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Charmless hadronic B decays at BABAR

Marcella Bona*

Università di Torino, Dipartimento di Fisica and INFN, I-10125 Torino, Italy
E-mail: bona@to.infn.it
on behalf of the BABAR Collaboration

ABSTRACT: Using 22.7M $B\bar{B}$ events collected with the *BABAR* detector at SLAC, we present preliminary measurements of the branching fractions for charmless hadronic decays of B mesons into two-body, quasi two-body and three-body final states with pions, kaons, and ρ and a_0 resonances. In the search for exclusive $B^0 \to \pi^+\pi^-\pi^0$, we measure $\mathcal{B}(B^0 \to \rho^{\pm}(770)\pi^{\mp}) = (28.9 \pm 5.4 \pm 4.3) \times 10^{-6}$, together with the relative asymmetry $\mathcal{A}_{\text{phys}} = -0.04 \pm 0.18 \pm 0.02$. We also set the upper limits on $B^0 \to \rho^0(770)\pi^0$, non-resonant $B^0 \to \pi^+\pi^-\pi^0$, $B^0 \to a_0^{\pm}(\to \eta\pi^{\pm})\pi^{\mp}$ and $B^0 \to K^0\bar{K}^0$.

1. Introduction

Measurement of the rates and CP asymmetries for B decays into the charmless final states can be used to constrain the angle α of the unitarity triangle [1]. In the case of three body $\pi^+\pi^-\pi^0$ decays, such measurements of α would exploit interference between the $B^0 \to \rho^{\pm}\pi^{\mp}$ modes and the colour-suppressed $B^0 \to \rho^0\pi^0$.

In the case of $B^0 \to a_0^{\pm}\pi^{\mp}$, the absence of second-class currents, together with the assumption of factorization, provide new constraints on CP observables. The kinematics do not allow interference between the oppositely-charged resonances in the Dalitz plot as in the $B^0 \to \rho(770)\pi$, but in the absence of second-class currents might lead to enhanced direct CP violation [2].

In the case of $B^0 \to K^0\bar{K}^0$, the decay rate is expected to be small $(10^{-6} - 10^{-7})$ in the Standard Model [3]. Final-state rescattering effects can lead to enhancement of the branching fraction and the possibility of large strong phases, with correspondingly large CP-violating charge asymmetries [4, 5]. Observation of the $K^0\bar{K}^0$ decay mode would provide important information about the strength of final-state rescattering in charmless B decays.

*Speaker.

2. Analysis

The data sample used consists of 22.74 million $B\bar{B}$ events, collected at the PEP-II asymmetric e^+e^- collider at SLAC, with the *BABAR* detector [6]. Hadronic events are selected based on track multiplicity and event topology. We use only good quality tracks. Candidate K^0_S mesons are reconstructed from pairs of oppositely-charged tracks that form a well-measured vertex and have invariant mass within 3.5 standard deviations (σ) of the nominal K^0_S mass [7]. Candidate photons are defined as showers in the electromagnetic calorimeter that have the expected lateral shape and are not matched to a track. Candidate π^0 mesons are reconstructed by combining pairs of photons with an invariant mass between 100 and 160 MeV/c^2; the π^0 candidates are then kinematically fitted with their mass constrained to the nominal π^0 mass [7]. Pion candidates (except K^0_S and a_0 daughters) are required to fail kaon selection criteria.

We reconstruct the decay $B \to a_0\pi$ in the mode $a_0 \to \eta\pi$, $\eta \to \gamma\gamma$. To be associated with an η decay a pair of candidate photons is required to satisfy $0.470 < m_{\gamma\gamma} < 0.615\,\mathrm{GeV}/c^2$ and the η center-of-mass (CM) momentum must be larger than $0.9\,\mathrm{GeV}/c$. The pion track and η candidate form an a_0 candidate if $0.90 < m_{\eta\pi} < 1.08\,\mathrm{GeV}/c^2$.

Candidate B mesons are selected by exploiting the kinematic constraints provided by the $\Upsilon(4S)$ initial state. First we define an energy-substituted mass m_{ES}, where $\sqrt{s}/2$ is substituted for candidate's energy [1]. The second variable used is the difference ΔE between the B-candidate energy and $\sqrt{s}/2$. For all modes the m_{ES} resolution is dominated by the beam energy spread and is approximately $2.5\,\mathrm{MeV}/c^2$, while ΔE resolution is mode dependent and dominated by momentum resolution. Candidates are selected in the range $5.2 < m_{ES}(m_{EC}) < 5.3\,\mathrm{GeV}/c^2$ and accepted, depending on the decay topology, in various ΔE ranges, restrictive enough to suppress background due to other types of B decays.

