T_{cc} and other exotic states with two open heavy quarks

E. Oset, R. Molina, A. Feijoo, W. H. Liang, L.R. Dai, L.Roca, A.Martinez Torres, K. Khemchandani

IFIC, Universidad de Valencia and CSIC

Local hidden gauge approach and chiral Lagrangians

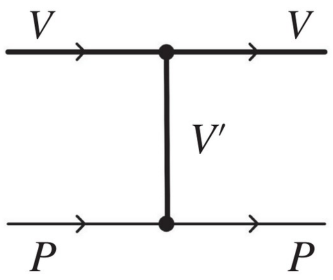
Predictions for molecular D* K*bar and D*D* states in 2010

Discussion to the light of the T_{cc} state

Predictions for D(s)(*)D(s)(*) and B(s)(*)B(s)(*) states

VP INTERACTION IN THE LOCAL HIDDEN GAUGE APPROACH

Bando et al Phys Rep. 164



Neglecting the p/M_V

$$\mathcal{L}_{VVV} = ig\langle (V_\mu \partial_\nu V^\mu - \partial_\nu V_\mu V^\mu) V^\nu \rangle$$

$$g = M_V/2f \ (M_V \approx 800 \text{ MeV}, \ f = 93 \text{ MeV})$$

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

$$-it = -g(V^\mu \partial_\nu V_\mu - \partial_\nu V_\mu V^\mu)_{ij} V^\nu_{ji} \frac{i}{q^2 - M_V^2} V^{\nu\prime}_{lm} [P, \partial_{\nu'} P]_{ml}$$

$$\sum_{pol} \epsilon^\nu_{ji} \epsilon^{\nu'}_{lm} = \left(-g^{\nu\nu'} + \frac{q^\nu q^{\nu'}}{M_V^2} \right) \delta_{jl} \delta_{im}$$

$$-it = -i \frac{g^2}{M_V^2} \langle (V^\mu \partial_\nu V_\mu - \partial_\nu V_\mu V^\mu)[P, \partial^\nu P] \rangle$$

$$\mathcal{L} = -\frac{1}{4f^2} \langle [V^\mu, \partial_\nu V^\mu][P, \partial^\nu P] \rangle$$

Chiral Lagrangian of M. C. Birse, Z. Phys. A 355, 231 (1996)

New interpretation for the Ds2*(2573) and the prediction of novel exotic charmed mesons

R. Molina, T. Branz, E. Oset, PHYSICAL REVIEW D 82, 014010 (2010)

State predicted of D* K*bar nature. The local hidden gauge for VV interaction has an extra contact term

$$\mathcal{L}_{VVVV} = \frac{1}{2}g^2\langle[V_\mu, V_\nu]V^\mu V^\nu\rangle$$

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

Spin projection operators

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

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

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

TABLE XI. Amplitudes for $C = 1$, $S = -1$ and $I = 0$.

J	Amplitude	Contact	V exchange	~Tota
0	$D^*\bar{K}^* \to D^*\bar{K}^*$	$4g^2$	$-\frac{g^2(p_1+p_4).(p_2+p_3)}{m^2_{D^*_s}} + \frac{1}{2}g^2(\frac{1}{m^2_\omega} - \frac{3}{m^2_\rho})(p_1 + p_3).(p_2 + p_4)$	$-9.9g$
1	$D^*\bar{K}^* \to D^*\bar{K}^*$	0	$\frac{g^2(p_1+p_4).(p_2+p_3)}{m^2_{D^*_s}} + \frac{1}{2}g^2(\frac{1}{m^2_\omega} - \frac{3}{m^2_\rho})(p_1 + p_3).(p_2 + p_4)$	-10.2
2	$D^*\bar{K}^* \to D^*\bar{K}^*$	$-2g^2$	$-\frac{g^2(p_1+p_4).(p_2+p_3)}{m^2_{D^*_s}} + \frac{1}{2}g^2(\frac{1}{m^2_\omega} - \frac{3}{m^2_\rho})(p_1 + p_3).(p_2 + p_4)$	-15.9

TABLE XII. Amplitudes for $C = 1$, $S = -1$ and $I = 1$.

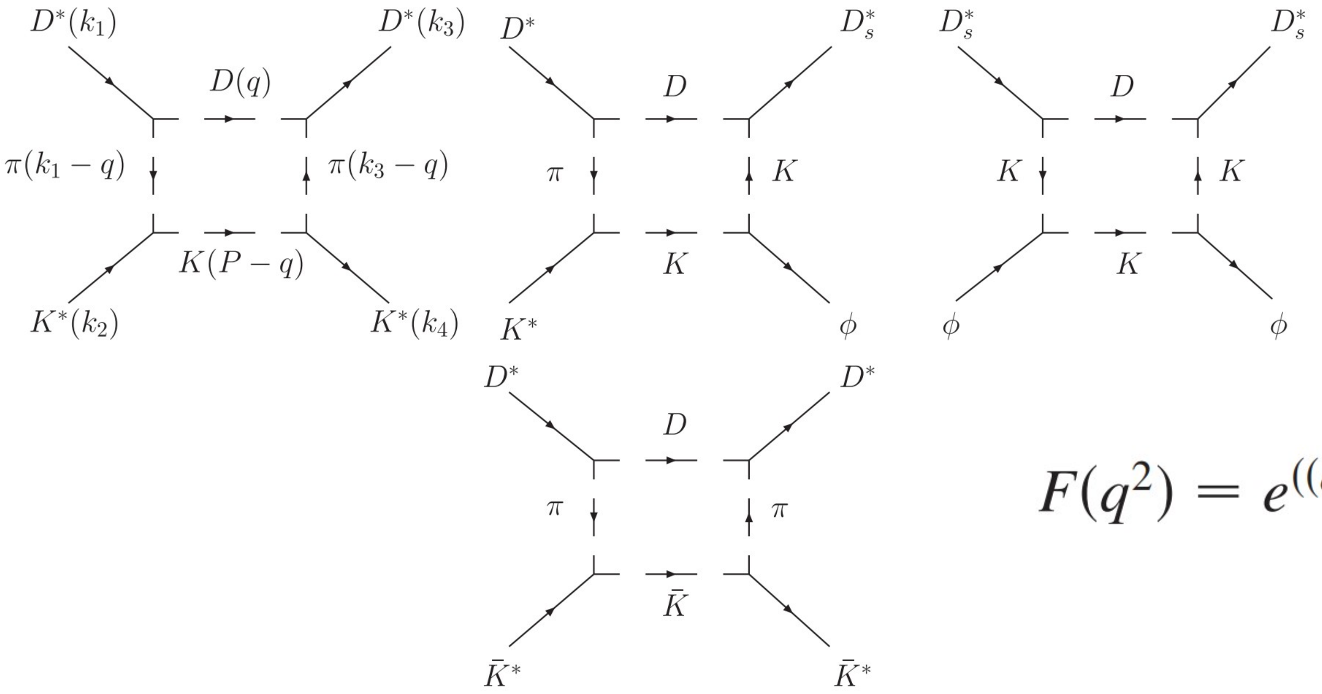
J	Amplitude	Contact	V exchange	~Tot
0	$D^*\bar{K}^* \to D^*\bar{K}^*$	$-4g^2$	$\frac{g^2(p_1+p_4).(p_2+p_3)}{m^2_{D^*_s}} + \frac{g^2}{2}(\frac{1}{m^2_\omega} + \frac{1}{m^2_\rho})(p_1 + p_3).(p_2 + p_4)$	$9.7g$
1	$D^*\bar{K}^* \to D^*\bar{K}^*$	0	$-\frac{g^2(p_1+p_4).(p_2+p_3)}{m^2_{D^*_s}} + \frac{g^2}{2}(\frac{1}{m^2_\omega} + \frac{1}{m^2_\rho})(p_1 + p_3).(p_2 + p_4)$	$9.9g$
2	$D^*\bar{K}^* \to D^*\bar{K}^*$	$2g^2$	$\frac{g^2(p_1+p_4).(p_2+p_3)}{m^2_{D^*_s}} + \frac{g^2}{2}(\frac{1}{m^2_\omega} + \frac{1}{m^2_\rho})(p_1 + p_3).(p_2 + p_4)$	$15.7g$

$$T = (\hat{1} - VG)^{-1}V.$$

$$G_i = i\int \frac{d^4q}{(2\pi)^4} \frac{1}{q^2 - M_1^2 + i\epsilon} \frac{1}{(P-q)^2 - M_2^2 + i\epsilon}$$

G is regularized either with a cutoff in the three momentum or dimensional regularization, with qmax, or a subtraction constant α.

Decay terms, added to V and iterated in the Bethe Salpeter equation.
Through its imaginary part they provide the decay to DKbar



$$F(q^2) = e^{((q^0)^2-|\vec{q}|^2)/\Lambda^2}$$

TABLE VI. $C = 1$; $S = -1$; $I = 0$. Mass and width for the states with $J = 0$ and 2.

