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The $Y(4260)$ and $Y(4360)$ enhancements within coupled-channels

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Introduction

Ideas about dynamical poles:

scalar mesons

Boglione, Penington, PRD **65**, 114010 (2002)

van Beveren, Rijken, Metzger, Dullemond, Rupp, Ribeiro, ZPC **30**, 615 (1986)

van Beveren, Rupp, IJTPGTNO **11**, 179 (2006) [arXiv:hep-ph/0605317]

open-charm axial mesons

van Beveren, Rupp, PRL **91**, 012003 (2003)

charmonium scalar

Gamermann, Oset, Strottman, and Vacas, PRD **76**, 074016 (2007)

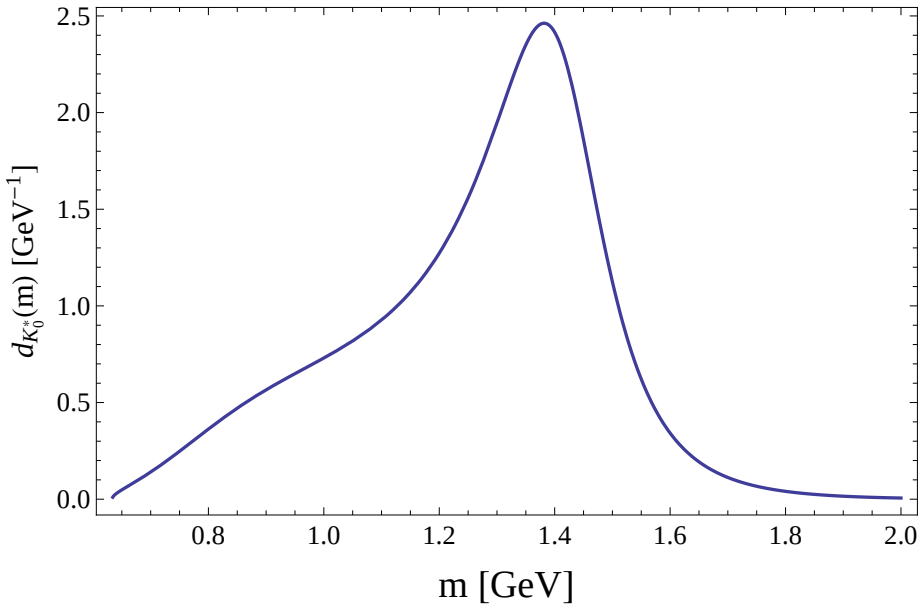
Within similar models to the one we present here

$a_0(980)$

Wolkanowski, Giacosa, Rischke, PRD **93**, 014002 (2016)

$K_0^*(800)$

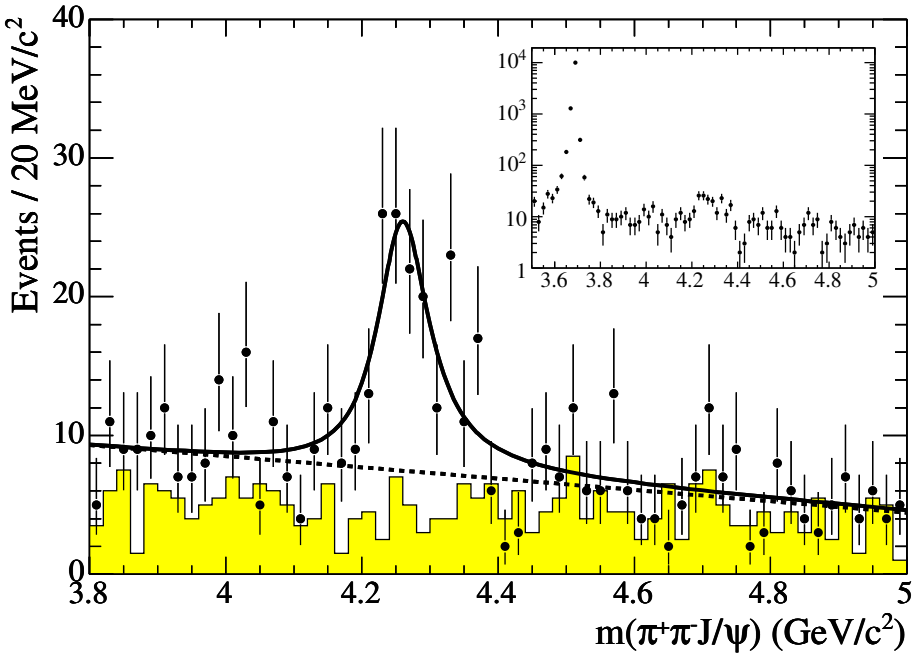
Wolkanowski, Sołtysiak, Giacosa, NPB **909**, 418 (2016)



