Direct CP violation in B decays

M. Kreps
Institut für Experimentelle Kernphysik, University of Karlsruhe, Germany

We review recent experimental results on direct CP violation. The hot topic is a measurement in charmless two-body decays of B^0, B^+. In connection to this the first analogous measurements in B_s^0 and Λ_b^0 decays are now available. Furthermore first evidence for direct CP violation in B^+ decays is obtained from Dalitz plot analyzes of the $K^+\pi^-\pi^+$ final state at B-factories. The last group of discussed results probes the $b \to c\bar{c}d$ transition in attempt to resolve the discrepancy between Belle and *BABAR* experiments in CP violation in the $B^0 \to D^+D^-$ decays.

1. Introduction

Measurements of the direct CP violation form an important test of the CKM mechanism of CP violation in the standard model. In addition it provides a window for searches for new physics beyond the standard model. Direct CP violation is a decay property, where the amplitudes for the processes $B \to f$ and $\overline{B} \to \overline{f}$ are different. Experimentally it manifests as the difference in the decay widths of the two charge conjugated states. In the case of decays to the flavor eigenstates, the experimental observable is the time integrated asymmetry

$$A_{CP} = \frac{\Gamma(B \to f) - \Gamma(\overline{B} \to \overline{f})}{\Gamma(B \to f) + \Gamma(\overline{B} \to \overline{f})}.$$

For decays to a common final state one has to disentangle the CP violation induced by the mixing from the direct CP violation. This requires a study of the time dependent asymmetry

$$\begin{aligned} A_{CP}(t) &= \frac{\mathrm{d}\Gamma/\mathrm{d}t(\overline{B} \to f) - \mathrm{d}\Gamma/\mathrm{d}t(B \to f)}{\mathrm{d}\Gamma/\mathrm{d}t(\overline{B} \to f) + \mathrm{d}\Gamma/\mathrm{d}t(B \to f)} \\ &= \mathcal{S} \sin \Delta m t + \mathcal{A} \cos \Delta m t, \end{aligned}$$

where Δm is the mixing frequency, $\mathcal{S}$ is the CP violation in the interference of the decays with and without mixing, and $\mathcal{A}$ is the direct CP violation.

To have an observable direct CP violation, at least two interfering amplitudes with different weak and strong phases are required. In case of the two amplitudes A_1 and A_2 with relative weak phase ϕ and relative strong phase δ the decay widths are

$$\begin{aligned} \Gamma(B \to f) &\propto |A_1 + A_2 \mathrm{e}^{i\phi} \mathrm{e}^{i\delta}|^2 \\ \Gamma(\overline{B} \to \overline{f}) &\propto |A_1 + A_2 \mathrm{e}^{-i\phi} \mathrm{e}^{i\delta}|^2. \end{aligned}$$

With some algebra one can easily see that the asymmetry is

$$A_{CP} \propto \sin\phi \sin\delta.$$

The necessary condition for an observable direct CP violation is to have both the relative weak phase as well as the relative strong phase different from 0 or π.

The direct CP violation is rather well understood theoretically, but difficult to predict. The difficulty comes from the fact that A_{CP} depends not only on the weak phase, but also on the strong phase, which involves non-perturbative long distance effects and it is this part, which makes predictions difficult.

The importance of the direct CP violation is manifold. It is crucial for determining the angle γ of the Cabibbo-Kobayashi-Maskawa (CKM) matrix. In addition it can provide useful tests of the theoretical tools as well as tests of the CKM mechanism of CP violation. It also has potential for the discovery of physics beyond the standard model. The best decays for searches of new physics are those, which are dominated by a single CKM phase. Observation of the direct CP violation in such decays would imply the presence of a second amplitude and thus evidence for new physics.

In this paper we review recent experimental results on direct CP violation. We start in section 2 with the charmless two-body decays of B^0, B^+, B_s^0, and Λ_b^0. In section 3 we discuss the first evidence for direct CP violation in $B^+ \to K^+\pi^-\pi^+$ decays. Section 4 reviews measurements in the $b \to c\bar{c}d$ transition with section 5 focusing on $B^+ \to J/\psi K^+$ decays.

2. Charmless two body b-hadron decays

Direct CP violation is most thoroughly studied in b-hadron decays to charmless two body final states. Several dozens of different decays are already studied experimentally. In Fig. 1 we show a summary of the most precise measurements in decays to a flavor specific final state [1].

