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Abstract

Using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY, we have searched for the decay $D^0 \to K^+\pi^-$. No events were observed, leading to an upper limit on $\Gamma(D^0 \to K^+\pi^-)/\Gamma(D^0 \to K^-\pi^+)$ of 0.9% at the 90% confidence level.

1 Introduction

The transition $D^0 \to K^+\pi^-$ [1] can occur either through the vacuum transition $D^0 \to \overline{D^0}$ followed by $\overline{D^0} \to K^+\pi^-$, or through a doubly Cabibbo-suppressed decay (DCSD) of the D^0 meson. $D^0 \leftrightarrow \overline{D^0}$ transitions are allowed in the Standard Model via "box" diagrams (Fig. 1) [1], but are substantially suppressed in comparison with $K^0 \leftrightarrow \overline{K^0}$ and $B^0 \leftrightarrow \overline{B^0}$ transitions. Indeed, short-distance contributions to the mixing parameter $r_D^{mix} = \Gamma(D^0 \to \overline{D^0} \to \overline{f})/\Gamma(D^0 \to f)$ are expected to be less than 10^{-8} [2]. The influence of the long-distance effects can be roughly estimated assuming that $D^0 \leftrightarrow \overline{D^0}$ transitions are mediated by pairs of pseudoscalar mesons, such as kaons or pions [3,4]. Using experimental values for $\Gamma(D^0 \to K^+K^-)$, $\Gamma(D^0 \to K^0\overline{K^0})$, $\Gamma(D^0 \to \pi^+\pi^-)$ and $\Gamma(D^0 \to \pi^0\pi^0)$ [5] , an estimate of $r_D^{mix} \sim 10^{-3}$ is derived [4]. A larger value for r_D^{mix} would signify new physics beyond the Standard Model [3,4]. Examples include flavour-changing neutral currents mediated by the exchange of a Higgs scalar with a mass of a few TeV/c^2, which could lead to r_D^{mix} as large as 0.5% [6,7].

In the framework of the Standard Model, the value for $r_{DCSD}^{K\pi} = \Gamma(D^0 \to K^+\pi^-)/\Gamma(D^0 \to K^-\pi^+)$ is proportional to $\tan^4\theta_c$, with predictions varying from 0.0027 to 0.0054 [4,8]. Current experimental bounds on $r_{DCSD}^{K\pi}$ [5,9,10] lie close to these estimates. Investigation of DCSD channels might provide a sensitive test of the Higgs sector [4].

The time evolution of the relative width for $D^0 \to K^+\pi^-$ decays is described by contributions from both mixing and DCSD:

$$r_D^{K\pi}(t) = \frac{\Gamma(D^0(t) \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} \propto r_{mix}^{K\pi}(t) + r_{DCSD}^{K\pi} + r_{int}^{K\pi}(t),$$

including an interference term

$$r_{int}^{K\pi}(t) = 2\sqrt{r_{mix}^{K\pi}(t)}\sqrt{r_{DCSD}^{K\pi}}\cos\phi$$

with unknown phase ϕ. In this expression, $r_{DCSD}^{K\pi}$ is independent of the decay time, while $r_{int}^{K\pi}(t)$ and $r_{mix}^{K\pi}(t)$ are proportional to t and t^2 respectively. $D^0 - \overline{D^0}$ mixing

[1] References in this paper to a specific charged state are to be interpreted as implying the charged-conjugate state also.

and DCSD processes can be distinguished without a time evolution analysis only in the decay of pairs of $D^0\overline{D^0}$ mesons with known relative orbital angular momentum (for example in ψ'' decays) [4,11]. The measurement of $r_D^{K\pi}$ reported here is sensitive to the sum of these contributions.

The search for $D^0 \to K^+\pi^-$ was made using D^{*+} mesons reconstructed from their daughter particles in the cascade decay $D^{*+} \to D^0\pi^+$, followed by $D^0 \to K^-\pi^+$. In this case DCSD or $D^0-\overline{D^0}$ mixing will appear as a signal in the channel $D^{*+} \to \overline{D^0}\pi^+$. The small Q-value of the D^{*+} decay results in excellent mass resolution, allowing a D^{*+} signal to be obtained with very low background. The charge of the soft pion tags whether a D^0 or $\overline{D^0}$ was produced. A value for $r_D^{K\pi}$ is determined by a comparison of the signal in the mass distribution of "wrong-sign" $D^0\pi^-$ versus "right-sign" $D^0\pi^+$ combinations

$$r_D^{K\pi} = \frac{N_{\overline{D^0}\pi^+}}{N_{D^0\pi^+}}.$$

This method minimizes systematic uncertainties and provides an almost model independent result.

