RF Gun

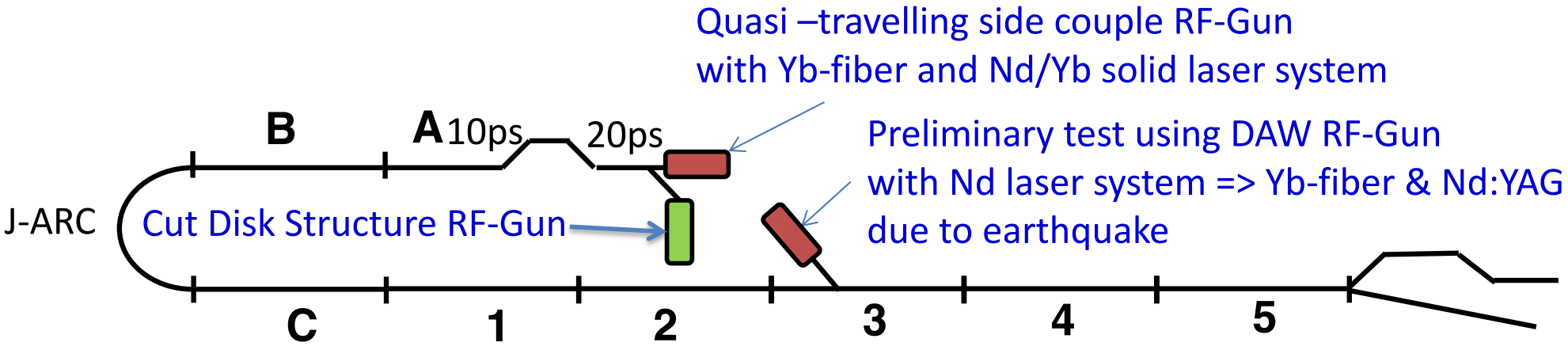
SuperKEKB review @ 14, Mar, 2018

SuperKEKB upgrade for low emittance electron beam

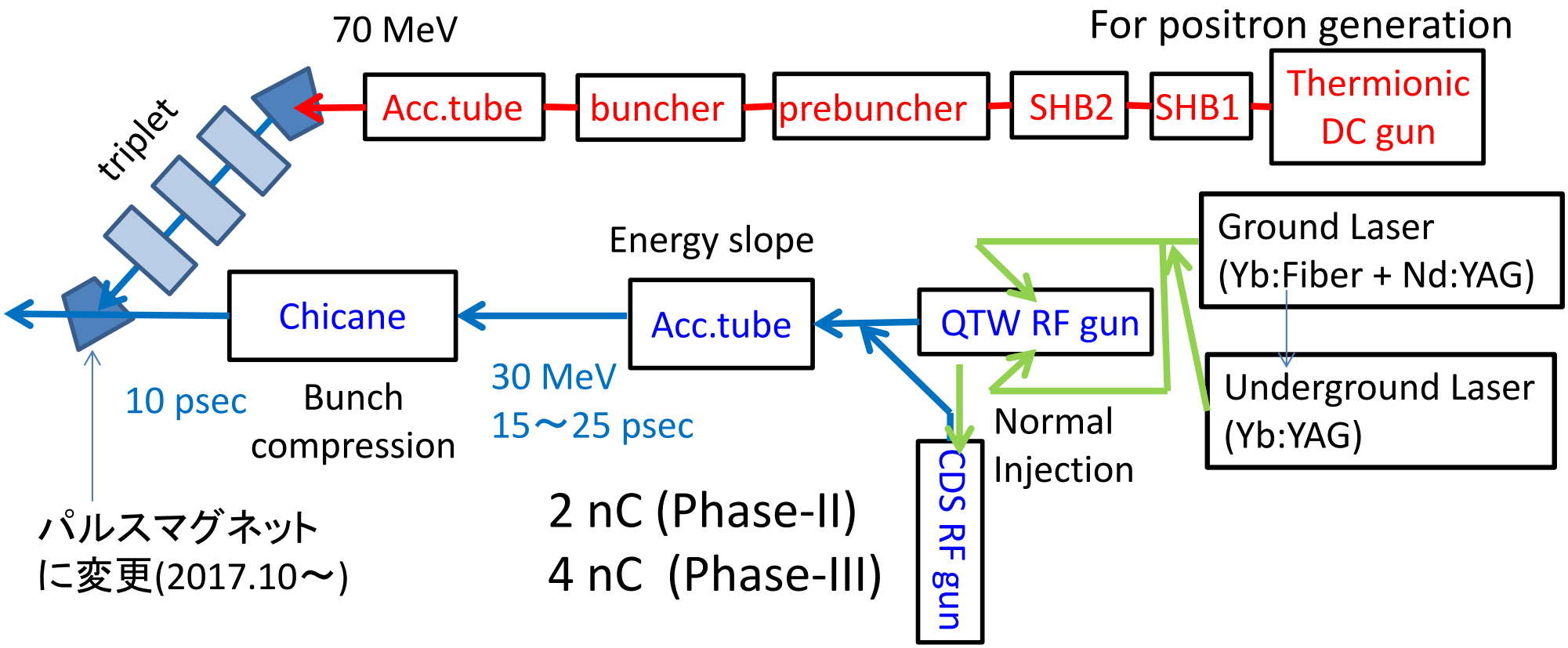
High charge &low emittance is required for SuperKEKB.

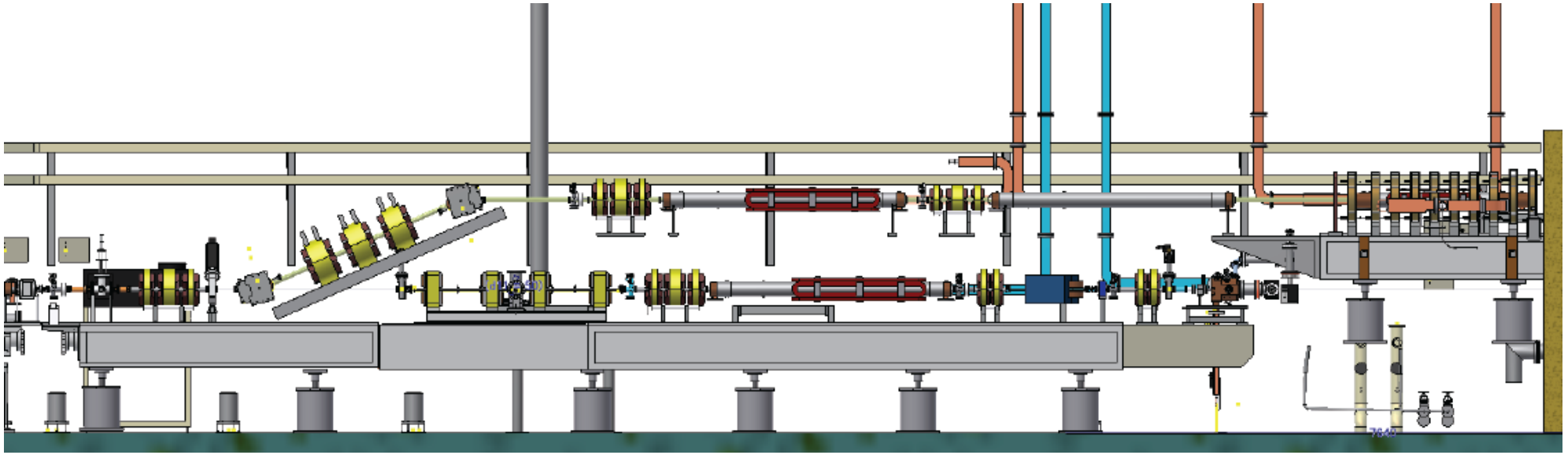
	KEKB obtained (e+ / e-)	SuperKEKB Phase-II required (e+ / e-)	SuperKEKB Phase-III required (e+ / e-)
Beam energy	3.5 GeV / 8.0 GeV	4.0 GeV / 7.0 GeV	4.0 GeV / 7.0 GeV
Bunch charge	e- → e+ / e- 10 → 1.0 nC / 1.0 nC	e- → e+ / e- 10 → 0.5 nC / 1.0 nC	e- → e+ / e- >10? → 4.0 nC / 4.0 nC
Beam emittance (γε)[1σ]	2100 μm / 300 μm	40 μm / 150 μm	15 μm / 20 μm

4 nC 10 mm-mrad electron beam generated by RF gun.
+ 10mm-mrad emittance preservation is required.



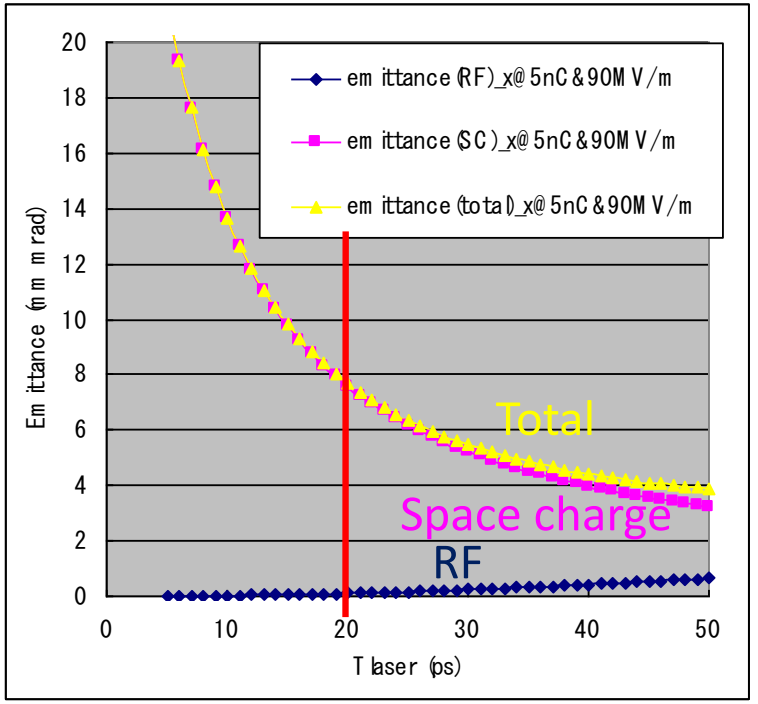
Injector configuration





RF-Gun for 5 nC

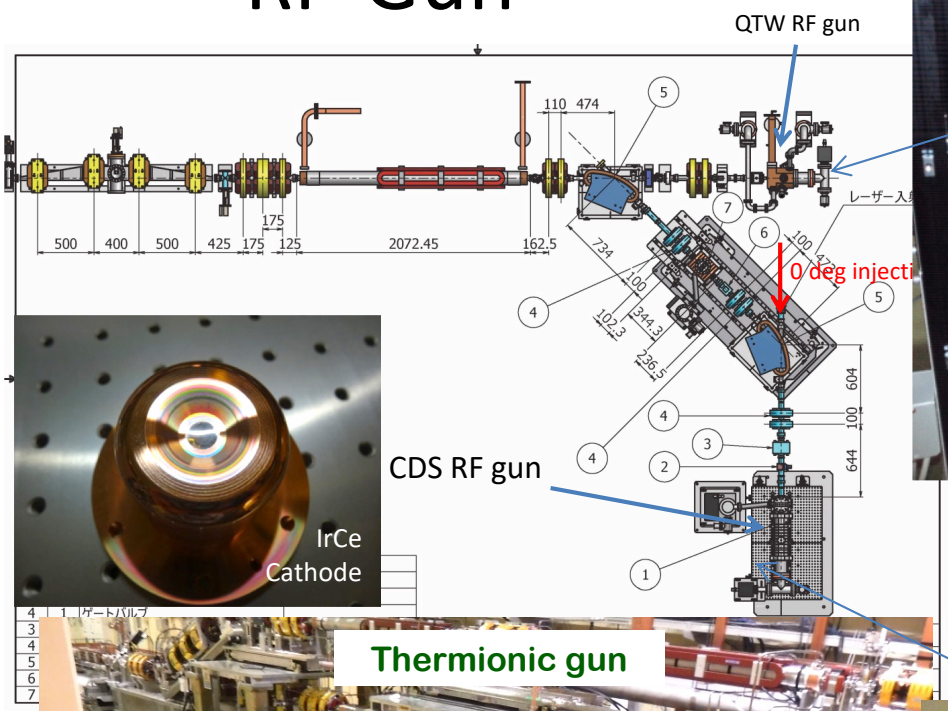
- Space charge is dominant.
  - Longer pulse length : 20 - 30 ps
- Stable operation is required.
  - Lower electric field : < 100MV/m
- Focusing field must be required.
  - Solenoid focus causes the emittance growth.
  - **Electric field focus preserve the emittance**.



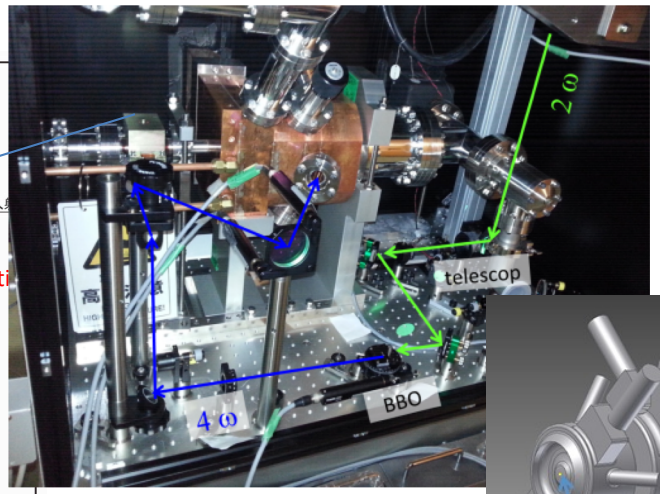
Epaxial coupled cavity : BNL

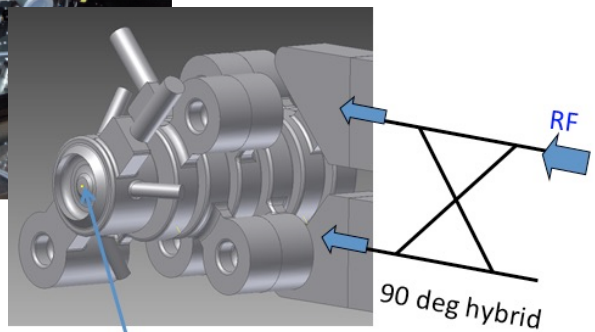
Annular coupled cavity : Disk and washer / Side couple

