Search for the K^-pp bound state using the photon induced reaction at BL33LEP

One of the missions of hadron physics is to investigate the interaction between hadrons and search for new types of nuclei within the framework of quantum chromodynamics. It is well known that π's exist as virtual particles in nuclei. However, the low-energy interaction between a π and a nucleon is repulsive, and π's are not bound in nuclei. In the case of antikaons, the interaction is highly complicated owing to the existence of $\Lambda(1405)$ below the K^-pp mass threshold. The interaction between an antikaon and a nucleon is strongly attractive if the isospin of the system is zero. This indicates the existence of a bound state of antikaons in nuclei called kaonic nuclei. Kaonic nuclei are a totally new type of nucleus and contain real mesons as components. If such nuclei exist, we can extract invaluable information on the properties of hadrons in nuclei. Intensive studies have been performed theoretically and experimentally to prove the existence of kaonic nuclei, especially the K^-pp bound state (the bound state of a K^- and two protons), the simplest kaonic nucleus. The structure of the K^-pp bound state has been studied by various theoretical approaches. The binding energy (B.E.) and width (Γ) were predicted to be 9 – 95 MeV and 34 – 110 MeV, respectively. The predicted B.E. is much larger than those of ordinary nuclei (~8 MeV per nucleon).

Experimental evidence of the K^-pp bound state was reported by the FINUDA collaboration (B.E. = $115^{+6}_{-5}\,(stat)^{+3}_{-4}\,(syst)$ MeV, $\Gamma = 67^{+14}_{-11}\,(stat)^{+2}_{-3}\,(syst)$ MeV) [1] and the DISTO collaboration (B.E. = 103 ± 3 $(stat)$ ± 5 $(syst)$ MeV, $\Gamma = 118 \pm 8$ $(stat)$ ± 10 $(syst)$ MeV) [2]. The measured B.E.'s and Γ's are different from each other, and measured B.E.'s are much larger than the values predicted using theoretical models. The experimental studies do not provide sufficient proof to conclude the existence of the K^-pp bound state, and search experiments with different reactions are awaited.

This situation has motivated us to perform a new experiment to search for the K^-pp bound state using a photon-induced reaction at the LEPS (Laser Electron Photon experiment at SPring-8) facility [3]. We adopted the $\gamma d \rightarrow K^+\pi^-X$ reaction using the photon beam with energies ranging from 1.5 to 2.4 GeV. We detected K^+ and π^- at forward angles, and searched for a peak structure corresponding to K^-pp bound state production in the missing mass spectrum. Figure 1 shows the schematic diagram of this reaction. In the effective Lagrangian approaches, a K^- or K^{*-} is exchanged if a K^+ is detected at very forward angles. The momentum transfer squared $|t|$ is sufficiently small that the exchanged K^- or K^{*-} is on mass-shell. From this point of view, the $\gamma d \rightarrow K^+\pi^-X$ reaction is regarded as the virtual $K^-d \rightarrow \pi^-X$ or $K^{*-}d \rightarrow \pi^-X$ reaction, which has not been used for the search for the K^-pp bound state up to now.

The experiment was performed at **BL33LEP**. A linearly polarized photon beam was produced by backward Compton scattering of an ultraviolet laser from 8 GeV electrons. The recoiled electrons were detected with a tagging counter, and the energies of the photon were measured with a resolution of 12 MeV when they are in the range from 1.5 to 2.4 GeV. The data used in this work was collected during 2002/2003 and 2006/2007 with a 150-mm-long liquid deuterium target. A total of 7.6×10^{12} photons were incident on the target. Charged particles produced in the target were detected with a spectrometer at forward angles. The spectrometer consists of a dipole magnet equipped with tracking devices and scintillation counters. The momenta were measured by track reconstruction with a resolution of 6 MeV/c for 1 GeV/c particles. The particle species were identified from the time-of-flight information, and K^+ and π^- were selected for analysis. The missing mass of the $\gamma d \rightarrow K^+\pi^-X$ reaction ($MM_d(K^+\pi^-)$) was calculated in the following kinematic region: $\cos\theta^{lab}_{K/\pi} > 0.95$, $0.25 < p_K < 2.0$ GeV/c, $0.25 < p_\pi < 0.6$ GeV/c, where θ^{lab} and p are the scattering angle and momentum in the laboratory system, respectively. Then, the differential cross section was measured by applying acceptance correction for each event.