2 Data analysis

The data used for this study were obtained with the ARGUS detector in the region around $\sqrt{s} = 10$ GeV on the $\Upsilon(4S)$ resonance and in the continuum, together comprising an integrated luminosity of 360 pb^{-1}. The ARGUS detector, its trigger and particle identification capabilities are described in detail elsewhere [12].

Identification of charged hadrons is based on momentum and energy loss (dE/dx) measurements in the main drift chamber and on a time-of-flight (TOF) measurement. A normalized likelihood ratio for the possible mass hypotheses e, μ, π, K, or p is calculated for each charged particle on the basis of this information [12]. For a given particle, all hypotheses with a likelihood ratio greater than 10% are accepted in this analysis. Lepton identification combines additional information from the electromagnetic calorimeter and the muon chambers in computing the likelihood ratio. Only those leptons having a combined likelihood ratio greater than 75% are selected, with the further requirement that the muons should also have at least one hit in the outer muon chambers. Furthermore, electrons and muons should have a polar angle, θ, with respect to the beam direction such that, $|\cos\theta| \leq 0.9$. Contamination from photon conversion is suppressed by eliminating electron candidates which have an invariant mass of less than 100 MeV/c^2 when combined with any other oppositely charged particle in the event consistent with an electron hypothesis. Finally, electrons from reconstructed e^+e^- secondary vertices that are consistent with photon

conversion are also removed.

A mass-constraint fit is applied to all $K^-\pi^+$ combinations with invariant masses within ± 30 MeV/c^2 of the D^0 nominal mass [5]. Combinations with large uncertanty in the experimental determination of the mass of D^0 candidate are rejected by requiring this error to be less than 30 MeV/c^2. To decrease combinatorial background from random $K^-\pi^+$ combinations all $(K^-\pi^+)\pi^\pm$ candidates are required to have scaled momentum $x_p \geq 0.6$, where $x_p = p/p_{max}$, $p_{max} = \sqrt{E^2_{beam} - M^2_{D^{*+}}}$. The distribution of $\cos\vartheta^*_K$, where ϑ^*_K is defined to be the angle between the kaon and D^0 boost direction, as measured in the D^0 rest frame, should be isotropic. A requirement that $|\cos\vartheta^*_K| \leq 0.75$ substantially suppresses combinatorial background, which peaks at $\cos\vartheta^*_K = \pm 1$.

The main difficulty in searching for a signal in this analysis comes from correlated sources of background:

1. Cabibbo-suppressed decays $D^0 \to \pi^-\pi^+$ and $D^0 \to K^-K^+$, where $\pi \leftrightarrow K$ misidentification causes a contribution to "wrong-sign" $D^0\pi$ combinations.
2. Decays with a missing π^0 ($D^0 \to \pi^-\pi^+\pi^0$, $D^0 \to K^-\pi^+\pi^0$, $D^0 \to K^-K^+\pi^0$), where misidentification of one (or both) charged particle also causes these channels to contribute to "wrong-sign" combinations.
3. Semileptonic decays of D^0 mesons, such as $D^0 \to K^-l^+\nu$, $D^0 \to \pi^- l^+\nu$.
4. Decays $D^0 \to K^-\pi^+$ which, due to double misidentification, can contribute to the "wrong-sign" distribution.

The behaviour of these background sources has been studied by Monte Carlo simulation. Feeddown from Cabibbo-suppressed decays is drastically reduced by the requirements $|\cos\vartheta^*_K| \leq 0.75$ and $|\Delta M| = |M(K^-\pi^+) - M(D^0)| \leq 30$ MeV/c^2. Contributions of background sources 2 and 3 were found to be negligible.

The most serious source of background originates from the decay $D^0 \to K^-\pi^+$ which could simulate DCSD due to double misidentification ($\pi^+ \to$ "K^+", $K^- \to$ "π^-"). The result of a Monte Carlo simulation of such events is shown in Figure 2, which demonstrates the correlation between ΔM and $\cos\vartheta^*_K$ for doubly-misidentified events. This source of background is removed by excluding from further analysis the region between two solid lines. A suppression factor of 400 is obtained by this means, while only reducing the efficiency for a potential "wrong-sign" signal by a factor 0.58.

All cuts used in this analysis have been optimized on the basis of the Monte Carlo studies. The procedure minimizes the ratio of the upper limit on a signal in the "wrong-sign" ($D^0\pi^-$) distribution to number of "right-sign" ($D^0\pi^+$) events, generated without $D^0 - \overline{D^0}$ mixing or DCSD channels. The minimum value for this ratio corresponds to a low background level, leading to a $D^0 \to K^+\pi^-$ signal with maximal significance.

