RF-Gun and beam transport

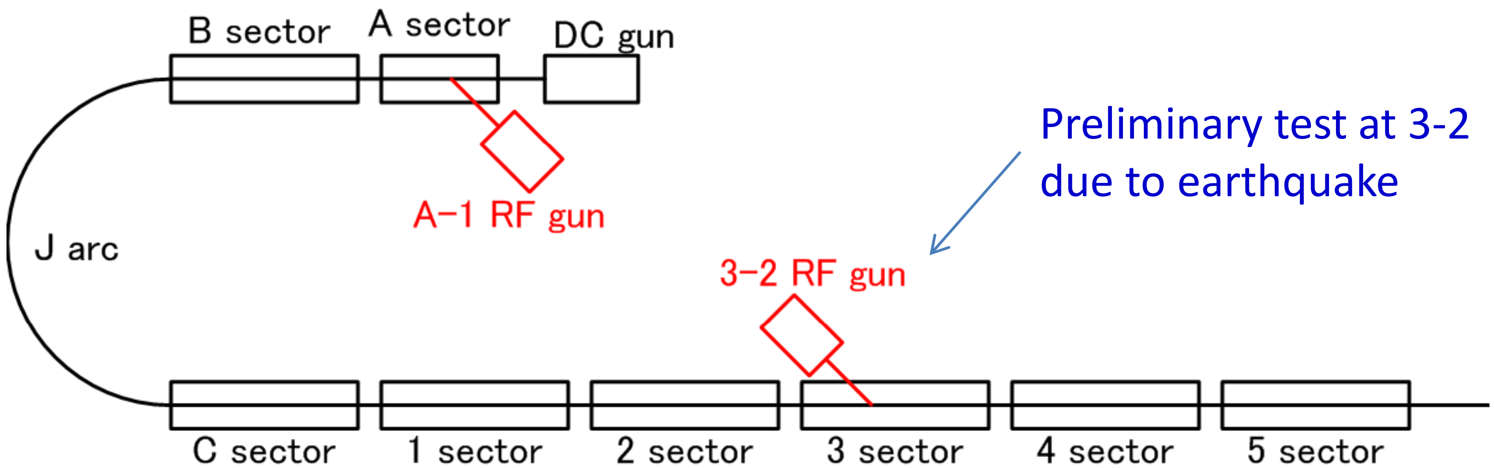
Mitsuhiro Yoshida

SuperKEKB upgrade for low emittance electron beam

High charge low emittance is required for SuperKEKB.

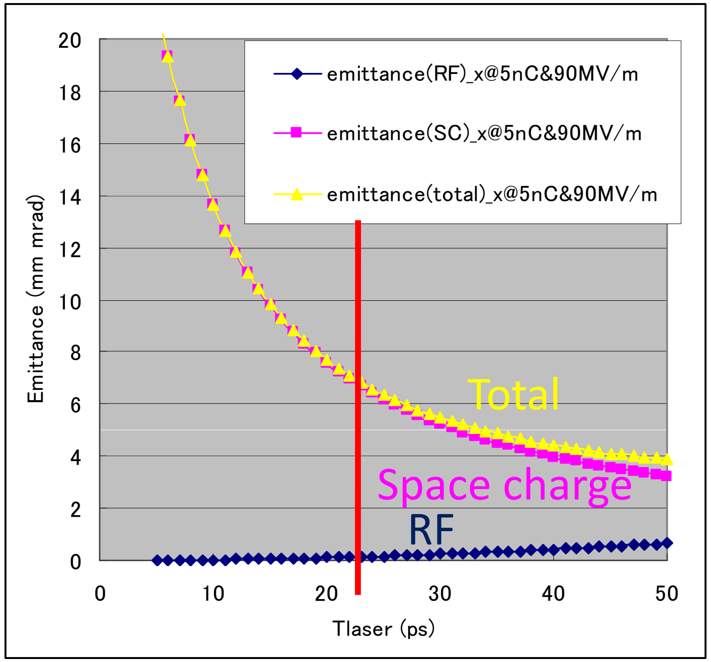
	KEKB obtained (e+ / e-)	SuperKEKB required (e+ / e-)
Beam energy	3.5 GeV / 8.0 GeV	4.0 GeV / 7.0 GeV
Bunch charge	e- → e+ / e- 10 → 1.0 nC / 1.0 nC	e- → e+ / e- 10 → 4.0 nC / 5.0 nC
Beam emittance (γε)[1σ]	2100 μm / 300 μm	6 μm / 20 μm

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



- RF-Gun
  - **Design of RF-Gun cavity**
    - **Disk-And-Washer (DAW)**
    - **Quasi travelling wave side couple**
  - Cathode
  - Laser
  - Test stand and schedule
- Emittance preservation
  - Alignment
  - Beam transport
  - Beam diagnostics

RF-Gun for 5 nC

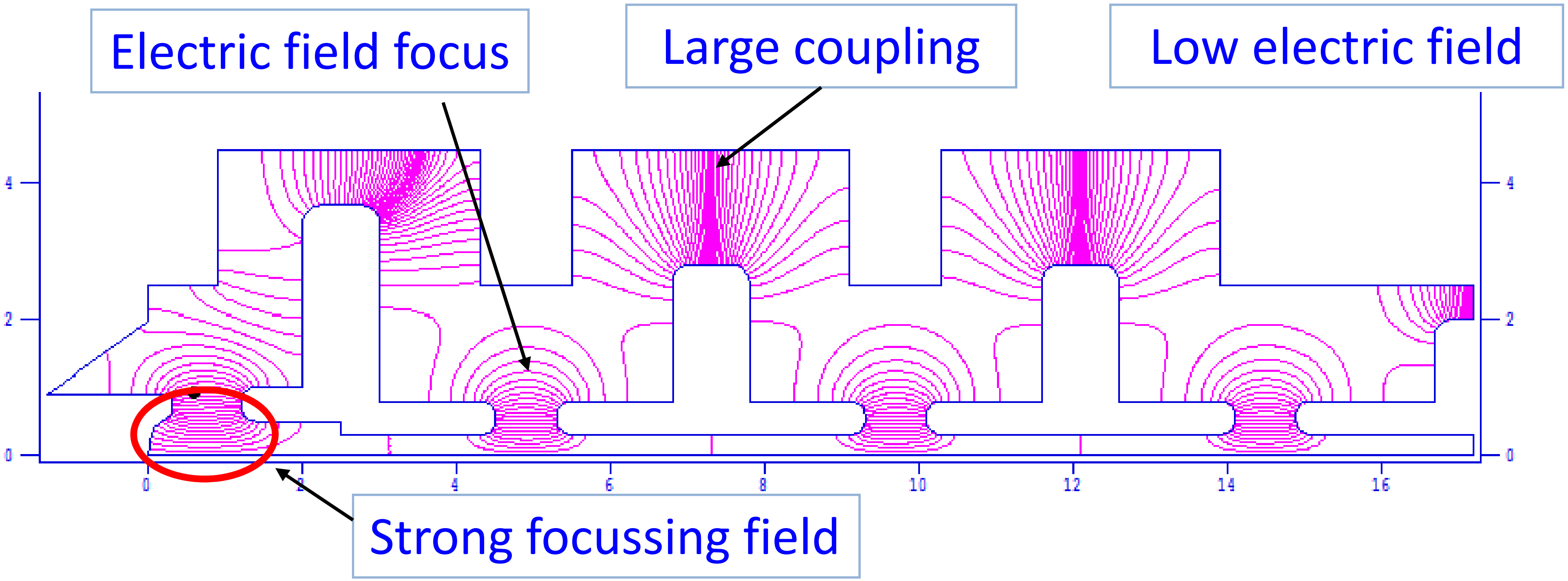


- Space charge is dominant.
  - Longer pulse length : 20 - 30 ps
- Stable operation is required.
  - Lower electric field : < 100MV/m
- Focusing field must be required.
  - Solenoid focus causes the emittance growth.
  - **Electric field focus preserve the emittance**.

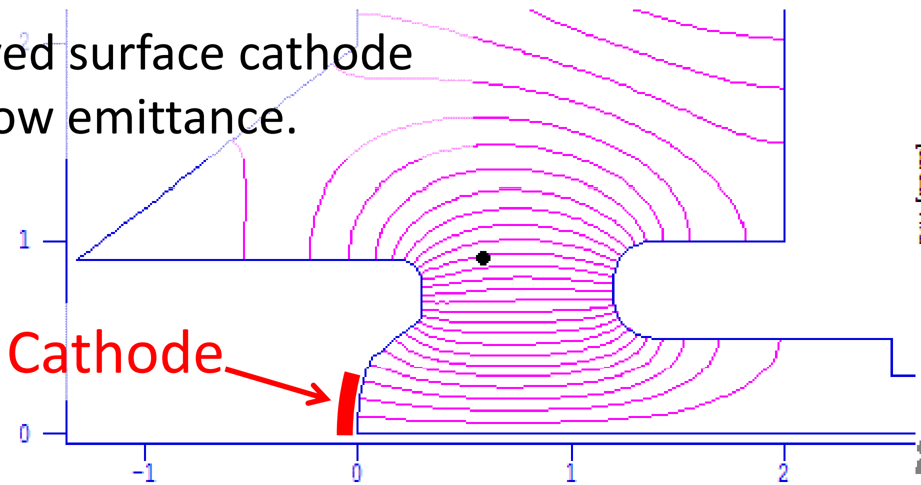
~~Epxial coupled cavity~~ : BNL

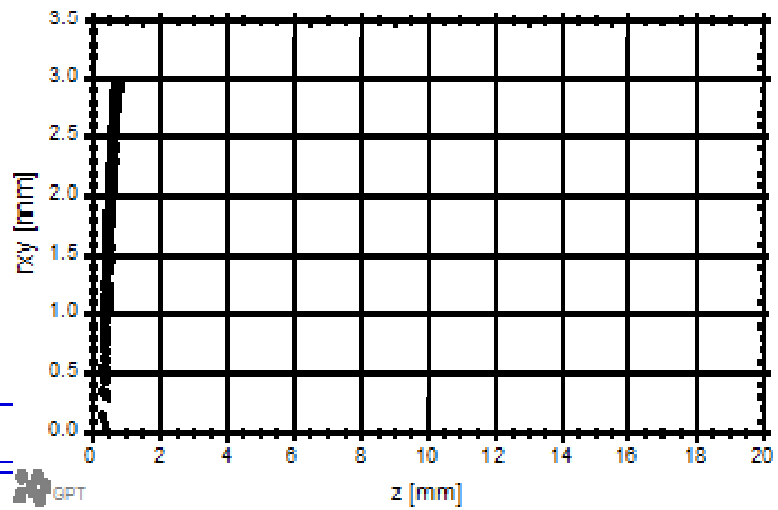
Annular coupled cavity : Disk and washer / Side couple

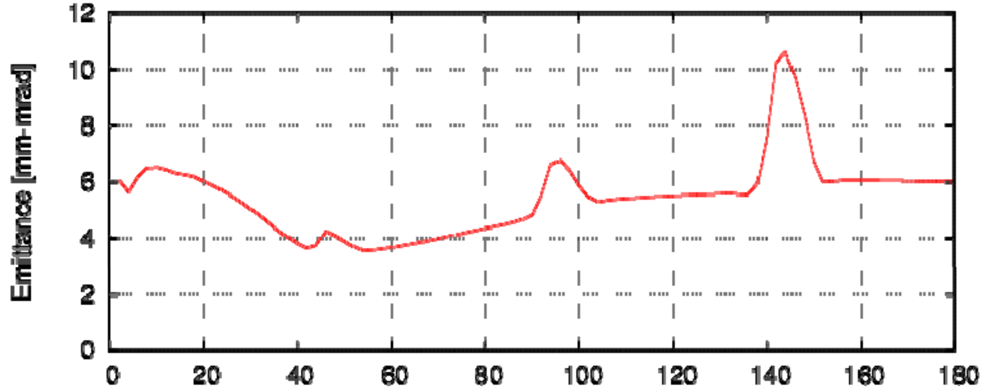
DAW (Disk and Washer) type RF-Gun



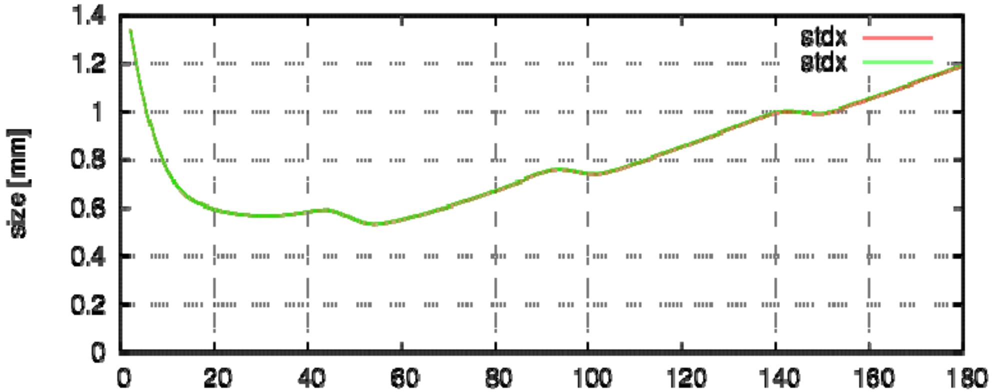
Curved surface cathode
for low emittance.



