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$f_0(600)$, $\kappa(800)$, $\rho(770)$ and $K^*(892)$, quark mass dependence from unitarized SU(3) Chiral Perturbation Theory

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Abstract. We study the strange and non-strange quark mass dependence of the parameters of the $f_0(600)$, $\kappa(800)$, $\rho(770)$ and $K^*(892)$ resonances generated from elastic meson-meson scattering using unitarized one-loop Chiral Perturbation Theory. We fit simultaneously all experimental scattering data up to 0.8-1 GeV together with lattice results on decay constants and scattering lengths up to a pion mass of 440 MeV. Then, the strange and non-strange quark masses are varied from the chiral limit up to values of interest for lattice studies. In these amplitudes, the mass and width of the $\rho(770)$ and $K^*(892)$ present a similar and smooth quark mass dependence. In contrast, both scalars present a similar non-analyticity at high quark masses. Nevertheless the $f_0(600)$ dependence on both quark masses is stronger than for the $\kappa(800)$ and the vectors. We also confirm the lattice assumption of quark mass independence of the vector two-meson coupling that, in contrast, is violated for scalars.

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INTRODUCTION

Although QCD is well established as the theory of strong interactions, the hadronic realm is beyond the reach of perturbative calculations. In that regime, lattice methods are a useful tool to calculate QCD observables, but results on light meson resonances are few and usually obtained at very large quark masses compared with their physical values. Very recently [1], an alternative technique, based on Chiral Perturbation Theory (ChPT) and dispersion relations, has been applied to calculate the dependence of the $f_0(600)$ (or “sigma”) and $\rho(770)$ resonances on the averaged u and d quark mass, \hat{m} . In this talk we report our progress extending this study to include the strange quark within a unitarized SU(3) ChPT formalism [2]. Our aim is threefold: to confirm previous results within a more general formalism, to analyze the dependence on the \hat{m} of the $K^*(892)$ and $\kappa(800)$ strange resonances and then, to study the dependence of all the $f_0(600)$, $\kappa(800)$, $\rho(770)$ and $K^*(892)$ parameters in terms of the strange quark mass m_s .

For unitarization we use the well-known one-loop elastic Inverse Amplitude Method (IAM) that provides a remarkable description of $\pi\pi$ and $K\pi$ data up to ~ 1 GeV, while generating the poles associated to the $f_0(600)$, $\rho(770)$, $K^*(892)$ and $\kappa(800)$ resonances [3]. This is achieved using Low Energy Constants (LECs) compatible with those of standard ChPT. Previous descriptions come from fitting only to experiment (see details in [4]), and therefore are mostly sensitive to the LECs that govern the s dependence of partial waves. In order to get better determinations of the LECs that carry an explicit meson mass dependence, now we have fitted also to lattice results on M_π , M_K , f_π , f_K and scattering lengths [5].

In Fig. 1 we present two new fits: “Fit I” describes best the data, but we show also “Fit II” to give an idea of the typical size of the systematic uncertainties. It also makes clear that we don’t need any fine tuning of the LECs to describe the experimental and lattice results together.

DEPENDENCE ON THE MASS OF THE LIGHT QUARKS

The \hat{m} is a parameter of ChPT closely related to the pion mass that we can vary to study the corresponding change in the resonances. It is known [3] that the IAM works for Goldstone bosons masses at least as high as 500 MeV. Since we want pions always lighter than kaons and etas in order to apply the elastic approximation, we will show results up to $M_\pi < 440$ MeV but not beyond, since then $M_K \simeq 600$ MeV. In terms of quark masses, this means $\hat{m}/\hat{m}_{\text{phys}} \leq 9$.

Light vector mesons. The $\rho(770)$ and $K^*(892)$ vector resonances are well established $q\bar{q}$ states belonging to an SU(3) octet. In the first two rows of Fig. 2, we show their dependence on the non-strange quark masses. For each resonance, its mass and width are defined from the position of the associated pole in the second Riemann sheet,

