Recent results on $CP$ violation in charm and $\tau$ decays from $BABAR$

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Abstract. In the Standard Model $CP$ violation in charm decays is expected to be very small, at the level of 0.1% or below, while $CP$ violation in $\tau$ decays is predicted to be negligible. A significant excess of $CP$ violation with respect to the Standard Model predictions would be a signature of new physics. We report on recent searches for $CP$ violation in charm meson decays and in $\tau$ lepton decays at $BABAR$, using a data sample corresponding to an integrated luminosity of about 470 $fb^{-1}$. In particular, we report on searches for $CP$ violation in the decay modes with a $K^0_S$ in the final state, such as $D^+ \rightarrow K^0_SK^+$, $D^+_s \rightarrow K^0_SK^+$ and $D^+_s \rightarrow K^0_SP^+$ and $\tau^+ \rightarrow \pi^+K^0_S\nu_{\tau}$, and in the 3-body $D^+ \rightarrow K^+K^-\pi^+$ decay. A lifetime ratio analysis of $D^0 \rightarrow K^+K^-\pi^+$ with respect to $D^0 \rightarrow K^-\pi^+$ decays, which is sensitive to $D^0$-$\bar{D}^0$ mixing and $CP$ violation, is also presented here.

1. Introduction
In the Standard Model (SM) $CP$ violation ($CPV$) is accommodated by the CKM [1, 2] mechanism which regulates the mixing of the three families of quarks. This mechanism has been proved to work well according to the experimental results that have been provided mostly by the $B$-Factory experiments, $BABAR$ and Belle, during the last decade. However, the CKM mechanism is not sufficient to describe the absence of antimatter in the universe, and so this represents an open question for both experimental and theoretical physicists. Other sources of $CP$ violation are currently under investigation, and the charm and $\tau$ sectors offer interesting probes for this purpose.

In the charm meson decays $CPV$ is expected to be at the level of 0.1% or less [3, 4], however the predictions are affected by large theoretical uncertainties due to long distance interactions. The recent evidence of $CPV$ in the difference of time-integrated asymmetries between $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$ singly Cabibbo-suppressed (SCS) decays, from the LHCb [5] and the CDF [6, 7] experiments, has renewed the interest for searching new physics (NP) in the charm sector. While the observed asymmetries need to be further assessed \(^1\), the present results are marginally compatible with the SM but are not conclusive for establishing NP [10, 11, 12]. The study of other SCS decays with identical quark transitions should help in understanding the source of any observed $CPV$ in charm decays, while evidence of indirect $CP$ violation in $D^0$-$\bar{D}^0$ mixing would be a clear sign of NP. In $\tau$ decays $CPV$ is expected to be negligible in the SM, and any

\(^1\) At the time of the writing of this document, new results were presented by the LHCb Collaboration [8, 9] that do not confirm evidence for $CPV$ in the difference of time-integrated asymmetries between $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$ decays.
2. Search for $CP$ violation in $D^+ \to K_s^0 K^+$ and $D_s^+ \to K_s^0 \pi^+$ decays

In $D$ meson decays with a $K_s^0$ in the final state, $CP$-violating asymmetries defined as

$$A_{CP} = \frac{\Gamma(D^+_{(s)} \to K_s^0 h^+) - \Gamma(D^-_{(s)} \to K_s^0 h^-)}{\Gamma(D^+_{(s)} \to K_s^0 h^+) + \Gamma(D^-_{(s)} \to K_s^0 h^-)}$$

(1)

can receive contributions from $CP$ in $\Delta C = 1$ quark transitions ($A_{CP}^{\Delta C}$), and from $CP$ in $K^0$-$\bar{K}^0$ mixing ($A_{CP}^{K^0}$). In the SM, $A_{CP}^{\Delta C}$ is difficult to calculate precisely, however it is expected to be very small, at the level of $10^{-3}$ or less [3, 4]. The value for the contribution from $K^0$-$\bar{K}^0$ mixing is precisely determined to be $A_{CP}^{K^0} = [\pm 0.332 \pm 0.006]\%$ [13], where the $\pm$ sign depends on whether a $K^0$ (+) or a $\bar{K}^0$ (-) is produced in the decay. The SM prediction has to be corrected for the detector acceptance as a function of the decay time [14], and the correction is at the level of few percent at the $B$ factories. A sizeable deviation of the measured $A_{CP}$ value from the $A_{CP}^{K^0}$ predicted value would indicate $CP$ violation in the $\Delta C = 1$ quark transition, and might indicate new physics effects.

