RFgun and Electron Beam

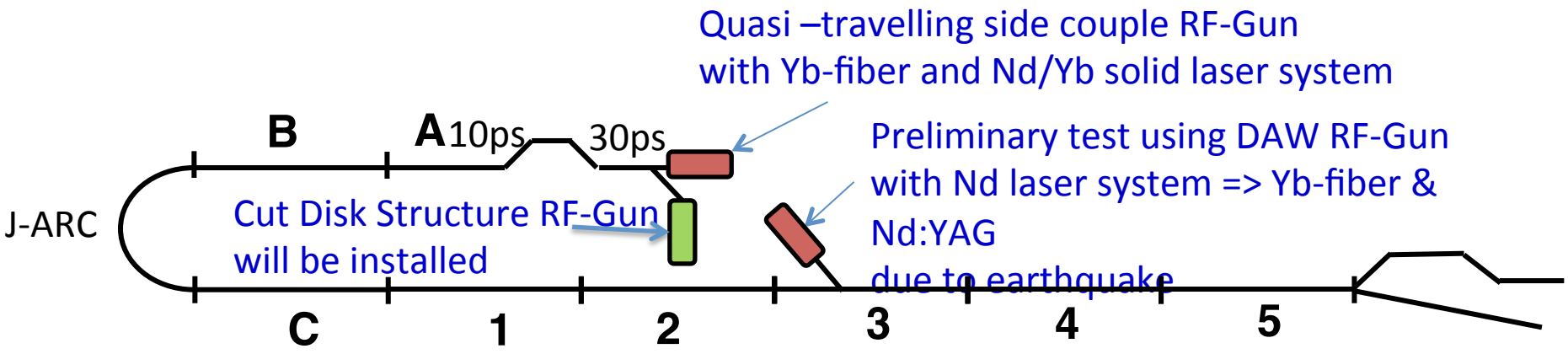
SuperKEKB review @ 14, June, 2016

SuperKEKB upgrade for low emittance electron beam

High charge low emittance is required for SuperKEKB.

	KEKB obtained (e+ / e-)	SuperKEKB required (e+ / e-)
Beam energy	3.5 GeV / 8.0 GeV	4.0 GeV / 7.0 GeV
Bunch charge	e- → e+ / e- 10 → 1.0 nC / 1.0 nC	e- → e+ / e- 10 → 4.0 nC / 5.0 nC
Beam emittance ($\gamma\varepsilon$)[1σ]	2100 μm / 300 μm	6 μm / 20 μm

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



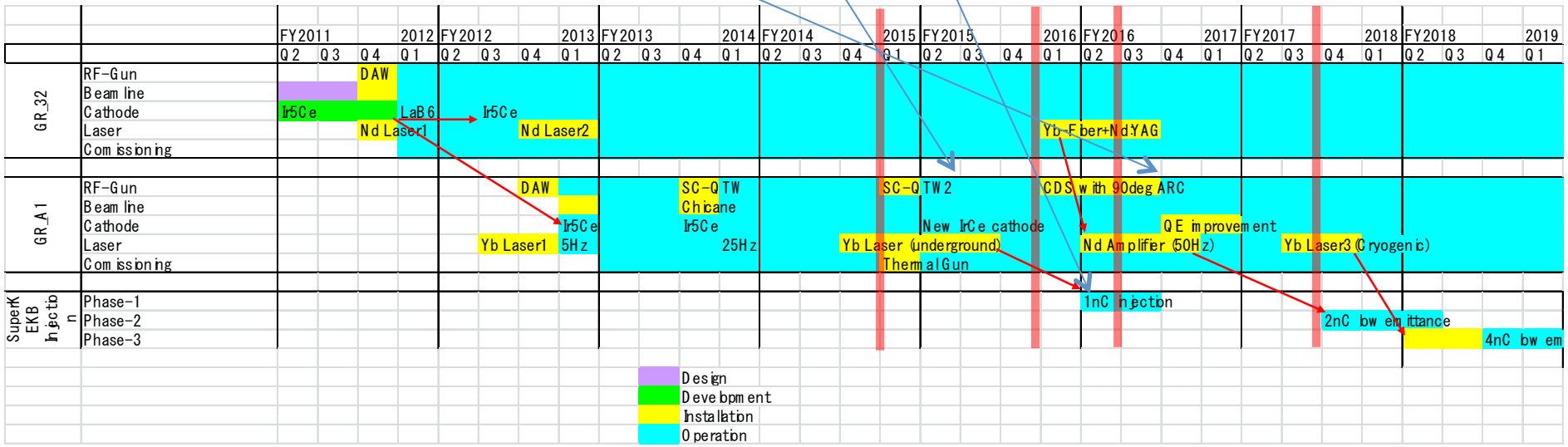
Schedule

- Last Year
  - Reconfigure thermal gun for positron generation
  - Step by step RF-Gun RF ageing.
- Done
  - SuperKEKB injection using stabilized existing undergroud laser (25Hz)
  - New laser system in 3-2 and A-1 ground laser room
    - Increase stability & pulse energy from fiber laser
    - Simplify the laser system (Nd/Yb Regenerative amplifier)
- On going
  - Third RF-Gun (nomal laser injection / cavity modification / cathode change)
  - Simple Nd amplifier for Phase-I & II stable injection

Following the RF-Gun reviewer's comments

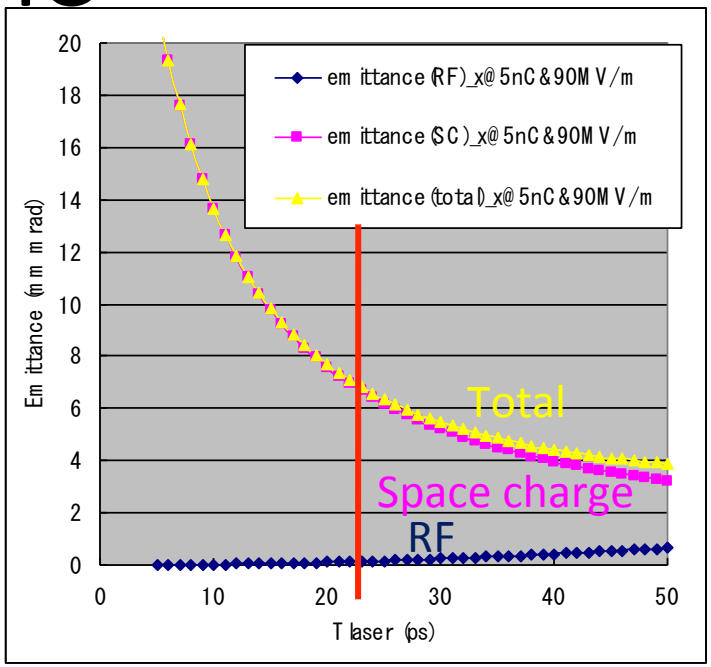
(Postponed the pulse shaping until Phase-III)

10 ps gaussian is enough for Phase-I (1nC) & II (2nC), postponed the pulse shaping until Phase-III



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

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**

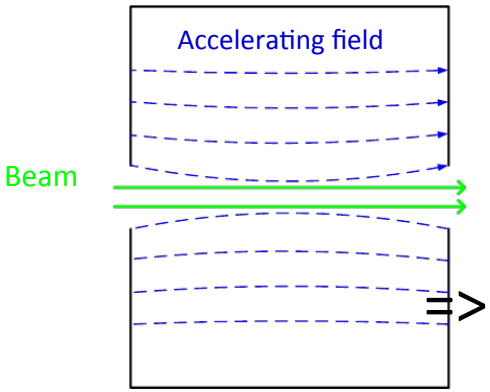
  => Reduce beam divergence and projected emittance dilution
- Cathode : Long term stable cathode
  - Middle QE (QE=10^{-4}～10^{-3} @266nm) and long lifetime
  - Solid material (no thin film) => Metal composite cathode

  => Started from LaB_6 (short life time)

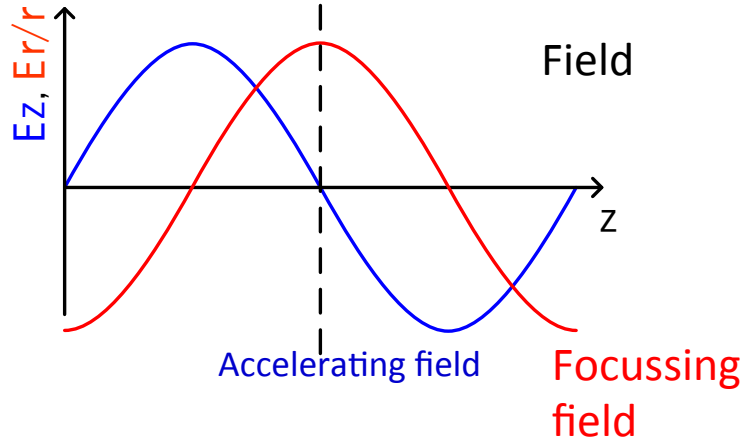
  => **Ir_5Ce has very long life time and QE>10^{-4}** @266nm
- Laser : Stable laser without/with temporal manipulation
  - LD pumped laser medium
    - Nd doped solid laser => 3-2
    - **Yb doped fiber and Nd/Yb solid hybrid laser** => A-1
  - Temporal manipulation => Yb (posteponded until Phase-III)

