Measurement of the absolute branching fraction of $D^+ \to \bar{K}^0 e^+ \nu_e$ via $\bar{K}^0 \to \pi^0\pi^0$ postprint

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Abstract

By analyzing 2.93 fb−1 data collected at the center-of-mass energy √s=3.773 GeV with the BESIII detector, we measure the absolute branching fraction of the semileptonic decay D+→K¯0e+ e to be B(D+→K¯0e+ e)=(8.59±0.14±0.21)% using K¯0→K0S→ 0 0, where the first uncertainty is statistical and the second systematic. Our result is consistent with previous measurements within uncertainties.

Full Text

Preamble

Measurement of the absolute branching fraction of D → K̄ e via K̄ →

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By analyzing 2.93 fb^{1} of data collected at a center-of-mass energy of $\sqrt{s} = 3.773$ GeV with the BESIII detector, we measure the absolute branching fraction of the semileptonic decay $D \to \bar{K} e$ (with $\bar{K} \to$) to be ($D \to \bar{K} e$) = (8.59 ± 0.14 ± 0.21)%, where the first uncertainty is statistical and the second systematic. Our result is consistent with previous measurements within uncertainties.

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Introduction

The study of semileptonic decays of D mesons provides valuable insights into both strong and weak interaction effects in charmed meson decays. The absolute branching fraction of the semileptonic decay $D \to \bar{K} e$ can be used to extract the form factor f (0) of the hadronic weak current [1], which is crucial for calibrating lattice quantum chromodynamics calculations of f (0) and for testing the unitarity of the quark mixing matrix. Additionally, the measured ($D \to \bar{K} e$) can be used to test isospin symmetry in $D \to K e$ decays [2-4]. Therefore, improving the measurement precision of ($D \to \bar{K} e$) will help advance our understanding of D meson decay mechanisms.

Measurements of ($D \to \bar{K} e$) and ($D \to K e$) via $\bar{K} \to$ have been performed by the MARKIII, BES, CLEO, and BESIII Collaborations [2-5]. Recently, a measurement of ($D \to K e$) has been carried out by the BESIII Collaboration [6]. However, no measurement of ($D \to \bar{K} e$) using $\bar{K} \to$ has been reported thus far. As a first step, we present in this paper a measurement of ($D \to \bar{K} e$) using $\bar{K} \to$, based on an analysis of 2.93 fb^{1} of e e collision data [7] accumulated at $\sqrt{s} = 3.773$ GeV with the BESIII detector [8]. Since there is currently no room to improve our measurement of f (0) [9], we focus solely on measuring ($D \to \bar{K} e$) in this work.

BESIII Detector and Monte Carlo Simulation

The BESIII detector is a cylindrical detector with 93% solid-angle coverage that operates at the BEPCII collider. It consists of several main components. A 43-layer main drift chamber (MDC) surrounding the beam pipe performs precise determination of charged particle trajectories and provides ionization energy loss (dE/dx) measurements used for charged particle identification (PID). An array of time-of-flight counters (TOF) is located radially outside the MDC and provides additional charged particle identification information. A CsI(Tl) electromagnetic calorimeter (EMC) surrounds the TOF and measures the energies of photons and electrons. A solenoidal superconducting magnet located outside the EMC provides a 1 T magnetic field in the central tracking region. The iron flux return of the magnet is instrumented with approximately 1272 m^2 of resistive plate muon counters (MUC) arranged in nine layers in the barrel and eight layers in the endcaps, used to identify muons with momentum greater than 0.5 GeV/c. Further details about the BESIII detector are described in Ref. [8].

A GEANT4-based [10] Monte Carlo (MC) simulation software package, which includes the geometric description and simulation of the detector response, is used to determine detection efficiencies and estimate potential backgrounds. An inclusive MC sample is produced at $\sqrt{s} = 3.773$ GeV, including generic (3770) decays, initial state radiation (ISR) production of (3686) and J/ , QED processes (e e , ,), and $\bar{q}q$ (q = u, d, s) continuum processes. The (3770) decay events are generated using a combination of the MC generators KKMC [11] and PHOTOS [12], which incorporate the effects of ISR [13] and final state radiation (FSR). Known decay modes of charmonium states are generated using EvtGen [14] with branching fractions taken from the Particle Data Group (PDG) [15], and the remaining events are generated using LundCharm [16]. The D → $\bar{K}$ e signal is modeled by the modified pole model [17].

