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Search for neutral B-meson decays to $a_0\pi$, a_0K, $\eta\rho^0$, and ηf_0

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We present a search for B^0 decays to charmless final states involving an η meson, a charged pion, and a second charged pion or kaon. The data sample corresponds to 383×10^6 $B\bar{B}$ pairs collected with the *BABAR* detector operating at the PEP-II asymmetric-energy B factory at SLAC. We find no significant signals and determine the following 90% C.L. upper limits: $\mathcal{B}(B^0 \to a_0^- \pi^+) \times \mathcal{B}(a_0^- \to \eta\pi^-) < 3.1 \times 10^{-6}$, $\mathcal{B}(B^0 \to a_0^- K^+) \times \mathcal{B}(a_0^- \to \eta\pi^-) < 1.9 \times 10^{-6}$, $\mathcal{B}(B^0 \to a_0(1450)^- \pi^+) \times \mathcal{B}(a_0(1450)^- \to \eta\pi^-) < 2.3 \times 10^{-6}$, $\mathcal{B}(B^0 \to a_0(1450)^- K^+) \times \mathcal{B}(a_0(1450)^- \to \eta\pi^-) < 3.1 \times 10^{-6}$, $\mathcal{B}(B^0 \to \eta\rho^0) < 1.5 \times 10^{-6}$, and $\mathcal{B}(B^0 \to \eta f_0(980)) \times \mathcal{B}(f_0(980) \to \pi^+\pi^-) < 0.4 \times 10^{-6}$.

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We investigate the decays of a B^0 meson to final states with an η meson, a charged pion, and either a second charged pion or kaon. The Dalitz plots for the decays without an intermediate charmed meson are expected to have contributions from quasi-two-body decays such as $B^0 \to a_0^- \pi^+$, $B^0 \to a_0^- K^+$, $B^0 \to \eta\rho^0$, $B^0 \to \eta f_0$, and $B^0 \to \eta K^{*0}$ [1]. The last of these has been investigated recently [2] so in this paper we concentrate on the others, where a_0 is either $a_0(980)$ or $a_0(1450)$ and f_0 is $f_0(980)$. Measurements of B decays involving a scalar meson are interesting since they provide information on such B decays and the nature of scalar mesons. Several B decays involving scalar mesons have been observed, either with an $f_0(980)$ [3,4] or $K^*(1430)$ [2,3,5] in the final state.

Specific predictions can be made for the decays $B \to a_0\pi$ if factorization is assumed and if the decay involves only tree or penguin (loop) processes. The dominant amplitude is shown in Fig. 1(a). The companion tree amplitude, shown in Fig. 1(b), is expected to be greatly suppressed, since, neglecting light-quark mass splittings, the virtual W cannot produce an a_0 meson [6]. This is a firm prediction of the standard model because the weak current has a G-parity even vector part and a G-parity odd axial-vector part. The latter can produce an axial-vector or pseudoscalar particle while the former produces a vector particle, but neither can produce a G-parity odd scalar meson (e.g. a_0). Thus the decay $B \to a_0\pi^\pm$ is expected to be "self-tagging"—the pion charge specifies the B flavor. Penguin processes such as shown in Fig. 1(c) are allowed, but are suppressed relative to the tree processes. The decays with a kaon in the final state should be dominated by the penguin processes [Fig. 1(c)], though there is a cancellation between two terms in the penguin amplitudes for these decays [7].

