The Physics and Applications of High Brightness Electron Beams, ICFA Workshop

Laser Pulse Circulation System for Monochromatic Hard-X-ray Source

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Background for medical use

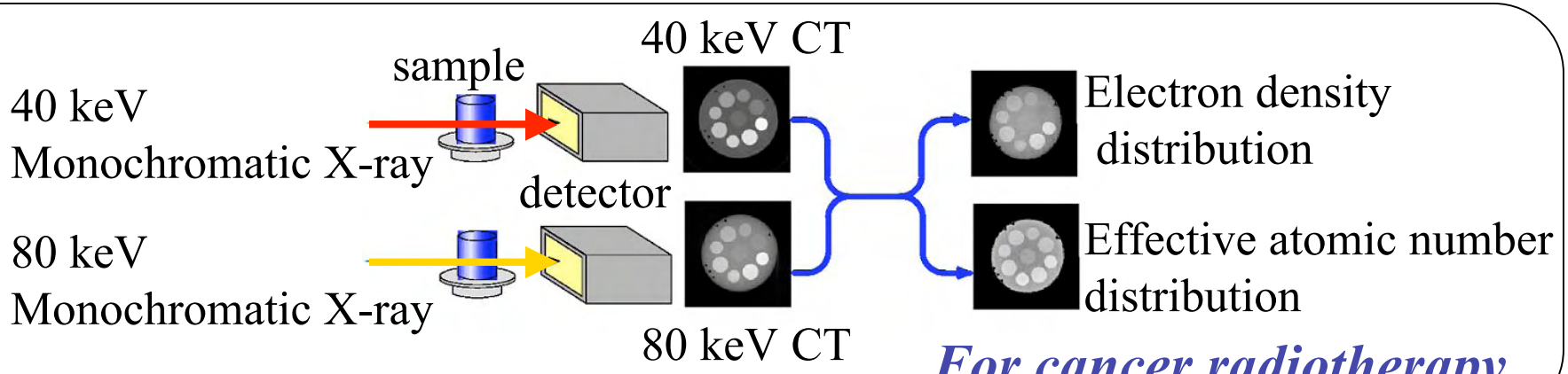
Tunable Monochromatic Hard-X-ray-Source

Synchrotron radiation facility

- High intensity(10^{11}～10^{13}photons/s), but huge size and high cost, difficulty in diffusion
- It takes about a few minutes when we change the X-ray energy

