Search for $b \to u$ Transitions in Exclusive Hadronic B-Meson Decays

D. Bortoletto,[1] M. Goldberg,[1] N. Horwitz,[1] M. D. Mestayer,[1] G. C. Moneti,[1] V. Sharma,[1] I. P. J. Shipsey,[1] T. Skwarnicki,[1] S. E. Csorna,[2] T. Letson,[2] I. C. Brock,[3] T. Ferguson,[3] M. Artuso,[4] C. Bebek,[4] K. Berkelman,[4] E. Blucher,[4] J. Byrd,[4] D. G. Cassel,[4] E. Cheu,[4] D. M. Coffman,[4] G. Crawford,[4] R. DeSalvo,[4] J. W. DeWire,[4] P. S. Drell,[4] R. Ehrlich,[4] R. S. Galik,[4] B. Gittelman,[4] S. W. Gray,[4] A. M. Halling,[4] D. L. Hartill,[4] B. K. Heltsley,[4] J. Kandaswamy,[4] R. Kowalewski,[4] D. L. Kreinick,[4] Y. Kubota,[4] J. D. Lewis,[4] N. B. Mistry,[4] J. Mueller,[4] R. Namjoshi,[4] S. Nandi,[4] E. Nordberg,[4] C. O'Grady,[4] D. Peterson,[4] M. Pisharody,[4] D. Riley,[4] M. Sapper,[4] A. Silverman,[4] S. Stone,[4] H. Worden,[4] M. Worris,[4] A. J. Sadoff,[5] P. Avery,[6] D. Besson,[6] L. Garren,[6] J. Yelton,[6] T. Bowcock,[7] K. Kinoshita,[7] F. M. Pipkin,[7] M. Procario,[7] Richard Wilson,[7] J. Wolinksi,[7] D. Xiao,[7] P. Baringer,[8] P. Haas,[8] Ha Lam,[8] A. Jawahery,[9] C. H. Park,[9] D. Perticone,[10] R. Poling,[10] R. Fulton,[11] M. Hempstead,[11] T. Jensen,[11] D. R. Johnson,[11] H. Kagan,[11] R. Kass,[11] F. Morrow,[11] J. Whitmore,[11] W.-Y. Chen,[12] R. L. McIlwain,[12] D. H. Miller,[12] C. R. Ng,[12] E. I. Shibata,[12] W.-M. Yao,[12] E. H. Thorndike,[13] M. S. Alam,[14] N. Katayama,[14] I. J. Kim,[14] W. C. Li,[14] X. C. Lou,[14] and C. R. Sun[14]

[1]*Syracuse University, Syracuse, New York 13210*
[2]*Vanderbilt University, Nashville, Tennessee 37235*
[3]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*
[4]*Cornell University, Ithaca, New York 14853*
[5]*Ithaca College, Ithaca, New York 14850*
[6]*University of Florida, Gainesville, Florida 32611*
[7]*Harvard University, Cambridge, Massachusetts 02138*
[8]*University of Kansas, Lawrence, Kansas 66045*
[9]*University of Maryland, College Park, Maryland 20742*
[10]*University of Minnesota, Minneapolis, Minnesota 55455*
[11]*Ohio State University, Columbus, Ohio 43210*
[12]*Purdue University, West Lafayette, Indiana 47907*
[13]*University of Rochester, Rochester, New York 14627*
[14]*State University of New York at Albany, Albany, New York 12222*

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From a data sample of 242000 $B\bar{B}$ pairs collected with the CLEO detector at the $\Upsilon(4S)$ resonance, we set upper limits for the branching ratios for exclusive hadronic decays of B mesons arising from $b \to u$ transitions. Model-dependent limits for the ratio of the Kobayashi-Maskawa matrix elements V_{ub}/V_{cb} are presented.

