Improved Measurements of Branching Fractions and $CP$ Asymmetries in $B \rightarrow \eta h$ Decays

P. Chang,24 K. Abe,40 I. Adachi,7 H. Aihara,42 D. Anipko,1 A. M. Bakich,38 E. Barberio,19 A. Bay,17 U. Bitenc,13 I. Bizjak,13 A. Bondar,1 A. Bozek,25 M. Bracko,18,13 T. E. Browder,6 Y. Chao,24 A. Chen,22 K.-F. Chen,24 W. T. Chen,22 B. G. Cheon,3 R. Chistov,12 S.-K. Choi,48 Y. Choi,37 Y. K. Choi,37 S. Cole,38 J. Dalseno,19 M. Dash,46 J. Dragic,7 S. Eidelman,1 S. Fatima,13 N. Gabyshchev,1 A. Go,22 A. Gorišek,13 H. Ha,15 J. Haba,7 K. Hara,20 H. Hayashii,21 M. Hazumi,7 D. Heffernan,30 T. Hokuue,20 Y. Hoshi,40 S. Hou,22 W.-S. Hou,24 T. Iijima,20 K. Inami,20 A. Ishikawa,42 H. Ishino,43 R. Itoh,7 M. Iwasaki,42 Y. Iwasaki,7 H. Kaji,20 J. H. Kang,47 S. U. Kataoka,21 H. Kawai,2 T. Kawasaki,27 H. Kichimi,7 H. J. Kim,16 Y. J. Kim,5 K. Kinoshita,4 S. Korpar,18,13 P. Krokovny,7 R. Kumar,31 C. C. Kuo,22 A. Kuzmin,1 Y.-J. Kwon,47 M. J. Lee,35 S. E. Lee,35 T. Lesiak,25 S.-W. Lin,24 F. Mandl,10 T. Matsumoto,14 S. McOnie,38 H. Miyata,27 Y. Miyazaki,20 R. Mizuk,12 G. R. Moloney,19 T. Mori,20 Y. Nagasaki,8 M. Nakao,7 S. Nishida,7 O. Nitoh,45 S. Ogawa,39 T. Ohshima,20 S. Okuno,14 Y. Onuki,33 H. Ozaki,7 F. Pakhlov,12 G. Pakhlova,12 H. Park,16 L. S. Peak,38 R. Pestotnik,13 L. E. Piilonen,46 Y. Sakai,7 N. Satoyama,36 T. Schietinger,17 O. Schneider,17 J. Schümann,7 C. Schwanda,10 A. J. Schwartz,4 K. Senyo,20 M. E. Sevior,19 M. Shapkin,11 H. Shibuya,39 B. Shwartz,1 J. B. Singh,31 A. Somov,4 N. Soni,31 S. Stanič,28 M. Starič,13 H. Stoeck,38 T. Sumiyoshi,44 F. Takasaki,7 M. Tanaka,7 G. N. Taylor,19 Y. Teramoto,29 X. C. Tian,32 I. Tikhomirov,12 K. Trabelsi,7 T. Tsuboyama,7 T. Tsukamoto,7 S. Uehara,7 T. Uglov,12 K. Ueno,24 Y. Unno,9 S. Uno,7 Y. Usoskin,4 G. Varner,6 K. E. Varvell,38 S. Villa,17 C. C. Wang,24 C. H. Wang,23 M.-Z. Wang,24 M. Watanabe,27 Y. Watanabe,43 R. Wedd,19 J. Wicht,17 E. Won,15 A. Yamaguchi,41 Y. Yamashita,26 M. Yamauchi,7 C. C. Zhang,9 Z. P. Zhang,34 V. Zhilich,1 and A. Zupanc,13
(The Belle Collaboration)

