Recent progress for 4-Mirror Compton cavity at KEK

Junji Urakawa (KEK, Japan) at PosiPol2012, 2012.9.06
Under development of Quantum Beam Technology Program(QBTP) supported by MEXT from 2008.9 to 2013.3 (5 years project) + 5 years extension?

Contents :

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 (Takahashi-san will give a talk about this. So, I skip this part.)

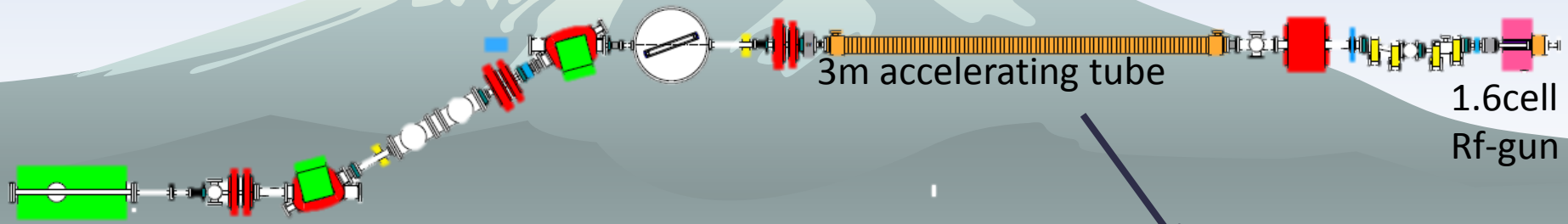
b). 2D four mirror optical cavity to generate X-ray. LUCX project

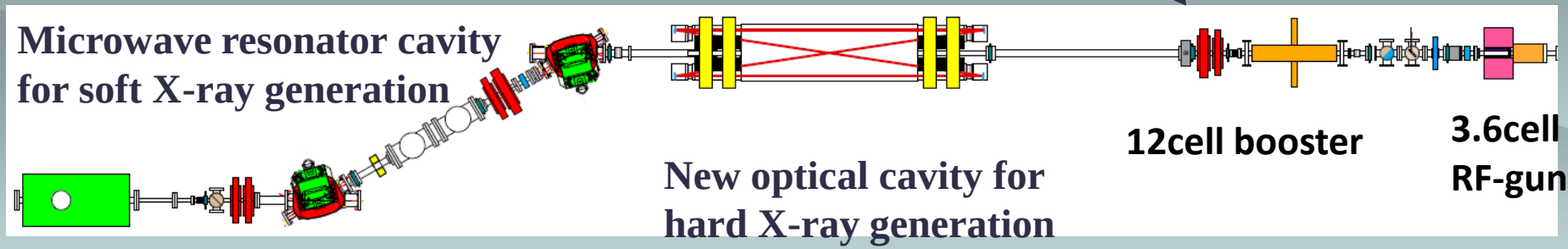
c). 2D four mirror cavity to generate X-ray with two cylindrical lenses

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

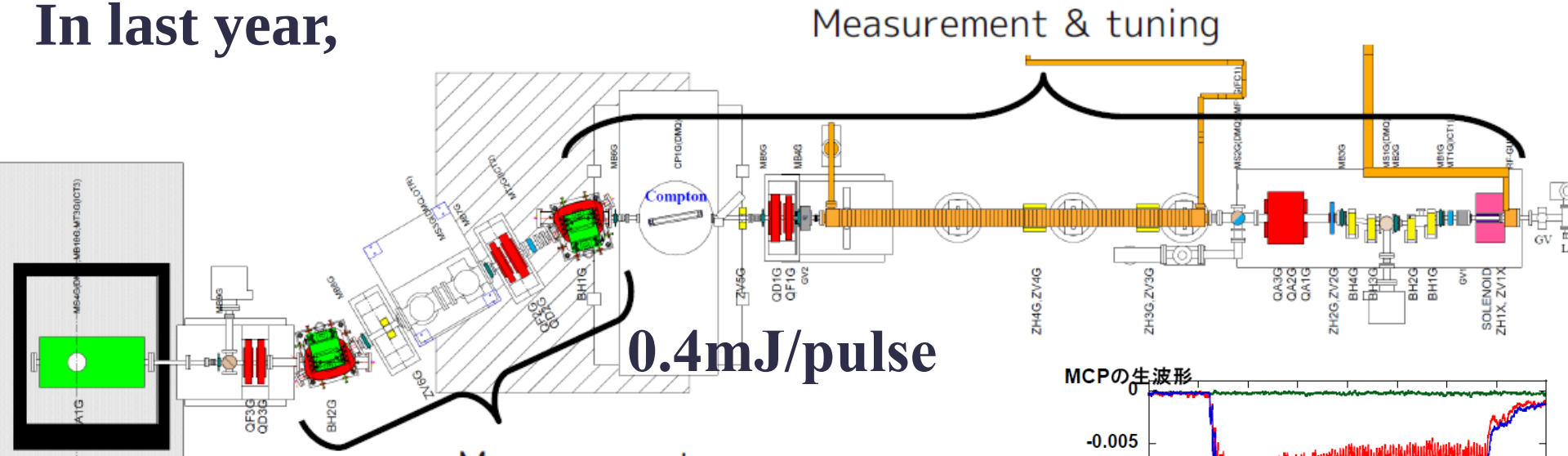
b). Recent plan for LUCX project

- To downsize the accelerator, we have planed to install 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 June.



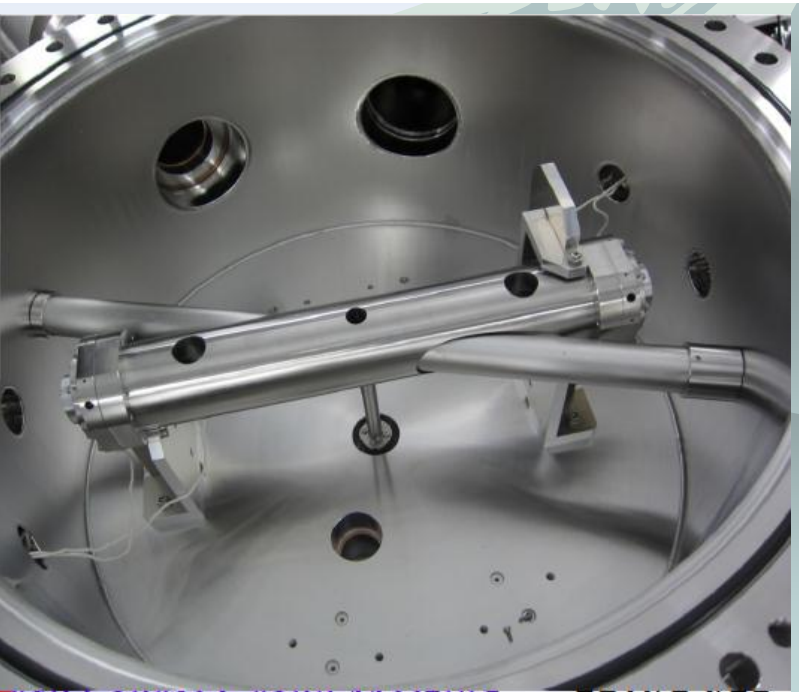


In last year,



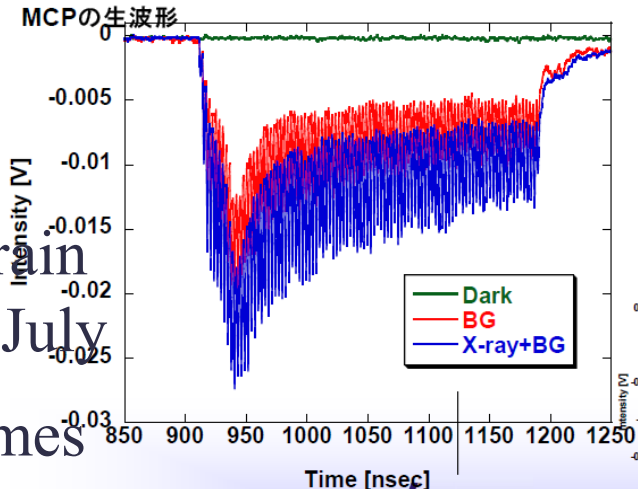
Measurement
&
tuning if possible

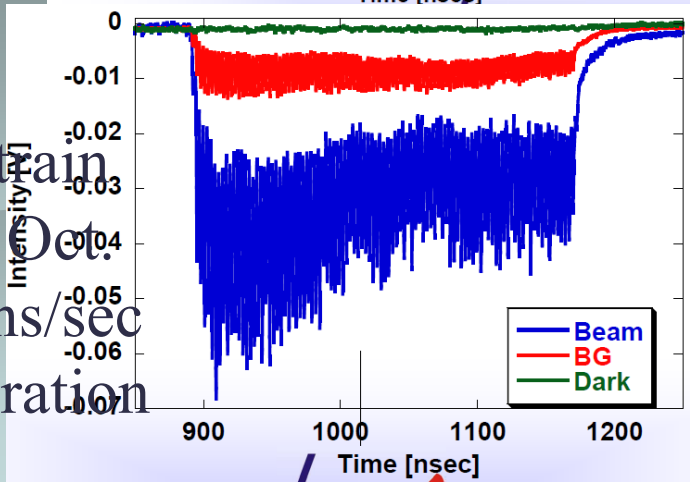
X-ray yield
334 photons/train
at detector on July

