Vol. 2 (2009) *Acta Physica Polonica B Proceedings Supplement* No 2

LIGHT AND NOT SO LIGHT SCALAR MESONS*

George Rupp, Susana Coito

Centro de Física das Interacções Fundamentais, Instituto Superior Técnico
Technical University of Lisbon, 1049-001 Lisboa, Portugal

Eef van Beveren

Centro de Física Computacional, Departamento de Física
Universidade de Coimbra, 3004-516 Coimbra, Portugal

(Received October 2, 2009)

A multichannel description of the light scalar mesons in the framework of the Resonance Spectrum Expansion is generalised by including vector–vector and scalar–scalar channels, besides the usual pseudoscalar–pseudoscalar channels. Experimental data for the isoscalar, isodoublet and isovector cases are fitted up to energies well above 1 GeV. The resulting pole positions of the light and intermediate scalar mesons are compared to the listed resonances. Possible further improvements are discussed.

PACS numbers: 14.40.Cs, 14.40.Ev, 11.80.Gw, 11.55.Ds

1. Introduction

The light scalar mesons represent nowadays one of the hottest topics in hadronic physics. Despite the growing consensus on the existence of a complete light scalar nonet, comprising the $f_0(600)$ (alias σ), $K_0^*(800)$ (alias κ), $a_0(980)$ and $f_0(980)$, which are now all included [1] in the PDG tables, their interpretation and possible dynamical origin in the context of QCD-inspired methods and models remains controversial. Moreover, their classification with respect to the intermediate scalars $f_0(1370)$, $K_0^*(1430)$, $a_0(1450)$ and $f_0(1500)$ [1] is also subject to continued debate. For a brief historical discussion of the main theoretical and phenomenological approaches to the light scalars and the corresponding references, see Ref. [2].

In the present work, the successful multichannel description of the light scalar mesons in Ref. [3] is further generalised by including, besides the usual pseudoscalar–pseudoscalar (PP) channels, also all vector–vector (VV) [2]

* Presented by G. Rupp at the International Meeting "Excited QCD", Zakopane, Poland, February 8–14, 2009.

and scalar–scalar (SS) channels comprising light mesons. This is crucial for an extension of the applicability of the approach to energies well above 1 GeV, so as to make more reliable predictions for the intermediate scalar resonances as well.

2. Resonance Spectrum Expansion

We shall study the scalar mesons in the framework of the Resonance Spectrum Expansion (RSE) model [4], in which mesons in non-exotic channels scatter via an infinite set of intermediate s-channel $q\bar{q}$ states, *i.e.*, a kind of Regge propagators [5]. The confinement spectrum for these bare $q\bar{q}$ states can, in principle, be chosen freely, but in all successful phenomenological applications so far we have used a harmonic-oscillator (HO) spectrum with flavour-independent frequency, as in Refs. [6] and [7]. Because of the separability of the effective meson–meson interaction, the RSE model can be solved in closed form. The relevant Born and one-loop diagrams are depicted in Figs. 1 and 2, respectively, from which it is obvious that one can straightforwardly sum up the complete Born series. For the meson–meson–quark–antiquark vertex functions we take a delta shell in coordinate space, which amounts to a spherical Bessel function in momentum space. Such a transition potential represents the breaking of the string between a quark and an antiquark at a certain distance r_0, with overall coupling strength λ, in the context of the $^3P_0$ model.

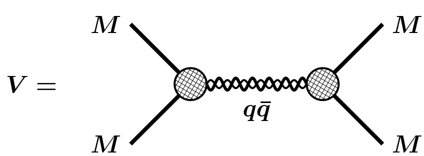

Fig. 1. Born term of the RSE effective meson–meson interaction (see text).

