

Charm Physics with BES-III at BEPC-II

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We report on the charm physics potential at BES-III at BEPC-II which will make significant contribution to quark flavor physics this decade. The charm physics program will include studies of leptonic, semileptonic and hadronic charm decays, and tests for physics beyond the Standard Model. Event samples of the order of 30 million $D\bar{D}$ pairs, 2 million $D_S^+D_S^-$ pairs at threshold and 10×10^9 J/ψ decays will be produced with one year design luminosity. High precision charm data will enable us to validate forthcoming Lattice QCD calculations at the few percent level. These can then be used to make precise measurements of CKM elements, V_{cd} , V_{cs} , V_{ub} , V_{cb} and V_{ts} , which are useful to improve the accuracy of test of the CKM unitarity.

1. Introduction

BES-III at BEPC-II under construction in Beijing will focus on charm and QCD physics in the range $\sqrt{s} = 2.0 - 4.2$ GeV. The physics program at BES-III includes a variety of measurements that will improve the understanding of the Standard Model (SM) processes as well as provide the opportunity to probe for physics that lies beyond the SM. However, the possibility of new physics may be diluted by the large hadronic uncertainty in D decays. The study of weak interactions in the charm sector, and the extraction of quark mixing matrix parameters remain limited by our capacity to cope with non-perturbative QCD. Thus, it will be of great benefit if we can understand the effects of strong coupling in QCD. High precision predictions of QCD will then remove road blocks for many weak and flavor physics measurements.

Lattice QCD (LQCD) [1] had matured over the last decade. Recent advances in LQCD have produced a wide variety of calculations of non-perturbative quantities with accuracies in the 10-20% level for D decay constant and form factors. We finally can expect the first LQCD results with 1-3% errors. BES-III will provide crucial data to validate them and help guide the development of QCD calculation techniques for a full understanding of non-perturbative QCD effects. This

will improve the measurements of charm meson decay constants, V_{cs} and V_{cd} to 1% level.

Table 1
 τ -Charm productions at BEPC-II in one year's running (10^7 s).

Data Sample	Central-of-Mass (MeV)	#Events per year
J/ψ	3097	10×10^9
$\tau^+\tau^-$	3670	12×10^6
$\psi(2S)$	3686	3.0×10^9
$D^0\bar{D}^0$	3770	18×10^6
D^+D^-	3770	14×10^6
$D_S^+D_S^-$	4030	1.0×10^6
$D_S^+D_S^-$	4170	2.0×10^6

Beginning in mid-2007, the BEPC-II accelerator will be operated at center-of-mass (CM) energies corresponding to $\sqrt{s} = 2.0 - 4.2$ GeV. The designed luminosity over this energy region will range from $1 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$ down to about $0.6 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$ [2], yielding around 5 fb^{-1} each at $\psi(3770)$ and at $\sqrt{s} = 4170$ MeV [3] above $D_S^+D_S^-$ threshold and 3 fb^{-1} at J/ψ peak in one year's running with full luminosity [2]. These integrated luminosities correspond to samples of 2.0 million $D_S^+D_S^-$, 30 million $D\bar{D}$ pairs and 10×10^9 J/ψ decays. Table 1 summarizes the data set per year at BES-III. In this report, all preliminary

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sensitivity studies are based on 20 fb^{-1} luminosity at $\psi(3770)$ peak for D physics, the same luminosity also for D_S physics at $\sqrt{s} = 4170 \text{ MeV}$.

2. Unique Features of the Charm Physics at BES-III

Many of the measurements related to charm decays have been done by other experiments such as BES-II and CLEO-c, and many are also accessible to the B-factory experiments. What are BES-III's advantages to running at the open charm threshold?

