Search for the Charmless Decays $B \rightarrow p\bar{p}\pi$ and $p\bar{p}\pi\pi$

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From a sample of 332 000 $B\bar{B}$ pairs produced in e^+e^- annihilations at the $\Upsilon(4S)$ resonance we derive upper limits for the branching fractions for the decays $B^- \rightarrow p\bar{p}\pi^-$ and $\bar{B}^0 \rightarrow p\bar{p}\pi^+\pi^-$ in several final-state momentum configurations. The results do not confirm recently reported observations of charmless B decays.

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In the standard model,[1] the weak decay of the b quark proceeds through the charged-current coupling to the c quark or to the u quark. The relative amplitudes are proportional to the Cabibbo-Kobayashi-Maskawa matrix[2] elements V_{cb} and V_{ub}. So far, the only positive indication of charmless B decay is the reported observation by the ARGUS collaboration[3] of the decays $B^- \rightarrow p\bar{p}\pi^-$ and $\bar{B}^0 \rightarrow p\bar{p}\pi^+\pi^-$ at the branching-ratio level of 5×10^{-4} each. In this Letter we report upper limits for these branching ratios, measured by the CLEO collaboration at the Cornell Electron Storage Ring (CESR), using a larger data sample and a recently improved detector.

The CLEO detector has been described elsewhere.[4] Until recently the charged-particle tracking was accomplished with 27 cylindrical layers of drift-chamber cells in a 1-T magnetic field. The rms momentum resolution was $(\delta p/p)^2=(0.006)^2+(0.007p)^2$ (with p in GeV/c), and the rms resolution in track ionization (used for particle identification) was 11%. A new drift-chamber system was recently installed with 64 layers of tracking, resulting in a momentum resolution, $(\delta p/p)^2=(0.007)^2+(0.0023p)^2$, and an rms resolution in ionization of 6.5%.[5]

With the improved detector, CLEO completed an extensive data run (the "second run") with 212 pb^{-1} of integrated luminosity collected on the $\Upsilon(4S)$ resonance (242 000 $B\bar{B}$ pairs produced) and 100 pb^{-1} in the continuum below $B\bar{B}$ threshold. This supplements the "first run" of 78 pb^{-1} of resonance data (90 000 $B\bar{B}$) and 40 pb^{-1} of continuum data with the earlier detector configuration.[6] Since there are differences in resolution for the two data sets, we have analyzed them independently before combining results.

In order to distinguish correctly reconstructed rare B decays from the large background of chance combinations of particles, either in $B\bar{B}$ events with other decay modes or in non-$B\bar{B}$ continuum events, we use kinematic constraints, continuum suppression by topological cuts, and particle identification by ionization. There are two kinematic constraints, energy and momentum conservation. Since the energy of each B is the beam energy, we require that ΔE, the difference between the beam energy and the sum of the measured energies of the candidate decay products, be less than 50 MeV (65 MeV for the first run) in absolute value. This balance is sensitive to the correctness of the mass assignment for each of the presumed decay products. The rms resolution in ΔE is 25 to 30 MeV (35 to 40 MeV in the first run). Since we calculate the mass of the candidate B from the beam-constrained formula, $M^2 = E_{\text{beam}}^2 - (\sum \mathbf{p}_{\text{obs}})^2$, the momentum constraint is equivalent to the requirement that the correctly reconstructed candidates show a narrow peaking at the known B-meson mass. A constrained kinematic fit that adjusts the measured momenta to satisfy energy conservation produces the same results. Note that the beam-constrained mass is not sensitive to the mass assignments of the decay products. The expected rms mass resolution is 2.6 MeV (2.9 MeV in the first run). The direction of the B momentum is not constrained, but should be distributed as $\sin^2\theta_B$ with respect to the beam axis. To suppress combinatoric background, which tends to be isotropic in reconstructed B direction, we require $|\cos\theta_B| < 0.8$, which results in a 5.6% loss in efficiency for real B decays.

Particles in non-$B\bar{B}$ continuum events tend to align close to the quark-antiquark direction, while any axis calculated for the products of a candidate B decay should be uncorrelated with the axis for the rest of the particles in the same event. For each event containing a candidate decay, we therefore compute two sphericity axes, one for the decay and the other for all remaining charged particles, and require that the angle α between the two axes satisfy $|\cos\alpha| < 0.7$.

We have checked the mass resolution and efficiency for B decay reconstruction using the charmed modes $B^- \rightarrow D^0\pi^- \rightarrow (K^-\pi^+)\pi^-$ and $B^- \rightarrow \psi K^- \rightarrow (e^+e^-)K^-$ or $(\mu^+\mu^-)K^-$. With the kinematic and topological cuts just described (plus the requirement that the $K\pi$ mass be close to the D mass or that the dilepton mass be near the ψ), clear signals at the expected rates are evident in the invariant-mass distributions. The product branching ratios for these two-step modes are about 2×10^{-4} and 1×10^{-4}, respectively.

