

The $T_{cs/c\bar{s}}$ (2900) in the hidden gauge approach

R. Molina, T. Branz and E. Oset



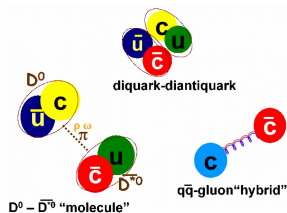
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Intro

Since the X(3872) many exotics discovered ...

- $Z_c(3900)$, BESIII, 2013
close to $D\bar{D}^*$, $c\bar{q}q\bar{c}$ ($q = u, d$)
- $Z_{cs}(3985)$, BESIII, 2021
close to $\bar{D}_s^*D/\bar{D}_sD^*$, $c\bar{q}s\bar{c}$
- $X_0(2866)$, $X_1(2900)$ now $T_{cs}(2900)$,
LHCb, 2020
close to $D^*\bar{K}^*$, $c\bar{q}s\bar{q}$
- $T_{cc}(3875)$, LHCb, 2021
close to DD^* , $c\bar{q}c\bar{q}$
- $T_{c\bar{s}}(2900)$, LHCb, 2022
close to D^*K^* , $c\bar{s}q\bar{q}$



⇒ Do not fit into $q\bar{q}$ basic mesons of the quark model predictions
... Are the meson-meson molecules? tetraquarks?
... Dynamics of the interaction?

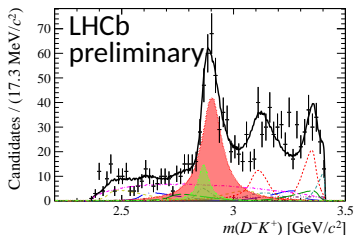
New flavor exotic tetraquark ($C = -1, S = 1, I_3 = 0$)

LHCb (2020)

Two states $J^P = 0^+, 1^-$ decaying to $\bar{D}K$. First clear example of an heavy-flavor exotic tetraquark, $\sim \bar{c}\bar{s}ud$. Now $T_{cs}(2900)$

$$X_0(2866) : M = 2866 \pm 7 \quad \text{and} \quad \Gamma = 57.2 \pm 12.9 \text{ MeV},$$

$$X_1(2900) : M = 2904 \pm 5 \quad \text{and} \quad \Gamma = 110.3 \pm 11.5 \text{ MeV}.$$

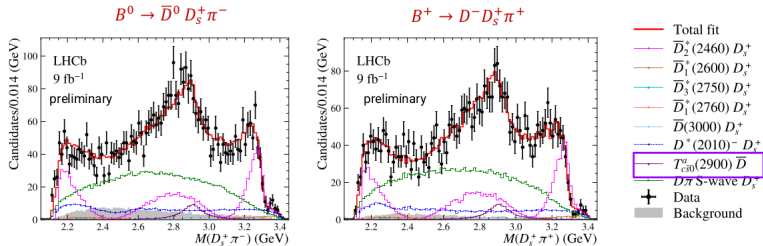


R. Aaij et al. (LHCb Collaboration), PRL125(2020), PRD102(2020)

New exotic tetraquark seen in $D_s^+ \pi^+$ ($C = 1, S = 1, I = 1$)

LHCb (2022)

One state decaying $T_{c\bar{s}}(2900)$ decaying to $D_s^+ \pi^-$ and $D_s^+ \pi^+$ has been observed.



- The analysis favors $J^P = 0^+$
- Mass, $m = 2908 \pm 11 \pm 20$ MeV
- Width, $\Gamma = 136 \pm 23 \pm 11$ MeV

LHCb-PAPER-2022-026

Note that,

$D^* K^*$ th.: 2903 MeV

$D_s^* \rho$ th.: 2890 MeV

- 2010. Prediction of several flavour exotic states

PHYSICAL REVIEW D **82**, 014010 (2010)

New interpretation for the $D_{s2}^*(2573)$ and the prediction of novel exotic charmed mesons

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In this manuscript we study the vector-vector interaction within the hidden-gauge formalism in a coupled channel unitary approach. In the sector $C = 1, S = 1, J = 2$ we get a pole in the T matrix around 2572 MeV that we identify with the $D_{s2}^*(2573)$, coupling strongly to the $D^*K^*(D_s^*\phi(\omega))$ channels. In addition we obtain resonances in other exotic sectors which have not been studied before such as $C = 1, S = -1, C = 2, S = 0$ and $C = 2, S = 1$. These “flavor-exotic” states are interpreted as D^*K^* , D^*D^* and D^*D^* molecular states but have not been observed yet. In total we obtain nine states with different spin, isospin, charm, and strangeness of non- $C = 0, S = 0$ and $C = 1, S = 0$ character, which have been reported before.

