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Search for deeply-bound $\bar{K}$-nuclear states via the ^{3}He(inflight-K^-, n) reaction at J-PARC

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The J-PARC E15 experiment at the K1.8BR beam-line in the J-PARC hadron hall aims to search for the simplest K-nuclear bound state, K^-pp, by the in-flight $^3\mathrm{He}(K^-,n)$ reaction. The first physics data taking was performed in May 2013. By irradiating 5×10^9 kaons on the helium-3 target, 3×10^5 forward-neutrons were successfully recorded. In this report, results of the semi-inclusive $^3\mathrm{He}(K^-,n)$ and the exclusive $^3\mathrm{He}(K^-,\Lambda pn)$ channels are discussed.

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1. Introduction

The $\bar{K}N$ interaction has been figured out to be strongly attractive by extensive measurements of the kaonic hydrogen atom [1] and low energy $\bar{K}N$ scattering [2]. As a consequence of the strongly attractive $I = 0$ $\bar{K}N$ interaction, existence of deeply-bound K-nuclear states has been widely discussed in the recent years. Available experimental information is limited. In particular, even in the simplest K-nuclear bound system, K^-pp, reported mass and width are scattered and rather conflicted each other [3]. In order to obtain a conclusive result on the K^-pp state, we measure the K^-pp state via the $^3\mathrm{He}(K^-,n)$ reaction. The K^-pp state is measured in a missing mass spectrum of the $^3\mathrm{He}(K^-,n)$ reaction and in a Λp invariant mass spectrum.

The E15 experiment at the K1.8BR beam-line aims to search for the simplest K-nuclear bound state [4]. K^-pp, by reconstructing the complete kinematics of the reaction channels to discriminate all background processes. An exclusive measurement is performed with the inflight $^3\mathrm{He}(K^-,n)$ reaction at 1.0 GeV/c. Such measurement allows us to investigate the K^-pp bound state both in the formation via missing-mass spectroscopy and its decay via invariant-mass spectroscopy, $K^-pp \rightarrow \Lambda p \rightarrow \pi^-pp$, respectively.

2. Experiment

An experiment setup, as shown in Fig. 1, is constructed at the K1.8BR beam line in the Hadron Experimental Hall of the J-PARC 50-GeV Proton Synchrotron (PS).

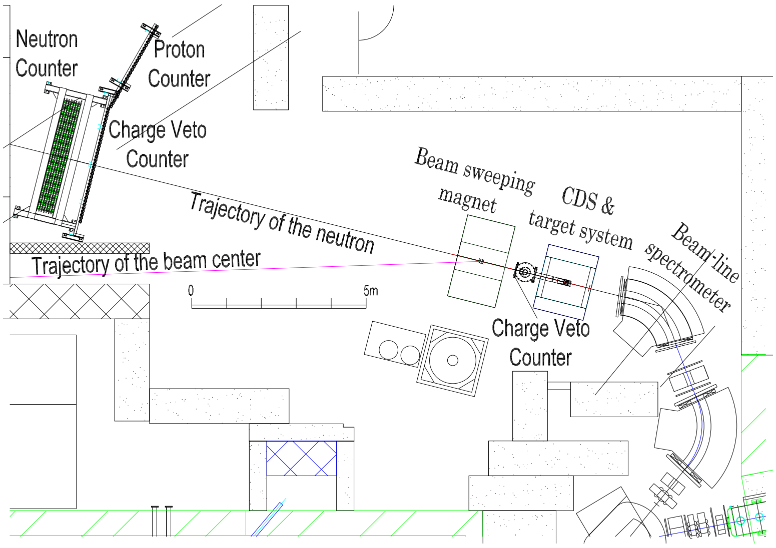

Figure 1: Schematic view of the K1.8BR spectrometer.

The experimental setup consists of three parts: a high-precision beam line spectrometer, a cylindrical detector system (CDS) around the liquid ^{3}He target system, and forward scattered particle detectors.

The kaon beam at a momentum of 1.0 GeV/c is identified by using an Aerogel Cherenkov counter. The kaon beam momentum is analyzed by the beam line spectrometer whose momentum resolution is 2.2 MeV/c at 1.0 GeV/c.

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The CDS is placed surrounding the target in order to identify the Λp final state from the $K^- pp$ state. The CDS consists of a solenoid magnet, a Cylindrical Drift Chamber (CDC), and a Cylindrical Detector Hodoscope (CDH). The details of the CDS system can be found in a separate paper [5]. The decay particles from the target are detected by the CDS which has a solid angle coverage of 59% of 4π. The CDC is operated in a magnetic field of 0.7 T. Charged particle trajectories reconstructed by the CDC give their momenta and flight lengths. Particle identification is performed by combining the TOF information obtained by CDH, Fig. 2 shows the distributions of the momentum versus $1/\beta$ reconstructed in the CDS, where $\pi^{\pm}$, K^-, p, and d are separately identified. The invariant mass of p and π^- is reconstructed as shown in Fig. 3. A clear peak of $\Lambda \to p\pi^-$ decay can be seen.