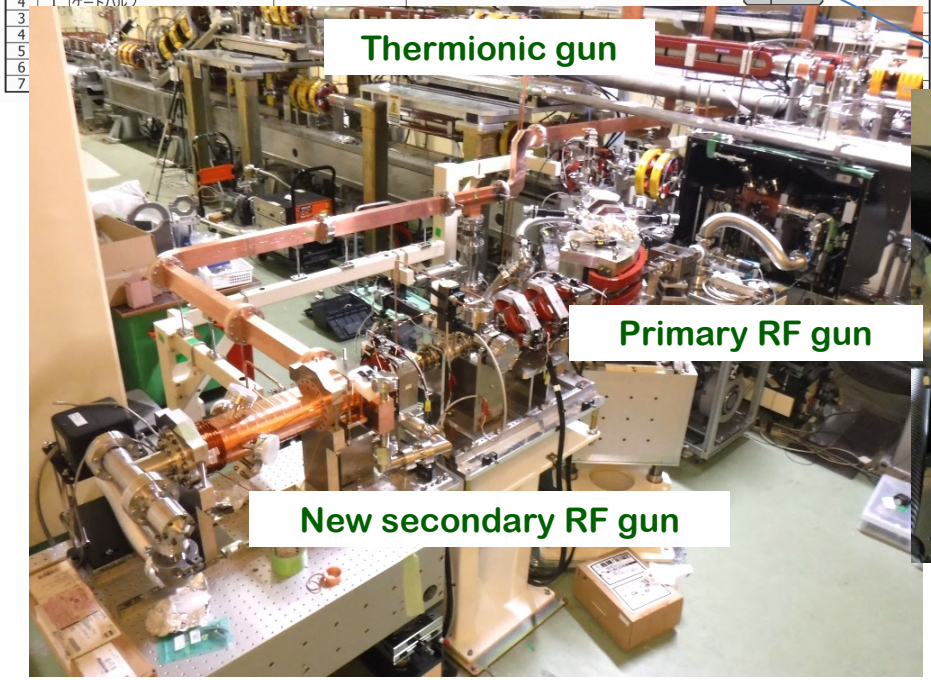
RF-Gun



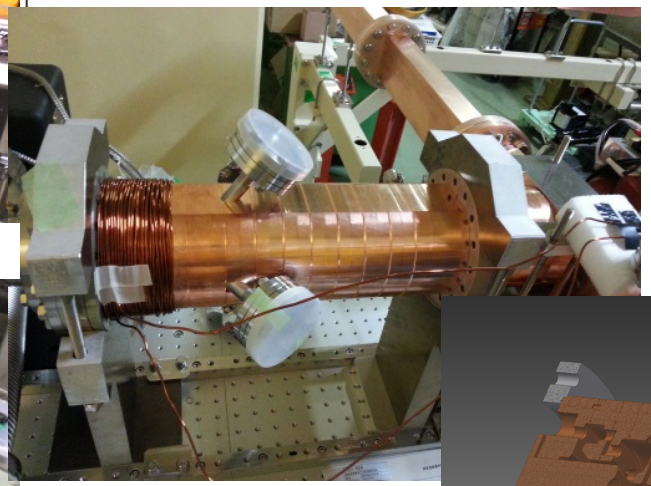
0-deg QTW RF gun

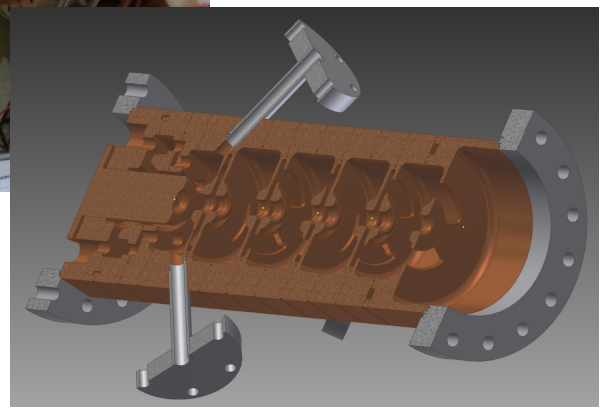






90-deg CDS RF gun





S-band RF-Gun development strategy for SuperKEKB

- Cavity : Strong electric field focusing structure
  - **Disk And Washer (DAW)** => 3-2
  - **Quasi Traveling Wave Side Couple => A-1**
  - **Cut Disk Structure => A-1 90 deg line and normal laser injection**

  => Reduce beam divergence and projected emittance dilution
- Cathode : Long term stable cathode
  - Middle QE (QE=10^{-4}～10^{-3} @266nm) and long lifetime
  - Solid material (no thin film) => Metal composite cathode

  => Started from LaB_6 (short life time)

  => **Ir_5Ce has very long life time with QE>10^{-4}** @266nm
- Laser : Stable laser without/with temporal manipulation
  - LD pumped laser medium
    - Nd doped solid laser => 3-2
    - **Yb doped fiber and Nd/Yb solid hybrid laser** => A-1 ground/underground
  - **Both side irradiation to QTW**
  - Temporal manipulation => posteponded until Phase-III

    => Minimum energy spread

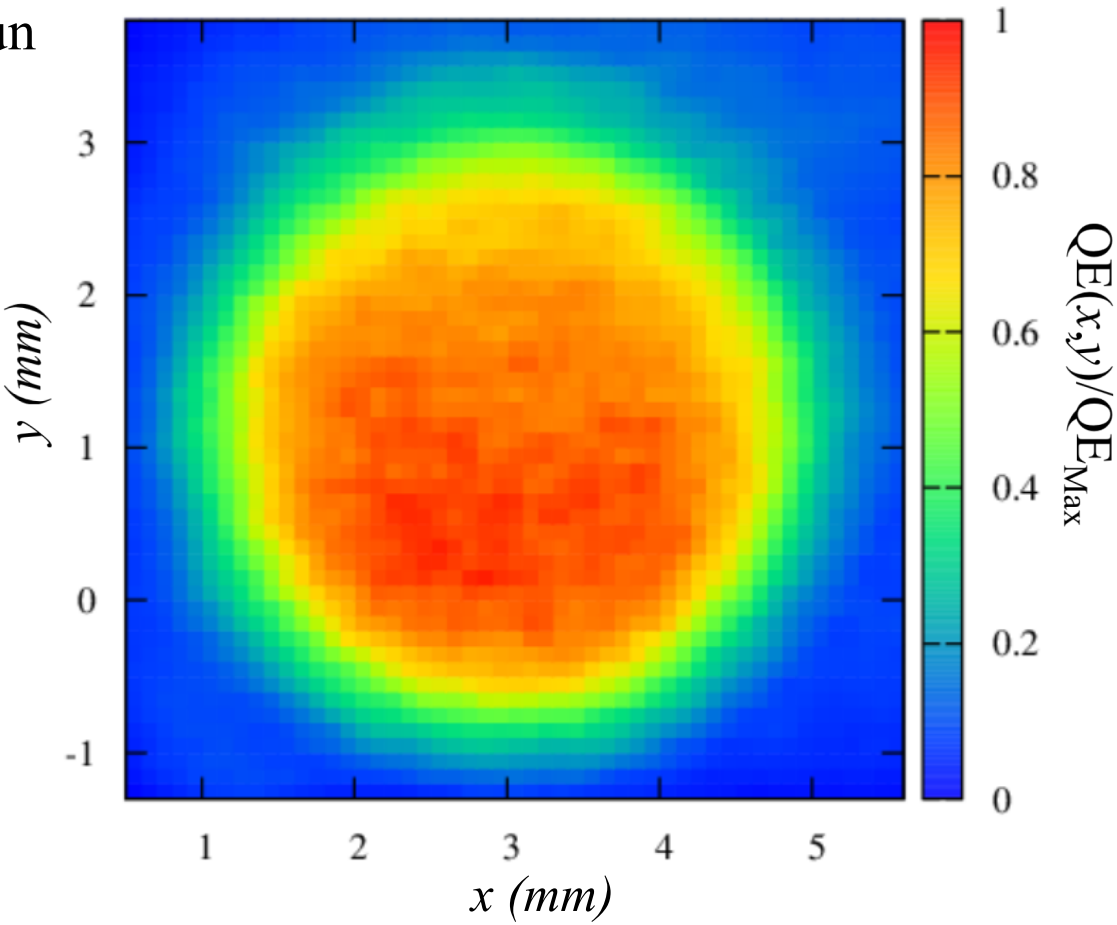
Cathode : Quantum Efficiency Map

Spatial dependence of QE on the Ir_7Ce_2 cathode surface was measured.

【Sample】

Photocathode in the QTWSC-RF gun using Spark Plasma Sintering (SPS)

【Results : Non-activation】

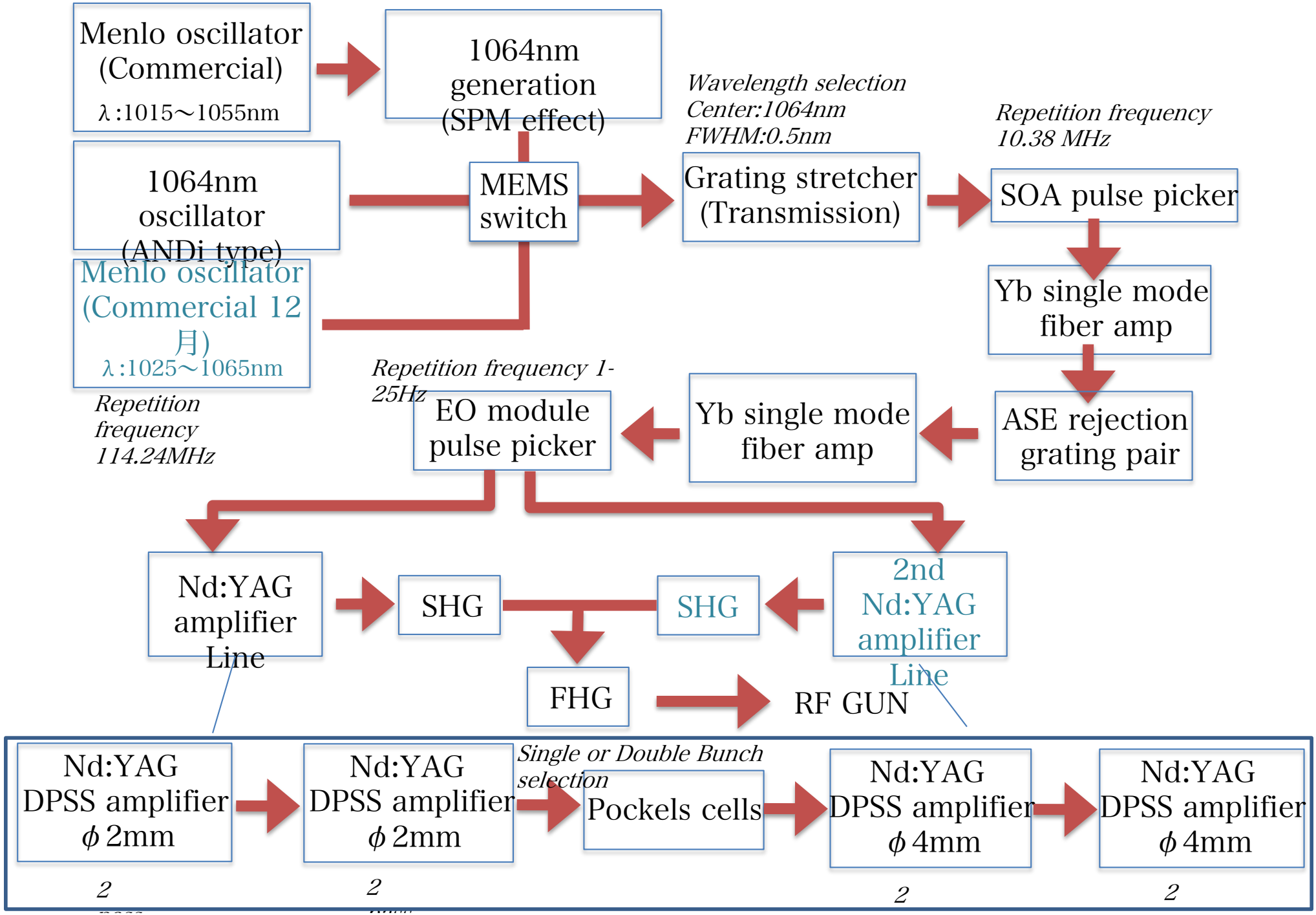


x, y : Position of focus lens

QE > 10^{-4} in off-line measurement (10^{-6} Pa).

QE = 10^{-5} in operation condition because of vacuum level (10^{-5} pa).

Redundant Yb:Fiber + Nd:YAG Hybrid Laser System



First MENLO Oscillator →1064nm Generation
Self Phase Modulation (SPM)

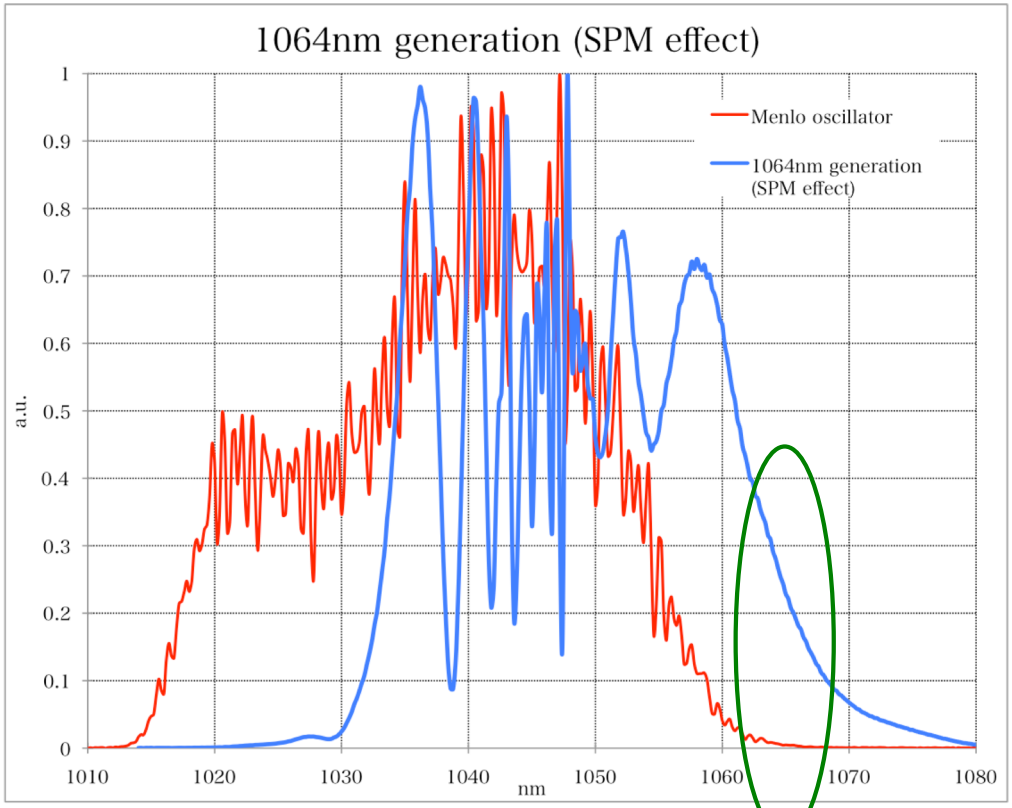
Menlo oscillator (Commercial)
λ:1015～1055nm

→ Grating pair (Dispersion compensation)

