Extended Abstract

Signature of $\Lambda(1405)$ Resonance in the Triton and Pion Momentum Spectrum due to Stopped Negative Kaon on ^{4}He

Jafar Esmaili*, Morteza Mirzaei

Department of Physics, Faculty of Basic Sciences, Shahrekord University, Shahrekord, Iran

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Abstract

In the present study, the trace of $\Lambda(1405)$ resonance in the triton and pion momentum spectrum due to resonant absorption of stopped kaon on ^{4}He has been calculated and investigated using the coupled-channel approach. For this purpose, different phenomenological and chiral kaon-nucleon potentials such as Akaishi-Yamazaki, Hyodo-Wise and one- and two-pole KEK and one- and two-pole SIDDHARTA have been used. Likewise, by calculation of the pion and triton deviation momentum spectra, we have shown that the effect of $\Lambda(1405)$ resonance is clearly visible in the spectra and such spectra can yield useful information regarding $\bar{K}N$ interaction and $\Lambda(1405)$ resonance.

Keywords: Stopped negative kaon, Kaonic nuclei, $\Lambda(1405)$ Resonance and momentum deviation spectrum

Introduction

The properties of the $\Lambda(1405)$ resonance have been studied for a long time. Traditionally, it has been considered as a meson-baryon bound state coupled to the $\Sigma\pi$ and $\bar{K}N$ channels. Starting from this $\Lambda(1405)$ Ansatz, Akaishi and Yamazaki constructed a phenomenological $\bar{K}N$ potential by a coupled channel procedure and predicted deeply bound dense kaonic nuclear systems [1]. Recently, on the other hand, in contrast to the Akaishi-Yamazaki's interpretation of $\Lambda(1405)$, some theories starting from the chiral SU(3) dynamic claim that $\Lambda(1405)$ consists of two poles around 1420 and 1400 MeV/c^2, which are coupled mainly to $\bar{K}N$ and $\Sigma\pi$ channels, respectively [2].

Then, the less attractive $\bar{K}N$ interaction leads to shallower binding of $\bar{K}$ nuclei. It is urgently important to ask a crucial question: where is the position of the I = 0 L = 0 K^-p quasi-bound state? This question is directly connected to the strength of the s-wave I = 0 $\bar{K}N$ interaction.

In the present study, the trace of $\Lambda(1405)$ resonance has been calculated and investigated in the triton and pion momentum spectrum due to resonant absorption of stopped kaon on ^{4}He using the coupled-channel approach.

* Corresponding Author: jafar.esmaili@gmail.com

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K^-p state as a Feshbach resonance

For a model setting we treat the K^-p quasi-bound state as a Feshbach resonance, which is embedded in the continuum of $\Sigma\pi$ [3]. We consider two channels of $\bar{K}N$ and $\Sigma\pi$ for simplicity [4, 5]. We employ a set of separable potentials with a Yukawa-type form factor [6],

$$\left\langle \vec{k}' \middle| V \middle| \vec{k} \right\rangle = g(\vec{k}')U_0 g(\vec{k}), \quad g(\vec{k}) = \frac{\Lambda^2}{\Lambda^2 + \vec{k}^2}$$

$$U_{ij} = \frac{1}{\pi^2}\frac{\hbar^2}{2\sqrt{\mu_i\mu_j}}\frac{1}{\Lambda}s_{ij}$$

where i (j) stands for the $\bar{K}N$ channel, 1, or the $\Sigma\pi$ channel, 2, μ_i (μ_j) is the reduced mass of channel i (j), and s_{ij} are nondimensional strength parameters.

Momentum spectrum of decay particles from stopped K^- on ^{4}He nuclei

In our calculation, we treat a single proton bound in a ^{4}He nucleus with a binding energy B_p and the remaining part of the nucleus as a spectator (*triton*). We have considered a potential between them so that it reproduces the experimental binding energy for the p + t system [7]. The momentum distribution of the decay particles in the K^- s-orbit absorption is given as

$$\frac{d\Gamma}{dk_t} = \frac{2(2\pi)^3}{\hbar^2c^2}\left|\psi_{nlm}^{atom}(0)\right|^2 \int_0^\infty dk_\Sigma k_\Sigma k_t E_\pi(X_0)\left| g(\frac{1}{2}(\vec{k}_\pi - \vec{k}_\Sigma))T_{21}(E_2)g(-\frac{1}{2}\vec{k}_t)F(-\vec{k}_t)\right|^2$$

$$E_2 = \sqrt{(E_i - E_t)^2 - \hbar^2c^2k_t^2} - M_\Sigma c^2 - m_\pi c^2$$

$$X_0 = \frac{(E_i - E_\Sigma - E_t)^2 - m_\pi^2c^4 - \hbar^2c^2(k_\Sigma^2 + k_t^2)}{2\hbar^2c^2k_\Sigma k_t}$$

where $\psi_{nlm}^{atom}(0)$ is a K^- atomic wave function; k_Σ, k_π and k_t are the momenta of Σ, π and triton, respectively, and the T_{21} involves the Λ^* resonance effect.

Triton and pion momentum spectrum

We have also calculated triton and pion momentum spectra for stopped K^- on ^{4}He with the s-orbit absorption for various models and parameters of $\Lambda(1405)$. For this purpose, different phenomenological and chiral kaon-nucleon potentials such as Akaishi-Yamazaki [1], Hyodo-Wise [8] and one- and two-pole KEK [9] and one- and two-pole SIDDHARTA [10] have been used. The calculated spectra shape based on the double pole models are compared with the corresponding single-pole cases. The double-pole cases are in excellent agreement with the corresponding single-pole cases, indicating clearly that the second pole does not bring any effect in T_{21} Momentum spectra. There is virtually no change of spectra, indicating that the second pole is irrelevant to these experimental observables.

To reveal the peak-like structure of the resonance, a new analysis technique, the **Deviation Spectrum Method**, was employed. This method enhances the visibility of resonance signals by producing spectra in which resonance structures appear more distinctly. By calculating the deviation momentum spectra of the pion and triton, we demonstrated that the resonance effect is clearly manifested in these spectra. Therefore,

the deviation spectra provide a powerful tool for extracting valuable information on the resonance properties and the underlying interaction responsible for its formation.

Conclusion

We investigate the momentum spectra of final-state particles in stopped K^- on ^{4}He to identify signatures of $\Lambda(1405)$ resonance. We used different models of potential to describe the $\bar{K}N$ - $\pi\Sigma$ interaction and the dependence of the extracted results to the $\bar{K}N$ models of interaction was studied. It was shown that the pion and triton spectra can be suitable for probing the structure of the $\Lambda(1405)$ resonance in K^- + ^{4}He reaction.

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