RF-Gun and Hardware for emittance preservation

SuperKEKB review @ 04 Mar, 2014

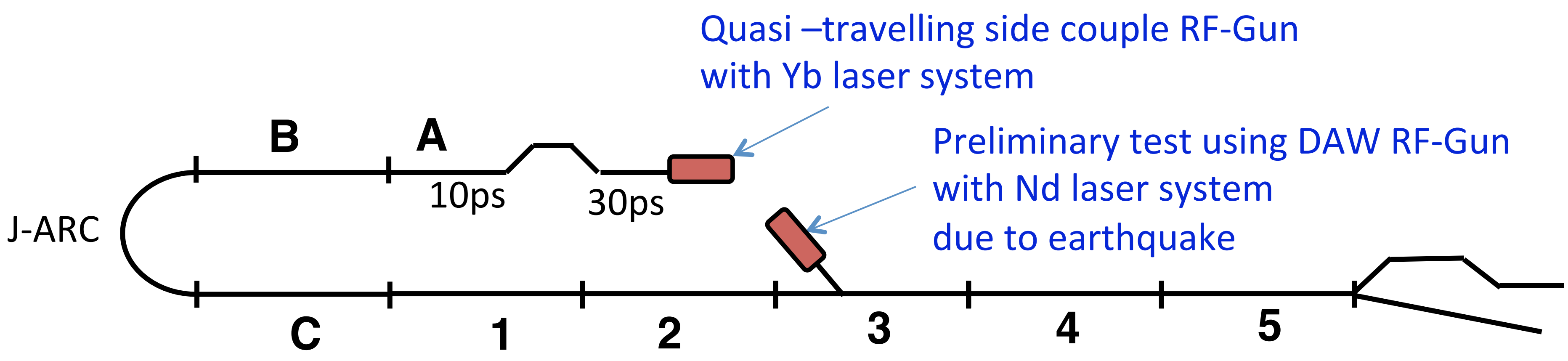
Mitsuhiro Yoshida

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 ($\gamma\varepsilon$)[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.



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 ($QE=10^{-4} \sim 10^{-3}$ @266nm)
  - Solid material (no thin film) => Metal composite cathode

    => Started from LaB_6 (short life time)

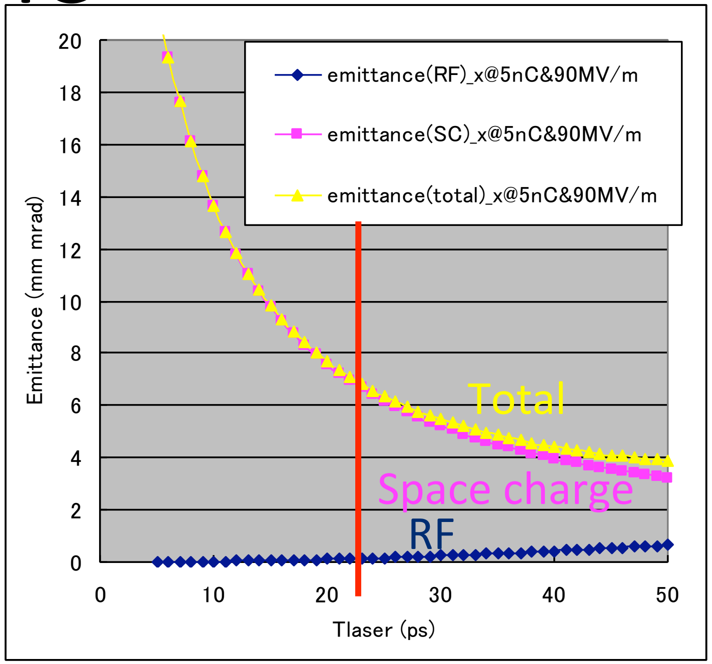
    => **Ir_5Ce has very long life time and $QE>10^{-4}$** @266nm
- Laser : Stable laser with temporal manipulation
  - LD pumped laser medium => Nd / Yb doped
  - Temporal manipulation => Yb doped

    => Minimum energy spread

- RF-Gun
  - **Design of RF-Gun cavity**
    - **Quasi travelling wave side couple**
  - Cathode
  - Laser
  - Test stand and schedule

RF-Gun for 5 nC

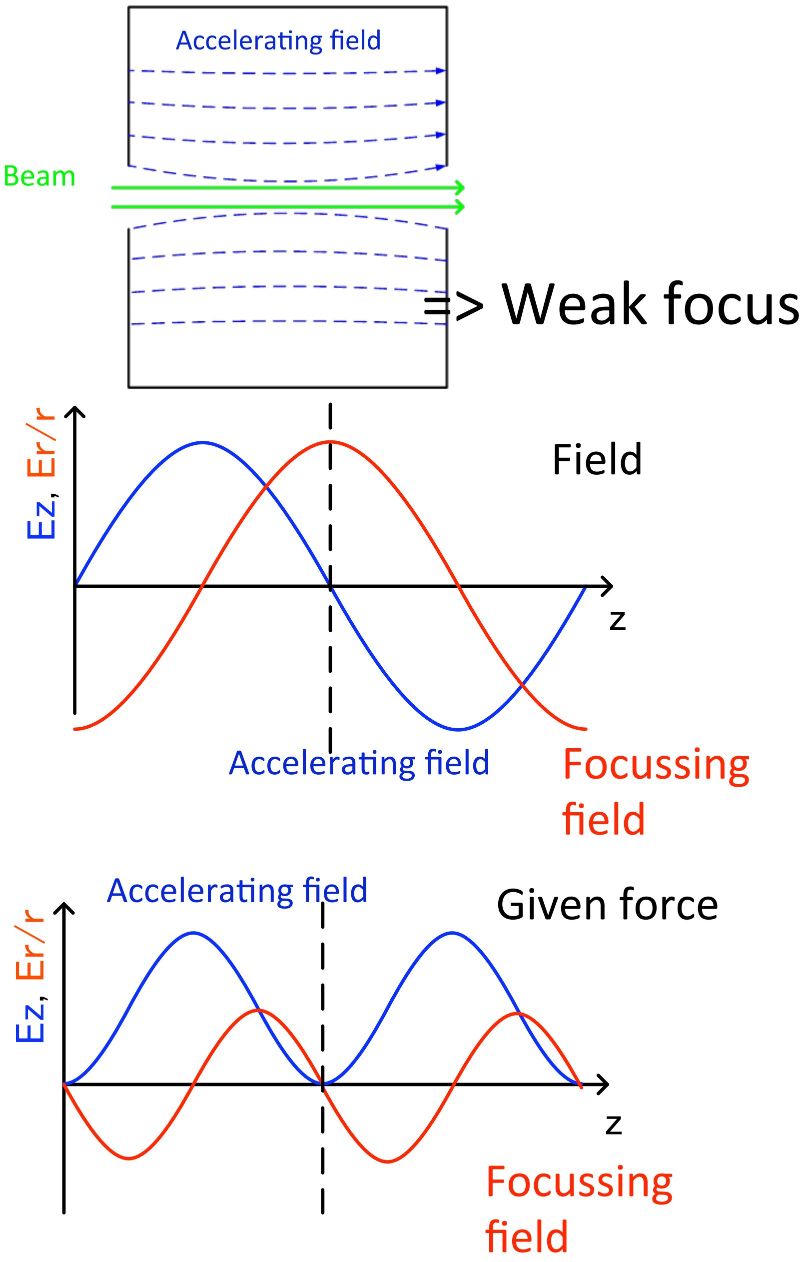
- Space charge is dominant.
  - Longer pulse length : 20 - 30 ps
- Stable operation is required.
  - Lower electric field : < 100MV/m
- Focusing field must be required.
  - Solenoid focus causes the emittance growth.
  - **Electric field focus preserve the emittance.**



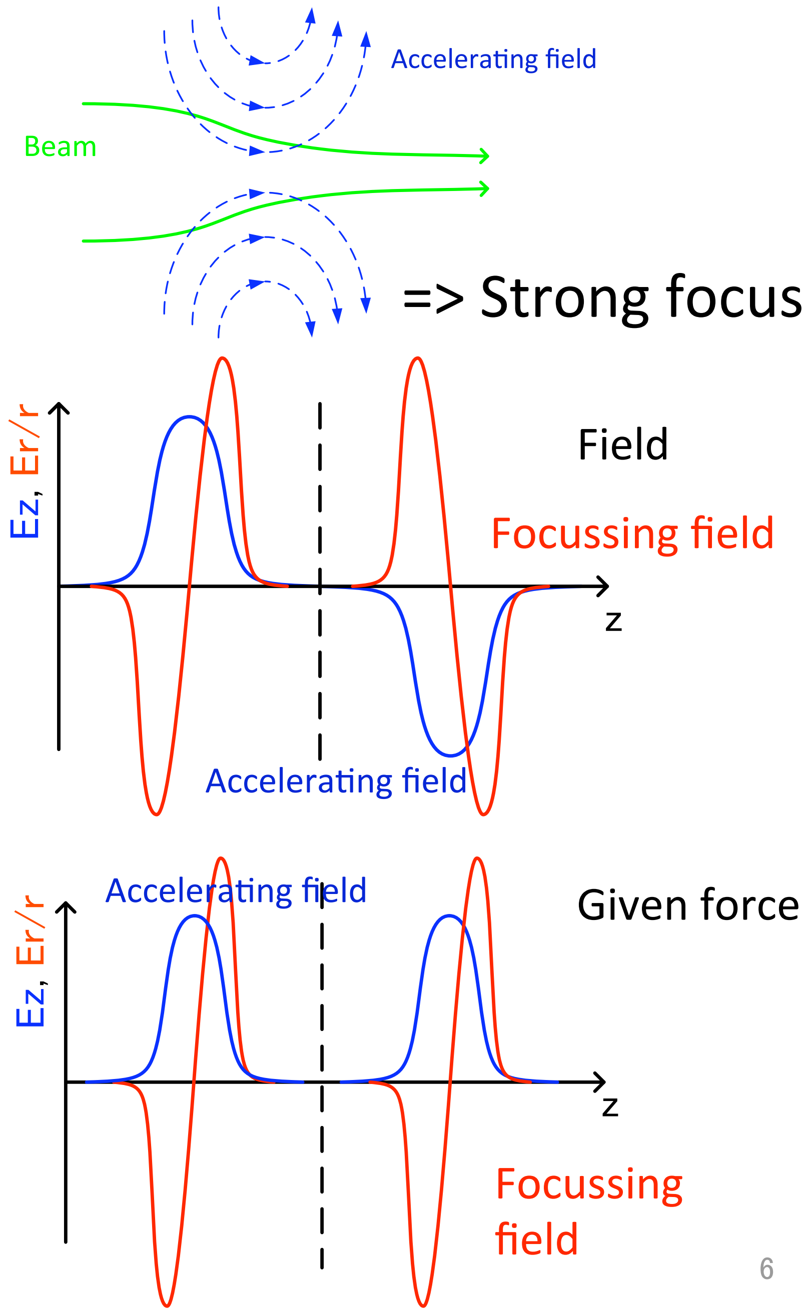
~~Epxial coupled cavity~~ : BNL

<u>Annular coupled cavity : Disk and washer / Side couple</u>

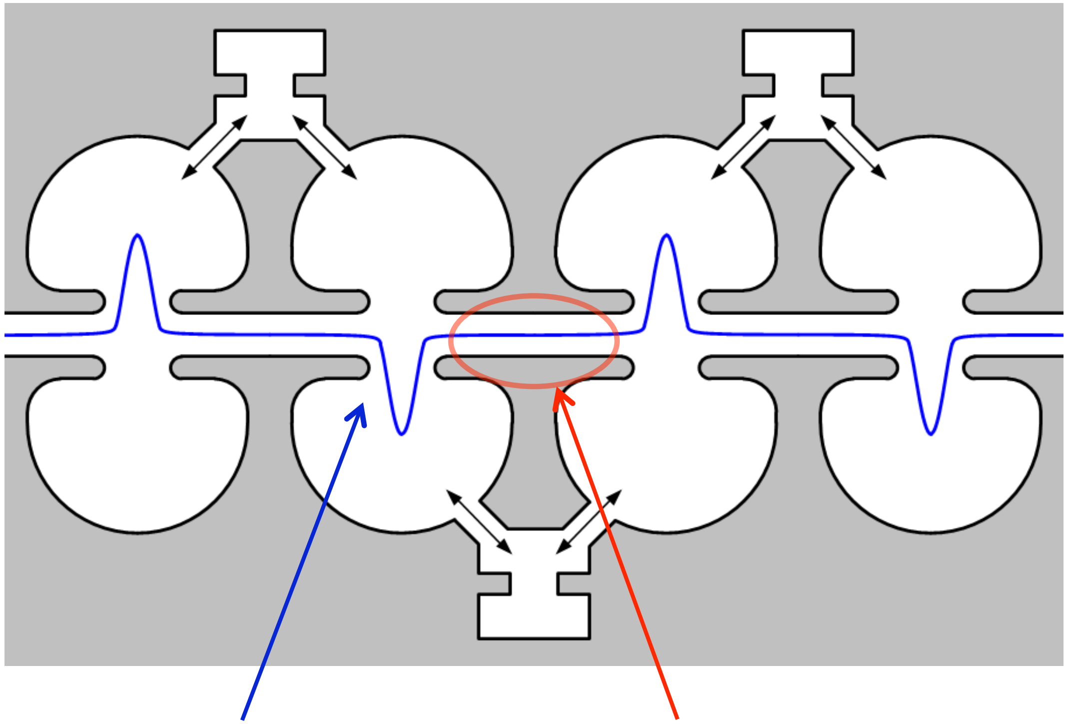
Pill-box cavity

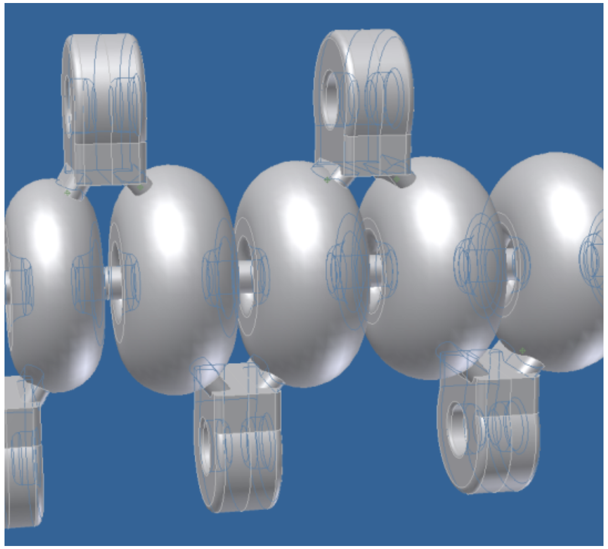


Annular coupled cavity with nose



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





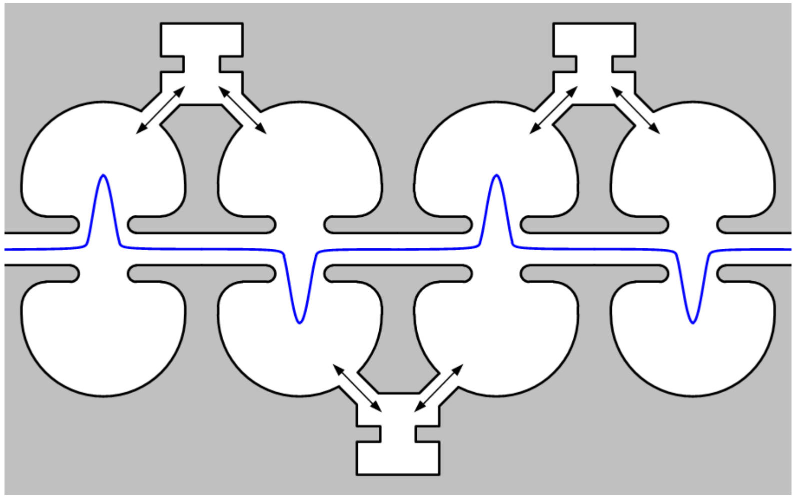
Concentrated field
has focusing effect

This structure has long drift space

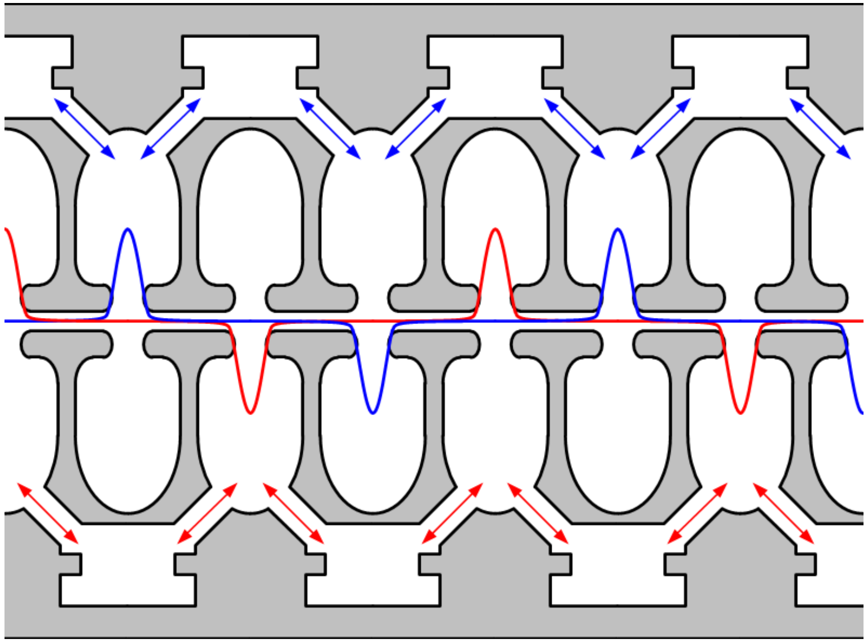
This structure has focusing field.
Long drift space is problem.

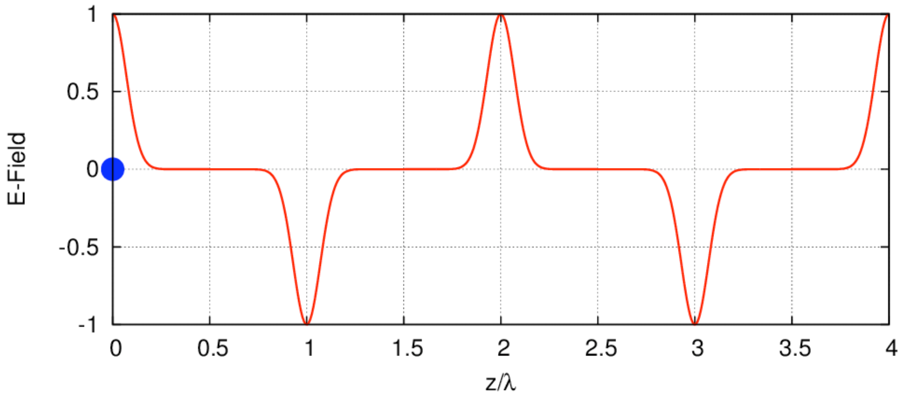
Design of a quasi traveling wave side couple RF gun

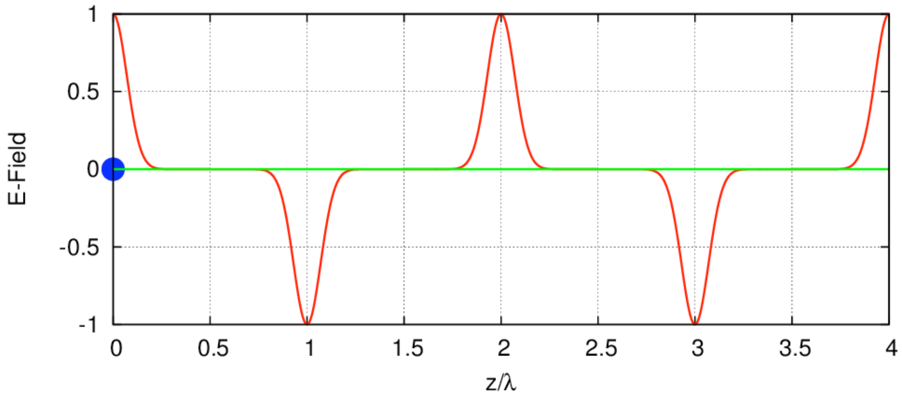
Normal side couple structure



Quasi traveling wave sidecouple structure



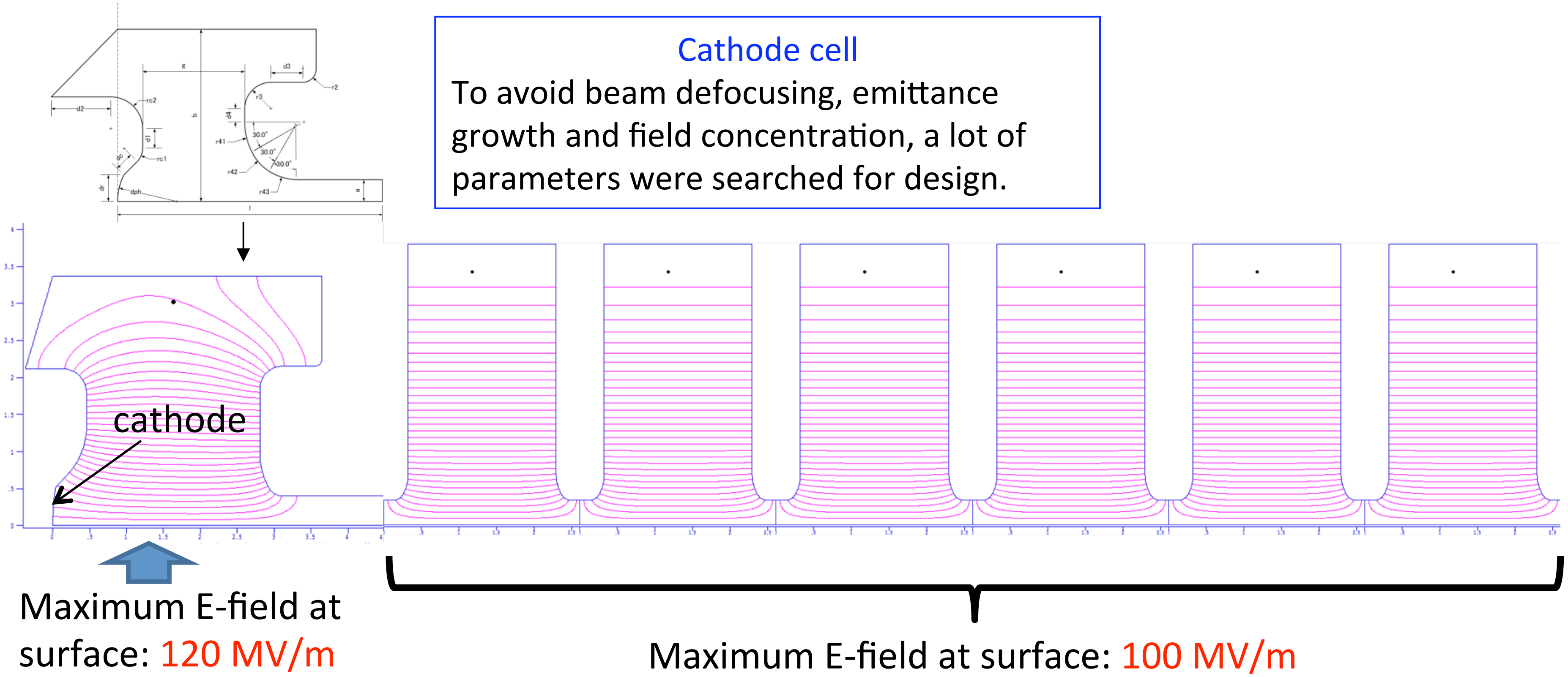




Quasi traveling wave side couple has stronger focusing and accelerated gradient than DAW.

Quasi traveling wave side couple RF gun

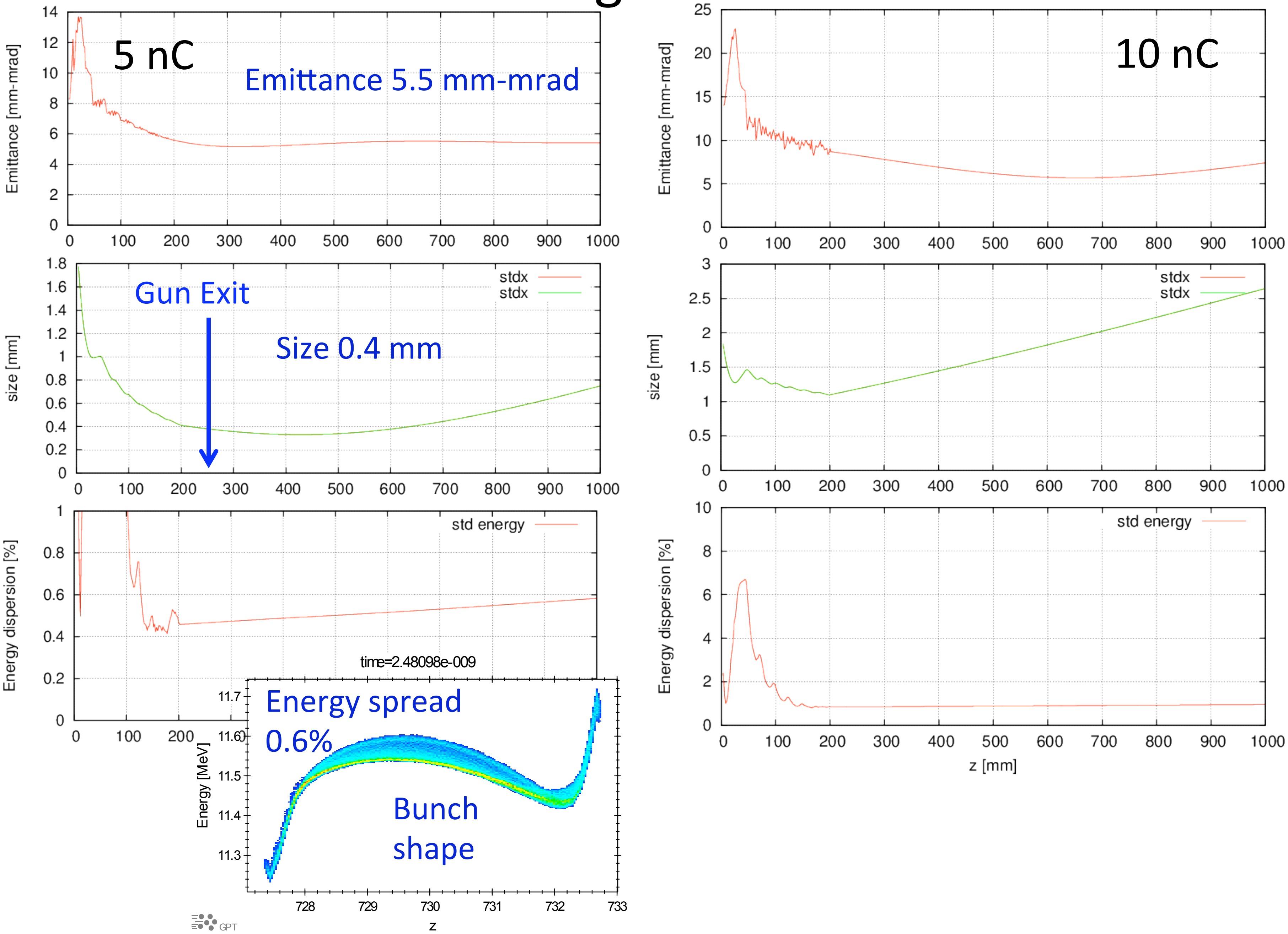
This RF gun has total of seven acceleration cavities. These are divided into two standing wave structure of 3 and 4 side coupled cavities respectively.



