Study of Branching ratio of $\Psi(3770) \rightarrow$ DDbar

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Phys. Rev. D81,011501(2010)

2010/04/16 -04/19, Nanchang city

Outline

- 1. Theoretical estimation of branching ratio of Ψ(3770)→non-DDbar
- 2. Experimental results about Ψ(3770)→non-DDbar
- 3. Combining BESII and Belle data to fit branching fraction of Ψ(3770) to DDbar.

Theoretical estimation of branching ratio of $\Psi(3770)$ → non-DDbar

- The $\psi(3770)$ can be viewed as a 1^3D_1 dominated state with a small admixture of 2^3S_1 and expressed as:

$$|\psi(3770)\rangle = \cos\theta |1^3D_1\rangle + \sin\theta |2^3S_1\rangle$$

$$|\psi(3686)\rangle = -\sin\theta |1^3D_1\rangle + \cos\theta |2^3S_1\rangle$$

$$\theta \sim -12^\circ$$

Y.B.Ding, D.H.Qin, and K.T.Chao, Phys.Rev.D44,3562(1991)
J.L.Rosner, Phys.Rev.D64,094002(2001)

$$\Gamma(\psi(3770) \to LH) = 467^{-187}_{+338}\, keV\,(\pm 50\%)$$

Z.G.He, Y.Fan, and K.T.Chao, Phys.Rev.Lett. 101, 112001(2008)

$$Br(\psi(3770) \to LH) = (2.0^{-0.80}_{+1.50})\%(\pm 50\%)$$

Together with the observed hadronic transitions and *E*1 transitions, the non-DDbar decay branching ratio of $\psi(3770)$ could reach about 5%.

Experimental results about $\Psi(3770) \rightarrow$ non-DDbar

BESII: $\sigma(\psi(3770) \to D\bar{D}) = 7.179 \pm 0.195 \pm 0.630 nb$

$BF(\psi(3770) \to non - D\bar{D}) = 14.5 \pm 1.7 \pm 5.8\%$ PLB641,145(2006)

Cleo-c: $\sigma(\psi(3770) \to D\bar{D}) = 6.38 \pm 0.08^{+0.41}_{-0.30} nb$

$\sigma(\psi(3770) \to non - D\bar{D}) = -0.01 \pm 0.08^{+0.41}_{-0.30} nb$ PRL96,092002(2006)

Cleo-c: $\sigma(\psi(3770) \to DD) = 6.57 \pm 0.04 \pm 0.10 nb$

$\sigma(\psi(3770) \to non - DD) = -0.21 \pm 0.09^{+0.41}_{-0.30} nb$

$BF(\psi(3770) \to non - D\bar{D}) = -3.3 \pm 1.4^{+6.6}_{-4.8}\%$ arXiv:1004,1358

$BF(\psi(3770) \to non - DD) < 9\%$ at 90% confidence level

Both BESII and CLEO-c found only a few channels with total branching fraction < 3% .

What we have already known

$\psi(3770)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$D\overline{D}$	(85.3 ± 3.2) %		285
$D^0\overline{D}^0$	(48.7 ± 3.2) %		285
D^+D^-	(36.1 ± 2.8) %		251
$J/\psi\pi^+\pi^-$	$(1.93 \pm 0.28) \times 10^{-3}$		560
$J/\psi\pi^0\pi^0$	$(8.0 \pm 3.0) \times 10^{-4}$		564
$J/\psi\eta$	$(9 \pm 4) \times 10^{-4}$		359
$J/\psi\pi^0$	$< 2.8 \times 10^{-4}$	CL=90%	603
$\gamma\chi_{c0}$	$(7.3 \pm 0.9) \times 10^{-3}$		–
$\gamma\chi_{c1}$	$(2.9 \pm 0.6) \times 10^{-3}$		–
$\gamma\chi_{c2}$	$< 9 \times 10^{-4}$	CL=90%	–
e^+e^-	$(9.7 \pm 0.7) \times 10^{-6}$	S=1.2	1886
$K^0_S K^0_L$	$< 1.2 \times 10^{-5}$	CL=90%	1820
$2(\pi^+\pi^-)$	$< 1.12 \times 10^{-3}$	CL=90%	1861
$2(\pi^+\pi^-)\pi^0$	$< 1.06 \times 10^{-3}$	CL=90%	1843
$2(\pi^+\pi^-\pi^0)$	< 5.85 %	CL=90%	1821
$\omega\pi^+\pi^-$	$< 6.0 \times 10^{-4}$	CL=90%	1794
$3(\pi^+\pi^-)$	$< 9.1 \times 10^{-3}$		1819
$3(\pi^+\pi^-)\pi^0$	< 1.37 %		1792
$3(\pi^+\pi^-)2\pi^0$	< 11.74 %	CL=90%	1759
$\eta\pi^+\pi^-$	$< 1.24 \times 10^{-3}$	CL=90%	1836
$\pi^+\pi^-2\pi^0$	$< 8.9 \times 10^{-3}$	CL=90%	1862

