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Recent Charm results from the B factories

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Summary. — I report on recent Charm physics results from *BABAR* and Belle experiments that are sensitive to physics beyond the Standard Model. I discuss the searches for *CP* violation in charged and neutral D meson decays and the recent evidence for *CP* violation in the difference of the *CP* asymmetries in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ modes and also the evidence in the $D^+ \to K^0_S\,\pi^+$ mode.

PACS 11.30.Er – Charge conjugation, parity, time reversal, and other discrete symmetries.
PACS 13.25.Ft – Decays of charmed mesons.

1. – Introduction

CP violation in D meson decays, though notoriously difficult to calculate precisely, is expected to be very small in the Standard Model: at the level of 10^{-3} or below [1, 2]. Relatively large *CP* asymmetries, at the percent level, might be a signature of new physics effects. Recent results from the LHCb experiment [3] reported evidence for direct *CP* violation measuring the difference of *CP* asymmetries in singly-Cabibbo-suppressed (SCS) $D^0 \to \pi^+\pi^-$ ([1]) and $D^0 \to K^+K^-$ decays, with a statistical significance of 3.5σ. The observed asymmetries are marginally compatible with the Standard Model (SM) but not conclusive for establishing new physics [4-6]. These intriguing results renew the interest for studying *CP* violation in charm meson decays. In particular, studying other decay modes with identical quark-level transitions, $c \to u\bar{d}d$ and $c \to u\bar{s}s$, is helpful for understanding if the observed evidence can be accommodated in the SM or not [4-6].

In addition, in the SM *CP* violation asymmetries in D meson decays with a K^0_S in the final state are expected to be $A_{CP} = [-0.332 \pm 0.006]\%$ [7], originated by *CP* violation in the $K^0\,\overline{K}{}^0$ mixing. The $\pm$ sign depends on the fact that a K^0 or a $\overline{K}{}^0$ is produced in the decay. The SM prediction has to be corrected for the detector acceptance as

([1]) Charge conjugation is implied throughout the paper unless otherwise stated.

TABLE I. – *Summary of the CP asymmetry results in SCS modes* $D^0 \to K^+K^-$ *and* $D^0 \to \pi^+\pi^-$.

Experiment	A_{CP}^{KK} (%)	$A_{CP}^{\pi\pi}$ (%)	ΔA_{CP} (%)
BABAR (2008) [9]	$0.00 \pm 0.34 \pm 0.13$	$-0.24 \pm 0.52 \pm 0.22$	–
LHCb (2012) [3]	–	–	$-0.82 \pm 0.21 \pm 0.11$
CDF (2012) [10, 11]	$-0.24 \pm 0.22 \pm 0.09$	$0.22 \pm 0.24 \pm 0.11$	$-0.62 \pm 0.21 \pm 0.10$
Belle (2012) [12]	$-0.32 \pm 0.21 \pm 0.09$	$0.55 \pm 0.36 \pm 0.09$	$-0.87 \pm 0.41 \pm 0.06$

a function of the decay time [8]. The correction is at the level of few percent at the B factories. Sizable difference from this value would indicate *CP* violation in the $\Delta C = 1$ quark transition, possibly due to new physics effects.

2. – Search for *CP* violation in singly-Cabibbo-suppressed decays

2˙1. *Evidence for direct CP violation in* $D^0 \to K^+K^-$ *and* $D^0 \to \pi^+\pi^-$ *decays.* – SCS are uniquely sensitive to new physics among all hadronic D decays in $c \to uq\bar{q}$ transitions and to new contributions to the $\Delta C = 1$ QCD penguin and chromomagnetic dipole operators [1]. In table I are reported the results for the *CP* asymmetries in the decay modes $D^0 \to K^+K^-$ (A_{CP}^{KK}), $D^0 \to \pi^+\pi^-$ ($A_{CP}^{\pi\pi}$) and the difference between the two asymmetries ($\Delta A_{CP} = A_{CP}^{KK} - A_{CP}^{\pi\pi}$). The *CP* asymmetries in the single modes are sensitive to direct and indirect *CP* violation, while ΔA_{CP} is mostly sensitive to direct *CP* violation. In the measurement of ΔA_{CP}, the systematic errors related to the asymmetries in the reconstruction and in the production of D^0 and $\overline{D}{}^0$ candidates cancel. The world average value is $\Delta A_{CP} = [-0.74 \pm 0.15]\%$ which is different from zero with a statistical significance of 4.9σ and it represents evidence for direct *CP* violation in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays.

