A Quark model for Heavy Mesons:
Strong Decays

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Abstract

I shortly review the application of a recently introduced constituent quark-meson model to the determination of some strong coupling constants governing the decays of charm heavy mesons with one pion in the final state. I present the model directly through its rules for computing amplitudes. For a detailed explanation of the model, the reader is referred to the original papers.

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A QUARK MODEL FOR HEAVY MESONS: STRONG DECAYS

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I shortly review the application of a recently introduced constituent quark-meson model to the determination of some strong coupling constants governing the decays of charm heavy mesons with one pion in the final state. I present the model directly through its rules for computing amplitudes. For a detailed explanation of the model, the reader is referred to the original papers.

1 Introduction

A Constituent-Quark-Meson model, CQM, has been recently discussed in a number of papers 1,2,3 stimulated by the original proposals of Ebert et al. 4. The main feature of this model is the emergence of effective (heavy meson)-(heavy quark)-(light quark) vertices. The effective Lagrangian predicting them, comes out from the bosonization of a primary Nambu-Jona-Lasinio (NJL) interaction involving light and heavy quark fields 4. This heavy-light sector Lagrangian, $L^{hl}$, incorporates heavy-flavour symmetries.

The heavy and light quarks are free in the meson because the model is not confining, however, unphysical thresholds for meson decays into real quark-antiquark pairs are avoided through the introduction of an infrared cutoff $\mu$ which prevents to explore energy regions below $\Lambda_{\text{QCD}}$.

The constituent light quark mass, $m = 300$ MeV, is dynamically generated by a NJL-gap equation and acts as the order parameter characterizing the transition between the broken and unbroken chiral symmetry phases. The light sector Lagrangian, $L^{ll}$, incorporates chiral symmetry and its spontaneous breakdown and resembles the Manohar-Georgi 5 effective Lagrangian, except for the absence of gluons and for a different structure of the light quark fields, remnant of the underlying NJL interaction.

2 Strong decays

In this paper I describe the application of CQM model to the evaluation of the strong coupling constants governing the decays $H \rightarrow H\pi$, $S \rightarrow H\pi$, $S \rightarrow S\pi$, $T \rightarrow H\pi$, $T \rightarrow S\pi$, where $H$, $S$ and $T$ are the superfields 6 representing respectively, the lowest negative parity spin doublet, $(0^{-}, 1^{-})$, and the higher spin positive parity doublets, $(0^{+}, 1^{+})$ and $(1^{+}, 2^{+})$, predicted by the Heavy Quark Effective Theory (HQET).

Such processes involve amplitudes that can be calculated in the CQM model through simple loop diagrams, such that in Fig. 1(a), in which the pion is coupled to the light quark line,
Figure 1: The CQM loop diagram is depicted in (a) while, in (b), is represented the same process described at the level of a mesonic effective Lagrangian, i.e., a Lagrangian in which the fundamental fields are meson fields.

according to the prescription in $L^H$, and mesons are attached to the ends by means of the effective vertices predicted in $L^H$.

The explicit calculation of such a diagram proceeds as an usual loop calculation in which the Feynman rules, derived by CQM, are used. With reference to Fig. 1(a), the loop integral is written as:

$$(-1) \frac{3}{16\pi^4} \frac{\sqrt{Z_M Z_{M'}} m_M m_{M'}}{3} \int^\text{reg} d^4\ell \frac{\text{Tr} \left[ (\gamma \cdot \ell + m) \left( -\frac{q^\mu}{2\gamma_5} \gamma_\mu \gamma_5 \right) (\gamma \cdot (\ell + q) + m) M'(v) M(v) \right]}{((\ell^2 - m^2)((\ell + q)^2 - m^2)(v \cdot \ell + \Delta_M)},$$

