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Measurement of the branching fraction and the CP-violating asymmetry for the decay $B^0 \to K_S^0 \pi^0$

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We measure the branching fraction and the *CP*-violating asymmetry of $B^0 \to K_S^0 \pi^0$ decays with 227 million $\Upsilon(4S) \to B\overline{B}$ events collected with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- collider at SLAC. We obtain a branching fraction $\mathcal{B}(B^0 \to K^0\pi^0) = (11.4 \pm 0.9 \pm 0.6) \times 10^{-6}$ and *CP*-violating asymmetry parameters $C_{K_S^0\pi^0} = 0.06 \pm 0.18 \pm 0.03$ and $S_{K_S^0\pi^0} = 0.35^{+0.30}_{-0.33} \pm 0.04$, where the first error is statistical and the second systematic.

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CP violation effects in decays of *B* mesons that are dominated by penguin $b \to s\overline{q}q$ ($q = u, d, s$) transitions are potentially sensitive to contributions from physics beyond the standard model (SM) [1]. The *B*-factory experiments have explored time-dependent *CP*-violating (CPV) asymmetries in several such decays [2], namely $B^0 \to \phi K_S^0$ [3,4], $B^0 \to \eta' K_S^0$ [3,5], $B^0 \to K^+K^-K_S^0$ [3,6], $B^0 \to f_0 K_S^0$ [7] and $B^0 \to K_S^0\pi^0$ [8]. Within the SM these asymmetries are expected to be consistent with the measurement of $\sin 2\beta$ in charmonium modes originating from the tree-level $b \to c\overline{c}s$ transition. These comparisons must take into account possible deviations for each mode, within the SM, due to contributions of other diagrams with different phases and rescattering effects. At this point none of the modes above shows a significant deviation from the SM expectation [9]. A major goal of the *B*-factory experiments is to reduce the experimental uncertainties of these measurements in order to improve the sensitivity to beyond-the-standard-model effects.

In this paper we present improved measurements of the CPV asymmetry in the decay $B^0 \to K_S^0\pi^0$, using data collected with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- collider, amounting to 226.6 ± 2.5 million $\Upsilon(4S) \to B\overline{B}$ decays. In the SM this decay is dominated by a top-quark-mediated $b \to s\overline{d}d$ penguin amplitude. If other contributions, such as the CKM suppressed $b \to s\overline{u}u$ tree amplitude, are ignored, the CPV asymmetry is governed by $\sin 2\beta$ [10], where $\beta \equiv \arg[-V_{cd}V_{cb}^*/V_{td}V_{tb}^*]$ and V is the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [11]. The bound on the deviation from $\sin 2\beta$ due to SM contributions with a different weak phase is about 0.2 from SU(3) flavor symmetry [12] and about 0.1 in model-dependent QCD calculations [13]. We also present an update of our measurement of the branching fraction of $B^0 \to K^0\pi^0$ [14], which, when combined with measurements of other $B \to K\pi$ branching fractions, can be used to extract the CKM angle $\gamma \equiv \arg[-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*]$ [15].

The *BABAR* detector, fully described in [16], provides charged-particle tracking through a combination of a five-layer double-sided silicon micro-strip detector (SVT) and a 40-layer drift chamber (DCH), both operating in a 1.5 T magnetic field. Charged-kaon and -pion identification is achieved through measurements of specific energy-loss (dE/dx) in the tracking system and of the Cherenkov angle (θ_c) in a detector of internally reflected Cherenkov light (DIRC). A CsI(Tl) electromagnetic calorimeter (EMC) provides photon detection and electron identification. Finally, the instrumented flux return (IFR) of the magnet allows discrimination of muons from pions. For event simulation we use the Monte Carlo event generator EVTGEN [17] and GEANT4 [18].

