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Development of Soft X-ray Source using Laser Compton Scattering

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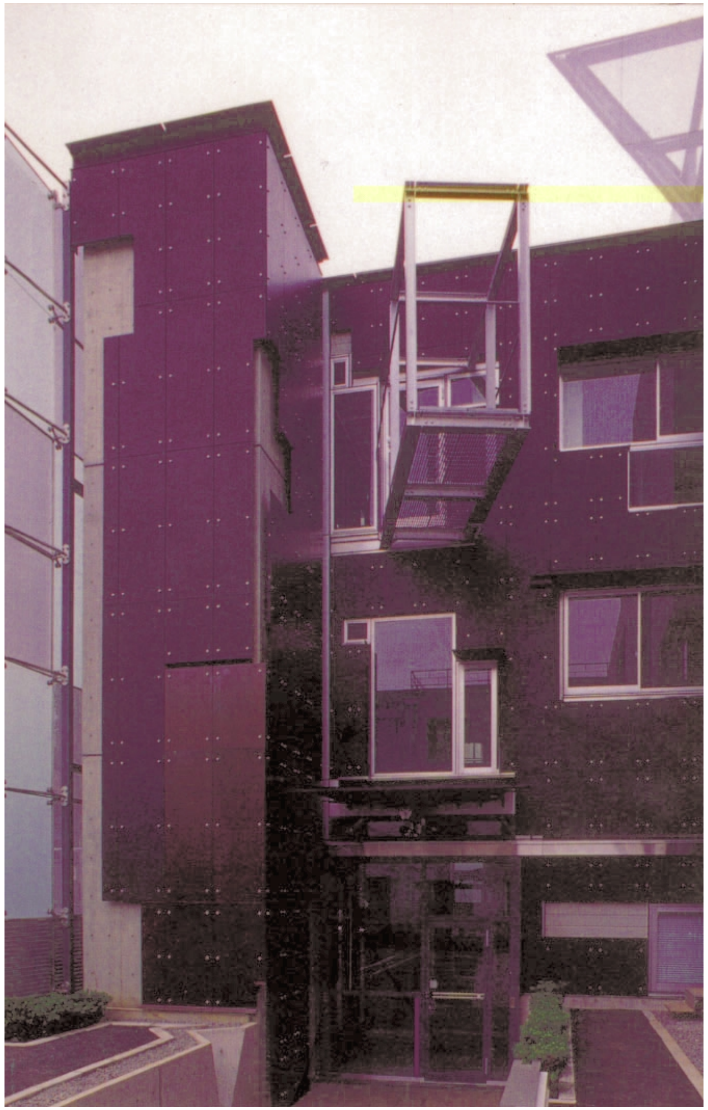
Out Line

- Introduction
  - About our project
  - Approach to the soft X-ray source
  - X-ray microscopy
- High quality electron beam generation system
  - Photo-cathode RF-gun system
  - Ng:YLF Laser system
  - Jitter measurement of laser

    Time domain demodulation technique
  - Electron beam diagnostics
- Laser Compton scattering experiment
  - Experimental setup
  - Estimation of generated X-ray
  - Back ground measurement
- Summary & Future Plan

Research Project at Waseda University



1999~
New research Project
"High-Tech Research Center Project"
(Ministry of Education, Culture, Sports, Science and Technology & Waseda University)

Purpose

High quality electron beam generation and Application Experiment
(pulse radiolysys and soft X-ray generation)

2000/9
Construction of new building completed

2001~
Main components installed

2002/4
Approval for our rf-gun system

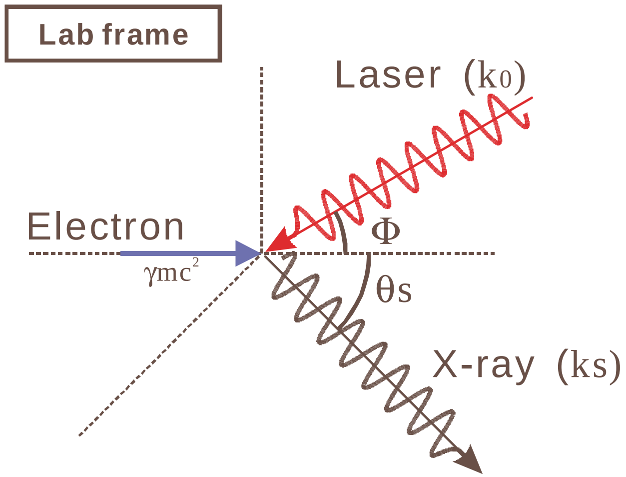
~ Beam Experiment

Soft X-ray Source

- **Laser Compton Scattering**

  between electron beam and laser pulse

  - **Short pulse X-ray**
  - **High intensity per pulse**
  - **Compact**
  - **Variable energy**
  - **Arbitrary energy spectrum**



- **Collision angle**
- **Laser wavelength**
- **Electron beam energy**
- **Detected angle**

….. etc.