Firstly, compared to the old BES experiment, BES-III is a state-of-the-art detector with modern technologies [2]. BES-I/BES-II was modeled on MARK-III detector. It has gone through several generations of development since then. In every resolution and performance parameter, for example, hit resolution, momentum and energy resolutions, mass resolution, particle identification (PID) capability, solid angle coverage, BES-III is superior to previous versions of BES detectors by substantial margins. The new detector consists of a He-based small cell drift chamber, Time-Of-Flight (TOF) counters for PID, a CsI(Tl) crystal calorimeter, a solenoid super-conducting magnet with a field of 1 Tesla and the magnet yoke interleaved with RPC counters as the muon chamber. The construction is expected to be completed in the middle of 2007. Photon energy resolution is $\Delta E/E = 2.5\%$ at $E_\gamma = 1.0 \text{ GeV}$. The momentum resolution is $\sigma_p/p = 0.5\%$ at $p = 1.0 \text{ GeV}/c$, and the dE/dx resolution for hadron tracks is about 6%. The time resolution of TOF is about 100 ps, combining energy loss (dE/dx) measurement in the draft chamber, give $10 \sigma \text{ K}/\pi$ resolution across the typical kinematic range. A 25% increase of solid angle coverage relative to BES improve efficiency for double-tag measurements greatly. The gains go as 1.25^N , where N is the total number of tracks and photons of the event [4]. This indicates a typical effective luminosity gain of 8 in such analyses. For partial wave analysis, the increase in solid angle coverage means angular distributions will be measured across the almost full angular range without large variations in acceptance. The J^{PC} and partial waves can be

measured reliably and precisely.

Secondly, BES-III will not be able to compete both BaBar and Belle in statistics on charm physics, especially on the rare and forbidden decays of charm mesons. However, data taken at charm threshold still have powerful advantages over the data at $\Upsilon(4S)$, which we list here [4]: 1) Charm events produced at threshold are extremely clean; 2) The measurements of absolute branching fraction can be made by using double tag events; 3) Signal/Background is optimum at threshold; 4) Neutrino reconstruction is clean; 5) Quantum coherence allow simple [5] and complex [6] methods to measure $D^0\bar{D}^0$ mixing parameters and check for direct CP violation.

3. Charm Decays and Production Cross Sections at BEPC-II

The main targets of the charm physics program at BES-III are absolute branching fraction measurements of leptonic, semileptonic and hadronic decays. The first measures decay constants and the second measures form factors and, in combination with theory, allows the determination of V_{cs} and V_{cd} . The third of those provides an absolute scale for all charm and hence beauty decays.

At $D\bar{D}$ or $D_S^+D_S^-$ threshold, no additional hadrons accompanying the $D\bar{D}$ or $D_S^+D_S^-$ pairs are produced. Reconstruction of one D or \bar{D} meson (called single tag or ST) tags the event as either $D^0\bar{D}^0$ or D^+D^- ($D_S^+D_S^-$). For a given decay mode i , we measure independently the D and \bar{D} ST yields, denoted by N_i and \bar{N}_i . We determine the corresponding efficiencies from Monte Carlo simulations (MC), denoted by ϵ_i and $\bar{\epsilon}_i$. Thus, $N_i = \epsilon_i \mathcal{B}_i N_{D\bar{D}}$ and $\bar{N}_i = \bar{\epsilon}_i \mathcal{B}_i N_{D\bar{D}}$, where \mathcal{B}_i is the branching fraction for mode i , assuming no CP violation, and $N_{D\bar{D}}$ is the total number of produced $D\bar{D}$ pairs at BES-III. Double tag (DT) events are the subset of ST events where both the D and \bar{D} are reconstructed. The DT yield for D mode i and \bar{D} mode j , denoted by N_{ij} , is given by $N_{ij} = \epsilon_{ij} \mathcal{B}_i \mathcal{B}_j N_{D\bar{D}}$, where ϵ_{ij} is the DT efficiency. As with ST yields, the charge conjugate DT yields and efficiencies, N_{ji} and ϵ_{ji} , are determined separately. Charge conjugate particles are implied, unless referring to ST and DT

yields. The absolute branching fraction \mathcal{B}_i can be obtained from $\mathcal{B}_i = \frac{N_{ij} \bar{\epsilon}_j}{\bar{N}_j \epsilon_{ij}}$. With the same method, we have the total number of $D\bar{D}$ pairs $N_{D\bar{D}} = \frac{N_i \bar{N}_j}{N_{ij}} \frac{\epsilon_{ij}}{(\epsilon_i \bar{\epsilon}_j)}$, which can be used to obtain the absolute cross-section of $D\bar{D}$ production.

