

**"XIIIth Quark Confinement and the Hadron Spectrum",  
Maynooth - Ireland, August 2, 2018**

**Radially excited  $\psi$  mesons and the Y  
enhancements**

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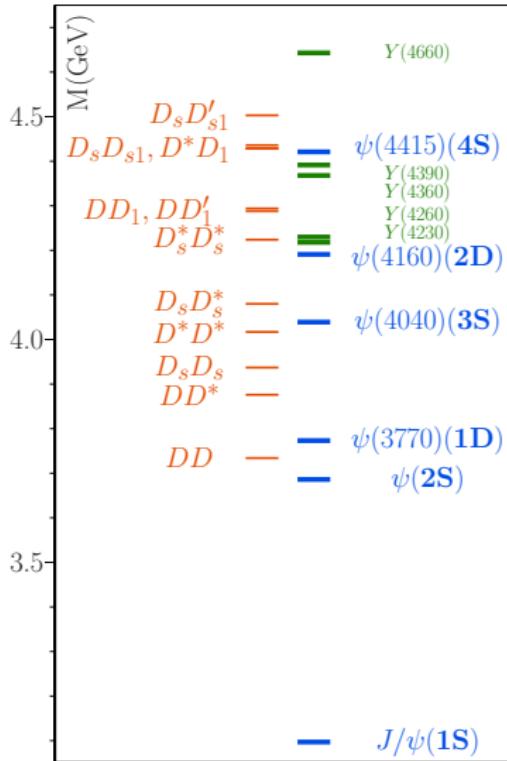


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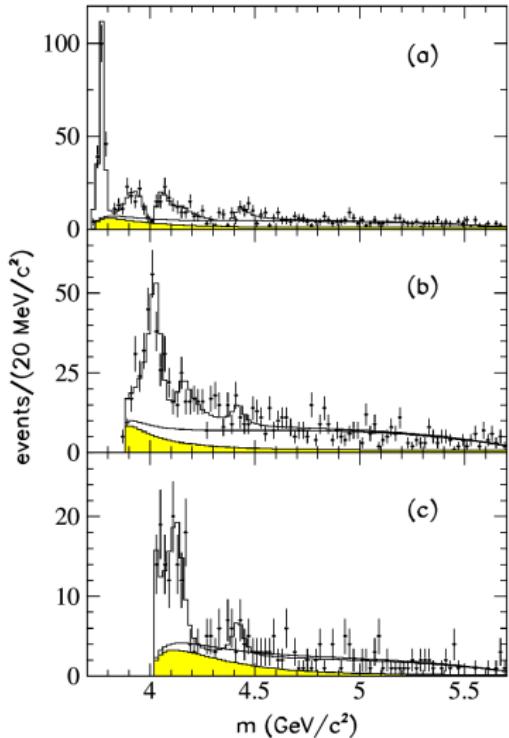
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JANA KOCHANOWSKIEGO W KIELCACH

# Introduction: The $\psi$ 's and the $Y$ 's

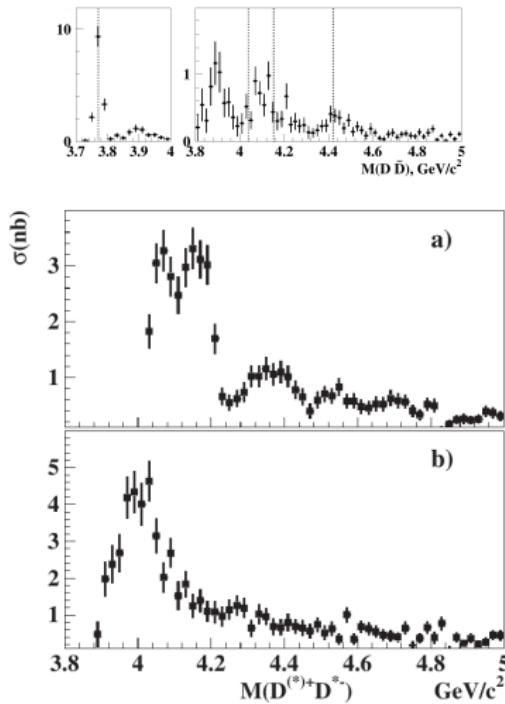


1<sup>--</sup> (PDG 2018)

Data:  $DD, DD^*, D^*D^*$  - how to identify the  $\psi$  states?