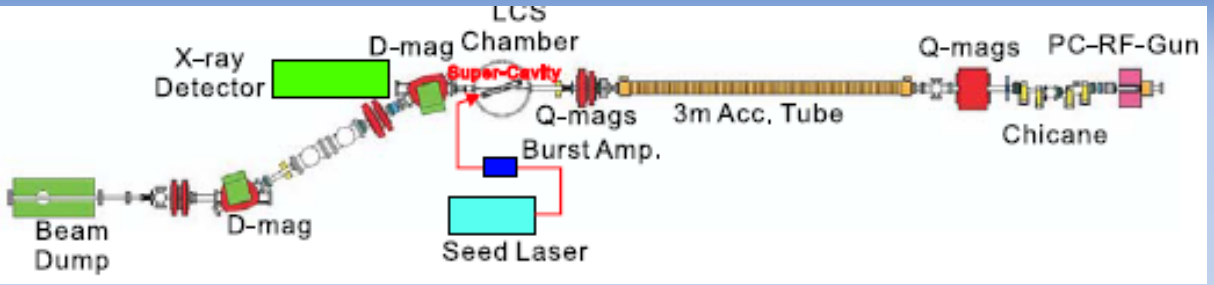


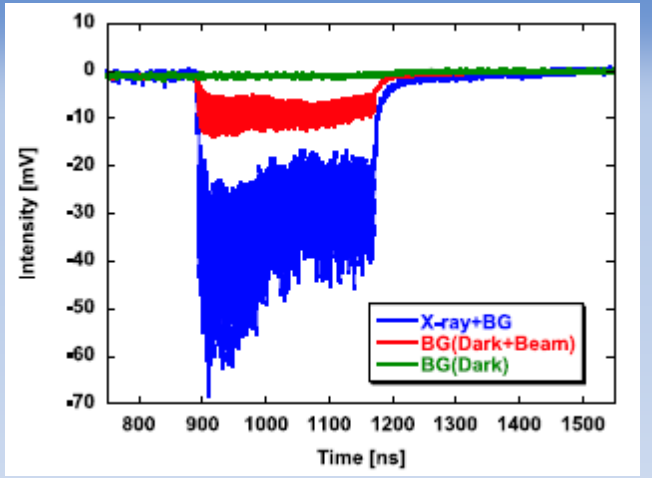
2～3 times

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



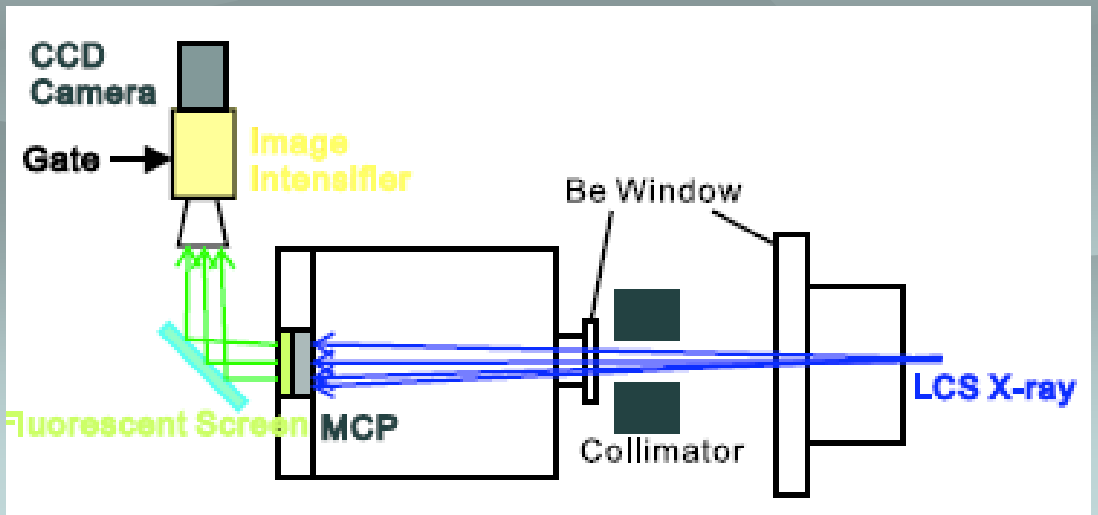


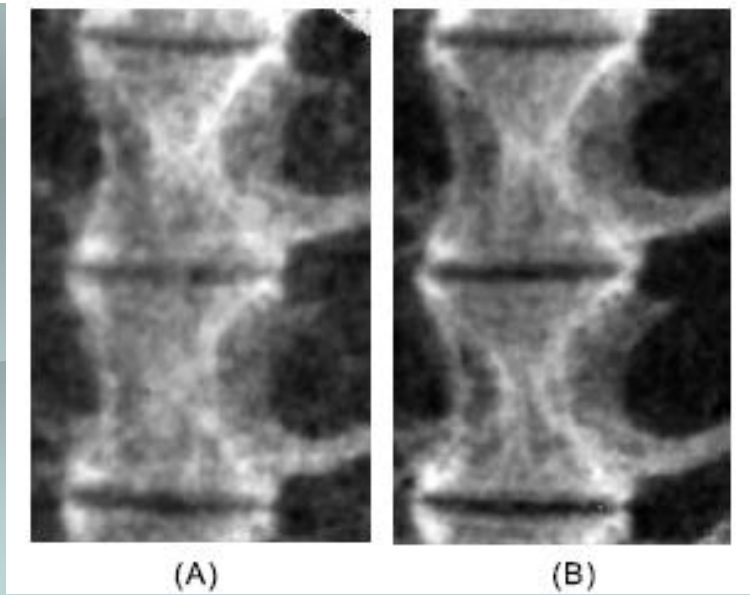


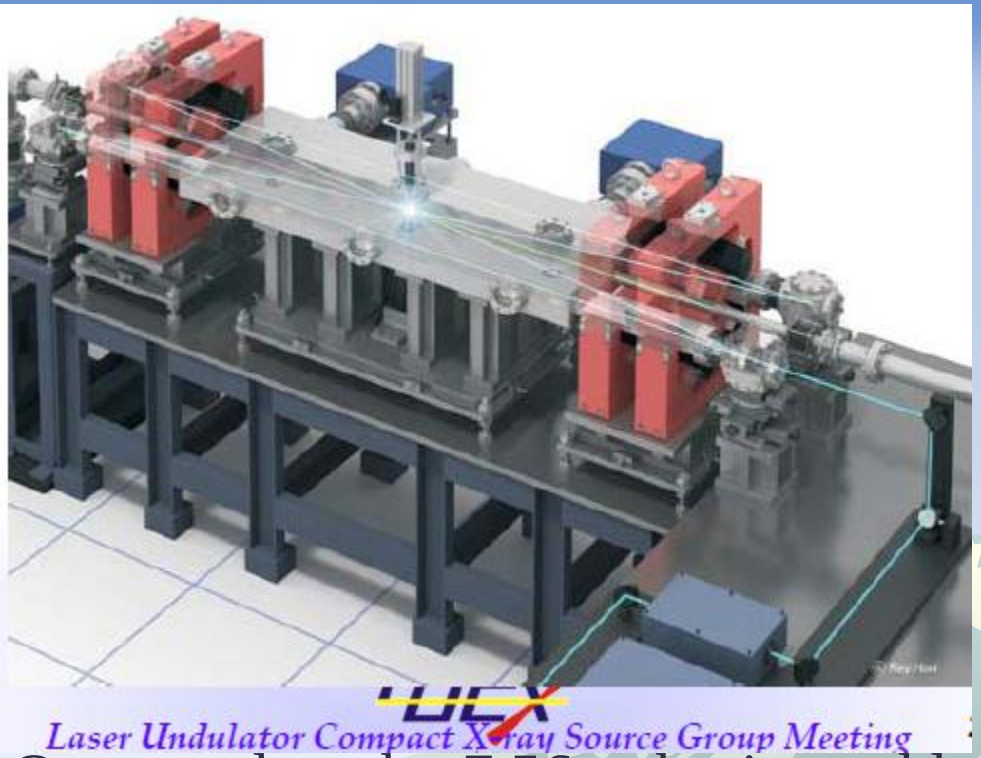


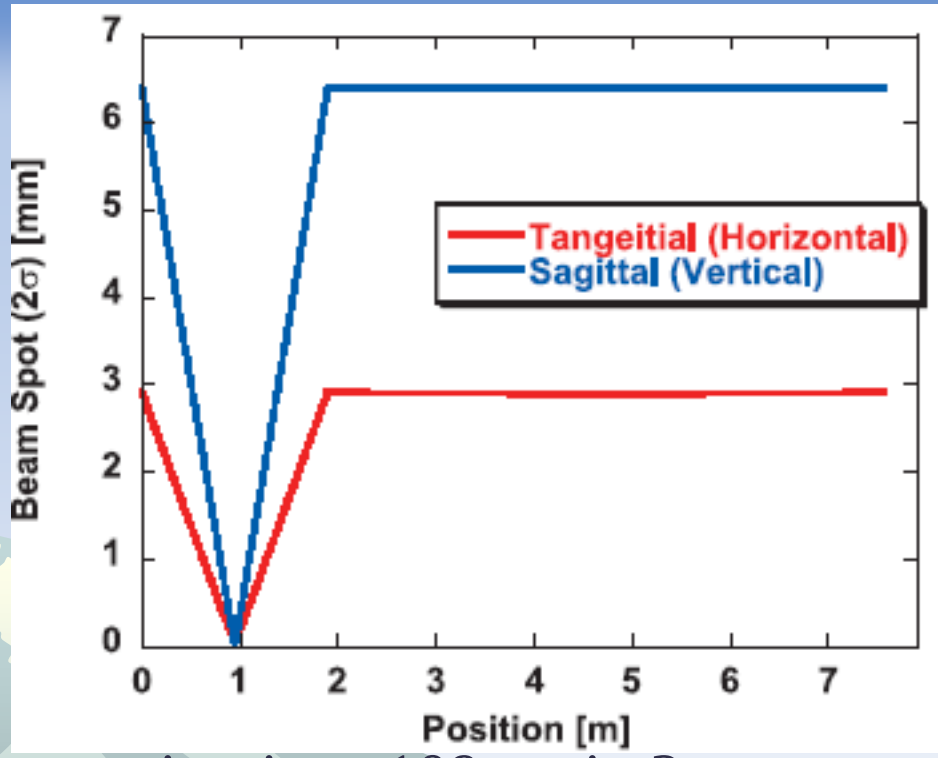
Electron beam		Laser pulse	
Quantity	Value	Quantity	Value
Energy	30 MeV	Wavelength	1064 nm
Charge	0.4 nC/bunch	Pulse energy	400 μJ
Number of bunches	100/train	Cavity finesse	2650
Bunch spacing	2.8 ns	Pulse spacing	2.8 ns
Beam size (rms)	200/53 μm (H/V)	Spot size (rms)	30.3 μm
Bunch length	10 ps (FWHM)	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.

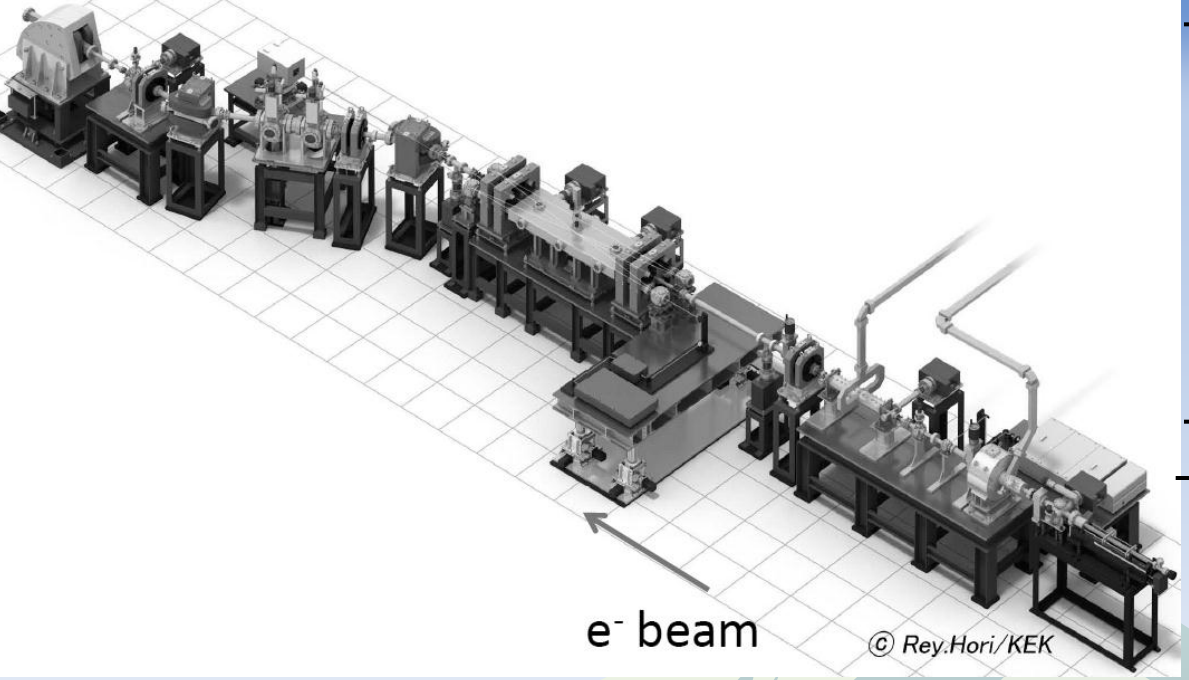






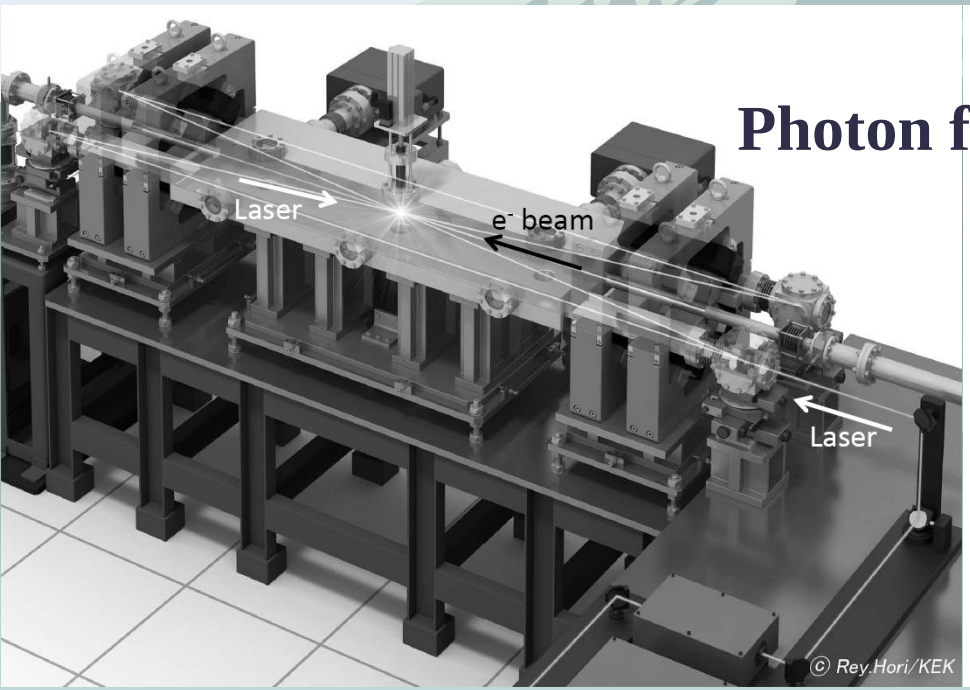


One turn length : 7.56m, horizontal laser waist size : 109μm in 2σ,
Crossing angle : **7.5 degrees**, vertical laser waist size : **50μm in 2σ,**
Horizontal laser size on laser injection plane mirror : 2.92mm,
Vertical laser size on laser injection plane mirror : 6.4mm
Laser pulse energy in cavity : 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.
Complete this device in this September and start the generation of X-ray from mid. of November. We will confirm the performance soon.

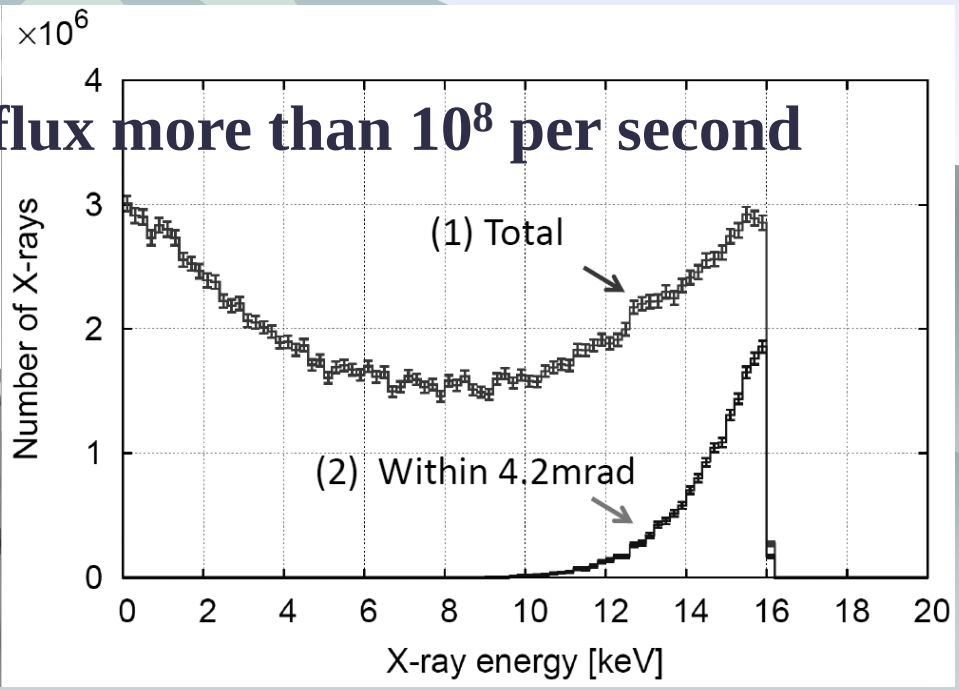


Energy	30MeV
Intensity	0.4nC/bunch
Number of bunch	1000
Beam size at the collision point (1σ)	33μm ×33μm
Bunch length	10ps
Bunch spacing	2.8ns

