Waseda University

Research Institute for Science and Engineering

Design of High Brightness Laser-Compton Light Source for EUV Lithography Research in Shorter Wavelength Region

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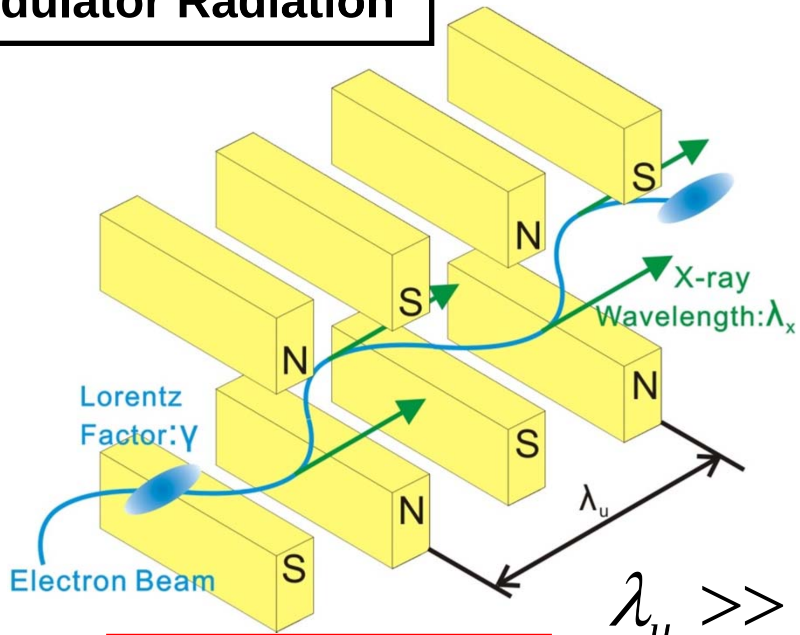
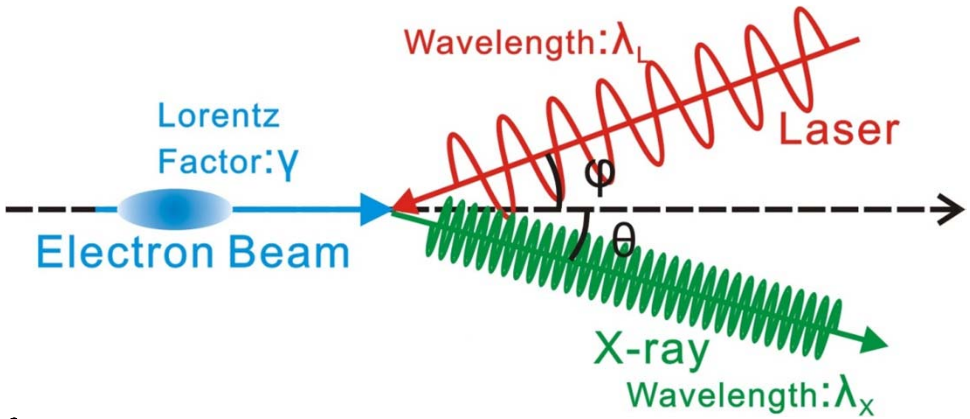
Laser Compton Scattering

