Prediction of an exotic state around 4240 MeV with $J^{PC} = 1^{-+}$ as the C-parity partner of Y(4260) in molecular picture[a]

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Outline

Background–Experimental status of $Y(4260)$

- BaBar: $e^+e^- \to \gamma_{\rm ISR} J/\psi\pi^+\pi^-$, Phys. Rev. Lett. **95**, 142001 (2005)
  $M = (4259 \pm 8^{+2}_{-6})$ MeV and $\Gamma = 50 \sim 90$ MeV.
  Confirmed by Belle and CLEO later.
- BESIII:
  - $e^+e^- \to J/\psi\pi^+\pi^-$, $Y(4260)$ contains two strictures $Y(4220)$ and $Y(4320)$ Phys. Rev. Lett. **118**, 092001 (2017)
  - $e^+e^- \to \omega\chi_{c0}$, Phys. Rev. **D93**, 011102 (2016)
  - $e^+e^- \to \pi^+\pi^- h_c$, Phys. Rev. Lett. **118**, 092002 (2017)
  - $e^+e^- \to D^0 D^{*-}\pi^+ +$ c.c. Phys. Rev. Lett.**122**.102002
  - $e^+e^- \to \eta J/\psi$ arXiv:2003.03705 [hep-ex]

  $M = (4219.6 \pm 3.3 \pm 5.1)$ MeV and $\Gamma = (56.0 \pm 3.6 \pm 6.9)$ MeV.
  Phys. Rev. **D95**, 092007 (2017)

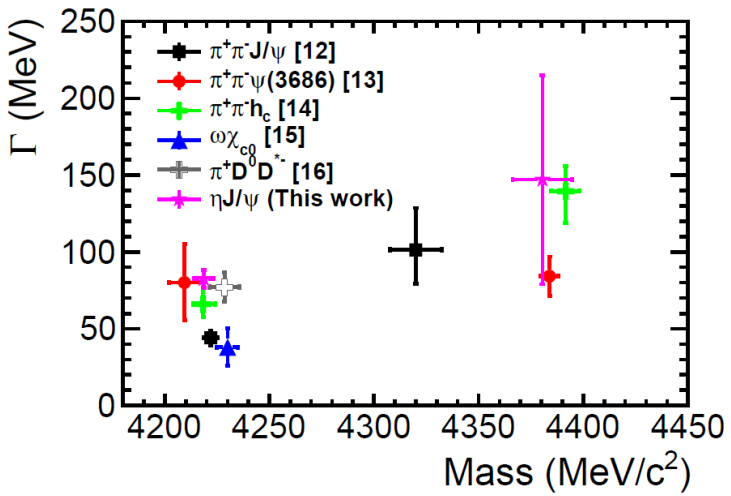

Figure: Mass of $Y(4220)$ from BESIII experiments arXiv:2003.03705 [hep-ex]

Background–Theoretical status of $Y(4260)$

- Charmonium $\psi(4S)$ or $\psi(4D)$
- Tetraquark states
- Molecular states: $D\bar{D}_1$
- Hybrid charmonium
- Non-resonant structures.

Phys. Rept. **639**, 1-121 (2016)

Purpose: Calculate explicitly the binding energy of $D\bar{D}_1$ system by solving the Schrödinger equation.

Hadronic molecules

- Hadronic molecule: shallow bound states of hadrons $\rightarrow$ Non-relativistic limit
- Interaction $\rightarrow$ Amplitude $\mathcal{M} \rightarrow$ Potential $V(\boldsymbol{q}) \rightarrow$ Schrödinger equation or LS equation $\rightarrow$ Bound states.
- Interaction: EFT with chiral symmetry and heavy quark spin symmetry (HQSS)
- Non-relativistic limit $\rightarrow$

$$V(\boldsymbol{q}) = \frac{-\mathcal{M}}{4m_1 m_2} \tag{1}$$

Meson exchange potential

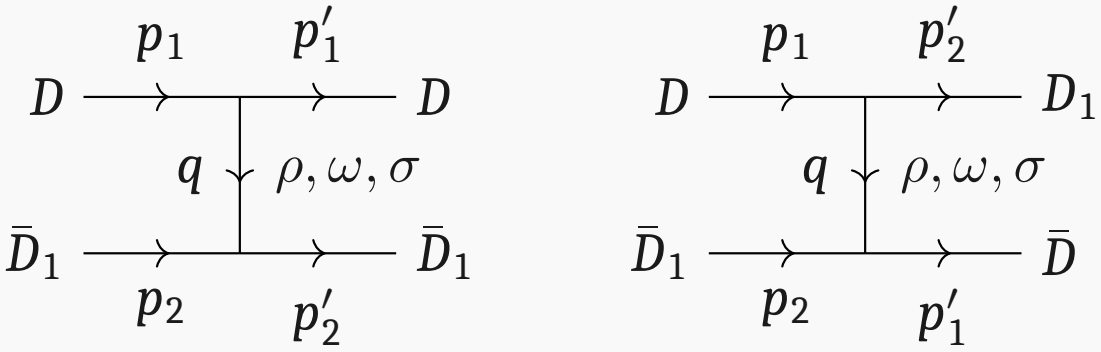

Figure: Feynman diagrams for vector meson and σ exchange between $D\bar{D}_1 + \text{c.c.}$. The right diagram has opposite sign in $C = +$ and $C = -$ cases.