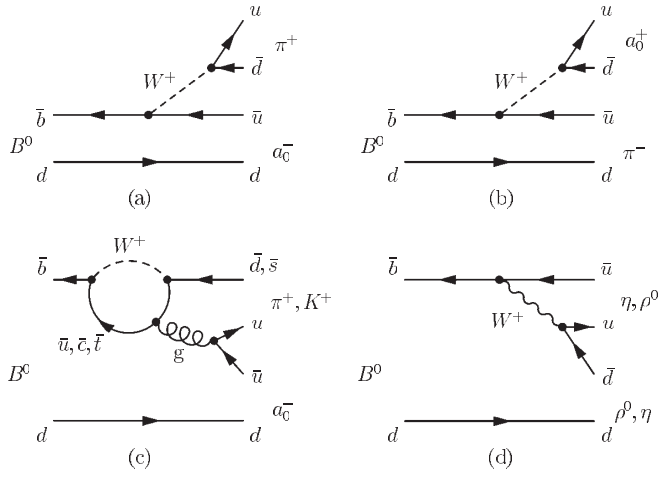

FIG. 1. Feynman diagrams for decays involving charged a_0 mesons: (a) dominant and (b) G-parity-suppressed tree diagrams for $B^0 \to a_0^\mp \pi^\pm$, (c) penguin diagram for $B^0 \to a_0^\mp \pi^\pm$ and $B^0 \to a_0^- K^+$ [a tree diagram similar to (a) also contributes to $B^0 \to a_0^- K^+$], (d) tree diagrams for $B^0 \to \eta\rho^0$ ($B^0 \to \eta f_0$ is similar with the ρ^0 being replaced by a f_0).

The theoretical expectations for these decays with an $a_0(980)$ meson [7–10] are larger than previous experimental limits [11]. The decays with a ρ^0 meson are expected to have branching fractions $\lesssim 1 \times 10^{-7}$ [12] since they are dominated by color-suppressed tree amplitudes [Fig. 1(d)]. There are no predictions for the decay $B^0 \to \eta f_0$, but it should have a small branching fraction for the same reason.

The nature of the a_0 meson is not well understood. It is thought to be a $q\bar{q}$ state with a possible admixture of a $K\bar{K}$ bound-state component due to the proximity to the $K\bar{K}$ threshold [13,14]. The a_0 mass is known to be about 985 MeV with a width of 71 ± 7MeV [15] for the dominant $a_0 \to \eta\pi$ decay mode [13]. The $a_0(1450)$ has a measured width of 265 MeV [13]. Since the branching fraction for $a_0 \to \eta\pi$ is not well known, we report the product branching fraction $\mathcal{B}(B^0 \to a_0^- X^+) \times \mathcal{B}(a_0 \to \eta\pi)$, where X indicates K or π. The properties of the $f_0(980)$ meson are well measured for the $\pi^+\pi^-$ channel that is used in this analysis [16].

Only limits for the following decays have been reported previously: $B^0 \to a_0(980)^- \pi^+$ and $B^0 \to a_0(980)^- K^+$ [11] and $B^0 \to \eta\rho^0$ [17–19]. There have been no previous searches for $B^0 \to \eta f_0$ or the decays with an $a_0(1450)$. The results presented here are based on data collected with the *BABAR* detector [20] at the PEP-II asymmetric-energy e^+e^- collider located at the Stanford Linear Accelerator Center. An integrated luminosity of approximately 347 fb^{-1}, corresponding to 383×10^6 $B\bar{B}$ pairs, was recorded at the $\Upsilon(4S)$ resonance (center-of-mass energy $\sqrt{s} = 10.58$ GeV).

The track parameters of charged particles are measured by a combination of a silicon vertex tracker, with five layers of double-sided silicon sensors, and a 40-layer central drift chamber, both operating in the 1.5 T magnetic field of a superconducting solenoid. We identify photons

