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Study of the $\chi_{c1}(1P)\pi^+\pi^-$ invariant mass spectrum in $B^\pm \to \chi_{c1}(1P)\pi^+\pi^-K^\pm$ decays at Belle

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Either $X(3872)$ or the still unconfirmed $\chi_{c1}(2P)$ charmonium may decay into the $\chi_{c1}(1P)\pi^+\pi-$ final state because of no obvious conflict in quantum numbers. 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, $B^\pm \to \chi_{c1}(1P)\pi^+\pi^-K^\pm$ decays are reconstructed and the $\chi_{c1}(1P)\pi^+\pi-$ invariant mass spectrum is discussed to look for possible contributions from $X(3872)$ or $\chi_{c1}(2P)$.

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1. Introduction

The Belle experiment at the KEK B-factory discovered many charmonium-like exotic hadrons. Among them is the especially puzzling $X(3872)$. It was first observed in the charged B meson decay $B^+ \to X(3872)K^+$ followed by $X(3872) \to J/\psi\pi^+\pi^-$ by the Belle Collaboration in 2003 [1]. This resonance has a much smaller width ($\Gamma < 1.2$ MeV at 90% CL) than other charmonia above the D meson pair threshold. Its existence has been confirmed by several other experiments. The $X(3872)$ mass is (3871.2 ± 0.5) MeV in the current world average [2] and it is quite close to the threshold of the charmed meson pair $D^0\bar{D}^{*0}$. There have been many speculations about the nature of this state and the $D^0\bar{D}^{*0}$ molecule is one of the most plausible hypotheses, the small binding energy implies that the size is likely to be so large (about a few fm) that it cannot explain the significant branching to J/ψ.

The Belle and Babar collaborations have observed the decay $X(3872) \to \gamma J/\psi$ which determines the charge conjugation number $C = +1$ [3]. In February 2013 the LHCb collaboration finally pinned down $X(3872)$'s quantum numbers to be $J^{PC} = 1^{++}$ [4]. Furthermore, not finding a charged partner [5] suggests isospin zero. This supports the hypothesis of $X(3872)$ being an admixture of a $D^0\bar{D}^{*0}$ molecule and an ordinary charmonium, possibly the still undiscovered $\chi_{c1}(2P)$ which has the same quantum numbers. The mass prediction for $\chi_{c1}(2P)$ is around 3920 MeV. Even if $X(3872)$ does not contain a $\chi_{c1}(2P)$ component, we still expect that $\chi_{c1}(2P)$ has a significant branching fraction to the $\chi_{c1}\pi^+\pi^-$ final state just like $\psi' \to J/\psi\pi^+\pi^-$ is one of the major decay modes. Since the $\chi_{c2}(2P)$ is relatively narrow [6], the $\chi_{c1}(2P)$ resonance would possibly be narrow as well. Summarizing the statements above, the $M_{\chi_{c1}\pi^+\pi^-}$ distribution in $B^{\pm} \to \chi_{c1}\pi^+\pi^-K^{\pm}$ is quite suitable to look for a signature.

2. Event Selection and Reconstruction

The preliminary results presented at *Hadron2013* are based on a data sample corresponding to 772 million $B\bar{B}$ events collected by the Belle detector [7] at the KEKB asymmetric-energy e^+e^- collider [8].

Among the charged tracks reconstructed by the Silicon Vertex Detector (SVD) and the central drift chamber (CDC), charged pions and kaons are selected using the information from the number of Cherenkov photons in the Aerogel Cherenkov Counter (ACC), the Time of Flight measurement (TOF) and the dE/dx measurement carried out by the CDC. Looking at the invariant di-pion mass, a vertex fit is applied to the pion pair and its convergence is required. In the case of the $X(3872) \to \chi_{c1}\pi^+\pi^-$ mode, the pions' transverse momenta with respect to the beam axis (p_T) are low because of the small Q-value (~ 80 MeV). Therefore reconstruction efficiency is limited by the Belle detector's acceptance for low p_T tracks. Such particles curl up in the CDC and can eventually be reconstructed several times. They may result in multiple B candidates in the event. When a charged pion is reconstructed twice or more, it appears to have the same charge with nearly identical three-momentum, or being oppositely-charged with nearly opposite three-momentum. Those duplicated tracks for charged pions with $p_T < 0.25$ GeV/c often appear as the track pair having $\cos(\theta_{\text{open}}) < -0.95$ for oppositely-charged tracks where θ_{open} is the opening angle between the two tracks. In addition, the difference between two tracks' absolute value of momentum is required to be less than 0.1 GeV/c. Among the tracks identified by the mentioned criteria, the one with the smallest $|dz|$ is chosen where dz is the z-component of the track's closest approach with respect to the interaction point (IP). This way we were able to reduce fake tracks and improve multiplicity of B candidates.

