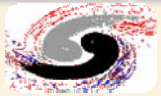

中国科学院高能物理研究所

Cross section lineshape of $e^+e^- \to D\bar{D}$ and $e^+e^- \to D\bar{D}^* + c.c.$

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IHEP, CAS

In collaboration with Qiang Zhao

Outline

- Motivation
- Part I : The lineshape of $e^+e^- \to D\bar{D}$
- Part II : The lineshape of $e^+e^- \to D\bar{D}^*$ + c.c.
- Summary

Motivation

- Lineshape anomaly in $D\bar{D}$ production.

- Charmed mesons pair production in e^+e^- annihilation as a probe for NPQCD mechanisms

Part I

The cross section lineshape of $e^+e^- \to D\bar{D}$

Y.-J. Zhang and Q. Zhao, PRD81, 034011 (2010)

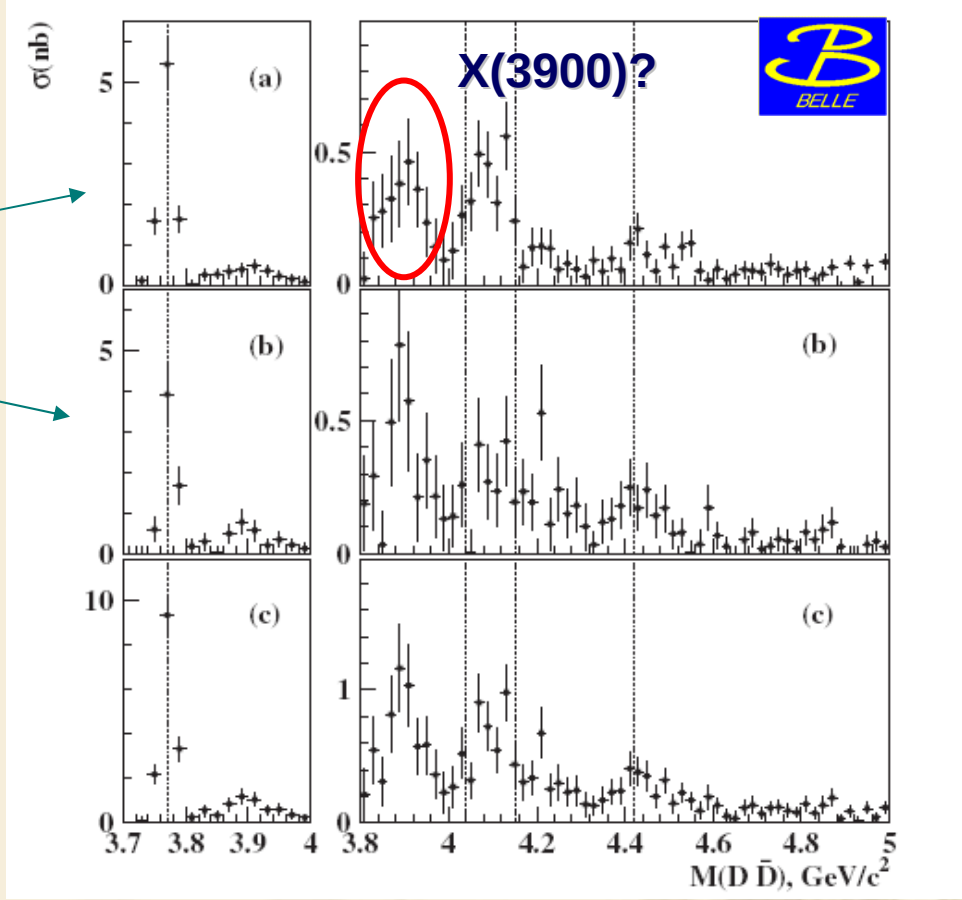
Experimental results

$$e^+e^- \to D^0\bar{D}^0$$

$$e^+e^- \to D^+D^-$$

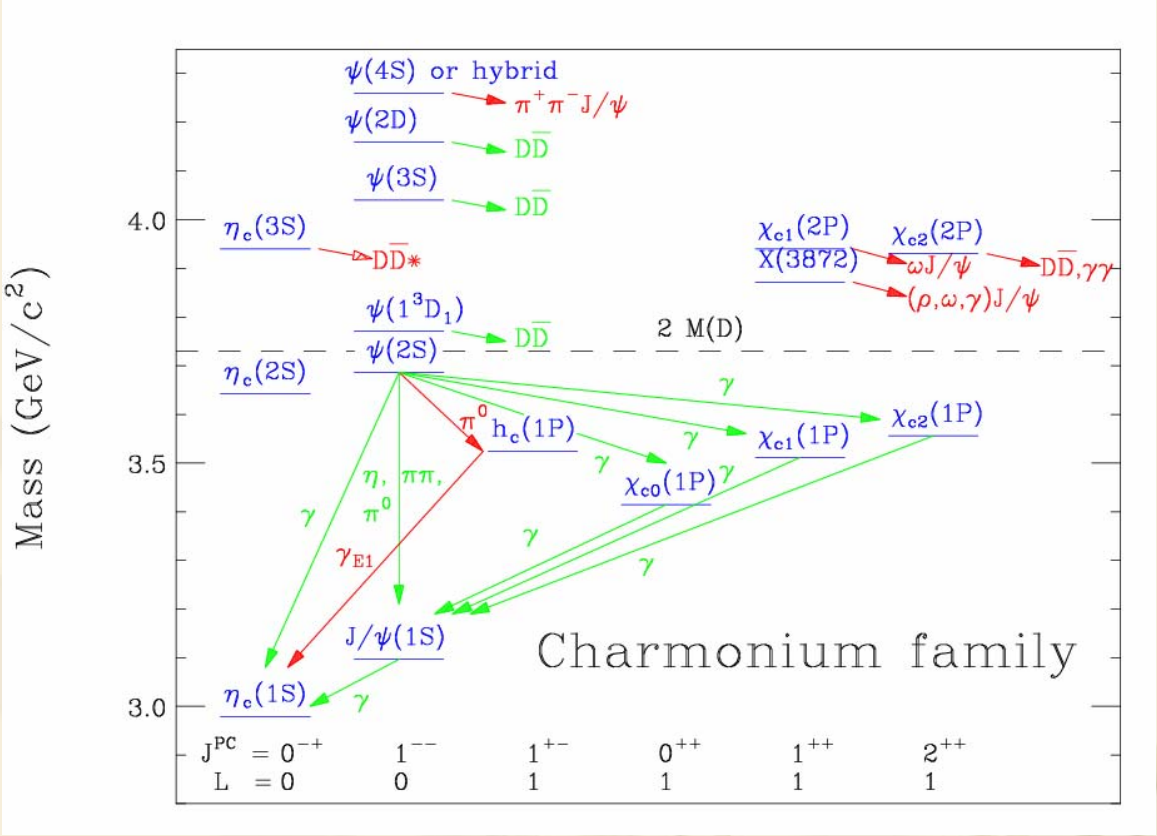
Belle, G. Pakhlova et al, 2006, PRD77, 011103(R)

