Branching Fraction Limits for $B^0$ Decays to $\eta', \eta'\pi^0$ and $\eta\pi^0$

B. Aubert, R. Barate, D. Boutigny, F. Couderc, Y. Karyotakis, J. P. Lees, V. Poireau, V. Tisserand, A. Zghiche, E. Grauges, A. Palano, M. Pappagallo, J. C. Chen, N. D. Qi, G. Rong, P. Wang, Y. S. Zhu, G. Eigen, I. Ofte, B. Stugu, G. S. Abrams, M. Battaglia, D. S. Best, N. Brown, J. Button-Shafer, R. N. Cahn, E. Charles, C. T. Day, M. S. Gill, A. V. Gritsan, Y. Groysman, R. G. Jacobsen, J. A. Kadyk, L. T. Kerth, Yu. G. Kolomensky, G. Kultartsev, G. Lynch, L. M. Mir, P. J. Oddone, T. J. Orimoto, M. Pripstein, N. A. Roe, M. T. Roman, W. A. Wenzel, M. Barrett, K. E. Ford, T. J. Harrison, J. A. Hart, C. M. Hawkes, S. E. Morgan, A. T. Watson, M. Fritsch, K. Goetzen, T. Held, H. Koch, B. Lewandowski, M. Pelizaerus, K. Peters, T. Schroeder, M. Steinke, J. T. Boyd, P. J. Burke, W. N. Cottingham, D. Walker, T. Cuhadar-Donszelmann, B. G. Fulsom, C. Hearty, N. S. Knecht, T. S. Mattison, J. A. McKenna, A. Khan, P. Kyberd, M. Saleem, L. Teodorescu, V. E. Blinov, A. D. Bukin, A. Buzylkaev, V. P. Golubev, I. M. Peruzzi, S. H. Robertson, J. R. Fry, A. Seiden, D. Kirkby, W. T. Ford, S. Abachi, C. J. Flacco, W. F. Wang, D. Kovalskyi, X. Li, M. R. Monge, J. A. McKenna, D. J. Bard, D. del Re, V. P. Druzhinin, M. T. Naisbit, D. J. Bard, B. T. Meadows, V. Klose, H. K. Hadavand, E. J. Hill, H. P. Paar, S. Rahatliou, V. Sharma, J. W. Berryhill, C. Campagnari, A. Cunha, B. Dahmes, T. M. Hong, J. D. Richman, T. W. Beck, A. M. Eiser, C. J. Flacco, C. A. Heusch, J. Kroseberg, W. S. Lockman, G. Nesom, T. Schalk, B. A. Schumm, A. Seiden, P. G. Wilson, M. C. Williams, M. G. Wilson, J. Albert, E. Chen, G. P. Dubois-Felsmann, A. Dvoretskii, D. G. Hitlin, I. Narshy, T. Piatenko, F. C. Porter, A. Ryd, A. Samuel, R. Andreae, G. Mancinelli, B. T. Meadows, M. D. Sokoloff, E. A. Antillon, F. Blanc, P. C. Bloom, S. Chen, W. T. Ford, J. F. Hirschauer, A. Kreisel, U. Nauenberg, A. Olivas, W. O. Ruddick, J. G. Smith, K. A. Ulmer, S. R. Wagner, J. Zhang, A. Chen, E. A. Ekkhart, A. Soifer, W. H. Toki, R. J. Wilson, F. Winklemmeier, Q. Zeng, D. D. Altenburg, E. Feltresi, A. Hauke, H. Jasper, B. Spaan, T. Brandt, V. Klose, H. M. Lackner, R. Roychoudhury, A. Petzold, J. Schubert, K. R. Schubert, R. Schierz, J. E. Sundermann, A. Volk, D. Bernard, G. R. Bonepa, P. L. 