The 11th Symposium on Accelerator Science and Technology, Harima Science Garden City, 1997

Present Status of the Polarized-Photon Generation System with the Laser-Compton-Backscattering of the ETL Electron Storage Ring TERAS

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Abstract

Since the first success of the storage of electrons, the 800 MeV electron storage ring, TERAS, has been used for many experiments. In one of the straight sections, we installed a polarized-photon facility with the laser-Compton-backscattering method. The project started in 1981, when TERAS was constructed, for the development of a high-energy, quasi-monochromatic, and highly polarized photons field for studies of nuclear physics, measurements of photo-induced cross sections, and detector calibration. We, here, introduce our polarized-photons generation system with a laser-Compton-backscattering method and show the present status of the facility together with some of the results from recent studies.

1. Introduction

In 1963, Milburn pointed out that highly-polarized high-energy photon beams could be obtained with a Compton backscattering of the laser light quanta from relativistic electrons [1]. His idea for the production of the polarized photon beams was based on the work by Feenburg and Primakoff [2], who pointed out that the energy degradation of the high energy electrons were due to the Compton scatterings with sunlight and starlight. Some facilities to generate the photon beams were constructed using the high energy electrons from a linear accelerator [3], and a electron storage ring [4].

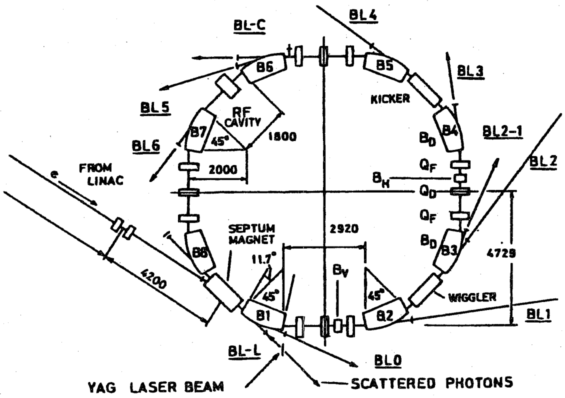

Fig.1 Layout of TERAS and the beam lines [5].

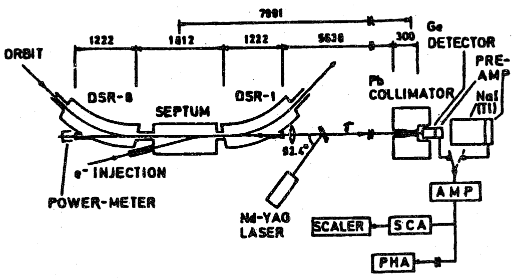

Fig. 2 Experimental arrangement [6].

Table 1 The ring parameters for TERAS.

Max. energy	800 MeV
Stored current	400 mA
Circumference	31.45 m
Radius of curvature	2.0 m
Lattice	$o/2B_dQ_fQ_dQfB_do/2$
Betatron freq.	x: 2.2
	z: 1.3
RF freq.	171.690 MHz

2. Laser-Compton-Backscattered photon beam Facility of ETL

The first storage of electrons in Tsukuba Electron Ring for Accelerating and Storage (TERAS) was achieved on Oct. 7, 1981. Figure 1 shows the layout of TERAS [5] and the beam lines for experiments and the injection straight section of the electrons from a linear accelerator. The main parameters of TERAS are summarized in Table 1. The 1/e life time is about 3.8 hours when the laser beam of 12 W was introduced into the storage ring