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In the standard model[1] of electroweak interactions, b quarks can decay to either c or u quarks via the charged weak current. The decay amplitudes for these two channels are proportional to the Kobayashi-Maskawa (KM) matrix elements V_{cb} and V_{ub}, respectively. While many $b \to c$ transitions have been observed,[2] the evidence[3] for $b \to u$ transitions in B-meson decay is controversial.[4] However, a nonzero value of V_{ub} is needed in order to account for CP violation in the standard model. It is very important, therefore, to probe any channel which might lead to evidence for $b \to u$ transitions. These considerations motivated the search for $b \to u$ transitions in exclusive B-meson decays to two or three hadrons described in this paper.

The results are based on a data sample collected by the CLEO experiment at the Cornell Electron Storage Ring (CESR). The CLEO detector has been described in detail elsewhere.[5] Its performance for charged-particle detection has been recently improved by installing a new tracking system, consisting of a 51-layer drift chamber, a three-layer straw-tube vertex detector, and a middle ten-layer vertex chamber. The momentum resolution for charged particles achieved with this new configuration is $(\delta p/p)^2 = (0.23\% p)^2 + (0.7\%)^2$, with p expressed in GeV/c. The rms ionization (dE/dx) resolution of the central drift chamber is 6.5%. In this analysis, only data collected with the improved detector were employed. The integrated luminosity of the data sample is 212 pb^{-1} collected at the $\Upsilon(4S)$ and 101 pb^{-1} collected in the continuum just below the $B\bar{B}$ threshold. This corresponds to approximately 242000 $B\bar{B}$ events. We assume that the branching ratios of the $\Upsilon(4S)$ to charged- and neutral-B-meson pairs are 57% and 43%, respectively.[6] The large luminosity and improvements in detector performance result in substantial improvements in the upper limits for some decays previously investigated[6] and the possibility of extending the search to additional final states.

Exclusive two- or three-body channels containing only nonstrange and noncharmed hadrons were considered in this search. They are summarized in Table I. Observed particles were grouped into candidate hadronic resonances by requiring the invariant mass of the composite system to be within $\frac{3}{4}\Gamma$ of the resonance mass (Γ is the width of the resonance). Resonances were observed via the decays $\rho^0 \to \pi^+\pi^-$, $f_0 \to \pi^+\pi^-$, $f_2 \to \pi^+\pi^-$, $a_1^- \to \rho^0\pi^-$, $a_2^- \to \rho^0\pi^-$, $\Delta^0 \to p\pi^-$, $\Delta^{++} \to p\pi^+$, and their charge conjugates. In order to reduce the combinatorial backgrounds, the dE/dx of charged particles was required to be within 2 standard deviations of the ionization expected for the particle assignment. In addition, the total energy of the tracks in a B-meson candidate, E_{tot}, had to be within 2 standard deviations of the beam energy E_b. The energy resolution for each decay mode was determined by Monte Carlo simulation of the CLEO detector; the result ranged between 25 and 37 MeV for all the modes investigated. In addition, the angle θ_B between the beam axis and the total reconstructed momentum $\mathbf{p}_{tot}$ of the candidate B meson was required to satisfy the condition $|\cos\theta_B| < 0.8$. This cut is useful since B mesons produced in $\Upsilon(4S)$ decays have a p-wave angular distribution, proportional to $\sin^2\theta_B$. For the decay $B^- \to \rho^0\pi^-$ we used the fact that the ρ^0 is polarized and required $|\cos\theta_H| > 0.5$, where θ_H is the angle of the π^- relative to the boost direction in the ρ^0 rest frame.

For the B decay channels shown in Table I continuum $q\bar{q}$ events are the dominant background. The spatial distribution of the decay products of the two B's are not correlated. Therefore the angle between a chosen decay product of one B with respect to the direction of the other B is spherical. On the other hand, continuum events are jetlike and so the direction of each particle tends to be aligned along the event axis. We have exploited this difference in topology by determining the sphericity axis of the tracks in an event that were not included in a B-meson candidate, and calculating the angle θ_s between this axis and the direction of a selected particle in the B candidate. The distribution of $\cos\theta_s$ should be uniform for real B decays. The $\cos\theta_s$ distribution for continuum events containing $\bar{B}^0 \to \pi^+\pi^-$ candidates is shown in Fig. 1; the shape is similar for all other modes. We required $|\cos\theta_s| < 0.7$.

