RESULTS OF THE BES-III EXPERIMENT

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Abstract

The BES-III experiment successfully takes data since 2009. For at least next ten years it will remain the world leading experiment in the τ-charm domain. Here the status of the BES-III experiment is presented and the recent results in charmonium physics and light hadron spectroscopy are reviewed.

1. The BEPC-II/BES-III Project

BEPC-II/BES-III is a major upgrade of the BES-II experiment at the Institute of High Energy Physics CAS in Beijing. The BEPC-II is a double-ring e^+e^- collider providing e^+e^- beams in the energy range of $\sqrt{s} = (2 - 4.6)$ GeV and a design peak luminosity of 10^{33} cm^{-2}s^{-1}. The BES-III apparatus [1] is a new high performance general purpose detector for measurements in the τ-charm energy region. It consists of the following main components: a helium-based Main Drift Chamber, a plastic scintillator Time-of-Flight system, a CsI(Tl) Electromagnetic Calorimeter, and a Muon Counter. Acceptance of charged particles and photons is 93% of 4π, and the charged particle momentum and photon energy resolutions at 1 GeV are 0.5% and 2.5% respectively.

The physics data taking started in March of 2009 and so far BES-III has collected the world largest data samples of J/ψ data (225M events), ψ' data (106M events), $\psi(3770)$ data (2.9 fb^{-1}) data and a

unique sample of $\psi(4010)$ data (0.5 fb^{-1}). The achieved peak luminosity is 0.65×10^{33} cm^{-2}s^{-1}.

The main goals of the experiment are precision measurements in the τ-charm domain that are possible with unprecedentedly high statistics to be accumulated [2].

The most interesting results are discussed in the next section.

2. Physics Results

2.1. Light hadron spectroscopy

2.1.1. The $p\bar{p}$ near threshold enhancement in $J/\psi \to \gamma p\bar{p}$

The anomalously strong enhancement in the $p\bar{p}$ invariant mass was first observed by BES-II collaboration in $J/\psi \to \gamma p\bar{p}$ [3]. Its important peculiarity is that it is not clearly seen in $\psi(2S) \to \gamma p\bar{p}$, $\Upsilon \to \gamma p\bar{p}$ and $\psi(2S) \to \omega p\bar{p}$, making unlikely a possibility for it to be a pure final state interaction (FSI) effect. There are different speculations on its nature and the most intriguing one is that it comes from a $p\bar{p}$ bound state, sometimes called baryonium.

The huge statistics of the BES-III experiment allows to perform a detailed study of this structure. The first published results [4] on $\psi(2S) \to \pi^+\pi^- J/\psi(J/\psi \to \gamma p\bar{p})$ confirms BES-II observation (see Fig. 1). In the analysis the data are fitted under assumption that the enhancement is produced by a S-wave state, giving $M = 1861^{+6\ +7}_{-13-26}$ MeV, $\Gamma \leq 38$ MeV at 90% C.L.

Recently a study of $J/\psi \to \gamma p\bar{p}$ has been performed. The preliminary results of partial wave analysis show that preferable quantum numbers are 0^{-+} and that the data description is significantly improved if FSI corrections are taken into account. The preliminary fit results are: $M = 1832.5 \pm 5(\text{stat})^{+15}_{-17}(\text{syst}) \pm 19(\text{mod})$ MeV and $\Gamma < 45$ MeV at 90% C.L.

2.1.2. X(1835), X(2120) and X(2370) in $J/\psi \to \gamma\pi^+\pi^-\eta'$

The state X(1835), decaying to $\pi^+\pi^-\eta'$, was discovered by the BES-II collaboration in the J/ψ radiative decay [5]. The study was motivated by an observation of the $p\bar{p}$ near threshold enhancement dis-

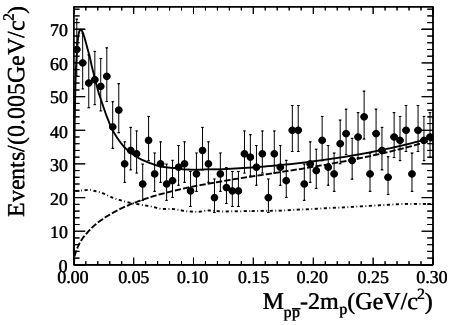

Fig. 1: The $p\bar{p}$ invariant mass for $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma p\bar{p}$ is shown. The solid line is the fit result, the dashed line is a background function and the dash-dotted indicates variation of an acceptance

cussed above. Its possible interpretations include a $p\bar{p}$ bound state, a glueball, a radial excitation of η' meson etc.