and electrons using a CsI(Tl) electromagnetic calorimeter (EMC). Further charged particle identification (PID) is provided by measurements of 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 select a_0 candidates from the decay channel $a_0 \to \eta\pi$ with the decays $\eta \to \gamma\gamma$ ($\eta_{\gamma\gamma}$) and $\eta \to \pi^+\pi^-\pi^0$ ($\eta_{3\pi}$). All charged tracks are required to originate from a common vertex. For the decays $B^0 \to \eta\rho^0$ and $B^0 \to \eta f_0$, we use the same η decay modes and $\rho^0 \to \pi^+\pi^-$ or $f_0 \to \pi^+\pi^-$. We apply the following requirements on the invariant masses (in MeV) relevant here: $500 < m_{\gamma\gamma} < 585$ for $\eta_{\gamma\gamma}$, $535 < m_{\pi\pi\pi} < 560$ for $\eta_{3\pi}$, $120 < m_{\gamma\gamma} < 150$ for π^0, and $510 < m_{\pi\pi} < 1060$ for ρ^0/f_0. For the $a_0(980)$ analysis we use a mass range $775 < m_{\eta\pi} < 1175$, while for $a_0(1450)$ we require $775 < m_{\eta\pi} < 1750$; the latter upper limit removes background from D decays. These requirements, except for π^0 and η, are chosen to remove $\lesssim 10\%$ of real signal and retain sufficient sidebands to characterize the background for subsequent fitting.

The average number of candidates found per selected event is in the range 1.04 to 1.17, depending on the final state. We choose the candidate with η mass closest to the nominal PDG value [13].

We make several PID requirements to ensure the identity of the pions and kaons. Secondary tracks from η, ρ^0, or f_0 decays must have measured DIRC, dE/dx, and EMC outputs consistent with pions. For the $B^0 \to a_0^-\pi^+$ ($B^0 \to a_0^- K^+$) decays, we require an associated DIRC Cherenkov angle between -2 and $+5$ (-5 and $+2$) standard deviations (σ) from the expected value for a pion (kaon); the requirement is more restrictive on the side where there is kaon (pion) background. The distributions are corrected as a function of momenta and angles so that the distributions are normalized Gaussians. These requirements keep >90% of the wanted particle species with a misidentification background of <10%.

A B-meson candidate is characterized kinematically by the energy-substituted mass $m_{ES} = (\frac{1}{4}s - \mathbf{p}_B^2)^{1/2}$ 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 calculated in the $\Upsilon(4S)$ frame. Signal events peak at zero for ΔE, and at the B nominal mass for m_{ES}. The ΔE (m_{ES}) resolution is about 30 MeV (3.0 MeV). We require $|\Delta E| \leq 0.2$ GeV and $5.25 \leq m_{ES} \leq 5.29$ GeV.

Backgrounds arise primarily from random combinations in continuum $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) events. We reduce these by using the angle θ_T between the thrust axis of the B^0 candidate in the $\Upsilon(4S)$ frame and that of the rest of the charged tracks and neutral clusters in the event. The distribution of $|\cos\theta_T|$ is sharply peaked near 1.0 for combinations drawn from jetlike $q\bar{q}$ pairs, and nearly uniform for B-meson decays. We require $|\cos\theta_T| <$ 0.7(0.8) for the $\eta_{\gamma\gamma}$ ($\eta_{3\pi}$) channels. We also use, in the fit described below, a Fisher discriminant $\mathcal{F}$ that combines the angles of the candidate direction with respect to the beam axis of the B momentum and B thrust axis [in the $\Upsilon(4S)$ frame], and moments describing the energy flow about the B thrust axis [21].

We use additional event-selection criteria to further reduce backgrounds from B decays. For the $\eta \to \gamma\gamma$ modes we remove backgrounds with one high-energy photon and a spurious low-energy photon such as $B \to K^*\gamma$ by requiring $|\cos\theta^{\eta}_{dec}| \leq 0.86$, where θ^{η}_{dec} is the angle of the photons in the η rest frame with respect to the direction of the particle recoiling against the η. Many backgrounds with low-energy π, K, or a_0 mesons are reduced with the requirement $|\cos\theta^{a_0}_{dec}| \leq 0.8$, where $\theta^{a_0}_{dec}$ is defined similarly to θ^{η}_{dec}. For $B^0 \to \eta\rho^0$ decays, we define $\mathcal{H}$ to be the magnitude of the cosine of the angle between the pion from the ρ and the B^0 momentum in the ρ rest frame, and require $\mathcal{H} < 0.75$ to remove background from $B^0 \to D^+(\eta\pi^+)\pi^-$ that populates a narrow region near $\mathcal{H} = 0.8$. These additional requirements reduce the backgrounds by a factor of 2–4, depending on the decay mode. We use Monte Carlo (MC) simulation [22] for an estimate of the residual $B\bar{B}$ background and to identify the few (mostly charmless) decays that survive the candidate selection and have characteristics similar to the signal (20—270 events, depending on mode). We include a component in the fit to account for them.