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



Photon flux more than 10^8 per second

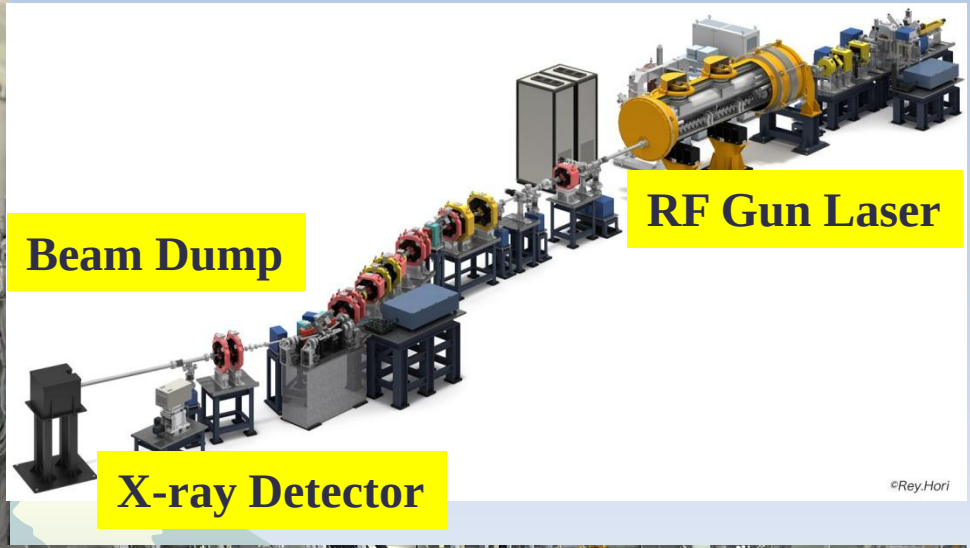


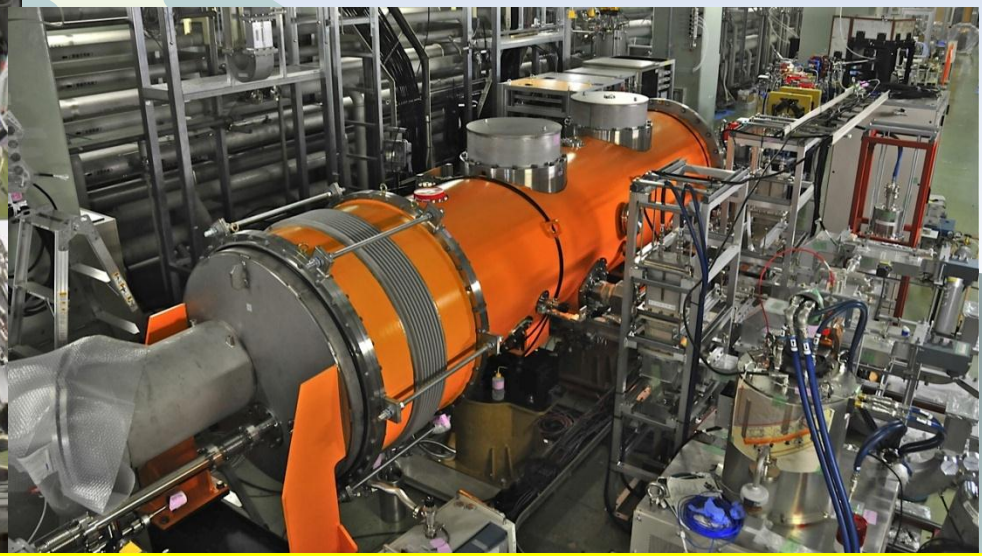
Quantum Beam Technology Program (QBTP)

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

To contribute the development for life science innovation and green innovation

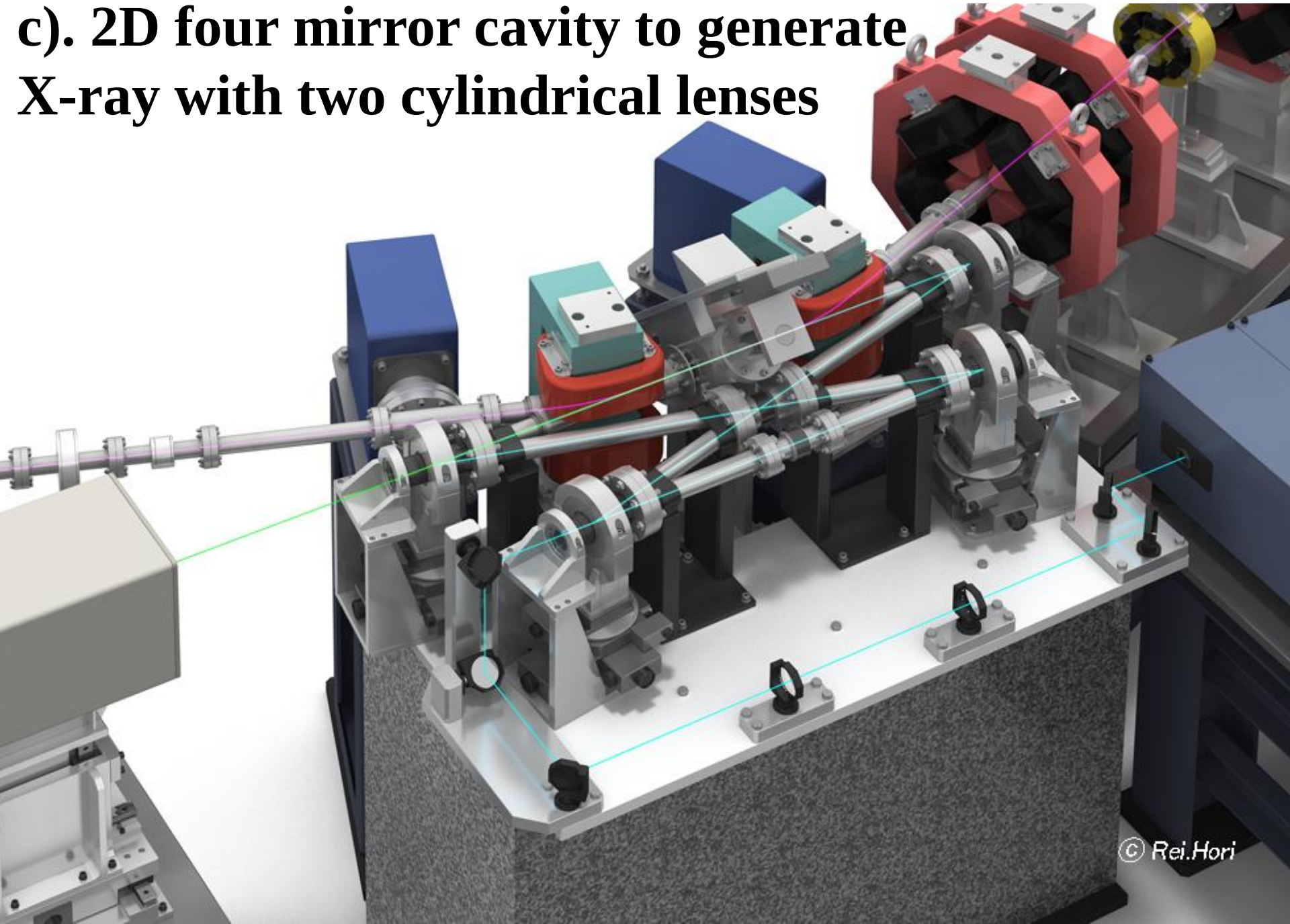
View of QBTP from Beam Dump

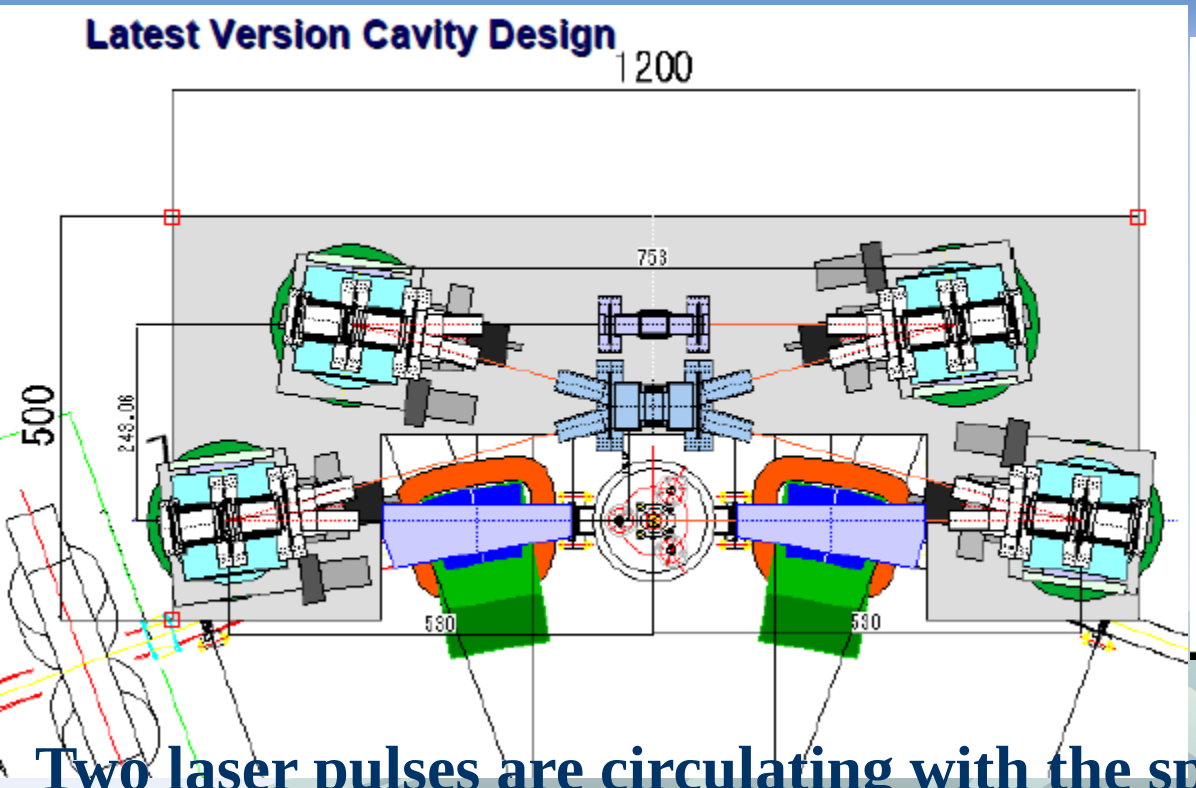


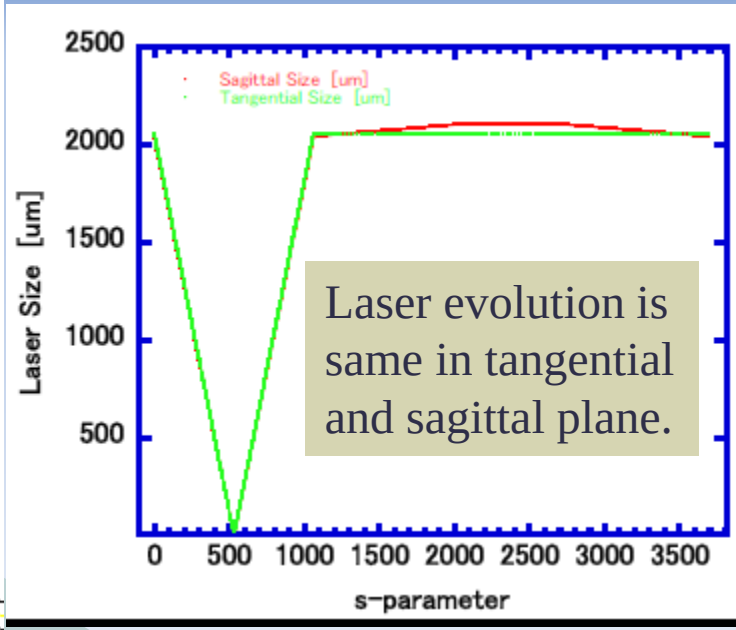


Quantum Beam Technology Program: Beam commissioning started from mid. of February.

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

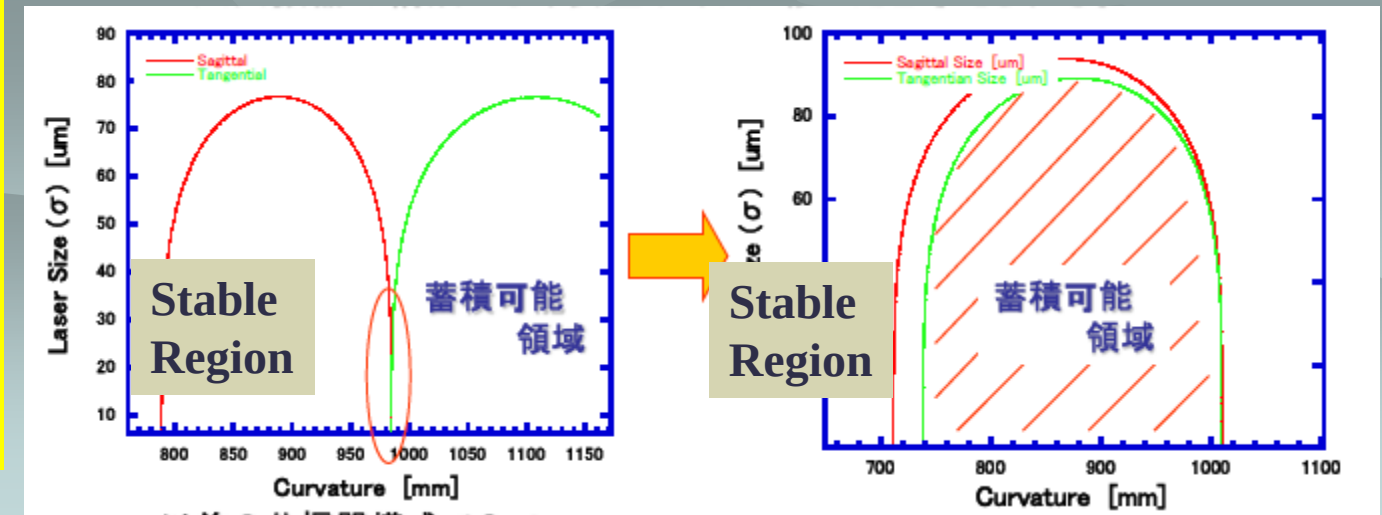






Two laser pulses are circulating with the spacing of 6.15ns in a ring optical cavity.

