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Study of B -> psi rho

CLEO Collaboration

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Study of $B \to \psi\rho$

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Abstract

We have studied the Cabibbo suppressed and color suppressed two body decays B to $\psi\rho$ ($\psi\omega$ or ψa_1). Using a data sample of 5.12 million B decays collected with the CLEO II detector we find the 90% confidence level upper limits for branching fractions of $B^0 \to \psi\rho^0$ and $B^0 \to \psi\omega$ to be $2.5 \cdot 10^{-4}$ and $2.7 \cdot 10^{-4}$, respectively. We also update the branching fraction $B^- \to \psi\pi^-$ to be $(5.6 \pm 2.7) \cdot 10^{-5}$.

Introduction

Recently, the observation of the decay $B^- \to \psi\pi^-$ has been reported by CLEO [1] and later by CDF [2]. Here we extend the study of Cabibbo suppressed and color suppressed B decays to ψH_d final states, where H_d is a ρ, ω, or a_1 meson. If two body decays of B mesons to final states with charmonium are governed mainly by the color suppressed spectator diagram shown in Fig. 1(a), we expect the ratio of branching fractions to be:

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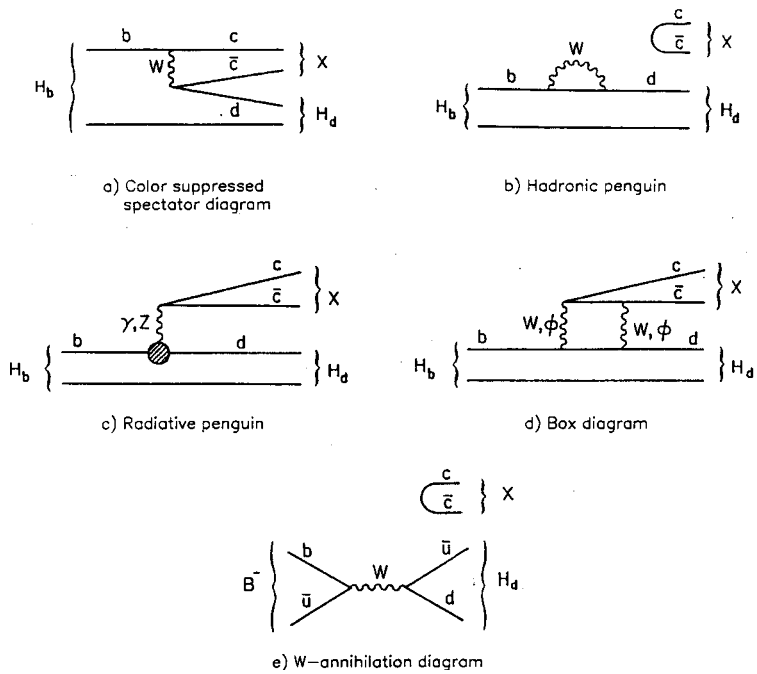

FIG. 1. Diagrams contributing to $B^0 \to \psi\rho^0$ decay. $\mathrm{H_b}$, $\mathrm{H_d}$, and X indicate respectively, b flavored hadrons, d flavored hadrons and charmonium mesons, while ϕ indicates a charged Higgs boson.

$$\frac{\mathcal{B}(B \to \psi H_d)}{\mathcal{B}(B \to \psi H_s)} \approx \mid V_{cd}/V_{cs} \mid^2 \quad (\times 0.5 \text{ for the neutral modes}). \tag{1}$$

Because of the large Cabibbo suppression combined with the color suppression in the spectator $b \to c\bar{c}d$ decay process, interference with rare or exotic processes (shown in Fig. 1(b-e)) could be significant. In particular, the interference could lead to observable CP violation asymmetries in charged B decay modes at the few percent level [3]. In addition, the measurements of the branching ratios for $B \to \psi H_d$ could probe the validity of some exotic models. For example, a model proposed by Gronau and Wakaizumi [4], based on the extension of the gauge group to $SU(2)_L \times SU(2)_R \times U(1)$, has been shown to imply [5]: $(b \to c\bar{c}d)/(b \to c\bar{c}s) = \mathcal{O}(10^{-7})$, which is much smaller than the Standard Model prediction given by Eq.(1).

