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Observation of Cabibbo-Suppressed Decay $D^0 \to \pi^-\pi^+$ and $D^0 \to K^-K^+$

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The D° Cabibbo-suppressed decay modes $\pi^-\pi^+$ and K^-K^+ have been observed and the following ratios of D° partial decay widths have been measured: $\Gamma(D^\circ\to\pi^-\pi^+)/\Gamma(D^\circ\to K^-\pi^+) = 0.033\pm 0.015$ and $\Gamma(D^\circ\to K^-K^+)/\Gamma(D^\circ\to K^-\pi^+) = 0.113\pm 0.030$.

We report here the first observation of Cabibbo-suppressed decays of charmed particles.[1] The mechanisms for the Cabibbo-allowed and Cabibbo-suppressed decays in the standard model[2] are illustrated in Fig. 1. The angle θ_A is the familiar Cabibbo angle θ_C measured in strange-particle decays, while the angle θ_B can be thought of as a new Cabibbo angle which can be measured in charmed-particle decays. The ratios $\Gamma(D^0\to K^-K^+)/\Gamma(D^0\to K^-\pi^+)$ and $\Gamma(D^0\to\pi^-\pi^+)/\Gamma(D^0\to K^-\pi^+)$ are proportional to $\tan^2\theta_A$ and $\tan^2\theta_B$, respectively. If one assumes[3] $\theta_A=\theta_B$ and SU(3) invariance, one predicts[4]

$$\frac{\Gamma(D^0\to K^-K^+)}{\Gamma(D^0\to K^-\pi^+)} = \frac{\Gamma(D^0\to\pi^-\pi^+)}{\Gamma(D^0\to K^-\pi^+)} = \tan^2\theta_C \approx .05\,. \quad (1)$$

Phase-space corrections will raise the $\pi^-\pi^+$ rate by 7% and lower the K^-K^+ rate by 8%.

The data reported here were collected by the Mark II detector at SPEAR. The data sample contains 49 000 detected multihadronic events, corresponding to an integrated luminosity of 2.84 pb^{-1}, accumulated at the center-of-mass energy $3.771\pm .002$ GeV, near the peak of the $\psi(3770)$ resonance.[5]

A schematic drawing of the Mark II detector is shown in Fig. 2. Starting from the interaction region, the detector consists of two layers of cylindrical scintillation counters, 16 layers of cylindrical drift chambers,[6] 48 time-of-flight (TOF) scintillation counters, an aluminum solenoidal coil which produces a 4.1-kG axial field, eight lead–liquid-argon shower counters, iron hadron absorbers, which in part serve as the magnetic flux return, and two planes of proportional tubes for muon detection. There are also shower detectors in the endcap regions of the detector.

Signals derived from the cylindrical scintillation counters, the drift chambers, and a timing reference from the beam are processed to give event triggers. The trigger requires at least one charged track to be within the central 75% of 4π sr covered by the detector and a second charged

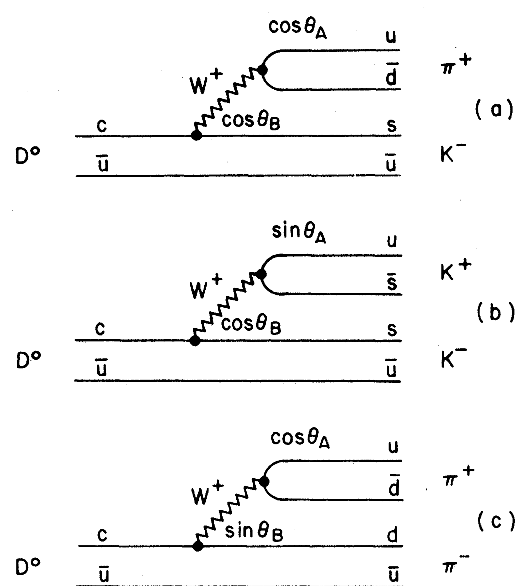

FIG. 1. Quark diagrams for D^0 decays to two charged particles.

