Hadron Loop Effects on Exotic Charm Mesons

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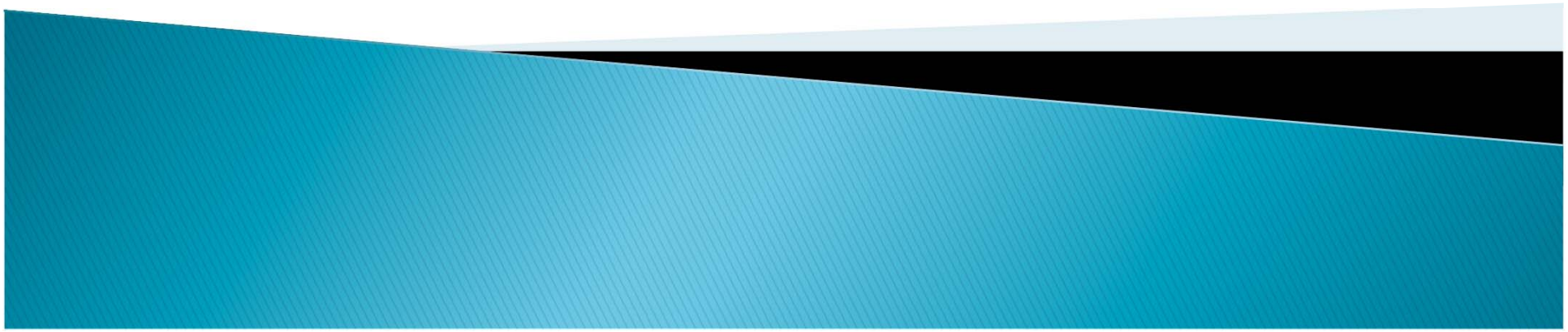

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About X(3872)

- First observation: 2003, Belle, KEKB
- $B^- \rightarrow K^- \pi^+ \pi^- J/\psi$ decay
  Sharp peak of the invariant mass distribution of $\pi^+ \pi^- J/\psi$
- Mass: (3871.4 ± 0.6) MeV
- Width: less than 2.3 MeV
- Quantum Number: $J^{PC} = 1^{++}$
- Other decay mode:
  $X(3872) \rightarrow \gamma J/\psi$、 $X(3872) \rightarrow \pi^+ \pi^- \pi^0 J/\psi$

Problems of X(3872) as C C-bar State

- Ground state energy of $^3P_1$ c c-bar state by the quark model is 3950 MeV, which is about 80 MeV higher than the observed mass of X(3872).

- If X(3872) is c c-bar state, it is isoscalar.
  $X(3872) \rightarrow \rho^0 J/\psi \rightarrow \pi^+ \pi^- J/\psi$: isovector
  This decay means large isospin breaking.

- Is X(3872) isospin mixed state?

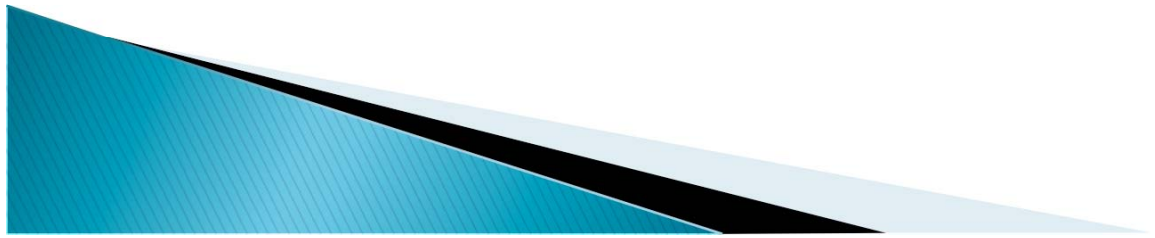
D^0 D^{*0}-bar Molecule

- $m_D + m_{D^*} = (3871.81 \pm 0.36)$ MeV
  X(3872) is a very shallow bound state of D^0 D^{*0}-bar D^0 D^{*0}-bar Molecule
- How about the production rate of such molecular-like state by the B-decay?
- How about cusp
- $m_\rho + m_{J/\psi} = 775 + 3097 = 3872$ MeV
- $m_\omega + m_{J/\psi} = 783 + 3097 = 3880$ MeV

Tetra quark

- Color triplet scalar Diquark + vector antidiqaurk structure
- Compact object: easy to create.