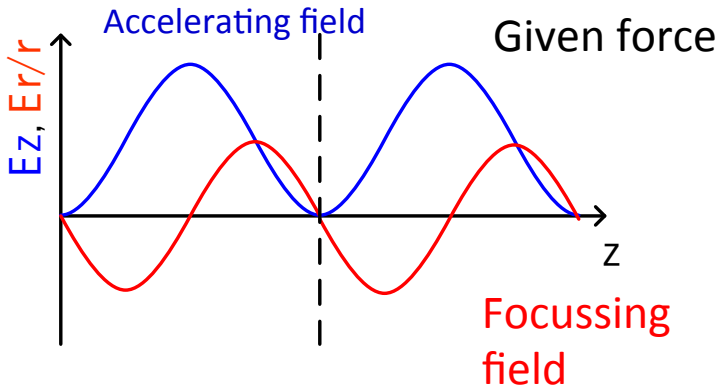
    => Minimum energy spread

Pill-box cavity

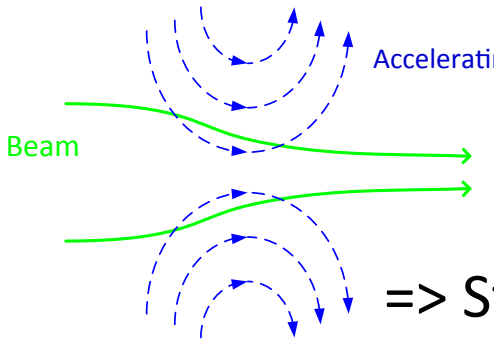


=> Weak focus

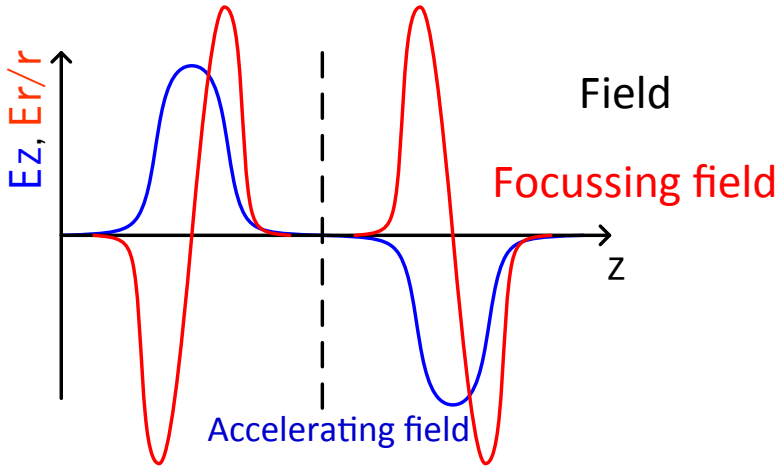


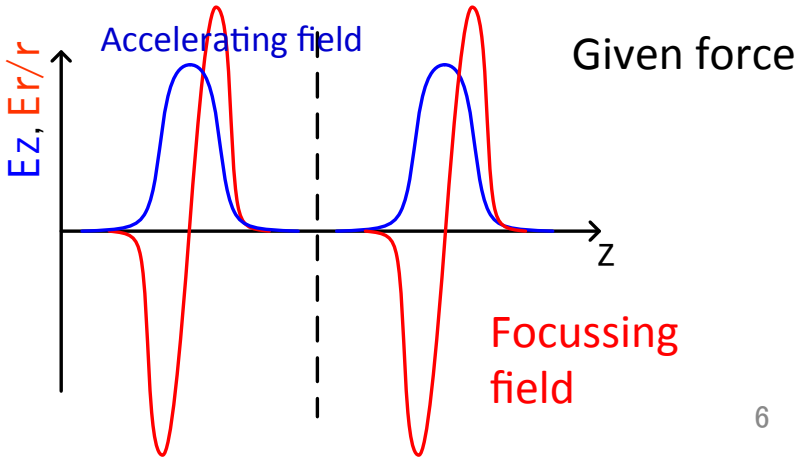


Annular coupled cavity with nose

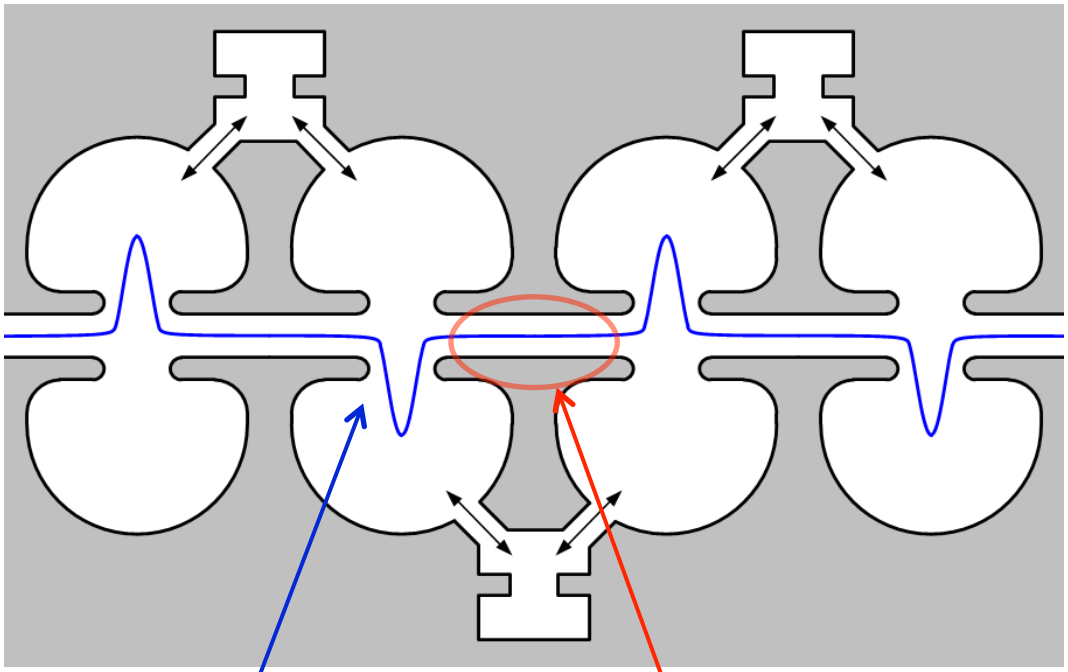


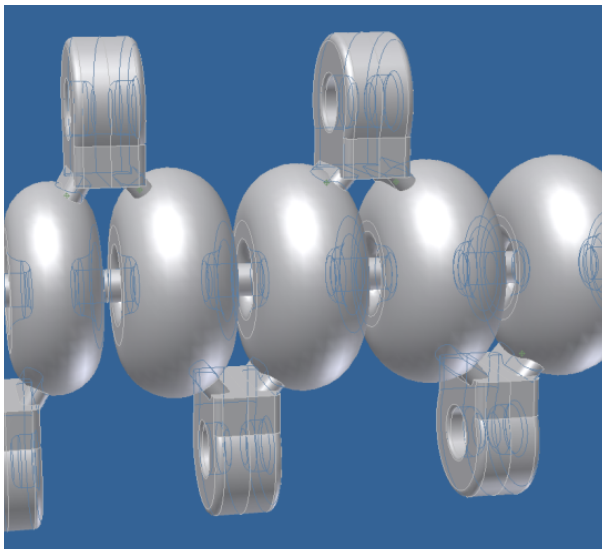
=> Strong focus





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





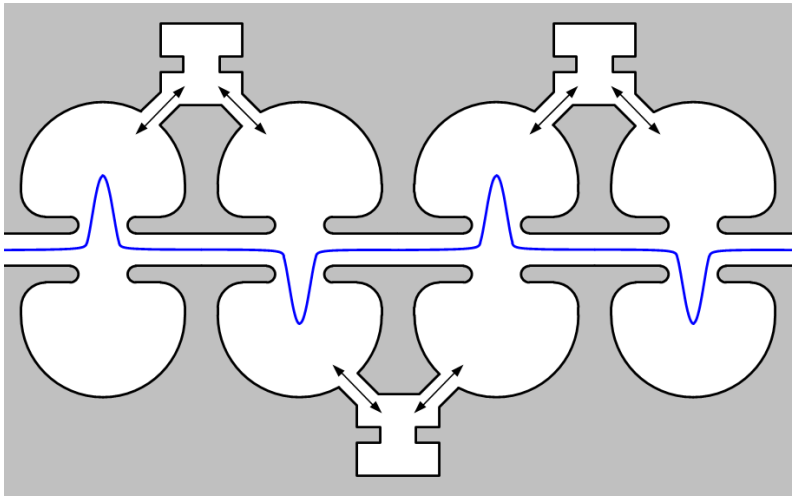
Concentrated field
has focusing effect

This structure has long drift space

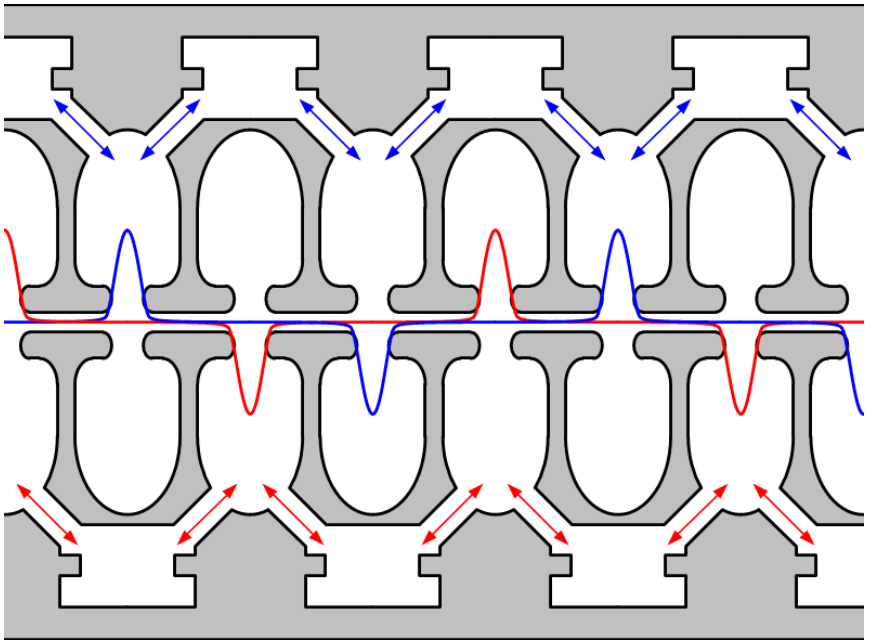
This structure has focusing field.
Long drift space is problem.

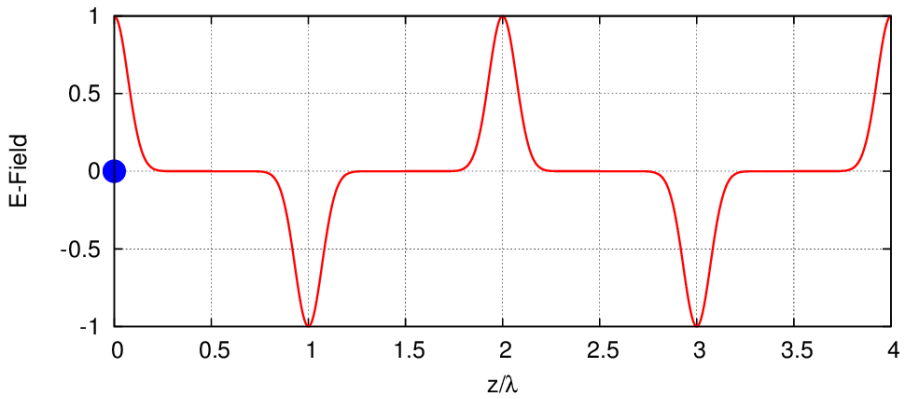
Design of a quasi traveling wave side couple RF gun

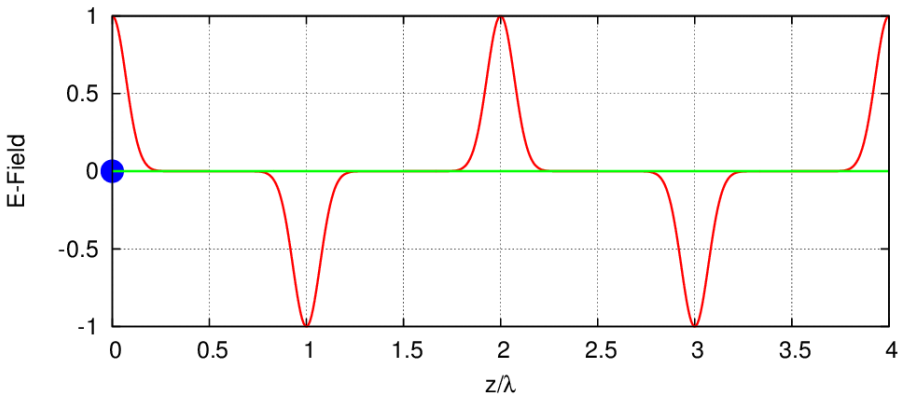
Normal side couple structure



Quasi traveling wave sidecouple structure

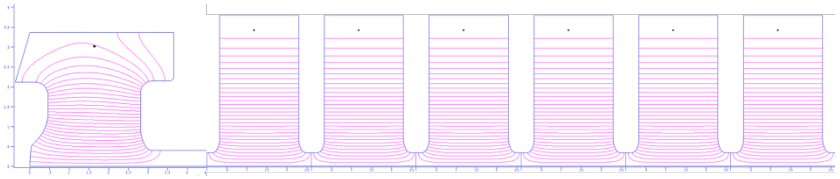




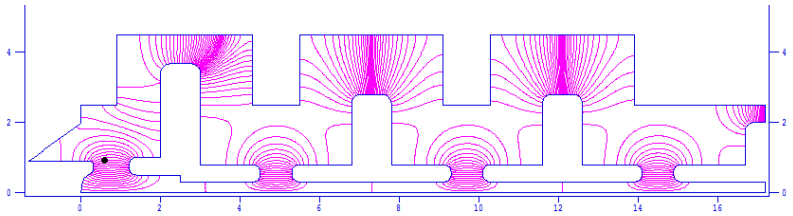


Quasi traveling wave side couple has stronger focusing and accelerated gradient than DAW.

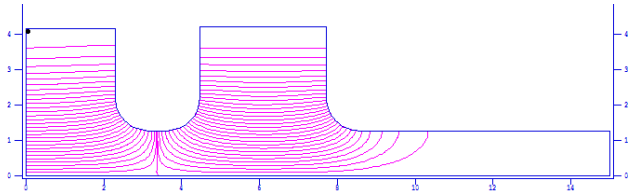
RF-Gun comparison



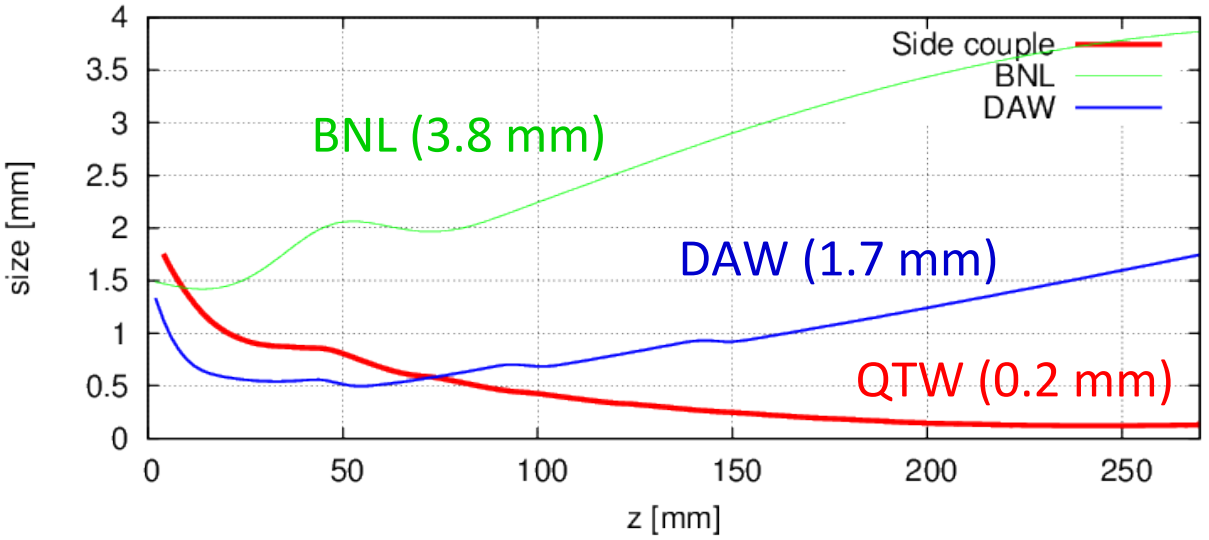
Quasi traveling wave side couple RF gun
(100 MV/m, 6mm-mrad, 13.5 MeV)



