CLEO CONF 98-24
ICHEP98 1073

Evidence for $B \to \eta_c K$ decays

CLEO Collaboration

(July 21, 1998)

Abstract

B meson decays to η_c have been searched for using CLEO II data. An excess of events has been observed for the $B^{\pm} \to \eta_c K^{\pm}$ decay in the channel $\eta_c \to \phi\phi$ with a significance of 3.9σ. The measured branching fraction is $(1.54^{+1.39}_{-0.87}(stat) \pm 0.15(syst) \pm 0.60(\eta_c\ br.\ fr.)) \times 10^{-3}$. Upper limits have been set for the decays $B^0 \to \eta_c K^0$, $B^0 \to \eta_c K^{*0}$ and $B^{\pm} \to \eta_c K^{*\pm}$.

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Little is known about η_c production in B decays. The two-body B decays into η_c and a strange meson have attracted considerable attention following the observation of an unexpectedly large rate for B decays to η' [1]. Several mechanisms were proposed to explain such a large rate. Among them, the possibility of a substantial "intrinsic charm" component of the η' [2, 3, 4] was suggested. This intrinsic charm content of the η' mesons could lead to an enhanced rate of η_c production.

Both inclusive and exclusive B decays η_c states are of further theoretical interest as a testing ground for QCD calculations of quark dynamics and factorization. These rates are expected to be comparable to those of the corresponding B decays into the J/ψ and may be used to extract the poorly known decay constant f_{η_c} [5, 6, 7]. The theoretical expectations are summarized in Table 1.

In this study we search[1] for the decays:

- $B^+ \to \eta_c K^+$
- $B^0 \to \eta_c K^0$
- $B^+ \to \eta_c K^{*+}$
- $B^0 \to \eta_c K^{*0}$.

We use the η_c decay channel $\eta_c \to \phi\phi$ with each ϕ decaying into K^+K^-. This mode has a clean and distinct experimental signature of four charged kaons, which compensates for its very low branching fraction $Br(\eta_c \to \phi\phi) = (0.71 \pm 0.28)\%$ [8]. We reconstruct the K^{*0} in both the $K^+\pi^-$ and $K_s\pi^0$ modes and the K^{*+} in both the $K^+\pi^0$ and $K^0\pi^+$ modes.

Table 1: Phenomenological estimates of η_c production in B decays[2]

Prediction	Reference
$Br(B \to \eta_c K^+) = (0.9 \sim 1.61) \times 10^{-3}$	[6]
$Br(B \to \eta_c K^\circ) = (0.89 \sim 1.98) \times 10^{-3}$	[6]
$Br(B \to \eta_c K^{\star +}) = (0.5 \sim 2.03) \times 10^{-3}$	[6]
$Br(B \to \eta_c K^{\star\circ}) = (0.5 \sim 1.63) \times 10^{-3}$	[6]
$Br(B \to \eta_c K^-) = (1.801 \pm 0.286) \times 10^{-3}$	[7]
$Br(B \to \eta_c K^\circ) = (1.229 \pm 0.414) \times 10^{-3}$	[7]
$Br(B \to \eta_c X_s) = (4.612 \pm 1.153) \times 10^{-3}$	[7]
$Br(B \to \eta_c X) = 0.70 \pm 0.08$	[5]
$Br(B \to \eta_c X) \approx 0.5$	[2]

[1]Throughout this note the charge conjugate state is implied.

[2]The papers [2] and [5] discuss the relative rates of the η_c and J/ψ in B decays. In extracting the branching fractions for inclusive B decays to η_c we have neglected the Cabbibo-suppressed B decays.

This analysis uses data collected with the CLEO II detector[9] at the Cornell e^+e^- storage ring CESR. The data sample corresponds to an integrated luminosity of 3.1 fb^{-1} collected at the peak of the $\Upsilon(4S)$ resonance and contains approximately 3.3 million $B\bar{B}$ pairs. The continuum $e^+e^- \rightarrow qq$ background was studied using 1.6 fb^{-1} of off-resonance data taken 60 MeV below the $\Upsilon(4S)$ peak.

