Improved measurement of the absolute branching fraction of $D^+ \to \bar{K}^0\mu^+\nu_\mu$ postprint

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Abstract

By analyzing 2.93 fb−1 of data collected at s√=3.773 GeV with the BESIII detector, we measure the absolute branching fraction B(D+→K¯0 +)=(8.72±0.07stat.±0.18sys.)%, which is consistent with previous measurements within uncertainties but with significantly improved precision. Combining the Particle Data Group values of B(D0→K− +), B(D+→K¯0e+ e), and the lifetimes of the D0 and D+ mesons with the value of B(D+→K¯0 +) measured in this work, we determine the following ratios of partial widths: Γ(D0→K− +)/Γ(D+→K¯0 +)=0.963±0.044 and Γ(D+→K¯0 +)/Γ(D+→K¯0e+ e)=0.988±0.033.

Full Text

Improved Measurement of the Absolute Branching Fraction of D → K̄ __

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Abstract

By analyzing 2.93 fb ^{1} of data collected at √s = 3.773 GeV with the BESIII detector, we measure the absolute branching fraction B(D → K̄ _) = (8.72 ± 0.07_stat ± 0.18_sys)%, which is consistent with previous measurements within uncertainties but with significantly improved precision. Combining the Particle Data Group values of the lifetimes of the D and D mesons with the value of B(D → K̄ _) measured in this work, we determine the following ratios of partial widths: Γ(D → K _)/Γ(D → K̄ _) = 0.963 ± 0.044 and Γ(D → K̄ e _e)/Γ(D → K̄ _) = 0.988 ± 0.033, where the uncertainties are statistical and systematic, respectively.

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Introduction

Experimental studies of D semileptonic decays provide helpful information to understand D decay mechanisms. Their decay branching fractions (B) can serve to test isospin conservation and leptonic universality in D semileptonic decays. Isospin conservation implies that the partial widths (Γ) of D → K _ and D → K̄ _ should be equal. Furthermore, Ref. [1] predicts that Γ(D → K̄ e _e) differs from Γ(D → K̄ _) by about 3% due to different form factors and phase space. Using the branching fractions and the lifetimes of the D and D mesons (_D , _D), taken from the Particle Data Group (PDG) [2], we obtain Γ(D → K _)/Γ(D → K̄ _) = 0.91 ± 0.07 and Γ(D → K̄ e _e)/Γ(D → K̄ _) = 1.04 ± 0.07, where the uncertainties are dominated by B(D → K̄ _) [2]. Thus, an improved measurement of B(D → K̄ _) will be helpful to understand D decay mechanisms with better accuracy. B(D → K̄ _) can also be used to precisely determine the form factor f_+^K(0) and the quark mixing matrix element |V_cs| from D semileptonic decays [3].

Previous measurements of B(D → K̄ _) come from MARKIII [4], FOCUS [5] and BESII [6]. In this paper, by analyzing 2.93 fb ^{1} of data [7] collected at the center-of-mass energy of √s = 3.773 GeV by the BESIII detector [8], we determine the absolute branching fraction of D → K̄ _ . Throughout the paper, charge conjugation is implied.

II. BESIII Detector and Monte Carlo Simulation

The BESIII detector is a cylindrical detector with a solid-angle coverage of 93% of 4 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 determinations of charged particle trajectories and provides a measurement of the specific ionization energy loss (dE/dx) that is used for charged particle identification (PID). An array of time-of-flight counters (TOF) is located radially outside the MDC and provides additional PID information. A CsI(Tl) electromagnetic calorimeter (EMC) surrounds the TOF and is used to measure 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 of the detector. The iron flux return of the magnet is instrumented with about 1272 m^2 of resistive plate muon counters (MUC) arranged in nine layers in the barrel and eight layers in the endcaps that are used to identify muons with momentum greater than 0.5 GeV/c. More details about the BESIII detector are described in Ref. [8].

