Prediction of a narrow 0^{--} exotic hadronic state

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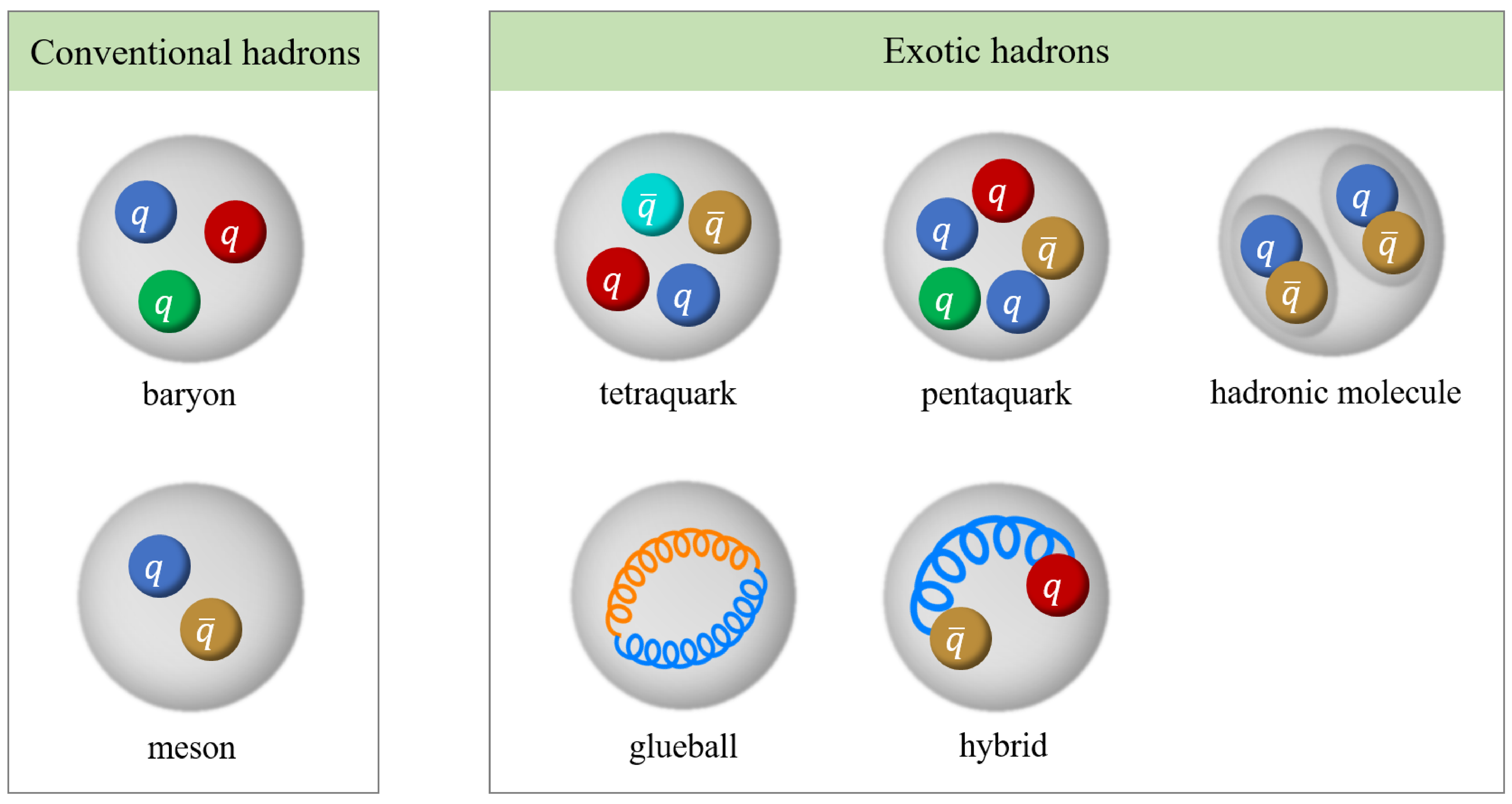
Abstract

