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Development of Polarized HD Target for Future LEPS Experiments at SPring-8*

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Abstract: We are carrying out hadron photoproduction experiments by using polarized photon beams at SPring-8 in Japan. In 2005, we started developing a polarized HD target for future experiments using both the polarized photon beams and the polarized target. The polarized HD target is an idealistic target for experiments observing reactions with small cross sections because the HD does not include heavy nuclei which produce many background events. The measurement of double polarization asymmetries is expected to give much important information to investigate the nucleon hidden structure, hadron photoproduction dynamics, and exotic hadron property. We report on the present status of the development of the polarized HD target at RCNP.

Key words: strangeness; photon; target

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1 Physics Motivation for Constructing the Polarized HD Target

Polarized HD target project[1] was started in April 2005. The first purpose of the project is to investigate the $s\bar{s}$-quark content of proton and neutron by measuring double polarization asymmetries for the ϕ meson photoproduction[2]. In addition, we investigate the bump structure which was found in the differential cross sections for the ϕ meson photoproduction on the proton[3]. The energy dependence of the double polarization asymmetries is expected to clarify what contribution makes the bump structure. Another purpose is to determine the spin-parity of the Θ^+ particle[4]. The measurement of the double polarization asymmetries gives much important information for this purpose. At the LEPS beam line of SPring-8, the circularly and linearly polarized photon beams with the maximum energy of 3.0 GeV are produced by backward Compton scattering. We can perform the measurement of almost all polarization observable for hadron photoproduction by using both the polarized photon beams and the polarized HD target. We are developing the polarized HD target for future LEPS experiments at SPring-8.

It is generally accepted that the low-energy properties of nucleon are well described in terms of three constituent u and d quarks. Therefore, recent experimental results are very surprising. For example, experiments from the lepton deep inelas-

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tic scattering indicate that there may be non-negligible strange quark content in the nucleon and that the strange quarks give 10%—20% contributions to the nucleon spin[5, 6]. A similar conclusion has been drawn from the elastic νp scattering[7]. The analysis of the pion nucleon sigma term also suggests that the proton may contain an admixture of 20% strange quarks[8]. Experiments on annihilation reactions $p\bar{p}\rightarrow\phi X$ at rest show a strong violation of the OZI rule[9]. The G0 experiment shows non-negligible $s\bar{s}$-quark content of the proton by measuring parity-violating asymmetries in the elastic electron-proton scattering[10]. However, it has been also argued that such experimental results could be understood with little or no strangeness content in the nucleon. In 2007, the HAPPEX experiment gives strong constraints on the electric and magnetic strange nucleon form factors[11]. The nucleon form factors are found to be close to zero. This controversy should be solved by providing new experimental information on the $s\bar{s}$-quark content of the nucleon.

The φ meson photoproduction is dominated by the diffractive production within the vector-meson-dominance model through Pomeron exchange as shown in Fig. 1(a). Conventional meson exchanges, such as pseudoscalar(π, η) meson exchange shown in Fig. 1(b), in the t channel are strongly suppressed by the OZI rule. If the proton has the $s\bar{s}$-quark content, the $s\bar{s}$ knockout and uud knockout processes are possible in the φ meson photoproduction as shown in Fig. 1(c, d) because the φ meson is a nearly pure $s\bar{s}$ state. In the case of the φ meson photoproduction on the neutron, the same knockout processes are possible (Fig. 1(e, f)).

Theoretical calculations by Titov et al. with the Pomeron-photon analogy and a relativistic harmonic oscillator quark model show that the beam-target asymmetry (C_{zz}^{BT}) for the $s\bar{s}$ direct knockout φ meson photoproduction (Fig. 1(c)) is very sensitive to the $s\bar{s}$-quark content in the nucleon[2, 12]. The interference of the vector-meson dominance model amplitude and the knockout amplitude gives distinct contributions to the asymmetry at small φ meson angles. The asymmetry C_{zz}^{BT} is defined as

$$C_{zz}^{BT}=\frac{d\sigma\left(\frac{1}{2}\right)-d\sigma\left(\frac{3}{2}\right)}{d\sigma\left(\frac{1}{2}\right)+d\sigma\left(\frac{3}{2}\right)}\ , \qquad (1)$$

where dσ represents dσ/dt. 1/2 and 3/2 denote the sum of the initial proton and photon helicities. Since the optimal photon beam energy range is expected to be 2—3 GeV, the LEPS experiments are quite suitable for this purpose.

