THE PUZZLE OF THE IOTA: A COMMENT ON THE DECAY†

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We show that the "$\delta(980)$ dominance" of the decay $\iota(1440) \to K\bar{K}\pi$, in apparent contradiction to the non-observance of the decay $\iota \to \eta\pi\pi$, can be explained in the $K\bar{K}$ molecule interpretation of the S^* and δ scalar mesons via $K\bar{K}$ final state interactions in the potential $V_{K\bar{K}}$ which binds the $K\bar{K}$ system. We are unable to distinguish conclusively between a primary phase space and primary $K^*\bar{K}$ + c.c. distribution; however, we note that the latter interpretation would be consistent with the expected $K^*\bar{K}$ + c.c. branching ratio of the (mainly) ω-like state of the radially excited pseudoscalar meson nonet. This makes the existence of the reported $\eta(1275)$ meson crucial for deciding whether the ι is an ordinary meson or something new.

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Talk given by P.J. O'Donnell.

The main object of this talk is to suggest a resolution[1] of a puzzle associated with the ι which no one seems to like[2]: the $K\bar{K}\pi$ decay of the ι appears to be dominated by $\delta\pi$, but the $\eta\pi\pi$ mode which is expected from $\delta \to \eta\pi$ is not seen. We will show that these apparently contradictory facts have a natural explanation if (see abstract above) the δ is not a $q\bar{q}$ meson but rather a $K\bar{K}$ molecule bound by a short-range attractive potential $V_{K\bar{K}}$: the $K\bar{K}$ seen in ι decay then peak at low $K\bar{K}$ mass as a result of final state interactions produced by $V_{K\bar{K}}$. There is an analog to this behaviour which has been known in nuclear physics for some time[3]: the nn system produced in $\pi^- d \to nn\gamma$ shows an extremely strong peaking at low nn mass as a result of the strong short-range attractive nn potential which nearly produces isotriplet partners to the deuteron. Note that physically the peaking of the $K\bar{K}$ spectrum at low mass results from a distortion of the $K\bar{K}$ plane waves and not from direct scattering through the δ pole: it would persist even if, for example, the δ had a width of only 1 MeV.

We have considered two possible modes of decay.

A. Primary Phase Space Decay

First, we show that the $K\bar{K}$ molecule interpretation of the δ, with the parameters deduced in Ref. 4, produces an acceptable description of the data if the primary $K\bar{K}\pi$ spectrum is a phase space distribution. That is, we assume that we have a Hamiltonian H_0 describing the ι, K, $\bar{K}$, and π states consisting of only kinetic energy terms and $V_{K\bar{K}}$ which we perturb with a primary decay interaction ($\emptyset(x)$ is the field of meson $\emptyset$)

$$H_{D3} = g_3 \iota(x)\bar{K}(x)K(x)\pi(x) \tag{1}$$

The usual prejudice is that such a direct three body decay is much suppressed in strength relative to a two body decay mode like $K^*\bar{K}$ + c.c. (which is the only kinematically allowed quasi-two body mode of the ι to two orbital ground state mesons). Since we find, however, that the final state interaction strongly enhances the ι decay rate in the sector of the Dalitz plot corresponding to low $K\bar{K}$ masses, we do not believe that this primary mechanism can be ruled out.

This option is usually treated in the coupled channel partial wave formalism[5]. However, we can also express the effect of final state interactions by observing that the coupling (1) leads to an amplitude for ι decay proportional to the $K\bar{K}\pi$ "wavefunction at the origin" and if $V_{K\bar{K}}$ is attractive, this factor is enhanced over the free particle case.

The differential decay rate of the ι at any kinematic point within the Dalitz plot will therefore be enhanced by the ratio of $|\psi(0)|^2$ to its free value. For our purposes it is quite sufficient to consider $V_{K\bar{K}}$ ($r_{K\bar{K}}$) to be a square well of depth V_o for $r_{K\bar{K}} < a$ (from Ref. 4, $V_o \simeq 500$ MeV and $a \simeq 1$ fm) in which case

$$\left|\frac{\psi(0)}{[\psi(0)]_{free}}\right|^2 = \frac{E_\rho+V_o}{E_\rho+E_B f(E_\rho)} \equiv d(E_\rho) \tag{2}$$

where

$$f(E_\rho) = \frac{V_o}{E_B}\cos^2\{\sqrt{\frac{E_\rho}{V_o}+1}(\frac{\pi}{2}+\sqrt{\frac{E_B}{V_o}})\} \to 1 \tag{3}$$

for E_ρ small with respect to $\sqrt{E_B V_o}$. In obtaining this result we have eliminated the range parameter a in favour of the binding energy E_B of the weakly bound $K\bar{K}$ system. We note that as $E_\rho \to 0$ the enhancement factor (10) becomes $\frac{V_o}{E_B}$ which is a factor of the order of 50! The resulting Dalitz plot and its $m_{K\bar{K}}$ and $m_{K\pi}$ projections compare well with the data. Note that the full width of the ι has been enhanced by $V_{K\bar{K}}$ by almost an order of magnitude so one can maintain the prejudice that g_3 should be small even though experimentally $\Gamma_\iota \simeq 100$ MeV.

