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Research Article

High energy and high brightness laser compton backscattering gamma-ray source at IHEP☆

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Abstract

Based on the LINAC of BEPCII, a high-polarized, high bightness, energy-tunable, monoenergetic laser compton backscattering (LCS) gamma-ray source is under construction at IHEP. The gamma-ray energy range is from 1 MeV to 111 MeV. It is a powerful and hopeful research platform to reveal the underlying physics of the nuclear, the basic particles and the vacuum or to check the exist basic physical models, quantum electrodynamic (QED) theories. In the platform, a 1.064 μm Nd:YAG laser system and a 10.6 μm CO_2 laser system are employed. All the trigger signals to the laser system and the electron control system are from the only reference clock at the very beginning of the LINAC to make sure the temporal synchronization. Two optical transition radiation (OTR) targets and two charged-couple devices (CCD) are used to monitor and to align the electron beam and the laser beam. With the LCS gamma-ray source, it is proposed to experimentally check the gamma-ray calibrations, the photon-nuclear physics, nuclear astrophysics and some basic QED phenomena.

PACS codes: 29.40.-n; 07.85.-m; 29.30.kv

Keywords: laser compton scattering; Calibration; Photon-nuclear physics; Gamma-gamma collider; Nuclear astrophysics; QED; Gamma-gamma scattering; Detection

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1. Introduction

Based on the 2.5 GeV high-energy electron accelerator, BEPCII at IHEP, a laser compton backscattering (LCS) is under construction to generate high-polarized, high-brightness and monoenergetic gamma rays within a wide energy range, which is a milestone of the experimental study of photon-nuclear physics [1−3] and quantum electrondynamics (QED) phenomena. The LCS gamma-ray source has especially important applications for gamma-ray calibrations, photon-nuclear physics, gamma-gamma collider and so on. For the flash X-ray radiography, the response functions of the image system require series of high-brightness and monoenergetic gamma-ray sources. In a wide energy range, the key data of photon-nuclear physics, such as those of nuclear resonance fluorescence (γ,γ'), (γ,n) reactions [1] and (γ,p) reactions can be acquired and checked experimentally with the LCS gamma-ray sources [4]. In the nuclear astrophysics, the LCS gamma-ray source can help to open the mystery veil of some heavy-elements formations [5]. Also importantly, with two LCS gamma-ray sources, we can establish a gamma-gamma collider, by which one can validate some QED effects experimentally, such as gamma-gamma scattering, electron-positron generation, Delbrüeck scattering [6] and vacuum polarization and so on. In addition, in the near future, with 100 MeV or 100 GeV gamma-gamma collider, one can obtain $\mu(0)$, Higgs particles and can study the related new physics [7].

Based on the important applications, the LCS gamma-ray sources have been appreciated extensively and have been built or planned to build around the world, such as the LADON in Italy [8], the SPARC_LAB Thomson source [9], the LEGS in the NSLS [10], the OK-4 and the HIγS in Duke University [11], the VEPP-4M in Russia, the ELI-NP [12,13], the AIST-LCS and the NewSUBARU [14] in Japan, the SLEGS in Shanghai [2,15] and the LCS-gamma ray source in IHEP. In 1980, Federici and coworkers [8] obtained gamma rays of energy continuously adjustable from 5 MeV to 78 MeV with LCS. The LEGS facility [10] also proposed 300−700 MeV gamma ray beams with 2.5 GeV electron beams or a free electron laser (FEL). At HIγS, the gamma-ray energy reached 225 MeV and the flux exceeded 10^7 photon/s. Several photon-nuclear reactions, such as ^{28}Si $(\overrightarrow{\gamma}, \mathrm{p})$ ^{27}Al [16], D $(\overrightarrow{\gamma},\mathrm{p})$n [17,18] were performed by the LCS gamma-ray sources. The SPARC_LAB Thomson source [9] could provide an X-ray energy tunability in the range of 20−500 keV, with measured photon flux of about 10^4. In the proposals of the ELI-NP-GBS (gamma beam system) [12,13], high intensity X-/γ- ray beams in the energy range of 1−20 MeV will be obtained with an electron beam energy tunable from 75 MeV to 750 MeV. The proposed flux can reach 10^9 /s. Recently, a 51.7 keV LCS X-ray with flux of 10^{6-7} /pulse was achieved in Tsinghua University, named Tsinghua Thomson scattering X-ray source (TTX). Xi'an Gamma-ray Light Source (XGLS) has been proposed to obtain a 3 MeV gamma ray beam with a 400 MeV electron beam. SLEGS is planned to generate gamma-ray in the energy range of 2−20 MeV and 300−500 MeV, with the flux of 10^{5-7} photon/s (low energy) and 6×10^6 photon/s (high energy) at SSRF. Besides of conventional accelerators, the laser-plasma acceleration can also be used to generate Compton gamma-ray [19,20]. For the Thomson scattering of a high intensity laser pulse from electrons, it is valuable to improve the scattering gamma-ray yield with proper laser chirping [21]. To make the duration of the laser pulse roughly equal to $2Z_R/c$ with Z_R, i.e., the Rayleigh length, it is the optimal case for the diffracting laser pulse. Another interesting way to increase the photon yield of the source is to use plasma channel [19].

From 2012, based on the high energy electron beam at BEPCII, the LCS gamma-ray source in the energy range of 1−100 MeV, with the flux of 10^{4-5} was proposed. Different from the collision between the laser pulse with the cyclotron-electron beam, there is no need to worry about the quality of the electron beam after LCS. Therefore, we planned to employ 10 ps ultra-intense laser pulse to increase the gamma-ray flux to 10^8/pulse.

Although three big LCS facilities have been proposed in China, they still cannot satisfy the large demand for high-brightness polarized gamma-ray sources. It is absolutely necessary to push the progress of the LCS gamma-ray source.

2. LCS gamma-ray source based on BEPCII at IHEP

2.1. Parameters of the electron beam and the laser systems

At IHEP of CAS, the linac accelerator can supply electron beams of 10 ps and 2 nC in the energy range of 0.2−2.5 GeV. In the first stage, the conventional thermionic cathode gun is still used. A nanosecond Nd:YAG laser system is employed. The parameters of the electron beam and the laser system are shown in Table 1. λ and ω_0 stand for the wavelength of the laser, the diameter of the saddle of the laser pulse in the interaction region, respectively. $\sigma_{x,y}$ is the size of the electron beam in the interaction region, $\varepsilon_{x,y}$ is the normalized emittance of the electron beam.

It is known that there is an excellent approximation of the gamma-ray energy from the LCS [8]:

$$E_\gamma = \frac{x}{1+x+z}E_e, \tag{1}$$

where $x = \frac{4E_eE_l}{(m_ec^2)^2}$, $z = \theta^2\gamma^2$, $\gamma = \frac{E_e}{m_ec^2}$, $E_l = 2\hbar\pi c/\lambda$ is the energy of a single photon, θ is the angle between the emitted gamma and the electron. To avoid the pair production, the optimum value of x is about 4.8. With Eq. (1) and Table 1, the

Table 1
Parameters of electron beams and laser pulses.

Electron beams at E2 line		Nd:YAG laser system	
Energy (GeV)	0.2−2.5	λ (nm)	1064
Duration (ps)	10	Duration (ns)	8−10
Charge (nC)	1−2	E_l (J)	2
$\sigma_{x,y}$ (mm)	1.2	ω_0 (mm)	2.4
$\varepsilon_{x,y}$ (mm•mrad)	338 (370)		
Frequency (Hz)	12.5	Frequency (Hz)	12.5

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