2.1. $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$ decays

The CP violation in the decay $B^0 \to K^+\pi^-$ is the only direct CP violation, which has been observed in a single experiment with more than 5 standard deviations. Together with results in the decay $B^+ \to K^+\pi^0$ this generated a considerable amount of interest. In

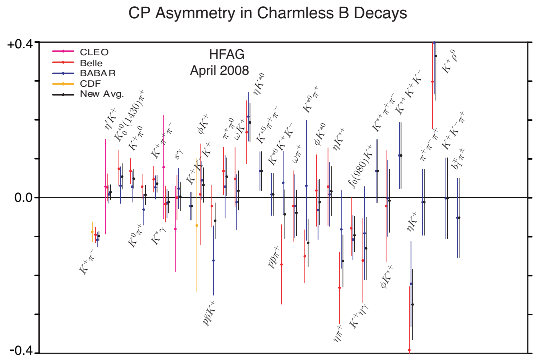

Figure 1: Summary of the most precise measurements of direct CP violation in charmless two body decays of the B^+ and B^0 mesons to a flavor specific final state [1].

the case of $B^+ \to K^+\pi^0$, two measurements are available. The Belle experiment [2] used 535 million $B\overline{B}$ pairs and measures

$$A_{CP} = 0.07 \pm 0.03 \pm 0.01.$$

The *BABAR* experiment [3], using 383 million $B\overline{B}$ pairs, measures in the decay $B^+ \to K^+\pi^0$

$$A_{CP} = 0.03 \pm 0.04 \pm 0.01.$$

Averaging those two measurements yields

$$A_{CP} = 0.05 \pm 0.025.$$

Both experiments use thier sample also to measure the direct CP asymmetry in the $B^0 \to K^+\pi^-$ decay. Belle obtains [2]

$$A_{CP} = -0.094 \pm 0.018 \pm 0.008$$

with a significance of 4.8 standard deviations. *BABAR* measures [4]

$$A_{CP} = -0.107 \pm 0.018^{+0.007}_{-0.004}$$

with a significance of 5.5 standard deviations. Two other measurements exist for the $B^0 \to K^+\pi^-$ decay. The CLEO experiment measures [5]

$$A_{CP} = -0.040 \pm 0.160 \pm 0.020$$

and the CDF experiment, using 1 fb^{-1} of $p\overline{p}$ collisions, measures [6]

$$A_{CP} = -0.086 \pm 0.023 \pm 0.009,$$

which has a significance of 3.5 standard deviations. Averaging the four mentioned measurements one obtains

$$A_{CP} = -0.097 \pm 0.012.$$

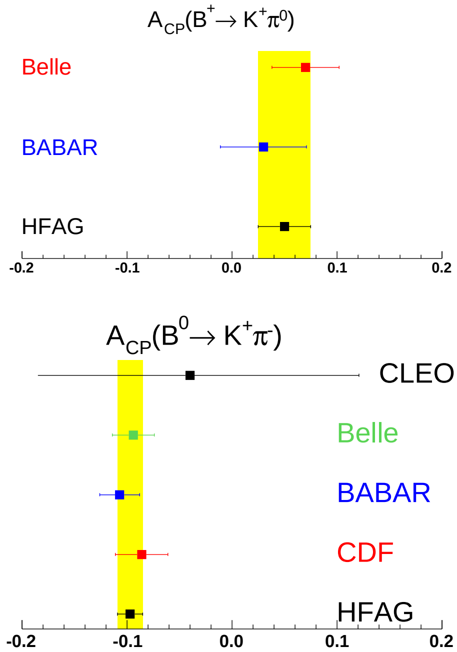

Figure 2: Summary of the measurements of the direct CP violation in the $B^0 \to K^+\pi^-$ (bottom) and the $B^+ \to K^+\pi^0$ (top) decays.

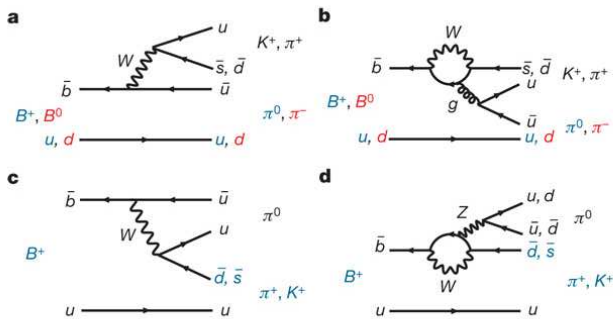

Figure 3: Contributions to the decay $B \to K\pi$. The possible processes are a) tree, b) penguin, c) color suppressed tree, and d) electroweak penguin amplitudes. The first two contribute to both $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$ decays, while the last two contribute only to the decay $B^+ \to K^+\pi^0$. The figure is reproduced from Ref. [2].

