Search for the K^-pp bound state via the in-flight $^3\mathrm{He}(K^-, n)$ reaction

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Abstract. In the J-PARC E15 experiment, a K^-pp search was performed via the $^3\mathrm{He}(K^-, n)$ reaction at 1.0 GeV/c. A forward-going neutron is detected by a neutron counter with 15 m flight length, and decay particles from K^-pp are simultaneously measured by a cylindrical detector system that surrounds a liquid $^3\mathrm{He}$ target system. In March and May, 2013, we carried out the first physics data-taking with 5×10^9 incident

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kaons on the ^{3}He target, and we have obtained a preliminary exclusive analysis result of ^{3}He(K^-, Λp)n reaction.

1 Introduction

The $\bar{K}N$ interaction is one of the keys to understanding meson-baryon interactions in low-energy quantum chromodynamics (QCD) incorporating three flavors in the nuclear system. In particular, the investigation of deeply bound kaonic nuclei have been progressed in both the theoretical[1]-[12] and experimental[13],[14] sides in the last decade. There are various theoretical predictions of the K^-pp state at present, thus it is quite important to compare the theoretical calculations with experimental studies. However, the experimental situation is also controversial; The FINUDA[13] and the DISTO[14] collaborations have claimed observations of the deeply-bound K^-pp state, while LEPS[15] group recently reported null results of the K^-pp population. Therefore, we need to investigate the K^-pp state in different reactions and to understand background processes, such as multi-nucleon absorption processes of K^- The E15 experiment was proposed to search for the simplest kaonic nuclear bound states, namely K^-pp, via the in-flight ^{3}He(K^-, N) reaction using 1.0 GeV/c K^- beam [16]. This experiment has an advantage that an exclusive measurement can be performed by a simultaneous measurement of missing mass spectrum using the primary nucleon and invariant mass spectroscopy via the decay particles from K^-pp. We have obtained the missing-mass spectrum of ^{3}He(K^-, n) as well as the exclusive result of ^{3}He(K^-, Λp)n reaction. a detail of the missing-mass analysis of ^{3}He(K^-, n) is reported in [17]. By the reconstructing the exclusive ^{3}He(K^-, Λp)n channel, we have also examined not only the expected $K^-pp \rightarrow \Lambda p$ decay but also multi-nucleon absorption processes of in-flight K^-. There is no data about in-flight K^- multi-nucleon absorption on ^{3}He. Thus our data might become important hints for further understanding of the $\bar{K}N$ interaction.

2 Experiment overview

The E15 experiment is performed at the K1.8BR beam-line in the Hadron hall at the J-PARC. The spectrometer consists of high precision beam-line spectrometer, a liquid ^{3}He target system and a cylindrical detector system (CDS) which surrounds the target to detect the decay particles from the target region, and forward time-of-flight (TOF) counters to detect neutron or proton (whose flight length is about 15 m). Details of other detectors in K1.8BR are discribed in [18].

3 Performance of detectors

3.1 Beam-line spectrometer

The beam-line spectrometer is composed of beam line magnets, trigger counters, beam trackers, and a kaon identification counter. The beam trigger is generated by a coincidence signal of a beam hodoscope detector (BHD) and a time-zero counter (T0); the flight length between the BHD and T0 is 7.7 m. The kaon beam with momentum around 1.0 GeV/c is identified by using an aerogel Cherenkov counter (AC) with a refractive index of 1.05. The kaon beam is tracked with two beam trackers (BLC1 and BLC2) and the momentum of the kaon is analyzed with this tracking information together with the beam optics of a dipole magnet in between BLC1 and BLC2.

3.2 Cylindrical Detector System (CDS)

The CDS consists of the solenoid magnet, the Cylindrical Drift Chamber (CDC), and the Cylindrical Detector Hodoscope (CDH). The decay particles from the target are reconstructed by the CDC which operates in a magnetic field of 0.7 T. The CDH is used for particle identification and as a charged particle trigger. We checked the tracking efficiency of the CDS with kaon beam data. We estimated the tracking efficiency as 93.1 ±1.0%.

