Recent Results from CLEO Collaboration

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Recent CLEO results on beauty and charm meson decays presented at the International Conference on Flavor Physics (ICFP2001) are discussed. The results include exclusive rare B decays ($B \to PP$, PV, VV, $\phi K^{(*)}$, $l^+l^-K^{(*)}$), inclusive $b \to s\gamma$, and CP violation measurements in beauty and charm mesons. Preliminary results on rare B decays using CLEO III data are also included.

1 Introduction

The Cornell Electron Storage Ring (CESR) is a symmetric e^+e^- collider operating at the $\Upsilon(4S)$ resonance. The CLEO II and II.V detector configurations are described in detail elsewhere [1]. The integrated luminosity of the full CLEO II+II.V data is 9.2 fb^{-1} at the $\Upsilon(4S)$ 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 CLEO III data consists of 6.9 fb^{-1} at the $\Upsilon(4S)$ resonance and 2.3 fb^{-1} at energies just below the $B\bar{B}$ threshold.

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.

The analyses results described in this paper are mostly related to the CP violation study in beauty and charm meson decays. All simulated event samples were generated using GEANT-based simulation of the CLEO detector response.

2 $B \to PP$, PV, VV Decays

The CLEO collaboration has studied two-body charmless hadronic decays of B mesons into final states containing two pseudo-scalar mesons, one pseudo-scalar and one vector meson, and two vector mesons where the meson can be charged or neutral π, K, ρ or K^* etc. These charmless hadronic B decays are very important in the study of CP violation in B meson system, especially in the future measurements of the CKM angles α and γ [2].

2.1 $B \to PP$ Results

The CLEO collaboration has observed two-body charmless hadronic B decays of $B \to \pi^+\pi^-$, $K^\pm\pi^\mp$, $K^\pm\pi^0$, $K^0\pi^\pm$, $K^0\pi^0$ using CLEO II+II.V data. Upper limits are set for other PP decays. The detail of the analyses can be found in published CLEO papers [3,4]. The results are summarized in Tables 1.

Table 1: $B \to PP$ results using full CLEO II+II.V data.

Mode	$N_{\rm sig}$	Sig.	Efficiency	$BR \times 10^6$
$\pi^+\pi^-$	$20.0^{+7.6}_{-6.5}$	4.2σ	48%	$4.3^{+1.6}_{-1.4} \pm 0.5$
$\pi^\pm\pi^0$	$21.3^{+9.7}_{-8.5}$	3.2σ	39%	< 12.7 (90%C.L.)
$\pi^0\pi^0$	$6.2^{+4.8}_{-3.7}$	2.0σ	29%	< 5.7 (90%C.L.)
$K^\pm\pi^\mp$	$80.2^{+11.8}_{-11.0}$	11.7σ	48%	$17.2^{+2.5}_{-2.4} \pm 1.2$
$K^\pm\pi^0$	$42.1^{+10.9}_{-9.9}$	6.1σ	38%	$11.6^{+3.0+1.4}_{-2.7-1.3}$
$K^0\pi^\pm$	$25.2^{+6.4}_{-5.6}$	7.6σ	14%	$18.2^{+4.6}_{-4.0} \pm 1.6$
$K^0\pi^0$	$16.1^{+5.9}_{-5.0}$	4.9σ	11%	$14.6^{+5.9+2.4}_{-5.1-3.3}$
K^+K^-	$0.7^{+3.4}_{-0.7}$	0.0σ	48%	< 1.9 (90%C.L.)
$K^\pm K^0$	$1.4^{+2.4}_{-1.3}$	1.1σ	14%	< 5.1 (90%C.L.)
$K^0\bar{K}^0$	0	0.0σ	5%	< 17 (90%C.L.)

Recently, preliminary results on these decay modes using CLEO III data are reported at Lepton Photon 2001 Conference [5]. The CLEO III data consists of 6.9 fb^{-1} at the Υ(4S) resonance and 2.3 fb^{-1} at energies just below the $B\bar{B}$ threshold. The preliminary results summarized in Table 2 are based on about half of the CLEO III data. They are in good agreement with previous published CLEO results using CLEO II+II.V data (Table 1).

2.2 $B \to PV$ and VV Results

The CLEO collaboration has observed charmless hadronic B decays of $B \to \pi^\pm\rho^0$ and $\pi^\pm\rho^\mp$ using the full CLEO II+II.V data. Upper limits are set for other PV and VV decays. The detail of the analyses can be found in published CLEO papers [6,7]. The results are summarized in Tables 3.