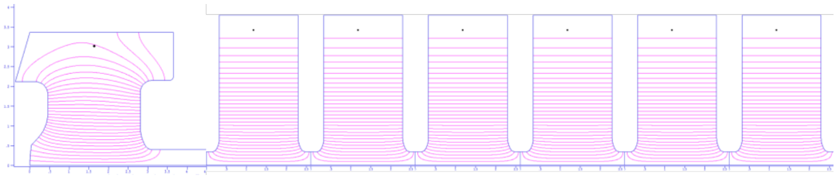
Emittance: 5.5 mm-mrad @ 5 nC

This RF gun can generate 10 nC beam

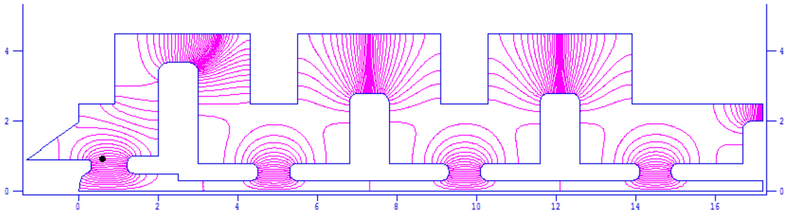
Beam tracking simulation result



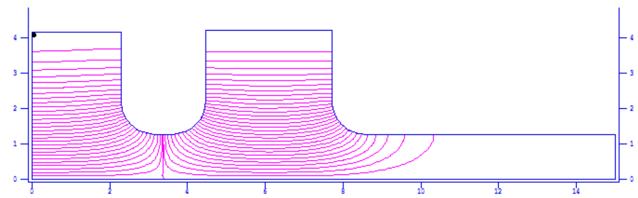
RF-Gun comparison



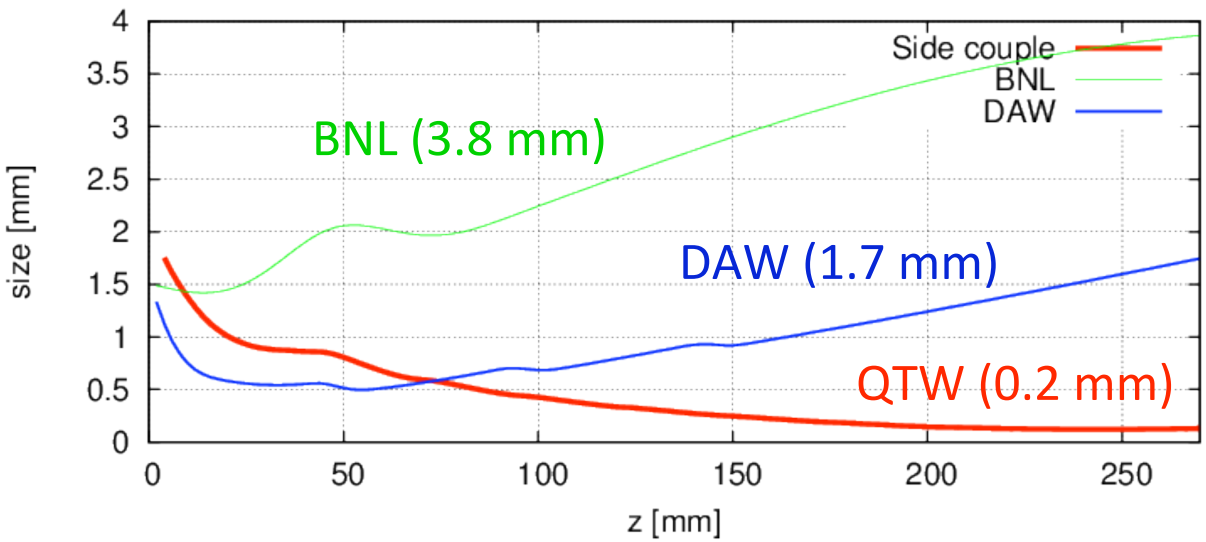
Quasi traveling wave side couple RF gun
(100 MV/m, 6mm-mrad, 13.5 MeV)



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

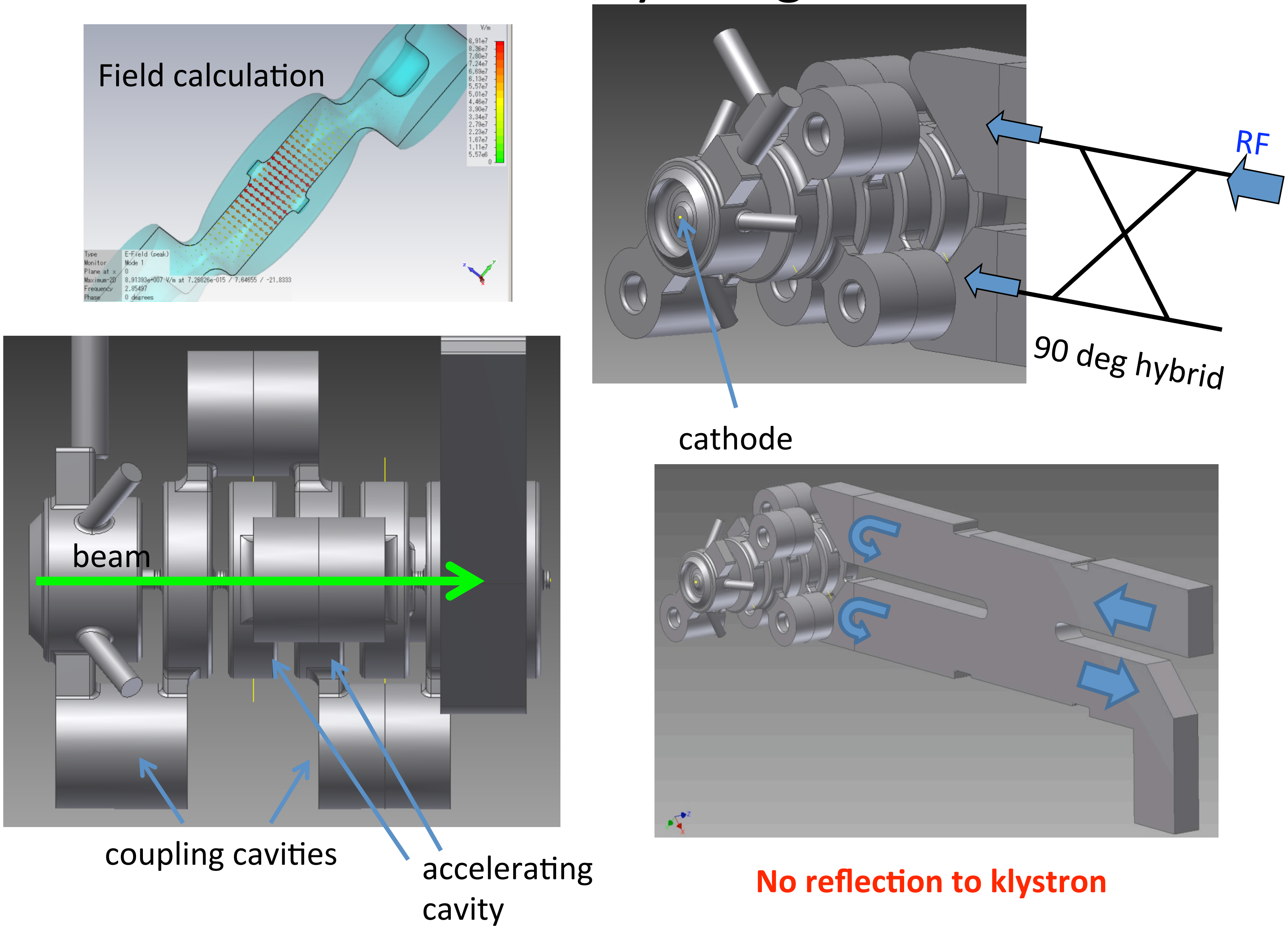


BNL-type RF gun
(120 MV/m, 11.0 mm-mrad, 5.5 MeV)



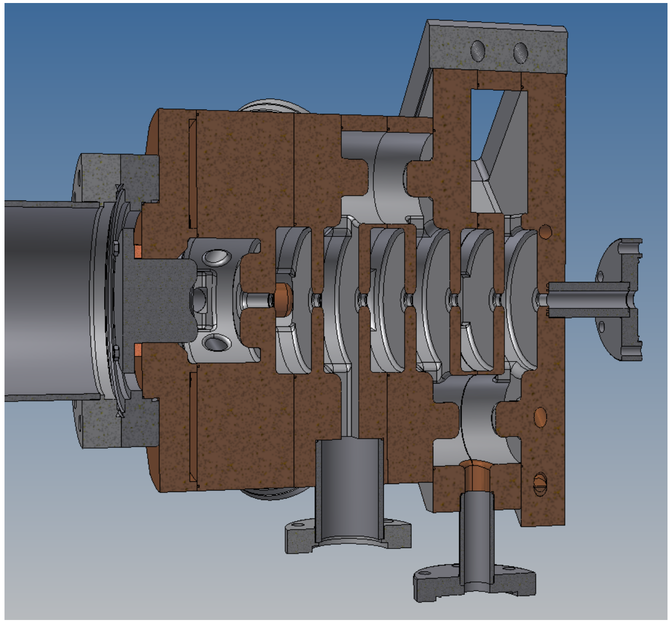
Beam Size

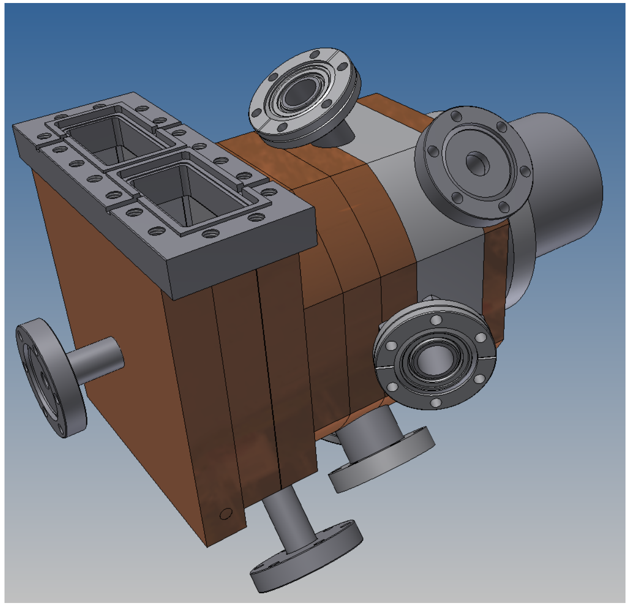
Cavity design

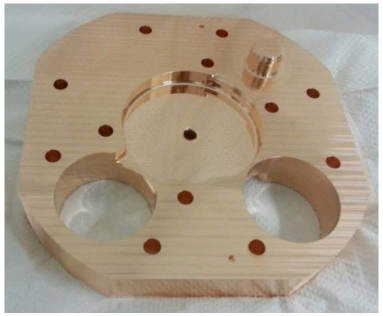


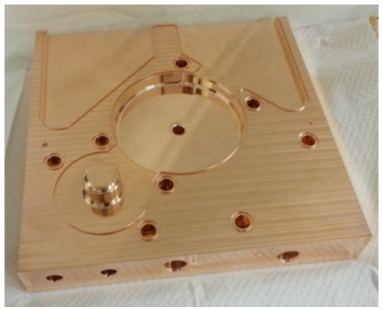
No reflection to klystron

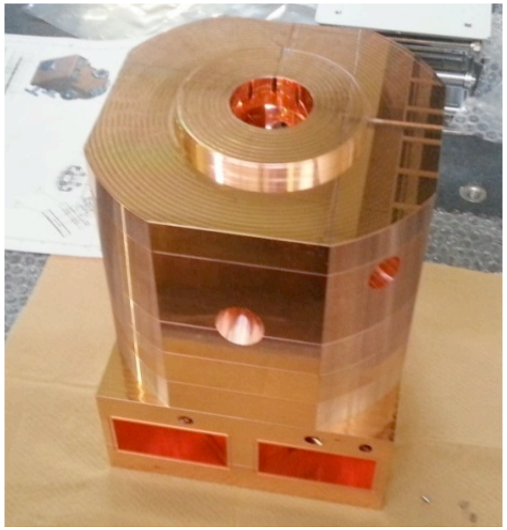
Mechanical design and manufacturing

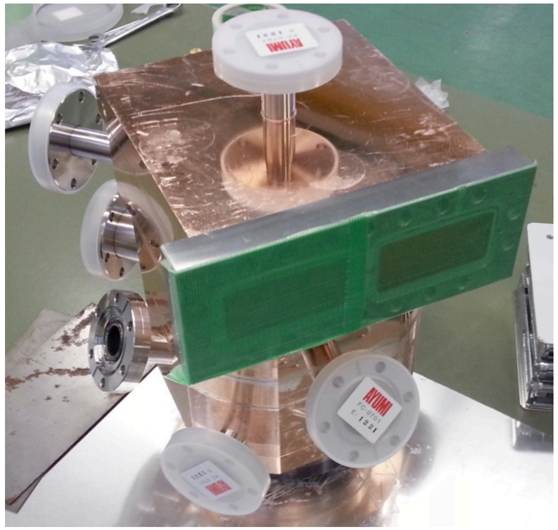






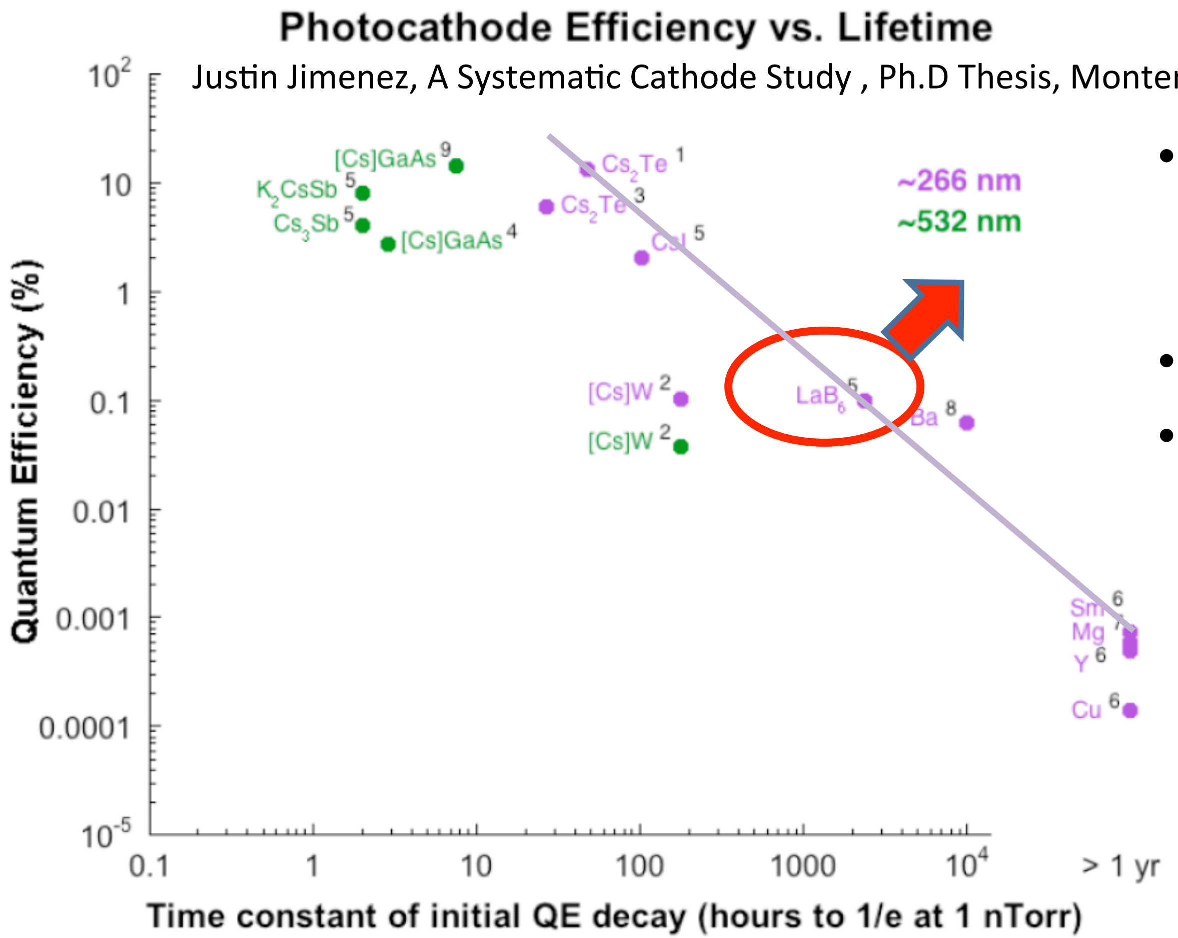






- RF-Gun
  - Design of RF-Gun cavity
  - **Cathode**
    - **Advantage of LaB6**
    - **Measurement equipment of quantum efficiency**
    - **Laser cleaning & Heat treatment**
  - Laser
  - Test stand and schedule

Cathode : Advantage of LaB_6 or Ir_5Ce



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

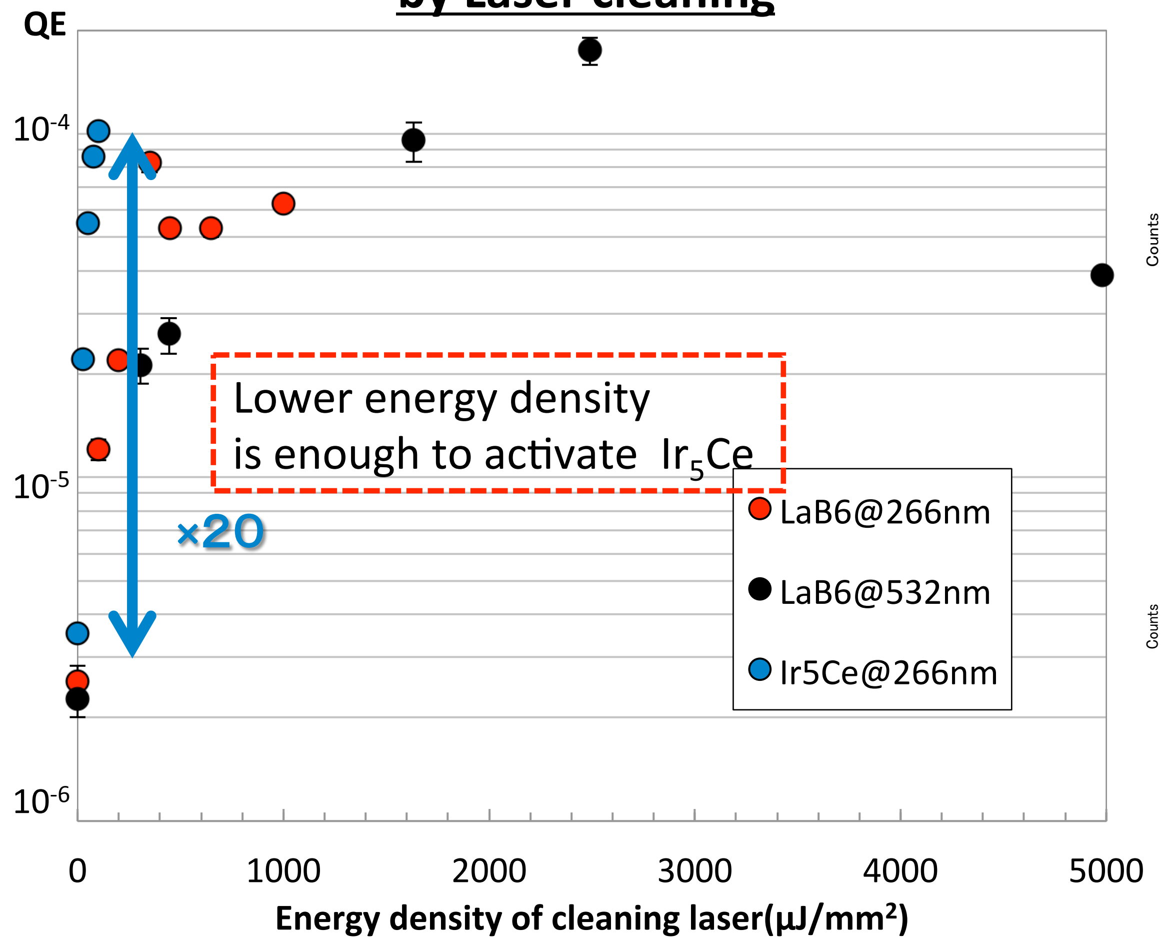
Best choice for SuperKEKB 5 nC long time operation

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

Ir_5Ce Cathode

Quantum efficiency improvement by Laser cleaning

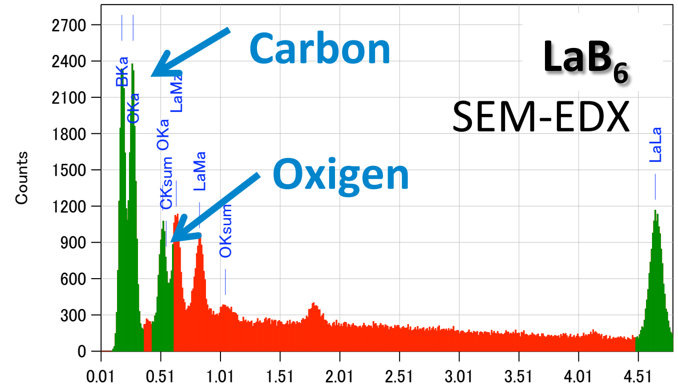


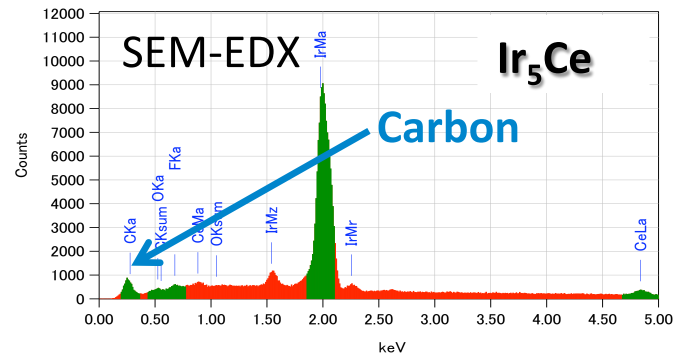
Condition

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}**

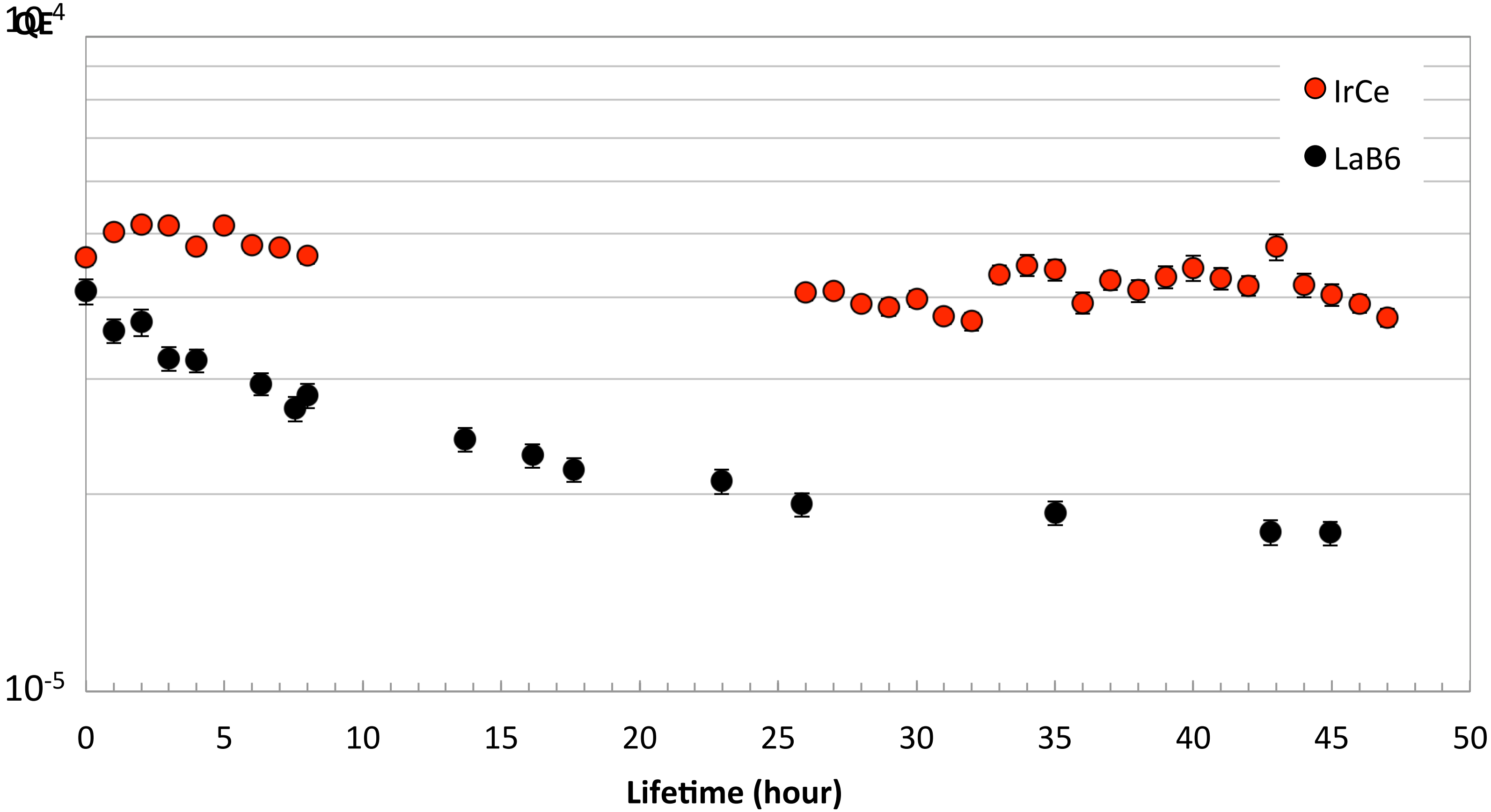
[SUPER-KEKB e Linac]

Laser Power ; 233μJ/pulse

(λ=266nm)

Target value ; 5nC

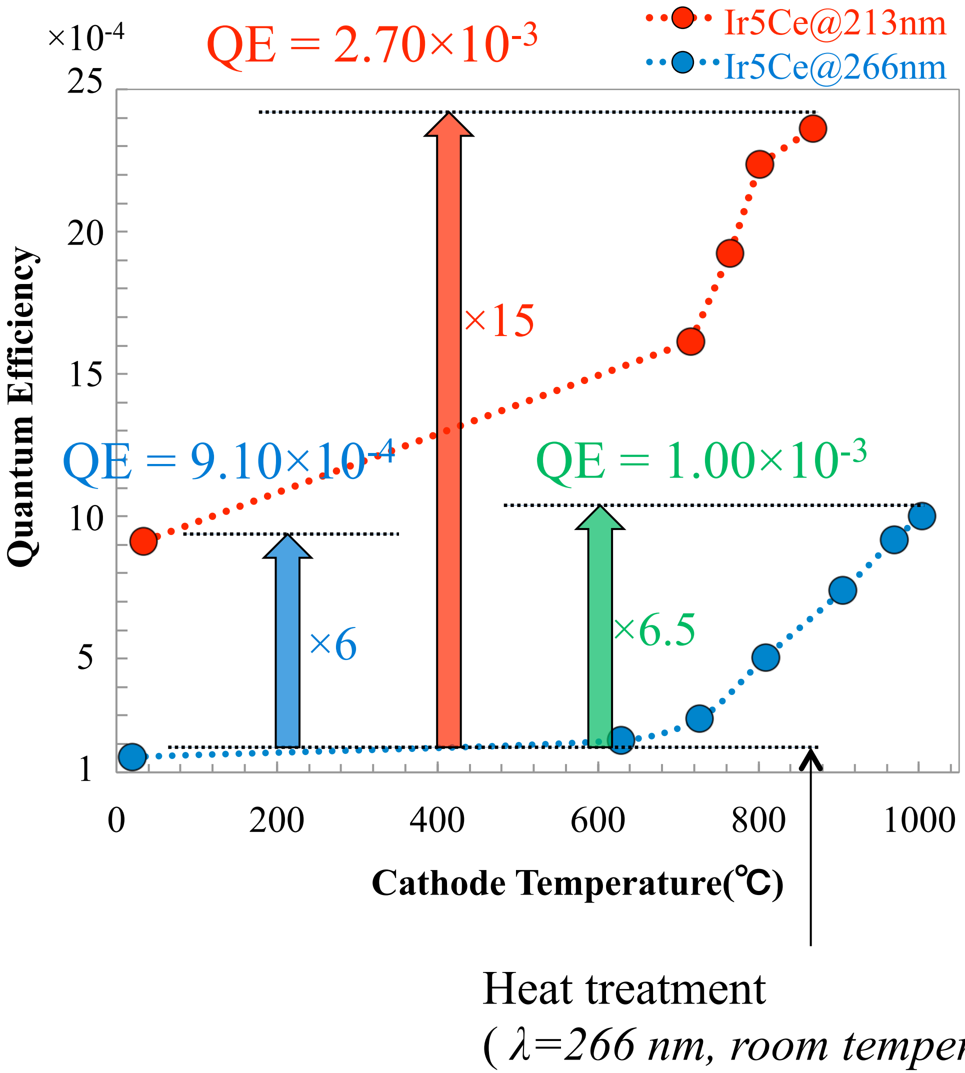
Lifetime measurement (LaB_6 / Ir_5Ce)



Condition

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

Enhancement of QE



Laser system

- Nd:YAG laser 4th harmonics (266 nm)
- Nd:YAG laser 5th harmonics (213 nm)

Heater : Ta heater

Irradiation of shorter-wavelength laser

QE = 9.10×10^{-4} (*λ=213 nm, room temperature*)

Heating

QE = 1.00×10^{-3} (*λ=266 nm, 1004℃*)

Irradiation of shorter-wavelength laser
＋Heating
QE = 2.36×10^{-3} (*λ=213 nm, 868℃*)

Future prospects

【 Current KEK A1 laser system 】

- W=10mJ/pulse @1030 nm, 20ps → 3nC/bunch
- Total loss : 70 %
  - transmission loss : ~50%
  - loss from the miss alignment at cathode : ~60%

⇨ QE=1.54×10^{-4} *@266nm, room temperature*

To generate 5nC beams → W = 16mJ/pulse *@1030nm,20ps*

To generate 15nC beams → W=48 mJ/pulse *@1030nm,20ps*

(for positron generation)

QE enhancement scheme leads to relax the laser power.

