

# LUMINOSITY INCREASE IN LASER-COMPTON SCATTERING BY CRAB CROSSING\*

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## Abstract

Laser-Compton scattering X-ray (LCS-X) sources has been expected as a compact and powerful source, beyond X-ray tubes. It will enable laboratories and companies, opening new X-ray science. It is well known that luminosity depends on the collision angle of laser and electron beam. Head-on collision is ideal in the point of maximizing the luminosity, though difficult to create such system especially with optical enhancement cavity for laser. In collider experiments, however, crab crossing is a promising way to increase the luminosity. We are planning to apply crab crossing to LCS, to achieve a higher luminosity leading to a more intense X-ray source. Electron beam will be tilted to half of the collision angle using an rf-deflector. Although crab crossing in laser-Compton scattering has been already proposed [1], it has not been demonstrated yet anywhere. The goal of this study is to experimentally prove the luminosity increase by adopting crab crossing. In this conference, we will report about our compact accelerator system at Waseda University, laser system favorable for crab crossing LCS, and expected results of crab crossing LCS.

## INTRODUCTION

Laser-Compton scattering (LCS) has been expected as an attractive X-ray source for years. Brilliance of almost  $10^{10}$  has been achieved [2], and exceeding  $10^{12}$  has been designed [3]. Comparing with magnetic undulators, LCS could be explained as “laser undulator”, which the undulator period equivalent to laser wavelength ( $\sim 1$   $\mu\text{m}$ ) while magnetic undulator is the order of cm. Figure 1 shows the comparison of undulator radiation and LCS.

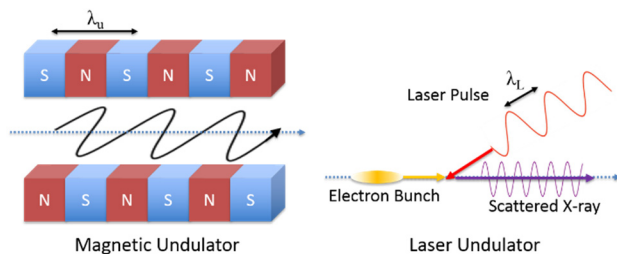


Figure 1: Comparison of undulator radiation and LCS.

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In order to produce 1-Å photons, LCS needs to provide a beam of 25-MeV energy, assuming 6 GeV for undulator radiation ( $K = 1$ ,  $\lambda_u = 2$  cm) and 4 GeV for synchrotron radiation ( $\rho = 12$  m). Low required beam energy enable the whole system compact and low cost so that laboratories and hospitals may take care. The schematic drawing of LCS is shown in Fig. 2.

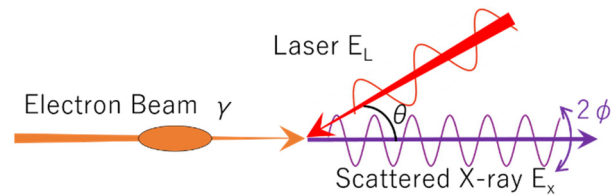


Figure 2: Schematic drawing of LCS.

In Fig. 2,  $\gamma$ ,  $E_L$ ,  $E_X$ ,  $\theta$ ,  $\phi$  represents the Lorentz factor of electron beam, energy of laser photon, energy of scattered X-ray, colliding angle, and scattering angle, respectively. The maximum X-ray energy  $E_X^{MAX}$  would be obtained along the electron beam axis  $\phi=0$  and written as:

$$E_X^{MAX} \approx 2\gamma^2(1 + \beta \cos \theta)E_L, \quad (1)$$

where  $\beta$  is the velocity of electrons relative to the speed of light. We can see in Eq. (1) that scattered photon energy is tunable by controlling the beam energy or the collision angle.

The number of scattered photons is given by the product of cross section and luminosity:

$$N = \sigma L = \sigma P G. \quad (2)$$

Since the total cross section is unchangeable once the laser wavelength and beam energy is decided, it is necessary to increase the luminosity as much as possible. Luminosity can be expressed as the product of power factor ( $P$ ) and geometric factor ( $G$ ) as seen in Eq. (2). Power factor is the product of the number of electrons in a bunch and the number of photons in a laser pulse. Geometric factor is written as Eq. (3) when assuming Gaussian for both electron bunch and laser pulse. Here  $\sigma_x$ ,  $\sigma_y$ ,  $\sigma_z$  represents the electron bunch sizes of horizontal, vertical, and longitudinal respectively, and prime ones are those of laser pulse. We substitute our beam parameters, shown in Table 1, into the equation for the geometric factor,

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$$G = \frac{1 + \beta \cos \theta}{2\pi \sqrt{\sigma_y^2 + \sigma'_y{}^2} \sqrt{\sigma_x^2 (\beta + \cos \theta)^2 + \sigma'_x{}^2 (1 + \beta \cos \theta)^2 + (\sigma_z^2 + \sigma'_z{}^2) \sin^2 \theta}} \quad (3)$$

