Eur Phys J C **33**, s01, s223–s225 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2003-03-113-2

EPJ C direct
electronic only

B decays into charm at CLEO

Measurement of the branching fraction and helicity amplitudes in $B \to D^{\star}\rho$ decays

István Dankó (CLEO Collaboration)

Rensselaer Polytechnic Institute, 110 8th St., Troy NY 12180, USA

Received: 17 October 2003 / Accepted: 27 October 2003 /
Published Online: 31 October 2003 –

Abstract. Recent measurements of the branching fractions and helicity amplitudes of the decays $B^- \to D^{\star 0}\rho^-$ and $\bar{B}^0 \to D^{\star +}\rho^-$ by the CLEO collaboration are presented. The fraction of longitudinal polarization in the $\bar{B}^0 \to D^{\star +}\rho^-$ decay is found to be consistent with the factorization hypothesis, although the helicity amplitudes show evidence for nonzero final-state interaction phases.

PACS. 13.25.Hw Decays of bottom mesons – 12.39.St Factorization – 14.40.Nd Bottom mesons

1 Introduction

Hadronic decays of heavy mesons are complicated by final-state interactions resulting from gluon exchange among the decay products. The factorization hypothesis, which is widely used in heavy-quark physics to describe hadronic two-body decays, assumes that the decay products hadronize independently since they are fairly energetic and separate rapidly making the complicated final-state interactions less important [1].

If the factorization hypothesis is valid then certain hadronic two-body B meson decays are analogous to similar semileptonic decays evaluated at the same momentum transfer. One sensitive test of the factorization hypothesis is to examine the polarization in B meson decays into two vector mesons [2]. For example, the fraction of longitudinal polarization, Γ_L/Γ, in $\bar{B}^0 \to D^{\star +}\rho^-$ should be equal to that in $\bar{B}^0 \to D^{\star +}\ell^-\bar{\nu}$ at $q^2 = m_\rho^2$.

When a pseudoscalar B meson decays into $D^\star$ and ρ, the final state can be in helicity states $|\lambda_{D^\star}, \lambda_\rho\rangle = |0,0\rangle$, $|1,1\rangle$ or $|-1,-1\rangle$, where $\lambda_{D^\star}$ and λ_ρ are the helicities of the $D^\star$ and ρ, respectively. The contribution of each helicity mode to the final state is represented by the complex helicity amplitudes $H_k = |H_k|e^{i\alpha_k}$ ($k = 0,+,-$ correspond to the $|0,0\rangle$, $|1,1\rangle$, and $|-1,-1\rangle$ helicity states, respectively). We can determine the magnitude and phases of the helicity amplitudes by studying the angular distribution of the decay. Then, the fraction of longitudinal polarization is defined as

$$\frac{\Gamma_L}{\Gamma} = \frac{|H_0|^2}{|H_0|^2 + |H_+|^2 + |H_-|^2}.$$

2 Experimental technic

This analysis uses all the data collected by the CLEO II [3] and CLEO II.V [4] detectors at the Cornell Electron Storage Ring (CESR) which is a symmetric e^+e^- collider. The data consist of an integrated luminosity of 9.1 fb^{-1} collected at the Υ(4S) resonance, corresponding to 9.7 million $B\bar{B}$ events, as well as 4.6 fb^{-1} of continuum data collected 60 MeV below the Υ(4S) resonance. The latter data sample is used to study the nonresonant $e^+e^- \to q\bar{q}$ ($q = u, d, c, s$) background.

Candidate $D^{\star +}$ and $D^{\star 0}$ mesons are reconstructed in the modes $D^{\star +} \to D^0\pi^+$ and $D^{\star 0} \to D^0\pi^0$, with the D^0 decaying into $K^-\pi^+$, $K^-\pi^+\pi^0$, or $K^-\pi^+\pi^-\pi^+$ (charge conjugate modes are implied). The reconstructed D^0 invariant mass and $D^\star - D^0$ mass difference are required to be within 2.5σ of the nominal values. The mass resolutions are obtained from Monte Carlo simulations, and the $D^0 \to K^-\pi^+\pi^0$ resolution includes a π^0 energy dependence. The ρ^- candidates are selected from $\pi^-\pi^0$ combinations which have an invariant mass within 150 MeV/c^2 of the nominal mass. The π^0 candidates are formed from pairs of photons detected in the barrel section of the calorimeter with minimum photon energy of 30−65 MeV depending on the source ($D^{\star 0}$, D^0, or ρ^-) of the π^0.