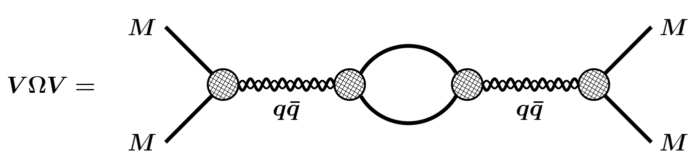

Fig. 2. One-loop term of the RSE effective meson–meson interaction (see text).

Spectroscopic applications of the RSE are manifold. In the one-channel formalism, the κ meson was once again predicted, before its experimental confirmation, in Ref. [8], 1st paper, after its much earlier prediction in Ref. [7]. In the 2nd paper of Ref. [8], the low mass of the $D_{s0}^*(2317)$ was shown to be due to its strong coupling to the S-wave DK threshold, an explanation that is now widely accepted. The 3rd paper of Ref. [8] presented a similar solution to the whole pattern of masses and widths of the charmed axial-vector mesons.

Multichannel versions of the RSE model have been employed to produce a detailed fit of S-wave PP scattering and a complete light scalar nonet [3], with very few parameters (also see below), and to predict the $D_{sJ}(2860)$ [9], shortly before its observation was publicly announced.

Finally, the RSE has recently been applied to production processes [10] as well, in the spectator approximation. Most notably, it was shown that the RSE results in a *complex* relation between production and scattering amplitudes (papers 1–3 in Ref. [10]). Successful applications include the extraction of κ and σ signals from data on 3-body decay processes (4th paper in Ref. [10]), the deduction of the string-breaking radius r_0 from production processes at very different energy scales (5th paper), and even the discovery of signals hinting at new vector charmonium states in $e^+e^- \to \Lambda_c\bar{\Lambda}_c$ data (6th paper).

3. Light and intermediate scalar mesons

3.1. Published results for S-wave PP scattering

In Ref. [3], hereafter referred to as BBKR, two of us (E.vB., G.R.) together with Bugg and Kleefeld applied the RSE to S-wave PP scattering up to 1.2 GeV, coupling the channels $\pi\pi$, $K\bar{K}$, $\eta\eta$, $\eta\eta'$, $\eta'\eta'$ for $I=0$, $K\pi$, $K\eta$, $K\eta'$ for $I=1/2$, and $\eta\pi$, $K\bar{K}$, $\eta'\pi$ for $I=1$. Moreover, in the isoscalar case both an $n\bar{n}$ and an $s\bar{s}$ channel were included, so as to allow dynamical mixing to occur via the $K\bar{K}$ channel. The very few parameters, essentially only the overall coupling λ and the transition radius r_0, were fitted to scattering data from various sources, for $I=0$ and for $I=1/2$, and to the $a_0(980)$ line shape, determined in a previous analysis, for $I=1$. Moreover, the parameters λ and r_0 varied less than $\pm 10\%$ from one case to another. Overall, a good description of the data was achieved (see BBKR for details). Poles for the light scalars were found at (all in MeV)

$$\sigma: 530-i226\,, \quad \kappa: 745-i316\,, \quad f_0(980): 1007-i38\,, \quad a_0(980): 1021-i47\,.$$

No pole positions for the intermediate scalar mesons were reported in BBKR, as the fits were only carried out to 1.1 GeV in the isovector case, and to 1.2 GeV in the others. Nevertheless, corresponding poles at higher energies were found, but these were, of course, quite unreliable.

In the following, we shall present preliminary results for fits extended to higher energies, and with more channels included.

3.2. Isoscalar scalar resonances with PP, VV and SS channels included

For $I=0$, the VV channels that couple to $n\bar{n}$ and/or $s\bar{s}$ are $\rho\rho$, $\omega\omega$, $K^*\bar{K}^*$ and $\phi\phi$, for both $L=0$ and $L=2$, while the SS channels are $\sigma\sigma$, $f_0(980)f_0(980)$, $\kappa\kappa$ and $a_0(980)a_0(980)$, with $L=0$ only. We fit the parameters λ and r_0 to sets of S-wave $\pi\pi$ phase shifts compiled by Bugg and Surovtsev [11], which yield a somewhat larger scattering length than in BBKR, *viz.* $0.21m_\pi^{-1}$. The results of the fits are shown in Fig. 3, left-hand

