Vol. 45 (2014) *ACTA PHYSICA POLONICA B* No 3

A SEARCH FOR DEEPLY-BOUND KAONIC NUCLEAR STATES BY IN-FLIGHT ^{3}He(K^-, n) REACTION AT J-PARC*

F. Sakuma[m], S. Ajimura[a], G. Beer[b], H. Bhang[c], M. Bragadireanu[d] P. Buehler[e], L. Busso[f,g], M. Cargnelli[e], S. Choi[c], C. Curceanu[h] S. Enomoto[i], D. Faso[f,g], H. Fujioka[j], Y. Fujiwara[k], T. Fukuda[l] C. Guaraldo[h], T. Hashimoto[k], R.S. Hayano[k], T. Hiraiwa[a], M. Iio[n] M. Iliescu[h], K. Inoue[i], Y. Ishiguro[j], T. Ishikawa[k], S. Ishimoto[n] T. Ishiwatari[e], K. Itahashi[m], M. Iwai[n], M. Iwasaki[o,m], Y. Kato[m] S. Kawasaki[i], P. Kienle[p], H. Kou[o], Y. Ma[m], J. Marton[e], Y. Matsuda[q] Y. Mizoi[l], O. Morra[f], T. Nagae[j], H. Noumi[a], H. Ohnishi[m], S. Okada[m] H. Outa[m], K. Piscicchia[h], M. Poli Lener[h], A. Romero Vidal[h] Y. Sada[j], A. Sakaguchi[i], M. Sato[m], A. Scordo[h], M. Sekimoto[n], H. Shi[k] D. Sirghi[h,d], F. Sirghi[h,d], K. Suzuki[e], S. Suzuki[n], T. Suzuki[k] K. Tanida[c], H. Tatsuno[h], M. Tokuda[o], D. Tomono[m], A. Toyoda[n] K. Tsukada[r], O. Vazquez Doce[h,s], E. Widmann[e], B.K. Wuenschek[e] T. Yamaga[i], T. Yamazaki[k,m], H. Yim[t], Q. Zhang[m], J. Zmeskal[e]

(J-PARC E15 Collaboration)

[a]Research Center for Nuclear Physics (RCNP), Osaka University, Osaka, 567-0047, Japan
[b]Department of Physics and Astronomy, University of Victoria, Victoria BC V8W 3P6, Canada
[c]Department of Physics, Seoul National University, Seoul, 151-742, South Korea
[d]National Institute of Physics and Nuclear Engineering — IFIN HH, Romania
[e]Stefan-Meyer-Institut für subatomare Physik, 1090 Vienna, Austria
[f]INFN Sezione di Torino, Torino, Italy
[g]Dipartimento di Fisica Generale, Universita' di Torino, Torino, Italy
[h]Laboratori Nazionali di Frascati dell' INFN, 00044 Frascati, Italy
[i]Department of Physics, Osaka University, Osaka, 560-0043, Japan
[j]Department of Physics, Kyoto University, Kyoto, 606-8502, Japan
[k]Department of Physics, The University of Tokyo, Tokyo, 113-0033, Japan
[l]Laboratory of Physics, Osaka Electro-Communication University, Osaka, 572-8530, Japan
[m]RIKEN Nishina Center, RIKEN, Wako, 351-0198, Japan
[n]High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan
[o]Department of Physics, Tokyo Institute of Technology, Tokyo, 152-8551, Japan
[p]Technische Universität München, 85748, Garching, Germany
[q]Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, 153-8902, Japan
[r]Department of Physics, Tohoku University, Sendai, 980-8578, Japan
[s]Excellence Cluster Universe, Technische Universität München, 85748, Garching, Germany
[t]Korea Institute of Radiological and Medical Sciences (KIRAMS), Seoul, 139-706, South Korea

(Received January 7, 2014)

* Presented at the II International Symposium on Mesic Nuclei, Kraków, Poland, September 22–25, 2013.

We report on preliminary results of the J-PARC E15 experiment aiming to search for the simplest kaonic-nuclear bound-state, K^-pp, via in-flight ^{3}He(K^-,n) reaction. The first physics data-taking was performed with 5×10^9 incident kaons on the ^{3}He target, and 3×10^5 neutrons were collected by a forward neutron counter placed 15 m away from center of the target at 0 degrees. The semi-inclusive neutron spectrum shows clear peak structure composed of the quasi-elastic $K^-n\to K^-n$ and the charge exchange $K^-p\to\bar{K}^0n$ reactions as expected.

