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Rare B Decays at *BABAR*

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Abstract

We report recent results in the search for the rare B meson decays $B \rightarrow \rho\gamma$ and $B^0 \rightarrow \pi^0\pi^0$. These results are based on 56.4 fb^{-1} collected by the BaBar Collaboration at the SLAC PEP-II e^+e^- B Factory. We set new 90% confidence level upper limits $\mathcal{B}(B^0 \rightarrow \rho^0\gamma) < 1.5 \times 10^{-6}$, $\mathcal{B}(B^+ \rightarrow \rho^+\gamma) < 2.8 \times 10^{-6}$, and $\mathcal{B}(B^0 \rightarrow \pi^0\pi^0) < 3.4 \times 10^{-6}$.

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1 The BaBar Detector

The results presented in this paper are based on an integrated luminosity of 56.4 fb^{-1} collected on the $\Upsilon(4S)$ resonance with the BaBar detector [1] at the PEP-II asymmetric e^+e^- collider of the Stanford Linear Accelerator Center.

Charged particles are detected and their momenta measured by a combination of a 5 double-sided layer silicon vertex tracker and a 40-layer drift chamber, photons are detected by a CsI electromagnetic calorimeter. These detectors operate inside a 1.5 T solenoidal field.

Charged particle identification is achieved by the average energy loss in the tracking devices and by a unique, internally reflecting ring imaging Cherenkov detector.

2 B Decay Reconstruction

The B meson candidates are kinematically identified using two independent variables. $\Delta E = E_B^* - E_{Beam}^*$ is peaked at zero for signal since the B mesons are produced via $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ and therefore the energy of the B meson in the $\Upsilon(4S)$ rest frame is the beam energy E_{Beam}^* . $m_{ES} = \sqrt{E_{Beam}^{*2} - \mathbf{p}_B^{*2}}$ is a measure of the B meson mass where we have substituted E_B^* by the beam energy E_{Beam}^* which is known with better precision than E_B^* . \mathbf{p}_B^* is the momentum of the B meson candidate in the $\Upsilon(4S)$ rest frame calculated from the measured momenta of the decay products.

Rare B decay modes suffer from large backgrounds due to random combinations of tracks produced in the light quark–antiquark continuum. The distinguishing feature of such backgrounds is their characteristic event shape resulting from the two-jet production mechanism. A quantity that characterizes the event shape is the angle between the thrust axis of the B candidate and the thrust axis of the rest of the event where the thrust axis is defined as the axis that maximizes the sum of the magnitudes of the longitudinal momenta. This angle is small for continuum events, where the B candidate daughters tend to lie in the $q\bar{q}$ jets, and uniformly distributed for true $B\bar{B}$ events.

We further suppress background using a Fisher discriminant constructed as an optimized linear combination of the scalar sum of the center-of-mass momenta of all charged tracks and photons (excluding the B candidate decay products) flowing into 9 concentric cones centered on the thrust axis of the B candidate. The more spherical the event, the lower the value of the Fisher discriminant.

All analyses have been performed as *blind analyses*, *i.e.*, the region in ΔE and m_{ES} where the signal is expected is concealed until all the selection criteria are determined either from Monte Carlo events, data sidebands in the ΔE – m_{ES} plane (region outside the signal region) or data control samples.

Yields are extracted using extended maximum likelihood fits to the ΔE , m_{ES} , and Fisher discriminant (for $B^0 \rightarrow \pi^0\pi^0$) or resonance mass distribution (for $B \rightarrow \rho\gamma$) for signal and background.

In the following charge conjugate modes are implied throughout.

3 A Search for $B \rightarrow \rho\gamma$

The measurement of the branching fraction for $B \rightarrow \rho\gamma$ is mainly aiming at the determination of the quark–mixing matrix element $|V_{td}|$. The measurement of $|V_{td}|$ is also the main motivation for