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

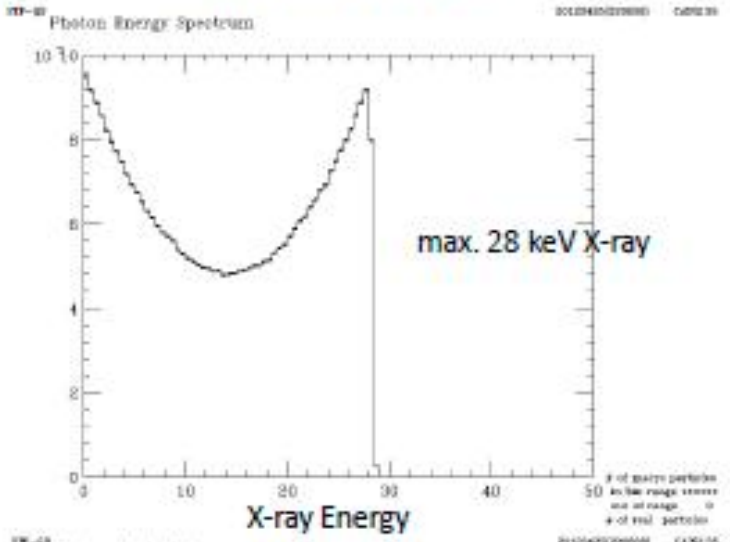


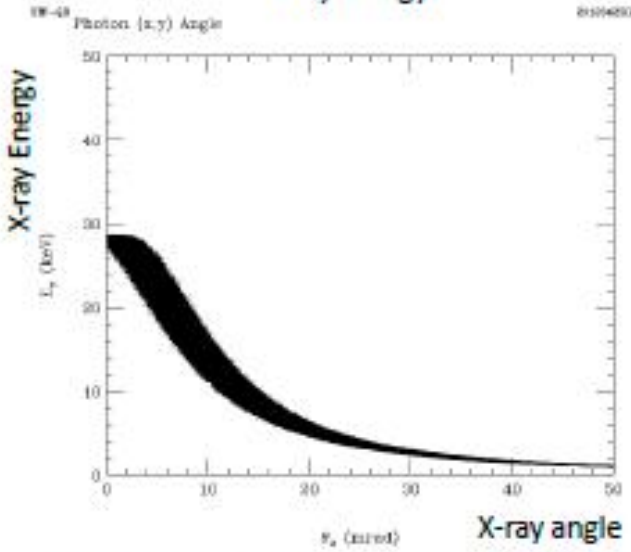
Plan of X-ray generation by Inverse-compton scattering

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	

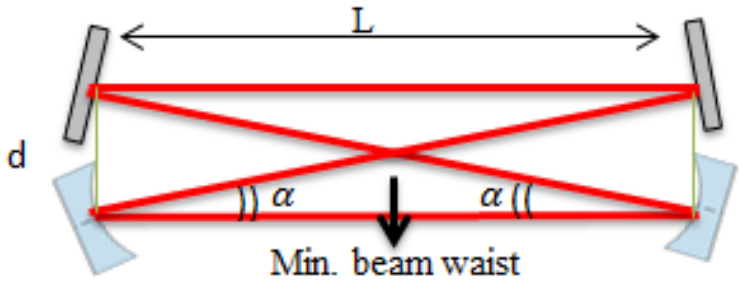
40MeV, head-on collision



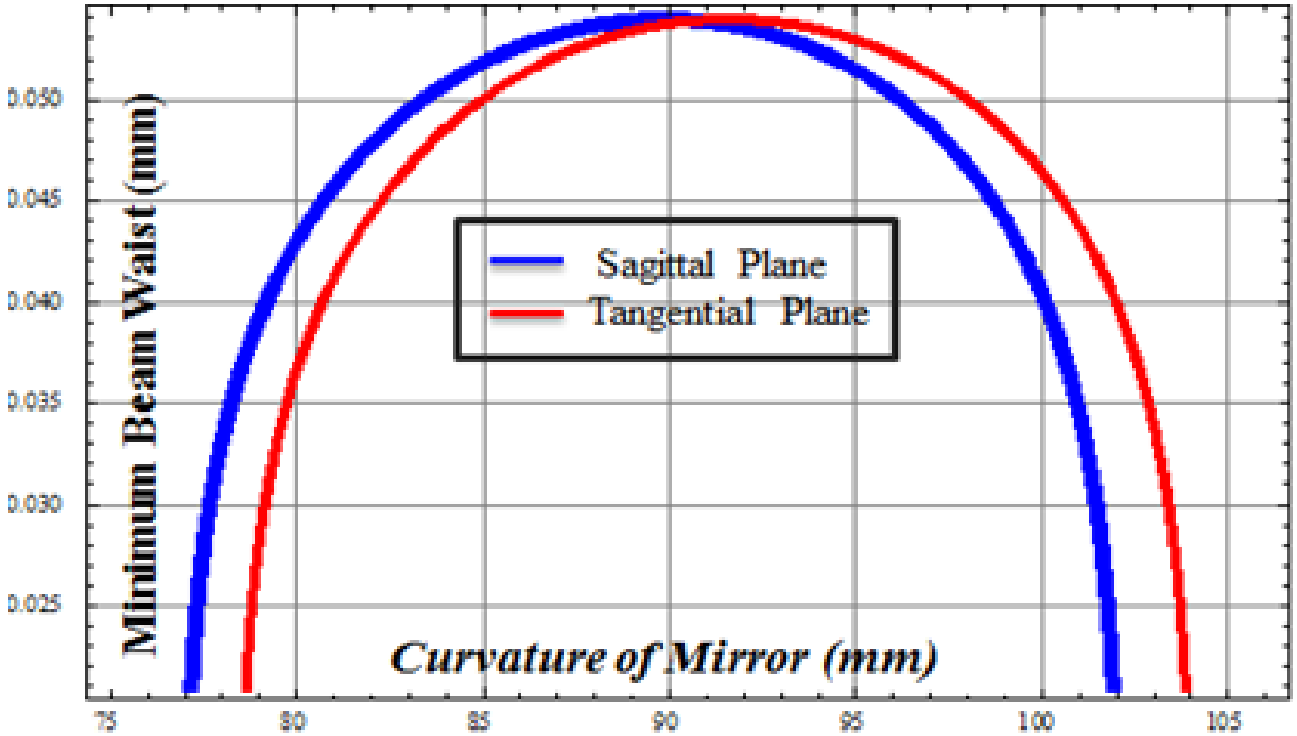


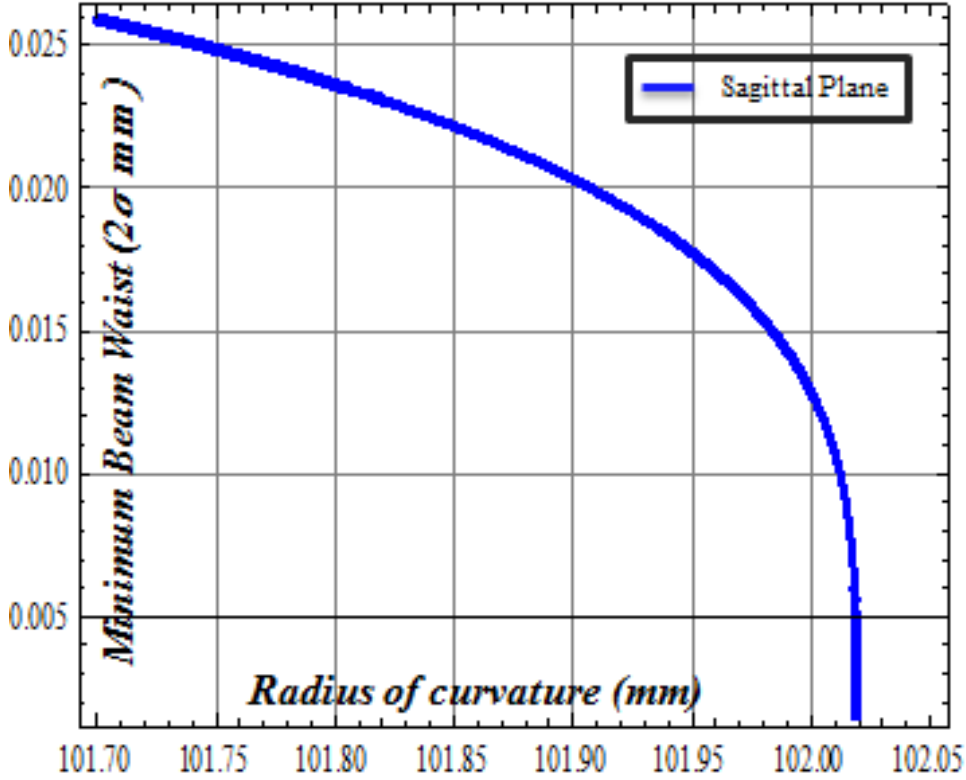
target: 1.3×10^{10} photons/sec/1%bw

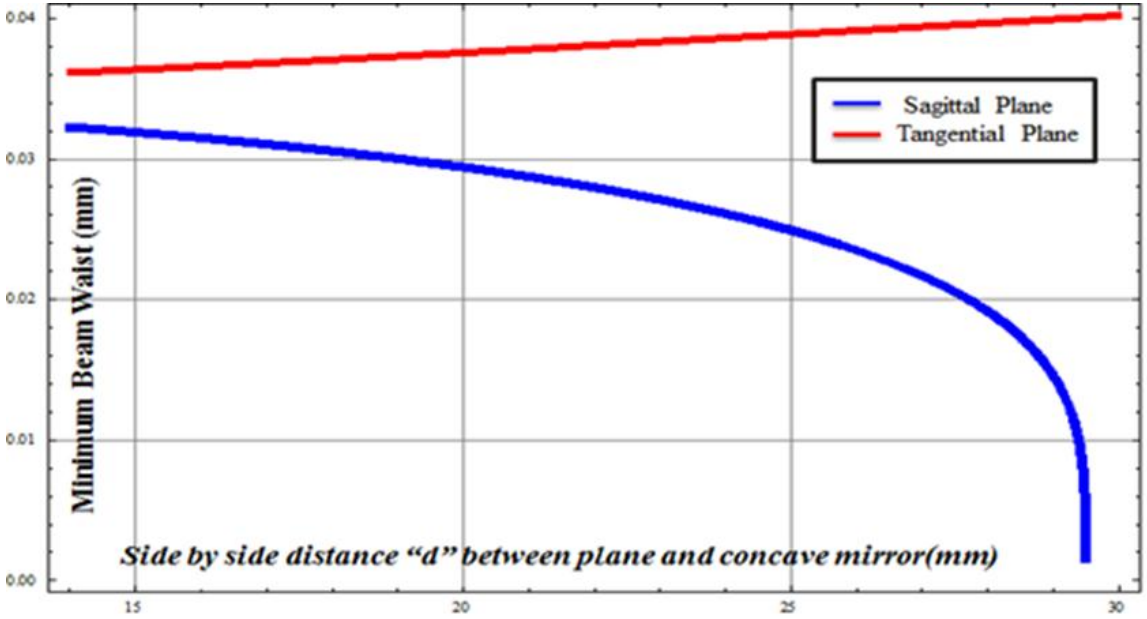
d). Compact 2D four mirror optical cavity to measure the beam profile quickly as laser wire.

