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Observation of the decay $D^0 \rightarrow K^-\pi^+e^+e^-$

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We report the observation of the rare charm decay $D^0 \rightarrow K^-\pi^+e^+e^-$, based on 468 fb^{-1} of e^+e^- annihilation data collected at or close to the center-of-mass energy of the $\Upsilon(4S)$ resonance with the *BABAR* detector at the SLAC National Accelerator Laboratory. We find the branching fraction in the invariant mass range $0.675 < m(e^+e^-) < 0.875\,\text{GeV}/c^2$ of the electron pair to be $\mathscr{B}(D^0 \rightarrow K^-\pi^+e^+e^-) = (4.0 \pm 0.5 \pm 0.2 \pm 0.1) \times 10^{-6}$, where the first uncertainty is statistical, the second systematic, and the third due to the uncertainty in the branching fraction of the decay $D^0 \rightarrow K^-\pi^+\pi^+\pi^-$ used as a normalization mode. The significance of the observation corresponds to 9.7 standard deviations including systematic uncertainties. This result is consistent with the recently reported $D^0 \rightarrow K^-\pi^+\mu^+\mu^-$ branching fraction, measured in the same invariant mass range, and with the value expected in the Standard Model.

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The decay $D^0 \to K^-\pi^+e^+e^-$ is expected to be very rare in the standard model (SM) as it cannot occur at tree level. Short-distance contributions to the $D^0 \to K^-\pi^+e^+e^-$ branching fraction proceed through loop and box diagrams and are expected to be $\mathscr{O}(10^{-9})$. However, decays with long-distance contributions, such as $D^0 \to XV$, where X is an accompanying particle or particles and V is a vector or pseudoscalar meson decaying to two leptons, could contribute at the level of $\mathscr{O}(10^{-6})$ through photon pole amplitudes or vector meson dominance,

Over the last few years there have been a number of measurements of the decays of B mesons to final states involving one or more charged leptons. Some of these measurements suggest a possible deviation from the assumption that all leptons couple equally (see for example Refs [1, 2, 3]). The possibility therefore exists that a deviation from lepton universality will be seen in D meson decays.

Recently, the LHCb Collaboration measured $\mathscr{B}(D^0 \to K^-\pi^+\mu^+\mu^-) = (4.17 \pm 0.12 \pm 0.40) \times 10^{-6}$ in the mass range $0.675 < m(\mu^+\mu^-) < 0.875\,\mathrm{GeV}/c^2$, where the decay is dominated by the ρ^0 and ω resonances [4].

We report here the observation of the decay $D^0 \to K^-\pi^+e^+e^-$with data recorded with the BABAR detector at the PEP-II asymmetric-energy e^+e^- collider operated at the SLAC National Accelerator Laboratory. The data sample corresponds to $424\,\mathrm{fb}^{-1}$ of e^+e^- collisions collected at the center-of-mass energy of the $\Upsilon(4S)$ resonance (onpeak) and an additional $44\,\mathrm{fb}^{-1}$ of data collected 40 MeV below the $\Upsilon(4S)$ resonance (offpeak) [5]. The BABAR detector is described in detail in Refs. [6, 7].

Events are required to contain at least five charged tracks. Candidate D^0 mesons are formed from four charged tracks reconstructed with the appropriate mass hypothesis for the $D^0 \to K^-\pi^+e^+e^-$ and $D^0 \to K^-\pi^+\pi^+\pi^-$ decays. (Charge conjugation is implied throughout.) Particle identification (PID) is applied to the charged tracks and the same criteria are applied to the signal and normalization modes [7]. The four tracks must form a good-quality vertex with a χ^2 probability for the vertex fit greater than 0.005. In the case of $D^0 \to K^-\pi^+e^+e^-$, a bremsstrahlung energy recovery algorithm is applied to the electrons. The electron-positron pair must have an invariant mass $m(e^+e^-) > 0.1\,\mathrm{GeV}/c^2$. The D^0 candidate momentum in the PEP-II center-of-mass system, p^*, must be greater than $2.4\,\mathrm{GeV}/c$.

