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Study of Y^* in Nuclei through C(K^-, π^+)X Spectrum at 1.8 GeV/c in the J-PARC E05 Experiment

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We measured the (K^-, π^+) reaction spectra at 1.8 GeV/c for the graphite and the polyethylene targets in the J-PARC E05 pilot experiment. By comparing the spectra for these two targets, it was found that Σ^{*-}(1385) in the ^{11}B nucleus is quite broadened. Furthermore, we also compared broadness of Σ^{*-}(1385) with K^*(892) obtained in the (K^-, p) spectrum. Σ^{*-}(1385) seems to be much more broadened in nuclei than K^*(892). We gave a possible interpretation, which is related to compositeness of decuplet baryons, for this situation.

KEYWORDS: Strangeness, hypernuclear, decuplet baryon, Σ(1385)

1. Introduction

Understanding of behavior of decuplet baryons in nuclei is not simple due to its short life time comparing to those of octet baryons. Δ in nuclei have been energetically studied in past experimental and theoretical works, and today, it is an important part of the nuclear physics. On the other hand, behavior of the decuplet hyperons, Y^*, in nuclei is still unknown. Although the property of Y^* in free space has been well studied, no systematic study of Y^* in nuclei has been studied. In this article, we focus on $\Sigma^*(1385)$ in nuclei. One of the recent topic about $\Sigma^*(1385)$ in nuclei was reported in J-PARC E27 experiment [1]. In this experiment, a Y^* peak structure produced via the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c was seen in the missing mass spectrum. However, its peak position was shifted to the lighter mass side than that expected by a Monte Carlo simulation. This phenomena is still open question. Here, we report about $\Sigma^{*-}(1385)$ produced via the C(K^-, π^+)X double charge-exchange reaction at 1.8 GeV/c. The experimental condition and the analysis are described in Sec.2, and the result is shown in Sec.3. The discussion on our result is given in Sec.4.

2. Experiment

We performed the J-PARC E05 pilot experiment, which was search for the Ξ^- hypernucleus via the (K^-, K^+) reaction at the K1.8 beam line in J-PARC in 2015. The K^- beam with a momentum of 1.8 GeV/c were driven onto the graphite target of 9.364 g/cm^2 during physics data taking. In addition, the calibration data set for the polyethylene target of 9.538 g/cm^2 was also taken at the same beam momentum. In this experiment, the (K^-, π^+) events were simultaneously taken as a by-product with the pre-scale factor of three. As we discussed in Sec.4, the (K^-, p) events were also taken. Here, we report about the (K^-, π^+) spectra in these data sets. The effective number of K^- beams used in this analysis were 24.9×10^9 and 3.18×10^9 for the graphite and the polyethylene targets, respectively. (Note that these numbers already contain several analysis efficiencies and the pre-scale factor.)

Beam and scattered particles momenta were measured by the beam line spectrometer and the super conducting kaon spectrometer (SKS) complex [2], respectively. The beam line spectrometer consisted of a scintillating fiber tracker [3], multi-wire drift chambers (MWDC) [4], and the analyzer magnets arranged in a *QQDQQ* configuration. In addition, two timing hodoscope counters and two aerogel Čerenkov counters were installed for K^- beam identification. On the other hand, the SKS complex was comprised of MWDC and the SKS magnet. In this experiment, the SKS complex components were arranged so as to maximize an acceptable momentum range. Then, the wide momentum range of 1.1-2.5 GeV/c was achieved. Owing to this feature, the Σ^- and the $\Sigma^{*-}(1385)$ events were simultaneously taken in the same data set. The scattered π^+ was identified by an aerogel Čerenkov counter, a Lucite Čerenkov counter, and a time-of-flight (TOF) wall in a trigger level. Owing to the aerogel Čerenkov counters, a contamination from other beam and scattered particles were well suppressed. Finally, we selected K^- and π^+ by the time-of-flight information. Thus, we calculated the missing mass spectra for the (K^-, π^+) events. Momentum calibration for the spectrometers was done using the Σ^- and the Ξ^- missing mass peaks obtained in the data set with the polyethylene target. The missing mass resolution was also evaluated from these peaks and was 7 MeV in FWHM, which was sufficient to discuss a broad structure such as Y^*.

