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Experiment studies on the polarized gamma-rays generation at KEK-ATF*

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Abstract Polarized positrons can be created through electron-positron pair creation from circularly polarized gamma-rays. Laser-Compton scattering is an efficient method to generate circularly polarized gamma-rays. A high finesse 2-mirror optical stacking cavity had been installed on the straight section of the electron storage ring at KEK-ATF. A 1064 nm circularly polarized pulsed laser beam was stacked in the cavity. Polarized gamma-rays with a maximum energy of 28.3 MeV were produced via inverse Compton scattering of the enhanced laser pulse off an electron beam of 1.28 GeV. The number of generated gamma photons per collision was estimated by a photon detector. It was found that the experimental result was in agreement with the simulated value.

Key words polarized gamma-rays, Compton scattering, optical stacking cavity

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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 physics study. A novel method for creating a highly polarized positron beam through electron-positron pair creation from the polarized gamma-rays that are generated from the inverse Compton scattering of circularly polarized laser-photons was proposed in 1996[1]. A polarized positron generation experiment based on this method had been done at the extraction line of KEK-ATF in 2002[2, 3]. That experiment made the proof-of-principle of the proposed method.

The laser-Compton scattering based positron source is now an alternative scheme for the ILC positron source[4]. In order to meet the high requirements of the ILC positron source, high finesse 2-mirror stacking cavities are supposed to be installed at the collision points to enhance the laser power. The number of photons would be increased by enhancing the laser power at the collision points, and that means the intensity of the positron beam generated by photons through pair creation would be increased as well.

2 Experimental scheme

As a preliminary experiment, one 2-mirror optical stacking cavity was installed on the KEK-ATF storage ring. As shown in Fig. 1, a 1064 nm circularly polarized pulsed laser light is going to be enhanced in the optical stacking cavity and then makes a 12° collision with the 1.28 GeV electron beam. Table 1 shows the parameters of the laser, electron beam and optical stacking cavity.

Polarized gamma-rays are expected to be generated via the inverse Compton scattering of the enhanced laser pulse off the electron beam. Fig. 2 shows the differential cross section of the inverse Compton scattering for right-handed polarized laser photons with the 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 helicities of the right-handed and left-handed for the gamma-rays, respectively. It was found that

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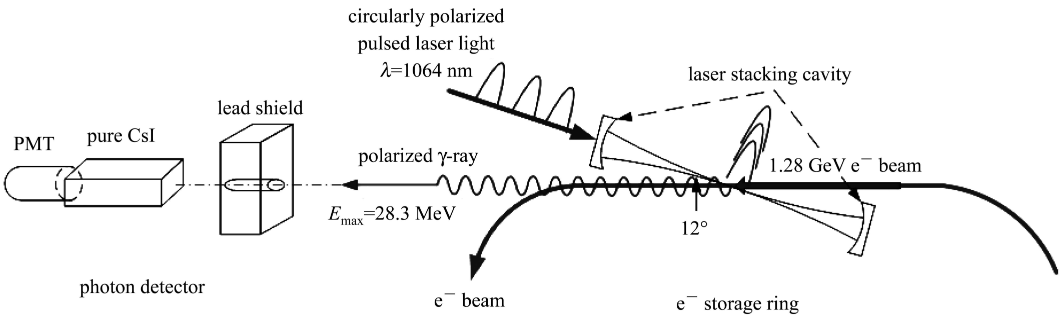

Fig. 1. The scheme of the preliminary experiment at KEK-ATF.

Table 1. Parameters of the laser, the electron beam and the optical stacking cavity.

laser light		electron beam		optical stacking cavity	
type	YAG(1064 nm)	energy	1.28 GeV	cavity length	420 mm
frequency	357 MHz	bunch size	σ_x=78 μm	mirror curvature	210.5 mm
power	10 W(28 nJ/pulse)		σ_y=6 μm	mirror reflectivity	99.6%
pulse width	7 ps(FWHM)	emittance	$\varepsilon_x=1.0\times10^{-9}$ m·rad	design finesse	780
polarization	500:1		$\varepsilon_y=0.5\times10^{-11}$ m·rad	waist size	30 μm

