GAMMA BEAM MODULATION IN SHANGHAI LASER ELECTRON GAMMA SOURCE *

Zirui Hao†, Gongtao Fan, Hongwei Wang, Hanghua Xu, Longxiang Liu, Yue Zhang,
Shanghai Advanced Research Institute, Chinese Academy of Sciences, Shanghai, China

Abstract

Shanghai Laser Electron Gamma Source (SLEGS) is one of the beamlines of the Shanghai Synchrotron Radiation Facility, which dedicate to producing gamma beams in the slant-scattering for the first time. SLEGS utilizes the Gamma Modulation System (GMS) to modulate the gamma beam, which consists of a double collimator system, attenuator system, and X/gamma imaging system.

Measurements have demonstrated the gamma rays modulation capabilities of SLEGS beamline. The quasi-monochromatic gamma beams with an energy spread of 4 % are produced by using an aperture of 1 mm of the collimator system at back-scattering mode. The best energy resolution under slant-scattering mode is 10 % at the same collimator. To ensure precise alignment of the collimator system, the MiniPIX is employed to capture electron-induced bremsstrahlung, providing indirect feedback on the position of the gamma beam. The attenuator system allows for easy regulation of the gamma beam flux. Additionally, the measured flux at various interaction angles is consistent with the simulation trend.

INTRODUCTION

SLEGS is a Laser Compton Scattering (LCS) beamline in the Shanghai Synchrotron Radiation Facility [1]. The beamline provides quasi-monochromatic gamma rays in the energy range of 0.4–21.7 MeV with a flux of 10^5-10^7 photons/s by inverse Compton scattering between beams of 10640-nm 100 W CO_2 laser photons and 3.5 GeV electrons from the Shanghai Light Source storage ring. Due to the fixed energy of the electron beam in the storage ring, SLEGS achieves gamma energy modulation by changing the interaction angle between the laser and the electron. This paper will introduce the Gamma Modulation System (GMS) and the modulation results for the SLEGS gamma beam, including beam resolution modulation, flux modulation, and energy modulation.

GAMMA MODULATION SYSTEM

The Interaction Chamber

The energy of the gamma rays produced by LCS can be represented by Equation (1):

$$E_\gamma = \frac{(1-\beta\cos\theta)E_L}{1-\beta\cos\theta_c + [1-\cos(\theta-\theta_c)]E_L/E_e} \quad (1)$$

where, the E_γ is the gamma energy, the E_L and the E_e are the energy of the laser photon and the electron beam, separately. θ is the interaction angle, while θ_c is the gamma emission angle with respect to the electron beam axis. $\beta = v/c$ is the relativistic velocity of the electron beam, represented by the ratio of the electron's velocity (c) to the speed of light (v).

The typical LCS gamma rays are produced through the back-scattering mode, where the energy of the gamma beam is modified by changing the energy of the electron beam. However, SLEGS employs the slant-scattering mode, which modifies the gamma energy by changing the interaction angle (θ) between the laser and the electron. The heart that enables the slant-scattering mode is the interaction chamber [2], capable of continuously adjusting the interaction angle within the range of 20° to 160°.

The Collimator System

The collimator is a critical component in many facilities. In the LCS facility, due to the correlation between the gamma emission angle (θ_c) and the E_γ, collimator is mainly used to adjust the resolution (bandwidth) of the gamma beam.

SLEGS has a two-stage collimation [3]. The first one is the coarse collimator, which is placed before the shielding wall. It is used for the preliminary filtering of the gamma beam and keeping the secondary particles within the shielding wall. The secondary collimator has two options: a three-hole collimator and a fine collimator, both placed in the optical hutch. The lead three-hole collimator has three apertures of 1 mm, 2 mm, and 3 mm, which are the typical apertures used in the experiments. The fine collimator is utilized to accommodate experiments that require other apertures.

The Attenuator

The flux varies under different collimator apertures, which can affect the resolution of the gamma beam at the same time. The attenuator is designed to independently reduce the beam flux. The attenuator consists of 8 copper bricks, with thicknesses of 15 mm, 25 mm, 25 mm, 50 mm, 100 mm, 100 mm, 100 mm, and 200 mm, each controlled by its own hydraulic pump. The attenuator, along with the three-hole collimator and the fine collimator, is enclosed in a shielding hutch to reduce background.

The Alignment Equipment – MiniPIX

Collimator alignment is the crucial step before each experiment. The MiniPIX [4] is used to take a image of the beam spot. Therefore, the offset of the collimator relative to the center of the beam can be obtained, and the position of the collimator can be adjusted accordingly.

---

* Work supported by SLEGS group

† haozr@sari.ac.cn

GAMMA BEAM MODULATION RESULTS

This section presents the beam modulation results of the SLEGS beamline, which were mainly conducted under the conditions of the laser power of 5 W and an electron beam current of 210 mA. The results show the energy spectra and corresponding flux with different collimator apertures. Additionally, the energy spectra of various interaction angles are shown. The attenuation capability of the attenuator on the flux is also demonstrated.

