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A Measurement of $\mathcal{B}(D^0 \to K^-\pi^+\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+)$

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Abstract

Using a sample of 3.1 fb^{-1} integrated luminosity accumulated with the CLEO II detector at the Cornell Electron Storage Ring, we measure the ratio of branching fractions $\mathcal{B}(D^0 \to K^-\pi^+\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+) = 3.81 \pm 0.07 \pm 0.26$, the most precise determination of this quantity to date.

13.20.Fc,13.25.-k,13.25.Ft,14.40.Lb

Precision studies of the hadronic decays of charmed mesons are important for a variety of reasons. In the case of simple, yet relatively common, decay modes such as $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+\pi^0$ [1], precise knowledge of the total branching fractions is important since many B physics analyses depend on these to extract meaningful results. Any uncertainty in the charm decays will translate directly into larger systematic errors for the heavier quark analyses. These modes are also used as normalization for many charmed meson branching ratio measurements, in particular $D^0 \to K^-\pi^+\pi^0$ is a useful reference for other channels involving a π^0 in the final state.

Past determinations of the ratio of branching fractions $R = \mathcal{B}(D^0 \to K^-\pi^+\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+)$ are shown in Table 1 [2–7]. There are two hints that suggest the current world average value of this ratio may be too low. First, the PDG average and fitted values are not in good agreement [8]. Second, in studies [9] of the decay of B mesons to charmed final states, the measured B branching ratios are consistently higher when the D^0 is reconstructed in the $K^-\pi^+\pi^0$ decay than when the $K^-\pi^+$ mode is used.

ARGUS [2]	1992	$3.04 \pm 0.16 \pm 0.34$
NA14 [3]	1991	$4.0 \pm 0.9 \pm 1.0$
CLEO 1.5 [4]	1991	$2.8 \pm 0.14 \pm 0.52$
Mark III [5]	1988	$3.17 \pm 0.42 \pm 43$
E516 [6]	1984	4.2 ± 1.4
Mark II [7]	1981	2.85 ± 1.13
PDG Ave.		3.07 ± 0.29
PDG Fit		3.51 ± 0.28

Table 1. Previous measurements of $\mathcal{B}(D^0 \to K^-\pi^+\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+)$. Mark II and Mark III results were reported as absolute branching fractions. The systematic error shown here for Mark III is the sum in quadrature of the systematic errors of the two branching fractions.

In this analysis we use an integrated luminosity of 3.1 fb^{-1} of e^+e^- collisions accumulated with the CLEO II detector at the Cornell Electron Storage Ring (CESR), running at center of mass energies at or just below the $\Upsilon(4S)$ resonance. Details of the CLEO II detector are described elsewhere [10].

To reconstruct $D^0 \to K^-\pi^+$ decays we consider all pairs of well-fitted oppositely-charged tracks. When reconstructing $D^0 \to K^-\pi^+\pi^0$ decays we include two electromagnetic showers each with energy above 100 MeV to form the π^0 candidate. To reduce the rate of fake π^0's from random shower combinations and to increase the resolution, we require that both showers be in the central region of our detector [11], and neither shower be near any charged tracks entering the calorimeter. The invariant mass of the two photons is required to be between 115 MeV/c and 155 MeV/c ($\approx 3.5\sigma$). To improve the measurement of the π^0 4-vector, the two photons are kinematically fitted to the known π^0 mass.

The D^0 mesons are required to be produced via the decay $D^{*+} \to D^0\pi^+$. Reconstructing this decay sequence provides additional kinematic information which allows us to reduce the combinatoric background significantly. In addition, for the dominant Cabibbo favored $D^0 \to K^-\pi^+(\pi^0)$ mode, the "slow" pion from the D^{*+} decay is known to have the same charge as the pion from the decaying D^0, allowing us to assign masses to the D^0 daughter tracks without the use of extra particle identification information.

