International Journal of Modern Physics A

Measurements of Absolute Branching Fractions for Exclusive D^0 Semileptonic Decays and Determinations of V_{cs} and V_{cd}

F. Liu
Representing the CLEO Collaboration
Southern Methodist U. Group, Wilson Lab, Cornell University, Ithaca, New York 14853

Based on a data sample of 60 pb^{-1} collected at the $\psi(3770)$ resonance with the CLEO-c detector at CESR, we present improved measurements of absolute branching fractions for exclusive D^0 semileptonic decays into $K^-e^+\nu$, $\pi^-e^+\nu$ and $K^{*-}e^+\nu$, and the first observation and measurement of $D^0 \to \rho^- e^+\nu$. The determinations of the CKM matrix elements V_{cs} and V_{cd} are given.

1. Introduction

In the Standard Model (SM), the three generation quark mixing is described by the unitary Cabibbo-Kobayashi-Maskawa (CKM) matrix [1]. It governs all flavor transitions of quarks and CP symmetry violation due to a complex phase of it. Precision determinations of the CKM matrix elements from weak decays of the relevant quarks provide powerful tests of the Standard Model.

Charm meson ($c\bar{q}$) semileptonic decays allow the measurements of the CKM matrix elements V_{cs} and V_{cd}. The differential decay rate for exclusive semileptonic decays $D \to Pe^+\nu$ (P stands for a pseudoscalar meson) with the electron mass neglected can be expressed as [2]:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} \left|V_{cq'}\right|^2 p_P^3 \left|f_+(q^2)\right|^2 , \tag{1}$$

where G_F is the Fermi coupling constant, q^2 is the four-momentum transfer squared between the parent D meson and the final state meson, p_P is the momentum of the pseudoscalar meson in the D rest frame, and $V_{cq'}$ is the relevant CKM matrix element, either V_{cs} or V_{cd}. $f_+(q^2)$ is the form factor that measures the probability that the flavor changed quark (q') from $c \to q'\ell\nu$ transitions and the spectator anti-quark ($\bar{q}$) will form a meson in the final state.

To determine V_{cs} and V_{cd}, we need theoretical input of the absolute normalization of the form factor describing the decay at a fixed q^2 point, usually at $q^2 = 0$. D semileptonic decays can also offer tests of the theoretical predictions of the form factors. Since the charm meson semileptonic decay form factors are closely related to those of B meson semileptonic decays by heavy quark symmetry, precise knowledge of the charm semileptonic form factors will in turn help improve the determination of the CKM matrix element V_{ub}.

2. Analysis Technique and Event Selection

The data sample of 60 pb^{-1} used for this analysis was collected at the $\psi(3770)$ resonance with the CLEO-c detector [2] at the Cornell Electron Storage Ring (CESR).

In this analysis, we take advantage of the unique kinematics of the $D\bar{D}$ threshold production at the $\psi(3770)$ resonance which provides very powerful means to reject backgrounds from misidentified and missing particles. We fully reconstruct one D^0 meson of the produced $D^0\bar{D}^0$ pairs as a tag. We identify an electron and a set of hadrons recoiling against the tag, reconstructing the missing momentum and missing energy. The difference between the missing energy and missing momentum in a event $U = E_{miss} - p_{miss}$ will peak at zero if the event is correctly reconstructed due to the undetected neutrino.

