Detecting the long-distance structure of the X(3872)[1]

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Abstract

We study the $X(3872) \to D^0\bar{D}^0\pi^0$ decay within a $D\bar{D}^*$ molecular picture for the $X(3872)$ state. This decay mode is more sensitive to the long-distance structure of the $X(3872)$ resonance than its $J/\psi\pi\pi$ and $J/\psi 3\pi$ decays, which are mainly controlled by the details of the $X(3872)$ wave function at short distances. We show that the $D\bar{D}$ final state interaction can be important, and that a precise measurement of this partial decay width can provide valuable information on the interaction strength between the $D^{(*)}\bar{D}^{(*)}$ charm mesons.

Heavy Meson-Antimeson EFT

In the heavy quark limit, some underlying QCD symmetries arise. Heavy Quark Spin Symmetry is the most known. This symmetry states that the heavy quark spin effects have to be subleading. This constrain imposes that the most general lagrangian to study heavy meson-heavy antimeson molecular bound states, that respects this symmetry at leading order, only consists of a contact potential that depends on four low-energy constants:

$$\begin{aligned}\mathcal{L} \;=\; & \frac{C_A}{4}\mathrm{Tr}\left[\bar{H}^{(Q)a}H_a^{(Q)}\gamma_\mu\right]\mathrm{Tr}\left[H^{(\bar{Q})a}\bar{H}_a^{(\bar{Q})}\gamma^\mu\right] + \frac{C_A^\tau}{4}\mathrm{Tr}\left[\bar{H}^{(Q)a}\vec{\tau}_a^{\,b}H_b^{(Q)}\gamma_\mu\right]\mathrm{Tr}\left[H^{(\bar{Q})c}\vec{\tau}_c^{\,d}\bar{H}_d^{(\bar{Q})}\gamma^\mu\right]\\ &+ \frac{C_B}{4}\mathrm{Tr}\left[\bar{H}^{(Q)a}H_a^{(Q)}\gamma_\mu\gamma_5\right]\mathrm{Tr}\left[H^{(\bar{Q})a}\bar{H}_a^{(\bar{Q})}\gamma^\mu\gamma_5\right] + \frac{C_B^\tau}{4}\mathrm{Tr}\left[\bar{H}^{(Q)a}\vec{\tau}_a^{\,b}H_b^{(Q)}\gamma_\mu\gamma_5\right]\mathrm{Tr}\left[H^{(\bar{Q})c}\vec{\tau}_c^{\,d}\bar{H}_d^{(\bar{Q})}\gamma^\mu\gamma_5\right]\end{aligned}$$

In order to obtain the values of the undetermined LECs (expressed as C_{0A}, C_{0B}, C_{1A} and C_{1B} w.l.o.g.) of the theory, we fit them to experimental data. Hence, we have assumed that the $X(3872)$ is a $D\bar{D}^*$ with quantum numbers $J^{PC} = 1^{++}$ and the $Z_b(10610)/Z_b'(10650)$ are $B\bar{B}^*$ and $B^*\bar{B}^*$ with quantum numbers $J^{PC} = 1^{++}$, respectively. These two assumptions are pretty sound as these resonances are close to their corresponding threshold.

Using these pieces of experimental data we get three linear combinations of the undetermined LECs and our results will be a function of the fourth LEC C_{0A}. Then, we solve the Lippmann-Schwinger Equation as bound states and resonances appear as poles in the T-matrix. A gaussian regulator Λ is needed for the treatment of ultraviolet divergences in the loop function. Further details can be found in [1].

This procedure has also been followed in [2], where the Z_c was found as a virtual state or [3], where some pentaquark-like states were also predicted.

X(3872) Short-distance decays

In short-distance decays, the heavy quark and the heavy antiquark must be very close so they can produce a J/ψ product in the final state.