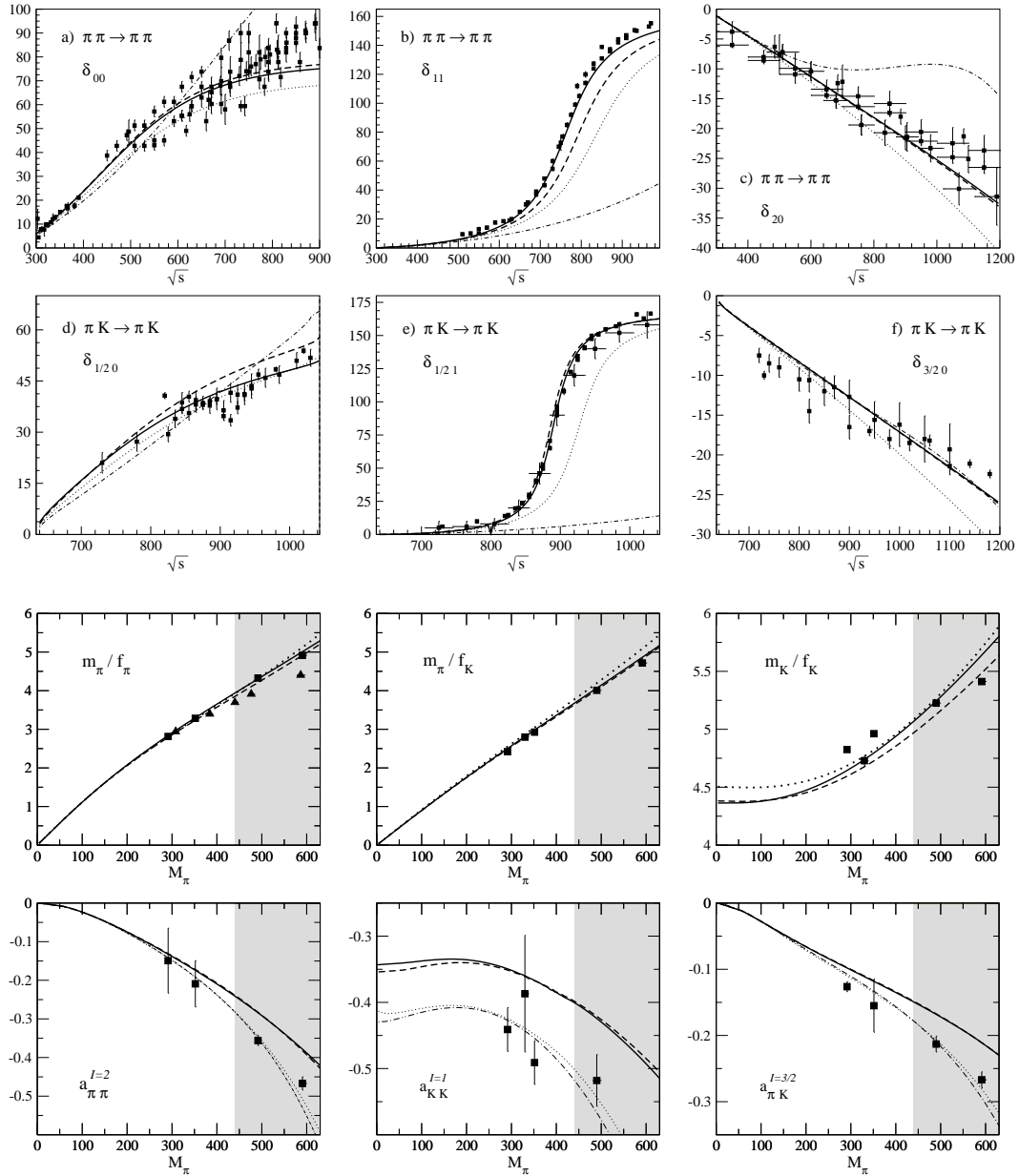


FIGURE 1. Two upper rows: results of our IAM fits versus experimental data on $\pi\pi$ and πK scattering. Two lower rows: result of the unitarized fits to lattice calculations of f_π , f_K , m_π/f_π and the $\pi^+\pi^+$, K^+K^+ , $K^+\pi^+$ scattering lengths. The continuous and dashed lines correspond, respectively, to Fits I and II. For comparison we show the results of the IAM if we used the ChPT LECs obtained from K_{I4} [6] (dotted line) and the results of standard non-unitarized ChPT with the sets of LECs given in [7] (dot-dashed line). The lattice data come from [5] and the references for the experimental data are given in [4].

through the usual Breit-Wigner identification $\sqrt{s_{pole}} \equiv M - i\Gamma/2$, and its coupling to two mesons is given by the residue of the amplitude at the pole position.

The results obtained for the $\rho(700)$ resonance are very consistent with the previous SU(2) results in [1] (dotted line in Fig. 2). Besides, the similarity of the behavior of $\rho(770)$ and $K^*(892)$ is evident. Their masses increase smoothly as the quark mass increases, but much slower than the pion mass. This means that the thresholds grow faster than the masses of the resonances, and as a consequence there is a strong phase space suppression. In fact, the decrease of

their widths agrees remarkably well with the expected reduction coming only from phase space suppression without a dynamical effect through the vector coupling to two mesons (thin lines). Accordingly, we see that $g_{\rho\pi\pi}$ and $g_{K^*\pi K}$ are remarkably constant, which is an assumption made in lattice studies of the $\rho(770)$ width [8].