Unfavorable for vital observation

Spring-8, Japan



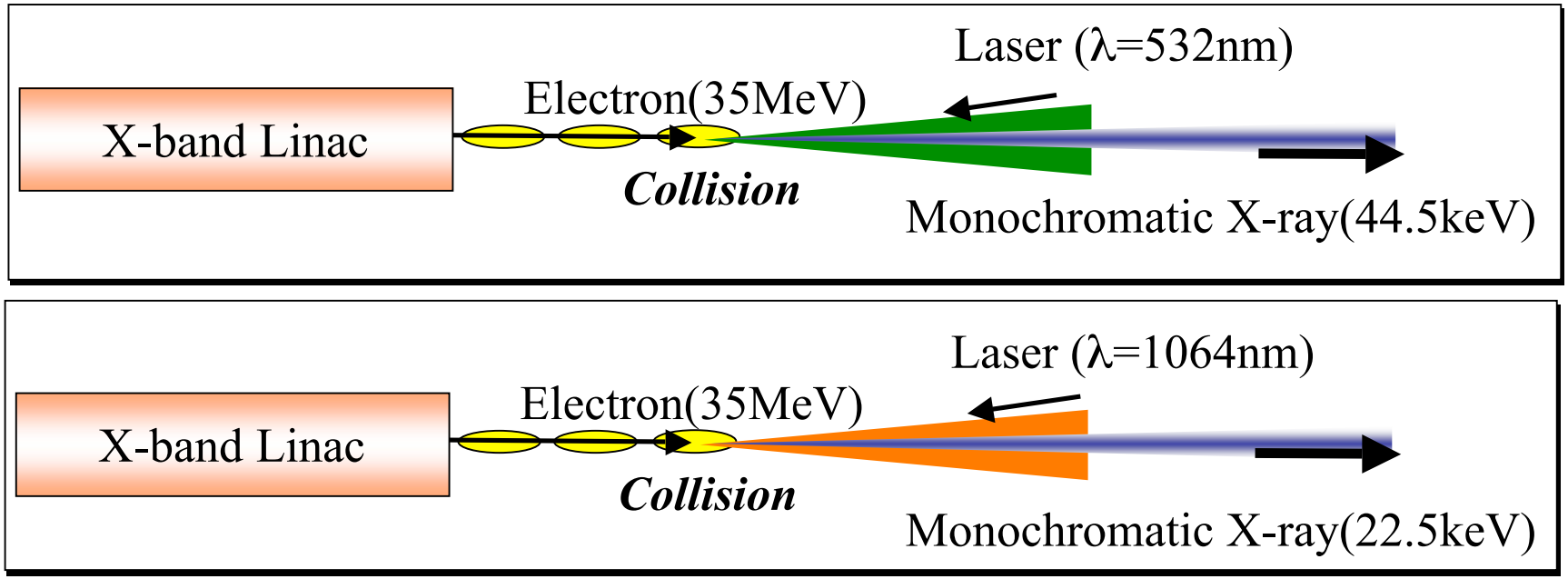
For cancer radiotherapy

We need more smaller system for vital observation

Laser Electron Compton Scattering Tunable Monochromatic Hard-X-ray Source

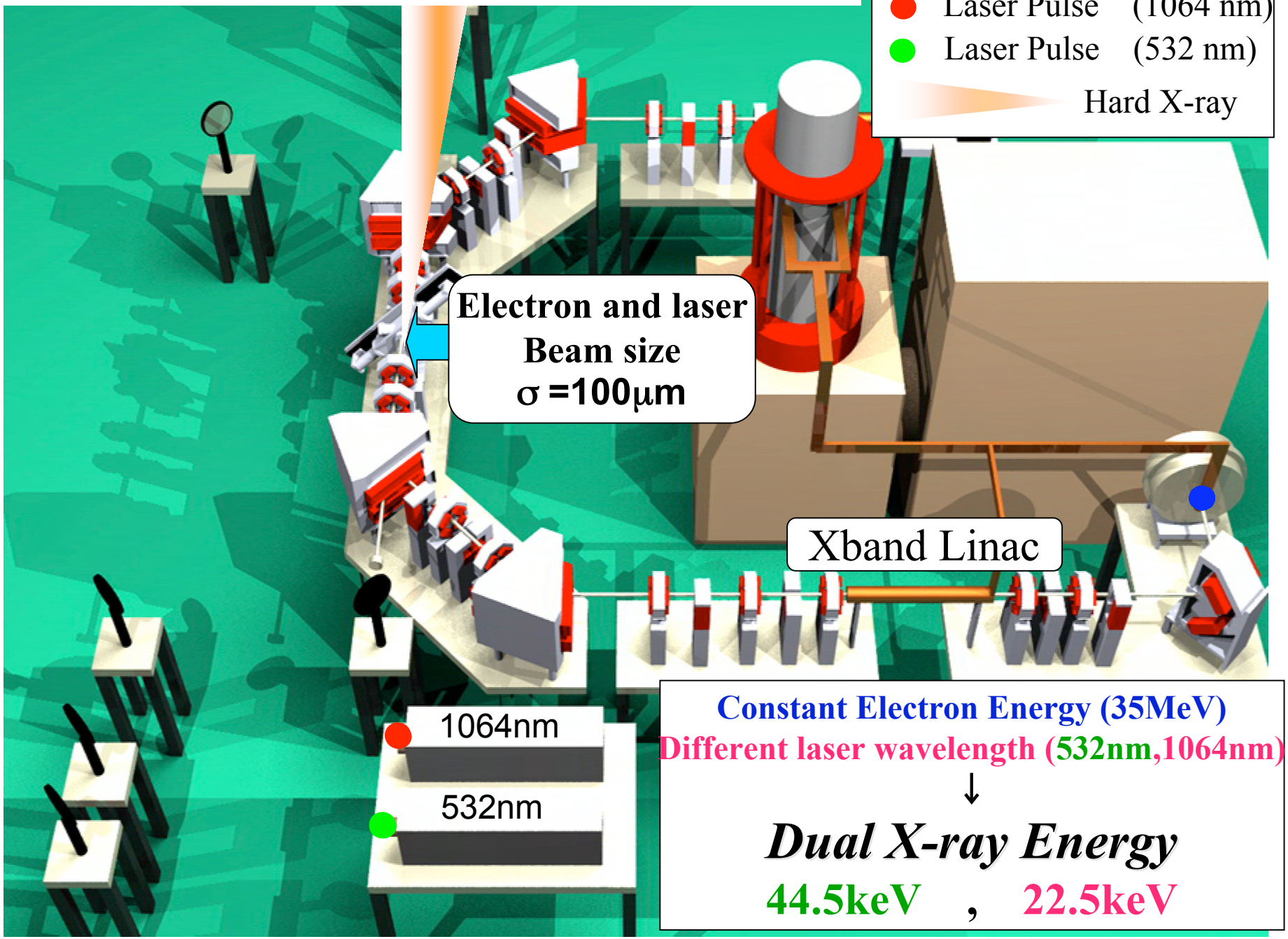
The X-ray energy is depend on electron energy and laser wavelengh.

Same electron energy + different laser wavelength = different monochromatic X-ray

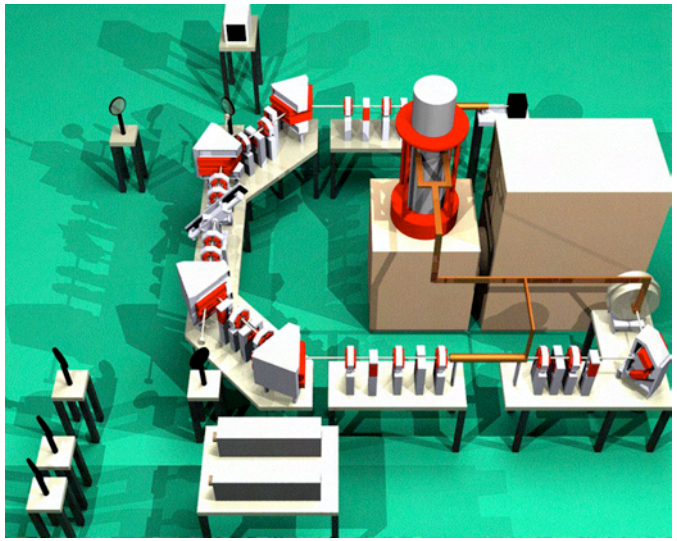


Two laser system will be installed and they collide with 35MeV electron beam by turns and it takes about 40ms to change the laser wavelength, then the 44.5keV and 22.5keV X-ray will be generated by turns.The intensity will be 10^8photons/s.

The smaller system for vital observation



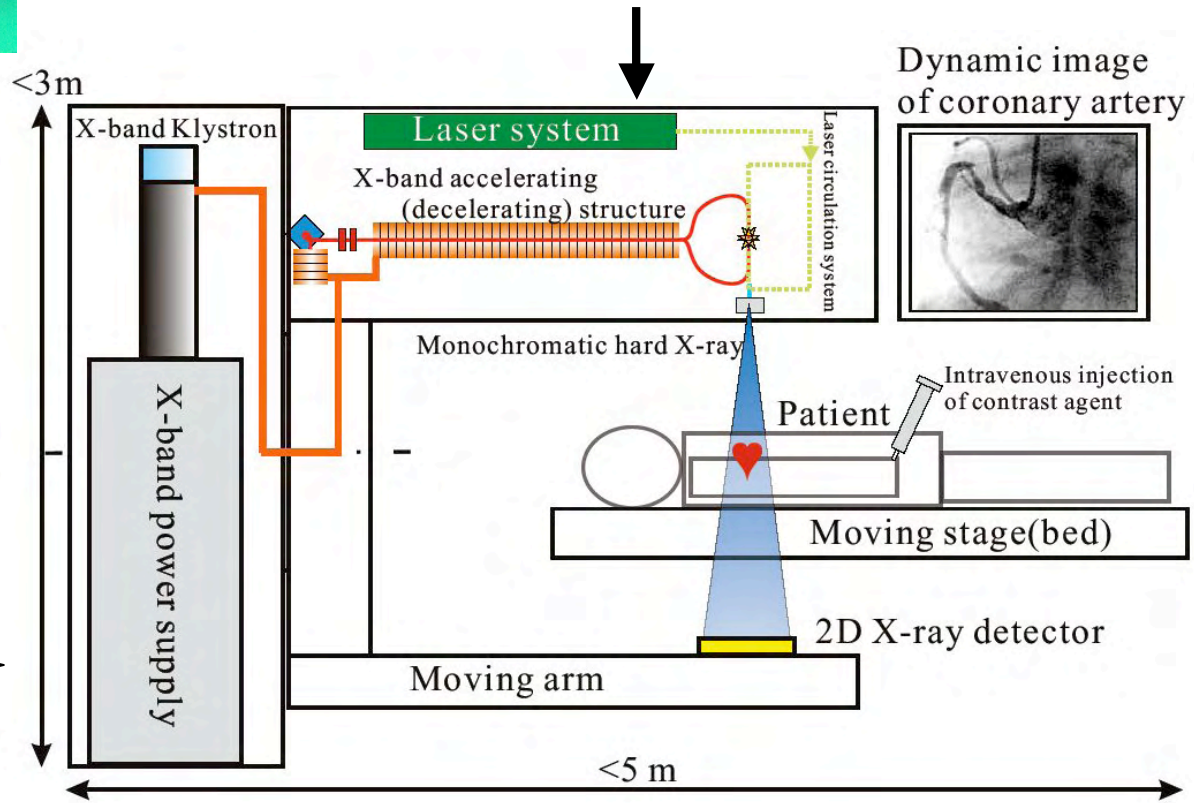
Final goal



Now we are developing the experiment proof of laser electron Compton scattering X-ray source.

