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Measurements of the effective $B^0_{(s)} \to h^+h^{'-}$ lifetimes

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Measurements of the effective lifetimes in the $B^0_s \to K^+K^-$, $B^0_d \to K^+\pi^-$ and $B^0_s \to \pi^+K^-$ decays are presented using pp collision data collected at a centre-of-mass energy of 7 TeV by the LHCb experiment, corresponding to 1.0 fb^{-1} of integrated luminosity. The analysis uses a data-driven approach to correct for the decay time acceptance. The measured effective lifetimes are

$$\begin{aligned}
\tau_{B^0_s \to K^+K^-} &= 1.407 \pm 0.016\,(\text{stat}) \pm 0.007\,(\text{syst})\ \text{ps},\\
\tau_{B^0_d \to K^+\pi^-} &= 1.524 \pm 0.011\,(\text{stat}) \pm 0.004\,(\text{syst})\ \text{ps},\\
\tau_{B^0_s \to \pi^+K^-} &= 1.60 \pm 0.06\,(\text{stat}) \pm 0.01\,(\text{syst})\ \text{ps}.
\end{aligned}$$

This is the most precise determination to date of the effective lifetime in the $B^0_s \to K^+K^-$ decay and provides constraints on contributions from physics beyond the Standard Model to the B^0_s mixing phase and the width difference $\Delta\Gamma_s$.

The 15th International Conference on B-Physics at Frontier Machines at the University of Edinburgh
14 -18 July, 2014
University of Edinburgh, UK

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 http://pos.sissa.it/

PoS(Beauty2014)062

1. Motivation

The study of the charmless $B^0_{(s)} \to h^+h^{'-}$ decay family, where $h^{(')}$ is either a pion or a kaon, offers attractive and promising opportunities to investigate the heavy flavour sector. These decays are interesting as they proceed through both tree and penguin processes, as shown in Fig. 1, while also being subject to the phenomenon of neutral meson mixing. It is a combination of these factors that cause them to be sensitive to *CP* violation and possible manifestations of any physics that may lie beyond the Standard Model.

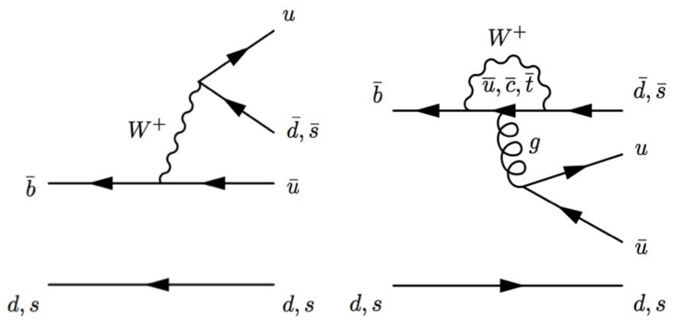

Figure 1: $B^0_{(s)} \to h^+h^{'-}$ (left) tree and (right) penguin processes.

The decay time distribution of a $B^0_{(s)} \to h^+h^{'-}$ decay, with equal contributions of both $B^0_{(s)}$ and $\bar{B}^0_{(s)}$ at the production stage, can be written as

$$\Gamma(t) \propto \left(1 - A_{\Delta\Gamma_{(s)}}\right) e^{-\Gamma^{(s)}_{\mathrm{L}} t} + \left(1 + A_{\Delta\Gamma_{(s)}}\right) e^{-\Gamma^{(s)}_{\mathrm{H}} t}, \tag{1.1}$$

where $\Gamma^{(s)}_{\mathrm{H}}$ and $\Gamma^{(s)}_{\mathrm{L}}$ are the decay widths of the heavy and light mass eigenstates respectively and $A_{\Delta\Gamma_{(s)}}$ is the decay rate asymmetry.

A single exponential distribution is used to measure the decay time distribution, although this yields the *effective* lifetime which may differ between decays due to the different relative proportions of the light and heavy eigenstate for the respective decays. The $B^0_s \to K^+K^-$ decay is predicted to have an initial state almost entirely consisting of the light mass eigenstate, thus the decay time distribution involves only one term. The Standard Model predictions also indicate a small amount of *CP* violation, where $A_{\Delta\Gamma_s}(B^0_s \to K^+K^-) = -0.972^{+0.014}_{-0.009}$ [1]. The $B^0_s \to \pi^+K^-$ flavour-specific lifetime is also measured, where the two mass eigenstates contribute equally. For the $B^0_d \to K^+\pi^-$ decay, the lifetime difference between the two mass eigenstates is so small that it can be neglected.

2. Methodology

The method to extract the effective lifetime is factorised into two components, a fit to the invariant mass and reconstructed decay time spectra. The two variables chosen are assumed to be uncorrelated. The reconstructed $B^0_{(s)} \to h^+h^{'-}$ invariant mass spectrum includes multiple final states that overlap, Figure 2, so particle identification is required to remove the contamination for each signal channel.

