Investigate the pentaquark resonance in the NK system

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A dynamical calculation of pentaquark systems with quark contents \( uudd \bar{s} \) is performed in the framework of quark delocalization color screening model with the help of resonating group method. The effective potentials between baryon and meson clusters are given, and the possible bound states or resonances are investigated. The single calculations show that the \( N\phi \) with \( I = 0, J^P = \frac{1}{2}^- \), \( \Delta K^* \) with \( I = 1, J^P = \frac{1}{2}^- \), and \( \Delta K^* \) with \( I = 2, J^P = \frac{3}{2}^- \) are all bound, but they all turn into scattering states by coupling with the corresponding open channels. A possible resonance state \( \Delta K^* \) with \( I = 1, J^P = \frac{3}{2}^- \) is proposed. The mass is around 2110.5 MeV, and the decay modes are \( NK \) in \( D \)-wave or \( NK\pi\pi \) in \( P \)-waves.

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I. INTRODUCTION

After decades of experimental and theoretical studies of hadrons, A lot of multiquark candidates have been proposed for the hadrons beyond the ordinary quark-antiquark and three-quark structures. On one hand, the underlying theory of the strong interaction, quantum chromodynamics (QCD) does not forbid the existence of the exotic hadronic states such as glue-balls (without quark/antiquark), hybrids (gluon mixed with quark/antiquark), compact multiquark states and hadron molecules. On the other hand, dozens of nontraditional charmonium- and bottomonium-like states, the so-called hadron molecules, have been observed during the past decades by the experimental collaborations.

The intriguing pentaquark states were also searched in various colliders. In 2003, the LEPS collaboration announced the observation of pentaquark \( \Theta^+(1540) \) [14], an exotic \( K^+\pi^0 \) or \( K^0\rho \) resonance, which inspired many theoretical and experimental work to search for pentaquarks. However, the existence of \( \Theta^+(1540) \) is not confirmed by other experimental collaborations [15] and it is still a controversial issue [16]. Relatively, a study on pentaquarks was scarce to some extent until the observation of two candidates of hidden-charm pentaquarks, \( P_c^+(4380) \) and \( P_c^+(4450) \) in the decay \( \Lambda_b^0 \rightarrow J/\psi K^- p \) by the LHCb Collaborations [17, 19]. A lot of theoretical calculations have been performed to investigate these two exotic candidates [20–30]. In 2017, CERN announced an exceptional new discovery that was made by the LHCb, which unveiled five new states all at one time [31]. These five states were also interpreted as exotic baryons [32–34].

Now that the hidden charm pentaquarks were observed in the charmed sector, possible pentaquarks should also be considered in the hidden strange sector, in which the \( c\bar{c} \) is replaced by \( s\bar{s} \). In fact, the \( N\phi \) bound state was proposed by Gao et al. in 2001 [35]. In Ref. [36], the \( N\phi \) resonance state was obtained by channel coupling in the quark delocalization color screening model (QDCSM). Ref. [37] showed that a bound state could be produced from the \( N\phi \) interaction with spin-parity \( \frac{3}{2}^- \) after introducing a Van der Waals force between the nucleon and \( \phi \) meson. In Ref. [38] the authors also studied possible strange molecular pentaquarks composed of \( \Sigma \) (or \( \Sigma^* \)) and \( K \) (or \( K^* \)), and the results showed that the \( \Sigma K \), \( \Sigma K^* \) and \( \Sigma^* K^* \) must be resonances states by coupling the open channels. Besides, J. He interpreted the \( N^+(1875) \) as a hadronic molecular states from the \( \Sigma K \) interaction [39].

