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Results on B to Charmonia Decays from CLEO

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We review some recent results on B to charmonia decays from CLEO based on 9.7×10^6 $B\bar{B}$ pairs collected with the CLEO detector. These include measurements of $B^0 \to J/\psi K_s^0$, $\chi_{c1}K_s^0$ and $J/\psi\pi^0$ branching fractions, search for direct CP violation in $B^\pm \to J/\psi K^\pm$ and $\psi(2S)K^\pm$, observation of $B \to \eta_c K$, study of χ_{c1}, χ_{c2} production and measurement of $f_{+-}/f_{00} \equiv \mathcal{B}[\Upsilon(4S) \to B^+B^-]/\mathcal{B}[\Upsilon(4S) \to B^0\overline{B}^0]$.

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1. CESR and CLEO

The Cornell Electron Storage Ring (CESR) is a symmetric e^+e^- collider operating at the Υ(4S) resonance. The CLEO II and II.V detector configurations are described in detail elsewhere [1,2]. The integrated luminosity is 9.2 fb^{-1} at the Υ(4S) resonance, which corresponds to about 9.7×10^6 $B\bar{B}$ pairs, and 4.6 fb^{-1} at energies just below the $B\bar{B}$ threshold. The results reviewed in this paper are based on this full data sample.

2. B^0 Decays for sin2β measurement

The origin of CP violation is one of the most important problems of experimental high energy physics. The study of B mesons has been attracting extensive world wide attention because it will allow for a decisive test of the quark-mixing sector in the Standard Model (SM). It is very important to test whether the SM provides the correct description of CP violation, in order to search for new physics beyond the SM. That is the major motivation for building the current generation of B factories, BABAR, BELLE and CLEO III. To check the SM predictions on CP violation in order to search for new physics beyond the SM, it is particularly important to measure the three sides and angles ($\alpha \equiv arg\ [-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}]$, $\beta \equiv arg\ [-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}]$, and $\gamma \equiv arg\ [-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}]$) of the CKM unitary triangle as precise as possible. Among these three CKM angles, only the angle β (sin2β) is expected to

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be cleanly measured in the near future using the gold plated $B^0 \to J/\psi K_s^0$ decay mode.

The first goal of these first-generation B factories is to observe CP violation in the B meson system which is predicted in the SM. Strong evidence of CP violation in the B system has been found through the Sin2β measurement from CDF [3]. Better measurements from BABAR and BELLE were shown this summer with lower central value than expected [4,5]. Besides the golden decay mode $B^0 \to J/\psi K_S^0$ where $K_S^0 \to \pi^+\pi^-$ in the sin2β measurement, similar decay modes $B^0 \to J/\psi K_S^0$ where $K_S^0 \to \pi^0\pi^0$, $B^0 \to \chi_{c1} K_S^0$, $B^0 \to J/\psi\pi^0$ etc can also be used. These decay modes will add about 15% more statistics to the sin2β measurement. This is very important when the sin2β measurements are dominated by statistics errors. Furthermore, the tree-penguin interference in $B^0 \to J/\psi\pi^0$ may allow the removal of the β and $\beta + \pi$ ambiguity [6].

2.1. *CLEO results on* $B^0 \to J/\psi K_S^0$, $\chi_{c1}K^0$ *and* $J/\psi\pi^0$

Clean and significant signals in $B^0 \to J/\psi K_S^0(\pi^0\pi^0)$, $\chi_{c1}K^0$ and $J/\psi\pi^0$ have been observed with very little backgrounds. The main results are summarized in the following table. The details of the analyses to obtain these results can be found in [7].

	Decay mode	Signal	Background	Efficiency (%)	$\mathcal{B}$ ($\times 10^{-4}$)
	$B^0 \to J/\psi\, K^0$				$9.5 \pm 0.8 \pm 0.6$
Update	$K_S^0 \to \pi^+\pi^-$	142	0.3 ± 0.2	37.0 ± 2.3	$9.8 \pm 0.8 \pm 0.7$
New	$K_S^0 \to \pi^0\pi^0$	22	1.1 ± 0.3	13.9 ± 1.1	$8.4^{+2.1}_{-1.9} \pm 0.7$
New	$B^0 \to \chi_{c1}\, K^0$	9	0.9 ± 0.3	19.2 ± 1.3	$3.9^{+1.9}_{-1.3} \pm 0.4$
New	$B^0 \to J/\psi\, \pi^0$	10	1.0 ± 0.5	31.4 ± 2.2	$0.25^{+0.11}_{-0.09} \pm 0.02$

3. Search for direct CP violation in $B^\pm \to \psi^{(\prime)}K^\pm$

Interfering amplitudes with different CP-even (strong and electromagnetic) and CP-odd (weak) phases are the necessary ingredients for direct CP-violation. In the case of $B^\pm \to \psi^{(\prime)}K^\pm$ decays, we do have interfering tree and penguin diagrams which could have a significant relative strong phase. However, the relative weak phase is very small. As a result, the asymmetry in $B^\pm \to \psi^{(\prime)}K^\pm$ in SM is well below the 4% expected precison of the CLEO measurement. On the other hand, new physics beyond the SM can introduce large direct CP violation in $B^\pm \to \psi^{(\prime)}K^\pm$. For instance, A CP asymmetry of about 10% in $B^\pm \to \psi^{(\prime)}K^\pm$ decays is possible in certain Two-Higgs doublet model [8]

The CP asymmetry is defined as follows:

$$\mathcal{A}_{CP} \equiv \frac{\mathcal{B}(B^- \to \psi^{(\prime)}\, K^-) - \mathcal{B}(B^+ \to \psi^{(\prime)}\, K^+)}{\mathcal{B}(B^- \to \psi^{(\prime)}\, K^-) + \mathcal{B}(B^+ \to \psi^{(\prime)}\, K^+)} = \frac{b - \overline{b}}{b + \overline{b}}$$

About 534 $B^\pm \to J/\psi\, K^\pm$ signal events and 120 $B^\pm \to \psi(2S)\, K^\pm$ signal events are observed. No sign of direct CP violation is observed. The results are summarized in the following table. The details of the analysis to obtain these results can be found in [9].