3.1. Leptonic Charm Decays

From the leptonic decays of D^\pm and D_S^\pm mesons, the decay constants f_D and f_{D_S} can be determined to a precision of about 1%. The decay constants measure the non-perturbative wave function of the meson at *zero* inter-quark separation and appear in all processes where constituent quarks must approach each other at distances small compared to the meson size [4].

Table 2

Expected errors on the branching fractions for leptonic decays and decay constants at BES-III with 20 fb^{-1} at $\psi(3770)$ peak.

Decay Modes	Error (%) on \mathcal{B}	Error (%) on $f_{D(S)}$
$D^+ \rightarrow \mu^+ \nu$ (f_D)	2.0	1.5
$D_S^+ \rightarrow \mu^+ \nu$ (f_{D_S})	2.0	1.1
$D_S^+ \rightarrow \tau^+ \nu$ (f_{D_S})	1.5	0.9

Measurements of leptonic decays at BES-III will benefit from the fully tagged D^+ and D_S^+ decays available at the $\psi(3770)$ and at $\sqrt{s} \sim 4170$ MeV [3]. The leptonic decay of $D^+(D_S^+) \rightarrow \mu^+ \nu$ is detected in tagged events by observing a single charged track of the correct sign, missing energy, and a complete accounting of the residual energy in the calorimeter. The pure $D\bar{D}$ pair in the initial state and cleanliness of the full tag reconstruction make this measurement essentially background-free. The leptonic decay rates for D^+ and D_S^+ can be measured with a precision of 1-2% level. This will allow the validation of theoretical calculations of the decay constants at the 1% level. Table 2 summarizes the expected precision in the decay constant measurements. It should be noted that the $D^+ \rightarrow \tau^+ \nu$ decay is re-

ported by CLEO-c with upper limit of 2.1×10^{-3} at 90% CL [7]. At BES-III, the sensitivity will be $10^{-5} - 10^{-6}$ level.

3.2. Semileptonic Charm Decays

Semileptonic widths for $D \rightarrow X_{s(d)} l^+ \nu$ directly probe the elements of the CKM matrix. When $J^P(X_{s,d}) = 0^-$, the differential width is given by:

$$\frac{d\Gamma(D \rightarrow X_{s(d)} l^+ \nu)}{dq^2} = \frac{G_F^2}{24\pi^3} p^3 |V_{cs(d)}|^2 p^3 |F(q^2)|^2, \quad (1)$$

where q^2 is the momentum transfer squared between the D meson and the final state hadron in the D rest frame, and $F(q^2)$ is the hadronic form factor at $c \rightarrow Ws(d)$ vertex. The form factor can be predicted from a number of different theoretical approaches [8] including LQCD [1]. In addition to its own intrinsic interest, the analogous form factor is needed for extracting b -quark matrix elements such as V_{ub} in B semileptonic decays, so it is important to demonstrate the reliability of any one calculation.

Absolute branching ratios in critically interesting modes, such as, $D \rightarrow \pi l \nu$, $D \rightarrow K l \nu$, $D \rightarrow \eta(\eta') l \nu$, $D \rightarrow \rho l \nu$, $D \rightarrow K^* l \nu$, $D_S \rightarrow \phi l \nu$ and $D_S \rightarrow K^* l \nu$, will be measured to be less than 1%, and the form factor slopes to 1.5%. The measurement in each case is based on the use of tagged events where the cleanliness of the environment provides nearly background-free signal samples. This will lead to the determination of the CKM matrix elements V_{cs} and V_{cd} with a precision of 1% level assuming knowledge of the relevant form factors with 1.5% uncertainties from LQCD. Form factors in all modes can be measured across the full range of q^2 with excellent resolution. Measurements of the vector and axial-vector form factors $V(q^2)$, $A_1(q^2)$ and $A_2(q^2)$ will also be possible at the $\sim 2\%$ level. Table 3 summarizes the most recent results and the expected fractional errors on the branching ratios at BES-III.