Data sample and event selection

The data sample used in this analysis was collected with the CLEO II detector at the Cornell Electron Storage Ring. The integrated luminosity is 2.39 fb^{-1} at the $\Upsilon(4S)$ resonance (corresponding to 5.12±0.09 million B mesons) and 1.13 fb^{-1} (off-resonance) at energies just below the $B\bar{B}$ threshold.

A detailed description of the CLEO II detector has been given elsewhere [6]. The components of the detector most relevant to this analysis are the charged particle tracking, the CsI electromagnetic calorimeter, and the muon counters. The tracking system comprises a set of precision drift chambers totaling 67 layers inside a 1.5T solenoidal magnet. It measures both momentum and specific ionization (dE/dx) of charged particles.

The analysis technique is similar to the one used in Ref. [1]. Charged pions are identified as well reconstructed tracks that have dE/dx consistent within 3 standard deviations with that expected for pions. Candidate π^0 mesons are selected by calculating the invariant mass of photon pairs detected in the calorimeter and retaining those with an invariant mass within 2.5 standard deviations of the known π^0 mass. Electron candidates are identified by their energy deposition in the calorimeter, which must equal their measured momentum, and their dE/dx, which must be consistent with that expected for electrons. Muon candidates are required to penetrate the muon detectors to a depth of at least 3 nuclear interaction lengths.

ψ mesons are detected in both their di-electron and di-muon decay channels. ψ candidates are selected by requiring that the difference (Δm_ψ) between the dilepton invariant mass and the known ψ mass be within the intervals -30 MeV $< \Delta m_\psi <$ 30 MeV and -90 MeV $< \Delta m_\psi <$ 30 MeV for di-muons and di-electrons, respectively. The asymmetric interval for the di-electron channel is chosen because of the tail in the di-electron invariant mass distribution resulting from final state radiation and energy losses in the detector materials [1,7]. The lepton momenta are then kinematically fitted by constraining the dilepton invariant mass to the known ψ mass. The fitting procedure improves the overall energy resolution for B mesons by a factor of two.

The ρ, ω, and a_1 candidates are selected using the $\pi\pi$, $\pi^+\pi^-\pi^0$, and $\rho\pi$ decay channels respectively. The difference between the mass reconstructed from the candidate daughter particles and the nominal mass of the resonance is required to be less than 150 MeV, 20 MeV, and 200 MeV for ρ, ω, and a_1 respectively.

We select events with a spherical shape to suppress continuum background.

Results and background estimation

The analysis technique is discussed focusing on the $B^0 \to \psi\rho^0$ decay mode. Similar methods are adopted for all the modes considered in this paper.

B candidates are identified by examining the correlation between the total energy of the decay products and the beam constrained mass M_B defined as $M_B = \sqrt{E_B^2 - \Sigma_i \overrightarrow{p}_i^{\,2}}$, where E_B is the known beam energy, the $\vec{p_i}$ correspond to the fitted l^+ and l^- momenta and the π^+ and π^- momenta. The total energy is defined as $E_{TOT} = E_\psi + E_{\pi^+} + E_{\pi^-}$, where π^+ and π^- are the pions forming the ρ^0 candidate. For a signal event E_{TOT} is equal to E_B. We define ΔE as $E_{TOT} - E_B$. The energy resolution for this mode is determined using Monte Carlo simulation and found to be $\sigma_{\Delta E} \approx 11$ MeV. All the Monte Carlo samples used in this analysis contain a full simulation of the detector response, including the effects of tracking, chamber efficiencies, multiple scattering, final state radiation, and other known measurement uncertainties. The resolution in M_B is 2.5 MeV, and is predominantly due to the spread in the beam energy. Fig. 2(a) shows the distribution of candidates in the $\Delta E - M_B$ plane. The signal should peak at the point (ΔE=0 GeV, M_B=5.28 GeV). Fig. 2(a) shows $B \to \psi\rho^0$ signal region chosen to be a rectangular domain delimited by the $\pm 3\sigma$ lines , centered around the point ΔE=0 GeV, M_B=5.28 GeV. The two large clusters of events below and above the signal region correspond to ψ's from the decays $B \to \psi K^*$ decay, and to $B \to \psi K^+$ decay combined with a random π^- respectively. Nine candidate events are found in the signal region. The reconstruction efficiency ϵ for this decay using the selection criteria described above varies from 15.5% for longitudinally polarized ρ^0, to 19.3% for transverse polarization. For non-polarized ρ^0 ($2\Gamma_\mathrm{L}/\Gamma_\mathrm{T} = 1$) $\epsilon = 17.2\%$.