Part of branching ratio results from PDG

About non-DDbar decays

$\psi(3770)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
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$J/\psi\eta$	$(9 \pm 4) \times 10^{-4}$		359
$\gamma\chi_{c0}$	$(7.3 \pm 0.9) \times 10^{-3}$		–
$\gamma\chi_{c1}$	$(2.9 \pm 0.6) \times 10^{-3}$		–
$\phi\eta$	$(3.1 \pm 0.7) \times 10^{-4}$		1703

So, are there abundance non-DDbar decay channels not found yet ?
Or , we might misunderstand the branching ratio of non-DDbar decay .

Combining BESII and Belle data to fit branching fraction of Ψ(3770) to DDbar.

- Motivation:

BESII: $\sigma(\psi(3770)\to D\overline{D}) = 7.179 \pm 0.195 \pm 0.630 nb$

$BF(\psi(3770)\to non-D\overline{D}) = 14.5 \pm 1.7 \pm 5.8\%$ PLB641,145(2006)

Cleo-c: $BF(\psi(3770)\to non-D\overline{D}) = -3.3 \pm 1.4^{+6.6}_{-4.8}\%$ arXiv:1004,1358

$BF(\psi(3770)\to non-D\overline{D}) < 9\%$ at 90% confidence level

Both BESII and CLEO-c found only a few channels with total branching fraction less than 3% .

- Consider the continuum distribution

from $e^+e^- \to \gamma^* \to D\overline{D}$

- Interference of charmonium states need to be considered.

Continuum term

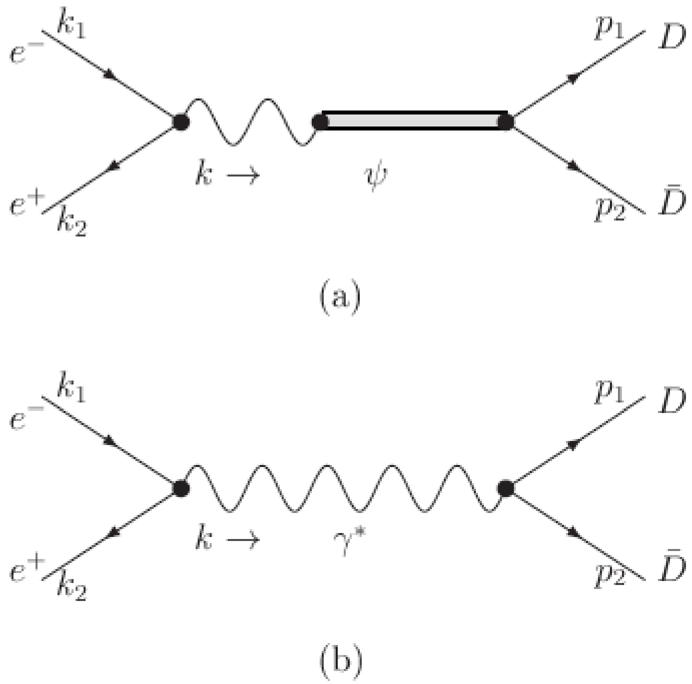


FIG. 1: Feynman diagrams for $e^+e^- \to D\bar{D}$ near the resonance $\psi(3770)$.