A GEANT4-based [9] Monte Carlo (MC) simulation software package, which includes the geometric description of the detector and its response, is used to determine the detection efficiency and to estimate the potential backgrounds. An inclusive MC sample, which includes the D D̄ , D D , and non-DD̄ decays of (3770), the initial state radiation (ISR) production of (3686) and J/ , the q q̄ (q = u, d, s) continuum process, the Bhabha scattering events, and the di-muon and di-tau events, is produced at $\sqrt{s}$ = 3.773 GeV. The (3770) decays are generated by the MC generator KKMC [10], in which ISR effects [11] and final state radiation (FSR) effects [12] are simulated. The known decay modes of the charmonium states are generated using EvtGen [13] with the branching fractions set to PDG values [14], and others are generated using LundCharm [15]. The D → K̄ _ signal is simulated with the modified pole model [16].

III. Method

In e e collisions at $\sqrt{s}$ = 3.773 GeV, the (3770) resonance decays predominately into a D D̄ or a D D pair. In an event where a D meson (called the single tag (ST) D meson) is fully reconstructed, the presence of a D meson is guaranteed. In the systems recoiling against the ST D mesons, we can select the semileptonic decays of D → K̄ _ (called the double tag (DT) events).

For a specific ST mode i, the ST and DT yields observed in data are given by:

N_i^ST = 2 N_D D B_i^ST _i^ST

N_i^DT = 2 N_D D B_i^ST B(D → K̄ _) _i^DT

where N_D D is the number of D D pairs produced in data, B_i^ST and B(D → K̄ _) are the branching fractions for the ST mode i and the D → K̄ _ decay, _i^ST is the efficiency of reconstructing the ST mode i (called the ST efficiency), and _i^DT is the efficiency of simultaneously finding the ST mode i and the D → K̄ _ decay (called the DT efficiency).

Based on these two equations, the absolute branching fraction for D → K̄ _ can be determined by:

B(D → K̄ _) = (Σ_i N_i^DT) / (N_tot^ST ·¯_D →K̄ _)

where ¯_D →K̄ _ = Σ_i (N_i^ST _i^DT) / N_tot^ST is the efficiency of reconstructing the D → K̄ _ decay by the ST yields in data, and N_tot^ST = Σ_i N_i^ST.

IV. Single Tag D Meson Reconstruction

The ST D mesons are reconstructed using six hadronic decay modes: K , K , K_S , K_S , K_S and K K . The decays of K_S → and → are identified in K_S → and → , respectively.

All charged tracks used in this analysis are required to be within a polar-angle ( ) range of |cos | < 0.93. Except for those from K_S decays, all tracks are required to originate from an interaction region defined by V_xy < 1.0 cm and |V_z| < 10.0 cm, where V_xy and V_z refer to the distances of closest approach of the reconstructed track to the Interaction Point (IP) in the xy plane and the z direction (along the beam), respectively.

The charged kaons and pions are identified by the dE/dx and TOF information. The combined Confidence Levels for pion and kaon hypotheses (CL_ and CL_K) are calculated, respectively. A charged track is identified as a kaon (pion) if the confidence levels satisfy CL_K > CL_ (CL_ > CL_K).

The charged tracks from K_S decays are required to satisfy |V_z| < 20.0 cm. The two oppositely charged tracks are assigned as without PID. The pair is constrained to originate from a common vertex and is required to have an invariant mass within |M_{ } - M_K_S | < 12 MeV/c^2, where M_K_S is the K_S nominal mass [2]. The K_S candidate is required to have a decay length larger than 2 standard deviations of the vertex resolution away from the IP.

Photon candidates are selected using the information from the EMC. It is required that the shower time be within 700 ns of the event start time, the shower energy be greater than 25 (50) MeV if the crystal with the maximum deposited energy in that cluster is in the barrel (endcap) region [8], and the opening angle between the candidate shower and any charged tracks be greater than 10°. To reconstruct , the invariant mass of the accepted pair is required to be within (0.115, 0.150) GeV/c^2. To improve resolution, a kinematic fit is performed to constrain the invariant mass to the nominal mass [2].

