R&D status for gamma-ray and X-ray generation based on Compton scattering at KEK

Junji Urakawa (KEK, Japan) at Sapphire day, 2013.2.19

Under development of Quantum Beam Technology Program(QBTP) supported by MEXT
from 2008.9 to 2013.3 (5 years project) + 5 years extension?

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4. Compact 2D four mirror optical Cavity to measure the beam profile quickly as laser wire
5. Mirror development
6. New plans and schedule

1. Introduction

Four projects are going to develop 4-mirror optical cavity system for accumulating the energy of laser pulse.

a). 3D four mirror cavity for laser Compton scattering to generate polarized gamma-ray (Ryuta Tanaka will give a talk about this. So, I skip this part.)

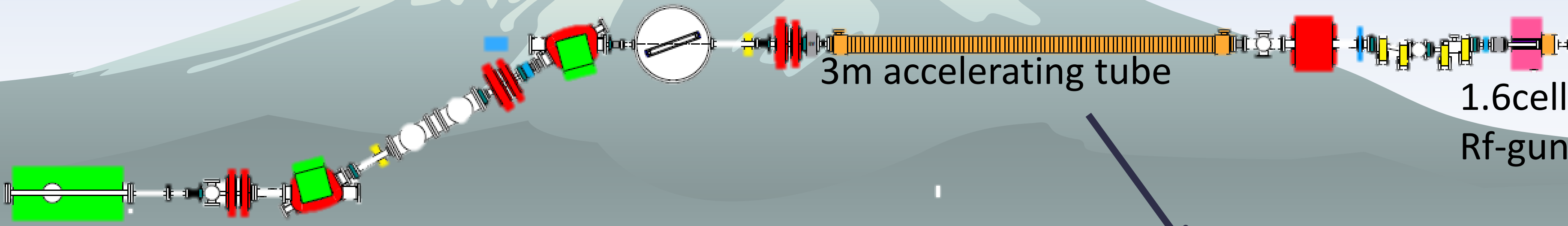
b). 2D four mirror optical cavity to generate X-ray. LUCX project

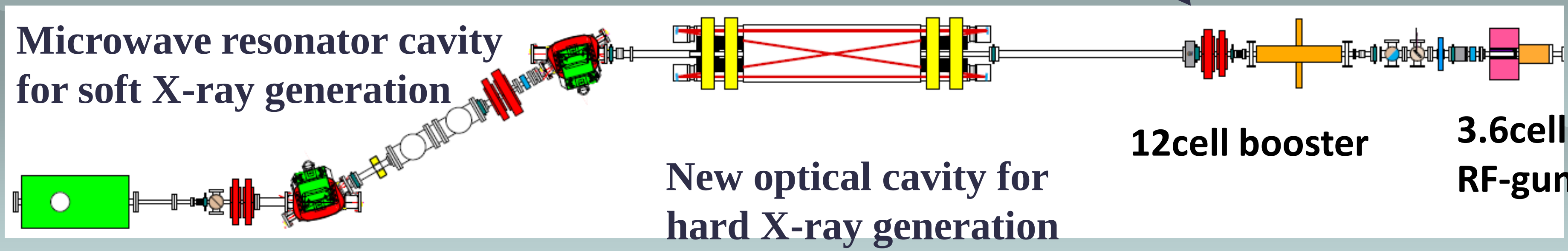
c). 2D four mirror cavity to generate X-ray with two cylindrical lenses

d). Compact 2D four mirror optical cavity for fast laser wire scanner to measure beam profile

b). Recent plan for LUCX project

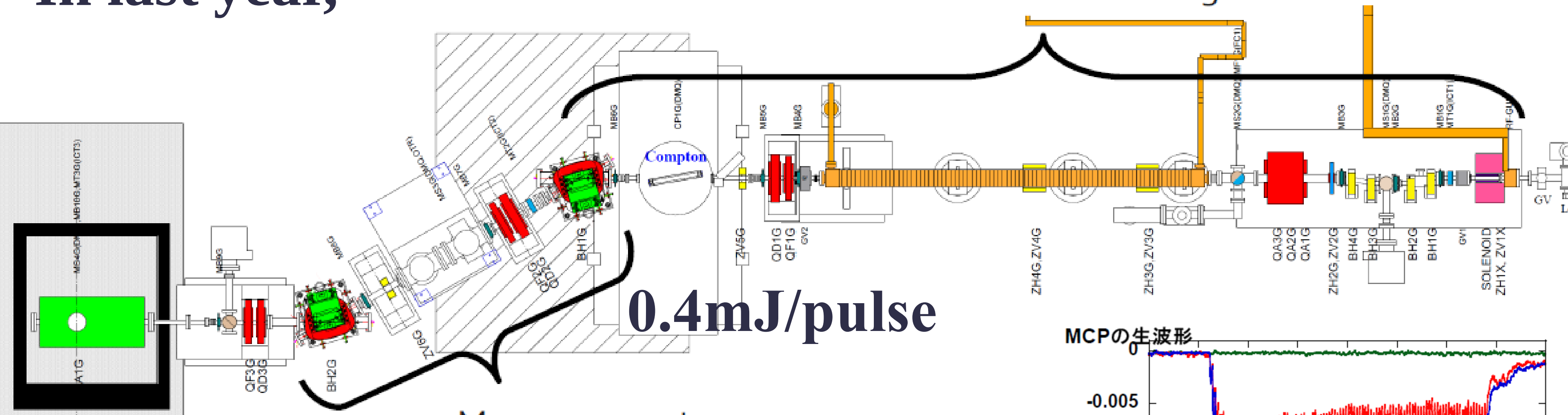
- To downsize the accelerator, we have installed a 3.6cell rf-gun and a 12cell booster.
  - 3.6cell rf-gun
    - Beam test has been started from Jan 2012.
  - 12cell booster
    - This booster was installed in last June.





In last year,

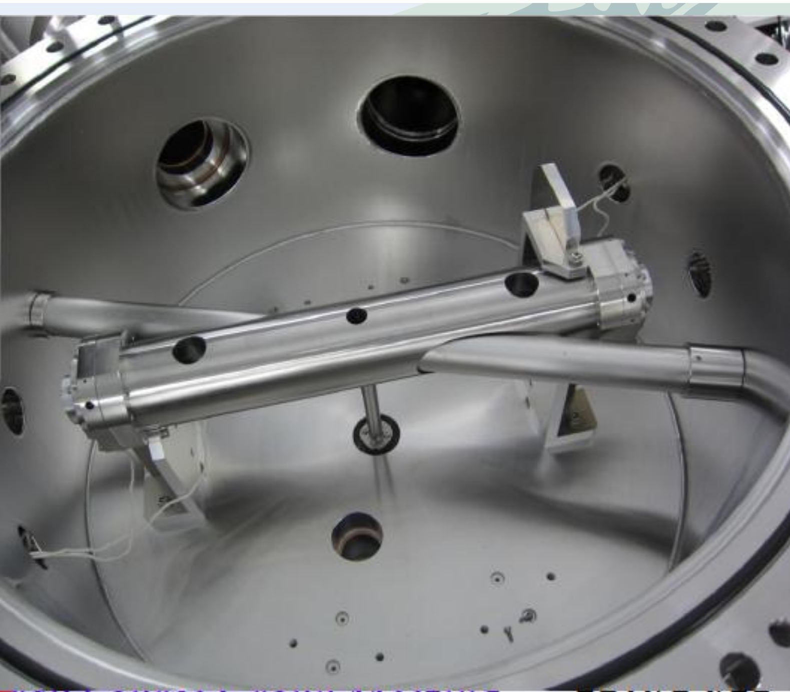
Measurement & tuning



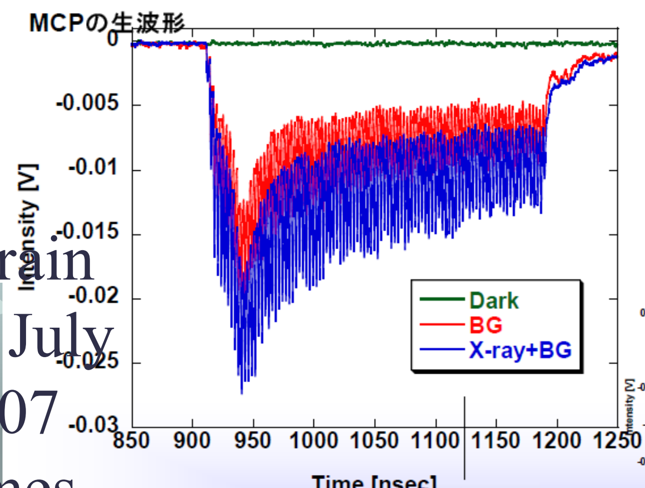
0.4mJ/pulse

Measurement
&
tuning if possible

357MHz mode-locked laser

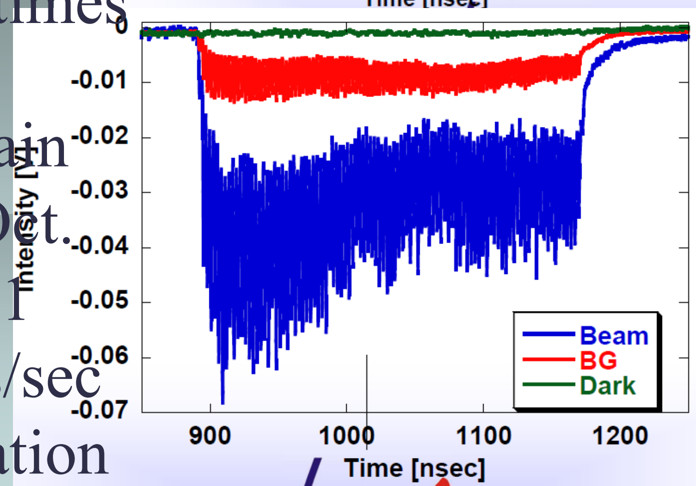


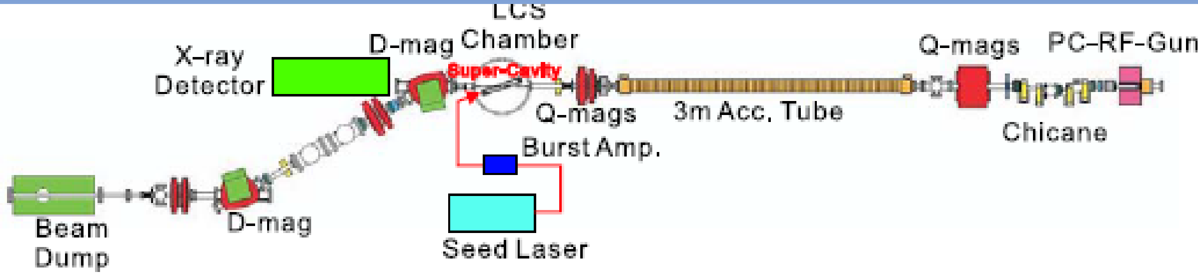
X-ray yield
334 photons/train
at detector on July
2007

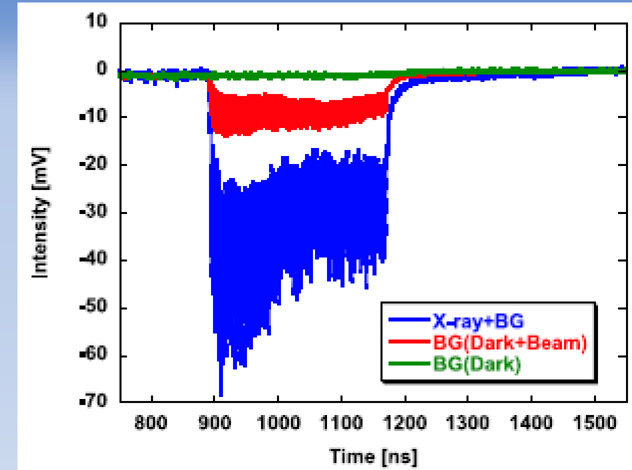


2〜3 times

X-ray yield
1447photons/train
at detector on Oct.
2011
2.1×10^5photons/sec
at 12.5Hz operation

