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THREE-BODY RESONANCE POLE OF STRANGE DIBARYON IN THE $\overline{K}NN - \pi YN$ COUPLED SYSTEM

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Abstract

$\overline{K}NN$ three body resonance has been studied by $\overline{K}NN - \pi YN$ coupled channel Faddeev equation. The S-matrix pole has been investigated using the scattering amplitude on the unphysical Riemann sheet. As a result we found a three-body resonance of strange dibaryon system with the binding energy $B \sim 79$MeV and the width $\Gamma \sim 74$MeV.

1 Introduction

The meson-nucleus bound state has been an important tool to study the meson properties inside the nuclear medium. The $\overline{K}$-nuclear system is particularly interesting because of the $I = 0$ resonance $\Lambda(1405)$ below the $\overline{K}N$ threshold. The attractive nature of the kaon-nucleus interaction obtained from the analysis of the kanonic atom [1] might be largely related to the $\Lambda(1405)$. In a few nucleon system, where one hopes to learn about the kaon-nucleon interaction with less ambiguity on nuclear many body dynamics, possible deeply bound states of the kaon in nuclei have been proposed by Akaishi and Yamazaki [2]. The predicted binding energy B and width Γ of the smallest nuclear system K^-pp is $(B, \Gamma) = (48, 61)$MeV. FINUDA collaboration reported a signal of the K^-pp bound state from the analysis of the invariant mass distribution of $\Lambda - p$ in the K^- absorption reaction on nuclei [3]. The reported central value of the binding energy is $(B, \Gamma) = (115, 67)$MeV.

The binding energy of K^-pp resonance will be strongly influenced by the dynamics of the $\Lambda(1405)$ resonance. For the resonance interaction in a few body system, it will be very important to take into account fully

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the kaon-nucleon dynamics in the $\overline{K}NN$ system including the decay of the $\Lambda(1405)$ into the $\pi\Sigma$ state. The purpose of this work is to study the strange dibaryon system by taking into account the three-body dynamics using the $\overline{K}NN - \pi YN$ coupled channel Faddeev equation with the relativistic kinematics. The resonance can be studied from the pole of the S-matrix or scattering amplitude [4]. We briefly explain our procedure to search the three-body resonance in Sec. 2. The structure of the $\Lambda(1405)$ has been a long standing issue. The chiral Lagrangian [5] approach is able to describe well the low energy $\overline{K}N$ reaction. In this work, we describe a $\overline{K}N - \pi\Sigma$ state using the s-wave meson-baryon potentials guided from the lowest order chiral Lagrangian. The model of the two-body meson-baryon interaction used in this work is explained in Sec. 3. We report our result on the $\overline{K}NN$ dibaryon resonance in Sec. 4. This work is based on our previous works(see Refs. [6]).

2 AGS equation and resonance pole

Our starting point is the Alt-Grassberger-Sandhas(AGS) equation [7] for the three-body scattering problem. It is possible because all of our two-body interactions are separable forms. The AGS equation for the three-body scattering amplitude $X_{i,j}$ is given as

$$X_{i,j} = (1-\delta_{i,j})Z_{i,j} + \sum_{n\neq i}\int d\mathbf{p}_n Z_{i,n}\tau_n X_{n,j}. \quad (1)$$

Here we represent the spectator particle $i = 1, 2, 3$ and the interacting particles j, k. Scattering t-matrix for particle j, k is denoted as an isobar propagator τ_i and a driving term $Z_{i,j}$ denotes the particle exchange interaction. After anti-symmetrizing the amplitude for two nucleons [8] and the partial wave expansion of the amplitude restricting s-wave, the AGS-equation reduces into the following coupled integral equation,

$$X_{l,m}(p_l,p_m) = Z_{l,m}(p_l,p_m) + \sum_n \int dp_n p_n^2 K_{l,n}(p_l,p_n)X_{n,m}(p_n,p_m). \quad (2)$$

Here we used simplified notation for the kernel $K = Z\tau$. The AGS-equation of Eq. (2) is the Fredholm type integral equation with the kernel $K = Z\tau$. Using the eigenvalue $\eta_a(W)$ and the eigenfunction $|\phi_a(W)>$ of the kernel for given energy W, the scattering amplitude X can be written as

$$X = \sum_a \frac{|\phi_a(W)><\phi_a(W)|Z}{1-\eta_a(W)}. \quad (3)$$

At the energy $W = W_p$ where $\eta_a(W_p) = 1$, the amplitude has a pole and therefore W_p gives the bound state or resonance energy.

