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K^-pp search experiments at J-PARC

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Abstract. There are two experiments at J-PARC looking for a K^-pp bound state. One experiment, E15, is a search in the ^{3}He(K^-,n) reaction at the incident beam momentum of 1 GeV/c. And the other, E27, is a search in the d(π^+, K^+) reaction at 1.69 GeV/c. The status of the data taking and some preliminary analysis results are presented.

1 Introduction

Bound states of $\bar{K}$ in nuclei, called "Kaonic Nuclei" or "Kaonic nuclear clusters", recently attract much attention both theoretically and experimentally. If they exist, it is a new form of hadronic many-body systems with strangeness composed of meson and baryon.

While our understandings on the $\bar{K}N$ interaction near the binding threshold have been in progress [1] together with the nature of $\Lambda(1405)$ resonance, we still have some theoretical ambiguities whether the real part of the $\bar{K}$-nucleus potential is deeply attractive (−(150-200) MeV) or shallow (−(40-60) MeV) [2].

Among the kaonic nuclear clusters, the simplest one, K^-pp, would be a key for experimental verifications. There are positive results reported by the FINUDA [4] and DISTO [5] collaborations observing Λp pairs in the decay of K^-pp, while a recent inclusive measurement for the $d(\gamma, K^+\pi^-)X$ reaction at LEPS/SPring-8 [6] was not able to observe the signal. The binding energy of the K^-pp system was calculated with several few-body techniques and found to be in a range of $\sim 20 - 90$ MeV [2, 3]. The width was also estimated to be broad (≥40 MeV). New measurements to extract a definite conclusion on the existence of the K^-pp bound state have been awaited at J-PARC.

2 J-PARC E15

The J-PARC E15 experiment is an experiment to search for the K^-pp bound state in the ^{3}He($K^-, n/p$) reactions at 1 GeV/c. The experimental setup at the K1.8BR beam line [7] in the Hadron hall of J-PARC is shown in Fig. 1.

The incident K^- is scattered in the backward direction in K^-n quasi-elastic scattering and absorbed by a "pp" pair in ^{3}He to form the K^-pp bound state. The forward neutron is detected with a neutron time-of-flight counter. The neutron counter has a solid-angle coverage of ∼22.1 msr with a flight path of ∼15 m. The missing-mass spectrum of the (K^-, n) would give us the information of the K^-pp, when

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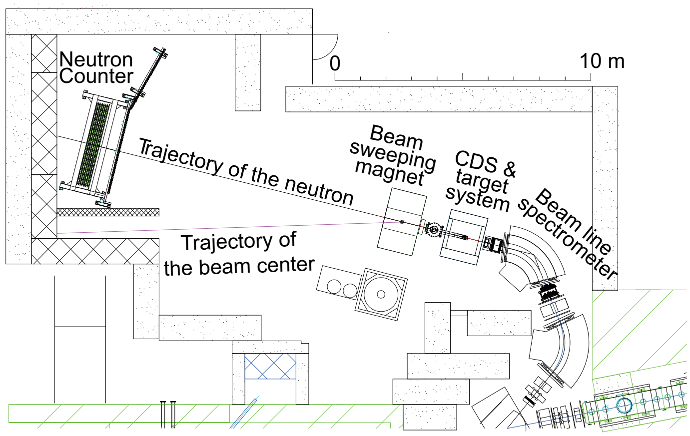

Figure 1. Schematic view of the K1.8BR spectrometer for the E15 experimental setup.(Taken from Ref. [8]) It consists of a beam line spectrometer, a cylindrical detector system (CDS), and a neutron time-of-flight counter located ∼15 m downstream from the liquid ^{3}He target.

the production cross section is large enough. Further, in E15, we will measure the invariant mass of Λp pairs which are supposed to be emitted from the decay of $K^- pp \rightarrow \Lambda p/\Sigma^0 p$. The three charged particles, $\pi^- pp$, in the final state are detected with a cylindrical detector system (CDS) surrounding a liquid ^{3}He target in the polar-angle acceptance from 54 to 126 degrees. Thus, we can measure the missing mass with the mass resolution of about 10 MeV/c^2 in σ and the invariant mass with the resolution of about 10 MeV/c^2 at the same time. We also have a capability to measure the forward proton spectrum, which will be interesting to compare with the neutron spectrum.

In March and May, 2013, the physics data taking of E15 was carried out for a short period of about 4 days. Here, we report preliminary analysis results. Figure 2 shows a preliminary missing-mass distribution of the $^3\mathrm{He}(K^-, n)X$ reaction obtained in a semi-inclusive condition by requiring at least one charged particle in the CDS. This condition is needed to obtain a reaction vertex for the neutron time-of-flight measurement. The mass resolution estimated from the time-of-flight resolution is also shown in the figure. The inset shows the missing mass spectrum when a K^0_s is detected in the CDS as $K^0_s \rightarrow \pi^+\pi^-$. A large peak corresponding to the quasi-free reaction of K^-"p" $\rightarrow K^0_s n$ is prominent. By comparing the two spectra, an excess of events below the K^-+p+p binding threshold indicated by a vertical dotted line is significant in the semi-inclusive spectrum. Further analyses on the semi-inclusive spectrum are on-going.

