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Searches for Charmless Decays $B^0 \to \eta\omega$, $B^0 \to \eta K^0$, $B^+ \to \eta\rho^+$, and $B^+ \to \eta'\pi^+$

The *BABAR* Collaboration

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Abstract

We present measurements of branching fractions for four previously unobserved B-meson decays with an η or η' meson in the final state. The data sample corresponds to 182 million $B\overline{B}$ pairs produced from e^+e^- annihilation at the $\Upsilon(4S)$ resonance. We measure the following branching fractions in units of 10^{-6}: $\mathcal{B}(B^0 \to \eta\omega) = 1.2 \pm 0.6 \pm 0.2$ (< 2.3 at 90% C.L.), $\mathcal{B}(B^0 \to \eta K^0) = 2.5 \pm 0.8 \pm 0.1$, $\mathcal{B}(B^+ \to \eta\rho^+) = 8.6 \pm 2.2 \pm 1.1$, and $\mathcal{B}(B^+ \to \eta'\pi^+) = 4.2 \pm 1.0 \pm 0.5$, where the first error quoted is statistical and the second systematic. The charge asymmetries are $\mathcal{A}_{ch}(B^+ \to \eta\rho^+) = (7 \pm 19 \pm 2)\%$ and $\mathcal{A}_{ch}(B^+ \to \eta'\pi^+) = (24 \pm 19 \pm 1)\%$. All results are preliminary.

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1 INTRODUCTION

We report results for measurements of the decay branching fractions of B^0 to the charmless final states[6] $\eta\omega$ and ηK^0, and of B^+ to $\eta\rho^+$ and $\eta'\pi^+$. None of these decays have been observed definitively [1, 2, 3]. Measurements of the related decays $B^+ \to \eta K^+$, $B^+ \to \eta\pi^+$, and $B \to \eta' K$ were published recently [2, 4]. Charmless decays with kaons are usually expected to be dominated by $b \to s$ loop ("penguin") transitions, while $b \to u$ tree transitions are typically larger for the decays with pions and ρ mesons. However the $B \to \eta K$ decays are especially interesting since they are suppressed relative to the abundant $B \to \eta' K$ decays due to destructive interference between two penguin amplitudes [5]. The CKM-suppressed $b \to u$ amplitudes may interfere significantly with penguin amplitudes, possibly leading to large direct *CP* violation in $B^+ \to \eta\rho^+$ and $B^+ \to \eta'\pi^+$[6]; numerical estimates are available in a few cases [7, 8]. We search for such direct *CP* violation by measuring the charge asymmetry $\mathcal{A}_{ch} \equiv (\Gamma^- - \Gamma^+)/(\Gamma^- + \Gamma^+)$ in the rates $\Gamma^\pm = \Gamma(B^\pm \to f^\pm)$, for each observed charged final state $f^\pm$.

Charmless B decays are becoming useful to test the accuracy of theoretical predictions [8, 9, 10, 11, 12, 13, 14, 15, 16]. Phenomenological fits to the branching fractions and charge asymmetries can be used to understand the importance of tree and penguin contributions and may provide sensitivity to the CKM angle γ [16].

2 THE *BABAR* DETECTOR AND DATASET

The results presented here are based on data collected with the *BABAR* detector [17] at the PEP-II asymmetric e^+e^- collider [18] located at the Stanford Linear Accelerator Center. The samples come from an integrated luminosity of 166 fb^{-1} recorded at the $\Upsilon(4S)$ resonance (center-of-mass energy $\sqrt{s} = 10.58$ GeV). This corresponds to 182 ± 2 million $B\overline{B}$ pairs.

Charged particles from the e^+e^- interactions are detected and their momenta measured by a combination of a vertex tracker (SVT) consisting of five layers of double-sided silicon microstrip detectors 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 the average energy loss (dE/dx) in the tracking devices and by an internally reflecting ring imaging Cherenkov detector (DIRC) covering the central region.

3 SAMPLE SELECTION

We reconstruct η, η', ω, ρ^+, ρ^0, π^0, and K^0_S candidates through their decays $\eta \to \gamma\gamma$ ($\eta_{\gamma\gamma}$), $\eta \to \pi^+\pi^-\pi^0$ ($\eta_{3\pi}$), $\eta' \to \eta\pi^+\pi^-$ ($\eta'_{\eta\pi\pi}$), $\eta' \to \rho^0\gamma$ ($\eta'_{\rho\gamma}$), $\omega \to \pi^+\pi^-\pi^0$, $\rho^+ \to \pi^+\pi^0$, $\rho^0 \to \pi^+\pi^-$, $\pi^0 \to \gamma\gamma$, and $K^0_S \to \pi^+\pi^-$. We make the requirements given in Table 1 on the invariant mass of these particles' final states. For the η, ω, and η' invariant masses these requirements are set loose enough to include sidebands, as these mass values are treated as observables in the maximum-likelihood (ML) fit described below. For K^0_S candidates we further require the three-dimensional flight distance from the beam spot to be greater than three times its uncertainty in a fit that requires consistency between the flight and momentum directions. For modes with $B \to \eta \to \gamma\gamma$

[6] Except as noted explicitly, we use a particle name to denote either member of a charge conjugate pair.

