Laser Compton scattering γ-ray beamline at NewSUBARU

Laser Compton scattering γ-ray (LCSγ) beamline BL01 [1-3] at NewSUBARU has been upgraded. A new irradiation hutch for the γ-ray beam has been added in collaboration with Konan University. The user use of γ-ray beams with photon energy of up to 76.3 MeV has begun with maximum γ-ray beam power of 0.33 mW.

The LCSγ's are unique photon source generated by scattering of laser photon by relativistic electron beam. Schematic of LCSγ is shown in Fig. 1. The maximum γ-ray photon energy at head on collision is calculated by kinematics as

$$E_\gamma = 4E_L\gamma^2 / (1+\gamma^2\theta^2 + 4\gamma E_L/mc^2) \,,$$

where $\gamma = 1+E_e/mc^2$ is the Lorentz factor, E_e is an electron energy, mc^2 is the rest energy of electrons, E_L is a laser photon energy, θ is the scattering angle of γ-ray relative to the electron beam axis, and $4\gamma E_L/mc^2$ is the recoil effect. When the Nd:YVO_4 laser (wavelength of 1064 nm) is scattered by a 1-GeV electron, the maximum scattered photon energy is E_γ =17.5 MeV. The angular distribution of the γ-ray photon energy is calculated by the above equation, as shown in Fig. 2. A quasi-monochromatic γ-ray beam is obtained by extracting small angle scattering using an axial collimator. Polarization of the laser beam is also conserved at the beam axis. Due to these special features of the LCSγ, this γ-ray source was used for nuclear physics and an astro-nuclear physics research, as well as generation of useful isotopes, non-destructing inspection of bulk material by γ-ray radiography and positron annihilation.

In brief, the experimental setup is as follows: a beam of 974-MeV electrons is injected from the SPring-8 linear accelerator into the NewSUBARU storage ring. The energy of the storage electrons is a relative value with ~1% uncertainty based on the magnetic field strength and the beam optics of the storage ring [4], hereafter referred to as the "nominal" energy in this paper.

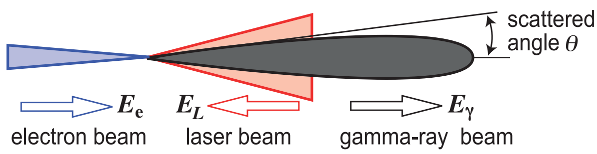

Fig. 1. Schematic of laser Compton scattering γ-ray generation at head-on collision.

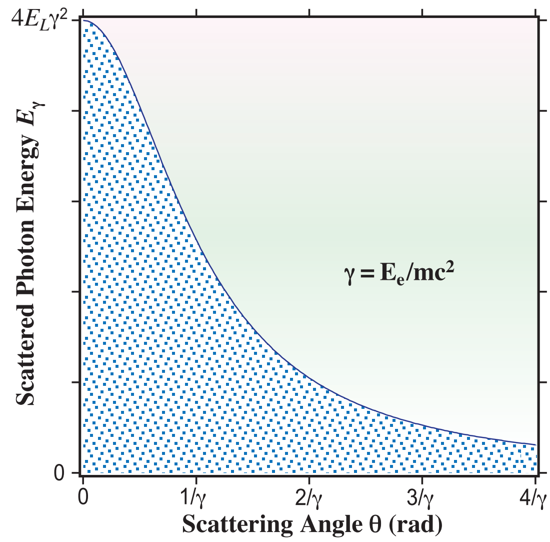

Fig. 2. Dependence of the γ-ray photon energy on the scattering angle θ.

We performed absolute calibration of electron beam energies of the storage ring NewSUBARU in the nominal energy range of 0.55 - 1.0 GeV [5]. The technique of laser Compton backscattering has been developed to accurately determine electron beam energies [6] as an alternative to the technique of resonant spin depolarization [7], which is limited to high energy electrons because of spin depolarization time [8].

We also performed the energy calibration systematically with the following steps, (1) production of low-energy LCSγ beams in collisions of CO_2 laser photons with electrons at ten nominal energies, from 974 MeV to 550 MeV; (2) measurements of LCSγ beams with a high-purity germanium (HPGe) detector; (3) energy calibration of the HPGe detector with standard γ-ray sources.

Figure 3 indicates the experimental setup for the measurement in the γ-ray beamline BL01 of the NewSUBARU synchrotron light facility. A grating-fixed CO_2 laser (INFRARED INSTRUMENTS, IR-10-WS-GF-VP) oscillated at a single line of the strongest master transition P(20). The central wavelength of the P(20) transition is known (=10.5915 μm ± 3 Å) with a bandwidth of 1.3 Å in FWHM. The accuracy of the wavelength of CO_2 laser is 4.1×10^{-5}.