Table 1: Parameters of Electron Beam and Laser Pulse

	Electron Beam	Laser Pulse
Energy	4.2 MeV	1.2 eV (1030 nm)
Intensity	40 pC	10 mJ
Transverse Size	40 μm	50 μm
Duration	3 ps (rms)	0.43 ps (rms)

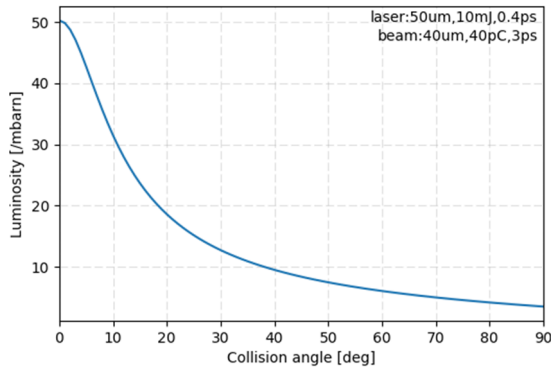


Figure 3: Luminosity as a function of collision angle.

For these values, the luminosity depends on collision angle as depicted in Fig. 3.

We can see that the luminosity is maximum when collision angle is zero, i.e. head-on collision and monotonically decrease as collision angle increase. Despite this fact, head-on collision is hard to realize especially with an optical enhancement cavity [4], considering the interference of cavity mirrors and electron beam path. In addition, scattered X-ray must get across a mirror. This might cause damages to the mirror. Due to these facts, quite a few LCS X-ray sources have a certain colliding angle which causes luminosity loss [5]. One method to overcome this problem is the crab crossing.

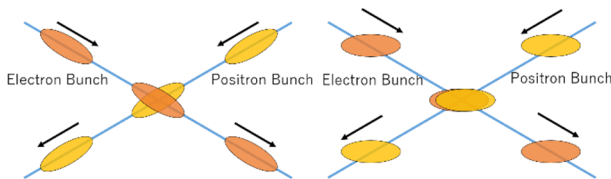


Figure 4: Schematic drawing of crab crossing.

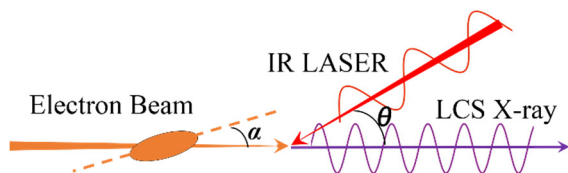


Figure 5: Schematic of crab crossing LCS.

## CRAB CROSSING LCS

### Effect of Crab Crossing

Crab crossing is a proven technique in colliders that allows an angle crossing without luminosity loss. Figure 4 depicts the schematic of crab crossing.

Luminosity is increased by tilting the bunch. In LCS, since it is a collision of electron bunch and laser, we are planning to tilt only the electron beam with an rf-deflector. Figure 5 shows the schematic of crab crossing LCS. Luminosity is maximized when the tilt angle  $\alpha$  is half of collision angle [1]. The enhancement ratio between ordinary crossing and crab crossing would be:

$$\frac{G_{\text{crab}}}{G_{\text{non-crab}}} = \sqrt{\frac{(\sigma_x^2 + \sigma'_x{}^2) \cos^2 \frac{\theta}{2} + (\sigma_z^2 + \sigma'_z{}^2) \sin^2 \frac{\theta}{2}}{\sigma_x^2 + \sigma'_x{}^2 \cos^2 \frac{\theta}{2} + \sigma_z^2 \sin^2 \frac{\theta}{2}}} \quad (4)$$

Using those parameters listed in Table 1, the enhancement ratio (crab ratio) in our system is shown in Fig. 6.

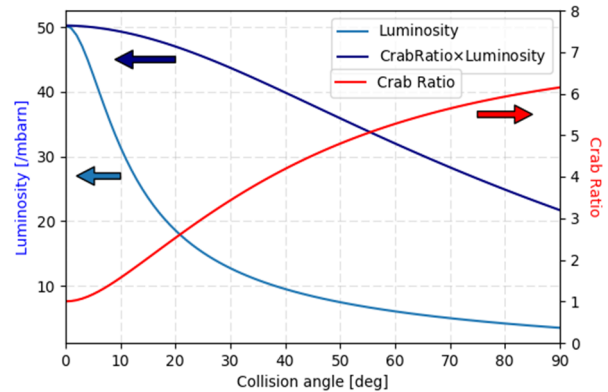


Figure 6: Enhancement ratio of crab crossing.

