

UNIVERSIDAD DE
MURCIA

Two pole structure of $D_0^*(2400)$

Based on: Phys. Lett. B **767**, 465 (2017)
[arXiv:1610.06727]

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In collaboration with:
P. Fernández-Soler, F. K. Guo, J. Nieves



Outline

- 1 Introduction**
 - Why is $D_0^*(2400)$ interesting?
 - Theoretical interpretations
 - Experimental situation, LQCD simulations
- 2 Formalism: T -matrix for $D\pi$, $D\eta$, $D_s\bar{K}$**
 - Scattering in infinite volume
 - Energy levels in a finite volume
- 3 Results**
 - Comparison with LQCD
 - Spectroscopy
 - Amplitudes
- 4 $SU(3)$ light-flavor limit and other predictions (charm & bottom)**
 - $SU(3)$ light-flavor limit
 - Predictions for other sectors
- 5 Conclusions**
 - Chiral dynamics and two-pole structure(s)
 - Conclusions

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Introduction: Why is $D_0^*(2400)$ interesting?

- Lightest open-charm $J^P = 0^+$ states: $\left\{ \begin{array}{l} D_{s0}^*(2317), \quad (S, I) = (1, 0) \\ D_0^*(2400), \quad (S, I) = \left(0, \frac{1}{2}\right) \end{array} \right.$
- Lightest systems to test **ChPT with heavy mesons**, besides $D^* \rightarrow D\pi$.
- $D\pi$ interactions (where it shows up) are relevant, since $D\pi$ appears as a final state in many reactions that are being considered now (*i.e.*, $Z_c(3900)$ and $\bar{D}^* D\pi$)
- **Problems** with simple quark models expectations:
 - $D_{s0}^*(2317)$ is around **150 MeV below** the predicted mass.
 - Naively, one would expect D_{s0}^* ($\sim c\bar{s}$) to be **heavier** than D_0^* ($\sim c\bar{n}$).
- $D_0^*(2400)$ is important in **weak interactions and CKM** parameters:
 - It determines the shape of the scalar form factor $f_0(q^2)$ in semileptonic $D \rightarrow \pi$ decays.
 - Relation to $|V_{cd}|$: $f_+(0) = f_0(0)$ and $d\Gamma \propto |V_{cd} f_+(q^2)|^2$.
 - Even more interesting: the bottom analogue $|V_{ub}|$.

Introduction: Theoretical interpretations

$c\bar{q}$ states

- Dai *et al.* Phys. Rev. D **68**, 114011 (2003)
 Narison, Phys. Lett. B **605**, 319 (2005)
 Bardeen *et al.*, Phys. Rev. D **68**, 054024 (2003)
 Lee *et al.*, Eur. Phys. J. C **49**, 737 (2007)
 Wang, Wan, Phys. Rev. D **73**, 094020 (2006)

Pure tetraquarks

- Cheng, Hou, Phys. Lett. B **566**, 193 (2003)
 Terasaki, Phys. Rev. D **68**, 011501 (2003)
 Chen, Li, Phys. Rev. Lett. **93**, 232001 (2004)
 Maiani *et al.*, Phys. Rev. D **71**, 014028 (2005)
 Bracco *et al.*, Phys. Lett. B **624**, 217 (2005)
 Wang, Wan, Nucl. Phys. A **778**, 22 (2006)

$c\bar{q}+$ tetraquarks or meson–meson

- Browder *et al.*, Phys. Lett. B **578**, 365 (2004)
 van Beveren, Rupp, Phys. Rev. Lett. **91**, 012003 (2003)

Heavy-light meson–meson molecules

- Barnes *et al.*, Phys. Rev. D **68**, 054006 (2003)
 Szczepaniak, Phys. Lett. B **567**, 23 (2003)
 Kolomeitsev, Lutz, Phys. Lett. B **582**, 39 (2004)
 Hofmann, Lutz, Nucl. Phys. A **733**, 142 (2004)
 Guo *et al.*, Phys. Lett. B **641**, 278 (2006)
 Gamermann *et al.*, Phys. Rev. D **76**, 074016 (2007)
 Faessler *et al.*, Phys. Rev. D **76**, 014005 (2007)
 Flynn, Nieves, Phys. Rev. D **75**, 074024 (2007)
 Albaladejo *et al.*, Eur. Phys. J. C **76**, 300 (2016)

