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Some topics on charmonium decays at BESⅢ experiment *

CHEN Hai-Xuan(陈海璇)[1)]

(Institute of High Energy Physics, CAS, Beijing 100049, China)

Abstract The construction of BESⅢ detector has been finished and the data taking is under plan. Some physics topics on charmonium decays at BESⅢ experiment are discussed in this paper. The measurement of properties of η_c and η_c' at BESⅢ is discussed and the expected precision of the measurement is estimated based on BOSS. Also the χ_{cJ} decay and the measurement of hyperon decay parameters are mentioned.

Key words BESⅢ, charmonium decays, spin-singlet charmonium, spin-triplet charmonium, hyperon decay parameter

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1 Introduction

The new Beijing Spectrometer (BESⅢ) is a large solid-angle magnetic spectrometer which will work at updated Bejing Electron Positron Collider (BEPCⅡ) at τ-charm energy region. With high luminosity of BEPCⅡ, many good experiments on charmonium decays can be performed at BESⅢ. Three topics are discussed in this paper.

The BEPCⅡ[1, 2] is designed to work at τ-charm energy region with a peak luminosity of $10^{33}\text{cm}^{-2}\cdot\text{s}^{-1}$ at $D\bar{D}$ threshold. At the beginning of data taking, the expected peak luminosity is $3\times10^{32}\text{cm}^{-2}\cdot\text{s}^{-1}$. By supposing the average luminosity to be half of the peak luminosity and the running time of the BESⅢ to be 50 000 seconds per day, 25 million J/ψ events or 5 million ψ′ events can be collected in one day if it is running at J/ψ peak or ψ′ peak.

The BESⅢ detector[1, 2] consists of a beryllium beam pipe, a helium-based small-celled drift chamber, Time-Of-Flight (TOF) counters for particle identification, a CsI(Tl) crystal calorimeter, a superconducting solenoidal magnet with the field of 1 Tesla, and a muon identifier of Resistive Plate Counters (RPC) interleaved with the magnet yoke plates. The preliminary version of the BES Offline Software System (BOSS)[3] has been implemented successfully. The detector simulation[4] is based on Geant4[5].

2 Spin-singlet charmonium

The mass difference between spin-singlet charmonium and spin-triplet charmonium is used to determine the hyperfine splitting of the spin-spin interaction in non-relativistic potential models[6, 7]. The theoretical prediction is not in agreement with the current experimental measurement. Fig. 1 shows one of the comparisons between the prediction of lattice QCD[8] and the experiment. It can be seen that there is large deviation between the theoretical prediction and the experiment.

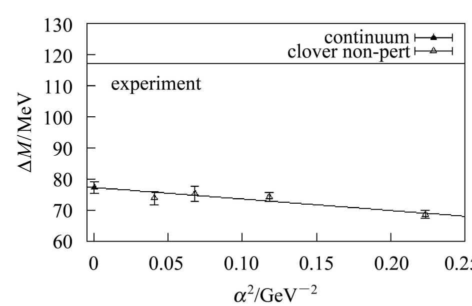

Fig. 1. Continuum extrapolation of the hyperfine splitting with the non perturbatively improved clover Dirac operator. The bare quark mass is tuned to maintain an approximately constant mass $M(^3S_1)\sim 3095$ MeV[8].

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1) E-mail: chenhx@ihep.ac.cn

The hyperfine splittings in charmonium S-wave are appreciable from PDG[9]:

$$\Delta M_{\rm hf}(1S) = M_{{\rm J}/\psi} - M_{\eta_c} = (116.5 \pm 1.2)\ {\rm MeV}/c^2,$$

$$\Delta M_{\rm hf}(2S) = M_{\psi'} - M_{\eta'_c} = (48.1 \pm 4.0){\rm MeV}/c^2.$$

In these two experimental mass differences between spin-singlet and spin-triplet charmonia, the errors come totally from the measurements of spin-singlet charmonia since spin-triplet charmonia have been measured with high precision in the previous measurements[9]. The key point to improve to experimental mass difference between spin-singlet and spin-triplet charmonium is precise measurement of the mass of spin-singlet charmonium.

