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Running of the $^3P_0$ strength in heavy meson strong decays

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The phenomenological $^3P_0$ decay model has been extensively applied to calculate meson strong decays. The strength γ of the decay interaction is regarded as a free flavor independent constant and is fitted to the data. We calculate through the $^3P_0$ model the total strong decay widths of the mesons which belong to charmed, charmed-strange, hidden charm and hidden bottom sectors. The mass and wave function of the mesons involved in the strong decays are given by a constituent quark model that describes well the meson phenomenology from the light to the heavy quark sector. A global fit of the experimental data shows that, contrarily to the usual wisdom, the γ depends on the reduced mass of the quark-antiquark in the decaying meson. With this scale-dependent strength γ, we are able to predict the decay width of orbitally excited B mesons not included in the fit.

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1. Introduction

Meson strong decay is a complex nonperturbative process that has not yet been described from first principles of QCD. Several phenomenological models have been developed to deal with this topic. The most popular is the $^3P_0$ model which was first proposed by Micu [1] assuming that a quark-antiquark pair is created with vacuum quantum numbers, $J^{PC} = 0^{++}$.

An important characteristic, apart from its simplicity, is that the model provides the gross features of various transitions with only one parameter, the strength γ of the decay interaction, which is regarded as a free constant and is fitted to the data. It is generally believed that γ is roughly flavor-independent.

Our purpose here is to find a scale dependence of γ from the light to the heavy quark sector using a fit to the decay widths of the mesons which belong to charmed, charmed-strange, hidden charm and hidden bottom sectors calculated with the $^3P_0$ model. We choose for the fit those mesons with an asterisk in Table 1.

The wave functions for the mesons involved in the open-flavor strong decays are the solutions of the Schrödinger equation with the potential model described in Ref. [2]. The model has been successfully applied to mesons containing heavy quarks in, e.g., Refs. [3, 4, 5].

2. Running of the strength γ of the decay interaction

This contribution is based on the work published in Ref. [6]. Here, we will summarize it very briefly, for details the reader is referred to that reference.

The strength γ parameter of the $^3P_0$ model should be related to fundamental QCD parameters, among them the strong coupling constant, and so one expects that γ depends on some scale defined by the quark sector. To elucidate the γ dependence on this scale, we calculate through the $^3P_0$ model the total strong decay widths of the mesons which belong to different flavor sectors.

Once the experimental data have been established, we propose a scale-dependent strength γ, given by $\gamma(\mu) = \frac{\gamma_0}{\log\left(\frac{\mu}{\mu_0}\right)}$, where μ is the reduced mass of the quark-antiquark in the decaying meson and, $\gamma_0 = 0.81 \pm 0.02$ and $\mu_0 = (49.84 \pm 2.58)\,\text{MeV}$ are parameters determined by a global fit.

Table 1 shows our results for the total strong decay widths. We get a quite reasonable global description.

One may wonder what happens in other sectors in which the fit has not been carried out. As an example, we can focus on the orbitally excited B mesons. There are two well established states, the $B_1(5721)$ and $B_2^*(5747)$ mesons. The predicted widths for these states are

$$\Gamma(B_1(5721)) = 20.4\,\text{MeV}, \text{ Exp.: } 20.4 \pm 4.5 \pm 9.6\,\text{MeV}, \tag{2.1}$$

$$\Gamma(B_2(5747)) = 32.9\,\text{MeV}, \text{ Exp.: } 22.7 \pm 5.0 \pm 10.7\,\text{MeV}, \tag{2.2}$$

in good agreement with the data. Moreover, as the reduced mass in the B meson is closer to that of the light meson than to that of the heavy meson, this data cannot be reproduced if we use a γ value which fits the bottomonium decays.

	Meson	I	J	P	C	n	Mass (MeV)	$\Gamma_{\text{Exp.}}$ (MeV) [7]	$\Gamma_{\text{The.}}$ (MeV)
	$D^*(2010)^\pm$	1/2	1	-1	-	1	2010.25 ± 0.14	0.096 ± 0.022	0.036
	$D_0^*(2400)^\pm$	1/2	0	$+1$	-	1	2403 ± 38	283 ± 42	212.01
$(*)$	$D_1(2420)^\pm$	1/2	1	$+1$	-	1	2423.4 ± 3.1	25 ± 6	25.27
	$D_1(2430)^0$	1/2	1	$+1$	-	2	2427 ± 36	384 ± 150	229.12
$(*)$	$D_2^*(2460)^\pm$	1/2	2	$+1$	-	1	2460.1 ± 4.4	37 ± 6	64.07
	$D(2550)^0$	1/2	0	-1	-	2	2539.4 ± 8.2	130 ± 18	132.07
	$D^*(2600)^0$	1/2	1	-1	-	2	2608.7 ± 3.5	93 ± 14	96.91
	$D_J(2750)^0$	1/2	2 3	-1	-	1	2752.4 ± 3.2	71 ± 13	229.86 107.64
	$D_J^*(2760)^0$	1/2	1	-1	-	3	2763.3 ± 3.3	60.9 ± 6.2	338.63
$(*)$	$D_{s1}(2536)^\pm$	0	1	$+1$	-	1	2535.12 ± 0.25	1.03 ± 0.13 [8]	0.99
$(*)$	$D_{s2}^*(2575)^\pm$	0	2	$+1$	-	1	2572.6 ± 0.9	20 ± 5	18.67
	$D_{s1}^*(2710)^\pm$	0	1	-1	-	2	2710 ± 14	149 ± 65	170.76
	$D_{sJ}^*(2860)^\pm$	0	1 3	-1	-	3 1	2862 ± 6	48 ± 7	153.19 85.12
	$D_{sJ}(3040)^\pm$	0	1	$+1$	-	3 4	3044 ± 31	239 ± 71	301.52 432.54
$(*)$	$\psi(3770)$	0	1	-1	-1	3	3775.2 ± 1.7	27.6 ± 1.0	26.47
	$\psi(4040)$	0	1	-1	-1	4	4039 ± 1	80 ± 10	111.27
	$\psi(4160)$	0	1	-1	-1	5	4153 ± 3	103 ± 8	115.95
	$X(4360)$	0	1	-1	-1	6	4361 ± 9	74 ± 18	113.92
	$\psi(4415)$	0	1	-1	-1	7	4421 ± 4	62 ± 20	159.02
	$X(4640)$	0	1	-1	-1	8	4634 ± 8	92 ± 52	206.37
	$X(4660)$	0	1	-1	-1	9	4664 ± 11	48 ± 15	135.06
$(*)$	$\Upsilon(4S)$	0	1	-1	-1	6	10579.4 ± 1.2	20.5 ± 2.5	20.59
	$\Upsilon(10860)$	0	1	-1	-1	8	10865 ± 8	55 ± 28	27.89
	$\Upsilon(11020)$	0	1	-1	-1	10	11019 ± 8	79 ± 16	79.16

Table 1: Strong total decay widths calculated through the $^3P_0$ model of the mesons which belong to charmed, charmed-strange, hidden charm and hidden bottom sectors. The symbol $(*)$ refers to those mesons whose total decay widths has been taken for the fit.

3. Conclusions

We propose a scale-dependent strength γ of the phenomenological $^3P_0$ decay model as a function of the reduced mass of the quark-antiquark pair of the decaying meson. The results predicted by the $^3P_0$ model with the suggested running of the γ parameter are in a global agreement with the experimental data, being remarkable in most of the cases studied.

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