The 6th International Workshop on Future Tau Charm Facilities

FTCF, 2024, Guangzhou

Hidden-charm pentaquark candidates with strangeness

Jia-Jun Wu (UCAS)

Collaborator: C. Xiao, S. Nakamura, B. Zou

Phys.Rev.D 108 (2023) 1, L011501

Phys.Rev.D 103 (2021) 5, 054016

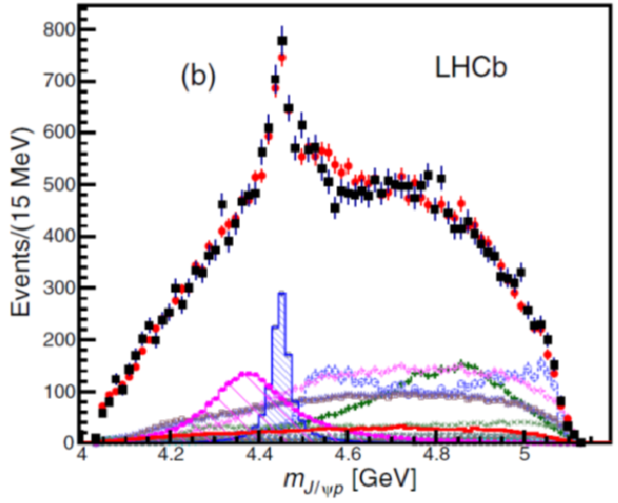
FTCF2024 2024. 11. 21 Guangzhou

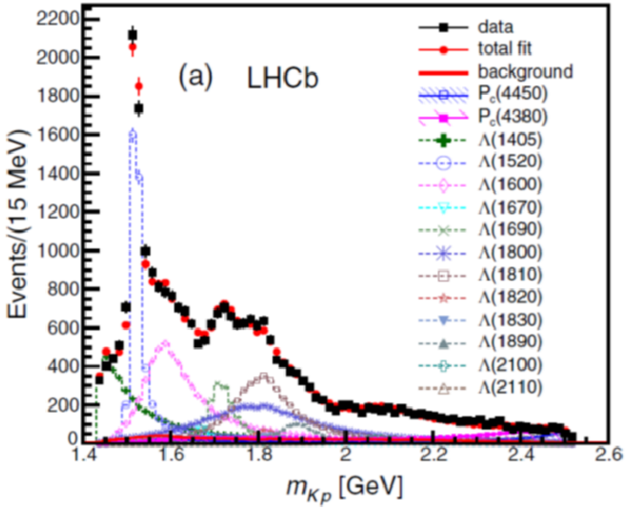
中国科学院大学
University of Chinese Academy of Sciences

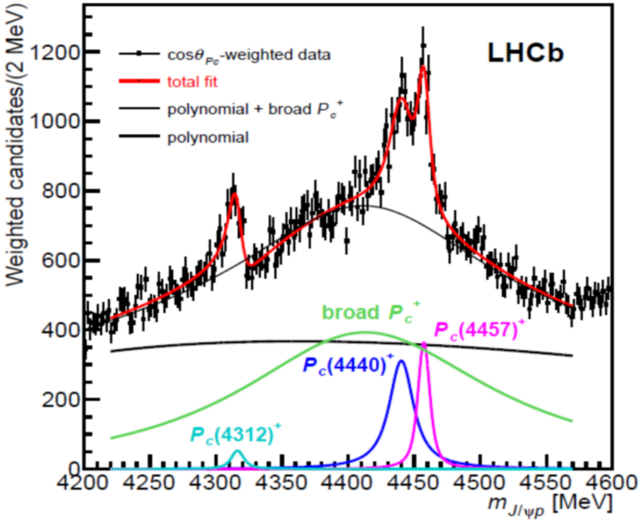
Outline

- Introduction of hidden pentaquark states
- Coupled-channel model prediction
- Data-driven analysis of $B^- \to J/\psi \Lambda \bar{P}$
- Summary

Introduction of P_c states

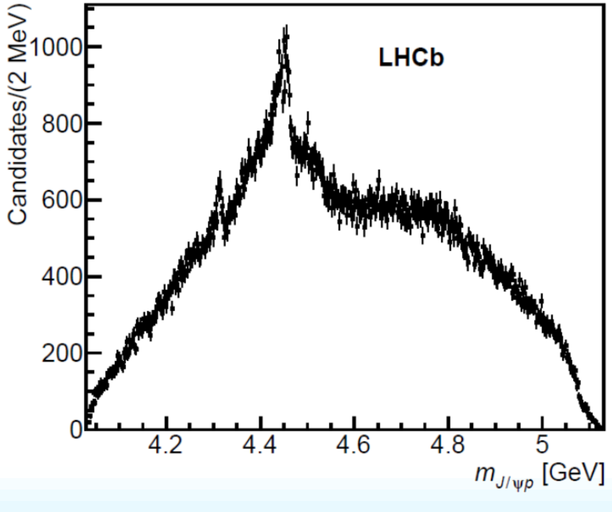


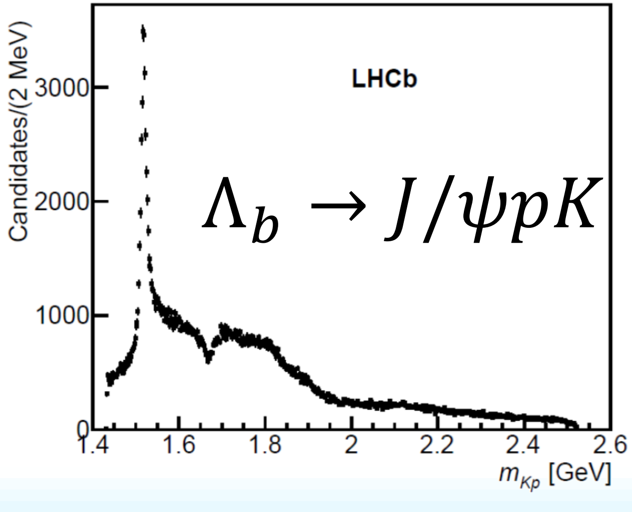




$\bar{D}\Sigma_c$ threshold: 4320 MeV
$\bar{D}^*\Sigma_c$ threshold: 4465 MeV

LHCb
PRL 115 (2015) 072001
1834 Citations
PRL 122 (2019) 222001
808 Citations





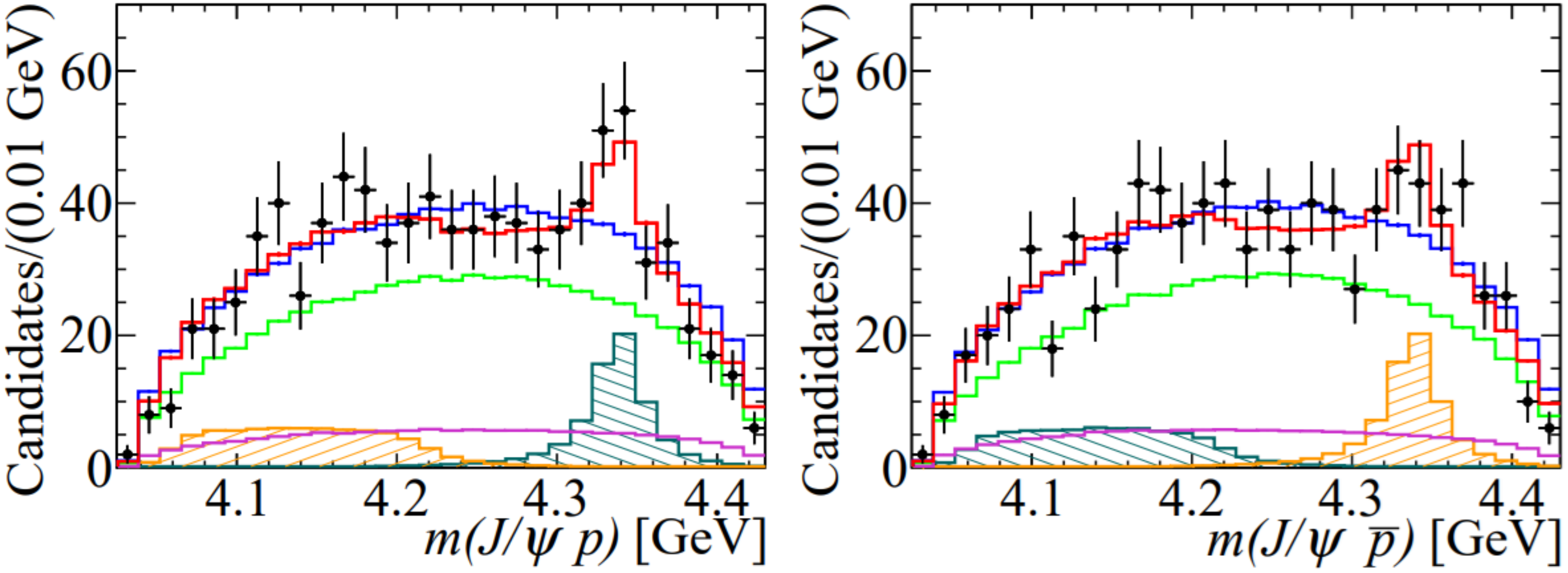
$\Lambda_b \to J/\psi p K$

Pc (4380)	$4380 \pm 8 \pm 29$	$205 \pm 18 \pm 86$
Pc (4450)	$4449.8 \pm 1.7 \pm 2.5$	$39 \pm 5 \pm 19$

Pc (4312)	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+3.7}_{-4.5}$
Pc (4440)	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+8.7}_{-10.5}$
Pc (4457)	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+5.7}_{-1.9}$

Unit: MeV

Introduction of P_c states



LHCb PRL 128 (2022) 6, 062001
112 Citations

$\bar{D}\Sigma_c$ threshold: 4320 MeV

$$M_{P_c} = 4337\ ^{+7}_{-4}\ ^{+2}_{-2}\ \text{MeV},$$
$$\Gamma_{P_c} = 29\ ^{+26}_{-12}\ ^{+14}_{-14}\ \text{MeV},$$

