Study of Weak Hyperon-Nucleon Interaction by the $pn \to p\Lambda$ Reaction

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The strong interaction between nucleons has been studied extensively in a wide incident energy range, and microscopic models based on boson-exchange potentials have been developed to reproduce the interaction. By assuming the SU(3) symmetry of the quark flavors (u, d and s), one can extend the models of the nucleon-nucleon interaction to models of the hyperon-nucleon and hyperon-hyperon strong interactions. Recently developed models of the hyperon-nucleon interaction were compared with experimental data on binding energies of ground states and level schemes of Λ hypernuclei, and also with the data of hyperon-nucleon scattering.

On the other hand, the weak sector of the nucleon-nucleon and the hyperon-nucleon interactions was poorly known. The weak sector of the nucleon-nucleon interaction is hard to be investigated due to the background of the strong interaction. The weak interaction between nucleons can be observed as a small magnitude of interference between the strong interaction and the parity-violating part of the weak interaction. The weak sector of the hyperon-nucleon interaction has been studied through the $\Lambda N \to NN$ decay, so called the non-mesonic decay, of the Λ hypernuclei. Since the decay of the Λ hypernuclei happens only by the weak interaction, there is no difficulty of the background by the strong interaction and we can estimate the magnitude of the weak interaction by measuring the life-time and the branching ratio in the decay of the Λ hypernuclei. Further, we can study both the parity-violating and the parity-conserving weak interactions separately by measuring the decay asymmetry of the weak decay [1, 2]. Unfortunately, there is no theoretical interpretation which describes all experimental observations perfectly at the same time. One of reasons of the difficulty is that the theoretical calculation treats only the very initial stage of the weak decay process ($\Lambda N \to NN$ process) but experimentally the inter-nuclear cascade process follows the weak decay. So, some ambiguous correction of the effect of the inter-nuclear cascade process is necessary to compare the experimental data with the theoretical calculations. Another reason of the difficulty is the contribution of the higher order diagrams, like the $\Lambda NN \to NNN$ process. The processes with the higher order diagrams are different from the $pn \to p\Lambda$ process theoretically, but there is no way to distinguish the processes experimentally.

To use the advantages of the hyperon-nucleon system in studying the weak interaction and to remove the ambiguities in the comparison of the experimental data with the theoretical predictions, we are proposing to study the inverse reaction of the weak decay process, i.e., the $pn \to p\Lambda$ reaction, at the incident beam energy below the threshold of the associated production of the strangeness [3]. Since the incident beam energy is below the threshold of the associated production, the $pn \to p\Lambda$ reaction happens only through the weak interaction. It means there is no physical background. The energy threshold of the direct $pn \to p\Lambda$ process

beam intensity	160 nA $= 10^{12} protons/sec$
target thickness (Be)	1 cm $= 6 \times 10^{23} neutrons/cm^2$
cross section	$10^{-39} cm^2$
detection efficiency	0.07

Table 1: Assumptions in the yield estimation of the $pn \to p\Lambda$ reaction.

by the weak interaction is $E_p = 368 MeV$, and a proton beam over the threshold energy is available at the Ring Cyclotron Accelerator facility of the Research Center for Nuclear Physics (RCNP), Osaka University.

Apparently, the study of the $pn \to p\Lambda$ reaction is complementary to the study of the non-mesonic decay of the Λ hypernuclei. Further, the advantage of the $pn \to p\Lambda$ reaction at the threshold energy region is that the inverse reaction of the weak decay followed by the inter-nuclear cascade process does not contribute to the reaction because the inter-nuclear collision at the initial stage easily decreases the proton energy below the threshold. With the similar reason, the inverse reaction of the higher order processes in the non-mesonic weak decay does not contribute to the reaction. Another advantage of the $pn \to p\Lambda$ reaction is the availability of the good quality of polarized proton beam at the Ring Cyclotron Accelerator facility. The measurement of the helicity dependence of the reaction cross section is a complementary observable with the decay asymmetry of the weak decay process. *Challenges in the measurement of the $pn \to p\Lambda$ reaction are the small reaction cross section, $10^{-39} cm^2$, and the reduction of strong instrumental backgrounds.*

The yield of the $pn \to p\Lambda$ reaction is estimated to be 4 events/day with assumptions listed in Table 1. With 30 days beam-time, we can obtain about 120 events of the $pn \to p\Lambda$ reaction, and the number is enough to estimate the magnitude of the weak interaction with a precision better than that currently obtained from analysis of the non-mesonic weak decay process.