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

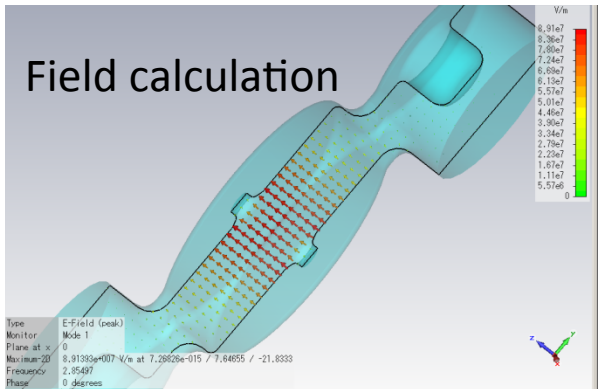


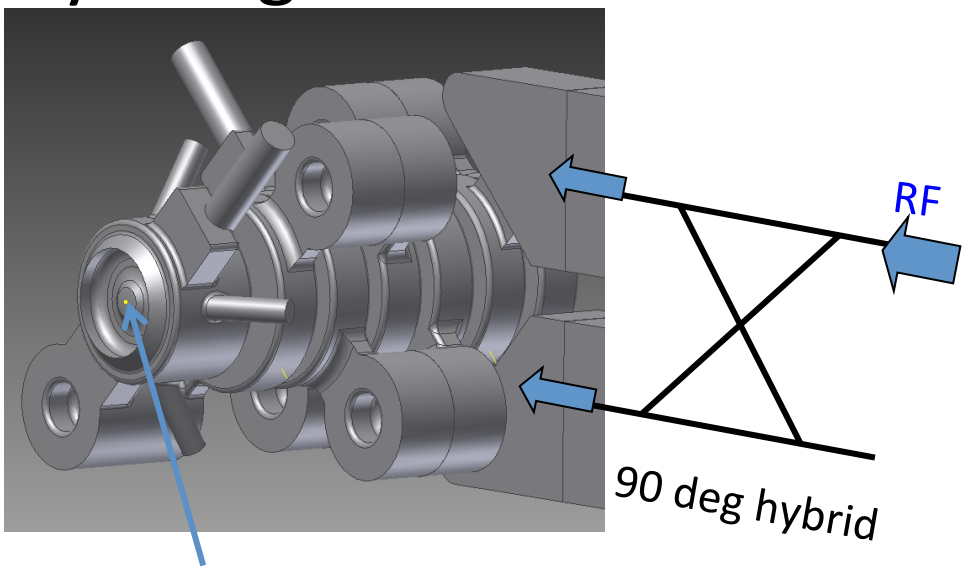
BNL-type RF gun
(120 MV/m, 11.0 mm-mrad, 5.5 MeV)