Besides the $B \to VV$ decays in Table 3, CLEO collaboration also searched and observed $B \to \phi K^{(*)}$ decays which are clear signature of gluonic penguin process. The detail of the analyses can be found in [8]. The results are summarized in Table 4.

Table 2: Preliminary $B \to PP$ results using part of CLEO III data.

Mode	$N_{\rm sig}$	Sig.	Efficiency	$BR \times 10^6$
$\pi^+\pi^-$	$3.9^{+1.5}_{-1.2}$	2.2σ	35%	$3.2^{+3.3+1.0}_{-2.5-1.0}$
$\pi^\pm\pi^0$	$11.5^{+5.6}_{-4.5}$	3.4σ	29%	$11.7^{+5.7+2.2}_{-4.6-2.4}$
$\pi^0\pi^0$	$2.7^{+2.4}_{-1.6}$	2.9σ	29%	< 11 (90%C.L.)
$K^\pm\pi^\mp$	$29.2^{+7.1}_{-6.4}$	5.4σ	46%	$18.6^{+4.5+3.0}_{-4.1-3.4}$
$K^\pm\pi^0$	$12.9^{+6.5}_{-5.5}$	3.8σ	32%	$13.1^{+5.8+2.8}_{-4.9-2.9}$
$K^0\pi^\pm$	$14.8^{+4.9}_{-4.1}$	6.2σ	12%	$35.7^{+12.0+5.4}_{-9.9-6.2}$
$K^0\pi^0$	$3.0^{+2.9}_{-2.5}$	1.6σ	8.5%	$10.4^{+10.0+2.9}_{-8.3-2.9}$
K^+K^-	$1.0^{+2.4}_{-1.7}$	0.6σ	36%	< 4.5 (90%C.L.)
$K^\pm K^0$	$0.5^{+1.9}_{-1.1}$	0.8σ	12%	< 18 (90%C.L.)
$K^0\bar{K}^0$	$0.0^{+0.5}_{-0.5}$	0.0σ	13%	< 13 (90%C.L.)

Table 3: $B \to PV$ and VV results using full CLEO II+II.V data.

Decay Mode	$BR \times 10^6$	Theoretical Prediction $\times 10^6$
$\pi^\pm\rho^0$	$10.4^{+3.3}_{-3.4} \pm 2.1$	$0.4 - 13.0$
$\pi^\pm\rho^\mp$	$27.6^{+8.4}_{-7.4} \pm 4.2$	$12 - 93$
$\pi^0\rho^0$	< 5.5	$0.0 - 2.5$
$K^\pm\rho^0$	< 17	$0.0 - 6.1$
$\pi^\pm K^{*0}$	< 16	$3.4 - 13.0$
$K^\pm K^{*0}$	< 5.3	$0.2 - 1.0$
$\rho^0\rho^0$	< 4.6 (5.9)	$0.54 - 2.5$
$K^{*0}\rho^0$	< 13 (19)	$0.7 - 6.2$
$K^{*0}\bar{K}^{*0}$	< 8.7 (10)	$0.28 - 0.96$

3 Inclusive $b \to s\gamma$

Inclusive $b \to s\gamma$ is electroweak-penguin process which is sensitive to $V^*_{ts}V_{tb}$ and new physics beyond the SM. The experimental challenge in this analysis is to suppress huge backgrounds from continuum. Photon candidate in the momentum range of 2.0GeV $< E_\gamma <$ 2.7GeV are selected. Lepton tag, Event shape variables (using neural net) and "pseudo reconstruction" techniques are used to suppress the continuum background. The measurement result, in comparison with prediction in the SM are:

- $\mathcal{B}(b \to s\gamma) = (2.85 \pm 0.35 \pm 0.22) \times 10^{-4}$
- SM prediction: $\mathcal{B}(b \to s\gamma) = (3.28 \pm 0.33) \times 10^{-4}$

Table 4: Observation of $B \to \phi K^{(*)}$ decays using full CLEO II+II.V data.

