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Exclusive Semileptonic D and B Decays from CLEO

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We report on the latest results for D and B semileptonic decays from CLEO. Using 56 pb^{-1} of data collected at the $\psi(3770)$ with the CLEO-c detector at the Cornell e^+e^- storage ring, we present improved measurements of the absolute branching fractions of D decays to $Ke^+\nu_e$, $\pi e^+\nu_e$, $K^*e^+\nu_e$, and $\rho e^+\nu_e$, including the first observations and absolute branching fraction measurements of $D^0 \to \rho^- e^+\nu_e$ and $D^+ \to \omega e^+\nu_e$. These measurements are used to make the most precise to date tests of isospin invariance in semileptonic D^0 and D^+ decays. The results are compared with theoretical predictions and measurements from other experiments. Prospects for measuring semileptonic form factors at CLEO-c with a larger data sample are briefly discussed. The status of an exclusive $B \to \pi/\rho l \nu_l$ analysis with the full CLEO $\Upsilon(4S)$ data set comprising 15.4 millions of $B\bar{B}$ pairs is presented.

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1. Exclusive D Semileptonic Decays

Semileptonic decays are the principal process to determine the CKM matrix elements as the strong interaction binding effects in these decays are confined to the hadronic current. They are parameterized by form factors that are calculable, for example, by lattice quantum chromodynamics (LQCD) and QCD sum rules. Nevertheless, form factor uncertainties dominate the precision with which the CKM matrix elements can be determined. In charm quark decays, couplings V_{cs} and V_{cd} are tightly constrained by the unitarity of the CKM matrix. Therefore, measurements of charm semileptonic decay rates and form factors rigorously test theoretical predictions.

We report herein measurements with the first CLEO-c data [55.8 pb^{-1} at the $\psi(3770)$] of the absolute branching fractions of D decays to $Ke^+\nu_e$, $\pi e^+\nu_e$, $K^*e^+\nu_e$ and $\rho e^+\nu_e$, including the first observations and absolute branching fraction measurements of $D^0 \to \rho^- e^+\nu_e$ and $D^+ \to \omega e^+\nu_e$ [2], and compare them to recent measurements from other experiments and theoretical predictions. We also briefly review the prospects for measuring semileptonic form factors with a larger CLEO-c data set.

The $\psi(3770)$ lies about 40 MeV above the $D\bar{D}$ production threshold and decays predominantly to a pair of D mesons. Candidate events are selected by reconstructing a $\bar{D}$, called a tag, in a hadronic final state. The absolute branching fractions of D semileptonic decays are then measured by their reconstruction in the system recoiling from the tag. Tagging a $\bar{D}$ meson in a $\psi(3770)$ decay provides a D with known four-momentum, allowing a semileptonic decay to be reconstructed with no kinematic ambiguity, even though the neutrino is undetected.

The data sample comprises approximately 60,000 (32,000) of neutral (charged) tags, reconstructed in eight (six) D hadronic final states. After a tag is identified, we search for a positron and a set of hadrons recoiling against the tag. The tag and the semileptonic decay are then combined and semileptonic decays are identified using the variable $U \equiv E_{\rm miss} - |\vec{p}_{\rm miss}|c$, where $E_{\rm miss}$ and $\vec{p}_{\rm miss}$ are the missing energy and momentum of the D meson decaying semileptonically. If the decay products of the semileptonic decay have been correctly identified, U is expected to be zero, since only a neutrino is undetected.

The absolute branching fractions in Table 1 are determined using $\mathcal{B} = N_{\rm signal}/\epsilon N_{\rm tag}$, where $N_{\rm signal}$ is the number of fully reconstructed $D\bar{D}$ events obtained by fitting the U distribution, $N_{\rm tag}$ is the number of events with a reconstructed tag, and ϵ is the effective efficiency for detecting the semileptonic decay in an event with an identified tag. Signal yields for $D^0 \to \rho^- e^+\nu_e$ and $D^+ \to \omega e^+\nu_e$ are significant and represent the first observations of these modes. The largest contributors to the systematic uncertainty are associated with the tracking efficiency, the π^0 and K^0_S reconstruction efficiencies, the extraction of D tag yields, the positron and hadron identification efficiencies. The the total systematic uncertainty ranges from 2.8% to 7.8% by mode (Table 1). Most systematic uncertainties are measured in data and will be reduced with a larger data set.

