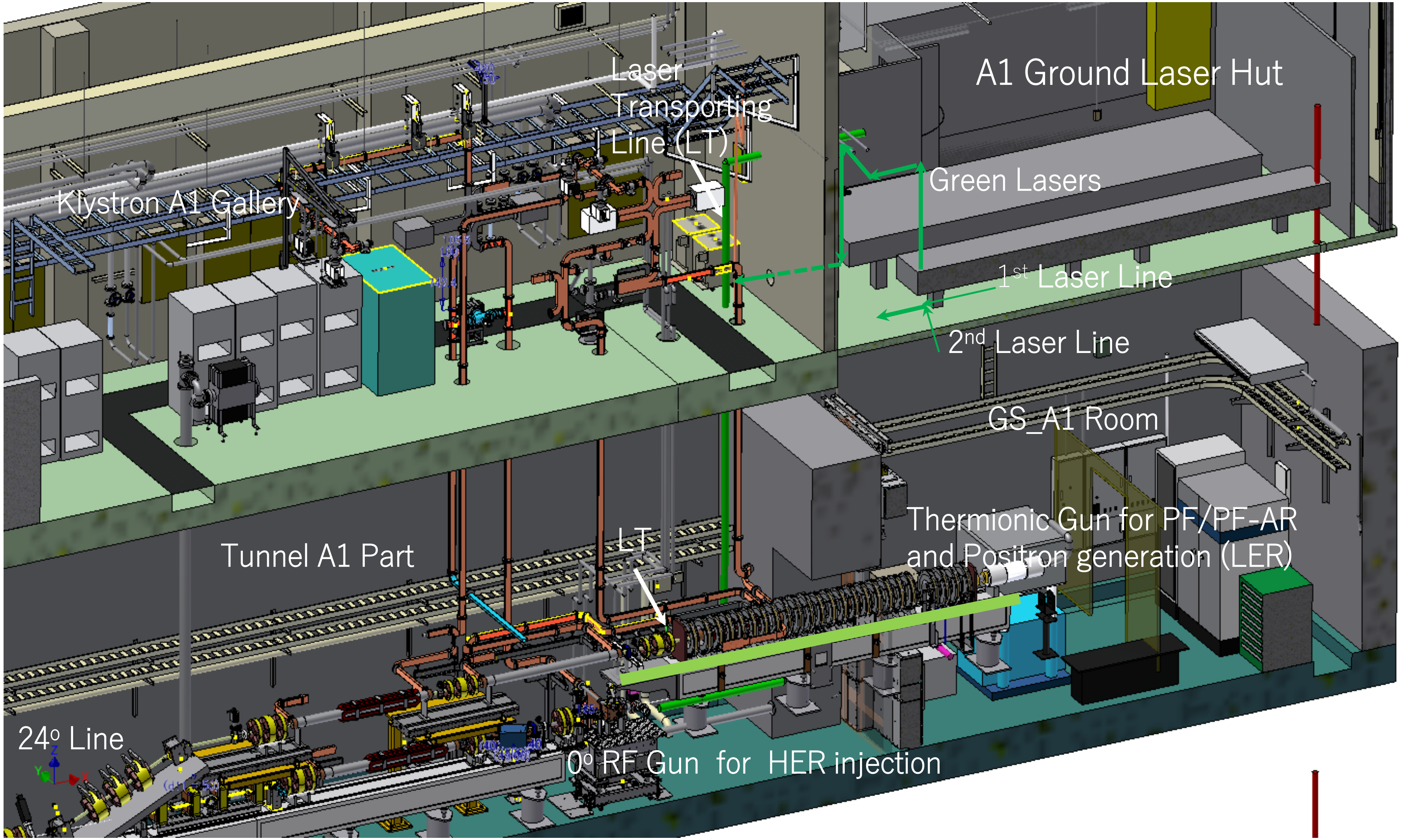
The 28th KEKB Accelerator Review Committee/ Injector / RF-Gun and electron-beam

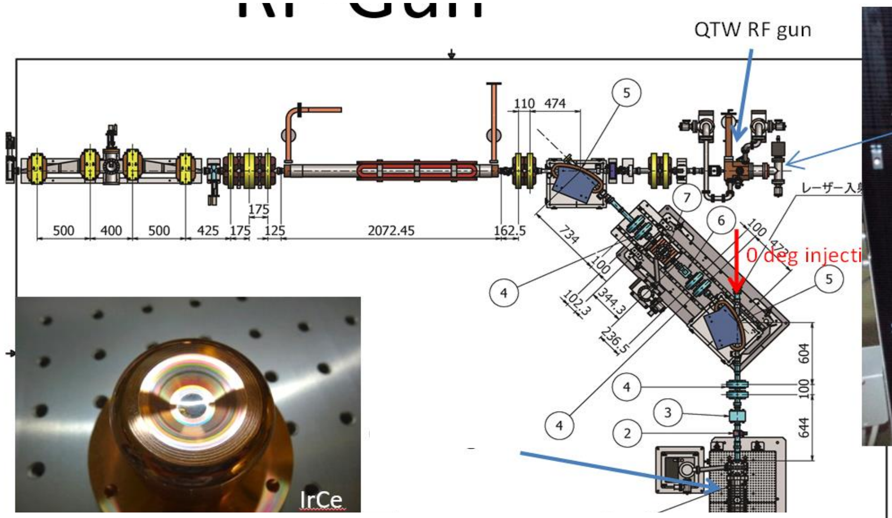
2025.01.14

Mitsuhiro Yoshida (INJ-Group of Injector Linac)

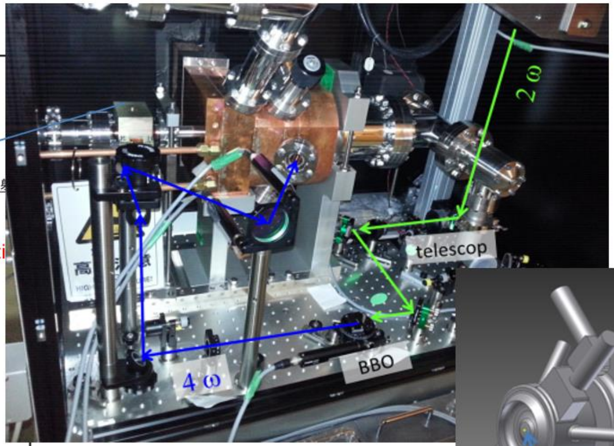
LINAC Injector system

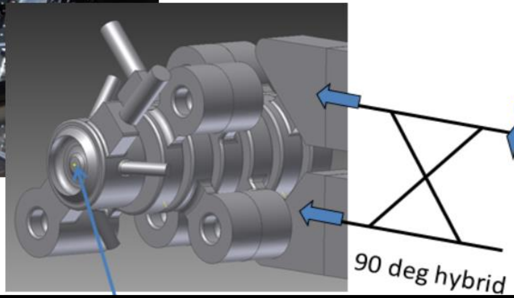


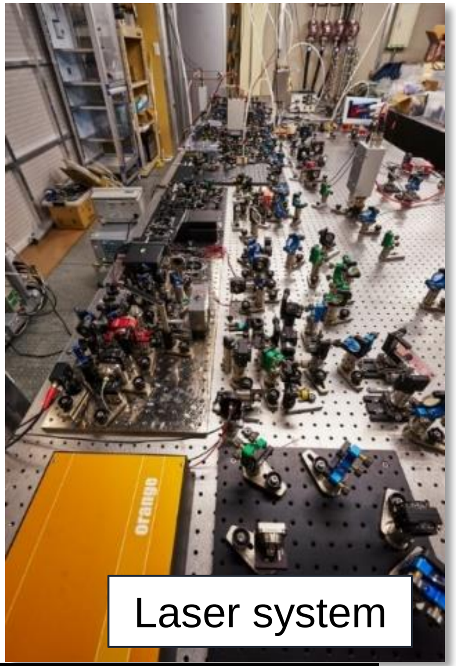
Low emittance and high charge photocathode rf e- gun

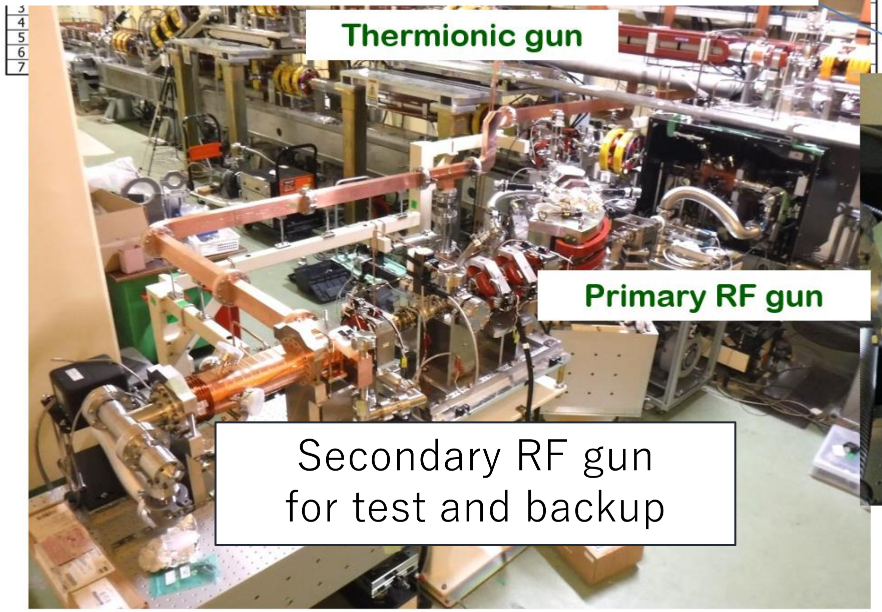


Ir_7Ce_2 cathode : Infinite lifetime and no pollution

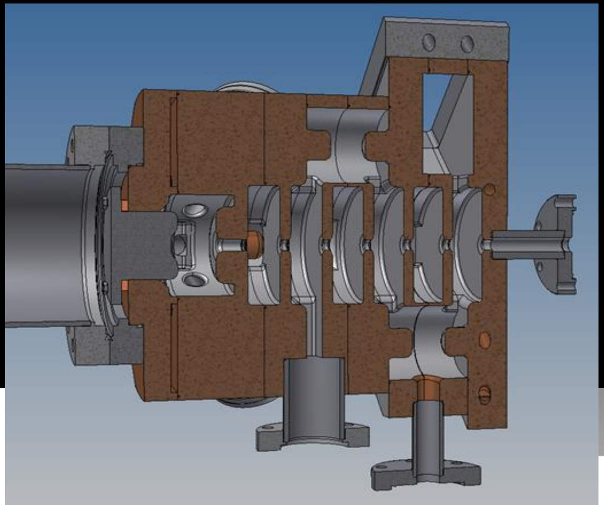


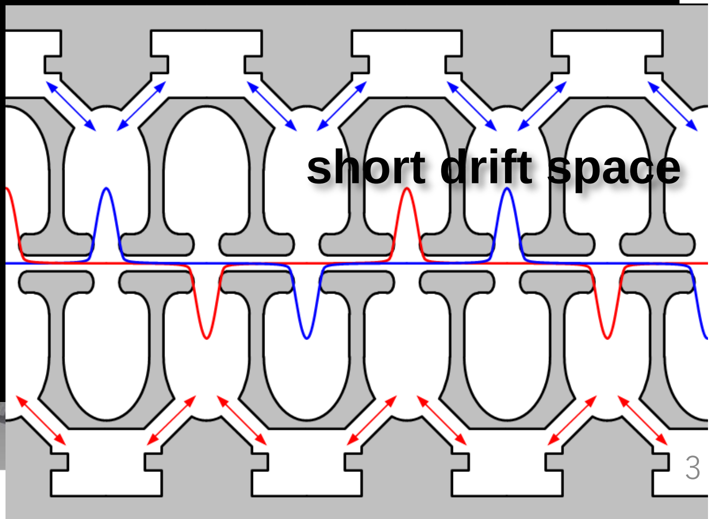






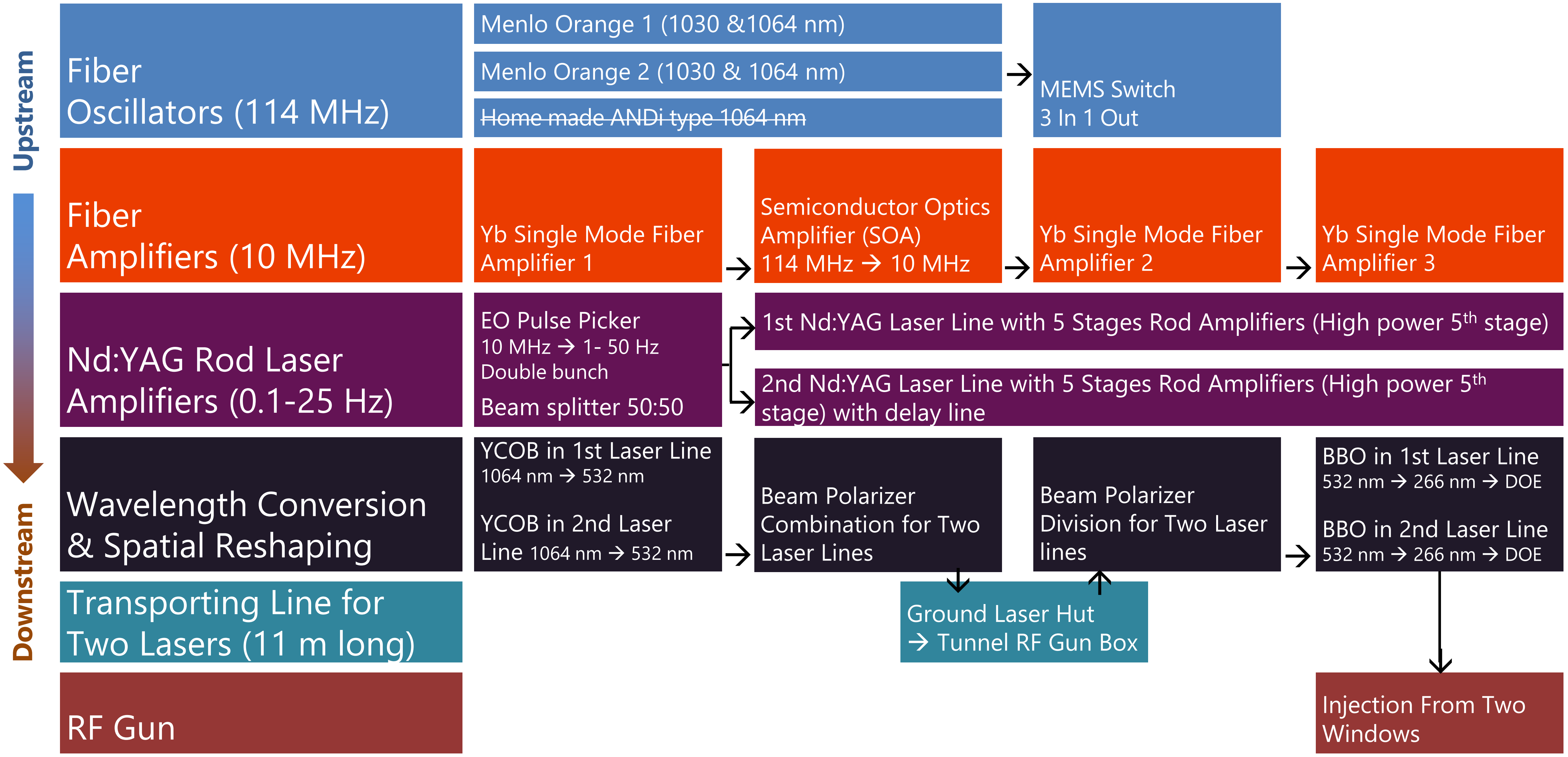
- Photocathode: Ir_7Ce_2
- Cavity: QTWSC (Quasi Travelling Wave Side Couple)
  - Strong focusing electric field





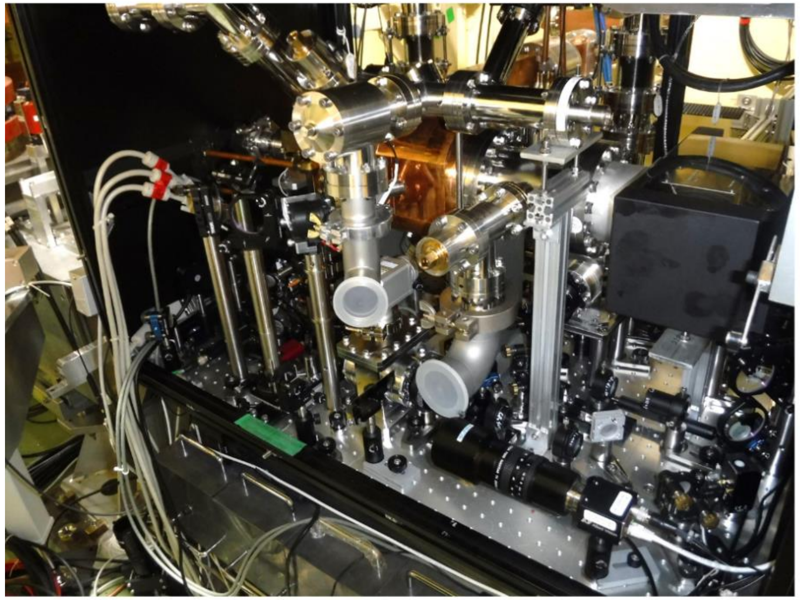
Laser System for RF Gun

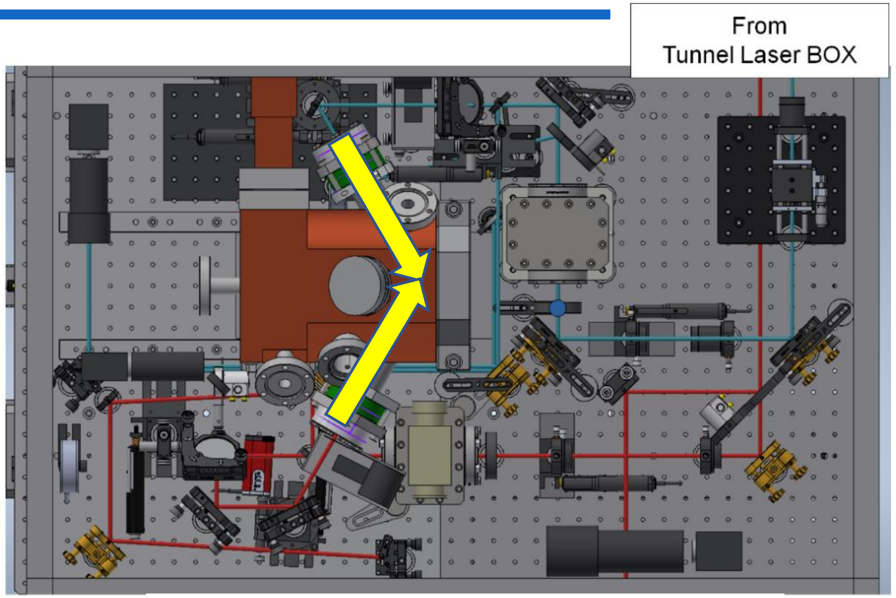
Yb-Fiber and Nd:YAG Hybrid Laser System



Laser System for RF Gun area

Two Laser Beams Injection for e^- Beam Generation

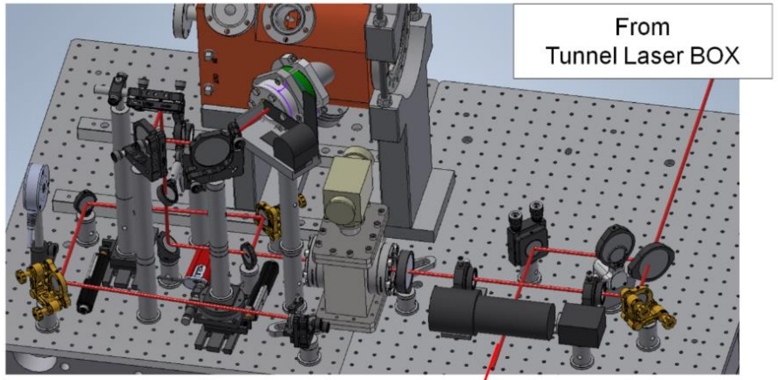




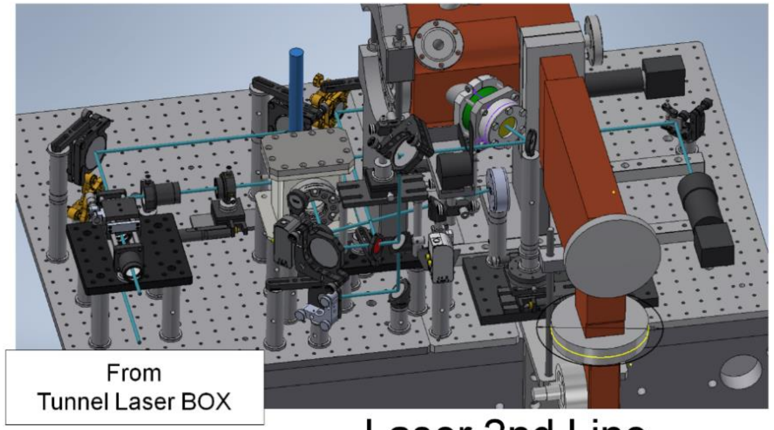
Total view of RF-Gun laser

Inclined laser irradiation makes higher than twice QE
(Schottky effect
and surface plasmon)

Laser irradiation from both direction leads better emittance

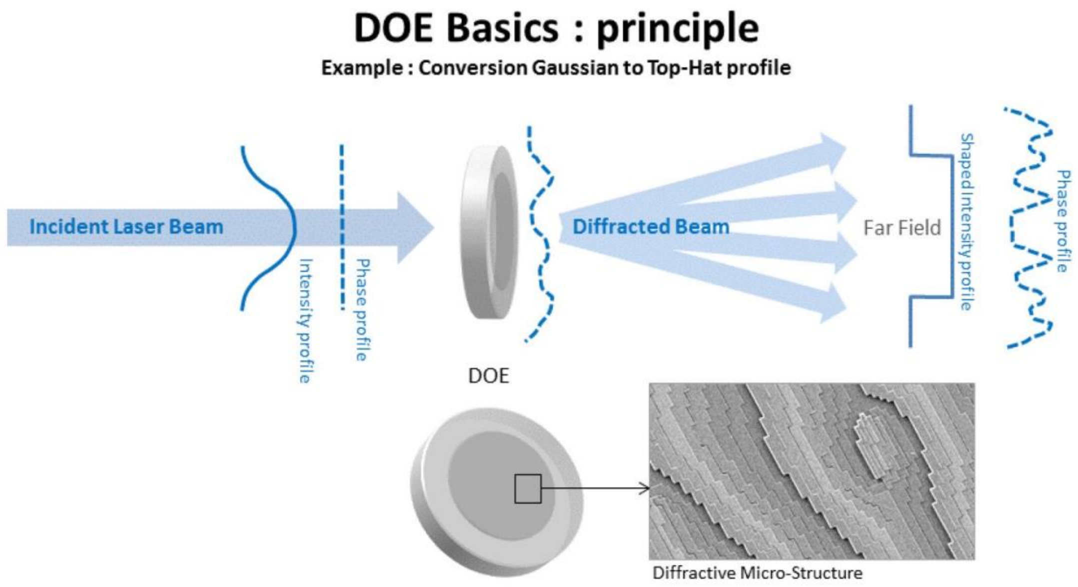


Laser 1st Line

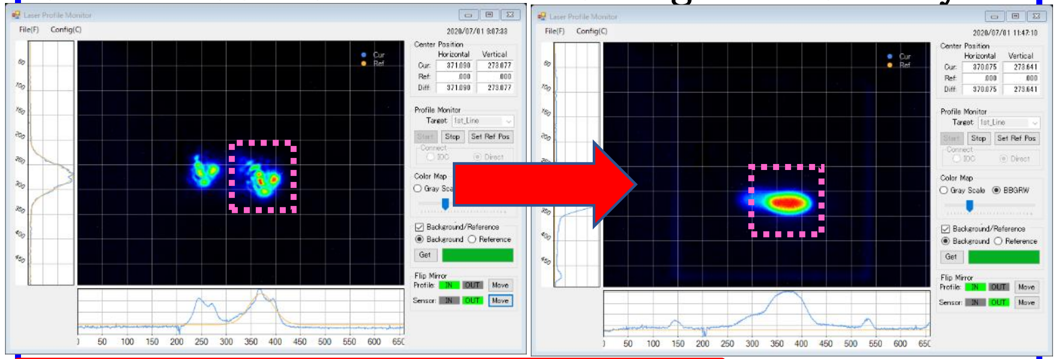


Laser 2nd Line

DOE for reshaping of laser spatial distribution



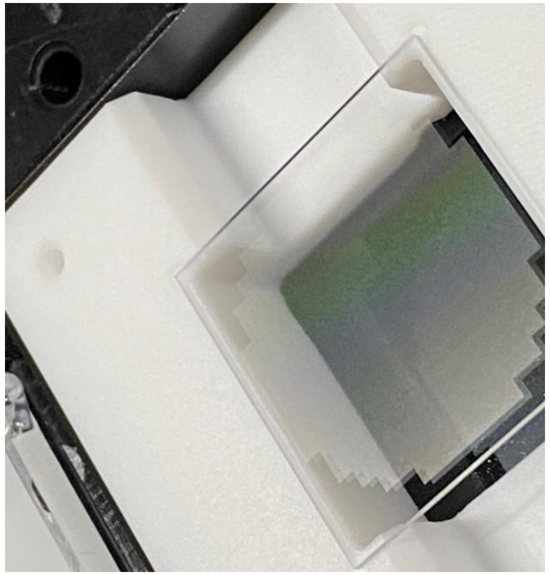
DOE (diffractive optical element) were installed at 1st /2nd (in summer '20/ '21) line laser: Laser beam homogenizer for low emittance beam with the high intensity

