# Hadronic B Decays at CLEO

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I present highlights of recent CLEO results on the hadronic decay modes of the B meson. Topics covered include two body rare B decays modes, a new measurement of $(B^0 \to D^0 K^+)/(B^0 \to D^0 \pi^+)$, an in depth study of the decay $B^0 \to D^* \rho$, as well as a preliminary search for charge asymmetry in the decay $B^0 \to K^* \pi$.

## 1 The CLEO Detector and CLEO Data

The CLEO detector has had three incarnations. The original CLEOII detector, as described in Ref [1], consists of drifts chambers using an argon ethane gas mixture, time of flight counters, a CsI calorimeter, and muon chambers. It was upgraded to include a 3 layer 2 sided silicon vertex detector, and the drift gas in the drift chamber was changed to a helium propane mixture to give improved tracking and $dE/dx$ particle identification. This configuration was named the CLEOII.5 detector [2]. A subsequent major overhaul included installation of a four layer double sided silicon vertex detector, a new drift chamber, and a RICH detector. This configuration is referred to as the CLEOIII detector [3]. The datasets which are used in the following were taken mainly at the $\Upsilon(4S)$ resonance, which decays equally to $B^0\overline{B}^0$ and $B^+B^-$. One third of the data are taken off peak to gain an understanding of continuum backgrounds. The CLEOII and CLEOII.5 sample comprise some 9 million B pairs, while the CLEOIII sample contains approximately 6 million B pairs. It is worth noting that the CESR accelerator produced the $\Upsilon(4S)$ at rest, allowing for a kinematic constraint on the reconstruction of its decay.

## 2 Rare Two Body Hadronic B Decays

Rare two body B decays are studied among other reasons because they can provide insight into the CKM mixing angle $\gamma$. Their inherent small expected Standard Model branching ratios also allow for the possibility of detection of new physics due to the interference of penguin diagrams with Standard Model diagrams. In addition of course, they provide us with a sample independent of decays to charm final states to test our theoretical expectations. The result presented here will comprise an analysis using the CLEOIII detector, which is then combined with the CLEOII+CLEOII.5 samples to produce the final CLEO results on rare two body hadronic B decays from a sample of 15 million B pairs.

The branching ratios reported herein result from $B^0$ decays to $\pi\pi$, $K\pi$, $KK$, $K^0\pi^0$, $K^0\overline{K}^0$,$\pi^0\pi^0$, $p\overline{p}$ and $\Lambda\overline{\Lambda}$. Also included are results from $B^+$ decays to $\pi\pi^0$, $K\pi^0$, $\pi K^0$, $KK^0$ and $p\overline{\Lambda}$.

### 2.1 The CLEOIII Analysis Method

The CLEOIII data was analyzed in much the same fashion as that of CLEOII and CLEOII.5 - see Ref [4]. A series of hard, but well understood, quality cuts were placed on tracks, showers in the calorimeter, $\pi^0$'s and $K_s$'s. Cuts were also placed on the beam constrained B mass, $M_B = \sqrt{E^2_{Beam} - p^2_{Candidate}}$, for the final state in question, as well as on $\Delta E = E_{Candidate} - E_{Beam}$ and the cosine of the sphericity angle of the candidate.

For charged $\pi$ and $K$ final states, the particle identification likelihoods of the RICH and $dE/dx$ were combined and cut on. The cut efficiency was calibrated using data decays $D^* \to (K\pi)\pi$ and chosen to accept 90% of real $\pi$'s and $K$'s, while allowing only an 11 % fake rate for $\pi$'s faking $K$'s, and an 8% fake rate for K's faking $\pi$'s. For proton identification, only the RICH detector was used, and cuts were calibrated on data decays of $\Lambda \to p\pi$, as well as $D^* \to (K\pi)\pi$, resulting in a measured 76% (71%) $p$ ( $\overline{p}$) efficiency and a 1% fake rate from charged K's.