We reconstruct the D^{*+} by combining "slow" pion candidates, having momentum between between 225 MeV/c and 425 MeV/c, with all D^0 candidates. We require the measured mass difference, $\Delta M = M(D^{*+}) - M(D^0) - 145\mathrm{MeV}/c^2$, to be within 2.5 σ of the accepted value (-1.92 MeV/c^2 and 1.92 MeV/c^2) as shown in Fig. 1. Data in a mass difference sideband (6.0 to 9.5 MeV/c^2) are used to estimate the rate of fake $D^{*+} \to D^0\pi^+$ decays.

We compute the scaled momentum x_{D^*} of the D^*, defined as the measured momentum of the D^* divided by the maximum possible D^* momentum, $p^2_{\max} = E^2_{beam} - M^2_{D^*}$, and require that $x_{D^*} > 0.6$. Since most of the combinatoric background is at low values of x_{D^*}, and the D^* mesons are produced with a hard fragmentation spectrum, using this cut, dramatically reduces the background as well as restricting our analysis to continuum $e^+e^- \to c\bar{c}$ reactions.

Combinations of particles which pass the above cuts are shown in Figs. 2 and 3. In both figures we see a large number of events in the D^0 signal region. We fit the D^0 mass peak with the sum of two bifurcated Gaussians [12]. The background is fit between 1.7 and 2.0 GeV with a straight line. After making the sideband subtraction the fitted yields were 15,013 $\pm$ 204 events for $D^0 \to K^-\pi^+\pi^0$ and 9,808 $\pm$ 127 events for $D^0 \to K^-\pi^+$.

Large samples of GEANT [13] based Monte Carlo $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ ($D^0 \to K^-\pi^+\pi^0$) events were analyzed to determine the reconstruction efficiency of these modes to be 20.4% and 8.2% respectively. The $D^0 \to K^-\pi^+\pi^0$ Monte Carlo included the resonant substructure of the three body decay using published amplitudes [14].

Using the yields found from data and the above efficiencies, we find the ratio of branching fractions to be $R = 3.81 \pm 0.07$ where the error shown is only statistical.

To obtain an estimate of the systematic errors associated with the above ratio, several potential sources were explored. Using Monte Carlo, we looked at the variation in the efficiency for $D^0 \to K^-\pi^+\pi^0$ as a function of the details of the resonant substructure. Using other measurements of the resonant substructure [15,16], we assign a 3.4% systematic error.

To investigate the fitting procedure, we start by varying the sideband in ΔM and find a change of 0.3% in R. We also fit the signal with a larger background window and a second order polynomial and find a similar change. Changing the signal fitting function to a single Gaussian, a bifurcated Gaussian, a double Gaussian, a bifurcated double Gaussian or a bifurcated double Gaussian with the shape constrained by the detector simulation Monte Carlo changes R by less than 1.5%. Extracting the signal yields from the ΔM distribution instead from the D^0 mass plot also produces less than 1.5% variation in the final ratio.

We have also varied the cuts used in the analysis. When the mass difference requirements are tightened to be within 1.25 MeV/c^2 of the nominal mass difference value (about 1.5σ), we observe a 0.8% change in the ratio.

From a study of the decays $\eta \to \gamma\gamma$ and $\eta \to \pi^0\pi^0\pi^0$, we assign a 5.5% systematic error for uncertainty in the overall π^0 finding efficiency.

Sources of Systematic Error	
Monte Carlo Statistics	1.7 %
π^0 finding efficiency	5.5 %
$K^-\pi^+\pi^0$ resonant substructure	3.4 %
Fitting	1.5 %
$M(D^{*+}) - M(D^0)$ cut	0.8 %
Total	6.9 %

Table 2. Sources of systematic uncertainty as described in the text.

Table 2 summarizes the investigated sources of systematic error and the contribution of each to the ratio of branching fractions. We add these in quadrature to arrive at an estimate of the total systematic error of 6.9%.