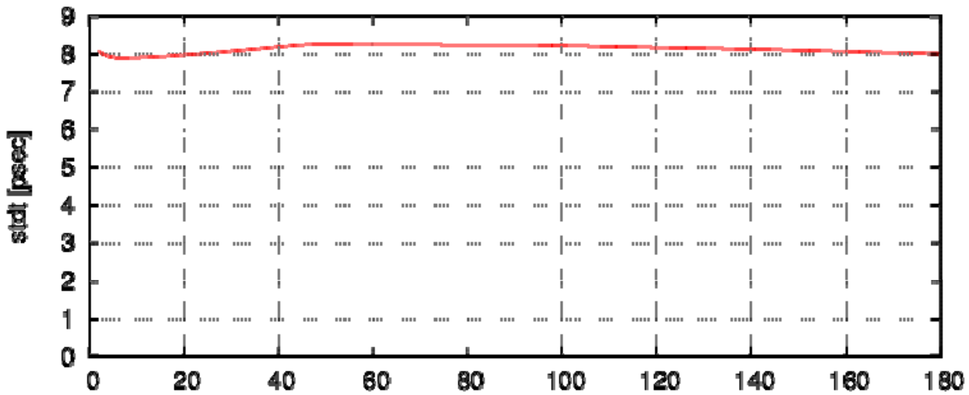




Emittance
6 mm-mrad
(5 nC)

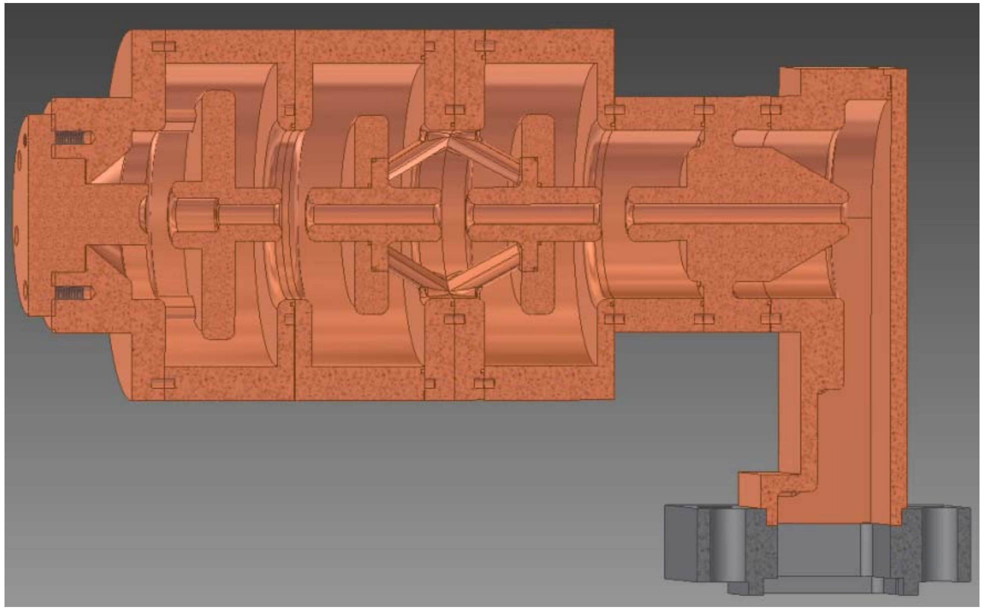


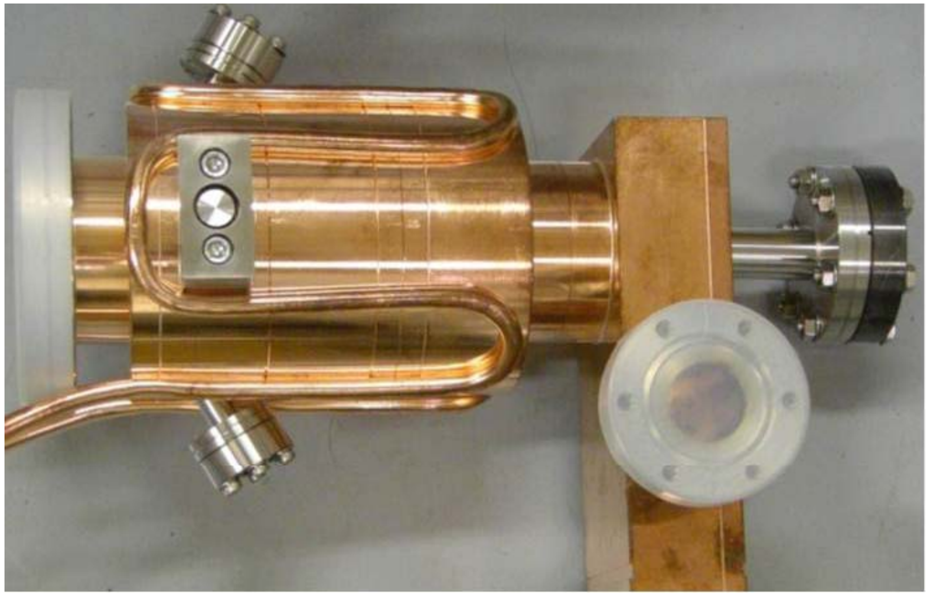
Beam size (σ)
1.2 mm



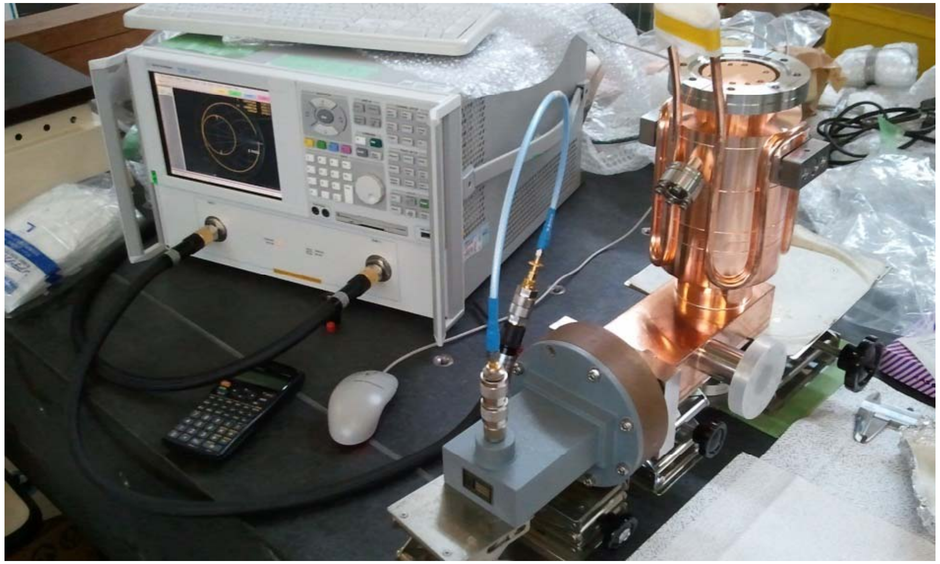
Bunch length (σ)
8 psec

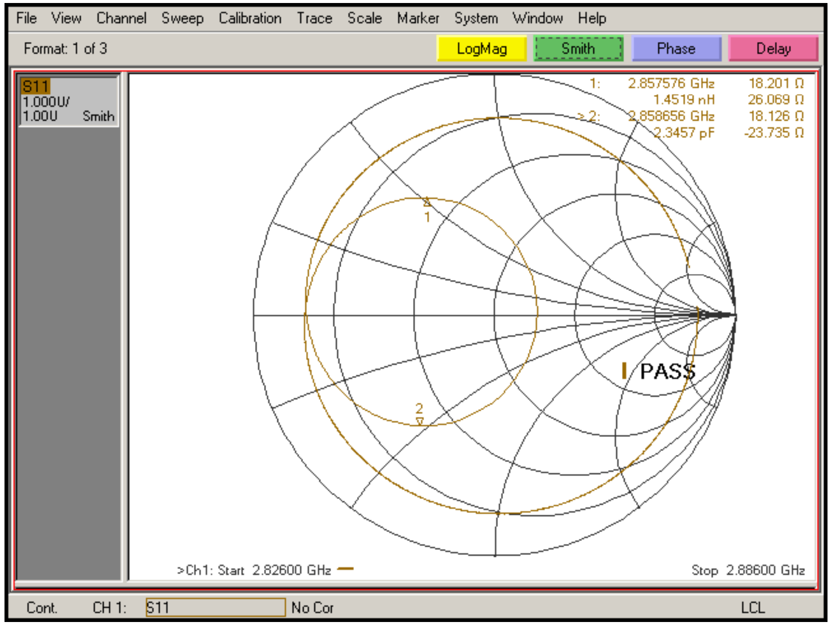
Fabrication

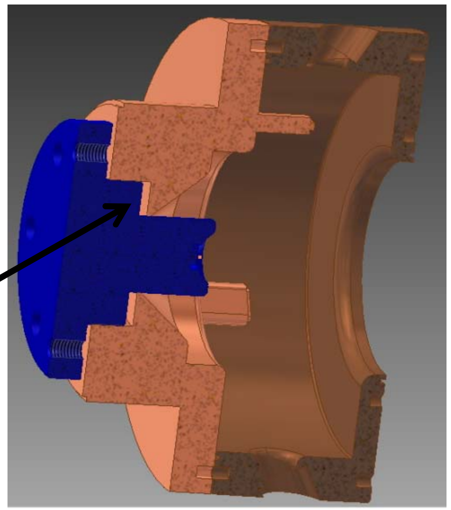




Network analyzer measurement and adjustment of resonant frequency







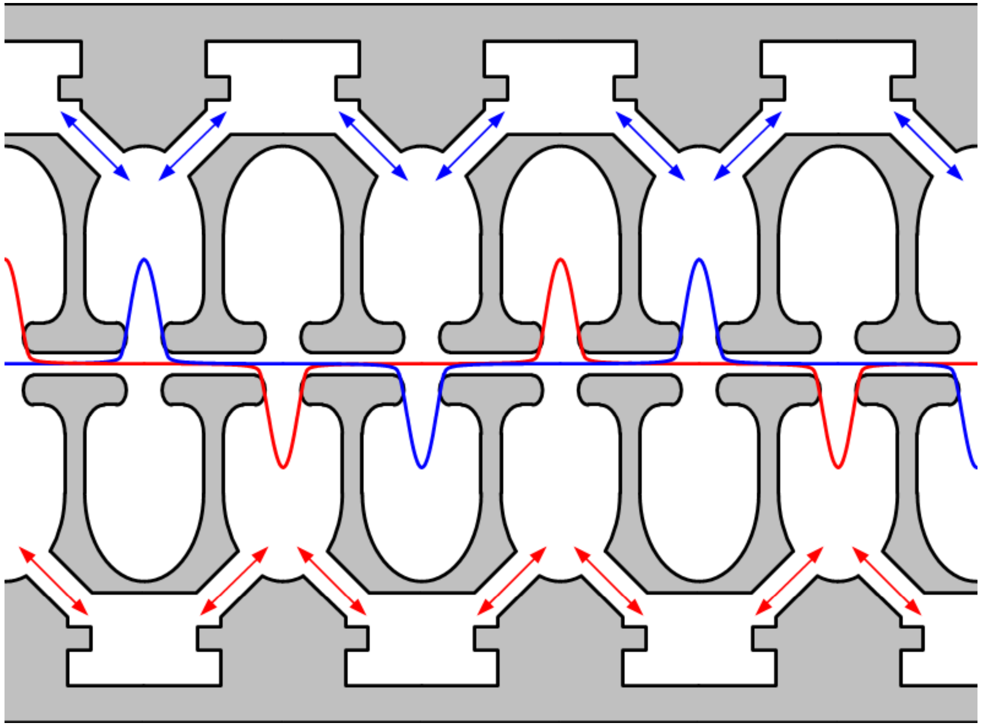
Adjust with spacer on cathode rod

Result from smith chart

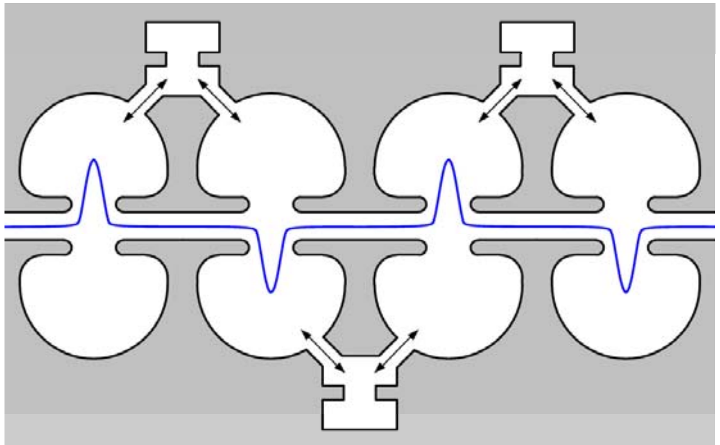
Reflection ratio	$G = 0.119$
Coupling	$\beta = 1.27$
Q factor	$Q_0 = 6007.3$
Loaded Q	$Q_L = 2646.4$

Design of a quasi traveling wave side couple RF gun for A1 sector

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



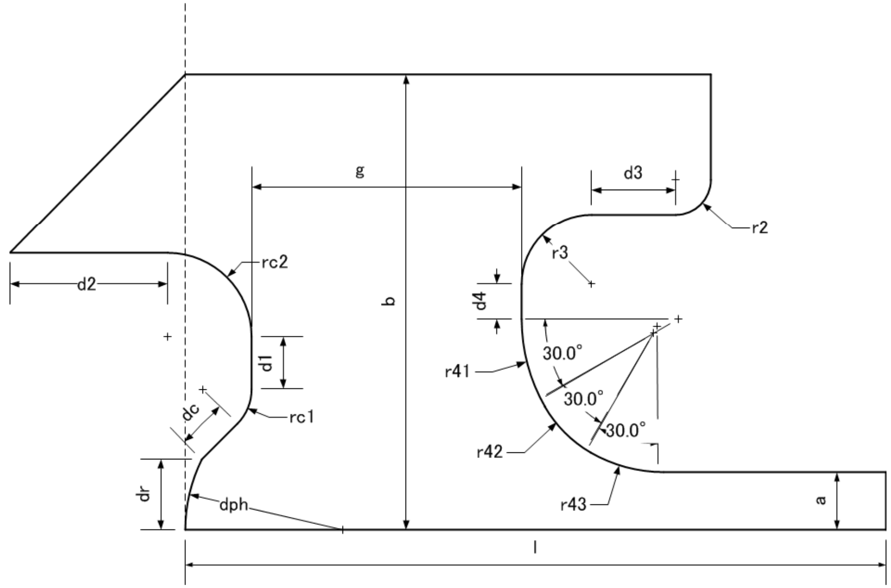
Quasi traveling wave side couple structure



Normal side couple structure

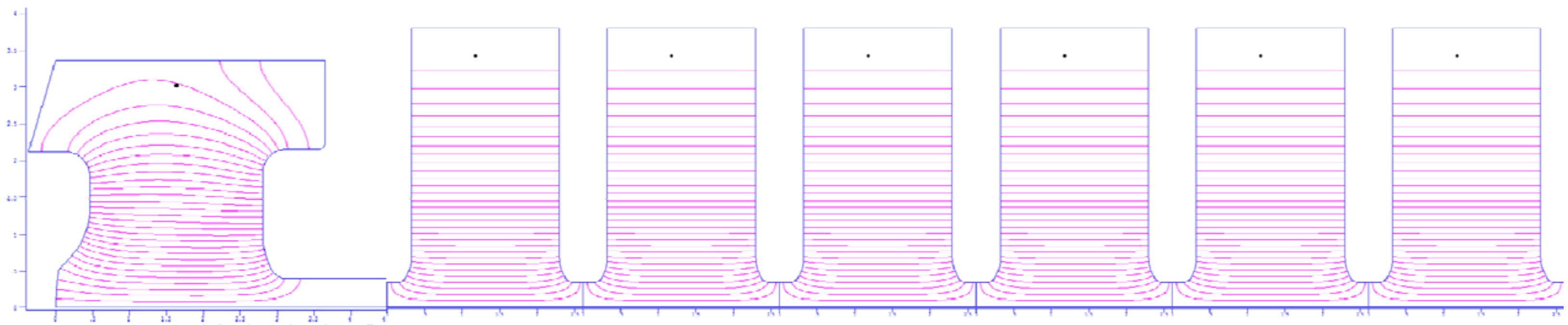
2D Designing of the quasi traveling wave side couple RF gun

Optimize 1st cell by using downhill simplex method.



