Spin Physics at SPring-8 - Recent Results

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Abstract. We have been carrying out hadron photoproduction experiments at SPring-8 since the completion of the LEPS beam-line in 2000. The photoproduction of the $\phi$, $K$, $\eta$, and $\pi^0$ mesons is studied by using linearly polarized photon beams with energies of $E_{\gamma}=1.5-2.9$ GeV. Introducing a polarized nucleon target is expected to upgrade the LEPS experiments to a new level. The measurement of double spin polarization asymmetries provides important information to investigate the hidden nucleon structure, hadron photoproduction dynamics, and exotic hadron properties. We started developing a polarized HD target in 2005. Five large refrigerators necessary for the polarized target have been already obtained. We plan to carry out an experiment using polarized photon beams and the polarized HD target in 2011-2012. We also started constructing a new beam-line (LEPS2) at SPring-8 in 2010. The large acceptance E949 spectrometer, which has been used at BNL, will be transported to the LEPS2 beam-line in 2011. With these new developments, advanced studies of spin physics are expected in future experiments.

1. Introduction
We constructed the LEPS beam-line at SPring-8 in 2000 and carried out hadron photoproduction experiments by using linearly polarized photon beams with energies of $E_{\gamma}=1.5-2.4$ GeV in 2000-2006 and $E_{\gamma}=1.5-2.9$ GeV in 2007-2010. The physics subjects of the experiments are summarized as follows:

(1) $\phi$ meson production
$\gamma p \rightarrow \phi p$ [1], $\gamma d \rightarrow \phi d$ [2], $\gamma d \rightarrow \phi pn$ [3,4], and $\gamma A \rightarrow \phi X$ [5] reactions.

(2) Strangeness production
$\gamma p \rightarrow K^+\Lambda$ [6,7,8], $\gamma p \rightarrow K^+\Sigma^0$ [6,7,9], $\gamma n \rightarrow K^+\Sigma^-$ [9], $\gamma p \rightarrow K^+\Sigma^0(1385)$ [10],
$\gamma n \rightarrow K^+\Sigma^-(1385)$ [11], $\gamma p \rightarrow K^+\Lambda(1405)$ [10], and $\gamma p \rightarrow K^+\Lambda(1520)$ [12,13] reactions.

(3) Pseudo scalar meson production
$\gamma p \rightarrow \pi^0 p$ [14] and $\gamma p \rightarrow \eta p$ [15] reactions.

(4) Search for exotic baryon resonance states
$\gamma n \rightarrow K^-X$ reaction [16,17].

Figure 1 shows the reaction mechanisms for $\phi$ meson photoproduction, which is dominated by diffractive production within the vector-meson-dominance model through Pomeron exchange. Meson exchanges in the t-channel are suppressed by the OZI rule. The Pomeron exchange, $s\bar{s}$-knockout, and other reaction mechanisms are studied in $\phi$ meson photoproduction. We found a bump structure at $E_{\gamma} \sim 2$ GeV in the differential cross sections [1]. Although spin density
matrices have been measured, the bump structure cannot be easily explained by the known reaction mechanisms.

Another bump structure was found at a similar energy in the cross sections for the $\gamma p \rightarrow K^+\Lambda(1520)$ reaction [13]. One explanation for this structure is a nucleon resonance in the s-channel, although there is no established nucleon resonance with a mass of $W \approx 2.11$ GeV and a width of 140 MeV in the PDG particle listings [18].

Two positive experimental results were published for the 5-quark baryon resonance state $(\theta^+)$ [16,17]. However, the statistics of the data is still insufficient to establish this state. In 2006-2007, we took additional data with three times higher statistics than earlier data [17], and the data analysis is underway. If this state is established, the spin-parity should be determined by measuring polarization observables.

For further studies of the spin physics, we started developing a polarized HD target in 2005 [19]. Implementing a polarized nucleon target is expected to upgrade the LEPS experiments to the next step. For example, the measurement of double spin polarization asymmetries for $\phi$ meson photoproduction on the proton and neutron gives important information on the $s\bar{s}$ quark content in the nucleon. The contribution of the $s\bar{s}$ knockout process is weak compared with the dominant Pomeron exchange process in $\phi$ meson photoproduction. However, the beam-target double spin polarization asymmetry is very sensitive to the $s\bar{s}$ quark content in the nucleon [20]. Since the optimal photon energy range is 2-3 GeV [21] as shown in figure 2, the LEPS experiments are quite suitable for this purpose. We will measure the energy dependence of the asymmetry precisely and investigate the nucleon hidden structure and the nature of the bump structure found at $E_\gamma \approx 2$ GeV [1].

Figure 1. (a) Diffractive production process within the vector-meson-dominance model through Pomeron exchange. (b) Pseudo-scalar meson exchange process. (c) Direct $s\bar{s}$ content knockout process.

