# Study of the Decay $D^0 \to K^- \pi^+ \pi^0$ in High-Energy Photoproduction

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Results are presented from an experiment observing photoproduction of the $D^*$ at a mean energy of 105 GeV. Clean signals are seen for the decay $D^{*\pm} \to \pi^\pm D^0$ with the $D^0$ decaying into both $K^\mp \pi^\pm$ and $K^\mp \pi^\pm \pi^0$. Analysis of the Dalitz plot for the $K\pi\pi$ mode gives branching fractions for $K^- \rho^+$, $K^{*-}\pi^+$, and $\bar{K}^{*0}\pi^0$ final states.

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The nonleptonic weak decays of the charmed mesons have been the subject of much experimental and theoretical effort. One important question is whether the ratios of branching fractions for the various two-body and quasi-two-body $D^0$ decay modes ($K\pi$, $K\rho$, and $K^*\pi$) are consistent with an $I = \frac{1}{2}$ final state, which is expected if the decay is dominated by $W$ exchange.[1] We report the results of an experiment using the tagged photon spectrometer at Fermilab which observed the decay $D^{*+} \to \pi^+ D^0$ with the $D^0$ decaying into both $K^-\pi^+$ and $K^-\pi^+\pi^0$. (The charge-conjugate states are implicitly included in all decay modes.) The $K^-\pi^+\pi^0$ sample represents the largest reported to date, and it was used to measure the branching ratio for the $K\rho$ and $K^*\pi$ modes, as well as that for nonresonant $K^-\pi^+\pi^0$ decay.

The $D^*$ events were produced by tagged photons of energy between 60 and 160 GeV, generated by a 170-GeV electron beam in a 0.2-radiation-length copper radiator. The tagged photons impinged on a 1.5-m liquid-hydrogen target, which was placed at the front end of the spectrometer shown in Fig. 1.[2] Recoil protons were measured and identified in the recoil detector,[3] and the missing mass of the forward state was computed by a very fast data driven processor.[4] The trigger demanded that the recoil system detect either a single proton at the primary vertex with a high missing mass or at least three charged tracks. The forward charged particles were analyzed with drift chambers and two magnets of large aperture, with a momentum resolution for fast tracks of $\Delta P/P = 0.004 + 0.005P/(1\ \text{GeV}/c)$. Two multicell Cherenkov counters identified charged tracks, separating pions from kaons in the momentum range 6–36 GeV/$c$. Photons were detected either in the forward segmented liquid

 

