RF-Gun for SuperKEKB

SuperKEKB review @ 05 Mar, 2013

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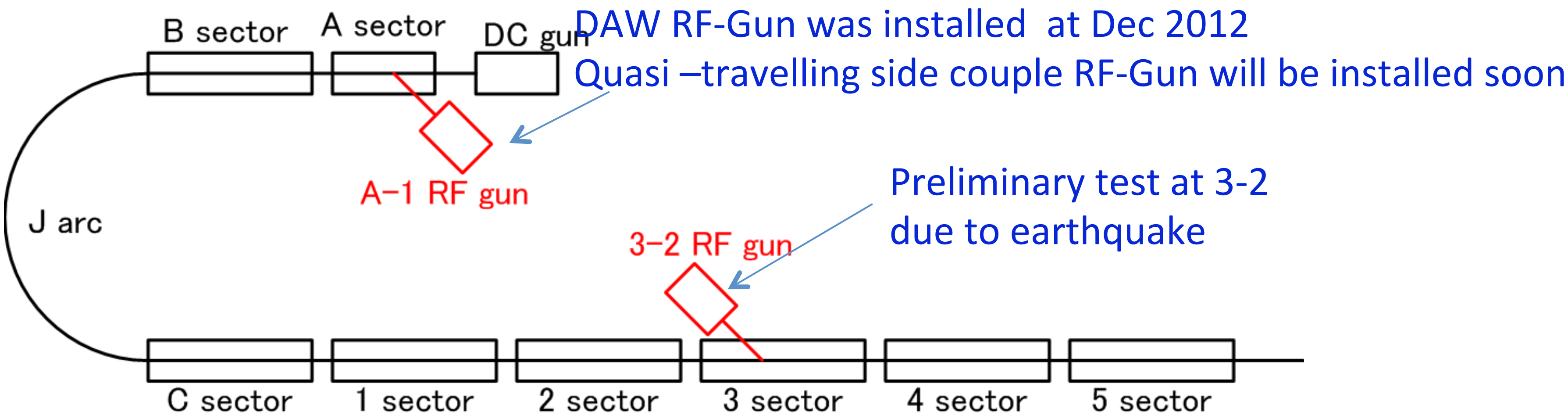
SuperKEKB upgrade for low emittance electron beam

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 development strategy for SuperKEKB

- Cavity : Strong electric field focusing structure
  - Disk And Washer (DAW) => 3-2, A-1(test)
  - Quasi Traveling Wave Side Couple => A-1

  => Reduce beam divergence and projected emittance dilution
- Cathode : Long term stable cathode
  - Middle QE ($QE=10^{-4}\sim10^{-3}$ @266nm)
  - Solid material (no thin film) => Metal composite cathode

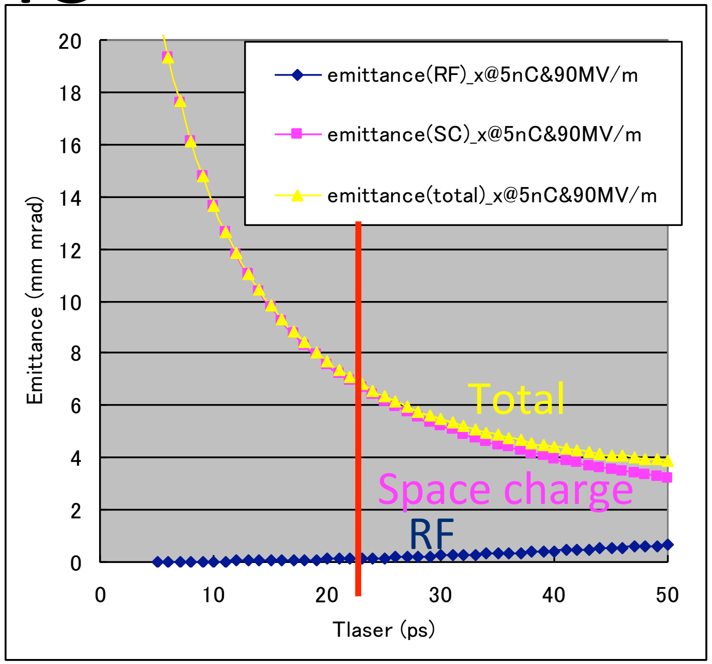
    => Started from LaB_6 (short life time)

    => Ir_5Ce has very long life time and $QE>10^{-4}$ @266nm
- Laser : Stable laser with temporal manipulation
  - LD pumped laser medium => Nd / Yb doped
  - Temporal manipulation => Yb doped

    => Minimum energy spread

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

RF-Gun for 5 nC

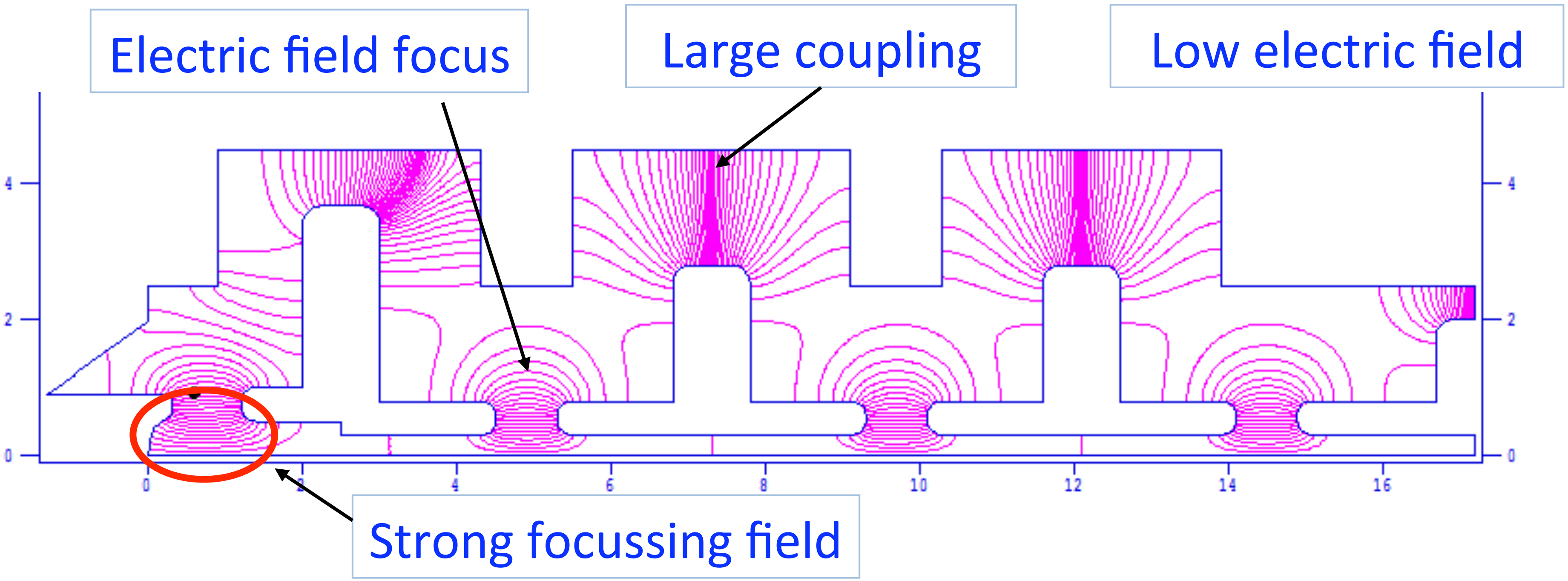


- Space charge is dominant.
  - Longer pulse length : 20 - 30 ps
- Stable operation is required.
  - Lower electric field : < 100MV/m
- Focusing field must be required.
  - Solenoid focus causes the emittance growth.
  - **Electric field focus preserve the emittance.**

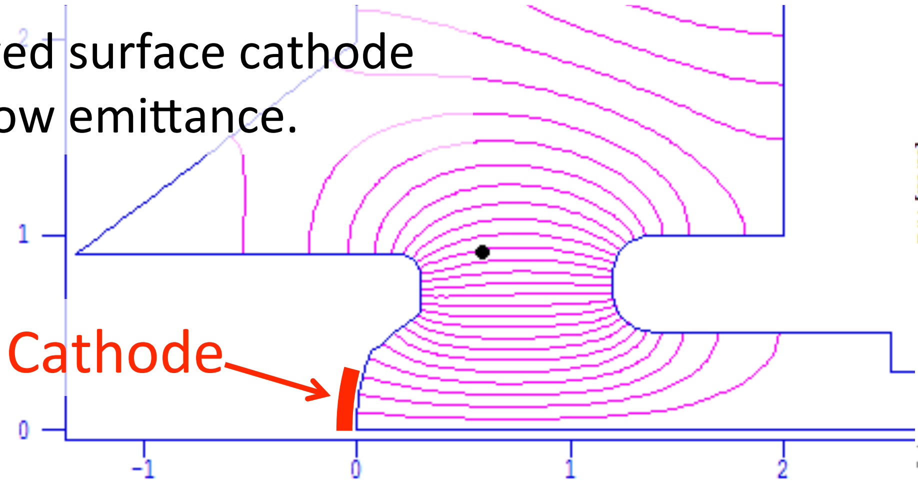
~~Epxial coupled~~ cavity : BNL

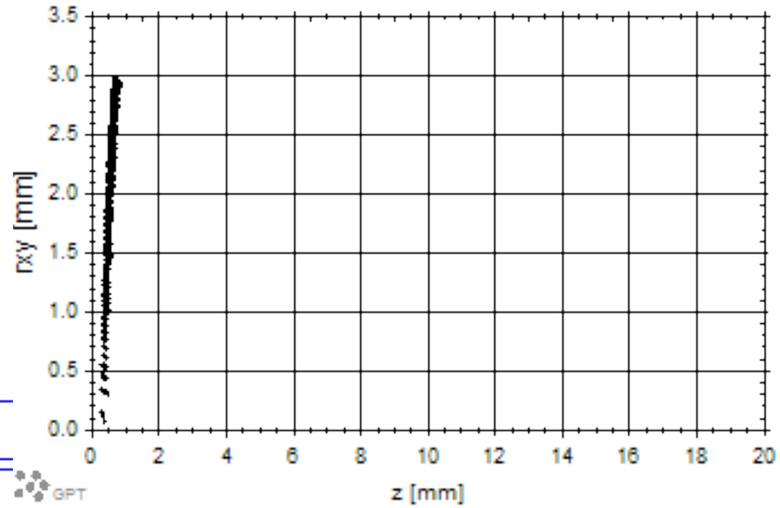
Annular coupled cavity : Disk and washer / Side couple

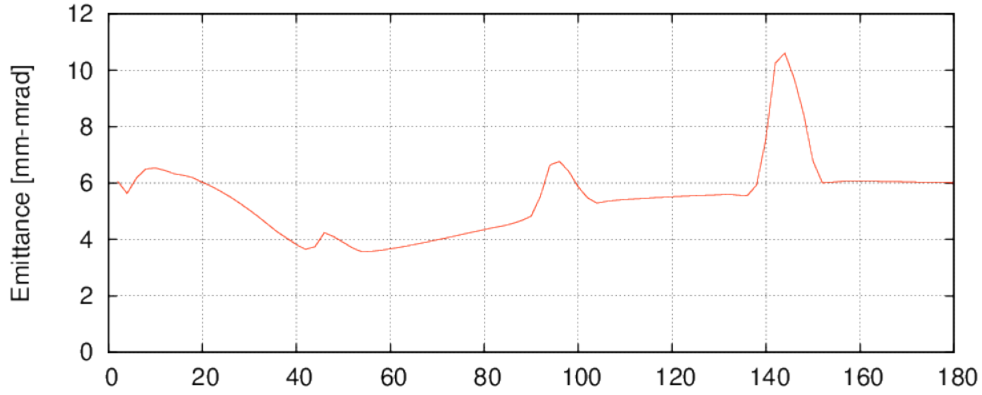
DAW (Disk and Washer) type RF-Gun



Curved surface cathode
for low emittance.