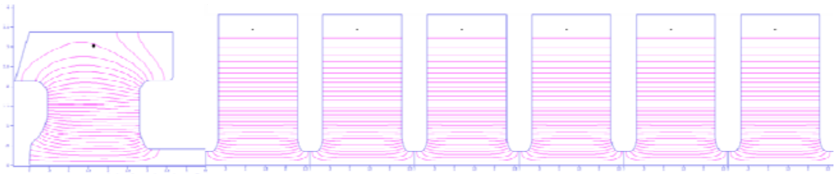
1st cell dimensional parameter

Surface E-field is limited at 120 MV/m

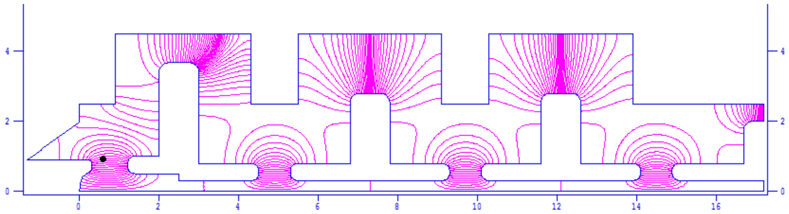


Improved surface E-field 120 MV/m

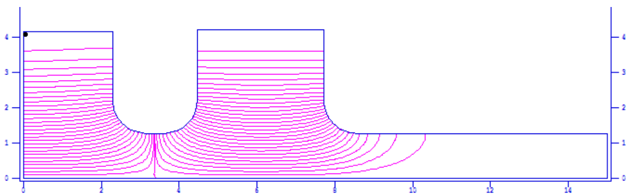
RF-Gun comparison



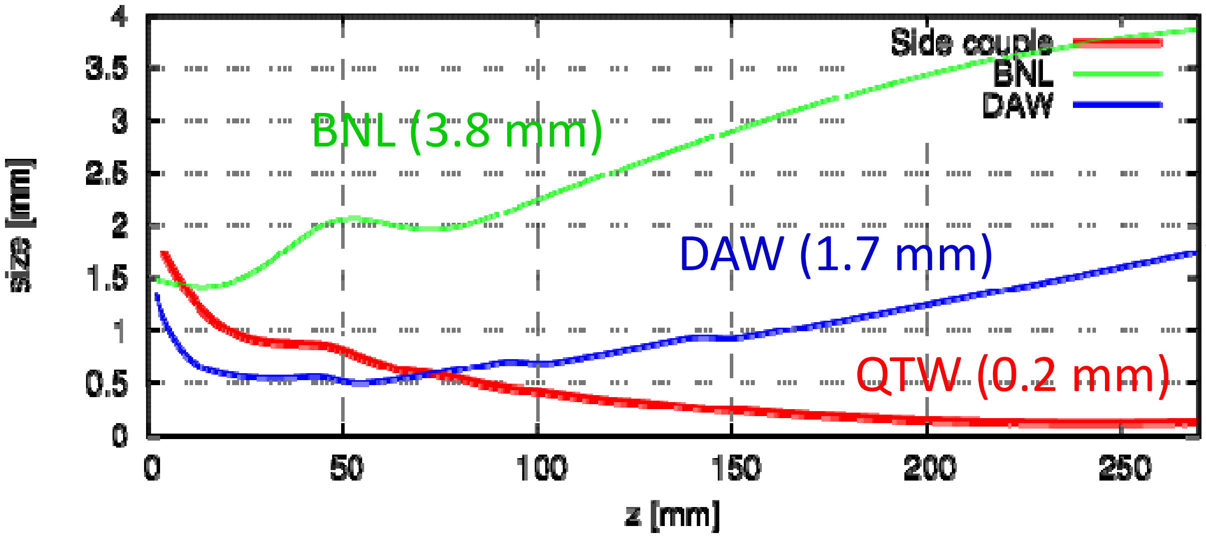
Quasi traveling wave side couple RF gun
(100 MV/m, 6mm-mrad, 13.5 MeV)



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



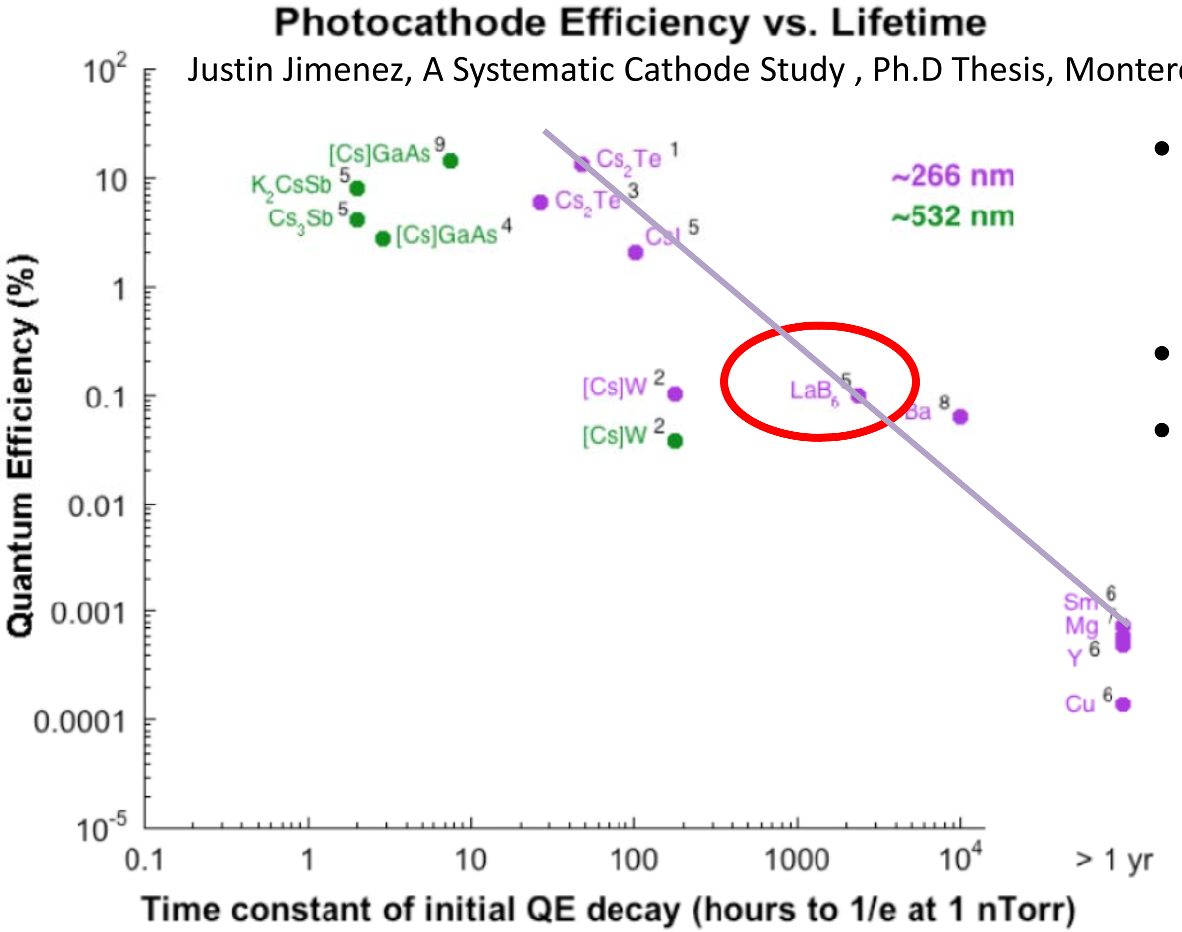
BNL-type RF gun
(120 MV/m, 11.0 mm-mrad, 5.5 MeV)



Beam Size

- RF-Gun
  - Design of RF-Gun cavity
  - **Cathode**
    - **Advantage of LaB6**
    - **Measurement equipment of quantum efficiency**
    - **Laser cleaning & Heat treatment**
  - Laser
  - Test stand and schedule
- Emittance preservation
  - Alignment
  - Beam transport
  - Beam diagnostics

Cathode : Advantage of LaB_6



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

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

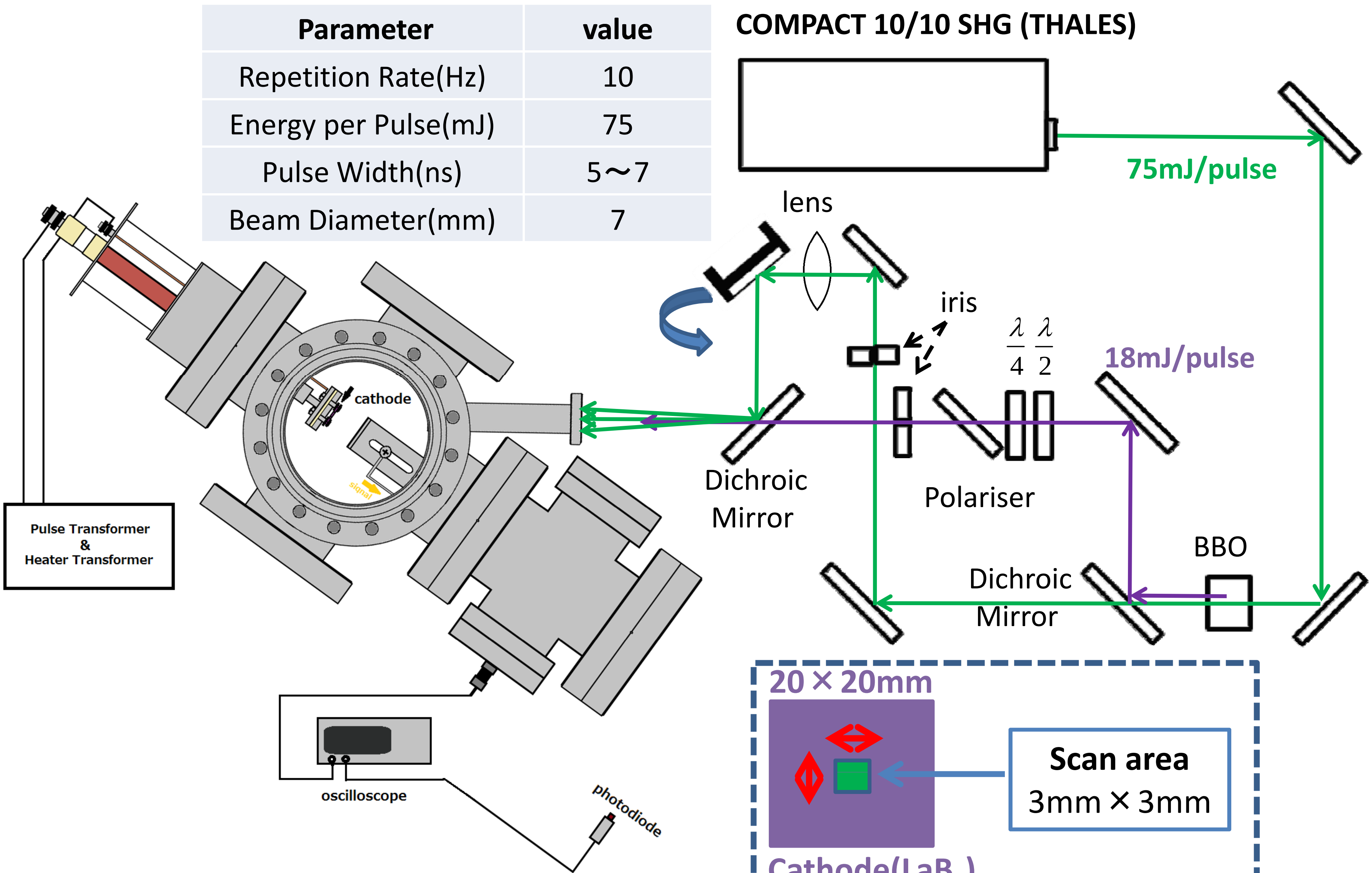
Best choice for SuperKEKB 5 nC long time operation

