Decay behaviors of the P_c hadronic molecules

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Overview

1. Disentangling the hadronic molecule nature of the pentaquark-like structure
   - LHCb's observation of pentaquark states
   - Predictions prior to LHCb observation
   - Explanations after LHCb observation
2. The decay width of the P_c to all possible final states
3. Heavy meson - heavy baryon coupled-channel interactions in Jülich-Bonn model
4. Summary and prospects

LHCb's observation of pentaquark states

R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **115** (2015) 072001
Observation of $J/\psi p$ resonances consistent with pentaquark states in $\Lambda_b^0 \to J/\psi K p$ Decays.

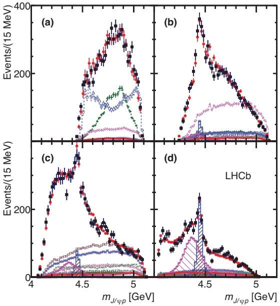


Figure: $m_{J/\psi p}$ in m_{Kp} intervals for the fit with two P_c^+ states: (d) $m_{Kp} > 2.$ GeV

- M=$4380 \pm 8 \pm 29$ MeV, $\Gamma = 205 \pm 18 \pm 86$ MeV.
- M=$4450 \pm 2 \pm 3$ MeV, $\Gamma = 39 \pm 5 \pm 19$ MeV.
- Significances $> 9\sigma$ for both.
- The preferred spin is one having spin-3/2 and the other 5/2.
- The two states have opposite parity.

Listed in C. Patrignani *et al.* [Particle Data Group], Chin. Phys. C **40** no.10, 100001 (2016) and 2017 update.

Predictions prior to LHCb observation

Theoretical groups

ITP, IHEP, IMP, Peking U., UCAS, Valencia U., Georgia U., Bonn U., etc.

J. J. Wu, R. Molina, E. Oset and B. S. Zou,
Phys. Rev. Lett. **105** (2010) 232001, Phys. Rev. C **84** (2011) 015202.

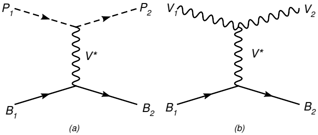


Figure: The Feynman diagrams of pseudoscalar-baryon (a) or vector- baryon (b) interaction via the exchange of a vector meson. P_1, P_2 is D^-, $\bar{D}^0$ or D_s^-, and V_1, V_2 is D^{*-}, $\bar{D}^{*0}$ or D_s^{*-}, and B_1, B_2 is Σ_c, Λ_c^+, Ξ_c, Ξ_c' or Ω_c, and V^* is ρ, K^*, ϕ or ω.

Dynamically generated $\bar{D}^{(*)}\Sigma_c$, $\bar{D}_s^{(*)}\Sigma_c$ and $\bar{D}^{(*)}\Xi_c^{(\prime)}$ bound states.

	(I, S)	z_R (MeV)	g_a		
	$(1/2, 0)$		$\bar{D}\Sigma_c$	$\bar{D}\Lambda_c^+$	
$N_{c\bar{c}}^*$		4269	2.85	0	
	$(0, -1)$		$\bar{D}_s\Lambda_c^+$	$\bar{D}\Xi_c$	$\bar{D}\Xi_c'$
$\Lambda_{c\bar{c}}^*$		4213	1.37	3.25	0
		4403	0	0	2.64

Table: Pole positions z_R and coupling constants g_a for the states from $PB \to PB$.

	(I, S)	z_R (MeV)	g_a		
	$(1/2, 0)$		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	
$N_{c\bar{c}}^*$		4418	2.75	0	
	$(0, -1)$		$\bar{D}_s^*\Lambda_c^+$	$\bar{D}^*\Xi_c$	$\bar{D}^*\Xi_c'$
$\Lambda_{c\bar{c}}^*$		4370	1.23	3.14	0
		4550	0	0	2.53

Table: z_R and g_a for the states from $VB \to VB$.

	(I,S)	M	Γ	Γ_i					
	$(1/2,0)$			πN	ηN	$\eta' N$	$K\Sigma$		$\eta_c N$
$N^*_{c\bar{c}}$		4261	56.9	3.8	8.1	3.9	17.0		23.4
	$(0,-1)$			$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$
$\Lambda^*_{c\bar{c}}$		4209	32.4	15.8	2.9	3.2	1.7	2.4	5.8
		4394	43.3	0	10.6	7.1	3.3	5.8	16.3

Table: Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $PB \to PB$, with units in MeV.