We obtain yields and branching fractions from extended unbinned maximum-likelihood fits, with input observables ΔE, m_{ES}, m_{res} for the $a_0(1450)$ fits, these observables plus $\mathcal{F}$ for the $a_0(980)$ fits, and these plus $\mathcal{H}$ for the $\eta\rho^0/\eta f_0$ fits. The observable m_{res} denotes the $\eta\pi$ mass for the a_0 analyses and the η and $\pi^+\pi^-$ masses for the $\eta\rho^0/\eta f_0$ fits. Early MC studies showed that a fit to the restricted low-mass range yields ~20% better sensitivity for $a_0(980)$, due to simplified PDF description and lower $B\bar{B}$ backgrounds. Thus we employ separate fits to determine the $a_0(980)$ and $a_0(1450)$ yields. The $a_0(1450)$ fit has a component for $a_0(980)$ with the yield fixed to the value found in the $a_0(980)$ fit, corrected for the small efficiency difference. No $a_0(1450)$ component is used for the $a_0(980)$ fit since none of the subsamples have evidence of $a_0(1450)$ signals.

For each event i and hypothesis j (signal, continuum background, $B\bar{B}$ background), we define a product of probability density functions (PDF)

$$\mathcal{P}^i_j = \mathcal{P}_j(m_{ES}{}^i)\mathcal{P}_j(\Delta E^i)\mathcal{P}_j(m^i_{res})[\mathcal{P}_j(\mathcal{F}^i)][\mathcal{P}_j(\mathcal{H}^i)]. \quad (1)$$

The bracketed variables $\mathcal{F}$ and $\mathcal{H}$ are not used in all fits. For all decays except for those involving $a_0(1450)$, the absence of significant correlations among observables in the background is confirmed with the background-dominated data samples entering the fits. For the $a_0(1450)$ decays, we find a substantial correlation in data

between $\mathcal{F}$ and the $\eta\pi$ invariant mass, due to the large $\eta\pi$ mass range. We therefore require $\mathcal{F} < 0$ for these modes, which keeps 90% of the signal, and exclude $\mathcal{F}$ from the fit. For the signal component, we correct for effects due to the neglect of small correlations (more details are provided in the systematics discussion below). The $B\bar{B}$ background yield is free in the $\eta\rho^0/\eta f_0$ fits and is found to be in agreement with expectations from MC simulations. For the decays involving a_0 mesons, we fix the $B\bar{B}$ yield to the value predicted by MC and include the uncertainty in the systematic errors (see below).

The likelihood function is

$$\mathcal{L} = \exp\left(-\sum_j Y_j\right)\prod_{i=1}^{N}\left[\sum_j Y_j \mathcal{P}_j^i\right], \qquad (2)$$

where Y_j is the yield of events of hypothesis j that we find by maximizing $\mathcal{L}$, and N is the number of events in the sample.