The candidate D^{*+} is formed by combining the D^0 candidate with a charged pion with a momentum in the laboratory frame greater than $0.1\,\mathrm{GeV}/c$. The pion is required to have a charge opposite to that of the kaon in the D^0 decay. A vertex fit is performed with the D^0 mass constrained to its known value and the requirement that the D^0 meson and the pion originate from the interaction region. The χ^2 probability of the fit is required to be greater than 0.005. The D^0 meson mass $m(D^0)$ must be in the range $1.81 < m(D^0) < 1.91\,\mathrm{GeV}/c^2$ and the mass difference, $\Delta m = m(D^{*+}) - m(D^0)$, between the reconstructed masses of the D^{*+} and D^0 candidates is required to satisfy $0.143 < \Delta m < 0.148\,\mathrm{GeV}/c^2$. The average reconstruction efficiency for the $D^0 \to K^-\pi^+\pi^+\pi^-$ decay is $\hat{\varepsilon}_{\mathrm{norm}} = (20.1 \pm 0.2)\%$. In the mass range $0.675 < m(e^+e^-) < 0.875\,\mathrm{GeV}/c^2$, the average reconstruction efficiency for the $D^0 \to K^-\pi^+e^+e^-$ decay is $\hat{\varepsilon}_{\mathrm{sig}} = (8.9 \pm 0.2)\%$.

The $D^0 \to K^-\pi^+e^+e^-$ branching fraction is determined relative to that of the normalization decay channel $D^0 \to K^-\pi^+\pi^+\pi^-$ using

$$\frac{\mathscr{B}(D^0 \to K^-\pi^+e^+e^-)}{\mathscr{B}(D^0 \to K^-\pi^+\pi^+\pi^-)} = \frac{\hat{\varepsilon}_{\mathrm{norm}}}{N_{\mathrm{norm}}} \frac{\mathscr{L}_{\mathrm{norm}}}{\mathscr{L}_{\mathrm{sig}}} \sum_i^{N_{\mathrm{sig}}} \frac{1}{\varepsilon^i_{\mathrm{sig}}}, \tag{1}$$

where $\mathscr{B}(D^0 \to K^-\pi^+\pi^+\pi^-)$ is the branching fraction of the normalization mode [8], and $N_{\rm norm}$ and $\hat{\varepsilon}_{\rm norm}$ are the $D^0 \to K^-\pi^+\pi^+\pi^-$ fitted yield and the reconstruction efficiency calculated from simulated $D^0 \to K^-\pi^+\pi^+\pi^-$ decays, respectively. The fitted $D^0 \to K^-\pi^+e^+e^-$ signal yield is represented by $N_{\rm sig}$ and $\varepsilon^i_{\rm sig}$ is the reconstruction efficiency for each signal candidate i calculated as a function of $m(e^+e^-)$ and $m(K^-\pi^+)$ from simulated $D^0 \to K^-\pi^+e^+e^-$ decays. The symbols $\mathscr{L}_{\rm sig}$ and $\mathscr{L}_{\rm norm}$ represent the integrated luminosities used for the signal $D^0 \to K^-\pi^+e^+e^-$ decay ($468.2 \pm 2.0\,{\rm fb}^{-1}$) and the normalization $D^0 \to K^-\pi^+\pi^+\pi^-$ decay ($39.3 \pm 0.2\,{\rm fb}^{-1}$), respectively [5].

The $D^0 \to K^-\pi^+e^+e^-$ and $D^0 \to K^-\pi^+\pi^+\pi^-$ yields are determined from extended unbinned maximum likelihood fits to the Δm and the four-body mass distributions. Asymmetric Gaussian-like and Cruijff functions are used for the peaking features and Chebychev polynomials or ARGUS functions [9] for the backgrounds. The fitted yield for the $D^0 \to K^-\pi^+\pi^+\pi^-$ normalization data sample is $260\,870 \pm 520$ candidates. For the $D^0 \to K^-\pi^+e^+e^-$ signal mode, the fitted yield is 68 ± 9 candidates in the range $0.675 < m(e^+e^-) < 0.875\,{\rm GeV}/c^2$. The significance $S = \sqrt{-2\Delta\ln\mathscr{L}}$ of the signal yield in this mass range, including statistical and systematic uncertainties, is 9.7 standard deviations (σ), where $\Delta\ln\mathscr{L}$ is the change in the log-likelihood from the maximum value to the value when the number of $D^0 \to K^-\pi^+e^+e^-$ signal candidates is set to $N_{\rm sig} = 0$.