X-ray microscopy

Soft X-ray

(absorbed in Oxygen, Nitrogen , Carbon)

⬇

"Water window"

(250-500 eV : 2.5-5 nm)

Abs-Coef.(water)

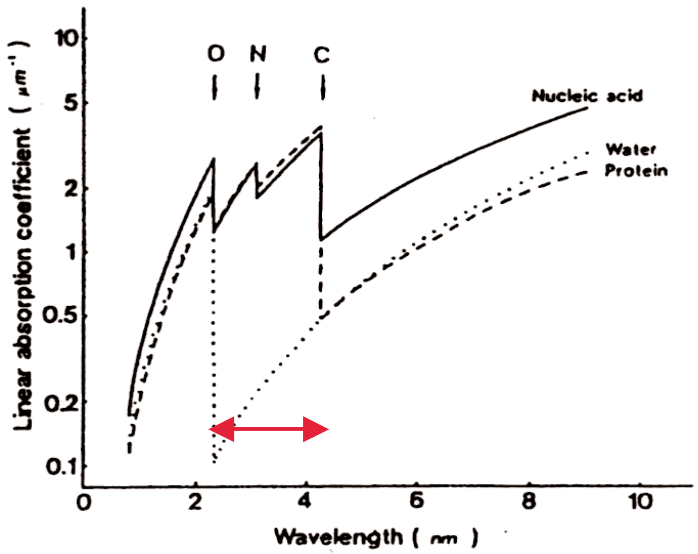
< Abs_Coef. (protain)

⬇

Dehydration of the specimens
Not necessary

Biological observation

Element	K-shell absorption edge [nm] ([eV])
O	2.332 (531.73)
N	3.099 (400.13)
C	4.368 (283.88)



1. **Short Pulse**
   ⇒ **Less Irradiation Damage**
2. **Variable Energy**
   ⇒ **image contrast**
3. **Compact**
   ⇒ **Stable**

High quality electron beam generation

Photo-cathode RF-GUN system

(BNL type 1.6 cell S-band rf-gun)

1. Low emittance beam

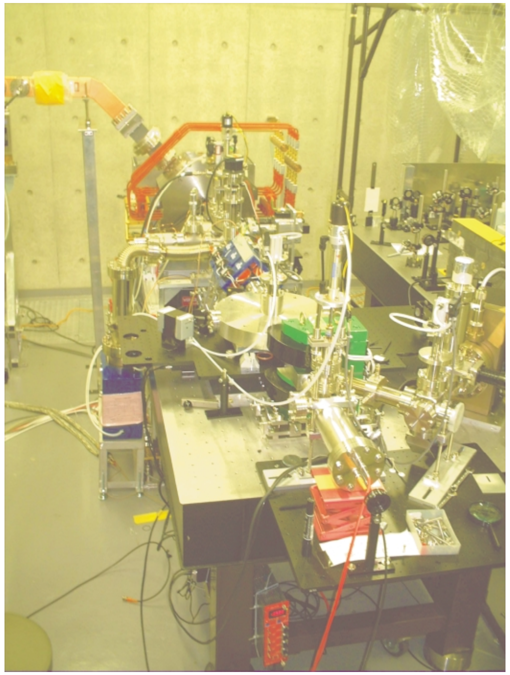
High field acceleration

--- suppress emittance growth due to space charge effect

2. Short bunch beam

Time structure of beam is controlled laser pulse

Not necessary buncher system → compact



•Stable rf source
•Stable laser system

•Beam diagnosis

Laser System

Laser Medium	Nd:YLF
Pulse Width (FWHM):	10 ps
Pulse Energy	
UV (262 nm) / IR(1047 nm)	200 uJ / 2 mJ
Repetition Rate	1-25 Hz (usually 5 Hz)

- Timing stabilizer (119MHz seed light)
- Intensity stabilizer (25 Hz UV light)

Jitter measurement (with RF dependence)

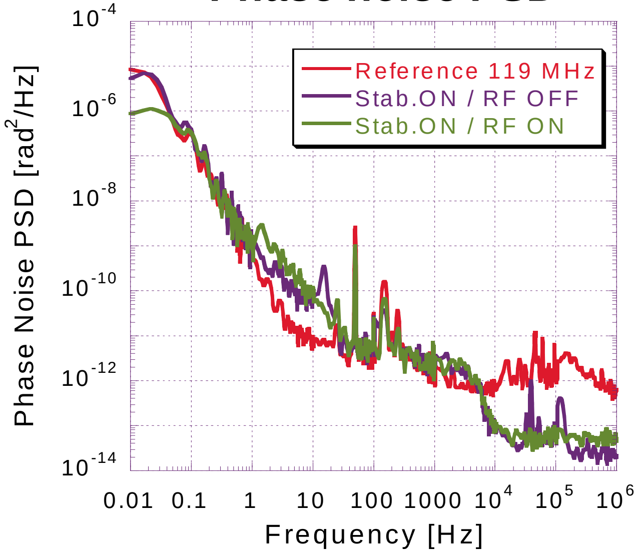
Time domain demodulation technique

(Vector Signal Analyzer)

