

# Recent BES results on hadron spectroscopy

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**Abstract** Light hadron spectroscopy is a powerful tool in hadronic physics. Several recent BES results on hadron spectroscopy are reported in this proceeding, including the confirmation of the enhancement in  $p\bar{p}$  invariant mass in radiative  $J/\psi$  decays, the observation of a charged  $\kappa^\pm$  decaying to  $K^\pm\pi^0$  and the measurement of exclusive decays of the  $\chi_{c0}$  and  $\chi_{c2}$  to  $\pi^0\pi^0$  and  $\eta\eta$ .

**Key words** hadron spectroscopy, BESIII, X(1860), charged  $\kappa$ ,  $\chi_{cJ}$  decays

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## 1 Introduction

In addition to the spectrum of ordinary  $q\bar{q}$  meson states and  $qqq$  baryon states, QCD-motivated models predict a rich spectrum of  $gg$  glueballs,  $q\bar{q}g$  hybrids and  $qq\bar{q}\bar{q}$  four quark states [1, 2].  $J/\psi$  decays provide an excellent laboratory for testing these predictions.

Beijing Spectrometer (BESIII)/Beijing Electron-Positron Collider (BEPC II)[3] is the major upgrade of BES II/BEPC [4]. The BESIII detector is designed to study hadron spectroscopy and  $\tau$ -charm physics [5]. The cylindrical BESIII is composed of a Helium-gas based drift chamber (MDC), a Time-Of-Flight (TOF) system, a CsI(Tl) Electro-Magnetic Calorimeter (EMC) and a RPC-based muon chamber (MUC) with a superconducting magnet providing 1.0 T magnetic field in the central region of BESIII. The nominal detector acceptance is 93% of  $4\pi$ . The expected charged particle momentum resolution and photon energy resolution are 0.5% and 2.5% at 1 GeV respectively.

In this proceeding, we present some recent results from analyses of hadron spectroscopy at BES II and BESIII.

## 2 Charged $\kappa$

In the field of hadron spectroscopy, whether the low mass iso-scalar scalar meson, the  $\sigma$ , exists or not had been an important but controversial prob-

lem for many years. Recently, its evidence has been reported [6] not only in  $\pi\pi$  scattering, but also in various production processes. The  $\sigma$  meson with a mass around 600 MeV/ $c^2$  and a broad width around 500 MeV/ $c^2$  is, now, widely accepted [7]. The existence of the  $\sigma(600)$  suggest now as well the possibility of a nonet ( $\sigma(600)$ ,  $\kappa(900)$ ,  $f_0(980)$ ,  $a_0(980)$ ) as described in various models, e.g. in Ref. [8]. Evidences for the neutral  $\kappa$  have recently been reported by E791 in  $D^+ \rightarrow K^-\pi^+\pi^+$  decays [9] and by BES II in  $J/\psi \rightarrow \bar{K}^*(892)^0 K^+\pi^-$  reactions [10]. The FOCUS experiment presented evidence for the existence of a coherent  $K\pi$  S-wave contribution to  $D^+ \rightarrow K^+\pi^-\mu^+\nu$  [11]. The existence of a neutral  $\kappa^0$  motivates the search for a charged partner. In this proceeding, we present the search for a charged  $\kappa^\pm$  in  $J/\psi \rightarrow K^*(892)^+\kappa^- \rightarrow K_S^0\pi^+K^-\pi^0$  decays.

Figure 1 shows the projected invariant mass of  $K^{*\pm}\pi^0$  of the selected  $J/\psi \rightarrow K^*(892)^+\kappa^- \rightarrow K_S^0\pi^+K^-\pi^0$  events. Besides strong contributions from  $K^*(892)^\pm$ ,  $K^*(1410)^\pm$  and  $K^*(1430)^\pm$ , a significant  $J^P = 0^+$  low mass component is needed to describe the data. The partial wave analysis yield the pole position of that  $0^+$  component displayed in dark color is  $m - i\frac{\Gamma}{2} = (849 \pm 1_{-28}^{+14}) - i(288 \pm 01_{-30}^{+64})$  MeV/ $c^2$ . This result is in agreement with a recent CLEO analysis of the resonance structure in  $D^0 \rightarrow K^+K^-\pi^0$  decays [12], which suggests a  $\kappa^\pm$  component with parameters  $m = (855 \pm 15)$  MeV/ $c^2$  and  $\Gamma = (251 \pm 48)$  MeV/ $c^2$ . Moreover the results are in reasonable agreement with

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the properties of the neutral  $\kappa^0$ .