Table 1: Selection requirements on the invariant mass of B daughter resonances (in MeV).

State	Requirement
$\eta_{\gamma\gamma}$	$490 < m(\gamma\gamma) < 600$
$\eta_{3\pi}$	$520 < m(\pi\pi\pi) < 570$
$\eta'_{\eta\pi\pi}$	$910 < m(\eta\pi\pi) < 1000$
$\eta'_{\rho\gamma}$	$910 < m(\rho\gamma) < 1000$
ω	$735 < m(\pi\pi\pi) < 825$
ρ^+	$470 < m(\pi\pi) < 1070$
ρ^0	$510 < m(\pi\pi) < 1060$
π^0	$120 < m(\gamma\gamma) < 150$
K^0_S	$486 < m(\pi\pi) < 510$

we impose a mode-dependent requirement on the decay angle to reject backgrounds reconstructed as very asymmetric decays.

We make several PID requirements to ensure the identity of the charged pions and kaons. Secondary pions in $\eta_{3\pi}$, η', and ω candidates are rejected if their DIRC, dE/dx, and EMC outputs satisfy tight consistency with kaons, protons, or electrons. For the B^+ decays to an η' meson and a charged pion or kaon, the latter (primary) track must have an associated DIRC signal with a Cherenkov angle within 3.5 standard deviations (σ) of the expected value for either the π or K hypothesis. The discrimination between pion and kaon primary tracks is treated in the ML fit.

The number of candidates found per event is at or below about 1.10 for all modes except for those with the final states $\eta_{3\pi}\rho$ and $\eta_{3\pi}\omega$ where it is about 1.3. We choose the candidate whose daughter resonance mass(es) lie nearest the expected mean value.

A B-meson candidate is characterized kinematically by the energy-substituted mass $m_{\rm ES} = [(\frac{1}{2}s + \mathbf{p}_0 \cdot \mathbf{p}_B)^2/E_0^2 - \mathbf{p}_B^2]^{\frac{1}{2}}$ and energy difference $\Delta E = E_B^* - \frac{1}{2}\sqrt{s}$, where the subscripts 0 and B refer to the initial $\Upsilon(4S)$ and to the B candidate, respectively, and the asterisk denotes the $\Upsilon(4S)$ frame. The resolution on ΔE ($m_{\rm ES}$) is about 30 MeV (3.0 MeV). We require $|\Delta E| \leq 0.2$ GeV and $5.25 \leq m_{\rm ES} \leq 5.29$ GeV, and include both of these observables in the ML fit.

4 BACKGROUNDS

Backgrounds arise primarily from random combinations in continuum $e^+e^- \to q\overline{q}$ events ($q = u, d, s, c$). We reject these by using the angle $\theta_{\rm T}$ in the $\Upsilon(4S)$ frame between the thrust axis of the B candidate and that of the rest of the charged tracks and neutral calorimeter clusters in the event. The distribution of $|\cos\theta_{\rm T}|$ is sharply peaked near 1.0 for combinations drawn from jet-like $q\overline{q}$ pairs, and nearly uniform for B-meson pairs. We require $|\cos\theta_{\rm T}| < 0.9$ for all modes except the high-background $B^+ \to \eta'_{\rho\gamma}\pi^+$ decay. For this mode we determined that the sensitivity is maximal with $|\cos\theta_{\rm T}| < 0.65$, based on the expected signal yield and its background-dominated statistical error. In the ML fit we also use a Fisher discriminant $\mathcal{F}$ [19] that combines four variables defined in the $\Upsilon(4S)$ frame: the angles with respect to the beam axis of the B momentum and B thrust axis, and the zeroth and second angular moments $L_{0,2}$ of the energy flow about the B thrust axis. The moments are defined by $L_j = \sum_i p_i \times |\cos\theta_i|^j$, where θ_i is the angle with respect to the B thrust axis of track or neutral cluster i, p_i is its momentum, and the sum excludes the B candidate daughters.

For the $\eta \to \gamma\gamma$ modes we use additional event-selection criteria to reduce $B\overline{B}$ backgrounds from several charmless final states. We reduce background from $B \to \pi^+\pi^0$, $K^+\pi^0$, and $K^0\pi^0$ by rejecting $\eta_{\gamma\gamma}$ candidates that share a photon with any π^0 candidate having momentum between 1.9 and 3.1 GeV/c in the $\Upsilon(4S)$ frame. Additionally, for $B^0 \to \eta K^0$ we require $E^*_\gamma < 2.4$ GeV to suppress background from $B \to K^*\gamma$ and related radiative-penguin decays.