With high statistics of D sample at BES-III, many unobserved semileptonic D decays will be accessible, such as $D^+ \rightarrow f_0 l \nu$, $D^+ \rightarrow \eta(\eta') l \nu$, $D^+ \rightarrow \bar{K}^{**} l \nu$ and $D^+ \rightarrow \phi l \nu$, where \bar{K}^{**} is the excited kaon mesons including $\bar{K}_1(1270)$, $\bar{K}^*(1410)$ and $\bar{K}^*(1430)$. These measurements

Table 3

Uncertainties on the branching fractions for D and D_S semileptonic decay modes and precision of form factor parameters at BES-III (assuming 20 fb⁻¹ data at $\psi(3770)$ peak). The precision of parameters is mainly limited by the uncertainties on V_{cd} and V_{cs} .

Decay Modes	Error (%) on \mathcal{B} PDG2004	Expected Error (%) on \mathcal{B} at BES-III	Form Factor Type	Expected Error (%) on Form factor at BES-III
$D^0 \rightarrow Kl\nu$	4.6	0.2	PS \rightarrow PS	1.0
$D^0 \rightarrow \pi l\nu$	9.6	0.4	PS \rightarrow PS	1.0
$D^+ \rightarrow \pi l\nu$	50.0	0.8	PS \rightarrow PS	1.0
$D^+ \rightarrow \bar{K}^* l\nu$	10.0	0.3	PS \rightarrow V	2.0
$D_S^+ \rightarrow \phi l\nu$	25.0	1.2	PS \rightarrow V	1.0

will provide another lab to study the $K\pi$ and $\pi\pi$ S-wave [9].

The ratio of decay widths $\Gamma(D_S \rightarrow \eta' e\nu)/\Gamma(D_S \rightarrow \eta e\nu)$, using $|V_{cs}| = 0.975$ [10],

$$\frac{\Gamma(D_S \rightarrow \eta' e\nu)}{\Gamma(D_S \rightarrow \eta e\nu)} \sim 0.28 \times |\cot\phi|^2, \quad (2)$$

depends on the content of the η and η' mesons, where ϕ is the mixing angle in the $\eta - \eta'$ flavor mixing scheme [11]. We note that the decays $D_S \rightarrow \eta(\eta')l\nu$ involve the strange content of $\eta(\eta')$, and $D^+ \rightarrow \eta(\eta')l\nu$ involve the non-strange content. Therefore, $D^+ \rightarrow \eta(\eta')l\nu$ and $D_S \rightarrow \eta(\eta')l\nu$ could provide combined testing of a $\eta - \eta'$ mixing scheme [12]. The uncertainty on mixing angle ϕ is about 13% with current D_S^+ data [11], at BES-III, the error will be 2% level.

3.3. Absolute Hadronic Branching Fraction and $e^+e^- \rightarrow D\bar{D}, D\bar{D}^*$, and $D^*\bar{D}^*$ Cross Sections

Absolute branching fraction measurements are important since, for a lot of analyses at higher energies as well as in the B -system, an inaccurate knowledge of D , D_S decays can result in large systematic errors. Using double-tagged events at threshold leaves only major systematic error contributions from efficiency uncertainties in the tracks and showers.

The rate for the critical normalizing modes $D \rightarrow K\pi$, $D^+ \rightarrow K\pi\pi$, and $D_S \rightarrow \phi\pi$ will be established to a precision of order less than 1.0%. At BES-III, the statistic is high enough that we can measure Cabibbo-suppressed decays of D mesons, especially the $D \rightarrow 4\pi$, 5π or even

Table 4

Unobserved 3-body D decays, $D^0 \rightarrow P^0 P^0 X^0$, where P^0 is pseudoscalar and X^0 is any kind of particle allowed in the final states. f_0 and a_0 are the scalar $f_0(980)$ and $a_0(980)$, respectively. N/A represents not available.