The resulting data were then used in an extended maximum likelihood fit using $M_B$, $\Delta E$, $\cos\theta_B$ and $\mathcal{F}$, where the Fisher discriminant, $\mathcal{F}$ is a linear combination of the direction of the thrust axis of the candidate, 9 Virtual Calorimeter bins[a] and the momenta of the highest electron, $\mu$, $K$, and proton in the event[b]. The signal Fisher shape is derived from Monte Carlo studies, and a common background Fisher shape is used in all modes. The resulting Fisher shapes give a 1.4 $\sigma$ separation between the signal peaks and background peaks. The event likelihood is formed using each of the 13 modes above, as well as cross feeds from other B modes, and a term representing the non-B background.

### 2.2 Results

The CLEO III measurements using the likelihood functions described above are combined with the CLEOII and CLEOII.5 results reported in Ref [4] and Ref [5] and reported in Table 1. For some modes previously unpublished likelihood functions are used. The baryonic modes and the $K^0_S K^0_S$ mode were analyzed here with the full CLEO II data set for the first time. Full details can be found in Ref [6]. All results are competitive with recent results from the BaBar and Belle collaborations [7].

### 2.3 The ratio $B(B^- \to D^0 K^-)/B(B^- \to D^0\pi^-)$

Using the same technique as described above, we also examined the ratio of branching fractions of $B^- \to D^0 K^-$ to $B^- \to D^0\pi^-$ using the decays $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$, and $D^0 \to K^-\pi^+\pi^-\pi^+$. We apply particle identification only to the fast $K$ and $\pi$ in the decay and account for the feed-through from the $\pi$ channel into the $K$ channel. The ratio allows for a small systematic error due mainly to particle identification uncertainties. The result is:

$$\frac{B(B^- \to D^0 K^-)}{B(B^- \to D^0\pi^-)} = (9.9^{+1.4+0.7}_{-1.2-0.6}) \times 10^{-2} \quad (1)$$

## 3 The Decay $B \to D^*\rho$

Using the CLEOII and CLEOII.5 data sample, and using an extended maximum likelihood fit in the B candidate mass and $\rho$ candidate mass, we report:

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

[a] The Virtual Calorimeter consists of a weighted scalar sum of momenta in 10 degree bins around the candidate sphericity bins.

[b] This last term is new to the CLEO3 analysis.

Table 1: Experimental results for CLEO II, CLEO III, and both datasets combined. Significances include systematic errors. Note that the $p\bar{p}$ analysis in Ref. [5] was done in only a subset of the full CLEO II dataset, so the "combined" result is simply the CLEO III upper limit. Upper limits are 90% confidence level. CLEO II results are taken from Ref. [5] except for the $K^0\overline{K^0}$, $p\bar{\Lambda}$ and $\Lambda\bar{\Lambda}$ modes which were analyzed in this work with the full CLEO II dataset for the first time.

