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PHOTOPRODUCTION EXPERIMENT WITH POLARIZED TARGET AT SPring-8*

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Measurement of double polarization asymmetries for ϕ photoproduction with the polarized target and a polarized photon beam is a sensitive means to investigate small and exotic amplitudes, such as an $s\bar{s}$-quark content of nucleons, via interferences with dominant amplitudes and the determination of the spin value of produced hadrons as the pentaquark. In order to realize the double polarization measurements to study the $s\bar{s}$-quark content as well as exotic hadron structures, We started to construct a frozen-spin polarized HD target at the LEPS facility on the new basis of recent technology developments in cryogenic and high magnetic field. We discuss the experiment for ϕ-meson photoproduction which will be performed in 10 days (40 days) with the result of 20% (10%) accuracy for the double polarization asymmetry measurement.

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1. Introduction

It is generally accepted that the low-energy properties of nucleon is well described in terms of three constituent u and d quarks. The constituent quark model predicts that the ratio (μ_n/μ_p) of the neutron and proton magnetic moments is $-2/3$, which agrees with the experimental value -0.685. However, the recent experiments from the lepton deep inelastic scattering address a serious question; the magnetic moments from constituent quarks only contribute 10%. Measurements of the nucleon spin structure functions

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indicate that there may be non-negligible strange quark content and that the strange quarks give 10−20% contributions to the nucleon spin [1–3].

A similar conclusion has been drawn from the elastic νp scattering at BNL [4]. Analysis of the pion nucleon sigma term also suggest that proton might contain an admixture of 20% strange quarks [5, 6]. Experiments on annihilation reactions $p\bar{p} \rightarrow \phi X$ at rest [7–9] show a strong violation of the OZI rule [10]. However, it has also been argued that such experimental results could be understood with little or no strangeness content in the nucleon. These experimental as well as theoretical situations remain the $s\bar{s}$ content of nucleon as a long-standing problem in physics. Thus, this controversy should be solved by providing new experimental information on the $s\bar{s}$ content of nucleon.

The ϕ photoproduction is one of the promising reactions to give direct experimental data for studying the $s\bar{s}$ contents of nucleon. The ϕ meson has the almost pure $s\bar{s}$ wave function. Thus, there is a possibility of pinning down the $s\bar{s}$ components in a nucleon through the knockout process, where the $s\bar{s}$ pair couples to the photon is knocked out as a ϕ meson. Although the $s\bar{s}$ knockout amplitude is much smaller than that from the dominant Pomeron exchange process in the ϕ meson photoproduction, it is predicted that double polarization asymmetries with a polarized proton target and a polarized beam are sensitive to the $s\bar{s}$ content via an interference effect. Theoretical calculations suggest that the effect of the $s\bar{s}$ content is detectable via beam-target asymmetry $C_{\rm BT}$ measurements at $E_\gamma \sim 2$ GeV [11], and that the LEPS energy region ($E_\gamma = 1.5 \sim 2.4$ GeV) is suitable to perform the $C_{\rm BT}$ measurement.

2. $C_{\rm BT}$ measurement in ϕ-meson photoproduction

The beam-target asymmetry is defined as

$$C_{\rm BT} = \frac{d\sigma(\rightrightarrows) - d\sigma(\leftrightarrows)}{d\sigma(\rightrightarrows) + d\sigma(\leftrightarrows)}\,, \tag{1}$$

where the arrows represent the spin projections of the incoming photon and the target protons, and the notations ($\rightrightarrows$) and ($\leftrightarrows$) correspond to the initial states with the total spin equal to $\frac{3}{2}$ and $\frac{1}{2}$, respectively.

The beam-target asymmetry appears as an interference between the amplitudes with different parity-exchange properties.