$I[J^P]$	$\sqrt{s}_{\text{pole}}$ (MeV)	Model	Γ (MeV)
$0[0^+]$	2848	A, $\Lambda = 1400$ MeV	23
		A, $\Lambda = 1500$ MeV	30
		B, $\Lambda = 1000$ MeV	25
		B, $\Lambda = 1200$ MeV	59
$0[1^+]$	2839	Convolution	3
$0[2^+]$	2733	A, $\Lambda = 1400$ MeV	11
		A, $\Lambda = 1500$ MeV	14
		B, $\Lambda = 1000$ MeV	22
		B, $\Lambda = 1200$ MeV	36

R. Aaij et al. (LHCb Collaboration), Phys. Rev. Lett. 125, 242001 (2020)

R. Aaij et al. (LHCb Collaboration), Phys. Rev. D 102, 112003 (2020)

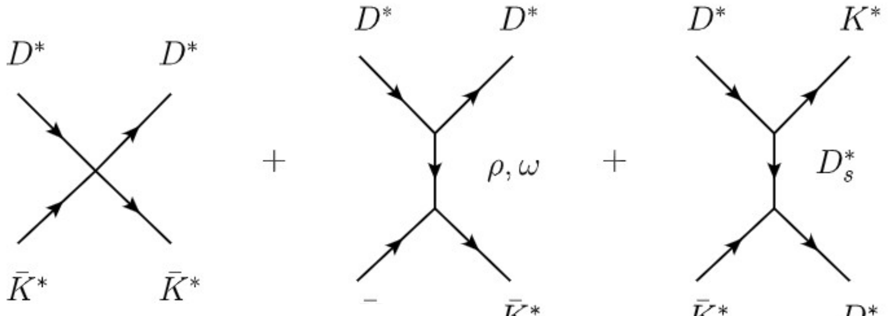
$$X_0(2866) : M = 2866 \pm 7 \quad \text{and} \quad \Gamma = 57.2 \pm 12.9\,\text{MeV},$$

Decaying to DKbar

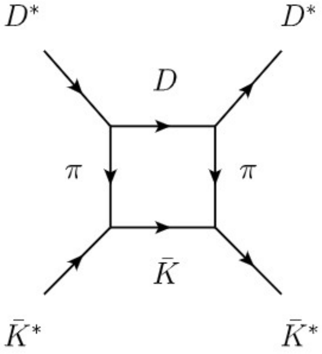
$$X_1(2900) : M = 2904 \pm 5 \quad \text{and} \quad \Gamma = 110.3 \pm 11.5\,\text{MeV}$$

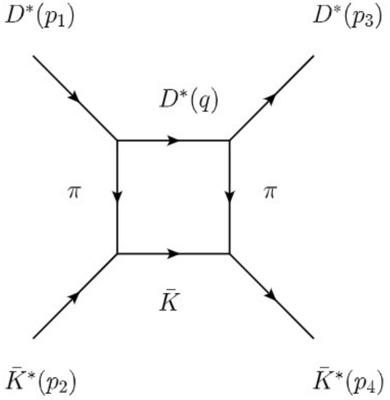
The state predicted corresponds to the $X_0(2866)$

Revision to the light of experimental results   R. Molina, E. O. Phys.Lett.B 811 (2020) 135870



Decay mode





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

with $G' = \frac{3g'}{4\pi^2 f}$; $g' = -\frac{G_V m_\rho}{\sqrt{2} f^2}$, $G_V \simeq 55$ MeV,

q_{max} is chosen to fit the exact mass

Λ to get the precise width of X_0

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

No D Kbar decay

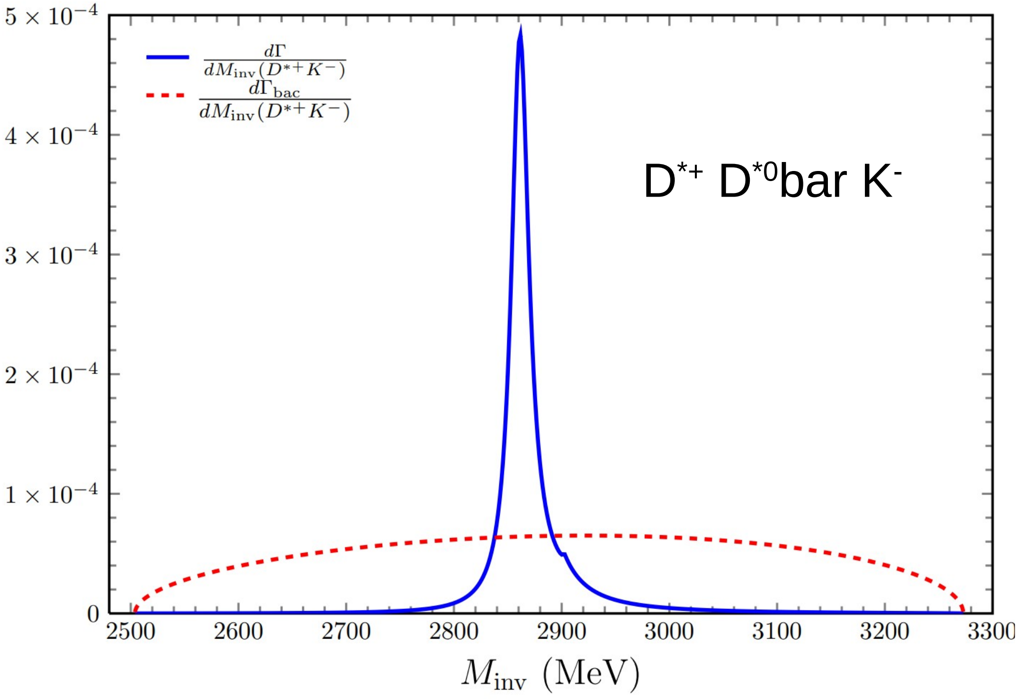
No D* Kbar decay

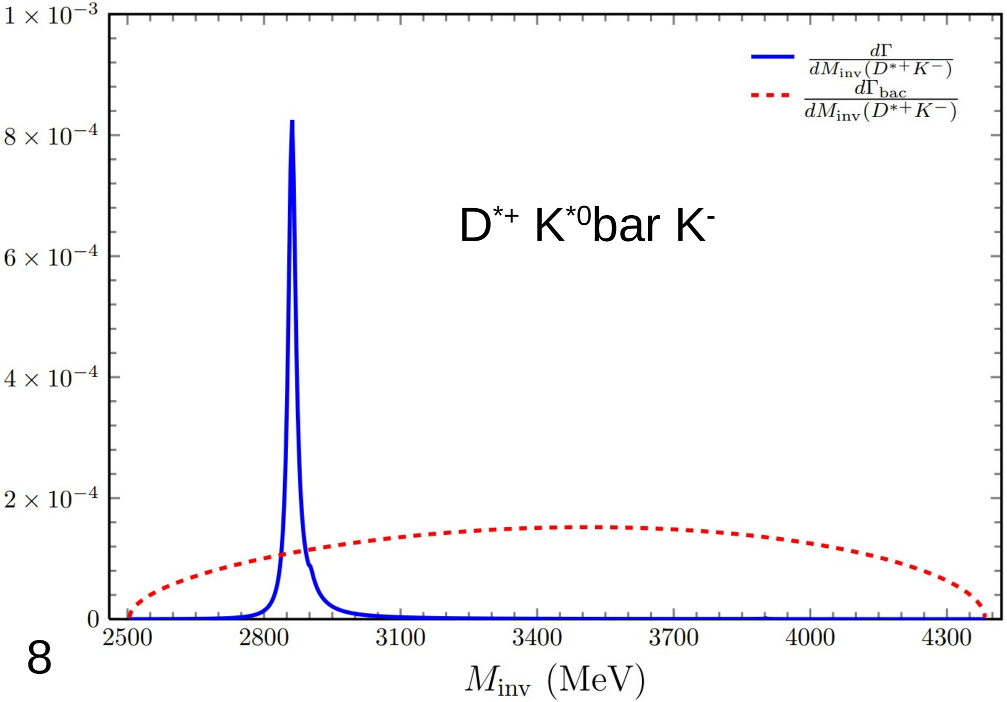
The $\bar{B}^0 \to D^{*+}\bar{D}^{*0}K^-$ reaction to detect the $I=0, J^P=1^+$ partner of the $X_0(2866)$

L.R. Dai, R. Molina, E. O, Arxiv 2202.00508

Looking for the exotic $X_0(2866)$ and its $J^P=1^+$ partner in the $\bar{B}^0 \to D^{(*)+}K^-K^{(*)0}$ reactions

Arxiv 2202.11973





In

R. Molina, T. Branz, E. Oset, PHYSICAL REVIEW D 82, 014010 (2010)

Predictions were done for a 1^+ D* D* state

TABLE IV. $C = 2$; $S = 0$; $I = 0$. Quantum numbers, pole positions, and couplings g_i in units of MeV. Here $\alpha = -1.4$.

