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Adachi, I

Adye, T

Ahmed, H

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First evidence for $\cos 2\beta > 0$ and resolution of the CKM Unitarity Triangle ambiguity by a time-dependent Dalitz plot analysis of $B^0 \rightarrow D^{(*)}h^0$ with $D \rightarrow K_S^0\pi^+\pi^-$ decays

I. Adachi^{B, 31, 28} T. Adye^{A, 108} H. Ahmed^{A, 116} J. K. Ahn^{B, 54} H. Aihara^{B, 132} S. Akar^{A, 99} M. S. Alam^{A, 118}
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 A. Jawahery^{A, 72} C. P. Jessop^{A, 93} S. Jia^{B, 5} Y. Jin^{B, 132} K. K. Joo^{B, 19} T. Julius^{B, 76} A. B. Kaliyar^{B, 39} K. H. Kang^{B, 55}
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 P. Kim^{A, 113} G. J. King^{Ab, 138} K. Kinoshita^{B, 20} H. Koch^{A, 8} P. Kodyš^{B, 18} Yu. G. Kolomensky^{A, 7} S. Korpar^{B, 71, 46}
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 J. A. McKenna^{Ab, 9} B. T. Meadows^{A, 20} M. Merola^{Bab, 84} K. Miyabayashi^{B, 85} T. S. Miyashita^{A, 17} H. Miyata^{B, 92}
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 R. Mussa^{Ba, 135} E. Nakano^{B, 95} M. Nakao^{B, 31, 28} T. Nanut^{B, 46} K. J. Nath^{B, 37} M. Nayak^{B, 141, 31} H. Neal^{A, 113}
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L. Zani^{A,ab,102} Z. P. Zhang^{B,110} V. Zhilich^{B,11,12} V. Zhukova^{B,59,81} V. Zhulanov^{B,11,12} and A. Zupanc^{B,62,46}

(The ^ABABAR and ^BBelle Collaborations)

¹Laboratoire d'Annecy-le-Vieux de Physique des Particules (LAPP),
Université de Savoie, CNRS/IN2P3, F-74941 Annecy-Le-Vieux, France

²Universitat de Barcelona, Facultat de Física, Departament ECM, E-08028 Barcelona, Spain

³INFN Sezione di Bari and Dipartimento di Fisica, Università di Bari, I-70126 Bari, Italy

⁴University of the Basque Country UPV/EHU, 48080 Bilbao, Spain

⁵Beihang University, Beijing 100191, China

⁶University of Bergen, Institute of Physics, N-5007 Bergen, Norway

⁷Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA

⁸Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany

⁹Institute of Particle Physics^a; University of British Columbia^b, Vancouver, British Columbia, Canada V6T 1Z1

¹⁰Brookhaven National Laboratory, Upton, New York 11973, USA

¹¹Budker Institute of Nuclear Physics SB RAS, Novosibirsk 630090, Russian Federation

¹²Novosibirsk State University, Novosibirsk 630090, Russian Federation

¹³Novosibirsk State Technical University, Novosibirsk 630092, Russian Federation

¹⁴University of California at Irvine, Irvine, California 92697, USA

¹⁵University of California at Riverside, Riverside, California 92521, USA

¹⁶University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA

¹⁷California Institute of Technology, Pasadena, California 91125, USA

¹⁸Faculty of Mathematics and Physics, Charles University, 121 16 Prague, Czech Republic

¹⁹Chonnam National University, Kwangju 660-701, South Korea

²⁰University of Cincinnati, Cincinnati, Ohio 45221, USA

²¹University of Colorado, Boulder, Colorado 80309, USA

²²Deutsches Elektronen-Synchrotron, 22607 Hamburg, Germany

²³Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) and
Institute of Modern Physics, Fudan University, Shanghai 200443, China

²⁴INFN Sezione di Ferrara^a; Dipartimento di Fisica e Scienze della Terra, Università di Ferrara^b, I-44122 Ferrara, Italy

²⁵INFN Laboratori Nazionali di Frascati, I-00044 Frascati, Italy

²⁶INFN Sezione di Genova, I-16146 Genova, Italy

²⁷Justus-Liebig-Universität Gießen, 35392 Gießen, Germany

²⁸SOKENDAI (The Graduate University for Advanced Studies), Hayama 240-0193, Japan

²⁹Hanyang University, Seoul 133-791, South Korea

³⁰University of Hawaii, Honolulu, Hawaii 96822, USA

³¹High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan

³²J-PARC Branch, KEK Theory Center, High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan

³³Humboldt-Universität zu Berlin, Institut für Physik, D-12489 Berlin, Germany

³⁴IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Spain

³⁵Indian Institute of Science Education and Research Mohali, SAS Nagar, 140306, India