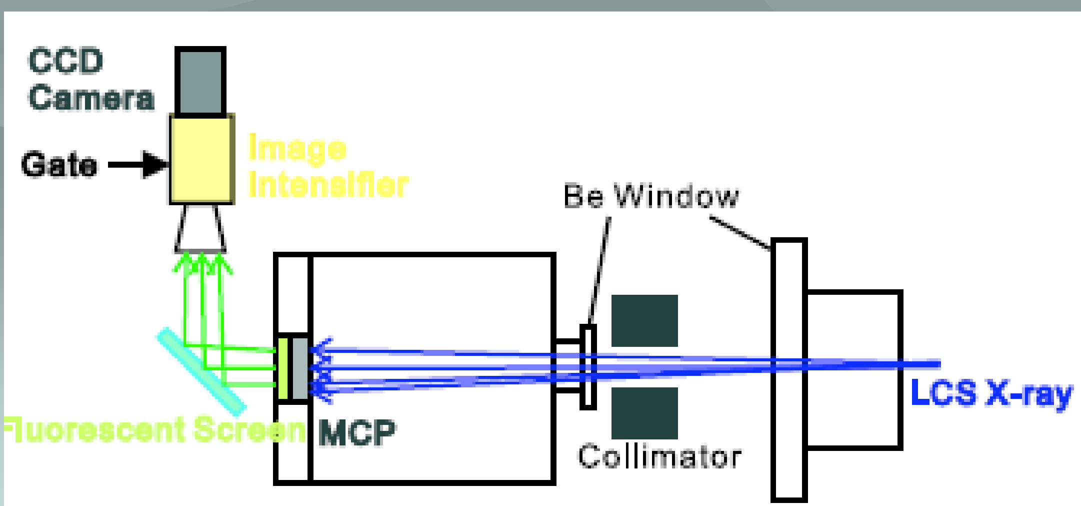


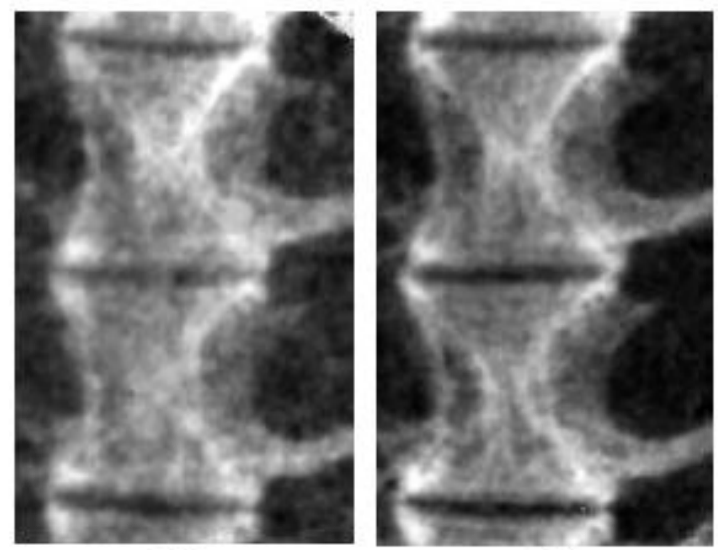




Electron beam		Laser pulse	
Quantity	Value	Quantity	Value
Energy	30 MeV	Wavelength	1064 nm
Charge	0.4 nC/bunch	Pulse energy	400 μJ
Number of bunches	100/train	Cavity finesse	2650
Bunch spacing	2.8 ns	Pulse spacing	2.8 ns
Beam size (rms)	200/53 μm (H/V)	Spot size (rms)	30.3 μm
Bunch length	10 ps (FWHM)	Pulse duration	7 ps (FWHM)
Repetition rate	1.56-12.5 Hz	Colliding angle	20 deg

The mirror of two mirror cavity had the surface damage around 2 to 6mJ/pulse.

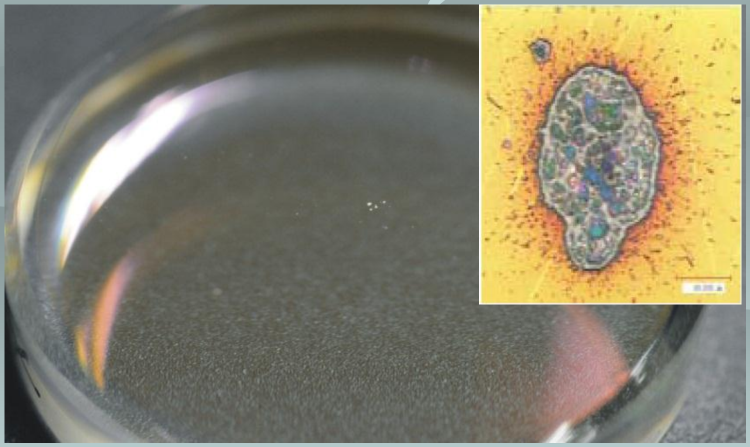




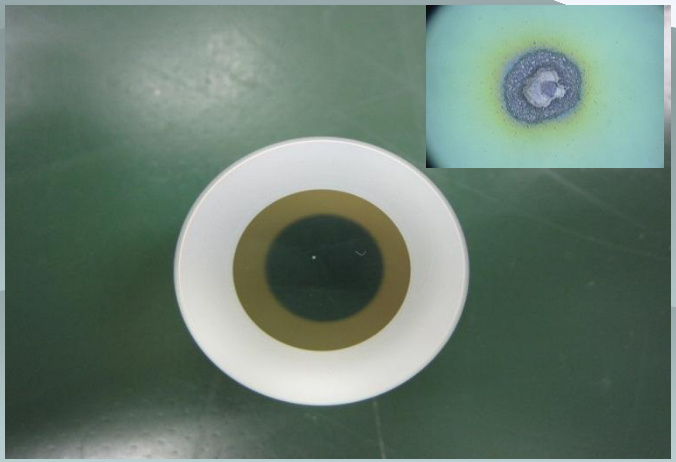
(A) (B)

We destroyed the mirror coating two times. First occurred when the waist size was ~100μm with burst amplification and 42cm two mirror cavity. Second occurred when the waist size was 30μm with the burst amplification and the 42cm two mirror cavity. Now we are using 4 mirror cavity with smaller waist size at IP. From our experience, we have to reduce the waist size to increase the laser size on the mirror and need precise power control for the burst amplification. I guess about storage laser pulse energy from 2mJ to 4mJ destroyed the mirror coating with the waist size of 30μm. Also, we found the damaged position was not at the center.

2008



2011



Development for stronger mirror : I want to start the collaboration with NAO (Gravitational Wave Observatory group), Tokyo University (Ohtsu Lab.), Japanese private Co., LMA and LAL hopefully.

1. Enlarge mirror size : we started the change from one inch to two inch mirror.
2. LMA is preparing mirrors with reflectivity of 99.999% and loss (absorption and scattering) less than 6ppm.
3. We ordered many substrates with micro-roughness less than 1 A to approach low loss mirror.
4. We understood the necessity of good clean room to handle the high reflective mirrors in the case of the mirror which has high reflectivity more than 99.9%.
5. We have to develop how to make the stronger surface which has higher damage threshold.

Measurement of surface roughness for super-polish. Reduce the loss ,which means low absorption and scattering.

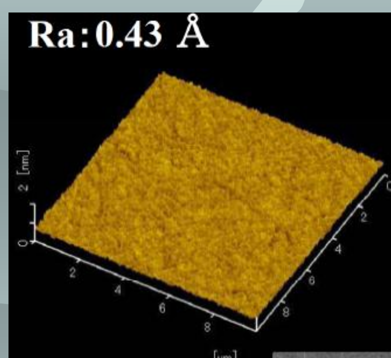
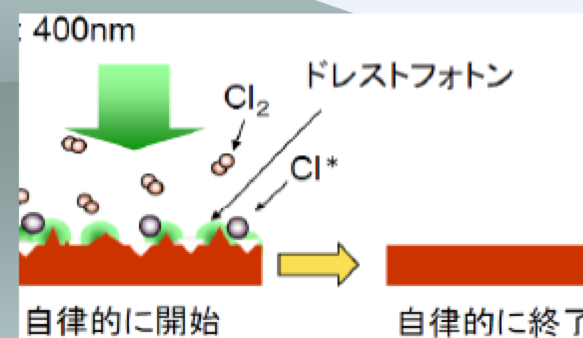
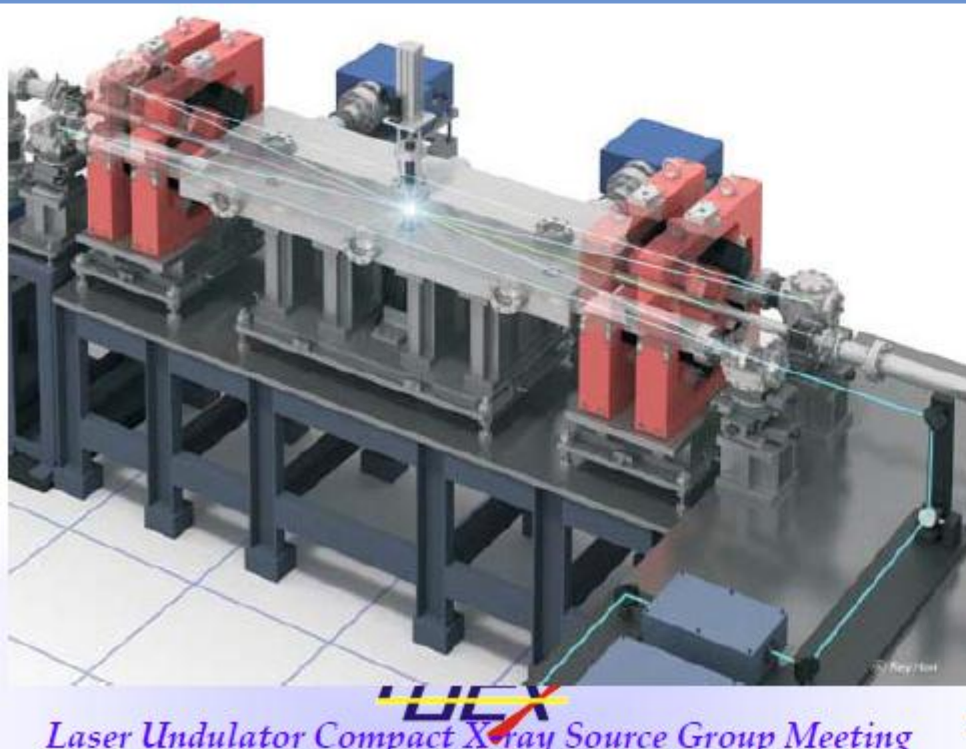
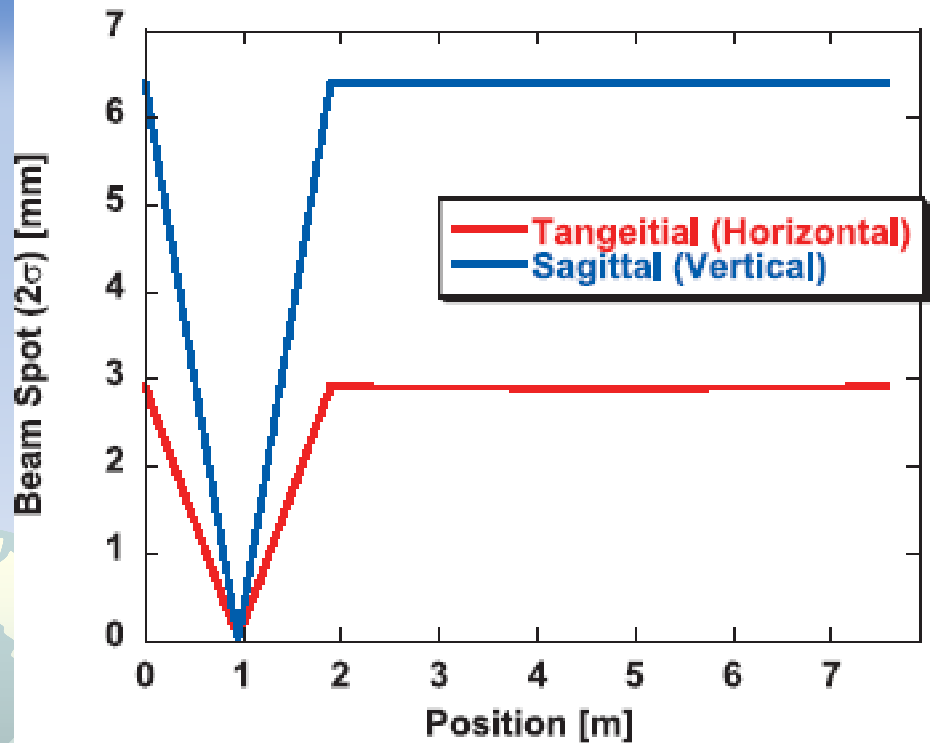


Photo-chemical etching occurred by dressed photon.