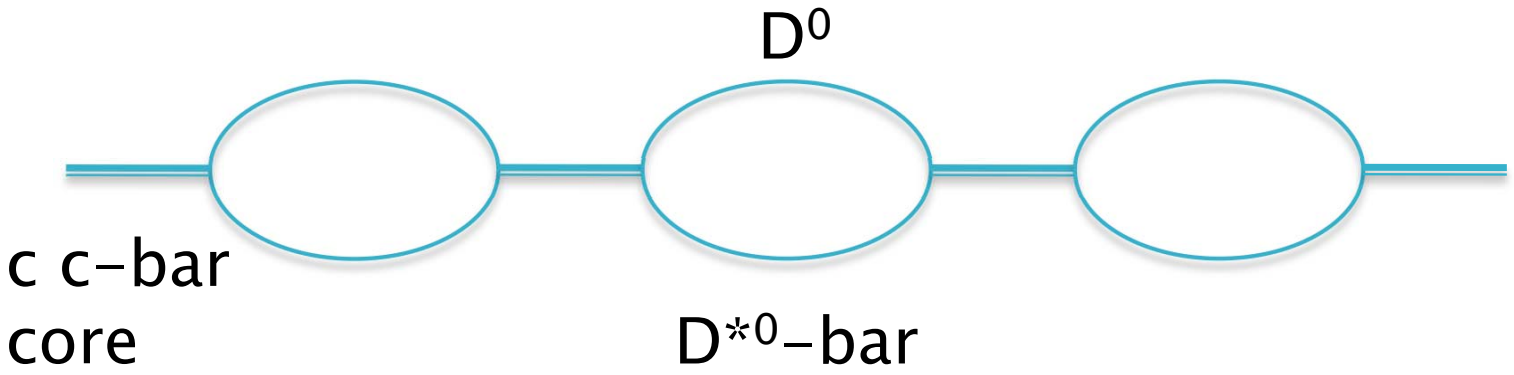
- Isospin multiplets with electric charge states should exist, but not observed.



Purpose

- To study the hadron loop effects: intermediate state of D^0 D^{*0}-bar
- Intermediate states of D^0 D^{*0}-bar + ω J/ψ: difference of the threshold
- Calculate the energy spectrum using the Green's function method with simple separable interaction. We study only the qualitative feature.

