Experimental Plan of X-ray Generation using Optical Resonator

～LUCX Project at KEK～

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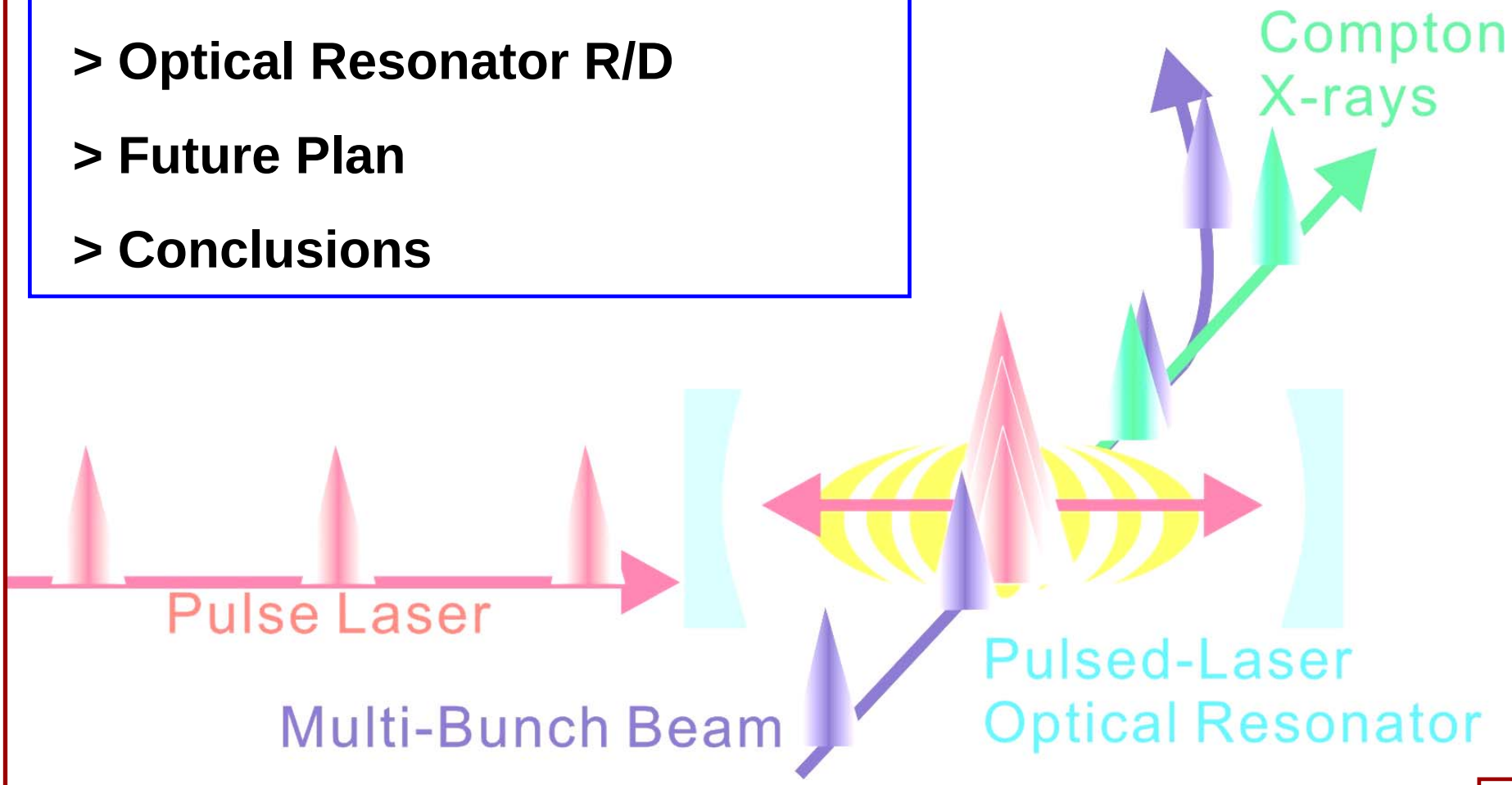


Introduction ~Compact X-ray Sources~

Compact X-ray source is required from various fields.

>**Medical Diagnosis** Angiography, Mammography …

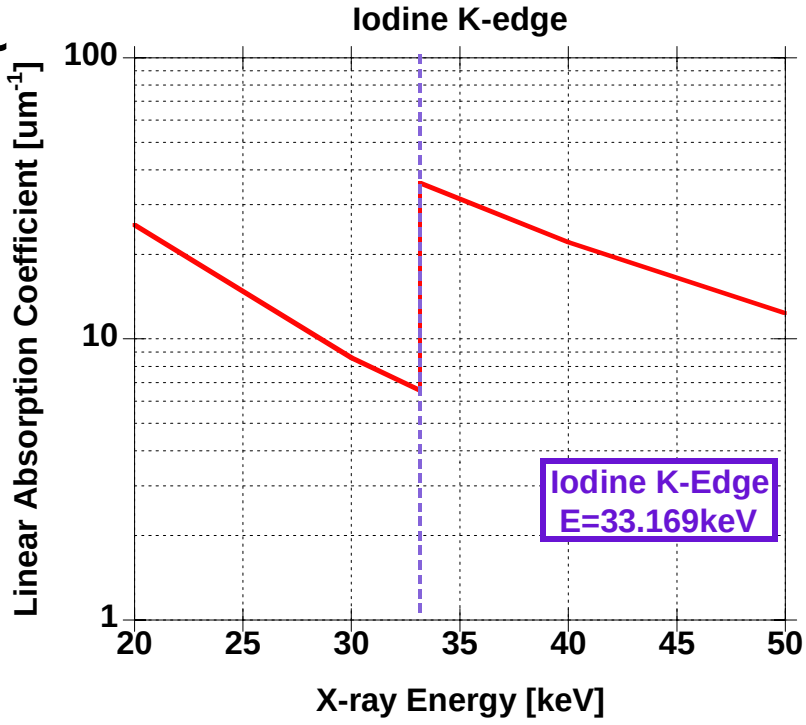
>**Biological Sciences** Soft X-ray microscopy …

>**Drug Manufacturing** X-ray crystal structure analysis …

One example ~Medical Application~

33keV x-rays can use for
K-edge digital subtraction angiography.