	(I,S)	M	Γ	Γ_i					
	$(1/2,0)$			ρN	ωN	$K^*\Sigma$			$J/\psi N$
$N^*_{c\bar{c}}$		4412	47.3	3.2	10.4	13.7			19.2
	$(0,-1)$			$\bar{K}^*N$	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$
$\Lambda^*_{c\bar{c}}$		4368	28.0	13.9	3.1	0.3	4.0	1.8	5.4
		4544	36.6	0	8.8	9.1	0	5.0	13.8

Table: M, Γ and Γ_i for the states from $VB \to VB$.

Explanations after LHCb observation

Theoretical interpretations of the hidden-charm pentaquark states

(H. X. Chen, W. Chen, X. Liu and S. L. Zhu, Phys. Rept. **639** (2016) 1)

1. **The molecular scheme: bound molecular states of $\bar{D}^{(*)}\Sigma_c^{(*)}$**

   R. Chen, X. Liu, X. Q. Li and S. L. Zhu, Phys. Rev. Lett. **115** (2015) 132002

   L. Roca, J. Nieves and E. Oset, Phys. Rev. D **92** (2015) no.9, 094003

   J. He, Phys. Lett. B **753** (2016) 547

   Q. F. Lü and Y. B. Dong, Phys. Rev. D **93** (2016) no.7, 074020

2. **Diquark-diquark-antiqurk state with $\bar{c}[cu][ud]$ configuration**

   L. Maiani, A. D. Polosa and V. Riquer, Phys. Lett. B **749** (2015) 289

   V. V. Anisovich *et al.*, arXiv:1507.07652 [hep-ph]

3. **Diquark-triquark state with $[cu][ud\bar{c}]$ configuration**

   R. F. Lebed, Phys. Lett. B **749** (2015) 454

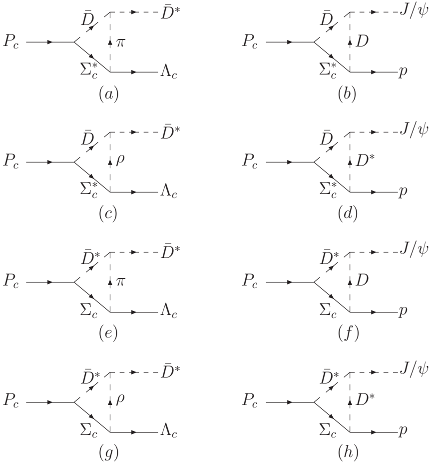
   R. Zhu and C. F. Qiao, Phys. Lett. B **756** (2016) 259

4. **Kinematic effects**

   F. K. Guo, U. G. Meißner, W. Wang and Z. Yang, Phys. Rev. D **92** (2015) 071502

   X. H. Liu, Q. Wang and Q. Zhao, Phys. Lett. B **757** (2016) 231

C. W. Shen, F. K. Guo, J. J. Xie and B. S. Zou, Nucl. Phys. A **954** (2016) 393



Assuming that the P_c is an S-wave hadronic molecular state of either $\bar{D}^*\Sigma_c$ or $\bar{D}\Sigma_c^*$ and calculate its partial decay widths to $\bar{D}^*\Lambda_c$ and $J/\psi p$, which are proceed through the triangle loop diagram with mesons exchange.

Using the Lorentz covariant orbital-spin (L-S) scheme, the effective Lagrangians for the first vertices are:

$$\mathcal{L}_{P_c(\frac{3}{2}^-)\Sigma_c\bar{D}^*} = g_{P_c\Sigma_c\bar{D}^*}\bar{\Sigma}_c P_{c\mu}\bar{D}^{*\mu},$$

$$\mathcal{L}_{P_c(\frac{3}{2}^-)\Sigma_c^*\bar{D}} = g_{P_c\Sigma_c^*\bar{D}}\bar{\Sigma}_c^{*\mu} P_{c\mu}\bar{D},$$

