J/ψ DECAY IN THE C^3P_0 MODEL

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The Fock-Tani representation, is a field theoretic formalism to treat problems involving both composite particles and their constituents. The application of the Fock-Tani transformation to a pair creation Hamiltonian produces the characteristic expansion in powers of the wave function. In lowest order of this expansion, we obtain the model known in the literature: the 3P_0 model. In higher orders, the Corrected 3P_0 model (C^3P_0) is obtained by introducing the bound state kernel. In this work, we use the C^3P_0 model to calculate the J/ψ decay rates in the following channels: $\rho\pi$, $\omega\eta$, $\omega\eta'$, $K^{*+}K^-$, $K^{*0}\bar{K}^0$, $\phi\eta$, $\phi\eta'$. We consider that the J/ψ is a mixture given by $c_1[u\bar{u} + d\bar{d}] + c_2 s\bar{s} + c_3 c\bar{c}$.

Keywords: J/ψ Decay; C^3P_0 model; Fock-Tani formalism.

1. The C^3P_0 model

The C^3P_0 model is obtained using the Fock-Tani formalism (FTf) for mesons decays.^{1,2} The starting point of the model is the definition of a microscopic Hamiltonian. The microscopic pair creation Hamiltonian H_I can be defined as

$$H_I = V_{\mu\nu} q_\mu^\dagger \bar{q}_\nu^\dagger, \quad (1)$$

where the pair creation potential $V_{\mu\nu}$ is given by

$$V_{\mu\nu} \equiv 2m_q \gamma \delta(\vec{p}_\mu + \vec{p}_\nu) \bar{u}_{s_\mu f_\mu c_\mu}(\vec{p}_\mu) v_{s_\nu f_\nu c_\nu}(\vec{p}_\nu), \quad (2)$$

and γ is the pair production strength. Applying the Fock-Tani transformation to H_I we obtain a Hamiltonian with an expansion in powers of wave functions. In lowest

order of this expansion obtains

$$\begin{aligned} H^{C^3P_0} &= H_m + \delta H_m \\ &= -\Phi_\alpha^{*\rho\xi} \Phi_\beta^{*\lambda\tau} \Phi_\gamma^{\omega\sigma} V^{C^3P_0} m_\alpha^\dagger m_\beta^\dagger m_\gamma, \end{aligned} \quad (3)$$

where $V^{C^3P_0}$ is a condensed notation for

$$\begin{aligned} V^{C^3P_0} &= \left[\delta_{\mu\lambda} \delta_{\nu\xi} \delta_{\omega\rho} \delta_{\sigma\tau} - \frac{1}{2} \delta_{\sigma\xi} \delta_{\lambda\omega} \Delta(\rho\tau; \mu\nu) \right. \\ &\quad \left. + \frac{1}{4} \delta_{\sigma\xi} \delta_{\lambda\mu} \Delta(\rho\tau; \omega\nu) + \frac{1}{4} \delta_{\xi\nu} \delta_{\lambda\omega} \Delta(\rho\tau; \mu\sigma) \right] V_{\mu\nu} \end{aligned} \quad (4)$$

and $\Delta(\rho\tau; \lambda\nu) = \Phi_\alpha^{\rho\tau} \Phi_\alpha^{*\lambda\nu}$ is the *bound-state kernel*, the basic quantity for these corrections. The C^3P_0 amplitude is obtained by the following matrix element,

$$\langle BC | H^{C^3P_0} | A \rangle = \delta(\vec{P}_A - \vec{P}_B - \vec{P}_C) h_{fi}^{C^3P_0}, \quad (5)$$

where

$$h_{fi}^{C^3P_0} = h_{fi} + \delta h_{fi}. \quad (6)$$

The term h_{fi} of the Eq. (6) is shown in Fig. 1(a) and it is identical to the decay amplitude obtained with the 3P_0 model. The three implicit terms in δh_{fi} correspond to the bound-state correction and are represented in the Fig. 1(b), (c) and (d). The

Fig. 1. Diagrams representing the decay amplitude of the C^3P_0 model, $h_{fi}^{C^3P_0}$. The diagrams (a), (b), (c) and (d) correspond, respectively, to the four implicit terms in the Eq. (6).

differential decay rate is obtained through the combination of the relativistic phase space with the $h_{fi}^{C^3P_0}$ decay amplitude

$$\frac{d\Gamma_{A \rightarrow BC}}{d\Omega} = 2\pi P \frac{E_B E_C}{M_A} |h_{fi}^{C^3P_0}|^2. \quad (7)$$

2. Numerical Calculation

As a testing ground for the C^3P_0 model in the charm sector, we calculate the J/ψ decay rates in the following channels: $\rho\pi$, $\omega\eta$, $\omega\eta'$, $K^{*+}K^-$, $K^{*0}\bar{K}^0$, $\phi\eta$, $\phi\eta'$.

