CP-violation studies with charm decays at LHCb

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1 Introduction

The LHCb detector [1] at the Large Hadron Collider (LHC) is a single arm spectrometer dedicated to studying the properties of charm (D) and beauty (B) hadrons. LHCb has two Ring Imaging Cherenkov (RICH) detectors, giving kaon-pion separation in the momentum range 2-100 GeV/c, a tracking system with a momentum resolution between 0.3% and 0.5% over the same range, and a silicon vertex detector able to measure D and B hadron lifetimes with a resolution of approximately 50 fs.

The interest in studying CP-violation (CPV) in the charm sector stems from the fact that it is predicted to be small in the Standard Model. The argument, summarized in [2], is that charm hadrons decay into quarks of the first two generations whose mixing matrix is real, and hence there is no CPV possible in the dominant tree-level decays. CPV can manifest itself through penguin or box diagrams, but since these are suppressed by $V_{cb}V_{ub}^*$ the allowed level of Standard Model CPV does not exceed 1%. Although there is currently no evidence [3] for CPV in the charm sector, effects of up to 1% have not been completely ruled out by experiment. This makes it important to improve the precision of charm CPV measurements to below the 0.1% level, in order to constrain the precise nature of CPV in charm.

LHCb is ideally poised to carry out such a programme because of the LHC's large open charm cross-section of 6.10 ± 0.93 mb [4]: one in every ten LHC interactions results in the production of a charm hadron. This amounts to approximately 1.5 MHz of produced events which contain a charm hadron, of which only about 1 kHz can be written to storage for offline analysis. For this reason LHCb deploys a number of efficient real-time selection algorithms, called triggers, to select the most interesting charm events for later analysis. As a result, LHCb collects e.g. around 5×10^3 tagged $D^{*\pm} \to (D^0 \to K^+K^-)\,\pi^\pm$, or around 3×10^5 untagged $D^0 \to K^-\pi^+$, decays per pb^{-1} of integrated luminosity; at the time of writing, it already has the world's largest samples of two body D^0 decays on tape.

2 Time-integrated CP asymmetries in D^0 decays

The LHCb measurement of time-integrated CP asymmetries in two-body D^0 meson decays using data collected during 2010 running is described in detail in [5]. Time integrated asymmetries are measured for both tagged

$$A_{\text{raw}}(f) = \frac{N\left(D^0 \to f\right) - N\left(\overline{D}^0 \to f\right)}{N\left(D^0 \to f\right) + N\left(\overline{D}^0 \to f\right)}, \tag{1}$$

and untagged

$$A_{\text{raw}}(f)^* = \frac{N\left(D^{*+} \to D^0(f)\,\pi^+\right) - N\left(D^{*-} \to \overline{D}^0(f)\,\pi^-\right)}{N\left(D^{*+} \to D^0(f)\,\pi^+\right) + N\left(D^{*-} \to \overline{D}^0(f)\,\pi^-\right)}, \tag{2}$$

D^0 decays into final state f. In the case of decays into self-conjugate final states ($K^+K^-, \pi^+\pi^-$) only tagged asymmetries can be measured. The measured asymmetries are labeled "raw" as they are made up of not only the CP asymmetries, but also of various production and detection asymmetries caused by the initial matter-antimatter asymmetry present in LHC collisions and the nature of the LHCb detector. In particular, the efficiency of the RICH particle identification varies with the track charge and transverse momentum. In order to cancel these nuisance asymmetries, the difference of raw asymmetries in the KK and $\pi\pi$ modes is defined

$$\Delta A_{CP} = A_{\text{raw}}\left(K^+K^-\right)^* - A_{\text{raw}}\left(\pi^+\pi^-\right)^*. \tag{3}$$

This difference is obtained by measuring the number of signal events in each mode; example fits to the tagged mass spectra are shown in Fig. 1. Although the production and detection asymmetries cancel in this difference, they can vary as a function of the D^* momentum transverse to the LHC beamline (p_T) and pseudorapidity (η). Instead of relying on an average cancellation, fits are performed in twelve (p_T,η) bins and a weighted average used to arrive at the final value of ΔA_{CP}. Additional robustness checks are performed by varying the particle identification criteria, using an alternative signal selection, and monitoring the result stability as a function of time. The final result obtained with a dataset corresponding to approximately 37 pb^{-1} of integrated luminosity is

$$\Delta A_{CP} = (-0.28 \pm 0.70 \pm 0.25)\%, \tag{4}$$

where the first uncertainty is statistical and the second systematic, dominated by the modelling of the signal lineshape.

