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Author
Wiss, J.E.

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Lawrence Berkeley Laboratory and Department of Physics
University of California, Berkeley, California 94720

and

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

We have studied the Dalitz plot for the recently observed charged state decaying into $K^{\mp}\pi^{\pm}\pi^{\pm}$ at 1876 MeV/c^2 and we find that the final state is incompatible with a natural spin parity assignment. This information, coupled with the earlier observation of the $K^{\pm}\pi^{\mp}$ decay mode (a final state of natural spin parity) of the neutral state at 1865 MeV/c^2, suggests parity violation in the decays of these objects if they are members of the same isomultiplet as their proximity in mass suggests.

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†Fellow of Deutsche Forschungsgemeinschaft

‡Permanent address Varian Associates, Palo Alto, California

ΦPermanent address LPNHE, Universite Paris VI, Paris, France

††Permanent address Laboratori Nazionali, Frascati, Rome, Italy

‡‡Permanent address Centre d'Etudes Nucleaires de Saclay, France

ΦΦPermanent address Institut de Physique Nucleaire, Orsay, France

We have recently reported our observation in e^+e^- annihilation of a narrow, charged state of mass 1876 MeV/c^2 decaying into the exotic decay mode $K^{\mp}\pi^{\pm}\pi^{\pm}$.[1] The proximity in mass of this state to the neutral state decaying into $K\pi$ and $K3\pi$ at 1865 MeV/c^2 suggests that they are members of the same isomultiplet, and so they are expected to have the same parity. Since the $K\pi$ final state has natural spin parity, a demonstration that the $K\pi\pi$ final state of the charged member of the isomultiplet is inconsistent with natural spin parity implies a parity violation in the decay. In this Letter we present evidence, based on a study of the $K^{\mp}\pi^{\pm}\pi^{\pm}$ Dalitz plot for such a parity violation, suggesting that the decay proceeds via the weak interaction as expected for the predicted (D^+, D^0) isodoublet of charm.[3]

The present analysis is based on $K\pi\pi$ events observed among a sample of ∿44,000 hadronic events taken from 3.9 GeV to 4.25 GeV center-of-mass energy. These data were taken with the SLAC-LBL magnetic detector at SPEAR.

The $K\pi\pi$ combinations are selected with the aid of the time-of-flight system described in Ref. 2. In the present analysis we have used a modified form of the time-of-flight (TOF) weighting technique described earlier.[1,2] A given track in a multi-prong hadronic event is assigned a definite particle identity on the basis of the agreement between its observed TOF over a 1.5 - 2.0 meter flight path and that predicted for either a π or a K with a momentum as measured. Specifically we compute a χ^2 value for both the π and K hypotheses (χ^2_π and χ^2_K) based on the observed and expected TOF and the 0.4 ns rms resolution of the TOF system. Tracks satisfying the requirements $\chi^2_K < \chi^2_\pi$, $\chi^2_K < 3$ are called kaons. Protons and anitprotons are separated from kaons in a similar fashion. The remaining tracks are called pions.[4] The above technique allows the direct study of scatter plots and in particular the Dalitz plot for the $K\pi\pi$ system.

In order to obtain a relatively clean sample of $K\pi\pi(1876)$ events we make use of the result that for the E_{cm} region, $3.9 < E_{cm} < 4.25$ GeV; the recoil mass (M_{rec}) spectrum shows a sharp spike near 2 GeV.[1] We thus used a data sample with the E_{cm} region chosen as above coupled with a cut $1.96 < M_{rec} < 2.04$ GeV/c^2. Figure 1a and 1b show the resulting exotic and nonexotic $K\pi\pi$ invariant mass distributions. A fit to the spectrum of Fig. 1b was appropriately scaled to serve as a background for Fig. 1a, which shows a fit to a Gaussian peak over this background. Figure 2a shows the (folded) Dalitz plot for $K^{\mp}\pi^{\pm}\pi^{\pm}$ events with the additional invariant mass (M) requirement $1.86 < M < 1.92$ GeV/c^2. We find a sample of 126 events in the Dalitz plot of Figure 2a of which we estimate 58 are background. In Figure 2b we show a background Dalitz plot consisting of 112 nonexotic combinations $K^{\mp}\pi^{+}\pi^{-}$ satisfying the same mass and missing mass cuts as the exotic combinations of Figure 2a.