4 Analysis of $^3\text{He}(K^-, \Lambda p)n$ reaction

In March and May, 2013, we carried out the first physics data-taking with 5×10^9 incident K^-'s on the ^{3}He target. To analyze $K^- pp$ which decays to Λp and multi-nucleon absorption, we selected the $^3\text{He}(K^-, \Lambda p)n$ reaction. The Λp are detected with the CDS, and a missing neutron is identified from missing mass spectrum of $^3\text{He}(K^-, \Lambda p)X$. In Fig. 1(a), we show a missing-mass of the $^3\text{He}(K^-, \Lambda p)X$. A clear missing-neutron peak is seen. The cut condition for a missing neutron is defined as the red colored region in Fig. 1(a). Then we obtained data of the $^3\text{He}(K^-, \Lambda p)n$ reaction, which is the first measurement of in-flight K^- multi-nucleon absorption. The number of events of the $^3\text{He}(K^-, \Lambda p)n$ reaction is about 200. To check phase space distribution, we plotted three body energy correlation of final state, which is Dalitz plot with kinematic energy (Fig. 1(b)). Vertical axis of Fig. 1(b) is kinetic energy of neutron in the $^3\text{He}(K^-, \Lambda p)n$ reaction. Spectator neutron in two-nucleon absorption processes has only Fermi momentum. Therefore if two-nucleon absorption processes which spectator is neutron are dominant, points in Dalitz plot are distributed in region in which kinetic energies of neutron are low (orange circle area in Fig. 1(b)). But our data is distributed widely in Dalitz plot. It suggests that three-nucleon absorption processes are dominant in the $^3\text{He}(K^-, \Lambda p)n$ reaction. When uniform phase-space distribution is assumed, total cross section of this reaction is a few hundred μb.
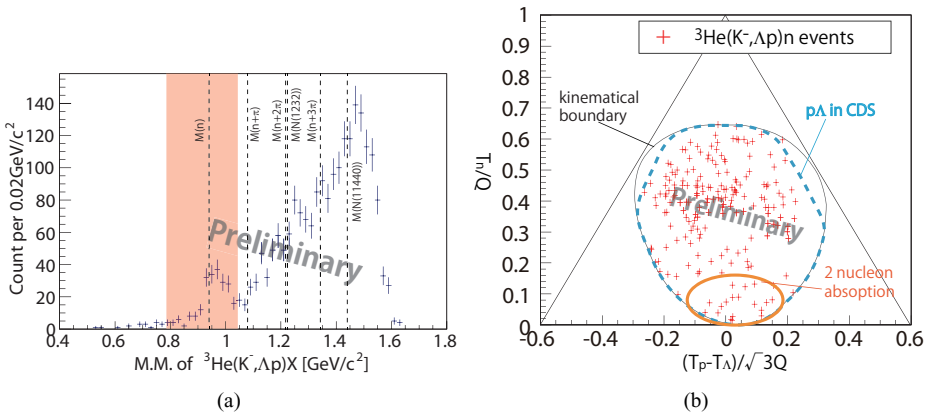

Figure 1. Missing mass spectra of $^3\text{He}(K^-, \Lambda p)X$ (a) and Dalitz plot of $^3\text{He}(K^-, \Lambda p)n$ reaction (b). In (b), Vertical axis is kinetic energy of neutron in final state, and horizontal axis means subtraction of proton kinetic energy and Λ kinetic energy. All kinetic energies are normalized to the total energy ,Q.

5 Conclusion

Our expriment, J-PARC E15 experiment is a search for the kaonic nucleus K^-pp via the ^{3}He(K^-, n) reaction at 1.0 GeV/c. In the J-PARC E15 experiment, we are able to simultaneously measure formation reaction and decay of K^-pp. In March and May, 2013, we carried out the first physics data-taking with 5x10^9 incident kaons on the ^{3}He target, and we have obtained an exclusive analysis result of ^{3}He$(K^-, \Lambda p)n$ reaction, which is the first measurement of in-flight K^- multi-nucleon absorption. Our data suggest that three nucleon absorption processes are dominant in the ^{3}He$(K^-, \Lambda p)n$ reaction. When uniform phase-space distributions are assumed, total cross section of this reaction is a few hundred μb. To understand existence of K^-pp in this reaction, we should consider all reactions and global fitting of the ^{3}He$(K^-, \Lambda p)n$ reaction is needed. We will report soon final result about exclusive ^{3}He$(K^-, \Lambda p)n$ reaction.

Acknowledgements

References

 [1] Y. Akaishi and T. Yamazaki, Phys. Rev. C **65**, 044005 (2002).
 [2] T. Yamazaki and Y. Akaishi, Phys. Lett. B **535**, 70 (2002).
 [3] T. Yamazaki and Y. Akaishi, Phys. Rev. C **76**, 045201 (2007).
 [4] D. Jido *et al*., Nucl. Phys. A **725**, 181 (2003).
 [5] T. Hyodo and A. Weise, Phys. Rev. C **77**, 035204 (2008).
 [6] N. V. Shevchenko et al., Phys. Rev. C **76**, 044004 (2007).
 [7] T. Nishikawa and Y. Kondo, Phys. Rev. C **77**, 055202 (2008).
 [8] S. Wycech and A. M. Green, Phys. Rev. C **79**, 014001 (2009).
 [9] A. Dot*é*, T. Hyodo, and W. Weise, Phys. Rev. C **79**, 014003 (2009).
[10] Y. Ikeda and T. Sato, Phys. Rev. C **79**, 035201 (2009).
[11] J. Yamagata-Sekihara *et al*., Phys. Rev. C **80**, 045204 (2009).
[12] T. Koike and T. Harada, Phys. Rev. C **80**, 055208 (2009).
[13] M. Agnello *et al*., Phys. Rev. Lett. **94**, 212303 (2005).
[14] T. Yamazaki *et al*., Phys. Rev. Lett. **104**, 132502 (2010).
[15] A. O. Tokiyasu *et al*., Phys.Lett. B **728**, 616 (2014).
[16] M. Iwasaki, T. Nagae (E15 collaboration)., J-PARC E15 proposal.
        http://j-parc.jp/NuclPart/pac_0606/pdf/p15-Iwasaki.pdf
[17] T. Hashimoto(E15 collaboration)., arXiv:1408.5637[nucl-ex] (2014)
[18] K. Agari *et al*., Prog. Theor. Exp. Phys. 02B011 28 (2012)