In Fig. 2 we show a graphical summary of the measurements. In both decays, all measurements are consistent with each other. What is clearly different is the direct CP asymmetry in B^0 and B^+ decays. This difference is in contradiction with the naïve expectation that both asymmetries should be the same. In Fig. 3 Feynman diagrams of all contributions to the given decays are shown. The contributions are tree (Fig. 3a), penguin (Fig. 3b), color suppressed tree (Fig. 3c), and electroweak penguin (Fig. 3d) amplitudes. While the first two are present in both B^+ and

B^0 decays, the other two are present only in the B^+ decays. The naïve expectation that the two direct CP asymmetries should be same comes from the neglection of color suppressed tree and electroweak penguin amplitudes in the case of B^+ decays. While the difference in CP asymmetry could be generated by a new physics contribution to the electroweak penguin amplitude [7, 8], it is also too early to exclude that the standard model with enhanced color suppressed tree amplitude can explain the observed difference [9]. It can be concluded that while the situation is tantalizing, it is not conclusive and it is too early to claim the observation of new physics beyond the standard model.

2.2. $B_s \to K^-\pi^+$ decays

While at the B-factories one can study only B^+ and B^0 mesons, the Tevatron experiments have access to all b-hadron species. One of the important outcomes is that the CDF experiment, together with the direct CP violation in $B^0 \to K^+\pi^-$, also measures the direct CP violation in the decay $B_s \to K^-\pi^+$ [6].

The standard model expectations vary strongly with the calculation method and generally have large uncertainties [10–12]. In the context of the standard model a relation between the amplitudes in $B^0 \to K^+\pi^-$ and $B_s \to K^-\pi^+$ decays was predicted [13, 14]. In terms of the decay widths it has the form

$$\frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(B_s^0 \to K^-\pi^+) - \Gamma(\overline{B}_s^0 \to K^+\pi^-)} = 1.$$

This relation can be translated into a relation between the direct CP asymmetries between $B^0 \to K^+\pi^-$ and $B_s \to K^-\pi^+$ decays and has the form

$$\frac{A_{CP}(B_s^0 \to K^-\pi^+)}{A_{CP}(B^0 \to K^+\pi^-)} = -\frac{\mathcal{B}(B^0 \to K^+\pi^-)\tau(B^0)}{\mathcal{B}(B_s^0 \to K^-\pi^+)\tau(B_s)},$$

where $\mathcal{B}$ denotes the corresponding branching fraction and τ the mean lifetime. Using measured values for $\mathcal{B}$, lifetimes, and $A_{CP}(B^0 \to K^+\pi^-)$ [1] one obtains

$$A_{CP}(B_s^0 \to K^-\pi^+) \approx +0.37. \quad (1)$$

In Fig. 4 we show a typical mass distribution observed by CDF using 1 fb^{-1} of data in the charmless two body b-hadron decays [15]. The signal for the decay $B_s^0 \to K^-\pi^+$ can be clearly separated and CDF measures

$$A_{CP}(B_s^0 \to K^-\pi^+) = +0.39 \pm 0.15 \pm 0.08. \quad (2)$$

The measurement is well consistent with the expectation from equation 1. It has 2.5 standard deviations significance of being nonzero. As CDF already has about 3 fb^{-1} of data available for analysis, it will be interesting to watch out for an analysis update, which has the potential to provide the first evidence for direct CP violation in the B_s^0 system.

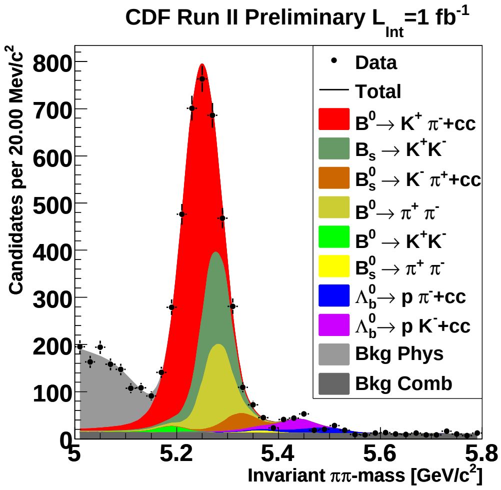

Figure 4: Typical invariant mass distribution in the analysis of charmless two body b-hadron decays at CDF [15].

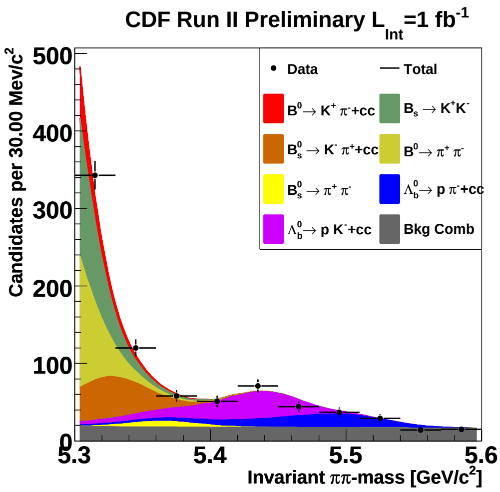

Figure 5: Invariant mass distribution of charmless two body decays. Shown is a more detailed view from Fig. 4, focusing on the region with Λ_b^0 decays [15].