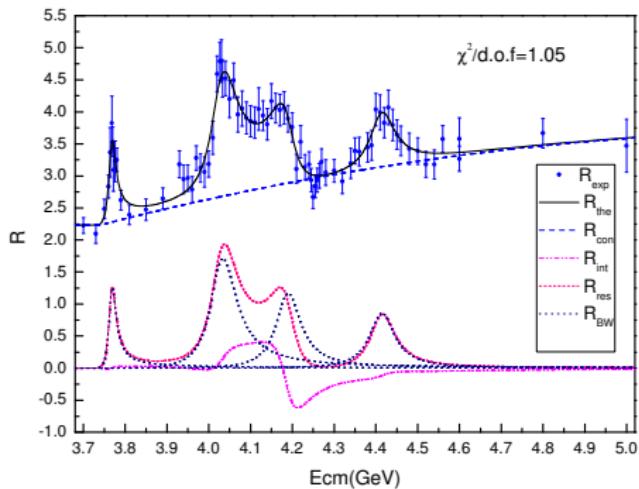


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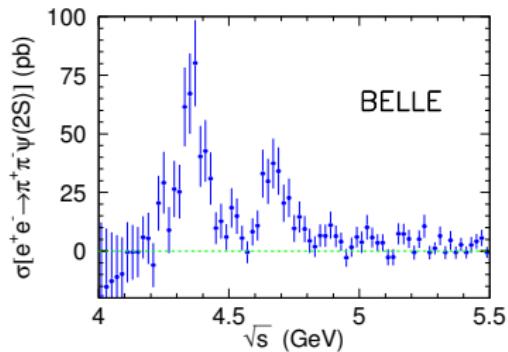
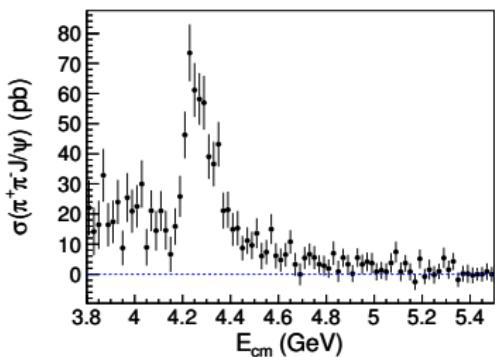
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The  $\psi$  spectrum: BES Collaboration, PLB 660, 315 (2008)

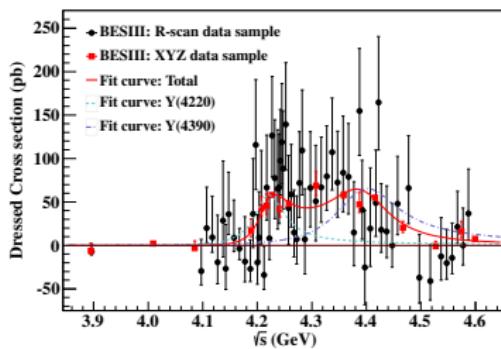
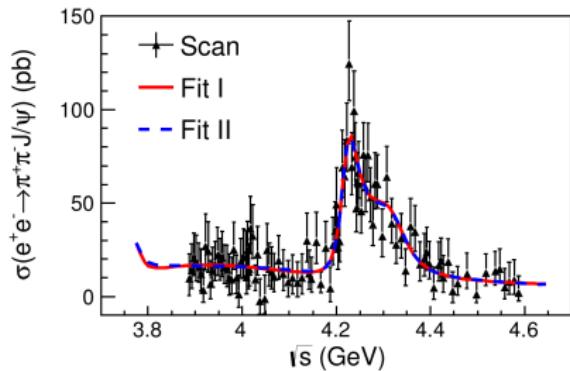


$\psi(3770), \psi(4040), \psi(4160), \psi(4415)$

Data: Channels  $J\psi\pi\pi$ ,  $\psi\pi\pi$ ,  $h_c\pi\pi$  - new  $Y$  states?