$$-F_{D\bar{D}}(s) = \frac{F_0 m^2_{\psi(3770)}}{s-a}$$

To well describe the data

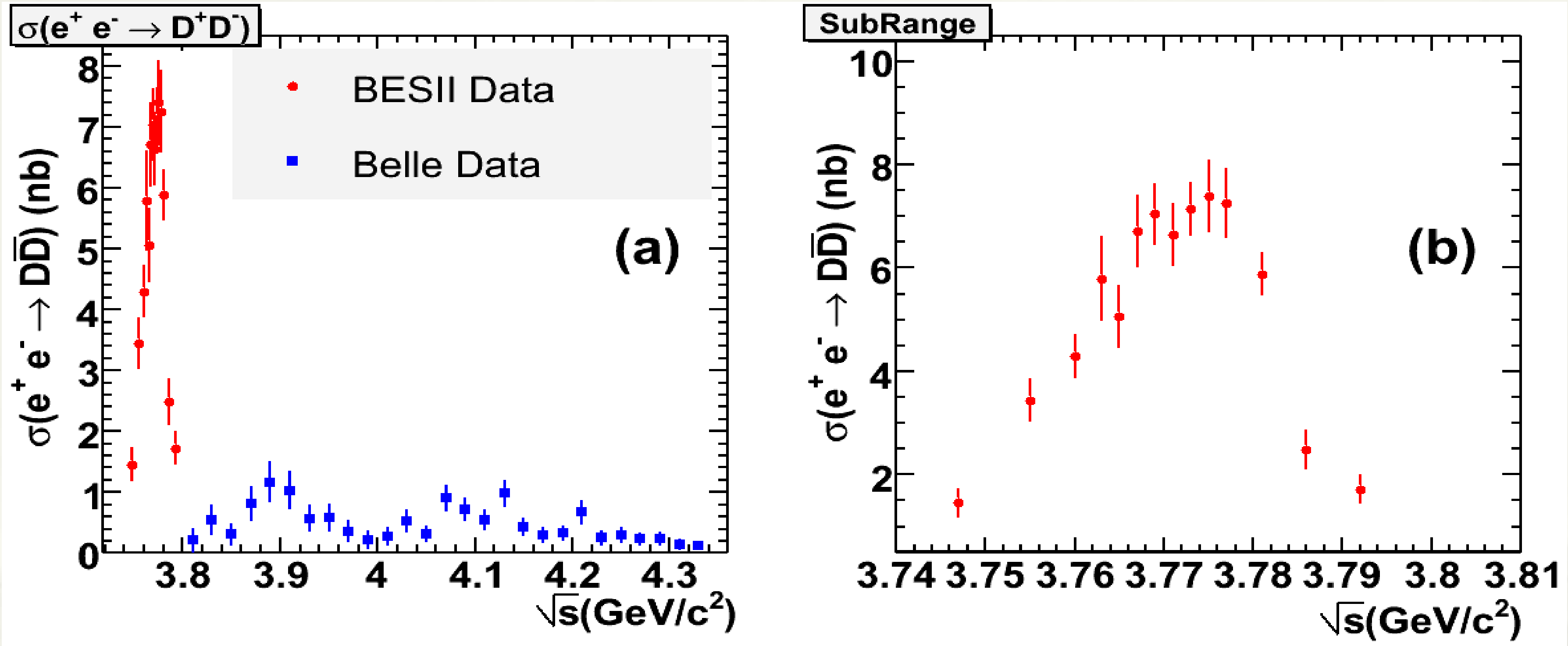
$$-F_{D\bar{D}}(s) = \frac{c_0}{s - m^2_{\psi(2S)} + i m_{\psi(2S)} \Gamma_{\psi(2S)}}$$

M.Z.Yang, Mod.Phys.Lett. A 23,3113(2008)

Data Set

- 1) Cross-sections at 14 energy points between 3.73 and 3.80 GeV from BESII data with total luminosity of about 15 pb^{-1}
  - M. Ablikim, et al., BES Collaboration, PLB 668(2008) 263-267.
  - Introduce ISR correction from reference: M. Ablikim, *et al*., BES Collaboration, PLB 603(2004) 130-137.
- 2) Cross-sections at 27 energy points between 3.81 and 4.33GeV from Belle data with integrated luminosity of 673 fb^{-1} (ISR).
  - Pakhlova *et al*. PR D77(2008)011103 (Belle)

Data Set



- Total data set: 41 data points.
- 14 data points from BESII, 27 data points from Belle

About G(3900)