The vertical lines are for ψ(4040), ψ(4160), ψ(4415) positions

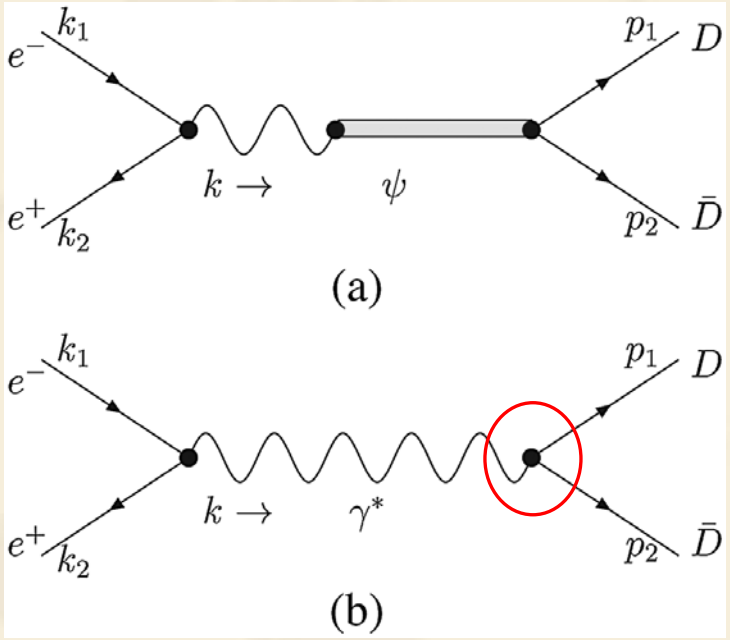


Further more

- Potential model describes charmonium spectrum well above open-charm threshold?
- Signal for exotic?
- How about the open-channel effect?



Vector meson dominance model



$$T_a = e^2 \bar{v}(k_2)\gamma_\mu u(k_1)\frac{1}{s}\frac{m_\psi^2}{f_\psi}\frac{1}{s - m_\psi^2 + i m_\psi \Gamma_\psi} \times g_{\psi D\bar{D}}(p_1 - p_2)^\mu,$$

$$T_b = e^2 \bar{v}(k_2)\gamma_\mu u(k_1)\frac{1}{s} g_c(s)(p_1 - p_2)^\mu,$$

$$\sigma(e^+e^- \to D\bar{D}) = \frac{8\pi\alpha_e^2}{3}\frac{|\vec{p}|^3}{s^{5/2}}\left| g_c(s) + \frac{m_{\psi'}^2}{f_{\psi'}}\frac{g_{\psi' D\bar{D}}}{s - m_{\psi'}^2 + i m_{\psi'}\Gamma_{\psi'}} + \sum_{\psi_i}\frac{m_{\psi_i}^2}{f_{\psi_i}}\frac{g_{\psi_i D\bar{D}}}{s - m_{\psi_i}^2 + i m_{\psi_i}\Gamma_{\psi_i}} e^{i\phi_i}\right|^2,$$