	P^0			
X^0	π^0	η	K_S	K_L
π^0	$\pi^0\pi^0\pi^0$	$\eta\eta\pi^0$	$K_S K_S \pi^0$	$K_L K_L \pi^0$
η	$\pi^0\pi^0\eta$	$\eta\eta\eta$	$K_S K_S \eta$	$K_L K_L \eta$
η'	$\pi^0\pi^0\eta'$	N/A	N/A	N/A
K_S	$\pi^0\pi^0 K_S$	$\eta\eta K_S$	$K_S K_S K_S$	$K_L K_L K_S$
K_L	$\pi^0\pi^0 K_L$	$\eta\eta K_L$	$K_S K_S K_L$	$K_L K_L K_L$
a_0	$\pi^0\pi^0 a_0$	N/A	N/A	N/A
f_0	$\pi^0\pi^0 f_0$	N/A	N/A	N/A

more pions final states [13]. The sensitivities of the measurements of these branching fractions will be $10^{-5} - 10^{-6}$ level at BES-III. Many unobserved 3-body D decays can also be observed at BES-III as listed in Table 4. One should note that the decays $D(D_S) \rightarrow V_1 V_2$ are very important to probe the final state interaction by measuring the polarization fractions, f_L , f_T (f_\perp and f_\parallel). At BES-III, these measurements will become available.

As discussed at the beginning of Section 3, we can obtain the $e^+e^- \rightarrow D\bar{D}$ cross sections by scaling $N_{D^0\bar{D}^0}$ and $N_{D^+\bar{D}^-}$ by the luminosity at each energy point. At $E_{cm} = 3773$ MeV, CLEO-c collaboration found peak cross sections of $\sigma(e^+e^- \rightarrow D^0\bar{D}^0) = (3.60 \pm 0.07_{-0.05}^{+0.07})$ nb, $\sigma(e^+e^- \rightarrow D^+\bar{D}^-) = (2.79 \pm 0.07_{-0.04}^{+0.10})$ nb,

$\sigma(e^+e^- \rightarrow D\bar{D}) = (6.39 \pm 0.10_{-0.08}^{+0.17})$ nb, and the ratio of charged D pairs and neutral D pairs production is about $0.776 \pm 0.024_{-0.006}^{+0.014}$ [14], where the uncertainties are statistical and systematic, respectively. The ratio is significantly deviated from one in $D\bar{D}$ pair production near threshold. It is mainly due to the substantial mass difference between the charged and neutral D mesons, which will produce a factor of $\frac{p_{+-}^3}{p_{00}^3} = 0.69$, where p_{+-} and p_{00} are the momentum of charged and neutral D mesons in $\psi(3770)$ rest frame. Recently, Voloshin pointed out [15] that this ratio should exhibit a prominent variation across the $\psi(3770)$ resonance due to the interference of the resonance scattering phase with the Coulomb interaction between the charged D mesons. The energy dependent ratio R is expressed by [15] :

$$R(E_{cm}) = \frac{\sigma(e^+e^- \rightarrow D^+D^-)}{\sigma(e^+e^- \rightarrow D^0\bar{D}^0)} = F_c \frac{p_{+-}^3}{p_{00}^3}, \quad (3)$$

where F_c is the correction factor of the Coulomb interaction, it is a function of relative phase of electromagnetic and strong interactions as described in ref. [15]. The expected variation of the ratio in the vicinity of $\psi(3770)$ peak is about a few percent level, which may be sufficient for a study in the upcoming BES-III experiment.

It is quite well known [16] that the cross sections of $e^+e^- \rightarrow D^*\bar{D}^*$, $D^*\bar{D}$, $D_S^{*+}D_S^{*-}$ and $D_S^{*+}D_S^-$ in the region just above the threshold of open charm production around 4.0 GeV display an intricate behavior which is yet to be studied in detail. This behavior is caused by the successive onset of specific channels with the D mesons by the strong dynamics in each of these channels and by the coupling between them [17]. Thus, a detailed experimental study of this region at BES-III will provide rich information about the strong dynamics of systems with heavy and light quarks.