화, P. N. Shen, J. S. Choi, W. Y. Lee, S. Muheim, S. Player, Y. Xie, M. Andreotti, D. Botet, C. Bozzi, R. Calabrese, G. Cibinneto, E. Lupti, M. Negri, L. Piemontese, F. Analli, R. Baldini-Ferroli, A. Calcetta, R. de Sangro, G. Finocchiaro, S. Pacetti, P. Patteri, I. M. Peruzzi, M. Piccolo, A. Zallo, A. Buzzo, R. Capra, R. Contri, M. Lo Vetere, M. M. Macri, M. R. Monge, S. Passaggio, C. Patrignani, E. Robutti, A. Santroni, S. Tosi, G. Brandenburg, K. S. Chaisangvathan, M. Morii, J. Wu, R. S. Dubitsky, J. Marks, S. Schenk, U. Uwer, W. Bhimji, D. A. Bowserman, P. D. Dauncey, U. Egede, R. L. Flack, J. R. Gaillard, J. A. Nash, M. B. Nikolich, W. Panduro Vazquez, X. Chai, M. J. Charles, W. F. Mader, U. Mallik, V. Ziegler, J. Cochran, H. B. Crawley, L. Dong, V. Eyges, W. T. Meyer, S. Prell, E. I. Rosenberg, A. E. Rubin, G. Schott, N. Arnaud, M. Davier, G. Grosdidier, A. Hocker, F. Le Diberder, V. Lepeltier, A. M. Lutz, A. Oyanguren, T. C. Petersen, S. Pruvot, S. Rodier, P. Routuel, M. H. Schune, A. Stocchi, W. F. Wang, G. Wormser, C. H. Cheng, D. J. Lange, D. M. Wright, C. A. Chavez, J. I. Forster, R. J. Fry, E. Gabathuler, R. Gamet, K. A. George, D. E. Hutchcroft, D. J. Payne, K. C. Schofield, C. Touramanis, A. J. Renken, F. Di Lodovico, W. Menges, R. Sacco, C. L. Brown, G. Cowan, H. U. Flaecher, D. A. Hopkins, P. S. Jackson, R. McMahnon, S. Ricciardi, F. Salvatore, D. N. Brown, C. L. Davis, J. Allison, N. R. Barlow, R. J. Barlow, Y. M. Chia, C. L. Edgar, M. P. Kelly, G. D. Lafferty, M. T. Naisbit, J. C. Williams, J. I. Yi, C. Chen, W. D. Hulsbergen, A. Jawahery, D. Kovalskyi, C. K. Lue, D. A. Roberts, G. Simi, G. Blaylock, C. Dallapiccola, S. S. Hertzbach, X. Li, T. B. Moore, S. Saremi, H. Staengle, Y. Willocq, R. Cowan, K. Koeneke, G. Sciolla, S. J. Sekula, M. Spitznagel, F. Taylor, R. K. Yamamoto, H. Kim, P. M. Patel, C. T. Potter, S. H. Robertson, L. Lazzaro, V. Lombardo, L. Palombo, J. M. Bauer, L. Cremaldi, V. Eschenburg.
We present the results of searches for neutral B meson decays to $\eta'\eta$, $\eta\pi^0$ and $\eta'\pi^0$, with a data sample expanded by about a factor of 2.6 over the one used for our previous measurements [1,2]. In the Standard Model (SM) the processes that contribute to these decays are described by color-suppressed tree and one-loop gluonic, electroweak or flavor-singlet penguin amplitudes. For $B^0 \rightarrow \eta'\pi^0$ and $B^0 \rightarrow \eta\pi^0$ the color-suppressed tree diagram is also suppressed by approximate cancellation between the amplitudes for the $\pi^0$ and for the isoscalar meson to contain the spectator quark, resulting from the mesons’ isospin couplings to the quarks. Estimates of the branching fractions for these modes have been obtained from calculations based on QCD factorization [3,4], perturbative QCD (for $B^0 \rightarrow \eta(0)\pi^0$) [5], soft-collinear effective theory [6], and flavor-SU(3) symmetry [7,8]. The expectations lie in the approximate ranges 0.2–1.0 $\times 10^{-6}$ for $B^0 \rightarrow \eta(0)\pi^0$, and 0.3–2 $\times 10^{-6}$ for $B^0 \rightarrow \eta'\eta$.

