Measurement of the Absolute Branching Fractions for D^0 Decays into $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$, $\overline{K^0}\pi^+\pi^-$

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Abstract

Using the ARGUS detector at the e^+e^- storage ring DORIS II we have measured the absolute branching ratios of the D^0 meson, $Br(D^0 \to K^-\pi^+) = (3.41 \pm 0.12 \pm 0.28)\%$, $Br(D^0 \to K^-\pi^+\pi^+\pi^-) = (6.80 \pm 0.27 \pm 0.57)\%$, and $Br(D^0 \to \overline{K^0}\pi^+\pi^-) = (5.03 \pm 0.39 \pm 0.49)\%$.

The $D^0 \to K^-\pi^+$ and $D^0 \to K^0_S\pi^+\pi^-$ decay modes are commonly used for normalizing other D^0 branching ratios. A precise measurement of these modes is necessary to improve the measurements of many D^0 branching ratios, as well as inclusive and exclusive B meson branching ratios, where the systematic error mainly consists of the uncertainty in Br($D^0 \to K^-\pi^+$).

In this paper we present a measurement of the absolute branching ratios for the $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$, $K^0_S\pi^+\pi^-$ decay channels[1] using a method similar to the one previously employed by HRS [1] and ALEPH [2]. In this approach, first the total number of D^0 mesons produced in the decay $D^{*+} \to D^0\pi^+$ is determined using a partial reconstruction technique. Subsequent reconstruction of the exclusive decay chains $D^0 \to K^-\pi^+, K^-\pi^+\pi^+\pi^-, K^0_S\pi^+\pi^-$ yields the numbers of D^0 decays of interest, thus allowing a measurement of the absolute branching ratios.

The data sample used for the analysis corresponds to an integrated luminosity of 355 pb^{-1} obtained with the ARGUS detector at the DORIS II storage ring while running on the $\Upsilon(4S)$ resonance and in the nearby continuum. The ARGUS detector is a 4π spectrometer described in detail elsewhere [3]. Charged particles are identified by coherently combining available information from several detector components into a likelihood ratio for each of the particle species e,μ,π,K and p. All particle hypotheses with a likelihood value in excess of 1 % were accepted. Energy clusters in the calorimeter of more than 80 MeV were considered as photons, if they were not associated with a charged track. K^0_S mesons were reconstructed from $\pi^+\pi^-$ pairs forming a secondary vertex [3]. An event selection cut on the total multiplicity $N_{tot} = N_{ch} + N_\gamma/2 \geq 6$ is applied to suppress contributions from QED and $\tau\tau$ processes, where N_{ch} is the charged multiplicity and N_γ is the neutral multiplicity.

D^{*+} mesons are produced copiously in the fragmentation of charmed quarks in the continuum process $e^+e^- \to c\overline{c}$. These D^{*+} have a hard momentum spectrum and therefore their direction coincides closely with the jet axis. The available energy, Q, in the $D^{*+} \to D^0\pi^+$ decay is only 6 MeV so that the angle between the D^* flight direction and the pion momentum vector and hence the angle between the jet axis and the pion momentum vector is also small. Therefore for $D^{*+} \to D^0\pi^+$ we expect $\cos\Theta$ close to unity, where Θ is the angle between the jet axis and the pion momentum vector. The uncorrelated background distribution is expected to have a smooth behaviour near $\cos\Theta = 1$, which can be checked using data.

The jet axis was defined to be the thrust axis of the event. In order to eliminate the influence of specific D^0 decay channels on the determination of this axis it was determined in the following way. Each event was divided into two hemispheres by the plane perpendicular to the thrust axis calculated for the whole event. The thrust axis was then calculated independently for each hemisphere and the distribution of the angle Θ between the momentum of a pion from one hemisphere and the thrust axis determined from the particles in the opposite hemisphere was studied.

[1] References to a specific particle state imply also the charge-conjugate state, except where stated otherwise.

