LEPS/RCNP proposal

Performance check of the polarized HD target

Organization

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1 Abstract

We have been studying the ϕ meson production, hyperon production, and exotic baryon production reactions since the construction of the SPring-8/LEPS experimental facility in 2000. We have been using linearly polarized photon beams with energies of E_γ=1.5-2.4 GeV mainly and the measurement of polarization observables is one of advantages of the LEPS experiments. To introduce a polarized target plays a very crucial role in upgrading the LEPS experiments toward the next step. We are developing a polarized Hydrogen-Deuteride (HD) target [1] for near future experiments at SPring-8/LEPS. 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, the measurement of the double polarization asymmetries provides important information to clarify bump structures found at $W \sim$2.1 GeV in the cross sections for the ϕ meson photoproduction [3] and $K^+\Lambda(1520)$ photoproduction [4] on the proton. With the polarized HD target, we can demonstrate the complete measurements for all the polarization observables in photoproduction at the GeV region.

We carried out the first production of the polarized HD target and measured the relaxation time and polarization degree of the target in 2008. It usually takes $2\sim3$ months to polarize the HD target and to fix the polarization. We continued the production process for 53 days. The relaxation time, which is the life time of the polarization, was found to be about 2 months at the experimental condition of T=300 mK and B=1 Tesla at SPring-8/LEPS [5]. The polarization degree was obtained as about 40% which is much smaller than the expected value. We think that bad linearity of the NMR signal height might cause the small polarization degree [6] and actual polarization degree should be much higher than 40%. Since LEGS collaboration, which is also developing the polarized HD target, obtained a polarization degree of about 60%, we expect we can also achieve at least the same polarization degree after some improvements. We are improving the NMR system to correctly measure the polarization now.

Before we carry out physics experiments using the polarized HD target at SPring-8/LEPS, some technical problems must be resolved.

1. The HD target system can be installed in the LEPS experiment hutch.
2. The HD target can be safely transferred from RCNP to SPring-8/LEPS.
3. The polarization of the HD target can be kept when the photon beams of $\sim$1 Mγ's/s are on the target.
4. Trigger rate for data taking is acceptable.

We would like to request the beam time of 10 days. The experimental conditions are listed in Table. 1. We believe that a plenty of data will be acquired for the meaningful analyses for physics if we will have an experiment with the beam even for 10 days. Of course, if the experimental run will be carried out in a perfect way, we hope to continue the run in a longer period.

Photon beam polarization	Circular polarization
Photon beam energy	E_γ=1.5-2.4 GeV
Photon beam intensity	10^6 γ's/sec
Spectrometer	Standard LEPS magnetic spectrometer Tagger, SC, AC, SVTX, DC1, DC2, DC3, and TOF wall

Table 1: Experimental conditions

2 Physics motivation

We have been studying the ϕ meson production [3, 7, 8], hyperon production [9, 10, 11, 12, 13, 14], and exotic baryon production [15, 16] reactions since the construction of the SPring-8/LEPS experimental facility in 2000. We have been using linearly polarized photon beams with energies of E_γ=1.5-2.4 GeV mainly and the measurement of complete polarization observables is one of advantages of the LEPS experiments. To introduce a polarized target also plays a very crucial role in upgrading the LEPS experiments toward the next step.

2.1 Strangeness content in the proton and neutron

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. Experiments from the lepton deep inelastic 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 [17, 18]. A similar conclusion has been drawn from the elastic νp scattering [19]. Analysis of the pion nucleon sigma term also suggests that the proton may contain an admixture of 20% strange quarks [20]. Experiments on annihilation reactions $p\bar{p} \rightarrow \phi X$ at rest show a strong violation of the OZI rule [21]. The G0 experiment shows non-negligible $s\bar{s}$-quark content of the proton by measuring parity-violating asymmetries in elastic electron-proton scattering [22], although its conclusion is still in controversy.