The J/ψ meson is reconstructed via its decay mode $J/\psi \to \ell^+\ell^-$, where ℓ stands for electron/positron or muon. Muons are identified on the basis of track penetration depth and hit pattern in the KL-muon (KLM) detector system. Electrons are identified using dE/dx in the CDC, E/p ratio (E being the energy deposited in the Electromagnetic Calorimeter (ECL) and p the momentum measured in the CDC and SVD), shower shape in the ECL and Cherenkov photons in the ACC. There is a loss of energy from electrons in form of emission of bremsstrahlung photons. Therefore four-momenta of photons within 0.05 radian of e^+ or e^- track direction are included in the invariant mass calculation to form $J/\psi \to e^+e^-$. Photons are reconstructed from the energy deposition in the ECL by requiring no match with any extrapolated charged track. However, even after this treatment, the mass distribution is still skewed which is taken into account by using an asymmetric invariant mass window of $2.95(3.03)\ \mathrm{GeV/c^2} \leq M_{ee(\mu\mu)} \leq 3.13\ \mathrm{GeV/c^2}$ to define a J/ψ candidate in the electron (muon) channel. A vertex fit and mass constraint are applied to the selected J/ψ candidates in order to improve momentum resolution. We furthermore apply a center-of-mass momentum cut of $p^*_{\ell\ell} < 2.0$ GeV/c to accept only those J/ψ mesons coming from B decays.

χ_{c1} mesons are reconstructed by combining a J/ψ candidate with a photon. Photon selection is done requiring $E_\gamma > 100$ MeV. To identify χ_{c1} we use the $J/\psi\gamma$ invariant mass and apply a mass window of $3.467\ \mathrm{GeV/c^2} \leq M_{J/\psi\gamma} \leq 3.535\ \mathrm{GeV/c^2}$. A mass-constrained fit is performed in order to improve momentum resolution. To reduce background from $\pi^0 \to \gamma\gamma$, a veto is applied where we calculate a likelihood function to distinguish an isolated photon from π^0 decays using the photon pair invariant mass, photon laboratory energy and polar angle [9]. We reject both photons in the pair if the π^0 probability is larger than 0.8.

The reconstruction of the B meson is done by combining the $\chi_{c1}\pi^+\pi^-$ system with a charged kaon. The kinematic variables of interest are the beam-constrained mass M_{bc} which is defined as $\sqrt{E^2_{\mathrm{beam}} - (p_{\chi_{c1}\pi\pi} + p_K)^2}$ and the difference-to-beam energy ΔE being $(E_{\chi_{c1}\pi\pi} + E_K) - E_{\mathrm{beam}}$, where E_{beam} is the beam energy in the center-of-mass frame, $p_{\chi_{c1}\pi\pi}$ and p_K the momenta and $E_{\chi_{c1}\pi\pi}$ and E_K the energies in the $\Upsilon(4S)$ rest frame (center of mass frame). The signal enhanced region is $|\Delta E| < 0.12$ GeV and $M_{\mathrm{bc}} > 5.27\ \mathrm{GeV/c^2}$. When more than one B candidates are found in an event, the best candidate is selected as the one having the closest beam-constrained mass of the B candidate compared to nominal B mass.

3. Background Estimation

We expect the dominant background for $B^{\pm} \to \chi_{c1}\pi^+\pi^-K^{\pm}$ decays to come from the B decays that have a real $J/\psi \to e^+e^-$ and $J/\psi \to \mu^+\mu^-$ in their final state. In order to understand the background, we use a large $B \to J/\psi X$ Monte Carlo sample which is corresponding to 100 times the data sample, where X denotes anything. We found that only $B^{\pm} \to \chi_{c2}\pi^+\pi^-K^{\pm}$ may form a small peak in the ΔE distribution around $\Delta E < -0.05$ GeV because of the χ_{c2}'s slightly higher mass that is constrained to be the χ_{c1} mass. All other backgrounds have shown to be smooth in the ΔE projection.

In the invariant mass spectrum of $\chi_{c1}\pi^+\pi^-$ the only peaking component is found to be a reflection from $\psi\prime$ when a $\psi\prime$ decays to $J/\psi\pi^+\pi^-$ and an additional, unrelated photon is picked up to form a fake χ_{c1} candidate. Because of the mass-constrained fit performed on the χ_{c1} candidates, combining the fake χ_{c1} with the daughter pion pair $\psi\prime$ results in a peak at 4.1 GeV/c^2. Since $\psi\prime$ is a narrow state, this peak is not interfering with the mass region of interest which is the $\chi_{c1}(2P)$ mass prediction or the $X(3872)$ mass ($\sim 3.92\ \text{GeV}/\text{c}^2$).

