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Identification of a Pseudoscalar State at 1440 MeV in J/ψ Radiative Decays

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From a partial-wave analysis of the $K\bar{K}\pi$ system in the decay $J/\psi \to \gamma K^+K^-\pi^0$, it is determined that the quantum numbers of the $K\bar{K}\pi$ resonance at 1440 MeV, previously identified as the $E(1420)$, are $J^{PC} = 0^{-+}$. This new particle has been named the ι.

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We have identified a pseudoscalar state with mass $M = 1440^{+20}_{-15}$ MeV in J/ψ radiative decays. This state was previously reported by the Mark II,[1] but was tentatively identified as the $E(1420)$ (a state[2] with spin and parity 1^+) as the spin of the state was not known. We, in collaboration with the Mark II group, have named this pseudoscalar the $\iota(1440)$.[3] Although the theoretical interpretation of this state is uncertain,[4] possible interpretations are a two-gluon bound state or a member of a radially excited $q\bar{q}$ nonet.

In this Letter, we report on a partial-wave analysis of the $K^+K^-\pi^0$ system in the process

$$J/\psi \to \gamma K^+K^-\pi^0. \tag{1}$$

The analysis is based on a sample of 2.2×10^6 produced J/ψ events. The data were collected with the Crystal Ball Detector at the Stanford Linear Accelerator Center e^+e^- storage ring facility SPEAR at the peak of the $J/\psi(3095)$ resonance. The detector consists primarily of a segmented array of NaI(Tl) crystals for high-resolution measurements of the energy and position of electromagnetic showers. The photon energy resolution is $\sigma/E = 2.6\%/E^{1/4}$ (E in GeV) and the photon angular resolution is 1–2 deg, depending on energy. The solid angle coverage of the main array is 93% of 4π sr and is extended to 98% with crystals in the end-cap regions. The beam pipe is surrounded by magnetostrictive spark chambers and multiwire proportional chambers for charged-particle tagging and tracking. The innermost spark-chamber layer covers 94% of the solid angle. Details on the detector, event trigger, and data reduction are described in detail elsewhere.[5]

Figure 1 shows the $K^+K^-\pi^0$ invariant-mass distribution for events which have two charged tracks and three γ's, each with observed energy greater than 40 MeV, and which satisfy three-constraint fits[6] to (1) with $\chi^2 < 15$. As there is no particle identification for charged particles, the kaon identification is by kinematics alone. A resonance is seen near 1400 MeV which we name the ι. Figure 2 shows the Dalitz plot for events with $1400 \leq M_{K\bar{K}\pi} < 1500$ MeV. Events are seen to be concentrated in the upper right region of the plot. This region corresponds to events with $K\bar{K}$ invariant mass near threshold. The shaded region in Fig. 1 shows the $K^+K^-\pi^0$ invariant-mass distribution for events with $M_{K\bar{K}} < 1125$ MeV. The background [which is due largely to processes other than (1)] is reduced considerably compared to the signal. Thus, the resonant structure appears to be correlated with a low-mass $K\bar{K}$ enhancement. We interpret this as evidence for the decay of the ι into $\delta(980)\pi$. Note, however, that the $K^*(892)$ bands on the Dalitz plot overlap in the δ region, thus possibly causing confusion as to whether the decay is primarily $\delta\pi$ or $K^*\bar{K}$ + c.c.

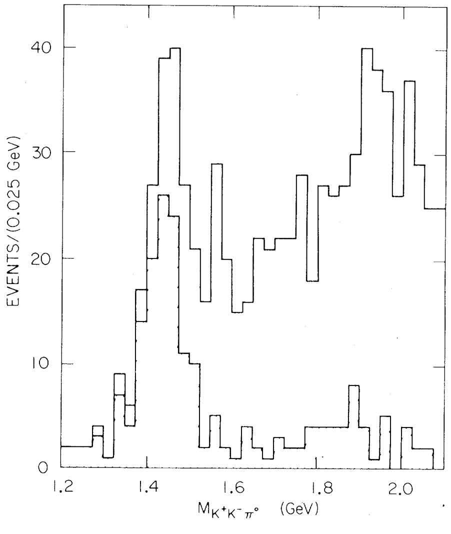

FIG. 1. $K^+K^-\pi^0$ invariant-mass distributions for events consistent with $J/\psi \to \gamma K^+K^-\pi^0$. Shaded region has the requirement $M_{K\bar{K}} < 1125$ MeV.