Introduction: Experimental situation, LQCD simulations

● Experimental situation:

	Collab.	M (MeV)	$\Gamma/2$ (MeV)	Ref.
Neu.	Belle	2308 ± 36	138 ± 33	Phys. Rev. D 69 , 112002 (2004)
	BaBar	2297 ± 22	137 ± 25	Phys. Rev. D 79 , 112004 (2009)
	FOCUS	2407 ± 41	120 ± 40	Phys. Lett. B 586 , 11 (2004)
Char.	LHCb	2360 ± 33	128 ± 29	Phys. Rev. D 92 , 012012 (2015)
	FOCUS	2403 ± 38	142 ± 21	Phys. Lett. B 586 , 11 (2004)

● Lattice QCD:

- Masses larger than the physical ones if using $c\bar{s}$ interpolators only.

Bali, Phys. Rev. D **68**, 071501 (2003)

UKQCD Collab., Phys. Lett. B **569**, 41 (2003)

- Masses consistent with D_0^* (2400) and D_{s0}^* (2317) obtained when “meson-meson” interpolators are employed.

Mohler, Prelovsek, Woloshyn, Phys. Rev. D **87**, 034501 (2013)

Mohler *et al.*, Phys. Rev. Lett. **111**, 222001 (2013)

Recent LQCD study with $D\pi$, $D\eta$ and $D_s\bar{K}$ coupled-channel scattering.
A bound state with large coupling to $D\pi$ is identified with D_0^* (2400).

Hadron Spectrum Collab., JHEP **1610**, 011 (2016)

cf. D. Wilson’s talk on Wednesday

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- Energy levels in a finite volume

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 - Spectroscopy
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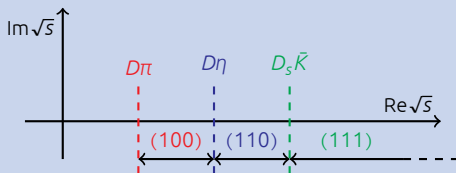
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$D\pi, D\eta, D_s\bar{K}$ scattering: infinite volume

- **Coupled channel T-matrix:** $D\pi, D\eta, D_s\bar{K}$ scattering [$J^P = 0^+, (S, I) = (0, \frac{1}{2})$].
- **Unitarity:** $T^{-1}(s) = V^{-1}(s) - \mathcal{G}(s)$
 - Normalization: $-ip_{ij}(s)T_{ij}(s) = 4\pi\sqrt{s}(\eta_i(s)e^{2i\delta_i(s)} - 1)$.
 - $\mathcal{G}_{ij}(s) = G(s, m_i, M_j)$, regularized with a subtraction constant $a(\mu)$ ($\mu = 1$ GeV).
- **Analytical continuations:** Riemann sheets (RS) denoted as $(\xi_1\xi_2\xi_3)$:

$$\mathcal{G}_{ij}(s) \rightarrow \mathcal{G}_{ij}(s) + i \frac{p_i(s)}{4\pi\sqrt{s}} \xi_i$$



$D\pi, D\eta, D_s\bar{K}$ scattering: infinite volume (II)

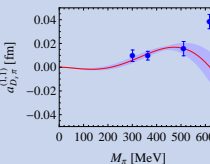
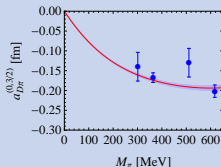
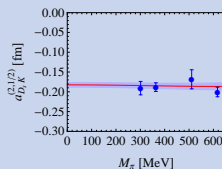
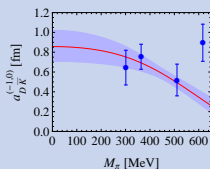
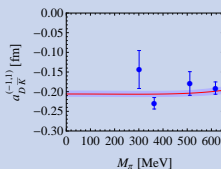
- Chiral symmetry used to compute the $\mathcal{O}(\rho^2)$ potential:

$$f^2 V_{ij}(s, t, u) = C_{\text{LO}}^{ij} \frac{s-u}{4} + \sum_{a=0}^5 h_a C_a^{ij}(s, t, u)$$

