A Study of B meson Decays to Charm at Belle

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With $10\text{ fb}^{-1}$ data from Belle, the results of b to c and u decays have been represented here. Several decay modes have been studied, which include charmonium, semileptonic decay and Cabibbo-suppressed decays mode. The preliminary results and the measurements of KM matrix elements will also be presented here.

1 Introduction

B decays provide a very rich ground for the test of the Standard Model (SM). The Kobayashi-Maskawa (KM) matrix is incorporated in weak decays sector of the Standard Model to explain the quark mixing and CP violation. Hence, the experimental measurements of all the KM matrix elements will either complete our understanding on the weak interaction or lead to the new physics beyond the Standard Model.

The charmonium mesons from B decays play an important role in the studies of CP violation phenomena. Their production mechanism also provides the test ground for low energy QCD. The Cabibbo-suppressed modes $B \to DK$ can provide a theoretically clean method to determine $\phi_3$ (also known as $\gamma$). Ratio of the Cabiboo-suppressed $B \to D^{(*)}K$ to the Cabiboo-allowed $B \to D^{(*)}\pi$ will give us information on Cabiboo mixing angle, pion and kaon decay constants assuming factorization and SU(3) symmetry. The measurements of B semileptonic decays branching ratio will give us the measurements of $V_{cb}$ and $V_{ub}$, another KM matrix elements.

In this paper, the KEKB storage ring, Belle detector and its performance will not be described here. The complete description can be found in reference elsewhere. This paper will be organized as the follows. The brief analysis techniques will be described in the section 2. Following that section will be the preliminary results of selected decay modes, where the more detailed analysis information can be found in [http://belle.kek.jp/belle/publications.html].

2 Analysis

2.1 General Features

The results are based on the 10.5 $\text{ fb}^{-1}$ data collected on the $\Upsilon(4S)$ energy (resonance) and 0.6 $\text{ fb}^{-1}$ data on the energy 60 $\text{ MeV}$ lower than the $\Upsilon(4S)$ resonance energy (off-resonance).

For exclusive decays, B candidates are identified through the beam constrained mass $M_B = \sqrt{E_{\text{beam}} - p_B^*}$ and $\Delta E = E_{\text{beam}} - E_B$, where $E_B, p_B^*$ are the B energy and momentum in CM frame and $E_{\text{beam}} = E_{CMS}/2$. For the two body decay modes, the daughter particles' momentum will generally fall between 2 and 3 GeV in CM frame which is very rare in general b to c decay. Therefore, the major dominant background will come from continuum events which is from
The branching ratios are: \( \text{Br} \) extracted through simultaneous fits on \( M_K B_2.3 K \) and \( J/\psi X \). The charged track multiplicity is greater than 4. The charmonium modes we reconstructed are \( J/\psi \rightarrow l^+l^- \), \( \psi(2S) \rightarrow l^+l^- (l = e \text{ or } \mu) \), \( \psi(2S) \rightarrow J/\psi \pi^+\pi^- \) and \( \chi_c \rightarrow J/\psi \gamma \). For \( J/\psi \) mode, with 530 \( \pm \) 43 from the resonance data and 30 \( \pm \) 7 from the off-resonance data, we got 17.5 \( \pm \) 127 after off-resonance data subtraction. The results show no direct \( J/\psi \) production from \( Y(4S) \) with the limit \( \text{Br}(Y(4S) \rightarrow J/\psi X) < 4.1 \times 10^{-4} \). This is incompatible with the CLEO measurement: \( (2.2 \pm 0.6 \pm 0.4) \times 10^{-3} \). All the observed ones are consistent with from \( ee \rightarrow \gamma^* \) process. We obtained \( \sigma(e^+e^- \rightarrow q\bar{q} \rightarrow J/\psi X) = (1.02 \pm 0.08 \pm 0.12) \) pb. The ratio R of \( J/\psi \), which is \( \sigma(e^+e^- \rightarrow q\bar{q} \rightarrow J/\psi X) / \sigma(e^+e^- \rightarrow \mu^+\mu^-) \), is \( (1.32 \pm 0.14 \pm 0.15) \times 10^{-3} \). The results for direct \( \psi(2S)X \) is \( \sigma(e^+e^- \rightarrow q\bar{q} \rightarrow \psi(2S)X) = (0.54 \pm 0.12) \) pb. Both the production cross-section of \( J/\psi \) and \( \psi(2S) \) agree well with NRQCD calculation.

For inclusive charmonium from B decays, the charmonium momentum in CM frame is required to be less than 1.7 GeV/c. \( \chi_c \) is identified through mass difference \( m(l^+l^-\gamma) - m(l^+l^-) \). Charge multiplicity and off-resonance data subtraction are also applied. Results are: \( \text{Br}(B \rightarrow J/\psi X) = (0.25 \pm 0.04 \pm 0.03) \times 10^{-2} \), \( \text{Br}(B \rightarrow \psi'(l^+l^-)X) = (0.25 \pm 0.04 \pm 0.03) \times 10^{-2} \), \( \text{Br}(B \rightarrow \psi(\psi\pi\pi)X) = (0.31 \pm 0.04 \pm 0.04) \times 10^{-2} \), \( \text{Br}(B \rightarrow \chi_{c1}X) = (0.39 \pm 0.03 \pm 0.05) \times 10^{-4} \), \( \text{Br}(B \rightarrow \chi_{c2}X) = (0.18 \pm 0.05 \pm 0.02) \times 10^{-4} \).