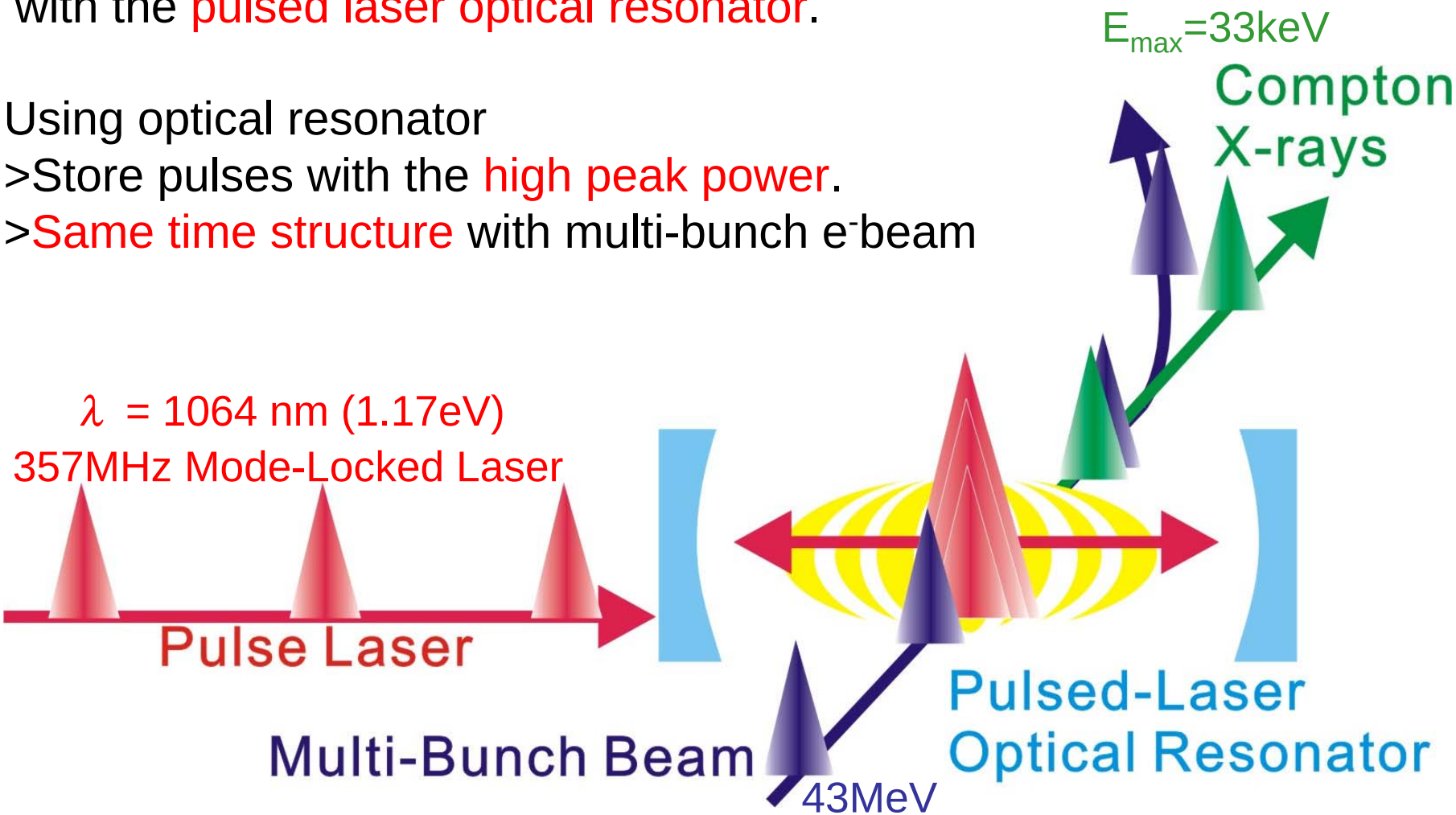
Angiography is a procedure
that enables blood vessels
to be visualized using
the absorption by Iodine at 33keV



Introduction ~Compact X-ray Sources~

We are developing an X-ray source based on Laser Undulator with the pulsed laser optical resonator.

Using optical resonator
>Store pulses with the high peak power.
>Same time structure with multi-bunch e^- beam



Generated from Photo-cathode RF-Gun

Introduction ~Comparison with SR source~

Merit of the X-ray source utilizing laser undulator

○ X-ray source utilizing an undulator at a GeV order storage ring.

High intensity, High stability
but, in general, large amount of money and huge facilities.

○ X-ray source based on Laser Undulator

X-rays can be produced by lower energy e^- beam.
The ring can be downsized. → Compact and Inexpensive

But, we need to demonstrate the method.

Merit of utilizing the pulsed laser resonator

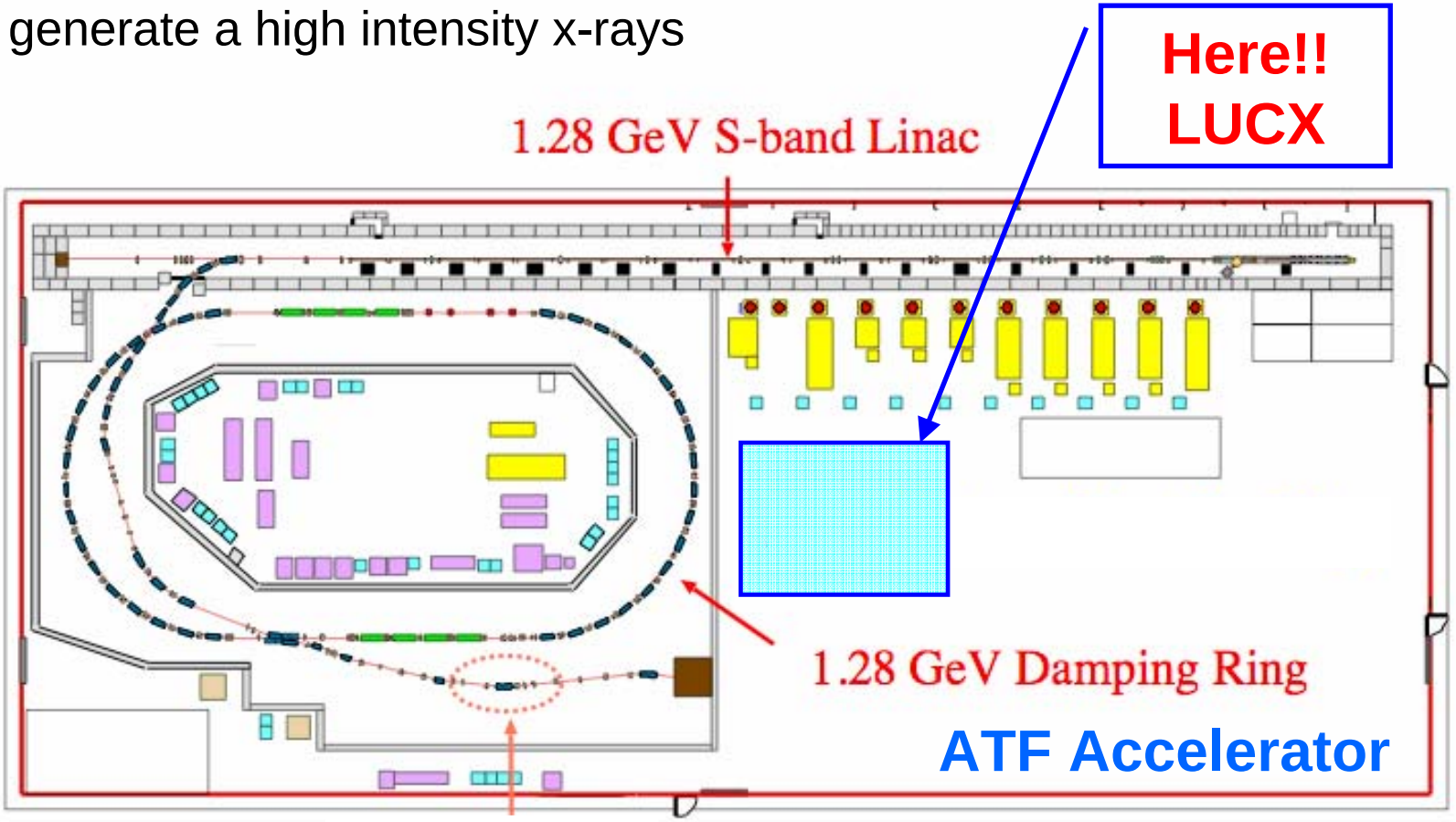
No amplifier system. → Laser system is compact.

