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Status and prospects of the LEPS2 solenoid spectrometer

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Summary. — The Laser Electron Photon Experiment at SPring-8 2 (LEPS2) beamline is a photon beam facility focused on hadron physics research, located in Japan. Utilizing backward Compton scattering, it produces a γ-ray beam from an 8 GeV electron storage ring shot by UV-laser light. This beamline specializes in high polarization, achieving up to 90% near the maximum beam energy. The facility aims to study exotic hadrons such as exotic nuclei and meson-baryon molecule candidates. The investigation focuses on the production of hadrons containing strange quarks, with an emphasis on exploring the properties of kaons in nuclei, the $\Lambda(1405)$ resonance, and related phenomena. The LEPS2 solenoid spectrometer, equipped with detectors for charged and neutral particles, has been operational since 2021, and physics data collection has commenced. This article provides an update on the current status of the experiment.

1. – Introduction

1˙1. *LEPS2 beamline*. – The Laser Electron Photon Experiment at SPring-8 2 (LEPS2) is a photon beam facility for hadron physics in Japan. At the LEPS2 beamline, we inject UV-laser light into the 8 GeV electron storage ring to obtain a γ-ray beam (laser electron photon) through backward Compton scattering (BCS) between the laser photons and the electron beam. The maximum photon beam energies are 2.4 GeV and 2.9 GeV, achieved using 355 nm and 266 nm laser wavelengths, respectively. One of the features of the BCS photon beam is its high polarization, reaching up to 90% near the maximum beam energy (fig. 1). We inject four lasers simultaneously, and obtain the typical photon beam intensity of 1.5–2 Mcps.

We deliver the γ-ray beam to the LEPS2 experimental building, which is located beyond the storage ring, irradiate the targets with the γ-rays, and measure hadron photoproduction. We plan to study exotic hadrons, such as a pentaquark candidate composed of five quarks, meson-baryon molecule candidates, and deeply bound anti-kaonic nuclei. For these experiments, a solenoid magnet with a 3 m diameter and a magnitude of 1 T was shipped from Brookhaven National Laboratory in the United States. We are developing detectors capable of detecting both photons and charged particles.

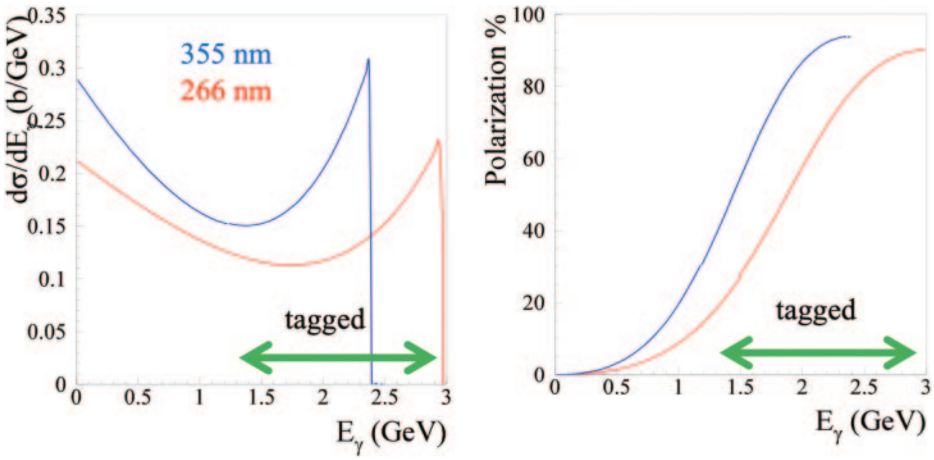

Fig. 1. – Energy and polarization degree distributions of BCS photons.

1·2. *Physics motivations.* – Using photon beam up to 2.4 or 2.9 GeV, we can produce hadrons with strange quarks. One of our physics motivation is to study properties of kaons in nuclei. Based on the assumption that $\Lambda(1405)$ is a $\bar{K}N$ molecule, some theorists predict $\bar{K}NN$ bound states [1, 2]. Depending on the strength of $\bar{K}N$ interactions in the theoretical model, the predicted binding energies of $\bar{K}NN$ are deep or shallow.

Several experimental studies have been performed to investigate $\bar{K}NN$ states. Recently, the J-PARC E15 Collaboration reported peak structures in the invariant mass spectra of Λp pairs produced via the $K^- + {}^3\mathrm{He} \to \Lambda pn$ reactions [3, 4]. Interpreting these peaks as a signal of the $\bar{K}NN$ bound state, they obtained a binding energy of about 42 MeV.

