Physics Goal Of BES3

The Standard Model (SM) has been successful in describing all relevant experiment phenomena and hence has been taken as a fundamental theory of elementary particle physics. Despite its success, SM leaves many unsolved questions. These questions can be classified into two categories. One is relevant to possible new physics at unexplored energy scale, another is relevant to nonperturbative physics, mostly related to Quantum Chromodynamics.

SM describes particle physics up to the energy scale around 100 GeV. It is expected that new particles and new interactions will appear at higher energy scale, say 1 TeV. Those new particles and new interactions are presumably needed to solve some inconsistency within SM and for the goal of the unification of all interactions. This all belongs to the first category.

The second category includes questions about nonperturbative effects. QCD as the fundamental theory of the strong interaction is well tested at short distance. But at long distance the nonperturbative effects become important and are not well understood, e.g., the hadronic structure. The distance, at which physics can be probed with BEPC, is at the overlap of long- and short distance. Therefore, at the energy ranges of BEPC physics phenomena are rich.

Experimentally efforts have been spent to study those questions of the two categories. The colliders at higher colliding energy like Tevatron and LHC will address the questions in the first category, while the colliders at lower energies can address the questions of the second category. Among them the Beijing Electron Positron Collider (BEPC) running at the energy from 2 GeV to 4.2 GeV is an important one, because it runs at the energy range where not only the short distance effects, but also the long distance effects can be probed.

Theoretically, the study of physics at the energy scale relevant to BEPC has been very active. To provide a good understanding of physics at the scale, theoretical tools, derived from QCD have been invented. For charmonia, one can use nonrelativistic QCD (NRQCD) and potential nonrelativistic QCD (pNRQCD) to get theoretical predictions for physics involving both short- and long-distance effects, where a factorization of the two different kinds of effects can be separated and the predictions are obtained without using any model. For charmed hadrons, one can, at least partly, rely on heavy quark effective theory (HQET) to study them. For physics involving long-distance effects only, one can employ lattice QCD to make predictions from the first principle, or QCD sum-rule method. Beside these theoretical tools derived from QCD, many phenomenological models are invented to deal nonperturbative effects, especially those at the scale around 1 GeV or smaller, like light hadron spectroscopy, decays of charmonia or D-mesons into light hadrons, etc. Many theoretical predictions obtained with the above mentioned methods exist and call for confirmations or tests from experimental side. BEPC and BEPC with upgrades is such a place to carry out the task of confirmations and tests. Also, the upgraded BEPC will be a place where new discoveries can be possibly made, e.g., new hadronic states.

In the past, fruitful results of physics have been obtained with BEPC and Beijing Spectrometers. Among them, the measurement of R-value at BEPC improves the limit of the mass range of undiscovered Higgs boson. At the pT threshold an anomalous enhancement has been observed in the decay J/ψ → γ p̅p. This observation stimulates many theoretical speculations. The observation of non D-̅D decays of ψ(3770) with BES2 is beyond theoretical expectations. The violation of the notorious 12% rule has been observed in different decay channels. There are many to mention. Beside these, Important results have been also obtained from CLEO-C Collaboration in U.S., among them, the most important results include: the discovery of the 1P state of charmonia, i.e., h1, the decay constant of D-meson is measured with error 8%, a large data sample of e+e− → D̅D at 3.773 GeV has been collected. This enables to measure absolute hadronic branching ratios more precisely, e.g., B(D̅0 → K−π+) and B(D+ → K−π+π+) have
been measured with errors at the level of 5%. It is expected that those observed phenomena will be studied in experiment with more precision in order to provide a better understanding.

The current upgrade of BEPC and the detector Beijing Spectrometer 3 (BES3) makes BEPC as an unique place to study physics of the energy scales up to 4GeV, which includes charmonium physics, D-physics, spectroscopy of light hadrons and τ-physics. Beside these it is also possible to use BPEC to search for new interactions. The upgraded BEPC will reach the luminosity \( L = 10^{33} \). At the peak of \( J/\psi \) BEPC will produce \( 10^{10} J/\psi \) per year. This will let BES3 to have the world largest data sample for studying \( J/\psi' \) and their decays. With the designed luminosity and one year running we expect the following particle productions near the threshold:

<table>
<thead>
<tr>
<th>( J/\psi )</th>
<th>CMS Mass</th>
<th>Peak Lum.</th>
<th>( \sigma )</th>
<th>No. of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.097</td>
<td>0.6</td>
<td>3400</td>
<td>( 10 \times 10^5 )</td>
<td></td>
</tr>
<tr>
<td>( \tau^+ \tau^- )</td>
<td>3.670</td>
<td>1.0</td>
<td>2.4</td>
<td>( 12 \times 10^6 )</td>
</tr>
<tr>
<td>( \psi(2S) )</td>
<td>3.686</td>
<td>1.0</td>
<td>640</td>
<td>( 3.2 \times 10^9 )</td>
</tr>
<tr>
<td>( D^+ D^- )</td>
<td>3.770</td>
<td>1.0</td>
<td>3.6</td>
<td>( 18 \times 10^6 )</td>
</tr>
<tr>
<td>( D_s D_s )</td>
<td>4.030</td>
<td>0.6</td>
<td>0.32</td>
<td>( 1.0 \times 10^6 )</td>
</tr>
<tr>
<td>( D_s D_s )</td>
<td>4.170</td>
<td>0.6</td>
<td>1.0</td>
<td>( 2.0 \times 10^6 )</td>
</tr>
</tbody>
</table>