Guo *et al.*, Phys. Lett. B **666**, 251 (2008)

Liu *et al.*, Phys. Rev. D **87**, 014508 (2013)

- Values of h_a and $a(\mu)$ have been **previously fixed**:
 - Fitted to reproduce scattering lengths obtained in a LQCD simulation
 - They are not fitted in this work. We make “**predictions**”



$D\pi, D\eta, D_s\bar{K}$ energy levels in a finite volume

- Periodic boundary conditions imposes

momentum quantization

- Lüscher formalism:

Commun. Math. Phys. **105**, 153 (1986)

Nucl. Phys. B **354**, 531 (1991)

infinite volume

finite volume

$$\vec{q} \in \mathbb{R}^3 \qquad \vec{q} = \frac{2\pi}{L} \vec{n}, \quad \vec{n} \in \mathbb{Z}^3$$

$$\int_{\mathbb{R}^3} \frac{d^3q}{(2\pi)^3} \qquad \frac{1}{L^3} \sum_{\vec{n} \in \mathbb{Z}^3}$$

- In practice, changes in the T -matrix: $T(s) \rightarrow \tilde{T}(s, L)$:

Döring *et al.*, Eur. Phys. J. **A 47**, 139 (2011)

$$\mathcal{G}_{ii}(s) \rightarrow \tilde{\mathcal{G}}_{ii}(s, L) = \mathcal{G}_{ii}(s) + \lim_{\Lambda \rightarrow \infty} \left(\frac{1}{L^3} \sum_{\vec{n}}^{|\vec{q}| < \Lambda} I_i(\vec{q}) - \int_0^\Lambda \frac{q^2 dq}{2\pi^2} I_i(\vec{q}) \right),$$

$$V(s) \rightarrow \tilde{V}(s, L) = V(s),$$

$$T^{-1}(s) \rightarrow \tilde{T}^{-1}(s, L) = V^{-1}(s) - \tilde{\mathcal{G}}(s, L),$$

- Free** energy levels: $E_{n,\text{free}}^{(i)}(L) = \omega_{i1}((2\pi n/L)^2) + \omega_{i2}((2\pi n/L)^2)$
- Interacting** energy levels $E_n(L)$: $\tilde{T}^{-1}(E_n^2(L), L) = 0$ (poles of the \tilde{T} -matrix).

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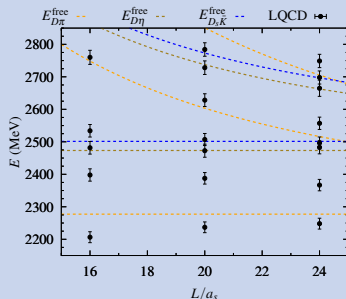
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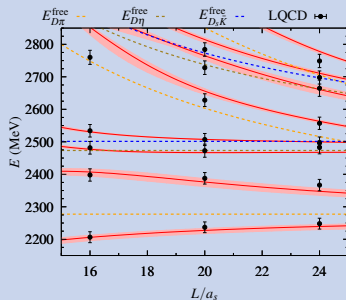
Results: Comparison with LQCD



M (MeV)	Latt.	Phys.
π	391	138
K	550	496
η	588	548
D	1886	1867
D_s	1952	1968

- LQCD: [G. Moir *et al.*, JHEP 1610, 011 (2016)]
- Bands: [M. A. *et al.*, Phys. Lett. B **767**, 465 (2017)]
- $E_n(L)$ are provided for $D\pi$, $D\eta$, $D_s\bar{K}$ in a recent LQCD simulation.
- We compute $E_n(L)$ and compare. No fit is performed.
- $E > 2.7$ GeV is probably beyond the range of validity for our T -matrix.
- Level below threshold, associated with a **bound state** (see below).
- Second level has large shifts w. r. t. thresholds: **Resonance?** (see below).

