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Study of $B^+ \to J/\psi\ K^{*+}(\to K_S^0\pi^+)$ decays

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Abstract

We report a study for reconstruction of the decay chain of $B^0 \to J/\psi K^{*+}$ followed by $J/\psi \to \mu^+\mu^-$, $K^{*+} \to K_S^0\pi^+$ and $K_S^0 \to \pi^+\pi^-$. The vertex displacement in the same decay where the signal B^+ vertex is reconstructed using all the available tracks or using only the tracks coming from K_S^0 gives an opportunity to investigate possible Data/MC difference in the vertex resolution.

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1. INTRODUCTION

Checking possible difference between experimental data and Monte Carlo simulation (MC) for the B decay vertex resolution is a key ingredient to perform time-dependent CP violation measurements. Among the $b \to s$ or $b \to d$ penguin diagram induced neutral B meson decays, there are several decay modes for which only $K_S^0 \to \pi^+\pi^-$ gives charged track information to reconstruct B decay vertex, for example, $B^0 \to K_S^0 K_S^0 K_S^0$, $K_S^0\pi^0$, $K_S^0 K_S^0$, $K_S^0\pi^0\gamma$ and so on. For these decay modes, the B decay vertex is reconstructed by the kinematical fit involving proper constraint on the interaction point (IP) and straight track of K_S^0 using its daughter charged pion pair. It is important to confirm there is no significant difference between data and MC for the $K_S^0 \to \pi^+\pi^-$ based B vertex resolution to figure out the vertex resolution function for time-dependent CP violation. Here, the vertex resolution is different from usual cases such as $B^0 \to J/\psi K^0$, $\pi^+\pi^-$ and so on where there are charged daughter tracks directly coming from the B decay vertex. The $B^0 \to J/\psi K^{*+}$ followed by $J/\psi \to \mu^+\mu^-$, $K^{*+} \to K_S^0\pi^+$ and $K_S^0 \to \pi^+\pi^-$ mode has an advantage compared to the $B \to D^{(*)}\pi$ mode as a calibration sample because it is free from finite charm meson lifetime that gives a sizable smearing in addition to the detector resolution itself. The vertex displacement in the same decay where the signal B^+ vertex is reconstructed using all the available tracks or using only the tracks coming from K_S^0 gives an opportunity to investigate possible Data/MC difference in the vertex resolution.

2. EVENT SELECTION AND RELEVANT QUANTITIES' DISTRIBUTIONS FOR THE SIGNAL MC

For charged tracks except for the $K_S^0 \to \pi^+\pi^-$ daughters, we require $|d_r| < 2$ cm and $|d_z| < 5$ cm. For $J/\psi \to \mu^+\mu^-$ reconstruction, both tracks are required to be identified as muons to satisfy `muonID`> 0.2. The $J/\psi \to \mu^+\mu^-$ candidates are selected by requiring $M_{\mu^+\mu^-}$, 3.05 GeV/$c^2 < M_{\mu^+\mu^-} < 3.15$ GeV/c^2 where $M_{\mu^+\mu^-}$ is the di-muon invariant mass. We require 0.491 GeV/$c^2 < M_{\pi^+\pi^-} < 0.504$ GeV/c^2 to select $K_S^0 \to \pi^+\pi^-$ candidates. In order to select $K^{*+} \to K_S^0\pi^+$ (and c.c.), the pion candidate track is required to satisfy `pionID`> 0.05 to reject obvious kaon and proton tracks. The K^{*+} candidates are selected by requiring 0.8 GeV/c^2 < $M_{K\pi}$ < 1.0 GeV/c^2 where $M_{K\pi}$ denotes the $K\pi$ invariant mass. The events having at least one candidate satisfying -0.3 GeV < ΔE < 0.3 GeV and 5.2 GeV/c^2 < $M_{\rm bc}$ are retained for further analysis. When multiple candidates are found in one event, we select the one having the highest χ^2-p-value. The resultant $M_{\rm bc}$ and ΔE distributions are shown in Fig. 1. We define B candidate signal box as 5.27 GeV/c^2 < $M_{\rm bc}$ < 5.29 GeV/c^2 and -0.06 GeV < ΔE < 0.04 GeV.