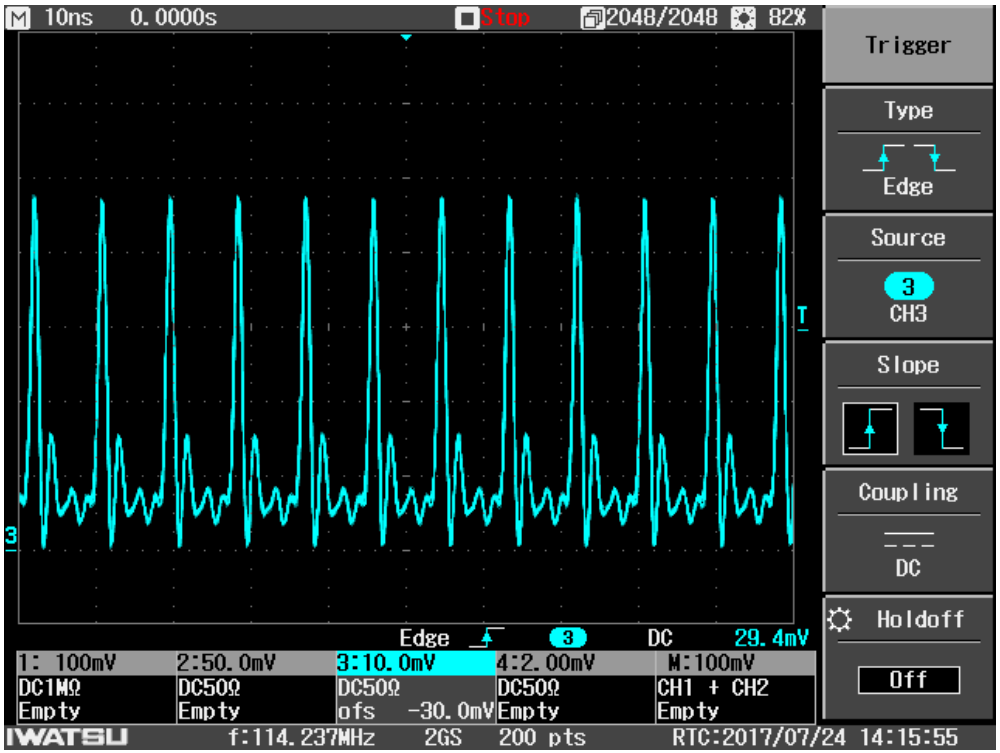
→ Band pass filter

→ YDFA

Self Phase Modulation (SPM) in the Yb-Fiber



1064nm

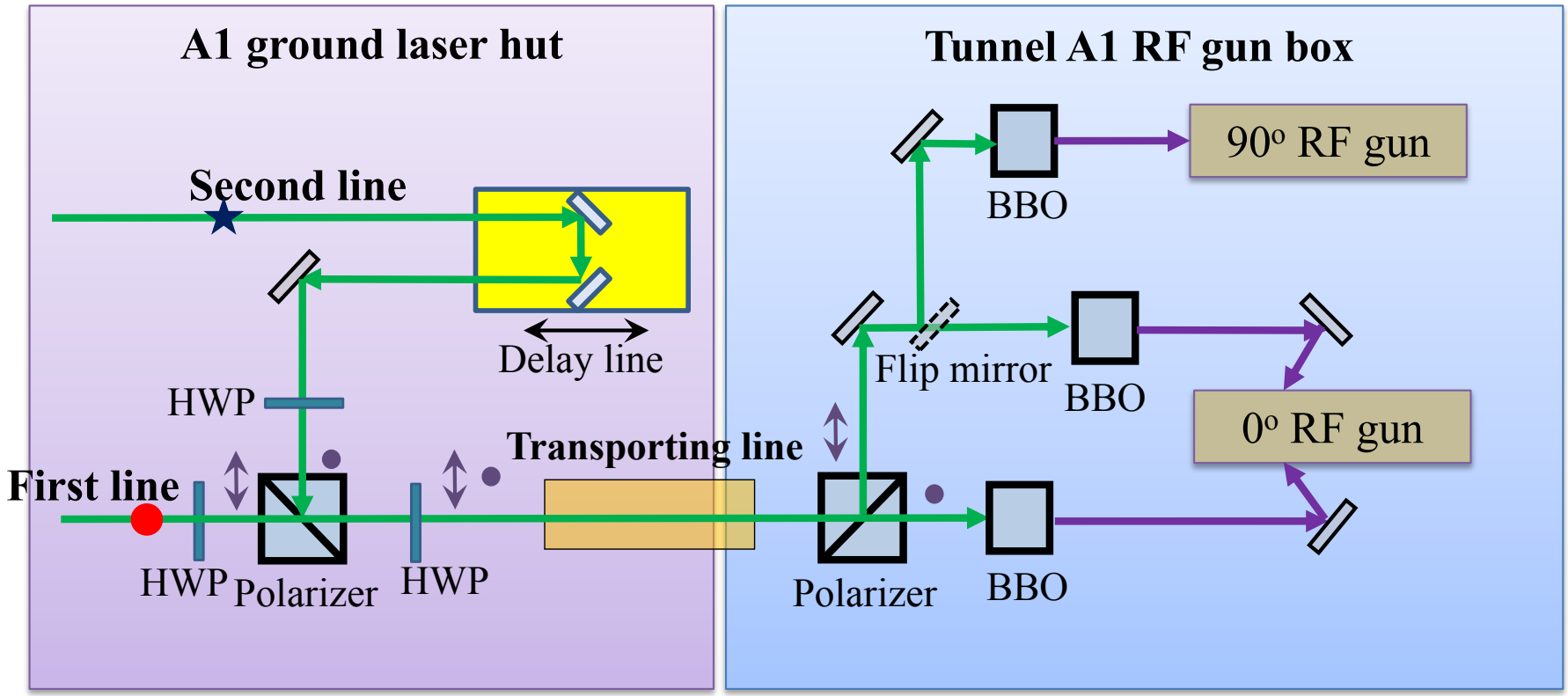


Nd-laser system for SuperKEKB phase II

- Nd laser system is used for SuperKEKB phase II

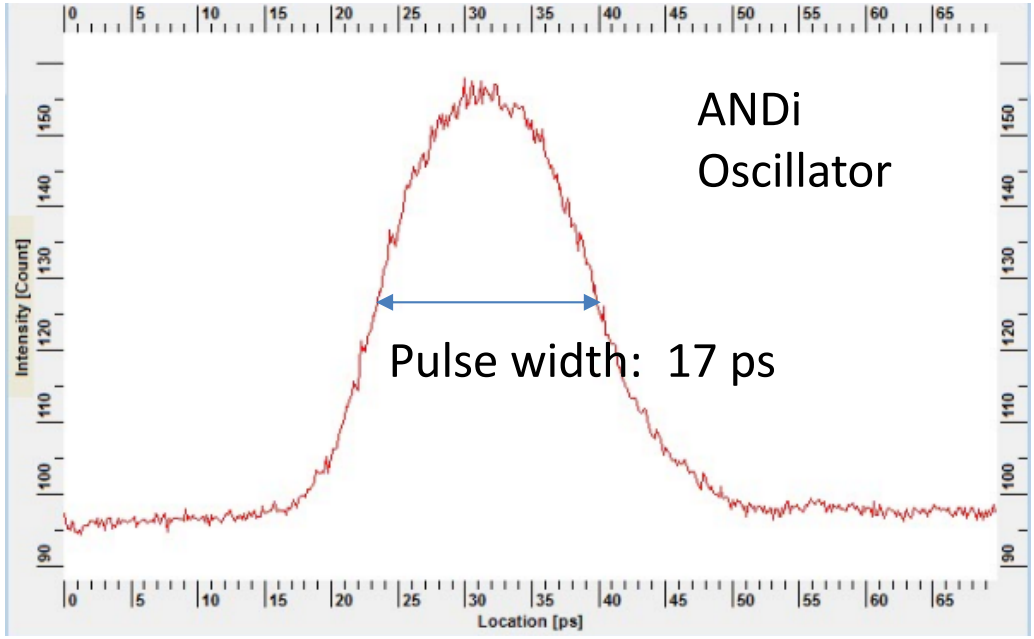
(Both SuperKEKB ARC (R70) and RF gun review comment)

- Two lasers synchronous injection, the second line is built.
- Two lasers injection → low emittance and high charge (3.6 nC achieved)



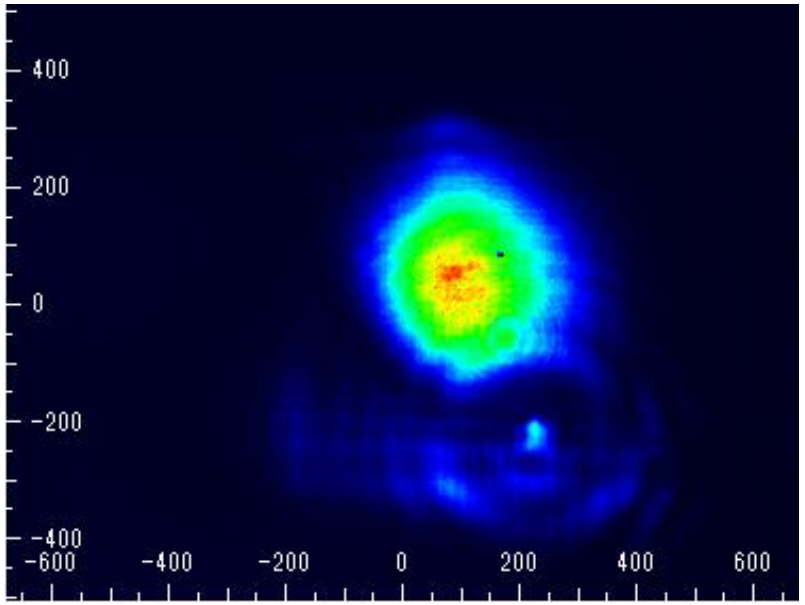
● Laser with vertical polarization, ↕ laser with horizontal polarization

Laser Beam Profile

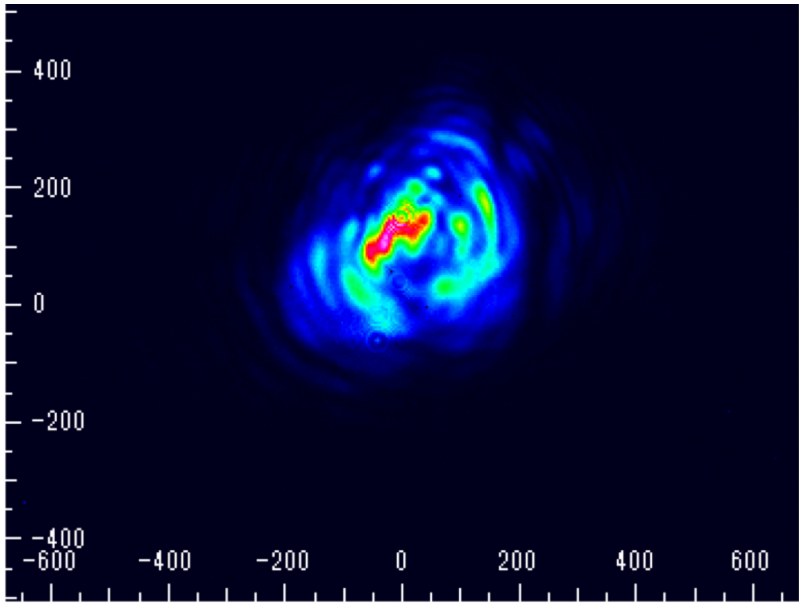


Virtual cathode monitor was installed
(SuperKEKB ARC)

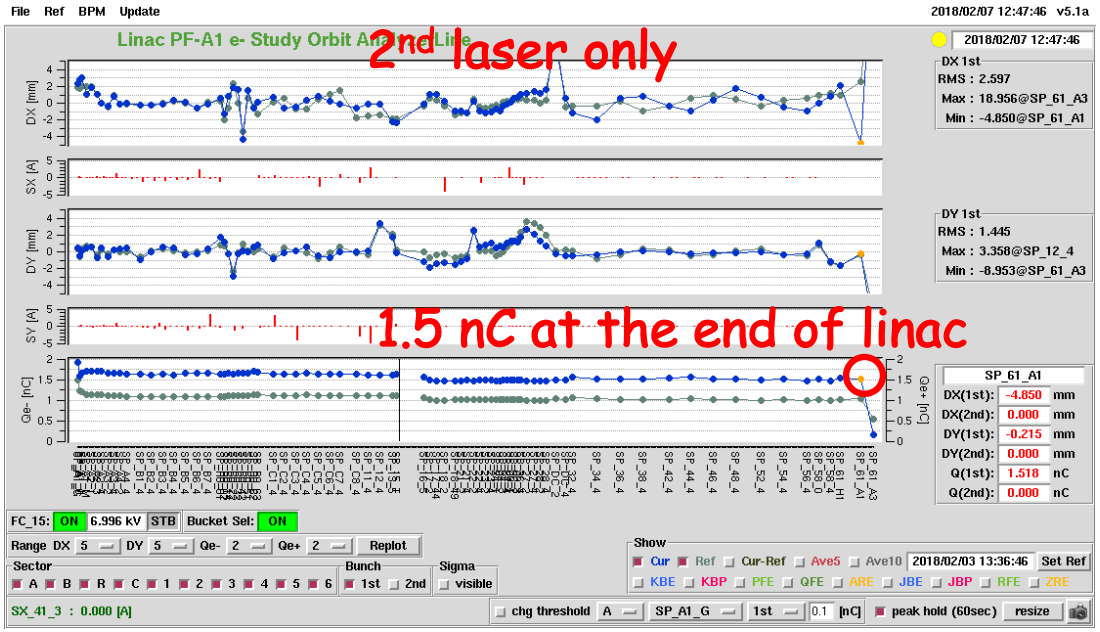
Laser Beam Profile (Current)

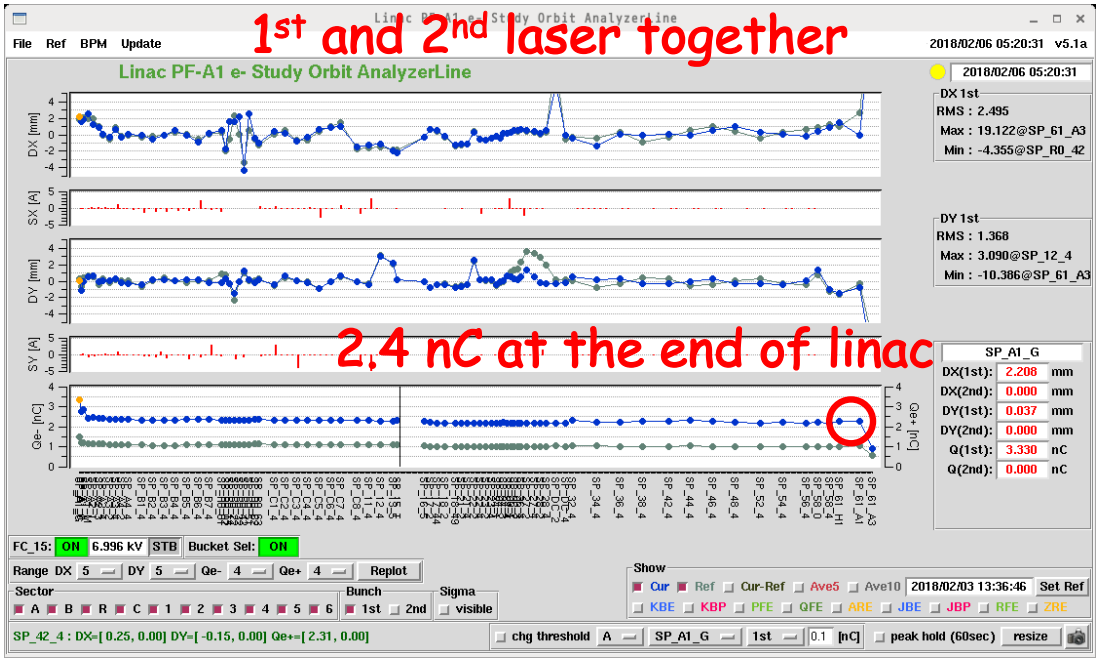


Laser Beam Profile (2017.4)

