BES-III experiment at BEPCII

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The Beijing Electron Collider has been upgraded (BEPCII) to a double ring collider with a design luminosity of $1\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at a center-of-mass energy of 3.78GeV. It will operate between 2.0 and 4.6 GeV in the center of mass. The *BES-III* experiment will be used to study the charm and τ physics. It is foreseen to collect on the order of 10 billion J/ψ events or 3 billion $\psi(2S)$ events per year according to the designed luminosity. About 32 million $D\overline{D}$ pairs and 2.0 million $D_S\overline{D}_S$ at threshold will be collected per year.

1. Introduction

The Hadron spectroscopy and the Charm physics are becoming more exciting, This revival interesting has been driven by the abundance of the physics results in the Charm energy region from BES and CLEOc. Recently, the experimental reports about the narrow D_{sJ} states, $X(3872)$, $X(3940)$, $Y(3940)$ and the newest unexpected $Y(4260)$ from the B factories and other related experiments, as well as the proton-antiproton threshold enhancement and $X(1835)$ observed at BESII also attracted great attention. In the meanwhile, the MIMD Lattice Calculation (MILC) and the High Precision QCD (HPQCD) collaborations predicted $f_{D^+} = 201\pm3\pm17$ MeV, CLEO-c collaboration also reported the result $f_{D^+} = 223\pm16\pm8$ MeV. The two results agree well within the errors of about 8% each other. It will challenge the theoretical prediction and provide important tests of the predictive powers of the lattice QCD.

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

Data Sample	CMS (MeV)	Luminosity ($10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	#Events per year
J/ψ	3097	0.6	10×10^9
$\tau^+\tau^-$	3670	1.0	12×10^6
$\psi(2S)$	3686	1.0	3.0×10^9
$D^0\overline{D}^0$	3770	1.0	18×10^6
D^+D^-	3770	1.0	14×10^6
$D_S^+D_S^-$	4030	0.6	1.0×10^6
$D_S^+D_S^-$	4170	0.6	2.0×10^6

The *BES-III* at BEPCII under construction in Beijing can accumulate 10×10^9 J/ψ, 3×10^9 $\psi(2S)$, 30 million $D\overline{D}$ or 2 million $D_S\overline{D}_S$-pairs per running year as listed in Table I, respectively. Coupled with what is available at CLEO-c, the *BES-III* will make it possible for the first time to study in detail the light hadron spectroscopy in the decays of the charmonium states and the charmed mesons. In addition, about 32 million $D\overline{D}$ pairs will be collected at *BES-III* in one year at $\psi(3770)$ peak. Many high precision measurements, including the CKM matrix elements related to the Charm weak decays, decay constants f_{D^+} (f_{D_S}), the Dalitz decays of D meson and the absolute decay branching fraction and so on, will be achieved. The *BES-III* analyses are likely to be essential in deciding if some intriguing signals in particular in the D decays are actually due to the new physics or not. With the modern techniques and the unprecedented high statistical data sample, searching for the rare decays of D, Charmonium and tau will be possible, such as the lepton number and flavor violated decays, invisible decays. The study of τ- Charm physics could reveal or indicate the possible presence of the new physics in the low energy region [1].

This paper will give a brief review on the τ-Charm physics in the next few years at *BES-III*.

2. BEPCII and *BES-III* detector

BECPII, the upgrade of Beijing Electron Positron Collider(BEPC), is currently under construction at Institute of High Energy Physics (IHEP), Beijing, China. The accelerator has two storage rings in the existing tunnel with a circumstance of 224 m, one for electron and one for positron, each with 93 bunches spaced by 8 ns [2]. The total beam current is 910 mA per ring, and the horizontal crossing angle of the two beams is designed to be $\pm$ 11 mrad. The beam energy range is between 1 to 2.3 GeV. The designed luminosity is $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at the beam energy of 1.89 GeV. The luminosity will be increased by two orders of magnitudes compared with BEPC. The bunch length is estimated to be 1.5 cm and the energy spread will be 5×10^{-4}. The upgrade of the Linac will provide the full energy injection of positron up to 1.89Gev with the rate of 50mA/min.. The *BES-III* detector [2] is the only experiment at BEPCII. The physics goal of BEPCII/*BES-III* is the precision measurement at the Charm energy region to test the Standard Model and to search for new phenomena beyond the Standard Model. At this moment, the LINAC has been installed on schedule. Its tuning was smoothly and reached all design specifications. The storage rings

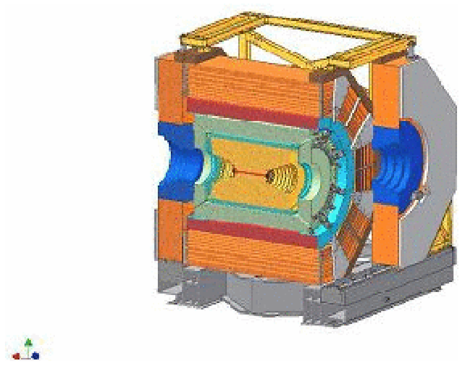

Figure 1: Schematics of the *BES-III* detector.

have installed, and provided the synchrotron radiation running from the end of 2006. The first electron positron collision was observed March 25, 2007. The *BES-III* detector has been moved into the interaction region in the beginning of 2008. The physics running at $\psi(2S)$ peak started in August 2008.

Compared to the old BES detector, *BES-III* is a state-of-the-art detector with modern technologies [2]. The BES/BES-II were modelled on the MARK-III detector. There are tremendous developments in the detector technology since then. The goals of the BES detector upgrade are: 1) Improving the detector resolution to match with the high statistics of the data samples; 2) To adapt with the high event rate of BEPC-II; 3) To modify the interaction region to provide the space for the supper-conducting quadrupoles. In every resolution and performance parameter, for example, the wire resolution, momentum and energy resolutions, mass resolution, particle identification (PID) capability, solid angle coverage, the *BES-III* is superior to previous versions of the BES detector by substantial margins. As shown in Fig. 1, the new detector consists of a Helium-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 Resistive Plate Chambers (RPC) counters as the muon chamber. The construction is expected to be completed by the end of 2007. The photon energy resolution is $\Delta E/E = 2.5\%$ at $E_\gamma = 1.0$ GeV (it was 23% for BES and BES-II). The momentum resolution is $\sigma_p/p = 0.5\%$ at $p = 1.0$ GeV/c, and the dE/dx resolution for hadron tracks is about 6%. The time resolution of TOF is about 100 ps, combining the energy loss (dE/dx) measurement in the draft chamber, give 10 σ K/π resolution across the typical kinematic range.

3. R values

The parameter R describes the cross section for the $e^+e^- \to$Hadrons normalized by the lowest QED cross section $\sigma(e^+e^- \to \mu^+\mu^-)$. The R measurements have been used to extract α_S [4] and to test pertubative QCD. R measurements also have an impact on the theoretical prediction of the anomalous magnetic moment of the muon $(g-2)_\mu$ [5]. The most interesting motivation to measure R comes from the SM global fits. R as a function of center-of-mass energy is the experimental input to measure $\Delta\alpha_{had}$, the hadronic vacuum correction to α_{QED} which is one of the ingredients to the electroweak global fits.