From the table one can see that there will be a huge data sample of \( J/\psi \) and \( \psi(2S) \), and a large data sample of \( D \)-mesons. This will enable not only precision measurements but also to make possible discoveries which have been not made because limited statistics. This yellow book presents the physics goals of BES3 or the research opportunities provided by BEPC. Those goals or opportunities will be discussed in a great detail in this book. A brief summary is given here.

- **Charmonium Decays and Their Transitions**

  The total decay width of \( J/\psi \) and \( \psi' \) can be measured with 1% level(?). There are many decay modes of \( J/\psi \). In the decays into two mesons, any of them can be any of a pseudo- and scalar, a vector or an axial vector, and a tensor meson. With the produced \( 10^{10} J/\psi \)'s these decay modes can be measured more precisely than before. Historically, there are some notorious problems related to decays of Charmonia. Among them the most well-known problems are \( \rho \tau \) puzzle, i.e., 12%-rule, and non \( D - \bar{D} \) decays of \( \psi(3770) \). With the huge data sample, more information from experiment can be provided and can lead to solutions of these problems.

  With the huge data sample, it is possible to see some Cabbibo-suppressed \( J/\psi \) decay channel. In such channels, the charm quark decays through the weak interaction, while the anti charm quark forms a \( D \)-meson with other dynamical freedoms. This gives a possibility to detect new physics at BEPC, if the branching ratios of those decays are larger than predicted with SM. Also, one can check the effects of flavor changing neutral current. In that sense, BES3 can make some contributions to exploring physics beyond SM.

- **Quarkonium transition**

- **Light Hadron Spectroscopy and Search for New Hadronic States**

  Using \( J/\psi \)-decays, one can study light hadron spectroscopy and search for new hadronic states. Especially, the large number of the produced \( J/\psi \) makes BEPC a glue factory, since a pair of a charm-
and anticharm quark are mostly annihilated into gluons. This is very useful to search glueballs, or gluon contents of light hadrons, e.g., in scalar mesons.

QCD predicts the existence of glueballs, especially, the study of lattice QCD predicts masses of various glueball, e.g., the $0^{++}$ glueball has a mass from 1.5 to 1.7GeV. But the existence of these various glueballs has been not confirmed with experiment. Also, from QCD as a relativistic quantum field theory, any hadron should have a gluon content if symmetries allow. Those gluon contents, especially, those in scalar mesons, are crucial to understand properties of light hadrons, like the scalars $f_0(1500, 1700)$. BEPC with the environment of rich gluons is an ideal place to study these issues.

Recently, evidences of exotic hadrons are given by experiment. In principle QCD does allow the existence of these exotic hadrons, which can not be classified with the traditional quark model. With the high-statistic data sample the search of these exotic can be performed and their quantum numbers can be determined if they exist.

In BES2, it has been observed the anomalous enhancement near the threshold of the $p\bar{p}$ system in the decay $J/\psi \rightarrow \gamma p\bar{p}$, and also in other baryonic systems. Various explanation for the enhancement exist, e.g., there can be a resonance just below the $p\bar{p}$ system. A satisfied explanation can not be concluded. With BES3 the enhancement can be studied more in detail and hopefully a final explanation can be established.

- **D-Physics**

  At BEPC, $D^+$ and $D_0$ mesons can be produced through the decay of $\psi(3770)$, and $D_s$ mesons can be produced through $e^+e^-$ annihilation at $s$ around $(4.63\text{GeV})^2$. The decay constants $f_D$ and $f_{D_s}$ can be measured through leptonic decays at BES3 with the expected errors in systematics to be 1.2% and 2.1%, respectively. Semileptonic- and exclusive semileptonic decays of $D$-mesons will also be studied to test various theoretical predictions. Moreover, through the study of the decay $D^0 \rightarrow K^- e^+ \nu_e$ and $D^0 \rightarrow \pi^- e^+ \nu_e$ one can extract the CKM matrix elements $V_{cs}$ and $V_{cd}$ with the expectation that the systematic error is around 1.6%.

  With BES3 it is possible to measure the $D-\bar{D}$ mixing and CP-violation. Theoretically, predictions for the mixing and CP-violation are unreliable. BES3 can provide new information about them from experiment.

  Rare- or forbidden decays are usually used to give strict tests of SM and to detect new physics beyond SM. With BES3 they can be studied systematically. Significant improvements of measuring their branching ratios are expected. The upper limits of branching ratios can be reduced with a factor of $10^{-2}$.

- **$\tau$-Physics**

  Beside presenting these physical goals or opportunities at BEPC2 with BES3, this yellow book also presents some useful tools relevant to BES3.
References