Search for the $\overline{K}NN$ bound state at LEPS/SPring-8

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The $\overline{K}NN$ bound states were searched for using the photon induced reactions at LEPS/SPring-8. We adopted the $d(\gamma, K^{+}\pi^{-})X$, $d(\gamma, K^{+})X$ and $d(\gamma, K^{+}\pi^{+})X$ reactions with photon energies from $1.5-2.4$ GeV to search for the $K^{-}pp$, $K^{-}pn$ and $K^{-}nn$ bound states. No peak structure corresponding to the $\overline{K}NN$ bound state production was observed in the region from 2.22 to 2.36 GeV$/c^2$ in the inclusive missing mass spectrum of each reaction. The upper limits of the production cross section for the $\overline{K}NN$ bound states were determined.

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1. Introduction

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, three-body kaonic nuclei, the $\overline{K}NN$ bound states, would give us rich information on the sub-threshold $\overline{K}N$ interaction as the simplest kaonic nuclei. There are three different charge states in the the $\overline{K}NN$ bound states: K^-pp, K^-pn and K^-nn. The notations in the isospin base are shown in Tab. 1. Various theoretical calculations were performed, and the binding energies (B.E.) and the widths (Γ) of the $\overline{K}NN$ bound states were derived. The calculated values are different from each other depending on the calculation methods and the $\overline{K}N$ interaction models. Experimental observation of the $\overline{K}NN$ bound states was reported by a few groups, although the interpretation of their results is not definitive. The experimental studies are not sufficient to resolve the disagreement in the theoretical calculations on the $\overline{K}NN$ bound states, especially the K^-pn or K^-nn bound state. A new experiments have been awaited. We proposed a new experiment to search for the $\overline{K}NN$ bound state using the photon induced reaction. By requiring a pion in addition to the K^+, three different charge states were searched for using the same data set; the K^-pp bound state was searched for in the $d(\gamma, K^+\pi^-)X$ reaction, the K^-pn bound state in the $d(\gamma, K^+)X$ reaction and the K^-nn bound state in the $d(\gamma, K^+\pi^+)X$ reaction. We measured the differential cross section of each reaction as a function of the missing mass, and searched for a peak structure in the region from 2.22 to 2.36 GeV/c^2.

Table 1: Representation of the $\overline{K}NN$ bound state in the charge and isospin base. The $\overline{K}N$ contents are also shown. Here, I denotes isospin and S spin.

charge space	isospin space	$\overline{K}N$ pair
K^-pp	$[\overline{K}(NN)_{I=1,S=0}]_{I=\frac{1}{2},I_z=\frac{1}{2}}$	$\frac{3}{4}(I=0)+\frac{1}{4}(I=I)$
K^-pn	$[\overline{K}(NN)_{I=0,S=1}]_{I=\frac{1}{2},I_z=0}$	$\frac{1}{4}(I=0)+\frac{3}{4}(I=I)$
K^-nn	$[\overline{K}(NN)_{I=1,S=0}]_{I=\frac{3}{2},I_z=\frac{1}{2}}$	$0(I=0)+1(I=I)$

2. Experiment

The experiment was performed at LEPS (Laser Electron Photon experiment at SPring-8). There, a high-intensity (10^6 cps) photon beam is available with energies from 1.5 to 2.4 GeV. The photon beam was produced by the backward Compton scattering process, and the energy was measured for each event by detecting the recoil electron with the tagging counter. The energy resolution was estimated to be 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 drift chambers for the tracking analysis and scintillating counters for the time-of-flight (TOF) measurement.

The momenta of the particles were reconstructed by the Kalman-filter method with a resolution of 6 MeV/c for 1.0 GeV/c particle, which corresponded to the missing mass resolution of 10 MeV/c^2 in the $d(\gamma, K^+\pi^-)X$ reaction. Particle species were identified with the TOF information, and K^+ and π^-/π^+ tracks were selected. The missing mass value was calculated in the following kinematical region: $\cos\theta^{lab}_{K^+/\pi^-} > 0.95$, $0.25 < p_{K^+} < 2.0$ [GeV/c], $0.25 < p_{\pi^-/\pi^+} < 0.6$ [GeV/c]. The differential cross section was measured by applying the acceptance correction to each track.