In addition to the hidden strange pentaquark, many theorists have also studied other possible pentaquark according to the information of the experiment. For instance, the \( \Lambda_c(2940) \) was reported by the BaBar Collaboration by analyzing the \( D^0\rho \) invariant mass spectrum [40], and it was confirmed as resonant structure in the final state of \( \Sigma_c(2455)\pi \rightarrow \Lambda_c\pi\pi \) by Belle [41]. Since the \( \Lambda_c(2940) \) are near the threshold of \( ND \), many works treat them as candidates of molecular states. So there are a lot of work on \( ND \) system. For example, Lifang et al. did a bound state calculation of \( ND \) system in QDCSM and interpreted \( \Lambda_c(2940) \) as a \( ND^* \) molecular state [42]. He et al. also proposed that \( \Lambda_c(2940) \) may be a \( D^*\rho \) molecular state with \( J^P = \frac{1}{2}^- \) [43]. Extending the study to the strange sector, we can also study the \( NK \) system, where the \( D \) meson is replaced by the \( K \) meson. In fact, many theoretical study have been devoted to the \( NK \) system. In Ref. [44], the authors use the standard non-relativistic quark model of Isgur-Karl to investigate the \( NK \) scattering problem, and the \( NK \) scattering phase shift showed no resonance was seen in the energy region \( 0–500 \text{ MeV} \) above the \( NK \) threshold. In Ref. [45], Barns and Swanson used the quark-Born-diagram (QBD) method to derive the \( NK \) scattering amplitudes and obtained reasonable results for the \( NK \) phase shifts, but they were limited to \( S \)-wave. In Ref. [46], the \( NK \) interaction was studied in the constituent quark model and...
the numerical results of different partial waves were in good agreement with the experimental date. Hence, it is worthwhile to make a systematical study of NK system by using different methods, which will deepen our understanding about the possible pentaquarks.

It is a general consensus that it is difficult to directly study complicated systems in the low-energy region by QCD because of the non-perturbative nature of QCD. So one has to rely on effective theories or QCD-inspired models to tackle the problem of the multiquark. One of the common approaches to study the multiquark system is the quark model. There are various kinds of the quark models, such as one-boson-exchange model, the chiral quark model, the QDCSM, and so on. Particularly, the QDSCM was developed in the 1990s with the aim of explaining the similarities between nuclear (hadronic clusters of quarks) and molecular force [47–49]. In this model, quarks confined in one cluster are allowed to escape to another cluster, this means that quark distribution in two clusters is not fixed, which is determined by the dynamics of the interacting quark system, thus it allows the quark system to choose the most favorable configuration through its own dynamics in a larger Hilbert space. The confinement interaction between quarks in different clusters is modified to include a color screening factor. The latter is a model description of the hidden-color channel-coupling effect [50].

This model has successful in describing nucleon-nucleon and hyperon-nucleon interactions and the properties of the deuteron [51–53]. It is also employed to study the pentaquark system in hidden-strange, hidden-charm, and hidden-bottom sectors [38–54]. In the present work, QD-CSM is employed to study the nature of NK systems, and the channel-coupling effect is considered. Besides, we also investigate the scattering processes of the NK systems to see if any bound or resonance state exists or not.

This paper is organized as follows. In the next section, the framework of the QD-CSM is briefly introduced. The results for the NK systems are shown in Sec. III, where some discussion is presented as well. Finally, the summary is given in Sec. IV.

II. THE QUARK DELOCALIZATION COLOR SCREENING MODEL (QDCSM)

The quark delocalization, color screening model (QDCSM) is an extension of the native quark cluster model [55] and was developed with aim of addressing multiquark systems. The detail of QDCSM can be found in refs. [47–50, 52, 53]. Here, we just present the salient features of the model. The model Hamiltonian is

\[
H = \sum_{i=1}^{5} \left( m_i + \frac{p_i^2}{2m_i} \right) - T_{CM} + \sum_{j>i=1}^{5} \left[ V^C(r_{ij}) + V^G(r_{ij}) + V^B(r_{ij}) \right],
\]

\[
V^G(r_{ij}) = \frac{1}{4} a_{ij} \lambda_i \cdot \lambda_j \left[ \frac{1}{r_{ij}} - \frac{\pi}{2} \delta(r_{ij}) \left( \frac{1}{m_i^2} + \frac{1}{m_j^2} + \frac{4 \sigma_i \cdot \sigma_j}{3m_i m_j} \right) \right] - \frac{3}{4m_i m_j r_{ij}^3} S_{ij},
\]

\[
V^B(r_{ij}) = V_\pi(r_{ij}) \sum_{a=1}^{3} \lambda^a_i \cdot \lambda^a_j + V_K(r_{ij}) \sum_{a=4}^{7} \lambda^a_i \cdot \lambda^a_j + V_\eta(r_{ij}) \left[ (\lambda_8^a \cdot \lambda_8^j) \cos \theta - (\lambda_0^a \cdot \lambda_0^j) \sin \theta \right]
\]