DOI: 10.1103/PhysRevD.82.014010

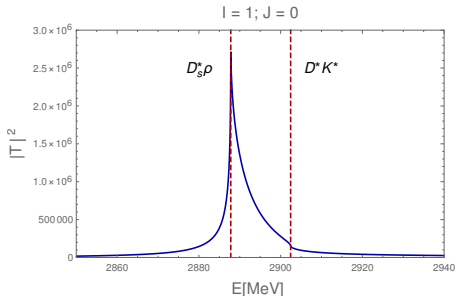
PACS numbers: 14.40.Rt, 12.40.Vv, 13.75.Lb, 14.40.Lb

- Free parameter fixed with $D_{s2}(2573)$; couples to D^*K^* , $c\bar{q}q\bar{s}$
- Flavour exotic states with $I = 0, J^P = \{0, 1, 2\}^+$ coupling to $D^*\bar{K}^*$ are predicted, $c\bar{q}s\bar{q}$
- Doubly charm states, $I = 0; J^P = 1^+$, close to D^*D^* are predicted, $c\bar{q}c\bar{q}$, and $I = 1/2; J^P = 1^+$, close to $D^*D_s^*$ $c\bar{q}c\bar{s}$

Phys. Rev. D 82 (2010), Molina, Branz, Oset

3.5 $C = 1; S = 1; I = 1$

In this sector the potential is attractive for the $D^*K^* \rightarrow D_s^*\rho$ reaction. For $J = 0$ and 1 this potential is around $-7g^2$ whereas it is by a factor of two bigger $-13g^2$ for $J = 2$ (see Table 14). In fact, we only obtain a pole for $J = 2$. For $J = 0$ and 1 we only observe a cusp in the $D_s^*\rho$ threshold. In Table 5 we show the pole position and couplings to the different channels. Both channels, D^*K^* and $D_s^*\rho$, are equally important as one can deduce from the corresponding couplings. The broad width of the ρ meson has to be taken into account



$$\alpha = -1.6$$

ρ width not included

$D^*K^* \rightarrow DK$ considered

Cusp around $D_s^*\rho$, D^*K^* th.

separated only by 14 MeV

Flavour exotic states

Molina,Branz,Oset, PRD82(2010)

C, S	Channels	$I[J^P]$	\sqrt{s}	$\Gamma_A (\Lambda = 1400)$	$\Gamma_B (\Lambda = 1200)$	State	\sqrt{s}_{exp}	Γ_{exp}
1, -1	$D^* \bar{K}^*$	0[0 ⁺]	2848	23	59	$X_0(2866)$ or $T_{CS}(2900)$	2866	57
		0[1 ⁺]	2839	3	3			
		0[2 ⁺]	2733	11	36			
1, 1	$D^* K^*, D_S^* \omega$ $D_S^* \phi$	0[0 ⁺]	2683	20	71	$D_{S2}(2573)$	2572	20
		0[1 ⁺]	2707	4×10^{-3}	4×10^{-3}			
		0[2 ⁺]	2572	7	23			
1, 1	$D^* K^*, D_S^* \rho$	1[0 ⁺]	Cusp structure around $D_S^* \rho, D^* K^*$			new $T_{C\bar{S}}(2900)$	2908	136
1, 1		1[1 ⁺]	Cusp structure around $D_S^* \rho, D^* K^*$					
1, 1		1[2 ⁺]	2786	8	11			
2, 0	$D^* D^*$	0[1 ⁺]	3969	0	0			
2, 1	$D^* D_S^*$	1/2[1 ⁺]	4101	0	0			

Table 1: Summary of the nine states obtained. The width is given for the model A, Γ_A , and B, Γ_B . All the quantities here are in MeV. Repulsion in $C = 0, S = 1, I = 1/2$; $C = 1, S = -1, I = 1$; $C = 1, S = 2, I = 1/2$; $C = 2, S = 0, I = 1$ and $C = 2, S = 2, I = 0$ is found.

Form factors in the $D^* D \pi$ vertex; Model A: $F_1(q^2) = \frac{\Lambda_b^2 - m^2}{\Lambda_b^2 - q^2} \pi$, Titov, Kampf EPJA7, PRC65 with $\Lambda_b = 1.4, 1.5$ GeV and

$g = M_\rho / 2 f_\pi$. Model B: $F_2(q^2) = e q^2 / \Lambda^2$ Navarra, Nielsen, Bracco PRD65 (2002), $\Lambda = 1, 1.2$ GeV and $g_D = g_{D^* D \pi}^{\text{exp}} = 8.95$ (experimental value). Subtraction constant $\alpha = -1.6$.

Many studies appeared after these discoveries ...