$K\pi$

Concerning the $Y(4260)$

A signal that has 1st been detected in

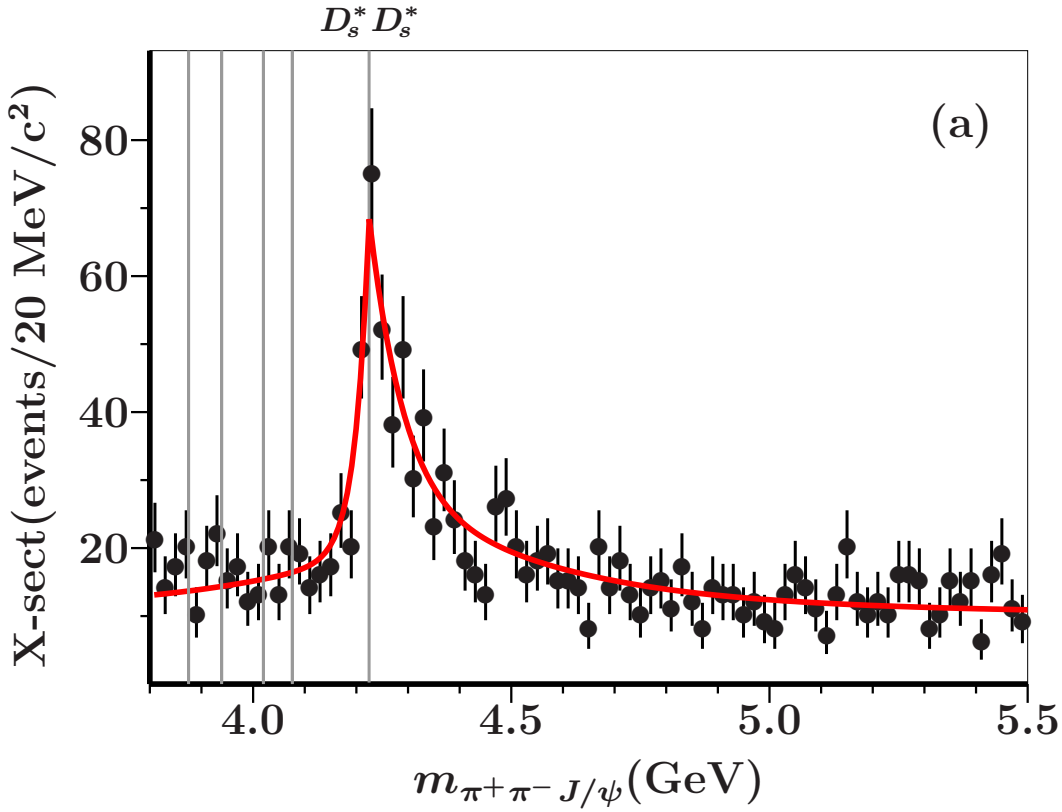


PRL**95**,142001 (2005) BABAR, $e^+e^- \to J/\psi\pi^+\pi^-$.

$M \sim 4.26$ GeV, $\Gamma = 50 - 90$ MeV

yet showing no decays to any of the open OZI-allowed decay channels!

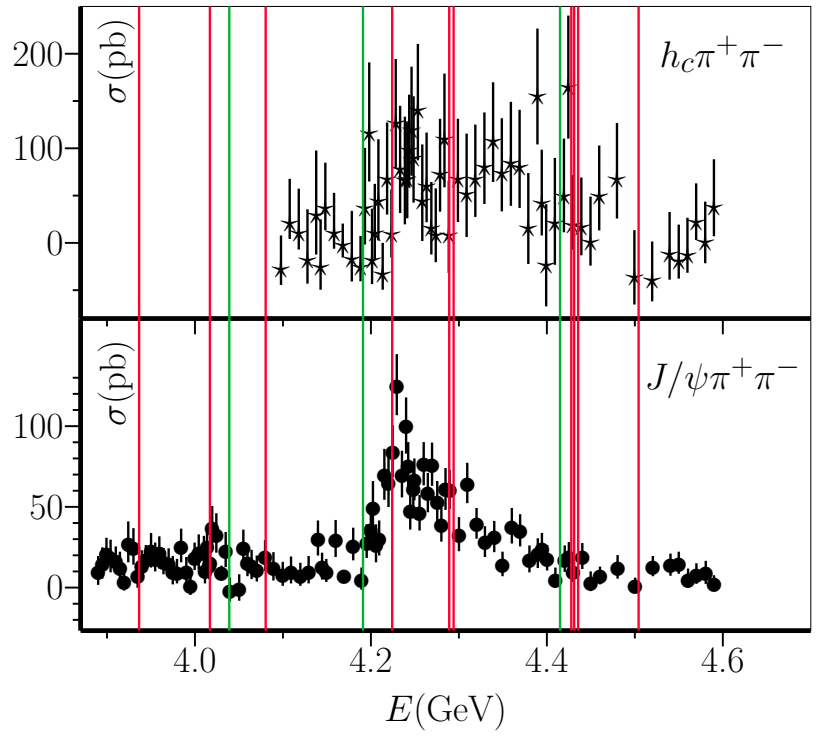
There is the idea that such enhancement might not be a true resonance



van Beveren, Rupp, PRL **105**, 102001 (2010)

van Beveren, Rupp, PRD **79**, 111501(R) (2009)