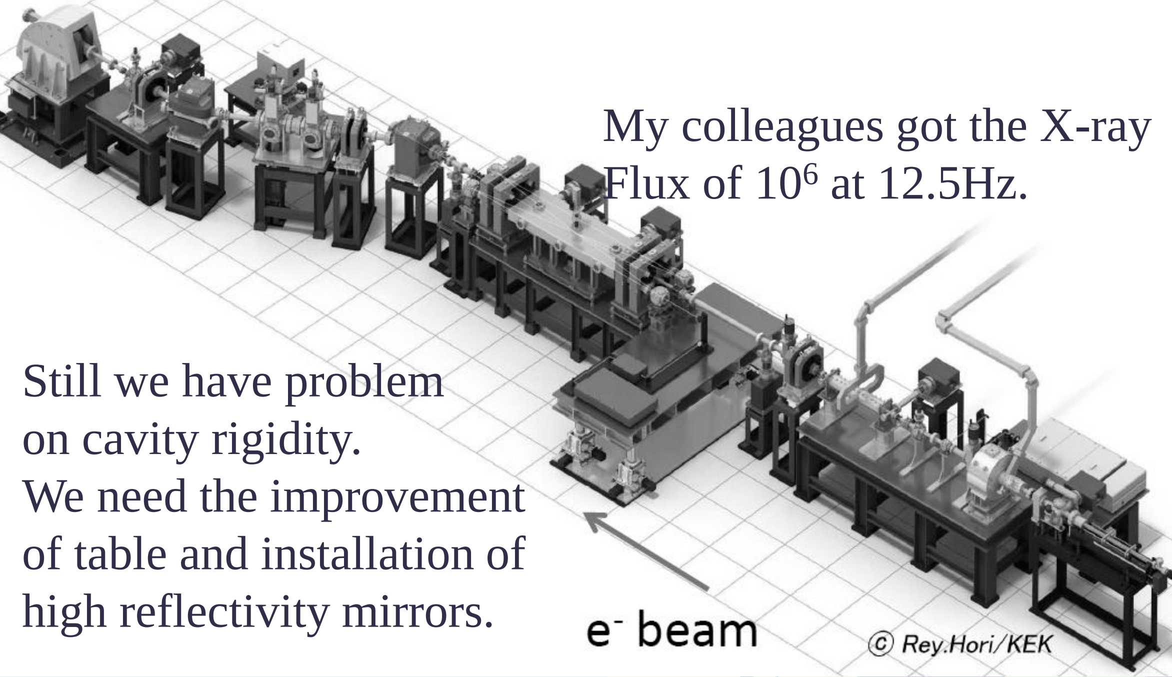


We learnt a lot of things which humidity in Japan is high and makes OH contamination to increase the mirror absorption. 50% humidity is suitable to handle the mirrors, especially high quality mirrors. We confirmed this problem. Hear next talk.





One turn length : 7.56m, horizontal laser waist size : 109μm in 2σ,
Crossing angle : **7.5 degrees**, vertical laser waist size : **50μm in 2σ,**
Horizontal laser size on laser injection plane mirror : 2.92mm,
Vertical laser size on laser injection plane mirror : 6.4mm
Laser pulse energy in cavity : 8mJ, distance between concave mirrors : 1.89m, **7.56m means this cavity has 9 laser pulses.**
Use two inch mirrors and increase the threshold damage energy.
Completed this device in this September last year and start the generation of X-ray from mid. of Feb.. We will confirm the performance soon.

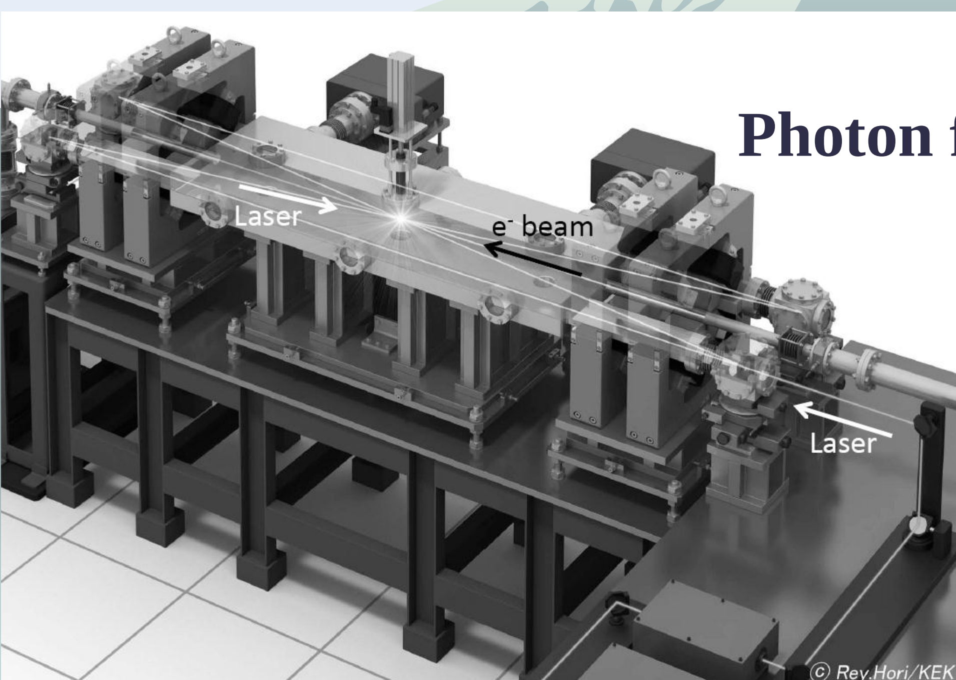


My colleagues got the X-ray Flux of 10^6 at 12.5Hz.

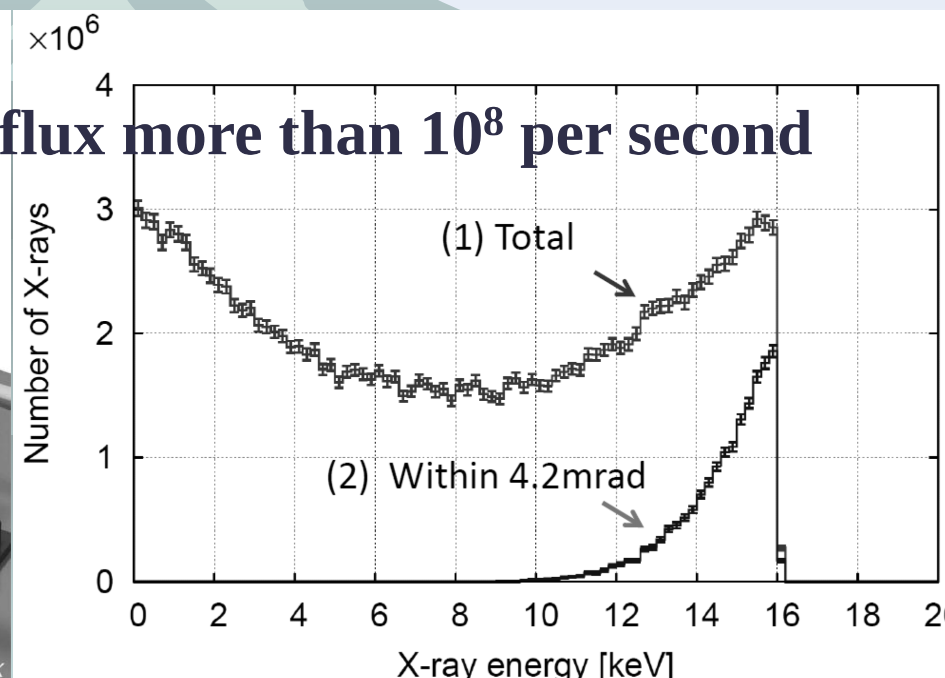
Still we have problem on cavity rigidity.
We need the improvement of table and installation of high reflectivity mirrors.

Energy	30MeV
Intensity	0.4nC/bunch
Number of bunch	1000
Beam size at the collision point (1σ)	33μm ×33μm
Bunch length	10ps
Bunch spacing	2.8ns

Energy	1.17eV(1064nm)
Intensity	8mJ/pulse
Waist size(1σ)	55μm ×25μm
Pulse length	7ps



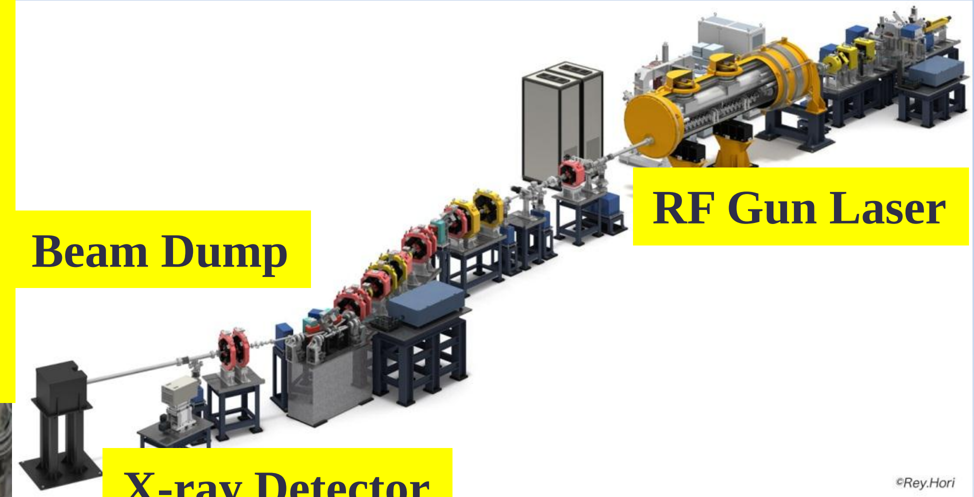
Photon flux more than 10^8 per second

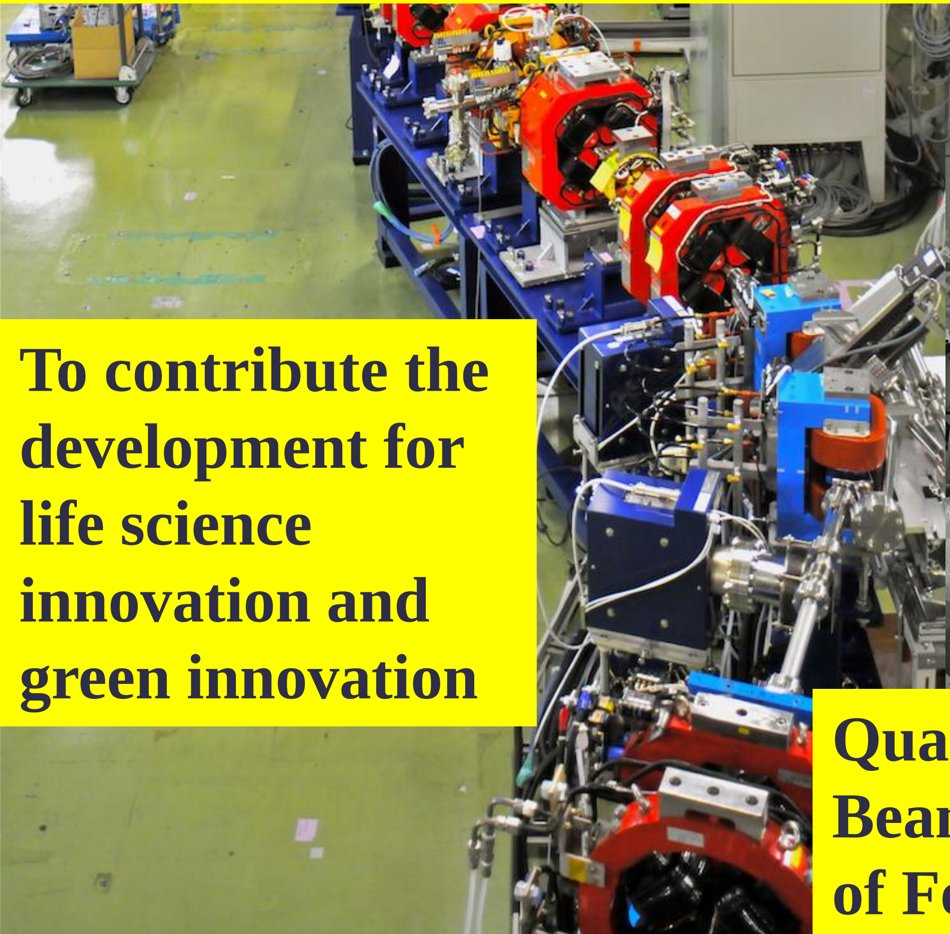


Quantum Beam Technology Program (QBTP)

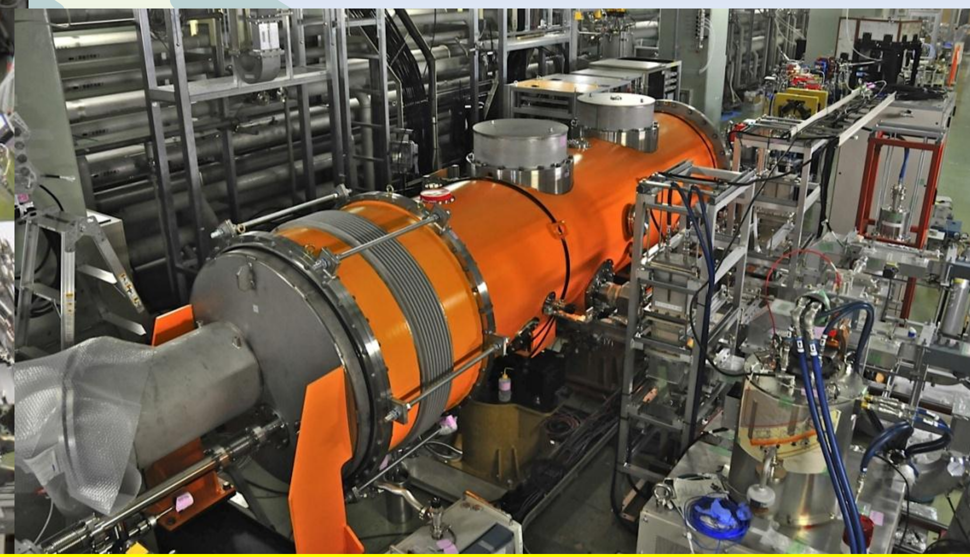
Development for Next Generation Compact High Brightness X-ray Source using Super Conducting RF Acceleration Technique