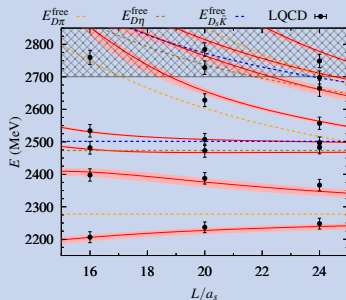
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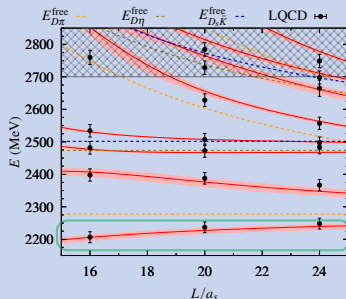
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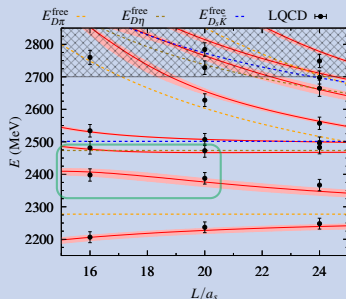
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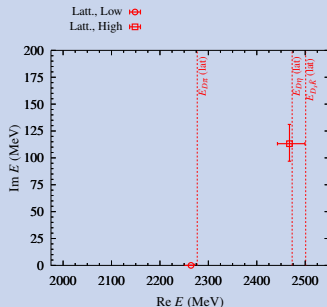
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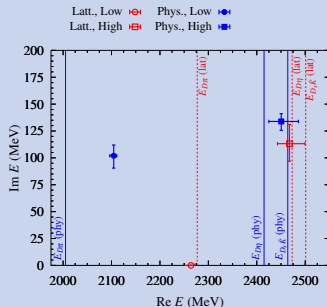


Meson Masses	M (MeV)	$\Gamma/2$ (MeV)	RS	$ g_{D\pi} $	$ g_{D\eta} $	$ g_{D_s K} $
lattice	2264^{+8}_{-14}	0	(000)	$7.7^{+1.2}_{-1.1}$	$0.3^{+0.5}_{-0.3}$	$4.2^{+1.1}_{-1.0}$
	2468^{+32}_{-25}	113^{+18}_{-16}	(110)	$5.2^{+0.6}_{-0.4}$	$6.7^{+0.6}_{-0.4}$	$13.2^{+0.6}_{-0.5}$
physical	2105^{+6}_{-8}	102^{+10}_{-12}	(100)	$9.4^{+0.2}_{-0.2}$	$1.8^{+0.7}_{-0.7}$	$4.4^{+0.5}_{-0.5}$
	2451^{+36}_{-26}	134^{+7}_{-8}	(110)	$5.0^{+0.7}_{-0.4}$	$6.3^{+0.8}_{-0.5}$	$12.8^{+0.8}_{-0.6}$

- We also study $DK, D_s\eta, (S, I) = (1, 0)$
 $D_{50}^*(2317): M = 2315^{+18}_{-28}$ MeV.

- For lattice masses, we find a **bound state** (000) and a **resonance** (110)
- For physical masses:
 - The bound state evolves into a **resonance** (100) above $D\pi$ threshold.
 - The resonance varies very little, and is still a **resonance** (110).
 - For both states, the coupling pattern is similar.
- PDG includes only one resonance, "suspiciously" lying between both.

