MODELING TWO-BOSON MASS DISTRIBUTIONS, $E(38\text{ MeV})$ AND $Z(57.5\text{ GeV})$*

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(Received June 27, 2016)

Besides general features of the Resonance Spectrum Expansion for two-boson mass distributions, experimental results are discussed. Furthermore, $E(38\text{ MeV})$ and $Z(57.5\text{ GeV})$ are highlighted.

DOI:10.5506/APhysPolBSupp.9.583

1. Introduction

The Resonance Spectrum Expansion (RSE) for two-boson mass distributions is a general expression for the two-boson scattering amplitude in the presence of an infinite tower of s-channel resonances. A complete derivation of the RSE formula at an elementary level can be found in Ref. [1]. Here, we will take a shortcut via the Breit–Wigner expression for the two-boson scattering amplitude $T(\sqrt{s}\,)$ in the presence of one resonance at $\sqrt{s}=M$, given by

$$T\left(\sqrt{s}\right)=\frac{\lambda^2\mathrm{Im}F(s)}{\sqrt{s}-M+\lambda^2F(s)}=\frac{\frac{\lambda^2\mathrm{Im}F(s)}{\sqrt{s}-M}}{1+\frac{\lambda^2F(s)}{\sqrt{s}-M}}\,, \tag{1}$$

* Presented at "Excited QCD 2016", Costa da Caparica, Lisbon, Portugal, March 6–12, 2016.

where $F(s)$ represents the two-boson loop function and λ the coupling strength of the three-boson vertex. Notice that the peak $M_{\rm R}$ of the resonance enhancement comes at $M_{\rm R} = M - \lambda^2 {\rm Re}F(s)$, whereas its width is given by $\Gamma_{\rm R} \approx -2\lambda^2 {\rm Im}F(s)$.

In the presence of an infinite tower of s-channel resonances, M_0, M_1, M_2, ..., the two-boson scattering amplitude takes the form

$$T\left(\sqrt{s}\right) = \frac{\lambda^2 {\rm Im}F(s) \sum\limits_{n=0}^{\infty} \dfrac{g_n^2}{\sqrt{s} - M_n}}{1 + \lambda^2 F(s) \sum\limits_{n=0}^{\infty} \dfrac{g_n^2}{\sqrt{s} - M_n}} \,, \tag{2}$$

where g_n represents the relative coupling of the two bosons to the $n^{\rm th}$ resonance [2]. In a multi-channel description, the ingredients of formula (2) turn into matrices. Properties of the scattering amplitude (2) have been studied in a series of papers (see *e.g.* [3] and references therein).

When the overall coupling λ is small, the corresponding mass distributions show narrow resonance peaks near the $M_{n=0,\,1,\,2,\,...}$ masses (seeds). However, when λ takes realistic values, the resonance peaks become broader and shift away from the seed masses yielding the experimentally observed resonance central masses and widths. Seeds represent the underlying quark–antiquark spectrum which is hence not identical to the observed resonance central mass spectrum.

It is opportune to mention here that formula (2) also applies to resonances below the strong thresholds. For example, it predicts as well the charmonium bound states $J/\psi(1S)$ and $\psi(2S)$ below the $D\bar{D}$ threshold as the resonances above that threshold [4, 5]. This property is due to full analyticity of formula (2) in the total invariant mass.

Observable quantum numbers, like total angular momentum, parity and C-parity are respected for $\lambda \neq 0$, but, internal quantum numbers, like radial excitation and relative angular momentum, are not. Hence, the resulting resonance "states" do not have pure radial excitation or relative angular momentum. For example, $J^{PC} = 1^{--}$ charm–anticharm vector bosons, which have seeds with internal angular momenta $\ell = 0$ (S) and $\ell = 2$ (D), turn into charmonium resonances with mixed configurations of S- and D-states. Moreover, the dominantly D-states almost decouple from scattering, leading to narrow resonances which hardly shift away from the seed masses, whereas the dominantly S-states couple more strongly to scattering, leading to broader resonances which shift hundreds of MeVs away from the seed masses. As a consequence, one can almost identify the seed spectrum with the dominantly D-states. Unfortunately, experimental observations are lacking.

A further consequence of realistic values for λ is the appearance of dynamically generated resonances which do not have a direct relation to the seeds. Examples are the low-lying scalar resonances [6] and the $D^*_{s0}(2317)$ resonance [7].

In Ref. [8], an expression has been deduced for production of boson pairs which relates the production (P) and scattering amplitudes according to

$$P\left(\sqrt{s}\right) = \mathrm{Im}Z(s) + T\left(\sqrt{s}\right) Z(s)\,, \tag{3}$$

where $Z(s)$ is a purely kinematic expression which contains no singularities. Resonance poles of the scattering amplitude (2) determine fully the singularity structure of the production amplitude (3). Consequently, resonances in scattering also show up in production. But, the shape of $\mathrm{Im}Z(s)$ is such that, in the ideal case of no further nearby thresholds, it rises sharply just above threshold. For larger invariant masses, $\mathrm{Im}Z(s)$ first reaches a maximum and then falls off exponentially. As a consequence, production amplitudes show non-resonant yet resonant-like enhancements just above threshold [9]. From the invariant mass at its peak, one can estimate [10] the interaction distance a by

$$2(pa)^2 \approx 1\,, \qquad \sqrt{s} = \sqrt{p^2 + m_1^2} + \sqrt{p^2 + m_2^2}\,, \tag{4}$$

where $m_{1,2}$ represent the masses of the produced bosons.