- ³⁶ Indian Institute of Technology Bhubaneswar, Satya Nagar 751007, India
- ³⁷ Indian Institute of Technology Guwahati, Assam 781039, India
- ³⁸ Indian Institute of Technology Hyderabad, Telangana 502285, India
- ³⁹ Indian Institute of Technology Madras, Chennai 600036, India
- ⁴⁰ Indiana University, Bloomington, Indiana 47408, USA
- ⁴¹ Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
- ⁴² Institute of High Energy Physics, Vienna 1050, Austria
- ⁴³ University of Iowa, Iowa City, Iowa 52242, USA
- ⁴⁴ Iowa State University, Ames, Iowa 50011, USA
- ⁴⁵ Advanced Science Research Center, Japan Atomic Energy Agency, Naka 319-1195
- ⁴⁶ J. Stefan Institute, 1000 Ljubljana, Slovenia
- ⁴⁷ Johns Hopkins University, Baltimore, Maryland 21218, USA
- ⁴⁸ Kanagawa University, Yokohama 221-8686, Japan
- ⁴⁹ Institut für Experimentelle Teilchenphysik, Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany
- ⁵⁰ Kennesaw State University, Kennesaw, Georgia 30144, USA
- ⁵¹ King Abdulaziz City for Science and Technology, Riyadh 11442, Kingdom of Saudi Arabia
- ⁵² Department of Physics, Faculty of Science, King Abdulaziz University, Jeddah 21589, Kingdom of Saudi Arabia
- ⁵³ Korea Institute of Science and Technology Information, Daejeon 305-806, South Korea
- ⁵⁴ Korea University, Seoul 136-713, South Korea
- ⁵⁵ Kyungpook National University, Daegu 702-701, South Korea
- ⁵⁶ Laboratoire de l'Accélérateur Linéaire, IN2P3/CNRS et Université Paris-Sud 11, Centre Scientifique d'Orsay, F-91898 Orsay Cedex, France
- ⁵⁷ École Polytechnique Fédérale de Lausanne (EPFL), Lausanne 1015, Switzerland
- ⁵⁸ Lawrence Livermore National Laboratory, Livermore, California 94550, USA
- ⁵⁹ P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow 119991, Russian Federation
- ⁶⁰ Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS/IN2P3, F-91128 Palaiseau, France
- ⁶¹ University of Liverpool, Liverpool L69 7ZE, United Kingdom
- ⁶² Faculty of Mathematics and Physics, University of Ljubljana, 1000 Ljubljana, Slovenia
- ⁶³ Queen Mary, University of London, London, E1 4NS, United Kingdom
- ⁶⁴ University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom
- ⁶⁵ University of Louisville, Louisville, Kentucky 40292, USA
- ⁶⁶ Ludwig Maximilians University, 80539 Munich, Germany
- ⁶⁷ Luther College, Decorah, Iowa 52101, USA
- ⁶⁸ Johannes Gutenberg-Universität Mainz, Institut für Kernphysik, D-55099 Mainz, Germany
- ⁶⁹ University of Malaya, 50603 Kuala Lumpur, Malaysia
- ⁷⁰ University of Manchester, Manchester M13 9PL, United Kingdom
- ⁷¹ University of Maribor, 2000 Maribor, Slovenia
- ⁷² University of Maryland, College Park, Maryland 20742, USA
- ⁷³ Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA
- ⁷⁴ Max-Planck-Institut für Physik, 80805 München, Germany
- ⁷⁵ Institute of Particle Physics^a; McGill University^b, Montréal, Québec, Canada H3A 2T8
- ⁷⁶ School of Physics, University of Melbourne, Victoria 3010, Australia
- ⁷⁷ INFN Sezione di Milano^a; Dipartimento di Fisica, Università di Milano^b, I-20133 Milano, Italy
- ⁷⁸ University of Mississippi, University, Mississippi 38677, USA
- ⁷⁹ University of Miyazaki, Miyazaki 889-2192, Japan
- ⁸⁰ Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7
- ⁸¹ Moscow Physical Engineering Institute, Moscow 115409, Russian Federation
- ⁸² Moscow Institute of Physics and Technology, Moscow Region 141700, Russian Federation
- ⁸³ Graduate School of Science, Nagoya University, Nagoya 464-8602, Japan
- ⁸⁴ INFN Sezione di Napoli^a and Dipartimento di Scienze Fisiche, Università di Napoli Federico II^b, I-80126 Napoli, Italy
- ⁸⁵ Nara Women's University, Nara 630-8506, Japan
- ⁸⁶ National Central University, Chung-li 32054, Taiwan
- ⁸⁷ National United University, Miao Li 36003, Taiwan
- ⁸⁸ NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands
- ⁸⁹ Department of Physics, National Taiwan University, Taipei 10617, Taiwan
- ⁹⁰ H. Niewodniczanski Institute of Nuclear Physics, Krakow 31-342, Poland
- ⁹¹ Nippon Dental University, Niigata 951-8580, Japan
- ⁹² Niigata University, Niigata 950-2181, Japan
- ⁹³ University of Notre Dame, Notre Dame, Indiana 46556, USA
- ⁹⁴ Ohio State University, Columbus, Ohio 43210, USA
- ⁹⁵ Osaka City University, Osaka 558-8585, Japan
- ⁹⁶ Pacific Northwest National Laboratory, Richland, Washington 99352, USA
- ⁹⁷ INFN Sezione di Padova^a; Dipartimento di Fisica, Università di Padova^b, I-35131 Padova, Italy