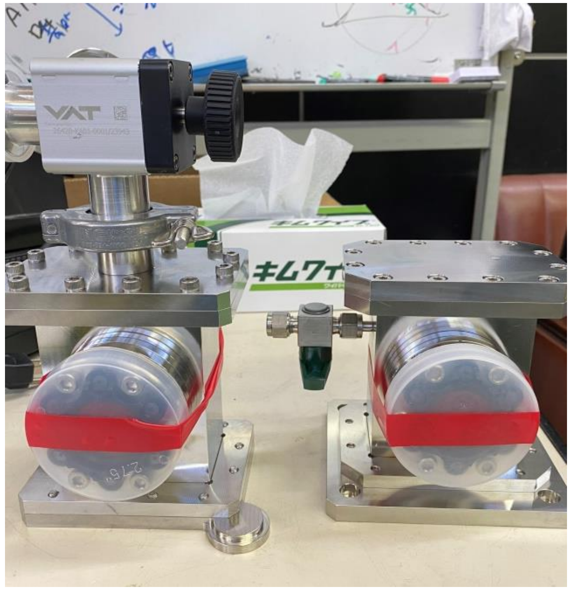


world first DOE application in UV laser

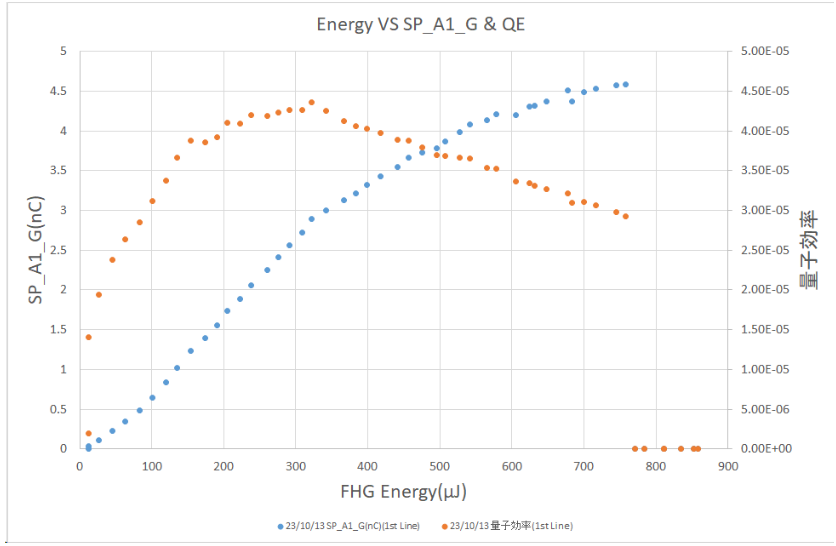
R. Zhang

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



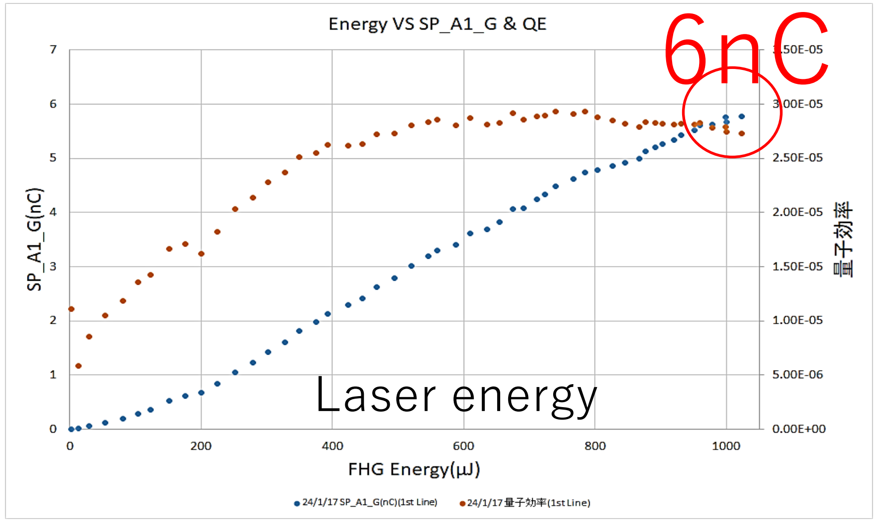


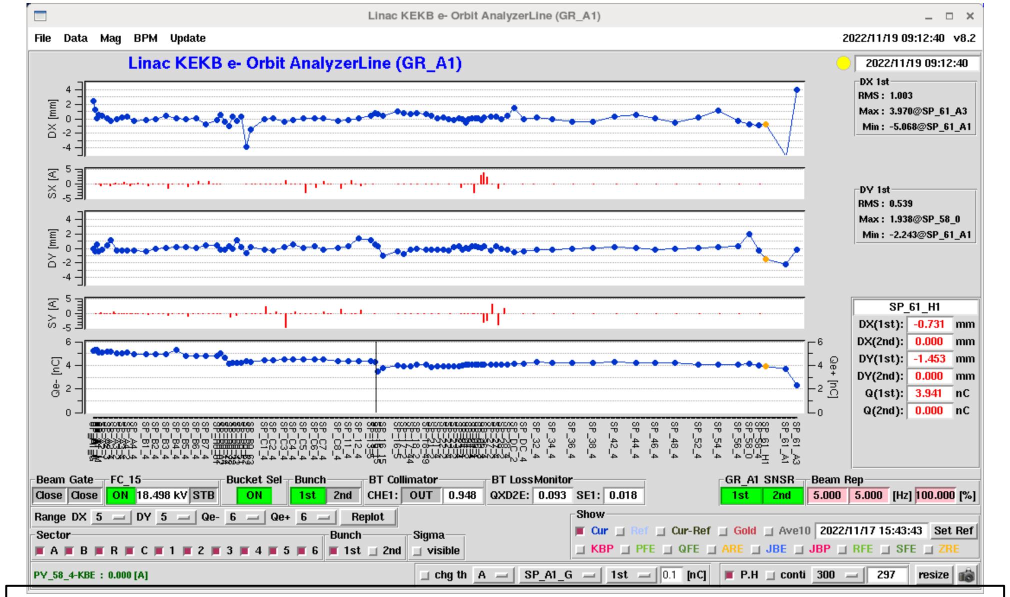
Bunch charge increased

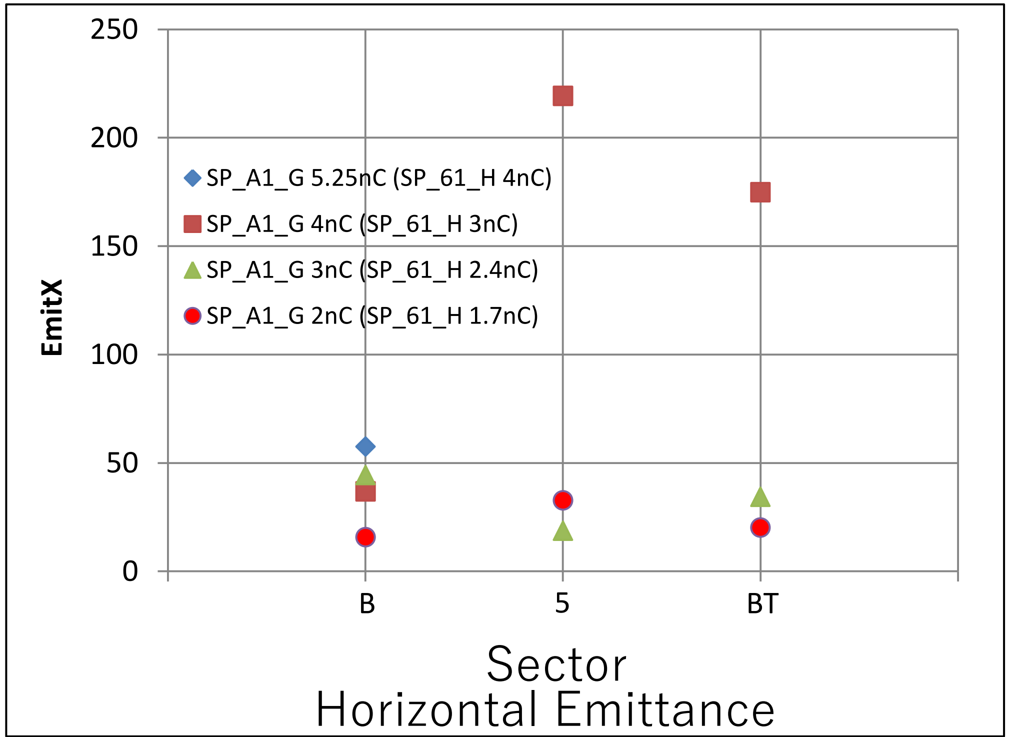


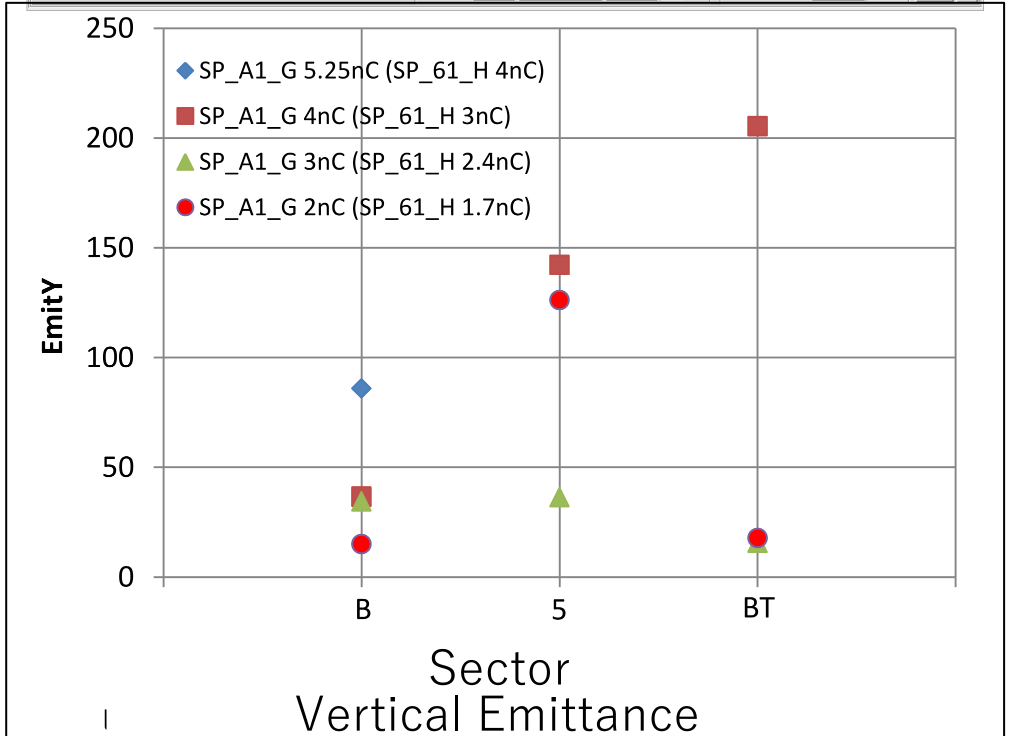
6nC output from RF-Gun and 4 nC at the LINAC end

RF-Gun output charge

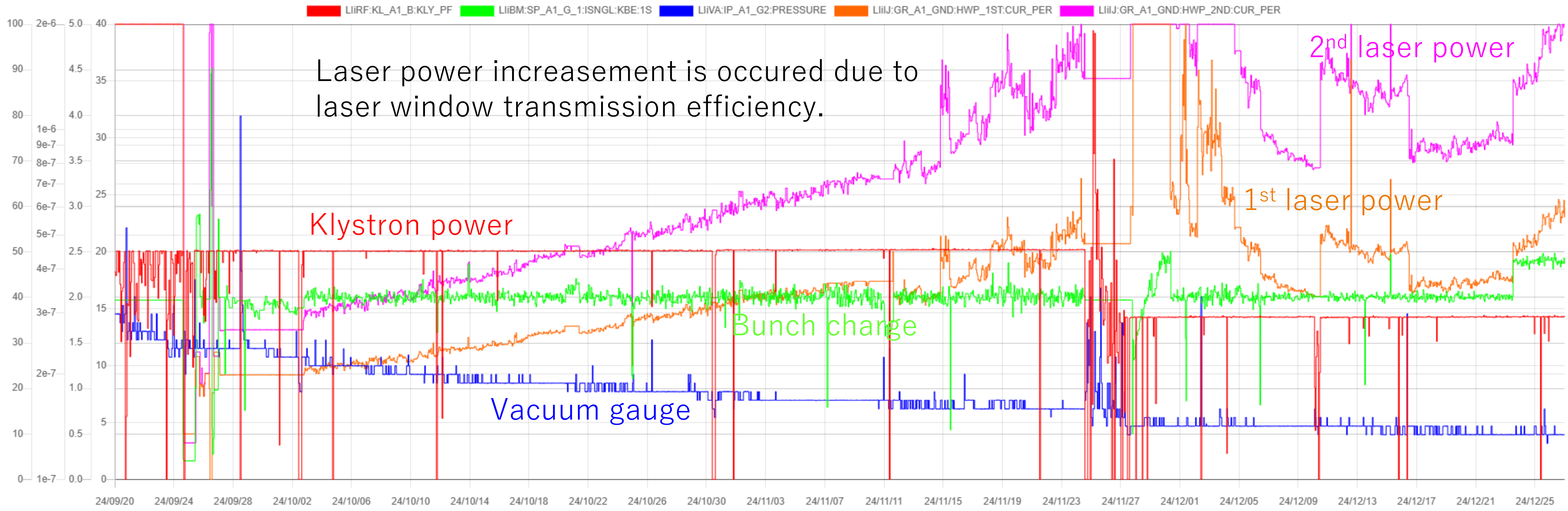






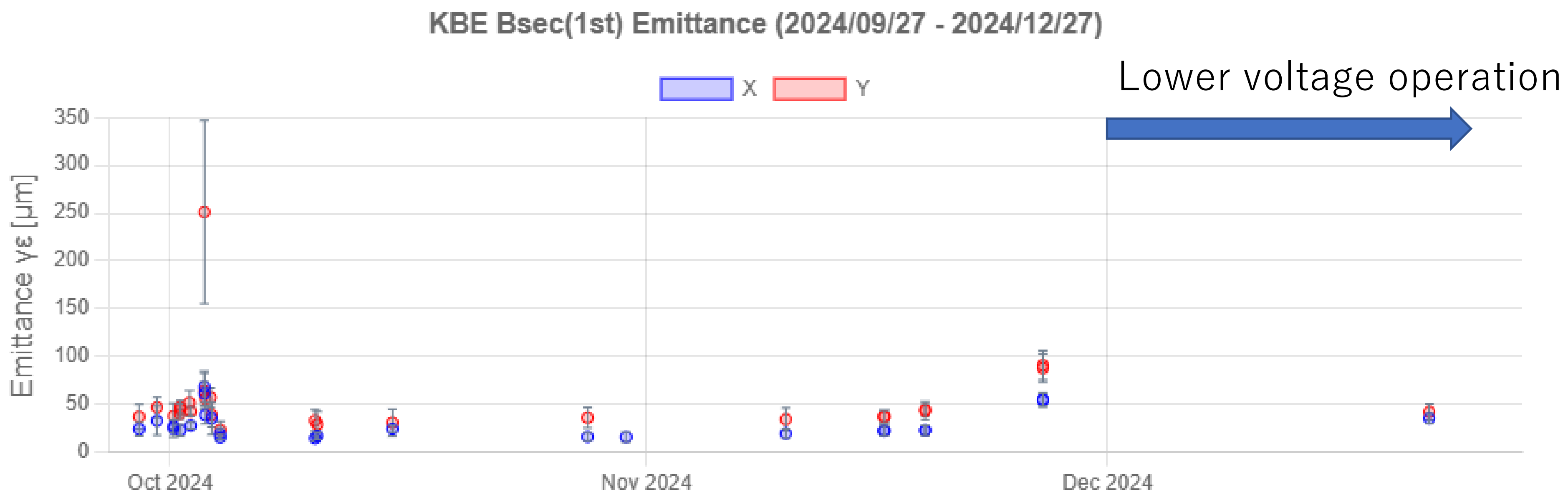


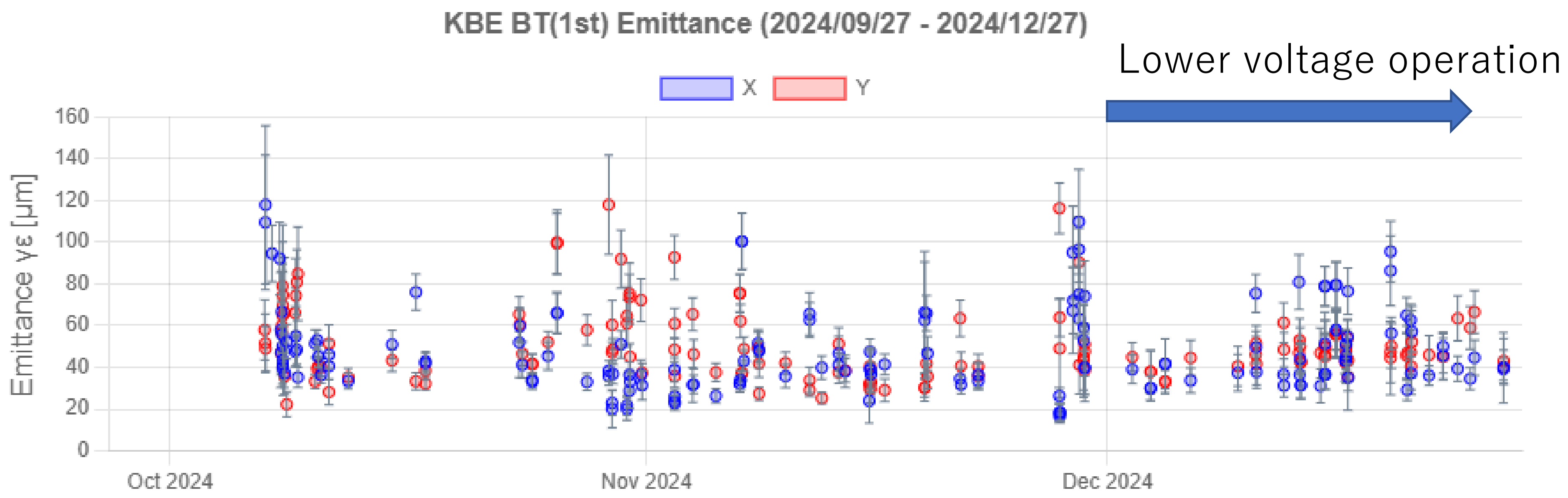
Operation history (charge and laser power)



Not fully recovered (9MW, 1 us) after serious dischargement.

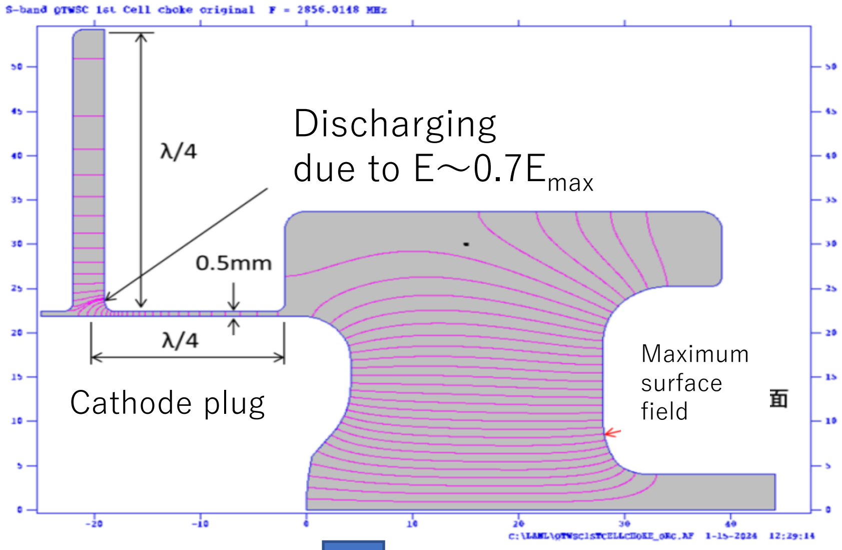
2nC Emittance history for 3-month





LINAC / RF-Gun recent trouble

Current RF-Gun cathode cell
with choke structure
for cathode thermal cleaning

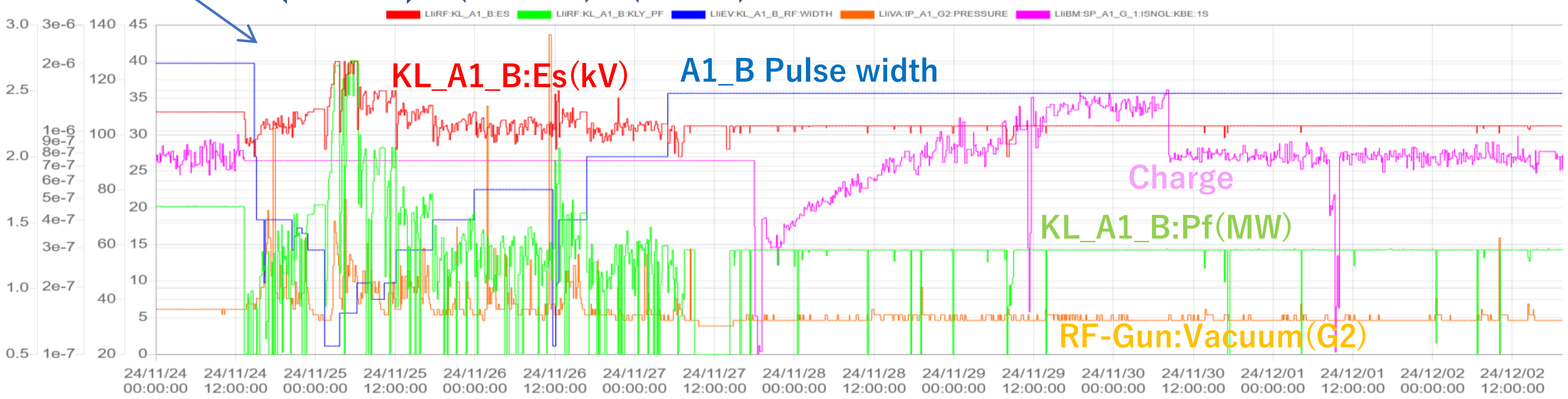


RF-Gun Serious discharge(11/24)

