Hidden-charm pentaquarks as hadronic molecules

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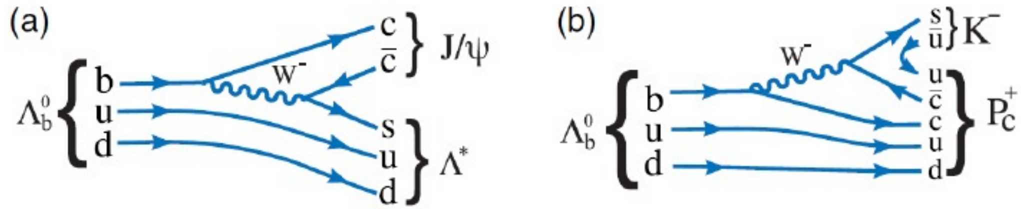
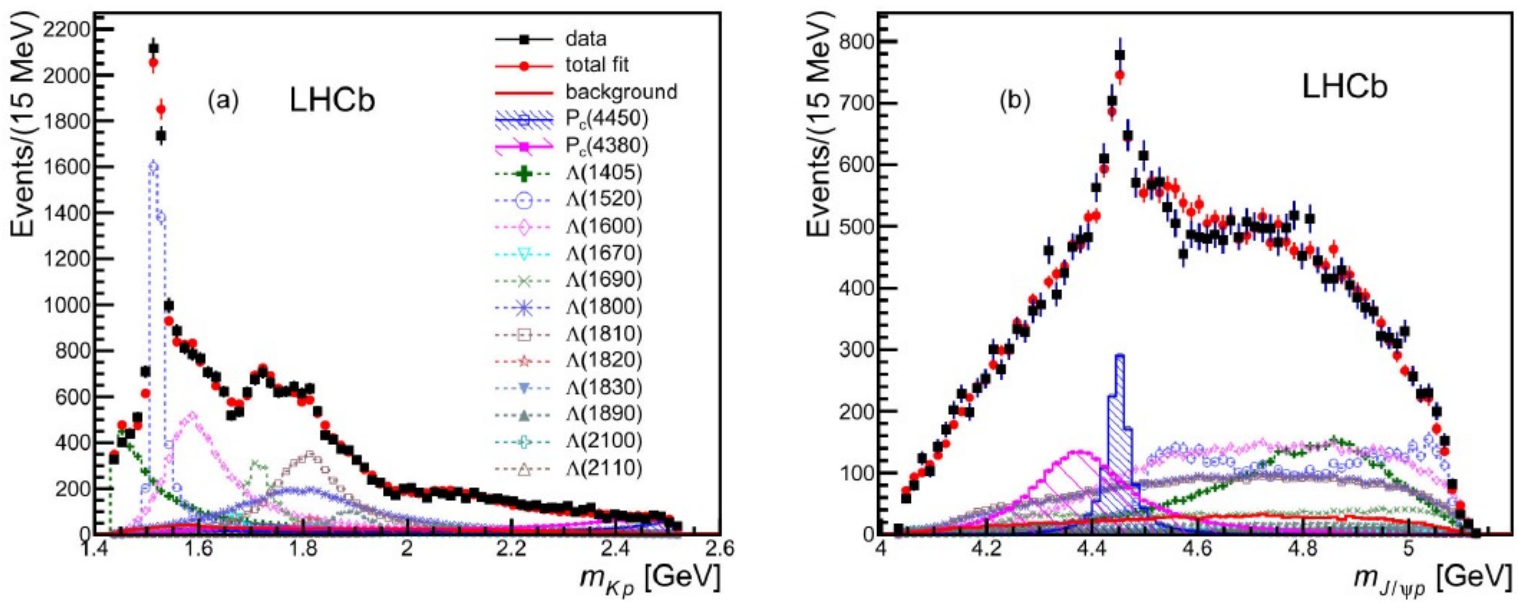
Hidden-charm pentaquarks

Discovered in $\Lambda_b^0 \to J/\psi p K^-$

LHCb, PRL115(2015)072001 [arXiv:1507.03414]





Two Breit–Wigner resonances needed:

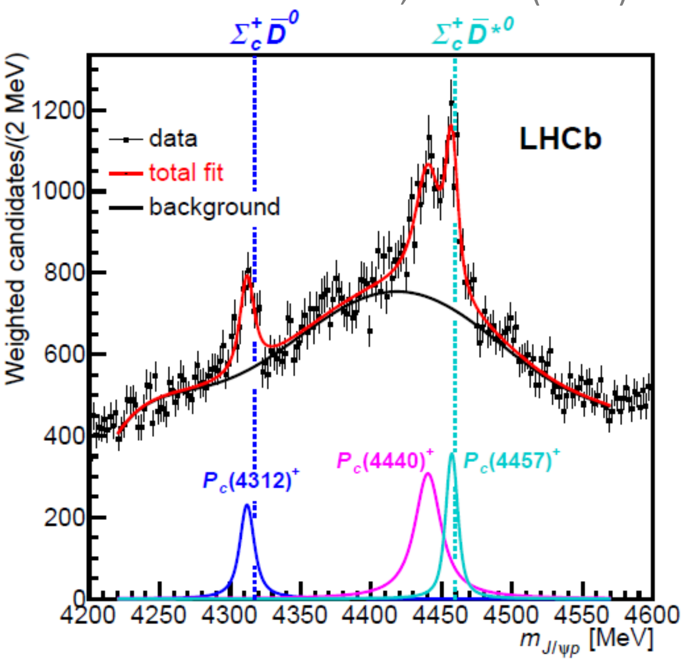
$$M_1 = (4380 \pm 8 \pm 29)\ \text{MeV}, \qquad \Gamma_1 = (205 \pm 18 \pm 86)\ \text{MeV},$$

$$M_2 = (4449.8 \pm 1.7 \pm 2.5)\ \text{MeV}, \qquad \Gamma_2 = (39 \pm 5 \pm 19)\ \text{MeV}.$$

Hidden-charm pentaquarks

- $P_c(4312, 4440, 4457)$ from Run-2 data

LHCb, PRL122(2019)222001

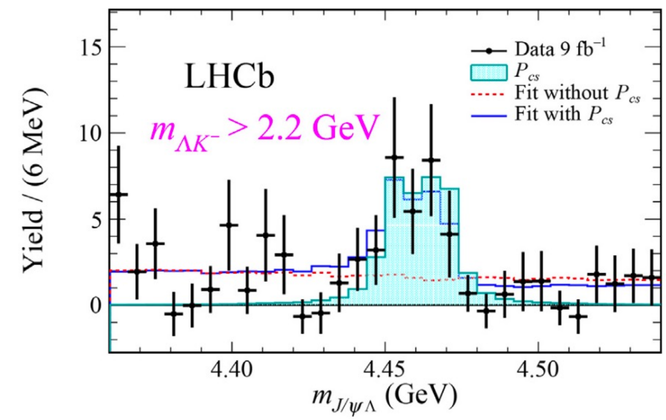


Other related talks:

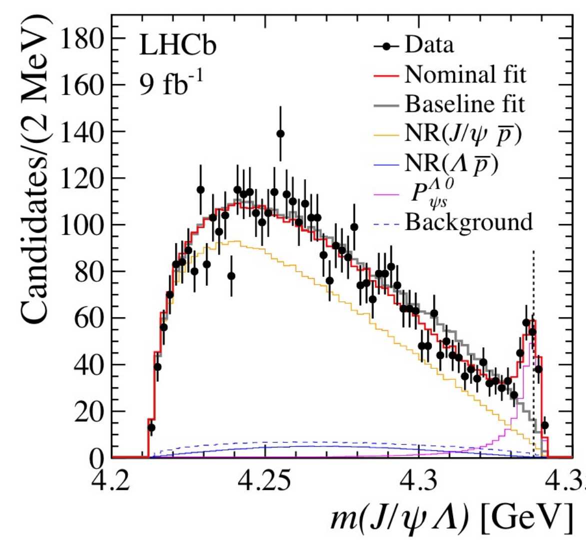
- M. Pavon Valderrama, hadronic molecules in EFT, Session-II, 07 Nov.
- S. Nakamura, $P_{cs}(4338)$ pole + cusps, Session-II, 07. Nov.
- T. Burns, production + triangle singularities, Session-III, 07 Nov.
- P. G. Ortega, P_{cs} in quark models, Session-III, 07 Nov.
- L.R.Torres Rojas, Session-I, 09 Nov.
- E. Santopinto, multiquarks, Session-II, 10 Nov.