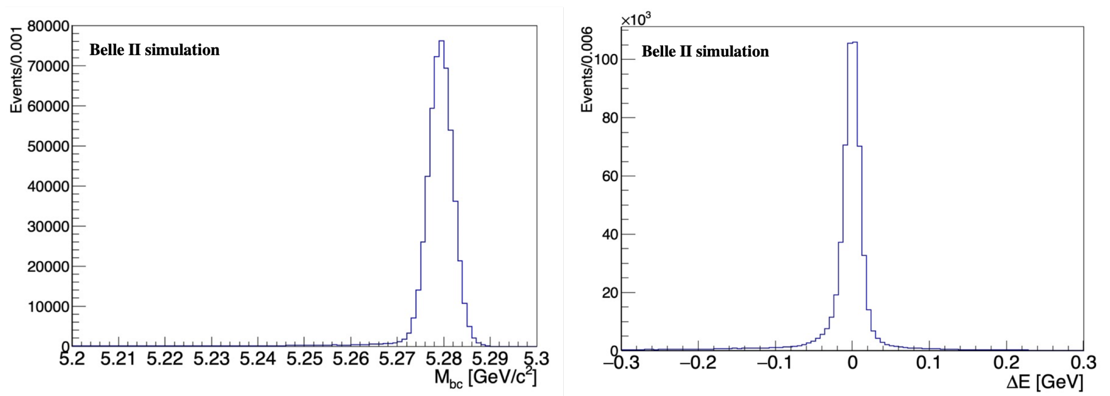

FIG. 1. $M_{\rm bc}$ (left) distribution in -0.06 GeV < ΔE < 0.04 GeV region and ΔE (right) distribution in 5.27 GeV/c^2 < $M_{\rm bc}$ < 5.29 GeV/c^2 for the signal MC events.

Calling the `TreeFit` program, we can reconstruct B decay vertex where $J/\psi \to \mu^+\mu^-$ is dominant to determine the vertex position. While, to see the $K_S^0 \to \pi^+\pi^-$ contribution to obtain the B vertex, the z_0 and d_0 errors are 1000 times inflated for the J/ψ daughter muon and the pion promptly coming from K^{*+} decay tracks[1]. The z-residual to be defined as the difference between the reconstructed and generated z coordinates and its distributions for two different vertex reconstruction methods are shown in Fig.2.

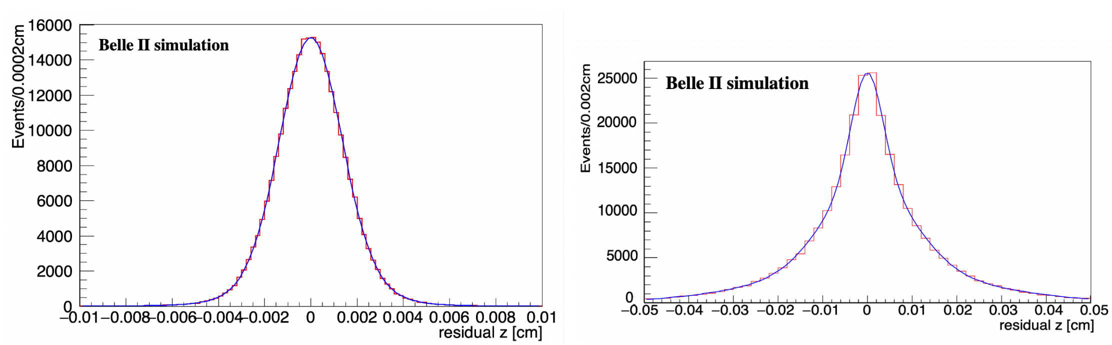

FIG. 2. Distributions of z-residual, difference between the reconstructed and generated z coordinates of the B decay vertex with usual (left) and $K_S^0 \to \pi^+\pi^-$-based (right) cases for the signal MC events in the signal region. Fit with triple Gaussian is performed and the standard deviation is obtained by the weighted average of three Gaussian's spread: $\sigma = 15.9 \pm 0.5$ μm and 157.7 ± 1.5 μm for usual and $K_S^0 \to \pi^+\pi^-$-based B vertex reconstruction cases, respectively.