\[
V_\chi(r_{ij}) = \frac{g_{\chi}^2}{4\pi} \frac{m_\chi^2}{12m_i m_j} \frac{\Lambda^2_\chi}{\Lambda^2_\chi - m_\chi^2} \left\{ (\sigma_i \cdot \sigma_j) \left[ Y(m_\chi r_{ij}) - \frac{\Lambda^3_\chi}{m_\chi^3} Y(\Lambda_\chi r_{ij}) \right] \right\} + \left[ H(m_\chi r_{ij}) - \frac{\Lambda^3_\chi}{m_\chi^3} H(\Lambda_\chi r_{ij}) \right] S_{ij}, \quad \chi = \pi, K, \eta,
\]

\[
V^C(r_{ij}) = -a_{ij} \lambda_i \cdot \lambda_j f(r_{ij}) + V_0,
\]

\[
f(r_{ij}) = \begin{cases} \frac{1}{r_{ij}^3} & \text{if } i,j \text{ occur in the same baryon orbit} \\ \frac{1 - e^{-r_{ij}^2/r_{ij}^2}}{r_{ij}^2} & \text{if } i,j \text{ occur in different baryon orbits} \end{cases}
\]

\[
S_{ij} = \frac{(\sigma_i \cdot r_{ij})(\sigma_j \cdot r_{ij}) - \frac{1}{3} \sigma_i \cdot \sigma_j}{r_{ij}^2},
\]

\[
H(x) = (1 + 3/x + 3/x^2) Y(x), \quad Y(x) = e^{-x}/x.
\]

where \(T_{CM}\) is the kinetic energy of the center-of-mass motion, and \(\sigma, \chi, \lambda^a\) are the SU(2) Pauli, SU(3) color, SU(3) flavor Gell-Mann matrices, respectively. \(S_{ij}\) is
the quark tensor operator; The subscripts $i, j$ denote
the quark index in the system. The $Y(x)$ and $H(x)$
are the standard Yukawa functions [56], the $\Lambda_{\chi}$
is the chiral symmetry breaking scale, and the $\alpha_{\chi}$
is the effective scale-dependent running quark-gluon coupling
constant [57], $\frac{g_{\alpha}^{2}}{4\pi}$ is the chiral coupling constant for scalar
and pseudoscalar chiral field coupling, determined from $\pi$-nucleon-nucleon coupling constant through

$$\frac{g_{\alpha}^{2}}{4\pi} = \left(\frac{3}{5}\right)^{2} \frac{g_{\pi NN}^{2} m_{\pi}^{2}}{4\pi m_{N}^{2}}$$

(8)

In the phenomenological confinement potential $V^C$, the
color screening parameter $\mu_{\text{qq}}$ is determined by fitting the
deuteron properties, $NN$ scattering phase shifts, and $N\Lambda$ and $N\Sigma$ scattering cross sections, respectively, with $\mu_{\pi q} = 0.45, \mu_{\pi q} = 0.19$ and $\mu_{s s} = 0.08$, satisfying the relation $\mu_{g g}^{2} = \mu_{q q}^{2} \mu_{s s}$ where $q$ represents $u$ or $d$.

The quark delocalization effect is realized by specifying
the single-particle orbital wave function in QDCSM as a
linear combination of left and right Gaussians, the single-
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relation

$$\mu$$

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The quark delocalization effect is realized by specifying
the single-particle orbital wave function in QDCSM as a
linear combination of left and right Gaussians, the single-
particle orbital wave functions used in the ordinary quark
cluster model are

$$\psi_{\alpha}(s_{i}, \epsilon) = (\phi_{\alpha}(s_{i}) + \epsilon \phi_{\alpha}(-s_{i}))/N(\epsilon), \quad (9)$$

$$\psi_{\beta}(s_{i}, \epsilon) = (\phi_{\beta}(-(s_{i}) + \epsilon \phi_{\beta}(s_{i}))/N(\epsilon), \quad (10)$$

$$N(\epsilon) = \sqrt{1 + e^{2} + 2\epsilon e^{-s_{i}^{2}/4\epsilon^{2}}}, \quad (11)$$

$$\phi_{\alpha}(s_{i}) = \left(\frac{1}{\pi b^{2}}\right)^{\frac{3}{2}} e^{-\frac{1}{2\epsilon}(r_{\alpha}^{-}\hat{r}_{i})^{2}}, \quad (12)$$

$$\phi_{\beta}(-s_{i}) = \left(\frac{1}{\pi b^{2}}\right)^{\frac{3}{2}} e^{-\frac{1}{2\epsilon}(r_{\beta}^{+}\hat{r}_{i})^{2}}, \quad (13)$$