- $P_{cs}(4459, 4338)$ with strangeness

$\Xi_b^- \to J/\psi \Lambda K^-$ LHCb, Sci.Bull. 66 (2021) 1278



$B^- \to J/\psi \Lambda \bar{p}$ LHCb, arXiv:2210.10346

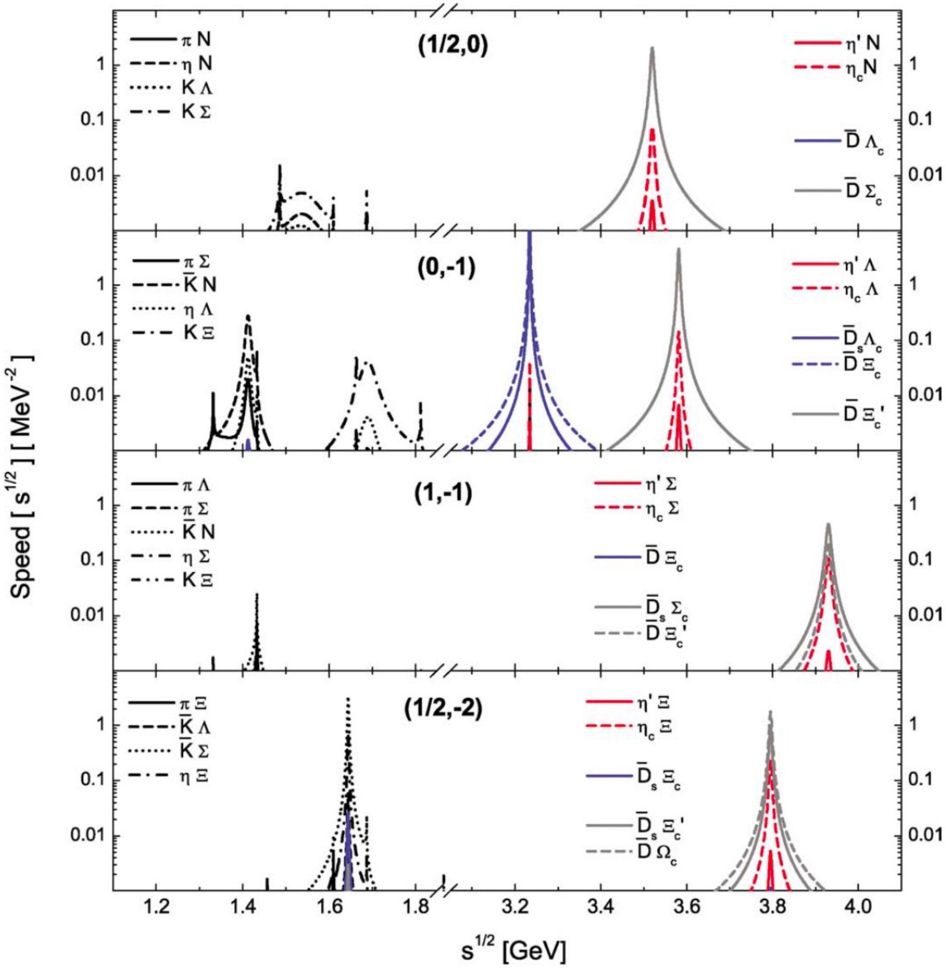


Prehistory: Predictions of $N^*_{c\bar{c}}$ with hidden-charm

- Channels $\pi N, \eta^{(\prime)}N, \ldots, \eta_c N, \Lambda_c\bar{D}, \Sigma_c\bar{D}$

  J. Hofmann, M.F.M. Lutz, NPA 763 (2005) 90

  Predicted hidden-charm ground states are well below 4 GeV

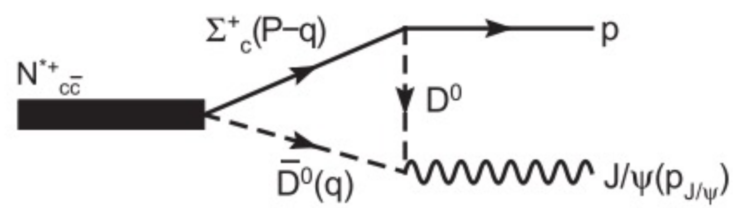


- Channels $\pi N, \eta^{(\prime)}N, \ldots, \eta_c N, \Lambda_c\bar{D}^{(*)}, \Sigma_c\bar{D}^{(*)}$

  J.-J. Wu, R. Molina, E. Oset, B.S. Zou, PRL 105 (2010) 232001

  Predicted hidden-charm states are all above 4.2 GeV

(I, S)	z_R (MeV)		g_a
$(1/2, 0)$		$\bar{D}\Sigma_c$	$\bar{D}\Lambda_c^+$
	4269	2.85	0
		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$
	4418	2.75	0

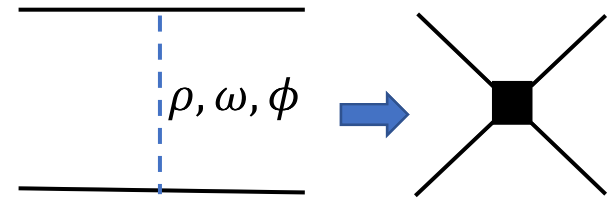


➢ Many more predictions followed

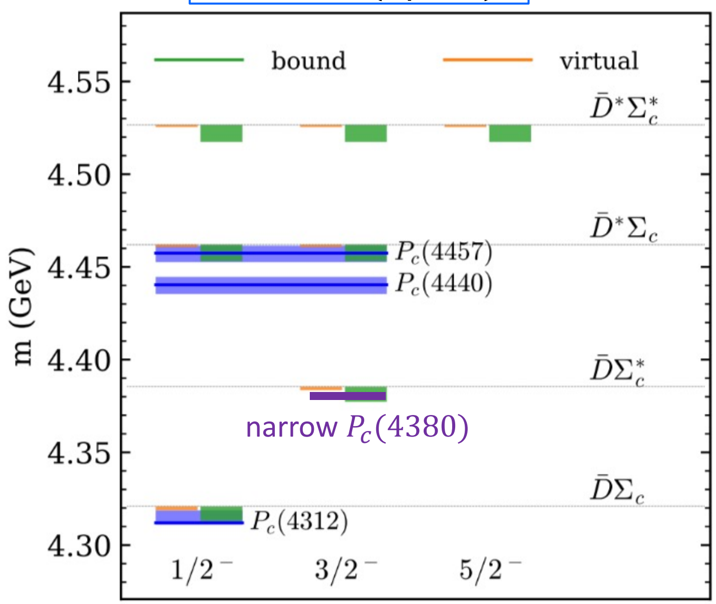
Survey of hidden-charm molecular pentaquarks

X.-K. Dong, FKG, B.-S. Zou, Progr.Phys. 41 (2021) 65

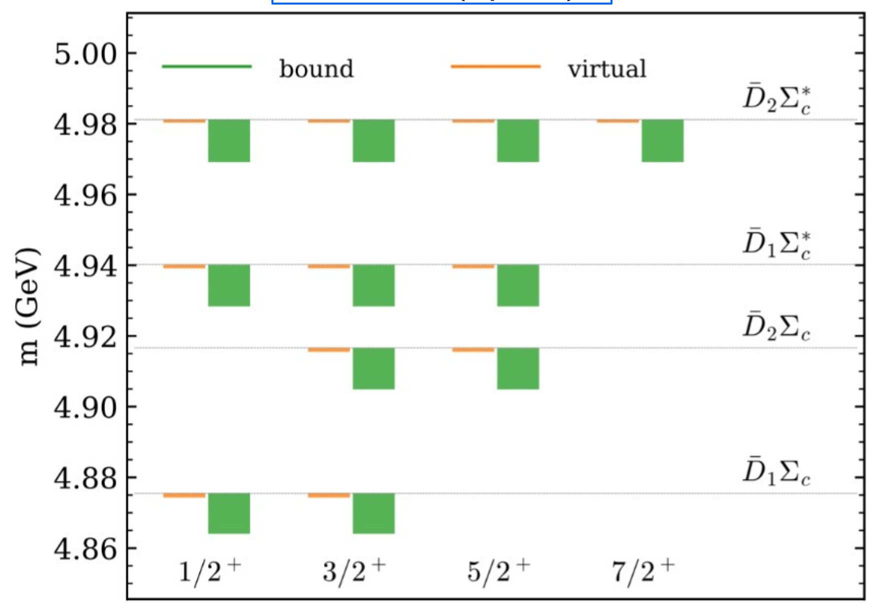
- Consider narrow charm mesons ($D_{(s)}^{(*)}, D_1, D_2, D_{s1}, D_{s2}$) and baryons ($\Lambda_c, \Sigma_c^{(*)}, \Xi_c^{(\prime)(*)}, \Omega_c^{(*)}$)
- Simple model:
  - light vector-meson exchange
  - Lippman-Schwinger equation, cutoff $\Lambda \in [0.5, 1.0]$ GeV
  - Hadronic molecules appear as bound or virtual state poles of the T matrix
  - P_c states