For the decay modes $p\bar{p}\pi$ and $p\bar{p}\pi\pi$ we require that the π candidate have ionization within 2 standard deviations of the expected value, and that the combined χ^2 for the proton and antiproton ionization be less than four. We determine the expected ionization distributions for π and p using secondaries from reconstructed Λ and K_S decays. Tracks with poor dE/dx measurements, usually because of steep dip angles, are rejected. We also require that none of the candidate decay products be identified as electrons or muons. If, after all data cuts, an event has more than one candidate decay with mass above 5.2 GeV, we accept only the one that best satisfies the energy constraint, for each of the two modes separately. The fraction of multiple solutions is 8% and 19% for $p\bar{p}\pi$ and $p\bar{p}\pi\pi$, respectively.

The invariant-mass spectra for the $p\bar{p}\pi$ and $p\bar{p}\pi\pi$ combinations satisfying the above cuts show no peaking at the B mass in either data set. To derive model-independent upper limits on the branching ratios, we also make use of the data from the running below $B\bar{B}$ threshold, scaled to the same integrated luminosity and beam energy. We count the net number of events [$\Upsilon(4S)$ resonance data minus scaled continuum data] within 5 MeV of the B mass, then divide by the total number of produced B's of the appropriate charge [assuming $B^0\bar{B}^0/(B^+B^- + B^0\bar{B}^0) = 0.43$], and by the detection efficiency. The fraction of multiple solutions is 8% and 19% for $p\bar{p}\pi$ and $p\bar{p}\pi\pi$, respectively. Note that in addition to any signal, this calculation includes background from other B and $\bar{B}$ decay modes incorrectly reconstructed as $p\bar{p}\pi$ or $p\bar{p}\pi\pi$. We form weighted averages of the results for the two runs, but because of the smaller event sample and larger background (due to poorer resolution in ΔE and dE/dx) the first run has less weight. The resulting upper limits are given in Table I.

The sensitivity of the search is limited by the fluctuations in the background, mainly from the non-$B\bar{B}$ events. It is conceivable that there are configurations of the final-state momentum vectors that are favored in the decay or disfavored in the background, so that a biased search may be more successful. In the following we list several kinematic regions and determine the partial branching ratio for decay into each selected region.

(1) Proton or antiproton at low momentum.— In addition to the criteria discussed above, we require that either the p or $\bar{p}$ have a momentum below 1.1 GeV/c. This is motivated by the inclusive baryon momentum spec-

TABLE I. 90%-confidence-level upper limits for the branching ratios, in units of 10^{-4}, from the various searches described in the text, combining the two data samples, and averaging charge-conjugate modes. The limits are obtained from the number of candidates within 5 MeV of the B mass in the data on the $\Upsilon(4S)$ minus scaled data from below $B\bar{B}$ threshold. The "Δ" and "N^*" refer to $p\pi$ mass ranges defined in the text.

	$B^- \rightarrow p\bar{p}\pi^-$	$\bar{B}^0 \rightarrow p\bar{p}\pi^+\pi^-$
Unbiased search	3.0	11.9
p or $\bar{p}$ at low momentum	2.8	8.4
Collinear p and $\bar{p}$	1.6	3.3
$\bar{p}\Delta^0$, $\Delta^0\bar{\Delta}^0$	1.3	1.2
$p\bar{\Delta}^{--}$, $\Delta^{++}\bar{\Delta}^{--}$	1.2	1.3
$\bar{p}N^{*0}$, $N^{*0}\bar{N}^{*0}$	1.1	2.5
$p\bar{N}^{*--}$, $N^{*++}\bar{N}^{*--}$	1.7	1.7
$\Delta^0\bar{N}^{*0}$ or $N^{*0}\bar{\Delta}^0$		2.8
$\Delta^{++}\bar{N}^{*--}$ or $N^{*++}\bar{\Delta}^{--}$		2.4

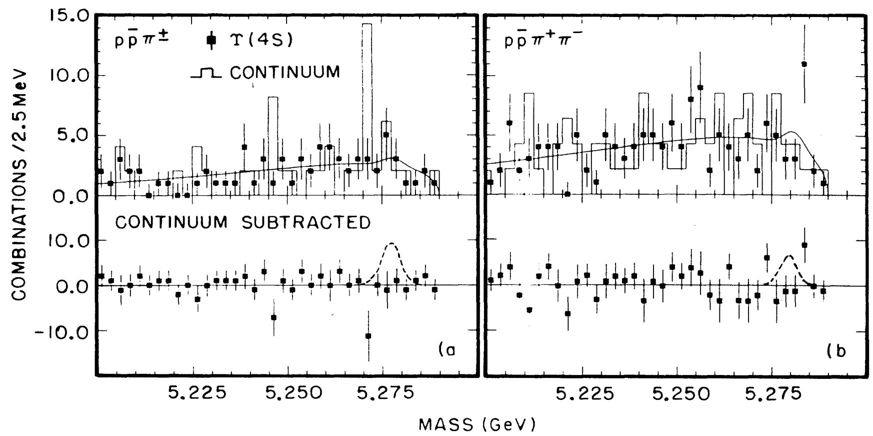

FIG. 1. Distributions in reconstructed mass for (a) $B^- \to p\bar{p}\pi^-$ and (b) $\bar{B}^0 \to p\bar{p}\pi^+\pi^-$ candidates from the collinear search, using the 1987 data sample: (top) data taken on the $\Upsilon(4S)$ resonance (points), scaled data taken below $B\bar{B}$ threshold (histogram), with the fit to the signal and background function described in the text (curve); (bottom) the difference between the $\Upsilon(4S)$ data and the below-threshold data (points), and the signal expected from the ARGUS branching ratio (dashed curve).