The widths of the isospin conjugate exclusive semileptonic decay modes of the D^0 and D^+ are related by isospin invariance of the hadronic current. The ratio $\frac{\Gamma(D^0\to K^- e^+\nu_e)}{\Gamma(D^+\to \bar{K}^0 e^+\nu_e)}$ is expected to be unity. The world average value is 1.35 ± 0.19 [3]. Using our results and the lifetimes of the D^0 and D^+ [3], we obtain: $\frac{\Gamma(D^0\to K^- e^+\nu_e)}{\Gamma(D^+\to \bar{K}^0 e^+\nu_e)} = 1.00 \pm 0.05({\rm stat}) \pm 0.04({\rm syst})$. The result is consistent with unity and with two recent less precise results: a measurement from BES II using the same technique and an indirect measurement from FOCUS [4]. The ratios of isospin conjugate decay widths for

Mode	Yield	$\mathcal{B}$ (%)	$\mathcal{B}$ (%) (PDG)
$D^0 \to K^- e^+ \nu_e$	1311 ± 37	$3.44 \pm 0.10 \pm 0.10$	3.58 ± 0.18
$D^0 \to \pi^- e^+ \nu_e$	116.8 ± 11.2	$0.26 \pm 0.03 \pm 0.01$	0.36 ± 0.06
$D^0 \to K^{*-} e^+ \nu_e$	219.3 ± 15.6	$2.16 \pm 0.15 \pm 0.08$	2.15 ± 0.35
$D^0 \to \rho^- e^+ \nu_e$	31.1 ± 6.3	$0.19 \pm 0.04 \pm 0.01$	—
$D^+ \to \bar{K}^0 e^+ \nu_e$	545 ± 24	$8.71 \pm 0.38 \pm 0.37$	6.7 ± 0.9
$D^+ \to \pi^0 e^+ \nu_e$	63.0 ± 8.5	$0.44 \pm 0.06 \pm 0.03$	0.31 ± 0.15
$D^+ \to \bar{K}^{*0} e^+ \nu_e$	422 ± 21	$5.56 \pm 0.27 \pm 0.23$	5.5 ± 0.7
$D^+ \to \rho^0 e^+ \nu_e$	27.4 ± 5.7	$0.21 \pm 0.04 \pm 0.01$	0.25 ± 0.10
$D^+ \to \omega e^+ \nu_e$	$7.6^{+3.3}_{-2.7}$	$0.16^{+0.07}_{-0.06} \pm 0.01$	—

Table 1: Signal yields and branching fractions in this work and a comparison to PDG [3]. The first uncertainty is statistical and the second systematic in the third column, and statistical or total in the other columns. The yield ($\mathcal{B}$) for $D^0 \to K^{*-} e^+ \nu_e$ is summed (averaged) over the two K^{*-} submodes of $K^- \pi^0$ and $K^0_S \pi^-$.

other semileptonic decay modes are given in Ref. [2] and are all consistent with isospin invariance. As the data are consistent with isospin invariance, the precision of each branching fraction can be improved by averaging the D^0 and D^+ results for isospin conjugate pairs. The isospin-averaged semileptonic decay widths, with correlations among systematic uncertainties taken into account, are given in Table 2.

Decay Mode	Γ $(10^{-2} \cdot \mathrm{ps}^{-1})$
$D \to K\ e^+ \nu_e$	$8.38 \pm 0.20 \pm 0.23$
$D^0 \to \pi^- e^+ \nu_e$	$0.68 \pm 0.05 \pm 0.02$
$D \to K^*\ e^+ \nu_e$	$5.32 \pm 0.21 \pm 0.20$
$D^0 \to \rho^- e^+ \nu_e$	$0.43 \pm 0.06 \pm 0.02$

Table 2: Isospin-averaged semileptonic decay widths with statistical and systematic uncertainties. For Cabibbo-suppressed modes, the isospin average is calculated for the D^0 using $\Gamma(D^0) = 2 \cdot \Gamma(D^+)$.

