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BESIII recent results

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Summary. — We present new results on exotic quark states and charm physics from the BESIII experiment located at the Beijing Electron Positron Collider II.

1. – Charm physics at BESIII

The open-charm physics program at BESIII includes studying pure leptonic, semileptonic and hadronic charm meson decays, searches for CP violations, neutral D mixing, rare or forbidden decays. The latter are sensitive to physics beyond the Standard Model. BESIII presented a study of $D^0 \to K^- e^+ \nu_e$ and $D^0 \to \pi^- e^+ \nu_e$ using $2.92\,\mathrm{fb}^{-1}$ recorded at the BESIII e^+e^- collider at $\sqrt{s} = 3.773\,\mathrm{GeV}$ [1]. We measure the absolute decay branching fractions $\mathcal{B}(D^0 \to K^- e^+ \nu_e) = (3.505 \pm 0.014 \pm 0.033)\%$ and $\mathcal{B}(D^0 \to \pi^- e^+ \nu_e) = (0.295 \pm 0.004 \pm 0.003)\%$. From a study of the differential decay rates we obtain the products of hadronic form factor and magnitude of the CKM matrix element $f_+^K(0)|V_{cs}| = 0.7172 \pm 0.0025 \pm 0.0035$ and $f_+^{\pm}(0)|V_{cd}| = 0.1435 \pm 0.0018 \pm 0.0009$. Combining these products with the values of $|V_{cs(d)}|$ from the Standard Model (SM) constraint fit, we extract the hadronic form factors $f_+^K(0) = 0.7368 \pm 0.0026 \pm 0.0036$ and $f_+^{\pm}(0) = 0.6372 \pm 0.0080 \pm 0.0040$. All of these measurements are the most precise to date. Another important result has been given using $2.92\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 3.773\,\mathrm{GeV}$, to obtain the first measurements of the absolute branching fraction $\mathcal{B}(D^+ \to K_L^0 e^+ \nu_e) = (4.48 \pm 0.027 \pm 0.103)\%$ and the related CP asymmetry $A_{CP} = (-0.59 \pm 0.60 \pm 1.48)\%$ [2]. From the differential decay rate distribution, the product of the hadronic form factor and the magnitude of the CKM matrix element, $f_+^K(0)|V_{cs}|$ is determined to be $0.728 \pm 0.006 \pm 0.011$. Using $|V_{cs}|$ from the SM constrained fit, we extract $f_+^K(0) = 0.748 \pm 0.007 \pm 0.012$.

BESIII presented, using $2.92\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 3.773\,\mathrm{GeV}$, an improved measurement of the branching fraction $\mathcal{B}(D^+ \to \omega e^+ \nu_e) = (1.63 \pm 0.11 \pm 0.08) \times 10^{-3}$ [3]. The parameters defining the corresponding hadronic form factor ratios at zero momentum transfer are determined for the first time; we measure $r_V = 1.24 \pm 0.09 \pm 0.06$ and

$r_2 = 1.06 \pm 0.15 \pm 0.05$. We also search for as yet unobserved decay $D^+ \to \phi e^+ \nu_e$. An improved upper limit $\mathcal{B}(D^+ \to \phi e^+ \nu_e) < 1.3 \times 10^{-5}$ is set at 90% confidence level (CL).

BESIII reported also a search for the flavor-changing neutral current process $D^0 \to \gamma\gamma$ using $2.92\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 3.773\,\mathrm{GeV}$ [4]. After reconstructing a hadronically decaying $\bar{D}$ in an event, we then search for D-decay candidates of interest in the event (double-tag technique). We find no signal and set an upper limit al 90% confidence level for the branching fraction of $\mathcal{B}(D^0 \to \gamma\gamma) < 3.8 \times 10^{-6}$. We also investigate D^0-meson decay into two neutral pions, obtaining a branching fraction of $\mathcal{B}(D^0 \to \pi^0\pi^0) = (8.24 \pm 0.21 \pm 0.30) \times 10^{-4}$, the most precise measurement to date and consistent with the current world average.

