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First Observation of the Decay $B \to J/\psi\phi K$

CLEO Collaboration

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Abstract

We present the first observation of the decay $B \to J/\psi\phi K$. Using $9.6 \cdot 10^6$ $B\overline{B}$ pairs collected with the CLEO detector, we have observed 10 fully reconstructed $B \to J/\psi\phi K$ candidates, whereas the estimated mean background is 0.5 events. We obtained $\mathcal{B}(B \to J/\psi\phi K) = (8.8^{+3.5}_{-3.0}(\mathrm{stat}) \pm 1.3(\mathrm{syst})) \cdot 10^{-5}$. This observation serves as the first conclusive evidence for the $s\overline{s}$ pair popping in the B meson decays. All quoted results are preliminary.

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No B meson decay requiring the $s\overline{s}$ pair popping has yet been observed. One such example is the charmless two-body $B \to \phi K$ decay. The diagram of the most likely mechanism responsible for the decay $B \to J/\psi \phi K$ [1] is shown in Fig. 1.

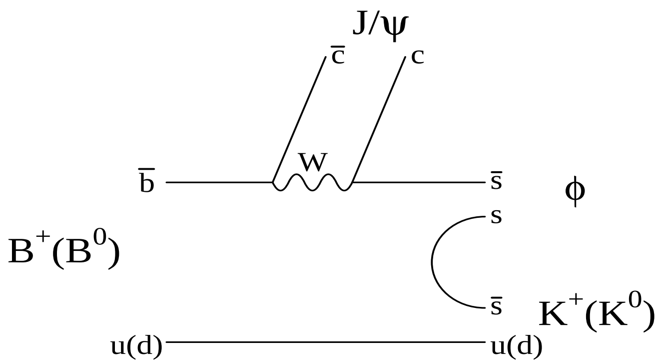

FIG. 1. Most likely $B \to J/\psi \phi K$ decay mechanism.

We searched for $B^+ \to J/\psi \phi K^+$ and $B^0 \to J/\psi \phi K^0_S$ decays, reconstructing $J/\psi \to \ell^+\ell^-$, $\phi \to K^+K^-$, and $K^0_S \to \pi^+\pi^-$. Both e^+e^- and $\mu^+\mu^-$ modes were used for the J/ψ reconstruction.

The data were collected at the Cornell Electron Storage Ring (CESR) with two configurations of the CLEO detector, called CLEO II [2] and CLEO II.V. The major component of the CLEO II.V upgrade is a three-layer silicon vertex detector [3]. The results of this search are based upon an integrated luminosity of 9.1 fb^{-1} of e^+e^- data taken at the $\Upsilon(4S)$ energy and 4.4 fb^{-1} taken below $B\overline{B}$ threshold. The Monte Carlo event samples used in this analysis were generated using GEANT-based [4] simulation of the CLEO detector response. Simulated events were processed in a similar manner as the real data.

Making requirements on such kinematic variables as invariant mass or energy, we took advantage of well understood track and photon shower error matrices to calculate the expected resolution for each combination. Therefore we extensively used normalized variables.

The normalized invariant mass distributions for the $J/\psi \to \ell^+\ell^-$ signal in data are shown in Fig. 2. We required the normalized invariant mass to be from -10 to $+3$ (from -4 to $+3$) for the $J/\psi \to e^+e^-(J/\psi \to \mu^+\mu^-)$ candidates; we also performed a fit constraining the mass of each J/ψ candidate to the nominal value. The resolution in the $\ell^+\ell^-$ invariant mass is about 10 MeV.

Electron candidates were identified based on the ratio of the track momentum to the associated shower energy in the CsI calorimeter and specific ionization loss in the drift chamber. The internal bremsstrahlung in the $J/\psi \to e^+e^-$ decay as well as the bremsstrahlung in the detector material produce a long radiative tail in the e^+e^- invariant mass distribution and impede the $J/\psi \to e^+e^-$ detection. We recovered some of the bremsstrahlung photons by selecting the photon shower with the smallest opening angle with respect to the original (evaluated at the interaction point) direction of the $e^\pm$ track, and then requiring this opening angle to be smaller than 5^0. The addition of the bremsstrahlung photons detected in the CsI calorimeter increased the $J/\psi \to e^+e^-$ reconstruction efficiency by about 25% of itself without adding more background.

