LEPS2 project: the second Laser-Electron Photon beamline at SPring-8

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1 Introduction

The Laser-Electron Photon facility at SPring-8 (LEPS) is a unique and very successful facility with the cleanest photon beam in the world at multi-GeV energies. The photon beam produced by means of laser-induced backward Compton scattering (BCS) from 8 GeV electrons has rather flat energy distribution with small spreading angles, unlike the Bremsstrahlung beam which has huge low-energy photons. The photon energies above 1.5 GeV are tagged by detecting recoiled electrons. The beam polarization is also high and nearly 100% at the maximum energy. Polarization observables play an important role to elucidate the photoproduction mechanism. The LEPS experiments have been carried out since 2000, mainly using the forward charged-particle spectrometer, to search for the pentaquark [1], and to study the ϕ-meson production [2, 3], hyperon photoproduction [4, 5, 6], etc. However, the low beam intensity ($\sim 10^6$/sec) and limited acceptance of the spectrometer have restricted the further investigation, especially for concluding the Θ^+ existence and determining its spin and parity. We need to measure precisely both the photo-production process and decay process simultaneously.

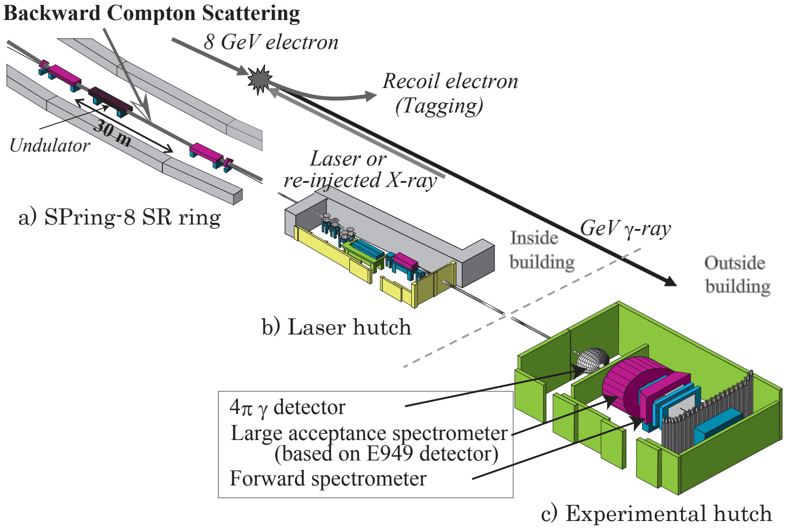

Figure 1: Schematic view of the LEPS2 facility

We have, therefore, started a project to construct the new Laser-Electron Photon beamline at SPring-8 (LEPS2). The project aims to improve both the intensity and maximum energy of the photon beam and expand the detector acceptance by adopting the BNL-E949 detector which is a hermetic detector in a large 1 T solenoid and capable to detect both charged particles and photons. In order to detect extremely forward going charged particles, a forward spectrometer may be used. A 4π γ-detector will also be constructed independently. The LEPS2 experimental hutch must have a much larger space to place the E949 magnet. We will construct the hutch outside the storage ring building by employing one of four beamlines with a 30-m straight section, BL31ID, which has the best beam emittance. An overall schematic view of the LEPS2 facility is illustrated in Fig. 1.

2 Physics motivation

The ultimate goal of the project is to understand the nature of hadrons, namely, color confinement, spontaneous breaking of chiral symmetry, creation of hadron masses, etc. In the very high energy region, a quark can be assumed to be a light, free particle, and perturbative QCD is applicable. In the low energy region, quarks are confined in a hadron and a constituent quark model has been very successful, in which quarks are assumed to be heavy particles. The link or the transition between the two regions is, however, not well understood. We will attack this problem by studying the next leading order effects in the non perturbative region, such as more than 3-quarks component of a baryon, meson-baryon resonances, modifications of hadron properties in nuclear matter, and the possible existence of pentaquark.

