Prediction of a 0^{--} exotic state and its possible detection

Teng Ji

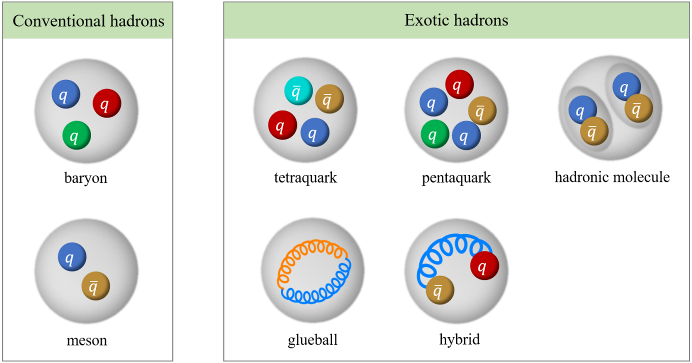
Institute of Theoretical Physics, CAS

Based on T. Ji, X.-K. Dong, F.-K. Guo and B.-S. Zou, Phys.Rev.Lett. 129 (2022) 10, 102002

April 8, 2023

2023 BESIII Charm Physics Workshop

Background



- Exotic quantums number such as $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}$.
- Some of 1^{-+} have been observed such as $\pi_1(1400), \pi_1(1600), \eta_1(1855)$.
- No 0^{--} has been observed yet.

Background

- $\psi(4230)$, which is called $Y(4260)$ previously, is a good candidate of hadronic molecules of 1^{--} $D\bar{D}_1$.
- Under HQSS, D and D^* belong to $s_\ell = 1/2$ multiplet, D_1 and D_2 belong to $s_\ell = 3/2$ multiplet.
- According to the experimental data:

$$m_{\psi(4360)} - m_{\psi(4230)} \approx m_{D^*} - m_D,$$
$$m_{\psi(4415)} - m_{\psi(4360)} \approx m_{D_2^*} - m_{D_1}.$$

- It is natural to treat $\psi(4360)$ and $\psi(4415)$ as hadronic molecules of 1^{--} $D^*\bar{D}_1$ and $D^*\bar{D}_2$ respectively.

Framework

Table 1: The hadronic molecules considered in this work and their possible experimental candidates. The masses with † are the experimental values of their candidates.

Molecule	Components	J^{PC}	Candidates	Mass (GeV)	E_B MeV
$\psi(4230)$	$\frac{1}{\sqrt{2}}(D\bar{D}_1 - \bar{D}D_1)$	1^{--}	$\psi(4230)$	$4.220 \pm 0.015^{\dagger}$	67 ± 15
$\psi(4360)$	$\frac{1}{\sqrt{2}}(D^*\bar{D}_1 - \bar{D}^*D_1)$	1^{--}	$\psi(4360)$	$4.368 \pm 0.013^{\dagger}$	62 ± 14
$\psi(4415)$	$\frac{1}{\sqrt{2}}(D^*\bar{D}_2 - \bar{D}^*D_2)$	1^{--}	$\psi(4415)$	$4.421 \pm 0.004^{\dagger}$	49 ± 4
$\psi_0(4360)$	$\frac{1}{\sqrt{2}}(D^*\bar{D}_1 - \bar{D}^*D_1)$	0^{--}	-	-	-

- $\psi(4230), \psi(4360)$ and $\psi(4415)$ as inputs to **predict the existence of $\psi_0(4360)$**.

Framework

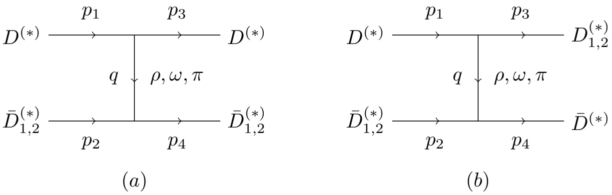


Figure 1: Feynman diagrams for the P, V-exchange potential. We will only consider t-channel firstly.

- $\mathcal{M}_{ij} = \frac{A_{ij}^V}{\boldsymbol{q}^2 + m_V^2} + \frac{A_{ij}^P}{\boldsymbol{q}^2 + m_P^2} + c_V B_{ij}^V + c_P B_{ij}^P$. c_V and c_P for renormalization.
- $V_{ij} = -\frac{1}{\Pi_{\alpha=1}^4 \sqrt{2m_\alpha}} \mathcal{M}_{ij} * e^{-\boldsymbol{q}^2/\Lambda^2}$, taking it into LSE to obtain $E_{B,ii}$.
- $\chi^2 \equiv \sum_i \left(\frac{E_{B,ii} - E_{\mathrm{exp},ii}^{\mathrm{cen}}}{E_{\mathrm{exp},ii}^{\mathrm{err}}} \right)^2$, minimizing χ^2 to obtain proper c_V, c_P, Λ.
- Predicting the properties of $\psi_0(4360)$.