Coupling between C C-bar core and D^0 D^{*0}-bar



Coupling between C C-bar core and D^0 D^{*0}-bar

- cc-bar core state: $|X\rangle$

$$S(E) = \frac{-1}{\pi}\mathrm{Im}\langle X|G(E)|X\rangle$$

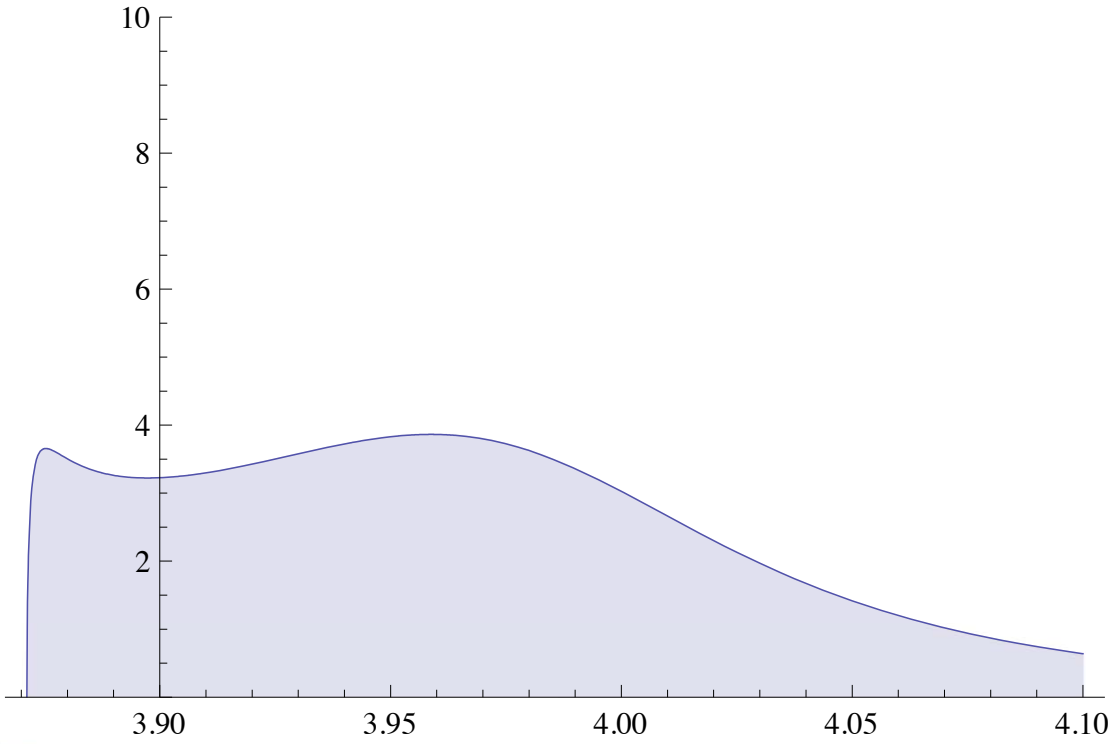
$$G(E) = \frac{1}{E - \hat{H} - i\varepsilon}$$

$$G(E) = G_X^0(E) + G_X^0(E)V_{XDD^*}G_{DD^*}^0(E)V_{XDD^*}G_X^0(E) + \cdots$$

$$\left\langle D^0\overline{D^{*0}}(\vec{q})\middle|V_{XDD^*}\middle|X\right\rangle = \frac{g}{\vec{q}^2 + \Lambda^2}$$

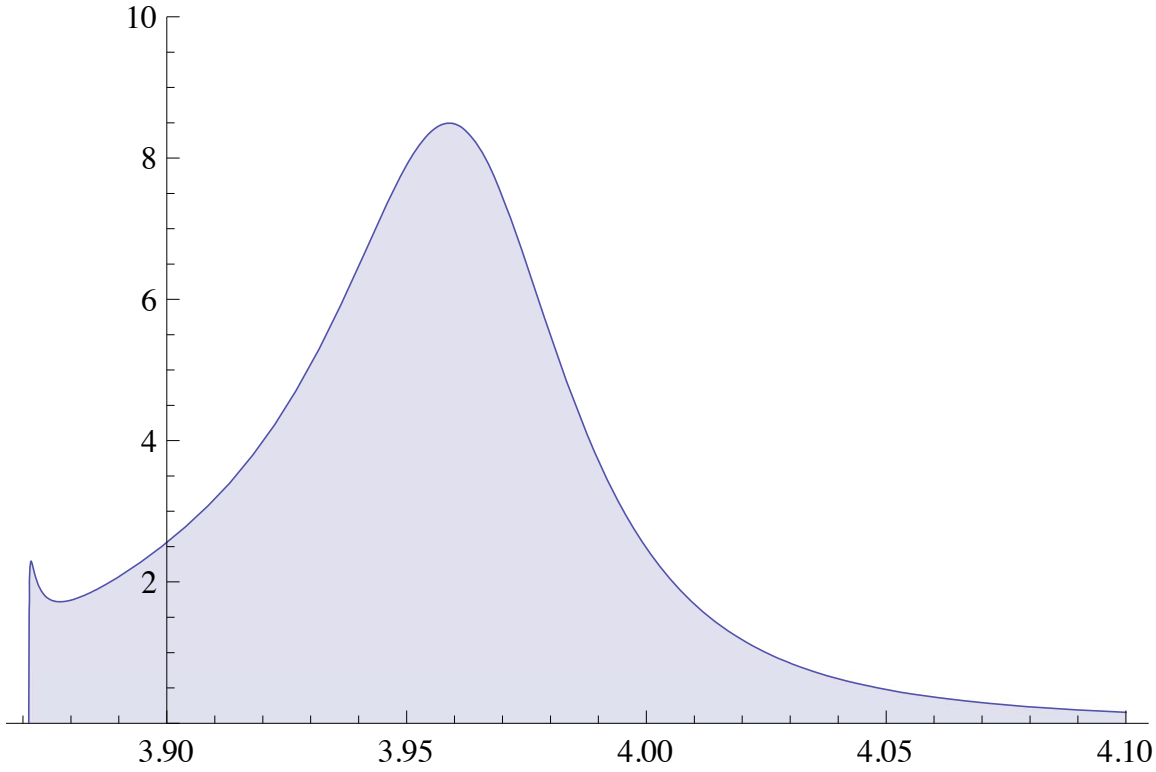
Coupling between C C-bar core and D0 D*0-bar