Figure 2 shows the layout of the ETL laser-Compton-backscattered photon beam facility. Five laser lights of different wavelength are currently available: the first and the second harmonic lights of *Q*-switched Nd:YAG laser (λ = 1064 nm), and the second, the third and the fourth harmonic lights of *Q*-switched Nd:YLF laser (λ = 1053 nm). The laser beams are guided to the collision region around the center of the 1.8 m injection straight section between DSR-1 and DSR-8, through a focusing lens L_1 (f = 1000 mm), a mirror and a second focusing lens L_2 (f = 2000 mm). The backscattered high-energy photons are collimated with a lead collimator of 100 × 100 mm² and 150 mm long with holes varying from 0.9 to 3.9 mmø, after passing through the glass window of a vacuum chamber, the second focusing lens, and the mirror. The distance between the collision point of electrons with the laser photons and the first collimator is 5 m. The second collimator which is a 150 mm thick lead wall with a 20 mmø hole, reduces background bremsstrahlung photons originating from collisions of the circulating electrons with the residual gas molecules within the ring. Because the electron orbit slightly changes as the electron energy of the storage ring, the center and the rotational angle in the horizontal plane of the collimator are movable and are adjusted to give the highest photon flux at the detector position. The photon flux is continuously monitored with a plastic scintillation detector with a thickness of 5 mm.

The size of the laser beam is about 24 mmø just before the entrance window of the vacuum chamber and about 11 mm height and 13 mm wide at the exit window because of the curved shape of the entrance window. The spectrum of the laser light was measured using a monochromator and a silicon photodiode [6].

3. Photon beam characteristics

The photon energy spectra were measured, at first, with a 33.9 cm^3 HP-Ge detector [6]. The measured pulse height spectrum for the laser-Compton-backscattered photons incident on the detector with the energy of 2.09 MeV is shown in fig. 3. The continuum found in a low energy region is due to multi-Compton scattered photons within the detector. Figure 4 shows the pulse height spectra for the 1.67 MeV photons [7] measured with (a) the HP-Ge detector and (b) an anti-Compton HP-Ge spectrometer with NaI(Tl) crystals as an anti-coincidence detector. The spectrum obtained with the anti-Compton spectrometer showed a sharp full energy peak with a reduced continuum. As the energy of the incident photons increase, the number of photons that deposit part of their energy becomes greater, because the anti-Compton method becomes less effective and the energy resolution of the HP-Ge detector also becomes worse.

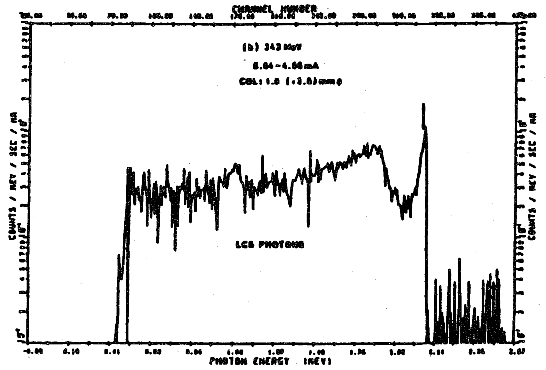

Fig. 3 Pulse height spectrum for 2.09 MeV photons [6].

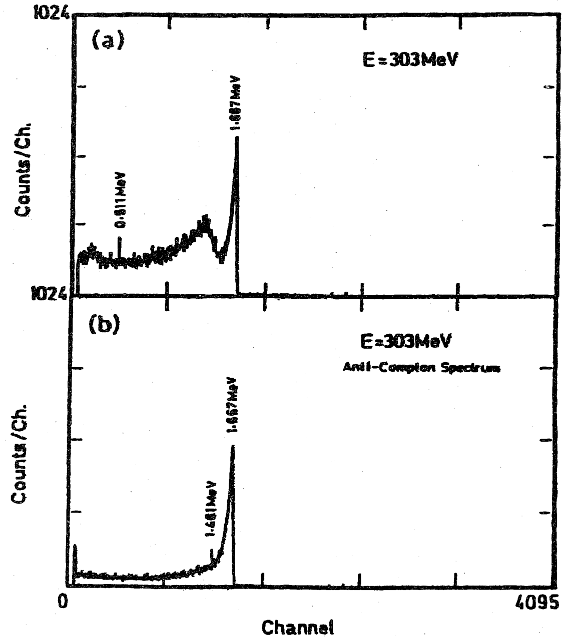

Fig. 4 Pulse height spectra for 1.67 MeV photons [7].