The main improvements on R values are from the BES-II collaboration reduced the error to 6 - 7% [7, 8] (before it was 15-20%). These measurements had a significant impact on the global fits to the prediction of the Higgs mass [6]. The *BES-III* can measure R in the two ways. By scanning the beam energies, the R values can be measured at a single point error of approximately 2% with of order 100 pb^{-1} of data from 2 to 4.6 GeV. An alternative approach consists of extracting R from the Initial State Radiation (ISR) events. The ISR events will allow *BES-III* to measure R below 2 GeV energy range which is what is the most needed to reduce the overall uncertainty in α_{had}. Such radiative return measurements of R look feasible statistically. In the region between $2 < \sqrt{s} < 3$ GeV *BES-III* will collect about 60k radiative return events fully contained in the detector of 1 fb^{-1} data while running at $\psi(3770)$. For crucial region $1 < \sqrt{s} < 2$ GeV, *BES-III* will accumulate about 50k radiative return events per inverse femtobarn.

4. Light Hadron Spectroscopy

Three main processes to study the light hadron spectroscopy are J/ψ radiative decay, J/ψ hadronic decay into mesons, and J/ψ hadronic decay into baryons and anti-baryons.

4.1. Glueball

Glueballs are a dramatic consequence of the local, unbroken, non-Abelian symmetry that is the unique defining property of QCD. The prediction that glueballs exist is simple and fundamental but has proven difficult to verify. We expect the puzzle to be answered soon, for two reasons. First, *BES-III* will provide huge J/ψ data samples — potentially several billion — allowing definitive studies of J/ψ decay and, especially, the partial wave analysis of the glueball-preferred radiative J/ψ decay channel. Second, in roughly the same time frame, lattice QCD (LQCD) will provide the reliable unquenched predictions for the glueball spectrum, mixing, and decays. This powerful combination of the theory and the experiment should suffice to finally resolve this fundamental and difficult issue [13].

For now we rely on a few simple ideas [13]:

- Glueballs are extra states, beyond the $\bar{q}q$ spectrum. To exploit this we must understand the "ordinary" $\bar{q}q$ spectrum very well, using data from J/ψ, B, and Z decays, and from $\bar{p}p$, πp, $\gamma\gamma$, and γN scattering. It is already clear that there are indeed "extra" $I, J^{PC} = 00^{++}$ states in the mass region where the scalar glueball is expected.

- Glueballs couple strongly to gluons so they are prominent in the radiative J/ψ decay, which proceeds via $\psi \to \gamma gg$. They couple weakly to photons so they are not prominent in the photon-photon scattering.

- Glueballs are flavor singlets so their decays should be $SU(3)_F$ symmetric. However, this may not be true of spin zero glueball decays because of the chiral suppression, as discussed below.

J/ψ radiative decays is one of the glueball rich processes. As shown in Fig. 2, after emitting a photon, the $c\bar{c}$ pair is in a $C = +1$ state and decays to hadrons dominantly through two gluon intermediate states. Simply counting the power of α_s we know that glueballs should have the largest production rate, hybrids the second, then the ordinary $q\bar{q}$ mesons.

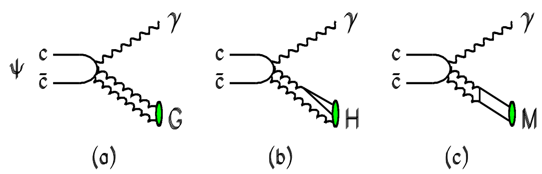

Figure 2: ψ radiative decays to (a) glueball, (b) hybrid, and (c) $q\bar{q}$ meson.

One thing worth noting is that the J/ψ radiative decay has a similar decay pattern as 0^{-+}, 0^{++} and 2^{++} charmoniums, *i.e.*, η_c, χ_{c0} and χ_{c2}, as it should be, since all of them decay through two gluons. The 4π, $\bar{K}K\pi\pi$, $\eta\pi\pi$ and $\bar{K}K\pi$ seem to be the most favorable final states for the two gluon transition at $1 \sim 3$ GeV. The branching ratios for J/ψ radiative decay to these four channels are listed in Table II. The sum of them is about half of all radiative decays. If glueballs exist, they should appear in these four channels. Therefore BES Collaboration had performed partial wave analyses (PWA) of these four channels [14–17] based on BES-I data. The main results have been summarized in Ref. [18]. Mesons with large branching ratios in the J/ψ radiative decays are a very broad $\eta(2190)$ for 0^{-+}, a broad $f_2(1950)$ for 2^{++}, $f_0(1500)$, $f_0(1710\text{-}1770)$ and $f_0(2100)$ for 0^{++}.

Table II Branching ratios for the four largest J/Ψ radiative decay channels (BR$\times 10^3$)

$\gamma 4\pi$	$\gamma\bar{K}K\pi\pi$	$\gamma\eta\pi\pi$	$\gamma\bar{K}K\pi$
14.4 ± 1.8 [19]	9.5 ± 2.7 [15]	6.1 ± 1.0 [9]	6.0 ± 2.1 [17]

In addition to the J/ψ radiative decays, the J/ψ hadronic decays to mesons also play very important role for the study of the light spectroscopy. There are mainly two physics objectives here:

(1) Looking for hybrids. Since the ψ decays to hadrons through three gluons, the final states involving a hybrid as shown in Fig. 3(a) are expected to have larger production rate than ordinary $q\bar{q}$ mesons as shown in Fig. 3(b,c).

(2) Extracting the $u\bar{u} + d\bar{d}$ and $s\bar{s}$ components of the associated mesons, M, via $\psi \to M + \omega/\phi$ as shown in Fig. 3(b,c).

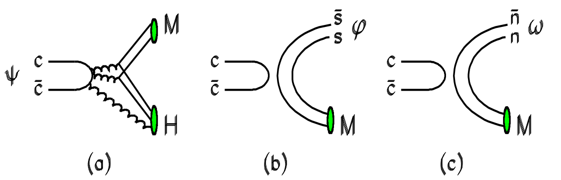

Figure 3: ψ hadronic decays to (a) hybrids, (b) $s\bar{s}$, and (c) $n\bar{n} \equiv \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$ mesons.

BES-III at BEPC-II will begin operation in 2008. At the design luminosity it will accumulate 10 billion J/ψ decays in a single year, enabling the definitive partial wave analysis of the decay products. We can look forward to better understanding of the scalar glueball candidates, including their multi-body decays. During the *BES-III* lifetime LQCD should begin to contribute reliable unquenched calculations of the spectrum, mixing and decays. In particular, LQCD can determine if chiral suppression survives non-perturbative effects and, if so, how it effects mixing and decays. The combination of *BES-III* and LQCD should allow us to finally identify and study the scalar glueball, as well as the glueballs and hybrids with other quantum numbers.