At the $\Upsilon(4S)$ resonance time-dependent CPV asymmetries are extracted from the distribution of the difference of the proper decay times, $\Delta t \equiv t_{CP} - t_{\rm tag}$, where t_{CP} refers to the decay time of the signal B (B_{CP}) and $t_{\rm tag}$ to that of the other B ($B_{\rm tag}$). The Δt distribution for $B_{CP} \to f$ follows

$$\mathcal{P}_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}[1 \pm S_f \sin(\Delta m_d \Delta t) \mp C_f \cos(\Delta m_d \Delta t)], \quad (1)$$

where the upper (lower) sign corresponds to $B_{\rm tag}$ decaying as B^0 ($\overline{B}^0$), τ is the B^0 lifetime and Δm_d is the mixing frequency. The coefficients C_f and S_f can be expressed in terms of the B^0-$\overline{B}^0$ mixing amplitude and the decay amplitudes for $B^0 \to f$ and $\overline{B}^0 \to f$ [19]. For decays to a *CP* eigenstate, like $K_S^0\pi^0$, C_f vanishes unless there is direct *CP* violation. If $B^0 \to K_S^0\pi^0$ proceeds purely through a top-quark penguin, $C_{K_S^0\pi^0} = 0$ and $S_{K_S^0\pi^0} = \sin(2\beta + 2\beta_s)$, where $\beta_s \equiv \arg[-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*]$ is small.

We search for $B^0 \to K_S^0\pi^0$ decays in $B\overline{B}$ candidate events selected using charged-particle multiplicity and event topology [20]. We reconstruct $K_S^0 \to \pi^+\pi^-$ candidates from pairs of oppositely charged tracks. The two-track combinations must form a vertex with a χ^2 consistency greater than 0.001 and a $\pi^+\pi^-$ invariant mass within $11.2\ \mathrm{MeV}/c^2$ of the nominal K_S^0 mass [21]. We form $\pi^0 \to \gamma\gamma$ candidates from pairs of photon candidates in the EMC, each of which is isolated from any charged tracks, carries a minimum energy of 50 MeV, and has the expected lateral shower shape. Candidates for $B^0 \to K_S^0\pi^0$ are formed from $K_S^0\pi^0$ combinations and constrained to originate from the e^+e^- interaction point using a geometric fit. We require that the consistency of the χ^2 of the fit, which has 1 degree of freedom, be greater than 0.001. We extract the K_S^0 decay length $L_{K_S^0}$ and the $\pi^0 \to \gamma\gamma$ invariant mass from this fit and require $110 < m_{\gamma\gamma} < 160\ \mathrm{MeV}/c^2$ and $L_{K_S^0}$ greater than 5 times its uncertainty.

For each B candidate we compute two kinematic variables, namely, the invariant mass m_B and the missing mass $m_{\mathrm{miss}} = \sqrt{(q_{e^+e^-} - \tilde{q}_B)^2}$, where $q_{e^+e^-}$ is the four-momentum of the initial e^+e^- system and $\tilde{q}_B$ is the four-momentum of the $B^0 \to K_S^0\pi^0$ candidate after a mass constraint on the B^0 is applied. By construction the linear correlation coefficient between m_{miss} and m_B vanishes. Compared to the kinematic variables $\Delta \mathrm{E} = E_B^* - \frac{1}{2}\sqrt{s}$ and $\mathrm{m_{ES}} = \sqrt{\frac{1}{4}s - p_B^{*2}}$ (where $s = q^2_{e^+e^-}$ and the asterisk denotes the e^+e^- rest frame), which were used in our previous analysis of this mode [8], the present combination of variables leads to a smaller correlation and a better background suppression for modes containing a high-momentum π^0 or photon. From simulation studies we determine the signal resolution for m_B to be about $40\ \mathrm{MeV}/c^2$. The distribution exhibits a lowside tail from energy leakage out of the EMC. The signal resolution for m_{miss}, about $5\ \mathrm{MeV}/c^2$, is dominated by the beam-energy spread. We select candidates with m_B within $150\ \mathrm{MeV}/c^2$ of the nominal B^0 mass [21] and with $5.11 < m_{\mathrm{miss}} < 5.31\ \mathrm{GeV}/c^2$. The region $m_{\mathrm{miss}} < 5.2\ \mathrm{GeV}/c^2$ is devoid of signal and used for background characterization.

