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PRESENT STATUS AND FUTURE PLANS FOR HYPERNUCLEAR PHYSICS IN JAPAN

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ABSTRACT

A present status of the hypernuclear physics mainly performed at KEK was presented; a particular emphasis was made on the production of the neutron-rich hypernucleus. Future perspectives at J-PARC were also discussed.

1 Neutron-rich Λ hypernuclear production

1.1 Physics motivation and theoretical background

It has been discussed that the study of neutron-rich Λ hypernuclei would give new information of hypernuclear physics such as the coherent Λ-Σ coupling, which was first introduced to solve the long-standing "overbinding problem" of ${}^{5}_{\Lambda}$He [1]. This coherent coupling becomes more effective as the excess neutron number of the nucleus becomes larger and eventually will affect the baryon interaction in high density nuclear matter like neutron stars [2, 3]. However, there have been few experimental efforts to produce neutron-rich Λ hypernuclei, which is difficult by the usual (K^-, π^-) or (π^+, K^+) reaction but is possible by using the double charge-exchange(DCX) mechanism like (π^-, K^+) or (K^-, π^+) reaction. In the past attempt by using (stopped-K$^-$, π^+) reaction [4], only the upper limits of the production cross section on ^{9}Be, ^{12}C and ^{16}O targets were given due to a limited statistics and a large background originating from Σ^+ decay. Recently FINUDA collaboration at DAPHNE is trying to observe neutron-rich hypernuclei by using (stopped-K$^-$, π^+) reaction with higher statistics than previous one, however, they also give an upper limit at present [5] because of an inherent background of Σ^+ decay in this reaction. In the present experiment, we used the in-flight (π^-, K^+) DCX reaction on a ^{10}B target in order to produce a $^{10}_{\Lambda}$Li hypernucleus for the first time with much less background.

A neutron-rich Λ hypernuclear production in the (π^-, K^+) reaction may proceed by the two-step mechanism of the meson charge-exchange, for example, $\pi^- p \to \pi^0 n$ followed by $\pi^0 p \to K^+ \Lambda$, or $\pi^- p \to K^0 \Lambda$ followed by $K^0 p \to K^+ n$. Another mechanism is the single-step process via a Σ^- admixture in the Λ hypernuclear state appearing due to the $\Sigma^- p \leftrightarrow \Lambda n$ coupling. Recently, there has been a theoretical calculation concerning both mechanisms on some light nuclear targets, where the two-step mechanism is found to be more dominant as compared to the single-step one [6]. The two-step transition with no angular momentum transfer ($\Delta l = 0$) in the charge-exchange process is found to favor for a maximum production cross section, which is possible for the target with a neutron orbit vacancy. As a result, the ground state cross section of the $^{10}_{\Lambda}$Li production in the (π^-, K^+) reaction on ^{10}B target is found as large as 70 nb/sr in the forward angle, which is significantly larger among others ($^{12}_{\Lambda}$Be or $^{16}_{\Lambda}$C) in the same calculation. The incident energy dependence of the cross section shows the maximum production at 1.05 GeV/c, same as the Λ hypernuclear production in the (π^+, K^+) reaction.

1.2 Experiment

The present experiment (KEK-PS-E521) [7] was performed in the K6 beam line of KEK 12-GeV proton synchrotron(PS) together with the superconducting kaon spectrometer(SKS) system [8]. The experimental target, ^{10}B, was 3.5