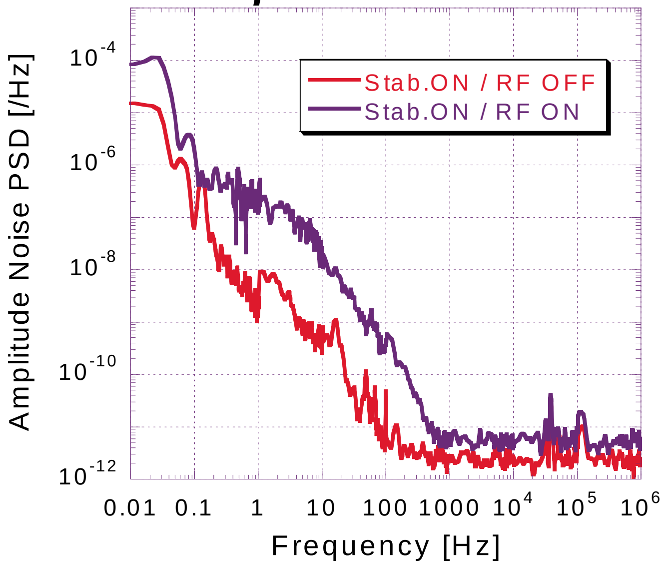
119 MHz laser signal

demodulation

Phase noise PSD



Amplitude noise PSD



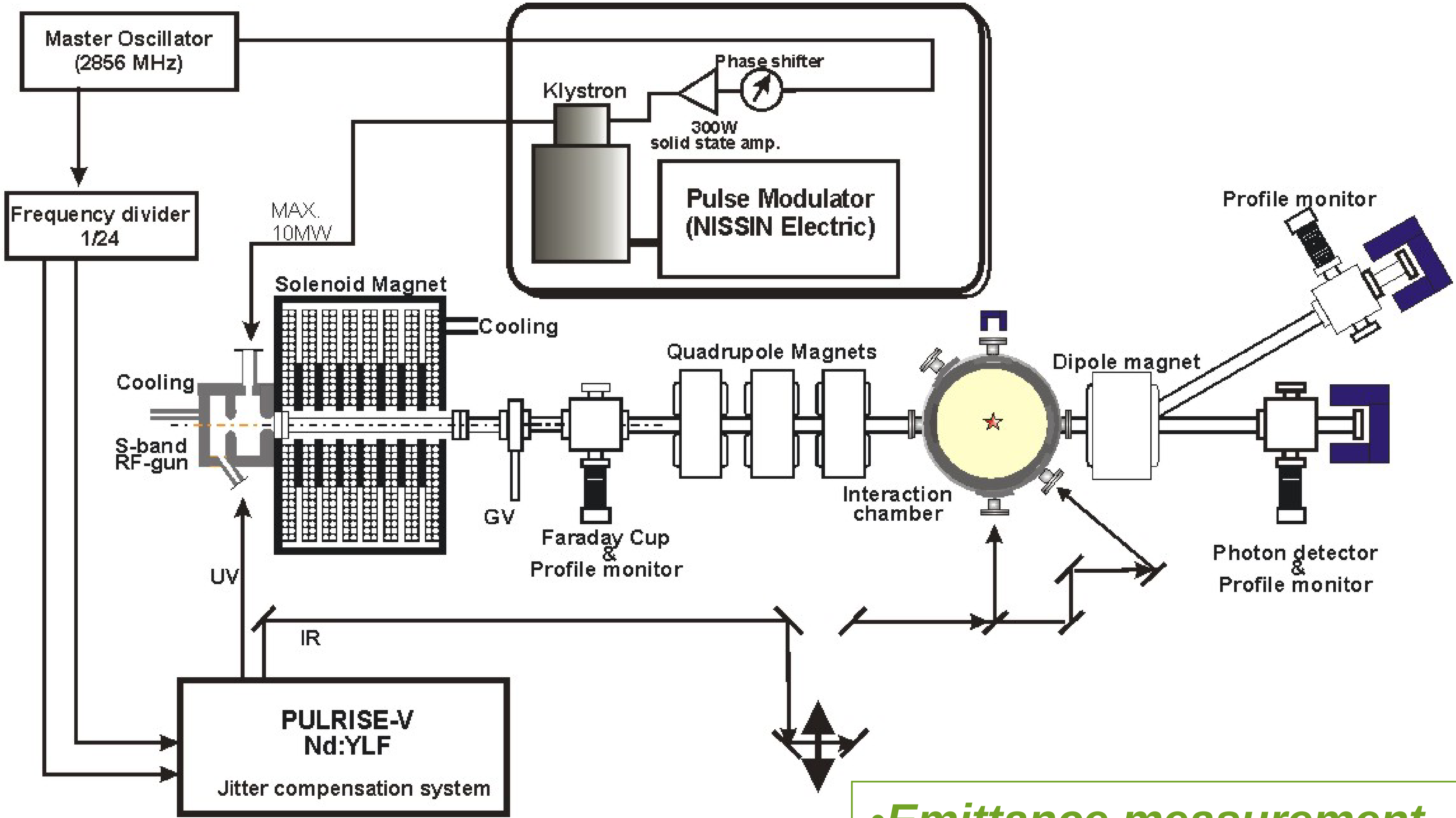
rms timing jitter

Reference	119 MHz	0.26 ps
RF ON		0.26 ps
RF OFF		0.25 ps

rms amplitude jitter

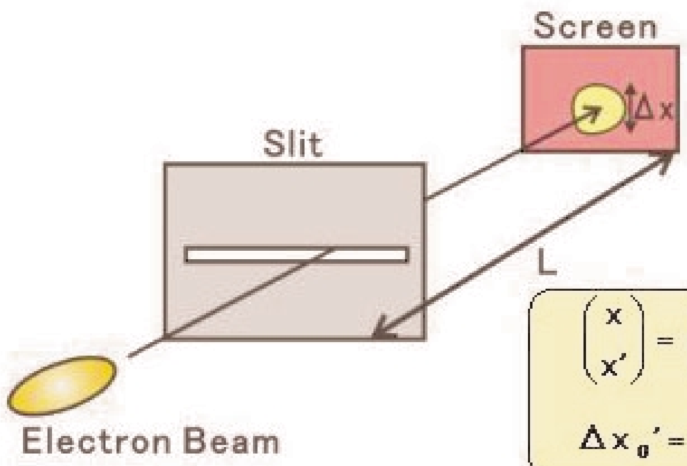
RF ON	0.11 %
RF OFF	0.03 %

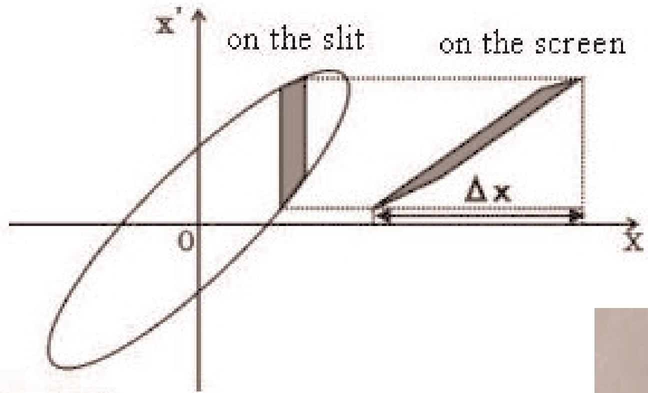