- First put forward in Couple-channel model

E. Eichten, K. Gottfried, T. Kinoshita, K. D. Lane, and T. M. Yan, Phys. Rev. D **21, 203 (1980).**

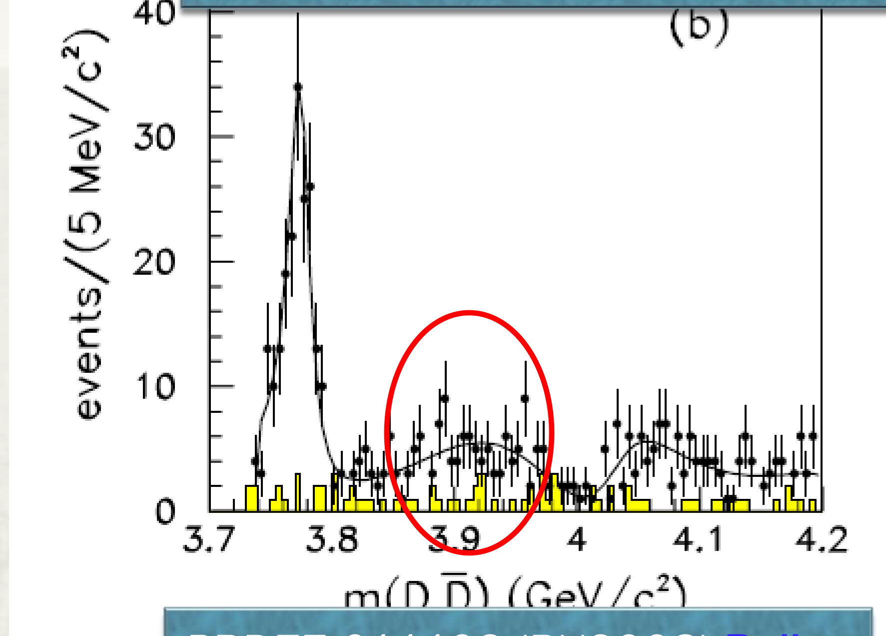
- Observed by *BABAR* and Belle Collaboration named G(3900)

$$f|P + c_1 W_1 e^{i\phi_1} + c_2\sqrt{G}e^{i\phi_2} + \ldots + c_n W_n e^{i\phi_n}|^2 + (1-f)B,$$

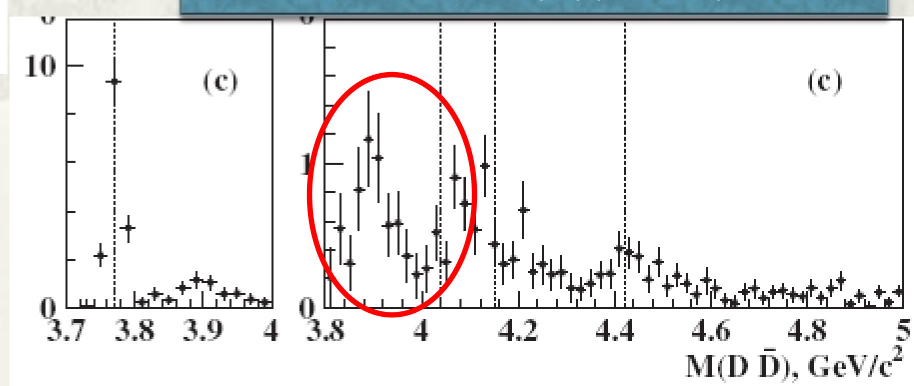
$$m(G(3900)) = (3943 \pm 17_{\rm stat} \pm 12_{\rm syst})\ {\rm MeV}/c^2,$$

$$\sigma(G(3900)) = (52 \pm 8_{\rm stat} \pm 7_{\rm syst})\ {\rm MeV}/c^2,$$

PRD76,111105(R)(2007) *BABAR*



PRD77,011103 (R)(2008) Belle



Formula for cross section

$$\sigma(e^+e^- \to D\bar{D}) = \frac{\pi}{3}\frac{(s-4m_{D^0}^2)^{3/2} + (s-4m_{D^+}^2)^{3/2}}{s^{5/2}}\alpha^2$$

$$\times\left| -F_{D\bar{D}}(s) + \sum_i \frac{g_{\psi_i D\bar{D}} Q_c f_{\psi_i} m_{\psi_i}}{s - m_{\psi_i}^2 + i m_{\psi_i}\Gamma_i} e^{i\phi}\right|^2$$

$$-F_{D\bar{D}}(s) = \frac{F_0 m_{\psi(3770)}^2}{s-a}$$

$$-F_{D\bar{D}}(s) = \frac{c_0}{s - m_{\psi(2S)}^2 + i m_{\psi(2S)}\Gamma_{\psi(2S)}}$$

$$\Gamma_{e^+e^-i} = \frac{4\pi}{3}\frac{Q_c^2\alpha^2 f_{\psi_i}^2}{m_{\psi_i}}$$