trum in B decays,[7] which is consistent with all baryon momenta being below 1 GeV/c, and by the fact that low-momentum protons can be unambiguously identified by dE/dx. This momentum requirement is satisfied for 34% (64%) of the total $p\bar{p}\pi$ ($p\bar{p}\pi\pi$) phase space.

(2) Nucleon-isobar submasses.— For this analysis we define a "Δ" as any $p\pi$ combination with invariant mass below 1.4 GeV, and an "N^*" as any $p\pi$ with mass between 1.4 and 1.8 GeV. Including the various charge and mass combinations, this corresponds to ten separate searches.

(3) Almost collinear p and $\bar{p}$.— Following the original search by ARGUS[3] we require that $\cos\beta < -0.98$, where β is the angle between the p and $\bar{p}$ momenta. For the $p\bar{p}\pi$ ($p\bar{p}\pi\pi$) mode this cut includes a 10% (4%) fraction of the total phase space.

No clear signal is seen in any of the searches. Sample mass distributions (for the collinear searches) are shown in Fig. 1. As in the unbiased searches we calculate in each case a model-independent upper limit (Table I) from the difference between the mass distribution measured on the $\Upsilon(4S)$ resonance and the scaled distribution measured in the continuum below $B\bar{B}$ threshold, corrected for detection efficiency. Each branching-ratio upper limit applies only for the selected kinematic region, with no assumption about how decays are distributed among regions.

In order to make a closer comparison to the ARGUS results for the collinear $p,\bar{p}$ searches, we also give upper limits in Table II using the model-dependent ARGUS technique.[3] That is, we fit the mass spectrum taken on the $\Upsilon(4S)$ resonance by a background of the assumed form

$$dN/dM = AM\sqrt{x}\exp(\alpha x),$$

where $x = 1 - M^2/E^2_{\text{beam}}$ and α is adjustable, plus a Gaussian at the B mass with the expected resolution (the continuous curves in Fig. 1). Note that in this method of extracting the signal, the background from incorrectly reconstructed $B\bar{B}$ events is also subtracted, provided it follows the assumed mass distribution. For comparison, Table II shows the ARGUS results[3] in their published form and also scaled by a factor of 0.7, their assumption for the fraction of decays satisfying the $p\bar{p}$ collinearity cut. This is done in order to compare more directly with our results for the partial branching fraction for decay into the momentum region allowed by the cut. In this scaled comparison we have used the ARGUS systematic error without the contribution from their acceptance assumption.[8] Our upper limits (Table II) are well below the scaled ARGUS result. Variations of our analysis procedure with different cuts produce similar limits.[9] Expressed as branching-ratio measurements for collinear p and $\bar{p}$ rather than upper limits, our results are $(0.4 \pm 0.6) \times 10^{-4}$ for $p\bar{p}\pi$ and $(1.0 \pm 1.3) \times 10^{-4}$ for $p\bar{p}\pi\pi$, assuming the ARGUS background formula. On

TABLE II. CLEO and ARGUS branching-ratio results (in units of 10^{-4}) for the $p\bar{p}\pi$ and $p\bar{p}\pi\pi$ modes with p and $\bar{p}$ approximately collinear. The branching ratios and 90%-confidence-level upper limits are calculated from a least-squares fit of the mass distribution (see text). To convert to branching ratios for the collinear $p,\bar{p}$ kinematic region we have scaled the ARGUS results by a factor of 0.7 (see text).

	$B^- \to p\bar{p}\pi^-$	$\bar{B}^0 \to p\bar{p}\pi^+\pi^-$
CLEO first run	< 4.5	< 5.6
second run	< 1.4	< 3.3
combined	< 1.4	< 2.9
ARGUS (Ref. 3)	$5.2 \pm 1.4 \pm 1.9$	$6.0 \pm 2.0 \pm 2.2$
scaled	$3.7 \pm 1.0 \pm 0.9$	$4.3 \pm 1.4 \pm 1.0$

purely statistical grounds the difference between the CLEO and scaled ARGUS measurements for each of these two branching ratios is 2.8 and 1.7, respectively, times the standard deviation in the difference.

In conclusion, we see no evidence for charmless B decays in the $p\bar{p}\pi$ and $p\bar{p}\pi\pi$ channels. We therefore have no experimental lower limit on $|V_{ub}/V_{cb}|$. Without a reliable model for B decays to baryons we cannot extract an upper limit on V_{ub} from our data.

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