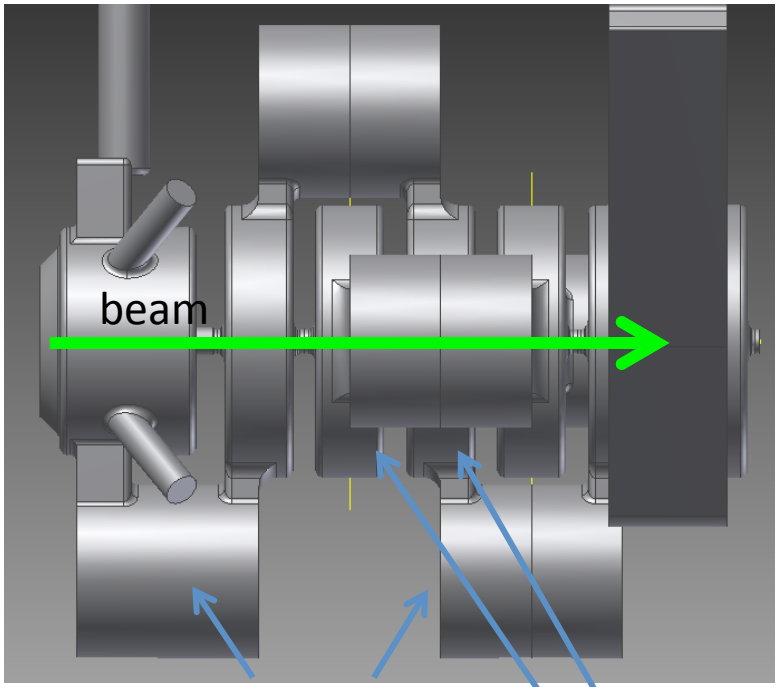


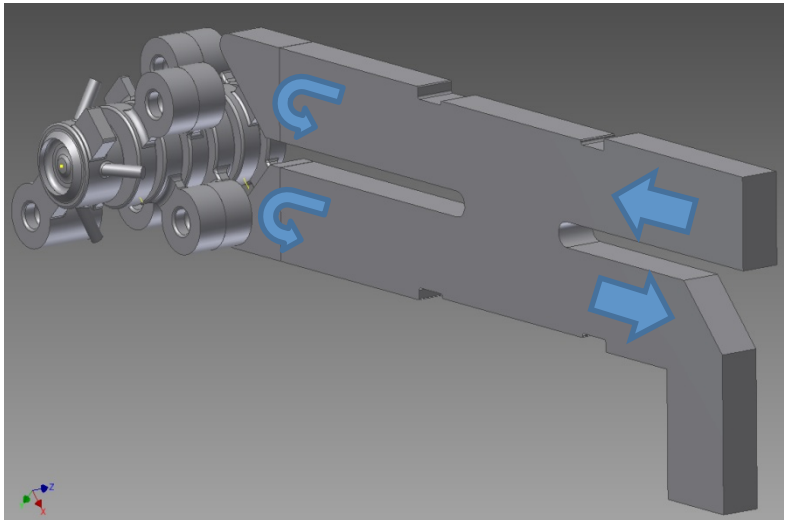
Beam Size

Cavity design



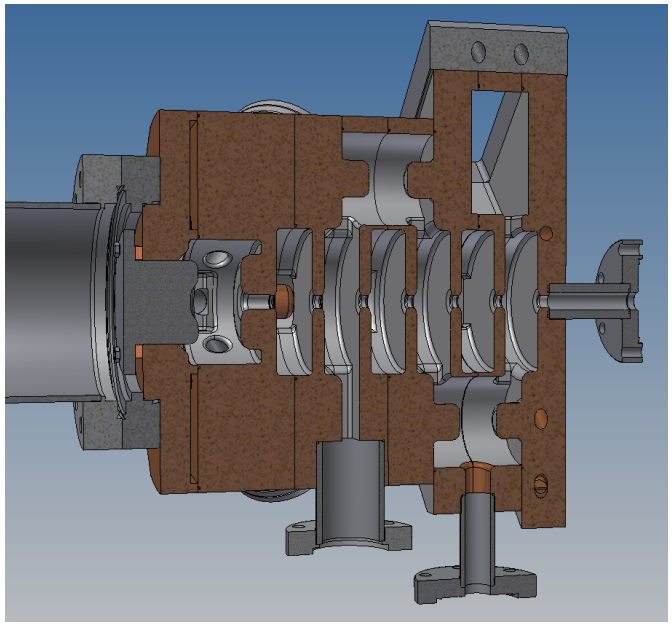


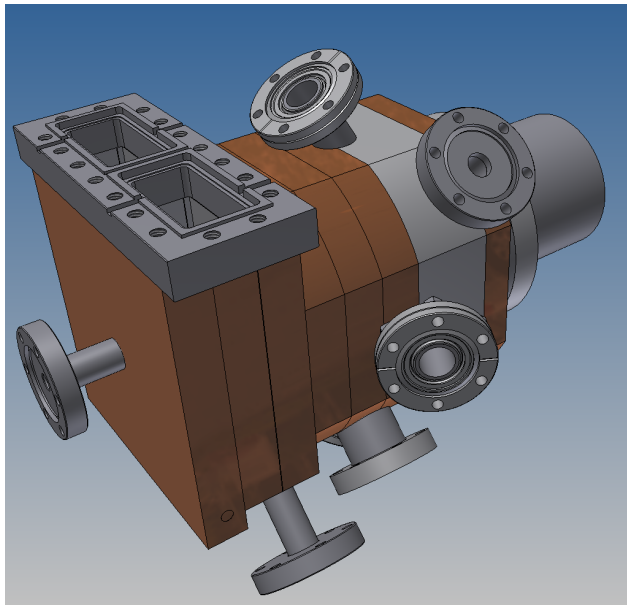


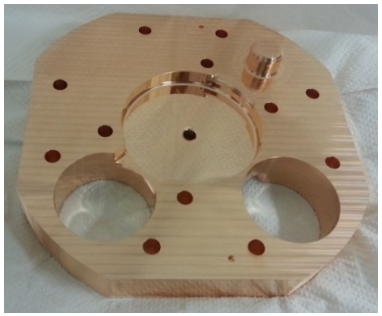


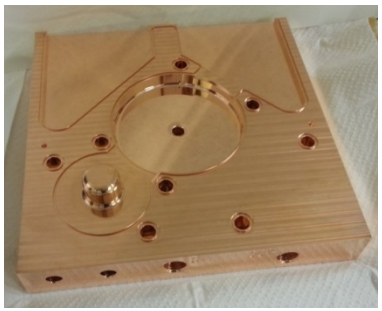
No reflection to klystron

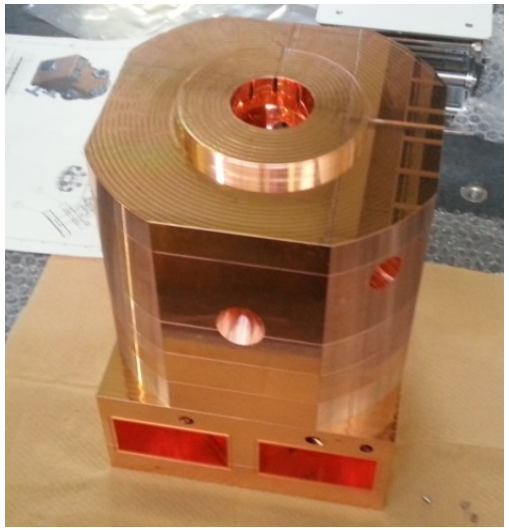
Mechanical design and manufacturing

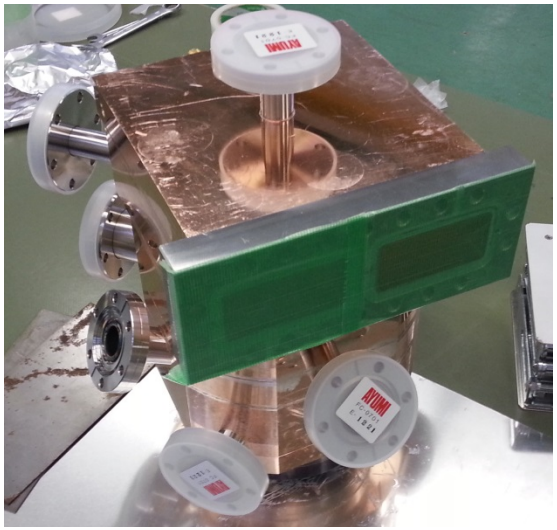




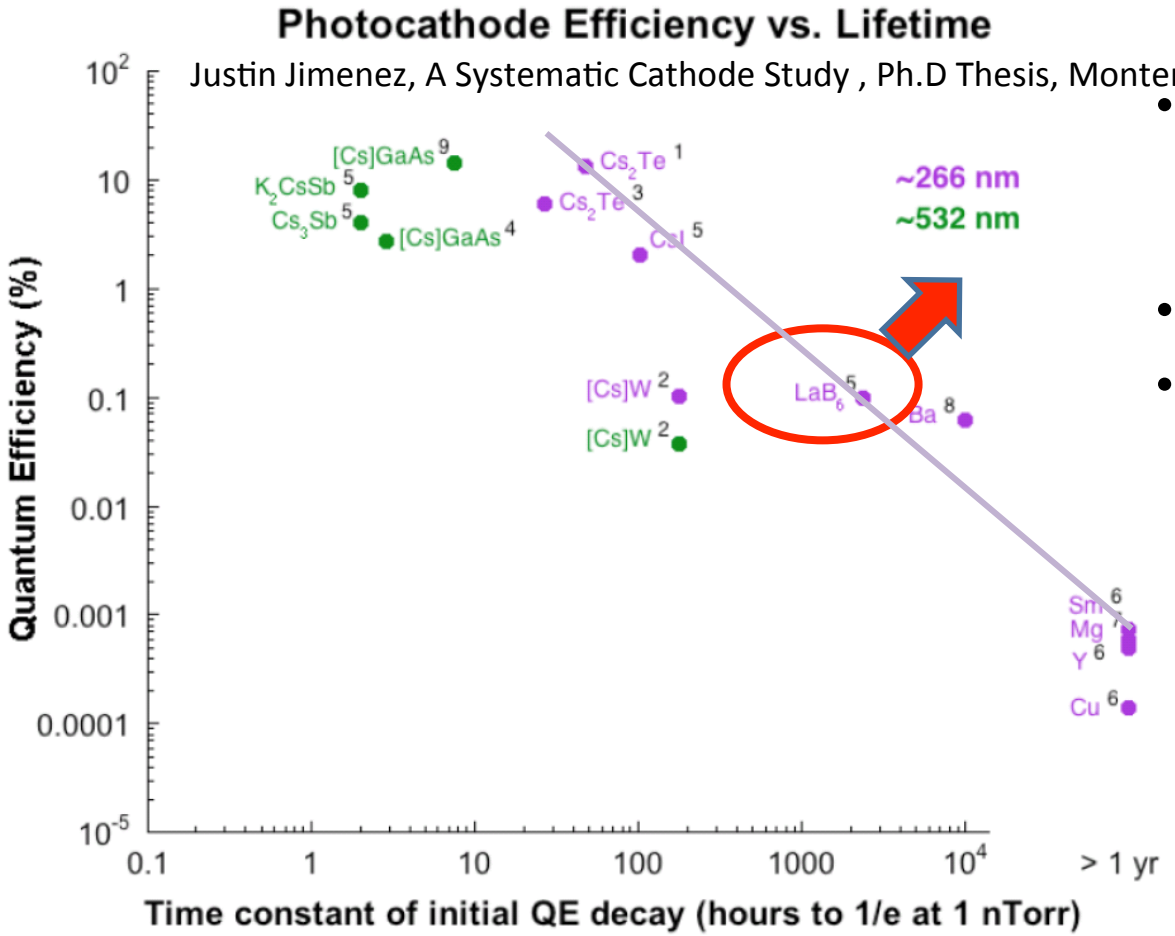








Cathode : Advantage of metal composite cathode (LaB_6 or Ir_5Ce)



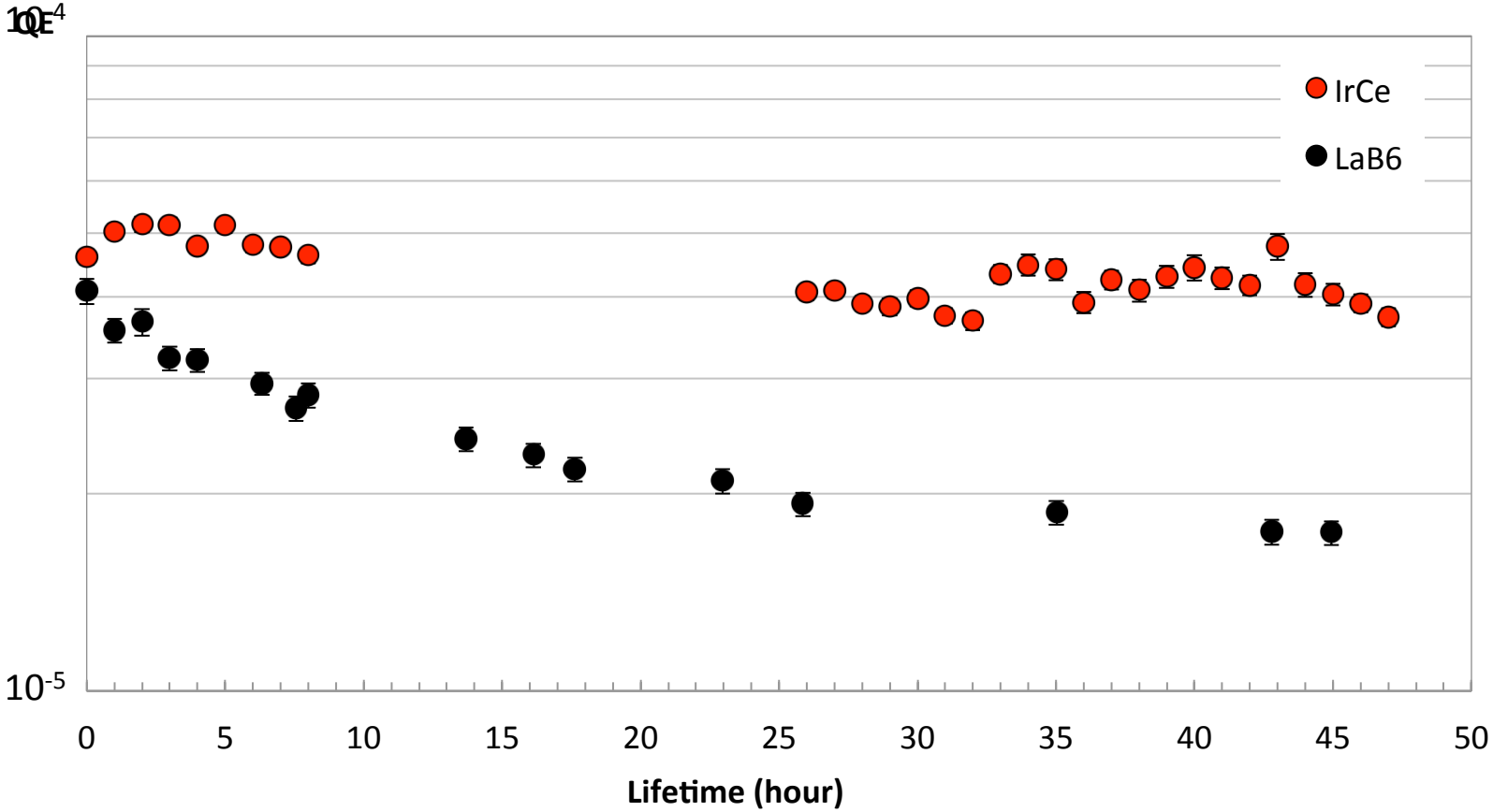
The thermocathodes can also be used as photoemitters [13]. LaB_6 should be noted as a promising photoemitter [14], which has a quantum yield of about 10^{-3} at a laser wavelength of 266 nm and $4 \cdot 10^{-4}$ at 532 nm for face (100).

- 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）

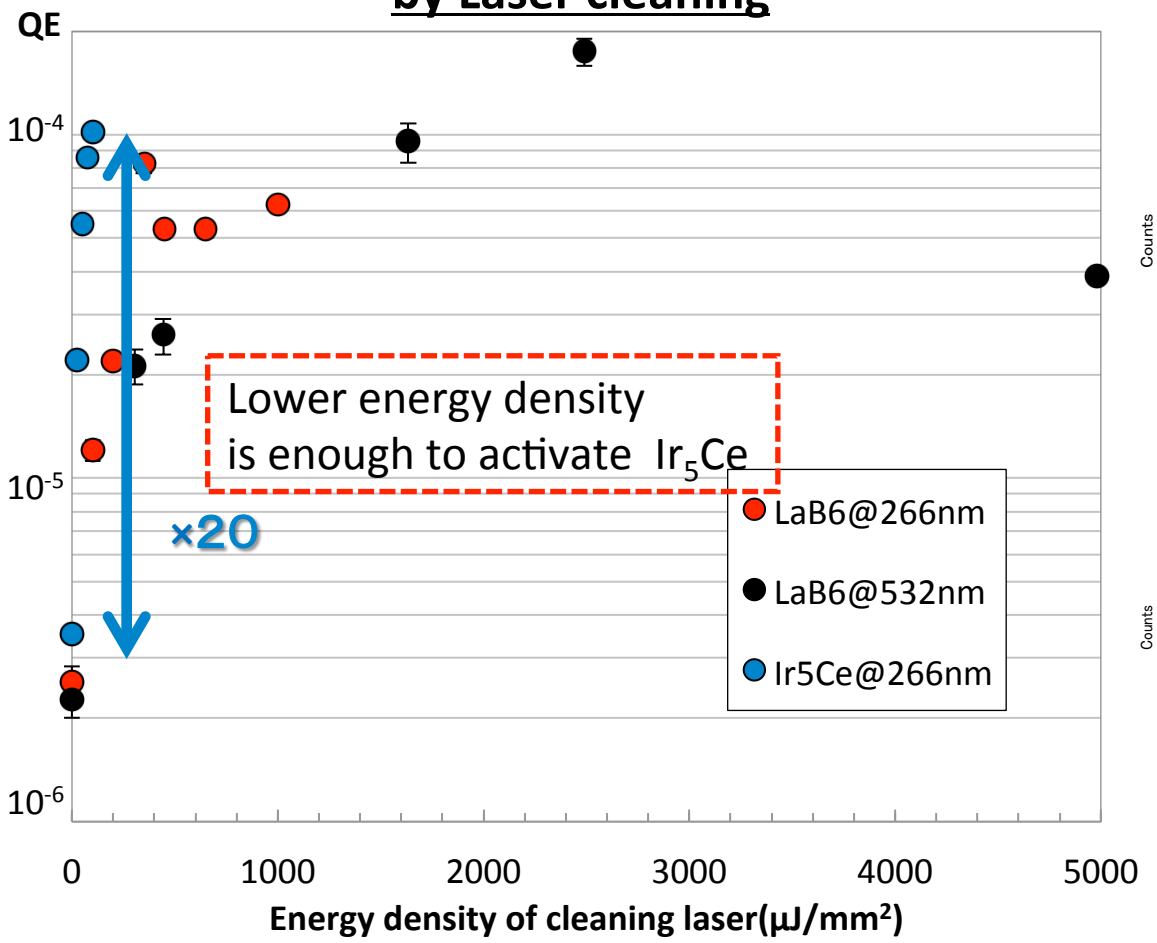


Condition

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

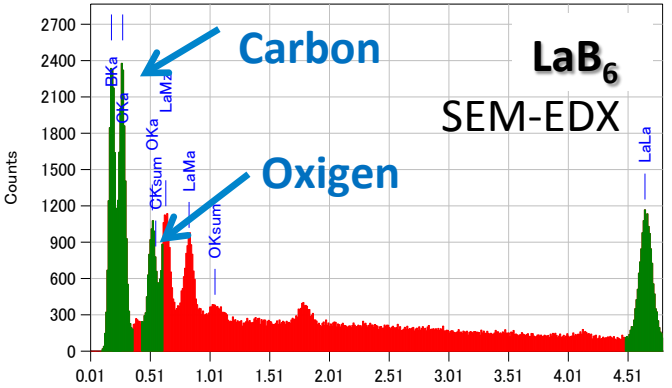
Ir_5Ce Cathode

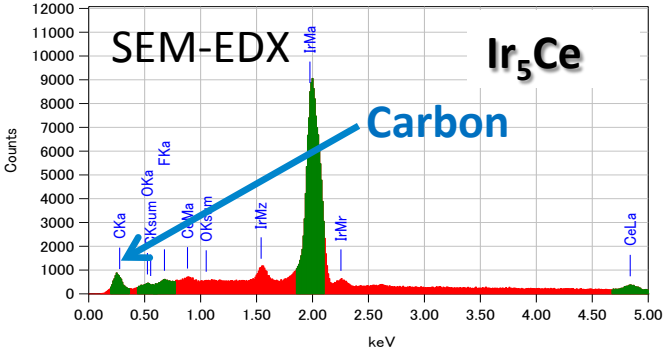
Quantum efficiency improvement by Laser cleaning



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

Cavity RF conditioning

Conditioning progress was too slow aroung 12 MW input.
Frequently brake down was big problem.

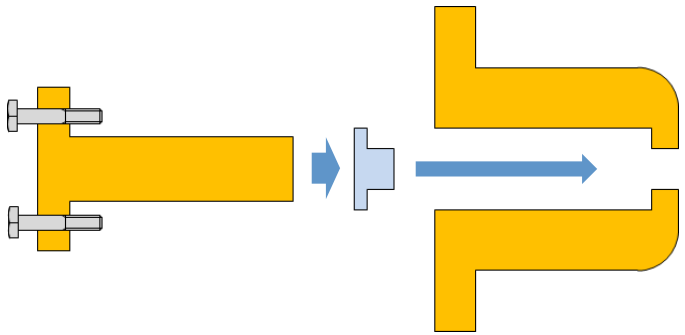
Cathode rod contact?
Cathode material fixation?
Cathode material sputtering due to laser?

We have to separate causes of brake down.

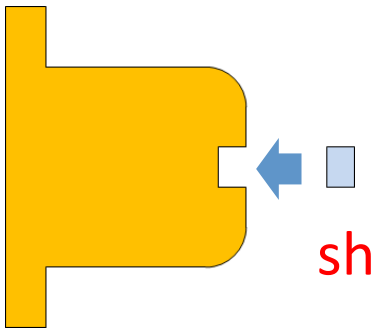
1. Cavity conditioning, used dummy cathode rod without cathode material (all Cu).
2. Replace new cathode rod with material (new fixation is shrinkage fit).
3. For reduce multipactoring effect, another cathode cell design is required.