$(I,S) = (1/2,0)$



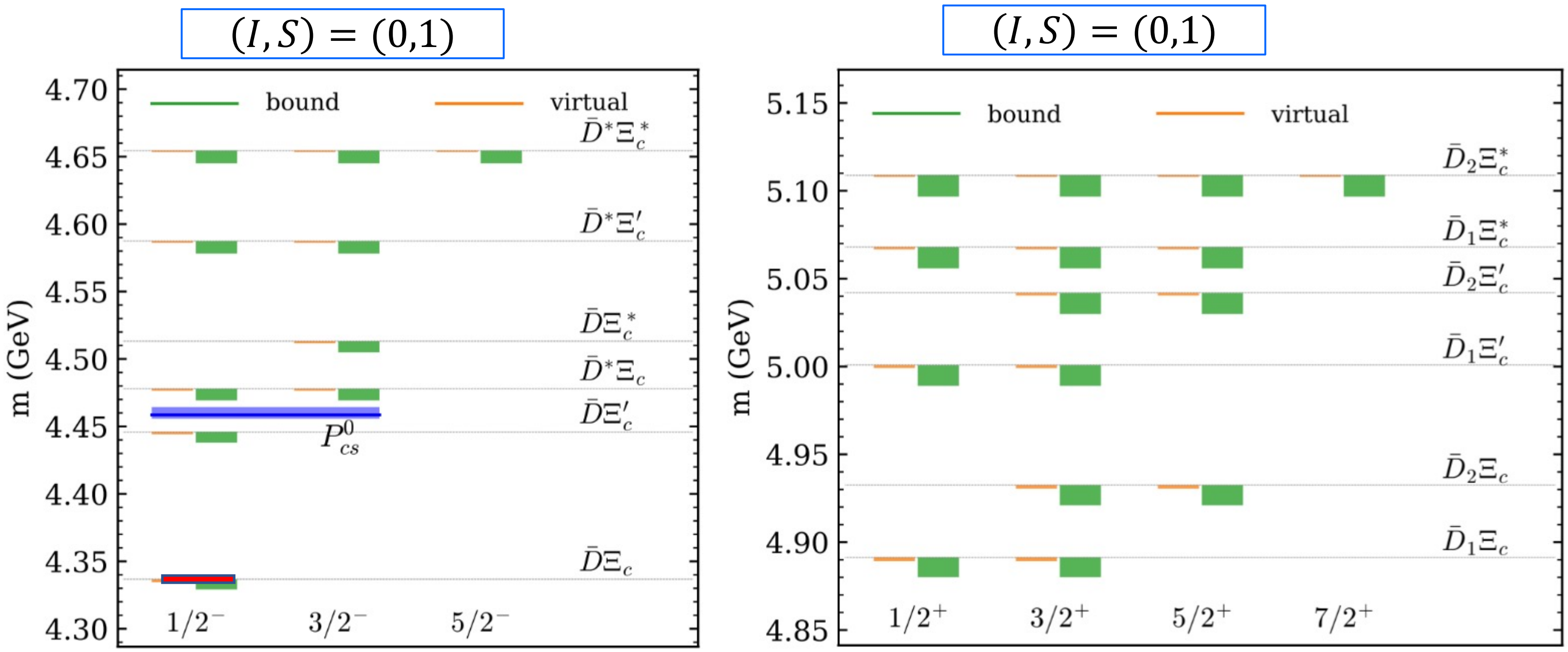
$(I,S) = (1/2,0)$



Survey of hidden-charm molecular pentaquarks

X.-K. Dong, FKG, B.-S. Zou, Progr.Phys. 41 (2021) 65

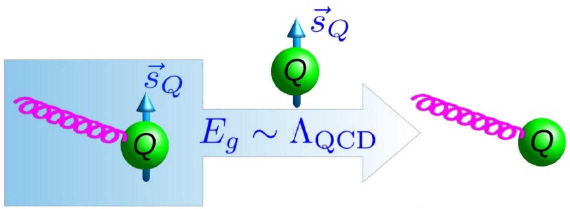
- P_{cs} states



- SU(3) charmed baryon multiplets
  - Sextet with ½⁺ : $\Sigma_c^{++,+,0}, \Xi_c^{\prime +,\prime 0}, \Omega_c^0$
  - Anti-triplet with ½⁺ : $\Lambda_c^+, \Xi_c^{+,0}$
  - Sextet with $3/2^+$: $\Sigma_c^{*++,*+,*0}, \Xi_c^{*+,*0}, \Omega_c^{*0}$

Systematics: heavy-quark spin symmetry

- Heavy quark spin symmetry (HQSS) implies a hidden-charm molecular family



Consider S-wave pairs of $\Sigma_c^{(*)}\bar{D}^{(*)}$ [$J_{\Sigma_c} = \frac{1}{2}$, $J_{\Sigma_c^*} = \frac{3}{2}$]:

$$J^P = \frac{1}{2}^- : \quad \Sigma_c\bar{D},\ \Sigma_c\bar{D}^*,\ \Sigma_c^*\bar{D}^*$$

$$J^P = \frac{3}{2}^- : \quad \Sigma_c^*\bar{D},\ \Sigma_c\bar{D}^*,\ \Sigma_c^*\bar{D}^*$$

$$J^P = \frac{5}{2}^- : \quad \Sigma_c^*\bar{D}^*$$

Spin of the light degrees of freedom s_ℓ: $s_\ell(D^{(*)}) = \frac{1}{2}$, $s_\ell(\Sigma_c^{(*)}) = 1$. Thus, $s_L = \frac{1}{2}, \frac{3}{2}$

For each isospin, 2 independent terms

$$\left\langle 1, \frac{1}{2}, \frac{1}{2} \left| \hat{\mathcal{H}} \right| 1, \frac{1}{2}, \frac{1}{2} \right\rangle, \qquad \left\langle 1, \frac{1}{2}, \frac{3}{2} \left| \hat{\mathcal{H}} \right| 1, \frac{1}{2}, \frac{3}{2} \right\rangle$$

Thus, the 7 pairs are in two spin multiplets: 3 with $s_L = \frac{1}{2}$ and 4 with $s_L = \frac{3}{2}$

Systematics: heavy-quark spin symmetry

- Seven P_c generally expected in this hadronic molecular model

  Xiao, Nieves, Oset (2013); Liu et al. (2018, 2019); Sakai et al. (2019); . . .