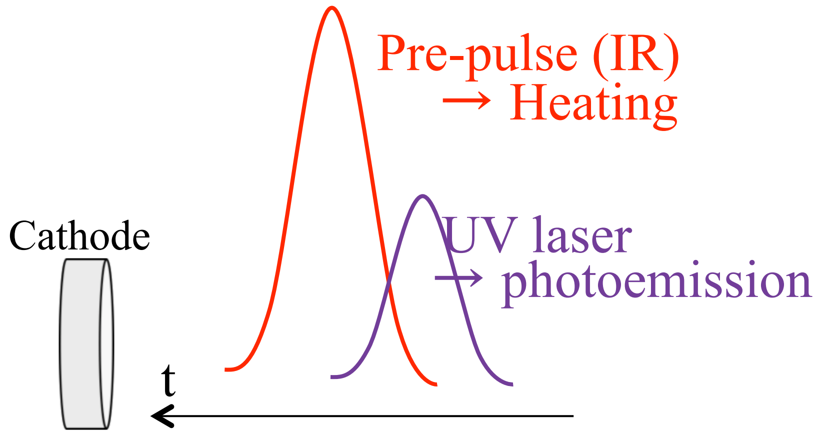
【Strategy for the new system of the QE enhancement】

①Irradiation of shorter-wavelength laser → CLBO + Yb:YAG 5th harmonics

②Heating → Pulse laser Heating

②Heating → The backside electron beam heating system

【 Scheme of Pre-Pulse laser Heating 】



【1D thermal diffusion】

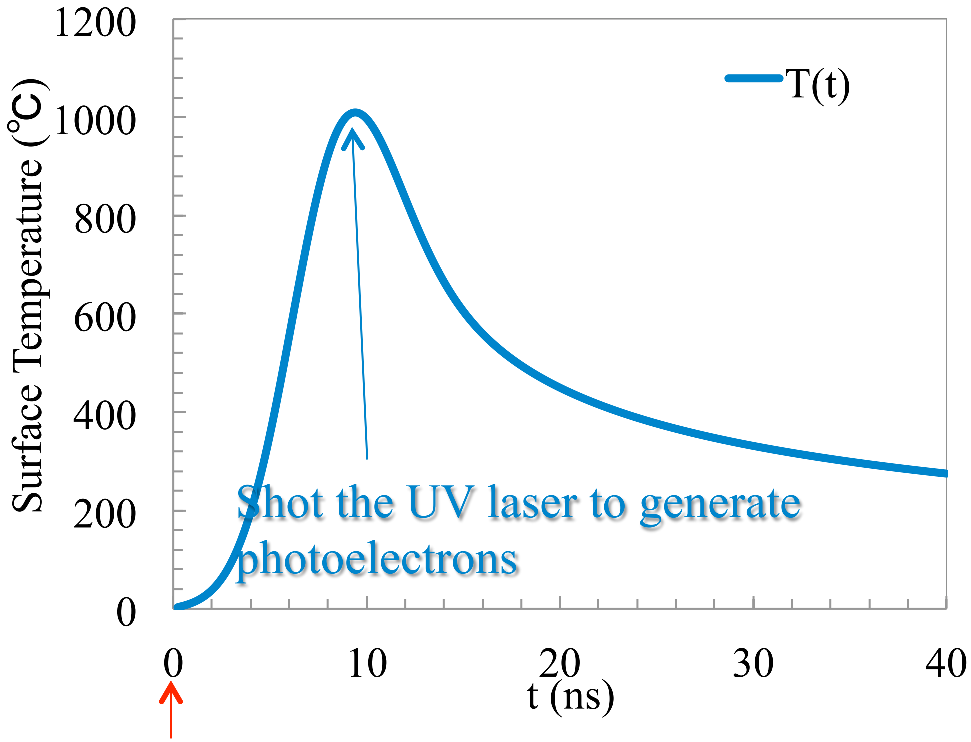
$$\frac{\partial}{\partial t}T(z,t)=\kappa\frac{\partial^2}{\partial z^2}T(z,t)+\frac{\alpha}{\rho C_P}\frac{P_0}{\pi r^2}e^{-\frac{(t-t_0)^2}{2\sigma^2}}\delta(z)$$

Merits

- No need to develop the heater fabrications
- Decrease the Dark current

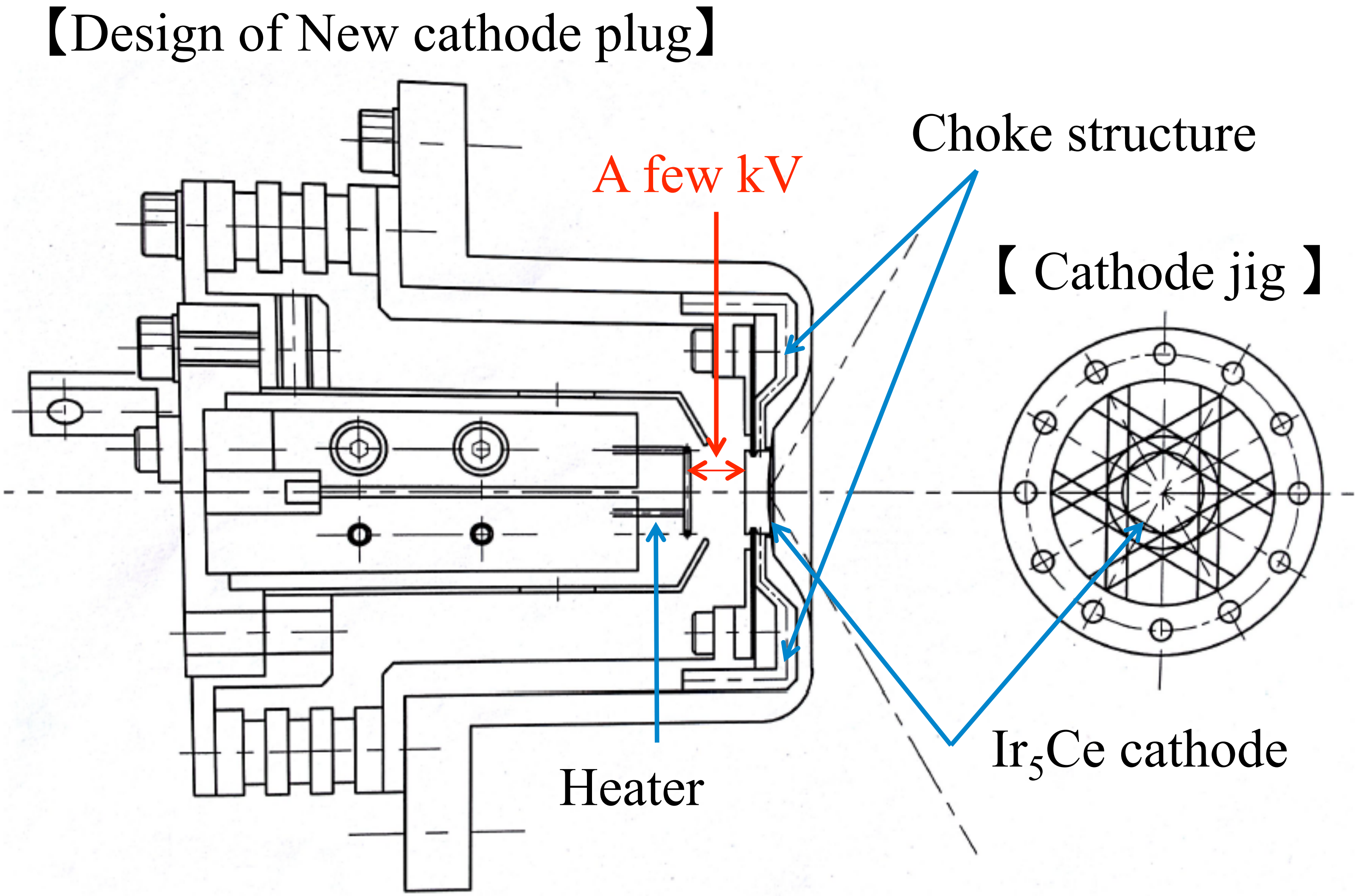
Laser parameter	
λ	*1064 nm*
σ	*2.5 ns*
r	*4 mm*
P_0	*45.963 MW*
W	***288 mJ/pulse***

Temperature variation after irradiation on Ir_5Ce cathode



Irradiation of pre-pulse

The backside electron beam heating system

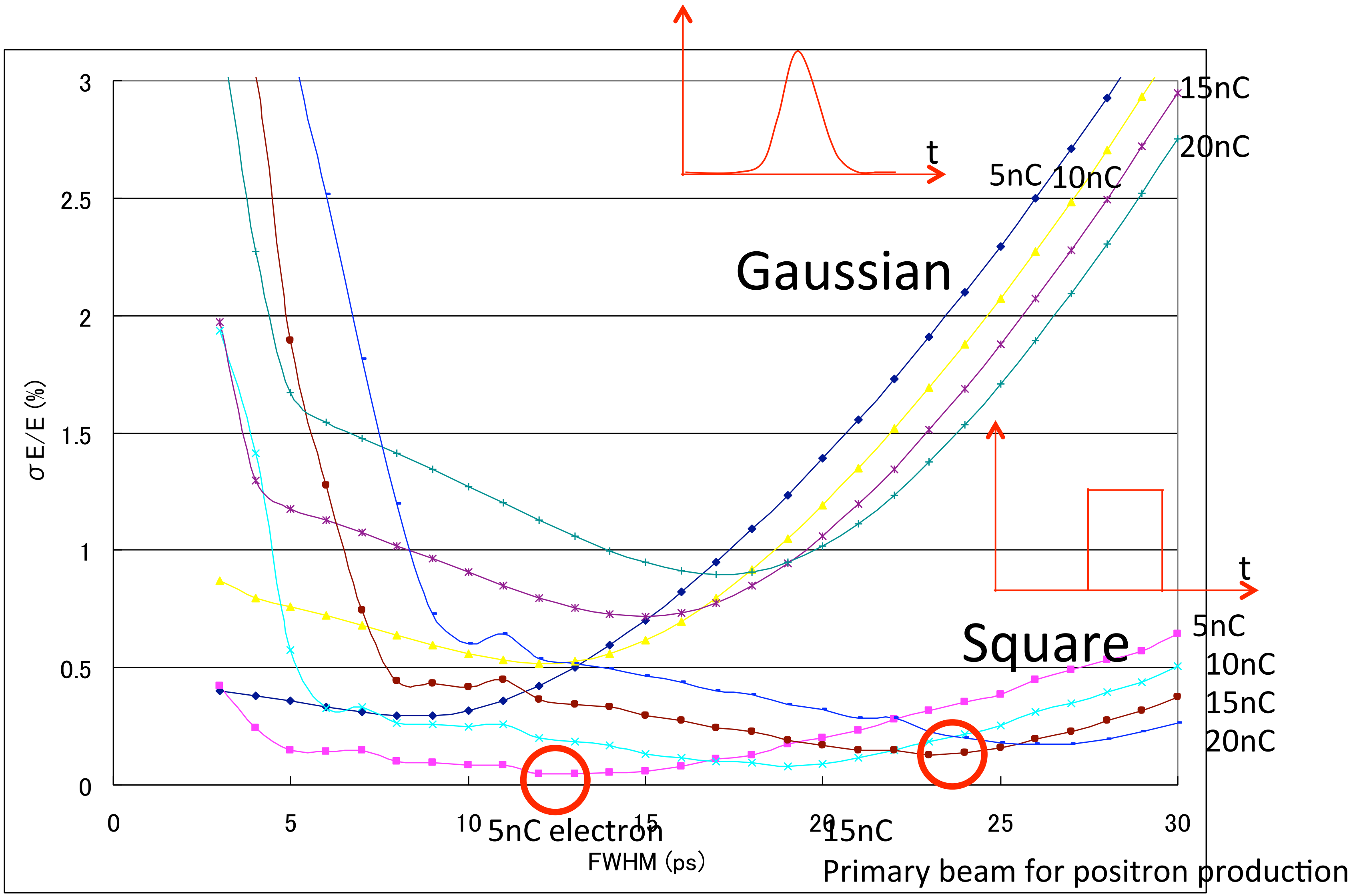


Further backside LD heating system will be developed.

- RF-Gun
  - Design of RF-Gun cavity
  - Cathode
  - **Yb Laser for spatial & temporal manipulation.**
  - Test stand and schedule

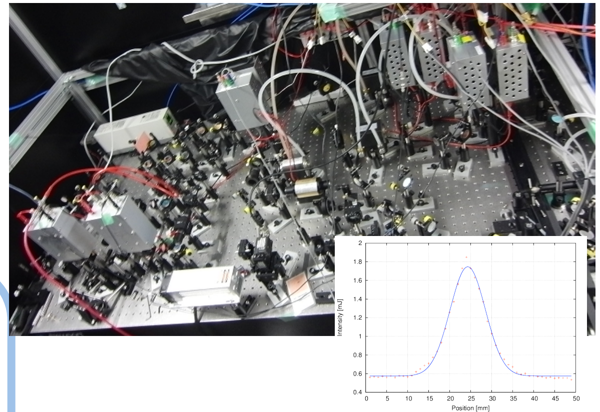
Energy spread reduction using temporal manipulation

Energy spread of 0.1% is required for SuperKEKB synchrotron injection.



Properties of laser medium

Nd laser system for 3-2 RF-Gun



Nd-doped

τ〜200μs, 40%

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

LD Pump (808nm) → 808nm → Nd:YVO4 / Nd:YAG → 1064nm → SHG(532nm) 40% / FHG(266nm) 20% / 5HG(213nm) 3%

Yb-doped

τ〜900μs, 40%

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

LD Pump (941/976nm) → 941/976nm → Yb-glass / Yb:YAG / Yb:BOYS → 1040nm → SHG(520nm) 40% / FHG(260nm) 20% / 5HG(208nm) 3%

⇒ Best for RF-Gun

Ti-doped

Pump τ=200μs, 40%

τ〜3μs, 40%

Pump (808nm) → 808nm → Nd:YAG → 1064nm → SHG (40%) → 532nm → Ti:Sapphire → 800nm → SHG(400nm) 40% / THG(266nm) 20% / FHG(200nm) 10%

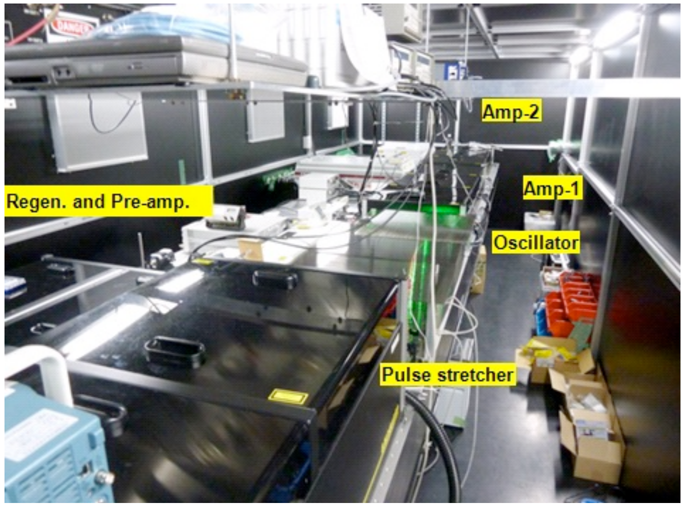
- ○ Very wide bandwidth
- ○ High breakdown threshold
- × Low cross section

(High breakdown threshold, Low cross section) } TW laser is based on Ti-Sapphire

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

	Material	Nd:YAG	Yb:YAG	Ti:Sapphire
Fluorescence	Wavelength	1064nm	1030nm	660−1100nm
	Fluorescent time	230ms	960ms	3.2ms
	Spectral width	0.67nm	9.5nm	440nm
	Fourier minimum Pulse width	2.48ps	165fs	2.59fs
Absorption	Wavelength	807.5nm	941nm	488nm
	Spectral width	1.5nm	21nm	200nm
	Quantum efficiency	76%	91%	55%

Ti:Sapphire laser system for beam monitor.

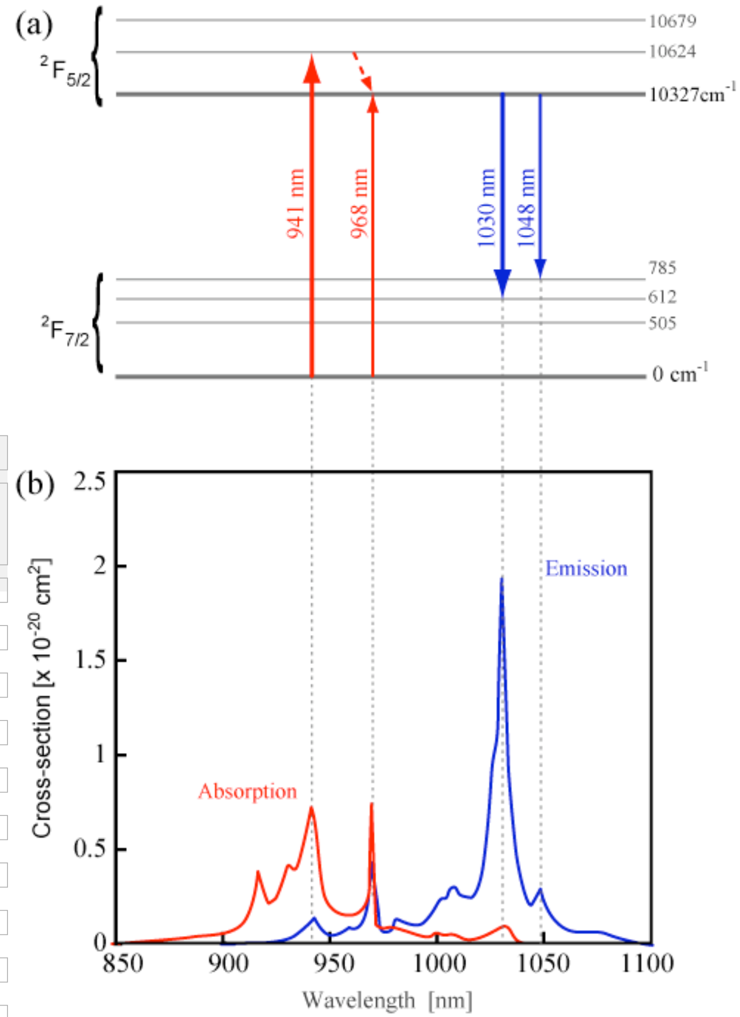


Characteristics of Yb doped laser

- Long fluorescent lifetime～1ms
- Wideband
- High quantum efficiency

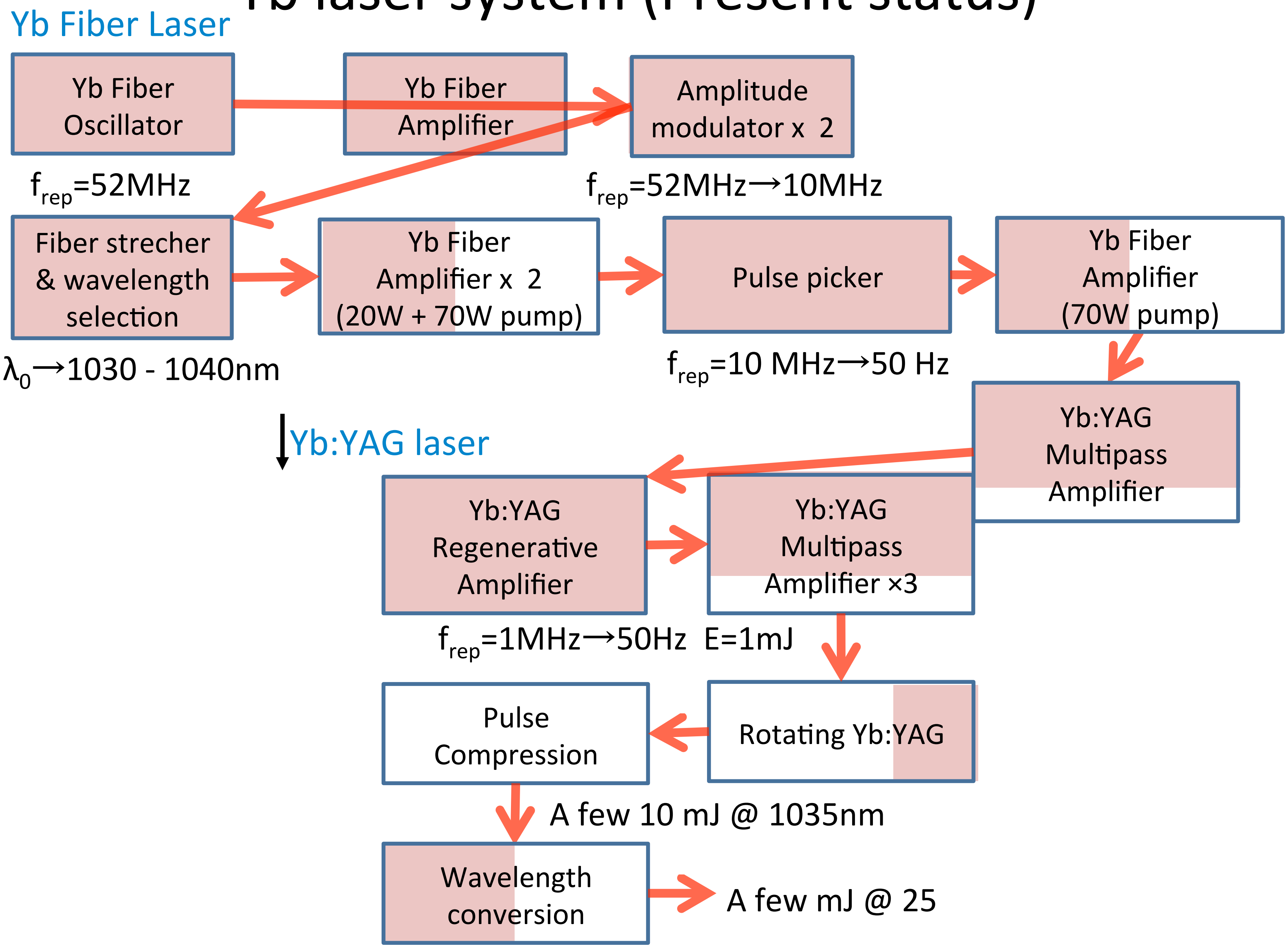
X Quasi-three level
=> Absorption at room temperature

X Small cross section

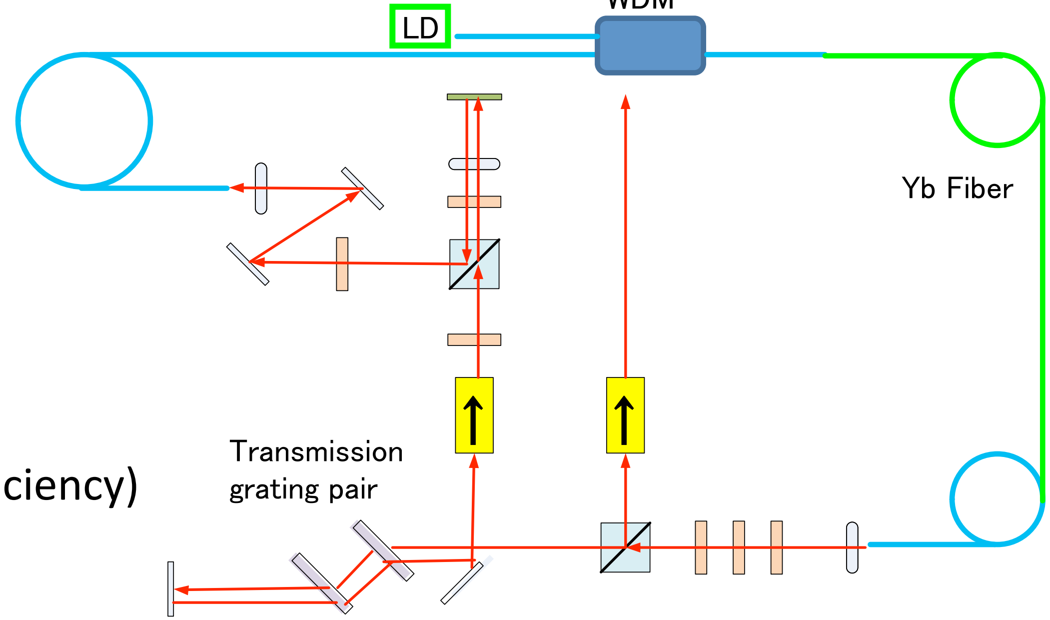


Yb Base material	Stimulated emission cross section [10-20cm2]	Fluorescence lifetime [ms]	Thermal conductivity [W/mK]	Fluorescence spectral width [nm]	Fourier minium [fs]	Experimental records	
						Pulse width [fs]	Average power [W]
YAG	2	0.95	**11**	9	120	340	0.11
						136	0.003
						730	16
						810	60
KYW	**3**	0.7	**3.3**	24	50	**71**	0.12
KGW	**3**	0.7	**3.3**	25	47	112	0.2
						176	1.1
glass	0.63	2	-	35	33	36	0.065
GdCOB	0.35	2.7	2.1	44	27	89	0.04
BOYS	0.2	2.5	1.8	60	19	69	0.08
						86	0.3
YVO4	-	1.2	-	-	-	61	0.054
CaCdAlO4	0.55	-	6.9	-	-	47	0.038

Yb laser system (Present status)



Yb Fiber Oscillator



Yb fiber oscillator:

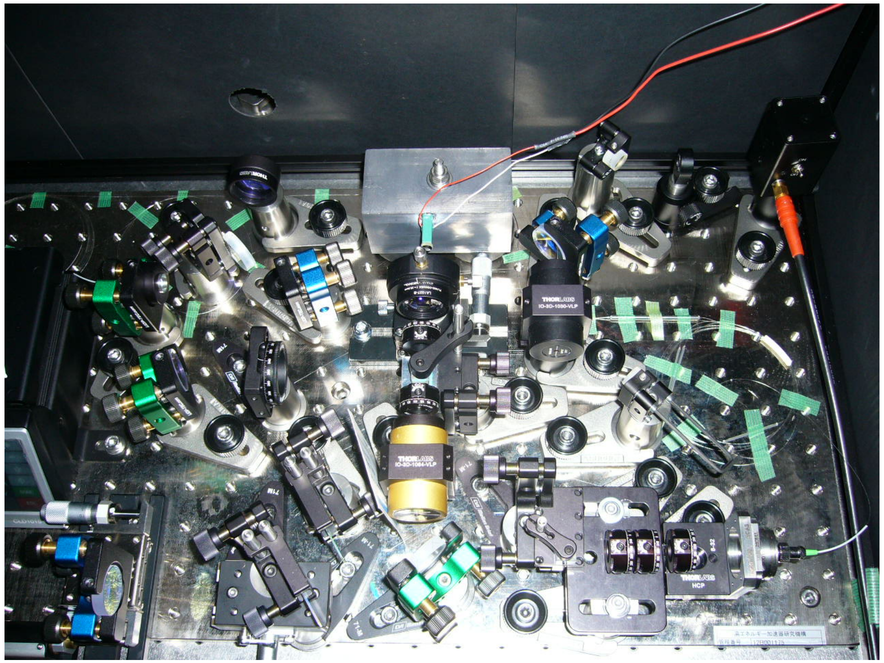
- 30 fs is possible using non-linear polarization rotation.