The final invariant mass distributions for "right-sign" ($D^0\pi^+$) and "wrong-sign" ($D^0\pi^-$) combinations are shown in figure 3. Selecting $D^0\pi^\pm$ combinations from the region 2008 $MeV/c^2 < M(D^0\pi^\pm) <$ 2012 MeV/c^2 (approximately $\pm 2\sigma$), 224 events in the "right-sign" and zero events in the "wrong-sign" distribution are observed. The expected combinatorial background is estimated from the nearby mass region 2014 – 2025 MeV/c^2. After background subtraction from the "right-sign" sample, a 90% CL upper limit on $r_D^{K\pi}$ is obtained:

$$r_D^{K\pi} = \frac{\Gamma(D^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} < 1.05\%.$$

The size of our sample is further enriched by study of D^0 mesons from the decay channel $\overline{B^0} \to D^{*+}\ell^-\bar{\nu}$. B mesons are reconstructed in this mode using the well-known recoil-mass technique described in [13]. The recoil-mass to the $(D^0\pi)\ell$ system

$$M^2_{recoil} = (E_{beam} - E_{D\pi} - E_{\ell^-})^2 - (\vec{p}_{D\pi} + \vec{p}_{\ell^-})^2.$$

is required to satisfy $|M^2_{recoil}| < 1\ GeV^2/c^4$, for lepton momentum p_ℓ in the range $1.0\ GeV/c < p_{\ell^-} < 2.3\ GeV/c$. D^0 candidates are required to satisfy all selection criteria described in the previous analysis, with the exception that the scaled momentum x_p of the $D^0\pi^\pm$ combinations must be less than 0.5.

The $D^0\pi^\pm$ invariant mass distributions obtained are shown in Figure 4. One observes 36 events in the signal region of the "right-sign" and zero in the "wrong-sign" distribution. The two data samples are completely independent and can be combined to obtain a more stringent upper limit on $r_D^{K\pi}$ (90% CL):

$$r_D^{K\pi} = \frac{\Gamma(D^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} < 0.9\%$$

The result is stable under substantial variation of the cuts, ranging from 0.6% to 0.9%.

Our new upper limit on r is shown in comparison with other experiments in Table 1. MARK III reported three events with strangeness ± 2 and 162 events with strangeness zero in a sample of $\psi'' \to D^0\overline{D^0}$ decays [16] and interpreted this as possible evidence for $D^0 - \overline{D^0}$ mixing ($r_D^{mix} \approx 1.6\%$). Figure 5 shows the best results obtained using three different experimental techniques. The dotted line corresponds to a model-dependent upper limit on r_{mix} from an analysis of dimuon events in pion-nucleon interactions by E615 [14]. The result of a D^0 time-evolution analysis by E691 [15] and our new limit are shown by the dashed and solid lines respectively.

The hatched area is the allowed range for $\sqrt{r_{mix}}$ and $\sqrt{r_{DCSD}}$ (90% CL). Our result considerably restricts the allowed region for r_{mix} and r_{DCSD} for all values of the interference angle ϕ.

In conclusion, no evidence is observed for the decay $D^0 \to K^+\pi^-$ leading to an upper limit on $r_D^{K\pi} = \Gamma(D^0 \to K^+\pi^-)/\Gamma(D^0 \to K^-\pi^+)$ of 0.9% at 90% confidence level. This is the best available limit on the DCSD of D^0 mesons (assuming negligible contribution from $D^0 - \overline{D^0}$ mixing).

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Table 1: The 90% CL upper limits on $\Gamma(D^0 \to K^+\pi^-)/\Gamma(D^0 \to K^-\pi^+)$.

	ARGUS	E691 [15]	CLEO [9]	ARGUS [10]
$r_D^{K\pi}$	0.9 %	1.5 - 3.4%*	1.1%	1.4 %

* depends on unknown phase ϕ.

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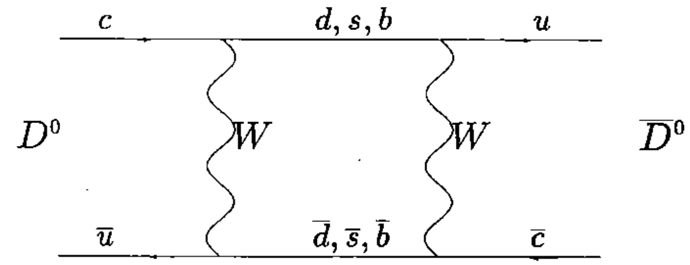

Figure 1: "Box"-diagrams for $D^0 \leftrightarrow \overline{D^0}$ transitions.