Another important result has been obtained, using $567\,\mathrm{pb}^{-1}$ data at $\sqrt{s} = 4.6\,\mathrm{GeV}$ [5], about the first measurement of the absolute branching fraction $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$ representing a significant improvement in precision over the current indirect determination.

In [6] we reported also the first measurement of the absolute hadronic branching fractions of Λ_c^+ using the same data sample. Among the measurements for twelve Λ_c^+ decay modes, the branching fraction for $\Lambda_c^+ \to pK^-\pi^+$ is determined to be $(5.84 \pm 0.27 \pm 0.23)\%$.

2. – The XYZ states

In the last decade, many new particles in the charmonium mass region were observed. Most of these new states have properties that are not consistent with conventional charmonium, and might be good candidate for exotic states. They are generally called XYZ states.

Recently, the Belle Collaboration reported evidence for a narrow resonance $X(3823) \to \gamma\chi_{c1}$ in B meson decays with 3.8σ significance and the mass and width suggested that this is a good candidate for the 1^3D_2 charmonium state [7]. In the following we denote the 1^3D_2 state as ψ_2.

BESIII reported a search for the production of the ψ_2 state via the process $e^+e^- \to \pi^-\pi^- X$ using $4.67\,\mathrm{fb}^{-1}$ data collected at center of mass energies that range from $\sqrt{s} = 4.19$ to $4.60\,\mathrm{GeV}$. The ψ_2 candidates are reconstructed in their $\gamma\chi_{c1}$ and $\gamma\chi_{c2}$ decay modes, with $\chi_{c1,c2} \to \gamma J/\psi$ and $J/\psi \to \ell^+\ell^-$ ($\ell = e$ or μ) [8].

An unbinned maximum-likelihood fit to the $M_{recoil}(\pi^+\pi^-)$ invariant-mass distribution is performed to extract the $X(3823)$ parameters. The signal shapes are represented by MC simulated $\psi(2S)$ and $X(3823)$ histograms, convolved with Gaussian functions with mean and width parameters left free in the fit to account for differences in mass scale and resolution, respectively, between data and MC simulation. The background is parameterized as a linear function. A simultaneous fit with a common $X(3823)$ mass is applied to the data sets with independent signal yields at $\sqrt{s} = 4.230$, 4.260, 4.360, 4.420 and 4.600 GeV (data sets with small luminosities are merged to nearby data sets with larger luminosities) for the $\gamma\chi_{c1}$ and $\gamma\chi_{c2}$ modes, respectively. Figure 1 shows the fit results where the $X(3823)$ is observed with statistical significance of 6.2σ in $\gamma\chi_{c1}$ modes. The $X(3823)$ parameters extracted from the fit are: $m = 3821.7 \pm 1.3 \pm 0.7\,\mathrm{MeV}/c^2$ and $\Gamma < 16\,\mathrm{MeV}$ al 90% CL. These measurements are in good agreement with the assignment of the $X(3823)$ as the $\psi(1^3D_2)$ charmonium states with $J^{PC} = 2^{--}$.

The CDF experiment first reported evidence for a new state called $Y(4140)$ in the decay $B^+ \to \phi J/\psi K^+$ [9]. In a subsequent analysis, CDF claimed the observation of the $Y(4140)$ with a statistical significance greater than 5σ [10]. However the existence

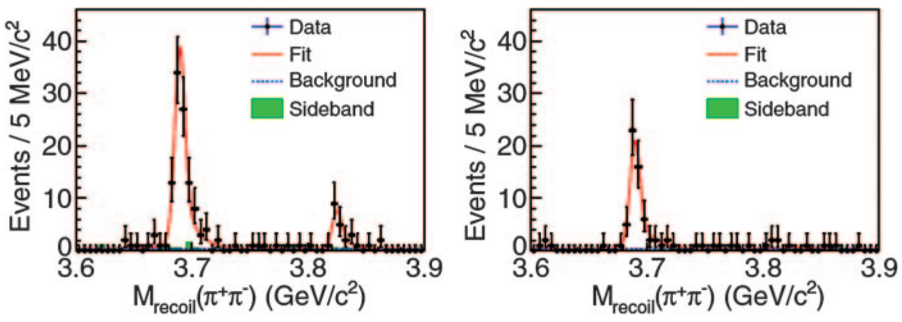

Fig. 1. – Simultaneous fit to the $M_{recoil}(\pi^+\pi^-)$ distribution of $\gamma\chi_{c1}$ events (left) and $\gamma\chi_{c2}$ events (right), respectively. Dots with error bars are data, red solid curves are total fit, dashed blue curves are background and the green shaded histograms are J/ψ mass sidebands events.