We use Monte Carlo (MC) simulation [20] for an initial estimate of the residual charmless $B\overline{B}$ background. Most of the contribution from $b \to c$ decays has a dependence on the ML fit observables that is similar to that for continuum events, and thus can be modeled as part of the continuum component. With a survey from MC we identify the few (mostly charmless) decays that may survive the candidate selection. We find these contributions to be negligible for several of our modes. Where they are not we include a component in the ML fit to account for them.

5 MAXIMUM LIKELIHOOD FIT

We obtain yields and $\mathcal{A}_{ch}$ from extended unbinned maximum-likelihood fits with input observables ΔE, $m_{\rm ES}$, $\mathcal{F}$, and $m_{\rm res}$ (the mass of the η, η', ρ^+, or ω candidate). For the ω decays we also use $\mathcal{H} \equiv |\cos\theta_H|$, and for charged modes the PID variable $S_{\pi,K}$. The helicity angle θ_H is defined as the angle, measured in the ω rest frame, between the normal to the ω decay plane and the flight direction of the ω with respect to its parent B. We incorporate PID information by using S_π (S_K), the number of standard deviations between the measured Cherenkov angle and that expected for pions (kaons).

For each event i, hypothesis j (signal, continuum background, $B\overline{B}$ background), and flavor (primary π^+ or K^+) k, we define the probability density function (PDF)

$$\begin{aligned} \mathcal{P}^i_{jk} &= \mathcal{P}_j({m_{\rm ES}}^i)\mathcal{P}_j(\Delta E^i_k)\mathcal{P}_j(\mathcal{F}^i)\mathcal{P}_j(m^i_{\rm res}) \\ &\quad \times \left[\mathcal{P}_j(S^i_k)\right]\left[\mathcal{P}_j(\mathcal{H}^i)\right]. \end{aligned} \tag{1}$$

The terms in brackets for S and $\mathcal{H}$ pertain to modes with a primary charged track or ω daughters, respectively. The absence of correlations among observables in the background $\mathcal{P}^i_{jk}$ is confirmed in the (background-dominated) data samples entering the fit. For the signal component, we correct for the effect of the neglect of small correlations (see below). The likelihood function is

$$\mathcal{L} = \exp\left(-\sum_{j,k} Y_{jk}\right) \prod_i^N \left[\sum_{j,k} Y_{jk}\mathcal{P}^i_{jk}\right], \tag{2}$$

where Y_{jk} is the yield of events of hypothesis j and flavor k found by maximizing $\mathcal{L}$, and N is the number of events in the sample.

For the signal and $B\overline{B}$ background components we determine the PDF parameters from simulation. For the continuum background we use $(m_{\rm ES}, \Delta E)$ sideband data to obtain initial values, before applying the fit to data in the signal region, and ultimately by leaving them free in the final fit. We parameterize each of the functions $\mathcal{P}_{\rm sig}(m_{\rm ES})$, $\mathcal{P}_{\rm sig}(\Delta E_k)$, $\mathcal{P}_j(\mathcal{F})$, $\mathcal{P}_j(S_k)$ and the peaking components of $\mathcal{P}_j(m_{\rm res})$ with either a Gaussian, the sum of two Gaussians or an asymmetric Gaussian function as required to describe the distribution. Slowly varying distributions (mass, energy or helicity-angle for combinatorial background) are represented by linear or quadratic dependencies. The peaking and combinatorial components of the ω mass spectrum each have their own $\mathcal{H}$ shapes.

The combinatorial background in $m_{\rm ES}$ is described by the function $x\sqrt{1-x^2}\exp\left[-\xi(1-x^2)\right]$, with $x \equiv 2m_{\rm ES}/\sqrt{s}$ and parameter ξ. Large control samples of B decays to charmed final states of similar topology are used to verify the simulated resolutions in ΔE and $m_{\rm ES}$. Where the control data samples reveal differences from MC in mass or energy offset or resolution, we shift or scale the resolution function used in the likelihood fits.

Before applying the fitting procedure to the data to extract the signal yields we subject it to several tests. Internal consistency is checked with fits to ensembles of "experiments" generated by Monte Carlo from the PDFs. From these we establish the number of parameters associated with the PDF shapes that can be left free in addition to the yields. Ensemble distributions of the fitted parameters verify that the generated values are reproduced with the expected resolution. The ensemble distribution of $\ln\mathcal{L}$ itself provides a reference to check the goodness of fit of the final measurement once it has been performed.

We evaluate possible biases from our neglect of correlations among discriminating variables in the PDFs by fitting ensembles of simulated experiments into which we have embedded the expected number of signal events randomly extracted from the fully simulated MC samples. We find a positive bias of $\lesssim 1$ event for the $\eta\omega$ and ηK^0 modes. For $\eta\rho^+$ and $\eta'\pi^+$ it is 7 to 17 events ($\sim 15\%$ of the yield). Events from a weighted mixture of simulated $B\overline{B}$ background decays are included where significant, and so the bias we measure includes the effect of crossfeed from these modes.