Results: Spectroscopy



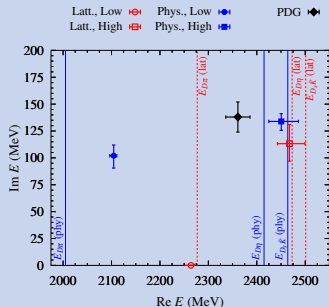
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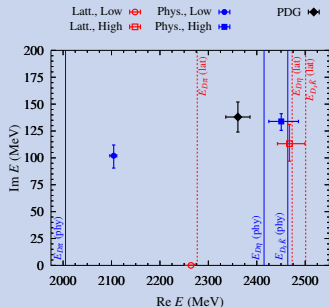
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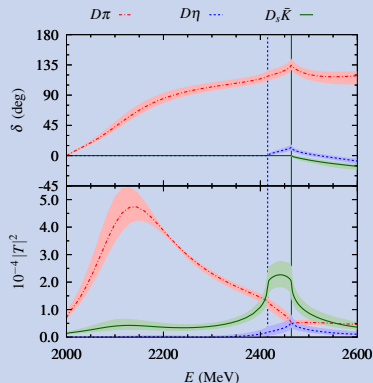
- The $D_0^*(2400)$ structure is actually produced by **two different states** (poles), together with complicated interferences with thresholds.
- This two-pole structure was previously reported, and receives now a robust support.

Kolomeitsev, Lutz, Phys. Lett. B **582**, 39 (2004)

Guo *et al.*, Phys. Lett. B **641**, 278 (2006)

Guo *et al.*, Eur. Phys. J. A **40**, 171 (2009)

Results: Amplitudes



- $-ip_i(s) T_{ii}(s) = 4\pi\sqrt{s} (\eta_i(s) e^{2i\delta_i(s)} - 1)$
- Lower pole at $\sqrt{s} = 2.1 - 0.1 i$ GeV:
 - $|T_{11}(s)|^2$ peaks at $\sqrt{s} \approx 2.1$ GeV
 - $\delta_{11}(s) = \pi/2$ at $\sqrt{s} \approx 2.2$ GeV.
- Higher pole at $\sqrt{s} = 2.45 - 0.13 i$ GeV:
 - Small enhancement in $|T_{D\pi}(s)|^2$.
 - Clear peak in the $D_s\bar{K}$ amplitude. Narrow, non-conventional shape, stretched between thresholds cusps.
- Possible tests in $B \rightarrow DPP'$ decays?

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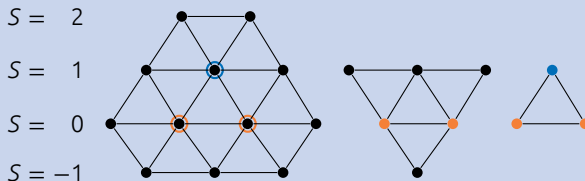
SU(3) light-flavor limit

- SU(3) flavor limit: $m_i \rightarrow m = 0.49$ GeV, $M_i \rightarrow M = 1.95$ GeV.
- Irrep decomposition: $\bar{\mathbf{3}} \otimes \mathbf{8} = \bar{\mathbf{15}} \oplus \mathbf{6} \oplus \bar{\mathbf{3}}$. T and V can be **diagonalized**:

$$V_d(s) = D^\dagger V(s) D = \text{diag} (V_{\bar{\mathbf{15}}}(s), V_{\mathbf{6}}(s), V_{\bar{\mathbf{3}}}(s)) = A(s) \text{diag} (1, -1, -3),$$

$$T_d(s) = \text{diag} (T_{\bar{\mathbf{15}}}(s), T_{\mathbf{6}}(s), T_{\bar{\mathbf{3}}}(s)).$$

$$T_A^{-1}(s) = V_A^{-1}(s) - G(s, m, M) \quad (\text{e.g., each } T_A(s) \text{ is "single channel"}).$$
- $\bar{\mathbf{15}}$ is repulsive. $\mathbf{6}$ and $\bar{\mathbf{3}}$ are attractive. "Curiously", $\bar{\mathbf{3}}$ admits a **$c\bar{q}$ interpretation**.