However, it has also been 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 which are close to zero [23]. New s quark polarization extracted by the HERMES experiment using semi-inclusive deep inelastic scattering is consistent with zero [24]. This discrepancy 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 one-pion-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). In case of the ϕ meson photoproduction on the neutron, the same processes are possible (Fig. 1(e, f)). Theoretical calculations by Titov *et al.* using 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].

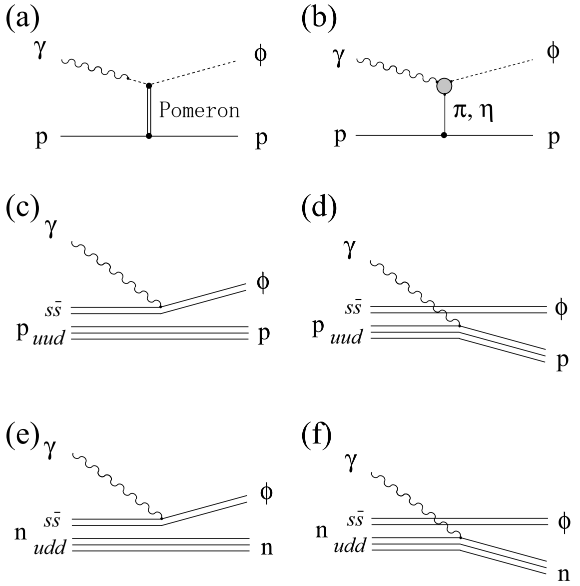

Figure 1: (a) Diffractive production process within the vector-meson-dominance model through Pomeron exchange. (b) One-pion-exchange process. (c, d) Direct knockout mechanism on the proton. (e, f) Direct knockout mechanism on the neutron.

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

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

where $d\sigma$ represents $d\sigma/dt$, and $\frac{1}{2}$ and $\frac{3}{2}$ denote the sum of the initial proton and photon helicities. Since the optimal photon beam energy range to see the strangeness content in the nucleon is expected to be 2-3 GeV as shown in Fig. 2, the LEPS experiment is quite suitable for this purpose.

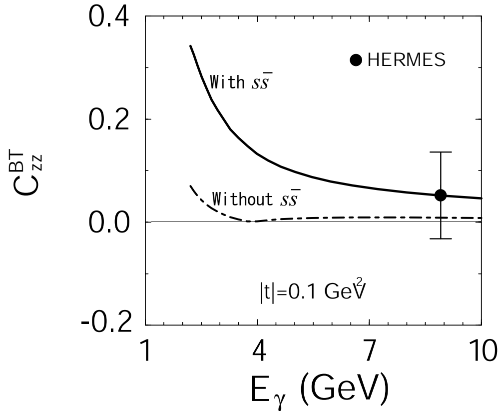

Figure 2: Theoretical calculations of the asymmetry C_{zz}^{BT} for the ϕ meson photoproduction on the proton by Titov *et al.* [25]. The $s\bar{s}$-quark content of 0.25% is assumed to be contained in the proton. The data point is taken from Ref. [26].

2.2 Unknown bump structures found in the cross sections

2.2.1 A bump structure found in the ϕ meson photoproduction

The ϕ meson photoproduction is dominated by the Pomeron exchange, which is the natural-parity exchange, at high energy regions. The contribution from the conventional meson exchange, which is the unnatural-parity exchange, has been considered to be large near the threshold energies. We carried out an experiment of the ϕ meson photoproduction on the proton by using linearly polarized photons of E_γ=1.5-2.4 GeV, and the natural-parity exchange is found to be dominant even near the threshold energies [3]. A bump structure is also found at W ~2.15 GeV in the energy dependence of the differential cross sections. These results are beyond our understanding, and a new process, such as a multigluon exchange, needs to be introduced to explain the results. In order to investigate this bump structure, detailed energy dependence of the double polarization asymmetries is expected to provide important informations [25]. The experiment using the circularly polarized photon beam and longitudinally polarized HD target plays important role for this study.