The CO_2 laser photons produced outside the storage ring vault were led through four mirrors and one lens into the vacuum tube of the ring to a collision

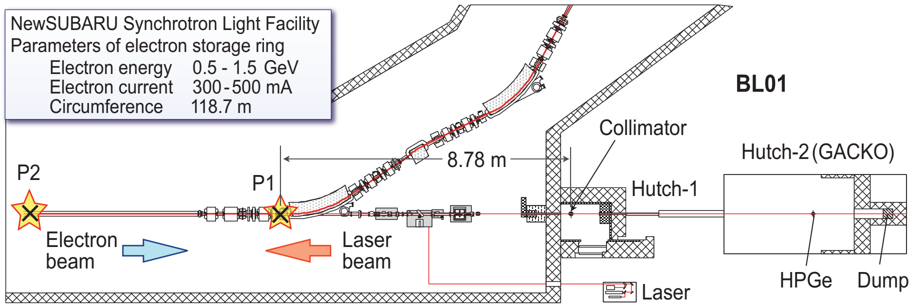

Fig. 3. Two γ-ray irradiation hutches are shown. Layout of laser Compton scattering γ-ray beam source in NewSUBARU BL01. Two collision points and two γ-ray irradiation hutches are shown.

point P1 in the straight section of the storage ring. The collision point P1 for the CO_2 laser is located at the distance of 8.78 m from a collimator set in the experimental Hutch 1. The collision point P2 for the Nd:YVO_4 laser is located at 18.47 m from the collimator. A coaxial HPGe detector (64 mm in diameter × 60 mm in length) was mounted in Hutch 2 and aligned with synchrotron radiation to measure the low-energy LCSγ's. The HPGe detector was calibrated with the standard γ-ray sources, ^{60}Co including the sum peak, ^{133}Ba, ^{137}Cs, and ^{152}Eu and a natural radioactivity ^{40}K. After the injection of electrons into the NewSUBARU storage ring, the electron beam was decelerated to the nominal energy of 950 MeV, and subsequently down to 550 MeV in steps of 50 MeV, followed by a production of the LCSγ beam and measurements with the HPGe detector at every energy.

The difference between the calibrated energy E(measure), and the nominal energy E(nominal), ΔE = E(measure) – E(nominal), is shown in Fig. 4. The 4th-order polynomial fit to the data gives

$$\Delta E = -4.6949 \times 10^{-10}(E^n)^4 + 1.3017 \times 10^{-6}(E^n)^3 - 1.3596 \times 10^{-3}(E^n)^2 + 0.63854(E^n) - 103.94$$

Here ΔE, E(measured) and E^n = E(nominal) are given in MeV. The difference between the nominal and calibrated energies is 10.92 MeV (1.36%) at the nominal energy of 800 MeV. The electron beams in the storage ring NewSUBARU have been systematically calibrated in the nominal energy range of 550 - 974 MeV by using low-energy LCSγ beams produced with a CO_2 laser. For more information about this experiment and analysis, please see Ref. [5].

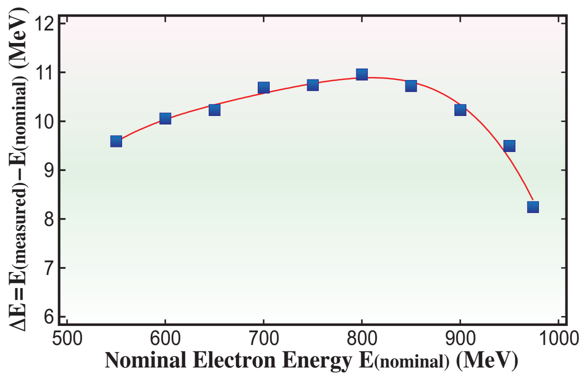

Fig. 4. The difference ΔE of the calibrated energy E(measured) from the nominal energy E(nominal) of the electron beams, ΔE = E(measured) – E(nominal), at the NewSUBARU storage ring.

S. Miyamoto[a,*], H. Utsunomiya[b], T. Shima[c] and S. Amano[a]

[a] NewSUBARU, LASTI, University of Hyogo
[b] Department of Physics, Konan University
[c] Research Center for Nuclear Physics, Osaka University

*E-mail: miyamoto@lasti.u-hyogo.ac.jp

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