Comparison of Undulator Radiation and Laser-Compton Scattering

Undulator Radiation



Laser-Compton Scattering



$$\lambda_u >> \lambda_L$$

$$E_X = 2\gamma^2 \cdot hc/\lambda_u$$

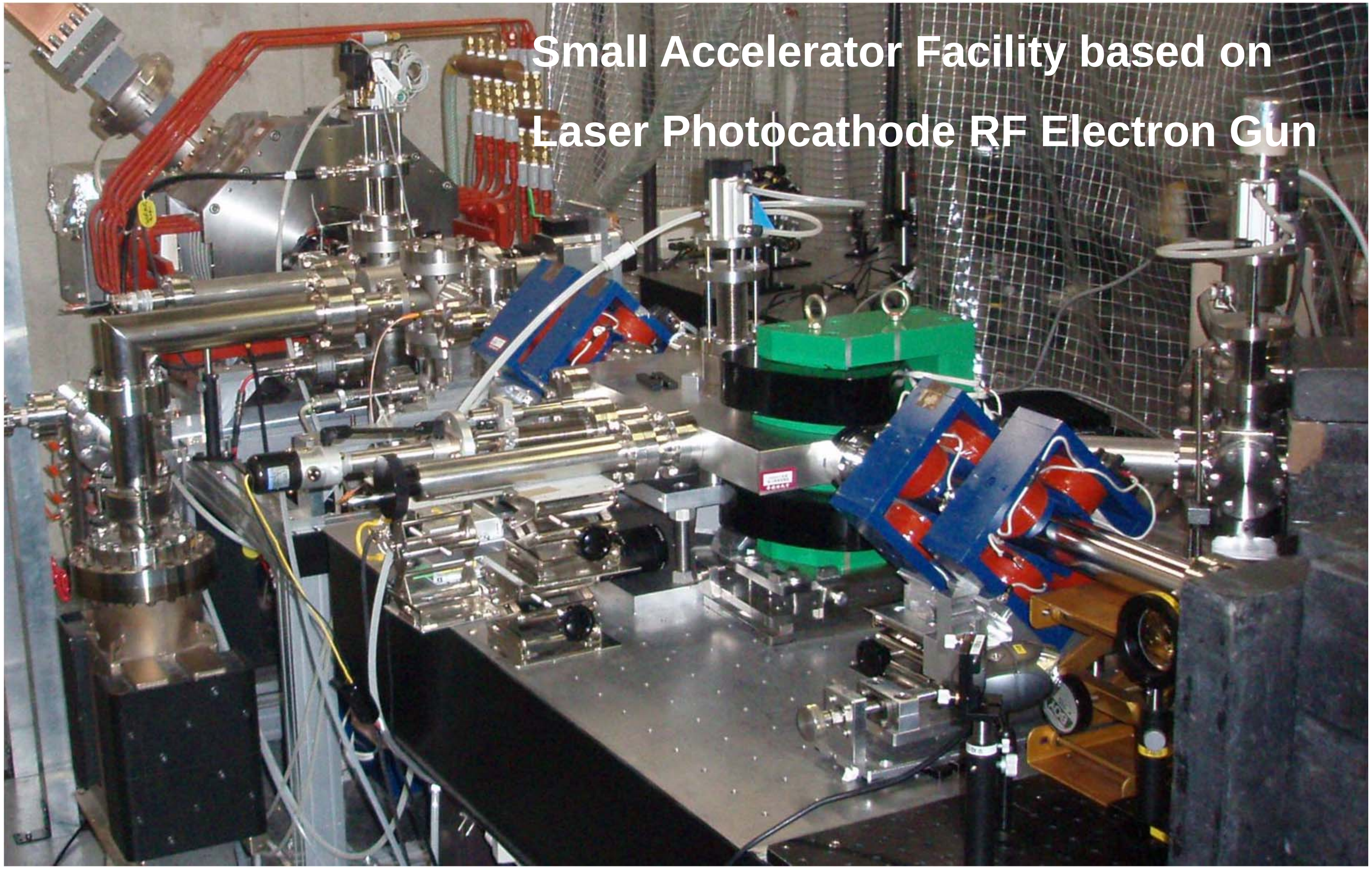
$$E_X = 2\gamma^2 \cdot hc/(\lambda_L/(\cos\phi + 1/\beta))$$

