Meson resonances from unitarized meson scattering at one loop in Chiral Perturbation Theory [1] [2]

J.R.Peláez[1,2] [3], and A. Gómez Nicola[2]

[1] Universita' degli Studi and INFN, Firenze, ITALY

[2] Dep. Física Teórica II. Universidad Complutense, Madrid. SPAIN

Abstract

We show the results for the scattering poles associated to the ρ, f_0, a_0, K^*, σ and κ resonances in meson-meson scattering. Our amplitudes are obtained from the complete one-loop meson-meson scattering amplitudes from Chiral Perturbation Theory. Once unitarized with the Inverse Amplitude Method, they describe remarkably well the data simultaneously in the low energy and resonance regions up to 1.2 GeV, using low energy parameters compatible with present determinations.

We report on our progress [1] on determining the poles that appear in the recent description [2] of meson-meson scattering by means of unitarized one-loop Chiral Perturbation Theory (ChPT). The interest of these poles is that, at least when they are close to the real axis, they are associated to Breit-Wigner resonances whose mass M_R and width Γ_R is related to the pole position as $\sqrt{s_{pole}} \simeq M_R - \Gamma_R/2$. When they are not so close to the real axis, their interpretation is much less clear.

Starting from one-loop Chiral Perturbation Theory [3] our unitarized amplitudes respect the spontaneous chiral symmetry pattern of QCD up to fourth order in the chiral expansion, i.e. in powers of meson masses or momenta over the chiral scale $4\pi f \simeq 1.2\,\mathrm{GeV}$. Nevertheless, since the ChPT amplitudes behave as polynomials at high energy, they violate partial wave unitarity, which we impose with the Inverse Amplitude Method (IAM).

Part of this program had already been carried first for partial waves in the elastic region, for which a single channel approach could be used, finding the ρ and σ poles in $\pi\pi$ scattering and that of K^* in $\pi K \to \pi K$ [4]. For coupled channel processes, an *approximate* form of this approach had already been shown [5] to yield a remarkable description of meson-meson scattering up to 1.2 GeV. When these partial waves were continued to the second Riemann sheet of the complex s several poles were found, corresponding to the

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[3] Marie Curie Fellow. MCI-2001-01155. E-mail: jrpelaez@fis.ucm.es

ρ, K^*, f_0, a_0, σ and κ resonances. (The κ pole can also be obtained in the elastic single channel formalism). The approximations were needed because at that time not all the meson-meson amplitudes were known to one-loop, and therefore only the leading order and the dominant s-channel loops were considered in a simplified calculation, neglecting crossed and tadpole loop diagrams. As a consequence the ChPT low energy expansion could only be recovered at leading order. The divergences were regularized with a cutoff, which violates chiral symmetry, making them finite, but not cutoff independent. Nevertheless, the cutoff dependence was weak and the description of the data remarkable. Still, due to this cutoff regularization, it was not possible to compare the eight parameters of the chiral Lagrangian, which are supposed to encode the underlying QCD dynamics, with those obtained from other low energy processes. That is, it was not possible to test the compatibility of the chiral parameters with the values already present in the literature.

Due to the controversial nature (or even existence) of the scalar states, it is very important to check that these poles are not just artifacts of the approximations, estimate the uncertainties in their parameters, and check their compatibility with other experimental information regarding ChPT.

The $K\bar{K} \to K\bar{K}$ amplitudes were thus calculated in [6], also unitarizing them coupled to the $\pi\pi$ states, and reobtaining the σ and f_0 and ρ poles. The whole calculation of meson meson scattering has been recently completed with the new $K\eta \to K\eta, \eta\eta \to \eta\eta$ and $K\eta \to K\pi$ amplitudes [2]. In addition the other five existing independent amplitudes have also been recalculated. The reason is that to one loop, one could choose to write all amplitudes in terms of just f_π (set IAM I[2]), or use all f_π, f_K and f_η (set IAM II [1]), etc... However, when one choice is made for one amplitude, the other ones have to be calculated consistently in order to to keep perturbative unitarity, which is needed for the IAM.

Thus, with our recently completed one-loop meson-meson calculation [2] within the standard $\overline{MS}-1$ scheme, we have been able to check that it is possible to find a simultaneous remarkable description of meson-meson scattering up to 1.2 GeV, including both the low energy and resonance regions. We have also been able to estimate the uncertainties in a fit to the whole meson-meson scattering. Furthermore, we have shown that this description can be obtained with a set of renormalized chiral parameters compatible with those already present in the literature (see Table I). The new amplitudes reproduce the low energy chiral expansion up to one loop, in a remarkable agreement with recent data on threshold parameters.

$(\mu = M_\rho)$	L_1^r	L_2^r	L_3	L_4^r	L_5^r	L_6^r	L_7	L_8^r
ChPT	0.4±0.3	1.35±0.3	-3.5±1.1	-0.3±0.5	1.4±0.5	-0.2±0.3	-0.4±0.2	0.9±0.3
IAM I	0.56±0.10	1.2±0.1	-2.79±0.14	-0.36±0.17	1.4±0.5	0.07±0.08	-0.44±0.15	0.78±0.18
IAM II	0.59±0.08	1.18±0.10	-2.93±0.10	0.2±0.004	1.8±0.08	0.0±0.5	-0.12±0.16	0.78±0.7

Table I. Chiral parameters ($\times 10^3$) obtained from IAM fits versus previous determinations at $O(p^4)$[3, 7].

Once we have checked the correct chiral low energy behavior, the scale invariance, and the compatibility of the parameters obtained from the complete IAM fit, we have very recently extended our amplitude to the complex plane in search of poles. Our results can be found in Table II.

Let us note that we find very stable results for all poles, with the exception of the a_0, which is very sensible to whether one chooses to truncate the series in terms of a single f_π , or also in terms of f_K and f_η. We can therefore conclude that the existence of those poles and their positions are robust results from the Inverse Amplitude Method when applied to one-loop ChPT meson-meson amplitudes.

$\sqrt{s_{pole}}$(MeV)	ρ	K^*	σ	f_0	a_0	κ
IAM I	760-i 82	886-i 21	443-i 217	988-i 4	cusp?	750-i 226
(errors)	± 52± i 25	± 50± i 8	± 17± i 12	± 19± i 3		±18±i 11
IAM II	754-i 74	889-i 24	440-i 212	973-i 11	1117-i 12	753-i 235
(errors)	± 18± i 10	± 13± i 4	± 8± i 15	${}^{+39}_{-127}\ {}^{+i\,189}_{-i\,11}$	${}^{+24}_{-320}\ {}^{+i\,43}_{-i\,12}$	± 52± i 33

Table II. Pole positions (with errors) in meson-meson scattering. When close to the real axis the mass and width of the associated resonance is $\sqrt{s_{pole}} \simeq M - i\Gamma/2$.

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