"2017 International Summer Workshop on Reaction Theory"
June 21, 2017, Bloomington, Indiana, USA

Line-shape analysis of the $\psi(3770)$

Susana Coito

Collaborator: Francesco Giacosa

Jan Kochanowski University, Kielce, Poland

NARODOWE CENTRUM NAUKI

UNIWERSYTET
JANA KOCHANOWSKIEGO W KIELCACH

Introduction

Mysteries in the data

The vector meson $\psi(3770)$, reported in PDG with average parameters $M = 3773.13$ MeV and $\Gamma = 27.2 \pm 1.0$ MeV, has a deformed, i.e., non–Breit-Wigner line-shape.

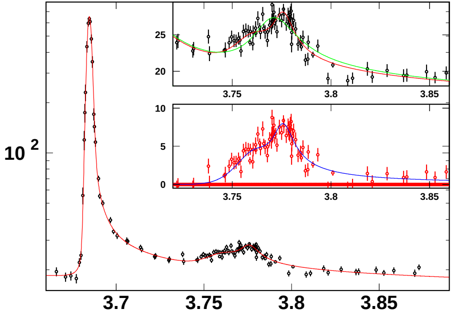
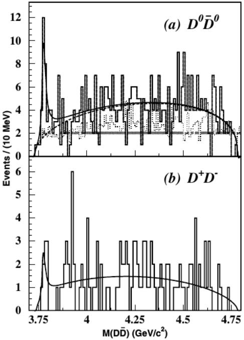


Figure: $\sigma = \sigma(E)$ in [nb, GeV]. PRL101,102004(2008) *BES*, $e^+e^- \rightarrow$ *hadrons*

Other data:

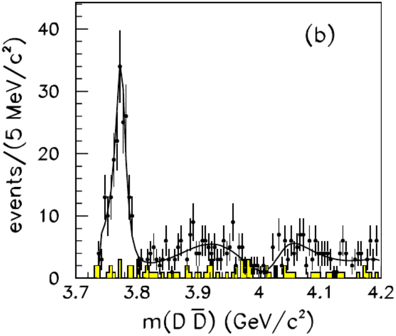
PRL93,051803(2004) Belle

$B^+ \to \psi(3770) K^+$



PRD76,111105(2007) BaBar

ISR



The Novosibirsk group: KEDR Collaboration, PLB711,292(2012).

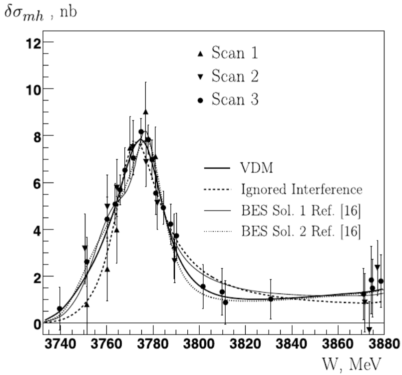
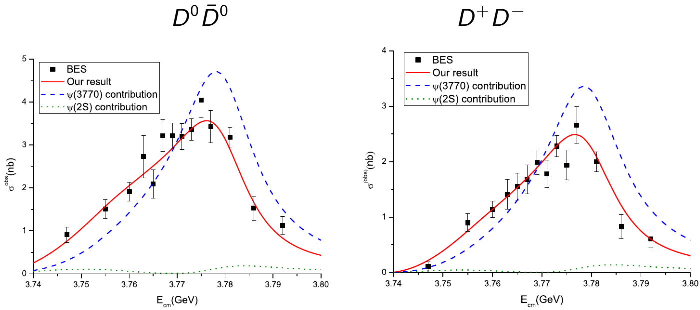


Figure: $e^+e^- \to D\bar{D}$

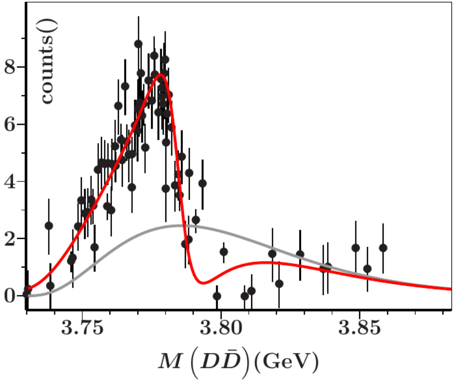
Analysis: interference between resonant and nonresonant part, where the nonresonant part is related to the nonresonant part of the form factor (use of vector dominance model).

