Flavor-spin symmetry of the $P_{\Psi}^{N}/H_{\Omega_{ccc}}^{N}$ and $P_{\Psi s}^{\Lambda}/H_{\Omega_{ccc}s}^{\Lambda}$ molecular states

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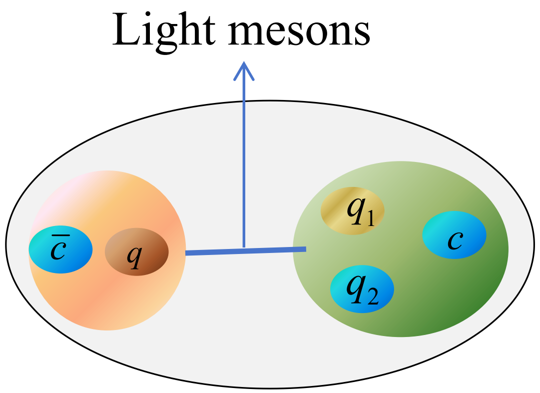
Outline

- Motivation
- Framework
- Numerical results and discussion
- Summary

Motivation

Hadronic Molecule

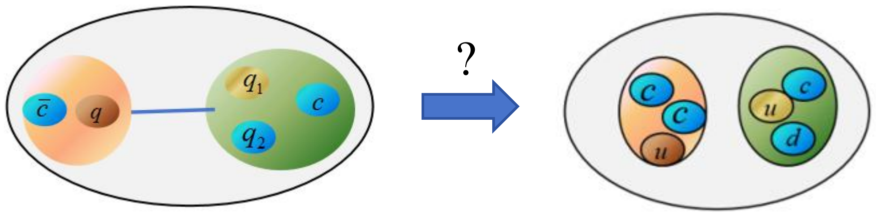


$P_{\psi}^{N}(4312)$, $P_{\psi}^{N}(4440)$, $P_{\psi}^{N}(4457)$, $P_{\psi}^{N}(4337)$
$P_{\psi s}^{\Lambda}(4338)$, $P_{\psi s}^{\Lambda}(4459)$...

Light quarks: provide the attractive force

Heavy quarks: stablize the system

LHCb, Phys. Rev. Lett. 115, 072001 (2015).
LHCb, Phys. Rev. Lett. 122, 222001 (2019).
LHCb, Phys. Rev. Lett. 128, 062001 (2022).
LHCb, Phys. Rev. Lett. 131, no.3, 031901 (2023).
LHCb, Sci. Bull. 66, 1278-1287 (2021).



$P_{\Psi}^{N}/P_{\Psi s}^{\Lambda}$ $H_{\Omega ccc}^{N}/H_{\Omega cccs}^{\Lambda}$

Motivation

Triply charmed hexaquark states

One-boson-exchange	R. Chen, F. L. Wang, A. Hosaka and X. Liu, Phys. Rev. D 97, no.11, 114011 (2018).
Lattice QCD	P. Junnarkar and N. Mathur, Phys. Rev. Lett. 123, no.16, 162003 (2019).
QCD sum rule	Z. G. Wang, Phys. Rev. D 102, no.3, 034008 (2020).
Effective field theory	Y. W. Pan, M. Z. Liu, F. Z. Peng, M. Sánchez Sánchez, L. S. Geng and M. Pavon Valderrama, Phys. Rev. D 102, no.1, 011504 (2020).

Motivation

Heavy diquark-antiquark symmetry (HDAS)

Quark content	System and threshold					
$(nnc)(n\bar{c})$	$\Lambda_c\bar{D}$	$\Lambda_c\bar{D}^*$	$\Sigma_c\bar{D}$	$\Sigma_c^*\bar{D}$	$\Sigma_c\bar{D}^*$	$\Sigma_c^*\bar{D}^*$
	4153.7	4295.0	4320.8	4385.4	4462.1	4526.7
$(nnc)(ncc)$	$\Lambda_c\Xi_{cc}$	$\Lambda_c\Xi_{cc}^*$	$\Sigma_c\Xi_{cc}$	$\Sigma_c^*\Xi_{cc}$	$\Sigma_c\Xi_{cc}^*$	$\Sigma_c^*\Xi_{cc}^*$
	5907.9	6013.5	6074.9	6139.5	6180.5	6245.1
$(nnc)(s\bar{c})$	$\Lambda_c\bar{D}_s$	$\Lambda_c\bar{D}_s^*$	$\Sigma_c\bar{D}_s$	$\Sigma_c^*\bar{D}_s$	$\Sigma_c\bar{D}_s^*$	$\Sigma_c^*\bar{D}_s^*$
	4255.5	4398.7	4422.5	4487.1	4565.7	4630.3
$(nsc)(n\bar{c})$	$\Xi_c\bar{D}$	$\Xi_c\bar{D}^*$	$\Xi_c'\bar{D}$	Ξ_c^*D	$\Xi_c'\bar{D}^*$	$\Xi_c^*\bar{D}^*$
	4336.7	4478.0	4446.0	4513.2	4587.4	4654.5
$(nnc)(scc)$	$\Lambda_c\Omega_{cc}$	$\Lambda_c\Omega_{cc}^*$	$\Sigma_c\Omega_{cc}$	$\Sigma_c^*\Omega_{cc}$	$\Sigma_c\Omega_{cc}^*$	$\Sigma_c^*\Omega_{cc}^*$
	6064.5	6158.5	6231.5	6296.1	6325.5	6390.1
$(nsc)(ncc)$	$\Xi_c\Xi_{cc}$	$\Xi_c\Xi_{cc}^*$	$\Xi_c'\Xi_{cc}$	$\Xi_c^*\Xi_{cc}$	$\Xi_c'\Xi_{cc}^*$	$\Xi_c^*\Xi_{cc}^*$
	6090.5	6196.1	6199.9	6267.4	6305.5	6373.0