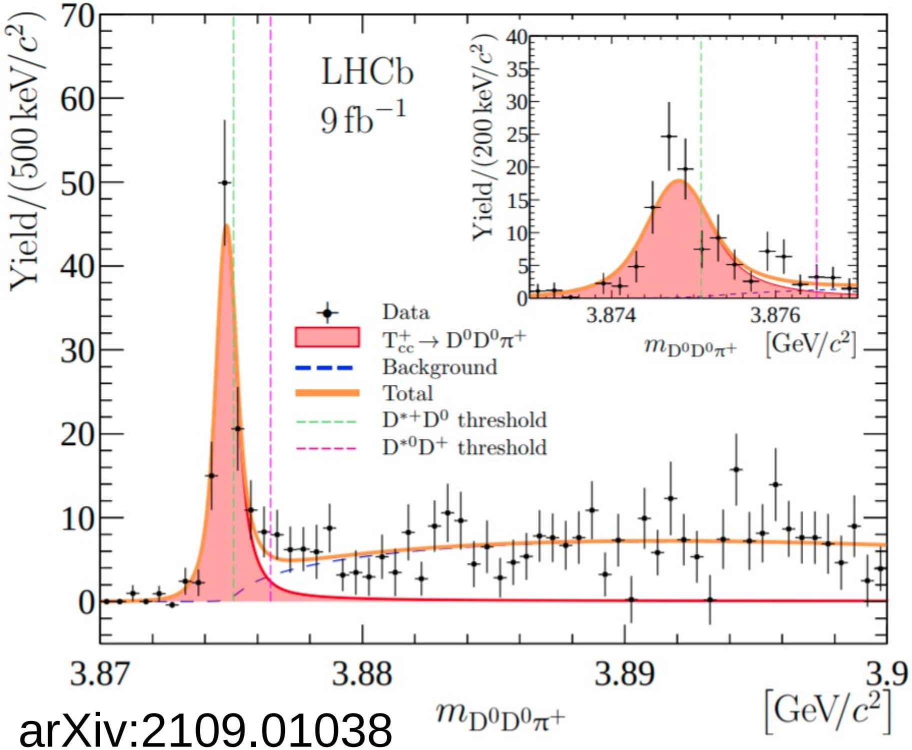
$I[J^P]$	$\sqrt{s}_{\text{pole}}$ (MeV)	$g_{D^*D^*}$
$0[1^+]$	3969	16 825

The interaction for D*D is the same since the contact term is zero for 1+

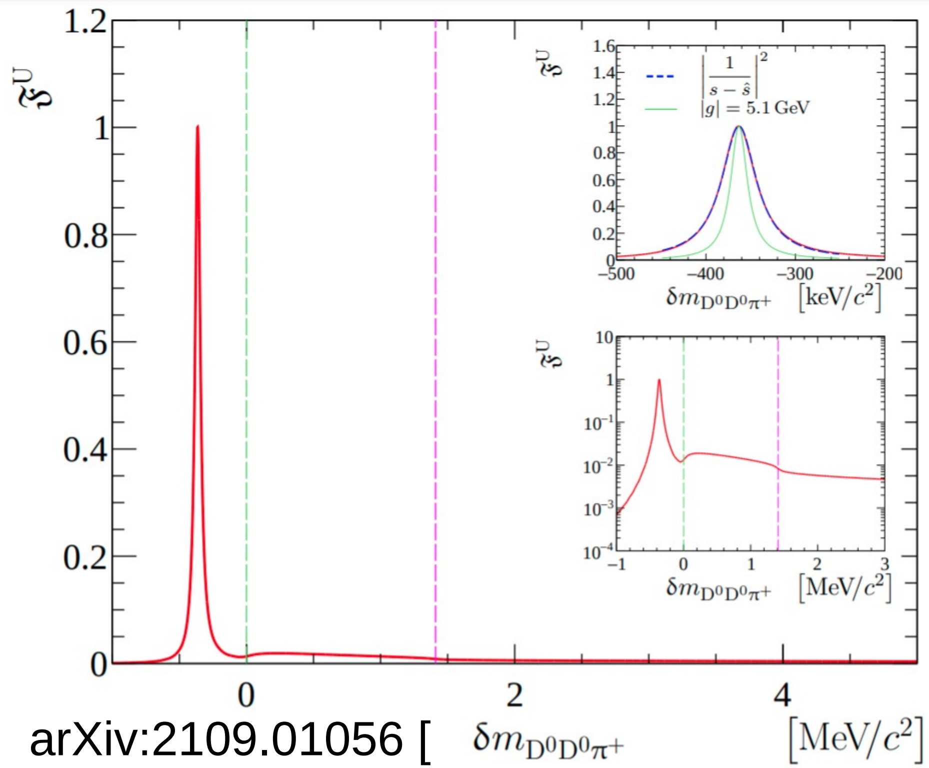
Thus, we predict a D*D bound state with mass with 141 MeV less , 3828 MeV. This overcounts the binding because D*D* are identical particles, Bose enhancement, and D* D are not, but we should expect a D*D bound state in 1+

This state was found as the Tcc of the LHCb collaboration

The Tcc discovery by the LHCb collaboration



arXiv:2109.01038



arXiv:2109.01056 [

Spectra without correction by experimental resolution

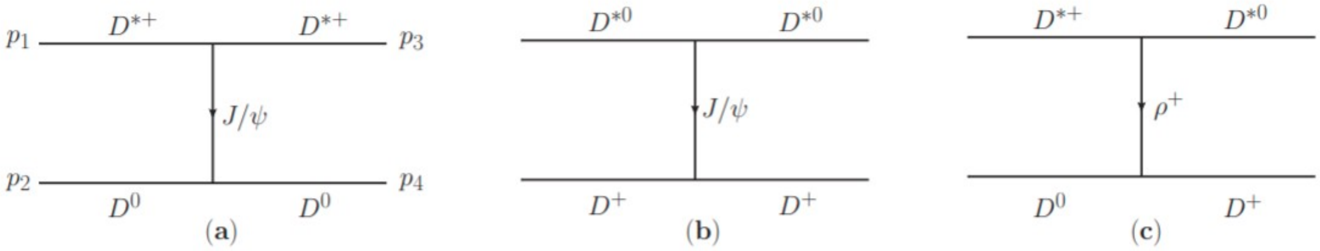
$$m_{\rm exp} = 3875.09\ \text{MeV} + \delta m_{\rm exp},$$

$$\delta m_{\rm exp} = -273 \pm 61 \pm 5^{+11}_{-14}\ \text{keV}. \quad \Gamma = 410 \pm 165 \pm 43^{+18}_{-38}\ \text{keV}$$

Spectra corrected by resolution and analyzed with a unitary amplitude

$$\delta m_{\rm exp} = -360 \pm 40^{+4}_{-0}\ \text{keV}, \qquad \Gamma = 48 \pm 2^{+0}_{-14}\ \text{keV}.$$

A. Feijoo, W.H. Liang, Eulogio Oset, Phys.Rev.D 104 (2021) 11, 114015



$$\mathcal{L}_{VPP} = -ig\,\langle [P, \partial_\mu P] V^\mu \rangle,$$
$$\mathcal{L}_{VVV} = ig\,\langle (V^\nu \partial_\mu V_\nu - \partial_\mu V^\nu V_\nu) V^\mu \rangle,$$
$$g = \frac{M_V}{2\,f}, \quad (M_V = 800 \text{ MeV}, \; f = 93 \text{ MeV}).$$

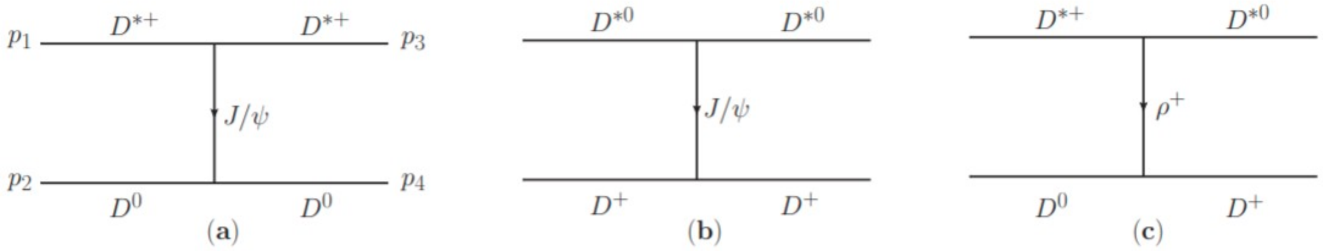
$$P = \begin{pmatrix} \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} + \frac{\pi^0}{\sqrt{2}} & \pi^+ & K^+ & \bar{D}^0 \\ \pi^- & \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} - \frac{\pi^0}{\sqrt{2}} & K^0 & D^- \\ K^- & \bar{K}^0 & -\frac{\eta}{\sqrt{3}} + \sqrt{\frac{2}{3}}\eta' & D_s^- \\ D^0 & D^+ & D_s^+ & \eta_c \end{pmatrix}
\qquad
V_\mu = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} & \bar{D}^{*0} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} & D^{*-} \\ K^{*-} & \bar{K}^{*0} & \phi & D_s^{*-} \\ D^{*0} & D^{*+} & D_s^{*+} & J/\psi \end{pmatrix}_\mu$$

$D^{*+}D^0, D^{*0}D^+$ the 1, 2 channels, the interaction that we obtain is

$$V_{ij} = C_{ij}\, g^2\, (p_1 + p_3)\cdot(p_2 + p_4)\, \vec{\epsilon}\cdot\vec{\epsilon}\,'$$
$$\to C_{ij}\, g^2\, \frac{1}{2}[3s - (M^2 + m^2 + M'^2 + m'^2)$$
$$-\frac{1}{s}(M^2 - m^2)(M'^2 - m'^2)]\, \vec{\epsilon}\cdot\vec{\epsilon}\,',$$

$$C_{ij} = \begin{pmatrix} \frac{1}{M^2_{J/\psi}} & \frac{1}{m^2_\rho} \\ \frac{1}{m^2_\rho} & \frac{1}{M^2_{J/\psi}} \end{pmatrix}$$

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



$$|D^*D, I=0\rangle = -\frac{1}{\sqrt{2}}(D^{*+}D^0 - D^{*0}D^+),$$
$$|D^*D, I=1, I_3=0\rangle = -\frac{1}{\sqrt{2}}(D^{*+}D^0 + D^{*0}D^+),$$

$$C_{00} = \frac{1}{M^2_{J/\psi}} - \frac{1}{m^2_\rho};\quad C_{11} = \frac{1}{M^2_{J/\psi}} + \frac{1}{m^2_\rho};\quad C_{01} = 0;$$

There is attraction in I=0, repulsion in I=1, but due to different masses there is a bit of isospin breaking

Convolution of the G function:
Origin of the width.