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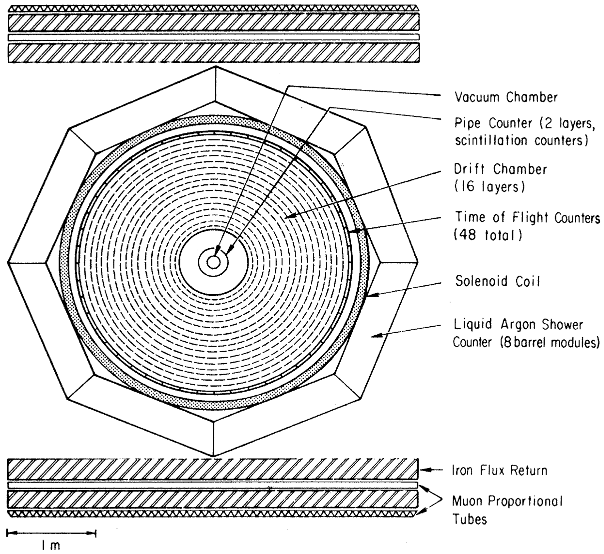

FIG. 2. Schematic drawing of the Mark II detector looking along the incident beams. Hadron absorbers and proportional tubes for muon detection on the sides are not shown.

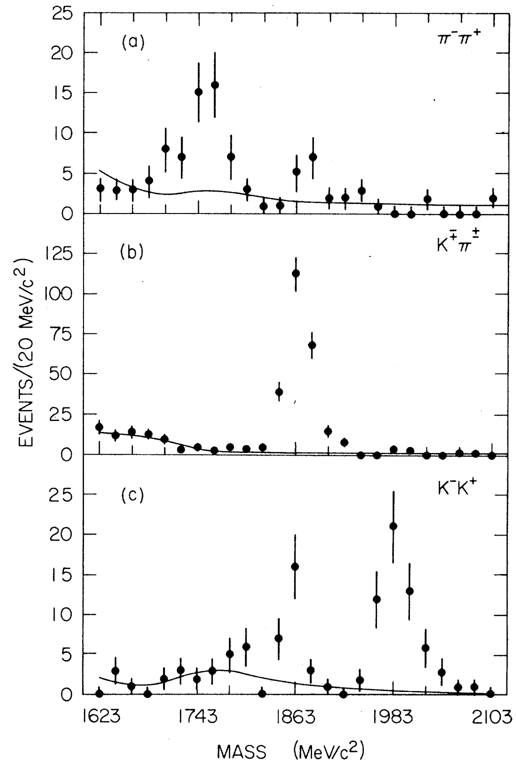

FIG. 3. Invariant mass of two-particle combinations which have a momentum within 30 MeV/c of the expected D^0 momentum and TOF information consistent with the indicated mode. Note that the vertical scale in (b) is five times the scale in (a) and (c). The TOF criteria ensure that no event is plotted in both (a) and (c), and that, for the most part, each event is plotted in only one plot. However, a few events from the peak in (b) are also present in the misidentification peaks in (a) and (c).

track within approximately 85% of 4π sr. Vertex position, tracking quality, shower counter pulse height, and time-of-flight cuts were imposed to select the sample of three- or more-prong events used in the present analysis from beam gas, cosmic-ray, and electromagnetic backgrounds. Subsequent data analysis relied only on drift chamber and time-of-flight information.

The drift chambers measure the azimuthal coordinates of charged tracks to a rms accuracy of 200μm at each layer. Polar coordinates are determined from the ten stereo layers oriented at $\pm 3°$ to the beam axis. When tracks are constrained to pass through the known beam position, the rms momentum resolution is

$$\delta p/p = [(0.005p)^2 + (0.0145)^2]^{1/2},$$

where p is measured in GeV/c. The tracking efficiency is greater than 95% for tracks with $p > 100$ MeV/c over 75% of 4π sr.

The TOF counters provide timing information over 75% of 4π solid angle. The flight path is between 1.5 and 2.3 m depending on polar angle and the average rms resolution for these data is 315 ps. Thus the TOF system provides about 2.5-standard-deviation π/K separation for momenta around 850 MeV/c, which is the typical particle momentum for the decays reported here.