	$I(J^P)$	Channel
P_ψ^N	$\frac{1}{2}(\frac{1}{2}^-)$	$\Lambda_c\bar{D}$,$\Lambda_c\bar{D}^*$,$\Sigma_c\bar{D}$,$\Sigma_c\bar{D}^*$,$\Sigma_c^*\bar{D}^*$
	$\frac{1}{2}(\frac{3}{2}^-)$	$\Lambda_c\bar{D}^*$,$\Sigma_c^*\bar{D}$,$\Sigma_c\bar{D}^*$,$\Sigma_c^*\bar{D}^*$
	$\frac{1}{2}(\frac{5}{2}^-)$	$\Sigma_c^*\bar{D}^*$
$P_{\psi s}^\Lambda$	$0(\frac{1}{2}^-)$	$\Lambda_c\bar{D}_s$,$\Lambda_c\bar{D}_s^*$,$\Xi_c\bar{D}$,$\Xi_c\bar{D}^*$,$\Xi_c'\bar{D}$,$\Xi_c'\bar{D}^*$,$\Xi_c^*\bar{D}^*$
	$0(\frac{3}{2}^-)$	$\Lambda_c\bar{D}_s^*$,$\Xi_c\bar{D}^*$,$\Xi_c^*\bar{D}$,$\Xi_c'\bar{D}^*$,$\Xi_c^*\bar{D}^*$
	$0(\frac{5}{2}^-)$	$\Xi_c^*\bar{D}^*$
$H_{\Omega_{ccc}}^N$	$\frac{1}{2}(0^+)$	$\Lambda_c\Xi_{cc}$, $\Sigma_c\Xi_{cc}$,$\Sigma_c^*\Xi_{cc}^*$
	$\frac{1}{2}(1^+)$	$\Lambda_c\Xi_{cc}$, $\Lambda_c\Xi_{cc}^*$, $\Sigma_c\Xi_{cc}$, $\Sigma_c^*\Xi_{cc}$, $\Sigma_c\Xi_{cc}^*$, $\Sigma_c^*\Xi_{cc}^*$
	$\frac{1}{2}(2^+)$	$\Lambda_c\Xi_{cc}^*$,$\Sigma_c^*\Xi_{cc}$,$\Sigma_c\Xi_{cc}^*$,$\Sigma_c^*\Xi_{cc}^*$
	$\frac{1}{2}(3^+)$	$\Sigma_c^*\Xi_{cc}^*$
$H_{\Omega_{cccs}}^\Lambda$	$\frac{1}{2}(0^+)$	$\Lambda_c\Omega_{cc}$, $\Xi_c\Xi_{cc}$,$\Xi_c'\Xi_{cc}$,$\Xi_c^*\Xi_{cc}^*$
	$\frac{1}{2}(1^+)$	$\Lambda_c\Omega_{cc}^*$,$\Xi_c\Xi_{cc}$, $\Xi_c\Xi_{cc}^*$,$\Xi_c'\Xi_{cc}$,$\Xi_c^*\Xi_{cc}$,$\Xi_c'\Xi_{cc}^*$,$\Xi_c^*\Xi_{cc}^*$
	$\frac{1}{2}(2^+)$	$\Xi_c\Xi_{cc}^*$,$\Xi_c^*\Xi_{cc}$,$\Xi_c'\Xi_{cc}^*$,$\Xi_c^*\Xi_{cc}^*$
	$\frac{1}{2}(3^+)$	$\Xi_c^*\Xi_{cc}^*$

The masses of Ξ_{cc}^* and $\Omega_{cc}^{(*)}$ baryon: D. Ebert, R. N. Faustov, V. O. Galkin and A. P. Martynenko, Phys. Rev. D 66, 014008 (2002).

Framework

Flavor wave function

Meson	$\lvert I m_I\rangle$	$\phi^M_{Im_I}$	Meson	$\lvert I m_I\rangle$	$\phi^M_{Im_I}$
$\bar{D}^{(*)0}$	$\lvert\frac{1}{2}\frac{1}{2}\rangle$	$u\bar{c}$	$\bar{D}^{(*)-}$	$\lvert\frac{1}{2}-\frac{1}{2}\rangle$	$d\bar{c}$
$\bar{D}_s^{(*)-}$	$\lvert 00\rangle$	$s\bar{c}$			
Baryon	$\lvert I m_I\rangle$	$\phi^B_{Im_I}$	**Baryon**	$\lvert I m_I\rangle$	$\phi^B_{Im_I}$
Λ_c^+	$\lvert 00\rangle$	$\frac{1}{\sqrt{2}}(du-ud)c$	$\Sigma_c^{(*)++}$	$\lvert 11\rangle$	uuc
$\Sigma_c^{(*)+}$	$\lvert 10\rangle$	$\frac{1}{\sqrt{2}}(ud+du)c$	$\Sigma_c^{(*)0}$	$\lvert 1-1\rangle$	ddc
Ξ_c^+	$\lvert\frac{1}{2}\frac{1}{2}\rangle$	$\frac{1}{\sqrt{2}}(us-su)c$	Ξ_c^0	$\lvert\frac{1}{2}-\frac{1}{2}\rangle$	$\frac{1}{\sqrt{2}}(ds-sd)c$
$\Xi_c^{\prime(*)+}$	$\lvert\frac{1}{2}\frac{1}{2}\rangle$	$\frac{1}{\sqrt{2}}(us+su)c$	$\Xi_c^{\prime(*)0}$	$\lvert\frac{1}{2}-\frac{1}{2}\rangle$	$\frac{1}{\sqrt{2}}(ds+sd)c$
$\Xi_{cc}^{(*)++}$	$\lvert\frac{1}{2}\frac{1}{2}\rangle$	ucc	$\Xi_{cc}^{(*)+}$	$\lvert\frac{1}{2}-\frac{1}{2}\rangle$	dcc
$\Omega_{cc}^{(*)+}$	$\lvert 00\rangle$	scc			