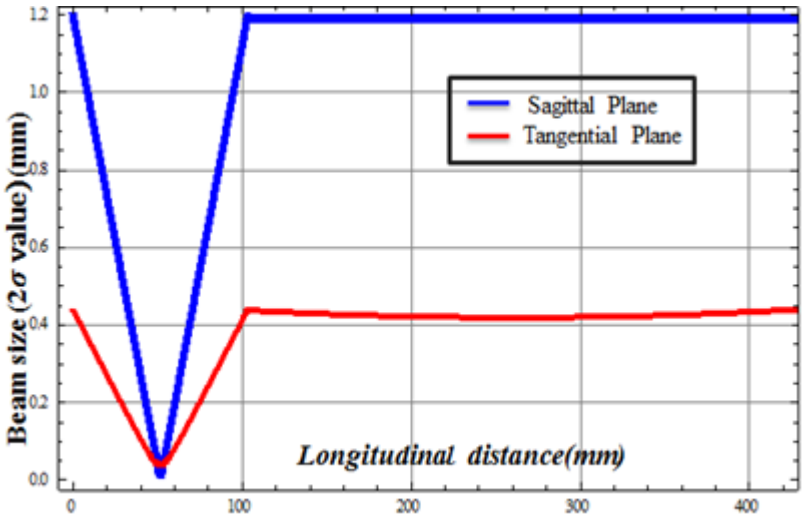


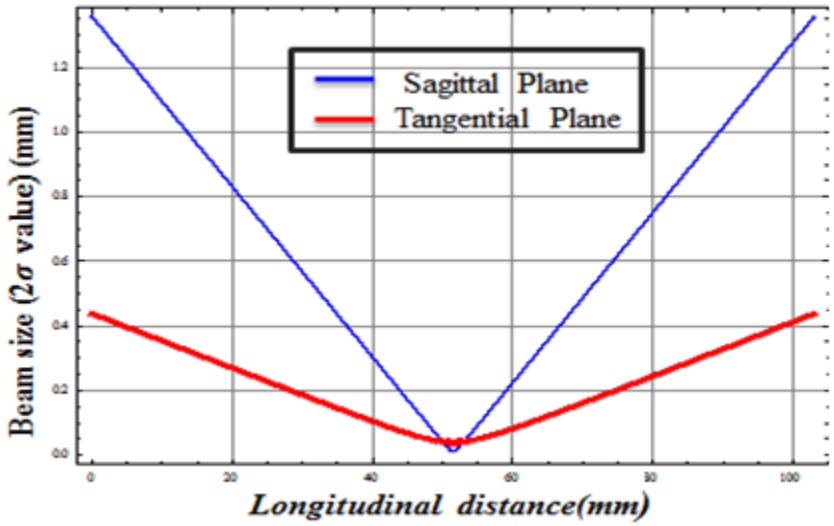
Length L (mm)	412	206	103
Distance d (mm)	116	58	29
Curvature ρ (mm)	408	204	102
Total path length (L_{Cav}) (mm)	1680	840	420
Aspect ratio (α) (radians)	0.2745	0.2745	0.2745
Min. beam waist in 2σ, (ω_s, ω_T)	(29.3, 80)μm	(21, 57)μm	(14, 40)μm

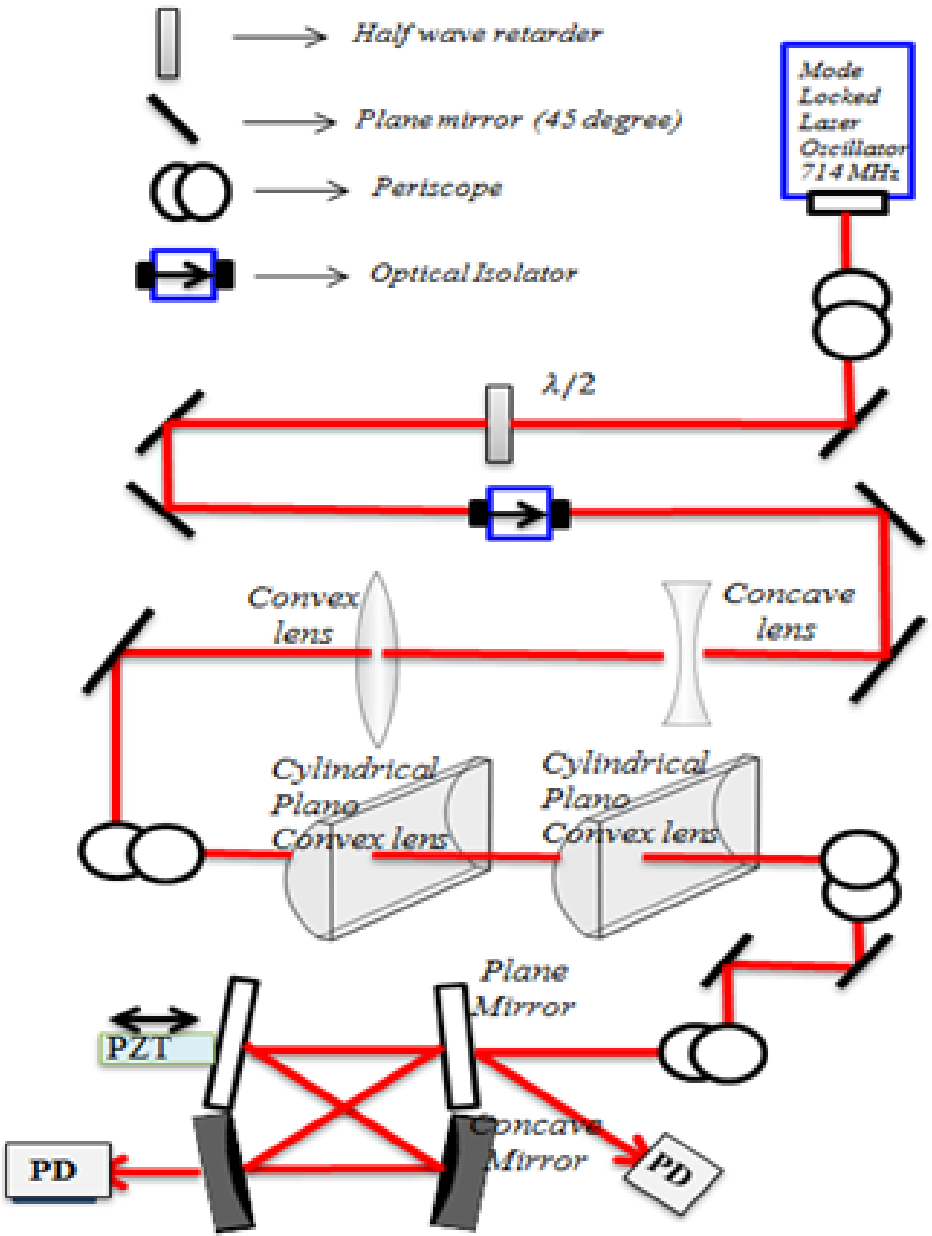


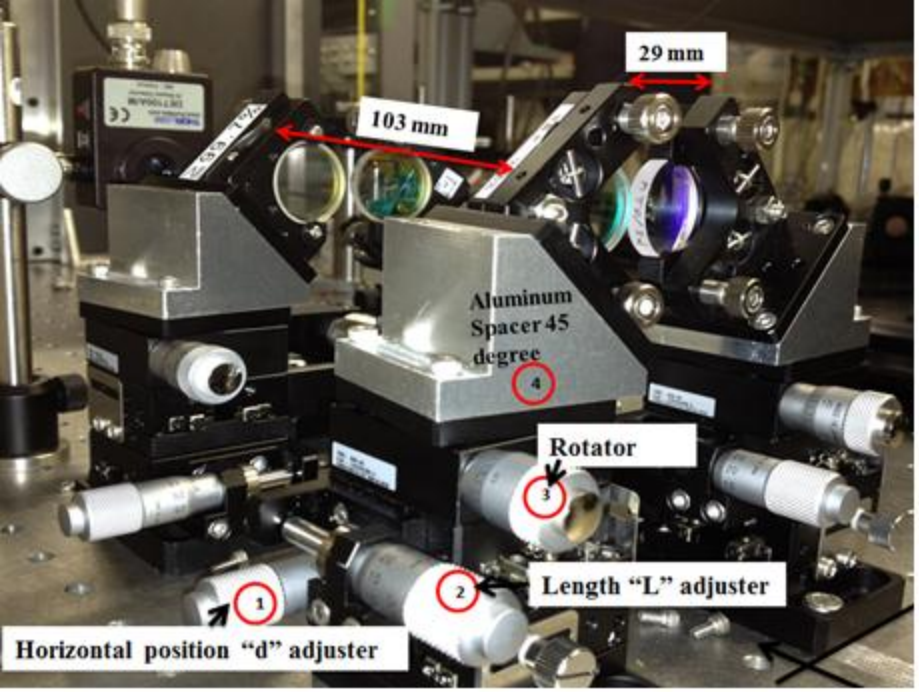

Sagittal Plane
Minimum Beam Waist (2σ mm)
Radius of curvature (mm)
0.025
0.020
0.015
0.010
0.005
101.70
101.75
101.80
101.85
101.90
101.95
102.00
102.05

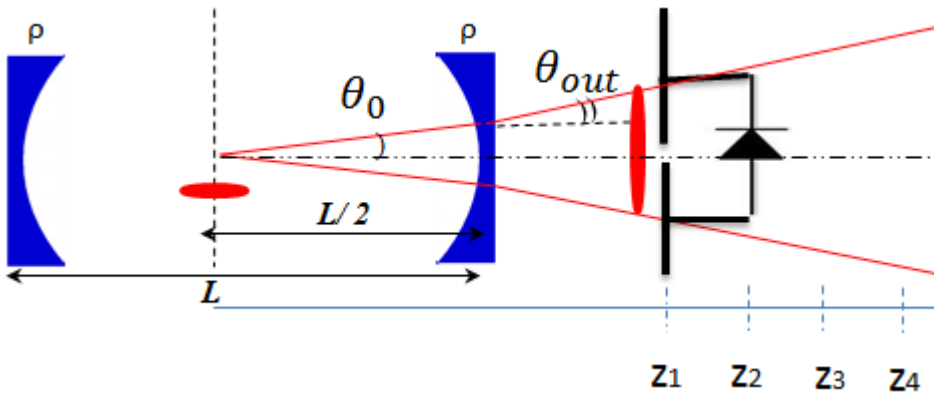

Sagittal Plane
Tangential Plane
Minimum Beam Waist (mm)
Side by side distance "d" between plane and concave mirror(mm)
0.04
0.03
0.02
0.01
0.00
15
20
25
30

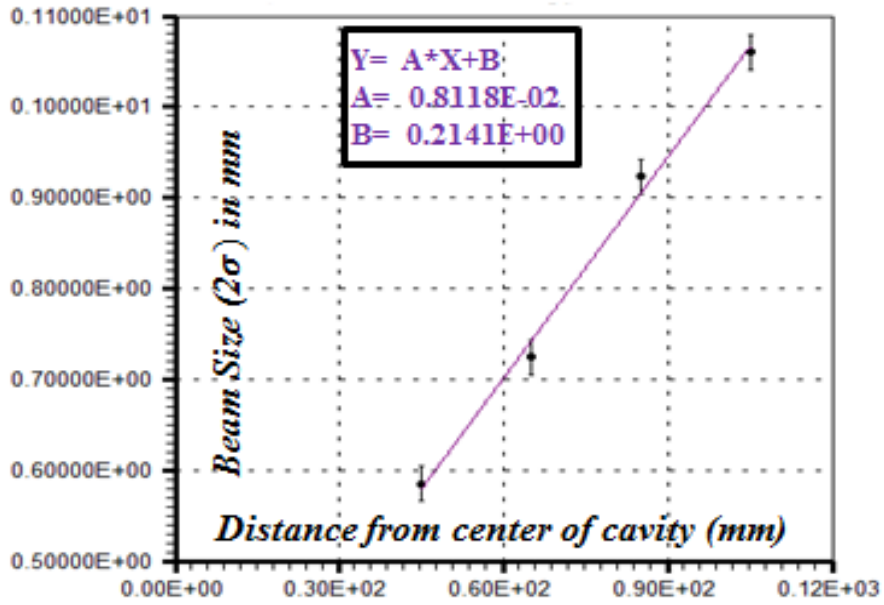

Beam size (2σ value) (mm)
Sagittal Plane
Tangential Plane
Longitudinal distance(mm)

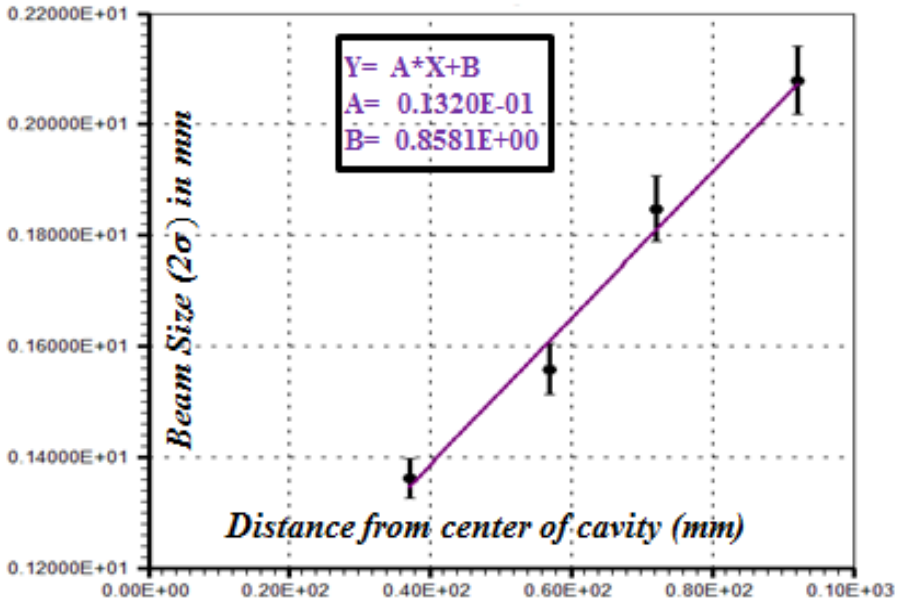

Beam size (2σ value) (mm)
Sagittal Plane
Tangential Plane
Longitudinal distance(mm)