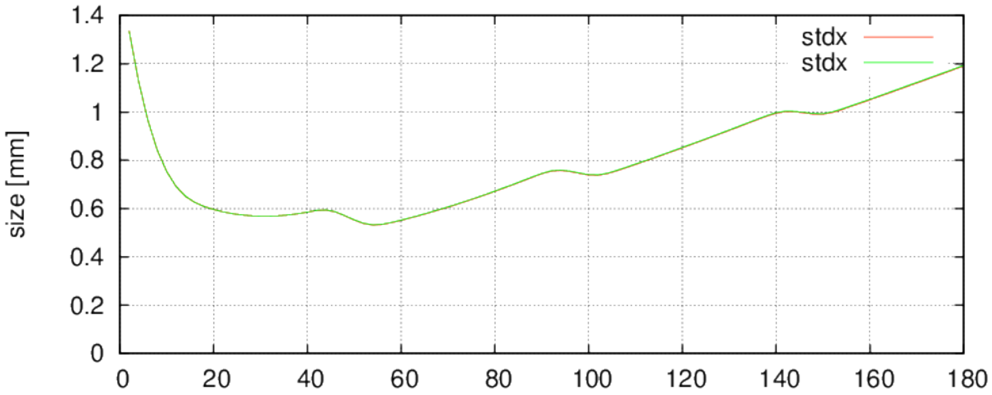




Emittance

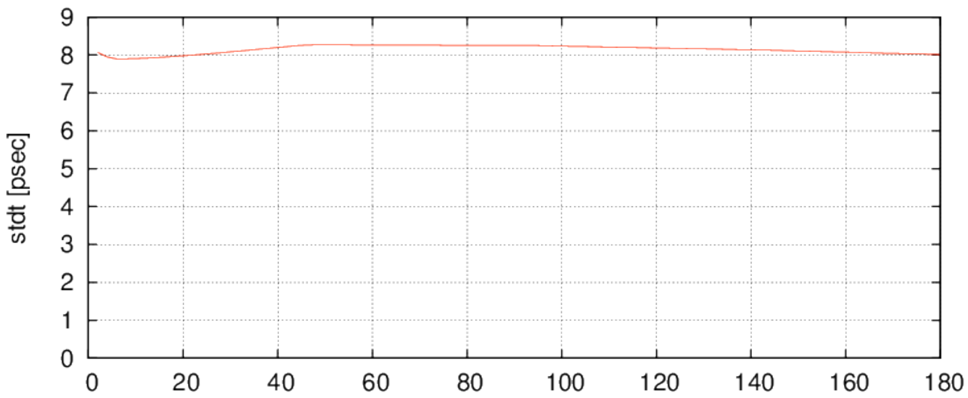
6 mm-mrad

（5 nC）



Beam size (σ)

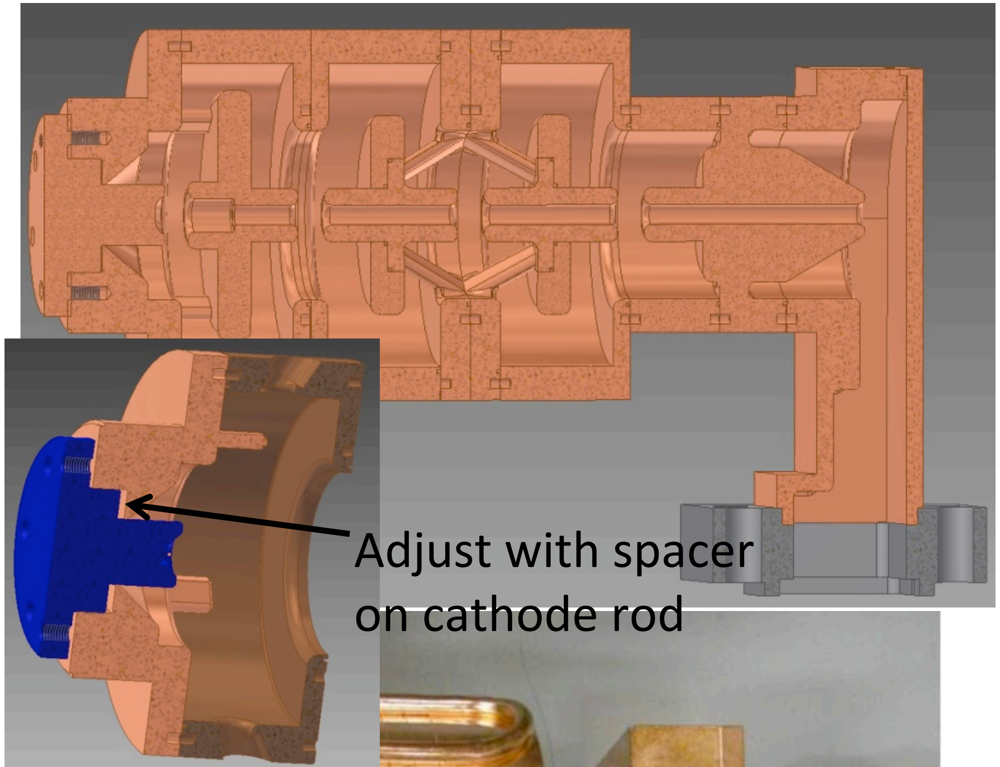
1.2 mm



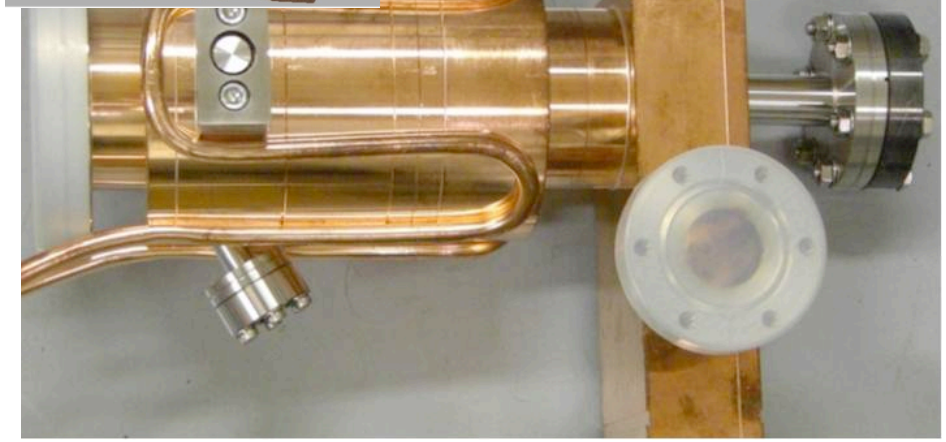
Bunch length (σ)

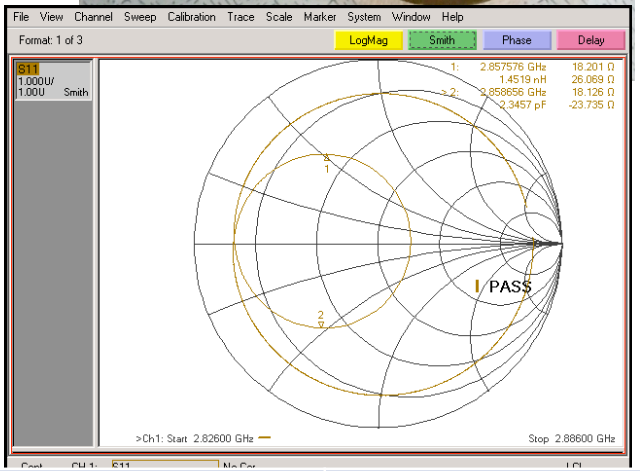
8 psec

Fabrication of DAW RF-Gun



Adjust with spacer on cathode rod

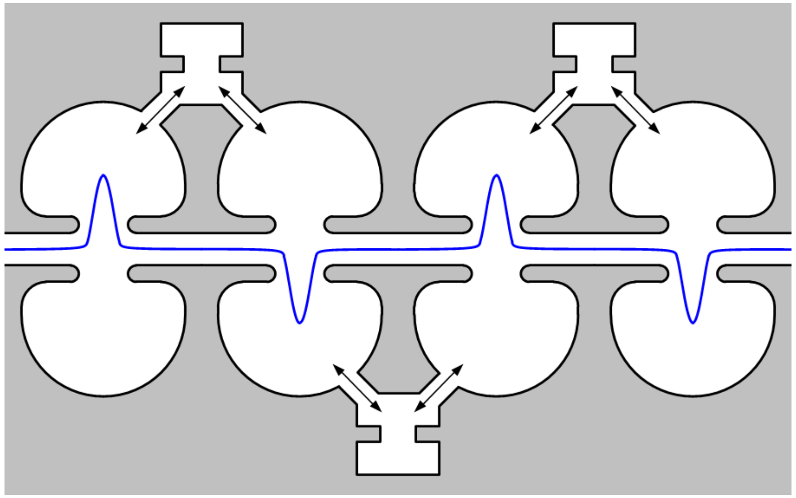


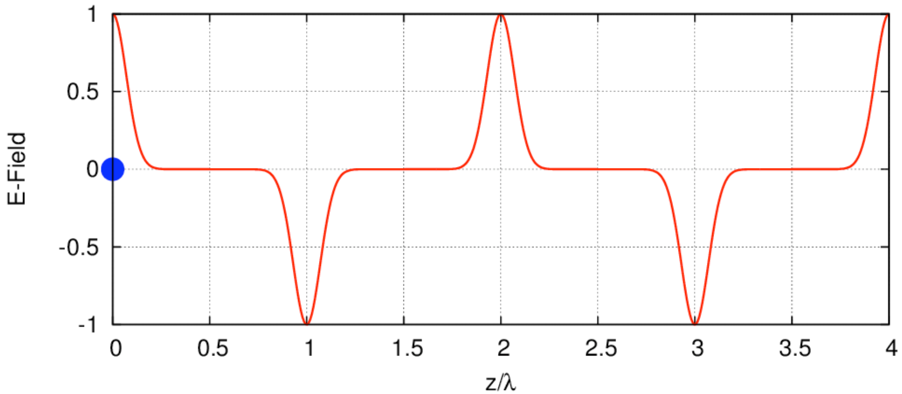


Reflection ratio	$G = 0.119$
Coupling	$\beta = 1.27$
Q factor	$Q_0 = 6007.3$
Loaded Q	$Q_L = 2646.4$