- He, Wang, Zhu, EPJC80, 1026 (2020), Karliner, Rosner, PRD102(2020), $X_0(2866)$, compact tetraquark
- X. H. Liu, Yan et al., EPJC80(2020), $X_0(2866)$, Triangle Singularity
- M. Z. Liu, Xie, Geng, PRD102(2020), $X_0(2866)$, $D^* \bar{K}^*$ molecule (one-boson ex.), $X_1(2900)$ cannot be, Qi, Wang et al. EPJC81(2021), X_1 is a $\bar{D}_1 K$ molecule (ρ, ω ex.)
- Ying-Hui Ge, X.H. Liu and H. W. Kei, 2207.09900, the $T_{c\bar{s}}$ could be a TS from the $\chi_{c1} D^* K^*$ loop. However, the TS peak around the $D_s^* \rho$ threshold from the $D^{**} D_s^* \rho$ loop cannot explain the $T_{c\bar{s}}(2900)$
- Du, Baru, Dong, Filin, Nieves, F. K. Guo, T_{cc} , PRD105, (2022), 3-body dynamics, $D^0 D^0 \pi^+$, contact+OPE, DD^* molecule
- Albaladejo, T_{cc} from DD^* , can have $l = 0$ or 1
- Feijoo, Liang, Oset, PRD104(2021), T_{cc} as DD^* , has $l = 0$, decay width to $D^0 D^0 \pi^+ \sim 43$ MeV
- Padmanath, Prelovsek, virtual s-wave bound state for $m_\pi = 280$ MeV of DD^* in LatticeQCD ...

The Local Hidden Gauge Approach

Lagrangian

$$\mathcal{L} = \mathcal{L}^{(2)} + \mathcal{L}_{III} \quad (1)$$

$$\mathcal{L}^{(2)} = \frac{1}{4}f^2 \langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + \chi^\dagger U \rangle \quad (2)$$

$$\mathcal{L}_{III} = -\frac{1}{4} \langle V_{\mu\nu} V^{\mu\nu} \rangle + \frac{1}{2}M_V^2 \langle [V_\mu - \frac{i}{g}\Gamma_\mu]^2 \rangle$$

$$D_\mu U = \partial_\mu U - ieQA_\mu U + ieUQA_\mu, \quad U = e^{i\sqrt{2}P/f} \quad (3)$$

$$\begin{aligned} \mathcal{L}_{V\gamma} &= -M_V^2 \frac{e}{g} A_\mu \langle V^\mu Q \rangle \\ \mathcal{L}_{VPP} &= -ig \langle V^\mu [P, \partial_\mu P] \rangle; \quad g = M_V/2f \\ \tilde{\mathcal{L}}^{(2)} &= \frac{1}{12f^2} \langle [P, \partial_\mu P]^2 + MP^4 \rangle. \end{aligned} \quad (4)$$

Local Hidden Gauge Approach

Vector-vector scattering

$$\mathcal{L}_{III} = -\frac{1}{4} \langle V_{\mu\nu} V^{\mu\nu} \rangle \rightarrow \mathcal{L}_{III}^{(3V)} = ig \langle (\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu \rangle$$

$$\mathcal{L}_{III}^{(c)} = \frac{g^2}{2} \langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu \rangle$$

$V_{\mu\nu} =$

$$\partial_\mu V_\nu - \partial_\nu V_\mu - ig[V_\mu, V_\nu]$$

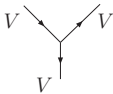
$$g = \frac{M_V}{2f}$$

$V_\mu =$

$$\begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} & \bar{D}^{*0} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} & D^{*-} \\ K^{*-} & \bar{K}^{*0} & \phi & D_s^{*-} \\ D^{*0} & D^{*+} & D_s^{*+} & J/\psi \end{pmatrix}_\mu$$



a)



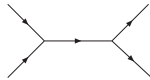
b)

\rightarrow



c)

+



d)

Local Hidden Gauge Approach

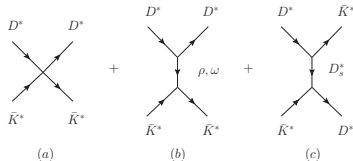


Figure 1: The $D^* \bar{K}^* \rightarrow D^* \bar{K}^*$ interaction at the tree level; (a) contact term; (b) exchange of light vectors; (c) exchange of a heavy vector.

