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Observation of the decay $B^+ \to \omega h^+$

CLEO Collaboration

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Abstract

We have searched for the decay of charged B mesons to the exclusive charmless state ωh^+, where h^+ can be either a pion or a kaon. We observed a signal, leading to a branching ratio measurement of $(2.8 \pm 1.0 \pm 0.5) \times 10^{-5}$, where the first error is statistical and the second systematic. The probability for the observed events to be a statistical fluctuation of the background is 1.2×10^{-4}, corresponding to 3.7 standard deviations. We also set an upper limit of 3.0×10^{-5} at the 90% confidence level for the decay $B^+ \to \eta h^+$.

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I. INTRODUCTION

The understanding of the relative contribution of second order hadronic penguin diagrams and tree level spectator diagrams in charmless hadronic decays of B mesons is an important step in the investigation of CP violation in the B meson system. For some exclusive final states one type of diagram is expected to dominate, but in others, such as $B^0 \to \pi^+\pi^-$, interference between the diagrams can complicate the extraction of meaningful quantities from an experimental result [1]. The first experimental observation of B decays to exclusive charmless hadron states was the sum of the decays $B^0 \to \pi^+\pi^-$ and $B^0 \to K^+\pi^-$ [2,3]. Recently, there has been confirmation of this result by the DELPHI collaboration [4]. They also claimed evidence for the sum of the decays $B^+ \to \rho^0\pi^+$ and $B^+ \to K^{*0}\pi^+$, although fairly stringent upper limits already exist for these modes [3,5]. The measurement of other such decays could help in refining phenomenological models used to make predictions. This paper reports on a search for the decays $B^+ \to \omega h^+$ and $B^+ \to \eta h^+$, where h^+ can be either a pion or a kaon [6]. Theoretical predictions for these decays vary from 3×10^{-7} to 1.1×10^{-5} [7–10]. Previous experimental upper limits for these modes are in the 10^{-4} range [11].

II. DATA SAMPLE AND EVENT SELECTION

This analysis made use of data collected with the CLEO-II detector at the Cornell Electron Storage Ring (CESR). The data sample corresponds to an integrated luminosity of 3.11 fb^{-1} taken on the $\Upsilon(4S)$ resonance and 1.61 fb^{-1} taken slightly below. The on resonance data sample contains 3.3×10^6 $B\overline{B}$ pairs. The CLEO-II detector has been described in detail elsewhere [12]. This analysis primarily makes use of the tracking system to measure the momentum and energy loss rate (dE/dx) of charged particles and of the CsI crystal calorimeter to measure the energy of photons.

In order to minimize bias, all cuts used in the analysis were set either based on experience from similar analyses or by using data samples not including any potential candidate events. The ω or η mesons in the final state were reconstructed from their $\pi^+\pi^-\pi^0$ decay channel. B^+ meson candidates were formed by combining the reconstructed ω or η with a charged hadron. The cuts used to select charged tracks and π^0's were the same as the ones described in reference [3]. A minimum of five charged tracks in total was required for each event. The measured dE/dx of charged pions from the decay of the ω or η was required to be within 3σ of the expected value. There were no dE/dx requirements for the other charged particle forming the B candidate. Photon pairs forming a π^0 were required to have a reconstructed mass within 2σ of the nominal π^0 mass. The π^0 momentum was obtained by kinematically fitting the photon momenta with the π^0 mass constrained to the nominal value. To reduce combinatoric background, the momenta of π^0's and charged particles used to form a candidate B meson had to be greater than 175 MeV/c.