$$BR(\psi_i \to D^0\overline{D^0}, D^+D^-) = \frac{g_{\psi_i D\bar{D}}^2 (m_{\psi_i}^2 - 4m_D^2)^{3/2}}{48\pi\Gamma_i m_{\psi_i}^2}$$

$$\sigma(e^+e^- \to D\bar{D}) = \frac{\pi}{3}\frac{(s-4m_{D^0}^2)^{3/2} + (s-4m_{D^+}^2)^{3/2}}{s^{5/2}}\alpha^2$$

$$\times\left| -F_{D\bar{D}}(s) + \sum_i \frac{1}{\alpha}\frac{1}{\sqrt{(m_{\psi_i}^2 - 4m_{D^0}^2)^{3/2} + (m_{\psi_i}^2 - 4m_{D^+}^2)^{3/2}}}\frac{6\sqrt{\Gamma_{eei} Br \Gamma_{\psi_i}}\, m_{\psi_i}^{5/2}}{s - m_{\psi_i}^2 + i m_{\psi_i}\Gamma_{\psi_i}} e^{i\phi_i}\right|^2$$

Formula for cross section

$$\sigma(e^+e^- \to D\overline{D}) = \frac{\pi}{3}\frac{(s-4m_{D^0}^2)^{3/2}+(s-4m_{D^+}^2)^{3/2}}{s^{5/2}}\alpha^2$$

$$\times\left|\begin{array}{l}\dfrac{c_0}{s-m_{\psi(3686)}^2+im_{\psi(3686)}\Gamma_{\psi(3686)}} \\ +\dfrac{1}{\alpha}\dfrac{1}{\sqrt{(m_{\psi''}^2-4m_{D^0}^2)^{3/2}+(m_{\psi''}^2-4m_{D^+}^2)^{3/2}}}\dfrac{6\sqrt{\Gamma_{ee}Br\Gamma_{\psi''}}m_{\psi''}^{5/2}}{s-m_{\psi''}^2+im_{\psi''}\Gamma_{\psi''}}e^{i\phi} \\ +c_1\sqrt{\dfrac{1}{\sqrt{2\pi}\sigma_{G(3900)}}e^{-\frac{(\sqrt{s}-M_{G(3900)})^2}{\sigma_{G(3900)}^2}}}e^{i\phi_1} \\ +\dfrac{1}{\alpha}\dfrac{1}{\sqrt{(m_{\psi(4040)}^2-4m_{D^0}^2)^{3/2}+(m_{\psi(4040)}^2-4m_{D^+}^2)^{3/2}}}\dfrac{6\sqrt{\Gamma_{ee}Br_2\Gamma_{\psi(4040)}}m_{\psi(4040)}^{5/2}}{s-m_{\psi(4040)}^2+im_{\psi(4040)}\Gamma_{\psi(4040)}}e^{i\phi_2} \\ +\dfrac{1}{\alpha}\dfrac{1}{\sqrt{(m_{\psi(4160)}^2-4m_{D^0}^2)^{3/2}+(m_{\psi(4160)}^2-4m_{D^+}^2)^{3/2}}}\dfrac{6\sqrt{\Gamma_{ee}Br_3\Gamma_{\psi(4160)}}m_{\psi(4160)}^{5/2}}{s-m_{\psi(4160)}^2+im_{\psi(4160)}\Gamma_{\psi(4160)}}e^{i\phi_2}\end{array}\right|^2$$

Fit method

- Least χ^2 fitting method
  - Fix Ψ(2S) 's width, mass to PDG value
  - Fix Ψ(4040)'s width, mass to PDG value
  - Fix Ψ(4160)'s width, mass to PDG value
  - Fix G(3900)'s width, mass to 3.9GeV and 52MeV suggested by *BABAR*'s fitting result.
    - B.Aubert , *et al*. PRD76,111105(*BABAR*)
    - E. Eichten, K. Gottfried, T. Kinoshita, K. D. Lane, and T. M. Yan, Phys. Rev. D 21, 203 (1980).
  - For Ψ(3770)'s total width, 2 methods:
    - 1) constant width
    - 2) s-dependent width

s-dependent total width of Ψ(3770)

$$\Gamma_T(s) = \Gamma_{D^0\overline{D^0}}(s) + \Gamma_{D^+D^-}(s) + \Gamma_{non-D\overline{D}}(s)$$

$$\Gamma_{D^0\overline{D^0}}(s) = \Gamma_0\theta(E_{cm} - 2M_{D^0})\frac{(p_{D^0})^3}{(p^0_{D^0})^3}\frac{1+(rp^0_{D^0})^2}{1+(rp_{D^0})^2}B_{00}$$