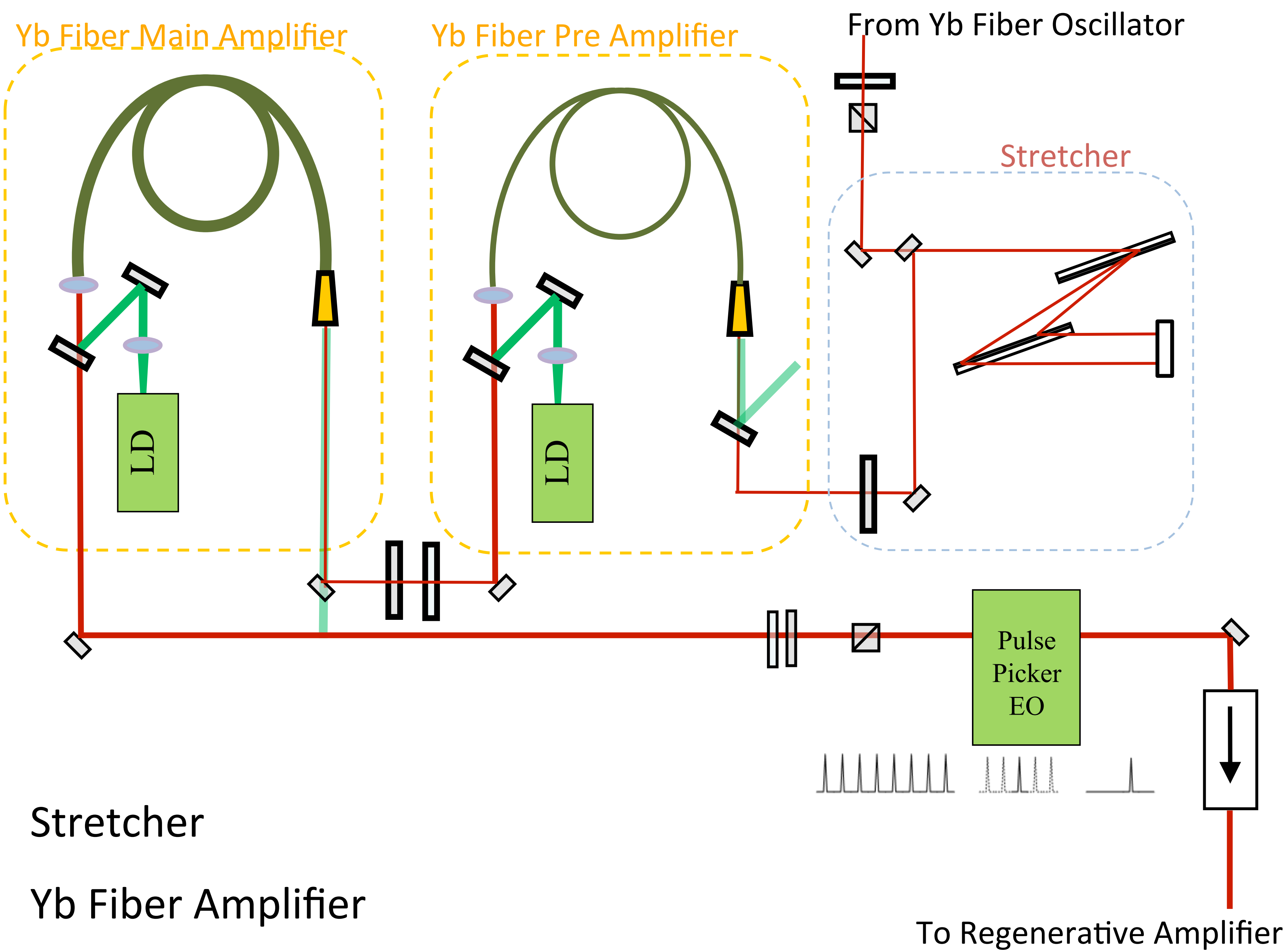
Improved items in FY2013:

- Transmission grating
  => Stable modelock (higher efficiency)
- Super-invar breadboard
  => Thermal stability.
- Piezo mirror on large lead block
  => Reduce vibration.

Remaining problem:

- Bunch structure at higher output power.
  => SESAM is not effective.
  => Replace some components.
- Synchronization performance is changing.



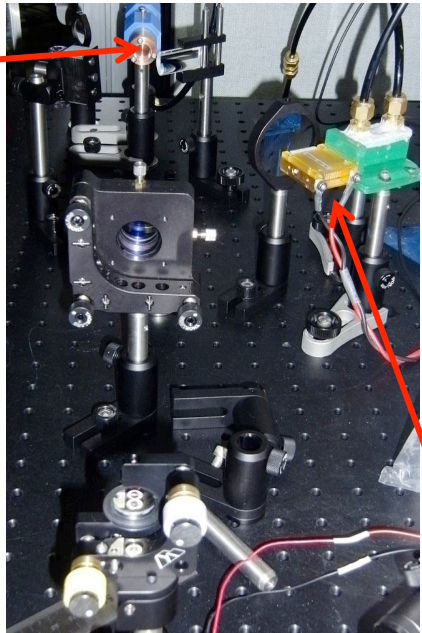


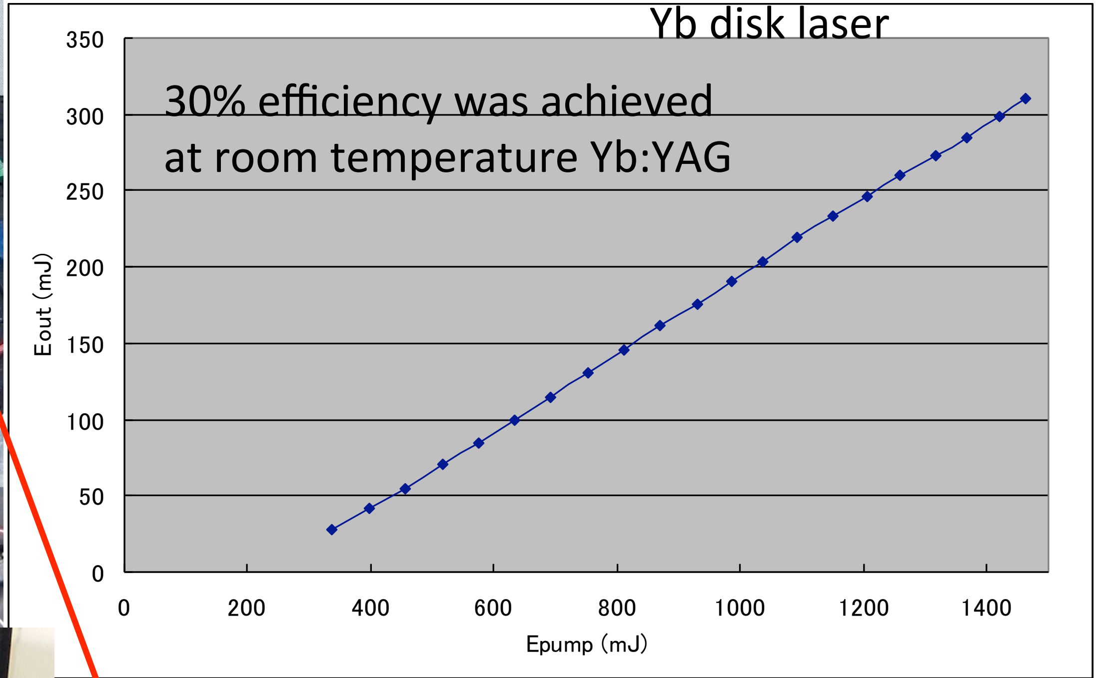
Stretcher

Yb Fiber Amplifier

Yb:YAG thin disk Laser

Yb:YAG disk
10 % doped
2mm thickness

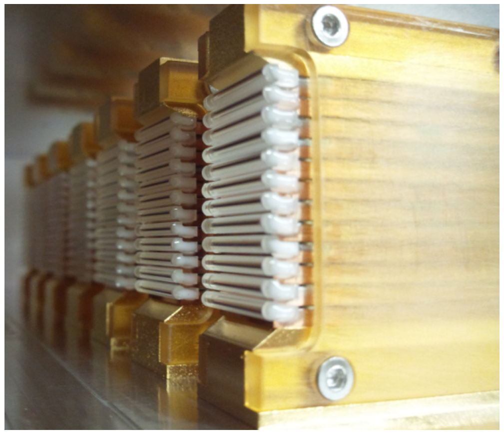




Regenerative amplifier using Yb disk laser

940nm LD (2.4 kW / module)

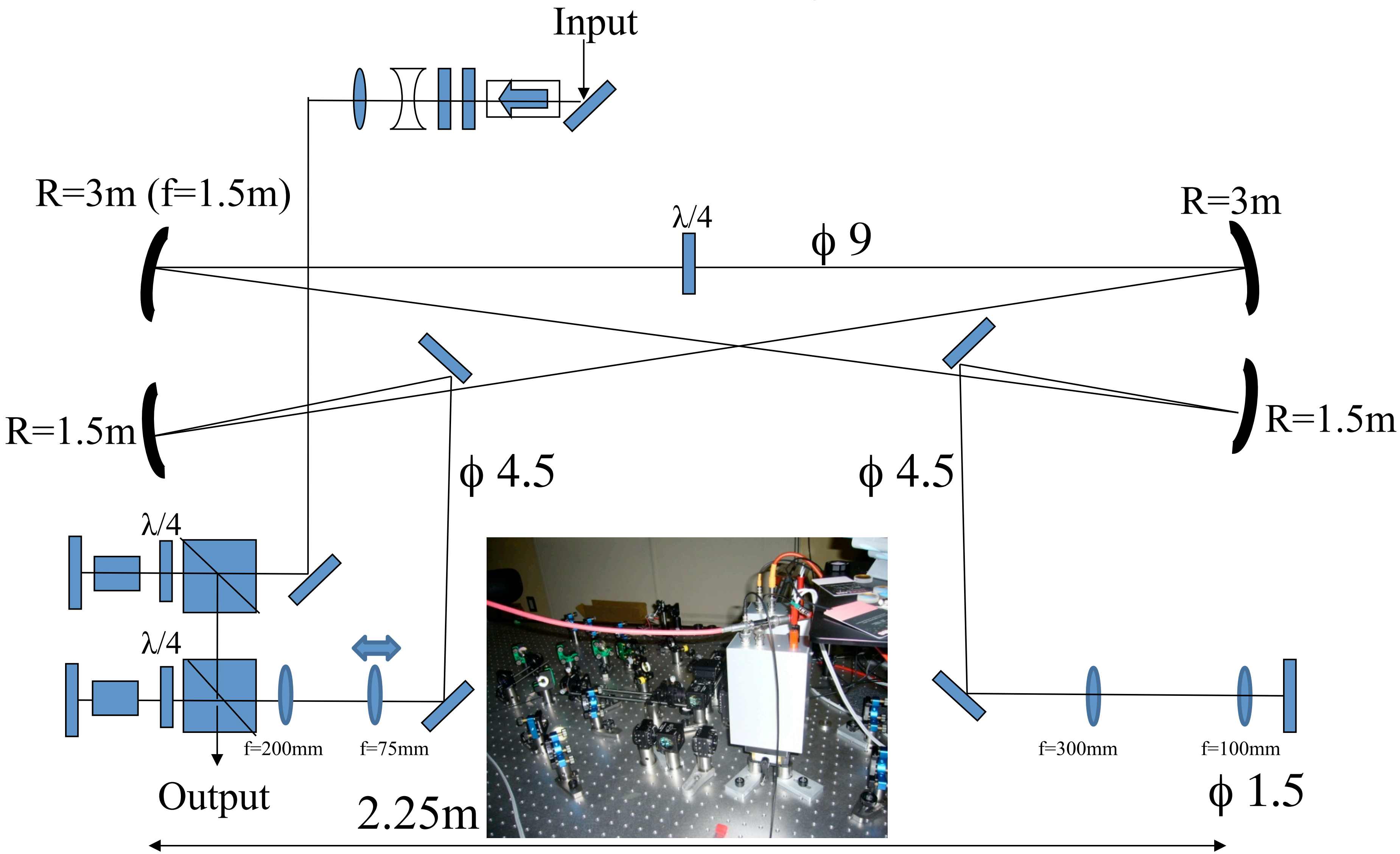
=> 4kW
=> 10kW x 6



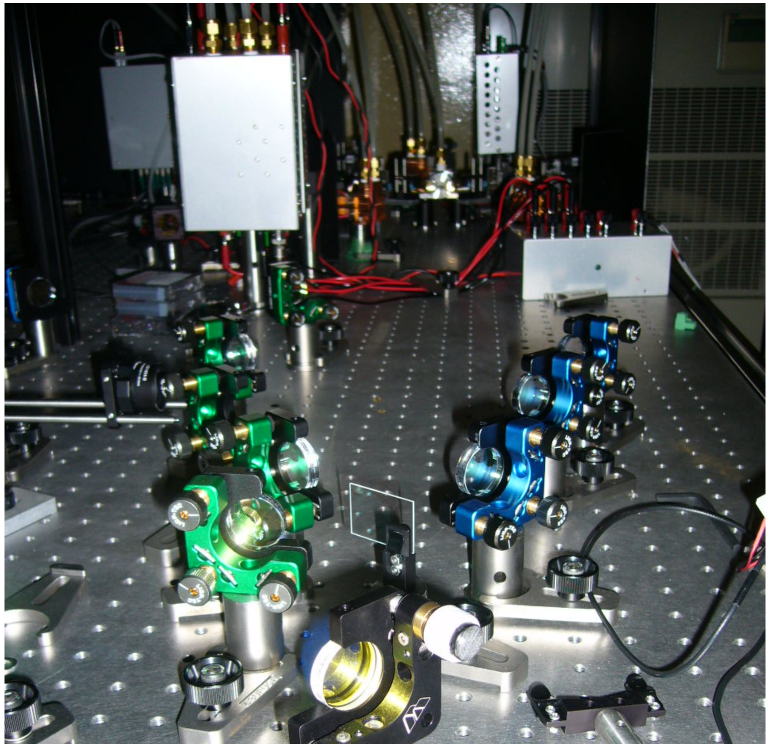
Large regenerative amplifier for 2-bunch operation

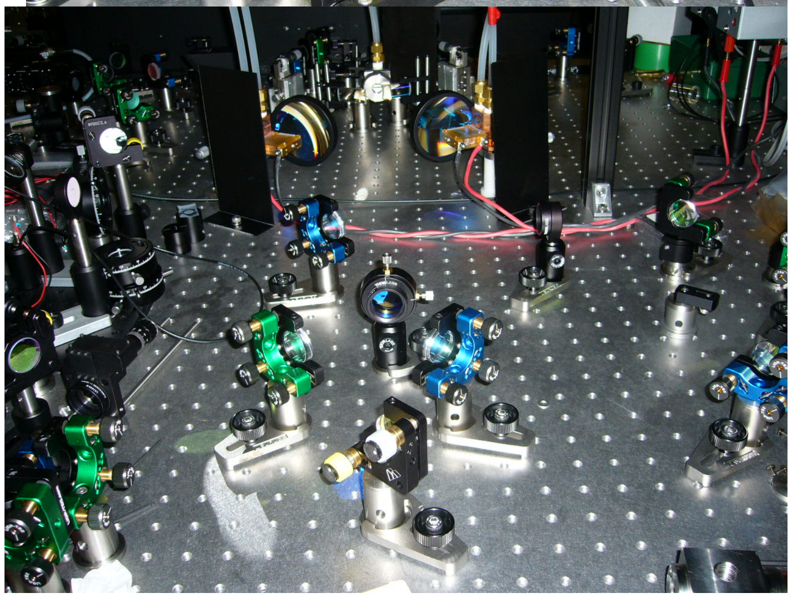
100ns (2-bunch)+20ns (Pockels cell speed) = 36m

=> round trip + polarization => resonator length > 9m : 2.25m×3 + 0.75m×4



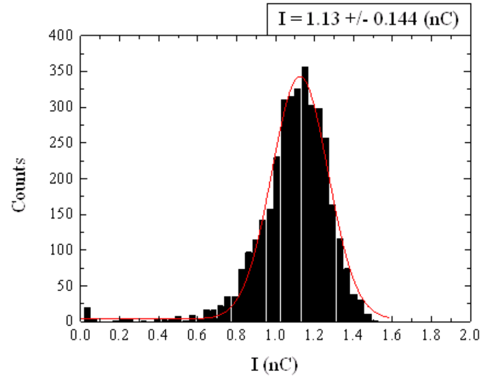
Main Amplifier





UV conversion (BBO SHG+FHG)
=> 2 mJ maximum @ 260 nm

Typical charge distribution



Current situation:

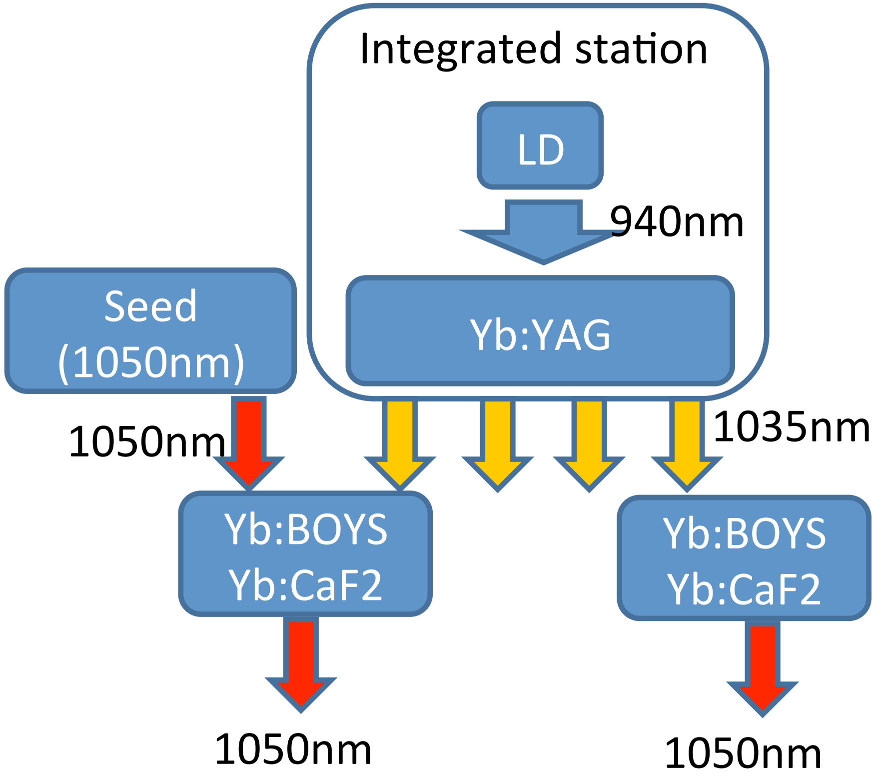
- Instability =>
- No spatial shaping
- No compressor

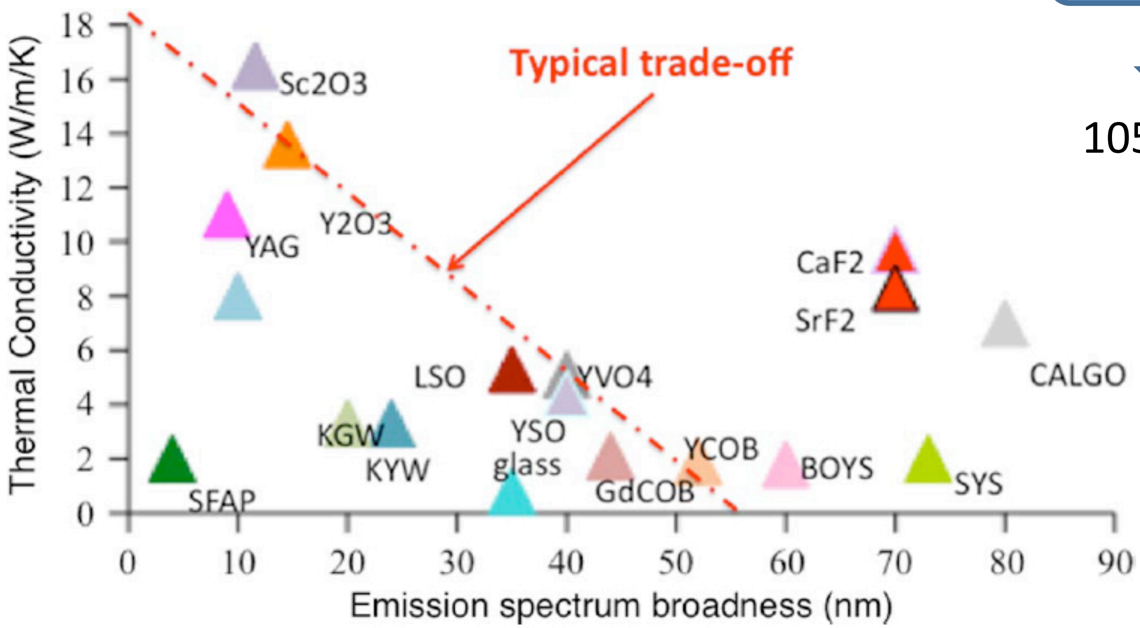
Laser instability is caused by:

- RF Synchronization of oscillator.
  => FPGA & electric modulator.
- ASE of fiber amplifier.
  => Multi-stage fiber amplifier.
- Gain instability of regenerative amplifier.
  => In-vacuum regenerative amplifier.
- Pointing fluctuation (Vibration ?)
  => Higher output power and cut the edge.

R&D for better performance of Yb disk laser

- 1035nm band is difficult to use for amplifier.
  - Thermal lens
  - Absorption
  - Low gain
- We got good performance for 1035nm Q-switch laser.
  => Cascade Yb laser is good candidate.
    - Very small thermal lens effect.
    - Less absorption.
    - Higher excitation density.
    - LD station => Easy to maintain LD stacks.





UV conversion efficiency improvement

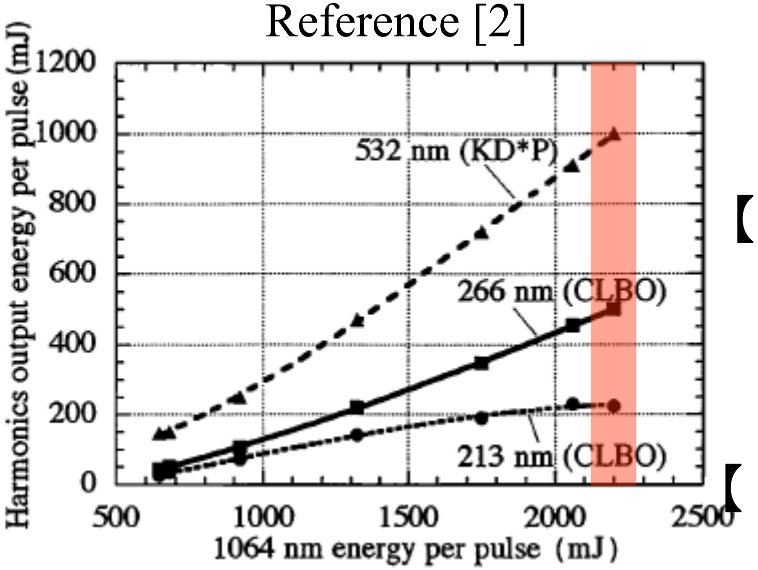
Reference [1]

Nd:YAG Laser [1]
Pulse width : 3.5 ns
Max Energy : 400 mJ/pulse
single longitudinal mode
single transverse mode (top-hat)

【 Conversion efficiency of fundamental wave 】

	Nd:YAG 1ω	Nd:YAG 2ω	Nd:YAG 4ω	Nd:YAG 5ω
Crystal		BBO	CLBO	CLBO
10 Hz	250 mJ	90.3 mJ	50.2 mJ	36.0 mJ
conversion efficiency (%)		36.12	20.08	70.71 % → **14.4**
100 Hz	250 mJ	90.3 mJ	44.9 mJ	19.8 mJ
conversion efficiency (%)		36.12	17.96	44.10 % → **7.92**

Reference [2]



【 QE of Ir_5Ce photocathode 】

QE = 1.54×10^{-4}@266nm

QE = 9.10×10^{-4}@213nm

×6

【 The optimal combination 】

Photocathode: Ir_5Ce compound
Laser : 5th harmonics (CLBO)

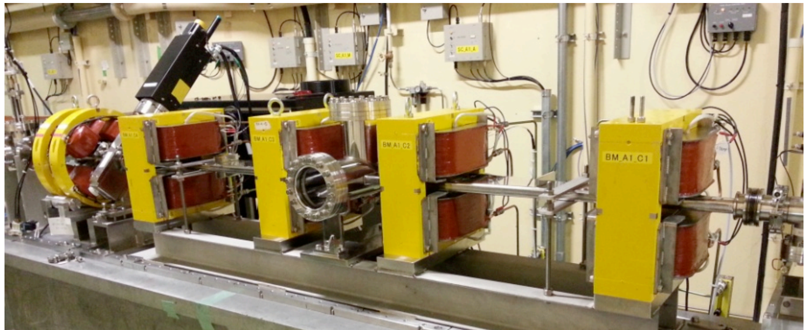
[1] K.Deki , et al., "$CsLiB_6O_{10}$ (CLBO)を用いた193nm光源の開発", 光技術情報誌「ライトエッジ」No.18
[2] Yap YK, et al., "High-power fourth- and fifth-harmonic generation of a Nd:YAG laser by means of a CsLiB(6)O(10).", Opt Lett. 1996 Sep 1;21(17):1348-50.