As the quantity we can directly compare between Data and MC, the $z_{\rm diff} \equiv z_{\rm usual} - z_{K_S^0}$ is thought to be functional, where $z_{\rm usual}$ and $z_{K_S^0}$ are the z coordinate for the usual and the $K_S^0 \to \pi^+\pi^-$-based B decay vertex reconstruction cases. The $z_{\rm diff}$ distribution for the signal

MC events found in the signal region is shown in Fig.3. As expected, we found the spread of z distribution is dominated by the B decay vertex resolution by the $K_S^0 \to \pi^+\pi^-$-based reconstruction.

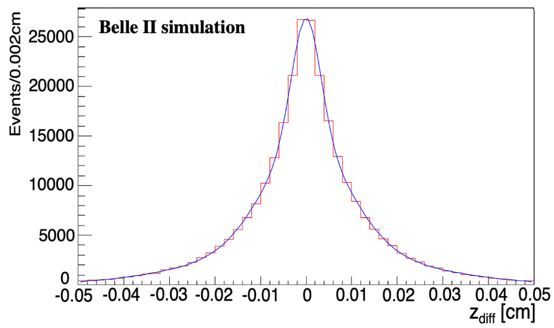

FIG. 3. Distributions of $z_{\mathrm{diff}} \equiv z_{\mathrm{usual}} - z_{K_S^0}$ where z_{usual} and $z_{K_S^0}$ are the z coordinate for the usual and the $K_S^0 \to \pi^+\pi^-$-based B decay vertex reconstruction cases.. Fit with triple Gaussian is performed and the standard deviation is obtained by the weighted average of three Gaussian's spread: $\sigma = 150.9 \pm 1.5$ μm.

3. ANALYSIS ON THE EXPERIMENTAL DATA

We analyzed the Belle II data collected on $\Upsilon(4S)$ resonance corresponding to 362 fb^{-1}. The resultant M_{bc} and ΔE distributions is shown in FIg.4. From the fit, we found 939 ± 33 signal events and 85 ± 22 background events in the signal region defined as 5.27 GeV/c^2 $< M_{\mathrm{bc}} <$ 5.29 GeV/c^2 and -0.06 GeV $< \Delta E <$ 0.04 GeV. Since expected background MC M_{bc} distribution exhibits a small peak at the same position as signal as shown in Fig.7, the possible difference of the estimated background events is derived by the MC distribution and it is found to be 110 events.

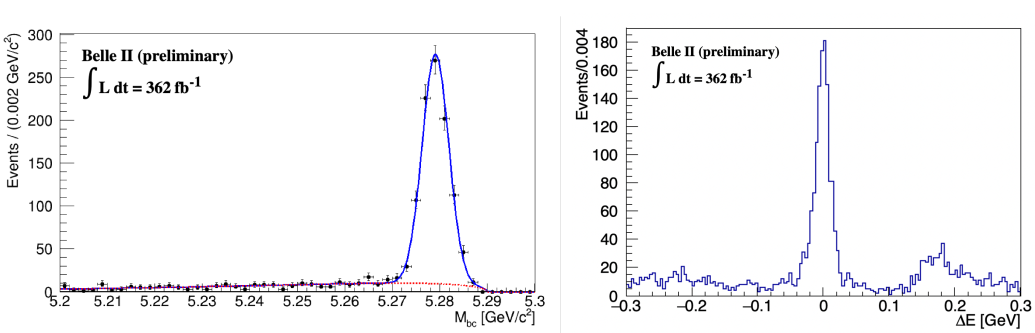

FIG. 4. M_{bc} (left) distribution in -0.06 GeV $< \Delta E <$ 0.04 GeV region and ΔE (right) distribution in 5.27 GeV/c^2 $< M_{\mathrm{bc}} <$ 5.29 GeV/c^2 in the Belle II experimental data corresponding to 362 fb^{-1}. For M_{bc} distribution, the fit with Gaussian signal + ARGUS background is performed and its result is drawn as the lines to express total (blue solid line) and background (red dashed line).

