Search for the $K^- pp$ bound state via the $^3\text{He}(K^-, n)$ reaction at 1 GeV/c
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Abstract. The J-PARC E15 experiment searches for the simplest kaonic nuclear bound state, $K^-pp$, via the $^3\text{He}(K^-,n)$ reaction at the K1.8BR beam-line in the J-PARC hadron
experimental facility. We performed the first data-taking in May, 2013, with $5 \times 10^9$ incident kaons on the $^3\text{He}$ target. The preliminary results are reported focusing on the forward-neutron spectrum, which shows a clear peak structure composed of the quasi-elastic $K^- n \rightarrow K^- n$ and the charge-exchange $K^- \pi^+ \rightarrow K^0 n$ reactions as expected.

1. Introduction

The $KN$ interaction is known to be strongly attractive in isospin 0 channels by the measurements of kaonic hydrogen x-rays[1] and low-energy $KN$ scattering[2]. Consequently, a possible existence of kaonic nuclear bound states was predicted more than 10 years ago[3]. However, the existence of such exotic states has not been established even for the lightest kaonic nucleus, so-called $K^- pp[4]$. New experimental data with various reaction are definitely important to clarify the nature of kaonic nuclei together with existing data in stopped-$K^-$[5], $pp$-collision[6], and $\gamma$-induced[7] reactions.

The J-PARC E15 experiment searches for $K^- pp$ bound state via the $^3\text{He}(K^-, n)$ reaction at 1 GeV/$c$[8]. This reaction channel is one of the simplest reaction among elementally-$K$ induced reactions. We expect a good signal-to-noise ratio in the region of interest since background neutrons from non-mesonic two-nucleon absorptions and hyperon decays are expected to be substantially suppressed and kinematically separated. In addition, by using a liquid $^3\text{He}$ target and a large acceptance detector surrounding it, the experiment is designed to detect the expected decay, $K^- pp \rightarrow \Lambda p \rightarrow \pi^- pp$, to fully reconstruct the reaction kinematics.

The first data-taking was performed in May 2013. About $5 \times 10^9$ kaons were irradiated on the helium-3 target during 88-hour machine time. In this paper, we describe our spectrometer system, its performance and a preliminary result of the forward neutron spectrum.

2. Experimental apparatus

A dedicated spectrometer was designed and constructed at the secondary beam-line K1.8BR in the J-PARC hadron experimental facility. Here, we briefly describe the spectrometer system shown in Fig. 1. More detailed information can be found elsewhere[9].

Figure 1. Schematic view of the J-PARC K1.8BR spectrometer. Taken from Ref. [9].
The K1.8BR beam line delivers secondary charged beams with momenta up to 1.2 GeV/c, which are purified with an electrostatic separator. At 1 GeV/c, a kaon is identified with an aerogel Cherenkov counter, and its momentum is analyzed by a beam-line spectrometer with a momentum resolution of 2.2 MeV/c ($\sigma$). A typical $K^-$ yield at an accelerator power of 24 kW was $1.5 \times 10^5$ per spill with a $K^-/\pi^-$ ratio of 0.45.

A liquid helium-3 target was placed at the center of a cylindrical detector system (CDS), which detects charged particles emitted in a reaction at the target. The main components of the CDS are a 15-layer cylindrical drift chamber (CDC) and a 36-segmented cylindrical detector hodoscope (CDH). The momentum of a charged particle is analyzed by the CDC and a particle identification is done together with the timing information provided by the CDH, as shown in Fig. 2. The CDH was also used as a trigger counter with a polar-angle acceptance from 54 to 126 degrees. Figure 3 shows the invariant-mass distribution of $\pi^+\pi^-$ pairs detected by the CDS, where the $K^0_s \rightarrow \pi^+\pi^-$ decay was successfully reconstructed. The CDC track also determines the reaction vertex point together with a beam-line drift chamber placed just upstream the target. The vertex information is essential to select reactions on helium-3 and to determine the flight-length for a forward-neutral particle.

One of the most unique features of our spectrometer system is the high-resolution large-acceptance neutron TOF counter array (NC). The NC locates at a distance of ~15 m from the target position and covers a solid angle of ~20 msr at 0 degree with 112-segment plastic scintillators. The detection efficiency for a 1 GeV/c neutron is estimated to be ~30%. Figure 4 shows a $1/\beta$ spectrum of forward neutral particles, where charged particles are removed by two types of charged-veto counter arrays and a beam-sweeping magnet. The $\gamma$-ray peak is clearly separated from the neutron continuum, which indicates a good accidental-background suppression. The TOF resolution of the system was evaluated to be ~160 ps ($\sigma$) by using the $\gamma$ peak. It corresponds to ~10 MeV/c ($\sigma$) momentum resolution in the region of interest (1.2–1.4 GeV/c). The uncertainty of the neutron momentum dominantly contributes to the missing-mass resolution of ~10 MeV/c$^2$ ($\sigma$) at around the $K^-pp$ binding threshold.
3. Preliminary results of the first data-taking

Figure 5 shows the $^3$He($K^-$, $n$)X missing-mass spectrum obtained under a semi-inclusive condition. Here, "semi-inclusive" means that we required at least one charged track in the CDS to reconstruct the reaction vertex. Thus, the obtained spectrum is somehow distorted by
the limited acceptance of the CDS. The most prominent structure in the spectrum is a peak structure around 2.4 GeV/c$^2$. The peak is a so-called quasi-free peak attributed to the quasi-elastic $K^-\text{n} \rightarrow K^-\text{n}$ and the charge-exchange $K^-\text{p} \rightarrow K^0\text{n}$ reactions. It is confirmed by requesting $K^0_s$ reconstructed in the CDS as superimposed in Fig. 5. The $K^0_s$-tagged spectrum also shows that the missing-mass scale is correctly tuned at a 10 MeV/c$^2$ level, and there is a tail-structure in the $K^-\text{pp}$ bound region which cannot be explained by the Fermi motion. To further investigate the bound-region structure, a few background sources were studied. The most trivial one is the accidental background evaluated from the left shoulder of the peak in the $1/\beta$ spectrum. An analytical conversion to the missing-mass spectrum is plotted in Fig. 5. Other background sources were also evaluated including neutrons and secondary $\gamma$-rays from known elementary processes, and contaminations from the target cell. These contributions explain observed yields in the deep-binding region, while we need other non-ordinary processes to explain the yield of the tail just below the $K^-\text{pp}$ binding threshold.

4. Summary

We successfully conducted the first data-taking of the J-PARC E15 experiment, which aimed to search for the $K^-\text{pp}$ bound state via the $^3\text{He}(K^-\text{n})X$ reaction at 1 GeV/c. The semi-inclusive neutron spectrum at forward angle, obtained with $5\times10^9$ incident kaons, shows a clear peak structure composed of the quasi-elastic $K^-\text{n} \rightarrow K^-\text{n}$ and the charge-exchange $K^-\text{p} \rightarrow K^0\text{n}$ reactions as expected. The analysis on the forward neutron will be finalized soon. Analyses of semi-inclusive $^3\text{He}(K^-\text{p})$ and exclusive $^3\text{He}(K^-\text{pn})$ channels are also in progress.

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