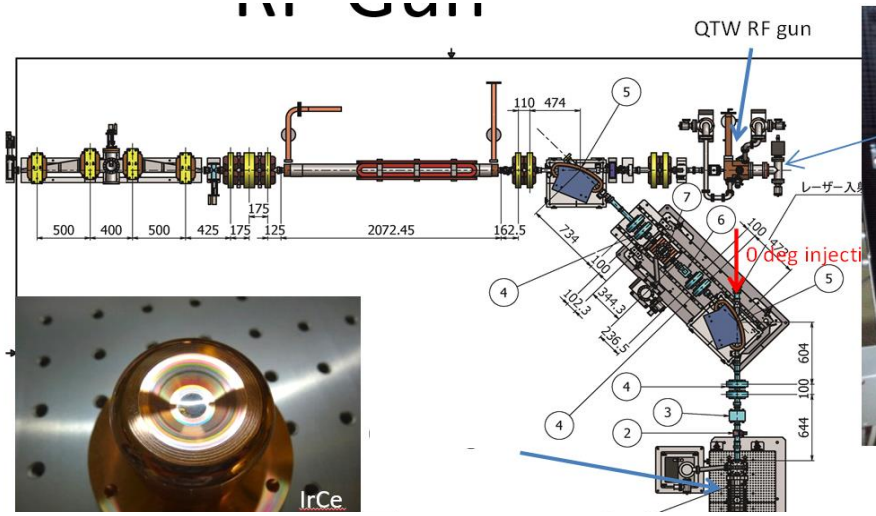
The 27th KEKB Accelerator Review Committee/ Injector / RF-Gun and electron-beam

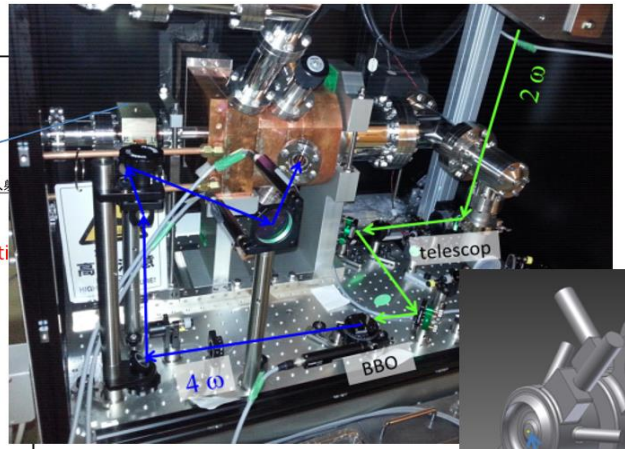
2024.03.25

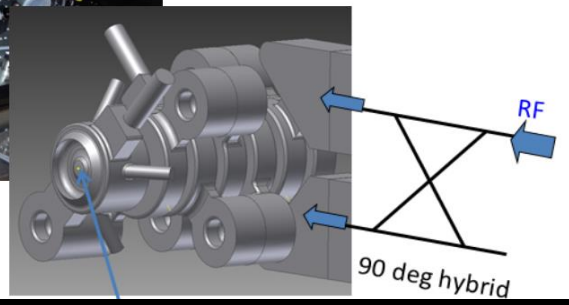
Mitsuhiro Yoshida (INJ-Group of Injector Linac)

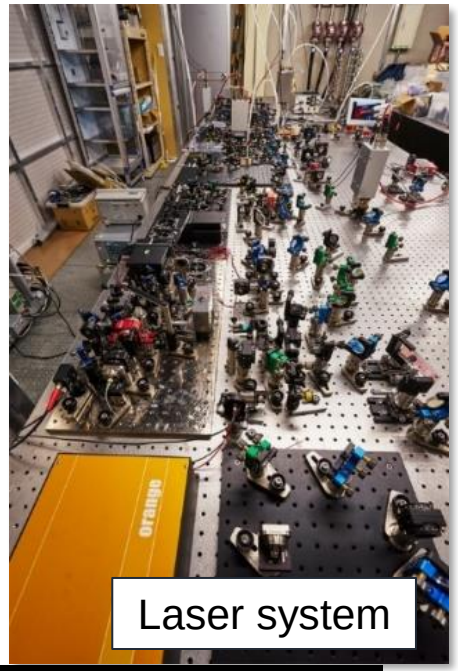
1

Low emittance and high charge photocathode rf e- gun

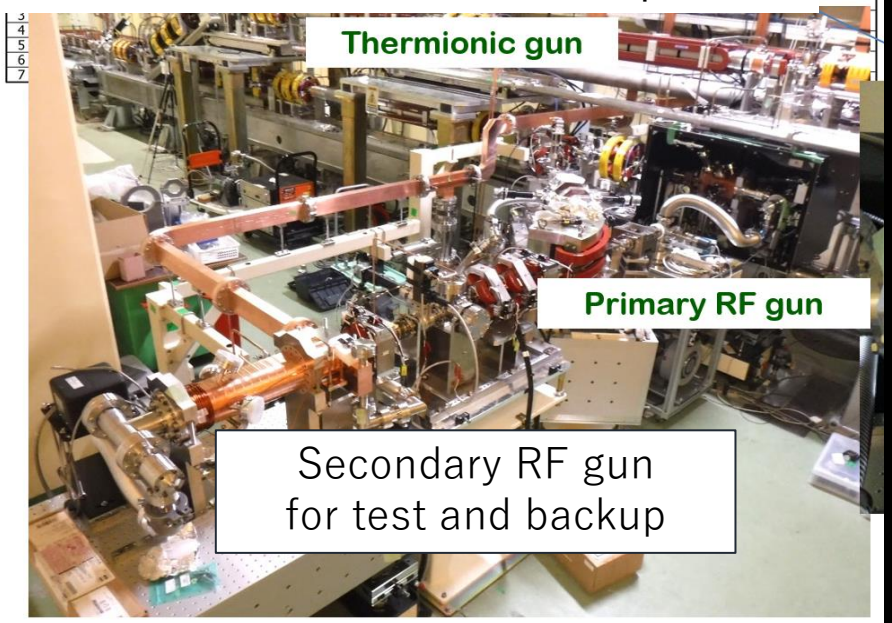




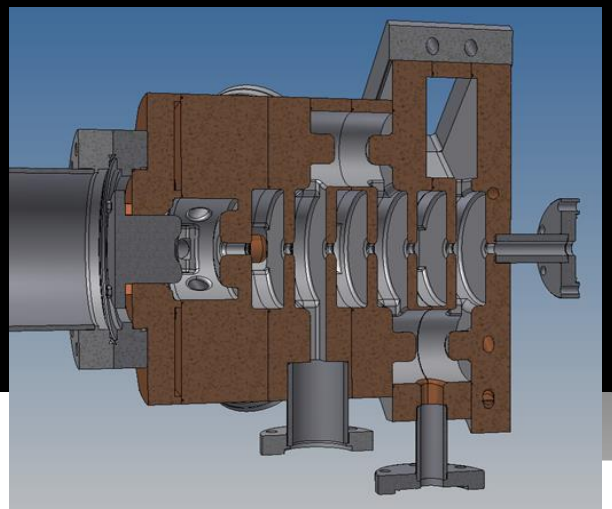


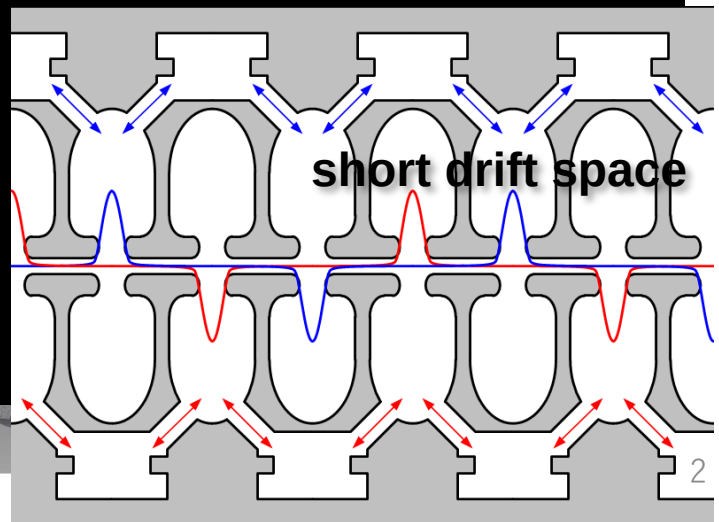


Ir_7Ce_2 cathode : Infinite lifetime and no pollution



- Photocathode: Ir_7Ce_2
- Cavity: QTWSC (Quasi Travelling Wave Side Couple)
  - Strong focusing electric field

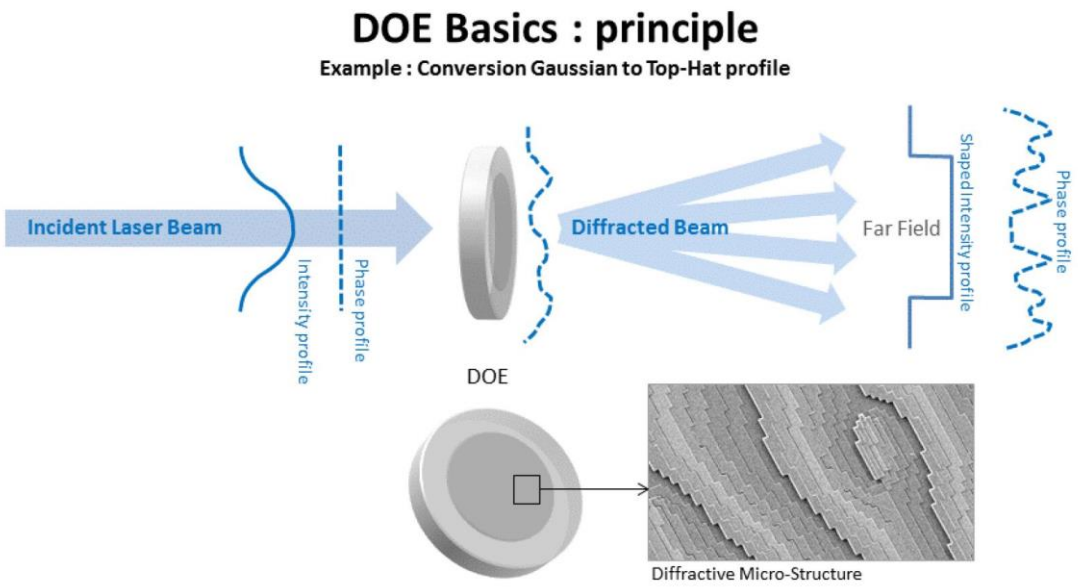




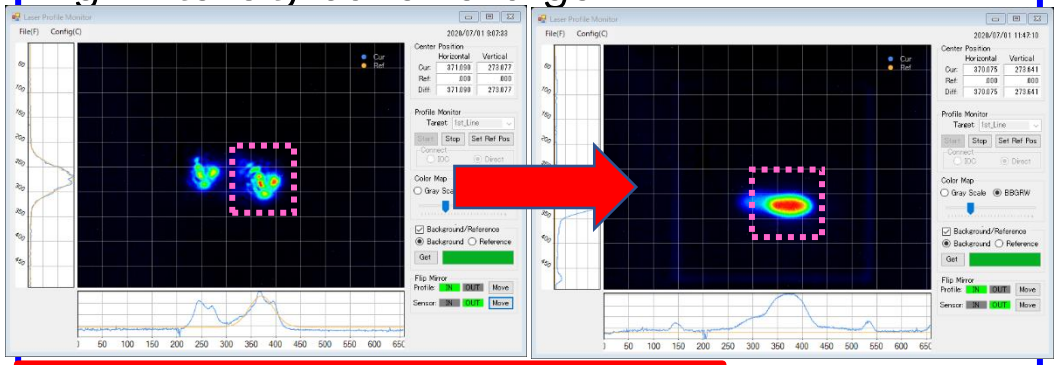
Recent Achievement

3

DOE for reshaping of laser spatial distribution



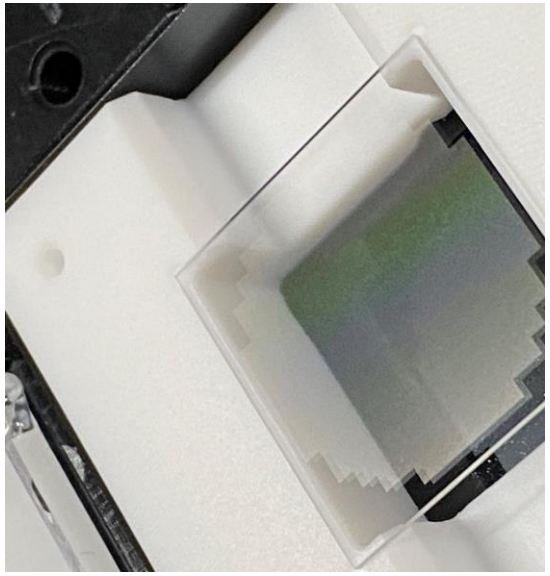
DOE (diffractive optical element) were installed at 1st /2nd (in summer '20/'21) line laser: Laser beam homogenizer for low emittance beam with the high intensity bunch charge.