The $s_{i}, i = 1, 2, ..., n$, are the generating coordinates, which are introduced to expand the relative motion wave function [48, 49, 51]. The mixing parameter $\epsilon(s_{i})$ is not an adjusted one but determined variationally by the dynamics of the multi-quark system itself. It is this assumption that allows the multi-quark system to choose its favorable configuration in the interacting process. It has been used to explain the cross-over transition between the hadron phase and the quark-gluon plasma phase [58]. All the other symbols in the above expressions have their usual meanings. All the parameters of the Hamiltonian are from our previous work of hidden strange pentaquark [38].

### III. THE RESULTS AND DISCUSSIONS

In this work, we investigate the $NK$ systems with $I = 0, 1, 2, J^{P} = \frac{1}{2}^{-}, \frac{3}{2}^{-}, \frac{5}{2}^{-}$ in the QDCSM. For the negative-parity, the orbital angular momentum $L$ between two clusters is set to 0. All the channels involved are listed in Table I. To investigate the properties of the $NK$ systems and to see if any bound or resonance state exists or not, three steps are invoked.

#### A. The effective potential calculation

Because the attractive potential is necessary for forming a bound state or a resonance, for the first step, the effective potentials of all the channels listed in the Table I are calculated. The effective potential between two colorless clusters is defined as,

$$V(s) = E(s) - E(\infty),$$

where $E(s)$ is the energy of the state at the separation $s$ between two clusters. The effective potentials of the $S$-wave $NK$ systems with $I = 0, 1, 2$ are shown in Figs. 1-3, respectively. For the $IJ^{P} = 0^{\frac{1}{2}^{-}}$ system (Fig. 1), one see that the potential of the $NK$ state is almost repulsive, which means that the $NK$ is difficult to form a bound state, while the potential of the $NK^{*}$ channel is attractive in the short range, a bound state or a resonance $NK^{*}$ is possible. For the $I = 1$ system, Fig. 2(a) shows the potential of the $NK^{*}$ system with $J^{P} = \frac{1}{2}^{+}$, in which the potential of the channel $NK$ shows repulsive property, while other two channels are attractive. The attraction between $\Delta$ and $K^{*}$ is much larger than that of the $NK^{*}$ channel, which indicates that it is possible for $\Delta K^{*}$ to form a bound or resonance state. In Fig.

![Fig. 1: The effective potential of different channels for the $NK$ system with $I = 0$.](image-url)
I. Introduction

In this section, we explore the possibility of bound states and resonance states in the system of NK. The potentials of the NK system are needed to check the existence of bound or resonance states. The energy of the system can be obtained by solving the eigen-equation. The details of solving the RGM equation can be found in Ref. [60, 61]. In the calculation, the baryon-meson separation is taken to be less than 6 fm (to keep the matrix dimension manageable). The binding energies and the masses of every single channel and those with channel coupling are listed in Table III.

![FIG. 2: The effective potential of different channels for the NK system with I = 1.](image1)

![FIG. 3: The effective potential of different channels for the NK system with I = 2.](image2)

2(b), the potentials of both the \( J^P = \frac{3}{2}^- \) channel \( \Delta K \) and \( \Delta K^* \) are weakly attractive and the potential of the channel NK* is repulsive. From Fig. 2(c), it is obvious that the potential of the \( J^P = \frac{5}{2}^- \) channel \( \Delta K^* \) has a strong attraction, it is interesting to explore the possibility of formation of bound or resonance state. For the \( I = 2 \) system, the potential of both the \( J^P = \frac{1}{2}^- \) and \( \frac{3}{2}^- \) \( \Delta K^* \) channels are attractive, a dynamic calculation is needed here to check the existence of bound or resonance states. The potentials of the \( \Delta K \) with the \( J^P = \frac{3}{2}^- \) and the \( \Delta K^* \) with the \( J^P = \frac{5}{2}^- \) are repulsive, bound or resonance state is impossible here.

B. The bound state calculation

In order to check whether the possible bound or resonance states can be realized, a dynamic calculation is needed. Here the RGM equation, which is a successful method in nuclear physics for studying a bound-state problem or scattering one, is employed. Expanding the relative motion wave function between two clusters by Gaussians, then the integro-differential equation of the RGM can be reduced to a algebraic equation, the generalized eigen-equation. The energy of the system can be obtained by solving the eigen-equation. The details of solving the RGM equation can be found in Ref. [61]. In the calculation, the baryon-meson separation is taken to be less than 6 fm (to keep the matrix dimension manageable). The binding energies and the masses of every single channel and those with channel coupling are listed in Table III.