Mode	$N(B^\pm)$	$N(B^-)$	$N(B^+)$	$\frac{N(B^-)-N(B^+)}{N(B^-)+N(B^+)}$	$\mathcal{A}_{CP}$
$B^\pm \to J/\psi\, K^\pm$	534	271	263	$(1.5 \pm 4.3)\%$	$(1.8 \pm 4.3 \pm 0.4)\%$
$B^\pm \to \psi(2S)\, K^\pm$	120	61	59	$(1.7 \pm 9.1)\%$	$(2.0 \pm 9.1 \pm 1.0)\%$

4. Observation of $B \to \eta_c K$

Unexpected large $B \to \eta' X$ branching fractions were observed at CLEO [10]. Among several theoretical explanations, a substantial intrinsic charm component in the η' has been proposed. If this is the case, the η' can be produced by the axial part of the $b \to c\bar{c}s(d)$ process, which also produces η_c. Exclusive B decays to charmonium states are also of theoretical interest as a testing ground for the QCD calculations of quark dynamics and factorization. In the absence of enhancing mechanisms, the B decay rate to $\eta_c X$ is expected to be comparable to that for the B decays to $J/\psi X$. The color-singlet production of χ_{c0} in B decays vanishes in the factorization approximation as a consequence of spin-parity conservation. However, the color-octet mechanism allows for the production of the χ_{c0} P-wave 0^{++} state via the emission of a soft gluon.

By performing maximum likelihood analysis, CLEO has observed the decay $B \to \eta_c K$ in both charged and neutral modes with branching fractions similar to those for $B \to J/\psi K$. The channel $B^0 \to \eta_c K^0$ can be used to extract the value of $\sin(2\beta)$ via future time-dependent asymmetry measurement. Upper limits on $B \to \chi_{c0} K$ decays are set that restricts possible enhancement of the χ_{c0} production due to the color-octet mechanism. The details of the analyses can be found in [11]. The branching fractions are measured to be:

$$\mathcal{B}(B^+ \to \eta_c\, K^+) = (0.69^{+0.26}_{-0.21} \pm 0.08 \pm 0.20) \times 10^{-3}$$
$$\mathcal{B}(B^0 \to \eta_c\, K^0) = (1.09^{+0.55}_{-0.42} \pm 0.12 \pm 0.31) \times 10^{-3}$$

5. Study of χ_{c1} and χ_{c2} production in B decays

Recent measurements of charmonium production at Tevatron [12] have brought surprises that resulted in better calculations of the inclusive charmonium production. Inclusive B decays to charmonium provides another test ground where theoretical predictions can be confronted with experimental data. A measurement of the χ_{c2}-to-χ_{c1} production ratio in B decays provides an especially clean test of charmonium production models. The $B \to \chi_{c2} X$ decay is forbidden at leading order in α_s in the color-singlet model [13], while this production ratio should be 5:3 if the color-octet mechanism dominates in $B \to \chi_{cJ} X$ [14].

Significant $B \rightarrow \chi_{c1}X$ signals have been observed, while the signal yield for $B \rightarrow \chi_{c2}X$ is consistent with zero. The results are shown in the following table. The details of the analysis to obtain these results can be found in [15].

Branching Ratio	Measured Value	95% C.L. Upper Limit
$\mathcal{B}(B \rightarrow \chi_{c1}X$	$(4.14\pm0.31\pm0.40)\times10^{-3}$	
$\mathcal{B}(B \rightarrow \chi_{c1}[direct]X)$	$(3.83\pm0.31\pm0.40)\times10^{-3}$	
$\mathcal{B}(B \rightarrow \chi_{c2}X)$	$(0.98\pm0.48\pm0.15)\times10^{-3}$	$< 2.0 \times10^{-3}$
$\mathcal{B}(B \rightarrow \chi_{c2}[direct]X)$	$(0.71\pm0.48\pm0.16)\times10^{-3}$	$< 1.7 \times10^{-3}$
$\frac{\mathcal{B}(B\rightarrow\chi_{c2}[direct]X)}{\mathcal{B}(B\rightarrow\chi_{c1}[direct]X)}$	$(0.18\pm0.13\pm0.04)$	< 0.44

6. Measurement of the Relative Branching Fraction of $\Upsilon(4S)$ to Charged and Neutral B-Meson Pairs

All the branching ratio measurements from the e^+e^- colliders operating at the Υ(4S) assumes equal production of charged and neutral B mesons. The best previous measurement of the admixture ratio of charged to neutral B meson production at the Υ(4S) yields a value accurate only to about 15% [16]. Better measurement of this ratio will result in better branching ratio measurements of all the charged and neutral B decays at the Υ(4S) which dominate all the B meson decays.

The relative branching fraction of Υ(4S) to charged and neutral B mesons is defined as:

$$\frac{f_{+-}}{f_{00}} \equiv \frac{\mathcal{B}[\Upsilon(4S)\rightarrow B^+B^-]}{\mathcal{B}[\Upsilon(4S)\rightarrow B^0\overline{B}^0]}$$

This ratio is measured to be:

$$\frac{f_{+-}}{f_{00}}=1.04 \pm 0.07 \pm 0.04$$

The details of the analysis can be found in [17].

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