We determine the PDF parameters from simulation for the signal and $B\bar{B}$ background components. We parameterize each of the functions $\mathcal{P}_{\rm sig}(\mathrm{m_{ES}})$, $\mathcal{P}_{\rm sig}(\Delta E)$, $\mathcal{P}_j(\mathcal{F})$, and $\mathcal{P}_{\rm sig}(\mathrm{m_{res}})$ with either the sum of two Gaussian functions, a Breit-Wigner shape, or an asymmetric Gaussian function, as required to describe the distribution. $\mathcal{P}_{\rm sig}(\mathcal{H})$ for $B^0 \to \eta\rho^0$ is described by a second order polynomial. The shape of the real-meson component of $\mathcal{P}_j(m_{\rm res})$ in the combinatorial background is described with the same parameters as for signal. The distributions of $m_{\rm res}$, ΔE, and $\mathcal{H}$ for $B\bar{B}$ and combinatorial background are represented by second order Chebyshev polynomials and/or the sum of two Gaussian functions. The $q\bar{q}$ combinatorial background in $m_{\rm ES}$ is described by the function [23] $f(x) = x\sqrt{1-x^2}\exp[-\xi(1-x^2)]$, with $x \equiv 2\mathrm{m_{ES}}/\sqrt{s}$ and free parameter ξ; for peaking $B\bar{B}$ background, generally with the same or similar final state as signal, we add a Gaussian function to the quantity $f(x)$.

Large control samples of $B \to D\pi$ with a topology similar to the signal are used to verify the simulated resolutions in ΔE and $m_{\rm ES}$. Where the control data samples reveal small differences from MC, we shift or scale the resolution used in the likelihood fits. Examples of many of these PDF shapes from a similar analysis are shown in Ref. [21]. Additionally, the signal parameters for the $a_0(980)$ mass (983.5 MeV) and width (80 MeV) are determined from an inclusive data set that is much larger than the sample used for this analysis; they are consistent with expectations from the natural-width values of Ref. [15]. The values for $a_0(1450)$ are taken from Ref. [13].

In Table I we show for each decay mode the measured product branching fraction, together with the quantities entering into its determination. In order to account for the uncertainties in the background PDF parameterization, we include as free parameters in the fit, in addition to the signal and background yields, the principal parameters describing the background PDFs. These include slopes for the polynomial shape for the ΔE and $m_{\rm res}$ distributions, the parameter ξ used for $m_{\rm ES}$, and three parameters describing the asymmetric Gaussian function for $\mathcal{F}$. For calculation of branching fractions, we assume that the decay rates of the $\Upsilon(4S)$ to B^+B^- and $B^0\bar{B}^0$ are equal [24]. We combine branching fraction results from the two

TABLE I. Signal yield with statistical error, yield bias correction, detection efficiency ϵ, relevant daughter branching fraction product $\prod \mathcal{B}_i$, significance (including additive systematic uncertainties), measured branching fraction $\mathcal{B}$, and the 90% C.L. upper limit on this branching fraction. For the a_0 and f_0 modes, $\mathcal{B}$ includes the daughter branching fractions for $a_0 \to \eta\pi$ or $f_0 \to \pi^+\pi^-$.