### 2.2 Charmonium Production

For direct charmonium production, the momentum of that charmonium in the CM frame is required to be greater than 2 GeV/c, which kinematically eliminate the charmonium from B decays. The charged track multiplicity is greater than 4. The charmonium modes we reconstructed are \( J/\psi \rightarrow l^+l^- \), \( \psi(2S) \rightarrow l^+l^- (l = e \text{ or } \mu) \), \( \psi(2S) \rightarrow J/\psi \pi^+\pi^- \) and \( \chi_c \rightarrow J/\psi \gamma \). For \( J/\psi \) mode, with 530 \( \pm \) 43 from the resonance data and 30 \( \pm \) 7 from the off-resonance data, we got 17.5 \( \pm \) 127 after off-resonance data subtraction. The results show no direct \( J/\psi \) production from \( Y(4S) \) with the limit \( \text{Br}(Y(4S) \rightarrow J/\psi X) < 4.1 \times 10^{-4} \). This is incompatible with the CLEO measurement: \( (2.2 \pm 0.6 \pm 0.4) \times 10^{-3} \). All the observed ones are consistent with from \( ee \rightarrow \gamma^* \) process. We obtained \( \sigma(e^+e^- \rightarrow q\bar{q} \rightarrow J/\psi X) = (1.02 \pm 0.08 \pm 0.12) \) pb. The ratio R of \( J/\psi \), which is \( \sigma(e^+e^- \rightarrow q\bar{q} \rightarrow J/\psi X) / \sigma(e^+e^- \rightarrow \mu^+\mu^-) \), is \( (1.32 \pm 0.14 \pm 0.15) \times 10^{-3} \). The results for direct \( \psi(2S)X \) is \( \sigma(e^+e^- \rightarrow q\bar{q} \rightarrow \psi(2S)X) = (0.54 \pm 0.12) \) pb. Both the production cross-section of \( J/\psi \) and \( \psi(2S) \) agree well with NRQCD calculation.

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### 2.3 \( B \rightarrow J/\psi K_1(1270) \)

In this decay modes, \( K_1(1270) \) is reconstructed through modes: \( K^+\pi^+\pi^- \), \( K^+\pi^-\pi^0 \) and \( K_\rho^+\pi^+\pi^- \). The feed-down from \( \psi(2s) \rightarrow J/\psi\pi\pi \) are also excluded here. The yields are extracted through simultaneous fits on \( M_B \) and \( \Delta E \) of B candidate while cutting \( K\pi \) in the \( K_1(1270) \) mass range. The results are shown in Fig. and the fitted numbers are 53.4 \( \pm \) 9.1 events for \( J/\psi K^+\pi^-\pi^- \), 19.3 \( \pm \) 5.1 events for \( J/\psi K^+\pi^-\pi^0 \) and 6.2 \( \pm \) 2.6 events for \( J/\psi K^0\pi^+\pi^- \). The branching ratio ratio are: \( \frac{\text{Br}(B \rightarrow J/\psi K_1^+(1270))}{\text{Br}(B \rightarrow J/\psi K^+)} = 1.30 \pm 0.34 \pm 0.28 \), \( \frac{\text{Br}(B \rightarrow J/\psi K_1^-(1270))}{\text{Br}(B \rightarrow J/\psi K^-)} = 1.80 \pm 0.34 \pm 0.34 \).
and obtain $(3\rho)$. The invariant mass of $D$ is required to be within $4\Delta E$ and also be applied to get a clean $D$ sample. The $\Delta E(B \to D^*K)$ distribution is shown in Fig. 2. The branching fraction we measure is $\mathcal{B}(B \to D^*K) = 0.079 \pm 0.009 \pm 0.006$, $\mathcal{B}(B \to D^+\pi^-) = 0.068 \pm 0.015 \pm 0.007$, $\mathcal{B}(B \to D^0\pi^-) = 0.078 \pm 0.019 \pm 0.009$ and $\mathcal{B}(B \to D^0\pi^-) = 0.074 \pm 0.015 \pm 0.006$.