Intermediate meson loops contribution

- Calculation in hadron degrees of freedom

$$
\begin{aligned}
i\langle BC|T|A\rangle &= \sum_{n=1}\frac{(-i)^n}{n!}\langle BC|\mathcal{H}^n|A\rangle \\
&= -i\langle BC|\mathcal{H}_{A;BC}|A\rangle - \frac{1}{2}\sum_k \langle BC|\mathcal{H}_{k;BC}|k\rangle\ \langle k|\mathcal{H}_{A;k}|A\rangle \\
&\quad + \cdots\cdots ,
\end{aligned}
$$

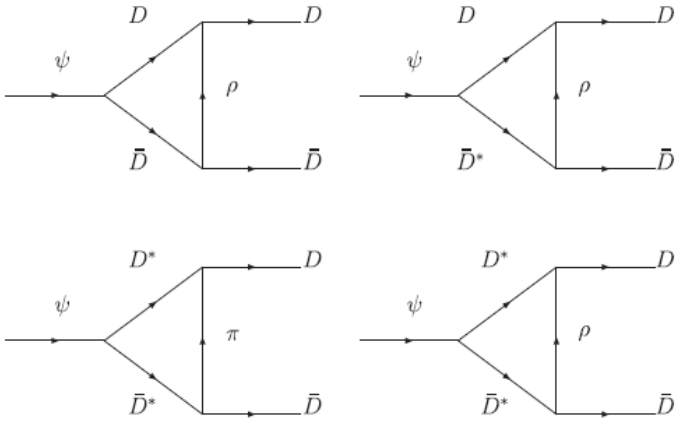


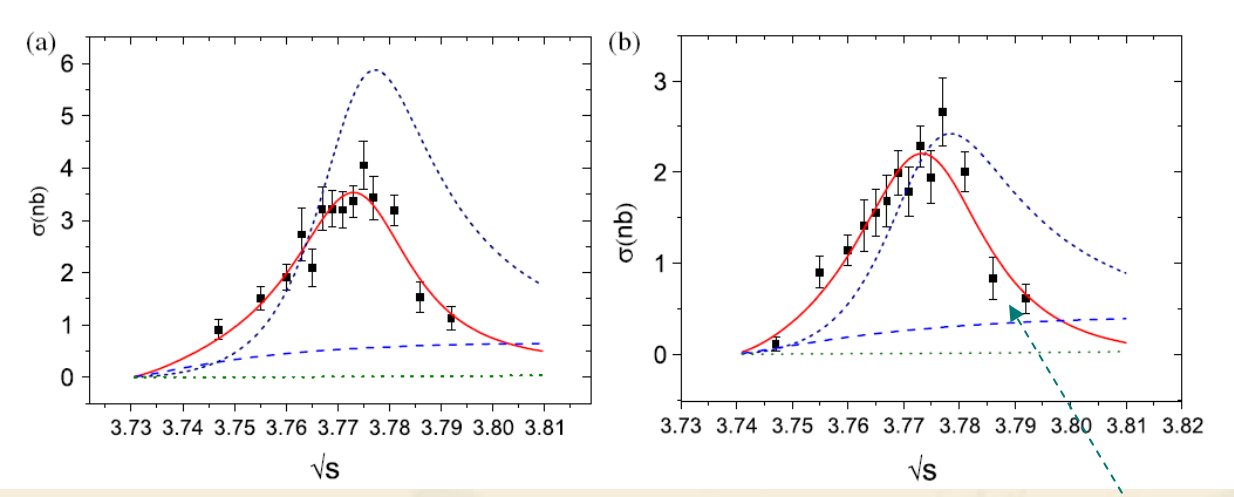
FIG. 2. Feynman diagrams for intermediate meson loops as corrections for the $D\bar{D}$ coupling to a charmonium state.

$$
T_L = -ie^2\bar{v}(k_2)\gamma_\mu u(k_1)\frac{1}{s}\frac{m_\psi^2}{f_\psi}\frac{1}{s-m_\psi^2+im_\psi\Gamma_\psi}
\times\int\frac{d^4p_2}{(2\pi)^4}\sum_{\text{polarization}}\frac{T_1T_2T_3}{a_1a_2a_3}\mathcal{F}(p_2^2).
$$

$$
\mathcal{F}(p^2) = \left(\frac{\Lambda^2 - m_{\text{ex}}^2}{\Lambda^2 - p^2}\right)^n, \qquad n = 1, 2
$$

For compensate the off-shell effects and kill the divergence

The numerical results



Fitted results:

	$e^+e^- \to D^0\bar{D}^0$	$e^+e^- \to D^+D^-$
$g_{\psi' D\bar{D}}$	9.05 ± 2.34	7.72 ± 1.02
$g_{\psi(3770) D\bar{D}}$	13.58 ± 1.07	10.71 ± 1.75
$m_{\psi(3770)}$ (MeV)	3774.0 ± 1.3	3774.0 ± 1.6
$\Gamma_{\psi(3770)}$ (MeV)	28.4 ± 2.9	29.6 ± 2.9
ϕ	$228.1° \pm 18.6°$	$190.6° \pm 21.1°$
χ^2/d.o.f.	12.28/9	13.32/9

The date are from BES.