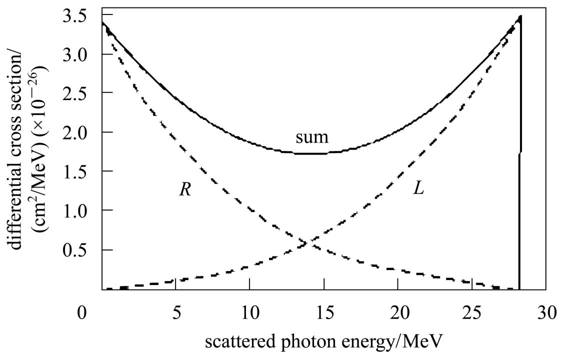

Fig. 2. Energy distribution of the scattered gamma photons.

the left-handed gamma-rays predominate in the high energy region. The gamma-rays show their polarization after cutting the low energy part by a lead shield.

A photon detector made of a PMT and a pure CsI scintillator was located at the downstream gamma-rays, as shown in Fig. 1. The signal from the photomultiplier was processed by a series of electronics circuits, as shown in Fig. 3.

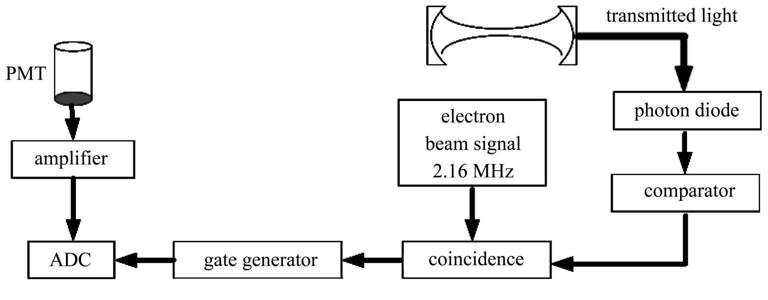

Fig. 3. DAQ scheme.

3 Experimental results and analysis

A very important factor of a stacking optical cavity is the finesse of cavity. In a resonant (cavity length equals integer times of half wave length of laser light) 2-mirror cavity, if the two mirrors have the same reflectivity R, the finesse F and the enhancement factor E of the cavity are defined as shown below:

$$F=\frac{\pi\sqrt{R}}{1-R},\quad E=\frac{F}{\pi}.$$

The reflectivity of mirrors used in this experiment was 99.6% and the expected finesse was around 780. Two piezoelectric ceramic transformers located on both sides of the cavity were used to adjust the distance between the two mirrors to keep the cavity on resonance.

The laser system and optical cavity are mounted on a moveable table, which could be moved with 0.8 μm accuracy both in the horizontal and vertical directions. Using this moveable table, the laser beam could be scanned to find the best collision point with the electron beam. Fig. 4 shows the results of the laser beam scan. The horizontal axis is the laser beam position in the horizontal or vertical directions and the vertical axis is the average generated photons per collision. The scan results showed a good Gaussian distribution in the vertical direction, but didn't in the horizontal direction. It was believed that the unsatisfactory results in the horizontal direction were due to the errors caused by the instability of the electron beam or laser beam.

After finding the best collision point of the laser beam and electron beam, a phase scan on the laser pulse was done. A phase shifter was used to scan the phase of the laser pulse. That means to keep the phase of the laser pulse in the stacking cavity synchronized with the electron bunch. Then a complete collision occurred between the laser pulse and the electron bunch and generated the maximum number of photons. Fig. 5 shows the timing scan result, in which the vertical axis is the average value of detected photons per collision, too.