We calculated the invariant mass M of B-meson candidates using E_b instead of E_{tot}. This (beam-constrained) mass resolution is nearly an order of magnitude better than it would have been were E_{tot} used. If more than one combination of tracks in a given event satisfied the selection criteria discussed above and had $M > 5.2$ GeV/c, the candidate with E_{tot} closest to E_b was used. Yields were obtained by counting events with M within 5 MeV of the B mass for the $\Upsilon(4S)$ data sample and continuum sample. No net signal remained after subtracting the scaled continuum from the $\Upsilon(4S)$ yield. This is illustrated in Fig. 2, which shows the mass distributions for $\bar{B}^0 \to \pi^+\pi^-$ candidates. The detection efficiency for each decay mode was estimated from a Monte Carlo simulation of the response of the CLEO detector to $B\bar{B}$ events where one B decays into the mode of interest. Whenever possible, the correct angular distributions were generated; in cases where these are not uniquely determined, the decays were generated with an isotropic distribution. The resulting efficiencies, summarized in

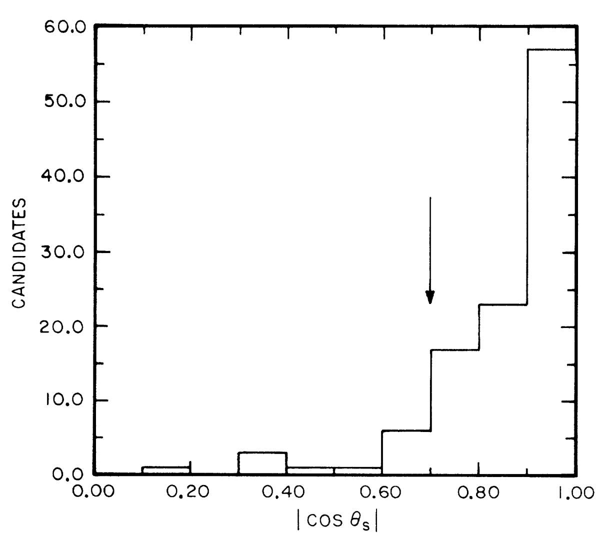

FIG. 1. $\cos\theta_s$ distribution for tracks in continuum events satisfying the other selection criteria $\bar{B}^0 \to \pi^+\pi^-$.

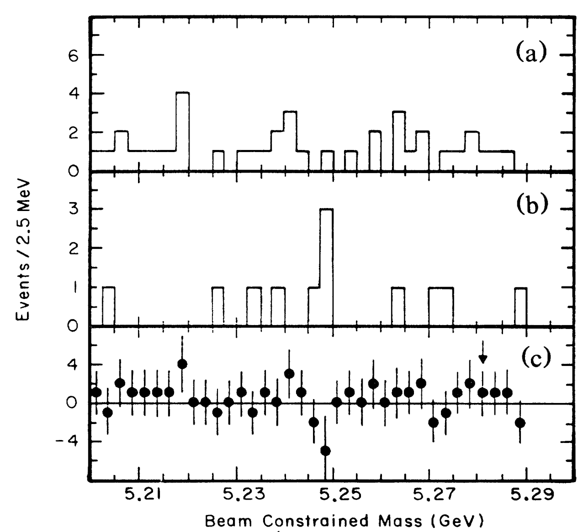

FIG. 2. The mass distributions for $\bar{B}^0 \to \pi^+\pi^-$ candidates: (a) at the $\Upsilon(4S)$; (b) in the continuum below the $\Upsilon(4S)$; and (c) the net distribution from $B\bar{B}$ events. The arrow indicates where a $\bar{B}^0$ signal should appear.