Spin wave function

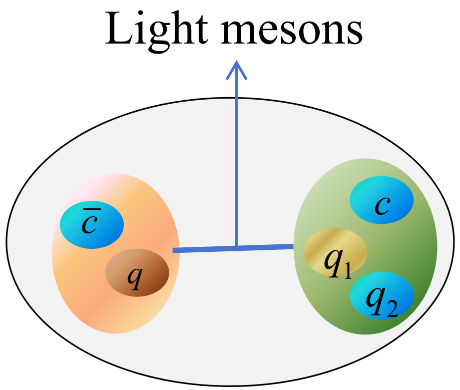
Hadron	$\lvert S m_S\rangle$	$\phi^M_{Sm_S}$	Hadron	$\lvert S m_S\rangle$	$\phi^M_{Sm_S}$
				$\lvert 11\rangle$	$\uparrow\uparrow$
$\bar{D}/\bar{D}_s$	$\lvert 00\rangle$	$\frac{1}{\sqrt{2}}(\uparrow\downarrow-\downarrow\uparrow)$	$\bar{D}^*/\bar{D}_s^*$	$\lvert 10\rangle$	$\frac{1}{\sqrt{2}}(\uparrow\downarrow+\downarrow\uparrow)$
				$\lvert 1-1\rangle$	$\downarrow\downarrow$
Hadron	$\lvert S m_S\rangle$	$\phi^B_{Sm_S}$	**Hadron**	$\lvert S m_S\rangle$	$\phi^B_{Sm_S}$
Λ_c/Ξ_c	$\lvert\frac{1}{2}\frac{1}{2}\rangle$	$\frac{1}{\sqrt{2}}(\uparrow\downarrow-\downarrow\uparrow)\uparrow$			
	$\lvert\frac{1}{2}-\frac{1}{2}\rangle$	$\frac{1}{\sqrt{2}}(\uparrow\downarrow-\downarrow\uparrow)\downarrow$		$\lvert\frac{3}{2}\frac{3}{2}\rangle$	$\uparrow\uparrow\uparrow$
Σ_c/Ξ_c'	$\lvert\frac{1}{2}\frac{1}{2}\rangle$	$-\frac{1}{\sqrt{6}}(\uparrow\downarrow+\downarrow\uparrow)\uparrow+\sqrt{\frac{2}{3}}\uparrow\uparrow\downarrow$	Σ_c^*/Ξ_c^*	$\lvert\frac{3}{2}\frac{1}{2}\rangle$	$\sqrt{\frac{1}{3}}(\uparrow\uparrow\downarrow+\uparrow\downarrow\uparrow+\downarrow\uparrow\uparrow)$
	$\lvert\frac{1}{2}-\frac{1}{2}\rangle$	$\frac{1}{\sqrt{6}}(\uparrow\downarrow+\downarrow\uparrow)\downarrow-\sqrt{\frac{2}{3}}\downarrow\downarrow\uparrow$	$/\Xi_{cc}^*/\Omega_{cc}^*$	$\lvert\frac{3}{2}-\frac{1}{2}\rangle$	$\sqrt{\frac{1}{3}}(\uparrow\downarrow\downarrow+\downarrow\uparrow\downarrow+\downarrow\downarrow\uparrow)$
Ξ_{cc}/Ω_{cc}	$\lvert\frac{1}{2}\frac{1}{2}\rangle$	$-\frac{1}{\sqrt{6}}\uparrow(\uparrow\downarrow+\downarrow\uparrow)+\sqrt{\frac{2}{3}}\downarrow\uparrow\uparrow$		$\lvert\frac{3}{2}-\frac{3}{2}\rangle$	$\downarrow\downarrow\downarrow$
	$\lvert\frac{1}{2}-\frac{1}{2}\rangle$	$\frac{1}{\sqrt{6}}\downarrow(\uparrow\downarrow+\downarrow\uparrow)-\sqrt{\frac{2}{3}}\uparrow\downarrow\downarrow$			

Total wave function:

$$|[H_1H_2]^I_J\rangle = \sum_{m_{I_1} m_{I_2}} C^{I,I_z}_{I_1,m_{I_1};I_2,m_{I_2}}\phi^{H_1}_{I_1,m_{I_1}}\phi^{H_2}_{I_2,m_{I_2}} \otimes \sum_{m_{S_1},m_{S_2}} C^{J,J_z}_{S_1,m_{S_1},S_2,m_{S_2}}\phi^{H_1}_{S_1,m_{S_1}}\phi^{H_2}_{S_2,m_{S_2}}$$

Framework

Hadronic Molecule



Boson exchange potential: S-wave interaction

Scalar mesons

Axial-vector mesons

$$\mathcal{V} = \tilde{g}_s \boldsymbol{\lambda}_1 \cdot \boldsymbol{\lambda}_2 + \tilde{g}_a \boldsymbol{\lambda}_1 \cdot \boldsymbol{\lambda}_2 \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2$$

$$\frac{g^2}{m_{\rm ex}^2 + q^2} \approx \frac{g^2}{m_{\rm ex}^2} \equiv \tilde{g}_s \text{ or } \tilde{g}_a$$

Effective potential: $V_{[H_1H_2]_J^I} = \left\langle [H_1H_2]_J^I \,|V|\, [H_1H_2]_J^I \right\rangle$

Single and coupled-channel Lippmann-Schwinger equation (LSE)

SU(3) breaking effect

$$\boldsymbol{\lambda}_1 \cdot \boldsymbol{\lambda}_2 = \sum_{i=1}^{8} \lambda_1^i \lambda_2^i$$

$$\boldsymbol{\lambda}_1 \cdot \boldsymbol{\lambda}_2 (\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2) = \sum_{i=1}^{8} \lambda_1^i \lambda_2^i (\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)$$

$$\tilde{g}_s \to \tilde{g}_s g_x \qquad \tilde{g}_a \to \tilde{g}_a g_x \qquad g_x \in [0,1]$$

for i =4, 5, 6, 7

Suppression factor g_x for the exchange of strange light meson

Parameters

$$\mathcal{V} = \tilde{g}_s \boldsymbol{\lambda}_1 \cdot \boldsymbol{\lambda}_2 + \tilde{g}_a \boldsymbol{\lambda}_1 \cdot \boldsymbol{\lambda}_2 \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2$$

$$\text{Scenario 1}: P_\psi^N(4440)|\Sigma_c\bar{D}^*;\frac{1}{2}^-\rangle, P_\psi^N(4457)|\Sigma_c\bar{D}^*;\frac{3}{2}^-\rangle$$
$$\text{Scenario 2}: P_\psi^N(4457)|\Sigma_c\bar{D}^*;\frac{1}{2}^-\rangle, P_\psi^N(4440)|\Sigma_c\bar{D}^*;\frac{3}{2}^-\rangle$$

$$\mathrm{Re}\left|\left|\mathbb{I} - \mathbb{V}_{1/2}^{P_\psi^N}\mathbb{G}_{1/2}^{P_\psi^N}\right|\right| = 0$$
$$\mathrm{Im}\left|\left|\mathbb{I} - \mathbb{V}_{1/2}^{P_\psi^N}\mathbb{G}_{1/2}^{P_\psi^N}\right|\right| = 0$$
$$\mathrm{Re}\left|\left|\mathbb{I} - \mathbb{V}_{3/2}^{P_\psi^N}\mathbb{G}_{3/2}^{P_\psi^N}\right|\right| = 0$$
$$\mathrm{Im}\left|\left|\mathbb{I} - \mathbb{V}_{3/2}^{P_\psi^N}\mathbb{G}_{3/2}^{P_\psi^N}\right|\right| = 0$$

$$\text{Scenario 1}: \tilde{g}_s = 8.28\,\mathrm{GeV}^{-2},\ \tilde{g}_a = -1.46\,\mathrm{GeV}^{-2},$$
$$\text{Scenario 2}: \tilde{g}_s = 9.12\,\mathrm{GeV}^{-2},\ \tilde{g}_a = 1.25\,\mathrm{GeV}^{-2}.$$