6 FIT RESULTS

Free parameters of the fit include signal and background yields, background PDF parameters, and for charged modes the signal and background $\mathcal{A}_{ch}$. The free background PDF parameters are mean, width, and skewness for $\mathcal{F}$, slope for ΔE, slope of the combinatorial component and peak fraction for resonance mass, and ξ for $m_{\rm ES}$.

The branching fraction for each decay chain is obtained from

$$\mathcal{B} = \frac{Y - Y_b}{\epsilon \prod \mathcal{B}_i N_B}\,, \tag{3}$$

where Y is the yield of signal events from the fit, Y_b is the fit bias discussed in the previous section, ϵ is the efficiency, $\prod \mathcal{B}_i$ is the product of daughter branching fractions that were forced to unity in the determination of ϵ, and N_B is the number of produced B^0 or B^+ mesons. In Table 2 we show for each decay mode the measured branching fraction together with the event yields and efficiencies. We assume that the decay rates of the $\Upsilon(4S)$ to B^+B^- and $B^0\overline{B}^0$ are equal. The estimated purity is the ratio of the signal yield to the effective background plus signal; the sum of effective bkg plus signal is represented by the square of the uncertainty of the signal yield.

In Figs. 1–4 we show projections onto $m_{\rm ES}$ and ΔE of subsamples enriched with a mode-dependent threshold requirement on the signal likelihood (computed without the PDF associated with the variable plotted).

7 STATISTICAL AND SYSTEMATIC UNCERTAINTIES

The statistical error on the signal yield and $\mathcal{A}_{ch}$ is taken as the change in value that corresponds to an increase of $-2\ln\mathcal{L}$ by one unit from its minimum. The significance is taken as the square root of the difference between the value of $-2\ln\mathcal{L}$ (with systematic uncertainties included) for zero

Table 2: Signal yield Y, estimated purity P, detection efficiency ϵ, daughter branching fraction product, significance S (with systematic uncertainties included), measured branching fraction, background ($\mathcal{A}_{ch}^{qq}$) and signal ($\mathcal{A}_{ch}$) charge asymmetries for each mode.

Mode	Y	P (%)	ϵ (%)	$\prod \mathcal{B}_i$ (%)	S σ	$\mathcal{B}$ (10^{-6})	$\mathcal{A}_{ch}^{qq}$ (%)	$\mathcal{A}_{ch}$ (%)
$\eta_{\gamma\gamma}\omega$	12^{+7}_{-6}	28	13	35	2.4	$1.4^{+0.7}_{-0.6}$		
$\eta_{3\pi}\omega$	-1^{+7}_{-5}	—	13	20	0.0	$-0.2^{+1.4}_{-1.0}$		
$\boldsymbol{\eta\omega}$					**2.2**	$\mathbf{1.2 \pm 0.6 \pm 0.2}$		
$\eta_{\gamma\gamma}K^0$	19^{+8}_{-7}	34	29	14	3.7	$2.7^{+1.1}_{-1.0}$		
$\eta_{3\pi}K^0$	6^{+5}_{-4}	30	22	8	2.1	$1.8^{+1.6}_{-1.1}$		
$\boldsymbol{\eta K^0}$					**4.2**	$\mathbf{2.5 \pm 0.8 \pm 0.1}$		
$\eta_{\gamma\gamma}\rho^+$	110^{+31}_{-29}	13	16	39	3.2	$8.1^{+2.9}_{-2.7}$	0.2 ± 0.5	20 ± 23
$\eta_{3\pi}\rho^+$	53^{+19}_{-17}	14	11	23	2.8	$9.7^{+4.3}_{-3.9}$	-0.1 ± 0.8	-18 ± 32
$\boldsymbol{\eta\rho^+}$					**4.2**	$\mathbf{8.6 \pm 2.2 \pm 1.1}$		$7 \pm 19 \pm 2$
$\eta'_{\eta\pi\pi}\pi^+$	55^{+12}_{-11}	41	27	18	4.9	$5.4^{+1.4}_{-1.3}$	-0.4 ± 1.4	19 ± 21
$\eta'_{\rho\gamma}\pi^+$	30^{+15}_{-14}	14	18	30	1.2	$1.9^{+1.6}_{-1.4}$	-1.2 ± 0.9	47 ± 44
$\boldsymbol{\eta'\pi^+}$					**4.8**	$\mathbf{4.2 \pm 1.0 \pm 0.5}$		$24 \pm 19 \pm 1$