2.2.2 A bump structure found in the $K^+\Lambda(1520)$ photoproduction

The excited spectrum of baryons contains signatures stemming from the constituents at a fundamental level. Quark model studies predict much more nucleon resonances (N^* and Δ^*) than have been observed by the πN and $N(\gamma,\pi)$ reactions experimentally [27]. These unobserved resonances are called 'missing resonance'. We have been studying the strangeness photoproduction to investigate the missing resonance [9, 10, 11, 12, 13, 14].

We found a bump structure at W ~2.11 GeV in the energy dependence of the differential cross sections for the $\vec{\gamma}p \rightarrow K^+\Lambda(1520)$ reaction at forward K^+ angles [4]. The full width of the bump structure is 130 MeV. Since there is no known nucleon resonance [28], which have the same mass and width, the bump structure is not explained without introducing a new nucleon resonance or a special reaction process, for example strong interference with the ϕ meson photoproduction. The width of 130 MeV is a few times smaller than the width of normal nucleon resonances at this mass region. Although we measured the photon beam asymmetries by using linearly polarized photon beams, the asymmetries can not give conclusive explanation for the bump structure. Additional observables by introducing the polarized HD target are needed to clarify the physics reasons why the bump structure is observed.

3 Status of the polarized HD target at RCNP

3.1 Characteristics of the polarized HD target

We selected the HD molecule as a polarized nucleon target. One of advantages of selecting the HD is that the HD does not include heavy elements, such as C and N. Good dilution factor is very important when we observe reactions with small cross sections using the photon beam. The HD molecule can become both a proton target and a neutron target. The HD is an idealistic polarized targets for the LEPS experiments, although thin aluminum wires (20% in weight) must be contained in the target cell to insure the cooling. In order to achieve high polarizations of proton and deuteron targets, we employ the static method using "brute force" at low temperature (10 mK) and high magnetic field (17 Tesla). The polarization can exceed 90% for the proton after aging process for 2∼3 months. The polarization of 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 time of about a year is achievable by keeping the HD target at low temperature below 300 mK with magnetic field of 1 Tesla during the experiment [29].

The characteristics of the polarized HD target are summarized in Table.2.

Method for polarizing target	Static method at B=17 Tesla at T=10 mK for 2∼3 months
Polarization degree for H	90%
for D	60%
Relaxation time for H	1 year at B=1 Tesla and at T=300 mK
for D	1 year at B=1 Tesla and at T=300 mK
Target size thickness	50 mm
diameter	25 mm

Table 2: Characteristics of the polarized HD target

3.2 How to polarize and install the HD target

Six refrigerators are operated to polarize the HD target at RCNP and install it at SPring-8/LEPS as shown in Fig. 3.

At RCNP, pure HD gas with an amount of 1 mol is produced by using the HD gas distillator [30], and the HD gas is solidified in a dilution refrigerator (DRS). The solid HD is aged for 2∼3 months at a high magnetic field of 17 Tesla and at a low temperature of 10 mK. The polarization of the solid HD is made and frozen by this aging. The polarized HD is transferred from the DRS to a ^{4}He refrigerator (SC) by using another ^{4}He refrigerator (TC1) in 30 minutes. The SC is transported to SPring-8/LEPS by using a truck in three hours.

At SPring-8/LEPS, the polarized HD is transferred from the SC to a dilution refrigerator (IBC) by using the last ^{4}He refrigerator (TC2) in 30 minutes. The IBC provides a magnetic field of 1 Tesla and a temperature of 300 mK during the physics experiment for a few months. The IBC has two superconducting magnets, which can rotate the direction of the HD polarization, for example from the longitudinal polarization to the transverse polarization.