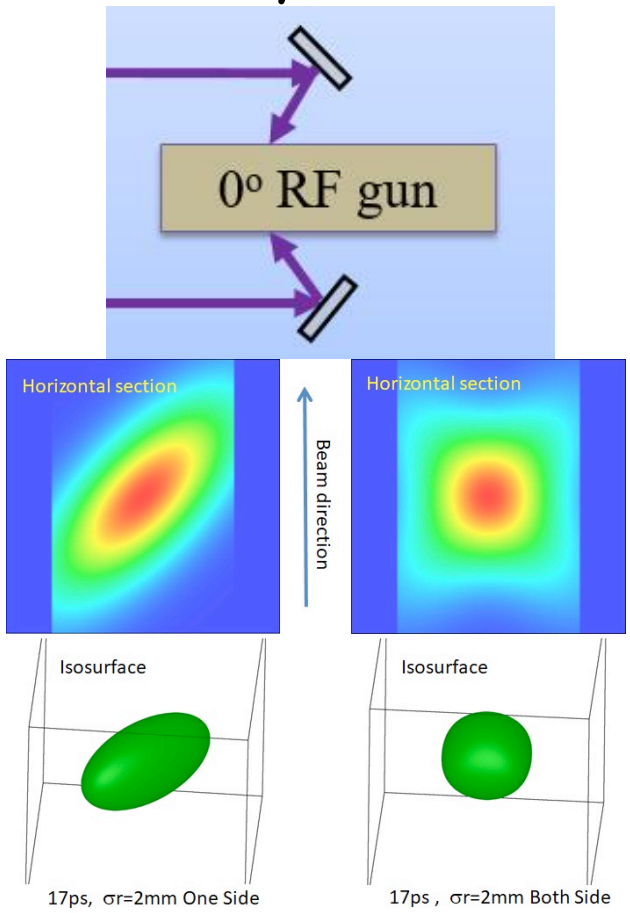


Nd-laser system for SuperKEKB phase II





- Irradiated by two lasers



B-sector Wire Scanner SP_A1_G 1.2nC

3-wire ABC : γεx=23.314、γεy=19.939

3-wire ABD : γεx=27.558、γεy=21.983

3-wire ACD : γεx=22.752、γεy=35.889

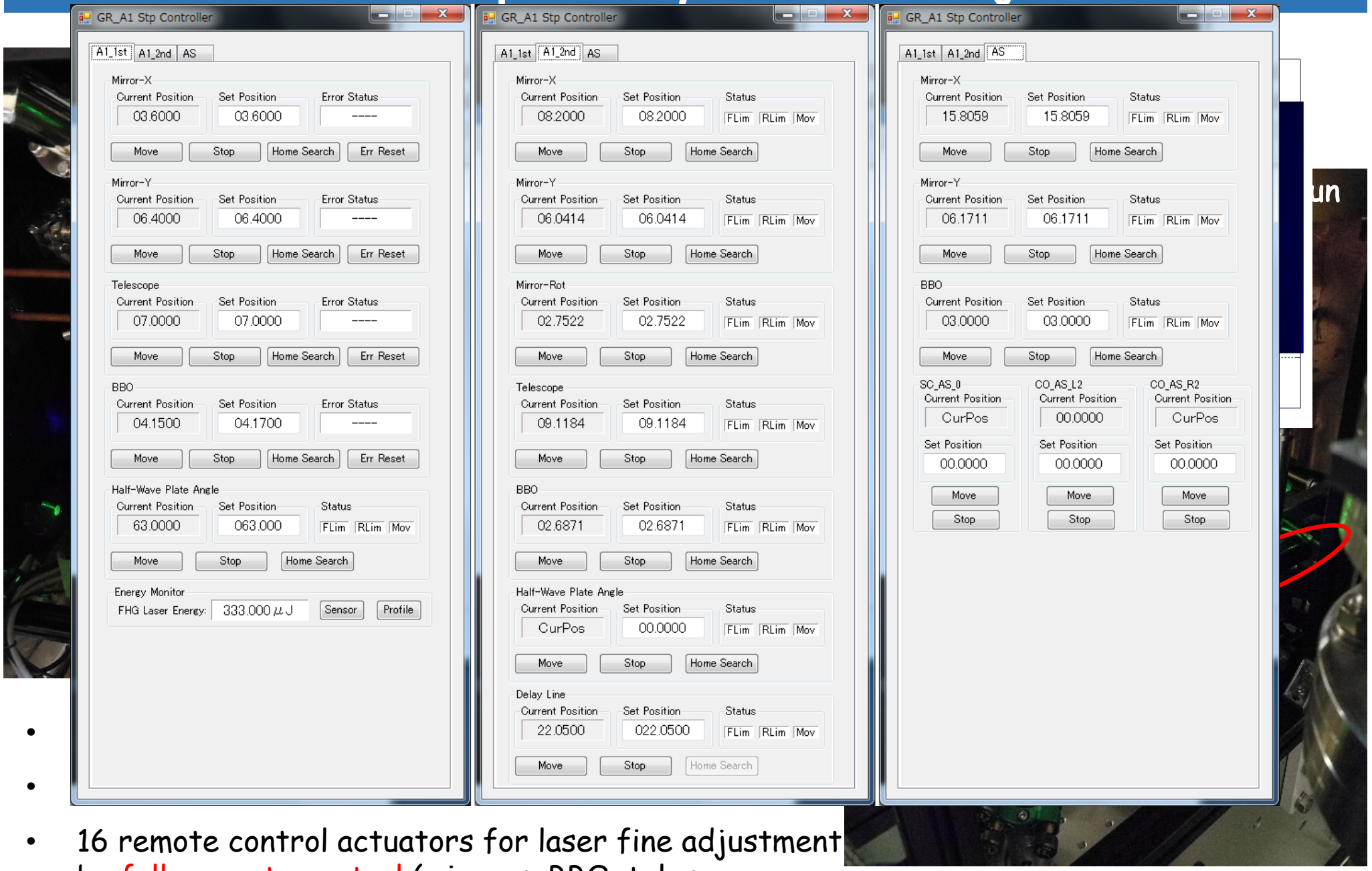
3-wire BCD : γεx=25.387、γεy=20.515

4-wire ABCD: γεx=24.958、γεy=18.640

Laser Monitors

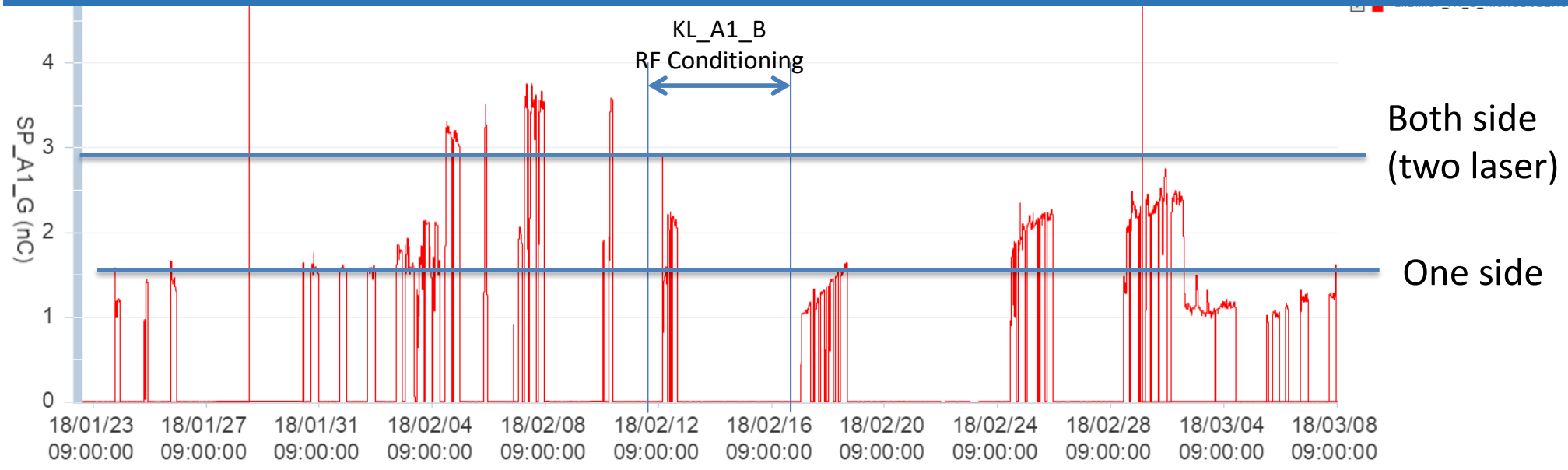
Laser monitors for fiber laser part and every amplifier stage were installed.
We can justify the error part immediately from these logs.
(SuperKEKB ARC R71)

Controllable optical system for adjustment



- 16 remote control actuators for laser fine adjustment by fully remote control (mirrors, BBO, telescope, wave plates)

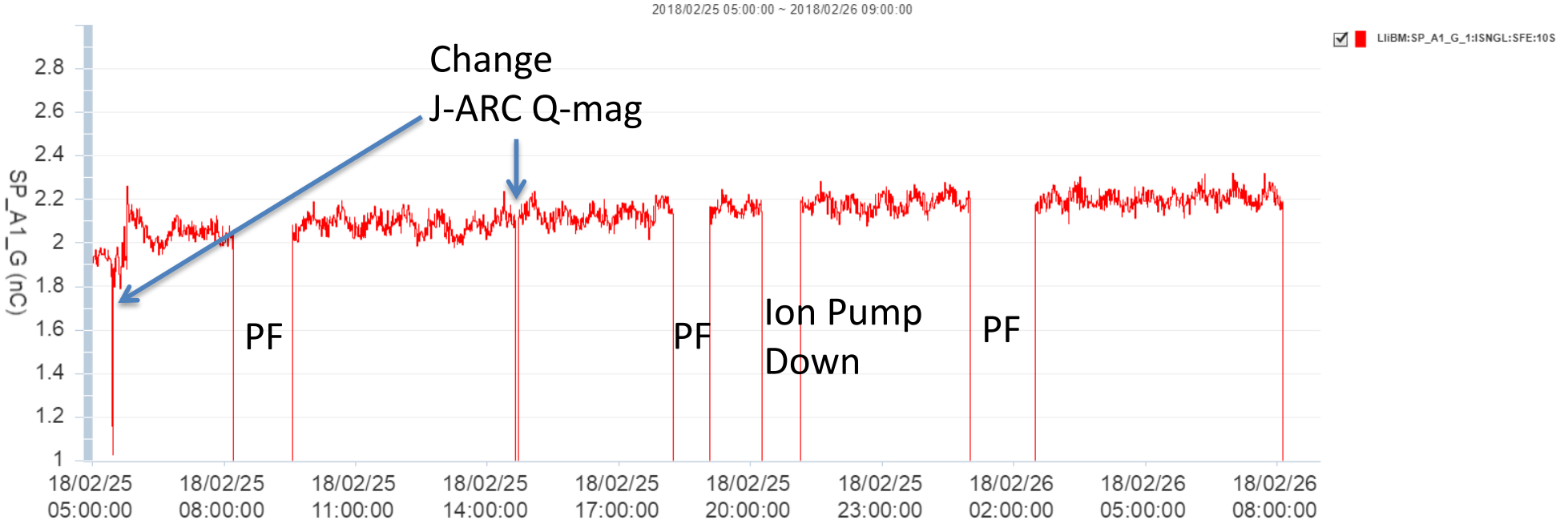
Long term (2.5 month) operation history



Both side (two laser)

One side

1-day operation history (No miss shot)



Summery for Phase-II & Upgrade for Phase-III

- Stable operation using Yb:Fiber+Nd:YAG laser with many monitors and remote controls.
- Required charge & emittance for Phase-II were achieved

Phase-III

- Current maximum charge output is 3nC due to lower quantum efficiency of 10^{-5} compare with off-line QE of over 10^{-4}.
  => <u>High quality IrCe cathode</u>
  <u>& Increase ion pump & Cathode cleaning system</u>
- Laser system with flat top pulse shaping using <u>pulse stacking method</u> for both Nd and Yb.

Single crystalline (SC) IrCe

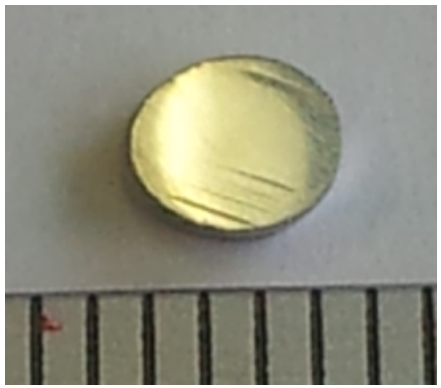
【Advantage of Single crystalline Metal】

- **Higher QE** than that of multicrystal[1]
- **Better QE uniformity** than that of multicrystal[2]

Our group collaborated with H. Sugawara (Kobe university) to develop the large size single crystalline IrCe compound.

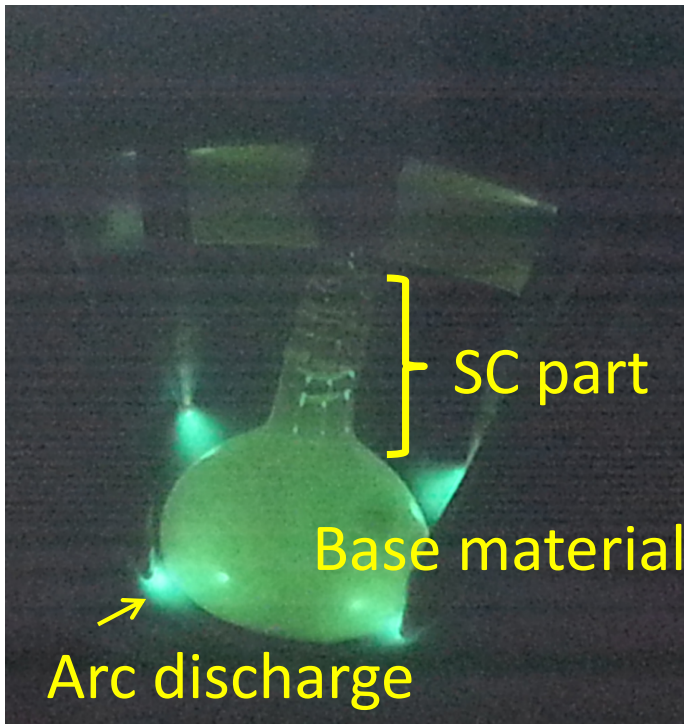
SC Growth Method
Czochralski Process

【Developed SC IrCe】



Succeeded in the crystal growth of 4mm diameter

【Czochralski Process】

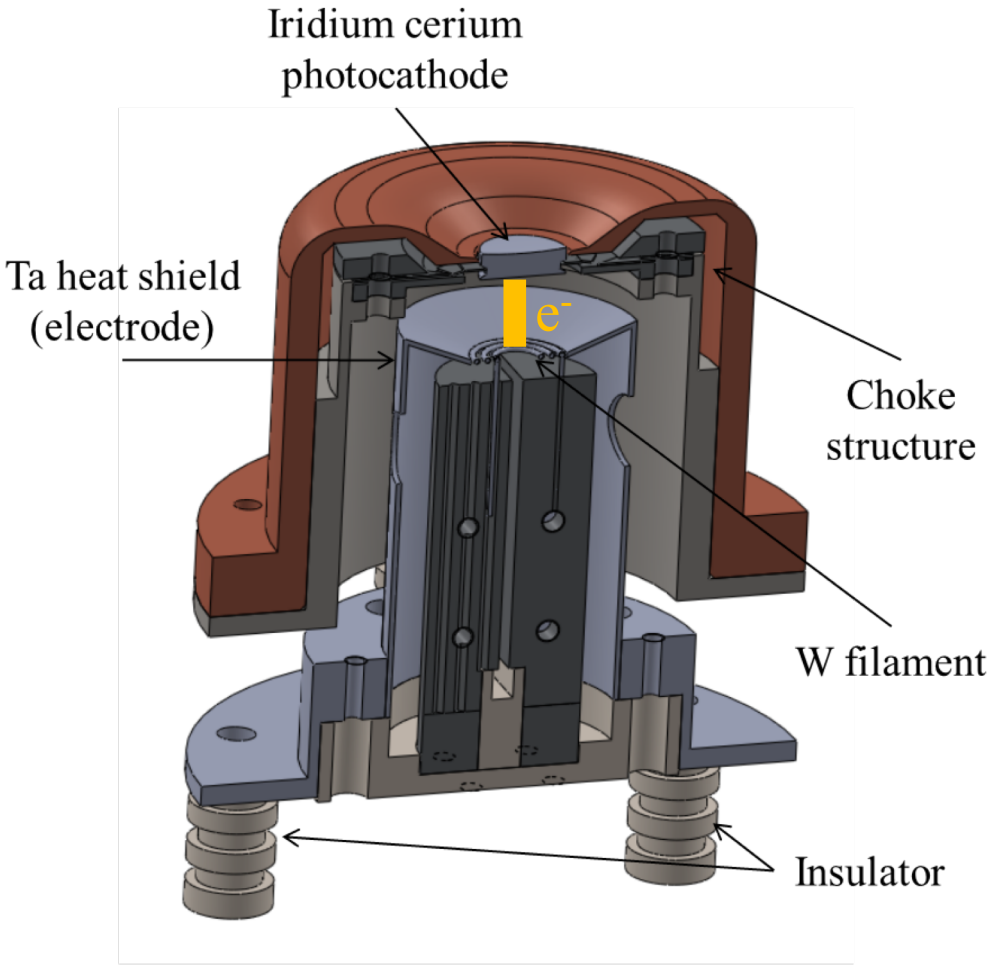


Larger-diameter crystal growth experiments are in progress.