A fit to the $K^+K^-\pi^0$ invariant-mass distribution with a relativistic Breit-Wigner resonance convoluted with a Gaussian ($\sigma = 20$ MeV, corresponding to the fitted mass resolution) plus a polynomial background yields 174 ± 30 resonance events. We obtain[7] the following ι resonance parameters:

$$M = 1440^{+20}_{-15}\ \text{MeV}, \quad \Gamma = 55^{+20}_{-30}\ \text{MeV},$$

where estimated systematic uncertainties are included in the quoted errors. (The mass error is dominated by systematic uncertainties while the error in the width is predominantly statistical.) The detection efficiency for

$$J/\psi \to \gamma\,\iota, \quad \iota \to K^+K^-\pi^0 \tag{2}$$

was determined to be 0.120 ± 0.024 by Monte Carlo calculation. From this and the number of observed ι events, the product branching ratio for (2) is calculated to be

$$B(J/\psi \to \gamma\,\iota) \times B(\iota \to K\bar{K}\pi) = (4.0 \pm 0.7 \pm 1.0) \times 10^{-3},$$

where the branching ratio has been corrected to account for all $K\bar{K}\pi$ charge combinations. This result is in good agreement with the Mark II result.[1]

The spin of the ι was determined from a partial-wave analysis of the $K^+K^-\pi^0$ system.[8] Con-

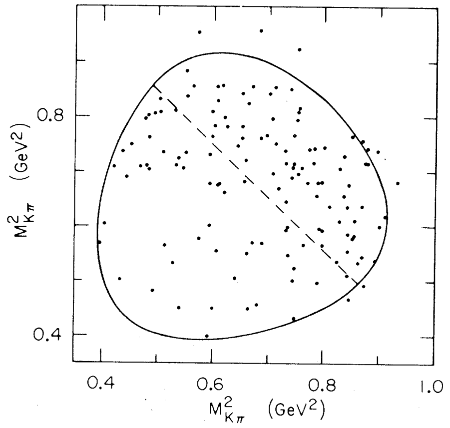

FIG. 2. $K^+K^-\pi^0$ Dalitz plot for events with $1400 \leq M_{K\bar{K}\pi} < 1500$ MeV. Solid curve shows boundary for $M_{K\bar{K}\pi} = 1450$ MeV. Dashed line shows $M_{K\bar{K}} = 1125$ MeV.

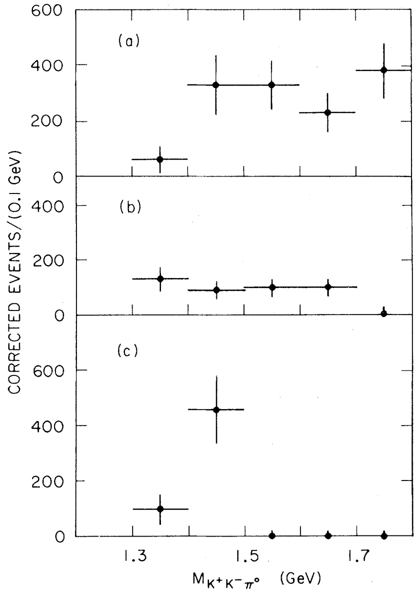

FIG. 3. Partial-wave contributions as functions of $K\bar{K}\pi$ mass for (a) $K\bar{K}\pi$ flat, (b) $K^*\bar{K}$ + c.c. ($J^P = 1^+$), and (c) $\delta\pi$ ($J^P = 0^-$).

tributions from five partial waves were included in the analysis:

$$K\bar{K}\pi \text{ flat}, \quad \delta\pi\ (J^P=0^-), \quad \delta\pi\ (J^P=1^+),$$
$$K^*\bar{K}+\text{c.c.}\ (J^P=0^-), \quad K^*\bar{K}+\text{c.c.}\ (J^P=1^+).$$

