Measurement of the Branching Fraction for $D^+ \to K^-\pi^+\pi^+$

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(Received 17 January 1994)

Using the CLEO II detector at the Cornell Electron Storage Ring we have measured the ratio of branching fractions, $\mathcal{B}(D^+ \to K^-\pi^+\pi^+)/\mathcal{B}(D^0 \to K^-\pi^+) = 2.35 \pm 0.16 \pm 0.16$. Our recent measurement of $\mathcal{B}(D^0 \to K^-\pi^+)$ then gives $\mathcal{B}(D^+ \to K^-\pi^+\pi^+) = (9.3 \pm 0.6 \pm 0.8)\%$.

PACS numbers: 13.25.Ft, 14.40.Lb

0031-9007/94/72(15)/2328(4)$06.00

The decay $D^+ \to K^-\pi^+\pi^+$ is the most commonly used mode for normalizing D^+ yields, since it has a relatively large branching fraction and is one of the simplest to reconstruct. A precise measurement of this branching fraction sets the overall scale for all D^+ branching fractions, and is thus a necessary quantity for reactions which involve D^+ mesons, e.g., charm production cross sections and measurement of form factors involved in D^+ semileptonic decays. In addition, measurements of B meson branching fractions containing a D^+ in the final state are also dependent on a precise determination of $\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$. Many of the current charm and bottom meson decay results are systematically limited by the precision of $\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$. Previous measurements of this decay mode were performed by the Mark III [1] and ACCMOR [2] Collaborations. Mark III used the relative number of singly detected $D^\pm$ mesons to the number of reconstructed D^+D^- events to determine the branching fraction. The ACCMOR Collaboration measured the ratio of $D^+ \to K^-\pi^+\pi^+$ relative to the total number of 3-prong decays, and used topological branching ratios determined by other experiments to obtain a branching fraction. However, ACCMOR could not easily distinguish D^+, D_s^+, and Λ_c^+ decay vertices, and had to rely on estimates of the relative production ratios of these particles. In this analysis, we use the exclusive yields, $N_{K\pi}$ and $N_{K\pi\pi}$, of the $(D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+)$ and the $(D^{*+} \to D^+\pi^0, D^+ \to K^-\pi^+\pi^+)$ decay sequences, respectively, to measure the ratio, $\mathcal{B}(D^+ \to K^-\pi^+\pi^+)/\mathcal{B}(D^0 \to K^-\pi^+)$, and apply our measurement of the branching fraction for $\mathcal{B}(D^0 \to K^-\pi^+)$ [3] to obtain $\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$.

The data used in this analysis consist of 1.79 fb^{-1} of e^+e^- collisions recorded with the CLEO II detector operating at the Cornell Electron Storage Ring (CESR). The CLEO II detector has been described in detail elsewhere [4]. Data were recorded at the $\Upsilon(4S)$ resonance and in the continuum both below and above (the e^+e^- center of mass energies ranged from 10.52 to 10.70 GeV).

We obtain clean samples of D^* mesons by requiring the π^0 and the π^+ emitted in their decays to fulfill strict selection criteria. To reconstruct π^0's, we start with neutral showers which satisfy isolation cuts and cannot be matched to any charged track in the event. These photon candidates must have $|\cos\theta_\gamma| \leq 0.71$ (θ_γ is the polar angle measured relative to the beam axis) to ensure that they lie in that portion of the electromagnetic calorimeter which has the best efficiency and resolution, and the least systematic uncertainty. In addition, photon energies have to be greater than 30 MeV. We then kinematically constrain $\gamma\gamma$ combinations with masses between 125 and 145 MeV/c^2 to the known π^0 mass to improve the momentum resolution. To reduce $\gamma\gamma$ combinatoric background, π^0 candidates are required to have momenta greater than 200 MeV/c. In addition, the kinematically constrained π^0 candidates must have $|\cos\theta_{\pi^0}| \leq 0.70$. Charged pions are selected if they have momentum greater than 200 MeV/c, and $|\cos\theta_{\pi^\pm}| \leq 0.70$. The polar angle cuts on π^+'s and π^0's ensure that D^{*+} mesons reconstructed with either charged or neutral pions have the same geometric acceptance.