3.4. $\psi(3770)$ non- $D\bar{D}$ Decays

It is well known that the $\psi(3770)$ decays most copiously into the OZI-allowed $D\bar{D}$ pair owing to the closeness of the mass threshold. Hadronic or radiative transitions to lower-lying $c\bar{c}$ states, decay to lepton pairs, or decay to light hadrons are

all available and predicted [18,19,20], but their branching fractions are highly suppressed. BES-II reported the first signal of non- $D\bar{D}$ decays of $\psi(3770)$, at $\sim 3\sigma$ significance, with $\mathcal{B}(\psi(3770) \rightarrow \pi^+\pi^-J/\psi) = (0.34 \pm 0.14 \pm 0.09)\%$ [21]. CLEO-c has also searched for the non- $D\bar{D}$ decays of $\psi(3770)$, including $\pi\pi J/\psi$, $\gamma\chi_{c1}$ and light hadron final states [22]. The CLEO-c collaboration measured cross section for $e^+e^- \rightarrow \psi(3770) \rightarrow$ hadrons at $E_{cm} = 3773$ MeV to be $(6.38 \pm 0.08_{-0.30}^{+0.41})$ nb [23]. The difference between this and the $e^+e^- \rightarrow \psi(3770) \rightarrow D\bar{D}$ cross section at the same energy is found to be $(-0.01 \pm 0.08_{-0.30}^{+0.41})$ nb, which indicates the non- $D\bar{D}$ decays would be smaller than 0.53 nb at 90% CL, or corresponds to an upper limit of 8.4% of the branching fraction at 90% CL. BESII also reported an upper limit of 30% of the branching fraction at 90% CL [24].

In order to understand the decay dynamics of non- $D\bar{D}$ decays and the line-shape of $\psi(3770)$ resonance, it is very important to measure the cross sections of inclusive hadron productions by using scan method in the vicinity of $\psi(3770)$ peak. At BES-III, the sensitivity to non- $D\bar{D}$ measurement is estimated to be less than 1% level by using scan method with one year integrated luminosity at different energy points near $\psi(3770)$ peak. A detailed MC simulation is in process.

The exclusive charmless $\psi(3770)$ decay modes should be searched at BES-III. The sensitivity to exclusive charmless $\psi(3770)$ decay modes at BES-III will be around $10^{-6} - 10^{-7}$ with 20 fb^{-1} data. One has to consider the interference between resonances and continuum, and also the interference between different resonances near $\psi(3770)$ [25].

4. $D^0 - \bar{D}^0$ Mixing, CP Violation and Physics Beyond the Standard Model

With the design luminosity of $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, BES-III will have the opportunity to probe for the possible new physics which may enter up-type-quark decays. It includes searches for charm mixing, CP violation and rare charm decays. The BES-III charm physics program also includes a variety of measurements that will improve the determination of ϕ_3/γ from B -factory experiments. The total number of charm mesons accumulated

at BES-III will be much smaller than that at B -factories which are about 500 fb^{-1} for each of them. However, the quantum correlations in the $\psi(3770) \rightarrow D\bar{D}$ system will provide a unique laboratory in which to study charm [6].

4.1. $D^0 - \bar{D}^0$ Mixing and CP Violation

$D^0 - \bar{D}^0$ mixing within the SM are highly suppressed due to GIM mechanism, thus, at BES-III, searches for neutral charm mixing and CP violation in charm decays may be essential in deciding if some intriguing signals are actually due to new physics.

The time evolution of $D^0 - \bar{D}^0$ system, assuming no CP violation in mixing, is governed by four parameters: $x = \Delta m/\Gamma$ and $y = \Delta\Gamma/2\Gamma$ which are the mass and width differences of D meson mass eigenstates and characterize the mixing matrix, δ the relative strong phase between Cabibbo favor (CF) and doubly-Cabibbo suppressed (DCF) amplitudes and R_D the DCF decay rate relative to the CF decay rate. The mixing rate R_M is defined as $\frac{1}{2}(x^2 + y^2)$ [26]. Standard Model based predictions for x and y , as well as a variety of non-Standard Model expectations, span several orders of magnitude [26] which is $x \sim y \sim 10^{-3}$. Presently, experimental information about charm mixing parameters x and y comes from the time-dependent analyses. The current experimental upper limits on x and y are on the order of a few times 10^{-2} .