These decays are also of interest in constraining the expected value of the time-dependent CP-violation asymmetry parameter $S_f$ in the decay with $f = \eta'K^0_S$ [9,10]. The leading-order SM calculation gives the equality $S_{\eta'K^0_S} = S_f/\sin^2\beta$, where the latter has been precisely measured [11], and equals $\sin2\beta$ in the SM. The CP asymmetry in the charmless modes is sensitive to contributions from new physics, but also to contamination from subleading SM amplitudes. The most stringent constraint on such contamination in $S_{\eta'K^0_S}$ comes from the measured branching fractions of the three decay modes studied in this paper [9,10]. Recently it has also been suggested [10] that $B^0 \rightarrow \eta'\pi^0$ and $B^0 \rightarrow \eta\pi^0$ can be used to constrain the contribution from isospin-breaking effects on the value of $\sin2\alpha$ in $B \rightarrow \pi^+\pi^-$ decays.

The results presented here are based on data collected with the BABAR detector [14] at the PEP-II asymmetric $e^+e^-$ collider [15] located at the Stanford Linear Accelerator Center. An integrated luminosity of 211 $fb^{-1}$, corresponding to 232 $\times 10^6$ $B\bar{B}$ pairs, was recorded at the $Y(4S)$ resonance (center-of-mass energy $\sqrt{s} = 10.58$ GeV).

Charged particles from the $e^+e^-$ interactions are detected, and their momenta measured, by a combination of five layers of double-sided silicon microstrip detectors and a 40-layer drift chamber, both operating in the 1.5 T magnetic field of a superconducting solenoid. Photons and electrons are identified with a CsI(Tl) electromagnetic calorimeter (EMC). Further charged particle identification (PID) is provided by the average energy loss $(dE/dx)$ in the tracking devices and by an internally reflecting ring imaging Cherenkov detector (DIRC) covering the central region.

We establish the event selection criteria with the aid of a detailed Monte Carlo (MC) simulation of the $B$ production and decay sequences, and of the detector response [14]. These criteria are designed to retain signal events with high efficiency. Applied to the data, they result in a sample much larger than the expected signal, but with well characterized backgrounds. We extract the signal yields from this sample with a maximum likelihood (ML) fit.

The $B$-daughter candidates are reconstructed through their decays $\pi^0 \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\gamma$ ($\eta\gamma\gamma$), $\eta \rightarrow \pi^+\pi^-\pi^0$ ($\eta\pi\pi\pi$), $\eta' \rightarrow \eta\gamma\pi^+\pi^-$ ($\eta'\eta\pi\pi$), and additionally for $\eta'\eta$ modes, $\eta' \rightarrow \rho^0\gamma$ ($\eta'\rho\gamma$), where $\rho^0 \rightarrow \pi^+\pi^-$. Table I lists the requirements on the invariant mass of these particles’ final states. Secondary charged pions in $\eta'$ and $\eta$ candidates are rejected if classified as protons, kaons, or electrons by their DIRC, $dE/dx$, and EMC PID signatures.

We reconstruct the $B$-meson candidate by combining the four-momenta of a pair of daughter mesons, with a vertex constraint if the ultimate final state includes at least two charged particles. Since the natural widths of the $\eta$, $\eta'$, and $\pi^0$ are much smaller than the resolution,