Mode	$N_{\rm sig}$	Sig.	Efficienty	$BR \times 10^6$
$\phi K^\pm$	$14.2^{+5.5}_{-4.5}$	5.4σ	54%	$5.5^{+2.1}_{-1.8} \pm 0.6$
ϕK^0	$4.2^{+2.9}_{-2.1}$	2.9σ	48%	< 12.3 (90%C.L.)
ϕK Combined		6.1σ		$5.5^{+1.8}_{-1.5} \pm 0.7$
$\phi K^{*0}(K^-\pi^+)$	$12.1^{+5.3}_{-4.3}$	4.5σ	38%	$9.9^{+4.3}_{-3.5} \pm 1.6$
$\phi K^{*0}(K^0\pi^0)$	$5.1^{+3.9}_{-2.8}$	2.7σ	20%	$46.3^{+35.7+5.9}_{-26.0-6.6}$
ϕK^{*0} Combined		5.1σ		$11.5^{+4.5+1.8}_{-3.7-1.7}$
$\phi K^{*\pm}(K^\pm\pi^0)$	$3.8^{+4.1}_{-2.8}$	1.5σ	25%	$9.3^{+10.1+1.7}_{-7.0-1.5}$
$\phi K^{*\pm}(K^0\pi^\pm)$	$4.0^{+3.1}_{-2.2}$	2.7σ	32%	$11.4^{+9.0}_{-6.3} \pm 1.8$
$\phi K^{*\pm}$ Combined		3.1σ		$10.6^{+6.4+1.8}_{-4.9-1.6}$
ϕK^* Combined		5.9σ		$11.2^{+3.6+1.8}_{-3.1-1.7}$

4 Exclusive $B \to l^+l^-K$ and $l^+l^-K^*$

Exclusive Flavor-Changing-Neutral-Current (FCNC) processes: $B \to l^+l^-K$ and $l^+l^-K^*$ are highly suppressed in the SM. The branching ratio of these processes in the SM are $\sim$ (10^{-6} to 10^{-7}) [9]. However, these branching ratios are sensitive to new physics beyond the SM (SUSY etc) [10]. The important issues in this analysis are:

- Select Lepton and Kaon (from pion backgrounds) candidates
- Suppress Physics Backgrounds:
  - $B \to J/\psi K^{(*)}$ where $J/\psi \to e^+e^-$ or $\mu^+\mu^-$
  - $B \to \psi(2S)K^{(*)}$ where $\psi(2S) \to e^+e^-$ or $\mu^+\mu^-$
- Suppress Continuum and other B backgrounds:
  - Event Shape variable, Missing Energy, etc

The detail of the analyses can be found in [11]. The results are summarized in Table 5.

5 *CP* asymmetry measurements in *B* meson decays

5.1 CP asymmetry measurement in inclusive $b \to s\gamma$

The CP asymmetry in inclusive $b \to s\gamma$ defined as: $\mathcal{A}_{CP} \equiv \frac{\Gamma(b\to s\gamma)-\Gamma(\bar{b}\to\bar{s}\gamma)}{\Gamma(b\to s\gamma)+\Gamma(\bar{b}\to\bar{s}\gamma)}$. is measured at CLEO using full CLEO II+II.V data. While $\mathcal{A}_{CP}$ is predicted

Table 5: Exclusive Flavor-Changing-Neutral-Current (FCNC) $B \to l^+l^-K$ and $l^+l^-K^*$ results using full CLEO II+II.V data.

Decay Mode	Efficiency	Evts Obsved	BR UL (90% CL)
$B \to K^0 e^+e^-$	5.3%	1	$< 7.6\times10^{-6}$
$B \to K^0 \mu^+\mu^-$	4.1%	0	$< 7.8\times10^{-6}$
$B \to K^\pm e^+e^-$	16.5%	1	$< 2.3\times10^{-6}$
$B \to K^\pm \mu^+\mu^-$	11.1%	1	$< 3.4\times10^{-6}$
$B \to K l^+l^-$	37.0%	3	$< 1.5\times10^{-6}$
$B \to K^{*\pm}(K^0\pi^\pm)e^+e^-$	1.9%	0	$< 12.8\times10^{-6}$
$B \to K^{*\pm}(K^0\pi^\pm)\mu^+\mu^-$	1.5%	0	$< 15.6\times10^{-6}$
$B \to K^{*\pm}(K^\pm\pi^0)e^+e^-$	1.5%	3	$< 46.0\times10^{-6}$
$B \to K^{*\pm}(K^\pm\pi^0)\mu^+\mu^-$	0.8%	0	$< 29.3\times10^{-6}$
$B \to K^{*0}(K^\pm\pi^\mp)e^+e^-$	7.1%	1	$< 5.0\times10^{-6}$
$B \to K^{*0}(K^\pm\pi^\mp)\mu^+\mu^-$	5.2%	0	$< 4.6\times10^{-6}$
$B \to K^{*0}(K^0\pi^0)e^+e^-$	0.7%	0	$< 35.8\times10^{-6}$
$B \to K^{*0}(K^0\pi^0)\mu^+\mu^-$	0.2%	0	$< 117.3\times10^{-6}$
$B \to K^* l^+l^-$	18.8%	4	$< 2.9\times10^{-6}$

in the SM to be $< 1.0\%$, $\mathcal{A}_{CP}$ can be as large as $\approx (10-40)\%$ due to non-SM contributions. Therefore, observation of large $\mathcal{A}_{CP}$ in inclusive $b \to s\gamma$ would indicate clear signature of new physics beyond the SM.

