Energy Upgrade of Laser-Electron Photon Beam

A few GeV photon beam is a powerful tool for investigating hadron interactions at the quark-nuclear scale ($\hbar c$ ~ 0.2 GeV·fm). A high energy photon couples to a pair of quark and antiquark interacting with a nucleon or a nucleus in a target material. The LEPS Collaboration has carried out experiments on photoproductions of hyperons [1], pentaquarks [2] and ϕ mesons [3,4] by using 1.5 – 2.4 GeV photons. If a higher energy photon beam is available, the kinematical regions for extracting cross sections and spin asymmetries can be expanded. In addition, other physics possibilities, including the search for ω-mesic nuclei [5] and the photoproductions of heavier hadrons like K*(892) will become feasible.

A laser-electron photon (LEP) beam was produced by injecting ultraviolet (UV) laser light into the storage ring at beamline **BL33LEP**, as shown in Fig. 1. The UV light was focused 35 m downstream by the expander optimized for the wavelengths of 280 nm and 351 nm. The laser light was back scattered by 7.960 GeV electrons at the straight section of the storage ring (Backward Compton Scattering or BCS). Here the energies of the laser photons are magnified by an order of 10^9. The maximum energy of the LEP beam (k_{max}) is calculated by:

$$_{\mathrm{max}} = \frac{(E_e + P_e)\, k_{\mathrm{laser}}}{E_e - P_e + 2k_{\mathrm{laser}}} \cong \frac{4E_e^2\, k_{\mathrm{laser}}}{m_e^2 + 4E_e\, k_{\mathrm{laser}}}$$

where E_e, P_e, and m_e are the energy, momentum and mass of the electrons in the ring, respectively. So far, the Ar laser with multi-wavelengths around 351 nm (k_{laser} = 3.5 eV) has been used in order to get the maximum LEP energy of 2.4 GeV. The LEP beam intensity was ~10^6/s with the laser power of 6 W. Recently, high power CW lasers with the wavelengths of 257/266 nm (k_{laser} = 4.8/4.7 eV) have become commercially available because of the doubling of the frequencies of visible lasers by second harmonic generation with a BBO crystal. These deep UV lasers were introduced to extend the maximum LEP energy to 3.0/2.9 GeV.

The energy upgrade was first tested with the 266 nm laser ('DeltaTrain' produced by Spectra-Physics). Figure 2 shows the energy spectrum measured using the tagging system. The tagging system analyzes the momenta of recoil electrons from BCS by means of the bending magnet of the storage ring. It was calibrated on the basis of the relation between gamma-ray energies and recoil-electron momenta in the bremsstrahlung radiations from the residual gas. Here the gamma-ray energy was measured at the forward spectrometer by adding momenta of pair-created electron and positron. The Compton edge of the energy spectrum was confirmed at 2.9 GeV. The lower side of the spectrum was limited because of the acceptance of the tagging system. Recently the 257 nm laser ('Sabre MotoFreD' produced by COHERENT) has been introduced for a long-term operation. A 20 W Ar laser (visible) pumped up the UV output of 1.0 - 1.5 W. The spot on the BBO crystal from which UV light was emitted was damaged in several days at the maximum power, and the crystal was mechanically shifted to different positions. The maximum laser power was maintained with the power tracking system. The typical LEP intensity was 2×10^5/s as expected from the ratio to the Ar laser power. Currently, the Ar laser (351 nm) or the deep UV laser (257 nm) is operated depending on a purpose of the physics program.

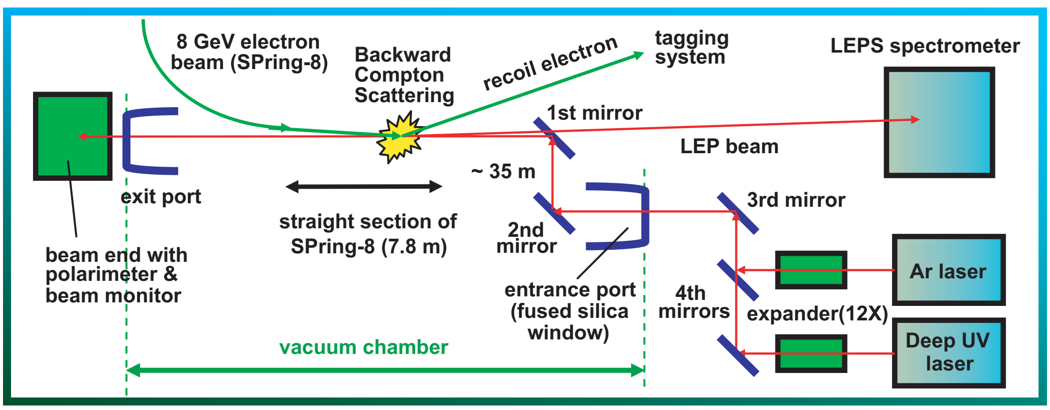

Fig. 1. Schematic view of the LEP beam production.