4.2. Scalar at BES

The scalar mesons are one of the most controversial subjects in hadron physics. Below 1.0 GeV, there are two $I = 0$ scalar candidates, σ ($\pi\pi$ S-Wave), $f_0(980)$ and one $I = 1/2$ $K\pi$ S-wave, κ, in the Particle Data Group (PDG) lists [9]. Between 1.0 GeV and 2.2 GeV, the following $I = 0$ scalar states are listed in PDG:

$f_0(1370)$, $f_0(1500)$ $f_0(1710)$ and one $I = 1/2$ scalar state: $K_0^*(1430)$. Scalar mesons have been traditionally studied in scattering experiments. However, in these experiments the mesons can be difficult to disentangle from non-resonant backgrounds. Radiative and hadronic J/ψ decays provide an excellent laboratory to probe these states.

Using the world largest J/ψ data sample in e^+e^- annihilation experiment, BES-II studied the scalars decay into pair of pseudoscalars ($\pi^+\pi^-$, $\pi^0\pi^0$, K^+K^- and $K_s^0K_s^0$) in J/ψ radiative decays as well as recoiling against a ϕ or an ω [20–23]. The full mass spectra and the scalar part in them are shown in Fig. 4.

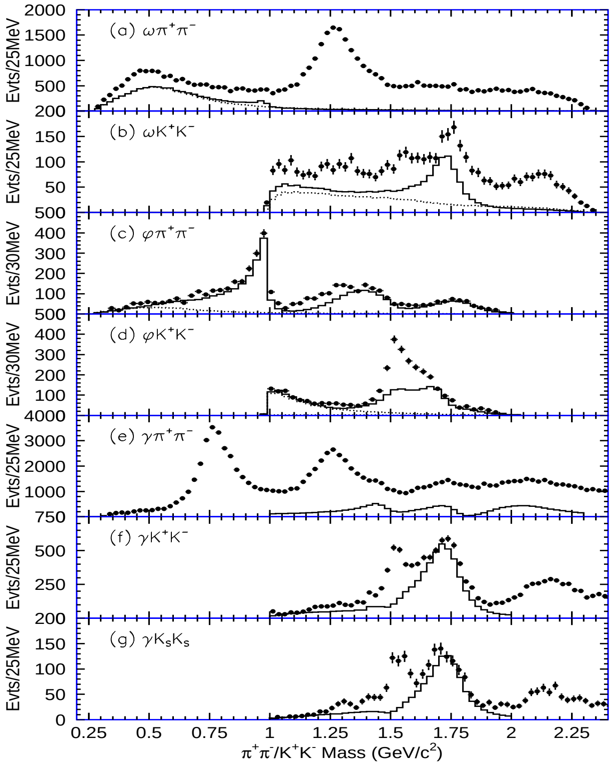

Figure 4: The invariant mass distributions of the pseudoscalar meson pairs recoiling against ω, ϕ, or γ in J/ψ decays measured at BES-II. The dots with error bars are data, the solid histograms are the scalar contribution from PWA, and the dashed lines in (a) through (c) are contributions of σ from the fits, while the dashed line in (d) is the $f_0(980)$. Notice that not the full mass spectra are analyzed in (e), (f), and (g). Results in (e) are preliminary, otherwise are published

4.2.1. σ and κ

From the analyses, BES-II sees significant contributions of σ particle in $\omega\pi^+\pi^-$ and ωK^+K^-, and also hint in $\phi\pi^+\pi^-$. In $J/\psi \to \omega\pi^+\pi^-$, there are conspicuous $\omega f_2(1270)$ and $b_1(1235)\pi$ signals. At low $\pi\pi$ mass, a large, broad peak due to the σ is observed as shown in Fig. 4(a). Two independent partial wave analyses are performed on $\omega\pi^+\pi^-$ data and four different parameterizations of the σ amplitude are tried [20], all give consistent results for the σ pole, which is at $(541\pm39)-i(252\pm42)$ MeV/c^2. Recently, an analysis of $\psi(2S) \to \pi^+\pi^-J/\psi$ has been performed to study the σ [24]. The pole position of σ is consistent with that from $J/\psi \to \omega\pi^+\pi^-$.

Events over all of the 4-body phase space for $J/\psi \to K^+K^-\pi^+\pi^-$ have been fitted. We find evidence for the κ in the process $J/\psi \to \overline{K}^*(892)^0\kappa$, $\kappa \to (K\pi)_S$. We select a $K^-\pi^+$ pair in the $\overline{K}^*(892)^0$ mass range 892 ± 100 MeV. Two independent PWA, by the covariant helicity amplitude method [25] and by the variant mass and width method [26] have been performed, providing a cross check with each other. They reproduce the data well, and the results are in good agreement. The low mass enhancement is well described by the scalar κ, which is highly required in the analyses. Parameter values of Breit-Wigner (BW) mass and width of the κ, averaged from those obtained by the two methods, are $878 \pm 23^{+64}_{-55}$ MeV/c^2 and $499\pm52^{+55}_{-87}$ MeV/c^2. The pole position is determined to be $(841 \pm 30^{+81}_{-73}) - i(309 \pm 45^{+48}_{-72})$ MeV/c^2 [27].

4.2.2. $f_0(980)$ in J/ψ Decays

Strong $f_0(980)$ is seen in $J/\psi \to \phi\pi^+\pi^-$ and ϕK^+K^- modes [22], from which the resonance parameters are measured to be $M = 965 \pm 8(stat) \pm 6(syst)$ MeV/c^2, $g_1 = 165 \pm 10(stat) \pm 15(syst)$ MeV/c^2 and $g_2/g_1 = 4.21 \pm 0.25(stat) \pm 0.21(syst)$, where M is the mass, and g_1 and g_2 are the couplings to $\pi\pi$ and $K\bar{K}$ respectively if the $f_0(980)$ is parameterized using the the Flatté's formula. The production of $f_0(980)$ is very weak recoiling against an ω or a photon, which indicates $s\bar{s}$ is the dominant component in it.

4.3. Scalar above 1.0 GeV in J/ψ Decays

In $J/\psi \to \phi\pi^+\pi^-$ decay, a scalar contribution near 1.4 GeV on $\pi^+\pi^-$ invariant mass distribution is found as shown in Fig. refscalars(c), it is due to the dominant $f_0(1370)$ interfering with a smaller $f_0(1500)$ component. The mass and width of $f_0(1370)$ are determined to be: $M = 1350 \pm 50$ MeV/c^2 and $\Gamma = 265 \pm 40$ MeV/c^2. In $\gamma\pi^+\pi^-$, a similar structure is observed in the same mass region, the fit yields a resonance at mass $1466 \pm 6(stat) \pm 16(syst)$ MeV/c^2 with width of $108^{+14}_{-11}(stat) \pm 21(syst)$ MeV/c^2, possibly the $f_0(1500)$ [22], and the contribution from the $f_0(1370)$ can not be excluded. While, the production of $f_0(1370)$ and $f_0(1500)$ in $\gamma K\bar{K}$ is insignificant [23].