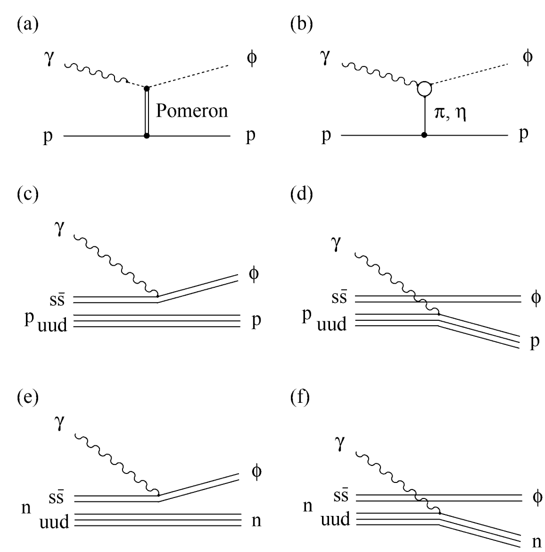

Fig. 1 (a) Diffractive production process within the vector-meson-dominance model through Pomeron exchange. (b) Pseudoscalar (π, η) meson exchange process. (c, d) Direct knockout mechanism on the proton. (e, f) Direct knockout mechanism on the neutron.

2 Characteristics of the Polarized HD Target

The frozen-spin molecular HD target was firstly proposed by Honig in 1967[13]. With long-standing efforts by Syracuse, BNL and ORSAY groups, the polarized HD target system is now being used for the actual experiments at LEGS[14, 15] and GRAAL[16, 17]. Although there are still many technical problems to improve the performance of the HD system, the principal developments seem to finish in our preparation for the LEPS experiments. The HD molecule is an idealistic target for experiments to observe reactions with small cross sections. One of important advantages of using the polarized HD target is that the HD molecule does not include heavy nuclei which produce many background events. The only impurity in the HD target is thin aluminum wires which are necessary 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.

The HD molecule can be polarized and have interesting properties. The proton with spin 1/2 and the deuteron with spin 1 are independently polarized and are independently reversible. In order to achieve high polarizations of proton and deuteron targets, we employ the static method using "brute force" at low temperature and high magnetic field. The low temperature and high magnetic field are very important to achieve high proton polarization as shown in Fig. 2. The polarization can exceed 90% for the proton after aging process for two months at 10 mK at 17 T. The polarization of

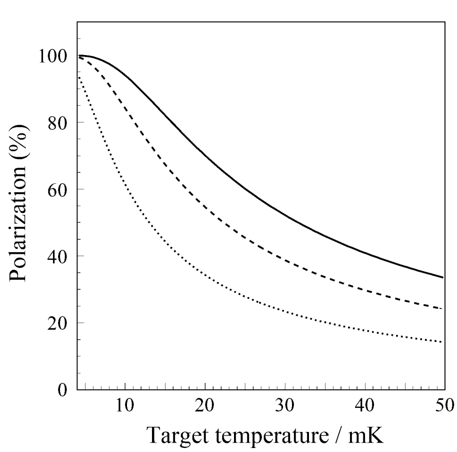

Fig. 2 —, ---, and ··· curves are the proton polarization at the magnetic fields of 17, 12, and 7 T, respectively.

60% for the deuteron can be obtained by transferring the proton polarization to the deuteron by using a method commonly known as "Adiabatic fast passage". The relaxation(polarization) time of one year, which is long enough for usual LEPS experiments, is achievable by keeping the HD target at low temperature below 300 mK with a magnetic field of 1 T during the experiments.

3 Present Status of the Polarized HD Target at RCNP

The polarization of the HD target is produced at RCNP of Osaka university and the target is transported to SPring-8, which is about 120 km distant from RCNP, by a cargo truck. During the whole process, the magnetic field above 0.3 T is provided to keep the polarization. Totally, five large refrigerators are used to maintain low temperature and magnetic field for holding the target polarization. We have two ^{3}He-^{4}He dilution refrigerators. One(DR) is to initially polarize the HD target at RCNP. The DR is fabricated by Leiden Cryogenics BV, and has a cooling power of 3 000 μW at 120 mK and a lowest temperature of below 6 mK. A super-conducting magnet, whose maximum magnetic field is 17 T at 4.2 K, is placed around the DR. The other dilution refrigerator (IBC) is to cool the target at 300 mK during the experiments at SPring-8. The IBC has two superconducting magnets with a magnetic field of 1 T. One magnet is for the vertical magnetic field, and the other is for the horizontal field. The polarization direction can be rotated by using the two magnets. Remaining three refrigerators are typical ^{4}He refrigerators used for the transportation from RCNP to SPring-8.

These five large refrigerators are ready for use now. We still need some improvements of a distillation system to purify the HD gas and of an NMR system. The purity of commercial HD gas is about 96%. The purity needed for a long relaxation time (~1 a) of the polarized HD target is greater than 99.9%. The performance of our HD gas distillation system is not enough to make such pure HD gas. We are improving the performance by modifying the inside structure of the gas distillation system. NMR signals we obtained in test measurements using liquid hydrogen at 0.5 T have some background noises. We are trying to reduce the noises and find a good method to correctly measure the polarization of the HD target.

4 Future Plan

We plan to polarize the HD in July 2008 for the first time and measure the polarization of the HD in the end of August 2008. If we succeed the polarization test, we will prepare for a hadron photoproduction experiment at SPring-8. The first photoproduction experiment using the polarized HD target will be scheduled in 2009.

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