Figure 2 shows the differential cross section as a function of $MM_d(K^+\pi^-)$. The dominant features in the obtained spectrum are the Λ and Σ peaks, which are mainly due to the quasi-free $\gamma N \rightarrow K^+Y^*$ processes followed by $Y^* \rightarrow Y\pi^-$ decay. Here, N, Y^*, and Y respectively denote the nucleon (p/n), hyperon resonances (Λ^*, Σ^* and so on), and the hyperon

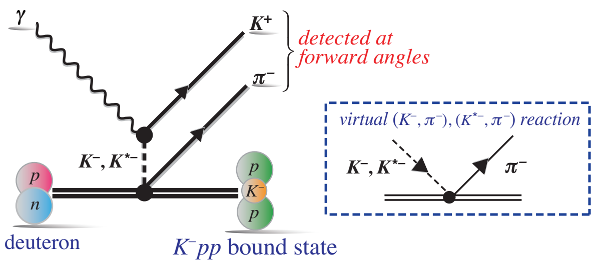

Fig. 1. Schematic diagram of the $\gamma d \rightarrow K^+\pi^-X$ reaction.

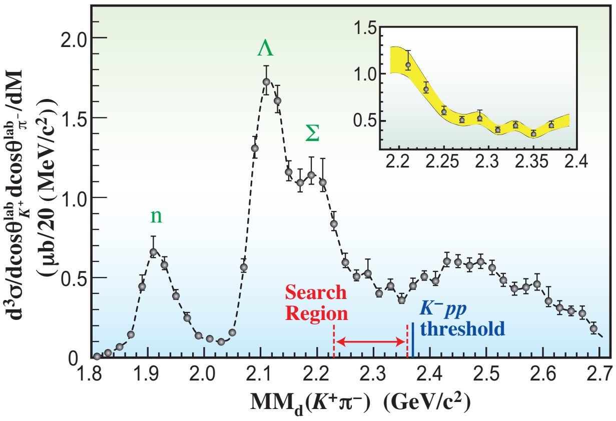

Fig. 2. Differential cross section of the $\gamma d \to K^+\pi^- X$ reaction as a function of $MM_d(K^+\pi^-)$. Inset: Differential cross section in the range from 2.2 to 2.4 GeV/c^2. The error band denotes the discrepancy between the 2002/2003 and 2006/2007 data sets.

(Λ/Σ). Quasi-free nucleons are actually bound in the deuteron. The peak around 1.9 GeV/c^2 is attributed to the $\gamma n \to K^+\Sigma^-$ process followed by $\Sigma^- \to \pi^- n$ decay. If the production cross section of the K^-pp bound state is large, a peak structure will appear in the mass region from 2.22 to 2.36 GeV/c^2. However, no peak structure was observed in the search region. More precise investigation revealed that the contribution in the search region was dominated by quasi-free processes such as $\gamma p \to K^+\Lambda(1520)$ or $\gamma p/n \to K^+\pi^-\Lambda/\Sigma$.

To quantify the search results, the upper limits of the cross section of the K^-pp bound state production were obtained under different B.E. and Γ assumptions. Figure 3 shows the upper limits of the production cross section of the K^-pp bound state for three Γ values as a function of assumed mass. The upper limits were determined as (0.17–0.55), (0.55–1.7), and (1.1–2.9) μb for signals with Γ = 20, 60, and 100 MeV, respectively. These values correspond to (1.5 – 5.0), (5.0 – 15), and (9.9 – 26)% of the production cross section of typical hyperon production as $\gamma N \to K^+\pi^- Y$.

In summary, we measured the differential cross section of the $\gamma d \to K^+\pi^- X$ reaction at BL33LEP. The peak structure corresponding to the K^-pp bound state was not observed in the mass region from 2.22 to 2.36 GeV/c^2 in the spectrum. The upper limits of the cross section of K^-pp bound state production were determined under various B.E.'s and Γ's. This work is the world's first search result of the K^-pp bound state using a photon-induced reaction. The production cross section in this reaction was found to be much smaller than those of typical hyperons.

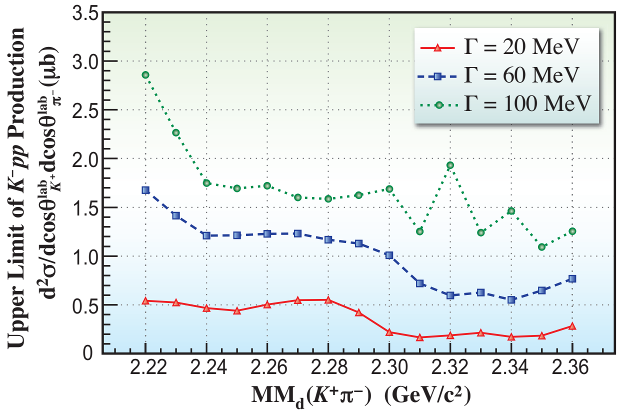

Fig. 3. Upper limit of the differential cross section of the K^-pp bound state in the $\gamma d \to K^+\pi^- X$ reaction as a function of assumed mass. Red, blue, and green lines are the results for Γ = 20, 60, and 100 MeV, respectively.

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References

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