HER Injection
unavailable
due to
RF-Gun down

KEKB
Tunnel
Access

LINAC
Maintenance
Day

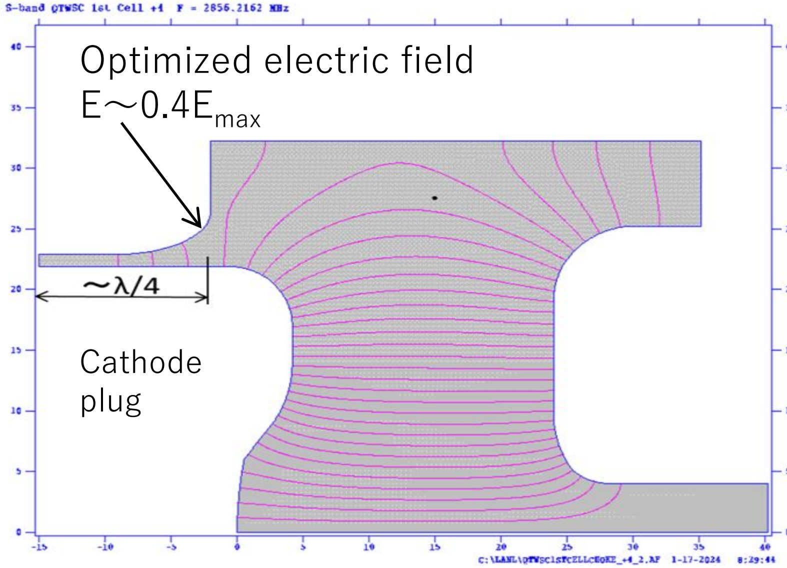


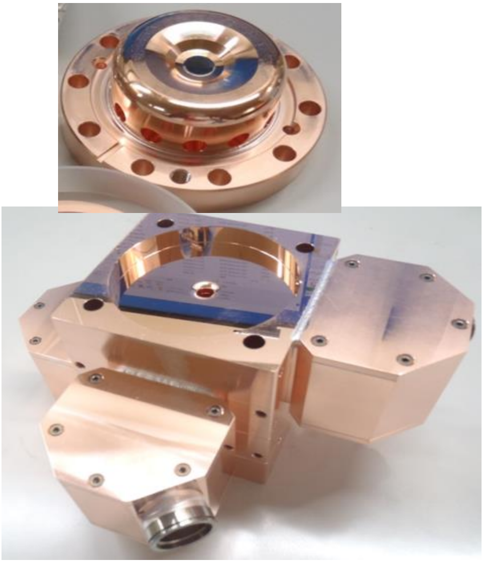
Normal operation
14MW, 1.1us

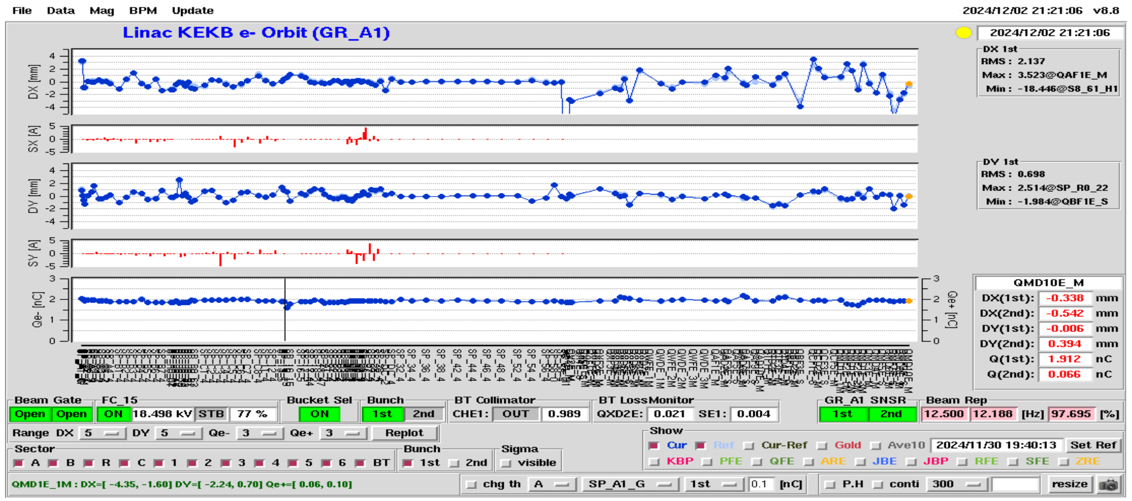
Not fully recovered
9MW, 1 us

Charge recovered

New RF-Gun cathode cell (install @ FY2025)







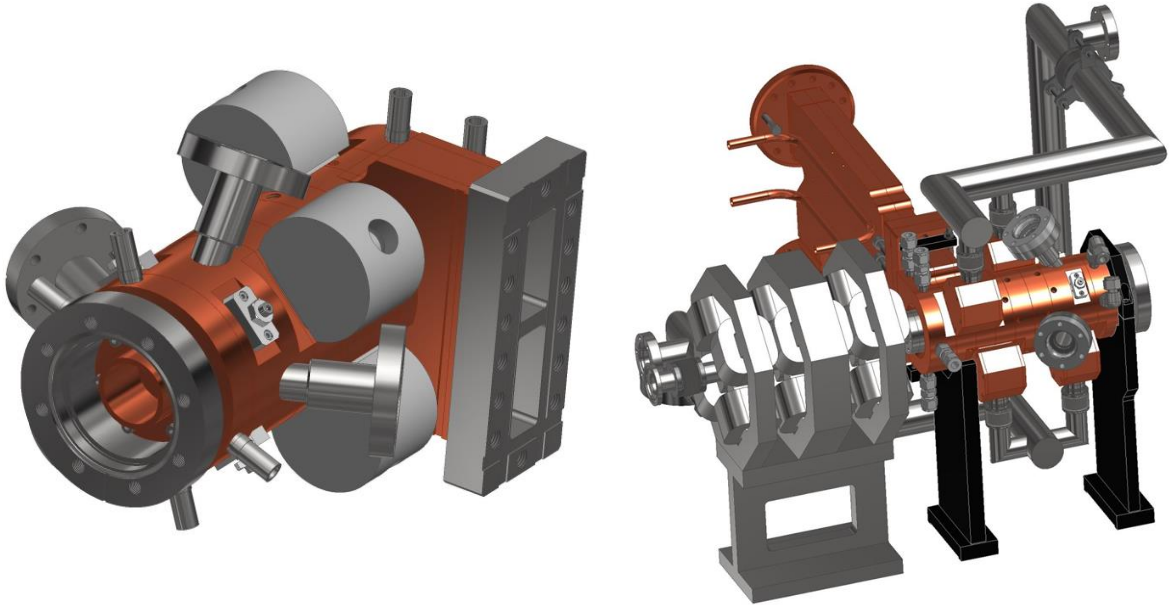
2nC， Normalized Emittance : 40 x 45 μm at BT1

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 due to lower voltage
- Focusing magnet



Current RF-Gun cathode cell
with choke structure
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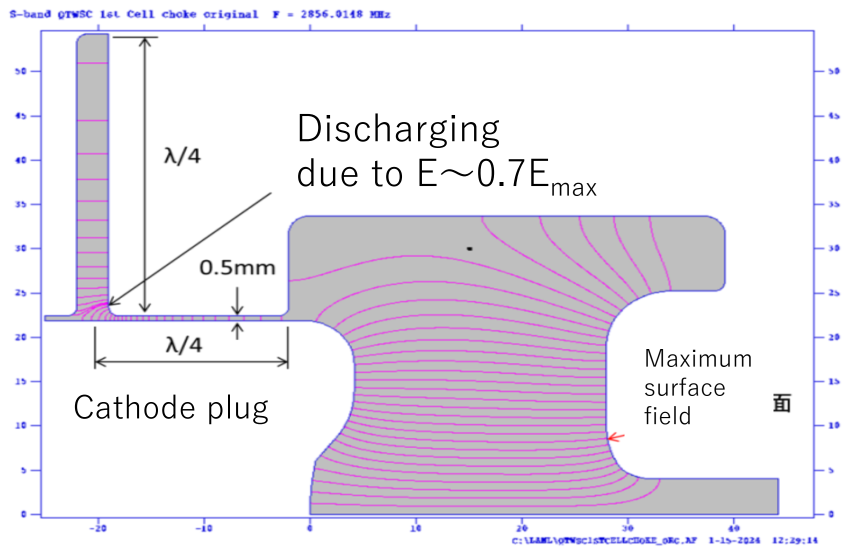
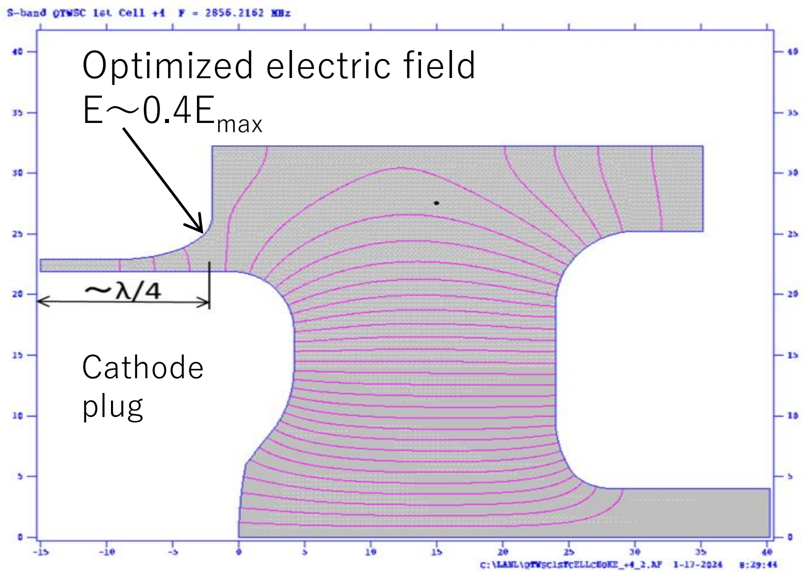
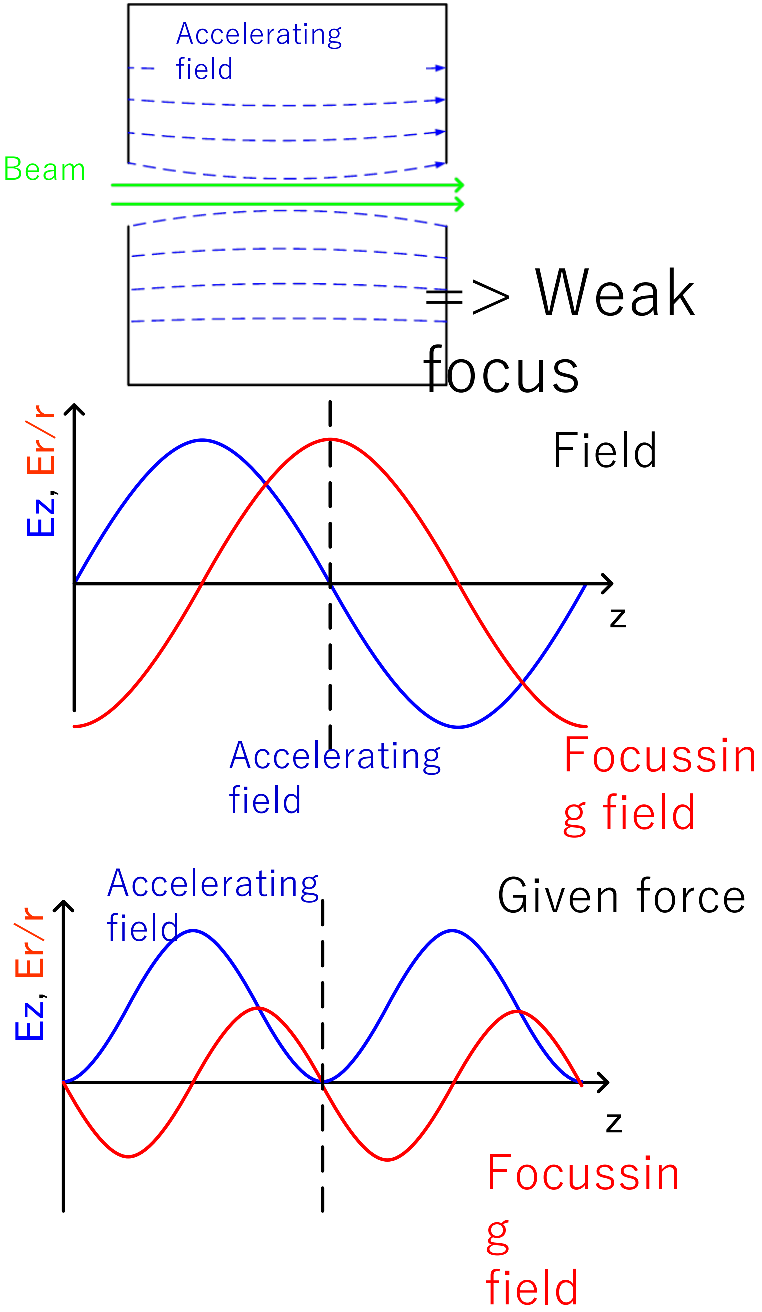


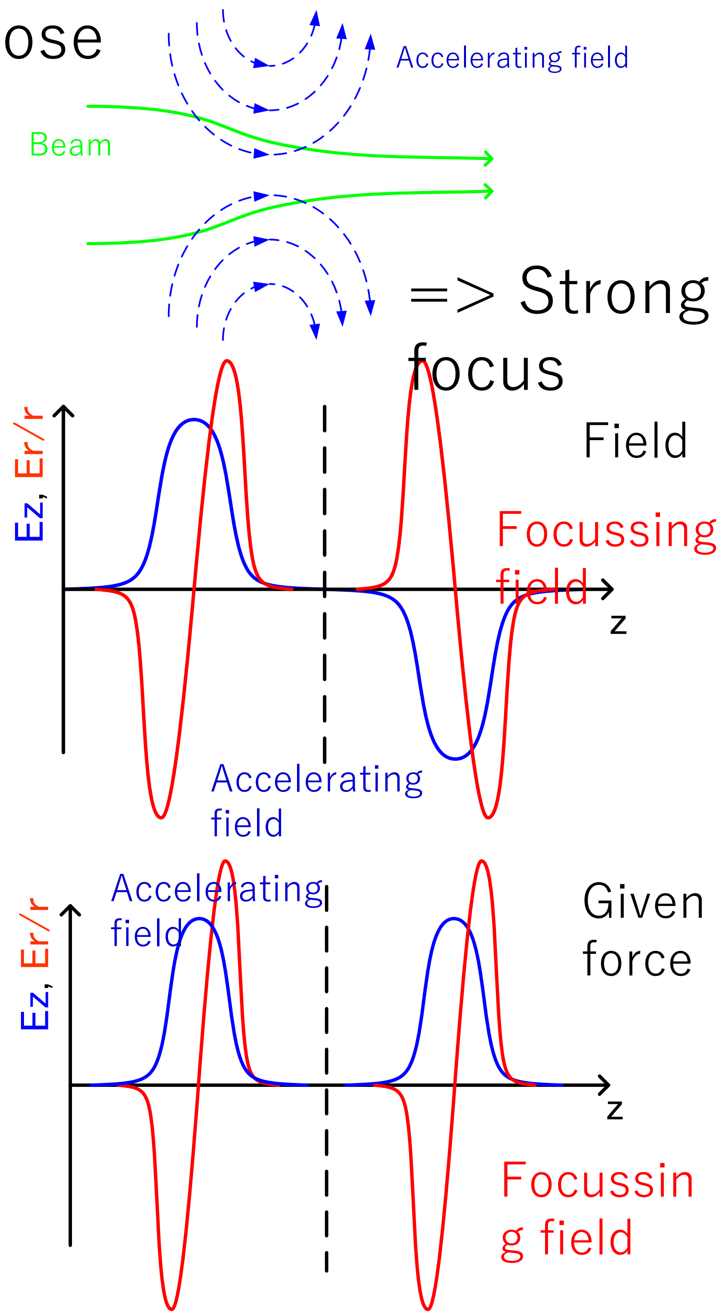
New RF-Gun cathode cell (install @ FY2025)



Pill-box cavity

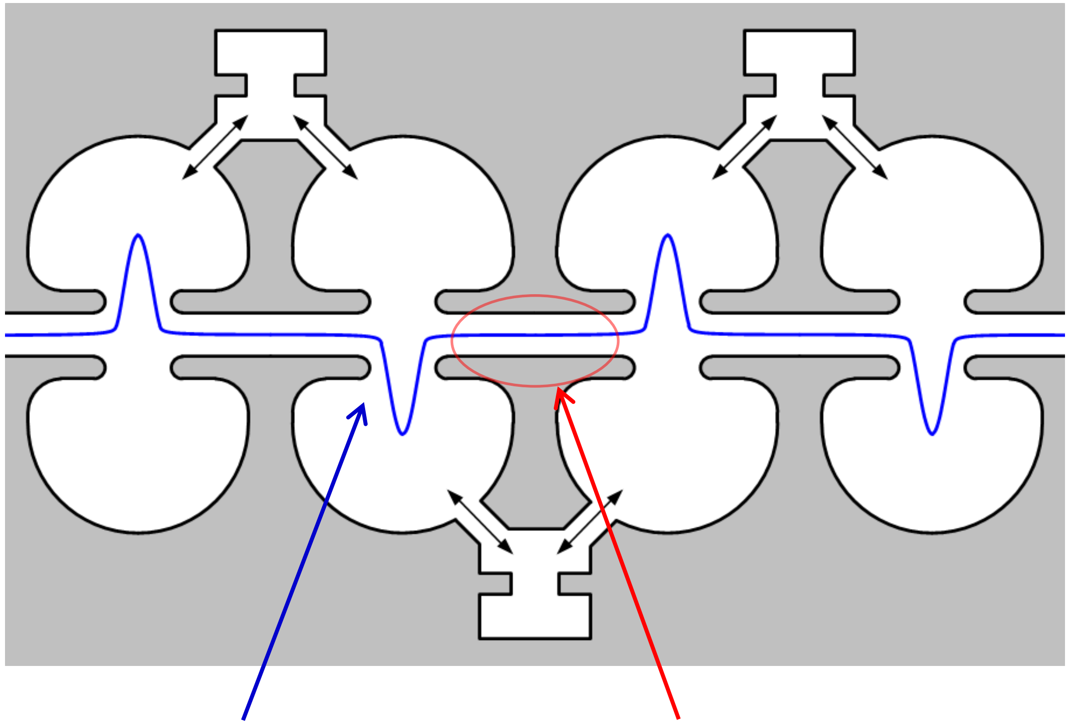


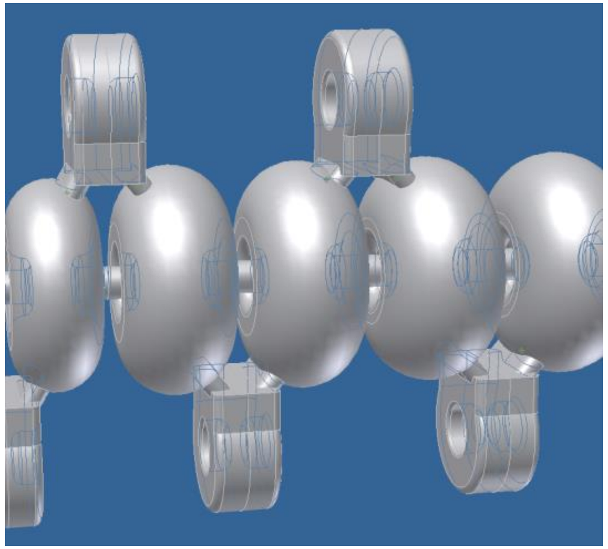
Annular coupled cavity with nose



Closed gap makes focus field

Side coupled cavity is one candidate (or DAW / ACS / CDS …)





Concentrated field has focusing effect

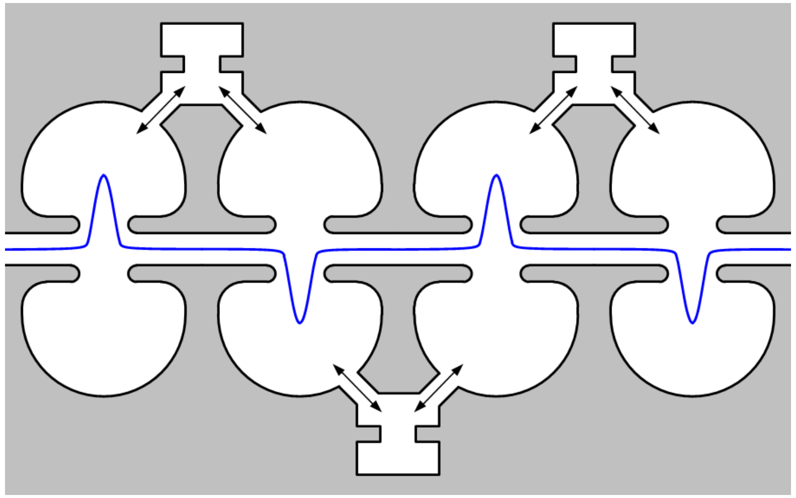
This structure has long drift space

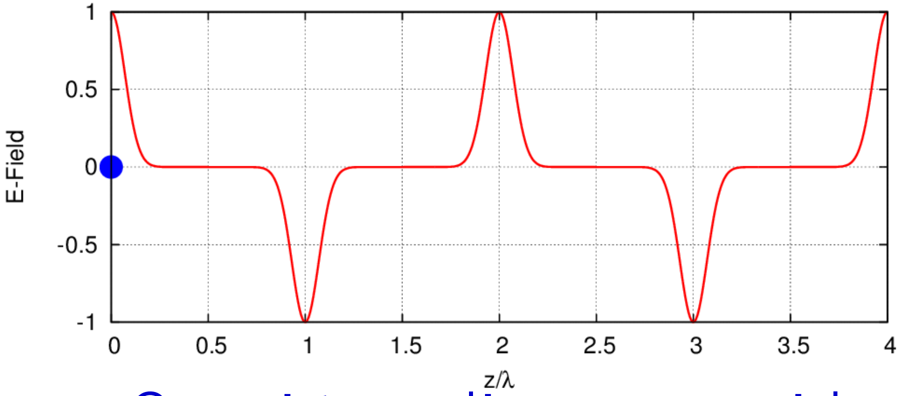
This structure has focusing field.

Long drift space is problem.

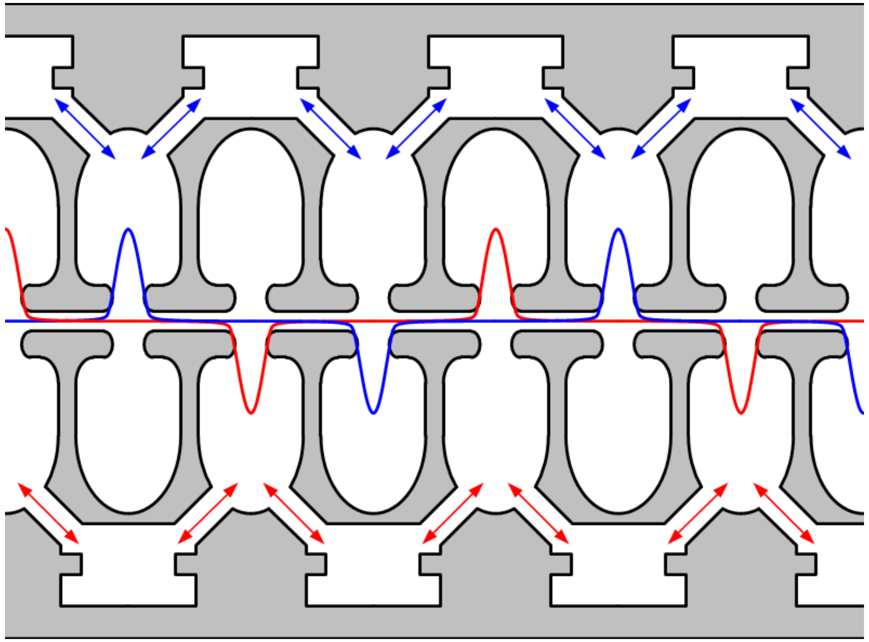
Design of a quasi traveling wave side couple RF gun

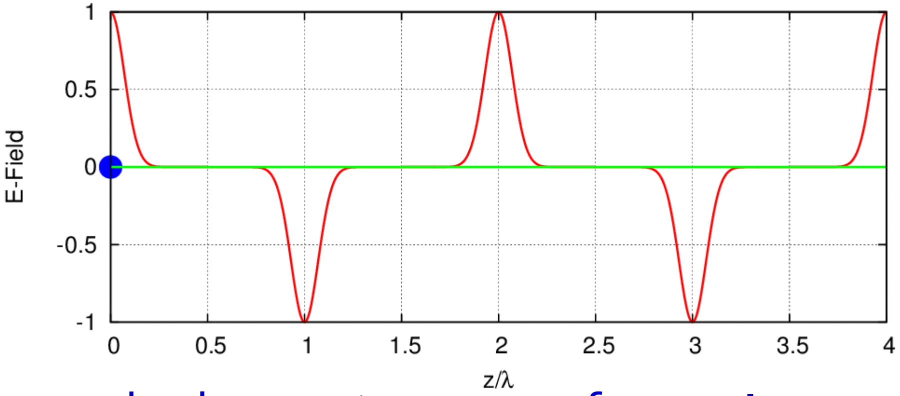
Normal side couple structure





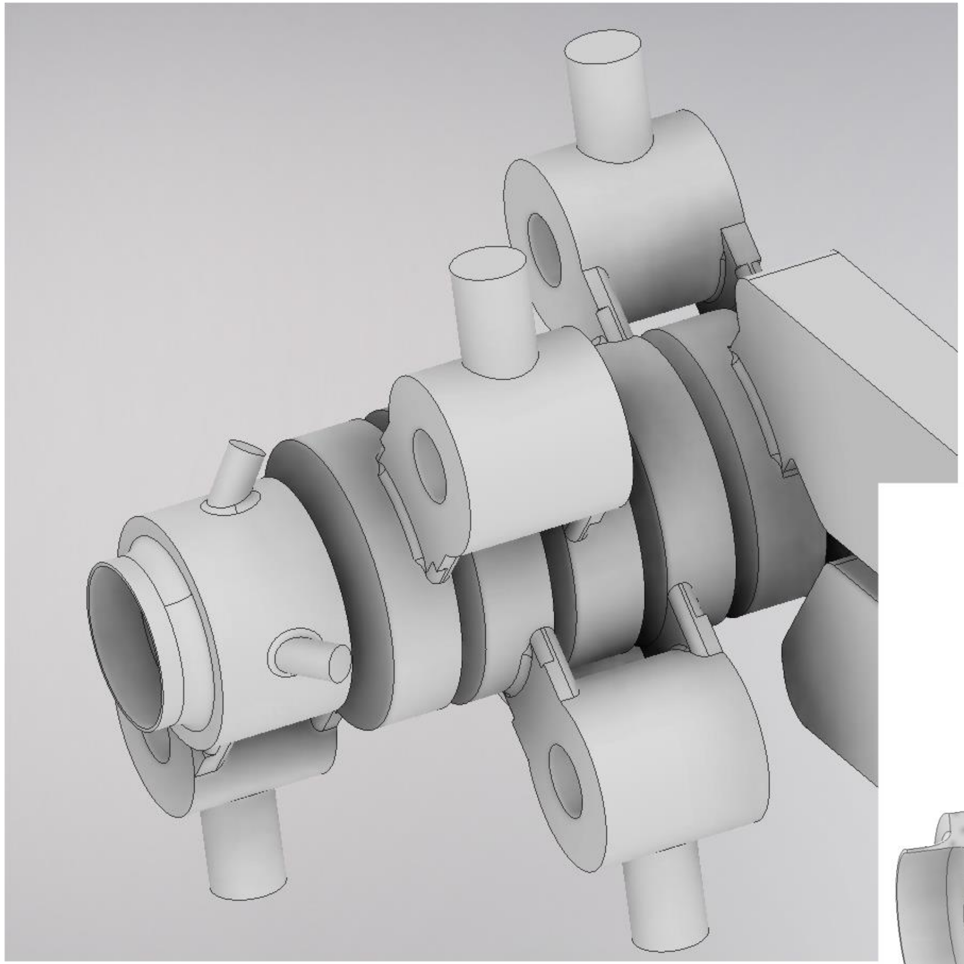
Quasi traveling wave sidecouple structure