Beam line and Beam diagnostics



•*Emittance measurement*

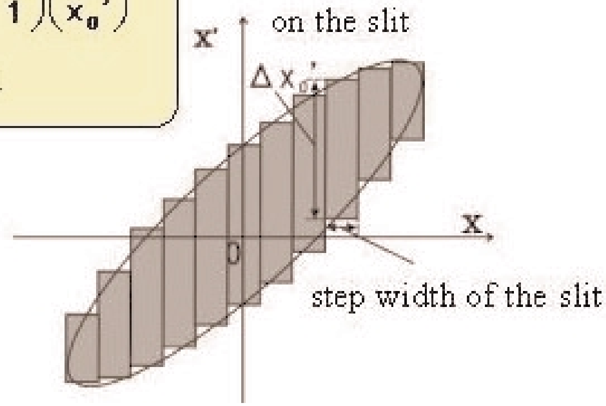
Emittance Measurement (Slit Scan)

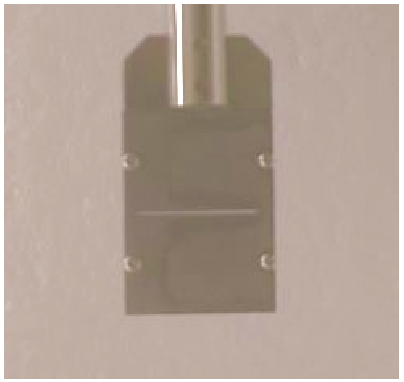




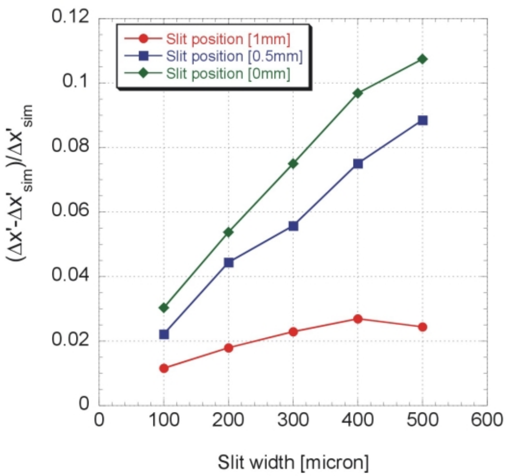
$$\begin{pmatrix} x \\ x' \end{pmatrix} = \begin{pmatrix} 0 & L \\ 1 & 1 \end{pmatrix} \begin{pmatrix} x_0 \\ x_0' \end{pmatrix}$$