Our final goal is shown below, it can be installed inside the hospital room.

Smaller system



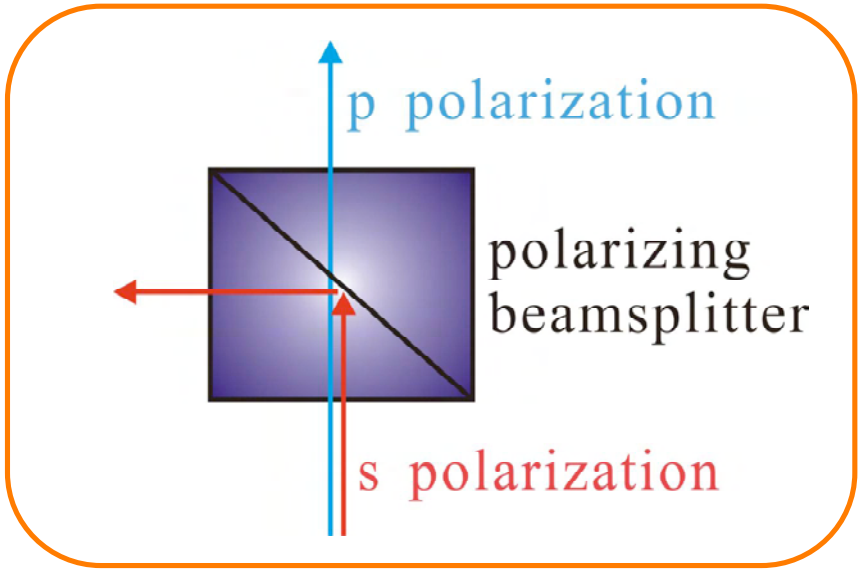
What is laser pulse circulation system?

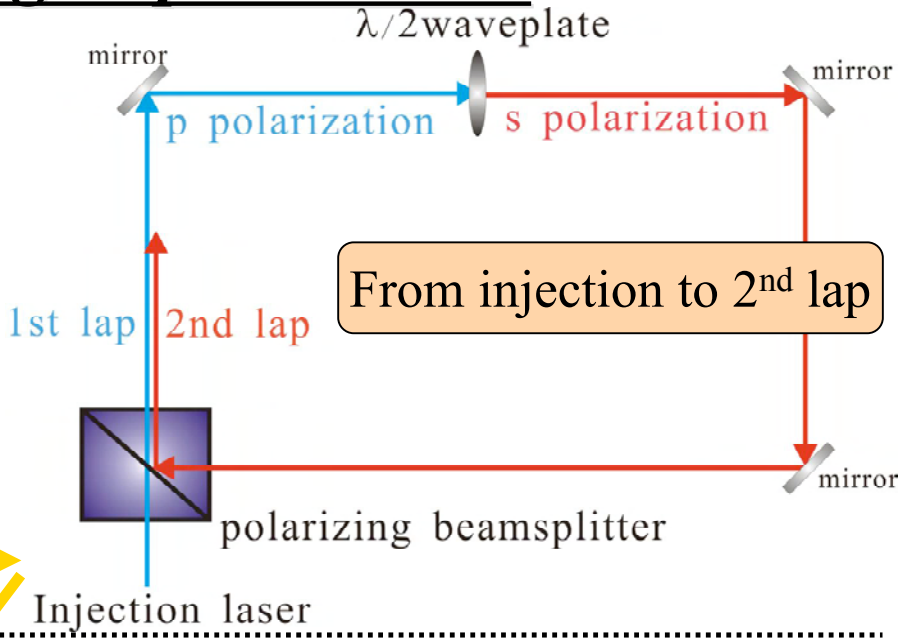
The LPCS (Laser Pulse Circulation System) can make the laser Pulse overlap with the electron beams at transverse and longitudinal direction. It will lead to the stable and efficient X-ray generation at the laser electron collision experiment.

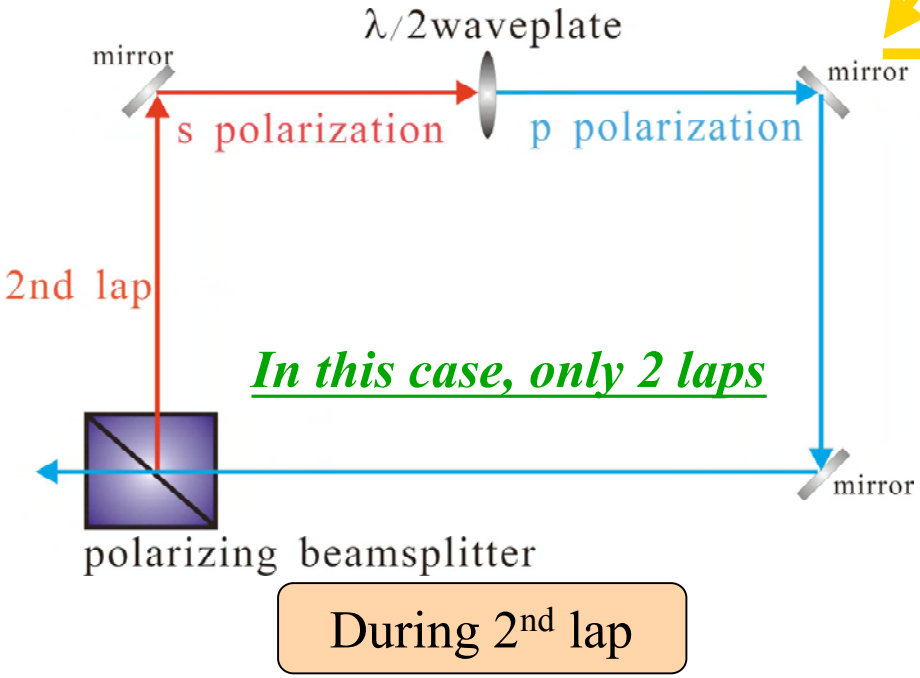
Longitudinal direction	Laser pulse(10ns,FWHM) is blocked into the circuit (5m) and it collides with electron beams(1μs).The collision period is about 20ns. →The recycle of laser pulse (one laser pulse collides 50times)
Transverse direction	It is more difficult to modify the position of electron beams because we have to change the magnet parameter, so we modify the position of laser from outside the circuit. →We change the transverse laser position and beam size(rms).