The K^+K^- invariant mass distributions from $\gamma K\bar{K}$ and ωK^+K^-, the $\pi^+\pi^-$ invariant mass distributions from $\gamma\pi^+\pi^-$, and $\phi\pi^+\pi^-$ show clear scalar contribution around 1.75 GeV/c^2. Two states are resolved from the bump, one is $f_0(1710)$ with $M \sim 1740$ MeV/c^2 and $\Gamma \sim 150$ MeV/c^2 which decays to $K\bar{K}$ mostly, and one possible new state $f_0(1790)$ with $M \sim 1790$ MeV/c^2 and $\Gamma \sim 270$ MeV/c^2 which couples to $\pi\pi$ stronger than to $K\bar{K}$. However, the existence of the second scalar particle needs confirmation: the signal observed in $\phi f_0(1790)$ is rather in the edge of the phase space, and the reconstruction efficiency of the ϕ decreases dramatically as the momentum of the ϕ decreases thus the momentum of the kaon from ϕ decays is very low and can not be detected [24]. Furthermore, there are wide higher mass scalar states above 2 GeV/c^2 as observed in $\gamma\pi^+\pi^-$ (Fig. 4e) and $\gamma K\bar{K}$ [9], whose tails may interfere with the $f_0(1710)$ and produce structure near the edge of the phase space.

The discussions of these measurements for understanding the nature of the scalar particles can be found in Refs. [28–30], where the J/ψ decay dynamics and the fractions of the possible $q\bar{q}$ and glueball components in the states are examined.

4.4. Excited Baryon in ψ Decay

Baryons are the basic building blocks of our world. If we cut any piece of object smaller and smaller, we will finally reach the nucleons, *i.e.*, the lightest baryons, and we cannot cut them smaller any further. So without mention any theory, we know that the study of baryon structure is at the forefront of exploring microscopic structure of matter. From theoretical point of view, since baryons represent the simplest system in which the three colors of QCD neutralize into colorless objects and the essential non-Abelian character of QCD is manifest, understanding the baryon structure is absolutely necessary before we claim that we really understand QCD.

The J/ψ and ψ' experiments at *BES-III* will provide an excellent place for studying excited nucleons and hyperons – N^*, Λ^*, Σ^* and Ξ^* resonances [41]. The corresponding Feynman graph for the production of these excited nucleons and hyperons is shown in Fig. 5 where ψ represents either J/ψ or ψ'.

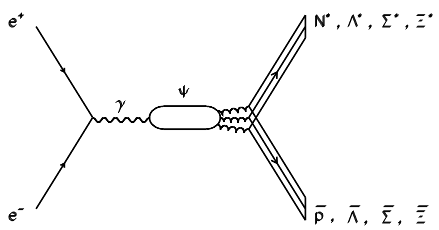

Figure 5: $\bar{p}N^*$, $\bar{\Lambda}\Lambda^*$, $\bar{\Sigma}\Sigma^*$ and $\bar{\Xi}\Xi^*$ production from e^+e^- collision through ψ meson.

Comparing with other facilities, our baryon program has advantages in at least three obvious aspects:

(1) We have pure isospin 1/2 πN and $\pi\pi N$ systems from $J/\psi \to \bar{N}N\pi$ and $\bar{N}N\pi\pi$ processes due to isospin conservation, while πN and $\pi\pi N$ systems from πN and γN experiments are mixture of isospin 1/2 and 3/2, and suffer difficulty on the isospin decomposition;

(2) ψ mesons decay to baryon-antibaryon pairs through three or more gluons. It is a favorable place for producing hybrid (qqqg) baryons, and for looking for some "missing" N^* resonances which have weak coupling to both πN and γN, but stronger coupling to g^3N;

(3) Not only N^*, Λ^*, Σ^* baryons, but also Ξ^* baryons with two strange quarks can be studied. Many QCD-inspired models[42, 43] are expected to be more reliable for baryons with two strange quarks due to their heavier quark mass. More than thirty Ξ^* resonances are predicted where only two such states are well established by experiments. The theory is totally not challenged due to lack of data. //*****

With two order of magnitude more statistics at *BES-III*, plenty "missing" Λ^*,Σ^* and Ξ^* hyperon resonances are expected to be produced and observed by high statistics *BES-III* J/ψ and ψ' data. The ψ' data will significantly extend the mass range for the study of baryon spectroscopy. These Ξ^* states cannot be produced by J/ψ decays due to limited phase space, but all can be produced by ψ' decays. The *BES-III* ψ' data will enable us to complete the Λ^*, Σ^* and Ξ^* spectrum and examine various pictures for their internal structures, such as simple 3q quark structure and more complicated structure with pentaquark components dominated [42].

Table III Measured J/ψ decay branching ratios (BR$\times 10^3$) for channels involving baryon anti-baryon and meson.

$p\bar{n}\pi^-$	$p\bar{p}\pi^0$	$p\bar{p}\pi^+\pi^-$	$p\bar{p}\eta$	$p\bar{p}\eta'$	$p\bar{p}\omega$
2.4 ± 0.2	1.1 ± 0.1	6.0 ± 0.5	2.1 ± 0.2	0.9 ± 0.4	1.3 ± 0.3
$\Lambda\bar{\Sigma}^-\pi^+$	$pK^-\bar{\Lambda}$	$pK^-\bar{\Sigma}^0$	$\bar{p}p\phi$	$\Delta(1232)^{++}\bar{p}\pi^-$	$pK^-\bar{\Sigma}(1385)^0$
1.1 ± 0.1	0.9 ± 0.2	0.3 ± 0.1	0.045 ± 0.015	1.6 ± 0.5	0.51 ± 0.32

The measured J/ψ decay branching ratios for channels involving baryon anti-baryon plus meson(s) are listed in Table III. With 10^{10} J/ψ events, all these channels will get enough statistics for partial wave analysis. Among these channels, the $\Sigma\bar{\Lambda}\pi + c.c.$ channels should have high priority for pinning down the lowest $1/2^-$ Σ^* and Λ^* as well as other higher excited Σ^* and Λ^* states. Another very important channel is $K^-\Lambda\bar{\Xi}^+ + c.c.$ which is the best channel for finding the lowest $1/2^-$ Ξ^* resonance and many other "missing" Ξ^* states with $\Xi^* \to K\Lambda$. This channel should be rather easy to be reconstructed by *BES-III*. One can select events containing K^- and Λ with $\Lambda \to p\pi^-$, then from missing mass spectrum of $K^-\Lambda$ one should easily identify the very narrow $\bar{\Xi}^+$ peak.

For 10^9 ψ' events, the $K^-\Lambda\bar{\Xi}^+ + c.c.$ and $p\bar{p}\phi$ channels should have high priority. These two channels are strongly limited by phase space in J/ψ decays. From ψ' decays, the phase space is much increased.

