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Absolute Branching Fraction Measurements of Inclusive Charged and Neutral D meson Semileptonic Decays*

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Abstract

We present a measurement of the inclusive branching fractions for the decays $D^+ \to Xe^+\nu_e$ and $D^0 \to Xe^+\nu_e$, using 281 pb^{-1} of data collected on the $\psi(3770)$ resonance with the CLEO-c detector. We find $\mathcal{B}(D^0 \to Xe^+\nu_e) = (6.45 \pm 0.17 \pm 0.15)\%$ and $\mathcal{B}(D^+ \to Xe^+\nu_e) = (16.19 \pm 0.20 \pm 0.36)\%$.

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I. INTRODUCTION

The study of the inclusive semileptonic widths of charged and neutral D mesons is a powerful laboratory to probe our quantitative understanding of QCD [1]. Under the assumption of isospin symmetry, the semileptonic widths of the D^+ and D^0 mesons should be equal. Thus, modulo correction introduced by Cabibbo suppressed partial widths, $\mathcal{B}(D^+ \to X\ell^+\nu_\ell)/\mathcal{B}(D^0 \to X\ell^+\nu_\ell)$ should be equal to τ^+/τ^0, the corresponding lifetime ratio.

The comparison between the shape of the D^+ and D^0 electron momentum spectra may uncover the relevance of weak annihilation diagrams [1]. In the naive factorization these effects are strongly suppressed, but there is no strong theoretical motivation for it. Non-factorizable effects may also influence the extraction of V_{ub} from inclusive B meson semileptonic decays, and thus it is important to understand them well.

The CLEO-c experiment provides a unique opportunity to study these decays, as it is accumulating a large sample of data taken just above $D\bar{D}$ threshold. Thus we can take advantage of D tagged samples, where one D meson is fully reconstructed. Our study of inclusive semileptonic decays is based on a 281 pb^{-1} data set, collected at the $\psi(3770)$ center-of-mass energy. In this analysis we use only $\bar{D}^0 \to K^+\pi^-$ and $D^- \to K^+\pi^-\pi^-$ tagging modes, because of their very low background levels. The tagging technique was developed by the Mark III collaboration [2] at SPEAR. It relies on the kinematic niceties available when studying $D\bar{D}$ pairs at a center-of-mass energy close to threshold. The use of tagged samples suppresses any other background source and provides the knowledge of the momentum and energy of the recoiling D. This property can be exploited in generating center-of-mass momentum spectra.

II. ANALYSIS METHOD

We select events containing either the decay $\bar{D}^0 \to K^+\pi^-$ or the decay $D^- \to K^+\pi^-\pi^-$. In this analysis we exploit the flavor information provided by the tagging D: the neutral D flavor is assigned on the basis of the charge of the daughter K, whereas for the charged D we use its charge as a flavor tag. (Charge conjugate modes are implied throughout this paper). Details on the tagging selection procedure are given in Ref. [3]. Good candidate tracks are combined to form specific final state. Two kinematic variables, beam constrained mass ($M_{\rm bc} \equiv \sqrt{E_{\rm beam}^2 - (\Sigma_i \vec{p}_i)^2}$ and $\Delta E \equiv E_{\rm beam} - \Sigma_i E_i$), are used to select the desired tag: here $E_{\rm beam}$ represents the beam energy and $(E_i, \vec{p}_i)$ represents the 4-vectors of the candidate daughters. We select events that are within 3σ of the expected ΔE(0 GeV) and $M_{\rm bc}(M_D)$. In order to determine the total number of tags, we count the events within the selected $\Delta E/M_{\rm bc}$ box from which we subtract the estimated background, extracted from studies of the sideband region. Our primary method is to use two control regions, 3σ wide, in the ΔE projection of candidate events with $M_{\rm bc}$ within 3σ of the expected $M_{\rm bc}$.

We start by measuring raw spectra of 3 different particle species in the momentum region between 0.2 - 1.0 GeV/c: e^+, π^+ and K^+ (right-sign) and e^-, π^- and K^- (wrong-sign) tagged by $\bar{D}^0$ or D^-. The π group include muons, as we do not have the ability of separating these two particle species in this momentum region. Charged tracks are required to be well-measured and must also be consistent with coming from the interaction point in three dimensions: we require the helical trajectory to be within a distance of 5 mm in the azimuthal projection and 5 cm in the polar view, where the azimuthal view it the bend view of the solenoidal magnet. Each track must include at least 50% of the hits expected for its momentum. Moreover, it must be within the fiducial volume of the RICH detector ($|\cos(\theta)| \leq 0.8$). Finally, we require the charged track momentum p_{track} to be greater or equal to 0.2 GeV/c, as the particle species separation becomes increasingly difficult at low momenta.

