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Unitary chiral dynamics in J/Ψ decays into VPP and the role of the scalar mesons

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Abstract

We make a theoretical study of the J/Ψ decays into $\omega\pi\pi$, $\phi\pi\pi$, $\omega K\bar{K}$ and $\phi K\bar{K}$ using the techniques of the chiral unitary approach stressing the important role of the scalar resonances dynamically generated through the final state interaction of the two pseudoscalar mesons. We also discuss the importance of new mechanisms with intermediate exchange of vector and axial-vector mesons and the role played by the OZI rule in the $J/\Psi\phi\pi\pi$ vertex, quantifying its effects. The results nicely reproduce the experimental data for the invariant mass distributions in all the channels considered.

The J/Ψ decay into a pseudoscalar meson pair and a vector meson has been claimed to be one of the most suited reactions to study the long controversial nature of the scalar mesons, on which the interpretation as $q\bar{q}$ mesons or as meson-meson molecules has mainly centered the discussion. In the last years, a chiral unitary coupled channel approach [1] has proved to be successful in describing meson-meson interactions in all channels up to energies ~ 1.2 GeV, far beyond the natural limit of applicability of the standard Chiral Perturbation Theory (ChPT), which is ~ 500 MeV where the pole of the lightest resonance, the σ meson, appears. In this approach the scalar mesons rise up naturally as dynamically generated resonances, in the sense that, without being included as explicit degrees of freedom, they appear as poles in the s-wave meson-meson scattering amplitudes. The aim of the present work [1] is to make a consistent and comprehensive description of the $J/\Psi \to VPP$ decays, including all the mechanisms able to influence the region of pseudoscalar pair invariant masses up to ~ 1.1 GeV, addressing the role played by the scalar mesons and the OZI rule. Following the framework of the chiral unitary approach, we will implement the final meson-meson state interaction in order to generate dynamically the scalar resonances involved.

The first mechanisms considered are those involving a direct coupling of the J/Ψ to the two pseudoscalars and the vector, implementing the final state interaction of the pseudoscalars pair, as is depicted in Fig. 1 for the $J/\Psi \to \omega\pi^+\pi^-$ channel. The thick dot in Fig. 1 means that one is considering the full $\pi\pi(K\bar{K}) \to \pi^+\pi^-$ t-matrix, involving the loop resummation of the Bethe-Salpeter equation and no just the lowest order $\pi\pi(K\bar{K}) \to \pi^+\pi^-$ amplitude. Actually this loop resummation is what dynamically generates the scalar resonances. The $J/\Psi VPP$ vertex can be constructed using $SU(3)$ arguments to relate the different isospin channels and parameterizing the amplitudes in a way which clearly manifest the role played by the OZI rule in this direct vertex, accounted for by means of a parameter λ_ϕ such that, if the OZI rule would be exact, then λ_ϕ would be zero.

In analogy with the approach in Ref. [3] (and in some sense to [4]), we consider next the mechanisms involving the sequential exchange of a vector or axial-vector meson as depicted in

[1] All the details of the model can be found in [2], on which the present contribution is based

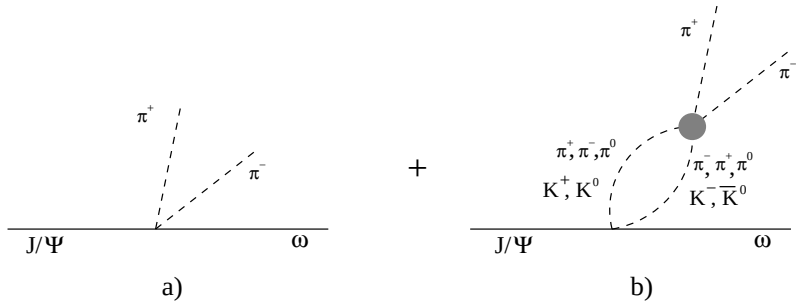

Figure 1: Diagrams with direct $J/\Psi VPP$ vertex at tree level, a), and with the iterated meson loops, b).

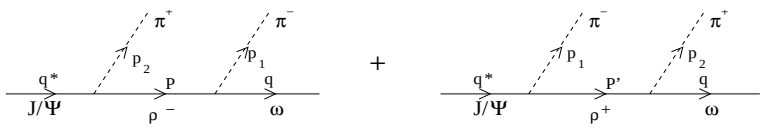

Figure 2: Diagrams for the tree level mechanisms with sequential vector meson exchange.

Fig. 2 for the vector meson case for the $\omega\pi\pi$ channel. The vertices needed are obtained from suitable phenomenological Lagrangians (see [2, 3, 5]). In Figs. 3 and 4 we show the mechanisms with the implementation of the FSI of the pseudoscalar mesons.