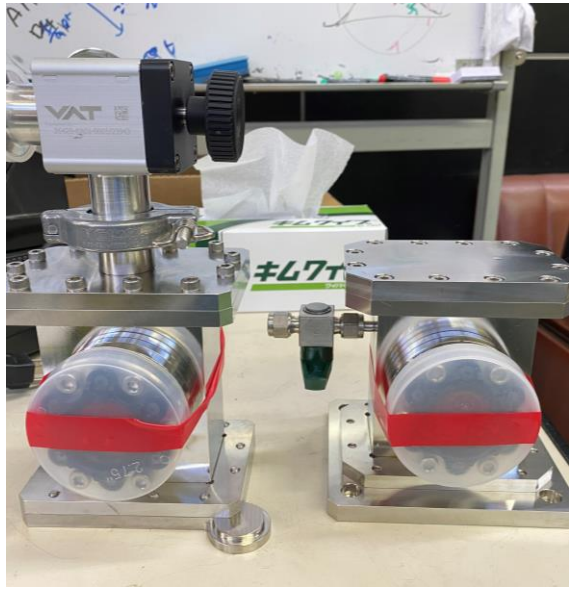


world first DOE application in UV laser

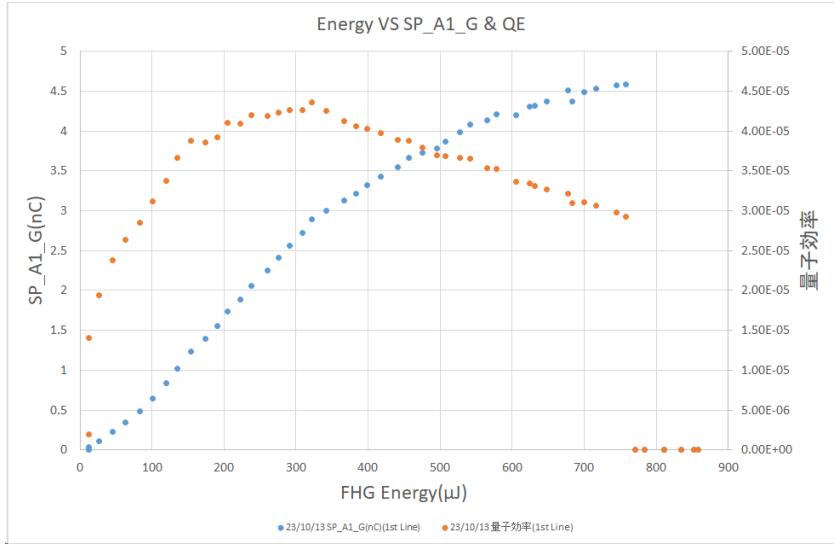
R. Zhang

New DOE for large area was installed at Jan, 2024.





Bunch charge increased

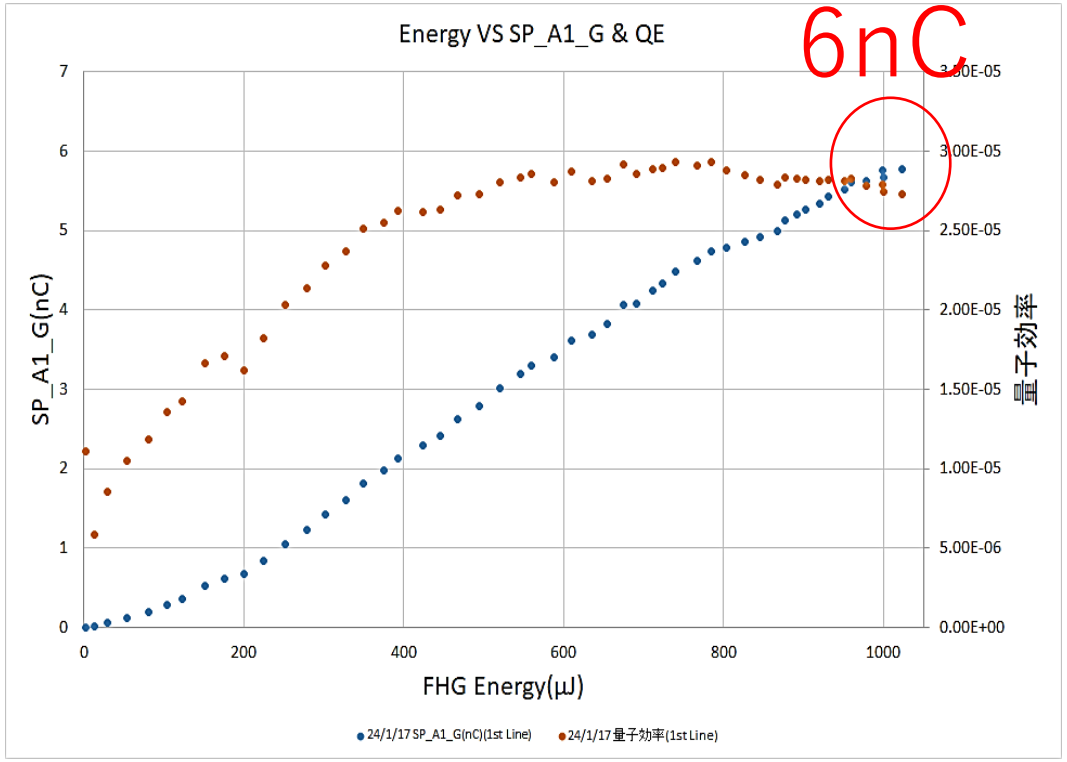


A1 Nd:YAG Laser amplifier system

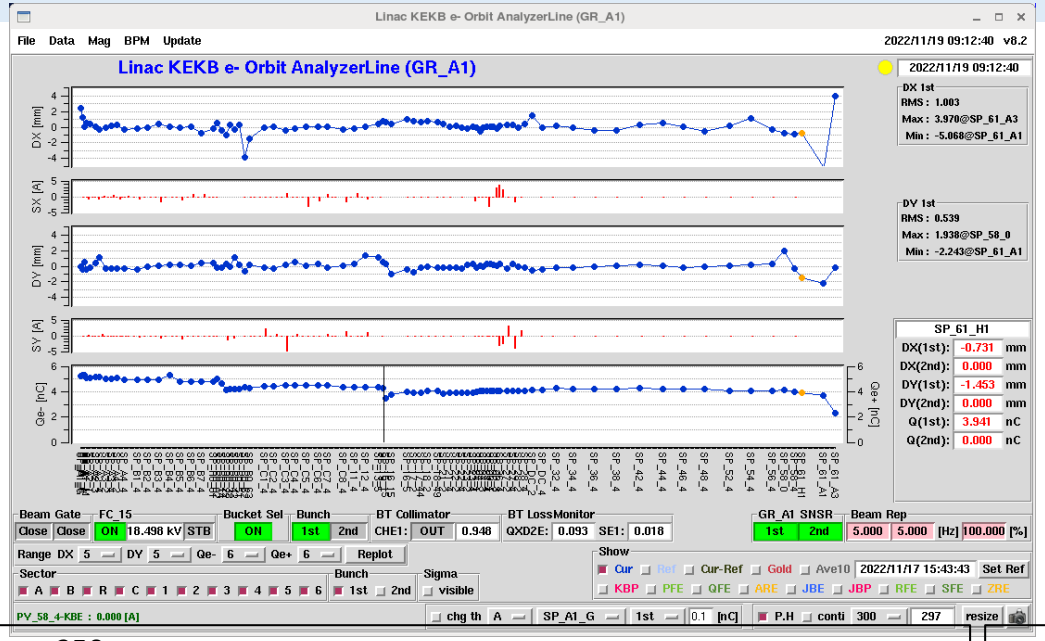
	Amp1	Amp2	Amp3	Amp4	Amp5
1st Line	Φ2mm LD	Φ2mm LD	Φ4mm LD	Φ4mm LD	Φ8mm VCSEL
2nd Line	Φ2mm LD	Φ2mm VCSEL	Φ4mm VCSEL	Φ6mm VCSEL	Φ10mm VCSEL

Laser Amplifier		Power supply	Rated Output	Setup Voltage(V)
1st Line	1stage	PWX750MHF	0～230V、10A、750W	66
	2stage	PWX750MHF	0～230V、10A、750W	67
	3stage	PWX1500MH	0～230V、20A、1500W	68.5
	4stage	PWX1500MH	0～230V、20A、1500W	68.5
	5stage	PWX1500MH	0～230V、20A、1500W	69
2nd Line	1stage	PWX750MLF	0～80V、28A、750W	66
	2stage	PWX750MLF	0～80V、28A、750W	74
	3stage	PWX750MHF	0～230V、10A、750W	72
	4stage	PWX750MHF	0～230V、10A、750W	85
	5stage	PWX1500H	0～650V、7A、1500W	233

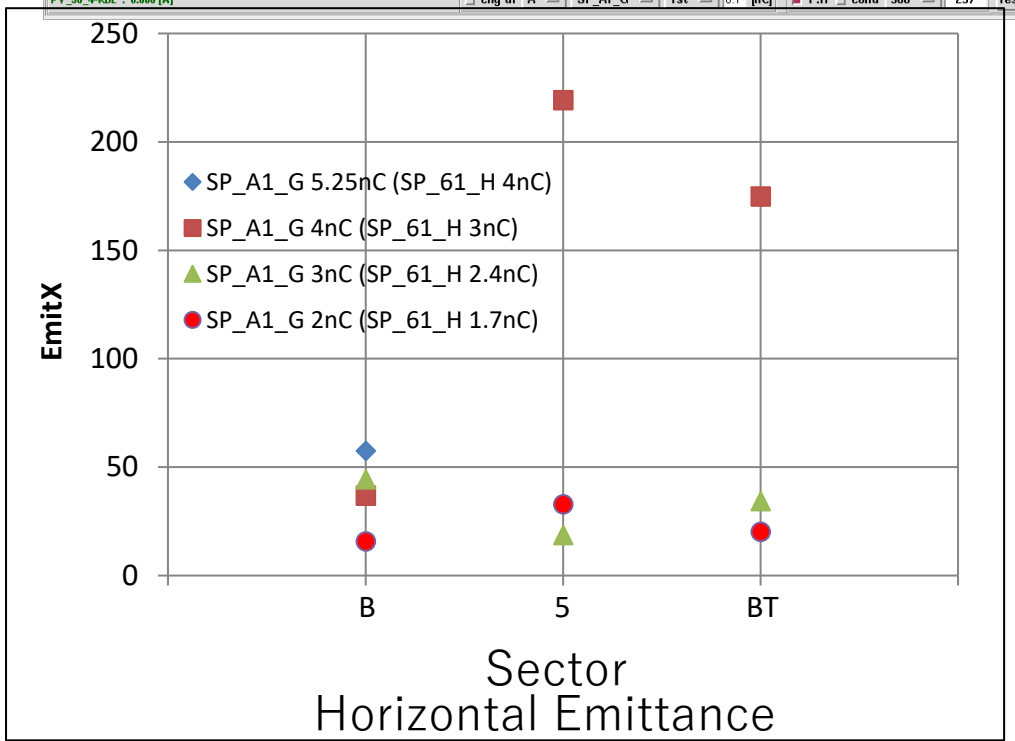
1st Charge vs laser power

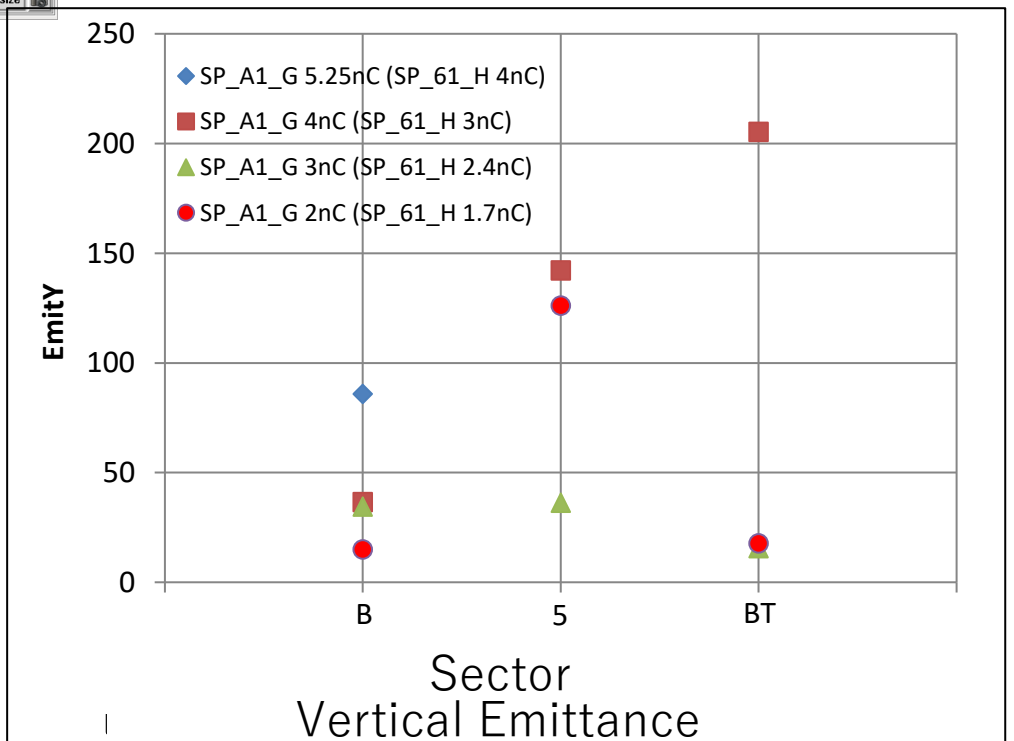


SP_61_H 4nC achievement / emittance achievement

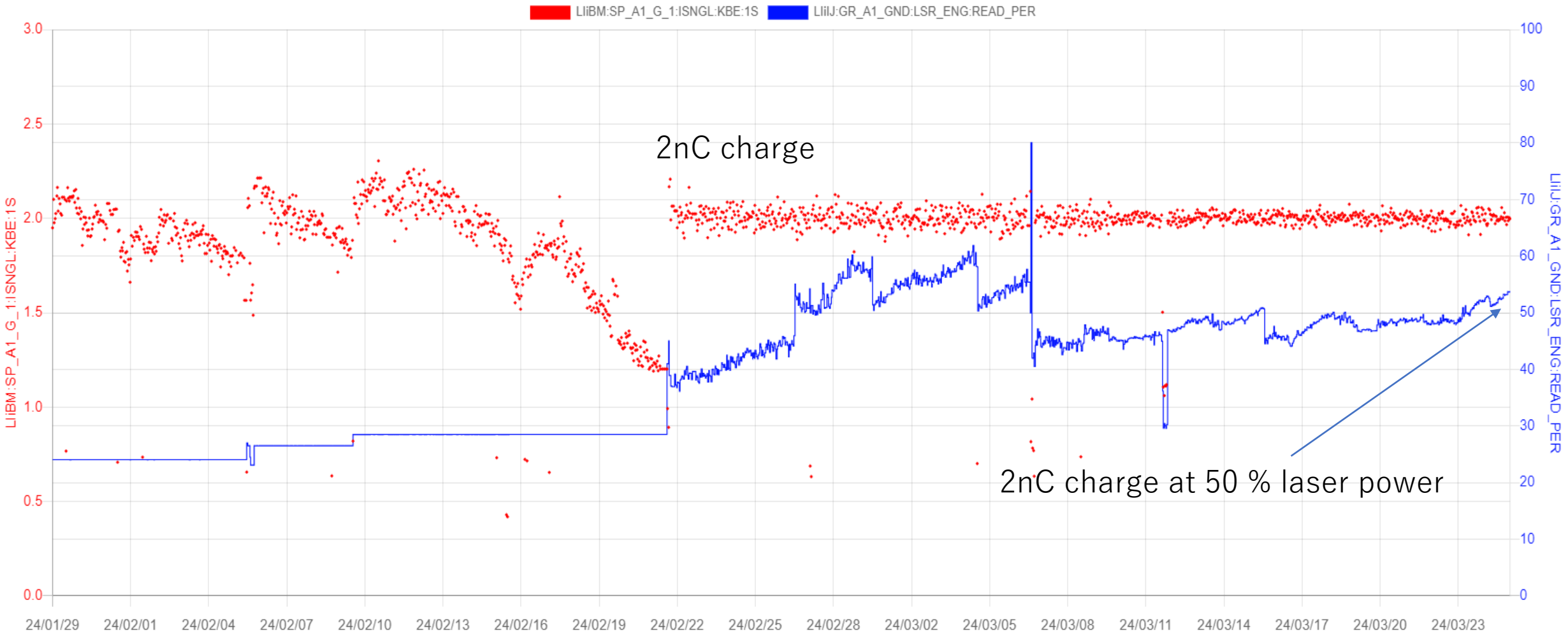


SP_A1_G 5.2nC, SP_61_H 4 nC reached.
B sector emittance
$\gamma \varepsilon$ x=57.534 ± 19.037), BmagX 2.090,
$\gamma \varepsilon$ y=85.974 ± 20.111, BmagY 1.104