Approximation

$$\epsilon_1^\mu = (0, 1, 0, 0)$$

$$\epsilon_2^\mu = (0, 0, 1, 0)$$

$$\epsilon_3^\mu = (|\vec{k}|, 0, 0, k^0)/m$$

$$k^\mu = (k^0, 0, 0, |\vec{k}|)$$

$$\vec{k}/m \simeq 0, \quad k_j^\mu \epsilon_\mu^{(l)} \simeq 0$$

$$\epsilon_1^\mu = (0, 1, 0, 0)$$

$$\epsilon_2^\mu = (0, 0, 1, 0)$$

$$\epsilon_3^\mu = (0, 0, 0, 1)$$

$$\mathcal{L}_{III}^{(3V)} = ig \langle (\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu \rangle = ig \langle [V_\mu, \partial_\nu V_\mu] V^\nu \rangle$$

Spin projectors

$$\mathcal{P}^{(0)} = \frac{1}{3} \epsilon_\mu \epsilon^\mu \epsilon_\nu \epsilon^\nu; \quad \mathcal{P}^{(1)} = \frac{1}{2} (\epsilon_\mu \epsilon_\nu \epsilon^\mu \epsilon^\nu - \epsilon_\mu \epsilon_\nu \epsilon^\nu \epsilon^\mu)$$

$$\mathcal{P}^{(2)} = \left\{ \frac{1}{2} (\epsilon_\mu \epsilon_\nu \epsilon^\mu \epsilon^\nu + \epsilon_\mu \epsilon_\nu \epsilon^\nu \epsilon^\mu) - \frac{1}{3} \epsilon_\mu \epsilon^\mu \epsilon_\nu \epsilon^\nu \right\}.$$

The $X_0(2866)$ or $T_{cs}(2900)$

Local Hidden Gauge Approach

Potential V : contact + vector-meson exchange (ρ, ω)

J Amplitude	Contact	V-exchange	\sim Total
0 $D^* \bar{K}^* \rightarrow D^* \bar{K}^*$	$4g^2 - \frac{g^2(p_1+p_4) \cdot (p_2+p_3)}{m_{D_s^*}^2} + \frac{1}{2}g^2\left(\frac{1}{m_\omega^2} - \frac{3}{m_\rho^2}\right)(p_1+p_3) \cdot (p_2+p_4)$		$-9.9g^2$
1 $D^* \bar{K}^* \rightarrow D^* \bar{K}^*$	0	$\frac{g^2(p_1+p_4) \cdot (p_2+p_3)}{m_{D_s^*}^2} + \frac{1}{2}g^2\left(\frac{1}{m_\omega^2} - \frac{3}{m_\rho^2}\right)(p_1+p_3) \cdot (p_2+p_4)$	$-10.2g^2$
2 $D^* \bar{K}^* \rightarrow D^* \bar{K}^*$	$-2g^2 - \frac{g^2(p_1+p_4) \cdot (p_2+p_3)}{m_{D_s^*}^2} + \frac{1}{2}g^2\left(\frac{1}{m_\omega^2} - \frac{3}{m_\rho^2}\right)(p_1+p_3) \cdot (p_2+p_4)$		$-15.9g^2$

Table 2: Tree level amplitudes for $D^* \bar{K}^*$ in $l = 0$. Last column: ($V_{\text{th.}}$).

J Amplitude	Contact	V-exchange	\sim Total
0 $D^* \bar{K}^* \rightarrow D^* \bar{K}^*$	$-4g^2 - \frac{g^2(p_1+p_4) \cdot (p_2+p_3)}{m_{D_s^*}^2} + \frac{1}{2}g^2\left(\frac{1}{m_\omega^2} + \frac{1}{m_\rho^2}\right)(p_1+p_3) \cdot (p_2+p_4)$		$9.7g^2$
1 $D^* \bar{K}^* \rightarrow D^* \bar{K}^*$	0	$-\frac{g^2(p_1+p_4) \cdot (p_2+p_3)}{m_{D_s^*}^2} + \frac{1}{2}g^2\left(\frac{1}{m_\omega^2} + \frac{1}{m_\rho^2}\right)(p_1+p_3) \cdot (p_2+p_4)$	$9.9g^2$
2 $D^* \bar{K}^* \rightarrow D^* \bar{K}^*$	$2g^2 - \frac{g^2(p_1+p_4) \cdot (p_2+p_3)}{m_{D_s^*}^2} + \frac{1}{2}g^2\left(\frac{1}{m_\omega^2} + \frac{1}{m_\rho^2}\right)(p_1+p_3) \cdot (p_2+p_4)$		$15.7g^2$

Table 3: Tree level amplitudes for $D^* \bar{K}^*$ in $l = 1$. Last column: ($V_{\text{th.}}$).

The interaction is attractive for $l = 0$ and repulsive for $l = 1$.

