# Measurement of the Form Factors for $\overline{B^0} \rightarrow D^{*+}\ell^-\overline{\nu}$

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**Abstract**

Using a sample of $2.2 \times 10^6$ $B\overline{B}$ pairs collected by the CLEO-II detector at the Cornell Electron Storage Ring, we have studied the form factors for the process $\overline{B^0} \rightarrow D^{*+}\ell^-\overline{\nu}$. We have obtained preliminary results 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 for the form factor slope, $\rho^2 = 1.01 \pm 0.15 \pm 0.09$.

The decay $B \rightarrow D^*\ell\nu$ is a key process for measuring the magnitude of the CKM matrix element $V_{cb}$ and for testing theoretical predictions for form factors in semileptonic decays. 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].

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

$$\begin{aligned} V(q^2) = A_2(q^2) &= A_1(q^2)\left[1 - \frac{q^2}{(m_B + m_{D^*})^2}\right]^{-1} \\ &= R^{*-1}\xi(q^2). \end{aligned} \tag{1}$$

Here $q^2$ is the invariant mass squared of the $\ell^-\overline{\nu}$ system and $R^* = 2\sqrt{m_B m_{D^*}}/(m_B + m_{D^*}) \approx 0.89$. In HQET, $\xi$ is normally written as a function of of $w$,

$$w = (m_B^2 + m_{D^*}^2 - q^2)/2m_B m_{D^*} = E_{D^*}/m_{D^*}. \tag{2}$$

HQET cannot predict $\xi(w)$ over the full range of $w$, but it does predict the absolute normalization in the zero-recoil configuration, $\xi(w = 1) = 1$. In our fits we assume that the Isgur-Wise function has the form $\xi(w) = 1 - \rho^2(w - 1)$, where $\rho^2$ 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 $B \rightarrow D^*\ell\nu$.

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

$$R_1 \equiv \left[1 - \frac{q^2}{(m_B + m_{D^*})^2}\right]\frac{V(q^2)}{A_1(q^2)} \tag{3}$$

$$R_2 \equiv \left[1 - \frac{q^2}{(m_B + m_{D^*})^2}\right]\frac{A_2(q^2)}{A_1(q^2)}. \tag{4}$$

These form factor ratios are slightly different from those used in studies of $D \rightarrow K^*\ell\nu$ and are defined in such a way that, in the limit of heavy-quark symmetry, they are constant. Moreover, in that limit, both form factor ratios are expected to be unity. The $b$ and $c$ quarks, however, are not infinitely heavy and corrections to the form factor ratios 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 that $\rho^2$ falls in the range from 0.5 to 2.

In order to extract the three parameters $R_1$, $R_2$, and $\rho^2$, we perform a fit to the joint four-dimensional distribution of the four kinematic variables which describe for the decay chain $\overline{B^0} \rightarrow D^{*+}\ell^-\overline{\nu}$,