The result is that the observed width and Dalitz plot for the decay $\iota \to K\bar{K}\pi$ are consistent with a primary phase space distribution for $K\bar{K}\pi$ which has been distorted by $K\bar{K}$ final state interactions expected in the $K\bar{K}$ molecule picture of the δ and S^* scalar mesons. Moreover, the primary coupling (1) may arise naturally via the chain $\iota \to \delta_2\pi \to K\bar{K}\pi$ where δ_2 is the broad ^3P_o quark model state predicted in Ref. 6. In this case the decay $\iota \to \eta\pi\pi$ would be expected to proceed with the same primary strength g_3 as $\iota \to K\bar{K}\pi$ (the $\delta_2 K\bar{K}$ and $\delta_2\eta\pi$ couplings are equal). The absence of the final state interactions means that this decay should eventually be seen in a uniformly populated Dalitz plot with an order of magnitude smaller rate.

B. Primary $K^*\bar{K}$ + c.c. Decay

The second possibility is that the primary decay of the ι is via the two body intermediate states $K^*\bar{K}$ + c.c. The general principle in favour of such a cascade decay scheme is enforced in this case by the existence of what should be a reliable prediction that if the ι is a 2^1S_o $q\bar{q}$ state, it should decay to $K^*\bar{K}$ + c.c. with a width comparable to that observed. (Although the ι is close to $K^*\bar{K}$ threshold, and the decay is in a P-wave, the predicted width remains substantial: compare to the SU(3) analog decay $\pi(1300) \to \rho\pi$ which has a measured width of several hundred MeV). Of course, so long as the nature of the ι remains moot, this particular prediction can only be used as a check on the $q\bar{q}$ content of the ι, but nevertheless the prejudice in favour of a two body intermediate state can be entertained in a variety of pictures and it is obviously interesting to ask whether it is also consistent with the data.

In the absence of $K\bar{K}$ final state interactions, the answer is that given originally[7]: the $\iota \to K\bar{K}\pi$ Dalitz plot is not compatible with simple $K^*\bar{K}$ + c.c. dominance. We believe, however, that the distorting effect of the $V_{K\bar{K}}$ is so strong that it can substantially modify a primary $K^*\bar{K}$ + c.c. Dalitz plot to look like the data. In this case we expect that the $K\bar{K}$ interaction does not grossly modify the undisturbed width for the simple two body decay $\iota \to K^*\bar{K}$ + c.c.; however, it can redistribute the events.

Before providing substantiation for this expectation, we will describe the physical picture which we see underlying this effect. If the decay $K^* \to K\pi$ were extremely slow, then for all practical purposes the outgoing particles from the ι decay would be a $K^*\bar{K}$ or $\bar{K}^*K$ (which we are assuming are non-interacting) and the Dalitz plot for $K\bar{K}\pi$ would indeed exhibit extremely narrow K^* bands. However, we believe that the free K^* lifetime is not sufficiently long for this approximation to be valid here: the produced K^*, for example, finds itself in the neighborhood of the $\bar{K}$ with a kinetic energy of 15 MeV and as a result the $K\pi$ plane wave into which the K^* is decaying will <u>become distorted by the presence of the $\bar{K}$</u>. This distortion now enhances not the decay rate of the ι (which has already decayed) but rather the decay rate of the K^*! We conclude that $V_{K\bar{K}}$ will distort the K^* bands by <u>producing an effective K^* width which will depend on position within the Daltiz plot</u> and which will become much broader in the low $K\bar{K}$ mass sector of the Dalitz plot. Such a phenomenon is not unfamiliar; it occurs in neutron decay in a nucleus where the Dalitz plot can be dramatically affected by distortion of the electron plane wave. An analogous situation occurs for the lifetimes of atomic levels which can be substantially modified if the atoms find themselves in an unusual environment (e.g., inside a crystal).

Note that the Dalitz plot in this case has a very different structure from a normal plot with an intermediate resonance R. If $V_{K\bar{K}}$ were zero then every horizontal slice through the Dalitz plot would reveal the same Breit-Wigner resonance shape in $M_{K\pi}$ with the free resonance width Γ_R, and thus a standard Argand diagram in this variable. If $V_{K\bar{K}} \neq 0$, then the density of the Dalitz plot will depend on both $M_{K\pi}$ <u>and</u> $M_{K\bar{K}}$. Slices of the Dalitz plot with fixed $M_{K\bar{K}}$ now show resonant behaviour, but with a resonance width Γ_R^{eff} which depends on $M_{K\bar{K}}$; Γ_R^{eff} will approximate the free Γ_R only for large $M_{K\bar{K}}$ where $V_{K\bar{K}}$ can be ignored.