Gamma Beam Spots

With MiniPIX, beam spots can be quickly photographed to align the collimator. Figure 1 shows the beam spots of the three apertures in the three-hole collimator and the 5 mm aperture in the coarse collimator. MiniPIX is responsive to the low-energy bremsstrahlung radiation generated by the electron beam. As the gamma rays and electron beam are coaxial, the beam spots taken by the MIiniPIX represent the position of the gamma beam.

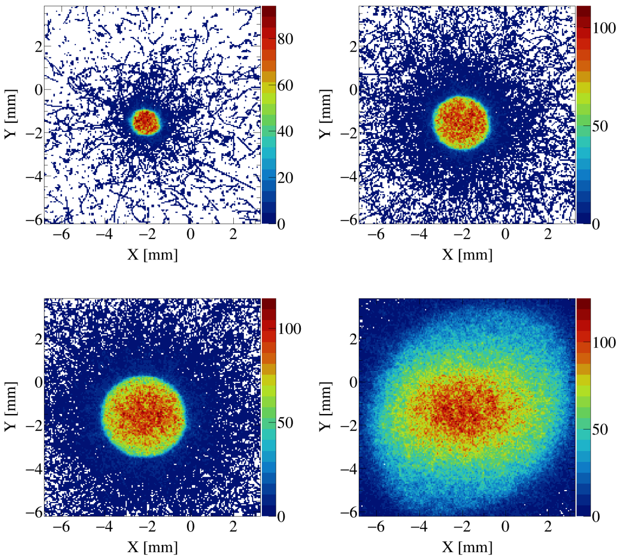

Figure 1: The beam spot of 5 mm aperture in the coarse collimator and the 1 mm, 2 mm, 3 mm apertures in the three-hole collimator taken by the MiniPIX.

Gamma Rays of Various Collimator Apertures

The 90° slant-scattering is a typical angle and the back-scattering is a common used interaction mode for LCS gamma rays, thus the energy spectra were measured under the two modes with various collimator apertures (see Fig. 2 and Fig. 3). A direct undolding method was used to obtain the gamma energy distribution from the detector response spectrum [5]. The resolution and flux of gamma beams corresponding to different collimator apertures are listed in Table 1, and these values are recommended for making experimental plans.

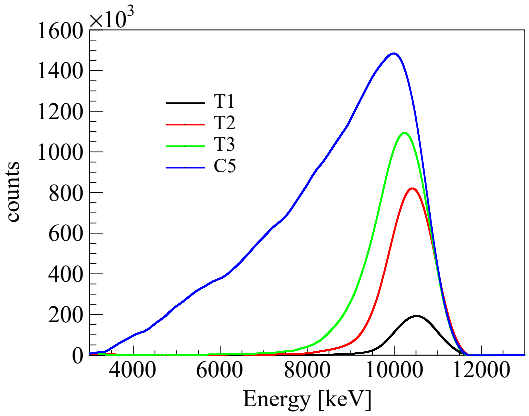

Figure 2: Energy spectra of the 90° slant-scattering mode with various collimator apertures.

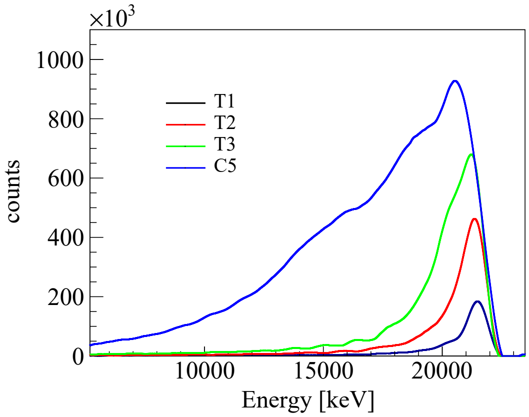

Figure 3: Energy spectra of the 180° slant-scattering mode with various collimator apertures.

Gamma Rays of Various Interaction Angles

The distinctiveness of SLEGS resides in its ability to modify the energy of gamma rays by adjusting the interaction angle between laser and electrons. However, the interaction cross section between the laser and electrons varies with the angle, resulting in variations in gamma beam flux at different angles. SLEGS is able to cover an interaction range from 20° to 160°, but only some of the energy spectra (T2) in the angle range of 75° to 108° is presented in Fig.4. Furthermore, the measured gamma flux, depicted as red dots in Fig.5, varies with the interaction angle, consistent with the simulated flux shown by the black line.

Gamma Flux Modulation

The attenuator is used for modifying the gamma flux. Figure 6 shows the measured gamma flux at various attenuator thicknesses with the 90° slant-scattering, with the laser power of 1.6 W and the T1 aperture. By exponential fitting the flux, the attenuation coefficient of copper was obtained, which is consistent with the NIST database [6].

Table 1: The properties of the gamma beam at 90° slant-scattering mode and back-scattering mode. 'T' for three-hole collimator and 'C' for coarse collimator, and the number is the collimator aperture (unit mm).