The BES-III analysis of this channel [6] confirms BES-II and reports an observation of two new states X(2120) and X(2370). The results of the fit to the $\pi^+\pi^-\eta'$ invariant mass spectrum are given in the Table 1. An important note is that the fit doesn't take into account a possible interference. The photon angular distributions for X(1835) are consistent with expectations for a pseudoscalar, but other possibilities are not excluded.

To determine spins, parities and to get more precise measurements of these states a partial wave analysis is needed, which will be possible as much higher statistics is available.

2.1.3. X(1870) and $\eta(1405)$ in $J/\psi \to \omega(\pi^+\pi^-\eta)$

The decay $J/\psi \to \omega(\pi^+\pi^-\eta)$ can be used to study $\eta(1405)$ production mechanism and a possible production of $X(1835)$ that is important for a glueball search.

T a b l e 1: Analysis results for $J/\psi \to \gamma\pi^+\pi^-\eta'$

resonance	M(MeV)	Γ(MeV)	stat. sign.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	20σ
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	6.4σ

The BES-III collaboration reports an observation of new process $J/\psi \to \omega X(1870)$, $X(1870) \to a_0^{\pm}\pi^{\mp}$ with the statistical significance more than 7.2σ [7]. Also in the lower $\pi^+\pi^-\eta$ mass region clear signals of $f_1(1285)$ and $\eta(1405)$ are seen and corresponding branching ratios measured for the first time. The $\pi^+\pi^-\eta$ mass spectra fit is performed under assumption of no interference resulting in $M = 1877.3 \pm 6.3^{+3.4}_{-7.4}$ MeV and $\Gamma = 51 \pm 12^{+19}_{-4}$ MeV. With the current statistics it is impossible to distinguish whether X(1870) is due to $X(1835)$, $\eta_2(1870)$, interference of both or is a new state. Further study using PWA will be performed as more J/ψ data are accumulated.

2.2. Charmonium spectrum and transitions

The charmonium spectrum and transitions are a perfect laboratory to test various QCD models and phenomenological mechanisms. Due to an interplay of perturbative and non-perturbative effects they allow one to study QCD beyond the perturbative regime.

2.2.1. h_c in $\psi' \to \pi^0 h_c$

The h_c is the least studied charmonium state below $D\bar{D}$ threshold. The precise measurement of its mass allows one to calculate a hyperfine 1P mass splitting $\Delta M_{hf} = \langle M(^3P_J)\rangle - M(^1P_1)$, where $\langle M(^3P_J)\rangle = \frac{1}{9}(M_{\chi_{c0}} + 3M_{\chi_{c1}} + 5M_{\chi_{c2}})$. This may give a hint to a spin-spin interaction of heavy quarks. Also the $Br(\psi' \to \pi^0 h_c)$ is a measure of an isospin violation in hadronic decays.

At BES-III $\psi' \to \pi^0 h_c$ is studied both exclusively and inclusively via registeration of a E1 photon from the $h_c \to \gamma\eta_c$ decay [8]. Fits to the π^0 recoil mass (see Fig. 2) allow one to measure a branching ratio for the $\psi' \to \pi^0 h_c$ decay and width of h_c for the first time. Combining results of inclusive and exclusive channels one obtains the first measurement of $Br(h_c \to \gamma\eta_c)$. These values a found to be $Br(\psi' \to \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$, $\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28$ MeV and $Br(h_c \to \gamma\eta_c) = (54.3 \pm 6.7 \pm 5.2) \times 10^{-2}$.