Undulation period can be shortened over 3-order of magnitude

High energy photon is produced with small accelerator system

Laser-Compton Experiment

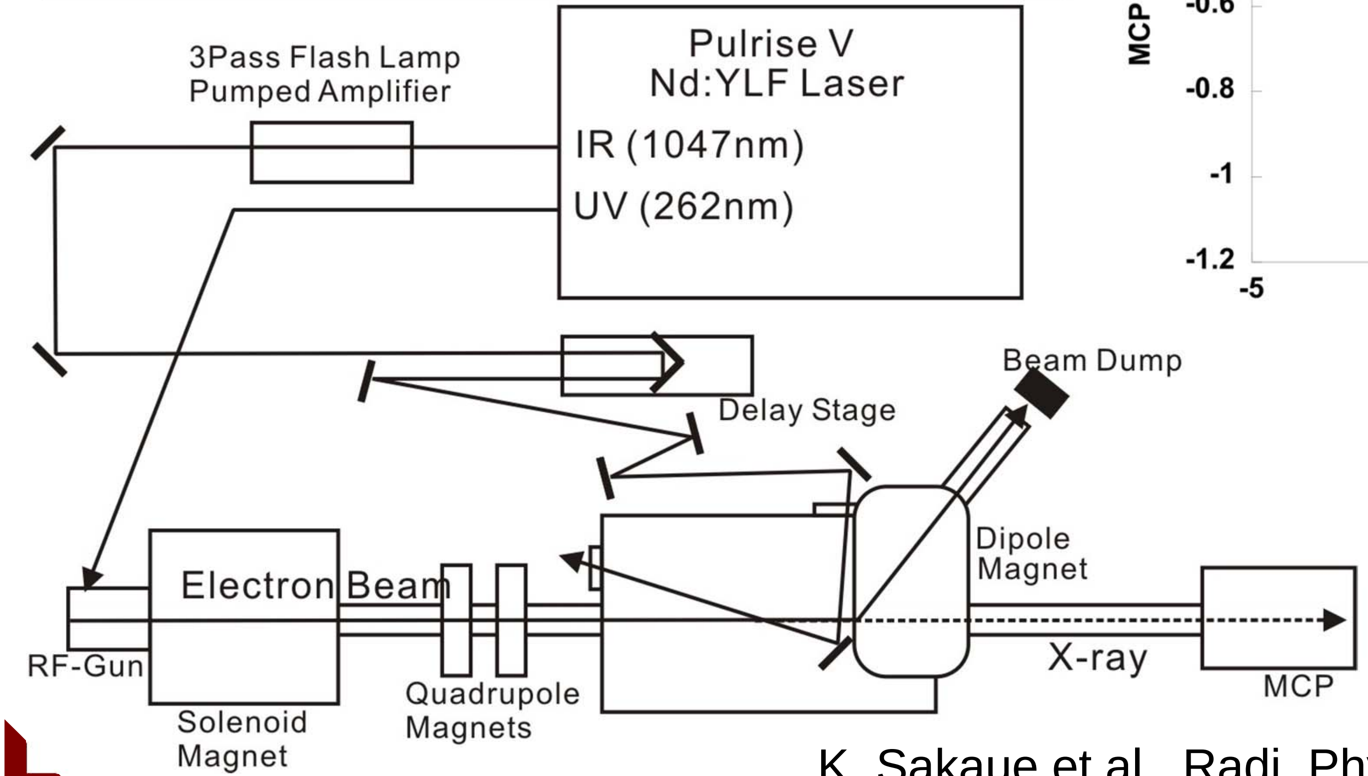
Facility Outlook at Waseda University

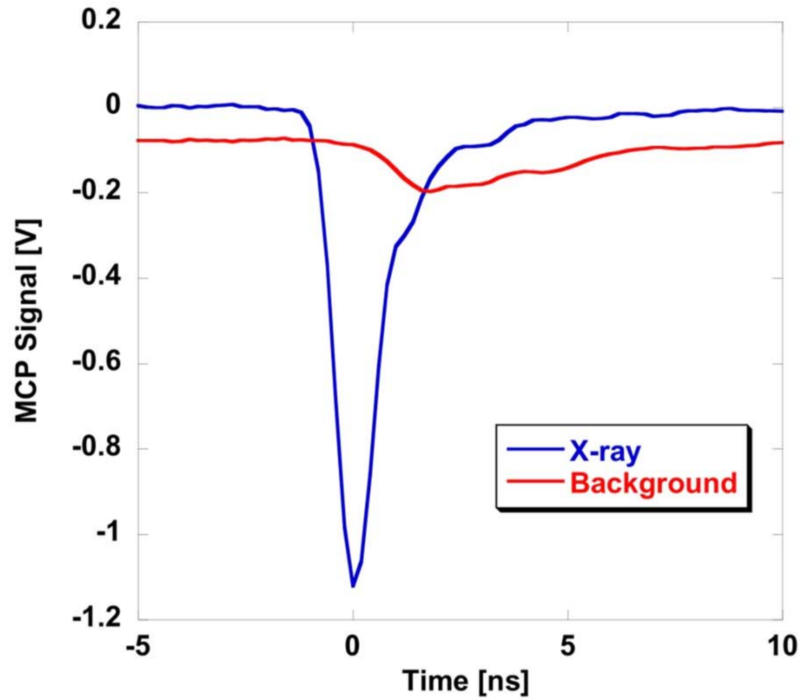


Soft X-ray Generation at Waseda

Results of Soft X-ray Generation

Electron beam		Laser beam	
Energy	4.6 MeV	Wavelength	1047 nm
Bunch charge	350 pC	Pulse energy	36 mJ
Size (horizontal)	251 μm	Size (horizontal)	42 μm
Size (vertical)	56 μm	Size (vertical)	42 μm
Bunch length	10 ps (FWHM)	Pulse duration	10 ps (FWHM)