Fig. 1 shows the absolute value $|C_{\rm BT}|$, which is calculated by taking into account the $s\bar{s}$-knockout process as a function of initial photon energy at $|t| = 0.1$ GeV^2. For convenience, the beam-target asymmetry for background processes is also shown in Fig. 1. We also show the recent data point obtained from the work of the HERMES collaboration [12]. One can see that the contribution of the $s\bar{s}$-knockout process decreases monotonically with increasing E_γ, because of the corresponding dynamical factor ("form-factor") which decreases rapidly with increasing E_γ. Thus, we may conclude:

1. The expected effect of the $s\bar{s}$ channel in the beam-target asymmetry in the $\gamma p \to \phi p$ process is large.
2. The optimum region for the study of this effect is $E_\gamma = 2 \sim 3$ GeV and $|t| \leq 0.4$ GeV^2.

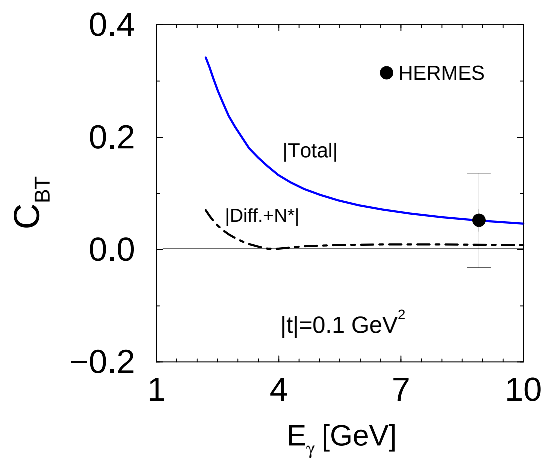

Fig. 1. The absolute values of beam-target asymmetry calculated without the $s\bar{s}$-knockout (dot-dashed curve) and with the $s\bar{s}$-knockout process (solid line) as a function of E_γ at $|t| = 0.1$ GeV^2. The data point is taken from Ref. [12]. The formulation for the calculations are given in Refs. [11,13,14]. Note that the nearly pure $s\bar{s}$ wave function for the ϕ meson and the $s\bar{s}$ content of 1% in the proton are assumed.

3. Estimations for experiment

In order to obtain the reliable $C_{\rm BT}$ value in ϕ-meson photoproduction, the key issue is a reliable measurement of beam-target asymmetry. The beam-target asymmetry ($C_{\rm BT}$) is calculated by

$$C_{\rm BT} = \frac{(\sigma_{\rm P} - \sigma_{\rm BG}) - (\sigma_{\rm A} - \sigma_{\rm BG})}{(\sigma_{\rm P} - \sigma_{\rm BG}) + (\sigma_{\rm A} - \sigma_{\rm BG})} = \frac{\sigma_{\rm P} - \sigma_{\rm A}}{\sigma_{\rm P} + \sigma_{\rm A} - 2\sigma_{\rm BG}}\,, \tag{2}$$

where $\sigma_{\rm P}$ ($\sigma_{\rm A}$) represents the spin parallel (anti-parallel) cross section from a HD target and $\sigma_{\rm BG}$ describes a common background contribution mainly from an unpolarized deuteron.

Defining the ratio $R = \frac{\sigma_{\rm BG}}{(\sigma_{\rm P}+\sigma_{\rm A})/2}$ using the background cross section $\sigma_{\rm BG}$ and an averaged cross section $(\sigma_{\rm P}+\sigma_{\rm A})/2$, we obtain a relation between $\sigma_{\rm P}$ and $\sigma_{\rm A}$ as $\sigma_{\rm A} = \frac{1-C_{\rm BT}(1-R)}{1+C_{\rm BT}(1-R)}\sigma_{\rm P}$. If it is assumed that $\sigma_{\rm P}$ and $\sigma_{\rm A}$ will be measured with the same precision, $\Delta\sigma_{\rm A}$ is written as $\frac{1-C_{\rm BT}(1-R)}{1+C_{\rm BT}(1-R)}\Delta\sigma_{\rm P}$. By using these relations, the following equation is obtained:

$$\frac{(\Delta C_{\rm BT})^2}{C_{\rm BT}^2} = \frac{\{1-C_{\rm BT}^2(1-R)\}^2 + C_{\rm BT}^2R^2}{2C_{\rm BT}^2(1-R)^2}\frac{(\Delta\sigma_{\rm P})^2}{\sigma_{\rm P}^2} + \frac{R^2}{(1-R)^2}\frac{(\Delta\sigma_{\rm BG})^2}{\sigma_{\rm BG}^2}. \quad (3)$$