For the $J/\psi \to \mu^+\mu^-$ reconstruction, one of the muon candidates was always required

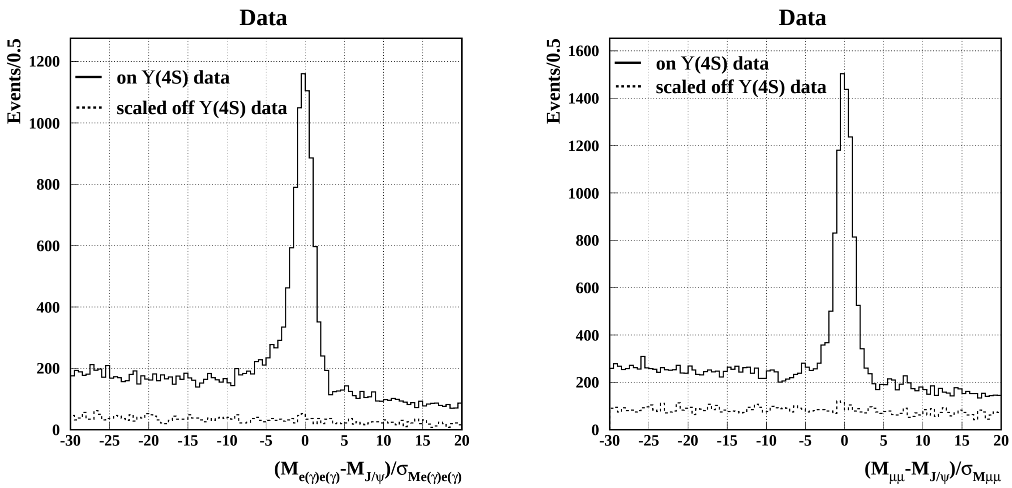

FIG. 2. $J/\psi \to e^+e^-$ (left) and $J/\psi \to \mu^+\mu^-$ (right) signal in data. The solid line represents $\Upsilon(4S)$ data; the dashed line represents the luminosity-scaled off resonance data showing the level of background from non-$B\overline{B}$ events.

to penetrate the steel absorber to a depth greater than 3 nuclear interaction lengths. If the second muon candidate was not expected, with high probability, to reach the muon chambers, then we only required its ionization signature in the CsI calorimeter to be consistent with that of a muon. Muons typically leave a narrow trail of ionization and deposit approximately 200 MeV of energy in the crystal calorimeter. Hadrons, on the other hand, quite often undergo a nuclear interaction in the CsI crystal, because they have to traverse 80% of a nuclear interaction length. Compared to imposing the absorber penetration requirement on both muon candidates, this procedure increased the $J/\psi \to \mu^+\mu^-$ reconstruction efficiency by about 20% of itself with moderate increase of background.

Charged kaons were distinguished using the specific ionization and the time of flight across the tracking volume. We selected $\phi \to K^+K^-$ candidates by requiring the K^+K^- invariant mass to be within 10 MeV/c^2 of the ϕ mass. We did not use the normalized K^+K^- invariant mass, because the ϕ width is comparable to the detector resolution.

The K_S^0 candidates were selected from the pairs of tracks forming well measured displaced vertices. The resolution in $\pi^+\pi^-$ invariant mass is about 4 MeV. After imposing a requirement on $\pi^+\pi^-$ invariant mass, we performed a fit constraining the mass of each K_S^0 candidate to the nominal value.

The $B \to J/\psi\phi K$ candidates were selected by means of two observables. The first observable is the difference between the energy of the B candidate and the beam energy $\Delta E \equiv E(J/\psi) + E(\phi) + E(K) - E_{\text{beam}}$. The resolution in ΔE is about 6 MeV. The second observable is the beam-constrained B mass $M_{bc} \equiv \sqrt{E_{\text{beam}}^2 - p_B^2}$, where p_B is the absolute value of the B candidate momentum. The resolution in M_{bc} is about 2.7 MeV/c^2; it is dominated by the beam energy spread. We used the normalized ΔE and M_{bc} variables to select the $B \to J/\psi\phi K$ candidates and defined the signal region as $|\Delta E/\sigma(\Delta E)| < 3$ and $|(M_{bc} - M_B^{\text{nominal}})/\sigma(M_{bc})| < 3$.