Build 6-1 ageing stand
A-1 RF-Gun
Third RF-Gun cavity

Current cathode

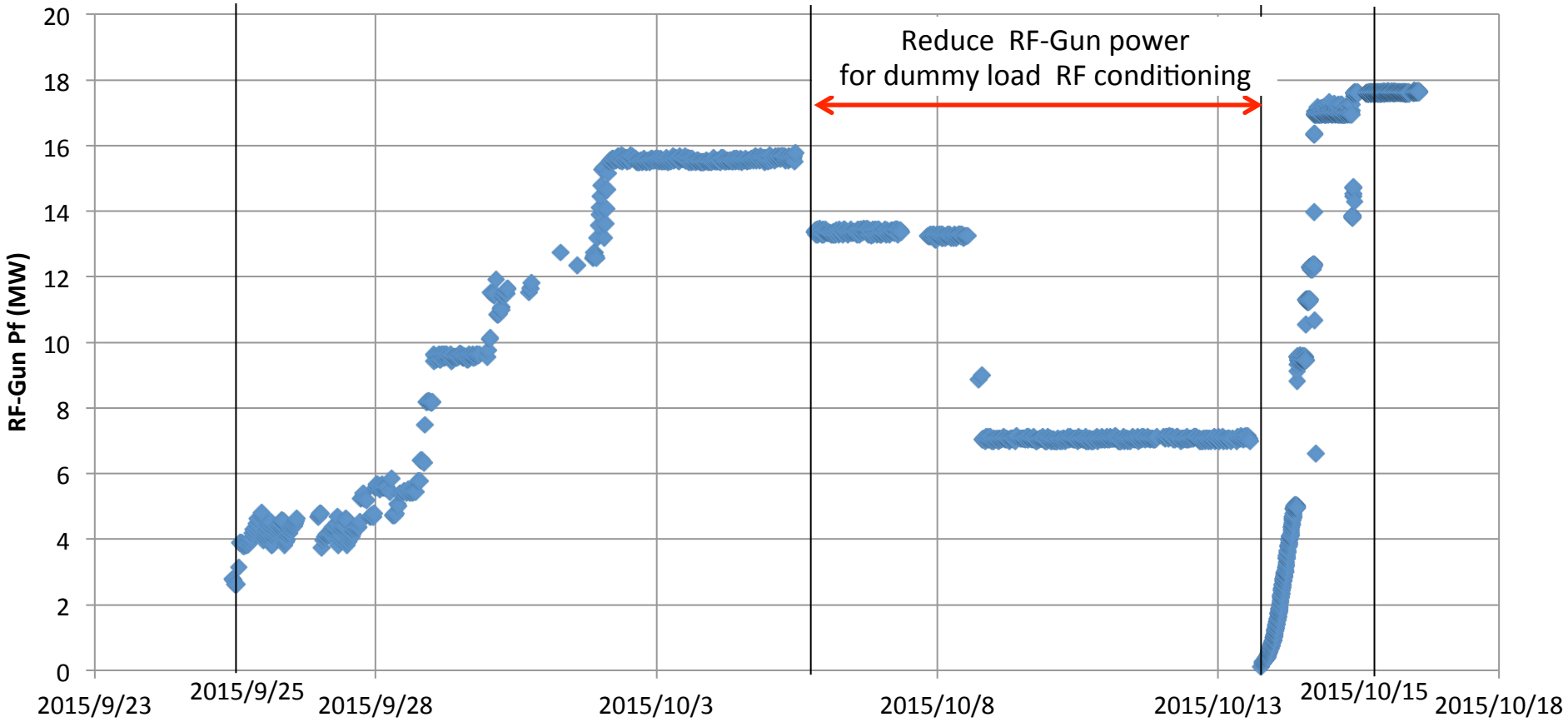


New cathode



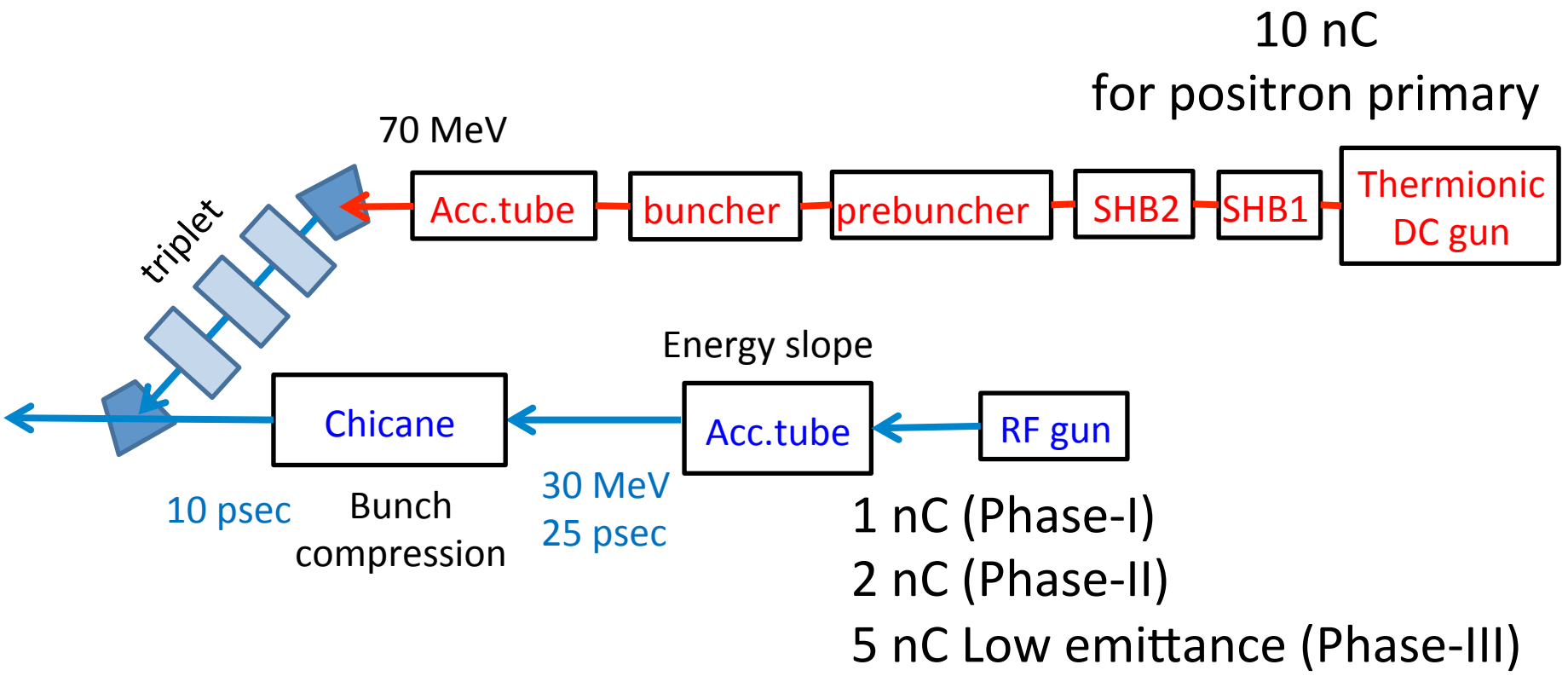
shrinkage fit

History of GR_A1 RF conditioning



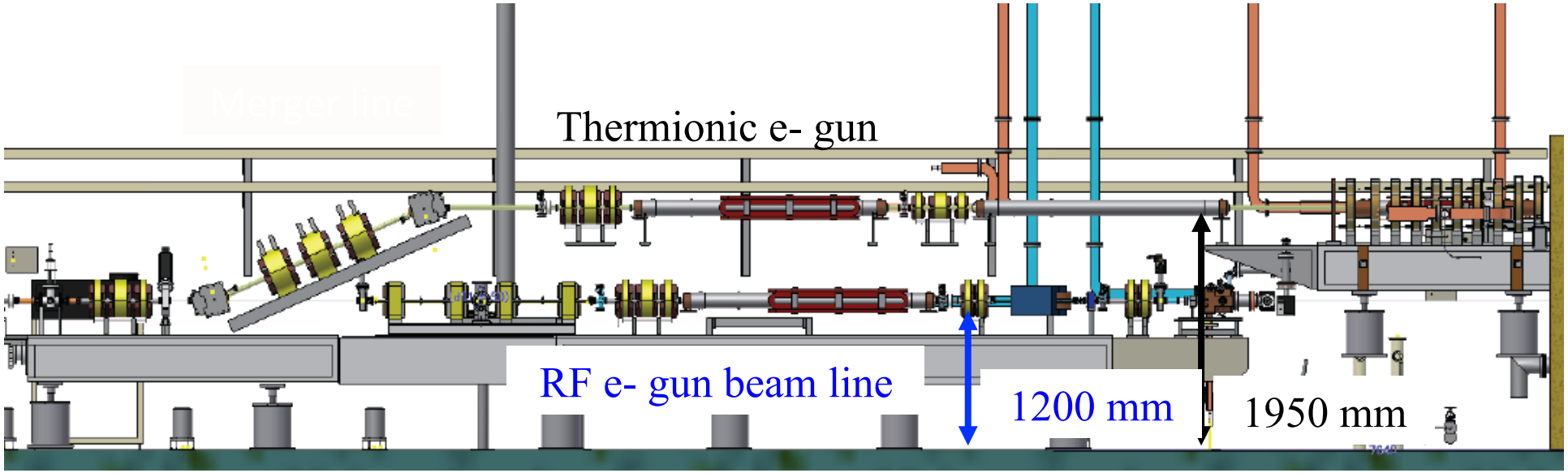
Curent injector beam line on up and down.

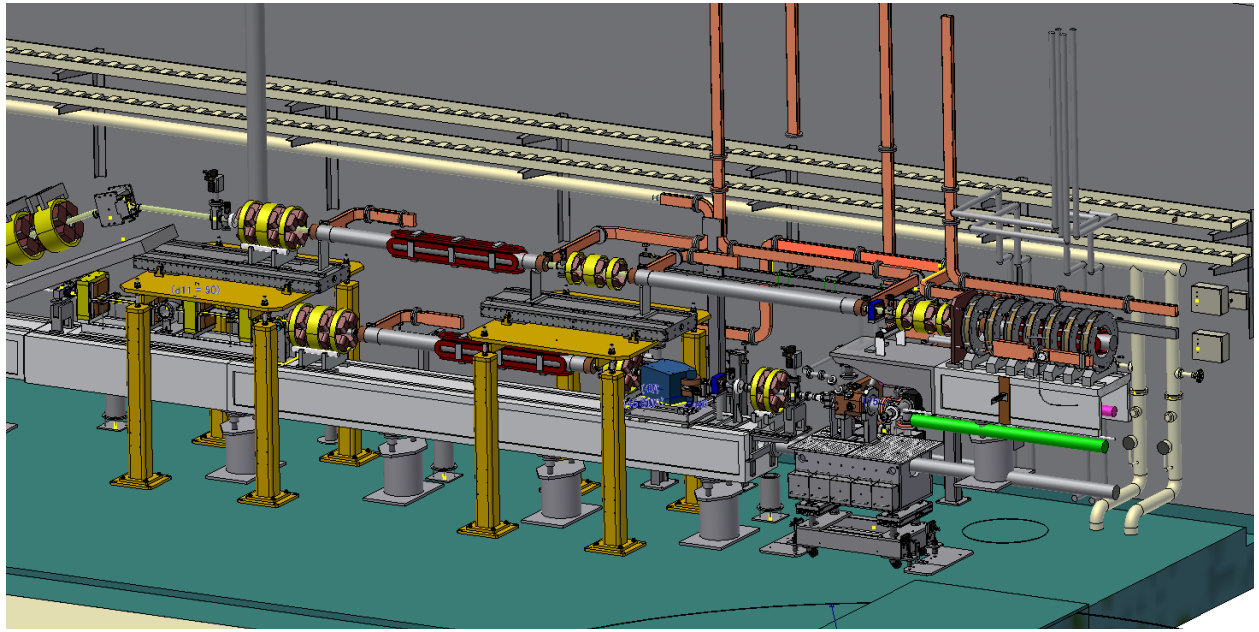
Thermionic DC gun was installed to upper beam line.