Single-channel case

$$\mathcal{O}^{\mathrm{f}} = \langle \boldsymbol{\lambda}_1 \cdot \boldsymbol{\lambda}_2 \rangle$$

$$\mathcal{O}^{\mathrm{fs}} = \langle (\boldsymbol{\lambda}_1 \cdot \boldsymbol{\lambda}_2)(\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2) \rangle$$

Flavor dominant/Isospin dominant

6 groups: A,B,C,D,E,F

System	$\mathcal{O}^{\mathrm{f}}$	$\mathcal{O}^{\mathrm{fs}}$	System	$\mathcal{O}^{\mathrm{f}}$	$\mathcal{O}^{\mathrm{fs}}$
$[\Lambda_c\bar{D}]_{\frac{1}{2}}$	$\frac{2}{3}$	0	$[\Lambda_c\Xi_{cc}]_{0,1}$	$\frac{2}{3},\frac{2}{3}$	0,0
$[\Lambda_c\bar{D}^*]_{\frac{1}{2},\frac{3}{2}}$	$\frac{2}{3},\frac{2}{3}$	0,0	$[\Lambda_c\Xi_{cc}^*]_{1,2}$	$\frac{2}{3},\frac{2}{3}$	0,0
$[\Sigma_c\bar{D}]_{\frac{1}{2}^{\mathrm{A}}}$	$-\frac{10}{3}$	0	$[\Sigma_c\Xi_{cc}]_{0^{\mathrm{B}},1}$	$-\frac{10}{3},-\frac{10}{3}$	$-\frac{20}{9},\frac{20}{27}$
$[\Sigma_c^*\bar{D}]_{\frac{3}{2}^{\mathrm{A}}}$	$-\frac{10}{3}$	0	$[\Sigma_c^*\Xi_{cc}]_{1,2^{\mathrm{C}}}$	$-\frac{10}{3},-\frac{10}{3}$	$-\frac{50}{27},\frac{10}{9}$
$[\Sigma_c\bar{D}^*]_{\frac{1}{2},\frac{3}{2}^{\mathrm{B}}}$	$-\frac{10}{3},-\frac{10}{3}$	$\frac{40}{9},-\frac{20}{9}$	$[\Sigma_c\Xi_{cc}^*]_{1,2^{\mathrm{B}}}$	$-\frac{10}{3},-\frac{10}{3}$	$\frac{100}{27},-\frac{20}{9}$
$[\Sigma_c^*\bar{D}^*]_{\frac{1}{2}^{\mathrm{D}},\frac{3}{2},\frac{5}{2}^{\mathrm{E}}}$	$-\frac{10}{3},-\frac{10}{3},-\frac{10}{3}$	$\frac{50}{9},\frac{20}{9},-\frac{10}{3}$	$[\Sigma_c^*\Xi_{cc}^*]_{0^{\mathrm{D}},1,2^{\mathrm{C}},3^{\mathrm{E}}}$	$-\frac{10}{3},-\frac{10}{3},-\frac{10}{3}$	$\frac{50}{9},\frac{110}{27},\frac{10}{9},-\frac{10}{3}$

System	$\mathcal{O}^{\mathrm{f}}$	$\mathcal{O}^{\mathrm{fs}}$	System	$\mathcal{O}^{\mathrm{f}}$	$\mathcal{O}^{\mathrm{fs}}$
$[\Lambda_c\bar{D}_s]_{\frac{1}{2}^{\mathrm{F}}}$	$-\frac{4}{3}$	0	$[\Lambda_c\Omega_{cc}]_{0^{\mathrm{F}},1^{\mathrm{F}}}$	$-\frac{4}{3},-\frac{4}{3}$	0,0
$[\Lambda_c\bar{D}_s^*]_{\frac{1}{2}^{\mathrm{F}},\frac{3}{2}^{\mathrm{F}}}$	$-\frac{4}{3},-\frac{4}{3}$	0,0	$[\Lambda_c\Omega_{cc}^*]_{1^{\mathrm{F}},2^{\mathrm{F}}}$	$-\frac{4}{3},-\frac{4}{3}$	0,0
$[\Xi_c\bar{D}]_{\frac{1}{2}^{\mathrm{A}}}$	$-\frac{10}{3}$	0	$[\Xi_c\Xi_{cc}]_{0^{\mathrm{A}},1^{\mathrm{A}}}$	$-\frac{10}{3},-\frac{10}{3}$	0,0
$[\Xi_c\bar{D}^*]_{\frac{1}{2}^{\mathrm{A}},\frac{3}{2}^{\mathrm{A}}}$	$-\frac{10}{3},-\frac{10}{3}$	0,0	$[\Xi_c\Xi_{cc}^*]_{1^{\mathrm{A}},2^{\mathrm{A}}}$	$-\frac{10}{3},-\frac{10}{3}$	0,0
$[\Xi_c'\bar{D}]_{\frac{1}{2}^{\mathrm{A}}}$	$-\frac{10}{3}$	0	$[\Xi_c'\Xi_{cc}]_{0^{\mathrm{B}},1}$	$-\frac{10}{3},-\frac{10}{3}$	$-\frac{20}{9},\frac{20}{27}$
$[\Xi_c^*\bar{D}]_{\frac{3}{2}^{\mathrm{A}}}$	$-\frac{10}{3}$	0	$[\Xi_c^*\Xi_{cc}]_{1,2^{\mathrm{C}}}$	$-\frac{10}{3},-\frac{10}{3}$	$-\frac{50}{27},\frac{10}{9}$
$[\Xi_c'\bar{D}^*]_{\frac{1}{2},\frac{3}{2}^{\mathrm{B}}}$	$-\frac{10}{3},-\frac{10}{3}$	$\frac{40}{9},-\frac{20}{9}$	$[\Xi_c'\Xi_{cc}^*]_{1,2^{\mathrm{B}}}$	$-\frac{10}{3},-\frac{10}{3}$	$\frac{100}{27},-\frac{20}{9}$
$[\Xi_c^*\bar{D}^*]_{\frac{1}{2}^{\mathrm{D}},\frac{3}{2},\frac{5}{2}^{\mathrm{E}}}$	$-\frac{10}{3},-\frac{10}{3},-\frac{10}{3}$	$\frac{50}{9},\frac{20}{9},-\frac{10}{3}$	$[\Xi_c^*\Xi_{cc}^*]_{0^{\mathrm{D}},1,2^{\mathrm{C}},3^{\mathrm{E}}}$	$-\frac{10}{3},-\frac{10}{3},-\frac{10}{3},-\frac{10}{3}$	$\frac{50}{9},\frac{110}{27},\frac{10}{9},-\frac{10}{3}$

