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Search for the B Meson Decay to $\eta' \ \phi$

The BABAR Collaboration

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Abstract

We present preliminary results of a search for the decay $B^0 \to \eta'\phi$. The data were recorded with the BABAR detector at the PEP-II asymmetric-energy B-meson Factory at SLAC and correspond to 89 million $B\overline{B}$ pairs produced in e^+e^- annihilation at the $\Upsilon(4S)$ resonance. We find no evidence for a signal and set a 90% CL upper limit of $\mathcal{B}(B^0 \to \eta'\phi) < 1.0 \times 10^{-6}$.

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1 Introduction

We present the results of a search for the charmless B meson decay $B^0 \to \eta' \phi$. This B decay mode to a pseudoscalar and a vector mesons is dominated by penguin contributions. A gluonic penguin diagram is shown in Fig. 1. The branching ratio of this decay mode is expected to be very small (in the range of 10^{-9} – 10^{-7}) [1]. The study of this decay is pertinent to the factorization model for nonleptonic decays and to the penguin mechanism.

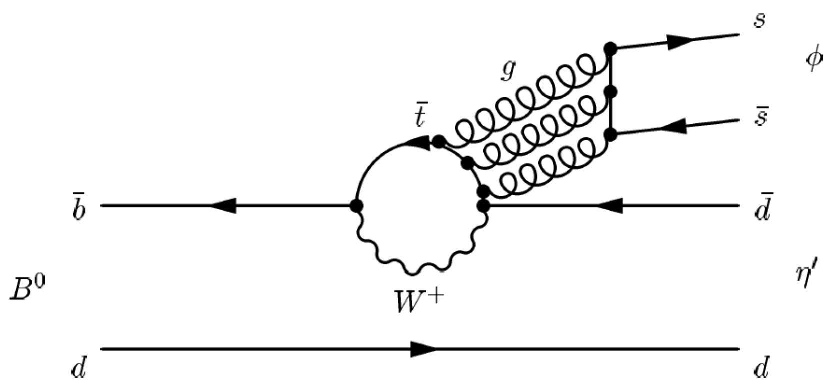

Figure 1: A gluonic penguin diagram for $B^0 \to \eta' \phi$.

CLEO, studying this decay with a sample of 3.3×10^6 $B\overline{B}$ pairs, found no evidence for a signal and set a 90% CL upper limit of $\mathcal{B}(B^0 \to \eta' \phi) < 31 \times 10^{-6}$ [2].

2 The *BABAR* Detector and Data

The results presented in this paper are based on data collected in 1999–2002 with the *BABAR* detector [3] at the PEP-II asymmetric e^+e^- collider located at the Stanford Linear Accelerator Center. An integrated luminosity of 81.9 fb^{-1}, corresponding to 89 million $B\overline{B}$ pairs, was collected at the $\Upsilon(4S)$ resonance ("on-resonance", center-of-mass energy $\sqrt{s} = 10.58$ GeV). An additional 9.6 fb^{-1} were collected about 0.040 GeV below this energy ("off-resonance") for the study of continuum background. The asymmetric beam configuration in the laboratory frame provides a boost of $\beta\gamma \approx 0.56$ to the $\Upsilon(4S)$, increasing the momentum range of the B-meson decay products up to 4.4 GeV/c. Charged particles are detected and their momenta measured by a combination of a silicon vertex tracker (SVT), consisting of five layers of double-sided detectors, and a 40-layer central drift chamber, both operating in the 1.5 T magnetic field of a solenoid. Photons and electrons are detected by a CsI(Tl) electromagnetic calorimeter (EMC).

Charged-particle identification (PID) is provided by the average energy loss ($\mathrm{d}E/\mathrm{d}x$) in the tracking devices and by an internally reflecting ring-imaging Cherenkov detector (DIRC) covering the central region. A Cherenkov-angle π/K separation of better than 4σ is achieved for tracks below 3 GeV/c, decreasing to $2.4\,\sigma$ at the highest momenta in the final states available in B-meson decays.

3 Event Selection

The B-meson decay $B^0 \to \eta'\phi$ is fully reconstructed through the observation of $\eta' \to \rho\gamma$ or $\eta' \to \eta\pi^+\pi^-$, where $\eta \to \gamma\gamma$ and $\phi \to K^+K^-$.

Monte Carlo (MC) simulation [4] of the decay mode under study and of the continuum and $B\overline{B}$ backgrounds is used to establish the event-selection criteria. The selection is designed to achieve high efficiency and retain sidebands sufficient to characterize the background for subsequent fitting. Photons are required to have an energy exceeding a threshold that depends on the mode-dependent combinatorial background of the specific mode: an $E_\gamma > 0.2$ GeV for $\eta' \to \rho^0\gamma$ candidates and $E_\gamma > 0.05$ GeV for $\eta' \to \eta\pi^+\pi^-$, $\eta \to \gamma\gamma$.

