CP violation in hadronic B-decays at LHCb

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1 Introduction

The LHCb Experiment[1] is an experiment dedicated to precision measurements of CP violation and rare decays in the heavy flavour sector. In b-physics LHCb profits from the large $b\bar{b}$ production cross section[2] that gives access to a high statistics sample of the full spectrum of b-hadrons. Due to the very large total cross section an effective on-line event selection is required where the rate is reduced by a first level hardware trigger and further by two levels of software triggers. LHCb is specifically adapted to trigger on the hadronic final states discussed in this paper which is particularly difficult in the high-multiplicity environment of a hadron machine.

The measurements of hadronic B-decays in LHCb can roughly be divided into two classes, decays dominated by tree diagrams and decays with a significant contribution from loop processes. The former is generally insensitive to processes beyond the Standard Model (SM), whereas the latter is not. The tree amplitude of decays into final states containing only pions, kaons and protons are proportional to the Cabibbo-Kobayashi-Maskawa (CKM) element $|V_{ub}|$. Hence these decays have a significant contribution from loop processes due to the small magnitude of this factor. First results from these charmless decays are discussed in Section 2.

Decays containing charmed hadrons in the final states are dominated by tree diagrams. LHCb has a rich programme of studying these decays, notably it can determine the pure SM value of the CKM angle γ. Due to space constraints this topic will not be covered in this paper.

2 Charmless hadronic two-body decays

CP violation in charmless decays can be studied via measurements of time dependent asymmetries, time integrated asymmetries or by measuring the specific lifetimes of different decay modes. For instance, LHCb can determine the CKM angle γ from measurements of the time dependent asymmetries in $B_d^0 \to \pi\pi$ and $B_s^0 \to KK$[3].

The time integrated asymmetries can be compared to SM predictions and compared between decay modes. The time integrated asymmetry in $B_d^0 \to K\pi$ should be similar to that of $B_s^0 \to KK$. This is an approximate test of u-spin symmetry, since the decays only differ in the the spectator quark.

The specific lifetime of a decay into a CP-even final state such as $B_s^0 \to KK$ is sensitive both to the the decay rate difference $\Delta\Gamma_s$ and to the amount of direct and mixing-induced CP violation present in the decay[4]. Hence a measurement of this lifetime combined with other lifetime measurements is an indirect measurement of CP violation.

2.1 $B_d^0 \to K\pi$ and $B_s^0 \to K\pi$ CP asymmetries

The time integrated CP asymmetries for $B_d^0 \to K\pi$ and $B_s^0 \to K\pi$, which are defined as

$$A_{CP}^{d,s}(B_{d,s} \to K\pi) = \frac{\Gamma(\overline{B}_{d,s}^0 \to K^\mp\pi^\pm) - \Gamma(B_{d,s}^0 \to K^\pm\pi^\mp)}{\Gamma(\overline{B}_{d,s}^0 \to K^\mp\pi^\pm) + \Gamma(B_{d,s}^0 \to K^\pm\pi^\mp)}, \tag{1}$$

were measured by LHCb using 37 pb^{-1} of data collected in 2010[5]. These asymmetries are determined from the signal yields in the two charge-conjugate final states, giving the raw asymmetries $A_{RAW}^{d,s}$. Two different selections were used for the B_d^0 and the B_s^0 asymmetries to optimise the sensitivity.

The raw asymmetries are related to the physical asymmetries by $A_{RAW}^{d,s} = A_{CP}^{d,s} + A_D(K\pi) + \kappa_{s,d} \cdot A_P(B_{d,s})$, where $A_D(K\pi)$ and $A_P(B_{d,s}^0)$ are the detection and production asymmetries and $\kappa_{s,d}$ is a smearing factor from the oscillations.

The $K\pi$ detection asymmetry is determined from high statistics charm samples of D^0 decaying to KK, $K\pi$ and $\pi\pi$. The CP asymmetries of these decays are known[6] and the initial flavour state can determined from self-tagging decay chain $D^{*\pm} \to D^0\pi_s^\pm$, where the initial flavour is determined by the charge of the slow pion π_s. This give enough observables to determine the detection asymmetry $A_D(K\pi)$.

The production asymmetry for the B_s^0 mesons is washed out by the fast oscillations. For B_d^0 the factor κ_d is non-negligible and the production asymmetry is assumed to be the same as for $B^\pm$. $A_P(B^+)$ is estimated from the decay $B^\pm \to J/\Psi(\mu^+\mu^-)K^\pm$ where the CP asymmetry is known to be negligibly small[6]. The preliminary values of the physical asymmetries are

$$A_{CP}^d = -0.074 \pm 0.033 \text{ (stat)} \pm 0.008 \text{ (syst)} \tag{2}$$

$$A_{CP}^s = 0.15 \pm 0.19 \text{ (stat)} \pm 0.02 \text{ (syst)}. \tag{3}$$

2.2 The $B_s^0 \to K^+K^-$ effective lifetime

The proper time distribution for the $B_s^0 \to K^+K^-$ decay is described by a double exponential due to the non-zero value of rate difference $\Delta\Gamma_s$ for the B_s^0 system. The decay rate can be parametrised as