The distributions of the normalized ΔE vs normalized M_{bc} for $B^+ \to J/\psi\phi K^+$ and

$B^0 \to J/\psi\phi K_S^0$ are shown in Fig. 3. We observed 8(2) events in the signal box for the $B^+ \to J/\psi\phi K^+$ ($B^0 \to J/\psi\phi K_S^0$) mode. Considering that K^0 can decay as K_S^0 or as K_L^0, and also taking into account $\mathcal{B}(K_S^0 \to \pi^+\pi^-)$ and the difference in reconstruction efficiencies, we expect to observe on average 4.3 $B^+ \to J/\psi\phi K^+$ candidates for every $B^0 \to J/\psi\phi K_S^0$ candidate.

The magnified signal box region for the sum of the two plots from Fig. 3 is shown in Fig. 4. The Dalitz plot for the 10 $B \to J/\psi\phi K$ signal candidates is shown in Fig. 5; the cosine of helicity angle distributions for the 10 signal candidates are shown in Fig. 6. The helicity angle for $J/\psi \to \ell^+\ell^-$ decay is defined as the angle between the lepton momentum in the J/ψ rest frame and the J/ψ momentum in the B rest frame. The same definition was used for the $\phi \to K^+K^-$ decay. No conclusion can be drawn yet either about the J/ψ and the ϕ polarizations or about the Dalitz plot structure of the $B \to J/\psi\phi K$ decay.

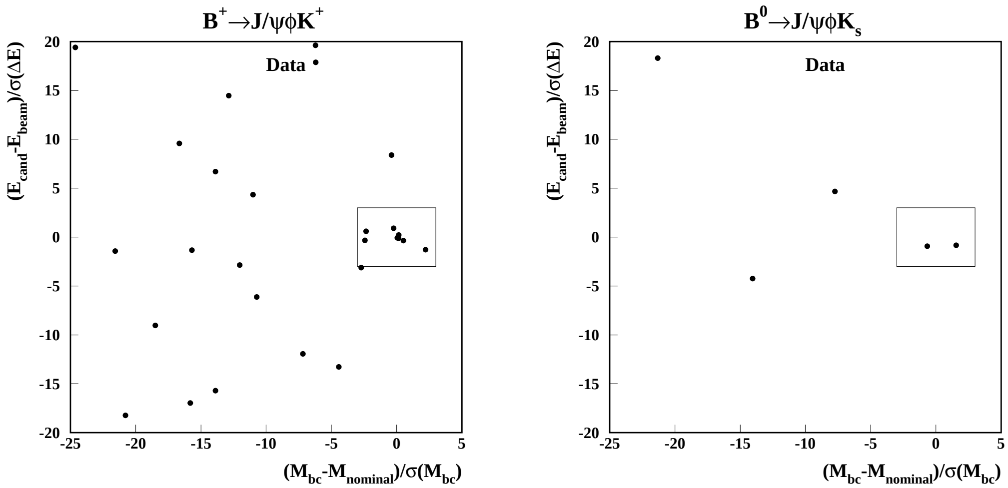

FIG. 3. The normalized ΔE vs normalized M_{bc} distribution for $B^+ \to J/\psi\phi K^+$(left plot) and $B^0 \to J/\psi\phi K_S^0$(right plot) candidates in data. There are 8(2) events in the signal box for the $B^+ \to J/\psi\phi K^+$ ($B^0 \to J/\psi\phi K_S^0$) mode.