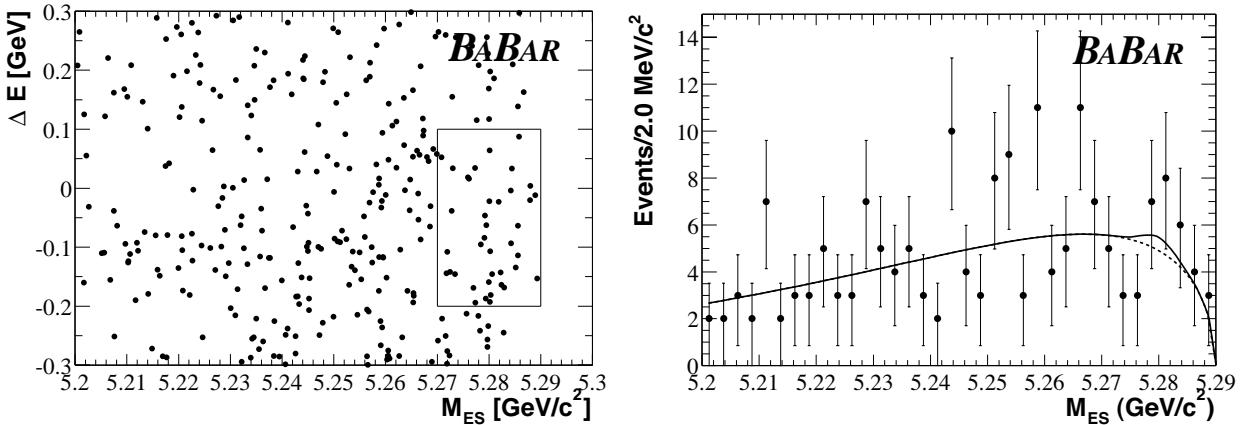


Figure 1: Left: ΔE vs m_{ES} distribution for $B^0 \rightarrow \rho^0\gamma$. The box outlines the signal region which was blinded during the analysis. Right: m_{ES} distribution for $B^+ \rightarrow \rho^+\gamma$. The result of the likelihood fit is overlaid as a solid line, the dashed line represents the background contribution.

performing $B^0 - \overline{B}^0$ mixing measurements. Both are sensitive to new physics contributions in their loop and box diagrams.

Assuming that the short-distance contribution of the magnetic moment operator is dominating these transitions, one derives

$$\frac{\Gamma(B \rightarrow \rho/\omega\gamma)}{\Gamma(B \rightarrow K^*\gamma)} = \left(\frac{|V_{td}|}{|V_{ts}|} \right)^2 \xi \Omega, \quad (1)$$

where ξ takes into account the decay form factors and Ω the different phase space factors [3]. With $|V_{ts}| \approx |V_{cb}|$ a precise measurement of the ratio of branching fractions provides therefore a strong constraint on $|V_{td}|$.

With the assumption of isospin invariance one also expects $\Gamma(B^+ \rightarrow \rho^+\gamma) = 2 \Gamma(B^0 \rightarrow \rho^0\gamma)$, if we assume in addition SU(3) symmetry we obtain $\Gamma(B^0 \rightarrow \rho^0\gamma) = \Gamma(B^0 \rightarrow \omega\gamma)$. The measurement of the branching fractions alone provides therefore a model independent way of testing to what extent the short distance contributions are dominating these decays.

The relations above have been used to convert the experimental upper bound on the ratio of the exclusive radiative B decays [4] $\mathcal{B}(B \rightarrow \rho/\omega\gamma)/\mathcal{B}(B \rightarrow K^*\gamma) < 0.34$ (90% confidence level), into a bound on $|V_{td}|/|V_{ts}| < 0.64 - 0.76$, depending on the estimate of the SU(3)-breaking parameters in the short distance contribution [5]. While this bound is at present not competitive with the corresponding bound from the unitarity of the quark-mixing matrix [2] and from the fits of the quark-mixing matrix elements [6], which yield $|V_{td}|/|V_{ts}| < 0.36$, one anticipates that the increased sensitivity in the radiative B decay modes at the high luminosity B factories will allow to test these relationships quantitatively.

Currently no measurements exist for the branching fraction of the decay $B \rightarrow \rho\gamma$, however, 90% confidence level upper limits have been obtained by the CLEO [7] and Belle collaborations [8]. CLEO obtains an upper limit of 17×10^{-6} for the neutral and 13×10^{-6} for the charged mode based on 9.7×10^6 $B\overline{B}$ events. Belle obtains an upper limit of 10.6×10^{-6} for the neutral and 9.9×10^{-6} for the charged mode based on 11×10^6 $B\overline{B}$ events.

Figure 1 shows our results for $B \rightarrow \rho\gamma$ after unblinding. On the left is shown the ΔE vs m_{ES} distribution for $B^0 \rightarrow \rho^0\gamma$. The box outlines the signal region which was blinded during the

