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The physics program of open charm and heavy $\mathrm{c\bar{c}}$ states at the BES-Ⅲ experiment *

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Abstract We present the physics program of the open charm and heavy $\mathrm{c\bar{c}}$ states above the $\mathrm{D\bar{D}}$ production energy threshold, which will be studied with the BES-Ⅲ detector at the BEPC-Ⅱ collider in the coming years. Based on some full Monte Carlo simulations with the BES-Ⅲ detector, we predict the accuracy levels on measuring some physical quantities related to D^0, D^+ and D_s^+ decays as well as some non-charmed decays of the heavy $\mathrm{c\bar{c}}$ states.

Key words D semileptonic decays, $\mathrm{D}_{(s)}^+$ purely leptonic decays, CKM matrix elements, Standard Model, $\mathrm{D^0\bar{D}^0}$ mixing, CP violation in D decays, Rare D and D_s^+ decays, non-charmed decays of heavy resonances

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1 Introduction

The purpose of precise measurements of the absolute decay branching fractions of the open charm (D^0, D^+ and D_s^+ mesons) is to overcome the non-perturbative QCD roadblock in precision tests of the standard model (SM) and to probe new physics (NP) beyond the SM. While the purpose of precise measurements of the non-charmed decay branching fractions of the heavy resonances above the $\mathrm{D\bar{D}}$ production energy threshold is to test the perturbative QCD (pQCD) calculations on the decays due to strong interaction and to search for some new structure(s) in the open charm energy region.

2 BES-Ⅲ experiment at BEPC-Ⅱ

The BES-Ⅱ is a double-ring machine with designed peak luminosity of 1×10^{33} $\mathrm{cm^{-2}s^{-1}}$ at the center-of-mass energy $\sqrt{s}=3.78$ GeV. The peak luminosity of the machine at 3.78 GeV achieved 30% of the designed peak luminosity in the summer of 2009, which is a factor 30 (5) bigger than that of the BEPC (CESR-c) luminosity. The BES-Ⅲ is a brand new detector [1] which works at the collision point of the BES-Ⅱ.

Up to the next summer, we will have 5 month for data taking around 3.773 GeV to accumulate the $\psi(3770)$ events. In the future, we are going to spend about 5 years on collecting the open charm data at 3.773 GeV, 4.03 GeV, and/or 4.17 GeV. Totally, we are going to collect about 120 M $\mathrm{D\bar{D}}$ events corresponding to about 140 M of $\psi(3770)$ events produced at the $\psi(3770)$ peak. This data sample is a factor 25 larger than $\mathrm{D\bar{D}}$ events collected by the CLEO-c collaboration. In addition, we are planning to make finer energy scan in the open charm energy region, covering the heavy $\mathrm{c\bar{c}}$ resonances and the charmonium-like states known as the X, Y and Z particles.

At the center-of-mass energies near the $\mathrm{D\bar{D}}$ and $\mathrm{D_s^+D_s^-}$ production thresholds, the D^0, D^+ and D_s^+ mesons are produced in pair. We can take the advantage of the fully reconstructed one of the open-charm pair to study the other anti-open-charm decays. This is called double tag analysis. The double tag analyses give us an opportunity to make absolute branching fraction measurements. Taking the advantage of the coherent events for $\psi(3770)$ production and decay to $\mathrm{D^0\bar{D}^0}$, as well as the coherent events for $\psi(4030)$ production and decay to $\mathrm{D^*\bar{D}}$, we can study the $\mathrm{D^0\bar{D}^0}$ mixing and CP violation in D meson decays. Using

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the double tag technique, we can clearly reconstruct the missing neutrino in the semileptonic and purely leptonic decays of the open charm mesons. These make the precisely measuring the branching fractions for $D^0 \to K^-(\pi^-)e^+\nu$ and $D^+_{(s)} \to \mu^+(\tau^+, e^+)\nu$ decays possible. These precisely measured branching fractions can be used to extract out the decay form factors $f^K_+(0)$ and $f^\pi_+(0)$, the CKM matrix elements $|V_{cs}|$ and $|V_{cd}|$, as well as the decay constants f_{D^+} and $f_{D^+_s}$. These quantities can be served as input constants for the precision test of the SM. With the open charm data samples, we can study the properties of the X, Y and Z particles, as well as search for some new structures in the open charm energy region.