DOI:10.5506/APhysPolB.45.767
PACS numbers: 13.75.Jz, 21.85.+d, 25.80.Nv

1. Introduction

The $\bar{K}N$ interaction has been figured out to be strongly attractive by extensive measurements of the anti-kaonic hydrogen atom [1] and low-energy K^-N scattering [2]. As a consequence of such strongly attractive $\bar{K}N$ interaction in $I=0$ channels, the possible existence of strongly-bound $\bar{K}$ nuclear-states has been widely discussed in recent years [3]. Experimentally, however, only a small amount of information is available [4], which is not sufficient to discriminate between a variety of conflicting interpretations. Therefore, new experimental data, especially experiments using the elementary $\bar{K}$ induced reaction, are eagerly awaited.

In this situation, we have performed an experimental search for the simplest kaonic nuclear bound state, K^-pp, by the ^{3}He(K^-,n) reaction at 1 GeV/c (J-PARC E15 [5]). The experiment investigates the K^-pp bound state exclusively both in the formation via missing-mass spectroscopy and its decay via invariant-mass spectroscopy using the emitted neutron and the expected decay, $K^-pp\to\Lambda p\to\pi^-pp$, respectively. By using the (K^-,n) reaction at 1 GeV/c and a large acceptance detector surrounding a liquid ^{3}He target system, background from two-nucleon absorption processes and hyperon decays are expected to be kinematically discriminated from the K^-pp signal.

2. K1.8BR spectrometer system at J-PARC

A dedicated spectrometer was designed and constructed at the secondary beam-line K1.8BR in the hadron hall of J-PARC [6]. The spectrometer consists of a high precision beam line spectrometer, a liquid helium target system, a Cylindrical Detector System (CDS) that surrounds the target to detect the decay particles from the target region, and a neutron time-of-flight counter array located $\sim$ 15 m away from the target position, as shown in Fig. 1.

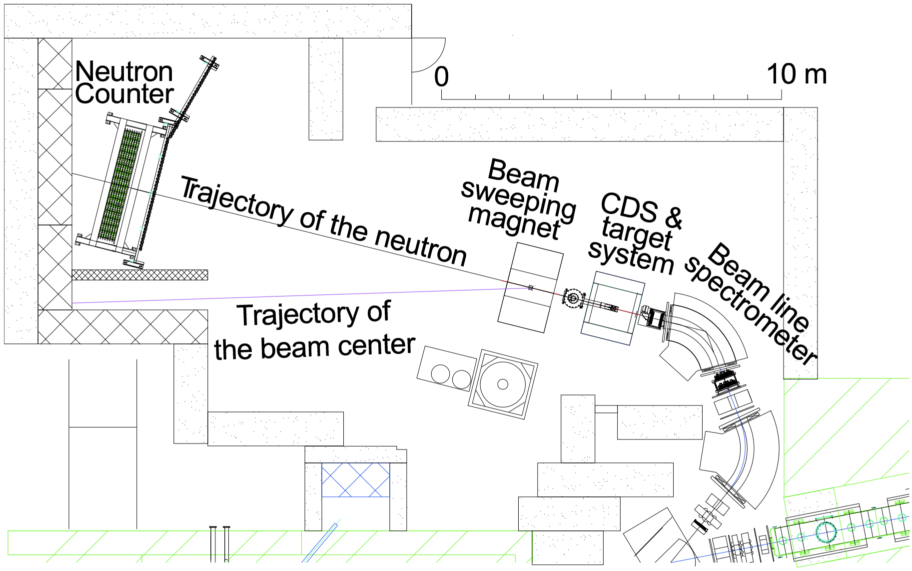

Fig. 1. Schematic view of the K1.8BR spectrometer [6].

2.1. K1.8BR beam line

The K1.8BR beam line is designed to deliver secondary beams of charged particles with momenta up to 1.2 GeV/c, which are purified by an electrostatic separator. The beam momentum is analyzed by a beam-line spectrometer with a momentum resolution of 2.2 MeV/c at 1 GeV/c, and kaons are identified by using an aerogel Cherenkov counter at a trigger level. The typical 1.0 GeV/c kaon yield at an accelerator power of 24 kW[1] was obtained to be 1.5×10^5 per spill with a K/π ratio of 0.45.