A laser pulse can be used again and again for collisions.

→ The laser power is efficiently used.

LUCX Accelerator ~Place of Accelerator~

For compact x-ray source, we constructed the accelerator in ATF building.
Purpose of this accelerator is
>To generate a high intensity multi-bunch beam
>To generate a high intensity x-rays

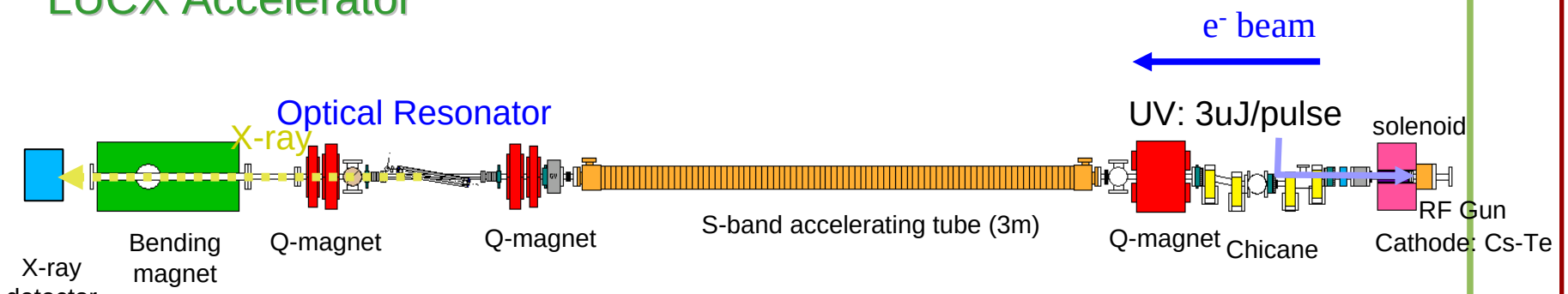


LUCX Accelerator ~Laser Undulator Compact X-ray source~

Photocathode RF-Gun and 3m-Linac
100Bunches/Train
43MeV
Multi-bunch e^- beam

Pulsed Laser
Optical Resonator
420mm (357MHz)
1064nm (Nd:VAN)

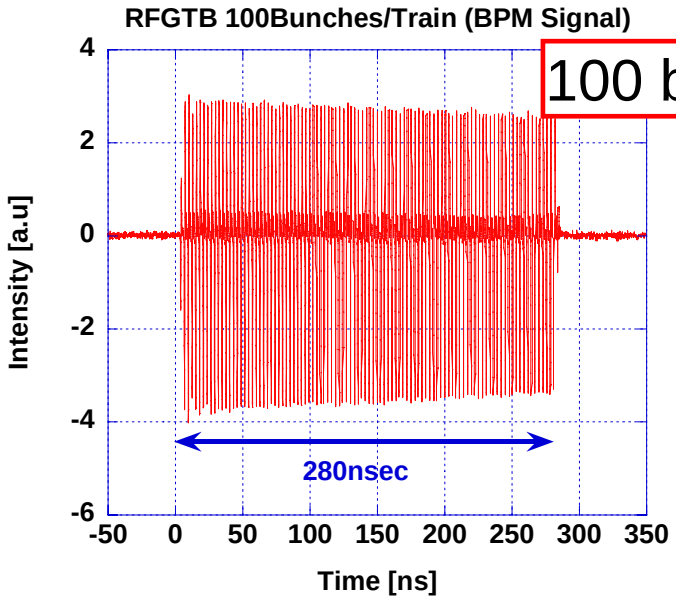
LUCX Accelerator

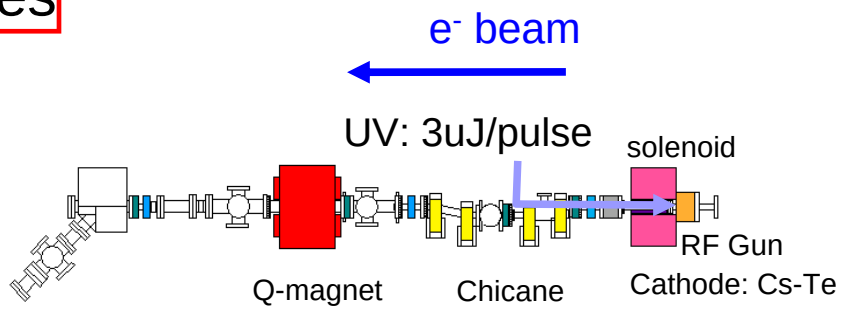


An electron beam is accelerated to 43 MeV.

LUCX Accelerator ~Multi-Bunch Beam Demonstration~

We have demonstrated a 100bunches multi-bunch operation with Cs-Te photo-cathode RF-Gun.