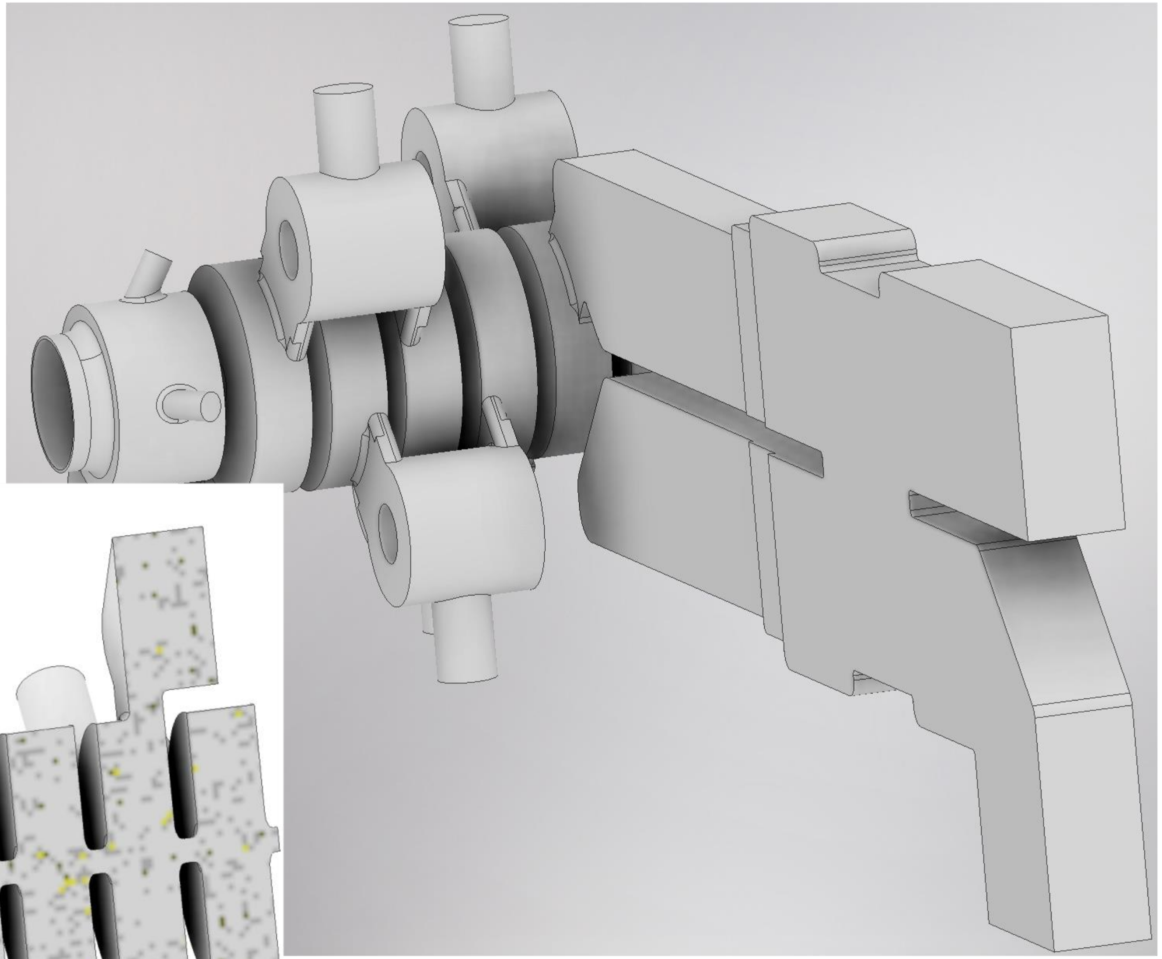


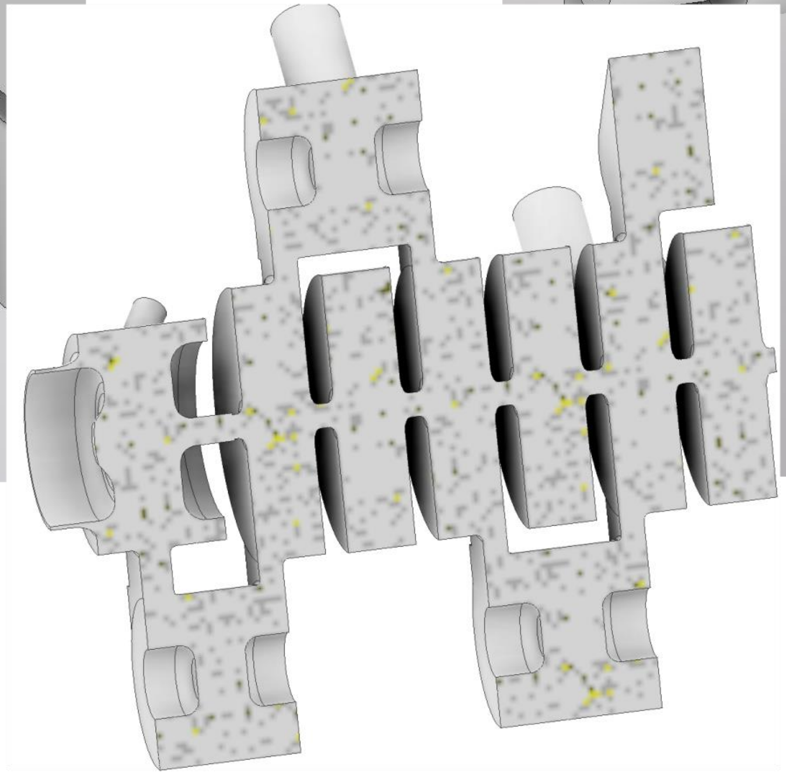


Quasi traveling wave side couple has stronger focusing and accelerated gradient than DAW.

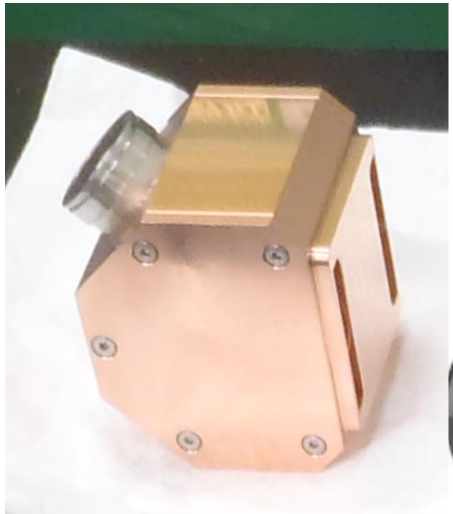
New Quasi Travelling Wave RF-Gun Cavity



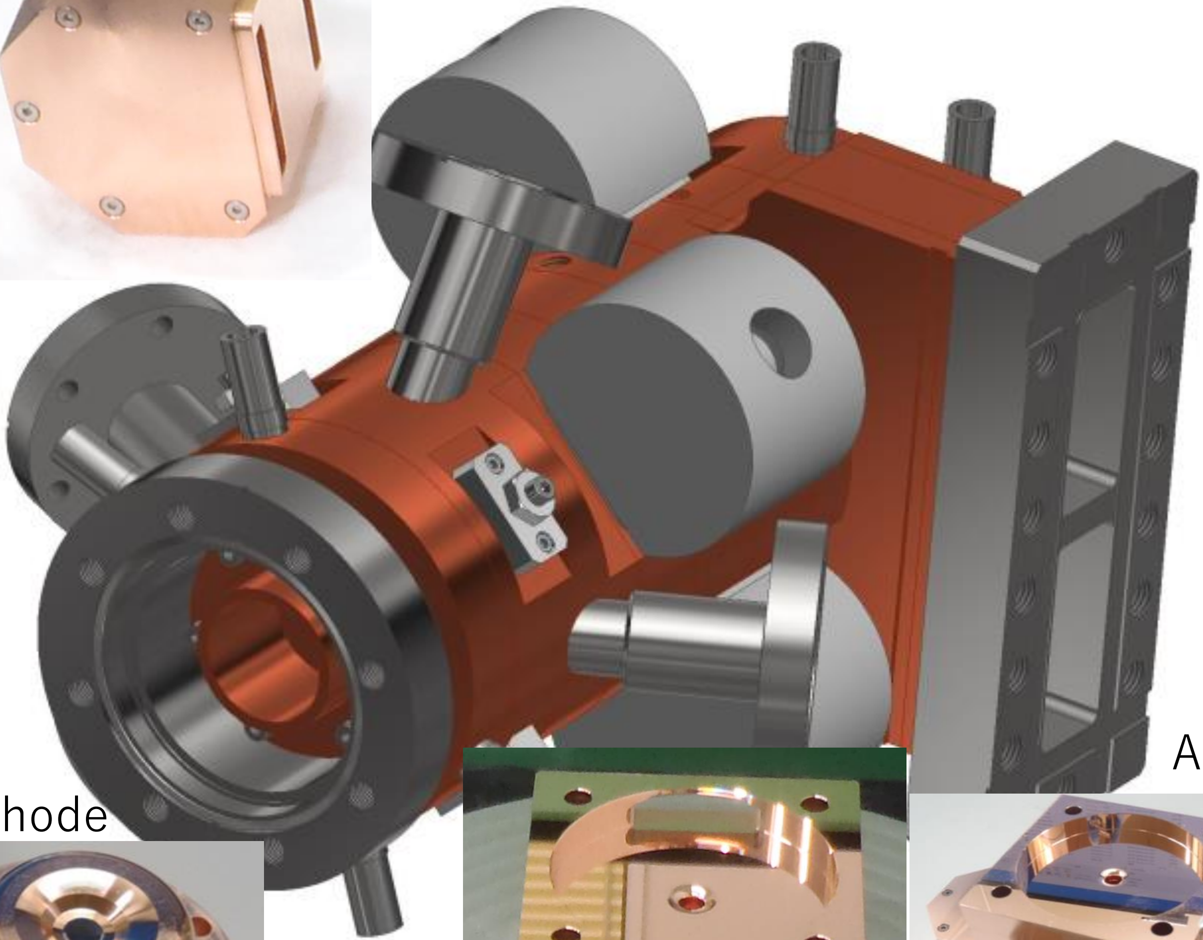


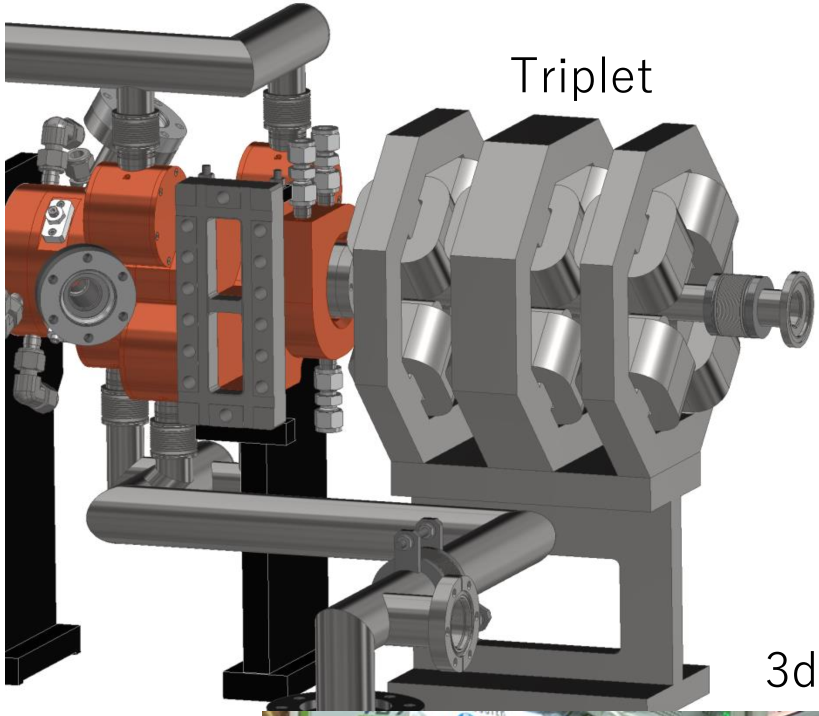


New RF-Gun cavity



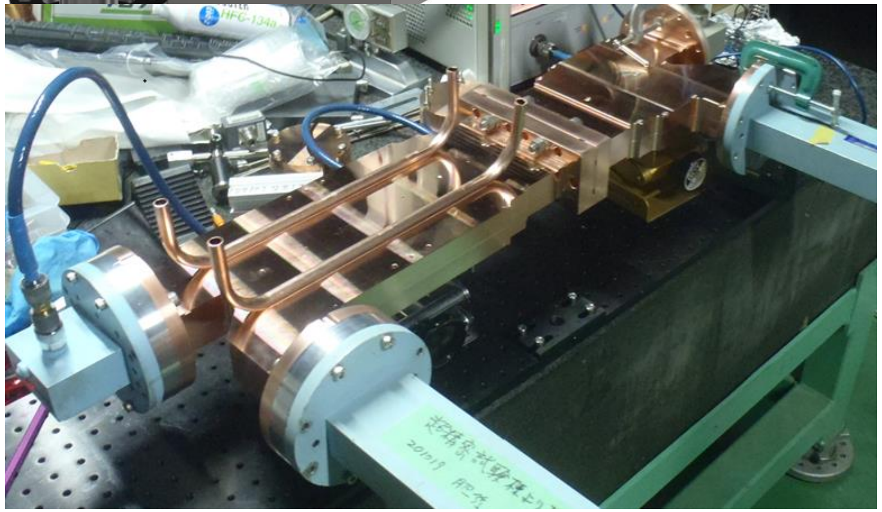
Side couple cavity



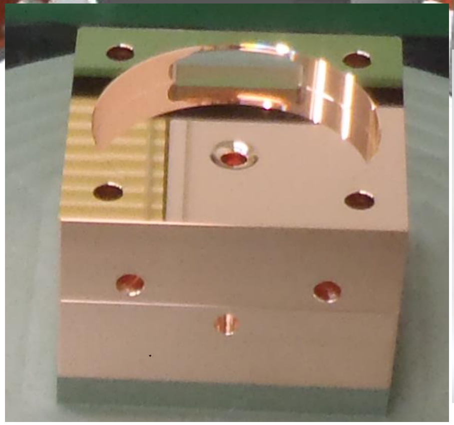


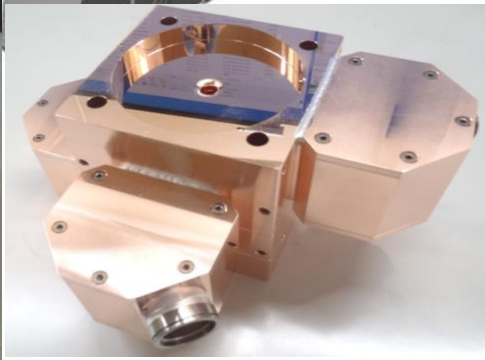
Triplet

3dB Hybrid

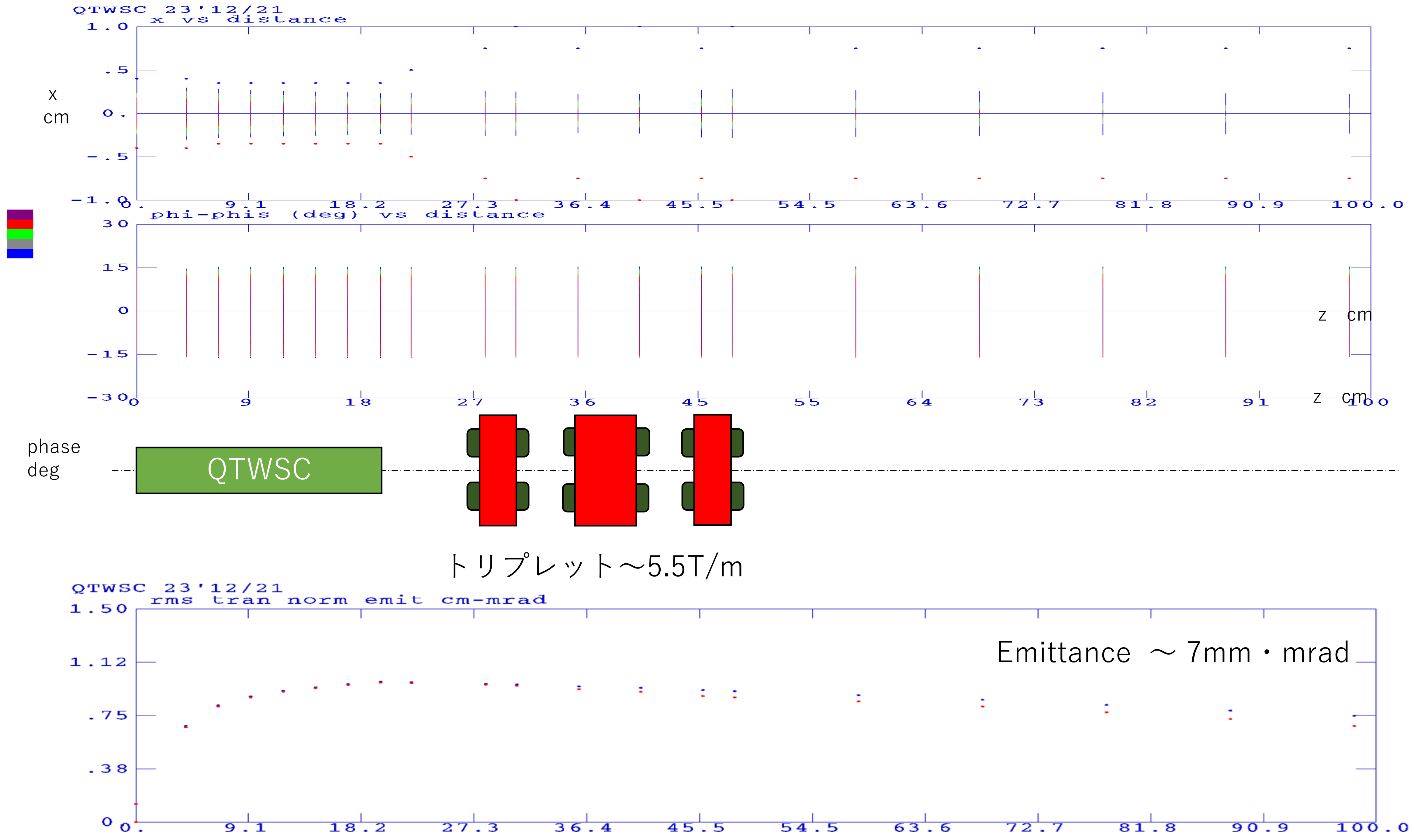


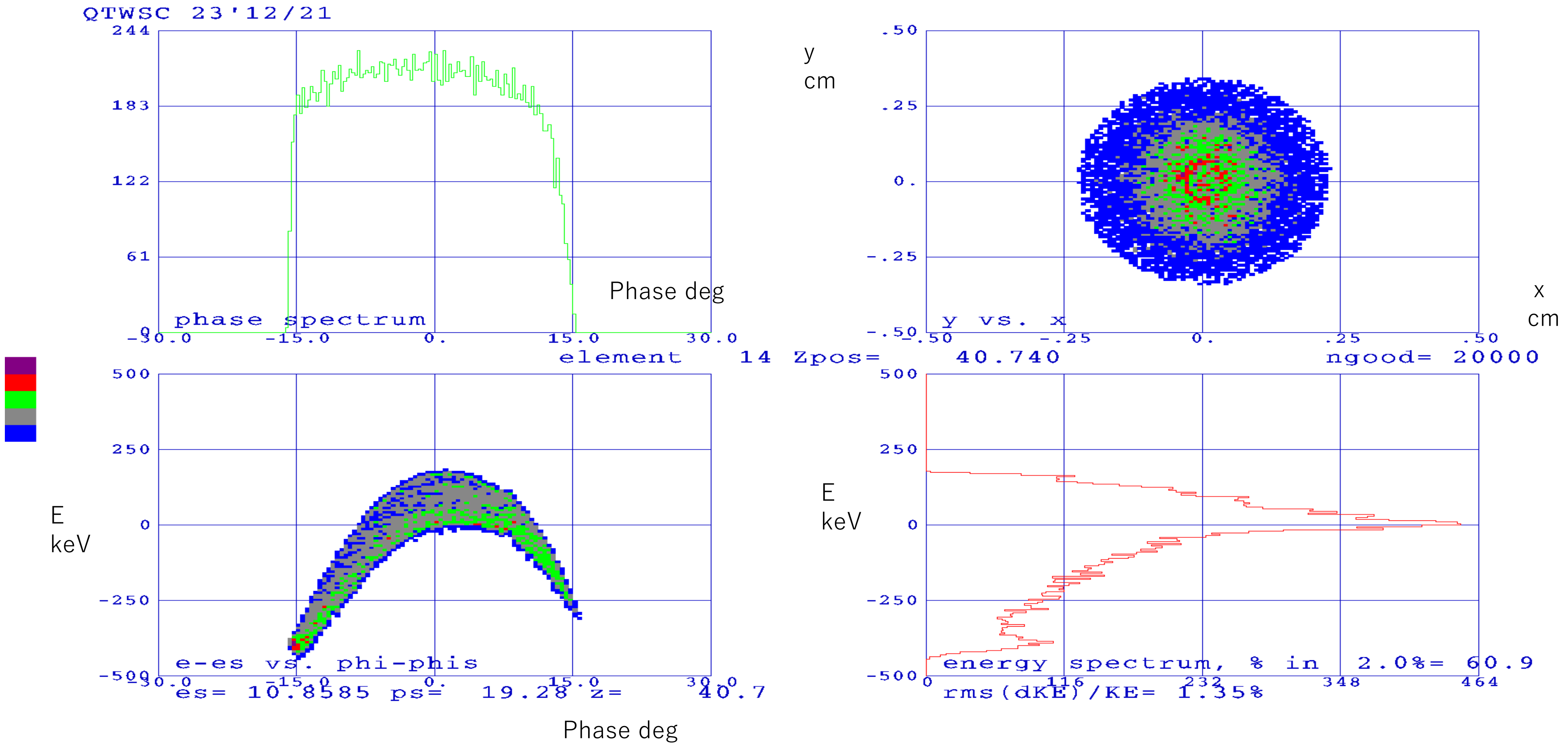
After blazing



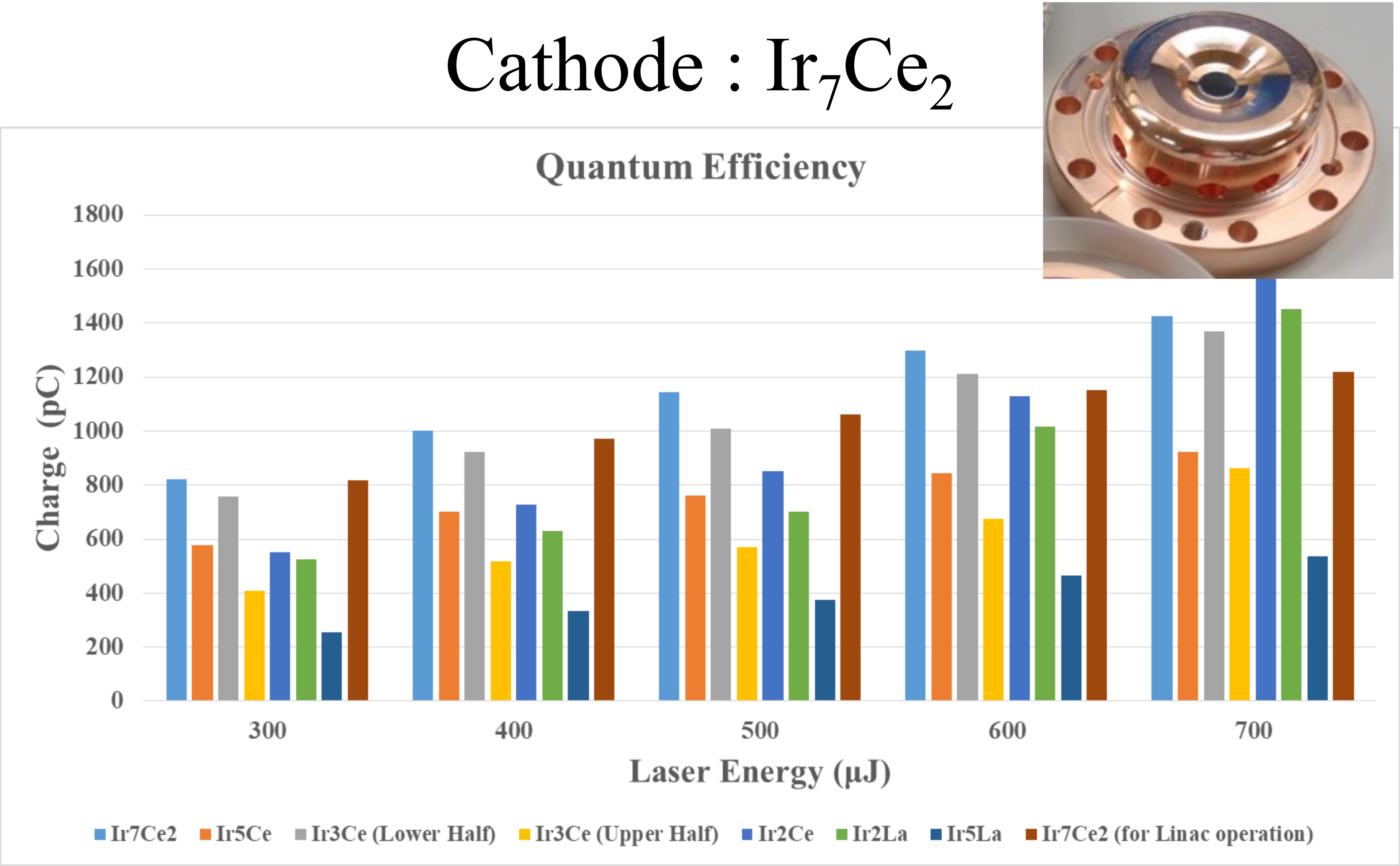


Cathode


QTWSC 23'12/21
x vs distance
x
cm
phi-phis (deg) vs distance
z cm
phase
deg
QTWSC
トリプレット～5.5T/m
QTWSC 23'12/21
rms tran norm emit cm-mrad
Emittance ～ 7mm・mrad