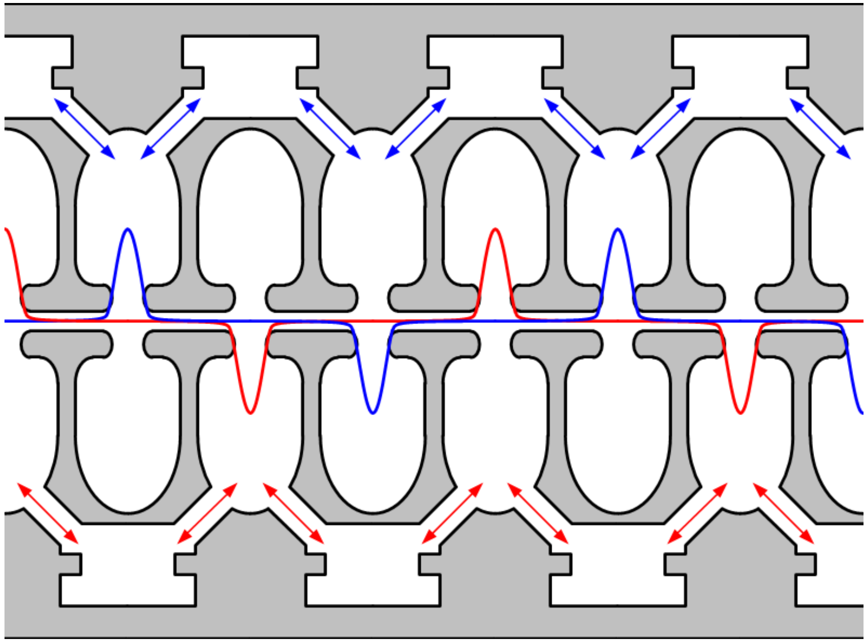
Design of a quasi traveling wave side couple RF gun

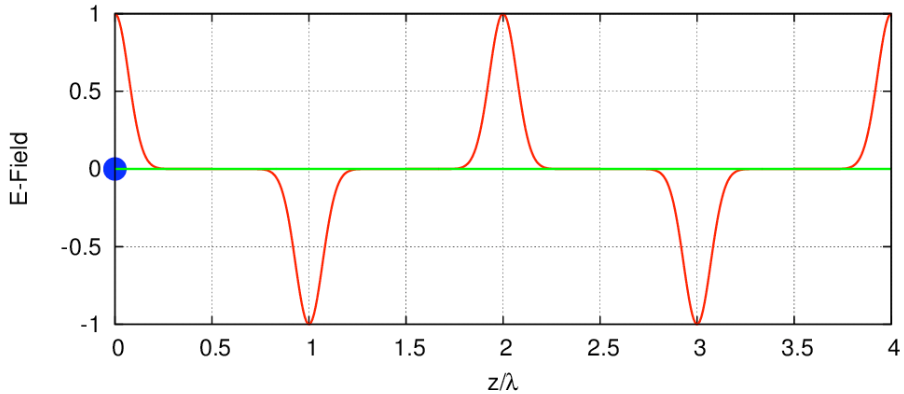
Normal side couple structure





Quasi traveling wave sidecouple structure

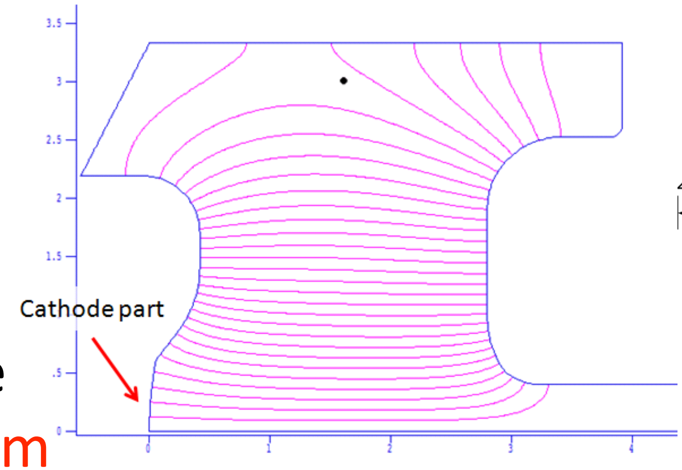


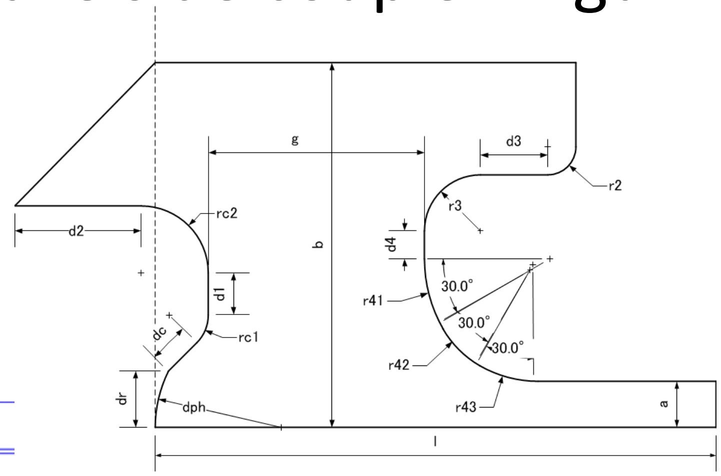


Quasi traveling wave side couple has stronger focusing and accelerated gradient than DAW.

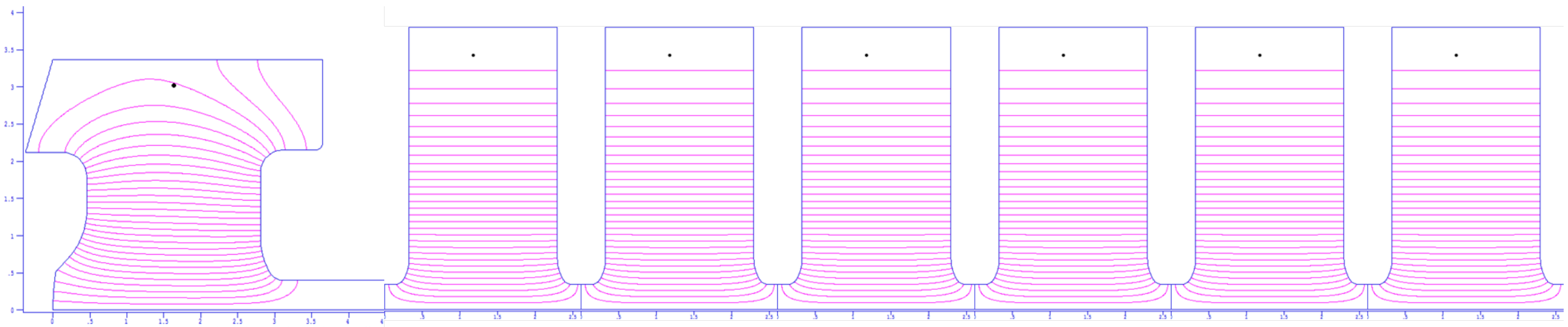
2D Designing of the quasi traveling wave side couple RF gun

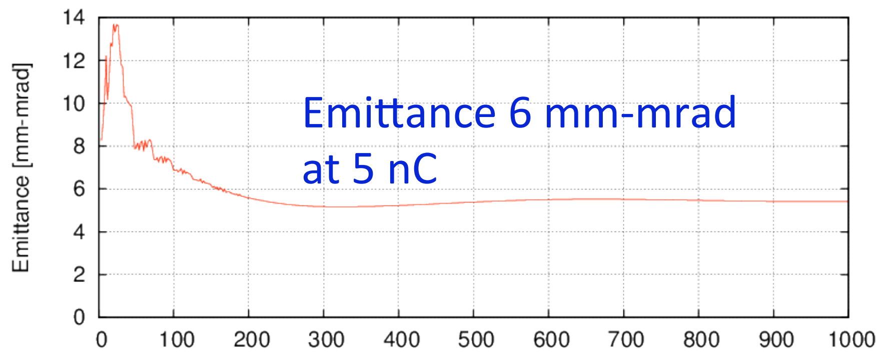
Optimize 1st cell by multi-dimensional parameters