The BABAR experiment has recently measured $CP$ asymmetries in the $D^+_{(s)} \to K_s^0 K^+$ and $D_s^+ \to K_s^0 \pi^+$ decay modes [15] using a data sample corresponding to an integrated luminosity of 469 fb$^{-1}$. For this analysis a technique similar to that used in the search for $CP$ in $D^+ \to K_s^0 \pi^+$ [16] was employed.

The reconstructed asymmetry $A_{rec}$ is defined as

$$A_{rec} = \frac{N_{D^+_{(s)}} - N_{D^-_{(s)}}}{N_{D^+_{(s)}} + N_{D^-_{(s)}}} = A_{CP} + A_{FB} + A_{e}$$

(2)

where $N_{D^+_{(s)}}$ ($N_{D^-_{(s)}}$) is the number of $D^+_{(s)}$ ($D^-_{(s)}$) decays determined from the fit to the reconstructed invariant mass distribution of the $D^+_{(s)}$ mesons, $A_{FB}$ is the forward-backward ($FB$) asymmetry, and $A_{e}$ is the detector-induced charge reconstruction asymmetry; $A_{FB}$ originates from the $FB$ asymmetry in $e^+e^- \to \phi$ production, coupled with the asymmetric acceptance of the detector, and is measured on data together with $A_{CP}$. The fits to the $m(K_s^0 h)$ distributions yield $(159.4 \pm 0.8) \times 10^3$ signal events for $D^+ \to K_s^0 K^+$, $(288.2 \pm 1.1) \times 10^3$ for $D_s^+ \to K_s^0 K^+$, and $(14.33 \pm 0.31) \times 10^3$ for $D_s^+ \to K_s^0 \pi^+$. Corrections for the detector-induced charge reconstruction asymmetry are estimated using a data control sample. The method exploits the fact that $\Upsilon(4S) \to BB$ events provide a sample of evenly populated positive and negative tracks, free of any physics-induced asymmetries, allowing the determination of detector-related asymmetries in the reconstruction of charged-particle tracks.

The $CP$-violating asymmetries $A_{CP}$ for the $D^+ \to K_s^0 K^+$, $D_s^+ \to K_s^0 K^+$, and $D_s^+ \to K_s^0 \pi^+$ decays are determined to be $[0.13 \pm 0.36(stat) \pm 0.25(syst)]\%$, $[-0.05 \pm 0.23(stat) \pm 0.24(syst)]\%$, and $[0.6 \pm 2.0(stat) \pm 0.3(syst)]\%$, respectively. The primary sources of systematic uncertainty are due to the statistical uncertainties in the determination of the charge asymmetry in track reconstruction efficiency.

The contribution to the $CP$ asymmetries due to the $\Delta C = 1$ transition is measured to be $[0.46 \pm 0.36(stat) \pm 0.25(syst)]\%$, $[0.28 \pm 0.23(stat) \pm 0.24(syst)]\%$, and $[0.3 \pm 2.0(stat) \pm 0.3(syst)]\%$ for the respective decay processes. The results are consistent with zero, and with the SM predictions within one standard deviation.
3. Search for direct CP violation in $D^+ \to K^+K^−\pi^+$ decay