$$1^{-+} : \frac{1}{\sqrt{2}} \left(|D\bar{D}_1\rangle + |\bar{D}D_1\rangle \right) \tag{2}$$

$$1^{--} : \frac{1}{\sqrt{2}} \left(|D\bar{D}_1\rangle - |\bar{D}D_1\rangle \right). \tag{3}$$

Decays

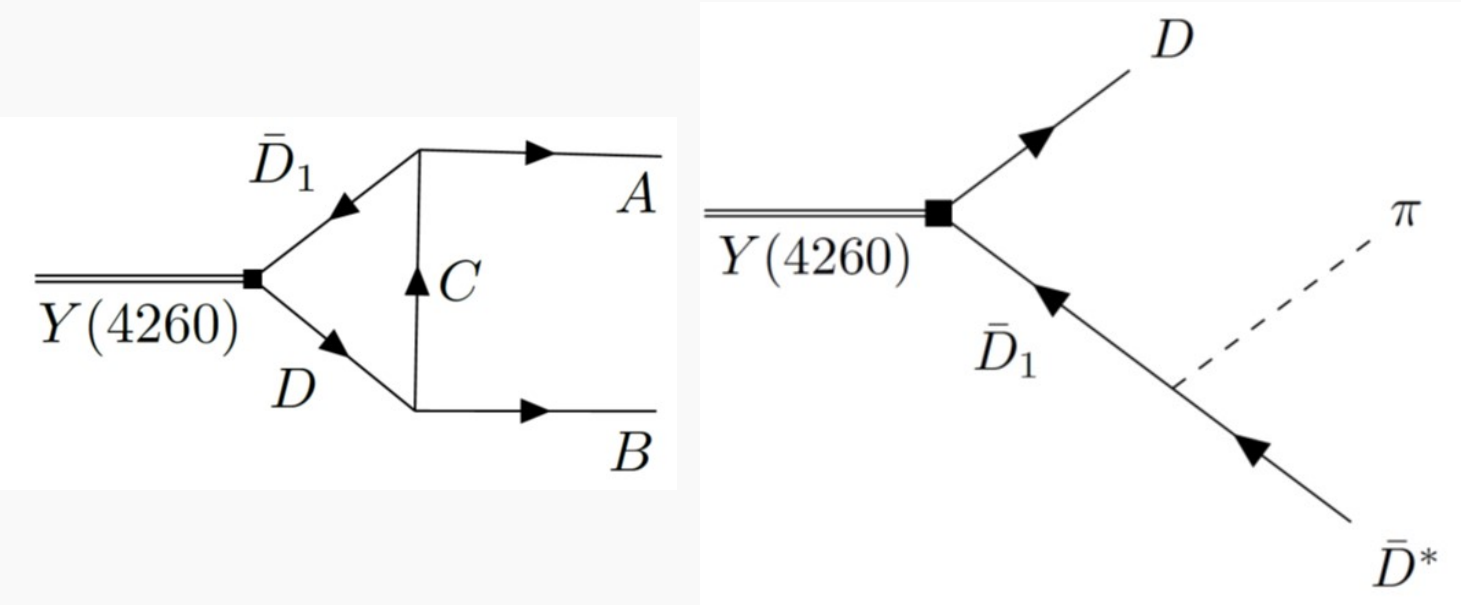

Figure: Feynman diagrams for the 2- and 3-body decays of $Y(4260)$. They are similar for $\eta_{c1}(4240)$.

Decays

Table: Two-body decay channels for the $D\bar{D}_1$ + c.c. molecule states considered in our calculation.

Molecule	Components	Final states	Exchanged particles
1^{--} $Y(4260)$	$D\bar{D}_1$ +c.c.	$\omega\sigma, J/\psi\sigma, \omega\chi_{c0}$	D
		$\bar{D}D^*, J/\psi\eta, \rho\pi$	D^*, ρ, ω
		$h_c\eta, Z_c\pi$	D^*
		$\bar{D}^*D^*$	π
		$\bar{D}D$	ρ, ω
1^{-+} $\eta_{c1}(4240)$	$D\bar{D}_1$ +c.c.	$\bar{D}D^*, \rho\pi$	D^*, ρ, ω
		$\chi_{c1}\eta, Z_c\pi$	D^*
		$\bar{D}^*D^*, J/\psi\omega$	π, D
		$\pi\pi, \eta_c\eta, \bar{D}D$	D^*, ρ, ω
		$\chi_{c0}\sigma$	D

