PROCEEDINGS OF SCIENCE

CP violation in HF decays - a summary of session

Maria Smizanska*
Physics Department, Lancaster University, UK
E-mail: maria.smizanska@cern.ch

A summary of the results presented at the session on CP violation in Heavy Flavours is given. The current precision achieved by recent measurements in decays of Heavy flavour hadrons is discussed in relation to the Standard model predictions and a potential sensitivity to new physics.

The XIth International Conference on Heavy Quarks and Leptons,
June 11-15, 2012
Prague, Czech Republic

*Speaker.

1. Introduction

Recently, important progress has been achieved on CP violation in decays of Heavy flavour hadrons, in particular D and B mesons. An up to date list of processes where CP violation has been established at a level above 5 σ includes: the CP violation from interference of mixing and decay in tree-dominated transitions, like $B^0 \to J/\psi K^0$, $B_s^0 \to J/\psi\phi$; the CP violation in the interference of mixing and decay in penguin transitions, like $B_s^0 \to \phi\phi$, and finally, the direct and the mixing-induced CP violation in hadronic-final-state decays of B-mesons, like $B^0 \to K\pi$ or $B \to DK$ and D-mesons, like $D^0 \to \pi^+\pi^-$ or $D^0 \to K^+K^-$. While experiments are confirming a consistency with the predictions of the CKM mechanism of the Standard Model (SM), the current level of experimental accuracy and the relevant theoretical uncertainties, leave room for additional sources of CP violation from new physics, in particular from the extensions of the SM.

At this conference all experiments contributing to CP violation in Heavy flavour decays presented their updates or overviews of recent results. While details are documented in the individual contributions to these proceedings, the current overview gives a view across the experiments, concentrating on four domains: charm decays, B_s^0 CP violation and angle ϕ_s, measurements of angle γ and the last section devoted to other selected topics. The overview is not exhaustive, but rather concentrated on the results presented at this conference.

2. CP violation in decays of Charm hadrons

Studies of CP violation in charm meson decays represent a specific direction of search for new physics in heavy flavours, probing the down sector, i.e. b, s, d quarks running in the SM loops, responsible for $D^0 - \overline{D^0}$ mixing and CP violation effects in D-meson decays. Nowadays charm mixing is well established: no mixing is excluded at 10.2 σ level [1], although no single experiment alone reaches a 5σ signature. The measurements are compatible with the SM expectation, however the long-range hadronic interactions in the $D^0 - \overline{D^0}$ transition amplitude makes theoretical predictions difficult and could potentially hide new physics effects [2]. After a non-zero charm mixing has been established, the efforts turned to CP violation in D-meson decays. The SM expectation is very small $\sim 10^{-3}$ and it is difficult to reach that level, neverthless the current experimental situation is favourable. Firstly, the charm cross section at LHC energy appears to be large: (6.10 ± 0.93) mb at 7 TeV [3], [4]. Secondly, there are large branching fractions ($> 10^{-3}$) for many CP sensitive modes that can be measured in LHCb detector with rather low SM backgrounds. So far most advanced are the measurements in the decay modes such as $\pi^+\pi^-$ and K^+K^- , where the CP violation after combining LHCb and CDF results is determined to be 3.8σ away from zero. Theoretical work ongoing to disentangle SM hadronic effects from possible new physics effects. In the experimental plan, there is evidently rich potential in a very broad range of modes which are under study at LHCb from data collected in 2011 and 2012: $D^0 \to hh$, $D^+ \to hhh$, $D^+ \to K_S h$ and $D^+ \to K_S hh$, where h denotes K or π mesons.

Common efforts of experiment and theory are directed to answer questions of validity of SM in charm physics or to discover possible contributions of new physics.