QTWSC 23'12/21
phase spectrum
Phase deg
y vs. x
y
cm
x
cm
element 14 Zpos= 40.740 ngood= 20000
e-es vs. phi-phis
es= 10.8585 ps= 19.28 z= 40.7
E
keV
Phase deg
energy spectrum, % in 2.0%= 60.9
rms(dKE)/KE= 1.35%
E
keV

Cathode : Ir_7Ce_2



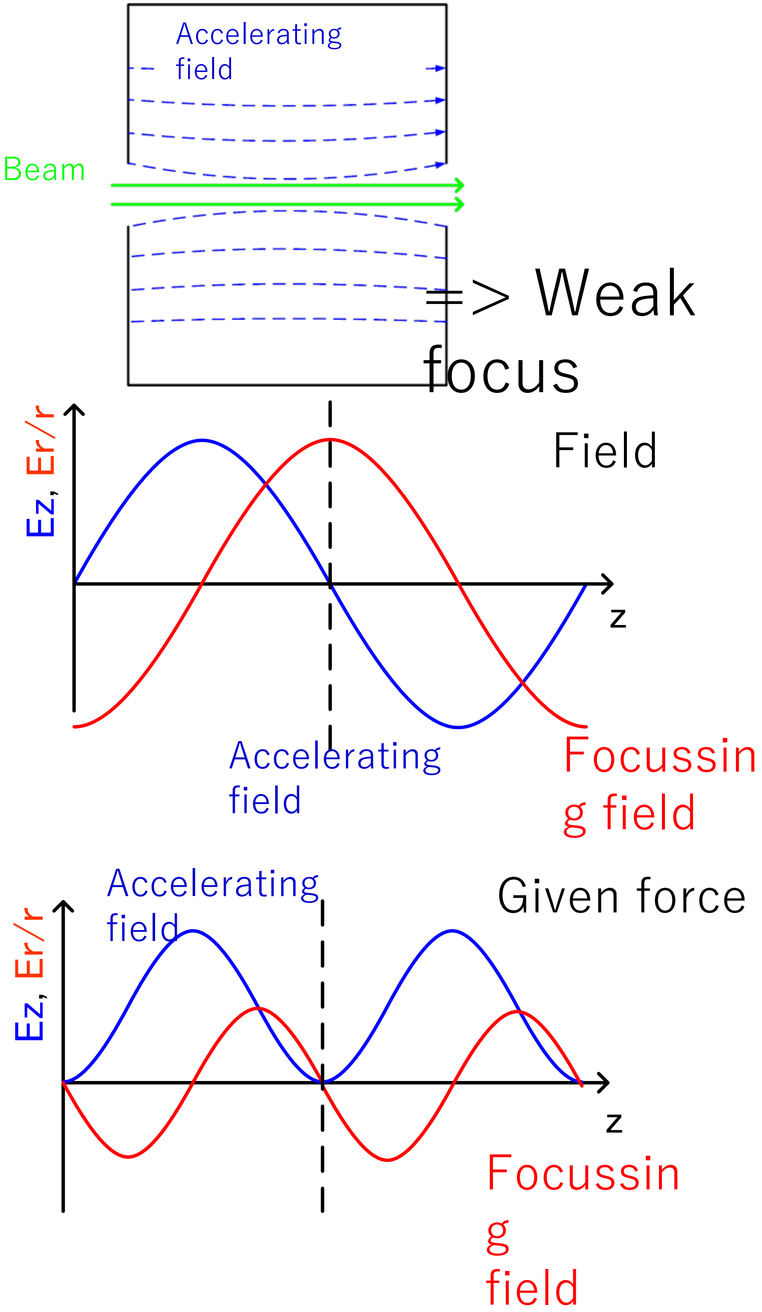
KEK house made IrCe cathode has best quantum efficiency

e- beam summary and issue

- Thermionic DC electron gun has worked fine to generate primary electron beam for positron production.
  - ==== To Do ====
  - Stability improvement : Dedicated power supply / Stabilizing temperature of high voltage station
- 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
    ==== To Do ====
  - Laser temporal shaping
  - New QTWSC RF-Gun will solve
    - Laser window deterioration
    - Higher voltage to avoid cathode plug dischargement
    - Lower dark current
    - Better energy slope
    - Better emittance according to higher voltage and unified focusing magnet
- Future plan
  - X-band Linearizer cavity is under design to reduce non-linear energy distribution.
  - Multi-bunch operation (4-7 bunches)

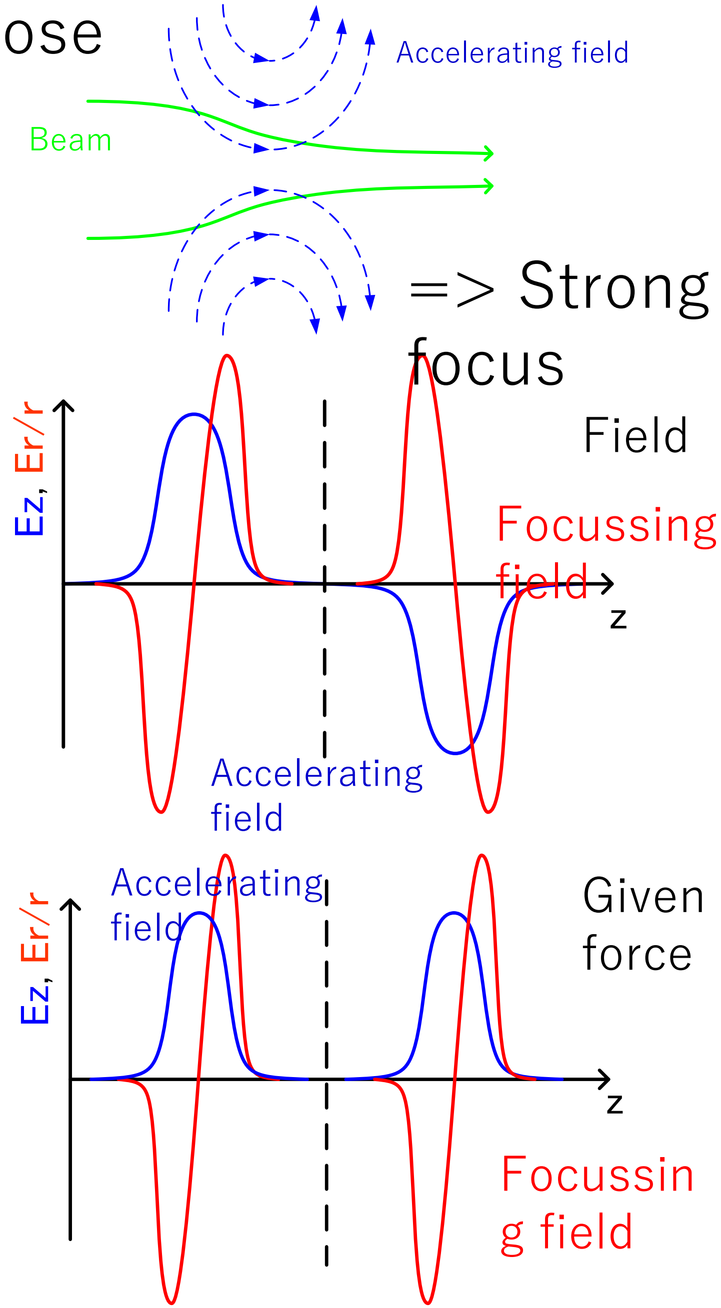
Backup

Pill-box cavity



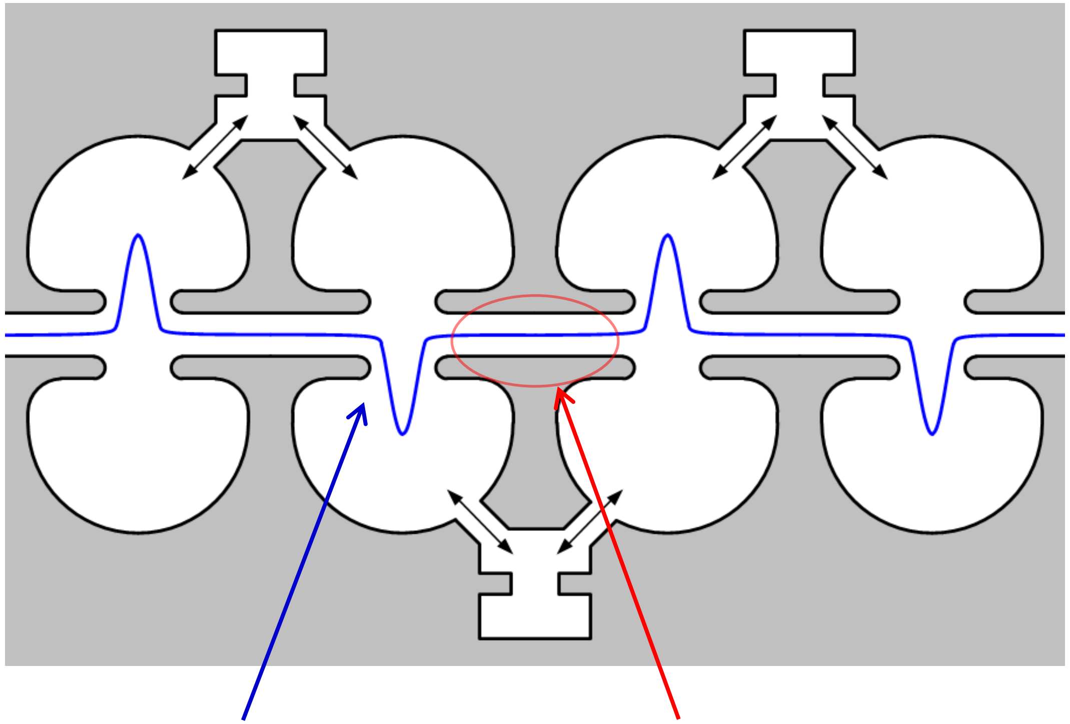
=> Weak focus

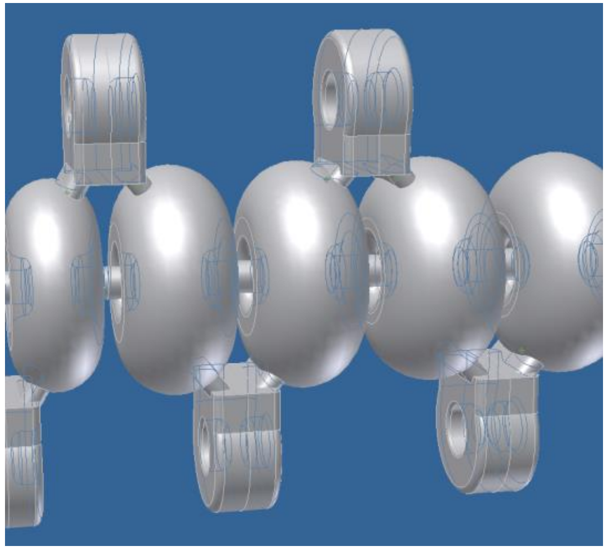
Annular coupled cavity with nose



=> Strong focus

Closed gap makes focus field
Side coupled cavity is one candidate (or DAW / ACS / CDS …)





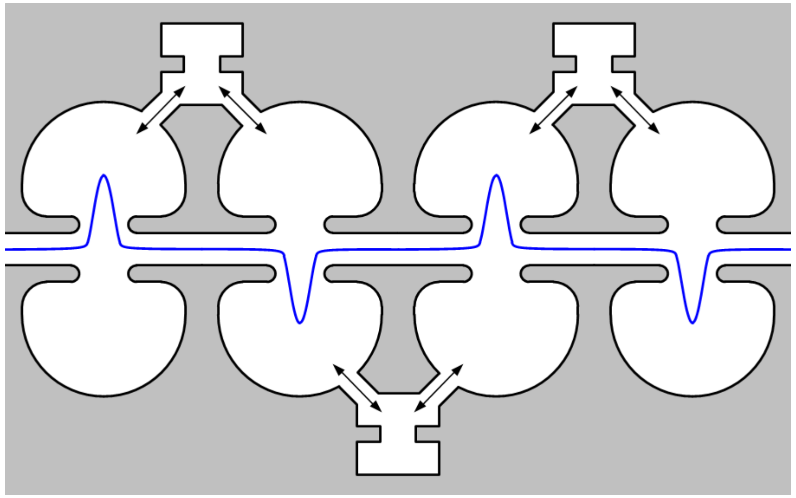
Concentrated field has focusing effect

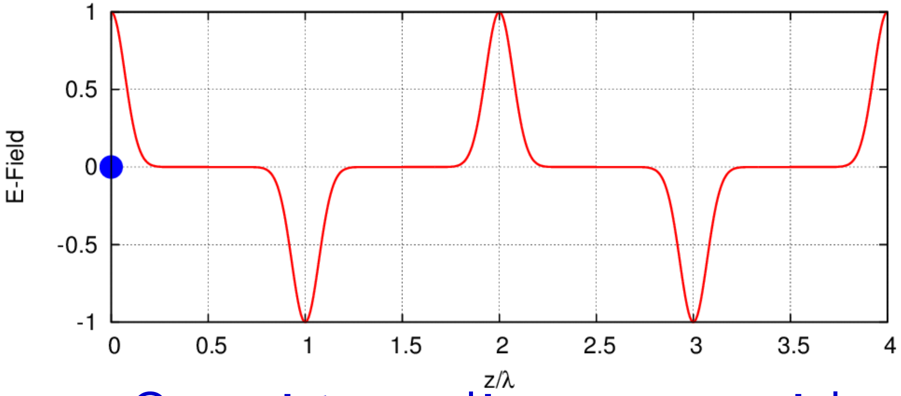
This structure has long drift space

This structure has focusing field.
Long drift space is problem.

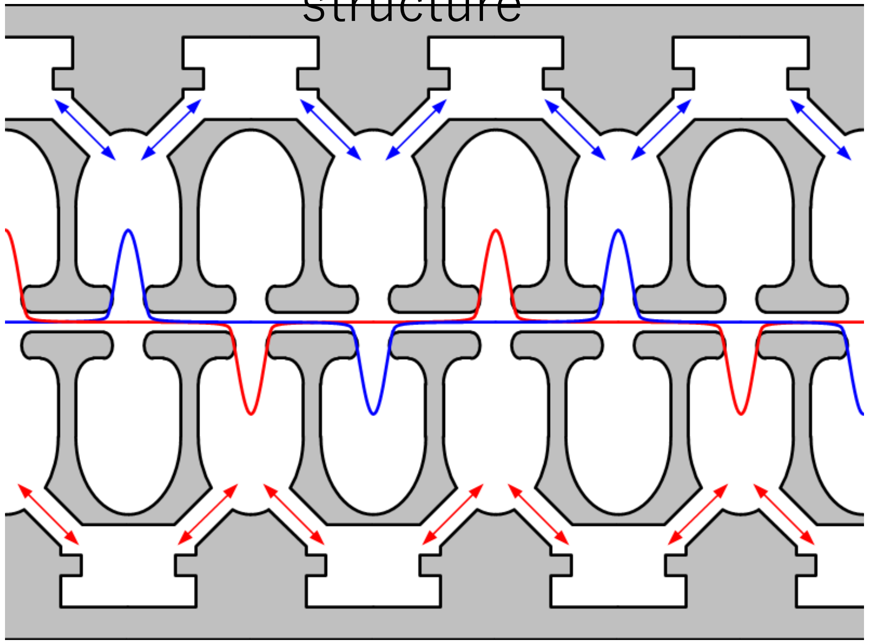
Design of a quasi traveling wave side couple RF gun

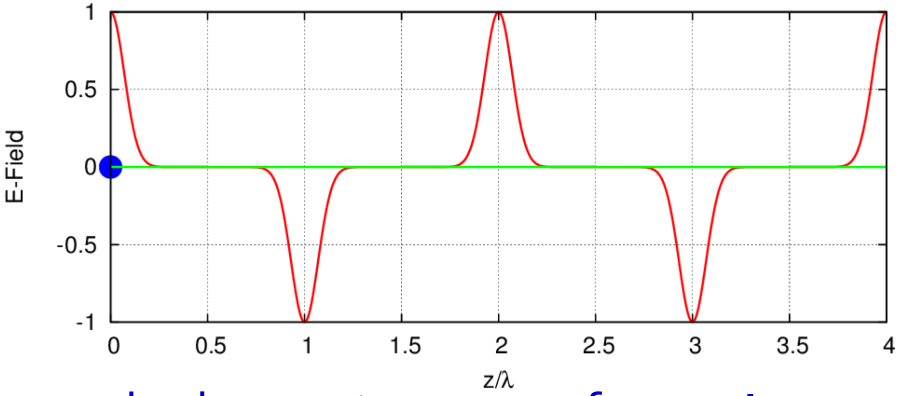
Normal side couple structure





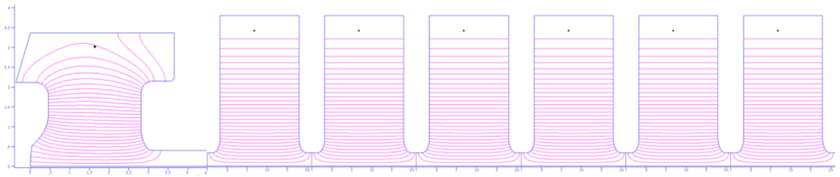
Quasi traveling wave sidecouple structure



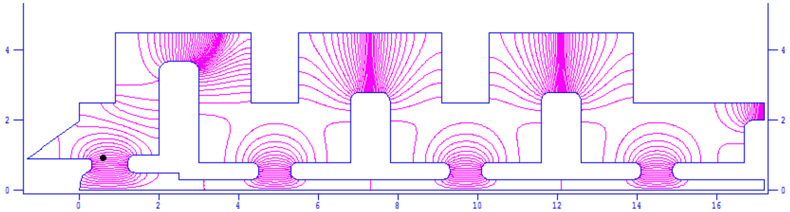


Quasi traveling wave side couple has stronger focusing and accelerated gradient than DAW.

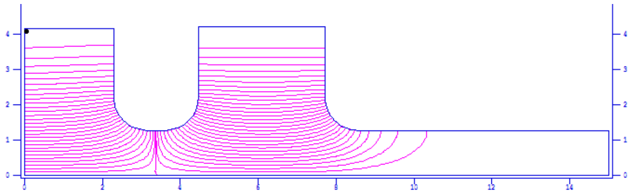
RF-Gun comparison



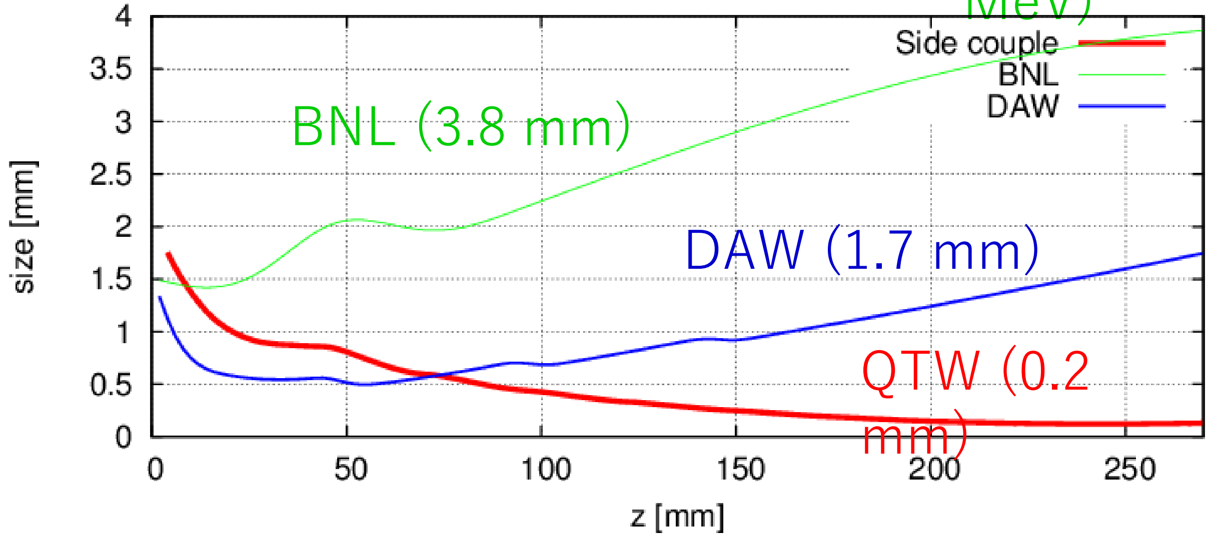
Quasi traveling wave side couple RF gun
(100 MV/m, 6mm-mrad, 13.5 MeV)



DAW-type RF gun
(90 MV/m, 5 mm-mrad, 3.2 MeV)

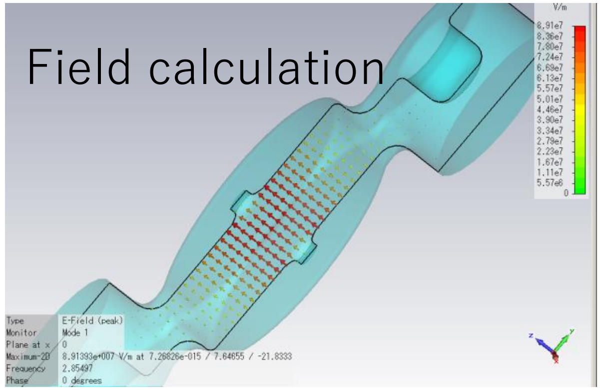


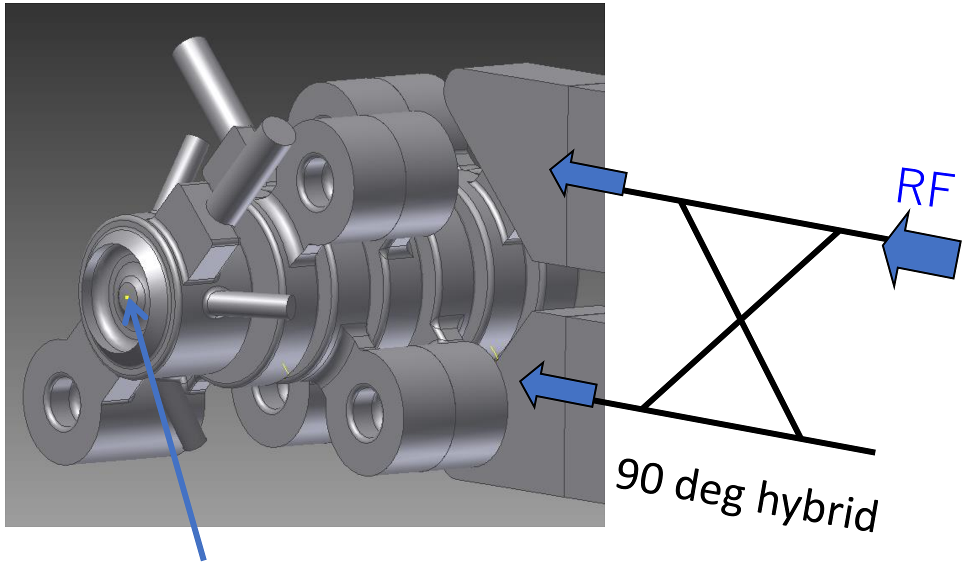
BNL-type RF gun
(120 MV/m, 11.0 mm-mrad, 5.5 MeV)