Lots of charmonium-like structures have been observed in the last two decades. Most of them have quantum numbers that can be formed by a pair of charm and anticharm quarks, thus it is difficult to unambiguously identify the exotic ones among them. By exploiting heavy quark spin symmetry, we present a robust prediction of the hadronic molecular scenario, where the $\psi(4230)$, $\psi(4360)$ and $\psi(4415)$ are identified as $D\bar{D}_1$, $D^*\bar{D}_1$ and $D^*\bar{D}_2^*$ bound states, respectively. We show that a flavor-neutral charmonium-like exotic state with quantum numbers $J^{PC}=0^{--}$, denoted as $\psi_0(4360)$, should exist as a $D^*\bar{D}_1$ bound state. The mass and width of the $\psi_0(4360)$ are predicted to be (4366 ± 18) MeV and less than 10 MeV, respectively. The $\psi_0(4360)$ is significant in two folds: no 0^{--} hadron has been observed so far, and a study of this state will enlighten the understanding of the mysterious vector mesons between 4.2 and 4.5 GeV, as well as the nature of previously observed exotic Z_c and P_c states. We propose that such an exotic state can be searched for in $e^+e^-\to\eta\psi_0(4360)$ and uniquely identified by measuring the angular distribution of the outgoing η meson.

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.

Method

Table 1: The hadronic molecules considered here and their possible experimental candidates. The masses with † are the experimental values.

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^{--}	$\psi(4230)$	$4.220\pm0.015^\dagger$	67 ± 15
$\psi(4360)$	$\frac{1}{\sqrt{2}}(D^*\bar{D}_1-\bar{D}^*D_1)$	1^{--}	$\psi(4360)$	$4.368\pm0.013^\dagger$	62 ± 14
$\psi(4415)$	$\frac{1}{\sqrt{2}}(D^*\bar{D}_2-\bar{D}^*D_2)$	1^{--}	$\psi(4415)$	$4.421\pm0.004^\dagger$	49 ± 4
$\psi_0(4360)$	$\frac{1}{\sqrt{2}}(D^*\bar{D}_1+\bar{D}^*D_1)$	0^{--}	-	-	-

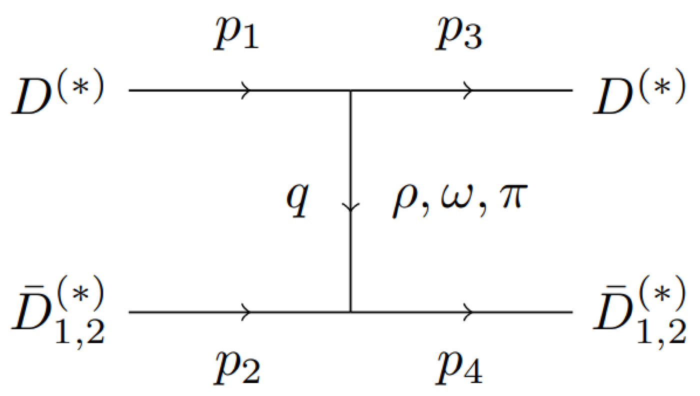


Figure 1: Feynman diagrams for the t channel P,V-exchange potential.

- $\mathcal{M}_{ij}=\frac{A^V_{ij}}{\boldsymbol{q}^2+m_V^2}+\frac{A^P_{ij}}{\boldsymbol{q}^2+m_P^2}+c_VB^V_{ij}+c_PB^P_{ij}$.
- $\psi(4230),\psi(4360)\,\&\,\psi(4415)$ as inputs.
- Defining $\chi^2=\sum_i\left(\frac{E_{B,ii}-E^{\rm cen}_{{\rm exp},ii}}{E^{\rm err}_{{\rm exp},ii}}\right)^2$.
- Minimizing χ^2 to obtain proper c_V,c_P,Λ.
- Predicting the properties of $\psi_0(4360)$.