The only two free parameters in our model are the coupling of the direct $J/\Psi VPP$ vertex and the OZI rule violation parameter, λ_ϕ. Fitting our model to the $J/\Psi \to \omega\pi^+\pi^-$ and $J/\Psi \to \phi\pi^+\pi^-$ experimental data we obtain values of λ_ϕ clearly different from zero ($\lambda_\phi = 0.12, 0.20$) and reasonably smaller than one, what manifests the OZI rule violation within reasonable values. In Fig. 5, left column, we show the results for $\omega\pi\pi$ and $\phi\pi\pi$ channels including an estimation of the theoretical error band. The experimental data shown in the figures have been obtained from [6–9]. Concerning the scalar mesons, it is important to stress first that the final shape and strength of the bump appearing in the $\pi\pi$ invariant mass distribution in the $\omega\pi\pi$ channel at ~ 500 MeV is determined by a subtle interference between the final state interaction in the direct $J/\Psi VPP$ mechanisms and the tree level direct $J/\Psi VPP$ decay. This means that the shape and position of the bump does not directly represent the physical properties of the σ meson, since it is distorted due to interferences with other terms not related to the σ meson. Therefore one has to be extremely careful when using the experimental data to extract the physical σ meson properties by fitting Breit-Wigner-like shapes. On the other hand, the relative weights of the $f_0(980)$ and the σ meson are well reproduced in both the $\omega\pi\pi$ and $\phi\pi\pi$ channels in spite of their large difference in these channels. This relative weight is mainly determined by the OZI rule violation parameter and the interferences of the "direct" terms with the other mechanisms, specially in the $f_0(980)$ region. In our model, since the scalar mesons are dynamically generated through the resummed meson-meson amplitude, the relative weight between the $f_0(980)$ and the σ mesons is related to the relative weight between the $K\bar{K} \to \pi\pi$ and $\pi\pi \to \pi\pi$, in $I = 0$, scattering amplitudes. Specially remarkable is the fair agreement in the $f_0(980)$ region of the $\omega\pi\pi$ channel despite the smallness of

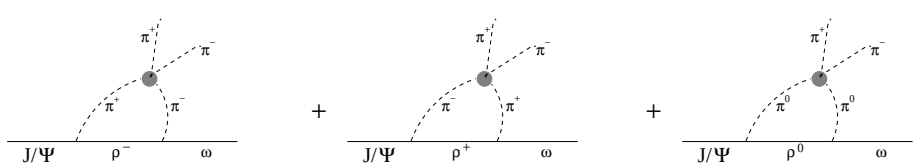

Figure 3: Sequential vector meson exchange diagrams with final state interaction of pions

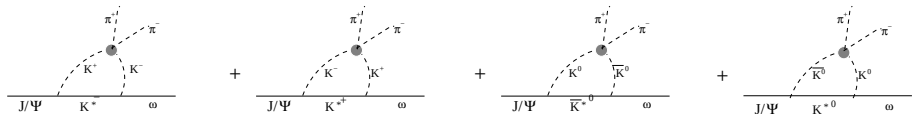

Figure 4: Sequential vector meson exchange diagrams with final state interaction of kaons

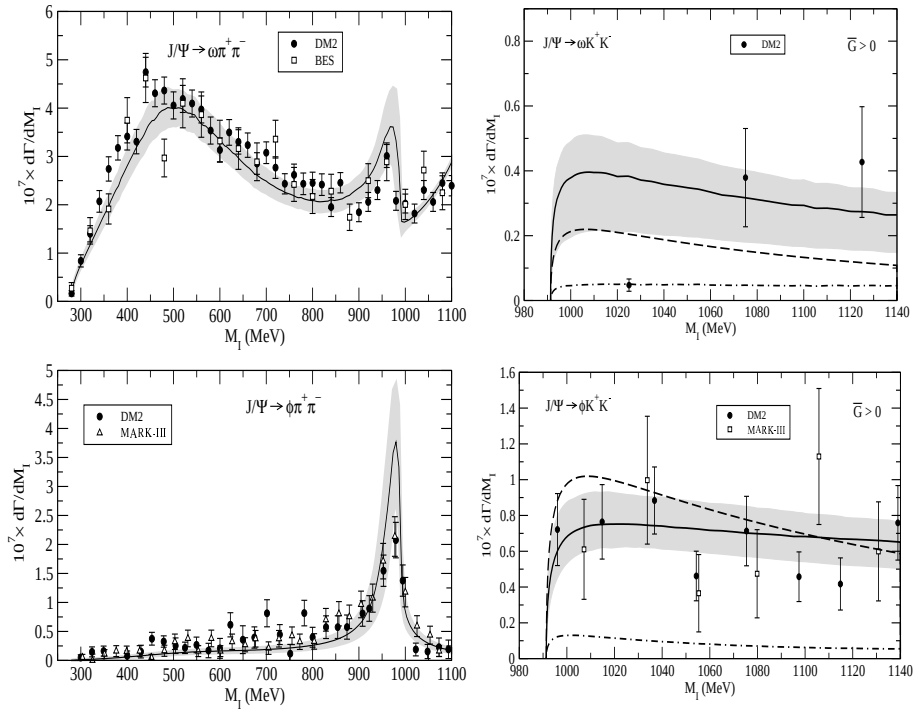

Figure 5:

the bump and the fact that many mechanisms contribute in this region.

Finally, in Figs.5, right column, we apply our results to the $\omega K\bar{K}$ and $\phi K\bar{K}$ decay channels, obtaining a fair agreement without introducing any extra freedom in the model. This is a nice test of the present model, both reproducing the absolute strength, and also the shape, which shows much strength close to threshold as a reflection of the proximity of the $f_0(980)$ resonance below threshold.

In conclusion, we have obtained a good description of these interesting J/Ψ decays combining phenomenological Lagrangians and the techniques of the chiral unitary approach to implement the final state rescattering of the pseudoscalar pairs, quantifying the controversial non-trivial role of the scalar mesons and the violation of the OZI rule. The fact that once more one is able to reproduce the shape and strength of the $f_0(980)$ and the σ resonances without the need to introduce them as explicit degrees of freedom provides an extra support to the idea of the nature of these resonances as dynamically generated from the interaction of the mesons.

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