Local Hidden Gauge Approach

J	Amplitude	Contact	V-exchange	\sim Total
0	$D^* K^* \rightarrow D^* K^*$	0	$\frac{g^2}{2} \left(\frac{1}{m_p^2} - \frac{1}{m_\omega^2} \right) (p_1 + p_3) \cdot (p_2 + p_4)$	$0.11g^2$
0	$D^* K^* \rightarrow D_s^* \rho$	$4g^2$	$-\frac{g^2(p_1+p_4)(p_2+p_3)}{m_{D^*}^2} - \frac{g^2(p_1+p_3) \cdot (p_2+p_4)}{m_{K^*}^2}$	$-6.8g^2$
0	$D_s^* \rho \rightarrow D_s^* \rho$	0	0	0
1	$D^* K^* \rightarrow D^* K^*$	0	$\frac{g^2}{2} \left(\frac{1}{m_p^2} - \frac{1}{m_\omega^2} \right) (p_1 + p_3) \cdot (p_2 + p_4)$	$0.11g^2$
1	$D^* K^* \rightarrow D_s^* \rho$	0	$\frac{g^2(p_1+p_4)(p_2+p_3)}{m_{D^*}^2} - \frac{g^2(p_1+p_3) \cdot (p_2+p_4)}{m_{K^*}^2}$	$-6.6g^2$
1	$D_s^* \rho \rightarrow D_s^* \rho$	0	0	0
2	$D^* K^* \rightarrow D^* K^*$	0	$\frac{g^2}{2} \left(\frac{1}{m_p^2} - \frac{1}{m_\omega^2} \right) (p_1 + p_3) \cdot (p_2 + p_4)$	$0.11g^2$
2	$D^* K^* \rightarrow D_s^* \rho$	$-2g^2$	$-\frac{g^2(p_1+p_4)(p_2+p_3)}{m_{D^*}^2} - \frac{g^2(p_1+p_3) \cdot (p_2+p_4)}{m_{K^*}^2}$	$-12.8g^2$
2	$D_s^* \rho \rightarrow D_s^* \rho$	0	0	0

Table 4: Tree level amplitudes for $D^* K^*$, $D_s^* \rho$ in $l = 1$. Last column: (V_{th}) for $C = 1$, $S = 1$ and $l = 1$.

The interaction is attractive for both $l = 0$ and $l = 1$, favoring a $J^+ = 2^+$ state. (see PRD82 (2010) Molina, Branz, Oset, for $l = 0$)

New flavor exotic tetraquark ($C = 1, S = -1$)

Two-meson loop function

$$G_i(s) = \frac{1}{16\pi^2} \left(\alpha + \text{Log} \frac{M_1^2}{\mu^2} + \frac{M_2^2 - M_1^2 + s}{2s} \text{Log} \frac{M_2^2}{M_1^2} \right. \\ \left. + \frac{p}{\sqrt{s}} \left(\text{Log} \frac{s - M_2^2 + M_1^2 + 2p\sqrt{s}}{-s + M_2^2 - M_1^2 + 2p\sqrt{s}} + \text{Log} \frac{s + M_2^2 - M_1^2 + 2p\sqrt{s}}{-s - M_2^2 + M_1^2 + 2p\sqrt{s}} \right) \right),$$

Bethe-Salpeter

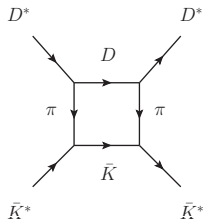
$$T = [\hat{1} - VG]^{-1}V$$

The states with $J^P = \{0, 2\}^+$ decay into $D\bar{K}$

$$\mathcal{L}_{VPP} = -ig \langle [P, \partial_\mu P] V^\mu \rangle$$

$$F(q) = e^{((p_1^0 - q^0)^2 - \vec{q}^2)/\Lambda^2} \quad \text{Navarra, PRD65(2002)}$$

with $q_0 = (s + m_D^2 - m_{\bar{K}}^2)/2\sqrt{s}$.



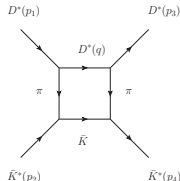
New flavor exotic tetraquark ($C = 1, S = -1$)

Recent work: [Molina, Oset PLB811 2020](#), $\alpha = -1.474$, $\Lambda = 1300$.

Evaluation of the decay width of the $J^P = 1^+$ state

$$\mathcal{L} = \frac{iG'}{\sqrt{2}} \epsilon^{\mu\nu\alpha\beta} \langle \delta_\mu V_\nu \delta_\alpha V_\beta P \rangle$$

$$\mathcal{L}_{VPP} = -ig \langle [P, \partial_\mu P] V^\mu \rangle$$



Amplitude:

