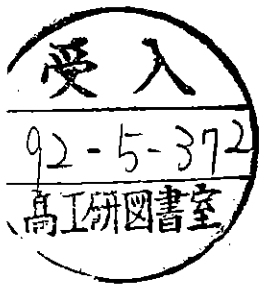
DEUTSCHES ELEKTRONEN – SYNCHROTRON

DESY 92-056
April 1992



A Search for $D^0 \to K^+\pi^-$

The ARGUS Collaboration

ISSN 0418-9833

NOTKESTRASSE 85 · D-2000 HAMBURG 52

DESY behält sich alle Rechte für den Fall der Schutzrechtserteilung und für die wirtschaftliche Verwertung der in diesem Bericht enthaltenen Informationen vor.

DESY reserves all rights for commercial use of information included in this report, especially in case of filing application for or grant of patents.

To be sure that your preprints are promptly included in the HIGH ENERGY PHYSICS INDEX, send them to the following (if possible by air mail):

DESY Bibliothek Notkestraße 85 W-2000 Hamburg 52 Germany	DESY-IfH Bibliothek Platanenallee 6 O-1615 Zeuthen Germany

DESY 92-056
April 1992

ISSN 0418-9833

A Search for $D^0 \to K^-\pi^-$

The ARGUS Collaboration

H. Albrecht, H.I. Cronström[1], H. Ehrlichmann, T. Hamacher, R.P. Hofmann, T. Kirchhoff, A. Nau, S. Nowak[2], M. Reidenbach, R. Reiner, H. Schröder, H.D. Schulz, M. Walter[2], R. Wurth
DESY, Hamburg, Germany

R.D. Appuhn, C. Hast, H. Kolanoski, A. Lange, A. Lindner, R. Mankel, M. Schieber, T. Siegmund, B. Spaan, H. Thurn, D. Töpfer, A. Walther, D. Wegener
Institut für Physik[3], Universität Dortmund, Germany

M. Paulini, K. Reim, H. Wegener
Physikalisches Institut[4], Universität Erlangen-Nürnberg, Germany

R. Mundt, T. Oest, W. Schmidt-Parzefall
II. Institut für Experimentalphysik, Universität Hamburg, Germany

W. Funk, J. Stiewe, S. Werner
Institut für Hochenergiephysik[5], Universität Heidelberg, Germany

K. Ehret, A. Hölscher, W. Hofmann, A. Hüpper, S. Khan, K.T. Knöpfle, J. Spengler
Max-Planck-Institut für Kernphysik, Heidelberg, Germany

D.I. Britton[6], C.E.K. Charlesworth[7], K.W. Edwards[8], E.R.F. Hyatt[6], H. Kapitza[8], P. Krieger[9,7], D.B. MacFarlane[6], P.M. Patel[6], J.D. Prentice[7], P.R.B. Saull[6], S.C. Seidel[7], K. Tzamariudaki[6], R.G. Van de Water[7], T.-S. Yoon[7]
Institute of Particle Physics[10], Canada

D. Reßing, M. Schmidtler, M. Schneider, K.R. Schubert, K. Strahl, R. Waldi, S. Weseler
Institut für Experimentelle Kernphysik[11], Universität Karlsruhe, Germany

G. Kernel, P. Križan, E. Križnič, T. Podobnik, T. Živko
Institut J. Stefan and Oddelek za fiziko[12], Univerza v Ljubljani, Ljubljana, Slovenia

L. Jönsson
Institute of Physics[13], University of Lund, Sweden

V. Balagura, I. Belyaev, M. Danilov, A. Droutskoy, A. Golutvin, I. Gorelov, G. Kostina, V. Lubimov, P. Murat, P. Pakhlov, F. Ratnikov, S. Semenov, V. Shibaev, V. Soloshenko, I. Tichomirov, Yu. Zaitsev
Institute of Theoretical and Experimental Physics[14], Moscow, Russia

[1] Supported in part by the Institute of Physics, University of Lund, Sweden.
[2] DESY, IfH Zeuthen.
[3] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054DO51P.
[4] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054ER12P.
[5] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 055HD21P.
[6] McGill University, Montreal, Quebec, Canada.
[7] University of Toronto, Toronto, Ontario, Canada.
[8] Carleton University, Ottawa, Ontario, Canada.
[9] Supported in part by the Walter C. Sumner Foundation.
[10] Supported by the Natural Sciences and Engineering Research Council, Canada.
[11] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054KA17P.
[12] Supported by the Department of Science and Technology of the Republic of Slovenia and the Internationales Büro KfA, Jülich.
[13] Supported by the Swedish Research Council.
[14] Supported in part by the International Technology Center BINITEC, Moscow, Russia.