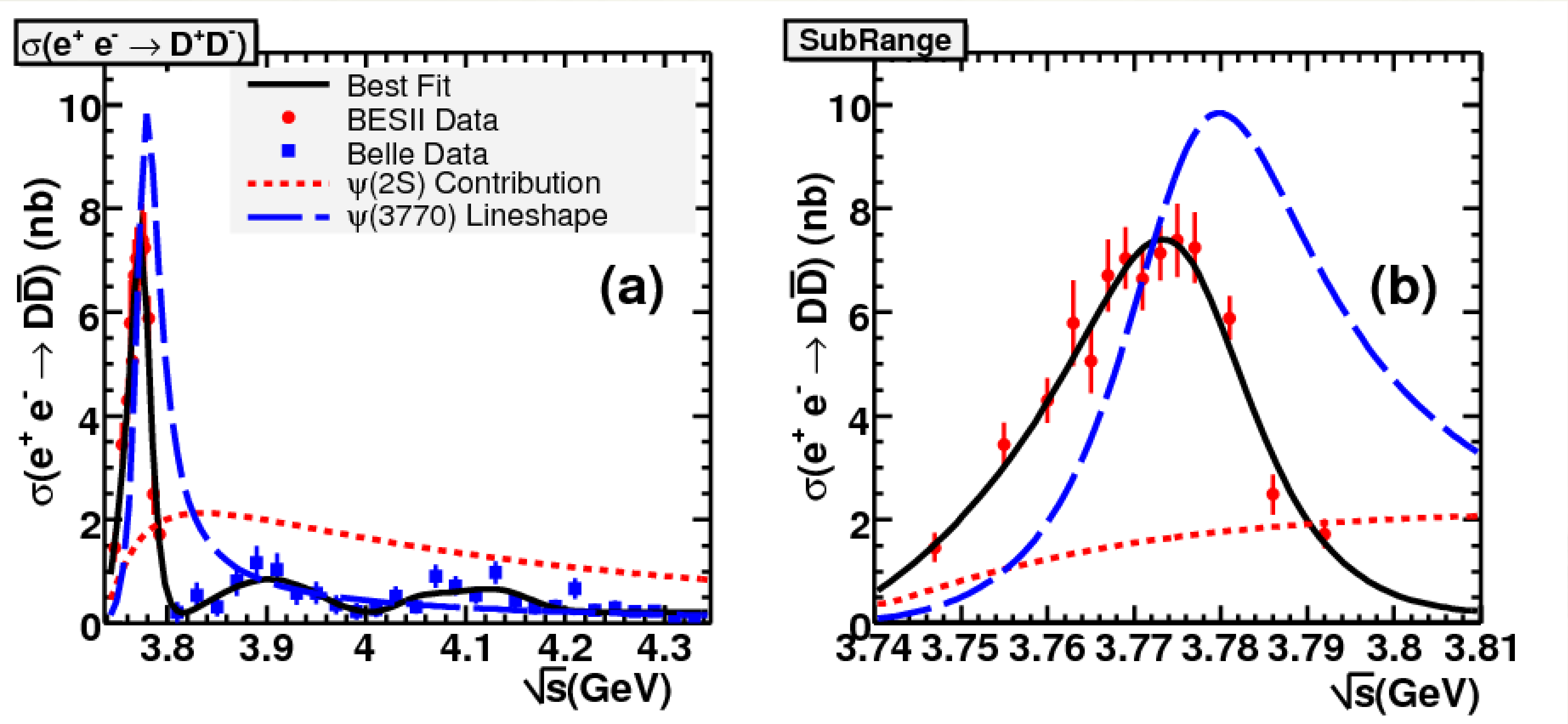
$$\Gamma_{D^+D^-}(s) = \Gamma_0\theta(E_{cm} - 2M_{D^+})\frac{(p_{D^+})^3}{(p^0_{D^+})^3}\frac{1+(rp^0_{D^+})^2}{1+(rp_{D^+})^2}B_{+-}$$

$$\Gamma_{non-D\overline{D}}(s) = \Gamma_0(1 - B_{00} - B_{+-})$$

Fix B_{00}/B_{+-} ratio to be 0.481/0.361 ~ 1.33 according to PDG value

M. Ablikim, *et al.*,
BES Collaboration, PLB 641,145(2006)

Best fit result



$\chi^2/\mathrm{dof} = 1.06$

Best fit results

$Br(\psi(3770) \to D\overline{D})$
$Br(\psi(4040) \to D\underline{D})$
$Br(\psi(4160) \to DD)$