To suppress background from continuum $e^+e^- \to q\overline{q}$ ($q = u, d, s, c$) events, we exploit differences in both production and decay properties. We require $|\cos\theta_B^*| < 0.9$, where θ_B^* is the angle between the B-candidate momentum and the e^- momentum in the e^+e^- rest frame. For true B mesons the distribution of $\cos\theta_B^*$ is proportional to $1 - \cos^2\theta_B^*$, whereas for continuum events it is nearly flat. To exploit the jetlike topology of continuum events, we calculate the ratio L_2/L_0 of two Legendre moments defined as $L_j \equiv \sum_i |\mathbf{p}_i^*||\cos\theta_i^*|^j$, where $\mathbf{p}_i^*$ is the momentum of particle i in the e^+e^- rest frame, θ_i^* is the angle between $\mathbf{p}_i^*$ and the thrust axis of the B candidate and the sum runs over all reconstructed particles except for the B-candidate daughters. We require $L_2/L_0 < 0.55$, which suppresses the background by more than a factor 3 at the cost of approximately 10% loss in signal efficiency. After all selections are applied the average candidate multiplicity in events with at least one candidate is approximately 1.007. When there are multiple candidates, we select the candidate with a reconstructed π^0 mass closest to the expected value.

For each $B^0 \to K_S^0\pi^0$ candidate we examine the remaining tracks in the event to determine the decay vertex position and the flavor of B_{tag}. Using a neural network based on kinematic and particle identification information [22] each event is assigned to one of five mutually exclusive tagging categories, designed to combine flavor tags with similar performance and Δt resolution. We parameterize the performance of this algorithm in a data sample (B_{flav}) of fully reconstructed $B^0 \to D^{(*)-}\pi^+/\rho^+/a_1^+$ decays. The average effective tagging efficiency obtained from this sample is $Q = \sum_c \epsilon_S^c(1 - 2w^c)^2 = 0.299 \pm 0.005$, where ϵ_S^c and w^c are the efficiencies and mistag probabilities, respectively, for events tagged in category $c = 1, 2, \ldots 5$. For the background, the fraction of events (ϵ_B^c) and the asymmetry in the rate of B^0 versus $\overline{B}^0$ tags in each tagging category are extracted from a fit to the data.

The proper-time difference is extracted from the separation of the B_{CP} and B_{tag} decay vertices. The B_{tag} vertex is reconstructed inclusively from the remaining charged particles in the event [20]. To reconstruct the B_{CP} vertex from the single K_S^0 trajectory we exploit the knowledge of the average interaction point (IP), which is determined on a run-by-run basis from the spatial distribution of vertices from two-track events. We compute Δt and its uncertainty from a geometric fit to the $\Upsilon(4S) \to B^0\overline{B}^0$ system that takes this IP constraint into account. We further improve the sensitivity to Δt by constraining the sum of the two B decay times ($t_{CP} + t_{\mathrm{tag}}$) to be equal to $2\tau_{B^0}$ with an uncertainty $\sqrt{2}\tau_{B^0}$, which effectively constrains the two vertices to be near the $\Upsilon(4S)$ line of flight. We have verified in a Monte Carlo simulation that this procedure provides an unbiased estimate of Δt.

The per-event estimate of the uncertainty on Δt reflects the strong dependence of the Δt resolution on the K_S^0 flight direction and on the number of SVT layers traversed by the K_S^0 decay daughters. In about 60% of the events both pion tracks are reconstructed from at least 4 SVT hits, leading to sufficient resolution for the time-dependent measurement. The average Δt resolution in these events is about 1.0 ps. For events which fail this criterion or for which $\sigma(\Delta t) > 2.5$ ps or $|\Delta t| > 20$ ps, the Δt information is not used. However, since C_f can also be extracted from flavor tagging information alone, these events still contribute to the measurement of C_f.