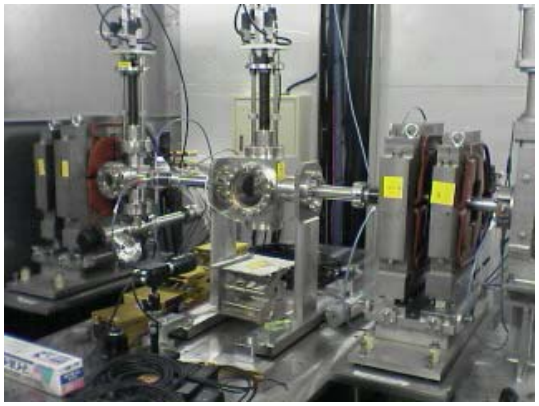
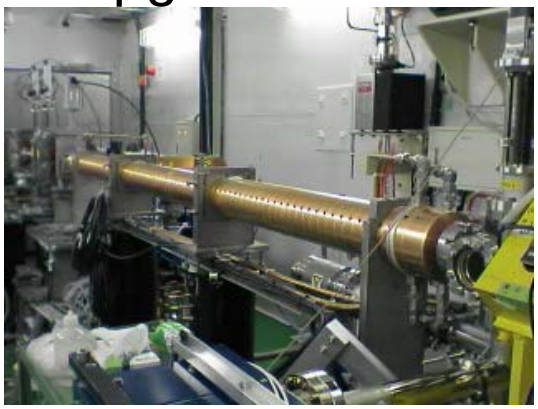
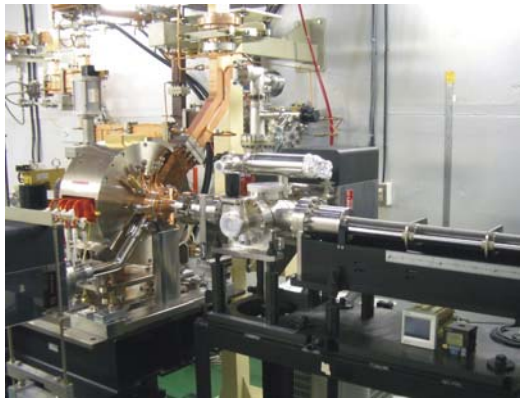


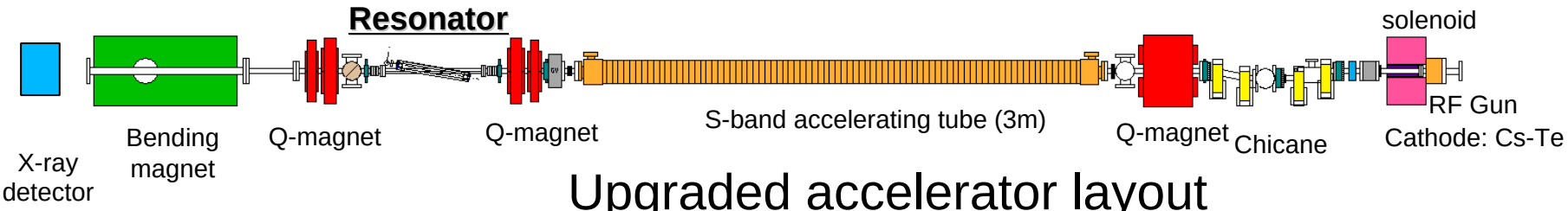


Energy	5 MeV
Intensity	300nC/train
Number of Bunch	100 bunches
Rep. Rate	12.5 Hz

LUCX Accelerator ~Multi-Bunch Beam Accelerator~

After demonstration, we upgraded the accelerator.



Upgraded accelerator layout

Construction has been finished.
Now we are processing
the wave guide and a linac tube.

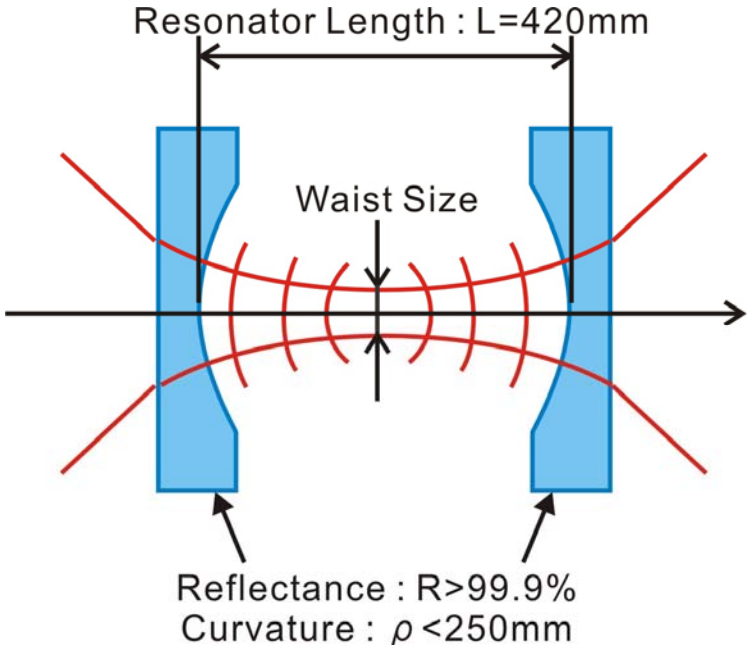
LUCX ~Required Spec of Optical Resonator~

We will install an optical resonator next summer.

Injection Laser : >6W@357MHz
⇨ Cavity Length : 420mm

Beam Waist : <170um
⇨ Mirror Curvature : <250mm

Enhancement Factor : >1000
(Finesse : >3000)
⇨ Mirror Reflectivity : >99.9%



At first, we develop the resonator finesse
to maximize the number of x-rays.