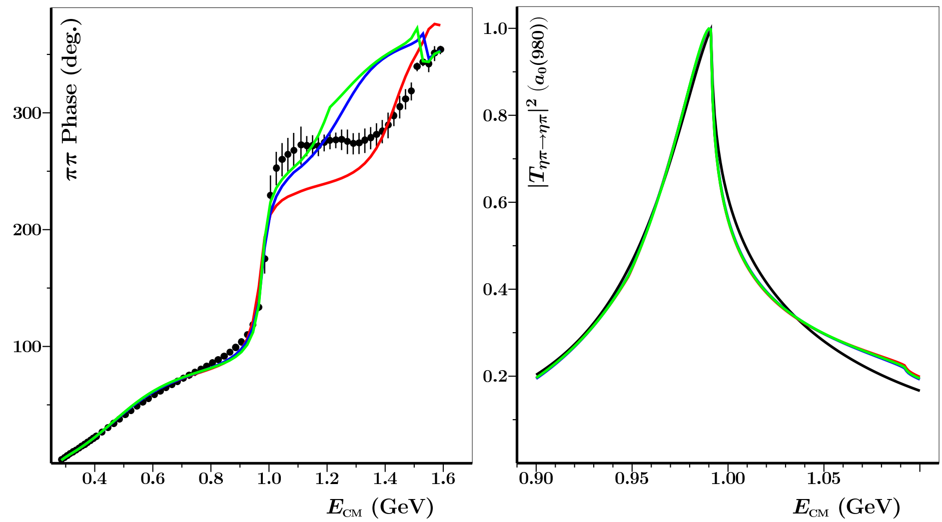

Fig. 3. Left: S-wave $I=0$ $\pi\pi$ phase shifts; dark/lower (red) curve: PP channels only; black/middle (blue) curve: also VV channels; light/upper (green) curve: also SS channels; data due to Ref. [11]. Right: $a_0(980)$ line shape; grey (green) curve: overlapping PP (red), VV (blue), and SS (green) predictions; black curve from data analysis [12].

plot, together with the curve from BBKR, where only PP channels were included and somewhat lower data were used just above the $\pi\pi$ threshold. All three fits are good up to 1 GeV, with only small differences among them. Thereabove, the VV and SS channels clearly produce very substantial effects, though overshooting between 1.2 and 1.6 GeV. Possible improvements are discussed below. With all channels included, we find the first four isoscalar poles at (all in MeV)

$$\sigma: 464-i217\,, \quad f_0(980): 987-i29\,, \quad f_0(1370): 1334-i185\,,$$
$$f_0(1500): 1530-i14\,.$$

Moreover, there is an extra broad state at $(1519-i219)$ MeV, probably of a dynamical origin. The present predictions for the $f_0(1370)$ and the

$f_0(1500)$ are clear improvements with respect to the case with PP and VV channels only [2]. In particular, the extra pole found here might help to explain the experimental difficulties in firmly establishing the $f_0(1370)$ and $f_0(1500)$.

3.3. $a_0(980)$ *and* $a_0(1450)$

In the isotriplet case, we fit λ and r_0, as well as the pseudoscalar mixing angle, to the $a_0(980)$ line shape, just as in BBKR, but now with the VV (ρK^*, ωK^*, ϕK^*) and SS ($a_0(980)\sigma$, $a_0(980)f_0(980)$, $\kappa\kappa$) channels added. Thus, the quality of the fit is slightly improved, though the differences with the PP and PP+VV cases are hardly visible in Fig. 3. The poles we find are $(1023 - i47)$ MeV (second sheet) for the $a_0(980)$ and $(1420 - i185)$ MeV for the $a_0(1450)$, which are very reasonable values [1].