Mode	Fit yield (events)	Bias (events)	ϵ (%)	$\prod \mathcal{B}_i$ (%)	Signif. (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{B}$ U.L. (10^{-6})
$a_0(980)^-\pi^+$					**2.4**	**$2.1 \pm 0.8 \pm 0.3$**	**<3.1**
$a_0(980)^-_{\gamma\gamma}\pi^+$	87 ± 23	16	15.3	39.4	3.3	$3.1^{+1.1}_{-1.0}$	
$a_0(980)^-_{3\pi}\pi^+$	4^{+12}_{-10}	1	11.8	22.6	0.1	$0.1^{+1.3}_{-1.1}$	
$a_0(980)^-K^+$					**2.0**	**$1.0 \pm 0.6 \pm 0.2$**	**<1.9**
$a_0(980)^-_{\gamma\gamma}K^+$	28^{+15}_{-13}	14	14.0	39.4	2.0	$1.1^{+0.7}_{-0.6}$	
$a_0(980)^-_{3\pi}K^+$	9^{+12}_{-9}	11	11.0	22.6	0.7	$0.7^{+1.2}_{-1.0}$	
$a_0(1450)^-\pi^+$					—	**$-3.5 \pm 2.2 \pm 0.8$**	**<2.3**
$a_0(1450)^-_{\gamma\gamma}\pi^+$	-47 ± 56	26	13.8	39.4	—	$-3.5^{+2.7}_{-2.6}$	
$a_0(1450)^-_{3\pi}\pi^+$	-24 ± 32	5	9.8	22.6	—	$-3.5^{+3.8}_{-3.6}$	
$a_0(1450)^-K^+$					**0.6**	**$0.8 \pm 1.5 \pm 0.3$**	**<3.1**
$a_0(1450)^-_{\gamma\gamma}K^+$	22 ± 36	12	13.3	39.4	0.3	$0.5^{+1.8}_{-1.7}$	
$a_0(1450)^-_{3\pi}K^+$	13 ± 24	0	9.7	22.6	0.6	$1.6^{+2.9}_{-2.7}$	
$\eta\rho^0$					**0.6**	**$0.4 \pm 0.7 \pm 0.2$**	**<1.5**
$\eta_{\gamma\gamma}\rho^0$	15^{+13}_{-11}	7	10.7	39.4	0.7	$0.5^{+0.8}_{-0.7}$	
$\eta_{3\pi}\rho^0$	4^{+12}_{-10}	5	8.4	22.6	—	$-1.4^{+1.6}_{-1.4}$	
ηf_0					—	**$-0.3 \pm 0.3 \pm 0.1$**	**<0.4**
$\eta_{\gamma\gamma}f_0$	-11^{+10}_{-8}	1	18.8	39.4	—	-0.4 ± 0.3	
$\eta_{3\pi}f_0$	-4 ± 11	-4	14.9	22.6	0.1	0.0 ± 0.5	

η decay channels by adding the values of $-2\ln\mathcal{L}$, adjusted for a fit bias (see below), and taking proper account of the correlated and uncorrelated systematic errors. We quote 90% confidence level (C.L.) upper limits, taken to be the branching fraction below which lies 90% of the total of the likelihood integral in the positive branching fraction region.

In Fig. 2 we show projections onto $m_{\rm ES}$ and $\eta\pi$ mass of subsamples enriched by a mode-dependent threshold requirement on the ratio of signal to total likelihood (computed without the variable plotted). We show analogous projections of $m_{\rm ES}$ and the $\pi^+\pi^-$ invariant mass in Fig. 3.

The significance is 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 the minimum, with other parameters free in both cases.