2.4 Cabiboo Suppressed $B \to D^{(*)}K$ decays

Due to the good particle identification system in Belle, we can easily reduce the Cabiboo favored $B \to D^{(*)}\pi$ feed-down and extract the $B \to D^{(*)}K$. The $D^{(*)}$ and $D^{(*)}$ candidate are reconstructed through $D^{(*)} \to D^0\pi^0$, $D^{(*)} \to D^0\pi^+$ and $D^{(*)} \to D^0\pi^0$ with $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-3(\pi^\pm)$ and $D^+ \to K^-\pi^+\pi^+, K_s\pi^+$, $K_s\pi^+\pi^0$, $K_s\pi^+\pi^+\pi^-$. The $K^{(*)}$ is reconstructed through $K_s\pi^+$. The invariant mass of $D$ is required to be within 4$r$ of the known $D$ mass. Vertex cuts will also be applied to get a clean $D$ sample. The $\Delta E$ distribution is shown in Fig. 3. Results are $\mathcal{B}(B \to D^0K) = 0.079 \pm 0.009 \pm 0.006$, $\mathcal{B}(B \to D^+\pi^-) = 0.068 \pm 0.015 \pm 0.007$, $\mathcal{B}(B \to D^0\pi^-) = 0.078 \pm 0.019 \pm 0.009$ and $\mathcal{B}(B \to D^0\pi^-) = 0.074 \pm 0.015 \pm 0.006$.

2.5 $|V_{cb}|$ measurements

Data used in these analysis ranges from 5.1 $pb^{-1}$ to 5.8 $pb^{-1}$. There are basically two methods for this measurement. One is to measure the lepton spectrum from dilepton events by tagging one lepton within $1.5 < \not\!p_T < 2.2 \ GeV/c$. The primary and the secondary lepton spectrum are then fitted simultaneously (Fig. 3). The branching fraction we measure is $\mathcal{B}(B \to Xe\nu_e) = (11.05 \pm 0.15 \pm 0.46)\%$. The $|V_{cb}|$ is extracted through the relation $|V_{cb}|^2 = \frac{\mathcal{B}(B \to D^{(*)}K)}{(\tau_B\gamma_c)}$, which give $|V_{cb}| = (4.15 \pm 0.09 \pm 0.26) \times 10^{-2}$ with $\gamma_c = 40 \pm 8$ from ACCM model and $|V_{cb}| = (4.05 \pm 0.09 \pm 0.24) \times 10^{-2}$ with $\gamma_c = 42 \pm 8$ from ISGW** model.

Another method is based on the Heavy Quark Effect Theory (HQET) which provide a accurate estimation of $|V_{cb}|$ through form factor at the zero recoil energy limit. The form factor can be approximated as $F_{D^{(*)}}(y) = F_D^{(*)}(1)(1 - \rho_{D^{(*)}}^2(y - 1))$. We fit $\rho^2$ and $|V_{cb}|F_{D^{(*)}}(1)$ simultaneously. Assuming a linear form factor, we obtain $|V_{cb}|F_{D^{(*)}}(1) = (3.57 \pm 0.11 \pm 0.13) \times 10^{-2}$, $\rho_{D^*}^2 = 0.93 \pm 0.02 \pm 0.02$ for $B \to D^*\nu\nu$. Using $F(1)D^* = 0.913 \pm 0.042$, we have $|V_{cb}| = (3.91 \pm 0.12(stat) \pm 0.15(sys) \pm 0.16(\nu\nu)) \times 10^{-2}$. For $D_l\nu$ mode, we use $F(1)D = 1.0 \pm 0.07$ and obtain $|V_{cb}|F_{D(1)} = (4.42 \pm 0.48 \pm 0.35) \times 10^{-2}$, $\rho_{D^*}^2 = 0.89 \pm 0.14 \pm 0.06$ and $|V_{cb}| =
\[ (4.42 \pm 0.48 (\text{stat}) \pm 0.35 (\text{sys}) \pm 0.30 (\text{theory})) \times 10^{-2}. \] Figure 4 show the fits results.

3 Conclusion

With 11 fb\(^{-1}\) data, various decay modes have been study which include charmonium mesons, Cariboo-suppress \(D^{(*)}K\) and \(|V_{cb}|\) measurement. Results are \(Br(\Upsilon(4S) \to J/\psi X) < 4.1 \times 10^{-4}\), \(\sigma(e^+e^- \to q\bar{q} \to J/\psi X) = (1.02 \pm 0.08 \pm 0.12)\) pb, \(\sigma(e^+e^- \to q\bar{q} \to \psi(2S)X) = (0.54 \pm 0.12)\) pb, \(\frac{Br(B \to J/\psi K^0(1270))}{Br(B \to J/\psi K^+)} = 1.30 \pm 0.34 \pm 0.28 \) and \(\frac{Br(B \to J/\psi K^+_{(1270)})}{Br(B \to J/\psi K^+)} = 1.80 \pm 0.34 \pm 0.34\) for charmonium meson. From dilepton analysis, we have \(Br(B \to Xe\bar{\nu}_e) = (11.05 \pm 0.15 \pm 0.46\)% and obtain \(|V_{cb}|F_{F_D^{(1)}}(1) = (3.57 \pm 0.11 \pm 0.13) \times 10^{-2}\), \(|V_{cb}|F_{D^{(*)}(1)} = (4.42 \pm 0.48 \pm 0.35) \times 10^{-2}\) from \(D^*l\nu\) and \(Dl\nu\) analysis respectively.

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