CLEO II is a general purpose solenoidal magnet detector with 67 layers of tracking devices inside a 1.5 T magnetic field. Photons are detected in a highly segmented CsI crystal calorimeter; pion/kaon separation is provided by a time of flight system and by the measurement of the ionization loss, dE/dx, in the main drift chamber. Muons are identified using proportional counters placed at three different interaction length depths of the magnet return yoke iron.

Two analysis methods are employed. The first one is the "Slice and Dice" method utilizing cuts designed to minimize background. It is used to establish the existence of the signal. The second method uses a more general, simultaneous maximum likelihood fit to several variables to provide better separation of signal from background. This method is analogous to that used in CLEO studies of rare B decays to η' [1].

We select events with at least 5 good tracks with impact parameter in the $r - \phi$ plane less than 5 mm and the distance of closest approach to the beam spot in z less than than 5 cm. Photon candidates are required to have energies greater than 30 MeV in the barrel or 50 MeV in the endcaps; showers associated with tracks are not considered as photon candidates.

Neutral pions are reconstructed from two photons with an effective mass within 3σ of the nominal π^0 mass. The K^0 candidates are required to have at least 5 mm flight distance from the primary vertex to the decay point and mass within $15MeV/c^2$ of the K_s mass. The K^* candidates are reconstructed in 4 submodes: $K^{\pm}\pi^{\pm}$, $K^{\pm}\pi^0$, $K_s\pi^{\pm}$ and $K_s\pi^0$. A $K\pi$ combination is considered a K^* candidate if its mass is within $80MeV/c^2$ of the nominal K^* mass.

The ϕ mesons are reconstructed in the K^+K^- decay channel by requiring the effective mass of the two kaons to be within 8 MeV of nominal ϕ mass. The kaon candidates must satisfy particle ID consistency cuts using both dE/dx and time of flight when available.

We require the two ϕ mesons to have an effective mass compatible with the η_c. The 1997 PDG values for the η_c mass and width are $m = 2979.8 \pm 2.1MeV/c^2$ and $\Gamma = 13.2^{+3.8}_{-3.2}MeV$. The intrinsic detector resolution for the η_c mass is found to be $\sim 6MeV/c^2$ from Monte Carlo studies. Folded with the natural width of the η_c, the mass distribution has a resolution of $\sigma = 9MeV/c^2$. We select candidates with a mass within $25MeV/c^2$ of the nominal mass. This window is broad enough to allow for the uncertainty in the η_c mass and width.

For the signal candidates, the effective mass of the η_c and the additional kaon or K^* should form the B mass, and the energy of the system should be equal to the beam energy. The energy resolution is 21 MeV. We use the beam energy constraint to improve the B mass resolution. The beam constrained mass resolution is 2.7 MeV. We define the signal box for the $\eta_c K^{(*)}$ final state as $|m(\eta_c K^{(*)}) - m(B)| < 7 MeV/c^2$ and $|E(\eta_c K^{(*)}) - E_{beam}| < 50 MeV$.

For a small number of events, multiple combinations of tracks fulfill all of the selection criteria. For these events we assign to each combination a weight equal to the inverse of the number of combinations.

There are several sources of background to our signal. These include

1. the combinatorial background in signal B decays
2. cross-feed from different submodes in $B \to \eta_c X$ decays
3. combinatorial background from generic $B\bar{B}$ production
4. combinatorial background from continuum production
5. high multiplicity $\tau^+\tau^-$ and two-photon events.

The combinatorial background from signal events are minimized by imposing restrictive mass selection criteria on the ϕ, η_c and B.

A substantial fraction of the background from generic B decays is due to semileptonic B decay where the decay lepton is energetic. For high momentum tracks the dE/dx and TOF information is insufficient to distinguish kaons from leptons. To remove this background we impose a lepton veto on all of the kaon candidates.

Continuum, tau pair and two-photon background events are expected to exhibit a jet-like event structure. These backgrounds are suppressed by requiring $R2 \leq 0.25$, where $R2$ is the ratio of two Fox-Wolfram moments.

For the decay $B \to \eta_c K^*$ with $K^* \to K^\pm \pi^0$ we require a negative K^* helicity, i.e. the daughter kaon should travel backwards in the K^* rest frame. This requirement results in selection of kaons with momenta $p \leq 1 GeV/c$ for which the particle identification is effective. This also avoids the large π^0 background from random photon combinations present at low π^0 momentum. This cut suppresses the background by a factor of 5 and reduce the efficiency by about 50%. This cut is not required for the other K^* decay modes where the backgrounds are significantly lower.