Both signal and background Dalitz plots are consistent with uniform population density. A uniformly populated Dalitz plot is incompatible with a $K\pi\pi$ final state of pure, natural spin parity.[5] For the case of a natural spin-parity state decaying into three pseudoscalars one expects a depopulation (or zero) along the Dalitz plot boundary. This follows from the necessity of constructing the matrix element from the vector product of the two independent center-of-mass momenta--a vector which vanishes on the Dalitz plot boundary where momenta are collinear. If, as in the case of $K^{\mp}\pi^{\pm}\pi^{\pm}$, two of the pseudoscalars are identical, one expects additional zeros. Since three pseudoscalars cannot be in a 0^+ spin parity state, 1^- and 2^+ exhaust natural spin parity combinations for spin less than 3. For the case of 1^- one expects an additional zero along the y-axis (symmetry axis), while in the case of 2^+ one expects a higher order zero at the top of the Dalitz plot.

In order to quantitatively rule out the $K\pi\pi$ final states of 1^- and 2^+ we have utilized the phenomenological matrix elements of Zemach.[5] These are the simplest matrix elements and are subject to multiplication by arbitrary form factors. Barring the presence of rapidly varying form factors, they can be expected to give a good approximation to the extent of the regions of depopulation, allowing a quantitative comparison with the experimental distribution.

For $J^P = 1^-$ the matrix element is constructed from an axial vector symmetric under the exchange of the two pions. The essential form of such a quantity is $(T_{\pi_1} - T_{\pi_2})\vec{\pi}_1 \times \vec{\pi}_2$, where $\vec{\pi}$ represents a pion momentum in the rest frame of the $K\pi\pi(1876)$, and T_π represents its kinetic energy. For the case of unpolarized porduction one then expects an intensity I_{1^-} given by

$$I_{1^-} \propto |T_{\pi_1} - T_{\pi_2}|^2 \; |\vec{\pi}_1 \times \vec{\pi}_2|^2 .$$

To compare the distribution of I_{1^-} with the data, we have divided the Dalitz plot into two discrimination regions divided by a contour of constant I_{1^-}. The particular contour was chosen so that an equal number of events would be found in each region for a phase space decay of the state $K\pi\pi(1876)$,[5] as determined by a Monte-Carlo calculation. Owing to the approximately uniform $K\pi\pi$ detection efficiency over the Dalitz plot these regions have nearly equal areas. Figures 3a and 3b show the $K^{\mp}\pi^{\pm}\pi^{\pm}$ invariant mass spectra for events with

Dalitz variables lying inside the two 1^- discrimination regions as indicated by the shaded area in the respective inserts.

A fit to a Gaussian signal over the scaled background of Fig. 1b reveals 34 ± 8 signal events in the peripheral region compared to 38 ± 9 signal events in the central region. Such a division is consistent with equal population with a χ^2 of 0.1 for one degree of freedom (DF) or a confidence level CL = 75%. On the other hand, a Monte-Carlo simulation of $K\pi\pi$ decays using the intensity distribution I_{1^-} gives an expected population division of 1:8.2 for peripheral to central region. This is effectively ruled out with a χ^2 of 18.1 (CL = 2×10^{-5}).

For 2^+ we construct a symmetric, traceless, second-rank tensor which is also symmetric under the exchange of the two pions. We use $A^{ij} = \Delta\pi^i q^j + \Delta\pi^j q^i$ where $\Delta\pi$ is the difference of the pion momenta and q is their cross product. For unpolarized production one expects an intensity given by:

$$I_{2^+} \propto \sum_i \sum_j A^{ij} A_{ji} = |\vec{\pi}_1 - \vec{\pi}_2|^2 \; |\vec{\pi}_1 \times \vec{\pi}_2|^2 \; .$$

Here we again divide the Dalitz plot into two regions, using a contour of constant I_{2^+} chosen to give equal population for phase space decay. I_{2^+} depopulates the peripheral region relative to the central region by 1:5.6. Figure 3b and 3c show the $K^{\mp}\pi^{\pm}\pi^{\pm}$ invariant mass spectra for events with Dalitz variables in the shaded 2^+ discrimination regions. Our fits give 31 ± 9 events in the peripheral regions and 35 ± 10 events in the central region. This result is again consistent with equal population with a χ^2 of 0.1 for one DF (CL = 75%), and inconsistent with I_{2^+} with a χ^2 of 9.4 for one DF (CL = 0.002). The observed sample population of the 2^+ peripheral discrimination region indicates the absence of a general boundary zero. The absence of such a zero argues against natural spin parity final states of spin 3 and greater as well.