The high intensity beam enables data collections with high statistics, which provides precise information on hadron interactions and properties, and may extract possible new physics. Also the high energy beam produces heavy hadrons which have not been studied well. The following list shows examples of physics subjects:

- Confirmations of the pentaquark Θ^+ [1] with the higher statistics and comparisons with other experiments. Precise measurements of differential cross sections are important for systematic understandings of reaction mechanisms and their properties if it exists. For this purpose, the photon beam in a wide energy range and the large acceptance spectrometer with better resolutions are essential. An experiment with polarized targets which are now being developed will help to determine its spin and parity.

- Study of the properties of queer baryons like $\Lambda(1405)$. It is currently not known whether $\Lambda(1405)$ is a KN bound state or a SU(3)-singlet quark state. A theory describes $\Lambda(1405)$ as a mixture of two baryons, one of which couples to $\pi\Sigma$ strongly and another couples to KN. The latter has a higher mass and a narrow width. We can prove the existence of such a state by controlling the parity of exchanged particles with use of linearly polarized photons and detecting vector K^* mesons.

- Further investigation of ϕ photoproduction near the threshold. It is one of the main subjects of research at LEPS and we have measured the energy dependence of ϕ photoproduction at small angles. A peak structure is seen in the cross section around E_γ=2.1 GeV. The model calculation including the Pomeron exchange and π and η exchange processes can not explain our data [2]. To fully investigate the nature of the structure, the measurement must be expanded to higher energies and larger angles.

- Searches for glueballs and hybrids to investigate gluonic aspects of the hadron confinement. A high energy beam is necessary because the lattice QCD predicts their masses to be $\sim$2 GeV/c^2 or more. Detecting double vector meson decays or radiative decays of glueballs with a combination of charged spectrometer and calorimeters is a good candidate to identify them.

- Measurements of the σ meson which is the key particle how hadrons get their masses from originally light quarks. Since σ decays to two π^0 and finally to four γ's, the 4π γ detector is needed to detect σ mesons. The cross section of Primakov process, which is a possible process for the production of σ, becomes larger as the photon energy increases. Thus the higher energy photon beam is desirable.

As for the each detail and other subjects concerning the LEPS2 project, one can see them in the LEPS2 Workshop pages (reached from the URL http:/www.rcnp.osaka-u.ac.jp/Divisions/np1-b/).

3 High intensity beam and high energy beam

A laser-electron photon (LEP) beam with higher intensity and higher energy is the key ingredients of LEPS2 in order to achieve the confirmation of Θ^+ and a lot of new physics possibilities. Currently two methods of the laser injection are planned to produce the higher intensity beam. In addition, an X-ray injection into SPring-8 ring is under consideration to increase the maximum beam energy.

One of the methods for the higher intensity beam is the simultaneous injection of multi-number of lasers into the storage ring (SR) of SPring-8. In this case the beam intensity is nearly proportional to the number

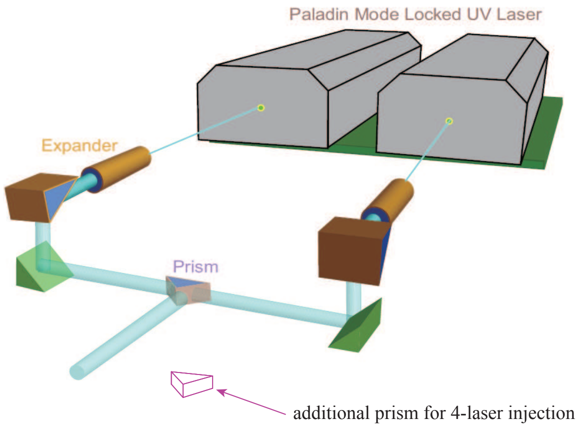

Figure 2: Two laser injection system tested at BL33LEP.

of lasers. A new optical system to inject two lasers has been tested at the current beamline (BL33LEP) and we have succeeded to increase the intensity in this method (see Fig. 2). However, due to the narrow aperture of the BL33LEP, it is difficult to increase the number of lasers more than two. In the LEPS2 beamline, we intend to broaden the aperture by modifying some beamline elements such as vacuum chambers and to inject four sets of solid state (355 nm) or deep-UV (257nm) lasers by adding two knife-edge prisms. Another method to increase beam intensity is to change the laser profile. Since the electron beam has an extremely elliptical shape (400-μm width $\times$ 10-μm hight), collision efficiency will be increased by compressing the laser shape in the vertical direction, which is technically possible by adding an optical element, shape transformer. We expect the beam intensities at LEPS2 by about an order of magnitude higher than those at LEPS.