$D_s D_s$, $D^* D^*$, $D_s D_s^*$, $D_s^* D_s^*$, $D D_1$, $D^* D_1$, $D_s D_{1s}$



$\psi(4040)$, $\psi(4160)$, $\psi(4415)$

Data: BESIII PRL**118**,092001(2017); PRL**118**,092002(2017)

Recent ideas about the $Y(4260)$ and the $Y(4390)$

- Possible identification of Y states with ψ states through coupling to decay channels in a "molecular" manner

- Interference between $\psi(4160)$ and $\psi(4415)$ states

Lu, Anwar, Zou, PRD **96**, 114022 (2017)

Chen, Liu, Matsuki, EPJC **78**, 136 (2018)

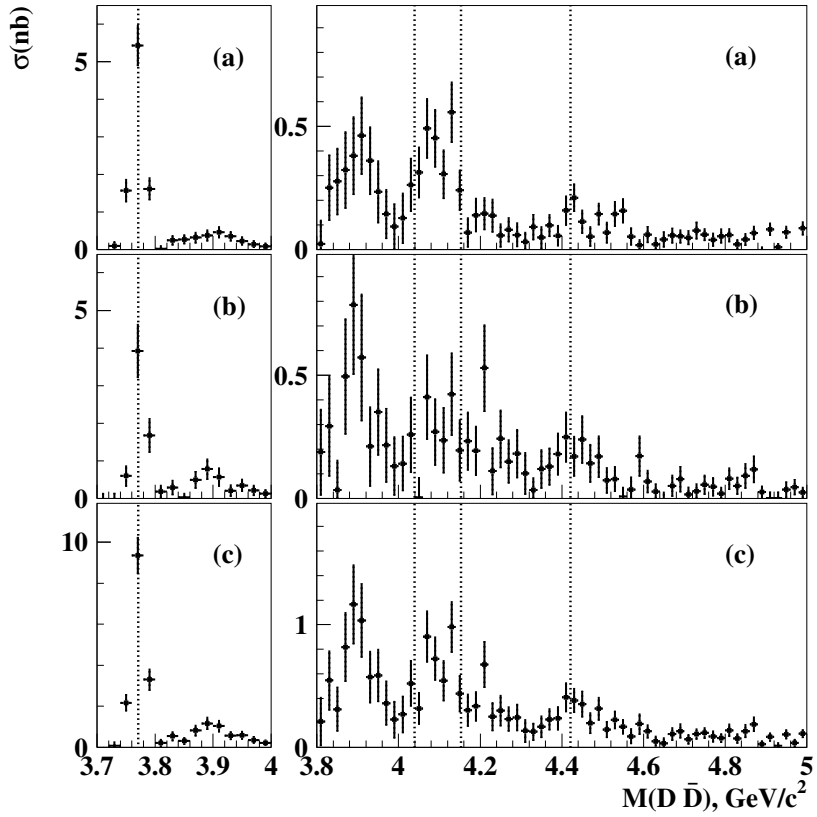
Zhang, Zhang, PRD **96**, 054008 (2017)

He, Chen, EPJC **77**, 398 (2017)

Wang, CPC **41**, 083103 (2017)

On the other hand, the determination of the ψ masses is not always easy to disentagle...

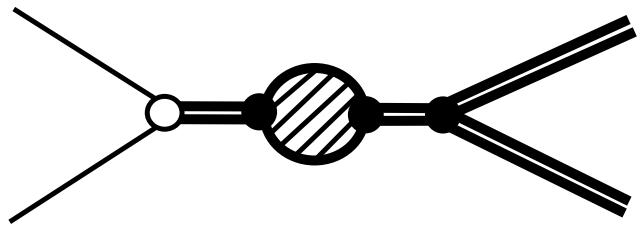
$\psi(3770)$, $\psi(4040)$, $\psi(4160)$, $\psi(4415)$



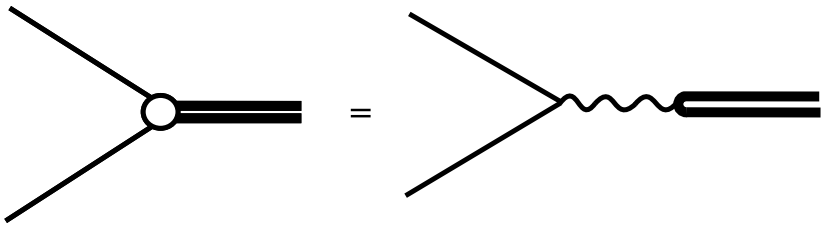
BELLE, PRD**77**,011103(R)(2008) $e^+e^- \to D\bar{D}$