About the presenter (Teng Ji)

- 2014 – 2018, undergraduate student, East China University of Science and Technology;
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Method

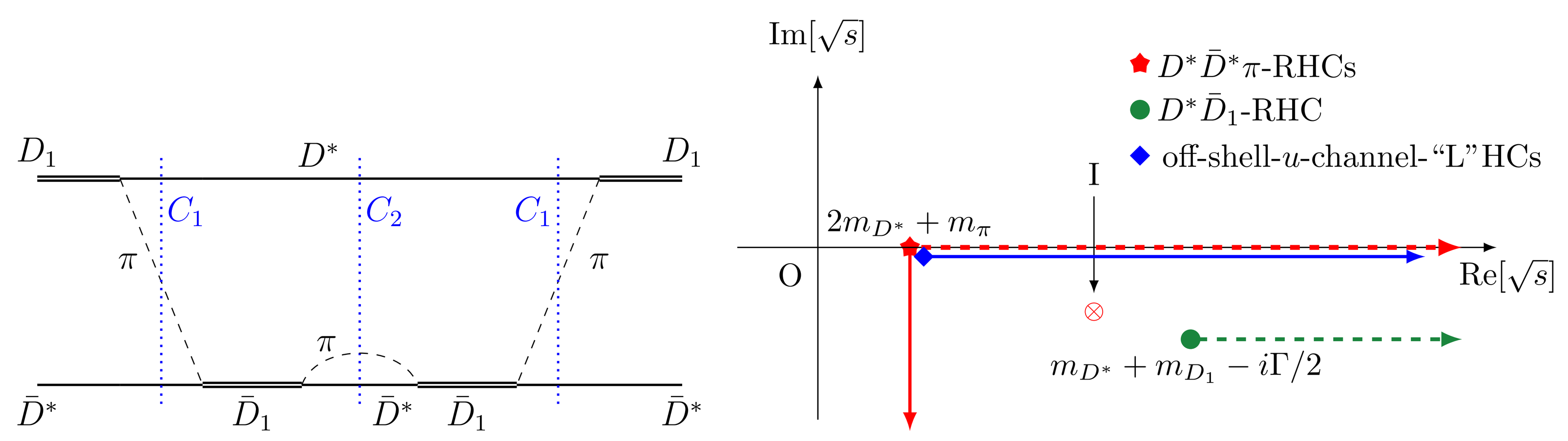

Figure 2: **Left**:An illustration of the three-body cuts (vertical dotted lines) introduced by the simultaneous onshellness of the intermediate particles. **Right**: The cuts encountered in the $D^*\bar{D}_1$ system.