A Gaussian regulator is added in the first vertex:

$$\Phi_{P_c}(|\vec{q}|^2/\Lambda^2) \equiv \exp(-|\vec{q}|^2/\Lambda^2).$$

The effective Lagrangian involved:

$$\begin{aligned}
\mathcal{L}_{PPV} &= g_{PPV}\phi_P(x)\partial_\mu\phi_P(x)\phi_V^\mu(x), \\
\mathcal{L}_{VVP} &= g_{VVP} i\varepsilon_{\mu\nu\alpha\beta}\partial^\mu\phi_V^\nu(x)\partial^\alpha\phi_V^\beta(x)\phi_P(x), \\
\mathcal{L}_{VVV} &= g_{VVV} i\left[\partial_\mu\phi_{V\nu}(x) - \partial_\nu\phi_{V\mu}(x)\right]\phi_V^\mu(x)\phi_V^\nu(x), \\
\mathcal{L}_{BPB^*} &= g_{BPB^*}\left[\bar{\psi}_{B^*\mu}(x)\psi_B(x) + \bar{\psi}_B(x)\psi_{B^*\mu}(x)\right]\partial^\mu\phi_P(x), \\
\mathcal{L}_{BVB^*} &= g_{BVB^*} i\left[\bar{\psi}_{B^*\nu}(x)\gamma^5\gamma_\mu\psi_B(x) - \bar{\psi}_B(x)\gamma^5\gamma_\mu\psi_{B^*\nu}(x)\right] \\
&\quad \left[\partial^\mu\phi_V^\nu(x) - \partial^\nu\phi_V^\mu(x)\right], \\
\mathcal{L}_{BBP} &= g_{BBP}\bar{\psi}_B(x)i\gamma^5\psi_B(x)\phi_P(x), \\
\mathcal{L}_{BBV} &= g_{BBV}\left[\bar{\psi}_B(x)\gamma_\mu\psi_B(x)\phi_V^\mu(x)\right. \\
&\quad \left. +2f_{BBV}\bar{\psi}_B(x)\sigma_{\mu\nu}\psi_B(x)\left(\partial^\mu\phi_V^\nu(x) - \partial^\nu\phi_V^\mu(x)\right)\right],
\end{aligned}$$

The order of the ratios R of these two channels are:

$$R_{\mathrm{I}} = \frac{\Gamma(P_c(4380) \to \bar{D}\Sigma_c^* \to \bar{D}^*\Lambda_c)}{\Gamma(P_c(4380) \to \bar{D}\Sigma_c^* \to J/\psi p)} \sim 10$$

$$R_{\mathrm{II}} = \frac{\Gamma(P_c(4380) \to \bar{D}^*\Sigma_c \to \bar{D}^*\Lambda_c)}{\Gamma(P_c(4380) \to \bar{D}^*\Sigma_c \to J/\psi p)} \sim 1$$

The dependence of both ratios on the cutoff is rather weak.

This ratio can be employed to tell the nature of the P_c resonances in the future experiments.

We also analyzed in details using the nonrelativistic formalism taking heavy quark spin symmetry(HQSS) into account.

Nonrelativistic formalism

$$\mathcal{L}_{HH\pi} = -\frac{g}{2}\left\langle H_a^\dagger H_b \vec{\sigma}\cdot\vec{u}_{ba}\right\rangle + \frac{g}{2}\left\langle \bar{H}_a^\dagger \vec{\sigma}\cdot\vec{u}_{ab}\bar{H}_b\right\rangle,$$

$$\mathcal{L}_{SB_{\bar{3}}\pi} = -\frac{\sqrt{3}}{2} g_2 B_{\bar{3},ab}^\dagger \vec{u}_{bc}\cdot\vec{S}_{ca} + \text{h.c.}.$$

$$\mathcal{L}_{P_c} = -\sqrt{\frac{2}{3}}\left(g_{P_c}\bar{D}_a^\dagger \vec{\Sigma}_{c,ab}^{*\dagger}\cdot\vec{P}_{c,b} + g'_{P_c}\bar{D}_a^{*i\dagger}\Sigma_{c,ab}^\dagger P_{c,b}^i\right).$$

where $\bar{H}_a = -\vec{\bar{D}}_a^* \cdot \vec{\sigma} + \bar{D}_a$, $\vec{u}_{ab} = -\sqrt{2}\vec{\partial}\phi_{ab}/F + \mathcal{O}(\phi^3)$,
$S_{ab}^i = B_{6,ab}^{*i} + \frac{1}{\sqrt{3}}\sigma^i B_{6,ab}$ and