The $\text{BaBar}$ experiment has recently searched for CPV in the singly Cabibbo-suppressed $D^+ \to K^+K^−\pi^+$ decay using a data sample corresponding to an integrated luminosity of 476 $\text{fb}^{-1}$ [17]. The 3-body decay proceeds mainly through quasi-two-body decays with resonant intermediate states, which allows the investigation of the Dalitz plot substructure for asymmetry in both magnitude and phase for each intermediate state. In the search for CPV, 5 different approaches were adopted involving: a measurement of the integrated CP asymmetry, a measurement of the CP asymmetry in four regions of the Dalitz plot, a comparison of the binned $D^+$ and $D^−$ Dalitz plots, a comparison of the Legendre-polynomial-moment weighted distributions in the $K^+K^−$ and $K^−\pi^+$ systems, and a comparison of the results of a parameterized fit to the $D^+$ and $D^−$ Dalitz plots. Only the last is model-dependent, while the previous four approaches are model-independent.

The center-of-mass (CM) momentum of the $D^+$ meson is required to be between 2.4 and 5.0 GeV/$c$. Particle identification is applied to two of the three tracks, requiring the presence of two oppositely charged kaon candidates. At low momentum, track reconstruction efficiency is reduced, and differences in nuclear cross sections can lead to asymmetries in the reconstruction of charged-particle tracks. Hence, the pion candidate is required to have $p_t > 300 \text{MeV}/c$, where $p_t$ is the magnitude of the momentum projection onto the plane perpendicular to the $e^+e^−$ collision axis. The signal yield is about 223,700 events, with signal purity of about 92%. In this case, the detector-induced charged-particle reconstruction asymmetry is estimated using a high purity control sample of $e^+e^− \to \tau^+\tau^−$ events for which $\tau^\pm \to \mu^\pm \nu\bar{\nu}$ or $\tau^\pm \to h^±h^±h^±\nu\bar{\nu}$, where two of the three hadrons ($h$) are required to be consistent with pions from $\rho^0$ decays.

The CP-violating decay rate asymmetry, $A_{CP}$, was determined to be $(0.37 \pm 0.30\text{(stat)} \pm 0.15\text{(syst)})\%$. The CP asymmetries in different regions of the Dalitz plot, defined by the reconstructed invariant mass squared values $m^2(K^+K^−)$ and $m^2(K−\pi^+)$, are reported in Table 1.

| Dalitz plot region | $A_{CP}$ (%) |
|-------------------|-------------|
| Below $K^+(892)^0$ (A) | $-0.7 \pm 1.6\text{(stat)} \pm 1.7\text{(syst)}$ |
| $K^+(892)^0$ (B) | $-0.3 \pm 0.4\text{(stat)} \pm 0.2\text{(syst)}$ |
| $\phi(1020)$ (C) | $-0.3 \pm 0.3\text{(stat)} \pm 0.5\text{(syst)}$ |
| Above $K^+(892)^0$ and $\phi(1020)$ (D) | $1.1 \pm 0.5\text{(stat)} \pm 0.3\text{(syst)}$ |

Table 1. CP asymmetry in regions of the Dalitz plot shown in Fig. 1. The first error is statistical and the second is systematic.

Model-independent techniques were used to search for CPV in the Dalitz plot. These were based on a comparison of the binned $D^+$ and $D^−$ Dalitz plots, and on a comparison of the Legendre-polynomial-moment weighted distributions in the $K^+K^−$ and $K^−\pi^+$ systems. The distributions of normalized residuals in equally populated bins ($\sim 1000$ events per bin) of the $D^+$ and $D^−$ Dalitz plots were fitted with a Gaussian function. The fit yielded a mean of $0.08 \pm 0.15$ and an r.m.s. deviation of $1.11 \pm 0.15$, which corresponds to a probability of 72% that the two Dalitz plots are consistent with no CPV. The comparison of Legendre-polynomial-moments for the $K^+K^−$ and $K^−\pi^+$ systems separately was found to be consistent with no CPV 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 CPV. The $D^+$ decay amplitude was parameterized as a coherent
sum of amplitudes describing the relevant two-body intermediate states (16 resonances) plus a constant amplitude over the Dalitz plot for the non-resonant (NR) contribution. The fit fractions of the resonant and NR amplitudes are reported in Table 2. The results of the fit to the $D^+$ and $D^-$ Dalitz plots do not show evidence of CPV for the following amplitudes: $\bar{K}^*(892)^0$, $\bar{K}^*(1430)^0$, $\phi(1020)$, NR, $\kappa(800)$, $a_0(1450)^0$, $f_0(980)$, $f_0(1370)$.