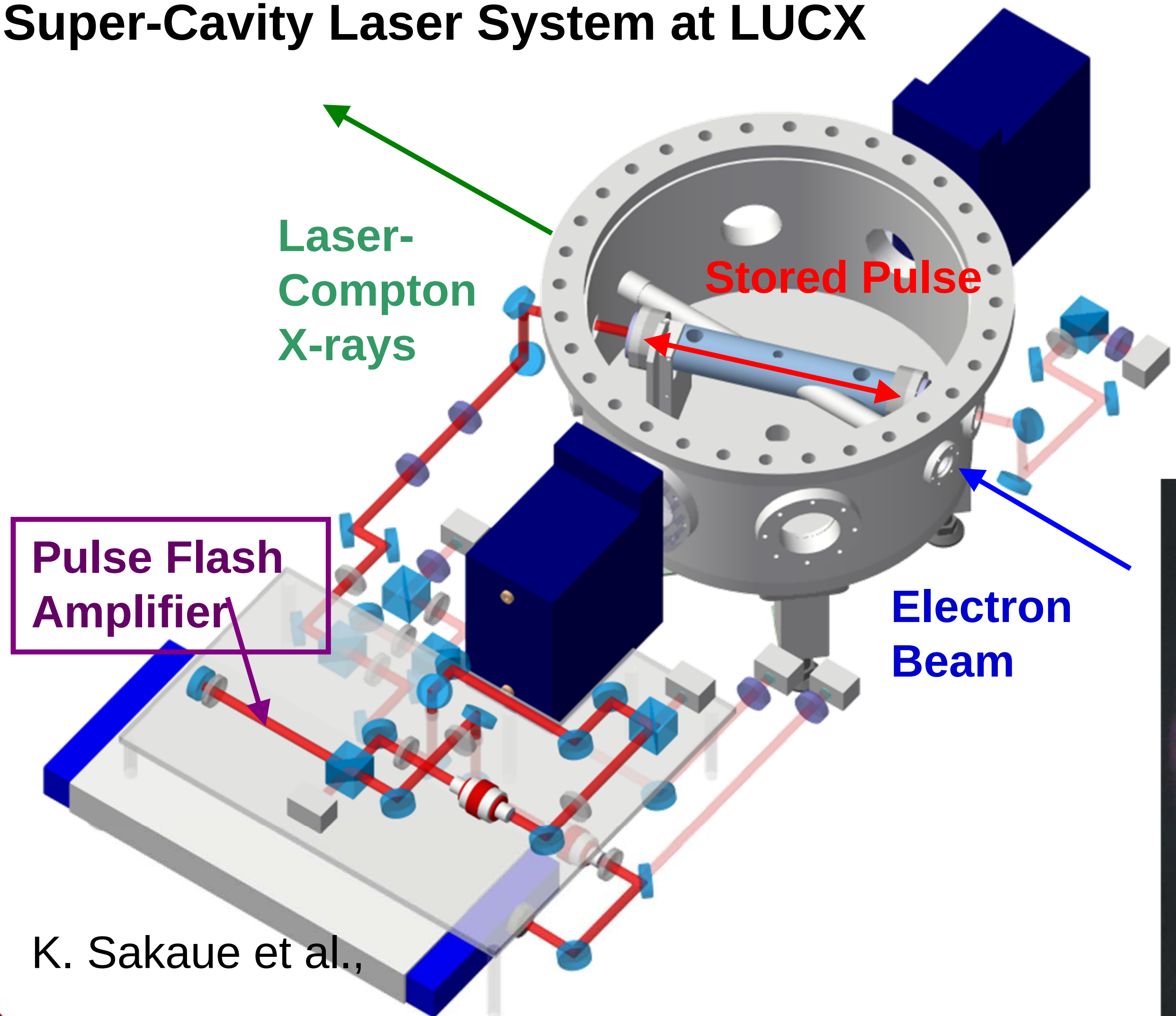


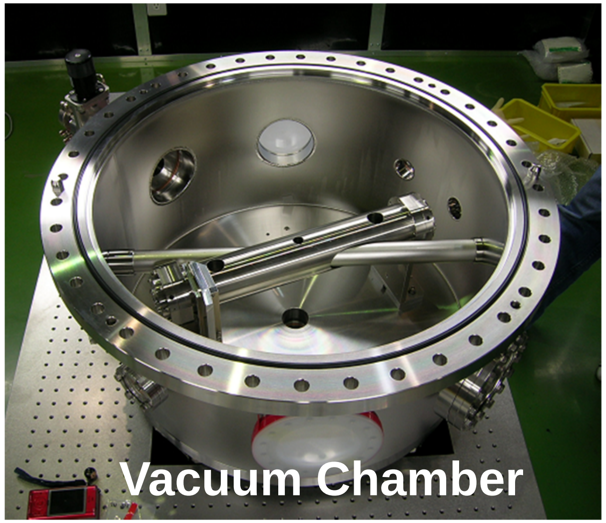
3.3 × 10^4Photons
were produced
in 1pulse
Ex~420eV (2.8nm)

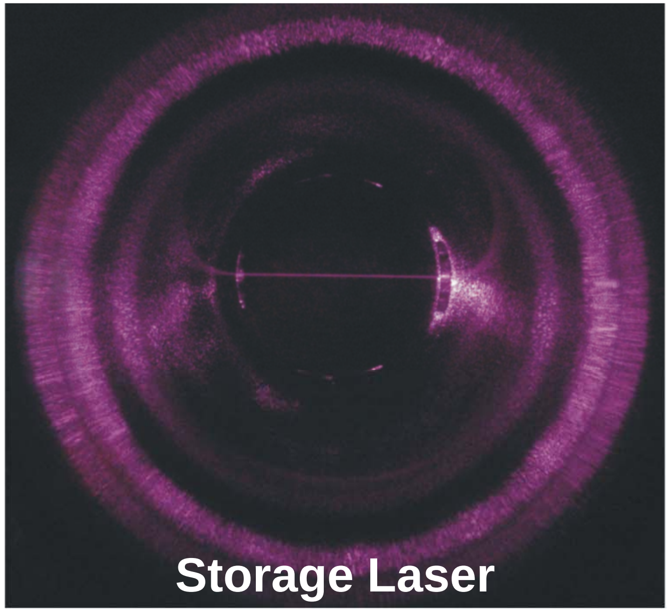
K. Sakaue et al., Radi. Phys. Chem. 77(2008)1134