Phenomenological Studies

- In PRD88,014010(2013) contribution of off-shell PV channels
- PLB718,1369(2013) production $e^+e^- \to D\bar{D}$, including interference with nonresonant background due to $\psi(2S)$, and rescattering of final states:



- PRD80,074001(2009) E. van Beveren, G. Rupp



Interference with background due to $D\bar{D}$ threshold enhancement

An Effective Lagrangian Model

Defining the Lagrangian

We consider the following decay of a vector to two pseudovectors:

$$\psi(3770) \to D^+ D^-$$

We define a Lagrangian density as

$$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_I$$

$$\mathcal{L}_0 = -\frac{1}{4}\Psi_{\mu\nu}\Psi^{\mu\nu} + \frac{1}{2}m_\psi^2 \psi_\mu \psi^\mu + \frac{1}{2}\Big(\partial_\mu D^+ \partial^\mu D^- - m_D^2 D^+ D^-\Big)$$

$$\Psi_{\mu\nu} = \partial_\mu \psi_\nu - \partial_\nu \psi_\mu$$

$$\mathcal{L}_I = ig\psi_\mu\Big(\partial^\mu D^+ D^- - \partial^\mu D^- D^+\Big)$$

The 3-level decay width is given by

$$\frac{d\Gamma(E)}{d\Omega} = \frac{d^3 p_1}{(2\pi)^3 2E_1} \frac{d^3 p_2}{(2\pi)^3 2E_2} \delta^4(P - p_1 - p_2) \frac{(2\pi)^4}{2\sqrt{s}}$$

Which turns, for the spherically symmetric case,

$$\Gamma(E) = \frac{1}{8\pi} \frac{p(E)}{s} |\mathcal{M}|^2.$$

The amplitude $|\mathcal{M}|^2$ is computed from the Lagrangian. It comes

$$|\mathcal{M}|^2 = \frac{g^2}{3} p^2(E) f(E),$$

where $f(E)$ is a cutoff function

$$f(E) = e^{-2p^2(E)/\Lambda^2}.$$

Free parameters:

g coupling for the vertex $\psi(3770)$ to D^+D^-, Λ cutoff parameter, $\Lambda \sim \frac{1}{\sqrt{<r^2>}}$

Propagator

The propagator for an unstable particle is given by

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

where the loop-function, or self-energy, is

$$\Sigma(E) = \Omega(E) + iE\Gamma(E)$$

Dispersion relation, cauchy principal value

$$\Omega(E) = \frac{1}{\pi} \int_{s_{th}}^{\infty} \frac{\sqrt{s'}\Gamma(s')}{s' - s}\ ds'$$

The introduction of $\Omega(E)$ in the propagator leads to a normalized spectral function.

Spectral function with D^+D^- loop but no rescattering

Considering the once-subtracted dispersion relation

$$\Omega_{1S}(E) = \Omega(E) - \Omega(m_\psi)$$

$$\Sigma(E) = \Omega_{1S}(E) + iE\Gamma(E)$$

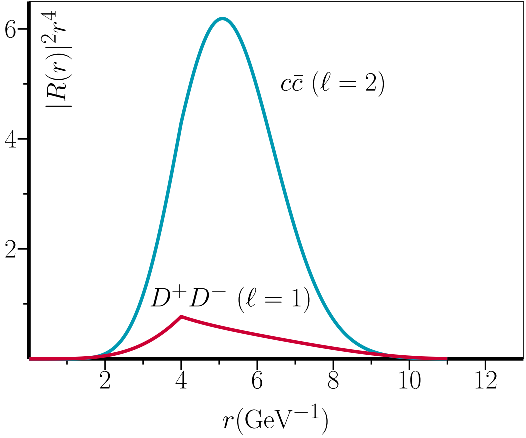
$$\Delta(E) = \frac{1}{E^2 - m_\psi^2 + \Omega_{1S}(E) + iE\Gamma(E)}$$