2. Exotics

With the formalism developed in Ref. [2], one not only can determine the relative coupling constants $g_{n=0,\,1,\,2,\,\ldots}$ of the seeds to the various two-boson channels, but also the number of two-boson channels which couple to each of the seeds. This number grows rapidly with radial excitation. As a consequence, higher radial excitations couple much more weakly to a given two-boson channel than the ground state. The relative coupling squared of the nth radial excitation to a given two-boson channel drops proportionally to the nth power of 4 times a polynomial in n, while the number of two-boson channels which couple to the nth radial excitation grows correspondingly. Most of those channels are closed for decay since the masses of the two bosons are too high. Nevertheless, the fifth or the sixth radial excitation of a certain flavor–antiflavor configuration couples more weakly to a given two-boson channel than to weak decay.

As an example, suppose that in experiment one measures a weak decay channel $J/\psi\pi^+$ [11] near the sixth or seventh radial excitation of the $c\bar{s}$ system. Then, one obtains a resonance signal for the excitation. Its mass is given by the mass of the seed and a hadronic shift, whereas its width is determined by all the open and closed strong two-boson channels. As long as the

open candidates are not yet looked for in experiment, one may prematurely conclude that the signal stems from an exotic quark system [12]. However, only a full inspection of all of the many possible strong decay channels for the corresponding $c\bar{s}$ system can resolve this and, since the various $c\bar{u}+u\bar{s}$, $c\bar{d}+d\bar{s}$ and $c\bar{s}+s\bar{s}$ two-boson channels and their excitations couple very weakly to the sixth or seventh radial excitation of the $c\bar{s}$ system, that may need some statistics. Moreover, the reconstruction of those channels out of kaons, pions and electron–positron pairs constitutes quite a larger challenge for experiment than measuring the rather easy weak $J/\psi\pi^+$ channel. We are thus still far away from the discovery of exotic quark configurations.

3. E(38 MeV) scalar boson

In Refs. [13, 14], a variety of indications were presented of the possible existence of a light boson with a mass of about 38 MeV. These indications amounted to a series of low-statistics observations all pointing to the same direction, and one high-statistics observation, which might be interpreted as the discovery of the $E(38\ \mathrm{MeV})$.

About three decades ago, it could be observed from the results of Ref. [15] that $^3P_0$ pair creation is associated with a light quantum. Nevertheless, values of 30–40 MeV for its flavor-independent mass did not seem to bear any relation to an observed quantity for strong interactions. However, in Refs. [13, 16], we have presented experimental evidence for the possible existence of a quantum with a mass of about 38 MeV, which in light of its relation to the $^3P_0$ mechanism we suppose to mediate quark-pair creation. Moreover, its scalar properties make it a perfect candidate for the quantum associated with the scalar field for confinement [17].

4. Weak substructure and the Z(57.5 GeV)

In Refs. [18, 19], we have indicated the possible existence of substructure in the weak sector, based on the observation that recurrences may exist for the Z boson. The corresponding data do not have sufficient statistics to yet conclude the existence of weak substructure, except perhaps for a clear dip at about 115 GeV in diphoton, four-lepton, $\mu\mu$ and $\tau\tau$ invariant-mass distributions. The latter structure indicates the possible opening of a two-particle threshold, probably pseudo-scalar partners of the Z boson with masses of about 57.5 GeV. Further possible recurrences of the Z boson, observed by us at 210 and 240 GeV, certainly need a lot more statistics.

Composite heavy gauge bosons and their spin-zero partners, the latter with a mass in the range of 50–60 GeV, were considered long ago [20] and studied in numerous works. To date, no experimental evidence of their existence has been reported. However, if a pseudo-scalar partner of the Z boson

with mass of about 57.5 GeV exists and, consequently, part of the structure observed in the mass interval 115–135 GeV is interpreted as a threshold enhancement, then it must be possible to verify its existence at the LHC, for example, in four-photon events.

More recently, the interest in weak substructure has revived [21–25]. The most popular among the proposed models is the Technicolor Model (TC) [26] for which one expects QCD-like dynamics but much stronger. From the structure of the threshold enhancement above 115 GeV, we deduced an interaction distance of the order of 0.008 fm [19]. Now, from QCD, we have learned that self-interactions lead to an appreciable contribution to the masses of resonances. Hence, for yet much stronger dynamics, we must expect that the masses of resonances are basically determined by the self-interactions and not so much by the masses and binding forces of the constituents. This has, indeed, been recognized in Ref. [25] where, in a perturbative fashion, the mass of the TC scalar resonance is lowered by several hundreds of GeVs. However, as we have argued that already for QCD unquenching should be incorporated beyond perturbative contributions, we assume that for weak substructure, it is indispensable to do so. This, furthermore, implies that the corresponding spectrum will also contain dynamically generated resonances and may even be dominated by such poles, rather than by those which stem from confinement.

5. Conclusions

Modeling the dynamics of strong interactions is useful. However, it must be accompanied by the study of scattering and production [27] in the presence of towers of resonances, not just isolated enhancements. The experiment, unfortunately, does not yet provide the necessary statistics to confront model results with measured cross sections.

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