PROCEEDINGS OF SCIENCE

Study of inclusive and exclusive multibody B decays to χ_{c1} and χ_{c2} mesons

Vishal Bhardwaj[*†]
Nara Women's University, Japan
E-mail: vishstar@gmail.com

In spite of the fact that the two-body B decays into χ_{c2} such as $B \to \chi_{c2}K^{(*)}$ are suppressed by the QCD factorization effect, the inclusive $B \to \chi_{c2}X$ branching fraction amounts to one third of the non-suppressed $B \to \chi_{c1}X$ decays because of the decay modes to multibody final states. Using a large-statistics $\Upsilon(4S)$ data sample corresponding to 772 million B meson pairs accumulated by the Belle detector at the KEKB e^+e^- collider, precise measurements of inclusive $B \to \chi_{c1}$ and χ_{c2} branching fractions are carried out. The multibody final states such as $\chi_{c2}K\pi$, $\chi_{c1}\gamma K\pi$ and so on are also investigated to look for new charmonium-like resonances.

XV International Conference on Hadron Spectroscopy-Hadron 2013
4-8 November 2013
Nara, Japan

[*]Speaker.
[†]for the Belle Collaboration

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike Licence. http://pos.sissa.it/

PoS(Hadron 2013)051

1. Introduction

Inclusive production of χ_{c2} mesons in B decays is relatively large [1, 2] in spite of the fact that two-body B decays into χ_{c2} are highly suppressed [3] (as in the factorization hypothesis [4]). A study of the differential branching fraction ($D\mathscr{B}$) in bins of χ_{cJ} ($J = 1,2$) [5] suggests that χ_{c2} is found to be coming from three-body or higher multiplicity decays [1, 2], which have not yet been observed. More experimental studies are needed to search for these multibody decay modes if one wishes to understand the B decays needed for precision studies. As inclusive production of χ_{c2} is large, one can naively expect that there can be some exotic intermediate states (charmonium or charmonium-like states) decaying into χ_{c2}, as B decays to $XK^{(*)}$ and then X decays into $\chi_{c2}\pi$, $\chi_{c2}\pi\pi$ where X is some unknown resonance.

Recently, Belle found a new charmonium state $X(3823)$ in the $B \to (\chi_{c1}\gamma)K$ final state, which is supposed to be the ψ_{2D} ($1^3D_2\ c\bar{c}$) charmonium having J^{PC} of 2^{--} [6]. In such case, one expects it to have a large branching fraction in the $B^0 \to X(3823)(\to \chi_{c1}\gamma)K^*(K^+\pi^-)$ [7] decay mode worth to be searched for.

2. Data sample and event selection

We use a data sample of 772×10^6 $B\overline{B}$ events collected with the Belle detector [8] at the KEKB asymmetric-energy e^+e^- collider [9] operating at the $\Upsilon(4S)$ resonance. All results presented here are preliminary.

To suppress continuum backgrounds we require the ratio of the second to zeroth Fox-Wolfram moments to be less than 0.5 [10]. As charged tracks coming from B decays originate from the interaction point (IP), the distance of closest approach to IP is required to be within 3.5 cm in the beam direction (z) and within 1.0 cm in the transverse plane (xy-plane). Photons are reconstructed from the energy deposition in the electromagnetic calorimeter by requiring no matching with any extrapolated charged track. The combined information from the central drift chamber, time-of-flight and aerogel threshold Cherenkov counters is used to identify charged kaons and pions on basis of the K-π likelihood ratio, $R_{K(\pi)} = \mathscr{L}_{K(\pi)}/(\mathscr{L}_K + \mathscr{L}_\pi)$. A track is identified as a kaon (pion) if the likelihood ratio $\mathscr{L}_{K(\pi)}$ is greater than 0.6.

The J/ψ meson is reconstructed via its decays to $\ell^+\ell^-$ ($\ell = e$ or μ). To reduce the radiative tail in the e^+e^- mode, the four-momenta of all photons within 50 mrad with respect to the original direction of the e^+ or e^- tracks are included in the invariant mass calculation, hereinafter denoted as $M_{e^+e^-(\gamma)}$. The reconstructed invariant mass of the J/ψ candidates is required to satisfy 2.95 GeV/$c^2 < M_{e^+e^-(\gamma)} <$ 3.13 GeV/c^2 or 3.03 GeV/$c^2 < M_{\mu^+\mu^-} <$ 3.13 GeV/c^2. For the selected J/ψ candidates, a vertex-constrained fit is applied and then a mass-constrained fit is performed in order to improve the momentum resolution.