| State | Invariant mass (MeV) | $E(\gamma)$ (MeV) |
|-------|---------------------|-------------------|
| $\pi^0$ | $120 < m(\gamma\gamma) < 150$ | > 50 |
| $\eta\gamma\gamma$ | $490 < m(\gamma\gamma) < 600$ | > 100 |
| $\eta\pi\pi\pi$ | $520 < m(\pi^+\pi^-\pi^0) < 570$ | > 30 |
| $\eta'\eta\pi\pi\pi$ | $910 < m(\pi^+\pi^-\pi^0) < 1000$ | > 100 |
| $\eta'\rho\gamma$ | $910 < m(\rho^0\gamma) < 1000$ | > 200 |
| $\rho^0$ | $510 < m(\pi^+\pi^-) < 1000$ | — |
we also constrain their masses to nominal values $^{17}$ in the fit of the $B$ candidate. From the kinematics of $\Upsilon(4S)$ decay we determine the energy-substituted mass $m_{ES} = \sqrt{\frac{1}{2}s - \mathbf{p}_B^2}$ and energy difference $\Delta E = E_B - \frac{1}{2}\sqrt{s}$, where $(E_B, \mathbf{p}_B)$ is the $B$-meson 4-momentum vector, and all values are expressed in the $\Upsilon(4S)$ frame. The resolution in $m_{ES}$ is 3.0 MeV and in $\Delta E$ is 24–50 MeV, depending on the decay mode. We require 5.25 GeV < $m_{ES}$ < 5.29 GeV and $|\Delta E| < 0.3$ GeV (< 0.2 GeV for $\eta'\eta$).

Backgrounds arise primarily from random combinations of particles in continuum $e^+e^- \rightarrow q\bar{q}$ events ($q = u, d, s, c$). We reduce these with requirements on the angle $\theta_T$ between the thrust axis of the $B$ candidate in the $\Upsilon(4S)$ frame and that of the rest of the charged tracks and neutral calorimeter clusters in the event. The distribution is sharply peaked near $|\cos \theta_T| = 1$ for $q\bar{q}$ jet pairs, and nearly uniform for $B$-meson decays. The requirement, which optimizes the expected signal yield relative to its background-dominated statistical error, is $|\cos \theta_T| < 0.7–0.9$ depending on the mode.

In the ML fit we discriminate further against $q\bar{q}$ background with a Fisher discriminant $F$ that combines several variables which characterize the energy flow in the event $^{11}$. It provides about one standard deviation of separation between $B$ decay events and combinatorial background (see Fig. 1). We also impose restrictions on decay angles to exclude the most asymmetric decays where soft-particle backgrounds concentrate and the acceptance changes rapidly. We define the decay angle $\theta_{\text{dec}}^k$ for a meson $k$ as the angle between the momenta of a daughter particle and the meson’s parent, measured in the meson’s rest frame. We require for the $\eta'\eta$ decays $|\cos \theta_{\text{dec}}| < 0.9$ and for $\eta(1)\pi^0$ $|\cos \theta_{\text{dec}}| < 0.95$. For $B^0 \rightarrow \eta'\eta\pi\gamma$ the requirement is $|\cos \theta_{\text{dec}}| < 0.86$ to suppress the background $B \rightarrow K\gamma$.

The average number of candidates found per selected event is in the range 1.06 to 1.23, depending on the final state. We choose the candidate with the smallest value of a $\chi^2$ constructed from the deviations from expected values of one or more of the daughter resonance masses. From the simulation we find that this algorithm selects the correct-combination candidate in about two thirds of the events containing multiple candidates, and that it induces negligible bias.

We obtain yields for each channel from a maximum likelihood fit with the input observables $\Delta E$, $m_{ES}$, $F$, and $m_{1(2)}$, the daughter invariant mass spectrum of the $\eta$ and/or $\eta'$ candidate. The selected sample sizes are given in the second column of Table 11. Besides any signal events they contain $q\bar{q}$ (dominant) and $B\bar{B}$ with $b \rightarrow c$ combinatorial background, and a fraction that we estimate from the simulation to be less than 0.2% of feed-across from other charmless $B\bar{B}$ modes. The latter events have ultimate final states different from the signal, but with similar kinematics so that broad peaks near those of the signal appear in some observables, requiring a separate component in the probability density function (PDF). The likelihood function is

$$\mathcal{L} = \exp\left(-\sum_{j} N_{j} \prod_{i} \sum_{j} Y_{j} \times \mathcal{P}_{j}(m_{ES}^{i})\mathcal{P}_{j}(\Delta E^{i})\mathcal{P}_{j}(F^{i})\mathcal{P}_{j}(m_{i}^{i}) \left[\mathcal{P}_{j}(m_{2}^{i})\right]^{j}\right)$$