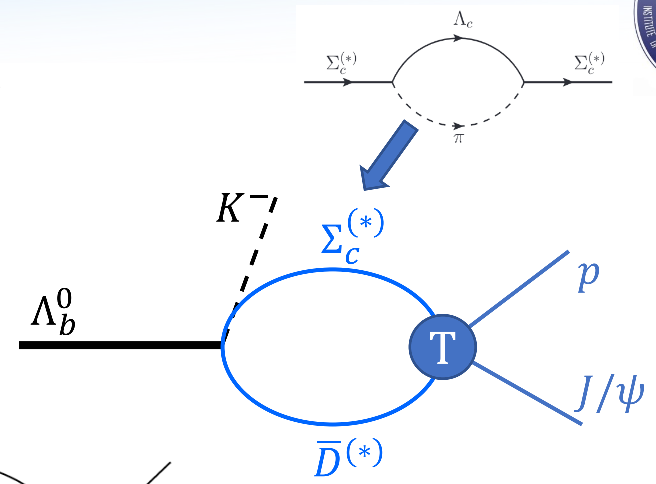
- Predictions using the masses of $P_c(4440, 4457)$ as inputs

  Liu et al., PRL122(2019)242001

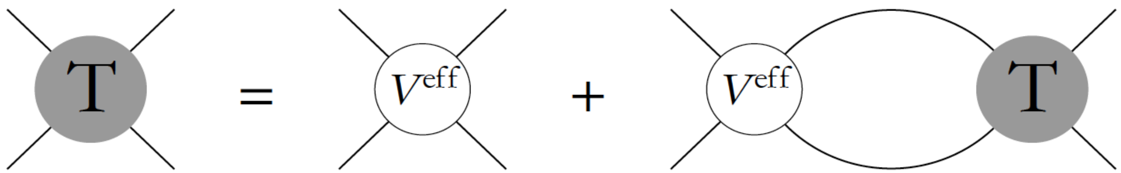
Scenario	Molecule	J^P	B (MeV)	M (MeV)
A	$\bar{D}\Sigma_c$	$\frac{1}{2}^-$	$7.8-9.0$	$4311.8-4313.0$
A	$\bar{D}\Sigma_c^*$	$\frac{3}{2}^-$	$8.3-9.2$	$4376.1-4377.0$
A	$\bar{D}^*\Sigma_c$	$\frac{1}{2}^-$	Input	4440.3
A	$\bar{D}^*\Sigma_c$	$\frac{3}{2}^-$	Input	4457.3
A	$\bar{D}^*\Sigma_c^*$	$\frac{1}{2}^-$	$25.7-26.5$	$4500.2-4501.0$
A	$\bar{D}^*\Sigma_c^*$	$\frac{3}{2}^-$	$15.9-16.1$	$4510.6-4510.8$
A	$\bar{D}^*\Sigma_c^*$	$\frac{5}{2}^-$	$3.2-3.5$	$4523.3-4523.6$
B	$\bar{D}\Sigma_c$	$\frac{1}{2}^-$	$13.1-14.5$	$4306.3-4307.7$
B	$\bar{D}\Sigma_c^*$	$\frac{3}{2}^-$	$13.6-14.8$	$4370.5-4371.7$
B	$\bar{D}^*\Sigma_c$	$\frac{1}{2}^-$	Input	4457.3
B	$\bar{D}^*\Sigma_c$	$\frac{3}{2}^-$	Input	4440.3
B	$\bar{D}^*\Sigma_c^*$	$\frac{1}{2}^-$	$3.1-3.5$	$4523.2-4523.6$
B	$\bar{D}^*\Sigma_c^*$	$\frac{3}{2}^-$	$10.1-10.2$	$4516.5-4516.6$
B	$\bar{D}^*\Sigma_c^*$	$\frac{5}{2}^-$	$25.7-26.5$	$4500.2-4501.0$

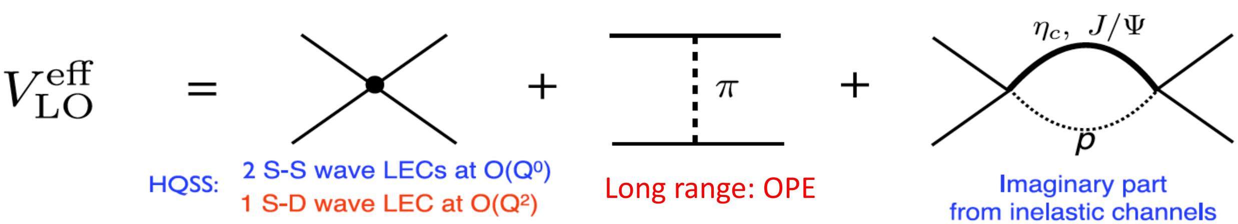
Fits to the LHCb data

M.-L. Du, V. Baru, FKG, C. Hanhart, U.-G. Meißner, J.A. Oller, Q. Wang, PRL124(2020)072001; JHEP08(2021)157



- Can the measured line shape be described?
- Assumed production mechanism
- Coupled channels: $\Sigma_c^{(*)}\bar{D}^{(*)}, J/\psi p, \eta_c p, (\Lambda_c\bar{D}^{(*)})$





- Lippmann-Schwinger equation regularized with a hard cutoff
- Three fit schemes
  - Scheme I: contact terms
  - Scheme II: Scheme I + OPE + S-D counterterms
  - Scheme III: Scheme II + $\Lambda_c\bar{D}^{(*)}$

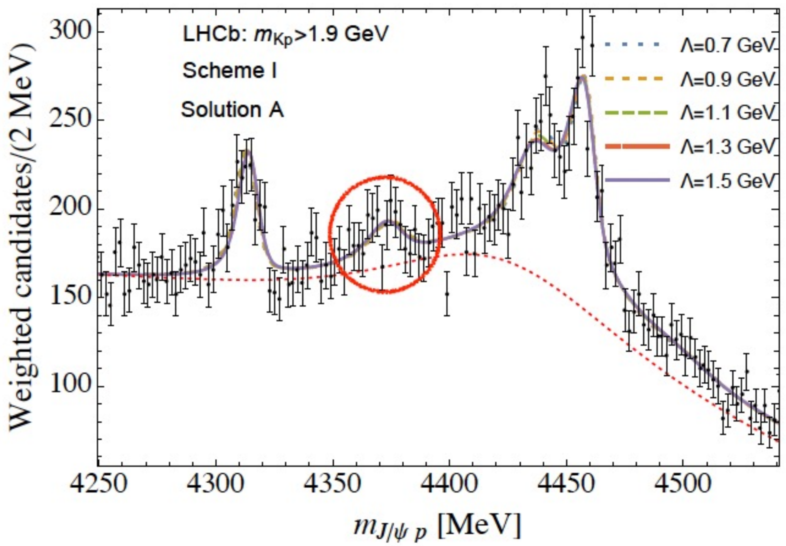
Scheme I: contact term

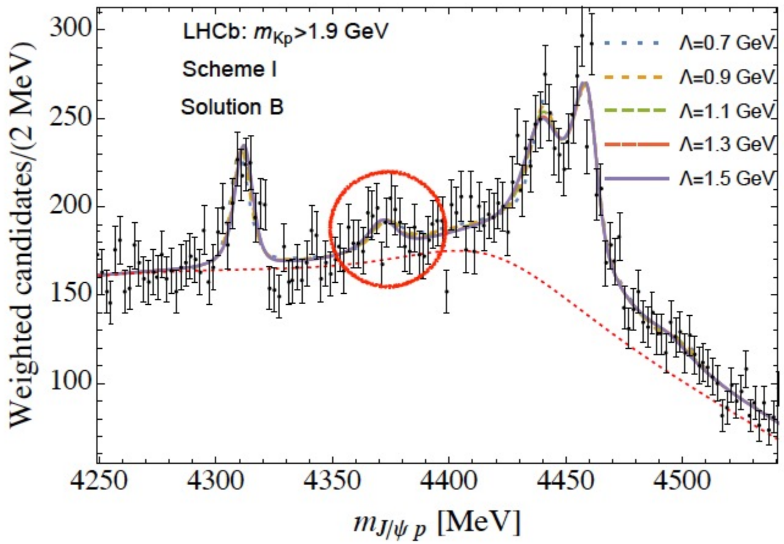
- Solution A: $J^P_{P_c(4440)} = \frac{1}{2}^-, J^P_{P_c(4457)} = \frac{3}{2}^-$