$$\Delta x_0' = \frac{\Delta x}{L}$$



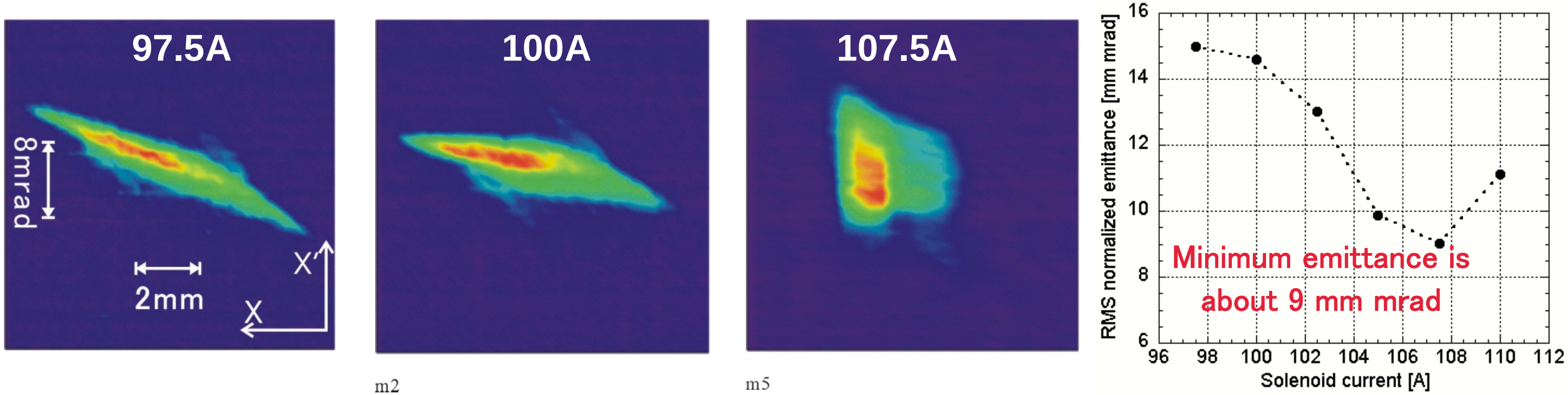


200um width tungsten slit

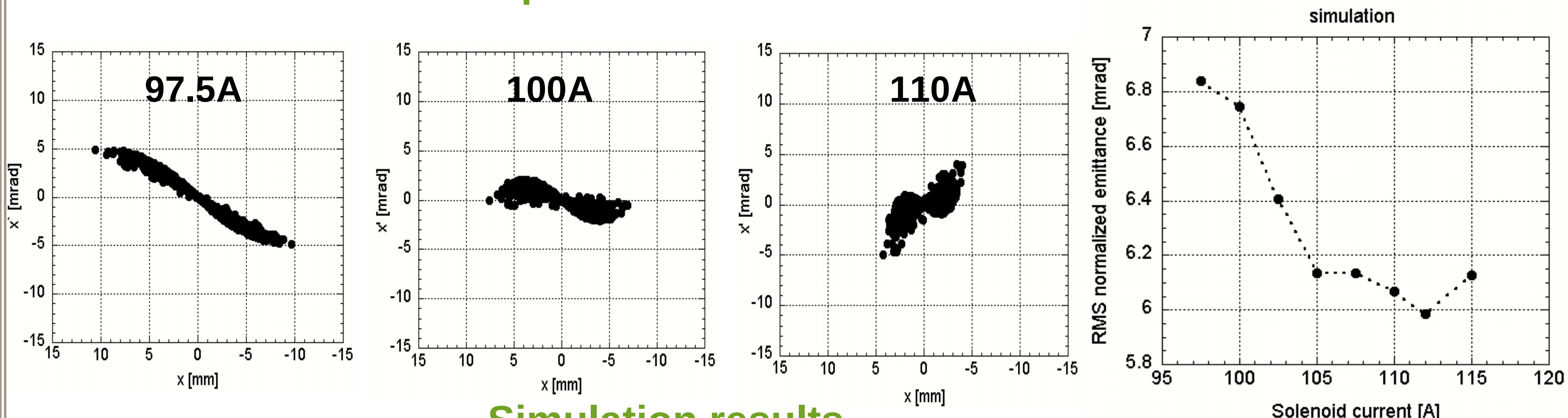


Beam Emittance has been measured using the single slit scan technique changing the solenoid current.

Emittance Measurement Results and Simulation Results (Parmela)