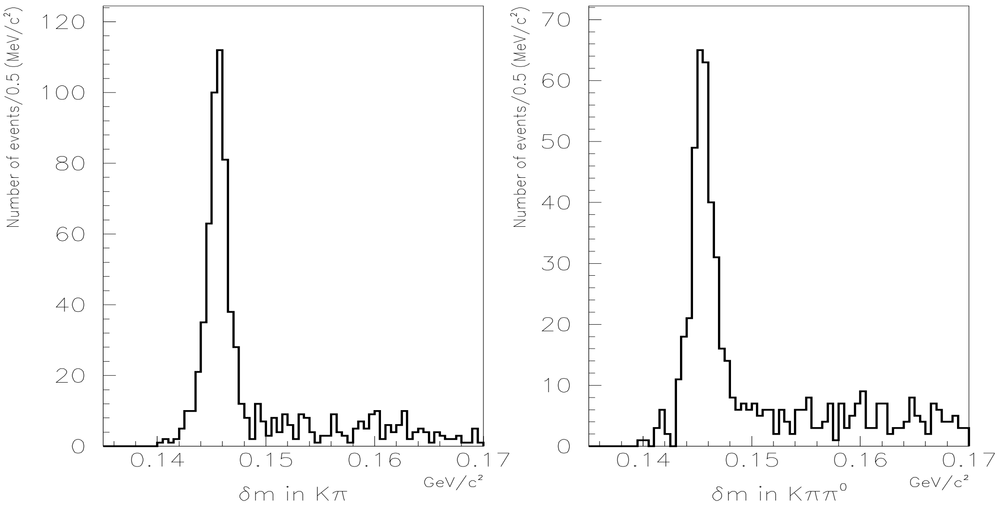


**Figure 1.** The distribution of $\delta m = M(D^{*+}) - M(D^0)$ for $D^0 \to K^-\pi^+$ candidates (left) and $D^0 \to K^-\pi^+\pi^0$ candidates (right) after all analysis cuts except the $\delta m$ cut.

$D^{*+} \to D^0\pi^+$. These kinematic variables are $q^2$, $\cos\theta_\ell$, $\cos\theta_V$, and $\chi$, where $\theta_\ell$ is the lepton decay angle in the $W$ rest frame, $\theta_V$ is the $D^0$ decay angle in the $D^{*+}$ rest frame, and where $\chi$ is the azimuthal angle, in the $\overline{B^0}$ 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 $D^*\ell$ candidates are required to be kinematically consistent with coming from the decay $B \to D^*\ell\nu$, where the $B$ meson is slow and a neutrino is missing. In order to minimize the uncertainty in the modeling of the backgrounds in the form factor fit, the cuts used in the analysis are designed to suppress the backgrounds strongly. For the two modes in which the $D^0$'s are reconstructed, figure 1 shows the distribution of $\delta m = m_{D^0\pi^+} - m_{D^0}$, after all cuts except that on $\delta m$. The signal region in $\delta m$ is $\pm 2$ MeV/c$^2$ around the nominal value, which is approximately a $2\sigma$ cut. To study the background from fake $D^*$'s, which is the dominant background in both $D^0$ channels, we select combinations from 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 uncorrected, experimental joint four-dimensional distribution using an unbinned maximum likelihood fit. This distribution is modelled as the convolution of the true four-dimensional distribution with the full smearing and acceptance function of the detector. 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. Instead of parameterizing the smearing and acceptance of the detector, this method uses a technique of re-weighting Monte Carlo events to evaluate the likelihood function numerically. In figure 2, the quality of the fit is shown in the four 1-dimensional projections. The plots show that the fit describes the data well in all four projections. The last plot, f), shows an example of a 2-dimensional projection, $\chi$ vs. $\cos\theta_V$. The dominant structure in this plot, the enhancement in the upper-left and lower-right quadrants and the depletion in the other two quadrants, is due to an interference term of the form $\sin\theta_V \cos\theta_V \cos\chi$. If parity were conserved in the decay $b \to cW$, the coefficient of this term would be zero. The observed structure is in agreement with the expectations from the standard model. If the $b \to c\ell\nu$ process had a $V + A$ coupling at the $b \to cW$ vertex, we would expect the pattern of enhanced and depleted regions to be reversed, which is in disagreement with the data. ( The observed pattern is also consistent with the hypothesis that both the $b \to cW$ and the $W \to \ell\nu$ vertices have a $V + A$ coupling. )

Table 1 shows the result of the fit for $R_1$, $R_2$, and $\rho^2$. 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 arise from the uncertainty in the modelling of backgrounds and from the fitting method itself. Our value of $\rho^2 = 1.01 \pm 0.15 \pm 0.09$ is in agreement with the measurement of $\hat{\rho}^2 = 0.84 \pm 0.13 \pm 0.08$, obtained as part of the CLEO measurement [4] of $|V_{cb}|$. Using the values of $R_1$ and $R_2$ reported above, Neubert [5] estimates that $\hat{\rho}^2 - \rho = -0.3 \pm 0.2$.

