

**Measurement of the  $CP$ -violating asymmetries in  $B^0 \rightarrow K_s^0 \pi^0$   
and of the branching fraction  $B^0 \rightarrow K^0 \pi^0$**

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(Received 20 July 2007; published 31 January 2008)

We present a measurement of the time-dependent  $CP$ -violating asymmetries in  $B^0 \rightarrow K_S^0 \pi^0$  decays based on  $383 \times 10^6 Y(4S) \rightarrow B\bar{B}$  events collected by the *BABAR* experiment at the PEP-II asymmetric-energy  $B$  Factory at the Stanford Linear Accelerator Center. We measure the direct  $CP$ -violating asymmetry  $C_{K_S^0 \pi^0} = 0.24 \pm 0.15 \pm 0.03$  and the  $CP$ -violating asymmetry in the interference between mixing and decay  $S_{K_S^0 \pi^0} = 0.40 \pm 0.23 \pm 0.03$ , where the first errors are statistical and the second are systematic. On the same sample, we measure the decay branching fraction, obtaining  $\mathcal{B}(B^0 \rightarrow K^0 \pi^0) = (10.3 \pm 0.7 \pm 0.6) \times 10^{-6}$ .

DOI: [10.1103/PhysRevD.77.012003](https://doi.org/10.1103/PhysRevD.77.012003)

PACS numbers: 13.25.Hw, 11.30.Er

The *BABAR* and Belle experiments have measured the weak phase  $\beta$  [1,2] of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [3] with a better precision than the standard model (SM) prediction [4] derived from measurements of other  $CP$ -conserving and  $CP$ -violating processes. The agreement between the theoretical and experimental results has shown that the CKM matrix correctly describes these measurements of  $\beta$  to good precision.

A major goal of the  $B$  Factory experiments is now to search for indirect evidence of new physics (NP). One strategy is to compare the measured value of the  $CP$  violation (CPV) parameters from  $b \rightarrow sc\bar{c}$  to independent determinations of the same quantities using processes that are sensitive to the contributions of NP effects through loop diagrams.

CPV in  $B$  decays to a final state  $f$  can be parameterized by  $C_f$ , measuring direct CPV, and  $S_f$ , measuring CPV in the interference between decays with and without mixing. In the standard model for penguin-dominated processes  $b \rightarrow sq\bar{q}$  ( $q = u, d, s$ ) [5],  $S_f$  and  $C_f$  are expected to be consistent with the values from  $b \rightarrow sc\bar{c}$  decays. Additional CKM suppressed contributions to the amplitude can induce only small deviations from this expectation. On the other hand, additional loop contributions from NP processes may produce observable deviations [6,7].

The CKM and color suppression of the tree-level  $b \rightarrow su\bar{u}$  transition leads to the expectation that the decay  $B^0 \rightarrow K_S^0 \pi^0$  is dominated by a top quark mediated  $b \rightarrow sd\bar{d}$  penguin diagram, which carries a weak phase  $\arg(V_{tb}V_{ts}^*)$ . If nonleading contributions are small,  $S_{K_S^0 \pi^0}$  is expected to be equal to  $\sin 2\beta$  and  $C_{K_S^0 \pi^0} \simeq 0$ .

In addition, it is possible to combine the direct  $CP$  asymmetries and the branching fractions of the four  $B \rightarrow K\pi$  modes to test precise sum rules [8–10]. The experimental uncertainty on these sum rules is dominated by the error on the direct  $CP$  asymmetry in  $B^0 \rightarrow K^0 \pi^0$ . Therefore a precise measurement of both the direct  $CP$  asymmetry, and the branching fraction, in this decay channel represents an important consistency test of the standard model.

The time-dependent  $CP$  asymmetries of the decay  $B^0 \rightarrow K_S^0 \pi^0$  ( $K_S^0 \rightarrow \pi^+ \pi^-$ ) have been measured by *BABAR* [11] and subsequently by Belle [12], and both

experiments have also measured the branching ratio [13,14]. In this work, we present an update of the results based on  $383 \times 10^6 Y(4S) \rightarrow B\bar{B}$  decays collected with the *BABAR* detector at the PEP-II  $e^+e^-$  collider, located at the Stanford Linear Accelerator Center.