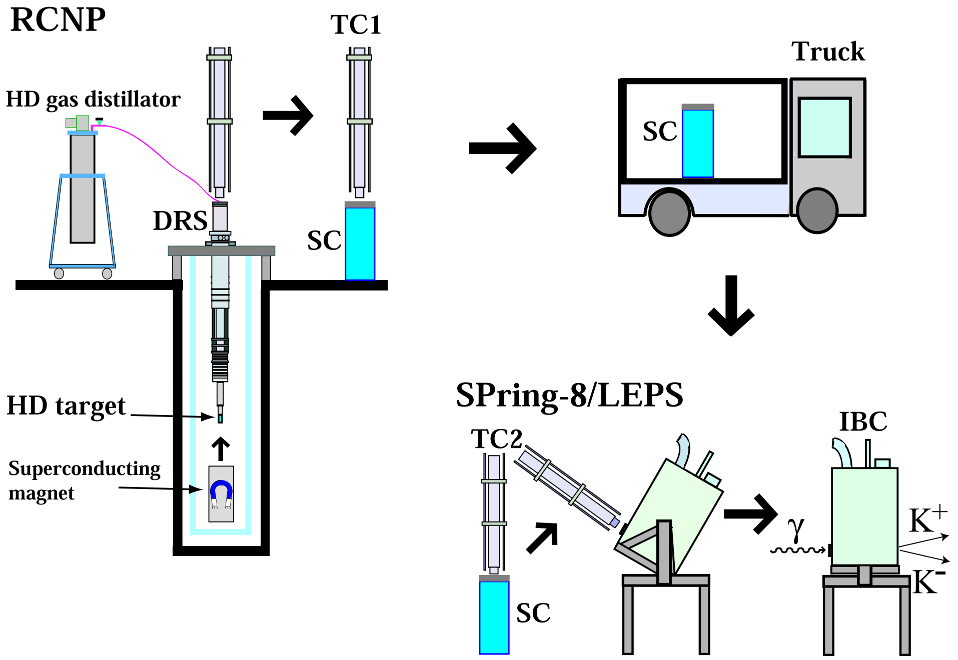

Figure 3: HD target transferred from RCNP to SPring-8/LEPS.

3.3 Result of the first production of the polarized HD target

3.3.1 Polarization degree of the proton

We produced a polarized HD target for the first time in 2008. After the aging time of 53 days at B=17 Tesla and at T=14 mK, the polarization degree of the hydrogen in the HD was measured by using the NMR system [31]. NMR spectra observed for the hydrogen are shown in Fig. 4. Before the aging, we observed NMR spectra at B=1 Tesla and at T=4.2 K as reference data. We assumed the linear relation between the polarization degree and the area of the NMR spectra, and the polarization degree was obtained as about 40%. Since the polarization degree expected by the aging process is about 90%, the polarization obtained is much smaller than the expectation. We think that bad linearity of the NMR signal height might cause the small polarization degree [6] and actual polarization degree should be higher than 40%. Since LEGS collaboration, which is also developing the polarized HD target, obtained a polarization degree of about 60%, we expect we can also achieve at least the same polarization degree after some improvements. We are improving the NMR system to correctly measure the polarization now.

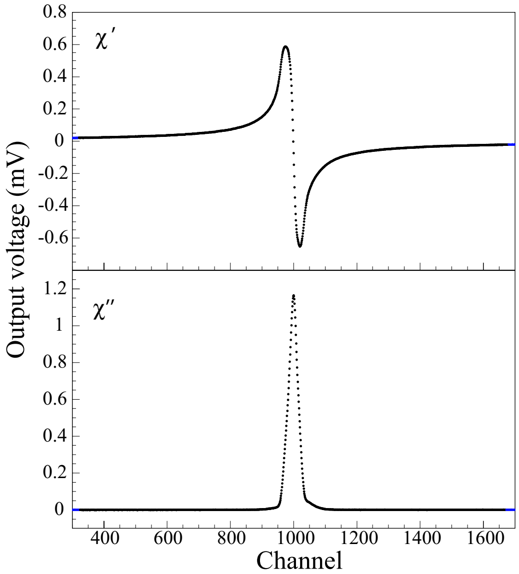

Figure 4: NMR signal for the hydrogen after the aging of 53 days.