State	Channels	(S, I)	$\bar{\mathbf{15}}$	$\mathbf{6}$	$\bar{\mathbf{3}}$
D_0^*	$D\pi, D\eta, D_s\bar{K}$	$(0, \frac{1}{2})$	✓	✓	✓
$D_{50}^*(2317)$	$DK, D_s\eta$	$(1, 0)$	✓	✗	✓

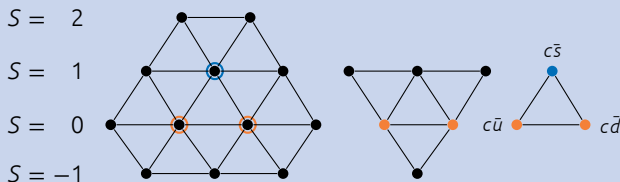
SU(3) light-flavor limit

- SU(3) flavor limit: $m_i \rightarrow m = 0.49$ GeV, $M_i \rightarrow M = 1.95$ GeV.
- Irrep decomposition: $\bar{\mathbf{3}} \otimes \mathbf{8} = \bar{\mathbf{15}} \oplus \mathbf{6} \oplus \bar{\mathbf{3}}$. T and V can be **diagonalized**:

$$V_d(s) = D^\dagger V(s) D = \text{diag} (V_{\bar{\mathbf{15}}}(s), V_{\mathbf{6}}(s), V_{\bar{\mathbf{3}}}(s)) = A(s) \text{diag} (1, -1, -3),$$

$$T_d(s) = \text{diag} (T_{\bar{\mathbf{15}}}(s), T_{\mathbf{6}}(s), T_{\bar{\mathbf{3}}}(s)).$$

$$T_A^{-1}(s) = V_A^{-1}(s) - G(s, m, M) \quad (\text{e.g., each } T_A(s) \text{ is "single channel"}).$$
- $\bar{\mathbf{15}}$ is repulsive. $\mathbf{6}$ and $\bar{\mathbf{3}}$ are attractive. "Curiously", $\bar{\mathbf{3}}$ admits a **$c\bar{q}$ interpretation**.



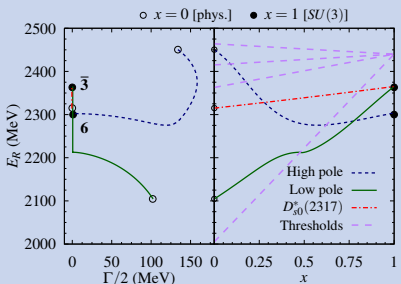
State	Channels	(S, l)	$\bar{\mathbf{15}}$	$\mathbf{6}$	$\bar{\mathbf{3}}$
D_0^*	$D\pi, D\eta, D_s\bar{K}$	$(0, \frac{1}{2})$	✓	✓	✓
$D_{50}^*(2317)$	$DK, D_s\eta$	$(1, 0)$	✓	✗	✓

SU(3) light-flavor limit (II)

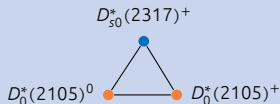
Connecting **physical** ($x = 0$) and **flavor SU(3)** ($x = 1$) limits:

$$m_i = m_i^{\text{phy}} + x(m - m_i^{\text{phy}}), \quad (m = 0.49 \text{ GeV}),$$

$$M_i = M_i^{\text{phy}} + x(M - M_i^{\text{phy}}), \quad (M = 1.95 \text{ GeV}).$$



- The **high D_0^*** connects with a **6 virtual state** (unph. RS, below threshold).
- The **low D_0^*** connects with a **$\bar{3}$ bound state** (ph. RS, below threshold).
- The **$D_{s0}^*(2317)$** also connects with the **$\bar{3}$ bound state**.



- The low D_0^* and the $D_{s0}^*(2317)$ are **SU(3) flavor partners**.
- This **solves the “puzzle”** of $D_{s0}^*(2317)$ being lighter than $D_0^*(2400)$: it is not, the lower D_0^* pole ($M = 2105 \text{ MeV}$) is lighter.

