BLED WORKSHOPS
IN PHYSICS
VOL. 12, NO. 1
p. 1

Proceedings of the Mini-Workshop
Understanding hadronic spectra
Bled, Slovenia, July 3 - 10, 2011

Meson dynamics in the vector-scalar sector*

L. Alvarez-Ruso[a], J. A. Oller[b], J. M. Alarcón[b]

[a] Instituto de Física Corpuscular, UVEG-CSIC, Valencia, Spain
[b] Departamento de Física, Universidad de Murcia, Murcia, Spain

Abstract. We have studied the $\phi(1020)f_0(980)$ and $\phi(1020)a_0(980)$ S-wave scattering at threshold energies employing chiral Lagrangians coupled to vector mesons by minimal coupling. The $\phi\, f_0$ ($\phi\, a_0$) interaction kernel is obtained by treating the $f_0(980)$ [$a_0(980)$] as bound (dynamically generated) state and resuming unitarity loops. We are able to describe the $e^+e^- \rightarrow \phi(1020)f_0(980)$ recent scattering data concluding that the $Y(2175)$ resonance has a large $\phi(1020)f_0(980)$ component. We also predict a strong $\phi(1020)a_0(980)$ interaction that can be studied in $e^+e^- \rightarrow \phi\pi^0\eta$. For some sets of parameters a clear resonant peak indicates the presence of an isovector companion of the $Y(2175)$.

1 Introduction

A new hadronic spectroscopy has emerged in the last decade thanks to the experimental activity carried out meanly at e^+e^- facilities (BES at IHEP, CLEO at LEPP, BABAR in SLAC, Belle at KEK) but also at $p\bar{p}$ colliders (CDF,D0 at FNAL) and in fixed target experiments such as HERA-B at DESY. Indeed, our understanding of meson spectroscopy has been challenged by the observation of several exotic states (extensive reviews can be found, for example, in Ref. [1]). These can be neutral mesons with quantum numbers that are not allowed for $q\bar{q}$ pairs ($J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$) but also states with conventional quantum numbers that cannot be easily accommodated into the constituent quark model. One such a state is the resonance $\phi(2170)$ (or $Y(2175)$, as we will refer to it from now on), a light unflavored meson with quantum numbers $J^{PC} = 1^{--}$, $I^G = 0^-$, mass of 2175 ± 15 MeV and width $\Gamma_Y = 61 \pm 18$ MeV (PDG estimates [2]). It was first observed by the BABAR Collaboration [3, 4] in the initial-state radiation process $e^+e^- \rightarrow \phi\, f_0(980)\,\gamma \rightarrow K^+K^-\pi\pi\gamma$ and also found by BES in $J/\Psi \rightarrow \eta\,\phi\, f_0(980)$ decay [5]. The Belle Collaboration has performed the most precise measurements so far of the reactions $e^+e^- \rightarrow \phi\,\pi^+\pi^-$ and $e^+e^- \rightarrow \phi\, f_0(980)$ finding $M_Y = 2079 \pm 13^{+79}_{-28}$ MeV and $\Gamma_Y = 192 \pm 23^{+25}_{-61}$ MeV [6]. The obtained width is larger than in previous measurements but the error is also large.

These experimental findings have triggered a considerable theoretical activity aimed at unraveling the nature and properties of the $Y(2175)$. It has been interpreted as a tetraquark [7–9], with a mass of 2.21 ± 0.09 GeV [7] or 2.3 ± 0.4 GeV [8] calculated using QCD sum rules with meson-meson $(s\bar{s})(s\bar{s})$ currents [7] and

* Talk delivered by L. Alvarez-Ruso

adding diquark-antidiquark $(ss)(\bar{s}\bar{s})$ ones [8]. In the diquark-antidiquark picture a prominent $Y(2175) \to \Lambda\bar{\Lambda}$ decay mode appears [9]. The $Y(2175)$ has also been identified with the lightest hybrid $s\bar{s}g$ state [10] with $K_1(1400)\,K$ and $K_1(1270)\,K$ as dominant decay channels. Conventional $s\bar{s}$ states in 2^3D_1 or 3^3S_1 configurations have been considered as their masses are expected to be compatible with the $Y(2175)$ [11] although the estimated widths are too large. Reference [12] studies the three-body $K\bar{K}\phi(1020)$ scattering with two-body pseudoscalar-pseudoscalar and vector-pseudoscalar interactions taken from unitarized chiral perturbation theory [13,14]. A resonance with 2170 MeV mass is generated albeit with a width of only 20 MeV.