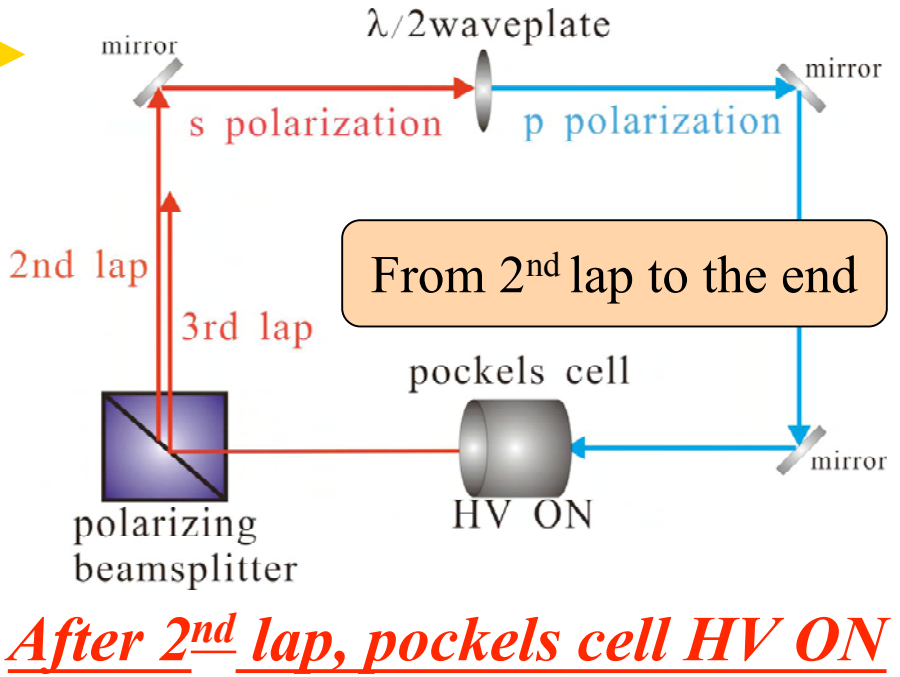
The X-ray intensity is calculated to be 10^8photon/s without LPCS. LPCS can intensify it 10times stronger, that is 10^9photons/s.