An effective Lagrangian model

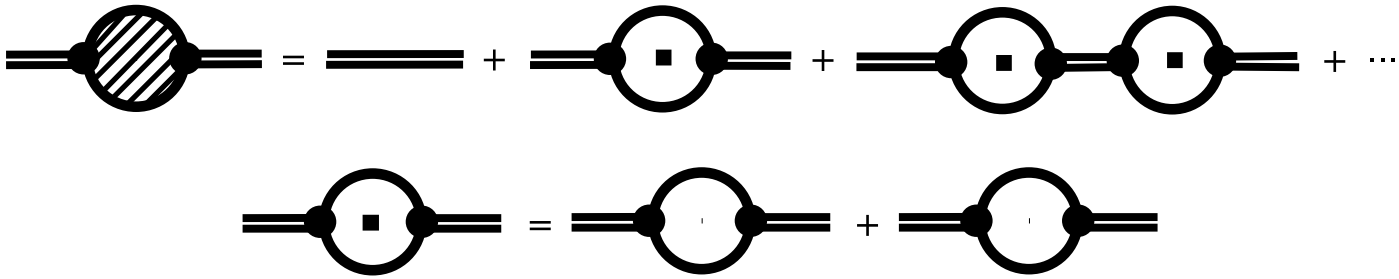
production experiment $\rightarrow$ interaction region $\rightarrow$ final hadrons



anihilation and production vertex



meson-meson loops $\Leftrightarrow$ coupled-channels



The case of the $\psi(3770)$ with $D^0\bar{D}^0$ and D^+D^- loops

S. Coito, F. Giacosa, arXiv:1712.00969

a Lagrangian density for a $V \to PP$

$$\mathcal{L}_{\psi D_i \bar{D}_i} = i g_{\psi D \bar{D}} \psi_\mu \sum_i^2 \left(\partial^\mu D_i \bar{D}_i - \partial^\mu \bar{D}_i D_i \right)$$

Vertex decay width and amplitude

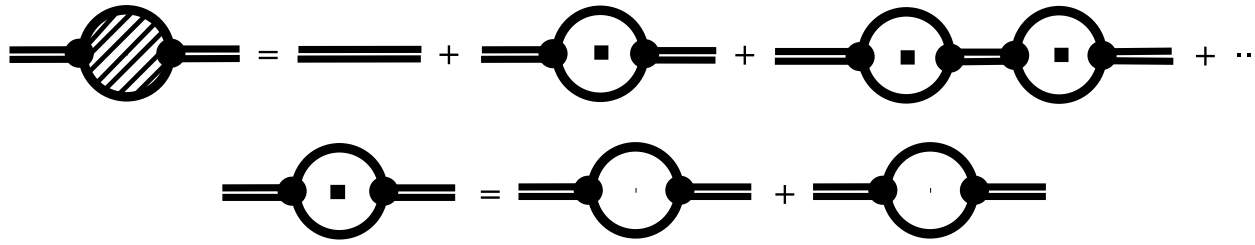
$$\Gamma_{\psi \to D_i \bar{D}_i}(s) = \frac{k_i(s, m_{D_i})}{8\pi s} |\mathcal{M}_{\psi \to D_i \bar{D}_i}|^2$$

$$|\mathcal{M}_{\psi \to D_i \bar{D}_i}|^2 = g^2_{\psi D \bar{D}} \frac{4}{3} k_i^2(s, m_{D_i}) f_\Lambda^2(s)$$

Form-factor

$$f_\Lambda(\mathbf{q_i}) = e^{-\mathbf{q_i}^2/\Lambda^2}$$

Building a propagator



$$G_{\mu\nu}(p) = \frac{1}{p^2 - m_\psi^2 + i\varepsilon}\Big(- g_{\mu\nu} + \frac{p_\mu p_\nu}{m_\psi^2}\Big)$$

$$\Delta_{\mu\nu}(p) = G_{\mu\nu}(p) + G_{\mu\mu'}(p)\Pi_{\mu'\nu'}(p)G_{\nu'\nu}(p) + \cdots ,$$

$$\Pi_{\mu\nu}(p) = g^2_{\psi D\bar{D}} \sum_i \Pi_{i\mu\nu}(p, m_{D_i})$$

$$\Pi(s) = \frac{1}{3}\left(-g^{\mu\nu} + \frac{p^\mu p^\nu}{p^2}\right)\Pi_{\mu\nu}(p) = g^2_{\psi D\bar{D}} \sum_i \Pi_i(s, m_{D_i})$$