$$-it = \frac{9}{2} (G' g m_{D^*})^2 \int \frac{d^4 q}{(2\pi)^4} \epsilon^{ijk} \epsilon^{i'j'k'} \left(\frac{1}{(p_1 - q)^2 - m_\pi^2 + i\epsilon} \right)^2 \frac{1}{q^2 - m_{D^*}^2 + i\epsilon} \frac{1}{(p_1 + p_2 - q)^2 - m_K^2 + i\epsilon} \\ \times \epsilon^{j(1)} \epsilon^{m(2)} \epsilon^{k(3')} q^i q^m \epsilon^{j'(1)} \epsilon^{m'(4)} \epsilon^{k'(3')} q^{i'} q^{m'} F^4(q) \quad (5)$$

$$t = \frac{9}{2} (G' g m_{D^*})^2 \int \frac{d^3 q}{(2\pi)^3} (\delta_{ii'} \delta_{jj'} - \delta_{ij'} \delta_{i'j}) \left(\frac{1}{(p_1 - q)^2 - m_\pi^2} \right)^2 \frac{1}{2\omega^*(q)} \frac{1}{2\omega(q)} \frac{1}{\sqrt{s} - \omega^*(q) - \omega(q) + i\epsilon} \\ \times \epsilon^{j(1)} \epsilon^{m(2)} \epsilon^{j'(3)} \epsilon^{m'(4)} q^i q^m q^{i'} q^{m'} F^4(q) \quad (6)$$

with $\omega^*(q) = \sqrt{m_{D^*}^2 + \vec{q}^2}$, $\omega(q) = \sqrt{m_K^2 + \vec{q}^2}$, $p_1^0 = m_{D^*}$, $q^0 = \omega^*(q)$. We use $\text{Im} \frac{1}{x+i\epsilon} = -i\pi \delta(x)$.

Decay of the $X_0(2900)$ to $D^* \bar{K}$

Taking now into account that,

$$\int \frac{d^3 q}{(2\pi)^3} f(\vec{q}^2) q^i q^m q^{i'} q^{m'} = \frac{1}{15} \int \frac{d^3 q}{(2\pi)^3} f(\vec{q}^2) \vec{q}^4 (\delta_{im} \delta_{i'm'} + \delta_{ii'} \delta_{mm'} + \delta_{im'} \delta_{m'i}) ,$$

one obtains,

$$4e^{j(1)} \epsilon^{m(2)} \epsilon^{j(3)} \epsilon^{m(4)} - e^{j(1)} e^{j(2)} \epsilon^{m(3)} \epsilon^{m(4)} - e^{j(1)} \epsilon^{m(2)} \epsilon^{m(3)} e^{j(4)} ,$$

which is a combination of the spin projectors, $5\mathcal{P}^{(1)} + 3\mathcal{P}^{(2)}$, **zero component for $J = 0$ (violates parity)**. The imaginary part for $J = 1$ is,

$$\text{Im}t = -\frac{3}{2} \frac{1}{8\pi} (G' g m_{D^*})^2 q^5 \left(\frac{1}{(m_{D^*}^* - \omega^*(q))^2 - \omega^2(q)} \right)^2 \frac{1}{\sqrt{s}} F^4(q)$$

$$\omega(q) = \sqrt{m_K^2 + \vec{q}^2}; \omega^*(q) = \sqrt{m_{D^*}^2 + \vec{q}^2}; q = \frac{\lambda^{1/2}(s, m_{D^*}^2, m_K^2)}{2\sqrt{2}}$$

Decay of the $X_0(2900)$ to $D^* \bar{K}$

$I(J^P)$	$M[\text{MeV}]$	$\Gamma[\text{MeV}]$	Coupled channels	state
$0(2^+)$	2775	38	$D^* \bar{K}^*$?
$0(1^+)$	2861	20	$D^* \bar{K}^*$?
$0(0^+)$	2866	57	$D^* \bar{K}^*$	$X_0(2866)$

Table 5: New results including the width of the $D^* K$ channel.

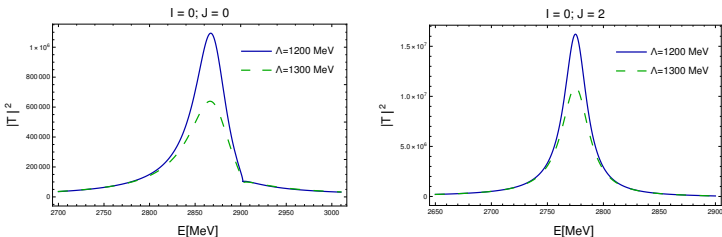


Figure 2: $|T|^2$ for $C = 1, S = -1, I = 0, J = 0$ and $J = 2$.