We select η',η , and ρ^0 candidates with the following requirements on the invariant masses (in GeV/c^2) of their final states: $0.920 < m_{\eta'} < 0.990$, $0.490 < m_\eta < 0.600$, and $0.500 < m_{\rho^0} < 0.995$. Tracks in η' (ϕ) candidates must have DIRC, dE/dx, and EMC responses consistent with the pion (kaon) hypothesis.

A B-meson candidate is characterized kinematically by the energy-substituted mass $m_{\rm ES} = \sqrt{(\frac{1}{2}s + \mathbf{p}_0 \cdot \mathbf{p}_B)^2/E_0^2 - p_B^2}$ and the missing energy $\Delta E = E_B^* - \frac{1}{2}\sqrt{s}$, where the subscripts 0 and B refer to the initial $\Upsilon(4S)$ and the B candidate, respectively, and the asterisk denotes the $\Upsilon(4S)$ rest frame. We require $|\Delta E| \leq 0.2$ GeV and $5.2 \leq m_{\rm ES} \leq 5.29$ GeV/c^2 . The resolutions on these quantities are about 0.030 GeV and 0.003 GeV/c^2, respectively.

To reject light-quark continuum background, we make use of the angle θ_T between the thrust axes of the B candidate and the rest of the tracks and neutral clusters in the event (ROE), calculated in the center-of-mass frame. The distribution of $|\cos\theta_T|$ is sharply peaked near 1 for combinations drawn from the jet-like $q\bar{q}$ events, and nearly uniform for the B meson decays. We apply the cut $|\cos\theta_T| < 0.9$. A second B candidate satisfying the selection criteria occurs in about 7% (18%) of the events in the decay mode $\eta' \to \rho^0\gamma$ ($\eta' \to \eta\pi^+\pi^-$). In this case we pick the combination with the η' mass closer to the PDG value [6].

To discriminate against tau-pair and two-photon backgrounds we require the event to contain at least five charged tracks.

The remaining continuum background dominates the samples and is modeled from sideband data in the maximum-likelihood (ML) fit described in section 4.

We use MC simulation of $B^0\overline{B}^0$ and B^+B^- pair production and decay to look for possible $B\overline{B}$ backgrounds. Other charmless B decays turn out to be the most likely other source of backgrounds in this study. To evaluate this source, we have produced a high statistics enriched sample of such B decays, using available estimates of the branching ratios. From these studies we find no evidence of a significant $B\overline{B}$ background.

4 Maximum Likelihood Fit

We use an unbinned, multivariate maximum likelihood fit to extract the signal yield. With the cuts described in Section 3, B-meson candidates are selected to match the kinematic structure of the decay mode $B^0 \to \eta'\phi$.

4.1 The Likelihood Function

The likelihood function incorporates several weakly correlated variables. For the kinematics of the B decay we use ΔE and $m_{\rm ES}$. We also include the mass of the η' and , for the B production and energy flow a Fisher discriminant $\mathcal{F}$. We combine the following four variables into a Fisher discriminant: the angles with respect to the beam axis in the center-of-mass frame of the B momentum and the B thrust axis, and the zeroth and second Legendre moments of the tracks and neutrals not used in reconstructing the decay $\eta'\phi$ computed with respect to the B-candidate thrust axis.

Thus, the input variables for the $\eta'_{\eta\pi\pi}$ channel are ΔE, $m_{\rm ES}$, m'_{η}, $\mathcal{F}$, and the angular variable $\mathcal{H}_\phi$. In the analysis of the $\eta'_{\rho\gamma}$ channel we add the angular variable $\mathcal{H}_\rho$. The angular variable $\mathcal{H}_\phi$ is the cosine of the angle between the direction of the daughter K^+ with respect to the direction of the parent B in the ϕ rest frame. The angular variable $\mathcal{H}_\rho$ is defined as the cosine of the angle between the direction of a ρ^0's daughter and the direction of the parent η' in ρ^0 rest frame. These variables have a $\sin^2\theta$ and $\cos^2\theta$ shape in signal events, respectively. In the continuum $q\bar{q}$ background the distributions of both angular variables are flat.

Since we measure the correlations among the observables in data to be small, we take the PDF for each event to be a product of the PDFs for the separate observables. We define two hypotheses j, where j can be either signal or continuum background. The product PDF (to be evaluated with the observable set for event i) is then given (for $\eta'_{\eta\pi\pi}$) by:

$$\mathcal{P}^i_j = \mathcal{P}_j(m_{\rm ES}) \cdot \mathcal{P}_j(\Delta E) \cdot \mathcal{P}_j(\mathcal{F}) \cdot \mathcal{P}_j(m_{\eta'}) \cdot \mathcal{P}_j(\mathcal{H}_\phi). \tag{1}$$

The extended likelihood function for all input events N is:

$$\mathcal{L} = \frac{\exp\left(-\sum_j N_j\right)}{N!} \prod_i^N \sum_j N_j \mathcal{P}^i_j \tag{2}$$

where N_j is the number of events of species j to be found by the fitter.