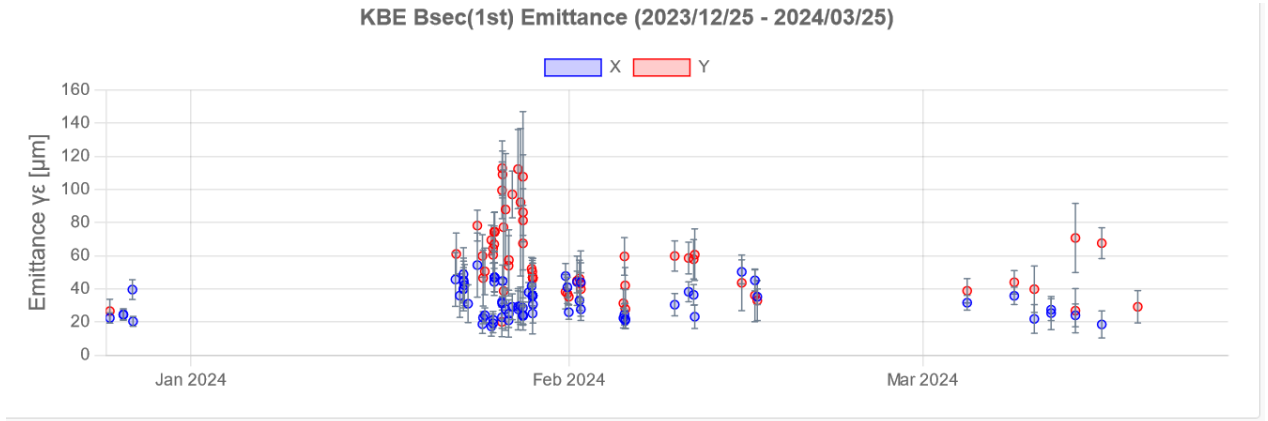


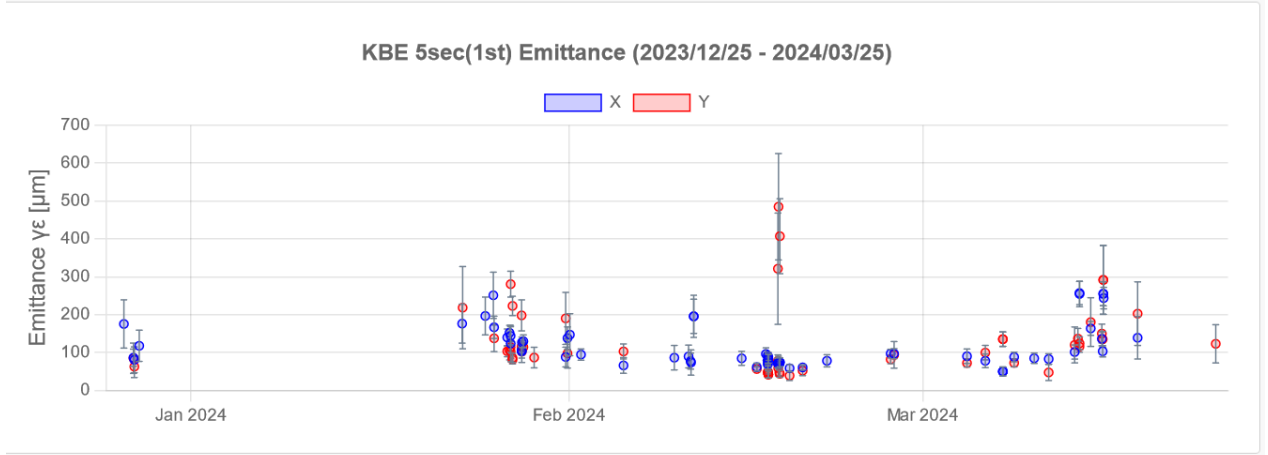
Operation history (charge and laser power)

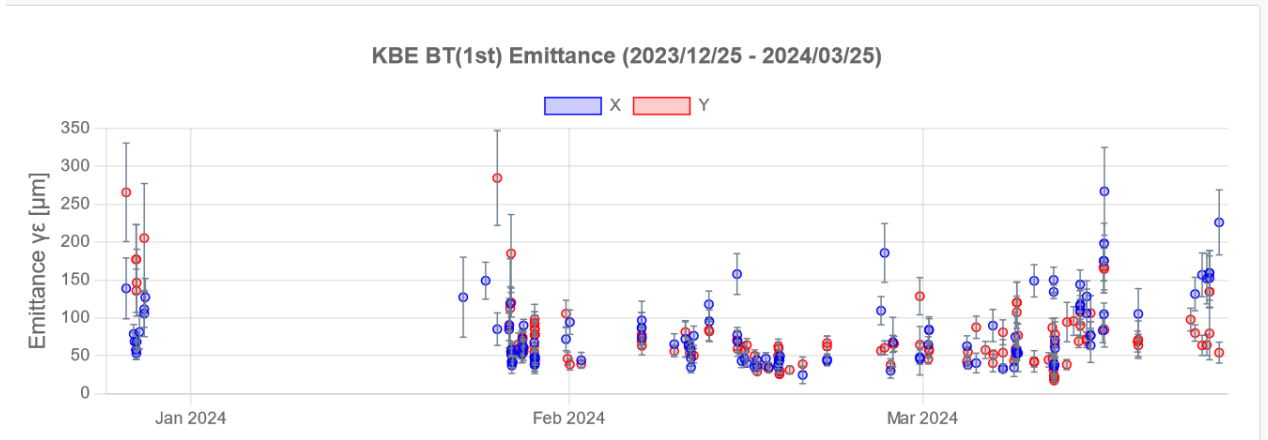


Charge decreasement is occured due to RF phase drift and window transmission efficiency.
=> Precise phase measurement system of RF-laser and new RF-Gun are under development.

Emittance history for 3-month



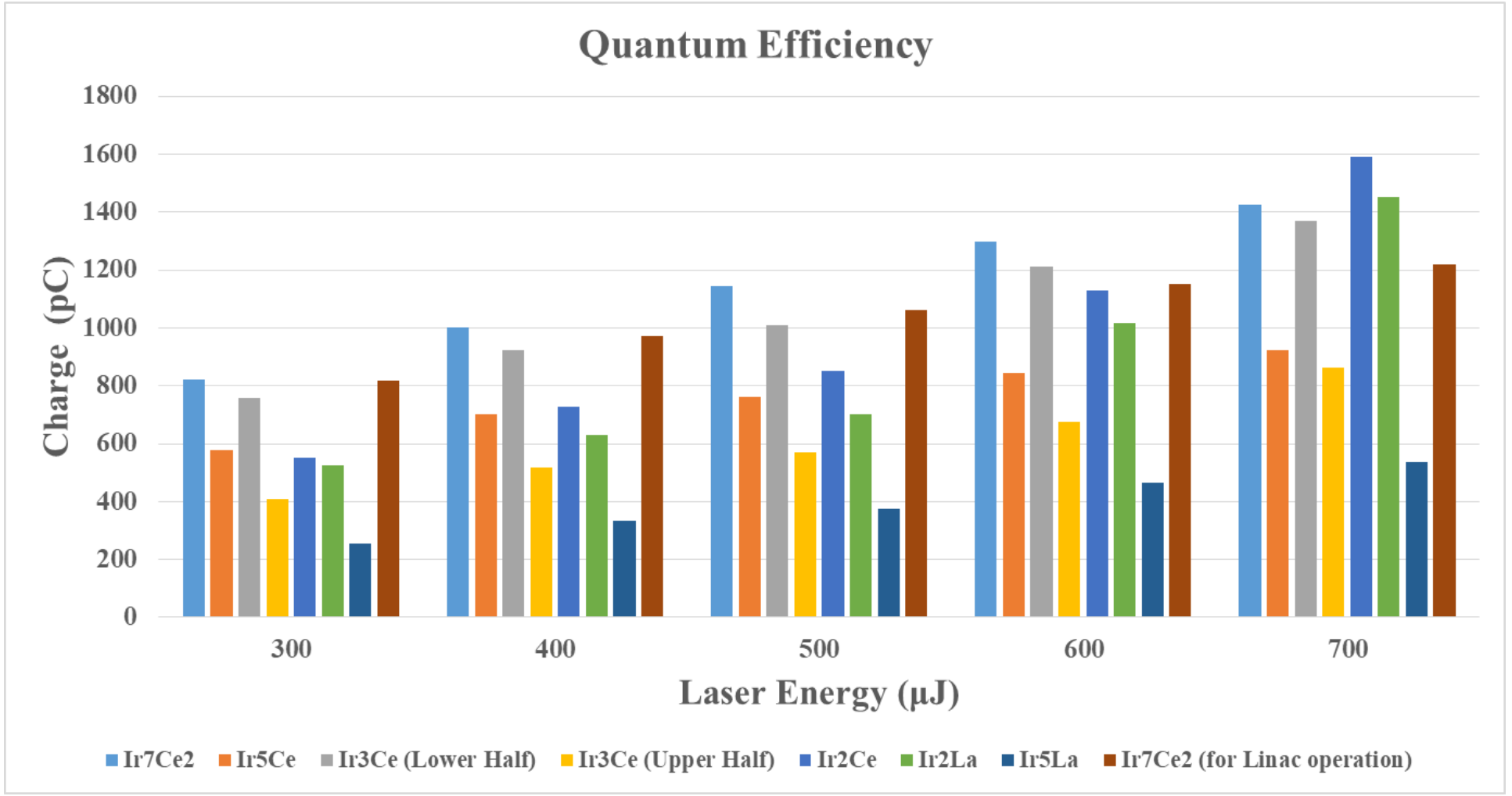




Upgraded part of RF-Gun

- Improvement of IrCe quantum efficiency
- Laser upgrade
  - Replacement of laser module
  - Flattening of temporal shaping
  - Larger area DOE to fully cover cathode
- Chiccane slit
- Beam commissioning
  - Semi-automated dispersion correction

