Hidden-charm pentaquark state with strangeness $S = -3$ in coupled-channel approach

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Outlines

Introduction

- Hidden-charm pentaquarks are exotic baryons that contain $c\bar{c}$.
  - $P_{c\bar{c}}$ $(qqqc\bar{c})$ in $J/\psi N$ mass distribution
    $P_{c\bar{c}}(4312)$, $P_{c\bar{c}}(4380)$, $P_{c\bar{c}}(4440)$, $P_{c\bar{c}}(4457)$ [LHCb]
  - $P_{c\bar{c}s}$ $(qqsc\bar{c})$ in $J/\psi\Lambda$ mass distribution
    $P_{c\bar{c}s}(4338)$, $P_{c\bar{c}s}(4459)$ [LHCb], $P_{c\bar{c}s}(4472)$ [Belle]
  - $P_{c\bar{c}ss}$ $(qssc\bar{c})$ not yet observed
  - $P_{c\bar{c}sss}$ $(sssc\bar{c})$ not yet observed
- Recent observations by CMS and LHCb: $\Lambda_b^0 \to J/\psi\Xi^- K^+$ and $\Xi_b^0 \to J/\psi\Xi^-\pi^+$ decays. [EPJC **84**, 1062 (2024); EPJC **85**, 812 (2025)]
- $\Xi_b^0 \to J/\psi\Omega^- K^+$ is a possible decay channel to observe $P_{c\bar{c}sss}$.
- The off-shell coupled-channel formalism successfully reproduces the $P_{c\bar{c}}$ and $P_{c\bar{c}s}$ candidate spectra.
  [PRD **110**, 094014 (2024); PRD **112**, 014041 (2025)]
- We predicted five negative-parity $P_{c\bar{c}ss}$ states.
  [PRD **112**, 034015 (2025)]

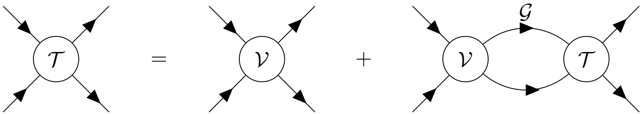
Off-shell coupled-channel formalism

We start from the S matrix, which can be written as

$$S_{fi} = \delta_{fi} - i(2\pi)^4 \delta^4(P_f - P_i)\mathcal{T}_{fi}$$

The Bethe-Salpeter equation for two-body interaction expressed as

$$\mathcal{T}_{fi}(p', p) = \mathcal{V}_{fi}(p', p) + \frac{1}{(2\pi)^4} \int d^4q \mathcal{V}_{fg}(p', q)\mathcal{G}_g(q)\mathcal{T}_{gi}(q, p)$$



In the Blankenbecler-Sugar scheme, the four-dimensional integral equation reduces to

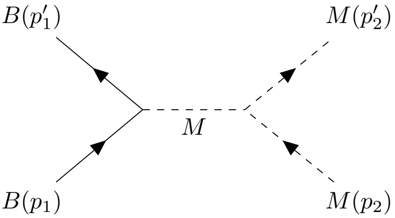
$$\mathcal{T}_{fi}(\mathbf{p}, \mathbf{p}') = \mathcal{V}_{fi}(\mathbf{p}, \mathbf{p}') + \frac{1}{(2\pi)^3} \int \frac{d^3q}{2E_{1g}E_{2g}} \mathcal{V}_{fg}(\mathbf{p}, \mathbf{q}) \frac{E_g}{s - E_g^2 + i\varepsilon} \mathcal{T}_{gi}(\mathbf{q}, \mathbf{p}')$$

Kernel amplitude

$$\mathcal{T}_{fi}(\mathbf{p},\mathbf{p}') = \mathcal{V}_{fi}(\mathbf{p},\mathbf{p}') + \frac{1}{(2\pi)^3}\int \frac{d^3q}{2E_{1g}E_{2g}}\mathcal{V}_{fg}(\mathbf{p},\mathbf{q})\frac{E_g}{s-E_g^2+i\varepsilon}\mathcal{T}_{gi}(\mathbf{q},\mathbf{p}')$$

Channels: $\bar{D}_s\,\Omega_c$, $\bar{D}_s\,\Omega_c^*$, $\bar{D}_s^*\,\Omega_c$, $\bar{D}_s^*\,\Omega_c^*$

Each amplitude is modeled by one meson exchange diagram



The amplitude of each diagram:

$$\mathcal{A} = IS \times F^2 \times \Gamma_1 \times \mathcal{P} \times \Gamma_2$$

So that $\mathcal{V} = \mathcal{A}_1 + \mathcal{A}_2 + \cdots$

The rule for vertices are governed by the effective Lagrangian which respects heavy quark spin symmetry, hidden local symmetry and SU(3) symmetry.