The $K^- \Lambda \bar{\Xi}^+ + c.c.$ channel should allow us to discover many "missing" Ξ^* resonances, while the $p\bar{p}\phi$ channel should allow us to find those N^* resonances with large coupling to $N\phi$ and hence large 5-quark components.

After analyzing the easier 3-body final states, 4-body and 5-body channels should also be investigated. Among them, $\Delta(1232)^{++}\bar{p}\pi^-$ in $p\bar{p}\pi^+\pi^-$ and $\Delta(1232)^{++}\bar{\Sigma}^-K^-$ in $p\bar{\Sigma}^-\pi^+K^-$ are very good channels for finding "missing" $\bar{\Delta}^{*--}$ decaying to $\bar{p}\pi^-$ and $\bar{\Sigma}^-K^-$, respectively. The spectrum of isospin 3/2 Δ^{++*} resonances is of special interest since it is the most experimentally accessible system composed of 3 identical valence quarks. Recently, the lowest $1/2^-$ baryon decuplet is proposed to contain large vector-meson-baryon molecular components [57]. In the new scheme, the $\Xi^*(1950)$ is predicted to be $1/2-$ resonance with large coupling to ΛK^*. The $\psi' \to \bar{\Xi}\Lambda K^*$ will provide a very good place to look for "missing" Ξ^* with large coupling to ΛK^*.

In summary, *BES-III* data can play a very important role in studying excited nucleons and hyperons, i.e., N^*, Λ^*, Σ^*, Ξ^* and Δ^{*++} resonances.

5. Charmonium Decays

There are 8 bound states of charmonium below the $D\bar{D}$ breakup threshold. These are spin triplets $J/\psi(1^3S_1)$, $\psi(2S)(2^3S_1)$, $\chi_{c0,1,2}(1^3P_{0,1,2})$ and spin singlets $\eta_c(1^1S_0)$, $\eta_c(2S)(2^1S_0)$, $h_c(1^1P_1)$. Only J/ψ and $\psi(2S)$ can be produced directly in e^+e^- annihilation. All states below $\psi(2S)$ can be produced from $\psi(2S)$ through radiative or hadronic transitions. Thus, $\psi(2S)$ data provides an excellent source for the studies of charmonium physics below the $D\bar{D}$ breakup threshold (see Fig. 6).

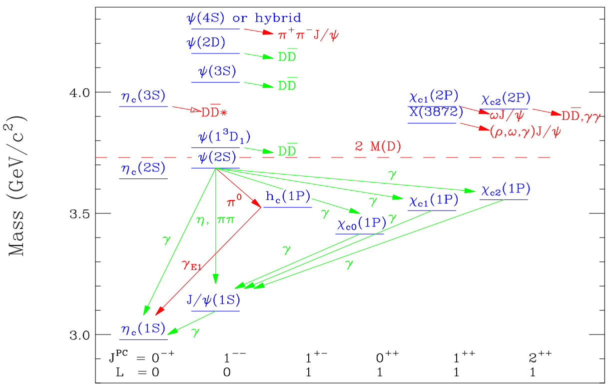

Figure 6: Spectra of the states of charmonium below $\psi(2S)$ from J. Rosner.

5.1. Charmonium physics with the $\psi(2S)$

Potential physics opportunities with $\psi(2S)$ at *BES-III* include the followings:

- Inclusive photon spectrum: absolute branching fractions for $\psi(2S) \to \gamma\eta_C$ and $\psi(2S) \to \gamma\eta_C(2S)$ will be measured, although no signal for the former is evident yet. Note that the mass of $\eta_C(2S)$ is now known from B meson decays at BELLE [58] and from $\gamma\gamma$ fusion from CLEO [59].

- Detail studies of χ_{C0}, χ_{C1} and χ_{C2}: high statistic single photon tags of the intermediate χ_C states will allow various measurements of their decay branching fractions. The Dalitz decays of χ_c will provide another opportunity for us to understand the light hadron spectroscopy.

- Hadronic decays of $\psi(2S)$: although h_C state had been seen at CLEO-c, a precise study of h_C mass and decays will be still the primary goal at *BES-III* with huge statistics. The decay $\psi(2S) \to \rho\pi$ will be also searched for, a branching ratio which is anomalously small by comparing to that in J/ψ decay. More decay modes can be explored in $\psi(2S)$ decays in order to clarify the so called "$\rho\pi$" puzzle.

- Radiative decay of $\psi(2S)$: radiative decay of vector charmonium is a glueball-rich process. Although one expects the majority of this data to come from J/ψ running, $\psi(2S)$ decay would also allow flavour tagging through the hadronic decays where a low-mass vector meson (ρ, ω, ϕ) replaces the radiative photon. In fact, the phase space in $\psi(2S)$ decay will allow to probe the spectrum with larger mass.

- Hadronic transition of $\psi(2S)$: The possibility of studying J/ψ decay using $\psi(2S)$ running and tagging the J/ψ from $\psi(2S) \to \pi\pi J/\psi$ is also being investigated. The decay rate is about 47% for $\psi(2S) \to \pi\pi J/\psi$ mode, in which the background from $e^+e^- \to q\bar{q}$ can be avoided comparing with these data at J/ψ peak.

5.2. Charmonium physics at the $\psi(3770)$

BES-III will take a large data sample (4 fbfb^1/per year) at the $\psi(3770)$. The main goal of this running will acquire a large sample of tagged D$\bar{\text{D}}$ events, but the opportunity presents itself for charmonium studies as well.

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 [72–74], but their branching fractions are highly suppressed. BES-II reported the first signal of non-$D\overline{D}$ decays of $\psi(3770)$, at $\sim 3\sigma$ significance, with $\mathcal{B}(\psi(3770) \to \pi^+\pi^- J/\psi) = (0.34 \pm 0.14 \pm 0.09)\%$ [75]. CLEO-c has also searched for the non-$D\overline{D}$ decays of $\psi(3770)$, including $\pi\pi J/\psi$, $\gamma\chi_{c1,c2}$ and light hadron final states [76]. The CLEO-c collaboration measured cross section for $e^+e^- \to \psi(3770) \to$ hadrons at $E_{cm} = 3773$ MeV to be $(6.38 \pm 0.08^{+0.41}_{-0.30})$ nb [77]. The difference between this and the $e^+e^- \to \psi(3770) \to D\overline{D}$ cross section at the same energy is found to be $(-0.01 \pm 0.08^{+0.41}_{-0.30})$ nb, which indicates the non-$D\overline{D}$ 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 [78]. These results would provide information on $1D_1/2S_1$ mixing.

In order to understand the decay dynamics of non-$D\overline{D}$ 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-$D\overline{D}$ 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 $\psi(3770)$ [79].

