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# THE MECHANISM OF OPEN-FLAVOR STRONG DECAYS

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# THE MECHANISM OF OPEN-FLAVOR STRONG DECAYS [†]

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In this contribution I discuss models of two-body strong hadron decays. These models are expected to play a vital role in future attempts to identify unconventional hadrons such as glueballs and hybrids, through accurate predictions of the decay modes of conventional $q\bar{q}$ states. First I review the most commonly used decay model, which is the $^3P_0$ model developed by Micu and LeYaouanc *et al.*, and show some of its successful predictions. Predictions of the $^3P_0$ model for some newly discovered states are also given. Finally I discuss some attempts to identify the fundamental QCD process which underlies $q\bar{q}$ pair production in the $^3P_0$ model. Our results indicate that the dominant $q\bar{q}$ pair production process is usually pair production through the linear scalar confining interaction. Pair production from OGE in most cases is found to be a smaller amplitude, with the notable exception of $^3P_0 \to {}^1S_0 + {}^1S_0$ decays such as $f_0(q\bar{q}) \to \pi\pi$.

## 1 Strong Decays and the $^3P_0$ Model

### *1.1 The Importance of Strong Decays*

Much of the current activity in hadron spectroscopy is concerned with searches for resonances that do not fit into the conventional $q\bar{q}$ quark model. These include glueballs, hybrids and multiquark states, with the latter probably realized as loosely-bound hadron-hadron "molecules".

These unusual states must be distinguished from a background of $q\bar{q}$ states, and since these new types of hadrons are all expected to be present in the spectrum at a relatively high mass of ≈ 2 GeV, the $q\bar{q}$ background will be quite rich; many orbital and radial excitations of the $q\bar{q}$ system ($q = u, d, s$) are expected in the mass range 1.5-2.5 GeV. Although one can try to avoid confusion with $q\bar{q}$ by searching for exotic resonances with quantum numbers such as $J^{PC} = 1^{-+}$ that are forbidden to $q\bar{q}$, in practice many of the candidates

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the produced pair does not go into a single hadron; the suppression of these "hairpin diagrams" is simply a rule based on observation, which is not understood at a fundamental level. Note however that it is a natural consequence of color-octet pair production. Subsequent work on this model[4] has usually been concerned with numerical predictions, and has not led to any widely accepted fundamental modifications. Recent studies have considered changes due to a spatial dependence of the pair production amplitude[5,6] (the flux-tube model is an example of these) or the effect of final state interactions on the decay amplitudes,[6] but the underlying "microscopic" QCD decay mechanism is usually not addressed; this is widely believed to be a complicated nonperturbative process involving "flux tube breaking".

A simple reformulation of the $^3$P$_0$ model is to regard the decays as due to an interaction Hamiltonian involving Dirac quark fields,[7]

$$H_I = g \int d^3x \, \bar{\psi}\psi \; . \tag{1}$$

In the nonrelativistic limit this leads to identical matrix elements to the usual $^3$P$_0$ model, given the identification

$$\gamma = \frac{g}{2m_q} \tag{2}$$

where $m_q$ is the quark mass of the produced pair. The operator $g\bar{\psi}\psi$ drives the decay $(q\bar{q})_A \to (q\bar{q})_B + (q\bar{q})_C$ through the $b^\dagger d^\dagger$ term.

This decay Hamiltonian gives matrix elements between one-meson and two-meson states which can be evaluated explicitly for a given set of quark model wavefunctions. For illustration we will show some results for decays of well established S- and P-wave $q\bar{q}$ states with SHO wavefunctions. (Details of these rates and the Feynman diagram representation of the $^3$P$_0$ model we developed to simplify the calculations are given by Ackleh *et al.*[7]) The $^3$P$_0$ decay rates are conveniently expressed as a common factor involving $x = |\vec{P}_B|/\beta = |\vec{P}_C|/\beta$ ($\beta$ is the SHO wavefunction width parameter in GeV) times a reduced rate $\hat{\Gamma}$ and phase space;

$$\Gamma_{A\to BC} = \pi^{1/2}\,\gamma^2\,\frac{E_B E_C}{M_A}\,x\,\hat{\Gamma}_{A\to BC} \; ; \tag{3}$$

$$\hat{\Gamma}_{\rho\to\pi\pi} = \left(\frac{2^{10}}{3^6}\right) \mathcal{A}_P(x)^2\, e^{-x^2/6} \tag{4}$$

$$\hat{\Gamma}_{f_2\to\pi\pi} = \left(\frac{2^{11}}{3^7\cdot 5}\right) \mathcal{A}_D(x)^2\, e^{-x^2/6} \tag{5}$$