$J^P=0^+$ is not allowed for a state which decays into three pseudoscalars. $J^P=1^-$, although allowed for $K^*\bar{K}$+c.c., would require the Dalitz plot to vanish at the boundaries, which is inconsistent with the data. Spins greater than 1 were not considered. Contributions from all partial waves except $K\bar{K}\pi$ flat were allowed to interfere with arbitrary phase. For each isobar contribution, the full angular decay distributions were included in the amplitudes. The ι and K^* helicities were allowed to be free parameters. The δ and K^* resonance parameters were taken to be the standard values.[9]

The analysis was done independently in each of five 100-MeV-wide bins for events with $K\bar{K}\pi$ masses between 1300 and 1800 MeV. Partial waves which did not contribute significantly to the likelihood were eliminated, leaving only three partial waves which provided significant contributions. These contributions, corrected for detection efficiency, are shown as functions of $K\bar{K}\pi$ mass in Fig. 3. The $K^*\bar{K}$+c.c. ($J^P=1^+$) contribution [Fig. 3(b)] is relatively small and independent of mass. On the other hand, the $\delta\pi$ ($J^P=0^-$) contribution [Fig. 3(c)] shows clear evidence for resonant structure in the ι signal region ($1400 \leqslant M_{K\bar{K}\pi} < 1500$ MeV). Thus, $J^{PC}=0^{-+}$ is preferred over $J^{PC}=1^{++}$. (The C parity is established as even by the production mechanism.) In addition, we find the 90% confidence-level upper limit

$$\frac{B(\iota \to K^*\bar{K}+\text{c.c.})}{B(\iota \to K^*\bar{K}+\text{c.c.})+B(\iota \to \delta\pi)} < 0.25.$$

Although the full partial-wave analysis did not include spin-2 amplitudes, an analysis[10] of the angular distribution $W(\theta_\gamma, \theta_\delta, \varphi_\delta)$ for the process

$$\psi \to \gamma\,\iota, \quad \iota \to \delta\pi$$

determined relative probabilities of 10^{-4} and 8×10^{-3} for spins 1 and 2 relative to spin 0.

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[6] Since only the angles but not the momenta of charged particles are measured, two possible constraints for this topology are removed.

[7] Fits to both distributions in Fig. 1 give consistent results for the mass and width.

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Hypercolor Unification

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It is found that the embedding of hypercolor in grand unification schemes requires an extended unified model of the form $G\otimes G\otimes G$ where $G\supseteq \mathrm{SU}(3)\otimes\mathrm{SU}(2)\otimes\mathrm{U}(1)$ is an ordinary grand unified simple group. For $G=\mathrm{SU}(7)$ properties of such a unified theory with naturally three ordinary families are explored.

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Theories of elementary-particle interactions based on unifying (but broken) gauge symmetries solve many theoretical questions, but introduce some of their own. Since symmetry breaking requires scalar fields (Higgs mesons), the couplings of fundamental scalars are new independent parameters, which must obey precise phenomenological constraints if the theory is to match the low-energy world. Hypercolor theories were invented to treat the Higgs particles of low-energy symmetry breaking not as fundamental but as composites, the hyperpions of a hyperquark dynamics.

The hypercolor idea, however, has had difficulty in providing realistic masses for ordinary fermions (quarks and leptons). Both extended-hypercolor and supersymmetric models have difficulties, but an alternative approach has been proposed[1] in which fundamental (superheavy) scalars couple light fermions to hyperquarks, and a finite anomalous dimension compensates the resulting superheavy-mass suppression.

If hypercolor is a reality, then the grand unification idea should be extended to include it. The present paper presents a model showing that this is possible, together with discussion of the constraints that complicate the model.

Hypercolor can be embedded in higher-rank simple symmetry groups, but a usual consequence is fast proton decay[2] because of the presence of fermions carrying both color and hypercolor. The only remedy for this seems to be, as suggested by Georgi,[3] to choose a semisimple gauge group (augmented by discrete symmetries[4]), to identify hypercolor and color in different factors, and to restrict fermions to representations of the type $(R,1)\oplus(1,R)$ (in the two-factor-group case). Thus hyperquarks are always color sing-