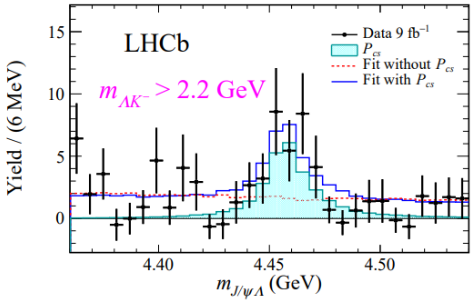
$3.1 - 3.7\sigma$

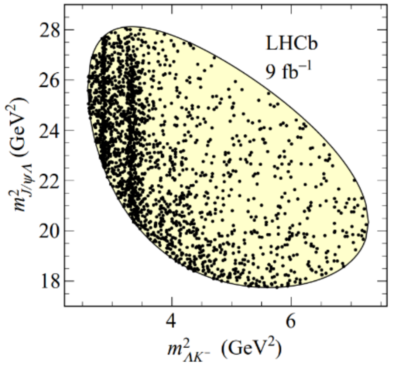
$B_s^0 \to J/\psi p\bar{p}$

Introduction of P_{cs} states

$P_{cs}(4459)$ $\Xi_b^- \to J/\psi\Lambda K^-$

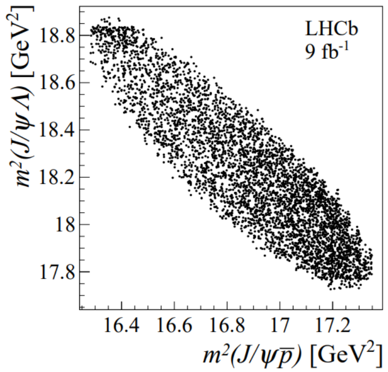
Sci.Bull. 66 (2021) 1278-1287 **246 Citations**

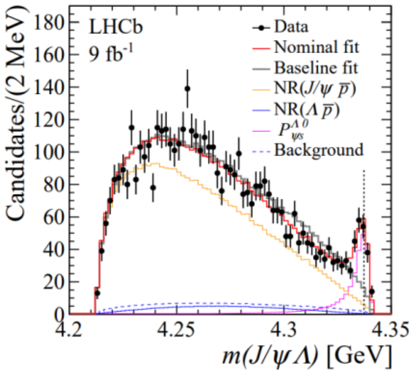




$P_{cs}(4338)$ $B^- \to J/\psi\Lambda\bar{p}$

PRL 131 (2023) 3, 031901 **136 Citations**





Mass $4458.8 \pm 2.9^{+4.7}_{-1.1}$ MeV

Width $17.3 \pm 6.5^{+8.0}_{-5.7}$ MeV

P $\sim 3\sigma$

Mass $4338.2 \pm 0.7 \pm 0.4$ MeV

Width $7.0 \pm 1.2 \pm 1.3$ MeV

$J^P = \frac{1}{2}^-$ P $> 15\sigma$

$\bar{D}\Xi_c$ threshold: 4335 MeV, $\bar{D}^*\Xi_c$ threshold: 4480 MeV

Introduction of P_{cs} states

1) Pcs(4338) -- $\bar{D}\Xi_c$,   &&   Pcs(4459)-- $\bar{D}^*\Xi_c$

QCD sum rule, X.-W. Wang and Z.-G. Wang,CPC 47, 013109 (2023)/2404.12146
K. Azizi, Y. Sarac, H. Sundu PRD 108 7, 074010 (2023)

Meson exchange, Wu, Molina, Oset and Zou, PRL 105, 232001， PRC 84, 015202 (2010)
L. Meng, B. Wang, and S.-L. Zhu, PRD 107 1, 0140(2023)
F.-L. Wang and X. Liu, PLB 835, 137583 (2022)
J.-T. Zhu, S.-Y. Kong, and J. He, PRD 107 3, 034029, (2023)
K. Chen, Z.-Y. Lin, and S.-L. Zhu, Phys.Rev.D 106 (2022) 11, 116017
Z.-Y. Yang, F.-Z. Peng, M.-J. Yan, M. Sanchez, and M. Pavon Valderrama, 2211.08211
C.-W. Xiao, J.-J. Wu, B.-S. Zou, PRD 103 5, 054016 (2021)
Qi Wu and Dian-Yong Chen, PRD 109 9, 094003 (2024)
M.-J. Yan, F.-Z. Peng, M. Sánchez, M. P. Valderrama, PRD 107 (2023) 7, 7 2207.11144

A constituent quark model, P. G. Ortega, D. R. Entem, and F. Fernandez, PLB 838, 137747 (2023)

Data-Driven Coupled-channel model PS. Nakamura, J.-J. Wuhys.Rev.D 108 (2023) 1, L011501

Triangle rescattering diagrams Yu-Kuo Hsiao,Shu-Ting Cai,and Yan-Li Wang,2409.04951

2) Pcs(4338) -- $\bar{D}^*\Xi_c$,   &&   Pcs(4459)-- $\bar{D}\Xi'_c$ A.Feijoo et al   PLB 839 (2023) 137760

3) Baryo-charmonia D. Germani, F. Niliani, A. D. Polosa Eur. Phys. J. C (2024) 84:755

4) MIT bag model W.-X. Zhang, C.-L. Liu and D.-j. Jia PRD 109 11, 114037 (2024)

5) Kinematic triangle-singularity T. J. Burns and E. S. Swanson, PLB 838, 137715 (2023)

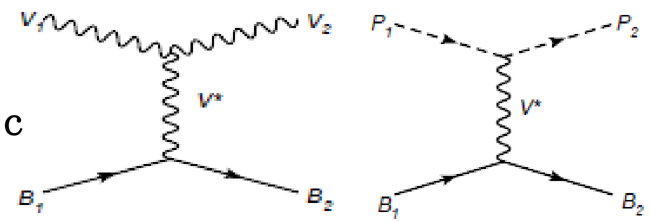
6) Magnetic moments to check the structure U.Ozdem, PLB 836, 137635 (2023)/ arXiv:2411.11442 [hep-ph] PLB 846 (2023) 138267

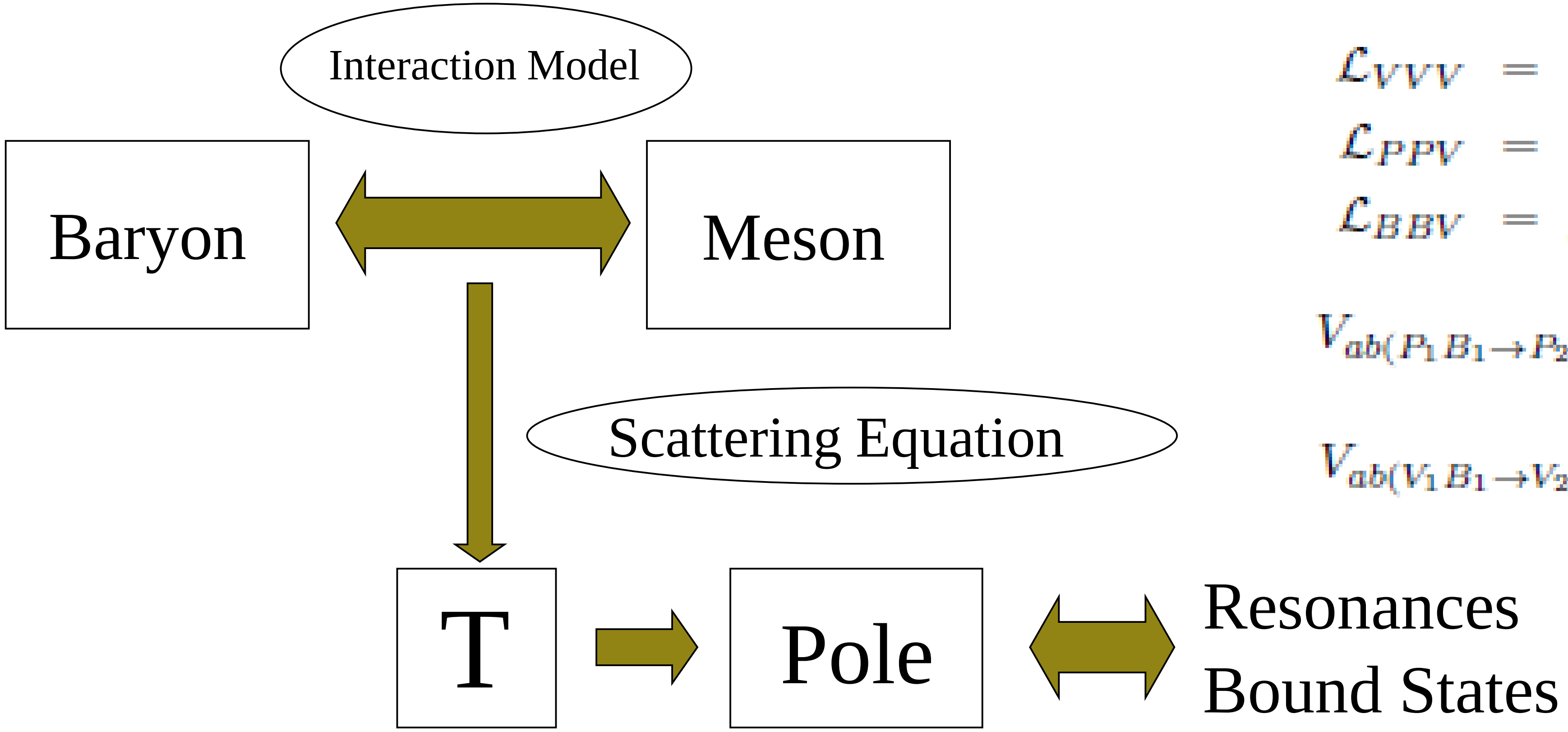
Coupled-channel model prediction

$\mathbf{J^P = 1/2^-}$

1) Molecular states: P_{cs} -- $\bar{D}\Xi_c$, $\bar{D}_s\Lambda_c$, $\bar{D}\Xi'_c$ $\bar{D}^*\Xi_c$, $\bar{D}_s^*\Lambda_c$, $\bar{D}^*\Xi'_c$