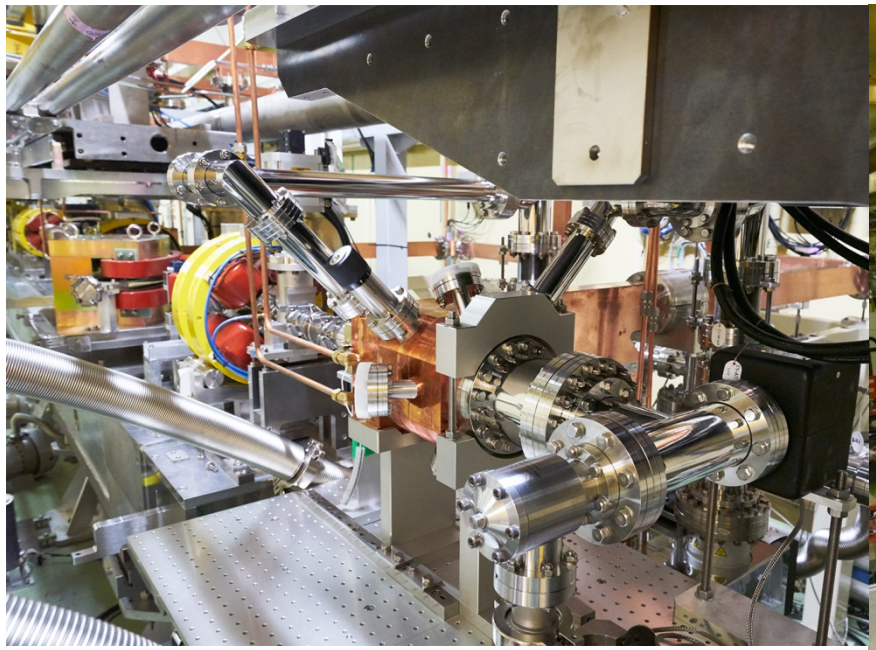


Current setup of unit A1

- Thermionic e- gun has been temporarily back in the end of May,2015.
  - Radiation control license inspection
  - 10 nC e- beam for e+ production
- Beam line remodeling
  - Keep the rf gun beam line almost unchanged (1st acc. stracture was removed)
  - Thermionic e- gun beam line: 1200 mm to 1950 mm
  - Spare magnets have been used for the merger beam line.







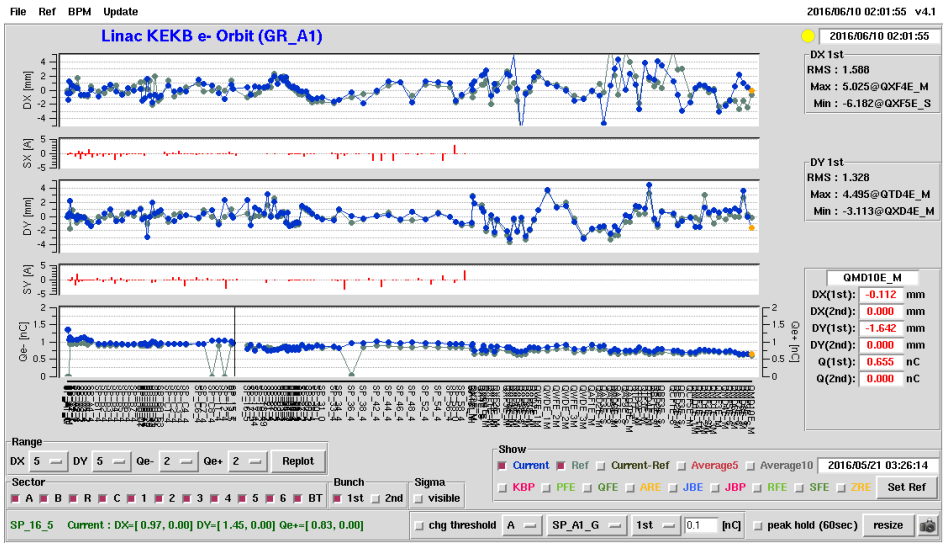

KAMIUCHI

Recent achievement

- Successful injection from RF-Gun to SuperKEKB HER ring with stabilized existing underground laser system.
- RF-Gun
  - The ageing process of the choke structure was done at 6-1 ageing station.
- Improvement on laser system(Zhou)
  - Yb fiber laser
    => 25 ps pulse length is obtained by strecher adjustment.
    Nd solid laser (3-2)
  - Yb solid laser (A-1 underground)

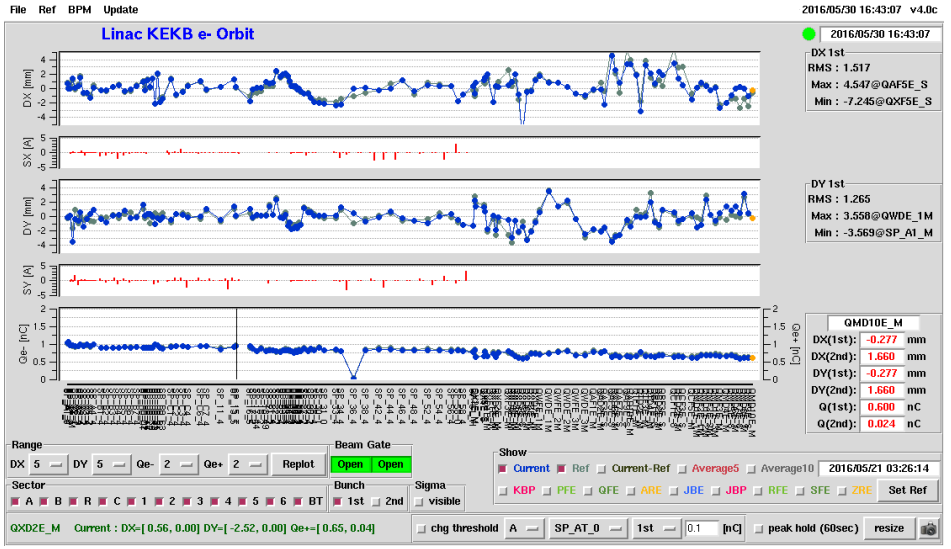
SuperKEKB HER (electron) injection

GR_A1 (RF-Gun)

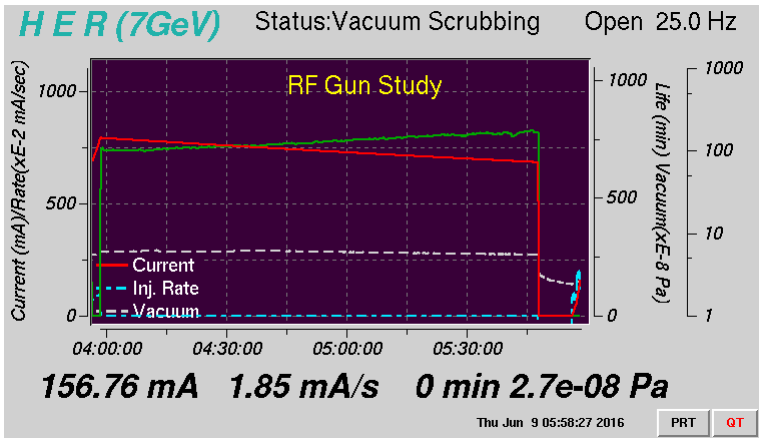


Current(blue) : 2016/06/10 02:01、GR_A1 KEKB HER e- injection
Ref(green) : 2016/05/21 03:26、GU_AT KEKB HER e- injection

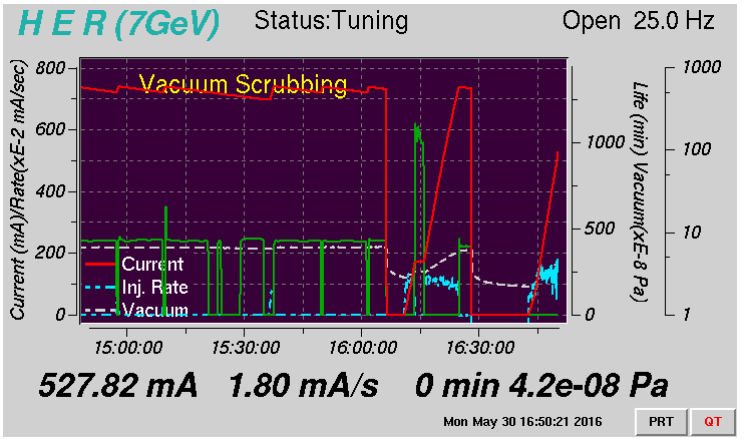
GU_AT (Thermal Electron Gun)



Current(blue) : 2016/05/30 16:43、GU_AT KEKB HER e- injection
Ref(green) : 2016/05/21 03:26、GU_AT KEKB HER e- injection