Recently, a large volume HP-Ge detector (520 cm^3) was installed at our laser-Compton-backscattered photon beam facility. Figure 5 shows the pulse height spectra for the 5.97 MeV photons measured with the new HP-Ge detector (dots) and the calculated ones (lines) with the Monte Carlo code EGS-4 [8]. A sharp cut-off of the incident photon energy at 5.97 MeV, a Compton-continuum due to the 5.97 MeV full energy peak, and the single- and the double-escape peaks are seen in the figure. The continua extending from the maximum photon-energy cut-off to the higher energy region is due to two-photon-induced events, in which two laser photon quanta, collided with the electrons, are backscattered and are incident on the detector within a resolving time of the counting system. It should be pointed out that the timing property of the backscattered photons are governed by that of the circulating electrons in TERAS, because the pulse width of the laser beam is 150 ns which is 25.8 times longer than the RF frequency of TERAS (171.69 MHz). So, 25.8 electrons bunches, each of which is separated 5.82 ns, sequentially collide with a continuous laser photon quanta of 150 ns pulse width, and generate backscattered photons.

We are trying to improve the photon yield by intensifying the laser power and the electron beam currents, and also aligning precisely the laser beam and the electron orbit. The alignment is, however, very sensitive to the movements of the lens and the mirror installed along the path of the laser beam, and also to the electron orbit, which changes slightly as the energy of the stored electrons. So, it takes more than a few minutes to align them every time before experiments. It is, now, our interests to find a method to align the laser beam and the electron orbit, precisely, in a relatively short time.

4. Applications using the Laser-Compton-Backscattered photons

The laser beams can be polarized with inserting a Glan laser prism, and the polarization axis can be rotated by 90° by using a λ/2 wave-plate. Therefore, the polarization axis of the laser-Compton-backscattered photons can be changed by 90° because the scattered photons retain the polarization of the original laser beam photons to a high degree, up to almost 100 % [1]. Using the polarized high-energy photon beams, measurements of photon absorption cross sections and nuclear resonance fluorescence are being undergone [9,10].

4.1 Measurement of Nuclear Resonance Fluorescence

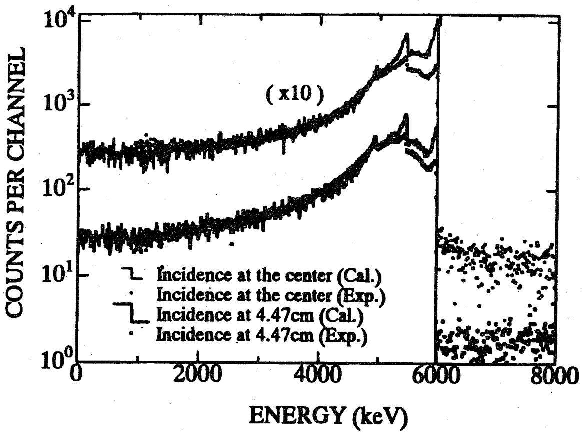

Fig. 5 Pulse height spectrum for 5.97 MeV photons.

The photon source is used for a measurement of a nuclear resonance fluorescence from the ^{208}Pb (γ_{pol},γ) reaction. In the experiment, the energy and the yield of the laser-Compton-backscattered photons was 5.52 MeV and 2×10^4 s^{-1} at a stored current of 300 mA and a laser power of 3 W, respectively. The upper part of fig. 6 shows the energy spectrum of elastically scattered photons in the plane parallel to the electric vector of the incident photons on the target, and the lower part shows that in the perpendicular plane. The 5.514 MeV 1^- level was clearly seen in the lower part of the energy spectra. The asymmetry:

$$A = \frac{1}{p}\frac{\sigma(0^\circ) - \sigma(90^\circ)}{\sigma(0^\circ) + \sigma(90^\circ)}$$

for the negative parity state is -1 and that for the positive parity is +1, under the condition of the scattering angle of 90° and the polarization of the incident photons of 100 % for a J = 0 target. In this expression σ(0°) represents the counts for the elastically scattered photons in the plane parallel to the electric vector of the incident photons, and σ(90°) represents those in the plane perpendicular to the electric vector. The asymmetry was measured -0.950 ± 0.047, which confirm the parity of the 5.514 MeV level to be negative.