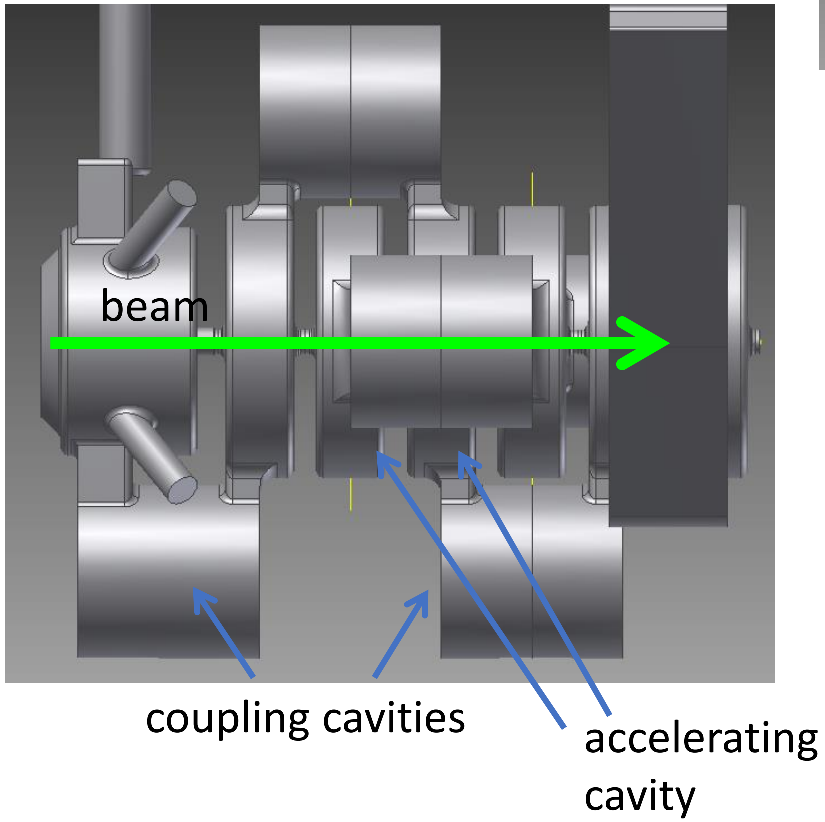


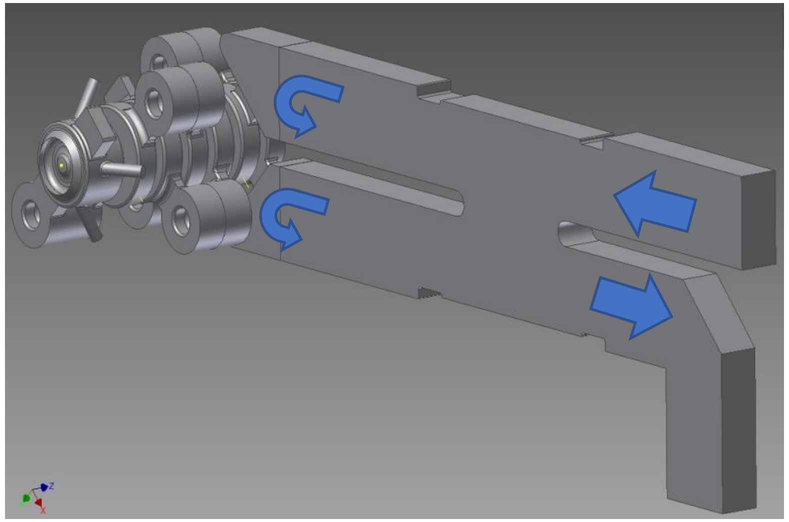
Beam Size

Cavity design



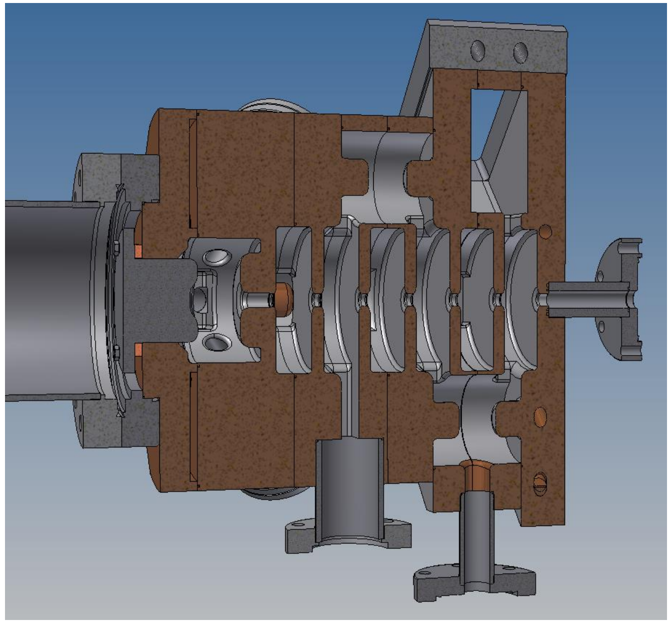


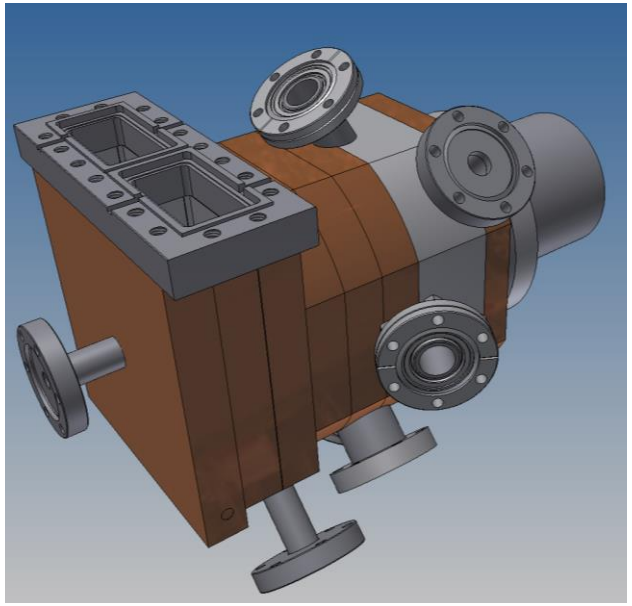


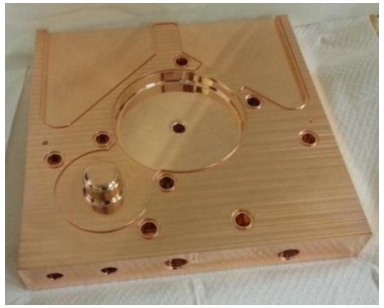


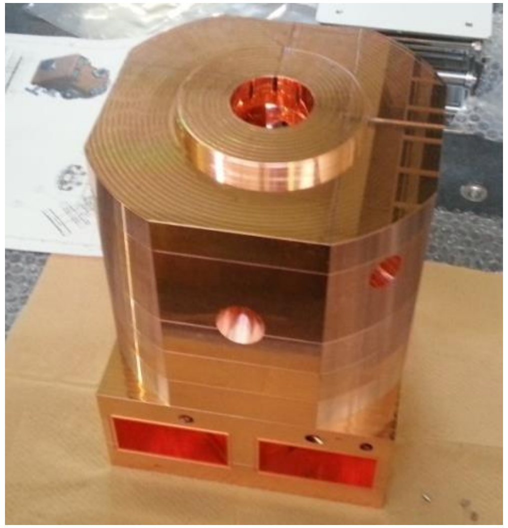
No reflection to klystron

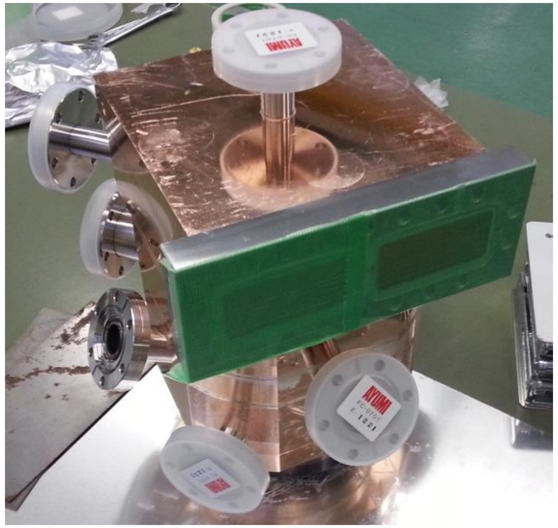
Mechanical design and manufacturing









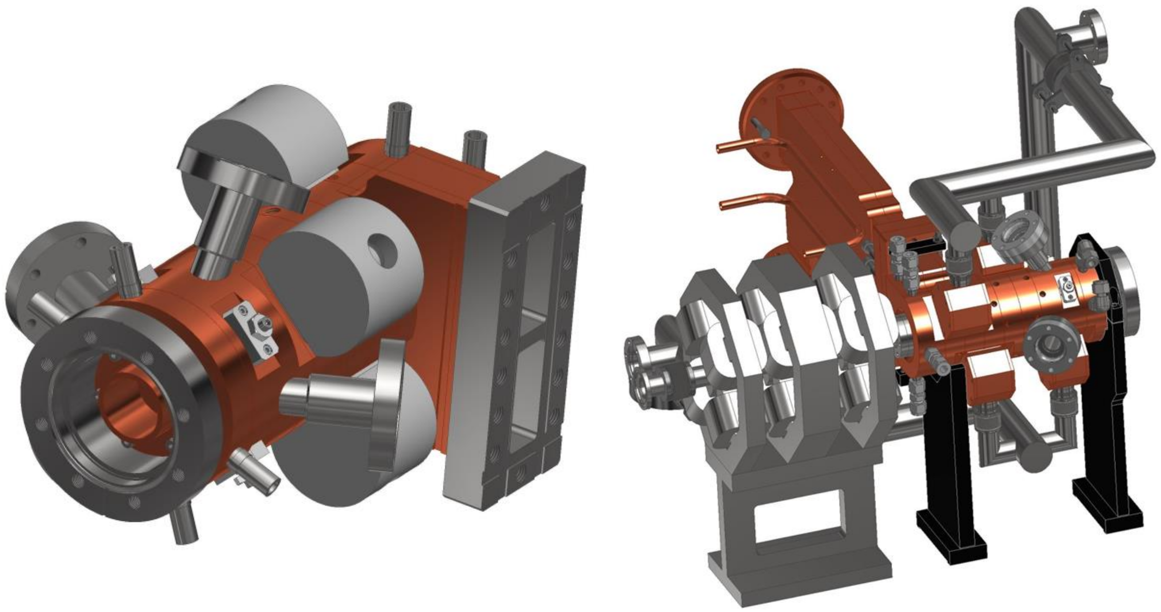


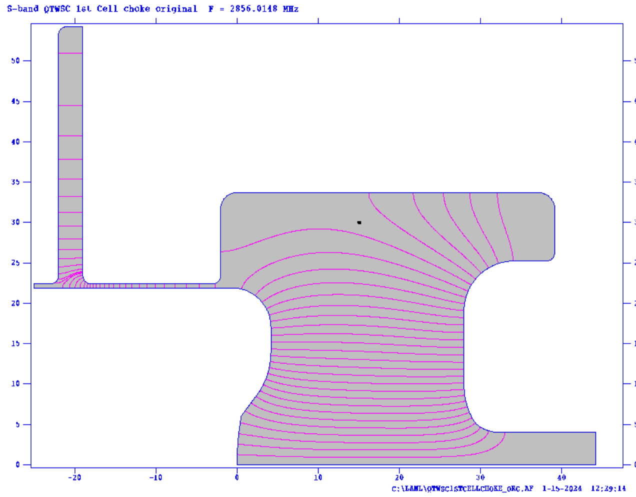
New Quasi-Travelling Wave Side Couple RF-Gun

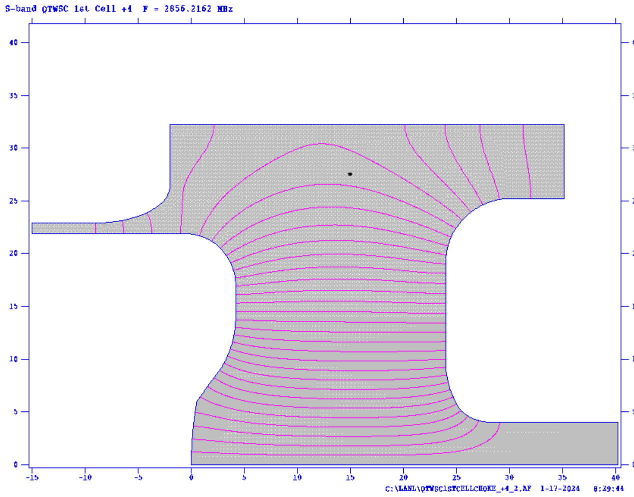
will be installed in next summer

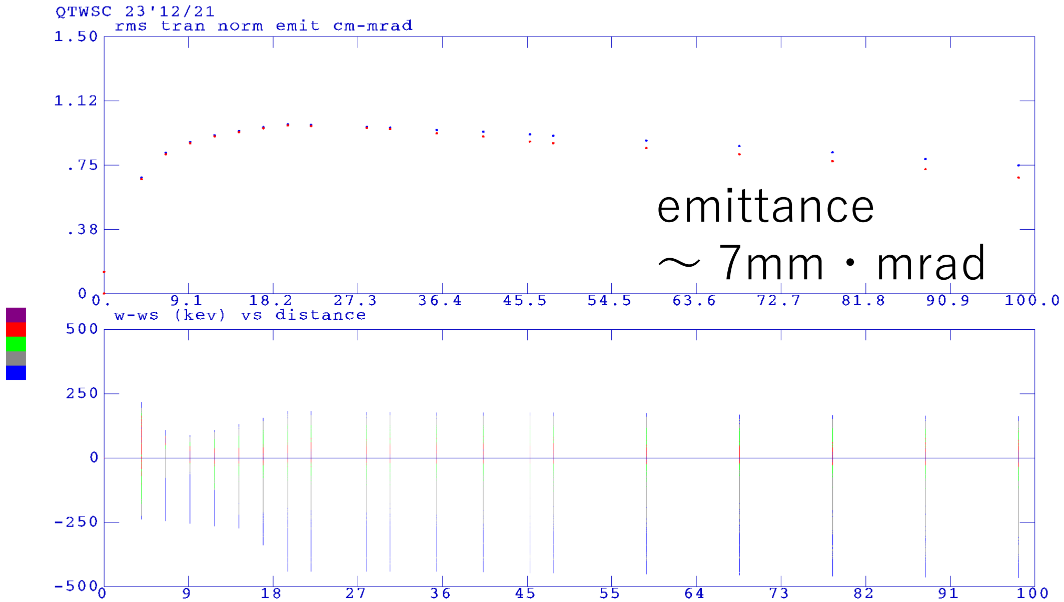
[Current RF-Gun issue]

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







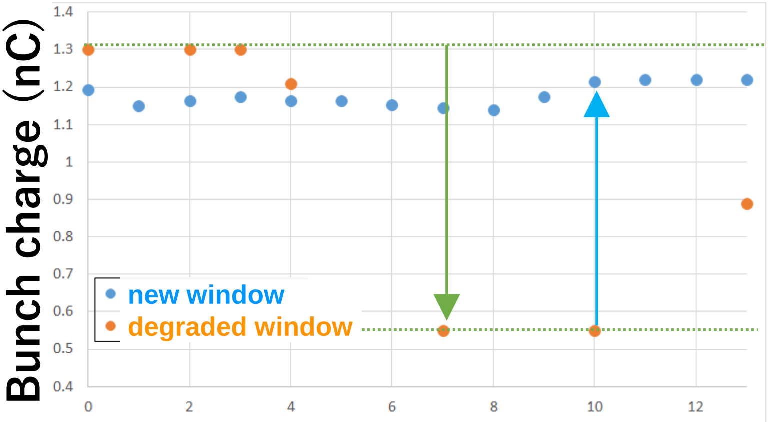


Issue of rf gun laser window degradation

e- beam issue

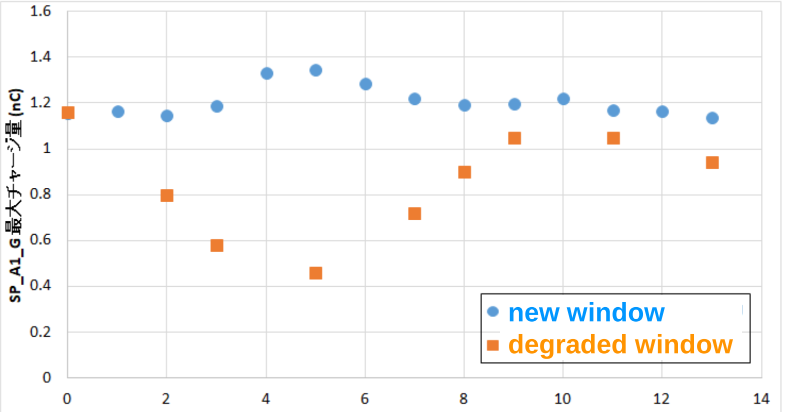
- Long term operation makes rf gun laser windows dirty for both of 1st and 2nd line.
- It decrease the transmittance of laser power through window and bunch charge intensity.
- After replacement of the laser window, the bunch charge intensity is recovered.
- Vacuum ion pump was installed between the 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

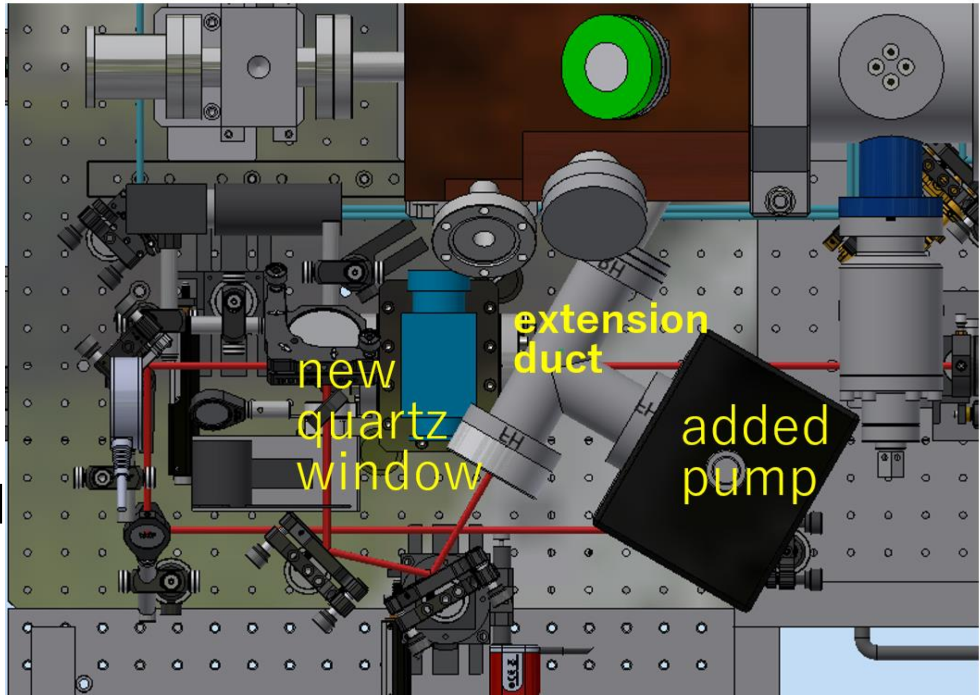


1st-line laser incident position [mm]

e- intensity by 2nd-line laser



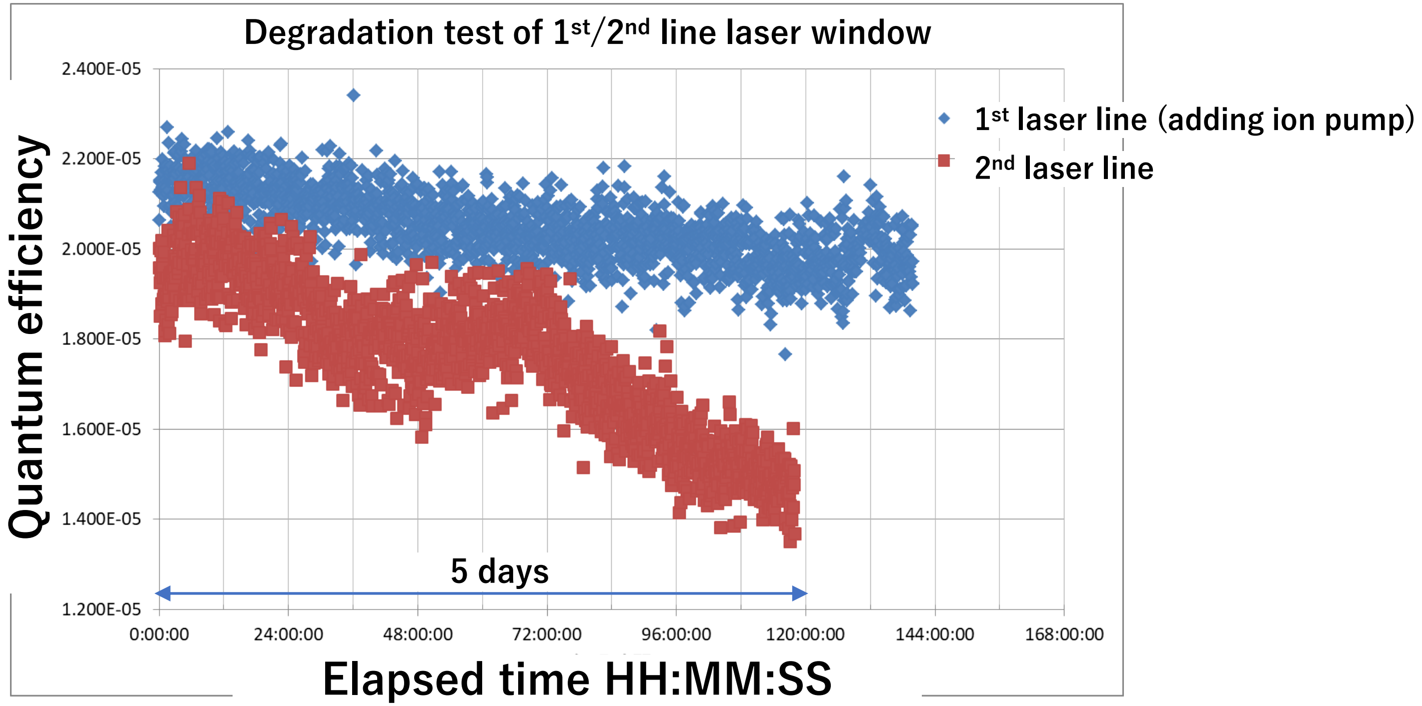
2nd-line laser incident position [mm]



M. Yoshida

Improvement of laser window degradation with ion pump

- 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.



