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Dipionic decays of psions in a local derivative coupling model*

B BAGCHI, V P GAUTAM and A NANDY
Department of Theoretical Physics, Indian Association for the Cultivation of Science, Jadavpur, Calcutta 700 032

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Abstract. A local derivative coupling model is used to study the $\psi' \to \psi\pi\pi$ and other dipionic decays of ψ and ψ'', as an alternative to the ϵ-model. The results obtained are quite satisfactory. We findt hat the existence of the ϵ-resonance is not essential in order to understand the dipionic decays of the psions at the present level of experimental data available.

Keywords. Decays of ψ-particles; ϵ-resonance; suppression factors in VDM.

1. Introduction

One of the puzzling features in the hadronic decay modes of the recently discovered ψ-particles has been the anomalous mass distribution of the dipion system in the decay

$$\psi' (3{\cdot}7) \to \psi (3{\cdot}1)\pi^+ \pi^-. \tag{1}$$

The experimental evidences that the $\pi\pi$ system is emitted in an S-wave, I=0 state (Abrams *et al* 1975, Tanenbaum *et al* 1976) with no correlation between the pion momenta and psion spins have led several authors to consider an essentially resonance model of the decay (Schwinger *et al* 1975; Harrington *et al* 1975, Pham *et al* 1976) in which an isoscalar $\pi\pi$ resonance, the ϵ(700), is exchanged between ψ', ψ and $\pi\pi$ states. However, the ϵ is a broad resonance with its mass and width not yet well established and it is known that the dipion spectrum in the ϵ-model varies with the values of the parameters used (Schwinger *et al* 1975, Harrington *et al* 1975). It is thus worthwhile to consider some other scheme which could describe the decay (1) and some related processes as uniquely as possible. In this paper we point out that to the level of the experimental data available, the existence of the ϵ is not necessary in order to understand the dominant decay mode of ψ' as well as the related decay processes for ψ and ψ''. We find that it is adequate to consider a local derivative coupling (LDC) model to describe the observed processes. In the following sections the dipionic cascade and radiative decays of psions are investigated to compare and contrast the LDC and ϵ-model predictions, while the $\phi 2\pi$ and $\omega 2\pi$ decay modes of ψ are used to extract information about some other decays of psions. The last section presents a short discussion and conclusion of our work.

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2. $\psi' \longrightarrow \psi\pi\pi$ and $\psi'' \longrightarrow \psi\pi\pi$ decays

We start with the model Lagrangian* for the decay $\psi' \rightarrow \psi\pi\pi$,

$$L_{\text{int}} = g_{\psi'\psi\pi\pi}\, m_{\psi'}^{-2}\, \psi'_{\mu}\psi^{\mu}\, (\partial_{\nu}\vec{\pi}) \cdot (\partial_{\nu}\vec{\pi}). \tag{2}$$

Here we have retained the simplest coupling of the ψ nad ψ' fields and are guided in our choice of the derivative form for the pion fields from current algebra considerations (Pasupathy 1976); $g_{\psi'\psi\pi\pi}$ is a dimensionless coupling constant. The LDC form (2) leads to a parameterless prediction for the decay spectrum in the dipion mass

$$\frac{d\Gamma}{dm_{\pi\pi}} = \frac{g^2_{\psi'\psi\pi\pi}}{4\pi}\, a\,(b+2)\,(b-1)^{1/2}\,(1-4c)^{1/2}\,(1-2c)^2 \tag{3}$$

where

$$a = m_{\psi}\, m^5_{\pi\pi} \Big/ 288\,\pi^2\, m^6_{\psi'},\quad b = \left(m^2_{\psi} + m^2_{\psi'} - m^2_{\pi\pi}\right)^2 \Big/ 4\, m^2_{\psi}\, m^2_{\psi'}$$

and $c = m^2_{\pi} / m^2_{\pi\pi}$. Figure 1 shows this decay spectrum; for comparison we have also included predictions of the ϵ-model and the phase space; the experimental data are from Particle Data Group (1976). An essentially similar result was obtained by Brown and Cahn (1975) from pure chiral symmetry considerations in a non-relativistic approximation.

It is evident that eq. (3) explains the general features of the decay spectra almost as well as the resonance model. While the ϵ-model predictions can be altered by fitting

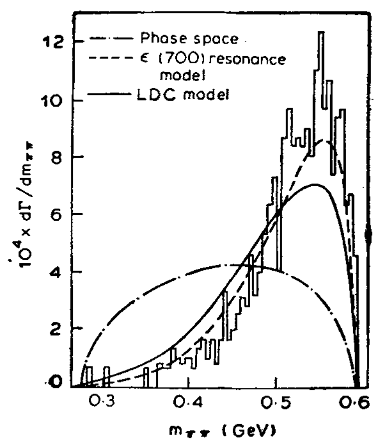

Figure 1. Dipion mass distribution in $\psi' \rightarrow \psi\pi\pi$ decay. The experimental data are taken from Köegerler *et al* (1976b).

