A Search for Deeply Bound Kaonic Nuclear States at J-PARC

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Abstract The J-PARC E15 experiment has the aims to search for the simplest kaonic nuclear bound state, \( K^-pp \), by the in-flight \(^3\text{He}(K^-, n)\) reaction. The exclusive measurement is performed by a simultaneous measurement of the missing mass using the knocked out neutron and the invariant mass via the expected decay, \( K^-pp \rightarrow \Lambda p \rightarrow p\pi^-p \). In this paper, an overview of the experiment and current data analysis of the engineering runs performed in February and June 2012 are presented.
1 Introduction

The $\bar K N$ interaction is expected to be strongly attractive, but this is still not fully understood. In particular, the simplest $K$-nuclear cluster, $K^- pp$, is interesting. In recent years, many theoretical works have supported the existence of the $K^- pp$ bound state, but the predicted binding energies and widths are widely divergent [1–4]. Experimentally, however, only little information is available [5,6], which is insufficient to discriminate among a variety of conflicting interpretations. In order to clarify this controversial issue, the J-PARC E15 experiment was proposed to search for the $K^- pp$, via the in-flight $^3\text{He}(K^-, n)$ reaction using a 1.0 GeV/$c K^-$ beam [7]. This experiment has the advantage that the exclusive measurement can be performed by a simultaneous measurement of the missing mass spectrum using the knocked out neutron and invariant mass spectroscopy via the expected decay $K^- pp \rightarrow \Lambda p \rightarrow p \pi^- p$.

2 Experimental Method and Apparatus

The E15 experiment is performed at the K1.8BR beam-line in the Hadron hall at J-PARC. The layout of the K1.8BR and the E15 spectrometer are shown in Fig. 1. The spectrometer consists of four parts—the Beam-line Spectrometer, the cylindrical detector system (CDS) with liquid $^3\text{He}$ target system, the Beam Sweeping Magnet and the Neutron TOF wall. A secondary $K^-$ beam is focused on the liquid $^3\text{He}$ target which is located at the center of the CDS. The decay particles from the expected decay $K^- pp \rightarrow \Lambda p \rightarrow p \pi^- p$ are detected by the CDS, and the neutron counter detects forward neutrons whose flight length is about 15 m. Incident kaons passing through the target are bent by the sweeping magnet which is placed right after the CDS.

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2.1 Beam-line Spectrometer

The beam-line spectrometer consists of beam line magnets, tracking chambers, hodoscopes, cherenkov counters and timing detectors. The beam trigger is generated by a coincidence signal of a Beam Hodoscope Detector and a Time Zero counter (T0).

2.2 Cylindrical Detector System (CDS)

A schematic view of the CDS with the target system is shown in Fig. 2. 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 provided by the solenoid magnet. The CDH is used for particle identification and as a charged particle trigger.

2.3 Neutron TOF Wall

A forward neutron generated by the in-flight ($K^-$, $n$) reaction is detected by the neutron TOF counter located 14.7 m down stream of the final focus point in which the experimental target is installed. The neutron TOF counter consists of an array of scintillation counters which has an effective volume of 3.2 m (horizontal) $\times$ 1.5 m (vertical) $\times$ 0.35 m (depth) segmented into 16-columns (horizontal) $\times$ 7-layers (depth) units. The average time resolution of the neutron counter, measured with cosmic rays, is $92 \pm 10$ ps ($\sigma$). The detection efficiency
for a $\sim 1\text{GeV}/c$ neutron is estimated to be $\sim 35\%$ from the Monte Carlo simulation using by the GEANT4 toolkit.

3 Analysis of Engineering Run

An engineering run with the full setup of the E15 experiment was conducted in June 2012. Based on this data, the performance of each spectrometer is shown below.

3.1 PID and Invariant Mass Spectrum in CDS

The identification of secondary charged particles was performed by the CDH using TOF measurements together with T0. Figure 3 shows the distributions of the momentum versus $1/\beta$. Pions, kaons, protons, and deuterons are clearly separated. Using the momentum reconstruction and the particle identification, the invariant mass of $p\pi^-$ was reconstructed as shown in Fig. 4. A clear peak of $\Lambda \rightarrow p\pi^-$ decay can be seen. The centroid of $\Lambda$ is obtained as $1113.6 \pm 0.1 \text{MeV}/c^2$ ($M_\Lambda = 1113.4 \text{MeV}/c^2$, PDG) with a resolution of $\sigma = 3.5 \pm 0.1 \text{MeV}/c^2$ (expected 3.5 MeV/$c^2$ from GEANT4 simulation); the CDS performance has been reproduced by the simulation.

3.2 Neutron TOF Spectrum

The resultant $1/\beta$ spectrum of the neutral particles between T0 and the neutron counter is shown in Fig. 5 in which charged particles are vetoed by the beam veto counter and the charge veto counter. $\gamma$ rays and neutrons

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

Fig. 4 Invariant mass spectrum of $p\pi^-$. The spectrum is fitted with a Gaussian and a background curve
are clearly separated in the spectrum. The TOF resolution between T0 and the neutron counter is typically 150 ps ($\sigma$). With the measured TOF resolution, the expected missing mass resolution for the $^3\text{He}(K^-, n)K^- pp$ reaction is evaluated to be 9 MeV/$c^2$ ($\sigma$), which satisfies the E15 requirement of less than 10 MeV/$c^2$ ($\sigma$).

4 Conclusion

The J-PARC E15 experiment is being performed to search for the simplest kaonic nuclear bound state, $K^- pp$, by the in-flight $^3\text{He}(K^-, n)$ reaction. The exclusive measurement can be performed by a simultaneous measurement of the missing mass using the primary neutron and the invariant mass via the expected decay, $K^- pp \rightarrow \Lambda p \rightarrow p\pi^- p$. Commissioning of the beam line spectrometer and engineering run with the full setup of the E15 experiment were successfully performed with a 1.0 GeV/$c$ kaon beam in February and June 2012, respectively. The results obtained show that the design goal of the spectrometer has been achieved. The experiments at K1.8BR are ready now, and physics output will be reported in the near future.

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