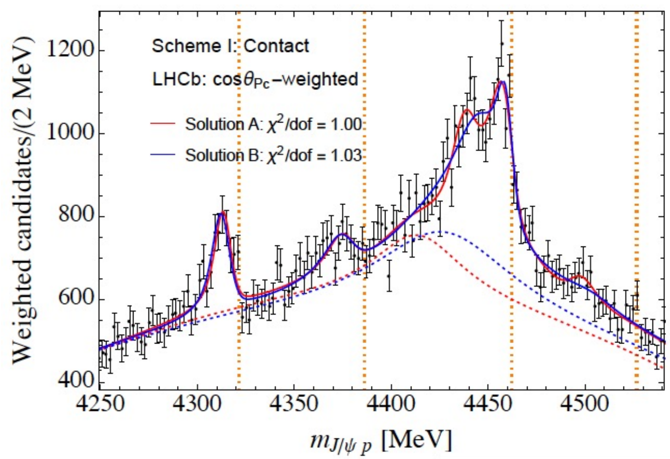
  $\chi^2/\text{dof} = 0.91$

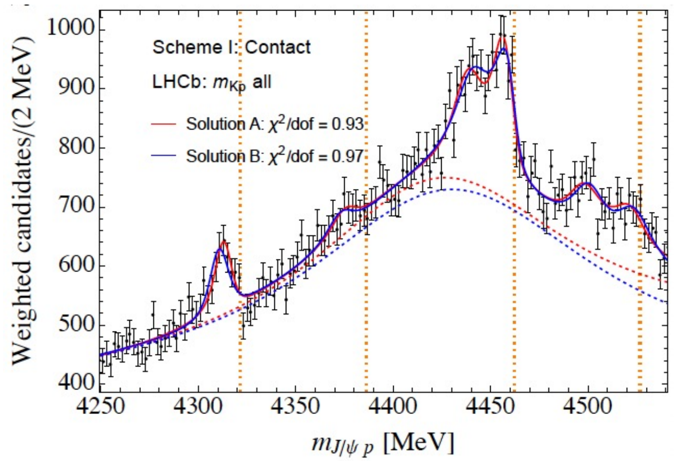
- Solution B: $J^P_{P_c(4440)} = \frac{3}{2}^-, J^P_{P_c(4457)} = \frac{1}{2}^-$

  $\chi^2/\text{dof} = 0.91$









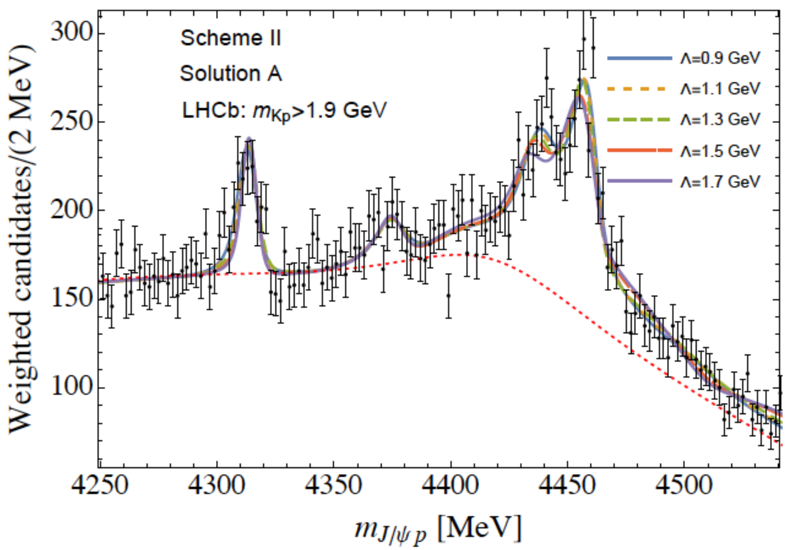
Scheme I: contact term

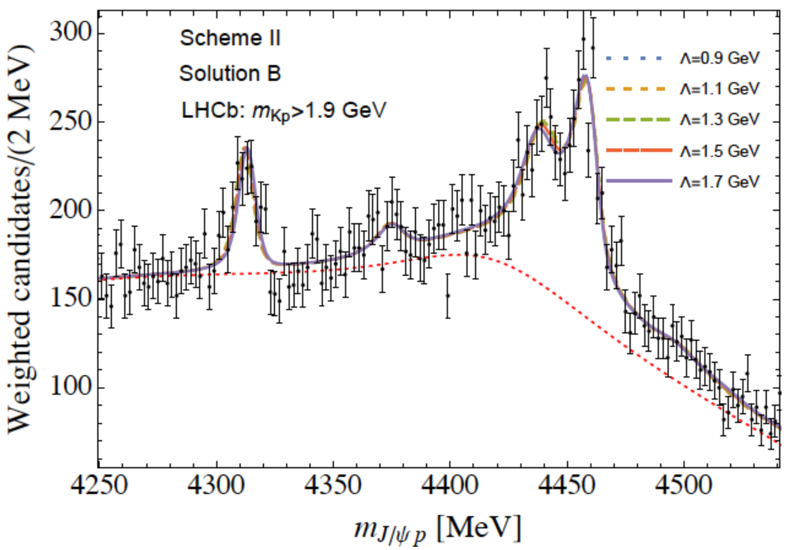
- Poles of the T-matrix from fits in Scheme I
  - Narrow $P_c(4380)$
  - 3 $\Sigma_c^*\bar{D}^*$ molecules with masses around 4.5 and 4.52 GeV; different mass ordering in the two solutions

			Solution A		Solution B
	Dominant channel ([MeV])	J^P	Pole [MeV]	J^P	Pole [MeV]
$P_c(4312)$	$\Sigma_c\bar{D}(4321.6)$	$\frac{1}{2}^-$	$4314(1)-4(1)i$	$\frac{1}{2}^-$	$4312(2)-4(2)i$
$P_c(4380)$	$\Sigma_c^*\bar{D}(4386.2)$	$\frac{3}{2}^-$	$4377(1)-7(1)i$	$\frac{3}{2}^-$	$4375(2)-6(1)i$
$P_c(4440)$	$\Sigma_c\bar{D}^*(4462.1)$	$\frac{1}{2}^-$	$4440(1)-9(2)i$	$\frac{3}{2}^-$	$4441(3)-5(2)i$
$P_c(4457)$	$\Sigma_c\bar{D}^*(4462.1)$	$\frac{3}{2}^-$	$4458(2)-3(1)i$	$\frac{1}{2}^-$	$4462(4)-5(3)i$
P_c	$\Sigma_c^*\bar{D}^*(4526.7)$	$\frac{1}{2}^-$	$4498(2)-9(3)i$	$\frac{1}{2}^-$	$4526(3)-9(2)i$
P_c	$\Sigma_c^*\bar{D}^*(4526.7)$	$\frac{3}{2}^-$	$4510(2)-14(3)i$	$\frac{3}{2}^-$	$4521(2)-12(3)i$
P_c	$\Sigma_c^*\bar{D}^*(4526.7)$	$\frac{5}{2}^-$	$4525(2)-9(3)i$	$\frac{5}{2}^-$	$4501(3)-6(4)i$

Scheme II: contact term + OPE + S-D counterterm

- Solution A: $J^P_{P_c(4440)} = \frac{1}{2}^-, J^P_{P_c(4457)} = \frac{3}{2}^-$
- Solution B: $J^P_{P_c(4440)} = \frac{3}{2}^-, J^P_{P_c(4457)} = \frac{1}{2}^-$



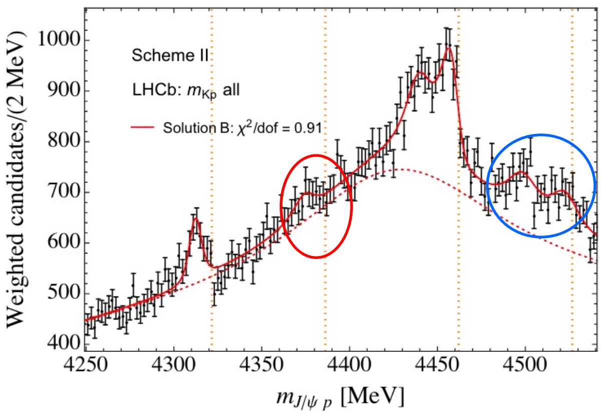


Residual cutoff dependence for solution A:
$\chi^2/\text{dof} = 1.01$ with $\Lambda = 1.3$ GeV