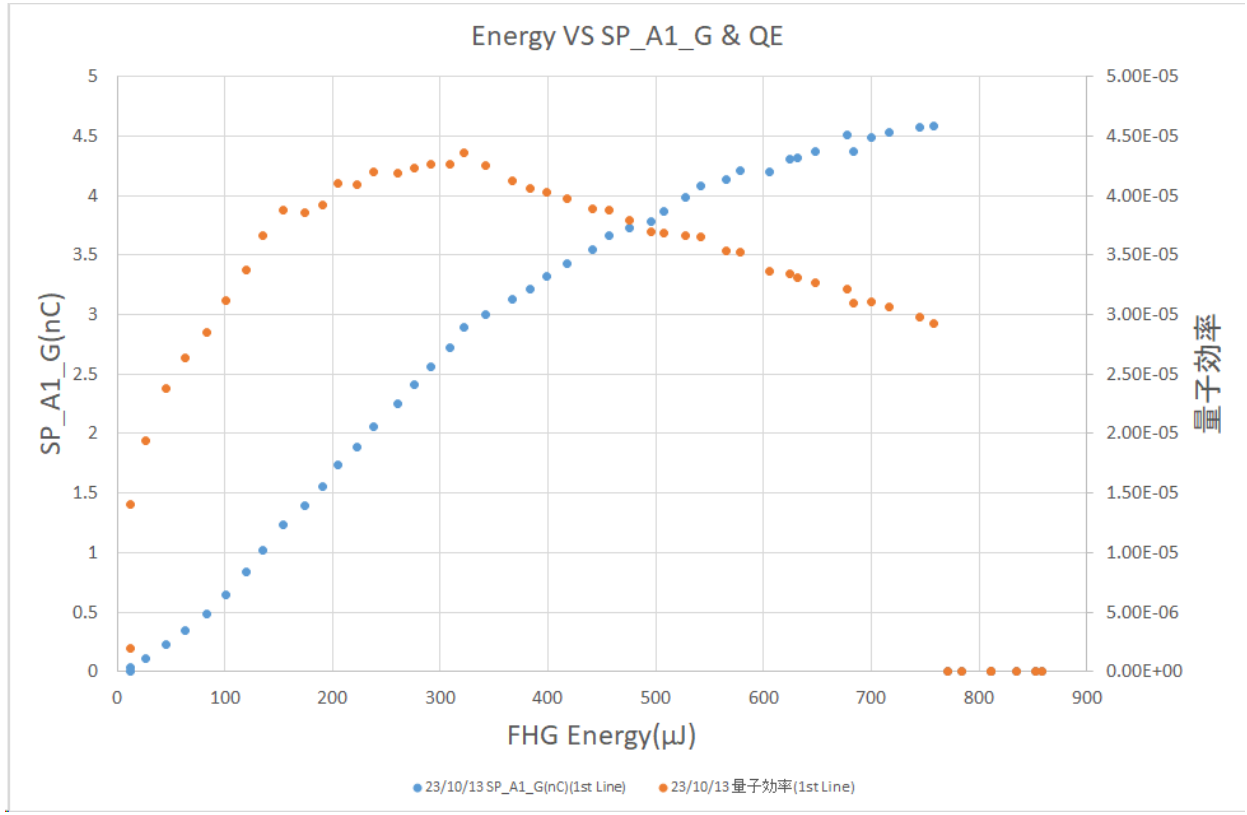
Cathode : Ir_7Ce_2



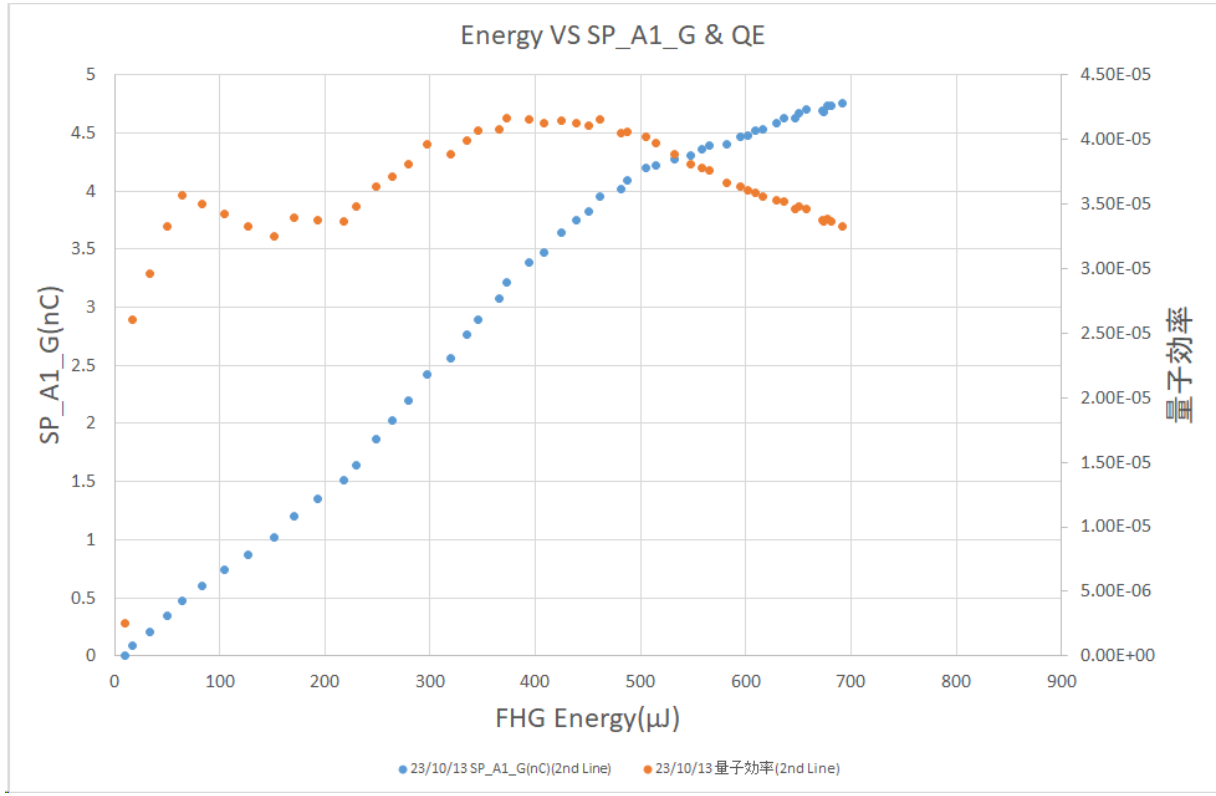
KEK house made IrCe cathode has best quantum efficiency