We extract the signal yield, S_f and C_f from an unbinned maximum-likelihood fit to m_B, m_{miss}, L_2/L_0, $\cos\theta_B^*$, Δt and the flavor tag variables. By exploiting sideband regions in data for the background and simulated events for the signal, we have verified that with the selection presented above these observables are sufficiently independent that we can construct the likelihood from the product of one-dimensional probability density functions (PDFs). The PDFs for signal events are parameterized from simulated events or from the B_{flav} sample. For background PDFs we select a functional form that describes the data in the sideband regions of the other observables, in which backgrounds dominate. We include these regions in the fitted sample and simultaneously extract the parameters of the background PDFs along with the signal yield and CPV asymmetries.

We obtain the PDF for the Δt of signal events from the convolution of Eq. (1) with a resolution function $\mathcal{R}(\delta t \equiv \Delta t - \Delta t_{\rm true}, \sigma_{\Delta t})$. The resolution function is parameterized as the sum of two Gaussians with a width proportional to the reconstructed $\sigma_{\Delta t}$, and a third Gaussian with a fixed width of 8 ps [20]. The first two Gaussians have a nonzero mean, proportional to $\sigma_{\Delta t}$, to account for the small bias in Δt from charm decays on the $B_{\rm tag}$ side. We have verified in simulation that the parameters of $\mathcal{R}(\delta t, \sigma_{\Delta t})$ for $B^0 \to K^0_S\pi^0$ events are similar to those obtained from the $B_{\rm flav}$ sample, even though the distributions of $\sigma_{\Delta t}$ differ considerably. We therefore extract these parameters from a fit to the $B_{\rm flav}$ sample. We assume that the background consists of prompt decays only and find that the Δt distribution is well described by a resolution function with the same functional form as used for signal events. The parameters of the background function are determined in the fit.

To extract the yield and the CPV asymmetries we maximize the logarithm of the extended likelihood

$$\mathcal{L}(S_f, C_f, N_S, N_B, f_S, f_B, \vec{\alpha}) = e^{-(N_S+N_B)}\prod_{i\in I}[N_S f_S \epsilon^c_S \mathcal{P}_S(\vec{x}_i, \vec{y}_i; S_f, C_f) + N_B f_B \epsilon^c_B \mathcal{P}_B(\vec{x}_i, \vec{y}_i; \vec{\alpha})] \times \prod_{i\in II}[N_S(1-f_S)\epsilon^c_S \mathcal{P}'_S(\vec{x}_i; C_f) + N_B(1-f_B)\epsilon^c_B \mathcal{P}'_B(\vec{x}_i; \vec{\alpha})],$$

where I (II) is the subset of events with (without) Δt information. The probabilities $\mathcal{P}_S$ ($\mathcal{P}'_S$) and $\mathcal{P}_B$ ($\mathcal{P}'_b$) are products of PDFs for signal (S) and background (B) hypotheses evaluated for the measurements $\vec{x}_i = \{m_B, m_{\rm miss}, L_2/L_0, \cos\theta^*_B, \text{tag}, \text{tagging category}\}$ and $\vec{y}_i = \{\Delta t, \sigma_{\Delta t}\}$. Along with the signal yield N_S and the coefficients S_f and C_f, the fit extracts the background yields N_B, the fractions of events with Δt information f_S and f_B, and the remaining parameters, collectively denoted by $\vec{\alpha}$. These include all parameters of background PDFs and some parameters of the signal PDFs, such as the mean values of m_B and $m_{\rm miss}$.