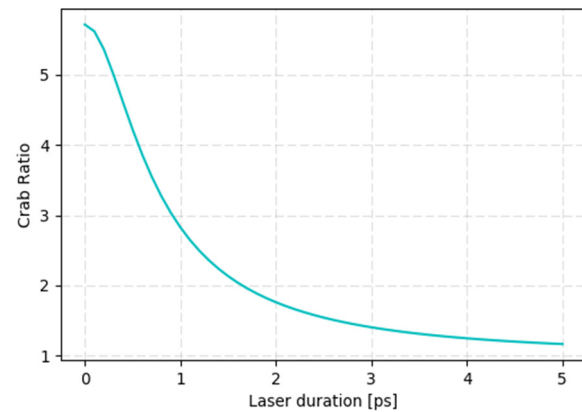


Figure 7: Pulse duration and enhancement ratio.

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We are planning to conduct the proof of principle experiment at 45 degrees and the expected enhancement ratio is 4.15. By comparing the blue lines, we can say that the luminosity is compensated by crab crossing.

The effect of pulse duration of colliding laser is shown in Fig. 7. Short and intense pulse makes crab crossing more effective. We are developing a laser system based on Yb fiber oscillator and Yb:YAG thin-disk regenerative amplifier for crab crossing LCS.

### CAIN Simulation

The expected spectra were calculated by a Monte-Carlo code, CAIN. Figure 8 shows the calculation of ordinary 45 degrees crossing (blue), 45 degrees crossing with crab crossing (green), and ideal head-on crossing (red).

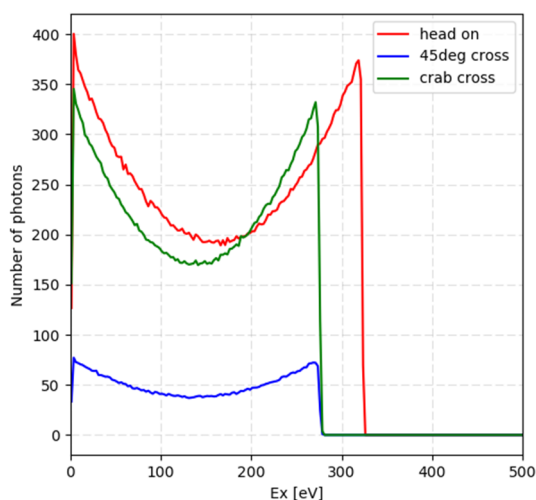


Figure 8: Calculated spectra by CAIN.

It is clear that the number of photons increase by crab crossing. We can also see that the maximum energy, i.e. the Compton edge does not change by crab crossing. The number of photons is listed in Table 2.

Table 2: Scattered Photons Calculated by CAIN

$(\theta, \alpha)$	Number of Photons
(0, 0)	32900
(45, 0)	5573
(45, 22.5)	24940

We can confirm that the total number of generated photons in crab crossing is more than 4 times larger than that of ordinary crossing. Furthermore, crab crossing enables almost 76 % of head-on likeness, while ordinary crossing is only 17 %.

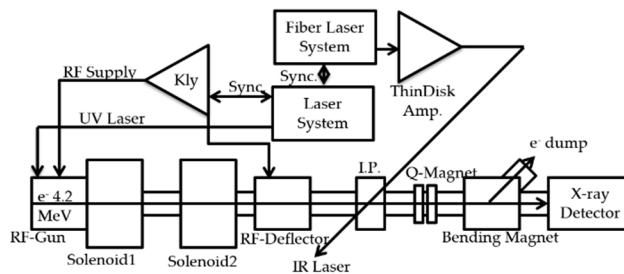


Figure 9: Experimental Setup for crab crossing LCS.

## EXPERIMENTAL SETUP

The experimental setup for crab crossing LCS is shown in Fig. 9. A 1.6-cell rf-gun with CsTe photocathode will generate a 4.2-MeV, 40-pC, 3-ps electron bunch. It will be focused at the interaction point (I.P.) by a solenoid magnet to maximize the luminosity. The rf-deflector will give tilt to the bunch for crab crossing. The bending magnet is necessary to separate the scattered X-rays from the electron beam. Finally, the MCP (Micro-Channel Plate) will be used as the X-ray detector. We have already done background measurement (transporting electron beam without laser collision) and confirmed it was sufficiently low. We are now developing a colliding laser system suitable for crab crossing LCS, based on fiber laser and thin-disk regenerative amplifier.

## CONCLUSION

We are planning to demonstrate the crab crossing LCS in our compact accelerator system in Waseda University. Luminosity increase is likely to be more than fourfold when the colliding angle is 45 deg. Encouraged by such good prospects, we are now concentrating on constructing the thin disk regenerative amplifier as a colliding laser, favorable for the crab crossing LCS.

## REFERENCES

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