The B^- and $\bar{B}^0$ mesons are reconstructed by combining the $D^\star$ and ρ^- candidates. We require that the difference between the reconstructed energy of the B candidate (E_B) and the beam energy (E_b), $\Delta E = E_B - E_b$, is consistent with 0 within 2.5σ. The resolution of ΔE varies from 10 MeV to 35 MeV, depending on the decay mode, and is also obtained from Monte Carlo simulations. We also calculate the beam-constrained B invariant mass by substituting the beam energy, E_b, for the B candidate energy: $M = \sqrt{E_b^2 - p_B^2}$, where p_B is the momentum of the B candidate. This improves the resolution of M by one order of magnitude, to ~ 3 MeV/c^2.

In order to suppress the four-flavor background from the continuum under the Υ(4S) resonance we restrict the second order normalized Fox-Wolfram moment ($R_2 < 0.5$), the polar angle of the reconstructed B meson candidate ($|\cos\Theta_B| < 0.95$), and the cosine of the sphericity angle, Θ_S, defined as the angle between the sphericity axis of the B decay products and the rest of the particles in the event (the maximum allowed value of $|\cos\Theta_S|$ depends on the D^0 decay mode).

We perform two unbinned maximum likelihood fits to determine the branching fraction and helicity amplitudes of the $B \to D^\star\rho$ decay. From the first fit we extract the number of signal and background events which are then fixed in the subsequent fit when we extract the helicity amplitudes. Since the acceptance of the detector depends on the angular distribution of the data (i.e. on the helicity amplitudes) due to detector smearing, the fits are iterated until convergence is achieved. The correct acceptance for any desired set of helicity amplitudes is calculated by reweighting our Monte Carlo sample generated with a flat angular distribution.

The probability distribution functions used in the likelihood function are factorized into three terms describing the beam constrained B ($D^\star\rho^-$) invariant mass distribution, the ρ^- ($\pi^-\pi^0$) invariant mass distribution, and the acceptance corrected angular distribution. Each component is appropriately parametrized for signal and background. The fitting method has been extensively tested on Monte Carlo samples to verify correct performance.

3 Results

The number of signal and background events are extracted by fitting the reconstructed candidate events with beam-constrained B invariant mass, M, between 5.20 and 5.30 GeV/c^2 and neglecting the angular distribution of both signal and background. The beam-constrained mass distribution with the result of the fit is shown on Fig. 1 for both $B^- \to D^{\star 0}\rho^-$ and $\bar{B}^0 \to D^{\star +}\rho^-$. Table 1 lists the number of signal events for each decay mode together with the corresponding selection efficiencies determined from Monte Carlo simulations.

Table 1. Number of signal events and efficiencies for each decay mode. Errors are statistical only

B type	D^0 decay mode	$n_{\rm signal}$	$\varepsilon(\%)$
	$K^-\pi^+$	148.9±13.8	6.56±0.04
B^-	$K^-\pi^+\pi^0$	177.4±16.6	2.20±0.02
	$K^-\pi^+\pi^-\pi^+$	136.0±15.2	3.04±0.03
	$K^-\pi^+$	196.3±14.6	10.88±0.05
$\bar{B}^0$	$K^-\pi^+\pi^0$	196.1±16.4	3.67±0.03
	$K^-\pi^+\pi^-\pi^+$	170.6±13.9	4.46±0.03

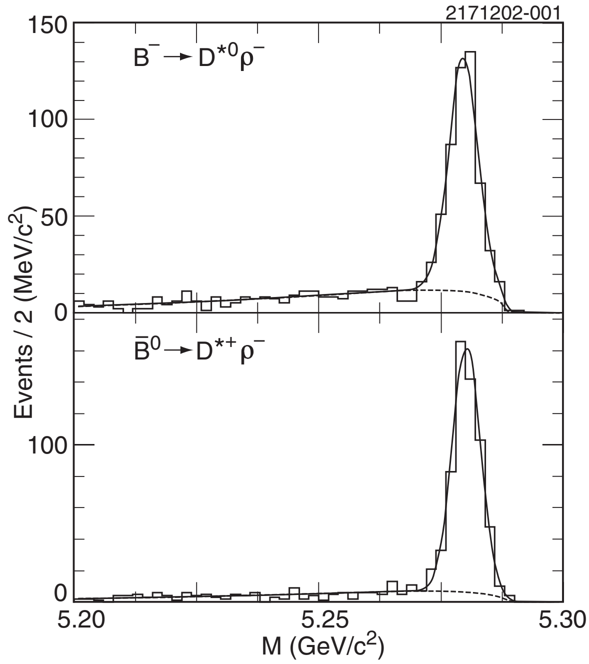

Fig. 1. Beam-constrained invariant B mass distribution of $B^- \to D^{\star 0}\rho^-$ (*top*) and $\bar{B}^0 \to D^{\star +}\rho^-$ (*bottom*) candidates along with the fit results (*dashed curves* indicate the background)

