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Search for $B \to X(3872)K\pi$ Decays

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We present results of the search for $X(3872)$, produced in $B \to X(3872)(K\pi)$ decay modes, where $X(3872)$ decays to $J/\psi\pi^+\pi^-$. We report the first observation of $B^0 \to X(3872)(K^+\pi^-)$ and measure the product of branching fractions to be $\mathscr{B}(B^0 \to X(3872)(K^+\pi^-)) \times \mathscr{B}(X(3872) \to J/\psi\pi^+\pi^-) = (8.55 \pm 1.34^{+0.48}_{-0.76}) \times 10^{-6}$. This analysis uses the full data sample collected with the Belle detector at the KEKB asymmetric-energy e^+e^- collider operating at the $\Upsilon(4S)$ resonance.

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1. Introduction

$X(3872)$ state has been discovered about eleven years ago by the Belle Collaboration in exclusive search of $B^{\pm} \to J/\psi\pi^+\pi^-K^{\pm}$ decay mode [1] and subsequently confirmed by the CDF [2], D0 [3], BaBar [4]. This state is also recently confirmed by LHCb [5] and CMS [6] experiments at LHC. Recent measurement by LHCb [7] experiment led to the conclusion that J^{PC} of $X(3872)$ to be 1^{++}. $B \to X(3872)K\pi$ decay mode can tell us more about the nature of $X(3872)$ decay. This analysis uses a whole data sample, 711 fb^{-1} (772×10^6 $B\overline{B}$ pairs), collected with the Belle detector at the KEKB asymmetric-energy e^+e^- (3.5 GeV on 8 GeV) collider operating at the $\Upsilon(4S)$ resonance.

2. Selection Criteria

Charged tracks are required to originate from the interaction point. For charged kaons (pions), we impose $\mathscr{R}_{K/\pi}(\mathscr{R}_{\pi/K}) > 0.6$, where $\mathscr{R}_{K/\pi} = \mathscr{L}_K/(\mathscr{L}_\pi + \mathscr{L}_K)$, with $\mathscr{L}_K$ ($\mathscr{L}_\pi$) is the likelihood value for the kaon (pion) hypothesis. We reconstruct J/ψ mesons in the l^+l^- decay channel ($l = e$ or μ) and include bremsstrahlung photons that are within 50 mrad of either the e^+ or e^- tracks (denoted as $e^+e^-(\gamma)$). The invariant mass of the J/ψ candidates is required to be within 3.00[3.06] GeV/c^2 $< M_{e^+e^-(\gamma)}[M_{\mu^+\mu^-}] <$ 3.13[3.13] GeV/c^2, where $M_{e^+e^-(\gamma)}$ $[M_{\mu^+\mu^-}]$ are the reconstructed invariant masses from $e^+e^-(\gamma)$ $(\mu^+\mu^-)$. The J/ψ candidate is then combined with a $\pi^+\pi^-$ pair for further analysis: both $X(3872)$ and ψ', used here for calibration, decay to the same final state. An additional cut is applied on the $M_{\pi^+\pi^-}$ variable: $M_{\pi\pi} > M(J/\psi\pi\pi) - (m_{J/\psi} + 0.2\ \text{GeV}/c^2)$ for $B^0 \to (J/\psi\pi^+\pi^-)(K^+\pi^-)$ decay mode. This cut corresponds to $M_{\pi^+\pi^-} >$ 389(575) MeV/c^2 for the $\psi'(X(3872))$ region and reduces significantly the combinatorial background. To further reduce the combinatorial background from $e^+e^- \to q\overline{q}$ continuum events (where q = u, d, s or c), we require $R_2 < 0.4$, where R_2 is the ratio of the second to zeroth normalised Fox-Wolfram moments [8]. To reconstruct B meson candidates, a $K\pi$ candidate is combined with the $J/\psi\pi^+\pi^-$ candidate. We select B candidates using two variables: the energy difference $\Delta E = E_B - E^*_{\text{beam}}$, and the beam constrained mass $M_{\text{bc}} = \sqrt{E^{*2}_{\text{beam}} - p^2_B}$, where p_B and E_B is the B candidate momentum and energy in the CM frame and E^*_{beam} is the run-dependent beam energy.