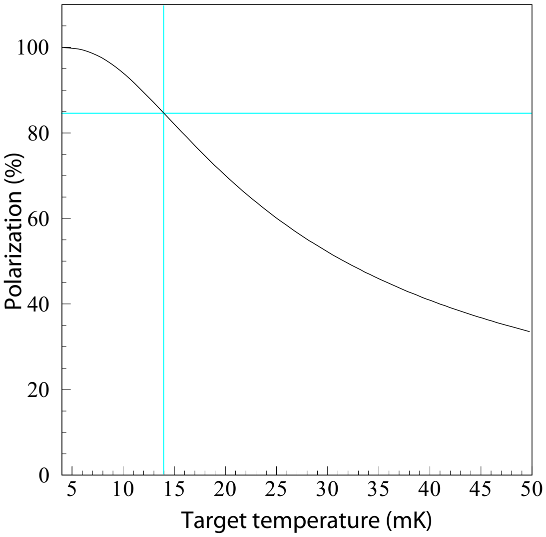

Figure 5: Temperature dependence of the proton polarization degree at B=17 Tesla. The temperature in aging the HD target was T=14 mK.

3.3.2 Relaxation time

The polarized HD target was stored in the same condition as the physics experiment at SPring-8/LEPS. We have measured the time dependence of the area of the NMR signal for two weeks at B=1 Tesla and T=300 mK as shown in Fig.6. The data are fit by the function,

$$S(t) = p_1 e^{-\frac{t}{p_2}} + p_3 e^{-\frac{t}{p_4}} \tag{2}$$

The first term is for the background hydrogen in the NMR wire and grease. The second term is for the hydrogen in the HD target. The polarization of the background hydrogen disappears in a short time, while that of the hydrogen in the HD target is kept for a long time. The relaxation time (p_4) for the hydrogen in the HD target was obtained as about 100 days.

We produce a new HD target by the aging of 2∼3 months, and the old HD target is replaced with the new target after 3 months' physics run. We can continuously carry out the experiments at SPring-8/LEPS. If we consider bad linearity of the polarization measurement, correct relaxation time may become about 50 days. It is long enough to produce a new HD target.

We also measured the relaxation times for the experimental conditions of TC1, TC2, and SC. The relaxation times are 141, 141, and 243 hours for the hydrogen of the HD target in TC1, TC2, and SC, respectively. If the initial polarization is assumed to be 100%, the polarization becomes 98% after transferring the HD target from RCNP to SPring-8/LEPS as shown in Fig. 7.

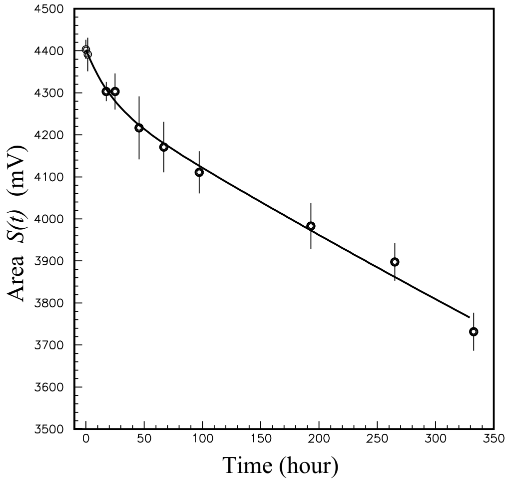

Figure 6: Time dependence of the area of the NMR signal (χ") for the hydrogen. The HD target was stored at B=1 Tesla and at T=300mK.

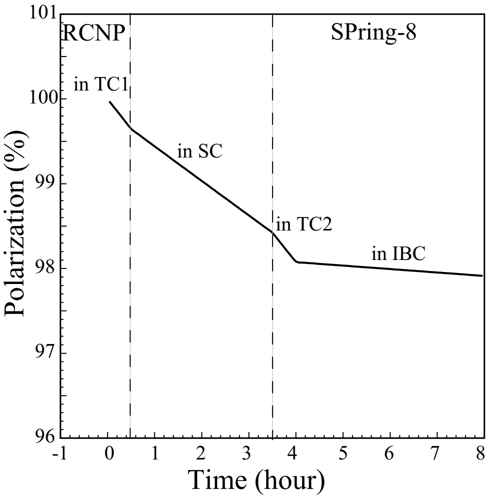

Figure 7: Polarization loss during the transferring the HD target from RCNP to SPring-8/LEPS. The initial polarization of the HD target is assumed to be 100%.

