MEASUREMENTS OF DIRECT CP VIOLATION IN CHARM DECAYS AT LHCb

Sascha Stahl
Physikalisches Institut Heidelberg, Heidelberg University, Germany

Two searches for direct CP violation in $D^0 \to h^- h^+$ (where $h = K$ or π) are presented using data corresponding to an integrated luminosity of 1.0 fb^{-1} collected in 2011 by LHCb in pp collisions at a centre-of-mass energy of 7 TeV. One analysis uses D^0 mesons produced via a D^* resonance and the other analysis uses D^0 mesons originating from semileptonic b-decays. In the first case the flavour is tagged by the charge of the accompanying pion and in the latter by the muon charge. The difference of the CP-violating asymmetries ($\Delta A_{CP} = A_{CP}(K^- K^+) - A_{CP}(\pi^- \pi^+)$) in the two decay channels is measured to be

$$\Delta A_{CP}\,(\text{muon tagged}) = (0.49 \pm 0.30\,(\text{stat}) \pm 0.14\,(\text{syst}))\%\ ,$$
$$\Delta A_{CP}\,(\text{pion tagged}) = (-0.35 \pm 0.15\,(\text{stat}) \pm 0.10\,(\text{syst}))\%\ ,$$
$$\Delta A_{CP}\,(\text{LHCb}) = (-0.15 \pm 0.16)\%\ .$$

These results do not confirm evidence for CP violation in the charm sector.

1 Introduction

CP violation has been well established in the decays of K and B mesons. However, CP violation in the decays of D mesons has not yet been discovered. It is generally expected to be well below the 1% level in the Standard model [1,2]. The results of measurements of direct CP violation in the decays $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ reported by LHCb, CDF and Belle in 2011 and 2012 showed an evidence for CP violation (reference). The world average for direct CP violation quoted by the Heavy Flavor Averaging Group (HFAG) was $\Delta a_{CP}^{\text{dir}} = (-0.678 \pm 0.147)\%$ [4]. This generated discussion in the theory community if the size of the reported asymmetry can be accomodated within the Standard Model or if it is a sign of physics beyond the Standard Model [3]. Here, two measurements performed by the LHCb experiment using data corresponding to an integrated luminosity of 1.0 fb^{-1} collected in 2011 in pp collisions at a centre-of-mass energy of 7 TeV are presented. The measurement in promptly produced charm is a preliminary update of the previous result based on 0.6 fb^{-1} [5]. The measurement using semileptonic b decays to tag the D flavour is a new and independent measurement to be published in Physics Letter B [6]. These two measurements have a sensitivity of the same order but complementary systematical uncertainties.

2 Method

In both analyses the raw asymmetry is defined as

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

where N denotes the observed yield. The initial flavour of the D^0 is determined by the accompanying particle.

In the prompt analysis the decay $D^{*\pm} \to D^0\pi^\pm$ is reconstructed. Thus a D^0 meson is tagged by a π^+ and a $\overline{D}^0$ meson by a π^-. In the semileptonic analysis the charge of the muon from the decay $B \to D^0\mu X$ is used to tag the flavour of the D^0 meson. The X denotes all particles in the decay which are not reconstructed. The measured raw asymmetry $A_{\rm raw}$ can be expressed to first order in terms of the production asymmetry, A_P, the detection asymmetry, A_D, and the *CP* asymmetry A_{CP} as

$$A_{\rm raw} \approx A_{CP} + A_D + A_P \ . \tag{2}$$

The detection asymmetry arises from the tagging particle, either a pion or a muon and the production asymmetry, either that of the D or of the the B, is given by the production mode of the D^0 meson. Thus both differ between the two analyses. The production and the detection asymmetry are independent of the reconstructed D final state. Taking the difference of $A_{\rm raw}$ measured in $D^0 \to K^-K^+$ and $A_{\rm raw}$ measured in $D^0 \to \pi^-\pi^+$ gives a measurement of the difference in *CP* asymmetries between the two final states

$$\Delta A_{CP} = A_{\rm raw}(K^-K^+) - A_{\rm raw}(\pi^-\pi^+) \approx A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) \ . \tag{3}$$

Both production and detection asymmetries depend on the kinematics of the decay. Therfore in both analyses a weighting of $D^0 \to K^-K^+$ relative to $D^0 \to \pi^-\pi^+$ decays is applied such that they both cover the same kinematical phase space.