| | CLEO II - Ref. 5 | | CLEO III | | Combined | |
|---|---|---|---|---|---|---|
| Mode | Significance | $\mathcal{B}\times 10^6$ | Significance | $\mathcal{B}\times 10^6$ | Significance | $\mathcal{B}\times 10^6$ |
| $\pi^+\pi^-$ | 4.2 | $4.3^{+1.6+0.5}_{-1.4-0.5}$ | 2.6 | $4.8^{+2.5+0.8}_{-2.2-0.5}$ | 4.4 | $4.5^{+1.4+0.5}_{-1.2-0.4}$ |
| $\pi^+\pi^0$ | 3.2 | $5.6^{+2.6+1.7}_{-2.3-1.7}$ | 2.1 | $3.4^{+2.8+0.8}_{-2.0-0.3}$ | 3.5 | $4.6^{+1.8+0.6}_{-1.6-0.7}$ |
| $\pi^0\pi^0$ | 2.0 | $(< 5.7)$ | 1.8 | $(< 7.6)$ | 2.5 | $(< 4.4)$ |
| $K^+\pi^-$ | 12 | $17.2^{+2.5+1.2}_{-2.4-1.2}$ | $> 7$ | $19.5^{+3.5+2.5}_{-3.7-1.6}$ | $> 7$ | $18.0^{+2.3+1.2}_{-2.1-0.9}$ |
| $K^0\pi^+$ | 7.6 | $18.2^{+4.6+1.6}_{-4.0-1.6}$ | 4.6 | $20.5^{+7.1+3.0}_{-5.9-2.1}$ | $> 7$ | $18.8^{+3.7+2.1}_{-3.3-1.8}$ |
| $K^+\pi^0$ | 6.1 | $11.6^{+3.0+1.4}_{-2.7-1.3}$ | 5.0 | $13.5^{+4.0+2.4}_{-3.5-1.5}$ | $> 7$ | $12.9^{+2.4+1.2}_{-2.2-1.1}$ |
| $K^0\pi^0$ | 4.9 | $14.6^{+5.9+2.4}_{-5.1-3.3}$ | 3.8 | $11.0^{+6.1}_{-4.6} \pm 2.5$ | 5.0 | $12.8^{+4.0+1.7}_{-3.3-1.4}$ |
| $K^+K^-$ | - | $(< 1.9)$ | - | $(< 3.0)$ | - | $(< 0.8)$ |
| $K^0K^-$ | - | $(< 5.1)$ | - | $(< 5.0)$ | - | $(< 3.3)$ |
| $K^0\overline{K^0}$ | - | $(< 6.1)$ | - | $(< 5.2)$ | - | $(< 3.3)$ |
| $p\bar{p}$ | - | $(< 7.0)$ | - | $(< 1.4)$ | - | $(< 1.4)$ |
| $p\bar{\Lambda}$ | - | $(< 2.0)$ | - | $(< 3.2)$ | - | $(< 1.5)$ |
| $\Lambda\bar{\Lambda}$ | - | $(< 1.8)$ | - | $(< 4.2)$ | - | $(< 1.2)$ |

$$B(\overline{B}^0 \to D^{*+}\rho^-) \quad = \quad (0.68 \pm 0.03 \pm 0.09 \pm 0.02)\% \tag{2}$$

where the first systematic error is dominated by $\pi^0$ reconstruction errors, and the second is due to $D$ and $D^*$ branching ratio uncertainties. From this we can extract the ratio of BSW coupling constants [8] $|a_2/a_1| = 0.21 \pm 0.03 \pm 0.05 \pm 0.04 \pm 0.04$, where the last uncertainty is from the error on the ratio of charged decays of the $\Upsilon(4S)$ to uncharged decays.

The differential decay rate can be described in terms of the helicity amplitudes $H_0$, $H_+$, and $H_-$ using the cosine of the opening angles of the $D^*$ and $\rho$ decays, and the relative angle of the two decays planes. These amplitudes are extracted from the data using an extended maximum likelihood fit whose inputs are the masses of the $B$ and $\rho$ candidates, and the angles described above. Acceptance corrections are taken into account in the fit. The results are listed in Table 2.

Table 2: Helicity amplitudes and phases for the decay $B \to D^*\rho$. The angles $\alpha_{(+,-)}$ are the phases of the helicity amplitudes $|H_{(+,-)}|$ relative to $|H_0|$. The results for the resulting relative longitudinal decay rates (or polarization) are also shown.

| | $D^{*0}$ | $D^{*+}$ |
|---|---|---|
| $\lvert H_0\rvert$ | $0.944 \pm 0.009 \pm 0.009$ | $0.941 \pm 0.009 \pm 0.006$ |
| $\lvert H_+\rvert$ | $0.122 \pm 0.040 \pm 0.010$ | $0.107 \pm 0.031 \pm 0.011$ |
| $\alpha_+$ | $1.02 \pm 0.28 \pm 0.11$ | $1.42 \pm 0.27 \pm 0.04$ |
| $\lvert H_-\rvert$ | $0.306 \pm 0.030 \pm 0.025$ | $0.322 \pm 0.025 \pm 0.016$ |
| $\alpha_-$ | $0.65 \pm 0.16 \pm 0.04$ | $0.31 \pm 0.12 \pm 0.04$ |
| $\Gamma_L/\Gamma$ | $0.892 \pm 0.018 \pm 0.016$ | $0.885 \pm 0.016 \pm 0.012$ |

From the amplitudes, one can form the relative longitudinal and transverse decay rates. The factorization ansatz [8] predicts that the longitudinal polarization of the $D^{*+}\rho^-$ decay should be equal to the longitudinal polarization of the semileptonic decay $\overline{B}^0 \to D^{*+}l^-\overline{\nu}$ evaluated at $q^2 = M_\rho^2$. The results are in agreement with this prediction. Full results are discussed in Ref [9].