Decay of the $X_0(2900)$ to $D^* \bar{K}$

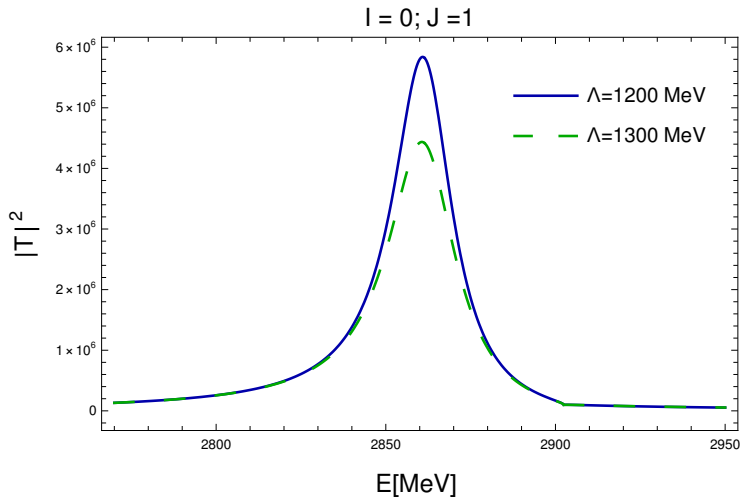


Figure 3: $|T|^2$ for $C = 1, S = -1, l = 0, J = 0$ and $J = 1$.

The $T_{c\bar{s}}(2900)$

$C = 1, S = 1, I = 1$ The $T_{c\bar{s}}(2900)$

Two channels: $D^* K^*$, $D_s^* \rho$. **New results**, $\alpha = -1.474$ to obtain the $T_{c\bar{s}}(2900)$ state in $D^* \bar{K}^*$. **We also consider both the ρ and K^* width.**

Convolution due to the vector meson mass distribution

$$\tilde{G}(s) = \frac{1}{N} \int_{(M_1-4\Gamma_1)^2}^{(M_1+4\Gamma_1)^2} d\tilde{m}_1^2 \left(-\frac{1}{\pi}\right) \mathcal{I}m \frac{1}{\tilde{m}_1^2 - M_1^2 + i\Gamma(\tilde{m})\tilde{m}_1} G(s, \tilde{m}_1^2, M_2^2),$$

with

$$N = \int_{(M_1-4\Gamma_1)^2}^{(M_1+4\Gamma_1)^2} d\tilde{m}_1^2 \left(-\frac{1}{\pi}\right) \mathcal{I}m \frac{1}{\tilde{m}_1^2 - M_1^2 + i\Gamma(\tilde{m})\tilde{m}_1}, \quad (7)$$

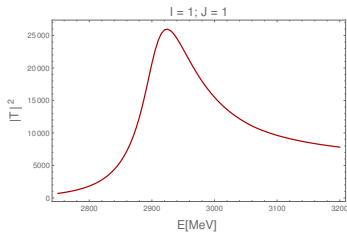
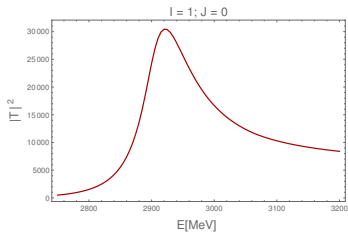
where M_1 and Γ_1 are the nominal mass and width of the vector meson.

$$\tilde{\Gamma}(\tilde{m}) = \Gamma_0 \frac{q_{\text{off}}^3}{q_{\text{on}}^3} \Theta(\tilde{m} - m_1 - m_2) \quad (8)$$

with

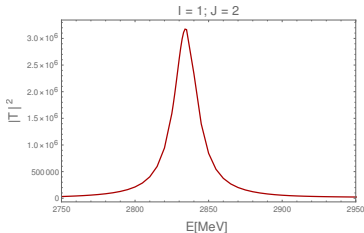
$$q_{\text{off}} = \frac{\lambda^{1/2}(\tilde{m}^2, m_1^2, m_2^2)}{2\tilde{m}}, \quad q_{\text{on}} = \frac{\lambda^{1/2}(M_1^2, m_1^2, m_2^2)}{2M_1}. \quad (9)$$

$C = 1, S = 1, I = 1$ The $T_{c\bar{s}}(2900)$



$(1, 0)$: $m = 2920$ MeV, $\Gamma = 130$ MeV $(1, 1)$: $m = 2922$ MeV, $\Gamma = 145$ MeV

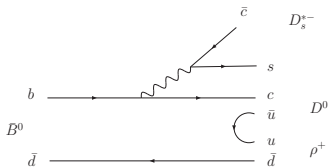
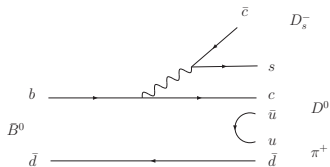
Exp. $m = 2908 \pm 11 \pm 20$ MeV, $\Gamma = 136 \pm 23 \pm 11$ MeV