Charge vs laser power from RF-Gun

4.5nC by only 1st line laser

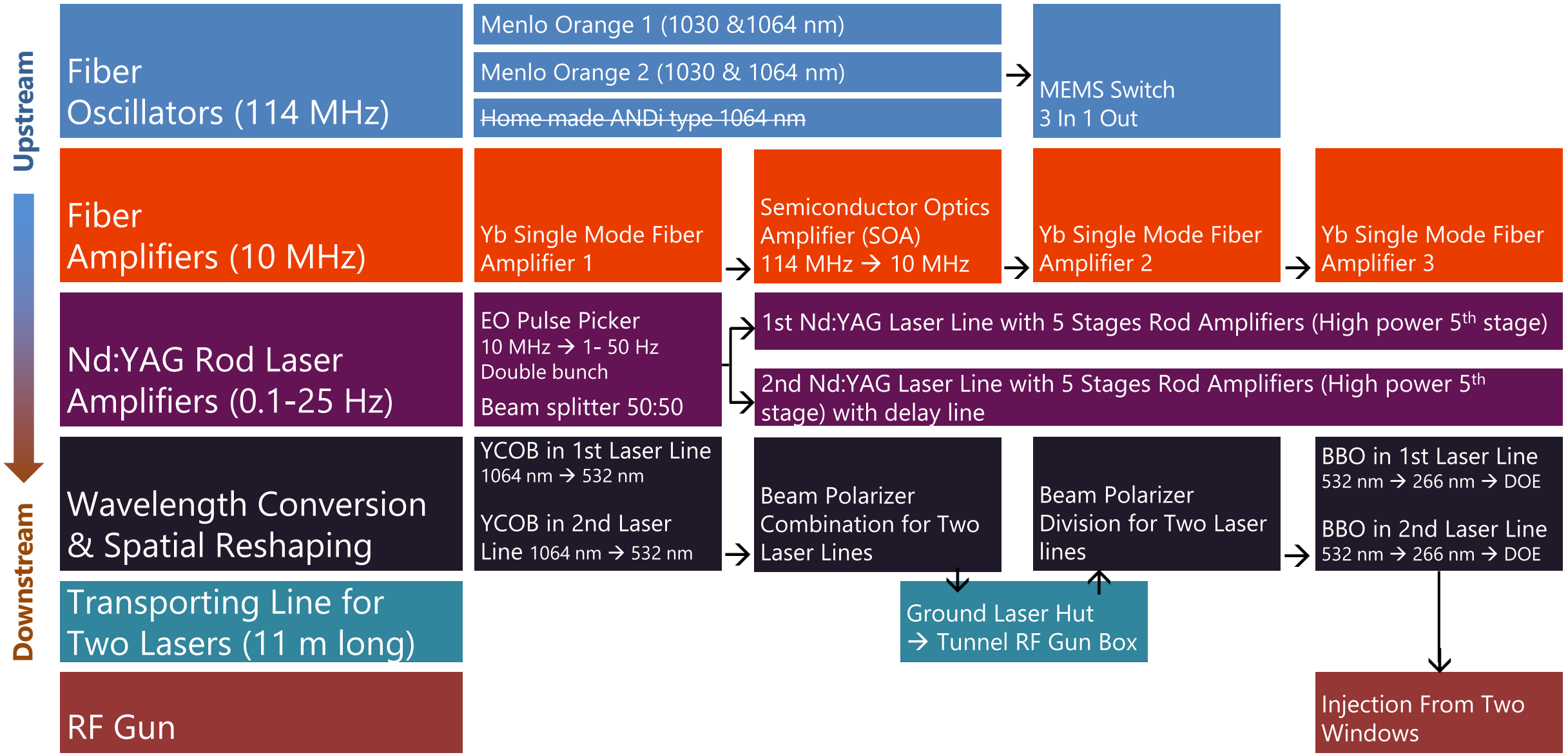


4.7nC by only 2nd line laser



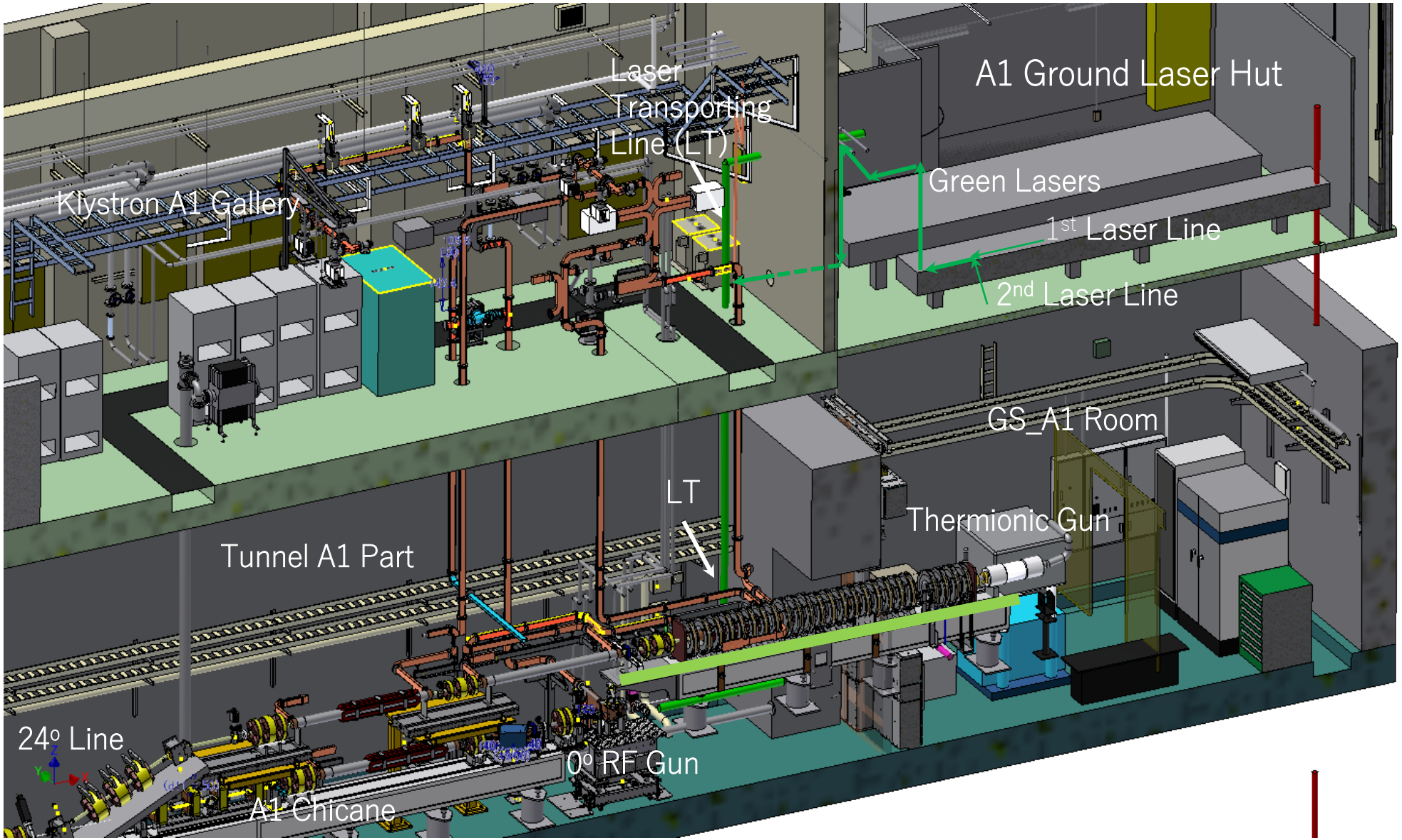
Laser System for RF Gun

Yb-Fiber and Nd:YAG Hybrid Laser System



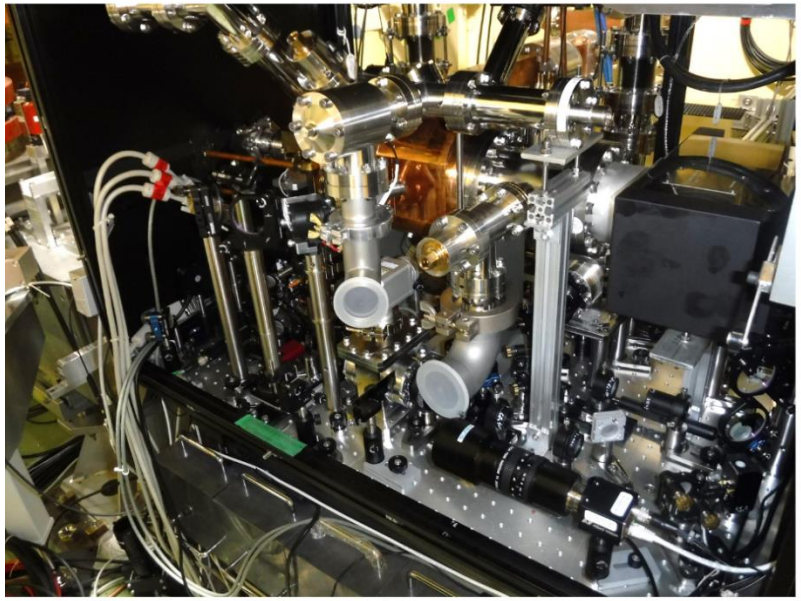
Laser System for RF Gun

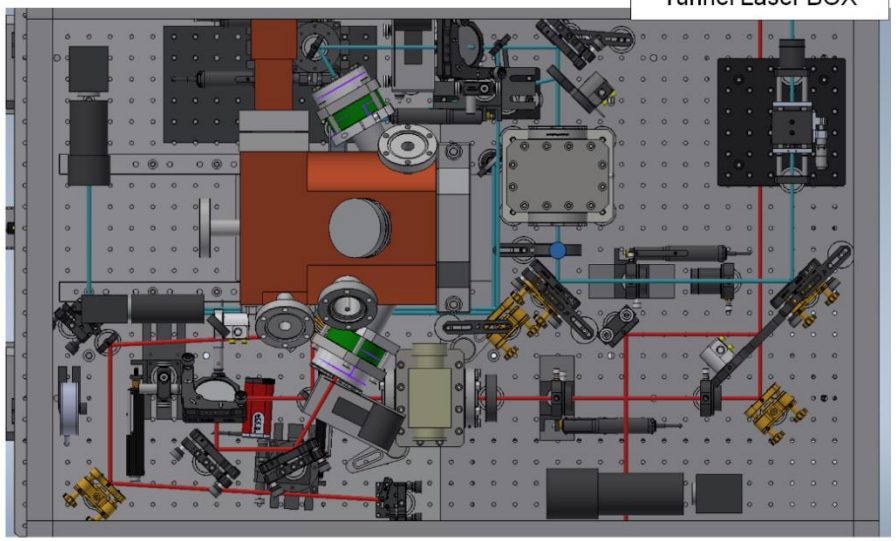
Yb-Fiber and Nd:YAG Hybrid Laser System



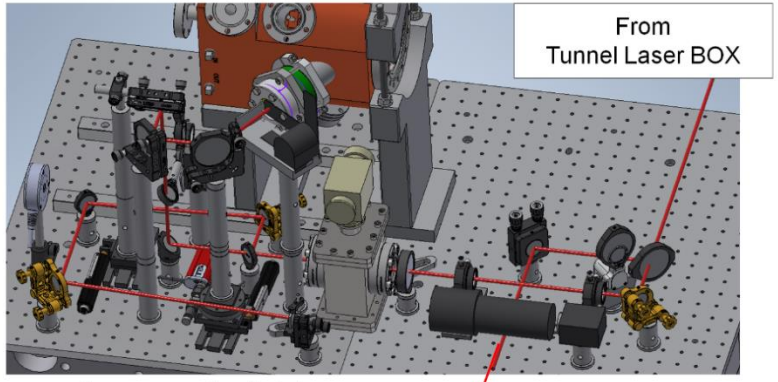
Laser System for RF Gun

Two Laser Beams Injection for e^- Beam Generation

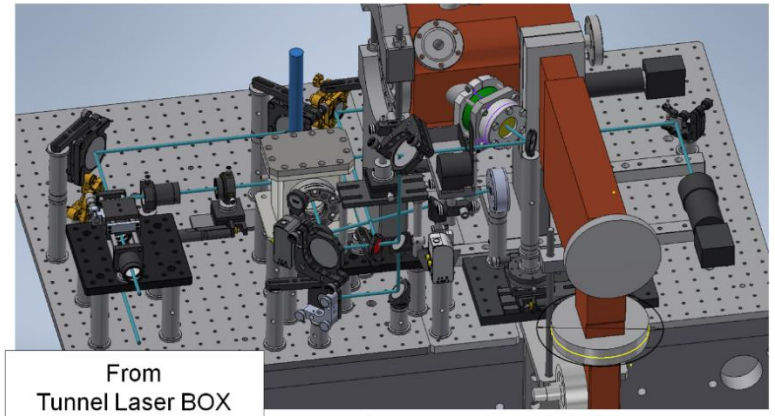




全体の様子



Laser 1st Line

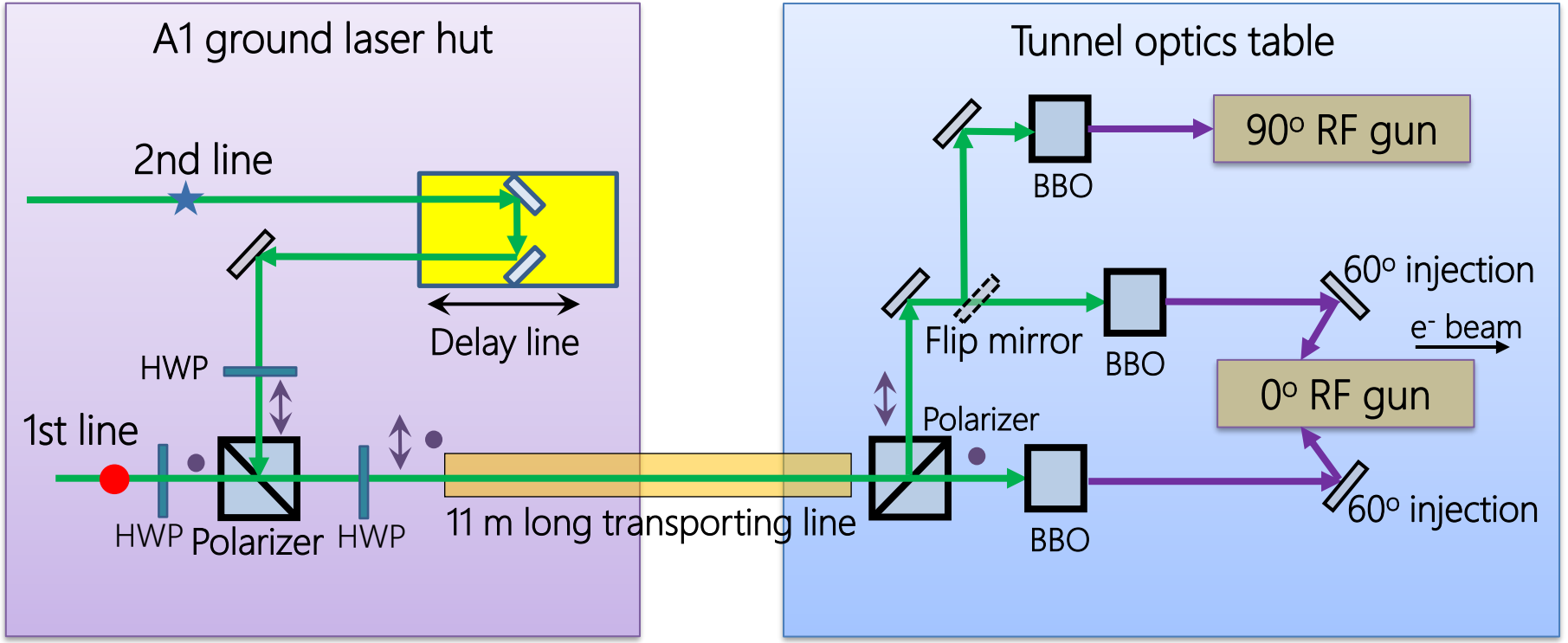


Laser 2nd Line

Laser System for RF Gun

Two Laser Beams Injection Mode for Better Beam Quality

Simple illustration for 2 lasers incidence (out of ratio)

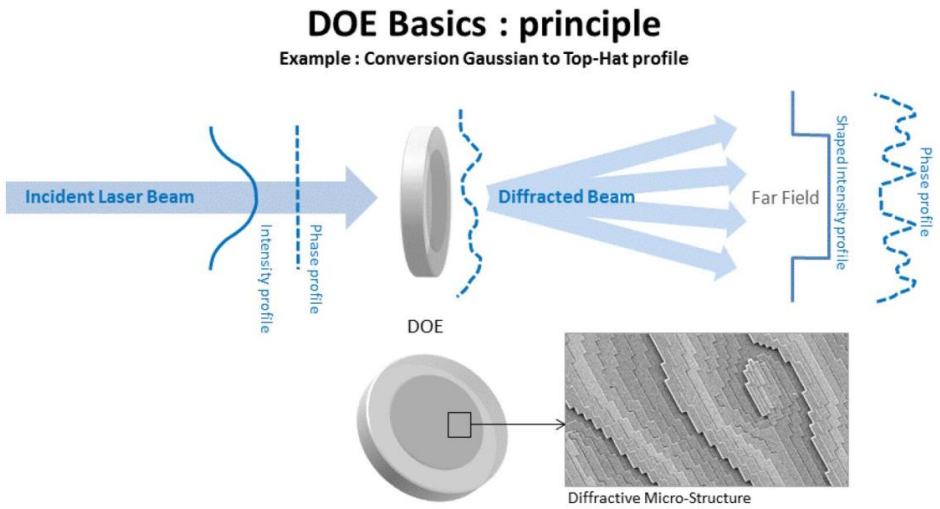


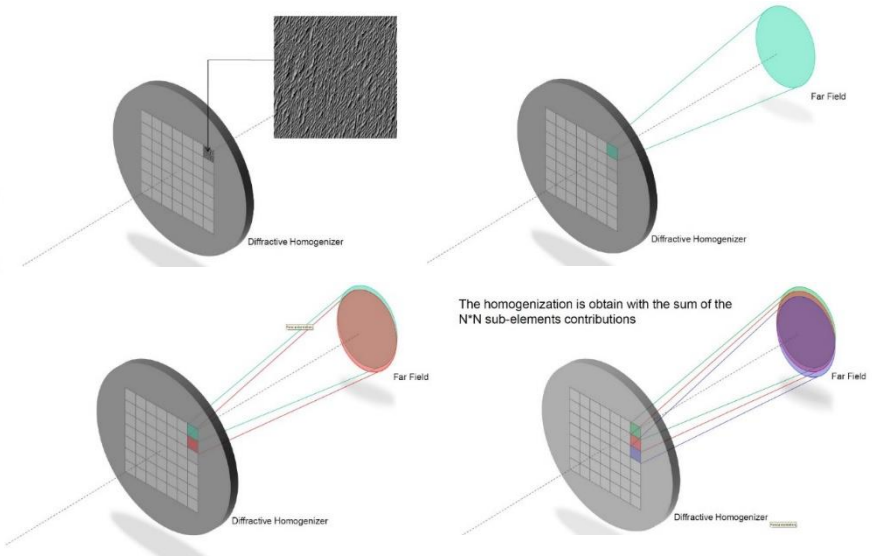
- Laser with vertical polarization, ↕ laser with horizontal polarization, HWP: half wave plate

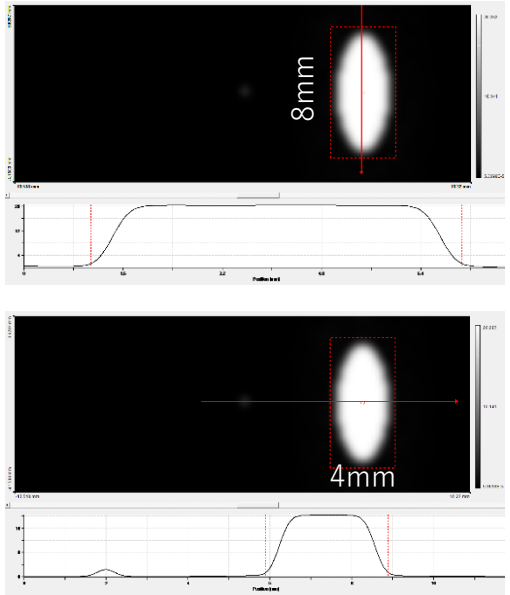
Laser System for RF Gun

Spatial Reshaping for Lower Emittance by DOE

- Spatial flat top distribution achieved by Diffractive Optical Element (DOE) for high quality e^- beam generation
- Principle: Diffraction optics by lens and micro-configuration
- Desired intensity distribution can be realized (phase coding)
- World's first application of DOE for UV laser



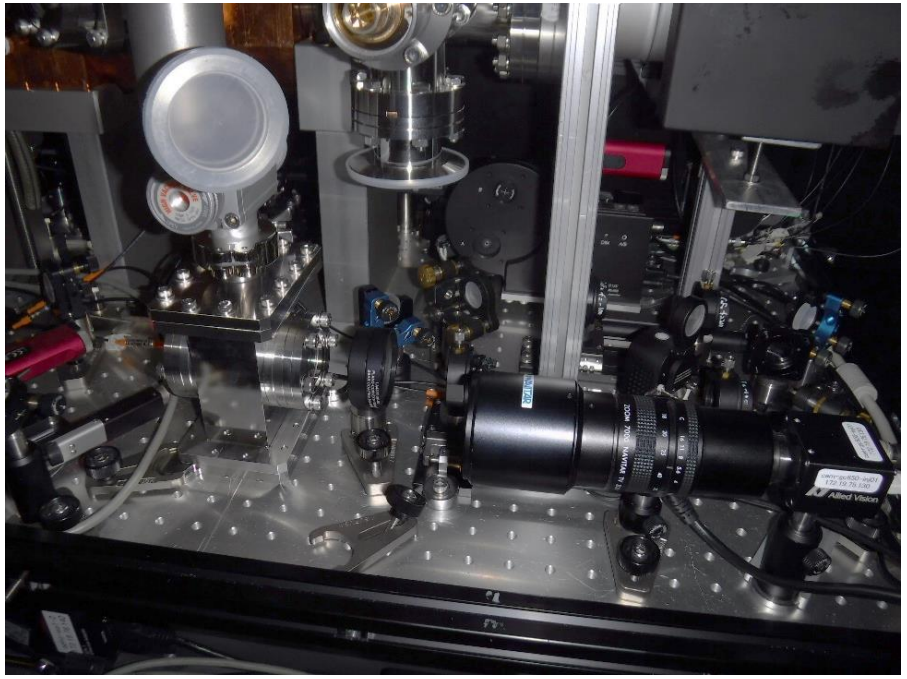


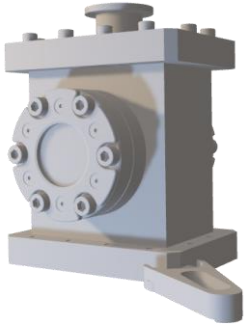


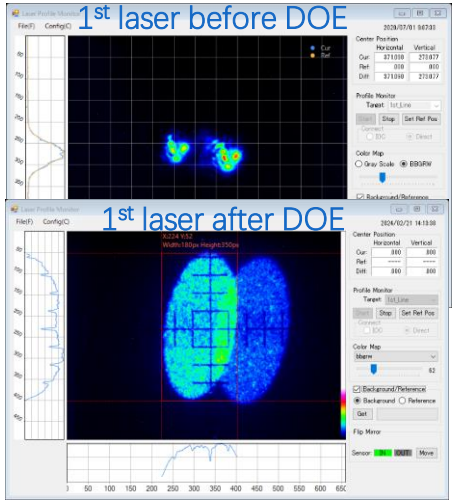
Laser System for RF Gun

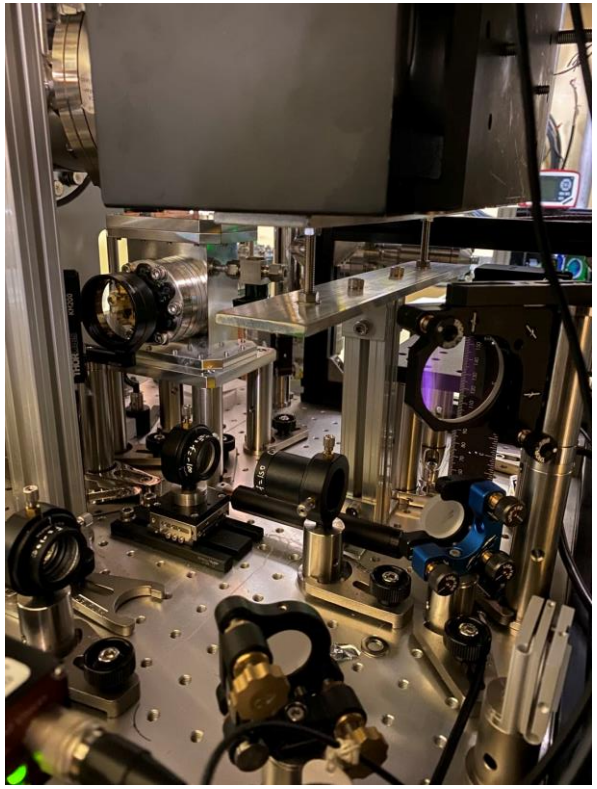
Spatial Reshaping for Lower Emittance

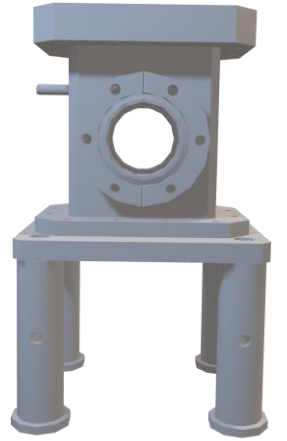
- Application DOE in 1st laser line from 2020c and in 2nd laser line from 2021c
- Elliptical flat-top spatial distribution on the surface of photocathode (LA-8mm SA-4mm) for lower emittance e^- generation and less discharge