The ratio of decay widths for $D \to \pi e^+ \nu$ and $D \to K e^+ \nu$ provides a test of the LQCD charm semileptonic rate ratio prediction [5]. Using the results in Table 2, we find $\frac{\Gamma(D^0 \to \pi^- e^+ \nu)}{\Gamma(D \to K e^+ \nu)} = (8.1 \pm 0.7(\mathrm{stat}) \pm 0.2(\mathrm{syst})) \times 10^{-2}$, consistent with LQCD and two recent results [6]. Furthermore, the ratio $\frac{\Gamma(D \to K^* e^+ \nu)}{\Gamma(D \to K e^+ \nu)}$ is predicted to be in the range 0.5 to 1.1. Using the isospin averages in Table 2, we find $\frac{\Gamma(D \to K^* e^+ \nu)}{\Gamma(D \to K e^+ \nu)} = 0.63 \pm 0.03(\mathrm{stat}) \pm 0.02(\mathrm{syst})$.

The modest in size data sample used in this analysis has provided the most precise to date measurements of D semileptonic branching fractions for all modes. CLEO-c has already collected a five times larger data sample of 281 pb^{-1} at the $\psi(3770)$. This data sample is being used to study form factors in $D \to K e^+ \nu_e$, $D \to \pi e^+ \nu_e$, $D \to K^* e^+ \nu_e$ and $D \to \rho e^+ \nu_e$. Our studies indicate that, for example, form factor shape parameter M_{pole} in a simple pole model with $f_+(q^2) = \frac{1}{1 - q^2/M^2_{\mathrm{pole}}}$ can be measured with a total uncertainty of about 2.0% for both $D \to K e^+ \nu_e$ and $D \to \pi e^+ \nu_e$ using 281 pb^{-1} at the $\psi(3770)$. This precision is comparable to that from recent unquenched LQCD calculations. Total uncertainties for $f_+(0)$ in $D \to Ke^+\nu_e$ and $D \to \pi e^+\nu_e$ are significantly smaller than those from LQCD. First results on form factors from CLEO-c and their comparison with LQCD predictions are expected to appear in the next few months.

2. Exclusive B Semileptonic Decays

CLEO is finishing studies of $B \to X_u l\nu_l$ using the complete CLEO II, II.V and III $\Upsilon(4S)$ data set. In this section we will briefly describe an update of the exclusive $B \to \pi/\rho l\nu_l$ analysis and a measurement of $|V_{ub}|$ in Ref. [7]. The technique described in Ref. [7] is used. The momentum of the undetected neutrino in the reconstruction of semileptonic decays is inferred from the missing momentum of the event. To reduce the uncertainty in the branching fractions from incomplete knowledge of form factors, rates are measured in q^2 bins. Crossfeeds among semileptonic modes are accounted for in a simultaneous binned maximum likelihood fit to all modes using isospin or constituent quark model constraints. $|V_{ub}|$ is obtained from the measured rates using light-cone sum rules for $q^2 \in [0;16)$ GeV^2 and LQCD for $q^2 \in [16;q^2_{\max})$ GeV^2.

In the current $B \to \pi/\rho l\nu_l$ analysis, in addition to the anticipated improvements in the statistical precision, significant improvements in the systematic uncertainty related to the $B \to \rho l\nu_l$ modeling are expected as the lepton momentum cut is lowered from 1.5 GeV/c to 1.0 GeV/c and the region of $\cos\theta_l < 0$ is included in the fit, where θ_l is the angle between the charged lepton in the W rest frame and W in the B rest frame. Changes to the q^2 binning are being made. Recent unquenched LQCD calculations for the form factor in $B \to \pi l\nu_l$ are used. Final CLEO results on $|V_{ub}|$ using 15.4 million $B\bar{B}$ events are forthcoming.

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FOCUS Collaboration measures $\Gamma(D^+ \to \bar{K}^{*0}\mu^+\nu_\mu)/\,\Gamma(D^+ \to \bar{K}^0\mu^+\nu_\mu)$ and $\Gamma(D^+ \to \bar{K}^{*0}\mu^+\nu_\mu)/\,\Gamma(D^+ \to K^-\pi^+\pi^+)$. Using the world average value of $\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$ they extract $\mathcal{B}(D^+ \to \bar{K}^0\mu^+\nu_\mu)$ and find a value much larger than that in the PDG.

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