FACTORIZATION AND COLOR-SUPPRESSION IN HADRONIC $B \rightarrow D^{(*)} n\pi$ DECAYS

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1. Introduction

We discuss recent results on hadronic $B$ decays using data obtained with the CLEOII detector [1]. The results are used to test the factorization hypothesis and color suppression.

Two body hadronic decays which involve the quark level transition $b \rightarrow c\bar{u}d$ fall into three general categories. Class I and class II decays involve neutral $B$ mesons which decay to a charged $D^{(*)}$ and a charged meson or to a neutral $D^{(*)}$ and a neutral meson. In these decays the transitions are mediated by external or internal (color-suppressed) diagrams, respectively. In class III decays a charged $B$ decays to a neutral charmed meson plus a light hadron where the final state quark configuration can result from either spectator diagrams. In the usual theoretical treatment [2,3,4,5] the decay amplitudes are expressed as linear functions of parameters $a_1$ and $a_2$, each assigned to the amplitude associated with the external and internal diagram, respectively.

2. Experimental Procedure

We have measured branching fractions for five class I decays: $B^0 \rightarrow D^{(*)+}\pi^-, D^{(*)+}\rho^-$ and $D^{*+}a_1^-$ and five class III modes $B^- \rightarrow D^{(*)0}\pi^-, D^{(*)0}\rho^-$ and $B^- \rightarrow D^{*0}a_1^-$ decays. The data sample used consists of 2.04 $fb^{-1}$ of data collected at the $\Upsilon(4S)$ by CLEO at the CESR $e^+e^-$ ring. The sample corresponds to $2 \times 10^6 B\bar{B}$ pairs. To determine the event yields we fully reconstructed the decay chains in their exclusive modes, formed beam-constrained mass distributions and then fit these to a Gaussian plus a background shape. The combined beam-constrained mass plots are shown in Figure 1. The various criteria used in selecting particle candidates used are described in greater detail in Refs: [6,7]. The branching fraction measurements obtained are listed in Table 1.

3. Determination of $|a_1|$ and the relative sign of $a_2/a_1$

To determine the values of $a_1$ and $a_2/a_1$ we use the branching fraction measurements in Table 1 and theoretical predictions for the branching fractions. The branching fractions of the first four class I decays are used as inputs in a least squares fit to obtain the following results

$$|a_1| = 1.14 \pm 0.024 \pm 0.022 \pm 0.050 \quad \text{BSWII}$$

$$|a_1| = 1.06 \pm 0.023 \pm 0.021 \pm 0.046 \quad \text{CDDFGN.}$$

(1)
Figure 1: Beam-constrained mass plots.

The first error is statistical, the second is the systematic error and the third is the error due to the uncertainty in the $B$ lifetime and production ratio [8]. The two models used, BSWII [3] and CDDFGN [4] employ Heavy Quark Effective Theory but differ mainly in the assumption used to model the $q^2$ dependence of form factors.

The magnitude of the fit parameter $a_1$ is consistent with the expectation from QCD and factorization. In class I decays the QCD coefficients which multiply the matrix elements are given by $a_1' = c_1(\mu) + \frac{1}{N_c}c_2(\mu)$. Using NLLA results for $c_1(\mu)$ and $c_2(\mu)$, at $\mu = 5$ GeV and setting $N_c = 3$ gives $a_1' = 1.04$.

To determine $a_2/a_1$ we form ratios of class III to class I decays and compare the results to theoretical model predictions. The values in Equation (2) are also determined by performing a least squares fit to data.

$$\frac{a_2}{a_1} = +0.15 \pm 0.036 \pm 0.047 \pm 0.107 \pm 0.084 \quad \text{BSWII}$$

$$\frac{a_2}{a_1} = +0.16 \pm 0.035 \pm 0.040 \pm 0.096 \pm 0.076 \quad \text{CDDFGN}$$

The positive sign of $a_2/a_1$ differs from the expectation obtained by extrapolating the charm results to the $B$ system. However, the sign is consistent with QCD and factorization (with small non-factorizable contributions).

4. Direct Tests of Factorization

To test factorization directly we make use of the fact that in this approximation hadronic amplitudes are products of two independent matrix elements. The matrix element describing the heavy to heavy transition is identical to that in the semileptonic transition while the production of the light meson from the vacuum can be described by
a simple expression involving numerical and decay constants. To perform direct tests of factorization we thus check that Equation (3)

\[
\frac{\Gamma(\bar{B}^0 \to D^{*+}h^-)}{\frac{d\Gamma}{dq^2}(\bar{B}^0 \to D^{**}l^-\bar{\nu}_l)|_{q^2=m_h^2}} = 6\pi^2 a_1^2 f_h^2 |V_{ud}|^2
\]  

(3)

is satisfied. The denominator in the LHS is determined, at each \(q^2\), by interpolating the differential \(q^2\) spectrum of the semileptonic decay widths [6]. The values for \(f_h\) and \(V_{ud}\) are taken from recent experimental results [9,10]. The comparison between the LHS \((R_{exp})\) and the RHS \((R_{th})\) is given in Table 2. These show consistency with factorization to present experimental precision.