The ratio $N_{K\pi\pi}/N_{K\pi}$ of the measured yields can be expressed in terms of branching ratios and efficiencies as

$$\frac{N_{K\pi\pi}}{N_{K\pi}} = \frac{N_{D^{*+}}\mathcal{B}(D^{*+} \to D^+\pi^0)\mathcal{B}_{K\pi\pi}\epsilon_{K\pi\pi}}{N_{D^{*+}}\mathcal{B}(D^{*+} \to D^0\pi^+)\mathcal{B}_{K\pi}\epsilon_{K\pi}}, \tag{1}$$

where $\mathcal{B}_{K\pi\pi}$ and $\mathcal{B}_{K\pi}$ are the relevant D^+ and D^0 branching fractions, respectively. The total number of D^{*+}'s produced in the data sample is $N_{D^{*+}}$ (which cancels in the ratio); $\epsilon_{K\pi\pi}$ and $\epsilon_{K\pi}$ are the efficiencies for reconstructing $D^+ \to K^-\pi^+\pi^+$ and $D^0 \to K^-\pi^+$, respectively, with their respective D^{*+} tags. Using isospin invariance, the CLEO II measurements of the D^{*+}-D^+ and D^{*+}-D^0 mass differences [5], and the fact that these decays are p wave, we estimate the ratio [6]

$$\frac{\mathcal{B}(D^{*+} \to \pi^+D^0)}{\mathcal{B}(D^{*+} \to \pi^0D^+)} = 2.21 \pm 0.07. \tag{2}$$

The efficiencies in Eq. (1) include the efficiency of reconstructing the D decay, as well as the efficiency for the slow pion emitted in the D^* decay. The D reconstruction efficiency is reliably simulated by the Monte Carlo because the main cuts on the D daughters are geometric. It is harder to simulate the efficiencies to detect the slow neutral and charged pions, since the efficiency for detecting charged tracks varies rapidly at low momentum [7], and the π^0 efficiency is known only to ±5%. We have checked the slow charged and neutral pion efficiencies from the data in several ways. The ratio of branching fractions for $\eta \to \pi^0\pi^0\pi^0$ and $\eta \to \gamma\gamma$ as measured in our data sample has been compared with the world average [8] to obtain an estimate of the accuracy of the photon finding efficiency. We find that this efficiency is simulated to an accuracy of ±2.5%. We have studied the charged particle tracking by comparing the yield of fully reconstructed $D^0 \to K^-\pi^+\pi^0$ with partially reconstructed $D^0 \to K^-\pi^0(\pi^+)$, where the π^+ is not detected. This check shows that the charged pion efficiency is simulated to a precision which is better than ±2%.

In addition, we have directly checked the ratio of slow neutral and charged pion efficiencies, $\epsilon_{\pi^0}/\epsilon_{\pi^+}$, from the data. Using yields for $D^{*+(0)} \to D^0\pi^{+(0)}$, where $D^0 \to K^-\pi^+$, we have measured the ratio of inclusive D^{*+} and D^{*0} production cross section in the continuum to be 1.06 ± 0.09. This result is consistent with unity, which is expected since the D^*'s are not being produced near threshold and the D^{*+}-D^{*0} mass difference is negligible compared to the center of mass energy. We have also studied this ratio by using the decays $\eta \to \pi^+\pi^-\pi^0$ and $K_s^0 \to \pi^+\pi^-, \pi^0\pi^0$; here we find that the Monte Carlo estimate for $\epsilon_{\pi^0}/\epsilon_{\pi^+}$ is 0.96 ± 0.05 times the value extracted from data. In summary, all our checks of the estimate for $\epsilon_{\pi^0}/\epsilon_{\pi^+}$ show that there is good agreement between Monte Carlo simulation and data. We assign a systematic error of ±5.4% due to this efficiency ratio in the final results.

