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Observation of $B \to \psi\pi$ Decays

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Abstract

We have found the first evidence for the Cabibbo suppressed, color suppressed decay $B^- \to \psi\pi^-$ in a data sample of 4 million B decays obtained by the CLEO detector at the Cornell Electron Storage Ring (CESR). The branching ratio is found to be $(4.3 \pm 2.3)\%$ of the Cabibbo allowed $B^- \to \psi K^-$ decay mode, which is consistent with theoretical expectations.

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B meson decays to final states including charmonium are expected to occur predominantly via the color suppressed spectator diagram shown in Fig. 1(a). These decays have well measured branching ratios into both exclusive and inclusive final states containing ψ mesons [1]. In particular, the decay modes $B^- \to \psi K^-$ and $\bar{B}^0 \to \psi \bar{K}^0$ have been detected with large signal to background ratios. To produce these final states the vector current [W in Fig. 1(a)] manifests as a $\bar{c}s$ pair, with the s quark and spectator anti-quark hadronizing as a kaon. If the theoretical description is correct, then there should be a Cabibbo suppressed decay with the vector current coupling to a $\bar{c}d$ pair. The corresponding decay modes would be $B^- \to \psi\pi^-$ and $\bar{B}^0 \to \psi\pi^0$ and their branching ratios would be a factor of $tan^2\theta_c$ smaller than the corresponding Cabibbo allowed rates. It should be noted that a model proposed by Gronau and Wakaizumi [2], based on a $SU(2)_L \times SU(2)_R \times U(1)$ gauge group, predicts [3]:

$$\frac{b \to c\bar{c}d}{b \to c\bar{c}s} = \mathcal{O}(10^{-7}), \qquad (1)$$

which is much smaller than the Standard Model prediction.

Since the $B \to \psi\pi$ modes are both color suppressed and Cabibbo suppressed, rare or exotic decay mechanisms may be large enough to interfere and thus enable the observation of direct CP violation in the charged decay mode [4]. The diagrams shown in Fig. 1(b-e), have been discussed by Dunietz [5] who predicts CP violation at a few percent level in the charged decay, but the calculations have large uncertainties due to the difficulty of evaluating the non-leptonic matrix elements. Furthermore, any non-standard model charged gauge boson could contribute to diagrams 1(b), 1(d) or 1(e).

We have studied the decays $B^- \to \psi\pi^-$ and $\bar{B}^0 \to \psi\pi^0$. The data sample was collected with the CLEO II detector at the Cornell Electron Storage Ring (CESR) and consists of 2.01 fb^{-1} taken at the $\Upsilon(4S)$ resonance and 0.96 fb^{-1} at energies just below the $B\bar{B}$ threshold. We have about 4 million B mesons in this sample.

A detailed description of the CLEO II detector has been given elsewhere [6]. The components most relevant to the results reported here are the charged particle tracking, the CsI electromagnetic calorimeter, and the muon counters. The tracking system comprises 67 layers of precision drift chamber inside a 1.5T solenoidal magnet. It measures both momentum and specific ionization (dE/dx) of charged particles. Electron candidates are identified on the basis of their energy deposition in the calorimeter, which must be equal to their measured momentum, and their dE/dx, which must be consistent with that expected for an electron. Muon candidates are required to penetrate the 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. Both lepton candidates must satisfy the requirements described above. Candidate π^0 mesons in the $\bar{B}^0 \to \psi\pi^0$ channel are selected by calculating the invariant mass of photon pairs detected in the calorimeter and retaining those pairs having their mass within 3σ of the known π^0 mass (σ being the r.m.s. measurement error of 7 MeV).

The di-electron and di-muon invariant mass spectra for Monte Carlo $B^- \to \psi\pi^-$ events are shown in Fig. 2(a) and 2(b), respectively. The asymmetric tail in the di-electron mass distribution is caused by final state radiation. Candidate ψ mesons are selected by requiring dilepton invariant masses within the intervals about the ψ mass (m_ψ) of -30 MeV $< m_\psi <$ 30 MeV and -90 MeV $< m_\psi <$ 30 MeV for di-muons and di-electrons, respectively.