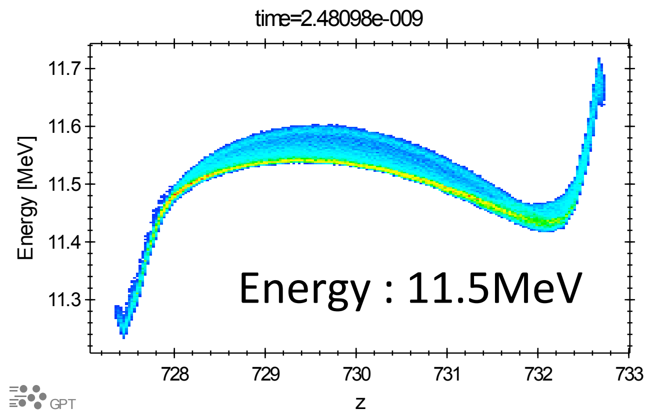




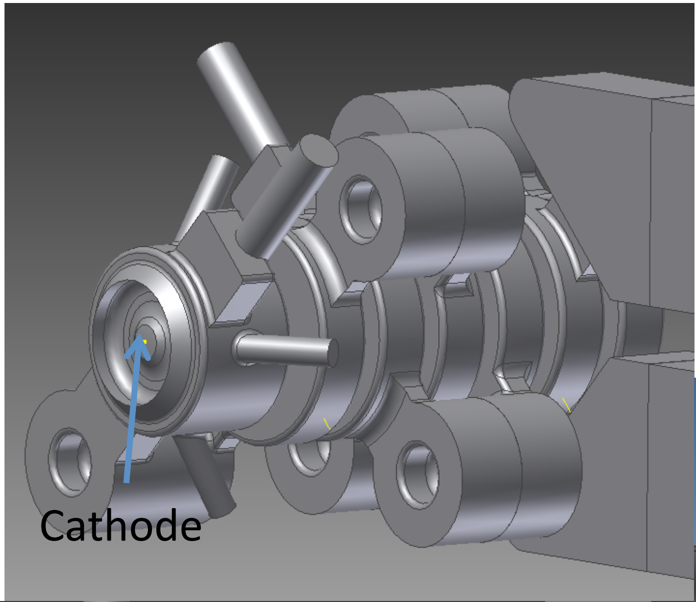
Maximum surface E-field is 120 MV/m

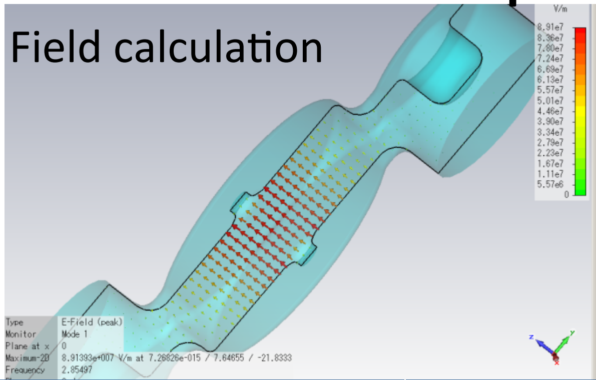


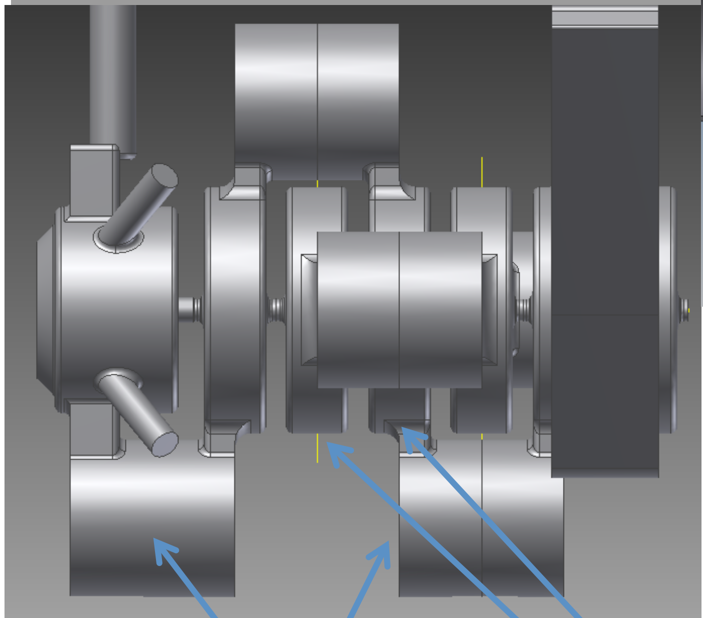


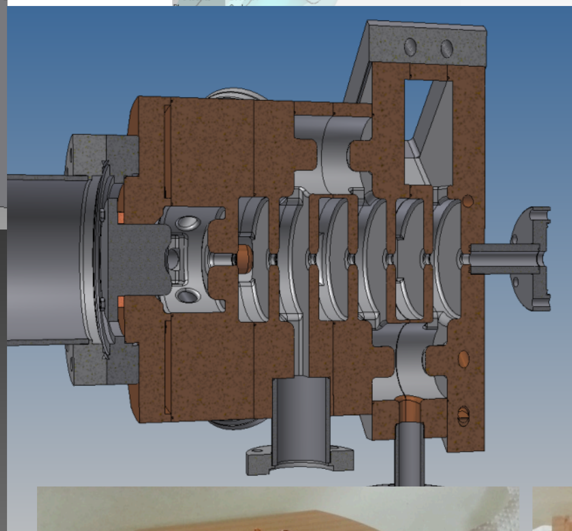


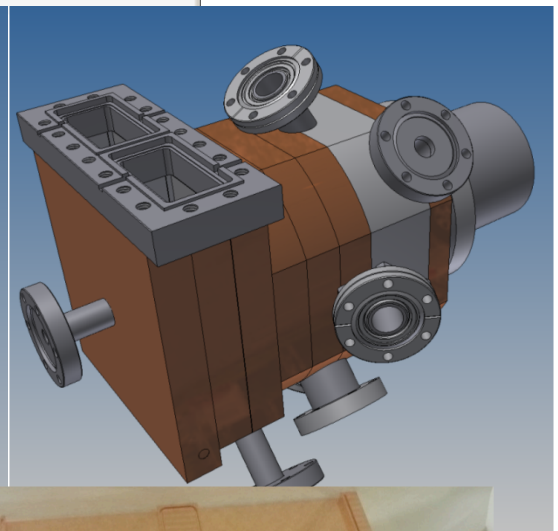
Quasi-traveling wave side couple

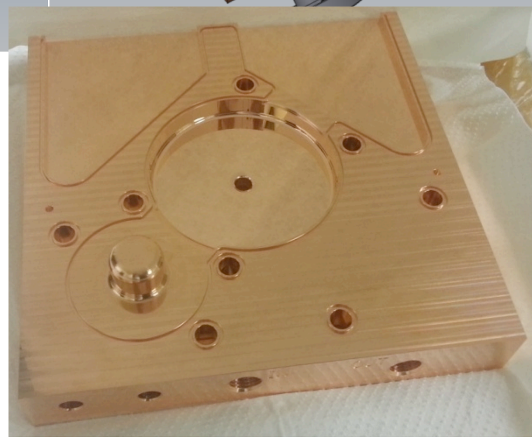








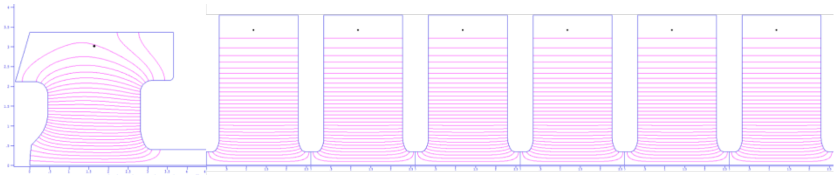




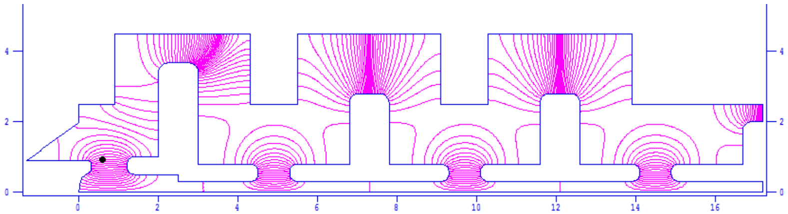
Coupling cavities

Acc. cav

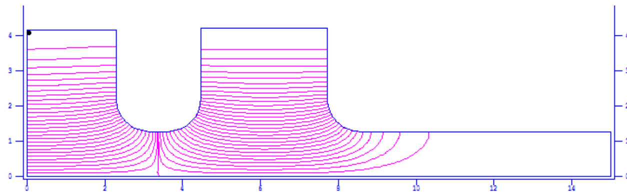
RF-Gun comparison



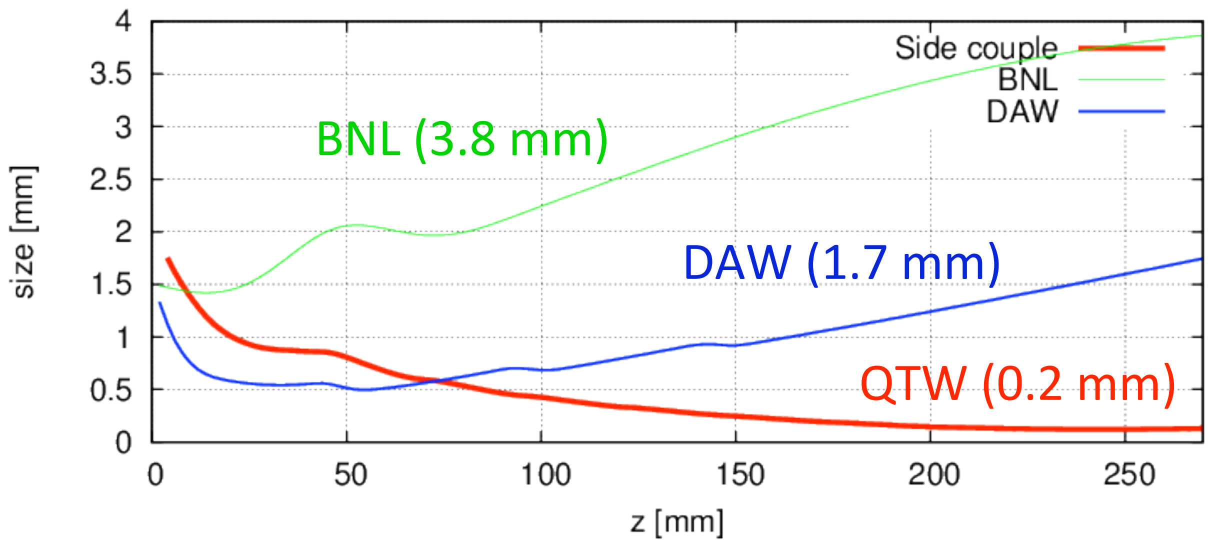
Quasi traveling wave side couple RF gun
(100 MV/m, 6mm-mrad, 13.5 MeV)



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



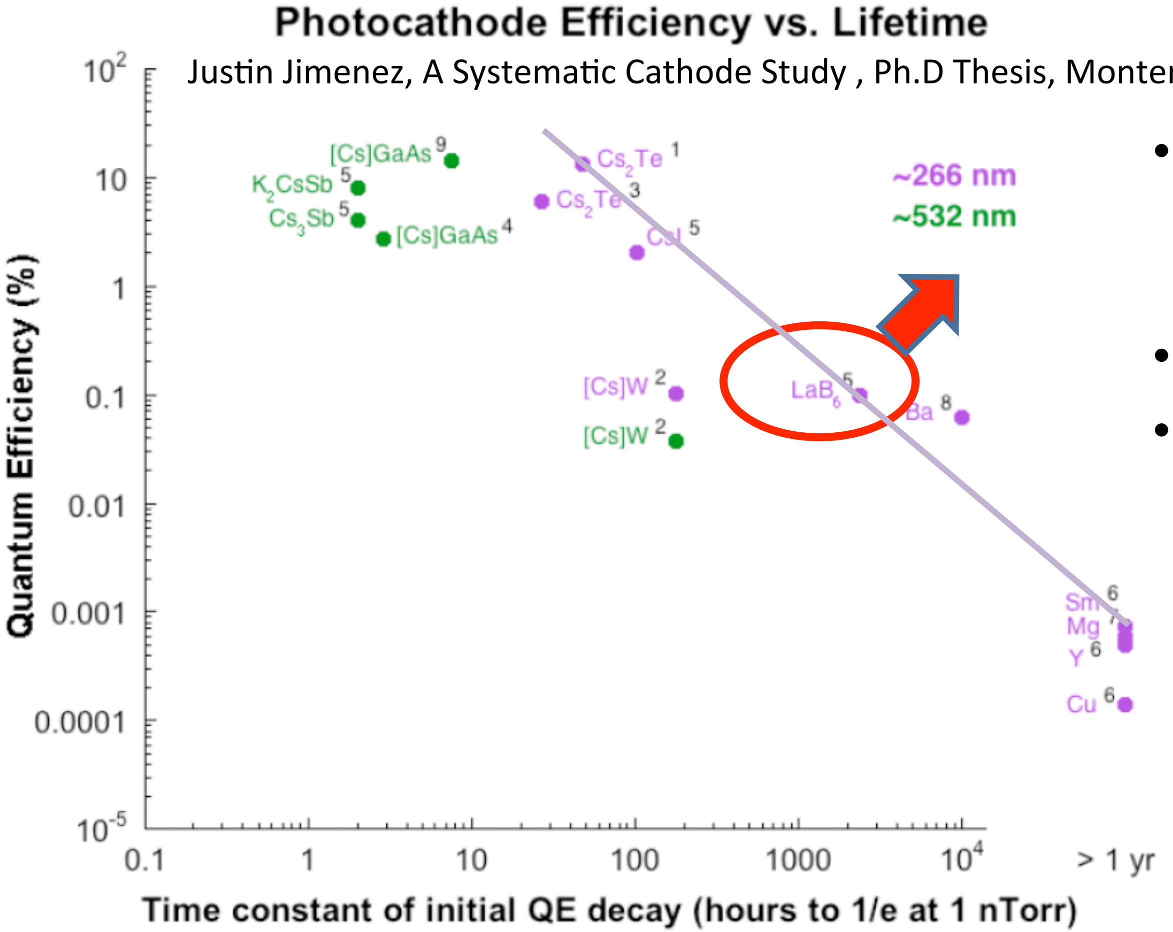
BNL-type RF gun
(120 MV/m, 11.0 mm-mrad, 5.5 MeV)