At BES-III, time-dependent analyses are not available. However, one can use the fact that $D^0\bar{D}^0$ pairs in $\psi(3770) \rightarrow D\bar{D}$ decays have the useful property that the two mesons are in the CP -correlated states [6], namely, one D state decayed into the final state with definite CP properties immediately identifies or tags CP properties of the state on the other side. It provides time-integrated sensitivity to R_M at 10^{-4} level by considering the decay $\psi(3770) \rightarrow (K^-\pi^+)(K^-\pi^+)$ hadronic final state only at BES-III. We have not estimated the double semileptonic channel yet, $\psi(3770) \rightarrow (l^\pm(KX))(l^\pm(KX))$. Sensitivity to $\cos\delta$ is 0.03 for $D^0 \rightarrow K\pi$ mode. Recently, a simultaneous determinations of the mixing, relative strong phase and R_D have been proposed by using various single tag, double tag and CP tag

rates at CLEO-c [6]. The sensitivities on x and y are improved greatly, but we have not estimated this method at BES-III yet.

For the direct CP violation, the SM predictions are as large as 0.1% for D^0 decays, and 1% level for D^+ and D_S decays [27]. At BES-III, one can also look at the CP violation by exploiting the quantum coherence at the $\psi(3770)$. Consider the case where both the D^0 and the \bar{D}^0 decay into CP eigenstates, then the decays $\psi(3770) \rightarrow f_+^i f_+^i$ or $f_-^i f_-^i$ are forbidden, where f_+ (f_-) denotes a $CP+$ eigenstate ($CP-$ eigenstate). This is because $CP(f_\pm^i f_\pm^i) = CP(f_\pm^i)CP(f_\pm^i)(-1)^l = -1$, while, for the $l = 1$ $\psi(3770)$ state, $CP(\psi(3770)) = +1$. Thus observation of a final state such as $(K^+K^-)(\pi^+\pi^-)$ constitutes evidence of CP violation. For $(K^+K^-)(\pi^+\pi^-)$ mode, the sensitivity at BES-III is about 1% level. Moreover, all pairs of CP eigenstates, where both eigenstates are even or both are odd, can be summed over for CP violation measurements at BES-III.

4.2. Dalitz Plot Analyses

Recent studies of multi-body decays of D mesons provide a direct probe of the final state interactions by looking at the interference between intermediate state resonances on the Dalitz Plot (DP). When D mesons decays into three or more daughters, intermediate resonances dominate the decay rates. These resonances will cause a non-uniform distribution of events in phase space on the DP. Since all events on the DP have the same final states, different resonances at the same location on DP will interfere. This provides the opportunity to measure both the amplitudes and phases of the intermediate decay channels, which in turn allows to deduce their relative branching fractions. These phase differences can even allow details about very broad resonances to be extracted by observing their interferences with other intermediate states.

The most important thing is that recent studies of multi-body decays of D mesons probe a variety of physics including light spectroscopy ($\pi\pi$, $K\pi$ and KK S-wave states), searches for CP violation and $D^0 - \bar{D}^0$ mixing. Currently, the decay $D^0 \rightarrow K_S\pi^+\pi^-$ plays very important role in

the determination of ϕ_3/γ . Recently BaBar and Belle [28] have reported $\gamma = (70 \pm 31_{-10}^{+12+14})^\circ$ and $\phi_3 = (77_{-19}^{+17} \pm 13 \pm 11)^\circ$, respectively, where the third error is the systematic error due to modeling of DP. The precision of these measurements will eventually be limited by the understanding of the $D^0 \rightarrow K_S \pi^+ \pi^-$ decays. Although K-matrix description of the $\pi\pi$ S-wave may yield improved models of the DP and the error on ϕ_3/γ may be decreased from $\pm 10^\circ$ to a few degrees, it is still a model-dependent way to extract the angle. At BES-III, by using the coherence of $D^0 \bar{D}^0$ pairs at $\psi(3770)$ peak, one can study the CP-tagged and flavor-tagged DP by doing binned analysis [29]. This method is a model-independent. According to the estimation in reference [29], the proposed super- B factory [30] with its design integrated luminosity of 50 ab^{-1} , would allow a measurement of ϕ_3/γ with accuracy below 2° . To keep the uncertainty due to D DP decays below that level, around 10^{-4} CP-tagged D decays are needed, corresponding to $\sim 10 \text{ fb}^{-1}$ data which can be obtained at BEPC-II with two years' luminosity.