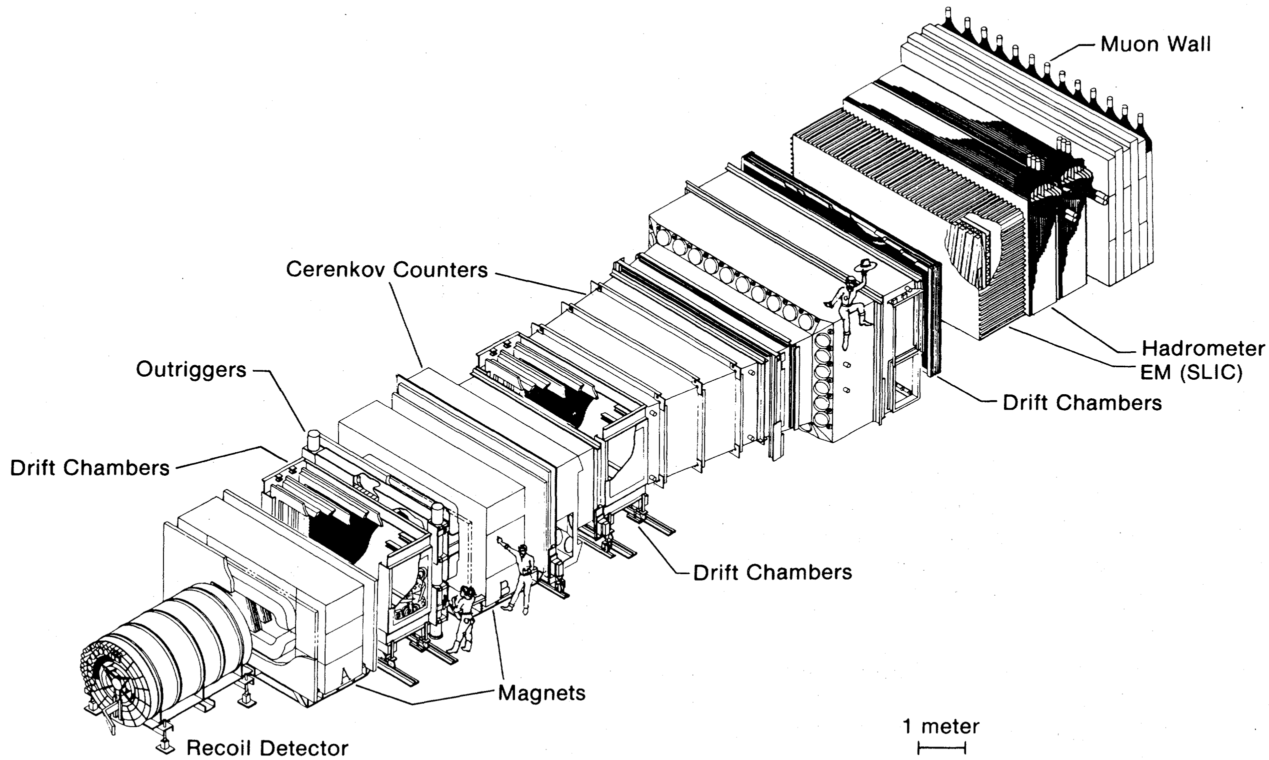


FIG. 1. The tagged photon spectrometer at Fermilab.

ionization calorimeter (SLIC)[5] or in smaller counters placed above and below the aperture of the second magnet (outriggers). Almost all the $\pi^0$'s from detected $D^0$ decays were seen in the SLIC, in which the energy resolution was about $15\%/E^{1/2}$ for photons, and the spatial resolution was a few millimeters.

To measure the ratio $B(D^0 \to K^-\pi^+\pi^0)/B(D^0 \to K^-\pi^+)$ the desired final states are $K^-\pi^+\pi^+$ and $K^-\pi^+\pi^+\pi^0$. For each mode a cut was applied on the probability that the three charged particles satisfy the $K^-\pi^+\pi^+$ hypothesis. In addition, for the $\pi^0$ sample, a cut was applied on a $\pi^0$ probability calculated from the mass of the two gammas and the background underneath the $\pi^0$ peak. To observe the decay cascade $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$, we chose $K^-\pi^+\pi^+$ combinations with $M_{K^-\pi^+}$ less than 60 MeV/$c^2$ from the $D^0$ mass. For such combinations the spectrum of the mass difference, $\Delta M = M_{K\pi\pi} - M_{K\pi}$ has a clear peak at the $D^{*+}$-$D^0$ mass difference. This spectrum is fitted well by a background of the form $aQ^{1/2}(1 - bQ)$ (where $Q = \Delta M - M_{\pi^+}$, and $a$ and $b$ are constants) plus a Gaussian centered at $\Delta M = 0.1454$ GeV/$c^2$ and of $\sigma = 1.2$ MeV/$c^2$, with $39 \pm 8$ events in the peak. A similar analysis was carried out for the $K^-\pi^+\pi^+\pi^0$ sample, and the fit to the $\Delta M$ plot with the same peak parameters as above yields $41 \pm 9$ events in the peak.

To determine the ratio $B(D^0 \to K^-\pi^+\pi^0)/B(D^0 \to K^-\pi^+)$, the ratio of the efficiencies for the two modes is needed. Many efficiency factors are common to both modes; the reconstruction efficiency and identification efficiency are the only factors which need to be calculated from Monte Carlo studies. The one strong difference between the two cases is the probability of reconstructing the $\pi^0$, which varies with the energy of the $\pi^0$ from a threshold at 4 GeV to a value of approximately 40% at 30 GeV and above. This efficiency was determined by adding to real events photon showers generated by a Monte Carlo program, and processing these events by the usual $\pi^0$-finding programs. A Monte Carlo calculation which used this $\pi^0$ efficiency gave for the ratio of efficiencies $\epsilon(K^-\pi^+\pi^0)/\epsilon(K^-\pi^+) = 0.25 \pm 0.04$. Using this number and the relative number of events in the two $D^*$ peaks, we calculate $B(D^0 \to K^-\pi^+\pi^0)/B(D^0 \to K^-\pi^+) = 4.2 \pm 1.4$. Combining this with the current average value for the $D^0 \to K^-\pi^+$ branching ratio, $(2.4 \pm 0.4)\%$,[6] yields a measurement of $B(D^0 \to K^-\pi^+\pi^0) = (10.3 \pm 3.7)\%$.