The analysis method will be discussed in detail for the $B^- \to \psi\pi^-$ decay mode. Candidates are identified by examining the correlation between the total energy of the decay products and the beam constrained mass M_B defined below. The total energy is defined as $E_{TOT} = E_{l^-} + E_{l^+} + E_{\pi^-}$, where l^- and l^+ are the leptons forming the ψ candidate. For a signal event E_{TOT} should be equal to the beam energy E_B. We define ΔE as $E_{TOT} - E_B$. An excellent resolution ($\sigma_{E_{TOT}} \approx 13$ MeV) is achieved by kinematically fitting the lepton pair constraining their invariant mass to the known ψ mass. A large potential source of background is the prolific $B^- \to \psi K^-$ channel. However, this background is very small because the difference in total energy between a B candidate produced by a correctly identified $\psi\pi^-$ final state and one produced by a misidentified ψK^- final state is about 65 MeV.

The beam constrained mass is defined as $M_B = \sqrt{E_B^2 - \Sigma_i \vec{p}_i^{\,2}}$, where E_B is the known beam energy and the $\vec{p}_i$ correspond to the l^+, l^- and π^- momenta. The resolution in M_B is 2.6 MeV, and is predominantly due to the spread in the beam energy. Fig. 3(a) shows the event distribution in the $\Delta E - M_B$ plane in the neighborhood of the signal region. The signal should peak at the point (ΔE=0 GeV, M_B=5.279 GeV). The $\psi\pi^-$ signal region is the rectangle with boundaries defined as -20 MeV $< \Delta E <$ 40 MeV and 5271.8MeV $< M_B <$ 5286.2MeV. Fig. 3(b) shows the projection onto the ΔE axis for events which have M_B within 3 σ of the known B^- mass. The $B^- \to \psi\pi^-$ peak, centered on zero, can be seen as well as the nearby peak corresponding to the ψK^- decay channel. Using the latter events for normalization, we cast our results in terms of the well known $\mathcal{B}(B^- \to \psi K^-)$ [7].

Our analysis yields 98 $B^- \to \psi K^-$ events and 5 $B^- \to \psi\pi^-$ events [8]. The reconstruction efficiency for these two channels using the selection criteria described here is 33.5% as determined from a Monte Carlo simulation of these decays in the CLEO II detector. All the Monte Carlo samples used in our analysis include a full simulation of the detector response, including the effects of tracking, chamber efficiencies, multiple scattering, final state radiation, etc.

Backgrounds in this analysis can be ascribed to two sources, the above mentioned feed-through from $B^- \to \psi K^-$ decay and other two body B decay modes involving an energetic ψ in the final state, such as $B \to \psi K^*$ or $\bar{B}^0 \to \psi \bar{K}^0$. The first, more important, background source is the feed-through of ψK^- events. Although it is impossible for these events to peak near zero ΔE, when interpreted as $\psi\pi^-$, tails of the distribution can account for some portion of the signal. In order to evaluate this contamination as accurately as possible, a high statistics Monte Carlo sample of $B^- \to \psi K^-$ is used to determine with high precision the expected background level in the $\psi\pi^-$ signal region. Fig. 3(b) shows as a dashed line the scaled ΔE distribution of 10,000 $B^- \to \psi K^-$ events which satisfy the M_B selection criterion. From this sample we derive an estimate of 0.75 ± 0.19 background events in the $\psi\pi^-$ signal region. An upper limit for the second background source can be obtained by examining the $\Delta E - M_B$ plane outside the ψK and $\psi\pi$ signal regions. A total of 7 events are found which gives a background estimate of 0.2 $\psi\pi^-$ events, assuming a flat background distribution. Monte Carlo studies, however, show that this background has a slope falling off in the $B^- \to \psi\pi^-$ signal region. Thus we estimate a contribution from this background source as 0.07 ± 0.07 events, with a total background estimate of 0.8 ± 0.2 events.