Wu, Molina, Oset and Zou, PRL 105, 232001， PRC 84, 015202 (2010)





$$\mathcal{L}_{VVV} = ig\langle V^\mu [V^\nu, \partial_\mu V_\nu]\rangle$$
$$\mathcal{L}_{PPV} = -ig\langle V^\mu [P, \partial_\mu P]\rangle$$
$$\mathcal{L}_{BBV} = g(\langle \bar{B}\gamma_\mu [V^\mu, B]\rangle + \langle \bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle)$$

$$V_{ab(P_1 B_1 \to P_2 B_2)} = \frac{C_{ab}}{4f^2}(E_{P_1} + E_{P_2}),$$
$$V_{ab(V_1 B_1 \to V_2 B_2)} = \frac{C_{ab}}{4f^2}(E_{V_1} + E_{V_2})\vec{\epsilon}_1 \cdot \vec{\epsilon}_2,$$

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

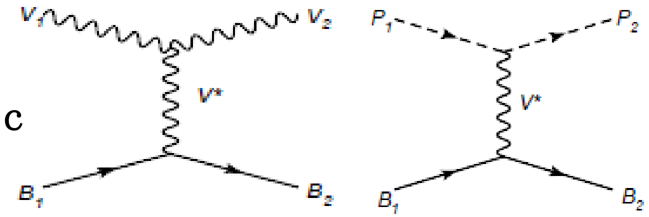
$$T_{ab} = \frac{g_a g_b}{\sqrt{s} - z_R}$$

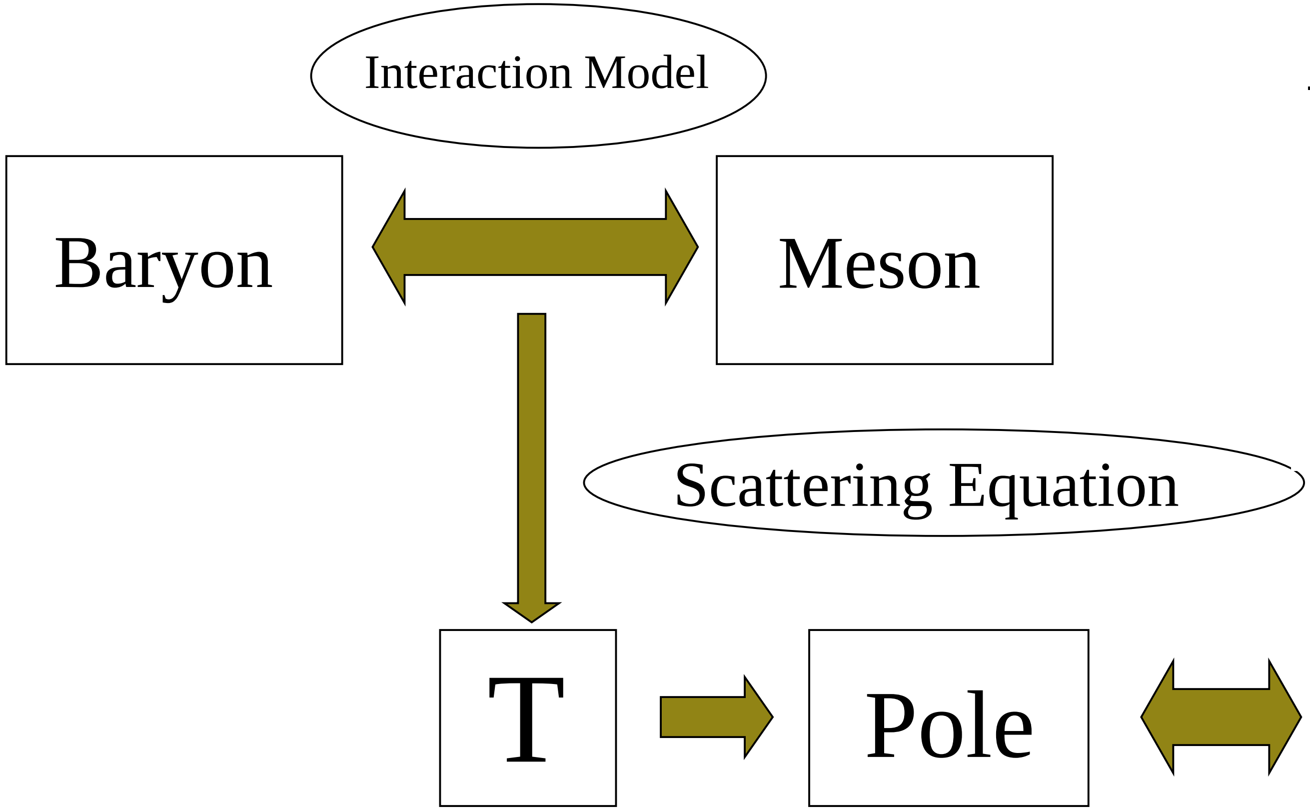
Coupled-channel model prediction

$J^P = 1/2^-$

1) Molecular states: P_{cs} -- $\bar{D}\Xi_c$, $\bar{D}_s\Lambda_c$, $\bar{D}\Xi'_c$ $\bar{D}^*\Xi_c$, $\bar{D}_s^*\Lambda_c$, $\bar{D}^*\Xi'_c$

Wu, Molina, Oset and Zou, PRL 105, 232001， PRC 84, 015202 (2010)





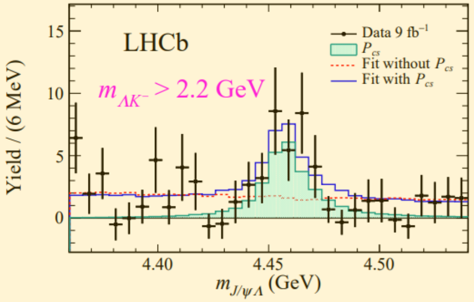
Resonances
Bound States

(I,S)	M	Γ	Γ_i					
$(0,-1)$			KN	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$
PB	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
$(0,-1)$			K^*N	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$
VB	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

Coupled-channel model prediction

$P_{cs}(4459)$ $\Xi_b^- \to J/\psi \Lambda K^-$

Sci.Bull. 66 (2021) 1278-1287 **246 Citations**



Mass $4458.8 \pm 2.9^{+4.7}_{-1.1}$ MeV

Width $17.3 \pm 6.5^{+8.0}_{-5.7}$ MeV

P $\sim 3\sigma$

Phys.Rev.D 103 (2021) 5, 054016

TABLE I. Potential matrix elements V_{ij} of Eq. (1) for the sector $J = 1/2, I = 0$.

$\eta_c\Lambda$	$J/\psi\Lambda$	$\bar{D}\Xi_c$	$\bar{D}_s\Lambda_c$	$\bar{D}\Xi_c'$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}^*\Xi_c^*$
μ_1	0	$-\frac{1}{2}\mu_{12}$	$-\frac{1}{2}\mu_{13}$	$\frac{1}{2}\mu_{14}$	$\frac{\sqrt{3}}{2}\mu_{12}$	$\frac{\sqrt{3}}{2}\mu_{13}$	$\frac{1}{2\sqrt{3}}\mu_{14}$	$\sqrt{\frac{2}{3}}\mu_{14}$
	μ_1	$\frac{\sqrt{3}}{2}\mu_{12}$	$\frac{\sqrt{3}}{2}\mu_{13}$	$\frac{1}{2\sqrt{3}}\mu_{14}$	$\frac{1}{2}\mu_{12}$	$\frac{1}{2}\mu_{13}$	$\frac{5}{6}\mu_{14}$	$-\frac{\sqrt{2}}{3}\mu_{14}$
		μ_2	μ_{23}	0	0	0	$\frac{1}{\sqrt{3}}\mu_{24}$	$-\sqrt{\frac{2}{3}}\mu_{24}$
			μ_3	0	0	0	$\frac{1}{\sqrt{3}}\mu_{34}$	$-\sqrt{\frac{2}{3}}\mu_{34}$
				$\frac{1}{3}(2\lambda+\mu_4)$	$\frac{1}{\sqrt{3}}\mu_{24}$	$\frac{1}{\sqrt{3}}\mu_{34}$	$-\frac{2}{3\sqrt{3}}(\lambda-\mu_4)$	$\frac{1}{3}\sqrt{\frac{2}{3}}(\mu_4-\lambda)$
					μ_2	μ_{23}	$\frac{2}{3}\mu_{24}$	$\frac{\sqrt{2}}{3}\mu_{24}$
						μ_3	$\frac{2}{3}\mu_{34}$	$\frac{\sqrt{2}}{3}\mu_{34}$
							$\frac{1}{9}(2\lambda+7\mu_4)$	$\frac{\sqrt{2}}{9}(\lambda-\mu_4)$
								$\frac{1}{9}(\lambda+8\mu_4)$

TABLE II. Potential matrix elements V_{ij} of Eq. (1) for the sector $J = 3/2, I = 0$.

$J/\psi\Lambda$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}\Xi_c^*$	$\bar{D}^*\Xi_c^*$
μ_1	μ_{12}	μ_{13}	$-\frac{1}{3}\mu_{14}$	$\frac{1}{\sqrt{3}}\mu_{14}$	$\frac{\sqrt{5}}{3}\mu_{14}$
	μ_2	μ_{23}	$-\frac{1}{3}\mu_{24}$	$\frac{1}{\sqrt{3}}\mu_{24}$	$\frac{\sqrt{5}}{3}\mu_{24}$
		μ_3	$-\frac{1}{3}\mu_{34}$	$\frac{1}{\sqrt{3}}\mu_{34}$	$\frac{\sqrt{5}}{3}\mu_{34}$
			$\frac{1}{9}(8\lambda+\mu_4)$	$\frac{1}{3\sqrt{3}}(\lambda-\mu_4)$	$\frac{\sqrt{5}}{9}(\lambda-\mu_4)$
				$\frac{1}{3}(2\lambda+\mu_4)$	$\frac{1}{3}\sqrt{\frac{5}{3}}(\mu_4-\lambda)$
					$\frac{1}{9}(4\lambda+5\mu_4)$

$$\mu_1 = \mu_3 = \mu_{24} = \mu_{34} = 0, \qquad \mu_2 = \mu_{23}/\sqrt{2} = \mu_4 = \lambda = -F, \quad F = \frac{1}{4f^2}(p^0 + p'^0),$$

$$\mu_{12} = -\mu_{13}/\sqrt{2} = \mu_{14}/\sqrt{3} = -\sqrt{\frac{2}{3}\frac{m_V^2}{m_{D^*}^2}}F,$$

Coupled-channel model prediction

TABLE I. Potential matrix elements V_{ij} of Eq. (1) for the sector $J=1/2, I=0$.