4. Measurement of $D^0-\bar{D}^0$ mixing, and search for indirect CP violation in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays

The BABAR experiment has recently updated the measurement of the mixing parameter $y_{CP}$ and the CP-violation parameter $\Delta Y$ [18]. The definitions of $\Delta Y$ and $A_{\Gamma}$ are the following:

$$\Delta Y = \frac{\Gamma^+ - \bar{\Gamma}^+}{2\Gamma} = (1 + y_{CP})A_{\Gamma},$$

Note that this definition for $\Delta Y$ uses a different sign convention than that used in previous BABAR publications [19, 20].
The uncertainties are statistical only.

The measurements are based on the ratio of lifetimes extracted simultaneously from a sample of $D^0$ mesons produced through the flavor-tagged process $D^{*+} \to D^0 \pi^+$, where the $D^0$ decays to $K^+ \pi^-$, $K^- K^+$, or $\pi^- \pi^+$; additional samples of untagged decays $D^0 \to K^- \pi^+$ and $D^0 \to K^- K^+$ are used for the measurement of $y_{CP}$. These have about 4 times the statistics of the corresponding flavor-tagged samples, but have lower purity.

The main selection criteria require that the center-of-mass momentum of the $D^0$ ($p^*$) be greater than 2.5 GeV/$c$, that $D^0$ daughter tracks be identified as kaons and pions, and require for the flavor-tagged sample that the reconstructed $\Delta m = m(D^{*+}) - m(D^0)$ be close to the value of 0.1455 GeV. The selection criterion on $p^*$ is used to reject $D$ mesons from $B$ decays, and to improve the signal significance.

The proper time $t$ and proper-time error $\sigma_t$ are obtained from the reconstruction of the 3-dimensional flight length ($\vec{L}$) and the momentum of the $D^0$ ($\vec{p}$) according to the relation $t = m/|\vec{p}|^2 \vec{L} \cdot \vec{p}$, where $m$ is the nominal mass of the $D^0$. The flight length is reconstructed by means of a simultaneous kinematic fit to the decay vertex and production vertex of the $D^0$, the latter being constrained to originate within the $e^+ e^-$ collision region. The most probable $\sigma_t$ value is about 40% of the nominal $D^0$ lifetime, and candidates with $\sigma_t < 0.5$ ps are retained for the fit.

The $\text{Babar}$ experiment 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 corresponding to an integrated luminosity of 468 fb$^{-1}$ [18]. The systematic uncertainties on $y_{CP}$ and $\Delta Y$ are reported in Table 3. The

### Table 2.

Fit fractions of the resonant and NR amplitudes in the Isobar model fit of the data. The uncertainties are statistical only.

| Resonance       | Fraction (%) |
|-----------------|-------------|
| $K^*(892)^0$    | 21.15 ± 0.20 |
| $\phi(1020)$   | 28.42 ± 0.13 |
| $K^*_0(1430)^0$| 25.32 ± 2.24 |
| NR             | 6.38 ± 1.82 |
| $\kappa(800)$  | 7.08 ± 0.63 |
| $a_0(1450)^0$  | 3.84 ± 0.69 |
| $f_0(980)$     | 2.47 ± 0.30 |
| $f_0(1370)$    | 1.17 ± 0.21 |
| $\phi(1680)$   | 0.82 ± 0.12 |
| $K^*_1(1410)$  | 0.47 ± 0.37 |
| $f_0(1500)$    | 0.36 ± 0.08 |
| $a_2(1320)$    | 0.16 ± 0.03 |
| $f_2(1270)$    | 0.13 ± 0.03 |
| $K^*_2(1430)$  | 0.06 ± 0.02 |
| $K^*(1680)$    | 0.05 ± 0.16 |
| $f_0(1710)$    | 0.04 ± 0.03 |
| $f_2'(1525)$   | 0.02 ± 0.01 |
| Sum            | 97.92 ± 3.09 |

where $\tau^+ = 1/\Gamma^+ (\bar{\tau}^+ = 1/\bar{\Gamma}^+)$ are the effective lifetimes for $D^0 (\bar{D}^0)$ decaying to the $CP$-even final states $K^+ K^-$ and $\pi^+ \pi^-$. In this analysis $CP$ conservation in the decay is assumed, and results are averaged over the $K^+ K^-$ and $\pi^+ \pi^-$ modes.

