Study of Radiative Decays of $X(3872)$ Using the Belle and the Belle II Detectors

Sourabh Chutia[1] and Vishal Bhardwaj[1]

Indian Institute of Science Education and Research Mohali, Punjab, India
(On behalf of the Belle II collaboration)
ph21070@iisermohali.ac.in, vishal@iisermohali.ac.in

Abstract. We present here a preliminary Monte Carlo (MC) simulation study of $X(3872) \to J/\psi\gamma$ and $X(3872) \to \psi(2S)\gamma$ in the decay of $B \to (c\bar{c}\gamma)K$ where B stands for $B^{\pm}$, B^0 and K stands for $K^{\pm}$, K^0_S. The previous Belle measurement did not find any significant signal for $X(3872) \to \psi(2S)\gamma$. We plan to measure the ratio of BF $R_{\psi\gamma} = \{\mathcal{B}(X(3872) \to \psi(2S)\gamma)/\mathcal{B}(X(3872) \to J/\psi\gamma)\}$ to probe the nature of the state combining the B-meson data collected by the Belle (and the Belle II) detectors which is expected to increase the sensitivity and significance. $B \to \chi_{c1,c2}K$ where $\chi_{c1,c2} \to J/\psi\gamma$ will be used as calibration mode.

1 Introduction

Since the discovery of the exotic state $X(3872)$ in 2003 by the Belle collaboration [1], its properties have been extensively studied with plenty of interesting models proposed to explain its nature. The ratio of branching fractions $R_{\psi\gamma} = \{\mathcal{B}(X(3872) \to \psi(2S)\gamma)/\mathcal{B}(X(3872) \to J/\psi\gamma)\}$ turns out to be a useful parameter to understand the nature of the state. In $\bar{D}^0D^{*0}$ molecular assumption [3, 4], $R_{\psi\gamma}$ is expected to be $<< 1$. Calculations based on the initial assumption of $\chi_{c1}(2P)$ or $c\bar{c}q\bar{q}$ tetraquark state [4] predicts $R_{\psi\gamma} \geq 1$. On the other hand, $\bar{D}^0D^{*0}$ molecule with a $c\bar{c}$ component model [4] covers a wide range of $R_{\psi\gamma}$ values.

The first measurement of $R_{\psi\gamma}$ comes from BaBar [2] and they found evidence of both $X(3872) \to J/\psi\gamma$ and $X(3872) \to \psi(2S)\gamma$ with $R_{\psi\gamma} = 3.4 \pm 1.4$. But, the Belle measurement [3] with 772×10^6 $B\bar{B}$ pairs did not find any significant signal for $X(3872) \to \psi(2S)\gamma$ and gave an upper limit of $R_{\psi\gamma} < 2.1$ at 90% C.L. A recent study from LHCb [4] measured $R_{\psi\gamma} = 1.67 \pm 0.25$ agreeing with the upper limit given by Belle. On the other hand, BESIII measurement [5] of $R_{\psi\gamma} < 0.59$ at 90% C.L still leads to a global debate and therefore urges for more experimental input. We aim to search for $X(3872) \to \psi(2S)\gamma$ using combined Belle and Belle II data.

2 Event Selection and Analysis

The J/ψ meson is reconstructed through its decays into l^+l^- pairs, where l can be either $e^{\pm}$ or $\mu^{\pm}$. The $\psi(2S)$ meson is reconstructed from l^+l^- and $J/\psi\pi^+\pi^-$

final states. Bremsstrahlung energy loss from $e^{\pm}$ is corrected by including photons within 50 mrad of each of the original e^+ or e^- tracks. Reconstruction of J/ψ, $\psi(2S)$ and K_S^0 are same as described in [3]. A vertex fit with mass constraint are applied to the selected J/ψ and $\psi(2S)$ candidates. Photons with loose energy cut of $E_\gamma > 90$ MeV are combined with a selected J/ψ or $\psi(2S)$ candidate to reconstruct $X(3872)$. A vertex fit with mass constraint is also applied on the $X(3872)$ candidates.

B candidates are reconstructed by combining $X(3872)$ with a charged kaon or a K_S^0. Selection of B candidates are based on two kinematic variables: beam-constrained mass $\left(M_{bc} = \sqrt{E_{beam}^2 - p_B^2}\right) > 5.27$ GeV/c^2 and energy difference $(\Delta E = E_B - E_{beam})$ $-0.2 < \Delta E < 0.2$ GeV. Here, E_{beam} is the run-dependent beam energy, E_B and p_B are reconstructed energy and momentum. In events with multiple B candidates, best B candidate is selected with a minimum value of $\chi^2_{M_{bc}} = \left(\frac{M_{bc}-5.279}{\sigma_{M_{bc}}}\right)^2$. Signal extraction is performed via two-dimensional unbinned maximum likelihood (UML) fit on $M_{\psi\gamma}$ and ΔE after mass-constraining $X(3872)$.