$\eta_c\Lambda$	$J/\psi\Lambda$	$\bar{D}\Xi_c$	$\bar{D}_s\Lambda_c$	$\bar{D}\Xi_c'$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}^*\Xi_c^*$
0	0	$\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{2}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$
	0	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{5\sqrt{2}}{6}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{3}\frac{m_V^2}{m_{D^*}^2}F$
		$-F$	$-\sqrt{2}F$	0	0	0	0	0
			0	0	0	0	0	0
				$-F$	0	0	0	0
					$-F$	$-\sqrt{2}F$	0	0
						0	0	0
							$-F$	0
								$-F$

Decay

Attractive potential

TABLE II. Potential matrix elements V_{ij} of Eq. (1) for the sector $J=3/2, I=0$.

$J/\psi\Lambda$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}\Xi_c^*$	$\bar{D}^*\Xi_c^*$
0	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{\sqrt{2}}{3}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{10}}{3}\frac{m_V^2}{m_{D^*}^2}F$
	$-F$	$-\sqrt{2}F$	0	0	0
		0	0	0	0
			$-F$	0	0
				$-F$	0
					$-F$

Phys.Rev.D 103 (2021) 5, 054016

$$F=\frac{1}{4f^2}(p^0+p'^0).$$

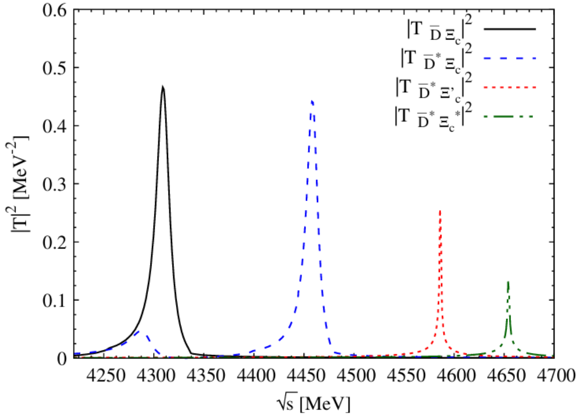
Coupled-channel model prediction

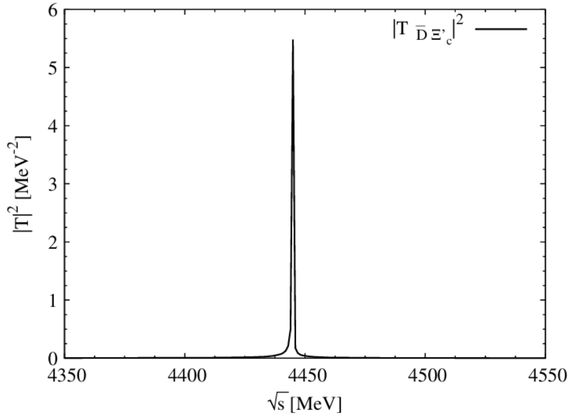
TABLE I. Potential matrix elements V_{ij} of Eq. (1) for the sector $J = 1/2, I = 0$.

$\eta_c\Lambda$	$J/\psi\Lambda$	$\bar{D}\Xi_c$	$\bar{D}_s\Lambda_c$	$\bar{D}\Xi_c'$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}^*\Xi_c^*$
0	0	$\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{2}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$
	0	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{5\sqrt{2}}{6}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{3}\frac{m_V^2}{m_{D^*}^2}F$
		$-F$	$-\sqrt{2}F$	0	0	0	0	0
			0	0	0	0	0	0
				$-F$	0	0	0	0
					$-F$	$-\sqrt{2}F$	0	0
						0	0	0
							$-F$	0
								$-F$

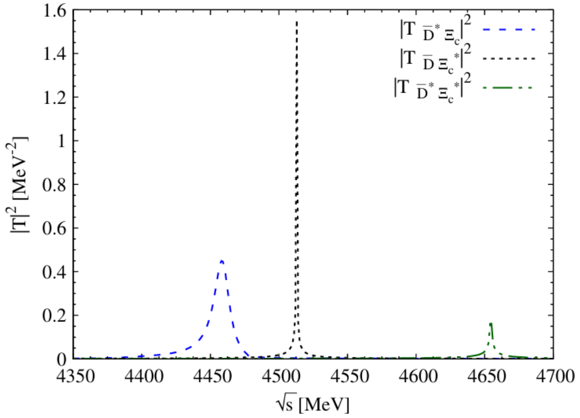
TABLE II. Potential matrix elements V_{ij} of Eq. (1) for the sector $J = 3/2, I = 0$.

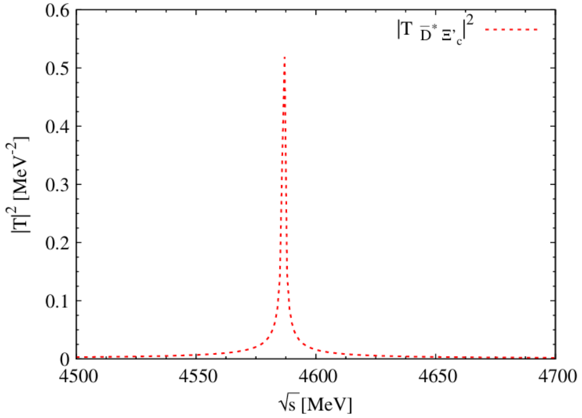
$J/\psi\Lambda$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}\Xi_c^*$	$\bar{D}^*\Xi_c^*$
0	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{\sqrt{2}}{3}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{10}}{3}\frac{m_V^2}{m_{D^*}^2}F$
	$-F$	$-\sqrt{2}F$	0	0	0
		0	0	0	0
			$-F$	0	0
				$-F$	0
					$-F$





J=1/2 I=0





J=3/2 I=0

Phys.Rev.D 103 (2021) 5, 054016

Coupled-channel model prediction

TABLE I. Potential matrix elements V_{ij} of Eq. (1) for the sector $J = 1/2, I = 0$.

$\eta_c\Lambda$	$J/\psi\Lambda$	$\bar{D}\Xi_c$	$\bar{D}_s\Lambda_c$	$\bar{D}\Xi_c'$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}^*\Xi_c^*$
0	0	$\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{2}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$
	0	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{5\sqrt{2}}{6}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{3}\frac{m_V^2}{m_{D^*}^2}F$
		$-F$	$-\sqrt{2}F$	0	0	0	0	0
			0	0	0	0	0	0
				$-F$	0	0	0	0
					$-F$	$-\sqrt{2}F$	0	0
						0	0	0
							[illegible]	0
								[illegible]

J=1/2 I=0

TABLE II. Potential matrix elements V_{ij} of Eq. (1) for the sector $J = 3/2, I = 0$.

$J/\psi\Lambda$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}\Xi_c^*$	$\bar{D}^*\Xi_c^*$
0	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{\sqrt{2}}{3}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{10}}{3}\frac{m_V^2}{m_{D^*}^2}F$
	$-F$	$-\sqrt{2}F$	0	0	0
		0	0	0	0
			[illegible]	0	0
				[illegible]	0
					[illegible]

J=3/2 I=0

TABLE III. Coupling constants to all channels for certain poles in the sector $J = 1/2, I = 0$.

Chan.	$\eta_c\Lambda$	$J/\psi\Lambda$	$\bar{D}\Xi_c$	$\bar{D}_s\Lambda_c$	$\bar{D}\Xi_c'$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}^*\Xi_c^*$
Thres.	4099.58	4212.58	4366.61	4254.80	4445.34	4477.92	4398.66	4586.66	4654.48
$4310.53 + i8.23$									
$\|g_i\|$	0.15	0.27	**2.33**	0.69	0.00	0.04	0.09	0.01	0.02
Γ_i	0.57	1.18	···	13.86	···	···	···	···	···
Br.	3.47%	7.16%	···	84.21%	···	···	···	···	···
$4445.12 + i0.19$									
$\|g_i\|$	0.10	0.06	0.00	0.00	**0.72**	0.08	0.04	0.01	0.01
Γ_i	0.29	0.08	0.00	0.00	···	···	0.04	···	···
Br.	74.74%	21.22%	0.01%	0.01%	···	···	10.62%	···	···
$4459.07 + i6.89$									
$\|g_i\|$	0.22	0.13	0.00	0.00	0.07	**2.16**	0.61	0.03	0.02
Γ_i	1.59	0.46	0.00	0.00	0.01	···	11.14	···	···
Br.	11.57%	3.31%	0.00%	0.00%	0.70%	···	80.86%	···	···
4586.66?									
$\|g_i\|$	···	···	···	···	···	···	···	···	···
4654.48?									
$\|g_i\|$	···	···	···	···	···	···	···	···	···

TABLE IV. Coupling constants to all channels for certain poles in the sector $J = 3/2, I = 0$.

Chan.	$J/\psi\Lambda$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}\Xi_c^*$	$\bar{D}^*\Xi_c^*$
Thres.	4212.58	4477.92	4398.66	4586.66	4513.17	4654.48
$4459.02 + i6.83$						
$\|g_i\|$	0.28	**2.16**	0.61	0.02	0.04	0.03
Γ_i	2.00	···	11.15	···	···	···
Br.	14.68%	···	81.64%	···	···	···
4586.66?						
$\|g_i\|$	···	···	···	···	···	···
4513.17?						
$\|g_i\|$	···	···	···	···	···	···
4654.48?						
$\|g_i\|$	···	···	···	···	···	···

Phys.Rev.D 103 (2021) 5, 054016

Coupled-channel model prediction

TABLE I. Potential matrix elements V_{ij} of Eq. (1) for the sector $J=1/2, I=0$.

$\eta_c\Lambda$	$J/\psi\Lambda$	$\bar{D}\Xi_c$	$\bar{D}_s\Lambda_c$	$\bar{D}\Xi_c'$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}^*\Xi_c^*$
0	0	$\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{2}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$
	0	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{5\sqrt{2}}{6}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{3}\frac{m_V^2}{m_{D^*}^2}F$
		$-F$	$-\sqrt{2}F$	0	0	0	0	0
			0	0	0	0	0	0
				$-F$	0	0	0	0
					$-F$	$-\sqrt{2}F$	0	0
						0	0	0
							[illegible]	0
								[illegible]

4310

4445

4459

J=1/2 I=0

TABLE II. Potential matrix elements V_{ij} of Eq. (1) for the sector $J=3/2, I=0$.