In summary, the study of the $\rho\pi$ puzzle between $\psi(2S)$ and J/ψ decays and the charmless decays of $\psi(3770)$ should not be isolated as they were since J/ψ, $\psi(2S)$ and $\psi(3770)$ are all charmonium states with very similar quantum numbers, and it is expected $\psi(2S)$ and $\psi(3770)$ are the mixtures of $2S$ and $1D$ states [71]. At *BES-III*, more data should be taken in the vicinity of $\psi(3770)$ peak in addition to the huge data sample at $psi(2S)$ and J/ψ peaks, so that results from these data may shed light on the puzzle and charmless decays of $\psi(3770)$.

5.3. Rare and Forbidden Charmonium Decays

With huge J/ψ and $\psi(2S)$ data samples, *BES-III* experiment will be approaching the statistics where rare ψ decays can provide important tests of the standard model and possible be able to uncover deviations.

5.3.1. Weak Decays of Charmonium

The low lying charmonium states below the open charm threshold usually decay through intermediate photons or gluons produced by the parent $c\bar{c}$ quark pair annihilation. These OZI violating but flavor conserving decays lead to narrow widths to J/ψ and $\psi(2S)$ states. In the standard model framework, the flavor changing weak decays of these states are also possible though these are expected to have rather low branching fractions. Huge J/ψ data sample at *BES-III* would afford to examine those rare decay processes, which may become detectable. The observation of any anomalous production rate of single charmed meson in J/ψ or $\psi(2S)$ decays at *BES-III* would be a hint of possible new physics either in the continuum via flavor-changing neutral currents [80] or in the decays of resonances due to unexpected effects of quark dynamics [81].

The inclusive branching fractions of J/ψ weak decays via a single quark of either c or $\bar{c}$ had been estimated to be $(2-4) \times 10^{-8}$ by ignoring any W-exchanged contribution and using the D^0 lifetime [82]. Such small branching ratios should make the observation of weak decays of J/ψ or $\psi(2S)$ extremely difficult despite the foreseen cleanness of events. However, at BEPC-II with a peak luminosity of $10^{33} cm^{-2}s^{-1}$ at $\psi(3770)$, the expected number of J/ψ is 10×10^9 per year of data taking, leading to $\cong 400$ weak decays when combined with the predicted branching ratio.

5.3.2. Search for the Invisible Decays of Quarkonium

Invisible decays of quarkonium states such as the J/ψ and the Υ, etc., offer a window into what may lie beyond the Standard Model (SM) [83, 84]. The reason is that apart from neutrinos, the Standard Model includes no other invisible final particles that these states can decay into. The searches for the invisible decays of π^0, η and η' have recently established in [85, 86].

Theories beyond the SM generally include new physics, such as, possibly, light dark matter (LDM) particles [88]. These can have the right relic abundance to constitute the nonbaryonic dark matter of the Universe, if they are coupled to the SM through a new light gauge boson U [89], or exchanges of heavy fermions. It is also possible to consider a light neutralino with coupling to the SM mediated by a light scalar singlet in the next-to-minimal supersymmetric standard model [90].

It had been shown that the measurements on the J/ψ invisible decay widths may be sensitive to constrain the physics model [91]. It is straightforward for one to calculate the branching ratio of the invisible decays of J/ψ and its observed decays into electron-positron pairs [91]. Within the SM the invisible mode consists solely of decays into three types of neutrino-antineutrino pairs. Neglecting polarization effects and taking into account e^+e^- production through a photon only, one get [91]:

$$\frac{\Gamma(J/\psi \to \nu\overline{\nu})}{\Gamma(J/\psi \to e^+e^-)} = \frac{27G^2M^4_{J/\psi}}{256\pi^2\alpha^2}\left(1-\frac{8}{3}sin^2(\theta_W\right)^2$$
$$= 4.54 \times 10^{-7}, \quad (1)$$

with G and α being the Fermi and the fine structure constants respectively. $M_{J/\psi}$ is mass of J/ψ. The uncertainty of the above formula is about 2-3% which mainly from the correction to J/ψ wave function, e^+e^- production through Z boson, electroweak radiative corrections [91]. At *BES-III*, one can then tag charmonium states which decay invisibly by looking for a particular radiative transition such as $\psi(2S) \to \pi^+\pi^- J/\psi$, $\psi(2S) \to \gamma\chi_c$ and so on, the soft $\pi^+\pi^-$ pairs or monoenergetic radiative γ can be used as tags of the invisible decays of J/ψ or χ_c states. At BESII, we performed the first search for invisible decays of the J/ψ using $\psi \to \pi^+\pi^- J/\psi$ events detected in a sample of 14.0 million $\psi(2S)$ decays. The upper limit on the ratio $\frac{\mathcal{B}(J/\psi\to\text{invisible})}{\mathcal{B}(J/\psi\to\mu^+\mu^-)}$ at the 90% confidence level is 1.2×10^{-2} [87].

5.3.3. Lepton Flavor Violating Processes in Decays of J/ψ

Lepton flavor violating (LFV) processes are strongly suppressed in the standard model by powers of small neutrino masses [92]. Therefore, such decays can be used to probe possible new physics. At present, there are many stringent bounds for μ, τ and Z boson decays, such as $BR(\mu \to 3e) \le 10^{-12}$, $BR(\mu \to e\gamma\gamma) \le 10^{-10}$ and somewhat weaker $O(10^{-6})$ bounds on LFV τ decays [9]. There have been a lot of studies both theoretically and experimentally on testing the lepton flavor conservation law [92, 93]. With huge J/ψ sample, the *BES-III* experiment will be able to make an additional experimental searching for lepton flavor violating processes of $J/\psi \to ll'$ (l and $l' = \tau, \mu, e$, $l \neq l'$) [94].

From 58 M J/ψ data at BESII, the following upper limits had been got [95]:

$$BR(J/\psi \to \tau^{\pm}e^{\mp}) < 8.3 \times 10^{-6}; \quad (2)$$
$$BR(J/\psi \to \tau^{\pm}\mu^{\mp}) < 2.0 \times 10^{-6}; \quad (3)$$
$$BR(J/\psi \to \mu^{\pm}e^{\mp}) < 1.1 \times 10^{-6}. \quad (4)$$

The sensitivity of the two-body lepton flavor violating decays of J/ψ could be $10^{-8} - 10^{-9}$ level at *BES-III* with one year luminosity at J/ψ peak. It will be a significant improvement.

6. Charm Physics

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, 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 [97]. 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 [97]: 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 [98] and complex [99] methods to measure the neutral D meson mixing parameters and check for direct CP violation.