Optical Resonator R/D ~Pulse Laser Optical Resonator~

Pulse Laser Optical Resonator

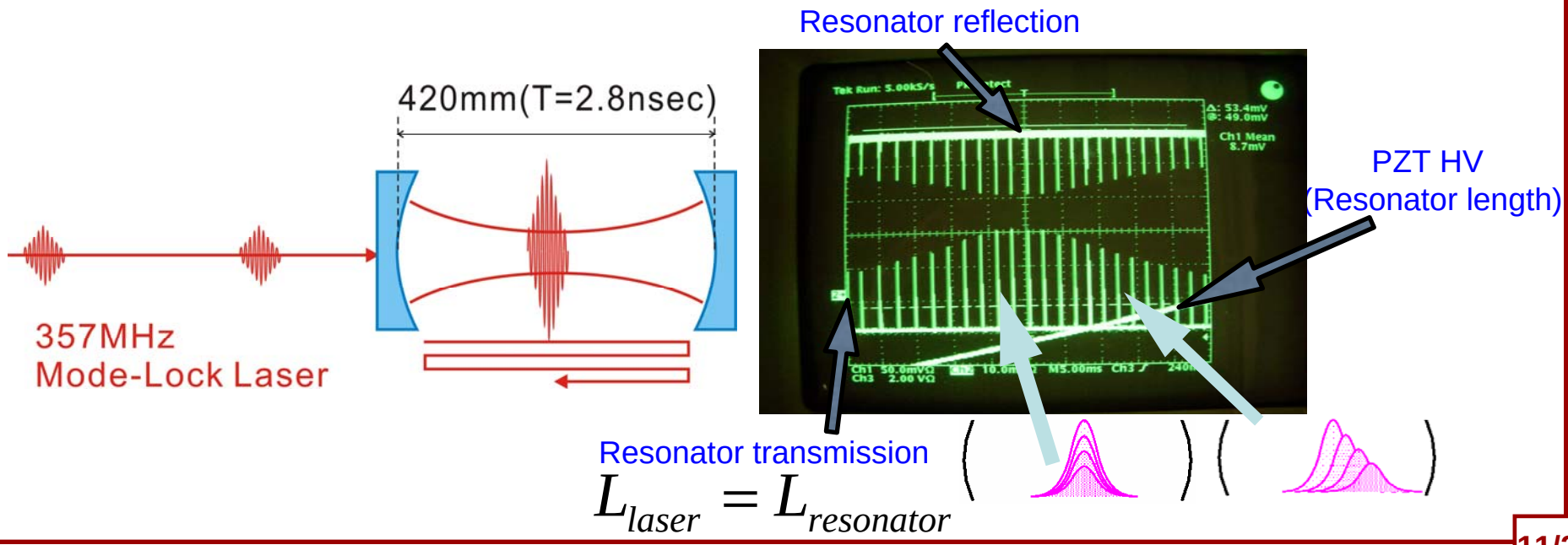
Resonance condition

>**Phase relation**

Resonator length = Integer of half wavelength

>**Envelop superposition**

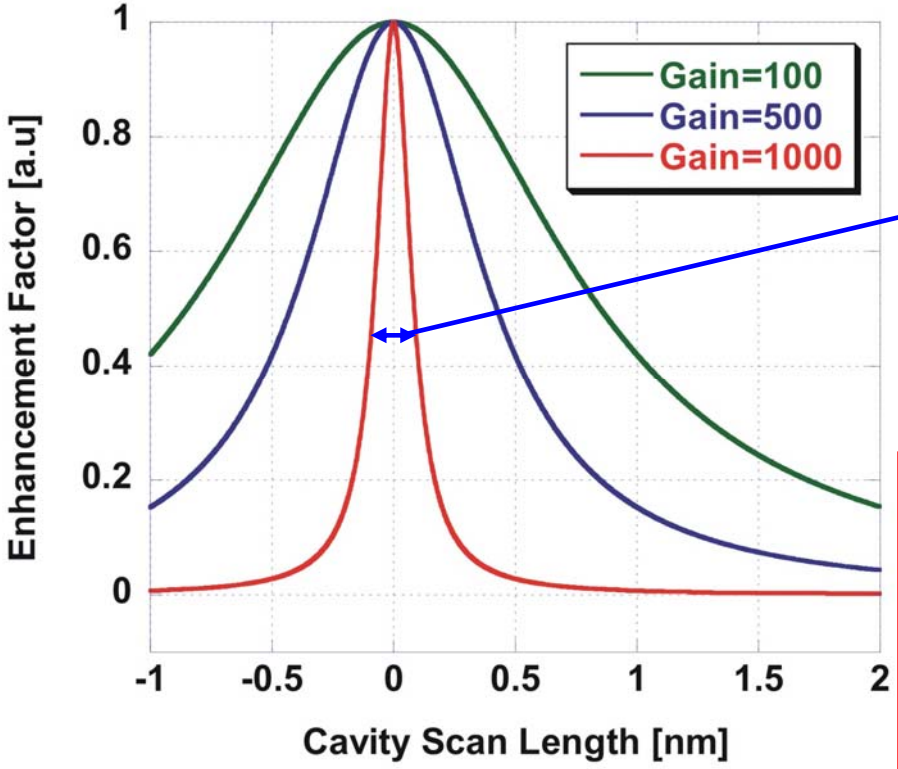
Laser repetition = Round trip time of the optical resonator



$$L_{laser} = L_{resonator}$$

Optical Resonator R/D ~Problems of Optical Resonator~

Width of resonance peak



Enhancement factor=1000
Peak width (FWHM)<0.2nm

No jitter is permitted!!

We should control
the resonator length <0.1nm

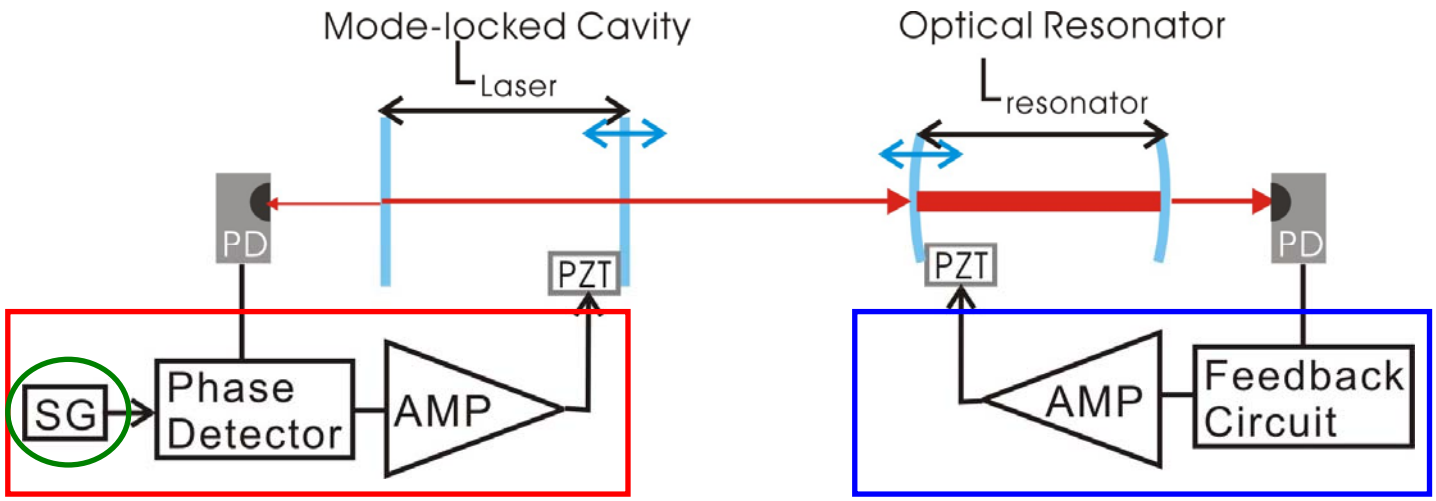
Where are the jitters come from?