$$\Delta(s) = \frac{1}{s - m_\psi^2 + \Pi(s)}$$

For N channels

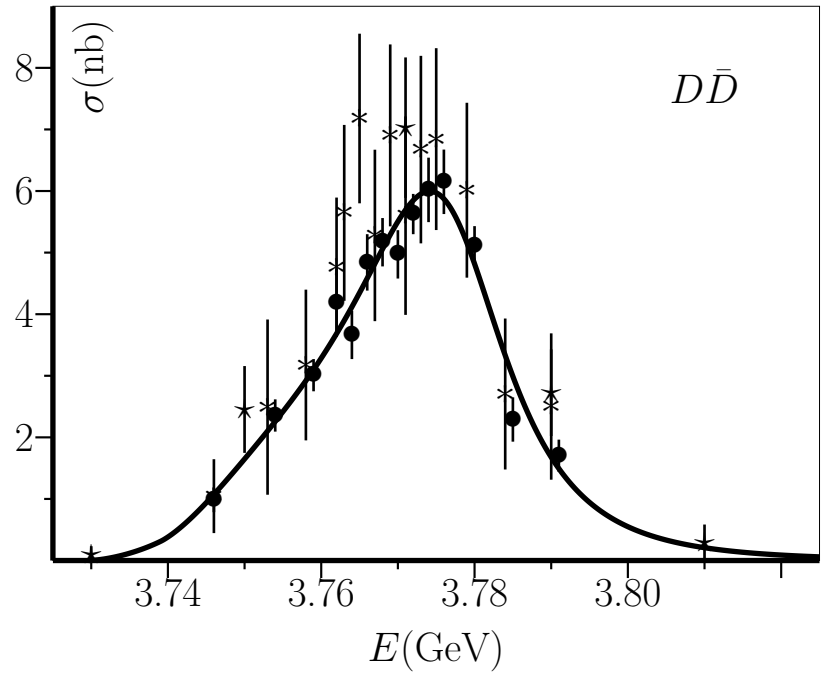
$$\Pi(s) = \sum_j^N \Big(\Omega_j(s) + i\sqrt{s}\Gamma_j(s)\Big), \quad \Omega,\ \Gamma \in \Re,$$

$$\Omega_j(s, m_1, m_2) = \frac{PP}{\pi} \int_{s_{th}}^{\infty} \frac{\sqrt{s}\Gamma_j(s', m_1, m_2)}{s' - s}\ \mathrm{d}s'$$

The unitarized spectral function is given by

$$\begin{aligned} d_\psi(E) &= -\frac{2E}{\pi} \mathrm{Im}\ \Delta(E) \\ &= \frac{2E^2}{\pi} \frac{\sum_j \Gamma_j(E^2)}{[E^2 - m_\psi^2 + \mathrm{Re}\,\Pi(E^2)]^2 + [\mathrm{Im}\,\Pi(E^2)]^2} \end{aligned}$$

The $\psi(3770)$ cross section



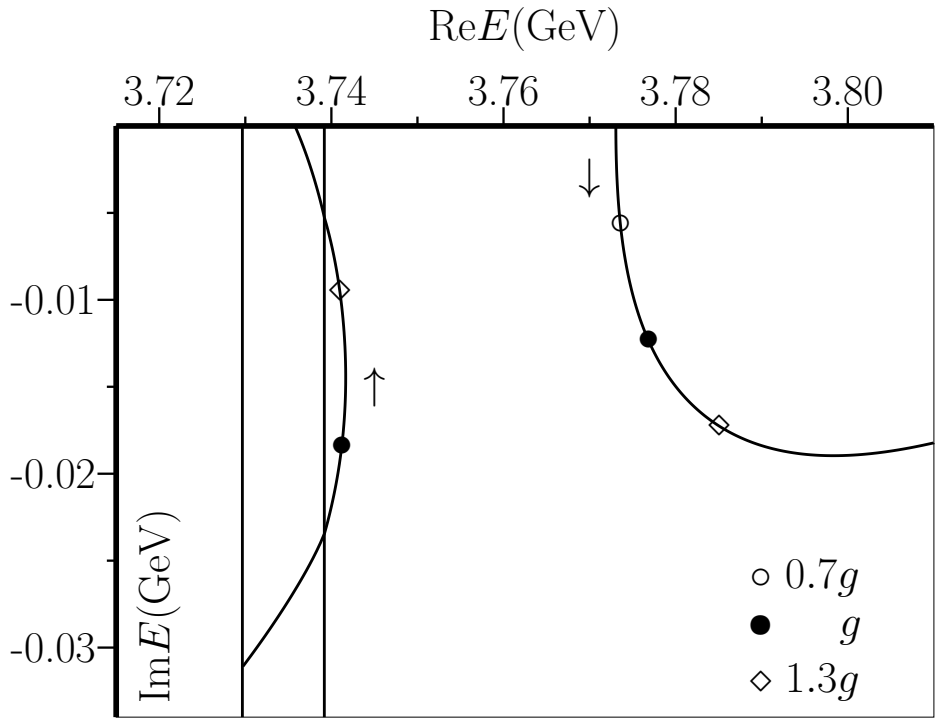
Data: BES PLB **668**,263 (2008); BES PRL **97**,121801 (2006)