The χ_{c1} and χ_{c2} candidates are reconstructed by combining J/ψ candidates with a photon having energy (E_γ) larger than 100 MeV in the laboratory frame. To reduce the combinatorial background coming from $\pi^0 \to \gamma\gamma$, we use a likelihood function that distinguishes an isolated photon from π^0 decays using the photon pair invariant mass, photon laboratory energy and polar angle [11]. We reject both γ's in the pair if the π^0 likelihood probability is larger than 0.3 (0.8) for an inclusive study ($B^0 \to \chi_{c2}K^+\pi^-$, $B^+ \to \chi_{c2}K^+\pi^-\pi^+$ and $B^0 \to \chi_{c1}\gamma K^+\pi^-$). The reconstructed

PoS(Hadron 2013)051

invariant mass of the χ_{c1} (χ_{c2}) is required to satisfy 3.467 GeV$/c^2 < M_{J/\psi\gamma} <$ 3.535 GeV$/c^2$ (3.535 GeV$/c^2 < M_{J/\psi\gamma} <$ 3.611 GeV$/c^2$). A mass-constrained fit is applied to the selected χ_{c1} and χ_{c2} candidates.

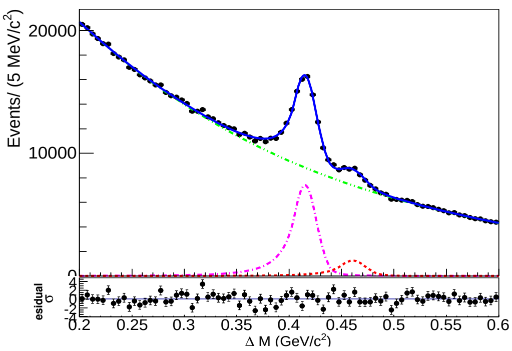
3. Results

3.1 $B \to \chi_{cJ} X$ study

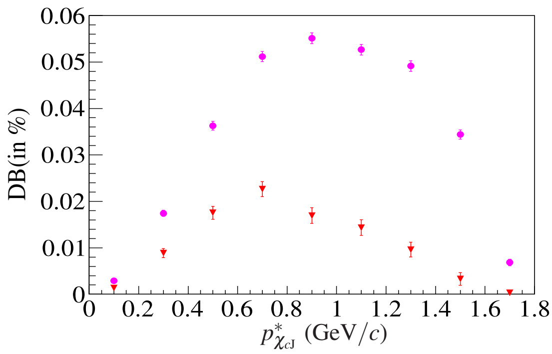
To identify the signal, we use $\Delta M \equiv M_{\ell\ell\gamma} - M_{\ell\ell}$, where $M_{\ell\ell\gamma}$ ($M_{\ell\ell}$) is the reconstructed mass of $J/\psi\gamma$ (J/ψ). We extract the signal yield using a one-dimensional binned maximum likelihood (1D BML) fit to the ΔM distribution. A double-sided Crystal Ball function is used to model the signal shapes of $B \to \chi_{c1} X$ and $B \to \chi_{c2} X$. Figure 2 (a) shows the fit to the ΔM distribution for $B \to \chi_{c1} X$ and $B \to \chi_{c2} X$ decays in the range of [0.2,0.6] GeV$/c^2$.

We used a 89.45 fb^{-1} continuum data sample to estimate the χ_{cJ} feed-down from continuum and possible χ_{cJ} production. The scaled χ_{c1} and χ_{c2} continuum yields are subtracted from the on-resonance yields. The reconstruction efficiency for full inclusive $B \to \chi_{c1} X$ and $B \to \chi_{c2} X$ is estimated to be 24.2% and 25.9%, respectively. Uncertainty on the efficiency is estimated to be 4.0%.

We use the Particle Data Group [12] values for secondary daughter branching fractions. After subtracting the ψ' feed-down contribution, we get the direct branching fractions $\mathscr{B}(B \to \chi_{c1} X)$ and $\mathscr{B}(B \to \chi_{c2} X)$ to be $(3.00 \pm 0.04 \pm 0.24) \times 10^{-3}$ and $(0.70 \pm 0.05 \pm 0.08) \times 10^{-3}$, respectively, where the first (second) error is statistical (systematic). The branching fractions are summarized in Table 1.



(a) ΔM distribution (in GeV$/c^2$)



(b) $p^*_{\chi_{cJ}}$ distribution (in GeV$/c$)

Figure 1: (a) BML fit to the ΔM distribution of the $B \to \chi_{cJ}(\to J/\psi\gamma)X$ decays in the data. The curves show the signal (magenta dot-dashed for χ_{c1} and red dashed for χ_{c2}) and the background component (green double-dotted dashed for combinatorial) as well as the overall fit (blue solid). The lower plot shows the pull of the residuals with respect to the fit. (b) Plots showing $D\mathscr{B}(B \to \chi_{c1} X)$ [magenta circle •] and $D\mathscr{B}(B \to \chi_{c2} X)$ [red triangle ▼] in bins of $p^*_{\chi_{cJ}}$.