In summary the distribution in the Dalitz plot is incompatible with the zeros expected for spin parity 1^- or 2^+ for the $K\pi\pi(1876)$. Parity violation then follows from the observation that the presumed isomultiplet state at 1865 MeV/c^2 decays into $K\pi$, a natural spin parity state.

We wish to thank W. Chinowsky for useful discussions.

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4. Tracks which lack reliable TOF information are included in the "pion" category.

5. C. Zemach, Phys. Rev. B133, 1201 (1964); see also B. W. Lee, C. Quigg, and J. L. Rosner, Fermilab PUB 76/73 Thy, August 1976 (unpublished).

6. A phase space decay is possible for the $K\pi\pi$ spin parity assignment of 0^-.

FIGURE CAPTIONS

Fig. 1. The $K\pi\pi$ mass distributions with the cuts designed to enhance the signal-to-background ratio: E_{cm} = 3.90 - 4.25 GeV and M_{rec} = 1.96 - 2.04 GeV/c^2. (a) Exotic combination $K^{\mp}\pi^{\pm}\pi^{\pm}$; (b) non-exotic combination $K^{\pm}\pi^{+}\pi^{-}$.

Fig. 2. Dalitz plots, folded around y-axis, for the $K\pi\pi$ system with the mass cuts M = 1.86 - 1.92 GeV/c^2 and the cuts given for Fig. 1. (a) Exotic combination $K^{\mp}\pi^{\pm}\pi^{\pm}$; (b) non-exotic combination $K^{\pm}\pi^{+}\pi^{-}$. Here $Q = T_k + T_{\pi_1} + T_{\pi_2}$.

Fig. 3. $M(K^{\mp}\pi^{\pm}\pi^{\pm})$ distributions for the same data sample as in Fig. 2. (a) "peripheral" and (b) "central" regions (on the folded plot) for a contour of a 1^- matrix element as indicated by the shaded regions of the inserts, (c) "peripheral" and (d) "central" regions for a contour of a 2^+ matrix element. The solid curves are fits to a Gaussian signal over the scaled backgrounds of Fig. 1b.

