MEASUREMENT OF THE FORM FACTORS FOR $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$

ANDERS RYD
Physics Department, University of California
Santa Barbara, CA 93106, USA

Representing the CLEO Collaboration.

ABSTRACT

Using a sample of 2.2×10^6 $B\bar{B}$ pairs collected by the CLEO-II detector at the Cornell Electron Storage Ring, we have studied the form factors for the process $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$. We have obtained the preliminary result for the form factor ratios $R_1 = 1.30 \pm 0.36 \pm 0.16$ and $R_2 = 0.64 \pm 0.26 \pm 0.12$ and the form factor slope $\rho^2 = 1.01 \pm 0.15 \pm 0.09$.

The decay $B \to D^*\ell\nu$ is a key process for measuring the magnitude of the CKM matrix element V_{cb} and for testing theoretical predictions of semileptonic decay form factors. This decay has a large branching fraction and very little background, which makes it well-suited experimentally for the detailed studies of the kinematic distributions that are required for the measurement of the form factors. This analysis is described in more detail elsewhere.[1]

Recently, there has been important progress in the theoretical understanding of the process $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ with the development of heavy quark effective theory (HQET).[2] HQET relates the three form factors $A_1(q^2)$, $V(q^2)$, and $A_2(q^2)$, that describe the decay $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$, to one form factor, the Isgur-Wise function, $\xi(q^2)$:

$$V(q^2) = A_2(q^2) = A_1(q^2)\left[1 - \frac{q^2}{(m_B + m_{D^*})^2}\right]^{-1} = R^{*-1}\xi(q^2), \qquad (1)$$

where $R^* = 2\sqrt{m_B m_{D^*}}/(m_B + m_{D^*}) \approx 0.89$. In HQET, ξ is normally written in terms of $w = (m_B^2 + m_{D^*}^2 - q^2)/2m_B m_{D^*} = E_{D^*}/m_{D^*}$. HQET cannot predict $\xi(w)$ over the full w range, but it gives us an absolute normalization in the zero-recoil configuration: $\xi(w = 1) = 1$. In our fits we assume $\xi(w) = 1 - \rho^2(w - 1)$, where ρ^2 is called the slope of the Isgur-Wise function or simply the form-factor slope. The linear form is expected to be a good approximation over the range of w available in the decay $B \to D^*\ell\nu$.

Following Neubert, [3] we define the form factor ratios

$$R_1 \equiv \left[1 - \frac{q^2}{(m_B + m_{D^*})^2}\right]\frac{V(q^2)}{A_1(q^2)} \qquad R_2 \equiv \left[1 - \frac{q^2}{(m_B + m_{D^*})^2}\right]\frac{A_2(q^2)}{A_1(q^2)}. \qquad (2)$$

These form factor ratios, which are both predicted to be unity in the heavy-quark symmetry limit, are slightly different from those used in studies of $D \to K^*\ell\nu$. They are defined in such a way that they are constant in the heavy-quark symmetry limit. However, the b and c quarks are not infinitely heavy, and corrections have been estimated by Neubert[3] who finds $R_1 \approx 1.3$ and $R_2 \approx 0.8$. Lattice QCD and QCD sum rules predict ρ^2 in the range from 0.5 to 2.

We perform a fit to the joint four-dimensional distribution for the decay $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$, $D^{*+} \to D^0\pi^+$ for the three parameters R_1, R_2, and ρ^2. The four kinematic variables are q^2 and the three angles $\cos\theta_\ell$, $\cos\theta_V$, and χ, where θ_ℓ is the lepton decay angle in the W rest frame, θ_V is the D^0 decay angle in the D^{*+} rest frame, and χ is the azimuthal angle in the $\bar{B}^0$ rest frame between the decay planes of the D^{*+} and the W.

The D^* is reconstructed in the mode $D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$ or $D^0 \to K^-\pi^+\pi^0$. Lepton candidates are either electrons or muons. The D^*–lepton candidates are required to be kinematically consistent with coming from the decay $B \to D^*\ell\nu$, where the B is slow ($\beta \approx 0.06$) and a neutrino is missing. The cuts used in the analysis are designed to suppress the background strongly to minimize the uncertainty in the modeling of the background in the form factor fit. Figure 1 shows the $\delta m = m_{D^*} - m_{D^0}$