$J/\psi\Lambda$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}\Xi_c^*$	$\bar{D}^*\Xi_c^*$
0	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{\sqrt{2}}{3}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{10}}{3}\frac{m_V^2}{m_{D^*}^2}F$
	$-F$	$-\sqrt{2}F$	0	0	0
		0	0	0	0
			[illegible]	0	0
				[illegible]	0
					[illegible]

4459

J=3/2 I=0

TABLE III. Coupling constants to all channels for certain poles in the sector $J=1/2, I=0$.

Chan. / Thres.	$\eta_c\Lambda$ 4099.58	$J/\psi\Lambda$ 4212.58	$\bar{D}\Xi_c$ 4366.61	$\bar{D}_s\Lambda_c$ 4254.80	$\bar{D}\Xi_c'$ 4445.34	$\bar{D}^*\Xi_c$ 4477.92	$\bar{D}_s^*\Lambda_c$ 4398.66	$\bar{D}^*\Xi_c'$ 4586.66	$\bar{D}^*\Xi_c^*$ 4654.48
$4310.53+i8.23$									
$\lvert g_i\rvert$	0.15	0.27	**2.33**	0.69	0.00	0.04	0.09	0.01	0.02
Γ_i	0.57	1.18	...	13.86	...	...	...	...	...
Br.	3.47%	7.16%	...	84.21%	...	...	...	...	...
$4445.12+i0.19$									
$\lvert g_i\rvert$	0.10	0.06	0.00	0.00	**0.72**	0.08	0.04	0.01	0.01
Γ_i	0.29	0.08	0.00	0.00	...	...	0.04	...	...
Br.	74.74%	21.22%	0.01%	0.01%	...	...	10.62%	...	...
$4459.07+i6.89$									
$\lvert g_i\rvert$	0.22	0.13	0.00	0.00	0.07	**2.16**	0.61	0.03	0.02
Γ_i	1.59	0.46	0.00	0.00	0.01	...	11.14	...	...
Br.	11.57%	3.31%	0.00%	0.00%	0.70%	...	80.86%	...	...
4586.66?									
$\lvert g_i\rvert$	...	...	...	...	...	...	...	...	...
4654.48?									
$\lvert g_i\rvert$	...	...	...	...	...	...	...	...	...

TABLE IV. Coupling constants to all channels for certain poles in the sector $J=3/2, I=0$.

Chan. / Thres.	$J/\psi\Lambda$ 4212.58	$\bar{D}^*\Xi_c$ 4477.92	$\bar{D}_s^*\Lambda_c$ 4398.66	$\bar{D}^*\Xi_c'$ 4586.66	$\bar{D}\Xi_c^*$ 4513.17	$\bar{D}^*\Xi_c^*$ 4654.48
$4459.02+i6.83$						
$\lvert g_i\rvert$	0.28	**2.16**	0.61	0.02	0.04	0.03
Γ_i	2.00	...	11.15	...	...	...
Br.	14.68%	...	81.64%	...	...	...
4586.66?						
$\lvert g_i\rvert$	...	...	...	...	...	...
4513.17?						
$\lvert g_i\rvert$	...	...	...	...	...	...
4654.48?						
$\lvert g_i\rvert$	...	...	...	...	...	...

Phys.Rev.D 103 (2021) 5, 054016

Coupled-channel model prediction

TABLE I. Potential matrix elements V_{ij} of Eq. (1) for the sector $J = 1/2, I = 0$.

$\eta_c\Lambda$	$J/\psi\Lambda$	$\bar{D}\Xi_c$	$\bar{D}_s\Lambda_c$	$\bar{D}\Xi_c'$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}^*\Xi_c^*$
0	0	$\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{1}{2}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$
	0	$-\frac{\sqrt{2}}{2}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{1}{2}\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\sqrt{\frac{1}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{5\sqrt{2}}{6}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{3}\frac{m_V^2}{m_{D^*}^2}F$
		$-F$	$-\sqrt{2}F$	0	0	0	0	0
			0	0	0	0	0	0
				$-F$	0	0	0	0
					$-F$	$-\sqrt{2}F$	0	0
						0	0	0
							[illegible]	0
								[illegible]

4310

4445

4459

J=1/2 I=0

TABLE II. Potential matrix elements V_{ij} of Eq. (1) for the sector $J = 3/2, I = 0$.

$J/\psi\Lambda$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}\Xi_c^*$	$\bar{D}^*\Xi_c^*$
0	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{2}{\sqrt{3}}\frac{m_V^2}{m_{D^*}^2}F$	$\frac{\sqrt{2}}{3}\frac{m_V^2}{m_{D^*}^2}F$	$-\sqrt{\frac{2}{3}}\frac{m_V^2}{m_{D^*}^2}F$	$-\frac{\sqrt{10}}{3}\frac{m_V^2}{m_{D^*}^2}F$
	$-F$	$-\sqrt{2}F$	0	0	0
		0	0	0	0
			[illegible]	0	0
				[illegible]	0
					[illegible]

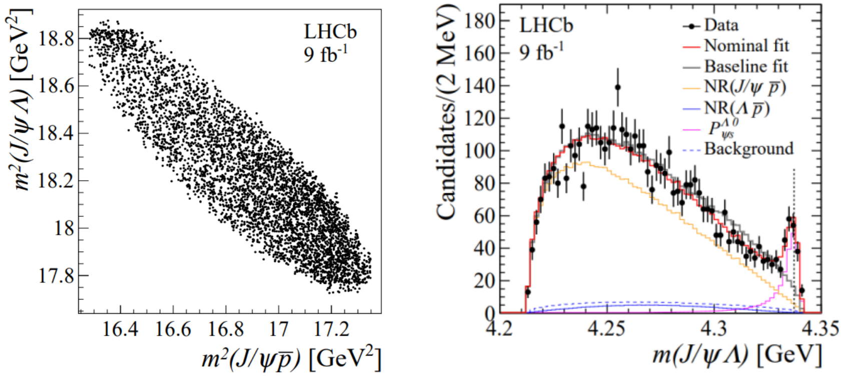
4459

J=3/2 I=0

Phys.Rev.D 103 (2021) 5, 054016

$P_{cs}(4338)$ $\quad B^- \to J/\psi\Lambda\bar{p}$

PRL 131 (2023) 3, 031901 **136 Citations**



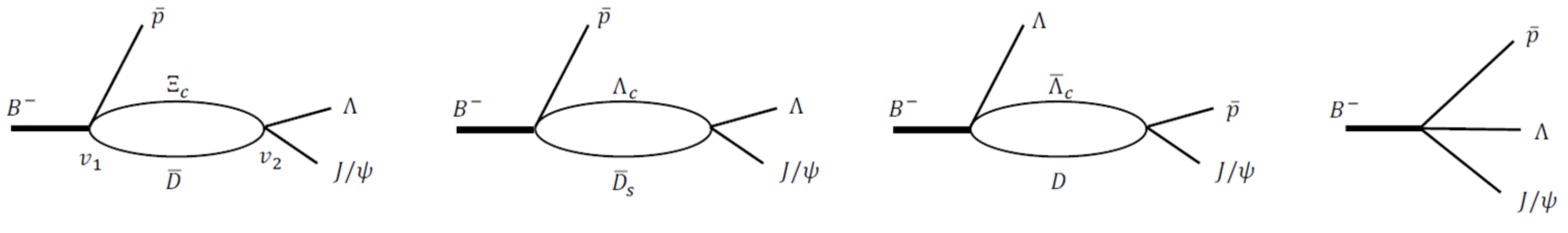
Mass $\quad 4338.2 \pm 0.7 \pm 0.4$ MeV

Width $\quad 7.0 \pm 1.2 \pm 1.3$ MeV

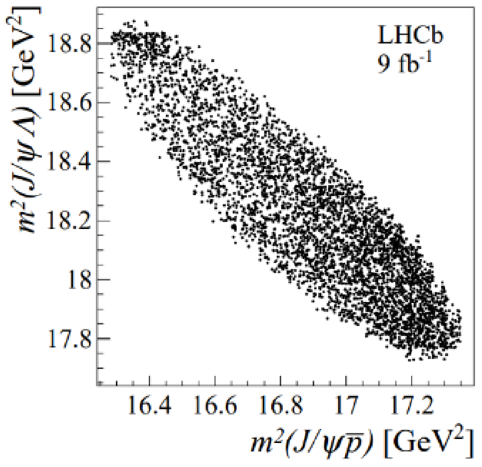
$J^P = \frac{1}{2}^-$ $\qquad$ P > 15σ

Data-driven analysis of $B^- \to J/\psi \Lambda \bar{P}$

S. Nakamura, J.J. Wu PRD 108 (2023) 9, L011501



(a) (b) (c) (d)



Vertex

$$v_1 = c^{1/2^-}_{\Xi_c \bar{D} \bar{p}, B^-} \langle t_{\bar{D}} t^z_{\bar{D}} t_{\Xi_c} t^z_{\Xi_c} | 00 \rangle f^0_{\Xi_c \bar{D}} F^0_{\bar{p} B^-} \quad f^L_{ij} = \frac{(1+q^2_{ij}/\Lambda^2)^{-2-\frac{L}{2}}}{\sqrt{E_i E_j}}, F^L_{kl} = \frac{(1+\tilde{p}^2_k/\Lambda^2)^{-2-\frac{L}{2}}}{\sqrt{E_k E_l}},$$

$$v_2 = h_{\gamma,\alpha} \langle t_{\alpha 1} t^z_{\alpha 1} t_{\alpha 2} t^z_{\alpha 2} | T T^z \rangle \, \boldsymbol{\sigma} \cdot \boldsymbol{\epsilon}_\psi \, f^0_\gamma Y_{00} \, f^0_\alpha Y_{00}$$