Fit parameters: m_ψ: 3773.05 $\pm$ 0.95 MeV

Λ: 272.55 $\pm$ 1.17 MeV

$\chi^2/d.o.f$ - 0.86

Pole trajectories

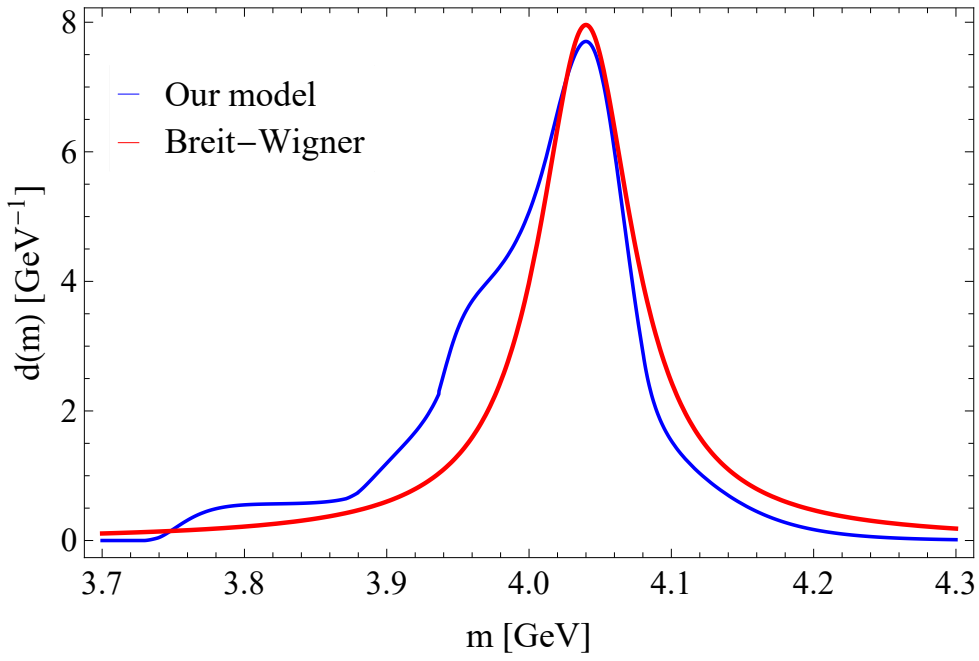


$\bullet$	3741.2 $-$ i18.5 MeV	3776.8 $-$ i12.3 MeV
$\circ$	-	3773.5 $-$ i5.5 MeV
$\diamond$	3741.0 $-$ i9.5 MeV	3784.9 $-$ i17.2 MeV

The $\psi(4040)$ and the $Y(4008)$

cf. poster of M. Piotrowska (collab. with F. Giacosa and P. Kovacs)

Total spectral function with channels DD, DD^*, and D^*D^*



Poles around: $\psi(4040)$: $4053 - i39$ MeV

$Y(4008)$: $3934 - i30$ MeV

The $\psi(4160)$ and the $Y(4260)$...

cf. S. Coito, PoS Hadron2017 (2018) 030.

Coupled-channels (through the loops):

below $\psi(4160)$ threshold: DD DD^* D^*D^* D_sD_s $D_sD_s^*$

above $\psi(4160)$ threshold: $D_s^*D_s^*$ DD_1 DD_1' (not seen yet)

suppressed channel, but seen in the experiment: $J/\psi f_0(980)$

... and the $\psi(4415)$ and $Y(4390)$

below $\psi(4415)$ threshold: DD DD^* D^*D^* D_sD_s $D_sD_s^*$ $D_s^*D_s^*$ DD_1 DD_1'

above $\psi(4415)$ threshold: D^*D_1 D^*D_1' D_sD_{s1} D_sD_{s1}'

suppressed channel, but see in the experiment: $J/\psi f_0(980)$

Interactions: $V \to PP,\ PV,\ VV,\ PA,\ VS$

$$PP: \mathcal{L}_I = ig_{VPP}\ \psi_\mu \Big(\partial^\mu D_1 \bar{D}_2 - \partial^\mu \bar{D}_2 D_1\Big) + h.c.$$

$$PV: \mathcal{L}_I = ig_{VPV}\ \tilde{\Psi}_{\mu\nu} D \bar{D}^{*\mu\nu} + h.c.\ ,$$