where $M$ and $M'$ are respectively the incoming and outcoming meson fields of the $H$, $S$ and $T$ type. $Z_M$ and $Z_{M'}$ are the heavy meson field renormalization constants. $m_M$ and $m_{M'}$ are the masses of the degenerate heavy meson doublets, $M$ and $M'$, introduced according to the normalizations of the annihilation operators in $H$, $S$ and $T$. $(-1)$ comes from the Furry theorem, $i^3$ from propagators and the other $i^3$ factor from the three effective vertices $q\pi q$, $qMQ$ and $Q M'q$, where $q$ and $Q$ denote respectively the light and heavy quark fields. The term $\left( -\frac{q^\mu}{2\gamma_5} \gamma_\mu \gamma_5 \right)$ is responsible for the derivative coupling of one pion to the light quark line. The integral should be calculated using the Schwinger proper time regularization method which allows to exponentiate the light quark propagators and to cut off the momenta running in the loop, according to the prescription:

$$\int d^4\ell_E \frac{1}{\ell^2_E + m^2} \rightarrow \int d^4\ell_E \frac{1}{\mu^2} \int_{1/\Lambda^2}^{1/\mu^2} dse^{-s(\ell^2_E + m^2)},$$

where, $\Lambda \simeq \Lambda_\chi \simeq 4\pi f_\pi \simeq 1 \text{ GeV}$, is the ultraviolet cutoff and $\mu = 300 \text{ MeV}$.

It is possible to perform a calculation beyond the soft pion limit, retaining $q$ in (1), being $q^\mu = (q_\pi, 0, 0, q_\pi)$ the pion momentum in the chiral limit and $q_\pi = \Delta_M - \Delta_{M'} \neq 0$. $\Delta_M$ and $\Delta_{M'}$ are the mass differences $m_M - m_Q$, $m_{M'} - m_Q$ and $m_Q$ is the mass of the heavy quark involved.

The result of the CQM loop calculation must be compared with the explicit expression one founds for the matrix element:

$$\langle M' \pi | i L_{\text{meson}} | M \rangle,$$

where $L_{\text{meson}}$ is the appropriate interaction term describing the transition $M \rightarrow M'$, as in Fig. 1(b), at the level of heavy meson chiral Lagrangian.

This comparison allows to extract the strong coupling constants introduced at the level of $L_{\text{meson}}$, e.g., $g$ defined by $L_{\text{meson}} = ig \text{Tr} \left[ HH \left( -\frac{q^\mu}{2\gamma_5} \gamma_\mu \gamma_5 \right) \right]$. With this approach, the results
Table 1: Strong coupling constants, with one pion in the final state, calculated through the CQM model. It is obvious to assume the soft pion limit $q_\pi \to 0$ (s.p.l.) for the processes $H \to H\pi$ and $S \to S\pi$. Some recent CLEO data give a mass $m_S$, for the $S$ multiplet, very close to $m_T$. Therefore the (s.p.l.) is applied also in the calculation of the process $T \to S\pi$. The theoretical error here reported is calculated letting the parameter $\Delta_H$ vary in the range $0.3, 0.4, 0.5$ GeV ($\Delta_S$ and $\Delta_T$ vary accordingly). $k$ and $\tilde h$ are published here for the first time.

| Decay channel | Coupling constant | CQM result         |
|---------------|-------------------|-------------------|
| $D^* \to D\pi$ | $g$               | $0.46 \pm 0.04$ (s.p.l.) |
| $D_0 \to D\pi$ | $h$               | $-0.56 \pm 0.11$  |
| $D_1^* \to D^*\pi$ | $h'$           | $0.65^{+0.45}_{-0.30}$ |
| $D_2^* \to D^*\pi$ |               |                  |
| $D_0 \to D_1\pi$ | $k$               | $-0.13 \pm 0.05$ (s.p.l.) |
| $D_1^* \to D_0\pi$ | $\tilde h$       | $0.91^{+0.5}_{-0.3}$ (s.p.l.) |
| $D_1^* \to D_1'^\prime\pi$ |          |                  |
| $D_2^* \to D_1'^\prime\pi$ |          |                  |

reported in Table 1 have been obtained. In Table 1 we refer to charm states because they are at the moment object of experimental search. CQM results seem encouraging if compared with other theoretical calculations. For example, the determination of the strong coupling in the process $S \to H\pi$ turns out to be very close to the QCD sum rule determination.\(^4\) The same happens for $g\(^1\).$

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