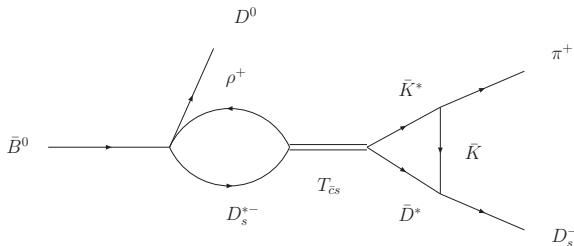
$(I, J) = (1, 2)$: $m = 2835$ MeV, $\Gamma = 20$ MeV

Production of the $T_{\bar{c}s}(2900)$

$\bar{B}^0 \rightarrow D_s^- D^0 \pi^+$ in B decays



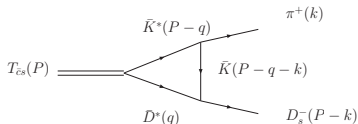
The $T_{\bar{c}s}(2900)$ can be produced by means of **external emission**



Production of the $T_{\bar{c}s}(2900)$ in B decays

$$T(E) = aG(E)_{D_s^* \rho} t_{D_s^* \rho \rightarrow \bar{D}^* \bar{K}^*}(E) t_L(E) + b \quad (10)$$

where $E = M_{inv}(\pi^+ D_s^-)$, and a, b are constants adjusted to reproduce the experimental data. b stands for the background. t_L is the amplitude for the triangle loop.



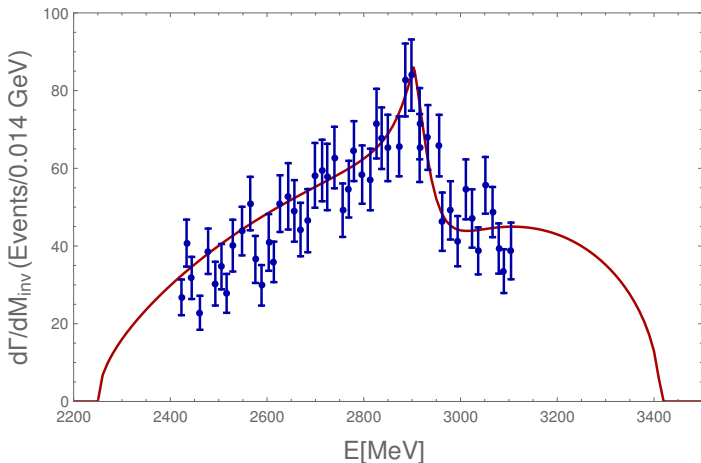
$$t_L = -g^2 \int \frac{d^3 q}{(2\pi)^3} (2\vec{k} + \vec{q})^2 F(\vec{k} + \vec{q}) \frac{1}{2\omega_{K^*}(q)} \frac{1}{2\omega_{D^*}(q)} \frac{1}{2\omega_K(\vec{q} + \vec{k})} \\ \times \left\{ \frac{1}{P^0 - \omega_{D^*}(q) - \omega_{K^*}(q) + i\epsilon} \frac{1}{P^0 - \omega_{D^*} - k^0 - \omega_K(\vec{q} + \vec{k}) + i\epsilon} \right. \\ \left. - \frac{1}{P^0 - \omega_{K^*}(q) - \omega_{D^*}(q) + i\epsilon} \frac{1}{\omega_{K^*}(q) + \omega(\vec{k} + \vec{q}) - k^0 - i\epsilon} \right\} \quad (11)$$

Production of the $T_{\bar{c}s}(2900)$ in B decays



$$\frac{d\Gamma}{dM_{Inv}} = \frac{1}{(2\pi)^3} \frac{1}{4M_B^2} p_D \tilde{p}_\pi |T|^2$$

$l = 1; J = 0$



Conclusions

Conclusions

- The $X_0(2866)$ or $T_{cs}(2900)$ is compatible with a $D^* \bar{K}^*$ resonance decaying to $D \bar{K}$. Its spin partners can be also searched for in B decays. Proposed reactions to observe the 1^+ state:
 $\bar{B}^0 \rightarrow D^{*+} \bar{D}^{*0} K^-$, Phys. Lett. B832 (2022), Dai, Molina, Oset,
 $\bar{B}^0 \rightarrow D^{*+} K^- \bar{K}^{*0}$, Phys. Rev. D105 (2022); and the 2^+ state:
 $B^+ \rightarrow D^+ D^- K^+$, Phys. Lett. B833 (2022), Bayar and Oset.
- The $T_{c\bar{s}}(2900)$ is more likely to be a failed bound state, or cusp structure around the $D^* K^*$, $D_s^* \rho$ thresholds. The width of the ρ is responsible for most of its width. There should be a bound state for $J^P = 2^+$ with mass of around 2830 MeV and width 20 MeV.