Light scalar mesons. The $f_0(600)$, or sigma, and the $\kappa(800)$ scalar mesons are still somewhat controversial. Their huge width makes their experimental identification complicated and there are no present lattice calculations with realistic quark masses. It is therefore more interesting to obtain predictions on their quark mass dependence.

In the third and fourth rows of Fig. 2 we show their dependence on the non-strange quark mass. As before, we find that for the $f_0(600)$ the results are in good agreement with the existing SU(2) calculation of [1].

The most prominent feature of the scalars behavior is the appearance of two branches for the mass. The reason is that for physical values of the quark mass, the poles associated to resonances appear as conjugated poles in the second Riemann sheet. As the quark mass increases these poles move closer to the real axis until they join in a single pole below threshold and then split again, now remaining in the real axis.

Despite the evident qualitative similarities, the quantitative behavior of the $f_0(600)$ and the kappa is rather different. In particular, the growth of the $f_0(600)$ mass before the “splitting point” is much faster than that of the $\kappa(800)$.

Regarding their width decrease, we show that for the scalars it cannot be attributed to the phase space reduction due to the increase of pion and kaon masses. Related to this, we see that their coupling constants to two mesons show a strong quark mass dependence. Moreover, they increase dramatically near the “apparent splitting point”.

DEPENDENCE ON THE MASS OF THE STRANGE QUARK

We will only vary the strange quark mass in the limited range $0.8 < m_s/m_{s\text{phys}} < 1.4$ to ensure that the kaon does not become too heavy to spoil the ChPT convergence nor too light to require a coupled channel formalism

Light vector mesons. In the two upper rows of Fig. 3 we show the kaon (or strange quark) mass dependence of the ρ and $K^*(892)$. As it could be expected, the properties of the $\rho(770)$ being non-strange are almost independent of the strange quark mass within the range of study.

Obviously, the $K^*(892)$ shows a strong m_s dependence. As the kaon mass is made heavier, the $K^*(892)$ mass grows much faster than it did when increasing the light quark mass. On the other hand, the $K^*(892)$ mass grows much slower than the kaon mass, so that phase space shrinks and the resonance width decreases almost exactly as it would be expected from phase space suppression only. Accordingly, its coupling to $K\pi$ is almost constant.

Light scalar mesons. In the lower two rows of Fig. 3, we show the variation of the sigma and $\kappa(800)$ properties. Again, the effect on the resonance in the $\pi\pi$ channel, the sigma, is very small.

On the contrary, the mass and width of the $\kappa(800)$ change by as much as 16% within the range of study. Finally we see again that the width decrease deviates significantly from what expected from only phase space suppression, in agreement with $g_{\kappa\pi K}$ depending quite strongly on the strange quark mass.

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REFERENCES

1. C. Hanhart, J. R. Peláez and G. Rios, Phys. Rev. Lett. **100**, 152001 (2008).
2. J. Nebreda and J. R. Peláez in preparation.
3. A. Dobado and J. R. Peláez, Phys. Rev. D **47** (1993) 4883; Phys. Rev. D **56** (1997) 3057.
4. A. Gomez Nicola and J. R. Peláez, Phys. Rev. D **65**, 054009 (2002).
5. S. R. Beane *et al.* [NPLQCD Collaboration], Phys. Rev. D **77**, 094507 (2008) and Phys. Rev. D **77**, 014505 (2008); S. R. Beane *et al.* Phys. Rev. D **74**, 114503 (2006); Ph. Boucaud *et al.* [ETM collaboration], Comput. Phys. Commun. **179**, 695 (2008).
6. G. Amoros, J. Bijnens and P. Talavera, Nucl. Phys. B **602**, 87 (2001).
7. J. R. Peláez, Mod. Phys. Lett. A **19**, 2879 (2004).
8. S. Aoki *et al.* [CP-PACS Collaboration], Phys. Rev. D **76**, 094506 (2007).