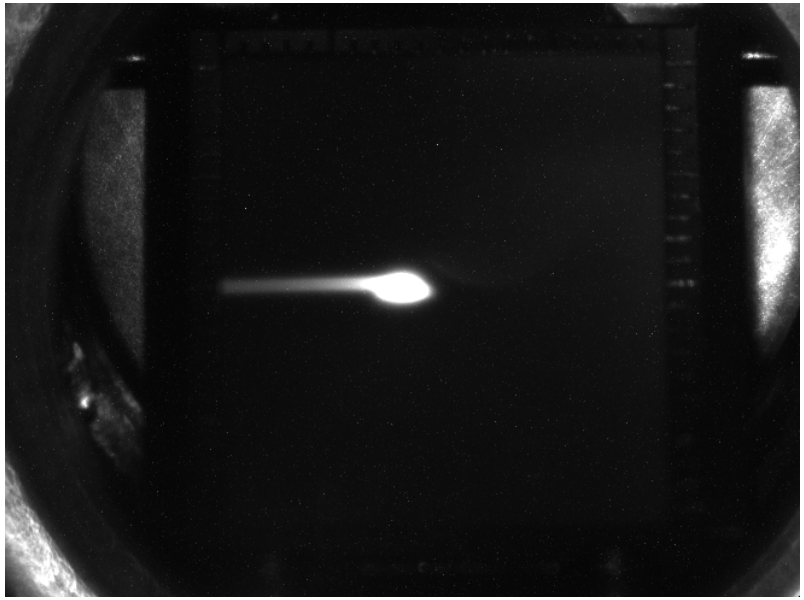


GR_A1 KEKB HER e- injection

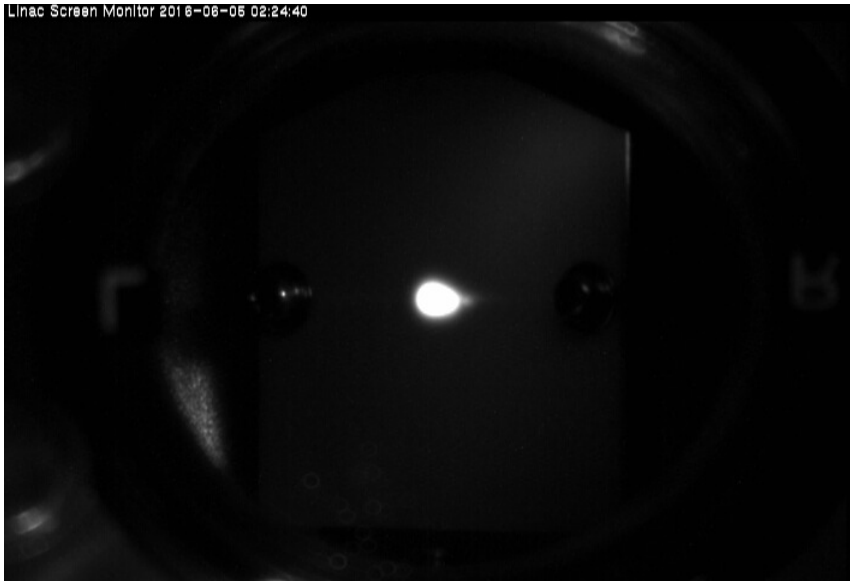


GU_AT KEKB HER e- injection

GR_A1 (RF-Gun) screen at J-ARC

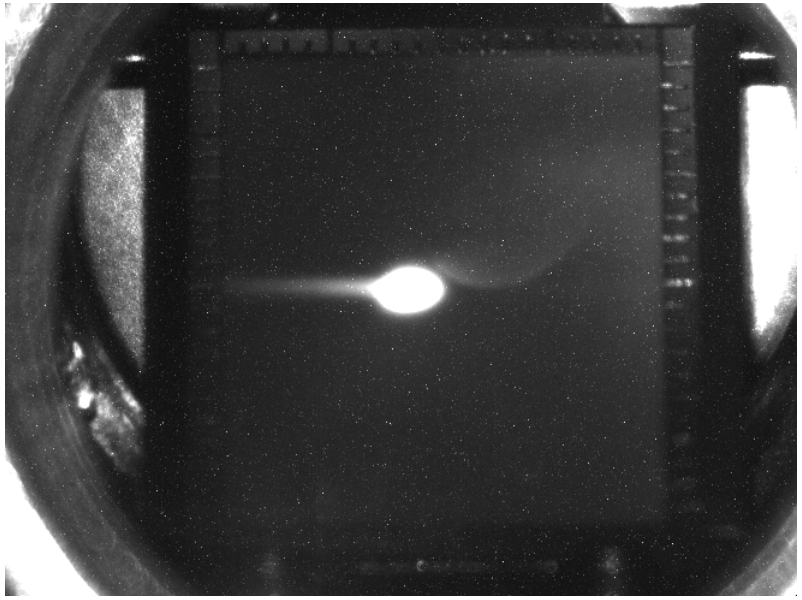


SC_R0_31

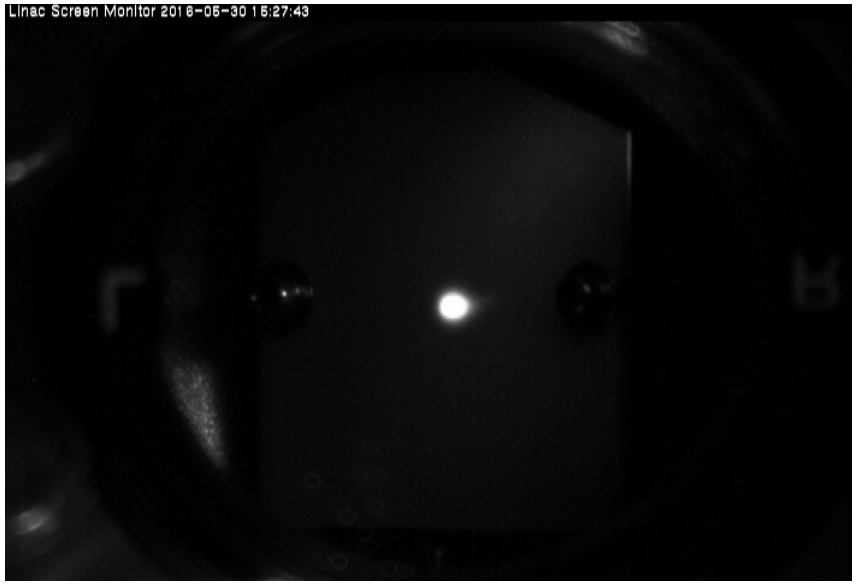


SC_61_H

GU_AT (Thermal Gun) screen at J-ARC

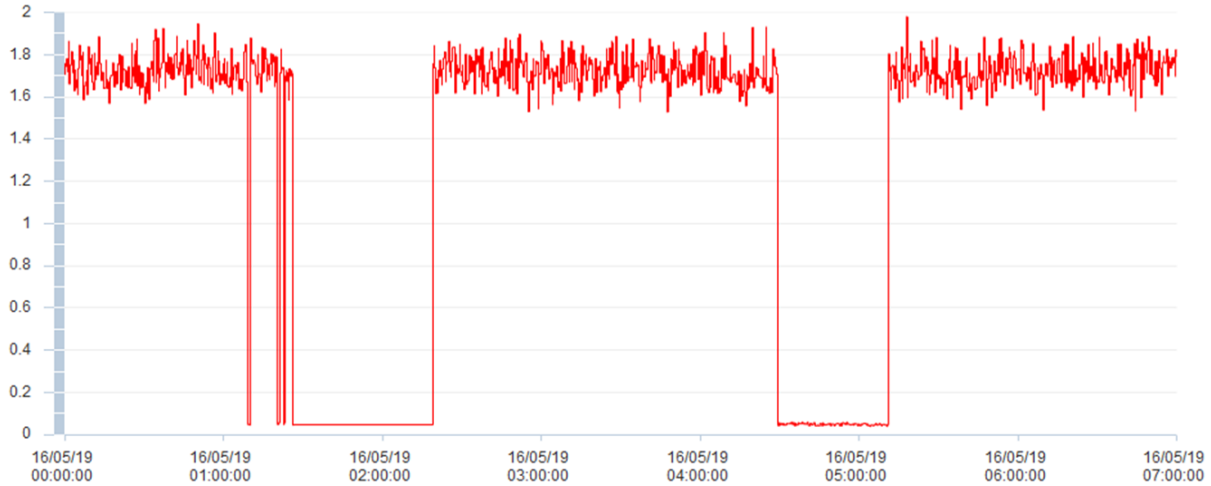


SC_R0_31

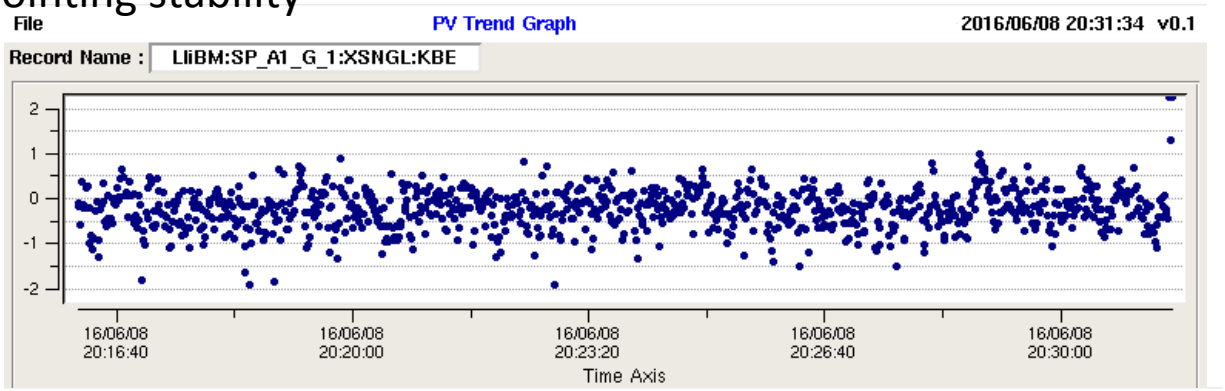


SC_61_H

7 hours beam charge stability. (5/19)

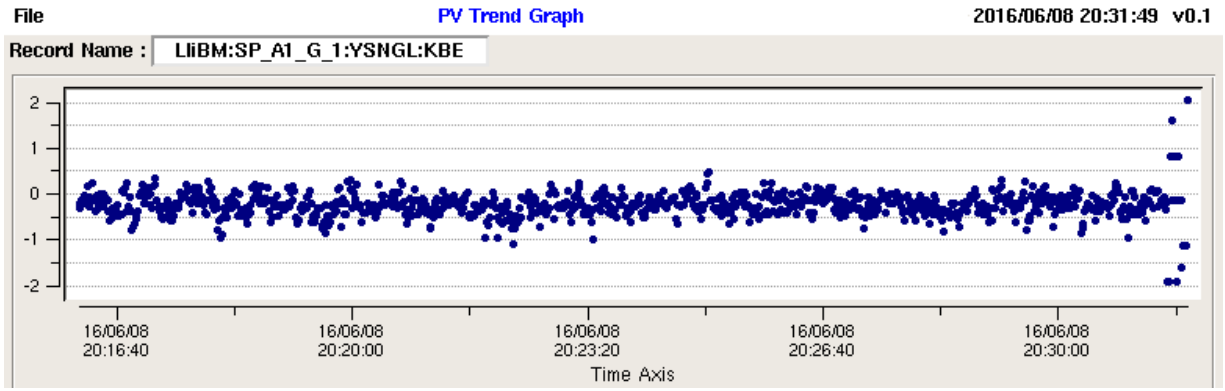


Pointing stability



X

1σ : 0.44 mm

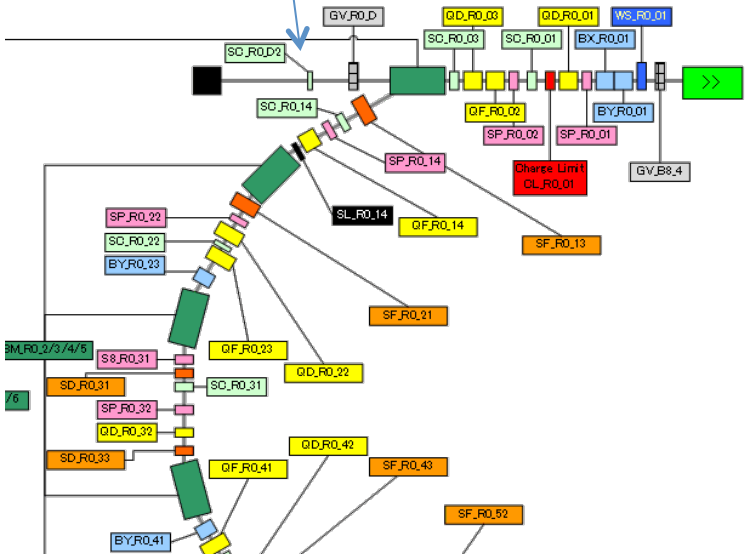


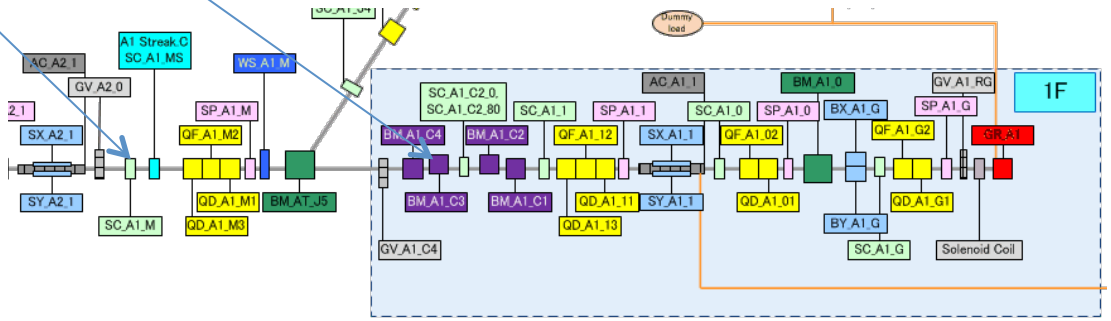
y

1σ : 0.23 mm

Emittance measurement (Q scan method)

	Horizontal (projection)	Vertical (projection)
A1 chicane	28.3 (31.8)	26.4 (29.4)
A1 M	20.3 (20.8)	17.7 (18.3)
B sector dump	48.5 (52.7)	21.7 (22.2)





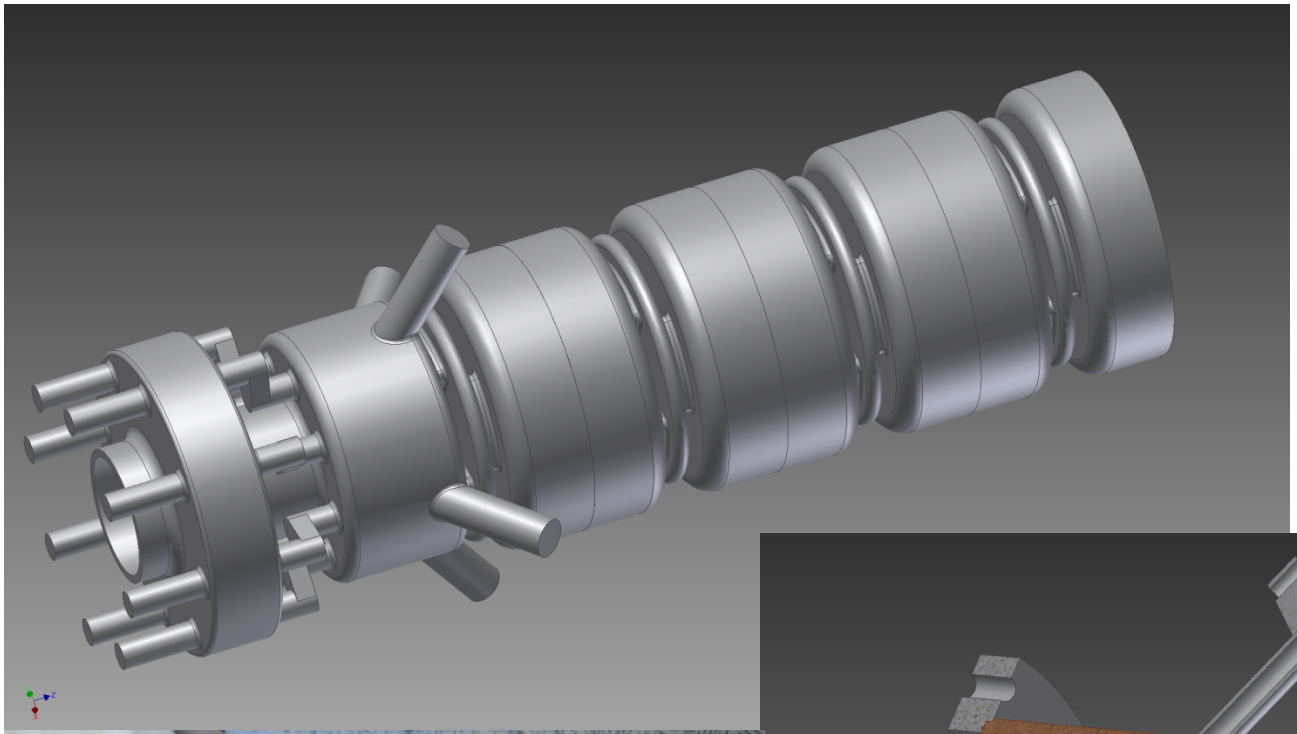
Should improve

- Laser Profile & jitter
- Perpendicular laser injection
- QE uniformity of IrCe cathode

