Heavy $K^*(4307)$ meson with hidden charm

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We report on a robust prediction of heavy $K^*$ meson by solving the Faddeev equations with fixed-center approximation for the three-body $KDD^*$ system. As the excited Kaon state, $K^*$ is an exotic hidden charm meson with $M - \eta \gamma/2 = 4307 \pm 2 - i 9 \pm 2$ MeV and $I(J^P) = 1/2(1^-)$. We further performed the evaluation of the decay width of $K^*(4307)$ to the open two-body channels. We expect that the above findings inspire an experimental investigation of this exotic $K^*$ meson and to study the so far unexplored heavy strange meson sector.

Keywords: Exotic hadrons; Few body systems; Heavy quark symmetry

1. Introduction

Recently, the exotic hadrons with the open/hidden heavy quark components have attracted great attention in the experimental and theoretical studies$^{1,2}$. However, in the strange sector, there is no experimental data available on heavy $K$ or $K^*$ meson states, leaving the heavy strange physics experimentally unexplored. In this Hadron conference, the COMPASS collaboration presented their preliminary results of the strange-meson spectrum$^3$.

From the theoretical side, we have explored the possibility of forming a heavy $K^*$ meson in the three-body $KDD^*$ system$^4$. All the two-body interactions, $KD$, $KD^*$, and $DD^*$, are stringently constrained by a large number of experimental ($D_{s0}^*(2317)$, $D_{s1}^*(2460)$, $X(3872)$, and $Z_c(3900)$) as well as the lattice QCD data, which lead to a unique system of $KDD^*$. Using the so-called fixed-center approximation (FCA)$^5$ to the Faddeev equations, we found a heavy $K^*$ meson around 4307 MeV with hidden charm.
In order to provide more information, we also studied the decay width of \( K^*(4307) \) from two-body decay processes\(^6\).

2. **\( K^*(4307) \) state in the \( KDD^* \) system**

For a three-body system, if the mass of the third particle \( P_3 \) is much smaller than a stable cluster composed of the two other particles \( P_1 \) and \( P_2 \), one can consider the use of the FCA to the Faddeev equations. Our \( KDD^* \) system exactly satisfies such criteria. We take the light kaon as the third particle to scatter off the cluster of \( D\bar{D}^* \), which can form the as \( X(3872) \) or \( Z_c(3900) \) states\(^7,8\).

Here, we briefly present the basic equations, in particular for the coupled-channel case, in the FCA framework. The details can be found in Ref.\(^4\). The total scattering amplitude is decomposed into two Faddeev partitions,

\[
T = T_{31} + T_{32},
\]

\[
T_{31} = t_{31} + t_{31}G_0t_{32} + t_{31}G_0t_{32}G_0t_{31} + \cdots = t_{31} + t_{31}G_0T_{32},
\]

\[
T_{32} = t_{32} + t_{32}G_0t_{31} + t_{32}G_0t_{31}G_0t_{32} + \cdots = t_{32} + t_{32}G_0T_{31},
\]

where the two-body amplitudes, \( t_{31} \) and \( t_{32} \), are the functions of the isospin 0 and 1 s-wave interactions of the \( KD \) and \( K\bar{D}^* \) subsystems\(^9,10\).

In the \( K[DD^*] \) system, we consider \( KX(3872) \) and \( KZ_c(3900) \) as coupled channels with total isospin \( I = 1/2 \). As shown in Ref.\(^4\), this makes that the \( t_{31} \) and \( t_{32} \) amplitudes can be written as \( 2 \times 2 \) matrices in the coupled channel space,

\[
t_{31} = \begin{pmatrix} (t_{31})_{11} & (t_{31})_{12} \\ (t_{31})_{21} & (t_{31})_{22} \end{pmatrix}, \quad t_{32} = \begin{pmatrix} (t_{32})_{11} & (t_{32})_{12} \\ (t_{32})_{21} & (t_{32})_{22} \end{pmatrix},
\]

Fig. 1. Modulus squared of the \( KX \) and \( KZ \) scattering amplitudes in \( I = 1/2 \) with different cutoffs. A cusp related to the three-body \( KDD^* \) threshold is observed in the \( KX \to KX \) amplitude.
where the element (11) denotes $K_X \rightarrow K_X$, the element (12) $K_X \rightarrow KZ_c$, and so on. The corresponding loop function $G_0$ is,

$$G_0 = \begin{pmatrix} (G_0)_{11} & 0 \\ 0 & (G_0)_{22} \end{pmatrix}. \quad (3)$$