M. Ablikim et al, PLB 668, 263 (2008)

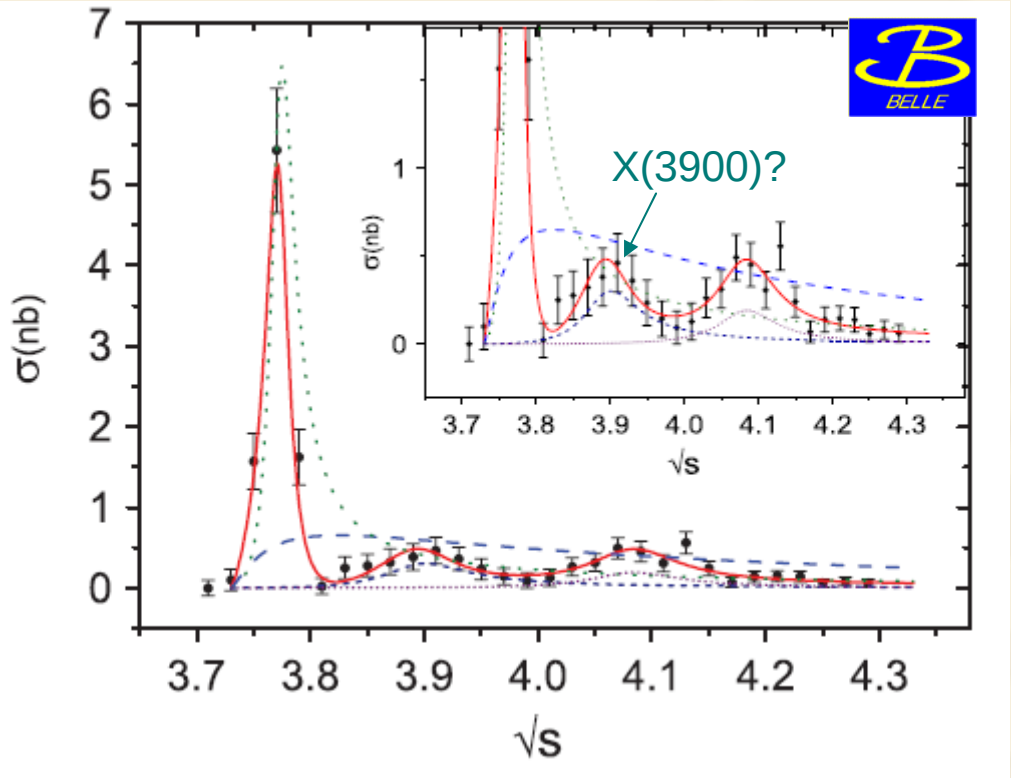


TABLE II. Fitting parameters from fit II. The results are obtained by fitting the Belle data [11] for $e^+e^- \to D^0\bar{D}^0$. We separately list the other two fitted quantities here: $g_{\psi' D^0\bar{D}^0} = 9.05 \pm 0.37$, $g_{\psi(3770)D^0\bar{D}^0} = 13.13 \pm 0.65$. The reduced χ^2 is $\chi^2/\text{d.o.f.} = 17.45/19$.

	M (GeV)	Γ (MeV)	$g_{VDD}/f_V(\times 10^{-2})$	ϕ
$X(3900)$	3.894 ± 0.011	89.8 ± 12.6	6.76 ± 0.89	$104.36° \pm 7.90°$
$\psi(3770)$	3.7724 ± 0.002	25.4 ± 1.4	23.2 ± 1.1	$198.85° \pm 4.19°$
$\psi(4040)$	4.0812 ± 0.008	96.2 ± 11.4	3.48 ± 0.34	$101.16° \pm 11.742°$