The use of a long straight section gives many advantages. The smallest divergence of the electron beam, as shown in Fig. 3, brings the small LEP beam size at the place even far from the collision point. Thus a large volume detector system can be constructed outside the experimental hall of the SR building. The spread of recoiled electrons at the tagging point is also narrow so that the tagger energy resolution will be better than the current BL33LEP. Moreover the interference problem in the CW multi-laser injection can be avoided by shifting the focus point of each laser along the electron beam axis.

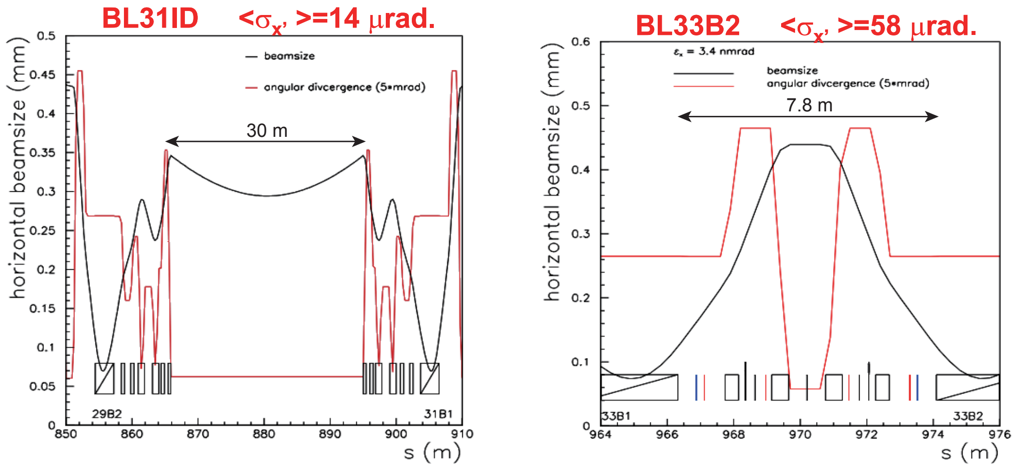

Figure 3: Comparison of the electron beam divergence for BL31ID and BL33LEP.

A LEP beam with much higher energies can be produced by injecting X-rays into SPring-8 ring. Some energy distributions of LEP for the laser injections and X-ray injections are shown in Fig. 4. In case of 100 eV photons, the maximum energy of BCS photons exceeds 7 GeV. Currently, X-ray from an helical undulator in the storage ring itself is considered as a possible source. Radiated X-ray is deviated from the beam axis by an ejecting/re-injecting mirror and introduced in a backward reflector as schematically shown in Fig. 5.

Reflectivity of a monolayer X-ray mirror at a fixed angle drops sharply with increasing energy after the total reflection angle gets larger than the given angle. At less than 100 eV, the X-ray with an injection angle of 10°

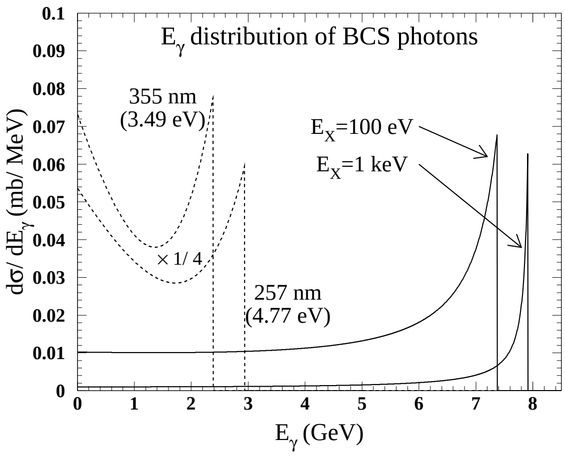

Figure 4: Differential cross section of the Compton back-scattering γ rays for different incident energy photons. The electron energy is 8 GeV.