[1] D.A. Reis, at al., 'Transverse Emittance Measurements from a Photocathode RF Gun with Variable Laser Pulse Length', SLAC-PUB-8018
[2] P.R. Boltona, et, al., 'Photoinjector design for the LCLS', SLAC-PUB-8962

Electron beam (EB) heating type cathode plug

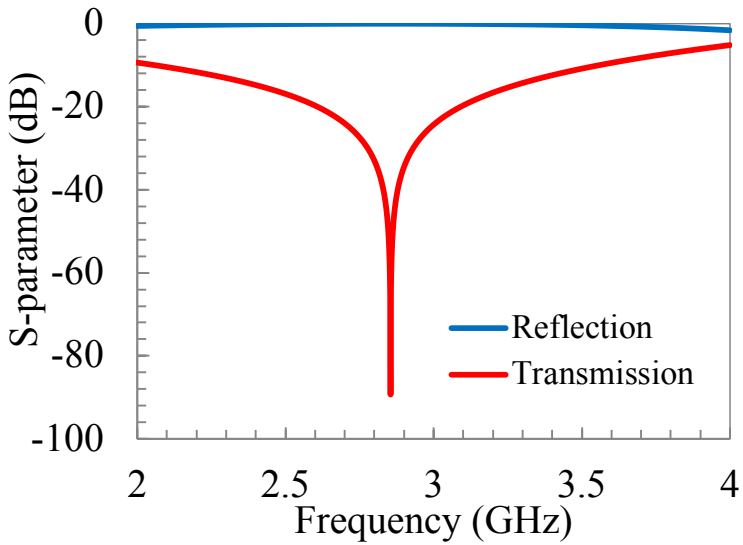
【Design of EB heating type cathode plug】

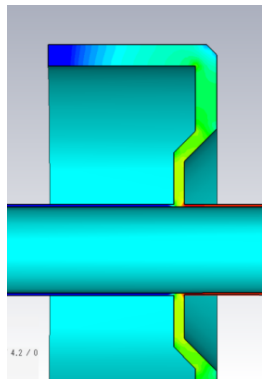


EB heating is …

a main cathode is bombarded by an accelerated electron beam as a thermal source behind the cathode.

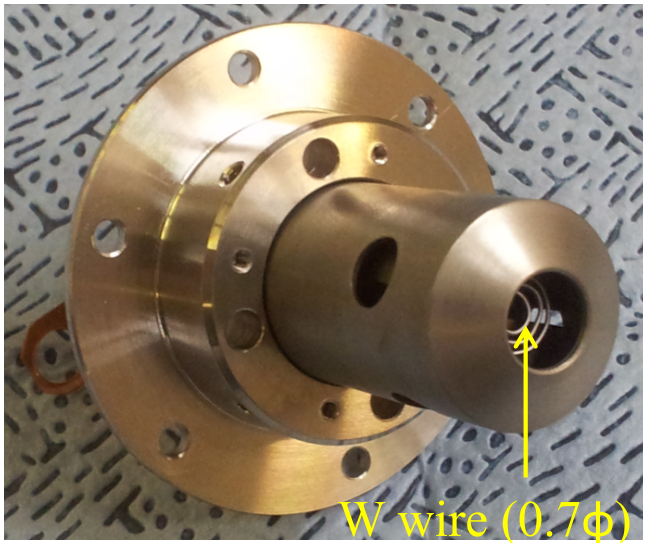
【 RF shielding structure 】

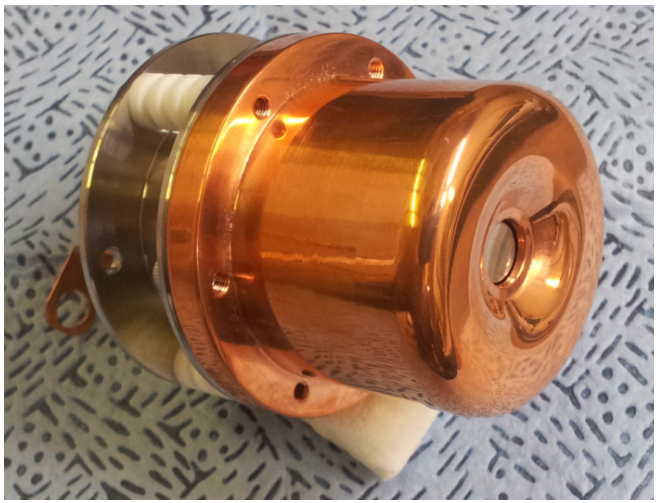




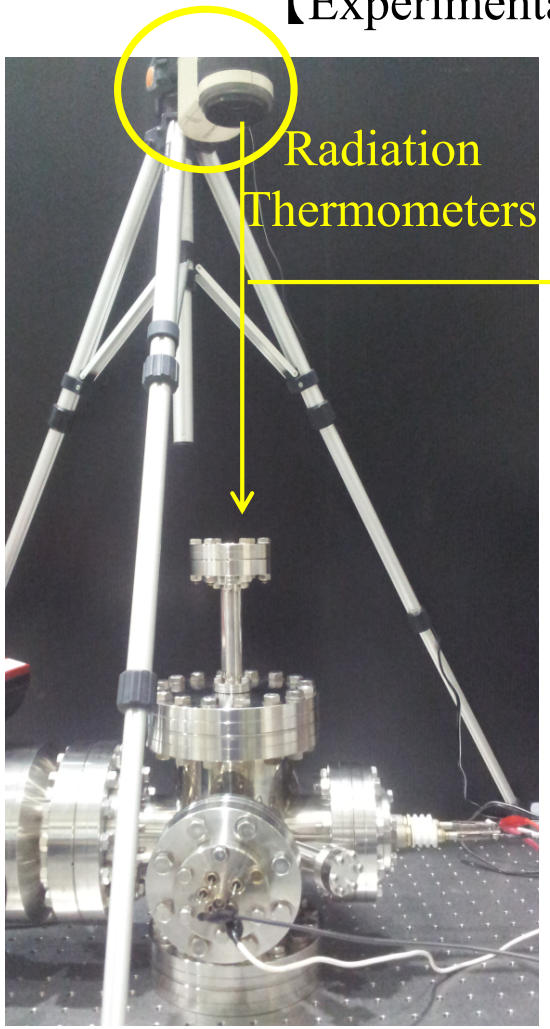
Heating Test

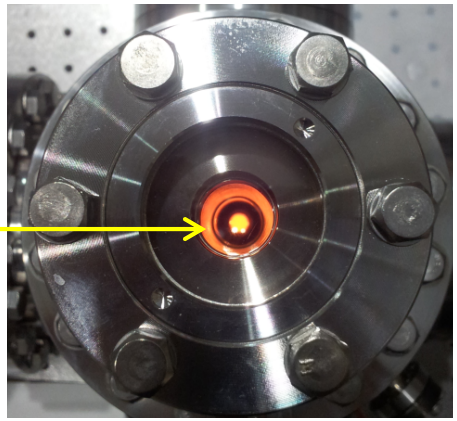
【Cathode plug】





【Experimental Setup & Results】





Heater Current (A)	16
Heater Voltage (V)	3.38
Intermediate electrode (V)	-25
High Voltage (kV)	2.3
Beam current (mA)	23
Beam Power (W)	**52.9**
Surface Temperature (degC)	**1029**

Heating a photocathode over 1000℃ by EB heating method was succeeded.

Pulse shaping in time domain

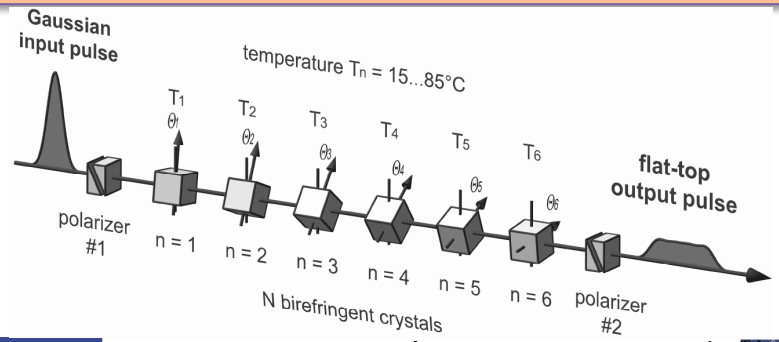
- In order to get low energy spread in a strong space charge effect, laser pulse with rectangular temporal shape is required

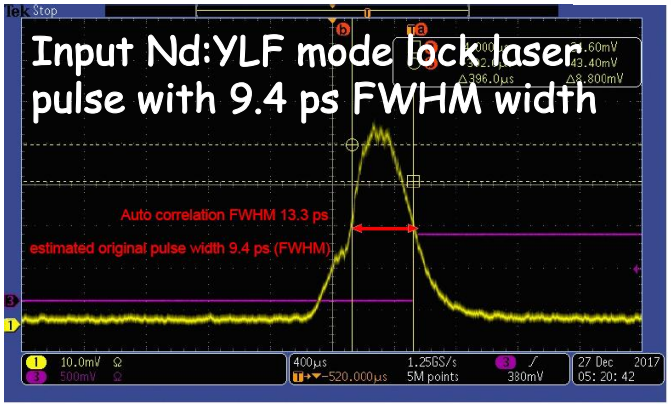
Temporal shaping scheme by pulse stacking technology for Nd laser system

Input laser pulse with temporal Gaussian shape (FWHM~10 ps)

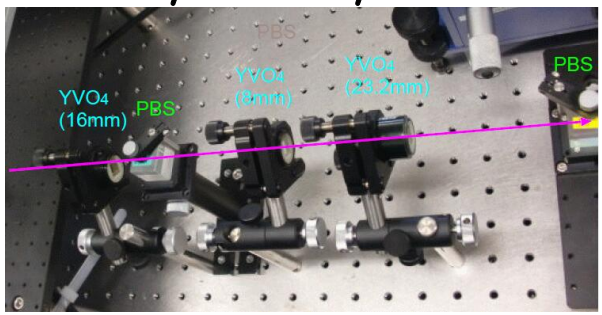
→ **Pulse stacking setup made by a crystal array (birefringent effect of crystal)** →

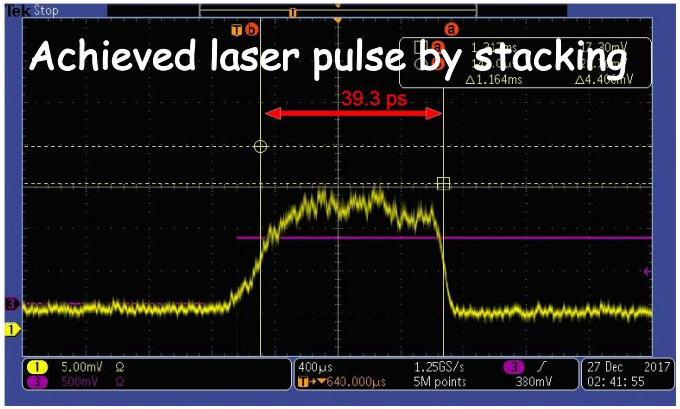
Output laser pulse with temporal rectangular shape (FWHM~40 ps)





Two stages stacking system made by YVO_4 crystals





- 30 ps and 40 ps rectangular laser pulses are achieved by one stage and two stages stacking system separately
- Available to both Nd and Yb laser system

* Supported by Dr. Yosuke Honda

Summery for Phase-II & Upgrade for Phase-III

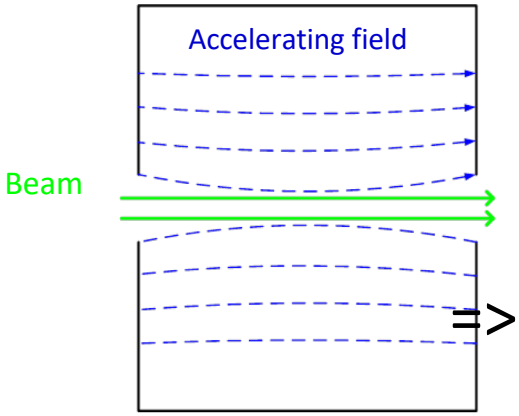
- Stable operation using Yb:Fiber+Nd:YAG laser with many monitors and remote controls.
- Required charge & emittance for Phase-II were achieved

Phase-III

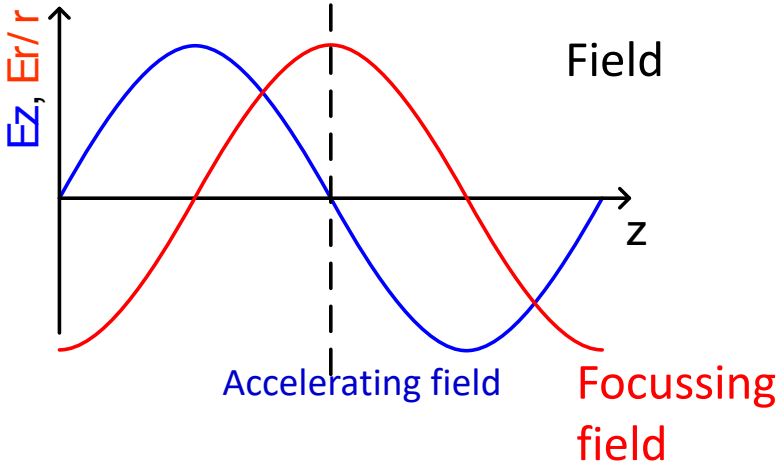
- Current maximum charge output is 3nC due to lower quantum efficiency of 10^{-5} compare with off-line QE of over 10^{-4}.
  => <u>High quality IrCe cathode</u>
  <u>& Increase ion pump & Cathode cleaning system</u>
- Laser system with flat top pulse shaping using <u>pulse stacking method</u> for both Nd and Yb.