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

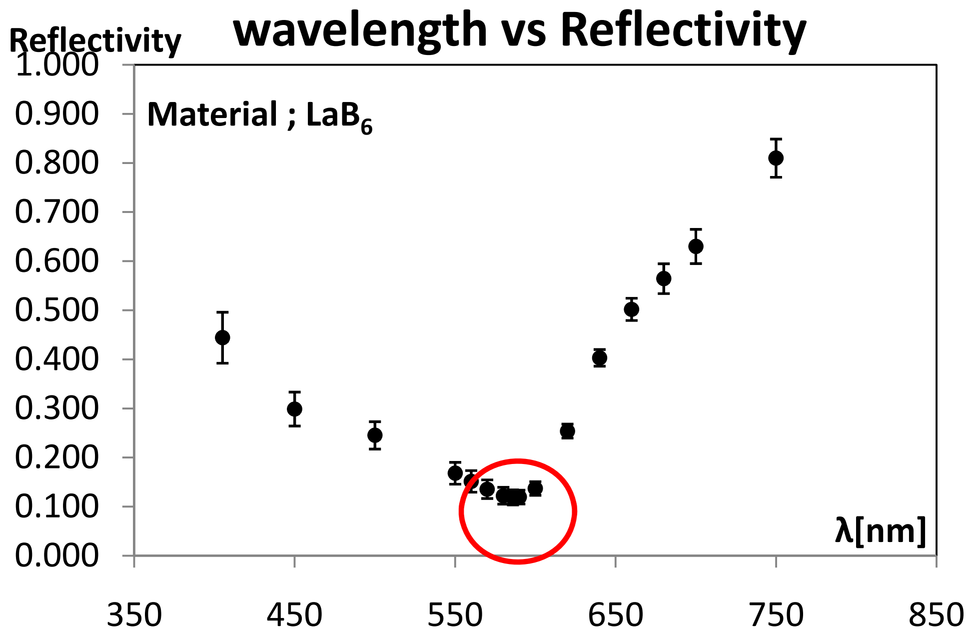
Quantum Efficiency Measurement with laser cleaning

Parameter	value
Repetition Rate(Hz)	10
Energy per Pulse(mJ)	75
Pulse Width(ns)	5～7
Beam Diameter(mm)	7

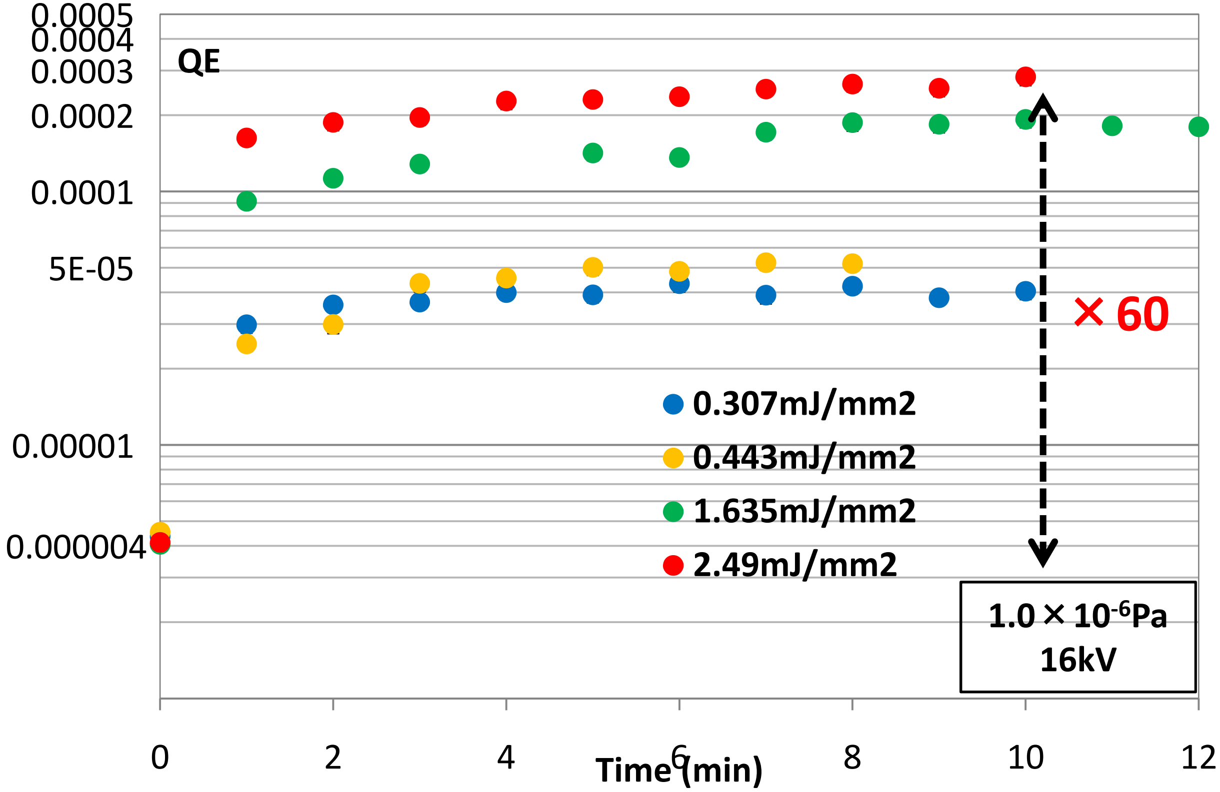


Reason for using the Nd:YAG 2nd Harmonic

- Strong absorption of 532nm
- Reuse of 532nm



Results of Laser Cleaning



Max **Q.E=3.499 × 10^{-4}**

Laser Power ; 250μJ(266nm)

Total Charge ; **20 nC**

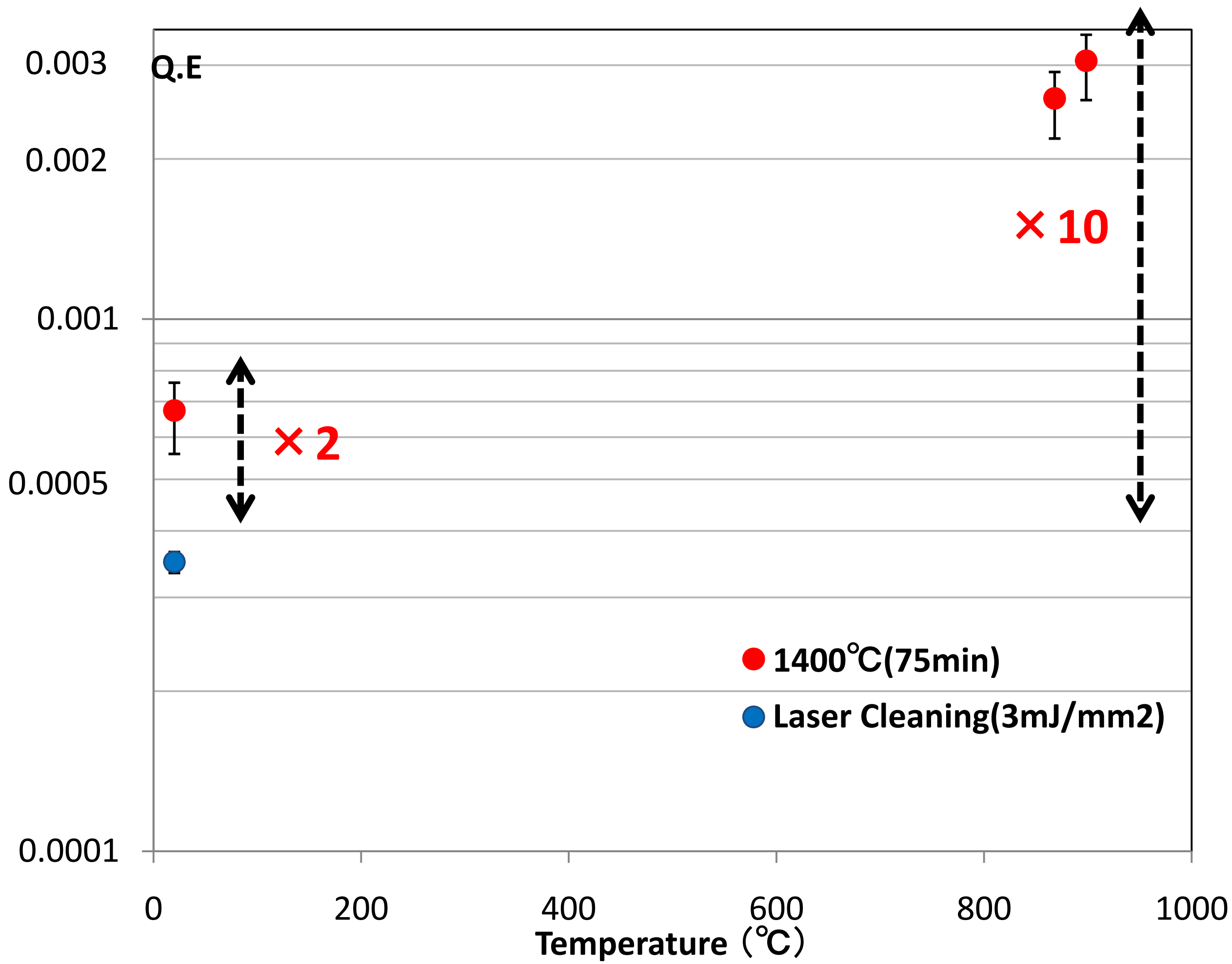
[SUPER-KEKB e Linac]

Laser Power ; **63μJ/pulse**

(λ=266nm)

Target value ; **5nC**

Results of Heater Treatment



Treatment Condition

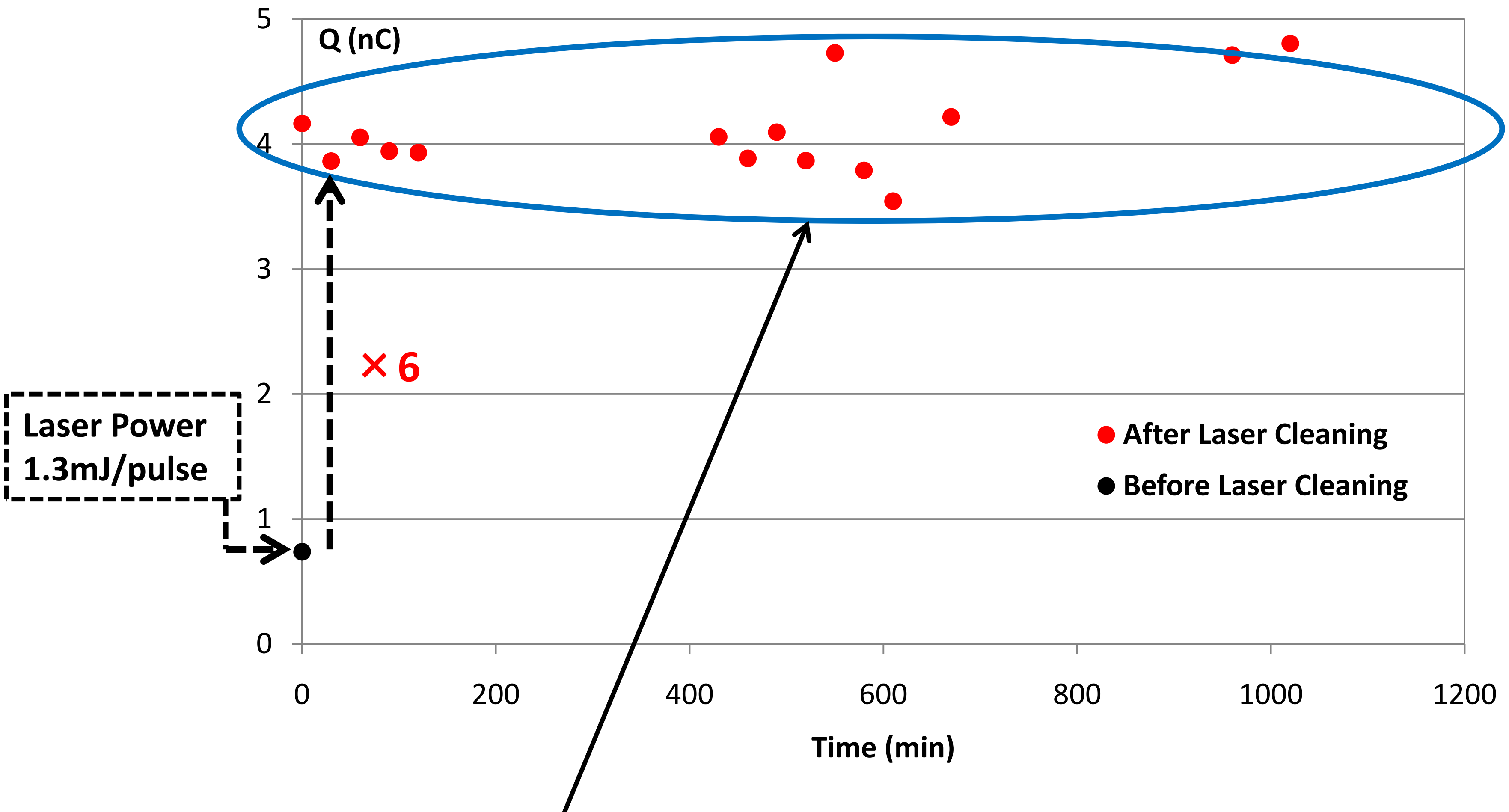
- Temperature ; **1673 K**
- Time ; **75 minute**

Max **Q.E =3.058 × 10^{-3}**

Laser Power ; 50μJ(266nm)
Total Charge ; 30 nC

[SUPER-KEKB e Linac]
Laser Power ; 8μJ/pulse
（λ=266nm）
Target value ; 5nC

Lifetime of LaB_6



Laser Power ; 1.4mJ/pulse → total charge ; 4nC
No decreasement of the total charge for 1000min.