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3. Mixing induced CP violation in B_s^0 decay $B_s^0 \to J/\psi\phi$

New phenomena beyond the predictions of the SM may alter *CP* violation in *B*-decays. One of the channels that is expected to be sensitive to new physics contributions is the decay $B_s^0 \to J/\psi\phi$. *CP* violation in this decay occurs due to interference between direct decays and decays occurring through $B_s^0 - \overline{B_s^0}$ mixing. The oscillation frequency of B_s^0 meson mixing is characterized by the mass difference Δm_s of the heavy (B_H) and light (B_L) mass eigenstates and by the *CP*-violating phase ϕ_s. In the SM the phase ϕ_s is small and can be related to CKM quark mixing matrix elements via the relation $\phi_s \simeq -2\beta_s$, with $\beta_s = \arg[-(V_{ts}V_{tb}^*)/(V_{cs}V_{cb}^*)]$; a value of $\phi_s \simeq -2\beta_s = -0.0368 \pm 0.0018$ rad [5] is predicted in the SM. Many new physics models predict larger ϕ_s values whilst satisfying all existing constraints, including the precisely measured value of Δm_s [6, 7]. Another physical quantity involved in B_s^0 - $\overline{B_s^0}$ mixing is the width difference $\Delta\Gamma_s = \Gamma_L - \Gamma_H$ of B_L and B_H. Physics beyond the SM is not expected to affect $\Delta\Gamma_s$ as significantly as ϕ_s [13]. The research on CP violation in $B_s^0 \to J/\psi\phi$ started by CDF and D0 experiments and from 2010 LHCb has been leading this measurement. The word's best results at the time of this conference are summarised in an overlay plot, Fig **??**, showing two-dimensional contours of ϕ_s and $\Delta\Gamma_s$ for the 68% and 95% confidence intervals. The CDF and D0 results have twofold ambiguity, shown in the Figure. Recently the negative $\Delta\Gamma_s$ solution was excluded by LHCb measurements [10]. This was an important milestone in $B_s^0 \to J/\psi\phi$ research. A precision on ϕ_s achieved by LHCb by 2011 data on $B_s^0 \to J/\psi\phi$, [8], was still slightly improved by two additional LHCb measurements using decays $B_s \to J/\psi f_0$ and $B_s \to J/\psi\pi\pi$, resulting in current word's best measurement $\phi_s = -0.002 \pm 0.083$ (stat.) $\pm$ 0.027 (syst.) rad. At this conference ATLAS presented a potential for $B_s^0 \to J/\psi\phi$ using 2010 data that were used to measure value of Γ_s. By this initial measurement, reproducing a PDG value, ATLAS demonstrated that this experiment is well equipped for a CP violation measurement in this channel and will be able to contribute to LHC potential.

Currently all existing measurements on ϕ_s are consistent with zero CP violation as well as with the small SM value and the errors are still too large to confirm or reject SM.

4. CKM angle γ

One of the methods to look for new physics is to test a consistency of the CKM matrix. The phase γ = arg $|V_{ud}| \cdot |V_{ub}|^* / |V_{cd}| \cdot |V_{cb}|^*$, extracted from CP violation in the $B \to DK$ decays and a ratio $||V_{ub}|/|V_{cb}||$ from the semileptonic and hadronic *B*-meson decays, always provide the two of Wolfenstein's parameters [14] of the CKM-matrix, ρ and η, even if new physics were present. One can then compare them with the SM prediction, as described in [15]. Direct measurements of γ are obtained from interference of b $\to$ u and b $\to$ c transitions and a precision is still dominated by B-factories. The current word's average value of γ is (66 $\pm$ 12) deg, [16]. This is still less precise than indirect constraint, γ = (67.1 $\pm$ 4.3) deg, [16]. Belle presented their recent time-independent measurement using the channel $B^- \to D(K_S\pi\pi)K^-$, with the result of $\phi_3 = 77.3 \pm$ 0.083 (stat.) $\pm$ 4.1 (syst.) $\pm$ 4.3 (th.) deg [17]. LHCb is starting to contribute with a rich potential of variety of channels. Already at this conference LHCb presents the world's most precise GLW/ADS measurements using decays $B \to DK$. In particular the 10 σ observation of the suppressed mode $B^- \to D(K^+\pi^-)K^-$ and the 5.8σ observation of non-zero CP violation in $B^- \to DK^-$, with D-