3 Precision test of the SM

3.1 The role of open charm in CKM physics

The goal of the CKM physics is to over-constrain the CKM matrix with a range of measurements in the flavor changing sector of the SM. If any significant deviation of the measured sides and angles from the triangle condition of the unitarity triangle is found, it is evident for new physics. The inputs to over-constrain the CKM matrix are $|V_{ud}|$, $|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$, $B(B \to \tau\nu)$, ϵ_K, Δm_d, Δm_s, $\sin 2\beta$, $\cos 2\beta$, α and γ. One of the main goals for precisely measuring the transition rates of B mesons is to over-constrain the CKM matrix parameters and to find this significant deviation, which can be used to precisely test the SM.

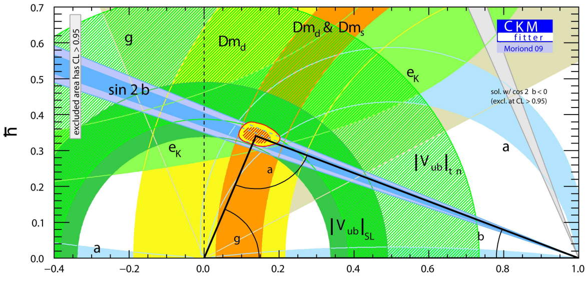

Fig. 1. The constraints in the $(\bar{\rho}, \bar{\eta})$ plane of B_d unitarity triangle including the most recent inputs in the global CKM fit.

However, at present, due to the limited capacity in dealing with non-perturbative strong interaction dynamics, extractions of the CKM matrix parameters suffer from large uncertainties. Fig. 1 shows the current status of the constraints on the CKM matrix. The rather large allowed region, except the width of $\sin 2\beta$, is mainly due to the theoretical uncertainties on the calculation of the hadronic current matrix elements (i.e. form factors of B semileptonic decays and B decay constants) from LQCD. In recent years, LQCD produced calculations of the charm and beauty decay form factors and decay constants with reduced uncertainties. These non-perturbative quantities need to be checked with experimental data. The semileptonic and purely leptonic decays of the D^0, D^+ and D^+_s can be used to test or calibrate the LQCD calculations of the form factors and decay constants. If the LQCD calculations of the open charm semileptonic decay form factors and decay constants pass the test with the open charm data, the calculated non-perturbative quantities related to B decays from LQCD can be used in B physics with much greater confidence. Using these calculations of the non-perturbative quantities combined with B factory data, together with the improvement in the measurement of $|V_{tb}|$ at Tevatron experiment, the uncertainties on the measurements of $|V_{ub}|$, $|V_{cb}|$, $|V_{td}|$ and $|V_{ts}|$ can be significantly reduced down. In turn, the over-constraint CKM matrix can give the improved knowledge of the B_d unitarity triangle which thereby maximizes to probe NP. To this end, the open charm semileptonic and purely leptonic decays really play some important roles in the precision tests of the SM and in probing NP.

In addition, any significant inconsistency between the precisely direct measurements of $|V_{cs}|$ and $|V_{cd}|$ from the open charm decays and those obtained from the CKM fit could provide a valuable indication of NP beyond the SM in the first two quark generation.

3.2 Semileptonic decays

The semileptonic decay rates of $\Gamma(D^0 \to K^-(\pi^-) e^+\nu)$ are related to the CKM matrix elements and the form factors by

$$\Gamma(D^0 \to K^- e^+\nu) = 1.53|V_{cs}|^2|f^K_+(0)|^2 \times 10^{11} s^{-1}$$

and

$$\Gamma(D^0 \to \pi^- e^+\nu) = 3.01|V_{cd}|^2|f^\pi_+(0)|^2 \times 10^{11} s^{-1}.$$

With the decay branching fractions for $D^0 \to K^-(\pi^-) e^+\nu$ and the well-known lifetime of the D^0 meson, we can extract out the $|V_{cs}|$ and $|V_{cd}|$ and/or form factors $f^K_+(0)$ and $f^\pi_+(0)$. The accuracy levels for determinations of the $|V_{cs}|$ and $|V_{cd}|$ are, respectively, about 1.6% and 1.8% with 4 fb^{-1} of $\psi(3770)$ data. These precise measurements of $|V_{cs}|$ and $|V_{cd}|$ will give great contribution to CKM unitarity. The systematic errors on the measured $|V_{cs}|$ and $|V_{cd}|$ are dominated by the uncertainties in the inputs of the form factors from LQCD calculations. In these determinations, we assume that the uncertainties of the form factors can be reduced to about 1.5%. The statistical uncertainties in the measured branching fractions for $D^0 \to K^- e^+ \nu$ and $D^0 \to \pi^- e^+ \nu$ are about 0.7% and 1.8%, respectively. The systematic errors on these measured branching fractions can be reduced to about 1% at the BES-III.

