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Indirect *CP* violation in $\mathrm{D}^0 \to \mathrm{h}^+\mathrm{h}^-$ decays at LHCb

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Indirect *CP* violation in the D^0 system can be probed by measuring the parameter A_Γ, defined as the *CP* asymmetry of the effective lifetime of the D^0 meson decaying to a *CP* eigenstate. This can be significantly enhanced beyond Standard Model predictions by new physics. Measurements of A_Γ using $\mathrm{D}^0 \to \mathrm{K}^+\mathrm{K}^-$ and $\mathrm{D}^0 \to \pi^+\pi^-$ decays reconstructed from pp collisions collected by the LHCb experiment, corresponding to an integrated luminosity of 1.0 fb^{-1}, are presented. The results are

$$A_\Gamma(\pi\pi) = (+0.33 \pm 1.06 \pm 0.14) \times 10^{-3},$$
$$A_\Gamma(\mathrm{KK}) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3},$$

where the uncertainties are statistical and systematic, respectively. These are the most precise measurements of their kind to date, and show no evidence of *CP* violation.

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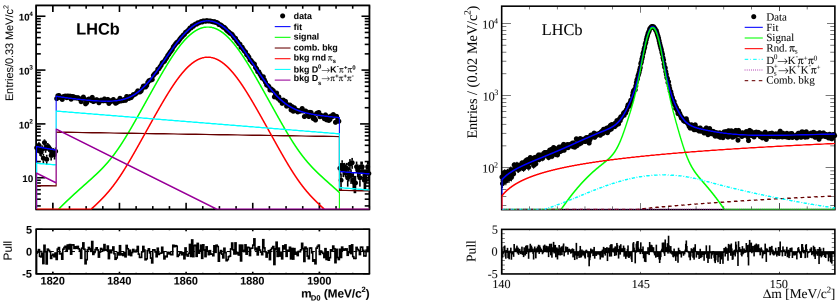

Figure 1: Fits to (left) the D^0 invariant mass distribution and (right) the $\Delta m \equiv m(D^{*+}) - m(D^0)$ distribution for $D^0 \to K^+K^-$ candidates from the data subset with magnet polarity down, recorded in the earlier of the two running periods. Only 10 % of candidates are retained in the regions of D^0 mass farthest from the signal peak.

1. Introduction

Similarly to the B^0 and B^0_s systems, the mass eigenstates of the D^0 system, $|D_{1,2}\rangle$, with masses $m_{1,2}$ and widths $\Gamma_{1,2}$, are superpositions of the flavour eigenstates $|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$, where p and q are complex and satisfy $|p|^2 + |q|^2 = 1$. This causes mixing between the $|D^0\rangle$ and $|\overline{D}^0\rangle$ states, and allows for "indirect" *CP* violation in mixing, and in interference between mixing and decay, when decaying to a *CP* eigenstate. Indirect *CP* asymmetries in the D^0 system can be significantly enhanced beyond Standard Model (SM) predictions by new physics [1]. In decays of D^0 mesons to a *CP* eigenstate f, indirect *CP* violation can be probed using [2]

$$A_\Gamma \equiv \frac{\hat{\Gamma}(D^0 \to f) - \hat{\Gamma}(\overline{D}^0 \to f)}{\hat{\Gamma}(D^0 \to f) + \hat{\Gamma}(\overline{D}^0 \to f)} \approx \eta_{CP}\left[\frac{1}{2}(A_m + A_d)y\cos\phi - x\sin\phi\right],$$

where $\hat{\Gamma}$ is the inverse of the effective lifetime of the decay, η_{CP} is the *CP* eigenvalue of f, $x \equiv 2(m_2 - m_1)/(\Gamma_1 + \Gamma_2)$, $y \equiv (\Gamma_2 - \Gamma_1)/(\Gamma_1 + \Gamma_2)$, $A_m \equiv (|q/p|^2 - |p/q|^2)/(|q/p|^2 + |p/q|^2)$, $A_d \equiv (|A_f|^2 - |\bar{A}_f|^2)/(|A_f|^2 + |\bar{A}_f|^2)$, with $\overset{(-)}{A}_f$ the decay amplitude, and $\phi \equiv arg(q\bar{A}_f/pA_f)$. The effective lifetime is defined as the average decay time of a particle with an initial state of $|D^0\rangle$ or $|\overline{D}^0\rangle$, *i.e.* that obtained by fitting the decay-time distribution of signal with a single exponential.

The LHCb detector is a forward-arm spectrometer, specifically designed for high precision measurements of decays of b and c hadrons [3]. During 2011 the experiment collected pp collisions at $\sqrt{s} = 7$ TeV corresponding to an integrated luminosity of 1.0 fb^{-1}. Due to the large $c\bar{c}$ production cross section [4], the decay-time resolution of approximately 50 fs for D^0 decays [5] and the excellent separation of π and K achieved by the detector [6], LHCb is very well suited to measure A_Γ with high precision.