is reflected by a diamond mirror with keeping a reflectivity as large as 80 %. Thus the backward reflector can be composed of multiple ($\sim$10) diamond mirrors, where we expect the reflectivity of the whole system is about 10%. An alternative scheme may be provided by a Si/Mo multi-layer mirror, which has 75 % reflectivity at the reflection angle of 90° for X-rays with energy of 100 eV in a band width of 1.6 %. A LEP beam intensity in a range between 4 GeV and 6 GeV is estimated about $2{\times}10^5$/sec by taking into account the intensity distribution of X-rays from the undulator and the realistic reflection rates at mirrors. All key techniques in this scheme is in concern with large angle X-ray reflection and mirror control for shaping and focusing of X-rays under highly radiative environment. An X-ray free-electron laser (XFEL) whose project has just started at SPring-8 might be another source of the X-rays, which can provide the quasi-monoenergetic photons.

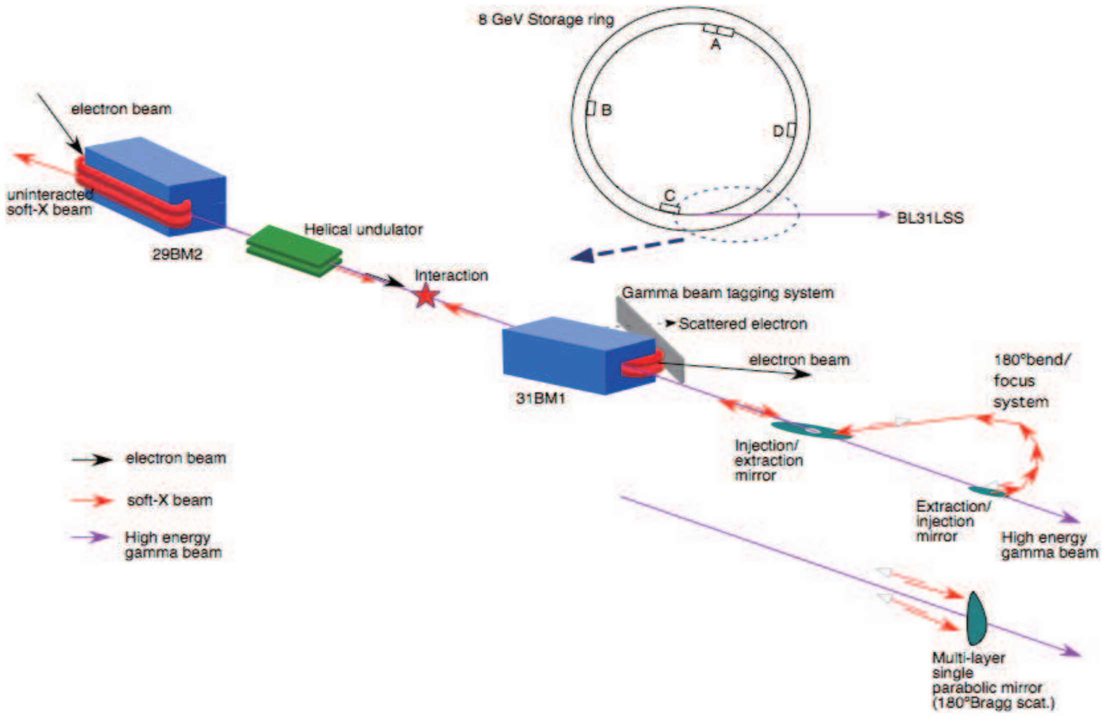

Figure 5: Schematic view of the X-ray re-injection.