Table 5

Current and projected 90%-CL upper limits on rare D^+ decay modes at BES-III with 20 fb^{-1} data at $\psi(3770)$ peak. We assume the selection efficiencies for all modes are 35%.

Mode	Reference Experiment	Best Upper limits(10^{-6})	BES-III ($\times 10^{-6}$)
$\pi^+ e^+ e^-$	CLEO-c [31]	7.4	0.03
$\pi^+ \mu^+ \mu^-$	FOCUS [32]	8.8	0.03
$\pi^+ \mu^+ e^-$	E791 [33]	34	0.03
$\pi^- e^+ e^+$	CLEO-c [31]	3.6	0.03
$\pi^- \mu^+ \mu^+$	FOCUS [32]	4.8	0.03
$\pi^- \mu^+ e^+$	E791 [33]	50	0.03
$K^+ e^+ e^-$	CLEO-c [31]	6.2	0.03
$K^+ \mu^+ \mu^-$	FOCUS [32]	9.2	0.03
$K^+ \mu^+ e^-$	E791 [33]	68	0.03
$K^- e^+ e^+$	CLEO-c [31]	4.5	0.03
$K^- \mu^+ \mu^+$	FOCUS [32]	13	0.03
$K^- \mu^+ e^+$	E687 [34]	130	0.03

Table 6

Current and projected 90%-CL upper limits on rare D^0 decay modes at BES-III with 20 fb^{-1} data at $\psi(3770)$ peak.

Mode	Reference Experiment	Best Upper limits(10^{-6})	BES-III ($\times 10^{-6}$)
$\gamma\gamma$	CLEO [37]	28	0.05
$\mu^+ \mu^-$	D0 [39]	2.4	0.03
$\mu^+ e^-$	E791 [33]	8.1	0.03
$e^+ e^-$	E791 [33]	6.2	0.03
$\pi^0 \mu^+ \mu^-$	E653 [40]	180	0.05
$\pi^0 \mu^+ e^+$	CLEO [38]	86	0.05
$\pi^0 e^+ e^-$	CLEO [38]	45	0.05
$K_S \mu^+ \mu^-$	E653 [40]	260	0.1
$K_S \mu^+ e^-$	CLEO [38]	100	0.1
$K_S e^+ e^-$	CLEO [38]	110	0.1
$\eta \mu^+ \mu^-$	CLEO [38]	530	0.1
$\eta \mu^+ e^-$	CLEO [38]	100	0.1
$\eta e^+ e^-$	CLEO [38]	110	0.1

4.3. Rare Charm Decays

Searches for rare-decay processes have played an important role in the development of the SM. Short-distance flavor-changing neutral current (FCNC) processes in charm decays are much more highly suppressed by the GIM mechanism than the corresponding down-type quark decays because of the large top quark mass. Observation of D^+ FCNC decays $D^+ \rightarrow \pi^+ l^+ l^-$ and $D^+ \rightarrow K^+ l^+ l^-$ could therefore provide indication of new physics or of unexpectedly large rates for long-distance SM processes like $D^+ \rightarrow \pi^+ V$, $V \rightarrow l^+ l^-$, with real or virtual vector meson V . Recently, CLEO-c report the branching fraction of the resonant decay $\mathcal{BR}(D^+ \rightarrow \pi^+ \phi \rightarrow \pi^+ e^+ e^-) = (2.8 \pm 1.9 \pm 0.2) \times 10^{-6}$. The lepton-number-violating (LNV) or lepton-flavor-violating (LFV) decays $D^+ \rightarrow \pi^- l^+ l^+$, $K^- l^+ l^+$ and $\pi^+ \mu^+ e^-$ are forbidden in the SM. Past searches have set upper limits for the dielectron and dimuon decay modes [16]. In Table 5 and Table 6, the current limits and expected sensitivities at BES-III are summarized for D^+ and D^0 , respectively. Detailed description on rare charm decays can be found in references [35,36]. The charm meson radiative decays

are also very important to understand final state interaction which may enhance the decay rates. In Ref. [35,36], the decay rates of $D \rightarrow V\gamma$ (V can be ϕ , ω , ρ and K^*) had been estimated to be $10^{-5} - 10^{-6}$, which can be reached at BES-III.

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