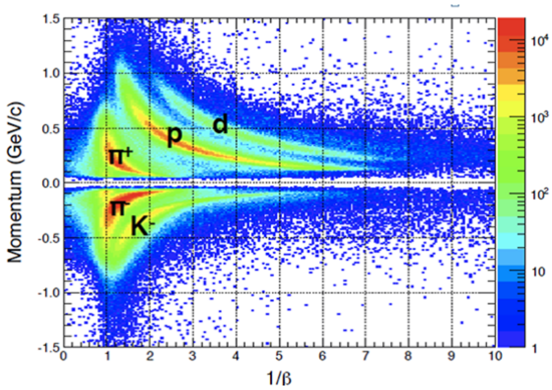

Figure 2: Distribution of the momentum versus $1/\beta$ obtained by the CDS.

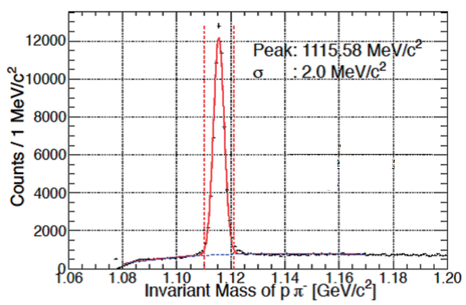

Figure 3: Invariant mass spectrum of $p\pi^-$. The spectrum is fitted with a Gaussian and a background curve.

A neutron TOF counter (NC), placed ~15 m downstream from center of the target at 0 degrees with respect to the beam direction, detects forward neutron generated by the in-flight (K^-, n) reaction. A $1/\beta$ spectrum of neutral particles detected by the NC is shown in Fig. 4.

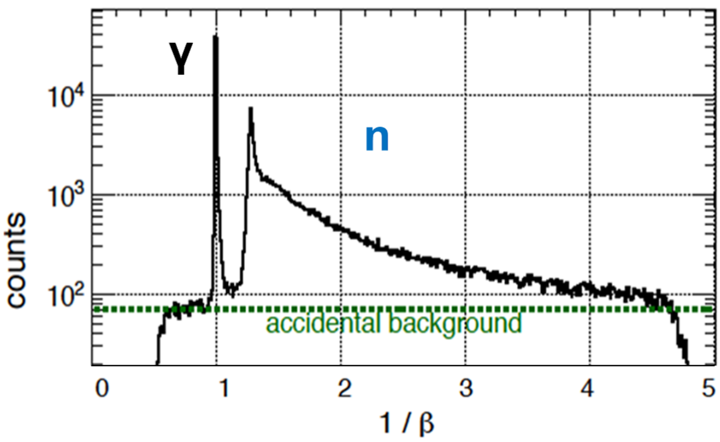

Figure 4: $1/\beta$ spectrum of neutral particles detected by the NC. The dotted line shows an accidental background evaluated from the left shoulder of the γ peak at $1/\beta = 1$.

Neutrons are clearly separated from gamma rays. A signal to noise ratio is found to be about

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100 at a neutron peak around $1/\beta \sim 1.3$. The TOF resolution is measured to be 150 *ps* (σ) at the gamma peak. A resolution of the K^-pp state in the missing mass of the $^3\mathrm{He}(K^-,n)$ reaction is estimated to be 9 MeV/c^2, which satisfies the experimental requirement of less than 10 MeV/c^2.

3. Preliminary Results of first physics run

The first physics-run of the E15 experiment was carried out in May 2013. By irradiating 5×10^9 kaons on the helium-3 target, 3×10^5 forward-neutrons were successfully recorded. Accumulated data corresponds to $\sim 1\%$ of statistics requested in the original proposal.

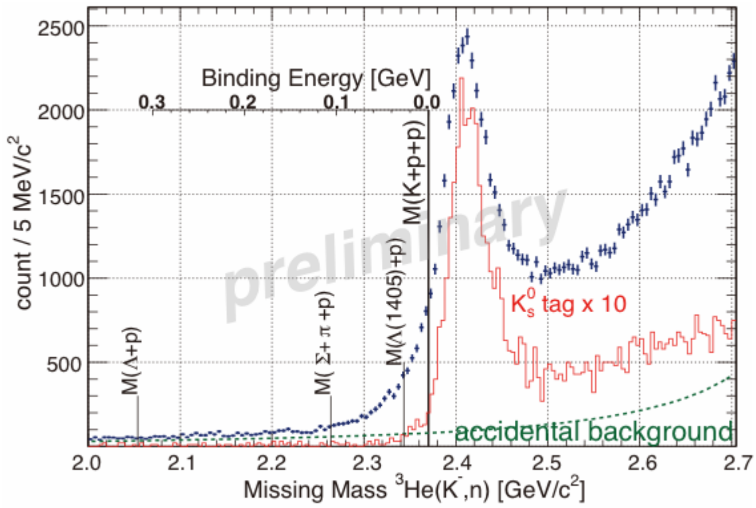

Figure 5: Missing mass of the $^3\mathrm{He}(K^-,n)$ reaction at forward angle. One or more charged tracks are required in the CDS to reconstruct the reaction vertex. A spectrum with K^0_s reconstructed in the CDS is overlaid with a scale factor of 10.