3. Results

We show the obtained (K^-, π^+) spectra for the reaction angle of 2-14 degree in lab. system in Fig.1 (a). The spectra for the polyethylene and the graphite targets are represented in black and red points with statistical error bars. When we calculated the missing mass, a proton at rest was assumed as the target. Note that the spectrum for the graphite target was scaled by a factor of 0.5. The Σ^- and the $\Sigma^{*-}(1385)$ peaks are clearly seen in the spectrum for the polyethylene target. In the spectrum for the graphite target, the Σ quasi-free events can be seen under the prominent Σ^- peak. However, almost no structure is seen around 1385 MeV/c^2. The spectrum shape around the $\Sigma^{*-}(1385)$ region is flat and indicates that $\Sigma^{*-}(1385)$ in the ^{11}B nucleus is quite broadened.

One can notice that the background contribution exists around the $\Sigma^{*-}(1385)$ region by comparing two spectra in Fig.1 (a). Then, we extracted the proton contribution as shown in Fig.1 (b) by

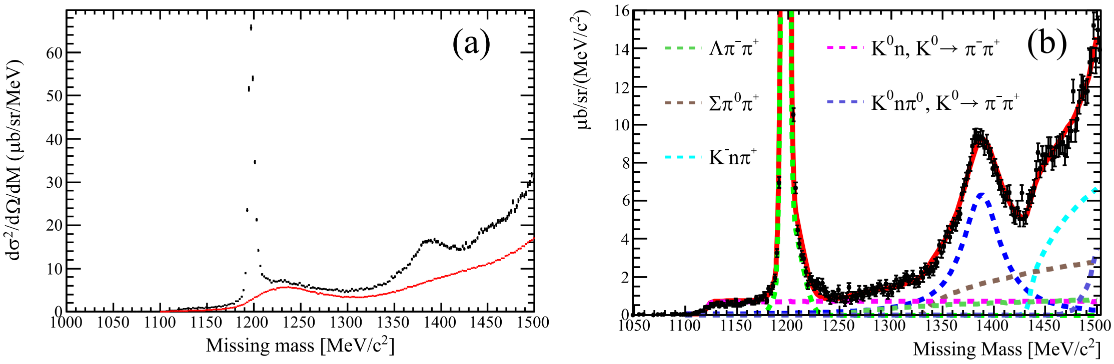

Fig. 1. (a) The (K^-, π^+) spectra for the reaction angle of 2-14 degree in lab. system. The spectra for the polyethylene and the graphite targets are shown by black and red points, respectively. The horizontal axis is the missing mass when assuming a proton at rest is the target. (b) The proton contribution obtained by subtracting the carbon contribution from the polyethylene spectrum. Possible background components and template fitting result are also shown.

subtracting the graphite spectrum from the polyethylene spectrum so as to understand background components. Possible background components of the (K^-, π^+) spectrum are listed in Fig.1 (b). Probability density functions (PDF) of these components were prepared by the Monte Carlo simulation. Thus, the spectrum was fitted as seen in Fig.1 (b) using background PDF and a Breit-Wigner function for $\Sigma^{*-}(1385)$ and a Gaussian function for Σ^-. The red line in Fig.1 is the sum of all the functions and represents the fitting result. In this fitting, area of PDF and the Breit-Wigner and the Gaussian functions were free parameters and phenomenologically determined to reproduce the experimental result. As the result, it was found that the cross section of $\Sigma^{*-}(1385)$ was around 80% of Σ^-. Even a bump structure is not seen in spite of non-negligible contribution from the $\Sigma^{*-}(1385)$ production.

4. Discussion

Thus far, we focused on broadness of $\Sigma^{*-}(1385)$ in the ^{11}B nucleus. Let us move to the (K^-, p) spectrum shown in Fig.2 in order to discuss this result. The (K^-, p) spectra for the polyethylene and the graphite targets are represented by black and red makers, respectively. In this reaction, the beam K^- remained in the target nuclus while the proton was knocked out to the forward angle. A peak at the K^- mass corresponds to the elastic scattering with protons in the polyethylene target. When we look toward the higher mass region, the bump structure of $K^*(892)$ is seen around 890 MeV/c^2 in the polyethylene target spectrum. Contrary to $\Sigma^{*-}(1385)$, this bump structure remained in the graphite target spectrum. Since the natural width of $\Sigma^{*-}(1385)$ and $K^*(892)$ are 39.4 ± 2.1 MeV and 50.3 ± 0.8 MeV [5], respectively, this result indicates that $\Sigma^{*-}(1385)$ is much broadened comparing to $K^*(892)$.