t-channel results

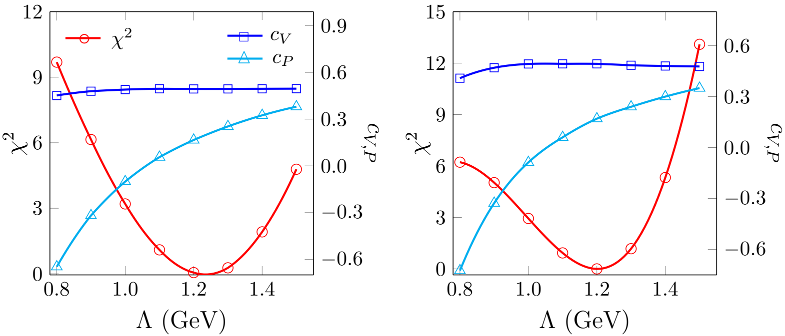
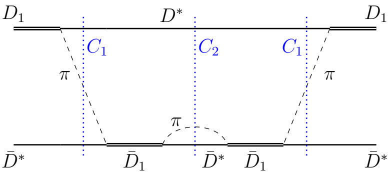


Figure 2: The best fitting for the single-channel (left) and coupled-channel (right) cases whose $c_V = 0.50$, $c_P = 0.18$

u-channel considered



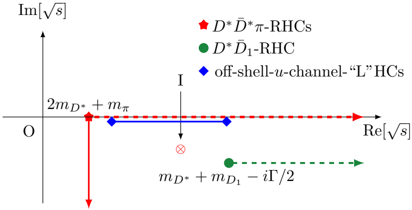


Figure 3: Illustration of three-body cuts (vertical dotted lines) and the cuts encountered in the $D^*\bar{D}_1$ system.

Table 2: Pole positions relative to the $D^*\bar{D}_1$ threshold in units of MeV with $c_V = 0.50$, $c_P = 0.18$.

System	1^{--}		0^{--}	
t-channel	-63.5 ± 13.8		-72.4 ± 17.4	
g_S	g_{S0}	g_{S1}	g_{S0}	g_{S1}
C_2	$-61.5 - 3.5i$	$-61.5 - 9.2i$	$-70.0 - 3.5i$	$-70.0 - 8.9i$
$C_1\&C_2$	$-65.8 - 6.6i$	$-73.1 - 14.2i$	$-65.8 - 0.30i$	$-59.4 - 1.1i$

We predict $m_{\psi_0} = 4366 \pm 18$ MeV and $\Gamma_{\psi_0} < 10$ MeV.

Experimental search

- The only channel for $\psi_0(4360)$ production in e^+e^- annihilation at $\sqrt{s} \sim 5$ GeV is P-wave $\eta\psi_0(4360)$.
- Hard to be distinguished from $\eta\psi(4360)$ with only invariant mass distribution of, e.g., $D\bar{D}^*$.
- Angular distribution is necessary.
- $e^+e^- \to \gamma^* \to \eta(p_1) + \psi_0(p_2)$

$$\mathcal{M}_0 \propto \epsilon(\gamma^*) \cdot q \tag{1}$$

- $e^+e^- \to \gamma^* \to \eta(p_1) + \psi(p_2)$

$$\mathcal{M}_1 \propto \epsilon_{\alpha\beta\gamma\delta}\epsilon^{\alpha}(\gamma^*)\epsilon^{*\beta}(\psi)P^{\gamma}q^{\delta} \tag{2}$$

where $P = p_1 + p_2$, $q = p_1 - p_2$.

Experimental search

- Polarizations of γ^* from e^+e^- are $m = \pm 1$, and $m = 0$ is suppressed.
- Sum over initial and final polarizations we have

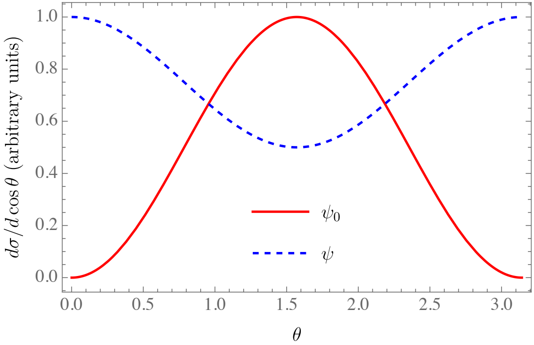


Figure 4: Angular distribution of $e^+e^- \to \eta\psi_{(0)}$. θ is the angle between the outgoing η and initial e^+e^- beam.

Summary

- Exotic $D^*\bar{D}_1$ molecules denoted as $\psi_0(4360)$ has been predicted from **t-channel** meson exchange.
- **Contact terms** are determined by reproducing the **experimental values** of $\psi(4230)$, $\psi(4360)$ and $\psi(4415)$ binding energies.
- Coupled-channel effects are found **negligible**.
- 3-body effects to the $D^*\bar{D}_1$ molecules are investigated.
- The effects of **u-channel π exchange** will change the binding energy by $\lesssim 10\ \mathrm{MeV}$, not change the qualitative conclusions.
- $\psi_0(4360)$ can be searched for in the $D^*\bar{D}^*$ final state in $e^+e^- \to \eta\psi_0 \to \eta D\bar{D}^*$ and it is **distinguishable** from $e^+e^- \to \eta\psi \to \eta D\bar{D}^*$.

Thank You!