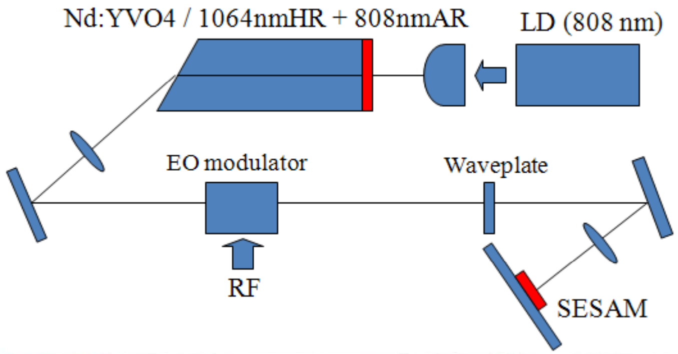
- RF-Gun
  - Design of RF-Gun cavity
  - Cathode
  - **Laser**
    - **Nd:YVO4 / Nd:YAG Solid state laser**
    - **Yb fiber laser**
  - Test stand and schedule
- Emittance preservation
  - Alignment
  - Beam transport
  - Beam diagnostics

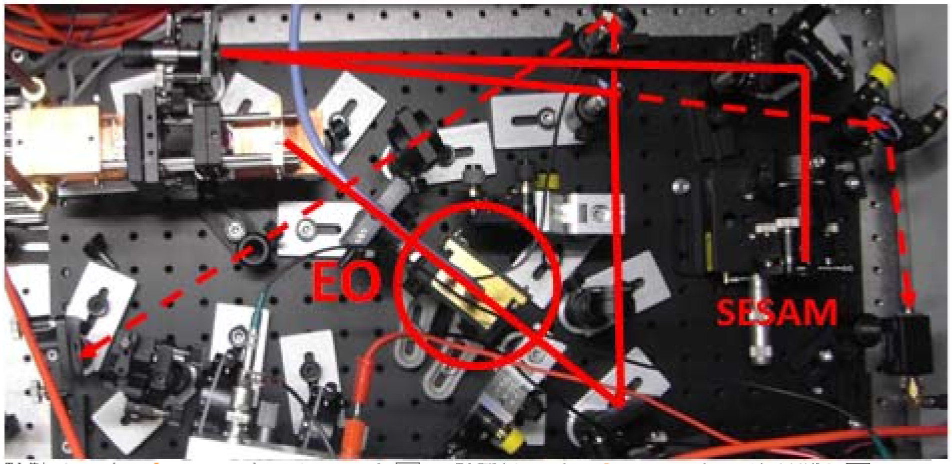
Laser

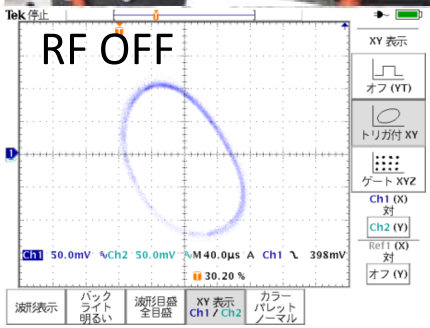
- Solid state (Nd:YVO4 + Nd:YAG)
  - Pulse width is determined by SESAM.
  - High power pump LD is available.
  - No abosorption at emission wavelength.
- Fiber + solid state amplifier (Yb:glass + Yb:KGW)
  - Wide bandwidth with non-linear polarization
    => pulse shaping
  - Stable / High efficiency
  - Difficulties : Self start, ASE, Absorption

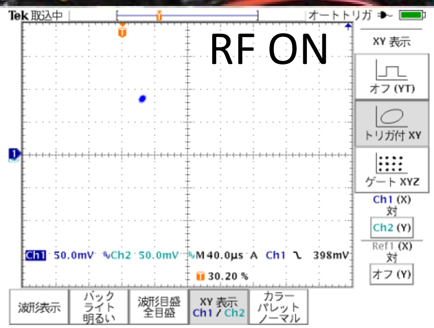
Oscillator & Regenerative amplifier

Oscillator (Active-passive hybrid modelocking)

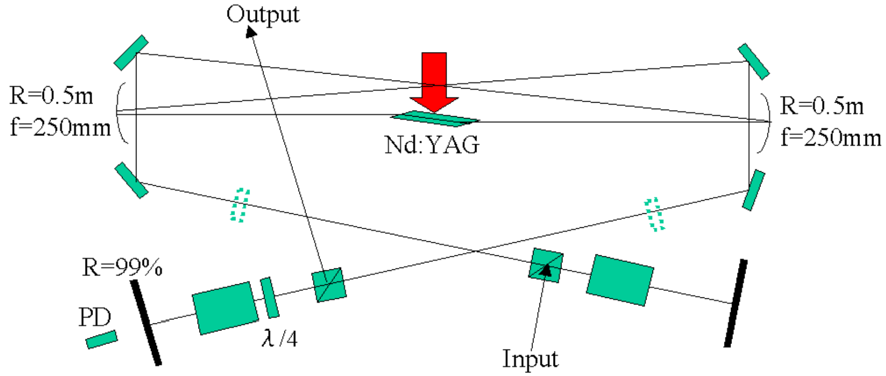


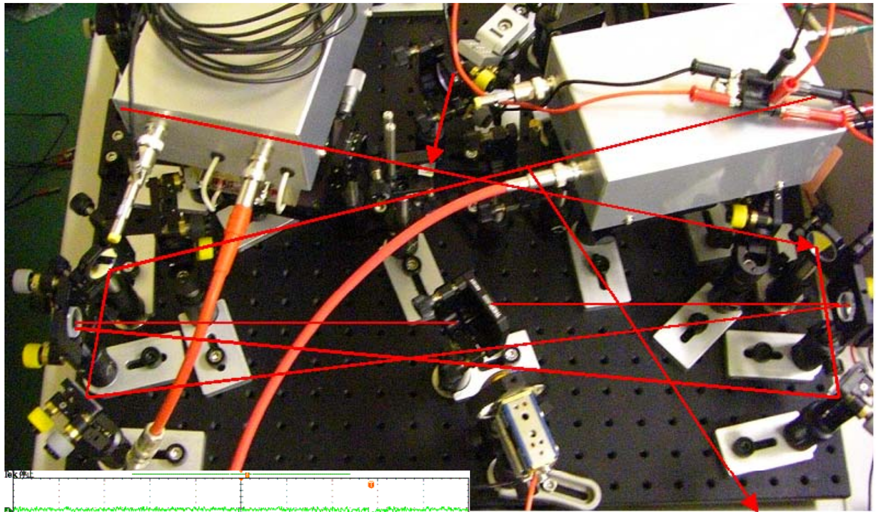


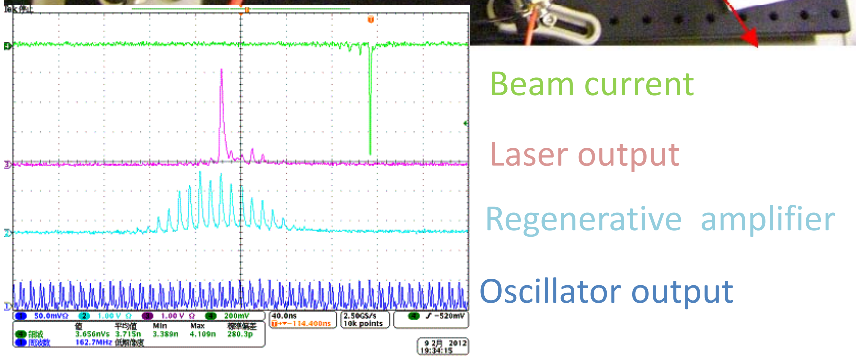




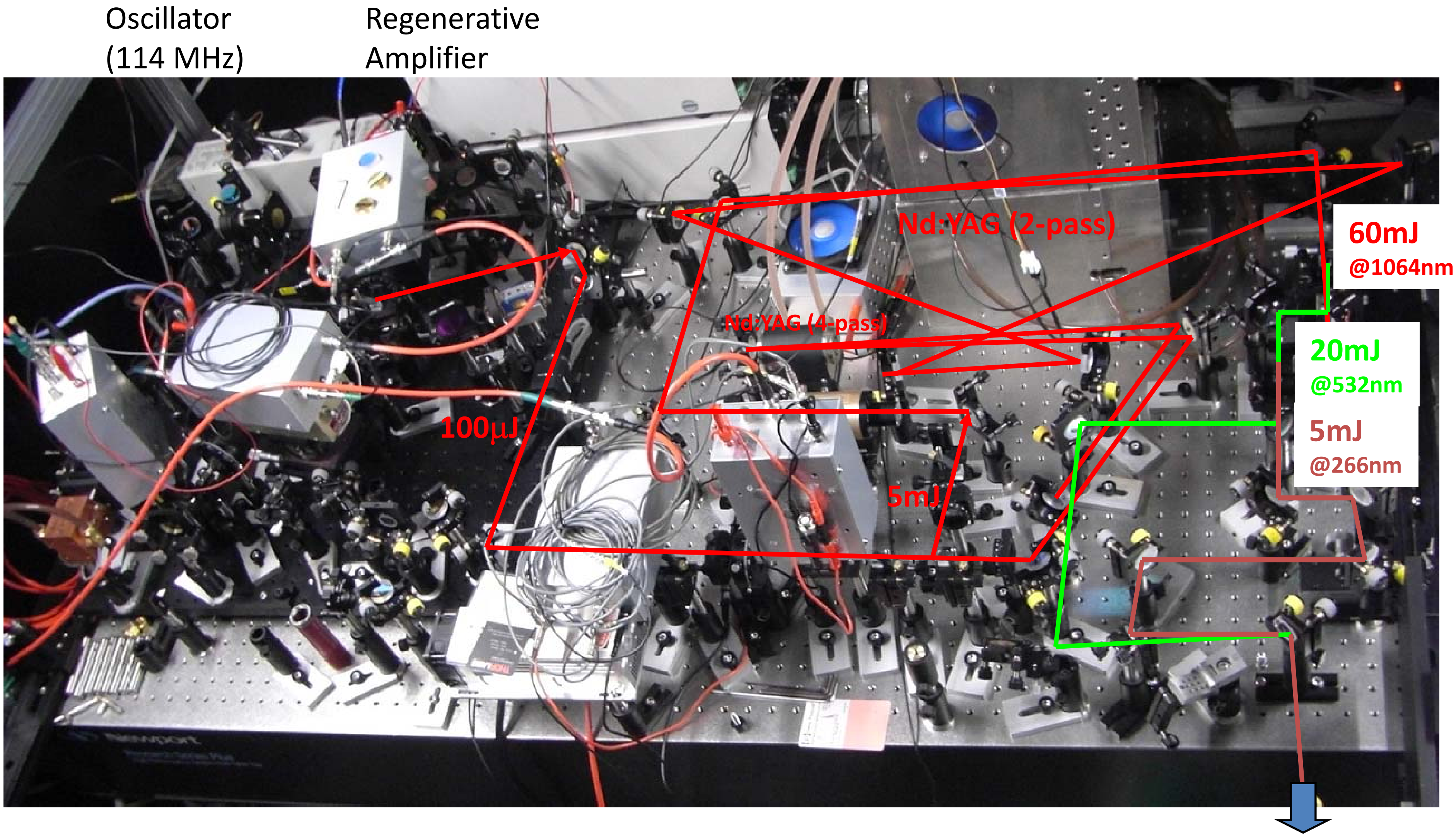
Regenerative amplifier for 2-bunch



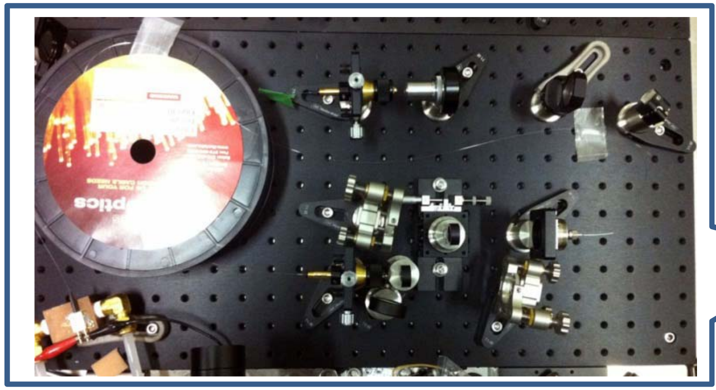


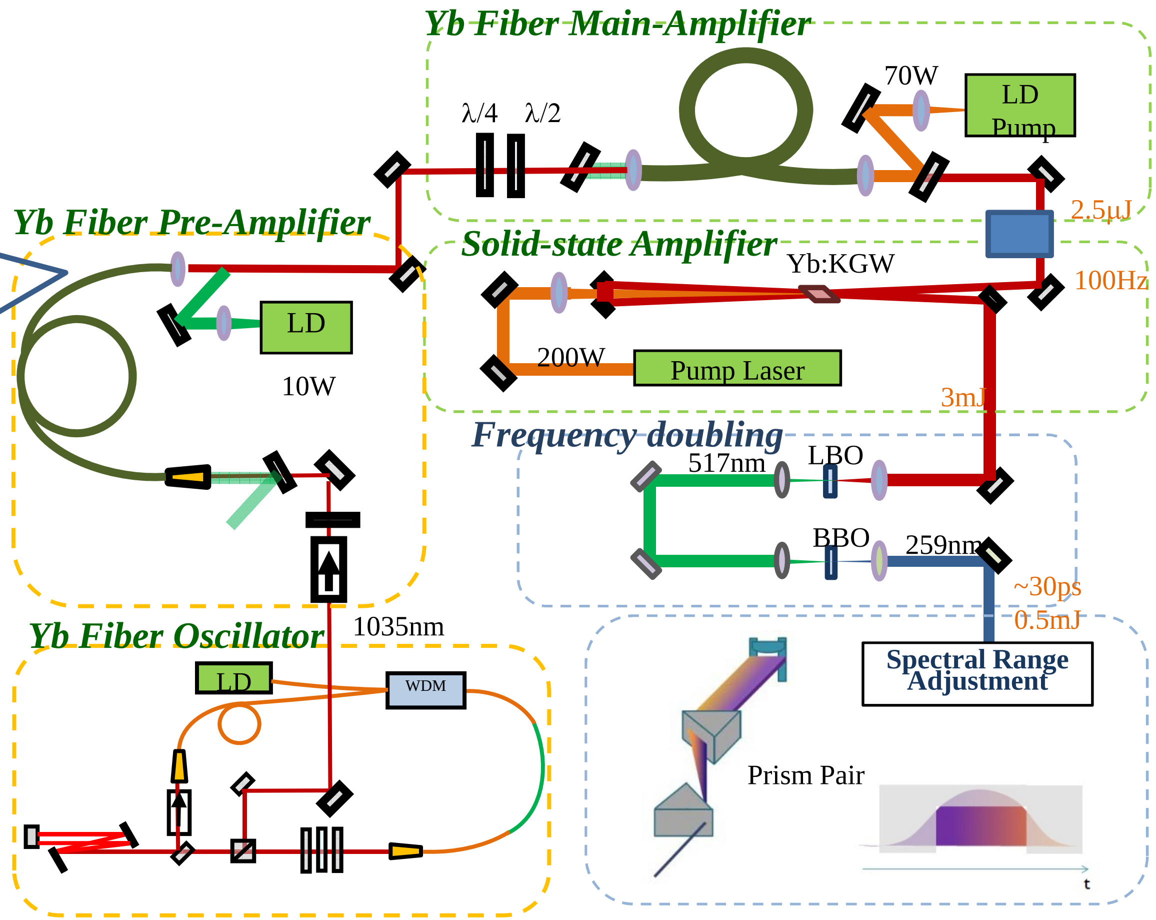


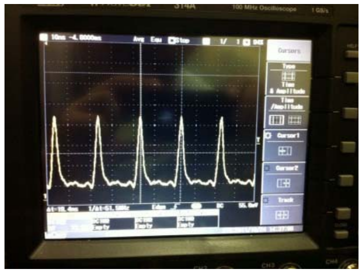
Solid state laser for preliminary test

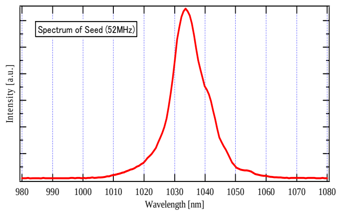


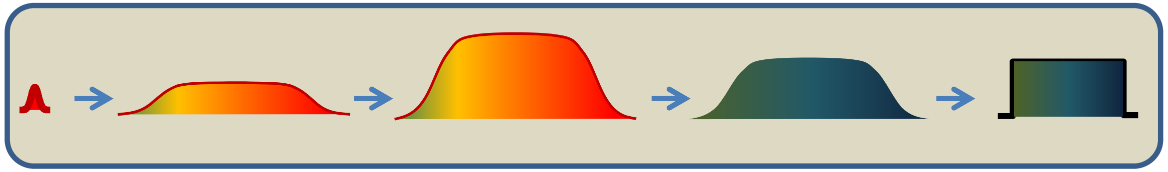
Yb-fiber & Yb solid state laser development