3. K^-pp in the $d(\gamma,K^+)X$ Reaction

As shown in Tab. 1, the K^-pp bound state has the largest number of $\overline{K}N$ pairs with $I=0$ among the three charge states. Therefore, the K^-pp bound state is expected to have the largest B.E. if exists. ($\overline{K}N$ interaction is strongly attractive in $I=0$ channel, and weakly attractive in $I=1$ channel.) There are two groups who observed a possible candidate of the K^-pp bound state signal. FINUDA group studied the stopped K^- reaction with the ^{6}Li, ^{7}Li and ^{12}C targets and observed a peak structure whose B.E. and Γ are $115^{+6}_{-5}(stat)^{+3}_{-4}(syst)$ MeV and $67^{+14}_{-11}(stat)^{+2}_{-3}(syst)$ MeV, respectively in the Λp invariant mass spectrum [2]. DISTO group studied the $pp \to \Lambda p K^+$ reaction and observed a peak structure whose B.E. and Γ are $103 \pm 3(stat) \pm 5(syst)$ MeV and $118 \pm 8(stat) \pm 10(syst)$ MeV, respectively in the K^+ missing mass spectrum [3]. Their measured B.E.s and Γs are inconsistent with each other, and the B.E.s are larger than almost all theoretically calculated values. To resolve the current controversial situation, many experiments have been proposed or carried out to search for the K^-pp bound state using different reactions in J-PARC, GSI and DAΦNE.

We adopted the $d(\gamma,K^+\pi^-)X$ reaction to search for the K^-pp bound state [4]. Figure 1-(a) shows the differential cross section of the $d(\gamma,K^+\pi^-)X$ reaction. The main components in the search region were the $\gamma p \to \Lambda(1520)K^+$ reaction and the $\gamma p \to Y\pi\pi^-K^+$ reaction by fitting the missing mass spectra with the spectra of the quasi-free processes generated by the Monte Carlo simulation. No peak structure was observed in the search region. The upper limit of the differential cross section of the K^-pp bound state production was determined with the likelihood ratio method. The spectra of selected quasi-free processes were used for describing the background shape. The upper limits were determined to be (0.17 – 0.55), (0.55 – 1.7) and (1.1 – 2.9) μb at 95% confidence level with the assumed widths of 20 MeV, 60 MeV and 100 MeV (Fig. 1-(b)).

4. K^-pn in the $d(\gamma,K^+)X$ Reaction

Almost all theoretical approaches predict that the K^-pn bound state is a weakly bound or unbound state. However, under the assumption that the interaction between a nucleon and $\Lambda(1405)$, which is partially regarded as $\overline{K}N$ bound state in I=0 channel, is independent of spin or isospin, the same B.E. and Γ are expected as those of the K^-pp bound state.

We adopted the $d(\gamma,K^+)X$ reaction to search for the K^-pn bound state. Figure 2-(a) shows the differential cross section of the $d(\gamma,K^+)X$ reaction. The main components in the search region were the $\gamma N \to Y\pi K^+$ processes. No peak structure was observed in the search region. The upper limit of the differential cross section of the K^-pn bound state production was determined with the same method as the case of the K^-pp bound state. A three-ordered polynomial function was used for the background shape. The upper limits were determined to be (0.010 – 0.083) and (0.042 – 0.20) μb at 95% confidence level with the assumed widths of 20 MeV and 60 MeV (Fig. 2-(b)).

5. K^-nn in the $d(\gamma,K^+\pi^+)X$ Reaction

The K^-nn bound state has been predicted as an unbound state by many theoretical models because it has only $\overline{K}N$ pairs with I=1. However, there is a study that the loosely K^-nn bound state exists if NN subsystem has the spin of two [5].