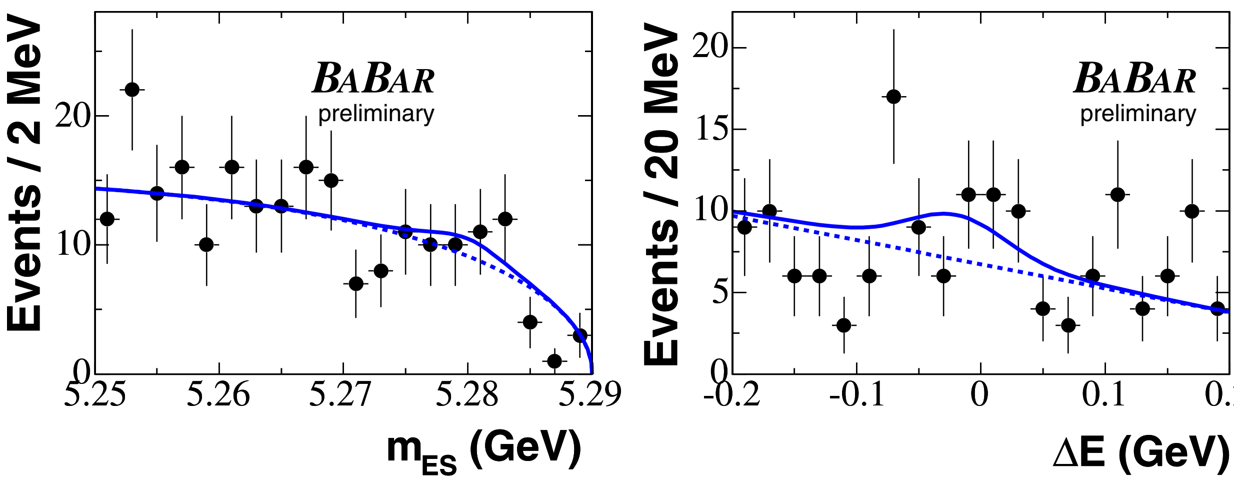

Figure 1: Projections of the B candidate $m_{\rm ES}$ (left) and ΔE (right) for $B^0 \to \eta\omega$. Points with errors represent data, solid curves the full fit functions, and dashed curves the background functions. These plots are made with a requirement on the likelihood and thus do not show all events in the data sample.

signal and the value at its minimum. For $\eta\omega$ we quote a 90% confidence level (C.L.) upper limit, taken to be the branching fraction below which lies 90% of the total of the likelihood integral in the positive branching fraction region. For the charged modes we also give the charge asymmetry $\mathcal{A}_{ch}$.

For the $B^+ \to \eta' h^+$ fits we obtain yields also for the $B^+ \to \eta' K^+$ decays. For both submodes these yields are consistent with the expectation from our previous measurements [4].

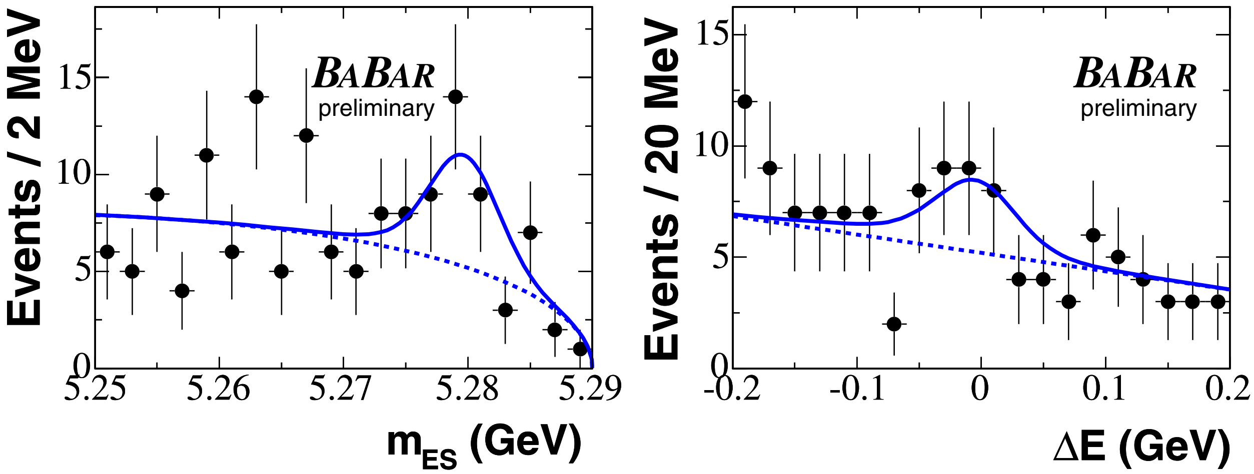

Figure 2: Projections of the B candidate $m_{\rm ES}$ (left) and ΔE (right) for $B^0 \to \eta K^0$. Points with errors represent data, solid curves the full fit functions, and dashed curves the background functions. These plots are made with a requirement on the likelihood and thus do not show all events in the data sample.