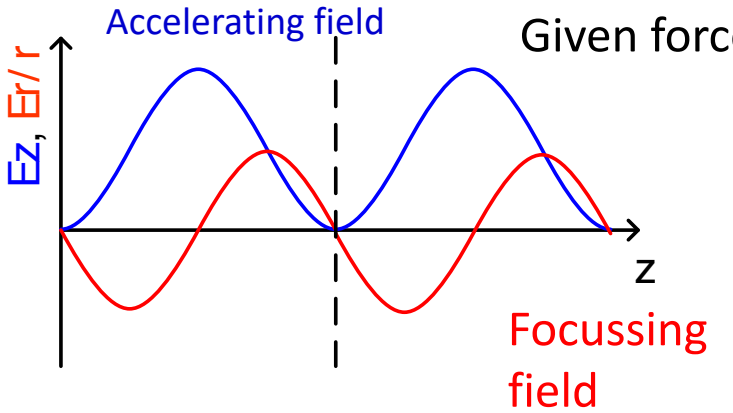
Backup

Pill-box cavity

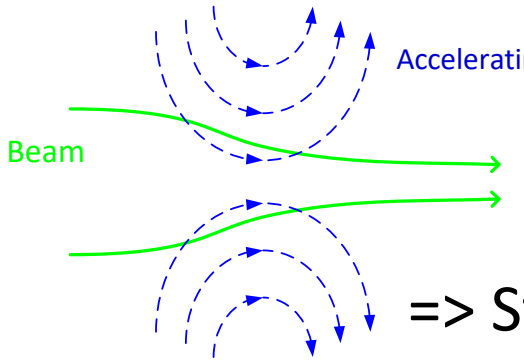


=> Weak focus

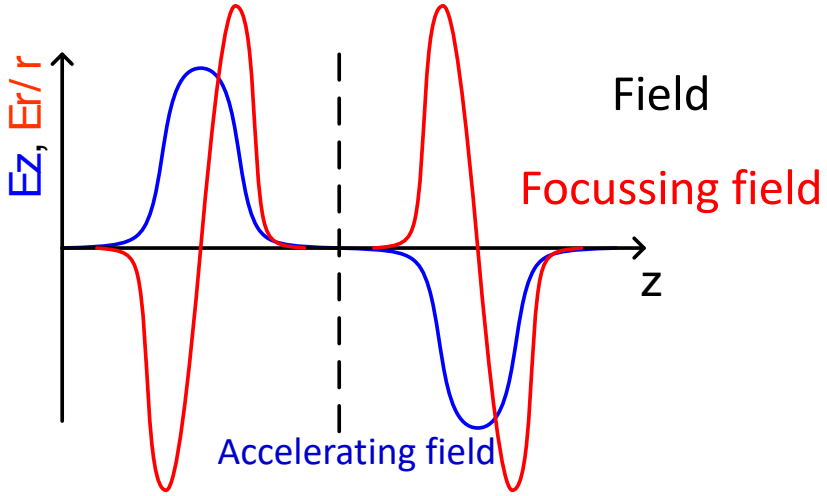


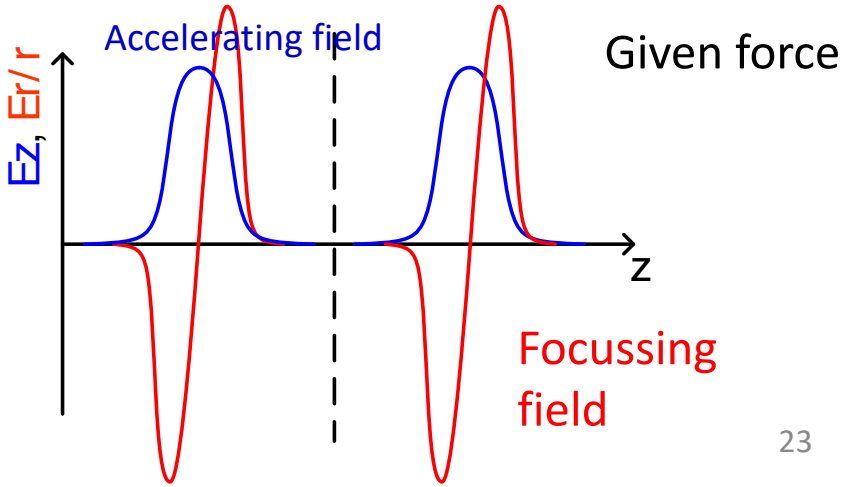


Annular coupled cavity with nose

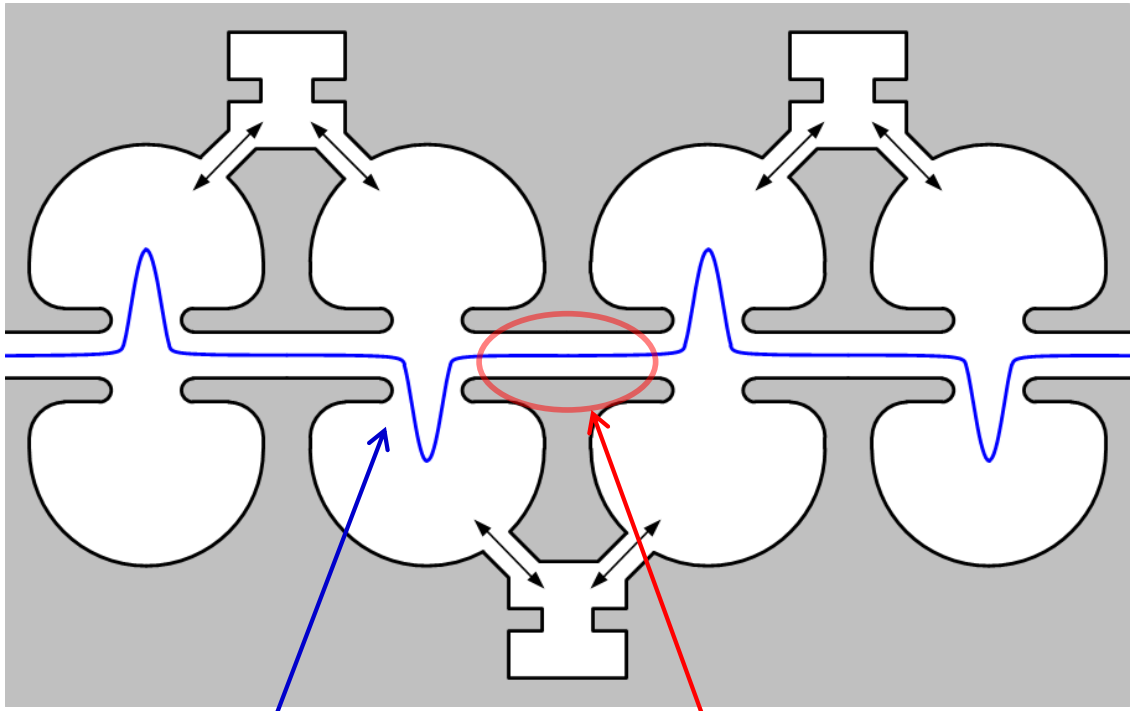


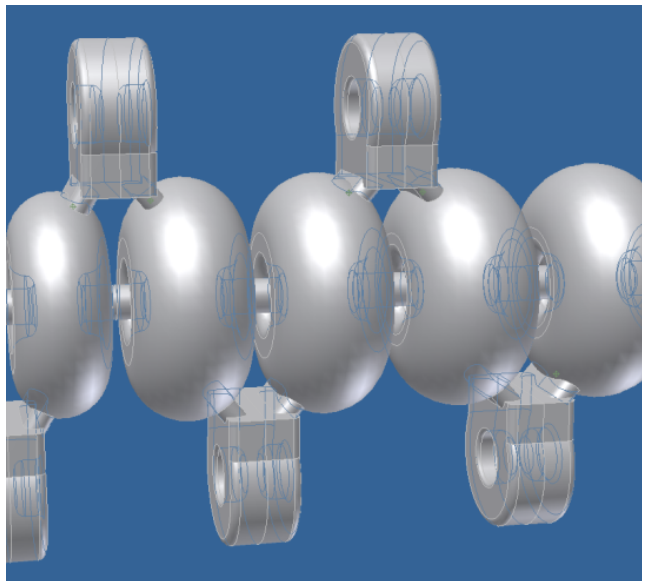
=> Strong focus





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





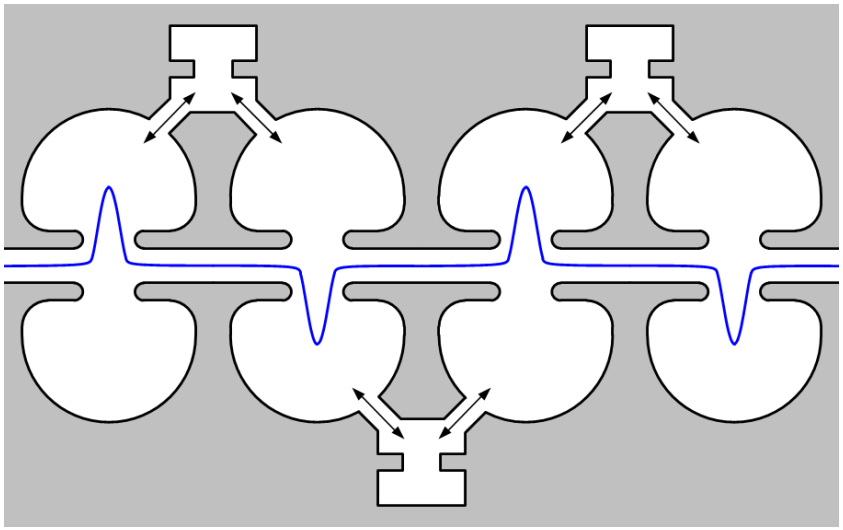
Concentrated field
has focusing effect

This structure has long drift space

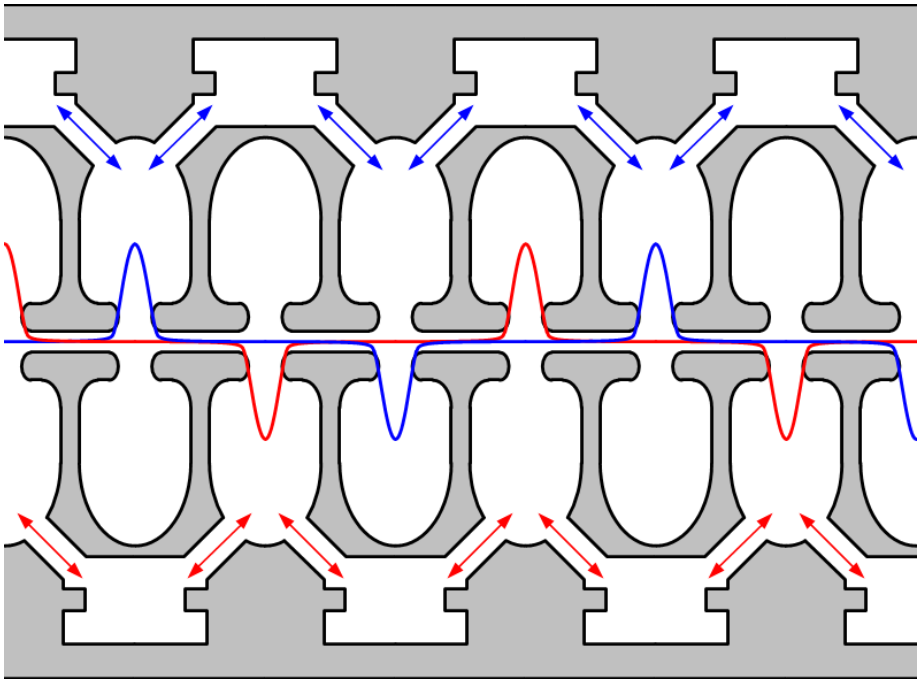
This structure has focusing field.
Long drift space is problem.

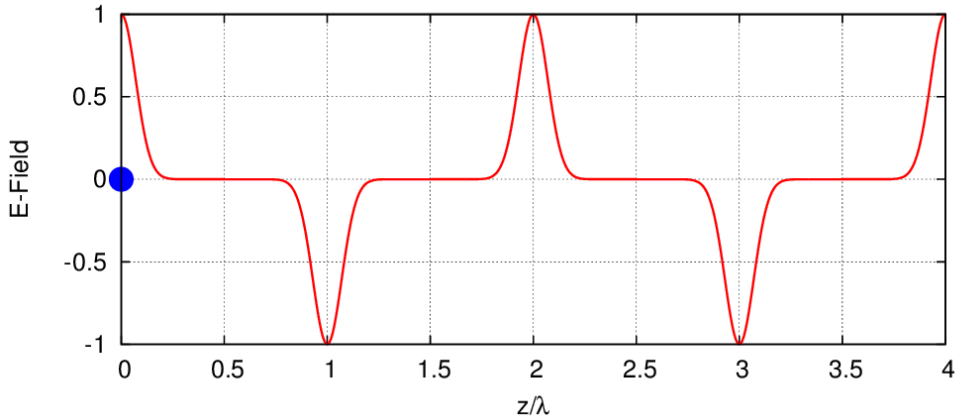
Design of a quasi traveling wave side couple RF gun

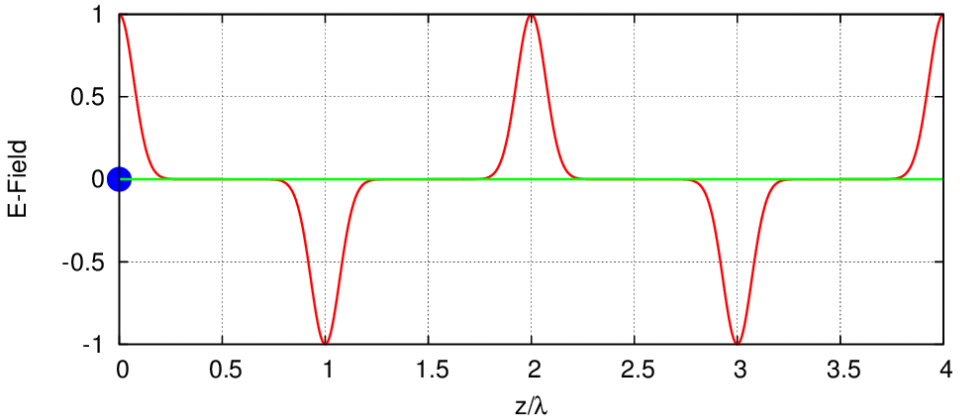
Normal side couple structure



Quasi traveling wave sidecouple structure

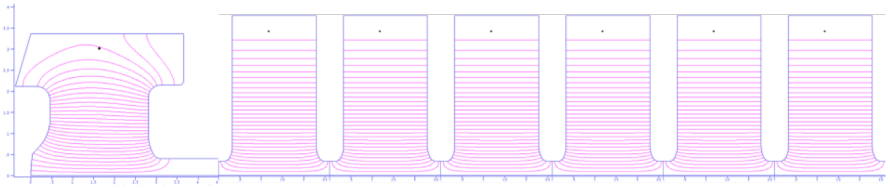




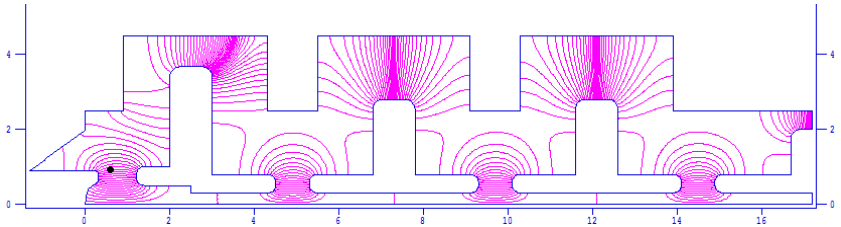


Quasi traveling wave side couple has stronger focusing and accelerated gradient than DAW.