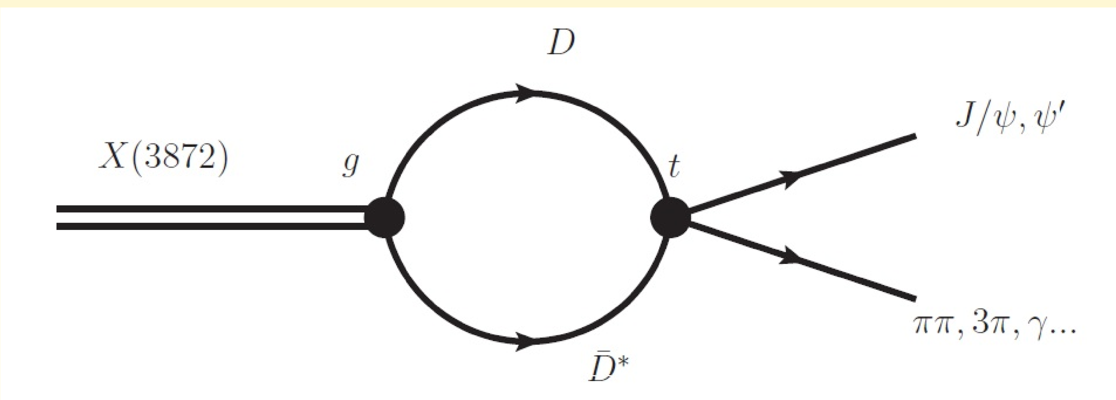

Fig.1 Mechanism for the short-distance decays of the $X(3872)$ into $J/\psi\pi\pi$, $J/\psi 3\pi$, $J/\psi\gamma$, $\psi'\gamma$ ... assuming the $X(3872)$ to be a $D\bar{D}^*$ molecule. The charge conjugated channel is not plotted.

X(3872) Long-distance decays

However, long-distance decays (where the final products are decays of the inner components of the resonance) are more interesting to probe the molecular nature of the resonance. For this reason, it is very exciting the study of the $X(3872) \to D^0\bar{D}^0\pi^0$ decay, where a $D^* \to D\pi$ decay has occurred. As a NLO correction, Final State Interactions in the $D\bar{D}$ system have been included. These processes have been displayed in Fig.2.

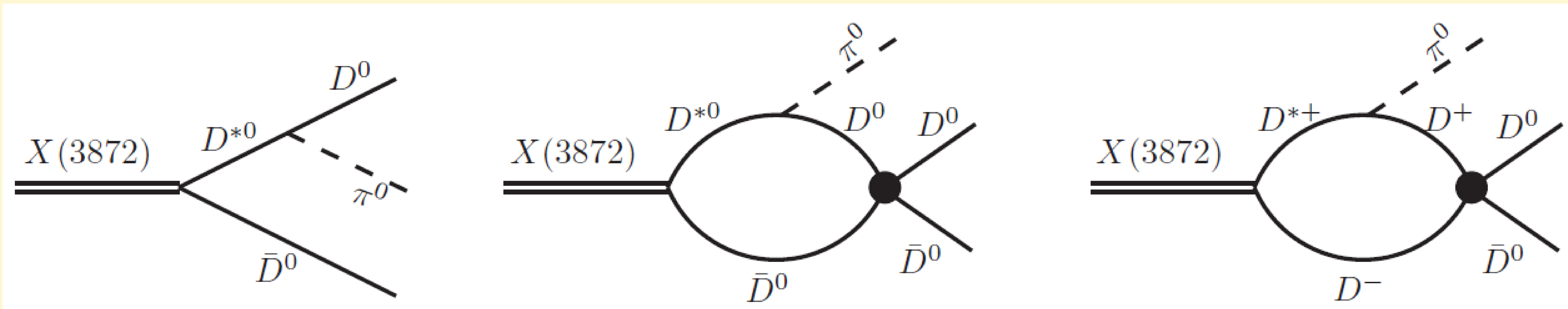

Fig.2. Feynman diagrams for the decay $X(3872) \to D^0\bar{D}^0\pi^0$. The charge conjugate channel is not shown.