Figure 5 shows the missing mass of the $^3\mathrm{He}(K^-,n)$ reaction. One or more charged tracks are required in the CDS to reconstruct the reaction vertex. In the spectrum, a clear peak from the quasi-elastic $K^-n \to K^-n$ and the charge exchange $K^-p \to K^0_s n$ reactions on ^{3}He is observed. The spectrum with K^0_s reconstructed in the CDS is overlaid in the figure, which is distributed from just above the K^-pp threshold (2.37 GeV/c^2). The spectrum shape of the quasi-elastic / charge exchange reaction is well reproduced by a Monte Carlo simulation. The excess below the Kpp threshold in the inclusive $^3\mathrm{He}(K^-,n)$ spectrum is hardly explained by the detector responses.

An exclusive $^3\mathrm{He}(K^-,\Lambda pn)$ channels is discussed. The missing mass of $^3\mathrm{He}(K^-,\Lambda p)$ reaction as shown in Fig. 6. A peak at the neutron mass can be seen in the spectrum. By gating the missing neutron mass region, we select the events of the Λpn final state. Dalitzs plot of Λpn is shown in Fig. 7. We found that the selected Λpn events are widely distributed over the kinematically allowed phase space. In particular, a certain fraction of the events have no correlation among three final particles, which indicates that 3-nucleon absorption of kaon is significantly seen in the Λpn. If the neutron detection by the NC is required, only a few events are left. The source of these events will be clarified by subsequent physics runs with higher statistics.

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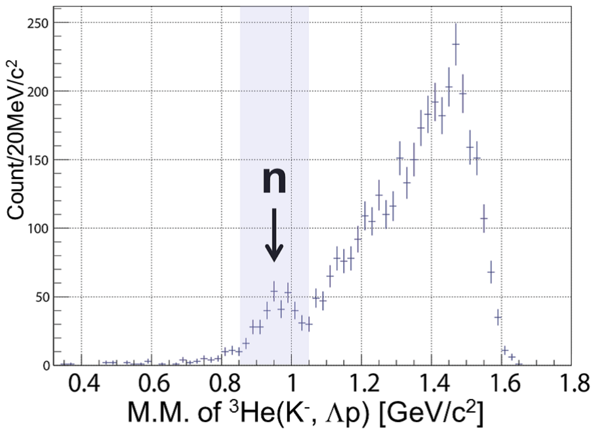

Figure 6: The missing mass of ^{3}He(K^-, Λp) reaction. Hatched area represents the selecting region of missing neutrons (0.85 < M. M. < 1.05 GeV/c^2)

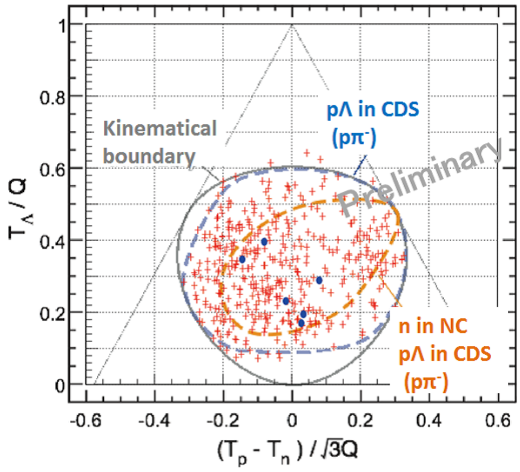

Figure 7: Dalitz plot of Λpn exclusive events. Neutrons are identified by two different methods; ^{3}He(K^-, Λp) missing mass (red crosses) and detection by NC (blue points). Areas surrounded by each dotted line show the detector acceptance, respectively.

4. Summary

The J-PARC E15 experiment is performed to search for the simplest kaonic nuclear bound state, K^-pp, by the in-flight ^{3}He(K^-,n) reaction at 1.0 GeV/c. The first physics data-taking was performed in May 2013. During the run, 5×10^9 kaons were incident on the ^{3}He target, and 3×10^9 neutrons were collected by the NC at zero degree. The semi-inclusive ^{3}He(K^-,n) spectrum shows clear peak structure composed of the quasi-elastic $K^-n \rightarrow K^-n$ and the charge exchange $K^-p \rightarrow K^0n$ reactions as expected. The exclusive ^{3}He(K^-, Λpn) analysis indicates 3-nucleon absorption processes are dominant. Further analyses of the semi-inclusive ^{3}He(K^-,n) and the exclusive ^{3}He(K^-, Λpn) channels are in progress.

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