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The $\pi_1(1400)$ Meson as a $K\bar{K}\pi\pi$ Molecule[1]

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Abstract.
In this paper the $\pi_1(1400)$ meson with $J^{PC} = 1^{-+}$ is speculated to be a molecule state which has a similar binding mechanism as the $f_1(1420)$. With analogy to the $f_1(1420)$ as a pion orbiting in a P-wave around an S-wave $K\bar{K}$ system, we have a pion orbiting in a P-wave around an S-wave $K\bar{K}\pi$ system resonating in the $\eta(1295)$. In order to completely derive the dynamics one would have to develop a true four-body scattering mechanism with Born terms connecting two- and three-body isobar states ($\eta(1295)$, $\rho(770)$, $a_0(980)$, $K_1(1270)$). Here we take a short cut and assume a simpler three-body Born term analogous to the final state rescattering mechanism that generated the $f_1(1420)$. The interactions of the $a_0(980)$ with the $\rho(770)$ through a kaon exchange, which would require a four-body treatment, are replaced by a modification of the P-wave $\pi\pi$ phase shift. If we allow this modification then binding like the $f_1(1420)$ can occur. Furthermore when the $\eta(1295)$ is formed in rescattering at momentum outside the $K\bar{K}$ $\pi\pi$ phase space, we assume the $\eta(1295)$ will couple to the ground state η since its quarks and quantum numbers are the same, thus creating $\eta\pi$ in a P-wave decay.

I INTRODUCTION

Mesons with manifestly exotic J^{PC} quantum numbers must lie outside the $q\bar{q}$ spectrum. Such states could be gluonic excitations such as a hybrid ($q\bar{q}g$) or a glueball (2g, 3g,...), or a multiquark($\bar{q}q\bar{q}q$) state. Reference [1] has reported the first of such exotic states in the $\eta\pi$ system with $J^{PC} = 1^{-+}(\pi_1(1400))$. Having isospin $I = 1$, it could not be a glueball, but it could be a hybrid or a multiquark state.

The flux-tube model [2,3] predicts the mass of the lowest-lying hybrid to be around 1.8 GeV/c^2, consistent with lattice calculations [4] of 1.7 to 2.1 GeV/c^2. Therefore one should look to models of multiquark systems.

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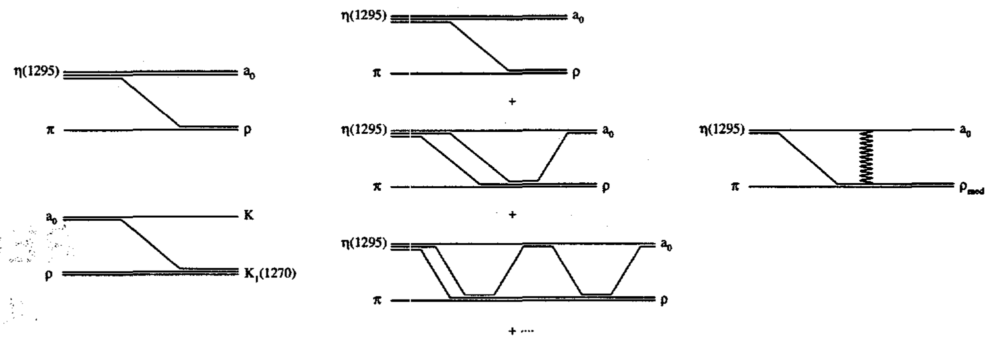

FIGURE 1. a) One-particle-exchange (OPE) Born terms for $K\bar{K}\pi\pi$ system; b) The set of infinite terms where all K and $\bar{K}$ exchanges are summed; c) The Born that is used in the three-body effective analysis, where the $\pi\pi$ P-wave is altered by the sum of terms in b.

Characteristic of bag-model S-wave multiquark states (which have nonexotic $J^P = 0^+$, 1^+ or 2^+) have been predicted [5], but those for a 1^- state have not. Likewise multiquark potential models [6] have only looked at the S-wave. Nils Törnquist [7] speculated that groups of mesons may bind to form particles, like protons and neutrons bind to form nuclei. In fact, I calculated the interactions between a kaon and an anti-kaon in a S-wave plus a pion orbiting them in a P-wave and very successfully explained the $f_1(1420)$ seen in $K\bar{K}\pi$ [8]. Following the same approach we can demonstrate the possibility that the $\pi_1(1400)$ is a $K\bar{K}\pi\pi$ molecule, where the $K\bar{K}\pi$ in a relative S-wave with the other π orbiting them in a P-wave. Since the $K\bar{K}\pi$ is resonating as the $\eta(1295)$, it is possible that the offshell $K\bar{K}\pi(\eta)$ would couple to the ground state η, thus creating a $\eta\pi$ P-wave decay mode.

II THE $K\bar{K}\pi\pi$ AS AN INTERACTING SYSTEM

As was done in Ref. [8], we need to arrange a set of Born terms connecting all of the possible intermediate isobar states of the $K\bar{K}\pi\pi$ system ($\eta(1295)$ π, $a_0(980)$ $\rho_1(770)$, $K_1(1270)$ $\bar{K}$ or $\bar{K}_1(1270)$ K). We assume that the only interaction among the particles occurs through one-particle exchange (OPE), thus connecting the above isobar states (Fig. 1a). In order to completely derive the dynamics one would have to develop a true four-body scattering mechanism with OPE Born terms connecting two- and three-body isobar states. We can take a short cut and use the three-body formalism developed in Ref. [8], if we note that the set of diagrams (Fig. 1b) could be summed using a true four-body formalism, and be replaced by the Born term of Fig. 1c. Here the $a_0(980)$ is treated as a stable particle and the $\pi\pi$ P-wave phase shift (ρ_{med}) is

