Understanding the 0^{++} and 2^{++} charmonium(-like) states near 3.9 GeV

Teng Ji

Institute of Theoretical Physics, CAS

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Charmonium(-like) states near 3.9 GeV

$X(3915)$: $\gamma\gamma \to J/\psi\omega$

- Belle: 0^{++} or 2^{++};
- BaBar: assuming helicity -2 dominant, 0^{++}, excluding 2^{++};
- $X(3915)$ is assigned to $\chi_{c0}(2P)$ in RPP;
- Discarding helicity-2 assumption, reanalysing BaBar's datas, arguing the possibility of 2^{++} *Z.Y. Zhou, et al., PRL115(2015)2,022001*.

$X(3930)$: $\gamma\gamma \to D\bar{D}$, $pp \to D\bar{D} + \text{anything}$ and $B \to D\bar{D}K$

- Belle and BaBar: 2^{++};
- LHCb: $0^{++}(\chi_{c0}(3930))$ and $2^{++}(\chi_{c2}(3930))$ coexist in the process of $B \to D\bar{D}K$.

$X(3960)$: $B \to D_s\bar{D}_sK$

- Candidate of $D_s\bar{D}_s$ molecular state *T. Ji, et al., PRD106(2022)9,094002*.

Our viewpoint

- Quantum numbers of $X(3915)$ is 2^{++};
- $X(3960)$ is $D_s^+ D_s^-$ molecular state;
- The peak structure in the $D^+ D^-$ invariant mass distribution near 3.93 GeV ($B^+ \to K^+ D^+ D^-$ process and $\gamma\gamma \to D\bar{D}$ process) includes two components: $X(3915)$ and $X(3960)$.
- Combined fitting the experiment data from LHCb and Belle: $(I)J^{PC} = (0)0^{++}$ $H\bar{H}$ re-scattering, 2^{++} BW and 0^{++} BW background in $\gamma\gamma \to D\bar{D}$.

$H\bar{H}$ re-scattering amplitute

- 0^{++} coupled channel: $D\bar{D}$, $D_s\bar{D}_s$, $D^*\bar{D}^*$, $D_s^*\bar{D}_s^*$.
- Interaction: $V_{ij} = 4\sqrt{m_{i1}m_{i2}m_{j1}m_{j2}}\,\tilde{V}_{ij}$, where

$$\tilde{V} = \frac{1}{2}\begin{pmatrix} 2\mathcal{C}_{0a} & \sqrt{2}(\mathcal{C}_{0a}-\mathcal{C}_{1a}) & 2\sqrt{3}\mathcal{C}_{0b} & \sqrt{6}(\mathcal{C}_{0b}-\mathcal{C}_{1b}) \\ \sqrt{2}(\mathcal{C}_{0a}-\mathcal{C}_{1a}) & \mathcal{C}_{0a}+\mathcal{C}_{1a} & \sqrt{6}(\mathcal{C}_{0b}-\mathcal{C}_{1b}) & \sqrt{3}(\mathcal{C}_{0b}+\mathcal{C}_{1b}) \\ 2\sqrt{3}\mathcal{C}_{0b} & \sqrt{6}(\mathcal{C}_{0b}-\mathcal{C}_{1b}) & 2(\mathcal{C}_{0a}-2\mathcal{C}_{0b}) & \begin{matrix}\sqrt{2}(\mathcal{C}_{0a}-2\mathcal{C}_{0b} \\ -\mathcal{C}_{1a}+2\mathcal{C}_{1b})\end{matrix} \\ \sqrt{6}(\mathcal{C}_{0b}-\mathcal{C}_{1b}) & \sqrt{3}(\mathcal{C}_{0b}+\mathcal{C}_{1b}) & \begin{matrix}\sqrt{2}(\mathcal{C}_{0a}-2\mathcal{C}_{0b} \\ -\mathcal{C}_{1a}+2\mathcal{C}_{1b})\end{matrix} & \begin{matrix}(\mathcal{C}_{0a}-2\mathcal{C}_{0b} \\ +\mathcal{C}_{1a}-2\mathcal{C}_{1b})\end{matrix} \end{pmatrix}.$$

- Scattering amplitude:

$$T = (1 - VG)^{-1}V,$$

where G is a 4×4 diagonal matrix, whose diagonal elements are the corresponding propagators of each channel.