The *BABAR* detector, which is described elsewhere [15], provides charged particle tracking through a combination of a five-layer double-sided silicon microstrip detector (SVT) and a 40-layer central drift chamber, both operating in a 1.5 T magnetic field to provide momentum measurements. Charged kaon and pion identification is achieved through measurements of particle energy loss in the tracking system and Cherenkov cone angle in a detector of internally reflected Cherenkov light. A segmented CsI(Tl) electromagnetic calorimeter (EMC) provides photon detection and electron identification. Finally, the instrumented flux return of the magnet allows discrimination between muons and pions.

We reconstruct  $K_S^0 \rightarrow \pi^+ \pi^-$  candidates from pairs of oppositely charged tracks. The two-track combinations must form a vertex with a  $\chi^2$  probability greater than 0.001 and a  $\pi^+ \pi^-$  invariant mass within  $11.2 \text{ MeV}/c^2$  ( $3.7\sigma$ ) of the  $K_S^0$  mass [16]. We form  $\pi^0 \rightarrow \gamma\gamma$  candidates from pairs of energy depositions in the EMC that are isolated from any charged tracks, carry a minimum energy of 50 MeV per photon, fall within the mass window  $110 < m_{\gamma\gamma} < 160 \text{ MeV}/c^2$ , and have the expected lateral shower shapes. Finally, we construct  $B^0 \rightarrow K_S^0 \pi^0$  candidates by combining  $K_S^0$  and  $\pi^0$  candidates in the event using kinematic and geometric information of the decay which constrains the  $B^0$  decay vertex to originate in the  $e^+e^-$  interaction region. We extract the flight length of the  $K_S^0$  from the fit and require that the reconstructed proper lifetime be greater than 5 times its uncertainty. We require that the  $\chi^2$  probability of the fit be greater than 0.001.

For each  $B^0$  candidate two independent kinematic variables are computed. The first one is  $m_B$ , the invariant mass of the reconstructed  $B$  meson,  $B_{CP}$ . The second one is  $m_{\text{miss}}$ , the invariant mass of the other  $B$ ,  $B_{\text{tag}}$ , computed from the known beam energy, applying a mass constraint to  $B_{CP}$  [14]. For signal decays,  $m_B$  ( $m_{\text{miss}}$ ) peaks near the  $B^0$  mass with a resolution of  $\sim 36 \text{ MeV}/c^2$  ( $\sim 5.3 \text{ MeV}/c^2$ ). Both the  $m_{\text{miss}}$  and  $m_B$  distributions exhibit a low-side tail from leakage of energy deposits out of the EMC. We select



candidates within the window  $5.11 < m_{\text{miss}} < 5.31 \text{ GeV}/c^2$  and  $5.13 < m_B < 5.43 \text{ GeV}/c^2$ , which includes the signal peak and a ‘‘sideband’’ region for background characterization. For the 0.8% of events with more than one reconstructed candidate, we select the combination with the smallest  $\chi^2 = \sum_{i=\pi^0, K_S^0} (m_i - m_i')^2 / \sigma_{m_i}^2$ , where  $m_i$  ( $m_i'$ ) is the measured (nominal) mass and  $\sigma_{m_i}$  is the estimated uncertainty on the measured mass of particle  $i$ .

