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AN UPPER LIMIT ON D^0-$\bar{D}^0$ MIXING

ARGUS Collaboration

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We have searched for D^0–$\bar{D}^0$ mixing in the cascade decay of D^{*+}, using the excellent particle identification of the ARGUS detector. No mixing was observed, leading to an upper limit of 1.4% (90% CL) for $\Gamma(D^0\to\bar{D}^0\to X')/\Gamma(D^0\to X)$.

Quark flavour is not conserved in weak interactions. One manifestation of this is the $K^0\leftrightarrow\bar{K}^0$ transition, which is allowed via the $\Delta S=2$ box diagram [1]. The analogue for neutral charm mesons, D^0–$\bar{D}^0$ mixing is, however, highly suppressed in the six-quark standard model of electroweak interactions [2] [#1], even after accounting for the long-distance effects [4]. Therefore, a recent report by the MARK III collaboration [5] of possible D^0–$\bar{D}^0$ mixing at about 1.6% level has generated considerable interest. While experimental sensitivities are still orders of magnitude away from the values predicted in the standard model, mixing searches are nevertheless desirable as a test for the high level D^0–$\bar{D}^0$ mixing predicted by some of the theoretical ideas which go beyond the standard model [6].

The two most common methods used to search for D^0–$\bar{D}^0$ mixing are (i) the study of the di-muon events (or tri-muon events in the case of μ-scattering experiments) arising from the semi-leptonic decays of the charm–anti-charm hadron pairs [7] and (ii) full reconstruction of the D^0 meson from its daughter particles in the cascade decay of the D^{*+} [8] [#2]. The first method is model-dependent, since it requires assumptions about the charm production cross section, the semi-leptonic branching fractions of all charmed particles, and the fraction of D^0 mesons produced in charmed quark fragmentation. We fully reconstruct the D^0 mesons from D^{*+} decays, a method which is completely model independent.

D^{*+} decays are also particularly suited to obtaining a signal essentially free of combinatorial background. This is due to the small Q-value for the decay $D^{*+}\to D^0\pi^+$, which leads to an excellent mass resolution for the D^{*+}, if the mass of the D^0 decay products is constrained by a kinematic fit to the nominal D^0 mass. Moreover, mixing searches are possible because the charge of the soft pion tags whether a D^0 or $\bar{D}^0$ was produced. In the weak decay of the $D^0(c\bar{u})$, the c quark decays to an s quark, and so the sign of the charged daughter kaon is negative; thus, the sign of the charged kaon from the D^0 decay is opposite to the sign of the pion from the D^{*+} decay. If mixing were to occur, the signs would be the same. The amount of mixing can be determined by comparing the signal with the same-sign combination versus that with the opposite-sign combination. We call the opposite-sign mode a right-charge combination, and the same sign-mode a wrong-charge combination.

The data sample used for our study corresponds to an integrated luminosity of 199 pb^{-1}, obtained with the ARGUS detector at the DORIS II storage ring on the $\Upsilon(2S)$ and $\Upsilon(4S)$ resonances, and in the nearby continuum. The configuration and performance of the ARGUS detector, and information on multihadron event selection and trigger conditions can be found in previous publications [9]. For this analysis we have used mostly information from the main drift chamber (momentum resolution of $\sigma_p/p=0.012$ at 1 GeV/c and dE/dx resolution of 5.4%) and the time-of-flight (TOF) counters (time resolution of $\sigma(t)=220$ ps).

The method of particle identification for charged particles is the same as used previously [9]. For each charged track, the e, μ, π, K and p particle assignments are used to obtain a corresponding χ^2 from the dE/dx and TOF measurements for each particle hy-

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[#1] See ref. [3] for a review.

[#2] In this paper references to a particular particle state should be taken to imply both the particle and its anti-particle.

pothesis. A likelihood ratio, l_i, for each of these particle hypotheses is then calculated:

$$l_i = \frac{w_i \exp(-\chi_i^2/2)}{\sum_j w_j \exp(-\chi_j^2/2)}, \quad i, j = \mathrm{e}, \mu, \pi, \mathrm{K}, \mathrm{p} ,$$

where the w_i are a priori weights. Weights are set to 1 for all hypotheses except that for π, which is set to 5, a rough approximation to the observed abundances. A track is used for all particle hypotheses for which the likelihood ratio exceeds 10%.

D^0 mesons are reconstructed in the decay channel $D^0 \to K^-\pi^+$. A mass-constraining kinematic fit is applied to all $K^-\pi^+$ combinations with an invariant mass within 30 MeV/c^2 of the D^0 mass. Next, we add a second pion of appropriate charge and compare the number of events above background at the D^{*+} mass in the $D^0\pi^+$ and $D^0\pi^-$ mass distributions.

Since the fragmentation of charmed quarks produces a hard D^{*+} momentum spectrum, a requirement that the scaled momentum of the D^{*+} system, $x_p \equiv P_{D^{*+}}/P_{\max}$, exceed 0.6 greatly reduces the combinatorial background. The distribution of $\cos\theta_K^*$, where θ_K^* is the angle between the kaon and D^0 flight direction in the D^0 rest frame, should be isotropic. In contrast, the distribution from random combinations of particles from the same jet tends to peak strongly at small forward angles. Therefore, we require $\cos\theta_K^* < 0.85$ to further suppress combinatorial background.