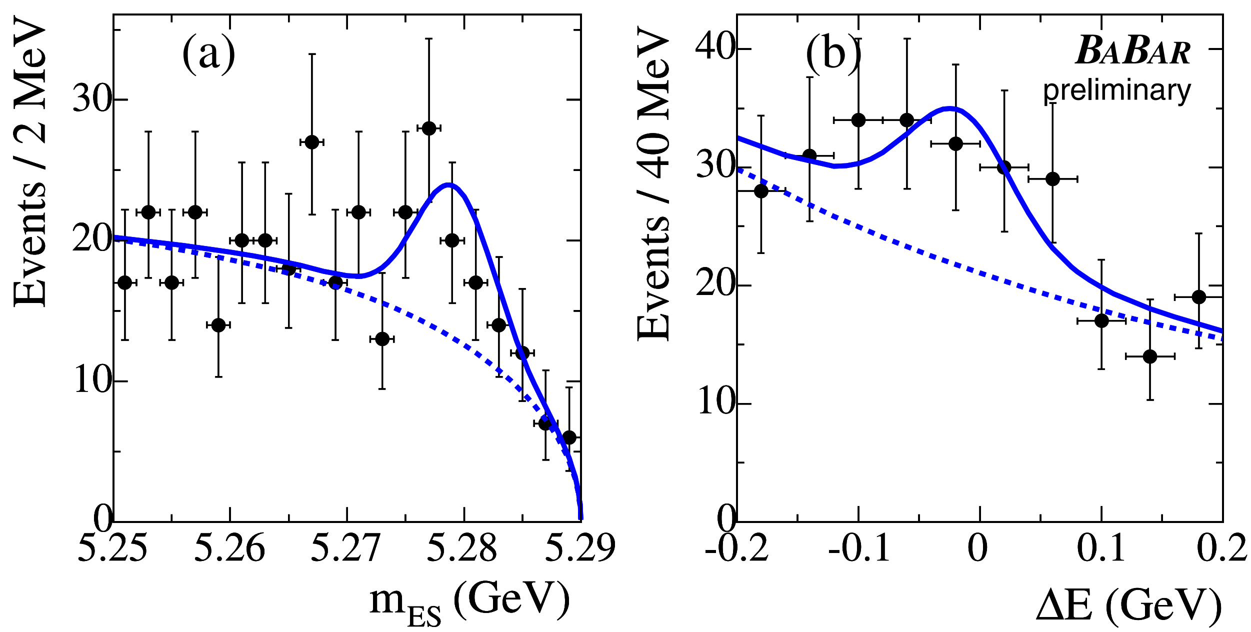

Figure 3: Projections of the B candidate $m_{\rm ES}$ (a) and ΔE (b) for $B^+ \to \eta\rho^+$. Points with errors represent data, solid curves the full fit functions, and dashed curves the background functions. These plots are made with a requirement on the likelihood and thus do not show all events in the data sample.