III. Measurement

A. Single Tag D Mesons

All charged tracks are required to be reconstructed within the good MDC acceptance |cos | < 0.93, where is the polar angle of the track with respect to the beam direction. All tracks except those from K decays must originate from the interaction region defined by V < 1.0 cm and |V_z| < 10.0 cm, where V and V_z are the distances of closest approach to the interaction point (IP) in the plane transverse to and along the beam direction, respectively.

For charged particle PID, we combine dE/dx and TOF information to calculate confidence levels for the pion and kaon hypotheses (CL_ and CL_K). A charged track is identified as a kaon (pion) if CL_K > CL_ (CL_ > CL_K).

K candidates are reconstructed via K → decays. The two oppositely charged tracks, assumed to be without PID, are required to originate from a common vertex. The distance between the interaction point and the K decay vertex must satisfy L < 20.0 cm. A combination is considered a K candidate if its invariant mass lies within |M_{ } - M_{K }| < 12 MeV/c^2, where M_{K } is the nominal K mass [18]. The combinations with L/ _L > 2 are retained, where _L is the uncertainty of the reconstructed decay length L.

Photon candidates are selected using EMC information. The shower time is required to be within 700 ns of the event start time. The shower energy must be greater than 25 MeV in the barrel region and 50 MeV in the endcap region. The opening angle between the candidate shower and the closest charged track must be greater than 10°. A combination is considered a candidate if its invariant mass falls in the range (0.115, 0.150) GeV/c^2. To obtain better mass resolution for the D candidates, the invariant mass is constrained to the nominal mass [18] via a kinematic fit.

The ST D mesons are reconstructed using six hadronic decay modes: K , K , K , K , K , and K K . The daughter particles K and are reconstructed via K → and → , respectively.

To measure the yield of ST D mesons, we fit the beam-energy constrained mass spectra M_{BC} = √(E^2_{beam} - |p*{mKn }|^2) of the accepted mKn combinations, as shown in Fig. 1 [Figure 1: see original paper]. Here, p*{mKn } is the measured momentum of the mKn combination. In the fits, the D signal is modeled by the MC-simulated M_{BC} distribution convolved with a double Gaussian function, and the combinatorial background is described by an ARGUS function [19]. Candidates in the ST D signal region defined as (1.863, 1.877) GeV/c^2 are retained for further analysis. Single-tag reconstruction efficiencies _{ST} are estimated by analyzing the inclusive MC sample. The ST yields N_{ST} and efficiencies are summarized in Table I. The total ST yield is N^{tot}_{ST} = 1,522,474.

To suppress combinatorial backgrounds, we define the variable ΔE = E_{mKn } - E_{beam}, which is the difference between the measured energy of the mKn (m = 1, 2, n = 1, 2, 3) combination (E_{mKn }) and the beam energy (E_{beam}). For each ST mode, if more than one mKn combination satisfies the selection criteria, only the one with the minimum |ΔE| is kept. The ΔE requirement is within (-25, +25) MeV for the K , K , K , and K K decay modes, and within (-55, +40) MeV for the K and K modes.

B. Double Tag Events

With a mass of 3.773 GeV, just above the open charm threshold, the (3770) resonance decays predominantly into D D̄ or D D meson pairs. In each event, if a D meson can be fully reconstructed via its decay into hadrons (called the single tag (ST) D), there must be a recoiling D meson. Using a double tag technique first employed by the MARKIII Collaboration [2], we can measure the absolute branching fraction of the D → K̄ e decay. Throughout this paper, charge conjugation is implied.

In the system recoiling against the ST D mesons, the D → K̄ e candidates (called double tag (DT) events) are selected via K̄ → . It is required that there be at least four good photons and only one good charged track not used in the ST selection. The good charged track, photons, and mesons are selected using the same criteria as in the ST selection. If multiple combinations satisfy these selection criteria, we choose the one with the minimum ^{2} from the kinematic fit.

C. Branching Fraction Determination

By weighting the DT efficiencies by the ST yields observed in data, we obtain the averaged reconstruction efficiency of D → K̄ e : ¯_{D →K̄ e } = (25.58 ± 0.11)%, which does not include the branching fractions of K̄ → and → .

The branching fraction of D → K̄ e is determined using:

(D → K̄ e) = (N_{DT} / N^{tot}*{ST}) × (1/*¯{D →K̄ e }) × (K̄ →) × (→)^2

where N_{DT} is the DT yield, N^{tot}*{ST} is the total ST yield,* ¯{D →K̄ e } is the averaged reconstruction efficiency, and (K̄ →) and (→) are the branching fractions of K̄ → and → [18], respectively. Here, we assume that K constitutes half of the neutral kaon decays.