For the \( I = 0, J^P = \frac{1}{2}^- \) system, the single channel calculation shows that the energy of the NK channel is above the threshold because the attraction between N and K is too weak to tie the two particles together, which means that there is no bound state in this channel. However, for the NK* state, the strong attractive interaction between N and K* leads to the energy of the NK* state below the threshold of the two particles, so the NK* state is bound in the single channel calculation. By coupling two channels of NK and NK*, the lowest energy is still above the threshold of the NK channel, which indicates that no bound state for \( I = 0, J^P = \frac{1}{2}^- \) system. However, we should check if the NK* is a resonance state in the channel coupling calculation, which is presented in the next sub-section.

For the \( I = 1 \) system, the state with \( J^P = \frac{1}{2}^- \) has three channels: NK, NK*, and \( \Delta K^* \). The NK and NK* are all unbound. It is reasonable. As shown in Fig.2(a), the effective potential between N and K is repulsive, and the one between N and K* is weakly attractive. So neither NK nor NK* is bound here. However, the attraction between \( \Delta \) and \( K^* \) is strong enough to bind \( \Delta \) and \( K^* \), so the \( \Delta K^* \) is a bound state with the binding energy of 68.1 MeV in the single calculation. Then the channel-coupling is also considered. The lowest energy is still above the threshold of the NK channel and it means that there is no bound state for \( I = 1, J^P = \frac{1}{2}^- \) system. The \( \Delta K^* \) may turn out to be a resonance state by coupling to the open channels, NK and NK*, which should be investigated in the scattering process of the open channels. The state with \( J^P = \frac{3}{2}^- \) includes three channels: NK*, \( \Delta K \) and \( \Delta K^* \). The effective potential of NK* is repulsive which make the state unbound. Both the \( \Delta K \) and \( \Delta K^* \) are also unbound due to the weakly attractive potentials between \( \Delta \) and \( K \) or \( K^* \) as shown in Fig.2(b). The coupling of all channels also cannot make any state bound. For the \( J^P = \frac{5}{2}^- \) system, there is only one channel: \( \Delta K^* \). The attraction between \( \Delta \) and \( K^* \) is large enough to form a bound state, and the binding energy is
TABLE II: The binding energies and the masses of every single channels and those of channel coupling for the molecular pentaquarks. The values are provided in units of MeV, \( ub \) and \(-\) represent unbound and the channel does not exist, respectively.

| Channel | \( IJ^P=0\frac{1}{2}^- \) | \( IJ^P=1\frac{1}{2}^- \) | \( IJ^P=1\frac{3}{2}^- \) | \( IJ^P=1\frac{5}{2}^- \) | \( IJ^P=2\frac{1}{2}^- \) | \( IJ^P=2\frac{3}{2}^- \) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( NK \)        | \( \text{ub} \) | \( \text{ub} \) | \( \text{-} \) | \( \text{-} \) | \( \text{-} \) | \( \text{-} \) |
| \( NK^* \)      | \(-62.3/1768.7\) | \( \text{ub} \) | \( \text{ub} \) | \( \text{-} \) | \( \text{-} \) | \( \text{-} \) |
| \( \Delta K \)  | \( \text{-} \) | \( \text{ub} \) | \( \text{ub} \) | \( \text{-} \) | \( \text{-} \) | \( \text{ub} \) |
| \( \Delta K^* \)| \( \text{-} \) | \(-68.1/2055.9\) | \( \text{ub} \) | \(-13.5/2110.5\) | \( \text{ub} \) | \(-10.2/2113.8\) |
| \( E_{cc} \)    | \( \text{ub} \) | \( \text{ub} \) | \( \text{ub} \) | \( \text{bound} \) | \( \text{ub} \) | \( \text{ub} \) |

The baryon mass and the meson mass, respectively, and the superscripts \( cal \), \( exp \) stand for the calculated and experimental.