4 Experiment

We would like to carry out an experiment for 10 days. In the experiment, the performance of the polarized HD target is checked. Since the relaxation time, which is the life time of the polarization, is expected to be long (more than 100 days after 3 months' aging), at least 10 days are needed to correctly measure it.

4.1 Experimental conditions

4.1.1 Photon beam

We want to use circularly polarized photon beams with energies of E_γ=1.5-2.4 GeV. We expect tagged photon intensity of about 10^6 γ's/sec.

4.1.2 Spectrometer

The HD target system consists of IBC(In Beam Cryostat), gas circulation system, compressor, and control unit. The IBC is installed just in front of the LEPS spectrometer as shown in Fig. 8. The gas circulation system and compressor are installed in the BL33LEP hutch. The control unit is placed outside the hutch. When the HD target is transferred from the TC2 to the IBC, the IBC is moved to outside by using the left door.

We want to use the standard LEPS spectrometer for investigating trigger rate and hadron S/N ratio. The standard LEPS spectrometer consists of a scintillation counter (SC), an aerogel cherenkov counter (AC), a silicon vertex detector (SVTX), three drift chambers (DC1, DC2, and DC3), and a TOF wall as shown in Fig. 9.

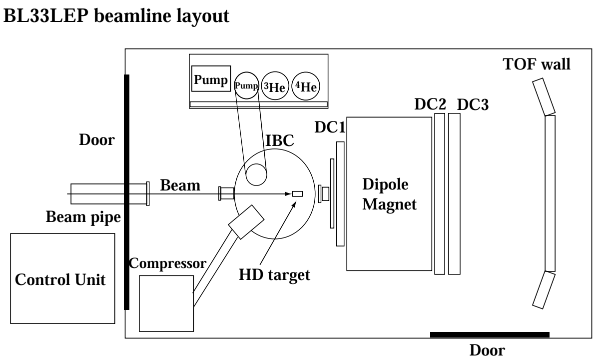

Figure 8: Layout of the HD target system in the BL33LEP beam line hutch.

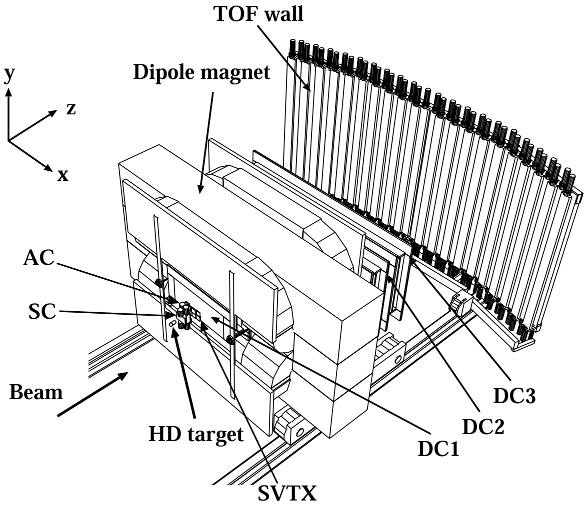

Figure 9: Standard LEPS magnetic spectrometer.

4.2 Preparation for experiment

Before the experiment at SPring-8/LEPS, we will finish the preparation listed below.

1. Practice of transferring the target by using a solid H_2 target will be carried out in the summer shutdown in 2009.
2. A new NMR system for correctly measuring the HD polarization degree will be finished.
3. A polarized HD target after the aging of 2∼3 months will be ready for the experiment.
4. Support frames for the IBC and TC2 will be constructed.
5. IBC and TC2 will be transferred from RCNP to SPring-8/LEPS.
6. Circularly polarized ultra-violet laser beam will be prepared.
7. Permission to do the experiment using the polarized HD target will be given by the safety office of SPring-8.