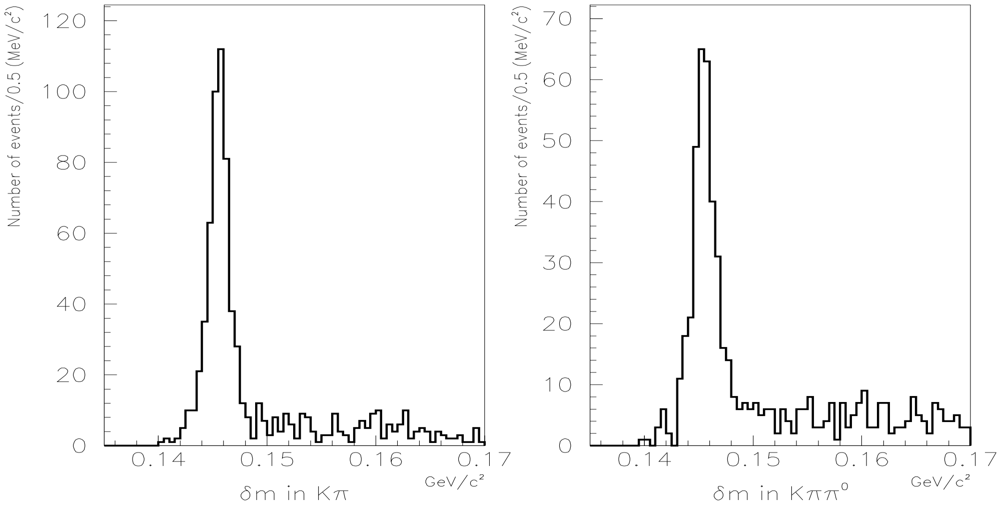

Fig. 1. The distribution of $\delta m = M(D^{*+}) - M(D^0)$ for $D^0 \to K^-\pi^+$ candidates (left) and $D^0 \to K^-\pi^+\pi^0$ candidates (right) after all analysis cuts except the δm cut.

distribution for the two modes in which the D^0's are reconstructed, after all cuts except that on δm. The signal region in δm is ± 2 MeV/c^2 around the nominal value; this is approximately a 2σ cut. To study the background from fake D^*'s, which is the dominant background in both $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+\pi^0$, we use the sideband region $0.15 < \delta m < 0.17$ GeV/c^2. After all event selection criteria are applied we have 783 events with a 16% background contamination.

We then fit the joint four-dimensional distribution using an unbinned maximum likelihood fit. We use a method that was originally developed by the E691 collaboration in their measurement of the $D \to K^*\ell\nu$ form factor ratios. This method uses a reweighting technique of MC events to numerically evaluate the likelihood function. The advantage of this method is that it directly incorporates the effects of smearing and acceptance. In Fig. 2, the fit is shown in the four 1-dimensional projections. The plots