2 ϕ(1020) f_0(980) scattering

In Ref. [15] we have studied the S-wave scattering of the vector meson $\phi(1020)$ with the scalar $f_0(980)$, the channel with the same quantum numbers as the $Y(2175)$. This is feasible because both the $\phi(1020)$ and the $f_0(980)$ are rather narrow resonances.

First we derive the kernel of the $\phi\, f_0$ interaction. For this we take advantage of the fact that the $f_0(980)$ scalar meson is successfully described as a $K\bar{K}$ bound state [13, 16]. This means that in the second Riemann sheet, in the vicinity of the $f_0(980)$ pole

$$-iT_{K\bar{K}} = \frac{\gamma_0^2}{k^2 - M_{f_0}^2} + \gamma_1 + \gamma_2(M_{f_0}^2 - k^2) + \ldots \,, \text{ and } \lim_{k^2 \to M_{f_0}^2} (M_{f_0}^2 - k^2)(-iT_{K\bar{K}}) = \gamma_0^2 \,. \tag{1}$$

Therefore, the $\phi(1020)f_0(980)$ interaction can be obtained from the $\phi(1020)K\bar{K}$ one by extracting the residue at the $f_0(980)$ double pole position that arises from the initial and final $K\bar{K}$ rescatterings.

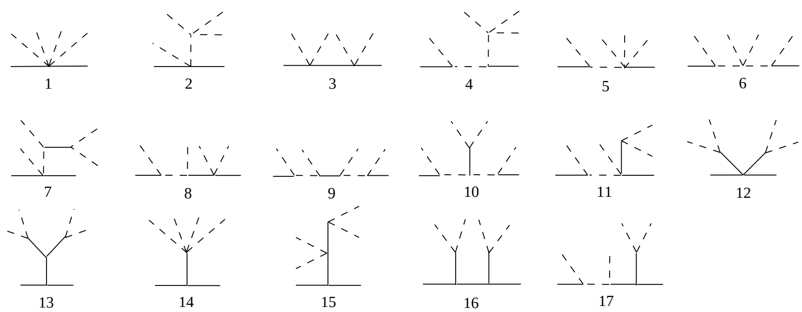

Fig. 1. Feynman diagrams for $\phi K\bar{K}$ scattering. Dashed lines denote kaons and solid ones, vector mesons.

The contributions to the $\phi(K\bar{K})_{I=0} \to \phi(K\bar{K})_{I=0}$ amplitude, determined with chiral Lagrangians coupled to vector mesons are depicted in Fig. 1. It can be shown [15] that close to the $\phi K\bar{K}$ threshold and taking into account that the

$f_0(980)$ is also close to the $K\bar{K}$ threshold, the dominant term is given by diagram 2.

The rescattering of initial and final $K\bar{K}$ pairs in this dominant amplitude gives rise to the diagram on the left hand side of Fig. 2. For the $(K\bar{K})^2$ vertices we take

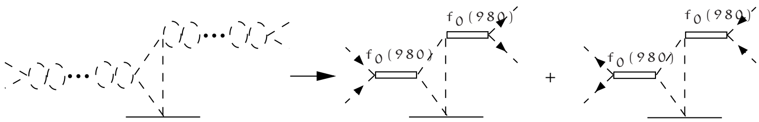

Fig. 2. Dominant contribution to the $\phi(K\bar{K})_{I=0}$ amplitude with $K\bar{K}$ initial and final state interactions that contain $f_0(980)$ poles.

