Fermi National Accelerator Laboratory

FERMILAB-Pub-76/63-THY
July 1976

Tests for Weak Decays of Charmed Particle Candidates

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ABSTRACT

Several tests, which will establish that the recently observed particles with an effective mass of 1.87 GeV/c^2 decay weakly, are discussed. If the objects decaying into $K^{\mp}\pi^{\pm}$ (and $K^{\mp}\pi^{\pm}\pi^{+}\pi^{-}$) and into $K^{\mp}\pi^{\pm}\pi^{\pm}$ are members of the same isomultiplet, a nonvanishing distribution of the latter events anywhere on the boundary of the Dalitz plot suffices to establish parity violation in their decays. (If a $K_S\pi^{+}\pi^{-}$ decay of the former or a $K_S\pi^{+}$ decay of the latter is observed, the isomultiplet assumption is unnecessary.) We further mention tests involving semileptonic decays and Cabibbo-suppressed decays.

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†Permanent Address: School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455. Supported in part by the United States Energy Research and Development Administration under Contract No. ER-(11-1)-1764.

§Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

Recently sharp peaks have been seen at an effective mass of 1.87 GeV/c^2 in $K^{\mp}\pi^{\pm}$, $K^{\mp}\pi^{\pm}\pi^{\pm}$, and $K^{\mp}\pi^{\pm}\pi^{+}\pi^{-}$ spectra.[1,2] It is very tempting to identify these peaks as the weak decay products of charmed mesons,[3,4] for several reasons. Their widths seem to be effectively zero, on a scale characterized by the experimental resolution of several tens of MeV. The minimum energy at which the new particles are produced in e^+e^- annihilations exceeds twice their mass, indicating associated production. The proximity in mass of the charged and neutral peaks is suggestive of the anticipated isodoublet structures (D^+, D^0) and $(\bar{D}^0, D^-)$. The observed charge states[1,2] of the final particles are those expected for charmed particle decays,[4] and are not characteristic of the strong decays of hadrons. It remains, however, to demonstrate directly that the weak interactions are indeed responsible for the observed decays, and that these weak decays obey the systematics expected for charmed particles.[3] In this note we describe several tests of the decay mechanism which can be applied in the near future.

The most direct indication of the presence of the weak interaction in the decays would be <u>parity violation</u>. To begin, suppose the $K^{\mp}\pi^{\pm}$ and $K^{\mp}\pi^{\pm}\pi^{\pm}$ peaks correspond to the decays of members of an isomultiplet with spin $J = 0$. Then parity must be violated, since $P\left[(K\pi)_{J=0}\right] = +$ while $P\left[(K\pi\pi)_{J=0}\right] = -$. It is indeed most likely that the observed peaks are due to J=0 objects,[4] but for the moment this is merely conjecture which may not be proved swiftly.

More generally, let us suppose that $K^{\mp}\pi^{\pm}$ and $K^{\mp}\pi^{\pm}\pi^{\pm}$ come from members of the same isomultiplet with arbitrary spin.

The $K\pi$ system must have natural spin-parity: $J^P(K\pi) = 0^+, 1^-, 2^+, \cdots$. In principle, the $K\pi\pi$ system may have either natural or unnatural spin-parity. However, the decay distribution of any natural spin-parity $K\pi\pi$ system must vanish at every point on the boundary of the Dalitz plot.[5] For, in order to write down a matrix element for the decay of a natural spin-parity object to $K\pi\pi$, one needs to form a pseudovector out of the two independent center-of-mass momenta. This pseudovector must vanish for collinear configurations, which are in one-to-one correspondence with points on the Dalitz-plot boundary.

