PROCEEDINGS OF SCIENCE

Exclusion of multifold solutions of the CKM Unitarity Triangle by a time-dependent Dalitz plot analysis of $\bar{B}^0 \to D^{(*)0}h^0$ with $D^0 \to K^0_S\pi^+\pi^-$ decays combining BABAR and Belle data

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We present results of a new analysis campaign, which combines the final data samples collected by the B factory experiments *BABAR* and Belle in single physics analyses to achieve a unique sensitivity in time-dependent *CP* violation measurements. The data samples contain $(471 \pm 3) \times 10^6$ $B\bar{B}$ pairs recorded by the *BABAR* detector and $(772 \pm 11) \times 10^6$ $B\bar{B}$ pairs recorded by the Belle detector in e^+e^- collisions at the center-of-mass energies corresponding to the mass of the $\Upsilon(4S)$ resonance at the asymmetric-energy B factories PEP-II at SLAC and KEKB at KEK. We present a measurement of $\sin 2\beta$ and $\cos 2\beta$ by a time-dependent Dalitz plot analysis of $B^0 \to D^{(*)}h^0$ with $D \to K^0_S\pi^+\pi^-$ decays. A first evidence for $\cos 2\beta > 0$, the exclusion of trigonometric multifold solutions of the Unitarity Triangle and an observation of *CP* violation are reported.

The European Physical Society Conference on High Energy Physics
5-12 July, 2017
Venice

*Speaker.

†This work was supported by Norwegian Research Council. I would like to thank the *BABAR* collaboration for the opportunity to present these results, in particular I would like to thank M. Röhrken and F.C. Porter for useful discussions.

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1. Introduction

In the Standard Model (SM), *CP* violation is caused by the phase of the CKM matrix [1]. The unitarity relation $V_{ub}^{*}V_{ud} + V_{cb}^{*}V_{cd} + V_{tb}^{*}V_{td} = 0$, which represents the so-called Unitarity Triangle (UT), provides a valuable tool to test the SM since many measurements in the B and K systems that determine sides and angles (α, β, γ) overconstrain the UT. Time-dependent *CP* asymmetries of $B^0 \to K^0 c\bar{c}$ decays where $c\bar{c}$ is a charmonium resonance provide measurements of $\sin 2\beta = 0.$ [2]. In the determination of β a two-fold ambiguity arises for $\beta \leq 90^\circ$, $\beta = 21.9^\circ$ and $\beta = 68.1^\circ$ [3]. To lift this ambiguity, a measurement of $\cos 2\beta$ is necessary. We perform a time-dependent Dalitz plot analysis of $\bar{B}^0 \to D^{(*)0}h^0$ with $D^0 \to K_S^0\pi^+\pi^-$ and $h^0 = \pi^0$, η, ω using *BABAR* and Belle data comprising of $(471 \pm 3) \times 10^6$ and $(772 \pm 11) \times 10^6$ $B\bar{B}$ events, respectively. The dependence on $\cos 2\beta$ arises from the interference of the D^0 and $\bar{D}^0$ amplitudes and the variation of their relative strong phases [4].

2. Selection of $\bar{B}^0 \to D^{(*)0}h^0$ Signal

The $D^0 \to K_S^0\pi^+\pi^-$ Dalitz plot amplitude model was built and tested with Belle $e^+e^- \to c\bar{c}$ data. It includes 13 intermediate two-body resonances as well as $\pi\pi$ and $K\pi$ S-waves. The S-wave contributions are modelled by the K-matrix [5] and LASS [6] parameterizations, respectively. In total, we reconstruct five $\bar{B}^0$ decay modes $(D^0\pi^0, D^0\eta, D^0\omega, D^{*0}\pi^0$ and $D^{*0}\eta)$ in which the D^0, D^{*0} and h^0 are reconstructed in the decays $D^0 \to K_S^0\pi^+\pi^-$, $D^{*0} \to D^0\pi^0$, and $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma$ or $\eta \to \pi^+\pi^-\pi^0$ and $\omega \to \pi^+\pi^-\pi^0$. To extract the signal yields we perform a three-dimensional fit of the variables ΔE (difference between B meson energy and beam energy), a transformed beam-constrained mass ($M'_{\rm bc}$), which removes correlations to ΔE, and a neural network output ($NN'_{\rm out}$) that combines event shape information from 16 modified Fox-Wolfram moments [7]. We observe 1129 ± 48 *BABAR* and 1567 ± 56 Belle signal events. Figure 1 shows the $M'_{\rm bc}$, ΔE and $NN'_{\rm out}$ distributions with fit projections overlaid after combining all five modes from both experiments.