Predictions for other sectors: charm

(S, I) Channels	$\overline{15}$ $\mathbf{6}$ $\overline{3}$	0^+		1^+	
		M	$\Gamma/2$	M	$\Gamma/2$
$(0, \frac{1}{2})$ $D^{(*)}\pi, D^{(*)}\eta, D_s^{(*)}\bar{K}$	✓ ✓ ✓	(R) 2105 $^{+6}_{-8}$	102 $^{+10}_{-12}$	(R) 2240 $^{+5}_{-6}$	93 $^{+9}_{-9}$
		(R) 2451 $^{+36}_{-26}$	134 $^{+7}_{-8}$		
$(1, 0)$ $D^{(*)}K, D_s^{(*)}\eta$	✓ ✗ ✓	(B) 2315 $^{+18}_{-28}$		(B) 2436 $^{+16}_{-22}$	
$(-1, 0)$ $D^{(*)}\bar{K}$	✗ ✓ ✗	(V) 2342 $^{+13}_{-41}$		–	
$(1, 1)$ $D_s^{(*)}\pi, D^{(*)}K$	✓ ✓ ✗		–		–

- **HQSS** relates 0^+ ($D_{(s)}P$) and 1^+ ($D_{(s)}^*P$) sectors: **similar resonance pattern**.
- Two pole structure: higher D_1 pole probably affected by ρ channels.
- $D\bar{K}$ [$0^+, (-1, 0)$]: this virtual state (from $\mathbf{6}$) has a large impact on the scattering length, $a_{(-1,0)}^{D\bar{K}} \simeq 0.8$ fm. (Rest of scattering lengths are $|a| \simeq 0.1$ fm.)

Predictions for other sectors: bottom

(S, I) Channels	$\overline{15}$ 6 $\overline{3}$	0^+		1^+	
		M	$\Gamma/2$	M	$\Gamma/2$
$(0, \frac{1}{2}) \quad \bar{B}^{(*)}\pi, \bar{B}^{(*)}\eta, \bar{B}_s^{(*)}\bar{K}$	✓ ✓ ✓	(R) 5537 $^{+9}_{-11}$	116 $^{+14}_{-15}$	(R) 5581 $^{+9}_{-11}$	115 $^{+13}_{-15}$
		(R) 5840 $^{+12}_{-13}$	25 $^{+6}_{-5}$		
$(1, 0) \quad \bar{B}^{(*)}K, \bar{B}_s^{(*)}\eta$	✓ ✗ ✓	(B) 5724 $^{+17}_{-24}$		(B) 5768 $^{+17}_{-23}$	
$(-1, 0) \quad \bar{B}^{(*)}\bar{K}$	✗ ✓ ✗	(V-B) thr.		(V-B) thr.	
$(1, 1) \quad \bar{B}_s^{(*)}\pi, \bar{B}^{(*)}K$	✓ ✓ ✗	-		-	

- **Heavy flavour symmetry** relates charm (D) and bottom (\bar{B}) sectors.
- $(0, \frac{1}{2})$: B_0^* , two-pole pattern also observed.
- $(-1, 0)$: $[B^{(*)}\bar{K}]$: very close to threshold. Relevant prediction. Can be either **bound or virtual (6)** within our errors.
- $(1, 1)$: $[\bar{B}_s\pi, \bar{B}K, 0^+]$, $X(5568)$ channel. No state is found: $\overline{15}$ and **6**. If it exists, it is not dynamically generated in $B_s\pi, B\bar{K}$ interactions.
- $(1, 0)$: Our results for B_{s0}^* and B_{s1} agree with **other results** from LQCD:

M. A. *et al.*, Phys. Lett. B **757**, 515 (2016); Guo *et al.*, Commun. Theor. Phys. **65**, 593 (2016)

Lang *et al.*, Phys. Lett. B **750**, 17 (2015); M. A. *et al.*, arXiv:1612.07782

Outline

- 1
 - Why is $D_0^*(2400)$ interesting?
 - Theoretical interpretations
 - Experimental situation, LQCD simulations