Belle



BES

## Some ideas concerning 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)

Gamermann, Oset, EPJA **36**, 189 (2008)

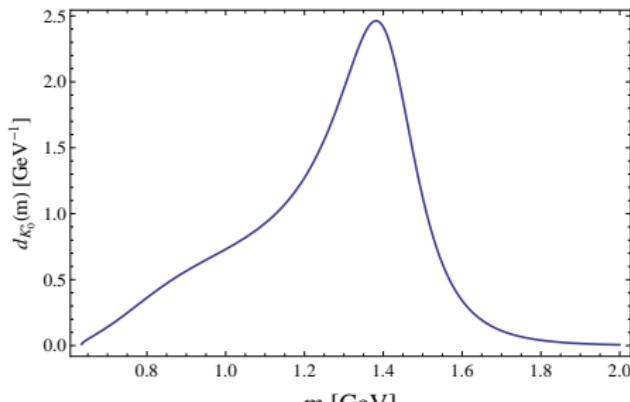
Within similar models to the one we present here:

$a_0(980)$

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

$K_0^*(800)$

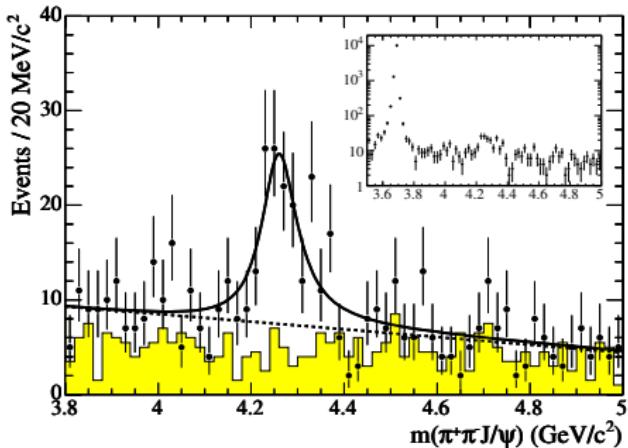
Wolkanowski, Sołtysiak, Giacosa, NPB **909**, 418 (2016)



$K\pi$

## Concerning the $Y(4260)$

A signal that has 1st been detected in

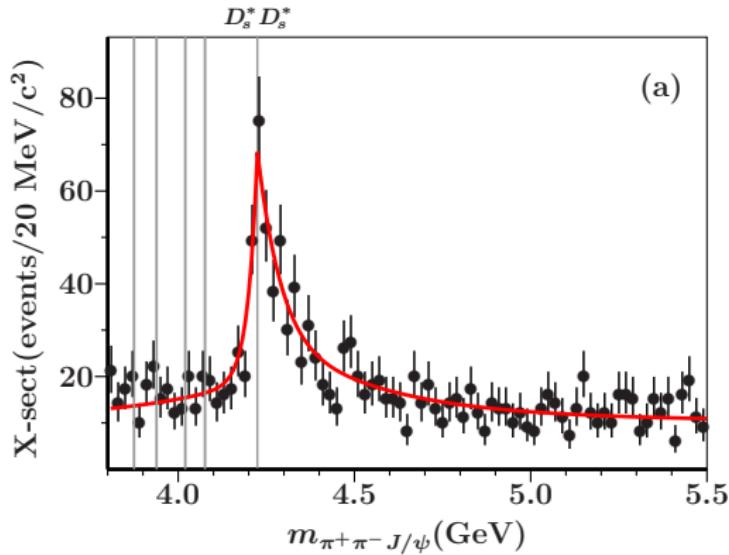


PRL95,142001 (2005) BABAR,  $e^+e^- \rightarrow J/\psi\pi^+\pi^-$ .