Since $B^0 \to X(3872)K^+\pi^-$ decay mode has J/ψ in the final state, the main background is expected to come from J/ψ inclusive decay modes. A large MC simulated $B \to J/\psi X$ samples corresponding to 100 times the experimental data is used to study this background.

3. $B^0 \to \psi' K^+\pi^-$ and $B^0 \to X(3872)K^+\pi^-$ decay modes

Above selection cuts isolate a very pure sample of $B^0 \to \psi' K^+\pi^-$. These events are used to calibrate the $M_{J/\psi\pi\pi}$ and ΔE resolution for $X(3872)$ region. To estimate the signal yield and shape of the $B^0 \to \psi' K^+\pi^-$ decay mode, we first perform a 2D fit in the ΔE and $M_{J/\psi\pi\pi}$ variables, respectively in the range $[-0.1, 0.1]$ GeV and [3.64, 3.74] GeV/c^2. The Product of a Crujiff function (used for ΔE fitting) and sum of two Gaussians (used for $M_{J/\psi\pi\pi}$ fitting) is used to model the signal shape. The background is divided into two components: peaking and combinatorial. The peaking background can either peak in $M_{J/\psi\pi\pi}$ and be flat in ΔE or vice versa. The peaking background in the $M_{J/\psi\pi\pi}$ dimension corresponds to decay modes as $B \to \psi' X$ whereas peaking background in ΔE dimension corresponds to all decay modes of the type $B \to J/\psi\pi\pi(K\pi)$ as the final state (where $J/\psi\pi\pi$ is not coming from ψ'). PDF for peaking background in each dimension is same as the signal PDF in that dimension. A Chebychev polynomial of 1^{st} order is used to parameterise the flat background in $M_{J/\psi\pi\pi}$ distribution and 2^{nd} order is used for the flat background in the ΔE distribution. The pure combinatorial background is flat in both dimensions and can be parameterised by the product of a Chebychev polynomial 1^{st} order for $M_{J/\psi\pi\pi}$ distribution and a 2^{nd} order for ΔE distribution. Figure 1 shows the signal enhanced projection plots for ψ' region. Our branching

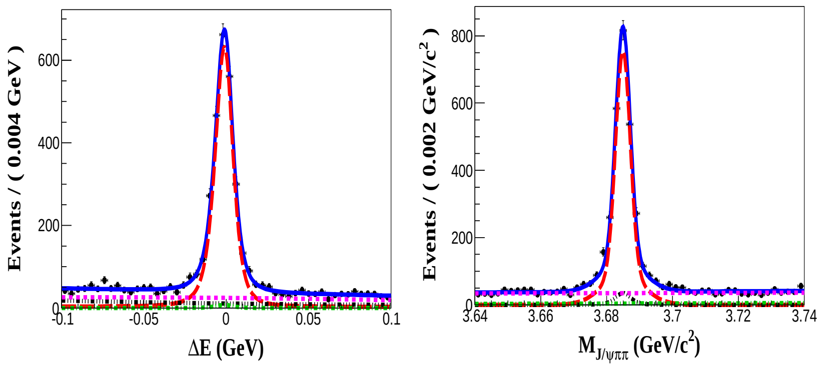

Figure 1: Signal region projections of data for the $B^0 \to (J/\psi\pi^+\pi^-)K^+\pi^-$ decay mode in the ψ' region. Left plot (right plot) is the projection for the $M_{J/\psi\pi\pi}$ signal region [3.678, 3.692] GeV/c^2 (ΔE signal region $[-0.02,\ 0.02]$ GeV). The red curve represents the signal in both dimensions, the black curve represents the peaking background in $M_{J/\psi\pi\pi}$ dimension which is flat in ΔE dimension, the green curve is the peaking background in ΔE which is flat in $M_{J/\psi\pi\pi}$ and the pink one represents the combinatorial background.

fraction comes out to be $(6.04 \pm 0.16^{+0.32}_{-0.33}) \times 10^{-4}$, where the first (second) error due to statistical (systematic), while the latest measurement for $B^0 \to \psi' K^+\pi^-$ is $(5.80 \pm 0.39) \times 10^{-4}$ [9], here error includes systematic as well as statistical uncertainty.