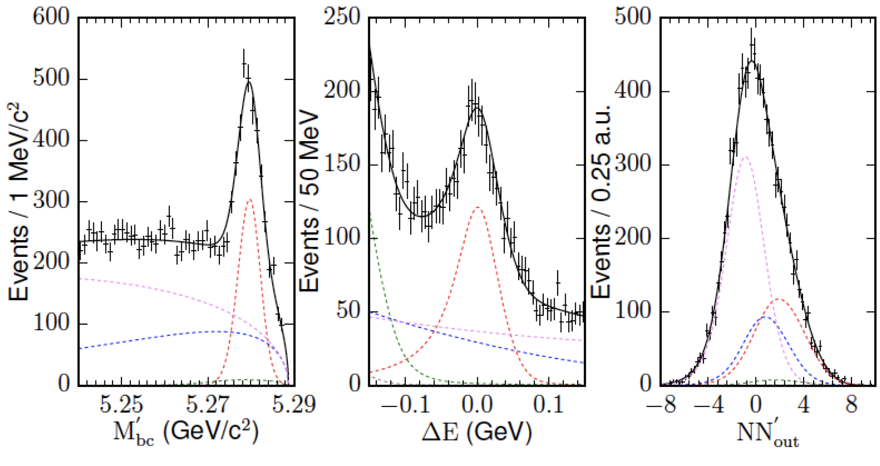

Figure 1: Fit projections of $M'_{\rm bc}$ (left), ΔE (middle and $NN'_{\rm out}$ (right) showing data (points with error bars), total fit (solid black line), signal (red dashed line), combinatorial background (blue dashed line), continuum background (magenta dashed line) and cross-feed (green dashed line).

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3. Time-dependent *CP* Analysis

We fit the proper time interval distributions with physics probability density functions that are convolved with experiment-specific resolution functions. We apply the *BABAR*- and Belle-specific flavor-tagging algorithms and use a common signal model for both experiments. We fix the B lifetimes (τ_{B^0}, $\tau_{B^\pm}$ and the $B^0\bar{B}^0$ mixing parameter Δm_d to the world average [8]. The only free parameters in the fit are $\sin 2\beta$ and $\cos 2\beta$. We measure $\sin 2\beta = 0.80 \pm 0.14_{\rm stat} \pm 0.06_{\rm sys} \pm 0.03_{\rm model}$, $\cos 2\beta = 0.91 \pm 0.22_{\rm stat} \pm 0.09_{\rm sys} \pm 0.07_{\rm model}$ yielding $\beta = (22.5 \pm 4.4_{\rm stat} \pm 1.2_{\rm sys} \pm 0.6_{\rm model})^\circ$. The largest systematic errors on $\cos 2\beta$ result from uncertainties in the Δt resolution functions, vertex reconstruction, possible fit bias and signal purity. The value of $\sin 2\beta$ is in good agreement with the world average of 0.679 ± 0.02 [8]. Our results yields the first evidence for $\cos 2\beta > 0$ at 3.7 standard deviations excluding the second result of $\beta = (68.1 \pm 0.7)^\circ$ at 7.3 standard deviations. This removes the ambiguity of extracting β from $\sin 2\beta$. Figure 2 shows the $2\Delta \ln L$ distributions as functions of $\sin 2\beta$, $\cos 2\beta$ and β.