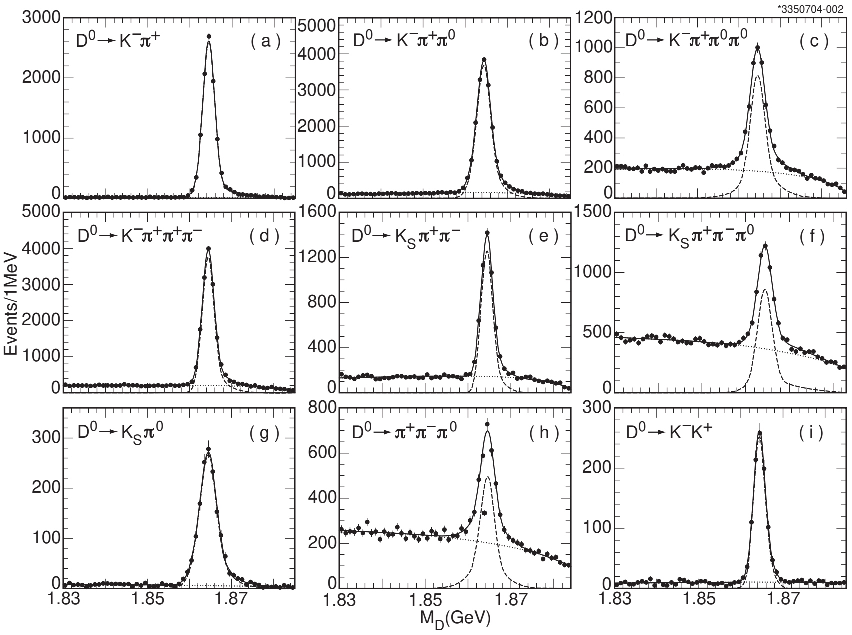

Fig. 1. Fits to the beam-constrained masses for different fully reconstructed D^0 decay modes. The signal is described by a Gaussian and a bifurcated Gaussian to account for the initial state radiation. The background is described by an Argus function [3].

We select events with a fully reconstructed D^0 meson where $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^0\pi^0$, $K^-\pi^+\pi^+\pi^-$, $K_S\pi^0$, $K_S\pi^+\pi^-$, $K_S\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^0$, and K^-K^+. Charge conjugate decays are implied throughout this paper. Within the tagged events, we select the subset in which the $\bar{D}^0$ meson semileptonically decays to a specific final state. The efficieny-corrected ratio of the event yields gives the absolute branching fraction for the exclusive semileptonic decay mode. The selection of the tag D^0 candidates is based on two variables $\Delta E = E_D - E_{beam}$ (the difference between the energy of the tag D^0 candidate (E_D) and the beam energy (E_{beam})), and the beam constrained mass $M_D = \sqrt{E_{beam}^2 - p_D^2}$, where p_D is the momentum of the tag D^0 candidate. We use RICH and dE/dx information to identify kaons and pions. In Fig. 1, we present the fits to the beam constrained masses of different tag modes. Multiple combinations have been eliminated by selecting the candidate with the minimum value of $|\Delta E|$. We have found about 60,000 tag D^0.

We find D^0 semileptonic decays into $K^-e^+\nu$, $\pi^-e^+\nu$, $K^{*-}e^+\nu$ ($K^{*-} \to K^-\pi^0$) and $\rho^-e^+\nu$ ($\rho^- \to \pi^-\pi^0$) against a tag D^0 by reconstructing the difference of the missing energy and missing momentum which should peak at zero. In Fig. 2, we present the comparision for the selected D^0 semileptonic decay events between data and MC, the comparison shows good agreement.

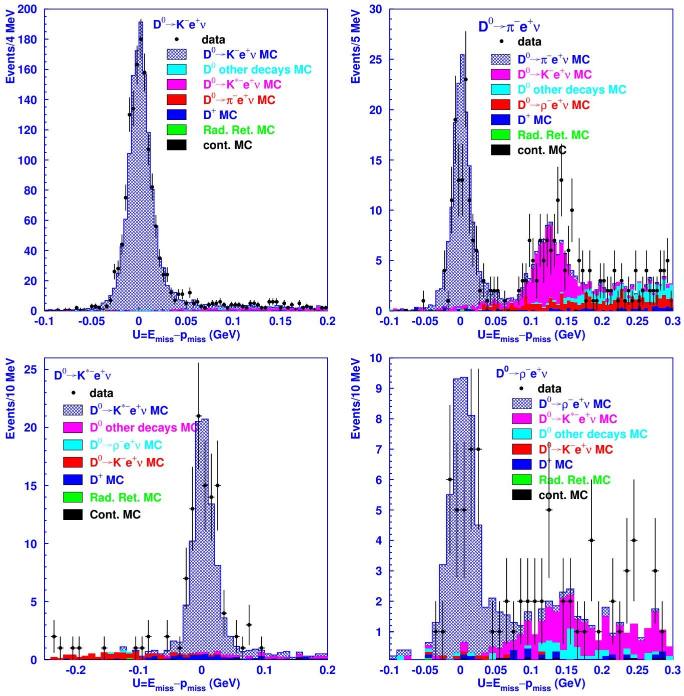

Fig. 2. Comparison for the selected D^0 semileptonic decays between data and MC.