4 Detector

To measure precisely both the photoproduction process and the decay process simultaneously is one of the most important requirements for the new detector system. Since the photoproduction cross section is small and the photon-beam experiment needs much longer beam time than that using hadron beams, a general-purpose detector with large solid angle to detect not only charged particles but also neutral particles like photons are desirable. Such a detector, in general, needs a large cost and a long construction time. An alternative choice is to move a similar detector system from other laboratory when the experiment using it was finished or no longer it would be used. One possible candidate is the BNL-E949 detector, which was used for the measurement of $K^+ \to \pi^+\nu\bar{\nu}$ decay from kaons at rest involved observation of the low-momentum π in the absence of other coincidence particles. Measurements of charged decay products were made in a 1 T magnetic field using an active target, a low-mass central drift chamber and a cylindrical range stack (RS) of scintillating detectors. Photons were detected in a 4π-sr calorimeter consisting of a lead/scintillator sandwich barrel detector surrounding the RS, and end caps of CsI crystals. Although central parts of detectors should be modified or removed for the photon-beam experiment, the inner bore size (2.96-m diameter and 2.2-m length) of 1 T solenoid magnet is sufficiently large for the further optimization of the detector system. Fortunately, a basic agreement to move the E949 detector to Japan and to use it at LEPS2 has been made.

Although the detector design for LEPS2 has still not been fixed, a schematic view of the current setup is shown in Fig. 6 with all the detector components installed in the E949 solenoid magnet. The inner part of the detector is devoted to triggering and tracking charged particles. The scattering angles as well as the particle trajectory for the momentum determination are measured by vertex detectors consisting of double-sided silicon strip detectors (SSD), forward tracking detectors made up of four sets of drift chambers (DC) surrounded by a barrel tracker, and a sideway tracking detector, either a cylindrical drift chamber (CDC) or a time projection chamber (TPC). To identify charged particles, we use the energy loss information from the range stack counters combined with time of flight (TOF) information.

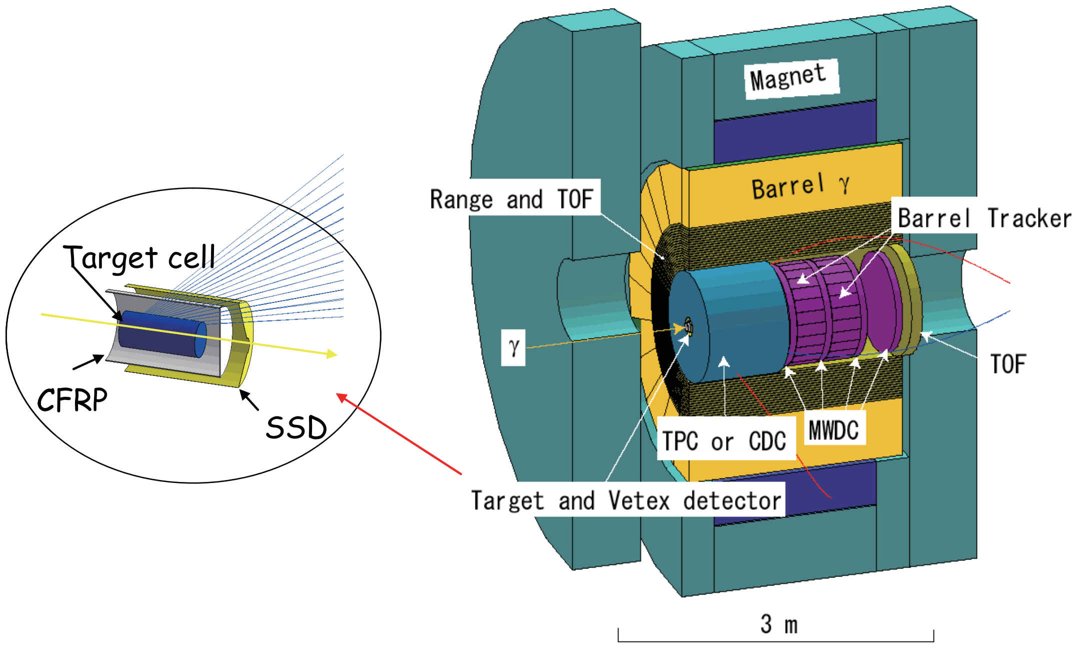

Figure 6: LEPS2 spectrometer with E949 solenoid magnet.