Results

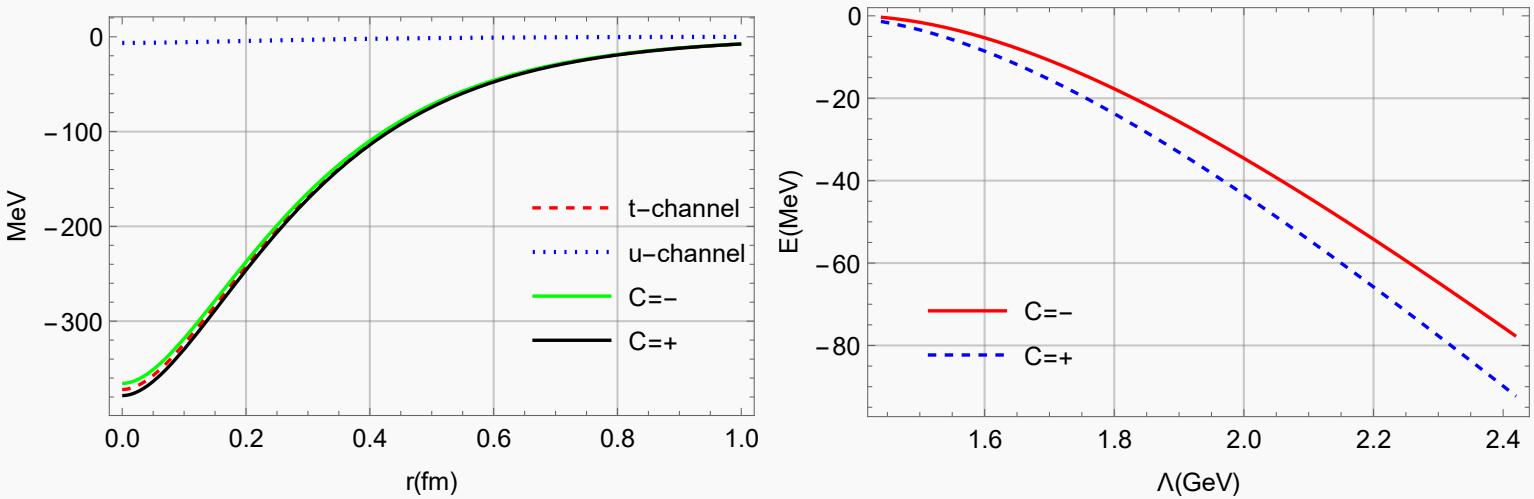

Figure: Left: The total potentials with $\Lambda = 1.5$ GeV. Right: Dependence of binding energies on the cutoff Λ.

Decay Width

Mode	Widths (MeV)					
	1^{--} $Y(4260)$			1^{-+} $\eta_{c1}(4240)$		
	$\Lambda_1 = 1.5$	$\Lambda_1 = 2.0$	$\Lambda_1 = 2.4$	$\Lambda_1 = 1.5$	$\Lambda_1 = 2.0$	$\Lambda_1 = 2.4$
$\pi\pi$	0	0	0	0.4	3.7	9.6
$D^*\bar{D}^*$	18.1	26.7	31.3	20.2	29.4	33.5
πZ_c	$\sim$0	$\sim$0	$\sim$0	$\sim$0	$\sim$0	$\sim$0
$\pi\rho$	0.1	0.8	2.3	0.06	0.4	1.3
$D\bar{D}$	0.02	0.02	0.02	0.02	0.02	0.02
$\eta\eta_c$	0	0	0	3.9	13.9	22.7
$\eta\chi_{c1}$	0	0	0	4.1	11.7	17.4
ηh_c	1.3	3.9	5.8	0	0	0
$\sigma\chi_{c0}$	0	0	0	0.4	1.0	1.3
$\eta J/\psi$	0.4	1.4	2.6	0	0	0
$\sigma J/\psi$	0.03	0.1	0.2	0	0	0
$\omega\sigma$	0.04	0.3	0.8	0	0	0
$\omega J/\psi$	0	0	0	0.003	0.01	0.02
$\omega\chi_{c0}$	0.03	0.09	0.1	0	0	0
$D\bar{D}^*$	0.04	0.07	0.08	0.04	0.06	0.08
$D\bar{D}^*\pi$	1.9	1.9	1.9	3.0	3.0	3.0
Total	21.9	35.3	45.1	32.1	63.2	88.9

Conclusion and outlook

- Schrödinger equation $\rightarrow 1^{--}$ and 1^{-+} $D\bar{D}_1$ + c.c. bound states.
- Binding energy and decay width of the 1^{--} molecule are consistent with the $Y(4260)$.
- The C-partner 1^{-+} molecule is predicted at around 4240 MeV. $\eta\eta_c$ and $\eta\chi_{c1}$ channels.
- Heavy Quark Symmetry, as well as $SU(3)_f$ symmetry, predicts other possible bound states: D^*D_1, $D^{(*)}D_2$,their D_s partners and bottom partners.

Thank you!