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

Cathode : Advantage of 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

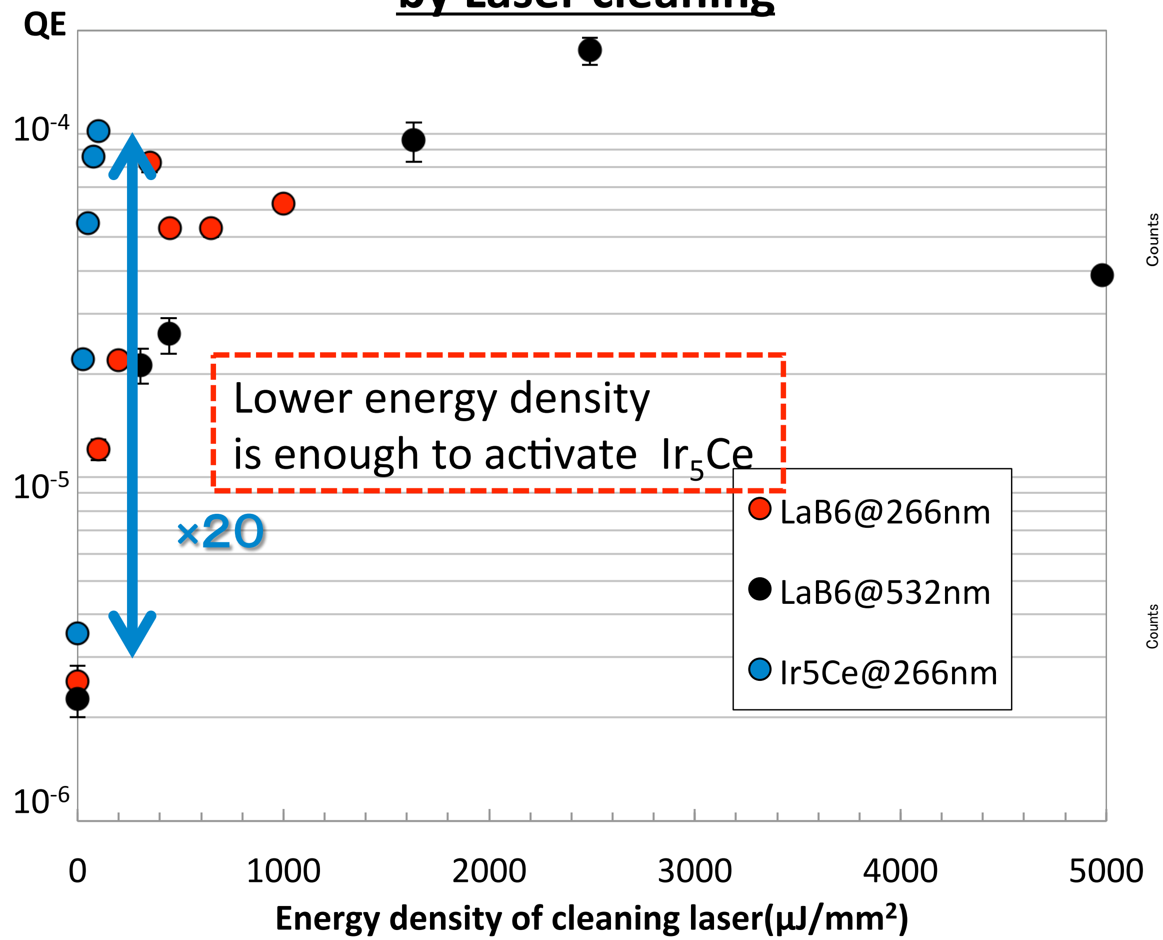
Best choice for SuperKEKB 5 nC long time operation

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

Ir_5Ce Cathode

Quantum efficiency improvement by Laser cleaning

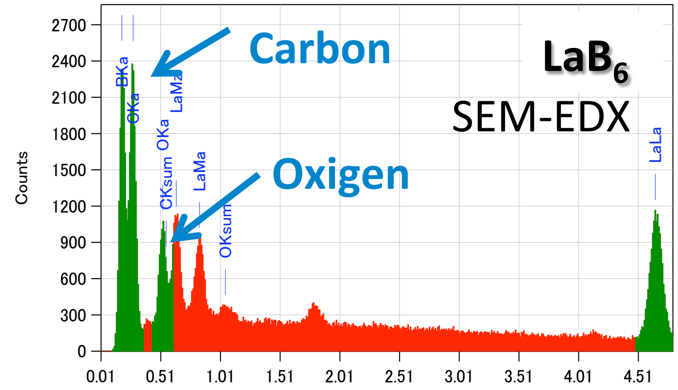


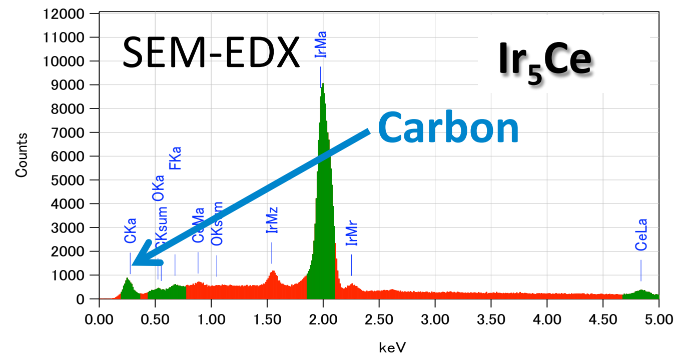
Condition

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}**

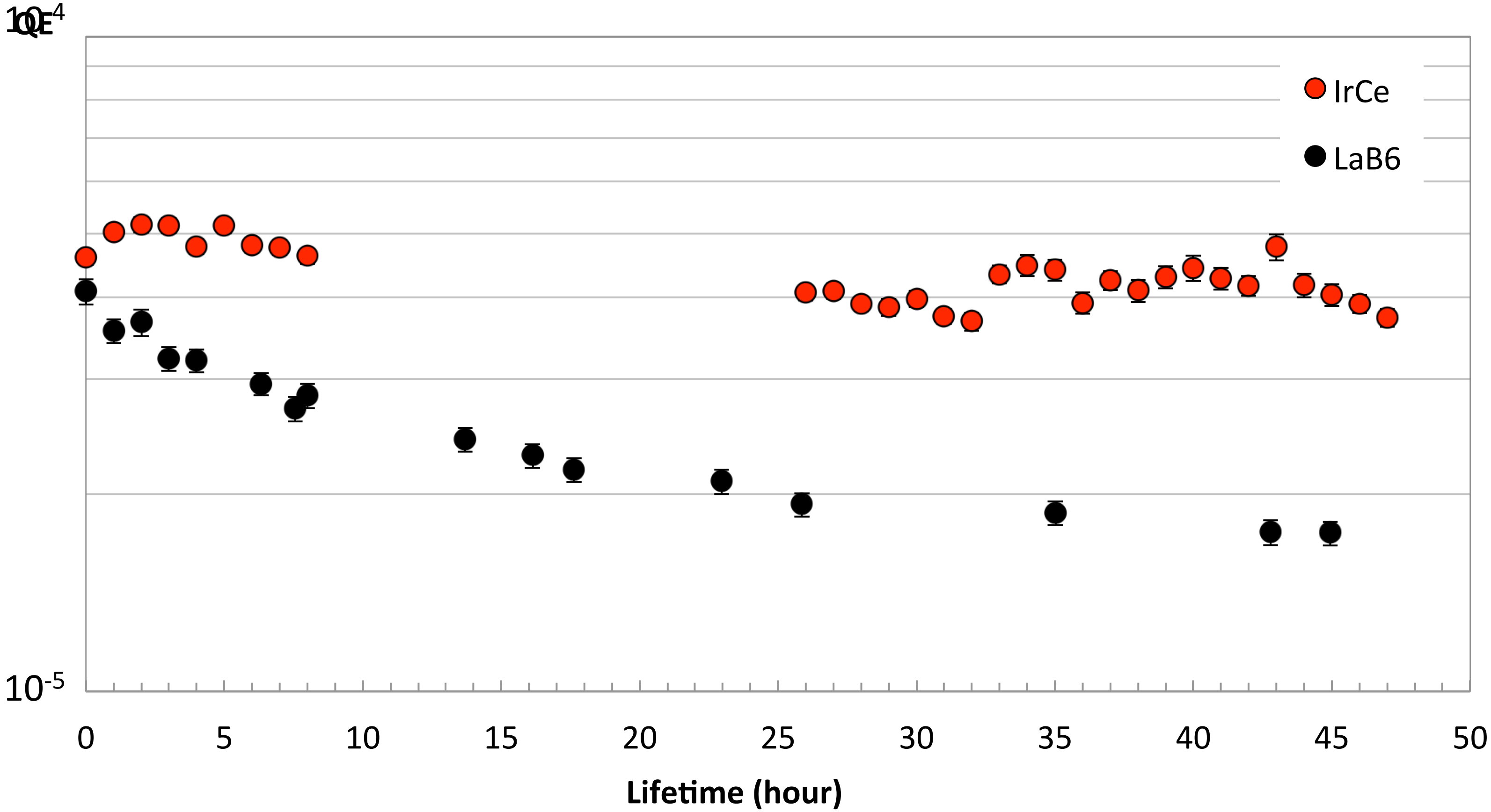
[SUPER-KEKB e Linac]

Laser Power ; 233μJ/pulse

(λ=266nm)

Target value ; 5nC

Lifetime measurement（LaB_6 / Ir_5Ce）



Condition

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

- RF-Gun
  - Design of RF-Gun cavity
  - Cathode
  - **Laser**
    - **Nd:YVO4 / Nd:YAG Solid state laser**
    - **Yb fiber laser**
  - Test stand and schedule

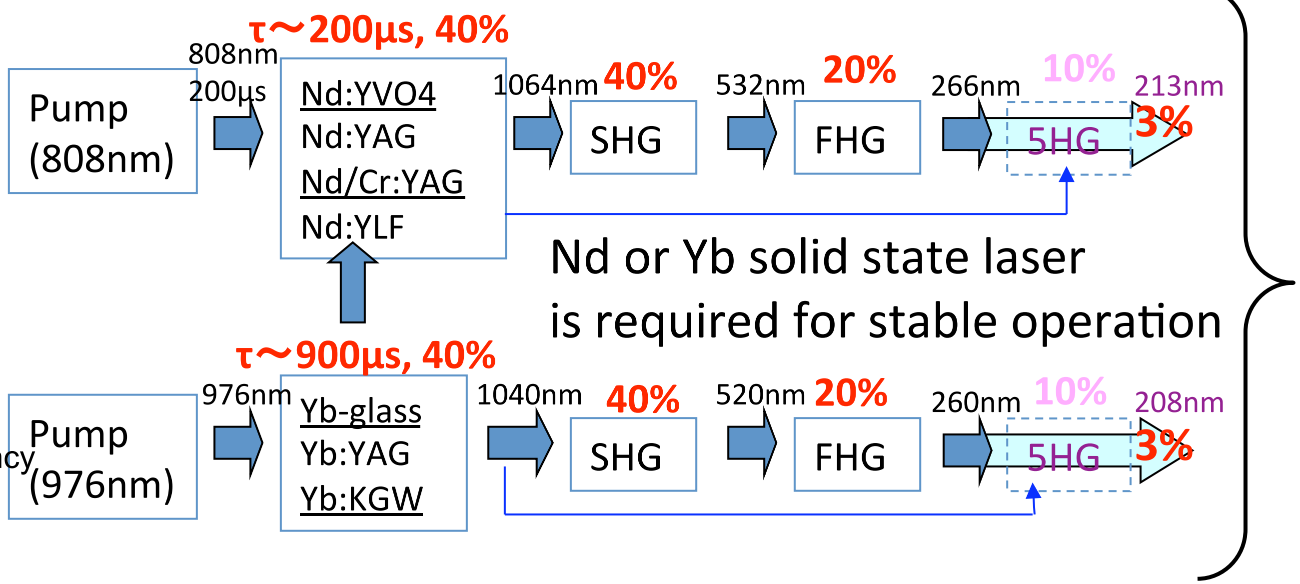
Laser medium and its effciency

Nd-doped

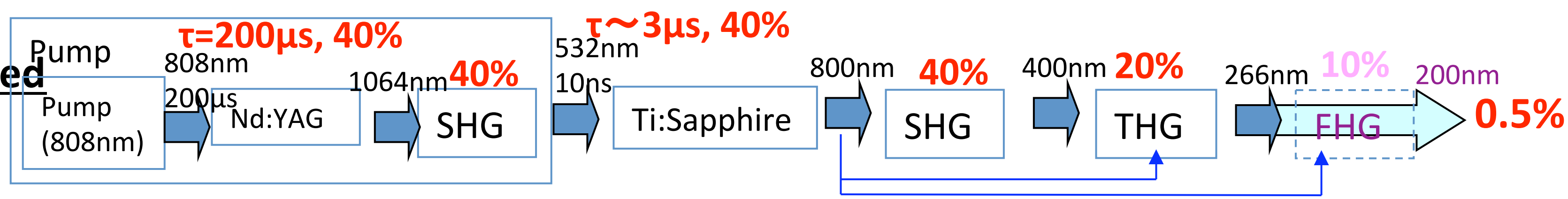
- ○ 4-state laser is easy to operate.
- ○ High power pump LD is available.
- ○ Large crystal is available
- × Pulse width is determined by SESAM. (Gaussian)