The fits to the $U = E_{miss} - p_{miss}$ distributions are shown in Fig. 3, and the yields are given in Table 1. The detail of event selection can be found in Ref. [4].

3. Results

The measured absolute branching fractions are given in Table 1, in comparison with the PDG values [5]. All results are preliminary. The errors are statistical and systematic, respectively. The dominant systematic error comes from uncertainties

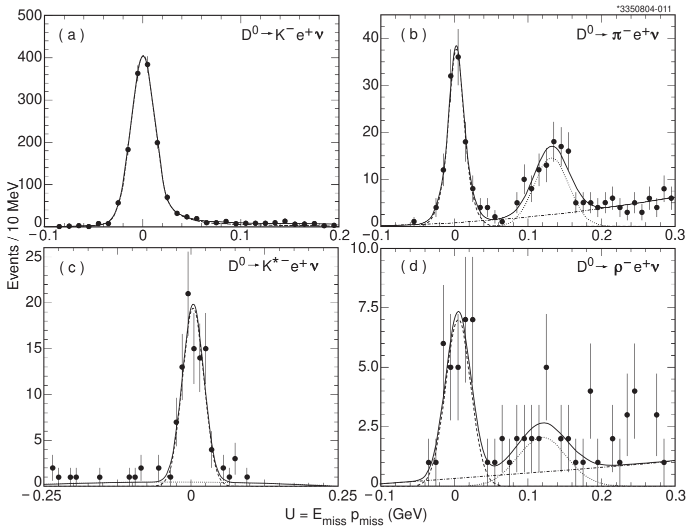

Fig. 3. Fits to $U = E_{\rm miss} - p_{\rm miss}$ distributions for $D^0 \to K^- e^+ \nu$, $\pi^- e^+ \nu$, $K^{*-} e^+ \nu$ and $\rho^- e^+ \nu$, with the other $\bar{D}^0$ fully reconstructed.

of track and π^0 reconstruction efficiency (3% per track and 4.4% per π^0) which will improve with more data sample and further study.

Based on a data sample of 60 pb^{-1} collected at the $\psi(3770)$ resonance, we have improved the absolute measurements of D^0 semileptonic decay branching fractions and presented the first observation of $D^0 \to \rho^- e^+ \nu$. Our results for $D^0 \to K^- e^+ \nu$ and $D^0 \to K^{*-} e^+ \nu$ are consistent with those from the PDG. Our result $\mathcal{B}(D^0 \to \pi^- e^+ \nu)$ is lower than the PDG value. The ratio $\frac{\mathcal{B}(D^0 \to \pi^- e^+ \nu)}{\mathcal{B}(D^0 \to K^- e^+ \nu)}$ is close to the CLEO III result $(8.2 \pm 0.6 \pm 0.5)\%$ [6], while lower than the PDG value.

Table 1. Absolute branching fraction measurements of the exclusive D^0 semileptonic decays, in comparison with the PDG. The uncertaities are statistical and systematic, respectively.