1 Budker Institute of Nuclear Physics, Novosibirsk
2 Chiba University, Chiba
3 Chonnam National University, Kwangju
4 University of Cincinnati, Cincinnati, Ohio 45221
5 The Graduate University for Advanced Studies, Hayama, Japan
6 University of Hawaii, Honolulu, Hawaii 96822
7 High Energy Accelerator Research Organization (KEK), Tsukuba
8 Hiroshima Institute of Technology, Hiroshima
9 Institute of High Energy Physics, Chinese Academy of Sciences, Beijing
10 Institute of High Energy Physics, Vienna
11 Institute of High Energy Physics, Protvino
12 Institute for Theoretical and Experimental Physics, Moscow
13 J. Stefan Institute, Ljubljana
14 Kanagawa University, Yokohama
15 Korea University, Seoul
16 Kyungpook National University, Taegu
17 Swiss Federal Institute of Technology of Lausanne, EPFL, Lausanne
18 University of Maribor, Maribor
19 University of Melbourne, Victoria
20 Nagoya University, Nagoya
21 Nara Women’s University, Nara
22 National Central University, Chung-Li
23 National United University, Miao Li
24 Department of Physics, National Taiwan University, Taipei
25 H. Niewodniczanski Institute of Nuclear Physics, Krakow
26 Nippon Dental University, Niigata
27 Niigata University, Niigata
28 University of Nova Gorica, Nova Gorica
29 Osaka City University, Osaka
30 Osaka University, Osaka
31 Panjab University, Chandigarh
32 Peking University, Beijing
We report improved measurements of $B$ decays with an $\eta$ meson in the final state using 492 fb$^{-1}$ of data collected by the Belle detector at the KEKB $e^+e^-$ collider. We observe the decays $B^{\pm}\to\eta\pi^{\pm}$ and $B^{\pm}\to\eta K^{\pm}$ and measure the branching fractions $B(B^{\pm}\to\eta\pi^{\pm})=(4.2\pm0.4{\,(stat)}\pm0.2{\,(sys)})\times10^{-6}$ and $B(B^{\pm}\to\eta K^{\pm})=(1.9\pm0.3{\,(stat)+0.2{\,(sys)}})\times10^{-6}$. The corresponding $CP$-violating asymmetries are measured to be $-0.23\pm0.09{\,(stat)}\pm0.02{\,(sys)}$ for $\eta\pi^{\pm}$ and $-0.39\pm0.16{\,(stat)}\pm0.03{\,(sys)}$ for $\eta K^{\pm}$. We also search for $B^0\to\eta K^0$ decays and set an upper limit of $1.9\times10^{-6}$ at the 90% confidence level.

\[ A_{CP} = \frac{N(B^-\to\eta h^-)-N(B^+\to\eta h^+)}{N(B^-\to\eta h^-)+N(B^+\to\eta h^+)} \]  

where $N(B^-\to\eta h^-)$ is the yield obtained for the $B^-\to\eta h^-$ decay and $N(B^+\to\eta h^+)$ denotes that of the charge-conjugate mode. The data sample consists of 535 million $B\bar{B}$ pairs (492 fb$^{-1}$) collected with the Belle detector at the KEKB $e^+e^-$ asymmetric-energy (3.5 on 8 GeV) collider\[^{11}\] operating at the $\Upsilon(4S)$ resonance. Throughout this paper, the inclusion of the charge-conjugate decay mode is implied unless otherwise stated.

The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Čerenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) comprised of CsI(Tl) crystals located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return located outside the coil is instrumented to detect $K^0_L$ mesons and to identify muons (KLM). The detector is described in detail elsewhere\[^{12}\]. In August 2003, the three-layer SVD was replaced by a four-layer device with greater radiation tolerance\[^{13}\]. The data sample used in this analysis consists of 140 fb$^{-1}$ of data with the old SVD (Set I) and 352 fb$^{-1}$ with the new one (Set II).

The event selection and $B$ candidate reconstruction are similar to those documented in our previous publication.
Two \( \eta \) decay channels are considered in this analysis: \( \eta \to \gamma\gamma (\eta_{\gamma\gamma}) \) and \( \eta \to \pi^+\pi^-\pi^0 (\eta_{3\pi}) \). We require photons from the \( \eta \) and \( \pi^0 \) candidates to have laboratory energies \( (E_{\gamma}) \) above 50 MeV. In the \( \eta_{\gamma\gamma} \) reconstruction, the photon energy asymmetry, \( \frac{|E_{\gamma 1} - E_{\gamma 2}|}{E_{\gamma 1} + E_{\gamma 2}} \), is required to be less than 0.9 to reduce the large combinatorial background from soft photons. Neither photon from \( \eta_{\gamma\gamma} \) is allowed to pair with any other photon having \( E_{\gamma} > 100 \) MeV to form a \( \pi^0 \) candidate. Candidate \( \pi^0 \) mesons are selected by requiring the two-photon invariant mass to be in a mass window between 115 MeV/\( c^2 \) and 152 MeV/\( c^2 \). The momentum vector of each photon is then readjusted to constrain the mass of the photon pair to the nominal \( \pi^0 \) mass.