Yb-doped

- ○ Wide bandwidth => pulse shaping
- ○ Long fluorescent time => High power
- ○ Fiber laser => Stable
- ○ Small state difference => High efficiency
- × ASE
- × Absorption



Ti-doped



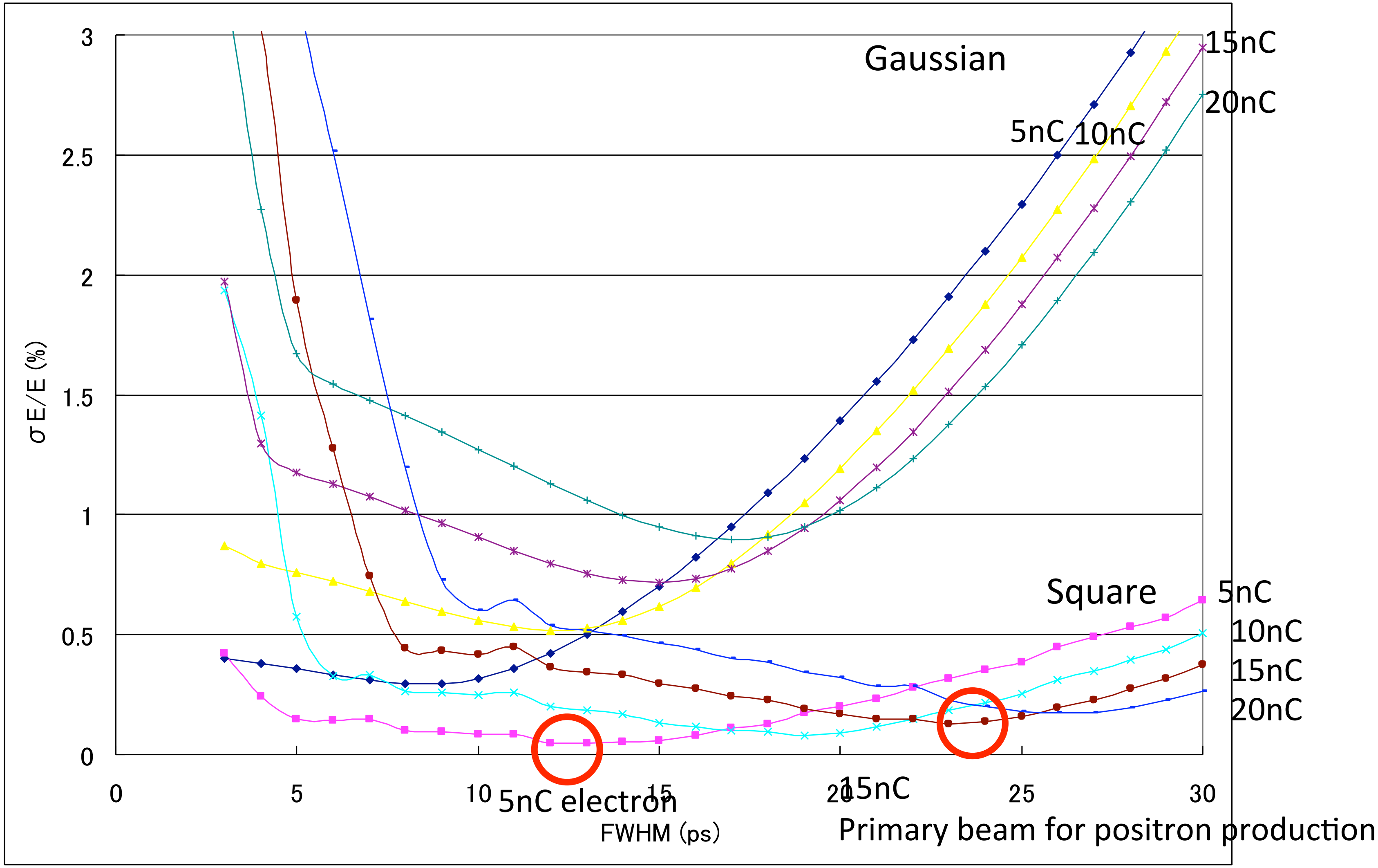
- ○ Very wide bandwidth
- ○ High breakdown threshold

} TW laser is based on Ti-Sapphire

- × Low cross section
- × Short fluorescent time => Q-switched laser is required for pumping

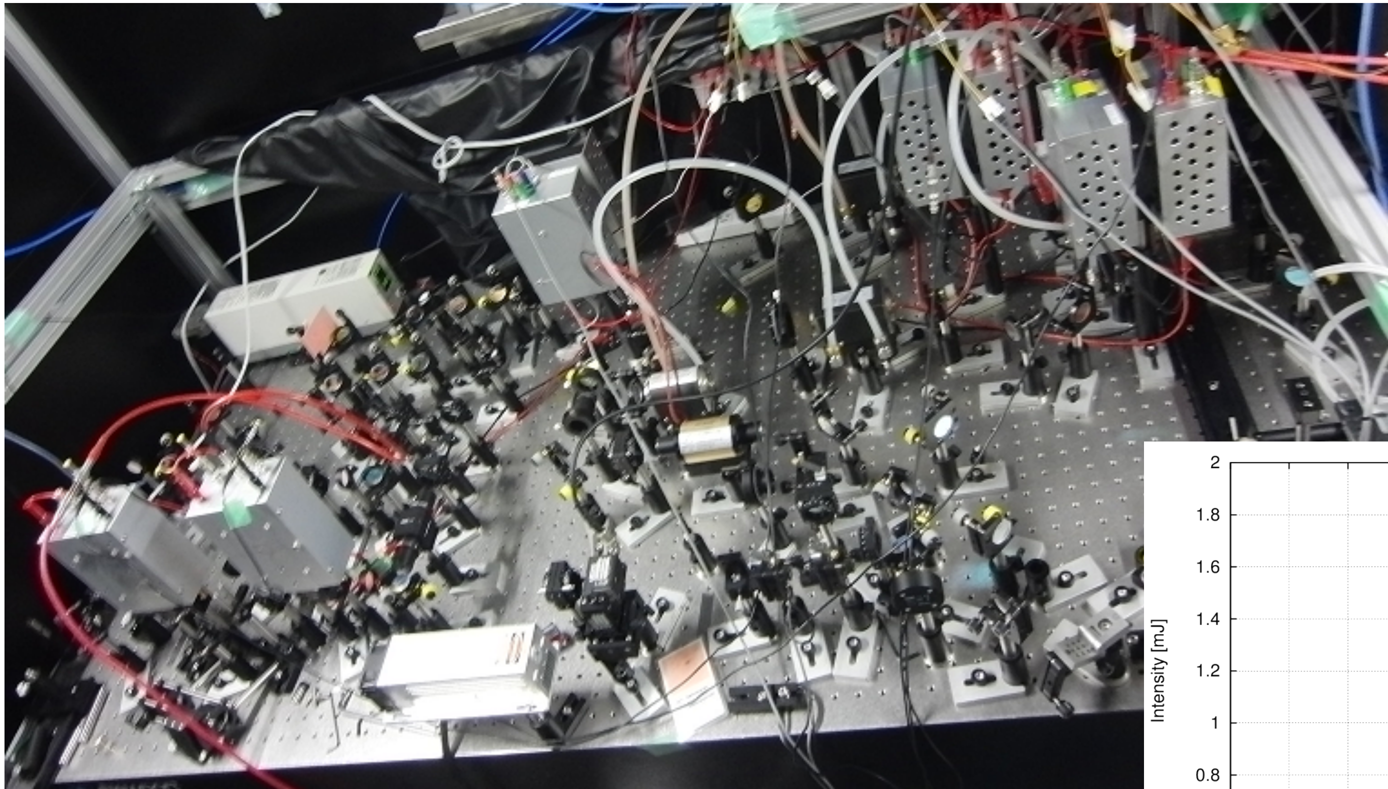
	Material	Nd:YAG	Ti-Sapphire	Yb:YAG
Fluorescence	Wavelength	1064 nm	660～ 1100 nm	1029 nm
	Fluorescent time	～0.23 ms	0.0032 ms	0.96 ms
	Spectral width	0.67 nm	440 nm	9.5 nm
	Fourier minimum pulse width	2480 fs	2.59 fs	165 fs
Absorption	Wavelength	807.5 nm	488 nm	941 nm
	Spectral width	1.5 nm	200 nm	21 nm
	Quantum efficiency	0.76	0.55	0.91

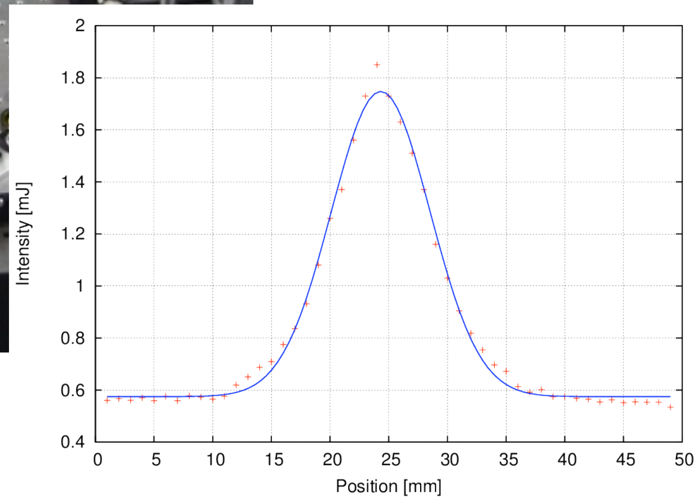
Energy spread reduction using temporal manipulation



Nd based laser system

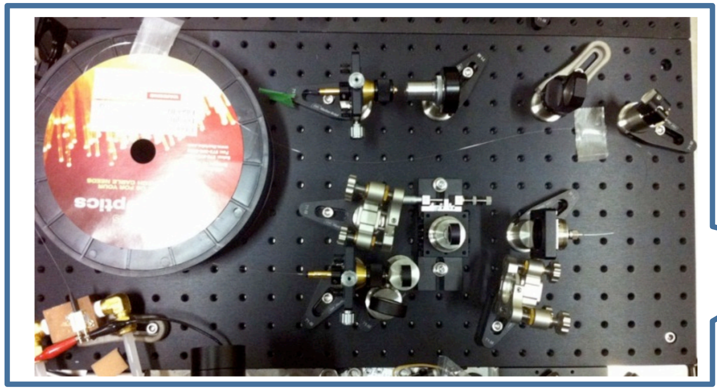
- Nd:YVO_4 oscillator + Nd:YAG multi-pass amplifier