We exploit topological observables, computed in the  $Y(4S)$  rest frame, to discriminate jetlike  $e^+e^-$  to  $q\bar{q}$  events ( $q = u, d, s, c$ ) from more spherical  $B\bar{B}$  events. We compute the value of  $L_2/L_0$ , where  $L_j \equiv \sum_i |\mathbf{p}_i^*| |\cos\theta_i^*|^j$ . Here,  $\mathbf{p}_i^*$  is the momentum of particle  $i$ , and  $\theta_i^*$  is the angle between  $\mathbf{p}_i^*$  and the sphericity axis [17] of the  $B_{CP}$  candidate, and the sum does not include the decay tree of the  $B_{\text{tag}}$ . In order to reduce the number of background events, we require  $L_2/L_0 < 0.55$ . We compute  $\cos\theta_B^*$ , the cosine of the angle between the direction of the  $B$  meson and the nominal direction of the magnetic field ( $z$  axis). This variable is distributed as  $1 - \cos^2\theta_B^*$  for signal events and nearly flat for background events. We select events with  $|\cos\theta_B^*| < 0.9$ . We also use the distribution of  $L_2/L_0$  and of  $\cos\theta_B^*$  to discriminate the signal from the residual background in a maximum-likelihood fit. Using a full detector simulation, we estimate that our selection retains  $(33.6 \pm 1.6)\%$  of the signal events, where this error includes statistical and systematic contributions. The selected sample of  $B^0 \rightarrow K_S^0 \pi^0$  candidates is dominated by random  $K_S^0 \pi^0$  combinations from  $e^+e^- \rightarrow q\bar{q}$  ( $q = u, d, s, c$ ) fragmentation. Using large samples of simulated  $B\bar{B}$  events, we find that backgrounds from other  $B$  meson decays can be generally neglected, but we include some specific  $B$  decay channels in our study of the systematic errors.

For each  $B^0 \rightarrow K_S^0 \pi^0$  candidate, we examine the remaining tracks and neutral candidates in the event to determine if the  $B_{\text{tag}}$  meson decayed as a  $B^0$  or a  $\bar{B}^0$  (flavor tag). We use a neural network to determine the flavor of the  $B_{\text{tag}}$  meson from kinematic and particle identification information [18]. Each event is assigned to one of six mutually exclusive tagging categories, designed to combine flavor tags with similar performance and vertex resolution. We measure the performance of this algorithm in a data sample ( $B_{\text{flav}}$ ) of fully reconstructed  $B^0 \rightarrow D^{(*)-} \pi^+ / \rho^+ / a_1^+$  decays. The average effective tagging efficiency obtained from this sample is  $Q = \sum_c \epsilon_S^c (1 - 2w^c)^2 = (30.5 \pm 0.3)\%$ , where  $\epsilon_S^c$  and  $w^c$  are the signal efficiency and mistag probability, respectively, for events tagged in category  $c$ , and the error is statistical only. We take into account differences in tagging efficiency (for signal and background) and mistag (only for signal) for  $B^0$  and  $\bar{B}^0$  events, in order to exclude any source of fake CPV effects. For the background, the fraction of events ( $\epsilon_B^c$ ) and the asymmetry in the rate of  $B^0$  versus  $\bar{B}^0$  tags in each tagging category are extracted from the fit to the  $B_{\text{flav}}$  data.

Time-dependent  $CP$  asymmetries are determined from the distribution of the difference of the proper decay times,  $\Delta t \equiv t_{CP} - t_{\text{tag}}$ , where the  $t_{CP}$  refers to the  $B_{CP}$  and  $t_{\text{tag}}$  to the  $B_{\text{tag}}$ . At the  $Y(4S)$  resonance, the  $\Delta t$  distribution follows

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

where the  $+(-)$  sign corresponds to  $B_{\text{tag}}$  decaying as  $B^0(\bar{B}^0)$ ,  $\tau$  is the neutral  $B$  lifetime,  $\Delta m_d$  is the mixing angular frequency,  $C_f$  is the magnitude of direct  $CP$  violation in the decay to final state  $f$ , and  $S_f$  is the magnitude of  $CP$  violation in the interference between mixing and decay. To account for flavor mistags we reduce  $S_f$  by the factor  $1 - 2w^c$ . For the case of penguin dominance, we expect  $S_{K_S^0 \pi^0} \simeq \sin 2\beta$ , and  $C_{K_S^0 \pi^0} \simeq 0$ .