Variables	Constant width		s-dependent
	Solution 1	Solution 2	
$m_{\psi(3770)}$ (MeV)	3776± 1	3776±1	3780±1
$\Gamma_{\psi(3770)}$ (MeV)	28.5±2.1	28.7±2.1	29.7±1.3
$\mathcal{BR}_1$ (%)	97.2± 8.9	101.1±9.0	98.3±10.4
$\mathcal{BR}_2$ (%)	25.3± 4.5	34.7±4.8	25.0±4.6
$\mathcal{BR}_3$ (%)	2.8± 1.8	40.4±3.8	2.9±1.7
c_0	8.75± 0.71	8.67±0.67	10.77±0.69
c_1	1.00±0.35	0.82±0.29	1.17±0.34
ϕ(rad.)	-2.63± 0.09	-2.56±0.09	-2.49±0.08
ϕ_1(rad.)	-1.89± 0.33	-1.55±0.36	-2.32±0.30
ϕ_2(rad.)	-2.14± 0.14	-1.62±0.11	-2.56±0.21
ϕ_3(rad.)	1.91± 0.44	-3.03±0.1	1.44±0.48

Statistical error Only!

The interference between structures and continuum term tends to be destructive

Why large contribution from Ψ(2S)

- The coupling of resonance with virtual photon:
  - Leptonic decay width→ decay constant

$$\Gamma_{e^+e^-\psi(2S)} = 2.36 \pm 0.04 keV \qquad \Gamma_{e^+e^-\psi(3770)} = 0.265 \pm 0.018 keV$$

$$f_{\psi(2S)} = 297 MeV \qquad f_{\psi(3770)} = 100 MeV$$

- The coupling of resonance with DDbar

$$Br(\psi(3770) \to D\overline{D}) \qquad c_0 = g_{\psi(2S)D\overline{D}} Q_c f_{\psi(2S)} m_{\psi(2S)}$$

$$g_{\psi(3770)D\overline{D}} = 12.8 \qquad g_{\psi(2S)D\overline{D}} = 12.0$$

- Conclusion: the large coupling of Ψ(2S) with the virtual photon.

About multiple solutions

- As the interference has been introduced, multiple solutions should exist.
- At least 8 solutions have been found, but many with *Br(Ψ(3770)→DDbar)* less than 70%. So they are abandoned as unphysical solutions.

Conclusion

- Our result concludes that taking into account the interference between $\Psi(3770)$, $\Psi(2S)$ and some higher structures is
  a good suggestion to study the DDbar branching fraction and the puzzle about non-DDbar branching fraction.
- More data sample is suggested for BESIII.

Conclusion

- Our result concludes that taking into account the interference between Ψ(3770), Ψ(2S) and some higher structures is

  a good suggestion to study the DDbar branching fraction and the puzzle about non-DDbar branching fraction.
- More data sample is suggested for BESIII.

谢谢！

Backup

Most recently updated result from Cleo-c

$$\sigma(e^+e^- \to \psi(3770) \to hadrons) = 6.36 \pm 0.08^{+0.41}_{-0.30} nb$$

arXiv:1004,1358

$$\sigma(\psi(3770) \to D\overline{D}) = 6.57 \pm 0.04 \pm 0.10 nb$$

$$\sigma(\psi(3770) \to non - D\overline{D}) = -0.21 \pm 0.09^{+0.41}_{-0.30} nb$$