Summarizing the above results we obtain a measurement of the ratio of branching fractions

$$R = \frac{\mathcal{B}(D^0 \to K^-\pi^+\pi^0)}{\mathcal{B}(D^0 \to K^-\pi^+)} = 3.81 \pm 0.07 \pm 0.26.$$

This measurement, with about 15,000 (10,000) events in the $K^-\pi^+\pi^0$ ($K^-\pi^+$) peak, is the most precise determination of the ratio to date. We combine this result with CLEO's recent measurement of the absolute branching fraction $\mathcal{B}(D^0 \to K^-\pi^+) = 0.0391 \pm 0.0008 \pm 0.0017$ [17] to extract the branching ratio

$$\mathcal{B}(D^0 \to K^-\pi^+\pi^0) = 0.149 \pm 0.004 \pm 0.012$$

which is comparable in both magnitude and uncertainty to the current Particle Data Group [8] best fit value for this mode of $\mathcal{B}(D^0 \to K^-\pi^+\pi^0) = 0.135 \pm 0.011$.

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[11] $|\cos\theta| < 0.71$ where θ is the angle between the beam direction and the direction of the shower from the interaction point.

[12] A bifurcated Gaussian has two σ's, one for the width above the mean and the other for the width below the mean. In the case of the double bifurcated Gaussian we constrain the mean and ratio of the left and right σ's to be identical for both Gaussians.

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FIGURES

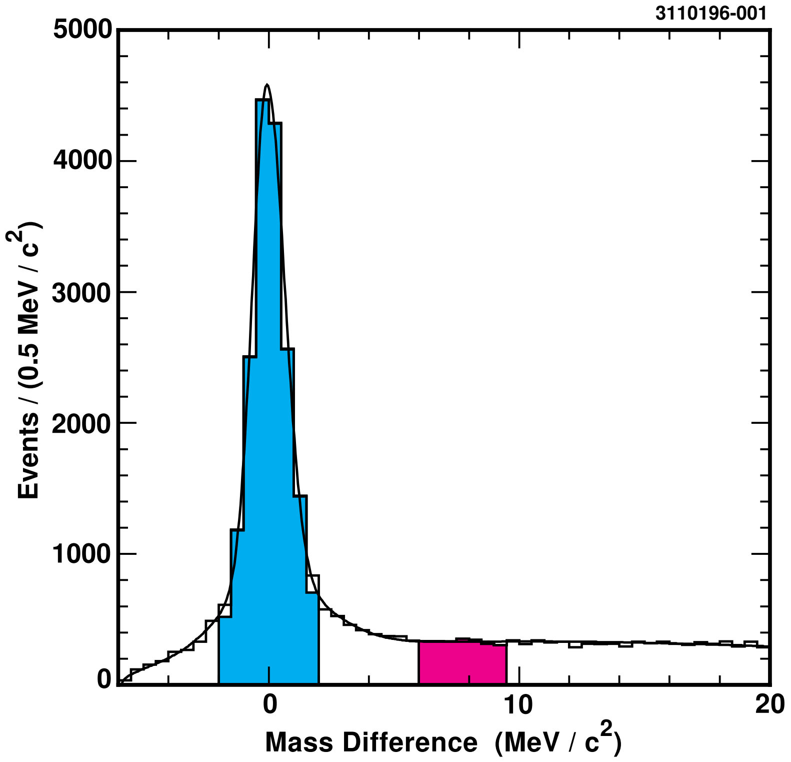

FIG. 1.

The mass difference $\Delta M = M(D^{*+}) - M(D^0) - 145\mathrm{MeV/c}^2$ for the $D^0 \to K^-\pi^+\pi^0$ mode. The shaded area represents the signal region and the filled area is the sideband region

