Charm mixing and CP violation at LHCb

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1 Introduction

LHCb [1], an experiment at the Large Hadron Collider (LHC), is dedicated to the study of b and c flavour physics. The abundance of charm particles produced in LHC offers an unprecedented opportunity for high precision measurements in the c sector, including measurements of CP violation and $D^0 - \overline{D}^0$ mixing. The high performance of LHCb detectors allows this potential to be fully exploited.

The charm sector is a promising field to probe for the effects of physics beyond the Standard Model (SM). The CP violation is expected to be small in the SM, while it can be enhanced by contribution from New Physics [3, 4]. Two measurements at the LHCb experiment are presented here: a measurement of time-integrated CP violation and measurements of time-dependent CP violation and mixing in two body D^0 decays.

2 Measurement of time-dependent CP violation in D^0 mixing

A measurement of CP violation in D^0 mixing can be performed in the study of two-body hadronic charm decays. It can be evaluated by the asymmetry of the proper-time (τ) of flavour-tagged decays to which both the direct and indirect CP violation could play a role [2]:

$$A_\Gamma \equiv \frac{\tau\left(\overline{D}^0 \to K^- K^+\right) - \tau\left(D^0 \to K^- K^+\right)}{\tau\left(\overline{D}^0 \to K^- K^+\right) + \tau\left(D^0 \to K^- K^+\right)} \approx \frac{1}{2}\,(A_m + A_d)\; y\,\cos\phi - x\,\sin\phi, \quad (1)$$

where $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta\Gamma/2\Gamma$ are the mixing parameters, ϕ is the CP violating weak phase, A_m represents a CP violation contribution from mixing and A_d from direct CP violation.

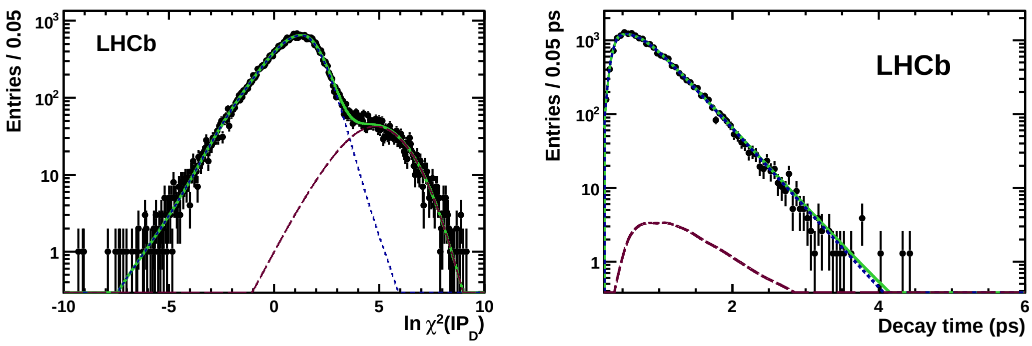

Figure 1: $\ln(\chi^2_{IP})$ fit projection, on the left, and lifetime fit projection, on the right, of $D^0 \to K^- K^+$ candidates on a logarithmic scale. The data are shown as points, the total fit (green), the prompt signal (blue), and the secondary signal (brown).

The flavour tagging of D^0 decays is obtained by reconstructing the decay $D^{*+} \to D^0 \pi_s^+$, where the charge of the slow pion (π_s) determines the flavour of the D^0 at the production. The trigger selection for heavy flavour decays reduces significantly the background, but it unavoidably biases the proper time distribution. A correction of these lifetime biasing effects is needed to properly extract A_Γ via absolute lifetime measurements. This analysis uses a data driven approach to evaluate the proper time acceptance, that describes the selection efficiency as a function of the D^0 proper time: the so-called 'swimming' method [5, 6, 7, 8]. The signal yield and the background contribution are extracted from fits to the reconstructed invariant mass. The main component of the remaining background is due to the secondary charm, i.e. D mesons produced from b hadron decays. This kind of background, indistinguishable by the invariant mass distribution, would bias the proper time measurements. A statistic separation is applied in the fit procedure using the variable $\ln(\chi^2_{IP})$[1] and its time dpendency. The lifetime measurement is obtained by a simultaneous fit of proper time and $\ln(\chi^2_{IP})$ including the acceptance function evaluated by the swimming method.

The measured lifetime is an effective lifetime since the fitted distribution includes also mistagged events, in which the D^0 is associated with a random slow pion. The mistag rate is evaluated by the fit of the difference between the mass of D^* and D^0 to be 1.8%. This has been take in account in the evaluation of A_Γ.

This measurement is based on a data sample equivalent to 0.03 fb^{-1} taken in 2010. The number of candidates selected is about 15k for each flavour tag, D^0 and $\overline{D}^0$. The results of the $\ln(\chi^2_{IP})$ and lifetime fit for $D^0 \to K^- K^+$ decays are

[1]The IP is the minimum distance of approach with respect to the primary vertex. The χ^2_{IP} is formed by using the hypothesis that the IP is equal to zero.

shown in Fig. 1. The asymmetry is evaluated from these lifetimes to be $A_\Gamma = (-5.9 \pm 5.9_{stat} \pm 2.1_{syst}) \cdot 10^{-3}$ [8]. This result is consistent with zero and hence shows no evidence of CP violation and it is in agreement with the current world average [9]. The main contributions to the systematic error are due to neglecting the combinatorial background and to the separation of prompt and secondary charm decays. The systematic uncertainty is expected to be significantly reduced by an improved treatment of the background events, which will be possible for a larger data sample.