	90° Slant-Scattering Mode				Back-Scattering Mode			
Apertures	T1	T2	T3	C5	T1	T2	T3	C5
Collimator Flux [10^4 counts/s]	1.3	4.9	10	30	1.5	6.6	11	38
Bandwidth [MeV]	1.1	1.2	1.4	3.7	0.9	0.9	1.8	4.4
Resolution [%]	10	11	13	34	4	4	8	20

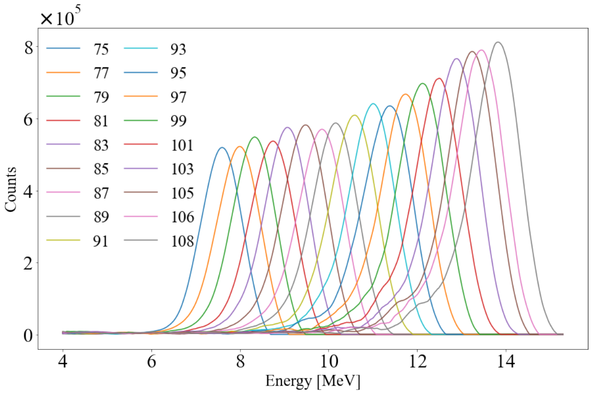

Figure 4: Gamma beam energy spectra at various interaction angles.

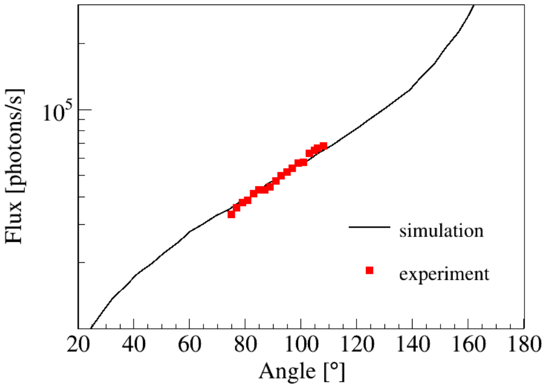

Figure 5: The gamma flux as a function of the interaction angles.

CONCLUSION

The Shanghai Laser Electron Gamma Source (SLEGS) has demonstrated its capability for gamma beam modulation through the Gamma Modulation System (GMS). During the test experiment, conducted with a laser power of 5 W and an electron beam current of 210 mA, we successfully generated quasi-monochromatic gamma beams. In back-scattering mode, utilizing the 1 mm aperture of the three-hole collimator, the gamma beam with an energy resolution of 4 % and flux of 1.5×10^4 photons/s was obtained. Furthermore, under the 90° slant-scattering mode, SLEGS produced gamma beams with an energy resolution of 10 % and flux of 1.3×10^4 photons/s. By employing the 5 mm aperture of the coarse collimator, the flux was notably increased to approximately 3×10^5 photons/s. The attenuator has proven effective in regulating gamma flux.

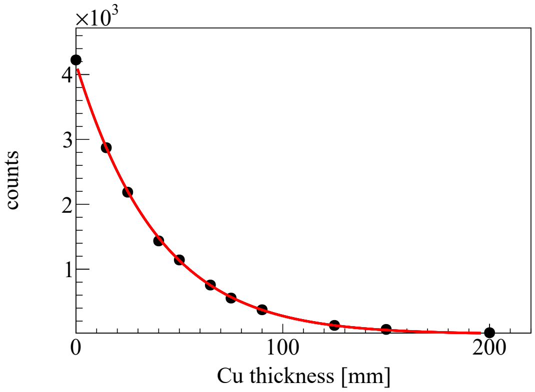

Figure 6: The gamma flux as a function of the interaction angles.

Additionally, the study presented gamma spectra around the 90° interaction angle, where the slant-scattering gamma flux correlated with the simulated trend, experimentally confirming the yield trend of the variable-angle LCS process.

ACKNOWLEDGEMENTS

This work was supported by National key research and development program (No.2022YFA1602404, 2023YFA1606901), the National Natural Science Foundation of China (No.12275338, No.12005280) and the Key Laboratory of Nuclear Data foundation (JCKY2022201C152).

REFERENCES

[1] H. Wang, *et al.*, "Commissioning of laser electron gamma beamline SLEGS at SSRF,"*Nucl. Sci. Tech.*, vol. 33, no. 7, p. 87, Jul. 2022. `doi:10.1007/s41365-022-01076-0`

[2] H. Xu *et al.*, "Interaction chamber for laser Compton slant-scattering in SLEGS beamline at Shanghai Light Source,"*Nucl. Instrum. Meth. A*, vol. 1033, p. 166742, Jun. 2022. `doi:10.1016/j.nima.2022.166742`

[3] Z. Hao *et al.*, "Collimator system of SLEGS beamline at Shanghai Light Source,"*Nucl. Instrum. Meth. A*, vol. 1013, p. 165638, 2021. `doi:10.1016/j.nima.2021.165638`

[4] `https://advacam.com/camera/minipix-tpx-standard/`

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPC82

[5] L. Liu *et al.*, “Energy profile of laser Compton slant-scattering γ-ray beams determined by direct unfolding of total-energy responses of a BGO detector,”*Nucl. Instrum. Meth. A*, vol. 1063, p. 169314, 2024. `doi:10.1016/j.nima.2024.169314`

[6] `https://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html`