In the simple "Slice and Dice" approach 2 events are found in the signal region for the $B \to \eta_c K$ channel with the expected background of 0.049 events. The background estimate is obtained by the extrapolation into the signal region of the m_B and E_B distributions observed in the Grand Side Band.

The event yields are obtained using unbinned maximum likelihood fits to the data. The likelihood is defined as

$$\mathcal{L} = e^{-(s+b)} \prod_{e=1}^{N} (sP_s(e) + bP_b(e))$$

where P is the normalized probability density function (PDF) for for event e evaluated for signal and background and s and b are the fractions of signal and background events in the data.

Five variables are used in the fit: m_B, $\Delta E = E_{cand.} - E_{beam}$, m_{η_c}, $cos\theta$ and χ. The last two variables describe the angular distribution if the decay $\eta_c \to \phi\phi \to K^+K^-K^+K^-$.

We parameterize the signal PDFs as follows: bifurcated Gaussian in m_B; double Gaussian in ΔE; Breit-Wigner smeared by double Gaussian in m_{η_c}; $1-x^2$ in $cos\theta$; sin^2 in χ. In the $\eta_c \to \phi\phi$ analysis, the signal η_c decays into two identical vector particles and only two combinations of ϕ helicities are allowed: $-1,-1$ or $+1,+1$. The full angular distribution depends on three angles

$$I(\Omega, \Omega', \Omega'') = const \times sin^2(\theta') \times sin^2(\theta'') \times sin^2(\chi),$$

where θ' and θ'' are the angles between positive kaon in each of the parent' ϕ rest frame and the ϕ's direction and χ is the angle between the planes formed by two vectors of kaons in each ϕ decay as measured in the η_c rest frame. The background is parameterized as follows: second order polynomial in scaled B momentum times a phase-space factor in m_B; linear function in ΔE; linear function in m_{η_c}; flat distribution in the angular variables $cos\theta$ and χ.

Table 2 shows a summary of the systematic errors we assign to our selection. The error is dominated by the uncertainty in the $\eta_c \to \phi\phi$ branching fraction. The next largest error is due to track finding.

Table 2: Systematic errors.

	Error per quantity, %	Error, %					
		$\eta_c K$	$\eta_c K_s$	$\eta_c(K\pi)$	$\eta_c(K\pi^0)$	$\eta_c(K_s\pi)$	$\eta_c(K_s\pi^0)$
Track finding	2	10	8	12	10	10	8
K_s reconstruction	5	0	5	0	0	5	5
π^0 finding	5	0	0	0	5	0	5
$R2$	1						
m_{η_c}	5						
ΔE criteria	negligible						
m_B criteria	negligible						
$Br(\eta_c \to \phi\phi)$	39						
total error, %		40.7	40.5	41.2	41.0	41.0	40.8

For the decay $B^\pm \to \eta_c K^\pm$ the resulting likelihood function is plotted as function of the number of signal events in Figure 1. The maximum likelihood is obtained for

$1.95^{+1.77}_{-1.10}$ signal events, corresponding to 3.93σ significance for the on-resonance data. The off-resonance data fits to zero yield. The systematic error due to uncertainties in the PDF shape parameters are included. Projections of the data onto each of the 5 variables used in the fit are shown in Figure 2 with the fit result overlayed. We find no evidence for the related decays to $\eta_c K^0$, $\eta_c K^{*0}$, and $\eta_c K^{*+}$ and set the upper limits shown in Table 3.

