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$\Lambda(1405)$ Spectroscopy via the In-flight $d(K^-, n)$ Reaction at the J-PARC K1.8BR

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The spectral shape of the Λ(1405) baryon was measured via the in-flight d(K-, n) reaction at the J-PARC K1.8BR beam-line (J-PARC E31). The second E31 physics run was carried out in January and February, 2018. Approximately 3.9×10^{10} kaons were irradiated on the deuteron target. The missing mass spectrum for the d(K^-, n) where the residual final-state particles were Σ^0 and π^0 (d(K^-, n)"$\Sigma^0\pi^0$" spectrum) was measured for the first time.

KEYWORDS: in-flight d(K-, n) reaction, Λ(1405), spectral shape,

1. Introduction

The Λ(1405) baryon is well-known hyperon with isospin *I*=0, spin-parity J^p=$1/2^-$, mass m∼1405 MeV, and width Γ∼50 MeV [1]. Λ(1405) is the lightest among negative-parity baryons although it contains a heavy strange quark. This is difficult to explain in a naïve quark model. Since Λ(1405) is located 27 MeV below the $\bar{K}N$ threshold, Λ(1405) has been speculated as a $\bar{K}N$ molecular state for a long time. According to the chiral unitary model, the pole appears at 1426-16i MeV in the S-wave $\bar{K}N$ scattering amplitude [2]. In the experimental situation, some reports about Λ(1405) show that measured spectral shapes are different in different Λ(1405) production reactions. Therefore, a further experimental measurement which is sensitive to the $\bar{K}N$-Λ(1405) coupling was proposed at the J-PARC K1.8BR beam-line (J-PARC E31 [3]). Since Λ(1405) cannot be formed directly from K^-p scattering in free space, we use the reaction of d(K^-, n) with an incident kaon momentum of 1 GeV/c. We measure the Λ(1405) spectrum shape given as a missing-mass distribution of the d(K^-, n) reaction and identifying the three final states: $\Sigma^-\pi^+$, $\Sigma^+\pi^-$, and $\Sigma^0\pi^0$ so that isospin amplitudes of *I*=0,1 and their interference are decomposed.

2. Experimental setup

The E31 experiment is performed at the K1.8BR beamline in the Hadron Experimental Hall at J-PARC. The schematic drawing of the K1.8BR spectrometer and experimental setup for the E31 experiment is shown in Fig. 1 [4]. The K^- beam momentum is analyzed by the beam-line spectrometer with a resolution of 2.2 MeV/c at 1.0 GeV/c. Decay charged particles associated with the d(K^-, n) reaction are detected by a cylindrical detector system (CDS) surrounding a deuterium target to obtain their momentum and time of flight. CDS is operated in a magnetic field of 0.7 T. The Neutron Counter (NC) and Proton Counter (PC), which detect neutrons and protons, respectively, are placed 15 m ahead in the forward direction. Since Λ(1405) recoils backward when a neutron is emitted at a forward angle, a decay proton in the $\Sigma^0\pi^0$ mode ($\Sigma^0\pi^0 \rightarrow \Lambda\gamma\pi^0 \rightarrow p\pi^-\gamma\pi^0$) is emitted backward, which is detected with a backward proton detector (BPD) and chamber (BPC) placed upstream of the target.

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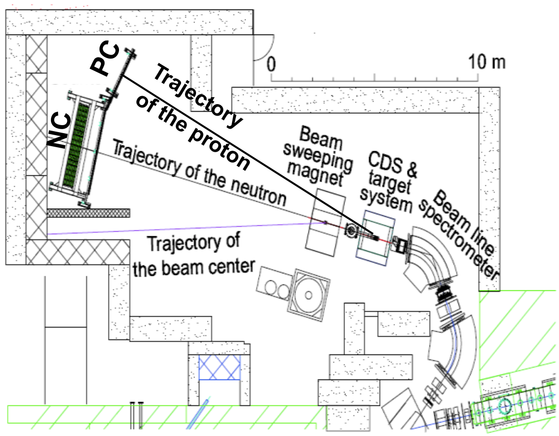

Fig. 1. Schematic view of the K1.8BR spectrometer.