Using the $|V_{cs}|$ and $|V_{cd}|$ as the inputs, obtained from CKM fit, we can determine the form factors for $D^0 \to K^- e^+ \nu$ and $D^0 \to \pi^- e^+ \nu$ decays. The uncertainties in the determinations of $f_+^K(0)$ and $f_+^\pi(0)$ can be reduced to 1.2% and 1.5%, respectively. These uncertainties are dominated by the uncertainties of $|V_{cs}|$ and $|V_{cd}|$. In the estimation of the uncertainties of $f_+^K(0)$ and $f_+^\pi(0)$, we assume that the uncertainties of $|V_{cs}|$ and $|V_{cd}|$ are about 1.0% obtained from the global CKM fitting.

With 4 fb^{-1} of $\psi(3770)$ data, we can measure the dependence of the form factors $f_+^{K(\pi)}(q^2)$ on square of the four momentum transfer q^2, and compare this dependence with the predictions from LQCD calculations. This comparison can be used to calibrate the LQCD calculations of these quantities at different four momentum transfer q^2.

With these $\psi(3770)$ data sample, we can precisely measure the inclusive semileptonic branching fractions for $D^0 \to l^+ X$, $D^+ \to l^+ X$ and $D_s^+ \to l^+ X$ (where $l = e, \mu$) decays to check whether the partial widths for these decays are identical, and we can, respectively, measure the decay branching fractions for $D^{0,+} \to e^+ X$ and $D^{0,+} \to \mu^+ X$ at the accuracy levels of about 0.3% and about 1.0% for statistical uncertainties. The systematic uncertainties for these two measured branching fractions can be reduced down to about 1%.

3.3 Purely leptonic decays

As we mentioned above, the LQCD predicts f_{D^+} and $f_{D_s^+}$. More precisely measuring the f_{D^+} and $f_{D_s^+}$ can be used to calibrate the LQCD calculations. The BES collaboration previously measured $f_{D^+}$with an uncertainty of 35% [2] for the first time. The CLEO-c collaboration made an improved measurement on f_{D^+} with an error of about 22% [3] and made another improved measurement with an uncertainty of 8% [4]. The CLEO-c expects to improve f_{D^+} measurement at the accuracy level of about 5% with 800 pb^{-1} of $\psi(3770)$ data sample. Based on a full Monte Carlo simulation, we expect that the BES-III collaboration will improve measurement of f_{D^+} at the accuracy level of about 2% (1.5%) with 4 (20) fb^{-1} of $\psi(3770)$ data sample. The dominated uncertainty in the measurement of f_{D^+} at the BES-III is the uncertainty of $|V_{cd}|$.

At present, the uncertainty in the calculated ratio of $f_{D^+}/f_{D_s^+}$ from the LQCD is 1% (or 4% from quenched lattice), while the uncertainty in the measured ratio is 8.1% (world average). If we can reduce the uncertainty of the ratio down to 3%, we can more precisely calibrate and test the LQCD calculations of this ratio. At the BES-III, we can reduce the uncertainty down to about 2% ∼ 3% with more than 4 fb^{-1} of open charm data to be taken at 3.773 and 4.17 GeV.

3.4 Absolute branching fractions

Using the double tag analysis, we can more precisely measure the absolute branching fractions for $D^0 \to K^- \pi^+$ and $D^+ \to K^- \pi^+ \pi^+$, which will be used to normalize the branching fractions for B and Z decays. These absolute branching fractions also affect determinations of the CKM matrix elements related to B semleptonic decays. From these analyses, we can also obtain the numbers of $D^0\bar{D}^0$ and D^+D^- produced in e^+e^- annihilation, which can be used to determine the observed cross sections for the $D^0\bar{D}^0$ and D^+D^- production. With these cross sections, we can obtain the non-$D\bar{D}$ branching fractions of the $\psi(3770)$ decays. These branching fractions can be used to test the pQCD calculations of the non-$D\bar{D}$ decays of the $\psi(3770)$ resonance. With 4 fb^{-1} of $\psi(3770)$ data taken at its peak, we can reduce the statistical uncertainties in the measured branching fractions for $D^0 \to K^- \pi^+$ and $D^+ \to K^- \pi^+ \pi^+$ down to about 0.5%. The systematic uncertainties in the measured branching fractions are about 1% at the BES-III experiment.