The measurements are based on the ratio of lifetimes extracted simultaneously from a sample of $D^0$ mesons produced through the flavor-tagged process $D^{*+} \to D^0 \pi^+$, where the $D^0$ decays to $K^- \pi^+$, $K^- K^+$, or $\pi^- \pi^+$; additional samples of untagged decays $D^0 \to K^- \pi^+$ and $D^0 \to K^- K^+$ are used for the measurement of $y_{CP}$. These have about 4 times the statistics of the corresponding flavor-tagged samples, but have lower purity.

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The $\text{Babar}$ experiment 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 corresponding to an integrated luminosity of 468 fb$^{-1}$ [18]. The systematic uncertainties on $y_{CP}$ and $\Delta Y$ are reported in Table 3. The
Table 3. Systematic uncertainties for \(y_{\text{CP}}\) and \(\Delta Y\) at BaBar. The total is the sum-in-quadrature of the entries in each column.

| Category          | \(\Delta y_{\text{CP}}\) (%) | \(\Delta(\Delta Y)\) (%) |
|-------------------|-------------------------------|--------------------------|
| Fit region        | 0.057                         | 0.022                    |
| Signal model      | 0.022                         | 0.000                    |
| Charm bkg         | 0.045                         | 0.001                    |
| Combinatorial bkg | 0.079                         | 0.002                    |
| Selection         | 0.059                         | 0.054                    |
| Total             | 0.124                         | 0.058                    |

\(y_{\text{CP}}\) measurement provides evidence for \(D^0_{\text{CP}}\) mixing at the 3.3\(\sigma\) level, and is the most precise measurement to date. The Belle experiment has recently presented an update of the corresponding analysis, and reports \(y_{\text{CP}} = [1.11 \pm 0.22 \text{(stat)} \pm 0.11 \text{(syst)}]\%\) and \(A_\Gamma = [-0.03 \pm 0.20 \text{(stat)} \pm 0.08 \text{(syst)}]\%\) using a data sample of 976 fb\(^{-1}\). The Belle measurement of \(y_{\text{CP}}\) corresponds to evidence for \(D^0_{\text{CP}}\) mixing at the 4.5\(\sigma\) level. The measurements of \(\Delta Y\) from BaBar, and \(A_\Gamma\) from Belle are compatible within error and consistent with no CPV. The new measurements supersede the previous BaBar [19, 20] and Belle results [22]. The updated HFAG averages, including the new results, are \(y_{\text{CP}} = (0.866 \pm 0.155)\%\) and \(A_\Gamma = (-0.022 \pm 0.161)\%\). The comparison with the previous HFAG average values \(y_{\text{CP}} = (1.064 \pm 0.209)\%\) and \(A_\Gamma = (0.026 \pm 0.231)\%\) indicates significant improvement in precision and a lower central value for \(y_{\text{CP}}\).

5. Search for CP violation in \(\tau^- \rightarrow \pi^- K^0_S (\geq 0 \pi^0) \nu_\tau\) decays

Bigi and Sanda [23] predicted that, in the SM, the decay of the \(\tau\) lepton to final states containing a \(K^0_S\) will exhibit a nonzero decay rate asymmetry due to CP violation in \(K^0-S\) mixing. The decay rate asymmetry defined as

\[
A_Q = \frac{\Gamma(\tau^+ \rightarrow \pi^+ K^0_S \nu_\tau) - \Gamma(\tau^- \rightarrow \pi^- K^0_S \nu_\tau)}{\Gamma(\tau^+ \rightarrow \pi^+ K^0_S \nu_\tau) + \Gamma(\tau^- \rightarrow \pi^- K^0_S \nu_\tau)}
\]