In addition to the forward-neutron triggered events, we have obtained the data with the CDS trigger only. In these events, we were able to clearly identify the $^3\mathrm{He}(K^-, \Lambda p)n$ reaction by looking at the missing mass of the undetected neutron in the $^3\mathrm{He}(K^-, \Lambda p)X$ missing-mass distribution. Thus, all the final state particles, $\Lambda + p + n$, were identified in about 200 events. A kind of Dalitz plot analysis was carried out [9]. It suggests that direct two-nucleon absorption processes with one nucleon as a spectator are not dominant and the events are widely distributed in the three-body phase space. Some details of the analysis were reported by Y. Sada [9] in this conference. The E15 experiment is scheduled to take ∼10 times more data in 2015, which will enable us more comprehensive analyses.

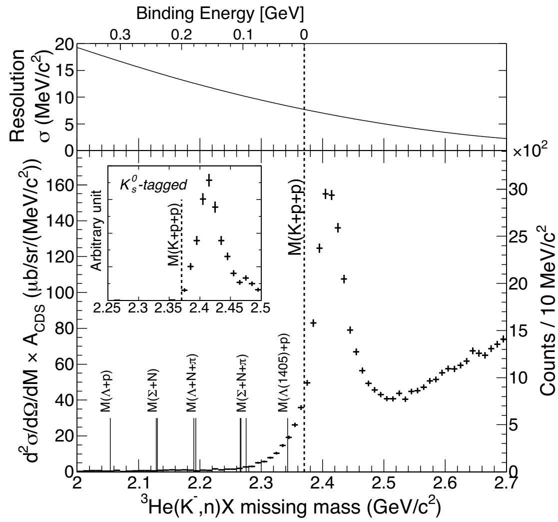

Figure 2. ^{3}He(K^-,n) semi-inclusive missing-mass spectrum along with the missing-mass resolution (σ) shown above. (Taken from Ref. [8]) The error bars denote statistical uncertainties only. The inset shows the K^0_S-tagged spectrum.

3 J-PARC E27

Another experiment is the E27 experiment searching for the K^-pp by using the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c. At this incident energy, we can produce not only Λ and Σ hyperons but also $\Sigma(1385)$ and $\Lambda(1405)$ hyperon resonances. Here we could expect the K^-pp bound state would be formed through the $\Lambda(1405)$ doorway state ($\Lambda^* p \to (K^-pp) \to \Lambda + p$) [10]. However, the sticking probability of $\Lambda(1405)$ in deuteron would be as small as 1% or less. So that the signal would be in the huge backgrounds of quasi-free hyperon and hyperon resonance productions.

Figure 3 shows a schematic view of the E27 experimental setup at the K1.8 beam line [11] of the J-PARC Hadron hall. At the end section of the K1.8 beam line, a beam line spectrometer (Q10+Q11+D4+Q12+Q13) was installed to measure the incident π^+ momentum by using a third-order beam transfer matrix. Four sets of tracking chambers (BC1–4) were installed, together with two beam hodoscopes (BH1, 2). Out-going K^+ momentum was analyzed with a superconducting kaon spectrometer (SKS). The SKS spectrometer was equipped with four sets of tracking chambers (SDC1–4) and trigger counters (TOF, LC, LAC).

For the E27 experiment, we installed a range counter system (RCA) surrounding a liquid deuterium target from ±39 degrees to ±122 degrees from the beam direction. There were three range counter arrays in each (left and right) side. Each range counter array had five layers of plastic scintillators. The separation between protons and charged pions was performed with the range information and time-of-flight measurement in the first layer. The flight path from the target center was ~50 cm. The energy of protons was obtained with the time of flight. By requiring one or two high-momentum (>250 MeV/c) proton(s), we could suppress most of the quasi-free backgrounds according to our simulations.

First, a missing-mass spectrum of the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c for the laboratory scattering angle from 2° to 16° is shown in Fig. 4. The missing-mass scale was calibrated with the

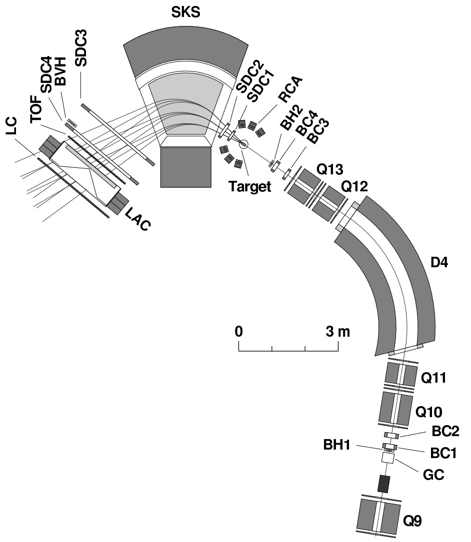

Figure 3. Schematic view of the E27 experimental setup in the K1.8 beam line.