of the $Y(4140)$ was not confirmed by the Belle [11] or LHCb [12] collaborations in the same process, nor by the Belle Collaboration in two-photon production [11]. Recently, the CMS [13] and D0 [14] collaborations reported the observation of the $Y(4140)$. The BaBar collaboration found no evidence for this resonance [15].

BESIII reported results of a search for $Y(4140)$ decays into $\phi J/\psi$ through the process $e^+e^- \to \gamma\phi J/\psi$ with data taken at center-of-mass energies of $\sqrt{s} = 4.23$, 4.25 and 4.36 GeV with 1094 pb^{-1}, 827 pb^{-1} and 545 pb^{-1}, respectively [16]. No significant signal is observed in the $\phi J/\psi$ invariant mass distribution. The upper limits of the product of cross section and branching fraction $\sigma[e^+e^-\gamma Y(4140)] \times \mathcal{B}(Y(4140) \to \phi J/\psi)$ at the 90% CL are estimated as 0.35, 0.28 and 0.33 pb at $\sqrt{s} = 4.23$, 4.26 and 4.36 GeV, respectively.

BESIII presented a study of the process $e^+e^- \to \pi^+\pi^- J/\psi$ [17] at a center of mass energy of $\sqrt{s} = (4.26 \pm 0.001)$ GeV, which corresponds to the peak to the $Y(4260)$ cross section. The analysis was performed with a 525 pb^{-1} data sample. We observed a charged structure in the $\pi^\pm J/\psi$ invariant mass spectrum, which we referred to as the $Z_c(3900)$. An unbinned maximum likelihood fit is applied to the $\pi^\pm J/\psi$ invariant mass distribution. The signal shape is parameterized as an S-wave Breit-Wigner function convolved with a Gaussian with a mass resolution fixed at the Monte Carlo simulated value. The significance is found to be greater than 8σ. The $Z_c(3900)$ parameters extracted from the fit are: $m = 3899.0 \pm 3.6 \pm 4.9\,\mathrm{MeV}/c^2$ and $\Gamma = 46 \pm 10 \pm 20$ MeV. This structure couples to charmonium and has an electric charge, which is suggestive of a state containing more quarks than just a charm and anticharm quark.

A recent BESIII analysis has searched for the neutral isospin partner of $Z_c(3900)^\pm$ [18]. Evidence for a structure in the invariant $J/\psi\pi^0$ mass distribution is observed by CLEO-c in the process $e^+e^- \to \pi^0\pi^0 J/\psi$ [19]. BESIII studied the same channel at three different center-of-mass energies, $\sqrt{s} = 4.23$, 4.26 and 4.36 GeV and we observed a clear structure in the invariant $J/\psi\pi^0$ mass with significance greater than 10σ. The mass and width are measured to be $3894.8 \pm 2.3 \pm 3.2\,\mathrm{MeV}/c^2$ and $29.6 \pm 8.2 \pm 8.2$ MeV, respectively. We interpret this state as the neutral partner of the four-quark candidate $Z_c^\pm(3900)$.