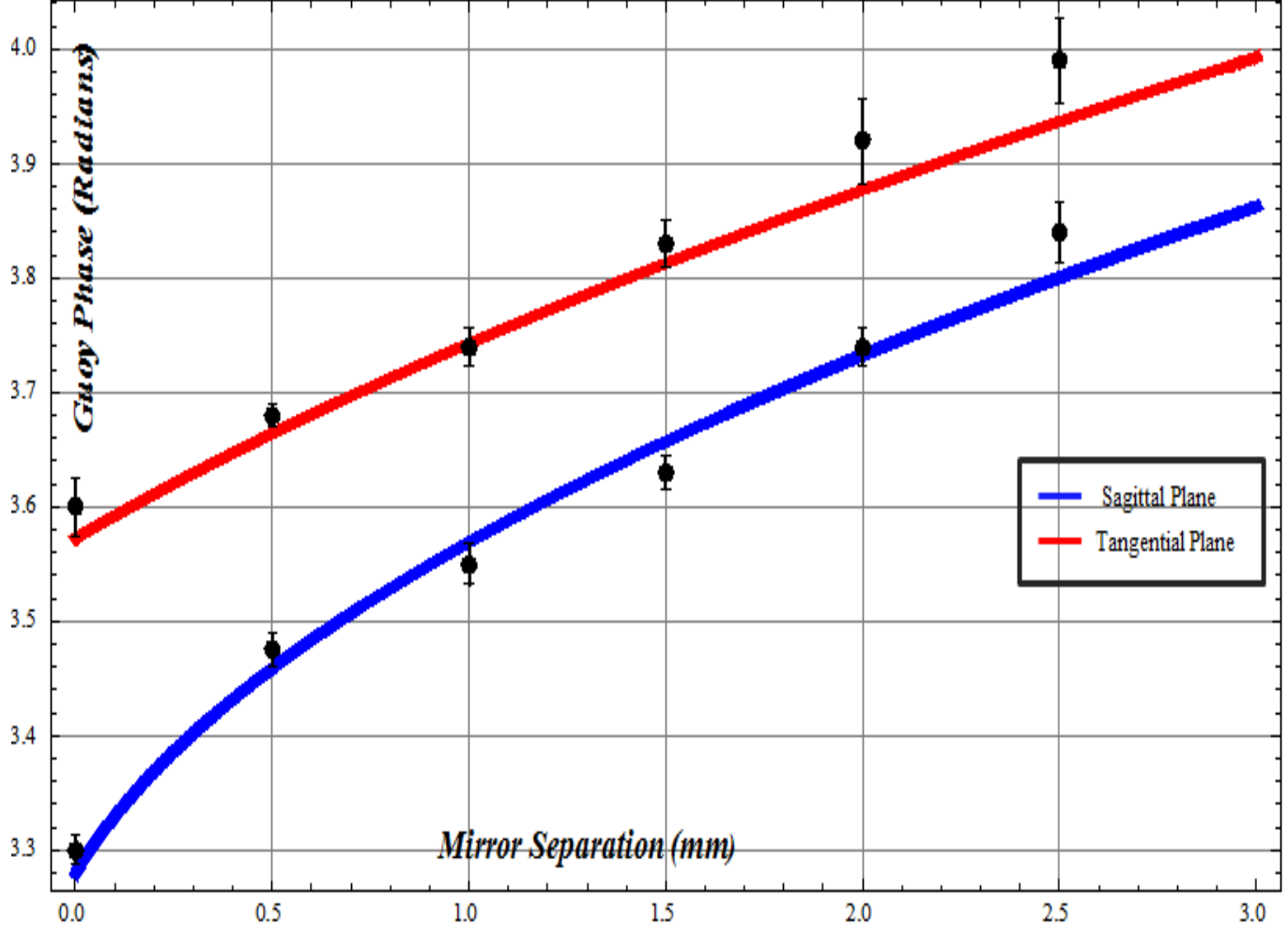

Half wave retarder
Plane mirror (45 degree)
Periscope
Optical Isolator
Mode Locked Laser Oscillator 714 MHz
λ/2
Convex lens
Concave lens
Cylindrical Plano Convex lens
Cylindrical Plano Convex lens
Plane Mirror
PZT
Concave Mirror
PD
PD


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


ρ
ρ
θ_0
θ_{out}
L/ 2
L
z_1
z_2
z_3
z_4

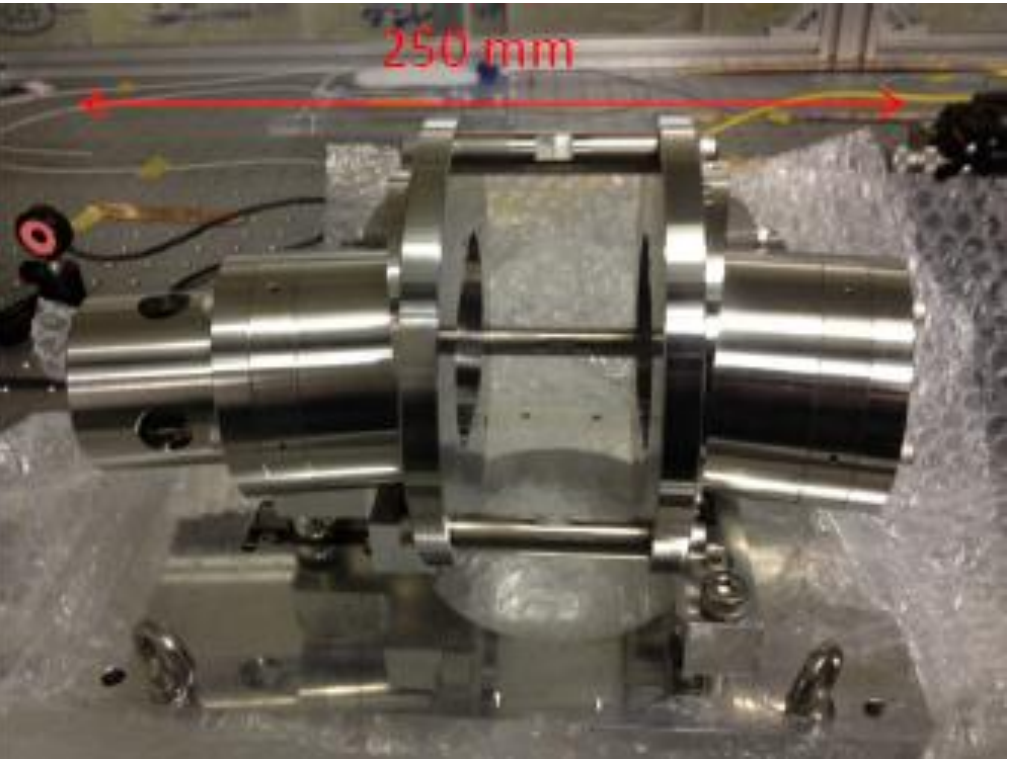

Y= A*X+B
A= 0.8118E-02
B= 0.2141E+00
Beam Size (2σ) in mm
Distance from center of cavity (mm)
0.11000E+01
0.10000E+01
0.90000E+00
0.80000E+00
0.70000E+00
0.60000E+00
0.50000E+00
0.00E+00
0.30E+02
0.60E+02
0.90E+02
0.12E+03

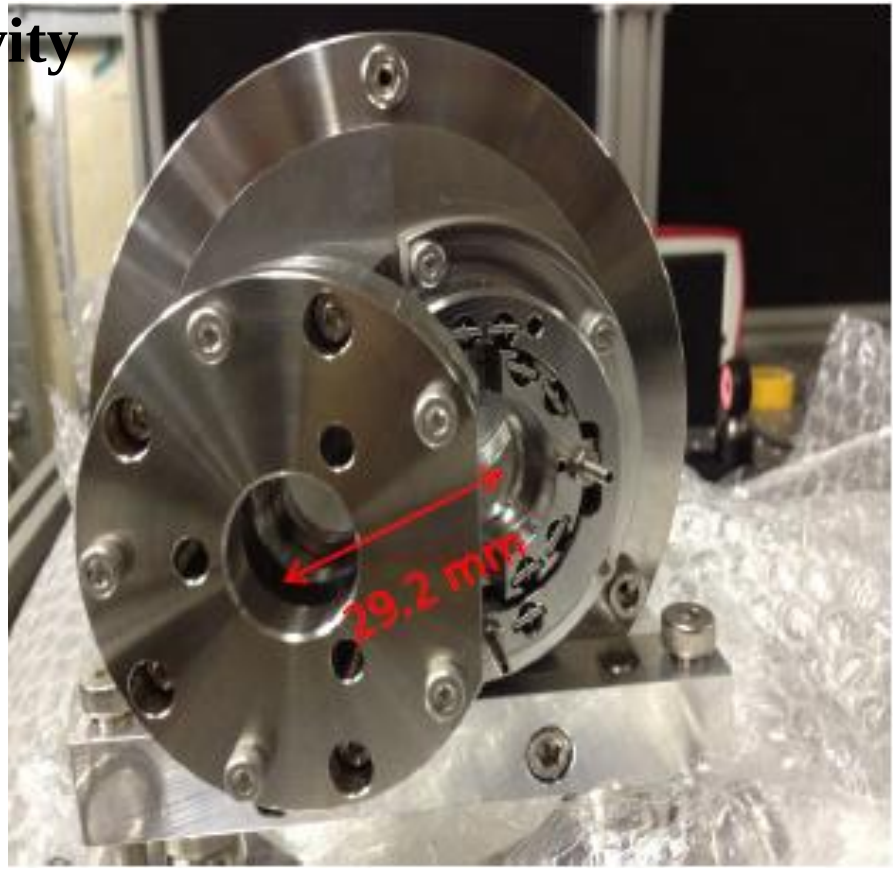

Y= A*X+B
A= 0.1320E-01
B= 0.8581E+00
Beam Size (2σ) in mm
Distance from center of cavity (mm)
0.22000E+01
0.20000E+01
0.18000E+01
0.16000E+01
0.14000E+01
0.12000E+01
0.00E+00
0.20E+02
0.40E+02
0.60E+02
0.80E+02
0.10E+03

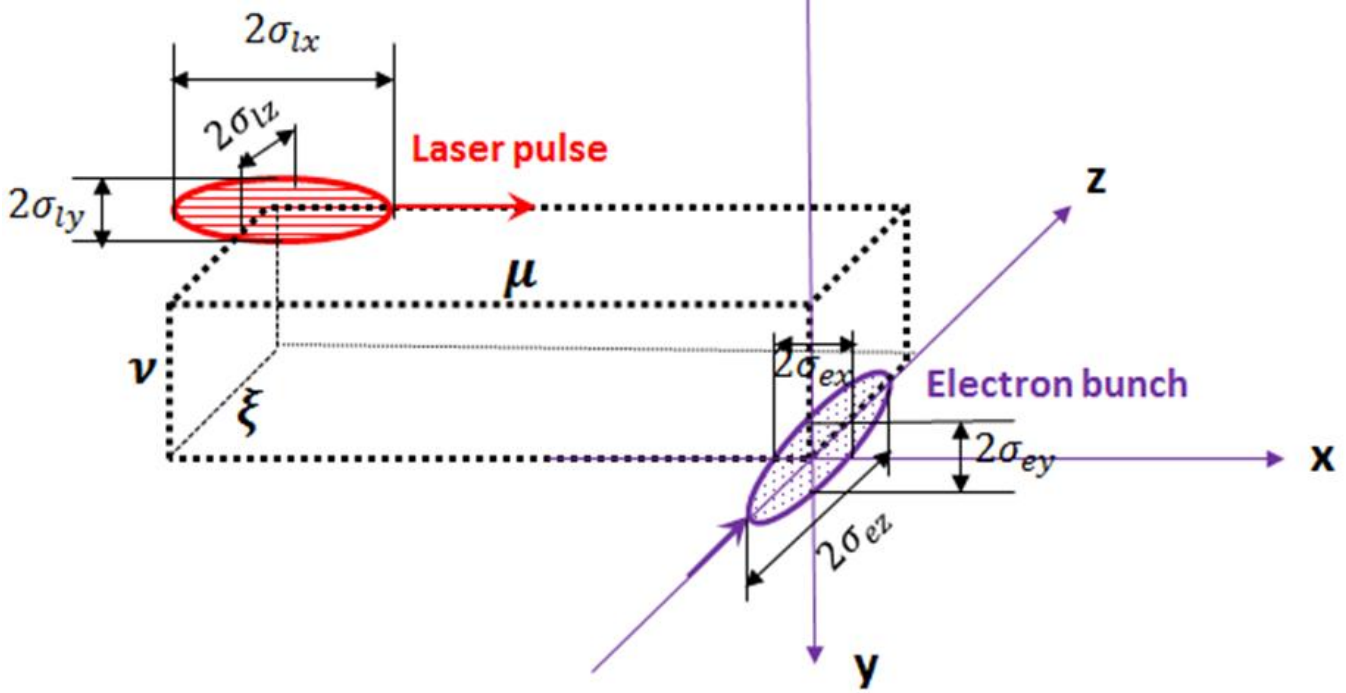


Method	Sagittal beam size (σ value)	Tangential beam size (σ value)
Divergence Method	$10.37 \pm 1.73\ \mu m$	$23.65 \pm 2.82\ \mu m$
Mode Difference Method	$13.74 \pm 1.81\ \mu m$	$21.82 \pm 3.63\ \mu m$

