PROCEEDINGS OF SCIENCE

Charmonium and X, Y at Belle

Anna Vinokurova[1]
Budker Institute of Nuclear Physics
Novosibirsk, Russian Federation
E-mail: vinokurovanna@gmail.com

We report results of a study of charmonium and X, Y states using the world-largest data sample accumulated with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. We present results from a study of $X(3872)\to J/\psi\pi^+\pi^-$ decays produced in exclusive $B\to K\pi^+\pi^- J/\psi$ decays. We report a study of $B\to(J/\psi\gamma)K$ and $B\to(\psi'\gamma)K$ decay modes. We measure the cross section for $e^+e^-\to\pi^0\pi^0 J/\psi$ from threshold up to 6 GeV using initial state radiation events from e^+e^- annihilation at $\sqrt{s}$=10.58 GeV. Using this data we search for evidence of Y(4260) decaying to $\pi^0\pi^0 J/\psi$. We report the results of a study of $B^\pm\to K^\pm\eta_c$ and $B^\pm\to K^\pm\eta_c(2S)$ decays followed by η_c and $\eta_c(2S)$ decays to $(K_S K\pi)^0$.

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1. Introduction

B-factories provide a great opportunity to study known charmonium states and discover new ones. Since 2002 more than 10 states that probably contain a ($c\bar{c}$) pair (so called "charmonium-like" states) have been discovered at B-factories. These states have mass above the open charm threshold and are in poor agreement with the charmonium potential model. But even for well established and expected states like η_c and $\eta_c(2S)$ a big scatter is observed in the measurements of their main parameters. In this talk we briefly describe some of the recent developments in physics of the charmonium and charmonium-like states obtained with the Belle detector operating at the KEKB asymmetric-energy e^+e^- collider.

2. X(3872)

2.1 X(3872)→J/ψπ⁺π⁻ [1]

We report a measurement of the difference in masses of X(3872) mesons produced in $B^+\to K^+\pi^+\pi^- J/\psi$ and $B^0\to K^0\pi^+\pi^- J/\psi$ decays, $\Delta M_{X(3872)}$ = (-0.69±0.97(stat)±0.19(syst)) MeV, that is consistent with zero and disagrees with theoretical predictions based on a diquark-diantiquark model for the X(3872) [2]. We conclude from this that the same particle is produced in the two processes and use a fit to the combined neutral and charged B meson data samples to determine $M_{X(3872)}$ = (3871.84±0.27(stat)±0.19(syst)) MeV (see Fig. 1). The width of the X(3872) signal peak is consistent with the experimental mass resolution and we set a 90% CL limit on its natural width of $\Gamma_{X(3872)} < 1.2$ MeV, improving the previous limit of 2.3 MeV.

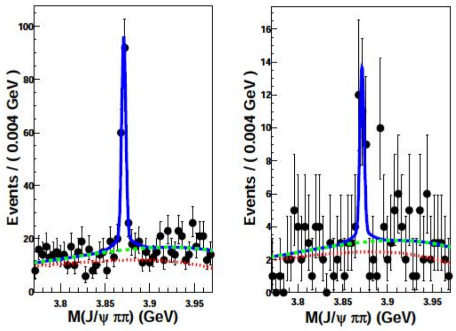

Fig. 1. The $M(\pi^+\pi^- J/\psi)$ distributions for $B^+\to K^+X(3872)$ (left) and $B^0\to K_S X(3872)$ (right) event candidates within the M_{bc} and ΔE signal regions.

We present a new measurement of the product branching fraction $BF(B^+\to K^+X(3872))\times BF(X(3872)\to\pi^+\pi^- J/\psi) = (8.61\pm0.82(stat)\pm0.52(syst))\times10^{-6}$.

An examination of the isospin-related $B\to K\pi^+\pi^0 J/\psi$ channel shows no evidence for a charged partner to the X(3872) decaying as $X^+\to\rho^+ J/\psi$ and we determine 90% CL upper limits on the product branching fractions $BF(B\to KX^+)\times BF(X^+\to \rho^+ J/\psi)$ of 4.2×10^{-6} and 6.1×10^{-6} for $K=K^+$ and $K=K^0$, respectively, for an X^+ partner state with mass between 3850 MeV and 3890 MeV.

A comparison of angular correlations among the final state decay products finds a good match between data and MC expectations for $J^{PC}=1^{++}$ with no free parameters (other than the overall normalization). The $J^{PC}=2^{-+}$ hypothesis has one complex free parameter and we found a value for which this hypothesis also matches the data reasonably well. For this parameter value, the differences between 1^{++} and 2^{-+} expectations are small but non-zero and a three-dimensional analysis could distinguish between the two cases with the much larger data sets expected at the LHCb, Belle II and SuperB experiments.