We now determine the exclusive yields and reconstruction efficiencies used in Eq. (1). The D^+ is reconstructed by requiring the K^- and π^+ tracks to have $|\cos\theta| \leq 0.81$, and to have momenta greater than 200 MeV/c. In Fig. 1 we present the invariant mass distribution of $K^-\pi^+\pi^+$ combinations, for which the mass difference, $\Delta_{M^0} = M_{K^-\pi^+\pi^+(\pi^0)} - M_{K^-\pi^+\pi^+}$, is within ± 5 MeV/c^2 of the value expected for $M_{D^{*+}} - M_{D^+}$. Using two Gaussians for the signal and a first order polynomial for the background, we obtain 1618 ± 91 events. To account for true D^+–random-π^0 combinations, which would peak in the D^+ mass plot but not in the mass difference plot, we also fit the Δ_{M^0} sidebands. Subtracting the Δ_{M^0} sideband contribution from the signal region yield gives the number of true $D^{*+} \to D^+\pi^0$ events. We observe 116 ± 40 events in the scaled sideband [9]. After subtraction, the net yield is 1502 ± 99 events. The efficiency $\epsilon_{K\pi\pi}$ is estimated from Monte Carlo simulation to be $(15.4 \pm 0.2)\%$.

The D^0 is tagged using the $D^{*+} \to D^0\pi^+$ decay, and is reconstructed by requiring the K^- and π^+ tracks to have $|\cos\theta| \leq 0.81$, and to have momenta greater than 200 MeV/c. In Fig. 2 we present the invariant mass distribution of $K^-\pi^+$ combinations, where the mass difference, $\Delta_{M^+} = M_{K^-\pi^+(\pi^+)} - M_{K^-\pi^+}$, is within ± 5 MeV/c^2 of the value expected for $M_{D^{*+}} - M_{D^0}$. Using two Gaussians for the signal and a first order polynomial for the background, we obtain 5555 ± 102 events. A fit to the Δ_{M^+} sidebands yields 103 ± 21 events [9]. The net yield is 5452 ± 104 events. The efficiency $\epsilon_{K\pi}$ is estimated to be $(59.5 \pm 0.6)\%$.

Substituting the exclusive yields, the efficiencies for reconstructing these final states, and the known ratio of $D^{*+} \to D\pi$ branching fractions in Eq. (1), we obtain

$$\frac{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)}{\mathcal{B}(D^0 \to K^-\pi^+)} = 2.35 \pm 0.16 \pm 0.16, \tag{3}$$

where the first error is statistical and the second is an estimate of the systematic uncertainty. The systematic error includes the uncertainty on the ratio of $D^{*+} \to D\pi$ branching fractions (±3.2%), the error due to $\epsilon_{\pi^0}/\epsilon_{\pi^+}$ (±5.4%), the error due to Monte Carlo statistics (±1.6%), and the uncertainty from the effects of resonant substructure on the $K\pi\pi$ final state (±1.3%). Using our measurement [3], $\mathcal{B}(D^0 \to K^-\pi^+) = (3.95 \pm 0.08 \pm 0.17)\%$, we obtain

$$\mathcal{B}(D^+ \to K^-\pi^+\pi^+) = (9.3 \pm 0.6 \pm 0.8)\%. \tag{4}$$

This result accounts for the effects of decay radiation in the final state, because we have used the radiatively corrected value for $\mathcal{B}(D^0 \to K^-\pi^+)$ [10]. The determination of statistical and systematic errors is described above. The systematic error also includes the error in our measurement of $\mathcal{B}(D^0 \to K^-\pi^+)$.