only on-shell amplitudes. The off-shell parts are proportional to the inverse of kaon propagators and cancel with them in the calculation of the loop, resulting in amplitudes that do not correspond anymore to the dominant triangular kaon-loop but to other topologies. After projecting into S-waves

$$\mathcal{M}^S_{I=0} = -t_{\phi K}\, T_{K\bar{K}}(k^2)\, T_{K\bar{K}}(k'^2)\, L_S \tag{2}$$

where $t_{\phi K}$ and $T_{K\bar{K}}$ are the full scattering amplitudes, $k^2(k'^2)$ is the initial (final) $K\bar{K}$ invariant mass and

$$L_S = \frac{1}{4\pi^2}\int_{-1}^{+1}\frac{d\cos\rho}{Q^2}\int_0^{1/2} dx\frac{1}{c}\left[\log\left(1-2x/c\right)-\log\left(1+2x/c\right)\right] , \tag{3}$$

with

$$c^2 = \frac{4}{Q^2}\left[x^2Q^2 + 2k^2x(1-2x) - m_K^2 + i\epsilon\right] . \tag{4}$$

Here $Q^2 = -2\mathbf{p}^2(1-\cos\rho)$ in terms of the relative angle ρ between the incoming $\mathbf{p}$ and outgoing $\mathbf{p}'$ ϕ three-momenta in the ϕf_0 CM frame.

The residue at the $f_0(980)$ double pole is the $f_0(980)\phi(1020)$ potential

$$V_{\phi f_0} = \frac{1}{\gamma_0^2}\lim_{k^2,k'^2\to M^2_{f_0}}(k^2-M^2_{f_0})(k'^2-M^2_{f_0})M^S_{I=0} = -t_{\phi K}\,\gamma_0^2\, L_S\ , \tag{5}$$

which is unitarized as schematically shown in Fig. 3 leading to the full ϕf_0 amplitude

$$T_{\phi f_0} = \frac{V_{\phi f_0}}{1 + V_{\phi f_0}\, G_{\phi f_0}} . \tag{6}$$

The loop function $G_{\phi f_0}$ is expressed in terms of a renormalization scale fixed to the ρ meson mass $\mu = 770$ MeV and a subtraction constant a_1 to be fitted to data [15].

We have performed fits to the $e^+e^- \to \phi f_0(980)$ BABAR and Belle data [4, 6]. The $\phi(1020)\, f_0(980)$ strong scattering amplitude is employed to correct the production process by final state interactions (FSI)

$$\sigma(s) = \frac{\sigma_{BG}(s)}{|1 + V_{\phi f_0} G_{\phi f_0}|^2} . \tag{7}$$

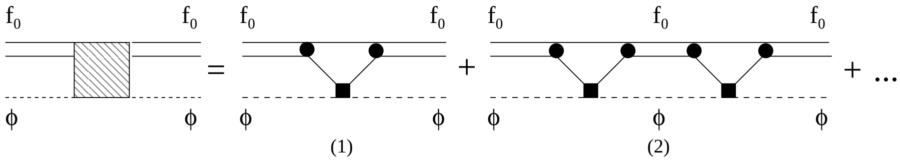

Fig. 3. Diagrammatic representation of the full $\phi f_0(980)$ amplitude.

For the nonresonant background production cross section the Belle fit (Fig. 6(b) of Ref. [6]) has been adopted. In our fits the $f_0(980)$ properties, pole position M_{f_0} and residue γ_0^2 are taken from two different studies [17, 18]; $t_{\phi K}$ and a_1 are free parameters. The results are presented in Table 1 and Fig. 4

	M_{f_0} [MeV] (fixed)	γ_0^2 [GeV^2] (fixed)	$t_{\phi f_0}$	a_1
Fit 1	980	16	-54 ± 4	-2.41 ± 0.14
Fit 2	988	13.2	-27 ± 1	-2.61 ± 0.14

Table 1. Fits to the $e^+e^- \to \phi(1020)f_0(980)$ BABAR [4] and Belle [6] data.