The mesons J/ψ , ϕ and ω are considered as the following mixture³

$$\begin{aligned} |\omega\rangle &= |n\bar{n}\rangle - 0.06|s\bar{s}\rangle - 1.5 \times 10^{-3}|c\bar{c}\rangle \\ |\phi\rangle &= 0.06|n\bar{n}\rangle + |s\bar{s}\rangle - 0.9 \times 10^{-3}|c\bar{c}\rangle \\ |J/\psi\rangle &= 1.5 \times 10^{-3}|n\bar{n}\rangle + 0.9 \times 10^{-3}|s\bar{s}\rangle + |c\bar{c}\rangle. \end{aligned} \quad (8)$$

A similar mixture occurs for η , η' and η_c .⁴ The contributions of the terms $|n\bar{n}\rangle$, $|s\bar{s}\rangle$ and $|c\bar{c}\rangle$ are:

$$\begin{aligned} |\eta\rangle &= 0.77|n\bar{n}\rangle - 0.63|s\bar{s}\rangle - 0.006|c\bar{c}\rangle \\ |\eta'\rangle &= 0.63|n\bar{n}\rangle + 0.77|s\bar{s}\rangle - 0.016|c\bar{c}\rangle \\ |\eta_c\rangle &= 0.015|n\bar{n}\rangle + 0.008|s\bar{s}\rangle + |c\bar{c}\rangle. \end{aligned} \quad (9)$$

With Eq. (8), the J/ψ decays become OZI-allowed. Like this, it is possible to uses the C^3P_0 model to study the channels proposed previously.

The spatial wave functions used are of type harmonic oscillator. Therefore, we have as free parameters, beyond the coupling constant γ , the widths β 's of the Gaussians. The mesons used in the bound-state kernel were the ϕ and ω and are allowed to mix as in Eq. (8). A particular notation is introduced for the Gaussian widths for the BSK meson: β_{ϕ_Δ} , β_{ω_Δ} and β_{J/ψ_Δ} . After the simulation the best fit to the experimental data is achieved with $\gamma = 0.3$, $\beta_{J/\psi} = 0.182$ GeV, $\beta_\rho = 0.6$ GeV, $\beta_\pi = 0.6$ GeV, $\beta_\omega = 0.36$ GeV, $\beta_\eta = 0.35$ GeV, $\beta_{\eta'} = 0.3$ GeV, $\beta_K = 0.4$ GeV, $\beta_{K^*} = 0.34$ GeV, $\beta_\phi = 0.34$ GeV, $\beta_{\phi_\Delta} = 0.3$ GeV, $\beta_{\omega_\Delta} = 0.6$ GeV and $\beta_{J/\psi_\Delta} = 0.3$ GeV. These results and the experimental values are shown in Table 1.

Table 1. J/ψ decay rates.

Decay	Γ^{Expt} (KeV) ⁵	$\Gamma^{C^3P_0}$ (KeV)
$\rho\pi$	1.57	1.26
$\omega\eta$	0.16	0.16
$\omega\eta'$	0.02	0.12
$K^{*+}K^-$	0.48	0.47
$K^{*0}\bar{K}^0$	0.41	0.48
$\phi\eta$	0.07	0.07
$\phi\eta'$	0.04	0.23

Fig. 2. J/ψ decay rates versus the $\beta_{J/\psi}$ Gaussian width obtained with the C^3P_0 model.

In the Fig. 2, are shown the J/ψ decay rates versus the $\beta_{J/\psi}$ Gaussian width obtained with the C^3P_0 model. The other parameters were fixed with the values mentioned previously. Through the graph, it is possible to observe that the $\beta_{J/\psi}$ Gaussian width that supplies the best adjustment should be in the interval of 0.15–0.20 GeV.

3. Conclusion

For the decays that possess η' as one of the mesons of the final state, the values that we obtained for the decay rates were above the experimental values. The mixture given by the Eq. (9) were not enough to solve this problem.

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