Spectral function
Mass distribution

$$\mathrm{Im}[D(s_V)] = \mathrm{Im}\left(\frac{1}{s_V - M_V^2 + iM_V\Gamma_V}\right)$$

$$G(\sqrt{s}, M_k, m_k) = \frac{\int_{(M_V-2\Gamma_V)^2}^{(M_V+2\Gamma_V)^2} ds_V\, G(\sqrt{s}, \sqrt{s_V}, m_k) \times \mathrm{Im}[D(s_V)]}{\int_{(M_V-2\Gamma_V)^2}^{(M_V+2\Gamma_V)^2} ds_V\, \mathrm{Im}[D(s_V)]}$$

$$G_l = i \int \frac{d^4q}{(2\pi)^4} \frac{M_l}{E_l(\mathbf{q})} \frac{1}{k^0 + p^0 - q^0 - E_l(\mathbf{q}) + i\epsilon}$$

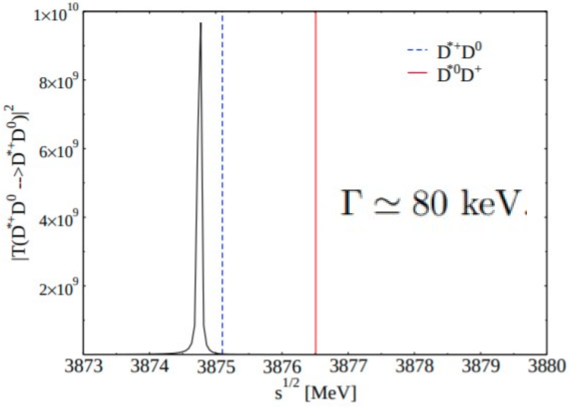
$$\Gamma_{D^{*+}}(M_{\text{inv}}) = \Gamma(D^{*+}) \left(\frac{m_{D^{*+}}}{M_{\text{inv}}}\right)^2 \cdot \left[\frac{2}{3}\left(\frac{p_\pi}{p_{\pi,\text{on}}}\right)^3 + \frac{1}{3}\left(\frac{p'_\pi}{p'_{\pi,\text{on}}}\right)^3\right]$$

where p_π is the π^+ momentum in $D^{*+} \to D^0\pi^+$ decay

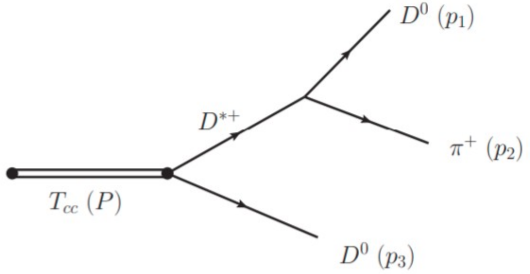
$p'_\pi, p'_{\pi,\text{on}}$ are the same magnitudes for $D^{*+} \to D^+\pi^0$.

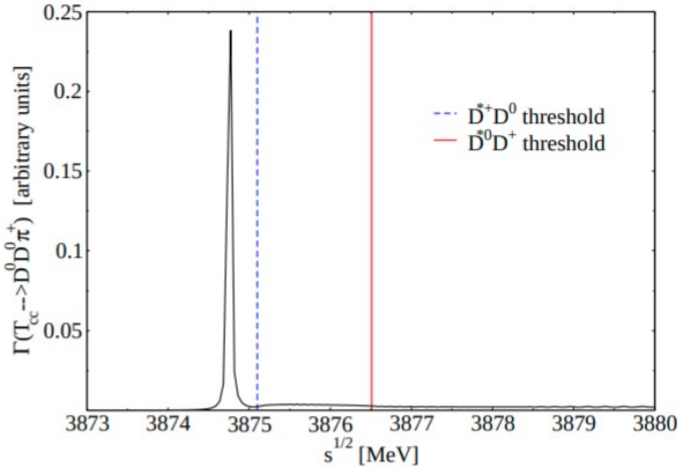
$$\Gamma_{D^{*0}}(M_{\text{inv}}) = \Gamma(D^{*0}) \left(\frac{m_{D^{*0}}}{M_{\text{inv}}}\right)^2 \cdot \left[0.647\left(\frac{p_\pi}{p_{\pi,\text{on}}}\right)^3 + 0.353\right]$$

$D^{*0} \to D^0\pi^0 \qquad D^{*0} \to D^0\gamma$

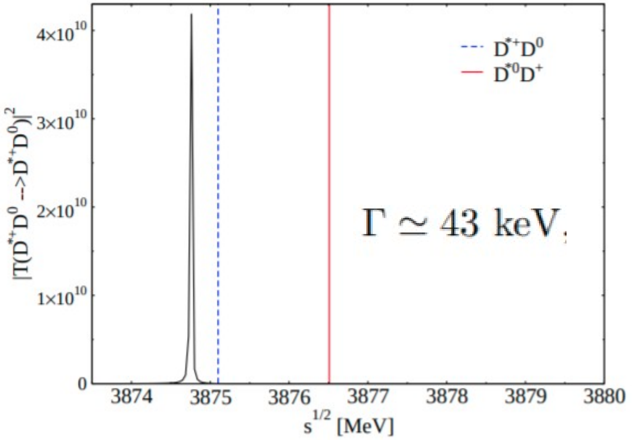


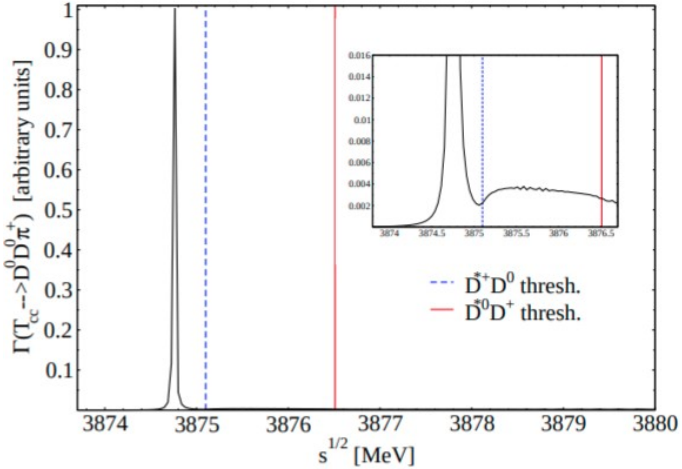
With mass of experimental raw data





With mass from unitary reanalysis of LHCb data , Mikhasenko





Works along the molecular structure of Tcc

L. Meng, G. J. Wang, B. Wang and S. L. Zhu, Phys. Rev. D 104, 051502 (2021)

Xi-Zhe Ling, Ming-Zhu Liu, Li-Sheng Geng, En Wang, Ju-Jun Xie, Phys.Lett.B 826 (2022) 136897

M. Albaladejo, arXiv:2110.02944 [hep-ph]

Meng-Lin Du, Vadim Baru, Xiang-Kun Dong, Arseniy Filin, Feng-Kun Guo, Christoph Hanhart, Alexey Nefediev, Juan Nieves, Qian Wang Phys.Rev.D 105 (2022) 1, 014024

Hong-Wei Ke, Xiao-Hai Liu, Xue-Qian Li, Eur.Phys.J.C 82 (2022) 2, 144

Xiang-Kun Dong, Feng-Kun Guo, Bing-Song Zou, Commun.Theor.Phys. 73 (2021) 12, 125201

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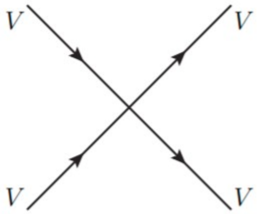
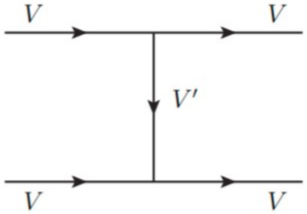
Prediction of new T_{cc} states of D^*D^* and $D_s^*D^*$ molecular nature

L. R. Dai,[1,2,*] R. Molina,[2,†] and E. Oset[2,‡] 2110.15270



(a)



(b)

TABLE XVI. Amplitudes for $C = 2$, $S = 0$, and $I = 0$.

J	Amplitude	Contact	V exchange	~Total
0	$D^*D^* \to D^*D^*$	0	0	0
1	$D^*D^* \to D^*D^*$	0	$\frac{1}{4}g^2(\frac{2}{m^2_{J/\psi}} + \frac{1}{m^2_\omega} - \frac{3}{m^2_\rho})\{(p_1 + p_4).(p_2 + p_3) + (p_1 + p_3).(p_2 + p_4)\}$	$-25.4g^2$
2	$D^*D^* \to D^*D^*$	0	0	0

TABLE XVII. Amplitudes for $C = 2$, $S = 0$, and $I = 1$.