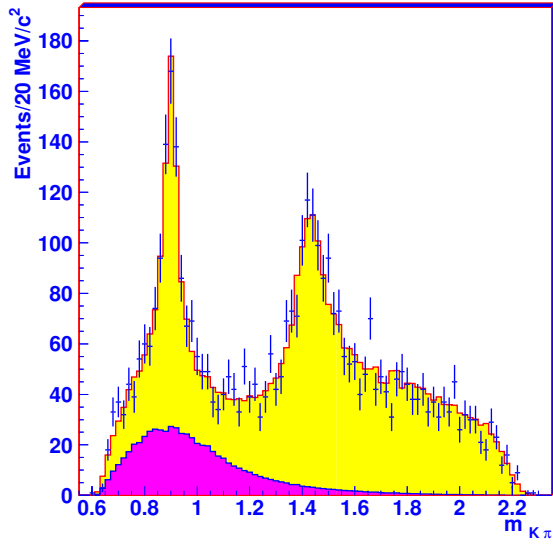


Fig. 1. (color online). Invariant mass  $m(K^+\pi^0) + \text{c.c.}$  from  $J/\psi \rightarrow K^*(892)^+\kappa^- \rightarrow K_S^0\pi^+\kappa^-\pi^0$  decays reconstructed by BES-II. The crosses represent data, the histogram is the fit result from a partial wave analysis.

### 3 Near threshold enhancement X(1860) in $J/\psi \rightarrow \gamma p\bar{p}$

A strong near-threshold mass enhancement is observed in the  $p\bar{p}$  invariant mass spectrum from  $J\psi \rightarrow \gamma p\bar{p}$  decays at BES II [13]. It is of interest to note that a corresponding mass threshold enhancement is not observed in either  $p\bar{p}$  cross section measurements or in B-meson decays [14]. The CLEO Collaboration published results on the radiative decay of the  $\Upsilon(1S)$  to the  $p\bar{p}$  system [15], where no  $p\bar{p}$  threshold enhancement is observed and the upper limit of the branching fraction is set at  $Br(\Upsilon(1S) \rightarrow \gamma X(1860))Br(X(1860) \rightarrow p\bar{p}) < 5 \times 10^{-7}$  at 90% C.L.. This enhancement is not observed in BES II  $\psi(2S) \rightarrow \gamma p\bar{p}$  data (, the upper limit is set at  $Br(\psi(2S) \rightarrow \gamma X(1860))Br(X(1860) \rightarrow p\bar{p}) < 5.4 \times 10^{-6}$  at 90% C.L.) [16] nor in BES II  $J/\psi \rightarrow \omega p\bar{p}$  data (, the upper limit is set at  $Br(J\psi \rightarrow \omega X(1860))Br(X(1860) \rightarrow p\bar{p}) < 1.5 \times 10^{-5}$  at 95% C.L.) [17].

This surprising experimental observation has stimulated a number of theoretical interpretations. Some have suggested that it is a  $p\bar{p}$  bound state (*baryonium*) [18]. Others suggest that the enhancement is primarily due to final state interactions (FSI) between the proton and antiproton [19].

Using a sample of  $1 \times 10^8$   $\psi(2S)$  decays collected by the BES III detector, X(1860) is confirmed

in the  $p\bar{p}$  invariant mass spectrum from  $\psi(2S) \rightarrow \pi^+\pi^-J/\psi, J\psi \rightarrow \gamma p\bar{p}$  decays shown in Fig. 2. A fit with  $S$ -wave BW yields the mass is  $1846.6 \pm 5.3 \text{ MeV}/c^2$  (stat.) and the width is smaller than  $33 \text{ MeV}/c^2$  at the 90% C.L. Fig. 3 shows the  $p\bar{p}$  invariant mass spectrum from  $\psi(2S) \rightarrow \gamma p\bar{p}$  decays. No significant enhancement near the  $p\bar{p}$  mass threshold is observed. These results consist with those of BES II.