Longitudinal LPCS by changing its polarization

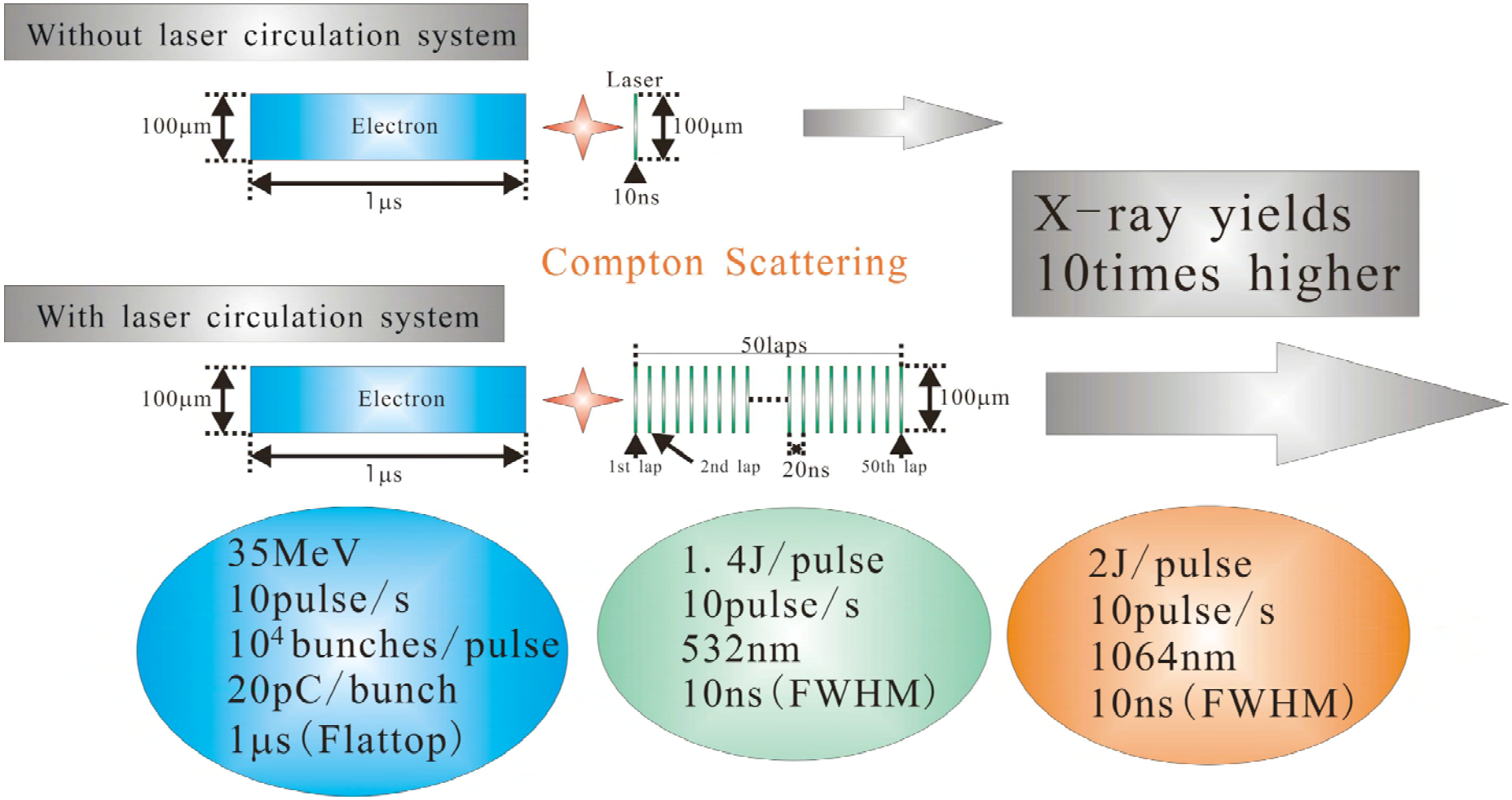




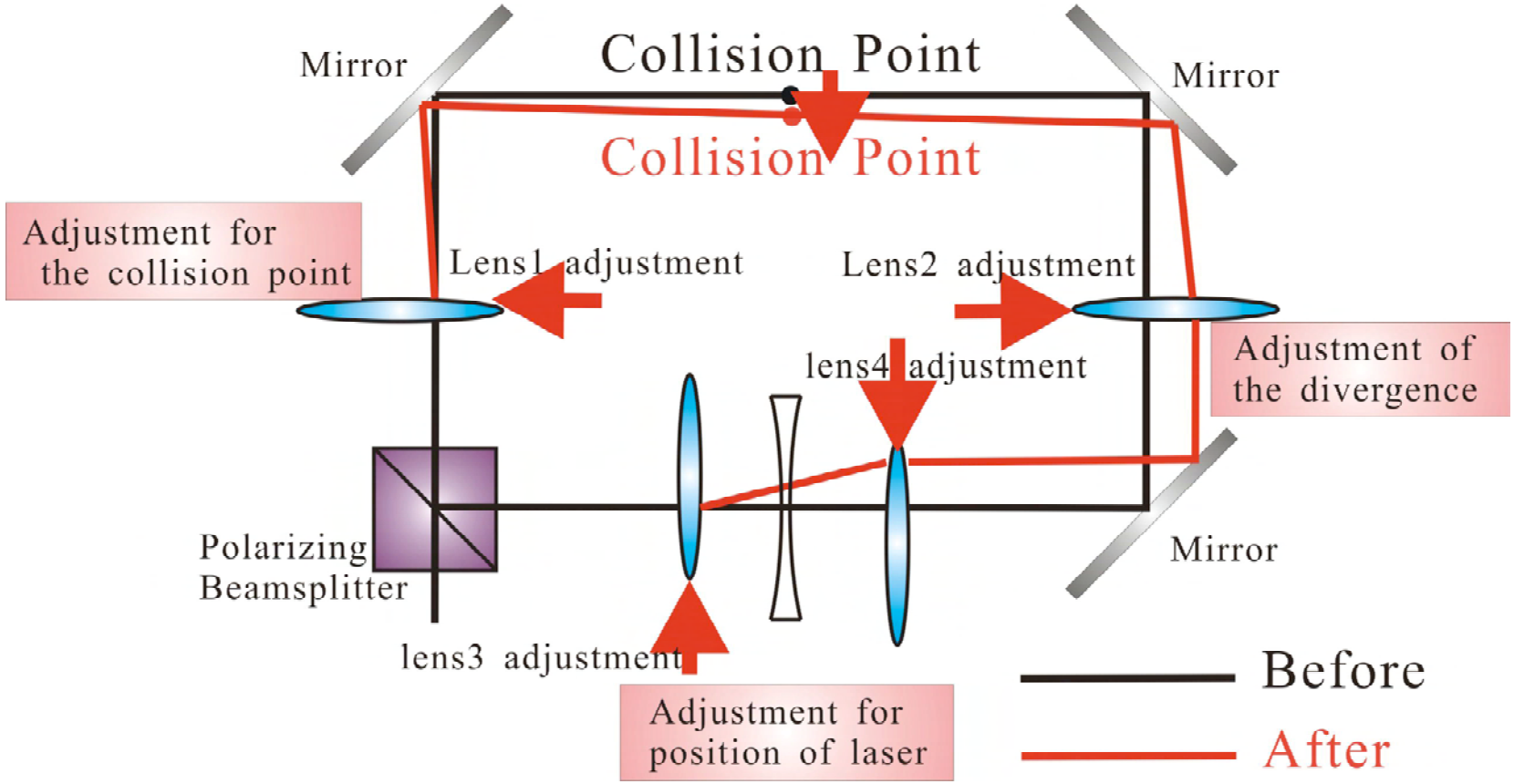




LPCS at the longitudinal direction



Transverse LPCS by shifting the lens position



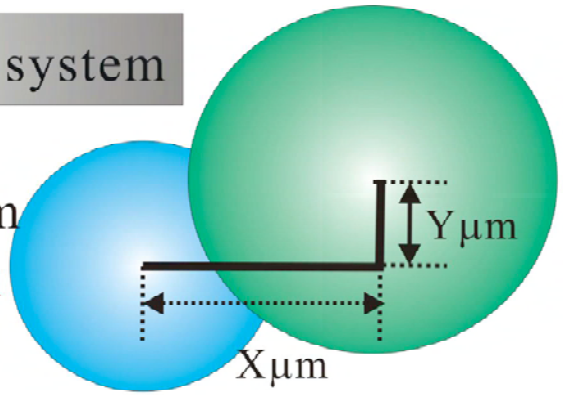
Same resolution

The distance of lens adjustment ⟷ The distance of collision point

The position of laser collision point can be changed with μm order, and the laser keeps the same condition without reference to the lens adjustment.

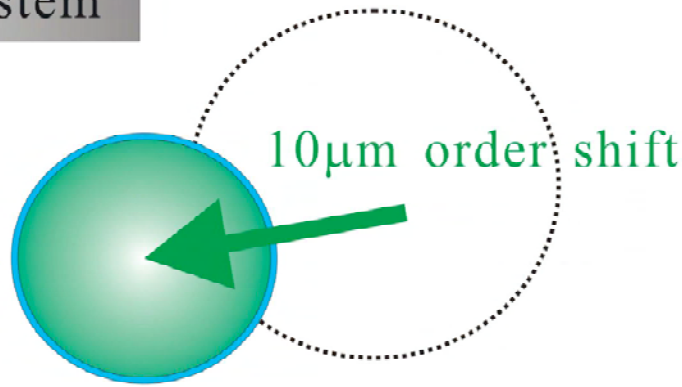
LPCS at the transverse direction

Without laser circulation system



Different size
Different position → Inefficient

With laser circulation system



Same size
Same position → Efficient

electron & laser beam size σ=100μm

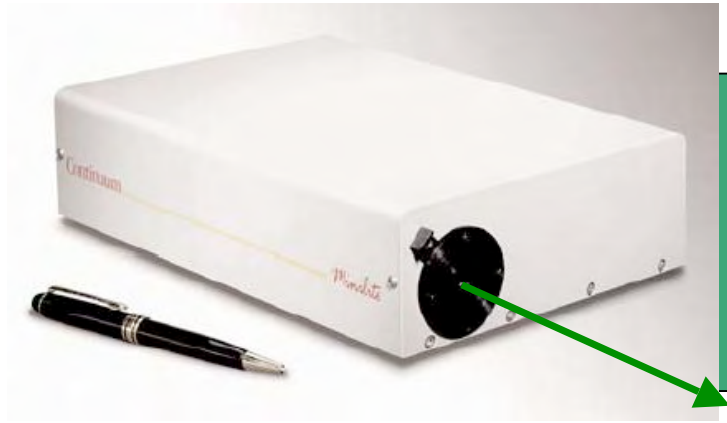
LPCS principle experiment

- ***Purpose***

  To establish by proof of Laser Pulse Circulation System for longitudinal and transverse direction.