The signal extraction procedure explained in previous section provides the total yield of the $B^0 \to \psi'(K^+\pi^-)$ decay mode. Extracting the different $K\pi$ components is not possible at this stage, so a fit of the $M_{K\pi}$ distribution is necessary. For this purpose, we perform 2D UML fit to each ΔE and $M_{J/\psi\pi\pi}$ distributions for 51 MeV wide $M_{K\pi}$ bin (19 bins in a range from 0.6 to 1.569 GeV/c^2). This method will provide a background-subtracted $M_{K\pi}$ distribution. After obtaining signal yield in each bin for ψ' region, we are doing χ^2 fit to the $M_{K\pi}$ distribution. PDF's used for fitting of $K^*(892)^0$, $K_2{}^*(1430)^0$ and $(K^+\pi^-)_{NR}$ components are HistPdf taken from signal MC. This fitting is shown in Figure 2 for ψ' region. Sum of yields obtained for each $(K\pi)$ component is consistent with the total yield obtained from 2D fit of $M_{J/\psi\pi\pi}$ and ΔE (Figure 1) and $\mathscr{B}(B^0 \to \psi' K^*(892)^0)$ obtained for data is $(6.11 \pm 0.19^{+0.34}_{-0.37}) \times 10^{-4}$, where first (second) error is due to statistical (systematic), while the branching ratio from PDG is $(6.1 \pm 0.5) \times 10^{-4}$ [10], here error includes systematic as well as statistical uncertainty.

A 2D fit is also performed for ΔE and $M_{J/\psi\pi\pi}$ in the range $[-0.1,\ 0.1]$ GeV and [3.82, 3.92] GeV/c^2 respectively (for $X(3872)$ region). Figure 3 shows the signal enhanced projection plots. Mean and resolution of $M_{J/\psi\pi\pi}$ and ΔE are fixed for $X(3872)$ region from signal MC after

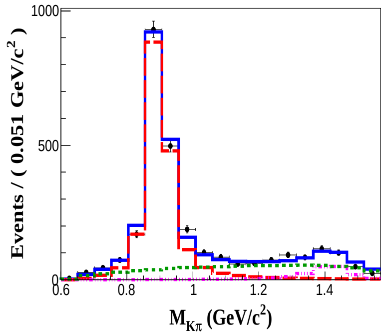

Figure 2: Fitting of $M_{K\pi}$ dimension in ψ' region (51 MeV-wide $M_{K\pi}$ bins) for data. The red curve represents $B^0 \to \psi' K^*(892)^0$, the green curve represents $B^0 \to \psi'(K^+\pi^-)_{NR}$ and pink one represents $B^0 \to \psi' K_2^*(1430)^0$.

a calibration factor obtained from the $B^0 \to \psi' K^+\pi^-$ decay mode. A Chebychev polynomial of 2^{nd} order is used for combinatorial backgrounds in ΔE, other polynomial are of 1^{st} order. A clear observation of $B^0 \to X(3872)K^+\pi^-$ decay mode is obtained with 135 ± 20 signal events.