- ⁹⁸ Panjab University, Chandigarh 160014, India
- ⁹⁹ Laboratoire de Physique Nucléaire et de Hautes Energies, IN2P3/CNRS, Université Pierre et Marie Curie-Paris6, Université Denis Diderot-Paris7, F-75252 Paris, France
- ¹⁰⁰ Peking University, Beijing 100871, China
- ¹⁰¹ INFN Sezione di Perugia^a; Dipartimento di Fisica, Università di Perugia^b, I-06123 Perugia, Italy
- ¹⁰² INFN Sezione di Pisa^a; Dipartimento di Fisica, Università di Pisa^b; Scuola Normale Superiore di Pisa^c, I-56127 Pisa, Italy
- ¹⁰³ University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA
- ¹⁰⁴ Princeton University, Princeton, New Jersey 08544, USA
- ¹⁰⁵ Theoretical Research Division, Nishina Center, RIKEN, Saitama 351-0198, Japan
- ¹⁰⁶ INFN Sezione di Roma^a; Dipartimento di Fisica, Università di Roma La Sapienza^b, I-00185 Roma, Italy
- ¹⁰⁷ Universität Rostock, D-18051 Rostock, Germany
- ¹⁰⁸ Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom
- ¹⁰⁹ CEA, Irfu, SPP, Centre de Saclay, F-91191 Gif-sur-Yvette, France
- ¹¹⁰ University of Science and Technology of China, Hefei 230026, China
- ¹¹¹ Showa Pharmaceutical University, Tokyo 194-8543, Japan
- ¹¹² Soongsil University, Seoul 156-743, South Korea
- ¹¹³ SLAC National Accelerator Laboratory, Stanford, California 94309 USA
- ¹¹⁴ University of South Carolina, Columbia, South Carolina 29208, USA
- ¹¹⁵ Southern Methodist University, Dallas, Texas 75275, USA
- ¹¹⁶ St. Francis Xavier University, Antigonish, Nova Scotia, Canada B2G 2W5
- ¹¹⁷ Stanford University, Stanford, California 94305, USA
- ¹¹⁸ State University of New York, Albany, New York 12222, USA
- ¹¹⁹ Sungkyunkwan University, Suwon 440-746, South Korea
- ¹²⁰ School of Physics, University of Sydney, New South Wales 2006, Australia
- ¹²¹ Department of Physics, Faculty of Science, University of Tabuk, Tabuk 71451, Kingdom of Saudi Arabia
- ¹²² Tata Institute of Fundamental Research, Mumbai 400005, India
- ¹²³ Department of Physics, Technische Universität München, 85748 Garching, Germany
- ¹²⁴ Excellence Cluster Universe, Technische Universität München, 85748 Garching, Germany
- ¹²⁵ Tel Aviv University, School of Physics and Astronomy, Tel Aviv, 69978, Israel
- ¹²⁶ University of Tennessee, Knoxville, Tennessee 37996, USA
- ¹²⁷ University of Texas at Austin, Austin, Texas 78712, USA
- ¹²⁸ University of Texas at Dallas, Richardson, Texas 75083, USA
- ¹²⁹ Toho University, Funabashi 274-8510, Japan
- ¹³⁰ Department of Physics, Tohoku University, Sendai 980-8578, Japan
- ¹³¹ Earthquake Research Institute, University of Tokyo, Tokyo 113-0032, Japan
- ¹³² Department of Physics, University of Tokyo, Tokyo 113-0033, Japan
- ¹³³ Tokyo Institute of Technology, Tokyo 152-8550, Japan
- ¹³⁴ Tokyo Metropolitan University, Tokyo 192-0397, Japan
- ¹³⁵ INFN Sezione di Torino^a; Dipartimento di Fisica, Università di Torino^b, I-10125 Torino, Italy
- ¹³⁶ INFN Sezione di Trieste and Dipartimento di Fisica, Università di Trieste, I-34127 Trieste, Italy
- ¹³⁷ IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain
- ¹³⁸ Institute of Particle Physics^a; University of Victoria^b, Victoria, British Columbia, Canada V8W 3P6
- ¹³⁹ Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA
- ¹⁴⁰ Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom
- ¹⁴¹ Wayne State University, Detroit, Michigan 48202, USA
- ¹⁴² University of Wisconsin, Madison, Wisconsin 53706, USA
- ¹⁴³ Yamagata University, Yamagata 990-8560, Japan
- ¹⁴⁴ Yonsei University, Seoul 120-749, South Korea

We present first evidence that the cosine of the CP -violating weak phase 2β is positive, and hence exclude trigonometric multifold solutions of the CKM Unitarity Triangle using a time-dependent Dalitz plot analysis of $B^0 \rightarrow D^{(*)}h^0$ with $D \rightarrow K_S^0\pi^+\pi^-$ decays, where $h^0 \in \{\pi^0, \eta, \omega\}$ denotes a light unflavored and neutral hadron. The measurement is performed combining the final data sets of the BABAR and Belle experiments collected at the $\Upsilon(4S)$ resonance at the asymmetric-energy B factories PEP-II at SLAC and KEKB at KEK, respectively. 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. The results of the measurement are $\sin 2\beta = 0.80 \pm 0.14$ (stat.) ± 0.06 (syst.) ± 0.03 (model) and $\cos 2\beta = 0.91 \pm 0.22$ (stat.) ± 0.09 (syst.) ± 0.07 (model). The result for the direct measurement of the angle β of the CKM Unitarity Triangle is $\beta = (22.5 \pm 4.4$ (stat.) ± 1.2 (syst.) ± 0.6 (model)) $^\circ$. The quoted model uncertainties are due to the composition of the $D^0 \rightarrow K_S^0\pi^+\pi^-$ decay amplitude

model, which is newly established by performing a Dalitz plot amplitude analysis using a high-statistics $e^+e^- \rightarrow c\bar{c}$ data sample. CP violation is observed in $B^0 \rightarrow D^{(*)}h^0$ decays at the level of 5.1 standard deviations. The significance for $\cos 2\beta > 0$ is 3.7 standard deviations. The trigonometric multifold solution $\pi/2 - \beta = (68.1 \pm 0.7)^\circ$ is excluded at the level of 7.3 standard deviations. The measurement resolves an ambiguity in the determination of the apex of the CKM Unitarity Triangle.

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In the standard model (SM) of electroweak interactions, the only source of CP violation is the irreducible complex phase in the three-family Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix [1]. The *BABAR* and Belle experiments discovered CP violation in the B meson system [2–5]. In particular, by time-dependent CP violation measurements of the “gold plated” decay mode¹ $B^0 \rightarrow J/\psi K_S^0$ and other decays mediated by $\bar{b} \rightarrow \bar{c}c\bar{s}$ transitions [6, 7], *BABAR* and Belle precisely determined the parameter $\sin 2\beta \equiv \sin 2\phi_1$,² where the angle β of the CKM Unitarity Triangle is defined as $\arg[-V_{cd}V_{cb}^*/V_{td}V_{tb}^*]$ and V_{ij} denotes a CKM matrix element. Inferring the CP -violating weak phase 2β from these measurements of $\sin 2\beta$ leads to the trigonometric two-fold ambiguity, 2β and $\pi - 2\beta$ (a four-fold ambiguity in β), and therefore to an ambiguity on the CKM Unitarity Triangle. This ambiguity can be resolved by also measuring $\cos 2\beta$, which is experimentally accessible in B meson decay modes involving multibody final states such as $B^0 \rightarrow J/\psi K_S^0 \pi^0$ [8, 9], $B^0 \rightarrow D^{*+}D^{*-}K_S^0$ [10, 11], $B^0 \rightarrow K_S^0 K^+ K^-$ [12, 13], $B^0 \rightarrow K_S^0 \pi^+ \pi^-$ [14, 15], and $B^0 \rightarrow D^{(*)}h^0$ with $D \rightarrow K_S^0 \pi^+ \pi^-$ decays (abbreviated as $B^0 \rightarrow [K_S^0 \pi^+ \pi^-]_D^{(*)} h^0$) [16–18]. However, no previous single measurement has been sufficiently sensitive to establish the sign of $\cos 2\beta$, to resolve the ambiguity without further assumptions.

