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The $T_{c\bar{s}}(2900)$ as a threshold effect from the interaction of the D^*K^*, $D_s^*\rho$ channels

Raquel Molina[1,*] and *Eulogio* Oset[1,**]

[1]Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Aptdo. 22085, 46071 Valencia, Spain

Abstract. We investigate the D^*K^* and $D_s^*\rho$ interaction in coupled channels within the hidden gauge formalism. A structure is developed around their thresholds, short of producing a bound state, which leads to a peak in the $D_s^+\pi^-$ mass distribution in the $B^0 \to \bar{D}^0 D_s^+\pi^-$ decay compatible with the experimental data. We conclude that the interaction between the D^*K^* and $D_s^*\rho$ is essential to produce the cusp structure that we associate to the recently seen $T_{c\bar{s}}(2900)$, and that its experimental width is mainly due to the decay width of the ρ meson. The peak obtained together with a smooth background reproduces fairly well the experimental mass distribution observed in the $B_0 \to \bar{D}^0 D_s^+\pi^-$ decay.

1 Introduction

The D^*K^* system was investigated in [1] and three states were found corresponding to $I = 0$; $J^P = 0^+, 1^+$ and 2^+. The 2^+ state was identified with the $D_{s2}^*(2573)$ state, and served to set the scale for the regularization of the loops, allowing predictions in the other sectors. There, the $I = 1$ interaction of the D^*K^* and $D_s^*\rho$ channels was also studied and, a cusp was found for $J = 0$ and $J = 1$ around the $D_s^*\rho$ threshold.

Recently, the LHCb Collaboration has observed an state in the $D_s^+\pi^-$, $D_s^+\pi^+$ mass distributions in the $B^0 \to \bar{D}^0 D_s^+\pi^-$ and $B^+ \to D^- D_s^+\pi^+$ decays, respectively, at 2900 MeV [2, 3]. Indeed, the state branded as $T_{c\bar{s}}(2900)$ with $J^P = 0^+$, as seen in $D_s^+\pi^-$ and $D_s^+\pi^+$, exhibits an $I = 1$ character and it has also been associated with $J^P = 0^+$. On the other hand, 2900 MeV is just the threshold of the D^*K^* channel. Thus, one is finding a $I = 1$ $J^P = 0^+$ state in the threshold of D^*K^* (the $D_s^*\rho$ is only 14 MeV below neglecting the ρ width), which could correspond to the cusp found in [1].

In the present work we look again at the interaction of D^*K^* and $D_s^*\rho$ channels, taking into account the K^* and ρ widths and also the decay of the states found into the $D_s\pi$ channel where it has been observed, comparing our results with the recent experimental findings.

2 Formalism

In Ref. [2] a peak is found in the $D_s\pi$ invariant mass in the $B^0 \to \bar{D}^0 D_s^+\pi^-$ and $B^+ \to D^- D_s^+\pi^+$ decays. In order to have a b quark rather than a $\bar{b}$ quark, we look at the reaction

*e-mail: Raquel.Molina@ific.uv.es
**e-mail: Eulogio.Oset@ific.uv.es

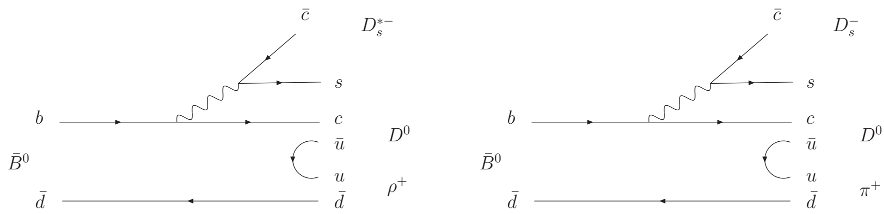

Figure 1. Left: $\bar{B}^0$ decay to $D_s^{*-}c\bar{d}$ with hadronization of the $c\bar{d}$ pair to produce $D_s^{*-}D^0\rho^+$. Right: $\bar{B}^0$ decay into $D_s^- D^0\pi^+$ (contribution to the background).

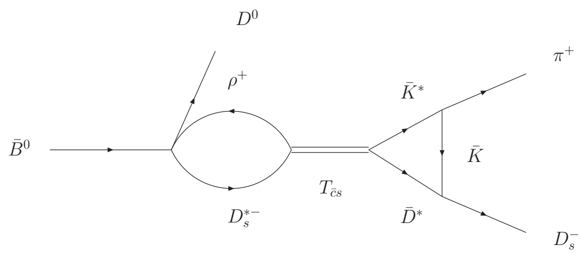

Figure 2. Mechanism by means of which the resonance is produced and decays into $\pi^+ D_s^-$.

$\bar{B}^0 \to D^0 D_s^{*-}\rho^+$. We produce this state with the external emission Cabibbo favored decay shown in Fig. 1 (left). In Fig. 1 (right) we depict the direct decay $\bar{B}^0 \to D_s^- D^0\pi^+$ considered as background.

