Measurement of the Branching Fraction and CP Asymmetry in Radiative $D^0 \to V\gamma$ Decays postprint

Authors: Abdesselam, A. and others

Date: 2016-08-23T00:00:00+00:00

Abstract

We report a measurement of the branching fractions of the radiative decays D0→V , where V= , K‾‾‾‾‾∗0 or 0. This is the first observation of the decay D0→ 0 . We measure preliminary branching fractions B(D0→)=(2.76±0.20±0.08)×10−5, B(D0→K‾‾‾‾‾∗0)=(4.66±0.21±0.18)×10−4 and B(D0→ 0)=(1.77±0.30±0.08)×10−5, where the first uncertainty is statistical and the second systematic. We also present the first measurement of CP asymmetry in these decays. The preliminary values are ACP(D0→)=−(0.094±0.066±0.001), ACP(D0→K‾‾‾‾‾∗0)=−(0.003±0.020±0.000) and ACP(D0→ 0)=0.056±0.151±0.006. The analysis was conducted using 943 fb−1 of data collected by the Belle detector at the KEKB e+e− collider.

Full Text

Measurement of the Branching Fraction and CP Asymmetry in Radiative D → V Decays

The Belle Collaboration

Author list and affiliations as provided in the original text

---

Abstract

We report a measurement of the branching fractions of the radiative decays D → V , where V = , K *or . This is the first observation of the decay D → . We measure preliminary branching fractions B(D →) = (2.76 ± 0.20 ± 0.08) × 10 , B(D → K*) = (4.66 ± 0.21 ± 0.18) × 10 and B(D →) = (1.77 ± 0.30 ± 0.08) × 10 , where the first uncertainty is statistical and the second systematic. We also present the first measurement of CP asymmetry in these decays. The preliminary values are A_CP(D →) = −0.094 ± 0.066 ± 0.001, A_CP(D → K*) = −0.003 ± 0.020 ± 0.000 and A_CP(D →) = 0.056 ± 0.151 ± 0.006. The analysis was conducted using 943 fb ¹ of data collected by the Belle detector at the KEKB e e collider.

PACS numbers: 11.30.Er, 13.20.Fc, 13.25.Ft, 14.40.Lb

Introduction

CP violation in the charm sector has long been a neglected field of study, gaining renewed interest only in recent years. The radiative decays D → V , where V is a vector meson, could be sensitive to New Physics via CP asymmetry. Theoretical studies [**?**, **?**] predict that in Standard Model (SM) extensions with chromomagnetic dipole operators, A_CP can rise to several percent for V = , , compared to the O(10 ³) SM expectation.

The radiative decay D → has been measured by the Belle and BABAR collaborations [**?**, **?**]. BABAR also observed the decay D → K *[**?**], while CLEO II produced an upper limit for the D → branching fraction [**?**]. The current world average values of the branching fractions are (2.70 ± 0.35) × 10 (mode) and (32.7 ± 3.4) × 10 (K* mode). For the mode, the upper limit is B(D →) < 24 × 10 (90% C.L.) [**?**]. No study of CP violation in decays D → V has been conducted to date.

We present here a measurement of the branching fractions and CP asymmetries in decays D → V , where V { , K* , }. This is the first observation and branching fraction measurement of the decay D → .

Detector and Data

The analysis is based on 943 fb ¹ of data collected by the Belle detector, operating at the asymmetric KEKB e e collider [**?**]. The data was collected at or near energies corresponding to the $\Upsilon(5S)$, $\Upsilon(4S)$, $\Upsilon(3S)$ and $\Upsilon(2S)$ resonances. The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter comprised of CsI(Tl) crystals (ECL) located inside a super-conducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return located outside of the coil is instrumented to detect K_L mesons and to identify muons (KLM). The detector is described in detail elsewhere [**?**, **?**].

Analysis Procedure

The analysis procedure was developed using a Monte Carlo (MC) simulation based on EvtGen [?] and GEANT3 [?] and includes final-state radiative effects (FSR) simulated by PHOTOS [?]. The selection criteria are optimized to maximize the figure of merit, defined as N_sig/√(N_sig + N_bkg), where N_sig (N_bkg) represent the number of signal (background) events. For estimating N_sig in the mode, we take B(D →) = 3 × 10 , as theory predicts it to be similar to the mode [?], since both are Cabibbo-suppressed decays.

