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Search for rare and forbidden decays of $D^0 \to \ell^+\ell^-$

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We report on a search for the flavor-changing neutral current decays $D^0 \to e^+e^-$ and $D^0 \to \mu^+\mu^-$, and the lepton-flavor violating decay $D^0 \to e^\pm\mu^\mp$. The measurement is based on $122\,\text{fb}^{-1}$ of data collected by the *BABAR* detector at the PEP-II asymmetric e^+e^- collider. No evidence is found for any of the decays. The upper limits on the branching fractions, at the 90 % confidence level, are 1.2×10^{-6} for $D^0 \to e^+e^-$, 1.3×10^{-6} for $D^0 \to \mu^+\mu^-$, and 8.1×10^{-7} for $D^0 \to e^\pm\mu^\mp$.

Keywords: FCNC; LFV; Charm ; Decay.

In the Standard Model (SM), the flavor-changing neutral current (FCNC) decays $D^0 \to e^+e^-$ and $D^0 \to \mu^+\mu^{-1}$ are highly suppressed by the Glashow-Iliopoulos-Maiani (GIM) mechanism[2]. The lepton-flavor violating (LFV) decay $D^0 \to e^\pm\mu^\mp$ is strictly forbidden in the SM[3]. Some extensions to the Standard Model can enhance the FCNC processes by many orders of magnitude. For example, R-parity violating supersymmetry can increase the branching fractions of $D^0 \to e^+e^-$ and $D^0 \to \mu^+\mu^-$ to as high as 10^{-10} and 10^{-6}, respectively[4]. The same model also predicts the $D^0 \to e^\pm\mu^\mp$ branching fraction to be of the order of 10^{-6}. As a result, searching for the FCNC and LFV decays in the charm sector is a potential way to test the SM and explore new physics. Similar arguments hold for rare K and B decays, but the charm decay is unique since it is sensitive to new physics coupling to the up-quark sector.

In this paper, we present a search for the decays of $D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$, and $D^0 \to e^\pm\mu^\mp$. The analysis is based on $122\,\text{fb}^{-1}$ of data collected on or near the $\Upsilon(4S)$ resonance by the *BABAR* detector[5] at the PEP-II asymmetric e^+e^- collider. Detail of this analysis can be found elsewhere.[6]

To ensure as clean a sample as possible, the reconstructed $D^0 \to \ell^+\ell^-$ candidate is required to originate from a $D^{*+} \to D^0\pi^+$ decay. A minimum value of $2.4\,\text{GeV}/c$ is imposed on the center-of-mass momentum of each D^0 candidate to further reduce the combinatorial background involving the decay products of B mesons. Tight particle selection criteria are also applied to the daughters of $D^0 \to \ell^+\ell^-$ decays.

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The averaged electron and muon efficiencies are about 95 % and 60 %, and their hadron misidentification probabilities are measured from τ decay control samples to be around 0.2 % and 2.0 %.

The decay $D^0 \to \pi^+\pi^-$ is used as the normalization mode because it is kinematically similar to $D^0 \to \ell^+\ell^-$ and therefore many common systematic uncertainties cancel in the calculation of their efficiency ratio. Apart from the particle identification, the selection of the $D^0 \to \pi^+\pi^-$ is identical to the criteria used for the $D^0 \to \ell^+\ell^-$ signal.

In order to avoid any possibility of bias, a blind analysis technique has been adopted. All the events inside a mass window centered on the D^0 mass were hidden from inspection until the final event selection criteria were established and all systematic uncertainties were determined. We determine the optimal selection criteria by maximizing the value $\epsilon_{\ell\ell}/N_{\rm sens}$, where $\epsilon_{\ell\ell}$ is the signal efficiency estimated using Monte Carlo, and $N_{\rm sens}$ is the averaged 90 % confidence level upper limit on the number of observed signal events that would be obtained by an ensemble of experiments with the expected background and no real signal[7].