Candidate e^+ are selected on the basis of a likelihood ratio constructed from three inputs: the ratio between the energy deposited in the calorimeter and the momentum measured in the tracking system, the specific ionization dE/dx measured in the drift chamber and RICH information [4]. Our selection criterion has an average efficiency of 0.95 in the momentum region 0.3-1 GeV/c, and 0.71 in the region 0.2-0.3 GeV/c. K and π candidates are selected on the basis of the specific ionization and RICH information. A particle identification variable (PID) is used to identify π and K species. It combines RICH and dE/dx information, if the RICH identification variable[5] is available and $p_{\mathrm{track}} > 0.7$ GeV/c; alternatively it relies on dE/dx only.

The true e^+ populations in the right and wrong-sign samples are extracted through an unfolding procedure, using the matrix:

$$\begin{pmatrix} n_e^m \\ n_\pi^m \\ n_K^m \end{pmatrix} = \begin{pmatrix} \varepsilon_e & f_{e\pi} & f_{eK} \\ f_{\pi e} & \varepsilon_\pi & f_{\pi K} \\ f_{Ke} & f_{K\pi} & \varepsilon_K \end{pmatrix} \times \begin{pmatrix} n_e^t \\ (n_\pi^t + \kappa n_\mu^t) \\ n_K^t \end{pmatrix}$$

here n_e^m, n_π^m, n_K^m represent the raw measured spectra in the corresponding particle species, and the coefficient κ accounts for the fact that the efficiency for π and μ selection is not necessarily identical, especially at low momenta. As we are focusing on the e^+ spectra, the disentangling of μ and π population is not addressed in this paper. Note that the matrix is almost diagonal.

The efficiencies appearing in this matrix account for track finding, track selection criteria as well particle identification losses. The tracking efficiencies and the π and K identification efficiencies are obtained from a Monte Carlo simulation of $D\bar{D}$ events in the CLEO-c detector. The e^+ identification efficiency is extracted from a radiative Bhabha sample. The effect of the difference between the $D\bar{D}$ event environment and the simpler radiative Bhabha environment (two charged tracks and one shower) is studied with embedded samples and a correction for this bias is performed on the measured spectrum. The off-diagonal elements are the product of the tracking efficiency for the given particle species and the fake probability f_{ab} that particle b is identified as particle a. The fake probabilities are determined using e samples from radiative Bhabhas, K from $D^+ \to K^-\pi^+\pi^+$ and π's from $D^+ \to K^-\pi^+\pi^+$ and $K^0_S \to \pi^+\pi^-$.

This unfolding procedure results in corrected "right-sign" and "wrong-sign" e^+ yields. The wrong-sign distribution give an estimate of the charge symmetric background, mostly produced by π^0 Dalitz decays and γ conversion. Monte Carlo studies indicate that the wrong-sign sample is an accurate representation of this background source. In $\bar{D}^0 \to K^+\pi^-$ tag, effect of mis-PID is negligible, the effect of doubly Cabibbo suppressed decay (DCSD) is corrected.

The same unfolding procedure is applied to control samples obtained from ΔE sidebands to estimate the contribution to the spectrum coming from background tags. The tags $\bar{D}^0 \to K^+\pi^-$ and $D^- \to K^+\pi^-\pi^-$ have very little background: the $\bar{D}^0$ sidebands give a projected right-sign background yield (14 e^+ compared to 2239 signal e^+) and the D^- sidebands contain 127 e^+ (1.5% of the signal yield).

Table I summarizes all the relevant yields and corrections affecting the extraction of the charged and neutral D semileptonic branching fractions.

	D^+	D^0
Tags	73732 ± 283	47379 ± 221
Signal Electrons		
Right-sign (raw)	8275 ± 91	2239 ± 47
Wrong-sign (raw)	228 ± 15	233 ± 15
Right-sign (unfolded)	9186 ± 101	2453 ± 52
Wrong-sign (unfolded)	231 ± 19	203 ± 18
Sideband Correction	157 ± 15	5 ± 5
Net electrons	8798 ± 104	2246 ± 56

TABLE I: Electron unfolding procedure. The errors reported here reflect only the statistical uncertainty.

Fig. 1 shows the D^+ and D^0 differential widths $d\Gamma/dp_e$, where p_e is the D laboratory momentum. The spectra have not been corrected for final state radiation.