Coupled-channel effect

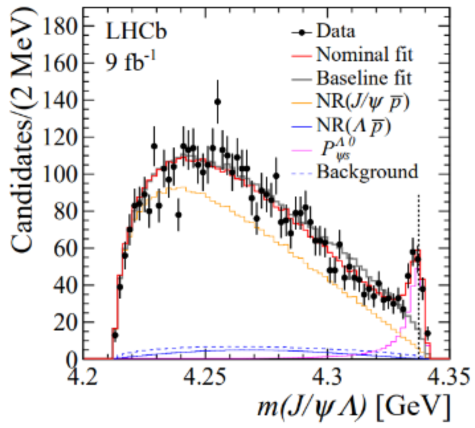
$$\sigma_\alpha(E) = \sum_{t^z} \int dq q^2 \frac{\langle t_{\alpha 1} t^z_{\alpha 1} t_{\alpha 2} t^z_{\alpha 2} | T T^z \rangle^2 \left[f^0_\alpha(q) \right]^2}{E - E_{\alpha 1}(q) - E_{\alpha 2}(q) + i\varepsilon} \quad [G^{-1}(E)]_{\beta\alpha} = \delta_{\beta\alpha} - h_{\beta,\alpha} \sigma_\alpha(E)$$

Amplitude

$$A^{\rm loop}_{\psi\Lambda(1/2^-)} = \sum_{\alpha,\beta}^{\Xi_c \bar{D}, \Lambda_c \bar{D}_s} h_{\psi\Lambda,\beta} \, c^{1/2^-}_{\alpha \bar{p}, B^-} \, \boldsymbol{\sigma} \cdot \boldsymbol{\epsilon}_\psi \, f^0_{\psi\Lambda}(p_\psi) \, \sigma_\beta(M_{\psi\Lambda}) \, G_{\beta\alpha}(M_{\psi\Lambda}) F^0_{\bar{p} B^-} \,,$$

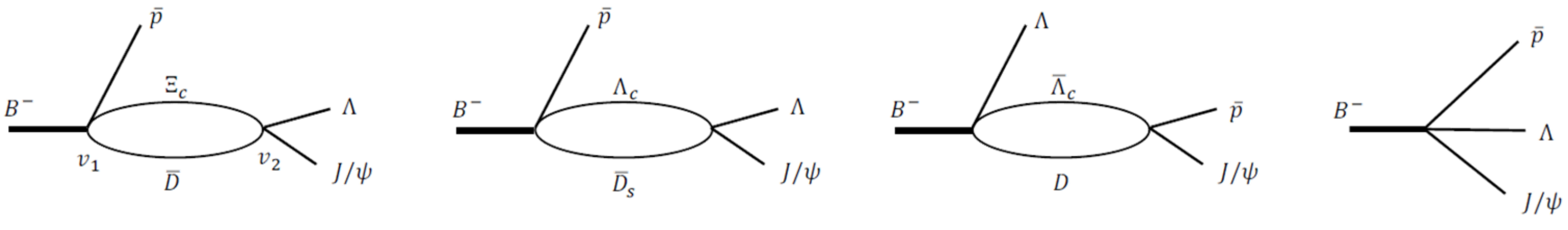
$$A^{\rm loop}_{\psi\bar{p}(1/2^+)} = h_{\psi\bar{p}, \bar{\Lambda}_c D} \, c^{1/2^+}_{\bar{\Lambda}_c D \Lambda, B^-} \, \boldsymbol{\sigma} \cdot \boldsymbol{\epsilon}_\psi \, f^0_{\psi\bar{p}}(p_\psi) \, \sigma_{\bar{\Lambda}_c D}(M_{\psi\bar{p}}) \, G_{\bar{\Lambda}_c D, \bar{\Lambda}_c D}(M_{\psi\bar{p}}) F^0_{\Lambda B^-} \,.$$

$$A^{\rm dir}_{\psi\bar{p}(1/2^+)} = c^{1/2^+}_{\psi\bar{p}\Lambda, B^-} \boldsymbol{\sigma} \cdot \boldsymbol{\epsilon}_\psi \, f^0_{\psi\bar{p}} F^0_{\Lambda B^-}$$



Data-driven analysis of $B^- \to J/\psi \Lambda \bar{P}$

S. Nakamura, J.J. Wu PRD 108 (2023) 9, L011501



(a) (b) (c) (d)

Vertex

$$v_1 = c^{1/2^-}_{\Xi_c \bar{D}\bar{p},B^-} \langle t_{\bar{D}} t^z_{\bar{D}} t_{\Xi_c} t^z_{\Xi_c} | 00 \rangle f^0_{\Xi_c \bar{D}} F^0_{\bar{p}B^-} \quad f^L_{ij} = \frac{(1+q^2_{ij}/\Lambda^2)^{-2-\frac{L}{2}}}{\sqrt{E_i E_j}}, F^L_{kl} = \frac{(1+\tilde{p}^2_k/\Lambda^2)^{-2-\frac{L}{2}}}{\sqrt{E_k E_l}},$$

$$v_2 = h_{\gamma,\alpha} \langle t_{\alpha 1} t^z_{\alpha 1} t_{\alpha 2} t^z_{\alpha 2} | T T^z \rangle \, \boldsymbol{\sigma} \cdot \boldsymbol{\epsilon}_\psi \, f^0_\gamma Y_{00} \, f^0_\alpha Y_{00}$$

Coupled-channel effect

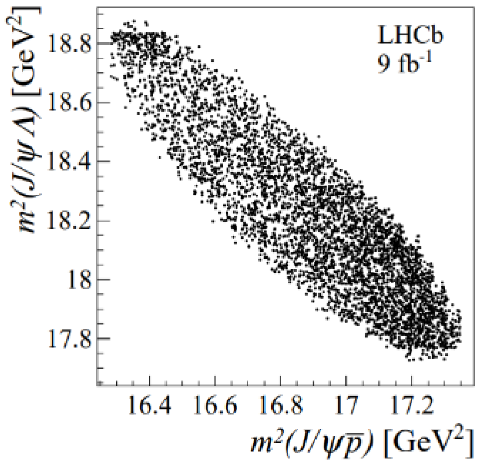
$$\sigma_\alpha(E) = \sum_{t^z} \int dq q^2 \frac{\langle t_{\alpha 1} t^z_{\alpha 1} t_{\alpha 2} t^z_{\alpha 2} | T T^z \rangle^2 \, [f^0_\alpha(q)]^2}{E - E_{\alpha 1}(q) - E_{\alpha 2}(q) + i\varepsilon} \quad [G^{-1}(E)]_{\beta\alpha} = \delta_{\beta\alpha} - h_{\beta,\alpha}\sigma_\alpha(E)$$

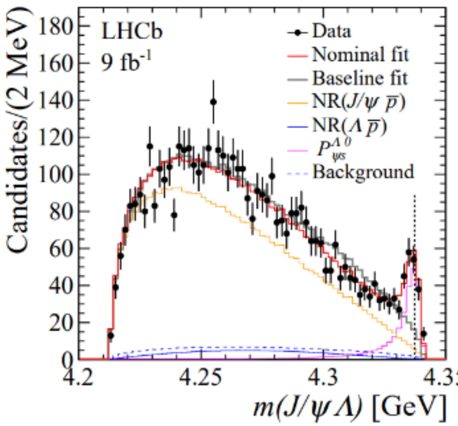
Amplitude

$$A^{\rm loop}_{\psi\Lambda(1/2^-)} = \sum_{\alpha,\beta}^{\Xi_c\bar{D},\Lambda_c\bar{D}_s} h_{\psi\Lambda,\beta} \, c^{1/2^-}_{\alpha\bar{p},B^-} \, \boldsymbol{\sigma} \cdot \boldsymbol{\epsilon}_\psi \, f^0_{\psi\Lambda}(p_\psi) \, \sigma_\beta(M_{\psi\Lambda}) \, G_{\beta\alpha}(M_{\psi\Lambda}) F^0_{\bar{p}B^-} \, ,$$

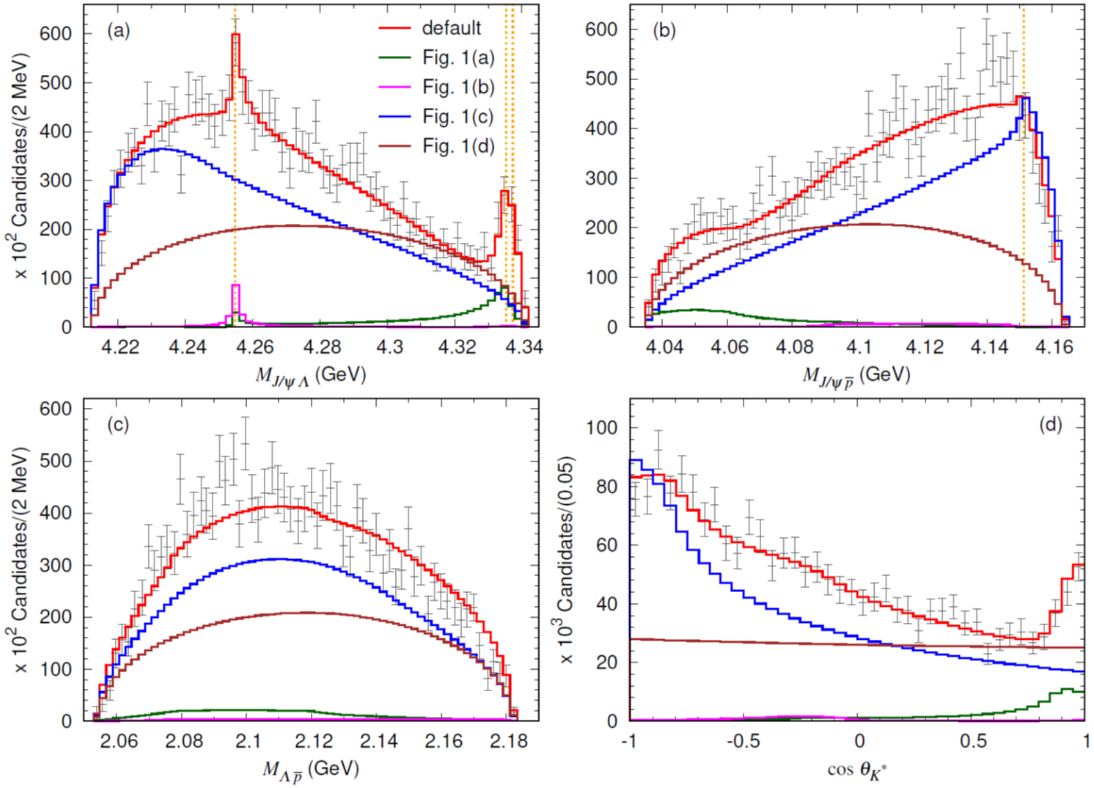
$$A^{\rm loop}_{\psi\bar{p}(1/2^+)} = h_{\psi\bar{p},\bar{\Lambda}_c D} \, c^{1/2^+}_{\bar{\Lambda}_c D \Lambda, B^-} \, \boldsymbol{\sigma} \cdot \boldsymbol{\epsilon}_\psi \, f^0_{\psi\bar{p}}(p_\psi) \, \sigma_{\bar{\Lambda}_c D}(M_{\psi\bar{p}}) \, G_{\bar{\Lambda}_c D, \bar{\Lambda}_c D}(M_{\psi\bar{p}}) F^0_{\Lambda B^-} \, .$$