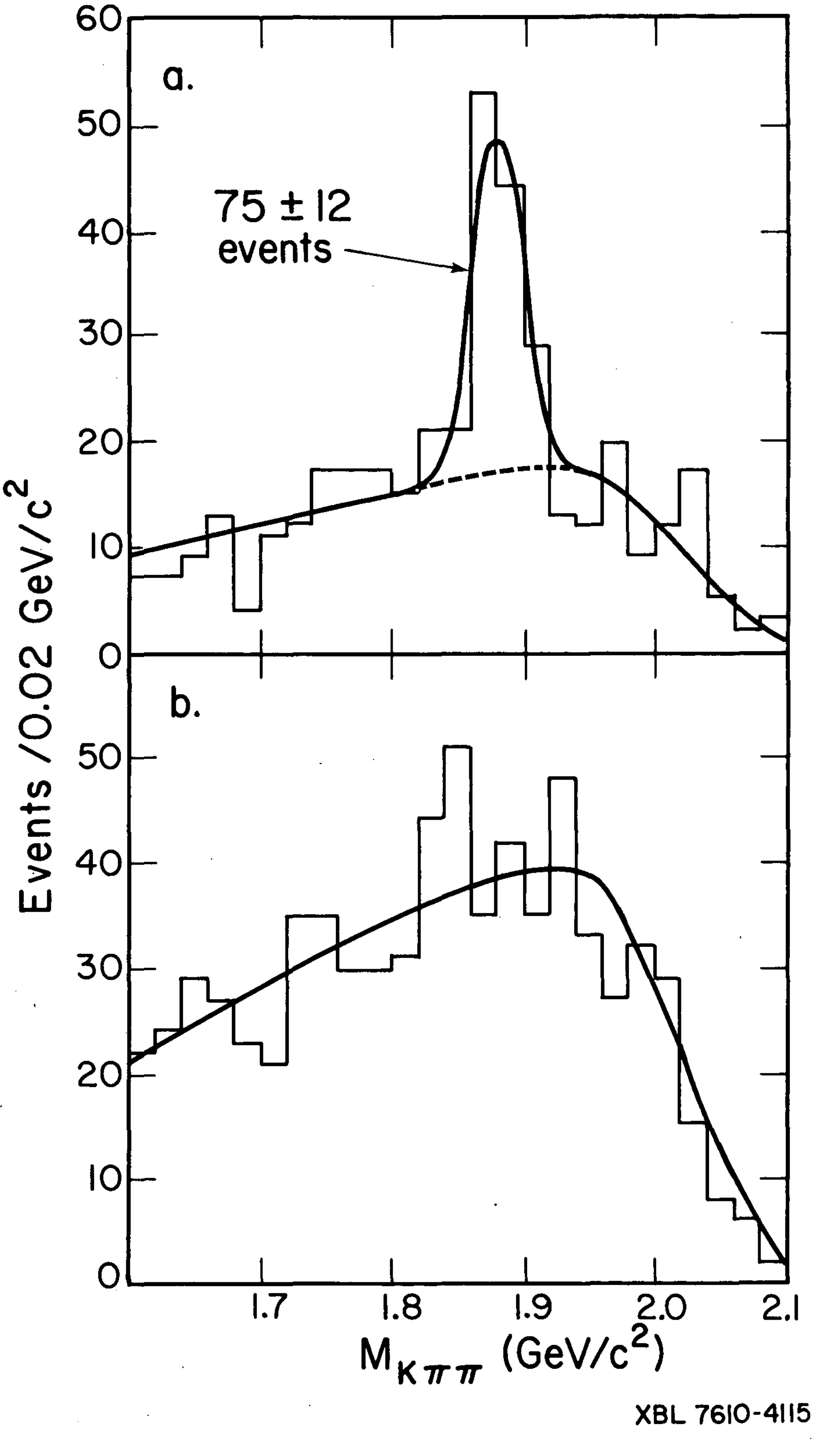
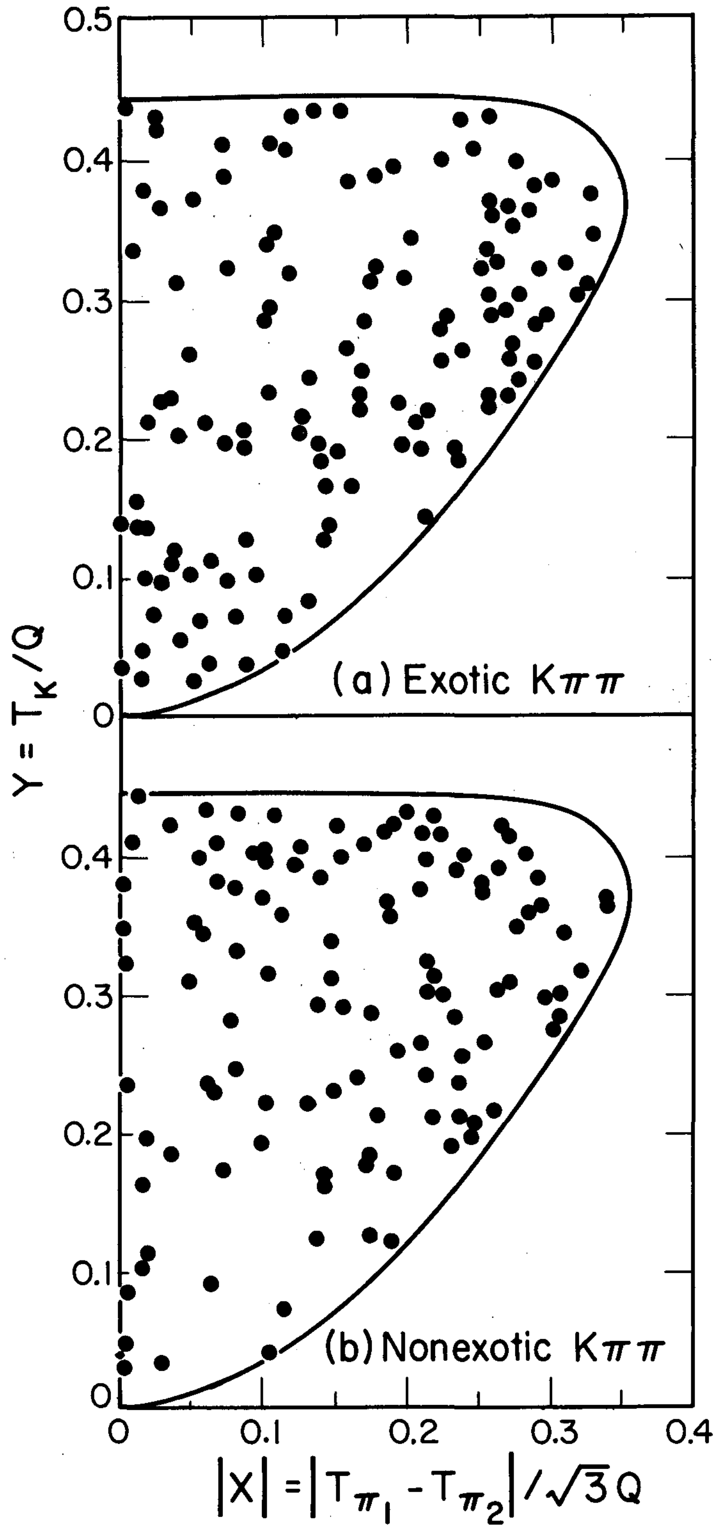