Results

The results obtained for the decay width of the process have been:

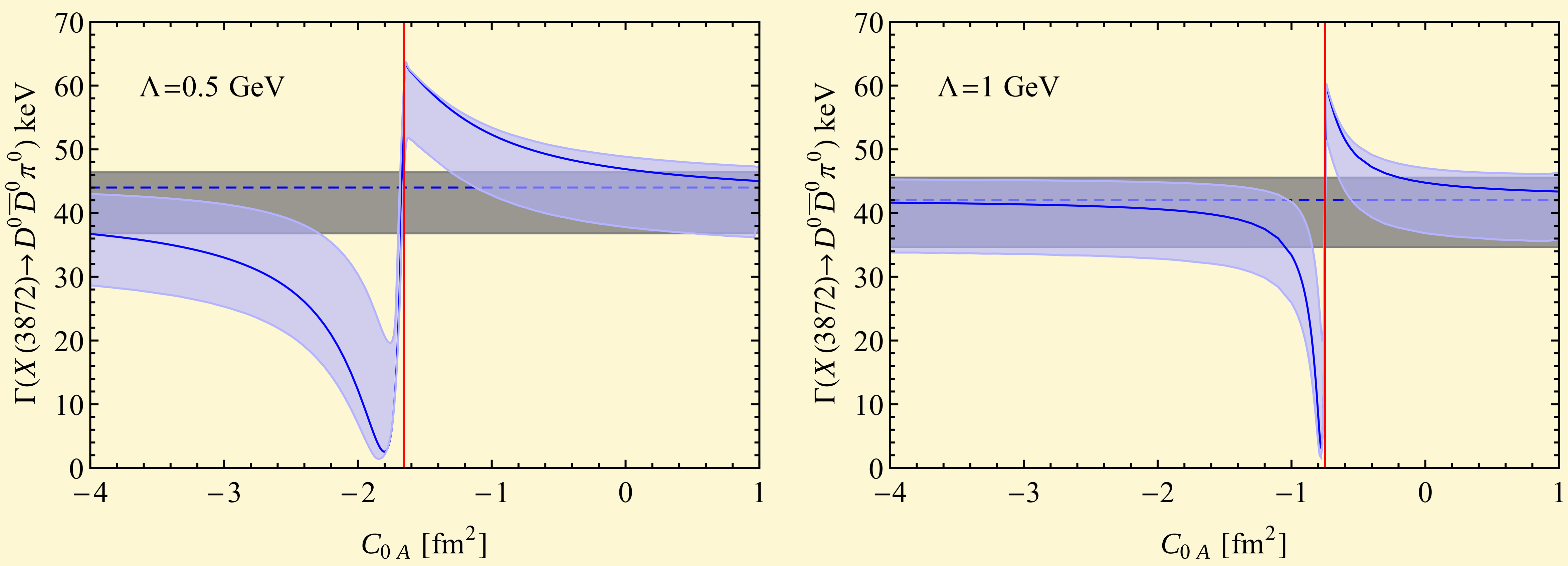

Fig.3. Dependence of the $X(3872) \to D^0\bar{D}^0\pi^0$ partial decay width on the low-energy constant C_{0A}. The UV cutoff is set to $\Lambda = 0.5$ GeV (1 GeV) in the left (right) panel. The blue error bands contain $D\bar{D}$ FSI effects, while the grey bands stand for the tree level predictions. The solid (full calculation) and dashed (tree level) lines stand for the results obtained with the central values of the parameters. The vertical lines denote the values of C_{0A} for which a $D\bar{D}$ bound state is generated at the $D^0\bar{D}^0$ threshold.

Conclusions

In this work, we explored the decay of the $X(3872)$ into the $D^0\bar{D}^0\pi^0$ using an EFT based on the hadronic molecule assumption for the $X(3872)$. This decay is unique in the sense that it is sensitive to the long-distance structure of the $X(3872)$ as well as the strength of the S-wave interaction between the D and $\bar{D}$.

We show that if there was a near threshold pole in the $D\bar{D}$ system, the partial decay width can be very different from the result neglecting the FSI effects. Thus, this decay may be used to measure the so far unknown parameter C_{0A} in this situation. Such information is valuable to better understand the interaction between a heavy and an anti-heavy meson.

It is also worth mentioning that since this decay is sensitive to the long-distance structure, the contribution of the $X(3872)$ charged component $(D^+D^{*-} - D^{*+}D^-)$ is not important even when the $D\bar{D}$ FSI is taken into account.

References

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