POSITRON GENERATION THROUGH LASER COMPTON SCATTERING GAMMA RAY*

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Abstract

We performed an experiment of positron generation through laser Compton scattering gamma ray. The gamma ray is produced from a laser light scattering off a high-energy electron beam in a storage ring. Pb slab is chosen as target to be irradiated by the gamma ray to generate positrons via pair creation. The generation rate is measured and the energy spectrum is worked out. The dependence of positron flux on the slab thickness is also investigated. About $4\text{x}10^3$ positrons/s at a few MeV can be generated by a 4 mm slab of Pb at the present experimental setup, and this value can be improved by optimizing experimental conditions.

INTRODUCTION

Positron sources are important for linear colliders and are valuable tools in research of materials science, atomic physics and solid state physics [1-4]. The proposal of positron generation through high-energy photon beams was presented several years ago [4-6], however, experiments are rare.

In this paper, we report an experiment for generating positron beams. The experiment is based on a high-energy gamma ray beam produced through Compton scattering of laser light from a high energy electron beam in a storage ring. The gamma ray is then arranged to impinge on a thin Pb target to generate positrons and electrons via pair creation reaction. The positrons can be separated from the electrons and scattering photons by magnetic field, and then can be provided to users.

LASER COMPTON SCATTERING GAMMA RAY

A laser Compton scattering (LCS) setup has been built on NewSUBARU storage ring. NewSUBARU is a racetrack shape electron storage ring synchrotron radiation facility [7]. The circumference of the ring is about 118 m, and that have two 12 m long straight sections. Electron beam is injected from 1 GeV linac. One of the straight sections of the ring was chosen to build interaction vacuum chamber, where the electron beam collides with the incoming laser light in a head-to-head manner. Thus, high energy photons are produced, going along the incident electron moving direction in a forward cone of angle $1/\gamma$, where γ is the relativistic factor of electron, namely, 0.5 mrad for 1 GeV electron beam. The laser light with wavelength of 1064 nm comes from a Nd:YVO laser, consequently, the produced high-energy photons are gamma ray photons, and the maximum gamma ray energy is 17.6 MeV .

NewSUBARU LCS Facility

The interaction point was designed at the centre of the straight section, where both the electron beam and the laser light transverse profiles were focused to the minimum. A reflected mirror is located at the downstream end to guide the laser light travelling along the beam line through the interaction point, and the light is reflected out of the chamber by another upstream mirror [8]. The produced gamma ray photons would go through the downstream mirror, come into the hatch and reach the detector or irradiate the target. A schematic setup graph is as shown in Fig.1.

The laser is installed at the outside of the shielding wall and is injected into the vacuum duct using three mirrors deliberately arranged and a convex lens with focal length of 5 m in a well-designed position, 7.5 m away from the laser and 15 m away from the center point of the straight section. This results in a focused spot of light with radius of 0.82 mm. The electron beam size is determined by the β function and emittance. For the NewSUBARU storage ring, at the center point of the straight section, these parameters are characterized as β_x =2.3 m, β_y=9.3 m, ε_x=40 nm, and ε_y=4 nm, resulting in the electron beam size of 0.30 mm for the horizontal direction and 0.19 mm for the vertical direction. Consequently, the size of electron beam is smaller than that of the laser beam at the interaction point.

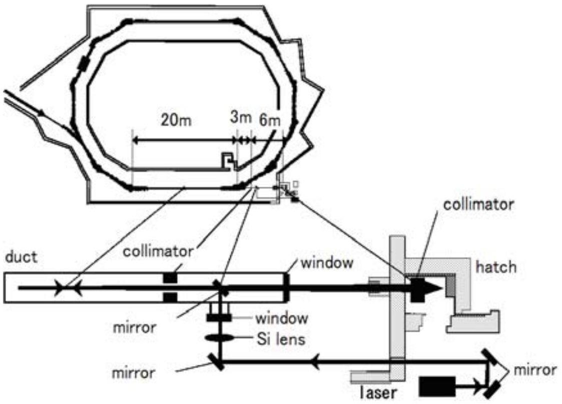

Figure 1:Schematic of laser Compton scattering gamma ray setup

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Gamma Ray Properties

The gamma ray detector is located about 18 m from the electron-photon collision point. A high-purity Germanium coaxial detector is used with the detection efficiency of 45%. The measurements of gamma ray photons are carried out at a lower current of several mA, to avoid saturations at the detector. An example of measured spectrum is shown in Fig. 2, with a lead collimator of 24 mm in diameter in front of the detector.