As for the z_{diff} distribution, the background probability density function (PDF) is determined by the M_{bc} sideband (5.20 GeV/c^2 $< M_{\mathrm{bc}} <$ 5.27 GeV/c^2 and -0.06 GeV $< \Delta E <$

0.04 GeV) events as shown in Fig.5. It is fitted with Gaussian and mean (μ) and standard deviation (σ) are found to be $\mu = 8.4 \pm 9.0$ μm and $\sigma = 140 \pm 7$ μm, respectively.

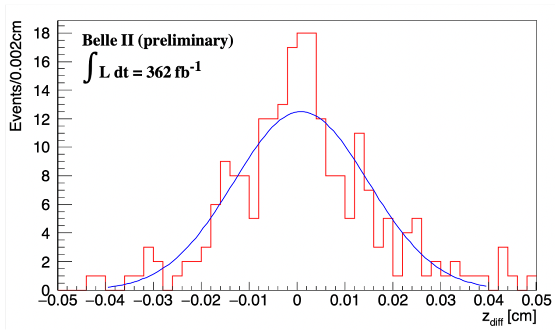

FIG. 5. The $z_{\rm diff} \equiv z_{\rm usual} - z_{K_S^0}$ distribution in the $M_{\rm bc}$ sideband (5.20 GeV/c^2 $< M_{\rm bc} <$ 5.27 GeV/c^2 and -0.06 GeV $< \Delta E <$ 0.04 GeV) region. The Gaussian's mean mean (μ) and standard deviation (σ) are found to be $\mu = 8.4 \pm 9.0$ μm and $\sigma = 140 \pm 7$ μm, respectively.

The signal $z_{\rm diff}$ distribution is fitted with double Gaussian for signal and the background PDF determined by the $M_{\rm bc}$ sideband events. The standard deviation of the signal distribution is found to be $\sigma = 142 \pm 7$ μm where statistical error only quoted. Systematic

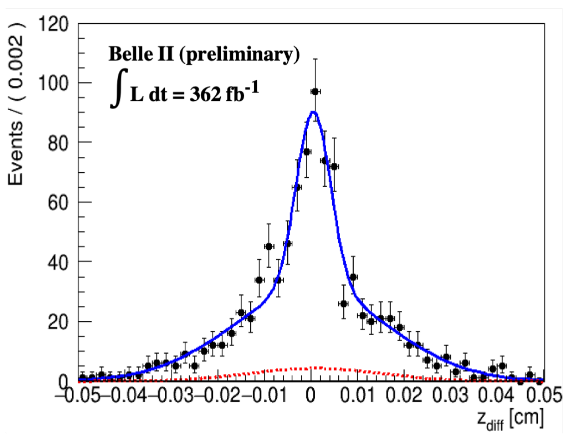

FIG. 6. The $z_{\rm diff}$ distribution in the Data signal box. The signal component is described by double Gaussian and its spread is found to be $\sigma = 142 \pm 7({\rm stat}) \pm 2({\rm syst})$ μm.

uncertainty is estimated by varying background PDF's μ, σ and background fraction and corresponding effects are found to be negligible, ± 1 μm and ± 1 μm, respectively. Changing the background from 85 events to 110 events to estimate potential peaking background's effect, the resultant $z_{\rm diff}$ spread change is found to be 1 μm. Summing up them in quadrature results in ± 1.7 μm, so the $z_{\rm diff}$ standard deviation is quoted to be $\sigma = 142 \pm 7({\rm stat}) \pm 2({\rm syst})$ μm. Compared to the one in MC, $\sigma = 150.9 \pm 1.5$ μm, we see a good agreement between Data and MC. Currently the resolution function for the $K_S^0 \to \pi^+\pi^-$-based B decay vertex reconstruction is mainly based on the knowledge obtained by the MC and validated with a possible control sample. The result by this work gives a strong support for currently taken procedure to compose vertex resolution function for $K_S^0 \to \pi^+\pi^-$-based B decay vertex reconstruction by carrying out an independent study.