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

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)

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

- Possible identification of  $Y$  states with  $\psi$  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)

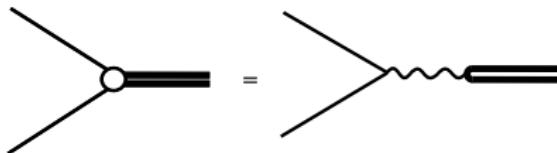
Wang, CPC **41**, 083103 (2017)

## An effective Lagrangian model

production experiment → interaction region → final hadrons



annihilation 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  $V \rightarrow PP$

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

Vertex decay width and amplitude

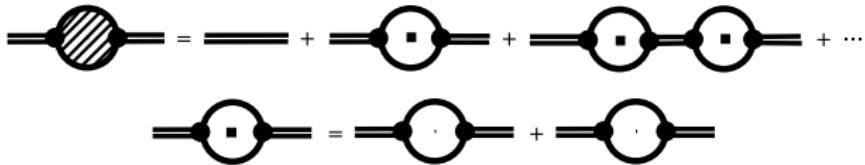
$$\Gamma_{\psi \rightarrow D_i \bar{D}_i}(s) = \frac{k_i(s, m_{D_i})}{8\pi s} |\mathcal{M}_{\psi \rightarrow D_i \bar{D}_i}|^2$$

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

Form-factor

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

Building a propagator



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

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

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

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

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

For N channels

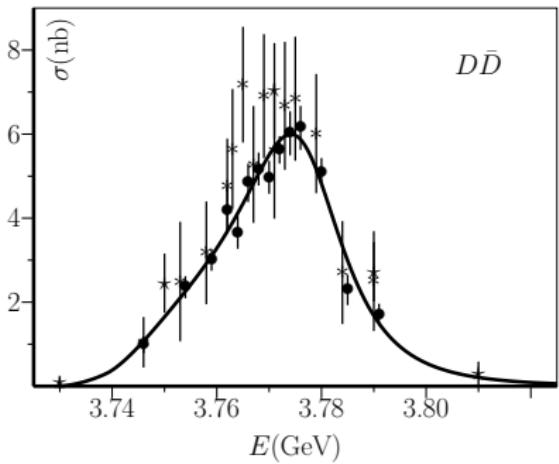
$$\Pi(s) = \sum_j^N \left( \Omega_j(s) + i\sqrt{s}\Gamma_j(s) \right), \quad \Omega, \Gamma \in \Re,$$

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

The unitarized spectral function is given by

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

## The $\psi(3770)$ cross section



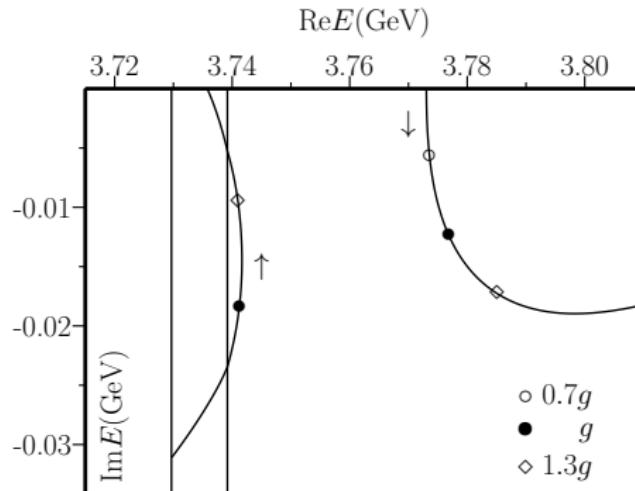
Data: BES PLB **668**,263 (2008); BES PRL **97**,121801 (2006)