The combinatorial background from $\Upsilon(4S) \to B\overline{B}$ events was estimated using a sample of simulated events approximately 32 times the data sample; the events containing the $B \to J/\psi K^+K^-K$ decays were excluded. We estimated the mean background from $\Upsilon(4S) \to B\overline{B}$ decays to be $0.25^{+0.10}_{-0.08}$ events. To estimate the background contribution from the $B \to J/\psi K^+K^-K$ decays, we reconstructed $B^+ \to J/\psi K^+K^-K^+$ and $B^0 \to J/\psi K^+K^-K_S^0$ candidates in data, requiring $|M(K^+K^-) - M_\phi^{\rm nominal}| > 20$ MeV/c^2 to exclude $B \to J/\psi\phi K$ events. We observed 7 $B \to J/\psi K^+K^-K$ candidates with the estimated $B\overline{B}$ combinatorial background of 2.8 events. Using the $B \to J/\psi K^+K^-K$ signal Monte Carlo, we estimated the mean background from the $B \to J/\psi K^+K^-K$ decays for the $B \to J/\psi\phi K$ signal to be $0.27^{+0.21}_{-0.17}$ events. In addition, we specifically considered $B^+ \to J/\psi K^{*0}\pi^+$ and $B^+ \to J/\psi\rho^0 K^+$ decays, where $K^{*0} \to K^+\pi^-$ and $\rho^0 \to \pi^+\pi^-$; we found the background from those decays for the $B \to J/\psi\phi K$ signal to be negligible. The combinatorial background from the continuum events was estimated using the data collected below $B\overline{B}$ threshold and a sample of simulated events approximately 3 times the data sample. We found the

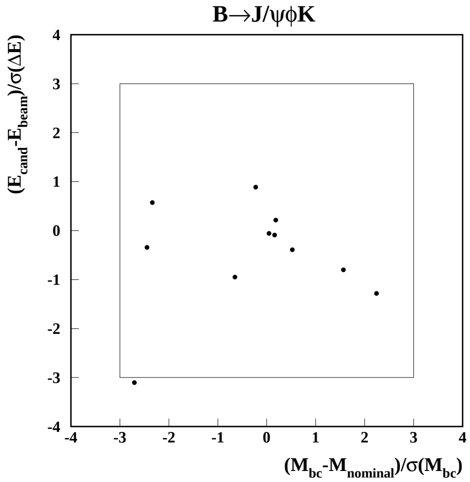

FIG. 4. Signal box close-up for the $B \to J/\psi\phi K$ candidates in data. There are 10 candidates in the signal box.

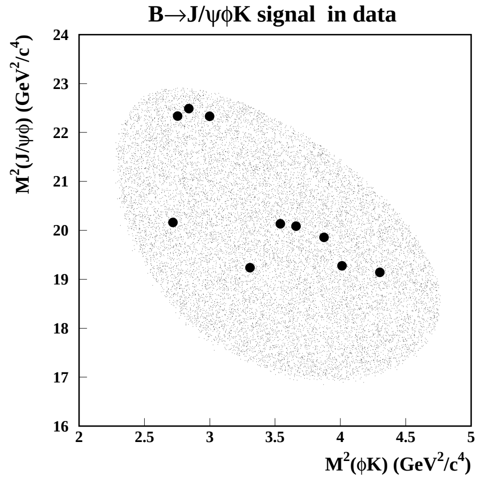

FIG. 5. Dalitz plot for the 10 $B \to J/\psi\phi K$ candidates in data overlaid on the uniform Dalitz plot obtained using the $B \to J/\psi\phi K$ signal Monte Carlo.

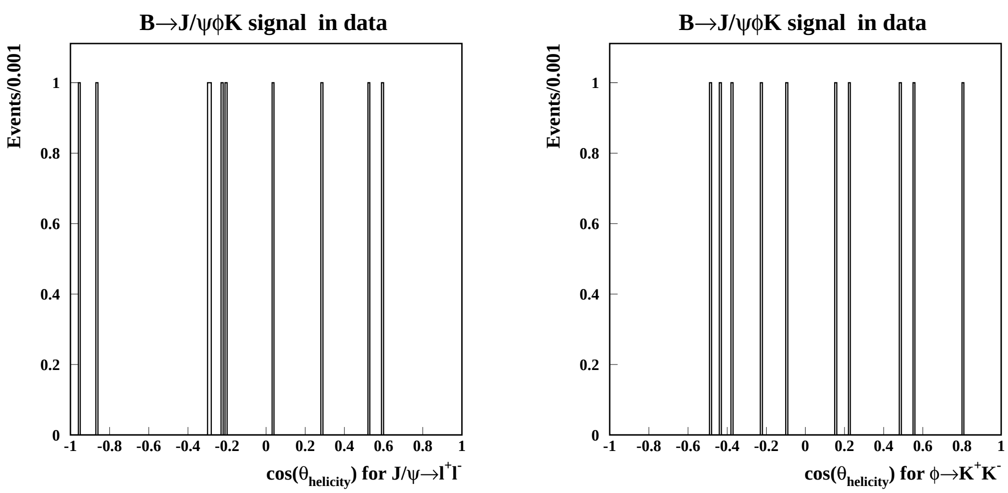

FIG. 6. Cosine of helicity angle for $J/\psi \to \ell^+\ell^-$ (left) and $\phi \to K^+K^-$ (right). The distributions for the 10 signal events in data are shown.