The reconstructed proper time difference  $\Delta t_r$  is computed from the measured  $\Delta z = z_{CP} - z_{\text{tag}}$ , the difference of the reconstructed decay vertex positions of the  $B_{CP}$  and  $B_{\text{tag}}$  candidates along the boost direction, and the known boost of the  $e^+e^-$  system. A description of the inclusive reconstruction of the  $B_{\text{tag}}$  vertex is given in [19]. For the  $B^0 \rightarrow K_S^0 \pi^0$  decay, where no charged particles are present at the decay vertex, we identify the vertex of the  $B_{CP}$  using the single  $K_S^0$  trajectory from the  $\pi^+ \pi^-$  momenta and the knowledge of the average interaction point (IP) [11], which is determined several times per hour from the spatial distribution of vertices from two-track events. We compute  $\Delta t_r$  and its uncertainty from a geometric fit to the  $Y(4S) \rightarrow B^0 \bar{B}^0$  system that takes this IP constraint into account. We further improve the sensitivity to  $\Delta t_r$  by constraining the sum of the two  $B$  decay times ( $t_{CP} + t_{\text{tag}}$ ) to be equal to  $2\tau$  with an uncertainty  $\sqrt{2}\tau$ , which effectively constrains the two vertices to be near the  $Y(4S)$  line of flight. We have verified in a full detector simulation that this procedure provides an unbiased estimate of  $\Delta t$ .

The per-event estimate of the uncertainty on  $\Delta t_r$  reflects the strong dependence of the  $\Delta t$  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 selected events, each pion track is reconstructed from at least one  $\phi$  hit and one  $z$  hit in the first three layers, leading to a sufficient resolution for the time-dependent CPV measurement. The average  $\Delta t$  resolution in these events is about 1.0 ps. For events which fail this criterion or for which  $\Delta t_r > 20$  ps or the error on  $\Delta t_r$  satisfies  $\sigma_{\Delta t_r} > 2.5$  ps, the  $\Delta t_r$  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  $C_f$  and to the signal yield.

We obtain the probability density function (PDF) for the time dependence of signal decays from the convolution of Eq. (1) with a resolution function  $\mathcal{R}(\delta t \equiv \Delta t_r - \Delta t, \sigma_{\Delta t_r})$ , where  $\Delta t$  is the true value of the proper time

difference from Monte Carlo. The resolution function is parameterized as the sum of a core and a tail Gaussian, each with a width proportional to the reconstructed  $\sigma_{\Delta t_r}$ , and a third Gaussian centered at zero with a fixed width of 8 ps [19]. We have verified in simulation that the parameters of  $\mathcal{R}(\delta t, \sigma_{\Delta t_r})$  for  $B^0 \rightarrow K_S^0 \pi^0$  decays are similar to those obtained from the  $B_{\text{flav}}$  sample, even though the distributions of  $\sigma_{\Delta t_r}$  differ considerably. Therefore, we extract these parameters from a fit to the  $B_{\text{flav}}$  sample. We find that the  $\Delta t_r$  distribution of background candidates is well described by a  $\delta$  function convolved with a resolution function with the same functional form as used for signal events. The parameters of the background function are determined together with the CPV parameters and the signal yield.

We extract the CPV parameters from an extended unbinned maximum-likelihood fit to kinematic, event shape, flavor tag, and decay time variables. We have verified that all correlations are negligible, so we construct the likelihood from the product of one-dimensional PDFs. Residual correlations are taken into account in the systematic uncertainty, as explained below.

The PDFs for signal events are parameterized from a large sample of fully reconstructed  $B$  decays in data and from simulated events. For background PDFs, we select the functional form from the background-dominated sideband regions in our data.