Single-channel case

	Scenario 1			Scenario 2	
System	Mass (MeV)	BE (MeV)	System	Mass (MeV)	BE (MeV)
$[\Sigma_c\bar{D}]_{\frac{1}{2}}{}^{\rm A}$	4312.6	-8.1	$[\Sigma_c\bar{D}]_{\frac{1}{2}}{}^{\rm A}$	4307.6	-13.1
$[\Sigma_c^*\bar{D}]_{\frac{3}{2}}{}^{\rm A}$	4376.9	-8.5	$[\Sigma_c^*\bar{D}]_{\frac{3}{2}}{}^{\rm A}$	4371.7	-13.6
$[\Sigma_c\bar{D}^*]_{\frac{1}{2},\frac{3}{2}}{}^{\rm B}$	4438.8,4457.5	$-23.2,-4.6$	$[\Sigma_c\bar{D}^*]_{\frac{1}{2},\frac{3}{2}}{}^{\rm B}$	4456.8,4440.9	$-5.3,-21.1$
$[\Sigma_c^*\bar{D}^*]_{\frac{1}{2}{}^{\rm D},\frac{3}{2},\frac{5}{2}}{}^{\rm E}$	4498.8,4510.3,4523.8	$-27.9,-16.4,-2.9$	$[\Sigma_c^*\bar{D}^*]_{\frac{1}{2}{}^{\rm D},\frac{3}{2},\frac{5}{2}}{}^{\rm E}$	4522.9,4516.6,4501.6	$-3.8,-10.1,-25.1$
$[\Xi_c\bar{D}]_{\frac{1}{2}}{}^{\rm A}$	4328.1	-8.2	$[\Xi_c\bar{D}]_{\frac{1}{2}}{}^{\rm A}$	4323.1	-13.3
$[\Xi_c\bar{D}^*]_{\frac{1}{2}{}^{\rm A},\frac{3}{2}}{}^{\rm A}$	4468.0,4468.0	$-9.7,-9.7$	$[\Xi_c\bar{D}^*]_{\frac{1}{2}{}^{\rm A},\frac{3}{2}}{}^{\rm A}$	4462.5,4462.5	$-15.1,-15.1$
$[\Xi_c'\bar{D}]_{\frac{1}{2}}{}^{\rm A}$	4436.8	-8.9	$[\Xi_c'\bar{D}]_{\frac{1}{2}}{}^{\rm A}$	4431.6	-14.1
$[\Xi_c^*\bar{D}]_{\frac{3}{2}}{}^{\rm A}$	4503.9	-9.3	$[\Xi_c^*\bar{D}]_{\frac{3}{2}}{}^{\rm A}$	4498.6	-14.6
$[\Xi_c'\bar{D}^*]_{\frac{1}{2},\frac{3}{2}}{}^{\rm B}$	4562.5,4581.8	$-24.5,-5.2$	$[\Xi_c'\bar{D}^*]_{\frac{1}{2},\frac{3}{2}}{}^{\rm B}$	4581.1,4564.7	$-5.9,-22.3$
$[\Xi_c^*\bar{D}^*]_{\frac{1}{2}{}^{\rm D},\frac{3}{2},\frac{5}{2}}{}^{\rm E}$	4625.3,4637.0,4651.2	$-29.2,-17.5,-3.4$	$[\Xi_c^*\bar{D}^*]_{\frac{1}{2}{}^{\rm D},\frac{3}{2},\frac{5}{2}}{}^{\rm E}$	4650.2,4643.6,4628.2	$-4.3,-11.0,-26.3$

Good flavor-spin symmetry

Single-channel case

	Scenario 1			Scenario 2	
System	Mass (MeV)	BE (MeV)	System	Mass (MeV)	BE (MeV)
$[\Sigma_c\Xi_{cc}]_{0^B,1}$	6060.8,6050.3	−14.0,−24.6	$[\Sigma_c\Xi_{cc}]_{0^B,1}$	6037.5,6048.1	−37.3,−26.8
$[\Sigma_c^*\Xi_{cc}]_{1,2^C}$	6123.7,6112.7	−15.9,−26.8	$[\Sigma_c^*\Xi_{cc}]_{1,2^C}$	6102.7,6113.2	−36.9,−26.3
$[\Sigma_c\Xi_{cc}^*]_{1,2^B}$	6143.0,6166.0	−37.5,−14.5	$[\Sigma_c\Xi_{cc}^*]_{1,2^B}$	6162.6,6142.4	−17.8,−38.0
$[\Sigma_c^*\Xi_{cc}^*]_{0^D,1}$	6198.3,6205.1	−46.8,−40.1	$[\Sigma_c^*\Xi_{cc}^*]_{0^D,1}$	6232.0,6227.7	−13.2,−17.4
$[\Sigma_c^*\Xi_{cc}^*]_{2^C,3^E}$	6217.7,6233.6	−27.4,−11.6	$[\Sigma_c^*\Xi_{cc}^*]_{2^C,3^E}$	6218.2,6201.9	−26.9,−43.2
$[\Xi_c\Xi_{cc}]_{0^A,1^A}$	6068.5,6068.5	−22.0,−22.0	$[\Xi_c\Xi_{cc}]_{0^A,1^A}$	6061.0,6061.0	−29.5,−29.5
$[\Xi_c\Xi_{cc}^*]_{1^A,2^A}$	6173.6,6173.6	−22.5,−22.5	$[\Xi_c\Xi_{cc}^*]_{1^A,2^A}$	6165.9,6165.9	−30.2,−30.2
$[\Xi_c'\Xi_{cc}]_{0^B,1}$	6184.7,6173.8	−15.2,−26.1	$[\Xi_c'\Xi_{cc}]_{0^B,1}$	6160.8,6171.6	−39.1,−28.3
$[\Xi_c^*\Xi_{cc}]_{1,2^C}$	6250.3,6239.1	−17.1,−28.3	$[\Xi_c^*\Xi_{cc}]_{1,2^C}$	6228.8,6239.6	−38.6,−27.8
$[\Xi_c'\Xi_{cc}^*]_{1,2^B}$	6266.2,6289.8	−39.2,−15.7	$[\Xi_c'\Xi_{cc}^*]_{1,2^B}$	6286.3,6265.7	−19.1,−39.8
$[\Xi_c^*\Xi_{cc}^*]_{0^D,1}$	6324.3,6331.2	−48.7,−41.8	$[\Xi_c^*\Xi_{cc}^*]_{0^D,1}$	6358.7,6354.3	−14.3,−18.6
$[\Xi_c^*\Xi_{cc}^*]_{2^C,3^E}$	6344.0,6360.4	−29.0,−12.6	$[\Xi_c^*\Xi_{cc}^*]_{2^C,3^E}$	6344.6,6327.9	−28.4,−45.1