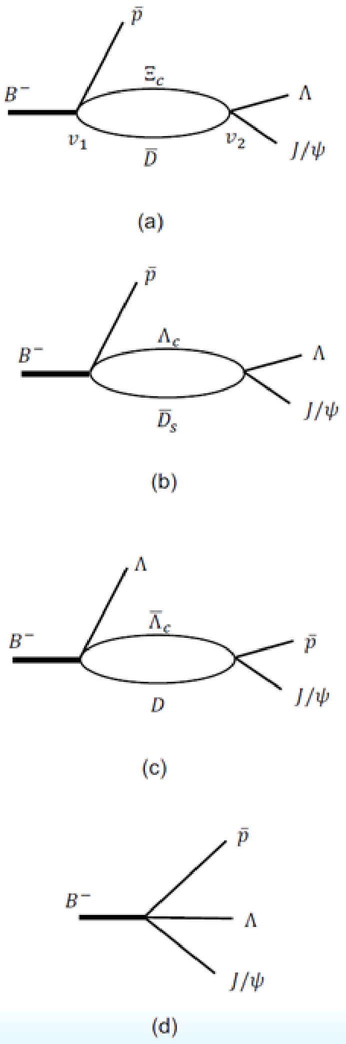
$$A^{\rm dir}_{\psi\bar{p}(1/2^+)} = c^{1/2^+}_{\psi\bar{p}\Lambda,B^-} \boldsymbol{\sigma} \cdot \boldsymbol{\epsilon}_\psi \, f^0_{\psi\bar{p}} F^0_{\Lambda B^-}$$

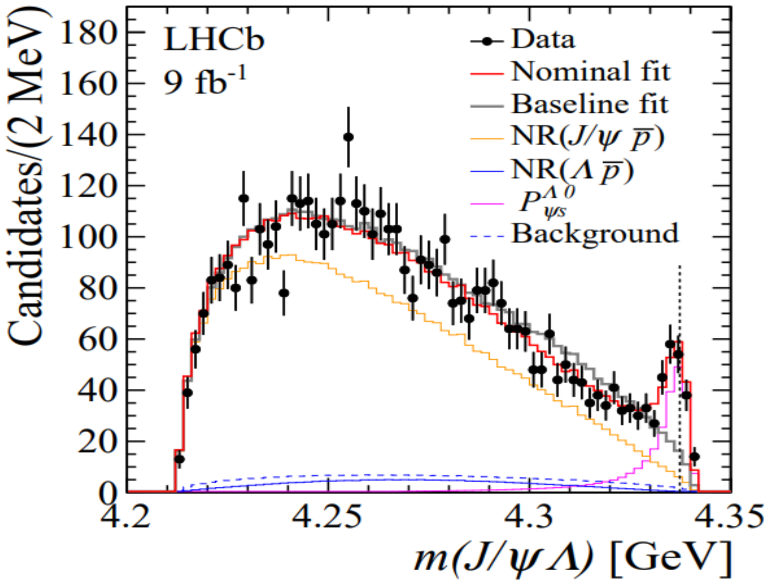




Data-driven analysis of $B^- \to J/\psi\Lambda\bar{P}$







Figs(a/b) for peak while Figs(c/d) for over all,

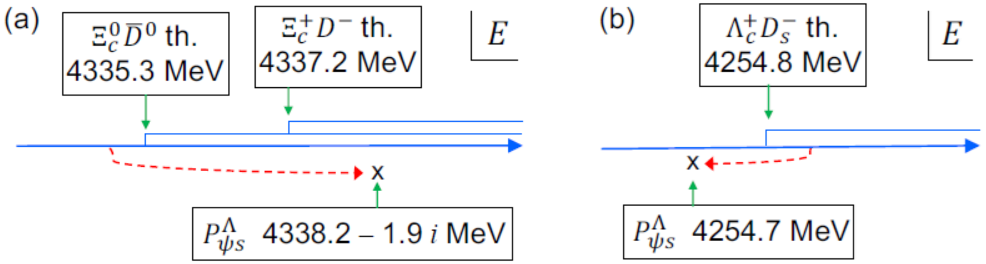
a. $\Xi_c\bar{D}$ color suppress
b. $\Lambda_c\bar{D}_s$, $\Lambda_c\bar{D}_s \to J/\psi\Lambda$ exchange D_s
c. $\bar{\Lambda}_c D$, $\bar{\Lambda}_c D \to J/\psi\bar{p}$ exchange D
d. color suppress but no loop

1. Our: USE Coupled-channel model，
LHCb: use BW model

2. Our: $NR(J/\psi\bar{p})$ dominated by S-wave,
LHCb: $NR(J/\psi\bar{p})$ dominated by P-wave，
While the Q~130MeV

3. Our: 9 parameters LHCb: 16 parameters

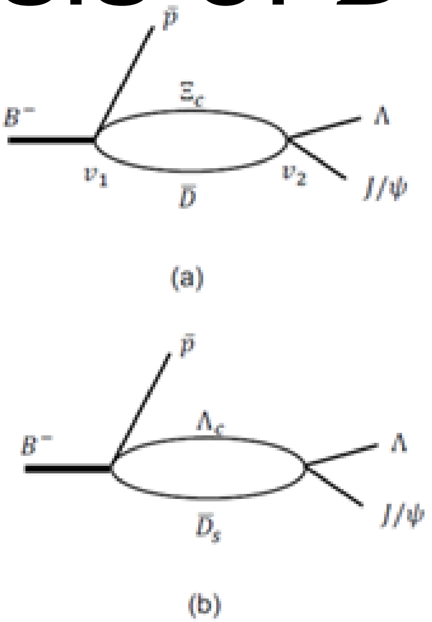
Data-driven analysis of $B^- \to J/\psi \Lambda \bar{P}$

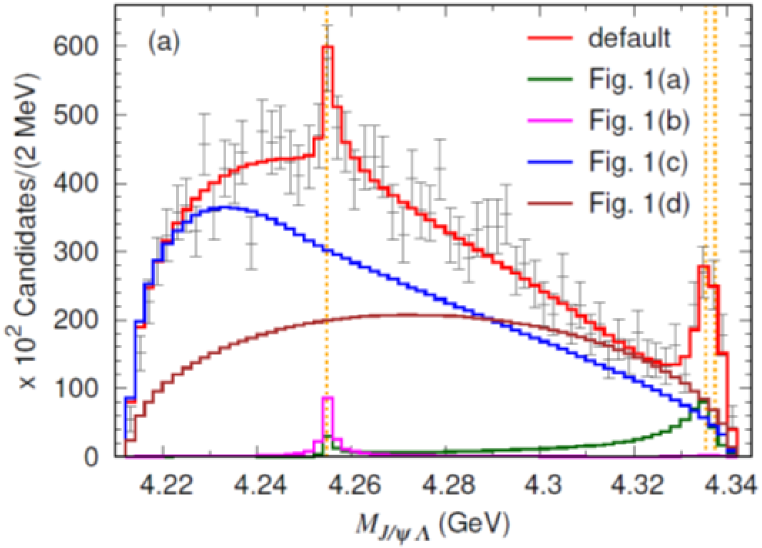


(I)	$P_{\psi s}^{\Lambda}(4338)$	$(4338.2 \pm 1.4) - (1.9 \pm 0.5)\,i$	(upp)
	$P_{\psi s}^{\Lambda}(4255)$	4254.7 ± 0.4	(upp)

All poles are obtained dynamically, not by hand

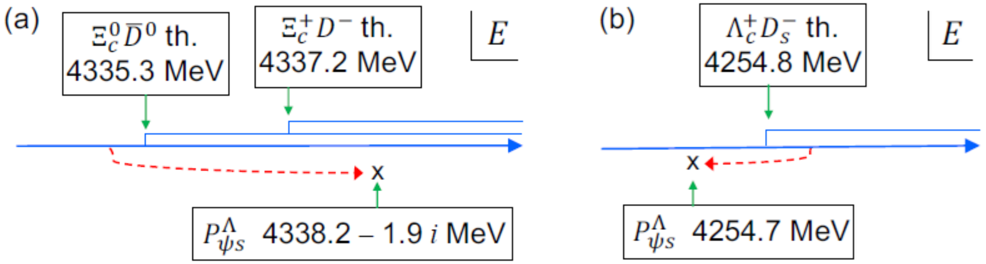
$P_{cs}(4338)$ is a resonance $P_{cs}(4254)$ is a virtual state





University of Chinese Academy of Sciences

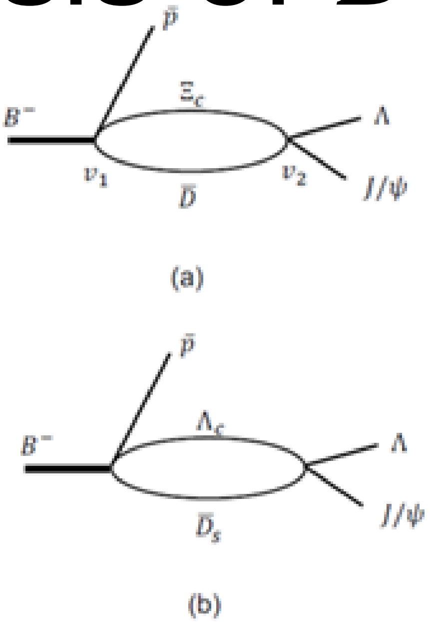
Data-driven analysis of $B^- \to J/\psi \Lambda \bar{P}$