Figure 2 (b) shows the obtained distribution of the $D\mathscr{B}$ in bins of $p^*_{\chi_{cJ}}$. It seems that χ_{c2} is mostly coming from multibody B decays.

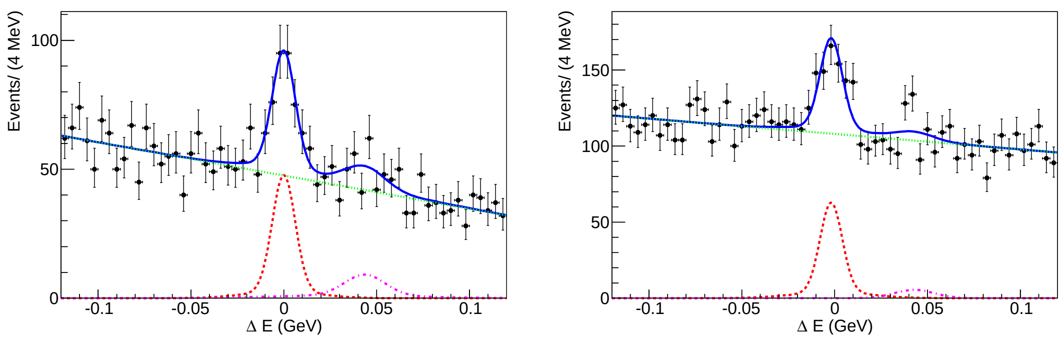
PoS(Hadron 2013)051

Table 1: Yields and branching fractions. Errors are statistical only.

	$B \to \chi_{c1} X$		$B \to \chi_{c2} X$	
	Yield (Y)	$\mathscr{B}$, 10^{-3}	Yield (Y)	$\mathscr{B}$, 10^{-3}
Fit	51286 ± 649	3.36 ± 0.04	9714 ± 453	1.05 ± 0.05
Continuum subtracted	50194 ± 657	3.29 ± 0.04	8991 ± 465	0.97 ± 0.05
$\psi' \to \chi_{c1}\gamma$ feed down subtracted	—	3.00 ± 0.04	—	0.70 ± 0.05

3.2 $B^0 \to \chi_{c2} K^+ \pi^-$ and $B^+ \to \chi_{c2} K^+ \pi^- \pi^+$ decay modes

Figure 3a (3b) shows the unbinned maximum likelihood (UML) fit to the ΔE distribution of the $B^0 \to \chi_{c2} K^+ \pi^-$ ($B^+ \to \chi_{c2} K^+ \pi^- \pi^+$) decay mode. We observe the $B^0 \to \chi_{c2} K^+ \pi^-$ ($B^+ \to \chi_{c2} K^+ \pi^- \pi^+$) decay with 206 ± 25 (269 ± 34) signal events, having a statistical significance of 9.7σ (8.7σ), for the first time. We also look at the $M_{\chi_{c2}\pi^+}$ and $M_{\chi_{c2}\pi^+\pi^-}$ distribution in order to search for any new resonance and find ourselves limited by the statistics.



(a) $B^0 \to \chi_{c2} K^+ \pi^-$ decay (b) $B^+ \to \chi_{c2} K^+ \pi^- \pi^+$ decay

Figure 2: 1D UML fit to the ΔE distribution of the (a) $B^0 \to \chi_{c2}\pi^+ K^-$ and (b) $B^+ \to \chi_{c2}\pi^+\pi^- K^-$ decay modes. The curves shows the signal [red dashed for $B^0 \to \chi_{c2} K^+ \pi^-$ in (a) and $B^+ \to \chi_{c2} K^+ \pi^- \pi^-$ in (b)], peaking background [magenta dotted-dashed for $B^0 \to \chi_{c1} K^+ \pi^-$ in (a) and $B^+ \to \chi_{c1} K^+ \pi^+ \pi^-$ in (b)] and the background component (green dotted for combinatorial) as well as the overall fit (blue solid).

3.3 $B^0 \to (\chi_{c1}\gamma) K^+ \pi^-$ decay mode

In our search for $B^0 \to X(3823) K^+ \pi^-$, we find a strong hint of a narrow peak at 3823 MeV in $M_{\chi_{c1}\gamma}$ with a significance of 2.5σ (systematics included). Figure 4 shows the UML fit to the $M_{\chi_{c1}\gamma}$ distribution for the $B^0 \to (\chi_{c1}\gamma) K^+ \pi^-$ decay mode. Using the central value of the measured branching fraction, we get $\frac{\mathscr{B}(B^0 \to X(3823) K^+ \pi^-)}{\mathscr{B}(B^+ X(3823) K^+)} = 2.5 \pm 1.0(\text{stat. only})$.