Fitting result

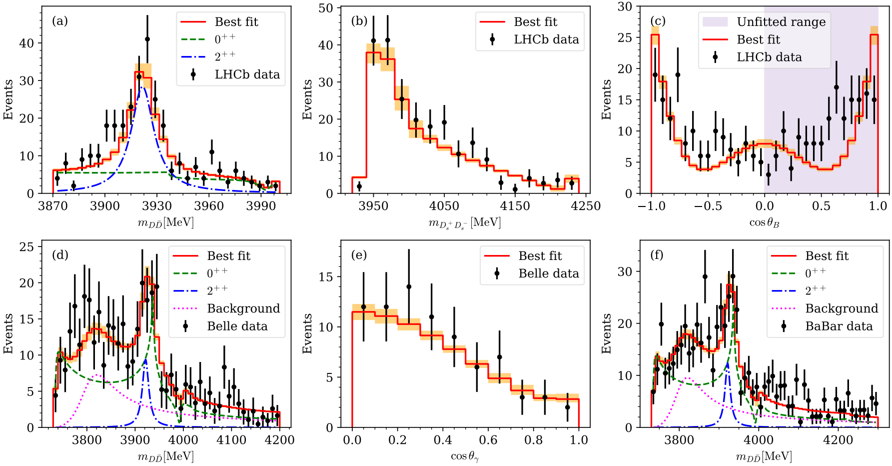

Figure 1: Best fitting with $\chi^2/\mathrm{d.o.f.} = 176.5/(173-20) = 1.15$.

Fitting result

- LECs from best fitting:

$$\mathcal{C}_{0X} = -0.73\ \mathrm{fm}^2 \text{(fixed)}$$
$$\mathcal{C}_{1X} = (-0.33 \pm 0.02)\ \mathrm{fm}^2$$
$$\mathcal{C}_{0a} = (-1.36 \pm 0.06)\ \mathrm{fm}^2$$
$$\mathcal{C}_{1a} = (-0.33 \pm 0.02)\ \mathrm{fm}^2$$

- 2^{++} coefficient

$$m_2 = (3922 \pm 2)\,\mathrm{MeV}, \quad \Gamma_2 = (16 \pm 3)\,\mathrm{MeV},$$

which in consistent with $m_2 = (3918.4 \pm 1.9)\,\mathrm{MeV}$, $\Gamma_2 = (20 \pm 5)\,\mathrm{MeV}$ in RPP.

- 0^{++} background: $\chi_{c0}(2P)$?

$$m_0 = (3815 \pm 10)\,\mathrm{MeV}, \quad \Gamma_0 = (90 \pm 13)\,\mathrm{MeV}.$$

- $H_{\gamma 2}/H_{\gamma 0} = 0.8 \pm 0.7$, which does not support the helicity-2 assumption.

Pole positions of 0^{++} coupled channel

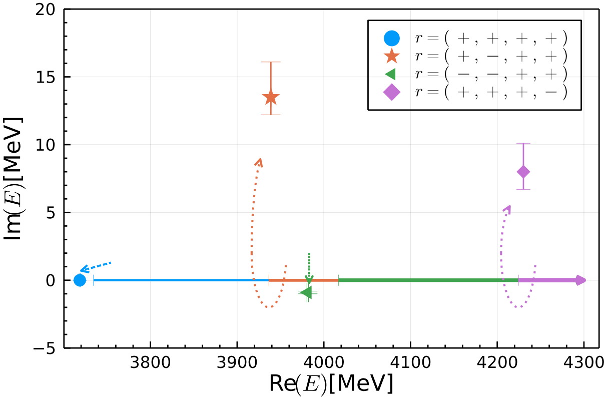

Figure 2: Pole positions and their errors from the best fitting parameters.

$D\bar{D}$ invariant mass distribution

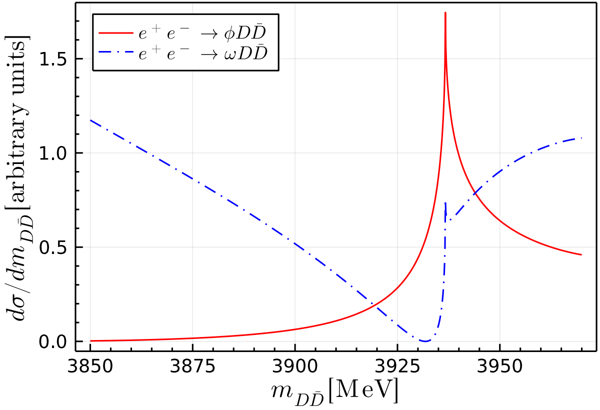

Figure 3: Predicted line shapes of $D\bar{D}$ invariant mass distribution at $E_{e^+e^-} = 5.4\,\text{GeV}$.

Summary

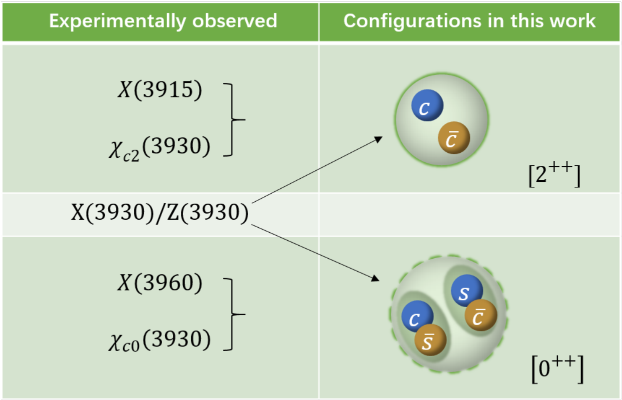

Figure 4: The structures which have been observed near 3.9 GeV and our assuming configurations.