The open-channel effects

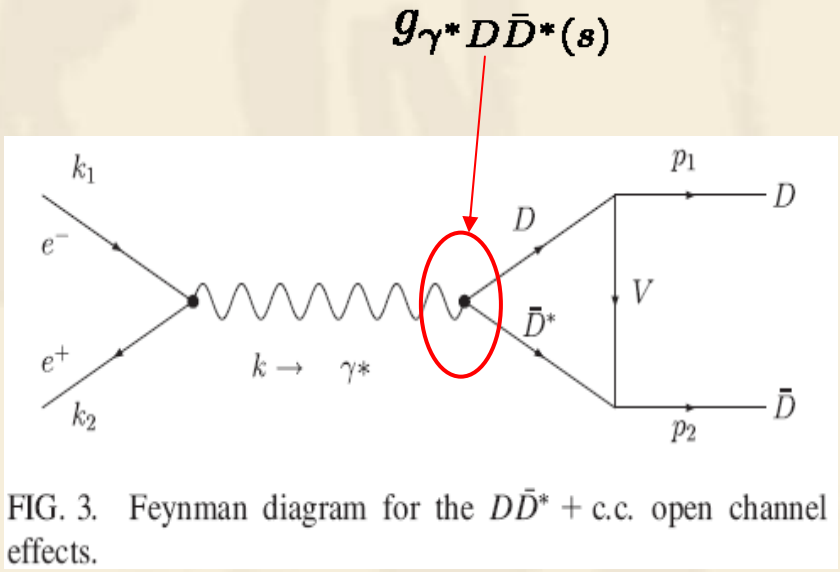
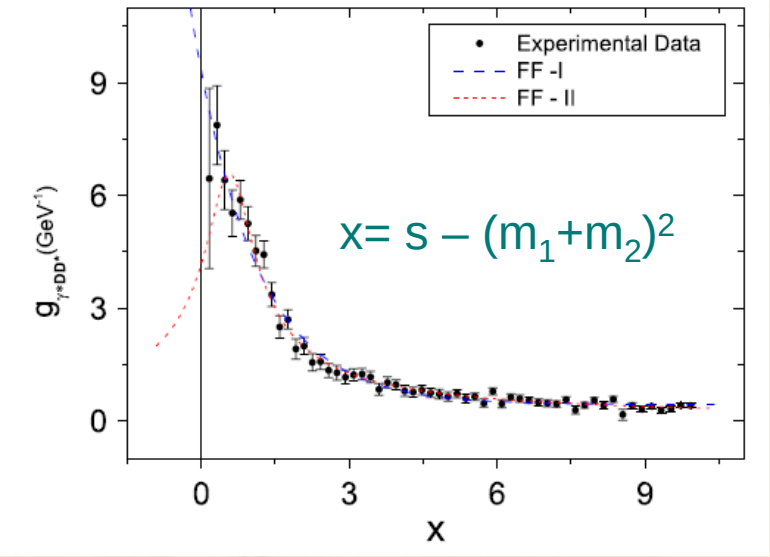


FIG. 3. Feynman diagram for the $D\bar{D}^*$ + c.c. open channel effects.

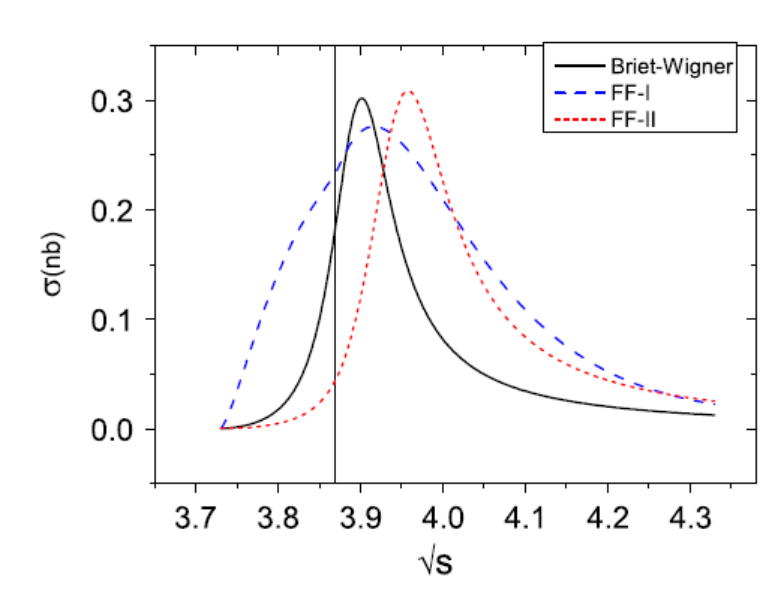


The date are from Belle.

Fit-I : $$g_{\gamma^* D\bar{D}^*}(s) = g_1 \exp[-(s-(m_D+m_{D^*})^2)/t_1] + g_0,$$

Fit-II : $$g_{\gamma^* D\bar{D}^*}(s) = \left| \frac{b_0}{s - m_X^2 + i m_X \Gamma_X} + b_1 \right|,$$

The open-channel effects



- The solid line, dashed line and dotted line are the exclusive contribution from the different approach.
- The open-channel effect cause the enhancement near the 3.9GeV.
- How about the open channel effects in other process?