- 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**

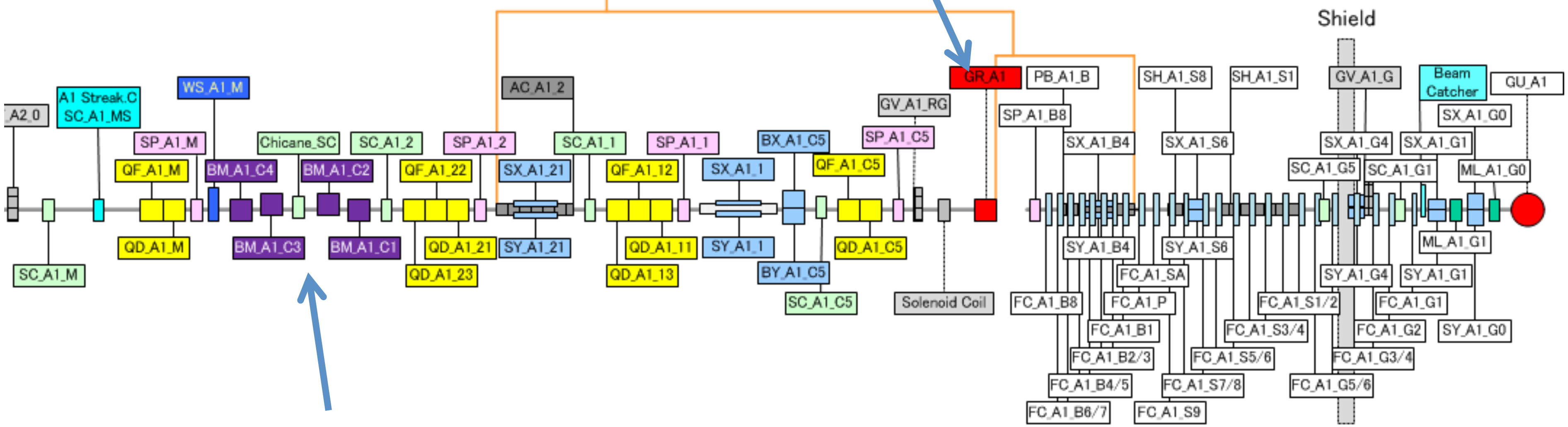
A-1 RF gun

- Quasi-travelling wave side couple RF-Gun
- Yb based laser system

Existing DC-Gun & pre-buncher

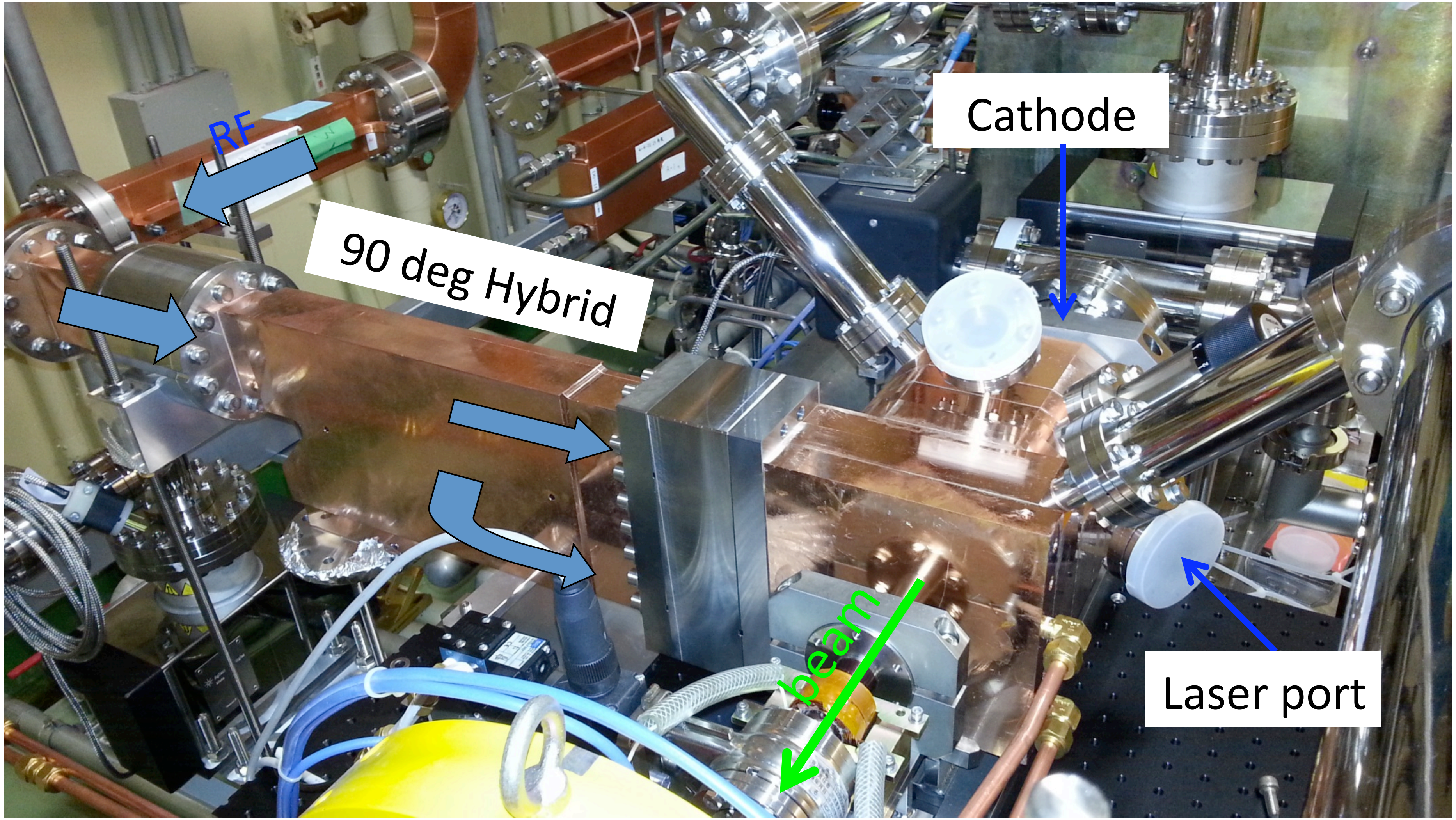


Installed RF-Gun

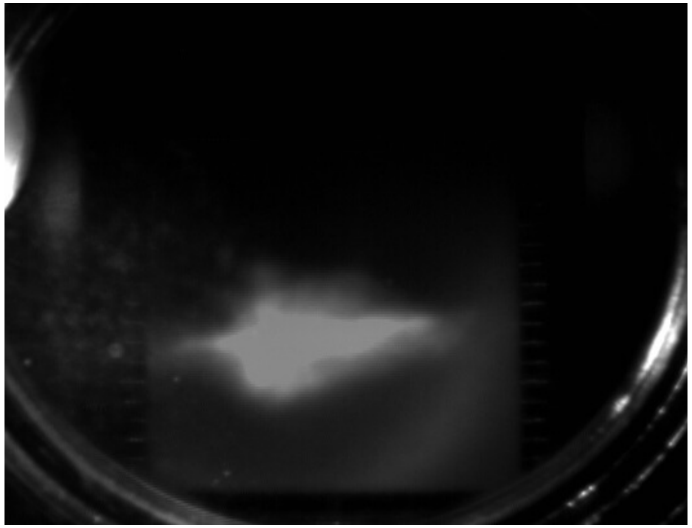


Chicane for bunch compression
30ps => 10ps

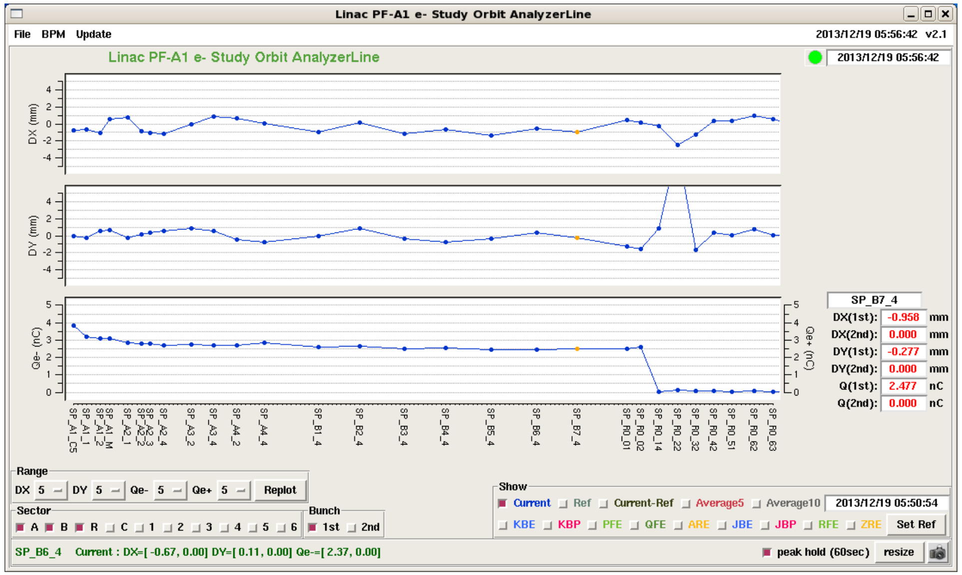
Installed RF gun



A-1 RF gun results

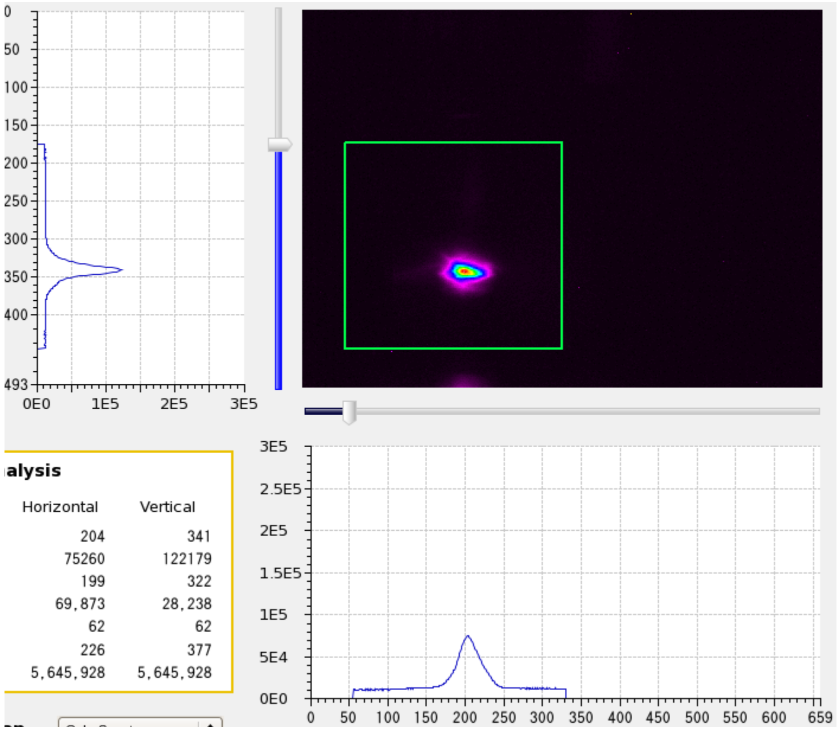


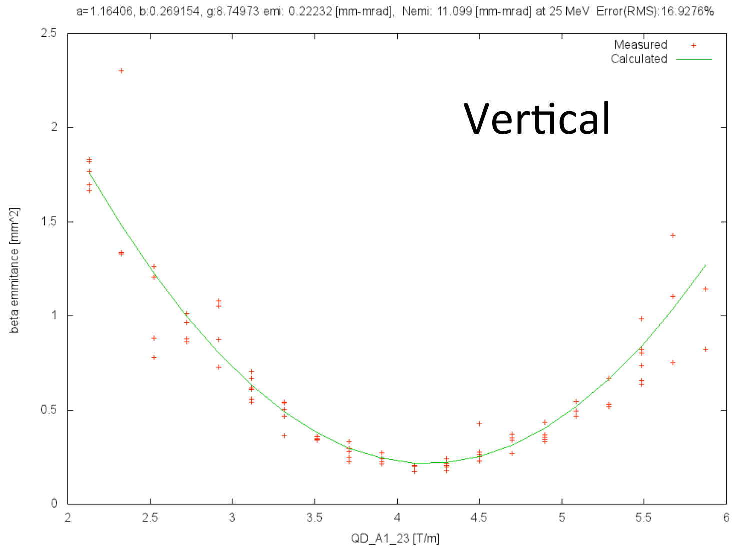
5.6 nC was achieved.
However beam profile is not good.

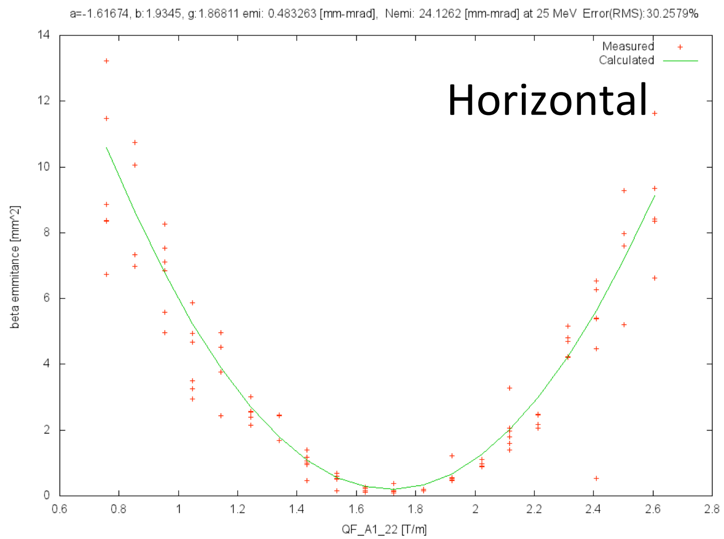


3 nC beam delivery was achieved.

Emittance measurement
Q scan







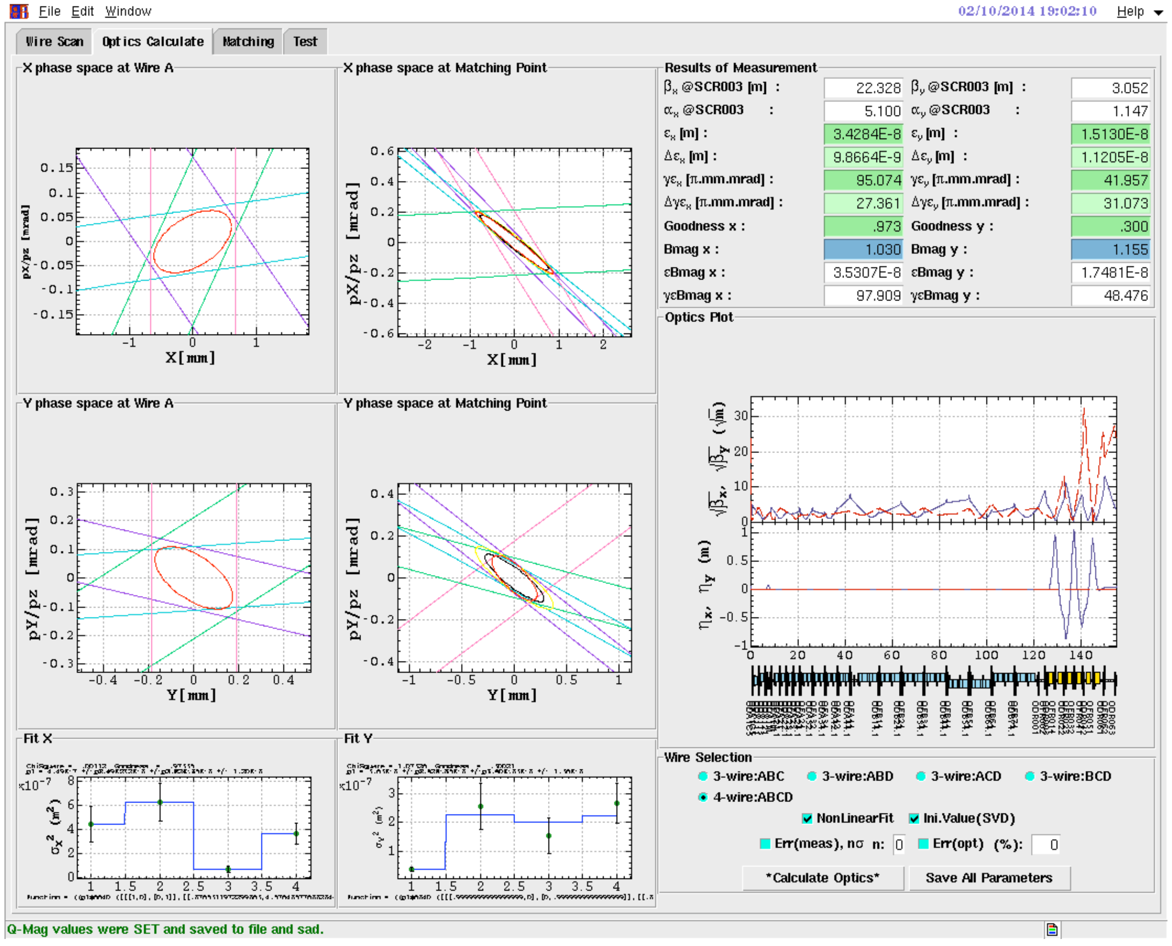
Using 30 um screen at 25 MeV

Normalized emittance

X: 24.1 ±7.2 mm-mrad Y: **<u>11.1</u>** ±1.8 mm-mrad

(Large horizontal emittance is due to laser incident angle.)

Emittance measurement
Wire scanner at B sector



Normalized emittance

X: 95.0 ±27.4 mm-mrad Y: 42.0 ±31.1 mm-mrad

(including the beam position jitter.)

Summary of RF-Gun

- RF-Gun cavity
  - **Quasi travelling wave side couple structure** is under operation.
- Cathode
  - Room temperature **Ir_5Ce** cathode has enough QE.
  - Laser cleaning & laser injection angle is effective.
  - R&D for the QE improvement.
- Laser & control
  - **Yb based laser system : A-1 RF-Gun**
    - **Yb-fiber :** Precise RF synchronization.
    - Yb-disk amplifier: High power output.
    - Temporal manipulation Under experiment.
  - Stability / Control: Improved but not enough.

Hardware development for emittance preservation

Hardware for emittance preservation

- Alignment
  - Initial alignment using laser tracker
    (will be presented by Kamitani)
  - Continuous monitor (HLS, Wire) + Active mover
  - Beam based alignment
- Temporal manipulation
  - Laser pulse shaping
  - Bunch compression
  - Additional hardware to compensate longitudinal wakefield
- Beam diagnostics for offset injection
  - RF Deflector

Requirement for alignment

- 0.3 mm is not enough with offset injection.

↓

- 0.1 mm in sector
- 0.3 mm in global

↓

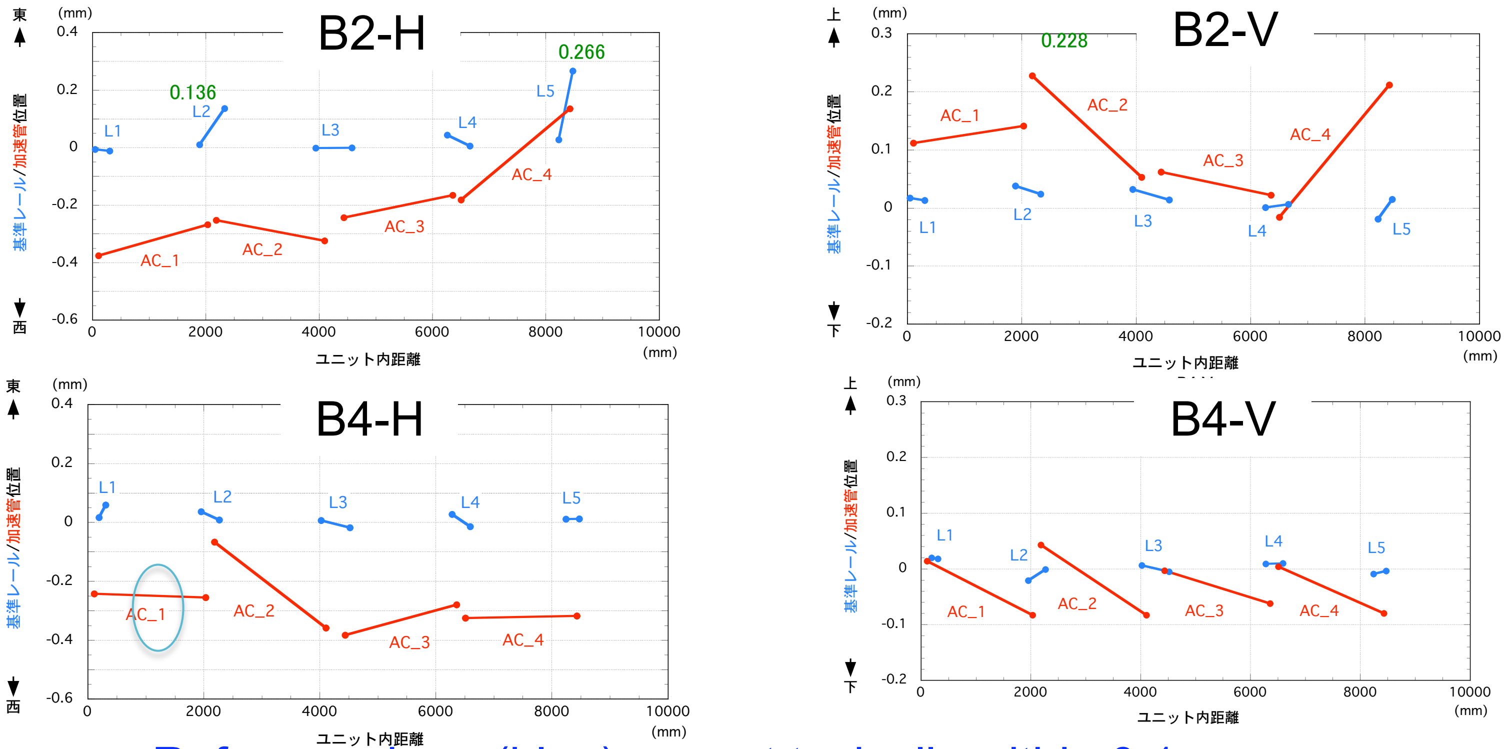
- Alignment
  - Initial alignment using laser tracker.
  - Continuous monitor (HLS + Wire) => Active mover.
- Beam based alignment
  - Orbit measurement without acceleration and magnet
  - Low charge (only dispersion) & high charge (wake) measurement
  - Higher order wakefield monitor

Hard ware alignment status

- **Girder alignment**
  - Done with laser PD, we assume $\sigma<0.3$mm
- **Accelerator structures**
  - Aligned on the girder reference points
  - Mostly and can be $\sigma<0.1$mm
- **Q magnets**
  - Set on a bridge aligned w.r.t. adjacent girder ends
  - Reflector bases are being mounted on old magnets.
  - New magnets are equipped with them.
  - Alignment can be checked by laser tracker .
  - Evaluation should also be done by beam.
  - Independent girders for magnets should be developed if needed.

Present situation on short-distance (local) alignment

Hard ware alignment on a 10m girder



Reference bars (blue) are set typically within 0.1mm.

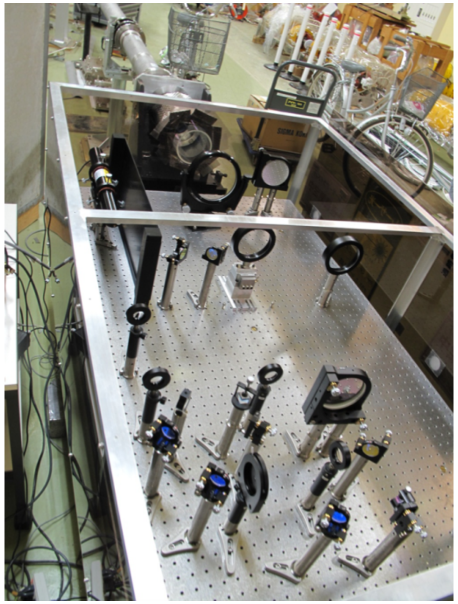
Hor. up to 0.5mm slope

Ver < 0.2mm

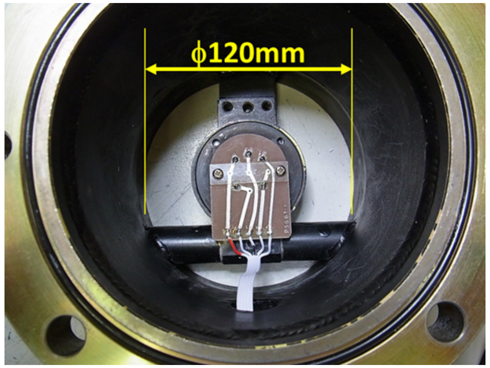
Systematic error may exists in H by 0.5mm, while V stays 0.2mm from reference bar.

K. Kakihara, 22 Nov. 2012

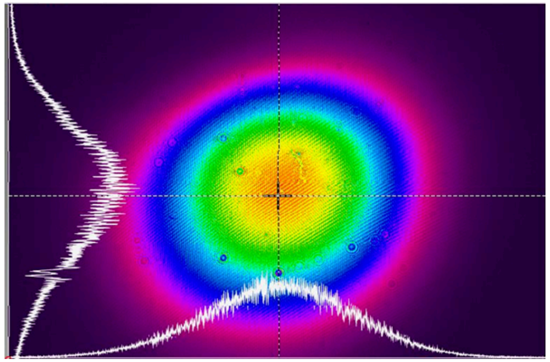
Laser straight over 500m as a reference



Laser system with tilt feedback



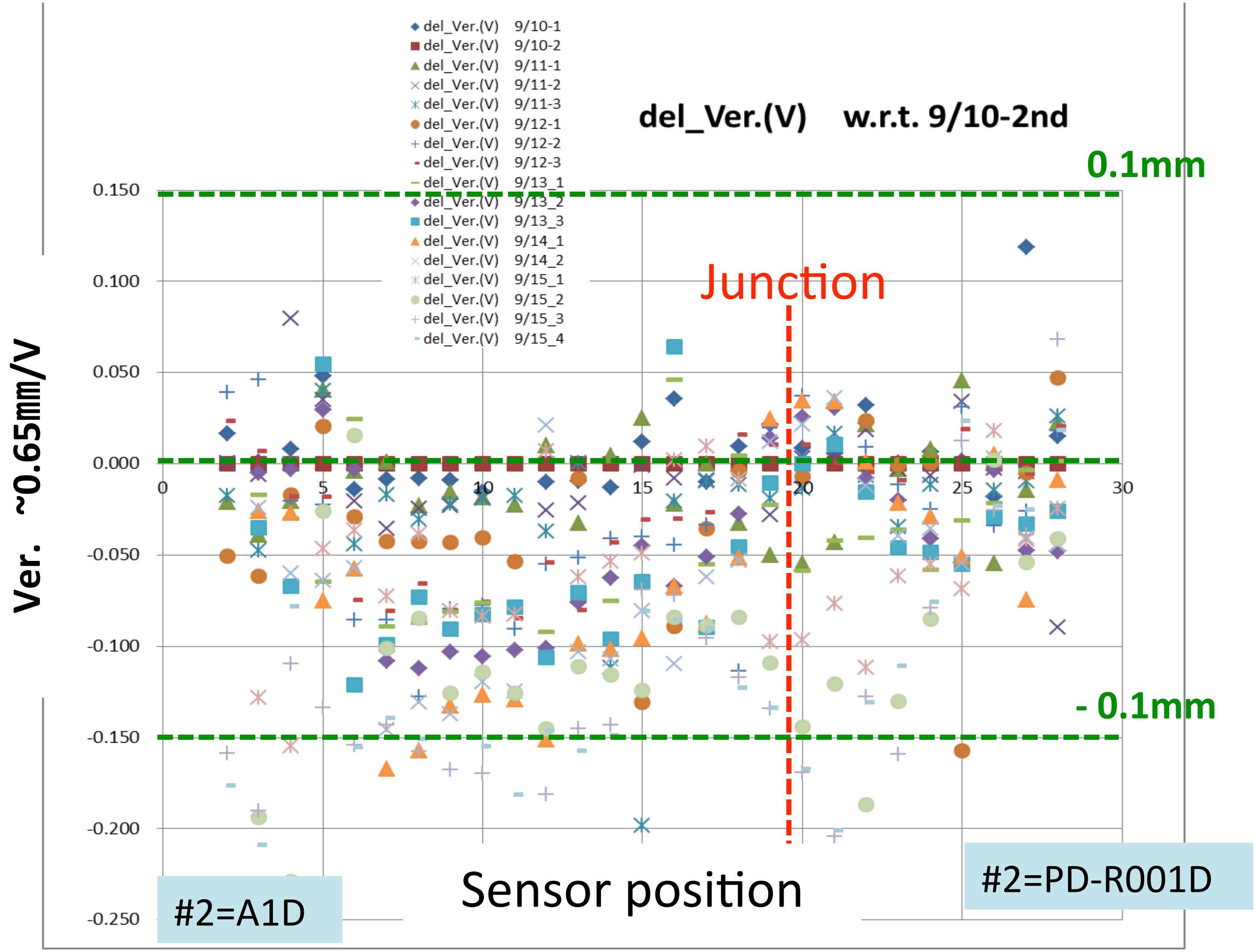
500m vacuum pipe



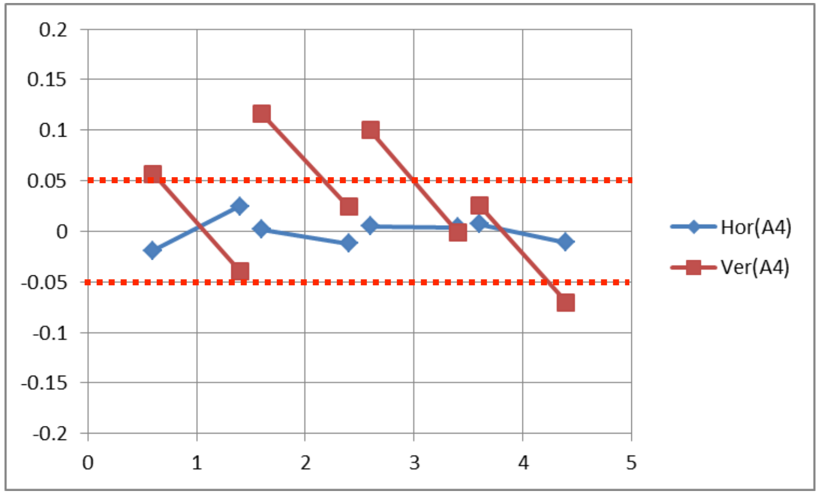
Spot size
4σx～21mm
4σy～18mm

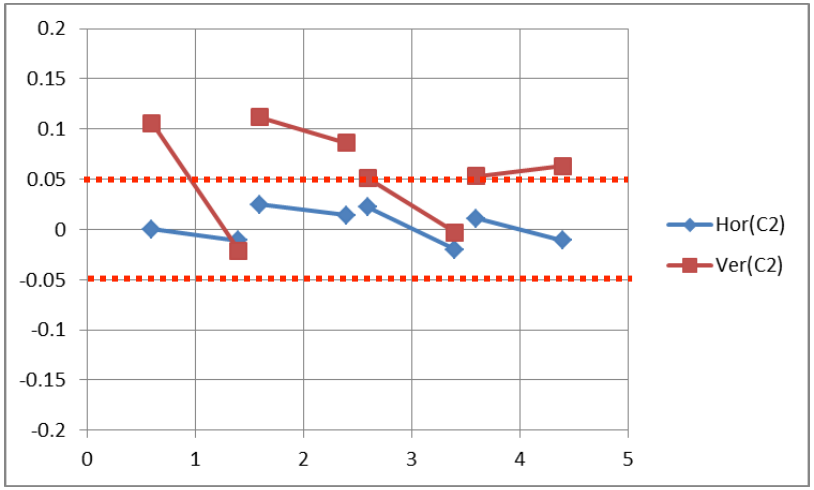
Can be used as a straight line.
The line connecting points at the ARC exit and BT entry is kept with FB.