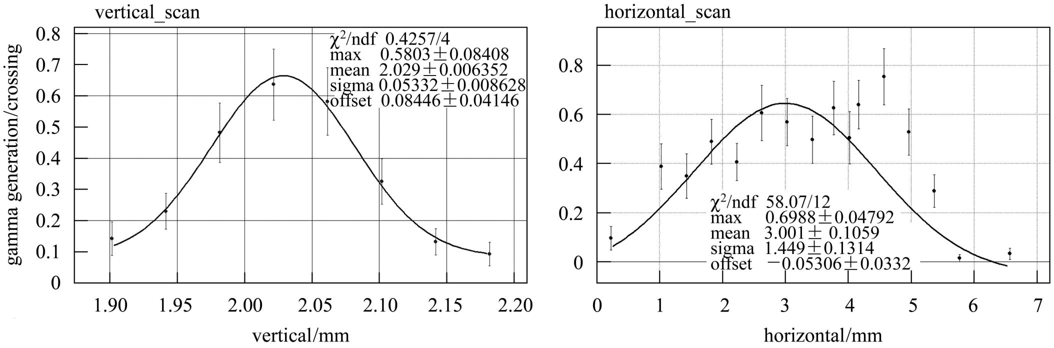

Fig. 4. Horizontal and vertical scan results of the laser beam.

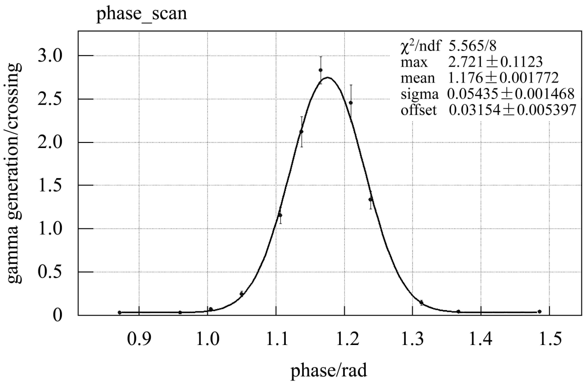

Fig. 5. Phase scan of the laser pulse.

As shown in Fig. 1, a lead shield located at the downstream gamma-rays was used to cut the lower energy part of the generated photons. According to the experiment set up, the slid angle of photons which could pass the lead shield and were detected at detector was limited to 0.26 mrad by a small aperture of the lead shield. Considering the relationship between the scattering angle and the scattering energy of the generated photons, the energies of the detected photons are distributed in a range of 16—28.3 MeV. Fig. 6 shows the energy spectrum of the detected photons. By analyzing the energy spectrum, the estimation value on the average number of generated photons per collision was around 3 photons/collision.

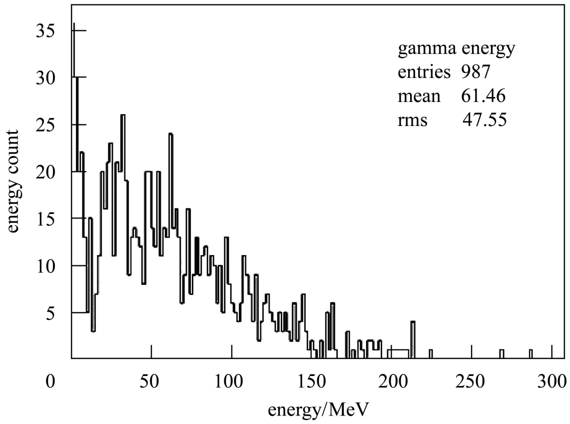

Fig. 6. Energy spectrum of the detected photons.

A bump scan means that introducing a bump in the electron beam orbit to change the beam direction at the collision point was made in the second experiment stage. The purpose of the bump scan was to make sure the direction of the gamma-rays was completely straight to the detector. Because of the limitation of the beam time, only a vertical bump scan was made. Fig. 7 shows the bump scan results. The horizontal axis shows the change of the electron beam orbit after introducing the bump and the vertical axis shows the average number of detected photons per collision. As shown in the bump scan results, the maximum of detected photons was around 3.5 photons/collision. It was a little higher compared with the no bump condition.

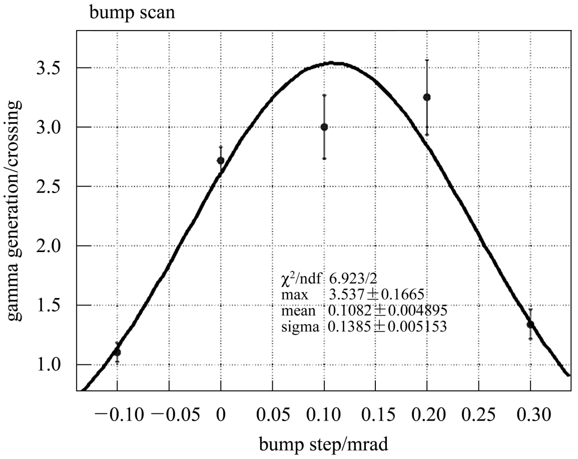

Fig. 7. Bump scan at the collision point.