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 $r_D^{mix} = \Gamma(D^0 \to \overline{D^0} \to \bar{f})/\Gamma(D^0 \to f)$ 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 $x_p = p/p_{max}$, $p_{max} = \sqrt{E_{beam}^2 - M_{D^{*+}}^2}$. 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).

Acknowledgements

It is a pleasure to thank U.Djuanda, E.Konrad, E.Michel, and W.Reinsch for their competent technical help in running the experiment and processing the data. We thank Dr.H.Nesemann, B.Sarau, and the DORIS group for the excellent operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

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.

References

[1] M.K.Gaillard and B.W.Lee, Phys.Rev. **D10** (1974) 897.

[2] H-Y. Cheng, Phys.Rev. **D26** (1982) 143;
A.Datta and D.Kumbhakar, Z.Phys. **C27** (1985) 515.

[3] L.Wolfenstein, Phys.Lett. **B164** (1985) 170.
J.F.Donoghue *et al.* Phys.Rev. **D33** (1986) 179.

[4] I.Bigi and A.I.Sanda, Phys.Lett. **B171** (1986) 320;
I.Bigi, Proceedings of the Charm Physics Workshop, Peking (1987).

[5] Particle Data Group: Review of Particle Properties,
Phys.Lett. **B239** (1990) 1.

[6] A.Datta, Phys.Lett. **B154** (1985) 287.

[7] T.Brown *et al.*,Phys.Lett. **B141** (1984) 95.

[8] L.L.Chau and H.Y.Cheng, Preprint UCDPHYS-PUB-91-26 (1991).

[9] R.Ammar *et al.* (CLEO Collaboration) , Phys.Rev. **D44** (1991) 3383.

[10] H.Albrecht *et al.* (ARGUS Collaboration) , Phys.Lett. **B199** (1987) 447.

[11] H.Yamamoto, Ph.D.Thesis, CALT-68-1318 (1985).

[12] H.Albrecht *et al.* (ARGUS Collaboration),
Nucl.Inst. and Methods **A275** (1989) 1.

[13] H.Albrecht *et al.* (ARGUS Collaboration), Phys.Lett. **B197** (1987) 452.

[14] W.C.Louis *et al.* (E615 Collaboration), Phys.Rev.Lett. **56** (1986) 1027.

[15] J.C. Anjos *et al.* (E691 Collaboration) , Phys.Rev.Lett. **60** (1988) 1239.

[16] R.H. Schindler, Proceedings of SLAC Summer Institute of Particle Physics
(1985).

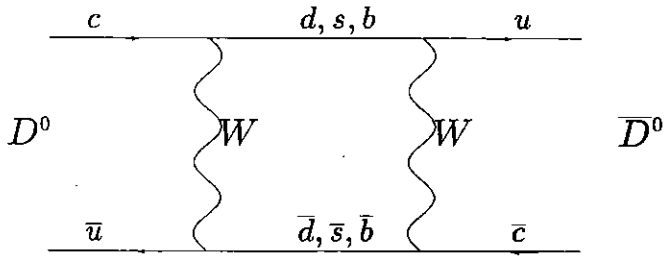


Figure 1: "Box"-diagrams for $D^0 \leftrightarrow \overline{D^0}$ transitions.