The largest source of background is from random combinations of tracks and neutrals produced in the $e^+e^- \to q\bar{q}$ continuum (where $q = u, d, s$ or c). In the CM frame this background typically exhibits a two-jet structure. In contrast, the low momentum and pseudo-scalar nature of B mesons from $\Upsilon(4S)$ decays leads to a more spherically symmetric event. This topology difference is exploited using event-shape quantities. The first variable is the angle θ_T between the thrust axes, in the CM frame, of the B candidate and the remaining tracks and photons in the event (ROE). We require $|\cos\theta_T| < 0.9$. Another quantity used is a Fisher discriminant $\mathcal{F}$, a linear combination of several discriminating variables like the scalar sum of the momenta of the ROE flowing into nine concentric cones centered on the thrust axis of the B candidate, in the CM frame [8]. Another set of discriminating variables is defined by $L_j^{(c,n)} = \sum_{i_{(c,n)}} p_i \times |cos\theta_i|^2$, which are the momentum-weighted sums of the cosines of the angles between the ROE charged tracks ($L_j^{(c)}$) or neutral clusters $L_j^{(n)}$ and the thrust axis of the B candidate. In the analysis of $B \to a_0\pi$ these variables are used in a non-linear (Neural Network) multi-variate analysis.

Global detection efficiencies, including branching fractions of intermediate states, are listed in Table 1. Appropriate control samples are used to determine efficiencies for π^0 and

[1] In $B^0 \to a_0\pi$ analysis m_{ES} is replaced with the energy-constraint mass $m_{EC} = \sqrt{s/4 - p_B^2}$ where p_B is obtained by applying kinematic constraints to the four-momenta of the B daughters.

K^0_S reconstruction, particle identification, and selection criteria for m_{ES} and ΔE.

Signal yields are determined with either a simple counting analysis, or with a maximum likelihood fit. For the counting analysis, the yield is defined as $N_S = N_1 - \mathcal{R}N_2$, where $\mathcal{R}$ is the background fraction of the number of candidates in the signal region to the number in the side-band region, N_1 is the number of candidates in the signal region for on-resonance data and N_2 is the number of candidates in on-resonance data observed in the side-band region. In the second technique, signal yields are determined from an unbinned maximum likelihood fit using m_{ES} or m_{EC}, ΔE, $\mathcal{F}$ or NN output, $\gamma\gamma$ mass (where applicable). In each of the fits, the likelihood for a given candidate is obtained by summing the product of event yields and probabilities over all possible signal and background hypotheses. Monte Carlo simulated data is used to validate the assumption that the fit variables are uncorrelated. The parameters of m_{ES}, m_{EC}, ΔE and $\mathcal{F}$ PDFs are determined from data and are cross-checked with Monte Carlo simulation.

Data for the $B^0 \to \pi^+\pi^-\pi^0$ final state can be represented on a Dalitz plot (see Fig. 1). We subdivide the Dalitz plot into distinct regions, each of which chosen to be sensitive to a single resonance such as the $\rho(770)$, $\rho(1450)$ and $f_0(400-1200)$. The regions are defined using the invariant mass of $\pi\pi$-pair combinations and the pair helicity angle defined as the angle between the direction of one of the pions and the direction of the parent B meson candidate computed in the $\pi\pi$-pair rest frame. A counting method is used in this analysis.

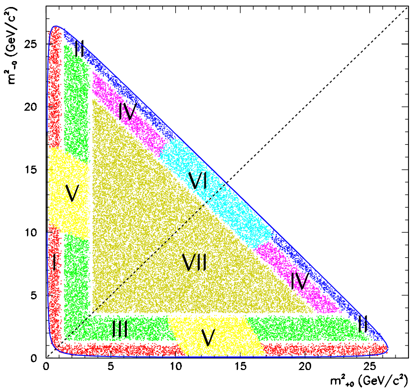

Figure 1: Separate region of the Dalitz plot are sensitive to different modes. I: $B^0 \to \rho^\pm\pi^\mp$. II: $B^0 \to \rho^0\pi^0$. III: $B^0 \to \rho\prime^\pm\pi^\mp$. IV: $B^0 \to \rho\prime^0\pi^0$. V: $B^0 \to$ charged scalar and $\pi^\mp$. VI: $B^0 \to$ neutral scalar and π^0. VII: $B^0 \to \pi^+\pi^-\pi^0$ at high mass.