A simulation code CAIN[5] was used to simulate this inverse Compton scattering process. The power of the laser in the stacking cavity was estimated by the power of the transmitted laser light. The measured power of the transmitted laser was 1.09 W, and the reflectivity of the mirror was 99.6%. So, the laser power in the stacking cavity was estimated as $1.09\ \text{W}/(1-99.6\%) = 272\ \text{W}$. The electron beam intensity was 0.6×10^{10}/bunch. Using these parameters, the simulation results from CAIN show the maximum number of generated photons was 4.5 photons/collision, as shown in Fig. 8. The experimental measurement was in agreement with the CAIN simulation, but a little lower in photons yield. In comparison with Fig. 4, Fig. 8 has a higher yield of generated photons and a narrower distribution width. This is because the simulation results were based on a complete collision between an electron beam in the best condition (beam size was 78 μm, 8 μm) and a laser beam. Unlike the simulation, the experimental results of the position scan shown in Fig. 4 were carried out before the phase scan. This means a partial collision occurred between the electron beam and the laser beam and this partial collision led to a lower yield of generated photons. And during this experiment, the exact size of the electron beam was not measured. Generally, it would be lager than the best condition according to the beam operation status. The larger electron beam size led to a wider distribution width in comparison with the simulation case, as shown in Fig. 4.

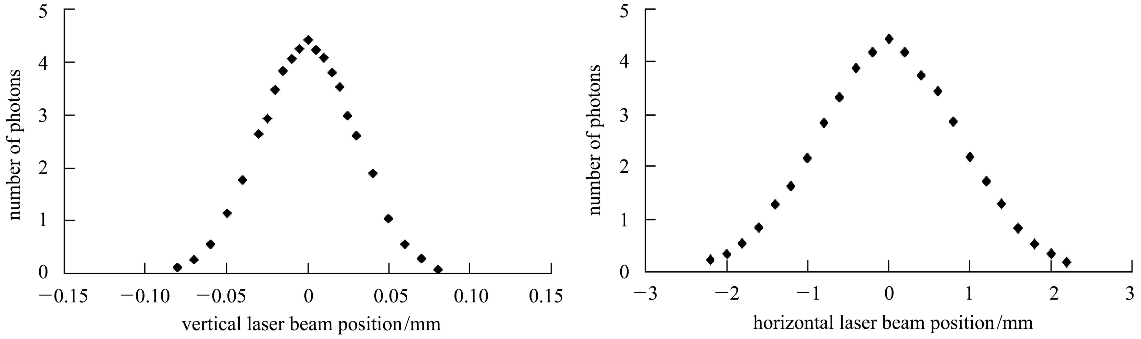

Fig. 8. Simulation results of the gamma photons' yield versus the laser beam position.

Laser power in the stacking cavity was determined by the incident power of the laser and the resonance status of the cavity. In this experiment, the long laser path before going into the cavity led to a heavy energy loss of the laser during the transmission from the laser source to the cavity. And the fact that the cavity didn't work on the completely resonant point led to a reduction of the stacked laser power. So, the number of generated photons was much lower than the designed value. Improvement on the laser transmission path and the cavity resonance status adjustment is necessary in future experiments to increase the yield of the gamma photons. Much higher reflectivity (99.9%) mirrors are supposed to replace the 99.6% reflectivity mirrors in the next experiment to get a high finesse around 3000.

4 Conclusion

As a preliminary experiment of the laser-Compton scattering based positron source, gamma-rays generated from the inverse Compton scattering between a 1.28 GeV electron beam and a 1064 nm pulse laser which were enhanced by a pulse stacking cavity have been detected. The first experimental result was in agreement with the simulation value. To increase the yield of the gamma photons will be the essential work in the future.

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