Assuming equal production of B^+B^- and $B^0\bar{B}^0$ at the Y(4S) resonance, the measured branching fractions are

$$\mathcal{B}(B^- \to D^{\star 0}\rho^-) = (0.98 \pm 0.06 \pm 0.16 \pm 0.05)\%,$$

$$\mathcal{B}(\bar{B}^0 \to D^{\star +}\rho^-) = (0.68 \pm 0.03 \pm 0.09 \pm 0.02)\%,$$

which are consistent with previous CLEO measurement [5], the recent BABAR measurement [6] and the world average. The first error quoted is statistical; the second is systematic error including uncertainties in the number of $B\bar{B}$ pairs, the background shape, the Monte Carlo statistics, and the charged particle tracking and π^0 detection efficiency, which is the dominant source of error; the third error is systematic due to uncertainties in the D^0 and $D^\star$ decay branching fractions.

Using the BSW prediction for the ratio of the branching fractions [1] we can extract the ratio of effective coupling strengths for color-suppressed (a_2) and color-allowed (a_1) modes of the $D^\star\rho$ final state:

$$a_2/a_1 = 0.21 \pm 0.03 \pm 0.05 \pm 0.04 \pm 0.04,$$

where the fourth error is due to the uncertainty in the ratio of B^+B^- to $B^0\bar{B}^0$ production at the Υ(4S).

In order to determine the helicity amplitudes, only the reconstructed events in the B signal region ($5.27 < M < 5.30$ GeV/c^2) are included in the fit. The number of signal and appropriately scaled background events are fixed from the previous fit and only the helicity amplitudes are allowed to float in the fit. The magnitude of the helicity amplitudes is normalized so that $|H_0|^2 + |H_+|^2 + |H_-|^2 = 1$, and the phases of H_+ and H_- are determined with respect

Table 2. The measured helicity amplitudes for $B^- \to D^{\star 0}\rho^-$ and $\bar{B}^0 \to D^{\star +}\rho^-$. The angles α_+ and α_- are the phases of the helicity amplitudes H_+ and H_- relative to H_0

	$B^- \to D^{\star 0}\rho^-$	$\bar{B}^0 \to D^{\star +}\rho^-$
$\mid H_0 \mid$	0.944±0.009±0.009	0.941±0.009±0.006
$\mid H_+ \mid$	0.122±0.040±0.010	0.107±0.031±0.011
α_+	1.02±0.28±0.11	1.42±0.27±0.04
$\mid H_- \mid$	0.306±0.030±0.025	0.322±0.025±0.016
α_-	0.65±0.16±0.06	0.31±0.12±0.04

to the phase of H_0. Table 2 lists the helicity amplitudes obtained for both B^- and $\bar{B}^0$ decays. The first error is statistical, the second is systematic. The main sources of systematic uncertainty are the acceptance parametrization, detector smearing, background level and shape, contribution from nonresonant $\pi^-\pi^0$, and the polarization dependence on the $\pi^-\pi^0$ invariant mass. The largest systematic error comes from the shape of the background angular distribution.

Our results indicate possible nontrivial helicity amplitude phases (α_+ and α_-) with a significance of 3.19σ and 2.75σ for $B^- \to D^{\star 0}\rho^-$ and $\bar{B}^0 \to D^{\star +}\rho^-$, respectively. The significance of nonzero phases is stable against all fit variations used to study the systematic uncertainties. Nonzero helicity amplitude phases could result from final state interactions, which can have significant implications for direct CP violation in B decays.