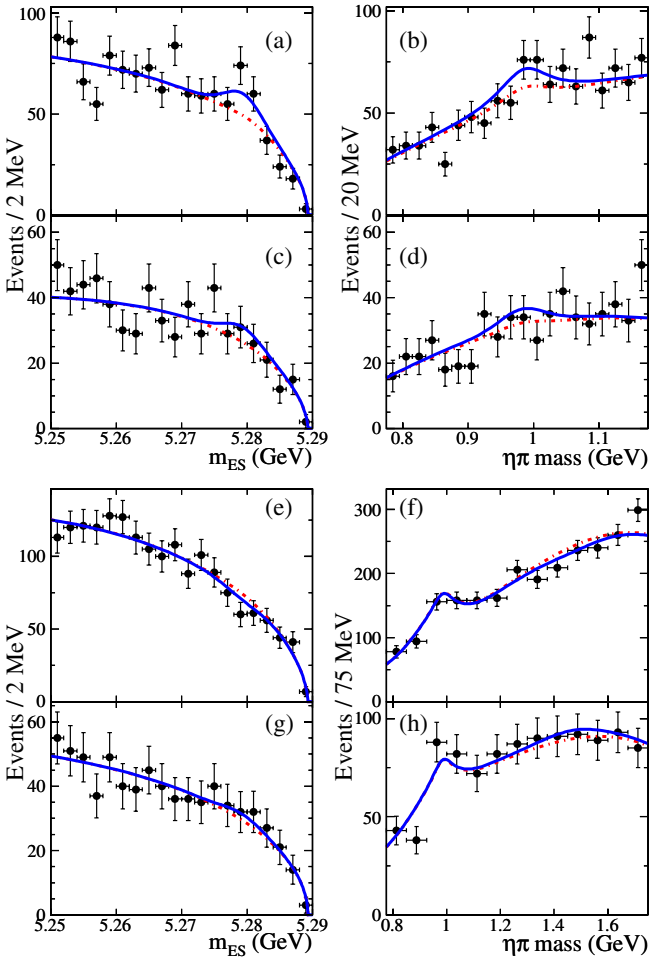

FIG. 2 (color online). Signal-enhanced projections of the B^0-candidate $m_{\rm ES}$ and $\eta\pi$ mass for (a, b) $a_0^-\pi^+$, (c, d) $a_0^-K^+$, (e, f) $a_0(1450)^-\pi^+$, and (g, h) $a_0(1450)^-K^+$. Points with errors represent data, solid curves the full fit functions (both signal modes combined), and dotted-dashed curves the background functions (the peaking $B\bar{B}$ background component is small). For the $a_0(1450)$ plots, the $a_0(980)$ signal is included in the background curves. These plots are made with a minimum requirement on the likelihood that has an efficiency for signal of 60%–70%.

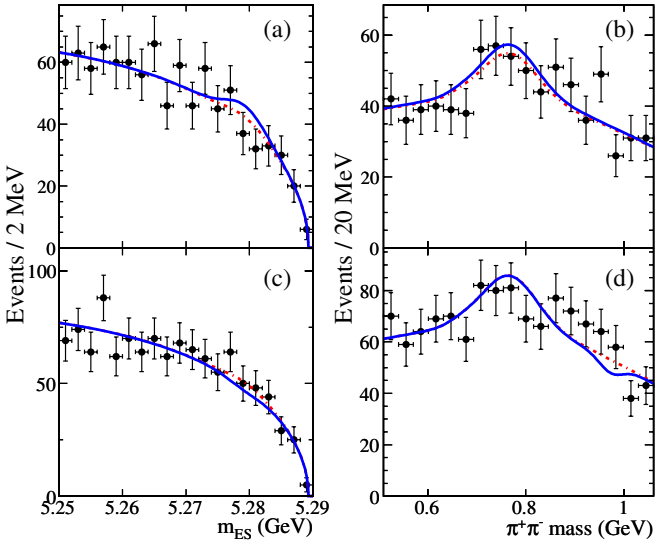

FIG. 3 (color online). Signal-enhanced projections of the B^0-candidate $m_{\rm ES}$ and $\pi^+\pi^-$ mass for (a, b) $\eta\rho^0$ and (c, d) ηf_0. Points with errors represent data, solid curves the full fit functions (both signal modes combined), and dotted-dashed curves the background functions (the peaking $B\bar{B}$ background component is small). These plots are made with a minimum requirement on the likelihood that has an efficiency for signal of 70%–90%.

Most of the yield uncertainties arising from lack of knowledge of the PDFs have been included in the statistical error since most background parameters are free in the fit. Varying the signal PDF parameters within their estimated uncertainties, we determine the uncertainties in the signal yields to be 0–9 events, depending on the final state. This uncertainty is substantial only for the modes with one of the a_0 resonances, where it is dominated by uncertainties in the parameterization of the a_0 signal shape. The neglect of correlations among observables in the fit can cause a systematic bias; the correction for this bias (between -4 and $+26$ events) and assignment of the resulting systematic uncertainty (0.1–13 events) is determined from simulated samples with varying background populations. For the a_0 modes where the $B\bar{B}$ background yield is fixed, we estimate the uncertainty from modeling the $B\bar{B}$ backgrounds by varying the expected $B\bar{B}$ yield by 100% (0.1–12 events).