$$B_{\bar{3}} = \begin{pmatrix} 0 & \Lambda_c^+ & \Xi_c^+ \\ -\Lambda_c^+ & 0 & \Xi_c^0 \\ -\Xi_c^+ & -\Xi_c^0 & 0 \end{pmatrix}, B_6 = \begin{pmatrix} \Sigma_c^{++} & \frac{1}{\sqrt{2}}\Sigma_c^+ & \frac{1}{\sqrt{2}}\Xi_c'^+ \\ \frac{1}{\sqrt{2}}\Sigma_c^+ & \Sigma_c^0 & \frac{1}{\sqrt{2}}\Xi_c'^0 \\ \frac{1}{\sqrt{2}}\Xi_c'^+ & \frac{1}{\sqrt{2}}\Xi_c'^0 & \Omega_c^0 \end{pmatrix}.$$

Nonrelativistic formalism

$$I^{ij} \equiv \frac{i}{4m_1m_2}\int\frac{d^4l}{(2\pi)^4}\frac{l^il^j}{(q^0-l^0-\omega_1+i\epsilon)(k^0+l^0-\omega_2+i\epsilon)\left(l^2-m_3^2+i\epsilon\right)},$$

$$\begin{aligned} I_S(m_1,m_2,m_3,\vec{q}^{\,2}) &= I^{ii}(m_1,m_2,m_3,\vec{q}\,), \\ I_D(m_1,m_2,m_3,\vec{q}^{\,2}) &= \frac{3}{2}I^{ij}(m_1,m_2,m_3,\vec{q}\,)(\frac{q_iq_j}{\vec{q}^{\,2}}-\frac{1}{3}\delta^{ij}). \end{aligned}$$

$$\begin{aligned} \sum_{\omega,\alpha,\lambda}\left|\mathcal{A}^{\rm OPE}_{\bar{D}\Sigma_c^*}\right|^2 &= 144N^2g_{P_c}^2m_{\Lambda_c}m_{P_c}m_{\Sigma_c^*}^2\times \\ & \left[2\left|I_D(m_D,m_{\Sigma_c^*},m_\pi,\vec{q}^{\,2})\right|^2+\left|I_S(m_D,m_{\Sigma_c^*},m_\pi,\vec{q}^{\,2})\right|^2\right], \\ \sum_{\omega,\alpha,\lambda}\left|\mathcal{A}^{\rm OPE}_{\bar{D}^*\Sigma_c}\right|^2 &= 48N^2g_{P_c}'^2m_{\Lambda_c}m_{P_c}m_{\Sigma_c}^2\times \\ & \left[5\left|I_D(m_D,m_{\Sigma_c^*},m_\pi,\vec{q}^{\,2})\right|^2+\left|I_S(m_D,m_{\Sigma_c^*},m_\pi,\vec{q}^{\,2})\right|^2\right]. \end{aligned}$$

Then we estimate the width of the three-body decay $P_c \to \bar{D}\pi\Lambda_c$.

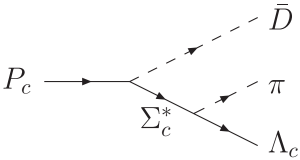


Figure: The three-body decay for $P_c(4380)$ being a $\bar{D}\Sigma_c^*$ hadronic molecule.

It turns out a width of about 10 MeV, much smaller than the reported width of the $P_c(4380)$.

Here, the value of the first vertex's coupling constant is:

$$g^2 = \frac{4\pi}{4Mm_2} \frac{(m_1 + m_2)^{5/2}}{(m_1 m_2)^{1/2}} \sqrt{32\epsilon},$$

where M, m_1 and m_2 are the masses of P_c, $\bar{D}(\bar{D}^*)$ and $\Sigma_c^*(\Sigma_c)$, respectively, and ϵ is the binding energy, which is valid for an S-wave shallow bound state.

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The decay width of the P_c to all possible final states

Y. H. Lin, C. W. Shen, F. K. Guo and B. S. Zou, Phys. Rev. D **95** (2017) no.11, 114017

All possible final states for the decay of $P_c(4380)$ with $J^P = \frac{3}{2}^-$ and $P_c(4450)$ with $J^P = \frac{3}{2}^-$ or $\frac{5}{2}^+$.