Laser PD meas. 9/10～9/16 Vertical



Accelerator structure alignment on a girder, measured w.r.t. PD arms





Examples showing the present status: Statistics of three units (C1, C2, C3)

Horizontal

Average = 2 microns
Stand. Dev. = 16 microns

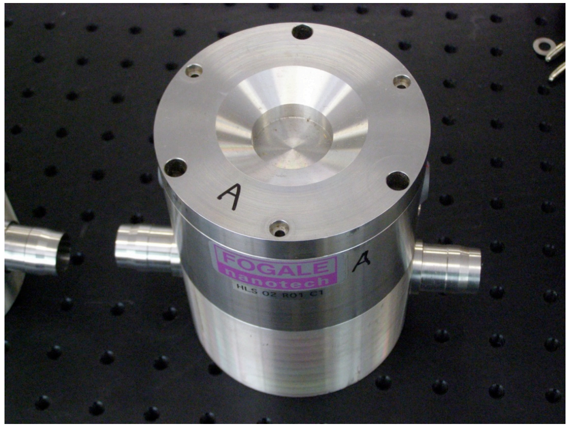
Easy adjustment by shimming

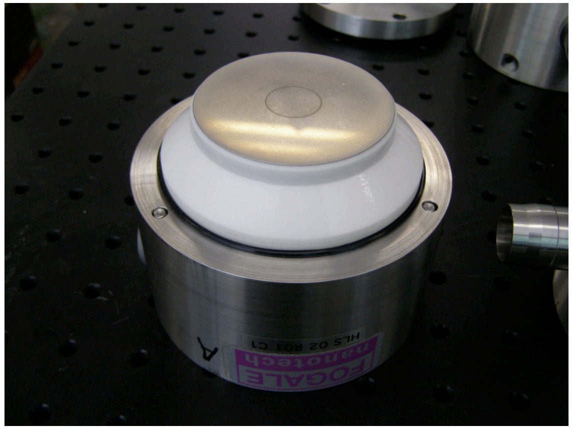
Vertical

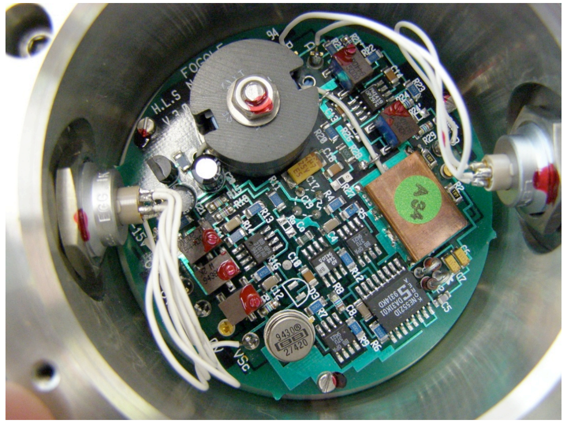
Average = 5 microns
Stand. Dev. = 51 microns

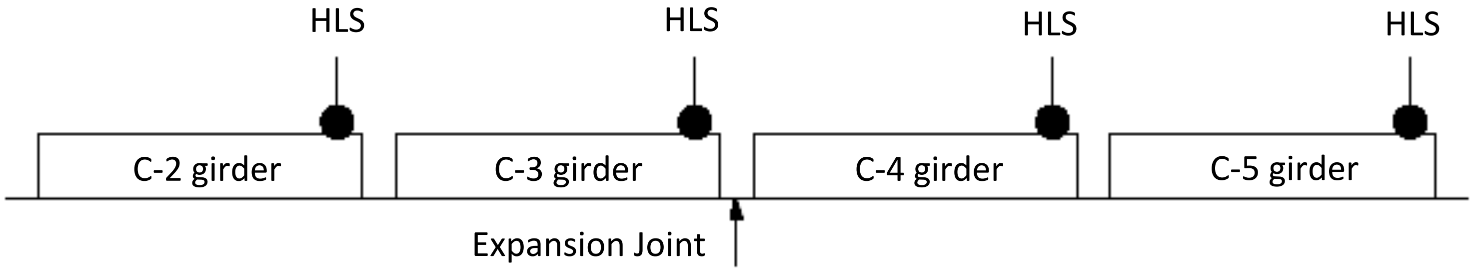
A little tedious but can be adjusted by screw bolts

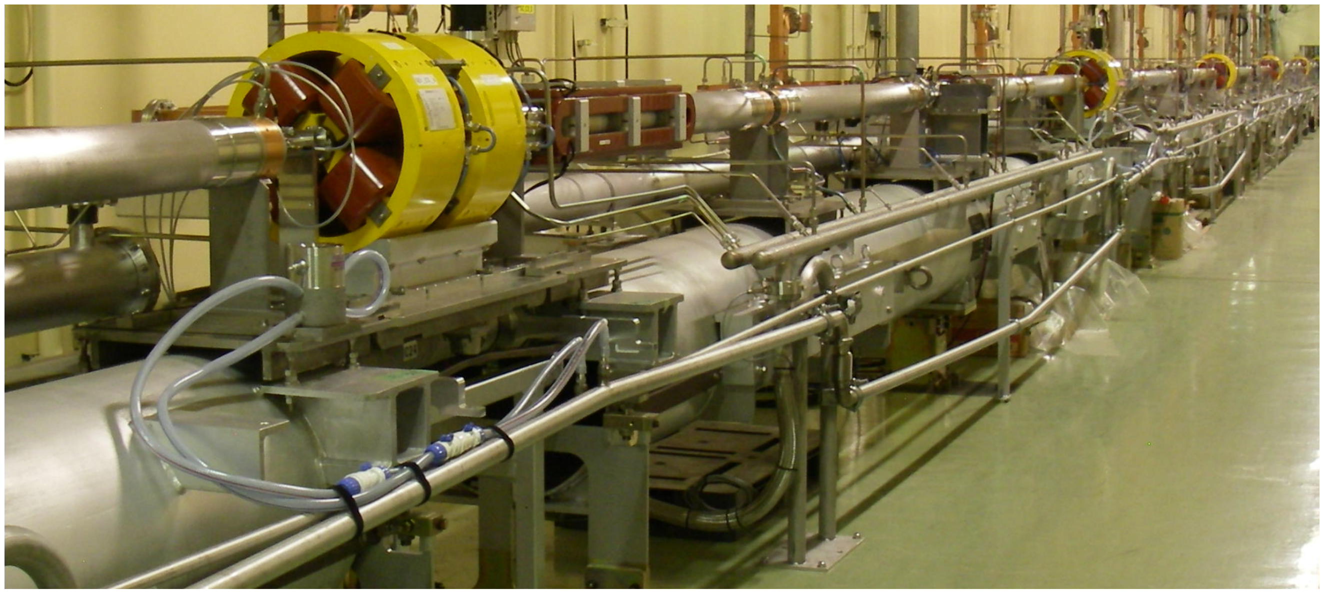
Hydro leveling system (HLS) for continuous monitor



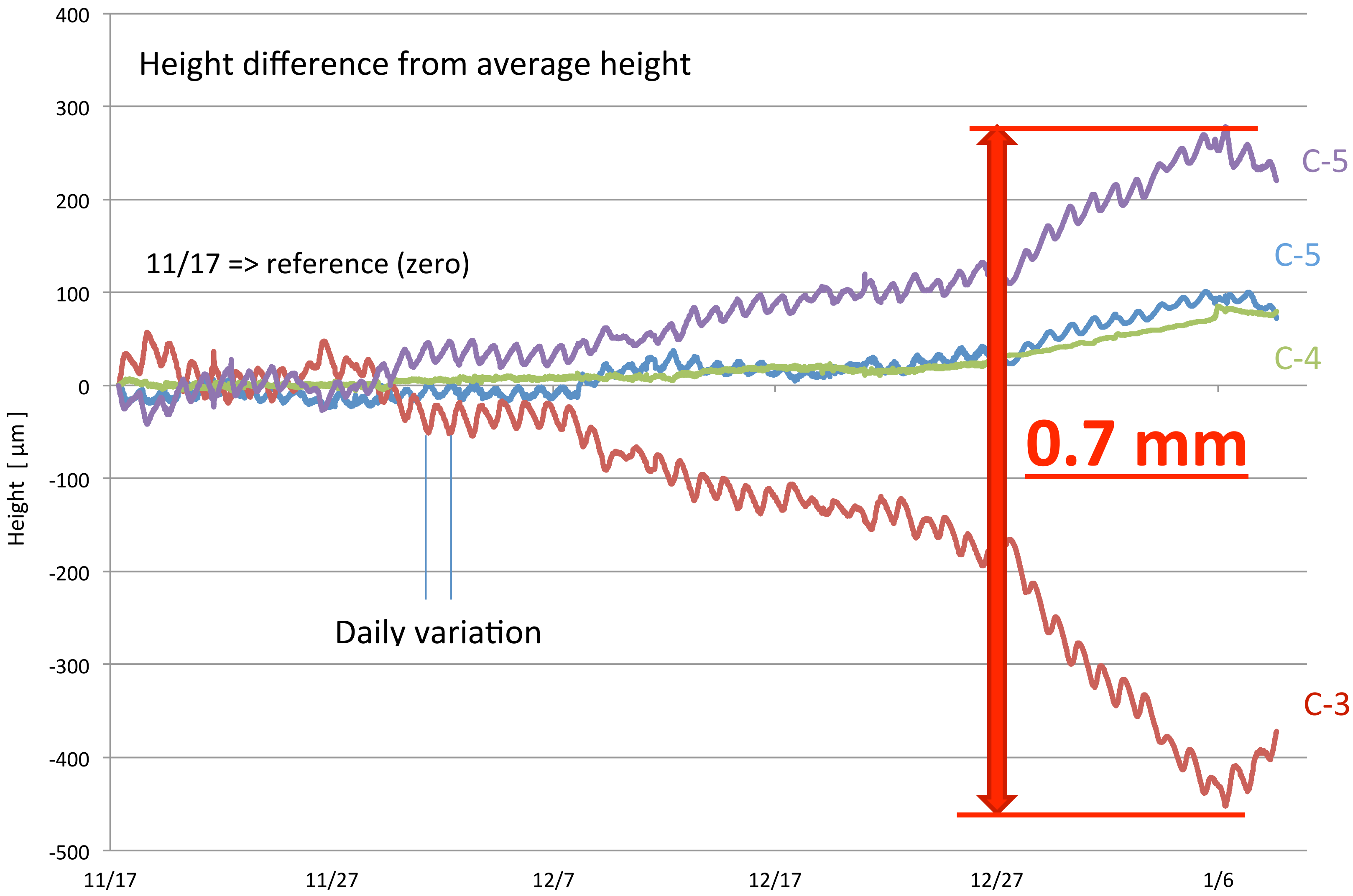








Long term measurement of girder height

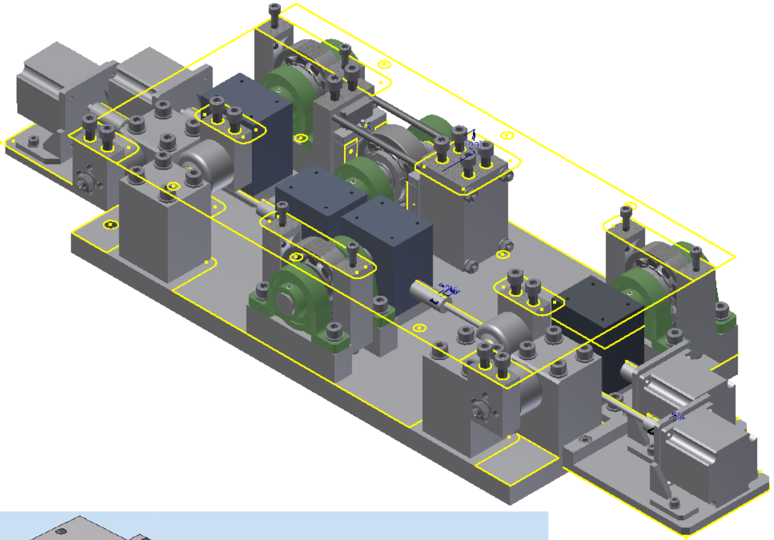


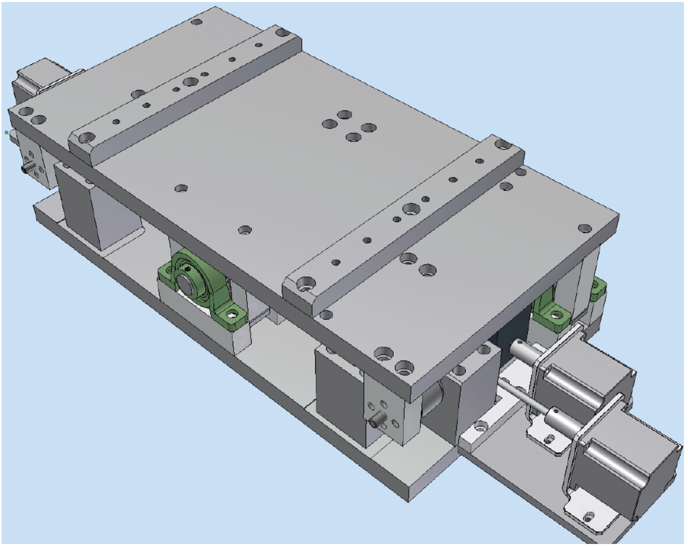
=> Continuous monitor & **Active movers** are required !!

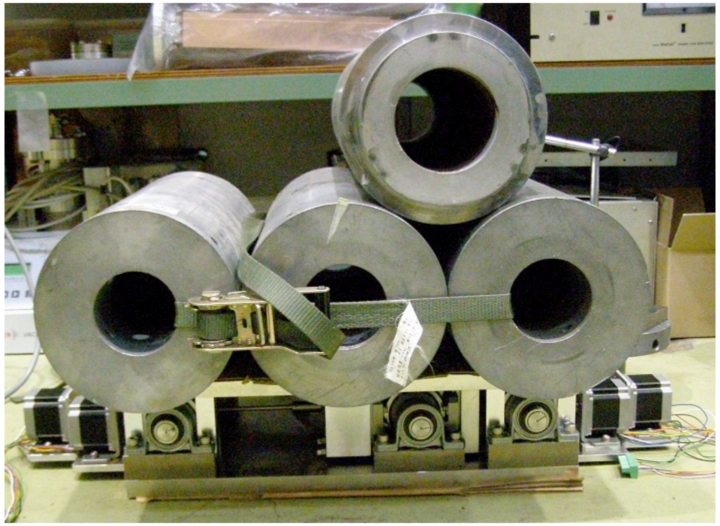
Active mover

- Eccentric Cam Movers
  5mm stroke, 125nm resolution

Specification	
Stroke	
X - axis Y - axis Z - rotation	± 2.5 mm ± 2.5 mm ± 0.42°
Resolution	
X - axis Y - axis Z - rotation	∼ 125 nm ∼ 125 nm ∼ 9.5×10^{-7} °
Geometry (X Y Z)	320 x 800 x 189 mm
Withstand load	12000 N
Weight	170 kg