Figure 1 shows the results of the fit to the $m(K^-\pi^+e^+e^-)$ and Δm distributions of the $D^0 \to K^-\pi^+e^+e^-$ signal mode in the mass range $0.675 < m(e^+e^-) < 0.875\,{\rm GeV}/c^2$. Figure 2 shows the projection of the fit to the $D^0 \to K^-\pi^+e^+e^-$ signal mode as a function of $m(e^+e^-)$ and $m(K^-\pi^+)$, where the background has been subtracted using the *sPlot* technique [10]. A peaking structure is visible in $m(e^+e^-)$ centered near the ρ^0/ω masses. A broader structure is seen in $m(K^-\pi^+)$ near the known mass of the $\bar{K}^*(892)^0$ meson. Both distributions are similar to the distributions shown in Ref. [4] for the decay $D^0 \to K^-\pi^+\mu^+\mu^-$.

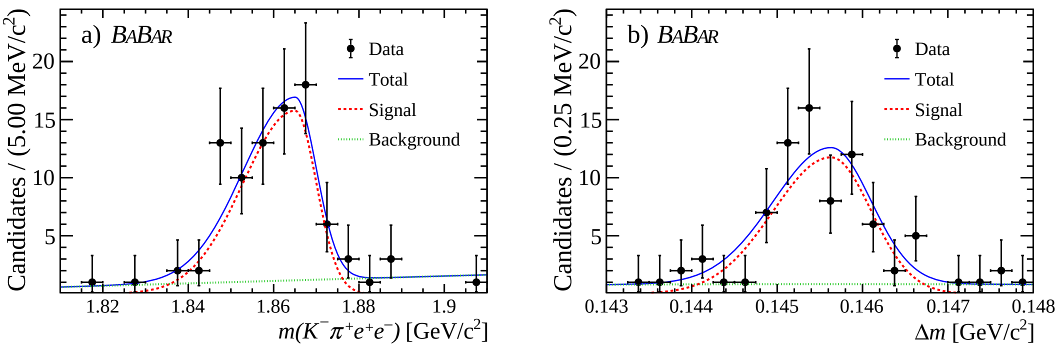

Figure 1: Fits to $D^0 \to K^-\pi^+e^+e^-$ data distributions for (a) $m(K^-\pi^+e^+e^-)$ and (b) Δm mass in the mass range $0.675 < m(e^+e^-) < 0.875\,{\rm GeV}/c^2$.

The overall systematic uncertainty in in the $D^0 \to K^-\pi^+e^+e^-$ branching fraction is 3.8%, where the uncertainty in the $D^0 \to K^-\pi^+\pi^+\pi^-$ branching fraction is excluded [8]. The branching fraction $\mathscr{B}(D^0 \to K^-\pi^+e^+e^-)$ in the mass range $0.675 < m(e^+e^-) < 0.875\,{\rm GeV}/c^2$ is determined to be $(4.0 \pm 0.5 \pm 0.2 \pm 0.1) \times 10^{-6}$, where the first uncertainty is statistical, the second systematic, and the third comes from the uncertainty in $\mathscr{B}\,(D^0 \to K^-\pi^+\pi^+\pi^-)$ [8]. This result is compatible

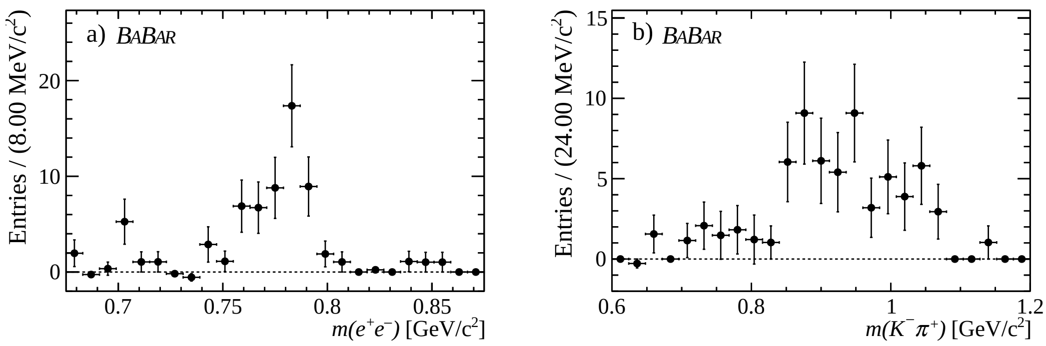

Figure 2: Projections of the fits to the $D^0 \to K^-\pi^+e^+e^-$ data distributions onto (a) $m(e^+e^-)$ and (b) $m(K^-\pi^+)$ in the mass range $0.675 < m(e^+e^-) < 0.875\,\mathrm{GeV}/c^2$.

within the uncertainties with $\mathscr{B}(D^0 \to K^-\pi^+\mu^+\mu^-)$ reported in Ref. [4] and with SM predictions [11].

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