The reconstructed mass of the ω meson was required to be within 20 MeV/c^2 of the nominal mass; for the η, the value was 10 MeV/c^2. Two event shape cuts were used to reject background from continuum quark production. First, the angle between the thrust axis of the charged particles and photons forming the candidate B and the thrust axis of the remainder of the event, $\theta_{\rm thr}$, was required to satisfy $|\cos\theta_{\rm thr}| < 0.7$. For this variable, continuum background is strongly peaked near 1.0 and signal is approximately flat. Second, a Fisher discriminant was formed with 11 variables : the momentum scalar sum of charged particles and photons in nine cones of increasing polar angle around the thrust axis of the candidate, the angle between the thrust axis of the candidate and the beam axis, and the angle between the candidate B direction and the beam axis. This discriminant was described in detail in reference [3]. The cut position was set at 0.5, where it rejects approximately 60% of the background while keeping 77% of the signal. Two additional cuts were used for the $B^+ \to \omega h^+$ mode. The square of the decay amplitude of the ω, normalized to be distributed between 0 and 1, had to be greater than 0.15. This cut selected the central region of the Dalitz plot where ω decays are enhanced, and minimized any isotropic background. Finally, the angle θ_h between the normal to the ω decay plane and the direction of the parent B in the rest frame of the ω is expected to have a $\cos^2\theta_h$ distribution for a pseudoscalar meson decaying to a pseudoscalar and a vector meson. Since the background is nearly flat, we required $|\cos\theta_h| > 0.5$.

Final candidate selection was based on constraining the energy and mass of the candidate B. For the energy, we defined the quantity $\Delta E = E_1 + E_2 - E_b$, where E_1 and E_2 are the energy of the two daughter particles and E_b is the beam energy. ΔE should peak at 0 for B mesons. In the analysis, the energy of each charged particle was calculated assuming it to be a pion. If h^+ were actually a kaon, the ΔE distribution would be shifted down by about 43 MeV. The mass of the candidate was defined as $M_B = \sqrt{E_b^2 - p_B^2}$, where p_B is the measured momentum of the candidate. Using the beam energy instead of the measured energy of the B candidate improved the mass resolution by about one order of magnitude. The cut positions were determined using a Monte Carlo simulation of signal events. The measured resolutions were 30 MeV and 3 MeV/c^2 for ΔE and M_B respectively. Candidates were selected in the region within 6 MeV/c^2 of the nominal B meson mass and $-103 < \Delta E < 60$ MeV. The asymmetry in the latter takes into account the shift in ΔE for kaons assumed to be pions.

III. BACKGROUND ESTIMATE

The primary source of background in this analysis was continuum quark production. The estimation of the contribution from this source was based on the ratio $\mathcal{A}$, where $\mathcal{A}$ was defined as the number of events in the ΔE—M_B signal region divided by the number of events in a "grand sideband" region defined by $|\Delta E| < 200$ MeV and $5.2 < M_B < 5.27$ GeV/c^2. The ratio was determined from a sample of Monte Carlo simulated continuum events about twice as large as the Υ(4S) resonance data sample. To further increase the statistical accuracy of the measurement, cuts not affecting the ratio were released. The accuracy of the Monte Carlo simulation was verified by comparing with the data sample taken below the Υ(4S) resonance. The measured value of $\mathcal{A}$ from this analysis was $(4.4 \pm 0.6)\%$, compared with $(4.6 \pm 1.1)\%$ for the off resonance data sample. The background estimate for each mode studied was obtained by multiplying the measured ratio $\mathcal{A}$ by the number of events observed in the grand sideband for the on resonance data sample.

Two other sources of background were studied. Generic $b \to c$ events were studied with a Monte Carlo generated sample approximately four times as large as the data sample. The contribution from this source was found to be negligible. The possibility of background originating from the as yet to be observed non-resonant decay $B^+ \to \pi^+\pi^-\pi^0 h^+$ was also considered. The study made use of real data and of a Monte Carlo generated sample at least 15 times as large as what can be expected in the data sample. Both approaches showed that the total contribution to the final result from this source was also negligible. Table I gives the number of expected background events for each mode.