A more subtle test of factorization [11] can be performed by comparing the polarization of final states in hadronic decays to the polarization in semileptonic decays. We have measured the fraction of \(\bar{B}^0 \to D^{*+}\rho^-\) decays which are polarized in the longitudinal direction to be \(\Gamma_L/\Gamma = 90.0 \pm 3.7 \pm 4.5\%\). The longitudinally polarized fraction of semileptonic decays at \(q^2 = m^2_{\rho}\) is 85\% which is in agreement our with results. The semileptonic value is extracted by fitting the differential \(q^2\) spectrum to model estimates [12].

5. Color-Suppression

Class II decays are defined as decays which can proceed only through internal spectator diagrams. These processes are products of the effective neutral term which gets multiplied by the scale dependent \(a_2'\). In class II decays the value of \(a_2'\) is significantly smaller than \(a_1'\) since it involves the difference of two numbers of similar size. We thus expect class II decays will be suppressed relative to class I decays.

To search for color-suppression we use the large sample of \(B\) mesons available and examine 10 modes: \(B^0 \to D^{(*)0}m^0\), where \(m^0 = \pi, \eta, \eta', \rho^0\) or \(\omega\). The procedure used to find the event yield was identical to that used for class I and class III modes. However, since no clear signals were obtained, limits were set for the branching fractions at the 90\% confidence level. The results are listed in Table 3.

6. Conclusion

By comparing hadronic decays allowed only through external diagrams to the corresponding semileptonic decay we show that to current experimental precision, decays of the type \(B^0 \to D^{(*)+}(n\pi)^-\) are consistent with the factorization hypothesis. Further evidence for factorization is suggested by both the sign of \(a_2/a_1\) and magnitude \(a_1\) when compared to expectations from QCD with factorization. Finally, we show that color-suppression is operative in \(b \to c\bar{u}d\) type transitions with our limits on class II decays.
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| $B^0$ Mode | $B$ (%) | $B^-$ Mode | $B$ (%) |
|------------|---------|------------|---------|
| $D^+\pi^-$ | 0.308 ± 0.026 ± 0.028 ± 0.031 | $D^0\pi^-$ | 0.534 ± 0.025 ± 0.033 ± 0.047 |
| $D^+\rho^-$ | 0.861 ± 0.078 ± 0.109 ± 0.086 | $D^{*0}\pi^-$ | 0.497 ± 0.044 ± 0.048 ± 0.057 |
| $D^{*+}\pi^-$ | 0.304 ± 0.024 ± 0.025 ± 0.027 | $D^0\rho^-$ | 1.022 ± 0.067 ± 0.109 ± 0.086 |
| $D^{*+}\rho^-$ | 0.844 ± 0.071 ± 0.096 ± 0.076 | $D^{*0}\rho^-$ | 1.444 ± 0.134 ± 0.188 ± 0.161 |
| $D^{*+}a_1^-$ | 1.205 ± 0.140 ± 0.138 ± 0.098 | $D^{*0}a_1^-$ | 1.898 ± 0.268 ± 0.236 ± 0.221 |

Table 2: Tests of factorization

| $q^2$ | $R_{\text{exp}}$ (GeV$^2$) | $R_{\text{th}}$ (GeV$^2$) |
|-------|-----------------|-----------------|
| $m_H^2$ | 1.3 ± 0.1 ± 0.2 | 1.2 ± 0.2 |
| $m_H^2$ | 3.4 ± 0.3 ± 0.5 | 3.3 ± 0.5 |
| $m_{a_1}^2$ | 3.8 ± 0.4 ± 0.5 | 3.0 ± 0.5 |

Table 3: Branching fraction limits for class II (color-suppressed) decays @ 90% C.L.

| Decay Mode | $N_{\text{obs}}$ | $B$ (%) | Decay Mode | $N_{\text{obs}}$ | $B$ (%) |
|------------|-----------------|---------|------------|-----------------|---------|
| $\bar{B}^0 \rightarrow D^0\pi^0$ | < 33.3 | < 0.033 | $\bar{B}^0 \rightarrow D^{*0}\pi^0$ | < 14.6 | < 0.055 |
| $\bar{B}^0 \rightarrow D^0\eta$ | < 9.4 | < 0.033 | $\bar{B}^0 \rightarrow D^{*0}\eta$ | < 3.6 | < 0.050 |
| $\bar{B}^0 \rightarrow D^0\eta'$ | < 2.3 | < 0.029 | $\bar{B}^0 \rightarrow D^{*0}\eta'$ | < 2.3 | < 0.13 |
| $\bar{B}^0 \rightarrow D^0\rho^0$ | < 33.7 | < 0.060 | $\bar{B}^0 \rightarrow D^{*0}\rho^0$ | < 19.1 | < 0.12 |
| $\bar{B}^0 \rightarrow D^0\omega$ | < 13.0 | < 0.057 | $\bar{B}^0 \rightarrow D^{*0}\omega$ | < 11.8 | < 0.12 |
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