Inserting the numbers for N_{DT}, N^{tot}*{ST},* ¯{D →K̄ e }, (K̄ →), and (→) into the equation, we obtain:

(D → K̄ e) = (8.59 ± 0.14)%

where the uncertainty is statistical only.

D. Systematic Uncertainties

In the measurement of the branching fraction, systematic uncertainties arise from several sources: fitting of the M_{BC} spectra for ST candidates, ΔE and M_{BC} requirements, K̄ ( ) mass requirements, reconstruction, electron tracking, electron PID, E_{extra } requirement, U_{miss} fit, ^{2}_{1+ ^{2} } selection method, MC statistics, and quoted branching fractions.

The uncertainty from fitting the M_{BC} spectra of ST candidates is estimated to be 0.5% by observing the relative change in ST yields between data and MC when varying the fit range, the combinatorial background shape, or the endpoint of the ARGUS function.

To estimate uncertainties from the ΔE, M_{BC}, and K̄ ( ) mass requirements, we examine the change in the branching fraction when enlarging the ΔE selection window by 5 or 10 MeV, varying the M_{BC} selection window by ±1 MeV, and using alternative K̄ ( ) mass windows of (0.460, 0.505), (0.470, 0.500), and (0.480, 0.500) GeV/c^2. The maximum changes in the branching fraction–0.3%, 0.2%, and 0.9%–are assigned as the systematic uncertainties.

The reconstruction efficiency is examined by analyzing DT hadronic decays D → K and D → K versus D̄ → K and K ( ) . The difference in reconstruction efficiencies between data and MC is found to be (1.0 ± 1.0)% per . The systematic uncertainty in reconstruction is taken to be 1.0% for each after correcting the MC efficiency of D → K̄ e to match the data.

The uncertainty in tracking or PID for electrons is estimated by analyzing e e → e e events and assigned to be 0.5%, which is the re-weighted difference in electron tracking (or PID) efficiencies between data and MC.

The uncertainty from the E_{extra } requirement is estimated to be 0.1% by analyzing DT hadronic D̄D decays. The uncertainty from the U_{miss} fit is assigned to be 0.5%, obtained by comparing the nominal branching fraction value with alternative measurements using different signal shapes from MC-truth matched events, alternative background shapes after changing relative ratios of dominant backgrounds (doubling each simulated background for D D̄ , D D , and q̄q continuum processes), and alternative fit ranges (±50 MeV).

The difference of 0.3% in acceptance efficiencies between data and MC, estimated from DT hadronic decays D → K versus D̄ → K , is assigned as a systematic uncertainty due to the ^{2}_{1+ ^{2} } selection method.

The K ( ) meson from the signal side is formed with photon candidates reconstructed under the assumption that they originate at the IP. We examine the DT efficiencies of signal MC events where the K lifetimes from the signal side are set to the nominal value and to zero, respectively. The difference between these two DT efficiencies, which is less than 0.2%, is taken as the systematic uncertainty for K ( ) reconstruction.

The uncertainties from MC statistics and (K̄ →) are 0.5% and 0.2% [18], respectively.

In our previous work, the uncertainty from the signal MC generator was estimated to be 0.1% by comparing DT efficiencies before and after re-weighting the q^2 (= (p_D - p_K)^2) distribution of D → K e signal MC events to the distribution found in data [9], where p_D and p_K are the four-momenta of the D and K mesons.

The systematic uncertainties are summarized in Table II. Adding all uncertainties in quadrature yields a total systematic uncertainty of 2.5%.

E. Validation

The analysis procedure is validated through an input-output check using an inclusive MC sample equivalent to a luminosity of 3.26 fb ^{1}. Applying the same selection criteria as in the data analysis, we obtain an ST yield of 1,683,631 ± 85, a DT yield of 5802 ± 1768, and a weighted reconstruction efficiency for D → K̄ e of (26.07 ± 0.11)%, where no efficiency correction has been performed. Based on these numbers, we determine the branching fraction to be (D → K̄ e) = (8.82 ± 0.13)%, where the uncertainty is statistical only. The measured branching fraction is in excellent agreement with the input value of 8.83%.

To validate the reliability of the MC simulation, we examine the cos and momentum distributions of K̄ and e from the D → K̄ e candidates, as shown in

Fig. 3 [Figure 3: see original paper]. The consistency between simulation and data is very good.

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