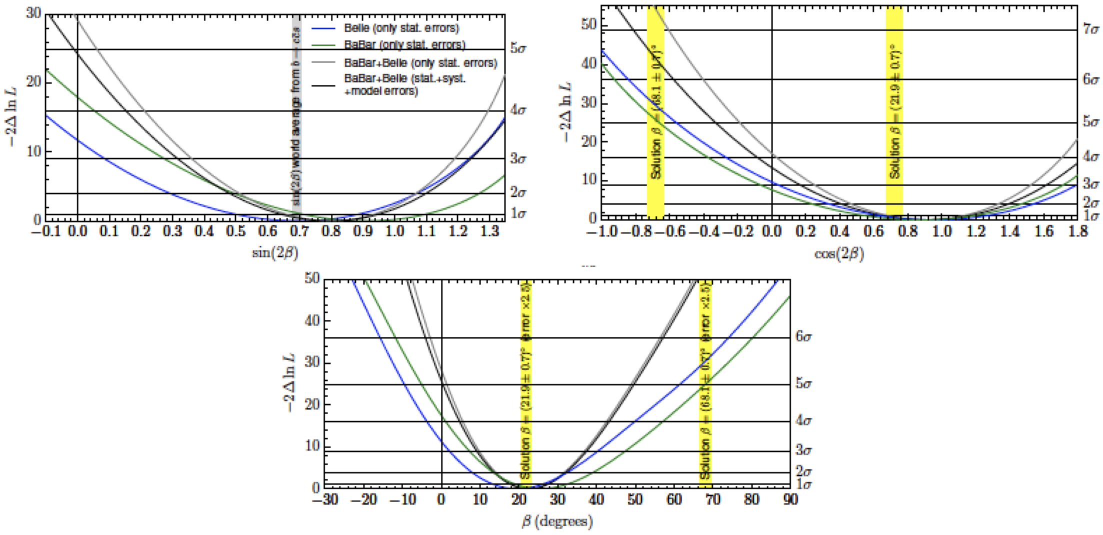

Figure 2: The $2\Delta \ln L$ distributions as functions of $\sin 2\beta$ (top left), $\cos 2\beta$ (top right) and β (bottom) for *BABAR* data (green line), Belle data (blue line) and both experiments combined (grey line) using statistical errors only. The result for both experiments including systematic uncertainties are shown by the black solid curves.

4. Conclusions

We have performed a time-dependent *CP* analysis of the decay mode $\bar{B}^0 \to D^{(*)0} h^0$ where the D^0 is reconstructed in the $K^0_S \pi^+ \pi^-$ final state using 1.1 ab^{-1} of *BABAR* and Belle data. We measure $\cos 2\beta = 0.91 \pm 0.22_{\rm stat} \pm 0.09_{\rm sys} \pm 0.07_{\rm model}$ from which we can exclude the solution $\beta = (68.1 \pm 0.7)^\circ$ at 7.3 standard deviations, lifting the ambiguity in the determination of the UT angle β. Our result for β agrees well with the world average.

References

[1] N. Cabibbo, Phys. Rev. Lett. 10, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Theor. Phys. 49, 652 (1973).

[2] The *BABAR* Collaboration (B. Aubert *et al*.), Phys.Rev.D79, 072009 (2009); the Belle Collaboration (I.Adachi *et al*.), Phys. Rev. Lett. 108, 171802 (2012).

[3] Heavy Flavor Averaging Group (R. van Kooten *et al*.), http://www.slac.stanford.edu/xorg/hfag/.

[4] A. Bondar, T. Gershon, and P. Krokovny, Phys. Lett. B624, 1 (2005).

[5] S.U. Chung *et al*., Annalen der Physik, 507, 404 (1995); I. Aitchison, Nucl. Phys. A 189, 417 (1972).

[6] The LASS Collaboration (D. Aston *et al*.), Nucl. Phys. B 296, 493 (1988).

[7] The *BABAR* and Belle Collaborations (A. Abdesselam, I. Adachi, A. Adametz *et al*.), Phys. Rev. Lett.115, 121604 (2015).

[8] K.A. Olive et al. (Particle Data Group), Chin. Phys. C 38, 090001 (2014).

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