where $N$ is the number of events in the sample, and for each component $j$, $Y_{j}$ is the yield of events and $\mathcal{P}_{j}(x^{i})$ the PDF for observable $x$ in event $i$. For the modes $B^0 \rightarrow \eta'\eta\pi\gamma$ we found no need for the $B\bar{B}$ background component. The factored form of the PDF indicated in Eq. $^{11}$ is a good approximation, particularly for the combinatorial $q\bar{q}$ component, since correlations among observables measured in the data (dominantly this component) are small. Distortions of the fit results caused by this approximation are measured in simulation and included in the bias corrections and systematic errors discussed below.

We determine the PDFs for the signal and $B\bar{B}$ background components from fits to MC data. We calibrate the resolutions in $\Delta E$ and $m_{ES}$ with large control samples of $B$ decays to charmed final states of similar topology (e.g. $B \rightarrow D(K\pi\pi)\pi$). For the combinatorial background the PDFs are determined in the fits to the data. However the functional forms are first deduced from fits of that component alone to sidebands in ($m_{ES}$, $\Delta E$), so that we can validate the fit before applying it to data containing the signal.

We use the following functional forms for the PDFs: sum of two Gaussians for $\mathcal{P}_{\text{sig}}(m_{ES})$, $\mathcal{P}_{\text{sig},B\bar{B}}(\Delta E)$, and the sharper structures in $\mathcal{P}_{B\bar{B}}(m_{ES})$ and $\mathcal{P}_{j}(m_{k})$; linear or quadratic dependences for combinatorial components of $\mathcal{P}_{B\bar{B},i}(m_{k})$ and for $\mathcal{P}_{i}(\Delta E)$; and a conjunction of two Gaussian segments below and above the peak with different widths, plus a broad Gaussian, for $\mathcal{P}_{j}(F)$. The $q\bar{q}$ background in $m_{ES}$ is described by the function $x\sqrt{1-x^{2}}\exp[-\xi(1-x^{2})^{2}]$, with $x = 2m_{ES}/\sqrt{s}$ and parameter $\xi$. These are discussed in more detail in $^{11}$, and some of them are illustrated in Fig. 11.

We allow the parameters most important for the determination of the combinatorial background PDFs to vary in the fit, along with the yields for all components. Specifically, the free background parameters are most or all of the following, depending on the decay mode: $\xi$ for $m_{ES}$, linear and quadratic coefficients for $\Delta E$, area and slope of the combinatorial component for $m_{k}$, and the mean, width, and width difference parameters for $F$. Results for the yields are presented in the third column of Table 11 for each sample.

We test and calibrate the fitting procedure by applying it to ensembles of simulated $q\bar{q}$ experiments drawn from the PDF into which we have embedded the expected number of signal and $B\bar{B}$ background events randomly.
extracted from the fully simulated MC samples. We find biases of 0–2 events, somewhat dependent on the signal size. The bias values obtained for simulations that reproduce the yields found in the data are given in the fourth column of Table III.

In Fig. 1 we show, as representative of the several fits, the projections of the PDF and data for the $B^0 \rightarrow \eta_{q\pi\pi} \pi^0$ sample. The goodness-of-fit is further demonstrated by the distribution of the likelihood ratio $\mathcal{L}_{sig}/[\mathcal{L}_{sig} + \sum \mathcal{L}_{bkj}]$ for data and for simulation generated from the PDF model, shown for the same decay mode in Fig. 2. We see good agreement between the model and the data. By construction the background is concentrated near zero, while any signal would appear in a peak near one.

We determine the reconstruction efficiencies, given in Table III, as the ratio of reconstructed and accepted events in simulation to the number generated. We compute the branching fraction for each channel by subtracting the fit bias from the measured yield, and dividing the result by the efficiency and the number of produced $B\bar{B}$ pairs. We assume equal decay rates of the $T(4S)$ to $B^+B^-$ and $B^0\bar{B}^0$. Table III gives the numbers pertinent to these computations. The statistical error on the signal yield or branching fraction is taken as the change in the central value when the quantity $-2\ln \mathcal{L}$ increases by one unit from its minimum value.