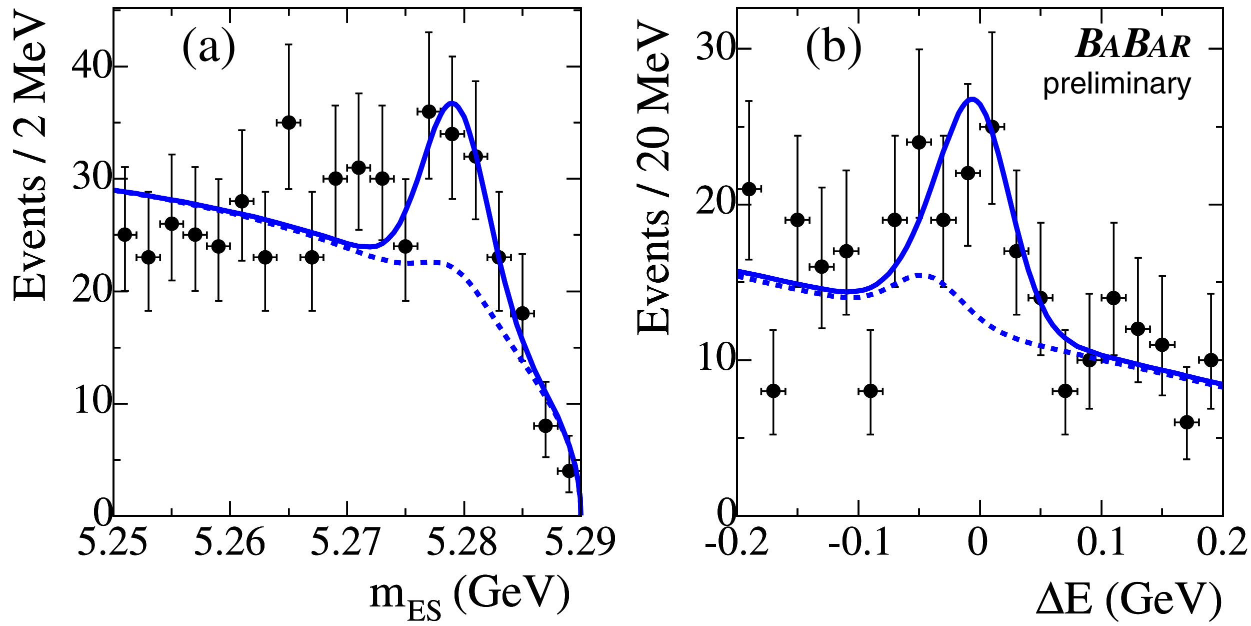

Figure 4: Projections of the B candidate $m_{\rm ES}$ (a) and ΔE (b) for $B^+ \to \eta^\prime \pi^+$. Points with errors represent data, solid curves the full fit functions, and dashed curves the continuum plus $B^+ \to \eta^\prime K^+$ background functions. These plots are made with a requirement on the likelihood and thus do not show all events in the data sample.

Most of the systematic 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. 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 the uncertainties in the signal PDFs to be 1–8 events, depending on the mode. The uncertainty in the fit bias correction is taken to be half of the correction itself. Similarly we estimate the uncertainty from modeling the $B\overline{B}$ backgrounds by taking half of the contribution of that component to the fitted signal yield. These additive systematic errors are small for the $\eta\omega$ and ηK^0 modes, but dominant for $\eta\rho^+$ and $\eta\pi^+$.

Uncertainties in our knowledge of the efficiency, found from auxiliary studies, include $0.8N_t$%, $1.5N_\gamma$%, and 3.4% for a K^0_S decay, where N_t and N_γ are the number of signal tracks and photons, respectively. Our estimate of the B production systematic error is 1.1%. Published data [21] provide the uncertainties in the B-daughter product branching fractions (1%). The uncertainties in the efficiency from the event selection are 1% (3% in $B^+ \to \eta^\prime_{\rho\gamma}\pi^+$) for the requirement on $\cos\theta_{\rm T}$ and $\sim$1% for PID. Using several large inclusive kaon and B-decay samples, we find a systematic uncertainty for $\mathcal{A}_{ch}$ of 1.1%, due mainly to the dependence of the reconstruction efficiency on the charge, for the high momentum pion from $B^+ \to \eta\pi^+$. The corresponding number for the softer charged pion from the ρ in $B^+ \to \eta\rho^+$ is 2%. The values of $\mathcal{A}_{ch}^{qq}$ (see Table 2) provide confirmation of this estimate.

The pairs of separate daughter-decay measurements for each mode are combined by adding the values of $-2\ln\mathcal{L}$ as functions of branching fraction, taking proper account of the correlated and uncorrelated systematic errors. We show these curves in Fig. 5.

8 SUMMARY OF RESULTS

In summary, we report preliminary results of searches for four charmless B-meson decays. We find significant signals for the previously-undetected $B^0 \to \eta K^0$, $B^+ \to \eta\rho^+$, and $B^+ \to \eta'\pi^+$. The measured branching fractions are

$$\begin{aligned}
\mathcal{B}(B^0 \to \eta\omega) &= (1.2 \pm 0.6 \pm 0.2) \times 10^{-6} \quad (< 2.3 \times 10^{-6})\,, \\
\mathcal{B}(B^0 \to \eta K^0) &= (2.5 \pm 0.8 \pm 0.1) \times 10^{-6}\,, \\
\mathcal{B}(B^+ \to \eta\rho^+) &= (8.6 \pm 2.2 \pm 1.1) \times 10^{-6}\,, \\
\mathcal{B}(B^+ \to \eta'\pi^+) &= (4.2 \pm 1.0 \pm 0.5) \times 10^{-6}\,,
\end{aligned}$$

where the first error quoted is statistical, the second systematic; the upper limit is taken at 90% CL. For the $B^\pm$ modes the charge asymmetries, are

$$\begin{aligned}
\mathcal{A}_{ch}(\eta\rho^+) &= (7 \pm 19 \pm 2)\%\,, \\
\mathcal{A}_{ch}(\eta'\pi^+) &= (24 \pm 19 \pm 1)\%\,.
\end{aligned}$$

Theoretical approaches to the study of these decays include those based on flavor SU(3) relations among many modes [9, 10, 15, 16], effective Hamiltonians with factorization and specific B-to-light-meson form factors [11], perturbative QCD [12], and QCD factorization [8, 13, 14]. Our branching fraction measurements are generally in agreement with the ranges of these theoretical estimates. From global fits to the growing body of data on charmless B decays the component amplitudes and theoretically uncertain parameters of these models are coming to be significantly over-constrained [10, 14, 16]. Our measurement of $\mathcal{A}_{ch}$ in $B^+ \to \eta'\pi^+$ excludes the larger-magnitude negative values among the theoretical estimates [7, 8].