3 Search for CP asymmetry in the time integrated two body D^0 decays

The time integrated asymmetry for a D^0 final state (f) is defined as

$$A_{RAW}(f) = \frac{N\left(D^0(f)\right) - N\left(\overline{D}^0(\overline{f})\right)}{N\left(D^0(f)\right) + N\left(\overline{D}^0(\overline{f})\right)} = \frac{N\left(D^{*+}\left(D^0(f)\pi_s^+\right)\right) - N\left(D^{*-}\left(\overline{D}^0(\overline{f})\pi_s^-\right)\right)}{N\left(D^{*+}\left(D^0(f)\pi_s^+\right)\right) + N\left(D^{*-}\left(\overline{D}^0(\overline{f})\pi_s^-\right)\right)}, \quad (2)$$

where $N(X)$ refers to the number of reconstructed events of decay X after background subtraction. The D^0 flavour is determined by the slow pion tagging method explained above.

The raw asymmetries may be written as a sum of various components, coming from both physics and detector effects: $A_{CP}^{RAW}(f)^* = A_{CP}(f) + A_P(D^*) + A_D(f) + A_D(\pi_s)$, where $A_{CP}(f)$ is the physics CP asymmetry, $A_P(D^*)$ the production asymmetry, $A_D(f)$ and $A_D(\pi_s)$ the detection asymmetry of the D^0 and of the slow pion.

Taking the asymmetry difference of the two final state, i.e. $D^0 \to KK$ and $D^0 \to \pi\pi$, the production and soft pion detection asymmetries will cancel. Moreover, for a two body decay of a spin-0 particle to a self-conjugate final state as in this case, there is no D^0 detector efficiency asymmetry contribution. No dependence remains on production or detection efficiencies, so this observable is extremely robust against systematic biases: $\Delta A_{RAW} = A_{RAW}(KK) - A_{RAW}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)$.

In a proton-proton collider, the production of heavy-flavour hadrons could not be CP symmetric in a given region of phase space. Possible variations of both selection efficiency and production and detection asymmetry as a function of p_T and η could generate second-order yield asymmetries that do not cancel out. A_{RAW} extraction is performed in bins of η and p_T. A binned maximum likelihood fit to the spectrum of the mass difference between D^* and D^0 (δ_m) is used to evaluate the yields. Examples of the fit are shown in Fig. 2.

Systematic uncertainties are assigned by repeating the analysis with an alternative description of the mass spectra lineshapes; with different fit windows for the D^0 mass; selecting events with only one candidate; varying the possible contribution of peaking background; comparing with the result obtained with different kinematic binning

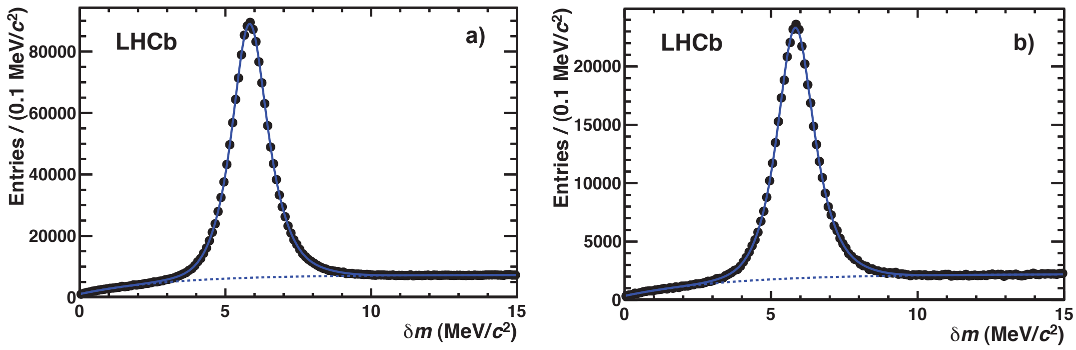

Figure 2: Fits to the δ_m spectra of $D^0 \to K^-K^+$ candidates (a) and of $D^0 \to \pi^-\pi^+$ candidates (b), with mass lying in the window between 1844 and 1884 MeV/c^2. The dashed line corresponds to the background component in the fit.

and with different fiducial cuts. The full change in result is taken as a systematic uncertainty and all uncertainties are added in quadrature.

The analysed data sample has an integrate luminosity of 0.6 fb^{-1} with a total signal yield of 1.8M tagged $D^0 \to K^-K^+$ and 381k tagged $D^0 \to \pi^-\pi^+$ candidates. A value of ΔA_{CP} is determined in each measurement bin using the result from $A_{RAW}(K^-K^+)$ and $A_{RAW}(\pi^-\pi^+)$. These values are found to be consistent throughout the (p_T, η) space, as well as for the different time periods and for both settings of the magnet polarity. A weighted average is therefore performed to yield the result $\Delta A_{CP} = (-0.82 \pm 0.21_{stat} \pm 0.11_{syst})\%$ [10]. This results to be the first evidence of CP violation in charm with a significance of 3.5 σ.

4 Conclusions

First evidence for CP violation in the charm sector has been observed by LHCb in the measurements of the integrated CP asymmetry. This measurement and the other searches of CP violation are obtained with only a sub-sample of data collected by LHCb experiment. Significant improvements in the precision up to per mille level are expected with the large data set collected in 2011 and in 2012 with an expected total integrated luminosity of about 3 fb^{-1}. In addition to these measurements, many others are under way, e.g. in 2-body decays the measurement of the mixing parameters using doubly Cabibbo-suppressed $D^0 \to K^+\pi^-$ decays. These results will allow to establish if and which New Physics effects are playing a role in the charm sector.

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