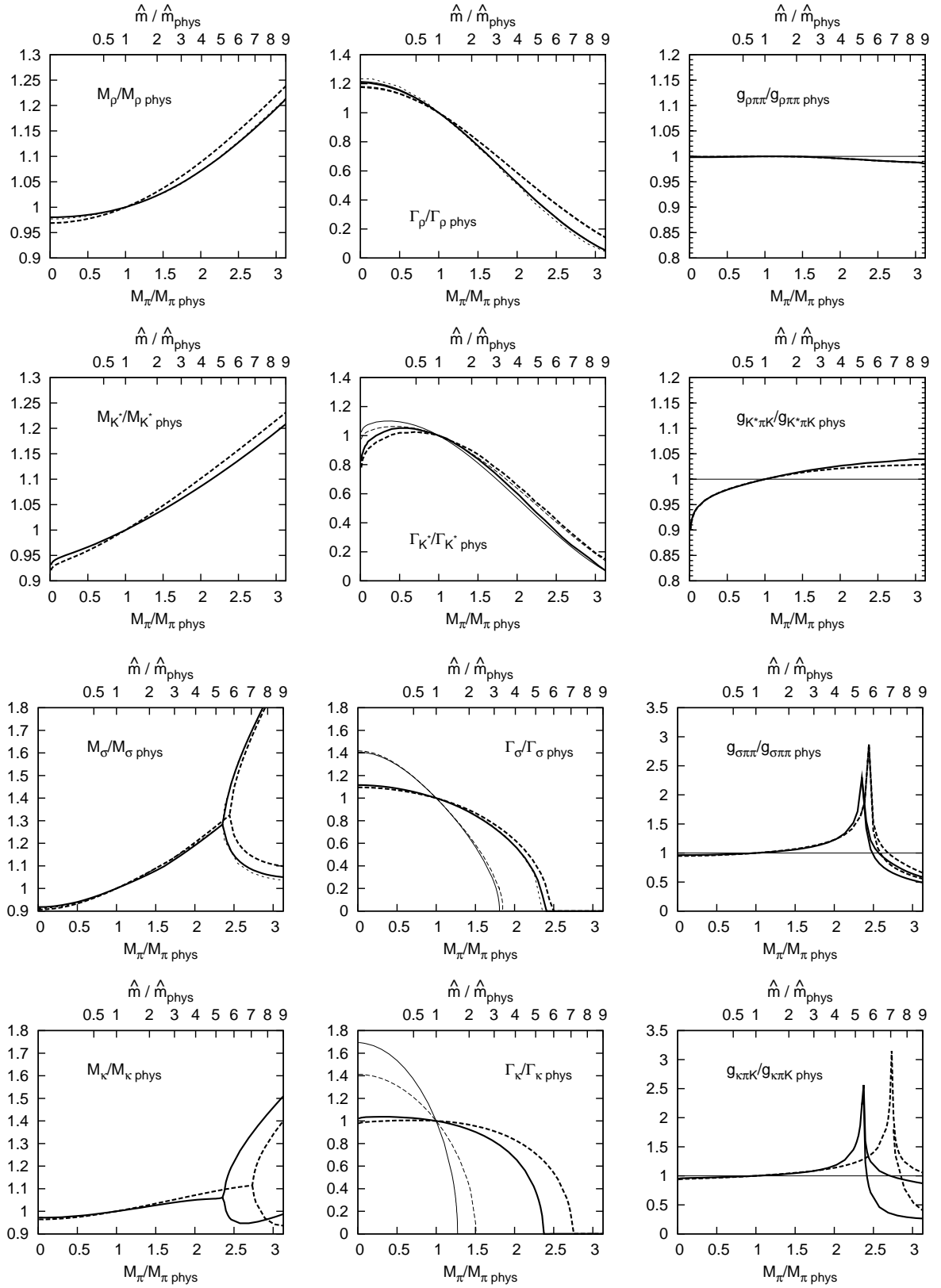


FIGURE 2. Dependence of the $\rho(770)$, $K^*(892)$, $f_0(600)$ and $\kappa(800)$ mass, width and coupling to two mesons with respect to the non-strange quark mass \hat{m} (horizontal upper scale), or the pion mass (horizontal lower scale). Note that we give all quantities normalized to their physical values. The thick continuous and dashed lines correspond to Fit I and Fit II, respectively. For the $\rho(770)$ and the $f_0(600)$ these results are very compatible with those in [1] using SU(2) ChPT (dotted line). The continuous (dashed) thin line shows the M_π dependence of the widths from the change of phase space only, assuming a constant coupling of the resonances to two mesons, $\rho(770)$ and $f_0(600)$ to $\pi\pi$ and $K^*(892)$ and $\kappa(800)$ to πK , calculated from the dependence of masses and momenta given by Fit I (II).