For background suppression, a FastBDT algorithm [6] is trained on equal number of signal and background for each decay mode separately, and a selection cut on the output BDT classifier is applied.

3 Signal and Background Parameterization

The signal in $M_{J/\psi\gamma}$ and ΔE for $X(3872) \to J/\psi\gamma$ is modeled using Johnson PDF [7] and sum of a Gaussian and a bifurcated Gaussian with a common mean while the background is modeled using first order and second order Chebyshev polynomial respectively. Figure 1 shows the 2D UML fit of ΔE and $M_{J/\psi\gamma}$.

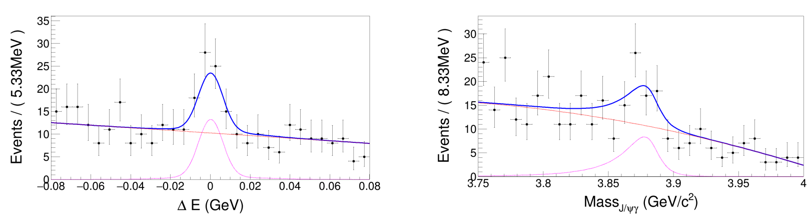

Fig. 1. 2D UML fit of ΔE and $M_{J/\psi\gamma}$ for $B^+ \to X(3872)[\to J/\psi\gamma]K^+$ in large $B \to J/\psi X$ MC sample (~ 75 times the size of Belle + Belle II data), scaled to Belle data.

In case of $X(3872) \to \psi(2S)\gamma$, major contribution to the background comes from $B^{\pm,0} \to \psi(2S)K^{*\pm,0}$ with broad peaking structure around the signal region. These backgrounds are modeled using NovosibirskA function in ΔE and sum of Gaussian and a bifurcated Gaussian in $M_{\psi(2S)\gamma}$ and the yield is floated keeping the ratio of $B^{\pm} \to \psi(2S)K^{\pm}$ and $B^0 \to \psi(2S)K^{*0}$ fixed. The remaining background is fitted using a third order polynomial in ΔE and sum of Gaussian and a bifurcated Gaussian in $M_{\psi(2S)\gamma}$. The signal in $M_{\psi(2S)\gamma}$ and ΔE for $X(3872) \to \psi(2S)\gamma$ is modeled using a sum of Novosibirsk function, Gaussian and bifurcated Gaussian and sum of double Gaussian and a bifurcated Gaussian with a common mean respectively. Figure 2 shows the 2D UML fit of ΔE and $M_{\psi(2S)\gamma}$.

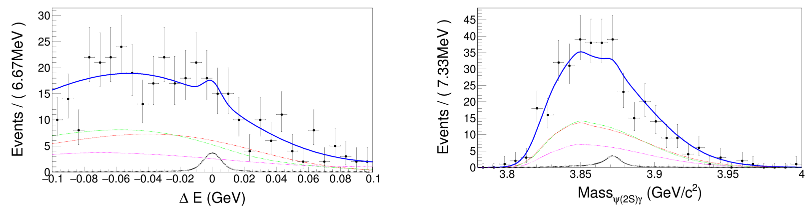

Fig. 2. 2D UML fit of ΔE and $M_{\psi(2S)\gamma}$ for $B^+ \to X(3872)[\to \psi(2S)\gamma]K^+$, $\psi(2S) \to l^+l^-$ in large $B \to \psi(2S)X$ MC sample ($\sim$ 75 times the size of Belle + Belle II data), scaled to Belle data. The black line corresponds to the signal, while the green, red and magenta line corresponds to $B^\pm \to \psi(2S)K^{*\pm}$, $B^0 \to \psi(2S)K^{*0}$ and rest of the background respectively.

4 Summary

We report an MC simulation study for the search of $X(3872) \to \psi(2S)\gamma$ and calculation of the parameter $R_{\psi\gamma}$. Backgrounds are studied using Belle $B \to J/\psi X$ and $B \to \psi(2S)X$ MC sample equivalent to 75 times data accumulated by the Belle and the Belle II detectors. We are currently investigating for the possible sources of background in Belle II generic MC. Once the study is finalized on MC we are going to look into the data

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