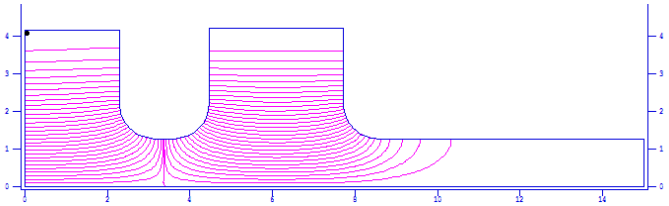
RF-Gun comparison



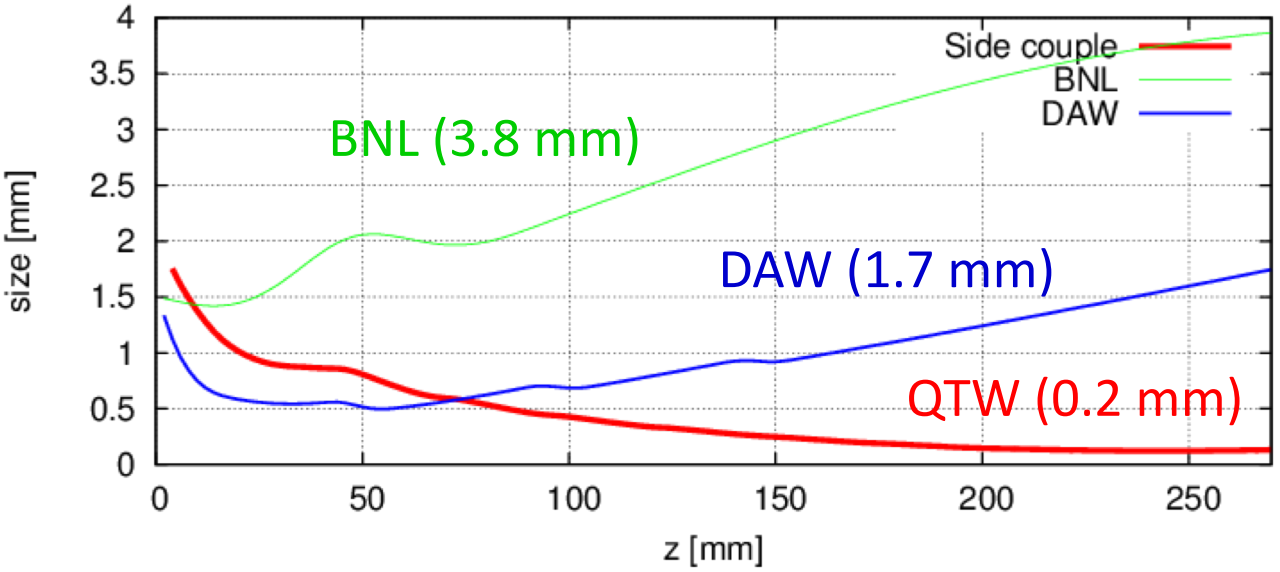
Quasi traveling wave side couple RF gun
(100 MV/m, 6mm-mrad, 13.5 MeV)



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

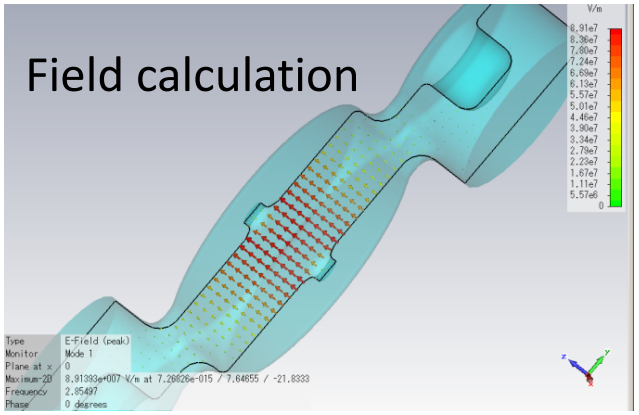


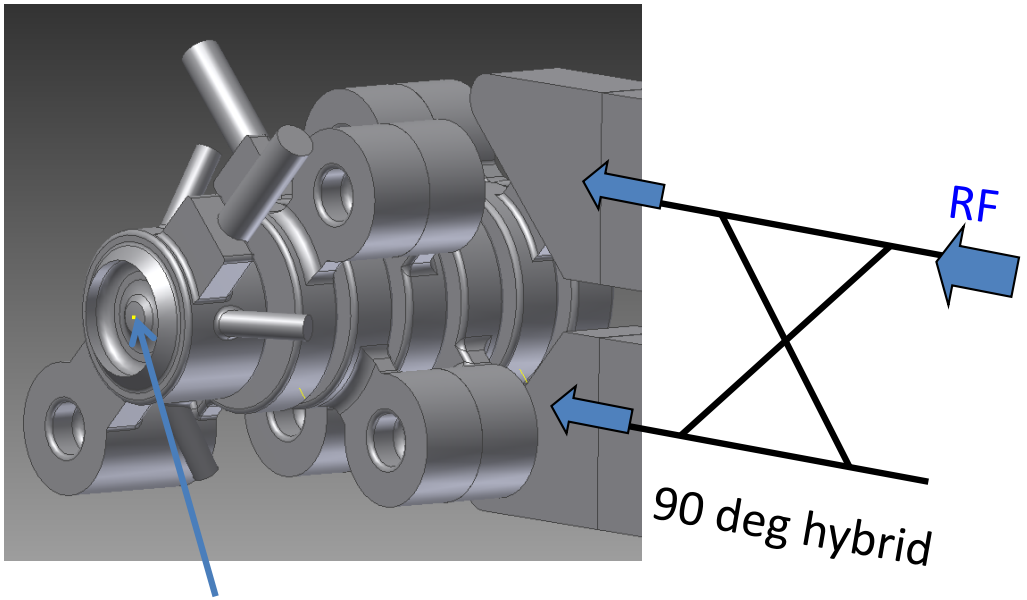
BNL-type RF gun
(120 MV/m, 11.0 mm-mrad, 5.5 MeV)

