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Simulation studies on the polarized positron generation from circularly polarized gamma-rays*

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Abstract: Polarized positrons can be generated through the electron-positron pair creation from circularly polarized gamma-rays hitting a conversion target. Laser-Compton scattering is an efficient method to generate circularly polarized gamma-rays. Simulation studies on these two processes have been done with the Monte Carlo codes, CAIN and GEANT4. Using CAIN to simulate the Laser-Compton scattering process, the energy spectrum of the generated polarized photons could be obtained. GEANT4 was used to study the yield, energy spectrum and the mean polarization of the positrons emanating from the conversion target. To increase the yield of the generated positrons, an optimization study on the thickness of conversion target was also performed.

Key words: polarized gamma-rays, Compton scattering, polarized positrons

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1 Introduction

It is widely believed that one of the next-generation accelerators at the energy frontier will be an electron-positron linear collider, the International Linear Collider (ILC), where the polarized positron beam, as well as the polarized electron beam, will play significant roles in the physics study. A novel method to generate highly polarized positron beam through electron-positron pair creation from polarized gamma-rays that are generated from the inverse Compton scattering of circularly polarized laser-photons was proposed in 1996 [1]. A proof-of-principle experiment of the polarized positron generation experiment based on this method was done at the extraction line of KEK-ATF in 2002 [2, 3].

Recently, the Monte Carlo method has been widely used in particle physics. In order to understand the processes of the Laser-Compton scattering and electron-positron pair creation, simulation studies are useful and necessary.

2 Laser-Compton scattering

The Compton scattering between an electron beam and a laser can generate photons with very high directivity and a wide energy range from several keV to hundreds of GeV by choosing appropriate electron energy and laser wavelength. On the other hand, Laser-Compton scattering is an efficient method to generate polarized gamma-rays by using a circularly polarized laser light [4]. The CAIN [5] Monte Carlo code was used to simulate the Laser-Compton scattering between the 1.28 GeV electron beam and the 1064 nm circularly polarized laser light. Table 1 shows the parameters of the laser light and the electron beam used in the simulation.

When the incident laser light is circularly polarized, the generated gamma rays are expected to be longitudinally polarized. Theoretically, the Klein-Nishina formula can be used to obtain the differential cross section of the Compton scattering [6]. Fig. 1 shows the differential cross section of the Compton scattering for right-handed polarized laser photons with a wavelength of 1064 nm backscattered off 1.28 GeV electrons as a function of the scattered gamma rays' energy. The R and L curves correspond to the right-handed and left-handed helicities of the gamma rays, respectively.

From Fig. 1, it can be found that the left-handed

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Table 1. Parameters of the laser light and the electron beam.

laser light		electron beam	
wavelength	1064 nm	energy	1.28 GeV
pulse energy	2.8 J	bunch charge	1.6 nC
beam size	29 μm (rms)	bunch length	20 ps (FWHM)
pulse width	5 ps (FWHM)	bunch size	σ_x=78 μm
polarization	100% circularly polarization		σ_y=6 μm

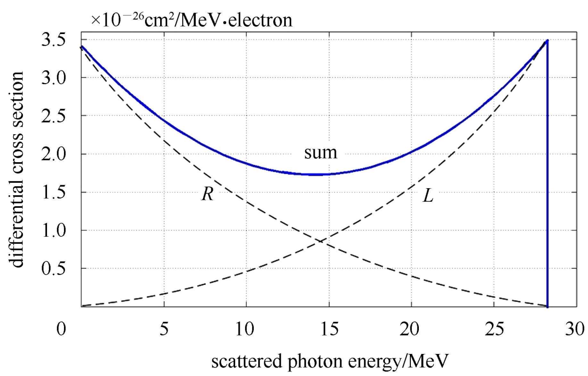

Fig. 1. Energy distributions of the scattered gamma photons.

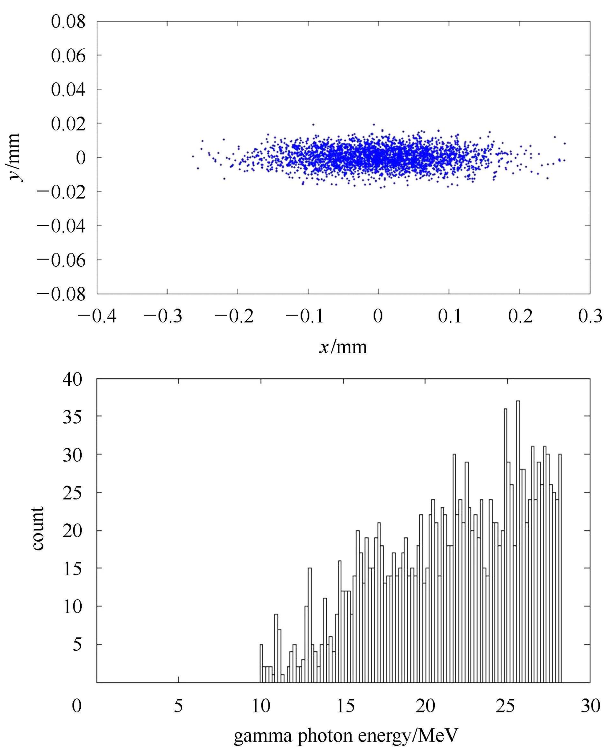

Fig. 2. The space distribution and energy spectrum of the generated photons with left-handed helicity.

