Recent Results in Charm Semileptonic Decays

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Abstract

New results in the field of charm semileptonic decays will be surveyed. Most importantly, there is a preliminary, new measurement of the absolute branching fraction for the decay $D^0 \to X e^+ \nu_e$.

1. Introduction

The measurements reviewed in this paper were made using the CLEO II and ARGUS detectors, 4π sollenoidal spectrometers which operate at e^+e^- storage rings with $E_{CM} \approx 10.58$ GeV. The charm hadrons studied here were created by the process $e^+e^- \to c\bar{c}$ followed by fragmentation (continuum production).

The signature of charm continuum production is that events have a two jet topology and that charm hadrons are produced with high momentum. Typically the charm hadron direction is almost parallel to the thrust axis of the event. Also, many of the charm mesons come from the decay chains, $D^* \to D\pi$ and $D_s^{*+} \to D_s^+\gamma$. In these cases, one can use a variant of the well known D^*-trick to dramatically improve the signal to background ratio. To illustrate this, consider the decay chain $D_s^{*+} \to D_s^+\gamma$, $D_s^+ \to \eta\ell^+\nu$, for which one can define the mass difference $M(\eta\ell^+\gamma) - M(\eta\ell)$. Although the unobserved ν is included in neither combination, the spectrum of this mass difference remains peaked, albeit less strongly peaked than for a fully reconstructed mode of the D_s^+.

Taken together these properties allow one to select efficiently, and with a good signal to background ratio, events which contain charm hadrons. Moreover they provide constraints from which one can recover some of the information carried away by the unobserved neutrino. Some of the CLEO analyses, for example, estimate the direction of the charm hadron by assuming that it is parallel to the thrust axis of the event. Up to a quadratic ambiguity, this allows one to reconstruct q^2, the invariant mass squared of the $\ell\nu$ system. Similarly, one can measure all of the decay angles in a decay chain such as $\Lambda_c \to \Lambda e^+\nu$, $\Lambda \to p\pi^-$. Given measurements of q^2 and of all of the decay angles, one can fit a multi-dimensional distribution (in q^2 and the decay angles) to obtain information about the form factors in the Λ_c decay. It is important to emphasize that none of the data presented here is sensitive to the shape of the form factors: the best that one can do, at present, is to assume a q^2 dependence for the form factors and then to measure the relative strength of the different form factors in a decay.

The form factor measurements presented here were made using a method, pioneered by E691, to fit observed (not efficiency corrected) multi-dimensional distributions. In this method, the observed distribution is described by the convolution of the physics function with the full detector response. The convolution is done by re-weighting Monte Carlo events, a method which deals both with large smearing of kinematic variables and with sharp changes in efficiency.

Because of space constraints, some information, either from previous experiments or from theory, has been quoted or alluded to without a proper reference. All of the proper references can be found in the papers in the bibliography.

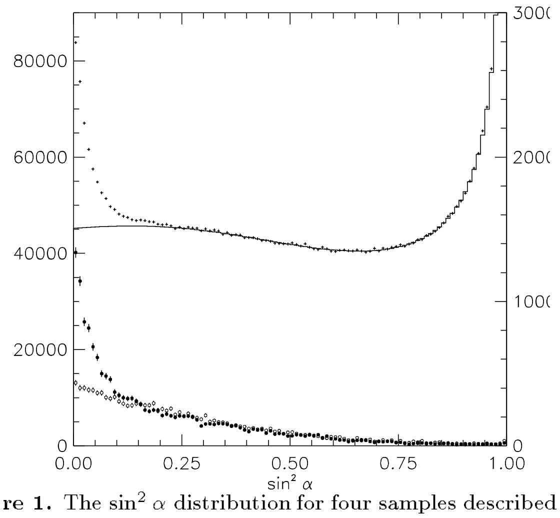

Figure 1. The $\sin^2\alpha$ distribution for four samples described in the text. The scale on the left hand side of the figure is for the upper two distributions while that on the right hand side is for the lower two distributions.

2. $\mathbf{B(D^0 \to Xe^+\nu_e)}$

In recent years there have been significant improvements in the measurements of branching fractions for exclusive charm semileptonic decays. Measurements of inclusive charm semileptonic branching fractions, however, have not kept pace: the 1994 PDG averages are still dominated by 1985 Mark III results with 10 to 15% uncertainties.