Fitting the data sample of 9726 $B^0 \to K^0_S\pi^0$ candidates, we find $N_S = 300 \pm 23$ signal decays with $S_{K^0_S\pi^0} = 0.35^{+0.30}_{-0.33}(\text{stat}) \pm 0.04(\text{syst})$ and $C_{K^0_S\pi^0} = 0.06 \pm 0.18(\text{stat}) \pm 0.03(\text{syst})$. The number of signal decays with Δt information is $f_s N_s = 186 \pm 18$. The total detection efficiency for $B^0 \to K^0_S\pi^0$ decays with $K^0_S \to \pi^+\pi^-$ and $\pi^0 \to \gamma\gamma$ is $(34.1 \pm 1.8)\%$. With the K^0_S and π^0 branching fractions taken from [21], taking into account

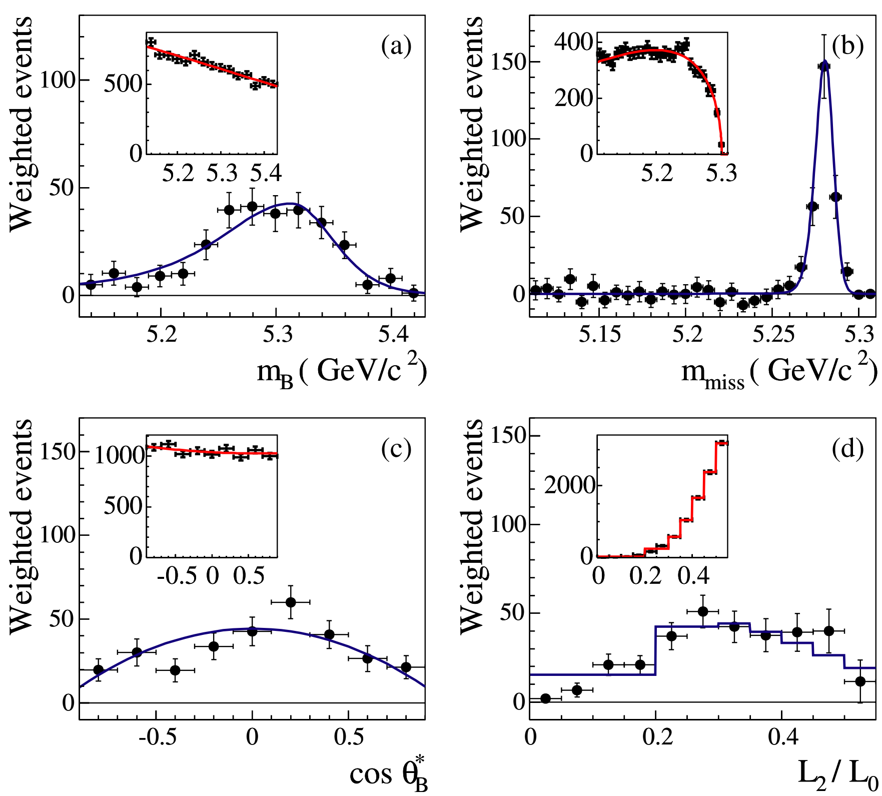

FIG. 1 (color online). Signal and background (inset) distributions, obtained with the weighting technique described in the text, for m_B (a) and $m_{\rm miss}$ (b), $\cos\theta^*_B$ (c) and L_2/L_0 (d). The curves represent the PDFs used in the fit and are normalized to the fitted yield.

$\mathcal{B}(K^0 \to K^0_S) = 1/2$ and assuming equal production of charged and neutral B mesons at the $\Upsilon(4S)$ resonance, we obtain a branching fraction $\mathcal{B}(B^0 \to K^0\pi^0) = (11.4 \pm 0.9(\text{stat}) \pm 0.6(\text{syst})) \times 10^{-6}$. The evaluation of the systematic uncertainties is described below.

Figure 1 shows the background-subtracted distributions of m_B, m_{miss}, $\cos\theta^*_B$ and L_2/L_0 for all $B^0 \to K^0_S\pi^0$ candidates in the fit. The background subtraction is performed with an event weighting technique [23]. Events contribute according to a weight constructed from the covariance matrix for the yields (N_S and N_B) and the probability $\mathcal{P}_S$ and $\mathcal{P}_B$ for the event, computed without the use of the variable that is being displayed. The curves represent the signal PDFs used in the fit. The insets show the corresponding signal-subtracted distributions with the background PDFs. Figure 2 shows the background-subtracted distributions of Δt for B^0- and $\overline{B}^0$-tagged events, and of the asymmetry $\mathcal{A}_{K^0_S\pi^0}(\Delta t) = [N_{B^0} - N_{\overline{B}^0}]/[N_{B^0} + N_{\overline{B}^0}]$ as a function of Δt.