To identify the ST D mesons, we define two variables: the energy difference ΔE = E_{mKn } - E_beam and the beam energy constrained mass M_BC = √(E_beam^2 - |p*{mKn }|^2) of the mKn (m = 1, 2; n = 1, 2, 3) final states, where E_beam is the beam energy, p*{mKn } and E_{mKn } are the measured momentum and energy of the mKn final state in the e e center-of-mass frame. For each ST mode, if there is more than one combination surviving, only the one with the minimum |ΔE| is kept.

To suppress combinatorial backgrounds, ΔE is required to be within (-25, +25) MeV for the K , K_S , K_S and K K final states, and be within (-55, +40) MeV for the K and K_S final states.

To obtain the ST yield, we apply a fit to the M_BC distributions of the accepted mKn final states for data. In the fits, the D signal is modeled by a MC-determined shape of the M_BC distribution convoluted with a double Gaussian function and the combinatorial background shape is described by the ARGUS function [17]. The fit results are shown in Figure 1 [Figure 1: see original paper]. The candidates with M_BC in the range (1.863, 1.877) GeV/c^2 (signal region) are kept for further analysis. The ST yields and the ST efficiencies estimated from the inclusive MC sample are summarized in Table 1 .

V. Systematic Uncertainty

The common systematic uncertainty in the measurement of B(D → K̄ _) with K_S → and K_S → arises from the uncertainties in the fits to the M_BC distributions, the ΔE and M_BC requirements, the tracking, the PID, the E_extra^ requirement, the M_{K̄ } requirement and the U_miss fit.

The uncertainty in the fits to the M_BC distributions is estimated to be 0.5% by examining the relative change of the yields of data and MC via varying the fit range, the combinatorial background shape or the endpoint of the ARGUS function.

To estimate the uncertainties in the ΔE and M_BC requirements, we examine the branching fractions by enlarging the ΔE windows by 5 or 10 MeV and varying the M_BC windows by ±1 MeV/c^2, respectively. The maximum changes of the branching fractions, which are 0.3% and 0.3% for ΔE and M_BC requirements, are assigned as the uncertainties, respectively.

The uncertainties in the tracking and PID for are estimated by analyzing e e → events. The differences of the two-dimensional (momentum and cos) weighted tracking efficiencies of data and MC are determined to be (+0.5, -0.2)% and (+0.5, -0.5)%, respectively. We assign 0.5% and 0.5% as the systematic uncertainties in the tracking and PID for after correcting for these differences, respectively. Due to different topologies, there may be difference between the weighted efficiencies for the muons in D → K̄ _ and e e → . This difference, which is estimated to be 0.5% by analyzing the two kinds of signal MC events, is considered as a systematic uncertainty.

By examining the doubly tagged hadronic D D̄ decays, we find that the difference of the acceptance efficiencies with E_extra^ _max < 0.15 GeV of data and MC is (+3.6, -0.1)%. So, we assign 0.1% as the uncertainty in the E_extra^ requirement after correcting the MC efficiency to data.

The uncertainty in the M_{K̄ } requirement is estimated to be 0.8% by comparing the branching fractions measured with alternative requirements of M_{K̄ } < 1.55 and 1.65 GeV/c^2 with the nominal value.

The uncertainty in the U_miss fit is estimated to be 0.8% by comparing the branching fractions measured using different signal shape, background shape and fit range with the nominal value. Here, to examine the uncertainty in the background shape, we vary the relative strengths of each of the components in the inclusive MC sample and shift the estimated numbers of other peaking backgrounds by 1 .

In our previous work, the uncertainty in the signal MC generator is estimated to be 0.1%, which is obtained by comparing the DT efficiencies before and after re-weighting the q^2 = (p_D - p_K)^2 distribution of the signal MC events of D → K e _e to data [19], where the p_D and p_K are the momenta of D and K mesons.

Adding these in quadrature, we obtain the total common systematic uncertainty _com^sys to be 1.6%.

For the measurement with K_S → , the independent systematic uncertainty arises from the uncertainties in the K_S → reconstruction, the MC statistics (0.4%), and B(K_S →) (0.1%) [2]. The uncertainty in the K_S → reconstruction is estimated to be 1.5% by studying J/ → K^* K^± and J/ → K K^± ^ + c.c. events [18]. Adding these uncertainties in quadrature, we obtain the total independent systematic uncertainty (_ind^sys) for K_S → mode to be 1.6%.