2. Methodology

The decay chain $D^{*+} \to D^0\pi^+_s$ is used to determine the flavour of the D^0 candidates at production, via the charge of the π_s meson. The *CP*-even K^+K^- and $\pi^+\pi^-$ final states are used to calculate A_Γ [7]. The predominant candidate selection criteria require the K^+K^- or $\pi^+\pi^-$ tracks to

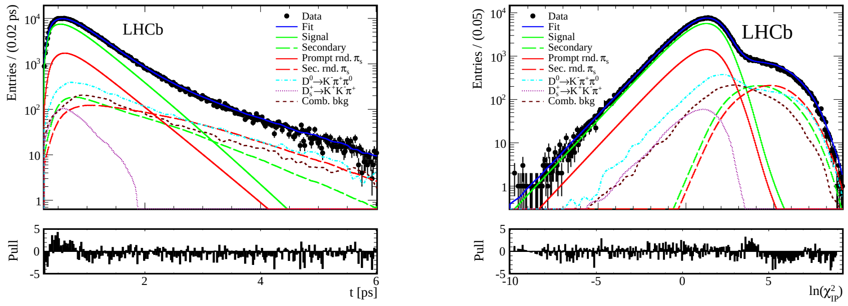

Figure 2: Fits to (left) the D^0 decay-time distribution and (right) the $\ln(\chi^2_{IP})$ distribution for $D^0 \to K^+K^-$ candidates from the data subset with magnet polarity down, recorded in the earlier of the two running periods.

have large impact parameter (IP), large transverse momentum (p_T), invariant mass within 50 MeV of the world average D^0 mass, and for the vector sum of their momenta to point closely back to the position of the pp collision. Using data corresponding to an integrated luminosity of 1.0 fb^{-1}, 4.8M $D^0 \to K^+K^-$ candidates and 1.5M $D^0 \to \pi^+\pi^-$ candidates are selected. The data are divided by D^0 flavour, the polarity of the LHCb dipole magnet, and two separate running periods. Combinatorial and partially reconstructed backgrounds are discriminated using a simultaneous fit to the distributions of D^0 mass and $\Delta m \equiv m(D^{*+}) - m(D^0)$. Examples of these fits are shown in Fig. 1 for $D^0 \to K^+K^-$ candidates, for data recorded with the magnet polarity down during the earlier of the two running periods.

A fit to the decay-time distribution of the candidates is then used to determine the effective lifetimes of the D^0 and $\overline{D}^0$ signal. Only candidates for which the D^{*+} is produced directly at the pp collision are considered as signal. The background from $B \to D^{*+}X$ decays is discriminated by simultaneously fitting the distributions of the decay time and the natural logarithm of the χ^2 of the hypothesis that the D^0 candidate originates directly from the pp collision ($\ln(\chi^2_{IP})$). The selection efficiency as a function of decay time is obtained from data using per-candidate acceptance functions, as described in detail in Ref. [8]. The decay-time and $\ln(\chi^2_{IP})$ distributions for combinatorial and specific backgrounds are obtained from the data using the discrimination provided by the mass and Δm fits to employ the $_s$Weights technique [9] with kernel density estimation [10]. Figure 2 shows fits to the distributions of decay time and $\ln(\chi^2_{IP})$ for $D^0 \to K^+K^-$ candidates, using the same data subset as Fig. 1. Inaccuracies in the fit model are examined as a source of systematic uncertainty, as discussed in the following section.

3. Results and systematics

The fits detailed in the previous section find

$$A_\Gamma(\pi\pi) = (+0.33 \pm 1.06 \pm 0.14) \times 10^{-3},$$
$$A_\Gamma(KK) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3},$$

where the uncertainties are statistical and systematic, respectively. These are the most precise measurements of their kind to date, and show no evidence of *CP* violation. The dominant systematic

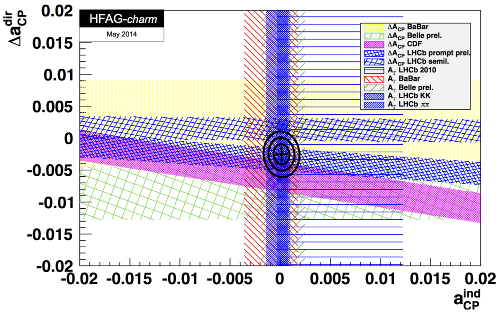

Figure 3: The world average of direct vs. indirect *CP* violation in $D^0 \to h^+h^-$ decays, reproduced from [11].

uncertainties arise from the modelling of the selection efficiency as a function of decay time, and the modelling of the background from $B \to D^{*+}X$ decays. Figure 3 shows the combined fit to measurements of direct and indirect *CP* violation in $D^0 \to h^+h^-$ decays, where these measurements dominate the constraints on $a_{CP}^{ind} \simeq -A_\Gamma$. The fit yields a world average of $a_{CP}^{ind} = (0.13 \pm 0.52) \times 10^{-3}$ and a p-value for zero *CP* violation of 5.1 % [11].

The precision of these measurements will be improved by the addition of 2.1 fb^{-1} of data already collected during 2012. Together with data to be recorded in run II, and, in time, following the LHCb upgrade, measurements with precisions of approximately 1×10^{-4} are possible, giving great potential for the discovery of indirect *CP* violation in the D^0 system.

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