gamma rays predominate in high energy region. That means the generated gamma rays will show their polarization after cutting the low energy part by a lead shield and a high cut threshold leading a high polarization degree. Fig. 2 shows the CAIN simulation results of the space distribution and the energy spectrum (10 MeV energy cutoff by passing a 5 mm diameter lead shield downstream) of the generated photons with left-handed helicity. It can be found that the simulation results are in agreement with the theoretical results.

3 Electron-positron pair generation

The positron is the anti-particle of the electron and can be generated from an electron-positron pair creation process, as shown in Fig. 3, in which an electron and a positron are simultaneously created in the vicinity of a nucleus or subatomic particle. In the conventional positron source, a high energy electron beam is usually used to impinge on the high-Z, high density target to generate positrons. The generated positrons' yield is limited by the incident electron beam power, which might cause damage to the target because of the energy deposition, and the generation of the polarized positrons is not possible. Recently, a photon-based new scheme in which a multi-MeV photon beam is converted in a thin target to positrons and electrons mostly by a pair creation process has been proposed. Compared with the conventional positron source, the photon-based scheme has a larger positron capture efficiency, and improved thermal stress. Another advantage is the possibility of producing polarized positrons. When a polarized photon creates an electron-positron pair in a thin target, the polarization state of the photon is transferred to the outgoing particles according to the expression given by Olson and Maximon in 1959 [7]. The circularly polarized photons created by Laser-Compton scattering hit the target and generate pairs of longitudinal polarized positrons and electrons.

To study the process of polarized positron generated from polarized gamma-rays hitting on a thin target, the Monte Carlo code GEANT4 was used to simulate the yield, energy spectrum and the mean polarization of the positrons emanating from the target. GEANT4 can simulate electromagnetic and nuclear

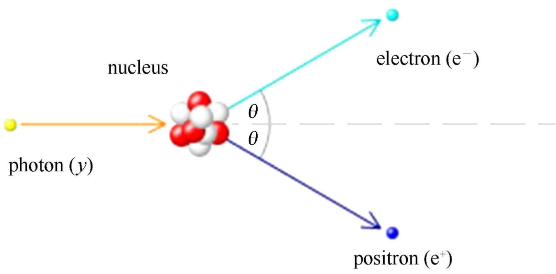

Fig. 3. The electron-positron pair creation process.

interactions during the passage of particles through matter [8]. In the simulation, the information of the incident polarized photons with an energy spectrum as shown in Fig. 2 and a left-handed helicity were obtained by CAIN. The material of the conversion target is tungsten with 1 mm in thickness. The positron energy spectrum from the polarized photon beam hitting the tungsten target is shown in Fig. 4 (the total spectrum). Because of the energy deposition in the conversion target, some generated positrons with low energy cannot be emanated from the target, only part of the total generated positrons could be detected after the target, as shown in Fig. 4 (the shadowed part). It can be found that the outgoing positrons have a large energy range from 0.5 MeV to 26 MeV and the positrons with low energy are dominant.

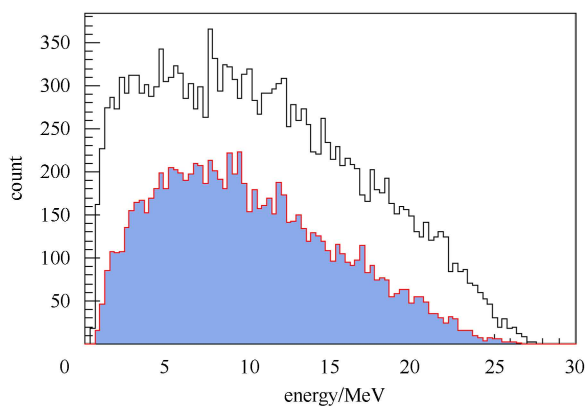

Fig. 4. The energy spectrum of generated positrons.