The upper part of fig. 7 shows the energy spectrum of photons from the nuclear resonance fluorescence of ^{208}Pb (γ_{pol},γ), elastically scattered in the plane parallel to the electric vector of the incident photons on the target, and the lower part shows that in the perpendicular plane. In the experiment, the energy and the yield of the laser-Compton-backscattered photons were 7.8 MeV with 13.4 % energy spread and ~10^5 s^{-1}, respectively. The polarization of the photons was calculated 98.2 %. From the figure, we can easily assign the parity of the 7.332 MeV to be negative.

4.2 Development of a Photoneutron Source

One of the outstanding advantage of the laser-Compton backscattered photons over the tagged bremsstrahlung photons [11,12] is that the maximum photon energy falls very sharply compared with that of the tagged photons. With the sharp cut-off of the maximum photon energy, a new system to control photo-induced reactions that have threshold energy is made. We are now developing a quasi-monoenergetic neutron source using the laser-Compton-backscattered photons as a photon switch. When the maximum energy of the incident photons exceeds the threshold energy for the photoneutron productions, neutrons whose energy spread was determined by the overlapping width of the photon energy and the reaction cross sections will be generated. If the width is small, as is the case for the laser-Compton-backscattered photons incident on a target, the neutrons will be of quasi-monoenergetic. Then, the photon-switched photoneutron source can be made by controlling the energy of the photons slightly lower and higher than the threshold energy. A wired Beryllium metal target is used to generate low and middle energy neutrons.

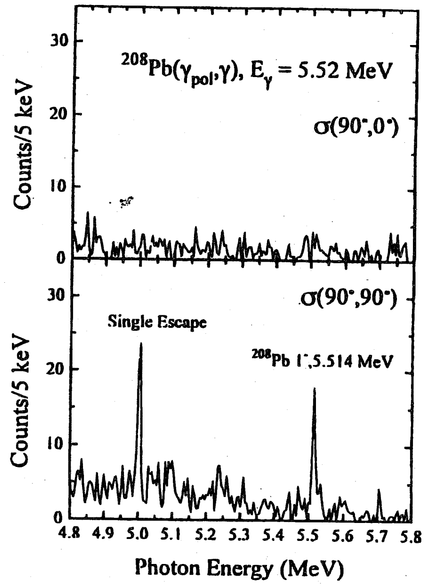

Fig. 6 Energy spectra of the nuclear resonance fluorescence for 5.52 MeV photons [9].

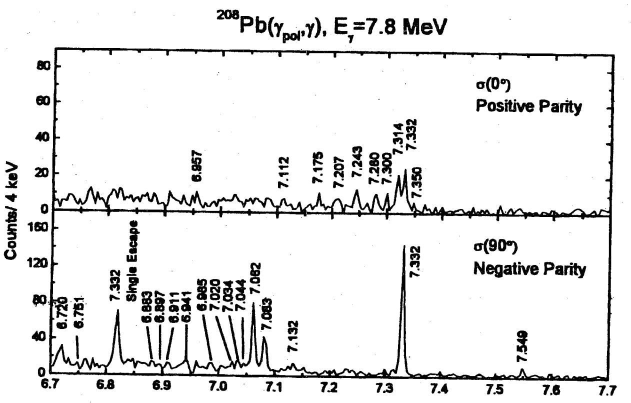

Fig. 7 Energy spectra of the nuclear resonance fluorescence for 7.8 MeV photons [10].

5. Conclusion

ETL laser-Compton-backscattered photon beam facility was introduced and the present status was presented together with some of the results from the recent studies using the photon source. The facility has now been operated periodically for many users for studies of nuclear physics, measurements of photo-induced cross sections, and the development of the photoneutron source.

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