A clear signal of the $pn \to p\Lambda$ reaction is a pair of proton and negative pion from the Λ decay in-flight, $\Lambda \to p\pi^-$, and the position of the Λ decay vertex away from the target. To reconstruct the Λ particle decay, both proton and negative pion are measured by a cylindrical drift chamber (CDC) installed in a longitudinal (parallel with the beam) solenoidal magnetic field ($B \sim 0.5T$). Fig.1 shows a drawing of CDC design which is now under construction. The inner and outer diameters of CDC are 110 mm and 409 mm, respectively, and the length is 1540 mm. The decay vertex of the Λ particle is determined precisely by a tracking with information from 2 layers of silicon strip detectors (SSD) surrounding the beam axis. A prototype SSD is now under development.

A strong background of proton is coming from elastic and quasi-elastic scattering of the beam protons by the target. Background negative pions are coming from the quasi-free $pn \to pp\pi^-$ reaction. To reduce the backgrounds, a collimator made of heavy metal is placed at the most inner part of the detector system so that protons and pions from the target do not hit neither CDC nor SSD. With an appropriate combination of the geometry of the collimator (mostly opening angle of the collimator) and the acceptances of CDC and SSD, we still can detect the decay products of the Λ particles with decay vertex at downstream of the target. From a Monte Carlo simulation calculation, the opening angle of about 15 degrees is optimum for the detection of proton and π^- particles from the Λ decay. A prototype collimator made

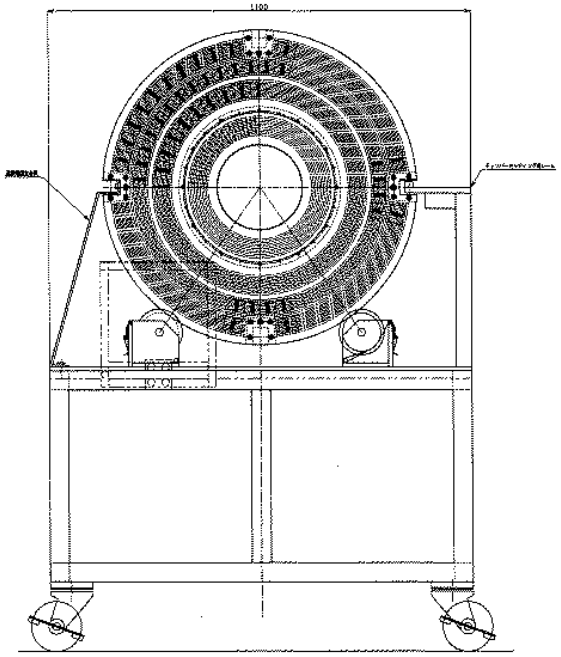

Figure 1: A drawing of the CDC design looking from downstream.

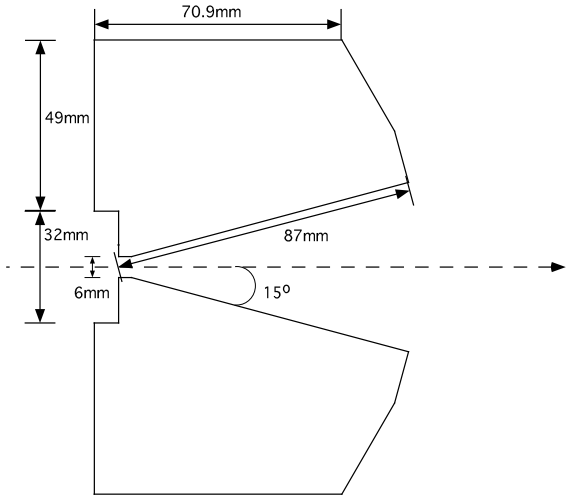

Figure 2: The design of the prototype collimator made of tungsten alloy.

of tungsten alloy (see Fig.2) was tested with 416 MeV proton beam, and proton and charged pion yields from the target were measured with and without the collimator. The prototype collimator easily reduced protons and pions from the target by about 2 order of magnitude. To obtain more reduction of the background especially for protons, a tuning of the collimator geometry is in progress.

References

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