We evaluate the scattering matrix using the Bethe-Salpeter equation in the D^*K^* and $D_s^*\rho$ channels,

$$T = [1 - VG]^{-1} V \,, \tag{1}$$

with G the diagonal loop function for the intermediate mesons and V the transition potential. However, the state is observed in $D_s\pi$, hence, the mechanism by means of which the reaction proceeds is given in Fig. 2. The amplitude for the process of Fig. 2 is given by,

$$t = aG_{\rho D_s^*}(M_{\rm inv}) t_{\rho D_s^*, K^* D^*}(M_{\rm inv}) \tilde{V}(\pi D_s, M_{\rm inv}) \,, \tag{2}$$

where a is a normalization constant that we do not evaluate, unnecessary to show the shape of the πD_s mass distribution in the $\bar{B}^0$ decay, and $M_{\rm inv}$ is the invariant mass distribution of the $D_s\pi$ final state. The vertex function $\tilde{V}$ corresponding to the triangle loop of Fig. 3 can be easily evaluated.

We assume the resonance to be in $J = 0$, and that the vectors have small momenta with respect to their masses. Then, the structure of the triangle diagram of Fig. 3 is given by

$$\tilde{V} = -i \int \frac{d^4q}{(2\pi)^4} \epsilon^l_{\bar{K}^*} \epsilon^l_{\bar{D}^*} \epsilon^i_{\bar{K}^*} \epsilon^j_{\bar{D}^*} \frac{(2k+q)^i (2k+q)^j}{(P-q-k)^2 - m_K^2 + i\epsilon} \frac{\theta(q_{\rm max} - q)}{(P-q)^2 - m_{K^*}^2 + i\epsilon} \frac{1}{q^2 - m_{D^*}^2 + i\epsilon} \,. \tag{3}$$

The loop function $\tilde{V}$ is naturally regularized with a cutoff $q_{\rm max}$, the same one used to regularize the D^*K^* and $D_s^*\rho$ loops when studying their interactions. The equivalent $q_{\rm max}$ used in [1] was 1100 MeV. We find,

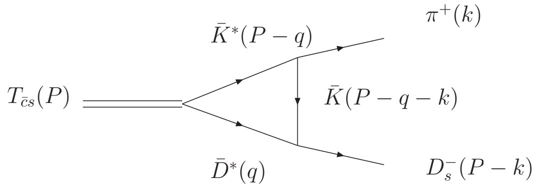

Figure 3. Triangle diagram accounting for the $R \to \pi \bar{D}_s$ decay of the R resonance of $I = 1$ generated with the $\rho \bar{D}_s$, $\bar{D}^* \bar{K}^*$ coupled channels.

$$\tilde{V} = -\int \frac{d^3q}{(2\pi)^3} \frac{(2\vec{k}+\vec{q})^2}{8\omega_{K^*}(q)\omega_{D^*}(q)\omega_K(\vec{q}+\vec{k})} \frac{1}{P^0-\omega_{D_s^*}(q)-\omega_{K^*}(q)+i\epsilon}$$
$$\times \left\{ \frac{1}{P^0-k^0-\omega_{D^*}(q)-\omega_K(\vec{q}+\vec{k})+i\epsilon} + \frac{1}{k^0-\omega_{K^*}(q)-\omega_K(\vec{q}+\vec{k})+i\epsilon} \right\} , \quad (4)$$

which shows the different cuts of the loop diagram when pairs of the internal particles of the loop are placed on-shell.

Then, we consider that the transition amplitude for $\bar{B}^0 \to D^0 D_s^- \pi^+$ is given by a constant background (considering the dominance of s-wave in the coupling of the bottom meson to the pseudoscalars), see Fig. 1 (right), together with the scattering amplitude of the diagram in Fig. 2, which accounts for the interaction of the VV coupled channels. It reads as

$$t' = aG_{\rho D_s^*}(M_{\rm inv}) t_{\rho D_s^*, K^* D^*}(M_{\rm inv}) \tilde{V}(\pi D_s, M_{\rm inv}) + b \ . \quad (5)$$

Therefore, the mass distribution of πD_s^- in the $\bar{B}^0$ decay is given by,

$$\frac{d\Gamma}{dM_{\rm inv}} = \frac{1}{(2\pi)^3} \frac{1}{4M_B^2} p_{D^0} \tilde{p}_\pi |t'|^2 \ , \quad (6)$$

where $p_{D^0} = \frac{\lambda^{1/2}(M_B^2, m_{D^0}^2, M_{\rm inv}^2)}{2M_B}$ and $\tilde{p} = \frac{\lambda^{1/2}(M_{\rm inv}^2, m_{D_s}^2, m_\pi^2)}{2M_{\rm inv}}$.