Subtracting the background sources, we have a net yield of 4.2 events, resulting in:

$$R = \frac{\mathcal{B}(B \to \psi\pi^-)}{\mathcal{B}(B \to \psi K^-)} = (4.3 \pm 2.3) \times 10^{-2} \qquad (2)$$

The expected value for R, taking into account the Cabibbo suppression factor and the slight difference in phase space between the two decays is 0.053. The agreement is quite good. This confirms the expectations from SU(3) symmetry in exclusive $B \to \psi$ decays [9]. Using the measured branching fraction $\mathcal{B}(B \to \psi K^-) = (1.10 \pm 0.15 \pm 0.09) \times 10^{-3}$ [7] , we obtain $\mathcal{B}(B \to \psi\pi^-) = (4.7 \pm 2.6) \times 10^{-5}$.

The decay mode $\bar{B}^0 \to \psi\pi^0$ is studied with the same technique. A single event in the signal region is obtained, with no other event in the $\Delta E - M_B$ plot. (In this case there is no analogous Cabibbo allowed channel to provide a large potential source of background.) A Monte Carlo simulation of this decay predicts an efficiency of 21.5%. Isospin symmetry implies $\mathcal{B}(\bar{B}^0 \to \psi\pi^0) = \frac{1}{2}\,\mathcal{B}(B^- \to \psi\pi^-)$. Therefore, extrapolating from the $\psi\pi^-$ yield, we expect 1.3 events in this channel. The absence of any other events in the ΔE-M_B plane allows us to set a 90 % C.L. upper limit on the background of 0.1 events. If we take a conservative approach and treat the one event as signal, we obtain a 90% C.L. upper limit for the branching fraction $\mathcal{B}(\bar{B}^0 \to \psi\pi^0)$ of 6.9×10^{-5}.

In conclusion we observe 5 $B^- \to \psi\pi^-$ events with an expected background of 0.8 events mostly due to $B^- \to \psi K^-$ misidentification, and 1 $\bar{B}^0 \to \psi\pi^0$ event with a background level less than 0.1 events. We measure the branching fraction for $(B \to \psi\pi^-) = (4.7 \pm 2.6) \times 10^{-5}$ and obtain an upper limit for the branching fraction for $\bar{B}^0 \to \psi\pi^0 < 6.9 \times 10^{-5}$ at 90% C.L. Our results show that the decay channels mediated by the $b \to c\bar{c}$ diagram occur at the expected rate thus confirming that charmonium is produced in B decays via the color suppressed diagram. This contradicts the predictions based on the Gronau-Wakaizumi scenario of right-handed b dominance. At these measured rates, $B \to \psi\pi$ decays should be useful probes of direct CP violation in B decays in the next generation of experiments at high luminosity e^+e^- or hadron machines.

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[4] The neutral decay mode is a CP eigenstate and observation of CP violation via the mixing amplitude here may be very interesting if a sufficiently large event rate could be obtained. The charged decays are "self-tagging" and thus less luminosity may be needed to observe a CP asymmetry.

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[7] See M. S. Alam *et al.* in Ref. 1. We also have checked our procedures by extracting a branching ratio for the $B^- \to \psi K^-$ decay mode in good agreement with our previously published number based on a subset of our data sample.

[8] There are 3 events with ψ detected in the di–muon channel and 2 events with ψ in the di-electron channel.

[9] M. J. Savage and M.B. Wise, Phys. Rev.**D39** 3346, (1989).

deviation contours expected for $B^- \to \psi\pi^-$ (centered at ΔE=0) and $B^- \to \psi K^-$ decays. b) The ΔE projection for events satisfying the condition $| M_B - M(B^-) | < 3 \times \sigma_{M_B}$. The data are shown