2.3. $\Lambda_b^0 \to pK^-$ and $\Lambda_b^0 \to p\pi^-$ decays

Two more decays in Fig. 4 are worth of mentioning. Those are the decays $\Lambda_b^0 \to pK^-$ and $\Lambda_b^0 \to p\pi^-$. In Fig. 5 we show a zoom of Fig. 4 into the mass region from 5.3 to 5.6 GeV/c^2 with a clear Λ_b^0 signal. This allows for the first time to study the direct CP violation in b-baryon decays in experiment.

The decays of Λ_b^0 to pK^- and $p\pi^-$ are not very well studied theoretically. Mohanta *et al.* [16] predict that in the standard model the CP asymmetries can reach a size of the order of 10%. On the other hand in supersymmetry models with R-parity violation the direct CP violation could be significantly suppressed

[17].

With the sample shown in Fig. 5, CDF measures the following CP asymmetries

$$\begin{aligned} A_{CP}(\Lambda_b^0 \to p\pi) &= 0.03 \pm 0.17 \pm 0.05, \\ A_{CP}(\Lambda_b^0 \to pK) &= 0.37 \pm 0.17 \pm 0.03. \end{aligned}$$

Both decays are still compatible with no direct CP violation, but in the case of $\Lambda_b^0 \to pK^-$ it is 2.1 standard deviations away from zero. Also both results are compatible with the expected value of direct CP violation. We can expect that at least in case of the decay $\Lambda_b^0 \to pK^-$ the next round of analysis by CDF will provide first evidence for direct CP violation in the b-baryon sector. Until then it would be welcome if the theory expectations could be refined for those decays.

3. Dalitz plot analysis of $B^+ \to K^+\pi^-\pi^+$

Many of the measurements shown in Fig. 1 involve broad resonances. The experimental study of those requires Dalitz plot analyses to resolve the broad resonances, which are often overlapping. Several three body final states were studied by Belle and *BABAR* using the Dalitz plot technique. The recent results include $B^0 \to K^+\pi^-\pi^0$ [18, 19], $B^0 \to K^+K^-K^0$ [20], $B^0 \to K_s\pi^+\pi^-$ [21] and most importantly $B^+ \to K^+\pi^-\pi^+$ [22, 23], which we discuss here in some detail.

The Dalitz plot analyses of $B^+ \to K^+\pi^-\pi^+$ are performed by both Belle and *BABAR* using $\approx$ 380 million $B\overline{B}$ pairs. The chosen Dalitz model slightly differs between the two experiments, but the extracted branching fractions for different components are consistent. The total CP asymmetry of the decay $B^+ \to K^+\pi^-\pi^+$ over the full Dalitz space is measured by Belle to be

$$A_{CP}(B^+ \to K^+\pi^-\pi^+) = 0.049 \pm 0.026 \pm 0.020.$$

BABAR measures the same quantity to be

$$A_{CP}(B^+ \to K^+\pi^-\pi^+) = 0.028 \pm 0.02 \pm 0.02 \pm 0.012.$$

The last uncertainty is due to the Dalitz model, which in case of the Belle result is included in the systematic uncertainty. In addition to the measurement over the full Dalitz plot, also measurements in different quasi-two-body final states were performed. In Fig. 6 we show the projection of the Dalitz plot fit from Belle on the invariant mass of the two pions, separately for B^+ and B^-. The analogous distributions from *BABAR* are shown in Fig. 7. The two decays which are noteworthy are $B^+ \to \rho^0(770)K^+$ and $B^+ \to f_2^0(1280)K^+$. For those Belle measures

$$\begin{aligned} A_{CP}(B^+ \to \rho^0(770)K^+) &= 0.30 \pm 0.11^{+0.11}_{-0.05}, \\ A_{CP}(B^+ \to f_2^0(1280)K^+) &= -0.59 \pm 0.22 \pm 0.04, \end{aligned}$$

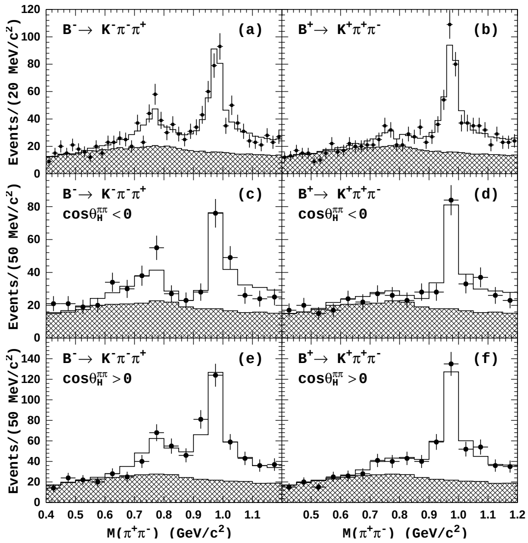

Figure 6: Projection of the Dalitz plot fit from Belle of $B^+ \to K^+\pi^-\pi^+$ on the $\pi^+\pi^-$ invariant mass in the region of the $\rho^0(770)$ and $f_0^0(980)$ resonances [22]. The left column shows B^- while the right one shows B^+. The top row contains all events. The middle and bottom row shows two distinct kinematic regions.