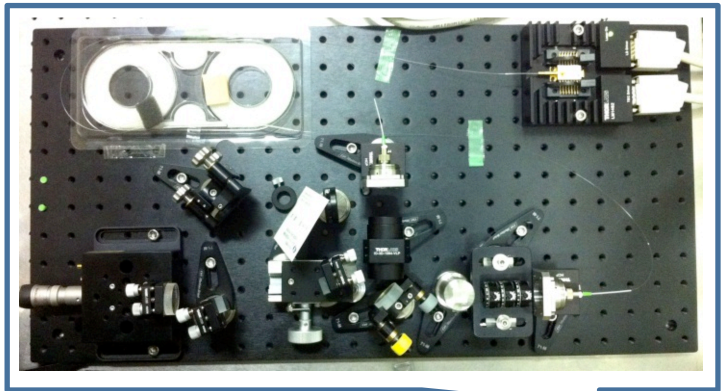


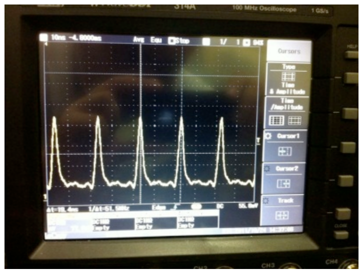


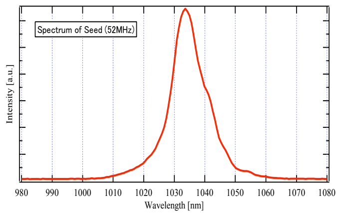
30 ps (10 mm)

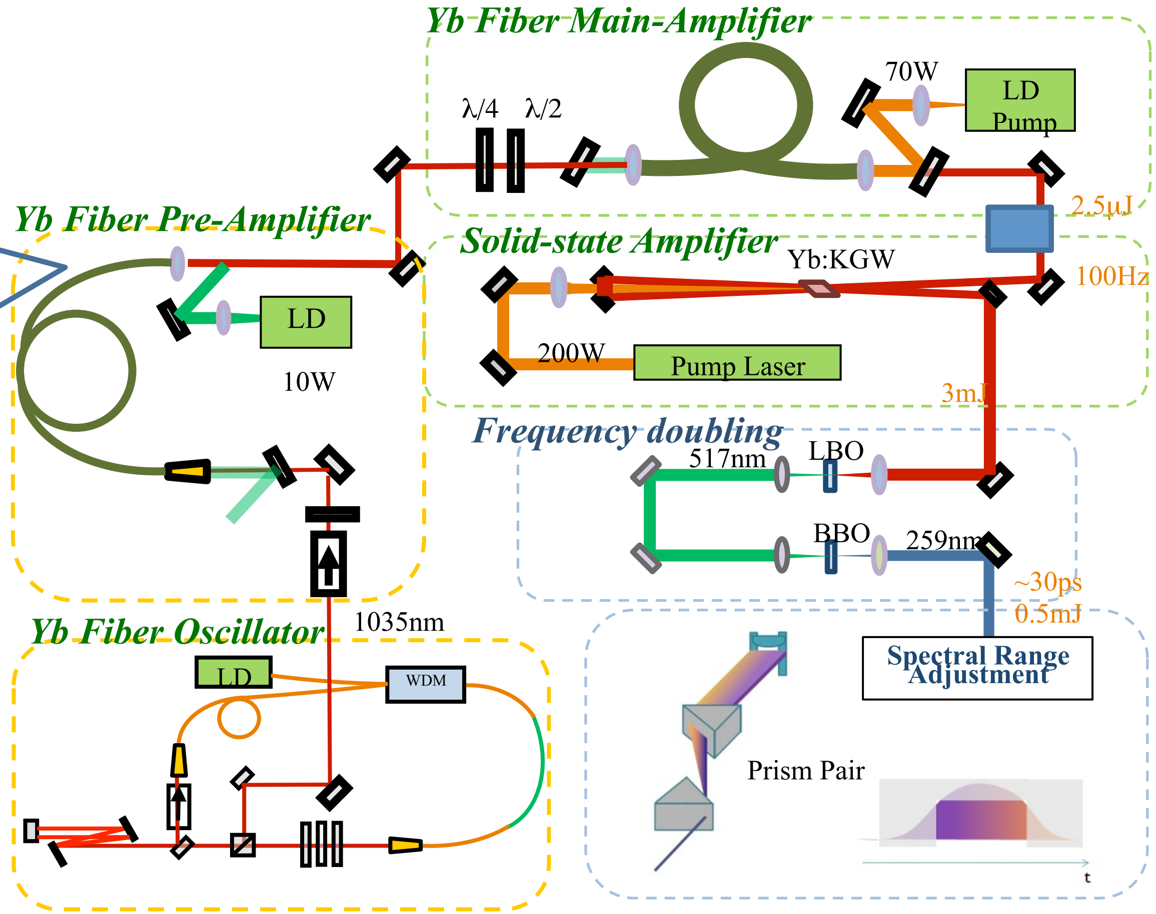
Yb-fiber & Yb solid state laser development

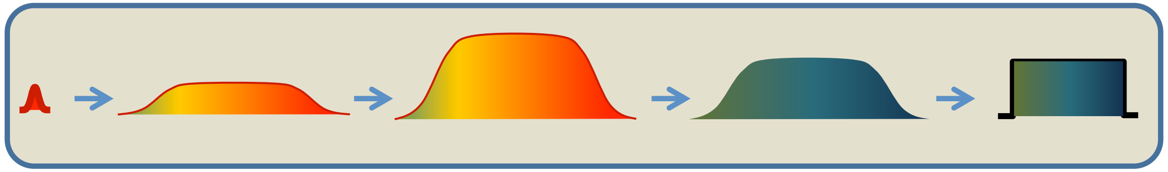








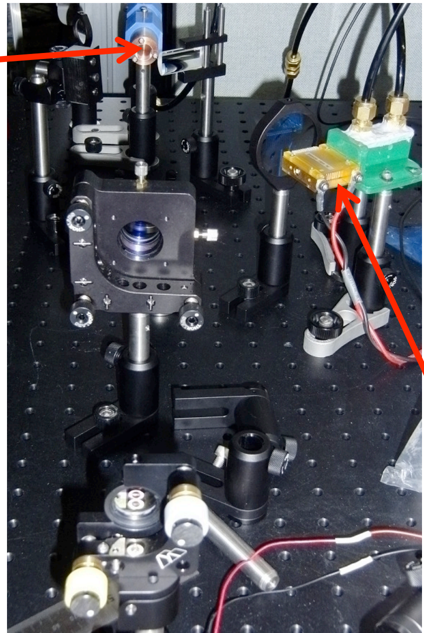


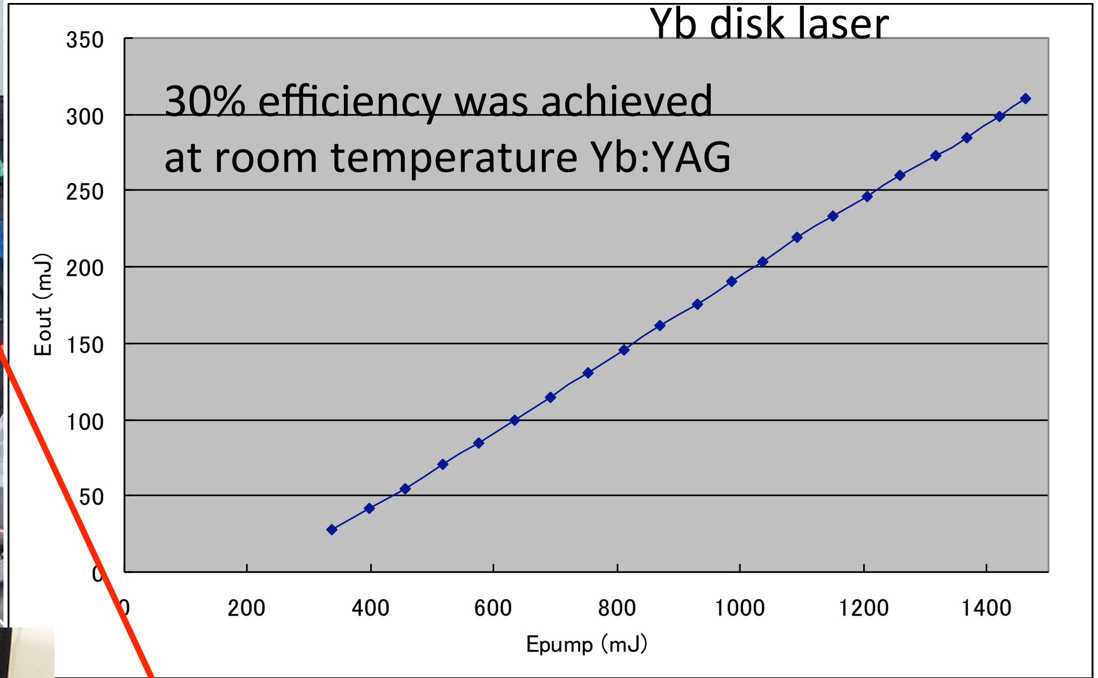


Oscillator & pre-amplifier are already working.

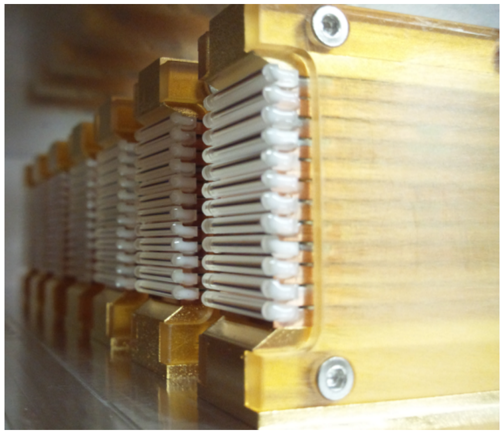
Yb disk Laser

Yb:YAG disk
10 % doped
2mm thickness





940nm LD (2.4 kW / module)