The D mesons are required to originate from the decay D → *D in order to provide a tag on the D flavor and to suppress combinatorial background. The signal decays are reconstructed in the following decay chains of the vector mesons: → K K , K* → K and → . We accept candidates in a mass window of 11 MeV/c² around the nominal mass [?], while for K* and , the mass windows are 60 MeV/c² and 150 MeV/c², respectively. Candidate photons are required to have an energy greater than 540 MeV. To suppress events with two photons from a decay forming a merged cluster, we require the ratio of the energy deposited in a 3 × 3 array of ECL crystals (E9) versus the energy deposited in the enclosing 5 × 5 array (E25) to be above 0.94.

When reconstructing both charm mesons, a vertex fit is applied and candidates with confidence levels exceeding 10 ³ are retained. For the D *, an additional interaction-point (IP) constraint is applied, which requires that both daughter particles originate from the e e interaction region. To suppress combinatorial background, we require the total energy released in the decay q M(D*) - M(D) - m( ) (where M is the invariant mass and m the nominal mass [?]) to lie in a 0.6 MeV/c² window around the nominal value [?]. The momentum of the D *in the center-of-mass system (CMS) must satisfy p_CMS(D*) > 2.42 GeV/c (mode), p_CMS(D *) > 2.17 GeV/c (K* mode) and p_CMS(D*) > 2.72 GeV/c (mode).

Normalization Method

Both the branching fraction and A_CP are obtained via normalization to other decay channels. The signal branching fraction B_sig is given by B_sig = B_norm × (N_sig/ _sig)/(N_norm/ _norm), where N is the extracted yield, the reconstruction efficiency and B the branching fraction for signal and normalization modes, respectively. For B_norm the world-average value [?] is used.

The extracted raw asymmetry A_raw = (N(D) - N(D̄))/(N(D) + N(D̄)) is given by A_raw = A_CP + A_FB + A_ ^±. Here, A_FB is the forward-backward production asymmetry [?], and A_ ^± the asymmetry due to different reconstruction efficiencies for positively and negatively charged particles. Both can be eliminated through a relative measurement of A_CP if the charged final-state particles are identical. The chosen normalization modes are D → K K (

mode), D → K (K* mode) and D → (mode). The CP asymmetry of the signal modes is A_CP^sig = A_CP^norm + A_raw^sig - A_raw^norm, where A_CP^norm is the nominal value of CP asymmetry of the normalization modes [**?**].

Background Suppression

The dominant background arises from decays comprising a instead of a photon with the subsequently decaying into a pair of photons. The final-state hadrons are the same as in our signal decays, but one of the daughter photons is missed in the reconstruction. To suppress such events, a dedicated veto is developed, comprising a neural network [**?**, **?**] variable obtained from two mass veto variables. The signal photon is paired once with each other photon in the event with an energy above 30 MeV, and once with each photon with an energy above 75 MeV. The pair in each set whose diphoton mass lies closest to m( ) is fed to the neural network. The final criterion on the veto variable rejects about 60% of background while losing about 15% of signal.

Fit Procedure

To extract the signal yield and CP asymmetry, a simultaneous two-dimensional unbinned extended maximum likelihood fit of D and D̄ samples is performed. The fit variables are the invariant mass of the reconstructed D meson and the cosine of the helicity angle _H, defined as the angle between the D and the positively or negatively charged hadron in the rest frame of the V meson (for D , we take K /K / for /K* / , and the opposite charged particles for D̄). By angular momentum conservation, the cos(_H) distribution of signal decays is proportional to 1 - $\cos^2$(_H). No background contribution is expected to exhibit a similar shape in cos(_H).

For the K *and signal modes, the helicity-angle range is reduced to -0.8 < cos(_H) < 0.4 to suppress certain peaking backgrounds. For the mode, the full cos(_H) range is used. The range of the D mass variable is set to 1.67 GeV/c^2 < M(D) < 2.06 GeV/c^2 for all three signal modes. The final full-reconstruction efficiencies, determined from MC simulation, are 9.7% (mode), 7.8% (K* mode) and 6.8% (mode).

The invariant-mass distribution of candidate signal events is modeled with a single Crystal-Ball function [**?**] for the and modes, and a combination of a Crystal-Ball and two Gaussians for the K *mode. To take into account possible differences between MC and data, a free offset and scale factor are implemented for the mean and width ( ) of the K* PDF, and the obtained values are applied to the other two signal modes.