Cross section (line-shape)

$$\sigma(E) = -g^2_{\psi e^+ e^-} \mathrm{Im}\Delta(E)$$

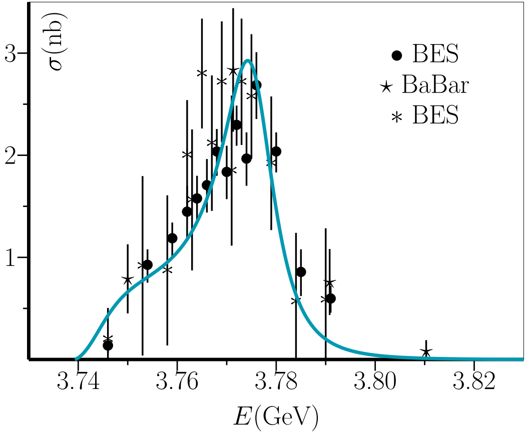
Estimating the cutoff through the wave-function of a system

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



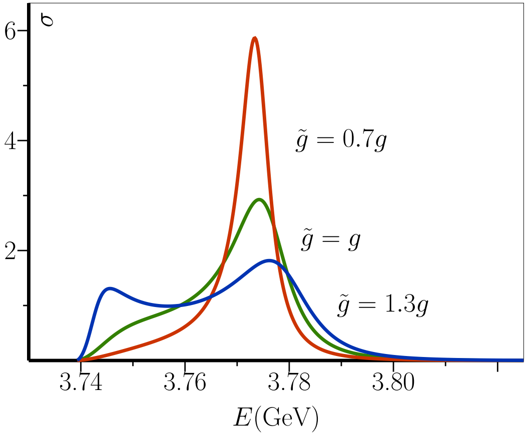
$\sqrt{< r^2 >} = 4.74\ \mathrm{GeV}^{-1} \sim 0.93$ fm.

Cutoff parameter: $\Lambda \sim \frac{1}{4.74\mathrm{GeV}^{-1}} = 211$ MeV



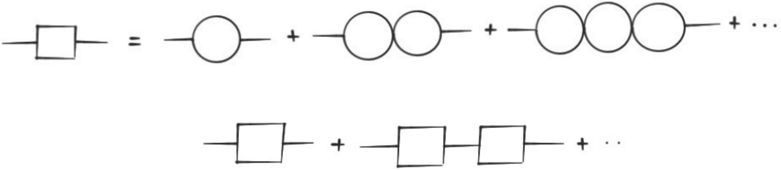
Two poles are found: $3744 - i11$ MeV and $3775 - i6$ MeV!

Dependence of the spectral function on the coupling g



$3741 - i20$ & $3774 - i3$ | $3744 - i11$ & $3775 - i6$ | $3743 - i4$ & $3778 - i9$

Spectral function with D^+D^- loop and rescattering of final states



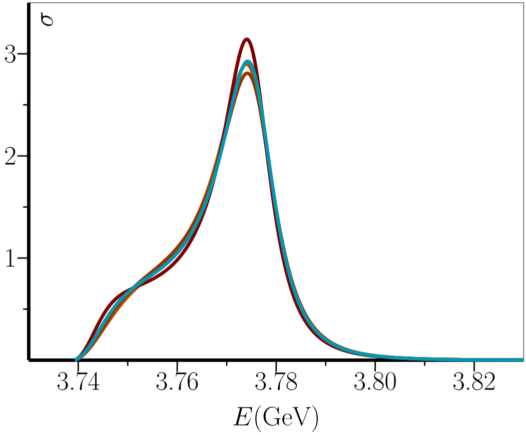
Redefining the loop function

$$\Sigma'(E) = \Sigma + \Sigma\lambda\Sigma + \cdots = \Sigma \sum_{n=0} (\lambda\Sigma)^n = \frac{\Sigma(E)}{1 - \lambda\Sigma(E)}$$