4 Probe for new physics

In the SM, the rates of $D^0\bar{D}^0$ mixing, CP violation in D decays and some rare D and D_s^+ decays are very small. The rates of the FCNC (flavor change neutral current) decays, LNV (lepton number violation) and LFV (lepton flavor violation) decays are extremely small. However, some NP beyond the SM may enhance the mixing rate, and the rates of the CP violation in D decays and the rare open charm decays. If we observe any of these decay processes from the open charm, we may observe some NP in the charm sector. So, searching for these decays can probe NP beyond the SM.

4.1 $D^0\bar{D}^0$ mixing

Due to short-distance and long-distance interactions, the neutral D meson will change its identity, that is $\mathrm{D}^0 \Longleftrightarrow \bar{\mathrm{D}}^0$. This is called $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing. There are two parameters to describe the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing. These are x and y, with

$$x = \Delta m/\Gamma,\ y = \Delta\Gamma/2\Gamma,\ \Delta m = m_2 - m_1$$

$$\Delta\Gamma = (\Gamma_2 - \Gamma_1),\ m = \frac{1}{2}(m_1 + m_2),$$

and

$$\Gamma = \frac{1}{2}(\Gamma_1 + \Gamma_2),$$

where m_1 and m_2 are the masses of weak eigenstates D^0_1 and D^0_2, respectively; similarly, Γ_1 and Γ_2 are the decay widths of D^0_1 and D^0_2, respectively. We define the CF (Cabbibo Favored) decay $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$ ($\bar{\mathrm{D}}^0 \to \mathrm{K}^+\pi^-$) as right sign events, while we define the $\mathrm{D}^0 \Longrightarrow \bar{\mathrm{D}}^0 \to \mathrm{K}^+\pi^-$ ($\bar{\mathrm{D}}^0 \Longrightarrow \mathrm{D}^0 \to \mathrm{K}^-\pi^+$) as wrong sign events. Obviously, searching for the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing events is to search for the wrong sign final states such as $\mathrm{D}^0\bar{\mathrm{D}}^0 \to (\mathrm{K}^-\pi^+)(\mathrm{K}^-\pi^+)$, ... Due to DCS (Double Cabbibo Suppressed) decay, the $\bar{\mathrm{D}}^0$ can also decay to the $\mathrm{K}^-\pi^+$ final states, which are the same as the one from the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing. So, at the time t after the D^0 (or $\bar{\mathrm{D}}^0$) produced, the wrong sign state (or wrong sign number of events) contributes from three components, which are given by

$$T_{\mathrm{ws}}(t) = \mathrm{e}^{-\Gamma t}(R_{\mathrm{D}} + \sqrt{R_{\mathrm{D}}}y'\Gamma t + \frac{x'^2 + y'^2}{4}\Gamma^2 t^2),$$

where R_{D} is the ratio of DCS decay rate over the CF decay rate,

$$\frac{x'^2 + y'^2}{4}\Gamma^2 t^2$$

describes the mixing, and the $\sqrt{R_{\mathrm{D}}}y'\Gamma t$ is due to the interference between the two amplitudes. The mixing parameters x and y are related to the strong phase difference between the DCS and CF decay amplitudes by the relations of $x' = x\cos\delta_{\mathrm{k}\pi} + y\sin\delta_{\mathrm{k}\pi}$ and $y' = -x\sin\delta_{\mathrm{k}\pi} + y\cos\delta_{\mathrm{k}\pi}$, where $\delta_{\mathrm{k}\pi}$ is the strong phase difference. The four parameters of x, y, R_{D} and $\delta_{\mathrm{K}\pi}$ control the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing.