The Single-stage Pulse Stacking Birefringent Filter

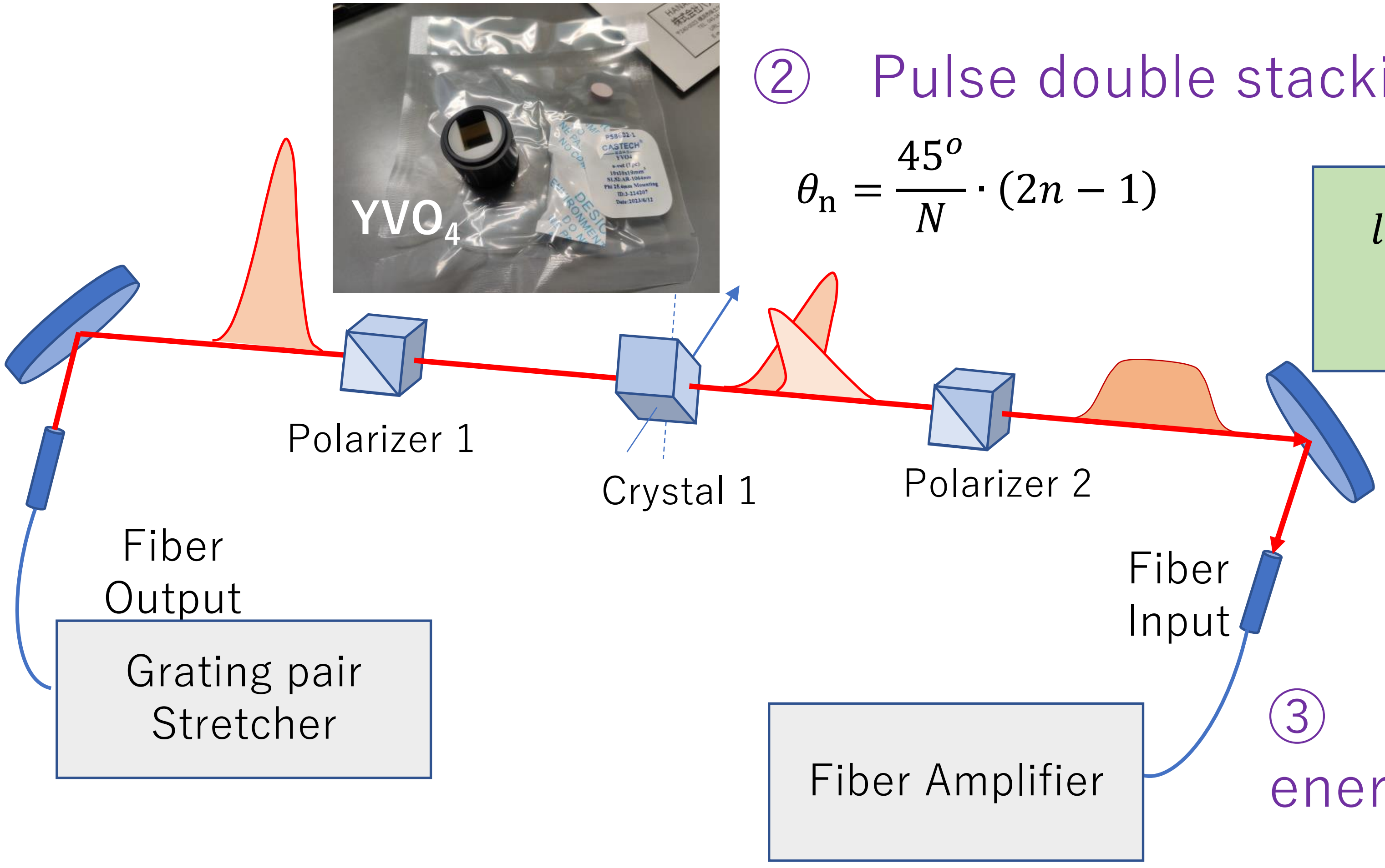
① Stretched pulse width to 18 ps.

② Pulse double stacking.

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

$l_{crystal} = 19\ mm$

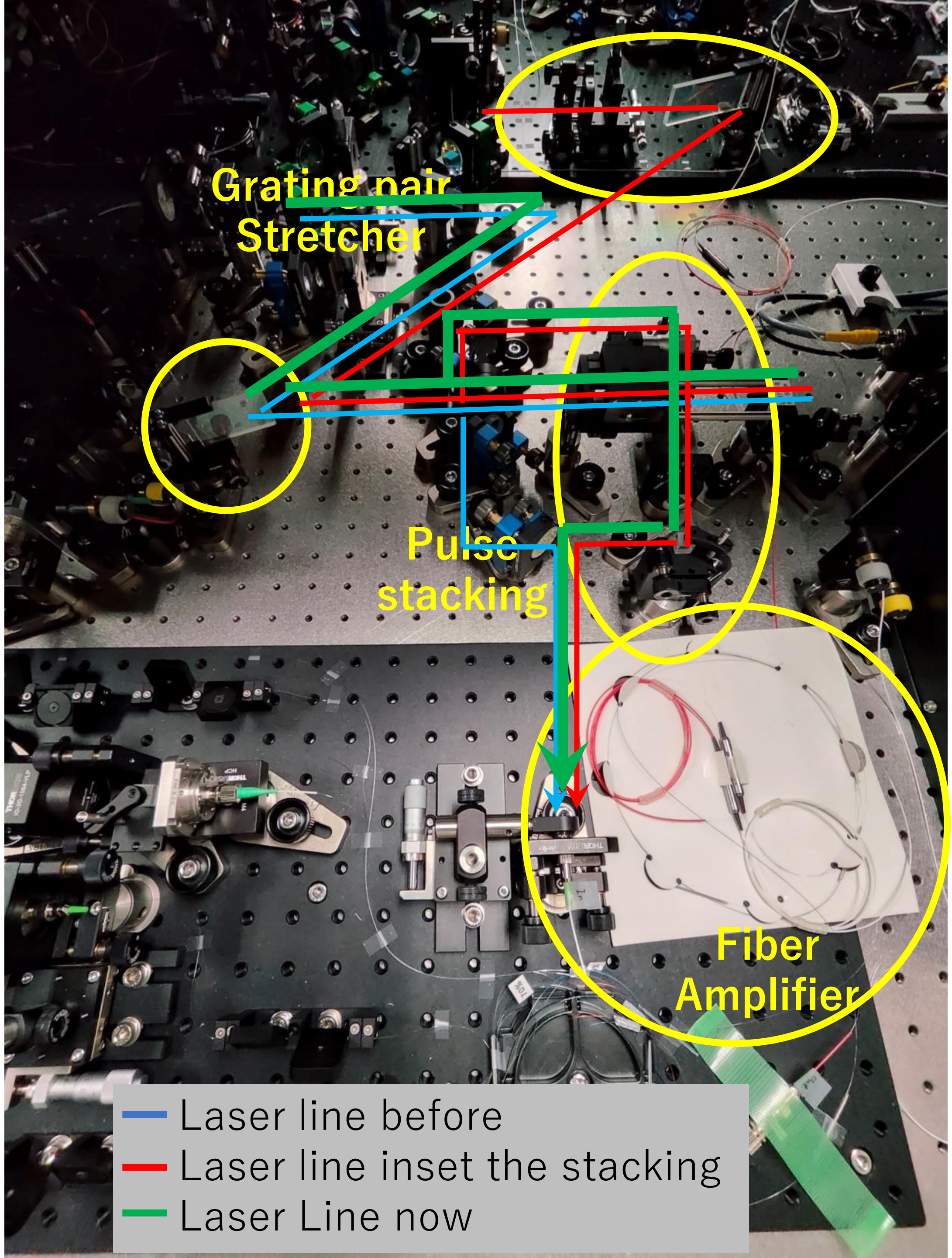
$\theta_1 = 45^o$



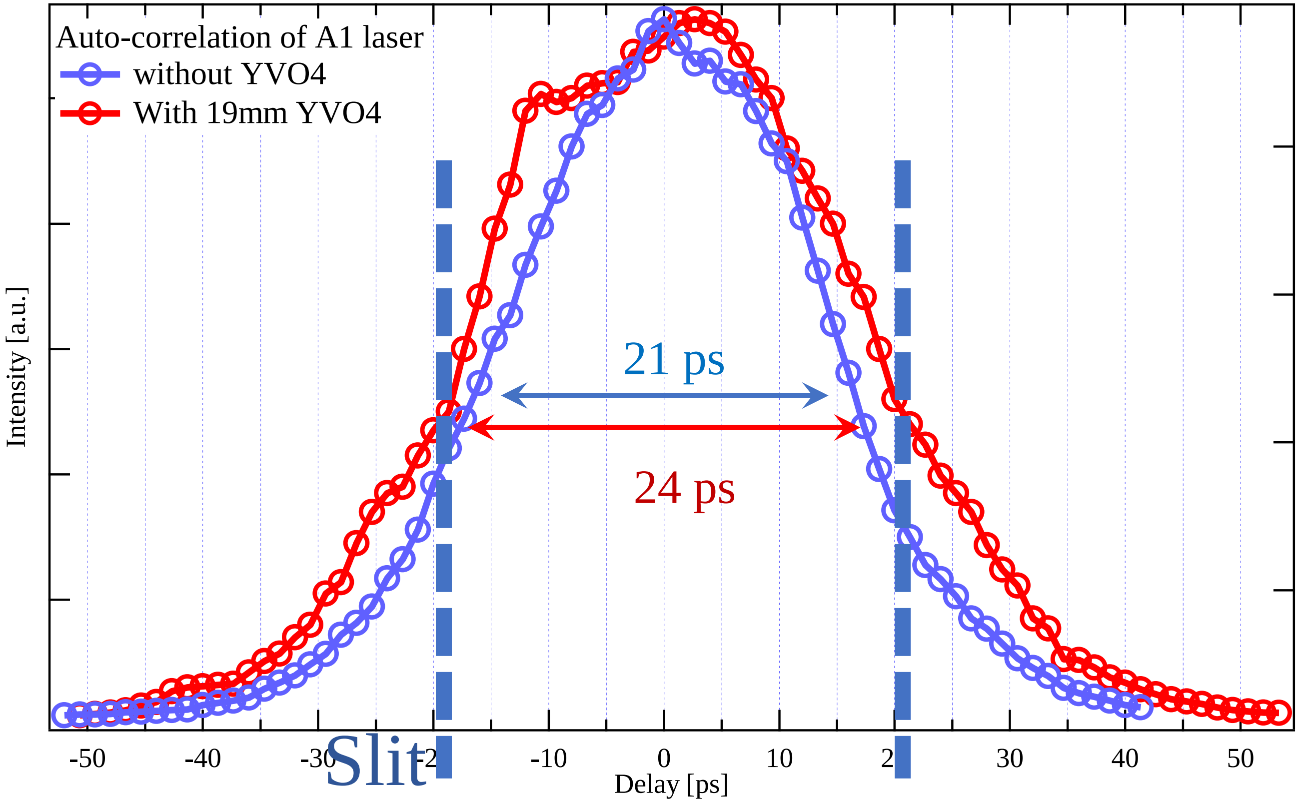
③ Compensate the energy loss.

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

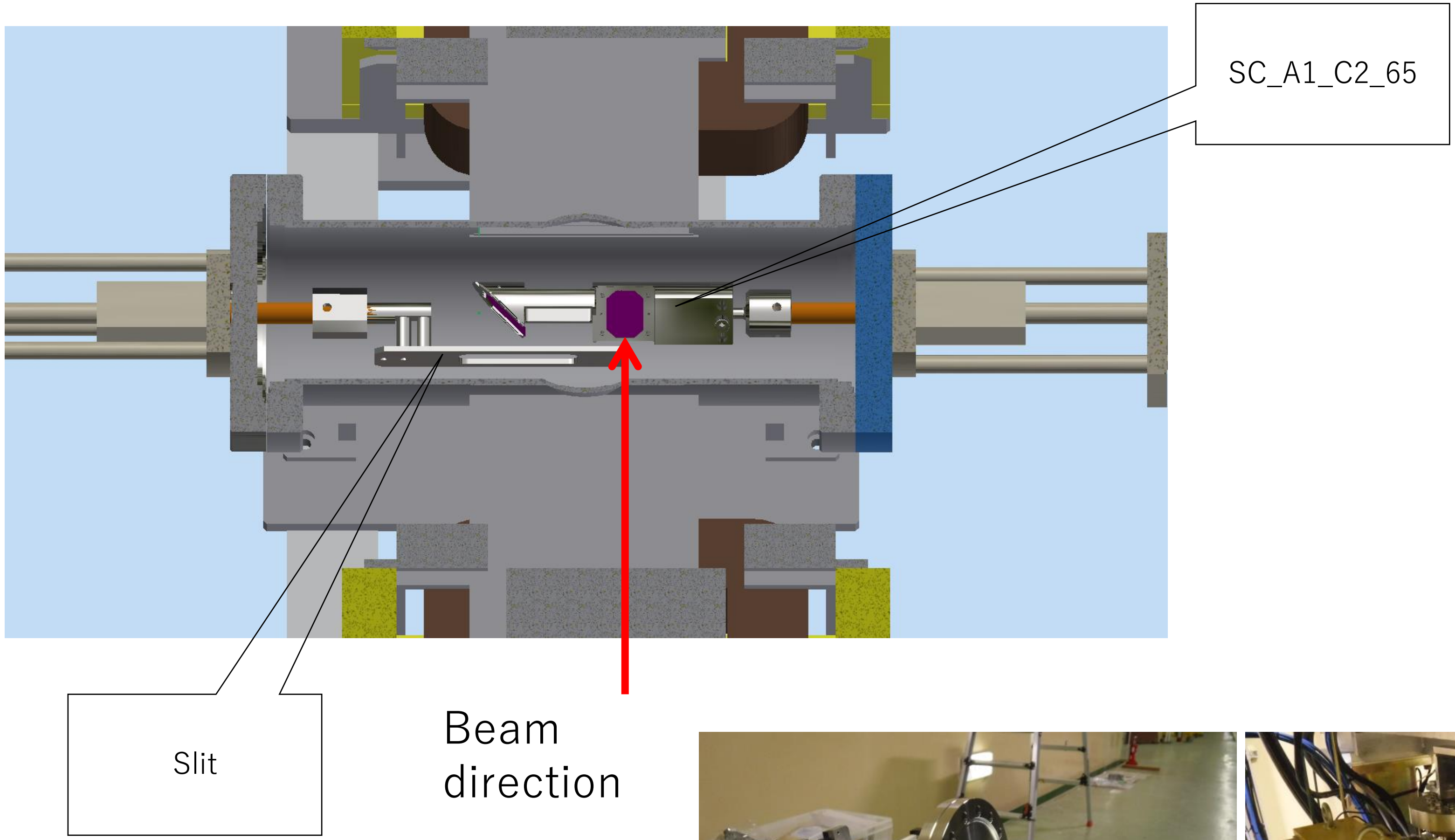
Setup diagram

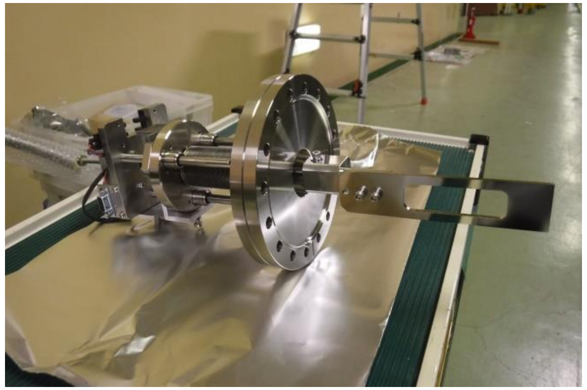


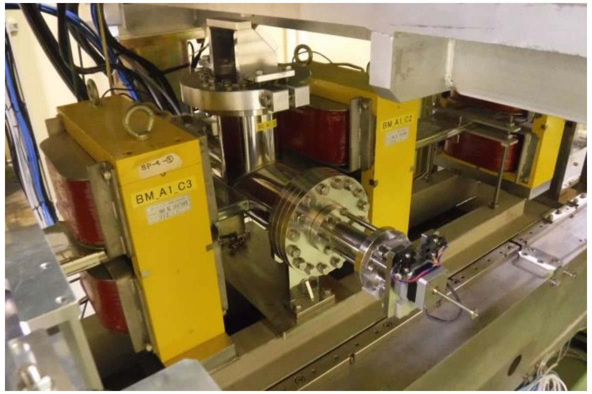
- The new fiber amplifier compensate the energy loss of the pulse stacking.
- After the modification, there is no impact on main laser amplification efficiency and electron generation rate.
- Due to the optical path expansion, it is necessary to adjust the phase delay of the SOA pulse picker and EO pulse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



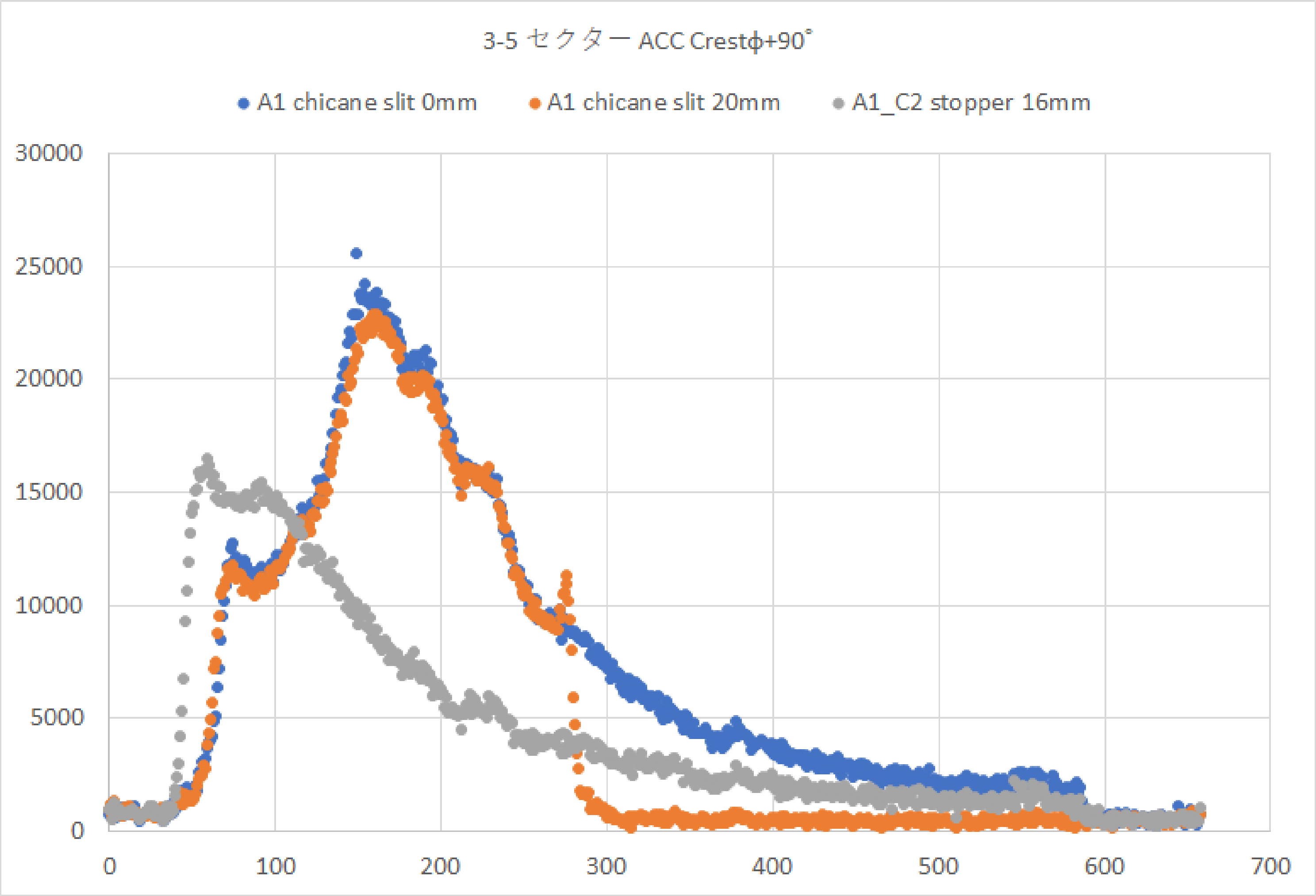
Chiccane slit





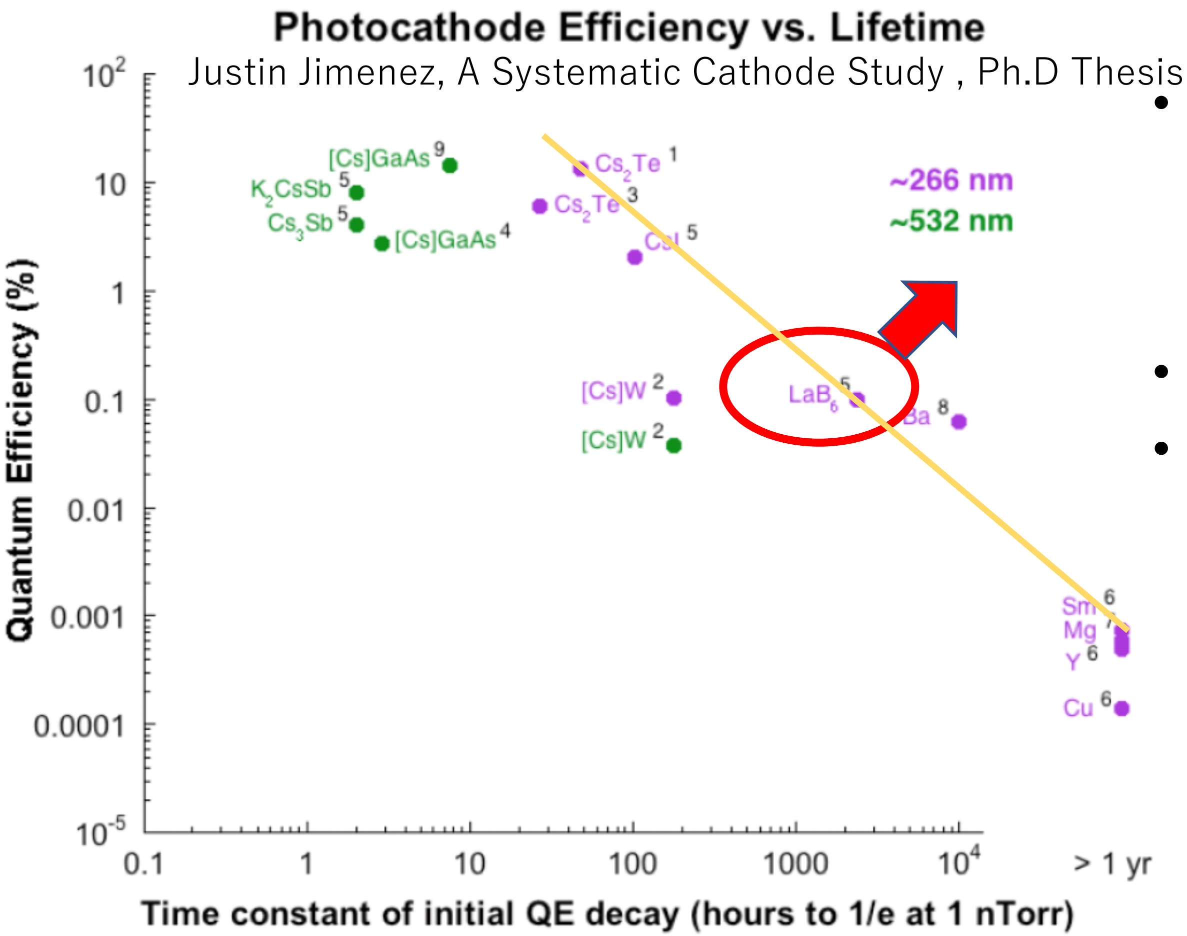


61 H (SB-3～5 +90°)


3-5 セクター ACC Crestϕ+90˚
A1 chicane slit 0mm
A1 chicane slit 20mm
A1_C2 stopper 16mm
30000
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700

Cathode : Advantage of metal composite cathode (LaB_6 or Ir_5Ce)

Justin Jimenez, A Systematic Cathode Study , Ph.D Thesis, Monterery, California



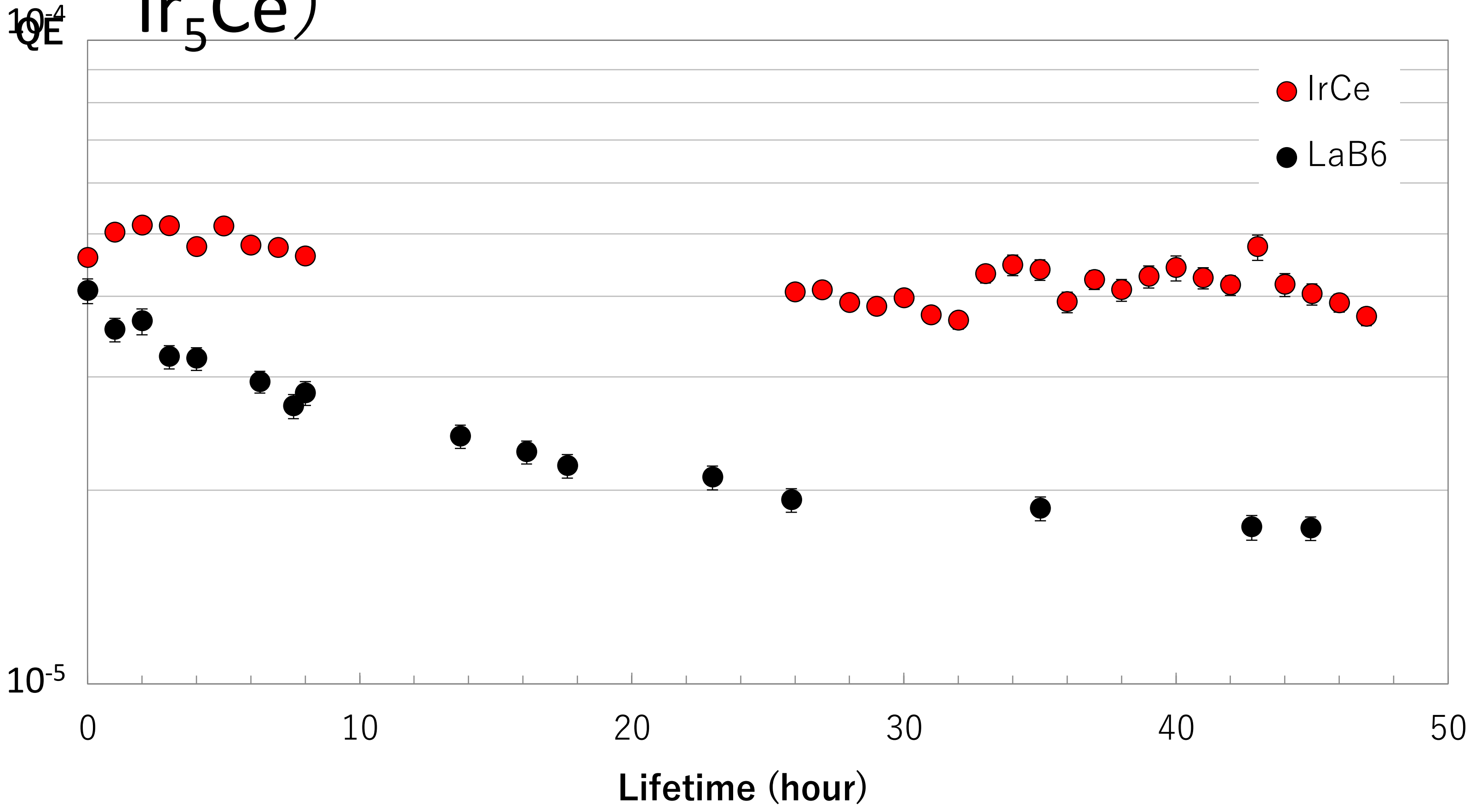
The thermocathodes can also be used as photoemitters [13]. LaB₆ should be noted as a promising photoemitter [14], which has a quantum yield of about 10^{-3} at a laser wavelength of 266 nm and $4 \cdot 10^{-4}$ at 532 nm for face (100).