BESIII studied the process $e^+e^- \to (D\bar{D}^*)^\mp\pi^\pm$ using 1090 pb^{-1} at $\sqrt{s} = 4.23$ GeV and 827 pb^{-1} at $\sqrt{s} = 4.26$ GeV using a double-tag technique [20]. The invariant-mass distribution of the $D\bar{D}^*$ system shows a clear enhancement at the $(D\bar{D}^*)^\pm$ threshold, labeled as $Z_c(3885)^\pm$ with a statistical significance greater than 10σ. The fit is done with

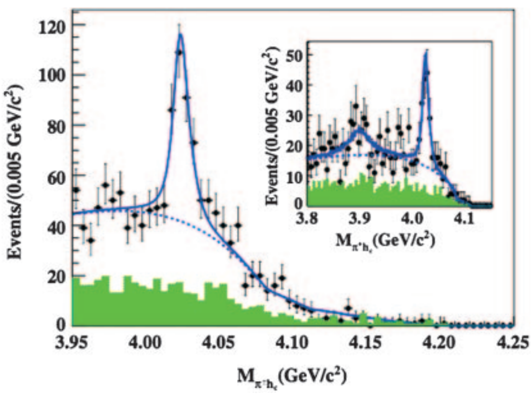

Fig. 2. – $e^+e^- \to \pi^+\pi^- h_c$: Sum of the simultaneous fits to the $M_{\pi^\pm h_c}$ distributions at 4.23, 4.26 and 4.36 GeV. The inset shows the sum of the simultaneous fit to the $M_{\pi^\pm h_c}$ distributions at 4.23 and 4.26 GeV with $Z_c(3900)$ and $Z_c(4020)$. Dots with error bars are data; shaded histograms are the normalized sideband background; the solid curves show the total fit, and the dotted curves the background from the fit.

a Breit-Wigner function plus a smooth threshold function and the parameters extracted from the fit of the $Z_c(3885)^\pm$ are: $m = 3881.7 \pm 1.6 \pm 1.6\,\mathrm{MeV}/c^2$ and $\Gamma = 26.6 \pm 2.0 \pm 2.1\,\mathrm{MeV}$. The bachelor $\pi^\pm$ angle distribution in analyzed in order to determine the $Z_c(3885)$ quantum numbers. The resulting distribution in consistent with a spin-parity assignment of $J^P = 1^+$ and rules out 0^- as well as 1^-. The results are consistent with the ones obtained using a single D tag technique [21]. An important issue is whether or not the $Z_c(3900)$ and $Z_c(3885)$ have the same origin. The determination of the J^{PC} quantum numbers of $Z_c(3900)$ would be necessary to answer this question.

Meanwhile BESIII studied the process $e^+e^- \to \pi^0(D\bar{D}^*)^0$ using $1092\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 4.23\,\mathrm{GeV}$ and 826 pb^{-1} at $\sqrt{s} = 4.26\,\mathrm{GeV}$ [22]. The invariant mass distribution of

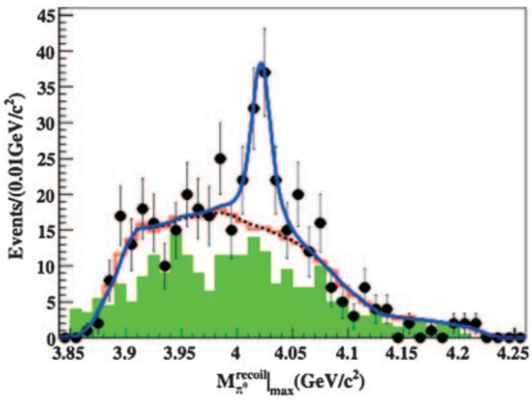

Fig. 3. – $e^+e^- \to \pi^0\pi^0 h_c$: Sum of the simultaneous fits to the $M^{recoil}_{\pi^0}$ distribution at 4.23, 4.26 and 4.36 GeV. Dots with error bars are data; the green shaded histogram shows the normalized h_c sidebands events; the black dashed curve is the background from the ft; the red histogram shows the result from a phase space Monte Carlo simulation; the solid blue line shows the total fit.

the $D\bar{D}^*$ system shows a clear enhancement, labeled as $Z_c(3885)^0$ with a statistical significance greater than 10σ. The parameters extracted from the fit of the $Z_c(3885)^0$ are: $m = 3885.7^{+4.3}_{-5.7} \pm 8.4\,\mathrm{MeV}/c^2$ and $\Gamma = 35^{+11}_{-12} \pm 15\,\mathrm{MeV}$. We interpret this state as the neutral partner of the $Z_c(3885)^{\pm}$.