At the ψ(3770) resonance, we can take the advantage of the quantum correlation coherent events to search for the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing events. If we only examine the final states of $\mathrm{K}^\pm\pi^\mp$ events, the DCS decay can not happen in the final states. In addition to the $\mathrm{K}^\pm\pi^\mp$ final states, the wrong sign semileptonic decays $\mathrm{D}^0 \Longrightarrow \bar{\mathrm{D}}^0 \to \mathrm{K}^+\mathrm{l}^-\nu$ ($\bar{\mathrm{D}}^0 \Longrightarrow \mathrm{D}^0 \to \mathrm{K}^-\mathrm{l}^+\nu$) only come from the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing. So, in the experiment we can directly search for the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing events in three modes: 1) $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$ VS $\bar{\mathrm{D}}^0 \to \mathrm{D}^0 \to \mathrm{K}^-\pi^+$; 2) $\mathrm{D}^0 \to \mathrm{K}^-\mathrm{l}^+\nu$ VS $\bar{\mathrm{D}}^0 \to \mathrm{D}^0 \to \mathrm{K}^-\mathrm{l}^+\nu$; 3) $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$ VS $\bar{\mathrm{D}}^0 \to \mathrm{D}^0 \to \mathrm{K}^-\mathrm{l}^+\nu$. These kinds of events can be called as wrong sign events. The $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing rates for the above three processes are

$$R_{\mathrm{mix}} \simeq \frac{N(\mathrm{K}^-\pi^+)(\mathrm{K}^-\pi^+)}{N(\mathrm{K}^-\pi^+)(\mathrm{K}^+\pi^-)},$$

$$R_{\mathrm{mix}} = \frac{N(\mathrm{K}^-\mathrm{l}^+\nu)(\mathrm{K}^-\mathrm{l}^+\nu)}{N(\mathrm{K}^-\mathrm{l}^+\nu)(\mathrm{K}^+\mathrm{l}^-\nu)},$$

$$R_{\mathrm{mix}} \simeq \frac{N(\mathrm{K}^-\mathrm{l}^+\nu)(\mathrm{K}^-\pi^+)}{N(\mathrm{K}^-\mathrm{l}^+\nu)(\mathrm{K}^+\pi^-)} - R_{\mathrm{D}},$$

respectively, where the N is the number of the events observed with different Kπ final states or different Klν final states.

From full Monte Carlo studies of the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing simulated with the BES-III detector, we find that the experimental sensitivity for observation of the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing with the Kπ mode is 1.5×10^{-4} for measuring the R_{mix}. In principle, the wrong sign semileptonic decay processes are ideal ones for searching for the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing. However, these processes suffer from large background. The experimental sensitivity for observation of the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing from the semileptonic decays is only about 1×10^{-3}.

We can also take the advantage of the quantum correlation coherent events produced at ψ(4030) to search for the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing events. In this case, the D^0 meson is produced in the decay of $\mathrm{D}^{*+}\mathrm{D}^- \to \pi^+ \mathrm{D}^0\mathrm{D}^-$. The wrong sign semileptonic decays of the $\mathrm{D}^0 \Longrightarrow \bar{\mathrm{D}}^0 \to \mathrm{K}^+\mathrm{l}^-\nu$ accompanied by a slow π^+, which are observed in the recoiling system against the singly tagged D^-, can be taken as the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing events. The experimental sensitivity for observation of the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing is estimated to be about 6×10^{-5} from 20 fb^{-1} data taken at 4.03 GeV [5].

4.2 CP violation in D decays

There are three types of the CP violation in D decays. These are 1) CP violation in the $\mathrm{D}^0\bar{\mathrm{D}}^0$ mixing matrix, 2) CP violation in the interference between mixing and decay. 3) Direct CP violation.

With both the D^0 and $\bar{\mathrm{D}}^0$ decay to their CP eigenstates, we can search for the direct CP violation decays of the D^0 meson. Since the $\mathrm{D}^0\bar{\mathrm{D}}^0$ is in P wave (L=1) state, the decays of both D^0 and $\bar{\mathrm{D}}^0$ to CP+ (even) or CP- (old) are forbidden by CP conservation. If we observe both the D^0 and $\bar{\mathrm{D}}^0$ decay to the same CP eigenstates, we may find the direct CP violation in D decays.

With 20 fb^{-1} of ψ(3770) data taken at its peak, we can accumulate about 5×10^5 CP+ and 5×10^5 CP- tags. The experimental sensitivity for observation of the direct CP violation in D^0 decays is about 10^{-3} at 90% C.L..