Candidate \( \eta_{3\pi} \) mesons are reconstructed by combining \( \pi^0 \) candidates with at least 250 MeV/\( c \) laboratory momentum with a pair of oppositely charged tracks that originate from the interaction point (IP). We impose the following requirements on the invariant mass of the \( \eta \) candidates in both data sets: 516 MeV/\( c^2 \) \(< M_{\eta\gamma} < 569 \) MeV/\( c^2 \) for \( \eta_{\gamma\gamma} \) and 539 MeV/\( c^2 \) \(< M_{3\pi} < 565 \) MeV/\( c^2 \) for \( \eta_{3\pi} \). After the selection of each candidate, the \( \eta \) mass constraint is implemented by readjusting the momentum vectors of the daughter particles.

Charged tracks are required to come from the IP. Charged kaons and pions, which are combined with \( \eta \) mesons to form \( B \) candidates, are identified using a \( K(\pi) \) likelihood \( L_K(L_{\pi}) \) obtained by combining information from the CDC \( (dE/dx) \), the TOF and the ACC. Discrimination between kaons and pions is achieved through a requirement on the likelihood ratio \( L_K/(L_{\pi} + L_K) \). Charged tracks with likelihood ratios greater than 0.6 are regarded as kaons, and less than 0.4 as pions. Charged tracks that are positively identified as electrons or muons are rejected. The \( K/\pi \) identification efficiencies (PID) and misidentification rates are determined from a sample of \( D^{\ast+} \to D^0\pi^+D^0 \to K^+\pi^- \) decays with kaons and pions in the same kinematic region of two-body \( B \) decays. The \( K^{(*)} (pion) \) identification efficiency is 83\% (90\%) and 6.4\% (11.7\%) of pions (kaons) will be misidentified as kaons (pions). The systematic error of the \( K/\pi \) selection is about 1.3\% for pions and 1.5\% for kaons, respectively.

\( K_0^0 \) candidates are reconstructed from pairs of oppositely-charged tracks with an invariant mass \( (M_{\pi\pi}) \) between 480 MeV/\( c^2 \) and 516 MeV/\( c^2 \). Each candidate must have a displaced vertex with a flight direction consistent with that of a \( K_0^0 \)-meson originating from the IP.

Candidate \( B \) mesons are identified using the beam-energy constrained mass, \( M_{bc} = \sqrt{E_{\text{beam}}^2 - P_B^2} \), and the energy difference, \( \Delta E = E_B - E_{\text{beam}} \), where \( E_{\text{beam}} \) is the run-dependent beam energy in the \( \Upsilon(4S) \) rest frame determined from \( B \to D^{(*)}\pi \) events, and \( P_B \) and \( E_B \) are the momentum and energy, respectively of the \( B \) candidate in the \( \Upsilon(4S) \) rest frame. The resolutions in \( M_{bc} \) and \( \Delta E \) are about 3 MeV/\( c^2 \) and 20–30 MeV, respectively. Events with \( M_{bc} > 5.2 \) GeV/\( c^2 \) and \( |\Delta E| < 0.3 \) GeV are selected for the analysis.