The extraction of Δt with the IP-constrained fit has been extensively tested on large samples of simulated $B^0 \to K^0_S\pi^0$ decays with different values of C and S. We have also exploited a control sample of approximately 1900 observed $B^0 \to K^0_S\pi^0$ decays with $J/\psi \to \mu^+\mu^-$ and $J/\psi \to e^+e^-$, using the procedure described in [8]. Based on these studies we assign a systematic uncertainty of 0.023 on S and 0.014 on C due to the Δt reconstruction and the choice of the resolution function. As a cross-check we measure the B^0 lifetime in $B^0 \to K^0_S\pi^0$ decays in data and find that it agrees with the world average. We evaluate the effect of a possible misalignment of the SVT by introducing misalignments in the simulation and assign a systematic uncertainty of 0.020 on S and 0.007 on C. We also consider large variations of the position and size of the interaction region, which we find to have negligible impact. We include a systematic uncertainty of 0.012 on S and 0.018 on C to account for imperfect knowledge of the PDFs used in the fit. Using simulated events we estimate a contribution of 2.3 ± 1.7 events from other B decays for which we assign a systematic uncertainty of 0.019 on S and 0.015 on C. Compared to our previous measurement [8] the total systematic uncertainty on C is significantly reduced as a result of a better understanding of the flavor tag asymmetry in background events.

The detection efficiency for signal events is obtained from a Monte Carlo simulation. The efficiency of the K^0_S selection is calibrated with a large sample of inclusive $K^0_S \to \pi^+\pi^-$ decays. The $\pi^0 \to \gamma\gamma$ efficiency is calibrated with $e^+e^- \to \tau^+\tau^-$ events with $\tau^- \to \rho^-\nu_\tau$. The systematic uncertainty associated with the efficiency is