The likelihood function is defined as

$$\begin{aligned} \mathcal{L}(S_f, C_f, N_S, N_B, f_S, f_B, \vec{\alpha}) = & \frac{e^{-(N_S+N_B)}}{N!} \prod_{i \in g} [N_S f_S \epsilon_S^c \mathcal{P}_S(\vec{x}_i, \vec{y}_i; S_f, C_f) + N_B f_B \epsilon_B^c \mathcal{P}_B(\vec{x}_i, \vec{y}_i; \vec{\alpha})] \\ & \times \prod_{i \in b} [N_S (1 - f_S) \epsilon_S^c \mathcal{P}'_S(\vec{x}_i; C_f) + N_B (1 - f_B) \epsilon_B^c \mathcal{P}'_B(\vec{x}_i; \vec{\alpha})], \end{aligned} \quad (2)$$

where the  $N$  selected events are partitioned into two subsets:  $i \in g$  events have  $\Delta t_r$  information, while  $i \in b$  events do not.  $f_S$  ( $f_B$ ) is the fraction of signal (background) events  $\in g$ , and the complement to one is the fraction of events  $\in b$ . The

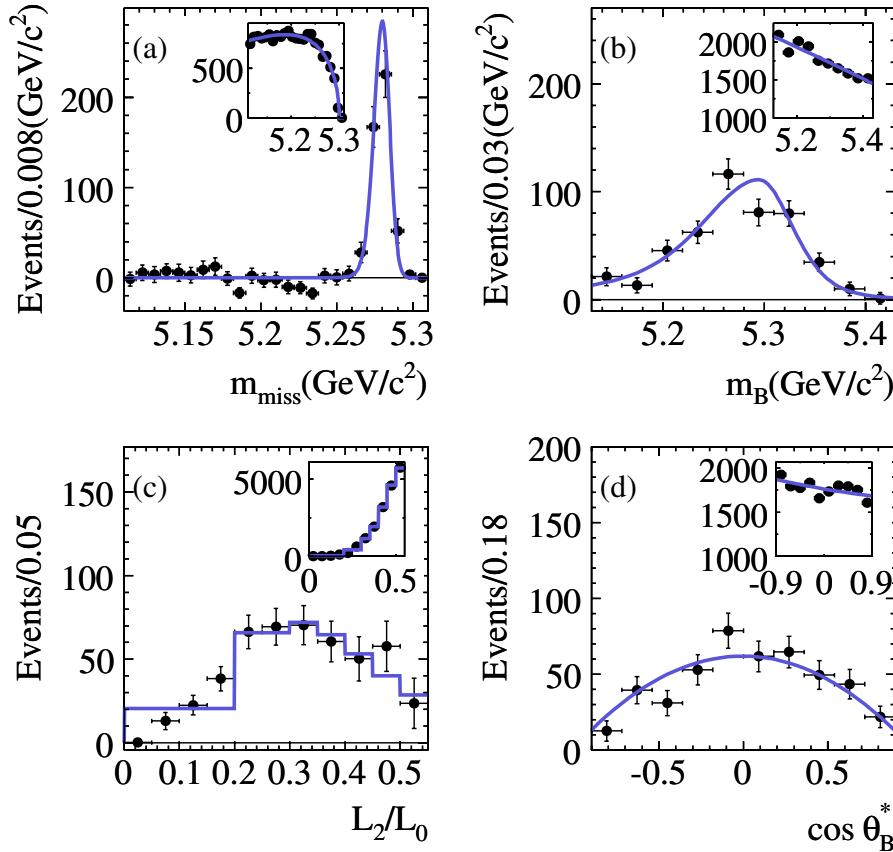


FIG. 1 (color online). Distribution of (a)  $m_{\text{miss}}$ , (b)  $m_B$ , (c)  $L_2/L_0$ , (d)  $\cos \theta_B^*$ , for background subtracted events on data (dots). The solid curve represents the shape of signal PDF, as obtained from the maximum-likelihood fit. The insets show the distribution of the data, and the PDF, for signal subtracted events. The binning of the  $L_2/L_0$  PDF is coarser where the signal is well separated from the background to reduce the number of free parameters.

probabilities  $\mathcal{P}_S$  and  $\mathcal{P}_B$  are products of PDFs for signal ( $S$ ) and background ( $B$ ) hypotheses evaluated for the measurements  $\vec{x}_i = \{m_B, m_{\text{miss}}, L_2/L_0, \cos\theta_B^*, \text{flavor tag, tagging category}\}$  and  $\vec{y}_i = \{\Delta t_r, \sigma_{\Delta t_r}\}$ .  $\mathcal{P}'_S$  and  $\mathcal{P}'_B$  are the corresponding probabilities for events without  $\Delta t_r$  information. In the formula,  $\vec{\alpha}$  represents the set of parameters that define the shape of the PDFs. Along with the  $CP$  asymmetries  $S_f$  and  $C_f$ , the fit extracts the yields  $N_S$  and  $N_B$ , the fraction of events  $f_S$  and  $f_B$ , and the parameters  $\vec{\alpha}$  which describe the background PDFs.