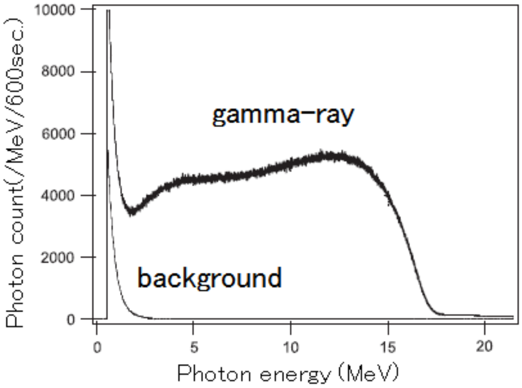

Figure 2: Experimental result of NewSUBARU LCS gamma-ray.

The clear difference between the two signals of laser Compton scattering gamma ray and the background shows a good signal-to-noise ratio. The background signal is due to the bremsstrahlung by the residual gases in the vacuum duct of the straight section. The maximum energy appears around 17 MeV, which is in agreement with the theoretical prediction. We simulated the process of generated gamma ray transport from the source to the detector including photons passing through the reflected mirror, output window, collimator, and being detected by the detector, by employing the EGS4 code. After processing the experimental data with 3 mm in diameter collimator, we achieved the actual gamma ray generation rate of 66.5 photons/mA/W/s. This yield is obtained by the gamma ray energy of 17.1-17.6MeV. Then, the maximum gamma ray photons' yield of more than 1.66×10^5 photon/s is expected under the condition of storage current 500 mA and laser power 5 W.

POSITRON EXPERIMENT

The positron generation experiment is arranged as shown in Fig.3. The laser Compton scattering gamma ray goes through a 3 mm collimator, an imaging plate numbered IP1 and irradiate a thin Pb target. An electromagnet is set just behind the target. The generated positrons and electrons are bent to opposite directions according to the magnetic pole, and are then separated, while the penetrated gamma ray photons and scattering photons are not influenced by the magnetic field and go forward. Another imaging plate numbered IP2 is located at a distance of 15 cm from the target, to image the positrons, electrons and photons. The imaging plate IP1 is used to record the total incidence gamma ray photons. Processing those images we can get information of generated positrons, electrons and photons, such as flux, generation rate and energy spectrum.

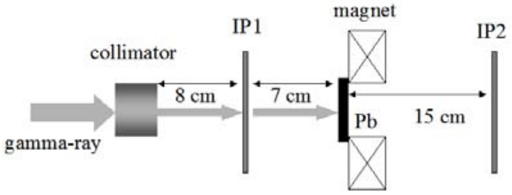

Figure 3: Schematic of experimental set up.

Generated positrons and electrons can be easily understood from Fig. 4, which is an example to show the images obtained at magnetic field B=0 and B=0.2 T, respectively. Both of the images come from the position of IP2 when a 2 mm thick Pb target is irradiated. It is seen that generated positrons, electrons, penetrated and scattering photons commix together when B=0 (see Fig. 4(a)), and are separated when B=0.2 T (see Fig. 4(b)). From Fig. 4 (b) we note that the quantity of electron is larger than that of positron, since electron is generated not only via pair creation but also via Compton scattering effect.