Good flavor-spin symmetry

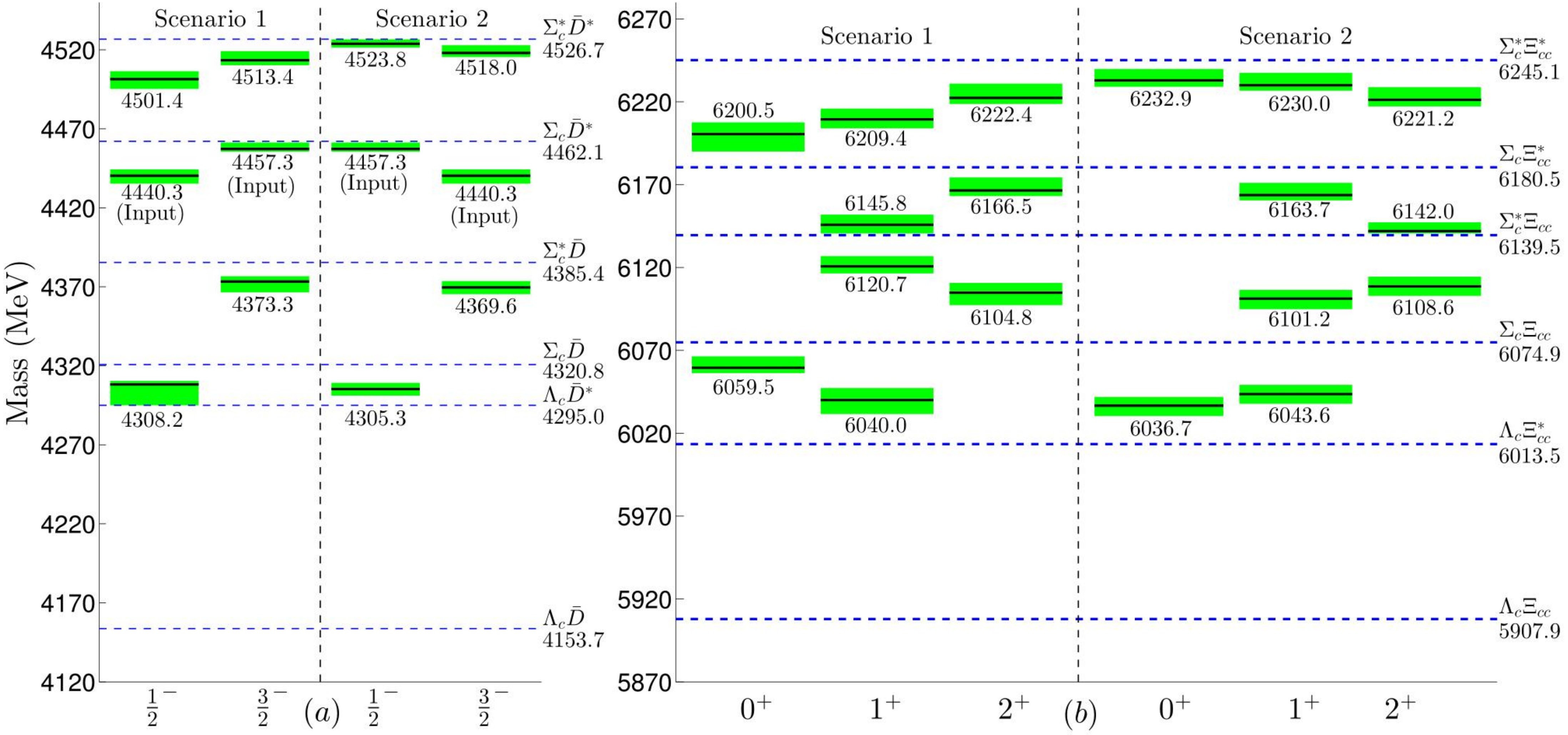
Coupled-channel effect?
SU(3) breaking effect?