Results

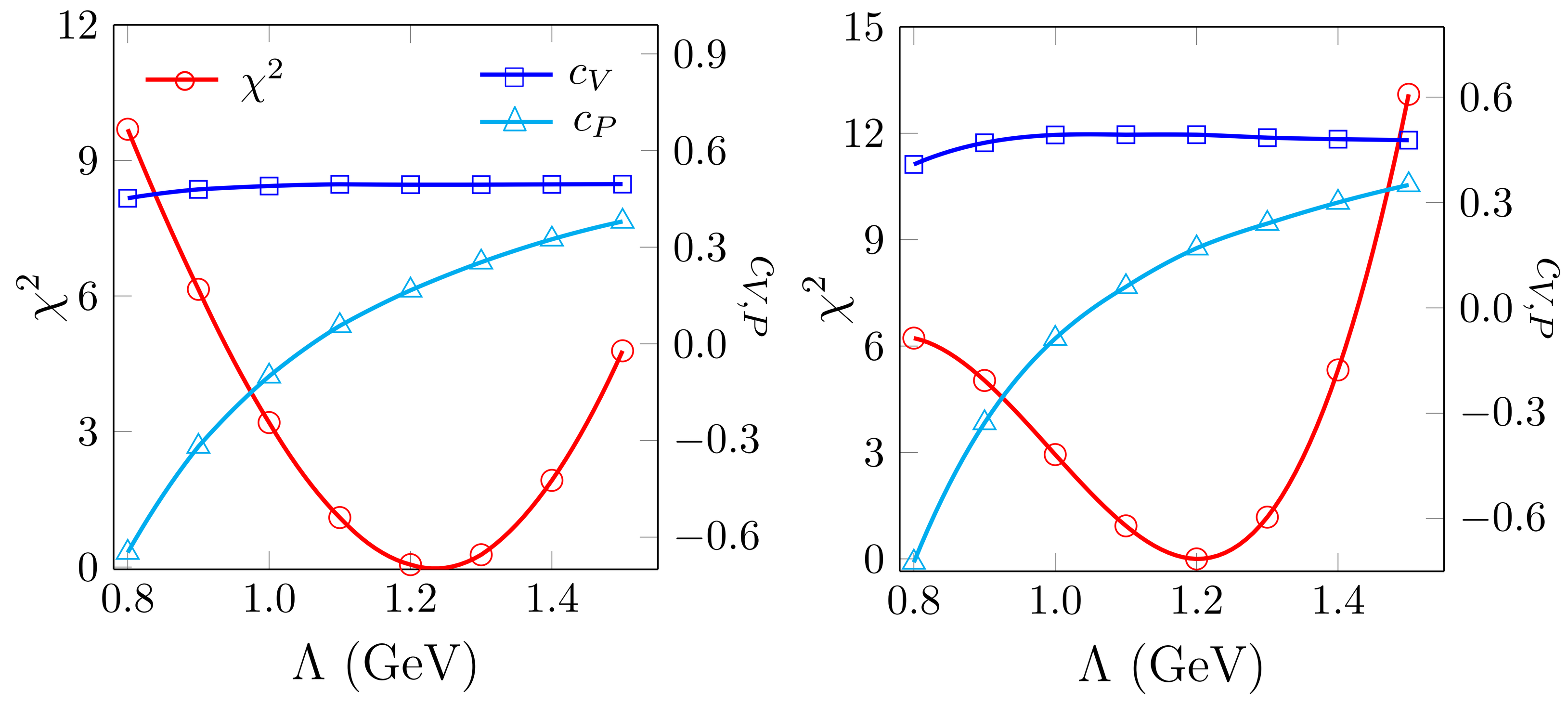

Figure 3: The best fitting for the single-channel (left) and coupled-channel (right) cases whose $c_V=0.50, c_P=0.18$

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

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 $m_{\psi_0}=4366\pm18$ MeV and $\Gamma_{\psi_0}<10$ MeV.

Experimental Search

- The only channel for $\psi_0(4360)$ production in e^+e^- annihilation at $\sqrt{s}\sim5$ 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.

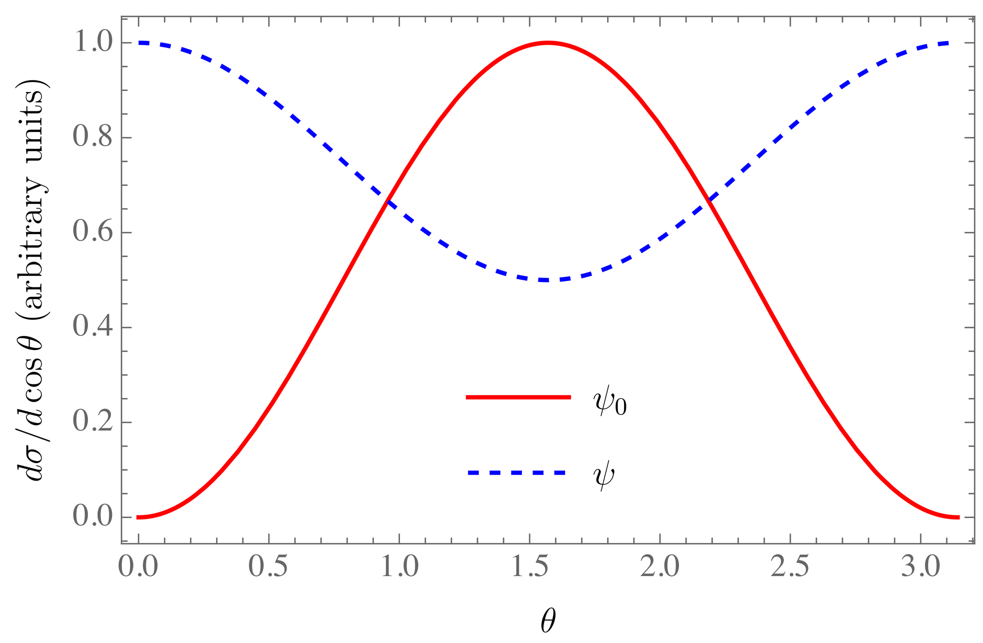

Figure 4: Angular distribution of $e^+e^-\to\eta\psi_{(0)}$. θ is the angle between the outgoing η and initial e^+e^- beam.

- BaBar and Belle, e^+e^- collision, ISR or B decay.
- LHCb, pp collision.
- BEPCII, which will be upgraded to about 5.6 GeV.