Initial state	Final states
$P_c(4380)(\bar{D}\Sigma_c^*)$	$\bar{D}^*\Lambda_c$, $J/\psi p$, $\bar{D}\Lambda_c$, πN, $\chi_{c0}p$, $\eta_c p$, ρN, ωp, $\bar{D}\Sigma_c$
$P_c(4380)(\bar{D}^*\Sigma_c)$	$\bar{D}^*\Lambda_c$, $J/\psi p$, $\bar{D}\Lambda_c$, πN, $\chi_{c0}p$, $\eta_c p$, ρN, ωp, $\bar{D}\Sigma_c$
$P_c(4450)(\bar{D}^*\Sigma_c)$	$\bar{D}^*\Lambda_c$, $J/\psi p$, $\bar{D}\Lambda_c$, πN, $\chi_{c0}p$, $\eta_c p$, ρN, ωp, $\bar{D}\Sigma_c$, $\bar{D}\Sigma_c^*$

More diagrams and Lagrangians are needed and used here.

The value of Λ_0 is varied from 0.5 to 1.2 GeV for an estimate of the two-body partial widths, since it denotes a hard momentum scale which suppresses the contribution of the two constituents at short distances $\sim 1/\Lambda_0$.

In addition, an off-shell form factor for the exchanged meson needs to be introduced, and we take the form:

$$F(q^2) = \frac{\Lambda_1^4}{(m^2 - q^2)^2 + \Lambda_1^4},$$

The parameter Λ_1 for the off-shell form factor varies for different system, and we will vary it in the range of 1.5 $\sim$ 2.4 GeV

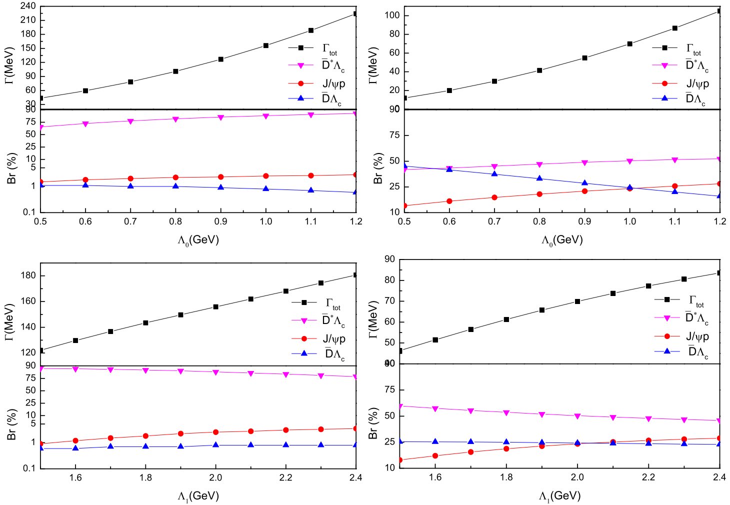

Figure: Dependence of the $P_c(4380)$ total width and branching fractions of $\bar{D}^*\Lambda_c$, $\bar{D}\Lambda_c$ and $J/\psi p$ on the cutoff Λ_0 and Λ_1 in different scenarios for the $P_c(4380)$: (left) S-wave $\bar{D}\Sigma_c^*$ molecule with $J^P = \frac{3}{2}^-$; (right) S-wave $\bar{D}^*\Sigma_c$ molecule with $J^P = \frac{3}{2}^-$. Upper Λ_1 is fixed at 2.0 GeV, and bottom Λ_0 is fixed at 1.0 GeV.

To estimate the partial widths of the $J^P = \frac{5}{2}^+$ $P_c(4450)$ state, we use the effective Lagrangian for the P-wave interaction among $P_c(4450)$, $\bar{D}^*$ and Σ_c:

$$\mathcal{L}_{\bar{D}^*\Sigma_c P_c} = g_{\bar{D}^*\Sigma_c P_c} \left(-g^{\nu\alpha} + \frac{p^\nu p^\alpha}{p^2} \right) \left(\partial_\alpha \bar{\Sigma}_c \bar{D}^{*\mu} - \bar{\Sigma}_c \partial_\alpha \bar{D}^{*\mu} \right) P_{c\mu\nu} + H.c.,$$

with p the momentum of the P_c state. The coupling constant $g_{\bar{D}^*\Sigma_c P_c}$ may be obtained from the compositeness condition.

