The $D_{s1}(2536)^+$ Decay Widths in the C3P0 Model

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Published 15 August 2017

The Fock-Tani representation is a field theory formalism appropriated for the simultaneous treatment of composite particles and their constituents. The 3P0 model is a typical decay model which considers only OZI-allowed strong decays. The model considers a quark-antiquark pair created with the vacuum quantum numbers in the presence of the initial state meson. It is described as the non-relativistic limit of the pair creation Hamiltonian. Applying the Fock-Tani transformation to the microscopic Hamiltonian of the pair creation produces the characteristic expansion in powers of the wavefunction, where the 3P0 model is the lowest order in the expansion. The corrected 3P0 model (C3P0) is obtained from higher orders in the expansion, by the introduction of the bound state kernel Δ , called the bound state correction. The goal of this work is to study the application of the 3P0 model and C3P0 model in detail for the strange charmed meson sector (D_{SJ} meson). In particular, we shall calculate the decay amplitudes and decay rates of the $D_{s1}(2536)^+$.

Keywords: Fock-Tani, C^3P_0 Model, Meson Decay.

PACS numbers: 11.15.Tk, 12.39.Jh, 13.25.-k

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1. Introduction

The Fock-Tani formalism was largely used in atomic physics (Ref. ¹) and hadron physics to describe hadron-hadron scattering interactions (Refs. ²⁻³) and meson decay (Ref. ⁴).

The 3P_0 model is a decay model that considers a quark-antiquark pair created with the vacuum quantum numbers which interact with a meson in the initial state, the pair creation Hamiltonian in this model (Ref. ⁵) is described in the non-relativistic limit. When the Fock-Tani transformation is applied to this Hamiltonian it produces an expansion in powers of the wavefunction. The 3P_0 model is the lowest order term in this expansion. The contribution of the higher orders terms in this expansion give origin to Corrected 3P_0 model (C^3P_0).

In this work we apply of C^3P_0 model on the charming-strange sector (D_{SJ} meson) and calculate the decay amplitudes and decay rates of the $D_{s1}(2536)^+ \rightarrow D^*(2010)^+ K^0$ up to first order correction.

2. The Meson in the Fock-Tani Formalism

In the Fock-Tani formalism we can write the meson creation operators in the following form

$$M_\alpha^\dagger = \Phi_\alpha^{\mu\nu} q_\mu^\dagger \bar{q}_\nu^\dagger, \quad (1)$$

where $\Phi_\alpha^{\mu\nu}$ is the bound-state wavefunction for two-quarks respectively. The quark and antiquark operators obey canonical anti-commutation relations, but the composite meson operators do not satisfy canonical commutation relations. The idea of the Fock-Tani formalism is to make a representation change, of form that the composite particles operators are described by operators that satisfy canonical commutation relations, $M \rightarrow m$, where

$$[m_\alpha, m_\beta] = 0; [m_\alpha, m_\beta^\dagger] = \delta_{\alpha\beta}, \quad (2)$$

where $m_\alpha^\dagger$ is the operators of the “ideal particles” creation.

This can be done and lead to a set of Heisenberg-like equations for the basic operators m , M , q and $\bar{q}$ which can be solved order by order in function of the wavefunctions $\Phi_\alpha^{\mu\nu}$ (Ref. ²)

3. The Microscopic Model (C^3P_0)

In this model we use the following Hamiltonian, inspired in the 3P_0 approach,

$$H = g \int d^3x \Psi^\dagger(\vec{x}) \gamma^0 \Psi(\vec{x}). \quad (3)$$

The quark field is respectively

$$\Psi(\vec{x}) = \sum_s \int \frac{d^3p}{(2\pi)^{3/2}} [u(\vec{p}, s)b(\vec{p}, s) + v(-\vec{p}, s)d^\dagger(-\vec{p}, s)] e^{i\vec{p} \cdot \vec{x}}, \quad (4)$$

and $\gamma = \frac{g}{2m_q}$, where m_q is the mass of both produced quarks. Note that the operator $g\Psi^\dagger\gamma^0\Psi$ leads to the decay $(q\bar{q})_A \rightarrow (q\bar{q})_B + (q\bar{q})_C$ through the $b^\dagger d^\dagger$ term. Introducing the following notation $b \rightarrow q$; $d \rightarrow \bar{q}$; $\mu = (\vec{p}', s')$ e $\nu = (\vec{p}, s)$, after the expansion one obtains

$$H_I = V_{\mu\nu} q_\mu^\dagger \bar{q}_\mu^\dagger, \quad (5)$$

where the sum (integration) is implied over repeated indexes and

$$V_{\mu\nu} \equiv -\gamma \delta_{f_\mu f_\nu} \delta_{c_\mu c_\nu} \delta(\vec{p}_\mu + \vec{p}_\nu) \chi_{s_\mu}^* [\vec{\sigma} \cdot (\vec{p}_\mu - \vec{p}_\nu)] \chi_{s_\nu}^c. \quad (6)$$