The specific Dalitz-plot distributions may be obtained by straightforward application of the method of Ref. 5, and are shown in Fig. 1. The additional zeroes for the $K^-\pi^+\pi^+$ decays are a result of the complete symmetry of the isotensor dipion state. This symmetry need not be present for $K_S\pi^+\pi^-$, for which arbitrary linear combinations of $I_{\pi\pi} = 0,1,2$ are possible.[6]

To summarize the parity test: <u>if the $K^-\pi^+\pi^+$ distribution does not vanish everywhere on the boundary of its Dalitz plot, parity must have been violated either in the $K\pi$ or the $K\pi\pi$ decay</u>. This argument makes use of the presumed isospin symmetry between the charged and neutral peaks at 1.87 GeV/c^2. The isospin assumption would be unnecessary if, for example, a $K_S\pi^+\pi^-$ decay of the $(K\pi, K3\pi)^0$ object could be observed.

Similar arguments can be applied to other two-body states such as $\pi^{\pm}\eta$ or $K^{\pm}K_S$ and other three-body states such as $\pi^{\pm}\pi^{+}\pi^{-}$. These are expected to be important decay modes of the $F^{\pm}$,[4,7] and can also arise (with amplitudes proportional to $\sin\theta_C\cos\theta_C$) in $D^{\pm}$ decays.

Several other tests for the weak interactions are available. If one could observe the particles at 1.87 GeV/c^2 decaying semileptonically, one would know they were stable with respect to strong and electromagnetic interactions. The GIM mechanism[3] would be established, moreover, if one found, for example, that

$$\frac{\Gamma(D^0 \to K^- e^+ \nu_e)}{\Gamma(D^0 \to \pi^- e^+ \nu_e)} = 0.6\cot^2\theta_C \simeq 11 \quad , \qquad (1a)$$

or that

$$\frac{\Gamma(D^+ \to K_S e^+ \nu_e)}{\Gamma(D^+ \to \pi^0 e^+ \nu_e)} = 0.6\cot^2\theta_C \simeq 11 \quad . \qquad (1b)$$

Here the coefficient of $\cot^2\theta_C$ is due to phase space.

The semileptonic decays of a charmed object could be observed in e^+e^- annihilations if a single lepton emerged from a cluster with definite missing mass[8] recoiling against a charmed meson candidate. The charmed meson with the greatest chance of a large semileptonic branching ratio is probably the $D^{\pm}$.[4] It may be very helpful to choose reactions in which the production of a $D^{\pm}$ is highly likely, e.g. in e^+e^- annihilations at 4.03 GeV opposite a $D^{*\mp}$ candidate.[2,9,10]

In neutrino reactions such as[11]

$$\nu N \rightarrow \mu^- e^+ K_S^0 + \cdots\cdots \quad , \tag{2}$$

the mass of a particle decaying semileptonically to $e^+ K_S{}^0 \nu$ can be obtained in an unconstrained kinematic fit by assuming that the only missing particle is a neutrino.[12] If the charged $K\pi\pi$ signal[2] is a $D^\pm$, there should be an accumulation of events in reaction (2) with effective mass

$$M(e^+ K_S{}^0 \text{"}\nu\text{"}) = 1.87\ \mathrm{GeV}/c^2 \ . \tag{3}$$

Charmed particles should undergo both <u>Cabibbo-suppressed and Cabibbo-favored decays</u>. Examples for semileptonic decays have already been noted in Eq. (1). Furthermore, if any particle is observed to decay to two final <u>hadronic</u> states of differing strangeness, it must be decaying weakly. For example, if the same particle decays to $K^-\pi^+$ and to $\pi^-\pi^+$ or K^-K^+; or to $K^-\pi^+\pi^+$ and to $\pi^-\pi^+\pi^+$; or to $\pi^+\eta$, K^+K_S and to $K^+\pi^0$, $K^0\pi^+$, $K^+\eta$, then the weak interactions must be involved. One expects, for example,[4]

$$\frac{\Gamma(D^0 \rightarrow K^-\pi^+)}{\Gamma(D^0 \rightarrow \pi^-\pi^+)} \approx \cot^2\theta_C \approx 18. \tag{4}$$

An observed ratio of this magnitude would be evidence for the GIM mechanism, as hadronic final-state interactions are expected to be comparable in the two cases.[4,7] The decay $D^+ \rightarrow \pi^-\pi^+\pi^+$, while Cabibbo-suppressed with respect to the "exotic" decay $D^+ \rightarrow K^-\pi^+\pi^+$, involves a non-exotic final state and hence may not experience the full force of the suppression.[4] We urge that $D^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ be searched for. If it is significant, the total nonleptonic decay rate of the $D^{\pm}$ may be considerably less than that of the D^{0}.