*That this type of Lagrangian can describe the decay mode $\psi' \rightarrow \psi\pi\pi$ is widely known; however, detailed calculations for this and other associated processes have not yet been carried out to our knowledge.

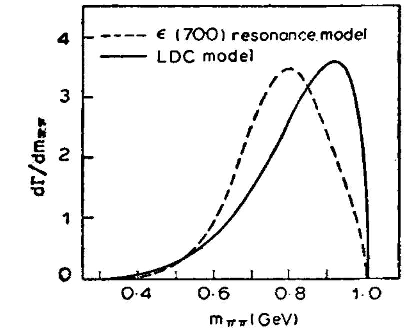

Figure 2. Dipion mass distribution in $\psi'' \to \psi\pi\pi$ decay.

the ϵ-parameters, the LDC model can be shape adjusted by using a suitable form factor at the 4-particle vertex. Such a form factor could arise from the loosely bound structure of the psions in the quark model. The close agreement of the two models is due to the fact that whereas (2) predicts a dipion spectrum increasing with the mass of the dipion, the resonance model implies a spectrum peaked close to the ϵ-mass which happens to be near the end of the available phase space. To distinguish between the two models then, a larger phase space is necessary. This is provided in the cascade decays of ψ'' (4·1) where again we would expect a $\psi''(4{\cdot}1) \to \psi(3{\cdot}1)\pi\pi$ decay in analogy to the decay (1). Assuming $g^2_{\psi''\psi\pi\pi} \approx g^2_{\psi'\psi\pi\pi}$ we have calculated the dipion mass spectra from the two models and, as shown in figure 2, these are distinctly different.* The decay width for the process turns out to be $\sim$2·5 MeV in the present model and $\sim$5 MeV with the resonance hypothesis. Our result is actually on the high side, for as Chaichian and Köegerler (1976) have shown in a nonrelativistic model, the coupling constant for the same process should decrease with increasing order of radial excitations, so that $g^2_{\psi''\psi\pi\pi}$ should actually be less than $g^2_{\psi'\psi\pi\pi}$. The evidence of more than one resonace at the 4·1 GeV level further complicates the picture so that our calculation overestimates the width and should therefore be considered as a prediction of only an upper limit to this decay rate. Köegerler *et al* (1976a) predict a width of 110 keV on the basis of a partial wave dispersion relation analysis.

3. $\psi \longrightarrow \omega\pi\pi$ and $\psi \longrightarrow \phi\pi\pi$ decays

For these processes we use an extended vector dominance model in which the ω or ϕ can couple to a ψ or ψ' state. Such a coupling could be mediated by the hypothetical O-meson (Palmer and Pinsky 1976). There are some complications from the fact that the intermediate vector mesons are now off the mass shell so that some suppression of these rates are to be expected; in keeping with conventional practice (Roy 1976; Pham 1976) we lump these suppressions at the ψ-ω and ψ-ϕ vertices.

We next assume in our simple model where we are interested in order-of-magnitude estimates only that all $VV'PP$ couplings are of equal magnitude for V, $V' = \omega, \phi, \psi, \psi'$

*It is to be noted, however, that with the recent changed parameters of the ϵ-model ($m_\epsilon = 1200$ MeV), the phase space available even in this process, viz. $\psi'' \to \psi\pi\pi$, will not give a clear separation of the peaks in the two models.

and all $VV'P$ couplings equal for these V, V's; correction factors can be introduced from symmetry considerations, but this takes us outside the point of view of this paper. We then have the relation

$$\frac{\Gamma\,(\psi \rightarrow \phi\ \pi\pi)}{\Gamma\,(\psi \rightarrow \omega\ \pi\pi)} \approx 1{\cdot}6\ \frac{\Gamma\,(\psi \rightarrow \eta\ \phi)}{\Gamma\,(\psi \rightarrow \eta\,\omega)}.$$

Using present experimental numbers for the two dipionic decays, we get $\Gamma(\psi\rightarrow\eta\phi)/\Gamma(\psi\rightarrow\eta\omega) \approx 0{\cdot}13$, which is in good agreement with other theoretical predictions (Heimann 1977). From this we also estimate that the ratio of $\eta\phi$ and $\eta\omega$ decays of ψ' will be $\sim 0{\cdot}12$.