The decays $B^0 \rightarrow D^{(*)}h^0$, with $D \rightarrow K_S^0 \pi^+ \pi^-$ and $h^0 \in \{\pi^0, \eta, \omega\}$ denoting a light neutral hadron, provide an elegant way to access $\cos 2\beta$ [19]. The $B^0 \rightarrow D^{(*)}h^0$ decay is predominantly mediated by CKM-favored $\bar{b} \rightarrow \bar{c}u\bar{d}$ tree amplitudes. Additional contributions from CKM-disfavored $\bar{b} \rightarrow \bar{u}c\bar{d}$ tree amplitudes that carry different weak phases are suppressed by $|V_{ub}V_{cd}^*/V_{cb}V_{ud}^*| \approx 0.02$ relative to the leading amplitudes and can be neglected at the experimental sensitivity of the presented measurement. The $D \rightarrow K_S^0 \pi^+ \pi^-$ decay exhibits complex interference structures that receive resonant and nonresonant contributions to the three-body final state from a rich variety of intermediate CP eigenstates and quasi-flavor-specific decays. Knowledge of the variations on the relative strong phase as a function of the three-body Dalitz plot phase space enables measurements of

both $\sin 2\beta$ and $\cos 2\beta$ from the time evolution of the $B^0 \rightarrow [K_S^0 \pi^+ \pi^-]_D^{(*)} h^0$ multibody final state.

Assuming no CP violation in B^0 - \bar{B}^0 mixing and no direct CP violation, the rate of the $B^0 \rightarrow [K_S^0 \pi^+ \pi^-]_D^{(*)} h^0$ decays is proportional to

$$\frac{e^{-\frac{|\Delta t|}{\tau_{B^0}}}}{2} \left\{ [|\mathcal{A}_{\bar{D}^0}|^2 + |\mathcal{A}_{D^0}|^2] - q (|\mathcal{A}_{\bar{D}^0}|^2 - |\mathcal{A}_{D^0}|^2) \cos(\Delta m_d \Delta t) + 2q\eta_{h^0} (-1)^L \text{Im} (e^{-2i\beta} \mathcal{A}_{D^0} \mathcal{A}_{\bar{D}^0}^*) \sin(\Delta m_d \Delta t) \right\}, \quad (1)$$

where Δt denotes the proper-time interval between the decays of the two B mesons produced in the $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^0 \bar{B}^0$ event, and $q = +1$ (-1) represents the b -flavor content when the accompanying B meson is tagged as a B^0 (\bar{B}^0). The parameters τ_{B^0} and Δm_d are the neutral B meson lifetime and the B^0 - \bar{B}^0 oscillation frequency, respectively. The symbols $\mathcal{A}_{D^0} \equiv \mathcal{A}(M_{K_S^0 \pi^-}^2, M_{K_S^0 \pi^+}^2)$ and $\mathcal{A}_{\bar{D}^0} \equiv \mathcal{A}(M_{K_S^0 \pi^+}^2, M_{K_S^0 \pi^-}^2)$ denote the D^0 and \bar{D}^0 decay amplitudes as functions of the Lorentz-invariant Dalitz plot variables $M_{K_S^0 \pi^-}^2 \equiv (p_{K_S^0} + p_{\pi^-})^2$ and $M_{K_S^0 \pi^+}^2 \equiv (p_{K_S^0} + p_{\pi^+})^2$, where the symbol p_i represents the four-momentum of a final state particle i . The factor η_{h^0} is the CP eigenvalue of h^0 . The quantity L is the orbital angular momentum of the Dh^0 or D^*h^0 system. The last term in Eq. (1) can be rewritten as

$$\text{Im} (e^{-2i\beta} \mathcal{A}_{D^0} \mathcal{A}_{\bar{D}^0}^*) = \text{Im} (\mathcal{A}_{D^0} \mathcal{A}_{\bar{D}^0}^*) \cos 2\beta - \text{Re} (\mathcal{A}_{D^0} \mathcal{A}_{\bar{D}^0}^*) \sin 2\beta, \quad (2)$$

which allows $\sin 2\beta$ and $\cos 2\beta$ to be treated as independent parameters.

Measurements of $\sin 2\beta$ and $\cos 2\beta$ in $B^0 \rightarrow D^{(*)}h^0$ with $D \rightarrow K_S^0 \pi^+ \pi^-$ decays are experimentally challenging. The branching fractions of the B and D meson decays are low ($\mathcal{O}(10^{-4})$ and $\mathcal{O}(10^{-2})$, respectively), and the neutral particles in the final state lead to large backgrounds and low reconstruction efficiencies. In addition, a detailed Dalitz plot amplitude model or other experimental knowledge of the relative strong phase in the three-body D meson decay is required. Previous measurements of these decays performed separately by *BABAR* and Belle were not sufficiently sensitive to establish CP violation [16–18], obtaining results far outside of

¹ In this Letter the inclusion of charge-conjugated decay modes is implied unless otherwise stated.