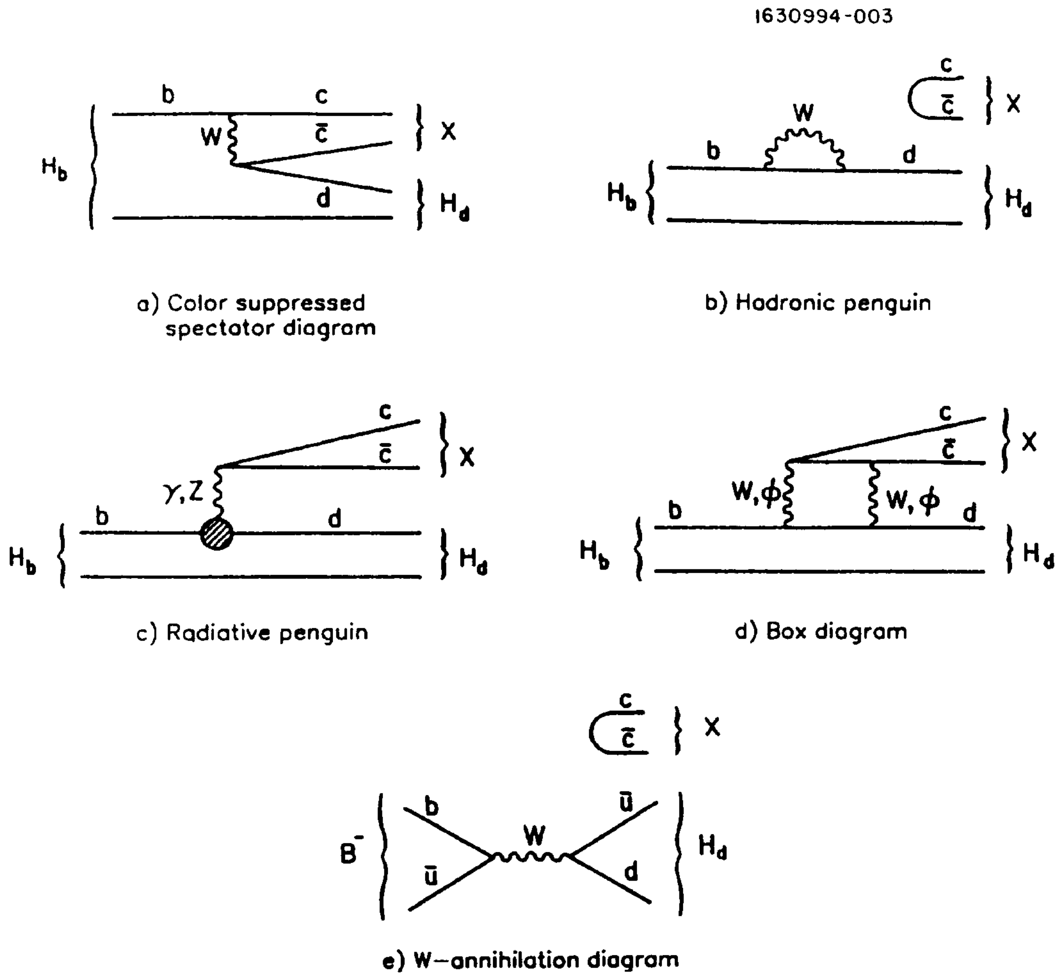

FIG. 1. Diagrams contributing to $B^- \to \psi\pi^-$ decay. H_b, H_d, and X indicate respectively, b flavored hadrons, d flavored hadrons and charmonium mesons, while ϕ indicates a charged Higgs boson.