60
50
40
30
20
10
0
a.
75 ± 12
events
b.
50
40
30
20
10
0
Events /0.02 GeV/c²
1.7
1.8
1.9
2.0
2.1
M Kππ (GeV/c²)
XBL 7610-4115

Fig. 1



XBL 7610-4116

Fig. 2

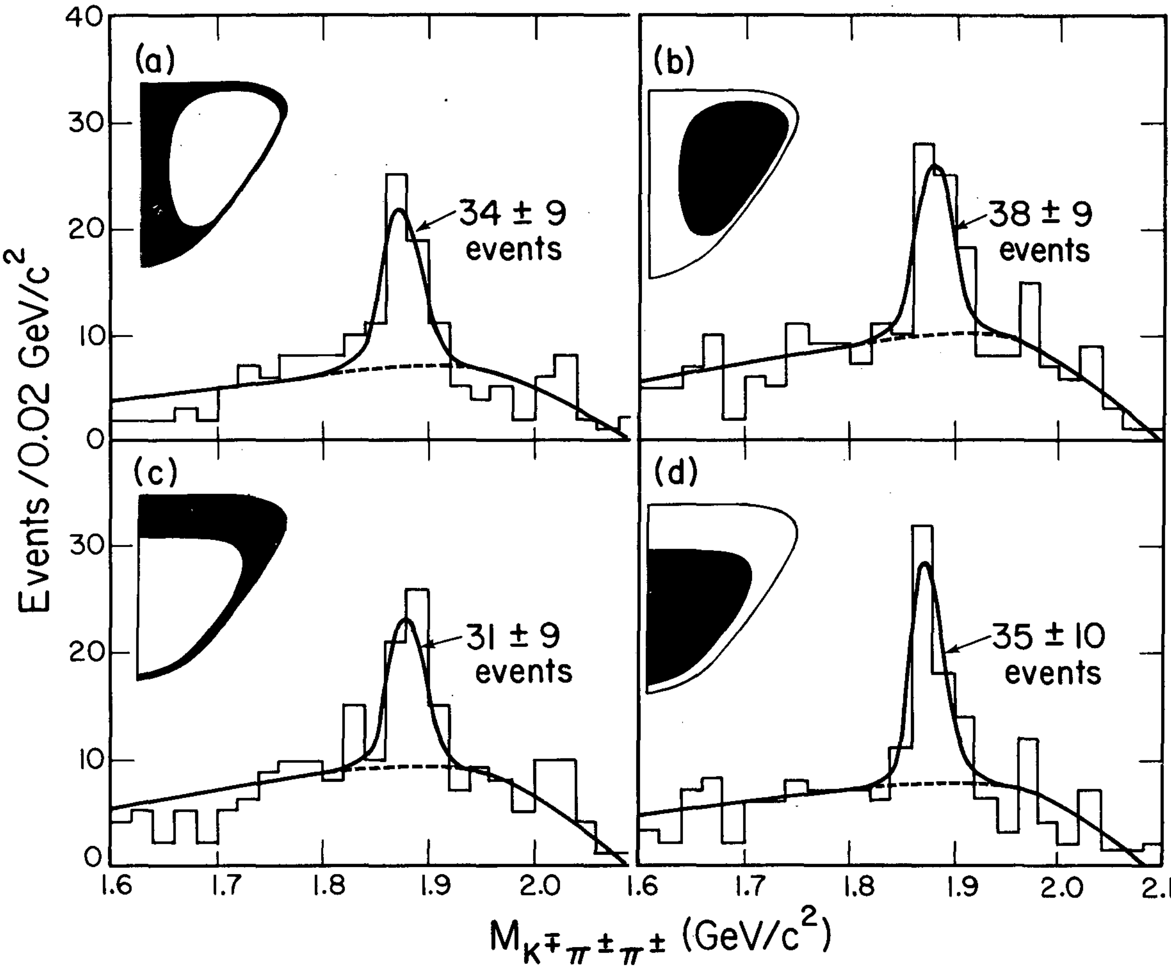


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Fig. 3

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720