4.3 Experimental schedule

Before we carry out physics experiments using the polarized HD target at SPring-8/LEPS, some technical problems must be resolved. We will check the following items in the experiment.

1. The HD target system can be installed in the LEPS experiment hutch.
2. The HD target can be safely transferred from RCNP to SPring-8/LEPS.
3. The polarization of the HD target can be kept when the photon beams of $\sim$1 $M\gamma'$s/s are on the target.
4. Trigger rate for data taking is acceptable.

The run plan of the experiment is shown in Fig. 10.

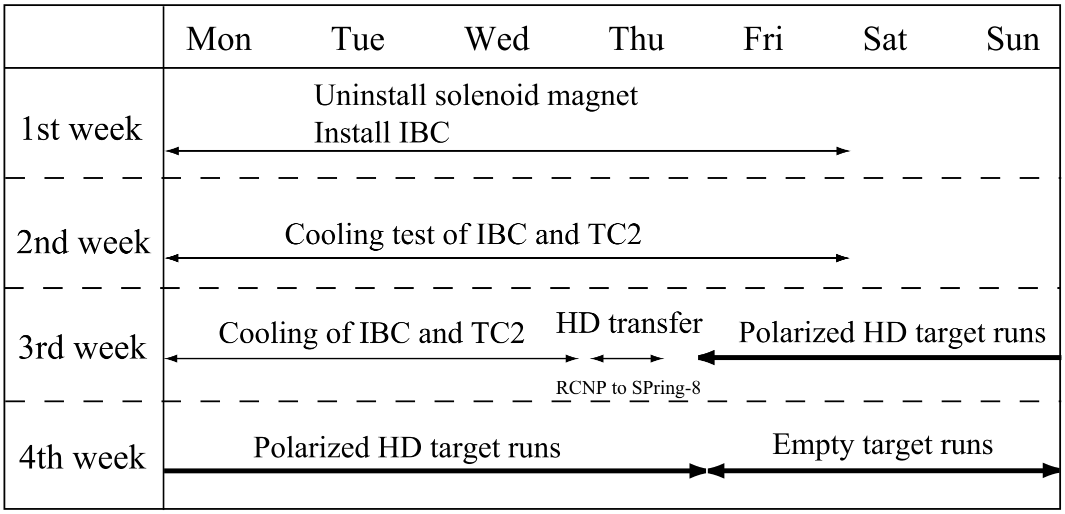

Figure 10: Run plan of the experiment.

5 Yield estimation for the strangeness photoproduction.

Although the number of ϕ mesons produced during this experiment is very small, we can observe some events for the strangeness photoproduction. The $K^+\Lambda$ photoproduction yield for 7 days' data taking is estimated as follows.

$$\begin{aligned} N_{K^+\Lambda} &= \frac{d\sigma}{d\cos\theta} \cdot d\cos\theta \cdot N_{Beam} \cdot N_{Target} \cdot \epsilon \\ &\sim 8800, \end{aligned}$$

where $\frac{d\sigma}{d\cos\theta} = 1.6\ \mu$b, $d\cos\theta$=0.4, N_{Beam}=$10^6\times$ 3600×24×7 γ's, N_{Target}=5×0.114/3×6.0×10^{23} free protons, and ϵ=0.2 is the efficiency considering the photon beam transmission rate (∼0.5), the analysis efficiency (∼0.6), and the acceptance of the spectrometer (∼0.6).

The number of events estimated to be observed by this experiment are about 5800, 4800, and 2600 events for the $K^+\Sigma^0$, $K^+\Sigma^0(1385)/K^+\Lambda(1405)$, and $K^+\Lambda(1520)$ reactions, respectively.

6 Cost estimation

The total cost estimated to produce the polarized HD target and to carry out the experiment for 10 days is about 58 k US dollars.

Item	Cost (k US dollars)
HD gas (4 moles)	10
Liquid helium for production (1500 litters)	30
Liquid helium for experiment (1000 litters)	15
Travel expenses RCNP to SPring-8	3
Total	58

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