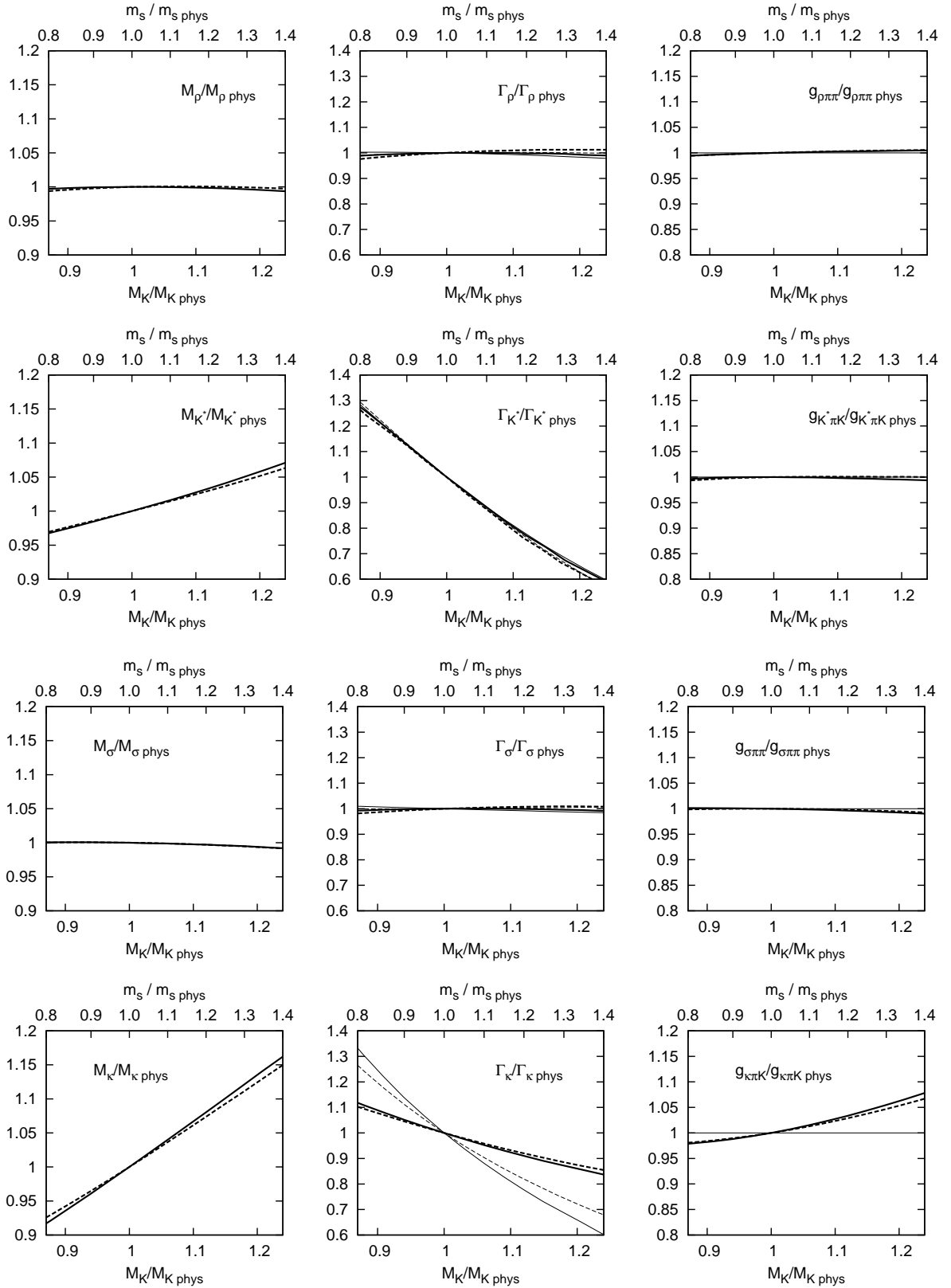


FIGURE 3. Dependence of the $\rho(770)$, $K^*(892)$, $f_0(600)$ and $\kappa(800)$ mass, width and coupling to two mesons with respect to the strange quark mass \hat{m} (horizontal upper scale), or the kaon mass (horizontal lower scale). Note that we give all quantities normalized to their physical values. The thick continuous and dashed lines correspond to Fit I and Fit II, respectively. The continuous (dashed) thin line shows the M_K dependence of the widths from the change of phase space only, assuming a constant coupling of the resonances to two mesons, $\rho(770)$ and $f_0(600)$ to $\pi\pi$ and $K^*(892)$ and $\kappa(800)$ to πK , calculated from the dependence of masses and momenta given by Fit I (II).