Similar to previous inclusive $b \to s\gamma$ branching ratio measurement analysis, we select photon candidate in the momentum range of 2.0GeV $< \mathrm{E}_\gamma <$ 2.7GeV. The s quark flavor is tagged by Lepton tag (from the other B), or the flavor of K in "pseudo reconstruction" with mistake rates, On-off subtraction, particle detection biases taken into account. The measurement results are:

- $\mathcal{A}_{CP} = (-0.079 \pm 0.108 \pm 0.022)(1.0 \pm 0.030)$ or
- $-0.27 < \mathcal{A}_{CP} < +0.10$ (90% C.L.)

5.2 CP asymmetry measurement in exclusive rare B decays

CP asymmetry in self tagging exclusive B decays are also measured at CLEO using full CLEO II+II.V data [12]. The CP asymmetry is defined as $\mathcal{A}_{CP} \equiv \frac{\mathcal{B}(\bar{B}\to\bar{f})-\mathcal{B}(B\to f)}{\mathcal{B}(\bar{B}\to\bar{f})+\mathcal{B}(B\to f)}$. In SM, the predicted CP asymmetry is $\approx \pm\, 0.1\%$ [13]. The results of CP asymmetry measurement in exclusive rare B decays: $B \to K^\pm\pi^\mp$, $K^\pm\pi^0$, $K_s^0\pi^\pm$, $K^\pm\eta'$, $\omega\pi^\pm$ and charmonia decays: $B \to J/\psi K^\pm$, $\psi(2S)K^\pm$ are summarized in Table 6. The CP asymmetries observed in these decay modes are all consistent with zero.

Table 6: CP asymmetry measurements for exclusive rare B decays using full CLEO II+II.V data.

Decay Mode	$N_{\rm sig}$	$\mathcal{A}_{CP}$	Prediction
$B \to K^{\pm}\pi^{\mp}$	80^{+12}_{-11}	-0.04 ± 0.16	(+0.037, + 0.106)
$B \to K^{\pm}\pi^{0}$	$42.1^{+10.9}_{-9.9}$	-0.29 ± 0.23	(+0.026, +0.092)
$B \to K^{0}_{s}\pi^{\pm}$	$25.2^{+6.4}_{-5.6}$	$+0.18 \pm 0.24$	+0.015
$B \to K^{\pm}\eta'$	100^{+13}_{-12}	$+0.03 \pm 0.12$	(+0.020, +0.061)
$B \to \omega\pi^{\pm}$	$28.5^{+8.2}_{-7.3}$	-0.34 ± 0.25	(−0.120, +0.024)
$B \to J/\psi K^{\pm}$	534	$+0.018 \pm 0.043$	< 0.04
$B \to \psi(2S) K^{\pm}$	120	$+0.020 \pm 0.092$	< 0.04

6 CP asymmetry measurement in charm meson decays

Cabibbo suppressed charm meson decays have all the necessary ingredients for CP violation – multiple paths to the same final state and a weak phase difference. However, in order to get sizable CP violation, the final state interactions need to contribute non-trivial phase shifts between the amplitudes, as the SM prediction for CP asymmetry is very small ($\sim 0.1\%$). Therefore, CP asymmetry in charm meson decays is another place to hunt for new physics beyond the SM.

All of the analyses presented in this paper use the same general technique. The D^0 candidates are reconstructed through the decay sequence $D^{\star +} \to D^0 \pi^+_{\rm s}$ [14]. The charge of the slow pion ($\pi^+_{\rm s}$) tags the flavor of the D^0 candidate at production. The charged daughters of the D^0 are required to leave hits in the silicon vertex detector and these tracks are constrained to come from a common vertex in three dimensions. The trajectory of the D^0 is projected back to its intersection with the CESR luminous region to obtain the D^0 production point. The $\pi^+_{\rm s}$ is refit with the requirement that it come from the D^0 production point, and the confidence level of the χ^2 of this refit is used to reject background.