The form factor is parameterized with free parameter Λ which chosen to be $\Lambda = \Lambda_0 + m$ with m is the exchange mass.

Kernel amplitude

Reactions	Exchange	IS
$\bar{D}_s\Omega_c \to \bar{D}_s\Omega_c$	ϕ, σ	1
$\bar{D}_s\Omega_c \to \bar{D}_s\Omega_c^*$	ϕ	1
$\bar{D}_s\Omega_c \to \bar{D}_s^*\Omega_c$	η	$\frac{1}{3}\sqrt{2}$
	ϕ	1
$\bar{D}_s\Omega_c \to \bar{D}_s^*\Omega_c^*$	η	$\frac{1}{3}\sqrt{2}$
	ϕ	1
$\bar{D}_s\Omega_c^* \to \bar{D}_s\Omega_c^*$	ϕ, σ	1
$\bar{D}_s\Omega_c^* \to \bar{D}_s^*\Omega_c$	η	$\frac{1}{3}\sqrt{2}$
	ϕ	1
$\bar{D}_s\Omega_c^* \to \bar{D}_s^*\Omega_c^*$	η	$\frac{1}{3}\sqrt{2}$
	ϕ	1
$\bar{D}_s^*\Omega_c \to \bar{D}_s^*\Omega_c$	η	$\frac{1}{3}\sqrt{2}$
	ϕ, σ	1
$\bar{D}_s^*\Omega_c \to \bar{D}_s^*\Omega_c^*$	η	$\frac{1}{3}\sqrt{2}$
	ϕ	1
$\bar{D}_s^*\Omega_c^* \to \bar{D}_s^*\Omega_c^*$	η	$\frac{1}{3}\sqrt{2}$
	ϕ, σ	1

Definitions and Terms

- The partial-wave cross section

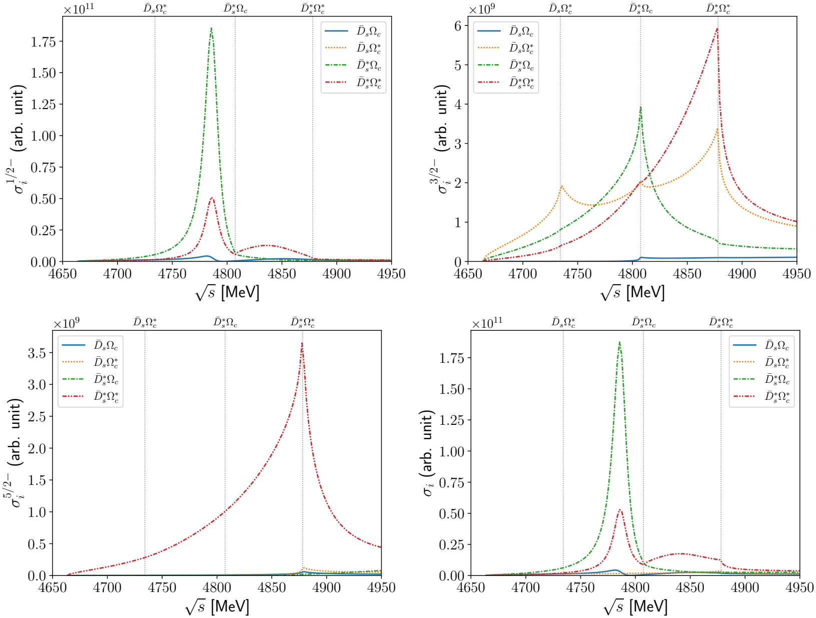
$$\sigma^{J\pm} = \frac{2J+1}{(2s_1+1)(2s_2+1)} \sum_{\lambda'\lambda} \mathrm{p}' \left| \mathcal{T}^{J\pm}_{\lambda'\lambda} \right|^2$$

- The pole position are determined by scanning the scattering amplitude in the complex energy plane.