2˙2. *Measurement of* $D^0\,\overline{D}{}^0$ *mixing and search for indirect CP violation in* $D^0 \to K^+K^-$ *and* $D^0 \to \pi^+\pi^-$ *decays.* – The *BABAR* and the Belle experiments have recently presented updated results for the measurement of the mixing parameter y_{CP} and the *CP* violation parameter ΔY (A_Γ for Belle). The measurements are based on the ratio of lifetimes simultaneously extracted from a sample of D^0 mesons produced through the flavour-tagged process $D^{*+} \to D^0\,\pi^+$, where D^0 decays to $K^-\pi^+$, K^-K^+, $\pi^-\pi^+$. *BABAR* uses the additional sample of untagged decays $D^0 \to K^-\pi^+$ and $D^0 \to K^-K^+$. The lifetimes of *CP*-even modes K^-K^+, $\pi^-\pi^+$ are compared to that of the *CP*-mixed mode $K^-\pi^+$ in order to measure y_{CP}, which is proportional to the ratio of the lifetimes, and ΔY (A_Γ) which is proportional to the difference of the effective lifetimes of D^0 and $\overline{D}{}^0$ into *CP*-even modes. *BABAR* measures $y_{CP} = [0.72 \pm 0.18(\text{stat}) \pm 0.12(\text{syst})]\%$ and $\Delta Y = [0.09 \pm 0.26(\text{stat}) \pm 0.06(\text{syst})]\%$ using a data sample of $468\,\text{fb}^{-1}$ [13]. Belle measures $y_{CP} = [1.11 \pm 0.22(\text{stat}) \pm 0.11(\text{syst})]\%$ and $A_\Gamma = [-0.03 \pm 0.20(\text{stat}) \pm 0.08(\text{syst})]\%$ using a data sample of $976\,\text{fb}^{-1}$. The y_{CP} measurements represent evidence for $D^0\,\overline{D}{}^0$ mixing with a significance of 3.3σ in the case of *BABAR* (most precise measurement up to date) and 4.5σ in the case of Belle [14].

2˙3. *Search for direct CP violation in charged D mesons with K^0_S in the final state.* – The *BABAR* experiment has recently measured, using 469 fb^{-1} of data, *CP* asymmetries in the $D^+ \to K^0_S\, K^+$ and $D^+_s \to K^0_S\, \pi^+$ decay modes [15] to be $A_{CP} = [0.13 \pm 0.36(\text{stat}) \pm 0.25(\text{syst})]\%$ and $A_{CP} = [0.6 \pm 2.0(\text{stat}) \pm 0.3(\text{syst})]\%$ respectively. The contribution to the *CP* asymmetries due to the $\Delta C = 1$ transition has been measured to be $A^{\Delta C}_{CP} = [0.46 \pm 0.36(\text{stat}) \pm 0.25(\text{syst})]\%$ and $A^{\Delta C}_{CP} = [0.3 \pm 2.0(\text{stat}) \pm 0.3(\text{syst})]\%$ for the two cases. Results are consistent with no *CP* violation in the $\Delta C = 1$ quark transition.

2˙4. *Search for direct CP violation in $D^+ \to K^+K^-\pi^+$ decay.* – The *BABAR* experiment has recently studied *CP* violation in the $D^+ \to K^+K^-\pi^+$ decay using a data sample of 476 fb^{-1} [16]. The 3-body decay studied proceeds mainly through quasi–two-body decays with resonant intermediate states, allowing to probe the Dalitz plot substructure for asymmetries in both the magnitudes and phases of the intermediate states. The *CP*-violating decay rate asymmetry, A_{CP} , was determined to be $(0.35 \pm 0.30(\text{stat}) \pm 0.15(\text{syst}))\%$. The *CP* asymmetries in different regions of the Dalitz plot, defined by the reconstructed invariant mass squared $m^2(K^-K^+), m^2(K^-\pi^+)$, were measured to be $A_{CP} = [-0.65 \pm 1.64(\text{stat}) \pm 1.73(\text{syst})]\%$ below the $\bar{K}^*(892)^0$ region, $A_{CP} = [-0.28 \pm 0.37(\text{stat}) \pm 0.21(\text{syst})]\%$ around the $\bar{K}^*(892)^0$ peak, $A_{CP} = [-0.26 \pm 0.32(\text{stat}) \pm 0.45(\text{syst})]\%$ around the $\phi(1020)$ peak, $A_{CP} = [1.05 \pm 0.45(\text{stat}) \pm 0.31(\text{syst})]\%$ above the $\bar{K}^*(892)^0$ and the $\phi(1020)$ regions.

Model-independent techniques were used to search for *CP* violation in the Dalitz plot and they were based on a comparison of the binned D^+ and D^- Dalitz plots and on a comparison of the Legendre-moment weighted distributions in the K^+K^- or $K^-\pi^+$ system. The distribution of normalized residuals of the D^+ and D^- Dalitz plots in equally populated bins (~ 1000 events per bin) were fitted with a Gaussian with a mean of 0.08 ± 0.15 and a width of 1.11 ± 0.15, which corresponds to a probability of 72% that the two Dalitz plots are consistent with no *CP* asymmetry. The comparison of Legendre-moment for the K^+K^- or $K^-\pi^+$ systems was found to be consistent with no *CP* violation with a probability of 11% and 13%, respectively.