Recently, the CLEO collaboration has measured $B(D^0 \to Xe^+\nu_e)$ using a method pioneered by HRS. When a D^* is created via continuum production, its momentum is nearly parallel to the thrust axis of the event. Because the Q value of the decay $D^{*+} \to D^0\pi^+$ is small, the lab frame angle between the π^+ and the thrust axis, α, is also small. The upper points in Fig. 1 show the distribution of $\sin^2\alpha$ for π^+ mesons with $0.225 \le p_{\pi^+} < 0.425$ GeV. The shape of the distribution for π^+ mesons which do not come from the decay $D^{*+} \to D^0\pi^+$ is shown as the solid outline histogram [1]. The excess near $\sin^2\alpha = 0$ is due to the decay $D^{*+} \to D^0\pi^+$ and provides a measure of the number of D^0 mesons produced. The solid data points in the lower part of the figure show the distribution of $\sin^2\alpha$ when there is also a positron within a 37° cone around the π^+. The positron must have momentum above 0.7 GeV. The hollow data points show the shape of the $\sin^2\alpha$ distribution for background processes. The excess near $\sin^2\alpha = 0$ is due to the decay chain $D^{*+} \to D^0\pi^+$, $D^0 \to Xe^+\nu$. The branching fraction $B(D^0 \to Xe^+\nu_e)$ is found by taking the the area between the lower two curves, dividing by the area between the upper two curves and then correcting for backgrounds and efficiency. This gives a preliminary result of,

$$B(D^0 \to X^-e^+\nu_e) = (6.97 \pm 0.18 \pm 0.30)\%. \qquad (1)$$

The uncertainties in this measurement represent a significant improvement over those in the 1994 PDG value, $(7.7 \pm 1.2)\%$.

3. $\mathbf{B(D_s^+ \to \eta\ell^+\nu)}$ and $\mathbf{B(D_s^+ \to \eta'\ell^+\nu)}$

Last year E653 obtained the first evidence for the decay $D_s^+ \to (\eta,\eta')\ell^+\nu$. They were, however, unable to separate the contributions from the η and the η'. This year CLEO has observed each of these decays separately [2]. They present preliminary results of,

$$\begin{aligned} R_\eta = \frac{B(D_s^+ \to \eta\,\ell^+\nu)}{B(D_s^+ \to \phi\,\ell^+\nu)} &= 1.74 \pm 0.34 \pm 0.24 \\ R_{\eta'} = \frac{B(D_s^+ \to \eta'\ell^+\nu)}{B(D_s^+ \to \phi\,\ell^+\nu)} &= 0.71^{+0.19\,+0.08}_{-0.18\,-0.10}. \end{aligned} \qquad (2)$$

They also report the pseudoscalar to vector ratio for D_s^+ semileptonic decay,

$$\frac{B(D_s^+ \to (\eta+\eta')\,\ell^+\nu)}{B(D_s^+ \to \phi\ell^+\nu)} = 2.46 \pm 0.39 \pm 0.26. \qquad (3)$$

In the non-strange sector the corresponding ratio is,

$$\frac{B(D \to K\ell^+\nu)}{B(D \to K^*\ell^+\nu)} = 1.75 \pm 0.15. \qquad (4)$$

Up to phase space corrections these two numbers should be equal to each other, which they are to within 1.5 standard deviations.

In the past, CLEO has reported an estimate for the scale of the D_s^+ branching fractions by making the assumption $\Gamma(D_s^+ \to \phi e^+\nu) = \Gamma(D \to K^*e^+\nu)$. This gave [3] $B(D_s^+ \to \phi e^+\nu) = (2.74 \pm 0.36)\%$ and $B(D_s^+ \to \phi\pi) = (5.1 \pm 0.4 \pm 0.4 \pm 0.7)\%$. A theoretically more robust assumption is that $\Gamma(D_s^+ \to Xe^+\nu) = \Gamma(D^0 \to Xe^+\nu)$, from which one obtains,

$$B(D_s^+ \to \phi e^+\nu) = \frac{(1 - f_{cs} - f_{misc})}{1 + R_\eta + R_{\eta'}} B(D^0 \to Xe^+\nu)\frac{\tau_{D_s^+}}{\tau_{D^0}}. \qquad (5)$$

Here $f_{cs}(\approx 0.05 \pm 0.01)$ is an estimate for the the fraction of Cabibbo suppressed D_s^+ decay modes and $f_{misc}(\approx 0.06 \pm 0.04)$ is an estimate for the fraction of miscellaneous modes, such as $f_0(975)$. Combining the above results with previous CLEO results and with E687 lifetime measurements gives,

$$\begin{aligned} B(D_s^+ \to \phi e^+\nu) &= (2.06 \pm 0.33)\% \\ B(D_s^+ \to \phi\pi^+) &= (3.82 \pm 0.74)\%. \end{aligned} \qquad (6)$$

Finally, CLEO reports,

$$\frac{B(D_s^+ \to \eta' e^+\nu)}{B(D_s^+ \to \eta e^+\nu)} = 0.41 \pm 0.13 \pm 0.05. \qquad (7)$$

This can be compared with the previously measured ratio,

$$\frac{B(D_s^+ \to \eta' \rho^+)}{B(D_s^+ \to \eta \rho^+)} = 1.20 \pm 0.33, \qquad (8)$$

which is far from the prediction of factorization, ≈ 0.3.