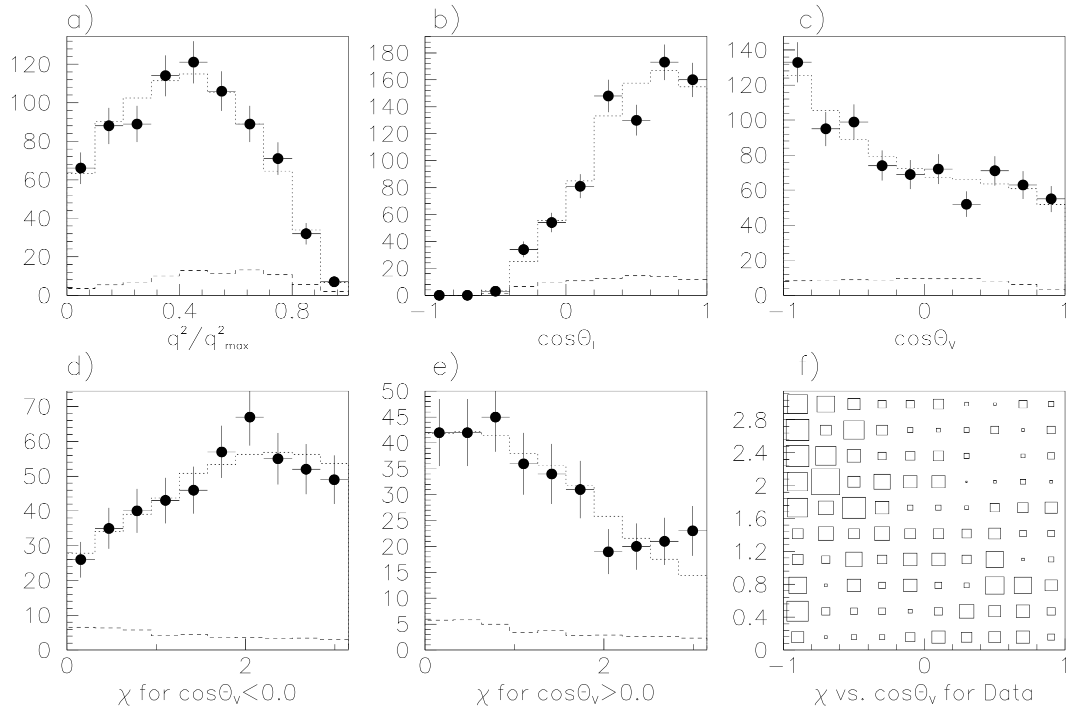

Fig. 2. In plots a) through e), the data are shown with error bars, the fit as the dotted line, and the background as the dashed line. In a) through c), the one dimensional projections on the q^2, $\cos\theta_\ell$, and $\cos\theta_V$ axes are shown. Plots d) and e) show the projection on the χ axis in a low and high $\cos\theta_V$ bin. The two-dimensional projection onto the plane χ vs. $\cos\theta_V$ is shown in f) for the data . The density of points is proportional to the size of the boxes.

show that the fit describes the data well in all four projections. The last plot, f), shows an example of a 2-dimensional projection, χ vs. $\cos\theta_V$. The structure in this plot — the enhancement in the upper-left and lower-right corner and the depletion in the opposite corners — is an effect of a parity-violating interference term. The observed structure is in agreement with the expectations from the standard model. If the $b \to c\ell\nu$ vertex had a $V+A$ coupling, we would expect that the pattern of enhanced and depleted regions to be the opposite, which is in disagreement with the data. Table 1 shows the result of the fit for R_1, R_2, and ρ^2. Since the errors on these quantities are highly correlated, we also present the off-diagonal elements of the correlation matrix. Several sources of systematic errors have been investigated. The dominant sources of systematic errors are from the uncertainty in the background modeling and the fitting method itself. Our value of $\rho^2 = 1.01 \pm 0.15 \pm 0.09$ is in agreement with the measurement of $\hat{\rho}^2 = 0.84 \pm 0.13 \pm 0.08$

in the CLEO measurement[4] of $|V_{cb}|$. Neubert[3] estimates that $\hat{\rho}^2 \approx \rho^2 - 0.09$.

Table 2 shows the results from a series of fits for R_1 and R_2 in which the slope ρ^2 was fixed to a series of values. If theoretical calculations of ρ^2 become sufficiently precise we would gain significantly in precision, especially for R_2.

In conclusion, we have performed the first simultaneous measurement of R_1, R_2, and ρ^2 for the decay $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$. We make a precise measurement of ρ^2 even with R_1 and R_2 floating. The measurement is in good agreement with estimated corrections to heavy-quark symmetry for the values of R_1 and R_2 and is in the range of predictions from lattice QCD and QCD sum rules for ρ^2.

Table 1. The preliminary result of the three parameter fit. The first error is statistical and the second is systematic.

	Fit Parameters	Correlation Coefficients	
R_1	$1.30 \pm 0.36 \pm 0.16$	$C(R_1 R_2)$	-0.83
R_2	$0.64 \pm 0.26 \pm 0.12$	$C(R_1 \rho^2)$	0.63
ρ^2	$1.01 \pm 0.15 \pm 0.09$	$C(R_2 \rho^2)$	-0.82

Table 2. The preliminary results of the two parameter fits for different slopes, ρ^2. The first error is statistical and the second is systematic. The correlation, $C(R_1 R_2)$, between the errors on R_1 and R_2 is strong.

ρ^2	R_1	R_2	$C(R_1 R_2)$
0.50	$0.77 \pm 0.21 \pm 0.16$	$1.11 \pm 0.10 \pm 0.10$	-0.67
0.75	$0.99 \pm 0.24 \pm 0.16$	$0.93 \pm 0.12 \pm 0.10$	-0.68
1.00	$1.29 \pm 0.27 \pm 0.16$	$0.65 \pm 0.15 \pm 0.10$	-0.73
1.25	$1.75 \pm 0.34 \pm 0.17$	$0.20 \pm 0.20 \pm 0.11$	-0.77

References

1. P. Avery *et al.* (CLEO), *Measurement of the Form Factors for* $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$, ICHEP94 Ref. 0144.
2. N. Isgur and M.B. Wise, Phys. Lett. B **232**, 113 (1989); **237**, 527 (1990); H. Georgi, Phys. Lett. B **240**, 447 (1990).
3. M. Neubert, *Heavy Quark Symmetry*, SLAC–PUB–6263, June 1993, to appear in Physics Reports.
4. B. Barish *et al.* (CLEO), *Measurement of the* $B \to D^*\ell\nu$ *Branching Fractions and* $|V_{cb}|$, ICHEP94 Ref. 0251, CLNS 94/1285.