Fitting the data sample of 18 111  $B^0 \rightarrow K_S^0 \pi^0$  candidates, we find  $N_S = 459 \pm 29$  signal decays with  $S_{K_S^0 \pi^0} = 0.40 \pm 0.23$  and  $C_{K_S^0 \pi^0} = 0.24 \pm 0.15$ , where the uncertainties are statistical only. The linear correlation coefficient between the CPV parameters is  $-7.3\%$ . Taking into account the selection efficiency and the total number of  $B\bar{B}$  pairs in the data sample, we obtain the branching fraction  $\mathcal{B}(B^0 \rightarrow K_S^0 \pi^0) = (10.4 \pm 0.7) \times 10^{-6}$  which does not include systematic corrections on the yield.

Figure 1 shows distributions for signal (background) events, where background (signal) is subtracted using an event weighting technique [20]. Figure 2 shows distributions of  $\Delta t_r$  for  $B^0$ - and  $\bar{B}^0$ -tagged events, and the asymmetry  $\mathcal{A}_{K_S^0 \pi^0}(\Delta t_r) = [N_{B^0} - N_{\bar{B}^0}]/[N_{B^0} + N_{\bar{B}^0}]$  as a function of  $\Delta t_r$  for background subtracted events.  $N_{B^0}$  ( $N_{\bar{B}^0}$ ) represents the number of events tagged as  $B^0$  ( $\bar{B}^0$ ).

In order to validate the IP-constrained vertexing technique for CPV measurements we examine  $B^0 \rightarrow J/\psi K_S^0$  decays in data, where  $J/\psi \rightarrow \mu^+ \mu^-$  or  $J/\psi \rightarrow e^+ e^-$ . In these events we determine  $\Delta t_r$  in two ways: by fully

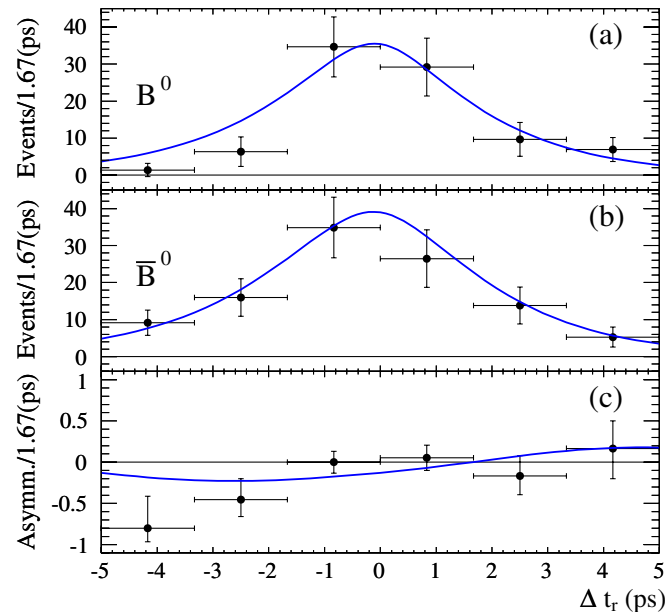


FIG. 2 (color online). Background subtracted distributions of  $\Delta t_r$  for events where  $B_{\text{tag}}$  is tagged as (a)  $B^0$  or (b)  $\bar{B}^0$ , and (c) the asymmetry  $\mathcal{A}(\Delta t_r)$ . The points are data and the curves are the PDF projections.

reconstructing the  $B^0$  decay vertex using the trajectories of charged daughters of the  $J/\psi$  and the  $K_S^0$  mesons (standard method), or by neglecting the  $J/\psi$  contribution to the decay vertex and using the IP constraint and the  $K_S^0$  trajectory only. This study shows that within statistical uncertainties, the IP-constrained  $\Delta t_r$  measurement is unbiased with respect to the standard technique and that the fit values of  $S_{J/\psi K_S^0}$  and  $C_{J/\psi K_S^0}$  are consistent between the two methods.

