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# Current and Future Charm Experiments

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Charm physics has been studied with many dedicated accelerators and experiments. In these proceedings, we review the status and the selected results of the current operating BEPCII/BESIII experiment. We also discuss the BESIII data taking plan for the future.

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# 1 Introduction

Since the 1960's, many electron-positron colliders have been built around the tau-charm energy regions, with a clear tendency of luminosity increasing in time (see Figure 1). The most renowned of these colliders was SPEAR, which discovered both the  $J/\psi$  and  $\tau$ , and began the era of  $\tau$ -charm physics.

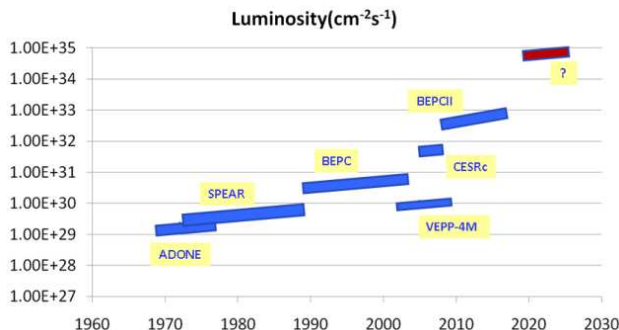


Figure 1: Dedicated  $e^+e^-$  colliders for charm physics

In the early 1990's, a precise measurement facility, named BEPC/BES, was built at the  $\tau$ -charm energy region in IHEP, China. It is the first accelerator built for high energy physics research in China. The luminosity was an order of magnitude higher than SPEAR. In the year 2004, CESR/CLEO decreased its collision energy to the charm energy region to start the CESRc/CLEOc programme, and became the highest luminosity charm facility then existing.

BEPCII/BESIII is a mainstream high energy physics project in China [1, 2]. It is an upgrade from its ancestor BEPC/BES. The designed peak luminosity is  $1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ , which is an order of magnitude higher than CESRc/CLEOc. BEPCII/BESIII started its test run in 2008 and took physics data in 2009. By the end of 2010, many physics results had already been published in journals.

Therefore, there have existed dedicated charm experiments for over 40 years. There is no doubt that this is a very interesting energy region with rich physics in it. The charm quark can be seen as a bridge which links perturbative QCD and non-perturbative QCD, and studies in charm physics can provide calibrations and tests of Lattice QCD. With high statistics production of charm mesons at threshold, we can precisely measure the CKM matrix elements  $V_{cd}$  and  $V_{cs}$ , the absolute branching fractions of charm meson decays, the decay constants  $f_{D^+}$  and  $f_{D_s}$ , light meson spectroscopy in Dalitz plot analyses etc. We can also probe neutral charm meson mixing, search for  $CP$  violation, and measure strong phase differences with the quantum correlation of the charm meson pairs.

Charm physics is a topic of interest at hadron colliders, i.e. the Tevatron and LHC. They take advantage of the huge charm production cross-section and the high

energy boost of the charm meson decay vertices. However, the  $e^+e^-$  experiments have much cleaner collision environment with almost 100% trigger efficiency. The quantum correlations and meson tagging techniques can be applied to the threshold production experiments, i.e. CLEOc and BESIII. There, many systematic uncertainties can be cancelled out while applying the "double tag" method which also leads to very pure samples.

## 2 BEPCII and BESIII performance

BEPCII is a double-ring  $e^+e^-$  collider with a designed peak luminosity of  $10^{33} \text{ cm}^{-2}\text{s}^{-1}$  at a beam current of 0.93 A. It covers the cms energy region from 2.0 GeV to 4.6 GeV. During the 2009 to 2011 operating period, both the accelerator and the detector performed remarkably well and the world largest data sample of  $J/\psi$ ,  $\psi'$  and  $\psi(3770)$  have been collected at threshold energy. This impressive early performance indicates that the experiment has great potential for improving our understanding of the physics that can be accessed in the  $\tau$ -charm regime. A short summary of the BEPCII/BESIII status and performance will be given below.

The BEPCII/BESIII upgrade project started in 2003 and successfully completed in 2008. BEPCII managed to accumulate a beam current of 500 mA in the storage ring, and obtained a collision luminosity close to  $10^{32} \text{ cm}^{-2}\text{s}^{-1}$  in March 2008. Installation of the BESIII detector was completed at the end of 2007 and the first full cosmic-ray event was recorded in March 2008. The detector was successfully moved to the interaction point on April 30, 2008. With a careful tuning of the machine, the first  $e^+e^-$  collision event was recorded by the BESIII detector on July 19, 2008. In the test run period, a total of 14 million  $\psi'$  events was collected until Nov. 2008. Over this period, the BEPCII performance continued to improve through lattice optimization, system debugging, and vacuum improvements. After a 1.5-month synchrotron radiation run and a winter maintenance, the machine resumed collision and its luminosity gradually improved to  $3 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ .

The official data taking for physics run started in March 2009. In this first run period, BESIII successfully collected 100 million  $\psi'$  events and 200 million  $J/\psi$  events, about a factor of 4 larger than the previous data samples from CLEOc and BESII, respectively. The peak luminosity was stable, typically at the level of  $2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  during the data taking at  $\psi'$ , and  $0.6 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  at  $J/\psi$ . An energy scan of the  $\psi'$  line-shape shows that the beam energy spread is about 1.4 MeV, and the effective peak cross section of  $\psi'$  production is about 700 nb.

Starting from December 2009, BESIII collected data around the  $\psi(3770)$  resonance. Up to the time of this write-up, more than  $1 \text{ fb}^{-1}$  data was recorded, which included  $75 \text{ pb}^{-1}$  data for an energy scan of the  $\psi(3770)$  line-shape. During the 2010 to 2011 run period, a peak luminosity of  $5.6 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  was achieved. The data

taking efficiency of the detector is more than 85%.

In common with many other general purpose detector for high energy physics, the cylindrical core of the BESIII detector consists of a helium-gas-based drift chamber (MDC), a plastic scintillator Time-of-Flight system (TOF), and a CsI(Tl) Electromagnetic Calorimeter (EMC), all enclosed in a superconducting solenoidal magnet providing a 1.0 T magnetic field. The solenoid is supported by an octagonal flux-return yoke with resistive plate counter muon identifier modules (MU) interleaved with steel. The charged particle and photon acceptance is 93% of  $4\pi$ , and the charged particle momentum and photon energy resolutions at 1 GeV are 0.5% and 2.5%, respectively.

A comprehensive Monte Carlo simulation software package, largely based on the first principle of particles interacting with detector materials, was developed to model the performance of the BESIII detector. Comparing with the data, good agreement was observed, not only on average numbers, but also in the shape of many distributions. Data analysis shows that the detector is in a very good condition and all the design specifications have been satisfied.

### 3 Selected result

The physics programme as BESIII is very rich [3]. Here, we just give some examples from the first published results [4, 5, 6] to show the potential for future precise and interesting measurements. These results ranged from the confirmation of BESII and CLEOC results, to completely new observations.

Figure 2 shows the prompt photon spectrum from  $\psi' \rightarrow \gamma\pi^0\pi^0$  and  $\psi' \rightarrow \gamma\eta\eta$  channels. Signals of  $\chi_{c0}$  and  $\chi_{c2}$  are observed and their branching ratios are measured [5]. The results are consistent with the CLEOC measurements[7].

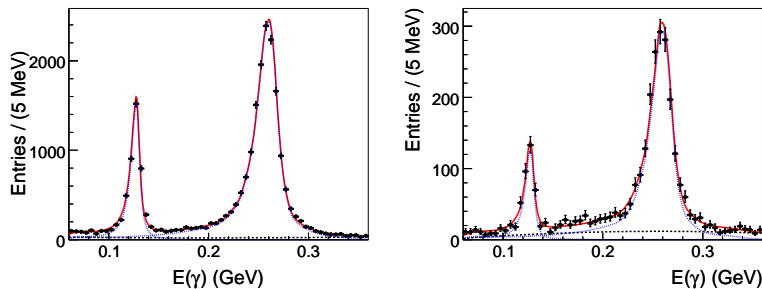


Figure 2: The radiative photon energy spectrum of  $\chi_{c0}$  and  $\chi_{c2}$  signals. Left plot is from selected  $\psi' \rightarrow \gamma\pi^0\pi^0$  events, and right plot is from selected  $\psi' \rightarrow \gamma\eta\eta$  events.

The last member of the charmonium family below the open charm threshold, called the  $h_c$ , was observed by CLEOC in 2005 from  $\psi'$  decays to  $\pi^0 h_c$ ,  $h_c \rightarrow \gamma\eta_c$  [8] and

Measured parameters	BESIII results	CLEOc results
Mass: $M_{h_c}$	$3525.40 \pm 0.13 \pm 0.18$ MeV	$3525.28 \pm 0.19 \pm 0.12$ MeV
Width: $\Gamma_{h_c}$	$0.73 \pm 0.45 \pm 0.28$ MeV	-
$B(\psi' \rightarrow \pi^0 h_c)$	$(8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$	-
$B(h_c \rightarrow \gamma \eta_c)$	$(54.3 \pm 6.7 \pm 5.2)\%$	-
$B(\psi' \rightarrow \pi^0 h_c) \times B(h_c \rightarrow \gamma \eta_c)$	$(4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$	$(4.19 \pm 0.32 \pm 0.45) \times 10^{-4}$

Table 1: Measured results in comparison with CLEOc. (In the fit,  $\Gamma_{h_c}$  is floated in the BESIII analysis while CLEOc fixes  $\Gamma_{h_c} = \Gamma_{\chi_{c1}} = 0.9$  MeV)

an improved measurement was performed recently [9]. BESIII performed a similar analysis with a larger data sample, and a clear signal can be seen by tagging the prompt photon in the  $h_c$  decays [4], as shown in Figure 3. In addition, BESIII looked for inclusive  $\pi^0$  production from  $\psi'$  decays and clear signals can be also seen. Thus, the branching fractions of  $\psi' \rightarrow \pi^0 h_c$ ,  $h_c \rightarrow \gamma \eta_c$  can be individually measured for the first time, together with the width of  $h_c$ . The results are listed in Table 1 in comparison with recent CLEO results [9]. Good agreement can be seen.