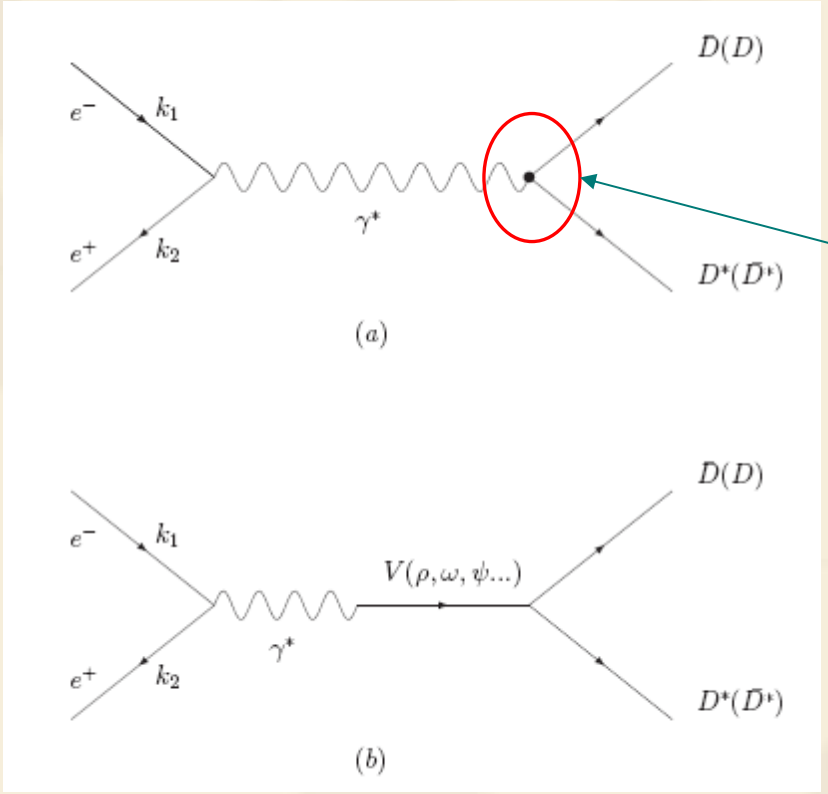
FF-I		FF-II	
$g_{\gamma^* D\bar{D}^*} = g_1 \exp[-(s-(m_D+m_{D^*})^2)/t_1] + g_0$		$g_{\gamma^* D\bar{D}^*} = \lvert \frac{b_0}{s-m_X^2+im_X\Gamma_X} + b_1 \rvert$	
g_1	8.86 ± 0.59	b_0	3.08 ± 0.31
t_1	1.28 ± 0.06	m_X (GeV)	3.943 ± 0.014
g_0	0.43 ± 0.02	Γ_X (MeV)	119.0 ± 10.0
		b_1	0.016 ± 0.045
χ^2/d.o.f.	68.86/53	χ^2/d.o.f.	47.67/52

Part II

The cross section lineshape of $e^+e^- \to D\bar{D}^* + c.c.$

Y.-J. Zhang and Q. Zhao, arXiv:1002.1612 [hep-ph]

Vector meson dominance model



$$g_{\gamma^* D^* \bar{D}}(s) = \sum_V \frac{M_V^2}{f_V} \frac{1}{s - M_V^2 + i\sqrt{s}\,\Gamma_V} g_{V D^* \bar{D}},$$

$$\frac{e}{f_V} = \left[\frac{3\Gamma_{V\to e^+e^-}}{2\alpha_e |\vec{p}_e|}\right]^{\frac{1}{2}}$$

$$\sigma(e^+e^- \to D^{*+}D^- + c.c.) = \frac{8\pi}{3}\frac{|\vec{p}|^3}{s^{3/2}}\alpha_e^2 \left|\sum_V \frac{M_V^2}{f_V}\frac{g_{V D^* D}}{s - M_V^2 + i\sqrt{s}\,\Gamma_V}\right|^2 .$$

Asymptotic behavior of the form factor

To avoid the violation of unitary, we have: $g_{\gamma^* D^* \bar{D}}(s) \sim s^{-2}$

$$\sum_{\rho_i} \frac{M_{\rho_i}^2}{f_{\rho_i}} g_{\rho_i D^* D} = 0 \,, \quad \text{and} \quad \sum_{V(I=0)} \frac{M_{V(I=0)}^2}{f_{V(I=0)}} g_{V(I=0) D^* D} = 0 \,.$$

Quark model and flavor symmetry leads:

$$f_{\omega_i} \simeq 3 f_{\rho_i}, \quad m_{\rho_i}^2 \simeq m_{\omega_i}^2 \,, \quad \text{and} \quad g_{\omega_i D^{*+} D^-} = -g_{\rho_i D^{*+} D^-} \,.$$

T. M. Aliev, E. Iltan, N. K. Pak and M. P. Rekalo, Z. Phys. C 64, 683 (1994).

The contributions come from the light vector mesons are very small !