A study of the off-resonance data sample shows the continuum background contribution to be negligible compared to that from B decays involving a ψ in the final state. The latter background has been studied with a high statistics Monte Carlo simulation of 10,000 events for each decay mode listed in the Table I. $B \to \psi K^*$ decays were found to be the main background source. Table I shows the expected number of background events in the signal region for each channel. The last two of them are the multibody $b \to \psi s$ decays. The errors in the Table I are due to uncertainties in the various branching ratios and to Monte Carlo statistics. This study indicates that 3.7±0.7 background events are expected in the signal region. Other B decays involving ψ' or χ_{c1} are found to contribute much less background.

TABLE I. Number of background events expected in the signal region.

Mode	ψK^{*0}	ψK^{*-}	ψK^-	ψK^0	
# of events	1.96 ± 0.53	0.79 ± 0.32	$0.0 + 0.03$	0.07 ± 0.05	
Mode	$\psi' K^-$	$\chi_{c1} K^-$	$\psi(KX)^0$	$\psi(KX)^-$	Total
# of events	0.22 ± 0.18	0.07 ± 0.04	0.41 ± 0.26	0.15 ± 0.15	3.67 ± 0.71

Fig. 2(b) shows the projection onto the ΔE axis for events which have M_B within 3 standard deviations of the known B^0 mass. The $\bar{B}^0 \to \psi\rho^0$ signal region is indicated by the solid diamonds. The background shape predicted by the Monte Carlo study discussed above is shown as a solid histogram. In order to test the reliability of this method of background estimation we have investigated how these eight channels populate the two dimensional $\Delta E - M_B$ plot and the results are consistent with the data. In addition we have used a sample of generic $b \to c$ Monte Carlo to perform an independent estimate. The ψ momentum distribution in this Monte Carlo sample is tuned to reproduce the measured spectrum for the inclusive $B \to \psi X$ decays [8]. Three candidate events are found in a sample of 4.68 million decays, consistent with our estimate above.

The systematic uncertainty in this analysis is about 20%, which is small compared to the statistical error. The uncertainty in the reconstruction efficiency is 16%, including contributions from particle reconstruction and the unknown ρ^0 polarization. There are 9 events observed in the $\bar{B}^0 \to \psi\rho^0$ signal region and 3.7 background events. If we use assume that the ρ polarization in the final state is the same as the K^* polarization in the corresponding Cabibbo favored decay mode, ($\Gamma_L/\Gamma = 0.8 \pm 0.09$ [7]), the detection efficiency is 16 %. The branching fraction for $\bar{B}^0 \to \psi\rho^0$ is $(1.1 \pm 0.7)\cdot 10^{-4}$ corresponding to a 90% C.L. upper limit of $2.5\cdot 10^{-4}$. Here and below the errors quoted are statistical if not explicitly stated otherwise. In order to be conservative, the background level has been decreased by 1σ and a reduced reconstruction efficiency of 14.4% has been used in the limit calculation.

If we assume that 5.3 events in the signal region come from $B \to \psi\rho$, then the ratio between Cabibbo suppressed and Cabibbo favored mode is 0.064 ± 0.043, which is consistent, albeit with some large error, with the Standard Model prediction which is about 0.026 in this case, under the assumption that the Cabibbo suppressed partial width is equally divided between the final states $\psi\rho^0$ and $\psi\omega$.