Applying the Fock-Tani transformation to H_I one obtains the effective Hamiltonian

$$H_{FT} = U^{-1} H_I U. \quad (7)$$

Now considering the transition $m_\gamma \rightarrow m_\alpha + m_\beta$, we are interested in to calculate the h_{fi} (decay amplitude) that is given by

$$\langle f | H_{FT} | i \rangle = \delta(P_\gamma - P_\alpha - P_\beta) h_{fi}, \quad (8)$$

where $|i\rangle = m_\gamma^\dagger|0\rangle$ and $|f\rangle = m_\alpha^\dagger m_\beta^\dagger|0\rangle$.

4. The Meson Wavefunction

The meson wavefunction is defined as

$$\Phi_\alpha^{\mu\nu} = \chi_{S_\alpha}^{s_1 s_2} f_{f_\alpha}^{f_1 f_2} C^{c_1 c_2} \Phi_{nl}^{\vec{P}_\alpha - \vec{p}_1 - \vec{p}_2}, \quad (9)$$

where χ is spin; f is flavor and C are color coefficients. The spatial parte is given by

$$\Phi_{nl}^{\vec{P}_\alpha - \vec{p}_1 - \vec{p}_2} = \delta(\vec{P}_\alpha - \vec{p}_1 - \vec{p}_2) \Phi_{nl}(\vec{p}_1, \vec{p}_2), \quad (10)$$

where $\Phi_{nl}(\vec{p}_i, \vec{p}_j)$ is given by

$$\Phi_{nl}(\vec{p}_i, \vec{p}_j) = \left(\frac{1}{2\beta}\right)^l N_{nl} |\vec{p}_i - \vec{p}_j|^l \exp\left[-\frac{(\vec{p}_i - \vec{p}_j)^2}{8\beta^2}\right] \mathcal{L}_n^{l+\frac{1}{2}}\left[\frac{(\vec{p}_i - \vec{p}_j)^2}{4\beta^2}\right] Y_{lm}(\Omega_{\vec{p}_i - \vec{p}_j}). \quad (11)$$

5. Applications of the Corrected 3P_0 Model

For this work we consider the decay process

$$D_{s1}(2536)^+ \rightarrow D^*(2010)^+ K^0. \quad (12)$$

The full expressions for the decay amplitudes h_{fi} has the following form

$$h_{fi} = \left[\frac{\gamma}{\pi^{1/4}(\rho + 1)^2} \right] \sum_{LS}^N \mathcal{C}_{LS} Y_{LM}(\Omega), \quad (13)$$

where the coefficients $\mathcal{C}_{LS}$ are polynomials which has a dependence on the P momentum and in β gaussian width of the mesons involved on the processes.

The decay amplitude h_{fi} can be combined with relativistic phase space to give the decay rate (Ref. ⁴⁻⁵). We obtain in this work the decay rates for the processes studied. This decay rates are given in the following form

$$\Gamma_{A \rightarrow BC} = 2\pi P \frac{E_B E_C}{M_A} \left(\frac{\gamma}{\pi^{1/4}(\rho + 1)^2} \right)^2 \sum_{LS}^N (\mathcal{C}_{LS})^2. \quad (14)$$

The experimental values extracted from “Particle Data Group 2010” (PDG - Ref. ⁶) and the theoretical values obtained with C^3P_0 model for this process are shown in the Tab. 1.

Table 1. Experimental values of the total decay rates and branching ratios for the meson D_2^* (2460).

Br. - Branching ratios	Br. Exp. (PDG)	C^3P_0
$\Gamma_{D^*(2010)+K^0}^{S-wave} / \Gamma_{D^*(2010)+K^0}$	$0.72 \pm 0.05 \pm 0.01$	0.72

For the theoretical results presented in table the γ and β (in GeV) are $\gamma = 1.651$, $\beta_{K^0} = 0.145$, $\beta_{D^*(2010)+} = 0.200$, $\beta_{D_s^{*+}} = 0.200$ and for the intermediate state $\beta_\eta = 0.111$ is the state 1^1S_0 and the intermediate state $\beta_\omega = 0.111$ is the state 1^3S_1 .

6. Conclusions

Here we present the Corrected 3P_0 model applied for one meson decay process of the charming-strange sector. In this sector the decay process is $D_{S,J}^* \rightarrow D^* K$. The result is close to the experimental range, requiring a better fit with current pdg data.

The next step will be to consider the other D decay channels and higher-order corrections in the Corrected 3P_0 model.

Acknowledgments

This work was partially financed by IFSUL and IF-UFRGS, Brazil.

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