2.2. Cylindrical detector system

Decay particles from the ^{3}He target are detected by a cylindrical detector system (CDS), which consists of a solenoid magnet, a cylindrical drift chamber (CDC), and a cylindrical detector hodoscope (CDH). A schematic view of the CDS with a liquid ^{3}He target system is shown in Fig. 2. The CDS has 15 layers of anode wires and a solid angle coverage of $\sim 60\%$ of 4π. Detailed tracking information on charged particles is obtained from the CDC, which operates in a solenoidal magnetic field of 0.7 T. Particle identification is obtained using time-of-flight (TOF) together with the trigger counter as shown Fig. 3.

[1] 3.0×10^{13} protons per pulse at 30 GeV with 6 seconds repetition-cycle.

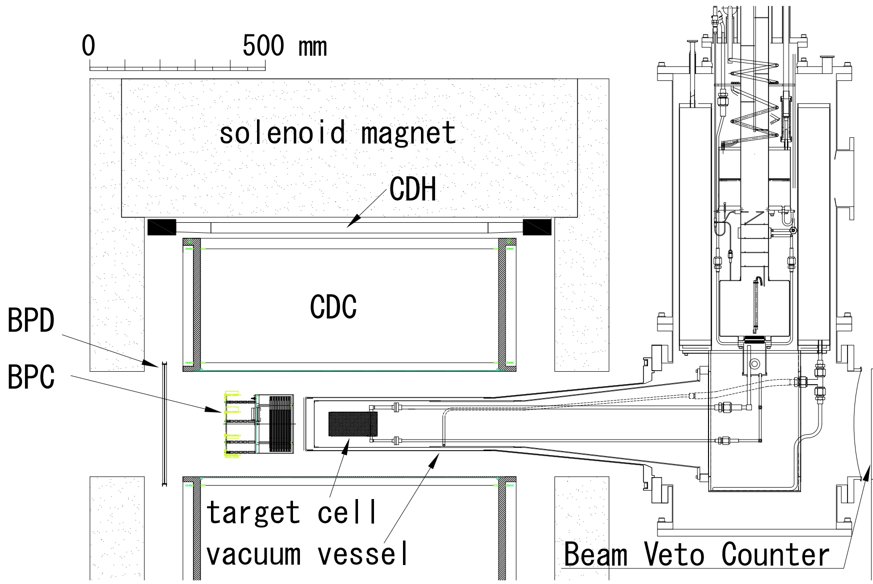

Fig. 2. Schematic drawing of the CDS with the target system [6].

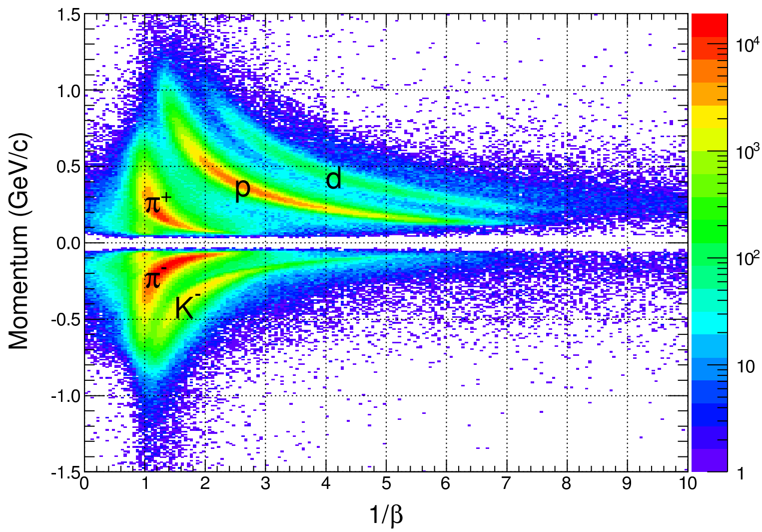

Fig. 3. Distributions of the momentum *versus* $1/\beta$ obtained by the CDS [7].

Using the momentum reconstruction and the particle identification, $K^0_{\rm S} \to \pi^+\pi^-$ (Fig. 4) and $\Lambda \to p\pi^-$ decays were successfully reconstructed as designed performance, which corresponds to invariant-mass resolution of 10 MeV$/c^2$ (σ) for the expected $K^-pp \to \Lambda p$ decay channel.