Longitudinal direction	To make the laser circulate by changing its polarization. To measure the LPCS and calculate the transfer efficiency and energy intension.
Transverse direction	To change the laser position by moving four lenses and to keep the circulation condition.

Q-switch Nd:YAG Laser



532nm

25mJ/pulse

10Hz

PHOTONIC SOLUTIONS, MINILITE2

Low energy laser

(MAX:25mJ/pulse)

second harmonic wave

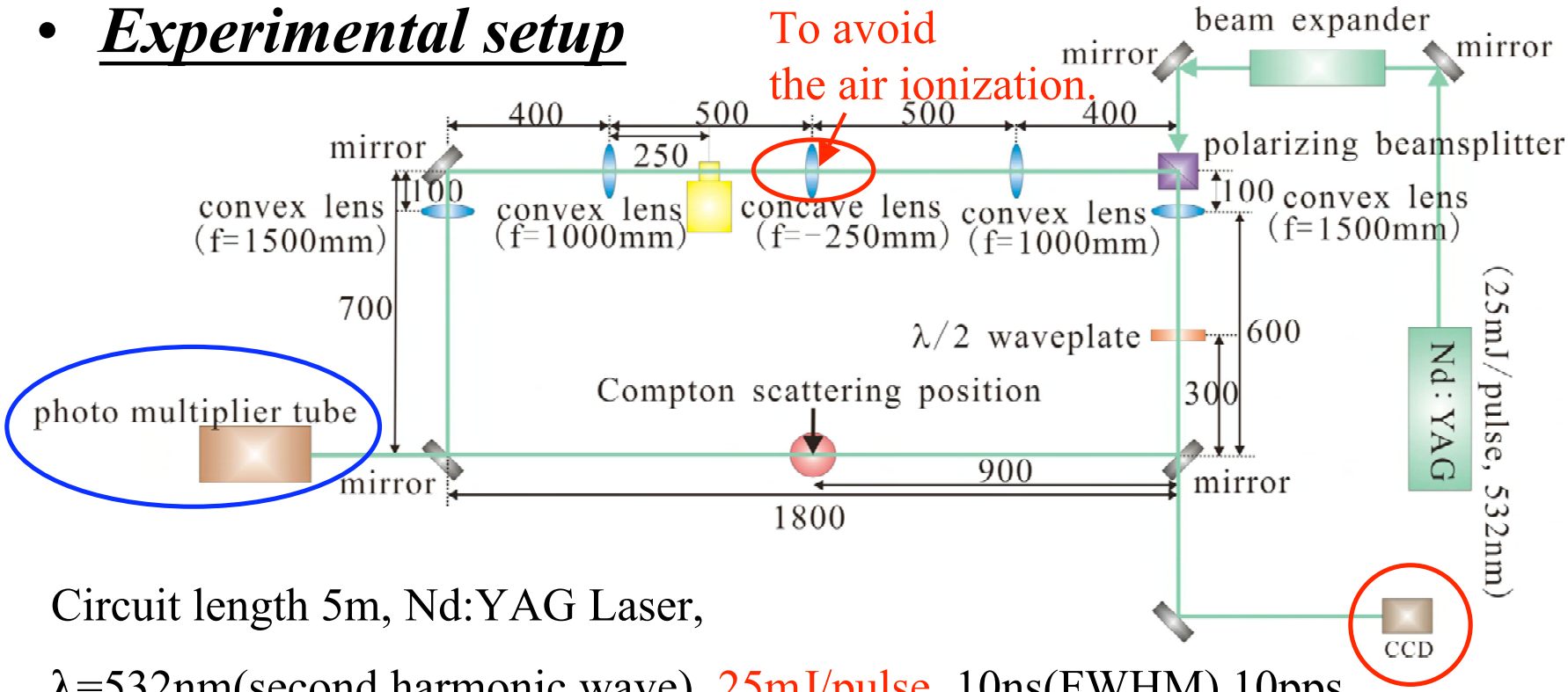
(λ=532nm)

Fundamental wave experiment will be held on 2005.12～

LPCS principle experiment

Low energy laser(532nm) and no electron beam

- ***Experimental setup***



Circuit length 5m, Nd:YAG Laser,

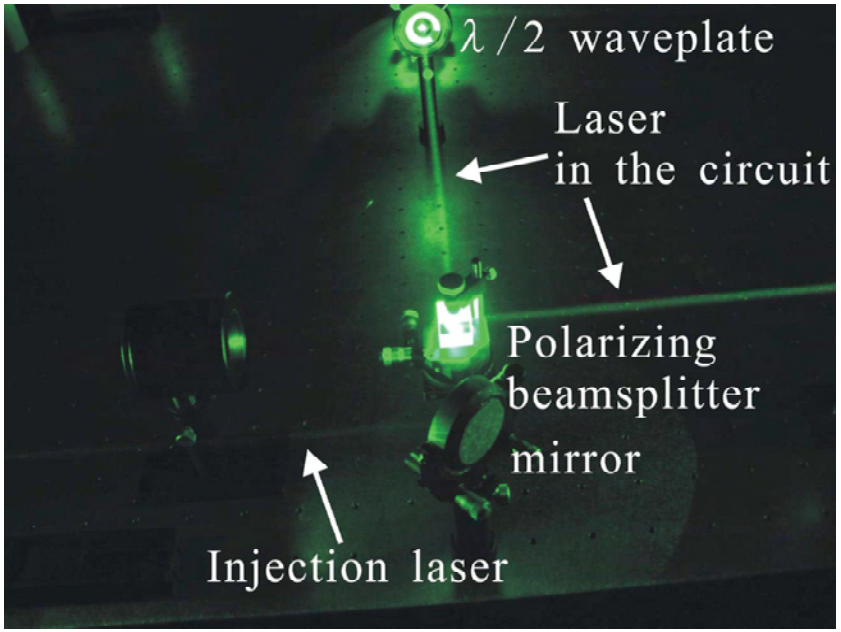
λ=532nm(second harmonic wave), 25mJ/pulse, 10ns(FWHM),10pps