4.3 The strong phase $\delta_{K\pi}$

With the double tag sample of CP eigenstate tag VS flavor tag mode of $K^{\mp}\pi^{\pm}$, we can measure the strong phase $\delta_{K\pi}$ appearing in the $D^0\bar{D}^0$ mixing. The uncertainty in the measured cos $\delta_{K\pi}$ is about ±0.05 for 20 fb^{-1} of ψ(3770) data.

4.4 Rare purely and semileptonic decays

In the SM, the charm FCNC (Flavour Change Neutral Current) decays are much high GIM suppressed. The branching fractions for purely leptonic rare decays $D^0 \to e^+e^-$ and $D^0 \to \mu^+\mu^-$ are at the levels of 10^{-23} and 10^{-13}, respectively. However, some NP may enhance these decay processes. For example, the R-parity violation SUSY gives these branching fractions up to 10^{-10} and 10^{-6}. So, observation of these charm FCNC decays and lepton number violation decays could indicate new physics. The decay $D^0 \to e^{\pm}\mu^{\mp}$ is strictly forbidden in the SM. In experiment, searching for these kinds of rare decays can probe NP.

From full Monte Carlo simulations with the BES-III detector, we find that, with 20 fb^{-1} of ψ(3770) data taken at its peak, the sensitivities for searching for the D rare purely or rare semileptonic decays can go down to about 10^{-8}, while the sensitivities for searching for the D_s^+ rare semileptonic decays can go down to $10^{-6} \sim 10^{-7}$ with 20 fb^{-1} of data taken at 4.17 GeV.

5 Charmed and non-charmed decays of heavy c$\bar{c}$ states

5.1 Measurements of the masses of D^0, D^+ and D_s^+

In recent years, some heavy charmonium-like states were found. To understand the nature of some of these states, precise masses of D^0, D^+ and D_s^+ mesons are needed. With the data to be taken at 3.773 and 4.03 or 4.17 GeV, we can measure these masses at the accuracy levels of less than 0.1 MeV.

5.2 Line shape for D$\bar{D}$ production

The line shapes of the cross sections for $e^+e^- \to D^0\bar{D}^0$, D^+D^-, D$\bar{D}$ are sensitive to the strong interaction dynamics for the D$\bar{D}$ production and decays. They are also sensitive to some possible new structure(s) existing around the D$\bar{D}$ threshold region. Precision measurements of these line shapes and the line shape for the ratio of the charged over the neutral D$\bar{D}$ yields provide some important information about the D$\bar{D}$ production dynamics and some evidence for new structure(s) in the open charm energy region.

The BES-II collaboration previously measured these line shapes in the ψ(3770) resonance region and found that these line shapes are anomalous [6] compared to the expected ones for only one simple ψ(3770) resonance assumption there around 3.770 GeV. Unfortunately, due to statistical limit, these measurements can not give definite conclusion about the production dynamics or whether there is a new structure around 3.770 GeV. The BES-III collaboration is going to precisely measure these line shapes with larger statistical energy scan data sample.

In addition to these line shapes, comparing the line shapes for inclusive K^0, K^{*0}, φ, η, η′, J/ψ, ψ(3686), and some other inclusive particle production with the ones for the simple heavy c$\bar{c}$ state production allows us to find some important information about the new structure(s) in the open charm energy region as well.

5.3 Non-charmed decays of heavy c$\bar{c}$ states

The non-charmed decays of the heavy c$\bar{c}$ states above the D$\bar{D}$ production threshold are sensitive to hadronic decay dynamics of the states. Potential modes expect that ψ(3770) decay to D$\bar{D}$ final states with ∼ 100% branching fraction. pQCD calculation expects that less than 3% of ψ(3770) decays into non-D$\bar{D}$ final states [7]. Recently, by analyzing the data taken around 3.773 GeV, the BES-II collaboration found that $(14.7 \pm 3.4)\%$ of ψ(3770) does not decay into D$\bar{D}$ final states [8]. Based on $SU(3)$ symmetry, D.H. Zhang et al. made a global analysis of the cross sections for $e^+e^- \to VP$ (Vector and Pseudoscalar mesons) final states at 3.760 and 3.773 GeV, which were measured by the CLEO-c collaboration, and found that ψ(3770) may decay to the non-D$\bar{D}$ final states with a total branching fraction of about 10% [9]. These conflict with the theoretical predictions. However, there are some arguments about the non-D$\bar{D}$ decays of $\psi(3770)$. Some authors [10] suggested that the long distance effects can enhance the non-D$\bar{D}$ decays of ψ(3770). M. B. Voloshin pointed out that large non-D$\bar{D}$ branching fraction of ψ(3770) decays may indicate that there is a sizeable four-quark component in the ψ(3770) wave function [11]. In addition to these arguments, if some new structure exists in the resonance region of the conventional single ψ(3770) around 3.773 GeV, the experimentally measured non-D$\bar{D}$ branching fraction of ψ(3770) decays would be large [12] in the case of assuming that there is only one simple ψ(3770) resonance.