The energy release in the $D^\star \to D^0\pi^+_{\rm s}$ decay, $Q \equiv M^\star - M - m_\pi$, obtained from the above technique is observed to have a width of $\sigma_Q = 190 \pm 2$ keV, [15] which is a combination of the intrinsic width and our resolution, where M and $M^\star$ are the reconstructed masses of the D^0 and $D^{\star +}$ candidates respectively, and m_π is the charged pion mass. The reconstruction technique discussed above has also been used by CLEO to measure the D^{*+} intrinsic width, $\Gamma_{D^{*+}} = 96 \pm 4 \pm 22$ keV (preliminary).[16]

We searched for direct CP violation in neutral charm meson decay to pairs of light pseudo-scalar mesons: K^+K^-, $\pi^+\pi^-$, $K^0_s\pi^0$, $\pi^0\pi^0$ and $K^0_sK^0_s$.

6.1 *Search for* CP *violation in* $D^0 \to K^+K^-$ *and* $D^0 \to \pi^+\pi^-$ *decay*

The slow charged pion and D^0 are produced by the CP-conserving strong decay of the $D^{\star +}$, so the slow pion serves as an unbiased flavor tag of the D^0. The decay asymmetry can be obtained from the apparent production asymmetry shown above because the production of $D^{\star\pm}$ is CP-conserving.

The asymmetry result is obtained by fitting the energy release (Q) spectrum of the $D^{\star +} \to D^0\pi^+_s$ events. The D^0 mass spectra are fit as a check. The background-subtracted Q spectrum is fit with a signal shape obtained from $K^+\pi^-$ data and a background shape determined using Monte Carlo. The parameters of the slow pion dominate the Q distribution, so all modes have the same shape. We do the fits in bins of D^0 momentum to eliminate any biases due to differences in the D^0 momentum spectra between the data and the MC. The preliminary results are:

- $A(K^+K^-) = 0.0005 \pm 0.0218(\text{stat}) \pm 0.0084(\text{syst})$
- $A(\pi^+\pi^-) = 0.0195 \pm 0.0322(\text{stat}) \pm 0.0084(\text{syst})$

The measured asymmetries are consistent with zero, and no CP violation is seen. These results are the most precise to date.[17]

6.2 *Search for* CP *Violation in* $D^0 \to K^0_S\pi^0$, $D^0 \to \pi^0\pi^0$ *and* $D^0 \to K^0_sK^0_s$ *decay*

This analysis[18] differs from the other analyses presented in this paper in some of its reconstruction techniques and in the data set used. The $\pi^0\pi^0$ and $K^0_s\pi^0$ final states do not provide sufficiently precise directional information about their parent D^0 to use the intersection of the D^0 projection and the CESR luminous region to refit the slow pion as described in the general experimental technique section. The $K^0_sK^0_s$ final state is treated the same for consistency. This analysis uses the data from both the CLEO II and CLEO II.V configurations of the detector.

The K^0_s and π^0 candidates are constructed using only good quality tracks and showers. The tracks (showers) whose combined invariant mass is close to the K^0_s (π^0) mass are kinematically constrained to the K^0_s (π^0) mass, improving the D^0 mass resolution. The tracks used to form K_s^0 candidates are required to satisfy criteria designed to reduce background from $D^0 \to \pi^+\pi^- X$ decays and combinatorics. Candidate events with reconstructed D^0 masses close to the known D^0 mass are selected to determine the asymmetry. The total number of D^0 and $\overline{D^0}$ candidates for a given final state is determined as follows. We fit the Q distribution outside of the signal region and interpolate the fit under the signal peak to determine the background in the signal region. We subtract the background in the signal region from the total number of events there to determine the total number of signal events. After background subtraction, we obtain 9099 ± 153 $K_s^0\pi^0$ candidates, 810 ± 89 $\pi^0\pi^0$ candidates, and 65 ± 14 $K_s^0 K_s^0$ candidates.

The difference in the number of D^0 and $\overline{D^0}$ to a given final state is determined by taking the difference of the number of events in the signal region, and the asymmetry is obtained by dividing by the number of candidates determined above. This method of determining the asymmetry implicitly assumes that the background is symmetric.

We obtain the results:

- $A(K_s^0\pi^0) = (+0.1 \pm 1.3)\%$
- $A(\pi^0\pi^0) = (+0.1 \pm 4.8)\%$
- $A(K_s^0 K_s^0) = (-23 \pm 19)\%$

where the uncertainties contain the combined statistical and systematic uncertainties. All measured asymmetries are consistent with zero and no indication of significant CP violation is observed. This measurement of $A(K_s^0\pi^0)$ is a significant improvement over previous results, and the other two asymmetries reported are first measurements.

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