- Low Workfunction (2.8 eV) and enough QE (10^{-4}) at room temperature.
- Inactive in air
- Recover by heating or laser cleaning

Best choice for SuperKEKB 5 nC long time operation

Physica Scripta. Vol. T71, 39-45, 1997.
Cathodes for Electron Guns
G. I. Kuznetsov

Lifetime measurement（LaB_6 / Ir_5Ce）

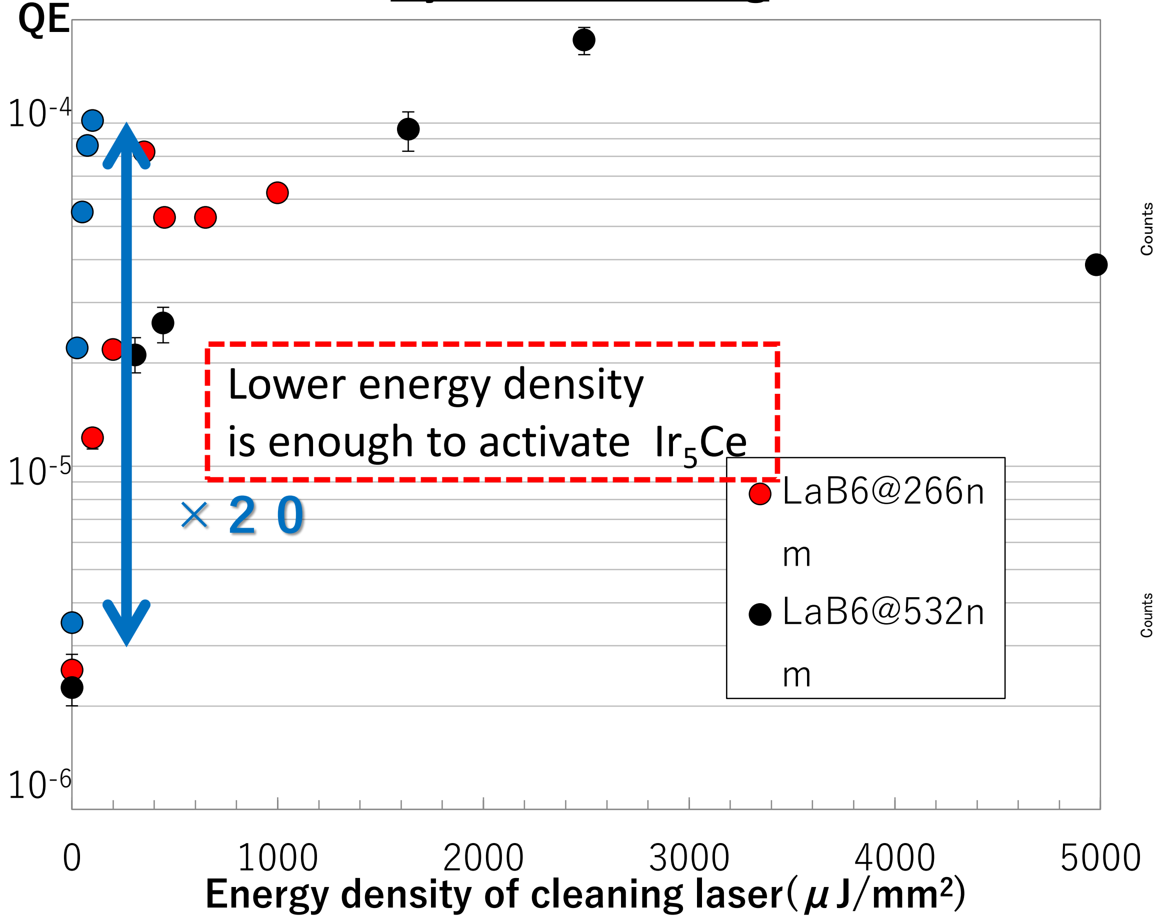


Conditio n

Continuous 00μJ@266nm)
Irradation => 2.5 nC emission

Ir_5Ce Cathode

Quantum efficiency improvement by Laser cleaning

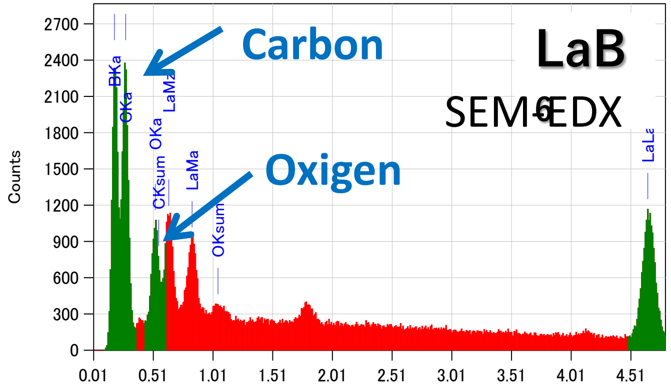


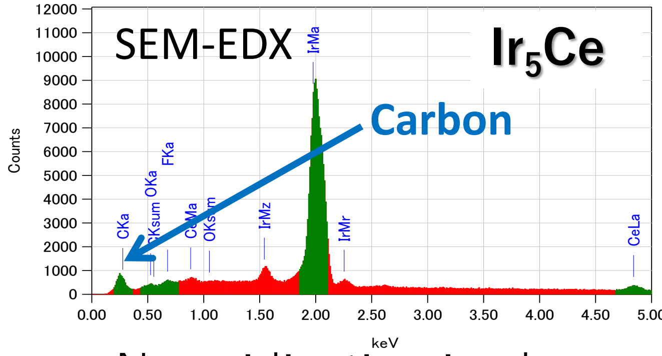
Condition

HV =

Vacu)$^{-6}$ Pa

Cleaning time ; 10 min





No oxidization is observed

Non activation

QE = 5.00×10^{-6}

×20

Laser cleaning

Max **QE = 1.00×10^{-4}**

[SUPER-KEKB e Linac]

Laser Power ; 233μJ/pulse

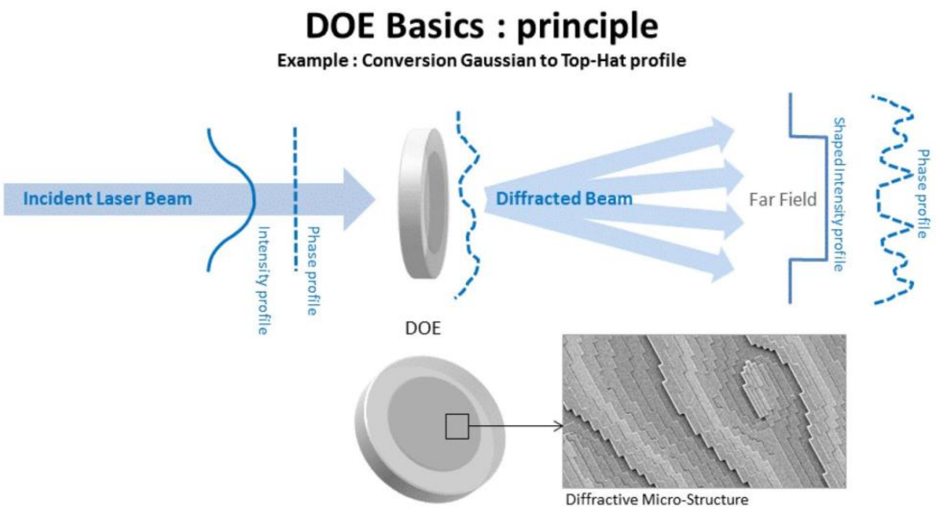
(λ=266nm)

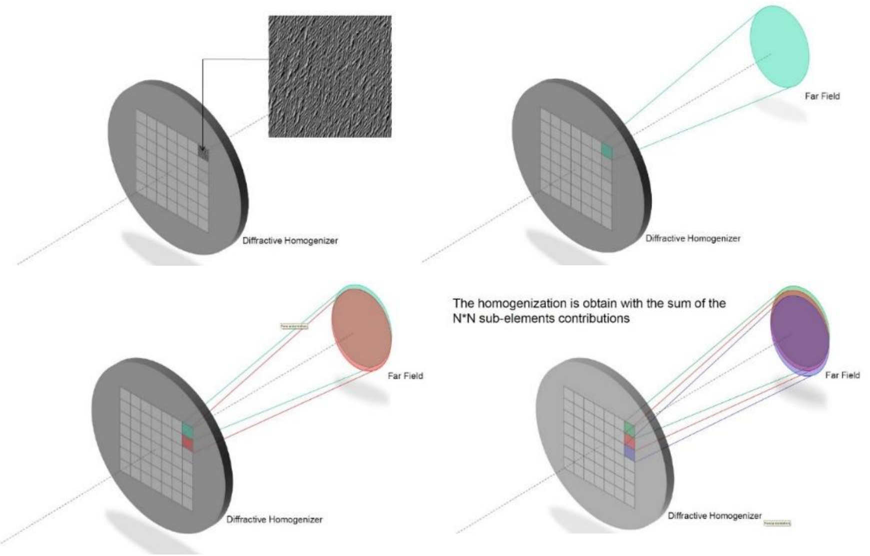
Target value ; 5nC

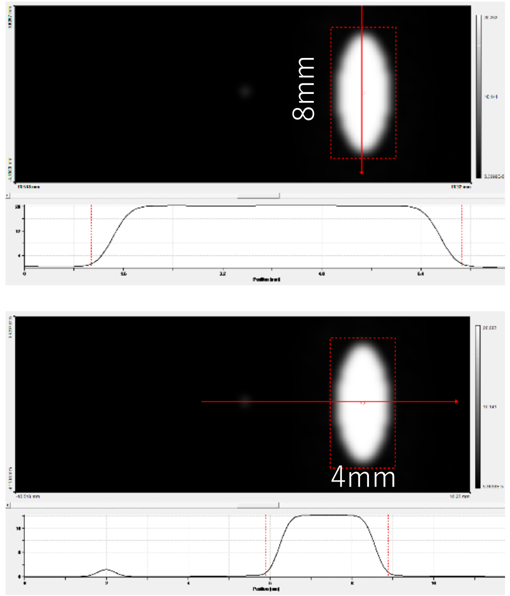
Laser System for RF Gun

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



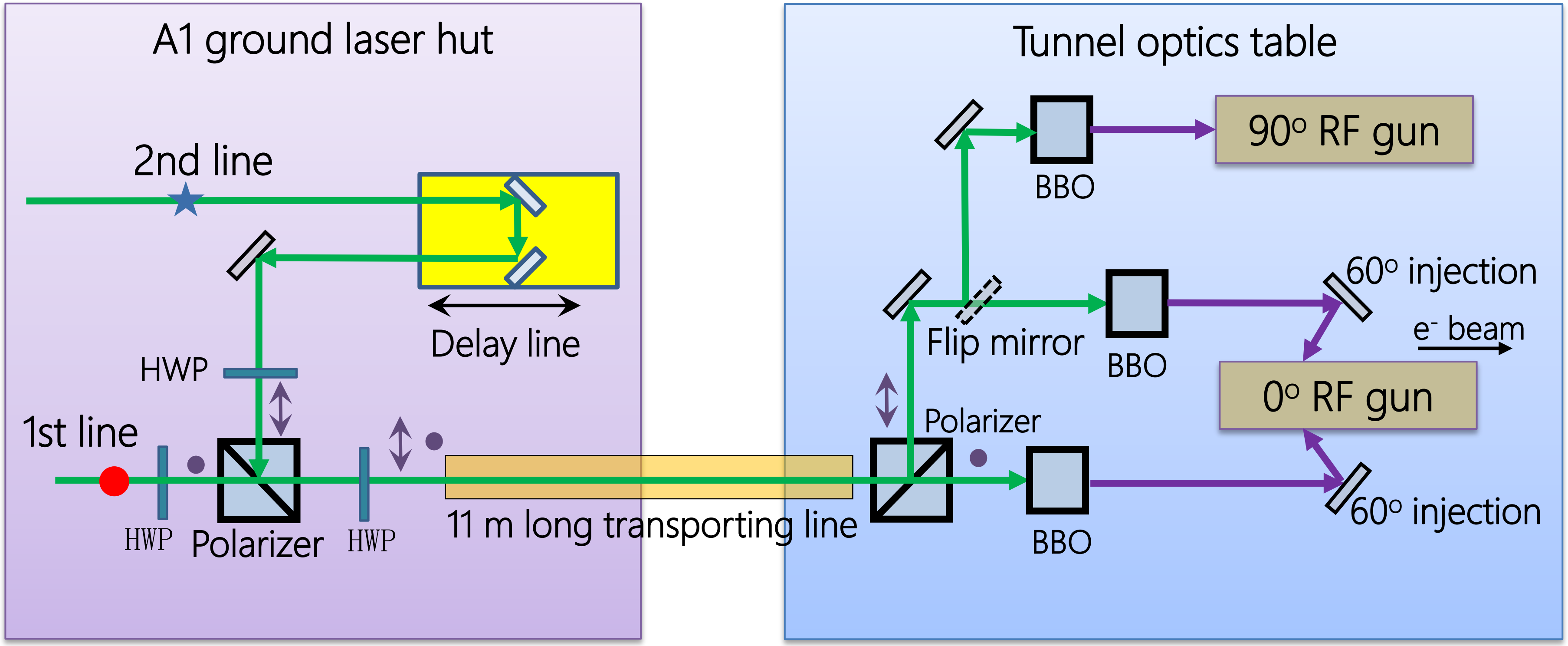




Laser System for RF Gun

Two Laser Beams Injection Mode for Better Beam Quality

Simple illustration for 2 lasers incidence (out of ratio)

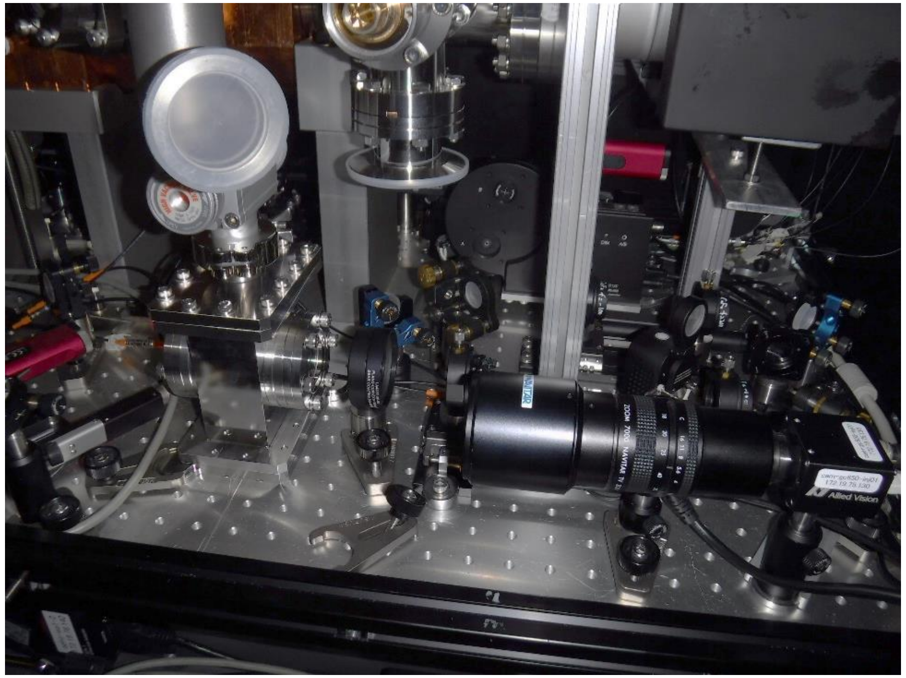


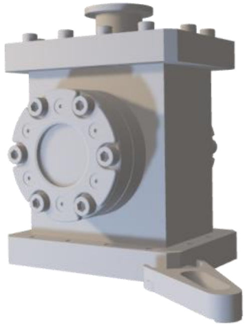
● Laser with vertical polarization, ↕ laser with horizontal polarization, HWP: half wave plate

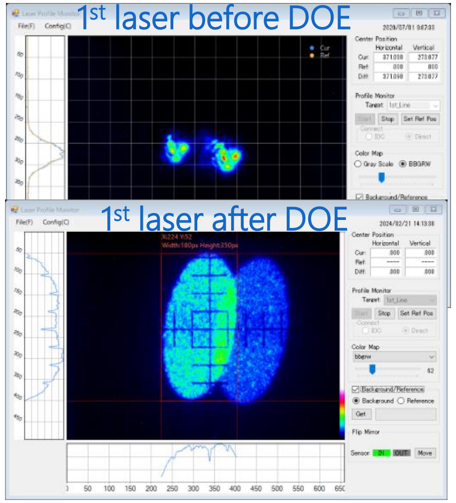
Laser System for RF Gun

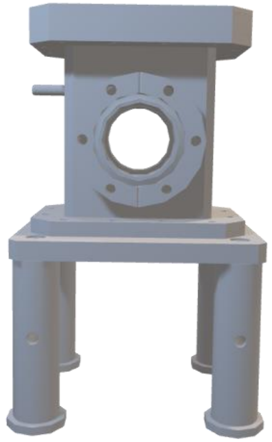
Spatial Reshaping for Lower Emittance

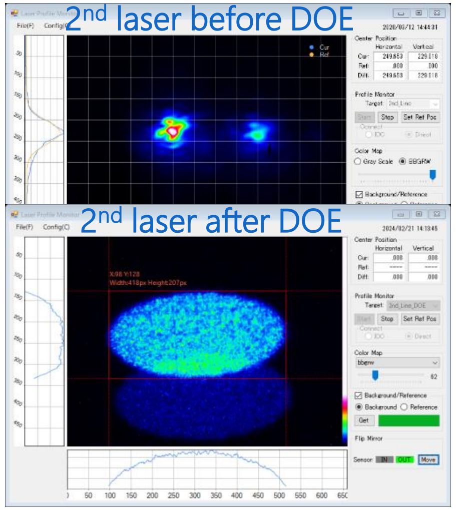
- Application DOE in 1st laser line from 2020c and in 2nd laser line from 2021c
- Elliptical flat-top spatial distribution on the surface of photocathode (LA-8mm SA-4mm) for lower emittance e^- generation and less discharge







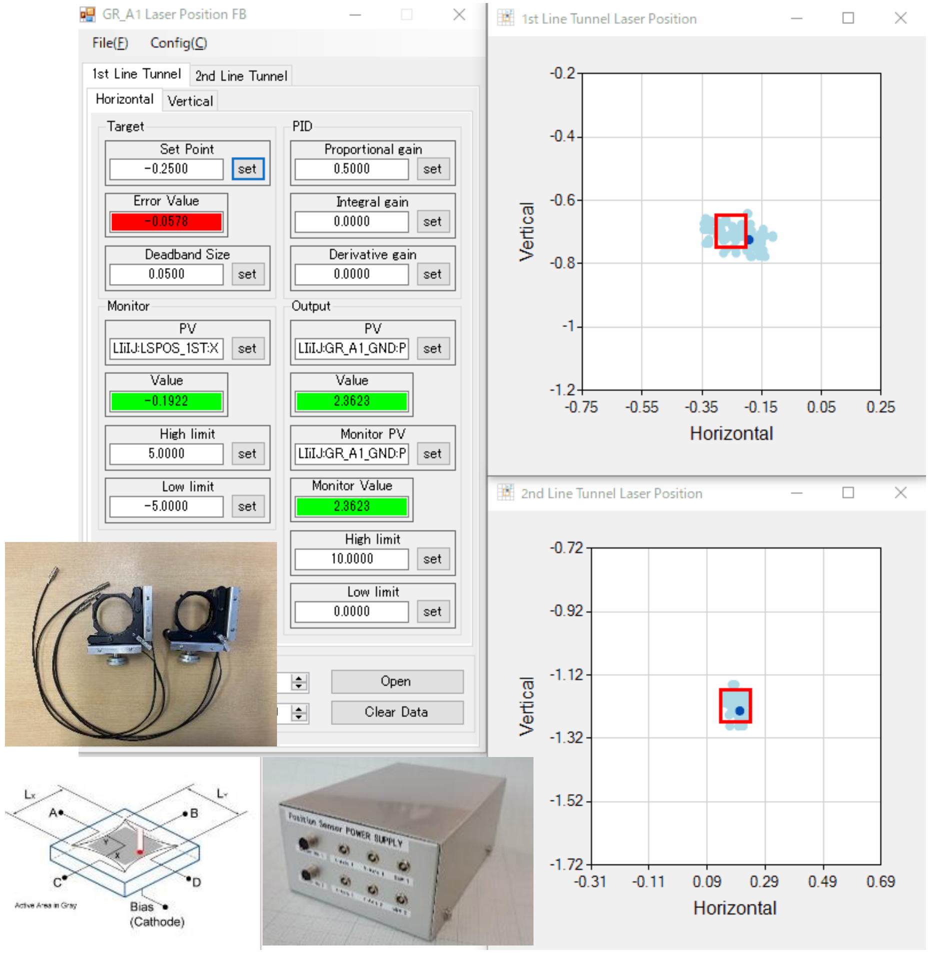




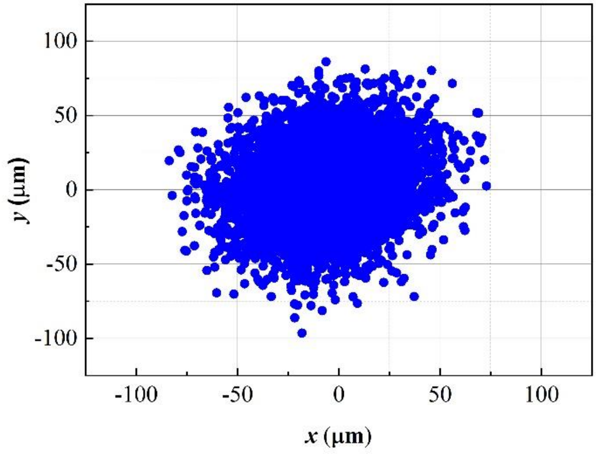
Laser System for RF Gun

Better Laser Pointing Stability for Stable and Long-term Operation

Laser position feedback system

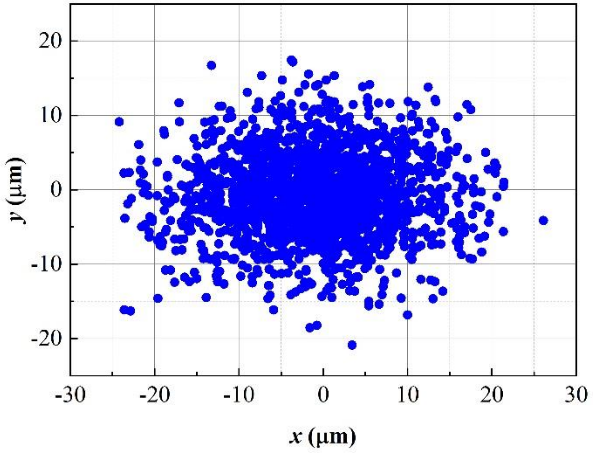


Laser pointing stability at virtual photocathode



Measured in 2019.06
without DOE & laser
position feedback

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



Measured in 2021.06
with DOE & laser
position feedback

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