Search for the K^-pp bound state using the $d(\gamma, K^+\pi^-)X$ reaction at $E_\gamma = 1.5-2.4\,\mathrm{GeV}$

Atsushi Tokiyasu (Okamura)

January, 2014

Strongly attractive $\overline{K}N$ interaction in $I = 0$ channel suggests the existence of deeply bound states of $\overline{K}$ in nuclei (kaonic nuclei). Since Akaishi and Yamazaki pointed out the possibility of the existence of the kaonic nuclei with widths narrow enough to be measured experimentally [1], intensive studies have been performed theoretically and experimentally. In particular, the K^-pp bound state would give us rich information on the sub-threshold $\overline{K}N$ interaction as the simplest kaonic nuclei. Various theoretical calculations support the existence of the K^-pp bound state. However, the calculated binding energy (B.E.) and the width (Γ) were different from each other. Experimental evidence of the K^-pp bound state was reported by the FINUDA collaboration (B.E.= $115^{+6}_{-5}(stat)^{+3}_{-4}(syst)\,\mathrm{MeV}$, Γ=$67^{+14}_{-11}(stat)^{+2}_{-3}(syst)\,\mathrm{MeV}$) [2] and by the DISTO collaboration (B.E.= $103 \pm 3(stat) \pm 5(syst)\,\mathrm{MeV}$, $\Gamma = 118 \pm 8(stat) \pm 10(syst)\,\mathrm{MeV}$) [3]. However, the interpretation of these results is not definitive.

In order to resolve the current controversial situation, we proposed a new experiment to search for the K^-pp bound state using the photon induced reaction. We adopted the $d(\gamma, K^+\pi^-)X$ reaction and searched for the exotic structure in the signal region of the K^-pp bound state (2.22 – $2.36\,\mathrm{GeV}/c^2$) in the missing mass ($MM_d(K^+\pi^-)$) spectrum [4]. We can specify the charge of the state as plus one and reduce the momentum transfer of the residual system by requiring π^- in addition to K^+. The photon induced reaction has been used for the study on the nature of hyperon with an outstanding success since 1980s. In the photon induced reaction, $\overline{K}$ can be exchanged in t-channel. This feature enables us to investigate the production mechanism of the K^-pp bound state from the different view point from hadron induced reactions such as (π^+, K^+) or (K^-, π^-).

The experiment was performed at LEPS facility (Laser Electron Photon experiment at SPring-8). There, a high-intensity ($10^6\,\mathrm{cps}$) photon beam with energies from 1.5 to 2.4 GeV by the backward Compton scattering process was used to investigate photon induced reactions on various targets. The incident photon energy was measured for each event by detecting the recoil electron with the tagging counter. The energy resolution was approximately 12 MeV. The data used in this analysis was collected during 2002/2003 and 2006/2007 with a 150 mm-long liquid deuterium target. Totally 7.6×10^{12} photons were incident on the target. Charged particles produced in the target were detected and identified at forward angles using the LEPS spectrometer consisting of a dipole magnet equipped with scintillator counters and tracking devices. The momenta of the particles were reconstructed by the Kalman-filter method with the resolution of $6\,\mathrm{MeV}/c$ for $1\,\mathrm{GeV}/c$ particle, which corresponded to the missing mass resolution of $10\,\mathrm{MeV}/c^2$ in the $d(\gamma, K^+\pi^-)X$ reaction. Particle species were identified with the

time-of-flight information, and K^+ and π^- tracks were selected. $MM_d(K^+\pi^-)$ was calculated in the following kinematical region: $\cos\theta^{lab}_{K^+} > 0.95$, $\cos\theta^{lab}_{\pi^-} > 0.95$, $0.25 < p_{K^+} < 2.0\,[\mathrm{GeV}/c]$, $0.25 < p_{\pi^-} < 0.6\,[\mathrm{GeV}/c]$.

The differential cross section of the $d(\gamma, K^+\pi^-)X$ reaction, $d^2\sigma/d\cos\theta^{lab}_{K^+}/d\cos\theta^{lab}_{\pi^-}$ was measured as a function of $MM_d(K^+\pi^-)$ by applying the acceptance correction for each track. The differential cross section of $K^+\pi^-$ production in the signal region was measured as $3.67 \pm 0.083(stat)^{+0.14}_{-0.058}(syst)\,\mu$b. Some peak structures corresponding to hyperon production processes were observed in the $MM_d(K^+\pi^-)$ spectrum. However, no peak structure corresponding to the K^-pp bound state production was observed in the region from 2.22 to 2.36 GeV/c^2 in the $MM_d(K^+\pi^-)$ spectrum.

To understand the obtained results accurately, a simultaneous template fitting was performed to the missing mass of $MM_p(K^+)$ and $MM_p(K^+\pi^-)$ assuming a nucleon target at rest. The spectra of the several quasi-free processes were generated by the Monte Carlo simulation and used for the fitting functions. The shape of the $MM_d(K^+\pi^-)$ spectrum was well reproduced using quasi-free processes without any exotic structures. The observed peak structures were found to be due to the hyperon productions such as $\gamma p \to \Lambda K^+\pi^-$ or $\gamma p \to \Sigma^0 K^+\pi^-$. The main contributions in the signal region were found to be the $\gamma p \to \Lambda(1520)K^+$ process ($22.3 \pm 2.7\,\%$) and four-body phase space hyperon production processes as $\gamma N \to Y\pi K^+\pi^-$ ($23.9 \pm 5.3\,\%$).

To quantify the search results, the upper limit of the cross section was derived with the likelihood ratio method. The selected quasi-free processes were used for the background, and the Breit-Wigner distribution with a fixed B.E. and Γ was used for the signal. The obtained upper limits of the cross section were (0.17 – 0.55), (0.55 – 1.7), (1.1 – 2.9) μb for the signal with Γ = 20 MeV, 60 MeV and 100 MeV depending on the B.E. ranging from 10 to 150 MeV. These values correspond to (1.5 – 5.0), (5.0 – 15) and (9.9 – 26) % of the typical hyperon production cross section as $\gamma N \to Y K^+\pi^-$.

In addition to the above analysis, searches were performed under the selected kinematical conditions: the large transferred momentum squared region ($|t| > 0.3\,\mathrm{GeV}^2/c^4$) or the small transferred momentum squared region ($|t| < 0.3\,\mathrm{GeV}^2/c^4$). A search was also performed in the $d(\gamma, K^{*0})X$ reaction by requiring that the invariant mass of K^+ and π^- was K^{*0} mass ($896\,\mathrm{MeV}/c^2$). A peak corresponding to the K^-pp bound state production was searched for in the $MM_d(K^+\pi^-)$ spectrum, but no signal was observed under any kinematical conditions described above.

The present work is the first search result of the K^-pp bound state using the photon induced reaction and excluded the possibility that the production cross section of the K^-pp bound state is as large as the typical hyperon production.

References

[1] T. Yamazaki, Y. Akaishi, Phys. Rev. C 76 (2007) 045201.

[2] M. Agnello, *et al.*, Phys. Rev. Lett 94 (2005) 212303.

[3] T. Yamazaki, *et al.*, Phys. Rev. Lett 104 (2010) 132502.

[4] A. O. Tokiyasu, *et al.*, Phys. Lett. B 728 (2014) 616.