To compute the systematic error associated with the signal yield and CPV parameters, each of the input parameters to the likelihood fit is shifted by  $\pm 1\sigma$  from its nominal value and the fit is repeated. Here,  $\pm 1\sigma$  is the associated error, as obtained from the  $B_{\text{flav}}$  sample (for  $\Delta t$  and tagging) or from Monte Carlo. This contribution to the systematic error takes into account the limited statistics we used to parametrize the shape of the likelihood in Eq. (2). We find a systematic error of 0.72 events on the yield, and of 0.006 (0.010) on  $S_{K_S^0 \pi^0}$  ( $C_{K_S^0 \pi^0}$ ). As an additional systematic error associated with the shape of the PDF, we also quote the largest deviation observed when the parameters of the individual signal PDFs are floated in the fit. This gives a systematic error of 11 events on the yield, and of 0.019 (0.018) on  $S_{K_S^0 \pi^0}$  ( $C_{K_S^0 \pi^0}$ ). The output values of the PDF parameters are also used to assign a systematic error to the selection efficiency of the cuts on the likelihood variables. Comparing the efficiency to the Monte Carlo simulation we obtain a relative systematic error of 3.7%. We evaluate the systematic error coming from the neglected correlations among fit variables using a set of simulated Monte Carlo experiments, in which we embed signal events from a full detector simulation with events generated from the background PDFs. Since the shifts are small and only marginally significant, we use the average shift in yield ( $-2.3$  events) and CPV parameters ( $-0.003$  on  $S_{K_S^0 \pi^0}$  and  $+0.015$  on  $C_{K_S^0 \pi^0}$ ) as the associated uncertainty.

We estimate the background from other  $B$  decays to be small in the nominal fit. We account for a systematic shift induced on the signal yield and a small systematic uncertainty induced on the CPV parameters by this neglected component by embedding simulated  $B$  background events in the data set and evaluating the average shift in the fit result:  $+4.5$  events on the signal yield,  $+0.003$  on  $S_{K_S^0 \pi^0}$ , and  $-0.002$  on  $C_{K_S^0 \pi^0}$ . We adjust the signal yield accordingly and we use half of the shift as a systematic uncertainty.

To quantify possible additional systematic effects, we examine large samples of simulated  $B^0 \rightarrow K_S^0 \pi^0$  and  $B^0 \rightarrow J/\psi K_S^0$  decays. We employ the difference in resolution function parameters extracted from these samples to evaluate uncertainties due to the use of the resolution function  $\mathcal{R}$  extracted from the  $B_{\text{flav}}$  sample. We also use the data–Monte Carlo difference of the resolution function in

TABLE I. Summary of contributions to the systematic error on  $S_{K_S^0\pi^0}$  and  $C_{K_S^0\pi^0}$ .

	$\Delta S(10^{-2})$	$\Delta C(10^{-2})$
Statistical precision of PDF parameters	0.6	1.0
Shape of signal PDF	1.9	1.8
$B\bar{B}$ background	0.3	0.2
Correlation among fit observables	0.3	1.5
Vertexing method and $\mathcal{R}(\Delta t_r, \sigma_{\Delta t_r})$	2.7	0.6
SVT alignment	0.2	0.1
Beam spot position calibration	0.4	0.1
$B^0$ lifetime	0.2	0.2
Mixing frequency	0.2	0.2
Tag side interference	0.1	1.4
Total	3.4	3.0

$B^0 \rightarrow J/\psi K_S^0$  decays to quantify possible problems in the reconstruction of the  $K_S^0$  vertex. We obtain a combined systematic error from this control sample of 0.027 on  $S_{K_S^0\pi^0}$  and 0.006 on  $C_{K_S^0\pi^0}$ .