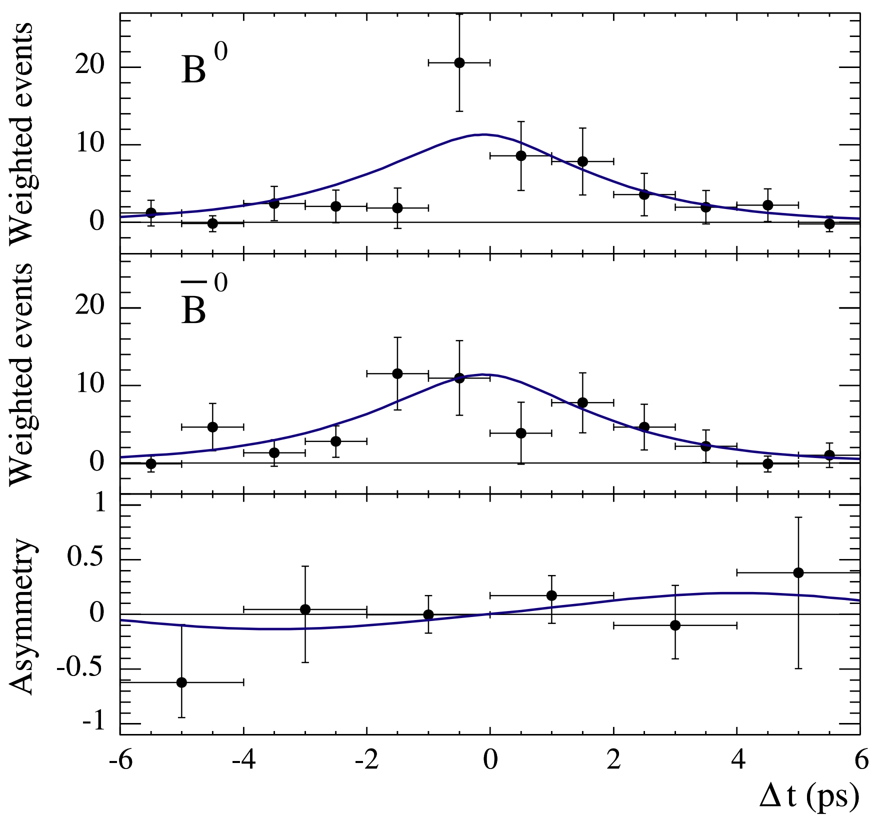

FIG. 2 (color online). Signal distribution for Δt, obtained with the weighting technique described in the text, with B_{tag} tagged as B^0 (top) or $\overline{B}^0$ (center), and the asymmetry $\mathcal{A}_{K^0_S\pi^0}(\Delta t)$ (bottom). The curves represent the PDFs for signal decays in the likelihood fit.

2.8% for K_S^0 and 3.0% for π^0. We assign additional systematic uncertainties of 1.2% for the L_2/L_0 cut, 2.0% for the selection on m_B and a total of 2.0% for uncertainties in the signal PDFs. Finally, we include a systematic uncertainty of 1.4% to account for unknown contributions from other B decays and a systematic uncertainty of 0.6% due to the uncertainty in the total number of $\Upsilon(4S) \to B\overline{B}$ decays.

In summary, we have reported improved measurements of the branching fraction and CP-violating asymmetry for the decay $B^0 \to K_S^0\pi^0$. The measured values of $S_{K_S^0\pi^0}$ and $C_{K_S^0\pi^0}$ are consistent with the Standard Model predictions. The measured branching fraction is consistent with measurements from other experiments [24]. These results supersede our previous measurements of the branching fraction [14] and CPV asymmetries [8], which were based on a subset of the data presented here.

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[1] Y. Grossman and M. P. Worah, Phys. Lett. B **395**, 241 (1997); M. Ciuchini, E. Franco, G. Martinelli, A. Masiero, and L. Silvestrini, Phys. Rev. Lett. **79**, 978 (1997); D. London and A. Soni, Phys. Lett. B **407**, 61 (1997).

[2] Unless explicitly stated, conjugate decay modes are assumed throughout this paper.

[3] K. Abe *et al.* (Belle Collaboration), Phys. Rev. Lett. **91**, 261602 (2003).

[4] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **93**, 071801 (2004).

[5] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **91**, 161801 (2003).

[6] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **93**, 181805 (2004).

[7] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **94**, 041802 (2005).

[8] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **93**, 131805 (2004).

[9] Z. Ligeti, hep-ph/0408267.

[10] R. Fleischer, Phys. Lett. B **365**, 399 (1996).

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

[12] M. Gronau, Y. Grossman, and J. L. Rosner, Phys. Lett. B **579**, 331 (2004).

[13] A. J. Buras, R. Fleischer, S. Recksiegel, and F. Schwab, Nucl. Phys. **B697**, 133 (2004); M. Ciuchini, E. Franco, G. Martinelli, A. Masiero, M. Pierini, and L. Silvestrini, hep-ph/0407073; J. Charles *et al.* (CKMfitter Group Collaboration), Eur. Phys. J. C **41**, 1 (2005).

[14] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **92**, 201802 (2004).

[15] M. Gronau, J. L. Rosner, and D. London, Phys. Rev. Lett. **73**, 21 (1994).

[16] B. Aubert *et al.* (BABAR Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).

[17] D. J. Lange, Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

[18] S. Agostinelli *et al.* (GEANT4 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[19] See, for example, D. Kirkby and Y. Nir, in S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).

[20] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. D **66**, 032003 (2002).

[21] S. Eidelman *et al.* (Particle Data Group Collaboration), Phys. Lett. B **592**, 1 (2004).

[22] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **89**, 201802 (2002).

[23] M. Pivk and F. R. Le Diberder, physics/0402083.

[24] Y. Chao *et al.* (Belle Collaboration), Phys. Rev. D **69**, 111102 (2004); A. Bornheim *et al.* (CLEO Collaboration), Phys. Rev. D **68**, 052002 (2003).