The dominant background comes from the \( e^+e^- \to q\bar{q} \) continuum, where \( q = u, d, s \) or \( c \). To distinguish signal from the jet-like continuum background, event shape variables and \( B \) flavor tagging information are employed. We combine the correlated shape variables into a Fisher discriminant \(^{[13]} \) and then compute a likelihood that is the product of probabilities based on this discriminant and \( \cos\theta_B \), where \( \theta_B \) is the angle between the \( B \) flight direction and the beam direction in the \( \Upsilon(4S) \) rest frame. A likelihood ratio, \( R = L_s/(L_s + L_{q\bar{q}}) \), is formed from signal \( (L_s) \) and background \( (L_{q\bar{q}}) \) likelihoods, obtained from Monte Carlo simulation (MC) and from data with \( M_{bc} < 5.26 \) GeV/\( c^2 \), respectively. Signal MC events for the charged \( B \) modes are generated with the PHOTOS \(^{[15]} \) simulation package to take into account final state radiation. Additional background discrimination is provided by \( B \) flavor tagging. Events that contain a lepton (such as those used in high quality tagging) are more likely to be \( B\bar{B} \) events so a looser \( R \) requirement is applied. The standard Belle \( B \) tagging package \(^{[16]} \) provides two outputs: a discrete variable \( (q) \) indicating the tagged side flavor and a dilution factor \( (r) \) ranging from zero for no flavor information to unity for unambiguous flavor assignment. Since the charged \( B \) modes are flavor specific, the wrong flavor tagged events are likely to be background and a tight \( R \) requirement can be applied. We divide the data into six sub-samples based on the \( q \) and \( r \) information for the charged modes and the \( r \) value only for the neutral mode. Continuum suppression is achieved by applying a mode-dependent requirement on \( \overline{R} \) for events in each sub-sample that maximizes \( N^s_{\exp}/\sqrt{N^s_{\exp} + N^q_{\bar{q}\bar{q}}_{\exp}} \), where \( N^s_{\exp} \) is the number of signal events expected from MC and \( N^q_{\bar{q}\bar{q}}_{\exp} \) denotes the number of background events estimated from data. After applying the \( R \) requirements, we select one candidate per event based on the best \( R \). The fraction of events with multiple candidates are \( \sim 1\% \) for the \( \gamma\gamma \) mode and \( \sim 2\% \) for the \( \pi^+\pi^-\pi^0 \) mode.

Using a large MC sample, all other backgrounds are found to be negligible except for \( \eta K^+ (\eta\pi^+) \) reflecting into the \( \eta\pi^+ (\eta K^+) \) sample, due to \( K^+ \to \pi^+(\pi^+ \to K^+) \) misidentification, and the feed-down from charmless \( B \) decays, predominantly \( B \to \eta K^*(892) \) and \( B \to \eta\rho(770) \). We include the reflection and charmless components in the fit used to extract the signal.

The signal yields and partial rate asymmetries are obtained using an extended unbinned maximum-likelihood (ML) fit with input variables \( M_{bc} \) and \( \Delta E \). The likeli-
The partial rate asymmetries and branching fractions, as well as corrections to the efficiency for detecting low momentum charged particles. Therefore, the raw asymmetry defined in Eq. 1 is corrected for the following:

$$L = e^{-\sum_j N_j} \times \prod_i \left( \sum_j N_j \rho_j^i \right) \quad \text{and} \quad (2)$$

$$\rho_j^i = \frac{1}{2} \left( 1 - q^i \cdot A_{CP} \right) P_j \left( M_{bc}, \Delta E^i \right), \quad (3)$$

where $i$ is the identifier of the $i$-th event and $N_j$ is the number of events for the category $j$, which corresponds to either signal, $q\bar{q}$ continuum, the reflection due to $K\pi$ misidentification, or background from other charmless $B$ decays. $P_j \left( M_{bc}, \Delta E^i \right)$ is the two-dimensional probability density function (PDF) in $M_{bc}$ and $\Delta E$, and $q$ indicates the $B$ meson flavor, $B^+(q = +1)$ or $B^-(q = -1)$. For the neutral $B$ mode, $P_j$ in Eq. 2 is simply $P_j \left( M_{bc}, \Delta E^i \right)$ and there is no component from charged particle misidentification.

In Ref. [17] we reported that in both data sets the PID efficiency is slightly different for positively and negatively charged particles. Therefore, the raw asymmetry defined in Eq. 1 must be corrected. This efficiency difference results in an $A_{CP}$ bias of $-0.005$ ($+0.005$) for $\eta\pi$ ($\eta K$). The bias is subtracted from the raw asymmetry.

The PDFs for the signal, the reflection background and the charmless feed-down are modeled with two-dimensional $M_{bc}\Delta E$ smooth functions obtained using large MC samples. The signal peak positions and resolutions in $M_{bc}$ and $\Delta E$ are adjusted according to the data-MC differences using large control samples of $B \rightarrow D\pi$ and $D^{0*} \rightarrow K^+\pi^-\pi^0$ decays. The continuum background in $\Delta E$ is described by a first- or second-order polynomial, while the $M_{bc}$ distribution is parameterized by an ARGUS function, $f(x) = x\sqrt{1 - x^2} \exp \left( -\xi(1 - x^2) \right)$, where $x = M_{bc}/E_{beam}$ [13]. The continuum PDF is thus formed by the product of an ARGUS function and a polynomial, where $\xi$ and the coefficients of the polynomial are free parameters.