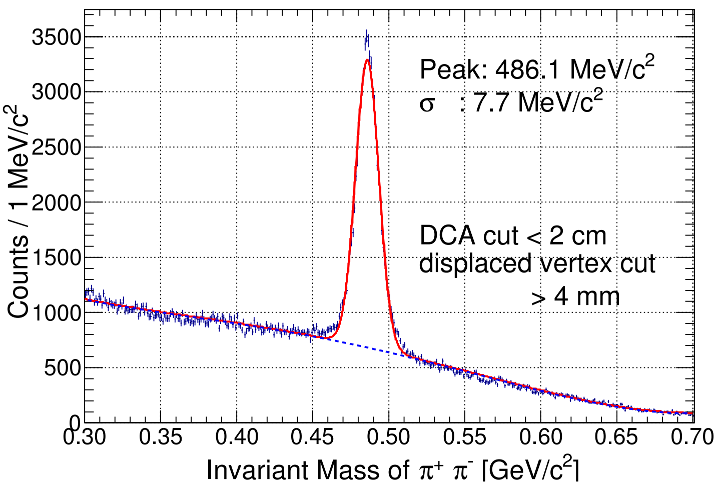

Fig. 4. Invariant mass spectrum of $\pi^+\pi^-$ [7]. The spectrum is fitted with a Gaussian and a background curve. The centroid and resolution of $K^0_{\rm S}$ are well reproduced by a detailed detector simulation.

2.3. Forward TOF counter arrays

A forward neutron generated by the in-flight (K^-,n) reaction is detected by a forward neutron TOF counter array (NC) with a flight length of $\sim$ 15 m. The NC covers a solid angle of $\sim$ 20 msr at zero degree, and the detection efficiency for a 1 GeV$/c$ neutron is estimated to be $\sim$ 35%. Figure 5 shows $1/\beta$ spectrum of the neutral particles measured by the NC, in which charged particles are vetoed by a beam- and a charge-veto counters. The spectrum shows clear separation of γ rays and neutrons with small accidental-background. The TOF resolution of the system is evaluated to be $\sim$ 160 ps using the γ peak in Fig. 5, which is equivalent to missing-mass resolution of $\sim$ 10 MeV$/c^2$ (σ) for $\sim$ 1.2 GeV$/c$ neutrons emitted from the quasi-elastic $K^-n \to K^-n$ and the charge exchange $K^-p \to \bar{K}^0 n$ reactions.

We also measure both the ^{3}He$(K^-,\,p)$ and the $(K^-,\,n)$ reactions with a forward proton TOF counter array to investigate the isospin dependence of the $\bar{K}N$ interaction.

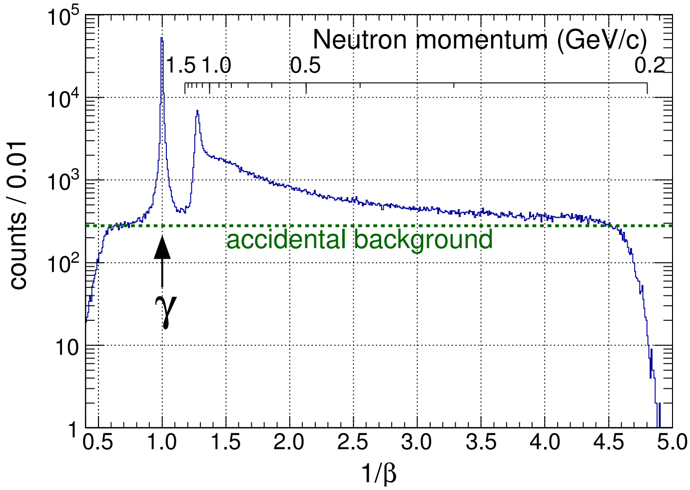

Fig. 5. $1/\beta$ spectrum of the neutral particles obtained by the NC [7]. The dotted line shows an accidental background contribution evaluated from the left shoulder of the γ peak.

3. Preliminary results of first physics run

The first physics run of the E15 experiment was carried out in March and May 2013. During the run, 5×10^9 kaons were incident on the ^{3}He target, and 3×10^5 neutrons were collected by the NC.