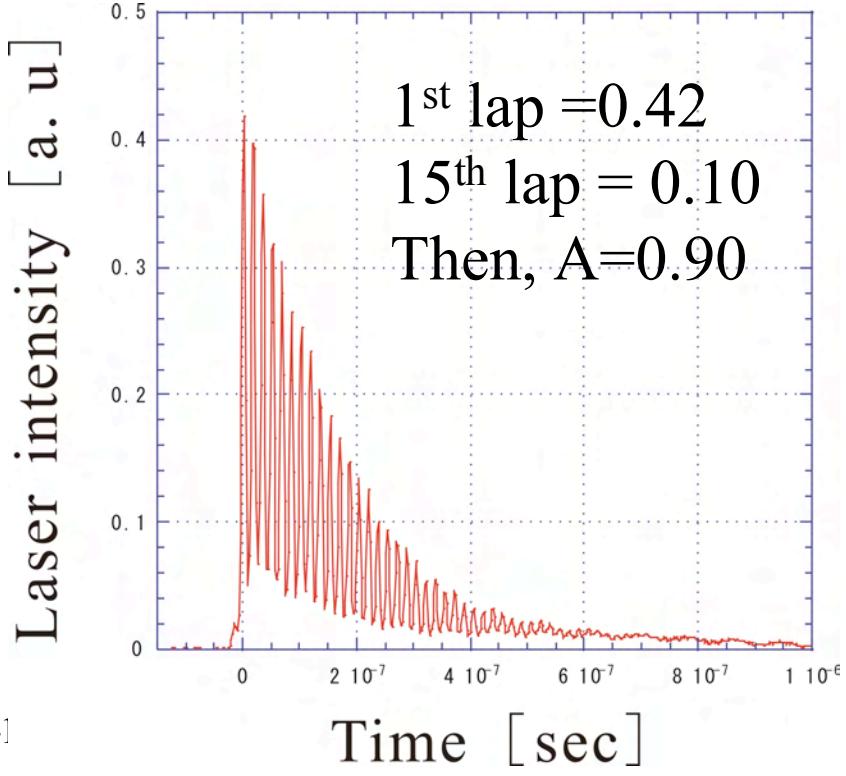
- ***How to measure the LPCS***

Longitudinal LPCS → Photo multiplier

Transverse LPCS → CCD camera (laser position and beam size)

LPCS experiment result, longitudinal direction





$$I_n = I_0 + I_0 A + I_0 A^2 + \cdots\cdots + I_0 A^{n-1}$$

$$I_n = \sum_{k=1}^{n} I_0 A^{k-1} = I_0 \frac{1 - A^n}{1 - A}$$

A=0.90, n=50

Then, ***10times higher intensity***

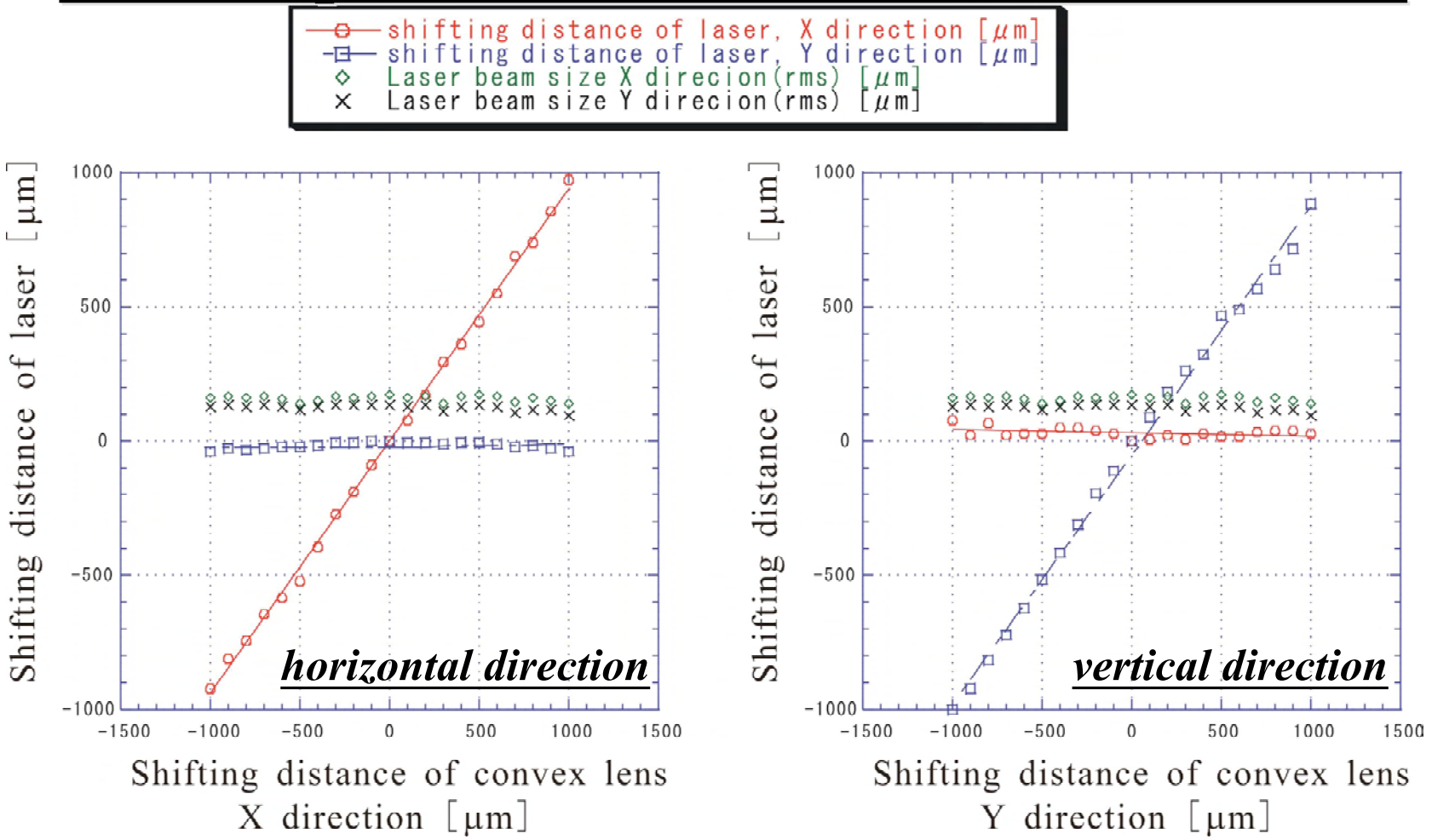
I_0: Incident laser pulse energy.