The partial rate asymmetries of the charmless $B$ backgrounds are fixed to zero in the fit while the $A_{CP}$ and normalizations of the reflection components are fixed to expectations based on the $B^+ \rightarrow \eta K^+$ and $B^+ \rightarrow \eta\pi^+$ partial rate asymmetries and branching fractions, as well as $K^+ \leftrightarrow \pi^+$ fake rates. The reflection yield and $A_{CP}$ are first input with the assumed values and are then recalculated according to our measured results.

Table II shows the measured branching fractions for each decay mode as well as other quantities associated with the measurements. The efficiency for each mode is determined using MC simulation and corrected for the data-MC discrepancy obtained from the control sample studies. In addition to the particle identification performance discrepancy, our MC slightly overestimates the efficiency for detecting low momentum $\pi^0$s, which results in a 3.1% correction for the $\eta\pi$ mode. The combined branching fraction for the two datasets is computed as the sum of the yield divided by its efficiency in each set divided by the number of $B$ mesons, while the partial rate asymmetry for the charged mode is computed using the sum of the yield divided by its efficiency in each set in Eq. 1. The combined branching fraction and partial rate asymmetry of the two $\eta$ decay modes are obtained from the weighted average assuming the errors are Gaussian. The number of $B^+B^-$ and $B^0\bar{B}^0$ pairs are assumed to be equal. Figure 1 shows the $M_{bc}$ and $\Delta E$ projections after requiring events to satisfy $-0.10$ GeV < $\Delta E$ < $0.08$ GeV and $M_{bc} > 5.27$ GeV/$c^2$, respectively.

![Fig. 1: $M_{bc}$ and $\Delta E$ projections for (a,b) $B^+ \rightarrow \eta\pi^+$, (c,d) $B^+ \rightarrow \eta K^+$, and (e,f) $B^0 \rightarrow \eta K^0$ decays with the $\eta\gamma\gamma$ and $\eta\pi\pi$ modes combined. Open histograms are data, solid curves are the fit functions, dashed lines show the continuum contributions and shaded histograms are the feed-down component from charmless $B$ decays. The small contributions around $M_{bc} = 5.28$ GeV/$c^2$ and $\Delta E = 0.05$ GeV in (a)-(d) are the reflection backgrounds from $B^\pm \rightarrow \eta K^\pm$ and $B^\pm \rightarrow \eta\pi^\pm$. Systematic uncertainties due to the signal PDFs used in the fit are estimated by performing the fit after varying the signal peak positions and resolutions by one standard deviation ($\sigma$). We also examine the changes in yield and $A_{CP}$ when the requirement of no asymmetry for the charmless background is removed. In $B^\pm \rightarrow \eta\pi^\pm$, the reflection yields are estimated to be $9.4 \pm 3.1$ events for the $\eta\gamma\gamma$ mode and $3.6 \pm 1.9$ for $\eta\pi\pi$ while in $B^\pm \rightarrow \eta K^\pm$, the reflection yields are $13.9 \pm 3.7$ for $\eta\gamma\gamma$ and $4.6 \pm 2.1$ for $\eta\pi\pi$. The reflection yields and their $A_{CP}$ values are varied by one standard deviation in the fit to obtain the corresponding systematic uncertainties. The quadratic sum of the deviations from the central value gives the systematic uncertainty in the fit. A statistical significance is calculated as $S = \sqrt{-2 \ln L_0 - (-2 \ln L_{\text{max}})}$, where $-2 \ln L_0$ is for zero signal yield and $-2 \ln L_{\text{max}}$ is for the best-fit value. The final significance including systematic uncertainties is...](image)
efficiency ratio using the requirement is studied by checking the data-MC efficiency, particle identification, and tracking efficiency. No obvious bias is observed and we use the systematic uncertainty in Table I. Figures 2 and 3 show the quadrature with the fit systematic error to give the final systematic error. The bias error of 0.01 is added in quadrature with the fit systematic error to give the final systematic error for the continuum contribution. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels $\overline{D}^0 \rightarrow K^-\pi^+$ and $\overline{D}^0 \rightarrow K^+\pi^-$.