The above uncertainties are additive in nature and affect the significance of the results. The largest multiplicative uncertainties include our knowledge of the efficiency and other quantities entering the branching fraction calculation. Selection efficiency uncertainties are 1%–2% for $\cos\theta_{\rm T}$ and 0.5%–0.8% due to the limited size of the MC samples. Uncertainties in the reconstruction efficiency found from auxiliary studies on inclusive control samples

[21], include $0.5\% \cdot N_t$ and $1.5\% \cdot N_\gamma$, where N_t and N_γ are the number of signal tracks and photons, respectively. The uncertainty on the total number of $B\bar{B}$ events is 1.1%. Published data [13] provide the uncertainties in the B-daughter product branching fractions (1%–2%).

In conclusion, we do not find significant signals for the B-meson decays presented here. The measured branching fractions and 90% C.L. upper limits are given in Table I. The limits for the $a_0(980)$ channels are smaller than expectations [7–10]. This has been cited as evidence that the $a_0(980)$ meson is a four-quark state, not the lowest-lying member of the $q\bar{q}$ scalar multiplet [9]. The limits for the $a_0(1450)$ channels and $B^0 \to \eta\rho^0$ are consistent with theoretical expectations [9,12]. There are no previous measurements or theoretical predictions for the $B^0 \to \eta f_0$ decay.

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[1] The named member of a charge-conjugate pair of particles stands for either.
[2] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **97**, 201802 (2006).
[3] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **72**, 072003 (2005); Phys. Rev. D **74**, 099903(E) (2006); A. Garmash *et al.* (Belle Collaboration), Phys. Rev. Lett. **96**, 251803 (2006); Phys. Rev. D **75**, 012006 (2007).
[4] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **73**, 031101 (2006); Phys. Rev. Lett. **97**, 201801 (2006).
[5] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **98**, 051801 (2007).
[6] S. Laplace and V. Shelkov, Eur. Phys. J. C **22**, 431 (2001).
[7] V. Chernyak, Phys. Lett. B **509**, 273 (2001).
[8] P. Minkowski and W. Ochs, Eur. Phys. J. C **39**, 71 (2005).
[9] H.-Y. Cheng, C.-Y. Chua, and K.-C. Yang, Phys. Rev. D **73**, 014017 (2006).
[10] Y.-L. Shen *et al.*, Eur. Phys. J. C **50**, 877 (2007).
[11] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **70**, 111102 (2004).
[12] A. Ali, G. Kramer, and C. D. Lü, Phys. Rev. D **58**, 094009 (1998); Y. H. Chen *et al.*, Phys. Rev. D **60**, 094014 (1999); H.-Y. Cheng and K. C. Yang, Phys. Rev. D **62**, 054029 (2000); M.-Z. Yang and Y.-D. Yang, Nucl. Phys. **B609**, 469 (2001); D. Du *et al.*, Phys. Rev. D **65**, 094025 (2002); M. Beneke and M. Neubert, Nucl. Phys. **B675**, 333 (2003); C.-W. Chiang *et al.*, Phys. Rev. D **69**, 034001 (2004); X. Liu *et al.*, Phys. Rev. D **73**, 074002 (2006).
[13] Y.-M. Yao *et al.* (Particle Data Group) J. Phys. G **33**, 1 (2006).
[14] V. Baru *et al.*, Phys. Lett. B **586**, 53 (2004).
[15] S. Teige *et al.*, Phys. Rev. D **59**, 012001 (1998).
[16] E. M. Aitala *et al.*, Phys. Rev. Lett. **86**, 765 (2001).
[17] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **70**, 032006 (2004).
[18] C. H. Wang *et al.* (Belle Collaboration), arXiv:hep-ex/0701057 [Phys. Rev. D (to be published)].
[19] S. J. Richichi *et al.* (CLEO Collaboration), Phys. Rev. Lett. **85**, 520 (2000).
[20] B. Aubert *et al.* (*BABAR* Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).
[21] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **70**, 032006 (2004).
[22] The *BABAR* detector Monte Carlo simulation is based on GEANT4: S. Agostinelli *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[23] H. Albrecht *et al.* (ARGUS Collaboration), Phys. Lett. B **241**, 278 (1990).
[24] See for instance B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **69**, 071101 (2004), and references therein.