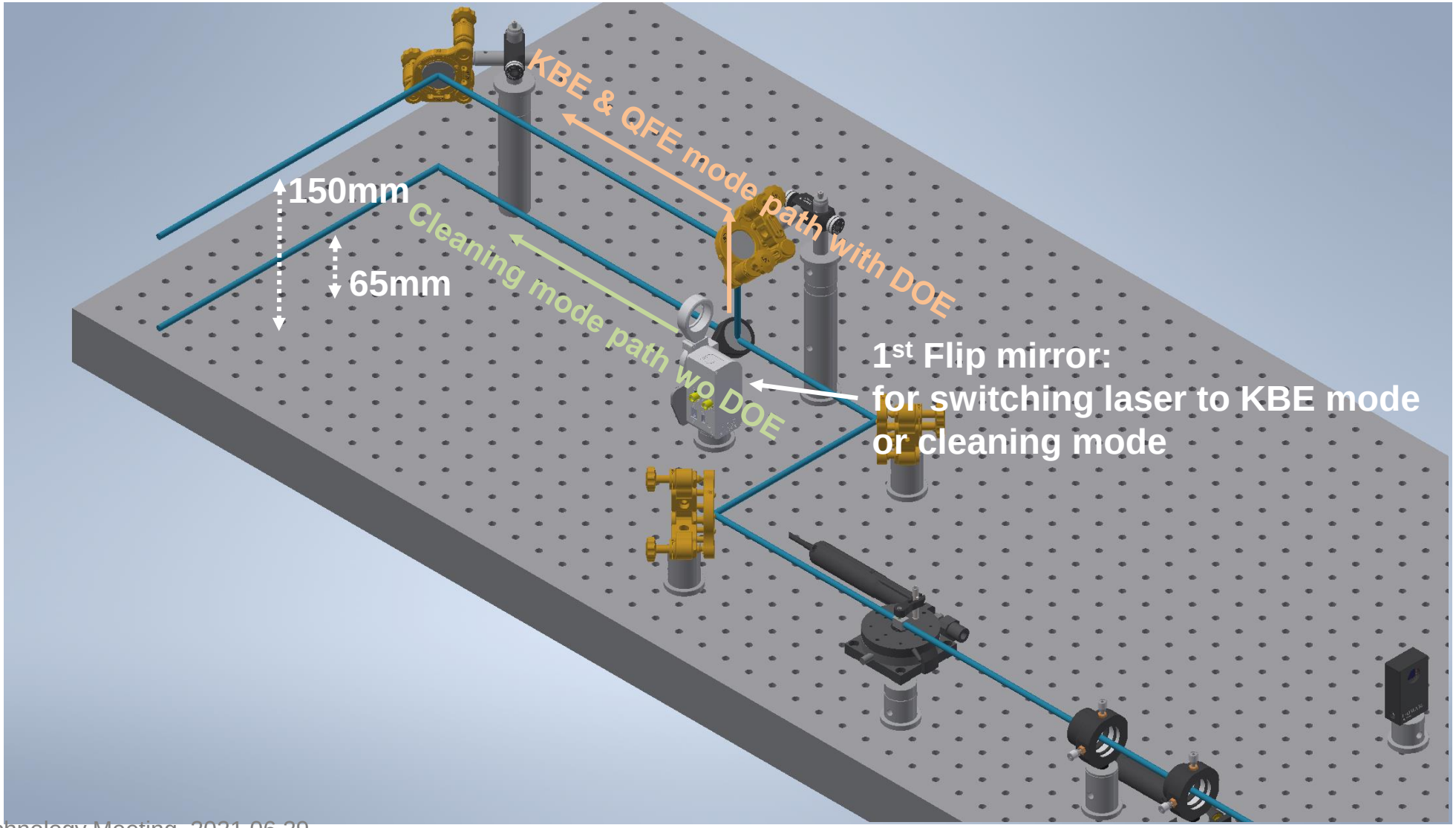
INJECTOR GROUP STATUS

Upgrade for Higher Charge from 2021c



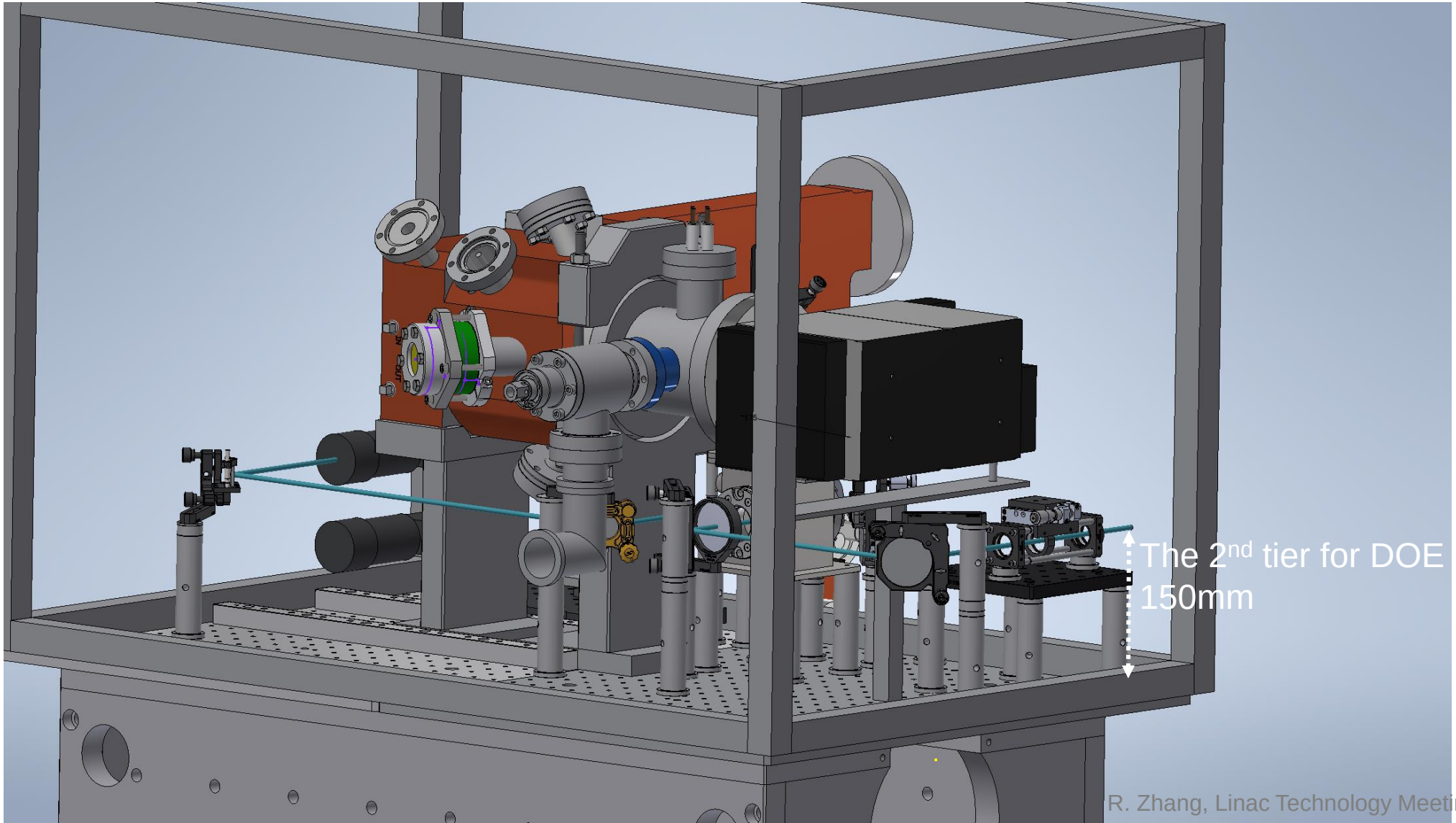
INJECTOR GROUP STATUS

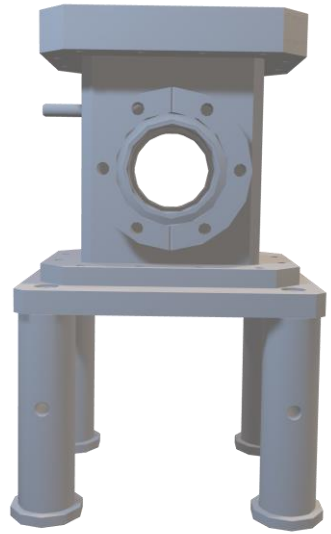