3 Determination of the asymmetries

3.1 Pion-tagged analysis

In the pion-tagged analysis the asymmetries in the $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays are determined by a chi-square fit to the binned $\delta m \equiv m(h^+h^-\pi^+) - m(h^+h^-) - m(\pi^+)$ distributions. The data set is further divided by magnet polarity and hardware trigger category. The hardware trigger distinguishes whether the D^{*+} candidate was used in the calorimeter trigger decision (TOS = Trigger On Signal) or if the event was triggered by something else (TIS = Triggered Independently of Signal). Both categories are disjoint. Two example distributions are shown in Fig. 1. The total number of signal candidates used in the pion-tagged analysis determined from the fit is 2.24×10^6 for $D^0 \to K^-K^+$ decays and 0.69×10^6 for $D^0 \to \pi^-\pi^+$ decays. The results of the individual asymmetry fits and the final ΔA_{CP} result are given in Table 1. The systematic uncertainty of this ΔA_{CP} measurement is determined to be 0.10%. The dominating systematic uncertainty is coming from selection cuts on the tagging pion.

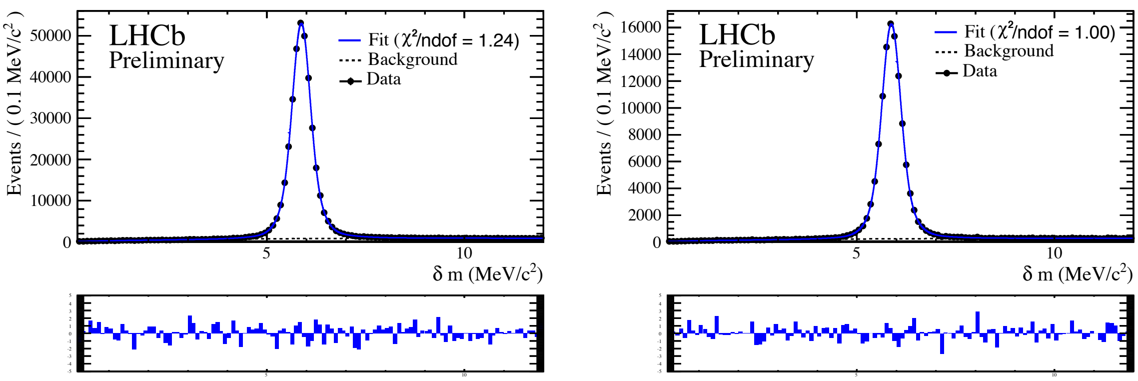

Figure 1: The δm distribution is shown for magnet up TOS (left) $D^0 \to K^-K^+$ and (right) $D^0 \to \pi^-\pi^+$

Table 1: Observed asymmetries with statistical uncertainties only. The data are divided into disjoint samples according to the $D^{*\pm}$ tag, the magnet polarity, and the hardware trigger category. The final result of ΔA_{CP} is given by the weighted average.

Quantity	Magnet polarity	Hardware trigger decision	Observed value [%]
ΔA_{CP}	Up	TOS	-0.62 ± 0.36
ΔA_{CP}	Down	TOS	-0.36 ± 0.30
ΔA_{CP}	Up	TIS	-0.30 ± 0.30
ΔA_{CP}	Down	TIS	-0.22 ± 0.25
ΔA_{CP}	combined		-0.35 ± 0.15

3.2 Muon-tagged analysis

In the muon-tagged analysis the asymmetries are determined by a binned maximum-likelihood fit to the D^0 mass distribution in the $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays. The sample is only divided into magnet polarity as 97% of the events are triggered by the hardware muon trigger. The events in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ are weighted to match their kinematics. Two example distributions are shown in Fig. 2. The results of the individual asymmetry fits and

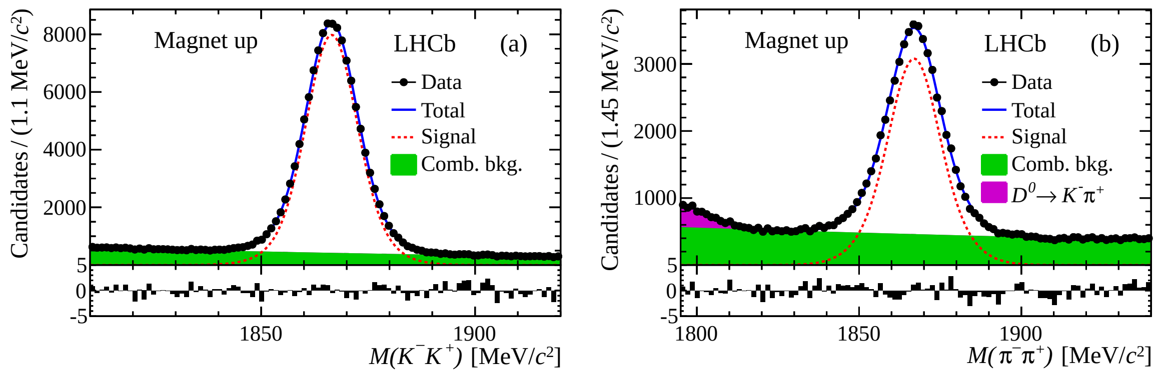

Figure 2: The D^0 mass distribution of the muon-tagged sample is shown for magnet up (left) $D^0 \to K^-K^+$ and (right) $D^0 \to \pi^-\pi^+$