Laser-Compton with Super-Cavity

Super-Cavity Laser System at LUCX





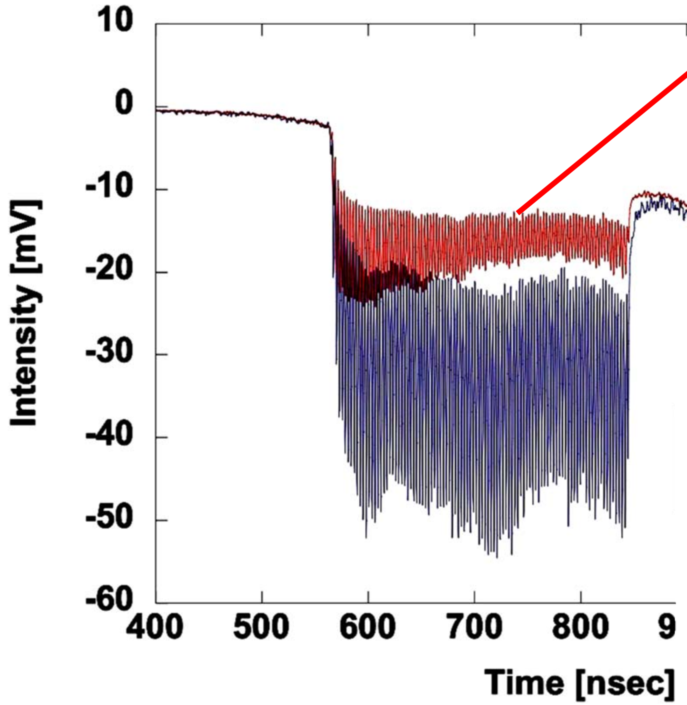


K. Sakaue et al.,

Nucl. Instrum. Meth. A637(2011)S107

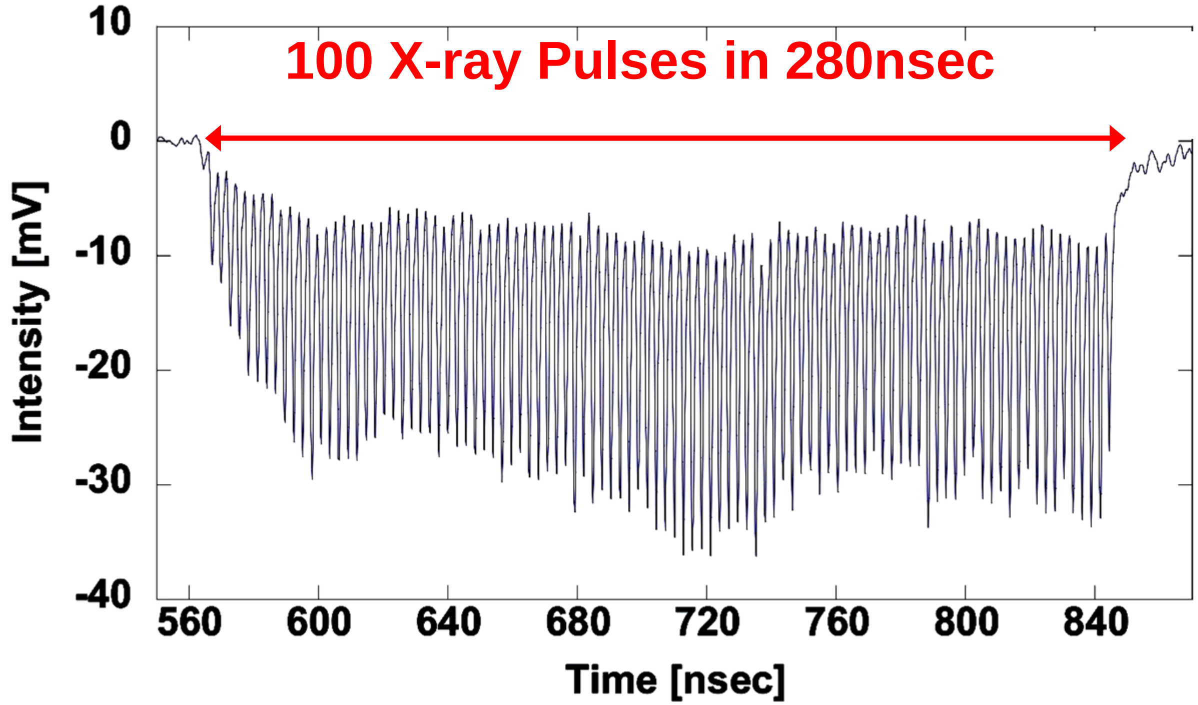
Laser-Compton with Super-Cavity

Waveform from Micro-Channel Plate



X-ray signal can be detected with laser on/off.