The requirements for the tracking system are that it can determine the momentum of charged particles even for the low momentum (∼100 MeV/c) particles and a similar momentum resolution should be realized as that of the LEPS spectrometer, typically $\Delta P/P$=1% for a 1-GeV/c kaon. A schematic view of the tracking system and calculated total momentum resolutions for the use of different gases are shown in Fig. 7, where the target is placed at the most upstream of the inner volume of the magnet. In case of the solenoidal magnetic field, to minimize the multiple scattering effects is essential to obtain a reasonable momentum resolution for the forward emitting paricles. Using a helium bag between the target and the forward tracker and employing the low-mass gases for the chamber gas are very effective to improve the momentum resolution.

In the present LEPS experiments, the forward charged-particle spectrometer is a unique and very successful

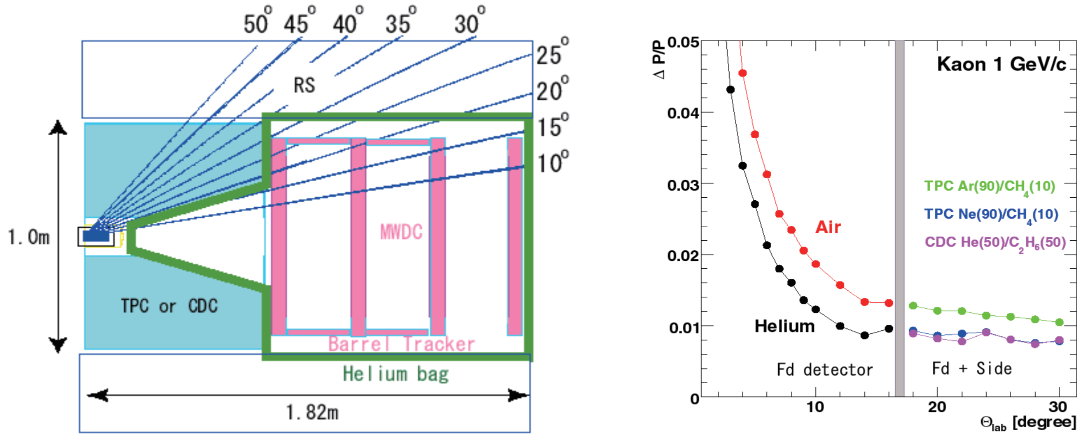

Figure 7: Schematic view of the tracking system (left) and the total momentum resolution $\Delta P/P$ as a function of laboratory angle for a 1-GeV/c kaon (right).

tool. Since the solenoid magnetic field is not suitable for the momentum measurement of very forward going charged particles, a forward spectrometer may optionally be used together with the E949 detector. A large solid-angle photon detector was also successfully used in the LEPS experiment. Since, at high energies, the cross section of Primakov process increases, such a detector is more effective for many experiments. An upgraded 4π photon detector system is also under consideration.

5 Collaboration

All the members of the LEPS collaboration group, consisting of about 50 researchers, will take part in the LEPS2 collaboration. The scale of the detector system is large and the wider range of subjects must be covered by the LEPS2 experiments. Thus, a larger collaboration of a few hundreds of researchers would be desirable. The RIKEN Radiation Laboratory has joined the collaboration as a core institute, joining RCNP, the Accelerator group of JASRI (Japan Synchrotron Radiation Institute) and LNS Tohoku University. Some new members have already come from the domestic and foreign universities and institutes. The project is open for the researchers in Japan and from all over the world through the virtual laboratory, which can be accessed at the URL http://www.hadron.jp.

The letter-of-intent for the LEPS2 project was submitted to SPring-8 in 2006, and it was favorably evaluated. We are actively trying to obtain the enough budget to construct whole system. A part of beamline construction will start in fiscal 2007.

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