ΔA_{CP} are given in Table 2. The total number of signal candidates determined from the fit is $(558.9 \pm 0.9) \times 10^3$ for $D^0 \to K^-K^+$ decays and $(221.6 \pm 0.8) \times 10^3$ for $D^0 \to \pi^-\pi^+$ decays. The systematic uncertainty of ΔA_{CP} is determined to be 0.14%. The main systematic uncertainty is coming from low lifetime backgrounds in the $D^0 \to \pi^-\pi^+$ decays below the $D^0 \to \pi^-\pi^+$ signal.

Table 2: Observed asymmetries with statistical uncertainties only. The data are divided into disjoint samples according to the D^0 decay mode, the magnet polarity. The final result of ΔA_{CP} is given by the arithmetic mean of the two magnet polarities.

	Magnet up	Magnet down	Mean
$A_{\rm raw}(K^-K^+)$	-0.39 ± 0.23	-0.20 ± 0.19	-0.29 ± 0.15
$A_{\rm raw}(\pi^-\pi^+)$	-1.25 ± 0.40	-0.29 ± 0.34	-0.77 ± 0.26
ΔA_{CP}	0.86 ± 0.46	0.09 ± 0.39	0.48 ± 0.30

4 HFAG combination

The Heavy Flavour Averaging Group (HFAG) has included the two previous reported results in their average of direct and indirect *CP* violation in charm decays [7]. The value obtained for the difference in direct *CP* violation is $\Delta a_{CP}^{\rm dir} = (-0.329 \pm 0.121)\%$ and the value for indirect *CP*

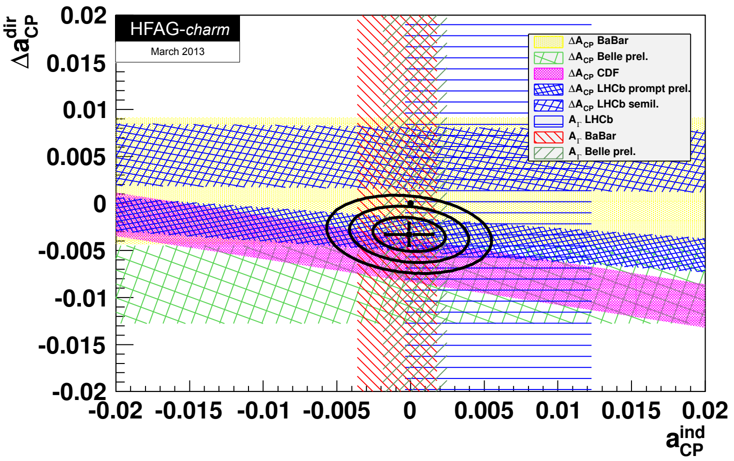

Figure 3: The D^0 mass distribution is shown for magnet up (left) $D^0 \to K^-K^+$ and (right) $D^0 \to \pi^-\pi^+$

violation is $a_{CP}^{\text{ind}} = (-0.010 \pm 0.162)\%$. The combined values together with all inputs is shown in Fig. 3.

5 Conclusion

The LHCb experiment has measured the size of direct *CP* violation with data taken in 2011 with two independent methods. The LHCb average quoted here, assumes that indirect *CP* violation is negligible. The *CP*-violating asymmetries are found to be

$$\begin{aligned} \Delta A_{CP}\,(\text{muon tagged}) &= (0.49 \pm 0.30\,(\text{stat}) \pm 0.14\,(\text{syst}))\% \ , \\ \Delta A_{CP}\,(\text{pion tagged}) &= (-0.35 \pm 0.15\,(\text{stat}) \pm 0.10\,(\text{syst}))\% \ , \\ \Delta A_{CP}\,(\text{LHCb}) &= (-0.15 \pm 0.16)\% \ . \end{aligned}$$

These results do not confirm evidence for *CP* violation in the charm sector. The measurements have been used in the latest average by HFAG giving $\Delta a_{CP}^{\text{dir}} = (-0.329 \pm 0.121)\%$ and $a_{CP}^{\text{ind}} = (-0.010 \pm 0.162)\%$.

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