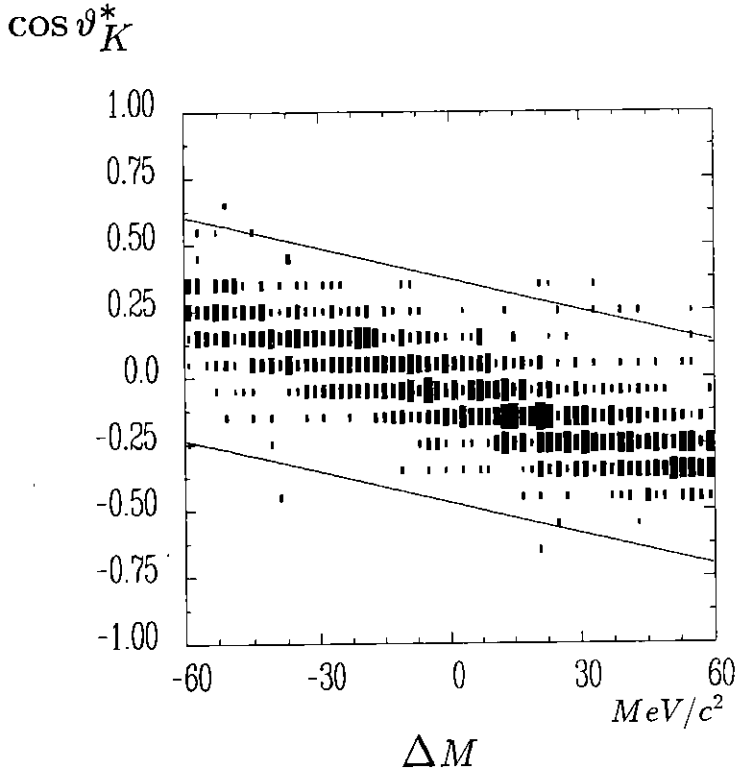


Figure 2: Two dimensional distribution $\cos\vartheta^*_K$ and ΔM for Monte Carlo events simulating the process $D^0 \to K^-\pi^+ \to$ "π^-""K^+".

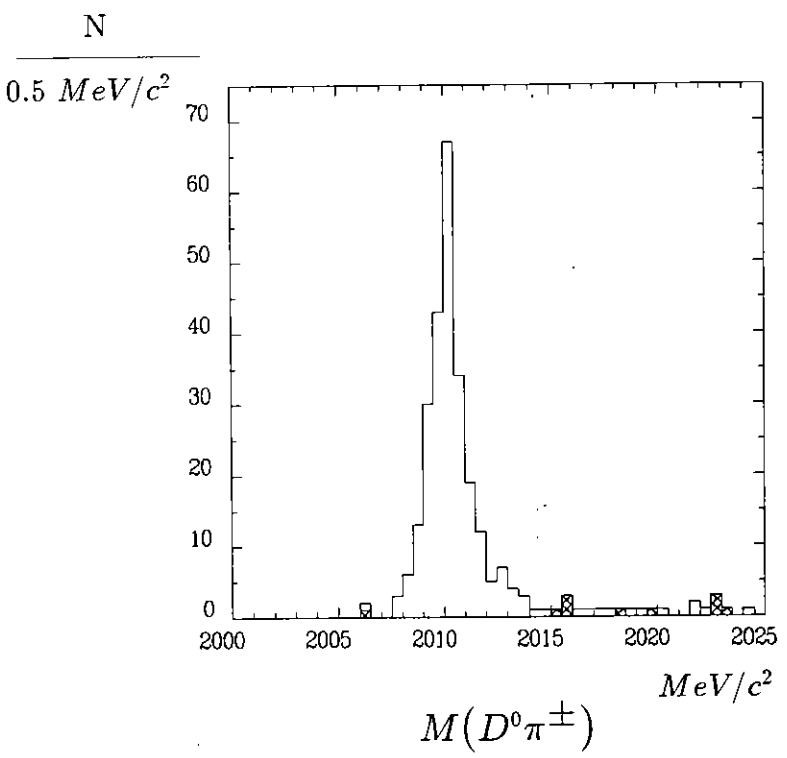


Figure 3: $D^0\ \pi^+$ (open histogram) and $D^0\ \pi^-$ (hatched histogram) invariant mass distributions for continuum events .