The $\cos\Theta$ distribution is shown in Figure 1 for two intervals of the pion momentum: $0.2 < p_\pi < 0.3\ GeV/c$ and $0.4 < p_\pi < 0.5\ GeV/c$. We attribute most of the peak in Figure 1a to the $D^{*+} \to D^0\pi^+$ decay. The smooth distribution in Figure 1b was obtained for pions with $0.4 < p_\pi < 0.5\ GeV/c$ which is above the kinematic limit for pions from D^{*+} mesons, produced in e^+e^- annihilation at a center of mass energy of 10 GeV. Pions with $p_\pi < 0.2\ GeV/c$ were excluded from the analysis in order to suppress the contribution from the decay chain $B \to D^{*+}X$, $D^{*+} \to D^0\pi^+$. This contribution was suppressed because no good jet axis can be defined for such events. The number of $D^{*+} \to \pi^+D^0$ decays was obtained by fitting the $\cos\Theta$ distribution shown in Figure 1a.

To determine the shape of the signal the same distribution for completely reconstructed D^{*+} mesons was obtained. D^{*+} mesons were reconstructed in the $D^{*+} \to D^0\pi^+$ decay channel followed by $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$, $K^0_S\pi^+\pi^-$ decays. D^0 candidates were required to have a measured mass within $\pm 50, \pm 30$, and $\pm 40\ MeV/c^2$ of the accepted D^0 mass [4] for the $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$, and $K^0_S\pi^+\pi^-$ channels, respectively. A kinematic fit was then applied which constrained the mass to the D^0 mass. Fitted D^0 candidates were combined with appropriately charged pions with momenta $0.2 < p_\pi < 0.3\ GeV/c$ as in the inclusive analysis. For each D^0 decay channel the $D^0\pi^+$ invariant mass distribution was fitted in bins of $\cos\Theta$ to get the shape of the signal.

The $D^0\pi^+$ invariant mass distributions are shown in Figure 2. The spectra were fitted with the sum of a Gaussian and a second-order polynomial times a square root threshold factor, to parametrize the background. The width of a Gaussian was fixed to 1 MeV/c^2, the resolution was determined from Monte Carlo study. The fit gives 1173 ± 37, 1430 ± 52, and 284 ± 22 D^{*+} mesons for the $K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$ and $K^0_S\pi^+\pi^-$ modes, respectively. The systematic error reflects uncertainties in signal and background shapes and ranges from 2.6% for $D^0 \to K^-\pi^+$ to 6% for $D^0 \to K^-\pi^+\pi^-\pi^+$. The efficiencies for D^0 reconstruction were found to be 0.67 ± 0.03 , 0.41 ± 0.02, and 0.110 ± 0.006 for the $K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, and $K^0_S\pi^-\pi^+$ channels, respectively.

The $\cos\Theta$ distributions obtained for the three D^0 meson decay channels are consistent within experimental errors and have been averaged. The averaged distribution was fitted with a third order inverse polynomial times an exponential function. The result of the fit is shown in Figure 3. The possible influence of specific D^0 decay channels on the shape of the $\cos\Theta$ distribution was studied with Monte Carlo simulations. We obtained similar $\cos\Theta$ distributions for the $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, $K^0_S\pi^-\pi^+$, $K^-\pi^+\pi^0$, $X\ell^+\nu$ decay channels and for mixtures of D^0 decays, according to the BSW model [5].

In order to study the background contribution we searched for specific decays that have a peak in the signal region. Such decays should satisfy the following requirements:

1) The decaying particle must be charmed in order to have a small opening angle with the thrust direction.

2) The energy release in the decay must be small for the daughter pion to have a small opening angle with the direction of the mother particle.

The only known decay which gives a considerable contribution and satisfies these require-

ments is $\Sigma_c \to \pi\Lambda_c$. The energy release, Q, in the decay is 30 MeV in comparison with 6 MeV for $D^{*+} \to \pi^+ D^0$. The shape of the $\cos\Theta$ distribution for this process was determined from a Monte Carlo simulation and is shown in Figure 3. The absolute value of this contribution was determined from [6]. Monte Carlo studies also showed that the $\cos\Theta$ distributions for other known continuum processes have no peak at $\cos\Theta = 1$. The same was found for the analogous distribution for pions from the decay chain $B \to D^{*+}X$, $D^{*+} \to D^0\pi$.