J	Amplitude	Contact	V exchange	~Total
0	$D^*D^* \to D^*D^*$	$-4g^2$	$\frac{1}{4}g^2(\frac{2}{m^2_{J/\psi}} + \frac{1}{m^2_\omega} + \frac{1}{m^2_\rho})\{(p_1 + p_4).(p_2 + p_3) + (p_1 + p_3).(p_2 + p_4)\}$	$24.3g^2$
1	$D^*D^* \to D^*D^*$	0	0	0
2	$D^*D^* \to D^*D^*$	$2g^2$	$\frac{1}{4}g^2(\frac{2}{m^2_{J/\psi}} + \frac{1}{m^2_\omega} + \frac{1}{m^2_\rho})\{(p_1 + p_4).(p_2 + p_3) + (p_1 + p_3).(p_2 + p_4)\}$	$30.3g^2$

TABLE XVIII. Amplitudes for $C = 2$, $S = 1$, and $I = 1/2$.

J	Amplitude	Contact	V exchange	~Total
0	$D_s^* D^* \to D_s^* D^*$	$-4g^2$	$\frac{g^2(p_1+p_4).(p_2+p_3)}{m_{K^*}^2} + \frac{g^2(p_1+p_3).(p_2+p_4)}{m_{J/\psi^2}}$	$19.0g^2$
1	$D_s^* D^* \to D_s^* D^*$	0	$-\frac{g^2(p_1+p_4).(p_2+p_3)}{m_{K^*}^2} + \frac{g^2(p_1+p_3).(p_2+p_4)}{m_{J/\psi^2}}$	$-19.5g^2$
2	$D_s^* D^* \to D_s^* D^*$	$2g^2$	$\frac{g^2(p_1+p_4).(p_2+p_3)}{m_{K^*}^2} + \frac{g^2(p_1+p_3).(p_2+p_4)}{m_{J/\psi^2}}$	$25.0g^2$

TABLE XIX. Amplitudes for $C = 2$, $S = 2$, and $I = 0$.

J	Amplitude	Contact	V exchange	~Total
0	$D_s^* D_s^* \to D_s^* D_s^*$	$-4g^2$	$\frac{g^2}{2}(\frac{1}{m_{J/\psi}^2} + \frac{1}{m_\phi^2})\{(p_1 + p_4).(p_2 + p_3) + (p_1 + p_3).(p_2 + p_4)\}$	$15.0g^2$
1	$D_s^* D_s^* \to D_s^* D_s^*$	0	0	0
2	$D_s^* D_s^* \to D_s^* D_s^*$	$2g^2$	$\frac{g^2}{2}(\frac{1}{m_{J/\psi}^2} + \frac{1}{m_\phi^2})\{(p_1 + p_4).(p_2 + p_3) + (p_1 + p_3).(p_2 + p_4)\}$	$21.0g^2$

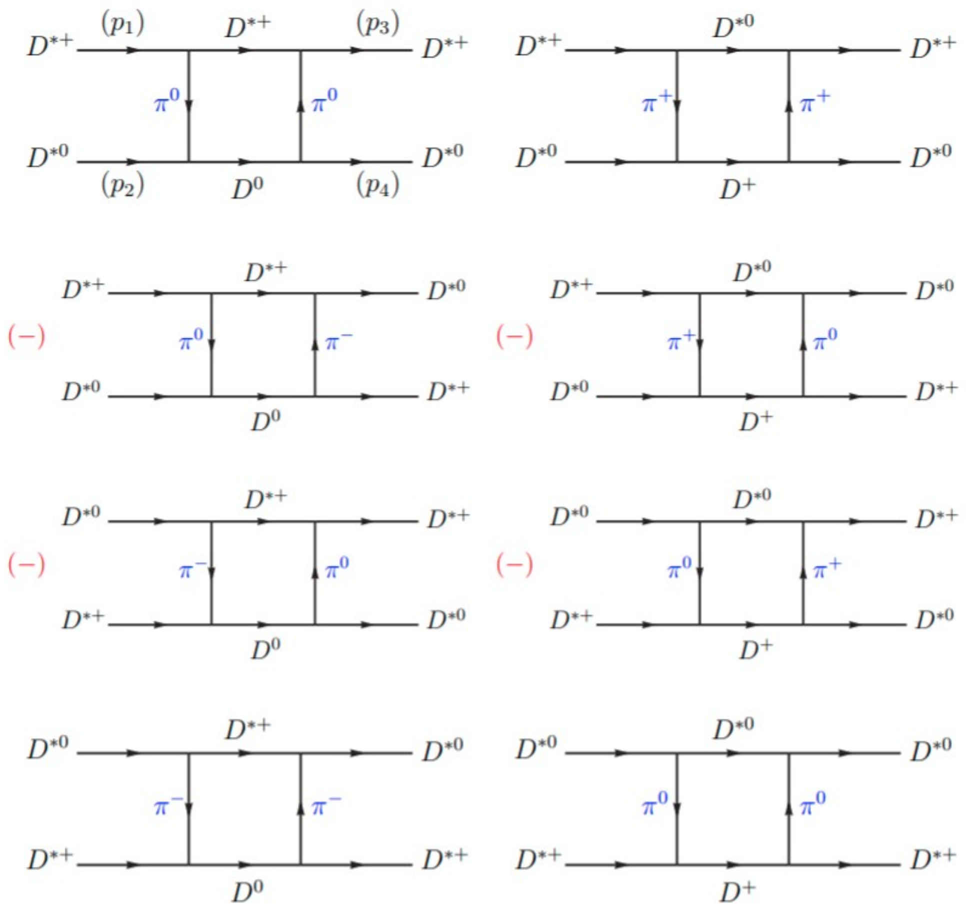
1. $D^*D^* \to D^*D$ decay

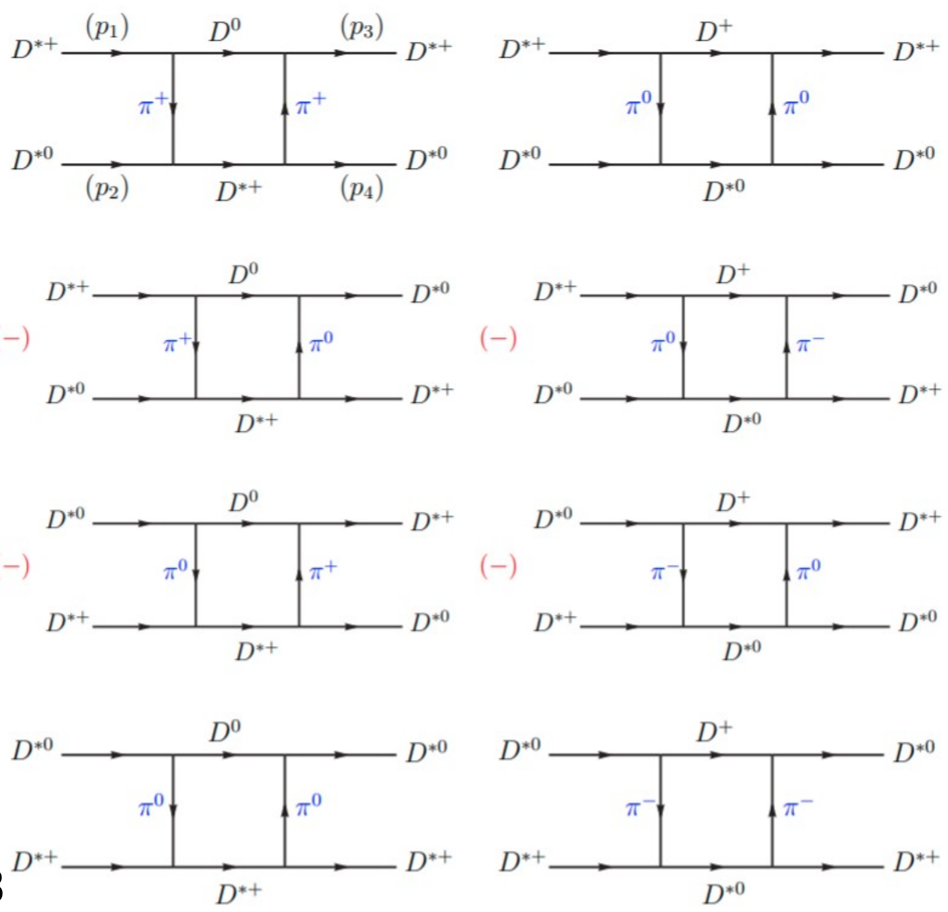
$$|D^*D^*, I=0\rangle = -\frac{1}{\sqrt{2}}|D^{*+}D^{*0} - D^{*0}D^{*+}\rangle$$

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

Plus p3 ⇔ p4

$$\mathcal{L}_{VVP} = \frac{G'}{\sqrt{2}}\,\epsilon^{\mu\nu\alpha\beta}\langle \partial_\mu V_\nu \partial_\alpha V_\beta P \rangle$$