>Mode-locked laser FB
Timing stabilizer FB causes a jitter

>Acoustic noises
1~2kHz acoustic jitter appears

Optical Resonator R/D ~Mode-locked laser FB jitter~

Our setup consists of two-cavities, controlled by FB circuit.



Mode-locked laser PLL
(Phase Locked Loop)

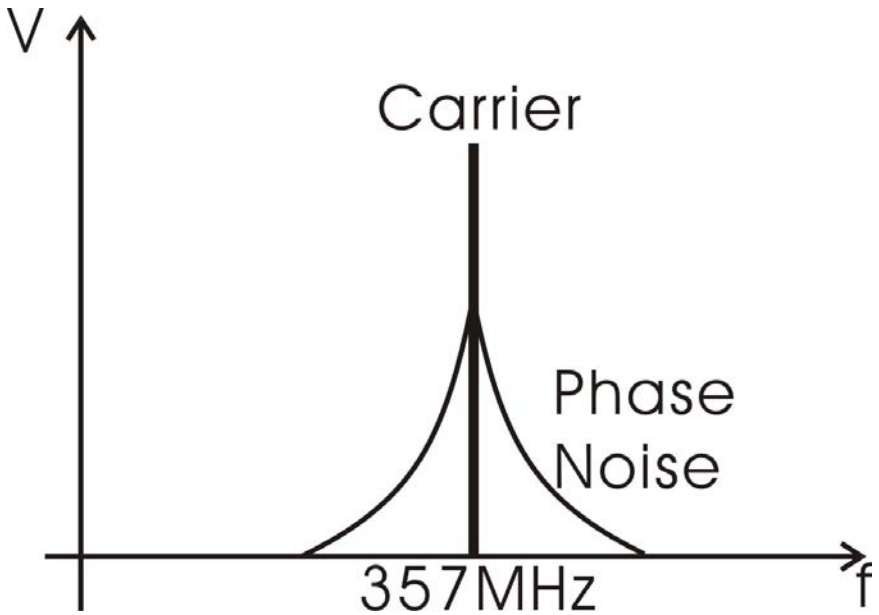
Resonator length is controlled by laser power in resonator to fix “on resonance”

We should adjust the both resonator length less than 0.1nm.

$$L_{laser} = L_{resonator}$$

Optical Resonator R/D ~Mode-locked laser FB jitter~

Mode-locked laser FB jitter source is "signal generator" that generates the reference signal of PLL.



Reference signal has small phase noise.

This noise must be **less than 0.1nm.**

↓

No SG is satisfied this condition.

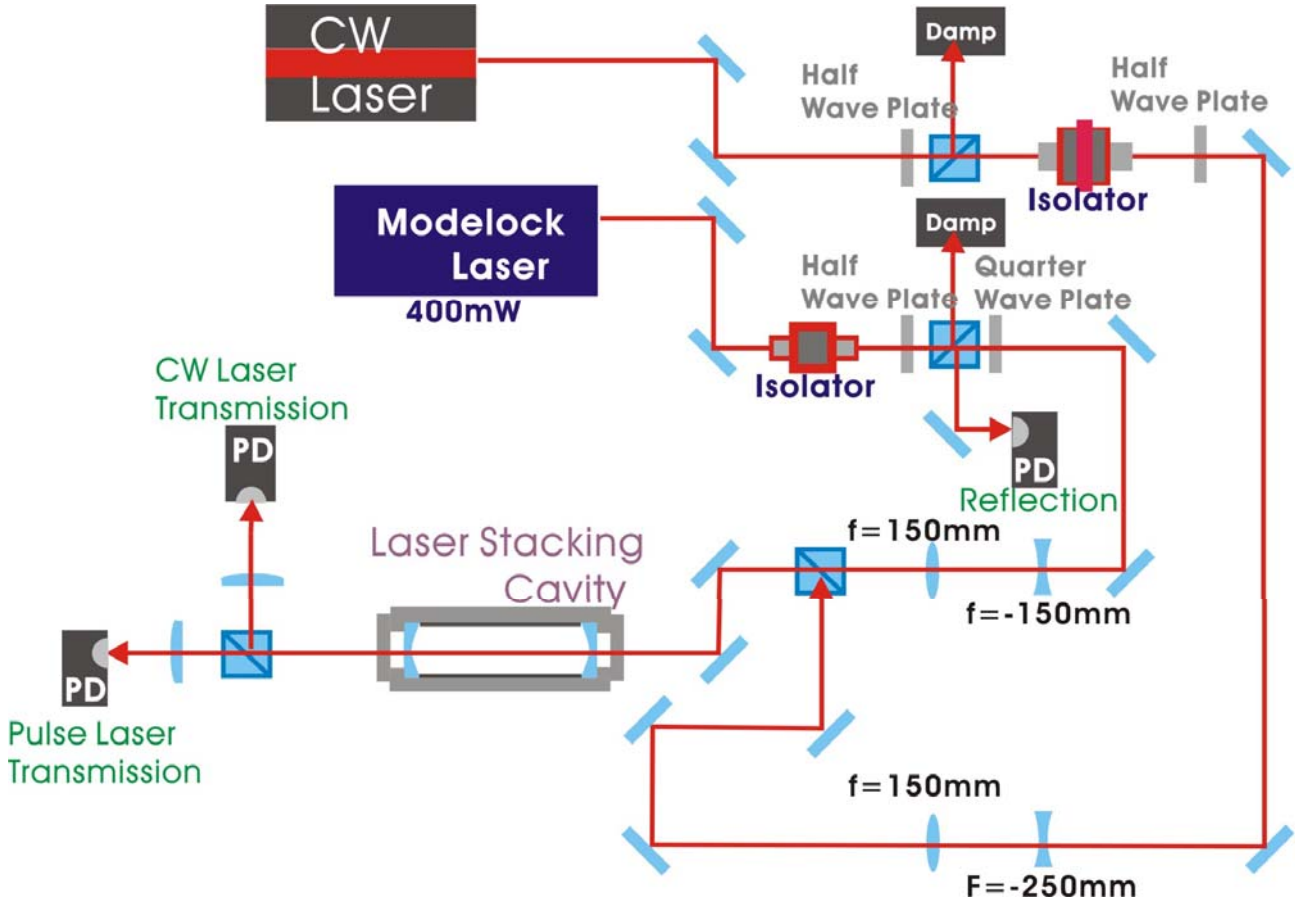
We made a feedback circuit to avoid the phase noises.