was predicted to be \((0.33 \pm 0.01)\%\), and a significant deviation from this value would be evidence of NP. As pointed out by Grossman and Nir [14], the SM prediction for \(A_Q\) has to be corrected for a factor due to the \(K^0_S-K^0_L\) interference, depending on the reconstruction efficiency of the \(K^0_S\) as a function of the \(K^0_S\) decay time. The correction factor was experimentally determined to be \((1.08 \pm 0.01)\%\) so that the corrected value for \(A_Q\) is \((0.36 \pm 0.01)\%\). The signal events include different \(\tau\) decay modes with a \(K^0_S\) in the final state, i.e., \(\tau^- \rightarrow \pi^- K^0_S (\geq 0 \pi^0) \nu_\tau\), where the number of reconstructed \(\pi^0\)'s is less than 3, and the value of the decay rate asymmetry is expected to be the same in the SM for the different \(\tau\) decay modes. This analysis is based on a data sample corresponding to an integrated luminosity of 476 fb\(^{-1}\) [24]. The events were reconstructed from \(e^+e^- \rightarrow \tau^+\tau^-\) reactions, where the \(\tau\) pairs are produced back-to-back in the \(e^+e^-\) CM system. Each event is divided into two hemispheres with respect to the event thrust axis [25, 26]: the “signal” hemisphere, where one charged prompt track and a \(K^0_S \rightarrow \pi^-\pi^-\) candidate are reconstructed, and the “tag” hemisphere, with an identified prompt lepton (\(e, \mu\)). After all selection criteria have been applied, 199,064 events in the \(e\)-tag sample, and 141,602 events in the \(\mu\)-tag sample are obtained. The sample composition is described in Table 4. It contains events from two other classes of decay mode: \(\tau^- \rightarrow K^- K^0_S (\geq 0 \pi^0) \nu_\tau\) and \(\tau^- \rightarrow \pi^- K^0_S \bar{K}^0 \nu_\tau\), that also have \(K^0_S\) mesons in the final states. The \(\tau^- \rightarrow \pi^- K^0_S \bar{K}^0 \nu_\tau\) events satisfy the selection criteria if one of the neutral kaons decays into \(\pi^+\pi^-\) and the other decays into \(2\pi^0\) or appears as a \(K^0_L\) meson. A control sample of \(\tau^- \rightarrow h^-h^-h^+(\geq 0 \pi^0) \nu_\tau\) (\(h = K, \pi\),
decays are determined to be $\Delta Y$. The parameter $\Delta Y$.

The summary of the systematic uncertainties in the decay-rate asymmetry $A_Q$ is obtained by the detector or the selection criteria. The decay rate asymmetries measured in the control sample agree with zero within the errors, 0.12% for the $e$ tag and 0.08% for the $\mu$ tag, which are taken as systematic uncertainties on the signal asymmetries.

The measured asymmetry $A$ is related to the signal asymmetry $A_1$, and the background asymmetries $A_2$ and $A_3$, by

$$A = \frac{f_1 A_1 + f_2 A_2 + f_3 A_3}{f_1 + f_2 + f_3} = \frac{f_1 - f_2}{f_1 + f_2 + f_3} A_Q$$

where $f_1$, $f_2$ and $f_3$ are, respectively, the fractions of $\tau^- \to \pi^- K_S^0(\geq 0 \pi^0)\nu_\tau$, $\tau^- \to K^- K_S^0(\geq 0 \pi^0)\nu_\tau$ and $\tau^- \to \pi^- K_S^0 \bar{K}_S^0\nu_\tau$ in the total selected sample, as shown in Table 4.