In addition to kaon-induced reactions, investigations of $\bar{K}NN$ using pions and photons have also been conducted. The J-PARC E27 Collaboration observed a peak structure that corresponds to $\bar{K}NN$ in the missing mass spectra of the $\pi^+ d \to K^+ X$ reaction, obtaining a strong binding energy of approximately 95 MeV [5]. On the other hand, in the investigations using the $\gamma d \to K^+ \pi^- X$ reaction by the LEPS Collaboration, no signals for $\bar{K}NN$ were found and an upper limit has been set [6]. In the measurements of the LEPS Collaboration, decay particles of $\bar{K}NN$ were not detected, resulting in a poor signal-to-noise ratio. Therefore, we plan to use the LEPS2 solenoid spectrometer to measure the decay particles of $\bar{K}NN$ and conduct investigations on $\bar{K}NN$ using a photon beam.

In addition to the $\bar{K}NN$ investigation, we also plan to study the properties of $\Lambda(1405)$ and $\Lambda(1380)$ in the $\gamma p \to K(890)^+ \Lambda^*$ reaction. In this measurement, by analyzing the azimuthal asymmetry of the decay of the $K(890)$ meson with respect to the linear polarization of the photon beam, we can identify particles exchanged in the t-channel, and can measure the mass distribution of $\Lambda(1405)$ and $\Lambda(1380)$ [7], and examine their coupling, $g_{KN\Lambda^*}$ and so on.

2. – Detector setup

The LEPS2 solenoid spectrometer consists of start counters (SCs), a time projection chamber (TPC), drift chambers (DCs), barrel resistive plate chambers (BRPCs), forward

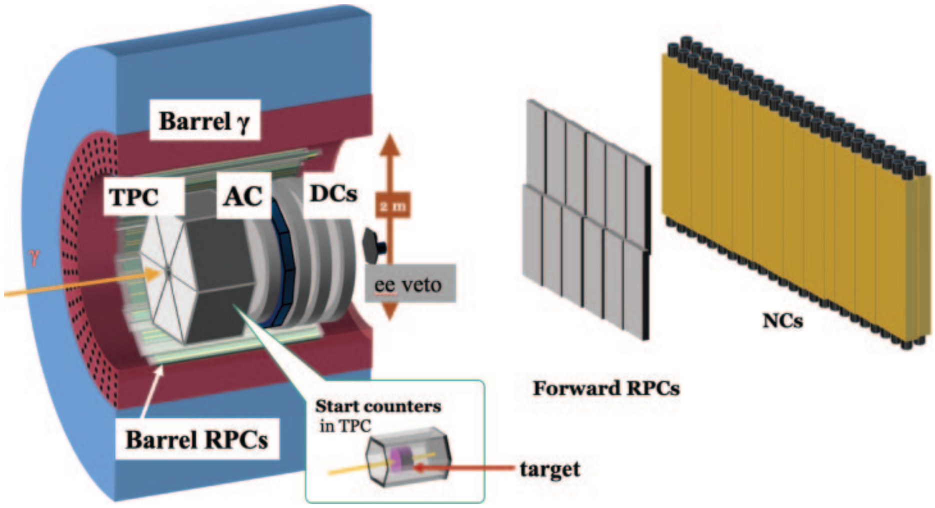

Fig. 2. – Setup of the LEPS2 solenoid spectrometer.

resistive plate chambers (FRPCs), barrel γ counters (Bγ's), neutron counters (NCs), and aerogel Cherenkov counters (ACCs). Figure 2 schematically depicts the solenoid spectrometer. A liquid hydrogen or deuterium target is installed in the TPC. Charged particles scattered at forward angles are detected with the DCs, while those scattered sideways are detected by the TPC. These particles undergo momentum analysis. The SCs, located close to the target, measure the timing of charged particle production using the RF information from the electron storage ring. The FRPCs detect charged particles scattered at forward angles approximately 4 m downstream from the target, while the BRPCs detect those with large scattering angles, located 0.9 m in the radial coordinate. Both FRPCs and BRPCs provide time-of-flight information for charged particles with a resolution below 100 ps. Using the momentum and velocity data, the mass of a charged particle can be determined. For high-momentum particles, ACCs are utilized for particle identification. In addition to charged particles, we can detect photons using Bγ's and neutrons using NCs, respectively.

3. – Status of the experiment

From 2021, we started physics data taking using both the liquid hydrogen and liquid deuterium targets with 2.4 GeV maximum beam energy. We successfully observed the trajectories of charged particles using the TPC and the DCs. The momenta of these particles were determined based on their trajectories in the TPC, and the particle types were identified using the time-of-flight (TOF) measurements taken with the RPCs and the ($\mathrm{d}E/\mathrm{d}x$) information from the TPC. Figures 3(a) and (b) display correlation plots for ($\mathrm{d}E/\mathrm{d}x$) *versus* particle momentum and for reconstructed mass *versus* momentum, respectively. Pions, kaons and protons can be indentified in these plots.

Figure 4(a) presents the invariant mass distribution of proton and negative pion pairs. A distinct peak of the Λ hyperon is visible at 1.12 GeV, illustrating that hadrons with a strange quark are produced and the momenta of the daughter particles are measured accurately. The energy of each incident photon was obtained using a tagging counter.