² *BABAR* uses the notation β and Belle uses ϕ_1 ; hereinafter β is used.

the physical region of the parameter space [16], and using different Dalitz plot amplitude models [16, 17], which complicates the combination of individual results.

In this Letter, we present measurements of $\sin 2\beta$ and $\cos 2\beta$ from a time-dependent Dalitz plot analysis of $B^0 \rightarrow D^{(*)}h^0$ with $D \rightarrow K_S^0\pi^+\pi^-$ decays that combines the final data samples collected by the *BABAR* and Belle experiments, totaling 1.1 ab^{-1} collected at the $\Upsilon(4S)$ resonance. The combined approach enables unique experimental sensitivity to $\cos 2\beta$ by increasing the available data sample and by applying common assumptions and the same Dalitz plot amplitude model simultaneously to the data collected by both experiments. As part of the analysis, an improved $D \rightarrow K_S^0\pi^+\pi^-$ Dalitz plot amplitude model is obtained from high-statistics $e^+e^- \rightarrow c\bar{c}$ data. This allows the propagation of the model uncertainties to the results on $\sin 2\beta$ and $\cos 2\beta$ obtained in $B^0 \rightarrow D^{(*)}h^0$ with $D^0 \rightarrow K_S^0\pi^+\pi^-$ decays in a straightforward way. In the following, the extraction of the $D^0 \rightarrow K_S^0\pi^+\pi^-$ Dalitz plot amplitude model parameters from Belle $e^+e^- \rightarrow c\bar{c}$ data is summarized. Thereafter, the time-dependent Dalitz plot analysis of the B meson decay combining *BABAR* and Belle, data is described. A more detailed description of the analysis is provided in Ref. [20].

To measure the $D^0 \rightarrow K_S^0\pi^+\pi^-$ decay amplitudes, we

$$\mathcal{A}(M_{K_S^0\pi^-}^2, M_{K_S^0\pi^+}^2) = \sum_{r \neq (K\pi/\pi\pi)_{L=0}} a_r e^{i\phi_r} \mathcal{A}_r(M_{K_S^0\pi^-}^2, M_{K_S^0\pi^+}^2) + F_1(M_{\pi^+\pi^-}^2) + \mathcal{A}_{K\pi_{L=0}}(M_{K_S^0\pi^-}^2) + \mathcal{A}_{K\pi_{L=0}}(M_{K_S^0\pi^+}^2). \quad (3)$$

The symbols a_r and ϕ_r represent the magnitude and phase of the r^{th} intermediate quasi-two-body amplitude \mathcal{A}_r contributing to the P - and D -waves. These amplitudes are parameterized using an isobar ansatz [31] by relativistic Breit-Wigner (BW) propagators with mass-dependent widths, Blatt-Weisskopf penetration factors [32], and Zemach tensors for the angular distributions [33]. The following intermediate two-body resonances are included: the Cabibbo-favored $K^*(892)^-\pi^+$, $K_2^*(1430)^-\pi^+$, $K^*(1680)^-\pi^+$, $K^*(1410)^-\pi^+$ channels; the doubly Cabibbo-suppressed $K^*(892)^+\pi^-$, $K_2^*(1430)^+\pi^-$, $K^*(1410)^+\pi^-$ modes; and the CP eigenstates $K_S^0\rho(770)^0$, $K_S^0\omega(782)$, $K_S^0f_2(1270)$, and $K_S^0\rho(1450)^0$. The symbol F_1 denotes the amplitude for the $\pi\pi$ S -wave using the K -matrix formalism in the P -vector approximation with 4 physical poles [34, 35]. The symbol $\mathcal{A}_{K\pi_{L=0}}$ represents the amplitude for the $K\pi$ S -wave using the LASS parametrization [36], which combines a BW for the $K_0^*(1430)^\pm$ with a coherent nonresonant contribution governed by an effective range and a phase shift.

The $D^0 \rightarrow K_S^0\pi^+\pi^-$ decay amplitude model param-

eters are determined by an unbinned maximum-likelihood Dalitz fit performed for events in the signal region of the flavor-tagged D^0 sample. The probability density function (p.d.f.) for the signal is constructed from Eq. (3) with a correction to account for reconstruction efficiency variations over the Dalitz plot phase space due to experimental acceptance effects [23], and an additional term to account for wrong flavor identifications of D mesons. In addition, the likelihood function contains a p.d.f. for the background that is constructed from the distributions taken from the M_{D^0} and ΔM data sidebands. The a_r and ϕ_r parameters for each resonance are floated in the fit and measured relative to the $K_S^0\rho(770)^0$ amplitude, which is fixed to $a_{K_S^0\rho(770)^0} = 1$ and $\phi_{K_S^0\rho(770)^0} = 0^\circ$. The masses and widths of the resonances are fixed to the world averages [37] except for those of the $K^*(892)$ and $K_0^*(1430)$, which are floated to improve the fit quality. The LASS parameters and several parameters in the K -matrix are floated in the fit.