Fits to the $M(\pi^+\pi^-)$ mass distribution that only consider contributions from $\rho\to\pi^+\pi^-$ decays favor S-wave ($J^P=1^+$) over P-wave ($J^P=2^-$). However, the addition of an interfering contribution from isospin-violating $\omega\to\pi^+\pi^-$ decays results in acceptable fits for both hypotheses. They may also be distinguished in future experiments.

The analysis is based on a 711 fb^{-1} data sample that contains 772 million $B\bar{B}$ meson pairs collected at the Υ(4S) resonance.

2.2 X(3872) radiative decays [3]

We observe $X(3872)\to J/\psi\gamma$ in the B decays using 772×10^6 $B\bar{B}$ events collected at the Υ(4S) resonance. We present the most precise measurement to date of the product branching fraction $BF(B^+\to X(3872)K^+)\times BF(X(3872)\to J/\psi\gamma) = (1.78^{+0.48}_{-0.44}\pm0.12)\times10^{-6}$ (see Fig. 2). We also report evidence for $B\to\chi_{c2}K$, and the ratio of $BF(B^+\to\chi_{c2}K^+)/BF(B^+\to\chi_{c1}K^+)$ is measured to be $(2.25^{+0.73}_{-0.69}\pm0.17)\%$. The measured branching fraction of $B\to\chi_{c2}K$ is even more suppressed than expected compared to a recent theoretical prediction [4].

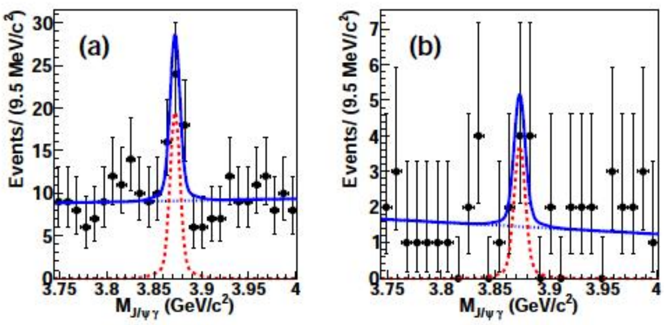

Fig. 2. $M_{J/\psi\gamma}$ distributions for (a) $B^+\to X(3872)(\to J/\psi\gamma)K^+$ and (b) $B^0\to X(3872)(\to J/\psi\gamma)K_S$ decays.

We find no evidence for $X(3872)\to\psi'\gamma$ and give an UL on its branching fraction as well as the following limit $BF(X(3872)\to\psi'\gamma)/BF(X(3872)\to J/\psi\gamma) < 2.1$ (at 90% CL). The X(3872) state may not have a large $c\bar{c}$ admixture with a $D^{*0}\bar{D}^0$ molecular component as was expected on the basis of the BaBar result [5].

3. Y(4260)[2]

We measure the cross section for $e^+e^-\to\pi^0\pi^0J/\psi$ from threshold up to 6 GeV using initial state radiation events from e^+e^- annihilation at $\sqrt{s}$=10.58 GeV (see Fig. 3(a)). We reconstruct the J/ψ in its di-muon decay mode. An unbinned maximum likelihood fit was performed to the

[2] The results of this section are preliminary and have not been published yet.

$M(\pi^0\pi^0 J/\psi)$ in order to search for evidence of Y(4260) decaying to $\pi^0\pi^0 J/\psi$ (see Fig. 3(b)). There were three components to the fit, the ψ(2S) term, a continuous term to account for possible non-resonant $\pi^0\pi^0 J/\psi$ production and a Y(4260) signal term. The number of ψ(2S) events measured from this fit is 629 ± 26, which compares well with the predicted number of events from MC: 635 ± 12. We measure $\Gamma_{e^+e^-}$ BF$(\pi^0\pi^0 J/\psi) = 3.19^{+1.82}_{-1.53}$ eV, which is consistent within large errors with $0.5\times\Gamma_{e^+e^-}$ BF$(\pi^0\pi^0 J/\psi)$ = $0.5\times 5.9^{+1.2}_{-0.9} = 3.0^{+0.6}_{-0.5}$ eV [6], which is the expectation from isospin. This production corresponds to $8.6^{+4.9}_{-4.0}$ Y(4260) events in the fit. This analysis is based on a data sample with an integrated luminosity of 791 fb^{-1}.