BESIII studied the process $e^+e^- \to \pi^+\pi^- h_c$ at 13 center-of-mass energies from 3.900 to 4.420 GeV [23]. The h_c is reconstructed via the decay $h_c \to \gamma\eta_c$ where the η_c is reconstructed into 16 hadronic decay modes. An unbinned maximum-likelihood fit is applied to the $M_{\pi^{\pm}h_c}$ distribution summed over the 16 η_c decay modes. An enhancement is clear and it is labeled as $Z_c(4020)^{\pm}$ as shown in fig. 2. The signal shape is parameterized as a constant width relativistic Breit-Wigner function convolved with a Gaussian with a mass resolution determined from data, while the background shape is parameterized as an ARGUS function. The statistical significance is greater than 8.9σ and the parameters extracted from the fit are: $m = 4022.9 \pm 0.8 \pm 2.7\,\mathrm{MeV}/c^2$ and $\Gamma = 7.9 \pm 2.7 \pm 2.6\,\mathrm{MeV}$. There is no significant evidence of the $Z_c(3900)$ structure in the $M_{\pi^{\pm}h_c}$ mass spectrum: adding the $Z_c(3900)$ mass and width fixed to [17], we find a significance of 2.1σ.

A neutral structure, the $Z_c(4020)^0$ is expected to couple to the $\pi^0 h_c$ final state and be produced in $e^+e^- \to \pi^0\pi^0 h_c$. BESIII studied the $e^+e^- \to \pi^0\pi^0 h_c$ at $\sqrt{s} = 4.23$, 4.25 and 4.36 GeV and reported the observation of the $Z_c(4020)^0$ in the $\pi^0 h_c$ spectrum with a statistical significance greater than 5σ [24]. The result is shown in fig. 3 and the fit is done using a Breit-Wigner function and fixing the width to the value extracted from [23]. The $Z_c(4020)^0$ mass extracted from the fit is $4023.9 \pm 2.2 \pm 3.8\,\mathrm{MeV}/c^2$. Further investigation are needed to understand the nature of $Z_c(4020)$.

BESIII studied the process $e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}$ at a center-of-mass energy $\sqrt{s} = 4.260\,\mathrm{GeV}$ [25]. The charged D meson from $D^{*\pm} \to D^{\pm}\pi^0$ is reconstructed by its decay into $K\pi\pi$, and at least one π^0 in the final state is required in order to suppress background events. In the recoil mass spectrum of the bachelor $\pi^{\mp}$, a structure near the $(D^*\bar{D}^*)^{\pm}$ threshold is observed with a statistical significance of 13σ and labeled as $Z_c(4025)^{\pm}$. The distribution is fitted with a Breit-Wigner function and the parameters extracted from the fit are: $m = 4026 \pm 2.6 \pm 3.7\,\mathrm{MeV}/c^2$ and $\Gamma = 24.8 \pm 5.6 \pm 7.7\,\mathrm{MeV}$. Unfortunately, the statistics do not allow to perform a spin-parity analysis of $Z_c(4025)^{\pm}$ and so further investigation of the $Z_c(4020)^{\pm}$ and $Z_c(4025)^{\pm}$ are mandatory in order to understand whether or not both are due to the same source.

BESIII studied also the process $e^+e^- \to (D^*\bar{D}^*)^0\pi^0$ using $1092\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 4.23\,\mathrm{GeV}$ and $826\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 4.26$ GeV [26]. In the recoil mass spectrum of the bachelor π^0, a structure is observed with a statistical significance of 7.4σ and labeled as $Z_c(4025)^0$. The distribution is fitted with a Breit-Wigner function and the parameters extracted from the fit are: $m = 4025.5^{+2.0}_{-4.7} \pm 3.1\,\mathrm{MeV}/c^2$ and $\Gamma = 23.0 \pm 6.0 \pm 1.0\,\mathrm{MeV}$. We interpret this state as the neutral partner of the the candidate $Z_c(4025)^{\pm}$.

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