IV. RESULTS

Table I also indicates the number of events observed after all cuts. Figures 1 and 2 show the ΔE versus M_B distributions of events after all other cuts for $B^+ \to \omega h^+$ and $B^+ \to \eta h^+$, respectively. The box indicates the signal region. For $B^+ \to \omega h^+$ there are 10 events in the box, significantly in excess of the estimated two from continuum background. For $B^+ \to \eta h^+$, no events were observed. Given the value of $\mathcal{A}$ used to estimate continuum background, the binomial probability of observing 10 events or more in the $B^+ \to \omega h^+$ signal region is 1.2×10^{-4}. This corresponds to 3.7 standard deviations for a gaussian distribution. Figures 3 and 4 show the projections of ΔE and M_B respectively. The distribution of $M - M_\omega$, where M is the reconstructed $\pi^+\pi^-\pi^0$ invariant mass and M_ω is the nominal ω mass, is shown in figure 5a for events in the ΔE—M_B signal region after all other analysis cuts except the ω mass cut. Figure 5b shows the same distribution for the off resonance data sample, which has about half the luminosity of the on resonance sample. This indicates that the events outside the ω mass cut in figure 5a are consistent with continuum background.

The efficiency for all cuts was measured using a Monte Carlo simulation of signal events that included all experimental resolutions and other detector effects. The systematic uncertainties for the various cuts were mostly based on measurements obtained with real data for earlier analyses [3]. The dominant uncertainty was due to the background estimation. The ratio $\mathcal{A}$ was conservatively allowed to vary by 30%, leading to an uncertainty of 7–9% in the final results. With an upwards variation of the background estimate by this amount, the $B^+ \to \omega h^+$ signal has a 3.1 standard deviation significance. Table I gives the measured efficiency for each mode, including the total systematic uncertainty of 19%.

Table II gives the branching ratio values obtained from this analysis. For $B^+ \to \omega h^+$ the branching ratio was calculated using the observed excess of events above background. The first error is statistical and the second systematic. For $B^+ \to \eta h^+$, an upper limit of 3.0×10^{-5} was set at the 90% confidence level. To take into account the systematic uncertainty, the efficiency was reduced by the estimated uncertainty when calculating the upper limit.

V. CONCLUSION

We have observed the decay $B^+ \to \omega h^+$, where h^+ is either a pion or a kaon. The measured branching ratio is $(2.8 \pm 1.0 \pm 0.5) \times 10^{-5}$, where the first error is statistical and the second systematic. The probability that the observed signal resulted from a background fluctuation is 1.2×10^{-4}. A more detailed analysis is currently under way using particle identification information in an attempt to extract branching ratios for the individual modes $B^+ \to \omega\pi^+$ and $B^+ \to \omega K^+$.

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TABLE I. Final results for each mode studied, including the background estimate and the efficiency. The efficiency includes the branching ratio of ω or η to $\pi^+\pi^-\pi^0$. The uncertainty on the background is statistical only. The uncertainty on the efficiency is the overall systematic uncertainty.

Mode	Background	Efficiency (%)	Events observed
ωh^+	2.0 ± 0.3	8.5 ± 1.6	10
ηh^+	0.7 ± 0.2	2.8 ± 0.5	0

TABLE II. Branching ratio measurements for the modes investigated. For $B^+ \to \omega h^+$ the first error is statistical and the second systematic.

Mode	Branching ratio ($\times 10^{-5}$)
$B^+ \to \omega h^+$	$2.8 \pm 1.0 \pm 0.5$
$B^+ \to \eta h^+$	< 3.0 (90% C.L.)

