Spin and Parity Analysis of $K\bar{K}\pi$ System in the D and E/Iota Regions

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We have performed a high-statistics experiment on the reaction $\pi^- p \to K^+ \bar{K}^0 \pi^- n$ at 8.0 GeV/c. A Dalitz-plot analysis of the $K^+ \bar{K}^0 \pi^-$ system finds that the $D(1285)$ is a $J^{PG}=1^{++}$ state coupling predominantly to a $\delta\pi$ decay channel, while the $E(1420)$ peak consists mostly of a $J^{PG}=0^{-+}$ wave with a substantial $\delta\pi$ decay mode. There is little evidence of a 1^{++} resonance at the E mass.

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A $J^{PC}=0^{-+}$ state called the $\iota(1440)$ is considered to be a prime glueball candidate because it is produced prominently in J/ψ radiative decays[1] where $C=+1$ glueballs are expected to be copiously produced. However, this assertion rests on the premise that it is distinct from the $E(1420)$ discovered earlier by Armenteros *et al.*[2] ($J^{PC}=0^{-+}$ or 1^{++}) and determined to be a 1^{++} state in a Dalitz-plot analysis in a later experiment by Dionisi *et al.*[3] Since the spin and parity analysis of the $E(1420)$ was based on limited statistics, it is desirable that a study of the spin and parity content of the E region be performed on a large-statistics sample.

Our study of the $K\bar{K}\pi$ system is based on more than ten times the statistics of Dionisi *et al.*, in the reaction

$$\pi^- p \to K^+ K_S \pi^- n \tag{1}$$

at 8 GeV/c. The data come from our experiment performed with the Brookhaven National Laboratory Multiparticle Spectrometer (MPS). The layout of the experiment is shown in Fig. 1. A tagged π^- beam at 8 GeV/c impinged on a 30-cm liquid-hydrogen target, located in the MPS magnet and surrounded on four sides by a lead-scintillator sandwich veto box (B) for rejection of backward particles. Within the MPS magnet and downstream of the veto box were located seven drift-chamber modules[4] with seven measuring planes each, interspersed with three proportional wire chambers (PWC's) (P_1, P_2, and P_3). In addition, a high-pressure Cherenkov counter hodoscope (C_1) with $\gamma_{\mathrm{threshold}}=10$ and two scintillation-counter hodoscopes (H_1 and H_2) were placed downstream of the MPS magnet.

The trigger required two charged particles traversing the first PWC ($P_1=2$), no signal from particles entering the target veto box ($\bar{B}$), a multiplicity increase to four at the second PWC ($P_2=4$), a forward-going positive particle traversing C_1, H_1, and H_2 with momentum $p \geq 1.5$ GeV/c (as measured on-line by P_2, P_3, and H_2), and its identification as a K^+ (or proton) by use of $\bar{C}_1$ and H_1 ($H_1 \cdot \bar{C}_1$). The on-line detection of K^+ (or proton) was made through the so-called

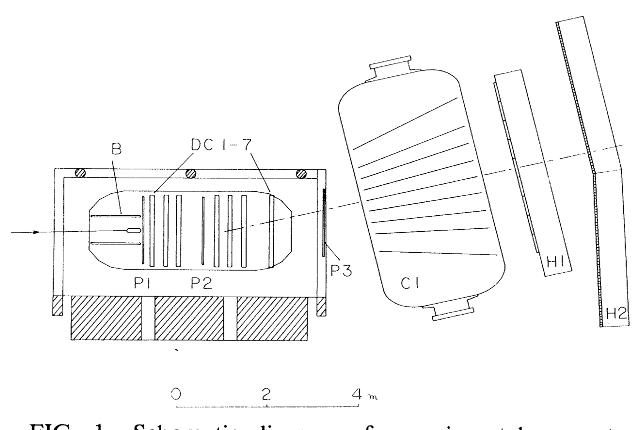

FIG. 1. Schematic diagram of experimental apparatus. Shown at the center is the 30-cm liquid hydrogen target surrounded by a lead-scintillator veto box (B). P_1, P_2, and P_3 are the proportional wire chambers; DC's are the drift-chamber modules; C_1 is the high-pressure Cherenkov counter; H_1 and H_2 are the scintillator-counter hodoscopes.

RAM-trigger, a three-dimensional ($128\times128\times128$) coincidence matrix system using random-access memories (RAM's). The trigger actually required a coincidence of two RAM's; $P_2\times P_3\times H_2$ for momentum selection and $P_2\times P_3\times(H_1\cdot\bar{C}_1)$ for nonpion identification. A total of 1.5×10^6 triggers was recorded in a 200-hour run at the alternating gradient synchrotron, yielding 55 000 events that satisfied a two-prong + V^0 topology.