Single vs multi-channel: finger prints of the flavor-spin symmetry

System-dependent

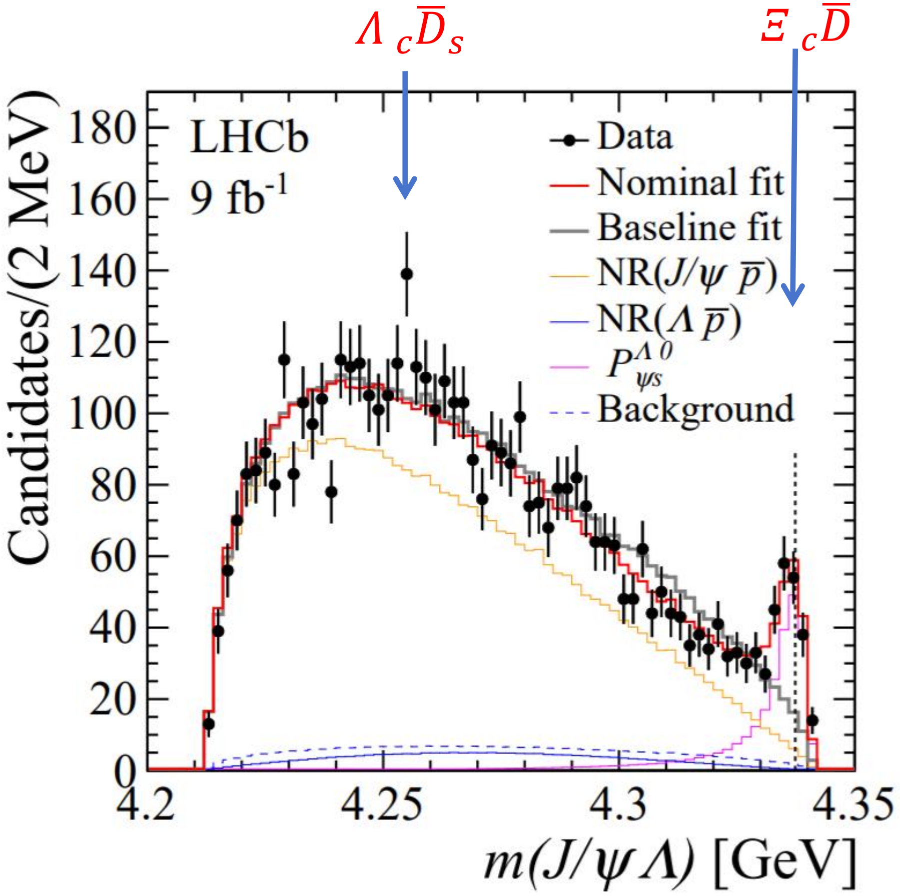
	Scenario 1		Scenario 2			Scenario 1		Scenario 2	
System	BE (SC)	BE (MC)	BE (SC)	BE (MC)	System	BE (SC)	BE (MC)	BE (SC)	BE (MC)
$[\Sigma_c\bar{D}]^{\dagger}_{\frac{1}{2}\mathrm{A}}$	-8.1	-12.6	-13.1	$\boxed{-15.5}$	$[\Sigma_c^*\bar{D}]^{\dagger}_{\frac{3}{2}\mathrm{A}}$	-8.5	-12.6	-13.6	$\boxed{-15.8}$
$[\Sigma_c\bar{D}^*]^{\dagger}_{\frac{3}{2}\mathrm{B}}$	-4.6	-4.8	-21.1	-21.8	$[\Xi_c'\bar{D}^*]^{\dagger}_{\frac{3}{2}\mathrm{B}}$	-5.2	-5.2	-22.3	-22.9
$[\Sigma_c\Xi_{cc}]^{\dagger}_{0\mathrm{B}}$	-14.0	-15.3	-37.3	-38.2	$[\Sigma_c\Xi_{cc}^*]^{\dagger}_{2\mathrm{B}}$	-14.5	-14.0	-38.0	-38.5
$[\Xi_c'\Xi_{cc}]^{\dagger}_{0\mathrm{B}}$	-15.2	-16.4	-39.1	-39.9	$[\Xi_c'\Xi_{cc}^*]^{\dagger}_{2\mathrm{B}}$	-15.7	-15.0	-39.8	-39.6
$[\Sigma_c^*\Xi_{cc}]_{2\mathrm{C}}$	-26.8	-34.8	-26.3	-30.9	$[\Sigma_c^*\Xi_{cc}^*]_{2\mathrm{C}}$	-27.4	-22.7	-26.9	-24.0
$[\Xi_c^*\Xi_{cc}]_{2\mathrm{C}}$	-28.3	-31.8	-27.8	-31.7	$[\Xi_c^*\Xi_{cc}^*]_{2\mathrm{C}}$	-29.0	-23.8	-28.4	-24.4
$[\Sigma_c^*\bar{D}^*]^{\dagger}_{\frac{1}{2}\mathrm{D}}$	-27.9	-25.3	-3.8	-2.8	$[\Xi_c^*\bar{D}^*]^{\dagger}_{\frac{1}{2}\mathrm{D}}$	-29.2	-26.0	-4.3	-3.2
$[\Sigma_c^*\Xi_{cc}^*]^{\dagger}_{0\mathrm{D}}$	-46.8	-44.7	-13.2	-12.2	$[\Xi_c^*\Xi_{cc}^*]^{\dagger}_{0\mathrm{D}}$	-48.7	-46.4	-14.3	-13.2
$[\Sigma_c^*\bar{D}^*]^{\dagger}_{\frac{5}{2}\mathrm{E}}$	-2.9	-2.9	-25.1	-25.1	$[\Xi_c^*\bar{D}^*]^{\dagger}_{\frac{5}{2}\mathrm{E}}$	-3.4	-3.4	26.3	-26.3
$[\Sigma_c^*\Xi_{cc}^*]^{\dagger}_{3\mathrm{E}}$	-11.6	-11.6	-43.2	-43.2	$[\Xi_c^*\Xi_{cc}^*]^{\dagger}_{3\mathrm{E}}$	-12.6	-12.6	-45.1	-45.1