Similar to previous D^0 - \bar{D}^0 oscillation analyses and measurements of the Unitarity Triangle angle γ [26] by *BABAR*, Belle and LHCb [27–30], the $D^0 \rightarrow K_S^0\pi^+\pi^-$ decay amplitude is parameterized as:

The results of the Dalitz fit are summarized in Table III of Ref. [20]. The data distributions and projections of the fit are shown in Fig. 1. By a two-dimensional χ^2

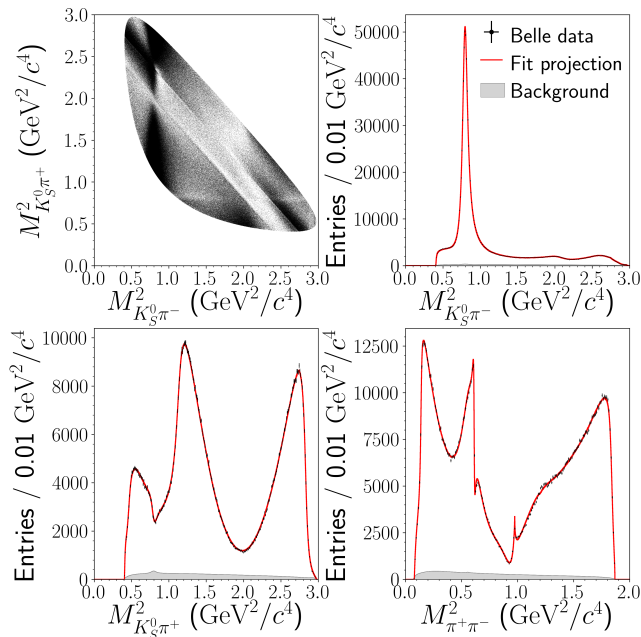


FIG. 1. (color online). The Dalitz plot data distributions (points with error bars) for $D^0 \rightarrow K_S^0 \pi^+ \pi^-$ from $D^{*+} \rightarrow D^0 \pi_s^+$ decays reconstructed from Belle $e^+e^- \rightarrow c\bar{c}$ data, and projections of the Dalitz fit. The red solid lines show the projections of the total fit function including background, and the grey regions show projections of the background.

test, a reduced χ^2 of 1.05 is obtained for 31 272 degrees of freedom based on statistical uncertainties only, indicating a relatively good quality of the fit [27–29, 38, 39].

The time-dependent Dalitz plot analysis of $B^0 \rightarrow D^{(*)}h^0$ with $D \rightarrow K_S^0 \pi^+ \pi^-$ decays is performed using data samples containing 471×10^6 $B\bar{B}$ pairs recorded with the BABAR detector [40, 41] at the asymmetric-energy e^+e^- (3.1 on 9 GeV) collider PEP-II [42] and 772×10^6 $B\bar{B}$ pairs recorded with the Belle detector [21] at the asymmetric-energy e^+e^- (3.5 on 8 GeV) collider KEKB [22] collected at the $\Upsilon(4S)$ [23].

The light neutral hadron h^0 is reconstructed in the decay modes $\pi^0 \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\gamma$ and $\pi^+\pi^-\pi^0$, and $\omega \rightarrow \pi^+\pi^-\pi^0$. Neutral D mesons are reconstructed in the decay mode $D \rightarrow K_S^0 \pi^+ \pi^-$, and neutral D^* mesons are reconstructed in the decay mode $D^* \rightarrow D\pi^0$. The decay modes $B^0 \rightarrow D\pi^0$, $D\eta$, $D\omega$, $D^*\pi^0$, and $D^*\eta$, where sufficient signal yields are reconstructed, are included in the analysis. The selection requirements applied to the reconstructed candidates are summarized in Ref. [20].

The $B^0 \rightarrow D^{(*)}h^0$ yields are determined by three-dimensional unbinned maximum likelihood fits to the distributions of the observables M'_{bc} , ΔE , and $C'_{NN_{out}}$. The beam-energy-constrained mass M'_{bc} defined in Ref. [43] is computed from the beam energy E_{beam}^* in the c.m. frame, the $D^{(*)}$ candidate momenta, and the h^0 candidate direction of flight. The quantity M'_{bc} provides an observable that is insensitive to possible correlations

with the energy difference $\Delta E = E_B^* - E_{beam}^*$ that can be induced by energy mismeasurements for particles detected in the electromagnetic calorimeters, for example, caused by shower leakage effects. The variable $C'_{NN_{out}}$ defined in Ref. [44] is constructed from the output of a neural network multivariate classifier trained on event shape information based on a combination of 16 modified Fox-Wolfram moments [45, 46] to identify background originating from $e^+e^- \rightarrow q\bar{q}$ ($q \in \{u, d, s, c\}$) continuum events. The fit model accounts for contributions from $B^0 \rightarrow D^{(*)}h^0$ signal decays, cross-feed from partially-reconstructed $B^0 \rightarrow D^*h^0$ decays, background from partially-reconstructed $B^+ \rightarrow \bar{D}^{(*)0}\rho^+$ decays, combinatorial background from $B\bar{B}$ decays, and background from continuum events. In total, a $B^0 \rightarrow D^{(*)}h^0$ signal yield of 1129 ± 48 events in the BABAR data sample and 1567 ± 56 events in the Belle data sample is obtained. The signal yields are summarized in Table IV of Ref. [20]. The M'_{bc} , ΔE , and $C'_{NN_{out}}$ data distributions and fit projections are shown in Fig. 2.

The time-dependent Dalitz plot analysis follows the technique established in the previous combined BABAR+Belle time-dependent CP violation measurement of $\bar{B}^0 \rightarrow D_{CP}^{(*)}h^0$ decays [25]. The measurement is performed by maximizing the log-likelihood function constructed from the events reconstructed from BABAR and Belle data [20]. The measurement includes all events used in the previous M'_{bc} , ΔE , and $C'_{NN_{out}}$ fits. In the log-likelihood function, the p.d.f.s are functions of the experimental flavor-tagged proper-time interval and Dalitz plot distributions for the signal and background components. The signal p.d.f.s are constructed from Eqs. 1 and 2 convolved with experiment-specific resolution functions to account for the finite vertex resolution [6, 47] and including the effect of incorrect flavor assignments [6, 48]. The p.d.f.s for the proper-time interval distributions of the combinatorial background from $B\bar{B}$ decays and background from continuum events account for background from non-prompt and prompt particles convolved with effective resolution functions. The partially-reconstructed $B^0 \rightarrow D^*h^0$ decays are modeled by the signal p.d.f. with a different set of parameters to account for this cross-feed contribution, and the background from partially-reconstructed $B^+ \rightarrow \bar{D}^{(*)0}\rho^+$ decays is parameterized by an exponential p.d.f. convolved with the same resolution functions as used for the signal.