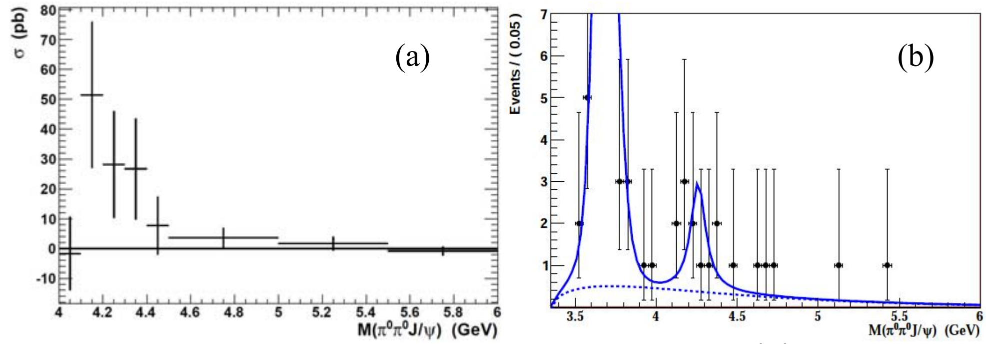

Fig. 3. (a) Cross-section as a function of mass. (b) Fit to $M(\pi^0\pi^0 J/\psi)$ spectrum.

4. η_c and η_c(2S) [7]

We report a study of the decay $B^\pm\to K^\pm(c\bar{c})$, where the $(c\bar{c})$ state decays to $(K_S K\pi)^0$ and includes the η_c and η_c(2S) states, using 535 million $B\bar{B}$ events collected at the Y(4S) resonance. Both decay channels contain $B^\pm\to K^\pm(K_S K\pi)^0$ decays without intermediate charmonia that interfere with the signal. For the first time, the analysis takes interference into account with no assumptions on the phase or absolute value of the interference. We perform a 2-dimensional fit of the invariant mass of $(K_S K\pi)^0$ and cosθ, where θ is the angle between K_S and K from B decay in the charmonium c.m.s. Projections of the fit are shown in Fig. 4.

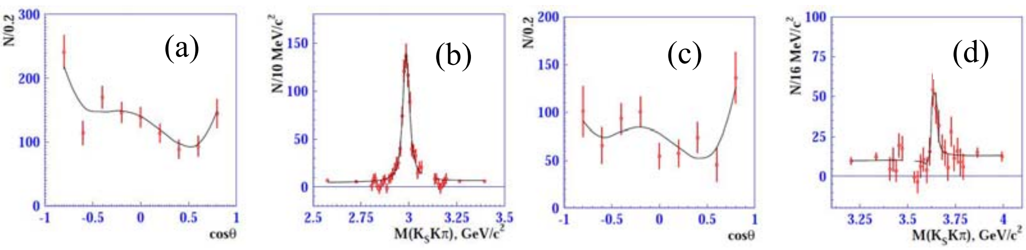

Fig. 4. Projections of the fit in the η_c (a, b) and η_c(2S) (c, d) cases.

As a result, we obtain an estimate of the model error for BF$(B^\pm\to K^\pm\eta_c)\times$BF$(\eta_c\to(K_S K\pi)^0)$ = $(26.7\pm1.4(\text{stat})\,^{+2.9}_{-2.6}(\text{syst})\pm4.9(\text{model}))\times10^{-6}$. For BF$(B^\pm\to K^\pm\eta_c(2S))\times$BF$(\eta_c(2S)\to(K_S K\pi)^0)$ = $(3.4\,^{+2.2}_{-1.5}(\text{stat+model})\,^{+0.5}_{-0.4}(\text{syst}))\times10^{-6}$ the model error from the interference is not listed separately.

We also obtain the masses and widths of η_c and $\eta_c(2S)$. For the η_c meson parameters the model error is negligibly small: $M(\eta_c) = 2985.4\pm1.5(\text{stat})^{+0.5}_{-2.0}(\text{syst})$ MeV, $\Gamma(\eta_c) = 35.1\pm3.1(\text{stat})^{+1.0}_{-1.6}(\text{syst})$ MeV. For the $\eta_c(2S)$ meson the model and statistical uncertainties cannot be separated: $M(\eta_c(2S)) = 3636.1^{+3.9}_{-4.2}(\text{stat+model})^{+0.7}_{-2.0}(\text{syst})$ MeV, $\Gamma(\eta c(2S)) = 6.6^{+8.4}_{-5.1}(\text{stat+model})^{+2.6}_{-0.9}(\text{syst})$ MeV.

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