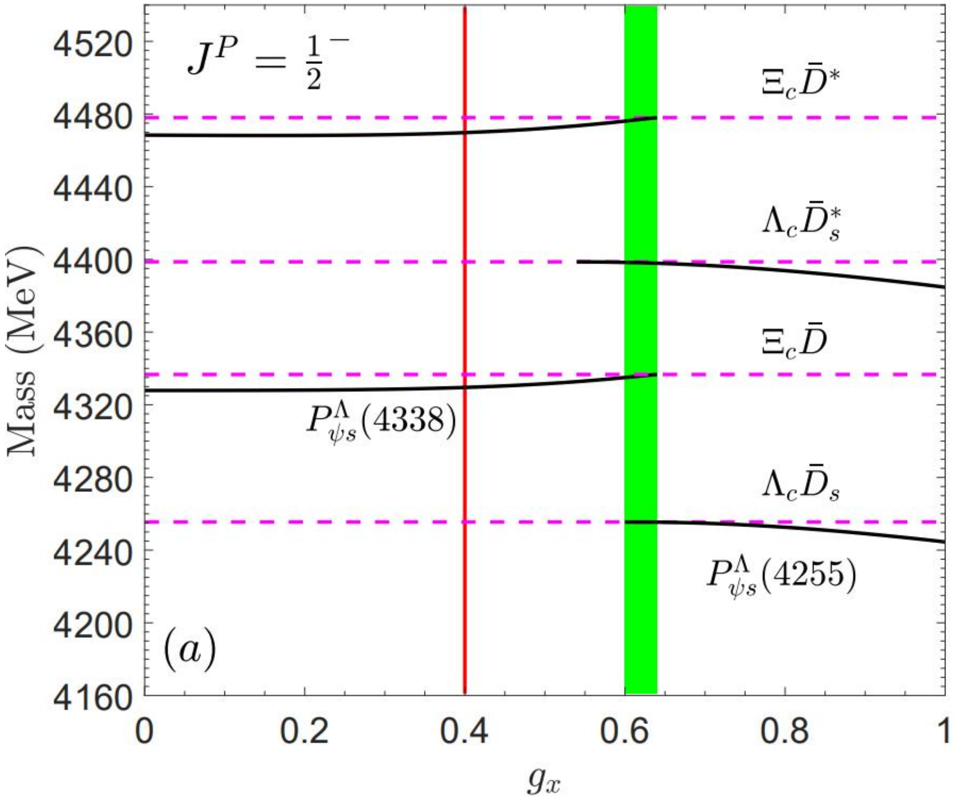
Multi-channel $P_{\Psi}^{N}/H_{\Omega_{ccc}}^{N}$ mass spectra



Consistent with: Y. W. Pan, M. Z. Liu, F. Z. Peng, M. Sánchez Sánchez, L. S. Geng and M. Pavon Valderrama, Phys. Rev. D 102, no.1, 011504 (2020).

SU(3) breaking factor g_x





$$\Xi_c\bar{D}^{(*)} - \Lambda_c\bar{D}_s^{(*)}$$

$$\Xi_c\Xi_{cc}^{(*)} - \Lambda_c\Omega_{cc}^{(*)}$$

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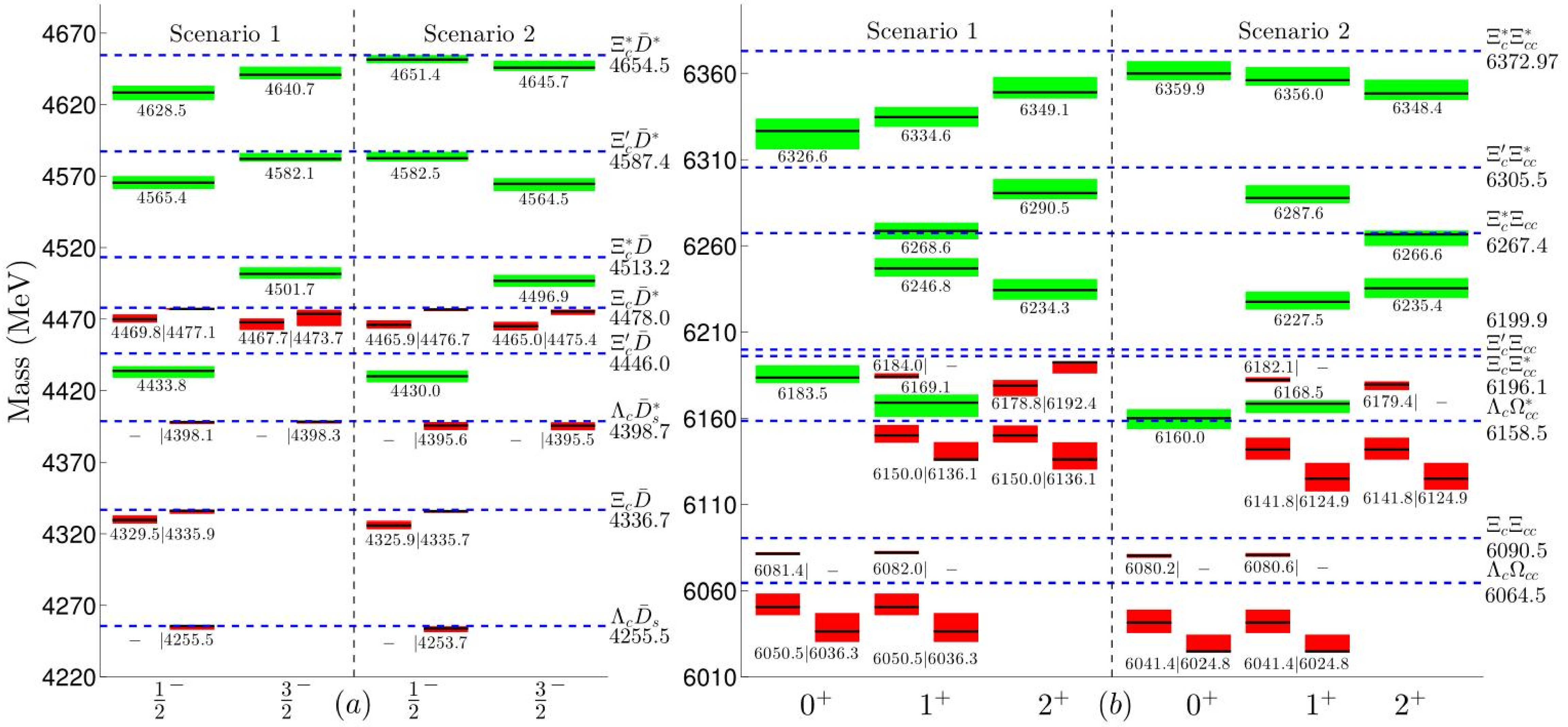
Multi-channel $P_{\psi s}^{\Lambda}/H_{\Omega_{ccc}s}^{\Lambda}$ mass spectra



Summary

We suggest two ways to check the existence of the flavor-spin symmetry among the $P_{\psi}^{N}/H_{\Omega_{ccc}}^{N}$ and $P_{\psi s}^{\Lambda}/H_{\Omega_{ccc}s}^{\Lambda}$ molecular community, i.e.,

1. The similar binding energies of the heavy flavor meson-baryon (di-baryon) systems attributed to the same contact potentials.

2. The mass arrangements of the $P_{\psi}^{N}/H_{\Omega_{ccc}}^{N}/P_{\psi s}^{\Lambda}/H_{\Omega_{ccc}s}^{\Lambda}$ mass spectra.

Thanks for your attention!