- Λ = 500MeV、 g = 0.03、 cc-bar core mass = 3950 MeV Bound state：3863 MeV

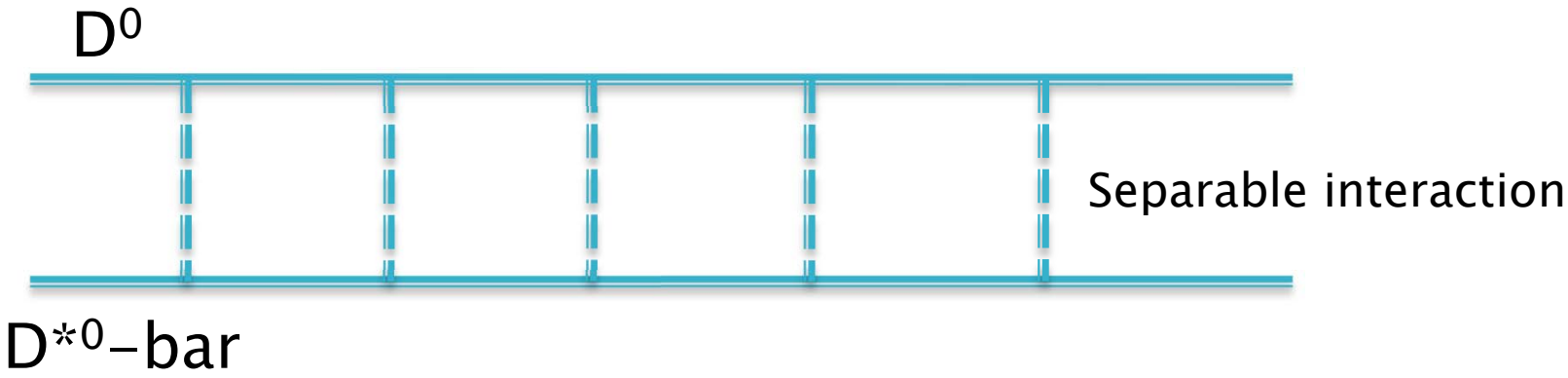


Coupling between C C-bar core and D0 D*0-bar

- Λ = 200MeV、 g = 0.01、 cc-bar core mass = 3950 MeV　Bound state：3862 MeV



D^0 D^{*0}-bar molecule



D^0 D^{*0}-bar molecule

$$\left|D^0\overline{D^{*0}}\right\rangle = \frac{\sqrt{\Lambda}}{\pi}\int d^3\vec{q}\,\frac{1}{\vec{q}^{\,2}+\Lambda^2}\left|D^0\overline{D^{*0}}(\vec{q})\right\rangle$$