In the fit, the parameters τ_{B^0} , τ_{B^+} , and Δm_d are fixed to the world averages [50], and the Dalitz plot amplitude model parameters are fixed to the results of the $D^0 \rightarrow K_S^0 \pi^+ \pi^-$ Dalitz plot fit described above. The signal and background fractions are evaluated on an event-by-event basis from the three-dimensional fit of the M'_{bc} , ΔE , and $C'_{NN_{out}}$ observables. The only free parameters are $\sin 2\beta$

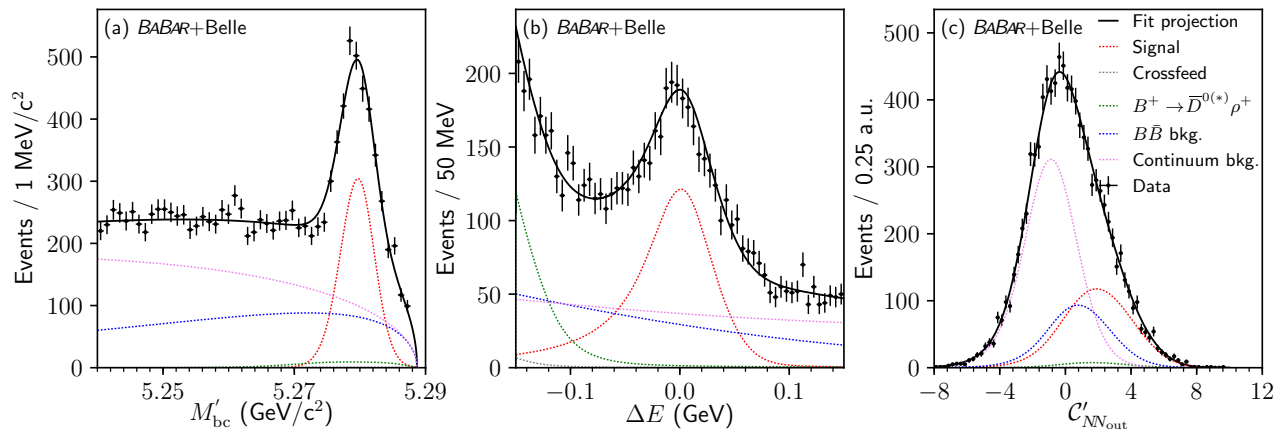


FIG. 2. (color online). Data distributions for a) M'_{bc} , b) ΔE , and c) $C'_{NN_{out}}$ (points with error bars) for the *BABAR* and *Belle* data samples combined. The solid black lines represent projections of the total fit function, and the colored dotted lines show the signal and background components of the fit as indicated in the legend. In plotting the M'_{bc} , ΔE , and $C'_{NN_{out}}$ distributions, each of the other two observables are required to satisfy $M'_{bc} > 5.272 \text{ GeV}/c^2$, $|\Delta E| < 100 \text{ MeV}$, or $0 < C'_{NN_{out}} < 8$ to select signal-enhanced regions.

and $\cos 2\beta$, and the results are

$$\begin{aligned} \sin 2\beta &= 0.80 \pm 0.14 \text{ (stat.)} \pm 0.06 \text{ (syst.)} \pm 0.03 \text{ (model)}, \\ \cos 2\beta &= 0.91 \pm 0.22 \text{ (stat.)} \pm 0.09 \text{ (syst.)} \pm 0.07 \text{ (model)}. \end{aligned} \quad (4)$$

The second quoted uncertainty is the experimental systematic error, and the third is due to the $D^0 \rightarrow K_S^0 \pi^+ \pi^-$ decay amplitude model. The evaluation of these uncertainties is described in detail in Ref. [20]. The linear correlation between $\sin 2\beta$ and $\cos 2\beta$ is 5.1%. The result deviates less than 1.0 standard deviations from the trigonometric constraint given by $\sin^2 2\beta + \cos^2 2\beta = 1$.

An alternative fit is performed to measure directly the angle β using the signal p.d.f. constructed from Eq. (1), and the result is

$$\beta = (22.5 \pm 4.4 \text{ (stat.)} \pm 1.2 \text{ (syst.)} \pm 0.6 \text{ (model)})^\circ. \quad (5)$$

The proper-time interval distributions and projections of the fit for $\sin 2\beta$ and $\cos 2\beta$ are shown in Fig. 3 for two different regions of the $D^0 \rightarrow K_S^0 \pi^+ \pi^-$ phase space. Figure 3a shows a region predominantly populated by *CP* eigenstates, $B^0 \rightarrow [K_S^0 \rho(770)^0]_D^{(*)} h^0$. For these decays, interference emerges between the amplitude for direct decays of neutral *B* mesons into these final states and those following B^0 - \bar{B}^0 oscillations. The time evolution exhibits mixing-induced *CP* violation governed by the *CP*-violating weak phase 2β , which manifests as a sinusoidal oscillation in the *CP* asymmetry. Figure 3b shows a region predominantly populated by quasi-flavor-specific decays, $B^0 \rightarrow [K^{*(892)\pm} \pi^\mp]_D^{(*)} h^0$. For these decays, the time evolution exhibits B^0 - \bar{B}^0 oscillations governed by the oscillation frequency, Δm_d , which appears as an oscillation proportional to $\cos(\Delta m_d \Delta t)$ in the corresponding asymmetry.