The - and (→)-type background M(D) distributions are described with either a Crystal-Ball or the combination of a Crystal-Ball or logarithmic Gaussian [?] with up to two additional Gaussians. For the mode, the only -type background is the decay D → . In the K *mode, and -type backgrounds are the decays D → K (1430) , K* , non-resonant K *, K , K* , K* and non-resonant K . For the mode, the backgrounds are , charged and K with the kaon being misidentified as pion. In all three signal modes, a remaining "catch-all" background comprises all other decays wherein the D is correctly reconstructed.

In the K *( ) mode, there are two additional backgrounds: the decay to K ( ) with the photon being emitted as FSR and the decay into K with the photon being emitted from a radiative decay of the charged meson. Since there are no missing particles, these decays exhibit the same M(D) distribution as the signal decays. We fix their yields to expectations based on MC and the known branching fractions [?]. The remaining combinatorial background is parametrized in M(D) with an exponential function in the mode and a second-order Chebyshev polynomial in the K* and modes. All parameters are left free in the fit.

The MC invariant-mass distribution M(D) of events from the dominant background is calibrated by reconstructing the forbidden decay D → K_S in simulation and data, which yields mostly background from decays D → K_S . The same particle identification criteria as for signal decays are applied, along with the q cut and the p_CMS(D*) cut as determined for the mode. K_S candidates in a ±9 MeV/c² window around the nominal mass are accepted. To calibrate to the data distribution, the simulation distribution is smeared with a Gaussian of width 7 MeV/c² and offset (-1.33 ± 0.25) MeV/c².

The cos(_H) signal distribution is parametrized as 1 - cos²(_H) with no free parameters for all three signal modes. For the V and V categories, the shape is close to cos²(_H) and described with a third-order (K* mode) or second-order (and mode) Chebyshev polynomial. In the mode, the parameters are left free to take into account possible interference between resonant and non-resonant amplitudes. For other background categories that do not in fact contain the vector resonance, the non-trivial distributions are parametrized in an ad hoc manner.

In the K *mode, the yield (and A_raw) of certain backgrounds that contain a low number of events is fixed: the decays to K (1430) , K* and the catch-all background. The same is done for backgrounds with a photon from FSR or radiative decay in the K *and modes. For the fit to data, all fixed yields are scaled by the ratio between reconstructed signal events in simulation and data of the normalization modes. We impose an additional constraint in the K* mode by assigning two common A_raw variables to all - and all -type backgrounds. Since all are Cabibbo-favored decays, A_CP is expected to be zero, while other asymmetries contributing to A_raw are expected to be the same for decays with the same final-state particles.

The fit results are shown in Figures 1, 2 and 3 for the , K *and modes, respectively. The signal component is denoted with the dashed red line. The extracted signal yields are 524 ± 35 (mode), 9104 ± 396 (K* mode) and 500 ± 85 (mode). The extracted raw asymmetries are -0.091 ± 0.066 (mode), -0.002 ± 0.020 (K* mode) and 0.056 ± 0.151 (mode). Here, the uncertainties are statistical only.

Normalization Mode Analysis

The analysis of the normalization modes is based on the previous analysis of the same modes by Belle [**?**]. The same selection criteria as for signal modes for particle identification, vertex fit, q and p_CMS(D*) are applied. The signal yield is extracted via background subtraction in a signal window (SW) of m(D), with the background being estimated from a symmetrical upper and lower sideband (USB and LSB). Based on MC, the fraction of background events in the signal window compared to all events in sidebands f = (N_bkg^SW)_MC/(N_LSB + N_USB)_MC is calculated and then used to calculate the number of background events in data in the signal window (N_bkg^SW)_DATA = f × (N_LSB + N_USB)_DATA.

The reliance on the fraction f determined from simulation is validated by comparing background distributions in a q sideband for simulation and data, which are proven to be in good agreement. We verify that the fraction is uniform for both D and D̄ samples. The signal window for the K K mode is ±14 MeV/c² around the nominal value [**?**], with the sidebands being ±(31-45) MeV/c² around the nominal value. For the K mode, the signal window is ±16.2 MeV/c² and sidebands are ±(28.8-45) MeV/c², and for the mode, the signal window is ±15 MeV/c² and sidebands are ±(20-35) MeV/c².

The efficiencies, determined from simulation, are 22.7% for K K , 27.0% for K and 21.4% for . We extract a signal yield of 362,274 events for K K , 4.02 × 10 events for K and 127,683 events for . The extracted raw asymmetries are (2.2 ± 1.7) × 10 ³ (K K), (1.3 ± 0.5) × 10 ³ (K) and (8.1 ± 3.0) × 10 ³ ( ).