Finally, the total $T$-matrix appearing in Eq. (1) becomes as,

$$T = T_{31} + T_{32} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}. \quad (4)$$

In Fig. 1, the modulus squared of the $K_X$ and $KZ_c$ scattering amplitudes in $I = 1/2$ are given with the momentum cutoff varying from 700 MeV to 750 MeV. We found that the mass and width of the heavy $K^*$ meson in the $KX$ configuration is $M - i\Gamma/2 = (4308 \pm 1) - i(8 \pm 1)$ MeV, and of the $KZ_c$ configuration is $M - i\Gamma/2 = (4306 \pm 1) - i(9 \pm 1)$ MeV. After averaging, the mass of the $K^*$ meson is $4307 \pm 2$ MeV with a width of $18 \pm 4$ MeV. Note that our result is consistent with the one of Ref. 13, where the Born-Oppenheimer approximation is applied to the $KDD^*$ system by solving the Schrödinger equation.

### 3. $K^*(4307)$ decay

In the following, we investigated the properties of the $K^*$ state and calculated the decay widths of the possible two-body channels. As shown in Fig. 1, the magnitude of the squared amplitude in the $KZ_c$ configuration

![Diagram](image)

Fig. 2. Main two-body decay channels for the predicted $K^*(4307)$ meson.
is around 200 times larger than that found in the $KX$ configuration. Thus, the decay width of $K^*(4307)$ is mainly from the subprocess $K^* \rightarrow KZ_c$. In Fig. 2, the open two-body decay channels, $J/\psi K^*(892)$, $\bar{D}D_s$, $\bar{D}D_s^*$, and $\bar{D}^*D_s^*$, via the triangle loops are presented.

For the details about the determination of the $t_i$ ($i = a, b, c, d$) amplitudes and the calculation of the triangular loops using the momentum cutoff regularization, we refer the reader to Ref. 6.

Once we have the $t_i$, the decay width of the $K^*(4307)$ meson to the two-body channels can be obtained

$$\Gamma_i = \int \frac{d\Omega}{4\pi^2} \frac{1}{8M_K^2} \frac{p_{c.m.}}{3} \sum |t_i|^2 = \frac{p_{c.m.}}{24\pi M_{K^*}^2} \sum |t_i|^2, \quad (5)$$

where $d\Omega$ represents the solid angle, $p_{c.m.}$ is the center of mass momentum of the particles in the final state, the factor 3 has its origin in the average over the $K^*(4307)$ meson polarizations and the symbol $\sum$ indicates summation over the polarization of the initial and final states.

With the momentum cutoff $\Lambda$ changing from 700 MeV to 800 MeV, as used in Ref. 4, the decay widths from different channels are

$$\Gamma_a = 6.97 \pm 0.27 \text{ MeV}, \quad \Gamma_b = 0.54 \pm 0.08 \text{ MeV}, \quad \Gamma_c = 0.54 \pm 0.07 \text{ MeV}, \quad \Gamma_d = 1.14 \pm 0.17 \text{ MeV}. \quad (6)$$

Besides, we also considered the width of $K^*(892)$ in the evaluation of the decay width of $K^*(4307) \rightarrow J/\psi K^*$. Since the mass of $K^*(4307)$ is far from the $J/\psi K^*(892)$ threshold, the decay width $\Gamma_a$ does not change.

4. Conclusion

In this talk, we presented a prediction of heavy $K^*(4307)$ meson with hidden charm in the $KD\bar{D}^*$ system by solving the Faddeev equations with the fixed center approximation. In order to provide more information about the internal structure on $K^*(4307)$, we calculated the decay width of $K^*(4307)$ to two-body channels. We are now working on the study of $B$ meson decay to $J/\psi \pi K$, which could be handled by e.g. LHCb experiment to investigate the signal of $K^*(4307)$ meson in the $J/\psi \pi K$ invariant mass distribution 12. Furthermore, along this line, the possible bound states with hidden bottom are also predicted in the $K^{(*)}B^{(*)}\bar{B}^{(*)}$ systems 13. We hope that the above studies could arouse interest to investigate the exotic states in the strange sector.
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