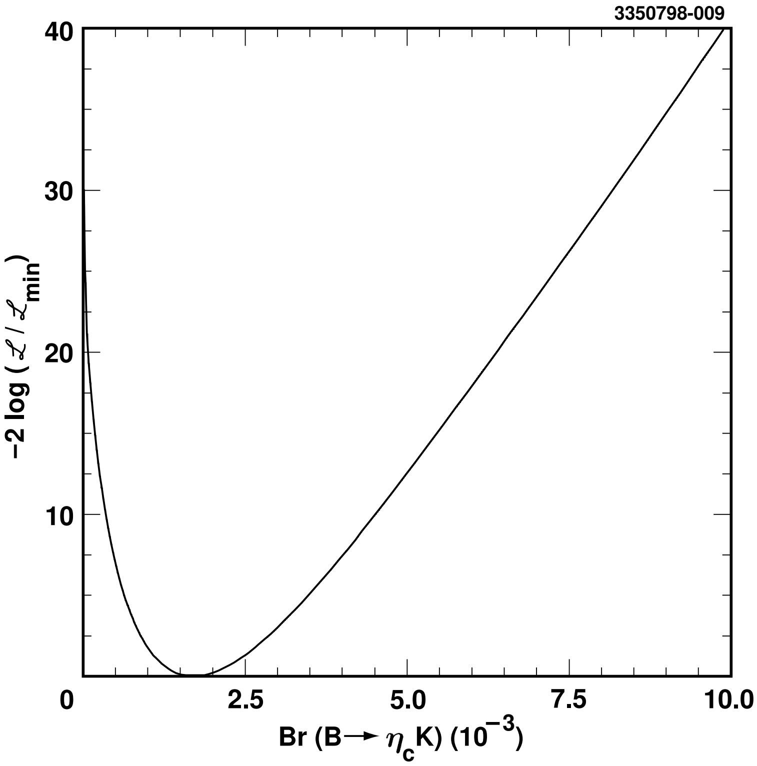

Figure 1: Likelihood function for $B^{\pm} \to \eta_c K^{\pm}$, $\eta_c \to \phi\phi$ as a function of the number of signal events.

In summary, we have observed an excess of events for the decay $B^{\pm} \to \eta_c K^{\pm}$ in the η_c decay channel $\eta_c \to \phi\phi$ with a significance of 3.9σ and a corresponding branching fraction of $Br(B^{\pm} \to \eta_c K^{\pm}) = (1.54^{+1.39}_{-0.87} \pm 0.15 \pm 0.60) \times 10^{-3}$, where the first error is statistical, the second systematic and the third the uncertainty associated with the $\eta_c \to \phi\phi$ branching fraction. Upper limits have been set for the related decays to $\eta_c K^0$, $\eta_c K^{*0}$, and $\eta_c K^{*+}$.

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation, the U.S. Department of Energy, Research Corporation, the Natu-

Table 3: Upper limits for $B \to \eta_c$ decay modes.

Decay Channel	Upper Limit
$B^0 \to \eta_c K^0$	6.8×10^{-3}
$B^0 \to \eta_c K^{\star 0}$	5.95×10^{-3}
$B^\pm \to \eta_c K^{\star\pm}$	18.5×10^{-3}

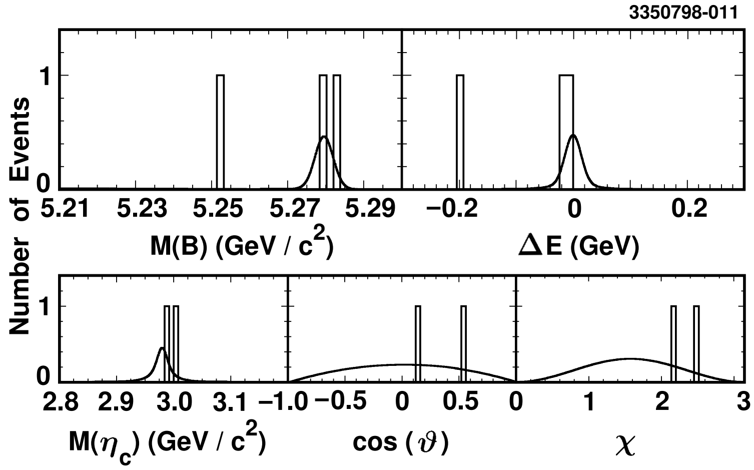

Figure 2: Fit result projections for $B^\pm \to \eta_c K^\pm$, $\eta_c \to \phi\phi$. Data, after cuts on all other variables, are overlaid with the sum of scaled signal and background distributions.

ral Sciences and Engineering Research Council of Canada, the A.P. Sloan Foundation, the Swiss National Science Foundation, and the Alexander von Humboldt Stiftung.

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