Two-body D^0 decay involving $K^\pm, \pi^\pm$ were identified in two steps. First, we make use of the property that D's can only be produced in pairs at 3.771 GeV and thus all D^0's have a unique momentum $p_D \approx 288$ MeV/c. Accordingly, candidates for two-body D^0 decay were required to be oppositely charged pairs having net momenta in the range $p_D \pm 30$ MeV/c. Second, TOF information and the measured individual track momenta allowed identification of specific $K\pi$, $\pi\pi$, or KK final states. TOF probabilities[7] for π, K, and proton were assigned to each track. To reduce backgrounds, the product of the individual probabilities for a given final-state hypothesis was required to be greater than 0.3; The results are insensitive to this requirement.

Final identification was made by computing the two-body invariant mass for each decay mode; these spectra are shown in Fig. 3. Correctly identified D^0's appear near the D^0 mass, 1863

MeV/c^2, while D^0's in which one particle has been misidentified will appear shifted by approximately 120 MeV/c^2 from the D^0 mass. In Fig. 3(b), the dominant $K^{\mp}\pi^{\pm}$ mode is clear; peaks due to misidentified $K\pi$ decays are present at 1743 and 1983 MeV/c^2 in Figs. 3(a) and 3(c), respectively. A clear K^-K^+ signal is present in Fig. 3(c) and there is an excess of $\pi^-\pi^+$ events over background in the D^0 region of Fig. 3(a).

To determine the number of signal events, the data of Fig. 3 were fitted by a maximum-liklihood technique with use of Poisson statistics. The shapes of the background functions used in these fits were derived from control regions with diparticle momenta between 50 and 110 MeV/c higher or lower than p_D. The magnitude of the background was determined both by fits to the data in Fig. 3 and by the number of events in the conregions. These backgrounds are displayed as smooth curves in Fig. 3. The fits give 234.5 ± 15.8 $K^{\mp}\pi^{\pm}$ decays, 22.1 ± 5.2 K^-K^+ decays, and 9.3 ± 3.9 $\pi^-\pi^+$ decays. The statistical probability that the $\pi^-\pi^+$ signal is purely a fluctuation in the background is about 7×10^{-3}.

The relative efficiencies for detecting the $\pi\pi$, $K\pi$, and KK modes are calculated from a Monte Carlo simulation to be 1.19, 1.00, and 0.84, respectively. The major effect is the probability that the K will decay in flight causing either its momentum or time of flight to be measured incorrectly. If we correct the number of events for these efficiencies, we have $\Gamma(D^0\to\pi^-\pi^+)/\Gamma(D^0\to K^-\pi^+)=0.033\pm0.015$ and $\Gamma(D^0\to K^-K^+)/\Gamma(D^0\to K^-\pi^+)=0.113\pm0.030$, where the quoted errors include estimates of systematic error added in quadrature.[8]

These results show that charmed-particle Cabibbo-suppressed decays exist and that they have roughly the expected magnitude. The $\pi^-\pi^+$ rate is lower than the prediction of Eq. (1) by about 1 standard deviation and the K^-K^+ rate is higher by about 2 standard deviations. Within the context of the standard model, a discrepancy in the K^-K^+ rate, which is sensitive to the "old" Cabibbo angle θ_A, would imply a corresponding violation of SU(3) invariance in either the weak or strong interactions. Accordingly, it is difficult to interpret our measurement of the $\pi^-\pi^+$ rate as a measurement of the new Cabibbo angle θ_B in any simple way.

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[1] Previous upper limits were given in M. Piccolo *et al.*, Phys. Lett. 70B, 260 (1977). Expressed in terms of ratios of partial widths, the 90%-confidence-level upper limits were $\Gamma(\pi^-\pi^+)/\Gamma(K^-\pi^+)<0.07$ and $\Gamma(K^-K^+)/\Gamma(K^-\pi^+)<0.07$.

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[6] W. Davies-White *et al.*, Nucl. Instrum. Methods 160, 227 (1979).

[7] See Ref. 1 for a discussion of this technique.

[8] The estimates of systematic error are 19% for the $\pi^-\pi^+$ rate and 10% for the K^-K^+ rate. A major contribution is the uncertainty in the background subtraction, which is relatively larger for the $\pi^-\pi^+$ signal simply because the signal itself is smaller.