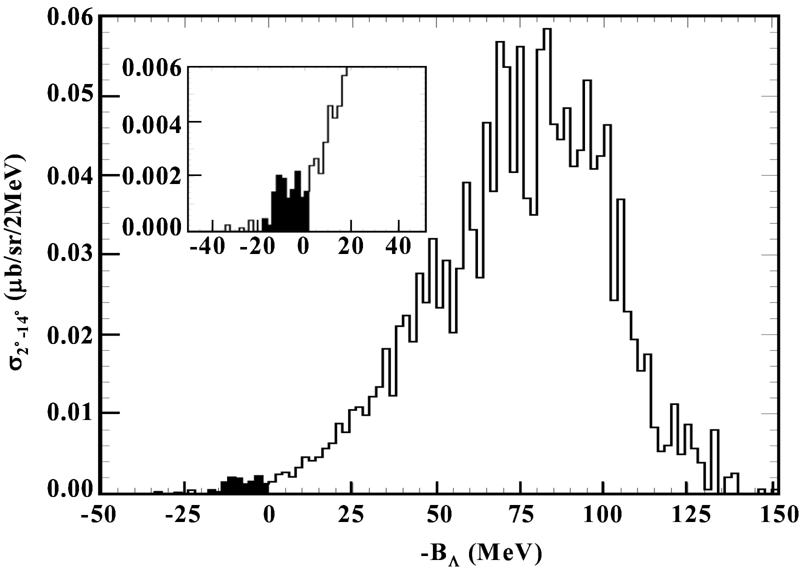

Figure 1: *Missing mass spectrum of the (π^-, K^+) reaction on ^{10}B target at 1.2 GeV/c. Horizontal axis shows the binding energy of a Λ, whereas vertical axis shows the cross section in terms of $\mu b/sr/2$ MeV.*

g/cm^2 in thickness and we started with the incident beam momentum of 1.05 GeV/c. The SKS was excited to 272A(2.2 Tesla), in which the central momentum was 720 MeV/c. The separated π^- beam intensity at the experimental target was typically 4×10^6/spill (4.0 sec). In the off-line analysis, incident π^- and outgoing K^+ momenta were obtained particle-by-particle by using the beam line and the SKS spectrometer, respectively. We clearly identified scattered kaons well separated from both pions and protons. Then, by selecting good kaons, the missing mass spectrum was obtained. The total number of π^- beam injection in this setting was about 440×10^9 but only 7 counts are found in the bound region and quasi-free(QF) events are also very small. The yield in the bound region is about one order of magnitude lower than expected from the theoretical calculation.

We then changed the beam momentum to 1.2 GeV/c, where the Σ^- production channel is open. In this case, the SKS was excited to 395A(2.6 Tesla), where the central momentum of SKS was 880 MeV/c. The total number of π^- beam injection in this setting was about 1080×10^9. In total we got about 40 counts in the bound region. Figure 1 shows the missing mass spectrum on ^{10}B at 1.2 GeV/c. The vertical axis is the cross section in terms of μb/sr/2MeV, which was done by taking into account experimental and analysis efficiencies as well as the SKS acceptance, calculated by a Monte Carlo Simulation code, GEANT.

In order to calibrate the horizontal axis as well as to check the accuracy of the cross section in the present experiment, we measured the (π^+, K^+) reaction on ^{10}B and ^{12}C targets of the same thickness (3.5 g/cm^2). The (π^+, K^+) reaction on ^{12}C target was measured at both 1.05 and 1.2 GeV/c incident momenta. The calibration of the horizontal axis was checked by reproducing the known ground state (g.s.) energy of the $^{12}_{\Lambda}$C (-10.76 MeV). The precision of the horizontal axis was obtained to be $\pm$ 0.23 MeV. The experimental energy resolution was obtained by fitting the g.s. peak of the $^{12}_{\Lambda}$C, which was 2.5 MeV in FWHM. We found cross sections of the (π^+, K^+) reaction on both ^{10}B and ^{12}C targets at 1.05 GeV/c reproduced very well previous measurements done with SKS, whereas the cross section at 1.2 GeV/c on ^{12}C gives new experimental information.