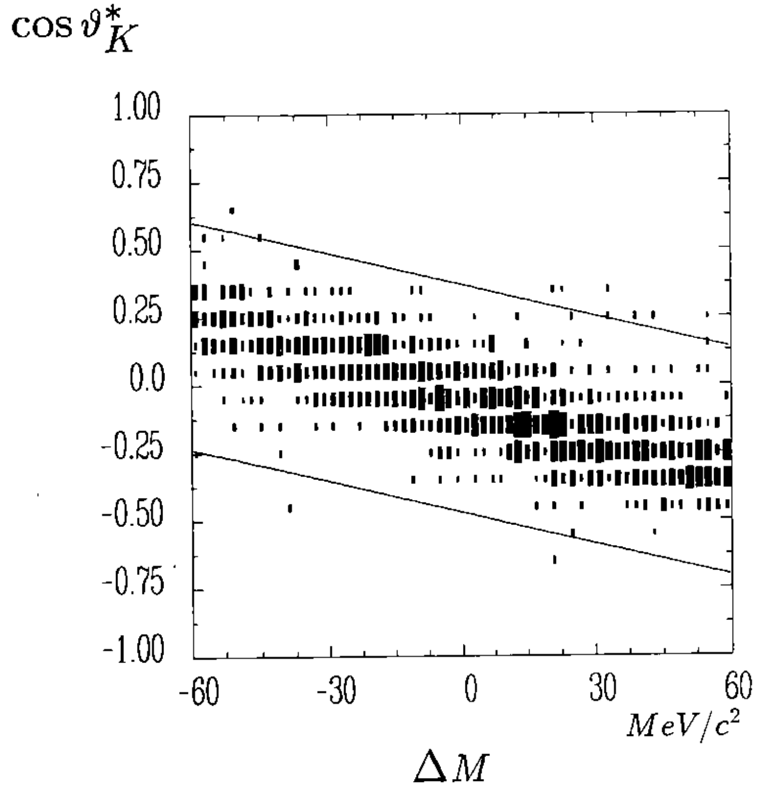

Figure 2: Two dimensional distribution $\cos\vartheta^*_K$ and ΔM for Monte Carlo events simulating the process $D^0 \to K^-\pi^+ \to$ "π^-""K^+".

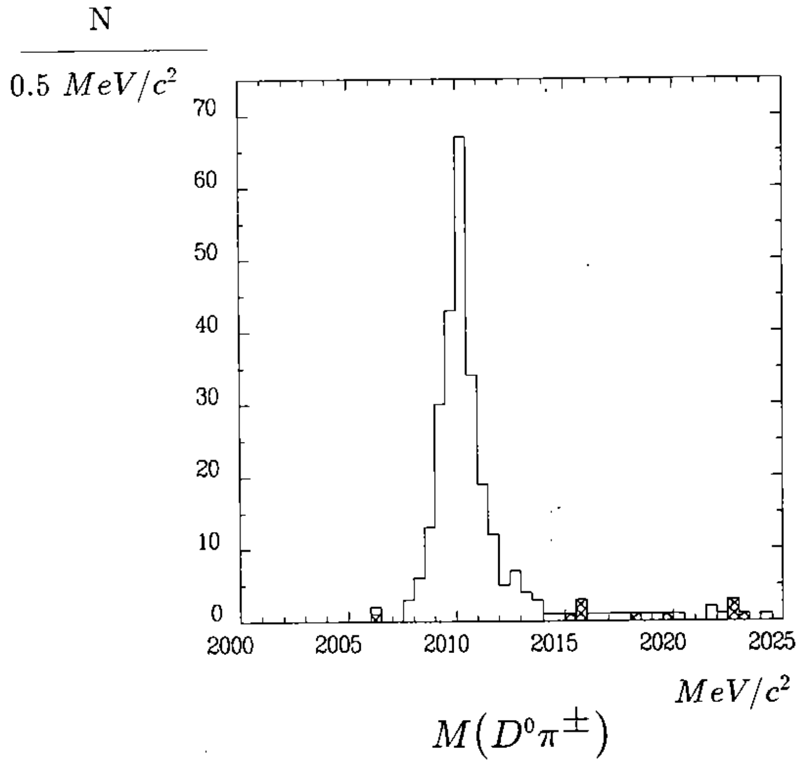

Figure 3: $D^0\ \pi^+$ (open histogram) and $D^0\ \pi^-$ (hatched histogram) invariant mass distributions for continuum events .