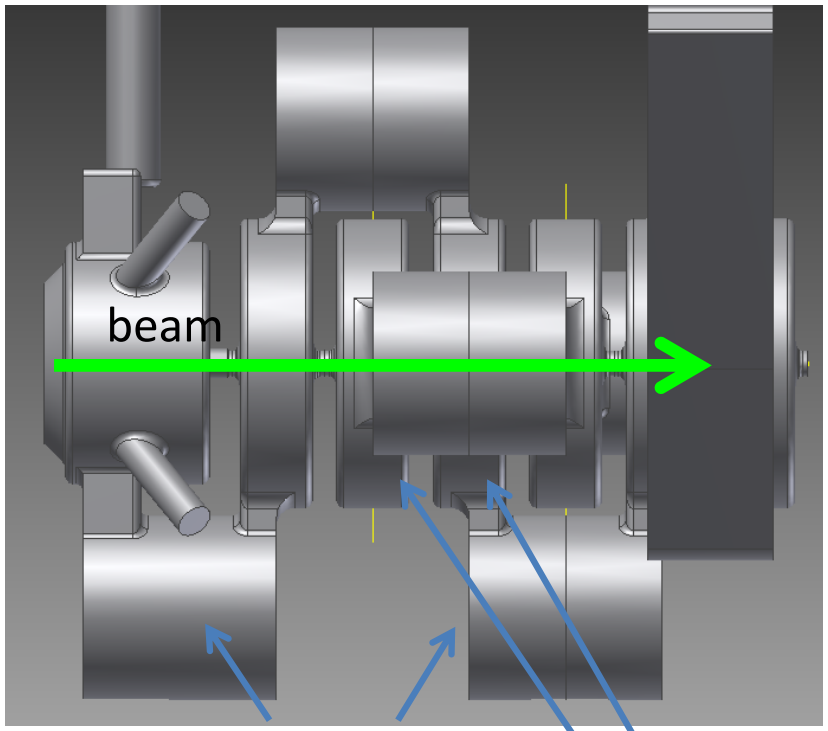


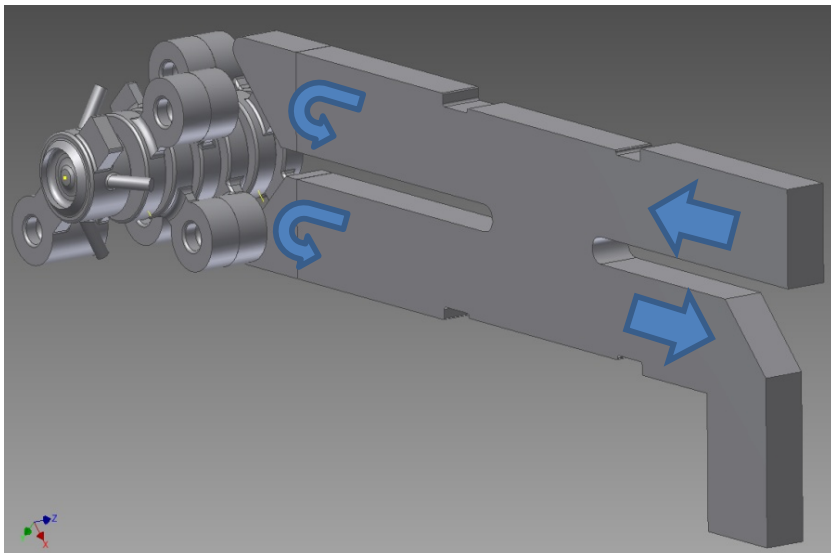
Beam Size

Cavity design



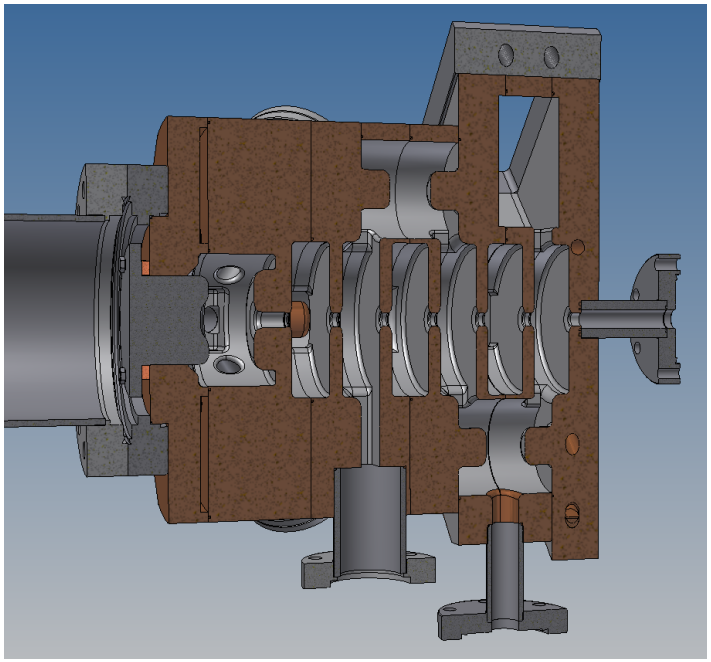


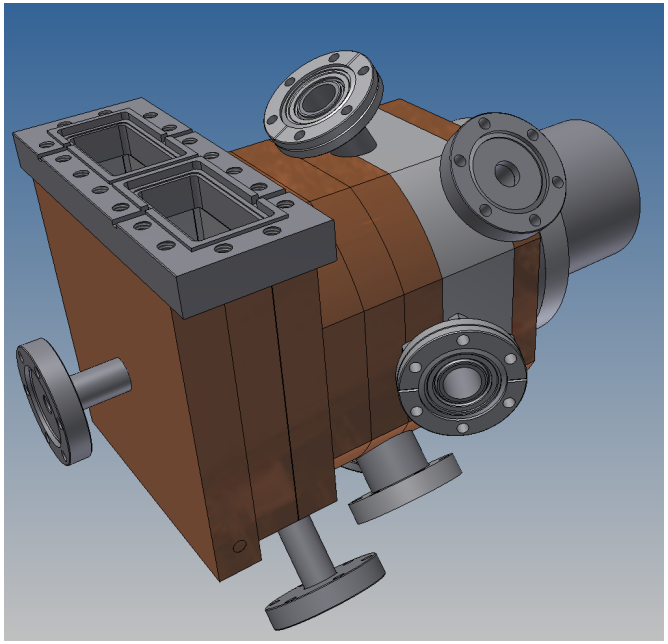


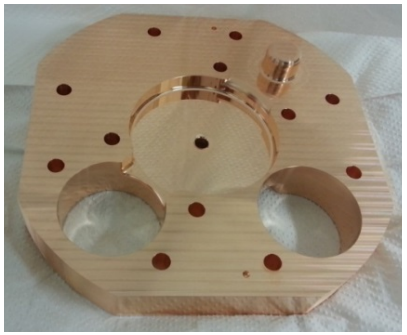


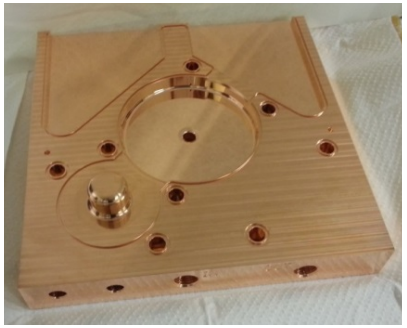
No reflection to klystron

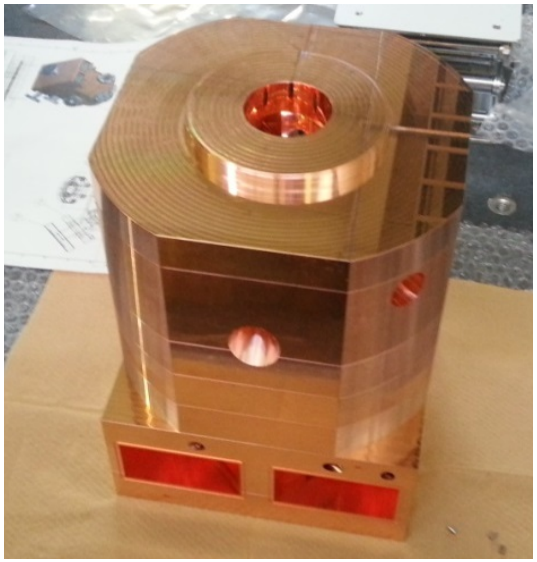
Mechanical design and manufacturing

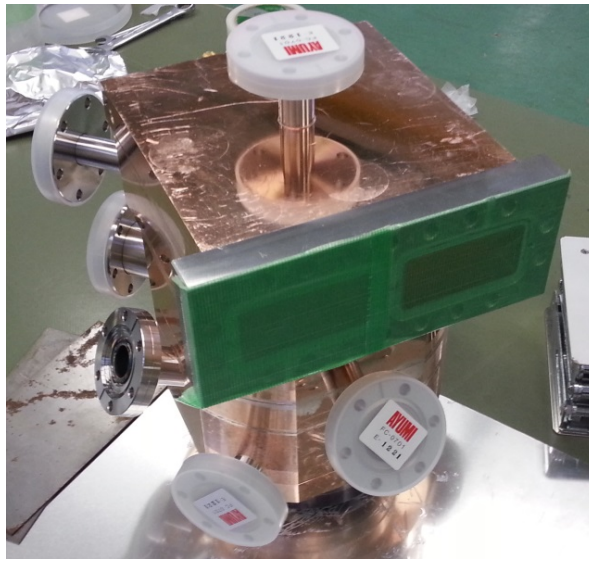




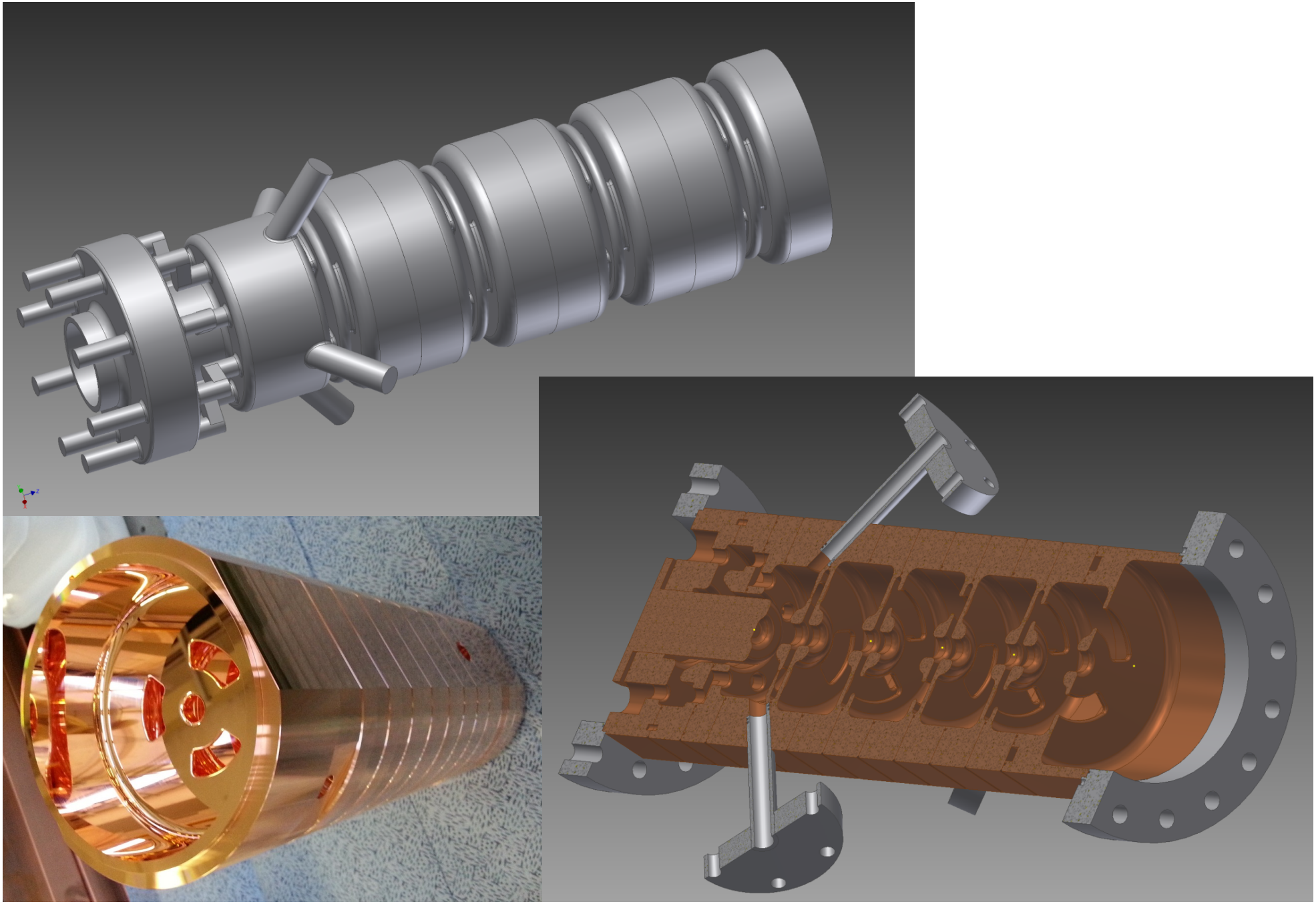




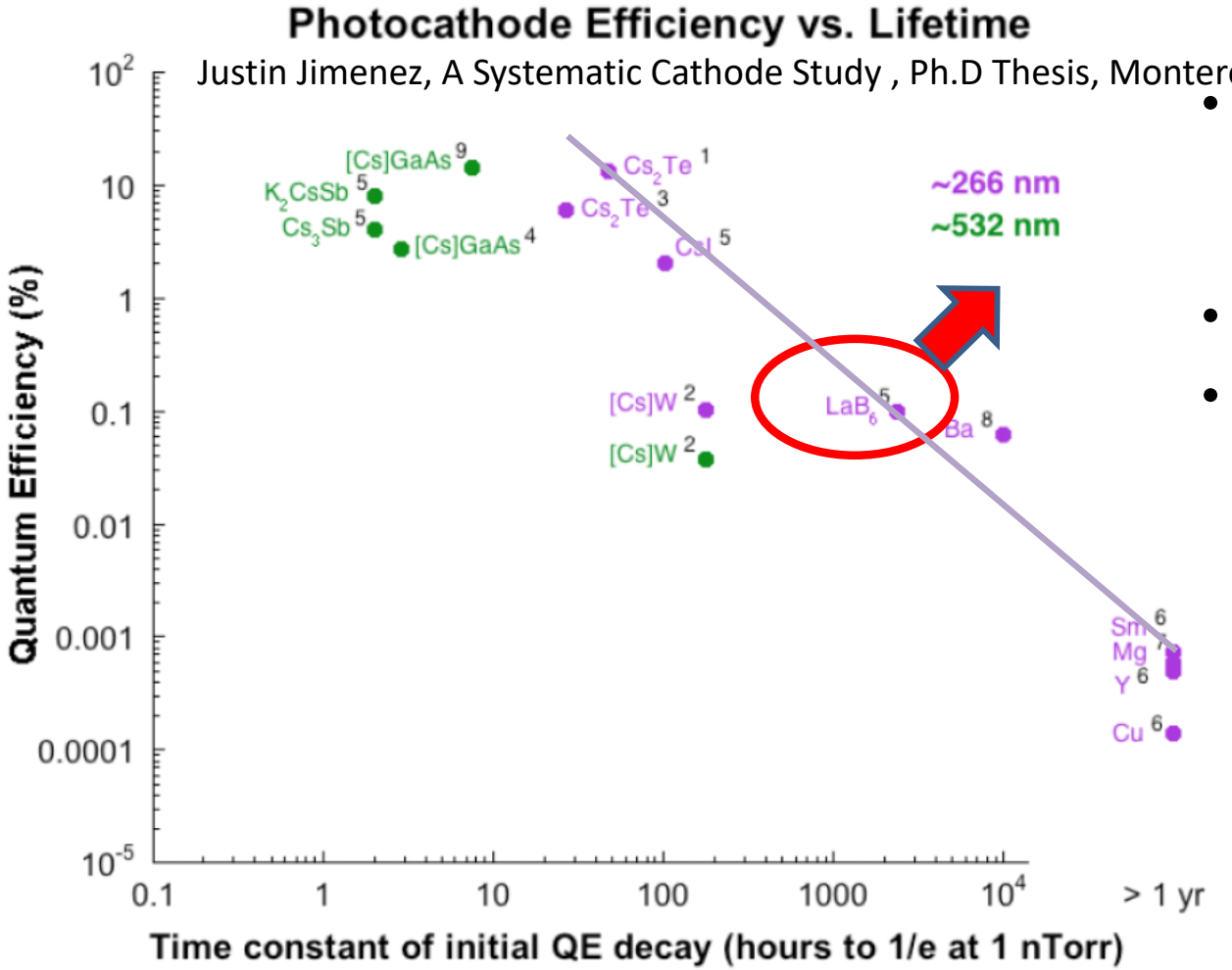




Cut Disk Structure(CDS) installed in 90-deg line



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



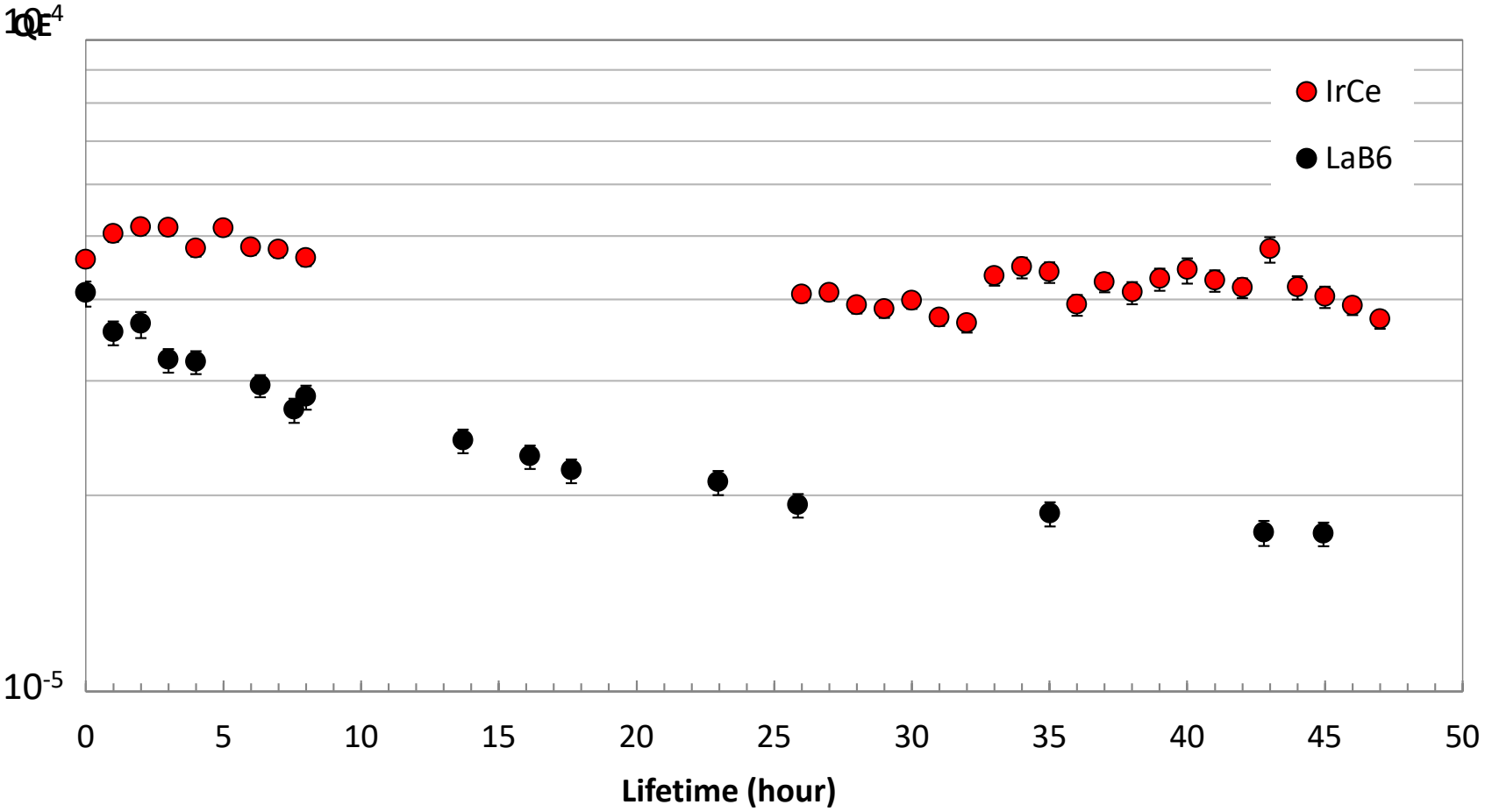
- Low Workfunction (2.8 eV) and enough QE (10^{-4}) at room temperature.
- Inactive in air
- Recover by heating or laser cleaning

Best choice for SuperKEKB 5 nC long time operation

The thermocathodes can also be used as photoemitters [13]. LaB_6 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).

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

Lifetime measurement（LaB_6 / Ir_5Ce）

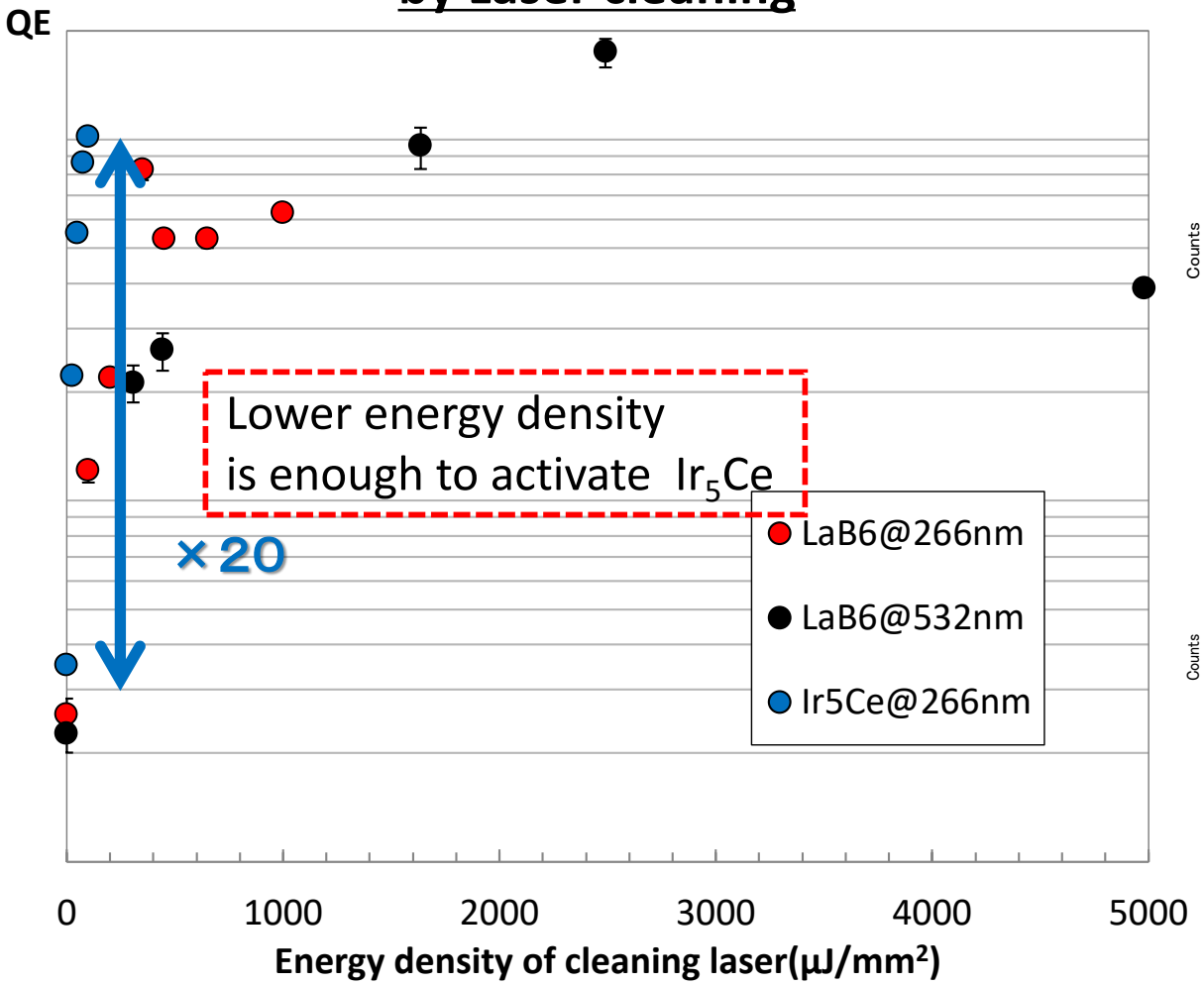


Condition

Continuous pulse laser 200μJ@266nm)
Irradation => 2.5 nC emission

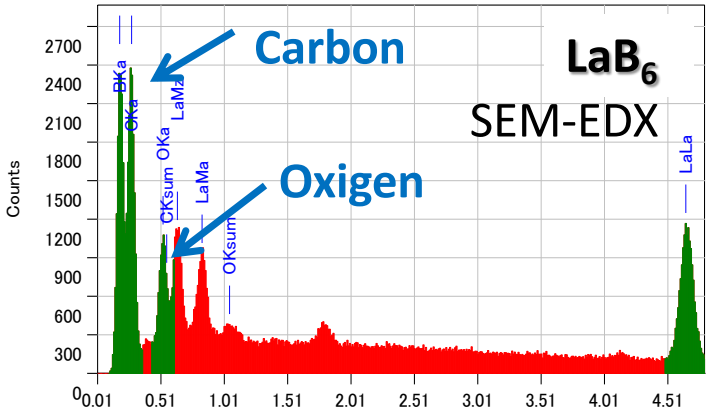
Ir_5Ce Cathode

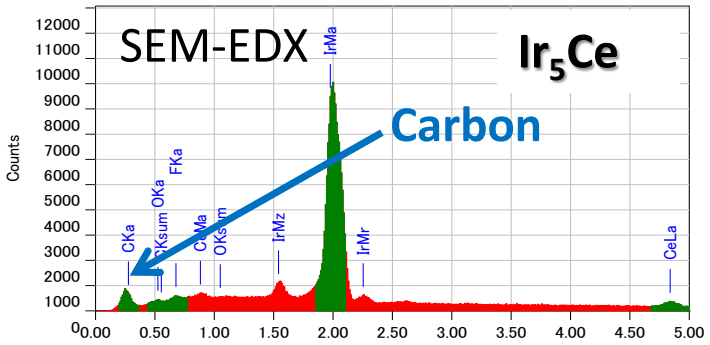
Quantum efficiency improvement by Laser cleaning



Condition

HV = 16kV
Vacuum ; 5.8×10^{-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

Second Nd laser line for SuperKEKB phase II