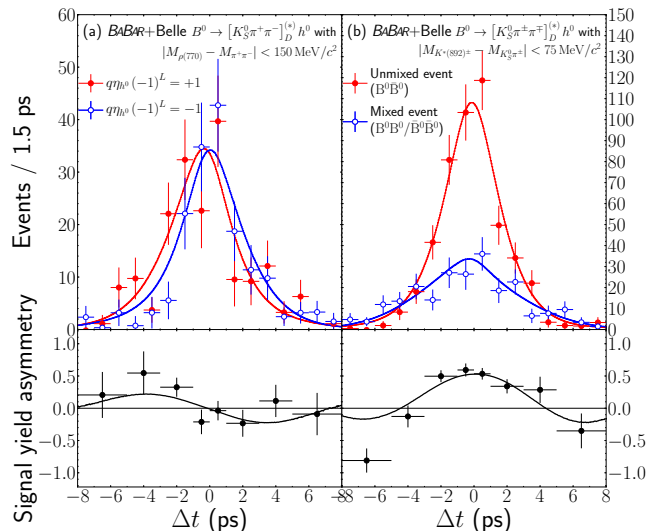


FIG. 3. (color online). Distributions of the proper-time interval (data points with error bars) and the corresponding asymmetries for $B^0 \rightarrow D^{(*)} h^0$ candidates associated with high-quality flavor tags for two different regions of the $D \rightarrow K_S^0 \pi^+ \pi^-$ phase space and for the *BABAR* and *Belle* data samples combined. The background has been subtracted using the *sPlot* technique [49], with weights obtained from the fit presented in Fig. 2.

The measurement procedure is validated by various cross-checks. The $B^0 \rightarrow \bar{D}^{(*)} h^0$ decays with the CKM-favored $D^0 \rightarrow K^+ \pi^-$ decay have very similar kinematics and background composition as $B^0 \rightarrow D^{(*)} h^0$ with $D \rightarrow K_S^0 \pi^+ \pi^-$ decays and provide a high-statistics control sample. Using the same analysis approach, the time-dependent *CP* violation measurement of the control sample results in mixing-induced and direct *CP*

violation consistent with zero, in agreement with the assumption of negligible CP violation for these flavor-specific decays. Measurements of the neutral B meson lifetime for $B^0 \rightarrow D^{(*)}h^0$ with $D \rightarrow K_s^0\pi^+\pi^-$ decays, and for the control sample without flavor-tagging applied, yield $\tau_{B^0} = (1.500 \pm 0.052 \text{ (stat.)})$ ps and $\tau_{B^0} = (1.535 \pm 0.028 \text{ (stat.)})$ ps, respectively, which are in agreement with the world average $\tau_{B^0} = (1.520 \pm 0.004)$ ps [50]. In addition, we have performed all measurements for data separated by experiment yielding consistent results [20].

The significance of the results is determined by a likelihood-ratio approach that accounts for the experimental systematic uncertainties and the Dalitz plot amplitude model uncertainties by convolution of the likelihood curves. The measurement of $\sin 2\beta$ agrees within 0.7 standard deviations with the world average of $\sin 2\beta = 0.691 \pm 0.017$ [50] obtained from more precise measurements using $\bar{b} \rightarrow \bar{c}c\bar{s}$ transitions. The measurement of $\cos 2\beta$ excludes the hypothesis of $\cos 2\beta \leq 0$ at a p -value of 2.5×10^{-4} , which corresponds to a significance of 3.7 standard deviations, providing the first evidence for $\cos 2\beta > 0$. The measurement of β excludes the hypothesis of $\beta = 0^\circ$ at a p -value of 3.6×10^{-7} , which corresponds to a significance of 5.1 standard deviations. Hence, we report an observation of CP violation in $B^0 \rightarrow D^{(*)}h^0$ decays. The result for β agrees well with the preferred solution of the Unitarity Triangle, which is $(21.9 \pm 0.7)^\circ$, if computed from the world average of $\sin 2\beta = 0.691 \pm 0.017$ [50]. The measurement excludes the second solution of $\pi/2 - \beta = (68.1 \pm 0.7)^\circ$ at a p -value of 2.31×10^{-13} , corresponding to a significance of 7.3 standard deviations. Therefore, the present measurement resolves an ambiguity in the determination of the apex of the CKM Unitarity Triangle.

In summary, we combine the final *BABAR* and Belle data samples, totaling an integrated luminosity of more than 1 ab^{-1} collected at the $\Upsilon(4S)$ resonance, and perform a time-dependent Dalitz plot analysis of $B^0 \rightarrow D^{(*)}h^0$ with $D \rightarrow K_s^0\pi^+\pi^-$ decays. We report the world's most precise measurement of the cosine of the CP -violating weak phase 2β and obtain the first evidence for $\cos 2\beta > 0$. The measurement directly excludes the trigonometric multifold solution of $\pi/2 - \beta = (68.1 \pm 0.7)^\circ$ without any assumptions, and thus resolves an ambiguity related to the CKM Unitarity Triangle parameters. An observation of CP violation in $B^0 \rightarrow D^{(*)}h^0$ decays is reported.

The $B^0 \rightarrow D^{(*)}h^0$ decays studied by the combined *BABAR* and Belle approach provide a probe for the CP -violating weak phase 2β that is theoretically more clean than the “gold plated” decay modes mediated by $\bar{b} \rightarrow \bar{c}c\bar{s}$ transitions [51]. Therefore, $B^0 \rightarrow D^{(*)}h^0$ decays can provide a new and complementary SM reference for 2β at the experimental precision achievable by the future high-luminosity B factory experiment Belle II [52].

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* Now at: University of Huddersfield, Huddersfield HD1 3DH, UK

† Also at: Università di Sassari, I-07100 Sassari, Italy

‡ Deceased

§ Now at: University of South Alabama, Mobile, Alabama 36688, USA

¶ Now at: Università di Bologna and INFN Sezione di Bologna, I-47921 Rimini, Italy

** Now at: European Organization for Nuclear Research (CERN), Geneva, Switzerland

†† Now at: Wuhan University, Wuhan 430072, China

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