- 2
 - Scattering in infinite volume
 - Energy levels in a finite volume

- 3
 - Comparison with LQCD
 - Spectroscopy
 - Amplitudes

- 4
 - $SU(3)$ light-flavor limit
 - Predictions for other sectors

- 5 **Conclusions**

- Chiral dynamics and two-pole structure(s)
- Conclusions

Chiral dynamics and two-pole structure(s)

- Other famous two-poles structures rooted in **chiral dynamics**:

$\Lambda(1405) [\Sigma\pi, N\bar{K}]$

Oller, Meißner, Phys. Lett. B **500**, 263 (2001)

Jido *et al.*, Nucl. Phys. A **725**, 181 (2003)

García-Recio *et al.*, Phys. Lett. B **582**, 49 (2004)

Magas *et al.*, Phys. Rev. Lett. **95**, 052301 (2005)

$K_1(1270)$

Roca *et al.*, Phys. Rev. D **72**, 014002 (2005)

Geng *et al.*, Phys. Rev. D **75**, 014017 (2007)

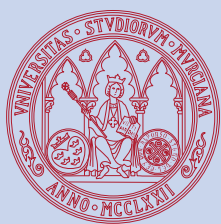
García-Recio *et al.*, Phys. Rev. D **83**, 016007 (2011)

- Chiral dynamics:**

- Incorporates the SU(3) light-flavor structure,
- Determines the strength of the interaction,
- Ensures lightness of Goldstone bosons, which in turn separates generating channels from higher hadronic channels.

Conclusions

- We have studied $D\pi$, $D\eta$, $D_s\bar{K}$ scattering $[0^+, (S, I) = (0, \frac{1}{2})]$
- So far only one pole reported experimentally, but...
- We have presented a strong support for the **existence of two $D_0^*(2400)$ poles**, based on a successful, no-fitting comparison of our T -matrix with the energy levels of a recent LQCD simulation.
- A $SU(3)$ study shows that $D_{s0}^*(2317)$ and the lower $D_0^*(2400)$ are **flavour partners**: they complete a $\bar{\mathbf{3}}$ multiplet.
- The lower pole ($M = 2105_{-8}^{+6}$ MeV) is **lighter** than $D_{s0}^*(2317)$, solving this apparent contradiction.
- Predictions for **other sectors** (heavy vectors, bottom sector) have been also given. In particular:
 - The two-pole structure is also seen in the **bottom sector**.
 - A very **near-threshold** state (bound or virtual) is predicted for BK ($\bar{B}\bar{K}$).



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Two pole structure of $D_0^*(2400)$

Based on: Phys. Lett. B **767**, 465 (2017)
[arXiv:1610.06727]

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In collaboration with:
P. Fernández-Soler, F. K. Guo, J. Nieves



Connecting $SU(3)$ and physical limits Riemann sheets

Riemann sheets:

$$\mathcal{G}_{ij}(s) \rightarrow \mathcal{G}_{ij}(s) + i \frac{\rho_i(s)}{4\pi\sqrt{s}} \xi_i$$

$SU(3)$ limit:

$$m_i = m_i^{\text{phy}} + x(m - m_i^{\text{phy}}), \quad (m = 0.49 \text{ GeV}),$$

$$M_i = M_i^{\text{phy}} + x(M - M_i^{\text{phy}}), \quad (M = 1.95 \text{ GeV}).$$

- Physical case ($x = 0$): RS specified by $(\xi_1 \xi_2 \xi_3)$, $\xi_i = 0$ or 1 .
- $SU(3)$ symmetric case ($x = 1$): all channels have the same threshold, so there are only two RS (000) and (111).
- To connect the **lower pole** with the T_6 virtual state,

$$\xi_3 = x \quad (1, 1, 0) \rightarrow (1, 1, x)$$

- To connect the **lower pole** with the $T_{\bar{3}}$ bound state,

$$\xi_1 = 1 - x \quad (1, 0, 0) \rightarrow (1 - x, 0, 0)$$