View of QBTP from Beam Dump



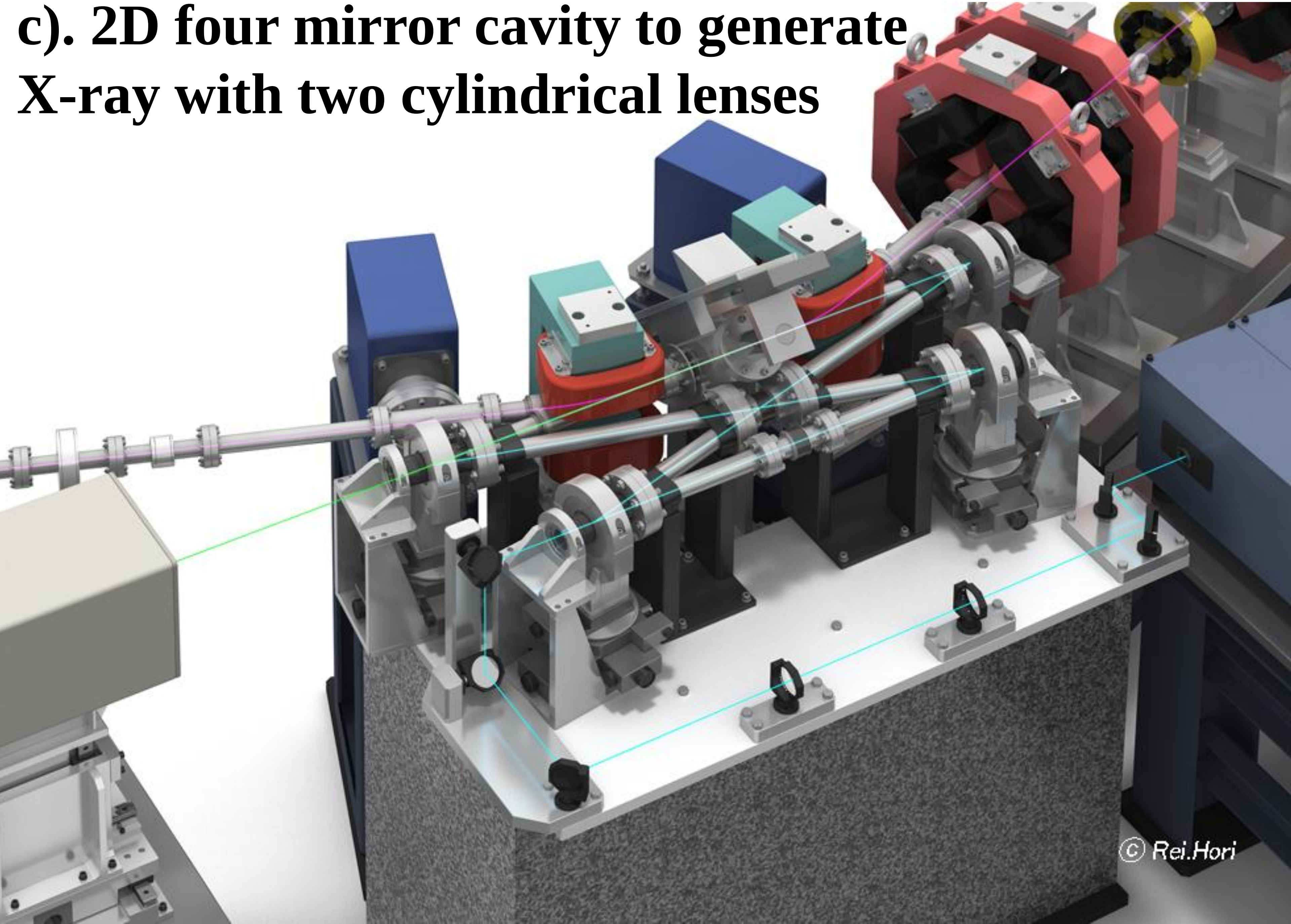


To contribute the development for life science innovation and green innovation



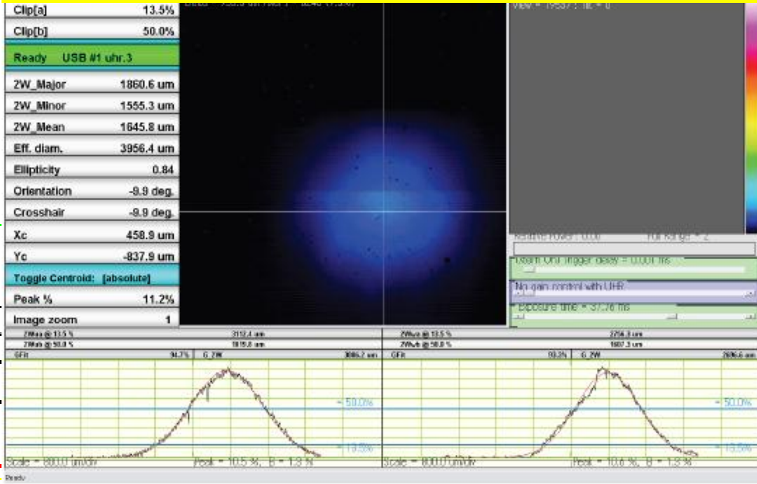
Quantum Beam Technology Program: Beam commissioning started from mid. of February 2012.

c). 2D four mirror cavity to generate X-ray with two cylindrical lenses

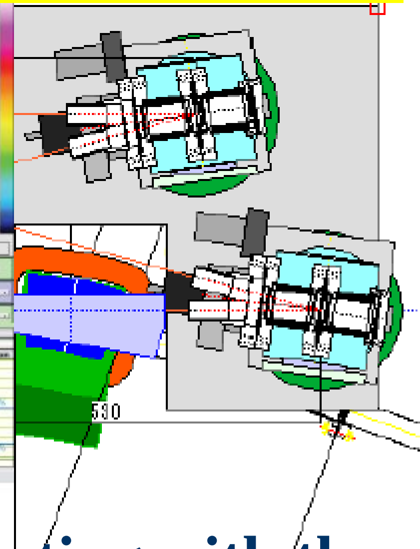


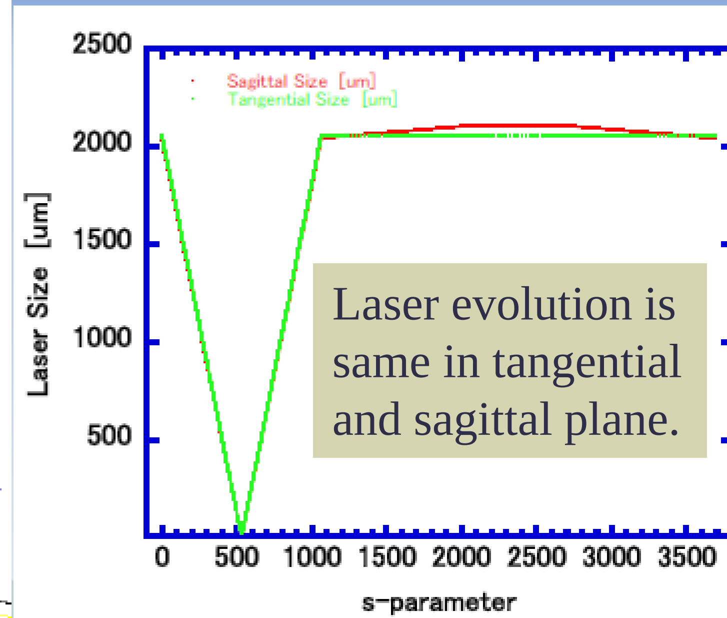
Latest Version Cavity Design

profile of Transmitted laser from cylindrical mirrors. We confirmed the effect of the cylindrical mirrors.



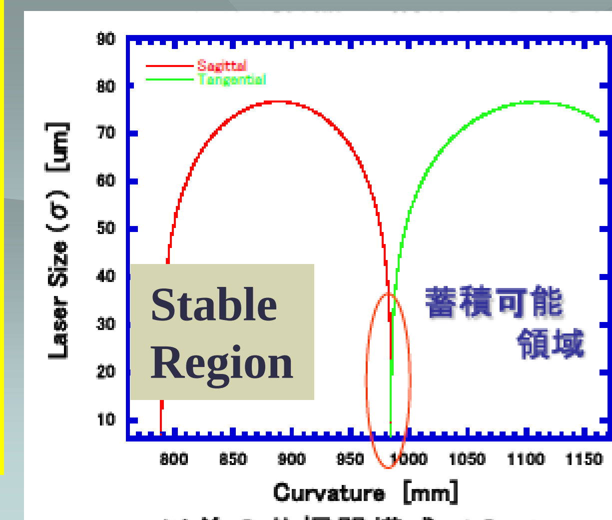
$2\omega_h$ = 3112.4um / $2\omega_v$ = 2756.3m

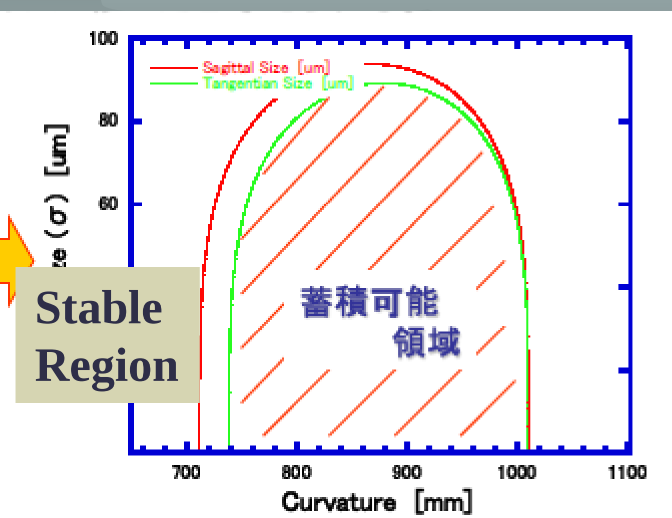




Two laser pulses are circulating with the spacing of 6.15ns in a ring optical cavity.

Change to 2D 4-mirror optical cavity with two cylindrical lenses instead of two plane mirrors.



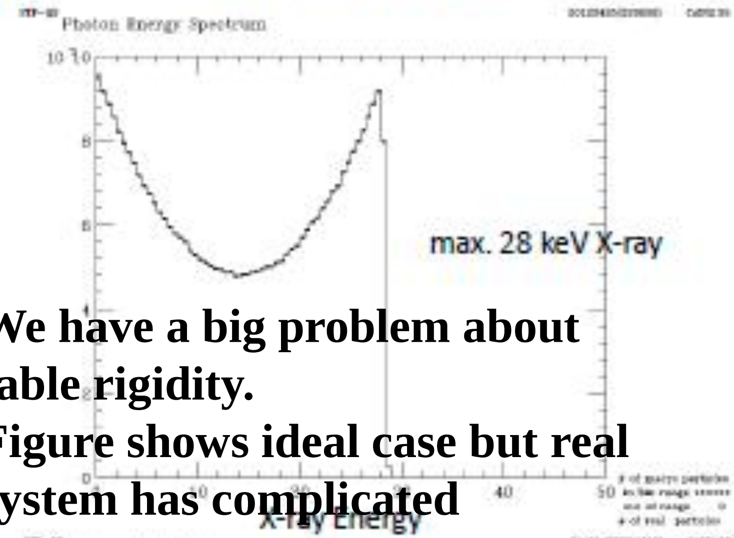


Plan of X-ray generation by Inverse-compton scattering

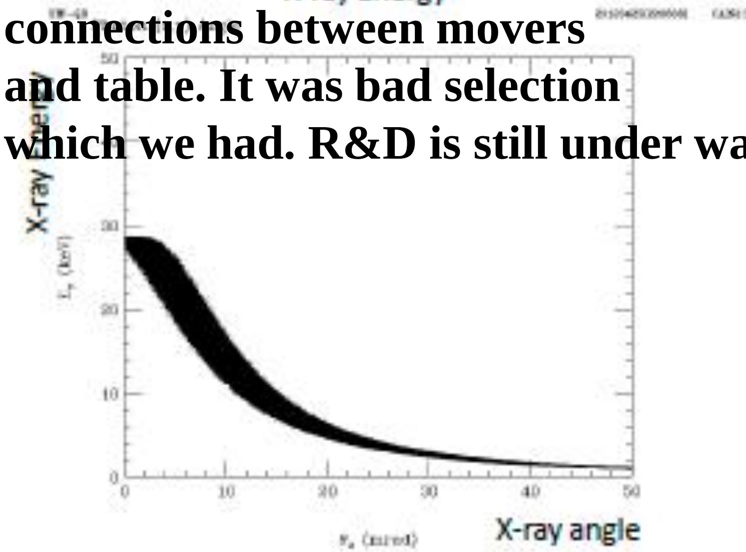
4-mirror laser accumulation, head-on with e-beam

	Electron	Laser
Energy	40MeV	1.17eV (λ=1064nm)
Energy spread	0.1% (rms)	
Beam size(rms)	10μm	10μm
Pulse width(FWHM)	12ps	12ps
Intensity	61.5 pC/bunch	50mJ/pulse
Number of bunches	162500	----
Emittance	0.5π mm mrad	
Collision angle	0deg (Head on)	
Rep. Rate	5Hz	

40MeV, head-on collision

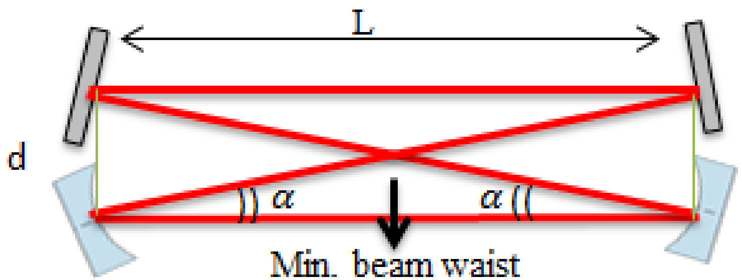


We have a big problem about table rigidity.
Figure shows ideal case but real system has complicated connections between movers and table. It was bad selection which we had. R&D is still under way.