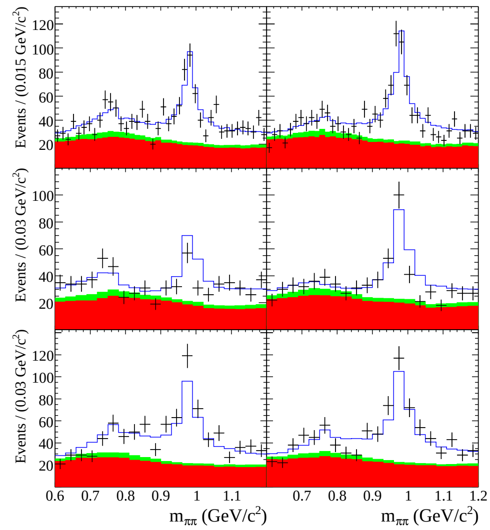

Figure 7: Projection of the Dalitz plot fit from *BABAR* of $B^+ \to K^+\pi^-\pi^+$ on the $\pi^+\pi^-$ invariant mass in the region of the $\rho^0(770)$ and $f_0^0(980)$ resonances [23]. The left column shows B^- while the right one shows B^+. The top row contains all events. The middle and bottom row shows two distinct kinematic regions.

and *BABAR* obtains

$$\begin{aligned} A_{CP}(B^+ \to \rho^0(770)K^+) &= 0.44 \pm 0.10^{+0.06}_{-0.14}, \\ A_{CP}(B^+ \to f_2^0(1280)K^+) &= -0.85 \pm 0.22^{+0.26}_{-0.13}. \end{aligned}$$

The asymmetry $A_{CP}(B^+ \to \rho^0(770)K^+)$ has a significance of 3.9 and 3.7 standard deviations for Belle and

BABAR respectively, thus providing first evidence for the direct CP violation in B^+ decays. Additionally, the asymmetry $A_{CP}(B^+ \to f_2^0(1280)K^+)$ from *BABAR* shows a significance of more than 3 standard deviations, but this decreases below 3 standard deviations with some variations in the Dalitz model. Direct CP asymmetries of all other decay modes in the Dalitz model are compatible with zero.

4. $b \to c\bar{c}d$ transition

Another topic which recently got a considerable amount of attention is the CP violation in $b \to c\bar{c}d$ transitions. While the standard model expects tiny direct CP violation in decays, governed by the $b \to c\bar{c}d$ quark level transition, the measurement in $B^0 \to D^+D^-$ decays by Belle yielded an unusually high value of [24]

$$A_{CP}(B^0 \to D^+D^-) = -0.91 \pm 0.23 \pm 0.06.$$

On the other hand the same measurement by *BABAR* [25] resulted in

$$A_{CP}(B^0 \to D^+D^-) = 0.11 \pm 0.22 \pm 0.07,$$

which is consistent with expectations, but inconsistent with the Belle measurement. This discrepancy and the fact that Belle measured a large CP violation prompted large interest and more work on related decays governed by the $b \to c\bar{c}d$ quark level transition.

4.1. $B^+ \to D^+\overline{D}^0$

The decay $B^+ \to D^+\overline{D}^0$ is an analog of the $B^0 \to D^+D^-$ decay proceeding with the same quark level transition. This decay was previously analyzed by *BABAR* using 231 million $B\overline{B}$ pairs [26]. In Fig. 8 the beam constrained mass distribution of $B^+ \to D^+\overline{D}^0$ events is shown. From 129 ± 20 signal events *BABAR* extracts

$$A_{CP}(B^+ \to D^+\overline{D}^0) = -0.13 \pm 0.14 \pm 0.02.$$

Recently Belle performed the same analysis using 657 million $B\overline{B}$ pairs [27]. The beam constrained mass distribution is shown in Fig. 9. Using 194.2 ± 20.4 signal events the measured direct CP asymmetry is

$$A_{CP}(B^+ \to D^+\overline{D}^0) = 0.00 \pm 0.08 \pm 0.02.$$

Both measurements are consistent with no direct CP violation, as expected within the standard model. But it is also difficult to make a firm statement about the CP violation in the decay $B^0 \to D^+D^-$ as spectator effects are different between $B^+ \to D^+\overline{D}^0$ and