Systematic Uncertainties

All systematic uncertainties are summarized in Table I. There are two main sources: those due to the selection criteria and those that arise from the signal extraction method, both for signal and normalization modes. Some of the uncertainties from the first group cancel if they are common to both the signal and respective normalization mode: all uncertainties related to particle identification of charged particles, vertex fit, and the imposed requirement on p_CMS(D*). A 2% uncertainty is ascribed to photon reconstruction efficiency [**?**]. Due to the presence of the photon in the signal modes, the resolution of the q distribution is worse than in the normalization modes and the related systematic uncertainties cannot be assumed to completely cancel out.

We separately estimate the systematic uncertainty due to the q cut using the control channel D → K* . For both MC and data, the efficiency of the q cut is estimated by calculating the ratio R of the signal yield, extracted with the cut imposed, and the signal yield extracted from the sample without the cut. Then, the double ratio R_MC/R_DATA(q) is calculated to assess the possible difference between MC and data. The obtained value is R_MC/R_DATA = 1.0100 ± 0.0016. We do not correct the efficiency by the central value; instead, we assign a systematic uncertainty of 1.16%.

The described double ratio is used to estimate also the uncertainties due to the cut on the veto variable and the E9/E25 ratio. For the veto, the control channel for which the efficiency of the veto is assessed is D → K_S . The veto is calculated by pairing the first daughter photon of the with all others except the second daughter. The ratio R of so-discarded events is calculated for MC and data. The obtained double ratio is R_MC/R_DATA(veto) = 1.002 ± 0.005. For E9/E25, the control channel is the previously used D → K_S sample. The obtained double ratio is R_MC/R_DATA(E9/E25) = 1.0003 ± 0.0096. While estimating the efficiency of the variable in question, all other selection criteria are applied. For both the veto and E9/E25, the double ratio is consistent with 1 within the margin of error. The error on the double ratio directly translates to the systematic uncertainty of the efficiency.

For the fit procedure, a systematic uncertainty must be ascribed to every item that is determined and fixed from MC but might differ in data. In these cases, the fit procedure is repeated with each parameter varied by its uncertainty. The biggest difference between the so obtained branching fraction or A_CP and the base values is taken as the systematic error. An uncertainty is assigned to the calibration offset of the -type backgrounds and, for the nominal width of the smearing, by varying the width by ±1 MeV/c². For the and modes, the uncertainty is calculated for the width scale factor and offset of the signal M(D) PDF.

The values of the fixed yields of some backgrounds in the K *and mode are varied according to the uncertainties of the respective branching fractions [**?**]. For the category with the FSR photon, a 20% variation is taken [**?**]. As the branching fractions contributing to the catch-all background in the K* mode are not known, we conservatively apply the largest variation from among other categories.

For the normalization modes, the procedure is repeated with sidebands taken at a different position, starting from ±25 MeV/c² from m(D). The statistical error on the fraction f is taken into account, as is the error on the nominal value of A_CP of the normalization modes. Since possible differences in the signal shape between MC and data could also affect f, a similar procedure as for the calibration of the background is performed. A systematic uncertainty is assigned for the case when f is obtained from MC smeared by a Gaussian of width 1.6 MeV/c^2.

Summary

In summary, we have conducted a measurement of the branching fraction and A_CP asymmetry in decays D → V , where V { , K , *}, relative to the decay modes D → K K (mode), D → K (K* mode) and D → (mode). We report branching fractions of the D → and D → K* modes and the first observation of the D → mode. The significance of the observation is greater than 5 , including systematic uncertainties. The significance is calculated as √(-2 ln(L /L_max)), where L is the likelihood value when the signal yield is fixed to zero and L_max is the likelihood value of the nominal fit. The systematic uncertainties are included by convolving the likelihood function with a Gaussian whose width corresponds to the systematic uncertainty that affects the signal yield.

The preliminary branching fractions are: - B(D →) = (2.76 ± 0.20 ± 0.08) × 10 - B(D → K*) = (4.66 ± 0.21 ± 0.18) × 10 - B(D →) = (1.77 ± 0.30 ± 0.08) × 10

where the first uncertainty is statistical and the second systematic. The result of the mode is improved compared to the previous Belle result and is consistent with the world average value [**?**]. Our branching fraction of the K* mode is 3.3 away from the result of the BABAR analysis. For the mode, the obtained value is close to that of the mode, which is in accordance with theoretical predictions.

We also report the first-ever measurement of A_CP in the decays D → V . The preliminary values are: - A_CP(D →) = -(0.094 ± 0.066 ± 0.001) - A_CP(D → K*) = -(0.003 ± 0.020 ± 0.000) - A_CP(D →) = 0.056 ± 0.151 ± 0.006

We report no observation of CP asymmetry in any of the D → V decay modes.