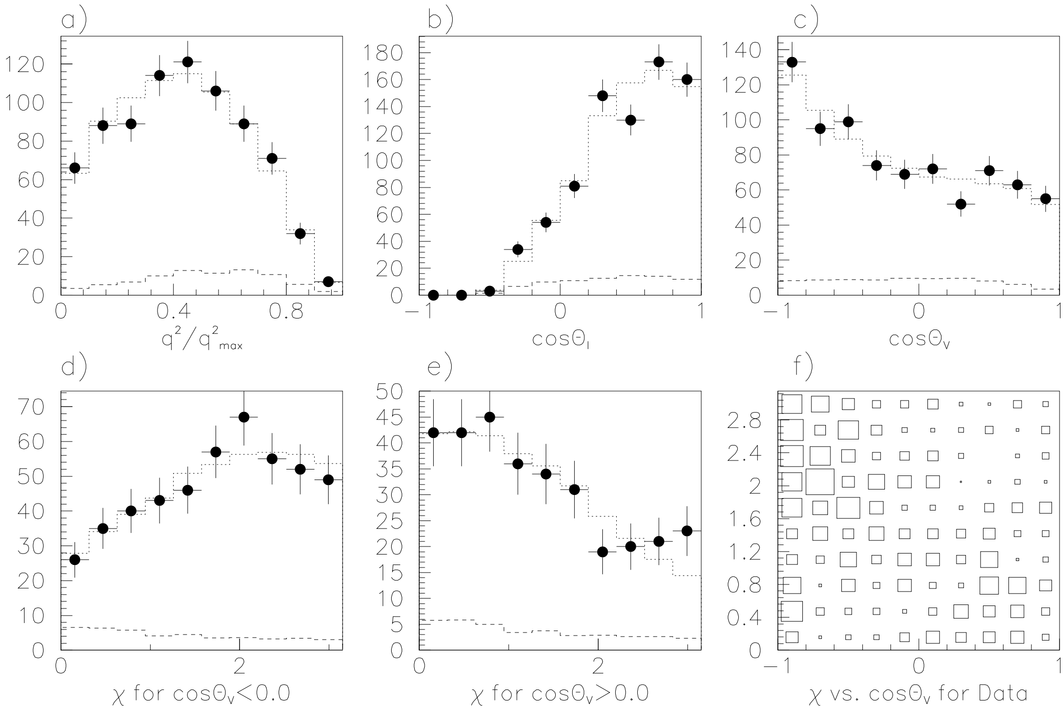


**Figure 2.** In plots a) through e), the data are shown with error bars, the full fit as the dotted line, and the contribution of the backgrounds as the dashed line. In a) through c), the one dimensional projections onto the $q^2$, $\cos\theta_\ell$, and $\cos\theta_V$ axes are shown. Plots d) and e)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

| Fit Parameters | | Correlation Coefficients | |
|---|---|---|---|
| $R_1$ | $1.30 \pm 0.36 \pm 0.16$ | $C(R_1R_2)$ | $-0.83$ |
| $R_2$ | $0.64 \pm 0.26 \pm 0.12$ | $C(R_1\rho^2)$ | $0.63$ |
| $\rho^2$ | $1.01 \pm 0.15 \pm 0.09$ | $C(R_2\rho^2)$ | $-0.82$ |

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

| $\rho^2$ | $R_1$ | $R_2$ | $C(R_1R_2)$ |
|---|---|---|---|
| 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 | $1.75 \pm 0.34 \pm 0.17$ | $0.20 \pm 0.20 \pm 0.11$ | $-0.77$ |

**Table 2.** The preliminary results of the two parameter fits for different slopes, $\rho^2$. The first error is statistical and the second is systematic. The correlation, $C(R_1R_2)$, between the errors on $R_1$ and $R_2$ is strong.

Table 2 shows the results from a series of fits for $R_1$ and $R_2$, in which the slope, $\rho^2$, was fixed to a series of values. If theoretical calculations of $\rho^2$ become sufficiently precise, this table shows the expected improvement in the precision with which the form factor ratios, especially $R_2$, will be known.

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

## References


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