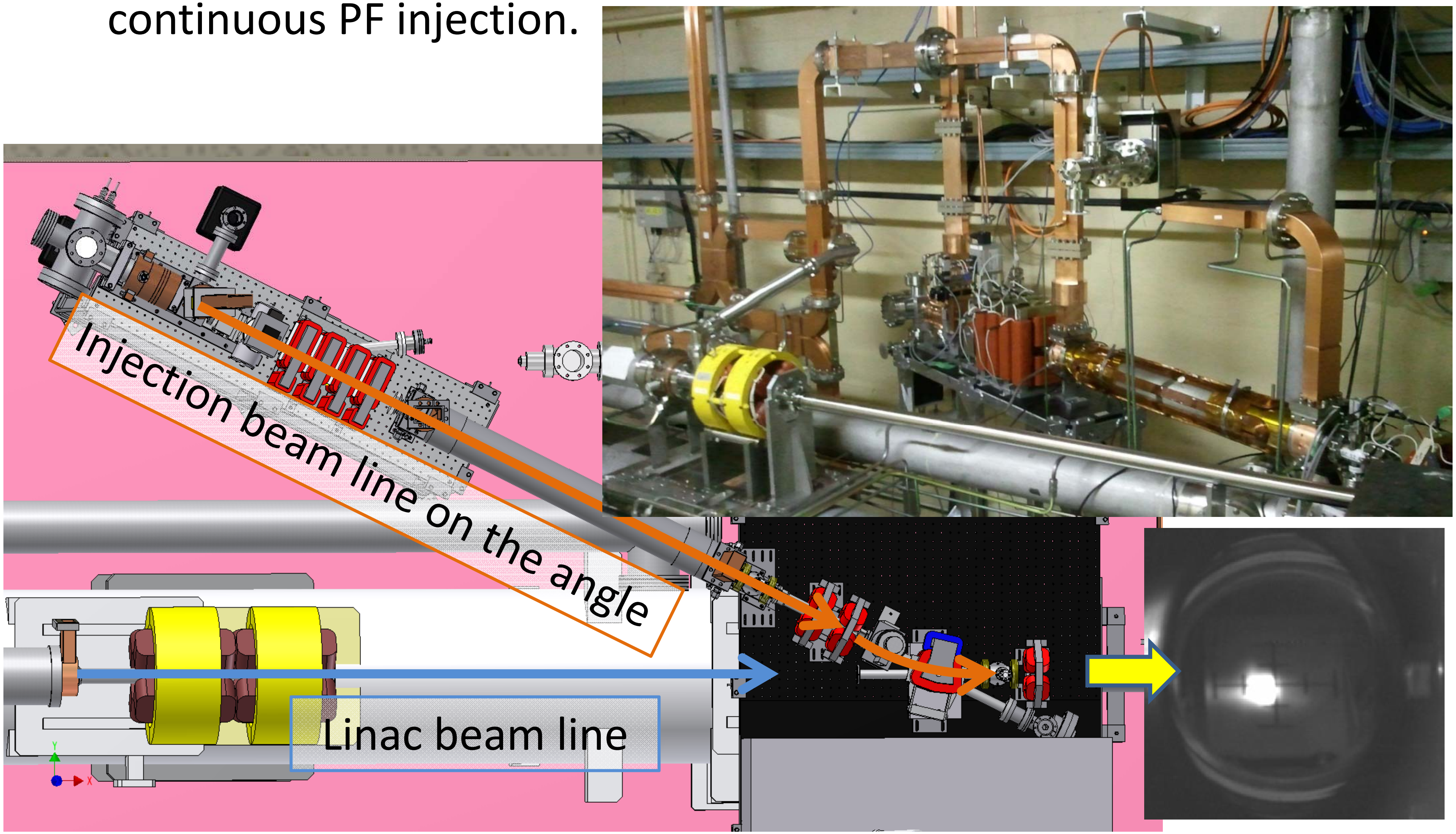


Oscillator & pre-amplifier are already working.

- RF-Gun
  - Design of RF-Gun cavity
  - Cathode
  - Laser
  - **Test stand and schedule**
    - **3-2 RF-Gun for preliminary test & PF injection**
    - **A-1 RF-Gun**
- Emittance preservation
  - Alignment
  - Beam transport
  - Beam diagnostics

3-2 RF gun installation

- DAW type RF-Gun was installed due to earth quake.
- Designing the injection beam line on the angle for continuous PF injection.



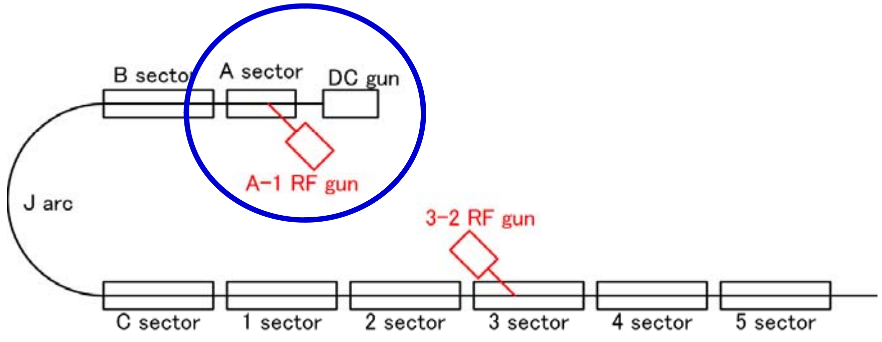
Present situation of RF-Gun commissioning from 2011.10-2012.02

- RF-Gun cavity
  - Ageing process was finished for **only one week**.
- Cathode
  - Room temperature 6mmϕ LaB_6 cathode was installed.
  - Laser cleaning was tested.

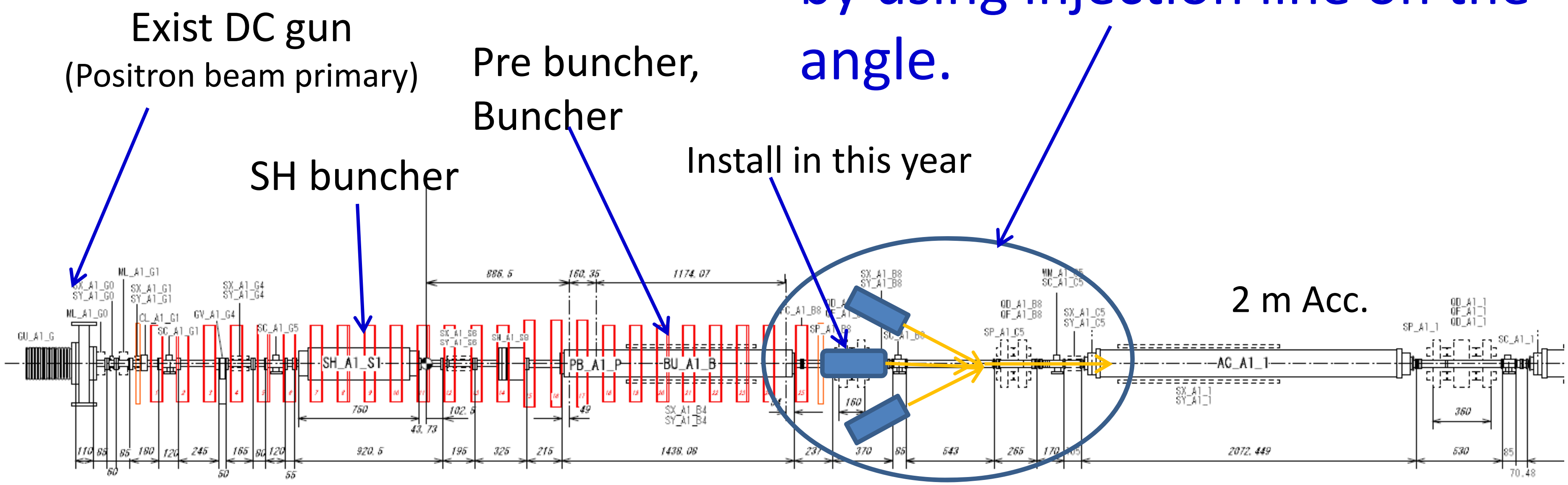
Thermal cathode is under development.

- Laser & **Control**
  - Synchronization: almost achieved.
  - Pulse picker : almost achieved.
  - Pointing fluctuation : feedback system will be installed.
  - Power : YAG module will be added.
Fight with destruction is necessary.

A1 new RF gun install schedule



Install new RF gun between A1 DC gun buncher and 2 m linac by using injection line on the angle.



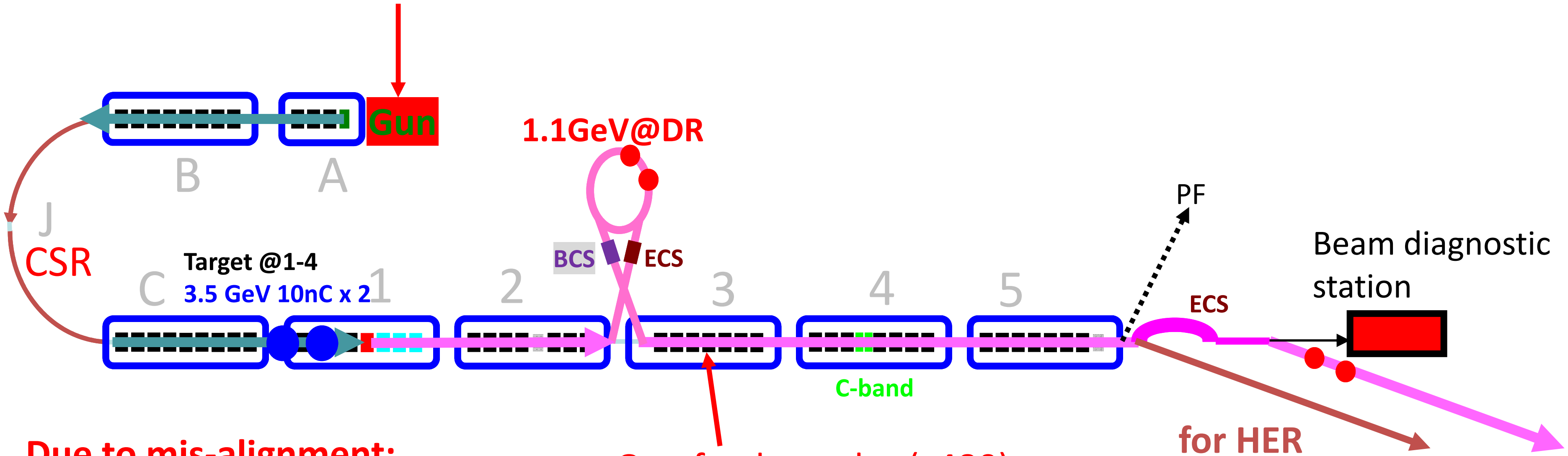
A1 sector

- RF-Gun
  - Design of RF-Gun cavity
  - Cathode
  - Laser
  - Test stand and schedule
- **Emittance preservation**
  - **Alignment**
  - Beam transport
  - Beam diagnostics

Overview of emittance source and growth

Current charge & emittance:
e^- :1 nC, 300 mm mrad
e^+ :1 nC, 2100 mm mrad

Longer bunch can reduce space charge effect inside RF-Gun and also CSR at J-ARC.