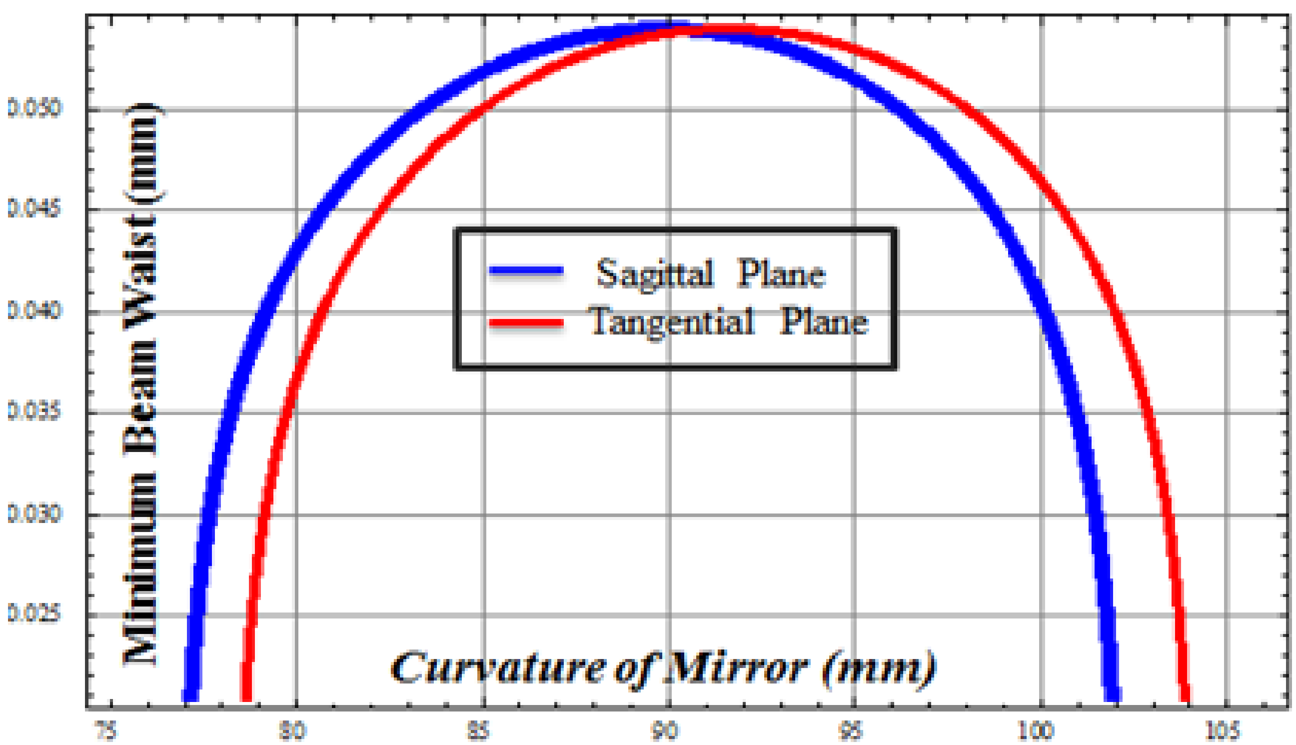


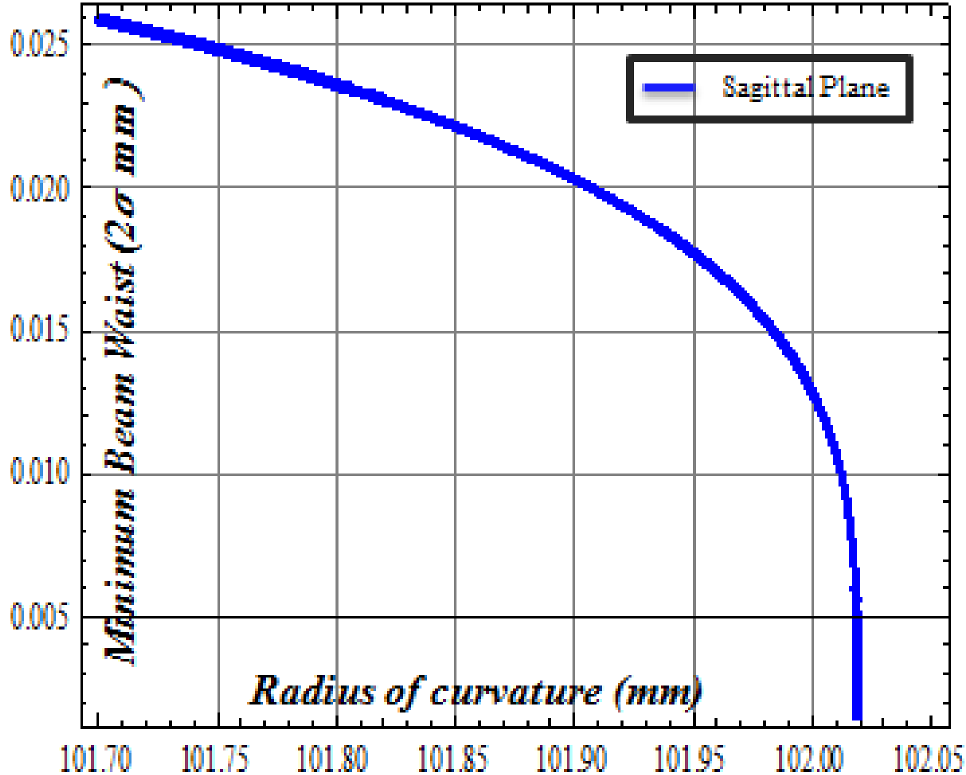
target: 1.3×10^{10} photons/sec/1%bw

d). Compact 2D four mirror optical cavity to measure the beam profile quickly as laser wire.

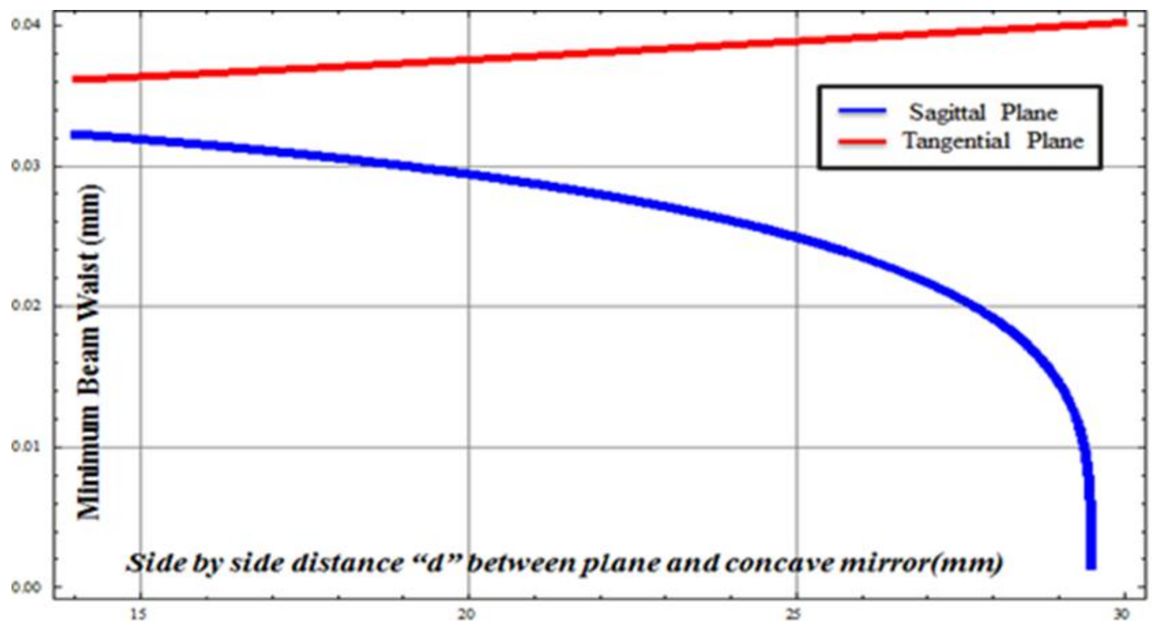


Length L (mm)	412	206	103
Distance d (mm)	116	58	29
Curvature ρ (mm)	408	204	102
Total path length (L_{Cav}) (mm)	1680	840	420
Aspect ratio (α) (radians)	0.2745	0.2745	0.2745
Min. beam waist in 2σ, (ω_s, ω_T)	(29.3, 80)μm	(21, 57)μm	(14, 40)μm

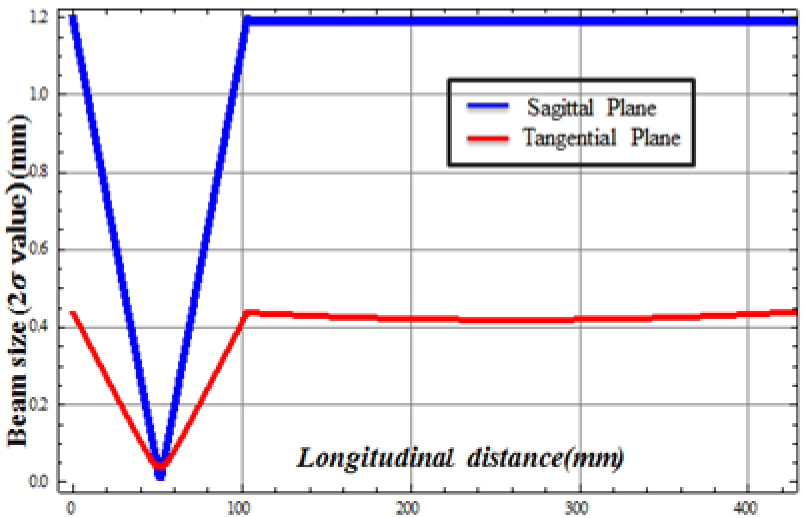




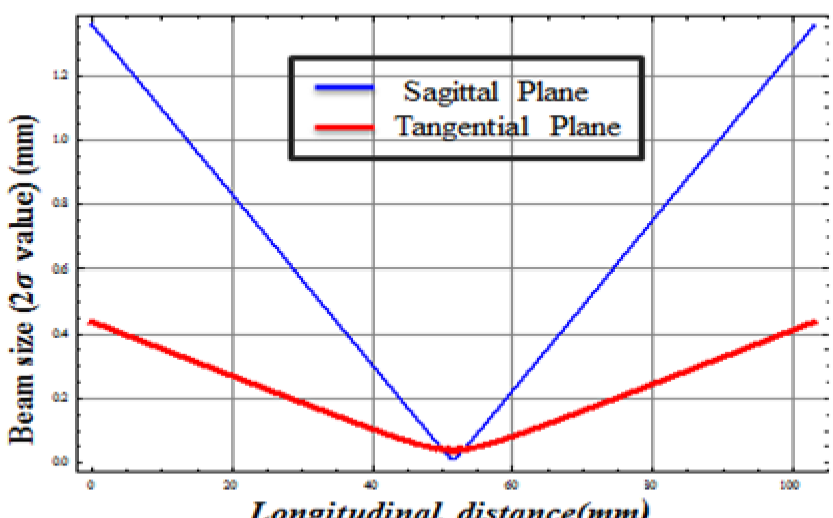
Sagittal Plane
Minimum Beam Waist (2σ mm)
Radius of curvature (mm)
0.025
0.020
0.015
0.010
0.005
101.70
101.75
101.80
101.85
101.90
101.95
102.00
102.05