4.2 Preparation of Inputs

The PDF determination for the likelihood fit is accomplished with use of Monte Carlo for the signal and on-resonance sideband data for the continuum background.

Peaking distributions (signal masses, ΔE and $\mathcal{F}$) are parameterized as Gaussian functions. To obtain good fits to these samples we employ a sum of two or three Gaussian functions or Gaussian functions with different widths above and below the central value. Slowly varying distributions (combinatoric background under mass or energy peaks) have linear behavior. The combinatoric background in $m_{\rm ES}$ is described by an empirical phase-space function [5]. $\mathcal{H}_\phi$ and $\mathcal{H}_\rho$ PDFs for signal are described by second-order polynomial (without the linear term) while those for the background are described by a linear and a second-order polynomial, respectively.

Control samples of B decays to charm final states of similar topology are used to account for the fidelity of the MC for variables describing B-decay kinematics. We adjust the MC resolutions and central values, when necessary, by comparing data and simulation in these control samples.

5 Systematics

The uncertainty in the values of the parameters used in the PDFs are a source of systematic error. Variation of these parameters by 1 σ induces an uncertainty of 0.03 signal events. The fitting procedure itself is a source of systematic uncertainty. Studies with simulated samples and background populations find that this uncertainty amounts to 0.21 signal events.

The remaining systematic uncertainties are multiplicative. Those due to MC statistics, track and photon multiplicities and B production are estimated from auxiliary studies. Published world averages [6] provide the B-daughter branching fraction uncertainties. The systematic error due to all these sources is estimated to equal 0.06 events.

The overall systematic error is 0.2 events (or 0.1×10^{-6} in terms of the branching fraction). This error is incorporated into the upper-limit calculation as described in the following section.

6 Fit Results

We find no signal events in the on-resonance sample and for this reason we adopt the Bayesian method to calculate the 90% CL upper limit. We perform ML fits in the physical region of the parameters and integrate the likelihood from zero to the branching fraction value where the integral reaches 90% of its asymptotic value.

The $\eta'_{\rho\gamma}\phi$ and $\eta'_{\eta\pi\pi}\phi$ modes are reconstructed with an overall efficiency of 3.3% and 2.1%, respectively. The measured value for the 90% CL upper limit is 1.6×10^{-6} for $\eta'_{\rho\gamma}\phi$ and 2.0×10^{-6} for $\eta'_{\eta\pi\pi}\phi$. We combine these upper limit measurements by forming for each decay mode a convolution of $\mathcal{L}$ from the fit with a Gaussian representing the uncorrelated systematic error. The curves of $-2\ln\mathcal{L}$ are shown in Fig. 2, for both decay modes and for the sum of the two.

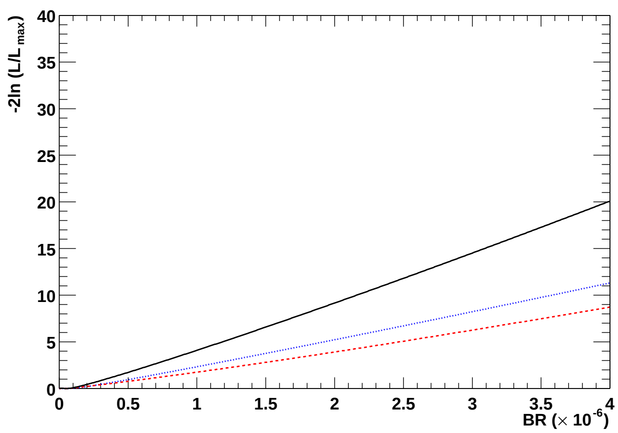

Figure 2: Distributions of $-2\ln\mathcal{L}$ vs. branching fraction for $\eta'\phi$ decays. Dotted, dashed and solid lines correspond to $\eta' \to \rho^0\gamma$, $\eta' \to \eta\pi^+\pi^-$ and to the combined decay modes, respectively.

7 Conclusion

We have performed a search for the charmless B^0 meson decay to $\eta'\phi$. We find no signal and we set a 90% CL upper limit:

$$\mathcal{B}(B^0 \to \eta'\phi) \quad < \quad 1.0 \times 10^{-6}.$$

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[5] With $x \equiv M_{ES}/E_b$ and ξ a parameter to be fitted, $f(x) \propto x\sqrt{1-x^2}\exp\left[-\xi(1-x^2)\right]$. See ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. B **241**, 278 (1990).

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