3. Preliminary results

Following to the 1st E31 physics run carried out in June 2016, we have performed the 2nd E31 physics run to observe the $d(K^{-}, n)$"$\Sigma^0\pi^0$" spectrum with further statistics in January and February in 2018, and completed the proposed beam time including the first run. Approximately 3.9×10^{10} kaons were irradiated on the deuterium target during the E31-2nd run.

The events, in which a proton is detected with BPD and BPC and π^- is detected with CDS, are analyzed to identify Λ production using the p π^- invariant mass. Fig. 2 shows the p π^- invariant mass distribution, where contribution from $K^-d \rightarrow \Sigma^-p$ ($\rightarrow n\pi^-p$) was rejected, as shown in Fig. 3.

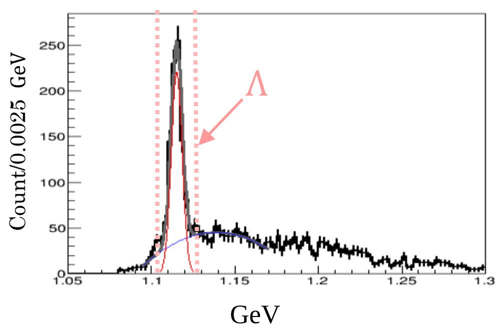

Fig. 2. p π^- invariant mass distribution. The Λ produced events are selected in the range from 1.10 GeV to 1.12 GeV.

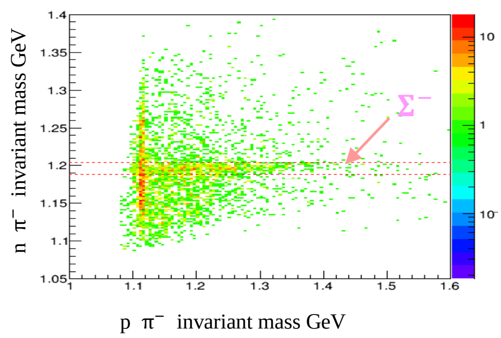

Fig. 3. Correlation between the p π^- invariant mass and the n π^- invariant mass. Σ^- contribution can be easily rejected with an n π^- invariant mass ranging from 1.18 GeV to 1.20 GeV.

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The $\Sigma^0\pi^0$ final state is separated from the $\Lambda\pi^0$ and $\Lambda(\pi\pi)^0$ final states by looking at the d(K^-, nΛ) missing mass spectrum, as shown in Fig. 4. The estimations of $\Lambda\pi^0$ and $\Lambda(\pi\pi)^0$ in Fig. 4 are performed by a Monte Carlo simulation(MC). The momentum distributions of forward neutrons in MC are generated to follow the data of d(K^-, nΛ) missing mass in the range from 0.00 GeV to 0.18 GeV for $\Lambda\pi^0$ and 0.30 GeV to 0.50 GeV for $\Lambda(\pi\pi)^0$ respectively. A magnitude of the $\Lambda\pi^0$ distribution is scaled so that the

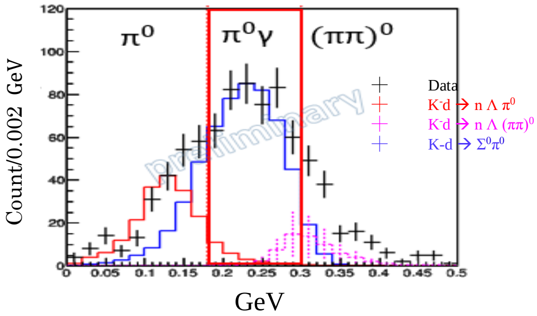

Fig. 4. d(K^-, nΛ) missing mass spectrum. The $\Lambda\pi^0\gamma$ events are selected in the range from 0.18 GeV to 0.3 GeV. The estimation of $\Lambda\pi^0$ (red) , $\Lambda(\pi\pi)^0$ (magenta) and $\Sigma^0\pi^0$ (blue) contributions are presented.