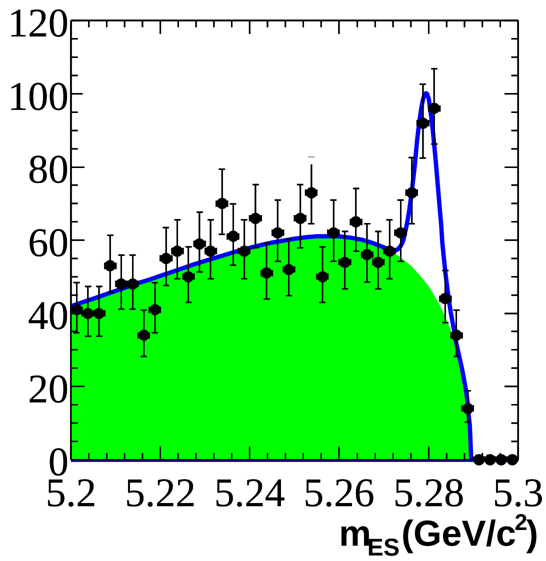

Figure 8: The beam constrained mass distribution of the $B^+ \to D^+\overline{D}^0$ events from *BABAR* [26].

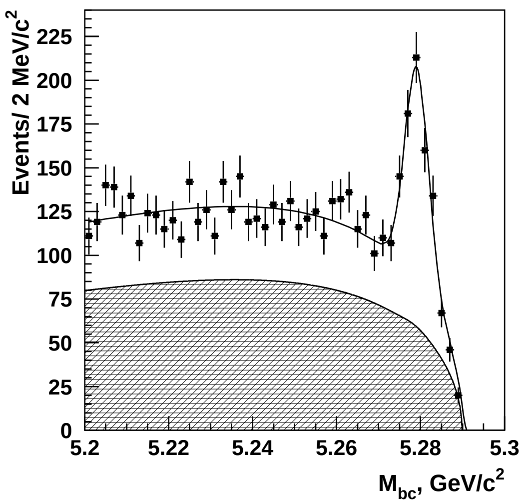

Figure 9: The beam constrained mass distribution of the $B^+ \to D^+\overline{D}^0$ events from Belle [27].

$B^0 \to D^+D^-$ decays so that the weak exchange and weak annihilation diagrams are missing in the B^+ case. While the two diagrams are expected to be negligible, it cannot be excluded that B^0 and B^+ would have different direct CP violation in those decays.

4.2. $B^0 \to D^{*+}D^{*-}$

Another decay in which one can test the $b \to c\bar{c}d$ transition is the decay $B^0 \to D^{*+}D^{*-}$. This decay proceeds through the same diagrams as the decay $B^0 \to D^+D^-$ and is therefore very useful in try-

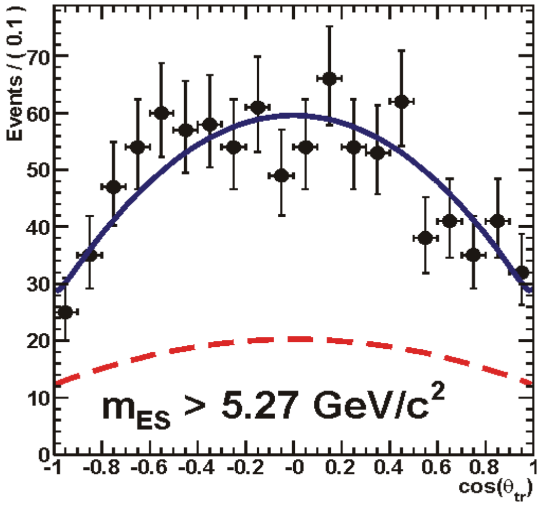

Figure 10: Distribution of $\cos\theta_{tr}$ used to disentangle the CP-even and CP-odd fraction in $B^0 \to D^{*+}D^{*-}$ from *BABAR* [28]. The dashed line represents the background distribution, the full line the fit projection, and the points with error bars show data.

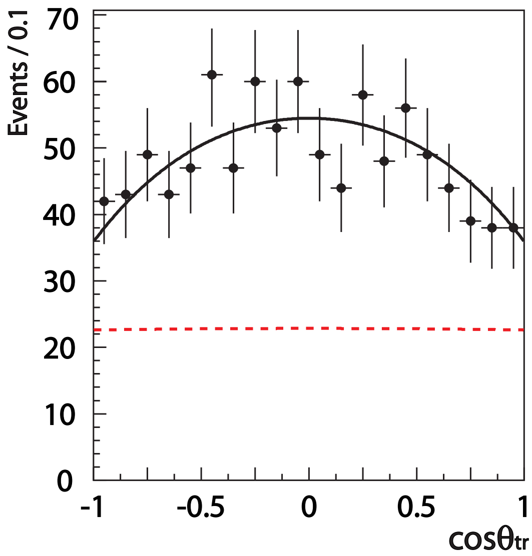

Figure 11: Distribution of $\cos\theta_{tr}$ used to disentangle the CP-even and CP-odd fraction in $B^0 \to D^{*+}D^{*-}$ from Belle [29]. The dashed line represents the background distribution, the full line the fit projection, and the points with error bars show data.

ing to understand the discrepancy between Belle and *BABAR* in the $B^0 \to D^+D^-$ decay. There is one complication in the measurement as the final state consists of two vector particles for which decays through different orbital momenta are possible. This causes that the final state is a mixture of CP-even and CP-odd final states, which needs to be taken into account.