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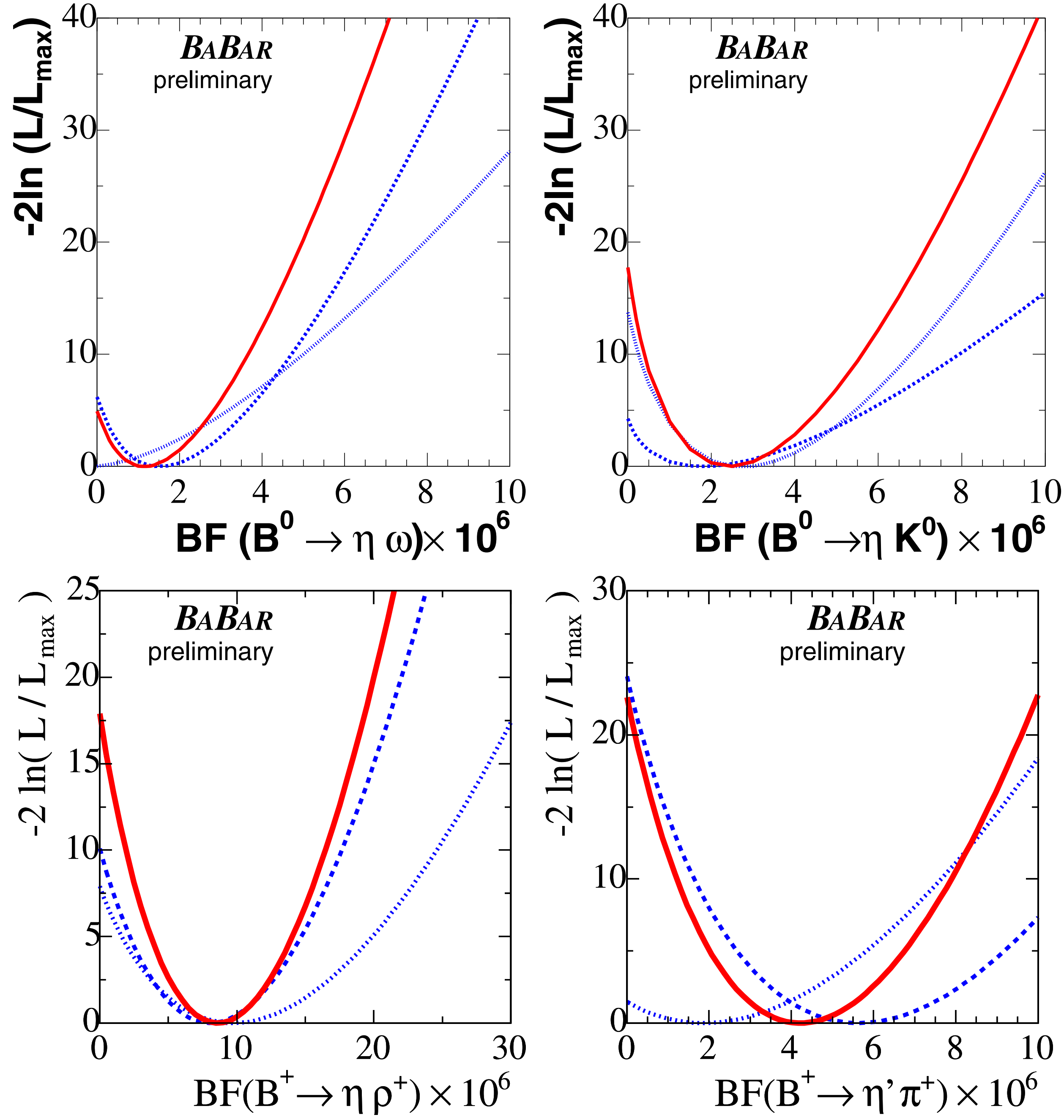

Figure 5: Plots of individual and combined $-2\ln\mathcal{L}$ for branching fraction fits are shown for the decay $B^0 \to \eta\omega$ (upper left), $B^0 \to \eta K^0$ (upper right), $B^+ \to \eta\rho^+$ (lower left), and $B^+ \to \eta'\pi^+$ (lower right). Each plot shows the daughter modes as curves that are dashed ($B^0 \to \eta_{\gamma\gamma}\omega$, $B^0 \to \eta_{3\pi}K^0$, $B^+ \to \eta_{\gamma\gamma}\rho^+$, $B^+ \to \eta'_{\eta\pi\pi}\pi^+$) or dotted ($B^0 \to \eta_{3\pi}\omega$, $B^0 \to \eta_{\gamma\gamma}K^0$, $B^+ \to \eta_{3\pi}\rho^+$, $B^+ \to \eta'_{\rho\gamma}\pi^+$), and the result of combining these as a solid curve.

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