PROCEEDINGS OF SCIENCE

Beauty to charmonium decays at LHCb experiment

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This proceeding reports the three most recent LHCb results regarding b-hadron decays with charmonium resonances in the final state. The first one is an updated search for the rare decay $B^0 \to J/\psi\,\phi$, the second is the first measurement of the mixing CP-violating phase in the $B_s^0 \to J/\psi\,(e^+e^-)\phi$ decay and the last is an updated measurement of τ_{L} using the $B_s^0 \to J/\psi\,\eta$ decay.

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1. Introduction

The b-hadron decays to final state with charmonium mainly proceed through $b \to \bar{c}cq$ tree-level transitions and have negligible penguin pollutions, making them excellent probes of Standard Model (SM) quantities. In addition, the presence of charmonium in the final states is a very clean experimental signature that allows the efficient collection of large samples of these decays. The LHCb experiment covers a wide range of physics topics in these decays, such as the measurements of branching ratios, *CP* violation in B mesons and life times of b-hadrons. This proceeding presents the three most recent results in the study of these decays at LHCb.

2. Search for the rare decay $B^0 \to J/\psi\,\phi$

The $B^0 \to J/\psi\,K^+K^-$ decay is a rare decay proceeding via the Cabibbo-suppressed $\bar{b}{\to}\bar{c}c\bar{d}$ transition. This decay was first observed by the LHCb experiment with a branching fraction of $(2.51 \pm 0.35) \times 10^{-7}$ [1]. The $B^0 \to J/\psi\,\phi$ decay has a potential contribution to this final state, which is suppressed by the Okubo-Zweig-Iizuka (OZI) rule. The mechanism to produce the ϕ meson in this decay is not exactly known, thus it is theoretically interesting [2–4]. It has been proposed that the $B^0 \to J/\psi\,\phi$ decay is dominated by the $\omega - \phi$ mixing mechanism, which proceeds through a small $d\bar{d}$ component in the ϕ wave function. Under this assumption, the branching fraction of $B^0 \to J/\psi\,\phi$ is predicted to be $(1.0 \pm 0.3) \times 10^{-7}$ [1, 2].

A search for the $B^0 \to J/\psi\,\phi$ decay was performed by the LHCb collaboration using a data sample with an integrated luminosity of $1\,\text{fb}^{-1} pp$ collision data. An upper limit for this decay was set to be 1.9×10^{-7} [1]. This study updates this search by using LHCb full data sample corresponding to an integrated luminosity of 9 fb^{-1}, including 3 fb^{-1} collected in Run 1 and 6 fb^{-1} in Run 2 period.

This analysis distinguishes the $B^0 \to J/\psi\,\phi$ signal from the non-resonant decay $B^0 \to J/\psi\,K^+K^-$ and background contamination by the sequential fits to the $m(J/\psi\,K^+K^-)$ and $m(K^+K^-)$ distributions. The $B_s^0 \to J/\psi\,\phi$ decay is used as the normalisation channel due to its abundant signal events. The fit results are shown in Figure 1. The branching fraction of $B^0 \to J/\psi\,\phi$ decay is measured to be $(6.8 \pm 3.0(\text{stat}) \pm 0.9(\text{syst})) \times 10^{-8}$ [1], where the first uncertainty is statistical and second systematic. This result indicates no significant signal is observed; the upper limit on its branching fraction at 90% CL is determined to be 1.1×10^{-7}, which is compatible with theoretical expectations and improved compared with the previous limit [5].

3. First measurement of *CP*-violating phase in the $B_s^0 \to J/\psi\,(e^+e^-)\phi$ decay

The interference between direct decays and decays through mixing of the B_s^0 meson to charge-parity (*CP*) eigenstates gives rise to a *CP*–violating phase, ϕ_s, which is precisely predicted to be $-37^{+0.8}_{-0.7}$ mrad in the SM [6]. The precise measurement of ϕ_s is an excellent test of the SM and also potentially sensitive to New Physics (NP) in mixing processes. In addition, the decay width difference between heavy (H) and light (L) mass eigenstates of B_s^0 meson, $\Delta\Gamma_s = \Gamma_L - \Gamma_H$, is also interesting.