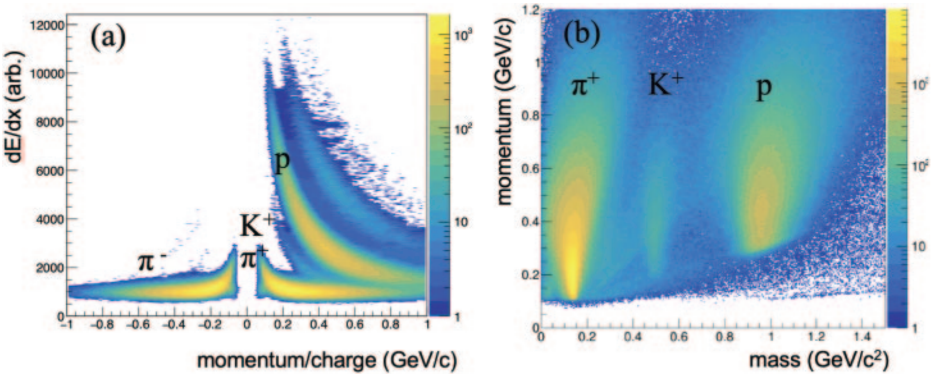

Fig. 3. – (a) A correlation plot of the dE/dx and momentum of charged particles measured with TPC. (b) A correlation plot of the momentum and reconstructed mass measured with TPC and BRPCs.

By using the Lorentz vectors of a proton or a positive kaon, which was determined with the TPC, we can identify mesons and hyperons using the missing-mass technique, respectively. Figures 4(b) and (c) depict the squared missing-mass distribution for the

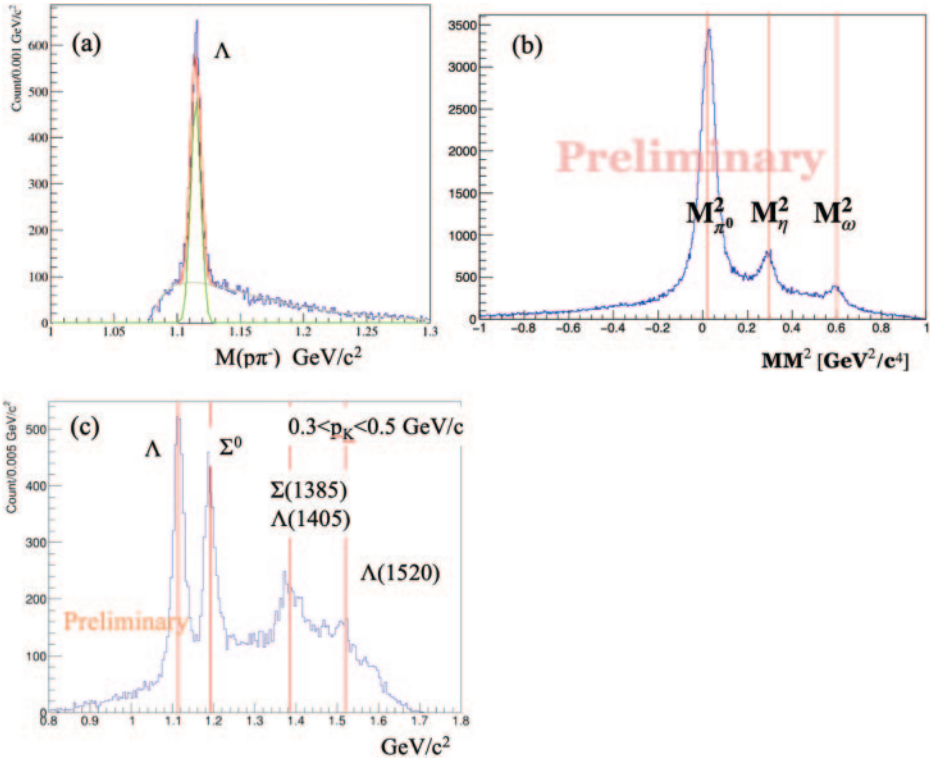

Fig. 4. – (a) An invariant mass distrubution of (p, π^-) pairs. (b) A missing-mass spectrum of $\gamma p \to pX$ reactions. (c) A missing-mass spectrum of $\gamma p \to K^+X$ reactions.

($\gamma p \to pX$) reactions and the missing-mass distribution for the ($\gamma p \to K^+X$) reactions, respectively. Clear peaks corresponding to the masses of (π^0), (η), and (ω) mesons can be discerned, confirming that the photon-beam energy has been measured accurately and the data correlation between the tagging counter and the TPC is valid. Analyses of other detectors are ongoing, and we continue to acquire more data for the study of exotic hadrons.

4. – Summary

We developed a solenoid spectrometer at the LEPS2 facility in SPring-8 for hadron physics research. This included the development of detectors for charged particles, photons, and neutrons. Data collection commenced in 2021 using liquid hydrogen and liquid deuterium targets. We have successfully observed the photoproduction of mesons and hyperons, and we continue to collect data for hadron physics, focusing on aspects such as strange hadrons and $\bar{K}NN$ bound states.

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