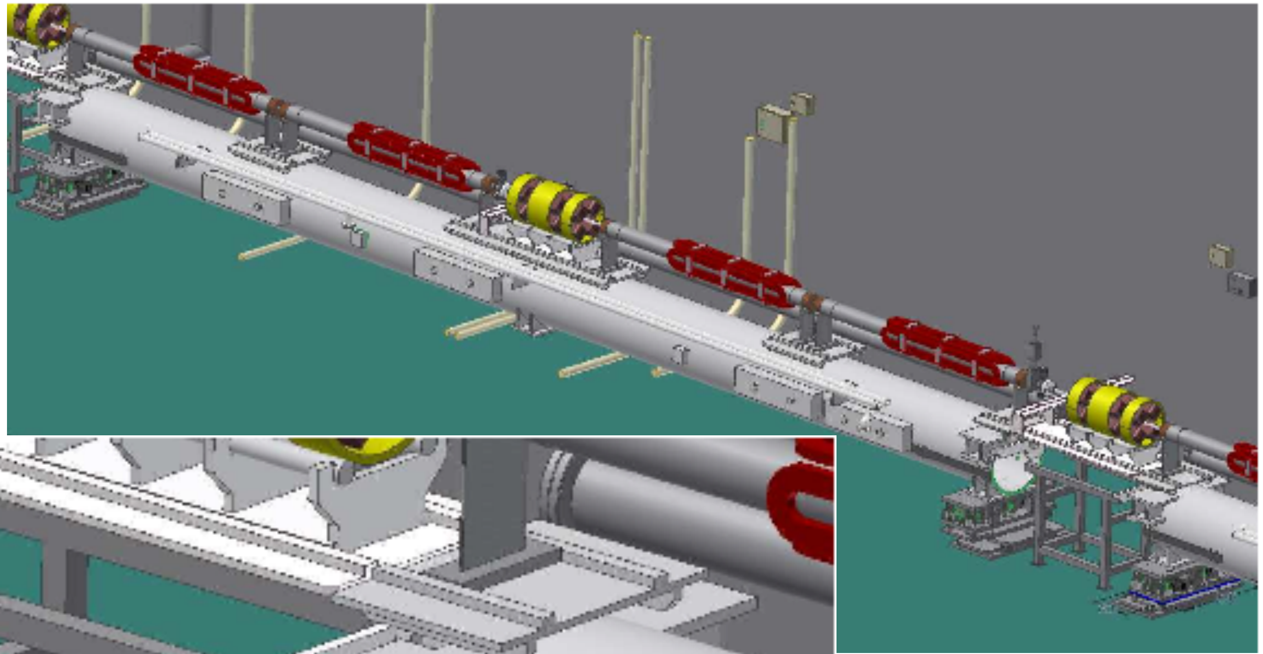


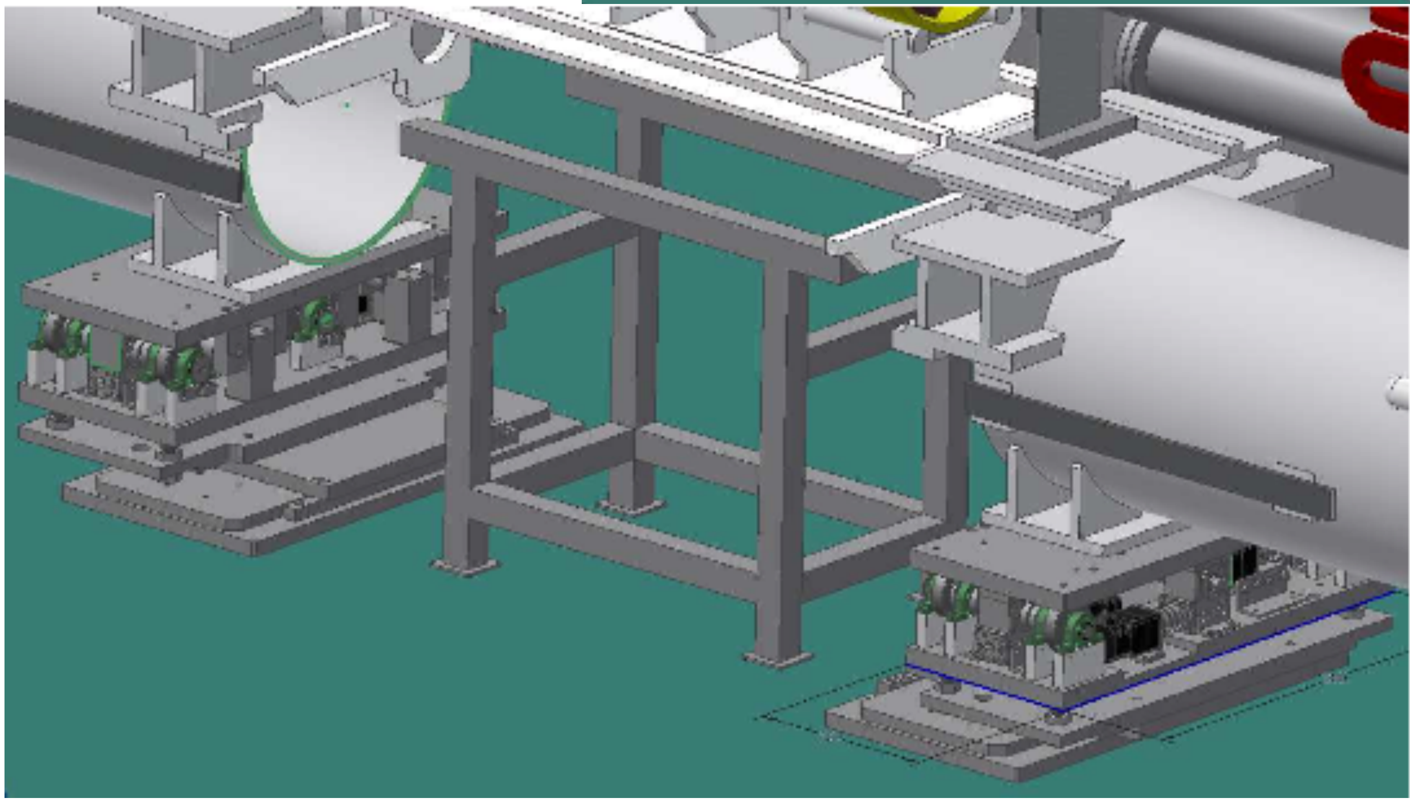




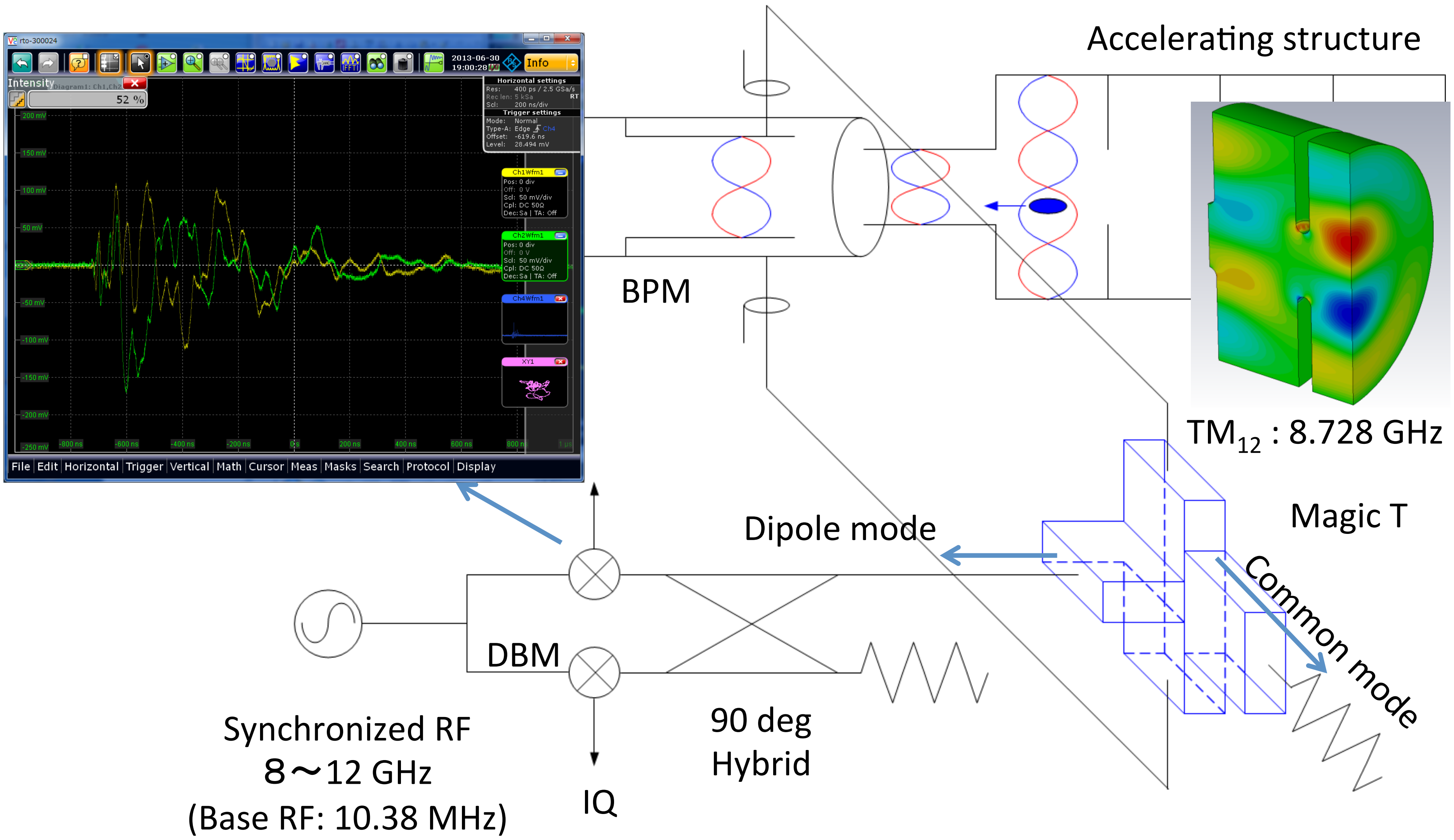
500 kg withstand load test

Active mover installation plan for girder

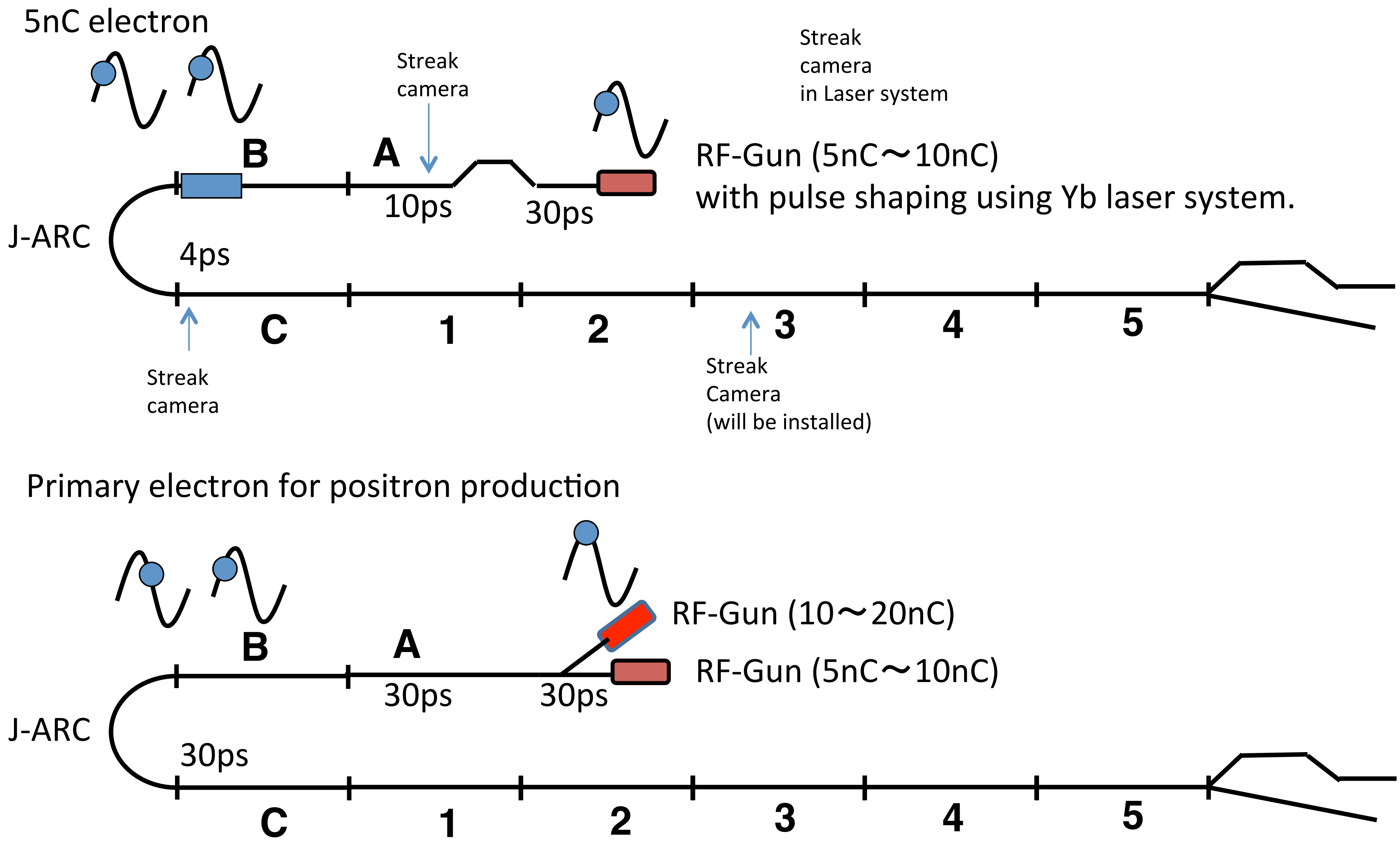




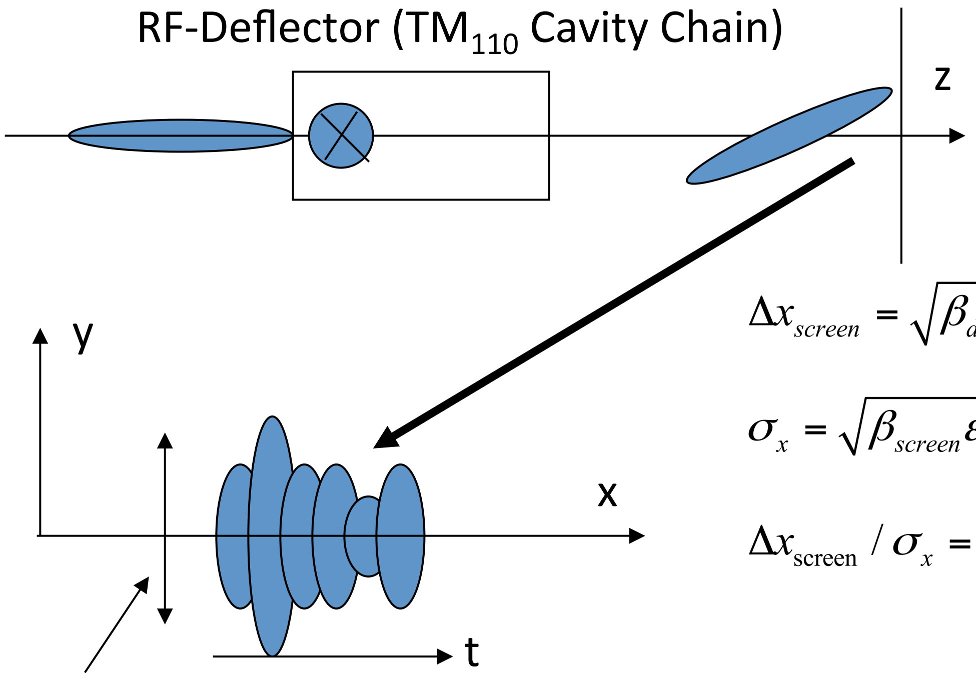
Preliminary test for higher order transverse wakefield monitor



Bunch compression
for 5nC electron & primary electron for positron production



X-band RF Deflector for Bunch Sliced Transverse Emittance Monitor



$$\sigma_y(t) = \sqrt{\beta_y \varepsilon_y(t)}$$

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

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

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

$$V_{deflector} = 10MV,\ f_{RF} = 2.856GHz,\ \Delta t = 10ps,\ \beta_{deflector} = 10m$$

$$\rightarrow \Delta x_{\mathrm{screen}} / \sigma_x = 3$$

$$V_{deflector} = 15MV,\ f_{RF} = 11.424GHz,\ \Delta t = 10ps,\ \beta_{deflector} = 10m$$

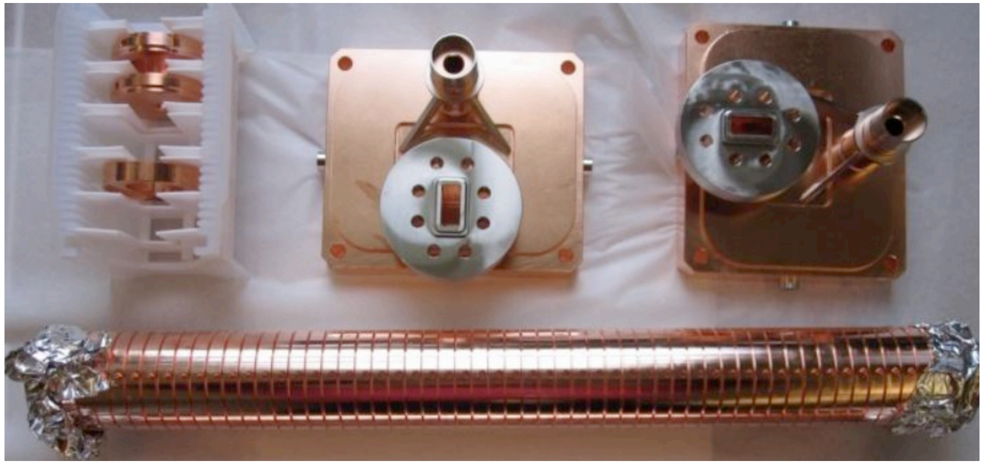
$$\rightarrow \Delta x_{\mathrm{screen}} / \sigma_x = 18$$

➡ Installation to the monitor beam line at 3rd switch yard (end of LINAC)

=> feedback to the initial offset to compensate the transverse wakefield.

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

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

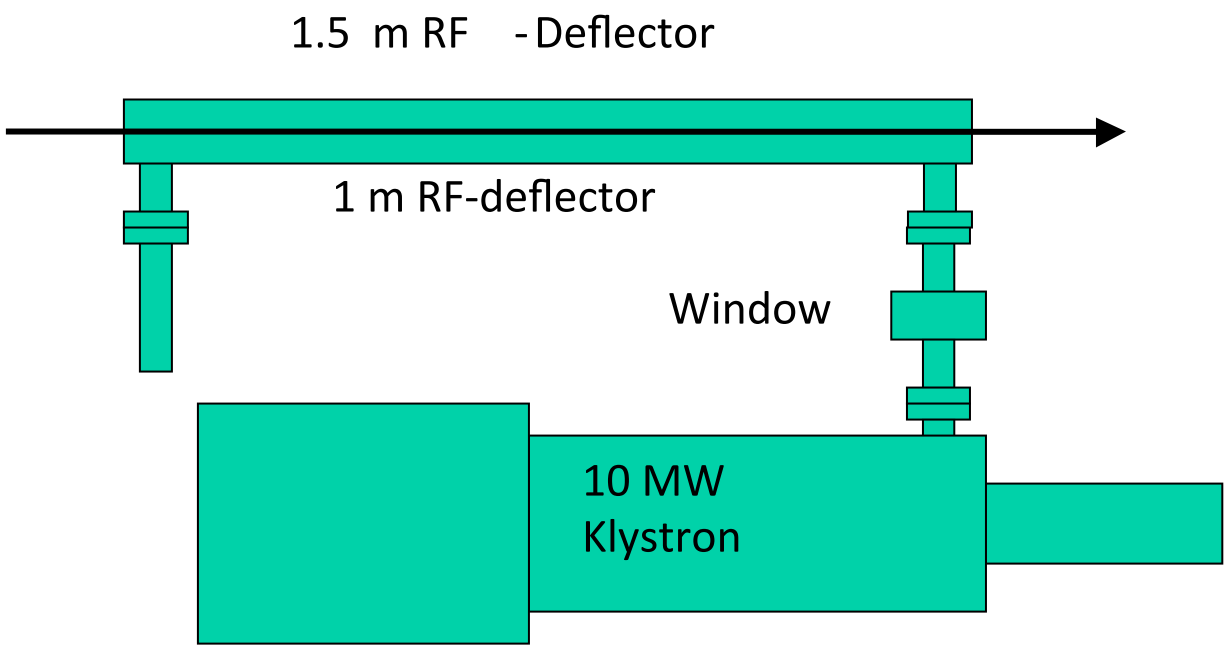


Input Power : 10MW

Deflecting Voltage : 15 MV

X-band Klystron (KEK)

- Based on existing 9GHz, 4 MW klystron
- 250 kV, ηP=0.7
- 10 MW output
- 2 window

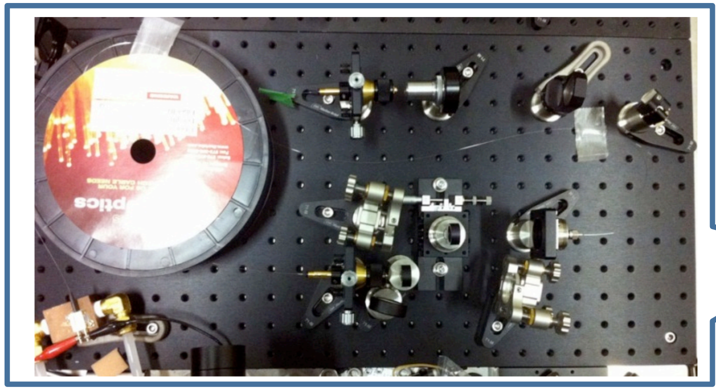


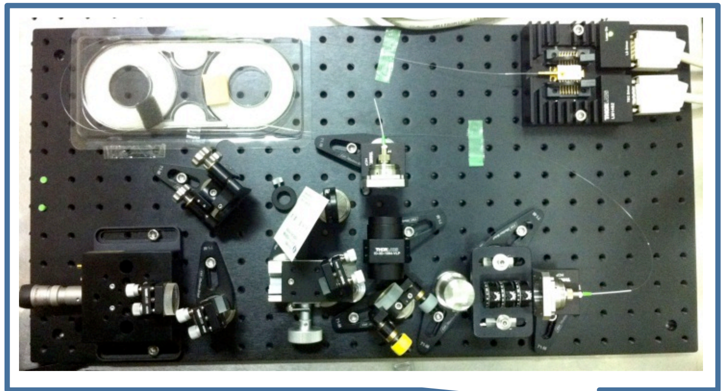
Summary of hardware for emittance preservation

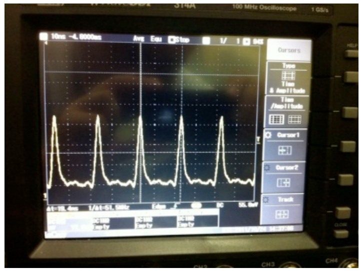
- Alignment
  - Initial alignment using laser tracker
  - Continuous monitor (HLS, Wire) => Active mover
  - Beam based alignment
- Temporal manipulation
  - Laser pulse shaping
  - Bunch compression
  - Additional hardware to compensate longitudinal wakefield
- Beam diagnostics for offset injection
  - RF Deflector
  - One shot emittance monitor

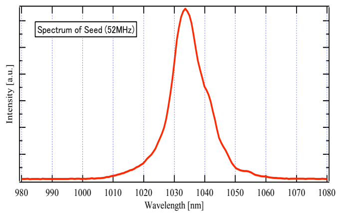
Backup

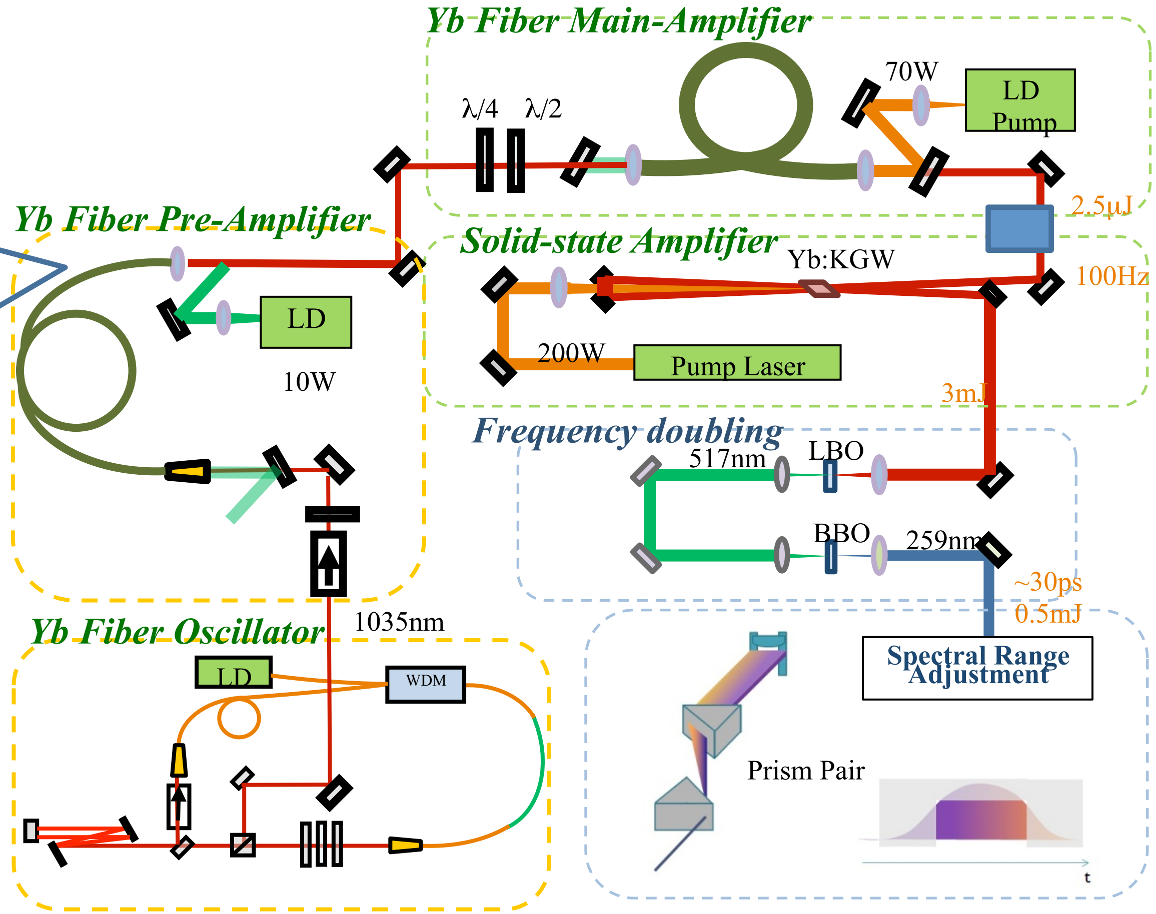
Yb-fiber & Yb solid state laser development

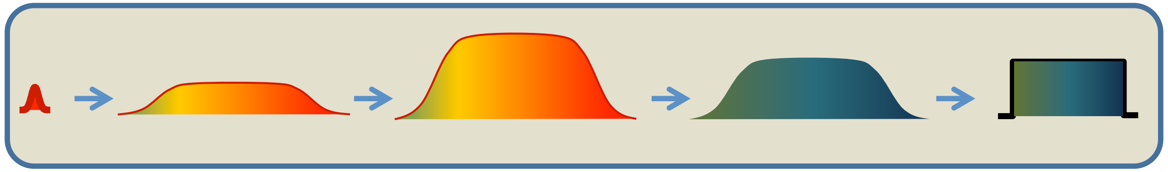






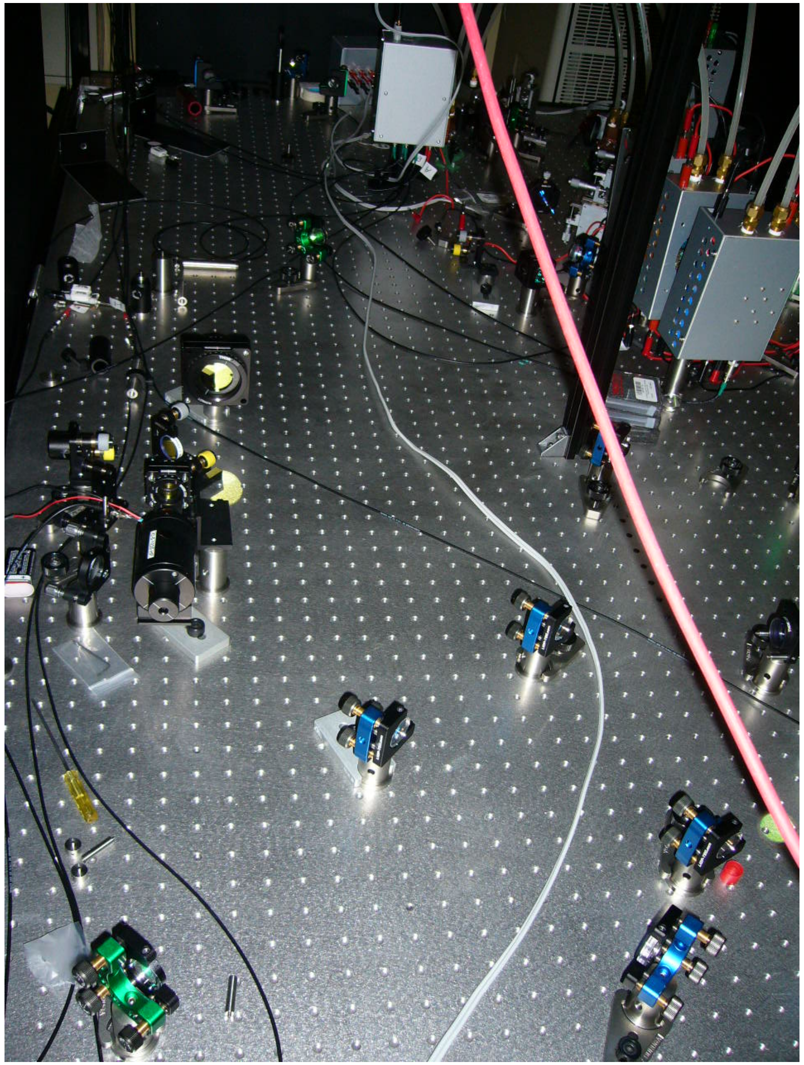


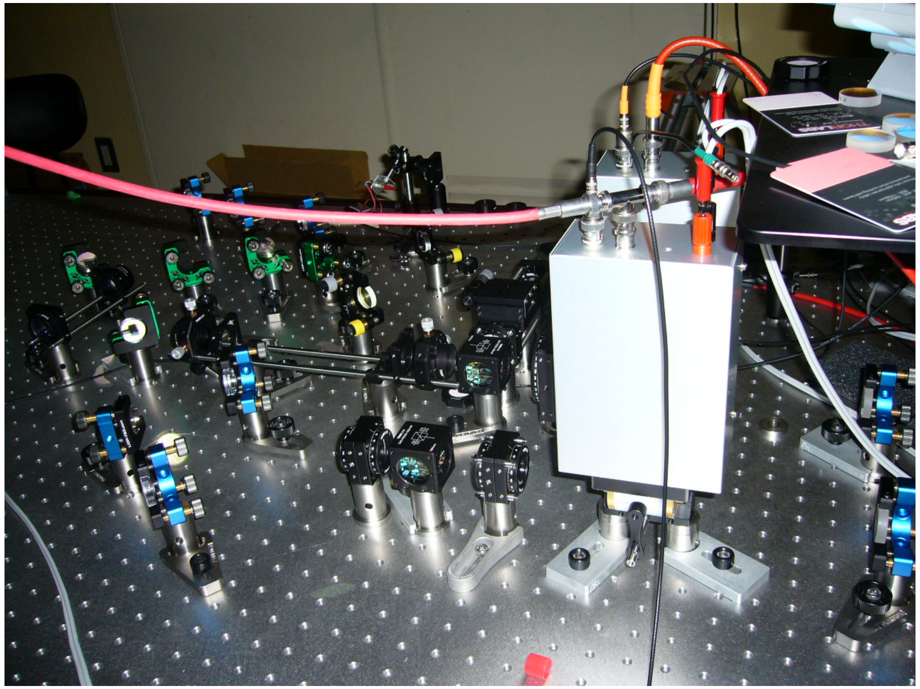




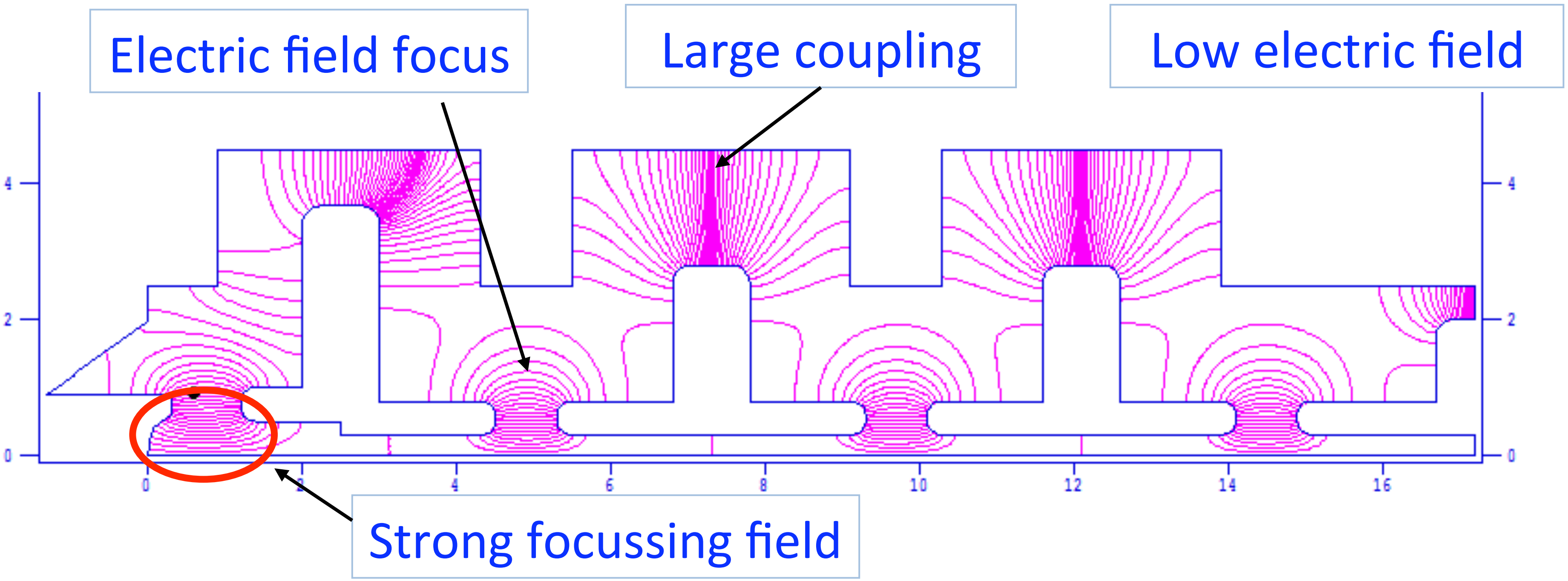
Oscillator & pre-amplifier are already working.