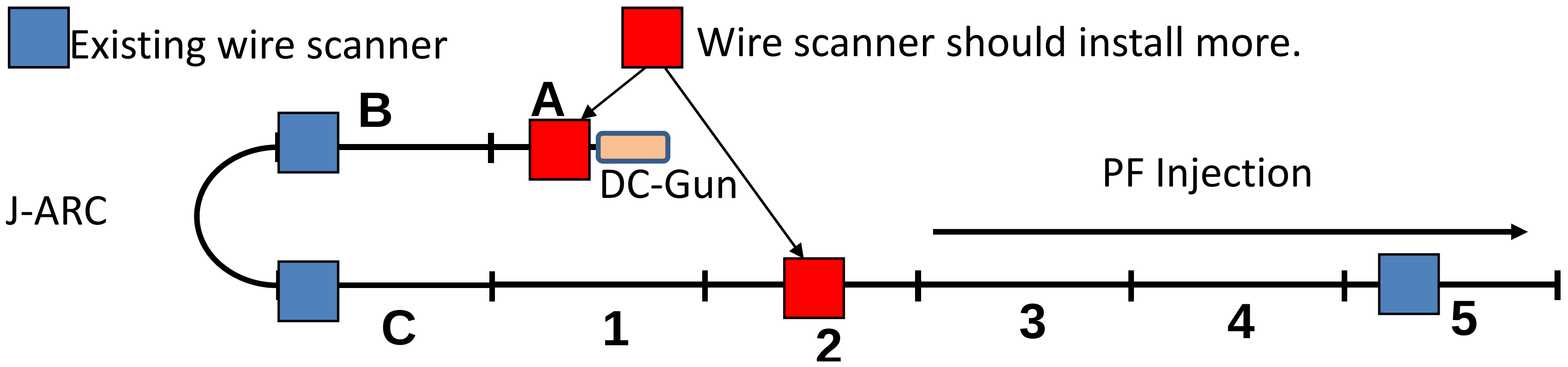
Due to mis-alignment:
- **Dispersion**
- **Short range wakefield**

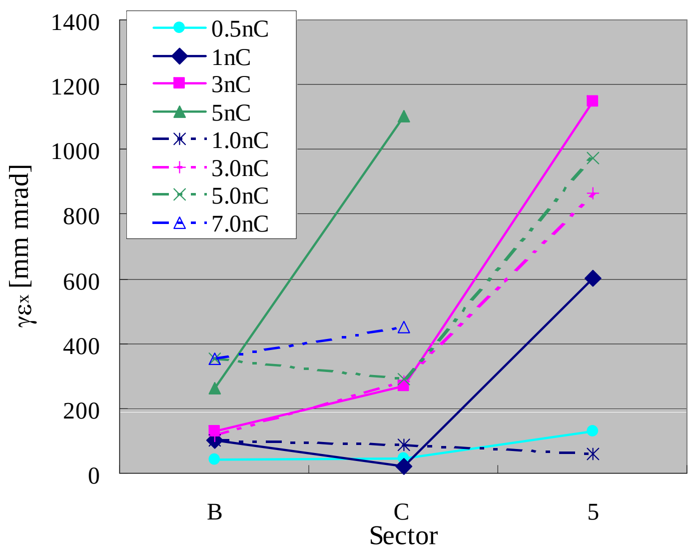
One feed coupler (x480) causes of RF emittance. ($\Delta\gamma\varepsilon$ ~ 1.2 mm mrad is estimated)

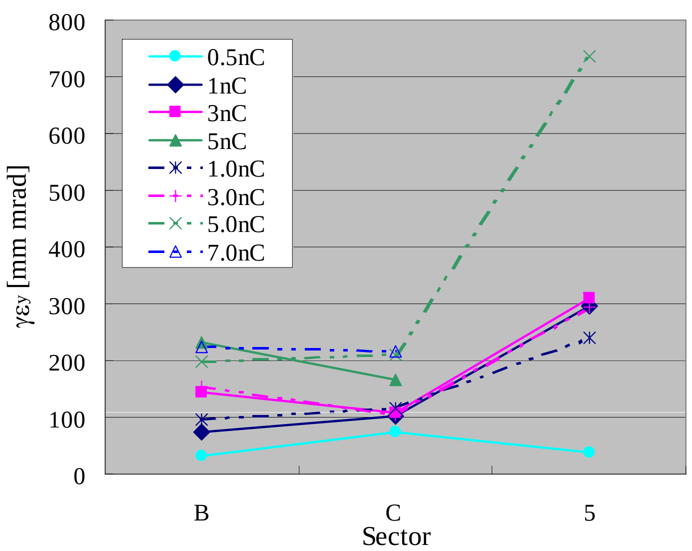
for HER
7.0 GeV 5nC x 2
ε_y < 20 mm mrad

Requirement:
for LER
4.0 GeV 4nC x 2
ε_y < 6 mm mrad

Emittance measurement







- RF-Gun
  - Design of RF-Gun cavity
  - Cathode
  - Laser
  - Test stand and schedule
- Emittance preservation
  - **Alignment**
  - Beam transport
  - Beam diagnostics

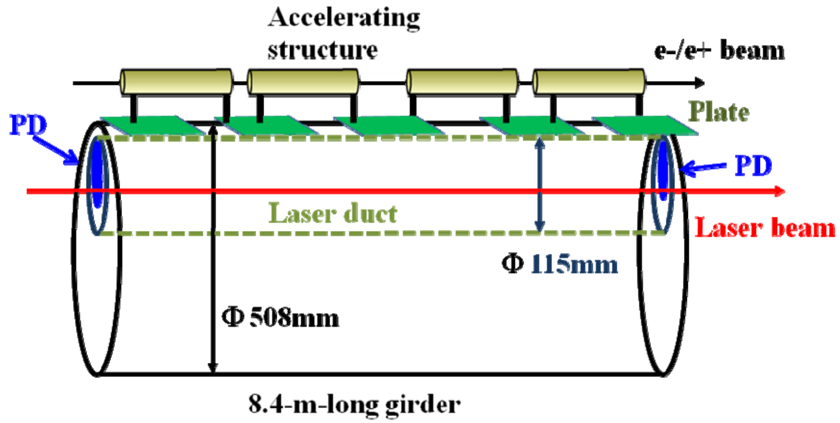
Alignment System

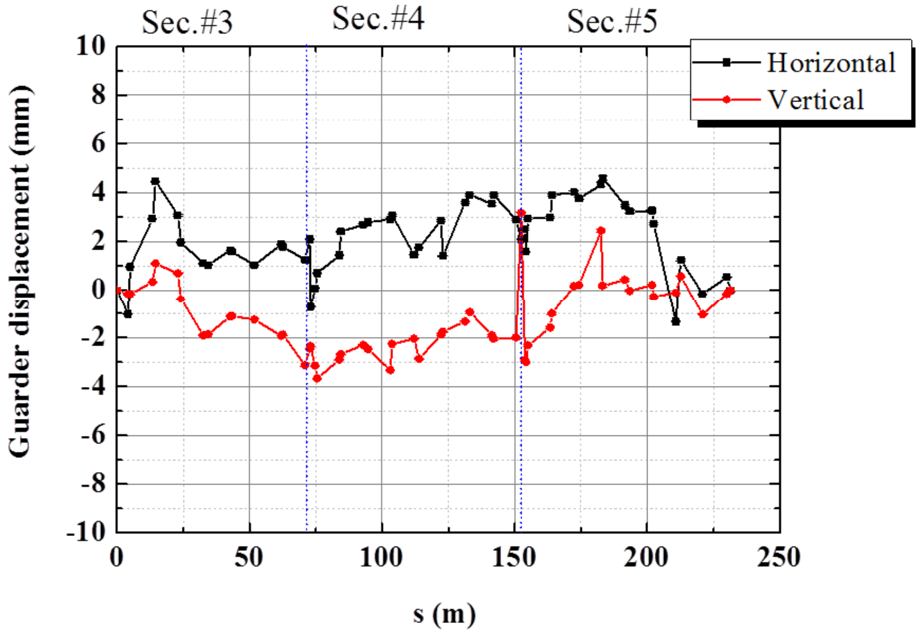
Laser Tracker

Target holder on coupler

Laser alignment system

(w/ quadrant-segmented photodiode (PD))

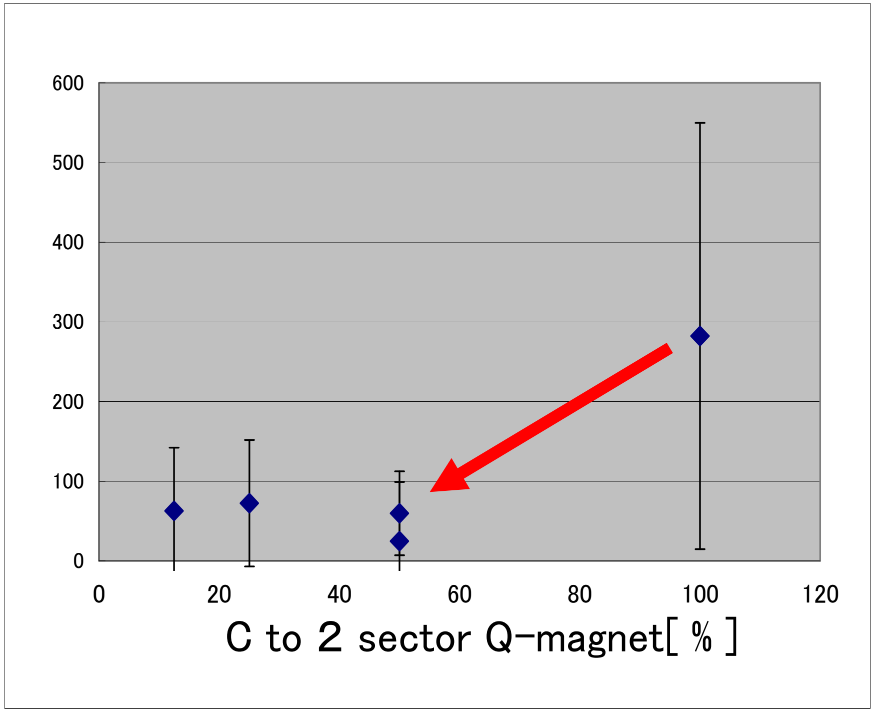




- RF-Gun
  - Design of RF-Gun cavity
  - Cathode
  - Laser
  - Test stand and schedule
- Emittance preservation
  - Alignment
  - **Beam transport**
  - Beam diagnostics

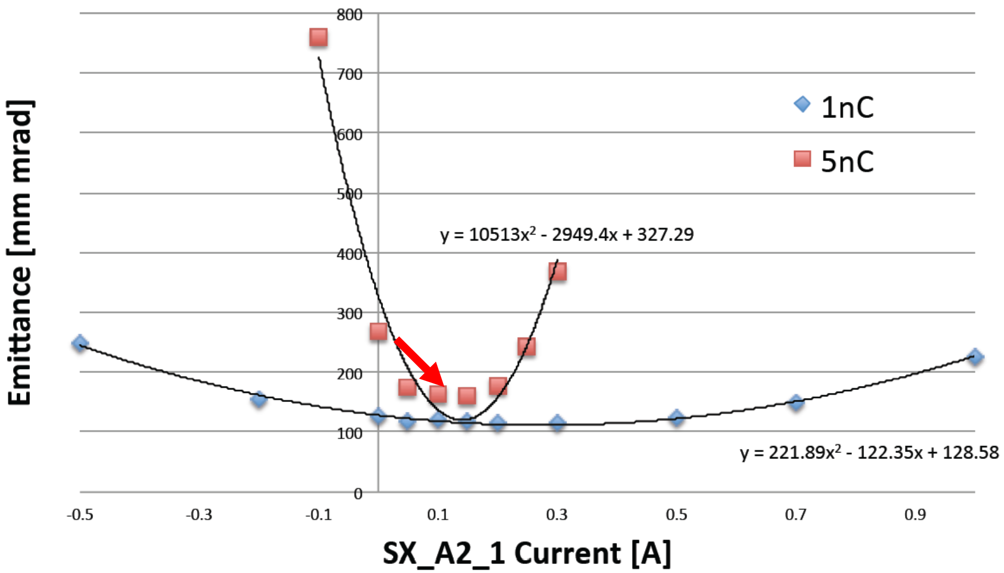
Test for emittance preservation

Dispersion reduction using weak lens
(C to 5 sector)

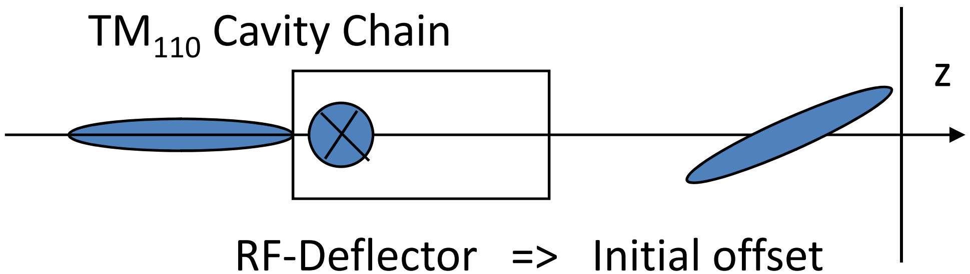


Dispersion compensation

Wakefield compensation by initial offset
(A to B sector)

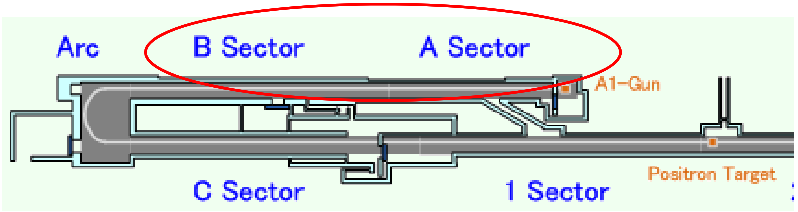


RF-Deflector => bunch slice emittance

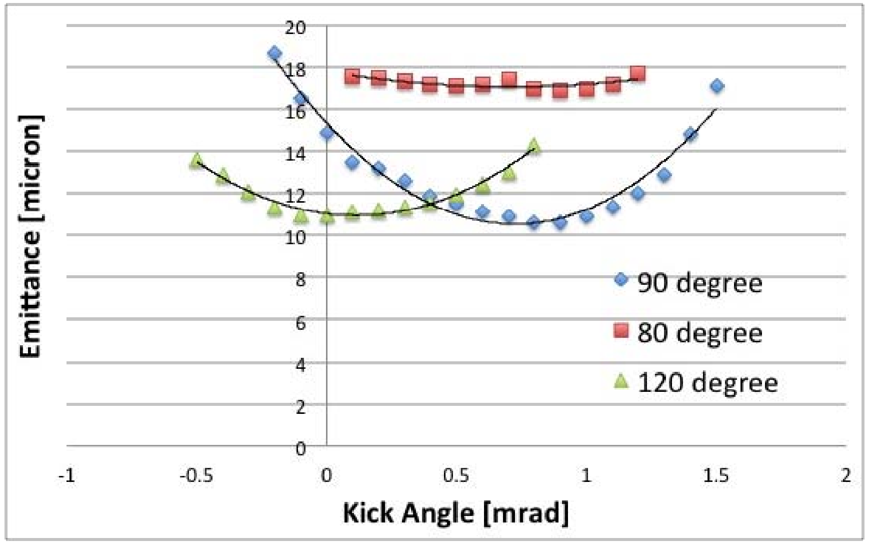


Simulation for emittance preservation

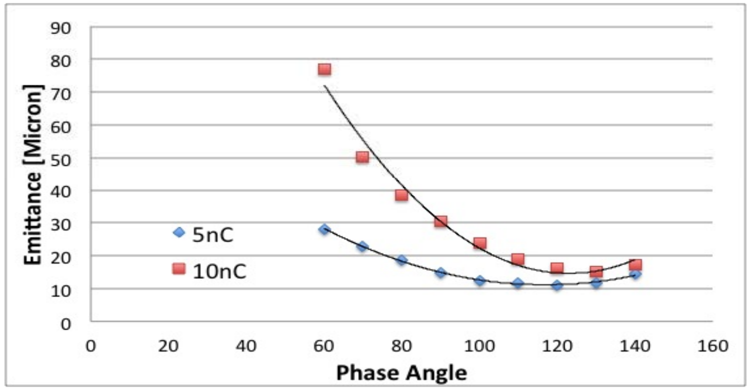
- Simulation test for A-B sector
- Mis-alignment of 0.3 mm
- Initial emittance : 6 mm mrad