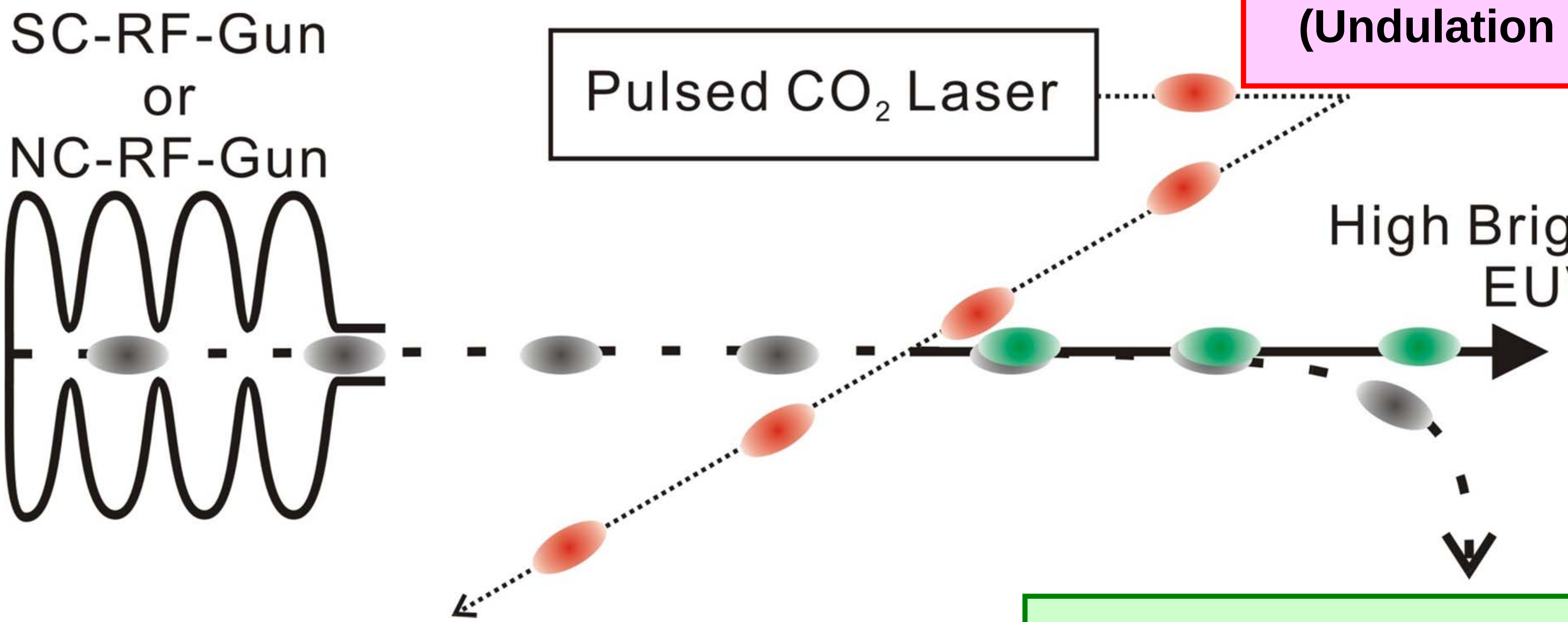
K. Sakaue et al., RSI 80(2009)123304



Design of EUV Light Source

Design of EUV Light Source based on Laser-Compton Scattering

Use CO_2 Laser for Longer Wavelength (Undulation Period)



RF-Gun can generate high brightness electron beam

Generated photon has around 6.7nm wavelength 7.2MeV electron & 10.6μm laser

Design of EUV Light Source

We have 2 case of designs

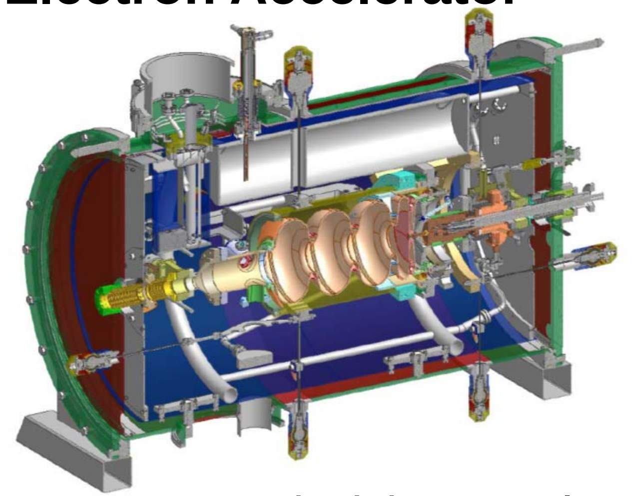
“Low Rep. Case (100kHz)” and “High Rep. Case (100MHz)”

	100kHz	100MHz	
Bunch charge	1nC/bunch	77pC/bunch	**Electron Beam**
Bunch length	3psec (rms)	3psec	
Pulse energy	1J/pulse	20µJ/pulse	
Pulse duration	20nsec	20psec	**Laser**
Enhancement	None	5000	
Source Size	10µm	20µm	
Colliding angle	0deg	5deg	
EUV power	12.8µW/2%bw	1mW/2%bw	**EUV**

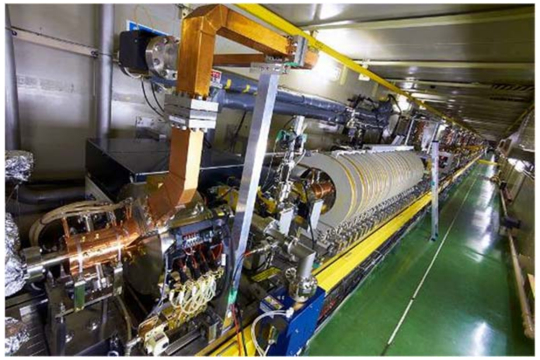
EUV Light Source (Low Rep. Case)

Components of Low Rep. Case

Electron Accelerator

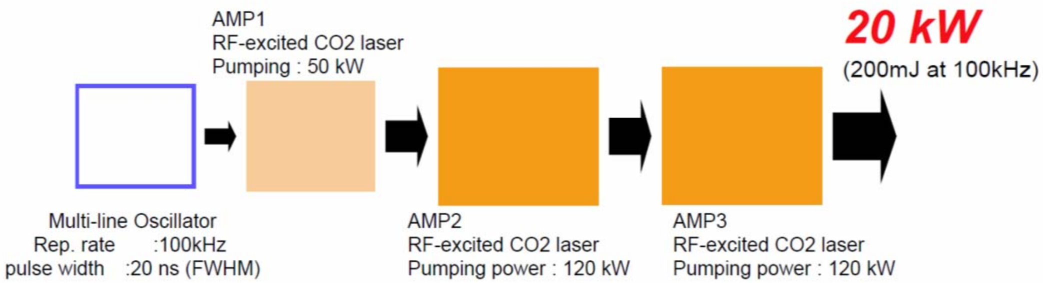


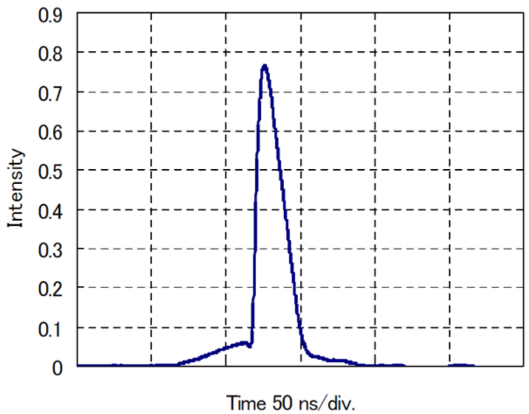
SC-RF-Gun (Teichert et al., FEL08)