A model-dependent technique based on a comparison of parameterized fits to the two Dalitz plots was also used to search for *CP* violation. The D^+ decay amplitude was parameterized as a coherent sum of amplitudes describing all the relevant two-body intermediate states (resonances) plus a constant amplitude over the Dalitz plot for the non-resonant (NR) contribution. The Dalitz plot is described with 16 resonances: the most relevant in terms of fit fractions are the $\bar{K}^*(892)^0$ $(21.15 \pm 0.20)\%$, the $\phi(1020)$ $(28.42 \pm 0.13)\%$ and the $\bar{K}^*(1430)^0$ $(25.32 \pm 2.24)\%$. The results of the fit to the D^+ and D^- Dalitz plot distributions do not show any evidence for *CP* violation in the following amplitudes: $\bar{K}^*(892)^0$, $\bar{K}^*(1430)^0$, $\phi(1020)$, NR, $\kappa(800)$, $a_0(1450)^0$, $f_0(980)$, $f_0(1370)$.

3. – Search for *CP* violation in Cabibbo-favored decays

3˙1. *Evidence for CP violation in $D^+ \to K^0_S\, \pi^+$.* – Evidence for *CP* violation was found by the *BABAR* and Belle experiments in the CF $D^+ \to K^0_S\, \pi^+$ decay. The Belle experiment has measured $A_{CP} = [-0.363 \pm 0.094(\text{stat}) \pm 0.067(\text{syst})]\%$ using 977 fb^{-1} of data [17], while the *BABAR* experiment has measured $A_{CP} = [-0.44 \pm 0.13(\text{stat}) \pm 0.10(\text{syst})]\%$ using 469 fb^{-1} of data [18]. The statistical significance of *CP* violation is about 3.2σ and 2.7σ respectively. Both results are compatible with the predictions of the SM of $(-0.332 \pm 0.006)\%$ corrected for the detector acceptance as a function of the decay time.

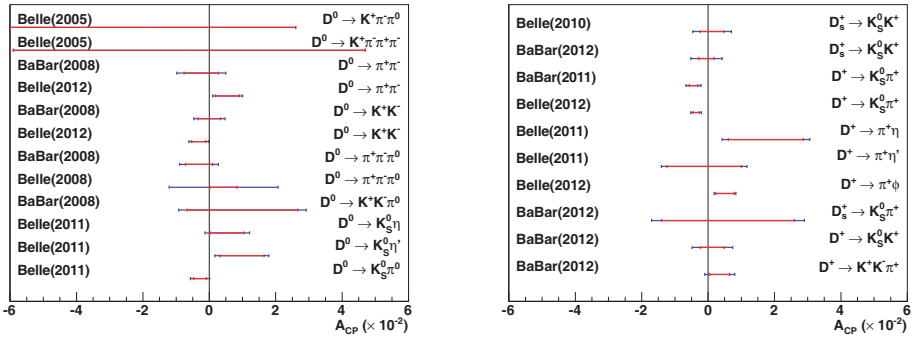

Fig. 1. – Summary of *CP* violation asymmetry results from the *B* factories for D^0 (left plot) and charged D mesons (right plot).

The *BABAR* experiment has also measured the *CP* violation asymmetry for the CF $D_s^+ \to K_S^0\, K^+$ decay to be $A_{CP} = [-0.05 \pm 0.23(\text{stat}) \pm 0.24(\text{syst})]\%$ and $A_{CP}^{\Delta C} = [0.28 \pm 0.23(\text{stat}) \pm 0.24(\text{syst})]\%$ [15], compatible with no *CP* violation in the $\Delta C = 1$ transition.

4. – Conclusions

Recent results from the *B* factories relative to *CP* asymmetries in time-integrated analyses and mixing and *CP* violation parameters in time-dependent analyses have been presented. A summary of the results is reported in fig. 1. The *B* factories have studied several SCS D decay modes with identical quark transitions to $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$, where evidence of *CP* violation was found with statistical significance of about 4.9σ, when combining all the available results. The measurements provide useful information for the understanding of the origin of the observed *CP* violation. The statistical error is the dominant source of uncertainty for the measurements presented here. The main systematic error in the measurements of *CP* asymmetries is relative to the charge tracking efficiency asymmetries of the detector which is determined using *ad hoc* control samples from data. Improvements in the precision of these measurement are therefore expected when larger data samples will be available from the present and future experiments.

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