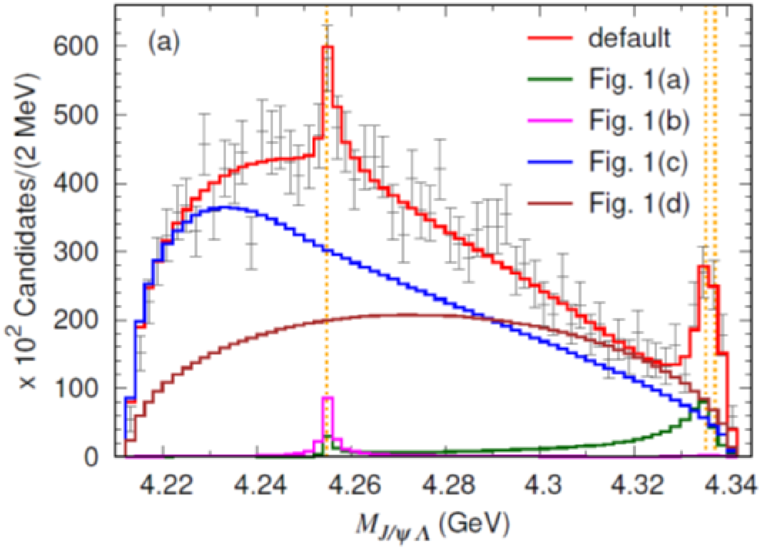


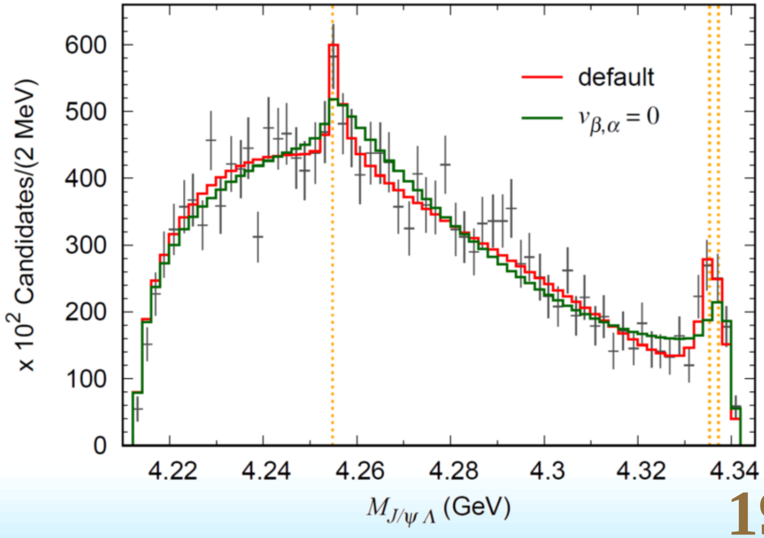
(I) $P_{\psi s}^{\Lambda}(4338)$	$(4338.2 \pm 1.4) - (1.9 \pm 0.5)\, i$	(upp)
$P_{\psi s}^{\Lambda}(4255)$	4254.7 ± 0.4	(upp)

All poles are obtained dynamically, not by hand

$P_{cs}(4338)$ is a resonance $P_{cs}(4254)$ is a virtual state



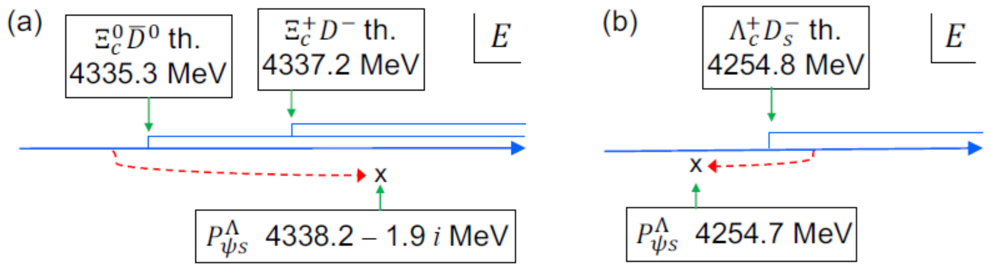




We close the coupled-channel and just calculate the single loop as shown here and re-fit the data.

The description of the peak of $P_{cs}(4338)$ is much worse. It indicates that the pure threshold cusp is not enough to form a $P_{cs}(4338)$ peak. We need a $P_{cs}(4338)$ resonance here.

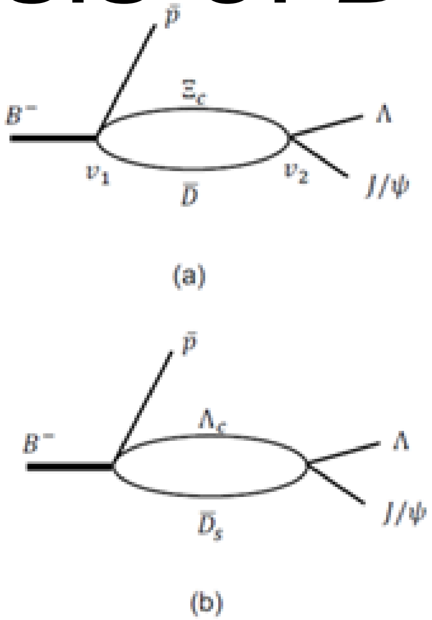
Data-driven analysis of $B^- \to J/\psi\Lambda\bar{P}$

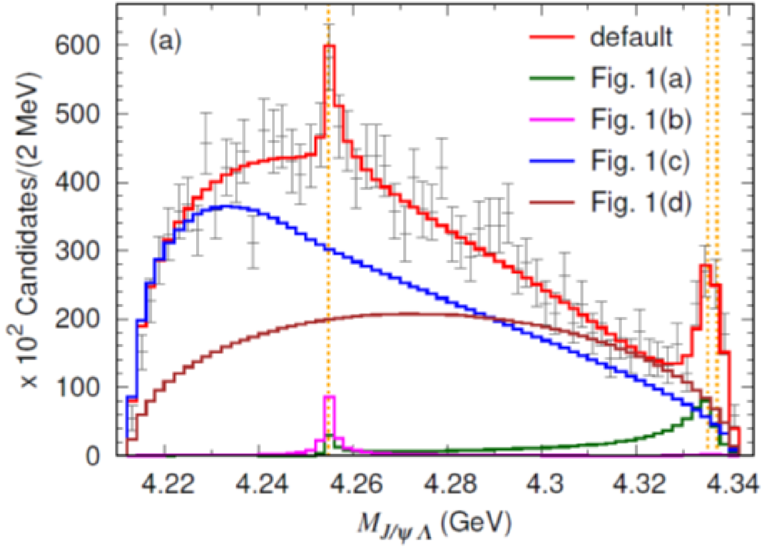


(I)	$P_{\psi s}^{\Lambda}(4338)$	$(4338.2 \pm 1.4) - (1.9 \pm 0.5)\,i$	(upp)
	$P_{\psi s}^{\Lambda}(4255)$	4254.7 ± 0.4	(upp)

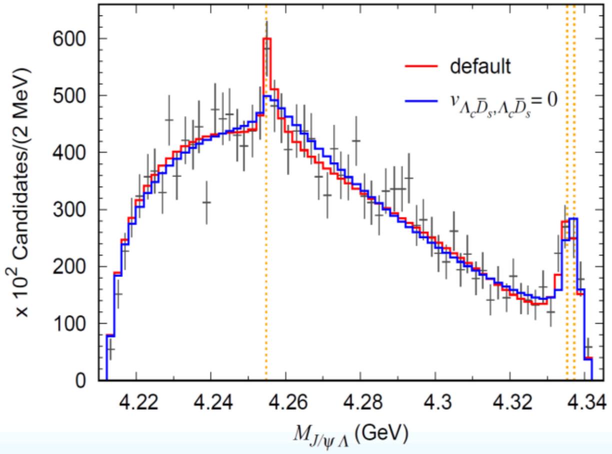
All poles are obtained dynamically, not by hand

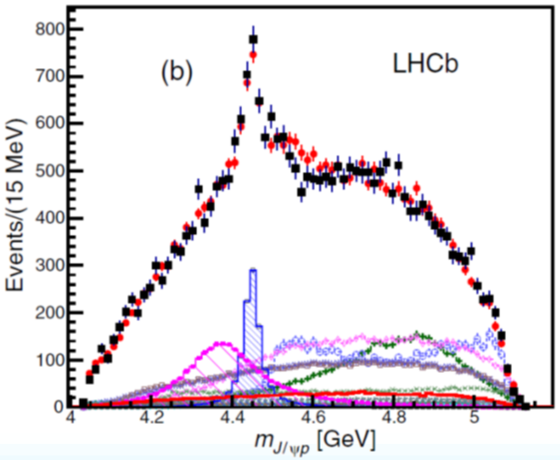
$P_{cs}(4338)$ is a resonance $P_{cs}(4254)$ is a virtual state

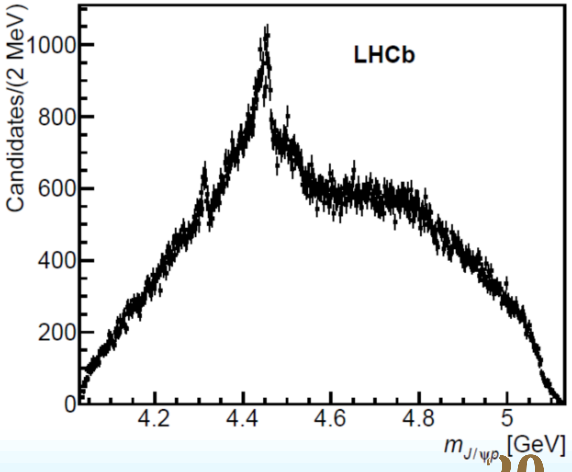




If we set $V_{\Lambda_c\bar{D}_s,\Lambda_c\bar{D}_s}$=0, the virtual pole will disappear, while the pole position of $P_{cs}(4338)$ will change.







Summary

- We discuss the possible P_{cs} states from the molecular candidates, $\bar{D}\Xi_c$–4310, $\bar{D}\Xi'_c$–4445, $\bar{D}^*\Xi_c$–4459 x2
- We also show the data-driven results from the experimental data. $\bar{D}\Xi_c$–4338 $\bar{D}_s\Lambda_c$–4254

Thanks for attention !