Experimental results



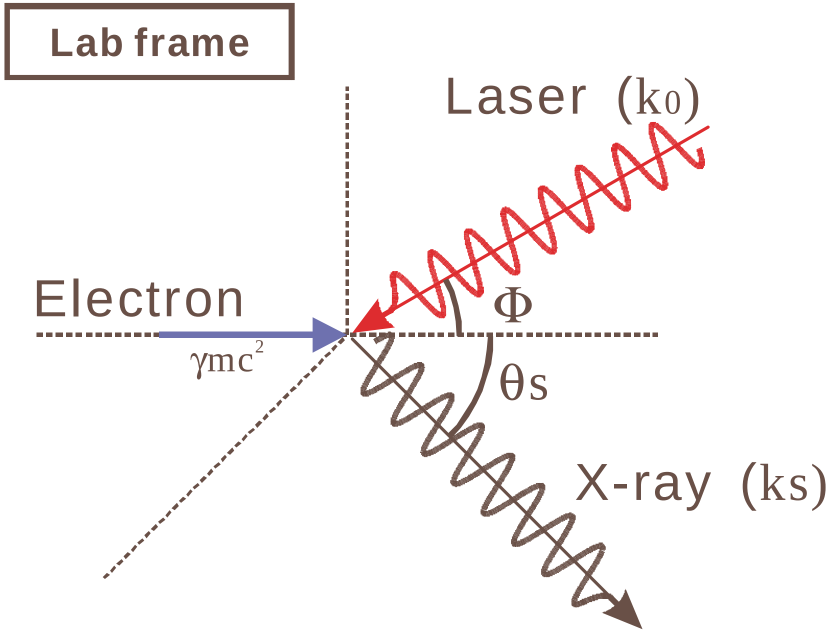
Simulation results

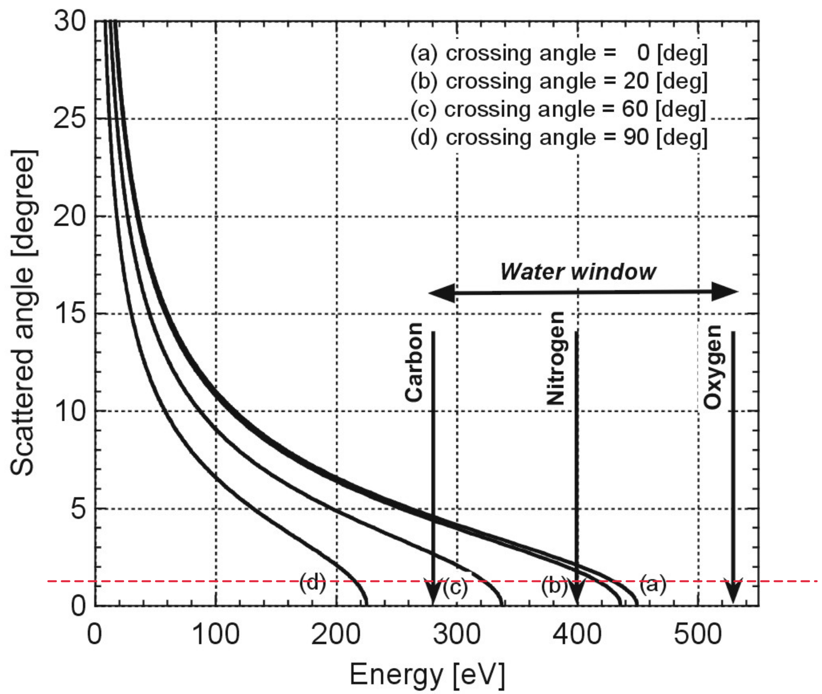
Laser Compton Scattering Experiment

Energy of generated X-ray

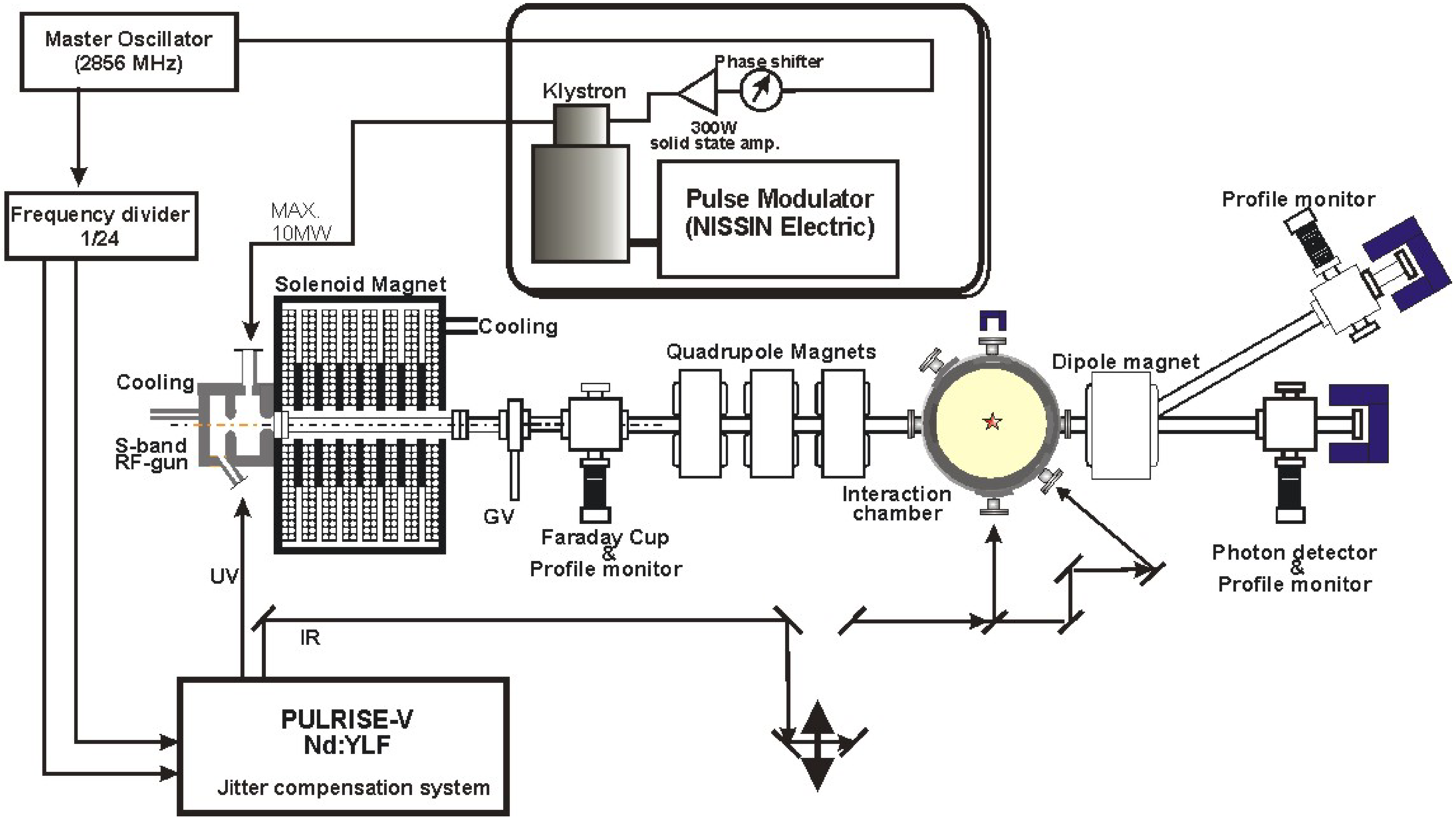
$$k_s = \frac{\gamma^2 m_0 c^2 (1+\beta\cos\phi)(1-\beta^2)k_0}{m_0c^2(1-\beta\cos\theta)+(1-\beta)(1+\cos\theta)(1+\beta\cos\phi)\gamma k_0}$$