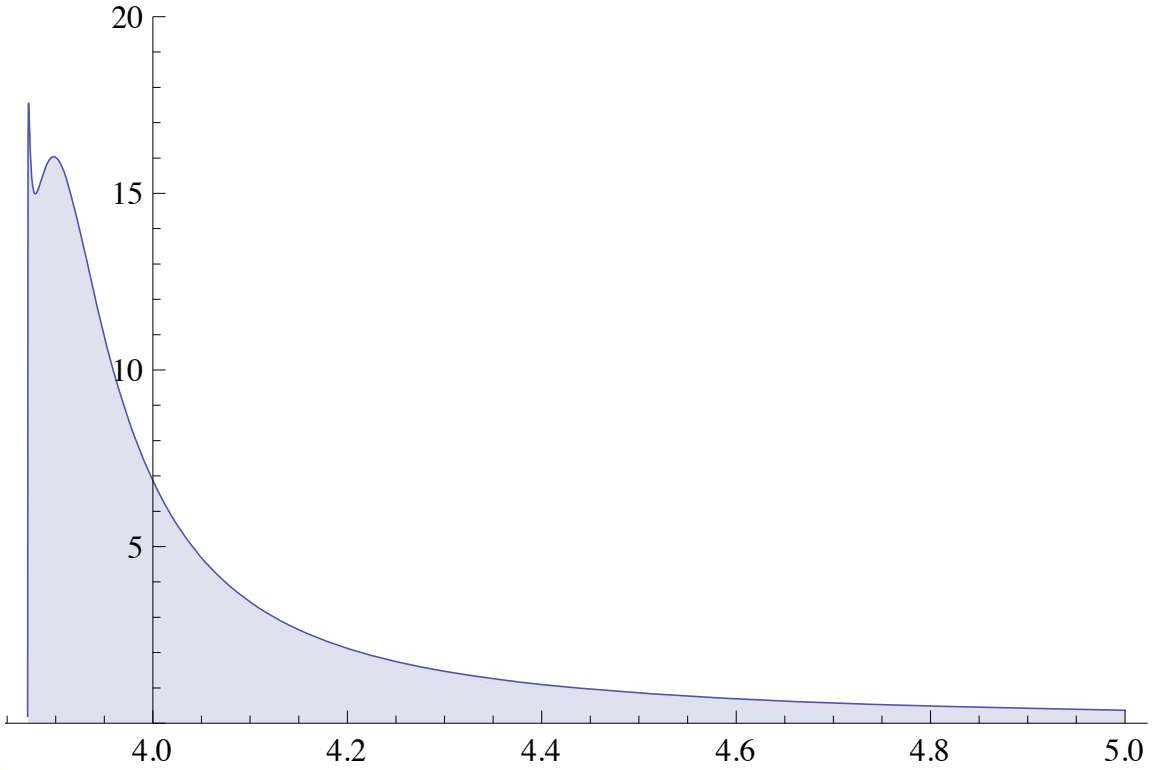
$$S(E) = \frac{-1}{\pi}\left\langle D^0\overline{D^{*0}}\middle|G(E)\middle|D^0\overline{D^{*0}}\right\rangle$$

$$G(E) = G^0_{DD^*}(E) + G^0_{DD^*}(E)V\,G^0_{DD^*}(E) + \cdots$$

$$\left\langle D^0\overline{D^{*0}}(\vec{q}\,')\middle|V\middle|D^0\overline{D^{*0}}(\vec{q})\right\rangle = g\left(\frac{1}{\vec{q}\,'^2+\Lambda^2}\right)\left(\frac{1}{\vec{q}^{\,2}+\Lambda^2}\right)$$