The study of the decay $B^- \to \psi\pi^-$ has been updated using this data sample and there are 7 $\psi\pi^-$ candidates with an expected background of 1.5 ± 0.2 events. The ratio $R =$

$\frac{\mathcal{B}(B^- \to \psi\pi^-)}{\mathcal{B}(B^- \to \psi K^-)} = (0.052 \pm 0.024)$ corresponds to the $\mathcal{B}(B^- \to \psi\pi^-)$ branching fraction of $(5.6 \pm 2.7) \cdot 10^{-5}$, with systematic error less than 11%.

The decay mode $\bar{B}^0 \to \psi\omega$ is studied with a similar technique. One event is found in the signal region with an expected background of 0.2 events. The reconstruction efficiency is 5.9% according to Monte Carlo simulation. The 90% C.L. upper limit for the branching fraction $\mathcal{B}(\bar{B}^0 \to \psi\omega)$ is found to be $2.7 \cdot 10^{-4}$. Our sensitivity to modes such as $B^- \to \psi\rho^-$ and $B^- \to \psi a_1^-$ is lower due to the higher combinatoric backgrounds in these modes. The 90 % C.L. upper limits are found to be $1.2 \cdot 10^{-3}$ and $7.7 \cdot 10^{-4}$ for $\mathcal{B}(B^- \to \psi a_1^-)$ and $\mathcal{B}(B^- \to \psi\rho^-)$ respectively. No background subtraction has been attempted in obtaining these upper limits. The results of this study are summarized in Table II.

TABLE II. Results.

Decay mode	Branching ratio or 90% C.L. upper limit	reference
$\bar{B}^0 \to \psi \bar{K}^{*0}$	$(1.69 \pm 0.31) \cdot 10^{-3}$	[7]
$B^- \to \psi K^-$	$(1.10 \pm 0.15) \cdot 10^{-3}$	[7]
$B^- \to \psi\pi^-$	$(5.6 \pm 2.7) \cdot 10^{-5}$	[1], this paper
$\bar{B}^0 \to \psi\pi^0$	$< 5.8 \cdot 10^{-5}$	[1], this paper
$\bar{B}^0 \to \psi\rho^0$	$< 2.5 \cdot 10^{-4}$	this paper
$\bar{B}^0 \to \psi\omega$	$< 2.7 \cdot 10^{-4}$	this paper
$B^- \to \psi\rho^-$	$< 7.7 \cdot 10^{-4}$	this paper
$B^- \to \psi a_1^-$	$< 1.2 \cdot 10^{-3}$	this paper

In conclusion, we have studied the decay $B \to \psi\rho$, together with a variety of Cabibbo suppressed color suppressed B meson decay modes and we have obtained the 90% C.L. upper limits $\mathcal{B}(\bar{B}^0 \to \psi\rho^0) < 2.5 \cdot 10^{-4}$, $\mathcal{B}(\bar{B}^0 \to \psi\omega) < 2.7 \cdot 10^{-4}$, $\mathcal{B}(B^- \to \psi\rho^-) < 7.7 \cdot 10^{-4}$, $\mathcal{B}(B^- \to \psi a_1^-) < 1.2 \cdot 10^{-3}$. The branching fraction for $B^- \to \psi\pi^-$ is updated to be $(5.6 \pm 2.7) \cdot 10^{-5}$, corresponding to a ratio $\mathcal{B}(B^- \to \psi\pi^-)/\mathcal{B}(B^- \to \psi K^-) = 0.052 \pm 0.024$, which is consistent with the Standard Model expectation of 0.053. Similarly none of the modes studied challenges the Standard Model prediction, within their limited statistical accuracy.