According to the strength of the magnetic field and the bending distance from the central point on the image, we can calculated the energy of generated positrons; the intensity of the particles can be achieved through processing the image. So, energy spectrum is worked out as shown in Fig. 5. It is seen that the positrons' energy has a peak appears at around 11 MeV, and a long tail up to 60 MeV. The tail over 17 MeV should not be real positron and electron data, and it could be the result of scattering photons from the stuffs around the image. From Fig.5 we can deduce that the contribution from Compton scattering effect is ~24%.

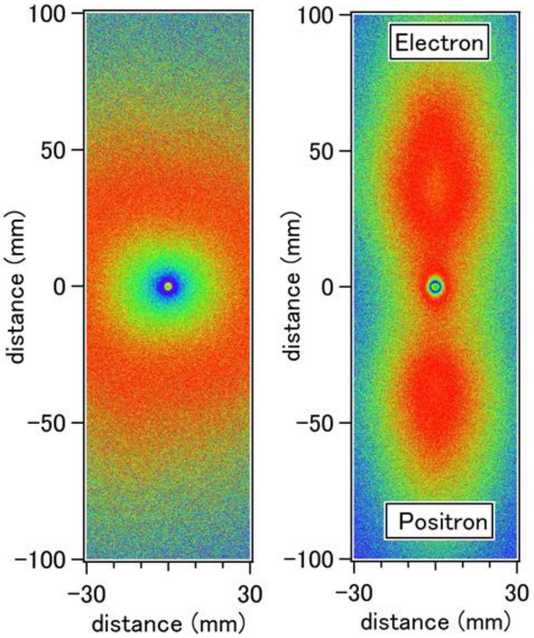

Figure 4: Images from position of IP2. (a) B=0 T and (b) B=0.4 T.

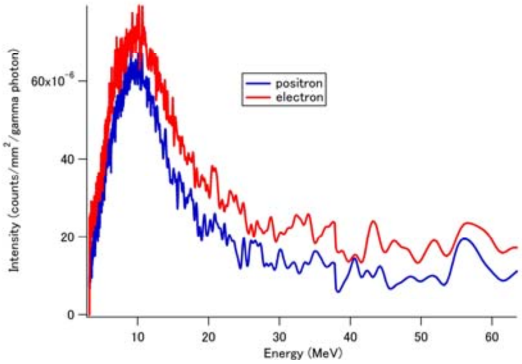

Figure 5: Energy spectra of positron and electron.

When the magnetic field is strong (0.4 T in our experiment), positrons and electrons are driven out of the central area, where only the photons are remained. To compare the two irradiated results of B=0 T and B=0.4 T, we can estimate the positron generation rate under the present experimental conditions (especially, using a 3 mm collimator). The relation of generation rate with the solid angle is given as Fig. 6. A series of targets with different thickness are irradiated and the data are shown in Fig.6, to illustrate the dependence of generation rate on the slab thickness. From Fig.6 we understand that the generation rate for the total positrons is about 0.023 per incident gamma photon for 4 mm target..

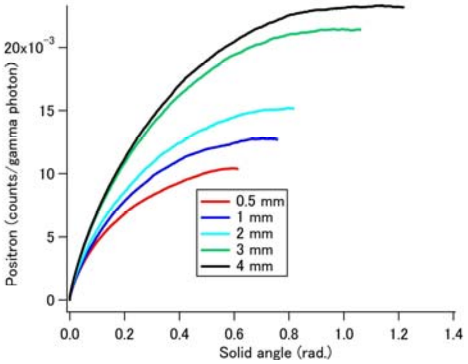

Figure 6: Positron generation rate vs solid angle.

Based on the above results, at the present experimental setup and top run conditions (storage current 500 mA and laser power 5 W), about 4x10^3 positrons/s can be generated when 4 mm target is used. And this value can be increased by using a large size collimator, an optimized thickness and a proper material of the target.

CONCLUSION

A series of positron generation experiments are carrying out at the NewSUBARU laser Compton scattering gamma ray facility. We use the imaging technic to detect the positrons and successfully delivered the positron generation rate. This work is going on to search the optimum conditions and materials to improve the yield of positrons.

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