Cutoff independence only for solution B:
$\chi^2/\text{dof} = 0.90$

Scheme II: contact term + OPE + S-D counterterm

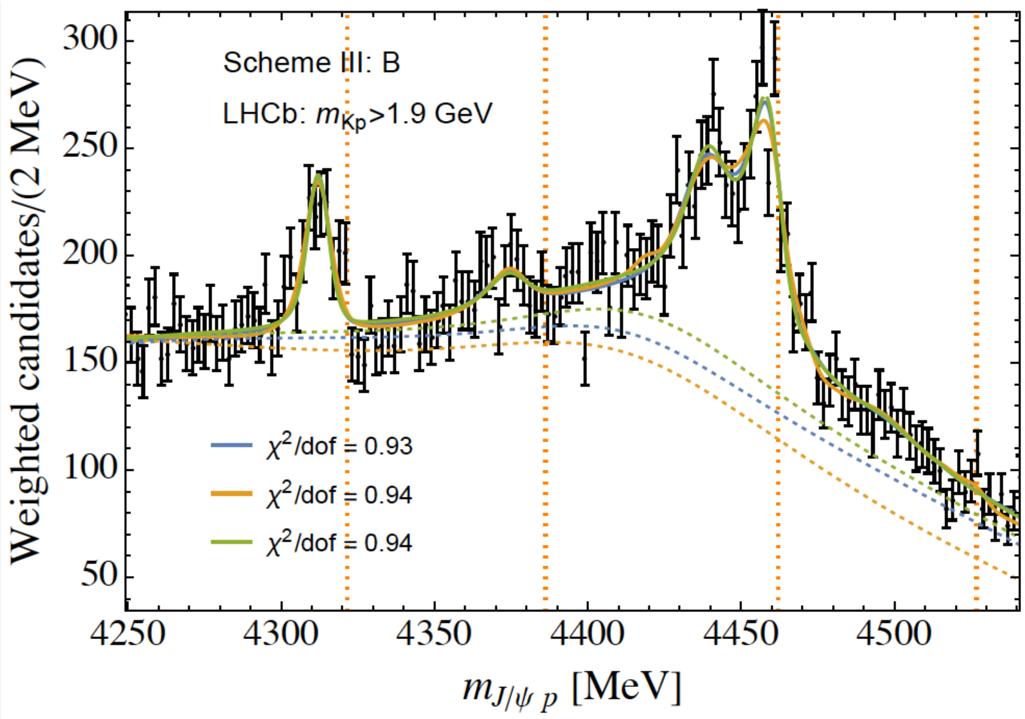
- Poles of 7 P_c states in Solution B
  - Narrow $P_c(4380)$
  - 3 $\Sigma_c^*\bar{D}^*$ molecules with masses around 4.5 and 4.52 GeV



	Dominant channel ([MeV])	Riemann sheet	J^P	Pole [MeV]
$P_c(4312)$	$\Sigma_c\bar{D}(4321.6)$	$++++$	$\frac{1}{2}^-$	$4313(1)-3(1)i$
$P_c(4380)$	$\Sigma_c^*\bar{D}(4386.2)$	$-+++$	$\frac{3}{2}^-$	$4376(1)-6(2)i$
$P_c(4440)$	$\Sigma_c\bar{D}^*(4462.1)$	$--++$	$\frac{3}{2}^-$	$4441(2)-6(2)i$
$P_c(4457)$	$\Sigma_c\bar{D}^*(4462.1)$	$--++$	$\frac{1}{2}^-$	$4461(2)-5(2)i$
P_c	$\Sigma_c^*\bar{D}^*(4526.7)$	$---+$	$\frac{1}{2}^-$	$4525(4)-9(1)i$
P_c	$\Sigma_c^*\bar{D}^*(4526.7)$	$---+$	$\frac{3}{2}^-$	$4520(3)-12(3)i$
P_c	$\Sigma_c^*\bar{D}^*(4526.7)$	$---+$	$\frac{5}{2}^-$	$4500(2)-9(6)i$

Scheme III: contact + OPE + S-D + $\Lambda_c\bar{D}^{(*)}$

- A more complete scheme
  - However, no effective constraints on $\Lambda_c\bar{D}^{(*)}$ can be derived solely from the $J/\psi p$ data



Summary

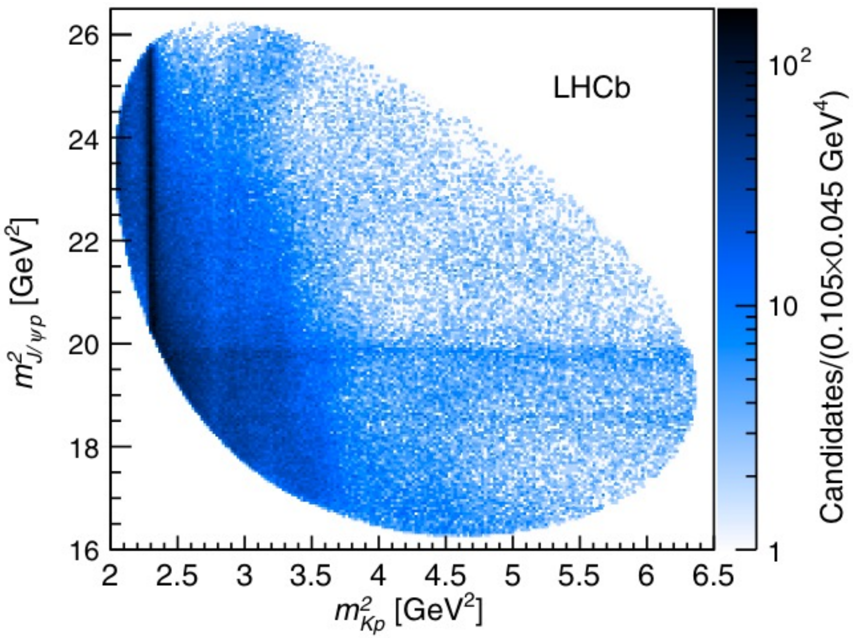
- Plenty of hidden-charm molecular pentaquarks are expected from the vector-meson exchange
- The LHCb data for $J/\psi p$ distribution can be well described in the $\Sigma_c^{(*)}\bar{D}^{(*)}$ molecular picture; suggested quantum numbers:
  - ½⁻: $P_c(4312, 4457)$; $3/2^-$: $P_c(4440)$
- States to be discovered:
  - Narrow $P_c(4380)$ with $3/2^-$
  - 3 $\Sigma_c^*\bar{D}^*$ molecules, but may lead to only two peaks at 4.50 and 4.52 GeV
  - SU(3) partners of $P_c(4312,4440,4457)$: 7 molecular states of $\Xi_c'\bar{D}^{(*)}$, $\Xi_c^*\bar{D}^{(*)}$
  - 1 more $\Xi_c\bar{D}^{(*)}$ molecule (in addition to $P_{cs}(4338, 4459)$)
  - Many more above 4.85 GeV

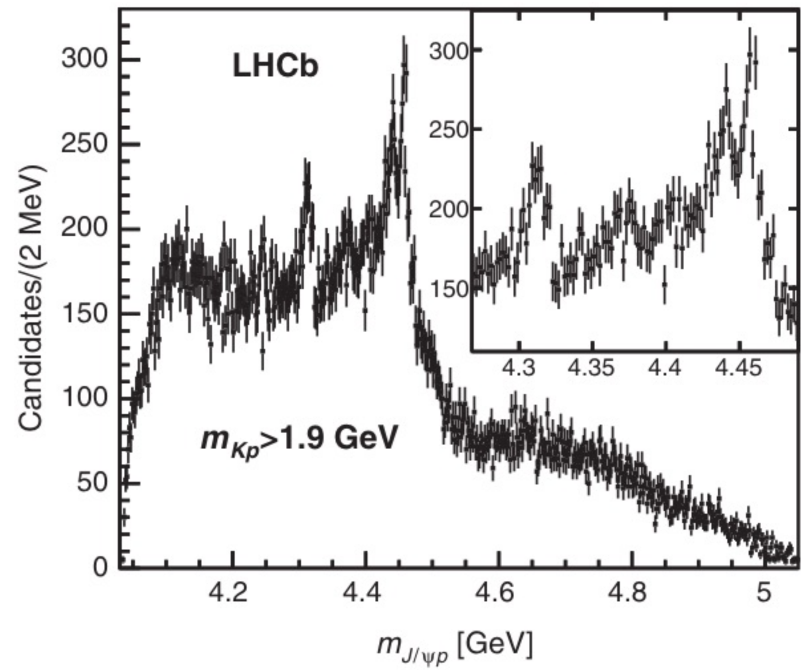
Thank you for your attention!