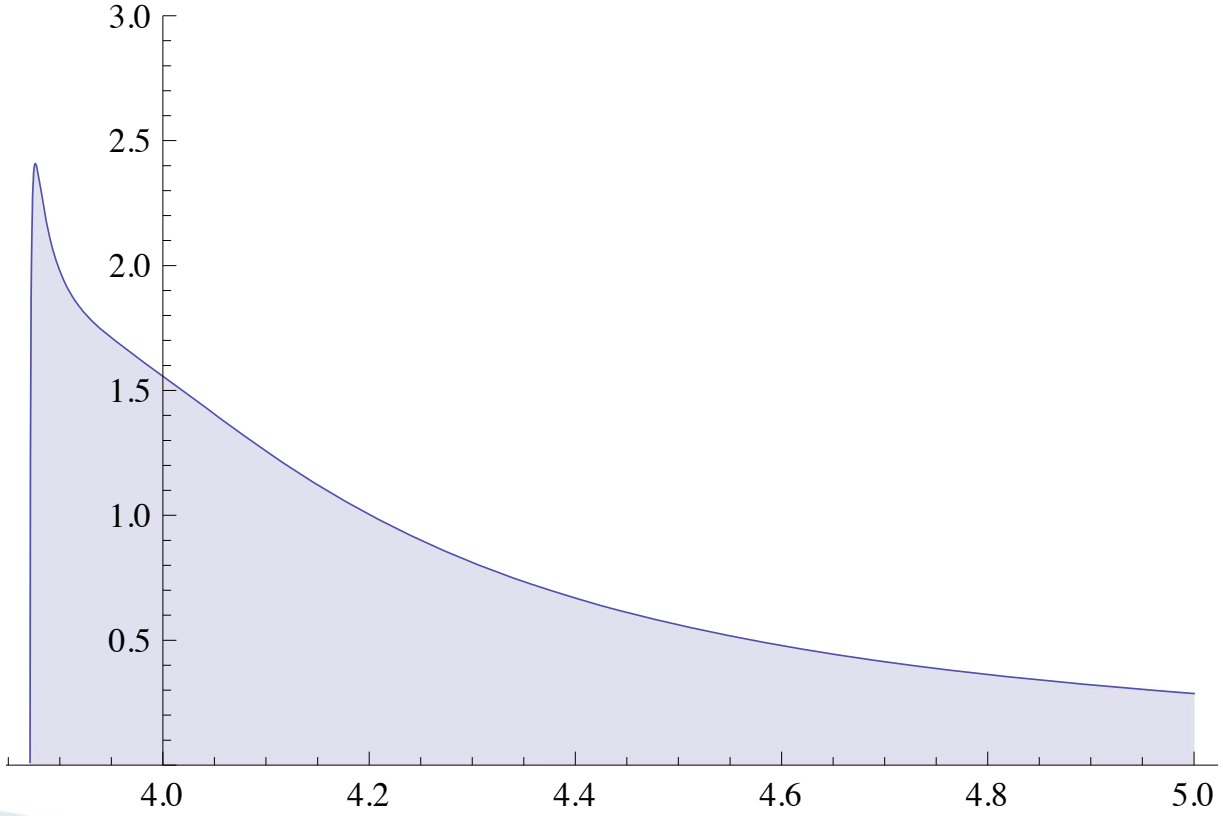
D^0 D^{*0}-bar molecule

- Λ = 200MeV、 g = -0.001、
  Bound state：3865 MeV

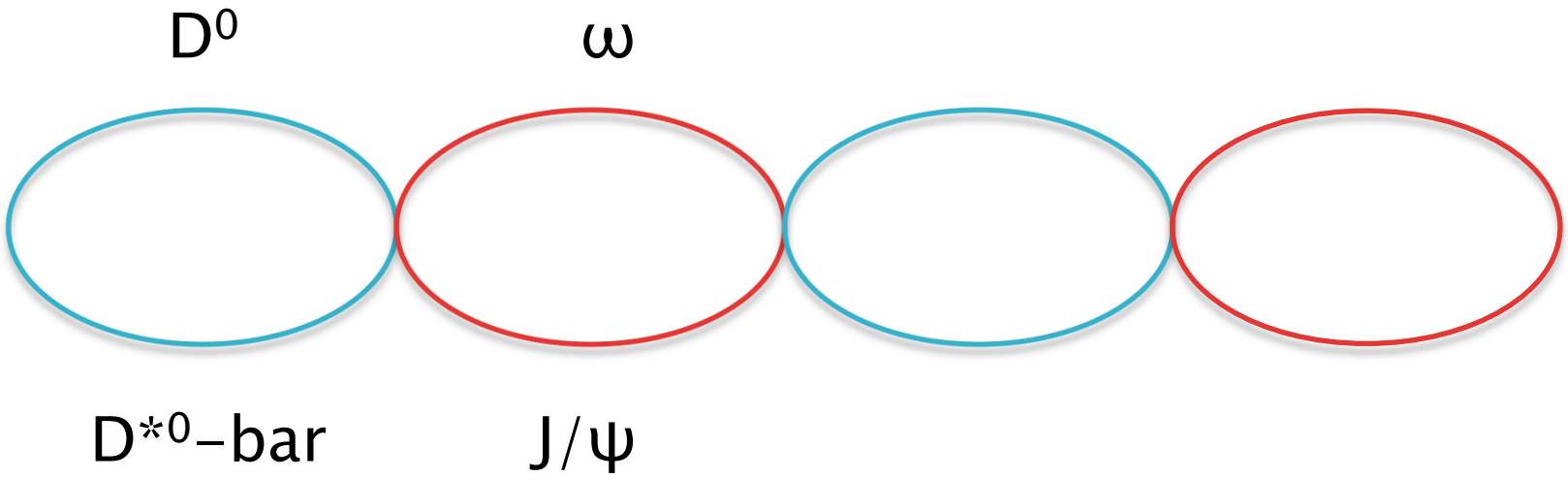


D^0 D^{*0}-bar molecule

- Λ = 500MeV、 g = -0.01、
  Bound state：3864 MeV



D^0 D^{*0}–bar + ω J/ψ coupling



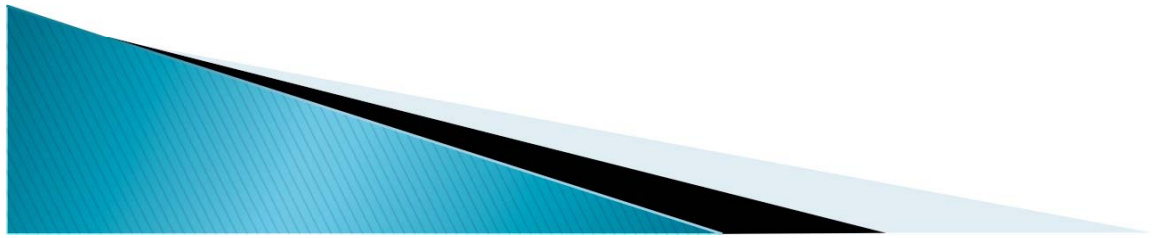
$D^0\ D^{*0}$–bar + ω J/ψ coupling

$$\left|D^0\overline{D^{*0}}\right\rangle = \frac{\sqrt{\Lambda}}{\pi}\int d^3\vec{q}\,\frac{1}{\vec{q}^{\,2}+\Lambda^2}\left|D^0\overline{D^{*0}}(\vec{q})\right\rangle$$

$$S(E) = \frac{-1}{\pi}\left\langle D^0\overline{D^{*0}}\middle|G(E)\middle|D^0\overline{D^{*0}}\right\rangle$$