Electron beam : 5 [MeV]
Laser light (Nd:YLF) : 1047 [nm]





Experimental Setup of Laser Compton Scattering



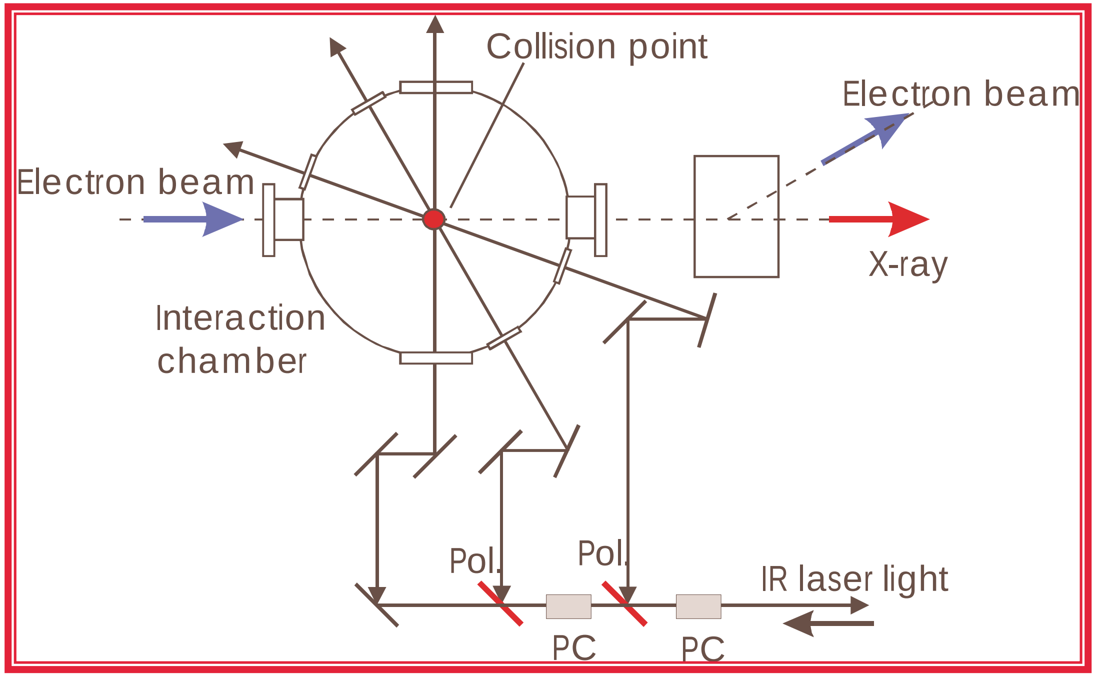
Requirement of Beam Parameters

Electron beam

Beam energy	5.0 MeV
Bunch charge/bunch	2 nC
Bunch length (FWHM)	10 ps
Beam size at focal point (σx/σy)	100/100 μm

Nd:YLF laser

Wave length	1047 nm
Energy/pulse	100 mJ
Pulse length (FWHM)	10 ps
Beam size at focal point (σx/σy)	30/30 μm



Generated X-ray

Collision angle (ϕ)	Ave. photon energy [eV]	Number of Photons [/ pulse]
20	435 (1.1% band width)	1.1×10^5
60	333 (1.1% band width)	3.4×10^4
90	222 (1.1%band width)	2.0×10^4

(within 20 m rad of detected angle)

Our Present Status

Electron beam

Beam energy	5.0 MeV
Bunch charge/bunch	0.5 nC
Bunch length (FWHM)	10 ps
Beam size (σx/σy)	300/300 μm

Nd:YLF laser

Wave length	1047 nm
Energy/pulse	1 mJ
Pulse length (FWHM)	10 ps
Beam size (σx/σy)	60/60 μm

Generated X-ray (within 20 m rad of detected angle)

Collision angle (φ)	Ave. photon energy [eV]	Number of Photons [/ pulse]
20	435 (1.1% band width)	26
60	333 (1.1% band width)	11
90	222 (1.1% band width)	6

Can't detect the X-ray signal

⇩

Laser Amplification

Near Future plan

Laser Amplification with flash lump pumped
Ng:YLF Crystal 2-pass Amplifier system

Under constructing

Up to 40 mJ/pulse

Electron beam

Beam energy	5.0 MeV
Bunch charge/bunch	0.5 nC
Bunch length (FWHM)	10 ps
Beam size (σx/σy)	200/200 μm