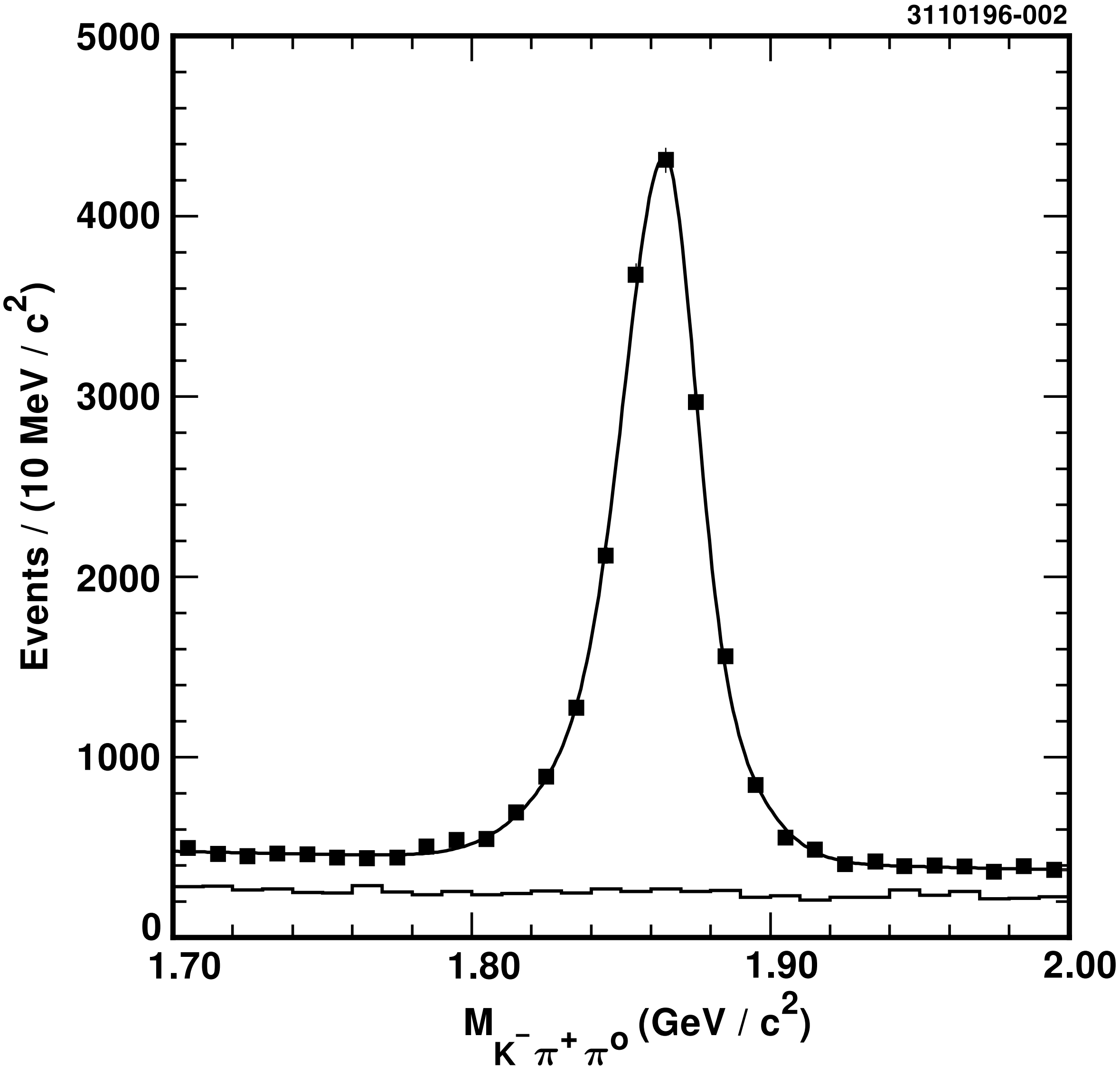

FIG. 2.

The $K^-\pi^+\pi^0$ invariant mass spectrum for selected events The fitted points are the mass difference signal region and the solid histogram is from the mass difference sideband. The failure of the sideband data to saturate the background is due to fake combinations of slow pions from real D^{*+} decays with fake $D^0 \to K^-\pi^+\pi^0$ candidates.