For the measurement with K_S → , the independent systematic uncertainty arises from the uncertainties in the selection, the K_S mass window, the MC statistics (0.5%), and the ²_{1+ ²_2} selection method. The reconstruction efficiency is verified by analyzing the hadronic decays D → K and D → K versus D̄ → K_S ( ) . The difference of the reconstruction efficiencies of data and MC is found to be (+1.0, -1.0)% per . After correcting the detection efficiency of the signal side for this difference, the systematic uncertainty in reconstruction is taken as 1.0% per .

Here, the photons from the K_S → decays are reconstructed under an assumption that the K_S meson decayed at the IP. We investigate the DT efficiencies of two kinds of signal MC events, in which the lifetimes of K_S meson from the signal side are set at the nominal value and 0, respectively. Their difference is less than 0.2%, which is considered as the systematic uncertainty of the K_S → reconstruction.

To avoid the effect of the D → K̄ peaking backgrounds, the uncertainty in the K̄ ( ) mass window is estimated by examining the D → K̄ e _e using the same K̄ ( ) selection criteria. We compare the branching fractions measured using alternative K̄ ( ) mass windows (0.460, 0.505), (0.470, 0.500), (0.480, 0.500) GeV/c^2 with the nominal value. The maximum change of the re-measured branching fractions, 0.9%, is taken as the systematic uncertainty.

The uncertainty in the ²_{1+ ²_2} selection method is estimated to be 0.3%, which is the difference of the acceptance efficiencies of the hadronic decays of D → K versus D̄ → K between data and MC.

Adding these in quadrature, we obtain the total independent systematic uncertainty (_ind^sys) for K_S → mode to be 2.3%.

Table 2 summarizes the systematic uncertainties in the measurement of B(D → K̄ _). Quadratically combining the independent uncertainties for K_S → and K_S → modes after considering their observed DT yields as weights, we obtain the independent uncertainty to be 1.4%. Adding the common and independent uncertainties in quadrature yields the total systematic uncertainty 2.1%.

VI. Branching Fraction

The branching fraction of D → K̄ _ is determined by:

B(D → K̄ _) = N_DT^prd / N_ST^tot

where N_DT^prd is the DT production yield corrected for detection efficiency and daughter decay branching fractions, which has been constrained to be the same for K_S → and K_S → modes in the simultaneous fits, and N_ST^tot is the total ST yield.

Inserting the numbers of N_DT^prd and N_ST^tot in Eq. (4), we obtain B(D → K̄ _) = (8.72 ± 0.07 ± 0.18)%, where the first uncertainty is statistical and the second systematic.

Furthermore, we examine the measured branching fractions for D → K̄ _ by separately using each of the ST modes, which are shown in Fig. 8 [Figure 8: see original paper]. We can see that they are consistent with the nominal result within uncertainties very well. Here, the uncertainties are statistical only. The average branching fraction over the six ST modes, weighted by their statistical uncertainties, is (8.70 ± 0.07)% and is consistent with our nominal result.

VII. Summary and Discussion

In summary, by analyzing 2.93 fb ^{1} of data collected at √s = 3.773 GeV with the BESIII detector, we measure the absolute branching fraction B(D → K̄ _) = (8.72 ± 0.07_stat ± 0.18_sys)%, which is consistent with previous measurements within uncertainties but with significantly improved precision. Combining the B(D → K̄ _) measured in this work with the _D , _D , B(D → K _) and B(D → K̄ e _e) taken from the world average [2], we determine the ratios of the partial widths Γ(D → K _)/Γ(D → K̄ _) = 0.963 ± 0.044, which supports isospin conservation holding in the exclusive semi-muonic decays of D and D mesons, and Γ(D → K̄ e _e)/Γ(D → K̄ _) = 0.988 ± 0.033, which is consistent with the predicted value in Ref. [1] within uncertainties.

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