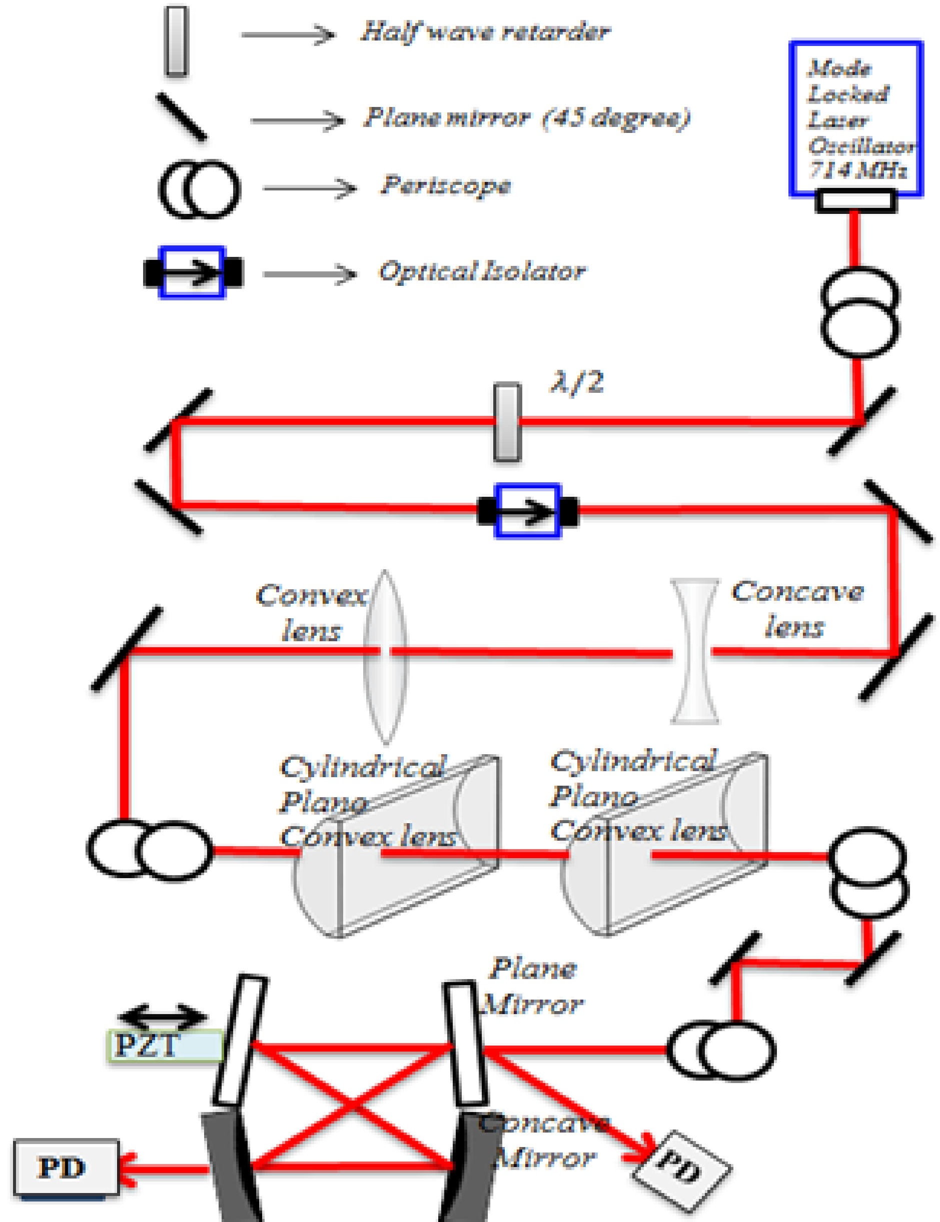
Sagittal Plane
Tangential Plane
Minimum Beam Waist (mm)
Side by side distance "d" between plane and concave mirror(mm)
0.04
0.03
0.02
0.01
0.00
15
20
25
30



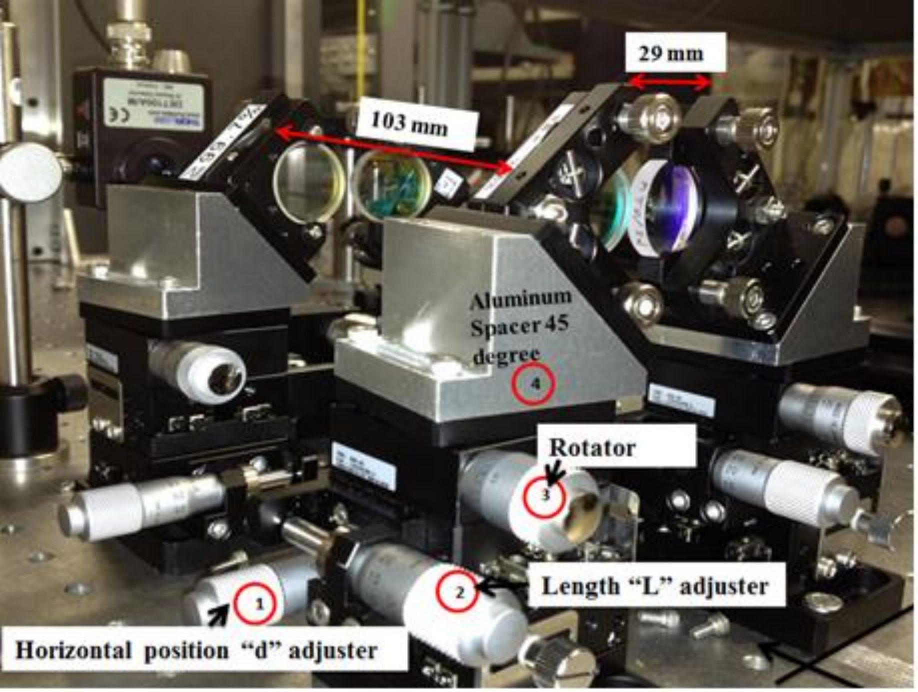
Sagittal Plane
Tangential Plane
Beam size (2σ value)(mm)
Longitudinal distance(mm)
0 100 200 300 400
0.0 0.2 0.4 0.6 0.8 1.0 1.2

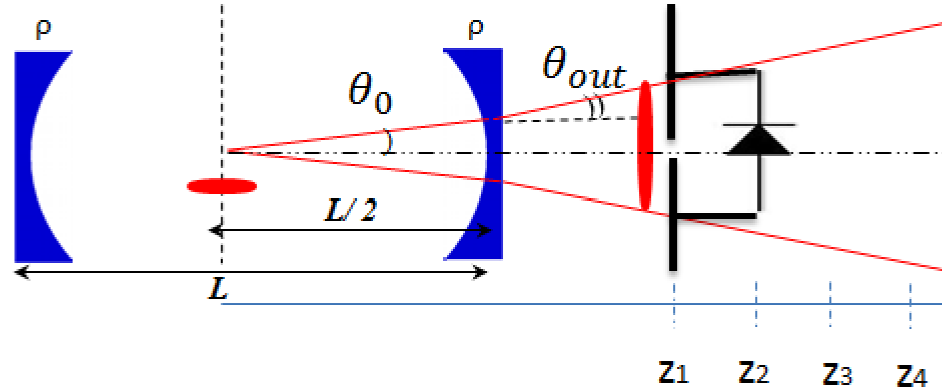


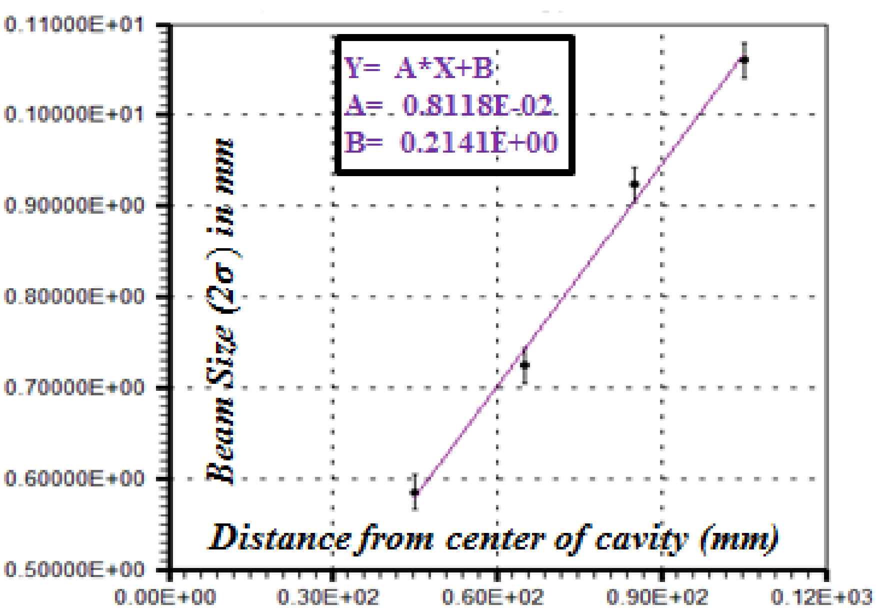
Sagittal Plane
Tangential Plane
Beam size (2σ value) (mm)
Longitudinal distance(mm)

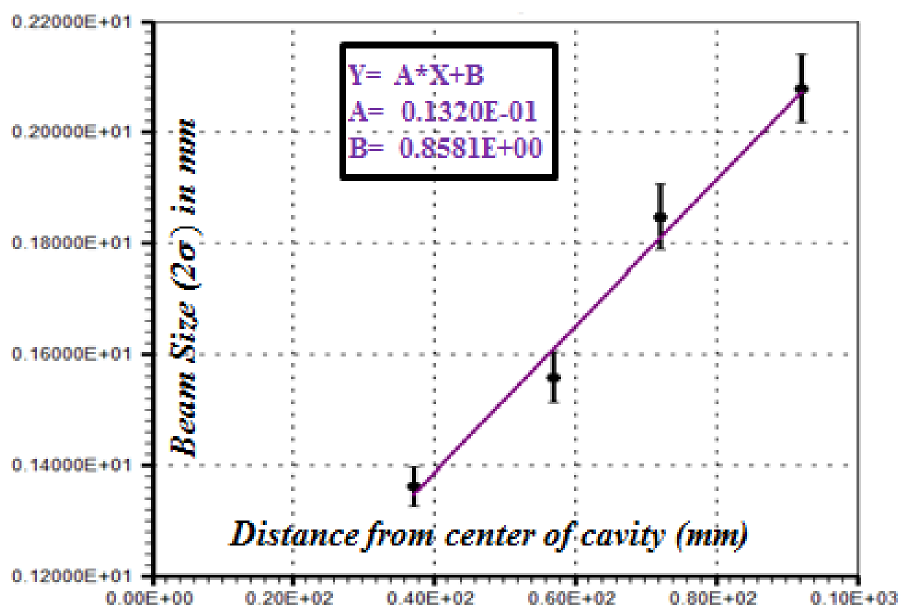


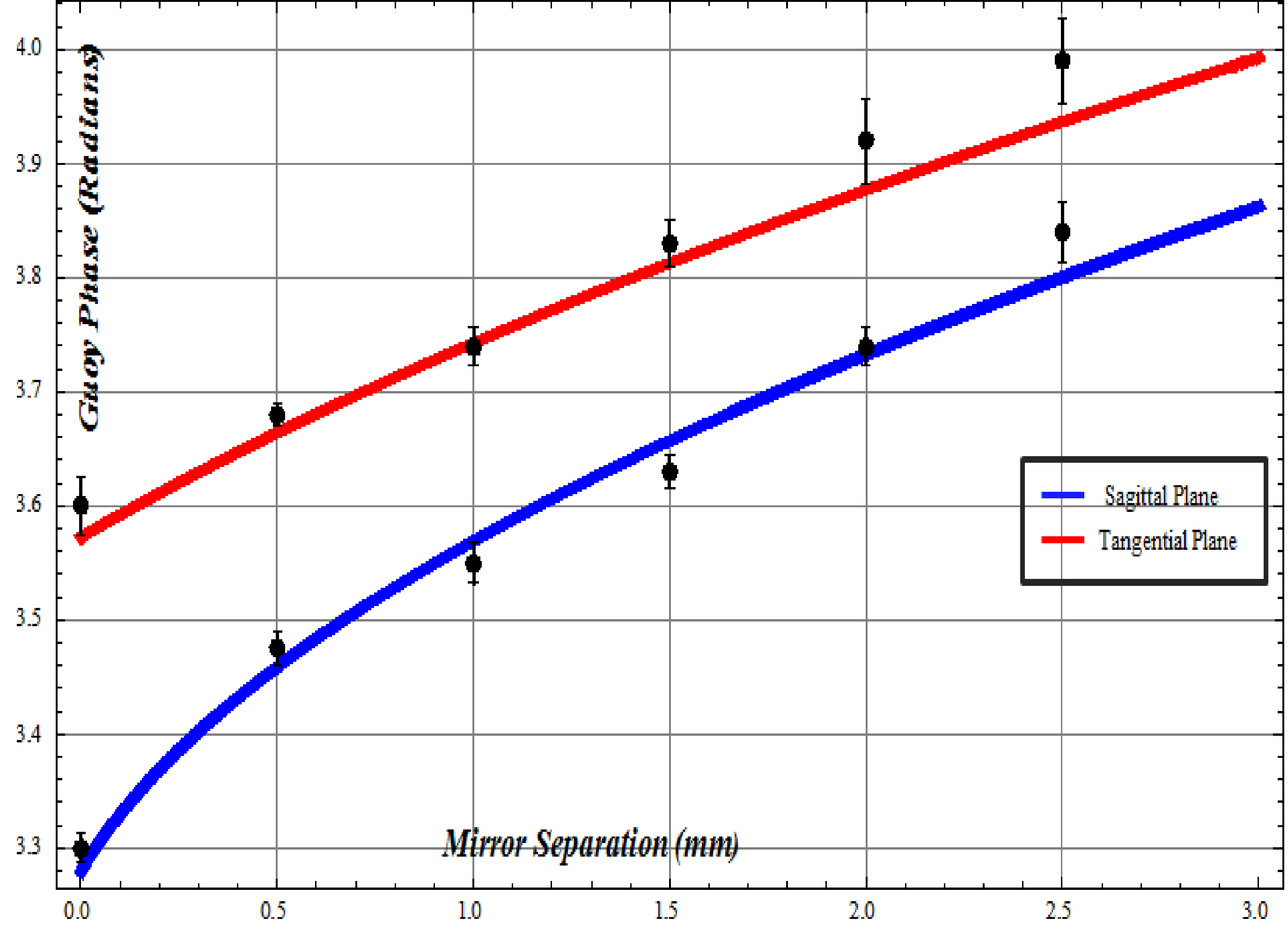
Half wave retarder
Plane mirror (45 degree)
Periscope
Optical Isolator
Mode Locked Laser Oscillator 714 MHz
λ/2
Convex lens
Concave lens
Cylindrical Plano Convex lens
Cylindrical Plano Convex lens
Plane Mirror
PZT
Concave Mirror
PD
PD


