In-medium properties of pseudoscalar mesons in symmetric nuclear matter

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Introduction

The investigation of the properties of hadrons and their structure in the nuclear medium is one of the most exciting topics in hadronic physics. Experimentally, the European Muon Collaboration (EMC) effect indicated the modification in nucleon structure function in a symmetric nuclear medium [1]. Extensive studies have been done to study the properties such as decay width and mass shift of pseudoscalar π and D mesons in the nuclear medium. However, limited work has been done to study the weak decay constant and distribution amplitude(DAs) of these mesons. In the present work, by using the light-front quark model(LFQM), we compute these quantities for the π and D meson in the nuclear medium. The medium effects are imposed through the in-medium quark masses calculated using the chiral SU(3) quark mean field (CQMF) model[2]. The study may be important to understand the formation of meson nuclear-bound states to be measured in modern experimental facilities [3]. Furthermore, the experiment using the pionic or kaonic Drell-Yan reaction process with heavy nuclear targets can probe the modifications of DAs in the nuclear medium and nuclei [4].

In-medium properties and structure of pseudoscalar mesons

In LFQM, mesons are described as a bound state of constituent quark and antiquark pair. The explicit form of the decay constant in LFQM is given by [5]

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

Here p = π or D and the operator $A = (1-x)m_q^* + x m_{\bar{q}}^*$. The ground state trial wave function in Gaussian basis for meson is given by

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

where β is the variational parameter related to the size of the wave function. The invariant meson mass is defined as

$$M_0^2 = \frac{\mathbf{k}_\perp^2 + m_q^{*2}}{x} + \frac{\mathbf{k}_\perp^2 + m_{\bar{q}}^{*2}}{1-x}, \quad (3)$$

and

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

takes account of variable transformation of $(k_z, \mathbf{k}_\perp)$ to $(x, \mathbf{k}_\perp)$,

$$k_z = \left(x - \frac{1}{2}\right)M_0 + \frac{(m_{\bar{q}}^{*2} - m_q^{*2})}{2M_0}. \quad (5)$$

The DAs of pseudoscalar mesons can be obtained as

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

In CQMF model, quarks are considered as degrees of freedom and are confined within

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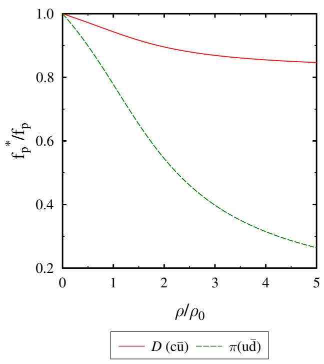

FIG. 1: The ratio of weak decay constant in-medium to free space f^*_p/f_p vs ρ/ρ_0 for π and D mesons.

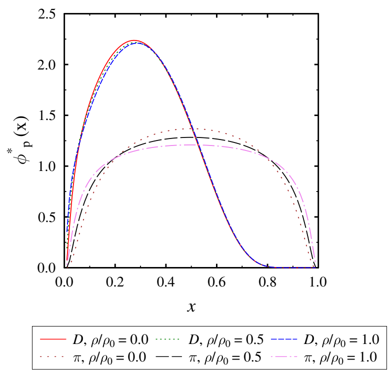

FIG. 2: In medium DAs of π and D mesons at different value of ρ/ρ_0 versus longitudinal momentum x

hadrons through a confining potential[2]. The quarks interact through the exchange of scalar fields (σ, ζ, δ) and vector fields (ω, ρ). The model integrates chiral symmetry, including its spontaneous and explicit breaking. In the CQMF model, the effective quark mass $m^*_q = -g^q_\sigma\sigma - g^q_\zeta\zeta - g^q_\delta\tau^q\delta$, with the couplings $g^{u/d}_\sigma = g^{u/d}_\delta = 2.72$, $g^{u/d}_\zeta = 0$, and $\tau^u = -\tau^d = 0.5$ being the third component of isospin quantum number.

Numerical Results

The model parameters used in LFQM are given in Table I.

m_c(MeV)	$\beta_{q\bar{q}}$(MeV)	$\beta_{q\bar{c}}$(MeV)	f_π (MeV)	f_D (MeV)
1800	309.37	478.673	130	206

TABLE I: The parameters required to obtain the desired result in LFQM.

In Fig.1, we show the ratio of the weak decay constant, in-medium to the free space value, for π and D mesons versus ρ/ρ_0. Our findings show that for π meson, the weak decay constant decreases rapidly with increasing ρ/ρ_0. This rapid change in decay constant of π meson is due to the strong impact of the nuclear medium on light quarks, indicating partial restoration of chiral symmetry. However, for D meson, it is clear that the reduction in weak decay constant is less pronounced due to heavy-light quark constituents.

Fig.2 shows the DAs of π and D mesons versus longitudinal momentum x for various values of ρ/ρ_0. We observe that when ρ/ρ_0 increases from 0 to 0.5 and subsequently to 1.0, the change in DA for π meson is noted to be 6.25% and 11.66% at x=0.5. For D meson, the change in DA is 1.15% and 1.88% at x=0.25. Additionally, for D meson, the variation in DAs becomes nearly negligible for higher values of x. These results indicate that the DAs of D meson show little variation due to the minor effect of the nuclear medium on heavy quarks, whereas the DAs of π meson experience significant modifications due to their light-light quark constituents.

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