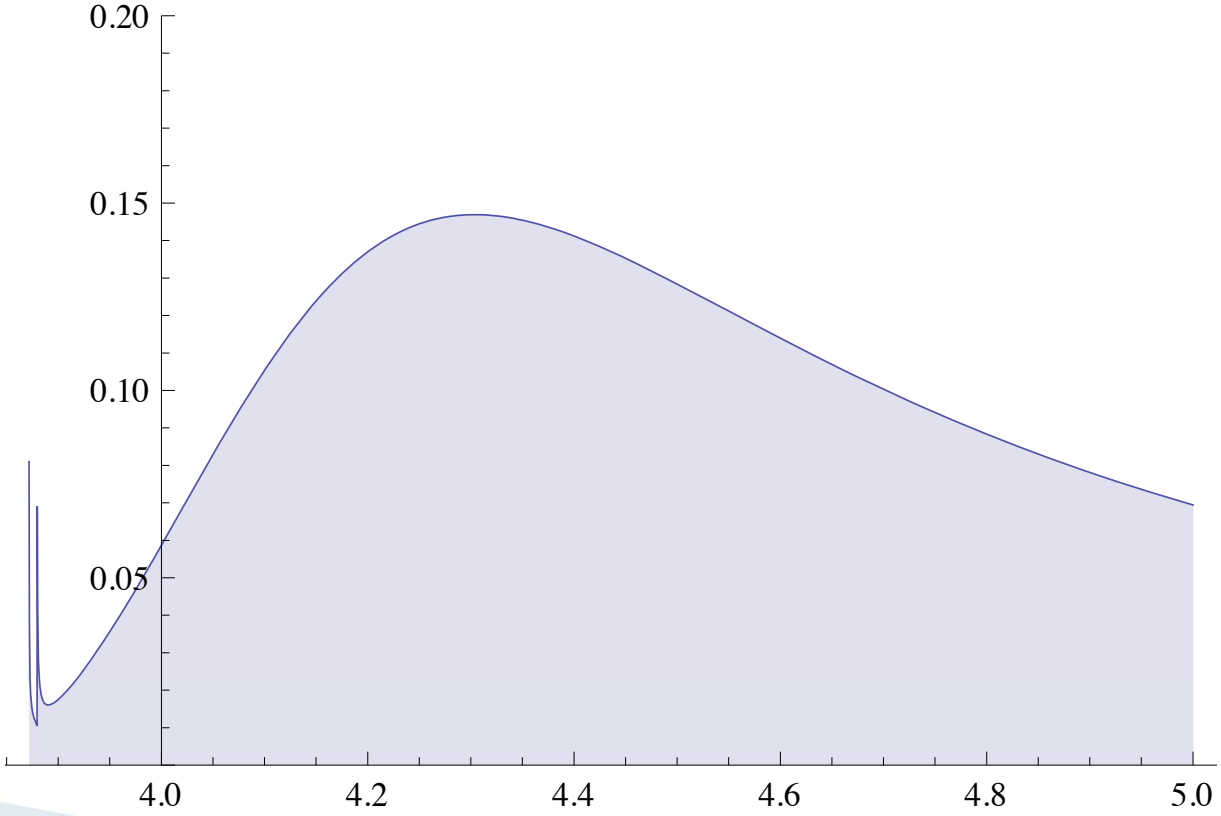
$$G(E) = G^0_{DD^*}(E) + G^0_{DD^*}(E)V_{DD^*\omega J/\psi}\,G^0_{\omega J/\psi}(E)V_{DD^*\omega J/\psi}G^0_{DD^*}(E) + \cdots$$

$$\left\langle \omega J/\psi(\vec{q}\,')\middle|V_{DD^*\omega J/\psi}\middle|D^0\overline{D^{*0}}(\vec{q})\right\rangle = g\left(\frac{1}{\vec{q}\,'^2+\Lambda^2}\right)\left(\frac{1}{\vec{q}^{\,2}+\Lambda^2}\right)$$



D^0 D^{*0}–bar + ω J/ψ coupling

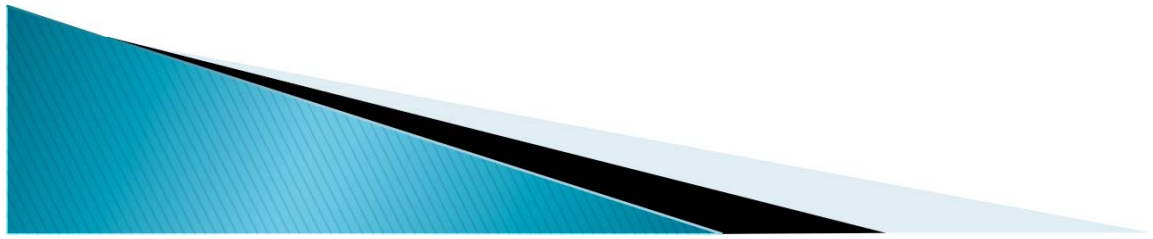
- Λ = 200MeV、 g = 0.02、
  Bound state：3865 MeV



Summary

- If there exists 3950 MeV C C-bar state, the effect of coupling to D^0D^{*0}-bar state gives rise to the 3872 MeV bound state easily.

- 3950 MeV C C-bar state pushes up by the coupling effect and the resonance state above 3950 MeV should exist. However, such state is not observed. It means the coupling to D^0D^{*0}-bar state should strong.



Summary

- In the case of D^0 D^{*0}-bar molecule picture, introduction of the weak attractive force gives rise to the shallow bound state. However the shape of the continuum spectrum seems to be different from the observation.