BABAR uses 383 million $B\overline{B}$ pairs providing a signal of 617 ± 33 $B^0 \to D^{*+}D^{*-}$ decays [28]. Belle recently presented a measurement based on 535 million $B\overline{B}$ pairs, which provides 545 ± 29 signal events [29]. Both experiments use a $\cos\theta_{tr}$ distribution to disentangle the CP-even and CP-odd fraction on a statistical basis. θ_{tr} is the polar angle of the pion from the D^{*+} decay in the D^{*+} rest frame with the z-axis being normal to the D^{*-} decay plane and the x-axis opposite to the D^{*-} momentum. The $\cos\theta_{tr}$ distribution together with the fit projection is shown for *BABAR* in Fig. 10 and for Belle in Fig. 11. The measured fraction of CP-odd component is $0.143 \pm 0.034 \pm 0.008$ for *BABAR* and $0.116 \pm 0.042 \pm 0.004$ for Belle. For the direct CP asymmetry *BABAR* measures

$$A_{CP}(B^0 \to D^{*+}D^{*-}) = -0.02 \pm 0.11 \pm 0.02,$$

and Belle measures

$$A_{CP}(B^0 \to D^{*+}D^{*-}) = -0.16 \pm 0.13 \pm 0.02.$$

Both measurements are consistent with each other and consistent with no direct CP violation. This favors in the $B^0 \to D^+D^-$ decays the *BABAR* measurement to be correct over the Belle measurement.

4.3. $B^0 \to J/\psi\pi^0$

The last discussed decay proceeding through the $b \to c\bar{c}d$ transition is the decay $B^0 \to J/\psi\pi^0$. In this decay, the tree amplitude is Cabibbo- and color-suppressed, thus providing a useful laboratory to test the penguin contribution from new physics beyond the standard model.

Both Belle and *BABAR* analyzed this decay recently. The Belle analysis is based on 535 million $B\overline{B}$ pairs which provides 290 signal events [30]. The measured direct CP asymmetry is

$$A_{CP}(B^0 \to J/\psi\pi^0) = -0.08 \pm 0.16 \pm 0.05.$$

The analysis from *BABAR* is based on 466 million $B\overline{B}$ pairs which yields 184 ± 15 signal events [31]. The result for the direct CP asymmetry is

$$A_{CP}(B^0 \to J/\psi\pi^0) = -0.20 \pm 0.19 \pm 0.03.$$

Measurements from both B-factory experiments are consistent with no direct CP asymmetry as expected in the standard model.

4.4. Summary

A graphical summary of the recent results on the direct CP violation in the B^0 decays governed by the $b \to c\bar{c}d$ transition is shown in Fig. 12. Taking into account also B^+ decays governed by the same transition, all measurements but $B^+ \to D^+\overline{D}^0$ from Belle

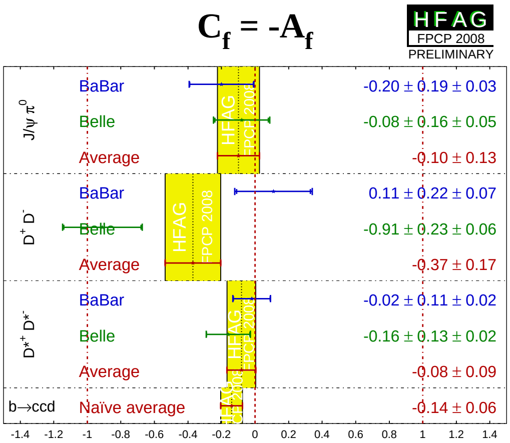

Figure 12: Summary of the current status of the direct CP violation in the B^0 decays governed by the $b \to c\bar{c}d$ transition [1].