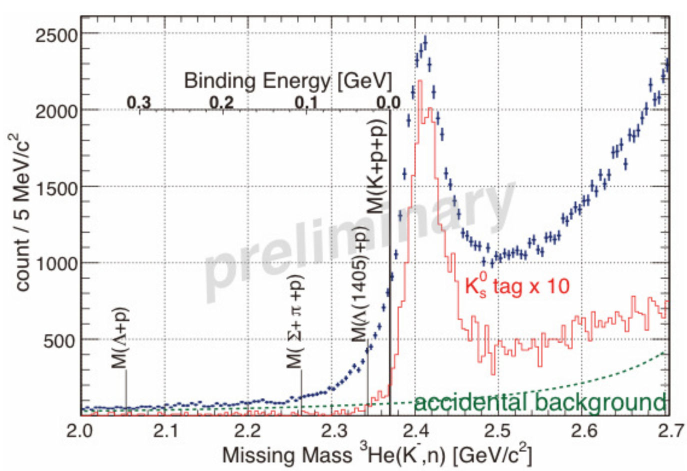

Fig. 6. Missing-mass spectrum of the $^3\mathrm{He}(K^-, n)$ reaction at forward angle [7]. One or more charged tracks are required in the CDS to reconstruct the reaction vertex. A spectrum with K^0_{S} tag in the CDS is overlaid with a scale factor of 10. The dotted line shows the accidental background obtained in Fig. 5.

Figure 6 shows the missing-mass spectrum of the $^3\mathrm{He}(K^-, n)$ reaction measured by the NC. It should be noted that 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 $K^-p \to \bar{K}^0 n$ reactions is seen just above mass threshold of one K^- and two protons (2.37 GeV/c^2). The K^0_S tagged spectrum overlaid in Fig. 6 is well reproduced by a Geant4-based Monte Carlo simulation with the evaluated missing-mass resolution of $\sim$ 10 MeV/c^2 (σ). So tail structure below the $K + p + p$ mass threshold seen in the spectrum is hard to be described by detector effects. Further analyses are in progress to understand the structure below the threshold.

4. Summary

The first physics data-taking of the J-PARC E15 experiment was conducted to search for the simplest kaonic-nuclear bound-state, K^-pp, via $^3\mathrm{He}(K^-, n)$ reaction at 1 GeV/c. 5×10^9 kaons were incident on the ^{3}He target, and 3×10^5 neutrons were collected by the NC at zero degree. The semi-inclusive $^3\mathrm{He}(K^-, n)$ spectrum shows clear peak structure composed of the quasi-elastic $K^-n \to K^-n$ and the charge exchange $K^-p \to \bar{K}^0 n$ reactions as expected. Further analyses of the semi-inclusive $^3\mathrm{He}(K^-, n)$ and a exclusive $^3\mathrm{He}(K^-, \Lambda pn)$ channels are in progress.

REFERENCES

[1] M. Iwasaki *et al.*, *Phys. Rev. Lett.* **78**, 3067 (1997); G. Beer *et al.*, *Phys. Rev. Lett.* **94**, 212302 (2005); M. Bazzi *et al.*, *Phys. Lett.* **B704**, 113 (2011).

[2] A.D. Martin, *Nucl. Phys.* **B179**, 33 (1981).

[3] Y. Akaishi, T. Yamazaki, *Phys. Rev.* **C65**, 044005 (2002); T. Yamazaki, Y. Akaishi, *Phys. Lett.* **B535**, 70 (2002); T. Yamazaki, Y. Akaishi, *Phys. Rev.* **C76**, 045201 (2007); N.V. Shevchenko *et al.*, *Phys. Rev.* **C76**, 044004 (2007); T. Nishikawa, Y. Kondo, *Phys. Rev.* **C77**, 055202 (2008); S. Wycech, A.M. Green, *Phys. Rev.* **C79**, 014001 (2009); A. Dote, T. Hyodo, W. Weise, *Phys. Rev.* **C79**, 014003 (2009); Y. Ikeda, T. Sato, *Phys. Rev.* **C79**, 035201 (2009); J. Yamagata-Sekihara *et al.*, *Phys. Rev.* **C80**, 045204 (2009); T. Koike, T. Harada, *Phys. Rev.* **C80**, 055208 (2009).

[4] M. Agnello *et al.*, *Phys. Rev. Lett.* **94**, 212303 (2005); T. Yamazaki *et al.*, *Phys. Rev. Lett.* **104**, 132502 (2010); L. Fabbietti *et al.*, *Nucl. Phys.* **A914**, 60 (2013); A.O. Tokiyasu *et al.*, `arXiv:1306.5320 [nucl-ex]`.

[5] M. Iwasaki, T. Nagae [E15 Collaboration], J-PARC E15 proposal, `http://j-parc.jp/NuclPart/pac_0606/pdf/p15-Iwasaki.pdf`

[6] K. Agari *et al.*, *Prog. Theor. Exp. Phys.* **2012**, 02B011 (2012).

[7] T. Hashimoto *et al.*, INPC2013 proceedings submitted to EPJ.