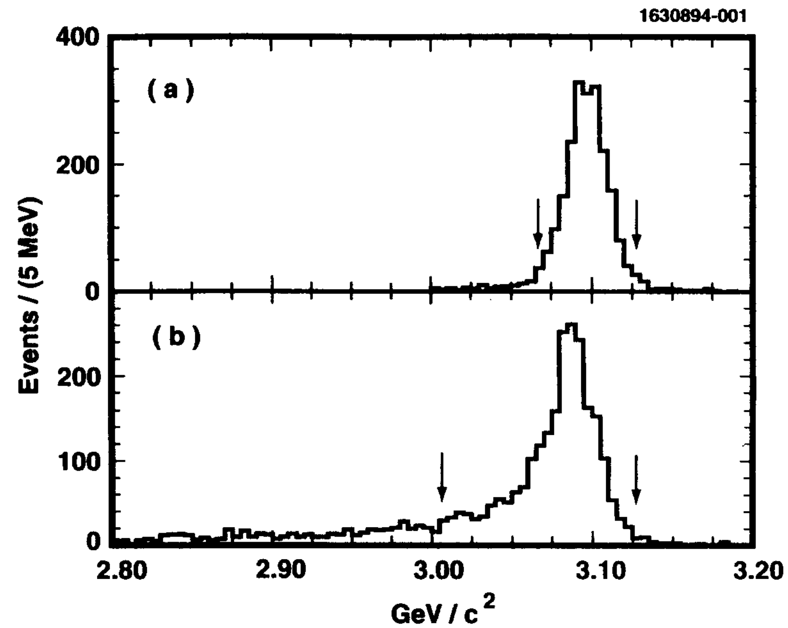

FIG. 2. Invariant mass for ψ meson from a Monte Carlo simulation of the decay $B^- \to \psi\pi^-$ in the CLEO II detector. a) $\psi \to \mu^-\mu^+$, b) $\psi \to e^-e^+$. The arrows show the regions used for further analysis.

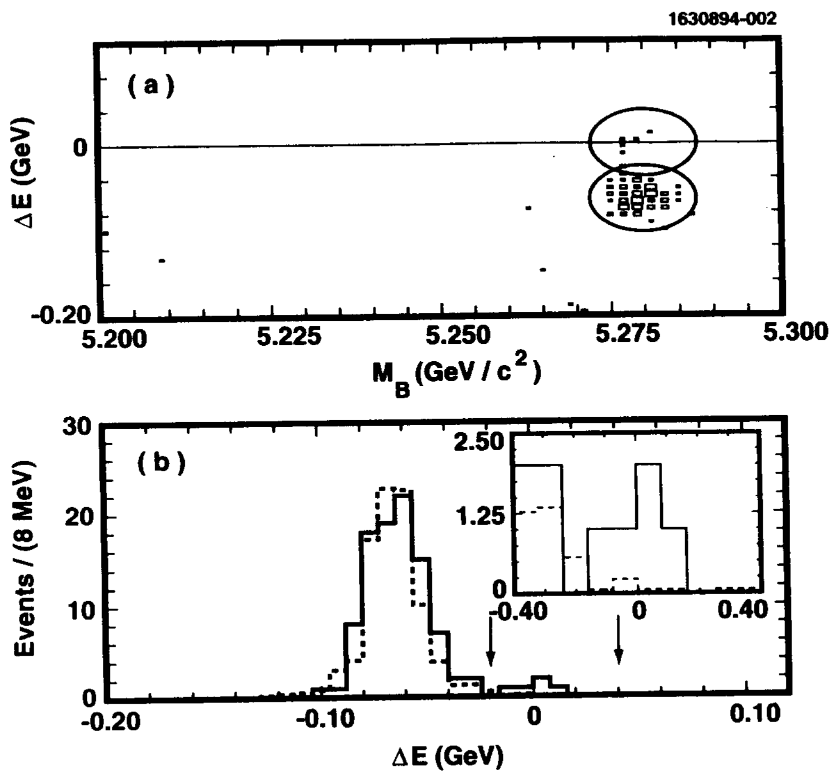

FIG. 3. (a) Correlation between ΔE (the energy difference) and M_B (the beam constrained B mass) for $\Upsilon(4S)$ data in the expected $B^- \to \psi\pi^-$ signal region. The ellipses show the 3 standard deviation contours expected for $B^- \to \psi\pi^-$ (centered at ΔE=0) and $B^- \to \psi K^-$ decays. b) The ΔE projection for events satisfying the condition $| M_B - M(B^-) | \leq 3 \times \sigma_{M_B}$. The data are shown as a solid line, while the full Monte Carlo simulation for $B^- \to \psi K^-$ is shown as a dashed line. The arrows show the $B^- \to \psi\pi^-$ signal region. A magnified view of this region is shown in the inset.