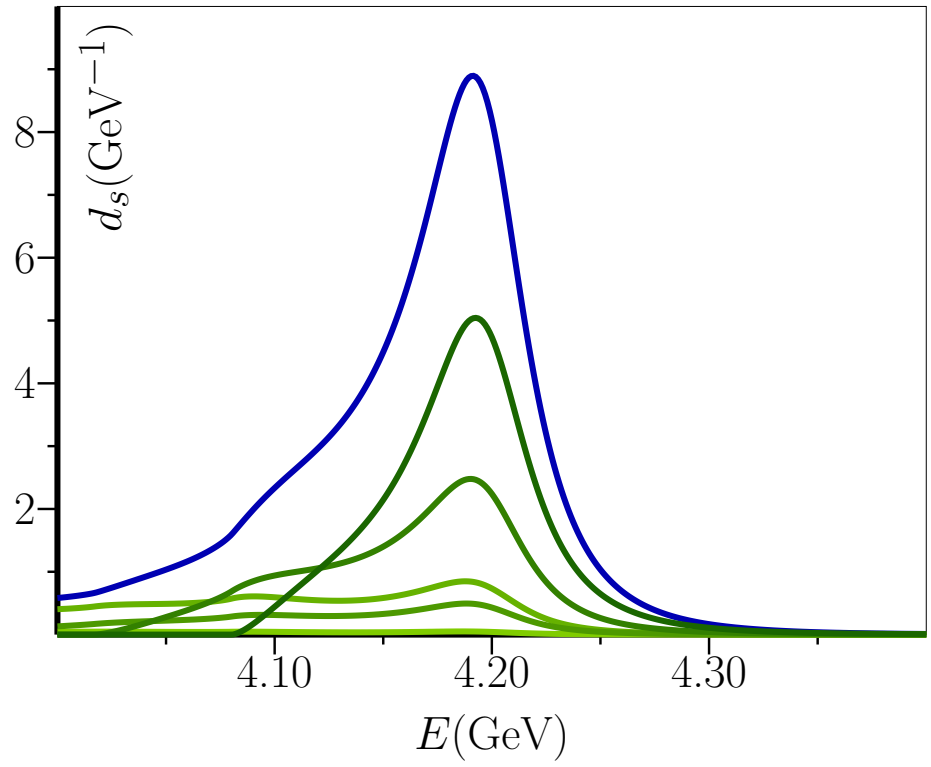
$$\tilde{\Psi}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\alpha\beta}\Psi^{\alpha\beta}\ ,\quad \Psi^{\alpha\beta} = \partial^\alpha \psi^\beta - \partial^\beta \psi^\alpha,\quad D^{*\mu\nu} = \partial^\mu D^{*\nu} - \partial^\nu D^{*\mu}$$

$$VV: \mathcal{L}_I = \frac{i}{2} g_{VVV}\ \Psi_{\mu\nu}\Big(D_1^{*\mu}\bar{D}_2^{*\nu} - D_1^{*\nu}\bar{D}_2^{*\mu}\Big) + h.c.,\ \ \Psi_{\mu\nu} = \partial_\mu\psi_\nu - \partial_\nu\psi_\mu\ .$$

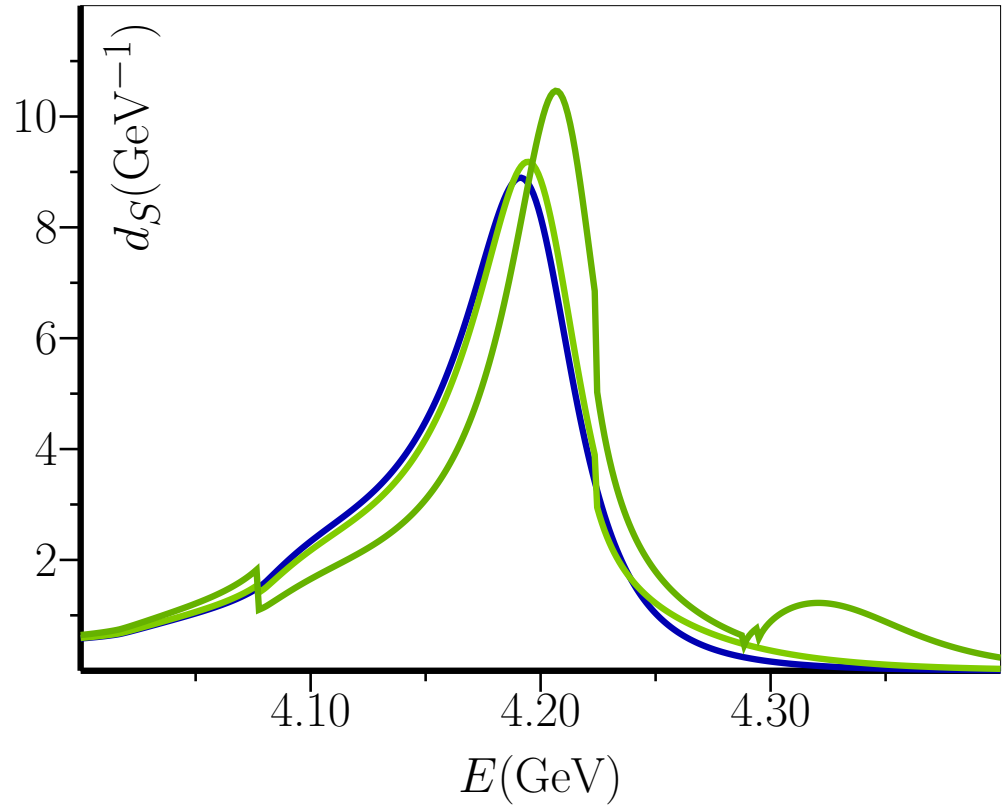
$$PA: \mathcal{L}_I = ig_{\psi D D_1}\psi_\mu D \bar{D}_1^\mu + h.c.$$