In order to extract the number of $D^{*+} \to \pi^+ D^0$ decays the $\cos\Theta$ distribution in Figure 1a was fitted with a third order inverse polynomial to parametrize the background and the signal term described above. The fixed Σ_c contribution was included in the fit, which yielded 51327 ± 757 D^0 mesons from D^{*+} decays. There are two main contributions to the systematic error. The uncertainty in the signal shape (5.9%) was evaluated by varying fitting parameters within their errors and using different fitting functions for the signal term. The systematic error resulting from the uncertainty in the Σ_c contribution is 1.1%.

Combining the number of $D^{*+} \to \pi^+ D^0$ with the number of $D^{*+} \to \pi^+ D^0$ for the $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, and $K^0_S\pi^+\pi^-$ decay channels we find

$$\begin{aligned} Br(D^0 \to K^-\pi^+) &= (3.41 \pm 0.12 \pm 0.28)\% \\ Br(D^0 \to K^-\pi^+\pi^-\pi^+) &= (6.80 \pm 0.27 \pm 0.57)\% \\ Br(D^0 \to \overline{K^0}\pi^-\pi^+) &= (5.03 \pm 0.39 \pm 0.49)\%. \end{aligned}$$

Our results are in agreement with the world average values [4] and consistent with the recent CLEO result [7] of $\mathrm{Br}(D^0 \to K^-\pi^+) = (3.91 \pm 0.08 \pm 0.17)\%$.

In order to check the stability of the results we varied the cuts on the pion momentum, total multiplicity, minimum photon energy, and modified the thrust axis definition. The obtained values of branching ratios ranged within errors.

In summary, we have measured the absolute branching ratios of the D^0 meson, $Br(D^0 \to K^-\pi^+) = (3.41 \pm 0.12 \pm 0.28)\%$, $Br(D^0 \to K^-\pi^+\pi^+\pi^-) = (6.80 \pm 0.27 \pm 0.57)\%$, and $Br(D^0 \to \overline{K^0}\pi^+\pi^-) = (5.03 \pm 0.39 \pm 0.49)\%$ by tagging $D^{*+} \to \pi^+ D^0$ decays through the excess over the background of low momentum pions correlated with the thrust direction. Our results are in agreement with the world average values[4].