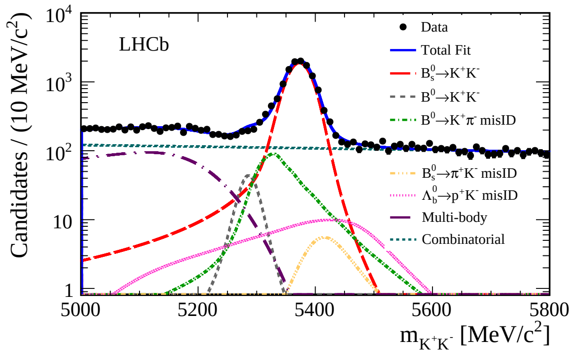

Figure 2: $B^0_s \to K^+K^-$ invariant mass spectrum with the result of the fit superimposed after kinematic and particle identification requirements.

To correct for acceptance effects in the reconstructed decay time distribution, a data-driven method is used to determine the per-event acceptance functions [3, 4]. Per-event *sWeights* [5], determined from the mass fit, are then used to distinguish between the signal and background components of the decay time spectrum, shown in Figure 3.

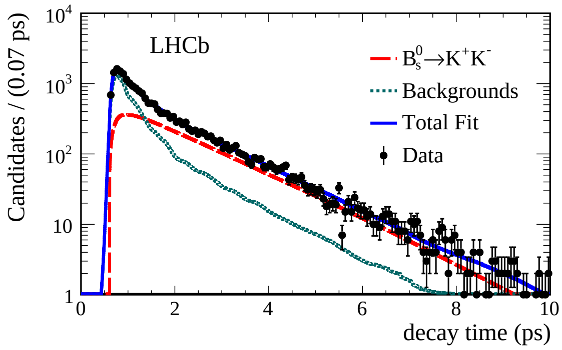

Figure 3: Decay time spectrum for $B^0_s \to K^+K^-$ with the result of the fit overlaid.

3. Results

The effective lifetime measurements of the $B^0_s \to K^+K^-$, $B^0_d \to K^+\pi^-$ and $B^0_s \to \pi^+K^-$ decays, using 1 fb^{-1} of data, are found to be

$$\tau_{B^0_s \to K^+K^-} = 1.407 \pm 0.016\,(\text{stat}) \pm 0.007\,(\text{syst})\text{ ps}, \tag{3.1}$$
$$\tau_{B^0_d \to K^+\pi^-} = 1.524 \pm 0.011\,(\text{stat}) \pm 0.004\,(\text{syst})\text{ ps}, \tag{3.2}$$
$$\tau_{B^0_s \to \pi^+K^-} = 1.60 \pm 0.06\,(\text{stat}) \pm 0.01\,(\text{syst})\text{ ps}. \tag{3.3}$$

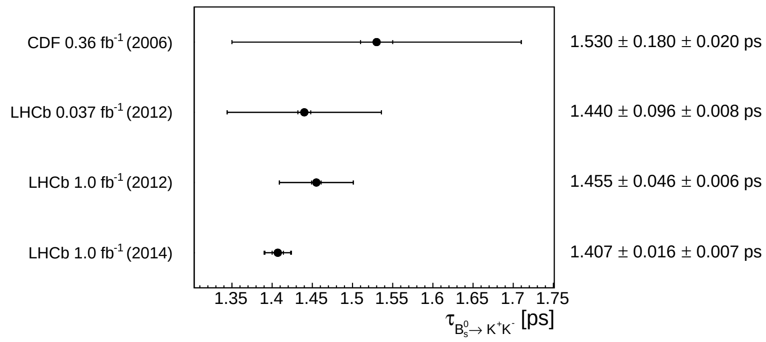

Figure 4: Evolution of the effective $B^0_s \to K^+K^-$ lifetime measurements.

The $B^0_s \to K^+K^-$ lifetime is the most precise measurement of this quantity, as shown in Figure 4, and combined with measurements of $\Delta\Gamma_s$ and Γ_s from [6] make a first direct determination of the asymmetry parameter $A_{\Delta\Gamma_s}$ to first order using

$$A_{\Delta\Gamma_s} = \frac{2\Gamma_s^2}{\Delta\Gamma_s} \tau_{B^0_s \to K^+K^-} - \frac{2\Gamma_s}{\Delta\Gamma_s}. \tag{3.4}$$

The value is found to be

$$A_{\Delta\Gamma_s} = -0.87 \pm 0.17 \pm 0.13, \tag{3.5}$$

which is consistent with the level of *CP* violation predicted by the Standard Model [1]. In the limit of no *CP* violation, the effective $B^0_s \to K^+K^-$ lifetime corresponds to a measurement of Γ_L of

$$\Gamma_\mathrm{L} = 0.711 \pm 0.008 \pm 0.004 \ \mathrm{ps}^{-1}. \tag{3.6}$$

The measured B^0_d effective lifetime is compatible with the current world average of 1.519 ± 0.007 ps [7], with the effective lifetime of the flavour-specific B^0_s also compatible with its respective world average of 1.463 ± 0.032 ps [7].

References

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