Coupling of charmonia to charmed mesons

Effective Lagrangians :

$$\mathcal{L}_{VDD} = g_{VDD}\{D\partial_\mu\bar{D} - \partial_\mu D\bar{D}\}V^\mu,$$
$$\mathcal{L}_{VD^*D} = -ig_{VD^*D}\varepsilon_{\alpha\beta\mu\nu}\partial^\alpha V^\beta \partial^\mu D^{*\nu}\bar{D} + h.c.$$

➔ Some couplings are not available.

$$g_{VD^*\bar{D}} = g_{VD\bar{D}} \times g_V,$$

➔ Relativistic potential model and the electromagnetic current give :

$$g_V = \frac{e_Q}{\Lambda_Q} + \frac{e_q}{\Lambda_q},$$

➔ Their coupling values generally have large discrepancies in different models.

P.Colangelo, F. De Fazio and G. Nardulli, Phys. Lett. B 334, 175 (1994)
R. Casalbuoni, A. Deandrea, N. Di Bartolomeo, R. Gatto, F. Feruglio and G. Nardulli, Phys. Rept. 281, 145 (1997)

The numerical results

For charmonium coupling to the charmed mesons, we assume:

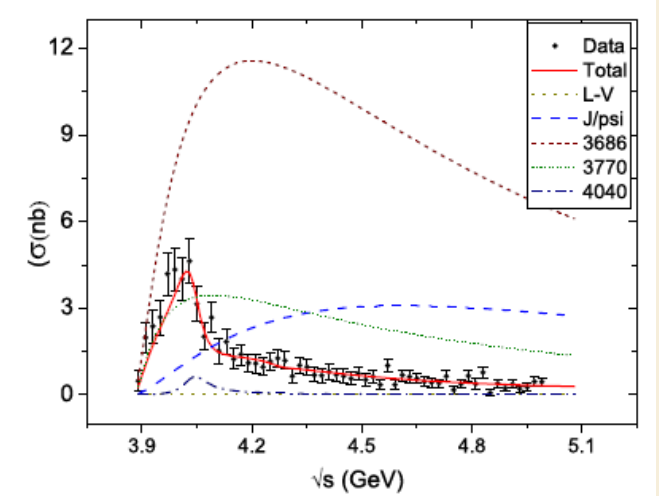
$$g_\psi \equiv g_{J/\psi} \simeq g_{\psi'} \simeq g_{\psi(3770)} \simeq g_{\psi(4040)} \ ,$$

then

$$\frac{\Gamma(\psi(4040) \to D\bar{D})}{\Gamma(\psi(4040) \to D^*\bar{D} + c.c.)} = \frac{|\vec{p}_1|^3}{g_\psi^2 M^2_{\psi(4040)} |\vec{p}_2|^3},$$

$$\frac{\Gamma(\psi(4040) \to D^0\bar{D}^0)}{\Gamma(\psi(4040) \to D^{*0}\bar{D}^0 + c.c.)} = 0.05 \pm 0.03,$$

$$g_\psi = 1.73 \pm 0.52 \ \mathrm{GeV}^{-1}$$

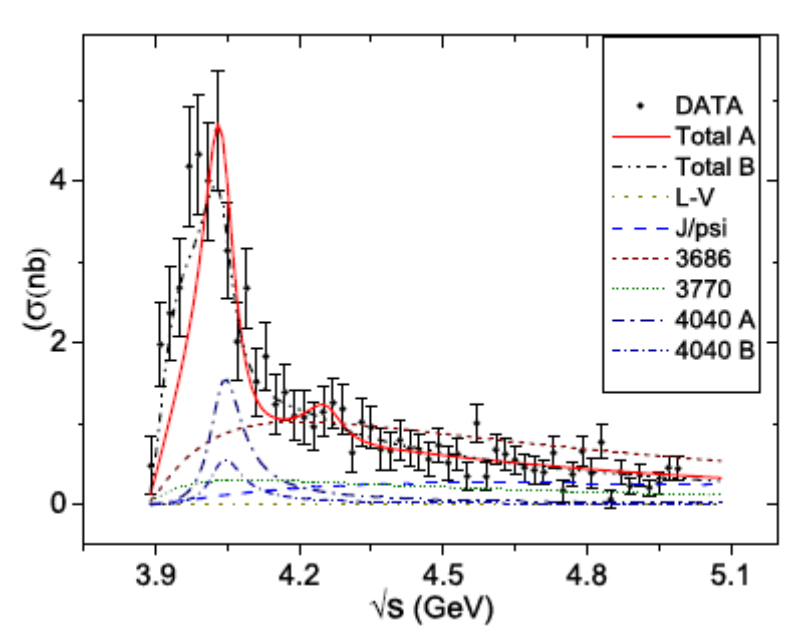


Particle Data Group 2008

TABLE II: Model parameters obtained from the χ^2 minimization fitting with $g_\psi = 1.73$ GeV^{-1}. Coupling $g_V^{\rm eff}$ is defined by $g_V^{\rm eff} \equiv \frac{M_V^2}{f_V} \times g_{VD^*\bar{D}}$. The phase angles are in radian. The reduced χ^2 is $\chi^2/\mathrm{d.o.f} = 41.2/51$.