However, being in a P-wave, the obtained coupling strength relies much more on the cutoff Λ_0. Thus, we can only make a rough estimate for the widths in this case.

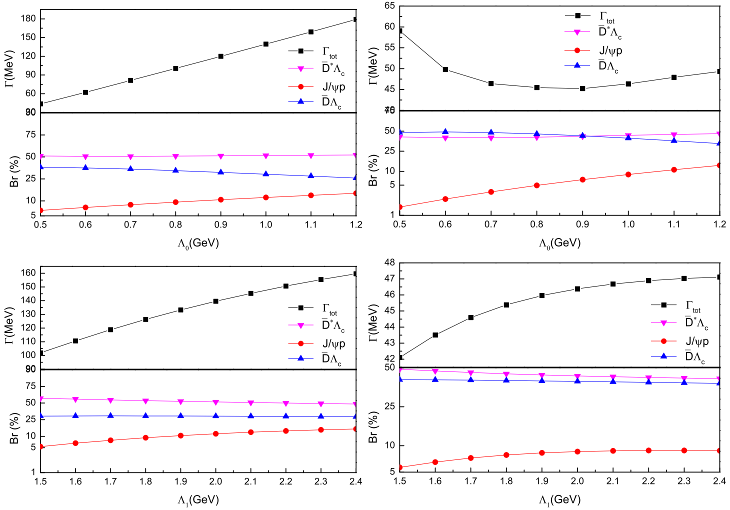

Figure: Dependence of the $P_c(4450)$ total width and branching fractions of $\bar{D}^*\Lambda_c$, $\bar{D}\Lambda_c$ and $J/\psi p$ on the cutoff Λ_0 and Λ_1 in different scenarios for the $P_c(4380)$: (left) S-wave $\bar{D}^*\Sigma_c$ molecule with $J^P = \frac{3}{2}^-$; (right) P-wave $\bar{D}^*\Sigma_c$ molecule with $J^P = \frac{5}{2}^+$. Upper Λ_1 is fixed at 2.0 GeV and bottom Λ_0 is fixed at 1.0 GeV.

The corresponding numerical results are obtained with $\Lambda_0 = 1.0$ GeV and $\Lambda_1 = 2.0$ GeV.

Mode	Widths (MeV)			
	$P_c(4380)$		$P_c(4450)$	
	$\bar{D}\Sigma_c^*(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{5}{2}^+)$
$\bar{D}^*\Lambda_c$	110.4	28.6	63.8	16.3
$J/\psi p$	2.7	19.8	17.7	2.6
$\bar{D}\Lambda_c$	1.2	13.7	36.0	14.9
πN	0.08	0.06	0.06	0.03
$\chi_{c0}p$	0.8	0.002	0.01	0.001
$\eta_c p$	0.2	0.05	0.1	0.02
ρN	1.6	0.4	0.2	0.1
ωp	6.1	1.3	0.8	0.4
$\bar{D}\Sigma_c$	0.01	0.09	1.1	0.2
$\bar{D}\Sigma_c^*$	-	-	8.9	0.5
$\bar{D}\Lambda_c\pi$	7.5	-	-	-
Total	130.6	64.0	139.7	35.0

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Heavy meson - heavy baryon coupled-channel interactions in Jülich-Bonn model

We use Jülich-Bonn dynamical coupled-channel formalism to calculate heavy meson - heavy baryon coupled-channel interactions.

The T-matrix of the interaction of a baryon and a meson is formulated as

$$\begin{aligned} T_{\mu\nu}(p'', p', z) &= V_{\mu\nu}(p'', p', z) + \sum_{\kappa} \int_0^{\infty} dp p^2 V_{\mu\kappa}(p'', p, z) \\ &\times G_{\kappa}(p, z) T_{\kappa\nu}(p, p', z) \end{aligned}$$

with

$$G_{\kappa}(p, z) = \frac{1}{z - E_a(p) - E_b(p) + i\epsilon}.$$

As an exploratory study, we first consider the $\bar{D}\Lambda_c - \bar{D}\Sigma_c$ interactions. The t-channel meson exchange and u-channel doubly-charmed baryon exchange are considered.

Several resonant and bound states with different spin and parity are dynamically generated.