29 mm
103 mm
Aluminum Spacer 45 degree
Rotator
Length "L" adjuster
Horizontal position "d" adjuster
1
2
3
4


ρ
ρ
θ_{out}
θ_0
L/ 2
L
Z1
Z2
Z3
Z4

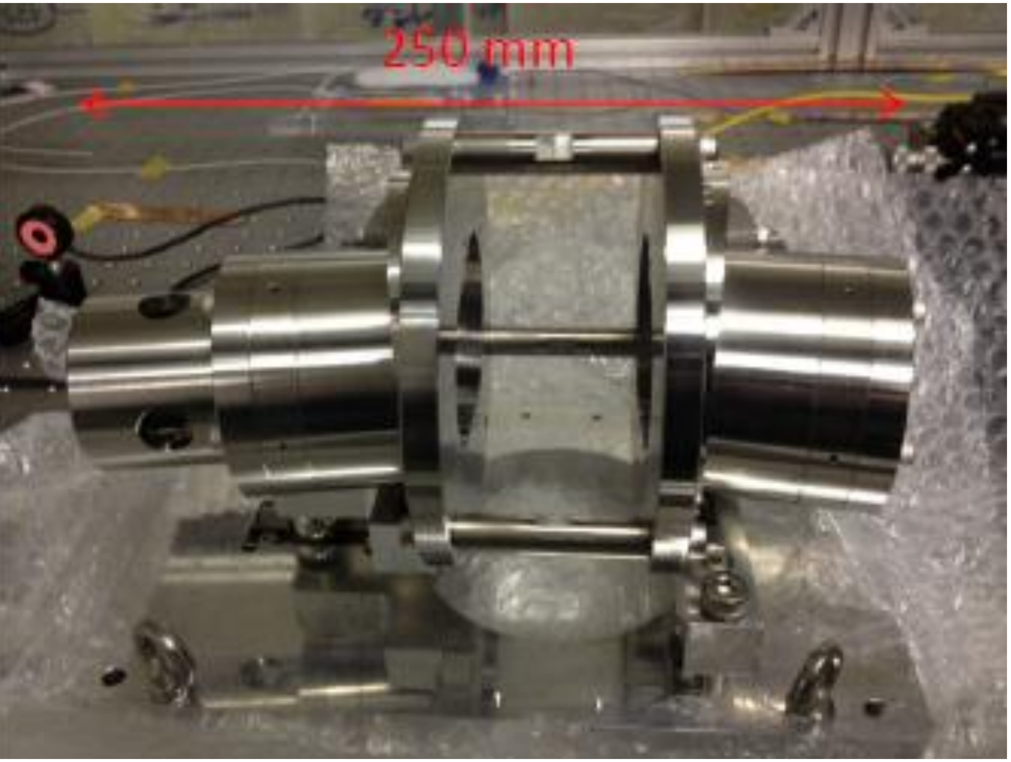

Y= A*X+B
A= 0.8118E-02
B= 0.2141E+00
Beam Size (2σ) in mm
Distance from center of cavity (mm)
0.11000E+01
0.10000E+01
0.90000E+00
0.80000E+00
0.70000E+00
0.60000E+00
0.50000E+00
0.00E+00
0.30E+02
0.60E+02
0.90E+02
0.12E+03

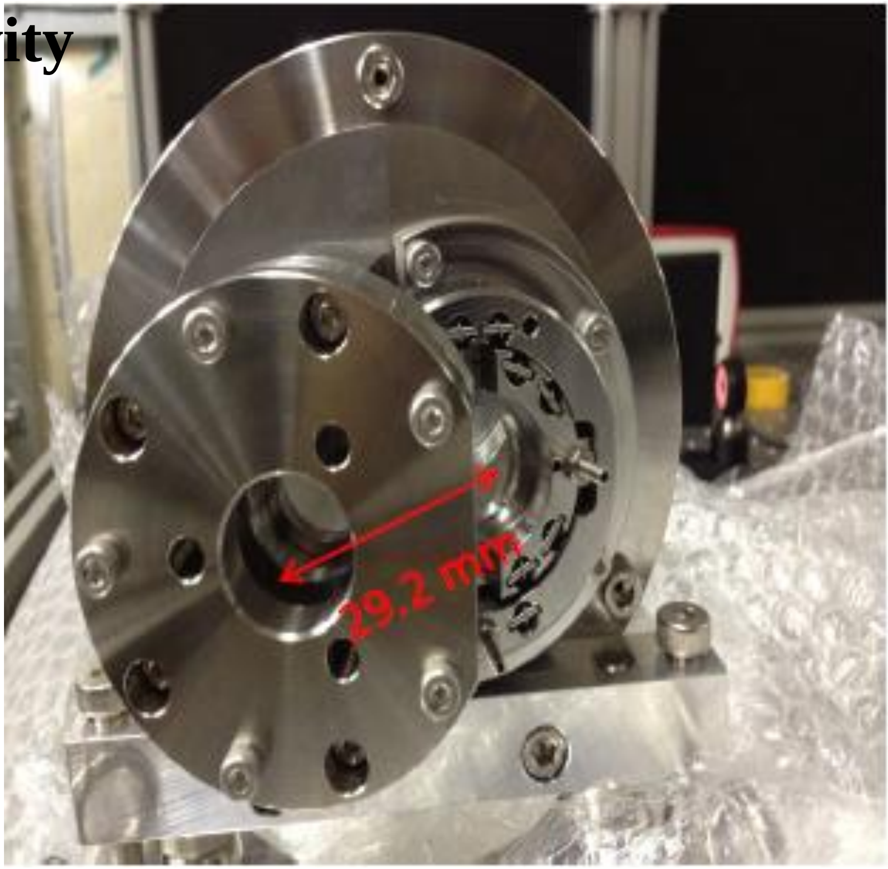

Y= A*X+B
A= 0.1320E-01
B= 0.8581E+00
Beam Size (2σ) in mm
Distance from center of cavity (mm)
0.22000E+01
0.20000E+01
0.18000E+01
0.16000E+01
0.14000E+01
0.12000E+01
0.00E+00
0.20E+02
0.40E+02
0.60E+02
0.80E+02
0.10E+03



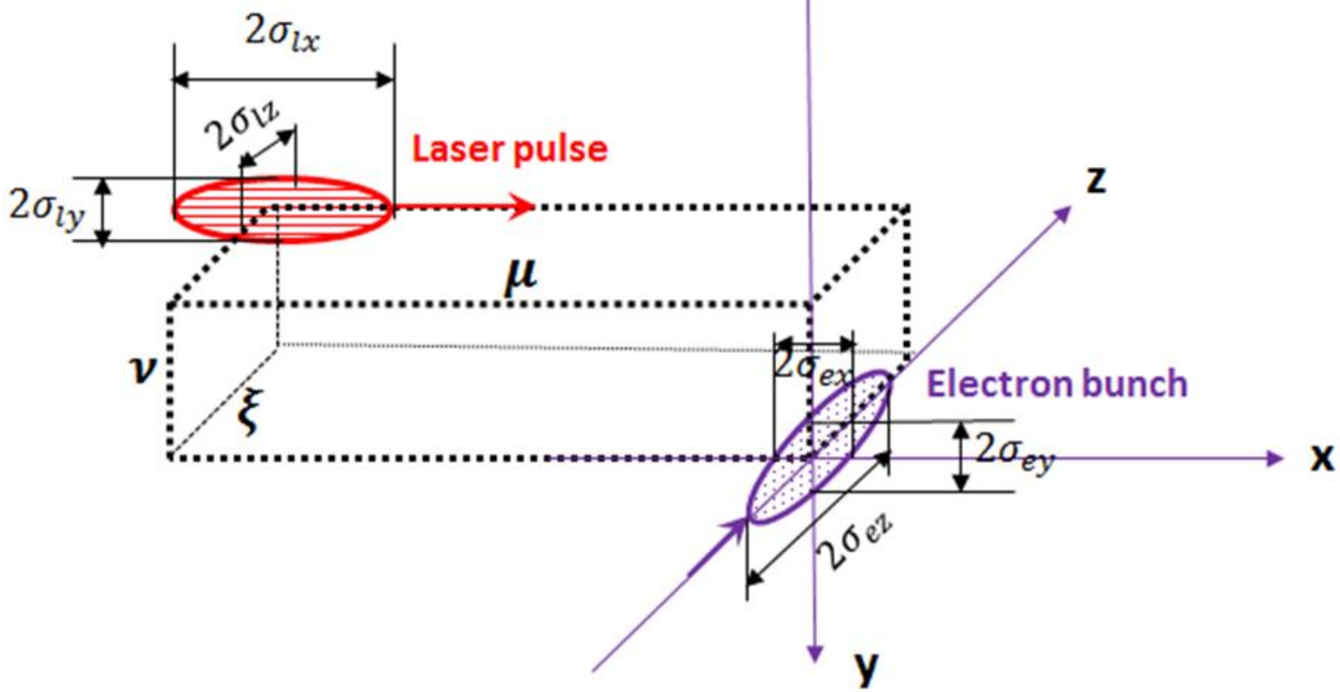
Method	Sagittal beam size (σ value)	Tangential beam size (σ value)
Divergence Method	$10.37 \pm 1.73\ \mu m$	$23.65 \pm 2.82\ \mu m$
Mode Difference Method	$13.74 \pm 1.81\ \mu m$	$21.82 \pm 3.63\ \mu m$