Upgrade for Higher Charge from 2021c



INJECTOR GROUP STATUS

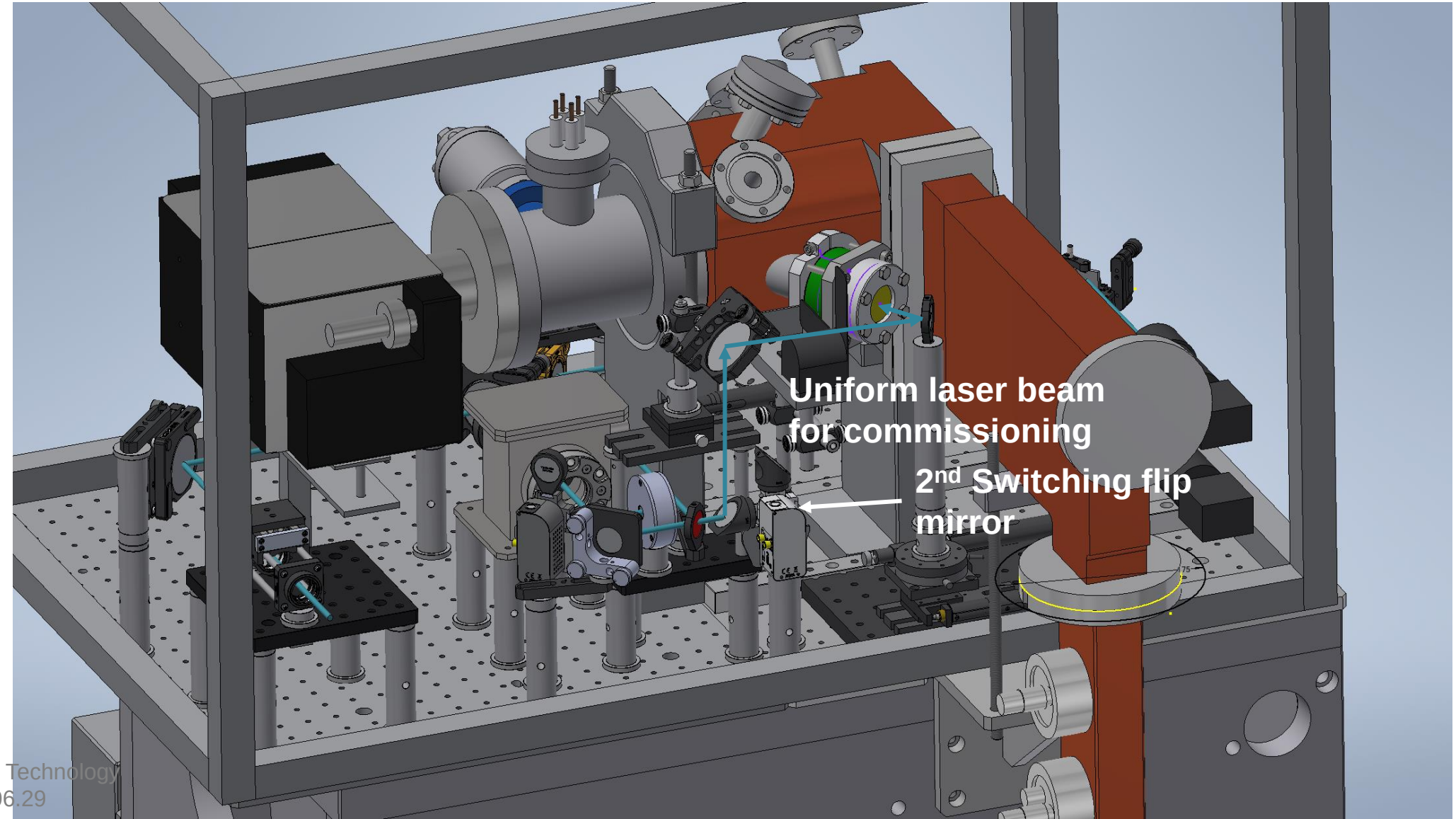
Upgrade for Higher Charge from 2021c





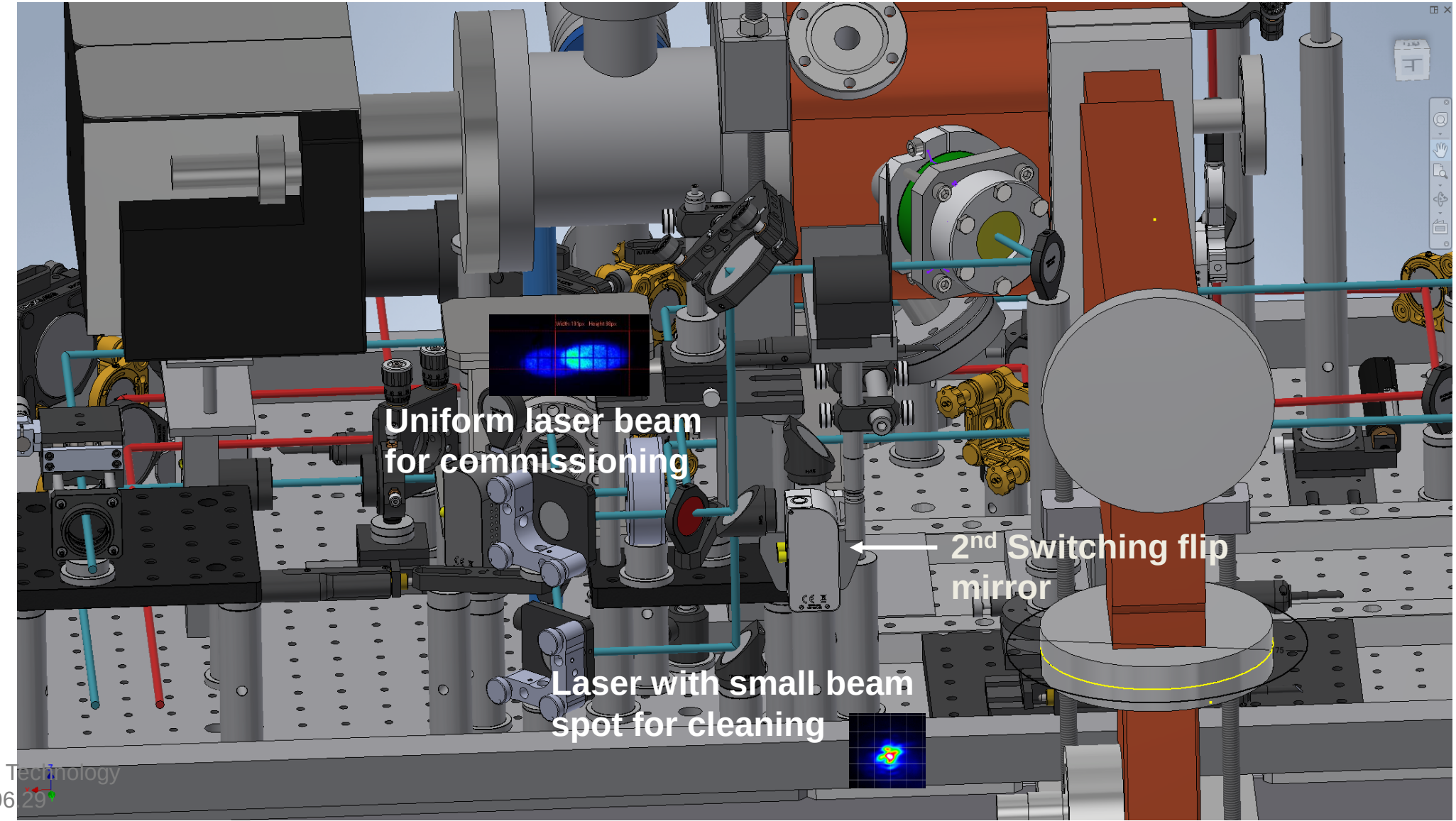
INJECTOR GROUP STATUS