Figure 2. Theoretical prediction of the beam-target double spin polarization asymmetry for $\phi$ meson photoproduction on the proton calculated by Titov [21]. The $s\bar{s}$ quark content of 0.25% is assumed to be contained in the proton for the solid curve. No $s\bar{s}$ quark content is assumed for the dashed curve.
2. LEPS beam-line at SPring-8

SPring-8, located at a distance of 120 km from Osaka (Japan), has 62 beam-lines. One of the beam-lines is used for the hadron photoproduction experiments (LEPS). Polarized photon beams are produced by backward Compton scattering of a laser from 8 GeV electrons. The energy range of the tagged photon beams is 1.5-2.9 GeV. The polarization degree of the linearly polarized photon beams is typically 90% at 2.9 GeV. Unpolarized LH$_2$, LD$_2$, and LHe targets have been used for the experiments. The momentum and time-of-flight (TOF) of produced charged particles are measured by the LEPS spectrometer (figure 3) consisting of a silicon vertex detector, three drift chambers, and a dipole magnet with a magnetic field of 0.7 T. Pions with momenta higher than 0.6 GeV/c and $e^+e^-$ pairs are rejected by an Aerogel Cherenkov counter.

![LEPS spectrometer at SPring-8](image)

Figure 3. LEPS spectrometer at SPring-8 [7].

3. Polarized HD target

3.1. Characteristics

In 1967, Honig first proposed the frozen-spin molecular HD target [22]. Such a polarized HD target is now being used for the actual experiments at LEGS [23-25] and GRAAL [26-28]. The HD molecule is an ideal target for experiments to observe reactions with small cross sections because the HD does not include heavy nuclei producing many background events. The only impurity in the HD target is thin aluminum wires which are needed to insure the cooling. They represent at most 20% in weight of the HD target. The target size is 2.5 cm in diameter and 5 cm in thickness.

We employ the static method using “brute force” at low temperature and high magnetic field to achieve high polarizations for the proton and deuteron targets. The degree of polarization can exceed 90% for H after the aging process of 2-3 months at B=17 T and T=10 mK. Deuteron polarization of up to 60% can be obtained by transferring the hydrogen polarization to the deuteron polarization by using a method known as “adiabatic fast passage”.

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3.2. Five large refrigerators
The polarization of the HD target is grown and frozen at RCNP of Osaka university, and the target is transported to SPring-8 by a truck. During the whole process, magnetic fields above 300 Gauss are provided to keep the target polarization. Five large refrigerators with superconducting magnets are used to maintain low temperatures and magnetic fields for holding the polarization. We have two $^3\text{He}-^4\text{He}$ dilution refrigerators and three typical $^4\text{He}$ refrigerators.

One dilution refrigerator is used to initially polarize the HD target at RCNP. This dilution refrigerator has a cooling power of 3000 μW at 120 mK and the lowest temperature of 6 mK. A superconducting magnet with a magnetic field of 17 T at T=4.2 K is placed around this dilution refrigerator. The other dilution refrigerator is used to cool the target at 300 mK during the experiments at SPring-8. The three typical $^4\text{He}$ refrigerators are used for the transportation of the HD target from RCNP to SPring-8.

3.3. First production of polarized HD target
We tried to produce a polarized HD target for the first time at the end of 2008 [29]. After aging the HD target for 53 days at B=17 T and T=14 mK, the polarization degree of the hydrogen in the HD target was measured using the NMR method. NMR signals for the hydrogen were clearly observed at B=1 Tesla and T=300 mK as shown in figure 4. Although a polarization degree expected for this aging condition was about 80% for the hydrogen, only about 40% was actually measured. The reason for this is supposed to be bad linearity of the NMR signal height. The NMR system and calibration method for measuring the polarization degree should be improved. The relaxation time was found to be about 100 days in the SPring-8 experimental condition of B=1 T and T=300 mK, which is acceptable for the LEPS experiments. Longer aging time will result in longer relaxation times. We will age the HD target for 2-3 months in the next production.

![Figure 4](image-url) NMR signals for the hydrogen after freezing the polarization by aging for 53 days at B=17 T and T=14 mK [29].

4. Summary and future plan
We have been carrying out hadron photoproduction experiments by using linearly polarized photon beams since the completion of the LEPS beam-line at SPring-8 in 2000. The development of the polarized HD target, which is expected to upgrade the LEPS experiments, started in 2005. We succeeded in polarizing and freezing the HD target for the first time in 2008. An experiment using polarized photon beams and the polarized HD target will be carried out in 2011-2012. We
started constructing a new beam-line (LEPS2) at SPring-8 in 2010. The E949 spectrometer, which has been used at BNL, with large acceptance for charged particles will be transported to the LEPS2 beam-line in 2011. Advanced studies of the spin physics are expected in future experiments at SPring-8.

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