TABLE I. Upper limits (90% C.L.) for exclusive $b \to u$ decays. The upper limits for the branching ratios are for the modes indicated; the upper limits for the number of events are for the modes indicated plus their charge conjugate. The detection efficiencies include branching ratios for daughter decays.

Mode	Detection efficiency	Events	Upper limits Branching ratio (units of 10^{-4})	$\lvert V_{ub}/V_{cb} \rvert$
$\bar{B}^0 \to \pi^+\pi^-$	0.45	8.9	0.9	0.21
$\bar{B}^0 \to a_1^{\pm}\pi^{\mp}$	0.064	7.6	5.7	0.30
$\bar{B}^0 \to a_2^{\pm}\pi^{\mp}$	0.055	4.0	3.5	...
$\bar{B}^0 \to a_1^+ a_1^-$	0.017	11.4	32.2	0.66
$\bar{B}^0 \to \rho^0\rho^0$	0.13	9.3	3.4	...
$B^- \to f_0\pi^-$	0.12	3.9	1.2	0.57
$B^- \to f_2\pi^-$	0.12	7.0	2.1	...
$B^- \to \rho^0 a_1^-$	0.052	7.7	5.4	0.39
$B^- \to \rho^0 a_2^-$	0.035	6.1	6.3	...
$B^- \to \pi^-\pi^+\pi^-$	0.29	13.5	1.7	...
$B^- \to \rho^0\pi^-$	0.22	8.9	1.5	...
$\bar{B}^0 \to p\bar{p}$	0.45	3.9	0.4	...
$\bar{B}^0 \to \Delta^0\bar{\Delta}^0$	0.013	4.8	17.6	...
$\bar{B}^0 \to \Delta^{++}\bar{\Delta}^{--}$	0.12	3.2	1.3	...
$\bar{B}^0 \to \Delta^{++}\bar{\Delta}^{--}$	0.12	3.2	1.3	...
$B^- \to \Delta^0\bar{p}$	0.083	7.3	3.3	...
$B^- \to \bar{\Delta}^{--}p$	0.25	8.3	1.3	...

Table I, include all intermediate branching ratios in the decay chains.[7] The corresponding 90%-confidence-level upper limits for the branching fractions are also reported in Table I.

The decay modes investigated have partial widths which are proportional to $\lvert V_{ub} \rvert^2$ through a model-dependent coefficient which contains the details of the wave functions and form factors which relate quark dynamics to hadron dynamics. In order to reduce the sensitivity to the uncertainties in the theoretical calculation, we used

$$\alpha_i \left| \frac{V_{ub}}{V_{bc}} \right|^2 = \frac{B(B \to X_i Y_i)}{B(B \to D^{*+}\pi^-)}, \tag{1}$$

to calculate $\lvert V_{ub}/V_{cb} \rvert$ from the results for a particular channel i.

The ratio on the right-hand side was calculated from the upper limits reported in this paper and our unpublished measurement,[8]

$$B(\bar{B}^0 \to D^{*+}\pi^-) = (0.46 \pm 0.12 \pm 0.1)\% . \tag{2}$$

The values of α_i were derived from the model of Bauer, Stech, and Wirbel.[9] This model has been applied with reasonable success to describe D-meson phenomenology[10] and should be reliable also for B decays, especially for two-body decays involving at least one heavy meson and no baryons in the final state.[11] Predictions from this model for specific branching ratios were used in the calculation for the channels for which they were available and gave meaningful limits for $\lvert V_{ub}/V_{cb} \rvert$. The upper limits obtained complement limits from the end point of the lepton spectrum,[12] since they have different systematic uncertainties. In particular, the limit obtained from $\bar{B}^0 \to \pi^+\pi^-$ is almost as stringent as the one from inclusive semileptonic B decays.

In conclusion, only upper limits for $b \to u$ transitions in exclusive hadronic B decays have been found in this extensive search. Although the value of $\lvert V_{ub}/V_{cb} \rvert$ has yet to be measured, the consistent upper limits collectively reinforce the conclusion that this ratio is small.

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