Upgrade for Higher Charge from 2021c



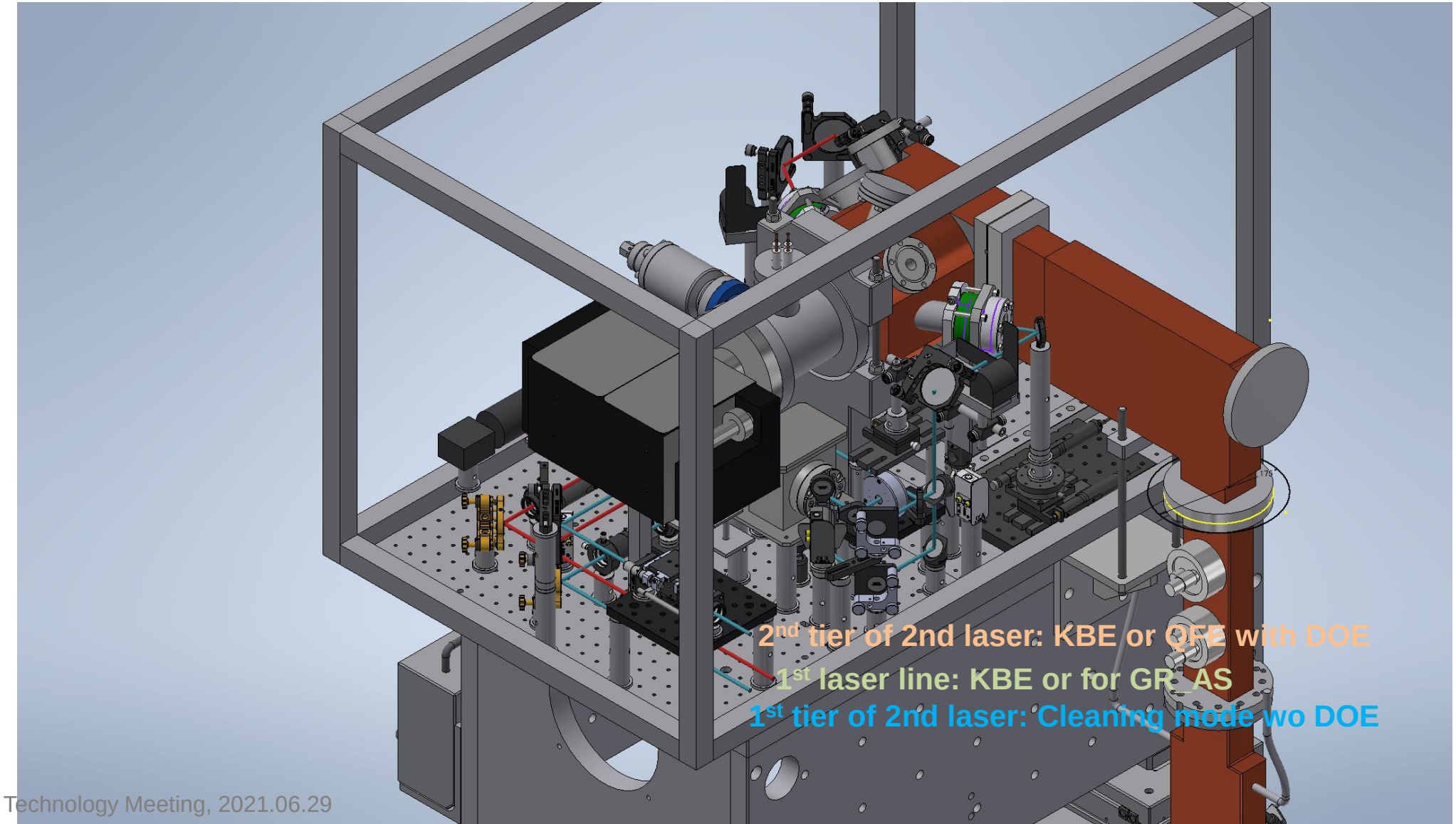
INJECTOR GROUP STATUS

Upgrade for Higher Charge from 2021c



INJECTOR GROUP STATUS

Two Tier Laser Configuration



SUMMARY

- **Smooth linac operation in 2021ab**
  - e^-: 1.5 nC @BT and unachievable double bunch injection
  - e^+: increased charge smoothly and working well
  - Successful 4-ring simultaneous top-up injection
  - Others effective improvements for efficient operation from all groups
- **Injector group status**
  - Laser systems working well in 2021ab commissioning
  - Upgrade of laser system for high performance operation from 2021c

THANKS !