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SEARCH FOR D^0-$\overline{D}^0$ MIXING USING SEMILEPTONIC DECAYS[1]

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Based on an 87-fb^{-1} dataset collected by the Babar detector at the PEP-II asymmetric-energy B-Factory, a search for D^0–$\overline{D}^0$ mixing has been made using the semileptonic decay modes $D^{*+} \to \pi^+ D^0, D^0 \to Ke\nu$ (+c.c.). The use of these modes allows unambiguous flavor tagging and a combined fit of the D^0 decay time and D^{*+}–D^0 mass difference (ΔM) distributions. The high-statistics sample of unmixed semileptonic D^0 decays is used to model the ΔM distribution and time-dependence of mixed events directly from the data. Neural networks are used to select events and reconstruct the D^0. A result consistent with no charm mixing has been obtained, $R_{\rm mix} = 0.0023 \pm 0.0012 \pm 0.0004$. This corresponds to an upper limit of $R_{\rm mix} < 0.0042$ (90% CL).

Keywords: Babar; PEP-II; charm; mixing; semileptonic.

Charm mixing is generally characterized by two dimensionless parameters, $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta\Gamma/2\Gamma$, where $\Delta m = m_2 - m_1$ ($\Delta\Gamma = \Gamma_2 - \Gamma_1$) is the mass (width) difference between the two neutral D mass eigenstates and Γ is the average width. If either x or y is non-zero, then D^0-$\overline{D}^0$ mixing will occur. The time evolution of a mixed neutral D meson decaying semileptonically has time-dependence,[2]

$$T_{\rm mix}(t) \cong T_{\rm unmix}(t)\ \frac{x^2+y^2}{4}\ \left(\frac{t}{\tau_{D^0}}\right)^2, \tag{1}$$

where t is the proper time of the D^0 decay, $T_{\rm unmix}(t) \propto e^{-t/\tau_{D^0}}$, and the approximation is valid in the limit of small mixing rates. The time-integrated mixing rate $R_{\rm mix}$ relative to the unmixed rate is

$$R_{\rm mix} = \frac{x^2+y^2}{2}. \tag{2}$$

We present a measurement of $R_{\rm mix}$ using an 87-fb^{-1} data sample collected on and just below the $\Upsilon(4S)$ resonance with the Babar detector[3] at the PEP-II asymmetric-energy e^+e^- storage ring. Neutral D candidates are selected by reconstructing the decay chain $D^{*+} \to \pi^+ D^0, D^0 \to Ke\nu$. The charge of the pion daughter of the charged D^* identifies the production flavor of the neutral D, while the charge of the electron identifies the decay flavor. These charges are the same for unmixed decays and different for mixed decays, denoted as *right-sign* (RS) and *wrong-sign* (WS) decays, respectively.

The measured mixing rate is parameterized as $R_{\rm mix} = n_{\rm WS}/n_{\rm RS}$. We fit the number of RS (WS) signal decays, $n_{\rm RS}$ ($n_{\rm WS}$), with a likelihood combining the D^{*+}-D^0 mass difference (ΔM) distribution with the unmixed and mixed (Eq. 1) decay time distributions, respectively. To avoid potential bias, we perform a blind analysis in which the event selection criteria, and procedures for fitting the data and extracting an upper limit (UL), are determined prior to examining the WS signal region ΔM and decay time distributions in the data.

Identified K and e candidates of opposite charges are combined to create neutral D candidate decay vertices, and the average PEP-II interaction point (IP), measured run-to-run, is taken as the production point. The pions from D^{*+} decays are relatively soft tracks with $p<450$ MeV/c in the $\Upsilon(4S)$ c.m. frame, and poorly reconstructed tracks and tracks inconsistent with an origin at the IP are rejected as pion candidates. The D^0 candidate momentum is reconstructed with neural networks (NN) using information from the three final-state particle candidates and the event thrust as inputs, and the D^{*+}–D^0 mass difference is then calculated using the tagging pion and NN D^0 candidates. The transverse momentum of a D^0 candidate, and the projections of the IP and K-e vertex loci on the r-ϕ plane, are used to calculate the candidate's proper decay time. Poorly reconstructed events with decay time uncertainties greater than $2\tau_{D^0}$ are discarded. The contribution of the NN D^0 momentum estimator to the total decay time uncertainty is negligible. Signal events are selected using an event selector NN with inputs similar to the above momentum estimator. A cut is made on the selector NN output such that the statistical sensitivity to mixed charm events is optimized for the 87-fb^{-1} dataset used. There are no differences in RS and WS reconstruction efficiencies in the final event selection.