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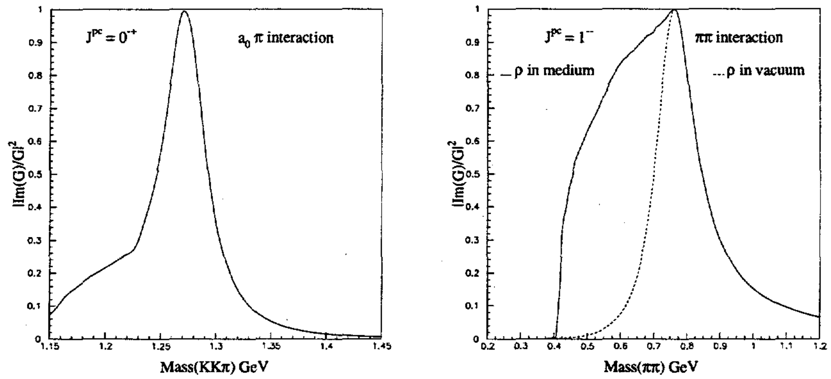

FIGURE 2. a) The absolute value squared of the imaginary part of the η (1290) propagator divided by the complete propagator, thus forming the square of the T-matrix scattering amplitude; b) The absolute value squared of the imaginary part of the $\pi\pi$ P-wave phase shift: the solid line is the modified phase shift; the dashed line is the original vacuum phase shift which is the ρ meson.

assumed to be modified by the sum of terms in Fig. 1b. With this assumption, then binding can occur if we use the N/D propagators for the $\eta(1295)$ and ρ_{med} shown in Fig. 2. In Fig. 2b we also show the unaltered P-wave phase shift (ρ). Fig. 3a shows the final state enhancement times the $\eta(1295)$ π P-wave kinematics. The bump is driven by the collision on the Dalitz plot of the $\eta(1295)$ Breit-Wigner (Fig. 2a) and the rapid increase of the $\pi\pi$ P-wave phase shift (Fig. 2b). The phase motion of the final state interaction is given in Fig. 3b.

III CONCLUSION

We have suggested the possibility that the $\pi_1(1400)$ is a final state interaction for the $K\bar{K}\pi$ system in a S-wave orbiting by a π in a P-wave. The $\eta\pi$ decay mode is generated by the off shell appearance of the η from the $K\bar{K}\pi$ system (0^{-+}). Our model thus predicts that a strong $J^{PC} = 1^{-+}$ should be seen in the $K\bar{K}\pi\pi$ system at around 1.4 GeV/c^2. If the $\pi_1(1400)$ is only seen in the $\eta\pi$ channel then its hard to understand three facts about its production. First, that the force between the η and π in a P-wave should be repulsive (QCD) [9]. This is not a problem if the $\eta\pi$ is a minor decay mode. Second, why should the production be so small compared to the a_2 which has only a 14% branching to $\eta\pi$? One would think it should be produced in unnatural parity exchange not natural. Again this is not a problem if minor decay mode. Third, why is the state only seen in diffractive and not charge exchange [10]? This means some isoscalar exchange is important which is of natural parity

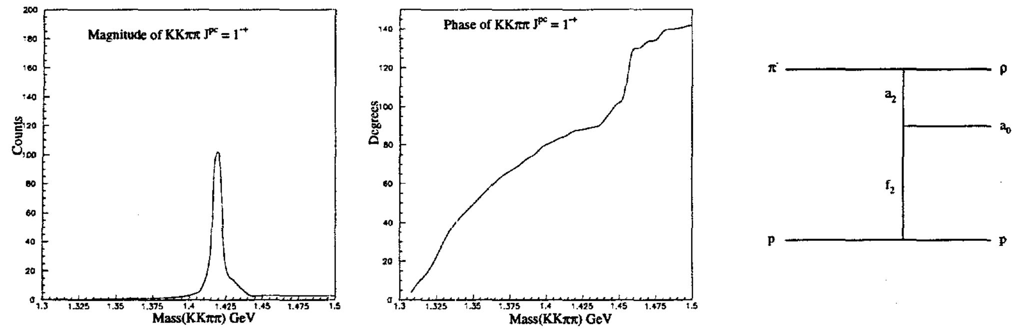

FIGURE 3. a) The value of 1 over the Fredholm determinate squared times the kinematics of P-wave $\pi\eta(1290)$; b) Phase motion of the Fredholm determinate; c) The Deck exchange mechanism which feeds the S-wave a_0 ρ system that will under go the final state interaction making the π_1 (1400).

(0^+, 1^-, 2^+). Figure 3c shows the only important deck-like exchange that can feed the ρ a_0 S-wave state and thus set the stage for the final state reaction.

Finally, it is reasonable to think that the largest decay amplitude would be the modes that have an $a_0(980)$ in the final state. However in Ref. 8 the same conclusion was initially drawn, except when one puts in all the numerical factors the a_0 modes become suppressed. The explanation comes from the very powerful attraction of the kaons in the a_0 mode. The isobar decay amplitude is proportional to $\sqrt{N}/D$ both N and D are large numbers while the ratio is near one at the threshold see Ref. 8. Thus the decay amplitude becomes proportional to $1/\sqrt{N}$. We predict that the major mode could be $\pi\pi$ P-wave having no ρ peak (work above) forming a $K\pi\pi$ or a $\bar{K}\pi\pi$ $J^p = 1^+$ plus a $\bar{K}$ or K with overall G-parity minus. The $K\pi\pi$ should more or less be a phase space distribution.

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