1.3 Results and discussion

As seen in figure 1, there are significant yields below the $^{10}_{\Lambda}$Li production threshold($-B_\Lambda$=0), which can be seen more clearly in an expanded view. Backgrounds are very small and the tail from the quasi-free events will not much contribute to the yields because of a good energy resolution (2.5 MeV in FWHM), which is confirmed in the $^{12}_{\Lambda}$C spectrum. Hence almost all events in the bound region are expected to come from the signal of the produced hypernucleus, $^{10}_{\Lambda}$Li. Unfortunately, no significant discrete peaks were observed, which may be due to the limited statics, the experimental resolution and possible complicated nuclear structure. Note that Akaishi calculated the ground state energy to be around -12 MeV [9], which may not be inconsistent with the present data.

From the present experimental result, we obtained the Λ hypernuclear production rate in the (π^-, K^+) reaction at 1.2 GeV/c as compared to that in the (π^+, K^+) reaction on the same target(^{10}B). For simplicity, the total cross sections only in the bound region (-15.0$\leq -B_\Lambda \leq$0 MeV) for both cases are compared. The total cross section of the bound region for the ^{10}B$(\pi^+, K^+)^{10}_{\Lambda}$B production was found to be 7.8 $\pm$ 0.3 μb/sr, whereas for the ^{10}B$(\pi^-, K^+)^{10}_{\Lambda}$Li production it was 0.012 $\pm$ 0.002 μb/sr, where the errors are only the statistical ones. Then we got the Λ hypernuclear production rate in the (π^-, K^+) reaction is 1.5×10^{-3} as compared to that in the (π^+, K^+) reaction. The production rate of $^{10}_{\Lambda}$Li at the beam momentum of 1.2 GeV/c is roughly twice higher than that at the beam momentum of 1.05 GeV/c.

We notice two important features of the reaction mechanism concerning the neutron-rich Λ hypernuclear production in contrast to the theoretical calculation based on a two-step mechanism with the meson charge-exchange. The production cross section is much smaller than expected in the calculation and the incident momentum dependence of the cross section shows opposite trend to that found in the calculation. Therefore the single-step process via a Σ^- admixture in the Λ hypernuclear state appearing due to the $\Sigma^- p \leftrightarrow \Lambda n$ coupling may contribute to the production. Further experimental as well as theoretical studies are necessary to understand the reaction mechanism.

2 Other hypernuclear experiments and future perspectives at J-PARC

I have also reported several experiments in hypernuclear physics at KEK and BNL including hypernuclear gamma-ray spectroscopy and double-Λ hypernuclear production. One of the main motivations of the hypernuclear gamma-ray spectroscopy is to observe γ transitions in several light Λ hypernuclear systems between the fine structures of Λ-hypernuclear states split by the ΛN spin-dependent interaction, such as the spin-orbit and spin-spin forces, and to extract the spin-dependent forces [10, 11]. One success is to determine a smaller spin-orbit interaction as compared to the nucleon case. Concerning the double-Λ hypernuclear production, we successfully observed a uniquely identified double-Λ hypernucleus $^{6}_{\Lambda\Lambda}$He by using the hybrid-emulsion technique, which gives an about four times smaller $\Lambda\Lambda$ interaction than previously believed [12]. In the BNL experiment E906 we are also claiming the production of the lightest double-Λ hypernucleus, $^{4}_{\Lambda\Lambda}$H, by using the Cylindrical Detector System [13].

All these hypernuclear physics will be more extensively pursued at J-PARC. We have already submitted six LOI's, which include the study of Ξ-

hypernucleus, double-Λ hypernucleus, hypernuclear gamma-ray spectroscopy and more exotic neutron-rich Λ hypernucleus, such as ${}^{6}_{\Lambda}$H. In the beginning we may have only one beam line with max. momentum of 1.8 GeV/c and reuse the present SKS with minor modifications, and would like to start the experiments around 2008. We want to have another beam line with max. momentum of 1.1 GeV/c and also a high-resolution, high-intensity beam line with a dispersion matching mode as early as possible, for which we may need additional budgets from all over the world.

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