Regenerative Amplifier

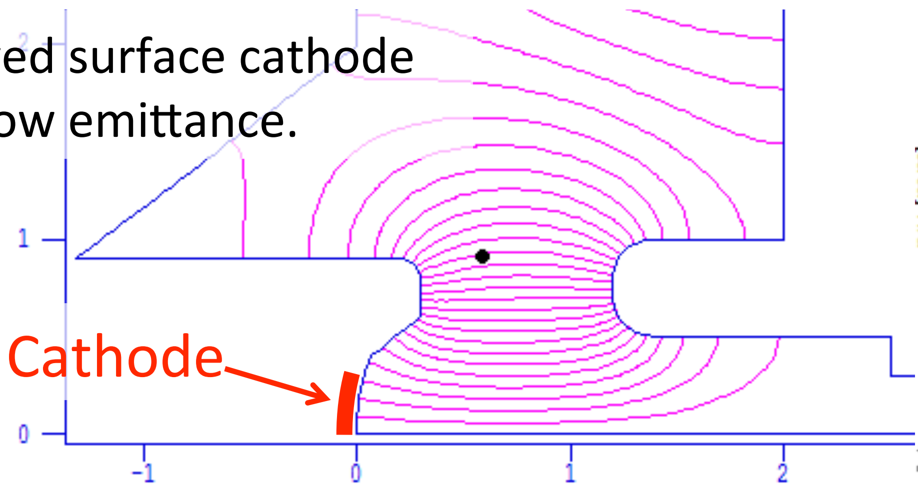


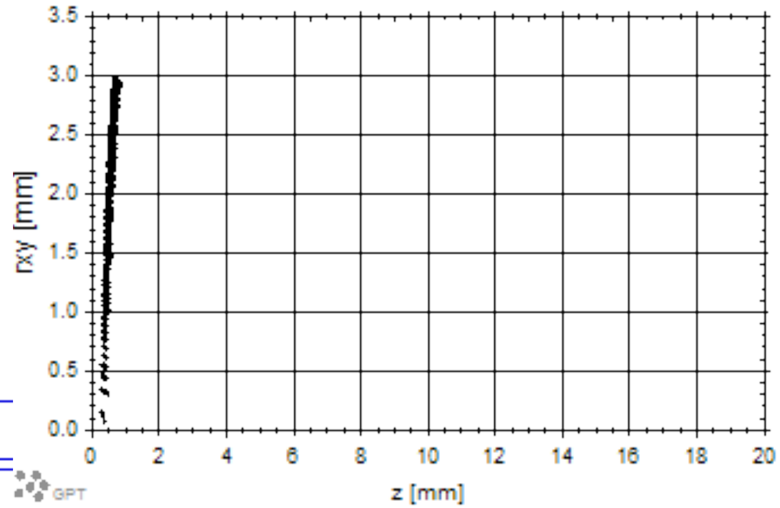


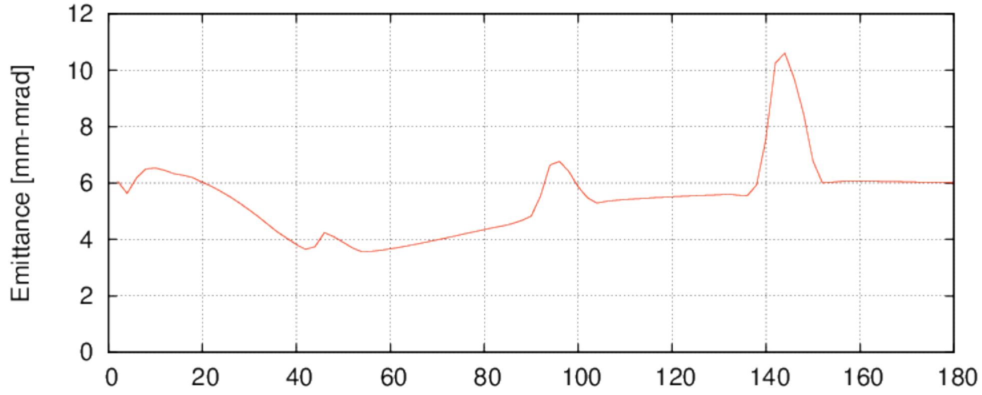
DAW (Disk and Washer) type RF-Gun



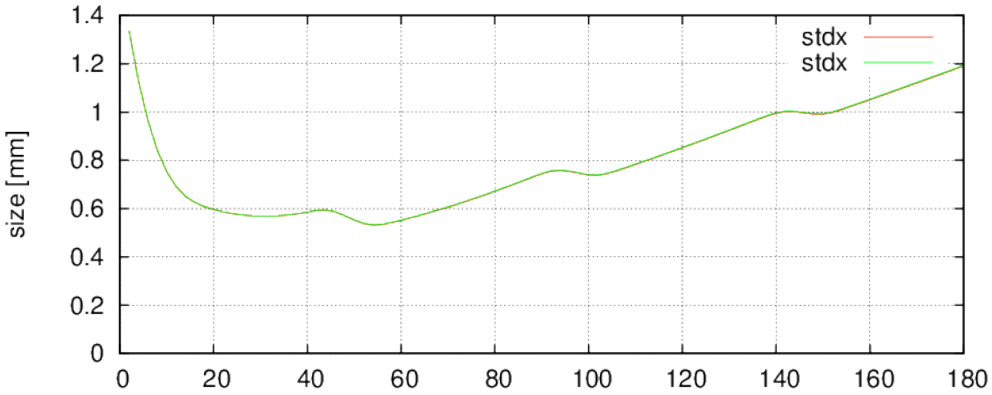
Curved surface cathode
for low emittance.



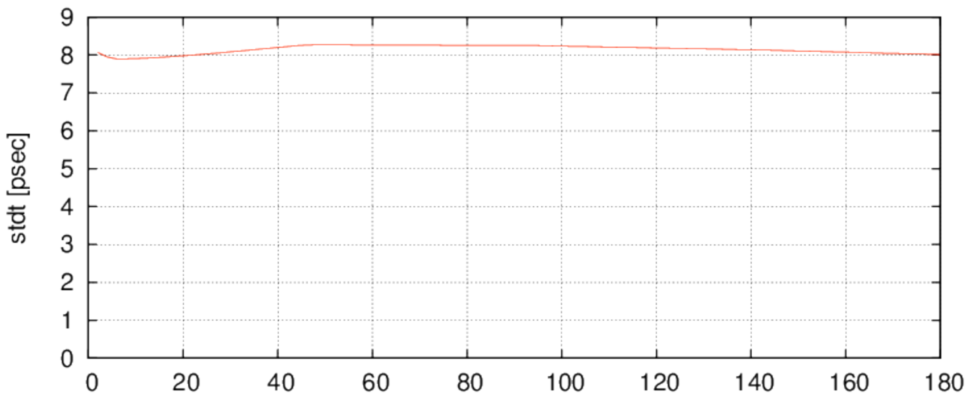




Emittance
6 mm-mrad
(5 nC)

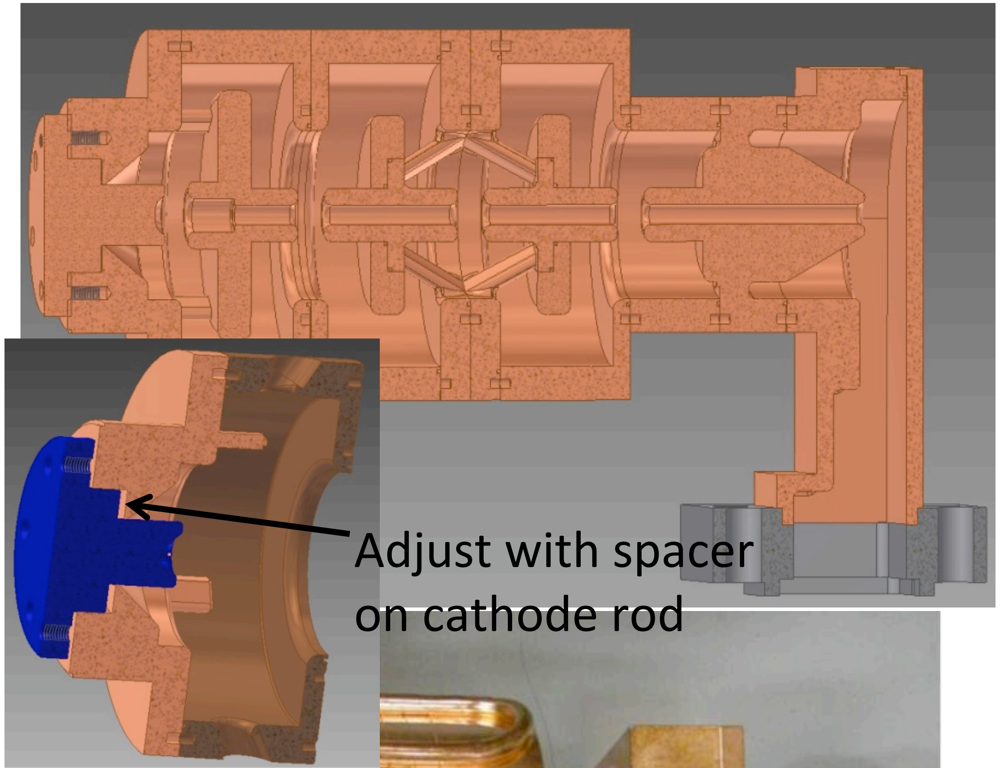


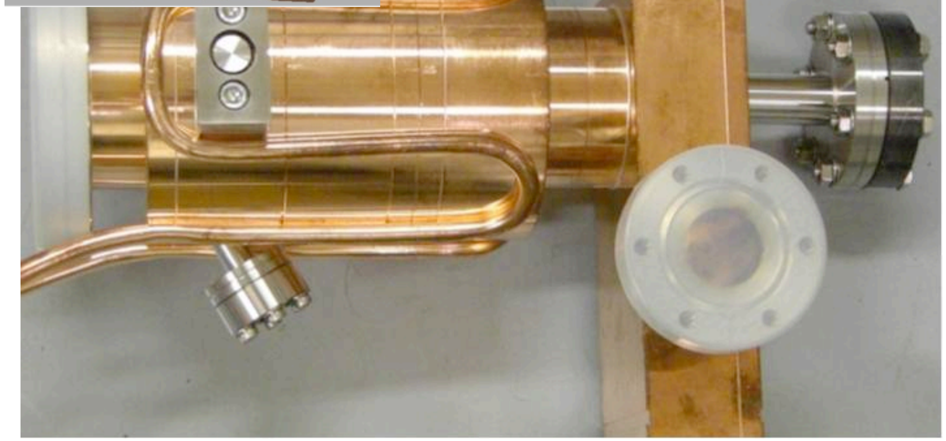
Beam size (σ)
1.2 mm

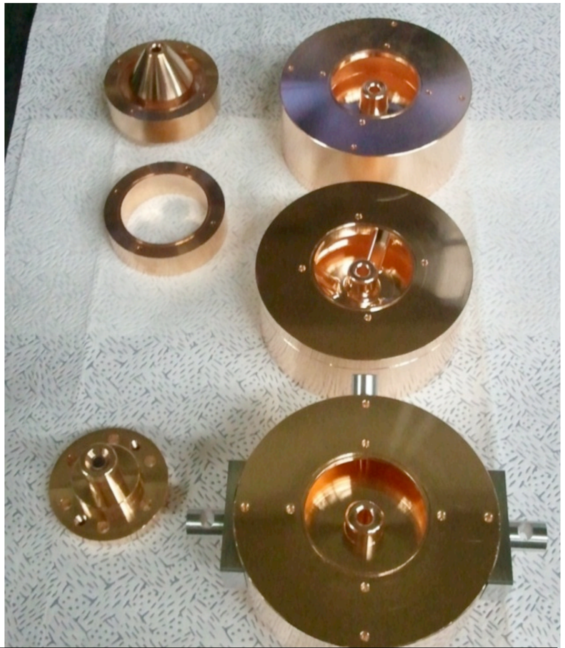


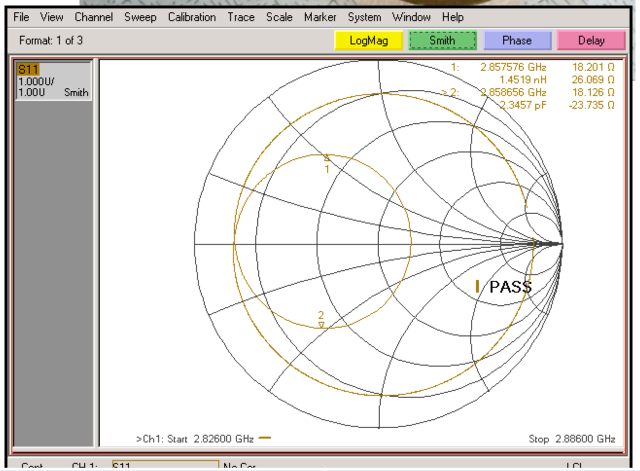
Bunch length (σ)
8 psec

Fabrication of DAW RF-Gun





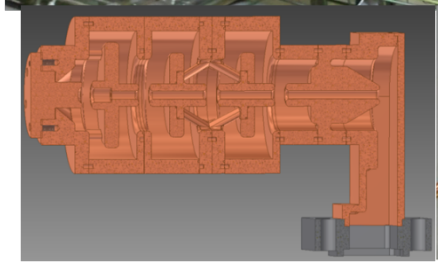


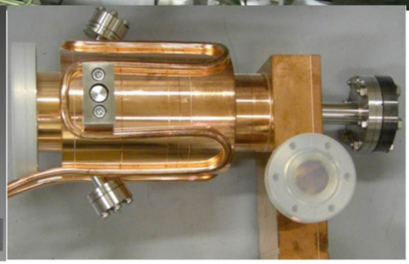


Reflection ratio	$G = 0.119$
Coupling	$\beta = 1.27$
Q factor	$Q_0 = 6007.3$
Loaded Q	$Q_L = 2646.4$

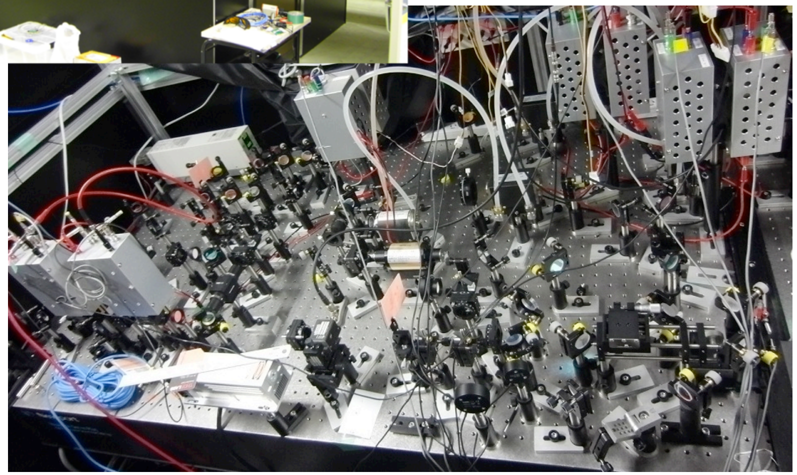
3-2 RF-Gun

3-2 RF-Gun (2011/10)



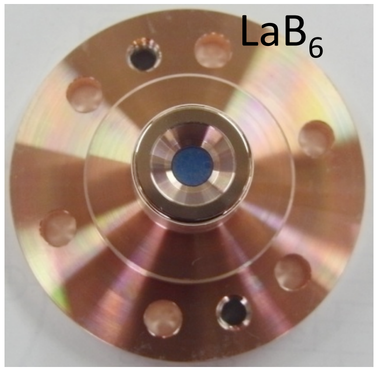


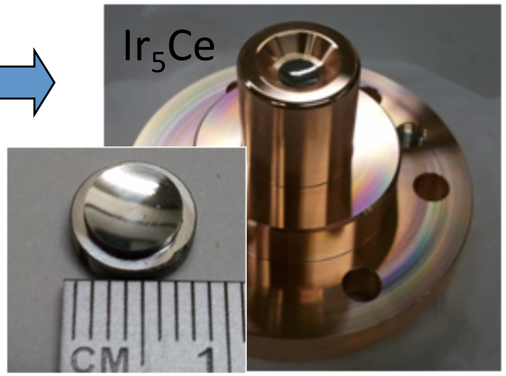
3-2 Laser hut



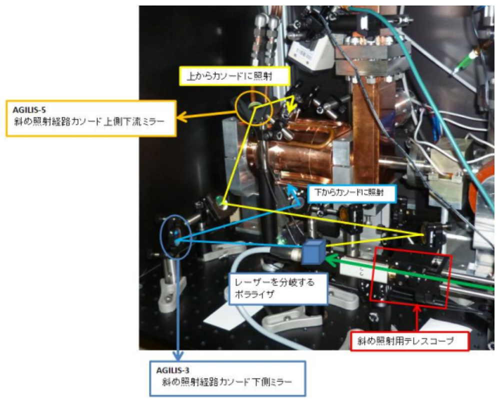
- 52MHz Oscillator
- DPSS Module
- AO + EO x 2 pulse picker

Cathode LaB6 => Ir5Ce（2012/03）



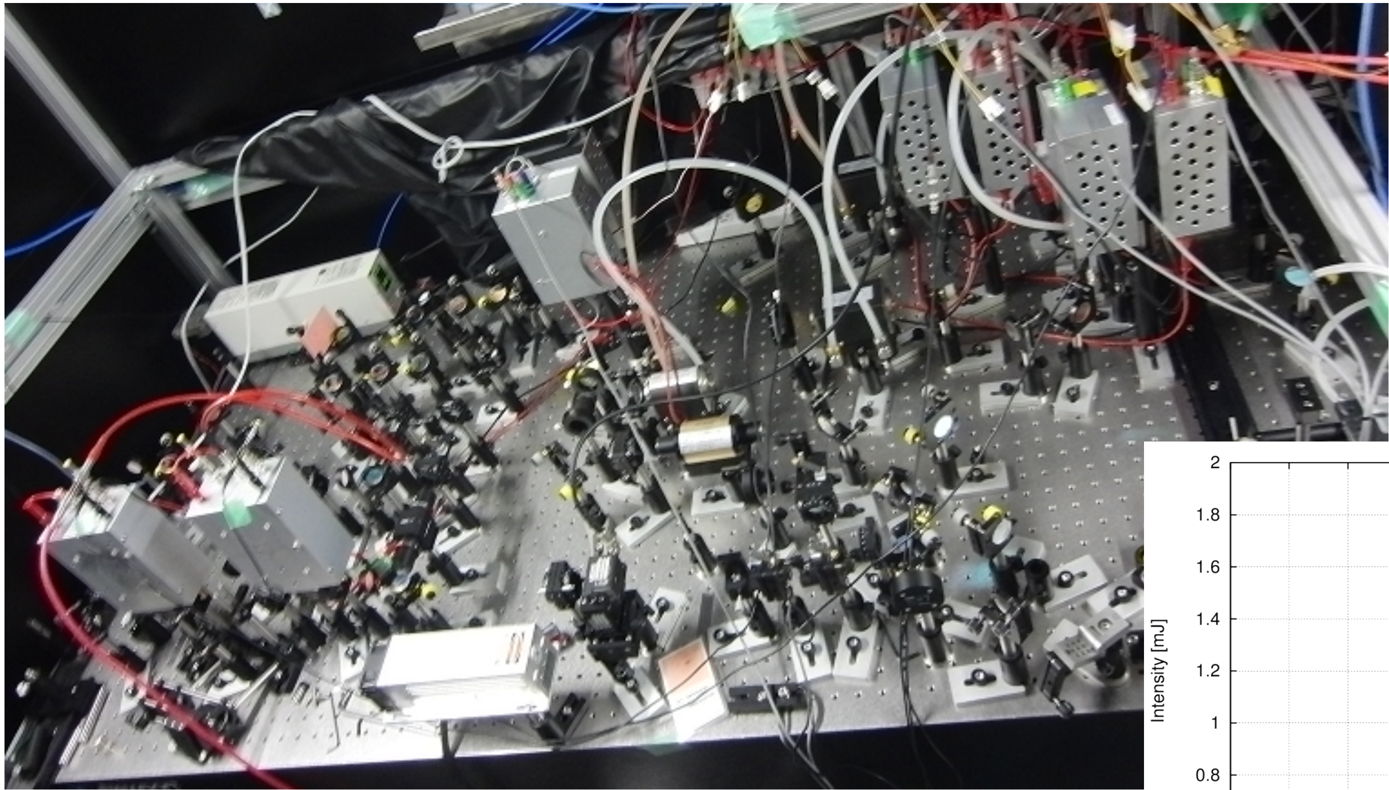


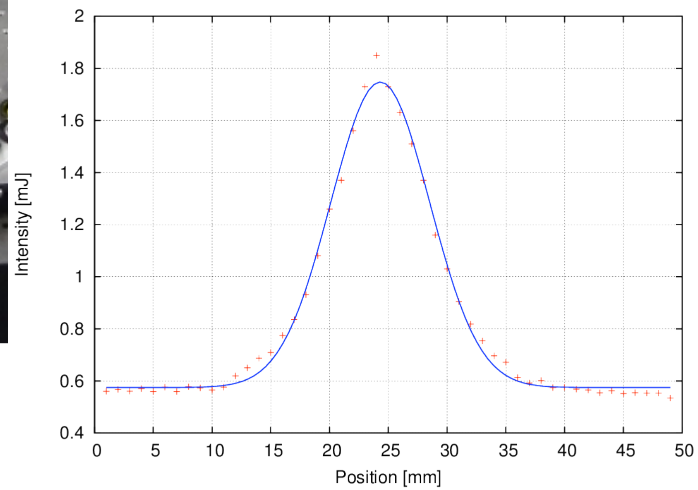
Laser injection with angle（2012/05）



Nd based laser system

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

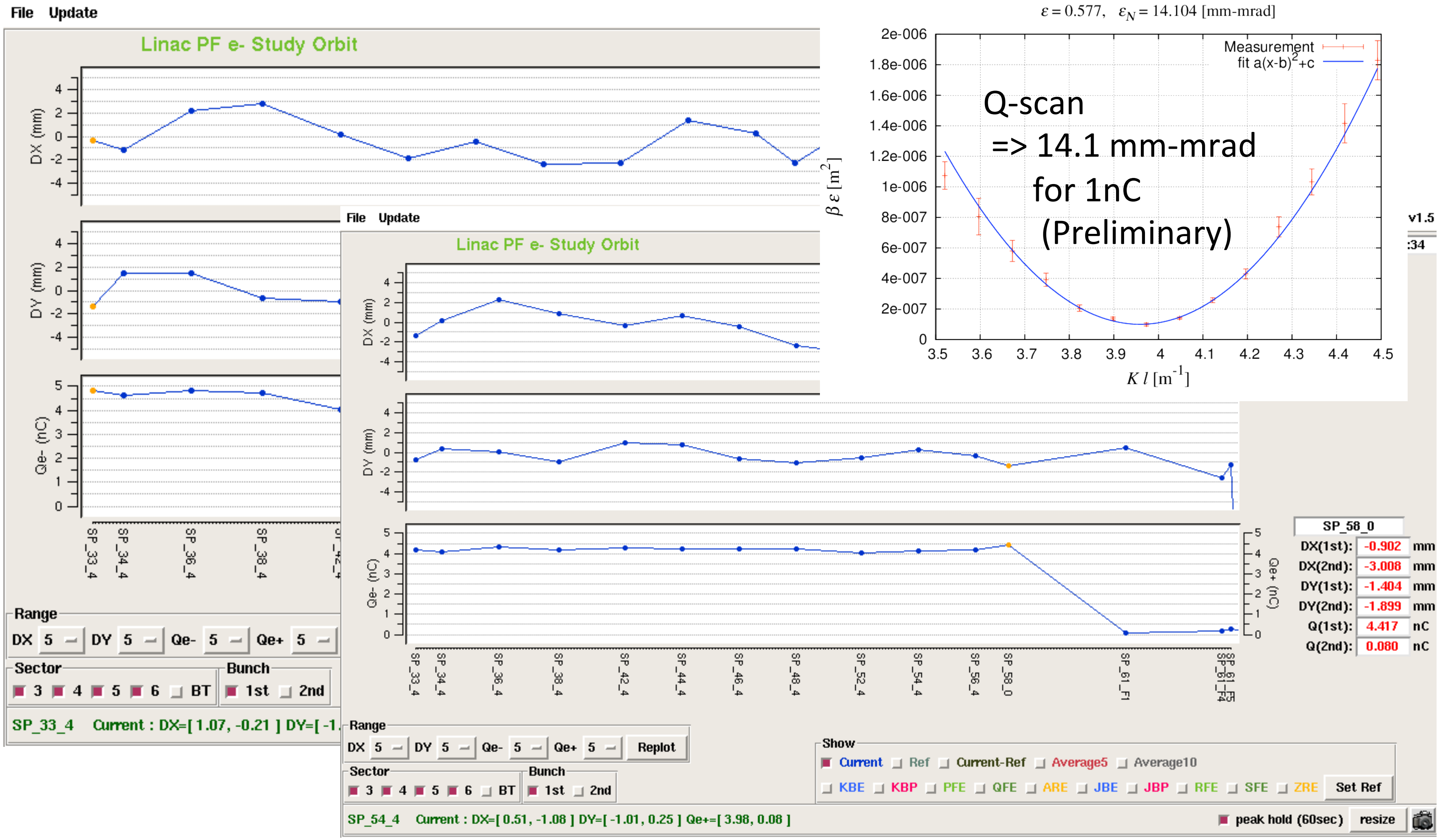




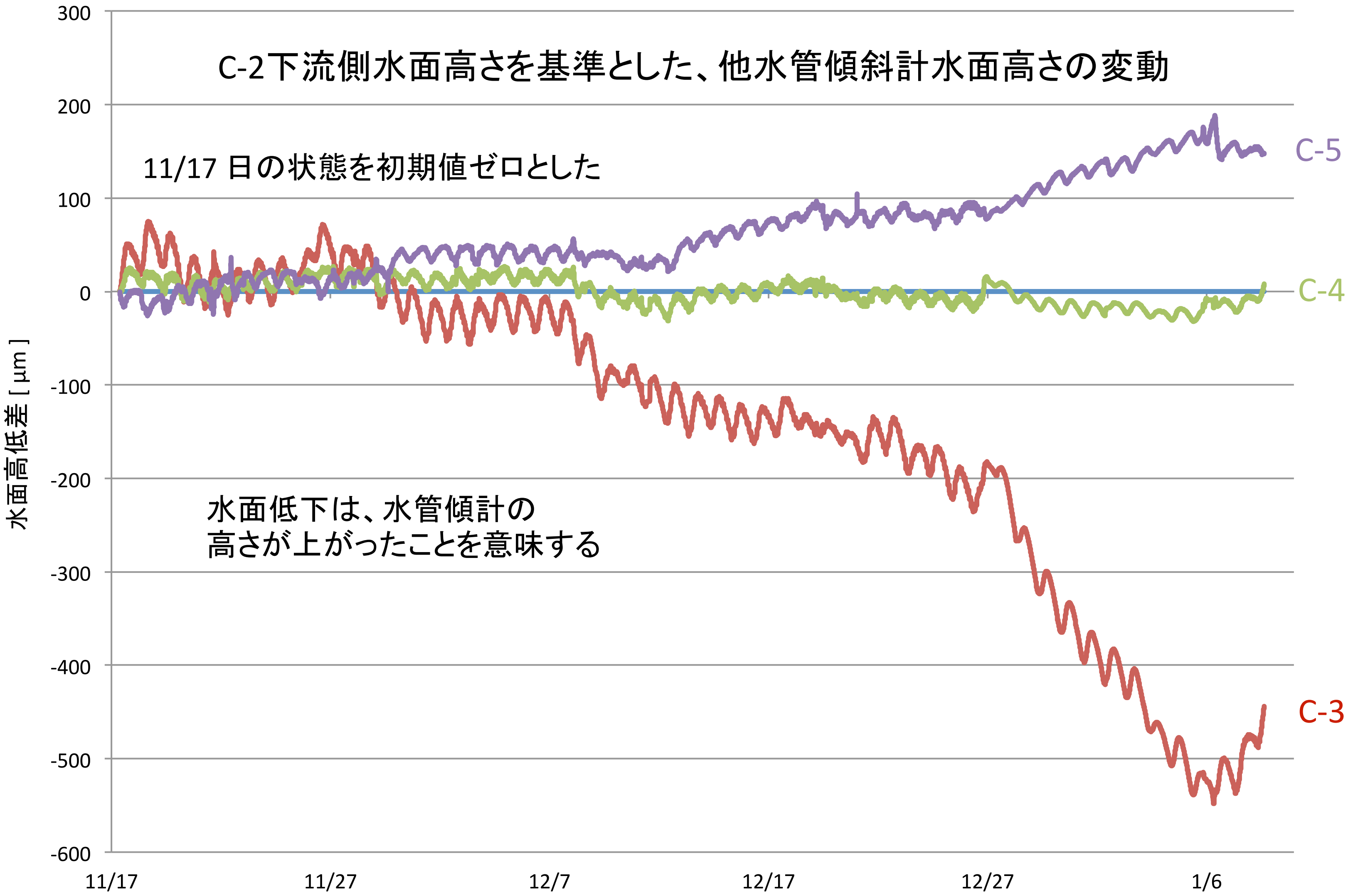
30 ps (10 mm)

5nC was achieved !

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



計測結果


C-2下流側水面高さを基準とした、他水管傾斜計水面高さの変動
11/17 日の状態を初期値ゼロとした
水面低下は、水管傾計の
高さが上がったことを意味する
水面高低差 [μm]
300
200
100
0
-100
-200
-300
-400
-500
-600
11/17
11/27
12/7
12/17
12/27
1/6
C-5
C-4
C-3

Beam diagnostic station