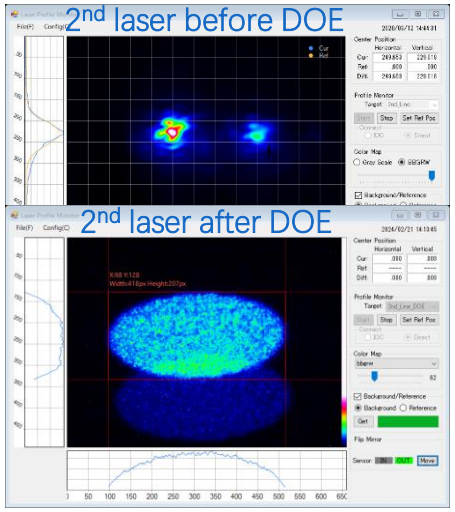








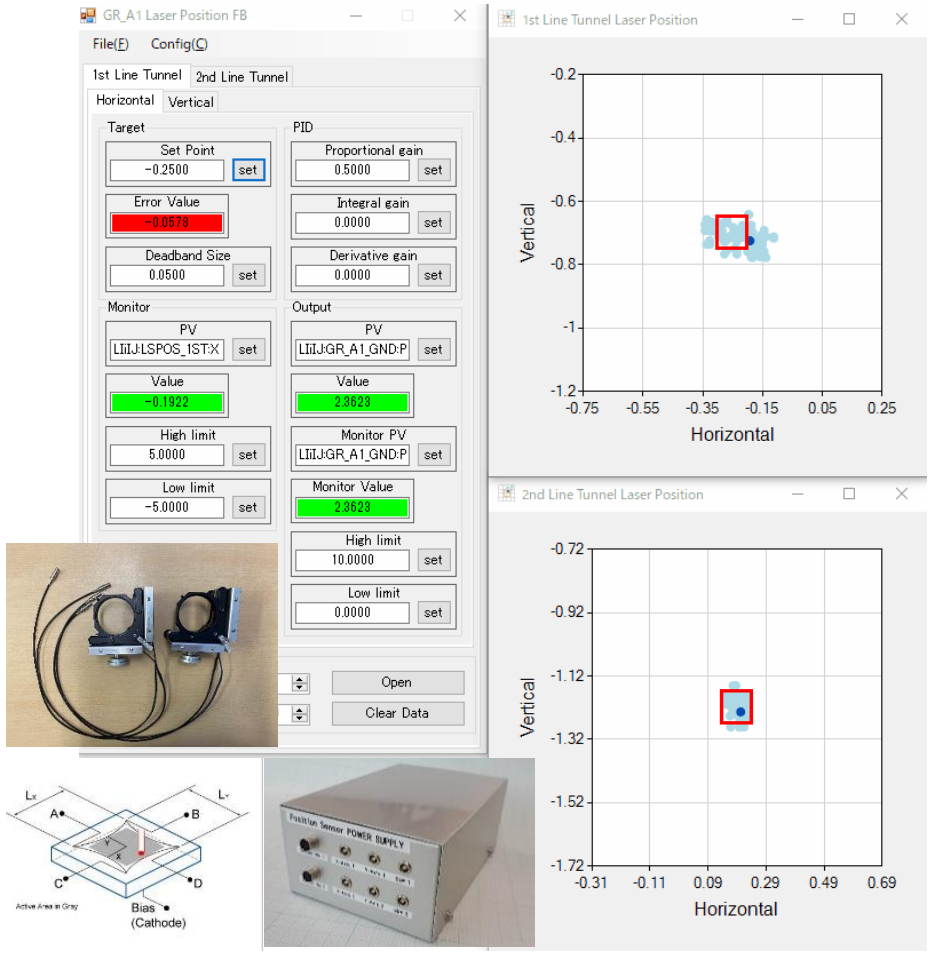




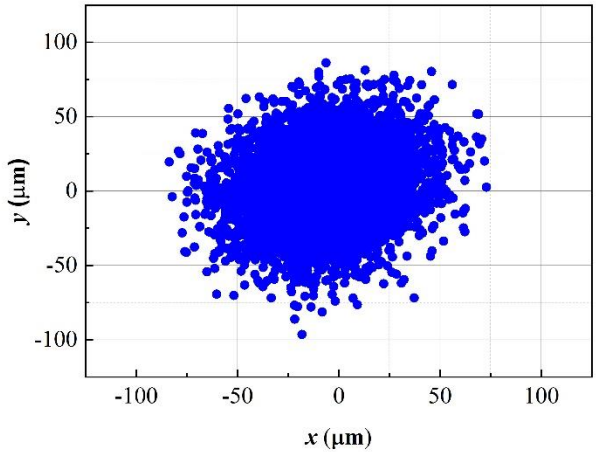
Laser System for RF Gun

Better Laser Pointing Stability for Stable and Long-term Operation

Laser position feedback system

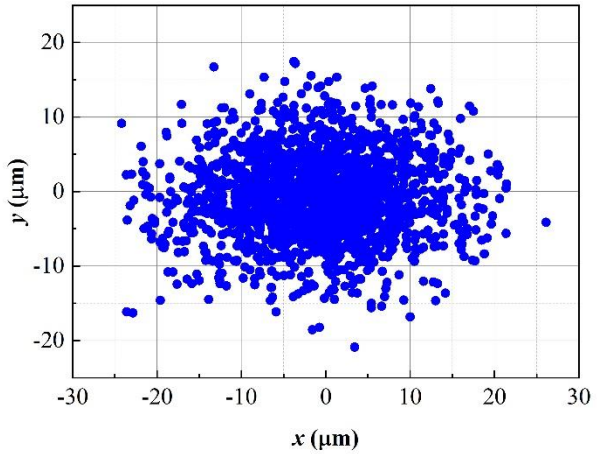


Laser pointing stability at virtual photocathode



Measured in 2019.06
without DOE & laser position feedback

H 2 σ : 48.04 ± 0.51 μm
V 2 σ : 46.08 ± 0.69 μm



Measured in 2021.06
with DOE & laser position feedback

H 2 σ : 24.30 ± 3.06 μm
V 2 σ : 10.08 ± 0.46 μm

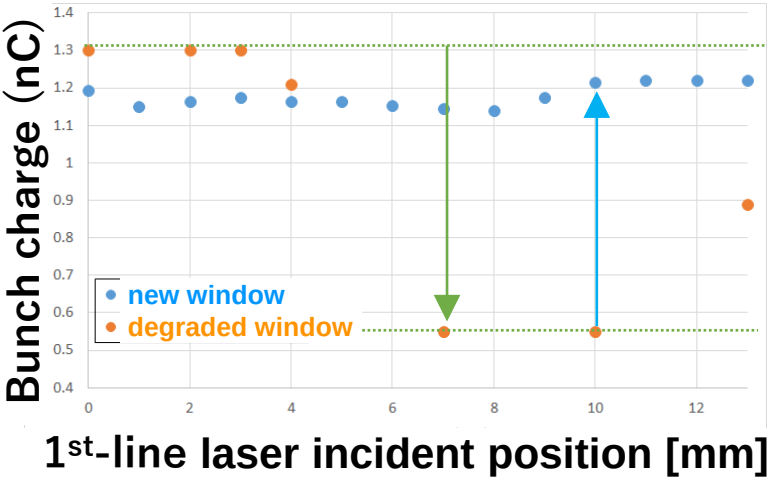
Improvement plan of electron beam

Issue of rf gun laser window degradation

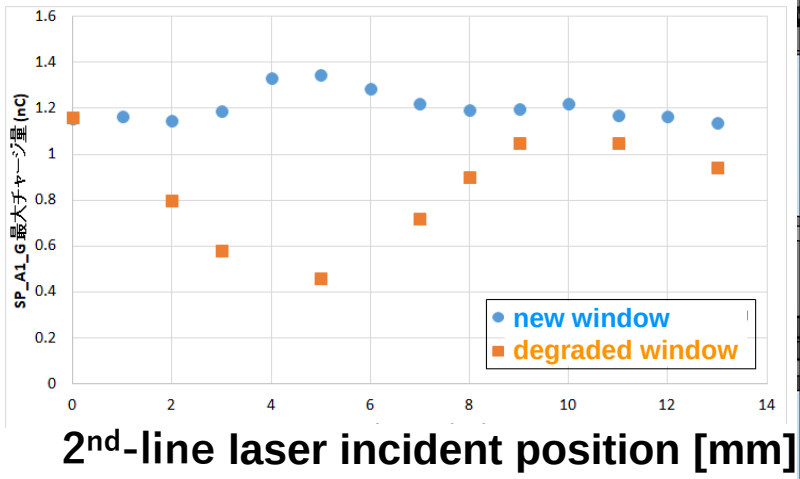
e- beam issue

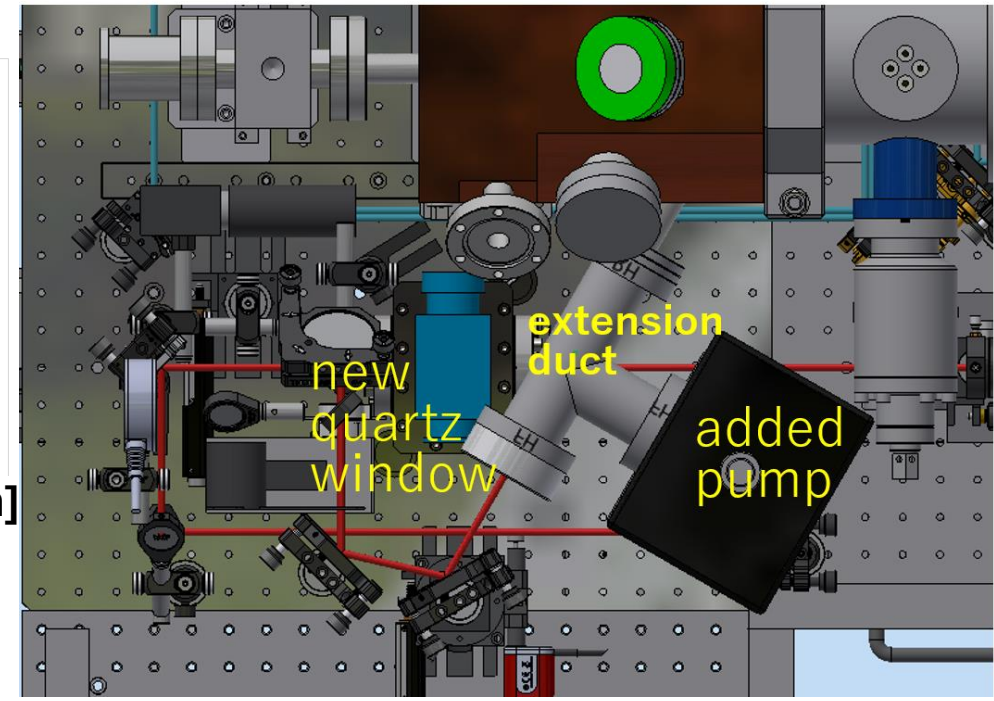
- Long term operation makes rf gun laser windows dirty for both of 1st and 2nd line.
- It decrease the transmittance of laser power through window and bunch charge intensity.
- After replacement of the laser window, the bunch charge intensity is recovered.
- Vacuum ion pump was installed between the laser window and rf gun cavity with the extension vacuum duct for the 1st line laser in this summer maintenance '22.

e- intensity by 1st-line laser



e- intensity by 2nd-line laser



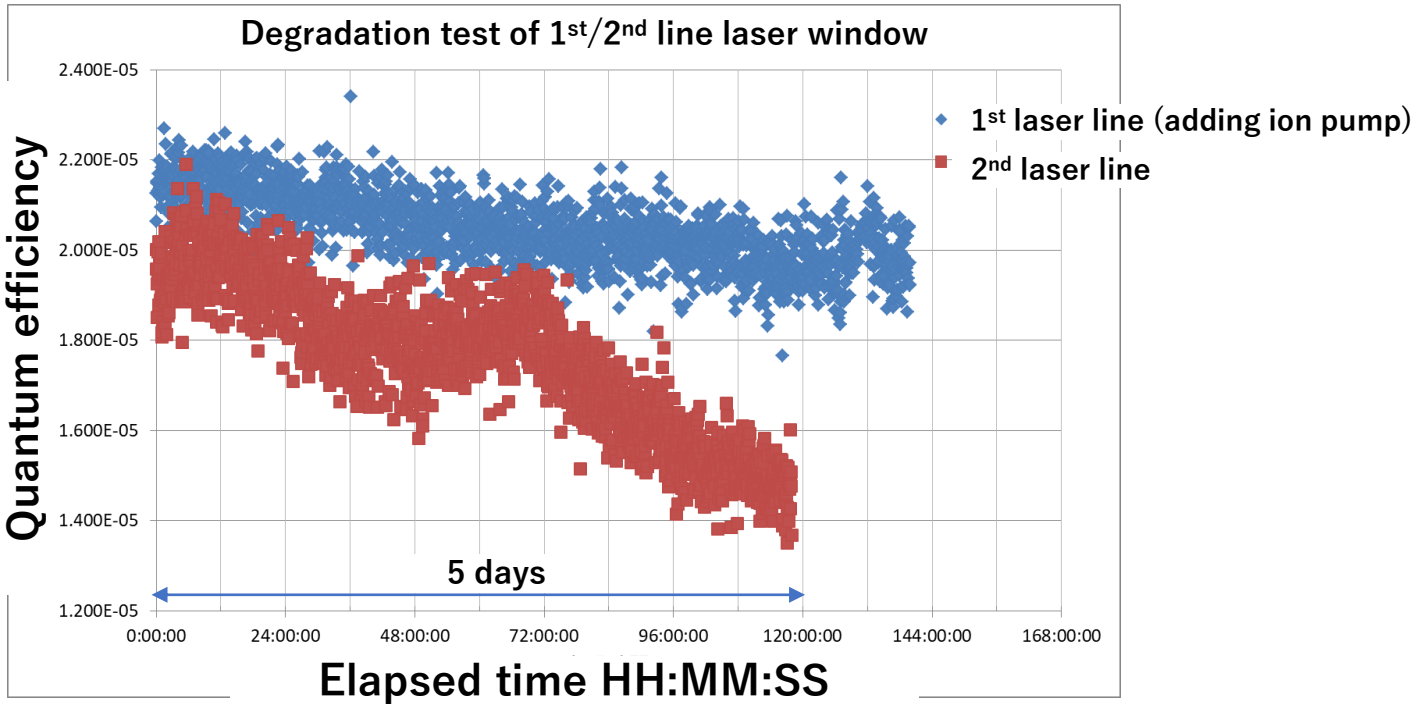


M. Yoshida

Improvement of laser window degradation with ion pump

e- beam issue

- Long term operation for keeping e- bunch charge is very important issue.
- Continuous beam test at e- beam repetition of 22 Hz has been conducted more than 5 days.
- Installed ion pump could help to mitigate the laser window degradation from the experimental results.
- This test will be continued until the end of this run. Further improvement is also being considered.