$$\Gamma_{B_s^0\to KK}(t) \propto \left[(1-A_{\Delta\Gamma})\, e^{-(\Gamma_s+\Delta\Gamma_s)t} + (1+A_{\Delta\Gamma})\, e^{-(\Gamma_s-\Delta\Gamma_s)t}\right] \tag{4}$$

where $A_{\Delta\Gamma}$ is the decay rate asymmetry. In the absence of CP violation, the CP even final state KK would only be accessible from the lighter, short-lived mass eigenstate. The SM predicts a small amount of CP violation where $A_{\Delta\Gamma}^{SM} = -0.972^{+0.014}_{-0.009}$[4]. Beyond Standard Model (BSM) processes may increase this value and hence alter the effective lifetime.

LHCb measured the specific lifetime of this decay using 37 pb^{-1} of data collected 2010[7] and modelling the proper time distribution with a single exponential. This gives an effective lifetime that is related to the parameters of the double exponential distribution in Equation 4[8]. The event selection introduces a bias of the observed proper time distribution, for instance, by choosing events with displaced decay vertices. The main experimental challenge in measuring the lifetime is to correct for this bias. Two independent methods were used.

One method measures the lifetime compared to the kinematically very similar $B_d^0 \to K\pi$ decay, where the acceptance functions cancel. The time integrated mass spectrum for both decays is fitted to extract the line shape parameters of the signal and combinatorial background. The sample is then split into 30 proper time bins with roughly the same number of events in each bin. A simultaneous fit across all time bin is performed, keeping the line shape parameters fixed and constraining the relative event yields of the $B_d^0 \to K\pi$ and $B_s^0 \to KK$ to follow an exponential distribution. This gives a measurement of the rate difference $\Gamma_{B_s^0\to KK} - \Gamma_{B_d^0\to K\pi}$.

Another method measures the absolute lifetime using per-event acceptance functions. These acceptance functions are determined by moving the primary vertex along the B meson momentum vector, emulating different hypothetical lifetimes and re-running the event selection for each lifetime[9]. This per-event information is used for conditional probabilities in an un-binned maximum likelihood fit. The lifetime distribution of the combinatorial background is modelled in a non-parametric way, as a sum of weighted gaussian kernel functions centred at the measured lifetime of each event[10]. The mass and time fits are shown in Figure 1.

The result of both methods agree and the preliminary value of the effective $B_s^0 \to KK$ lifetime is

$$\tau_{B_s^0\to KK} = 1.440 \pm 0.096 \text{ (stat)} \pm 0.008 \text{ (syst)} \pm 0.003 \text{ (model) ps}, \tag{5}$$

where the model error is related to the interpretation of single exponential fit.

3 Conclusions

LHCb has a rich programme studying CP violation in hadronic B decays and can determine the CKM angle γ from decays both sensitive and insensitive to BSM pro-

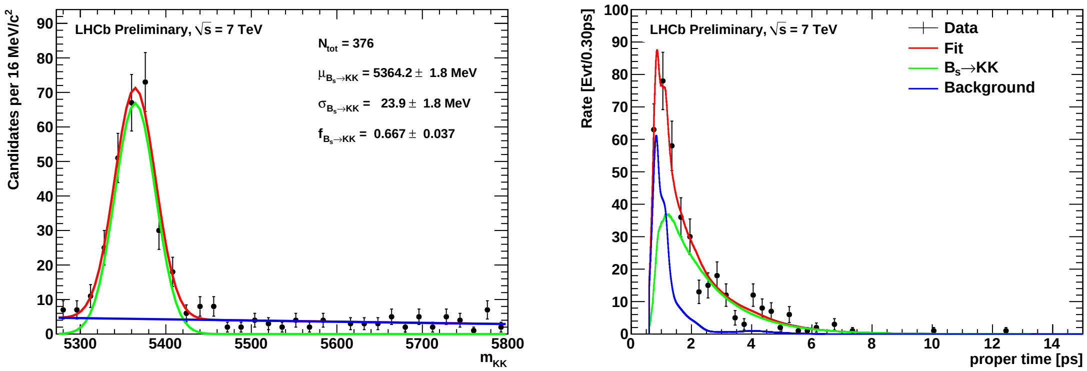

Figure 1: Left: Fit to the $B_s^0 \to K^+K^-$ mass spectrum with a Gaussian model of the signal and a first degree polynomial of the combinatorial background. Right: Fit to the total time distribution with the components of the signal and background shown in the plot. Both plots are for the absolute lifetime measurement.

cesses. This paper presents the direct CP violation measurements for $B_{d,s}^0 \to K\pi$ and a world best measurement of the effective lifetime of the decay $B_s^0 \to KK$ using the 2010 data set.

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