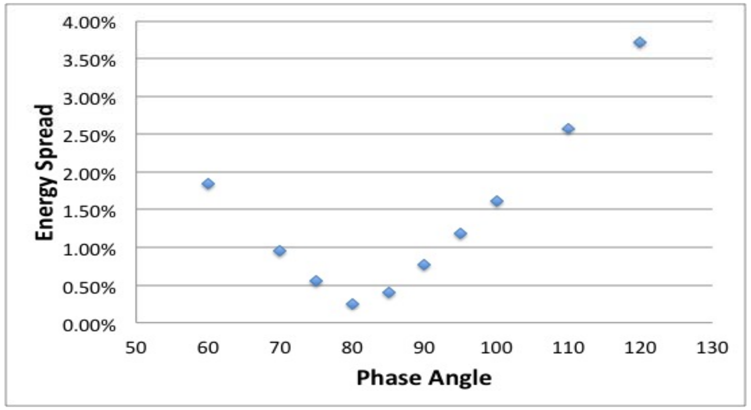


Initial offset



BNS damping



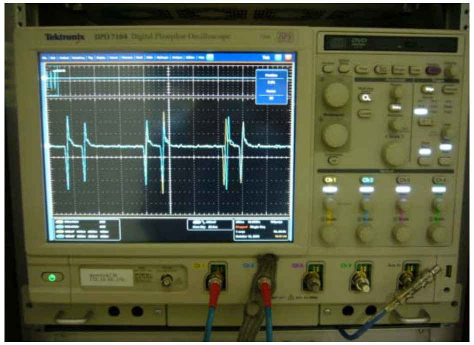


- RF-Gun
  - Design of RF-Gun cavity
  - Cathode
  - Laser
  - Test stand and schedule
- Emittance preservation
  - Alignment
  - Beam transport
  - **Beam diagnostics**

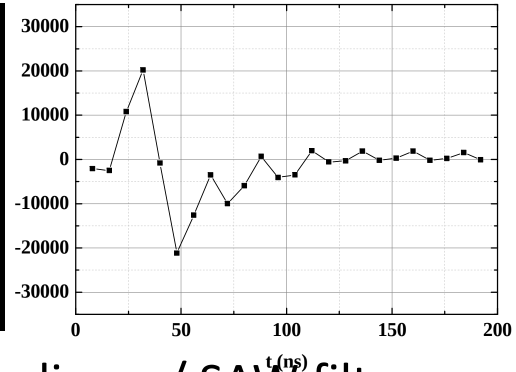
Measurement precision of stripline BPM

--- Results of 3BPM method (w/ 0.1 nC e- beam) ---

DAQ system	Current system (Oscilloscope)	Libera Brilliance Single Pass
Horizontal (μm)	56.84	20.24
Vertical (μm)	54.37	19.12

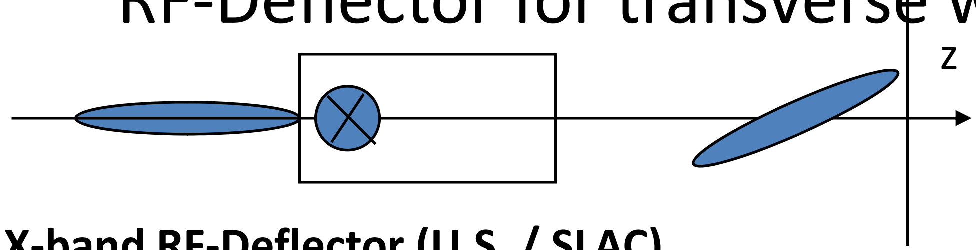


- Real time sampling 10 GSa/s
- Precision is limited by 8 bits ADC.



- Band-pass sampling w/ SAW filter
- ADC: 125 MHz, 16 bits
- Target precision: < 10 μm
- Upgrade of Libera
  (based-on Libera Brilliance plus)

RF-Deflector for transverse wakefield measurement



$$\Delta x_{screen} = \sqrt{\beta_{deflector}\beta_{screen}}\left(\frac{eV_{deflector}\omega_{RF}\Delta t}{E_{beam}}\right)\sin\left(\phi_{deflector\to screen} = \frac{\pi}{2}\right)$$

$$\sigma_x = \sqrt{\beta_{screen}\varepsilon_{screen}}$$

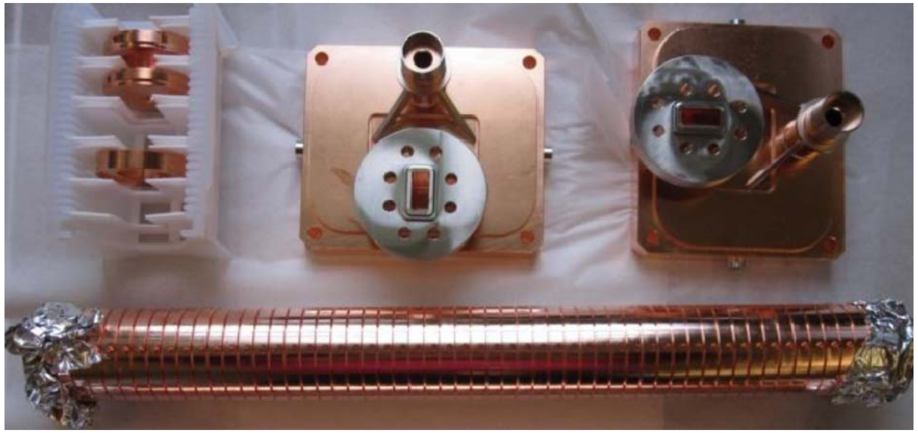
$$\Delta x_{screen} / \sigma_x = \sqrt{\frac{\beta_{deflector}}{\varepsilon_{screen}}}\left(\frac{eV_{deflector}\omega_{RF}\Delta t}{E_{beam}}\right)$$

$$V_{deflector} = 10MV,\ f_{RF} = 2.856GHz,\ \Delta t = 10\,ps,\ \beta_{deflector} = 10m$$
$$\to \Delta x_{screen} / \sigma_x = 3$$

$$V_{deflector} = 15MV,\ f_{RF} = 11.424GHz,\ \Delta t = 10\,ps,\ \beta_{deflector} = 10m$$
$$\to \Delta x_{screen} / \sigma_x = 18$$

X-band RF-Deflector (U.S. / SLAC)

-1 m structure same as the RF-deflector for LCLS

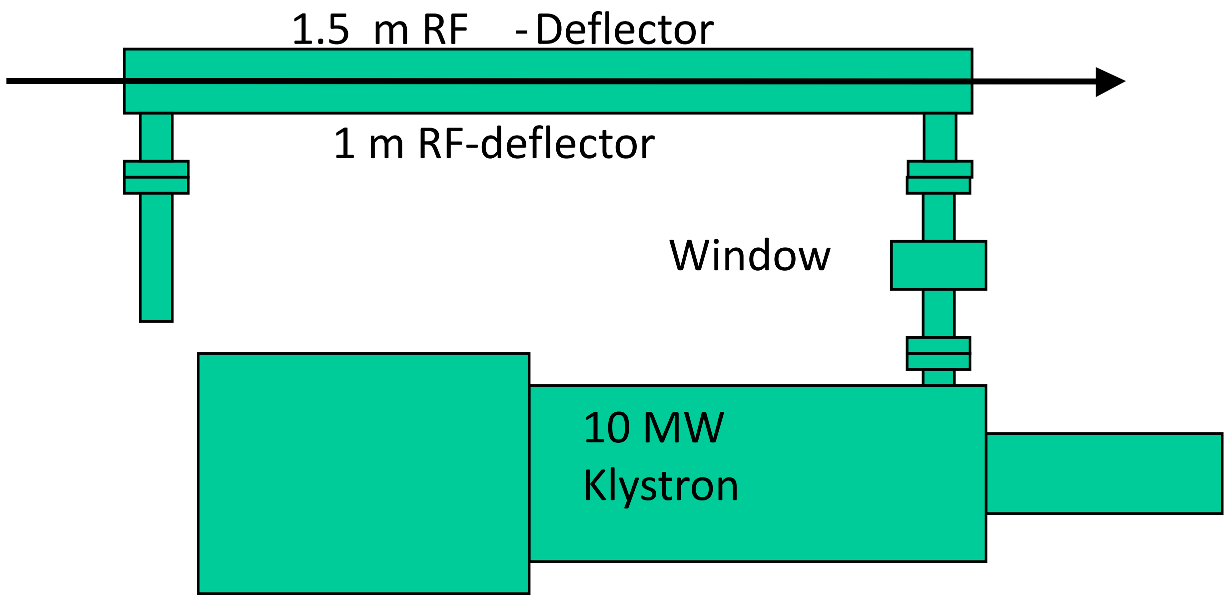


Input Power : 10MW

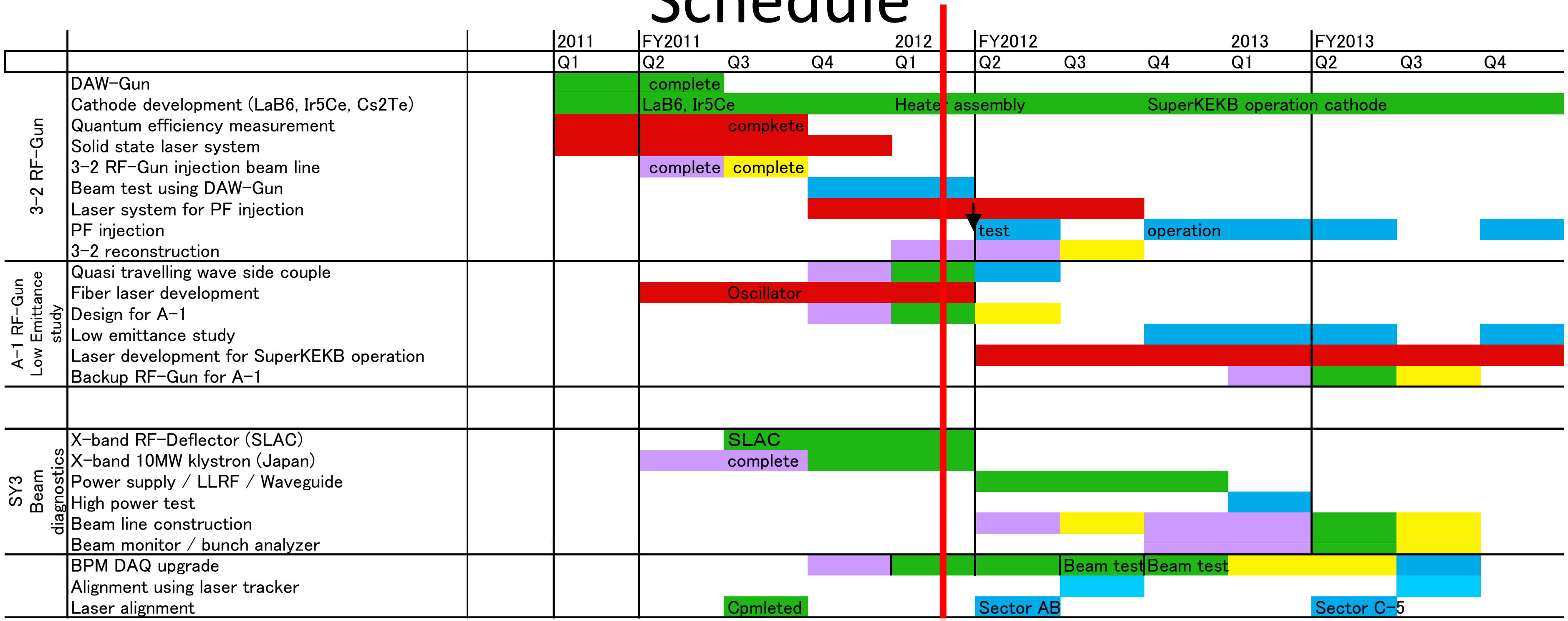
Deflecting Voltage : 15 MV

X-band Klystron (KEK)

- 250 kV, ηP=0.7
- 10 MW output
- 2 window



Schedule



Achievement

RF-Gun

- RF-Gun cavity
  - Disk and washer — complete
  - Quasi TW side couple — under design
- Cathode (LaB6) — QE > 10^{-4}
- Laser
  - Nd:YVO4 + YAG Solid state — 50 %
  - Yb Fiber laser — 25 %

Emittance preservation

- Alignment
  - Laser tracker — Tested for 3-5 sector recovery
  - Laser alignment — Tested in 3-5 sector
- Emittance preservation
- Beam diagnostics
  - BPM — 20 μm (should reduce to 10 μm)
  - Beam diagnostic station — RF-deflector development under US-Japan collaboration.