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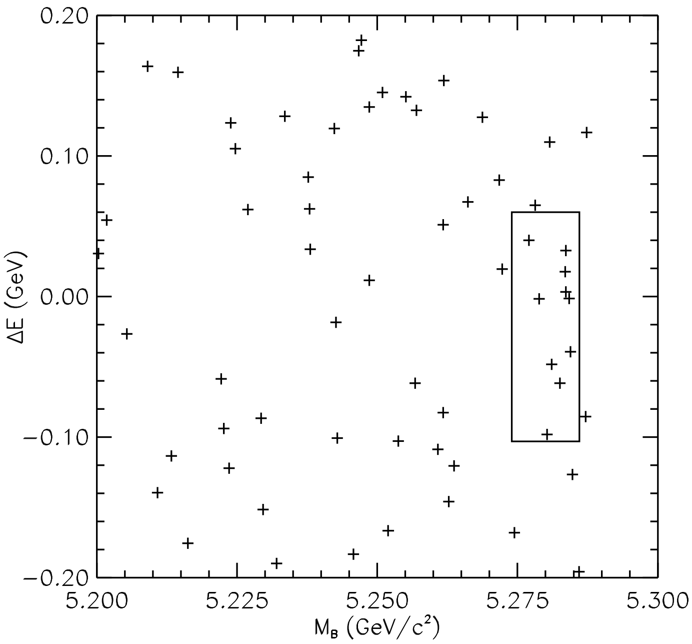

FIG. 1. ΔE versus M_B distribution for $B^+ \to \omega h^+$ after all other cuts. The box indicates the signal region.

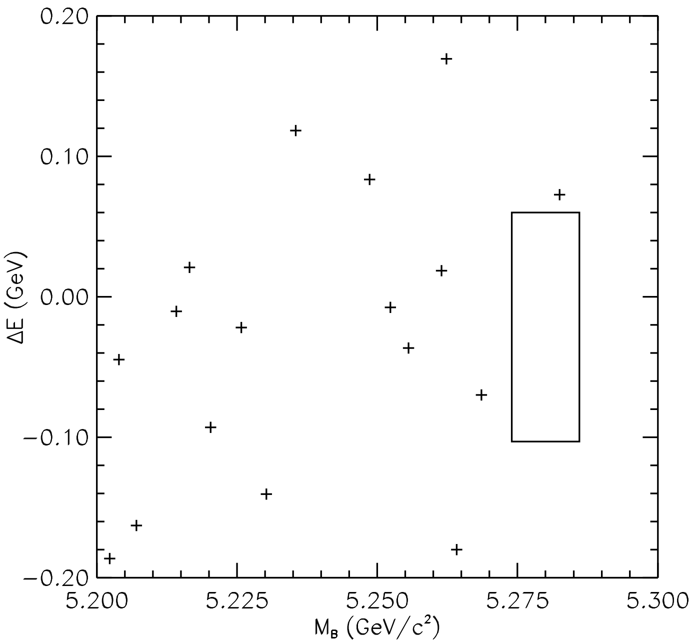

FIG. 2. ΔE versus M_B distribution for $B^+ \to \eta h^+$ after all other cuts. The box indicates the signal region.

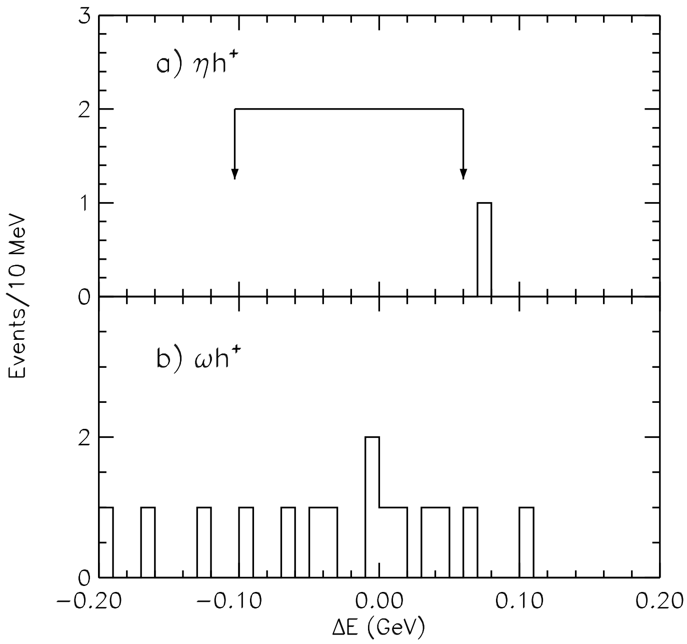

FIG. 3. ΔE projection for a) $B^+ \to \eta h^+$ and b) $B^+ \to \omega h^+$ after all other cuts, including the M_B cut. The arrows indicate the signal region.