## 4 Charge Asymmetry in $B^0 \to K^*\pi$

The investigation of charge asymmetries in neutral B decays can yield insights into CP violation. Using the CLEOII and CLEOII.5 data sample, we have investigated the asymmetry $\mathcal{A}_{CP}$ between the decays $\overline{B}^0 \to K^{*-}(892)\pi^+$ and $B^0 \to K^{*+}(892)\pi^-$ by looking at the asymmetry $\mathcal{A}_{+-}$ which is the difference in rates between the final states with a positive or negative fast $\pi$. Monte Carlo simulations indicate that $\mathcal{A}_{+-}$ is 99.99% correlated with $\mathcal{A}_{CP}$ for this particular decay mode. The final states of interest include $(K_s\pi^+)h^-$ and $(K^-\pi^0)h^+$, where $h$ indicates that the particle has not undergone particle identification cuts.

The asymmetry is extracted from a maximum likelihood fit using the $B$ candidate mass, $\Delta E$, the Dalitz plot, the B decay angle, $dE/dx(h^+)$ and a Fisher discriminant composed of the virtual calorimeter, the Fox-Wolfram event shape R2, and the cosine of the angle of the candidate thrust axis with respect to the beam. Included in the fit are distributions for the $K^{*+}(982)\pi^-/K^-$, $K^{*+}(1430)\pi^-/K^-$, $\rho^0 K_s^0$, $K_s\pi(\pi/K)$ non resonant decays, as well as $K^{*0}(892)\pi^0$, $K^{*0}(1430)\pi^0$, and $K^-\pi^+\pi^0$ non resonant decays. We exclude background slices in the Dalitz plot consisted with feed-throughs from the decays of $B$ mesons to $D\pi$, $\psi K_s$, and $\psi\pi^0$ final states. In addition to these signal modes, generic $B\overline{B}$ decays and continuum feed-through are in the likelihood.

The preliminary value extracted for $\mathcal{A}_{CP}$ is found to be:

$$\mathcal{A}_{CP}(B \to K^{*\pm}(892)\pi^{\mp}) = 0.26^{+.33+0.10}_{-.34-0.08}. \tag{3}$$

By integrating the likelihood function, this leads to a 90% confidence level interval of : $-0.31 < \mathcal{A}_{CP}(B \to K^{*\pm}(892)\pi^{\mp}) < 0.78$. The dominant systematic uncertainty for this measurement is our lack of knowledge of the interference terms between the various signal components. This result is the first limit on $\mathcal{A}_{CP}$ in this mode. Theoretical predictions for this asymmetry range from $-0.19$ to 0.47 as found in Ref [11].

## 5 Conclusions

We have presented the final combined CLEO results on rare 2 body B decay modes. These results are in agreement with, and still competitive with, recent results from both the BaBar and Belle collaborations [7]. A by product of this analysis has been a new result for the ratio of branching ratios $B(B^- \to D^0K^-)/B(B^- \to D^0\pi^-)$ which is again competitive with results from other collaborations.

We have also presented detailed results on the branching ratios and helicity amplitudes of the decay $B \to D^*\rho$, as well as a determination of the ratio of BSW coefficients $|a_2/a_1|$, and a confirmation of the factorization ansatz.

We have also presented the first limits on $\mathcal{A}_{CP}$ in the decay $B \to K^*\pi$.

The CLEO collaboration is now moving into a new era, dubbed the CLEO-c era, and will from herein concentrate on low energy $e^+e^-$ collisions near the charm production threshold. Although this represents a new physics sample, it is clear that the older $\Upsilon(4S)$ sample collected continues to bear fruit in analysis.

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