Acknowledgments

We thank the KEKB group for excellent operation of the accelerator; the KEK cryogenics group for efficient solenoid operations; and the KEK computer group, the NII, and PNNL/EMSL for valuable computing and SINET4 network support. We acknowledge support from MEXT, JSPS and Nagoya' s TLPRC (Japan); ARC (Australia); FWF (Austria); NSFC and CCEPP (China); MSMT (Czechia); CZF, DFG, EXC153, and VS (Germany); DST (India); INFN (Italy); MOE, MSIP, NRF, BK21Plus, WCU and RSRI (Korea); MNiSW and NCN (Poland); MES and RFAAE (Russia); ARRS (Slovenia); IKERBASQUE and

UPV/EHU (Spain); SNSF (Switzerland); MOE and MOST (Taiwan); and DOE and NSF (USA).

References

[1] G. Isidori and J. F. Kamenik, Phys. Rev. Lett. 109, 171801 (2012), arXiv:1205.3164 [hep-ph].

[2] J. Lyon and R. Zwicky, (2012), arXiv:1210.6546 [hep-ph].

[3] O. Tajima et al. (Belle Collaboration), Phys. Rev. Lett. 92, 101803 (2004).

[4] B. Aubert et al. (BaBar), Phys. Rev. D78, 071101 (2008), arXiv:0808.1838 [hep-ex].

[5] D. M. Asner et al. (CLEO), Phys. Rev. D58, 092001 (1998), arXiv:hep-ex/9803022 [hep-ex].

[6] K. A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014).

[7] S. Kurokawa and E. Kikutani, Nucl. Instrum. Meth. A499, 1 (2003).

[8] A. Abashian et al., Nucl. Instrum. Meth. A479, 117 (2002).

[9] *Reference omitted in original*

[10] D. J. Lange, Nucl. Instrum. Meth. A462, 152 (2001).

[11] R. Brun, F. Bruyant, M. Maire, A. C. McPherson, and P. Zanarini, (1987).

[12] P. Golonka and Z. Was, Eur. Phys. J. C45, 97 (2006), arXiv:hep-ph/0506026 [hep-ph].

[13] M. Feindt, (2004), arXiv:physics/0402093 [physics].

[14] M. Feindt and U. Kerzel, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 559, 190 (2006).

[15] T. Skwarnicki, A study of the radiative CASCADE transitions between the Upsilon-Prime and Upsilon resonances, Ph.D. thesis, Cracow, INP (1986).

[16] H. Ikeda et al. (Belle), Nucl. Instrum. Meth. A441, 401 (2000).

[17] M. Staric et al. (Belle), Phys. Lett. B670, 190 (2008), arXiv:0807.0148 [hep-ex].

[18] N. K. Nisar et al. (Belle), (2015), arXiv:1512.02992 [hep-ex].

[19] M. Benayoun, S. I. Eidelman, V. N. Ivanchenko, and Z. K. Silagadze, Mod. Phys. Lett. A14, 2605 (1999), arXiv:hep-ph/9910523 [hep-ph].

Table I. The systematic uncertainties.

Source	mode		K* mode		mode	
	B [%]	A_CP [×10 ³]	B [%]	A_CP [×10 ³]	B [%]	A_CP [×10 ³]
rec. eff.	2.00	0.00	2.00	0.00	2.00	0.00
veto	0.50	0.05	0.50	0.05	0.50	0.05
E9/E25	0.96	0.01	0.96	0.01	0.96	0.01
signal parametrisation	0.95	0.05	0.50	0.02	0.95	0.05
bkg. parametrisation	0.50	0.10	0.50	0.10	0.50	0.10
fixed bkg. yields	0.50	0.05	0.50	0.05	0.50	0.05
norm. modes systematics	0.50	0.05	0.50	0.05	0.50	0.05
total	2.89	0.13	2.89	0.13	2.89	0.13

Figure Captions

[Figure 1: see original paper] Distributions in M(D) (top row) and cos(_H) (bottom row) of the mode for D (left) and D̄ (right), with fit results superimposed.

[Figure 2: see original paper] Distributions in M(D) (top row) and cos(_H) (bottom row) of the K* mode for D (left) and D̄ (right), with fit results superimposed.

[Figure 3: see original paper] Distributions in M(D) (top row) and cos(_H) (bottom row) of the mode for D (left) and D̄ (right), with fit results superimposed.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.