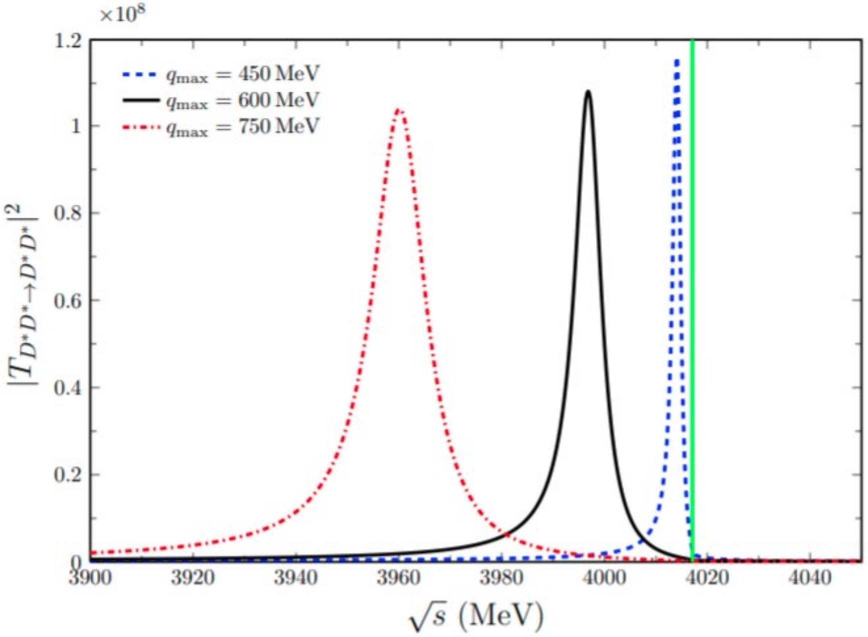
$$-i\,t = 4\,\frac{9}{2}\,\frac{1}{3}\int \frac{d^4q}{(2\pi)^4}\,\frac{1}{2E_{D^*}(\boldsymbol{q})}\,\frac{i}{p_1^0 - q^0 - E_{D^*}(\boldsymbol{q}) + i\epsilon}\,\frac{1}{2E_D(\boldsymbol{q})}$$
$$\times\ \frac{i}{p_2^0 + q^0 - E_D(\boldsymbol{q}) + i\epsilon}\,\frac{i}{q^2 - m_\pi^2 + i\epsilon}\,\frac{i}{(p_2 - p_4 + q)^2 - m_\pi^2 + i\epsilon}\,\boldsymbol{q}^4$$

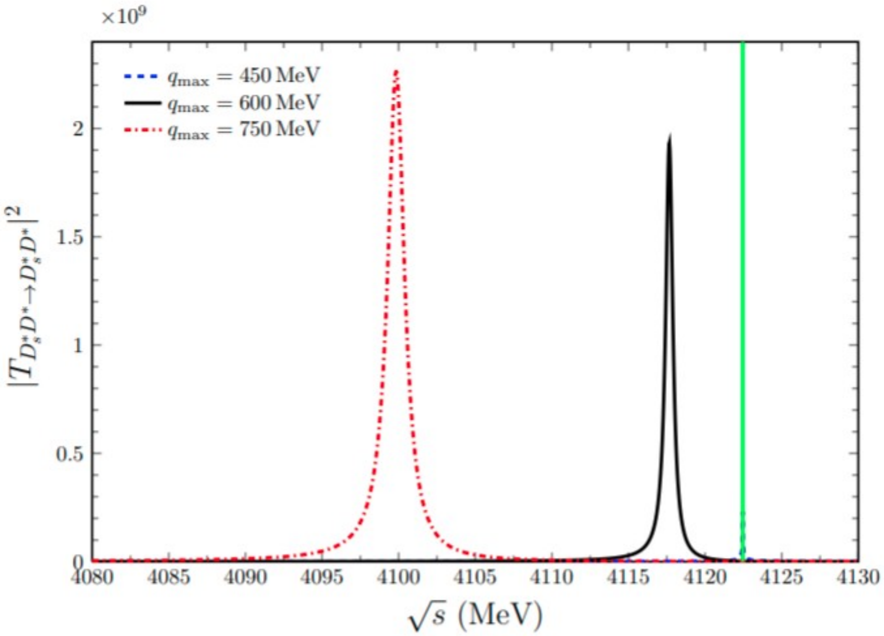
$$Im\tfrac{1}{x+i\epsilon} = -i\pi\delta(x)$$

$$ImV_{\text{box}} = -6\frac{1}{8\pi}\frac{1}{\sqrt{s}}q^5 E_{D^*}^2(\sqrt{2}g)^2(\frac{G'}{2})^2\left(\frac{1}{(p_2^0 - E_D(\boldsymbol{q}))^2 - \boldsymbol{q}^2 - m_\pi^2}\right)^2 F^4(q)\,F_{HQ}$$

$$q = \frac{\lambda^{1/2}(s, m_{D^*}^2, m_D^2)}{2\sqrt{s}}; \qquad E_{D^*} = \frac{\sqrt{s}}{2} \qquad F(q) = e^{((q^0)^2 - \boldsymbol{q}^2)/\Lambda^2} \qquad q^0 = p_1^0 - E_{D^*}(\boldsymbol{q}) \qquad F_{HQ} = \left(\frac{m_{D^*}}{m_{K^*}}\right)^2$$

$$\Lambda = 1200\ \text{MeV}$$



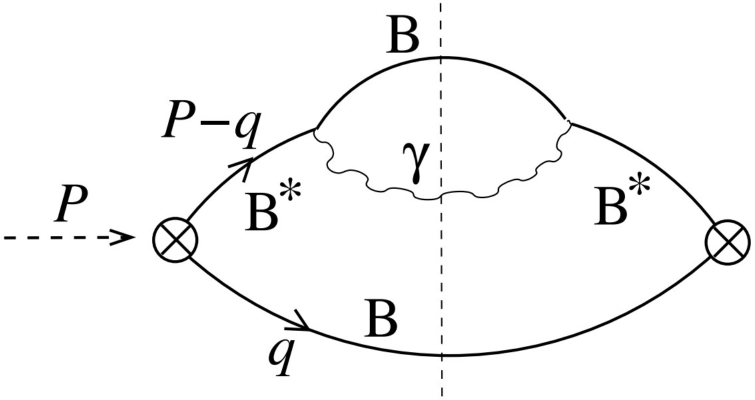


	$q_{\max} = 450$ MeV	$q_{\max} = 420$ MeV
$M_{D^*D^*}$	4014.08 MeV	4015.54 MeV
$B_{D^*D^*}$	3.23 MeV	1.56 MeV
$\Gamma_{D^*D^*}$	2.3 MeV	1.5 MeV
$M_{D_s^*D^*}$	4122.46 MeV (cusp)	4122.46 MeV (cusp)
$\Gamma_{D_s^*D^*}$	70 – 100 KeV	70 – 100 KeV

Masses and widths of the exotic molecular $B_{(s)}^{(*)} B_{(s)}^{(*)}$ states

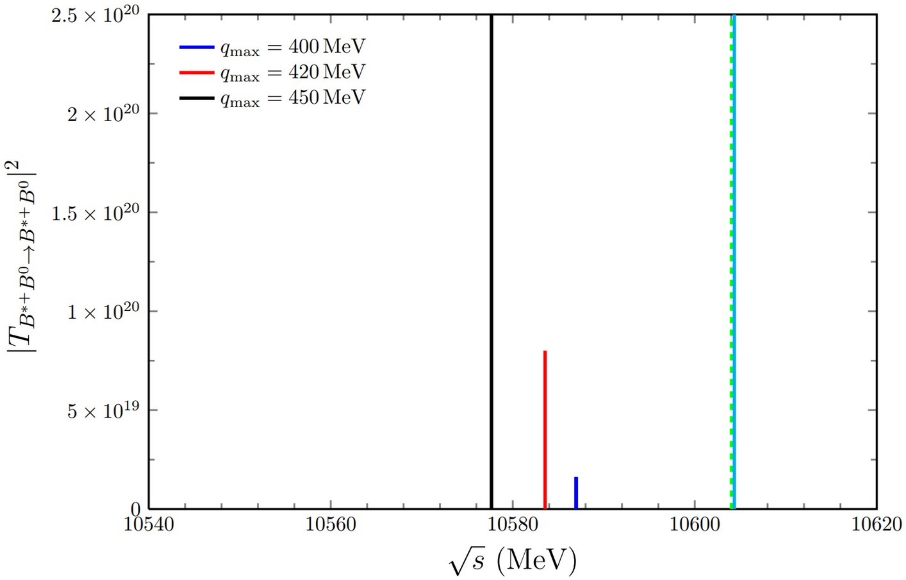
L.~R.~Dai, E.~Oset, A.~Feijoo, R.~Molina, L.~Roca, A.~M.~Torres and K.~P.~Khemchandani