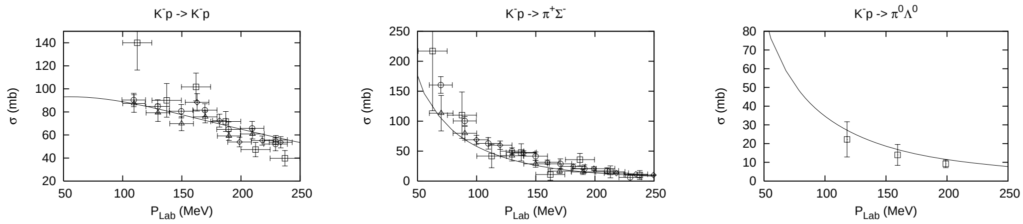

Figure 1: The total cross section of K^-p reaction together with data [10].

3 Two-body ingredients

In this section, we explain our model of the most important $\overline{K}N$ interaction. We start from the leading order chiral effective Lagrangian, and the meson-baryon potential can be written as

$$< \mathbf{p}', \alpha | V_{BM} | \mathbf{p}, \beta >= -C_{\alpha,\beta} \frac{1}{(2\pi)^3 8F_\pi^2} \frac{E_{M'}(\mathbf{p}') + E_M(\mathbf{p})}{\sqrt{4E_{M'}(\mathbf{p}')E_M(\mathbf{p})}} \times v_\alpha(\mathbf{p}') v_\beta(\mathbf{p}). \quad (4)$$

Here $\mathbf{p}$ and $\mathbf{p}'$ are the momentum of the meson in the initial state β and the final state α. The strength of the potential at zero momentum is determined by the pion decay constant F_π. The relative strength among the meson-baryon states is given by the constants $C_{\alpha,\beta}$, which are $C_{\overline{K}N-\overline{K}N} = 6$,$C_{\overline{K}N-\pi\Sigma} = \sqrt{6}$ and $C_{\pi\Sigma-\pi\Sigma} = 8$. The only parameter of our model is cut off Λ of the phenomenologically introduced vertex function $v_\alpha(\mathbf{p}) = \Lambda_\alpha^4/(\mathbf{p}^2 + \Lambda_\alpha^2)^2$. The cut off Λ is determined so as to reproduce the scattering length of $\overline{K}N$ given by Martin [9], which is summarized in Refs. [6]. In $I = 0$ channel, our model has a resonance. Our model predicts that the pole energy of the $\Lambda(1405)$ is $1420 - i30$MeV. Our model give satisfactory description of the total cross section of K^-p reaction at low energy shown in Fig. 1.

4 Result and Discussion

We have searched the resonance pole of the strange dibaryon ($J^\pi = 0^-, I = 1/2$) using the method described in Sec. 2 and the $\overline{K}N$ interaction explained in Sec. 3. NN interaction for $^1S_0$ channel and πN interaction are included in the AGS-equation. However YN interaction is not included in this work.

Our result of the $\overline{K}NN-\pi YN$ resonance pole energy is $W = M - i\Gamma/2 = 2m_N + m_K - 79.3 - i37.1$MeV. Our resonance has deeper binding energy and similar width compared with the prediction of Ref. [2]. Recently Shevchenko *et al.* [11] studied K^-pp system using coupled channel Faddeev equation with nonrelativistic kinematics. Their result is almost consistent with ours.

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