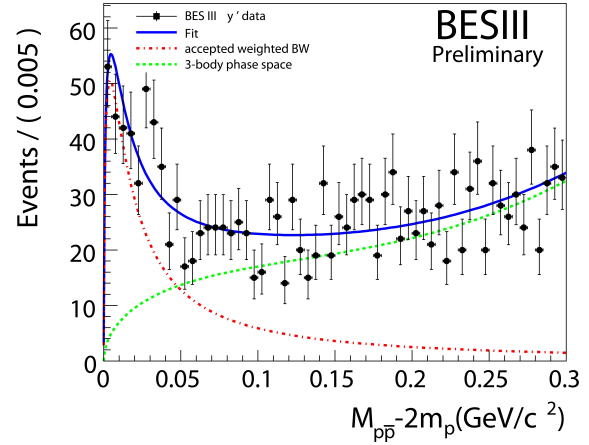


Fig. 2. (color online). The  $M_{p\bar{p}} - 2m_p$  distribution for  $\psi(2S) \rightarrow \pi^+\pi^-J/\psi, J\psi \rightarrow \gamma p\bar{p}$  candidate events. The dots with error bars are data. The solid curve is the result of fit described in the text. The red curve is the acceptance weighted BW of resonance. The green curve indicates the background.

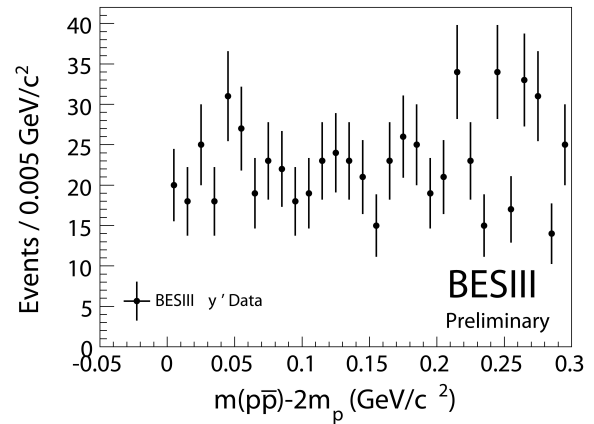


Fig. 3. (color online). The  $M_{p\bar{p}} - 2m_p$  distribution for  $\psi(2S) \rightarrow \gamma p\bar{p}$  candidate events.

### 4 Exclusive decays of the $\chi_{c0}$ and $\chi_{c2}$ to $\pi^0\pi^0$ and $\eta\eta$

In the constituent quark model, the  $\chi_{cJ}$  ( $J = 0, 1, 2$ ), mesons are  $c\bar{c}$  states in an  $L = 1$  configuration. As they cannot be produced directly in

$e^+e^-$  collisions, they are less well studied than the  $\psi$  states. However,  $\psi(2S) \rightarrow \gamma\chi_{cJ}$  decays yield many  $\chi_{cJ}$  mesons, and  $e^+e^- \rightarrow \psi(2S)$  is a very clean environment for  $\chi_{cJ}$  investigations. In the present analysis, we concentrate on the two-body decays of the  $\chi_{c0}$  and  $\chi_{c2}$  into  $\pi^0\pi^0$  and  $\eta\eta$  final states. Knowledge from these decay rates leads to information on the quark and gluon nature of both the  $\chi_c$  parents and their pseudo-scalar daughters, and a better understanding of the decay mechanisms of the  $\chi_c$  mesons [20].

Recently,  $\chi_{c0}$  and  $\chi_{c2}$  decays into two-meson final states have been studied by the CLEO-c collaboration using a sample of  $(2.59 \pm 0.05) \times 10^7$   $\psi(2S)$  decays [21]. In the present analysis, we improve the precision of the results for the all-neutral decay channels by using a sample of  $1 \times 10^8$   $\psi(2S)$  decays collected by the BESIII detector. Although these final states are subject to poorer resolution and efficiency than those with charged particles, they have the advantage of having no background from QED final states such as  $\gamma\rho$ .