Charmed particles should have lifetimes of 10^{-14} - 10^{-12} sec. if they correspond to the 1.87 GeV/c^2 objects. Such lifetimes can be measured in emulsions, but downstream particle identification and more accurate track momentum measurements will be necessary if one wishes to make a simultaneous determination of the mass.

To conclude: We have suggested several tests for weak decays of the new particles at 1.87 GeV/c^2 and of related objects. Foremost among these is the demonstration of parity violation, which may be possible quite soon. The remaining tests (semileptonic decays, apparent strangeness violations, lifetimes) may be possible in the foreseeable future as well.

One of us (J.L.R.) would like to thank the theory group at Fermilab for their hospitality during the course of this work.

FOOTNOTES AND REFERENCES

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[2]I. Peruzzi, et al., SLAC-Pub-1776.

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[4]M.K. Gaillard, B.W. Lee, and J.L. Rosner, Rev. Mod. Phys. 47, 277 (1975).

[5]C. Zemach, Phys. Rev. 133, B1201 (1964).

[6]It may be shown that the $D^+ \to K^-\pi^+\pi^+$ column of Fig. 1 is identical to the column labeled "I=1, except $3\pi^0$" in Fig. 2 of Ref. 5, and that the $D^0 \to K_S\pi^+\pi^-$ column contains Dalitz plots whose zeroes are the intersection of the columns "I=0," "I=1, except $3\pi^0$," and "I=2:$\pi^+\pi^-\pi^0$" in Fig. 2 of Ref. 5. The latter column has the property that the only place the distribution is required to vanish is along the whole boundary of the Dalitz plot, and only for natural spin-parity.

[7] Martin B. Einhorn and C. Quigg, Phys. Rev. D12, 2015 (1975); R.L. Kingsley, S.B. Treiman, F. Wilczek, and A. Zee, ibid. D11, 1919 (1975).

[8]We are grateful to W. Selove for sharing with us related ideas on this subject.

[9]The $K^{\mp}\pi^{\pm}\pi^{\pm}$ peak at 1.87 GeV/c^2 is seen in Ref. 2 recoiling against a sharp peak at 2.01 GeV/c^2 (the D^* candidate).