$$SV: \mathcal{L}_I = g\psi_\mu J/\psi^\mu f_0(980)$$

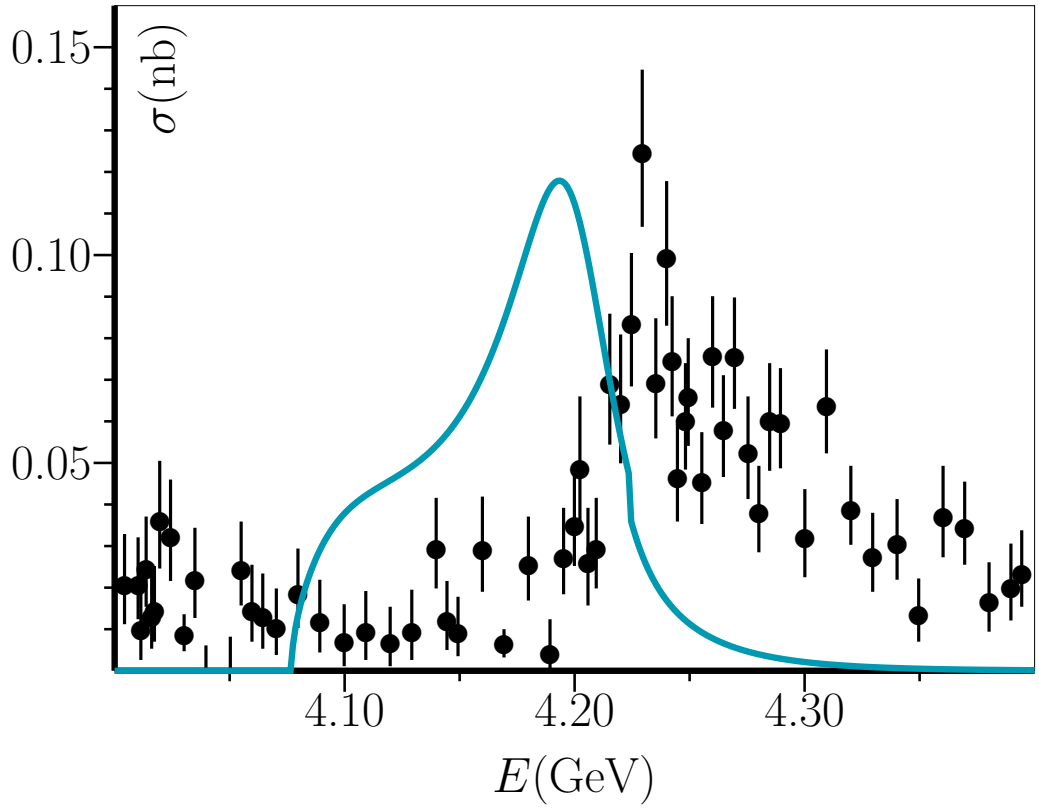
Line-Shape for the $\psi(4160)$



5 channels: DD DD^* D^*D^* D_sD_s $D_sD_s^*$



5 channels, $+D_s^* D_s^*$, and $+DD_1$ DD_1' (with an arbitrary coupling)



Channel $J/\psi f0(980)$ compared to $J/\psi\pi\pi$ data

Summary and Conclusions

• The ψ and Y spectra above $D\bar{D}$ threshold are very intriguing as there is a big quantum mixing

• Loops $\Leftrightarrow$ coupled-channels are important and simple Breit-Wigner fits are too naive

• We show results of an effective Lagrangian approach for the $\psi(3770)$, $\psi(4040)$ and $\psi(4160)$ interfering with their respective open-decay channels.

• In the presented results the $Y(4260)$ do not emerge as a companion pole of the $\psi(4160)$, but a full study of the interferences including closed-channels and mixing among the different ψ is still undergoing.

$\therefore$