Backgrounds predominantly come from prompt charm events, with minor contributions from uds and $b\overline{b}$ events. The backgrounds from misidentified charged particle species are negligible. Nearly all background events come from D^0 and D^+ semileptonic decays to final states including both a charged K and an e that are combined with a random π^+, and truly random combinatorics in which the K and e do not share a common charm parent. All of these combinatoric ΔM backgrounds are modeled from the data by combining K-e vertex and π candidates from different events. The resulting RS and WS background ΔM distributions are essentially identical.

An initial fit to the RS data is used to extract the unmixed signal mean lifetime, shape of the signal ΔM distribution, and number of RS signal events. We find $n_{\rm unmix} = 49620 \pm 265$ events. The fit value for the unmixed D^0 mean lifetime is, within its statistical error of $\sim$0.6%, consistent with the PDG value. The mixed WS signal PDF parameters are taken from this high-statistics RS fit and subsequently used in fitting the WS data. We find $n_{\rm mix} = 114 \pm 61$ events, leading to a value of $R_{\rm mix} = 0.0023 \pm 0.0012$ (stat). Fits to toy Monte Carlo data sets show that, for an assumed zero mixing rate, a fit number of mixed events greater than the result here is likely to occur in about 5% of experiments. The WS fit model is also tested for bias and correct error scaling with fits to simulated datasets containing 0, 50 and 100 mixed WS events ($R_{\rm mix} \sim 0$, 0.001, 0.002, respectively), and no evidence of bias or improperly scaled errors is seen. Goodness-of-fit is checked by comparing the minimized negative log likelihood (NLL) values of the RS and WS data fits with NLL distributions generated from toy MC — the data-fit NLL values lie well within the range predicted by the toy fits. No significant asymmetries are seen when the WS dataset is divided and fit based on the production flavor of the D^0-$\overline{D}^0$.

The systematic error includes variations of the WS combined mixed signal PDF, random combinatoric ΔM PDF shape, signal decay time resolution model, and background D^0 and D^+ decay time PDF's. By far, the dominant systematic is the statistical precision with which the RS ΔM PDF is known. There are no significant effects on $R_{\rm mix}$ attributable to the choice of vertexing algorithm, IP, K or e particle identification, NN event selector cut, decay time error cut, signal resolution model or ΔM sideband cut. Taking the total systematic error as the sum in quadrature of the above , $\sigma^{sys}_{R_{\rm mix}} = 0.0004 = 0.34\sigma^{stat}_{R_{\rm mix}}$.

A scan of the change in NLL for $n_{\rm mix}$ values in the region surrounding the fit minimum is used to calculate upper limits. By construction, the NLL scan includes only the statistical error of the fit — the systematic error is included as a small perturbation on the values of ΔNLL used to establish confidence intervals. The total error is taken as the sum in quadrature of the statistical and systematic errors, $\sigma^{total} = \sqrt{1+0.34^2}\ \sigma^{stat} = 1.06\ \sigma^{stat}$. The 95% CL UL is taken as the value of $n_{\rm mix}$ where the NLL value changes from its minimum by $\Delta{\rm NLL} = (0.5)(1.06)(1.96^2)(0.97) = 1.97$, where a one-sigma change is $\Delta{\rm NLL} = 0.5$, which yields $R_{\rm mix}<0.0046$ (95% CL). The factor of "0.97" in the preceding expression for the UL arises from the fraction of the *a posteriori* distribution of $n_{\rm mix}$ lying in the physical region. A similar calculation shows $R_{\rm mix}<0.0042$ at the 90% CL. The relatively small error ($\sim$0.5%) on $n_{\rm RS}$ is negligible and has been ignored.

References

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