4. $\psi \longrightarrow \pi\pi\gamma$ decay

The LDC model has been used to calculate the decay width for $\psi \rightarrow \pi\pi\gamma$ assuming a sequential decay in a vector dominance framework (Tsai *et al* 1975; Primakoff *et al* 1976):

$$\psi \rightarrow \pi\pi\ (\psi,\ \psi') \rightarrow \pi\pi\ \gamma. \tag{4}$$

Here one is immediately faced with the problem that the far off mass shell character of the ψ, ψ' imposes on the coupling constants certain suppression factors. A study of radiative decays of the ψ and ψ' into the pseudoscalars η and η' show (Nandy *et al* 1978) that, in VDM calculations where both ψ and ψ' are allowed in the intermediate state and making the conventional assumption that the full suppression can be taken at the electro-magnetic vertex, the suppression factor B is found to be in the range

$$\frac{1}{166{\cdot}5} < B < \frac{1}{56{\cdot}5}. \tag{5}$$

A suppression of this order of magntiude had been obtained earlier by Pham (1976), although Roy (1976) had obtained a much smaller number. Using the B given above and taking into account gauge invariance by replacing the vector fields ψ_μ, by the field strengths $\psi_{\mu\nu} \equiv \partial_\mu\, \psi_\nu - \partial_\nu\, \psi_\mu$, we get

$$0{\cdot}9 \text{ keV} < \Gamma\,(\psi \rightarrow \pi\pi\ \gamma) < 2{\cdot}6 \text{ keV} \tag{6}$$

which encompasses the results obtained by Sarma *et al* (1976).* In figure 3 we have exhibited the dipion spectra of the $\pi^+\,\pi^-$ as obtained in the LDC model as well as that obtained from standard ϵ-model with ϵ-mass and width at 700 and 600 MeV respectively, (Tsai *et al* 1975, Harrington *et al* 1975) using the vector dominance hypothesis; the third curve in the figure represents the distribution assuming the ϵ-mass to be 1200 MeV (Particle Data Group 1976).

*Sarma *et al* (1976) also show that asymptotic freedom arguments suggest that $\Gamma\,(\psi \rightarrow \pi\pi\gamma)$ can be at most a fraction of a keV.

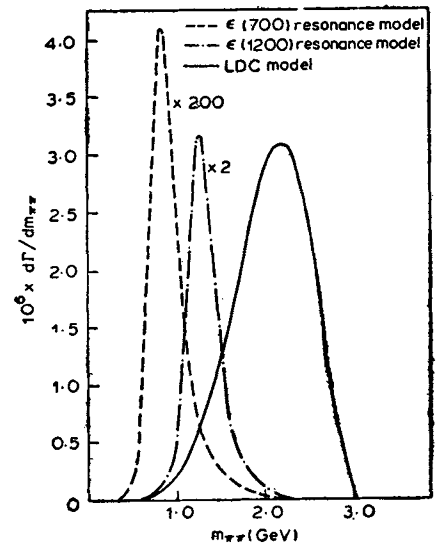

Figure 3. Dipion mass distribution in $\psi \to \pi\pi\gamma$ decay (for the ϵ-model distribution the ordinate has to be multiplied by the numbers indicated).

5. Discussions and conclusion

Thus we find that the LDC model provides an acceptable description of the dipionic decays of the ψ-particles. The available experimental data are generally insensitive to the detailed structure of the 4-particle vertex, although a form factor could improve the fit to the $\psi' \to \psi\pi\pi$ decay spectrum. As we remarked in section 2, the origin of such a form factor could be in the bound structure of the psions in a quark model including charm, or say the exchange of an ϵ between the psions and pions. But in view of the difficulties associated with the ϵ-model* and the lack of precise experimental information, it seems adequate at present to consider the 4-particle vertex merely as a local interaction and obtain order of magnitudes estimates of the transition amplitudes. This restriction still admits of certain modifications to the basic model: thus, for example, the vector fields can be replaced by the field strength form. This hardly alters the predictions for cascade decays of the higher ψ states, but has to be considered for the case of the $\psi \to \pi\pi\gamma$ process. Increasing complexity could also be introduced in the pion part of (1) but current algebra constraints seem to argue against this (Pasupathy 1976).

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*The mass of the ϵ has been changing widely: e.g. 410 MeV (Letessier and Tounsi 1971), 700 MeV (Particle Data Group 1974) and 1200 MeV (Particle Data Group 1976).

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