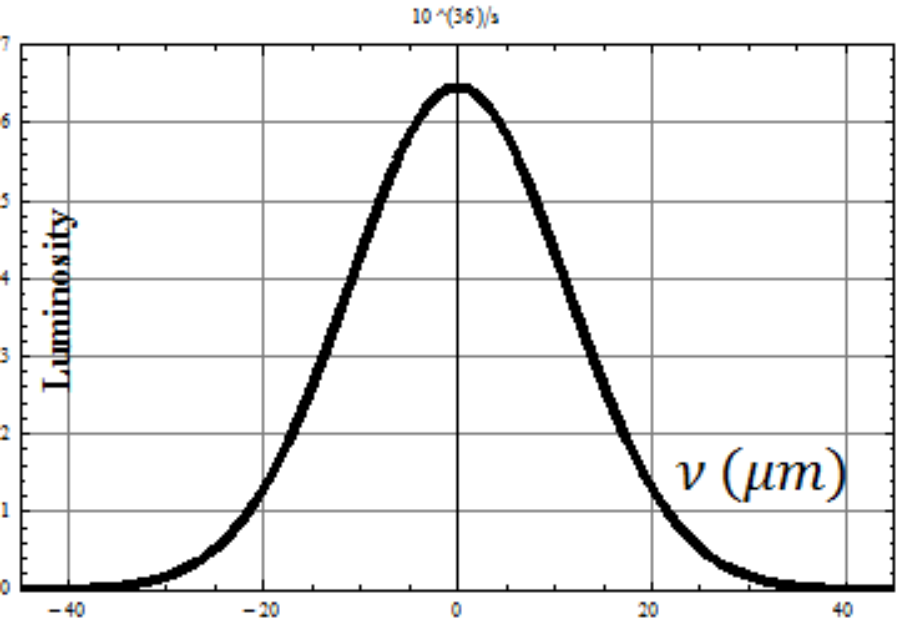
Compact fast scanning laser wire cavity

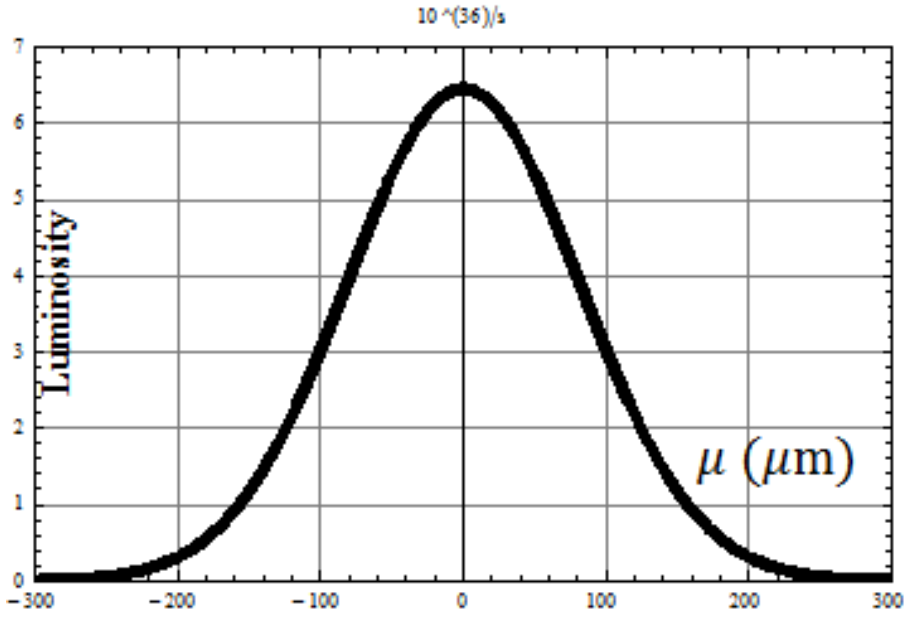


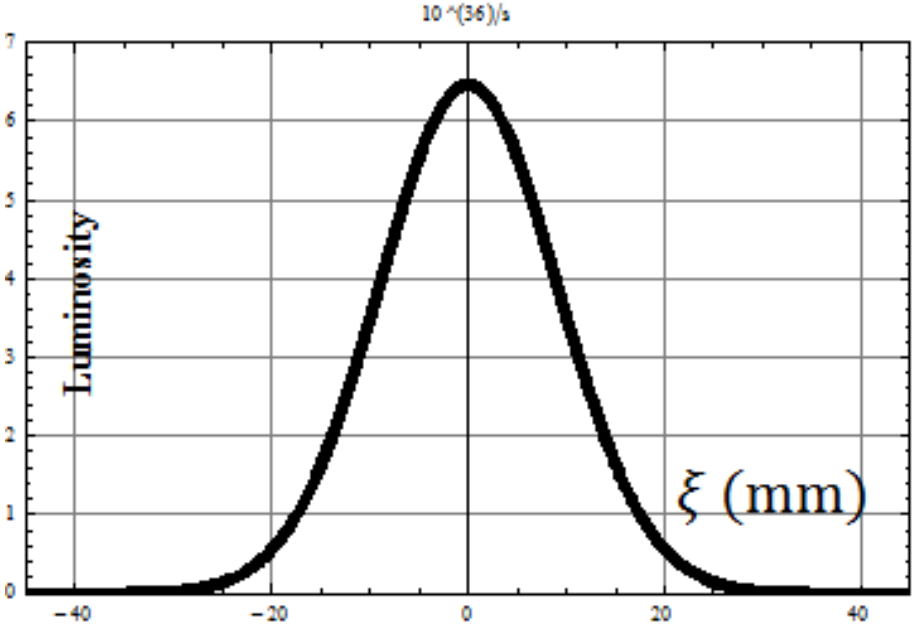




Electron beam energy	**1.28 GeV**
Electron beam size $(\sigma_{ex}, \sigma_{ey})$	**(80 , 10) μm**
Electron beam longitudinal size (σ_{ez})	**30 ps**
Number of electrons in one bunch	10^{10}
Circulation frequency of electron beam	**2.16 M Hz**
Single bunch electron beam current (I_e)	**3.456 mA**
Laser pulse energy	**100 μJ**
Laser minimum waist size $(\sigma_{ly}, \sigma_{lz})$	**(5, 14) μm**
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 8ppm. It means the scattering and absorptive loss are less than 2ppm.

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

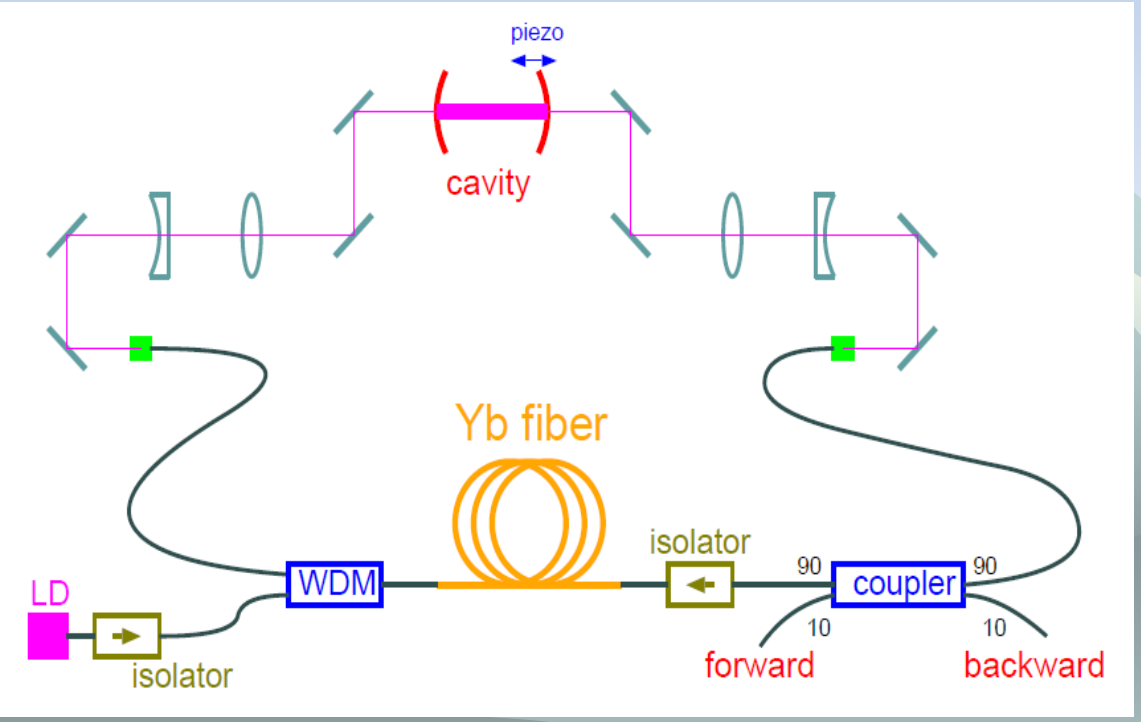
In this December, we will make the coating at LMA. Before this, we can use ordered mirrors to Japanese company ,which has about (99.99+0.005) % with the transmissivity more than 8ppm.

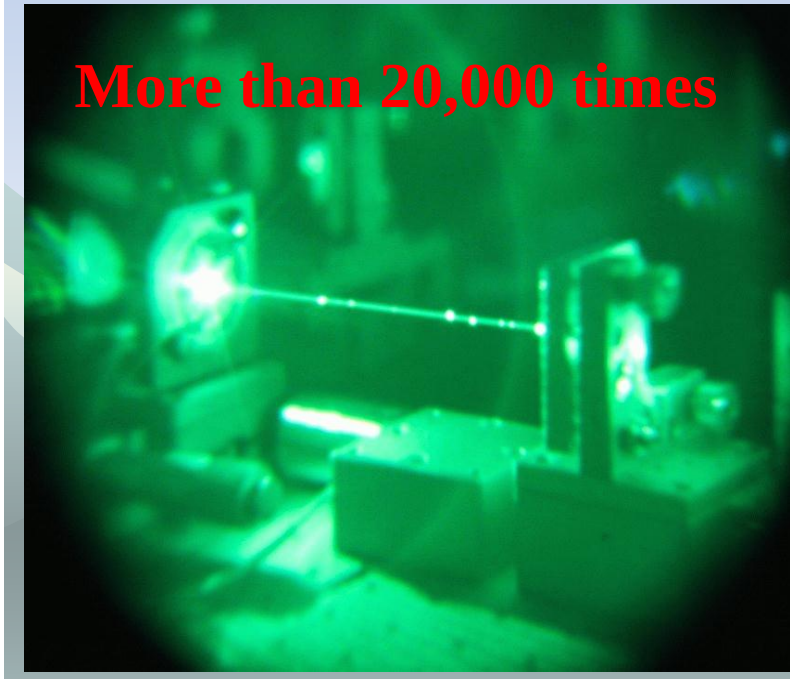
LIGO developed big mirror with loss under 1ppm many years ago.

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

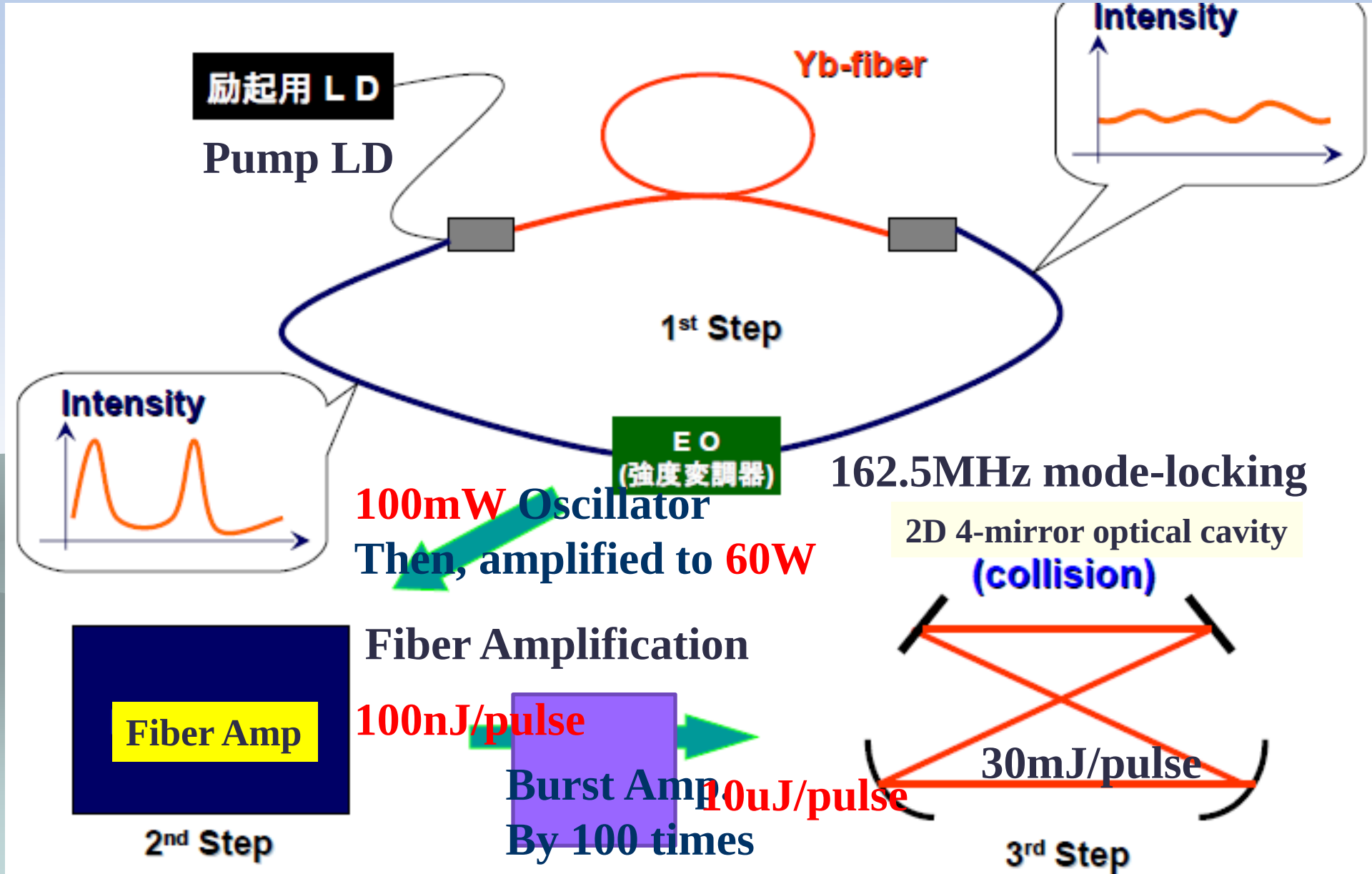
6. Laser development

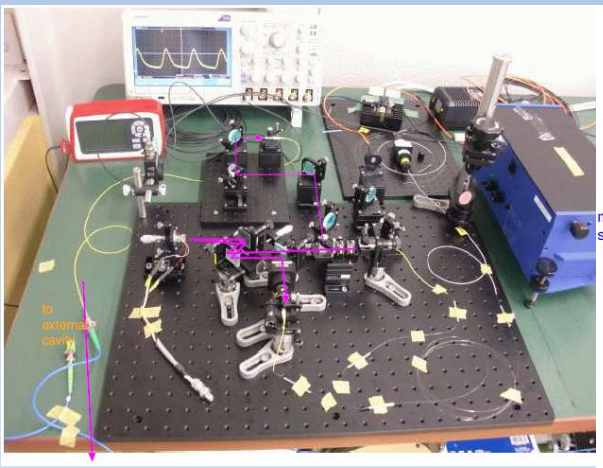
New laser storage scheme, so called ‘self-starting oscillator scheme‘