Titov suggested that 1% of strange quark contents would produce $C_{\rm BT} = 0.3$ in a small $|t|$ region [11]. The fraction R depends not only on coherent and incoherent cross sections from deuteron but on an offline cut for a missing mass of K^+ and K^- tracks, which will be affected by Fermi motion in deuteron. If R is assumed to be 0.5, Eqn. (3) is rewritten as $\frac{(\Delta C_{\rm BT})^2}{C_{\rm BT}^2} = 20.8\frac{(\Delta\sigma_{\rm P})^2}{\sigma_{\rm P}^2} + 1.0\frac{(\Delta\sigma_{\rm BG})^2}{\sigma_{\rm BG}^2}$. This means that 10% (20%) precision of $C_{\rm BT}$ requires 2.2% (4.4%) measurement of $\sigma_{\rm P}$, for example, by neglecting the second term. If only statistical error is taken into account, ~2000 (~500) events of ϕ photoproductions has to be collected for the successful measurement.

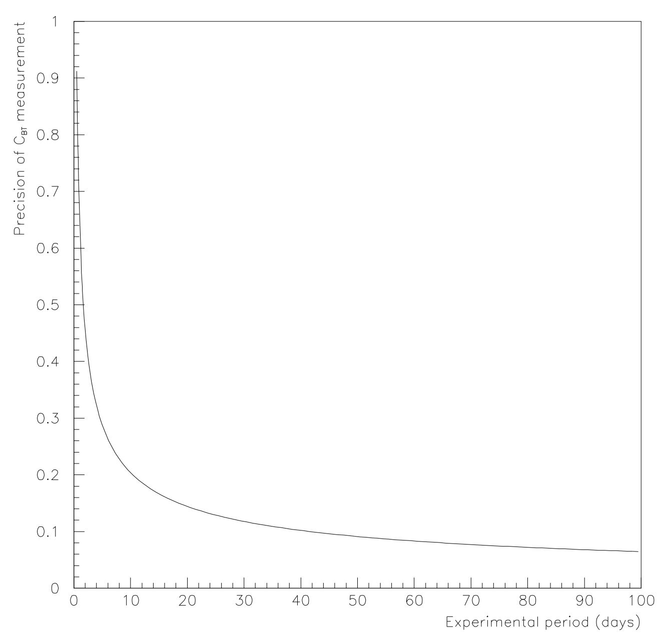

Fig. 2. Expected precision for the beam-target asymmetry measurement as a function of the experimental period.

In the LEPS experiment, it is possible to produce about 2000 events of ϕ photoproductions within 40 days in a K^+ and K^- detection mode by using a 5 cm-long LH_2 target (for the ϕ meson measurement, see the recent publication [15]). Since the measured counting rate of ϕ mesons are about 3 counts/hour with a 5 cm long H_2 liquid target, desired accuracy for the experimental purpose will be achievable.

Fig. 2 shows an expected precision of a beam-target asymmetry measurement as a function of the experimental period. We conclude that the beam time with 10–40 days will be achievable with present technologies for the HD target.

4. Fabrication and installation of the HD target

We start the actual construction of the HD production facility in 2005. Since there are many parts which are necessary to be developed at the RCNP side, we start the developments of small devices such as the NMR system with a small money in 2004. Obviously, we have started the actual designing phase for the installation of the HD target in 2004.

As the first stage of the HD target development, we clean up the existing building for the cryogenic system at RCNP. Twenty years ago, this building was used to produce liquid He for the superconducting solenoid magnet. But, the equipment became old now and it is not used for about 15 years. The building is almost empty. This building is very suitable for our purpose to produce the HD target at RCNP. The infrustructure such as the power line and air conditioning system will be improved to fit to the aim of the HD target production. This is also officially good since the building is not used in the correct political way for the cryogenic purposes for a long time. Fortunately, it has been decided at RCNP that this building should be used for the HD target in 2004.