We combine results where we have multiple decay channels by adding the functions $-2\ln \{[\mathcal{L}(B)/\mathcal{L}(B_0)] \otimes G(B:0,\sigma')\}$, where $B_0$ is the central value from the fit, $\sigma'$ is the systematic uncertainty, and $\otimes G$ denotes convolution with a Gaussian function. We give the resulting final branching fractions for each mode in Table III with the significance, taken as the square root of the difference between the value of $-2\ln \mathcal{L}$ (with additive systematic uncertainties included) for zero signal and the value at its minimum. The 90% C.L. upper limits are taken to be the branching fraction below which lies 90% of the total of the likelihood integral in the positive branching fraction region.

The systematic uncertainties on the branching fractions arising from lack of knowledge of the PDFs have been included in part in the statistical error since most background parameters are free in the fit. For the signal, the uncertainties in PDF parameters are estimated from the consistency of fits to MC and data in control modes. Varying the signal-PDF parameters within these errors, we estimate yield uncertainties of 0–2 events, depending on the mode.

### Table II: Number of events $N$ in the sample, fitted signal yield $Y_S$ in events (ev.), measured bias, detection efficiency $\epsilon$, daughter branching fraction product ($\prod B_i$), and measured branching fraction $B$ with statistical error for each decay chain, and for the combined measurements the significance $S$ (with systematic uncertainties included), branching fraction with statistical and systematic error, and in parentheses the 90% C.L. upper limits. The number of produced $B\bar{B}$ pairs is $(231.8 \pm 2.6) \times 10^6$.

| Mode | $N$ (ev.) | $Y_S$ (ev.) | Bias (ev.) $\epsilon$ (%) | $\prod B_i$ | $S$ ($\sigma$) | $B$ (10$^{-6}$) |
|------|-----------|-------------|-----------------------------|-------------|---------------|---------------|
| $\eta\pi\pi\pi \pi\pi$ | 539 | $2.0^{+4.4}_{-2.0}$ | $1.9 \pm 1.0$ | 13.8 | 3.95 | $0.1^{+2.4}_{-1.6}$ |
| $\eta\pi\pi\pi \eta\gamma$ | 1448 | $2.1^{+3.5}_{-2.2}$ | 0.7 $\pm$ 0.4 | 22.3 | 6.89 | $0.4^{+1.0}_{-0.6}$ |
| $\eta\eta\pi \pi\pi$ | 8268 | $-8.6^{+8.7}_{-7.0}$ | 0.0 $\pm$ 0.4 | 14.9 | 6.67 | $-3.8^{+3.8}_{-2.8}$ |
| $\eta\gamma\gamma \eta\gamma$ | 16861 | $1.5^{+10.5}_{-8.5}$ | 0.0 $\pm$ 0.5 | 21.8 | 11.63 | $0.2^{+1.8}_{-1.4}$ |
| $\eta\gamma$ | | | 0.4 | $0.2^{+0.7}_{-0.5}$ | $0.4$ | $(<1.7)$ |
| $\eta\pi\pi\pi^0$ | 2334 | $10.3^{+6.6}_{-4.7}$ | 1.2 $\pm$ 0.7 | 16.3 | 22.6 | $1.1^{+1.9}_{-0.9}$ |
| $\eta\gamma\pi^0$ | 5493 | $6.5^{+11.5}_{-9.6}$ | 1.2 $\pm$ 0.8 | 20.7 | 39.4 | $0.3^{+0.6}_{-0.5}$ |
| $\eta\pi^0$ | | | 1.3 | $0.6^{+0.5}_{-0.4}$ | $0.1$ | $(<1.3)$ |
| $\eta'\pi^0$ | 3663 | $7.9^{+6.9}_{-5.2}$ | 1.2 $\pm$ 0.6 | 17.5 | 17.5 | $1.4^{+0.8}_{-0.6}$ | $0.1$ | $(<2.1)$ |