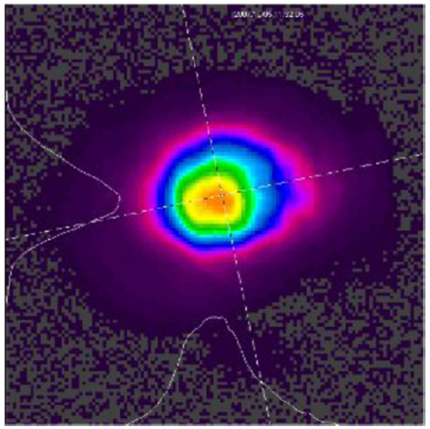


NC-RF-Gun (Now under testing at KEK)

CO_2 Laser







1J/pulse is also feasible technology

EUV Light Source (High Rep. Case)

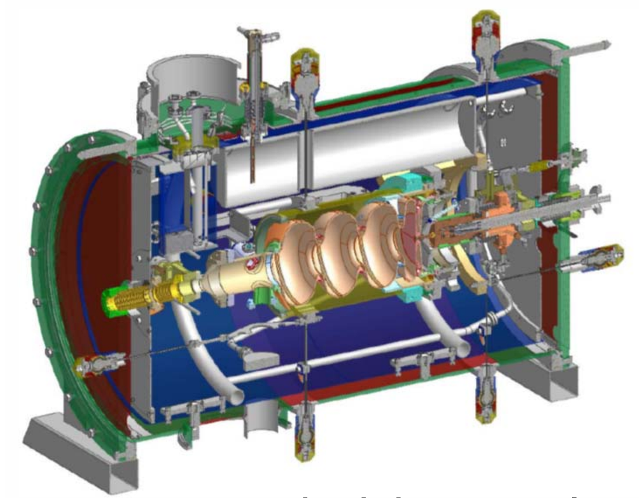
Components of High Rep. Case (Electron Beam)

>Almost same requirements with ERL (Energy Recovery Linac)

electron source

These will be mature in near future

SC-RF-Gun



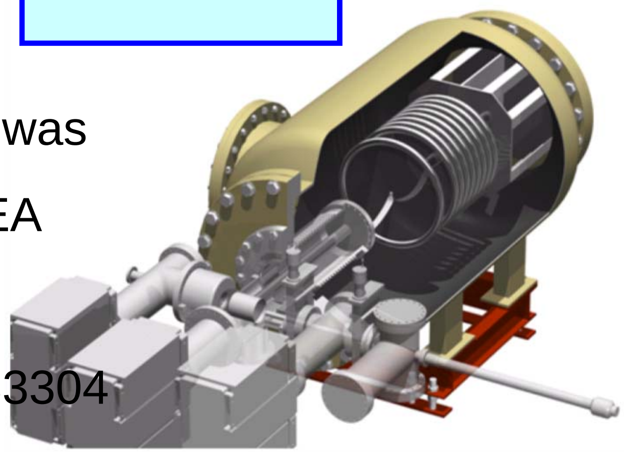
SC-RF-Gun (Teichert et al., FEL08)

DC-Gun & SC Linac

Photocathode DC-Gun → SC Linear Accelerator →

500kV DC-Gun was achieved at JAEA

R. Nagai et al., RSI 81(2010)033304

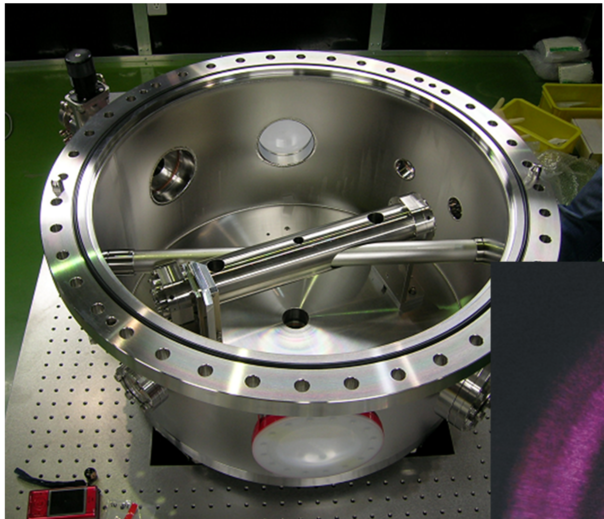


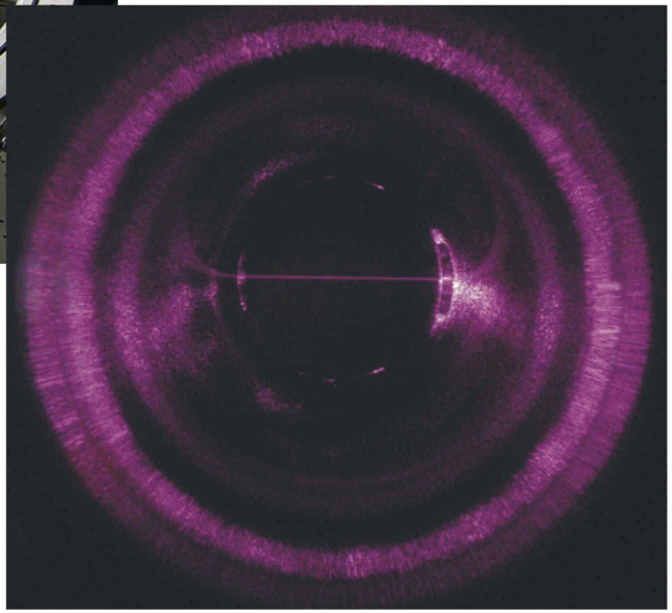
EUV Light Source (High Rep. Case)