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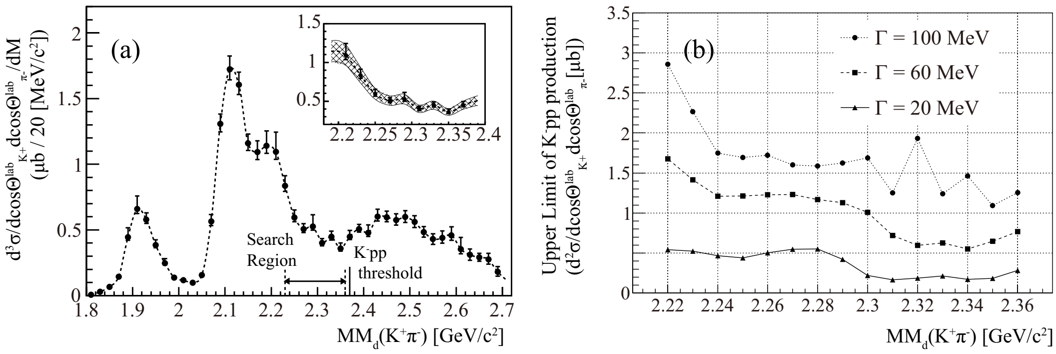

Figure 1: (a) Differential cross section of the $d(\gamma,K^+\pi^-)X$ reaction, $d^3\sigma/d\cos\theta^{lab}_{K^+}/d\cos\theta^{lab}_{\pi^-}/dM$. The error bars include both statistical and systematic errors. *Inset*: The differential cross section in the range from 2.2 to 2.4 GeV/c^2. The error band denotes the discrepancy between 2002/2003 and 2006/2007 data sets. (b) Upper limit of the differential cross section of the K^-pp bound state production as a function of assumed signal peak mass. The solid, broken and dotted lines are the results of Γ =20 MeV, 60 MeV and 100 MeV, respectively.

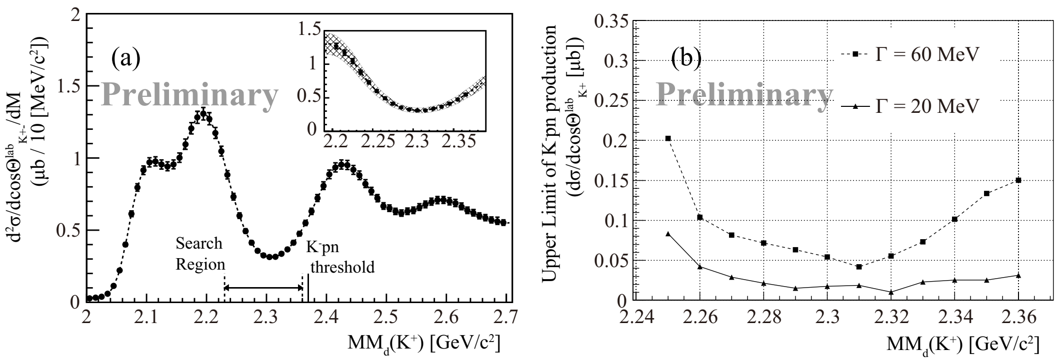

Figure 2: (a) Differential cross section of the $d(\gamma,K^+)X$ reaction, $d^2\sigma/d\cos\theta^{lab}_{K^+}/dM$. The error bars include both statistical and systematic errors. *Inset*: The differential cross section in the range from 2.2 to 2.4 GeV/c^2. The error band denotes the discrepancy between 2002/2003 and 2006/2007 data sets. (b) Upper limit of the differential cross section of the K^-pn bound state production as a function of assumed signal peak mass. The broken and dotted lines are the results of Γ =20 MeV and 60 MeV, respectively.