2.1 Results

We take into account the decay widths of the vector mesons K^* and ρ by means the convolution of the G function in Eq. (1) [4]. The result for the T matrix in $I = 1; J = 0$ is shown in Fig. 4. The cusp obtained for $J = 0$ has become wider. The position of the cusp is similar, it shows up slightly above the $D^* K^*$ threshold and around 2920 MeV, with a width coming basically from the decay of the ρ into $\pi\pi$. We have also obtained visible peaks in the scattering amplitudes for $J = 1$ and 2 [4].

Finally, we show the result of the invariant mass distribution of the decay $\bar{B}^0 \to D_s^- D^0 \pi^+$, Eq. (6), in comparison with the LHCb experimental data [2, 3] in Fig. 5 (left). In Eq. (6), we adjusted the constants a and b to reproduce well the experimental data around the $T_{c\bar{s}}(2900)$ resonance, and we obtain $a = 2.1 \times 10^3$ and $b = -1.45 \times 10^3$. As can be seen, our model describes well the experimental data. A peak is obtained around the threshold of the $D^* K^*$ channel. Since these results were obtained fixing the subtraction constant to obtain the $T_{cs}(2900)$, this also supports the molecular picture of this state as $D^* \bar{K}^*$ of [5]. Thus, our

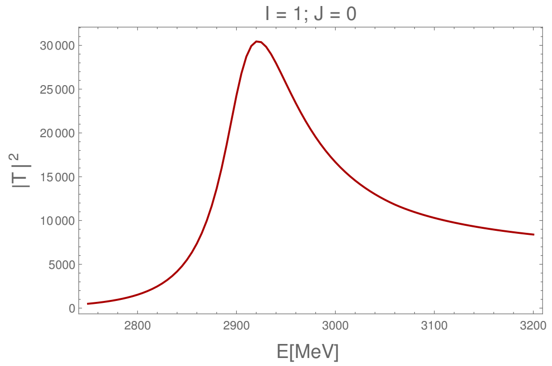

Figure 4. $|T|^2$ for $C = 1; S = 1; I = 1; J = 0$ with $\alpha = -1.474$.

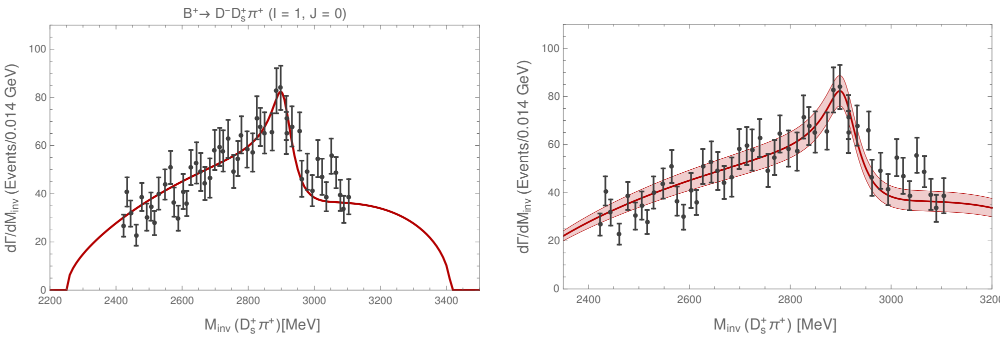

Figure 5. Left: invariant mass distribution for $D_s\pi$ from the decay $B \to \bar{D}D_s\pi$ compared to the experimental data from Ref. [2, 3]. Right: the same but with the error band obtained by changing the parameter for the background (b) 5% up and down.

model strongly supports the $T_{c\bar{s}}(2900)$ as a cusp structure originated by the non-diagonal interaction $D^*K^* \to D_s^*\rho$, with a width mainly due to the decay of the ρ meson into $\pi\pi$

Finally, it is interesting to give a band of errors by changing the background, we do this to show the sensitivity of the results to this background. We have done this, keeping the value of a, needed to get the strength of the peak of the distribution, by varying the parameter b of the background by 5% (up and down). This is shown in Fig. 5 (right). The band obtained overlaps with the errors of the data.

References

[1] R. Molina, T. Branz, E. Oset, Phys. Rev. D **82**, 014010 (2010), 1005.0335
[2] R. Aaij et al. (LHCb), Phys. Rev. Lett. **131**, 041902 (2023), 2212.02716
[3] R. Aaij et al. (LHCb), Phys. Rev. D **108**, 012017 (2023), 2212.02717
[4] R. Molina, E. Oset, Phys. Rev. D **107**, 056015 (2023), 2211.01302
[5] R. Molina, E. Oset, Phys. Lett. B **811**, 135870 (2020), 2008.11171
[6] C. Chen (CERN), Particle Zoo 2.0: New tetra- and pentaquarks at LHCb p. July 5 (2022)