We discuss the reason making this situation. Unfortunately we are not able to give a clear conclusion from our experimental result, but consider one possible scenario. The quite broadened $\Sigma^{*-}(1385)$ in nuclei cannot be explained by the Fermi motion only. The bump structure of $\Sigma^{*-}(1385)$ must be seen if the reason of broadness is only the Fermi motion as the peak structure of Σ^- in the graphite target spectrum is still seen in Fig.1 (a). Thus, we focus on the spreading width coming from the internal structure of $\Sigma^{*-}(1385)$. Recently, the CLAS collaboration reported the decay width ratio of $\Sigma^{*0}(1385)$ between $\Sigma^{*0}(1385) \to \Lambda\gamma$ and $\Sigma^{*0}(1385) \to \Lambda\pi^0$ [6]. They suggested that this decay width ratio was 1.5-3.0 times larger than several theoretical predictions, that is, the EM decay width was large. This implies compositeness of decuplet baryons discussed as the pion cloud effect in Δ [7]. Then, $\Sigma^{*-}(1385)$ in nuclei may be strongly coupled with the YN final state due to stripping out cloud π, i.e., Y^*N is a doorway to the YN channel. However, this scenario is the same as for Δ in nuclei The

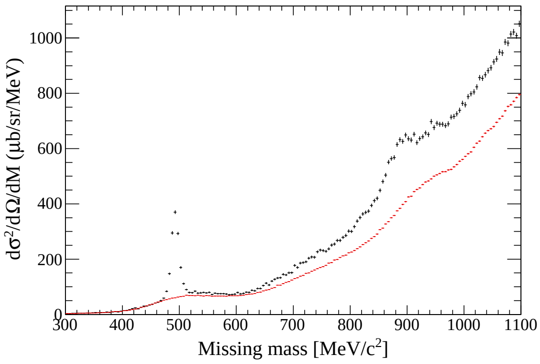

Fig. 2. The (K^-, p) spectra for the reaction angle of 3.5-4.5 degree in lab. system. The spectra for the polyethylene and the graphite targets are shown by black and red points, respectively. The horizontal axis is the missing mass when assuming a proton at rest is the target.

next point is the Pauli effect at the final state. When a ΔN system is converted to NN in nuclei, the converted nucleon is blocked by the Pauli principle, but the hyperon in the final state is free from the Pauli effect between nucleons. Thus, $\Sigma^{*-}(1385)$ could be quite broadened in nuclei.

As mentioned above, this is just the possible scenario. To give a clear explanation, a detailed theoretical treatment is necessary. In addition, we should measure A dependence of this phenomena to more clearly understand because the strength of the $Y^*N \to YN$ coupling effect is related to the number of surrounding nucleons.

5. Summary

Today, behavior of decuplet hyperon in nuclei is still not well known due to lack of experimental studies. In the J-PARC E05 pilot experiment, we measured the (K^-, π^+) spectra at the beam momentum of 1.8 GeV/c for the graphite and polyethylene targets. The clear peak structure of $\Sigma^{*-}(1385)$ exists in the spectrum for the polyethylene target coming from $K^- p \to \Sigma^{*-}(1385)\pi^+$ while almost no structure is seen for the graphite target. It indicates that $\Sigma^{*-}(1385)$ in the ^{11}B nucleus is quite broadened. Furthermore, we compared this result with $K^*(892)$ in nuclei obtained in the (K^-, p) spectrum in this experiment. Then, it was found that $\Sigma^{*-}(1385)$ was more broadened than $K^*(892)$. In this article, we give one possible scenario from the view point of the internal structure of $\Sigma^{*-}(1385)$. However, more theoretical and experimental studies are necessary to give the conclusion for this situation.

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