We adopted the $d(\gamma,K^+\pi^+)X$ reaction to search for the K^-nn bound state. In this reaction, only quasi-free processes from the proton target in deuterium contribute as background due to charge conservation of the reaction. Figure 3-(a) shows the differential cross section of the $d(\gamma,K^+\pi^+)X$ reaction. No peak structure was observed in the search region. The upper limit of the differential cross section of the K^-nn bound state production was determined with the same method as the case of the K^-pn bound state. The upper limits of the differential cross section were determined to be $(0.043-0.13)$ and $(0.097-0.25)\,\mu$b at 95% confidence level with the assumed widths of 20 MeV and 60 MeV (Fig. 3-(b)).

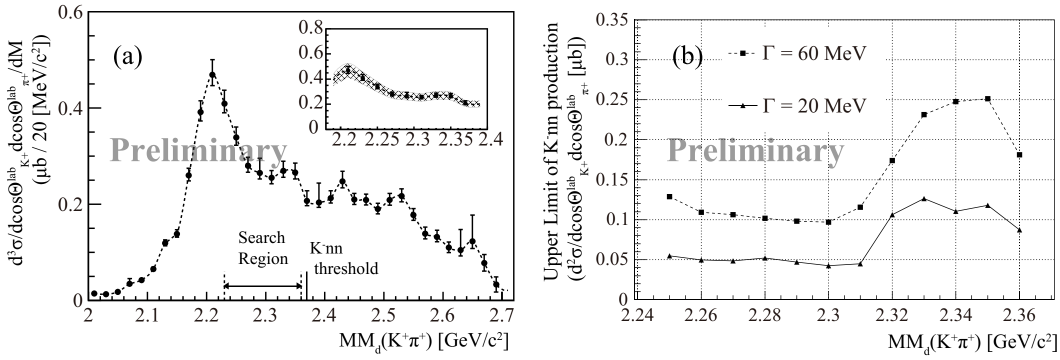

Figure 3: (a) Differential cross section of the $d(\gamma, K^+\pi^+)X$ reaction, $d^3\sigma/d\cos\theta^{lab}_{K^+}/d\cos\theta^{lab}_{\pi^+}/dM$. The error bars include both statistical and systematic errors. *Inset*: The differential cross section in the range from 2.2 to 2.4 GeV/c^2. The error band denotes the discrepancy between 2002/2003 and 2006/2007 data sets. (b) Upper limit of the differential cross section of the K^-nn bound state production as a function of assumed signal peak mass. The broken and dotted lines are the results of Γ =20 MeV and 60 MeV, respectively.

6. Summary and Outlook

We have performed an experiment to search for the $\overline{K}NN$ bound states using the photon induced reactions at E_γ =1.5 – 2.4 GeV at LEPS/SPring-8. We adopted the $d(\gamma, K^+\pi^-)X$ reaction to search for the K^-pp bound state, the $d(\gamma, K^+)X$ reaction for the K^-pn bound state, and the $d(\gamma, K^+\pi^+)X$ reaction for the K^-nn bound state. An peak structure corresponding to the $\overline{K}NN$ bound state production was searched for in the mass region ranging from 2.22 to 2.36 GeV$/c^2$ in the inclusive missing mass spectrum of each reaction. No peak structure was observed, and we determined the upper limits for the production cross section of the of the $\overline{K}NN$ bound states with various binding energies and widths.

In the next step, exclusive measurements are necessary for more precise investigation. It would be possible to reduce the background of quasi-free processes by detecting the decay particles from the $\overline{K}NN$ bound states, which are expected to decay to YN and $Y\pi N$. However, the exclusive measurement is difficult to perform at LEPS due to the small acceptance of the spectrometer for the multi-track events. One of the facilities where the upgraded search experiments will be performed is LEPS2, a new facility under construction in SPring-8. In LEPS2, ten times higher intensity beam than LEPS is available, and the spectrometer with the almost 4π acceptance will be installed.

References

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

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

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

[4] A. O. Tokiyasu *et al.*, Phys. Lett. B **728C**, 616-621 (2014).

[5] S. Wycech and A. M. Green, Phys. Rev. C **79**, 014001 (2009).