Additional information

- LHCb data 2019

LHCb, PRL122(2019)222001





- Color suppression might not be effective
  - Example:
    - $\Lambda_c^+ \to \Sigma^0 K^+$: color suppressed, $\mathcal{B} = (5.2 \pm 0.8)\times 10^{-4}$ PDG (2022)
    - $\Lambda_c^+ \to \Lambda K^+$: no color suppression, $\mathcal{B} = (6.1 \pm 1.2)\times 10^{-4}$

Additional information

- SU(3) multiplets of S-wave charmed baryons
  - Anti-triplet with ½$^+$:

$$B_{\bar{3}}^{(c)} = \begin{pmatrix} 0 & \Lambda_c^+ & \Xi_c^+ \\ -\Lambda_c^+ & 0 & \Xi_c^0 \\ -\Xi_c^+ & -\Xi_c^0 & 0 \end{pmatrix}$$

  - Sextet with ½$^+$:

$$B_6^{(c)} = \begin{pmatrix} \Sigma_c^{++} & \frac{1}{\sqrt{2}}\Sigma_c^+ & \frac{1}{\sqrt{2}}\Xi_c^{\prime +} \\ \frac{1}{\sqrt{2}}\Sigma_c^+ & \Sigma_c^0 & \frac{1}{\sqrt{2}}\Xi_c^{\prime 0} \\ \frac{1}{\sqrt{2}}\Xi_c^{\prime +} & \frac{1}{\sqrt{2}}\Xi_c^{\prime 0} & \Omega_c^0 \end{pmatrix}$$

  - Sextet with $3/2^+$:

$$B_6^{(c)*} = \begin{pmatrix} \Sigma_c^{*++} & \frac{1}{\sqrt{2}}\Sigma_c^{*+} & \frac{1}{\sqrt{2}}\Xi_c^{*+} \\ \frac{1}{\sqrt{2}}\Sigma_c^{*+} & \Sigma_c^{*0} & \frac{1}{\sqrt{2}}\Xi_c^{*0} \\ \frac{1}{\sqrt{2}}\Xi_c^{*+} & \frac{1}{\sqrt{2}}\Xi_c^{*0} & \Omega_c^{*0} \end{pmatrix}$$

Additional information

- Background

$$f_{\rm bgd}(E) = b_0 + b_1 E^2 + b_2 E^4 + \frac{g_r^2}{(m-E)^2+\Gamma^2/4},$$

- Poles from Scheme I

			Solution A		Solution B
	Dominant channel ([MeV])	J^P	Pole [MeV]	J^P	Pole [MeV]
$P_c(4312)$	$\Sigma_c\bar{D}(4321.6)$	$\frac{1}{2}^-$	$4314(1)-4(1)i$	$\frac{1}{2}^-$	$4312(2)-4(2)i$
$P_c(4380)$	$\Sigma_c^*\bar{D}(4386.2)$	$\frac{3}{2}^-$	$4377(1)-7(1)i$	$\frac{3}{2}^-$	$4375(2)-6(1)i$
$P_c(4440)$	$\Sigma_c\bar{D}^*(4462.1)$	$\frac{1}{2}^-$	$4440(1)-9(2)i$	$\frac{3}{2}^-$	$4441(3)-5(2)i$
$P_c(4457)$	$\Sigma_c\bar{D}^*(4462.1)$	$\frac{3}{2}^-$	$4458(2)-3(1)i$	$\frac{1}{2}^-$	$4462(4)-5(3)i$
P_c	$\Sigma_c^*\bar{D}^*(4526.7)$	$\frac{1}{2}^-$	$4498(2)-9(3)i$	$\frac{1}{2}^-$	$4526(3)-9(2)i$
P_c	$\Sigma_c^*\bar{D}^*(4526.7)$	$\frac{3}{2}^-$	$4510(2)-14(3)i$	$\frac{3}{2}^-$	$4521(2)-12(3)i$
P_c	$\Sigma_c^*\bar{D}^*(4526.7)$	$\frac{5}{2}^-$	$4525(2)-9(3)i$	$\frac{5}{2}^-$	$4501(3)-6(4)i$

Interactions from light-vector meson exchange

- Positive F means an S-wave attraction

X.-K. Dong, FKG, B.-S. Zou, CTP73(2021)125201

System	I	S	Thresholds [MeV]	Exchanged particles	F
$D^{(*)}\bar{D}^{(*)}/D^{(*)}D^{(*)}$	1	0/0	(3734, 3876, 4017)	ρ, ω	$-\frac{1}{2}, \frac{1}{2}/-\frac{1}{2}, -\frac{1}{2}$
	0				$\frac{3}{2}, \frac{1}{2}/\frac{3}{2}, -\frac{1}{2}$
$D_s^{(*)}\bar{D}^{(*)}/D_s^{(*)}D^{(*)}$	$\frac{1}{2}$	1/1	(3836, 3977, 3979, 4121)	K^*	$0/-1$
$D_s^{(*)}\bar{D}_s^{(*)}/D_s^{(*)}D_s^{(*)}$	0	0/2	(3937, 4081, 4224)	ϕ	$1/-1$
$\bar{D}^{(*)}\Lambda_c/D^{(*)}\Lambda_c$	$\frac{1}{2}$	0/0	(4154, 4295)	ω	$-1/1$
$\bar{D}_s^{(*)}\Lambda_c/D_s^{(*)}\Lambda_c$	0	$-1/1$	(4255, 4399)	–	0/0
$\bar{D}^{(*)}\Xi_c/D^{(*)}\Xi_c$	1	$-1/-1$	(4337, 4478)	ρ, ω	$-\frac{1}{2}, -\frac{1}{2}/-\frac{1}{2}, \frac{1}{2}$
	0				$\frac{3}{2}, -\frac{1}{2}/\frac{3}{2}, \frac{1}{2}$
$\bar{D}_s^{(*)}\Xi_c/D_s^{(*)}\Xi_c$	$\frac{1}{2}$	$-2/0$	(4438, 4582)	ϕ	$-1/1$
$\bar{D}^{(*)}\Sigma_c^{(*)}/D^{(*)}\Sigma_c^{(*)}$	$\frac{3}{2}$	0/0	(4321, 4385, 4462, 4527)	ρ, ω	$-1, -1/-1, 1$
	$\frac{1}{2}$				$2, -1/2, 1$
$\bar{D}_s^{(*)}\Sigma_c^{(*)}/D_s^{(*)}\Sigma_c^{(*)}$	1	$-1/1$	(4422, 4486, 4566, 4630)	–	0/0
$\bar{D}^{(*)}\Xi_c'^{(*)}/D^{(*)}\Xi_c'^{(*)}$	1	$-1/-1$	(4446, 4513, 4587, 4655)	ρ, ω	$-\frac{1}{2}, -\frac{1}{2}/-\frac{1}{2}, \frac{1}{2}$
	0				$\frac{3}{2}, -\frac{1}{2}/\frac{3}{2}, \frac{1}{2}$
$\bar{D}_s^{(*)}\Xi_c'^{(*)}/D_s^{(*)}\Xi_c'^{(*)}$	$\frac{1}{2}$	$-2/0$	(4547, 4614, 4691, 4758)	ϕ	$-1/1$
$\bar{D}^{(*)}\Omega_c^{(*)}/D^{(*)}\Omega_c^{(*)}$	$\frac{1}{2}$	$-2/0$	(4562, 4633, 4704, 4774)	–	0/0
$\bar{D}_s^{(*)}\Omega_c^{(*)}/D_s^{(*)}\Omega_c^{(*)}$	0	$-3/-1$	(4664, 4734, 4807, 4878)	ϕ	$-2/2$
$\Lambda_c\bar{\Lambda}_c/\Lambda_c\Lambda_c$	0	0/0	(4573)	ω	$2/-2$
$\Lambda_c\bar{\Xi}_c/\Lambda_c\Xi_c$	$\frac{1}{2}$	$1/-1$	(4756)	ω/K^*	$1, 0/-1, -1$
$\Xi_c\bar{\Xi}_c/\Xi_c\Xi_c$	1	$0/-2$	(4939)	ρ, ω, ϕ	$-\frac{1}{2}, \frac{1}{2}, 1/-\frac{1}{2}, -\frac{1}{2}, -1$
	0				$\frac{3}{2}, \frac{1}{2}, 1/\frac{3}{2}, -\frac{1}{2}, -1$
$\Lambda_c\bar{\Sigma}_c^{(*)}/\Lambda_c\Sigma_c^{(*)}$	1	0/0	(4740, 4805)	ω/K^*	$1, 0/-1, -1$