parameter	ϕ_{LV}	$\phi_{\psi'}$	$\phi_{\psi(3770)}$	$\phi_{\psi(4040)}$	$g^{\rm eff}_{\psi(4040)}$	$g^{\rm eff}_{\Upsilon(4260)}$
	-0.41 ± 0.17	2.36 ± 0.32	4.54 ± 0.22	-0.68 ± 0.21	0.37 ± 0.05	0.02 ± 0.03

The numerical results

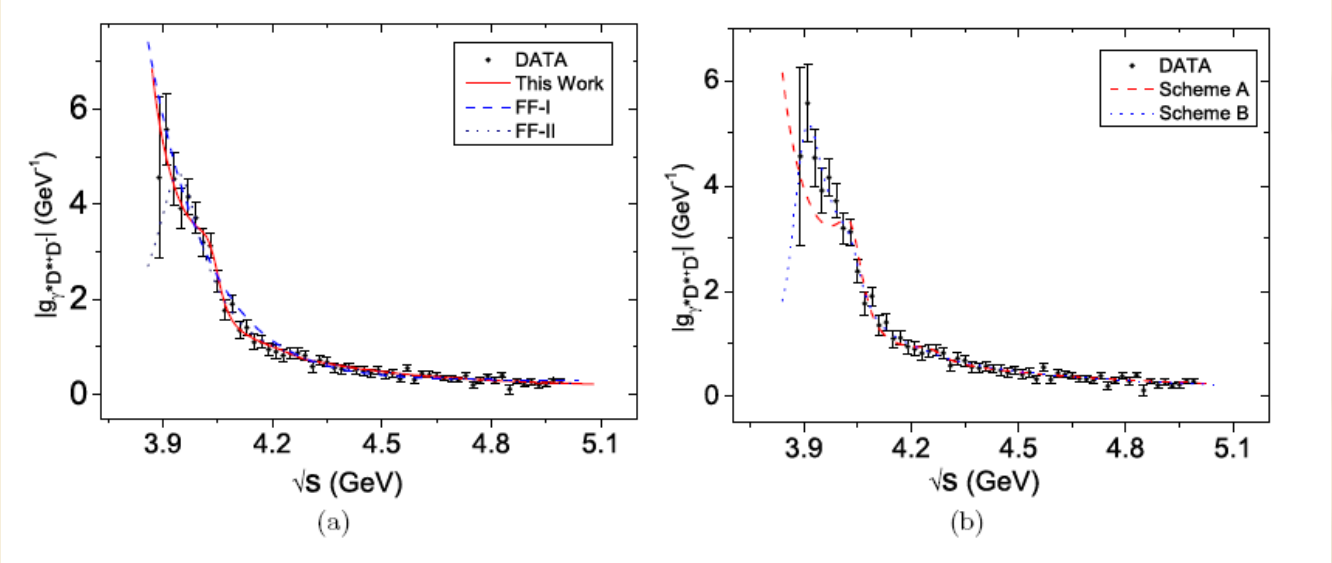


Heavy quark mass limit

TABLE III: Model parameters obtained from the χ^2 minimization fitting with $g_\psi = 0.52$ GeV^{-1}. We fix $m_X = 3.9$ GeV and $\Gamma_X = 89.8$ MeV, which are from Ref. [7]. The phase angles are in radian.

parameter	ϕ_{LV}	$\phi_{\psi'}$	$\phi_{\psi(3770)}$	$\phi_{\psi(4040)}$	$g^{\rm eff}_{\psi(4040)}$	$g^{\rm eff}_{Y(4260)}$	$g^{\rm eff}_{X(3900)}$	$\phi_{X(3900)}$	χ^2/d.o.f
Scheme A	5.72 ± 0.63	3.56 ± 0.10	3.69 ± 0.22	0.0 ± 0.11	0.58 ± 0.05	0.08 ± 0.03	-	-	63.9/51
Scheme B	5.69 ± 0.66	4.21 ± 0.43	2.23 ± 0.35	5.62 ± 0.27	0.35 ± 0.07	0.01 ± 0.04	1.89 ± 0.44	3.03 ± 0.26	38.8/49

The numerical results



The form factors obtained by different fitting schemes. With smaller coupling, an observed deficit might imply the presence of X(3900) or might reproduce by other open-channel effects.

Summary

- The open-channel effects can lead a enhancement near 3.9GeV in $e^+e^- \rightarrow$DD process.
- The interference between charmonia can reproduce the lineshape of $e^+e^- \rightarrow$DD,DD* process.
- More experimental data from BES-III will further clarify these issues.

Thank you!