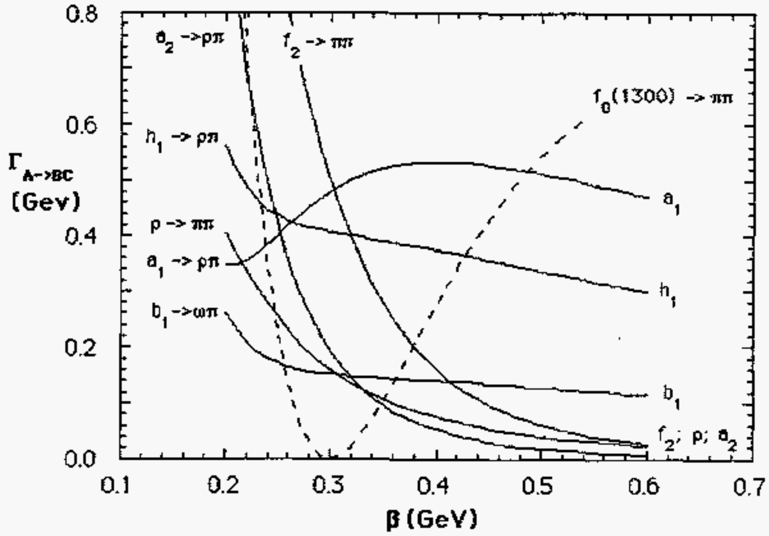

Figure 1: Representative ${}^3\mathrm{P}_0$ model meson decay rates for $\gamma = 0.5$; meson width parameter $\beta$ variable.

### *1.3 Problematical resonances in the ${}^3P_0$ Model*

Since the ${}^3\mathrm{P}_0$ model apparently gives a reasonably accurate description of open-flavor strong decays, its predictions for currently problematical resonances are of great interest. We will mention four of these, the $a_0(1450)$, $\xi(2230)$, $\pi(1800)$ and $f_0(1300)$. The results discussed here will be made available elsewhere. [10]

The $a_0(1450)$ $q\bar{q}$ candidate of Crystal Barrel [11] has been reported in $K\bar{K}$ and $\eta\pi$; in the ${}^3\mathrm{P}_0$ model one predicts that these modes are indeed important, with partial widths of about 100 MeV ($K\bar{K}$) and 200 MeV ($\eta\pi$), and that $\eta'\pi$ should also be a large mode, with a partial width of about 200 MeV.

The $\xi(2230)$ is especially interesting; originally Godfrey, Isgur and Kokoski[12] suggested that this might simply be a narrow ${}^3F_2$ $s\bar{s}$ state, based on ${}^3\mathrm{P}_0$ decay model predictions. Subsequent calculations of other modes, notably $K_1^*K$, have changed this conclusion, [10,13] and the ${}^3F_2$ $s\bar{s}$ is now predicted to be a broad state with a width of $\sim 500$ MeV. Thus, a narrow $f_2(2230)$ which couples strongly to $\phi\phi$ cannot be explained by the ${}^3\mathrm{P}_0$ model.

The $\pi(1800)$ discussed at this meeting [14] has been proposed as a hybrid candidate in part due to the weakness of the $\pi\rho$ mode. Actually this decay amplitude has a node near the physical point in the ${}^3\mathrm{P}_0$ model [10,15] so this is

$$K = \begin{cases} +\alpha_s/r & \text{color Coulomb OGE} \\ -\alpha_s/r & \text{transverse OGE} \\ +\frac{3}{4}\,br & \text{scalar confining interaction .} \end{cases} \tag{17}$$

The possibility that these decays occur through pair production from the confining interaction, as in our third microscopic decay Hamiltonian, was previously suggested by Eichten *et al.* [16] Unfortunately they assumed a *vector* confining interaction, which leads to disagreement with experiment in spectroscopy (for example in the $\chi_J$ $c\bar{c}$ states) as well as in decay amplitudes.