Decays	yields	$\mathcal{B}$	PDG
$D^0 \to K^- e^+ \nu$	1405.1±38.5	$(3.52 \pm 0.10 \pm 0.25)\%$	$(3.58 \pm 0.18)\%$
$D^0 \to \pi^- e^+ \nu$	109.1±10.9	$(0.25 \pm 0.03 \pm 0.02)\%$	$(0.36 \pm 0.06)\%$
$D^0 \to K^{*-} e^+ \nu$	88.0±9.7	$(2.07 \pm 0.23 \pm 0.18)\%$	$(2.15 \pm 0.35)\%$
$D^0 \to \rho^- e^+ \nu$	30.1±5.8	$(0.19 \pm 0.04 \pm 0.02)\%$	none
$\frac{\mathcal{B}(D^0 \to \pi^- e^+ \nu)}{\mathcal{B}(D^0 \to K^- e^+ \nu)}$		$(7.0 \pm 0.7 \pm 0.3)\%$	$(10.1 \pm 1.8)\%$
$\frac{\mathcal{B}(D^0 \to \rho^- e^+ \nu)}{\mathcal{B}(D^0 \to K^{*-} e^+ \nu)}$		$(9.2 \pm 2.0 \pm 0.8)\%$	none

4. Determinations of V_{cs} and V_{cd}

The form factor is conveniently parameterized with modified pole model

$$f_+(q^2) = \frac{f_+(0)}{(1 - q^2/M_{D^*_{(s)}})(1 - \alpha q^2/M_{D^*_{(s)}})}, \tag{2}$$

where the mass of the lowest pole is M_{D^*} for $D^0 \to \pi^- e^+ \nu$ and $M_{D^*_s}$ for $D^0 \to K^- e^+ \nu$, α is a parameter to correct the effects of higher resonance poles with effective pole mass at $M_{D^*_{(s)}}/\sqrt{\alpha}$. In Table 2, we present the determinations of the CKM matrix elements V_{cs} and V_{cd}, using our results of $\mathcal{B}(D^0 \to K^- e^+ \nu)$ and $\mathcal{B}(D^0 \to \pi^- e^+ \nu)$ and the parameterizations of the form factors from quenched Lattice QCD [7] and unquenched Lattice QCD [8]. The first error comes from the theorectical uncertainties of the parameterizations of the form factors. The second error is due to the uncertainties of the experimental measurements of the branching fractions and D^0 lifetime. Our results are consistent with the PDG values $|V_{cs}| = 0.996 \pm 0.013$ and $|V_{cd}| = 0.224 \pm 0.016$ [5]. It is clear that the errors of the determinations of V_{cs} and V_{cd} are dominated by theorectical uncertainties. More precise Lattice QCD results are essential for precision determinations of V_{cs} and V_{cd}.

Table 2. Determinations of $|V_{cs}|$ and $|V_{cd}|$.

Model	$\alpha^{D\to K}$	$f_+^{D\to K}(0)$	$\lvert V_{cs}\rvert$
Quenched LQCD	0.43±0.12	0.66±0.04	$1.070 \pm 0.068 \pm 0.040$
Unquenched LQCD	0.50±0.04	$0.73\pm0.03 \pm 0.07$	$0.957 \pm 0.100 \pm 0.036$
Model	$\alpha^{D\to \pi}$	$f_+^{D\to \pi}(0)$	$\lvert V_{cd}\rvert$
Quenched LQCD	0.36±0.16	0.57±0.06	$0.226\pm0.026 \pm 0.014$
Unquenched LQCD	0.44±0.04	$0.64\pm0.03 \pm 0.06$	$0.196\pm0.021 \pm 0.013$

5. Summary

We have improved the absolute branching fractions for exclusive D^0 semileptonic decays and determined the CKM matrix elements V_{cs} and V_{cd}. We expect better determinations of V_{cs} and V_{cd} with more data in the near future.

References

1. N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).
2. CLEO Collaboration, CLNS-01/1742 and references therein.
3. ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. B **241** (1990) 278.
4. K. Y. Gao *et al.*, CLEO Collaboration, hep-ex/0408077.
5. S. Eidelman *et al.*, Particle Data Group, Phys. Lett. B**592**, 1 (2004).
6. G. S. Huang *et al.*, CLEO Collaboration, hep-ex/0407035.
7. A. Abada *et al.*, Nucl. Phys. B **619**, 565 (2001).
8. C. Aubin *et al.*, hep-ph/0408306.