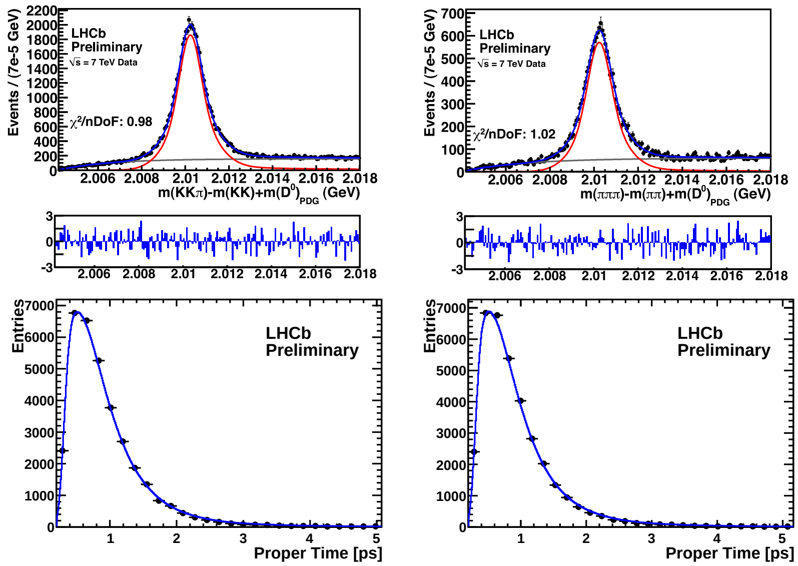

Figure 1: Top row: fits to the difference between the D^* and D^0 masses for a subset of the data, where the D^0 decays into K^+K^- (left) and $\pi^+\pi^-$ (right). Bottom row: fits to the $D^0 \to K^+K^-$ (left) and $\overline{D}^0 \to K^+K^-$ (right) lifetime. The fit results are 407.6 ± 2.4 and 409.2 ± 2.4 fs respectively (statistical errors only).

3 Time-dependent CP asymmetries in D^0 decays

The measurement of time-dependent CP asymmetry in the decays of D^0 mesons into a CP eigenstate can be related to the measurement of the lifetimes of the D^0 and $\overline{D}^0$ mesons in decays to this eigenstate, A_Γ:

$$A_\Gamma = \frac{\hat{\Gamma}\left(D^0 \to K^+K^-\right) - \hat{\Gamma}\left(\overline{D}^0 \to K^+K^-\right)}{\hat{\Gamma}\left(D^0 \to K^+K^-\right) + \hat{\Gamma}\left(\overline{D}^0 \to K^+K^-\right)} \approx \frac{A_m}{2} y \cos\left(\phi\right) - x \sin\left(\phi\right), \qquad (5)$$

where x, y are the D^0 mixing parameters, ϕ is the CP-violating weak phase, and $A_m \approx 1 - |\frac{q}{p}|^2$, where q, p are the amplitudes which define the mass eigenstates in terms of the flavour eignestates. $\hat{\Gamma}$ are the inverse lifetimes, fitted as single exponentials.

Because of the LHC's prodigious production of charm, LHCb is forced to deploy lifetime-biasing selections already at the trigger level, in order to maximize signal yield for a given output bandwidth. The analysis then pivots on the ability to measure the D^0 lifetime acceptance of this selection in a data-driven manner. This is done by measuring the lifetime acceptance on an event-by-event basis: for every event, the primary interaction from which the D^0 originated is moved along the direction of the D^0 momentum, thus varying the D^0 lifetime. At each point the full event selection chain, including the software trigger, is reevaluated, and the event accepted or rejected. This builds up the lifetime acceptance for that event, which is a sum of top-hat functions (since at each step the event either passes or fails). For more details of this procedure see [6, 7, 8]. At the time of the conference only a pseudo A_Γ measurement in the Cabbibo-Favoured control mode $D^0 \to K^-\pi^+$ was public: $A_\Gamma^{K\pi} = (-2 \pm 4) * 10^{-3}$, in agreement with the expectation of zero. The lifetime fits are shown in Fig. 1. The quoted uncertainty is statistical only.

4 Conclusion and outlook

This contribution has reviewed measurements of time-integrated and time-dependent CP asymmetries in the two-body decays of D^0 mesons performed with the LHCb detector at the LHC. The large open charm production cross-section of the LHC affords LHCb an unprecedented statistical reach in two-body D^0 decays, while the precise tracking and particle identification systems enable LHCb to reconstruct these signals with high purity. At the time of writing, LHCb's first measurements of time-dependent mixing and CP asymmetry parameters have been made public: [9]

$$y_{CP} = (5.5 \pm 6.3 \pm 4.1) \times 10^{-3}, A_\Gamma = (5.9 \pm 5.9 \pm 2.1) \times 10^{-3}, \tag{6}$$

based on 28 ± 3 pb^{-1} of data collected in 2010. The first uncertainty is statistical and the second systematic. LHCb has now collected over 1 fb^{-1} of integrated luminosity in 2011, and updates of all these measurements are in preparation with correspondingly reduced statistical uncertainties.

References

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