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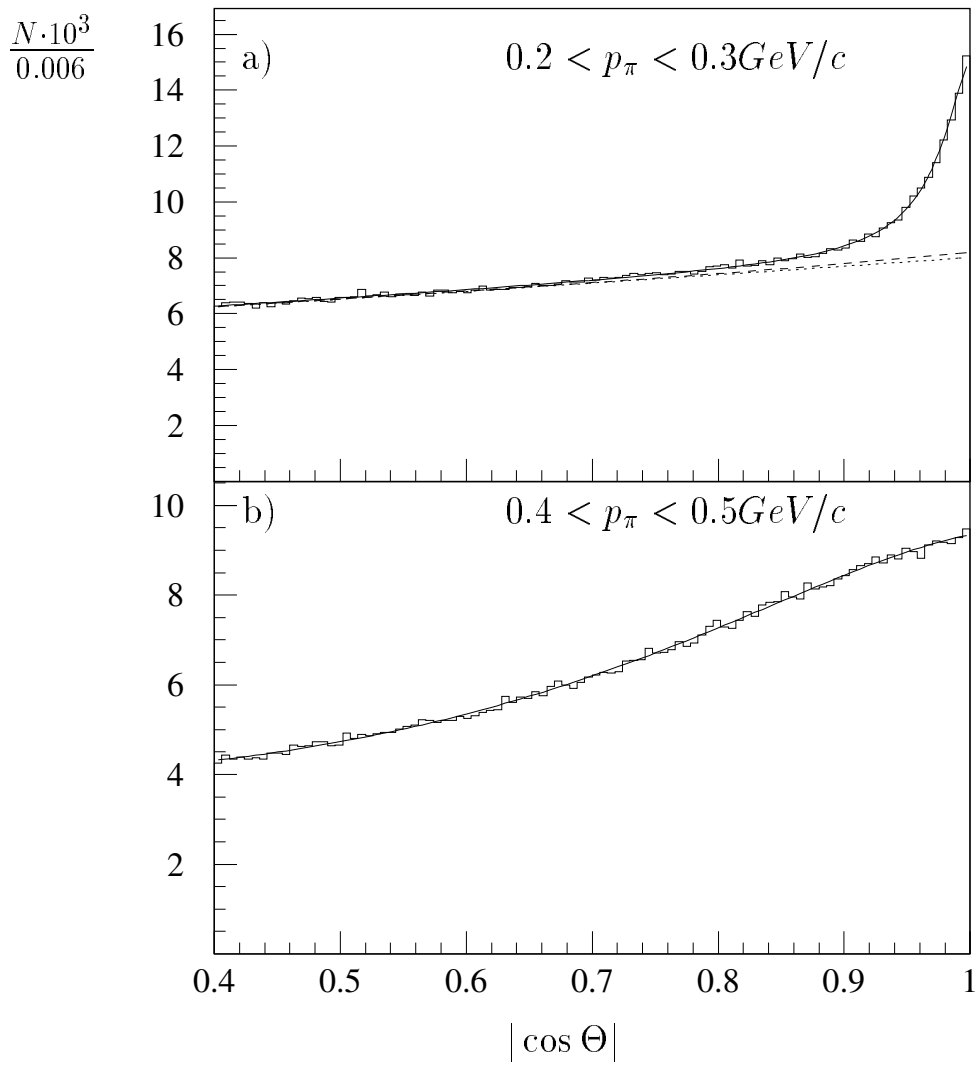

Figure 1: Distributions of $|\cos\Theta|$ for two intervals of the pion momentum. The dotted and dashed lines in Fig.1a represent background parametrization without and with the Σ_c contribution, respectively.