continuum background to be negligible. In summary, the estimated total mean background for the combined $B \to J/\psi\phi K$ signal is $0.52^{+0.23}_{-0.19}$ events.

We evaluated the reconstruction efficiency using $B \to J/\psi\phi K$ signal Monte Carlo sample, where we assumed a uniform Dalitz plot distribution and non-polarized J/ψ and ϕ. The reconstruction efficiency for the $B^+ \to J/\psi\phi K^+$ mode is 15.5%; for the $B^0 \to J/\psi\phi K^0_S$ mode is 10.3%. To study the decay model dependence of the reconstruction efficiency, we generated two additional signal Monte Carlo samples. One sample was generated with a uniform Dalitz plot distribution and 100% transverse polarization of J/ψ and ϕ. The other sample was generated assuming ϕ and K to be daughters of a hypothetical spin-0 resonance with the mass of 1.7 GeV/c^2 and the width of 100 MeV. We estimated the relative systematic error due to the decay model dependence of the reconstruction efficiency extraction to be 7%.

The other sources of the systematic error of the $\mathcal{B}(B \to J/\psi\phi K)$ measurement include track finding, track fitting, lepton and charged kaon identification, K^0_S finding, background subtraction, uncertainty on the number of $B\overline{B}$ pairs used for this measurement, statistics of the Monte Carlo samples, and the uncertainties on the daughter branching fractions $\mathcal{B}(J/\psi \to \ell^+\ell^-)$ and $\mathcal{B}(\phi \to K^+K^-)$ [6]. We estimated the total relative systematic error of the $\mathcal{B}(B \to J/\psi\phi K)$ measurement to be 15%.

For the branching fraction calculation we assumed equal production of B^+B^- and $B^0\overline{B}^0$ pairs at the $\Upsilon(4S)$ resonance and $\mathcal{B}(B^+ \to J/\psi\phi K^+) = \mathcal{B}(B^0 \to J/\psi\phi K^0) = \mathcal{B}(B \to J/\psi\phi K)$. We did not assign any systematic errors due to these two assumptions. We used the world average values of $\mathcal{B}(J/\psi \to \ell^+\ell^-)$, $\mathcal{B}(\phi \to K^+K^-)$, and $\mathcal{B}(K^0_S \to \pi^+\pi^-)$ [6]. We used the tables in Ref. [5] to assign the 68.27% C.L. intervals for the Poisson signal mean, given the total number of events observed and the known mean background. The resulting branching fraction is $\mathcal{B}(B \to J/\psi\phi K) = (8.8^{+3.5}_{-3.0}(\text{stat}) \pm 1.3(\text{syst})) \cdot 10^{-5}$.

In conclusion, we have fully reconstructed 10 $B \to J/\psi\phi K$ candidates with a total estimated mean background of 0.5 events. Assuming equal production of B^+B^- and $B^0\overline{B}^0$ pairs at the $\Upsilon(4S)$ resonance and $\mathcal{B}(B^+ \to J/\psi\phi K^+) = \mathcal{B}(B^0 \to J/\psi\phi K^0) = \mathcal{B}(B \to J/\psi\phi K)$, we have measured $\mathcal{B}(B \to J/\psi\phi K) = (8.8^{+3.5}_{-3.0}(\text{stat}) \pm 1.3(\text{syst})) \cdot 10^{-5}$. This observation serves as the first conclusive evidence for the $s\overline{s}$ pair popping in the B meson decays.

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[1] Charge conjugate modes are implied. $B \to J/\psi\phi K$ is either $B^+ \to J/\psi\phi K^+$ or $B^0 \to J/\psi\phi K^0$.

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