Fit parameters:  $m_\psi: 3773.05 \pm 0.95$  MeV

$\Lambda: 272.55 \pm 1.17$  MeV

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

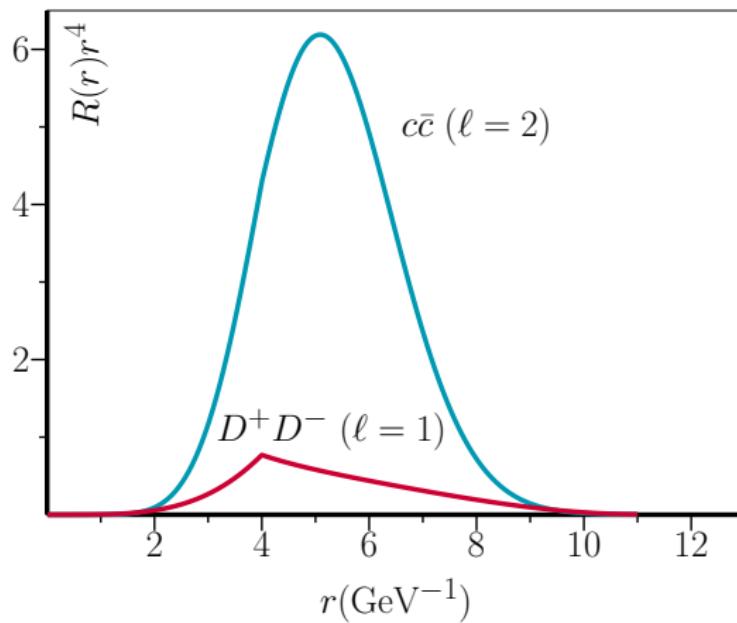
## Pole trajectories



- $3741.2 - i18.5 \text{ MeV}$      $3776.8 - i12.3 \text{ MeV}$
- -  $3773.5 - i5.5 \text{ MeV}$
- ◊  $3741.0 - i9.5 \text{ MeV}$      $3784.9 - i17.2 \text{ MeV}$

## The cutoff and the size of the system:

$c\bar{c}$  ( $D$  – wave) –  $D^+D^-$  ( $P$  – wave)