The $K^+K_S\pi^-$ spectrum in Fig. 2(a) for reaction (1), from a sample of $\approx 16\,000$ events after cuts on K_S mass, n mass, and $-t < 1.0$ GeV^2, is dominated

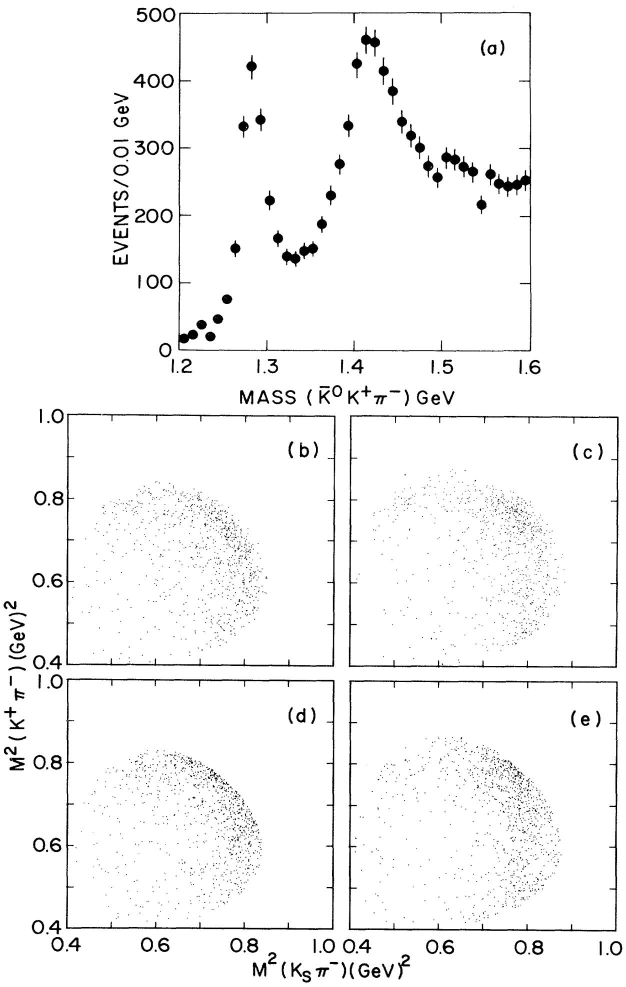

FIG. 2. (a) $K^+K_S\pi^-$ spectrum with $0.4 < MM^2 < 1.3$ GeV^2, $0.48 < M(\pi^+\pi^-) < 0.52$ GeV, and $t < 1.0$ GeV^2. (b) Dalitz plot of $M^2(K^+\pi^-)$ vs $M^2(K^0\pi^-)$ for $1.40 < M(K^+K_S\pi) < 1.42$ GeV. (c) Same as b for $1.42 < M(K^+K_S\pi^-) < 1.44$ GeV. (d) Monte Carlo-generated Dalitz plot for $M(K^+K_S\pi^-) = 1.41$ GeV with use of best-fit parameters and requirement that generated events be observable in our apparatus. (e) Same as (d) for $M(K^+K_S\pi^-) = 1.43$ GeV.

by peaks at the $D(1285)$ and the $E(1420)$ masses. A fit to the spectrum in Fig. 2(a) with two simple Breit-Wigner functions and a polynomial background gives $m = 1285 \pm 2$ MeV and $\Gamma = 22 \pm 2$ MeV for the $D(1285)$ and $m = 1421 \pm 2$ MeV and $\Gamma = 60 \pm 10$ MeV for the $E(1420)$. Our estimate of the experimental mass resolution is less than 7 MeV in the E region. By studying the $\pi^+\pi^-$ system from K_S decays and the missing-mass–squared distribution, we have checked our calculation of the mass resolution and also found that there are no systematic shifts in our mass determination.

It is conventional in a Dalitz-plot analysis to employ the Zemach amplitudes[5] to represent each J^{PG} wave, where G denotes the G parity. Since the $K\bar{K}\pi$ isospin is not determined directly in this experiment, we can measure only the G parity and not C. For the remainder of this paper, therefore, we shall use the notation J^{PG} to denote the states we determine (and not J^{PC}). For the $\bar{K}K\pi$ system from threshold to 1.56 GeV, it was found that the states $0^{-+}, 1^{++}, 1^{+-}$, 1^{-+}, and a flat background were sufficient to describe the data, and all of them were included in the fit. The Zemach amplitudes involve two possible intermediate states (isobars): $K^*(890) \to K\pi$ parametrized by a conventional Breit-Wigner form, and, following the previous spin and parity analysis[3] on the $K\bar{K}$ system, a coupled-channel $\delta(980) \to K\bar{K}$ as given by Flatté.[6] The data are fitted adequately with this parametrization even though it may not be justified, as the $D(1285)$ has a substantial $\eta\pi\pi$ decay mode[7] while no evidence exists for $E(1420)$ or $\iota(1440)$ decaying into $\eta\pi\pi$. We have tried different δ parametrizations, including a single S-wave Breit-Wigner function, and ascertained that the conclusions presented in this Letter are not affected. For the states $J^{PG} = 0^{-+}$ and 1^{++}, both $\delta\pi$ and $K^*\bar{K}$ decay modes are allowed, while for 1^{+-} and 1^{-+} only the $K^*\bar{K}$ decay mode is allowed. A 1^{++} state can couple to the final state $K^*\bar{K}$ (or its charge conjugate) via S- or D-wave orbital angular momentum, but including only the S wave was adequate to describe the data. States of different spin and parity do not interfere on the Dalitz plot, but the states 1^{++} and 1^{+-} can interfere and the degree of coherence was allowed to be arbitrary as a parameter in the fit.