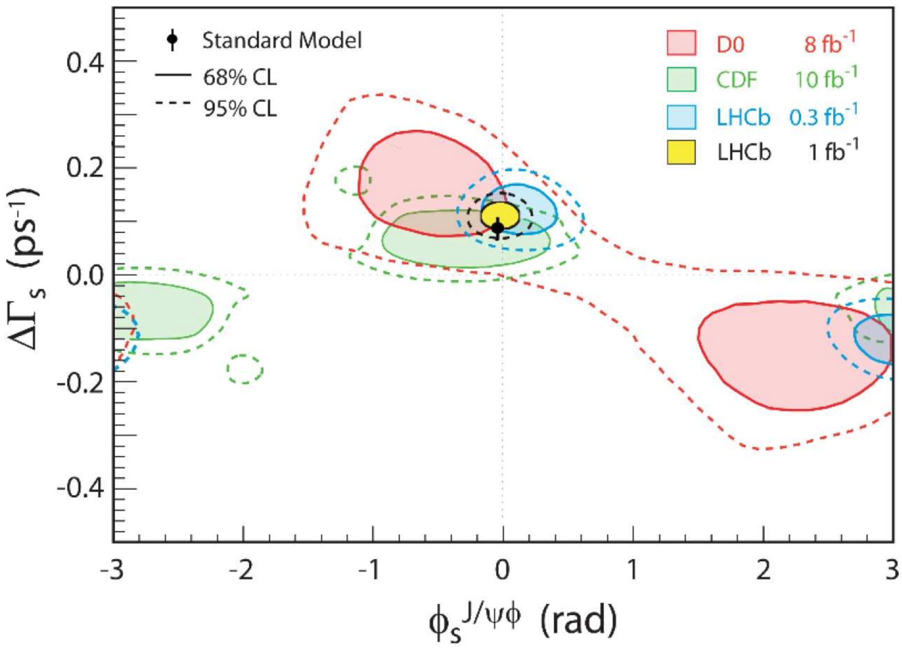

Figure 1: Likelihood contours in the $\phi_s - \Delta\Gamma_s$ plane for LHCb, CDF and D0 experiments. Two contours show the 68%, and 95% confidence intervals. Details about the contour plots can be found in [8, 9] for LHCb, in [11] for D0 and in [12] for CDF.

meson decays combined. Other modes sensitive to γ , on the way from LHCb are $B^0 \to DK^{*0}$, $B^0 \to D(hhh)^{\pm}$, $B_s^0 \to D_s K$, $B_s^0 \to D\phi$, $B_s^0 \to DK^+K^-$ and $B^0 \to DK^+\pi^-$.

Expected precision of LHCb at the end of 2012 on γ is 5 deg, but apparently it will not be conclusive with current theory uncertainties and a higher accuracy on γ (1 deg), is definitely required.

5. Other CP violation results

Searches for CP violation in charmless two-body decays provide another method of determination of the weak phase γ and of the mixing phases ϕ_s and ϕ_d. Both direct and a mixing-induced CP violation effects are studied. So far the research has been lead by B-factories and Tevatron experiments, CDF and D0, however LHCb has already provided several important results in the field. In particular it is the world's best significance (6σ) of a non-zero direct CP asymmetry in the decay $B^0 \to K\pi$ and the first evidence of a direct CP asymmetry in $B_s^0 \to K\pi$ with a significance 3σ. LHCb also presented results on angular analysis of a decay $B_s^0 \to \phi\phi$, that are in agreement with previous CDF ones, while improving a precision. This decay also carries an information on the mixing phase ϕ_s, however a precision is strongly limited by statistics. The LHCb potential for charmless two-body decays is enormous, since they can cover both beauty mesons and baryons: B^0, B_s^0 and Λ_b^0 and using their excellent Kπ separation they can clearly isolate all signals of $B^0(B_s^0) \to K\pi(\pi\pi;KK,pK)$, $\Lambda_b^0 \to p\pi(pK)$. Belle presented at this conference a new result on $B^0 \to a_1^{\pm}\pi^{\mp}$, showing the first evidence of a mixing-induced CP violation in this decay with a significance 3.1σ. The analysis was using final data sample, containing 772 millions of $b\bar{b}$ pairs.

6. Conclusion

Big progress in CP violation searches has been recently achieved in all experiments measuring decays of D and B mesons. The most important conclusion was that all measurements of CP violation to date confirmed a consistency with the predictions of the CKM mechanism of the SM. It is clear that new searches for additional CP violation effects, e.g. generated by extensions to the SM, will necessarily require substantial increase of experimental precisions. At LHC before the shutdown (2013) the precisions will be increased mainly due to growing statistics, however a radical improvement, necessary to reach relevant precisions, is expected from the upgraded LHC detectors [18], [19]. A higher-luminosity asymmetric-energy B factory [21] is going to be another strong contributor into CP violations of B-mesons.

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