J^P	A			B		
	z_R [MeV]	Couplings $[10^{-3}\ \text{MeV}^{-\frac{1}{2}}]$		z_R [MeV]	Couplings $[10^{-3}\ \text{MeV}^{-\frac{1}{2}}]$	
		$g_{\bar{D}\Lambda_c}$	$g_{\bar{D}\Sigma_c}$		$g_{\bar{D}\Lambda_c}$	$g_{\bar{D}\Sigma_c}$
$\frac{1}{2}^-$	$4295 - i\,3.7$	$1.4 + i\,0.2$	$13.2 + i\,0.8$	$4297 - i\,3.0$	$1.1 + i\,0.2$	$10.9 + i\,0.6$
$\frac{1}{2}^+$	$4334 - i\,28$	$1.1 - i\,1.1$	$-1.9 + i\,3.6$	$4334 - i\,30$	$1.0 - i\,1.0$	$-1.9 + i\,3.7$
$\frac{3}{2}^+$	$4325 - i\,54$	$0.3 - i\,1.1$	$0.8 - i\,4.5$	$4325 - i\,54$	$0.3 - i\,1.0$	$0.7 - i\,4.6$
$\frac{3}{2}^-$	$4380 - i\,147$	$0.5 - i\,1.9$	$-1.4 + i\,5.6$	$4378 - i146$	$0.5 - i\,1.7$	$-1.3 + i\,5.6$

C. W. Shen, D. Rönchen, U. G. Meißner and B. S. Zou, arXiv:1710.03885[hep-ph]

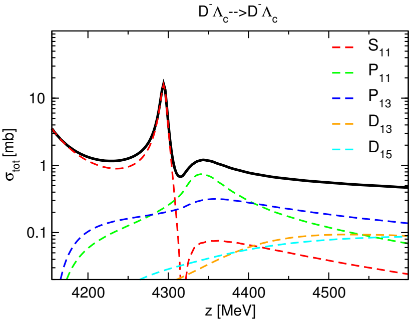

Figure: Partial-wave content of the total cross section for $D^-\Lambda_c \to D^-\Lambda_c$ using cut-off values A. Black line: full solution. Only dominant partial waves are shown.

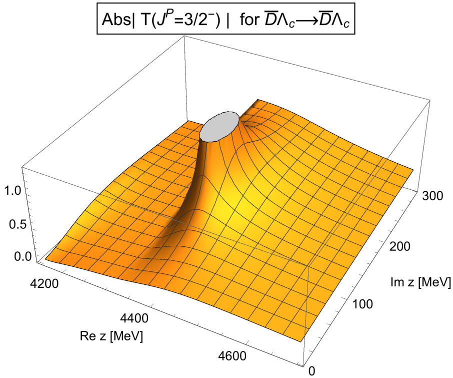

Figure: Absolute value of $T_{\bar{D}\Lambda_c\,\bar{D}\Lambda_c}$ (second Riemann sheet) with $J^P = 3/2^-$. The pole at $z_R = 4380 - i\,147$ MeV is clearly visible.

We also extended it to the hidden beauty sector to study the $B\Lambda_b - B\Sigma_b$ interactions.