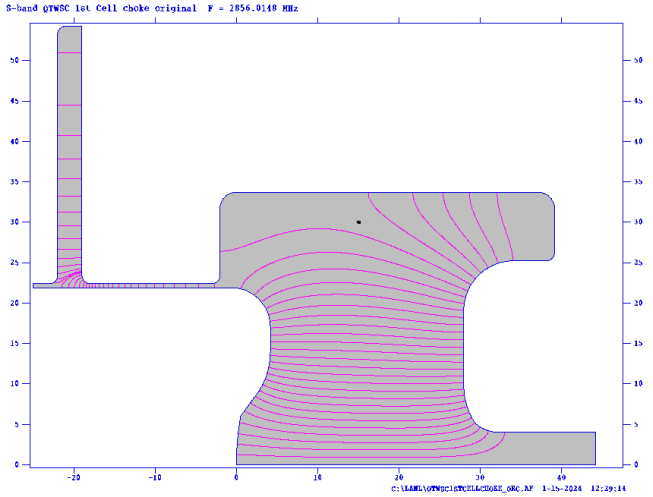


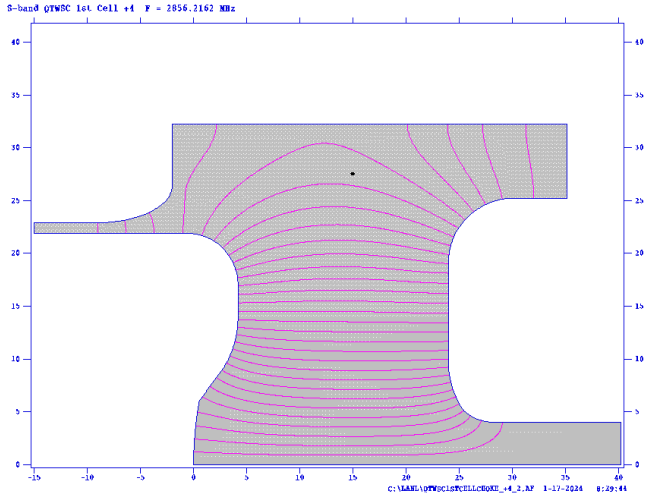
New Quasi-Travelling Wave Side Couple RF-Gun

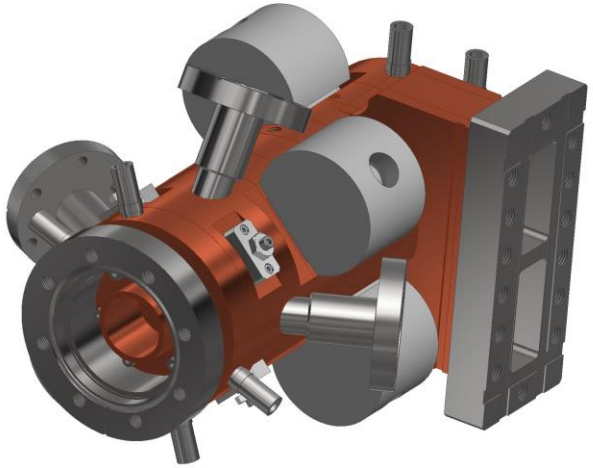
will be installed in next summer

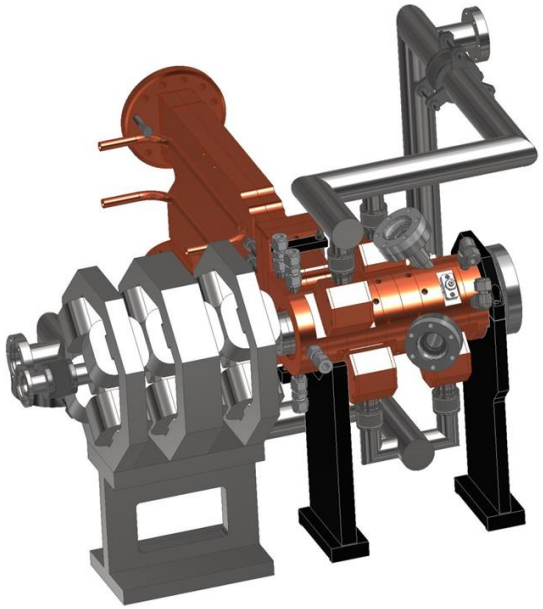
[Current RF-Gun issue]

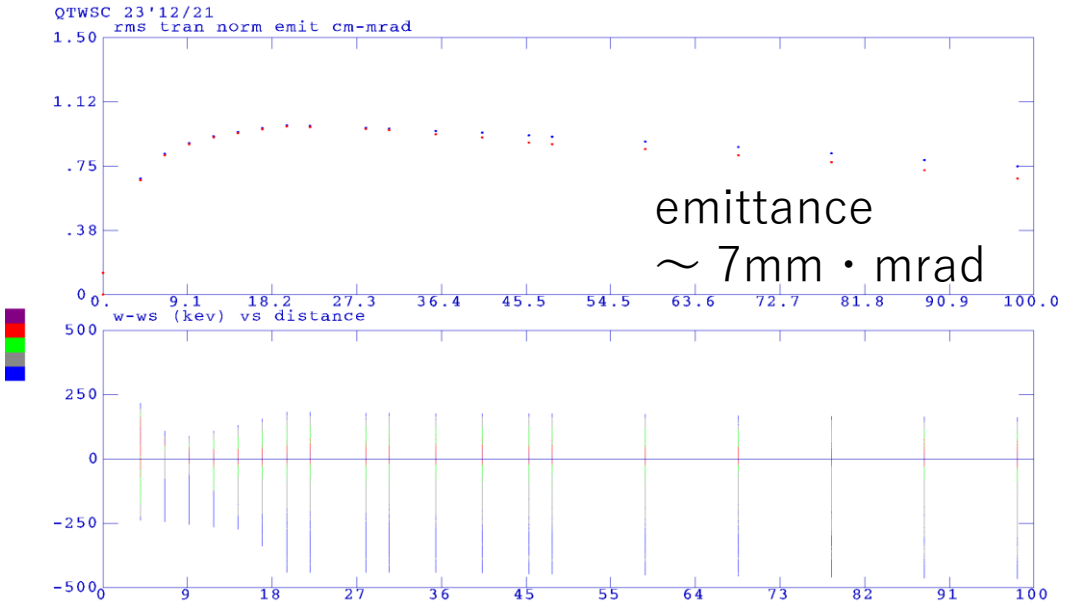
- Laser window life time
- Dischargement at choke structure
- Dark current
- Energy slope
- Focusing magnet











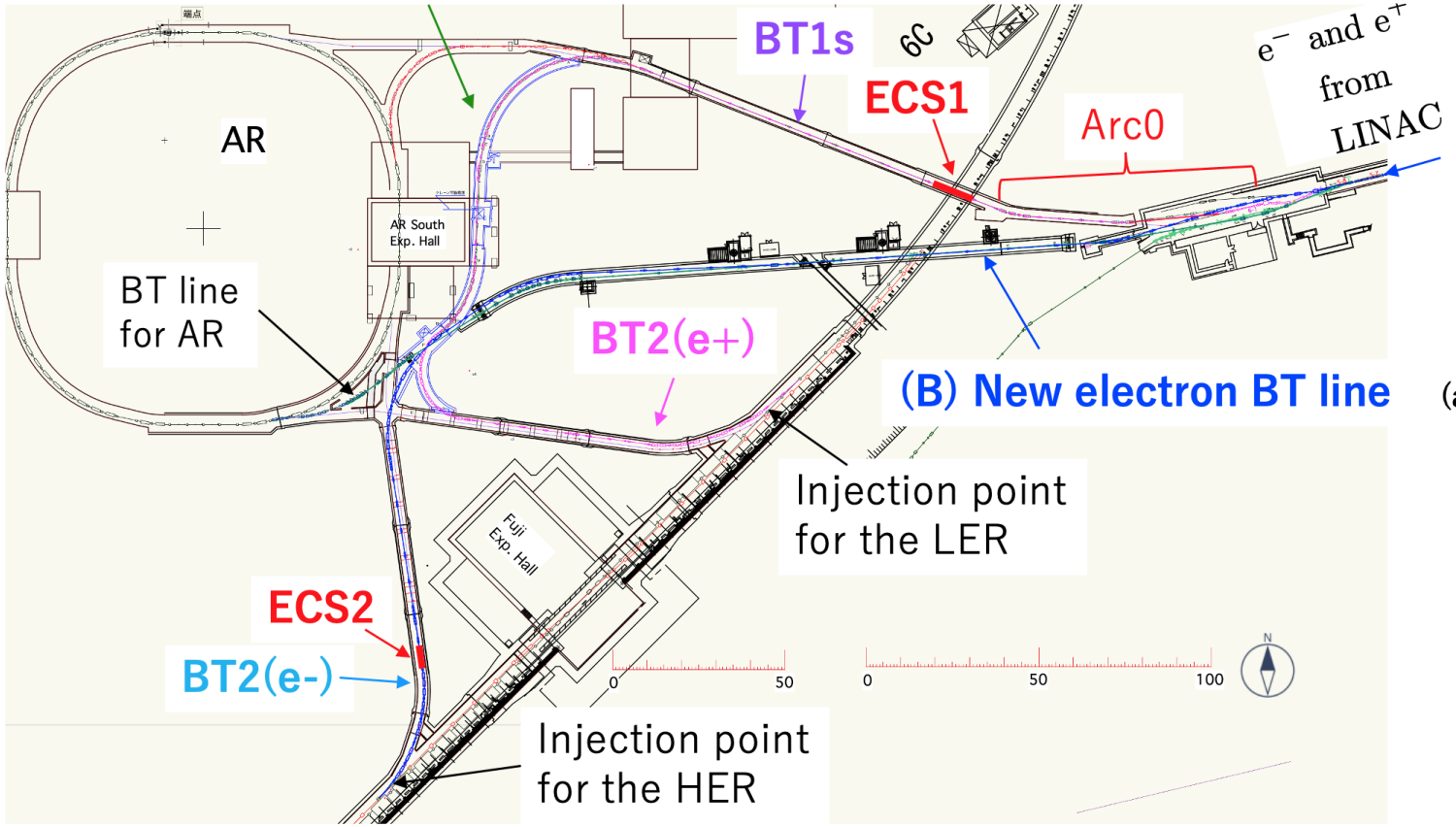
BTe accelerating structure installation

- Bunch compression to reduce short range transverse wakefield
  → Longitudinal wakefield causes large energy spread (>5ps @ 2nC)
- Harmful fine structure due to longitudinal wakefield

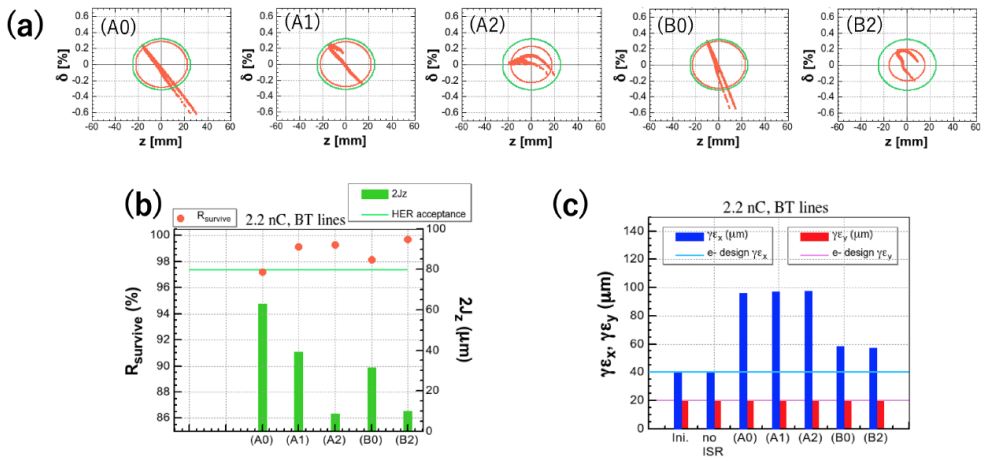
  => BT-ECS is effective for lower energy spread and smoothing
- Energy jitter reduction
- Additional voltage for 6S resonance and multi-bunch operation.