LHCb collaboration has performed the measurement of ϕ_s and $\Delta\Gamma_s$ in several channels, including $B_s^0 \to J/\psi\,(\mu^+\mu^-)K^+K^-$ decays with the invariant mass of K^+K^- zoomed in $\phi(1020)$

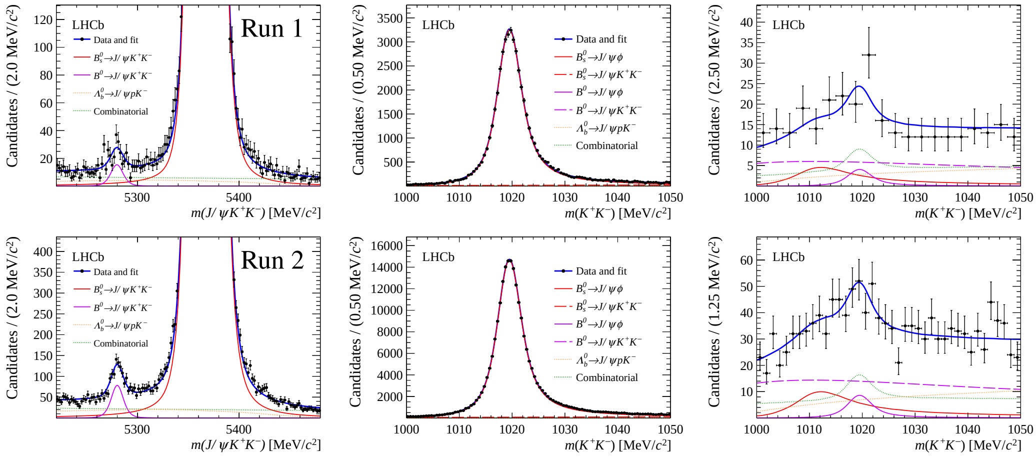

Figure 1: The distributions of $m(J/\psi\, K^+K^-)$ (left), and $m(K^+K^-)$ in B_s^0 (middle) and B^0 (right) regions, which are superimposed by fit results [5].

region and over 1.05 GeV/c^2 [7, 8], $B_s^0 \to J/\psi\,(\mu^+\mu^-)\pi^+\pi^-$ decays [9], $B_s^0 \to \psi(2S)(\mu^+\mu^-)\phi$ and $B_s^0 \to D_s^+ D_s^-$ decays [10, 11]. These results are combined to be $\phi_s = 0.042 \pm 0.025$ rad and $\Delta\Gamma_s = 0.081 \pm 0.005\,\text{ps}^{-1}$ [7].

This analysis performs the first measurement of *CP*-violating parameters in the $B_s^0 \to J/\psi\,(e^+e^-)\phi$ decay using LHCb full Run 1 data. The $m(e^+e^-K^+K^-)$ distribution is fitted to obtain a background subtracted data sample, which has an average decay-time resolution around 46 fs and a tagging power around 5% [12]. A flavour tagged time–dependent angular fit in the helicity basis is then performed with this data. The fit projections in the three helicity angles and decay-time are shown in Figure 2. The interesting parameters are measured to be $\phi_s = 0 \pm 0.28(\text{stat}) \pm 0.07(\text{syst})$ rad and $\Delta\Gamma_s = 0.115 \pm 0.045(\text{stat}) \pm 0.011(\text{syst})\,\text{ps}^{-1}$ [12]. These results are consistent with previous results and SM expectations.

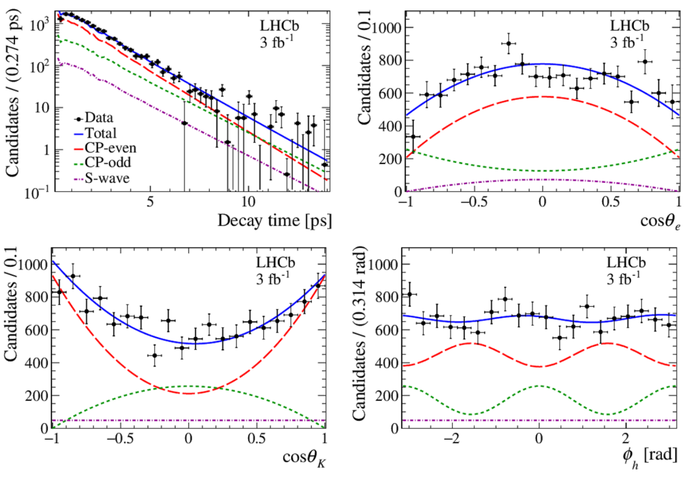

Figure 2: The distributions of three helicity angles and decay-time, which are superimposed by fit results [12].