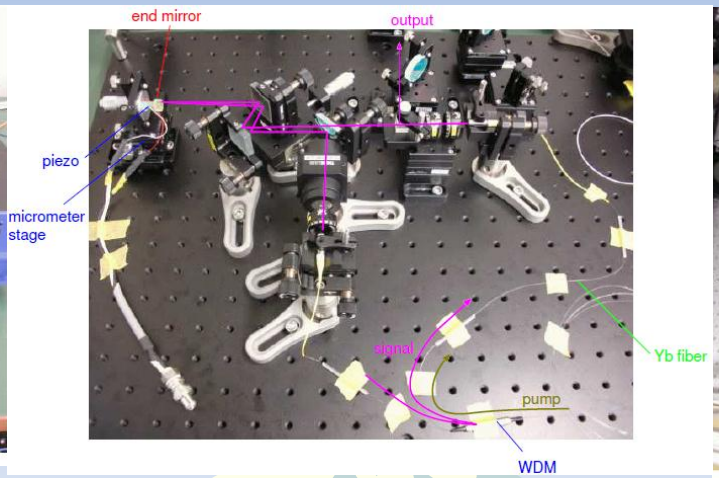


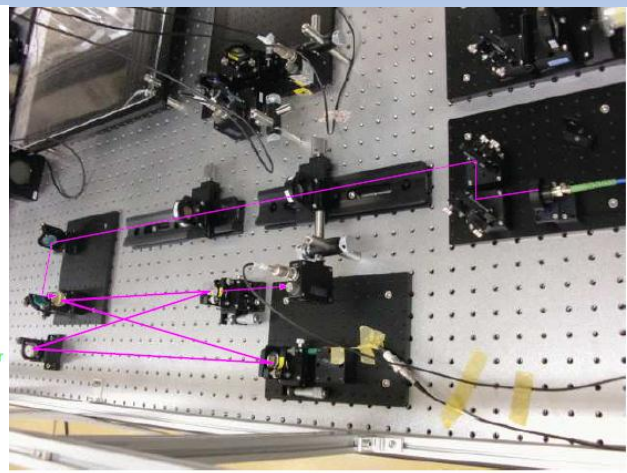


Laser System Development for Optical Cavity

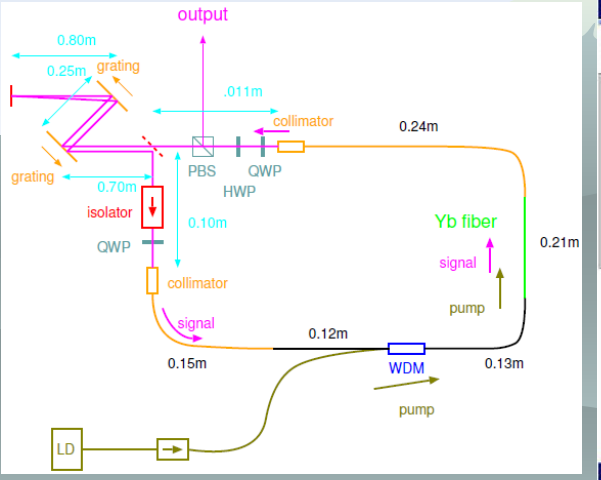


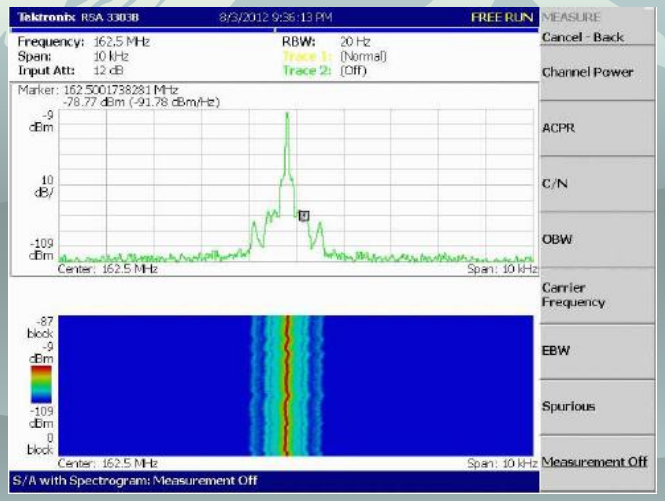


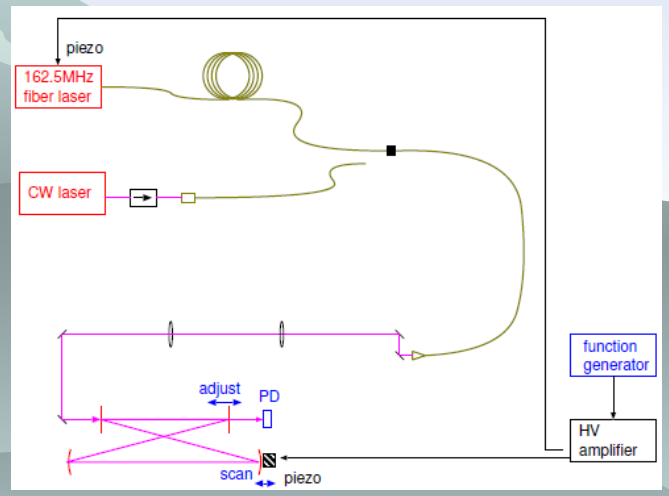




NLPR passive mode lock oscillator (162.5MHz)





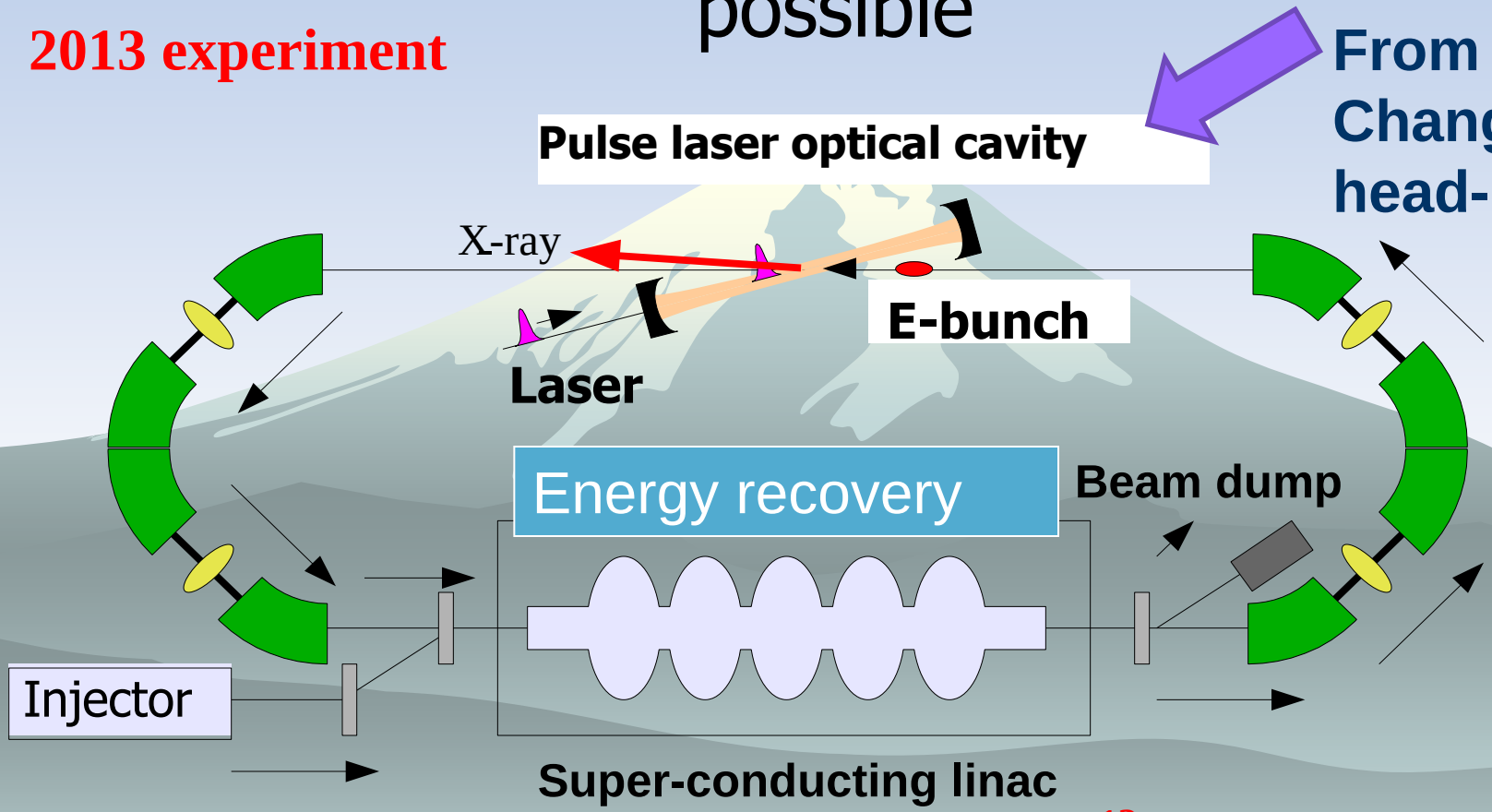


162.5MHz, 350fsec pulse duration, 43mW

7. New plans and schedule

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

2013 experiment



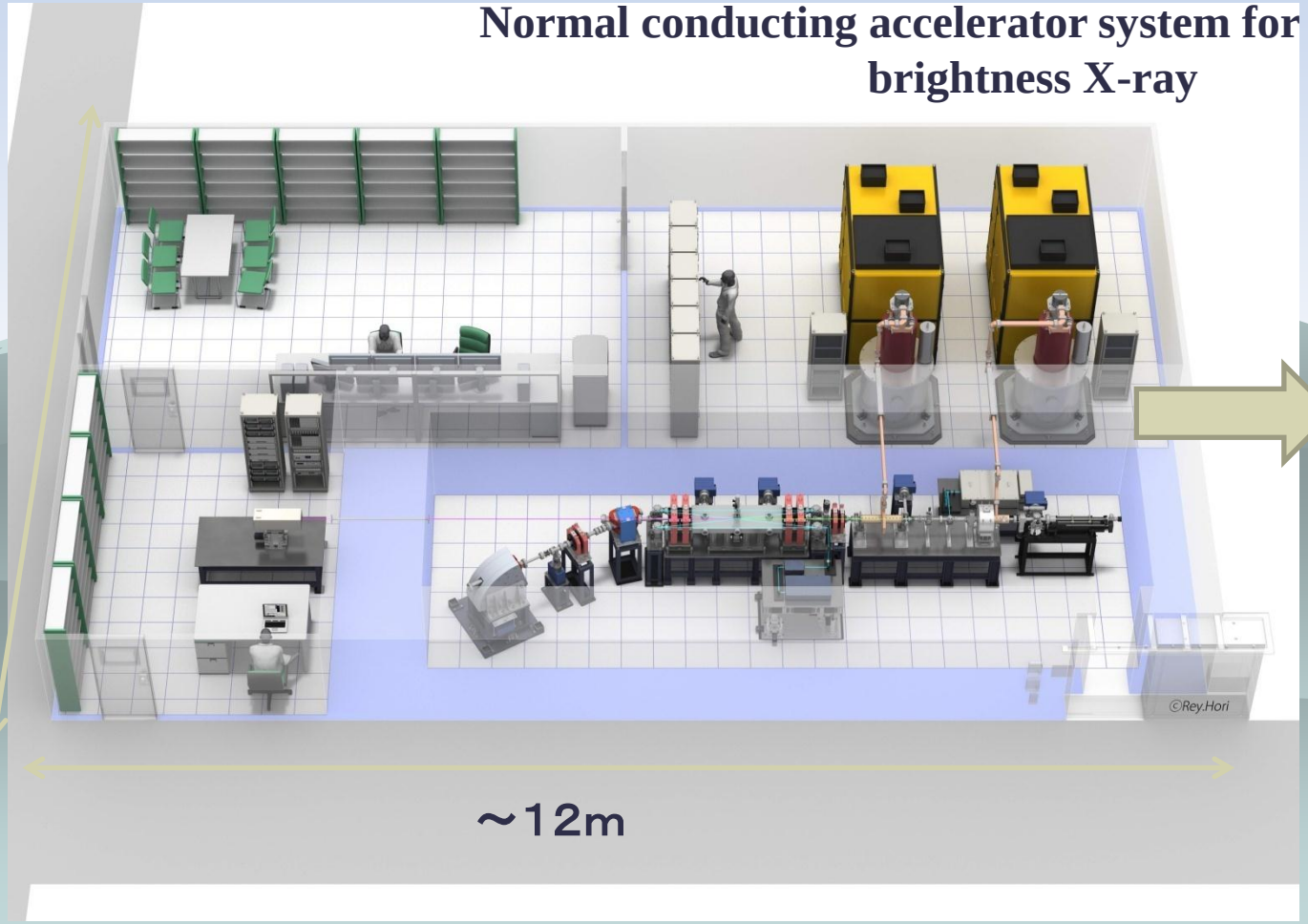
10^{13} photons/(sec･1%b.w.)

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.

Normal conducting accelerator system for compact high brightness X-ray



Downsizing to 6m x 8m