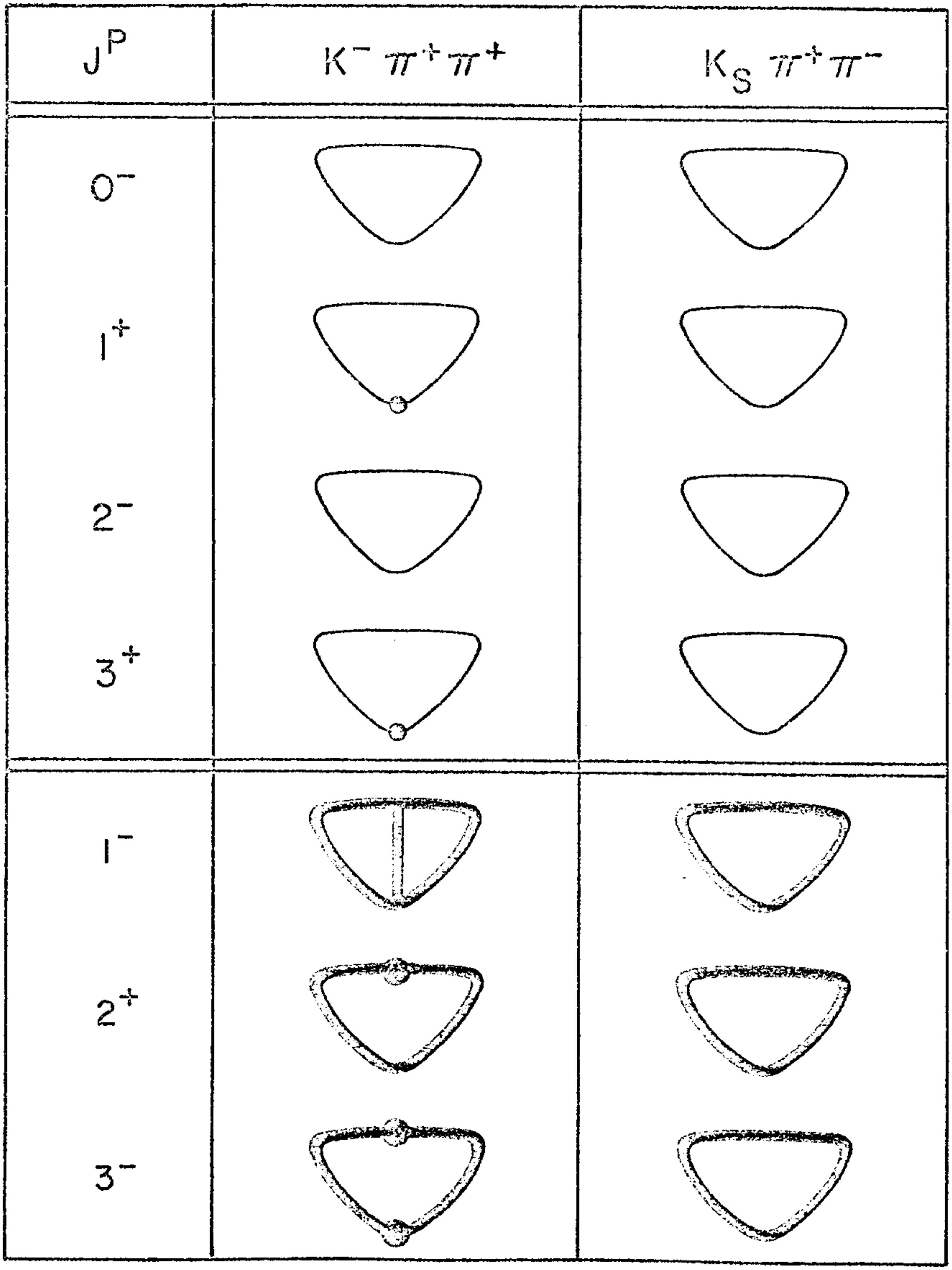
[10]Recent analyses of charmed meson pair production near threshold in e^+e^- reactions include those by Kenneth Lane and E. Eichten, Cornell University Report CLNS-335, June, 1976 (unpublished), and A. De Rujula, Howard Georgi, and S.L. Glashow, "Is Charm Found? " and "Charm Spectroscopy via Electron-Positron Annihilation," Harvard University Reports, June, 1976 (unpublished).

[11]J. von Krogh, et al., Phys. Rev. Lett. 36, 710 (1976); H. Deden, et al., Phys. Lett. 58B, 361 (1975); J. Blietschau, et al., ibid. 60B, 207 (1976).

[12]We thank M. L. Stevenson for pointing this out to us. For one candidate a mass of 1.84 GeV/c^2 has been deduced by this technique, neglecting Fermi motion. See M.L. Stevenson, et al., LBL-CERN-Hawaii-Wisconsin Collaboration, "Neutrino Interactions with $e^+\mu^-$ and Multiple K^0's," LBL-5319, presented at the XVIII International Conference on High Energy Physics, Tbilisi, 1976.

FIGURE CAPTION

Fig. 1 Regions of the $K\pi\pi$ Dalitz plot where the density must vanish because of the symmetry requirements are shown in black. [Compare Fig. 2 of Ref. 5.] The vanishing is of higher order (stronger) where black lines and dots overlap. Kinetic energy of the kaon is measured in the vertical direction.



J^P
$K^- \pi^+ \pi^+$
$K_S \pi^+ \pi^-$
0^-
1^+
2^-
3^+
1^-
2^+
3^-