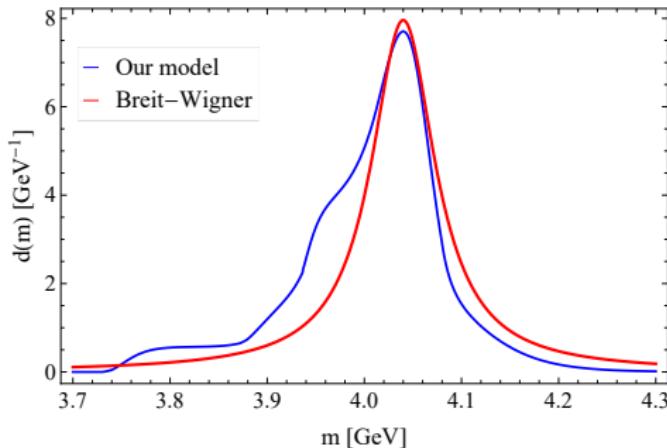


$$\sqrt{\langle r^2 \rangle} = 4.74 \text{ GeV}^{-1} \sim 0.93 \text{ fm.}$$

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

M. Piotrowska, 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

$\Lambda = 420$  MeV

**Interactions:**  $V \rightarrow PP, PV, VV, PA, VS$

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

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

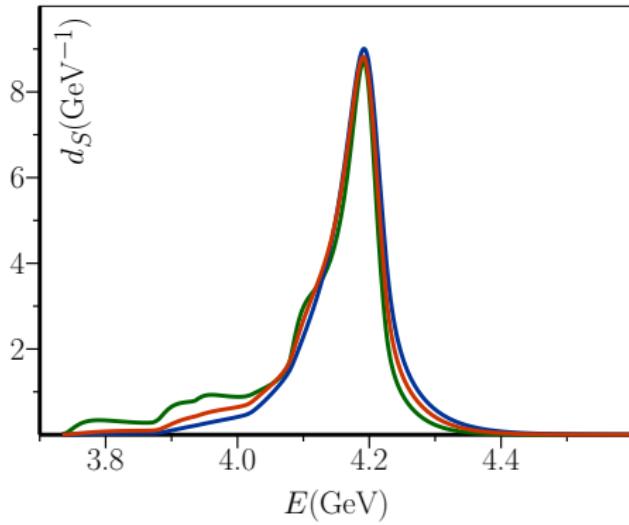
$$\tilde{\Psi}_{\mu\nu} = \frac{1}{2} \epsilon_{\mu\nu\alpha\beta} \Psi^{\alpha\beta} , \quad \Psi^{\alpha\beta} = \partial^\alpha \psi^\beta - \partial^\beta \psi^\alpha , \quad D^{*\mu\nu} = \partial^\mu D^{*\nu} - \partial^\nu D^{*\mu}$$

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

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

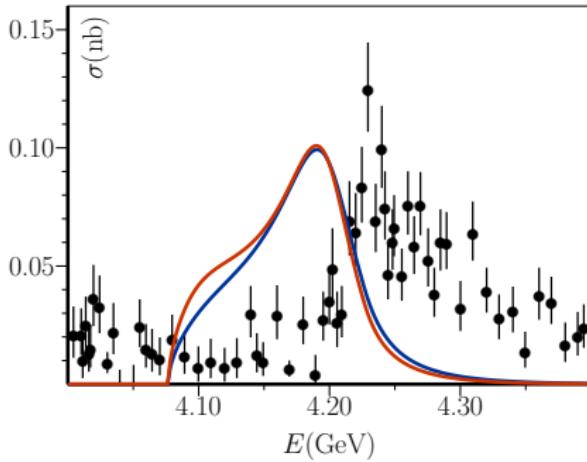
## Line-Shape for the $\psi(4160)$

$\Lambda = 400, 450, 500$  MeV



Loop channels:  $DD$   $DD^*$   $D^*D^*$   $D_sD_s$   $D_sD_s^*$   $D_s^*D_s^*$

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

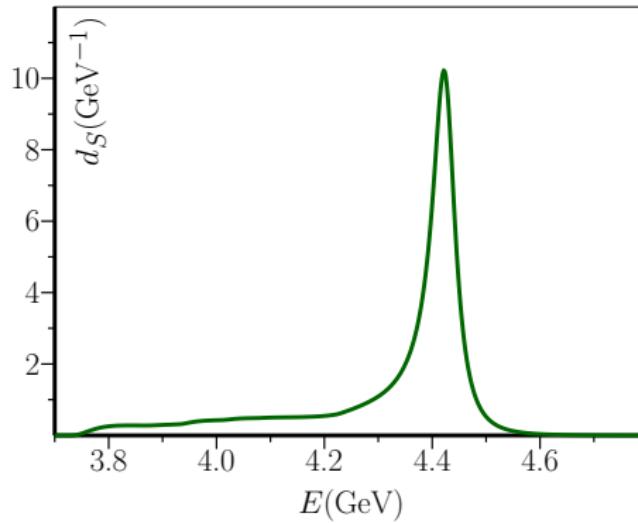


Channel  $J/\psi f_0(980)$  compared to  $J/\psi\pi\pi$  data

In Torres, Khemchandani, Gamermann, and Oset, PRD **80**, 094012 (2009), the authors couple the channels:  $J/\psi\pi\pi$  and  $J/\psi KK$  and get a peak about 4.15 GeV with width about 90 MeV.

## Line-Shape for the $\psi(4415)$

$\Lambda = 550$  MeV



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

## Summary and Conclusions

- The  $\psi$  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.
- The direct coupling of the  $\psi(4160)$  to the decay channels is not enough to generate the  $Y(4260)$ .
- The identification of the  $Y(4260)$  as an effect of the  $\psi(4160)$  is not excluded, and other interferences are under study.

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