↓

We decreased the fast part of the phase noise.

Optical Resonator R/D ~Acoustic Noises~

Our experimental setup of pulse resonator test bench
This setup is suitable to determine the component
that is affected by acoustic noises.



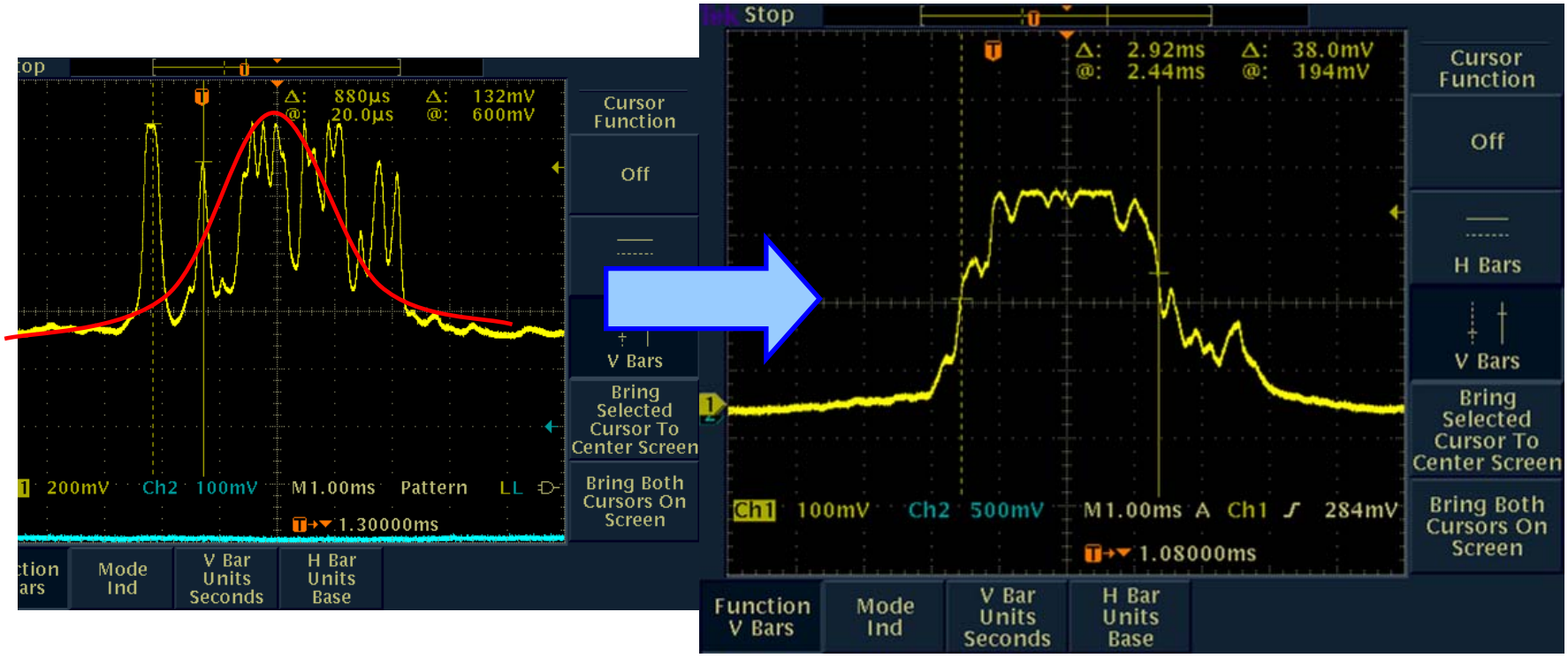
<Feature of setup>

CW laser and pulse laser are stacking in resonator at the same time

Using CW laser ->oscillator is only a **solid crystal** ->Almost acoustic noise is not affective to the oscillator

Optical Resonator R/D ~Acoustic Noises~

After determination of sources,
we make an effort to reduce acoustic noise jitters.
Ex) install dampers for high frequency jitter
soundproof materials