J^P	A			B		
	z_R [MeV]	Couplings $[10^{-3}\ \mathrm{MeV}^{-\frac{1}{2}}]$		z_R [MeV]	Couplings $[10^{-3}\ \mathrm{MeV}^{-\frac{1}{2}}]$	
		$g_{B\Lambda_b}$	$g_{B\Sigma_b}$		$g_{B\Lambda_b}$	$g_{B\Sigma_b}$
$\frac{1}{2}^-$	$10998 - i\,10$	$1.2 + i\,0.3$	$23.3 + i\,1.5$	$11005 - i\,7$	$1.0 + i\,0.3$	$22.4 + i\,1.3$
$\frac{1}{2}^+$	$11078 - i\,4.4$	$0.7 + i\,0.1$	$-0.9 + i\,4.1$	$11081 - i\,2.8$	$0.6 + i\,0.1$	$-0.6 + i\,3.6$
$\frac{3}{2}^+$	$11093 - i\,1.8$	$0.4 - i\,0.004$	$0.5 - i\,0.7$	$11093 - i\,1.5$	$0.4 - i\,0.01$	$0.5 - i\,0.7$
$\frac{3}{2}^-$	$11120 - i\,25$	$0.3 - i\,0.3$	$-1.1 + i\,1.6$	$11120 - i\,25$	$0.3 - i\,0.3$	$-1.1 + i\,1.6$
$\frac{5}{2}^-$	$11116 - i\,38$	$0.2 - i\,0.4$	$0.7 - i\,2.0$	$11116 - i\,38$	$0.2 - i\,0.4$	$0.7 - i\,2.0$
$\frac{5}{2}^+$	$11149 - i\,88$	$0.1 - i\,0.6$	$-0.8 + i\,2.6$	$11148 - i\,86$	$0.1 - i\,0.5$	$-0.8 + i\,2.5$
$\frac{7}{2}^+$	$11123 - i\,104$	$0.2 + i\,0.5$	$-0.1 + i\,2.6$	$11124 - i\,102$	$0.2 + i\,0.5$	$-0.1 + i\,2.5$
$\frac{7}{2}^-$	$11176 - i\,160$	$0.04 + i\,0.3$	$0.4 - i\,1.7$	$11171 - i\,168$	$0.1 + i\,0.5$	$0.4 - i\,2.3$

As the b-quark mass is heavier than the c-quark mass, there are more resonances observed for $B\Lambda_b - B\Sigma_b$ interactions and they are more tightly bound.

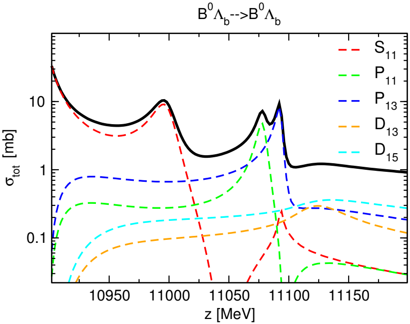

Figure: Partial-wave content of the total cross section for $B^0\Lambda_b \to B^0\Lambda_b$ using cut-off values A. Black line: full solution. Only dominant partial waves are shown.

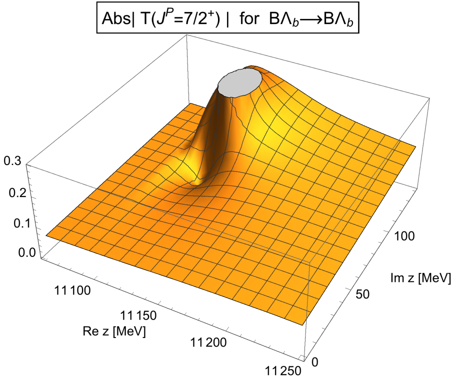

Figure: Absolute value of $T_{B\Lambda_b\, B\Lambda_b}$ (second Riemann sheet) with $J^P = 7/2^+$.

Overview

1. Disentangling the hadronic molecule nature of the pentaquark-like structure
   - LHCb's observation of pentaquark states
   - Predictions prior to LHCb observation
   - Explanations after LHCb observation
2. The decay width of the P_c to all possible final states
3. Heavy meson - heavy baryon coupled-channel interactions in Jülich-Bonn model
4. Summary and prospects

Summary and prospects

The relative ratio of the decays of $P_c^+(4380)$ to $\bar{D}^*\Lambda_c$ and $J/\psi p$ is very different for P_c being a $\bar{D}^*\Sigma_c$ or $\bar{D}\Sigma_c^*$ bound state with $J^P = \frac{3}{2}^-$.

From the total decay width, $P_c(4380)$ being a $\bar{D}\Sigma_c^*$ molecule state with $J^P = \frac{3}{2}^-$ and $P_c(4450)$ being a $\bar{D}^*\Sigma_c$ molecule state with $J^P = \frac{5}{2}^+$ is more reasonable.

More channels including $\bar{D}^*\Lambda_c$ and $\bar{D}^*\Sigma_c$ are taken into consideration in the Jülich-Bonn dynamical coupled-channel calculations.($\leftarrow$ in progress.)

Searching in the $\bar{D}^*\Lambda_c$ and $\bar{D}\Lambda_c$ system in the forthcoming experiments in LHCb, γp experiment at JLAB and πp experiment at JPARC can be used to disentangle the nature of these P_c states and to achieve a reliable picture of the pentaquark hadron spectrum.

THANKS
FOR
YOUR ATTENTION