We assign a systematic uncertainty of 0.002 on  $S_{K_S^0\pi^0}$  and 0.001 on  $C_{K_S^0\pi^0}$  to account for possible misalignments of the SVT. This does not include the effects associated with changes in the  $\Delta t$  resolution function since this is measured on data using the  $B_{\text{flav}}$  control sample. We consider large variations of the IP position and resolution, which produce a systematic uncertainty of 0.004 on  $S_{K_S^0\pi^0}$  and 0.001 on  $C_{K_S^0\pi^0}$ . Additional contributions come from the error on the known  $B^0$  lifetime (0.0022 on both  $S_{K_S^0\pi^0}$  and  $C_{K_S^0\pi^0}$ ), the value of  $\Delta m_d$  (0.0017 on both  $S_{K_S^0\pi^0}$  and  $C_{K_S^0\pi^0}$ ), and the effect of interference on the tag side [21] (0.0014 on  $S_{K_S^0\pi^0}$  and 0.014 on  $C_{K_S^0\pi^0}$ ). The systematic uncertainties on  $S_{K_S^0\pi^0}$  and  $C_{K_S^0\pi^0}$  are summarized in Table I.

For the branching fraction, systematic errors come from the knowledge of selection efficiency,  $(33.6 \pm 1.6)\%$ , the counting of  $B\bar{B}$  pairs in the data sample,  $(383.2 \pm 4.2) \times 10^6$   $B\bar{B}$  pairs, and the branching fractions of the  $B$  decay chain  $\mathcal{B}(K_S^0 \rightarrow \pi^+ \pi^-) = 0.6920 \pm 0.0005$  and  $\mathcal{B}(\pi^0 \rightarrow \gamma\gamma) = 0.9880 \pm 0.0003$  [16]. The systematic uncertainties on the branching fraction are summarized in Table II.

TABLE II. Summary of dominant contributions to the systematic error on the branching fraction.

	$\Delta \mathcal{B}/\mathcal{B}(\%)$
$\pi^0$ efficiency	3.0
$K_S^0$ efficiency	0.6
Cut on likelihood variables	3.7
Shape of signal PDF	2.5
$B\bar{B}$ background	0.5
Correlation among fit observables	0.5
Number of $B\bar{B}$	1.1
Resolution function	0.2
Total	5.6

In summary, we have performed a measurement of the time-dependent  $CP$  asymmetries of  $B^0 \rightarrow K_S^0\pi^0$  and the branching fraction  $B^0 \rightarrow K^0\pi^0$ . We measured the CPV parameters  $C_{K_S^0\pi^0} = 0.24 \pm 0.15 \pm 0.03$  and  $S_{K_S^0\pi^0} = 0.40 \pm 0.23 \pm 0.03$ , and the branching fraction  $\mathcal{B}(B^0 \rightarrow K^0\pi^0) = (10.3 \pm 0.7 \pm 0.6) \times 10^{-6}$ . The first errors are statistical and the second ones are systematic. These values are consistent with the standard model predictions and the experimental value of  $\sin 2\beta$ . The results presented in this work supersede previous ones [14]. Using the rate sum rule from [8] and the currently published results for the other three  $B \rightarrow K\pi$  modes we find a prediction for  $\mathcal{B}(B^0 \rightarrow K_S^0\pi^0)^{sr} = (9.0 \pm 0.7) \times 10^{-6}$  which is consistent with our experimental result. Using this result we find the difference between the experimental result and the prediction improves from  $1.3 \pm 1.1$  to  $0.9 \pm 1.0$ , which is consistent with zero.

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues, and for the substantial dedicated effort from the computing organizations that support *BABAR*. The collaborating institutions wish to thank SLAC for its support and kind hospitality. This work is supported by DOE and NSF (USA), NSERC (Canada), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MIST (Russia), MEC (Spain), and STFC (United Kingdom). Individuals have received support from the Marie Curie EIF (European Union) and the A. P. Sloan Foundation.

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