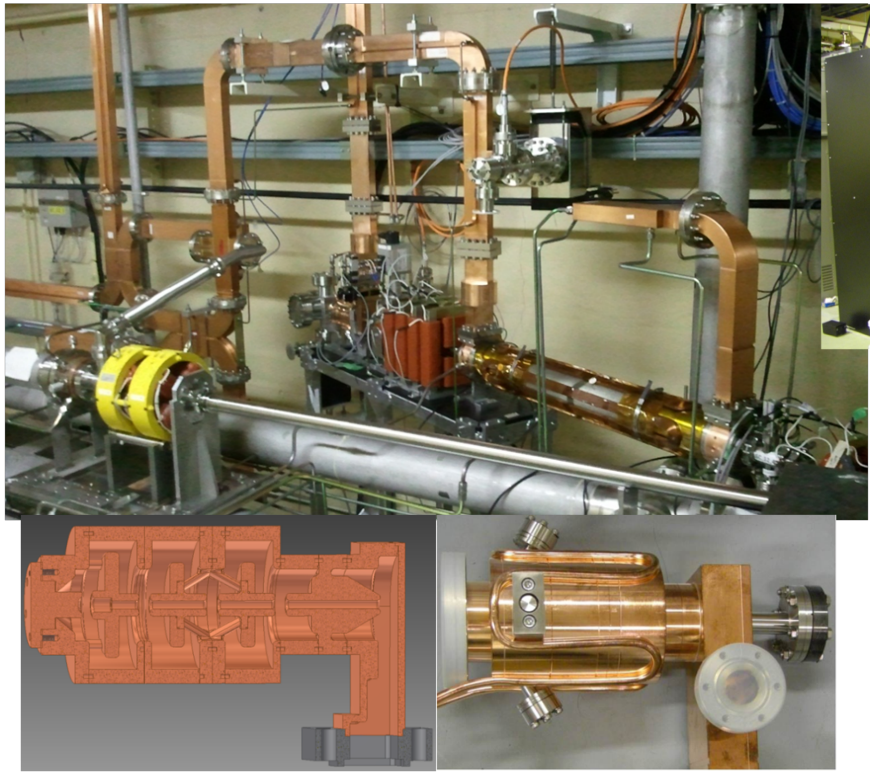


Regenerative amplifier using Yb disk laser

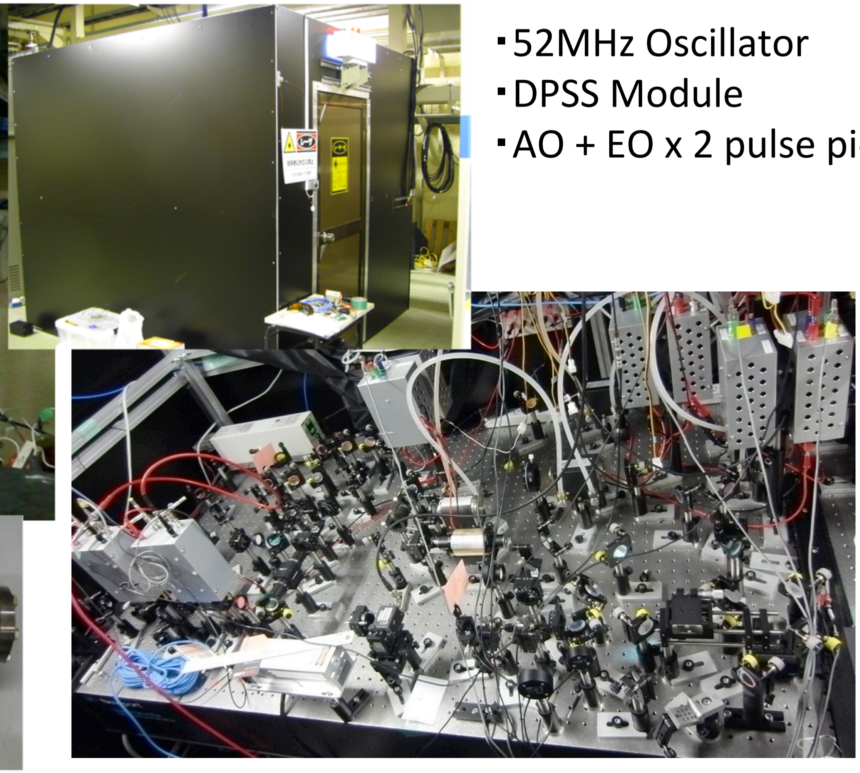
- RF-Gun
  - Design of RF-Gun cavity
  - Cathode
  - Laser
  - **Test stand and schedule**
    - **3-2 RF-Gun for preliminary test & PF injection**
    - **A-1 RF-Gun**

3-2 RF-Gun

3-2 RF-Gun (2011/10)

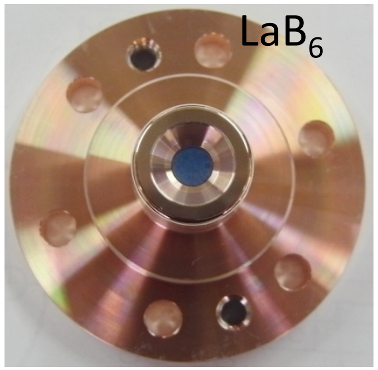


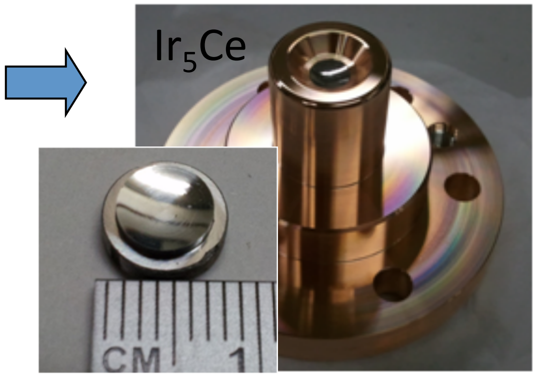
3-2 Laser hut



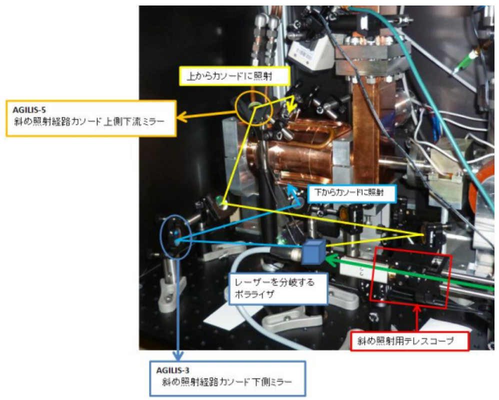
- 52MHz Oscillator
- DPSS Module
- AO + EO x 2 pulse picker

Cathode LaB6 => Ir5Ce（2012/03）



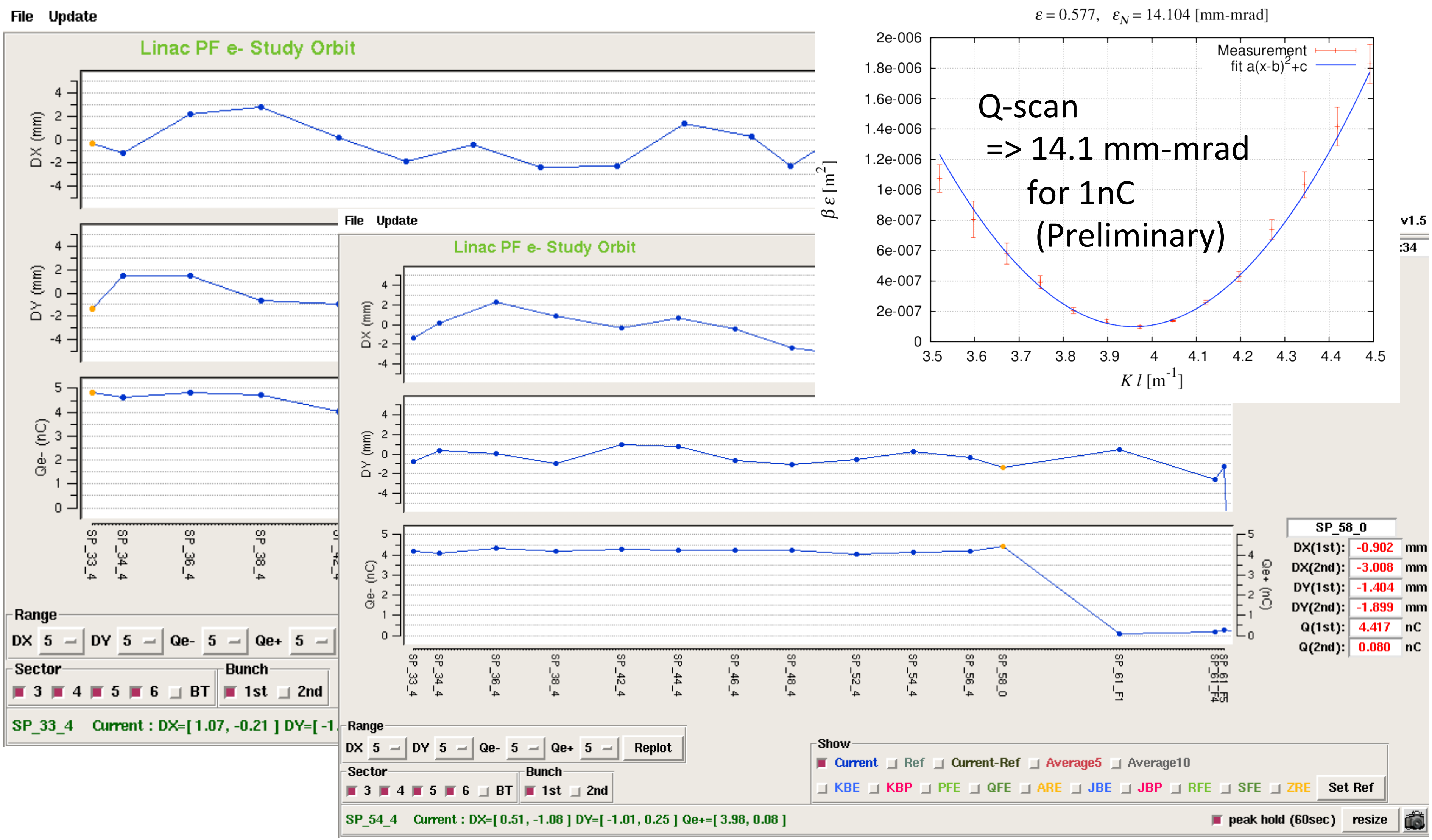


Laser injection with angle（2012/05）



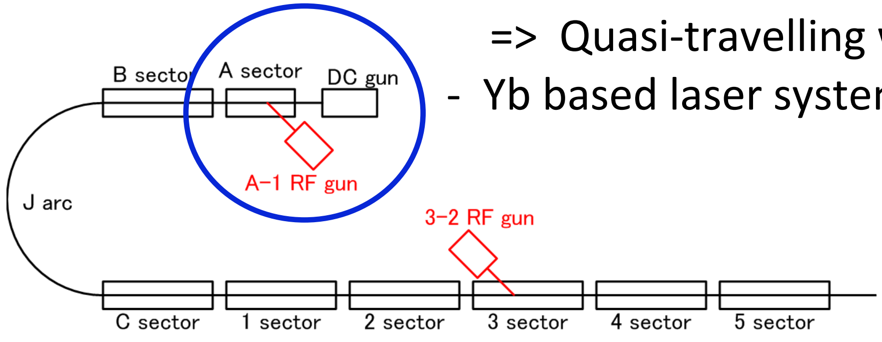
5nC was achieved !

- 4 mJ @ 266nm => 1.5 mJ on cathode



A-1 RF gun

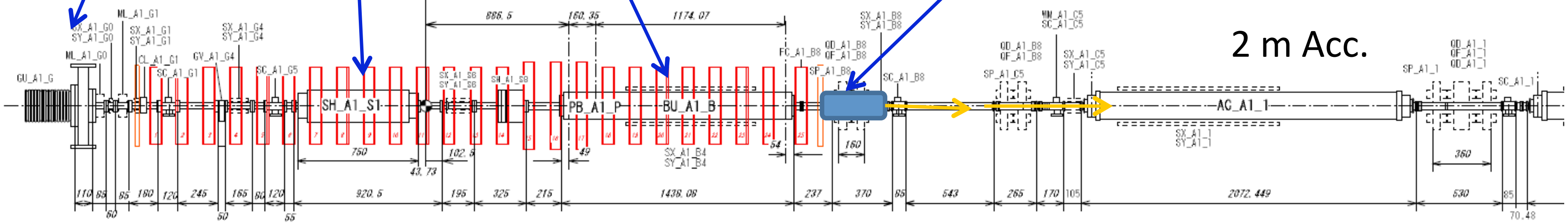
- DAW RF-Gun was installed
  => Quasi-travelling wave side couple RF-Gun will be installed soon.
- Yb based laser system is under test



Exist DC gun
(Positron beam primary)

Pre buncher,
Buncher

SH buncher



A1 sector

Summary

- RF-Gun cavity
  - **5nC Demonstration was done** using DAW-type RF-gun.
  - Quasi travelling wave side couple structure :
    Fabrication is almost done.
  - Ageing process was finished for less than **only one week**.
- Cathode
  - Room temperature 6mmϕ **Ir_5Ce** cathode has enough QE.
  - Laser cleaning & laser injection angle is effective.
- Laser & control
  - **Nd based laser system : 3-2 RF-Gun**
  - **Yb based laser system : A-1 RF-Gun**
    - **Yb-fiber :** Precise RF synchronization
    - Yb-disk amplifier: High power output
    - Temporal manipulation To be developed.
  - Stability / Control: under test