In-medium properties of light and heavy pseudoscalar mesons

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Introduction

Quantum chromodynamics (QCD) is the theory of strong interactions that treats partons as fundamental degrees of freedom. Since hadrons are composed of these partons, it is natural to expect that their internal structure will change when they are immersed in a nuclear medium, as demonstrated by the European Muon Collaboration [1].

In order to study the in-medium properties, such as weak decay constants and distribution amplitudes (DAs) of pseudoscalar mesons (K and B), we have used the light-front dynamics. DAs provide information about the coupling strength between quark and antiquark pairs within a hadron. These decay constants are correlated to the normalization of these leading twist DAs that can be extracted through the hard exclusive reaction processes [2].

The inputs required to investigate the in-medium properties of constituent quark flavors of mesons have been computed from the chiral SU(3) quark mean field (CQMF) model in which the quarks are treated as the degree of freedom and are confined inside baryons through confining potential. The quarks inside the hadrons interact through the exchange of scalar (σ, η and δ) and vector (ω, ρ and ϕ) fields. In the present work, we have presented the comparative analysis of the influence of finite baryon density ρ_B/ρ_0 on weak-decay constants and DAs of a light (K) and heavy (B) mesons at zero temperature.

Models description

The CQMF model includes chiral symmetry and its spontaneous breaking, which are the basic key ingredients of low energy QCD. The constituent quark flavors of hadron obtain their masses through the exchange of scalar field. The effective quark mass m_q^* is defined as

$$m_q^* = -g_\sigma^q \sigma - g_\zeta^q \zeta - g_\delta^q I^{3q} \delta + m_q^0, \quad (1)$$

where m_q^0 is zero for u and d quarks and it takes the value of 77 MeV for s quark flavor. The values of coupling constant $g's$ are fixed to get a reasonable binding energy of systematic nuclear medium [3]. In the LFQM, a meson state is described as the bound state of constituent quark q and antiquark $\bar{q}$. The invariant meson mass M_0^{*2} can be expressed as

$$M_0^{*2} = \frac{\mathbf{k}_\perp^2 + m_q^{*2}}{x} + \frac{\mathbf{k}_\perp^2 + m_{\bar{q}}^{*2}}{1-x}. \quad (2)$$

For the ground state of a meson, we have considered the trial wave function in Gaussian basis which can be written as

$$\phi_{1S}(x, \mathbf{k}_\perp) = \frac{4\pi^{3/4}}{\beta^{3/2}} \sqrt{\frac{\partial k_z}{\partial x}} \exp^{-\mathbf{k}^2/2\beta^2}, \quad (3)$$

where β is the variational parameter that corresponds to the size of the wave function. The Jacobian factor which is responsible for variable transformation from $(k_z, \mathbf{k}_\perp)$ to $(x, \mathbf{k}_\perp)$ is expressed as

$$\frac{\partial k_z}{\partial x} = \frac{M_0^*}{4x(1-x)}[1 - \frac{(m_q^{*2} - m_{\bar{q}}^{*2})^2}{M_0^{*4}}], \quad (4)$$

where $k_z = (x - 1/2)M_0^* + (m_{\bar{q}}^{*2} - m_q^{*2})/2M_0^*$ with m_q^* and $m_{\bar{q}}^*$ as the effective masses of quark and anti-quark of a meson. The in-medium decay constant for the case of pseudoscalar meson in the LFQM is given by

$$f_P^* = 2\sqrt{6} \int_0^1 dx \int \frac{d^2\mathbf{k}_\perp}{2(2\pi)^3} \frac{\phi_{1S}(x, \mathbf{k}_\perp)}{\sqrt{\mathcal{A}^2 + \mathbf{k}_\perp^2}} \mathcal{A}, \quad (5)$$

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(a)