Additional cuts were applied to remove correlated background sources arising from particle misidentification. Removal of such backgrounds is critical, since single-particle misidentification for the Cabibbo-suppressed $D^0 \to K^+K^-$ and $\pi^+\pi^-$ decays, and double misidentification of the allowed $D^0 \to K^-\pi^+$ mode, can feed events from the right-charge into the wrong-charge category. To suppress ambiguity in the identification of the daughter particles of the D^0, the ratio of the kaon to pion likelihood, l_K/l_π, must exceed unity for those particles used as kaons. Likewise, $l_\pi/l_K > 1$ was required for those particles used as pions. Further cuts are made using the total probability, P_{tot}, derived from the sum of the χ^2's from the particle identification of daughter particles and the χ^2 for the D^0 mass hypothesis. Specifically, the following ratios must be satisfied:

$$P_{\mathrm{tot}}(K^+\pi^-)/P_{\mathrm{tot}}(K^-\pi^+) < 10^{-3} ,$$

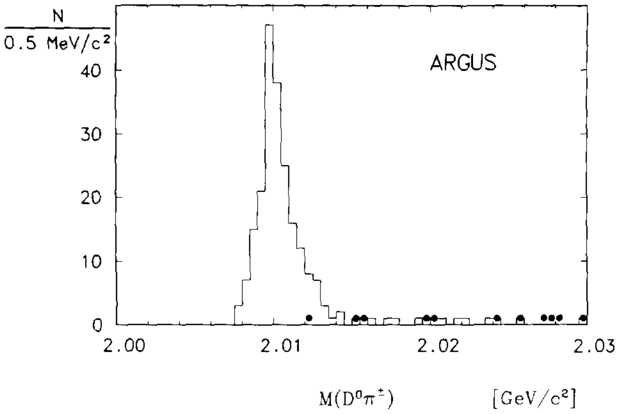

Fig. 1. Invariant mass distribution for right-sign combinations, $(K^-\pi^+)\pi^+$, shown by the histogram, and wrong-sign combinations, $(K^-\pi^+)\pi^-$, shown by the solid points.

and

$$P_{\mathrm{tot}}(K^+K^-)/P_{\mathrm{tot}}(K^-\pi^+) < 10^{-2} ,$$

$$P_{\mathrm{tot}}(\pi^+\pi^-)/P_{\mathrm{tot}}(K^-\pi^+) < 10^{-2} ,$$

where the correct assignment is taken to be $(K^-\pi^+)$. Contributions from doubly Cabibbo-suppressed decays, e.g., $\bar{D}^0 \to K^-\pi^+$, are expected [10] to have a rate proportional to $\sin^4\theta_c$, and are therefore neglected.

Fig. 1. shows the $D^0\pi$ invariant mass plots for both sign modes. We take $2.0085 < M(D^0\pi) < 2.0115$ GeV/c^2 as the signal region and find 162 events in the right-sign and no events in the wrong-sign categories, respectively. This yields an upper limit of 1.4% (90% CL) for $r = \Gamma(D^0 \to \bar{D}^0 \to X')/\Gamma(D^0 \to X)$. The cuts have been chosen to minimize the ratio of the expected number of background events to the number of right-sign signal events, where the former was estimated by extrapolating from the observed distribution above 2.015 GeV/c^2. If the expected background drops much below one event, it becomes self-defeating to continue optimizing. The procedure is unbiased, except that the actual number of background events is discrete. If we restrict ourselves to the case where no wrong-sign events are observed, then the limit changes between 1.2 and 1.4% as the cuts are varied. If one event appears, the limit ranges from 1.6 to 1.9%.

The mixing rate is related to the mass difference

(δm) and the difference in the decay widths ($\delta \Gamma$) of the two CP mass eigenstates [11],

$$r=\frac{(\delta m/\Gamma)^2+(\delta\Gamma/2\Gamma)^2}{2+(\delta m/\Gamma)^2-(\delta\Gamma/2\Gamma)^2},$$

where Γ is the mean decay width. From our limit, we find that $\delta m/\Gamma$ is less than 0.17 (90% CL), assuming $\delta\Gamma \ll \delta m$. Using a D^0 lifetime 4.3×10^{-13} s [12] this implies that $\delta m \leqslant 2.6\times10^{-4}$ eV.

In conclusion, we have observed no evidence for D^0–$\bar{D}^0$ mixing and set an upper limit of 1.4% at the 90% confidence level. This limit holds also for the doubly Cabibbo-suppressed decay $D^0 \to K^+\pi^-$. In comparison, the observations by MARK III of three events with strangeness ±2, which may possibly be due to D^0–$\bar{D}^0$ mixing, and 162 events with strangeness 0 [5] in a sample of $\psi'' \to D^0\bar{D}^0$ decay corresponds to a mixing rate of about 1.6% [11]. However, it should be noted that due to coherence effects, and the fact that MARK III uses several D^0 decay channels in combination, the two search methods have different sensitivities to the contribution of doubly Cabibbo-suppressed decays [10].

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