2.2.2. η_c resonance parameters from $\psi' \to \gamma\eta_c$

Despite η_c has been known for a long time its mass and width are known by an order of magnitude worser then for J/ψ, ψ' and χ_{cJ}. Be-

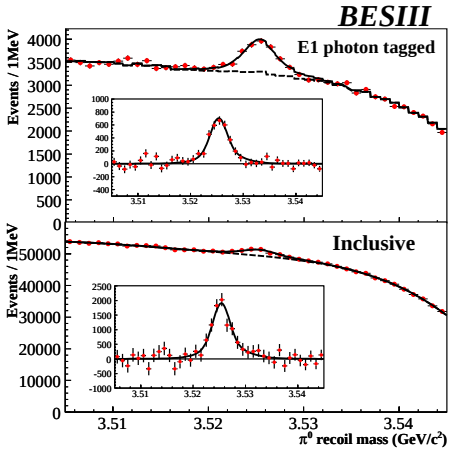

Fig. 2: The π^0 recoil mass (top – inclusive analysis, bottom – exclusive analysis). Fits are shown with a solid line and backgrounds with a dashed one

sides there are significant discrepancies in the η_c mass measurements between earlier experiments with radiative J/ψ transitions and recent studies with two photon processes.

In the BES-III inclusive analysis η_c is reconstructed from six hadron modes $K_S K\pi$, $KK\pi^0$, $2K2\pi\pi^0$, $\pi\pi\eta$, $K_S K3\pi$, 6π. The simultaneous fit to the mass spectrum takes into account the interference between η_c signal and non-η_c decays (treated as 0^{-+} component). The interference phases for different modes are found to be consistent with the same value and a single parameter is used in the final fit. Two solutions of relative phase are found, one for constructive interference and the other for destructive, however η_c mass and width remain unchanged regardless which solution is taken. It yields $M = 2984.3 \pm 0.6 \pm 0.6\,\text{MeV}, \Gamma = 32.0 \pm 1.2 \pm 1.0\,\text{MeV}$ that is currently the world best measurement, being consistent with two-photon production and $J/\psi \to \gamma\eta_c$ result by CLEO collaboration. This result is preliminary.

2.2.3. M1 transition $J/\psi \to \gamma\eta_c(2S)$

The $\eta_c(2S)$ state is observed for the first time in charmonium decays at BES-III. The $K_S K\pi$ invariant mass spectrum (see Fig. 3) is

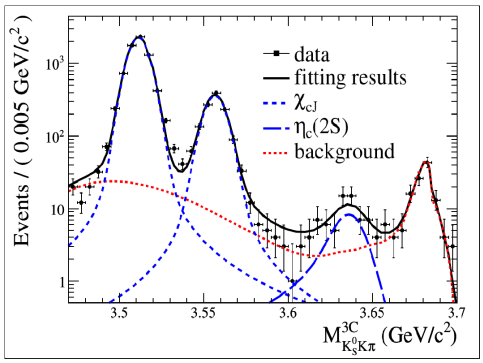

Fig. 3: The $\eta_c(2S)$ signal from the $K_S K\pi$ invariant mass spectrum

fitted with χ_{cJ}, $\eta_c(2S)$ and background contributions. The $\eta_c(2S)$ significance is found to be greater 5σ. This result is preliminary.

2.3. Charmonium decays

2.3.1. $\psi' \to \gamma P$, $(P = \pi^0, \eta, \eta')$

The radiative decay ψ' to a pseudoscalar is important for testing various phenomenological mechanisms like vector meson dominance, the $\eta_c - \eta^{(\prime)}$ mixing, two-gluon couplings $q\bar{q}$ states and a final state radiation by light quarks.

The BES-III reports the first evidence for $\psi' \to \gamma\pi^0$, $\psi' \to \gamma\eta$ and a new measurement of $\psi' \to \gamma\eta'$ [9] (see Table 2).

The ratio $R_X = \frac{Br(X\to\gamma\eta)}{Br(X\to\gamma\eta')}$, where X is J/ψ or ψ', can be predicted from the first order perturbation theory: it is expected that $R_{\psi'} \approx R_{J/\psi}$. Recently, CLEO collaboration reported $R_{\psi'} \ll R_{J/\psi}$, with $R_{\psi'} \leq 1.8\%$ at 90% C.L. and $R_{J/\psi} = (21.1 \pm 0.9)\%$ [10]. The BES-III analysis yields $R_{\psi'} = (1.10 \pm 0.38 \pm 0.07)\%$, confirming the CLEO result. Such a small $R_{\psi'}$ value challenges our understanding of charmonium states.