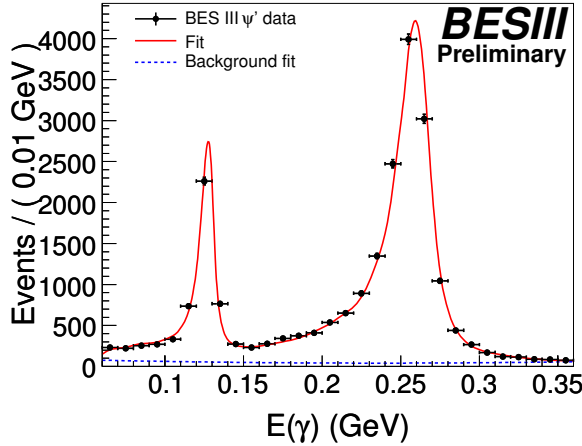


Fig. 4. (color online). The radiative photon energy distribution of selected  $\chi_c \rightarrow \pi^0\pi^0$  events. The dots with error bars are data. The solid curve is the result of a fit described in the text. The dashed curve is the background polynomial.

The radiative photon energy spectrum of  $\chi_{cJ} \rightarrow$

$\pi^0\pi^0$  candidates shown in Fig. 4 is fitted using an unbinned maximum likelihood fit with the  $\chi_{c0}$  and  $\chi_{c2}$  signal peaks. The fitting range is from 0.06 GeV to 0.36 GeV. The shapes of signals are obtained from Monte-Carlo simulation. A 2th-order Chebyshev polynomial is used to describe the background. The fit gives:  $Br(\chi_{c0} \rightarrow \pi^0\pi^0) = (3.25 \pm 0.03) \times 10^{-3}$ ,  $Br(\chi_{c2} \rightarrow \pi^0\pi^0) = (8.6 \pm 0.2) \times 10^{-4}$ , where the error is statistical only.

The fit to the radiative photon energy spectrum of  $\chi_{cJ} \rightarrow \eta\eta$  candidates shown in Fig. 5 gives:  $Br(\chi_{c0} \rightarrow \eta\eta) = (3.1 \pm 0.1) \times 10^{-3}$ ,  $Br(\chi_{c2} \rightarrow \eta\eta) = (5.9 \pm 0.5) \times 10^{-4}$ , where the error is statistical only.

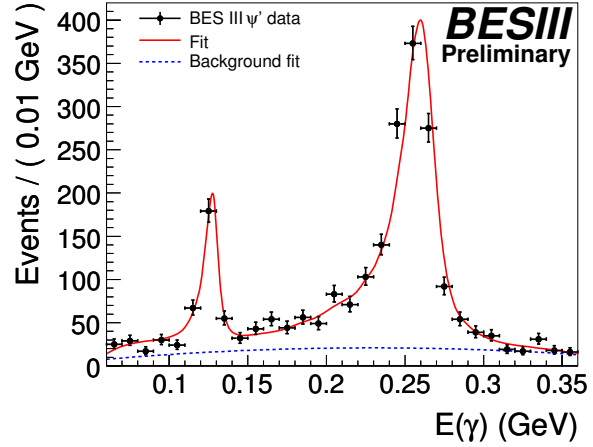


Fig. 5. (color online). The radiative photon energy distribution of selected  $\chi_c \rightarrow \eta\eta$  events. The dots with error bars are data. The solid curve is the result of a fit described in the text. The dashed curve is the background polynomial.

## 5 Summary

In summary it has been reported about the confirmation of the enhancement in  $p\bar{p}$  invariant mass in radiative  $J/\psi$  decays by BESIII, the measurement of exclusive decays of the  $\chi_{c0}$  and  $\chi_{c2}$  to  $\pi^0\pi^0$  and  $\eta\eta$  by BESIII, and the observation of a charged  $\kappa^\pm$  decaying to  $K^\pm\pi^0$  by BES II.

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