- 3m(longer) acceelerating structure are transferred from Harima

BTe-ECS (FY2024) to improve injection efficiency



	BT line	ECS	R_{56} [m]	V_c^{Total} [MV]
(A0)	Present	—	-0.11(Arc0)	—
(A1)	Present	"ECS1"	-1.0(Arc0)	72
(A2)	Present	"ECS2"	-4.3	34
(B0)	New	—	—	—
(B2)	New	"ECS2"	-1.6	70

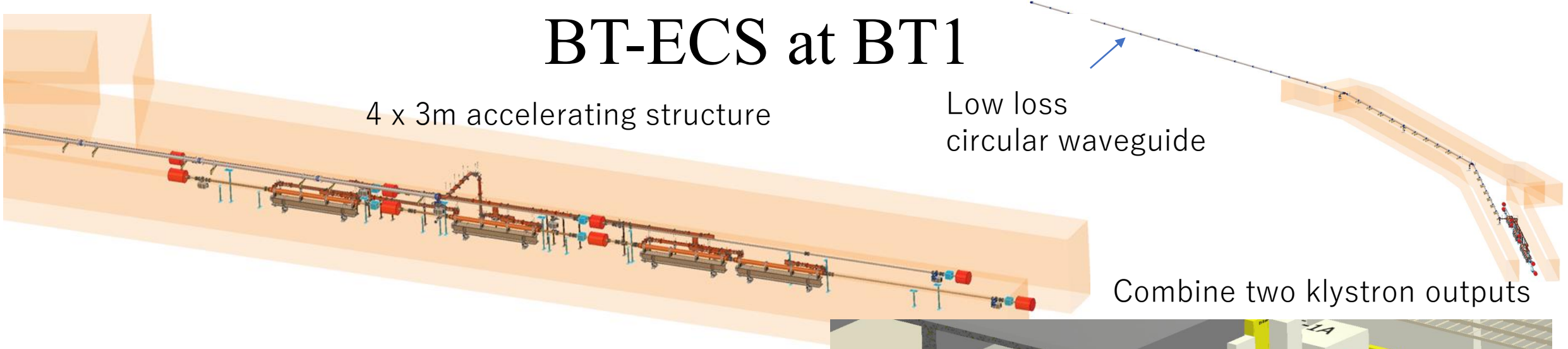


ECS1 was chosen due to building difficulty of ECS2

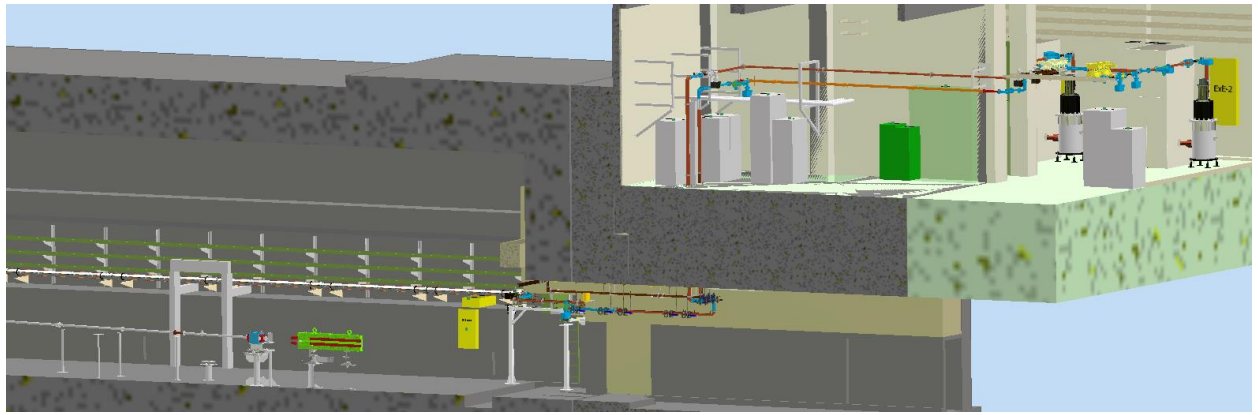
BT-ECS at BT1

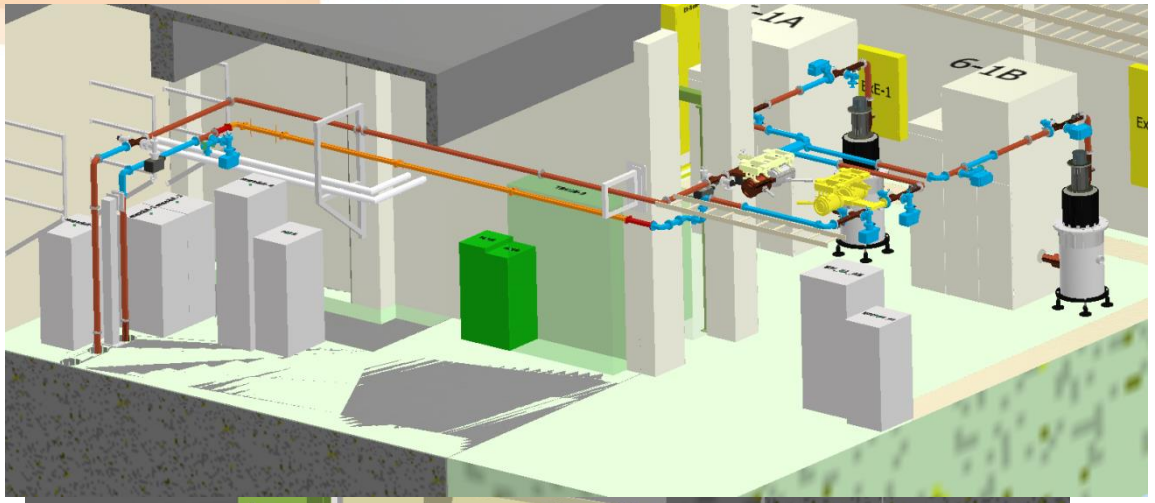
4 x 3m accelerating structure

Low loss
circular waveguide



Combine two klystron outputs





The Single-stage Pulse Stacking Birefringent Filter

② Pulse double stacking.

$$\theta_n = \frac{45^o}{N} \cdot (2n-1)$$

$$l_{crystal} = 19\ mm$$

$$\theta_1 = 45^o$$

Polarizer 1

Crystal 1

Polarizer 2

Fiber Output

Fiber Input

① Stretched pulse width to 18 ps.

Grating pair Stretcher

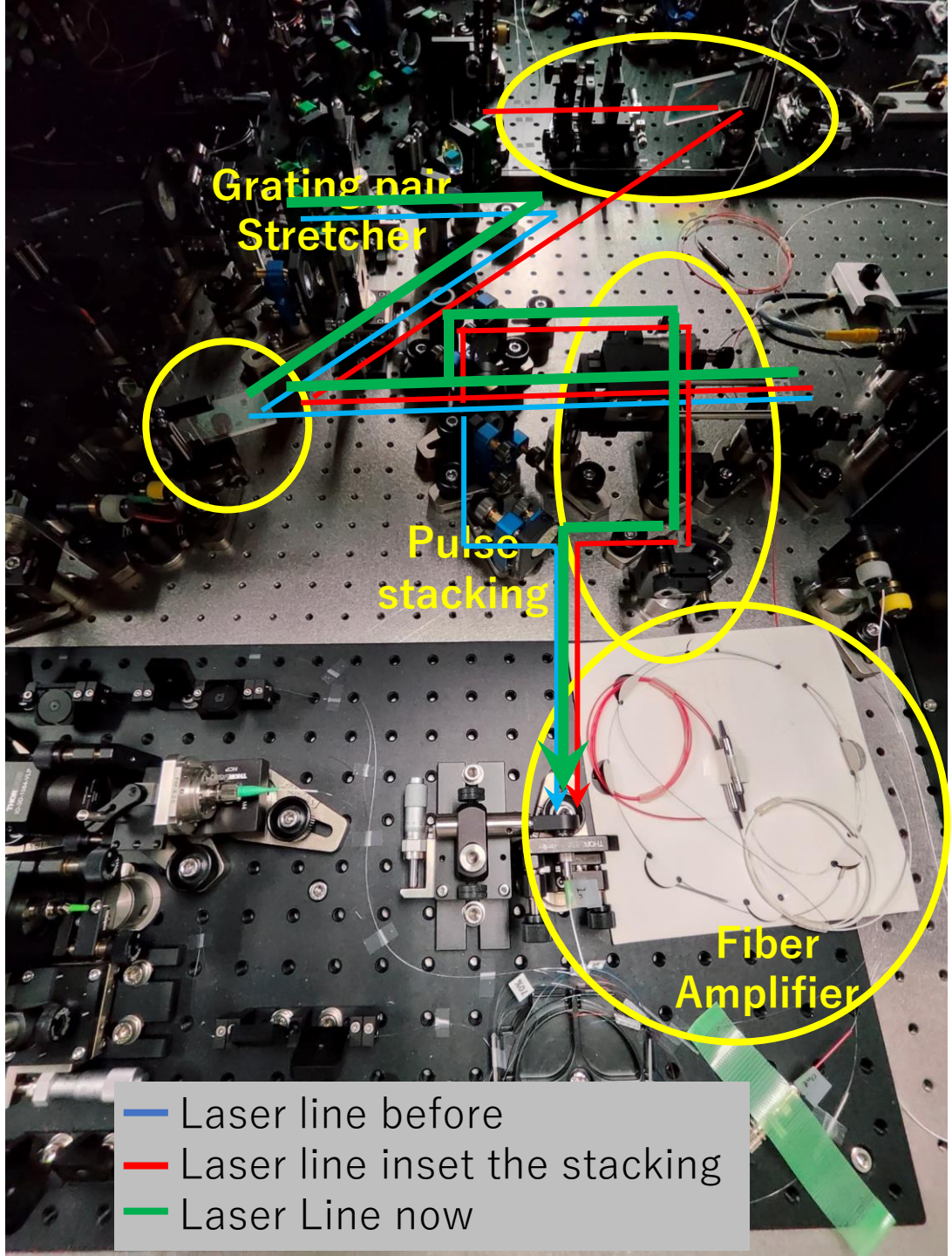
Fiber Amplifier

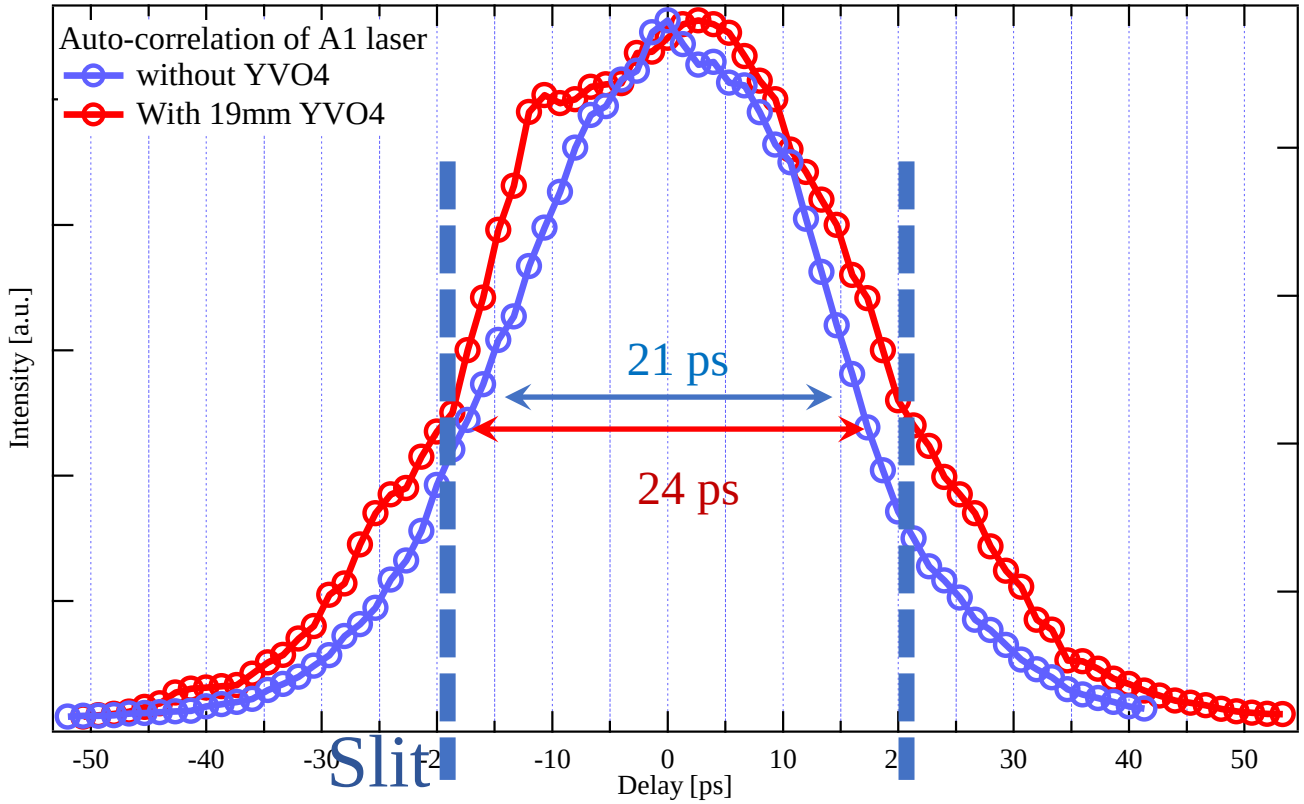
③ Compensate the energy loss.

Menlo Oscillator → Fiber Amplifier → OSA Pulse Picker → Fiber Amplifier & Noise cut off → EO Pulse Picker

Setup diagram

- The new fiber amplifier compensate the energy loss of the pulse stacking.
- After the modification, there is no impact on main laser amplification efficiency and electron generation rate.
- Due to the optical path expansion, it is necessary to adjust the phase delay of the SOA pulse picker and EO pulse picker.
- For double bunch amplification, the efficiency of the second pulse is reduced.





e- beam summary and issue

- Thermionic DC electron gun has worked fine to generate primary electron beam for positron production.
- Photocathode RF-Gun
  - Laser system and DOE element (fully covered 8 mm cathode area) worked fine without any significant trouble.
  - High bunch charge e- was demonstrated. Achieved 6 nC from e- gun and 4 nC at the linac end.
  - New piezo mirror feedforward system improve beam stability.
  - Better QE IrCe composite cathode was developed and under testing.
    ==== To Do ====
  - Gradual decrease of bunch charge due to laser window deterioration : new QTWSC RF-Gun will be installed.
  - Beam stability should be improved : Laser frequency comb in vacuum line(Zhou)
- KBE Beam Issue and study in LS1 period.
  - Emittance at linac end and BT1 is almost satisfied while bunch charge (2 nC) is less than final goal (4 nC).
  - However, emittance at BT2 is increased due to ISR, CSR, and some other reasons
    BT ARC4 realignment / Vacuum chamber / Straight injection line
  - Increase of 2nd bunch injection efficiency and improvement of its stability are important issues.
    => Fast Kicker / Long range wakefield suppression
  - Auto tuning : Dispersion compensation / Fast emittance measurement are under test
  - BTe-ECS is planned to install at FY2024 in BT1.
  - Temporal manipulation system for laser system.

=> Best temporal manipulation
for better emittance and lower energy spread