4. ΔE Distribution in Data

The $B^{\pm} \to \chi_{c1}\pi^+\pi^-K^{\pm}$ signal yield is extracted from an unbinned maximum likelihood fit performed on the ΔE distribution (see Fig.1). We made a first observation of the decay of $B^{\pm} \to \chi_{c1}\pi^+\pi^-K^{\pm}$ with a statistical significance of 29.6 σ. The signal yield recontructed in data is (1597 ± 76) events and very well comparable to the expected signal yield of 1700 events. We find the ΔE resolution to be consistent with the Monte Carlo expectation.

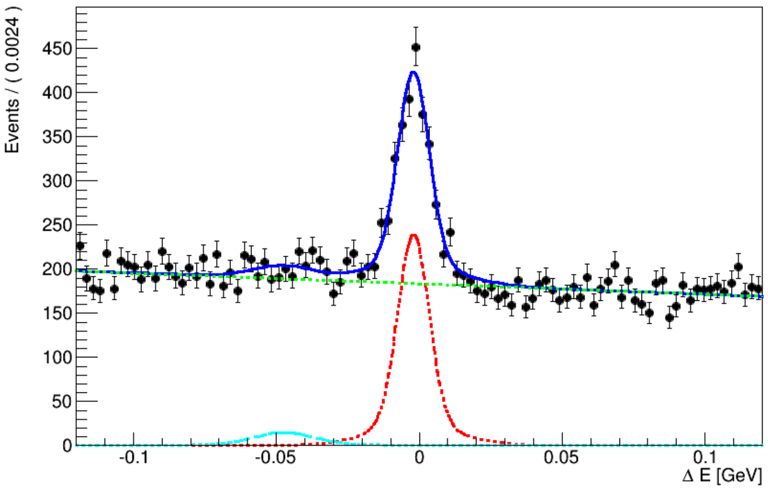

Figure 1: ΔE distribution of $B^{\pm} \to \chi_{c1}\pi^+\pi^-K^{\pm}$ including $B \to \chi_{c2}\pi^+\pi^-K$ (cyan) in data.

5. $M_{\chi_{c1}\pi\pi}$ Spectrum in Data

In order to identify a resonance we visited the $M_{\chi_{c1}\pi\pi}$ distribution in the $B^{\pm} \to \chi_{c1}\pi^{+}\pi^{-}K^{\pm}$ candidate events (see Fig.2). When we assume that $\mathscr{BR}(B^{\pm} \to X(3872)K^{\pm}) \times \mathscr{BR}(X(3872) \to \chi_{c1}\pi^{+}\pi^{-})$ is the same as $\mathscr{BR}(B^{\pm} \to X(3872)K^{\pm}) \times \mathscr{BR}(X(3872) \to J/\psi\pi^{+}\pi^{-})$, 15 events of $X(3872) \to \chi_{c1}\pi^{+}\pi^{-}$ are expected and such a signal yield is within our sensitivity reach. As the result, our data exhibits no signature of $X(3872) \to \chi_{c1}\pi^{+}\pi^{-}$. This result is compatible with the interpretation of $X(3872)$ as an admixture state of a $D^{0}\bar{D}^{*0}$ molecule and a χ_{c1}(2P), because the heavier counterpart state of $X(3872)$, containing $|\chi_{c1}(2\mathrm{P})\rangle$ as the main component, has a Q-value of about 100 MeV for the strong decay into $D^{0}\bar{D}^{*0}$ thus it becomes a very broad state.

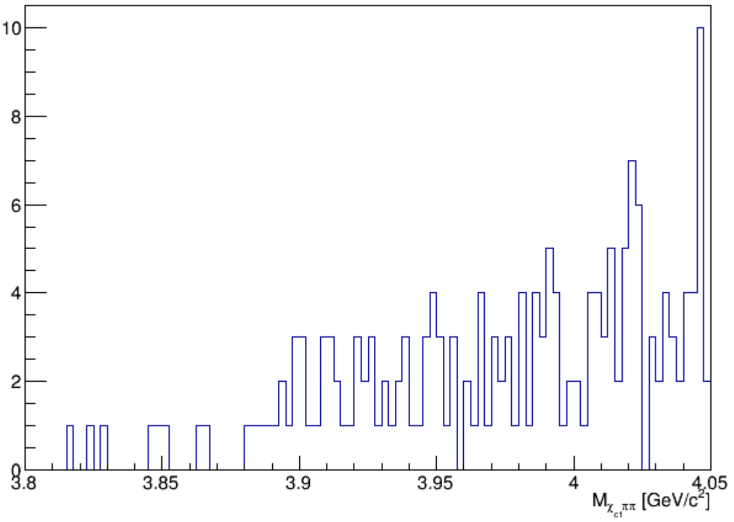

Figure 2: $M_{\chi_{c1}\pi^{+}\pi^{-}}$ distribution in data.

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