To well understand the nature and decay dynamics of $\psi(3770)$, we need to more precisely measure the non-$D\bar{D}$ decay branching fraction of $\psi(3770)$. With about 90 pb^{-1} of energy scan data sample taken in the range from 3.65 to 3.88 GeV, we can measure the non-$D\bar{D}$ decay branching fraction at an absolute accuracy level of about 2%.

Searching for the non-charmed decays of the heavy $c\bar{c}$ states and measuring the branching fractions of the non-charmed decays of the states provide a method to search for the new structure(s) in the open charm energy region. For example, the discovery of the first non-$D\bar{D}$ decay of $\psi(3770) \to J/\psi\ \pi^+\pi^-$ at the BES-II experiment [13] actually triggered the experimental physicist to search for this decay final state in B decays, which led to discover the X(3872) particle.

By searching for different kinds of non-charmed final states, such as J/ψ X final states and some other charmless final states, from the data taken in the open charm energy region, one may find some new state(s) produced in e^+e^- annihilation or from decays of the heavy $c\bar{c}$ states.

These non-charmed decays of the heavy $c\bar{c}$ and charmonium-like states will be studied with the data taken with the BES-III detector in the open charm energy region soon.

6 Summary

The open charm transitions play two important roles in testing the SM and in probing NP. The data taken at $\psi(3770)$ from the BES-II and the CLEO-c started an era of precision measurements of the absolute branching fractions of the D^0 and D^+ decays, which were used to test QCD techniques, especially to the LQCD calculations of the form factors and decay constants [14]. Five years ago, the BES-II measurements of the form factors $f_+^K(0)$ and $f_+^\pi(0)$ [15] changed the situation of that no precision measurement on the form factors can be used to test the LQCD calculations of these non-perturbative QCD quantities. A few months later, CLEO-c more precise measurements of these form factors were used to calibrate the LQCD calculations. In one or two years, the more precise measurements of the form factors and the decay constants from the BES-III will provide more stringent tests of the LQCD calculations of these quantities related to the non-perturbative QCD dynamics, which will quantify the accuracy (about $1\% \sim 2\%$) for the application of the LQCD to the B meson decays. Combining all measurements from BaBar and Belle, D0, CDF, and BTeV at Fermilab, ATLAS, CMS, and LHC-b at the LHC, CLEO-c, BES-III and experiments studying the rare kaon decays, together with the LQCD calculations of these quantities yields precise determinations of the CKM matrix elements, and in turn to more precisely test the SM and to probe NP.

In the area of searching for NP, the discovery of the $D^0\bar{D}^0$ mixing by the B factories points forward to search for the CP violation in the open charm sector and NP. With 20 fb^{-1} of data to be taken at the $\psi(3770)$ peak, the BES-III can search for the direct CP violation in the D decays at the sensitivity of 10^{-3}. For rare charm decays, the experimental sensitivities can go down to 10^{-8} with these $\psi(3770)$ data sample. This would give the newly tighter limits on the D meson rare decays. If some new physics enhance these rare decay rates upon to $10^{-7} \sim 10^{-8}$, the BES-III can find these rare decay processes and NP.

With the data to be taken in the energy region from 3.7 to 4.5 GeV with the BES-III detector, the BES-III collaboration has an opportunity to search for some new structure(s) in the resonance regions of the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$ conventional $c\bar{c}$ states or coming from these resonances decays. Searching for the new structure(s) can be performed by examining the line shapes of the cross sections for $e^+e^- \to$ hadrons, open-charm-pair, J/ψ X, $\psi(3686)$ X, K^0 X, ϕ X, η X, and so on. The direct measurements of the non-charmed decay branching fractions of the heavy states give us another method to search for the new structure(s) and to understand the production and decay dynamics of the heavy states.

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