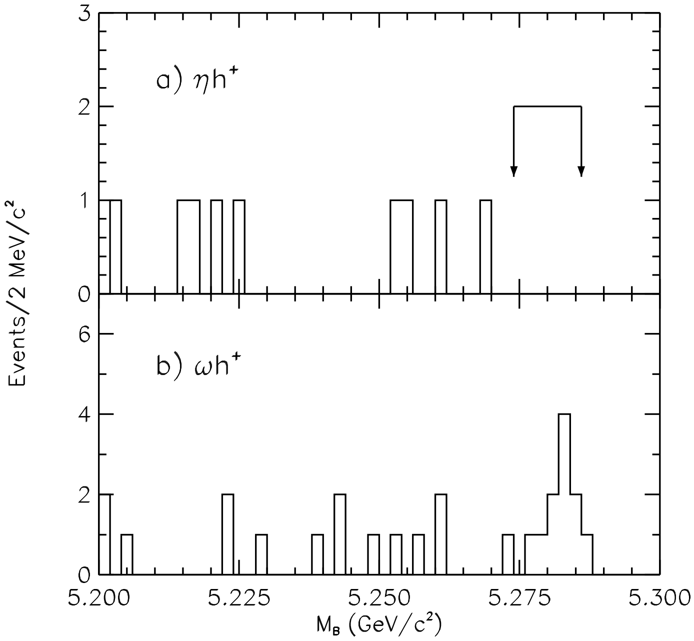

FIG. 4. M_B projection for a) $B^+ \to \eta h^+$ and b) $B^+ \to \omega h^+$ after all other cuts, including the ΔE cut. The arrows indicate the signal region.

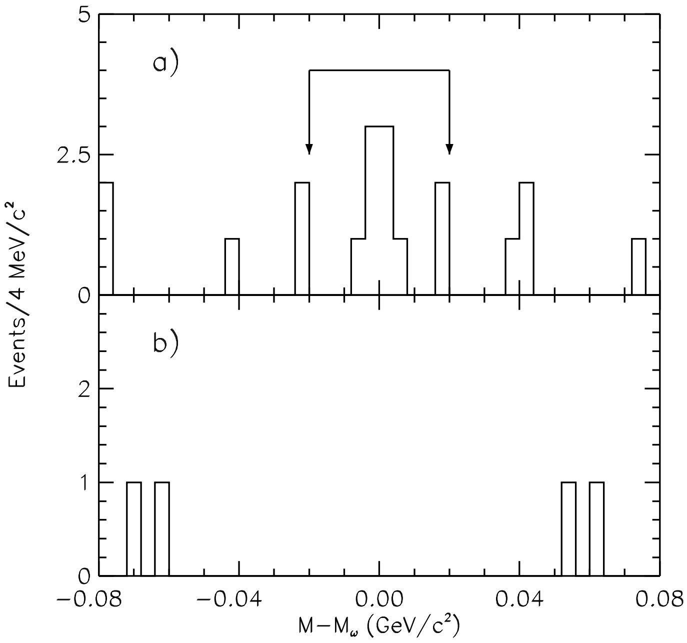

FIG. 5. Reconstructed $\pi^+\pi^-\pi^0$ mass minus nominal ω mass for $B^+ \to \omega h^+$ after all other cuts for the a) on resonance and b) off resonance data samples. The arrows indicate the ω mass cut signal region