4. Form Factors Ratios for $\mathbf{D_s^+} \to \phi \ell^+ \nu$

The decay $D_s^+ \to \phi e^+ \nu$ is described by three form factors, denoted by $A_1(q^2)$, $A_2(q^2)$, and $V(q^2)$. Using the method sketched in the introduction, the CLEO collaboration has measured the following ratios of the form factors [4],

$$\begin{aligned} R_2 = \frac{A_2(0)}{A_1(0)} &= 1.5 \pm 0.5 \pm 0.3 \\ R_V = \frac{V(0)}{A_1(0)} &= 0.9 \pm 0.6 \pm 0.3. \end{aligned} \qquad (9)$$

From this they compute, $\Gamma_L/\Gamma_T = 1.0 \pm 0.3 \pm 0.2$. Within these relatively large errors, the above results and previous measurements of the same quantities are consistent with each other. Factorization arguments suggest that R_2 and R_V should be the same for this decay as they are for the decay $D \to K^* \ell^+ \nu$. However the experimental results do not provide strong support for this argument — the values only agree at about the two standard deviation level.

5. First Observation of $\mathbf{\Xi_c^+} \to \mathbf{\Xi^0 e^+ \nu_e}$

CLEO has reported the first observation of the decay, $\Xi_c^+ \to \Xi^0 e^+ \nu_e$. In the same paper they also report on the previously observed decay $\Xi_c^0 \to \Xi^- e^+ \nu_e$. Their preliminary results are [5],

$$\begin{aligned} \sigma(\Xi_c^0) \cdot B(\Xi_c^0 \to \Xi^- e^+ \nu_e) &= (0.63 \pm 0.12 \pm 0.10) \text{ pb} \\ \sigma(\Xi_c^+) \cdot B(\Xi_c^+ \to \Xi^0 e^+ \nu_e) &= (1.55 \pm 0.33 \pm 0.25) \text{ pb}, \end{aligned}$$

where $\sigma(\Xi_c^0)$ is a shorthand for $\sigma(e^+e^- \to \Xi_c^0 X)$. If one assumes that $\Gamma(\Xi_c^+ \to \Xi^0 e^+ \nu) = \Gamma(\Xi_c^0 \to \Xi^- e^+ \nu)$ and $\sigma(\Xi_c^+) = \sigma(\Xi_c^0)$, then the above results can be used to determine the ratio of the lifetimes,

$$\frac{\tau(\Xi_c^+)}{\tau(\Xi_c^0)} = \frac{B(\Xi_c^+ \to \Xi^0 e^+ \nu)}{B(\Xi_c^0 \to \Xi^- e^+ \nu)} = 2.46 \pm 0.70^{+0.33}_{-0.23}.$$

This measurement is in agreement with previous, direct measurements of the lifetime ratio by E687 (4.06 ± 1.26) and NA32 (2.44 ± 1.68).

6. $\mathbf{\Lambda_c^+} \to \mathbf{\Lambda e^+ \nu_e}$

In the limit that the mass of the electron can be neglected and that the charm quark is heavy compared with Λ_{QCD}, the decay $\Lambda_c^+ \to \Lambda e^+ \nu_e$ is described by two form factors, denoted by $f_1(q^2)$ and $f_2(q^2)$. Körner and Krämer suggest that the q^2 dependence of both of these form factors should be given by a dipole form and that $f_2(q^2) < f_1(q^2)$. Using the method sketched in the introduction, the CLEO collaboration has made the first measurement of the ratio of these two form factors [6],

$$f_2/f_1 = -0.33 \pm 0.16 \pm 0.15. \qquad (10)$$

An alternative method for analyzing this decay is to measure various asymmetries in the decay angle distributions. The ARGUS collaboration selects Λ candidates which come from the decay chain $\Lambda_c^+ \to \Lambda \ell^+ \nu$, $\Lambda \to p\pi^-$, and then looks at the distribution of $\cos\theta_\Lambda$, where θ_Λ is the angle between the p direction in the Λ rest frame and the Λ momentum in the Λ_c^+ rest frame. This distribution has the form, $\frac{d\Gamma}{d\cos\theta_\Lambda} \propto (1 + \alpha_{\Lambda_c}\alpha_\Lambda \cos\theta_\Lambda)$, where α_Λ is the well known Λ asymmetry parameter and where α_{Λ_c} is the asymmetry parameter for the decay, $\Lambda_c^+ \to \Lambda \ell^+ \nu$. They obtain [7] $\alpha_{\Lambda_c} = -0.91 \pm 0.42 \pm 0.25$, which is in agreement with a previous CLEO result of $-0.89^{+0.17}_{-0.11}{}^{+0.09}_{-0.05}$. In principle one can infer the form factor ratio from this measurement but the sensitivity is very poor.

7. Conclusions

In the past year there has been an important improvement in the precision of the measurement of of the branching fraction $B(D^0 \to X e^+ \nu)$. There have also been several first observations, $D_s^+ \to \eta \ell^+ \nu$, $D_s^+ \to \eta' \ell^+ \nu$ and $\Xi_c^+ \to \Xi^0 e^+ \nu$. In addition, there has been a first measurement of the form factor ratio in the decay $\Lambda_c \to \Lambda e^+ \nu$. All of the main semileptonic decay modes in the D_s^+ sector have now been observed and one can ask if the patterns observed in the non-strange sector are reproduced in the decays of the D_s^+.

References

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