Recent results on quarkonium and quarkonuim-like states at Belle are presented.

1 Bottomonium results

1.1 Measurement of $e^+e^- \rightarrow b\bar{b}$ and $e^+e^- \rightarrow \Upsilon \pi^+\pi^-$ crossections

The crossections of $e^+e^- \rightarrow b\bar{b}$ and $e^+e^- \rightarrow \Upsilon \pi^+\pi^-$ in the region of the $\Upsilon(5S)$ and $\Upsilon(6S)$ resonances were measured. The results are shown in Fig. 1. Decays of the $\Upsilon(6S)$ to $\Upsilon(1S, 2S, 3S)\pi^+\pi^-$ are observed. The $R_X$ (ratios of the process $X$ crossection to $e^+e^- \rightarrow \mu^+\mu^-$ crossection) at 10.865 GeV are found to be: $R_{\Upsilon(1S)\pi^+\pi^-} = (2.4 \pm 0.1 \pm 0.7) \times 10^{-3}$, $R_{\Upsilon(2S)\pi^+\pi^-} = (4.2 \pm 0.2 \pm 1.1) \times 10^{-3}$, $R_{\Upsilon(3S)\pi^+\pi^-} = (1.3 \pm 0.1 \pm 0.5) \times 10^{-3}$. The mass of the $Y(5S)$ is measured; the result is 10880.4 $\pm$ 0.9 $\pm$ 1.4 MeV/c$^2$ for the $b\bar{b}$ sample and 10884.6 $\pm$ 1.4 $\pm$ 1.1 MeV/c$^2$ for the $\Upsilon\pi^+\pi^-$ sample.

![Figure 1 – CROSSECTIONS OF $e^+e^- \rightarrow b\bar{b}$ AND $e^+e^- \rightarrow \Upsilon \pi^+\pi^-$.](image-url)
1.2 Observation of $\Upsilon(4S) \rightarrow h_b \eta$

The decay $\Upsilon(4S) \rightarrow h_b \eta$ was observed. The $\eta$ is reconstructed in $\eta \rightarrow \gamma \gamma$ decay mode. The background-subtracted distribution of the $\eta$ recoil mass is shown in Fig. 2; the signal significance is $17\sigma$. The branching fraction is found to be $B(\Upsilon(4S) \rightarrow h_b \eta) = (1.83 \pm 0.16 \pm 0.17) \times 10^{-3}$. The same process with $h_b \rightarrow \gamma \eta_b$ is also studied. The difference of $\eta \gamma$ and $\eta$ recoil masses is shown in Fig. 2. The branching fraction of $h_b \rightarrow \gamma \eta_b$ is found to be $(52.8 \pm 4.7 \pm 4.2)\%$; the difference of $\eta_b$ and $h_b$ masses is $M(\eta_b) - M(h_b) = -494.0 \pm 1.3 \pm 2.8$ MeV/$c^2$, and $\eta_b$ width is $\Gamma(\eta_b) = 10.7 \pm 2.3 \pm 3.7$ MeV.

Figure 2 – The $\eta$ recoil mass and the difference of $\eta \gamma$ and $\eta$ recoil masses.

2 Charmonium results

2.1 Observation of $Z_c(4430)^+$

The $Z_c(3900)^+$ was observed in $J/\psi \pi$ invariant mass distribution in $Y(4260) \rightarrow J/\psi \pi^+ \pi^-$ (this state was also observed by BESIII Collaboration\(^2\) simultaneously). The crosssection of $J/\psi \pi^+ \pi^-$ via ISR and the distribution of the maximal $J/\psi \pi$ invariant mass ($\max(M(J/\psi \pi^+), M(J/\psi \pi^-))$) in the $Y(4260)$ region defined as $4.15$ GeV/$c^2 < M(J/\psi \pi^+ \pi^-) < 4.45$ GeV/$c^2$ are shown in Fig. 3. The resulting parameters of the $Z_c(3900)^+$ are $M = 3894.5 \pm 6.6 \pm 4.5$ MeV, $\Gamma = 63 \pm 24 \pm 26$ MeV, $B(Y(4260) \rightarrow Z_c(3900)^{\pm} \pi^{\mp}) \times B(Z_c(3900)^{\pm} \rightarrow \pi^{\mp} J/\psi)/B(Y(4260) \rightarrow J/\psi \pi^+ \pi^-) = (29.0 \pm 8.9)\%$.