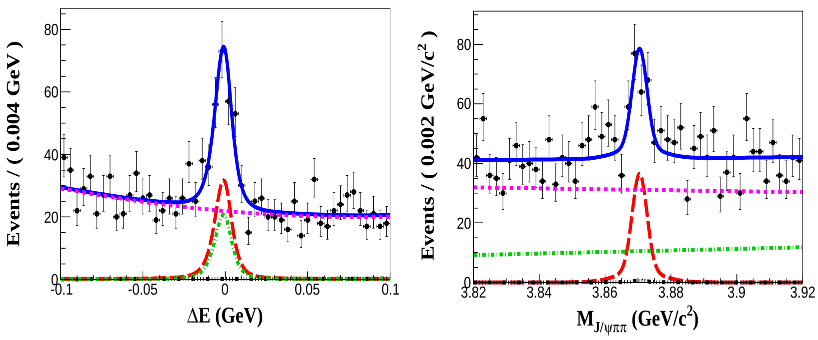

Figure 3: Signal region projections of data for $B^0 \to (J/\psi\pi^+\pi^-)K^+\pi^-$ decay mode for $X(3872)$ region. Left plot (right plot) is the projection for $M_{J/\psi\pi\pi}$ signal region [3.8634, 3.8775] GeV/c^2 (ΔE signal region [-0.02,0.02] GeV). The red curve represents the signal in both dimensions, the black curve represents the peaking background in $M_{J/\psi\pi\pi}$ dimension which is flat in ΔE dimension, the green curve is the peaking background in ΔE which is flat in $M_{J/\psi\pi\pi}$ and the pink one represents the combinatorial background.

From 2D UML fit, we obtain $\mathscr{B}(B^0 \to X(3872)(K^+\pi^-)) \times \mathscr{B}(X(3872) \to J/\psi\pi^+\pi^-) = (8.55 \pm 1.34^{+0.48}_{-0.76}) \times 10^{-6}$. A fit to $M_{K\pi}$ distribution is then performed. For this purpose, we perform 2D UML fit to each ΔE and $M_{J/\psi\pi\pi}$ distributions for 100 MeV wide $M_{K\pi}$ bin (8 bins in a range from 0.62 to 1.42 GeV/c^2). After obtaining signal yield in each bin, we are doing χ^2 fit to $M_{K\pi}$ distribution, which is shown in Figure 4 for full data sample for $X(3872)$ region. The yields obtained from data are (39 ± 15) and (98 ± 22) respectively for $B^0 \to X(3872)K^*(892)^0$ and $B^0 \to X(3872)(K^+\pi^-)_{NR}$ decay modes. In contrast to other charmonium states, for $X(3872)$ region $B^0 \to X(3872)(K^+\pi^-)_{NR}$ seems to be dominating as compared to $B^0 \to X(3872)K^*(892)^0$ decay mode.

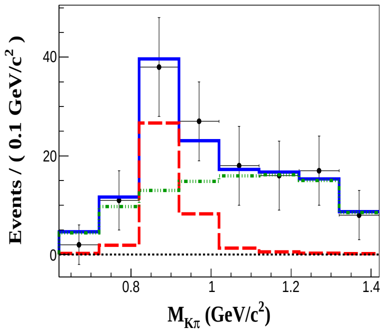

Figure 4: Fitting of $M_{K\pi}$ dimension in $X(3872)$ region (100 MeV-wide $M_{K\pi}$ bins) for data. Red (green) curve represents $B^0 \to X(3872)K^*(892)^0$ ($B^0 \to X(3872)(K^+\pi^-)_{NR}$) decay modes.

4. Discussion

We report the first statistically significant observation of $X(3872)$ in the decay $B^0 \to X(3872)K^+\pi^-$ and we obtain $\mathscr{B}(B^0 \to X(3872)K^+\pi^-) \times \mathscr{B}(X(3872) \to J/\psi\pi^+\pi^-) = (8.55 \pm 1.34^{+0.48}_{-0.76}) \times 10^{-6}$. Unlike other charmonium states, here $B^0 \to X(3872)(K^+\pi^-)_{NR}$ seems to be dominating as compared to $B^0 \to X(3872)K^*(892)^0$ decay mode.

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