2.1 η_c meson

The mass measurement of η_c meson has been done at BES II through η_c decay to $p\bar{p}$, $2(\pi^+\pi^-)$, $K_SK\pi$, $K^+K^-\pi^+\pi^-$ and $\phi\phi \rightarrow K^+K^-K^+K^-$ using 58 M J/ψ events[10]. The number of η_c signal events at BES II is less than 2000, and the resolution of four charged tracks' invariant mass is about 12 MeV after 4C kinematic fit. The error of this measurement is about 5.0 MeV. At BESIII, many decay channels can be used for the measurement of η_c mass such as:

$$J/\psi(\psi') \rightarrow \gamma\eta_c, \eta_c \rightarrow p\bar{p},$$

$$J/\psi(\psi') \rightarrow \gamma\eta_c, \eta_c \rightarrow K_SK\pi,$$

$$J/\psi(\psi') \rightarrow \gamma\eta_c, \eta_c \rightarrow K^+K^-\pi^+\pi^-,$$

$$J/\psi(\psi') \rightarrow \gamma\eta_c, \eta_c \rightarrow \pi^+\pi^-\pi^+\pi^-,$$

$$J/\psi(\psi') \rightarrow \gamma\eta_c, \eta_c \rightarrow 3(\pi^+\pi^-),$$

$$J/\psi(\psi') \rightarrow \gamma\eta_c, \eta_c \rightarrow K_SK\pi\pi^+\pi^-,$$

$$J/\psi(\psi') \rightarrow \gamma\eta_c, \eta_c \rightarrow \eta\pi^+\pi^-, \eta \rightarrow \gamma\gamma,$$

$$J/\psi(\psi') \rightarrow \gamma\eta_c, \eta_c \rightarrow \eta K^+K^-, \eta \rightarrow \gamma\gamma,$$

$$J/\psi(\psi') \rightarrow \gamma\eta_c, \eta_c \rightarrow \omega\phi, \omega \rightarrow \pi^0\pi^+\pi^-, \phi \rightarrow K^+K^-.$$

With good momentum resolution of MDC, the mass resolution of four charged tracks is about 6 MeV at BESIII without 4C kinematic fit. Fig. 2 shows the mass resolution of $\pi^+\pi^-\pi^+\pi^-$'s invariant mass distribution which is fitted with a double-Gaussian. It shows that the resolution of BESIII detector is much better than BES II so we can perform high precision measurement of η_c mass. Under good performance of BESIII detector, the detection efficiency at BESIII is higher than the one at BES II.

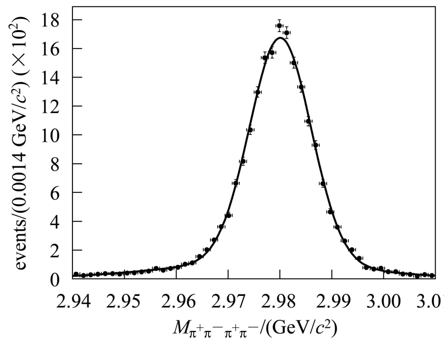

Fig. 2. Invariant mass distribution of $\pi^+\pi^-\pi^+\pi^-$ from MC simulation of $J/\psi \rightarrow \gamma\eta_c, \eta_c \rightarrow \pi^+\pi^-\pi^+\pi^-$ based on BOSS. The smooth line is the best fit to the mass distribution using a double-Gaussian.

If the non-relativistic Breit-Wigner is used to describe the line-shape of η_c resonance, the sensitivity of η_c mass measurement is calculated as

$$\delta m = \frac{\Gamma}{\sqrt{2N}} ,$$

where Γ is the width of η_c and N is the number of the signal events of η_c. By supposing $\Gamma = 27$ MeV and based upon the detection efficiencies got from the MC simulation, the expected statistical precision of η_c mass measurement is estimated to be about 0.05 MeV under 500 M J/ψ events, which can be collected with a month at BESIII. Supposing the systematic uncertainty is at the same level as statistical precision, the total precision of η_c mass measured at BESIII will be less than 0.1 MeV, which is 10 times improved comparing to PDG average[9]. ψ' sample can also be used to measure η_c mass and width and it is better than J/ψ sample for determining the η_c line-shape since ψ' resonance is far away to η_c resonance. If ψ' sample is used to measure η_c mass, it need 2.8×10^9 ψ' events to achieve the statistical precision of 0.05 MeV because of the low branching fraction of $\psi' \rightarrow \gamma\eta_c$ decay.

2.2 η'_c meson

Up to now, only two decay modes of η'_c were seen experimentally. With high luminosity of BEPC II, η'_c meson can be measured precisely at BESIII with large ψ' data sample. Comparing to η_c decays, some channels such as $\eta'_c \rightarrow K_SK\pi$, $\eta'_c \rightarrow K^+K^-\pi^+\pi^-$ and $\eta'_c \rightarrow \pi^+\pi^-\pi^+\pi^-$ can be used for η'_c measurement for their probable large branching fraction in η'_c decays. The MC simulation of $\psi' \rightarrow \gamma\eta'_c$, $\eta'_c \rightarrow \pi^+\pi^-\pi^+\pi^-$ based on BOSS shows the mass resolution is about 8 MeV without 4C kinematic fit (shown as Fig. 3) and detection efficiency at BESIII is high. Supposing the average efficiency of these three channels is 30% and these three decay modes of η'_c have the same branching fractions with η_c decays and the branching fraction of $\psi' \to \gamma\eta_c'$ is 10^{-4}, we can observe about 900 η_c' signal events with 600 M ψ' decays at BESIII. The measurement precision of η_c' can be improved using this large sample.