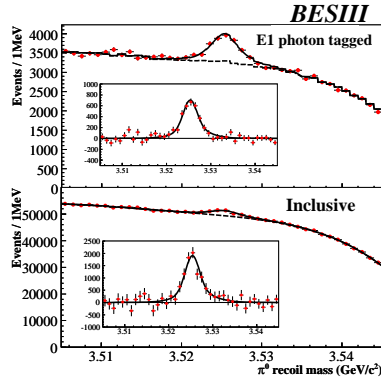


Figure 3: The  $\pi^0$  recoil mass spectrum and fit. Upper: tagged with the prompt photon in the  $h_c \rightarrow \gamma \eta_c$  decays ( $E1$ -tagged analysis). Lower: inclusive analysis of  $\psi' \rightarrow \pi^0 h_c$ .

The  $p\bar{p}$  threshold enhancement in  $J/\psi \rightarrow \gamma p\bar{p}$  decays, which was firstly observed [10] by BESII, was also confirmed [6] (see Figure 4). This enhancement is fitted with an  $S$ -wave Breit-Wigner resonance function, the peak mass is  $M = 1861_{-13}^{+6}(\text{stat})_{-26}^{+7}(\text{syst})$  MeV/ $c^2$  and the width is  $\Gamma < 38$  MeV/ $c^2$  at the 90% confidence level. These results are consistent with published BESII results.

Besides the topics of charmonium physics and light hadron spectroscopy, many CKM physics related analyses are also carrying on at BESIII. By exploiting the

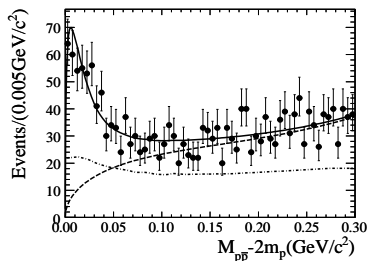


Figure 4: The  $p\bar{p}$  invariant mass spectrum for the  $\psi' \rightarrow \pi^+\pi^- J/\psi$  ( $J/\psi \rightarrow \gamma p\bar{p}$ ) after final event selection. The solid curve is the fit result; the dashed curve shows the fitted background function, and the dash-dotted curve indicates how the acceptance varies with  $p\bar{p}$  invariant mass

sample of  $\psi(3770)$  decays which is already the world's largest, some results of the  $D$  meson decays are expected to be published in 2011, including the measurements of the CKM matrix element  $V_{cd}$ , the decay constant  $f_{D^+}$ , and absolute branching fractions and direct  $CP$  violation for some decay channels.

## 4 Data taking plan

An important aspect of the BESIII running plan is the accumulation of a sizable  $\psi(3770) \rightarrow D\bar{D}$  sample. According to our assumptions, in two years, i.e. by summer 2011, BESIII will have a  $2.5 \text{ fb}^{-1}$   $\psi(3770)$  data sample, three times that of CLEOc approximately. Furthermore, three years from now, the current  $\psi'$  and  $J/\psi$  data samples will both be expanded by nearly an order of magnitude each, and, by the end of the five year period, we will have a data sample for  $D_s$  physics that is few times than that of the CLEOc sample.

With the few times larger open-charm dataset that will be available in 2011, BESIII will be able to make better informed decisions on the physics potential of a very high luminosity  $\tau$ -charm factory.

The long-term goals of BESIII include  $10 \text{ fb}^{-1}$  samples at  $\psi(3770)$  and at higher  $\psi$  states, and a few billion  $J/\psi$  and  $\psi'$  events. Of course the final sizes of the data samples will depend on the actual luminosity of BEPCII.

## 5 Summary

Currently, BEPCII is the highest luminosity  $e^+e^-$  collider in the energy region of  $\tau$ -charm threshold production. A peak luminosity of  $5.6 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  has been achieved in January 2011. The BESIII detector is also performing excellently with several physics results already having been published. In the next few years, a few

billion of  $J/\psi$ ,  $\psi'$  and approximately  $10 \text{ fb}^{-1}$  of open charm data will be accumulated. Due to the interesting and rich physics topics in the charm sector, more experiments are expected to contribute in this sector. These include the newly operational LHCb experiment, the approved Super KEK-B/Belle, which will be operational in 2014, the FAIR/PANDA experiment, planned to be operational in 2015 and the newly approved SuperB super flavor factory at Frascati. In addition, Novosibirsk has proposed a super-tau-charm factory project, which may also make substantial contributions to this field. These proceedings focus on the charm physics programme that has begun at BESIII, and the future prospects at this experiment. Note, however that a wide range of important measurements will also be performed at the Tevatron, at LHCb and the future Super B factory experiments.

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