The measured helicity amplitudes correspond to a longitudinal polarization fraction of

$$\frac{\Gamma_L}{\Gamma}(B^- \to D^{\star 0}\rho^-) = 0.892 \pm 0.018 \pm 0.016,$$

$$\frac{\Gamma_L}{\Gamma}(\bar{B}^0 \to D^{\star +}\rho^-) = 0.885 \pm 0.016 \pm 0.012,$$

where the uncertainties are statistical and systematic, respectively. At the current precision, the fraction of longitudinal polarization in $\bar{B}^0 \to D^{\star +}\rho^-$ decay is consistent with earlier CLEO measurement [5] and with the heavy quark effective theory (HQET) prediction of 0.895 ± 0.019 [7] using factorization and the measurement of the semileptonic form factors in $\bar{B}^0 \to D^{\star +}\ell^-\bar{\nu}$ [8]. The fraction of longitudinal polarization as a function of the square of the momentum transfer (q^2) is plotted in Fig. 2 for such a prediction and compared with our new result on $D^{\star +}\rho^-$, as well as with previous measurements for $D^{\star +}\rho'^-$ [9] and $D^{\star +}D_S^{\star -}$ [10].

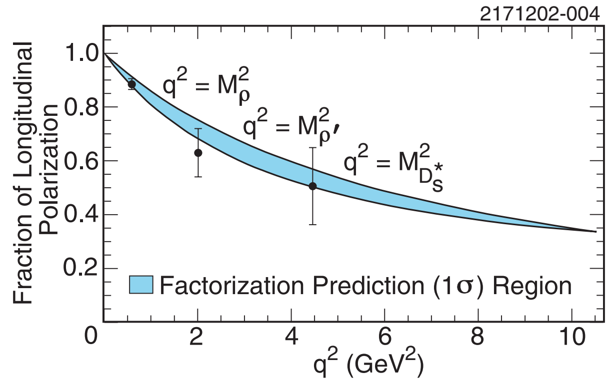

Fig. 2. The fraction of longitudinal polarization in $\bar{B}^0 \to D^{\star +}X$ decays as a function of $q^2 = M_X^2$, where X is a vector meson. *Dots with error bars* indicate the current polarization measurements for $X = \rho^-$, and earlier measurements for $X = \rho'^-$ and $X = D_S^{\star -}$. The *shaded region* represents the HQET prediction using factorization and extrapolating from the semileptonic form factor results

4 Conclusion

The CLEO collaboration has measured both the branching fractions and the helicity amplitudes of $B^- \to D^{\star 0}\rho^-$ and $\bar{B}^0 \to D^{\star +}\rho^-$ decays [11]. The values of the branching fractions, the ratio of a_2/a_1 and the degree of the longitudinal polarization are in good agreement with previous measurements and theoretical predictions. The fraction of longitudinal polarization confirms the validity of the factorization hypothesis at relatively low q^2, although the measurement of the helicity amplitudes indicates a strong possibility of nontrivial helicity amplitude phases which would arise from final-state interactions. Indications of final-state interaction phases have also been reported previously in the $D\pi$ [12] and the $J/\psi K^\star$ [13] systems.

References

1. M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C **34** (1987) 103
2. J. Körner and G. Goldstein, Phys. Lett. **89B** (1979) 105
3. CLEO Collaboration, Y. Kubota et al., Nucl. Instrum. Methods Phys. Res. A **320** (1992) 66
4. T.S. Hill, Nucl. Instrum. Methods Phys. Res. A **418** (1998) 32
5. CLEO Collaboration, M. S. Alam *et al.*, Phys. Rev. D **50** (1994) 43.
6. B. Brau, Int. J. Mod. Phys. A **16**, Suppl. 1A (2001) 440
7. J.L. Rosner, Phys. Rev. D **42** (1990) 3732; M. Neubert, Phys. Lett. B **264** (1991) 455; G. Kramer, T. Mannel, and W.F. Palmer, Z. Phys. C **55** (1992) 497; J. D. Richman, in *Probing the Standard Model of Particle Interactions*, ed. by R. Gupta, A. Morel, E. de Rafael, and F. David (Elsevier, Amsterdam 1999) p. 640
8. CLEO Collaboration, J. Duboscq et al., Phys. Rev. Lett. **76** (1996) 3898
9. CLEO Collaboration, J.P. Alexander et al., Phys. Rev. D **64** (2001) 092001
10. CLEO Collaboration, S. Ahmed et al., Phys. Rev. D **62** (2000) 112003
11. CLEO Collaboration, S.E. Csorna et al., Phys. Rev. D **67** (2003) 112002
12. CLEO Collaboration, T.E. Coan et al., Phys. Rev. Lett. **88** (2002) 062001; CLEO Collaboration, S. Ahmed et al., Phys. Rev. D **66** (2002) 031101(R)
13. CDF Collaboration, T. Affolder et al., Phys. Rev. Lett. **85** (2000) 4668