For the Dalitz-plot study, a sample of $K^-\pi^+\pi^+\pi^0$ events was chosen with somewhat looser Cheren-

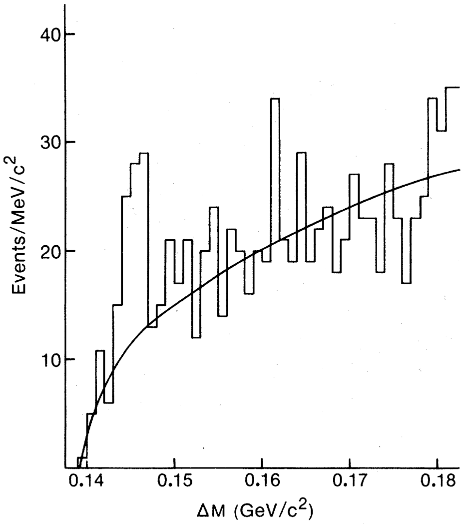


FIG. 2. $\Delta M = M_{K\pi\pi\pi} - M_{K\pi\pi}$ for events with $M_{K^-\pi^+\pi^0}$ within 50 MeV/$c^2$ of the $D^0$. The smooth curve is a fit to the background of the form described in the text.

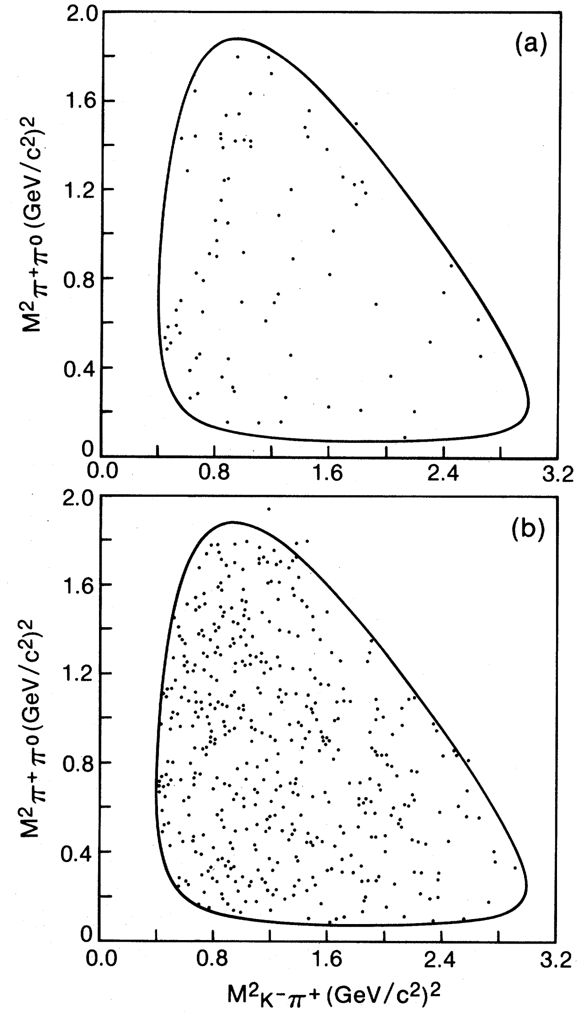


FIG. 3. The Dalitz plot for (a) the $D^0$ region and (b) the background sample. The boundary is drawn for the center of the $K^-\pi^+\pi^0$ mass range.

kov cuts and with $M_{K^-\pi^+\pi^0}$ within 50 MeV/$c^2$ of the $D^0$ mass. Figure 2 shows the $\Delta M$ spectrum for these events, with a clear peak at $\Delta M = 0.1454$ GeV/$c^2$. To obtain a clean sample for this analysis the 82 events with $\Delta M$ between 0.1440 and 0.1470 GeV/$c^2$ were selected; a fit to the $\Delta M$ spectrum determines the background to be 45% in this region. The Dalitz plot for these events is shown in Fig. 3(a). A high-statistics background sample was constructed by taking events in the $D^0$ mass range but with $\Delta M$ outside the $D^*$ range. (The $D^0$ fraction for these events is small.) The Dalitz plot for this sample, shown in Fig. 3(b), gave a good fit to uniform phase space times an efficiency which depended linearly on $M^2(K^-\pi^+)$, because of the energy dependence of the $\pi^0$ efficiency. We also examined this background for $\rho$ and $K^*$ and found that it was consistent with no contribution from these vector mesons. We made a maximum-likelihood fit to the Dalitz plot from the $D^*$ region, allowing a flat background with the acceptance correction as for the background, plus resonant contributions from $K^-\rho^+$, $K^{*-}\pi^+$, and $\overline{K}{}^{*-}\pi^0$. Each vector meson was described by a Breit-Wigner form with the appropriate decay angular distribution. Interference effects are small compared with the quoted errors, and were neglected. The results are shown in Table I. Only in the $K^-\rho^+$ mode is there evidence of a strong resonant contribution. We note that the $\cos^2\theta$ distribution for the $\rho \to \pi\pi$ decay means that the $\rho$ band is populated primarily at the edges of the Dalitz plot. (Here $\theta$ is the