The search for the ω-mesic nuclei is one of the physics programs involving the deep UV laser. The chiral symmetry broken in vacuum is theoretically expected to be restored partially at the nuclear density. The medium modification of ω-meson potential results in the mass reduction or nuclear bound state of the ω meson. A 2.75 GeV photon reacts with a nucleon, producing a rest ω meson, and has an advantage to form the bound state inside a nucleus. After one week test experiment with the 266 nm laser, the 257 nm laser was operated for four months. Carbon targets (~0.2 radiation lengths) were set with the forward spectrometer, which was used to detect a high momentum proton in the reaction $\gamma^{12}C \rightarrow p\omega\ ^{11}B$. In the latter experiment a time projection chamber was additionally placed around the target to detect ω meson decays. Figure 3 shows the distributions of the missing mass MMp(γ,p) with a carbon and a CH_2 target in the test experiment. The size of the carbon data was scaled to the LEP counts in the CH_2 data. Free ω photoproductions from rest protons are seen. The existence of the signals is being identified in the carbon data by seeking events below the energy threshold of the free ω photoproduction.

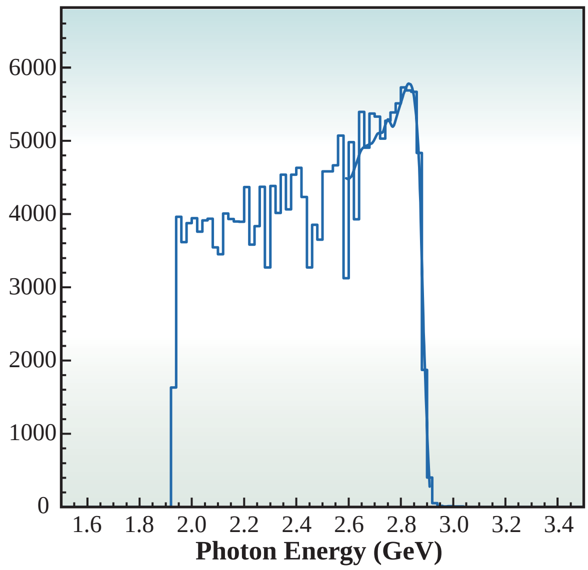

Fig. 2. LEP energy spectrum obtained with deep UV laser.

In summary, the maximum LEP energy has been extended to 3.0 GeV using the deep UV laser (257 nm). This energy is the highest among the world BCS facilities. The LEP intensity reached 2×10^5/s. In the future, a higher intensity beam will be tested with a technique to generate a laser beam collimated in a long distance by interference. In addition, a new optical system to inject multi-lasers is under consideration. The upgraded LEP beam is useful for exploring new fields in photoproduction experiments.

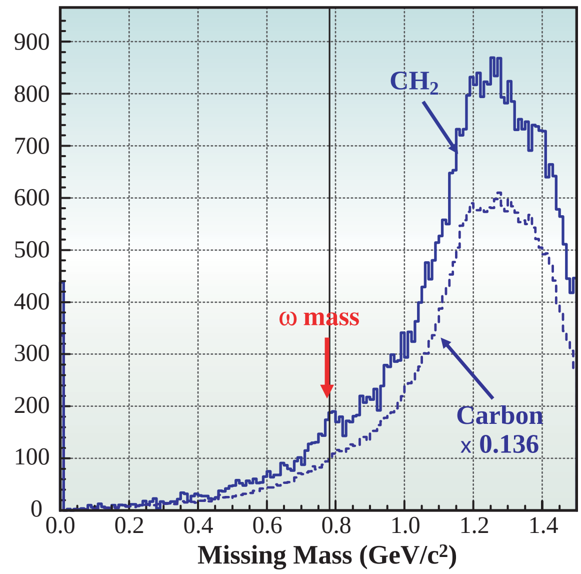

Fig. 3. Missing mass assuming the reaction p(γ,p)X.

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