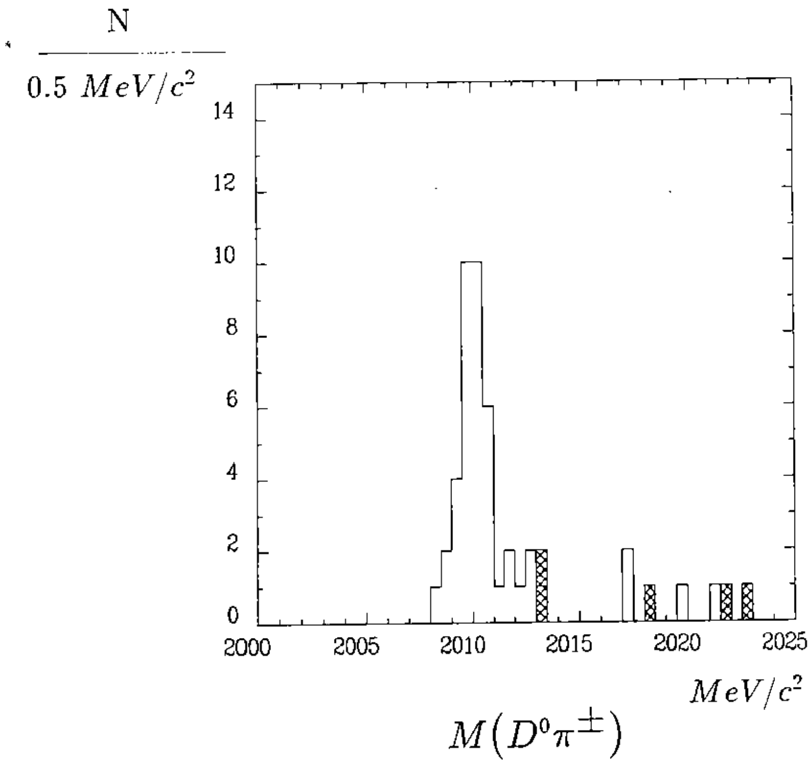

Figure 4: D^0 π^- (hatched histogram) and D^0 π^+ (open histogram) invariant mass distributions for $\overline{B}^0$ decays.

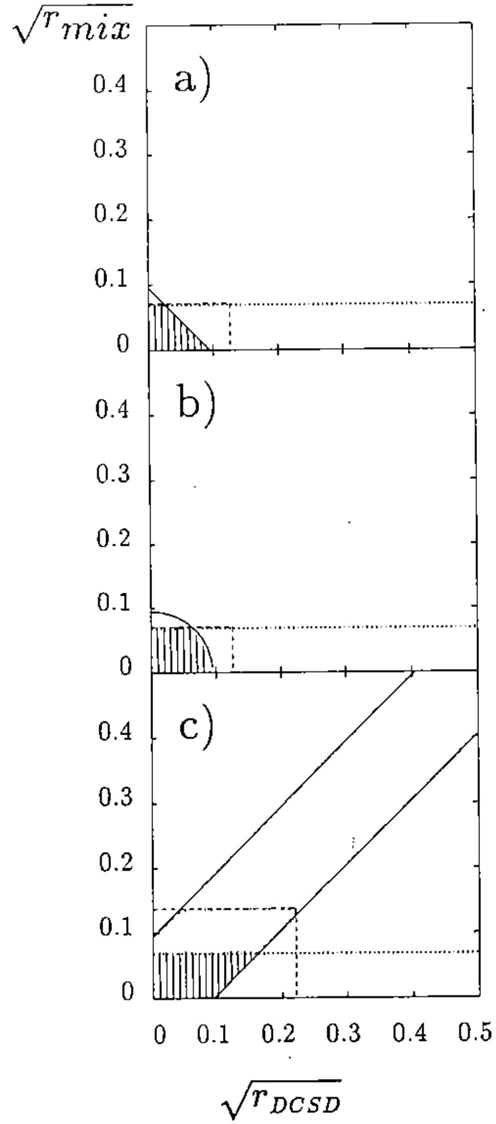

Figure 5: Allowed regions (90% CL) for $\sqrt{r_{mix}}$ and $\sqrt{r_{DCSD}}$ as a function of the interference phase ϕ. Results of this work (solid lines), E691 (dashed lines)[15] and E615 (dotted lines)[14] are represented for a) $\cos\phi = +1$, b) $\cos\phi = 0$, c) $\cos\phi = -1$