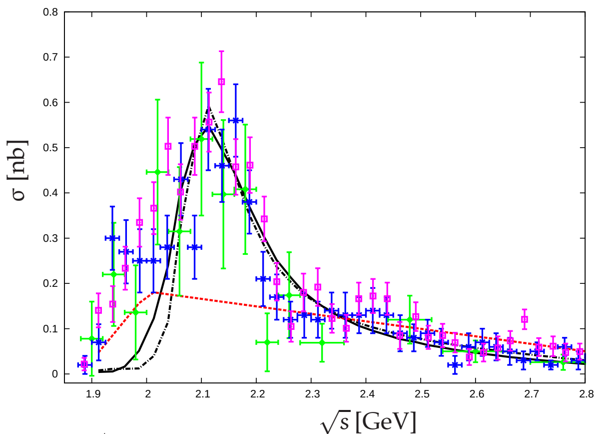

Fig. 4. Cross section for $e^+e^- \to \phi(1020)\, f_0(980)$. The experimental data are from Ref. [4] (diamonds and crosses) and Ref. [6] (empty boxes). The solid and dash-dotted lines correspond to the first and second fits of Table 1. The dashed line shows the background.

The description of the data is satisfactory, particularly the peak position and width. Worse is the agreement at $\sqrt{s} < 2$ GeV: the suppression of the theoretical curves happens because the $V_{\phi f_0}$ potential is large due to the $1/Q^2$ factor. We obtain negative values for a_1 as it should be for a dynamically generated resonance. Moreover, the resulting scale $\Lambda = (4\pi f)/\sqrt{|a_1|} \simeq 0.75$ GeV, preserves a natural size around M_ρ. The interpretation of the $t_{\phi K}$ values is more difficult due to the lack of information about the ϕK interaction close to threshold. Nevertheless one should recall that the $K_1(1400)$ resonance is only 100 MeV below this threshold. Therefore, the assumption that ϕK scattering is dominated by the $K_1(1400)$ would explain the negative sign of $t_{\phi K}$ because

$$t_{\phi K} \sim \frac{\gamma^2_{K_1 \phi K}}{M^2_{K_1} - (M_\phi + m_K)^2} < 0 \,. \tag{8}$$

Our fitted $t_{\phi K}$ values are very different from those used in Ref. [12], taken from Ref. [14] which does not contain the $K_1(1400)$. With a $t_{\phi K} \sim 12 - 7\,i$ as in Ref. [14] we would not describe the $e^+e^- \to \phi(1020)\, f_0(980)$ data. This means that even if the results of both Refs. [12, 15] support the interpretation of the Y(2175) as a dynamically generated resonance, the two descriptions are quantitatively different.

3 ϕ(1020) a_0(980) scattering

In the present contest, it is relevant to establish whether there is an isovector companion of the isoscalar Y(2175). It will help constraining theoretical models. In particular, the calculation of Ref. [12] does not find any resonance in the isovector $\phi(1020)a_0(980)$ S-wave channel. Experimentally, this resonance could show up in $e^+e^- \to \phi(1020)a_0(980) \to \phi(1020)\pi^0\eta$, as suggested in Ref. [19] or in $e^+e^- \to \phi(1020)a_0(980) \to \phi(1020)K^+K^-$ [20]. Our study of the $\phi(1020)a_0(980)$ [21] interaction proceeds as described in the previous section but replacing the scalar-isoscalar $f_0(980)$ by the scalar-isovector $a_0(980)$. The latter is treated as a dynamical resonance in coupled channels (mainly $K\bar{K}$ and $\pi^0\eta$) whose properties depend on the adopted approach (see Table 2). No new free parameters need to be introduced if one demands that the $e^+e^- \to \phi(1020)\, f_0(980)$ cross section is reproduced and takes $t_{\phi K}$, a_1 from Table 1.

	M_{a_0} [GeV]	$\gamma^2_{K\bar{K}}$ [GeV^2]
BS	$1.009 + i\,0.056$	$24.73 - i\,10.82$
N/D	$1.055 + i\,0.025$	$17.37 - i\,24.77$

Table 2. $a_0(980)$ properties, pole position M_{a_0} and residue $\gamma^2_{K\bar{K}}$, as obtained with the Bethe-Salpeter (BS) equation [13] and the N/D method [18].

We have investigated the corrections to the $e^+e^- \to \phi(1020)a_0(980) \to \phi(1020)\pi^0\eta$ reaction that arise from $\phi(1020)a_0(980)$ FSI finding strong modifications (see Fig. 5). If the $a_0(980)$ properties from the N/D method are taken, a strong peak around 2.03 GeV is observed, signaling the presence of the dynamically generated isovector 1^{--} resonance. For the BS pole no peak is generated but a strong reduction of the cross-section takes place. This result further supports the idea that a study of the $e^+e^- \to \phi(1020)a_0(980)$ reaction, which should be accessible at present e^+e^- factories, may provide novel relevant information about hadronic structure and interactions in the 2 GeV region.