The HD target project has been approved as the five year project from the government starting from 2005. Among all the equipments necessary to produce and exploit polarized HD, the key ingredient is the Dilution Refrigerator equipped with a high field superconducting coil. This type of equipment is commercially available and can be delivered within one year after the contract. The production of the polarized HD target is now not a big problem, if we consider the recent technology developments; *(i)* one can follows the protocol which is now rather well established by numerous polarization runs at Brookhaven and ORSAY, *(ii)* one can use a double distilled HD gas with a high quality, for which the distillation apparatus already exists and its performance is checked.

So far, we did not decide what kinds of In-beam Cryostat (IBC) will be optimal to perform the best experiments at SPring-8. In the case of the present LEGS and GRAAL IBC, we use a technology based on liquid ^{4}He and ^{3}He pumped baths, and the devices can be cooled down till 1.5 K and 0.5 K, respectively. They consume a significant (prohibitive) amount of ^{4}He, necessary to provide the cold source. A possible improvement would be to use a cryogenerator for the cold source. This improvement is under study at ORSAY; it increases the original cost significantly, but the savings in liquid ^{4}He is enormous. Another approach would be to use a small dilution unit, in order to reach at temperatures below 0.5 K, which is extremely attractive in view of the increase of relaxation times at lower temperatures. Such an approach has been chosen by the LEGS facility at BNL, and has been tested during the year 2003. It seems to be obvious that the SPring-8 IBC will be fabricated in a sophisticated way by taking into account all the lessons which will be learned during the coming year both at LEGS in US and at ORSAY in France. Therefore, the best choice will be clear, allowing the development of the best IBC for SPring-8 in parallel with the construction of the dilution refrigerator (DR).

The Transfer Cryostat (TC) and Storage Cryostat (SC) are more conventional cryogenic devices and it will be sufficient to correct the previous few misconceptions. The argumentation developed here shows that within a delay of 3 years, one can have an experiment performed at SPring-8.

5. Final remarks

We start to construct a polarized HD target for photoproduction experiments at LEPS facility at SPring-8, where a polarized photon beam is available in the energy region from 1.5 to 2.4 GeV. We aim to perform the experiment of ϕ photoproduction off a nucleon at forward angles as a main physics. Measurement of the double polarization asymmetries for the ϕ photoproduction with the polarized target and the circularly polarized photon beam enables us to investigate small and exotic amplitudes via the interference with dominant amplitudes. We can study the interesting subjects such as the $s\bar{s}$-quark content of nucleons, which is currently considered to be non-negligible. A measurement of a beam-target asymmetry at small $|t|$ (forward angles) with a 1.5–2.4 GeV photon beam is promising to extract a small component via a large interference effect by comparing with other competitors. The measurement of the double polarization asymmetries for the ϕ photoproduction is now interesting from the viewpoint of the recent G0 experiment [16], in which non negligible $s\bar{s}$-quark content of protons are indicated.

Other subjects in hadron physics, such as the spin-determination of the pentaquark particle can be also accessible in a clear method via the polarization observables by using the HD target. At present moment, the existences of the Θ^+ pentaquark particle at 1540 MeV itself are in the controversial situation [17]. Theoretically, the problems addressed stem from the fact that the spin and parity values are not uniquely determined: The candidates are $1/2^+$, $1/2^-$, $3/2^+$, $3/2^-$, depending on the theoretical models. In order to determined the spin and parity values of the Θ^+, the polarization measurements are discussed theoretically [18, 19]. Experimentally, the spin-parity determination is difficult because of the poor statistics of the measured Θ^+ yields. However, if the HD polarized target becomes available with a long relaxation time, it is possible to make a complete measurements of the polarization observables for the Θ^+ particles with a long run at SPring-8. However, we should await long to perform this kind of a long run experiment after the final setup of the HD target.

Double polarization measurements to detect K mesons yielding the Λ and Σ particles would be also the interesting subjects to be studied in view of the reaction dynamics involving strange quarks. These kinds of measurements will be included as a short term program after the completion of the HD target.

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