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

A. Bala∗†
Panjab University, Chandigarh
E-mail: garg.supriya@gmail.com

We present results of the search for $X(3872)$, produced in $B \rightarrow X(3872)(K\pi)$ decay modes, where $X(3872)$ decays to $J/\psi\pi^+\pi^-$. We report the first observation of $B^0 \rightarrow X(3872)(K^+\pi^-)$ and measure the product of branching fractions to be $\mathcal{B}(B^0 \rightarrow X(3872)(K^+\pi^-)) \times \mathcal{B}(X(3872) \rightarrow J/\psi\pi^+\pi^-) = (8.55 \pm 1.34^{+0.44}_{-0.76}) \times 10^{-6}$. 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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∗Speaker.
†On behalf of Belle Collaboration

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1. Introduction

The $X(3872)$ state has been discovered about eleven years ago by the Belle Collaboration in an exclusive search of $B^0 \rightarrow J/\psi \pi^+ \pi^- K^0_S$ 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 $1^{++}$. $B \rightarrow X(3872) K \pi$ decay mode can tell us more about the nature of $X(3872)$ decay. This analysis uses a whole data sample, $711 \text{ fb}^{-1}$ ($772 \times 10^6$ $BB$ pairs), collected with the Belle detector at the KEKB asymmetric-energy $e^+ e^-$ 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 $R_{K/\pi}(R_{\pi/K}) > 0.6$, where $R_{K/\pi} = L_{K} / (L_{\pi} + L_{K})$, with $L_{K}$ ($L_{\pi}$) is the likelihood value for the kaon (pion) hypothesis. We reconstruct $J/\psi$ mesons in the $e^+ e^-$ decay channel ($l = e$ or $\mu$) and include bremsstrahlung photons that are within $50 \text{ mrad}$ of either the $e^+$ or $e^-$ tracks (denoted as $e^+ e^-(\gamma)$). The invariant mass of the $J/\psi$ candidates is required to be within $3.00[3.06] \text{ GeV}/c^2 < M_{e^+ e^-}(\gamma) [\mu^+ \mu^-] < 3.13[3.13] \text{ GeV}/c^2$, where $M_{e^+ e^-}(\gamma)$ [$\mu^+ \mu^-$] are the reconstructed invariant masses of $e^+ e^-(\gamma)$ ($\mu^+ \mu^-$). The $J/\psi$ candidate is then combined with a $\pi^+ \pi^-$ pair for further analysis: both $X(3872)$ and $\psi'$, used here for calibration, decay to the same final state. An additional cut is applied on the $M_{\pi^+ \pi^-}$ variable: $M_{\pi^+ \pi^-} > M(\psi \pi \pi) - (m_{J/\psi} + 0.2 \text{ GeV}/c^2)$ for $B^0 \rightarrow (J/\psi \pi^+ \pi^-)(K^+ \pi^-)$ decay mode. This cut corresponds to $M_{\pi^+ \pi^-} > 389(575)$ $\text{MeV}/c^2$ for the $\psi'(X(3872))$ region and reduces significantly the combinatorial background. To further reduce the combinatorial background from $e^+ e^- \rightarrow q\bar{q}$ 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 $M_{\text{bc}} = \sqrt{E_{\text{beam}}^2 - p_B^2}$, where $p_B$ and $E_B$ is the $B$ candidate momentum and energy in the CM frame and $E_{\text{beam}}$ is the run-dependent beam energy.

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

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

Above selection cuts isolate a very pure sample of $B^0 \rightarrow \psi' K^+ \pi^-$. These events are used to calibrate the $M_{J/\psi \pi \pi}$ and $\Delta E$ resolution for $X(3872)$ region. To estimate the signal yield and shape of the $B^0 \rightarrow \psi' K^+ \pi^-$ decay mode, we first perform a 2D fit in the $\Delta E$ 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 Crijff function (used for $\Delta E$ 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 $\Delta E$ or vice versa. The peaking background
in the $M_{J/\psi\pi\pi}$ dimension corresponds to decay modes as $B \rightarrow \psi' X$ whereas peaking background in $\Delta E$ dimension corresponds to all decay modes of the type $B \rightarrow J/\psi\pi\pi(K\pi)$ as the final state (where $J/\psi\pi\pi$ is not coming from $\psi'$). PDF for peaking background in each dimension is same as the signal PDF in that dimension. A Chebychev polynomial of 1st order is used to parameterise the flat background in $M_{J/\psi\pi\pi}$ distribution and 2nd order is used for the flat background in the $\Delta E$ distribution. The pure combinatorial background is flat in both dimensions and can be parameterised by the product of a Chebychev polynomial 1st order for $M_{J/\psi\pi\pi}$ distribution and a 2nd order for $\Delta E$ distribution. Figure 1 shows the signal enhanced projection plots for $\psi'$ region. Our branching 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 $B^0 \rightarrow \psi' K^+ \pi^-$ 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 $B^0 \rightarrow \psi'(K^+\pi^-)$ 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 $\Delta E$ 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 $\psi'$ region, we are doing $\chi^2$ 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 $\psi'$ 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 $\Delta E$ (Figure 1) and $\mathcal{B}(B^0 \rightarrow \psi'K^*(892)^0)$ 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 $\Delta E$ 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 $\Delta E$ are fixed for $X(3872)$ region from signal MC after

Figure 1: Signal region projections of data for the $B^0 \rightarrow (J/\psi\pi\pi)K^+\pi^-$ decay mode in the $\psi'$ region. Left plot (right plot) is the projection for the $M_{J/\psi\pi\pi}$ signal region $[3.678, 3.692]$ GeV/c$^2$ ($\Delta E$ 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 $\Delta E$ dimension, the green curve is the peaking background in $\Delta E$ which is flat in $M_{J/\psi\pi\pi}$ and the pink one represents the combinatorial background.
$B^0 \rightarrow X(3872)K^+\pi^-$ decay mode

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Figure 2: Fitting of $M_{K\pi}$ dimension in $\psi'$ region (51 MeV-wide $M_{K\pi}$ bins) for data. The red curve represents $B^0 \rightarrow \psi'K^*(892)^0$, the green curve represents $B^0 \rightarrow \psi'(K^+\pi^-)_{NR}$ and pink one represents $B^0 \rightarrow \psi'K^*_2(1430)^0$.

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

Figure 3: Signal region projections of data for $B^0 \rightarrow (J/\psi\pi^+\pi^-)K^+\pi^-$ 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/$c^2$ ($\Delta E$ 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 $\Delta E$ dimension, the green curve is the peaking background in $\Delta E$ which is flat in $M_{J/\psi\pi\pi}$ and the pink one represents the combinatorial background.

From 2D UML fit, we obtain $\mathcal{B}(B^0 \rightarrow X(3872)(K^+\pi^-)) \times \mathcal{B}(X(3872) \rightarrow J/\psi\pi^+\pi^-) = (8.55 \pm 1.34^{+0.48}_{-0.70}) \times 10^{-6}$. A fit to $M_{K\pi}$ distribution is then performed. For this purpose, we perform 2D UML fit to each $\Delta E$ 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 $\chi^2$ 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 $(39 \pm 15)$ and $(98 \pm 22)$ respectively for $B^0 \rightarrow X(3872)K^*(892)^0$ and $B^0 \rightarrow X(3872)(K^+\pi^-)_{NR}$ decay modes. In contrast to other charmonium states, for $X(3872)$ region $B^0 \rightarrow X(3872)(K^+\pi^-)_{NR}$ seems to be dominating as compared to $B^0 \rightarrow X(3872)K^*(892)^0$ decay mode.
4. Discussion

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

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References