6.1. Charm Decays and Production Cross Sections

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 $D\overline{D}$ or $D_S^+D_S^-$ threshold, no additional hadrons accompanying the $D\overline{D}$ or $D_S^+D_S^-$ pairs are produced. Reconstruction of one D or $\overline{D}$ meson (called single tag or ST) tags the event as either $D^0\overline{D}^0$ or D^+D^- ($D_S^+D_S^-$). For a given decay mode i, we measure independently the D and $\overline{D}$ ST yields, denoted by N_i and $\overline{N}_i$. We determine the corresponding efficiencies from Monte Carlo simulations (MC), denoted by ϵ_i and $\overline{\epsilon}_i$. Thus, $N_i = \epsilon_i \mathcal{B}_i N_{D\overline{D}}$ and $\overline{N}_i = \overline{\epsilon}_i \mathcal{B}_i N_{D\overline{D}}$, where $\mathcal{B}_i$ is the branching fraction for mode i, assuming no CP violation, and $N_{D\overline{D}}$ is the total number of produced $D\overline{D}$ pairs at *BES-III*. Double tag (DT) events are the subset of ST events where both the D and $\overline{D}$ are reconstructed. The DT yield for D mode i and $\overline{D}$ mode j, denoted by N_{ij}, is given by $N_{ij} = \epsilon_{ij}\mathcal{B}_i\mathcal{B}_j N_{D\overline{D}}$, 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 $\mathcal{B}_i = \frac{N_{ij}}{\overline{N}_j}\frac{\bar{\epsilon}_j}{\epsilon_{ij}}$. With the same method, we have the total number of $D\overline{D}$ pairs $N_{D\overline{D}} = \frac{N_i\overline{N}_j}{N_{ij}}\frac{\epsilon_{ij}}{(\epsilon_i\bar{\epsilon}_j)}$, which can be used to obtain the absolute cross-section of $D\overline{D}$ production.

6.1.1. 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 [97].

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

Decay Modes	Error (%) on $\mathcal{B}$	Error (%) on $f_{D(s)}$
$D^+ \to \mu^+\nu$ (f_D)	2.0	1.5
$D_S^+ \to \mu^+\nu$ (f_{D_S})	2.0	1.1
$D_S^+ \to \tau^+\nu$ (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 [96]. The leptonic decay of $D^+(D_S^+) \to \mu^+\nu$ 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 $D\overline{D}$ 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 IV summarizes the expected precision in the decay constant measurements. It should be noted that the $D^+ \to \tau^+\nu$ decay is reported by CLEO-c with upper limit of 2.1×10^{-3} at 90% CL [100]. At *BES-III*, the sensitivity will be $10^{-5} - 10^{-6}$ level.

6.1.2. Semileptonic Charm Decays

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

$$\frac{d\Gamma(D \to X_{s(d)}l^+\nu)}{dq^2} = \frac{G_F^2}{24\pi^3}p^3|V_{cs(d)}|^2p^3|F(q^2)|^2, \tag{5}$$

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 $c \to Ws(d)$ vertex. The form factor can be predicted from a number of different theoretical approaches [101] including LQCD [3]. 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, $D \to \pi l\nu$, $D \to Kl\nu$, $D \to \eta(\eta')l\nu$, $D \to \rho l\nu$, $D \to K^*l\nu$, $D_S \to \phi l\nu$ and $D_S \to K^*l\nu$, 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 V 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 $D+ \to f_0 l\nu$, $D+ \to \eta(\eta')l\nu$, $D^+ \to \overline{K}^{**}l\nu$ and $D^+ \to \phi l\nu$, where $\overline{K}^{**}$ is the exited koan mesons including $\overline{K}_1(1270)$, $\overline{K}^*(1410)$ and $\overline{K}^*(1430)$. These measurements will provide another lab to study the $K\pi$ and $\pi\pi$ S-wave [102].

The ratio of decay widths $\Gamma(D_S \to \eta' e\nu)/\Gamma(D_S \to \eta e\nu)$, using $|V_{cs}| = 0.975$ [103],

$$\frac{\Gamma(D_S \to \eta' e\nu)}{\Gamma(D_S \to \eta e\nu)} \sim 0.28 \times |cot\phi|^2, \tag{6}$$

depends on the content of the η and η' mesons, where ϕ is the mixing angle in the $\eta - \eta'$ flavor mixing scheme [104]. We note that the decays $D_S \to \eta(\eta')l\nu$ involve the strange content of $\eta(\eta')$, and $D^+ \to \eta(\eta')l\nu$ involve the non-strange content. Therefore, $D^+ \to \eta(\eta')l\nu$ and $D_S \to \eta(\eta')l\nu$ could provide combined testing of a $\eta - \eta'$ mixing scheme [105]. The uncertainty on mixing angle ϕ is about 13% with current D_S^+ data [104], at *BES-III*, the error will be 2% level.

6.1.3. Absolute Hadronic Branching Fraction and $e^+e^- \to D\overline{D}$,$D\overline{D}^*$, and $D^*\overline{D}^*$ 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

Table V 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*
$D^0 \to Kl\nu$	4.6	0.2	PS→ PS	1.0
$D^0 \to \pi l\nu$	9.6	0.4	PS→ PS	1.0
$D^+ \to \pi l\nu$	50.0	0.8	PS→ PS	1.0
$D^+ \to \overline{K}^* l\nu$	10.0	0.3	PS→ V	2.0
$D_S^+ \to \phi l\nu$	25.0	1.2	PS→ V	1.0

major systematic error contributions from efficiency uncertainties in the tracks and showers.

Table VI Unobserved 3-body D decays, $D^0 \to P^0P^0X^0$, 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	$\pi^0\pi^0\pi^0$	$\eta\eta\pi^0$	$K_SK_S\pi^0$	$K_LK_L\pi^0$
η	$\pi^0\pi^0\eta$	$\eta\eta\eta$	$K_SK_S\eta$	$K_LK_L\eta$
η'	$\pi^0\pi^0\eta'$	N/A	N/A	N/A
K_S	$\pi^0\pi^0K_S$	$\eta\eta K_S$	$K_SK_SK_S$	$K_LK_LK_S$
K_L	$\pi^0\pi^0K_L$	$\eta\eta K_L$	$K_SK_SK_L$	$K_LK_LK_L$
a_0	$\pi^0\pi^0a_0$	N/A	N/A	N/A
f_0	$\pi^0\pi^0f_0$	N/A	N/A	N/A

The rate for the critical normalizing modes $D \to K\pi$, $D^+ \to K\pi\pi$, and $D_S \to \phi\pi$ 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 $D \to 4\pi$, 5π or even more pions final states [106]. 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 VI. One should note that the decays $D(D_S) \to V_1V_2$ 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 6.1, we can obtain the $e^+e^- \to D\overline{D}$ cross sections by scaling $N_{D^0\overline{D}^0}$ and $N_{D^+D^-}$ by the luminosity at each energy point. At $E_{cm} = 3773$ MeV, CLEO-c collaboration found peak cross sections of $\sigma(e^+e^- \to D^0\overline{D}^0) = (3.60 \pm 0.07^{+0.07}_{-0.05})$nb, $\sigma(e^+e^- \to D^+D^-) = (2.79 \pm 0.07^{+0.10}_{-0.04})$ nb, $\sigma(e^+e^- \to D\overline{D}) = (6.39 \pm 0.10^{+0.17}_{-0.08})$ nb, and the ratio of charged D pairs and neutral D pairs production is about $0.776 \pm 0.024^{+0.014}_{-0.006}$ [107], where the uncertainties are statistical and systematic, respectively. The ratio is significantly deviated from one in $D\overline{D}$ 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 $\frac{p^3_{+-}}{p^3_{00}} = 0.69$, where p_{+-} and p_{00} are the momentum of charged and neutral D mesons in $\psi(3770)$ rest frame. Recently, Voloshin pointed out [108] 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 [108] :

$$R(E_{cm}) = \frac{\sigma(e^+e^- \to D^+D^-)}{\sigma(e^+e^- \to D^0\overline{D}^0)} = F_c\frac{p^3_{+-}}{p^3_{00}}, \qquad (7)$$

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. [108]. 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 [9] that the cross sections of $e^+e^- \to D^*\overline{D}^*$, $D^*\overline{D}$, $D_S^{*+}D_S^{*-}$ 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 [109]. 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.