The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels.

The systematic error of the efficiency arises from the $K_S^0$ reconstruction, $\eta\pi^\pm$ reconstruction, and $K_S^0$ branching fractions. The performance of the $K_S^0$ reconstruction is studied by checking the data-MC efficiency ratio using the $B^+ \rightarrow \overline{D}^0\pi^+$ control sample. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels. The systematic errors on the charged track reconstruction are estimated to be 1% per track using partially reconstructed $D^*$ events. The $\eta\pi^\pm$ and $\eta K^\pm$ reconstruction efficiencies are verified by comparing the $\eta$ decay angular distribution with the MC prediction, and by measuring the ratio of the branching fractions for the two $D$ decay channels.
TABLE II: The systematic uncertainties for the $B \rightarrow \eta h$ branching fractions, given in %. The fit systematic errors include the uncertainties due to the signal PDFs, the yields of the reflection backgrounds and the partial rate asymmetries of the charmless $B$ and reflection backgrounds.

| Sources | $\eta_\gamma \pi^\pm$ | $\eta_\pi K^\pm$ | $\eta_\gamma K^\pm$ | $\eta_\pi K^\pm$ | $\eta_\gamma K^0$ | $\eta_\pi K^0$ |
|---------|-------------------|------------------|-------------------|------------------|------------------|------------------|
| Fit     | ±4.3             | ±6.3             | ±6.3             | ±6.4             | ±6.2             | ±6.4             |
| $\mathcal{R}$ requirement | ±1.2             | ±1.2             | ±1.2             | ±1.2             | ±1.2             | ±1.2             |
| Tracking | ±1.0             | ±1.0             | ±1.0             | ±1.0             | ±1.0             | ±1.0             |
| PID     | ±1.3             | ±1.3             | ±1.3             | ±1.3             | ±1.3             | ±1.3             |
| $K^0_0$ reconstruction | –                | –                | –                | –                | –                | –                |
| $\gamma\gamma$ reconstruction | ±4.0             | ±4.0             | ±4.0             | ±4.0             | ±4.0             | ±4.0             |
| $\mathcal{B}(\eta \rightarrow \gamma\gamma)$ | ±0.7             | ±0.7             | ±0.7             | ±0.7             | ±0.7             | ±0.7             |
| $\mathcal{B}(\eta \rightarrow \pi^+\pi^-\pi^0)$ | –                | ±1.8             | –                | ±1.8             | –                | ±1.8             |
| $N_B$   | ±1.3             | ±1.3             | ±1.3             | ±1.3             | ±1.3             | ±1.3             |
| Sum     | ±5.6             | ±6.6             | ±6.4             | ±8.7             | ±9.1             | ±9.8             |

In summary, we have observed $B^\pm \rightarrow \eta \pi^\pm$ and $B^\pm \rightarrow \eta K^\pm$ decays: their branching fractions are measured to be $(4.2 \pm 0.4 \pm 0.2) \times 10^{-6}$ and $(1.9 \pm 0.3^{+0.2}_{-0.1}) \times 10^{-6}$, respectively. These results are consistent with our previously published measurements with statistical errors reduced by more than 40%. Compared with the earlier BaBar results, our measurements are more precise despite a 1.8$\sigma$ lower branching fraction on $B^\pm \rightarrow \eta K^\pm$. The $CP$-violating asymmetries are measured to be $A_{CP}(B^\pm \rightarrow \eta \pi^\pm) = -0.23 \pm 0.09 \pm 0.02$ and $A_{CP}(B^\pm \rightarrow \eta K^\pm) = -0.39 \pm 0.16 \pm 0.03$, which are 2.5$\sigma$ and 2.4$\sigma$ away from zero, respectively. It is interesting to note that the $A_{CP}$ values for these two modes obtained by the BaBar collaboration are also negative, slightly more than 1$\sigma$ away from zero for each mode. Larger data samples are needed to verify these large $CP$ asymmetries. Finally, we find a hint of an $\eta K^0$ signal with $\mathcal{B}(B^0 \rightarrow \eta K^0) = (1.1 \pm 0.4 \pm 0.1) \times 10^{-6}$. Since the measurement is not significant, we provide an upper limit at the 90% confidence level of $1.9 \times 10^{-6}$. A similar hint was also observed by the BaBar collaboration with a central value of $(1.5 \pm 0.7 \pm 0.1) \times 10^{-6}$. The combined average, $(1.2 \pm 0.4) \times 10^{-6}$, shows 3.4$\sigma$ evidence for the $CP$ eigenstate decay $B^0 \rightarrow \eta K^0$.