3.4. $K_0^*(800)$ *and* $K_0^*(1430)$

Adding the vector (ρK^*, ωK^*, ϕK^*) and scalar ($\sigma\kappa$, $f_0(980)\kappa$, $a_0(980)\kappa$) channels in the isodoublet sector does not allow a stable fit to be obtained. Moreover, the LASS data are known to violate unitarity above 1.3 GeV. So we just fit up to 1.3 GeV, with only the PP channels, getting parameters very close to the isoscalar case, including a reasonable pseudoscalar mixing angle. See further the conclusions for possible remedies. From the present PP fit we find the pole positions $(722 - i266)$ MeV for the κ and $(1400 - i96)$ MeV for the $K_0^*(1430)$, which are again reasonable values [1].

4. Conclusions and outlook

The preliminary results in this study indicate that a good description of both the light and the intermediate scalar mesons is feasible in the RSE, by taking into account additional sets of coupled channels that should become relevant at higher energies. However, some problems persist, like the too slow rise and subsequent overshooting of the $I=0$ $\pi\pi$ phase shift above 1 GeV, and the mentioned fitting problems in the isodoublet case. A possible cause of these difficulties is the assumed sharpness of several thresholds involving broad resonances on their turn, such as $\sigma\sigma$, $\rho\rho$, $\sigma\kappa$, *etc.*, which may result in too drastic effects at the opening of these channels. We are now studying ways to account for final-state resonances having non-zero widths, without destroying unitarity. It might also turn out to be necessary to consider more general transition potentials.

We thank the organisers for a very stimulating workshop. This work received partial financial support from the Fundação para a Ciência e a Tecnologia of the Ministério da Ciência, Tecnologia e Ensino Superior of Portugal, under contract CERN/FP/83502/2008.

REFERENCES

[1] C. Amsler *et al.* [Particle Data Group], *Phys. Lett.* **B667** (2008) 1. Note, however, that the $K_0^*(800)$ is still inexplicably omitted from the Summary Table, while its quoted "average" mass of (672 ± 40) MeV makes no sense whatsoever, in view of the recent experimental convergence towards a value of roughly 800 MeV.

[2] S. Coito, G. Rupp, E. van Beveren, `arXiv:0812.1527 [hep-ph]`.

[3] E. van Beveren, D.V. Bugg, F. Kleefeld, G. Rupp, *Phys. Lett.* **B641**, 265 (2006).

[4] E. van Beveren, G. Rupp, *Int. J. Theor. Phys. Gr. Th. Nonlin. Opt.* **11**, 179 (2006).

[5] E. van Beveren, G. Rupp, *Ann. Phys.* **324**, 1620 (2009).

[6] E. van Beveren, G. Rupp, T.A. Rijken, C. Dullemond, *Phys. Rev.* **D27**, 1527 (1983).

[7] E. van Beveren, T.A. Rijken, K. Metzger, C. Dullemond, G. Rupp, J.E. Ribeiro, *Z. Phys.* **C30**, 615 (1986).

[8] E. van Beveren, G. Rupp, *Eur. Phys. J.* **C22**, 493 (2001); *Phys. Rev. Lett.* **91**, 012003 (2003); *Eur. Phys. J.* **C32**, 493 (2004).

[9] E. van Beveren, G. Rupp, *Phys. Rev. Lett.* **97**, 202001 (2006).

[10] E. van Beveren, G. Rupp, *Ann. Phys.* **323**, 1215 (2008); *Europhys. Lett.* **81**, 61002 (2008); *Europhys. Lett.* **84**, 51002 (2008); *J. Phys. G* **34**, 1789 (2007); `arXiv:0712.1771 [hep-ph]`; E. van Beveren, X. Liu, R. Coimbra, G. Rupp, *Europhys. Lett.* **85**, 61002 (2009).

[11] D.V. Bugg, private communication; Yu.S. Surovtsev, private communication.

[12] D.V. Bugg, private communication.