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

With the design luminosity of 10^{33}cm^{-2}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 $\psi(3770) \to D\overline{D}$ system will provide a unique laboratory in which to study charm [99].

6.2.1. $D^0 - \overline{D}^0$ Mixing and CP Violation

$D^0 - \overline{D}^0$ 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 $D^0 - \overline{D}^0$ 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 $\frac{1}{2}(x^2 + y^2)$ [110]. Standard Model based predictions for x and y, as well as a variety of non-Standard Model expectations, span several orders of magnitude [110] 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 $D^0\overline{D}^0$ pairs in $\psi(3770) \to D\overline{D}$ decays have the useful property that the two mesons are in the CP-correlated states [99], 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 $\psi(3770) \to (K^-\pi^+)(K^-\pi^+)$ hadronic final state only at *BES-III*. We have not estimated the double semileptonic channel yet, $\psi(3770) \to (l^\pm(KX))(l^\pm(KX))$. Sensitivity to $cos\delta$ is 0.03 for $D^0 \to K\pi$ 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 [99]. 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 [111]. 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 $\overline{D}^0$ decay into CP eigenstates, then the decays $\psi(3770) \to f^i_+ f^i_+$ or $f^i_- f^i_-$ are forbidden, where f_+ (f_-) denotes a $CP+$ eigenstate ($CP-$ eigenstate). This is because $CP(f^i_\pm f^i_\pm) = CP(f^i_\pm)CP(f^i_\pm)(-1)^l = -1$, 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*.

6.2.2. 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 $D^0 - \overline{D}^0$ mixing. Currently, the decay $D^0 \to K_S\pi^+\pi^-$ plays very important role in the determination of ϕ_3/γ. Recently BaBar and Belle [112] have reported $\gamma = (70 \pm 31^{+12+14}_{-10-11})^o$ and $\phi_3 = (77^{+17}_{-19} \pm 13 \pm 11)^o$, 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 $D^0 \to K_S\pi^+\pi^-$ 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 $\pm 10^o$ to a few degrees, it is still a model-dependent way to extract the angle. At *BES-III*, by using the coherence of $D^0\overline{D}^0$ pairs at $\psi(3770)$ peak, one can study the CP-tagged and flavor-tagged DP by doing binned analysis [113]. This method is a model-independent. According to the estimation in reference [113], the proposed super-B factory [114] with its design integrated luminosity of 50 ab^{-1}, would allow a measurement of ϕ_3/γ with accuracy below 2^o. 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 fb^{-1} data which can be obtained at BEPC-II with two years' luminosity.

6.2.3. Rare Charm Decays

Table VII 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^{-8})	*BES-III* ($\times10^{-6}$)
$\pi^+e^+e^-$	CLEO-c [115]	7.4	5.6
$\pi^+\mu^+\mu^-$	FOCUS [116]	8.8	8.7
$\pi^+\mu^+e^-$	E791 [117]	34	5.9
$\pi^-e^+e^+$	CLEO-c [115]	3.6	5.6
$\pi^-\mu^+\mu^+$	FOCUS [116]	4.8	8.7
$\pi^-\mu^+e^+$	E791 [117]	50	5.9
$K^+e^+e^-$	CLEO-c [115]	6.2	6.7
$K^+\mu^+\mu^-$	FOCUS [116]	9.2	10.5
$K^+\mu^+e^-$	E791 [117]	68	8.3
$K^-e^+e^+$	CLEO-c [115]	4.5	6.7
$K^-\mu^+\mu^+$	FOCUS [116]	13	10.4
$K^-\mu^+e^+$	E687 [118]	130	8.3

Table VIII 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^{-8})	*BES-III* ($\times10^{-6}$)
$\gamma\gamma$	CLEO [120]	28	5.0
$\mu^+\mu^-$	D0 [122]	2.4	17.0
μ^+e^-	E791 [117]	8.1	4.3
e^+e^-	E791 [117]	6.2	2.4
$\pi^0\mu^+\mu^-$	E653 [123]	180	12.3
$\pi^0\mu^+e^+$	CLEO [121]	86	9.7
$\pi^0e^+e^-$	CLEO [121]	45	7.9
$K_S\mu^+\mu^-$	E653 [123]	260	10.6
$K_S\mu^+e^-$	CLEO [121]	100	9.6
$K_Se^+e^-$	CLEO [121]	110	7.5
$\eta\mu^+\mu^-$	CLEO [121]	530	15.0
$\eta\mu^+e^-$	CLEO [121]	100	12.0
ηe^+e^-	CLEO [121]	110	10.0

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 $D^+\to\pi^+l^+l^-$ and $D^+\to K^+l^+l^-$ could therefore provide indication of new physics or of unexpectedly large rates for long-distance SM processes like $D^+\to\pi^+V$, $V\to l^+l^-$, with real or virtual vector meson V. Recently, CLEO-c report the branching fraction of the resonant decay $\mathcal{BR}(D^+\to\pi^+\phi\to\pi^+e^+e^-) = (2.8\pm1.9\pm0.2)\times10^{-6}$. The lepton-number-violating (LNV) or lepton-flavor-violating (LFV) decays $D^+\to\pi^-l^+l^+$, $K^-l^+l^+$ and $\pi^+\mu^+e^-$ are forbidden in the SM. Past searches have set upper limits for the dielectron and dimuon decay modes [9]. In Table VII and Table VIII, 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 [119]. The charm meson radiative decays are also very important to understand final state interaction which may enhance the decay rates. In Ref. [119], the decay rates of $D\to V\gamma$ (V can be ϕ, ω, ρ and K^*) had been estimated to be $10^{-5}-10^{-6}$, which can be reached at *BES-III*.

7. Summary

We have considered the physics potential of BEPC-II, with a luminosity of order 10^{33}cm^{-2}s^{-1}. The *BES-III* project, starting the year 2008, will have a relevant impact on a wide of physics topics, ranging from precision tests of the SM to hadronic physics. It also offers interesting possibilities for flavour physics, charmed meson and τ physics.

In summary, the *BES-III* data will permit a broad suite of studies of weak and strong interaction physics. At the threshold, *BES-III* will provide unique opportunity for charm physics.

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