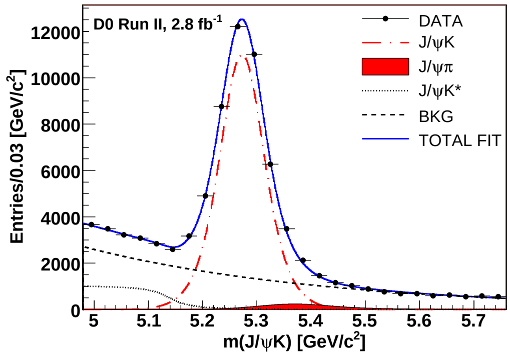

Figure 13: Invariant mass distribution of the $B^+ \to J/\psi K^+$ candidates from DØ [32].

are consistent with no direct CP violation as expected by the standard model. This is an indication that in case of the $B^0 \to D^+D^-$ decay the result observed originally by Belle is most probably due to a fluctuation rather than a sign of a new physics. On the other hand averaging all measurements from the B^0 decays yields

$$A_{CP}(b \to c\bar{c}) = -0.14 \pm 0.06,$$

which is naïvely 2.3 standard deviations from zero.

5. $B^+ \to J/\psi K^+$ decays

The last topic to discuss is a measurement of the direct CP violation in $B^+ \to J/\psi K^+$ by DØ [32]. This decay is governed by the $b \to c\bar{c}s$ transition. In the standard model tree and penguin amplitudes have a small relative weak phase. Therefore one expects a small direct CP violation on a subpercent level. On the other hand new physics contributions can enhance it to around 1% [33, 34]. The measurement of the direct CP violation in this decay can be a clean way of observing new physics, or important in constraining different models of new physics. In addition the same analysis has access to the decay $B^+ \to J/\psi\pi^+$ proceeding through the $b \to c\bar{c}d$ transition which allows another check of the large direct CP asymmetry seen by Belle in the $B^0 \to D^+D^-$ decays.

The analysis uses 2.8 fb^{-1} of data collected by the DØ detector using the dimuon trigger. The invariant mass distribution of selected events is shown in Fig. 13. After selection, 40222 ± 242 $B^+ \to J/\psi K^+$ and 1578 ± 119 $B^+ \to J/\psi\pi^+$ signal events are available. The most important effect which needs to be controlled is the asymmetry induced by the difference in the interaction of kaons with the detector material. This asymmetry is measured directly from data using the decay $D^{*+} \to D^0\pi^+$ with $D^0 \to \mu^+\nu_\mu K^-$ and assuming no direct CP violation in the semileptonic D^0 decays. The asymmetry due to the kaon interaction with material is found to be -0.0145 ± 0.0010. Taking this into account, DØ measures the direct CP asymmetries

$$\begin{aligned} A_{CP}(B^+ \to J/\psi K^+) &= 0.0075 \pm 0.0061 \pm 0.0027, \\ A_{CP}(B^+ \to J/\psi\pi^+) &= -0.09 \pm 0.08 \pm 0.03. \end{aligned}$$

Both asymmetries are consistent with zero as expected in the standard model. The sensitivity of the asymmetry $A_{CP}(B^+ \to J/\psi K^+)$ is approaching the interesting region where it can start to make constraints on new physics models.

6. Conclusions

The last year was very productive for experimental studies of the direct CP violation. We saw results from the *BABAR*, Belle, CDF and DØ experiments.

The topic which attracted the most attention in the last year is the direct CP violation in the $B^0 \to K^+\pi^-$ decay, which is most precisely measured and the only one seen in a single experiment with a significance of more than 5 standard deviations. The main point of discussions is its difference from the decay $B^+ \to K^+\pi^0$, which could be a sign of new physics, but could also be an effect of neglected standard model amplitudes, which could be sizable. In connection to this result it will be interesting to watch out for updates of the measurement in $B_s \to K^-\pi^+$ decays. The current measurement by CDF is 2.5 standard deviations from zero and consistent with the large expected direct CP

violation. With the next update we could have first evidence for CP violation in the B_s system.

The second important achievement in the previous year is the first analysis of the direct CP violation in the charmless two body Λ_b decays from CDF. While its significance of being nonzero is only 2.1 standard deviations for the decay $\Lambda_b \to pK^-$, the next update could result in the first evidence of the direct CP violation in the b-baryon sector.

The third important topic is the first evidence for direct CP violation in the B^+ sector in decays to ρK^+. This is seen by both Belle and *BABAR*, with a chance that the asymmetry in the decay to $f_2^0(1280)K^+$ will reach a significance of more than 3 standard deviations as well.

The last point which obtained considerable attention are decays governed by the $b \to c\bar{c}d$ transition. This interest was generated by the large CP violation seen by Belle in the $B^0 \to D^+D^-$ decay. In the last year new results most importantly on the $B^0 \to D^{*+}D^{*-}$ and $B^0 \to J/\psi\pi^0$ decays became available. For both decays, measurements are consistent with no CP violation, but the naïve average of the B^0 decays governed by the $b \to c\bar{c}d$ transition is 2.3 standard deviations from zero.

Altogether the last year provided many exciting results in the area of direct CP violation with promises for the near future. In that we might witness the first evidence for the direct CP violation in the B_s system as well as in the Λ_b system.

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