4. Measurement of $\tau_{\rm L}$ in the $B_s^0 \to J/\psi\,\eta$ decay

The decay width difference in B_s^0–$\overline{B}{}_s^0$ system is predicted to be $\Delta\Gamma_s = 0.091 \pm 0.013$ [13]. Experimentally, $\Delta\Gamma_s$ can be directly measured or inferred from measured life times $\tau_{\rm L}$ and $\tau_{\rm H}$, where $\tau_{\rm L,H} = 1/\Gamma_{\rm L,H}$. Precise measurement of $\tau_{\rm L}$ provides stringent tests of consistency of the SM that predicts $\tau_{\rm L} = 1.422 \pm 0.013$ [13, 14].

As reported in Sec. 3, the small value of ϕ_s results in small *CP* violation effects in the B_s^0–$\overline{B}{}_s^0$ mixing. Consequently, the mass eigenstates are also *CP* eigenstates up to a very good precision, implying that measurements of the effective lifetime in *CP*-even mode determines $\tau_{\rm L}$. Using LHCb full Run 1 data, $\tau_{\rm L}$ has been measured in the tree-level decays $B_s^0 \to J/\psi\,\eta(\gamma\gamma)$ [15], $B_s^0 \to D_s^+ D_s^-$ [16] and the loop dominated $B_s^0 \to K^+K^-$ [17].

The measurement of $\tau_{\rm L}$ in the $B_s^0 \to J/\psi\,\eta$ decay is updated by by using full Run 2 data. Since the final state of $B_s^0 \to J/\psi\,\eta$ decay is pure *CP* even, $\tau_{\rm L}$ in this decay can be directly measured by a simple decay-time fit instead of an amplitude analysis. A two-dimensional fit to the distributions of $J/\psi\,\eta$ mass and decay-time is performed. Fit projections of observables are shown in Figure 3. This study gives a result of $\tau_{\rm L} = 1.445 \pm 0.016(\text{stat}) \pm 0.008(\text{syst})$ ps, which agrees with Run 1 result of $\tau_{\rm L} = 1.479 \pm 0.034(\text{stat}) \pm 0.011(\text{syst})$ ps and is a factor of two more precise [18]. These two values are combined and then compared with previous results in Figure 4. The measurement presented in this proceeding is consistent with previous results of $\tau_{\rm L}$ and the combination is also consistent with the SM prediction.

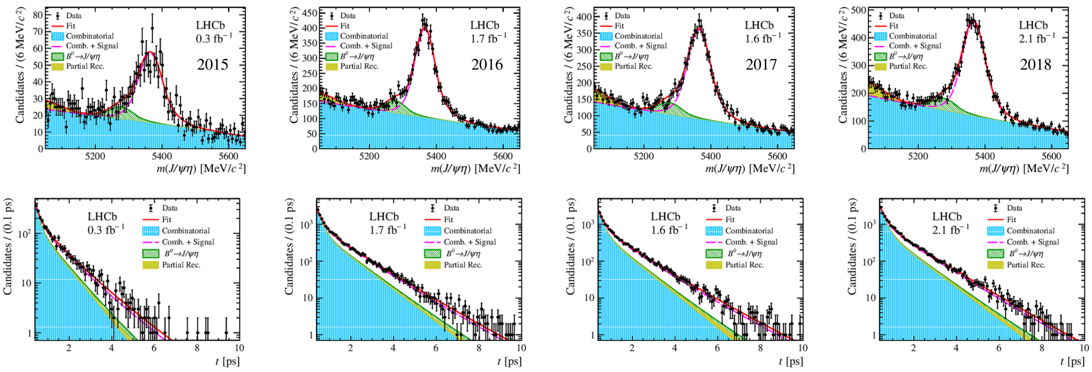

Figure 3: The distributions of $J/\psi\,\eta$ mass (top) and decay-time (bottom), which are superimposed by the fit results [18].

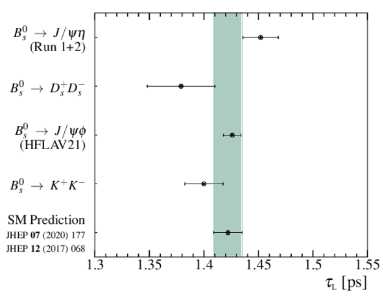

Figure 4: Comparison of $\tau_{\rm L}$ from LHCb measurements, HFLAV average and the SM prediction [18].

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