In the SM, $A_1 = -A_2$ since in the $\tau^- \to \pi^- K_S^0(\geq 0 \pi^0)\nu_\tau$ decays a $\bar{K}_S^0$ is produced, while in the $\tau^- \to K^- K_S^0(\geq 0 \pi^0)\nu_\tau$ decays is produced a $K_S^0$. For the $\tau^- \to \pi^- K_S^0 \bar{K}_S^0\nu_\tau$ decay, $A_3 = 0$ since the asymmetries of $K_S^0$ and $\bar{K}_S^0$ cancel each other. The measured asymmetry is $A = (-0.27 \pm 0.18 \pm 0.08)\%$, and dividing it by $(f_1 - f_2)/(f_1 + f_2 + f_3) = (0.75 \pm 0.04)\%$, we obtain the decay rate asymmetry $A_Q = (-0.36 \pm 0.23 \pm 0.11)\%$, where the errors are statistical and systematic, respectively. The most relevant systematic errors are reported in Table 5.

| Source                     | Fractions (%) |
|----------------------------|---------------|
|                            | $e$-tag  | $\mu$-tag  |
| $\pi^- \to \pi^- K_S^0(\geq 0 \pi^0)\nu_\tau$ | 78.8 ± 4.0 | 18.4 ± 4.0 |
| $\tau^- \to K^- K_S^0 (\geq 0 \pi^0)\nu_\tau$ | 4.2 ± 0.3 | 4.1 ± 0.3 |
| $\tau^- \to \pi^- K_S^0 \bar{K}_S^0\nu_\tau$ | 15.7 ± 3.7 | 15.9 ± 3.7 |
| Other background            | 1.40 ± 0.06 | 1.55 ± 0.07 |

Table 4. Composition of the $\tau$ sample after all selection criteria have been applied.

The decay-rate asymmetry $A_Q = [-0.36 \pm 0.23(\text{stat}) \pm 0.11(\text{syst})]\%$, has been measured for the first time, and is 2.8 standard deviations from the SM prediction of $(0.36 \pm 0.01)\%$ [24].

6. Conclusions

We have presented recent $B\bar{B}$ results relevant to searches for CPV in charm meson and tau decays, and also a measurement of the $D^0\bar{D}^0$ mixing parameter $y_{CP}$ and the CPV violation parameter $\Delta Y$. The CPV asymmetries for the $D^+ \to K^0 S^+ K^+\pi^-$, $D_s^+ \to K^0 S^+ K^+\pi^-$, and $D_s^+ \to K^0 S^+ K^+\pi^-$ decays are determined to be $[0.13 \pm 0.36(\text{stat}) \pm 0.25(\text{syst})]\%$, $[-0.05 \pm 0.23(\text{stat}) \pm 0.24(\text{syst})]\%$, and $[0.6 \pm 2.0(\text{stat}) \pm 0.3(\text{syst})]\%$, respectively. These results are consistent with no CPV and with the SM predictions within one standard deviation. The CPV asymmetry in the SCS $D^+ \to K^+ K^- \pi^+$ decay was measured to be $[0.37 \pm 0.30(\text{stat}) \pm 0.15(\text{syst})]\%$, and no evidence for CPV
was found in the Dalitz plot using model-independent and model-dependent techniques. In a
lifetime ratio analysis of the decays to \( CP \)-even eigenstates \( D^0 \to K^- K^+, \pi^- \pi^+ \) relative to \( D^0 \to K^+ \pi^+ \) decays, the mixing parameter was measured to be \( y_{CP} = [0.72 \pm 0.18 \text{(stat)} \pm 0.12 \text{(syst)}]\)% and the \( CPV \) parameter value \( \Delta Y = [0.09 \pm 0.26 \text{(stat)} \pm 0.06 \text{(syst)}]\)% was obtained. The former represents the most precise measurement of the mixing parameter \( y_{CP} \) to date. Finally, we presented the first measurement of the decay-rate asymmetry in \( \tau^- \to \pi^- K^0_S \geq 0 \pi^0 \nu_\tau \) decays, obtaining the value \( A_Q = [-0.36 \pm 0.23 \text{(stat)} \pm 0.11 \text{(syst)}]\)% This measurement is 2.8 standard deviations from the SM prediction of \( (0.36 \pm 0.01)\)%.

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