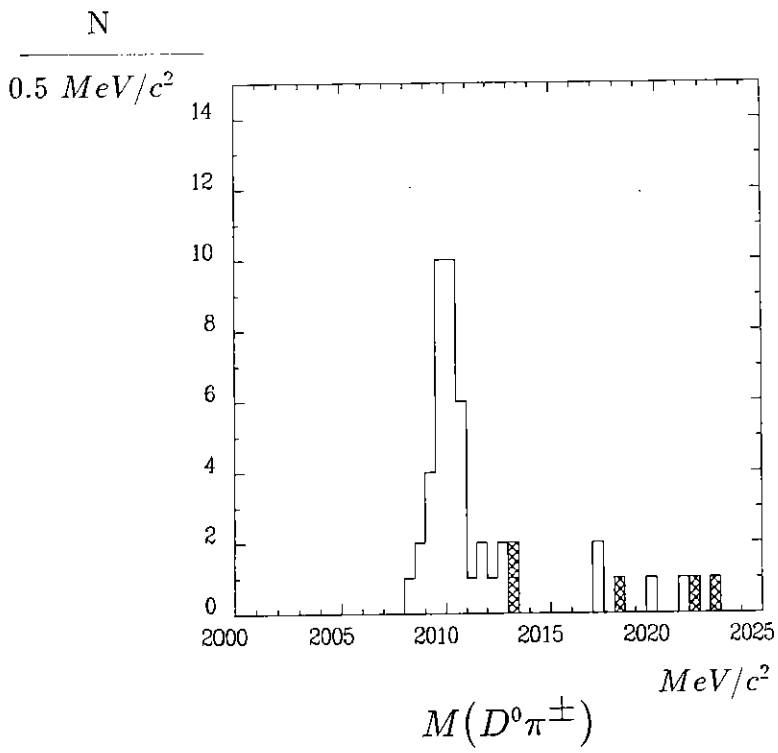


Figure 4: $D^0\ \pi^-$ (hatched histogram) and $D^0\ \pi^+$ (open histogram) invariant mass distributions for $\overline{B^0}$ decays.

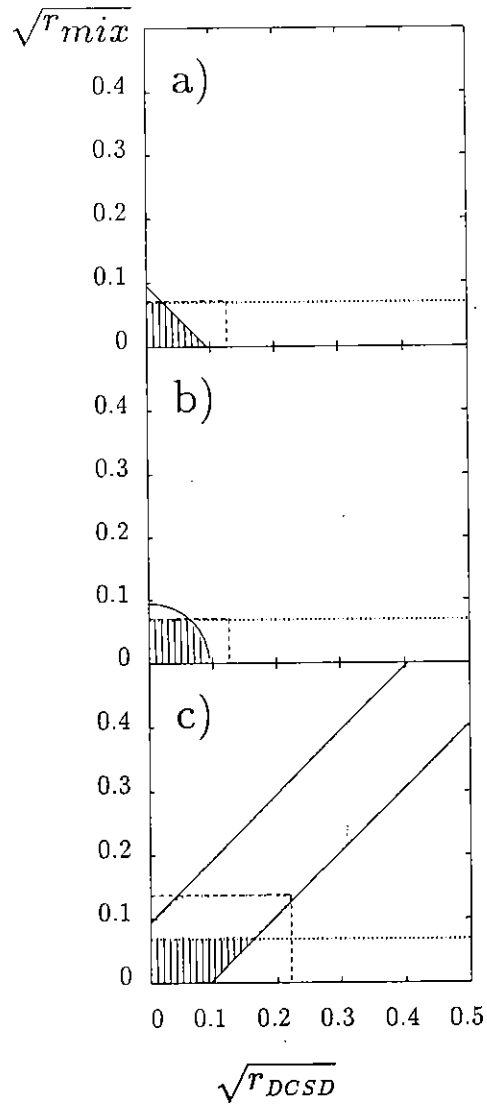


Figure 5: Allowed regions (90% CL) for $\sqrt{r_{mix}}$ and $\sqrt{r_{DCSD}}$ as a function of the interference phase ϕ. Results of this work (solid lines), E691 (dashed lines)[15] and E615 (dotted lines)[14] are represented for a) $\cos\phi = +1$, b) $\cos\phi = 0$, c) $\cos\phi = -1$