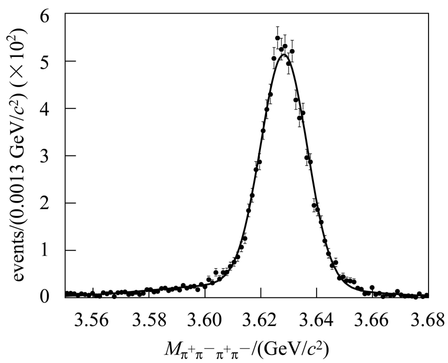

Fig. 3. Invariant mass distribution of $\pi^+\pi^-\pi^+\pi^-$ from MC simulation of $\psi' \to \gamma\eta_c'$, $\eta_c' \to \pi^+\pi^-\pi^+\pi^-$ based on BOSS. The smooth line is the best fit to the mass distribution using a double-Gaussian.

3 Spin-triplet charmonium χ_{cJ}

The importance of the Color Octet Mechanism (COM) in inclusive decays of *P*-wave charmonia has been emphasized for many years[11]. The measurement on χ_{cJ} decays will help in understanding of the COM, but there are still lots of unknown χ_{cJ} decay modes in current experimental data[9]. More experimental data of exclusive decays of *P*-wave charmonia with improved precision are important for further testing the effect of the COM. With relative large branching fraction of $\psi' \to \gamma\chi_{cJ}$, high precision measurement of *P*-wave charmonia χ_{cJ} can be performed at BESIII with large ψ' sample using many decay modes, such as $\chi_{cJ} \to PP$, $\chi_{cJ} \to VV$, $\chi_{cJ} \to SS$, $\chi_{cJ} \to B\bar{B}$ or $\chi_{cJ} \to$ multibody. With the new sample of 25 M ψ' decays, CLEO collaboration has reported many results on χ_{cJ} decays at HADRON 07[12], but we can do more at BESIII with larger ψ' sample. If the statistics is large enough, partial wave analysis can also be performed to intermediate states in multibody decays at BESIII.

4 Hyperon decay parameter

It is known that the hyperon decay parameters characterize parity violation[13], and it can be measured through hyperon nonleptonic decays. At BESIII, large sample of J/ψ and ψ' provide a good laboratory to measure the hyperon parameters through J/ψ or ψ' decays into a hyperon antihyperon pair. Decays $J/\psi \to \Lambda\bar{\Lambda}$ and $J/\psi \to \Sigma^0\bar{\Sigma}^0 \to \gamma\gamma\Lambda\bar{\Lambda}$ can be used to measure hyperon parameter $\alpha(\bar{\Lambda} \to \bar{p}\pi^+)$, and $\alpha(\bar{\Xi}^+ \to \bar{\Lambda}\pi^+)$ can be measured through $J/\psi \to \Xi^-\bar{\Xi}^+ \to \pi^+\pi^-\Lambda\bar{\Lambda}$. With 10^{10} J/ψ events, the measurement sensitivity of $\alpha(\bar{\Lambda} \to \bar{p}\pi^+)$ can be improved to be 3×10^{-3} in $J/\psi \to \Lambda\bar{\Lambda}$. The hyperon parameter $\alpha_\Lambda\alpha_\Omega$ can be measured through $\psi' \to \Omega^-\bar{\Omega}^+ \to K^-K^+\Lambda\bar{\Lambda}$. Up to now, there is no signal event of $\psi' \to \Omega^-\bar{\Omega}^+$ observed because of the limit of ψ' statistics. Details can be found in Ref. [14]. This measurement of hyperon decay parameter can not be performed at the beginning of data taking since it need quite large data sample.

5 Summary

Some measurements of charmonium decays at BESIII are discussed in this paper. To measure η_c mass with ten times improved precision comparing to current PDG average, 500 million J/ψ decays are needed at BESIII. Precise measurement of η_c' and χ_{cJ} can be performed at BESIII with large ψ' sample. With 10^{10} J/ψ sample, measurement sensitivity of $\alpha(\bar{\Lambda} \to \bar{p}\pi^+)$ can achieve 3×10^{-3}.

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