*FIG. 1: Plots of the $B^0 \rightarrow \eta_{q\pi\pi} \pi^0$ data distribution projected on each of the fit variables: (a) $\Delta E$, (b) $m_{ES}$, (c) $\eta'$ mass, and (d) $F$. The solid line represents the result of the fit, and the dashed line the background contribution. (The absence of signal here nearly hides the dashed curve.) The dotted line illustrates the expected shape for signal, normalized arbitrarily to the data.*
We find no evidence for these decays, and our upper limits will provide approximately 20% improvement of the prediction for the contribution of the color suppressed tree amplitude in $B^0 \rightarrow \eta' K^0$ decays. This translates into a 20% reduction of this theoretical uncertainty in $S_{\eta' K^0}$. We find a similar improvement in the corresponding uncertainty of sin2$\alpha$ measured with $B \rightarrow \pi^+ \pi^-$ decays [12, 13].

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), IHEP (China), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MIST (Russia), and PPARC (United Kingdom). Individuals have received support from CONACyT (Mexico), Marie Curie EIF (European Union), the A. P. Sloan Foundation, the Research Corporation, and the Alexander von Humboldt Foundation.

Theoretical estimates.

Previous measurements [1, 2, 18]. The range of sensitivity its represent two to three-fold improvement over the previous measurements [1, 2, 18]. The range of sensitivity is comparable to the range of the theoretical estimates.

These results can be used to constrain the expected value of the CP asymmetry $S_f$ in relation to sin2$\beta$ for the decay $B^0 \rightarrow \eta' K^0$. Using the method proposed by Gronau et al. [10], we estimate that our results will provide approximately 20% improvement of the prediction for the contribution of the color suppressed tree amplitude in $B^0 \rightarrow \eta' K^0$ decays. This translates into a 20% reduction of this theoretical uncertainty in $S_{\eta' K^0}$. We find a similar improvement in the corresponding uncertainty of sin2$\alpha$ measured with $B \rightarrow \pi^+ \pi^-$ decays [12, 13].

[1] M. Gronau, J.L. Rosner and J. Zupan, Phys. Lett. B 596 (2004).
[2] BABAR Collaboration (B. Aubert et al.), Phys. Rev. Lett. 93, 181806 (2004).
[3] M. Beneke et al., Nucl. Phys. B 591, 313 (2000).
[4] M. Beneke and M. Neubert, Nucl. Phys. B 675, 333 (2003).
[5] H. Wang et al., Nucl. Phys. B 738, 243 (2006).
[6] A. Williamson and J. Zupan, hep-ph/0601214 (2006).
[7] C.W. Chiang, M. Gronau, J.L. Rosner, Phys. Rev. D 70, 074012 (2004).
[8] C.W. Chiang, M. Gronau, J.L. Rosner, Phys. Rev. D 70, 034020 (2004).
[9] Y. Grossman, et al., Phys. Rev. D 68, 015004 (2003).
[10] M. Gronau, J.L. Rosner and J. Zupan, Phys. Lett. B 596, 107 (2004).
[11] BABAR Collaboration (B. Aubert et al.), Phys. Rev. Lett. 94, 161803 (2005); Belle Collaboration (K. Abe et al.), Phys. Rev. D 71, 072003 (2005).
[12] M. Gronau and J. Zupan, Phys. Rev. D 71, 074017 (2005).
[13] S. Gardner, Phys. Rev. D 72, 034015 (2005).
[14] BABAR Collaboration, B. Aubert et al., Nucl. Instr. Methods Phys. Res., Sect. A 479, 1 (2002).
[15] PEP-II Conceptual Design Report, SLAC-R-418 (1993).
[16] The \textit{BABAR} detector Monte Carlo simulation is based on GEANT4: S. Agostinelli \textit{et al.}, Nucl. Instr. Methods Phys. Res., Sect. A \textbf{506}, 250 (2003).

[17] Particle Data Group, S. Eidelman \textit{et al.}, Phys. Lett. B \textbf{592}, 1 (2004).

[18] P. Chang \textit{et al.}, Phys. Rev. D \textbf{71}, 091106 (2005).