$$BF(\psi(3770) \to non - D\overline{D}) < -3.3 \pm 1.4^{+6.6}_{-4.8} \%$$

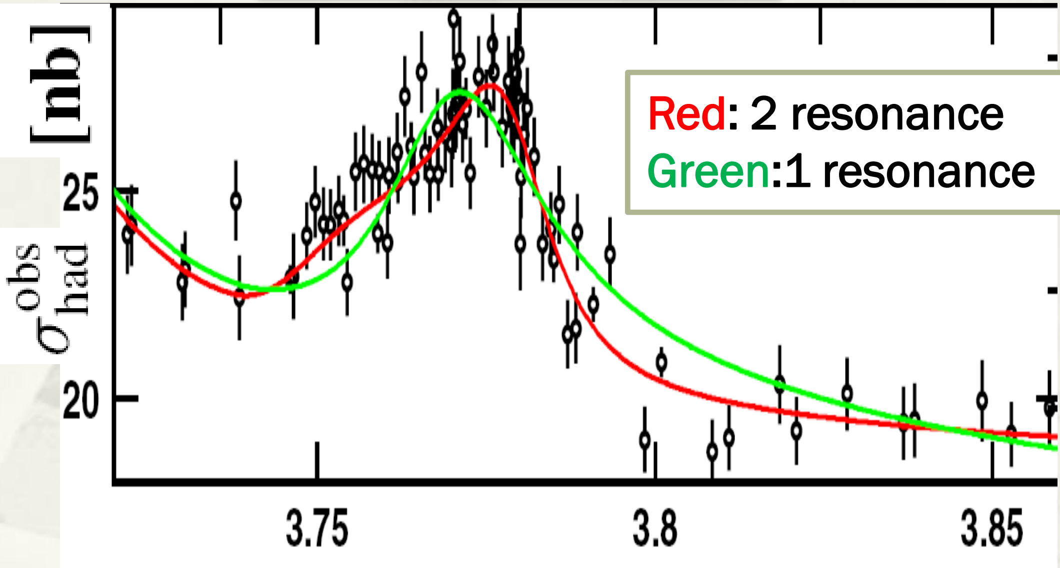
$$BF(\psi(3770) \to non - D\overline{D}) < 9\%$$ at 90% confidence level

Anomalous line shape of Ψ(3770)

BES Data (33 pb—1)

Fit with two coherent states favored over single resonance (7σ)

PRL101,102004(2008)



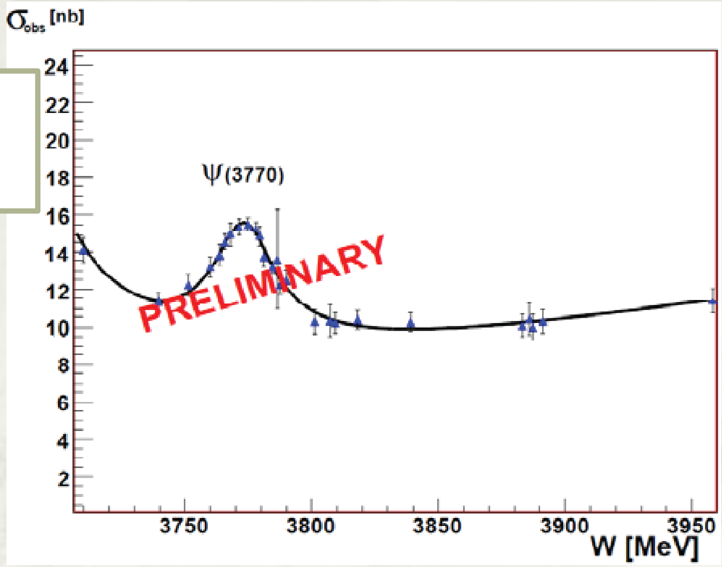
$$M_{\psi(3770)} = 3773.3 \pm 0.5 \pm 0.5\ \mathrm{MeV}$$
$$\Gamma_{\psi(3770)} = 28.2 \pm 2.1 \pm 0.1\ \mathrm{MeV}$$

$$M_1 = 3762.2 \pm 11.8 \pm 0.5\ \mathrm{MeV} \quad M_2 = 3781.0 \pm 1.3 \pm 0.5\ \mathrm{MeV}$$
$$\Gamma_1 = 49.9 \pm 32.1 \pm 0.1\ \mathrm{MeV} \quad \Gamma_2 = 19.3 \pm 3.1 \pm 0.1\ \mathrm{MeV}$$

KEDR Data 2.1 pb-1

Best fit: One resonance interfering With DDbar continuum

J.Brodzicka@Lepton Photon 2009



$$M_{\psi(3770)} = 3776.9 \pm 1.5 \pm 1.0\ \mathrm{MeV}$$
$$\Gamma_{\psi(3770)} = 25.1 \pm 3.1 \pm 3.0\ \mathrm{MeV}$$

Part of References

- M. Ablikim, *et al*., BES Collaboration, PLB 668(2008) 263-267.
- M. Ablikim, *et al*., BES Collaboration, PLB 603(2004) 130-137.
- Pakhlova *et al*. PR D77(2008)011103 (Belle)
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