4. MATERIALS THAT MAY BE INCLUDED IN BACKUP SLIDES

Generic MC sample is also visited to estimate amount of the background. As shown in Fig.7, the $B^+ \to J/\psi K^{*+}$ mode is expected to have high purity ~ 90 %. Comparison

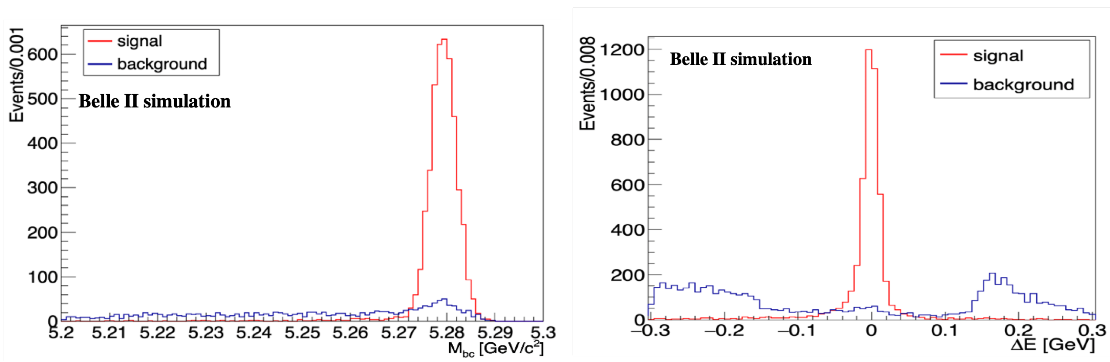

FIG. 7. $M_{\rm bc}$ (left) distribution in -0.06 GeV $< \Delta E <$ 0.04 GeV region and ΔE (right) distribution in 5.27 GeV/c^2 $< M_{\rm bc} <$ 5.29 GeV/c^2 for the background MC events where the signal MC expectation is superimposed.

between Data and signal MC $z_{\rm diff}$ distributios is shown in FIg.8.

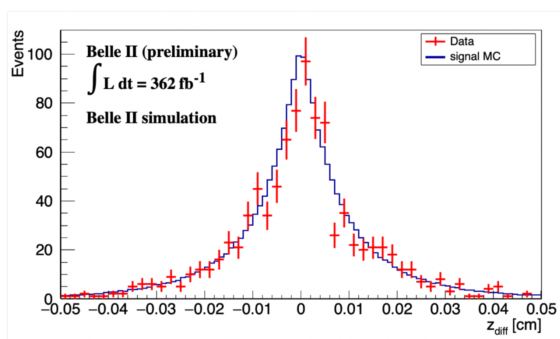

FIG. 8. The $z_{\rm diff}$ distribution to compare Data and signal MC.

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Appendix A: Event generation

Since the $B^+ \to J/\psi K^{*+}$ mode is a Pseudo-Scalar to Vector Vector ($P \to VV$) decay, the final state is a linear combination of three amplitudes. Usually the decay amplitude is expressed by the two transverse polarization amplitudes (H_+ and H_-) and one longitudinal polarization amplitude (H_0) basis. Experimentally, common formula is the transversity basis that is expressed as the linear combination of H_+, H_- and H_0;

$$A_\parallel = \frac{H_+ + H_-}{\sqrt{2}} \tag{A1}$$

$$A_\perp = \frac{H_+ - H_-}{\sqrt{2}} \tag{A2}$$

$$A_0 = H_0. \tag{A3}$$

Since the `SVVHELAMP` model in the `EvtGen` generator is based on the H_+, H_- and H_0 formalism, the $B \to J/\psi K^*$ decay's polarization measurement presented by the $A_\parallel$, $A_\perp$ and A_0 basis in PDG was converted.

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[1] H. Tanigawa developed the code to inflate specific tracks' d_0 and z_0 errors to see other tracks' contribution to determine the parent B decay vertex.