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The role of the next-to-leading order triangle-shaped diagram in two-body hadronic decays

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Abstract

The next-to-leading-order contribution to the amplitude of a two-body decay process is a triangle-shaped diagram in which the unstable state is exchanged by the emitted particles. In this work we calculate this diagram in the framework of a scalar quantum field theory and we estimate its role in hadronic physics, i.e., we apply our results to the well-known scalar–isoscalar resonances $f_0(500)$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ and the scalar–isovector resonance $a_0(1450)$. It turns out that, with the exception of the broad resonance $f_0(500)$, the next-to-leading-order contribution is small and can be neglected.

1. Introduction

The study of decays is an important subject of atomic, nuclear and particle physics [1]. Some subatomic particles possess a lifetime which is so short that they can be seen only through their decay products, and hence one usually calls them resonances. This is indeed the case for the recently discovered Higgs particle, see e.g. Refs. [2,3] and references therein. In the realm of the

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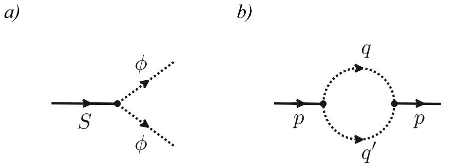

Fig. 1. (a) Decay process $S \to \phi\phi$ at leading order (tree-level). (b) Self-energy at leading order.

strong interactions also many hadrons were discovered via their decay processes [4]; in addition to that, decays turn out to be crucially important for the understanding of their quantum numbers and inner structure.

The main problem concerning the fundamental theory of quarks and gluons (Quantum Chromodynamics or QCD) is the fact that this theory is non-perturbative in the low-energy regime. Hence one relies on other approaches, as for instance effective models based on symmetries [5,6], where the physical degrees of freedom are not quarks and gluons, but composite particles, namely hadrons. Decays of hadrons have often been evaluated within such models in the lowest order approximation – in other words at tree-level, see e.g. Refs. [7–10] and references therein. In particular, in the recent work of Ref. [10] decays of various mesons up to 1.5 GeV were computed in a chirally and dilatation invariant framework and were found to be in agreement with the corresponding experimental values as provided by the PDG [11].

A two-body tree-level decay is the easiest nontrivial process in quantum field theory. It is depicted in Fig. 1a: The unstable bosonic particle S decays into two identical particles, denoted as ϕ. The decay amplitude is simply a constant in the case of scalar particles and non-derivative interactions. When derivatives and/or particles with nonzero total angular momentum J are considered, a dependence of the momenta appears in the tree-level amplitude(s).

The next step in the context of effective models has been the study of (hadronic) loops, see for instance Refs. [12–22] and references therein. The leading contribution to the self-energy is shown by the diagram in Fig. 1b. Both the mass and the width of the decaying particle are influenced by the quantum fluctuations due to the coupling to hadronic intermediate states. The optical theorem assures that the imaginary part of the one-loop diagram from Fig. 1b coincides with the tree-level decay formula. The unstable particle is described by a spectral function (i.e., an energy distribution), which is given by the imaginary part of the one-loop resummed propagator. Alternatively, the properties of the unstable particle can also be described as a complex pole in the appropriate unphysical Riemann sheet, a procedure first proposed by Peierls [23] a long time ago. The quantum theoretical treatment of unstable particles became an object of much interest, see e.g. Refs. [24–27]. The general outcome of such studies is – disregarding problems like mixing – that when the particle is narrow-shaped, quantum fluctuations have a small influence on its properties (i.e., mass and width) but are non-negligible for broad resonances. It turns out to be the ratio 'width over mass' that is decisive here: as long as this number is smaller than ~ 0.3 the loop contributions have a small impact [17].

There is, however, another open issue: what is the role of the next-to-leading order (NLO) diagram for hadronic decays? We depict this kind of triangle-shaped diagram in Fig. 2; it is proportional to the third power of the coupling constant. In the context of hadronic decays in effective field theories/models it is usually not taken into account. Nevertheless, one should stress that the coupling constant in hadronic models is in general not a small number, thus there is a priori no guarantee that the NLO diagram is smaller than the tree-level one.

The aim of this work is to close this gap. To this end, we evaluate the role of the triangle diagram from Fig. 2 in the case of a simple scalar field theory without derivative interactions. We do