We have performed a maximum-likelihood analysis with the logarithm of the likelihood given by

$$\ln L = \sum_{i=1}^{n} \ln \frac{F(\rho_i)}{\int F(\rho)A(\rho)\,d\rho}, \tag{2}$$

where $F(\rho)$ is the square of a sum of the J^{PG} amplitudes at a phase-space point ρ and $A(\rho)$ represents the finite acceptance of our apparatus. The Dalitz plots for the $K\bar{K}\pi$ mass regions 1.40–1.42 and 1.42–1.44 GeV are shown in Figs. 2(b) and 2(c). They illustrate that

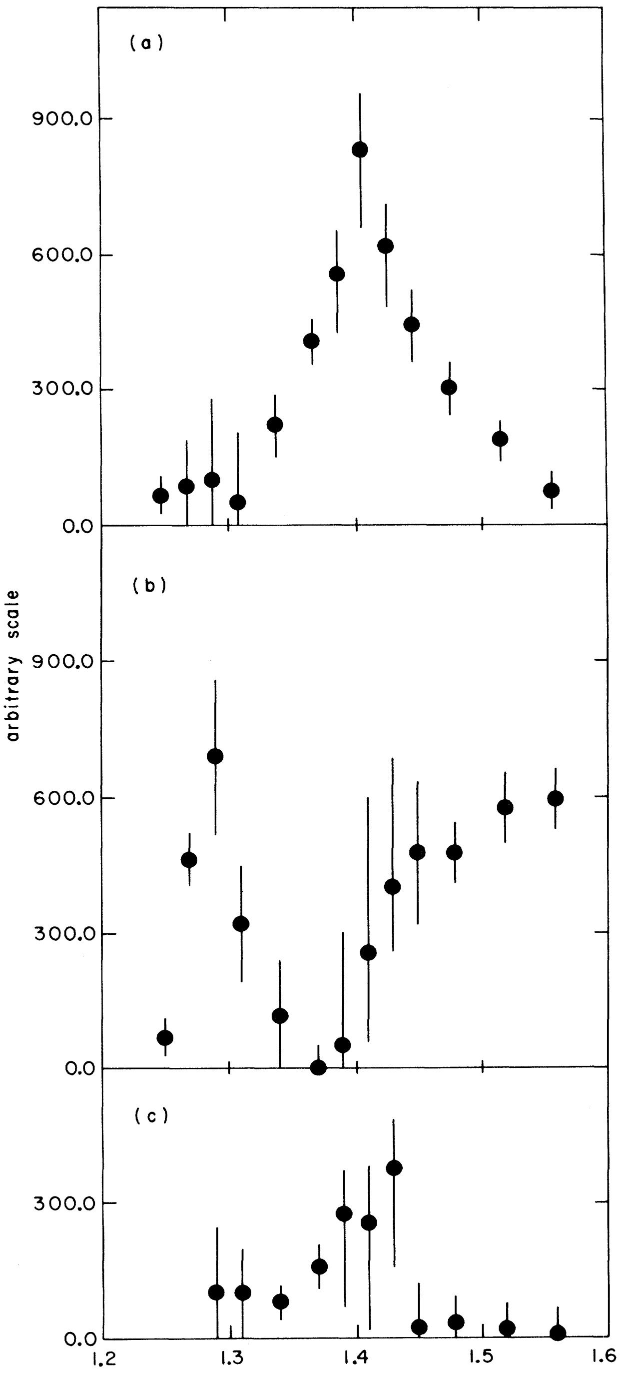

FIG. 3. (a) Acceptance-corrected distributions (with arbitrary scale) of the $J^{PG}=0^{-+}$ wave with combined $\delta\pi$ and $K^*\bar{K}$ decay modes as a function of $M(K^+K_S\pi^-)$. (b) $M(K^+K_S\pi^-)$ distribution of the $J^{PG}=1^{++}$ wave with combined $\delta\pi$ and $K^*\bar{K}$ decay modes ($\delta\pi$ below 1.38 and $K^*\bar{K}$ above). (c) $M(K^+K_S\pi^-)$ distribution of the $J^{PG}=1^{+-}$ wave with the $K^*\bar{K}$ decay mode.