$p(\pi^+, K^+)\Sigma^+$ and $p(\pi^+, K^+)\Sigma(1385)^+$ reactions at 1.69 GeV/c. The details of the inclusive spectrum analysis are described in Ref. [12]. Three prominent bump structures were observed as naively expected: quasi-free Λ, Σ^0 + Σ^+, and Y^*'s($\Sigma(1385)^0$ + $\Sigma(1385)^+$+$\Lambda(1405)$) production processes. Here we compare the spectrum with a simple quasi-free simulation (shown in a solid curve) taking account of the differential cross section of each elementary process and the Fermi motion of a nucleon in deuteron. Two distinct differences are notable. One difference is an excess at ~2.13 GeV/c^2 corresponding to the $\Lambda N \rightarrow \Sigma N$ threshold cusp. And the other is a "shift" of the Y^* bump by about 30 MeV/c^2 toward low mass side. In the K^-pp bound region around 2.3 GeV/c^2, there are large quasi-free processes.

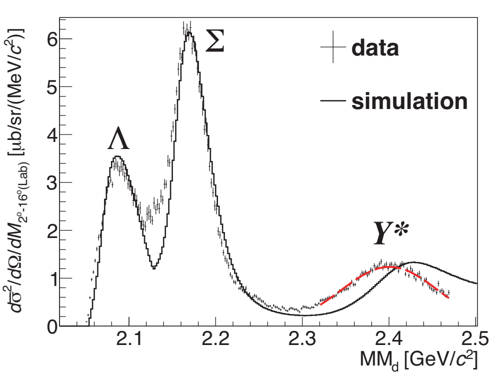

Figure 4. Missing-mass spectrum of the $d(\pi^+, K^+)$ reaction for the laboratory scattering angle from 2° to 16°.(Taken from Ref. [12]) The crosses and solid line show the experimental data and the simulated spectrum, respectively. The result of the Y^* peak fitting is also shown with a dashed red line for the experimental data.

Next, we require a proton in the range counter system. In order to examine which part of the missing mass tends to emit a high-momentum proton in the range counter system, we divide the coincidence spectrum by the inclusive spectrum, obtaining a proton coincidence rate histogram. A proton coincidence rate plot as a function of the (π^+, K^+) missing-mass is shown in Fig. 5. A spike at 2.13 GeV/c^2 due to the $\Lambda N \rightarrow \Sigma N$ threshold cusp is clearly observed. In addition, it shows a broad bump around 2.3 GeV/c^2 suggesting the "$K^- pp$"-like structure.

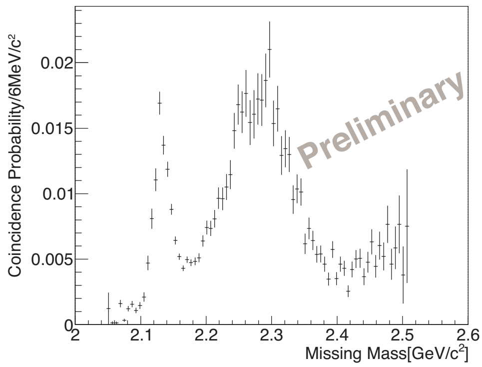

Figure 5. A preliminary spectrum of the proton coincidence rate in the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c as a function of the missing-mass. (Taken from Ref. [13]) A broad bump is observed around 2.3 GeV/c^2.

4 Summary

There are two experiments, E15 and E27, to search for the $K^- pp$ bound state at J-PARC. In the E15 experiment, the ^{3}He(K^-, n) reaction at 1 GeV/c is used. Preliminary analyses are in progress with the data taken in a short period of ~4 days. In the semi-inclusive ^{3}He(K^-, n) missing mass spectrum, an interesting excess of events in the $K^- pp$ bound region was observed. In the next beam time scheduled in 2015, about 10 times better statistics will be obtained. The E27 experiment used the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c. A pilot data taking for ~10 days was already carried out. In the $d(\pi^+, K^+)$ missing mass spectrum, a "shift" by ~30 MeV/c^2 of the bump structure corresponding to the quasi-free Y^* production processes, as well as a cusp structure at the $\Lambda N \rightarrow \Sigma N$ threshold, were observed. A preliminary coincidence study with one proton was performed. It suggests that there exist some enhancements of the proton coincidence rate at ~2.3 GeV/c^2, which could be a signal of the "$K^- pp$"-like structure.

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