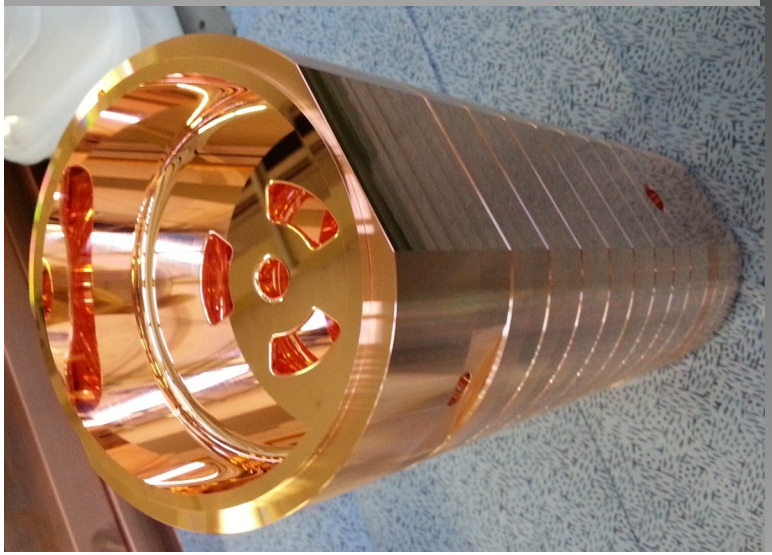
On-going R&D for RF-Gun

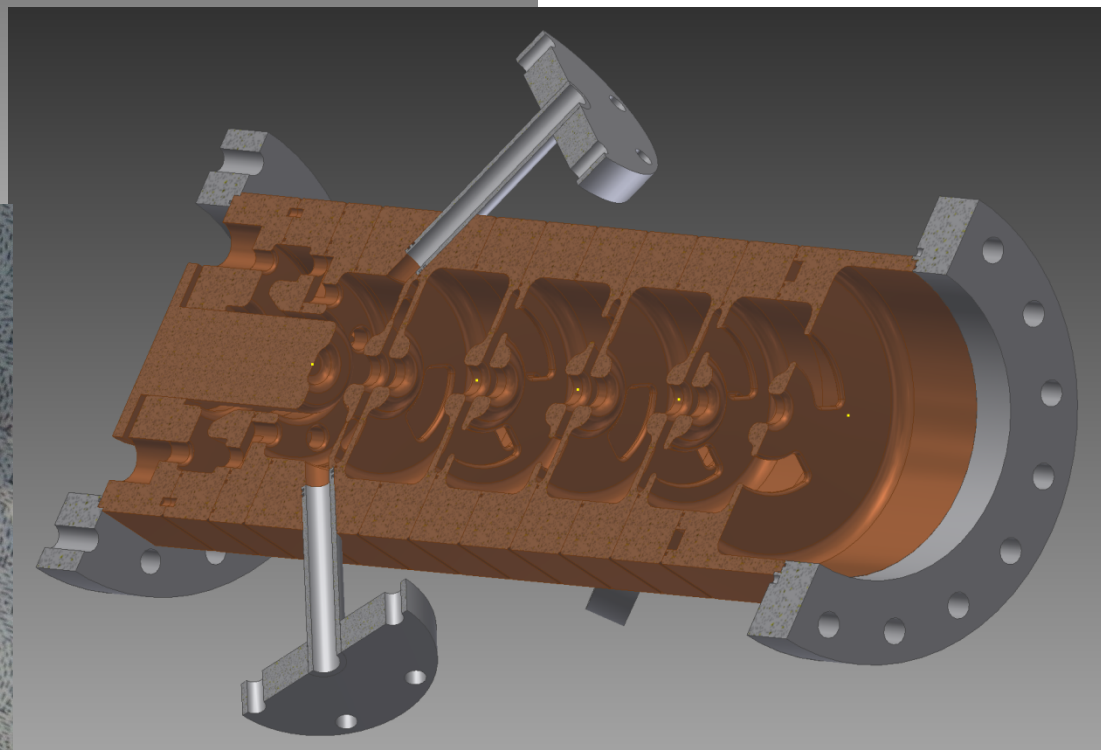
- RF-Gun
  - New CDS-type RF-Gun is under fabrication
    Larger beam aperture
    Simple structure enough for 5 nC generation
  - Second RF-Gun installation with 90-degree arc section.
- Cathode
  - QE improvement of IrCe cathode :
    Ir_7Ce_2 => better uniformity
    Single Crystal => better QE
  - Thermal assist for higher QE & cathode cleaning

Simple cavity RF gun is developed for test

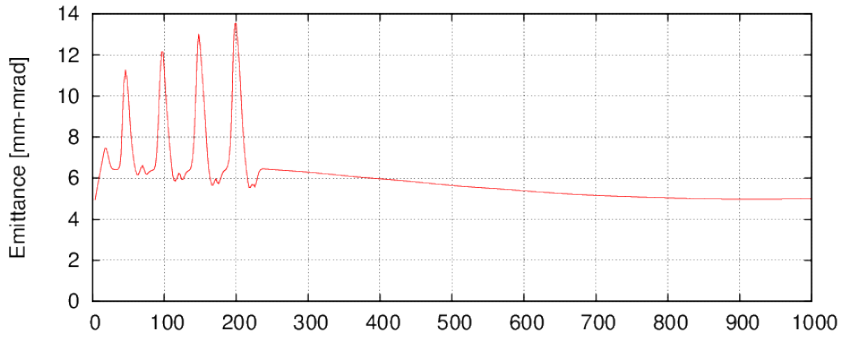


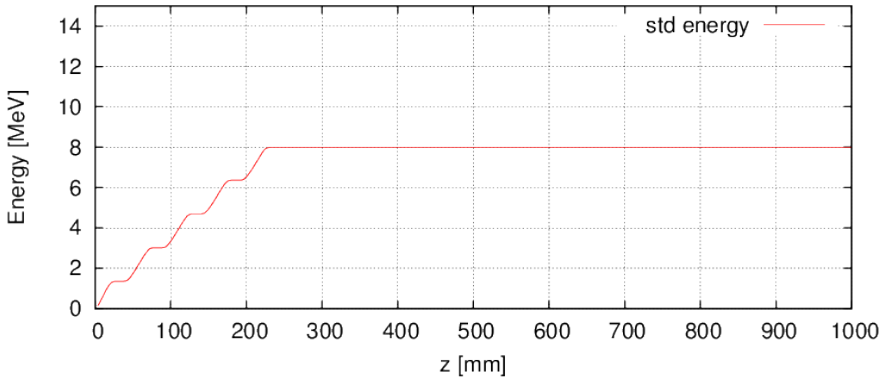
Cut Disk Structure (CDS)

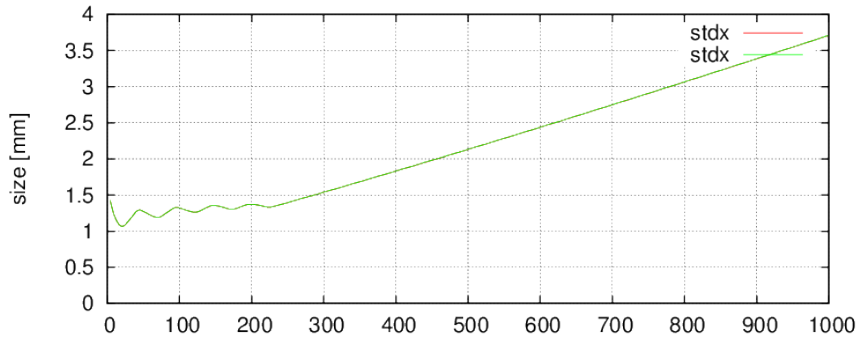


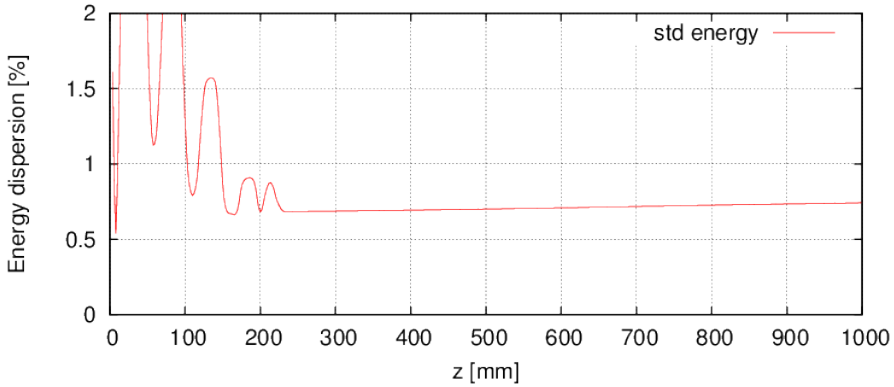


In the simulation, 5 nC beam generation is possible

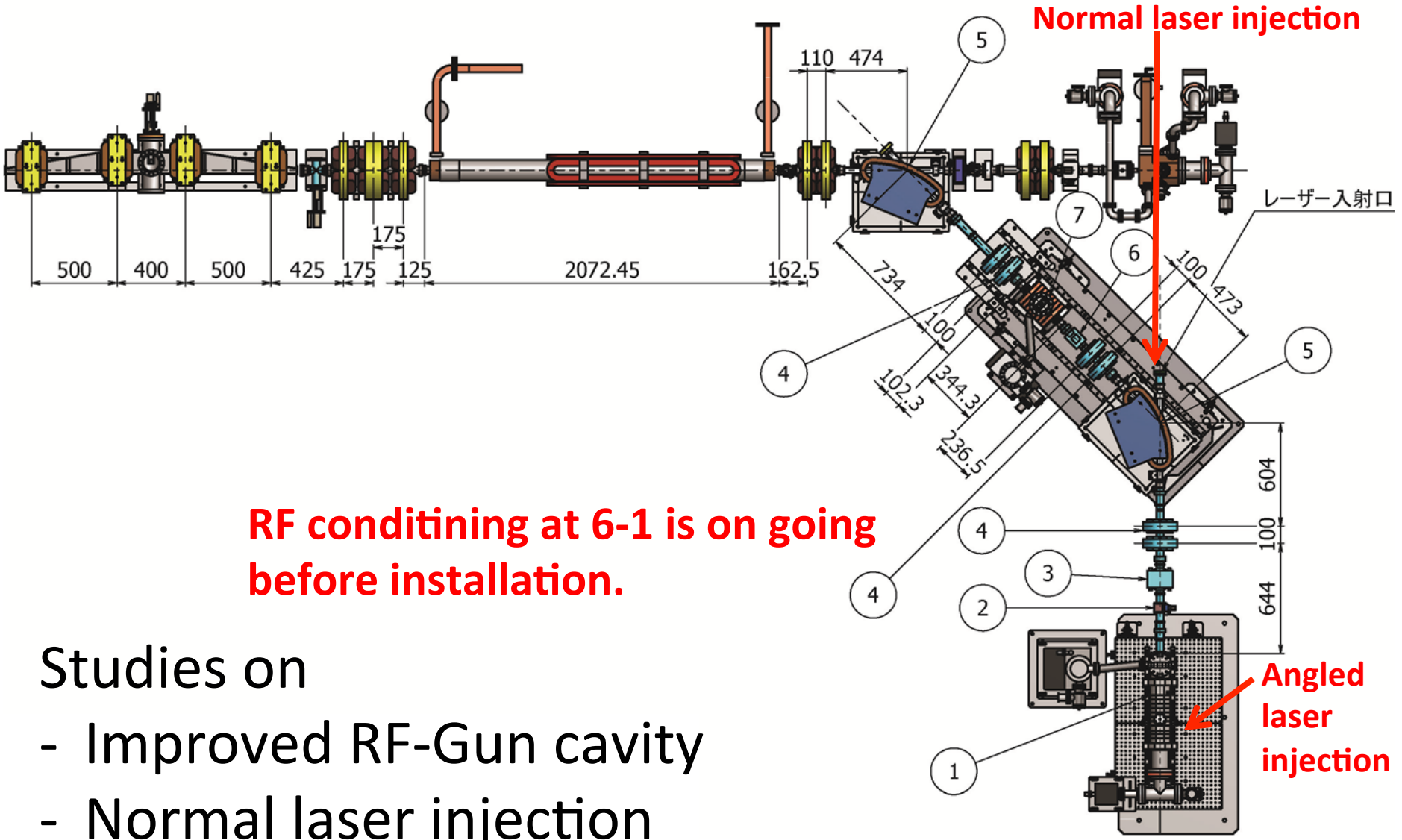








Second RF gun on the 45 degree line



RF conditining at 6-1 is on going before installation.

Studies on

- Improved RF-Gun cavity
- Normal laser injection
- Changeable cathode including alkaline cathode

Schedule

- Last Year
  - Reconfigure thermal gun for positron generation
  - Step by step RF-Gun RF ageing.
- Done
  - SuperKEKB injection using stabilized existing undergroud laser (25Hz)
  - New laser system in 3-2 and A-1 ground laser room
    - Increase stability & pulse energy from fiber laser
    - Simplify the laser system (Nd/Yb Regenerative amplifier)
- On going
  - Third RF-Gun (nomal laser injection / cavity modification / cathode change)
  - Simple Nd amplifier for Phase-I & II stable injection

Following the RF-Gun reviewer's comments

(Postponed the pulse shaping until Phase-III)

10 ps gaussian is enough for Phase-I (1nC) & II (2nC), postponed the pulse shaping until Phase-III