We thank the KEKB group for the excellent operation of the accelerator, the KEK Cryogenics group for the efficient operation of the solenoid, and the KEK computer group and the NII for valuable computing and Super-SINET network support. We acknowledge support from MEXT and JSPS (Japan); ARC and DEST (Australia); NSFC (contract No. 10175071, China); DST (India); the BK21 program of MOEHRD and the CHEP SRC program of KOSEF (Korea); KBN (contract No. 2P03B 01324, Poland); MIST (Russia); MESS (Slovenia); NSC and MOE (Taiwan); and DOE (USA).

[1] H. J. Lipkin, Phys. Lett. B 254, 247 (1991).
[2] CLEO Collaboration, S. J. Richichi et al., Phys. Rev. Lett. 85, 520 (2000); BaBar Collaboration, B. Aubert et al., Phys. Rev. Lett. 94, 191802 (2005); Belle Collaboration, J. Schuemann et al., Phys. Rev. Lett. 97, 061802 (2006).
[3] Belle Collaboration, P. Chang et al., Phys. Rev. D 71, 091106(R) (2005).
[4] BaBar Collaboration, B. Aubert et al., Phys. Rev. Lett. 95, 131803 (2005); BaBar Collaboration, B. Aubert et al., Phys. Rev. D 70, 032006 (2004).
[5] BaBar Collaboration, B. Aubert et al., Phys. Rev. Lett. 97, 201802 (2006).
[6] M. Bander, D. Silverman and A. Soni, Phys. Rev. Lett. 43, 242 (1979).
[7] M.-Z. Yang and Y.-D. Yang, Nucl. Phys. B 609, 469.
(2001).

[8] M. Beneke and M. Neubert, Nucl. Phys. B 651, 225 (2003).

[9] A. R. Williamson and J. Zupan, Phys. Rev. D 74, 014003 (2006), Erratum-ibid. D 74, 03901 (2006).

[10] S. Barshay, D. Rein and L. M. Sehgal, Phys. Lett. B 259, 475 (1991); A. S. Dighe, M. Gronau and J. L. Rosner, Phys. Rev. Lett. 79, 4333 (1997); C.-W. Chiang, M. Gronau, J. L. Rosner and D. A. Suprun, Phys. Rev. D 70, 034020 (2004); H. Wang, X. Liu, Z. Xiao, L. Guo and C.-D. Lu, Nucl. Phys. B 738, 243 (2006).

[11] S. Kurokawa and E. Kikutani, Nucl. Instr. and Meth. A 499, 1 (2003), and other papers included in this volume.

[12] Belle Collaboration, A. Abashian et al., Nucl. Instr. and Meth. A 479, 117 (2002).

[13] Z. Natkaniec et al. (Belle SVD2 Group), Nucl. Instr. and Meth. A 560, 1 (2006).

[14] R. A. Fisher, Ann. Eugenics 7, 179 (1936).

[15] E. Barberio and Z. Was, Comput. Phys. Commun. 79, 291 (1994); P. Golonka and Z. Was, hep-ph/0506026. We use PHOTOS version 2.13 allowing the emission of up to two photons, with an energy cut-off at 1% of the energy available for photon emission (i.e. approximately 26 MeV for the first emitted photon). PHOTOS also takes into account interference between charged final state particles.

[16] H. Kakuno et al., Nucl. Instr. and Meth. A 533, 516 (2004).

[17] Belle Collaboration, Y. Chao et al., Phys. Rev. Lett. 93, 191802 (2004).

[18] ARGUS Collaboration, H. Albrecht et al., Phys. Lett. B 241, 278 (1990).

[19] W.-M. Yao et al. (Particle Data Group), J. Phys. G. 33, 1 (2006).

[20] G. Nanava and Z. Was, hep-ph/0607019.