# Gamma-ray Source by Backward Compton Scattering at SPring-8

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## Introduction

LEPS and LEPS2 beamlines for hadron and nuclear physics experiments with a polarized γ-ray beam in the energy range of 1.5 − 2.4 GeV are running at SPring-8. In the case of collision between 8 GeV electrons and 355 nm laser light, the maximum energy of the γ-ray reaches 2.4 GeV. Although the γ-ray production by using the lasers has been established with the successful results, further improvements concerning the maximum energy are desired to advance hadron and nuclear physics. Monochromatic high energy γ-ray is also very important.

The recent activities of the LEPS and LEPS2 beamlines at SPring-8 are presented. Furthermore, theory of BCS process by an incident photon with higher photon energy and challenging study of quasi-monochromatic high energy γ-ray production by BCS using undulator X-ray radiation are also presented.

## LEPS and LEPS2 Activity

At SPring-8, two beamlines for nuclear and particle physics experiments using high energy γ-ray by BCS are under operation, which are called BL33LEP (LEPS) and BL31LEP (LEPS2). In experimental collaborators of these beamlines, a laser BCS γ-ray beam is referred as a Laser-Electron Photons (LEP) beam.

At the LEPS, which started from 1999, the ultraviolet (UV) laser light with the wavelength of 355 nm ($E_L$ = 3.49 eV) has been injected into the 8 GeV electron storage ring in order to produce BCS photon beam [1]. The beam intensity has exceeded the order of $10^6$ Hz in the tagged photon energy range of 1.5–2.4 GeV.

The construction of the LEPS2 beamline was approved in 2010, aiming one order of magnitude higher intensity and larger acceptance coverage compared with the LEPS experiments. We have successfully obtained the first photon beam at the LEPS2 beamline, resulting in the beam size of σ ~6 mm and the intensity of ~7 MHz for the γ-ray energy range of 0 to 2.4 GeV. A large BGO ($Bi_4Ge_3O_{12}$) crystal was used for the measurement of the photon energy spectrum of produced BCS γ-ray [2, 3].

The LEPS2 beamline utilizes a 30-m long straight section (LSS), the number of which is limited to only 4 of total 62 beamlines at SPring-8. The horizontal divergence of the electron beam at LSS is reduced to 14 μrad in σ, while the usual 7.8-m straight section including the LEPS beamline provides the divergence of 58 μrad. The BCS γ-ray beam spread at the LEPS2 beamline is determined not largely by the electron beam divergence but mostly by the Compton scattering angle. This achieves a well collimated photon beam with the radius below 10 mm even at the 135 m downstream from the Compton scattering point, enabling us to construct a large experimental site outside of the experimental hall, whose size is 12 m × 18 m in area with the height of 10 m.

## Theory of BCS

A schematic drawing of the BCS is shown in Fig. 1.

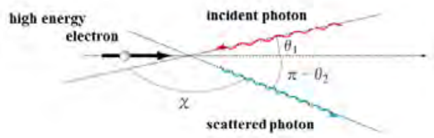


**Fig. 1** Schematic drawing of backward Compton scattering.

The scattered photon energy $k_2$ is written as

$$k_2 = k_1 \frac{1+\beta\cos\theta_1}{1+\beta\cos\theta_2 + \frac{k_1}{E_e}(1-\cos\chi)} \qquad (1)$$

where $k_1$ is the photon energy of the incident photon, $\beta$ is the velocity of the electron normalized by speed of light, $E_e$ is the electron energy, $\pi-\theta_1$ and $\pi-\theta_2$ are the angles between the direction of the electron beam and the directions of the photon before and after scattering, respectively, and $\chi$ is the scattering angle of the photons.

In the case of head-on collision, the maximum energy of the scattered photon, $k_{2\max}$, is obtained as

$$k_{2\max} = \frac{k_1(1+\beta)}{1+\beta+\frac{2k_1}{E_e}} \approx \frac{4k_1E_e^2}{(m_ec^2)^2+4k_1E_e} \qquad (2)$$

where we used the relation

$$1-\beta^2 = \frac{1}{\gamma^2} = \left(\frac{m_ec^2}{E_e}\right)^2 \qquad (3)$$

and $\beta \approx 1$. According to Eq. (2), when $k_1$ is very high (e.g. 10 keV), the maximum BCS γ-ray photon energy $k_{2\max}$ is nearly equal to 8 GeV for the electron beam of $E_e = 8$ GeV.

The spectral shape has been derived by Milburn [4] as

$$\frac{1}{\sigma_0}\frac{d\sigma}{d(k_2/E_e)} = \frac{3}{16\lambda}\left[\frac{\lambda^2(1-x)^2}{1+\lambda(1-x)}+2(1+x^2)\right] \qquad (4)$$

where $\sigma_0$ is the Thomson scattering cross-section, $\sigma_0 = 665$ mb, $\lambda = 2\gamma k_1/m_ec^2$ and $x = \cos\theta_0$, where $\theta_0$ is the photon scattering angle in the electron rest frame.

In case of low energy incident photon energy $k_1$ such as laser light, the second term of Eq. (4) becomes dominant and γ-ray spectrum is the parabolic shape with wide photon energy range. On the other hand, when incident photon energy is high, the first term of Eq. (4) becomes dominant and γ-ray spectrum damps in the low energy region.

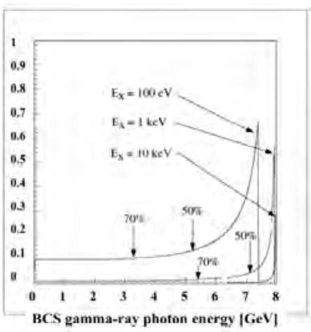


**Fig. 2** The spectrum of BCS γ-ray with incident photon energy as a parameter [5].

Furthermore, when incident photon energy is very high such as hard X-ray, higher-order term $(1 - x)^2$ (n > 2) of Eq. (4) becomes important and γ-ray spectrum uprises steeply near the maximum BCS γ-ray of $k_{2\max}$. Figure 2 shows the calculated spectrum of BCS γ-ray with incident photon energy as a parameter.

## Production of quasi-monochromatic γ-ray by BCS using X-ray undulator

X-ray undulator is very attractive to use it as incident photon source for BCS, so that we could produce a quasi-monochromatic γ-ray with photon energy close to the kinematic limit.

We plan to use a single crystal at a normal-incidence for reflecting X-ray undulator radiation and to go back to BCS interaction region in the straight section of the storage ring. We are now fabricating the mirror system for experiment of GeV photon production by BCS using undulator radiation and single crystal reflection at normal-incidence has been measured. We plan to use a diamond single crystal for Bragg mirror. Figure 3 shows the schematic drawing of quasi-monochromatic γ-ray production system by using an undulator, Bragg mirror of a normal-incidence single crystal, and BGO γ-ray detector with the diameter of 8 cm and the length of 30 cm.

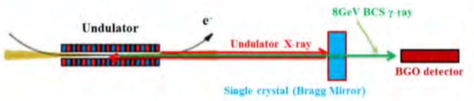


**Fig. 3** Schematic drawing of quasi-monochromatic γ-ray production system.

## References

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[5] Calculated by Schin Daté.