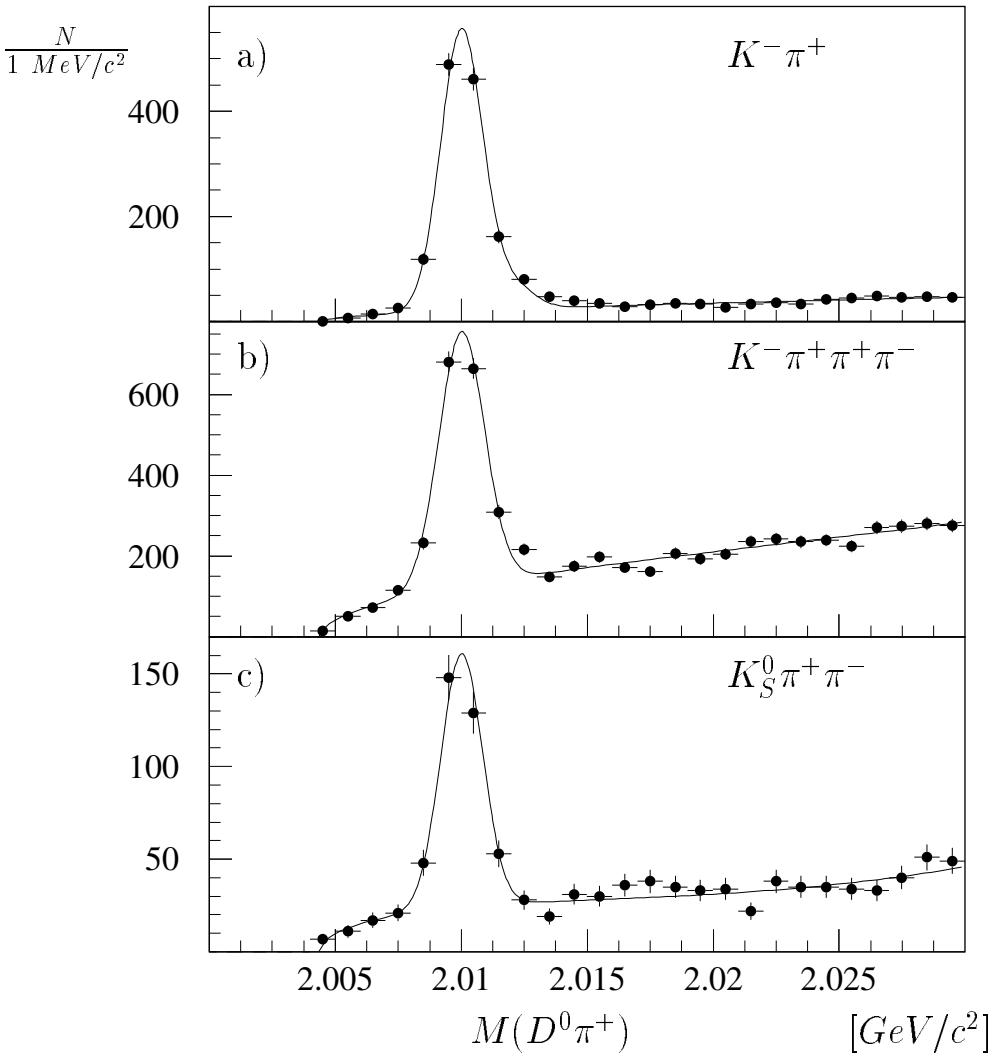

Figure 2: Invariant mass of D^0 π^+ combinations.

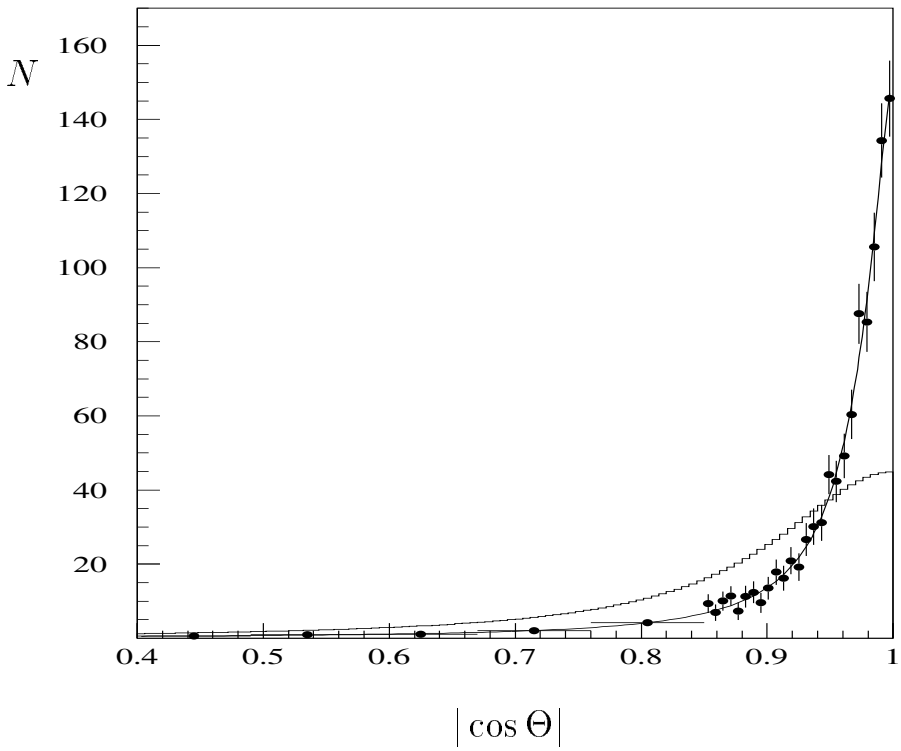

Figure 3: Averaged shape of the signal obtained from data (points with error bars) together with the Monte Carlo prediction for the Σ_c contribution (histogram). Both distributions are normalized to the same integral.