Figure 5 shows the mean longitudinal polarization of the generated positrons. It can be found that the outgoing positrons with −1 longitudinal polarization are dominant because the incident polarized photons have a left-handed helicity which means +1 longitudinal polarization. The average polarization of all outgoing positrons is around 57%. Fig. 6 shows the scatter plot of outgoing positrons' energy and longitudinal polarization distribution, a very important fact which can be found is that the high energy positrons have a high polarization. Positrons with energy close to that of the incoming photons are 100% longitudinally polarized, while positrons with lower energy have a lower polarization. If only the high energy part of the spectrum is considered, very high longitudinal polarization can be obtained. For example, positrons with energy higher than 15 MeV have a mean longitudinal polarization higher than 80%. It can be summarized that laser-Compton scattering is an efficient method to generate positrons with high longitudinal polarization by using electron-positron pair creation from polarized gamma rays.

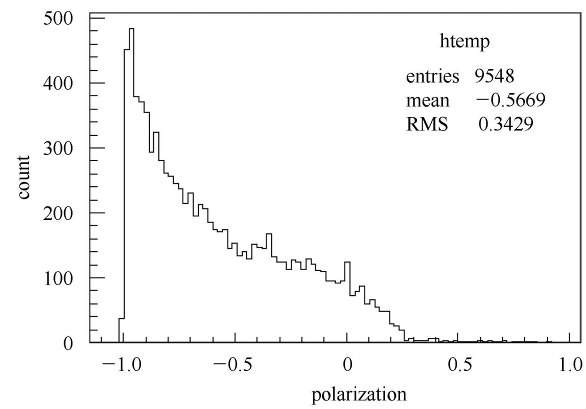

Fig. 5. Mean polarization of the generated positrons.

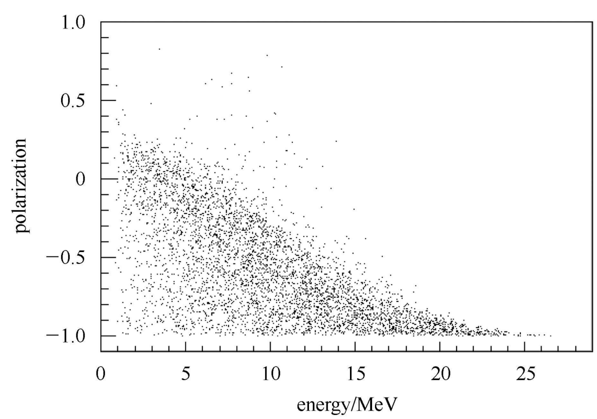

Fig. 6. Scatter plot of the positrons' energy and the polarization distribution.

Positron yield is another important parameter of the positron source, which is usually defined as the number of positrons per photon incident on the conversion target. It is determined by the energy of the incident radiation, the interaction area on the conversion target, and the target thickness. Generally, a thicker target is helpful for generating more particles because the creation of particles in the electromagnetic cascades (bremsstrahlung and pair creation) scales with the radiation length. However, a thicker target introduces a larger energy loss before the generated particles reach the target surface, and this kind of energy loss will lead to the reduction of outgoing particles; an optimization of the target thickness is necessary to get a high position yield. Fig. 7 shows the optimization results of the tungsten target thickness. It can be found that the positron yield reaches its maximum when the tungsten target thickness is around 1 mm if the incident gamma photons have a space distribution and energy spectrum as shown in Fig. 2. Here, 100000 photon events were used as the simulation input for the incident radiation

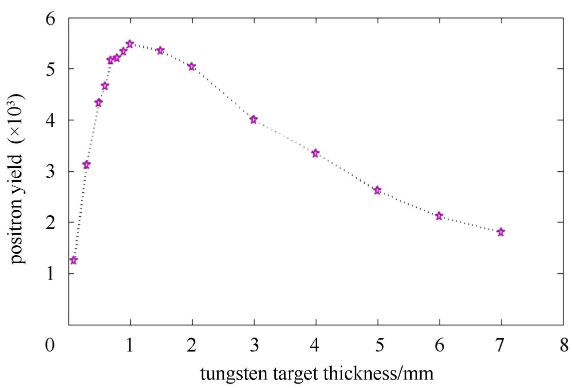

Fig. 7. Optimization of the target thickness.

and around 5400 outgoing positrons were collected, which means a 5.4% positron yield. It is much higher than a conventional positron source where an electron beam creates electron-positron pairs in an electromagnetic cascade [9].

4 Conclusion

Using CAIN to simulate the laser-Compton scattering process between the 1.28 GeV electron beam and the 1064 nm circularly polarized laser light, the space distribution and energy spectrum of the generated polarized photons were obtained. The information of the generated photons was used as GEANT4 input and the process of electron-positron pair creation from polarized photons was simulated. It can be found that the generated positrons have a high average longitudinal polarization in a high energy region. The electron-positron pair creation from polarized gamma rays is an efficient method to generate positrons with high longitudinal polarization. An optimization of the target thickness has been done to improve the positron yield, which is much higher than a conventional scheme.

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