I_n: Laser intensity in the laser pulse circulation system.

A: Transmission efficiency per one cycle.

n: Total number of the collisions.

LPCS experiment result, transverse direction

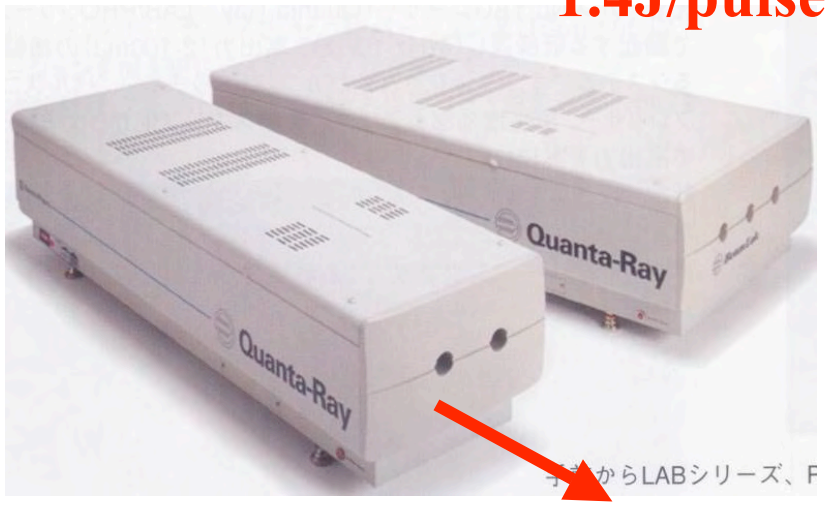


It can be proved that the transverse position of laser can be controlled independently with the same resolution of four convex lenses shifting (μm order). Laser can keep beam size while shifting its position.

LPCS for laser electron Compton scattering experiment

- ***High power Laser***

1.4J/pulse



Spectra Physics Quanta-ray Pro-290

Principle experiment
25mJ/pulse

PHOTONIC SOLUTIONS, MINILITE2

Principle experiment → Nd:YAG Laser, 25mJ/pulse,532nm,10ns(FWHM),10Hz

Both Q-switch Nd:YAG Laser

High power laser for Compton scattering

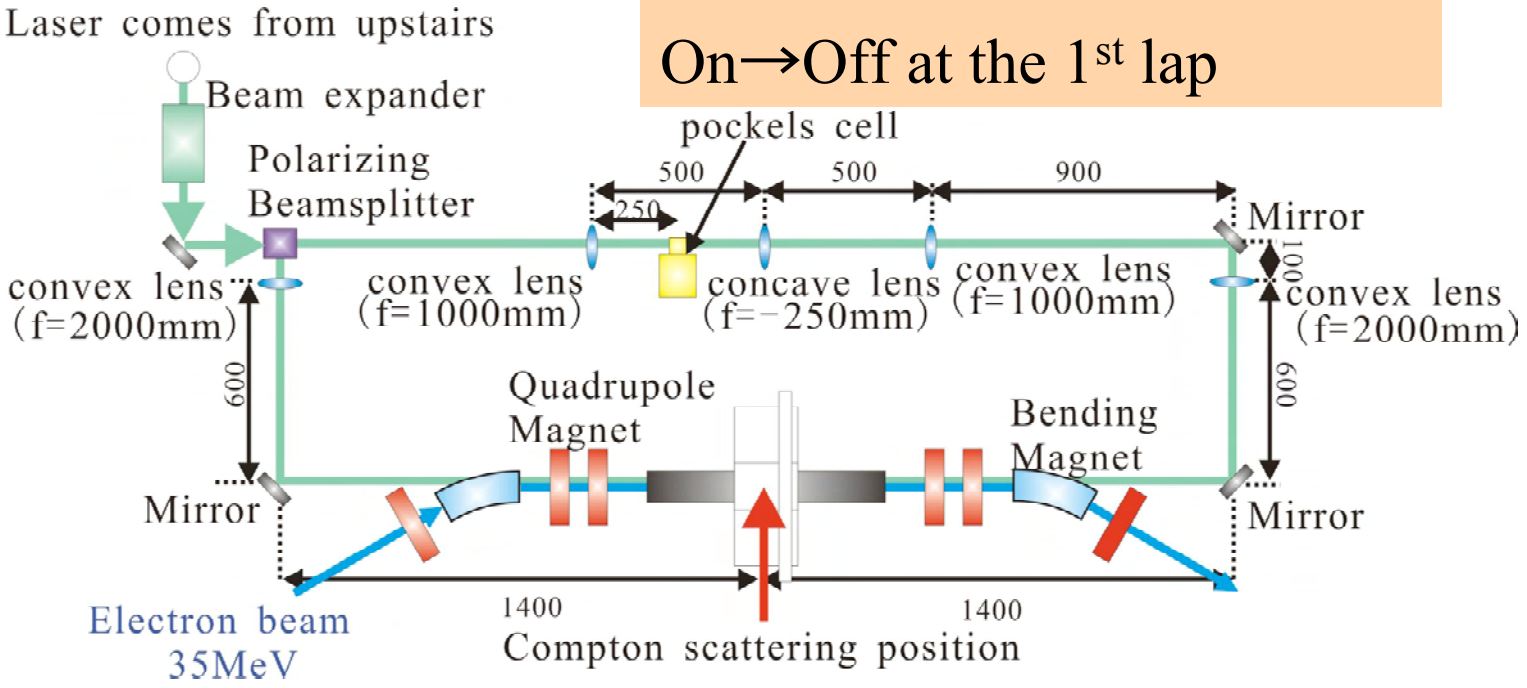
Nd:YAG Laser, 1.4J/pulse,532nm,10ns(FWHM),10pps

LPCS for laser electron Compton scattering experiment

•Experimental Setup

The voltage of pockels cell

On→Off at the 1st lap



What is the difference between principle experiment and this high power LPCS?

•Laser energy 25mJ/pulse→1.4J/pulse

•No need for λ/2 waveplate

At the 1st lap, the polarization will be changed from p to s, and the HV will be off quickly after that. So the laser keeps s polarization, at all times then we don't need λ/2 waveplate.

Summary

- Electron laser Compton scattering monochromatic hard X-ray source are now under construction at the Univ. of Tokyo, Japan.

- LPCS proof experiment has proved that the 25mJ laser could be blocked into the circuit by changing its polarization and its energy could be intensified 10times higher and could be changed its position with μm order.

- LPCS will be installed to the X-ray source in order to make 1.4J laser collide with the electron efficiently and intensify the X-ray yields from 10^8 to 10^9 photons/s.