Table 2: $\psi' \to \gamma P$ $(P = \pi^0, \eta, \eta')$

decay channel	$Br(\times 10^{-6})$	$Br^{\rm PDG}(\times 10^{-6})$ [14]	sign.
$\psi' \to \gamma\pi^0(\gamma\gamma)$	$1.58 \pm 0.40 \pm 0.13$	≤ 5	4.6σ
$\psi' \to \gamma\eta(3\pi)$	$1.38 \pm 0.48 \pm 0.09$	≤ 2	4.3σ
$\psi' \to \gamma\eta(\pi^+\pi^-\eta, \gamma\pi^+\pi^-)$	$126 \pm 3 \pm 8$	121 ± 8	

2.3.2. $\chi_{cJ} \to \gamma V$, $V = (\rho, \omega, \varphi)$

Doubly radiative decays $\psi' \to \gamma\chi_{cJ}$, $\chi_{cJ} \to \gamma V$, where V is one of ρ^0, ϕ and ω mesons, provide information on the flavour content of χ_{cJ} states and on the gluon hadronization dynamics in this process. Remarkably the branching ratios of these channels measured by CLEO collaboration [11] appeared to be much larger than ones predicted by the theory.

The BES-III collaboration presents [12] new measurements of $Br(\chi_{c1} \to \gamma\rho^0)$ and $Br(\chi_{c1} \to \gamma\omega)$, the first observation of $\chi_{c1} \to \gamma\varphi$ and upper limits for χ_{c0} and χ_{c2} decays to these final states. The branching ratios measured by BES-III are in agreement with CLEO results. It is also shown that decays $\chi_{c1} \to \gamma V$ are dominated by the longitudial component. The branching ratios of $\chi_{c1} \to \gamma V$ are shown in Table 3.

2.3.3. $\chi_{cJ} \to VV$, $V = (\omega, \varphi)$

Several modes of χ_{cJ} decays have been reported by BES-III: the first observation of $\chi_{c1} \to \varphi\varphi$, $\chi_{c1} \to \omega\omega$ and $\chi_{c0} \to \omega\varphi$; 4σ evidence for $\chi_{c1} \to \omega\varphi$ [13]. The precision of branching ratio measurements have been improved compared to the current world average values [14] (see Table 4).

The unexpectedly high branching ratios $\chi_{c1} \to VV$ indicate a significant violation of the helicity selection rule. In addition the measurements for $\chi_{cJ} \to \omega\varphi$ provides the first indication of the rate of doubly OZI suppressed χ_{cJ} decays.

3. Future Prospects

The BES-III running plan for 2012 is to collect 1 billion J/ψ events and 0.7 billion ψ'. The preliminary program for 2013-2015 includes

Table 3: $\psi' \to \gamma V$ ($P = \rho, \omega\, \varphi$)

decay channel	$Br(\times 10^{-6})$	sign.
$\chi_{c1} \to \gamma\varphi$	$25.8 \pm 5.2 \pm 2.3$	6σ
$\chi_{c1} \to \gamma\rho$	$228 \pm 13 \pm 22$	$> 10\sigma$
$\chi_{c1} \to \gamma\omega$	$69.7 \pm 7.2 \pm 6.6$	$> 10\sigma$

Table 4: $\chi_{cJ} \to \varphi\varphi, \omega\omega, \omega\varphi$

decay channel	$Br(\times 10^{-6})$	$Br^{\rm PDG}(\times 10^{-6})$ [14]
$\chi_{c0} \to \varphi\varphi$	$8.0 \pm 0.3 \pm 0.8$	9.2 ± 1.9
$\chi_{c1} \to \varphi\varphi$	$4.4 \pm 0.3 \pm 0.5$	–
$\chi_{c2} \to \varphi\varphi$	$10.7 \pm 0.3 \pm 1.2$	14.8 ± 2.8
$\chi_{c0} \to \omega\omega$	$9.5 \pm 0.3 \pm 1.1$	22.0 ± 7.0
$\chi_{c1} \to \omega\omega$	$6.0 \pm 0.3 \pm 0.7$	–
$\chi_{c2} \to \omega\omega$	$8.9 \pm 0.3 \pm 1.1$	19.0 ± 6.0
$\chi_{c0} \to \omega\varphi$	$1.2 \pm 0.1 \pm 0.2$	–
$\chi_{c1} \to \omega\varphi$	$0.22 \pm 0.06 \pm 0.02$	–
$\chi_{c2} \to \omega\varphi$	< 0.2 at 90% C.L.	–

taking data at higher energies ($\psi(4170)$, R-scan), accumulating more than 20 fb^{-1} data at $\psi(3770)$, acquiring data for τ-physics.

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