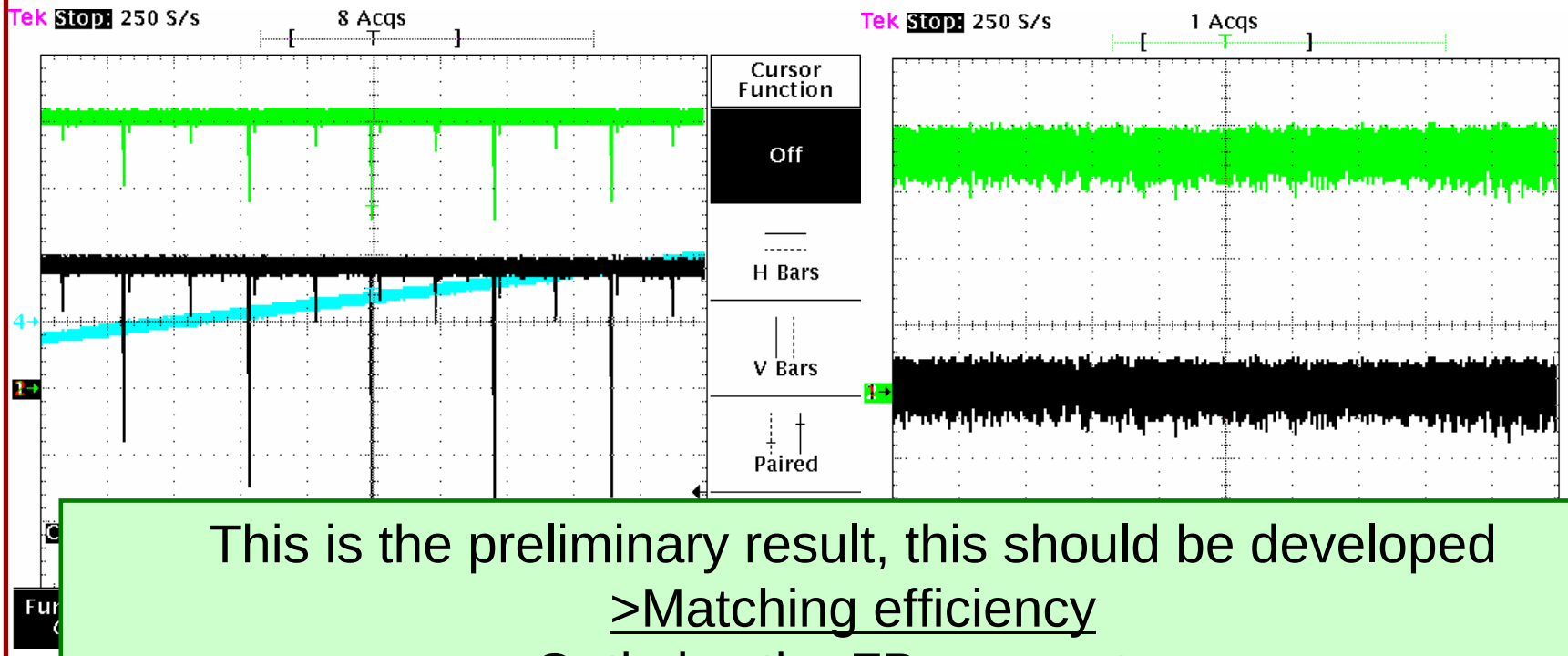


Optical Resonator R/D ~Current Status~

This is the current status of our resonator.

Finesse : 3000~

Intensity Jitter with FB : 15%~ peak-peak



This is the preliminary result, this should be developed

>Matching efficiency

>Optimize the FB parameters

>Resonator FB “on resonance”

Optical Resonator R/D ~Preparation of install resonator~

After several studies to characterize and reduce the jitters, we decide to install the resonator to LUCX accelerator.
The parameter of resonator is as follows.

Frequency Length	Finesse Reflectivity of mirror	Waist Size Curvature of mirror	Inject laser power	Laser power in resonator with FB
357MHz 420mm	~3000 ~99.9%	170um 250mm	6W @357MHz	Now measuring and developing

Schedule of LUCX ~Towards X-ray Generation~

May

ACCELERATOR
>Processing
>Produce the e^- beam

RESONATOR
>Resonator characteristic in TB
>Vacuum test of install chamber

June

ACCELERATOR
>100bunches/train operation
>Beam diagnostics

RESONATOR
>Resonator test in vacuum
>Set up the optical and electrical system

July

>Install the chamber with resonator in LUCX beam line
>Make collision e^- and laser
…and detect the X-rays

Expected X-ray at LUCX

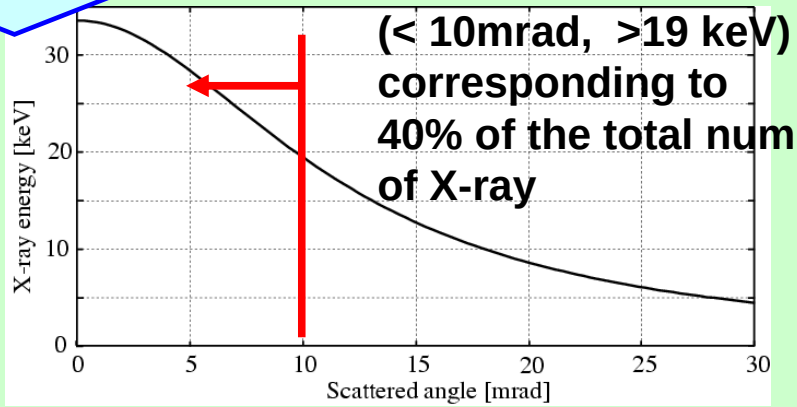
Parameter	Energy	Number	Beam Size	Repetition
Electron	43MeV	200nC /100Bunch	64um(H) 32um(V)	12.5Hz
Photon	1064nm 1.17eV	$6*10^3$Watt 17uJ/pulse	85um(H) 85um(V)	Continuous

Collision angle : 20deg

Take in account the acceptance (< 10mrad),

Expected number of X-rays

2.5 x 10^5 photons/sec



Future Plan ~Final Layout of High Intensity X-ray Source~

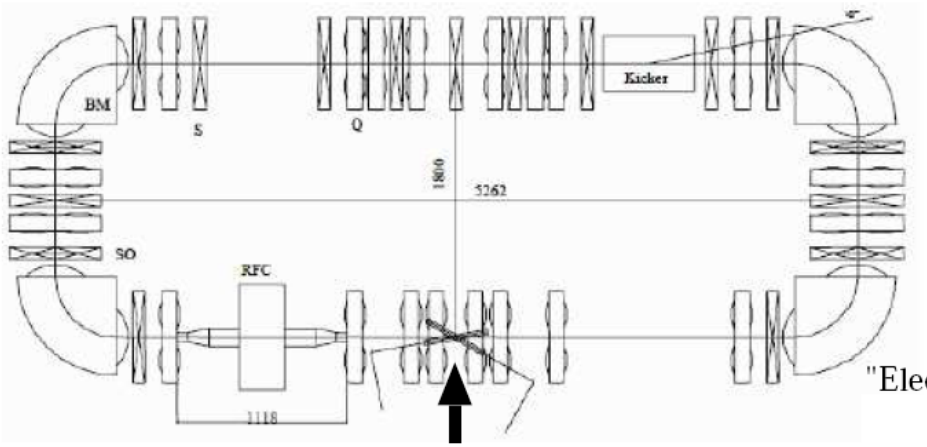
Final layout of our x-ray source

>Small storage ring (13.4m) and pulsed laser optical resonator

Using optical resonator, all bunches in storage ring can interact with laser

⇨ High intensity x-ray can generate

Parameter	Value
Beam Energy	40-82MeV
Number of circulating electron bunches	2; 4; 8; 16; 32
Electron bunch charge	2nC
Electron bunch current	45mA



Compton

storage ring 13.4m.

"Electron beam cooling by laser",
Nucl. Instr. And Meth. **A532**, 388, (2003)

Conclusions

>We have developed the multi-bunch beam accelerator and pulse laser optical resonator for LUCX x-ray generation.

>100bunches/train high quality multi-bunch beam has been generated using Cs-Te photo-cathode rf-gun.
>3m-long linac has been installed and now processing.

>We are studying about many jitter, to construct a stable pulse optical resonator system.
>Finesse ~3000 optical resonator will install in LUCX accelerator.

>In this summer, we will make collision and generate X-rays.

Thank you for your attentions!!