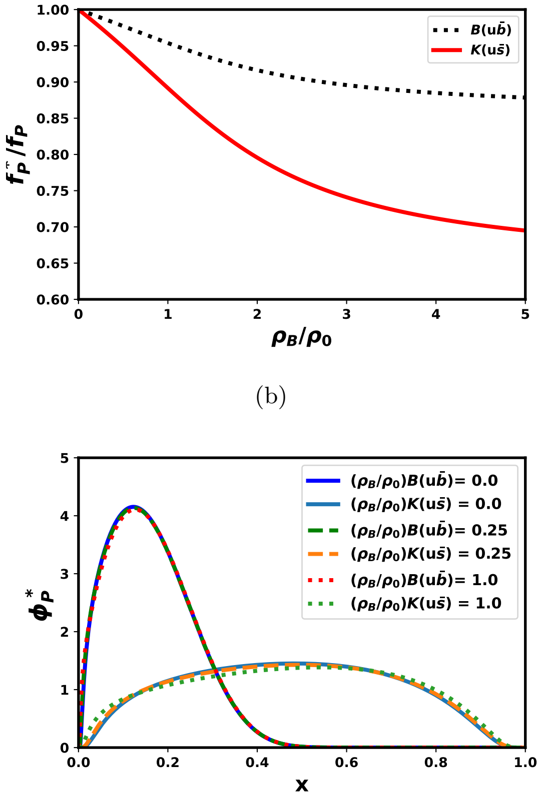

FIG. 1: (a) The ratios of weak-decay constants in-medium to free space; f_P^*/f_P versus ρ_B/ρ_0 and (b) DAs as a function of longitudinal momentum fraction x for different values of baryon density ρ_B/ρ_0.

with $\mathcal{A} = (1-x)m_q^* + xm_{\bar{q}}^*$. The medium-modified DA ϕ_P^*(x) can be obtained by integrating the LFWF over transverse momentum as

$$\phi_P^*(x) = \frac{2\sqrt{6}}{f_P^*}\int \frac{d^2\mathbf{k}_\perp}{2(2\pi)^3}\frac{\phi_{1S}(x,\mathbf{k}_\perp)}{\sqrt{\mathcal{A}^2+\mathbf{k}_\perp^2}}\mathcal{A}. \quad (6)$$

For free space, the weak-decay constants and DAs are denoted by f_P and ϕ_P, respectively.

Result and discussion

The model parameter used in this calculation are as follows; m_b=5200 MeV [4], $\beta_{q\bar{b}}$=519.536 MeV, $\beta_{q\bar{s}}$=366.915 MeV, f_B=188, f_K=156, $g_\sigma^u = g_\sigma^d = 2.72$, $g_\sigma^s = g_\zeta^u = g_\zeta^d = 0$, $g_\delta^u = 2.72$ and $g_\zeta^s = 3.847$ [3].

The ratios of weak-decay constant in-medium to vacuum for K and B mesons has been presented in Fig. 1(a) inferring the significant reduction in weak decay constants for K than B meson. This is due to the fact that K meson contains comparatively lighter quark flavors than B meson, and the chiral condensate of light quark flavors reduces faster as ρ_B increases. Hence, the in-medium weak decay constant ratios at ρ_0 follows the order as

$$1 > \frac{f_B^*}{f_B} > \frac{f_K^*}{f_K}. \quad (7)$$

In Fig. 1(b), we have presented the results for vacuum and in-medium DAs of B and K mesons as a function of longitudinal momentum fraction x carried by light quarks of both B and K mesons for $\rho_B = 0.25\rho_0$ and ρ_0. For K mesons, as we increase the baryon density, the distribution flattened and broadened over the range of x. This is attributed to the reduction of effective quark mass m_q^* that corresponds to the partial restoration of the chiral symmetry. For the case of B meson, no significant impact of the medium has been observed due to its heavy constituent quark flavor b.

References

[1] J. J. Aubert *et al.* [European Muon], Phys. Lett. B **123**, 275-278 (1983).
[2] H. M. Choi and C. R. Ji, Phys. Rev. D **75**, 034019 (2007).
[3] A. Kumar, S. Dutt and H. Dahiya, Eur. Phys. J. A **60**, 4 (2024).
[4] A. J. Arifi, P. T. P. Hutauruk and K. Tsushima, Phys. Rev. D **107**, 114010 (2023).