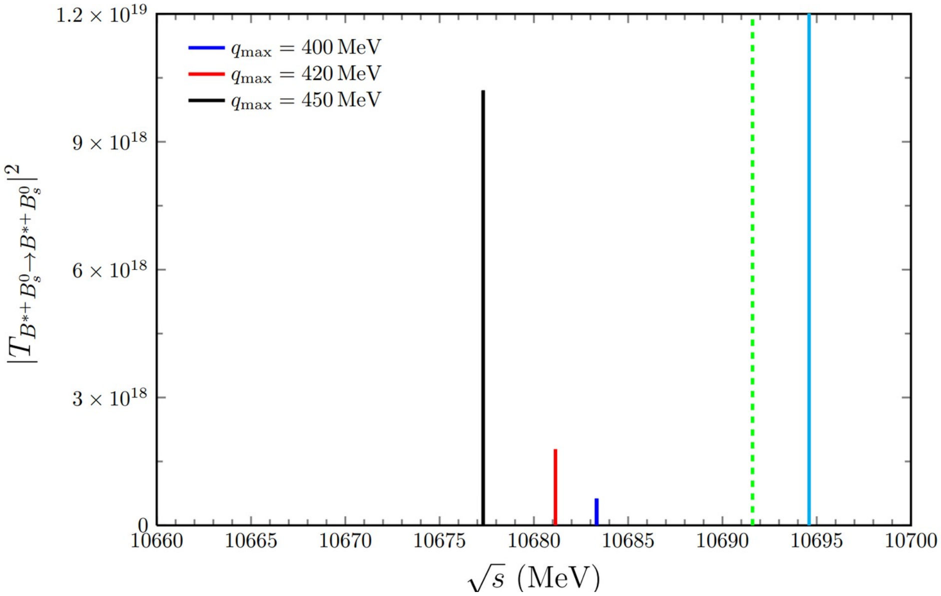
Arxiv 2201.04840

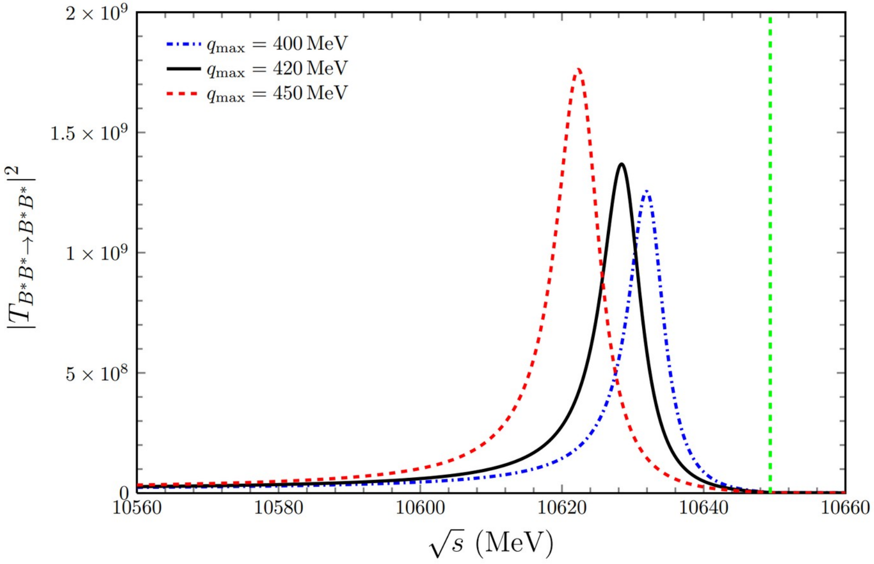


$$G(s) = i \int \frac{d^4q}{(2\pi)^4} \frac{1}{q^2 - m_B^2 + i\epsilon} \frac{1}{(P-q)^2 - m_{B^*}^2 + i\sqrt{(P-q)^2}\Gamma_{B^*}((P-q)^2)}$$

$$\Gamma_{B^*}(s') = \Gamma_{B^*}(m_{B^*}^2) \frac{m_{B^*}^2}{s'} \left(\frac{p_\gamma(s')}{p_\gamma(m_{B^*}^2)} \right)^3 \Theta(\sqrt{s'} - m_B)$$


$q_{\rm max} = 400$ MeV
$q_{\rm max} = 420$ MeV
$q_{\rm max} = 450$ MeV
$|T_{B^{*+}B^0 \to B^{*+}B^0}|^2$
$\sqrt{s}$ (MeV)


$q_{\rm max} = 400$ MeV
$q_{\rm max} = 420$ MeV
$q_{\rm max} = 450$ MeV
$|T_{B^{*+}B_s^0 \to B^{*+}B_s^0}|^2$
$\sqrt{s}$ (MeV)


$q_{\rm max} = 400$ MeV
$q_{\rm max} = 420$ MeV
$q_{\rm max} = 450$ MeV
$|T_{B^*B^* \to B^*B^*}|^2$
$\sqrt{s}$ (MeV)

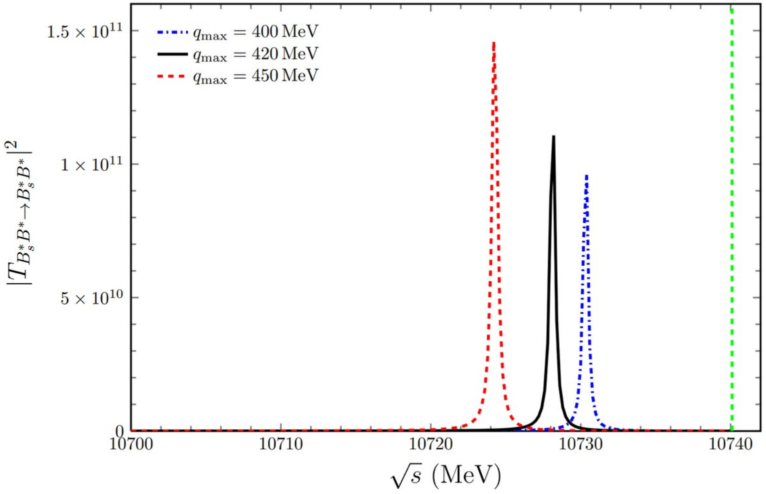

$q_{\rm max} = 400$ MeV
$q_{\rm max} = 420$ MeV
$q_{\rm max} = 450$ MeV
$|T_{B_s^*B^* \to B_s^*B^*}|^2$
$\sqrt{s}$ (MeV)

TABLE V. States of $J^P = 1^+$ obtained from different configurations. The binding B is referred to the closest threshold.

States	M (MeV)	B (MeV)	Γ
B^*B ($I=0$)	10583	21	14 eV
$B_s^*B - B^*B_s$ ($I=\frac{1}{2}$)	10681	11	45 eV
B^*B^* ($I=0$)	10630	19	8 MeV
$B_s^*B^*$ ($I=\frac{1}{2}$)	10728	12	0.5 MeV

Conclusions

In the recently observed states in the LHCb, Belle, Babar, BesIII, there are many states which qualify as dynamically generated from the interaction of hadron components: molecular states

Many of these states were predicted before. The experiment has served to fine tune some parameters which allow to make more refined predictions for other states not yet found.

The chiral unitary approach in the SU(3) sector has proved to be quite accurate to study the interaction of hadrons and eventually find poles in the t-matrix that correspond to states

The local hidden gauge aproach, with the exchange of vector mesons, is equivalent to the chiral unitary approach in SU(3). An extension of the LHGA has been done to the charm and bottom sectors, which respects heavy quark symmetry and turns out rather accurate interpreting results and making predictions.

More predictions have been made. We hope that they can be tested in the near future.

Attention must also be payed to hybrids of q qbar or qqq and molecular components. J. Nieves, F. K. Guo, David Rodriguez Entem ……

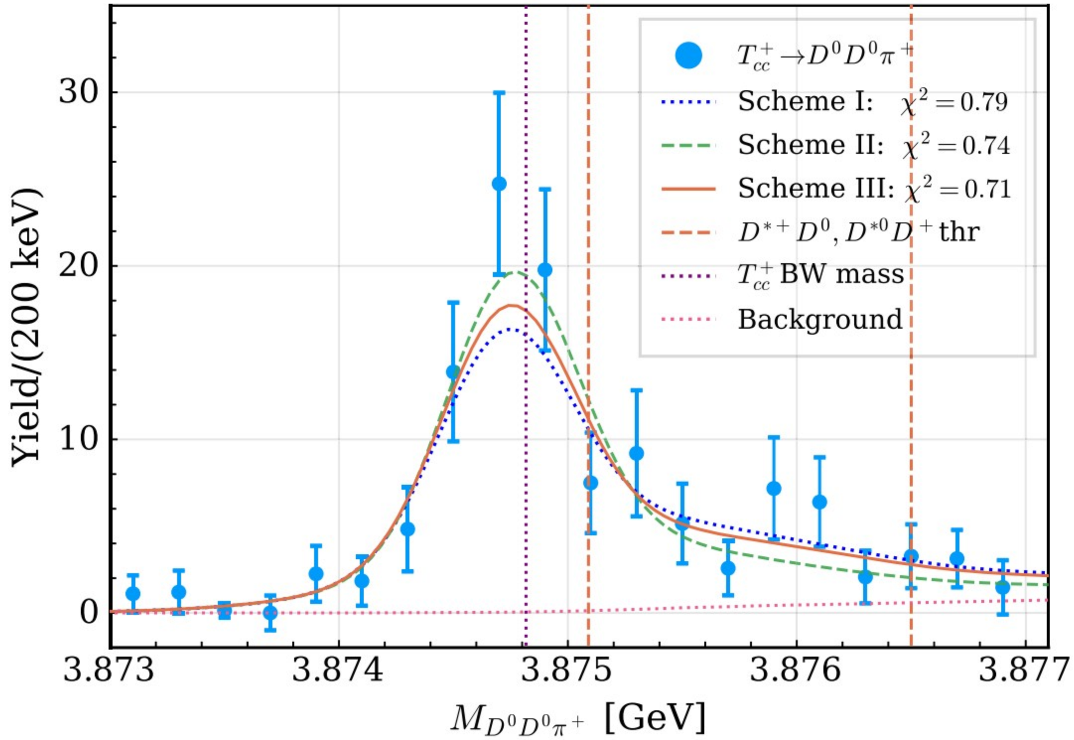


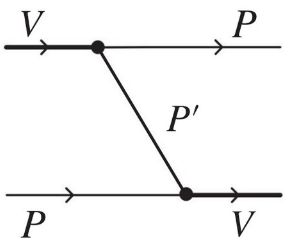
TABLE II. The pole position of the T_{cc}^+ relative to the $D^{*+}D^0$ threshold and the Riemann sheet (RS) where the pole is located in each scheme (see the text for details). The errors are statistical propagated from fitting to the LHCb data while the uncertainties from the cutoff variation are well within the errors quoted here.