The $D^0 \to \ell^+\ell^-$ background can be taken as a sum of two components: a peaking background from $D^0 \to \pi^+\pi^-$ decays, where both pions are misidentified as leptons, and a combinatoric background from other sources. The peaking background events, $N_{\rm bg}^{hh}$, are determined using MC with lepton misidentification rates measured from a control sample. The combinatoric background is estimated from the sideband with a looser selection applied and then scaling the corresponding yield to the final selection by the appropriate factor calculated from MC and control samples.

The invariant mass distribution of the dilepton candidates after applying the optimized event selection criteria is shown in Fig. 1. The number of events observed ($N_{\rm obs}$) and the expected background ($N_{\rm bg}$) are shown in Table 1, with no significant excess found in any decay mode. The systematic uncertainties of the background estimate arise predominantly from the finite data available in the mass sideband for the ee and $e\mu$ modes. For the $\mu\mu$ mode, it also has large contribution form t he estimate of muon misidentification since a significant fraction of the background is produced by misidentified $D^0 \to \pi^+\pi^-$ decays.

The branching fraction upper limits (UL) have been calculated including all uncertainties using an extended version[8] of the Feldman-Cousins method[7]. All of the uncertainties have a negligible effect on the limits. The results and a comparison to previous published results[9,10] are listed in Table 1. Our results substantially improve the present best limits. The upper limits for the branching fractions of the $e\mu$ and $\mu\mu$ modes begin to confine the allowed parameter space of R-parity violating supersymmetric models[4].

References

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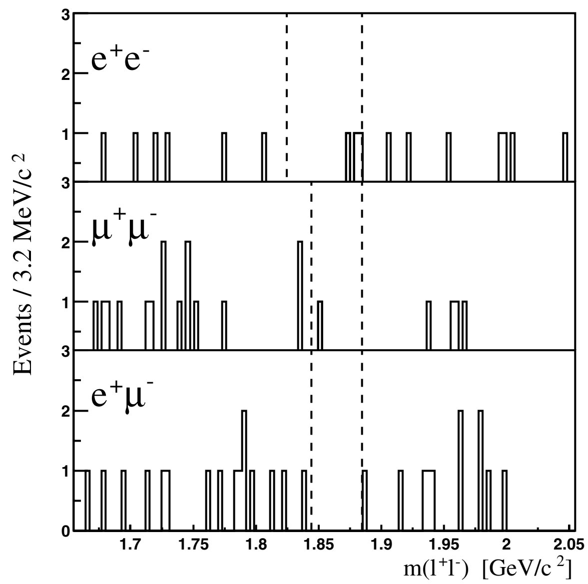

Fig. 1. The dilepton invariant mass distribution for each decay mode. The dashed lines indicate the optimized signal mass window.

Table 1. The summary of the number of expected background events ($N_{\rm bg}$), the sensitivity factor (S), number of observed events ($N_{\rm obs}$), and the branching fraction upper limits at the 90 % confidence level for each decay modes. The uncertainties quoted here are total uncertainties. The uncertainty of $N_{\rm bg}^{hh}$ is negligible for the ee and $e\mu$ decay modes.

	$D^0 \to e^+e^-$	$D^0 \to \mu^+\mu^-$	$D^0 \to e^\pm\mu^\mp$
$N_{\rm bg}^{hh}$	0.02	3.34 ± 0.31	0.21
$N_{\rm bg}^{\rm comb}$	2.21 ± 0.38	1.28 ± 0.32	1.93 ± 0.36
$N_{\rm bg}$	2.23 ± 0.38	4.63 ± 0.45	2.14 ± 0.36
$N_{\rm obs}$	3	1	0
UL obtained at 90 % CL	1.2×10^{-6}	1.3×10^{-6}	8.1×10^{-7}
Previous published limit[9,10]	6.2×10^{-6}	2.0×10^{-6}	8.1×10^{-6}

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