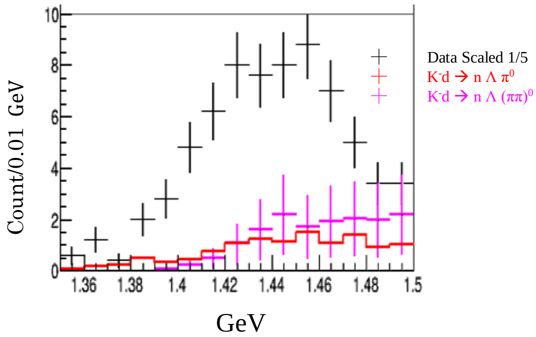

Fig. 5. Missing mass spectrum of d(K^-, n) "$\Sigma^0\pi^0$". Contaminations of $\Lambda\pi^0$ (red) and $\Lambda(\pi\pi)^0$ (magenta) in the d(K^- , n) "$\Sigma^0\pi^0$" spectrum.

peak fits data at the π^0 mass. The $\Lambda(\pi\pi)^0$ distribution is estimated by the data of $K^-d \to \Lambda\pi^+\pi^-n$. The contaminations of $\Lambda\pi^0$ and $\Lambda(\pi\pi)^0$ in the d(K^-, n)"$\Sigma^0\pi^0$" are found to be small, as shown in Fig. 5.

Finally, we considered the background of $K^-d \to \Sigma^+\pi^-n(\to p\pi^0\pi^-n)$. The $\Sigma^+\pi^-$ is one of the final state of $\Lambda(1405)$. The background $\Sigma^+\pi^-$ contribution also can be estimated by missing mass of d(K^-, n$p\pi^-$)"π^0" which is expected to be the same result as $\Lambda\pi^0$, as shown in Fig. 4 and Fig.5.

Figure 6 shows the preliminary result of the d(K^- , n) "$\Sigma^0\pi^0$" spectrum without acceptance correction. The $\Sigma^+\pi^-$ contribution is plotted in Fig.6. We observe significant yields below and above the $\bar{K}N$ threshold.

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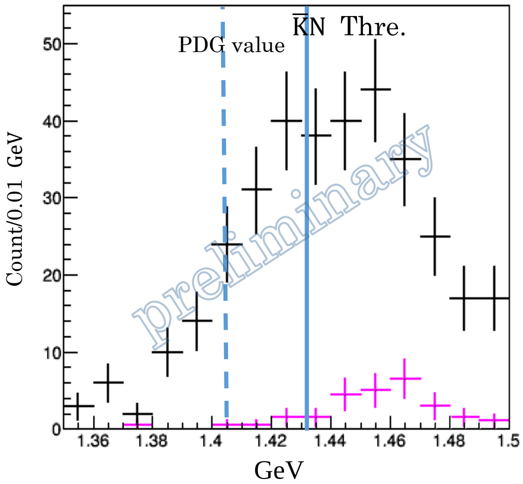

Fig. 6. Missing mass spectrum of d(K$^-$, n)"$\Sigma^0\pi^0$" The background contribution (magenta) from Λ selection using the p π^- invariant mass is presented.

4. Summary

The J-PARC E31 experiment was performed to investigate the spectrum shape of $\Lambda(1405)$ directly generated in $\overline{K}N \to \Sigma\pi$ process using the in-flight d(K$^-$, n) reaction at the incident kaon momentum of 1.0 GeV/c. We succeeded the identification of $\Sigma^0\pi^0$ final state in the E31-1st data, then observed the d(K$^-$, n)"$\Sigma^0\pi^0$" spectrum in the E31-2nd data with 4.5 times as many as the 1st data. The backgrounds of $\Lambda\pi^0$, $\Lambda(\pi\pi)^0$ as well as $\Sigma^+\pi^-$ are estimated to be very small.

We will finalize the d(K$^-$, n)"$\Sigma^0\pi^0$" spectrum by correcting detector's acceptance and efficiency, and obtain information on the scattering amplitude of $\overline{K}N \to \Sigma\pi$ below and above the $\overline{K}N$ threshold.

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