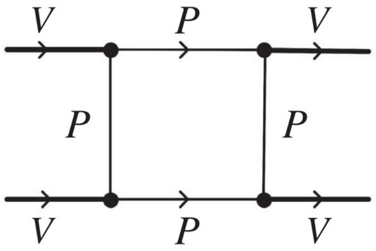
Scheme	I	II	III
Pole [keV]	$-368^{+43}_{-42} - i(37 \pm 0)$ (RS-I)	$-333^{+41}_{-36} - i(18 \pm 1)$ (RS-II)	$-356^{+39}_{-38} - i(28 \pm 1)$ (RS-II)

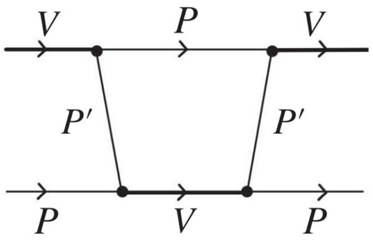
Unveiling the $K_1(1270)$ double-pole structure in the $\bar{B} \to J/\psi\rho\bar{K}$ and $\bar{B} \to J/\psi\bar{K}^*\pi$ decays

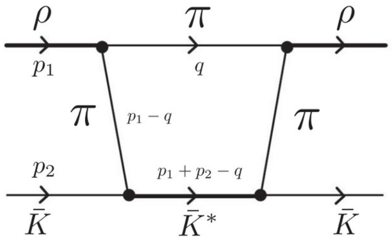
PHYSICAL REVIEW D **103,** 116019 (2021)

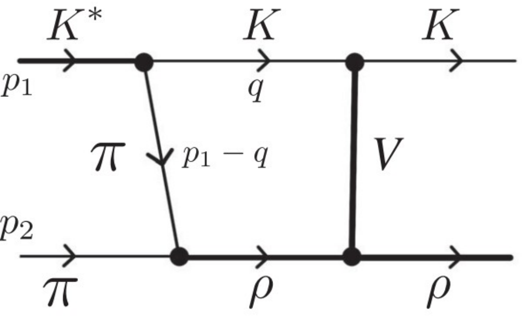
J. M. Dias,[*] G. Toledo,[1,†] L. Roca,[2,‡] and E. Oset[3,§]

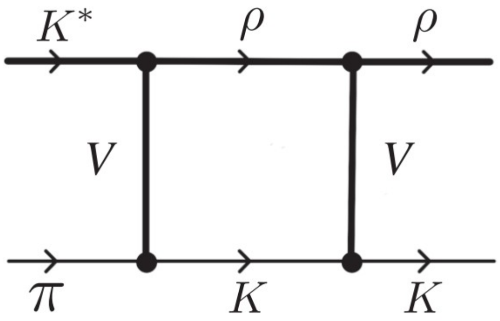


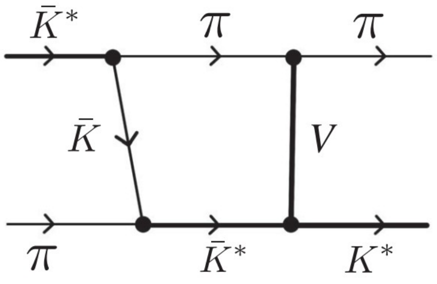




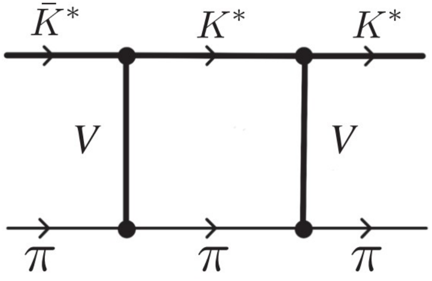








(a)



(b)

How much is the compositeness of a bound state constrained by a and r_0? The role of the interaction range

Arxiv 2201.04414

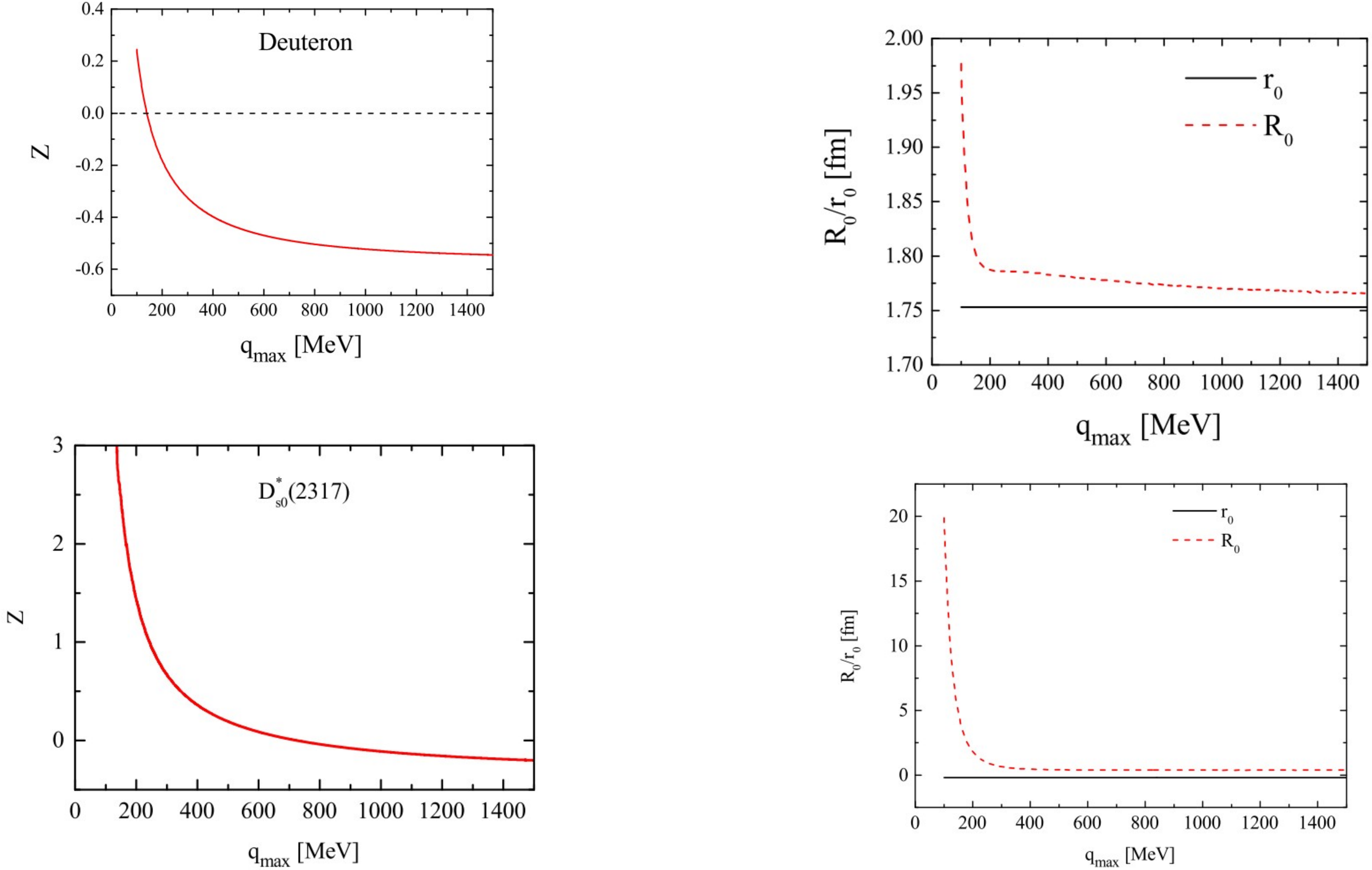
Jing Song,[1,2,*] L.R.Dai,[3,2,†] and E.Oset[2,‡]

$$V_{\text{eff}} = V_0 + \beta(s - s_0) \qquad T(s) = \frac{1}{[V_0 + \beta(s-s_0)]^{-1} - G(s)} \qquad T(s) = \frac{1}{[\frac{1}{G(s_0)} + \beta(s-s_0)]^{-1} - G(s)}$$

$$G_l = \int_{|q|<q_{\max}} \frac{d^3q}{(2\pi)^3} \frac{w_1(q)+w_2(q)}{2w_1(q)w_2(q)} \frac{1}{s-(w_1(q)+w_2(q))^2 + i\epsilon}$$

$$P_2 = 1 - P_1 = Z = -g^2 G(s_0)^2 \beta \qquad g^2 = \frac{1}{-G(s_0)^2\beta - \frac{\partial G}{\partial s}|_{s_0}}$$

$$8\pi\sqrt{s}\left\{[\frac{1}{G(s_0)} + \beta(s-s_0)]^{-1} - \text{Re}G(s)\right\} \approx \frac{1}{a} - \frac{1}{2} r_0 k^2$$


Deuteron
Z
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
200
400
600
800
1000
1200
1400
q_max [MeV]
R_0/r_0 [fm]
2.00
1.95
1.90
1.85
1.80
1.75
1.70
r_0
R_0
D*_s0(2317)
3
2
1
20
15
10
5