In conclusion, using yields of $D^+ \to K^-\pi^+\pi^+$ and $D^0 \to K^-\pi^+$, which have been tagged via $D^{*+} \to D\pi$ decays, and our measurement of $\mathcal{B}(D^0 \to K^-\pi^+)$ [3], we obtain $\mathcal{B}(D^+ \to K^-\pi^+\pi^+) = (9.3 \pm 0.6 \pm 0.8)\%$. This result agrees well with the Mark III measurement, $(9.1 \pm 1.3 \pm 0.4)\%$ [1], but is larger than the ACCMOR result, $(6.4 \pm 1.5)\%$ [2].

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation, the U.S. Department of Energy, the

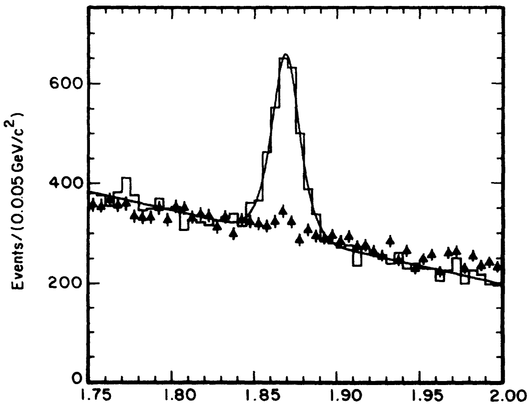

FIG. 1. Mass distribution for $D^+ \to K^-\pi^+\pi^+$ candidates tagged via $D^{*+} \to D^+\pi^0$ decays; the histogram represents events in the mass difference signal region; triangles with error bars represent events in the (scaled) mass difference sideband region. The solid line is the fit to the data.

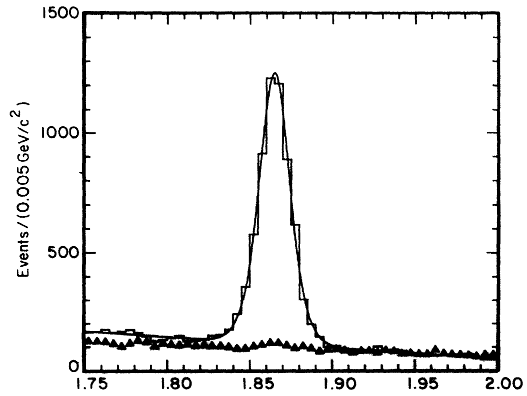

FIG. 2. Mass distribution for $D^0 \to K^-\pi^+$ tagged via $D^{*+} \to D^0\pi^+$ decays; the histogram represents events in the mass difference signal region; triangles represent events in the (scaled) mass difference sideband region. The solid line is the fit to the data.

SSC Fellowship of TNRLC, the Heisenberg Foundation, and the A.P. Sloan Foundation.

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[7] The average momentum for slow pions emitted in D^* decays which pass the selection criteria is approximately 260 MeV/c, whereas the average momenta of the D decay daughters is approximately 1.3 GeV/c for D^+ and 1.7 GeV/c for D^0. The efficiency for reconstructing kaons and pions from D decays is known to an accuracy of ±2% [3].

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[9] The scale factor is such that the number of events in the sideband region is the same as the number of events in the background under the mass difference signal. We investigated different mass difference sidebands to estimate the systematic error associated with this technique. The yields quoted in the text are obtained from the sideband where the D^{*+}-D mass difference is in the range 146.6–155.6 MeV/c^2 for D^{*+}-D^+, and 151.4–160.4 MeV/c^2 for D^{*+}-D^0.

[10] The effect of final state decay radiation on $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ is to reduce their reconstruction efficiencies by approximately 1%. Therefore, the ratio of the two efficiencies, $\epsilon_{K\pi}$ and $\epsilon_{K\pi\pi}$, is very insensitive to the effects of decay radiation. We used the program PHOTOS to estimate these effects [E. Barberio, B. van Eijk, and Z. Was, Comput. Phys. Commun. **66**, 115 (1991)].