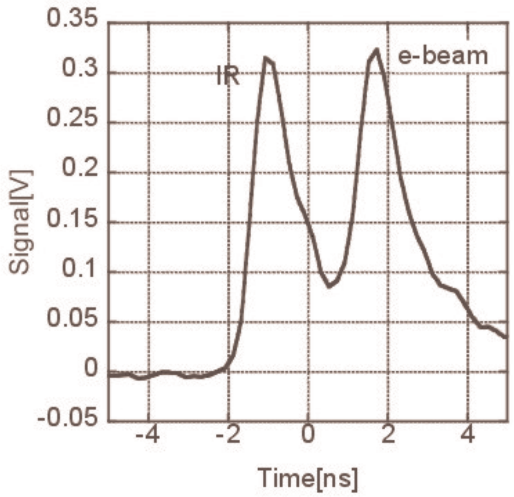
Nd:YLF laser

Wave length	1047 nm
Energy/pulse	40 mJ
Pulse length (FWHM)	10 ps
Beam size (σx/σy)	60/60 μm

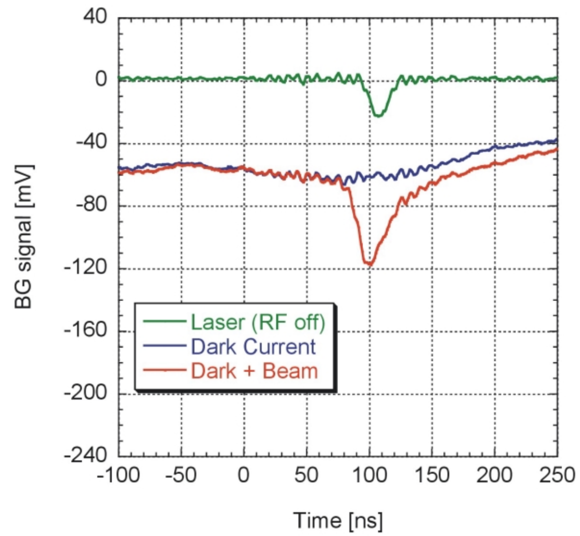
Generated X-ray (within 12 m rad of detected angle due to MCP size)

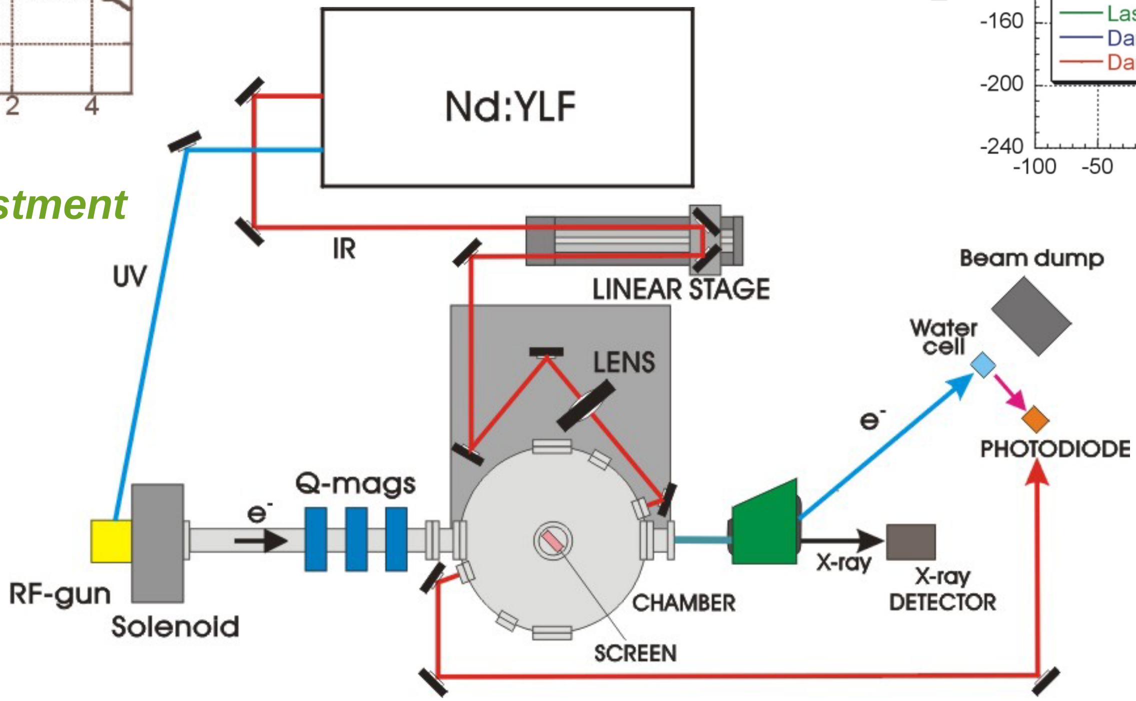
Collision angle (φ)	Ave. photon energy [eV]	Number of Photons
20	435 (0.39% band width)	1.8×10^3 / pulse

Timing Adjustment
and
Background Measurement



Timing Adjustment





Detector background

Summary & Future Plan

- Preparing of soft X-ray generation experiment
  and electron beam characterization have been started.
- We have to perform the optimization of all components.

2002 September ~

- Construct the Laser Amplifier System
- Start the Experiment of Laser Compton Scattering
  at 20° of the collision angle

2003 ~

- Soft X-ray generation will be performed
  at 20° , 60° , 90° of the collision angle

In Future

- Application to the soft X-ray microscopy
- Construct the X-ray focusing system
  for biological observation.