the K^* bands are stronger in the upper mass region. We have checked by examination of the Monte Carlo events generated from our fitted parameters that the data are indeed well described by our fits as shown in Figs. 2(d) and 2(e) (the sharp boundaries for Monte Carlo events are a consequence of the fact that the generated masses are set at 1.41 and 1.43 GeV, while the data range over 20-MeV mass bins, resulting in smeared boundaries). The results are displayed in Fig. 3, where the three important waves $0^{-+}, 1^{++}$, and 1^{+-} are given as a function of the $K\bar{K}\pi$ mass. The 1^{-+} wave and the background (not shown) were found to be negligible up to 1.4 GeV and thereafter slowly increase up to 1.56 GeV. It is seen that the 1^{++} wave is dominant at the $D(1285)$ mass, confirming that it is a 1^{++} state.[7] Although the $\delta\pi$ decay mode is definitely dominant for the D, a considerable amount of $K^*\bar{K}$ decay mode can be accomodated interfering destructively with the $\delta\pi$ mode.

The behavior of the 0^{-+} wave at the $E(1420)$ region shows clearly that the E peak seen in our data is mostly in a 0^{-+} state. In fact, we estimate that at least 70% of the E peak is attributable to a 0^{-+} wave. Analysis of the 0^{-+} state into $\delta\pi$ and $K^*\bar{K}$ decay modes indicates that the $\delta\pi$ mode is predominant, but that the $K^*\bar{K}$ decay mode is definitely required, with strong interference between them, to describe the data adequately. The 1^{++} state, which is mainly $K^*\bar{K}$ with little $\delta\pi$, exhibits a sharp rise with the onset of the $K^*\bar{K}$ threshold at 1.4 GeV and levels off above the E peak. Thus we conclude that the $E(1420)$ is not a 1^{++} state. The fits shown in Fig. 3 correspond to the solutions in which the 1^{++} ($\delta\pi$) wave is set equal to zero above 1.4 GeV. The asymmetric errors in the $E(1420)$ region reflect the fact that one can accomodate, in this mass region, a 1^{++} ($\delta\pi$) wave at the expense of the 1^{+-} and some 0^{-+}, depending largely on δ parametrization. Nevertheless, the 0^{-+} peak at the E mass remains with or without the 1^{++} ($\delta\pi$) wave. It can be seen from Table I that our data in the E region definitely require a $\delta\pi$ decay mode, in particular in the 1.40–1.42-GeV mass region. In contrast the 1^{++} ($K^*\bar{K}$) wave does not show a resonant behavior at the E mass. It is, in fact, difficult to accomodate a 1^{++} resonant state in our data; if we eliminate a 0^{-+} state from the E region, the logarithm of the likelihood drops off by ≈ 31 units (see Table I).

TABLE I. Differences in logarithm of likelihood (from the best fit).

Mass (GeV)	No $\delta\pi$	No 0^{-+}	No 1^{++}	No 1^{+-}
1.40–1.42	−39	−21	−5	−3
1.42–1.44	−17	−10	−15	−10

Likewise, elimination of a 1^{+-} wave results in the decrease of ≈ 13 units. Our results, therefore, contradict those of Dionisi *et al.*[2] and Armstrong *et al.*,[8] who find that the $E(1420)$ is a 1^{++} $(K^*\bar{K})$ state with no other waves required in the E region.

In summary, we conclude that the $D(1285)$ is largely a 1^{++} state while the $E(1420)$ is predominantly a 0^{-+} state, and both of them require a substantial $\delta\pi$ decay mode. It can be seen from Table I that our data in the E region definitely require a $\delta\pi$ decay mode, in particular in the 1.40–1.42-GeV mass region. We do not quote at this time the $\delta\pi/K^*\bar{K}$ branching ratio for the 0^{-+} $E(1420)$, as its value depends on the precise parametrization of the δ and the K^* (890) and is subject to a large systematic error. We should note, however, that the interference between the two decay modes is substantial with a relatively small statistical error. Our results are clearly in agreement with those of the J/ψ radiative decay,[1,9] and that of Baillon,[10] so that the $E(1420)$ and the $\iota(1440)$ may very well be the same 0^{-+} object. However, recently measured values of $m = 1458 \pm 7$ and $\Gamma = 99 \pm 6$ MeV for the $\iota(1440)$ in the J/ψ radiative decay[9] are somewhat higher than those of hadroproduced $E(1420)$. If the $\iota(1440)$ is to be identified with the $E(1420)$, it is unlikely to be a pure glueball and must be heavily mixed with a $q\bar{q}$ state because of its prominent production in a hadron-induced reaction such as ours.

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