Components of High Rep. Case (Laser Beam)

>Need to use Super-cavity technology

Demonstrated at 1μm wavelength K. Sakaue et al., RSI 80(2009)123304



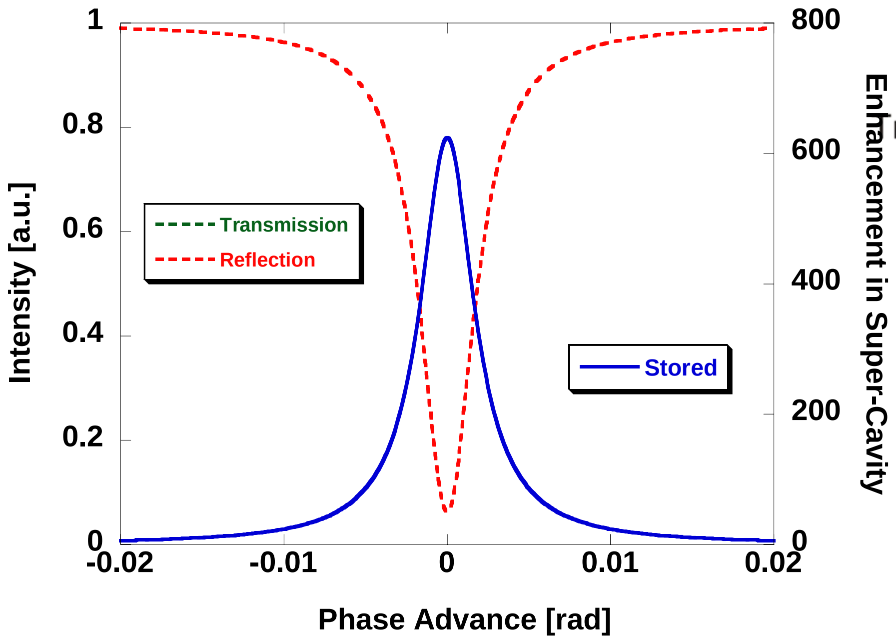


Need to R&D at 10.6μm CO_2 laser storage in optical super-cavity with enhancement of 5000

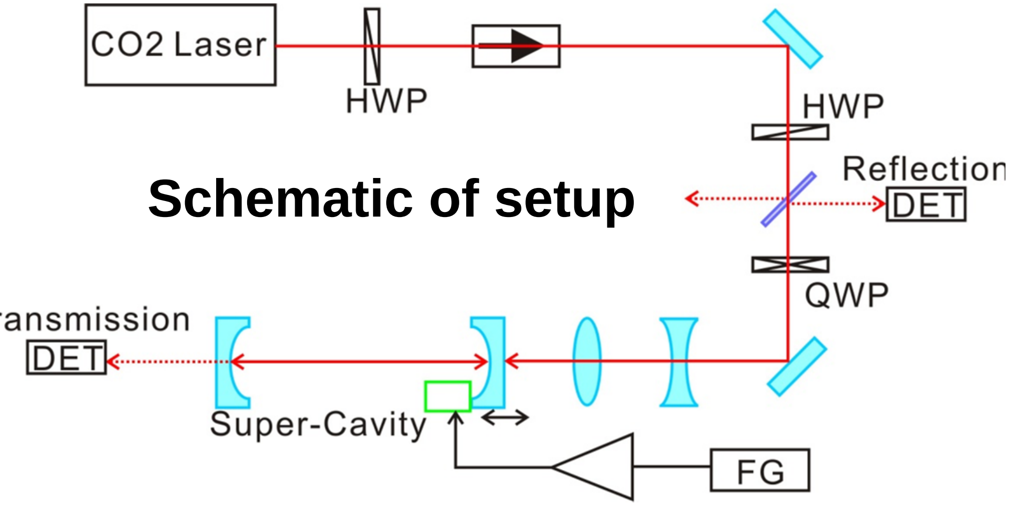
CO2 Laser Super-Cavity R&D

We started R&D of

CO2 laser Super-Cavity (CW)



Calculated results of enhancement in Super-cavity with commercial mirrors (HTrans Mirror and HRef Mirror)



Schematic of setup

CO2 laser Super-Cavity test bench

CO2 Laser Super-Cavity R&D

Study Plan of CO2 laser Super-Cavity

1^{st} step	CW storage demonstration	
2^{nd} step	High power test	Mirror damage test
3^{rd} step	Higher enhancement	Short pulsed CO2 laser development
	Need super-mirror development	Need short pulse demonstration Now considering QCL, DFG…

Summary

We have been developing a laser-Compton scattering

Soft X-ray was demonstrated by 4.6MeV electron and 1um laser

Super-Cavity Laser-Compton scattering was performed

2 types of EUV light source designed by our experiences of laser-Compton scattering

<Low Rep. Case (100kHz)>

SC(NC)-RF-Gun and CO2 laser will generate

10μW/2%b.w. EUV (6.7nm) <based on mature technologies

<High Rep. Case (100MHz)>

SC-RF-Gun (or DC-Gun+SC Linac) and CO2 laser with Super-cavity

1mW/2%b.w. EUV (6.7nm) <Need R&Ds, already started at Waseda