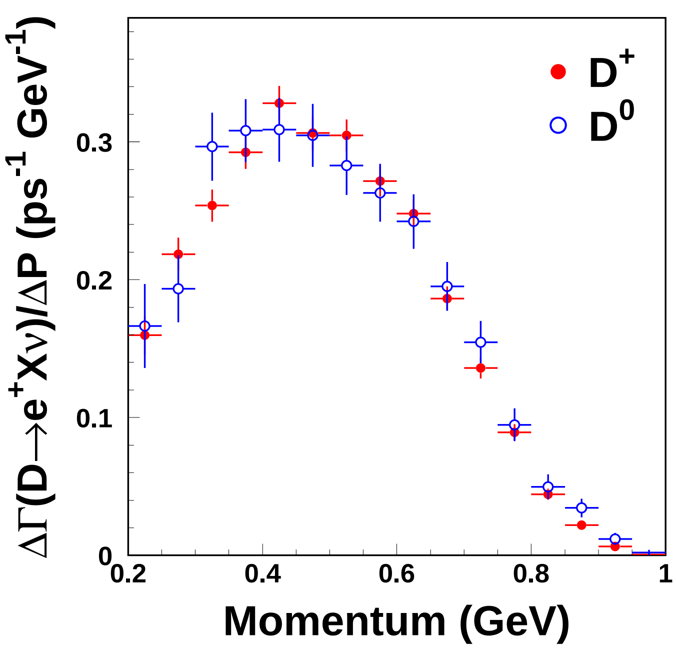

FIG. 1: Lepton momentum spectra in the laboratory for the decays $D^+ \to Xe^+\nu_e$ and $D^0 \to Xe^+\nu_e$. We have used the PDG2004 [6] average D lifetimes to normalize the two spectra.

We have considered several sources of systematic uncertainty. Contributions to the systematic errors common to D^+ and D^0 include tracking efficiency (1%), particle identification efficiencies (1%), fake probability determination and uncertainties in charge-symmetric background subtraction. The uncertainty on tracking and K and π identification are taken from the studies discussed in Ref. [3]. The systematic error on the electron identification efficiency (1%) is assessed comparing radiative Bhabha samples, embedded samples and Monte Carlo samples. Uncertainties associated with the knowledge of individual components of the unfolding matrix have been assessed with a toy Monte Carlo simulation, by varying the individual matrix elements within error incoherently. The uncertainty in this procedure is 0.6%. In addition, we have accounted for the uncertainties in the number of tags, final state radiation (FSR) uncertainty (1%). FSR effects are modeled with the PHOTOS [7] algorithm. Finally, the procedure of correcting for the portion of the spectrum below the momentum cut-off has an uncertainty of 1.0% for the D^+ and 1.4 % for the D^0.

We obtain the preliminary partial branching fractions for $p_e \geq 0.2$ GeV/c:

- $\mathcal{B}(D^+ \to Xe^+\nu_e) = (14.91 \pm 0.19 \pm 0.29)\%$.
- $\mathcal{B}(D^0 \to Xe^+\nu_e) = (5.97 \pm 0.16 \pm 0.11)\%$.

where the first error corresponds to the statistical uncertainty and the second the systematical uncertainty. We obtain the preliminary total branching fractions, after the correction of the unmeasured part of spectrum below 0.2 GeV/c:

- $\mathcal{B}(D^+ \to Xe^+\nu_e) = (16.19 \pm 0.20 \pm 0.36)\%$.
- $\mathcal{B}(D^0 \to Xe^+\nu_e) = (6.45 \pm 0.17 \pm 0.15)\%$.

The correction has been determined from a Monte Carlo simulation with a correction factor to account for the discrepancy in shape between observed spectra and simulated spectra.

By using the measured branching fractions and the known D lifetimes [6] we obtain the inclusive semileptonic widths:

- $\Gamma(D^+ \to Xe^+\nu_e) = 0.1557 \pm 0.0019 \pm 0.0035$ ps $^{-1}$,
- $\Gamma(D^0 \to Xe^+\nu_e) = 0.1572 \pm 0.0041 \pm 0.0037$ ps $^{-1}$.

The semileptonic widths of charged and neutral D mesons are consistent with isospin invariance within the experimental accuracy.

Finally, we can compare these widths with the sum of the semileptonic decay widths for the pseudoscalar and vector hadronic final states recently published by CLEO [8]. They obtain $\mathcal{B}(D^+ \to Xe^+\nu_e)_{\mathrm{excl}} = (15.1 \pm 0.5 \pm 0.5)\%$ and $\mathcal{B}(D^0 \to Xe^+\nu_e)_{\mathrm{excl}} = (6.1 \pm 0.2 \pm 0.2)\%$. The sum over exclusive modes and inclusive measurement are consistent within error, but more statistics is needed to develop a full understanding of the composition of the exclusive semileptonic width.

In summary, we report improved measurements of the absolute branching fractions for the inclusive semileptonic decays $D^+ \to Xe^+\nu_e$ and $D^0 \to Xe^+\nu_e$. We obtain $\mathcal{B}(D^+ \to Xe^+\nu_e) = (16.19 \pm 0.20 \pm 0.36)\%$ and $\mathcal{B}(D^0 \to Xe^+\nu_e) = (6.45 \pm 0.17 \pm 0.15)\%$. The corresponding inclusive semileptonic widths are $\Gamma_{D^+} = 0.1557 \pm 0.0019 \pm 0.0035$ ps^{-1} and $\Gamma_{D^0} = 0.1572 \pm 0.0041 \pm 0.0037$ ps^{-1}, consistent with the expected equality between D inclusive semileptonic widths. The composition of the inclusive spectra is dominated by the low lying resonances in the $c \to s$ and $c \to d$.

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