TABLE I. Contributions to $D^0 \to K^-\pi^+\pi^0$ decay from the results of the fit to the $D^0 \to K^-\pi^+\pi^0$ Dalitz plot. The category "nonresonant decays" does not include the contribution to the Dalitz plot from background below the $D^0$. The branching ratios quoted depend on the value $B(D^0 \to K^-\pi^+) = (2.4 \pm 0.4)\%$ for their normalization; the errors are dominated by the statistical errors in the present experiment, however.

| Channel | Fraction of $D^0 \to K^-\pi^+\pi^0$ decays | Branching ratio (%) |
|---|---|---|
| $K^-\rho^+$ | $0.31^{+0.20}_{-0.14}$ | $3.2^{+2.3}_{-1.8}$ |
| $\overline{K}{}^{*0}\pi^0$ | $0.06^{+0.09}_{-0.06}$ | $0.9^{+1.4}_{-0.9}$ |
| $K^{*-}\pi^+$ | $0.11^{+0.12}_{-0.08}$ | $3.4^{+3.9}_{-2.8}$ |
| Nonresonant decays | $0.51 \pm 0.22$ | $5.2 \pm 2.9$ |

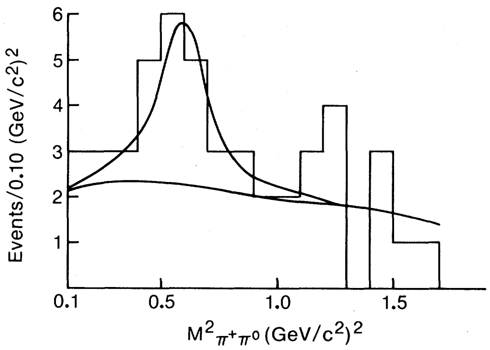


FIG. 4. $M^2(\pi^+\pi^0)$ for events from the $D^0 \to K^-\pi^+\pi^0$ sample with $|\cos\theta| > 0.5$ for the $\pi^+\pi^0$ system. The curves show the results of the fit to the entire Dalitz plot.

angle in the $\pi\pi$ center of mass, with $\theta = 0$ along the $K^-$ direction in that frame.) Figure 4 shows the $M^2(\pi^+\pi^0)$ spectrum for events with $|\cos\theta| > 0.5$, a cut which keeps $\frac{1}{2}$ of the smooth $\pi\pi$ spectrum but $\frac{7}{8}$ of the $\rho$; thus this plot projects the region of the Dalitz plot most sensitive to the $\rho$ contribution. The value of $0.31^{+0.20}_{-0.14}$ for the ratio $B(D^0 \to K^-\rho^+)/B(D^0 \to K^-\pi^+\pi^0)$ compares to the earlier value of $0.85^{+0.11}_{-0.15}$.[1] Combining this fraction with the $B(D^0 \to K^-\pi^+\pi^0)$ ratio above gives a branching ratio $B(D^0 \to K^-\rho^+) = (3.2^{+2.3}_{-1.8})\%$. The low fractions quoted in Table I for the $K^{*-}\pi^+$ and $\bar{K}^{*0}\pi^0$ contributions agree with the earlier experiment. Branching ratios listed in Table I for the $D^0 \to K^*\pi$ modes take into account the branching ratios for $K^* \to K\pi$ decay.

One of the crucial problems in the study of $D$ decays is to determine whether the dominant mode is one in which the light quark is a spectator, or one in which both the quark and antiquark couple to the weak vertex. If the non-spectator-quark decay dominates ($W$ exchange), the $D^+$ lifetime is longer than the $D^0$, since the only such modes available to the $D^+$ are Cabibbo suppressed. The non-spectator-quark diagram leads to an $I = \frac{1}{2}$ final state, although an $I = \frac{1}{2}$ state does not rule out spectator-quark decay. The $I = \frac{1}{2}$ state is characterized by the ratios

$$\frac{B(D^0 \to K^-\pi^+)}{B(D^0 \to \bar{K}^0\pi^0)} = \frac{B(D^0 \to K^{*-}\pi^+)}{B(D^0 \to \bar{K}^{*0}\pi^0)} = \frac{B(D^0 \to K^-\rho^+)}{B(D^0 \to \bar{K}^0\rho^0)} = 2.$$

Existing data for the first two channels were consistent with the ratio of 2, but the measurements for the last ratio were $B(D^0 \to K^-\rho^+) = (7.2^{+3.0}_{-3.1})\%$ and $B(D^0 \to \bar{K}^0\rho^0) = (0.1^{+0.6}_{-0.1})\%$.[1] For a pure $I = \frac{1}{2}$ state, one expects $B(D^0 \to K^-\rho^+) = 2 \times B(D^0 \to \bar{K}^0\rho^0) = (0.2^{+1.2}_{-0.2})\%$. The present measurement, $B(D^0 \to K^-\rho^+) = (3.2^{+2.3}_{-1.8})\%$, is consistent with that expectation.

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