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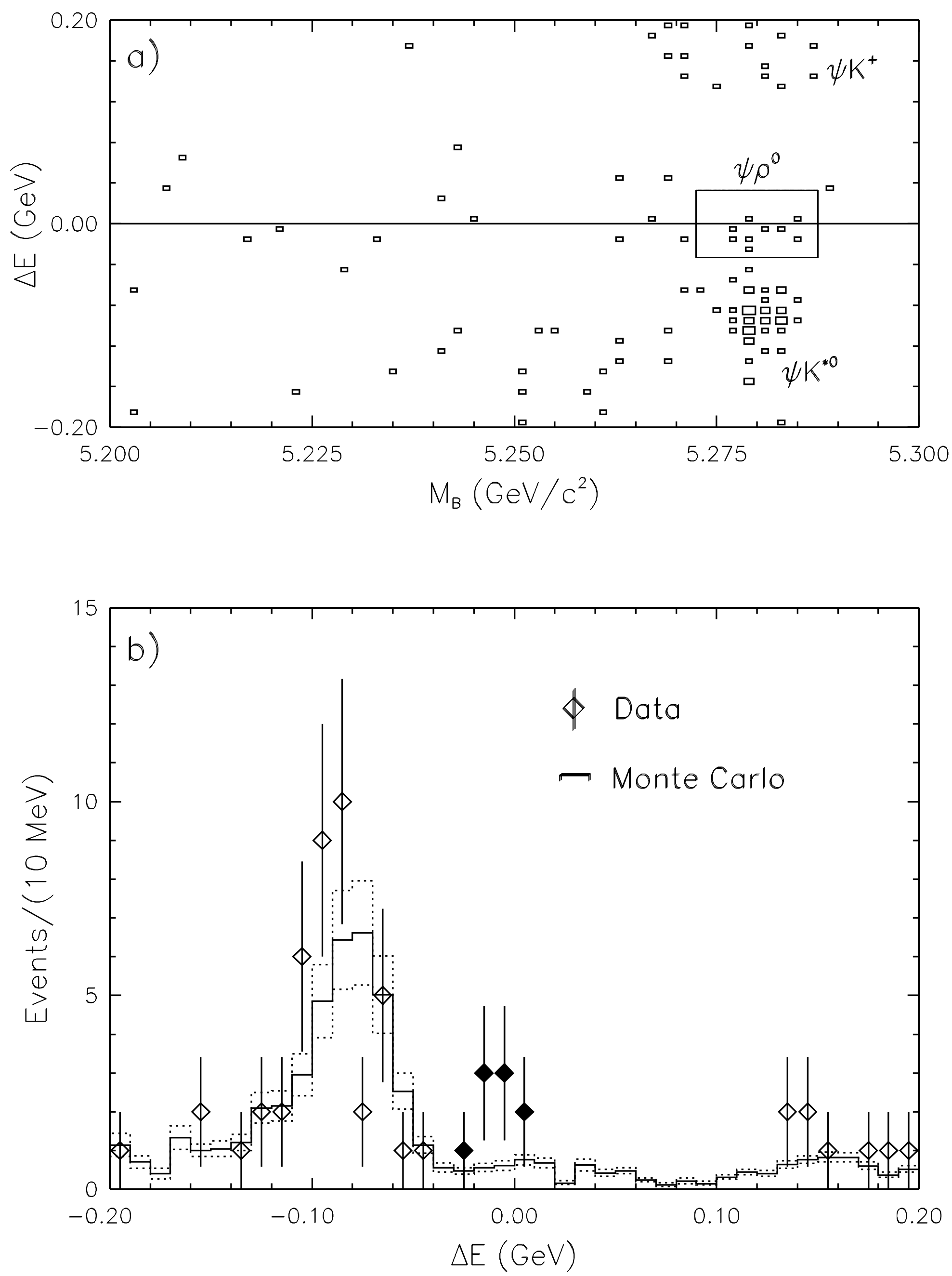

FIG. 2. (a) Correlation between ΔE (the energy difference) and M_B (the beam constrained B mass) for $\Upsilon(4S)$ data in the expected $B^- \to \psi\rho^0$ signal area. The box shows the 3 standard deviation signal region for $B \to \psi\rho^0$ decay. (b) The ΔE projection for events satisfying the condition $\mid M_B - M(B^0) \mid \leq 3 \cdot \sigma_{M_B}$. The data are shown as diamonds with error bars (solid diamonds are the entries in the signal region), while the solid histogram represents the Monte Carlo simulation for sum of the eight modes listed in the Table I. The dotted histograms indicate the one-sigma uncertainty in Monte Carlo simulation, which is due to the errors in various branching fractions.

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