The figures show the Dalitz plot and the $M_{K\bar{K}}$ and $M_{K\pi}$ projections. These figures were obtained using a Breit-Wigner form but with an effective width given by $\Gamma^{eff} \approx \Gamma(K^* \to K\pi)\sqrt{d(E_\rho)}$, where $d(E_\rho)$ is defined in Eq. (2) and $E_\rho = M_{K\bar{K}} - m_K - m_{\bar{K}}$. It can be seen that this mechanism seems to be consistent with the observed properties of the ι (for the Mark III data see Richman's talk, these proceedings). Lack of space prohibits me from showing the analogous figures for the primary phase space plot; these appear in the more complete account (ref. 1). However, we note here that the two mechanisms can be distinguished with more data on

$\iota \to K\bar{K}\pi$ at high $K\bar{K}$ mass.

III. Conclusions

We have shown that the "$\delta(980)$ dominance" of $\iota \to K\bar{K}\pi$, in apparent contradiction with $\iota \to \eta\pi\pi$, can be explained as a primary phase space and a $K\bar{K}$ final state interaction coming from a short range attractive potential consistent with a $K\bar{K}$ molecule interpretation of the δ and S^*. The present data can also be explained as going by the decay $\iota \to K^*\bar{K} \to K\bar{K}\pi$ modified in the final state by the same potential. Such a decay mode would be expected if the ι has mixing with radial excited $q\bar{q}$ states. Although we can not distinguish at present between these two scenarios we note that more data at high $K\bar{K}$ mass would allow a choice to be made. In either case, there are no outstanding impediments to accepting the iota as a bona fide resonance. The example of the ι may also serve as a warning against the use of the δ and S^* as quasi-two-body states in isobar analyses.

Furthermore, the $K\bar{K}\pi$ dominance of the iota decay modes no longer militates against the iota being an SU(3) singlet and therefore a glueball candidate. It was shown in these proceedings last year[8] that a "pure glueball" would mix substantially with $q\bar{q}$ states. The models[9] which allow for mixing with radial excitations can account for both the $\iota(1440)$ and radial excitation of the η-η' system such as that reported at a mass of 1275 MeV[10]. If the ι decay is really dominated by $K^*\bar{K}$ + cc., as seems possible, then the properties of the iota could be consistent with those of the mainly ω-like member of the 2^1S_0 pseudoscalar nonet. This makes the existence or non-existence of the reported $\eta(1275)$ meson critical for deciding whether the ι is an ordinary meson or something new.

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References:

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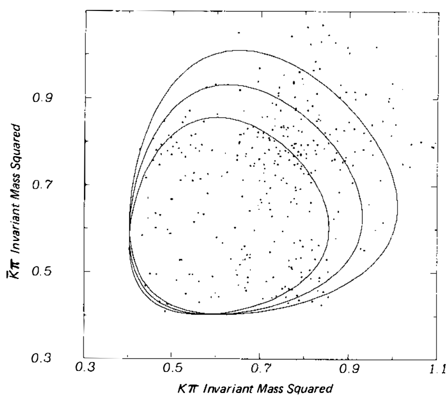

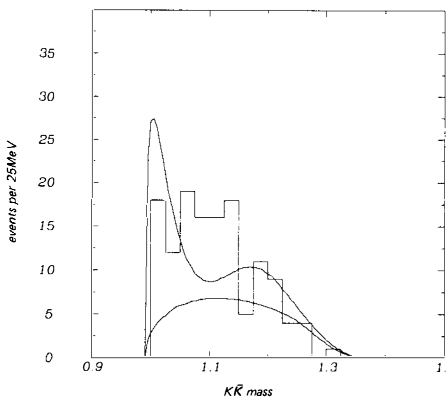

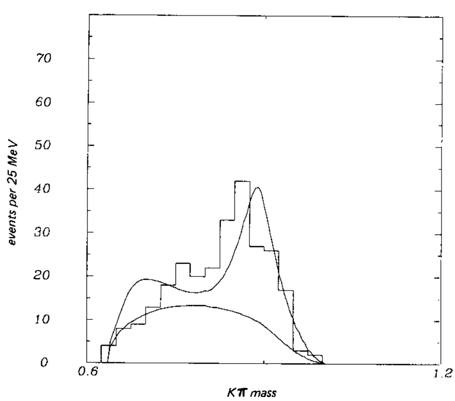

The figures show the Dalitz plot and invariant mass projections expected for $\iota \to K^* \bar{K} \to K\bar{K}\pi$.