- For the \( I=2 \) system, both \( \Delta K^* \) with \( J^P = \frac{1}{2}^- \) and \( J^P = \frac{5}{2}^- \) are unbound. For the \( J^P = \frac{3}{2}^- \) system, the \( \Delta K \) is unbound while the \( \Delta K^* \) is bound with the binding energy of \(-10.2 \text{ MeV} \) in the single channel calculation. However, the channel-coupling cannot push the lowest energy under the threshold of the \( \Delta K \) channel. So no bound state is obtained by channel-coupling. We will check if \( \Delta K^* \) is a resonance state by coupling the open channel.

It is worth to mention that a subtraction procedure is used here to obtain the mass of a bound state here. Because the quark model cannot reproduce the experimental masses of all baryons and mesons, the theoretical threshold and the experimental threshold for a given channel is different (the threshold is the sum of the masses of the baryon and the meson in the given channel). However, the binding energy, the difference between the calculated energy of the state and the theoretical threshold can minimize the deviation. So we define the mass of a bound state as \( M = M^{cal}(5g) - M^{exp}B - M^{cal}(M) + M^{exp}(B) + M^{exp}(M) \), where \( M(B) \) and \( M(M) \) denote the baryon mass and the meson mass, respectively, and the superscripts \( cal \), \( exp \) stand for the calculated and experimental.

C. The resonance state calculation

Resonances are unstable particles usually observed in the scattering process. The bound state in the single channel calculation may turn to be a resonance after coupling with open channels. Here, we calculate the baryon-meson scattering phase shifts and investigate the resonance states by using the RGM.

From the bound state calculation showed above, for the \( I = 0, J^P = \frac{1}{2}^- \) system, the single channel \( NK^* \) is bound, while the \( NK \) channel is unbound and is identified as the open channel. For the \( I = 1, J^P = \frac{1}{2}^- \) system, there are two open channels \( (NK, NK^*) \) and one bounded channel \( (\Delta K^*) \). For the \( I = 2, J^P = \frac{3}{2}^- \) system, it is similar to the \( I = 0, J^P = \frac{1}{2}^- \) system. The open channel and the bounded channel is \( \Delta K \) and \( \Delta K^* \), respectively. Here, we only consider the channel-coupling in \( S^- \)-wave, which is through the central force. The channel-coupling between the \( S^- \) and \( D^- \) wave states is very small, which is through the tensor force, and is ignored here. All the scattering phase shifts of the open channels are shown in Fig. 4.

For the \( I = 0, J^P = \frac{1}{2}^- \) system, there is no any resonance state appeared in the phase shifts of the open channel \( NK \), which means that the bound state \( NK^* \) in the single channel calculation turns into scattering state after coupling with the \( NK \) channel. The case is similar for both the \( I = 1, J^P = \frac{1}{2}^- \) system and the \( I = 2, J^P = \frac{3}{2}^- \) system. As shown in Fig. 4(b), no resonance state appeared in the phase shifts of the open channel \( NK \) or \( NK^* \), which indicates that the bound state \( \Delta K^* \) with \( I = 1, J^P = \frac{1}{2}^- \) is not a resonance state by coupling with the open channels. In Fig. 4(c), we can also see that \( \Delta K^* \) with \( I = 2, J^P = \frac{3}{2}^- \) is not a resonance by coupling to the open channel \( \Delta K \).

IV. SUMMARY

In the framework of the QDCSM, the pentaquark systems with quark contents \( uudd\bar{s} \) are investigated by means of RGM. All the effective potentials between baryon and meson are calculated to search for the strong
attraction, which is the necessary condition for forming bound state or resonance. The dynamic calculation show that the states $NK^*$ with $I = 0, J^P = \frac{1}{2}^-$, $\Delta K^*$ with $I = 1, J^P = \frac{1}{2}^-$, and $\Delta K^*$ with $I = 2, J^P = \frac{3}{2}^-$ are all bound in the single channel calculation due to the strong attraction of the states. However, all these bound states turns into scattering states by coupling with the open channels. It indicates that the effect of the coupling with the open channels cannot be neglected, because it will transfer the bound state into a resonance state or a scattering state. There is only one bound state in our calculation, which is the $\Delta K^*$ with $I = 1, J^P = \frac{5}{2}^-$ with the energy of 2110.5 MeV. However, in present calculation, we only consider all possible channels in $S$-wave. The $D$-wave $\Delta K$ channel can couple to $\Delta K^*$ through the tensor interaction. The coupling is expected to turn the bound state to a resonance with decay width of several MeV, which is our next work. The $\Delta K^*$ state can also decay to $NK\pi\pi$ in $P$-waves (two $P$-waves are needed to conserve the parity).

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