Compact fast scanning laser wire cavity

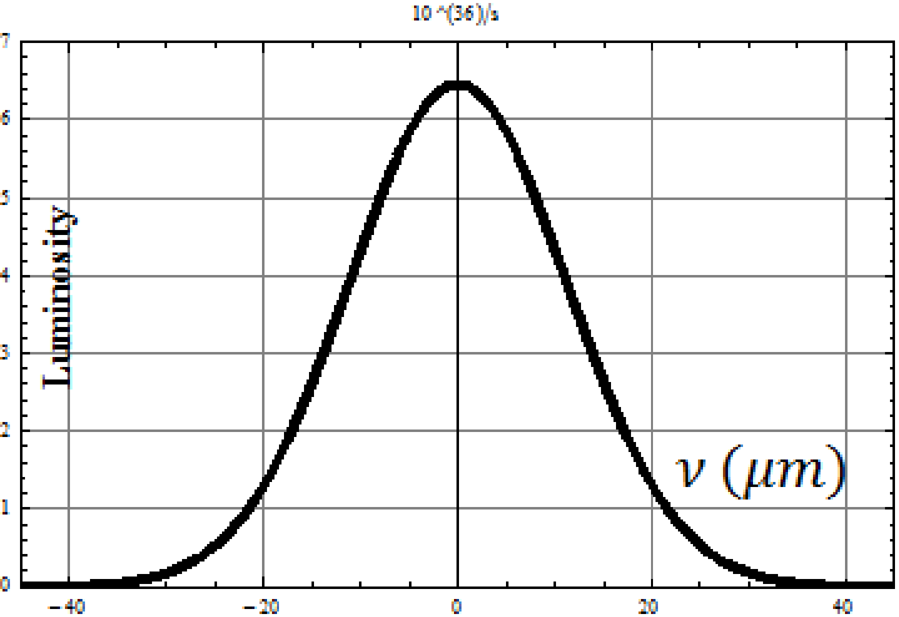


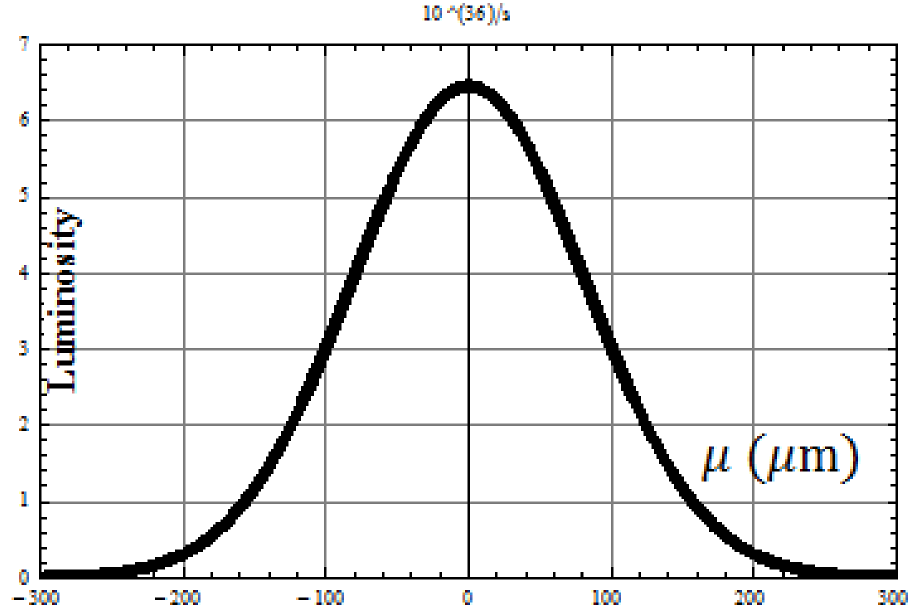


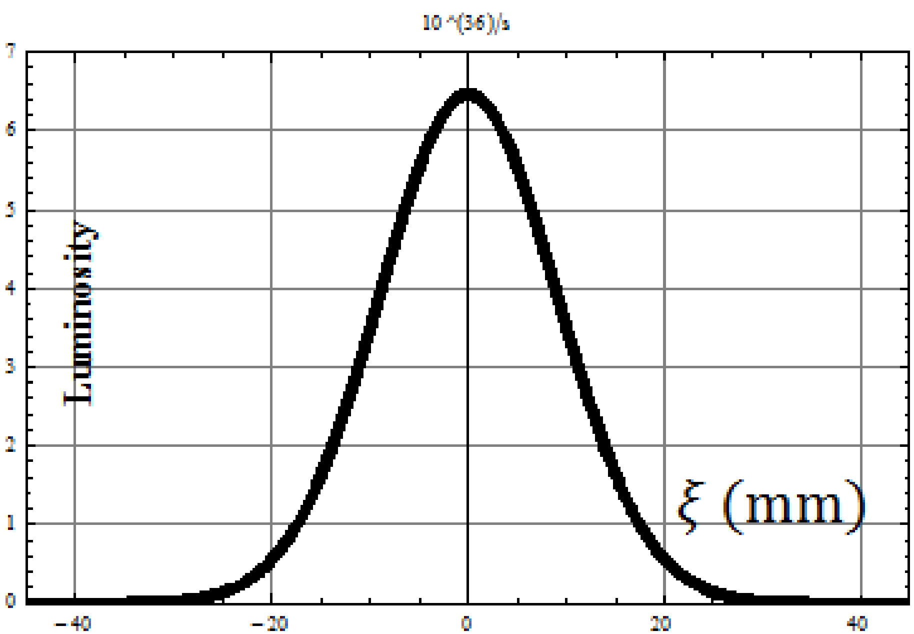
We tried the installation of this device to ATF damping ring to measure electron beam profile quickly. However, my student does not succeed The establishment of the laser system which has 600mW oscillator, fiber pre-amplifier, fiber amplifier and BBO crystal to generate green laser pulse. He confirmed the finesse of about 4500.
I hope he will succeed the installation and the laser establishment on time.



Electron beam energy	**1.28 GeV**
Electron beam size $(\sigma_{ex}, \sigma_{ey})$	**(80 , 10)** μ**m**
Electron beam longitudinal size (σ_{ez})	**30 ps**
Number of electrons in one bunch	10^{10}
Circulation frequency of electron beam	**2.16 M Hz**
Single bunch electron beam current (I_e)	**3.456 mA**
Laser pulse energy	**100 µJ**
Laser minimum waist size $(\sigma_{ly}, \sigma_{lz})$	**(5, 14)** μ**m**
Laser longitudinal size $(\sigma_{l\,pulse})$	**7.25 ps**
Laser wavelength (λ)	**532 nm, Green laser**







Cross section of the Compton scattering for existing detector at ATF damping ring : ~400mbarn

Counting rate : more than 10MHz

Present CW laser wire can make 10kHz counting rate and need 30 min. to get one beam profile.
So, we just need a few second to measure the beam profile in the case of this laser wire.

5. Mirror development

We made the contract to manufacture 99.999% reflective mirrors with LMA in Lion France. I requested the transmissivity more 2ppm. It means the scattering and absorptive loss are less than 6ppm.

We bought many mirror substrates from American companies, 1 inch, 2 inch and special sized mirror with sub-A micro-roughness.

In this Feb., we will make the coating at LMA. Before this, we can use ordered mirrors to Japanese company ,which has about (99.99+0.005) % with the transmissivity more than 8ppm.

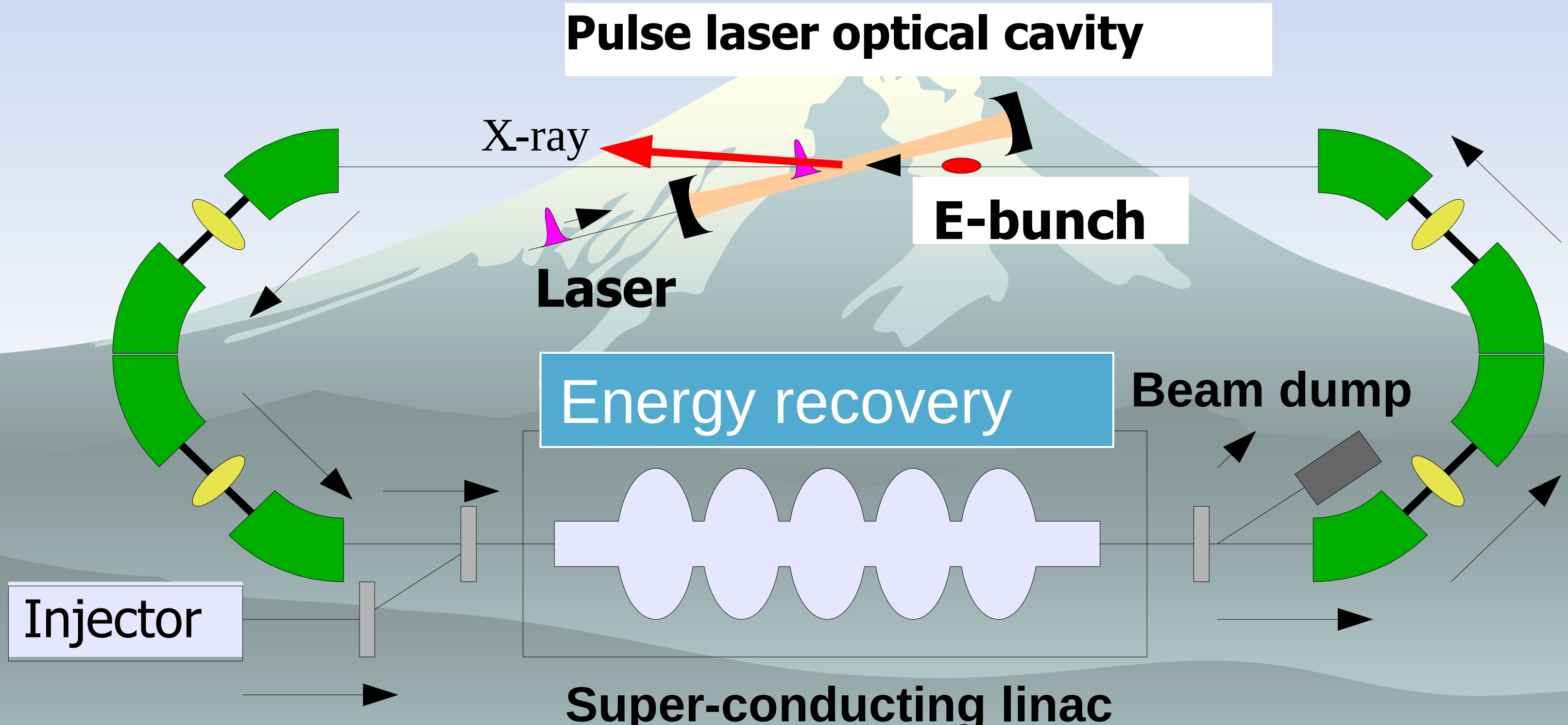
LIGO developed big mirror with loss under 1ppm many years ago.

We have a plan the development of thin thickness of concave mirror will start to realize X-ray high transmission.

6. New plans and schedule

High brightness X-ray generation at Compact ERL As a demonstration through beam experiment if possible

2014 experiment

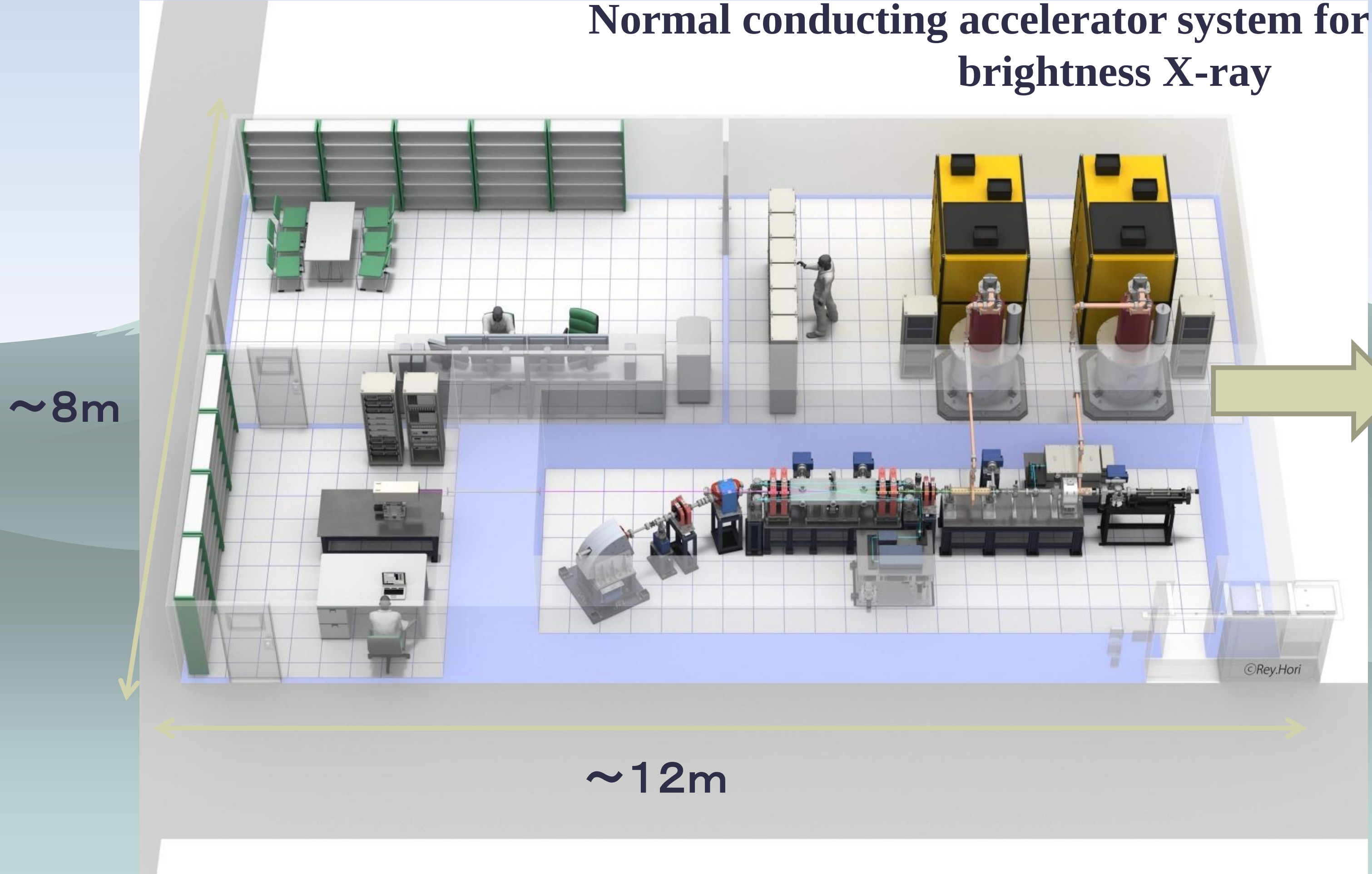


10^{13} photons/(sec･1%b.w.)

35MeV electron beam x 1μm laser = 23keV X-ray

New Quantum Beam Technology Program(QBTP) supported by MEXT from 2013.4 to 2018.3 (5 years project)

Approved project should include two Japanese Companies at least and the development for CW super conducting acceleration technologies. Normal conducting accelerator system and super conducting accelerator system for compact high brightness X-ray source should be realized by joint research with companies.



Downsizing to 6m x 8m