Interactions from light-vector meson exchange

- Positive F means an S-wave attraction

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System	I	S	Thresholds [MeV]	Exchanged particles	F
$\Lambda_c\bar{\Xi}_c'^{(*)}/\Lambda_c\Xi_c'^{(*)}$	$\frac{1}{2}$	$1/-1$	(4865, 4932)	ω	$1/-1$
$\Lambda_c\bar{\Omega}_c^{(*)}/\Lambda_c\Omega_c^{(*)}$	0	$2/-2$	(4982, 5052)	–	$0/0$
$\Sigma_c^{(*)}\bar{\Xi}_c/\Sigma_c^{(*)}\Xi_c$	$\frac{3}{2}$	$1/-1$	(4923, 4988)	ρ, ω, K^*	$-1, 1, 0/-1, -1, -2$
	$\frac{1}{2}$				$2, 1, 0/2, -1, -2$
$\Xi_c\bar{\Xi}_c'^{(*)}/\Xi_c\Xi_c'^{(*)}$	1	$0/-2$	(5048, 5115)	ρ, ω, ϕ	$-\frac{1}{2}, \frac{1}{2}, 1/-\frac{1}{2}, -\frac{1}{2}, -1$
	0				$\frac{3}{2}, \frac{1}{2}, 1/\frac{3}{2}, -\frac{1}{2}, -1$
$\Xi_c\bar{\Omega}_c^{(*)}/\Xi_c\Omega_c^{(*)}$	$\frac{1}{2}$	$1/-3$	(5165, 5235)	ϕ, K^*	$2, 0/-2, -2$
$\Sigma_c^{(*)}\bar{\Sigma}_c^{(*)}/\Sigma_c^{(*)}\Sigma_c^{(*)}$	2	$0/0$	(4907, 4972, 5036)	ρ, ω	$-2, 2/-2, -2$
	1				$2, 2/2, -2$
	0				$4, 2/4, -2$
$\Sigma_c^{(*)}\bar{\Xi}_c'^{(*)}/\Sigma_c^{(*)}\Xi_c'^{(*)}$	$\frac{3}{2}$	$1/-1$	(5032, 5097, 5100, 5164)	ρ, ω, K^*	$-1, 1, 0/-1, -1-2$
	$\frac{1}{2}$				$2, 1, 0/2, -1, -2$
$\Sigma_c^{(*)}\bar{\Omega}_c^{(*)}/\Sigma_c^{(*)}\Omega_c^{(*)}$	0	$2/-2$	(5149, 5213, 5219, 5284)	–	$0/0$
$\Xi_c'^{(*)}\bar{\Xi}_c'^{(*)}/\Xi_c'^{(*)}\Xi_c'^{(*)}$	1	$0/-2$	(5158, 5225, 5292)	ρ, ω, ϕ	$-\frac{1}{2}, \frac{1}{2}, 1/-\frac{1}{2}, -\frac{1}{2}, -1$
	0				$\frac{3}{2}, \frac{1}{2}, 1/\frac{3}{2}, -\frac{1}{2}, -1$
$\Xi_c'^{(*)}\bar{\Omega}_c^{(*)}/\Xi_c'^{(*)}\Omega_c^{(*)}$	$\frac{1}{2}$	$1/-3$	(5272, 5341, 5345, 5412)	ϕ, K^*	$2, 0/-2, -2$
$\Omega_c^{(*)}\bar{\Omega}_c^{(*)}/\Omega_c^{(*)}\Omega_c^{(*)}$	0	$0/-4$	(5390, 5461, 5532)	ϕ	$4/-4$

Interactions from light-vector meson exchange

- Positive F means an S-wave attraction

X.-K. Dong, FKG, B.-S. Zou, CTP73(2021)125201

System	I	S	Thresholds [MeV]	Exchanged particles	F
$D^{(*)}\bar{D}_{1,2}/D^{(*)}D_{1,2}$	0	0/0	(4289, 4330, 4431, 4472)	ρ, ω	$\frac{3}{2}, \frac{1}{2}/\frac{3}{2}, -\frac{1}{2}$
	1	0/0			$-\frac{1}{2}, \frac{1}{2}/-\frac{1}{2}, -\frac{1}{2}$
$D^{(*)}\bar{D}_{s1,s2}/D^{(*)}D_{s1,s2}$	$\frac{1}{2}$	$1/-1$	(4390, 4431, 4534, 4575)	–	0/0
$D_s^{(*)}\bar{D}_{1,2}/D_s^{(*)}D_{1,2}$	$\frac{1}{2}$	$-1/1$	(4402, 4436, 4544, 4578)	–	0/0
$D_s^{(*)}\bar{D}_{s1,s2}/D_s^{(*)}D_{s1,s2}$	0	$0/-2$	(4503, 4537, 4647, 4681)	ϕ	$1/-1$
$D_{1,2}\bar{D}_{1,2}/D_{1,2}D_{1,2}$	0	0/0	(4844, 4885, 4926)	ρ, ω	$\frac{3}{2}, \frac{1}{2}/\frac{3}{2}, -\frac{1}{2}$
	1				$-\frac{1}{2}, \frac{1}{2}/-\frac{1}{2}, -\frac{1}{2}$
$D_{s1,s2}\bar{D}_{1,2}/D_{s1,s2}D_{1,2}$	$\frac{1}{2}$	1/1	(4957, 4991, 4998, 5032)		0/0
$D_{s1,s2}\bar{D}_{s1,s2}/D_{s1,s2}D_{s1,s2}$	0	$0/-2$	(5070, 5104, 5138)	ϕ	1/1
$\Lambda_c\bar{D}_{1,2}/\Lambda_c D_{1,2}$	$\frac{1}{2}$	0/0	(4708, 4750)	ω	$-1/1$
$\Lambda_c\bar{D}_{s1,s2}/\Lambda_c D_{s1,s2}$	0	$-1/1$	(4822, 4856)	–	0/0
$\Xi_c\bar{D}_{1,2}/\Xi_c D_{1,2}$	1	$-1/-1$	(4891, 4932)	ρ, ω	$-\frac{1}{2}, -\frac{1}{2}/-\frac{1}{2}, \frac{1}{2}$
	0				$\frac{3}{2}, -\frac{1}{2}/\frac{3}{2}, \frac{1}{2}$
$\Xi_c\bar{D}_{s1,s2}/\Xi_c D_{s1,s2}$	$\frac{1}{2}$	$-2/0$	(5005, 5039)	ϕ	$-1/1$
$\Sigma_c^{(*)}\bar{D}_{1,2}/\Sigma_c^{(*)}D_{1,2}$	$\frac{3}{2}$	0/0	(4876, 4917, 4940, 4981)	ρ, ω	$-1, -1/-1, 1$
	$\frac{1}{2}$				$2, -1/2,1$
$\Sigma_c^{(*)}\bar{D}_{s1,s2}/\Sigma_c^{(*)}D_{s1,s2}$	1	$1/-1$	(4989, 5023, 5053, 5087)	–	0/0
$\Xi_c^{\prime(*)}\bar{D}_{1,2}/\Xi_c^{\prime(*)}D_{1,2}$	1	$-1/-1$	(5001, 5042, 5068, 5109)	ρ, ω	$-\frac{1}{2}, -\frac{1}{2}/-\frac{1}{2}, \frac{1}{2}$
	0				$\frac{3}{2}, -\frac{1}{2}/\frac{3}{2}, \frac{1}{2}$
$\Xi_c^{\prime(*)}\bar{D}_{s1,s2}/\Xi_c^{\prime(*)}D_{s1,s2}$	$\frac{1}{2}$	$-2/0$	(5114, 5148, 5181, 5215)	ϕ	$-1/1$
$\Omega_c^{(*)}\bar{D}_{1,2}/\Omega_c^{(*)}D_{1,2}$	$\frac{1}{2}$	$-2/-2$	(5117, 5158, 5188, 5229)	–	0/0
$\Omega_c^{(*)}\bar{D}_{s1,s2}/\Omega_c^{(*)}D_{s1,s2}$	0	$-3/-1$	(5230, 5264, 5301, 5335)	ϕ	$-2/2$