### *2.2 A Test Case:* $\Gamma(\rho \to \pi\pi)$ *in Microscopic Decay Models*

The rates for $\rho \to \pi\pi$ due to pair production from these OGE and confining interactions (treated separately to determine their relative importance) are [7]

$$\Gamma^{j^0Kj^0}_{\rho\to\pi\pi} = \left(\frac{2^6}{3^6\sqrt{\pi}}\right)\left(\frac{\alpha_s\beta}{m_q}\right)^2\frac{E_\pi^2}{M_\rho}x^3\left[{}_1\mathrm{F}_1\left(\frac{1}{2};\frac{3}{2};\xi\right) - \frac{2}{3}{}_1\mathrm{F}_1\left(\frac{1}{2};\frac{5}{2};\xi\right)\right]^2 e^{-x^2/6}\ , \tag{18}$$

$$\Gamma^{\vec{j}K\vec{j}}_{\rho\to\pi\pi} = \left(\frac{2^6}{3^6\sqrt{\pi}}\right)\left(\frac{\alpha_s\beta}{m_q}\right)^2\frac{E_\pi^2}{M_\rho}x^3\left[{}_1\mathrm{F}_1\left(\frac{1}{2};\frac{3}{2};\xi\right) + \frac{10}{9}{}_1\mathrm{F}_1\left(\frac{1}{2};\frac{5}{2};\xi\right)\right]^2 e^{-x^2/6} \tag{19}$$

and

$$\Gamma^{sKs}_{\rho\to\pi\pi} = \left(\frac{2^6 5^2}{3^6\sqrt{\pi}}\right)\left(\frac{b}{m_q\beta}\right)^2\frac{E_\pi^2}{M_\rho}x^3\left[{}_1\mathrm{F}_1\left(-\frac{1}{2};\frac{3}{2};\xi\right) + \frac{4}{45}{}_1\mathrm{F}_1\left(-\frac{1}{2};\frac{5}{2};\xi\right)\right]^2 e^{-x^2/6} \tag{20}$$

where $x = P/\beta$ and $\xi = P^2/48\beta^2$. Since the nonrelativistic quark model parameters for light hadrons are reasonably well established, we can immediately estimate the numerical importance of these three decay mechanisms. The decay rate each would predict for $\rho \to \pi\pi$ with the typical quark model parameters $\alpha_s = 0.6$, $m_q = 0.33$ GeV and $b = 0.18$ GeV$^2$ is shown in Fig. 2, again as a function of the meson wavefunction $\beta$. Evidently the dominant decay mechanism is pair production from the confining interaction, which gives a width of 326 MeV at $\beta = 0.4$ GeV. In comparison, transverse OGE gives a width of 14 MeV, and the color Coulomb interaction gives only 0.36 MeV.

This is a very satisfying result. Since we know that OGE pair production *must* be present but by itself fails the D/S ratio test in the crucial decay $b_1 \to \omega\pi$,[7] the obvious resolution is that this OGE decay amplitude is indeed present but is somewhat smaller than the nonperturbative pair production amplitude. We have confirmed this for $\rho \to \pi\pi$. The $^3\mathrm{P}_0$ model thus appears to in the decay of $^3\mathrm{P}_0$ $q\bar{q}$ states to pseudoscalar pairs. In this process we find a remarkably large decay amplitude due to transverse OGE, which gives the decay rate

$$\Gamma^{\vec{J}K\vec{J}}_{f_0\to\pi\pi} = \left(\frac{2^2}{3^5\sqrt{\pi}}\right)\left(\frac{\alpha_s\beta}{m_q}\right)^2 \frac{E_\pi^2}{M_{f_0}} x \Big[(72+x^2)\,{}_1\mathrm{F}_1\Big(\frac{1}{2};\frac{3}{2};\xi\Big) + \frac{4}{3}x^2\,{}_1\mathrm{F}_1\Big(\frac{1}{2};\frac{5}{2};\xi\Big) - \frac{80}{3}\,{}_1\mathrm{F}_1\Big(-\frac{1}{2};\frac{3}{2};\xi\Big)\Big]^2 e^{-x^2/6} \,. \qquad (21)$$

The factor of 72 is due to a specific term in the transverse OGE matrix element that vanishes in the other decays considered here, and is such a large factor that it predicts an $f_0(1300) \to \pi\pi$ decay width of several GeV given standard quark model parameters. This is so large as to be suspect, but does suggest that the $f_0(q\bar{q})$ and other scalar $q\bar{q}$ states may decay dominantly through an OGE mechanism rather than a nonperturbative $^3\mathrm{P}_0$-type interaction, and hence naturally have very large widths, contrary to the $^3\mathrm{P}_0$ result shown in Fig. 1. This remarkable result suggests that we may still have much to learn about the mechanism of open-flavor strong decays, which must be understood if we are to distinguish $q\bar{q}$ states from glueballs, hybrids and other exotica by their strong decays modes.

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4. The literature is extensive, so we only give a few representative references. For applications to charmonium see A. LeYaouanc, L.Oliver, O.Péne and