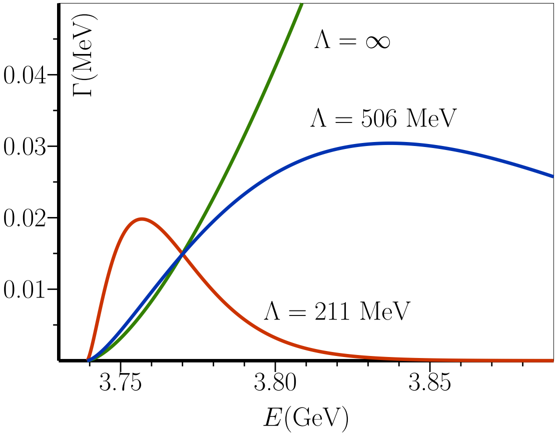
$$\Sigma_1(E) = \Sigma'(E), \quad \Sigma_2(E) = \Sigma'(E) - \Omega(m_\psi), \quad \Sigma_3(E) = \Sigma'(E) - \Omega'(m_\psi)$$

a new free parameter λ is introduced (rescattering coupling)

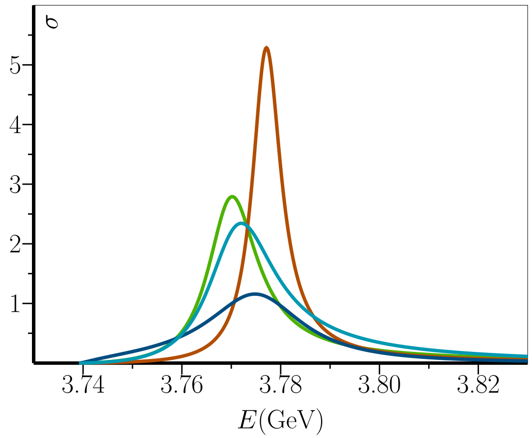
Influence of the rescattering over the spectral function, for $\Lambda = 211$ MeV



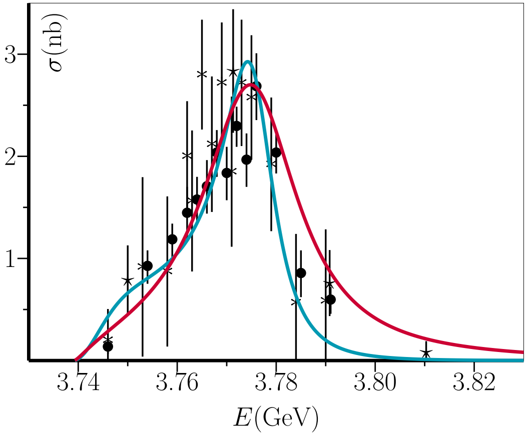
Width dependence on the cutoff



Influence of the rescattering over the spectral function, for $\Lambda = 506$ MeV



Fit with rescattering: channel D^+D^-



$\Lambda = 211$ MeV	$\Lambda = 506$ MeV
$3775 - i6$, $3744 - i11$	$3774 - i3$, $3742 - i13$

Summary and Perspectives

♦ Given the increasing number of XYZ states, and the existence of many thresholds in the charmonium energy region, correct analysis of data are very important to understand the signals.

♦ We are employing an effective Lagrangian approach to study the line-shape of the $\psi(3770)$. Independently of the final state rescattering, we find two poles associated with the cross section fitted to data.

$\therefore$