4. Summary

Belle presented first preliminary results at this conference. $\mathscr{B}(B \to \chi_{cJ} X)$ measured by Belle is consistent with the previous results. $D\mathscr{B}(B \to \chi_{cJ} X)$ measured in bins of $p^*_{\chi_{cJ}}$ shows a suppression of χ_{c2} production in higher momentum bins. Belle observed the $B^0 \to \chi_{c2} K^+ \pi^-$ and

PoS(Hadron 2013)051

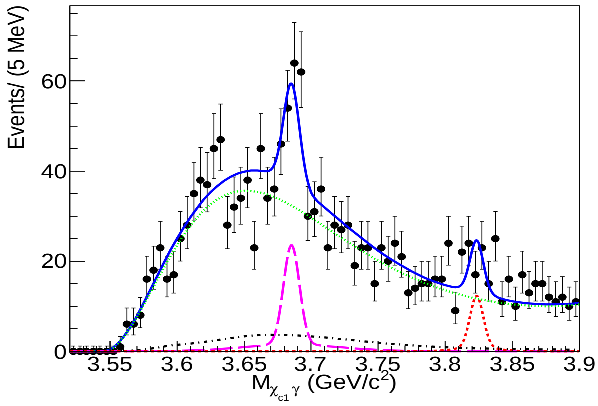


Figure 3: UML fit to the $M_{\chi_{c1}\gamma}$ distribution for the $B^0 \to (\chi_{c1}\gamma)K^+\pi^-$ decay in the data. The curves shows the signal (magenta long-dashed for $B^0 \to \psi'[\to \chi_{c1}\gamma]K^+\pi^-$ and red dashed for $B^0 \to X(3823)[\to \chi_{c1}\gamma]K^+\pi^-$) and the background component (black dotted-dashed for $B^0 \to \psi'[\nrightarrow \chi_{c1}\gamma]K^+\pi^-$ and green dotted for combinatorial) as well as the overall fit (blue solid).

$B^+ \to \chi_{c1}K^+\pi^+\pi^-$ decay modes for the first time, while no narrow resonance is found in the $M_{\chi_{c2}\pi^+}$ and $M_{\chi_{c2}\pi^+\pi^-}$ distributions. Inclusive and exclusive study of B decays having χ_{c2} in the final state suggests suppression of two-body B decay due to suppression of a tensor, while multi-body B decays into χ_{c2} are allowed. A hint of $X(3823)$ in $B^0 \to X(3823)K^+\pi^-$ is seen with a significance of 2.5σ (syst. included) and the large $\mathscr{B}(B^0 \to X(3823)K^+\pi^-)$ suggests its J to be 2. This further supports $X(3823)$ to be identified as the ψ_{2D} ($1^3D_2\ c\bar{c}$) state.

References

[1] K. Abe *et al.*, (Belle Collaboration), Phys. Rev. Lett. **89**, 011803 (2002).

[2] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **67**, 032002 (2003).

[3] V. Bhardwaj *et al.*, (Belle Collaboration), Phys. Rev. Lett. **107**, 091803 (2011).

[4] M. Neubert and B. Stech, Adv. Ser. Direct. High Energy Phys. **15**, 294 (1998) (arXiv:9705292v2 [hep-ph]), T.E. Browder, Acta Phys. Polon. B **28**, 805 (1997) (arXiv:9612491v1 [hep-ph]).

[5] Hereinafter, χ_{cJ} refers to either χ_{c1} or χ_{c2}, depending on which is reconstructed.

[6] V. Bhardwaj *et al.* (Belle Collaboration), Phys. Rev. Lett. **111**, 032001 (2013).

[7] Charge-conjugate and neutral modes are included throughout the paper unless stated otherwise.

[8] A. Abashian *et al.* (Belle Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 117 (2002); also see detector section in J. Brodzicka *et al.*, Prog. Theor. Exp. Phys. (2012) 04D001.

[9] S. Kurokawa and E. Kikutani, Nucl. Instrum. Methods Phys. Res., Sect. A **499**, 1 (2003), and other papers included in this Volume; T. Abe *et al.*, Prog. Theor. Exp. Phys. (2013) 03A001 and following articles up to 03A011.

[10] G.C. Fox and S. Wolfram, Phys. Rev. Lett. **41**, 1581 (1978).

[11] P. Koppenburg *et al.* (Belle Collaboration), Phys. Rev. Lett. **93**, 061803 (2004).

[12] J. Beringer *et al.* (Particle Data Group), Phys. Rev. D **86**, 010001 (2012) and 2013 partial update for the 2014 edition.

PoS(Hadron 2013)051