Search for ${}^{6}_{\Lambda}$H hypernucleus by the (π^-, K^+) reaction at J-PARC

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When a Λ hyperon is embedded into a nucleus, there are several interesting features theoretically expected for some specific hypernuclei. One example is the glue-like role of a Λ hyperon in hypernuclei. Since the Λ hyperon does not suffer from Pauli blocking by other nucleons, it can penetrate into the nuclear interior. The glue-like role gives a critical contribution to the binding especially around the proton- and neutron-drip lines, and may extend the boundary of nuclear stability. Another example is an effect of the ΛN-ΣN mixing. Since the mass difference of Λ and Σ, M_Σ-M_Λ $\sim$80 MeV/c^2 is narrower than that of ordinary nuclei, M_Δ-M_N $\sim$290 MeV/c^2, this situation makes the effect of ΛN-ΣN coupling important. A non-zero isospin of the core nucleus is essential for the large mixing because the core nucleus is a buffer of the isospin to compensate the isospin difference between Λ(I=0) and Σ(I=1). Therefore, we selected a ${}^{6}_{\Lambda}$H hypernucleus which has one proton, four neutrons, and one Λ hyperon.

The present experiment was proposed aiming at a precise spectroscopic investigation of light neutron-rich Λ hypernuclei, ${}^{6}_{\Lambda}$H by the (π^-, K^+) reaction at a beam momentum of 1.2 GeV/c by using the SKS spectrometer (J-PARC E10). The FINUDA group reported the binding energy of ${}^{6}_{\Lambda}$H based on three candidate events in the ^{6}Li(K^-_{stop}, π^+) reaction [1]. We would like to much improve the precision of the binding energy and establish the existence in high statistics. A high-intensity π^- beam at J-PARC and a large acceptance of the SKS spectrometer have good merits for this purpose. We also introduced high-rate tracking detectors such as scintillating fiber detectors and silicon strip detectors for the E10 experiment. By observing more than 100 events, not only the precise binding energy but also the production cross section can be obtained in a good statistical accuracy. It would be important in order to discuss the ΛN-ΣN mixing effect quantitatively.

The ${}^{6}_{\Lambda}$H production data by the ^{6}Li(π^-, K^+) reaction were taken for the first time in the K1.8 beam line of J-PARC Hadron Experimental Facility in two cycles in December 2012 and in January 2013. The K1.8 beam spectrometer and the SKS spectrometer in the K1.8 beam line have good momentum resolution $\Delta p/p$ less than 10^{-3}. They are good tools to investigate the hypernuclear spectroscopy. A ^{6}Li target 3.5 g/cm^2 in thickness was used. The pion beam momentum was selected to be 1.2 GeV/c. The total number of pions irradiated on the ^{6}Li target was 2.1×10^{12}. The beam intensity was 1.2–1.4$\times10^{7}$ pions/spill(2-second spill length).

In order to evaluate the missing-mass resolution in a kinematical condition close to that of the ^{6}Li$(\pi^-, K^+){}^{6}_{\Lambda}$H reaction, we measured the ^{12}C$(\pi^+, K^+){}^{12}_{\Lambda}$C reaction at the momentum of 1.2 GeV/c. For the missing-mass spectrum, a clear peak structure was observed, and the missing-mass resolution was estimated to be 3.23±0.02 MeV in FWHM.

We measured the $p(\pi^{\pm}, K^{+})$ reactions at 1.377 GeV/c to calibrate the beam momentum with a $(CH_2)_n$ target of 3.4 g/cm^2 in thickness. The pion beam momentum of 1.377 GeV/c was selected so that the produced K^+ momentum in the $p(\pi^{\pm}, K^{+})$ reaction coincides with that in the ^{6}Li$(\pi^-, K^+)^6_\Lambda$H reaction at 1.2 GeV/c. The peak positions of Σ^- and Σ^+ were adjusted to be the correct mass. The cross sections were consistent with old experimental data within 10%.

We have also conducted the beam-through run at 0.8, 0.9, 1.0 and 1.2 GeV/c with and without the ^{6}Li target. The systematic error of the incident pion beam momentum was estimated to be 1.34±0.02 MeV/c^2, and missing mass uncertainty was estimated to be 1.26±0.02 MeV/c^2.

The missing-mass spectrum of ^{6}Li(π^-, K^+) reaction was obtained with the kaon scattering angles of 2–14 degrees, where the estimation of spectrometer acceptance has small ambiguity. The scattered kaon was selected with the purity of more than 99% by cutting with the 2σ of mass squared resolution. In the missing-mass spectrum of ^{6}Li(π^-, K^+) reaction, no peak structure was observed. We estimated an upper limit of production cross section from the number of events with the missing-mass window, which is the 5.44 MeV for 2σ of missing-mass resolution. There were 3 events around the $^4_\Lambda$H+2n threshold (5801.7 MeV). We employed the upper limit of 6.68 events at 90% confidence level from the Poisson statistics, and the upper limit of production cross section was estimated to be 1.2 nb/sr at 90% confidence level.

The $^6_\Lambda$H hypernucleus is believed to have the $^4_\Lambda$H+2n structure dominantly and have the 0^+ ground and 1^+ excited states which are analogous to the 0^+ and 1^+ spin-doublets in $^4_\Lambda$H. Our reaction should favor the 1^+ direct population at forward angles because the dominant spin non-flip amplitude of the (π^-, K^+) reaction would not change the spin of $^6_\Lambda$H with the same spin of ^{6}Li. However, our result did not favor a simple interpretation of the FINUDA observation that both 0^+ and 1^+ states of $^6_\Lambda$H are bound. It suggests that reconsideration of the structure of the $^6_\Lambda$H hypernucleus as well as ^{5}H would be needed.

References

[1] M. Agnello *et al.* (FINUDA Collaboration), Phys. Rev. Lett. **108** (2012) 042501.