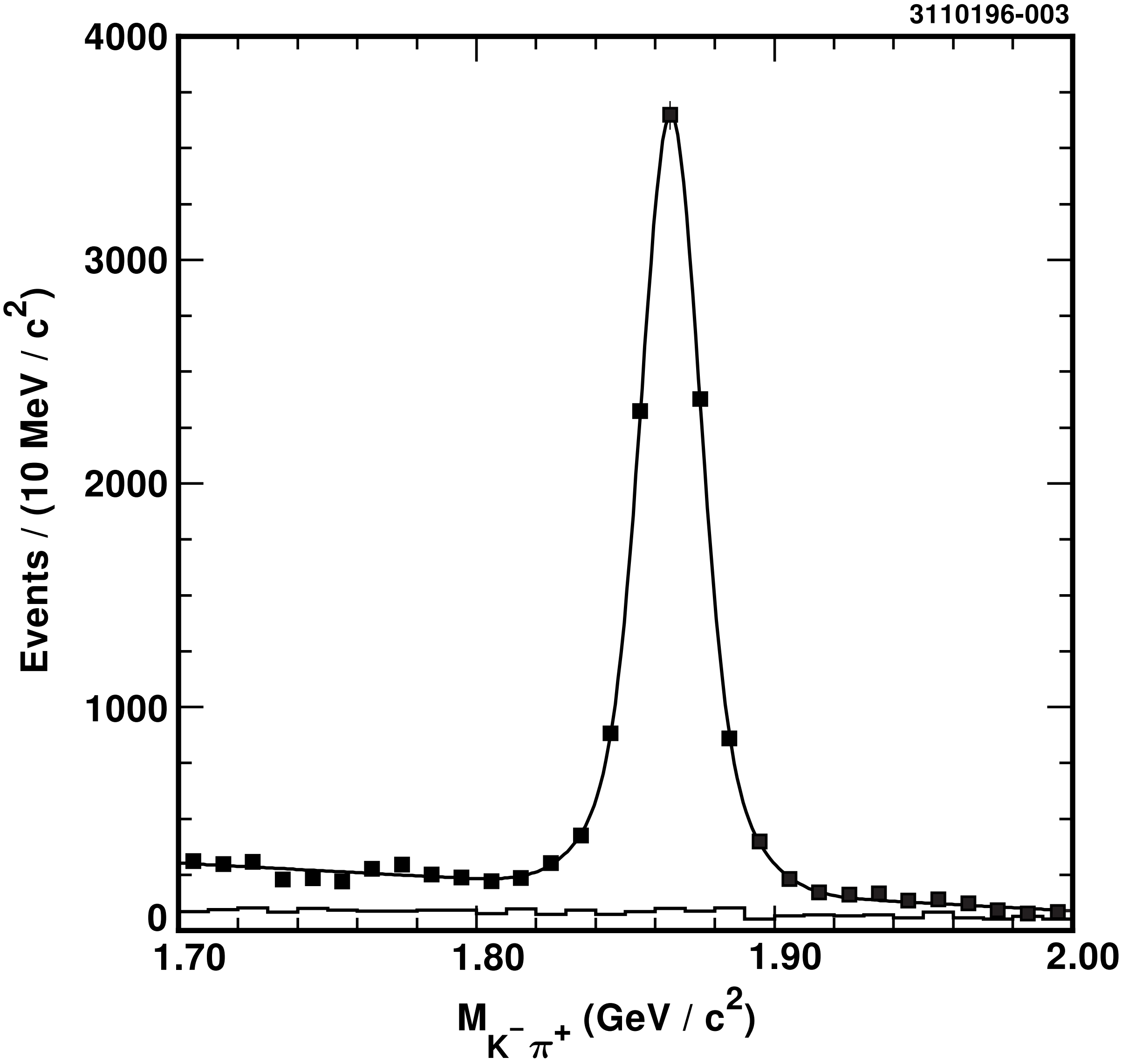

FIG. 3.

The $K^-\pi^+$ invariant mass spectrum for selected events The fitted points are the mass difference signal region and the solid histogram is from the mass difference sideband. The failure of the sideband data to saturate the background is due to fake combinations of slow pions from real D^{*+} decays with fake $D^0 \to K^-\pi^+$ candidates.