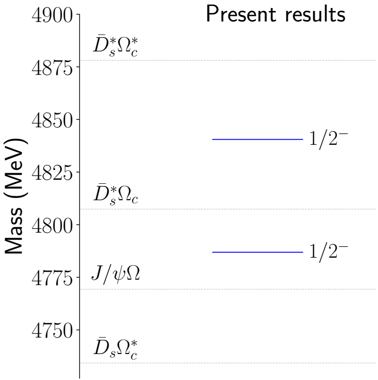
$$\sqrt{s_R} = M - i\Gamma/2$$

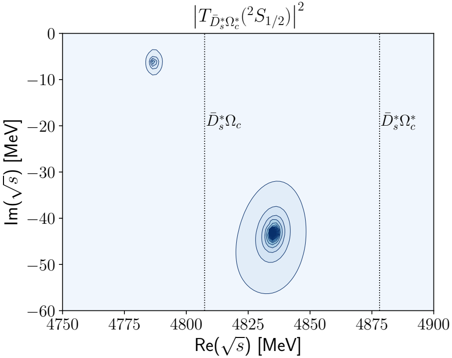
Results and Discussion

Elastic cross-section



Spectrum of $P_{c\bar{c}ss}$





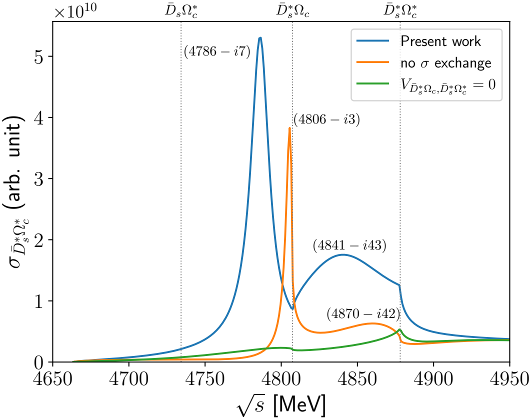
J^P	Name	$\sqrt{s_R}$ [MeV] M	Γ
$1/2^-$	$P_{c\bar{c}ss}(4787)$	4785.9	14.4
	$P_{c\bar{c}ss}(4840)$	4840.5	85.2

Other studies

- Meng *et al.* studied $P_{c\bar{c}sss}$ states as compact pentaquarks within a quark potential model. They found seven pentaquark states with spin-parity $J^P = 1/2^-$, with the lowest having a mass of 4855 MeV. [PLB **798**, 135028 (2019)]
- Wang *et al.* constructed hadronic potentials based on the one-boson-exchange model with four coupled channels: $\bar{D}_s\,\Omega_c$, $\bar{D}_s\,\Omega_c^*$, $\bar{D}_s^*\,\Omega_c$, $\bar{D}_s^*\,\Omega_c^*$. They predicted two triple-strangeness hidden-charm pentaquark states with $J^P = 3/2^-$ and $5/2^-$ as bound states of $\bar{D}_s^*\,\Omega_c$ and $\bar{D}_s^*\,\Omega_c^*$. [PRD **102**, 094013 (2020)]
- Roca *et al.* concluded that the meson-baryon interaction they employed was insufficient to generate a resonance state. [PRD **109**, 094005 (2024)]
- In the double- and triple-strangeness sectors, a single channel is insufficient to produce a resonance due to the repulsive nature of ϕ exchange.

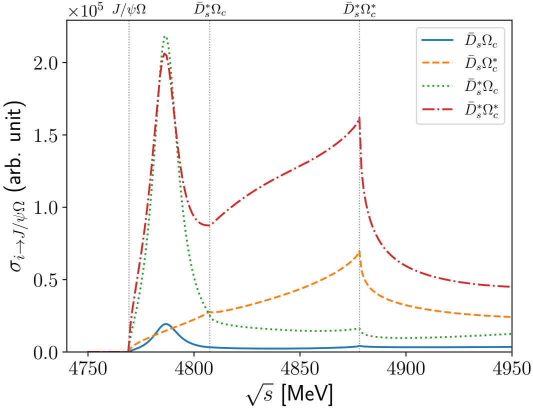
  $\rightarrow$ The off-diagonal components of the kernel matrix are important factors in producing resonance states.

Generation of $P_{c\bar{c}sss}$ states



The σ exchange is not essential for the generation of $P_{c\bar{c}sss}$ states.

Without the $\bar{D}_s^* \Omega_c \to \bar{D}_s^* \Omega_c^*$ kernel component, no resonance state is generated.



J^P	Name	$\sqrt{s_R}$ [MeV] M	Γ
$1/2^-$	$P_{c\bar{c}ss}(4787)$	4785.9	14.4
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We added the $J/\psi\Omega$ channel and found it has a negligible effect on the resonance properties.

The $P_{c\bar{c}sss}$ candidates might be discovered in $\Xi_b^0 \to J/\psi\Omega^- K^+$ decay.

Summary and Conclusion

- We investigated triple-strangeness hidden-charm pentaquarks using the coupled-channel formalism.
- The scattering amplitude revealed two resonances with $J^P = 1/2^-$, with one located below the $\bar{D}_s^*\Omega_c$ threshold and the other below the $\bar{D}_s^*\Omega_c^*$ threshold.
- The kernel component $\bar{D}_s^*\Omega_c \to \bar{D}_s^*\Omega_c^*$ is crucial for generating the two $P_{c\bar{c}sss}$ states.
- The $P_{c\bar{c}sss}(4787)$ might be discovered in the $J/\psi\Omega^-$ final state, specifically in the $\Xi_b^0 \to J/\psi\Omega^- K^+$ decay channel, while the other state is difficult to observe due to its broad width and screening by the cusp structure near the $\bar{D}_s^*\Omega_c^*$ threshold.

Thank You