Figure 3 – Crossection of $J/\psi \pi^+ \pi^-$ via ISR and maximal $J/\psi \pi$ invariant mass.
2.2 Analysis of $B^{\pm} \rightarrow \chi_{c1}\pi^+\pi^- K^{\pm}$

The decay mode $B^{\pm} \rightarrow \chi_{c1}\pi^+\pi^- K^{\pm}$ was observed (the significance is about 20$\sigma$; the $\Delta E$ distribution is shown in Fig. 4). The branching fraction is $\mathcal{B}(B \rightarrow \chi_{c1}\pi^+\pi^- K) = (3.94 \pm 0.19 \pm 0.30) \times 10^{-4}$. A search for resonances decaying to $\chi_{c1}\pi^+\pi^-$ was performed. The distribution of $\chi_{c1}\pi^+\pi^-$ invariant mass is shown in Fig. 4. No significant signal is found.

![Figure 4](image)

Figure 4 – The $\Delta E$ distribution and the $\chi_{c1}\pi^+\pi^-$ invariant mass distribution in the signal region.

2.3 Observation of $B \rightarrow X(3872)K\pi$

The decay mode $B^{0} \rightarrow X(3872)K^+\pi^-$ was observed. The $\Delta E$ distribution and the $J/\psi\pi^+\pi^-$ invariant mass distribution are shown in Fig. 5. The branching fraction product is found to be $\mathcal{B}(B^{0} \rightarrow X(3872)K^+\pi^-) \times \mathcal{B}(X(3872) \rightarrow J/\psi\pi^+\pi^-) = (8.6 \pm 1.3^{+0.5}_{-0.8}) \times 10^{-6}$. The $K^*(892)$ fraction is 0.29 $\pm$ 0.08.

![Figure 5](image)

Figure 5 – The $\Delta E$ distribution and the $J/\psi\pi^+\pi^-$ invariant mass distribution in the signal region.

2.4 Measurement of the $Z_c(4430)^+$ quantum numbers

An amplitude analysis of $B^{0} \rightarrow \psi'K^+\pi^-$ was performed, and the spin and parity of the $Z_c(4430)^+$ has been measured 3. The $Z_c(4430)^+$ signal is added to the amplitude with different $J^P$ hypotheses. The preferred assignment of the quantum numbers is $1^+$. The exclusion levels of the $0^-$, $1^-$, $2^-$ and $2^+$ hypotheses are $3.4\sigma$, $3.7\sigma$, $4.7\sigma$ and $5.1\sigma$, respectively. Projection of the fit results with and without the $Z_c(4430)^+$ ($J^P = 1^+$) onto $M^2(\psi'\pi)$ is shown in Fig. 6. The mass and width of the $Z_c(4430)^+$ are $M = 4485^{+22+28}_{-22-11}$ MeV/$c^2$, $\Gamma = 200^{+41+26}_{-46-35}$ MeV.

![Figure 6](image)
2.5 Amplitude analysis of $B \to J/\psi K\pi$

An amplitude analysis of $B^0 \to J/\psi K^+\pi^-$ was performed. Projections of the fit results onto $M^2(J/\psi\pi)$ are shown in Fig. 7. A new $Z_{c}^{+}$ state is observed with $7.2\sigma$ significance; the preferred quantum numbers are $J^P = 1^+$. It is referred to as the $Z_{c}(4200)^+$. The exclusion levels of the $0^-, 1^-, 2^-, 2^+$ hypotheses are $6.7\sigma, 7.7\sigma, 5.2\sigma, 7.6\sigma$. The mass and width of the $Z_{c}(4200)^+$ are $M = 4196^{+31+17}_{-29-6}$ MeV/$c^2$, $\Gamma = 370^{+70+70}_{-70-85}$ MeV. In addition, evidence for $Z_{c}(4430)^+ \to J/\psi\pi^+$ is found.

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References