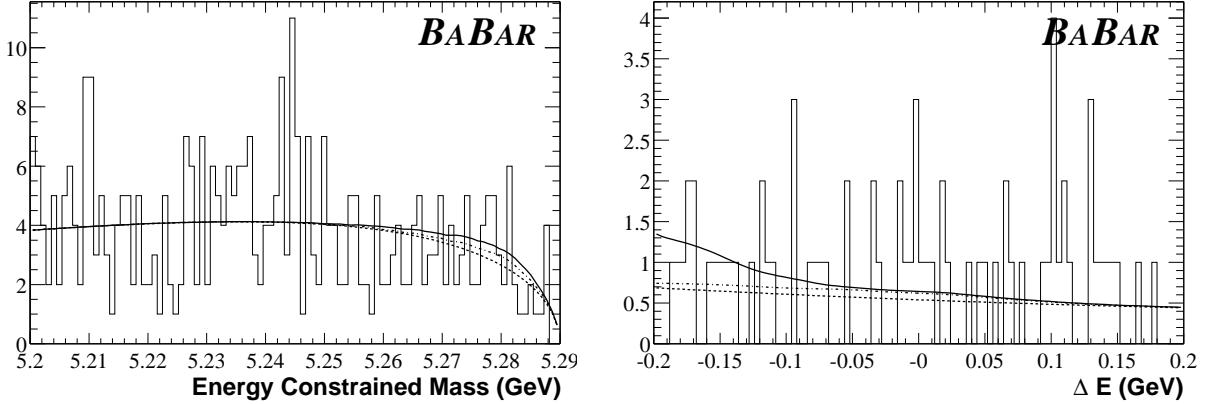


Figure 2: The m_{ES} (left) and ΔE (right) distributions for events passing the cut and count selection except for the cut on m_{ES} itself. The likelihood fit is overlaid with the correct scaling. The solid line is the overall probability density distribution function (PDF), the dashed line represents the continuum PDF while the dashed-dotted line represents the continuum and $B^0 \rightarrow \pi^0\pi^0$ PDFs combined.

analysis. On the right is shown the m_{ES} distribution for $B^+ \rightarrow \rho^+\gamma$. The result of the likelihood fit is overlaid as a solid line, the dashed line represents the background contribution. The extended maximum likelihood fit yields 3.1 ± 4.2 events for $B^0 \rightarrow \rho^0\gamma$ and 4.6 ± 5.8 events for $B^+ \rightarrow \rho^+\gamma$. We observe no signal and place the following 90% confidence level upper limits on the branching fractions:

$$\mathcal{B}(B^0 \rightarrow \rho^0\gamma) < 1.5 \times 10^{-6}, \quad \mathcal{B}(B^+ \rightarrow \rho^+\gamma) < 2.8 \times 10^{-6}.$$

This represents an improvement of an order of magnitude over previous measurements and reaches the range of theoretical predictions. The systematic uncertainty on the branching fraction is about 15% for both modes, where the largest contribution comes from the assumption of the number of ρ mesons in the background.

4 A Search for $B^0 \rightarrow \pi^0\pi^0$

The branching fraction for the decay $B^0 \rightarrow \pi^0\pi^0$ is interesting in the context of the determination of the angle α in the unitarity triangle. In the absence of penguin contributions, the asymmetry in $B^0 \rightarrow \pi^+\pi^-$ measures $\sin(2\alpha)$. An isospin analysis can be used to eliminate the penguin pollution in this case [9]. However, this analysis requires both the measurement of $B^0 \rightarrow \pi^0\pi^0$ and $\overline{B}^0 \rightarrow \pi^0\pi^0$, and therefore, although theoretically clean, this analysis is undermined by the small branching fraction of the decay $B^0 \rightarrow \pi^0\pi^0$. Theoretical predictions [10] are as high as 4.6×10^{-6} , some references [11] give limits in the range $10^{-7} - 10^{-6}$.

However, measuring a CP averaged decay rate for $B^0 \rightarrow \pi^0\pi^0$ is still interesting for $\sin(2\alpha)$. The phase angle obtained through the analysis of $B^0 \rightarrow \pi^+\pi^-$ decays gives only an effective parameter α_{eff} which is dependent on α , strong phases and the ratio of penguin to tree amplitudes. One can bound α via[12]

$$\sin^2(\alpha_{eff} - \alpha) = \frac{\langle \mathcal{B}(B^0 \rightarrow \pi^0\pi^0) \rangle_{CP}}{\mathcal{B}(B^+ \rightarrow \pi^+\pi^0)}$$

where $\langle \mathcal{B}(B^0 \rightarrow \pi^0\pi^0) \rangle_{CP} = \frac{1}{2} [\mathcal{B}(B^0 \rightarrow \pi^0\pi^0) + \mathcal{B}(\overline{B}^0 \rightarrow \pi^0\pi^0)]$.

Recent results from CLEO [13] and Belle [14] have hinted at the possibility of a branching fraction of the order of 2×10^{-6} . CLEO measures a limit of 5.7×10^{-6} based on 9.67×10^6 $B\bar{B}$ events, Belle 5.6×10^{-6} based on 31.7×10^6 $B\bar{B}$ events.

Figure 2 shows projections on m_{ES} (left) and ΔE (right) after unblinding with the likelihood function superimposed. The solid line is the overall probability density distribution function (PDF), the dashed line represents the continuum PDF while the dashed-dotted line represents the continuum and $B^0 \rightarrow \pi^0\pi^0$ PDFs combined. There is no evidence for observation of a signal for $B^0 \rightarrow \pi^0\pi^0$ yet. We place a 90% confidence level upper limit on the branching fraction of

$$\mathcal{B}(B^0 \rightarrow \pi^0\pi^0) < 3.4 \times 10^{-6}.$$

This upper limit is better than that of previous searches. The largest two systematic uncertainties arise from the parameterization of the continuum background and the Fisher discriminant distribution, the third largest from the assumption for the $B^+ \rightarrow \rho^+\pi^0$ background contribution.

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