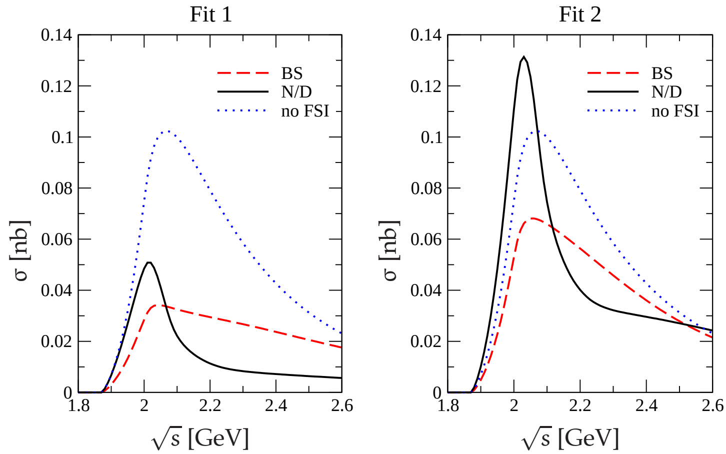

Fig. 5. $e^+e^- \to \phi(1020)a_0(980) \to \phi(1020)\pi^0\eta$ cross section. The dotted lines in both plots is the result of Ref. [19] where final state $\phi(1020)a_0(980)$ rescattering was not considered. The rest of the lines include FSI for the sets of parameters given in Tables 1, 2.

References

1. S. L. Zhu, Int. J. Mod. Phys. E **17** (2008) 283; N. Drenska *et al.*, Riv. Nuovo Cim. **033** (2010) 633-712; N. Brambilla *et al.*, Eur. Phys. J. **C71** (2011) 1534.
2. C. Amsler *et al.* [Particle Data Group], Phys. Lett. B **667** (2008) 1.
3. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **74** (2006) 091103.
4. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **76** (2007) 012008.
5. M. Ablikim, *et al.* [BES Collaboration], Phys. Rev. Lett. **100** (2008) 102003.
6. C. P. Shen *et al.* [Belle Collaboration], Phys. Rev. D **80** (2009) 031101.
7. Z. G. Wang, Nucl. Phys. A **791** (2007) 106.
8. H.-X. Chen, X. Liu, A. Hosaka and S.-L. Zhu, Phys. Rev. D **78** (2008) 034012.
9. N. V. Drenska, R. Faccini and A. D. Polosa, Phys. Lett. B **669** (2008) 160.
10. G.-J. Ding and M.-L. Yan, Phys. Lett. B **650** (2007) 390.
11. G.-J. Ding and M.-L. Yan, Phys. Lett. B **657** (2007) 49; T. Barnes, N. Black and P. R. Page, Phys. Rev. D **68** (2003) 054014.
12. A. Martinez Torres *et al.*, Phys. Rev. D **78** (2008) 074031.
13. J. A. Oller and E. Oset, Nucl. Phys. A **620** (1997) 438; (E)-ibid. A **652** (1999) 407.
14. L. Roca, E. Oset and J. Singh, Phys. Rev. D **72** (2005) 014002.
15. L. Alvarez-Ruso, J. A. Oller and J. M. Alarcón, Phys. Rev. D **80** (2009) 054011.
16. J. D. Weinstein and N. Isgur, Phys. Rev. Lett. **48** (1982) 659.
17. M. Albaladejo and J. A. Oller, Phys. Rev. Lett. **101** (2008) 252002.
18. J. A. Oller and E. Oset, Phys. Rev. D **60** (1999) 074023.
19. C. A. Vaquera-Araujo and M. Napsuciale, Phys. Lett. B **681** (2009) 434.
20. S. Gomez-Avila, M. Napsuciale and E. Oset, Phys. Rev. D **79** (2009) 034018.
21. L. Alvarez-Ruso, J. A. Oller and J. M. Alarcon, Phys. Rev. D **82** (2010) 094028.