There are four decay rates that are of interest for the decay mode $B^0 \to \rho^\pm\pi^\mp$, defined by $\Gamma_{\rho\pi} = \Gamma(B^0 \to \rho^+\pi^-)$ and $\Gamma_{\pi\rho} = \Gamma(B^0 \to \rho^-\pi^+)$ together with their *CP* conjugates $\bar{\Gamma}_{\rho\pi}$ and $\bar{\Gamma}_{\pi\rho}$. A non-zero value for the asymmetry, given by:

$$\mathcal{A}_{\text{phys}} = \frac{(\Gamma_{\rho\pi} + \bar{\Gamma}_{\pi\rho}) - (\bar{\Gamma}_{\rho\pi} + \Gamma_{\pi\rho})}{(\Gamma_{\rho\pi} + \bar{\Gamma}_{\pi\rho}) + (\bar{\Gamma}_{\rho\pi} + \Gamma_{\pi\rho})} \qquad (2.1)$$

would signify direct *CP* violation in at least one of the decays. [2]

3. Results and Systematics

The results of the fits or the counting method for the various topologies are summarized in Table 1. In those cases where no evidence of signal is found a 90% confidence level upper limit is computed. In the case of the counting analysis, we have used the classical

[2]The numerator in Eq. 2.1 is simply the difference of the two direct *CP* violations $(\Gamma_{\rho\pi} - \bar{\Gamma}_{\rho\pi})$ and $(\Gamma_{\pi\rho} - \bar{\Gamma}_{\pi\rho})$

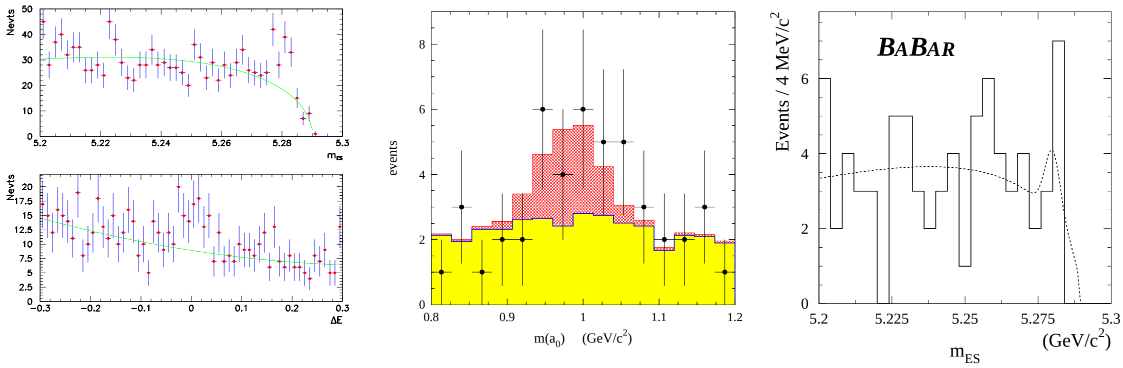

Figure 2: Left plot: m_{ES} and ΔE distributions for $B^0 \to \rho^\pm \pi^\mp$. Central plot: projection on the $\eta\pi$ invariant mass axis for $B^0 \to a_0(\eta\pi)\pi$ analysis. Right plot: m_{ES} distribution for $B^0 \to K^0 \bar{K}^0$. The curve is the projection of the maximum likelihood fit result. (Projections from likelihood fit are obtained after additional requirements on likelihood ratios)

method outlined in [1] and we have reduced the background estimate and the efficiency by one standard deviation (systematic) before making the calculation. In the case of the maximum likelihood analysis, the upper limit on the signal yield for mode k is given by the value of n_k^0 for which $\int_0^{n_k^0} \mathcal{L} dn_k / \int_0^\infty \mathcal{L}_{max} dn_k = 0.90$ where $\mathcal{L}_{max}$ is the likelihood as a function of n_k, maximized with respect to the remaining fit parameters. The result is then increased by the total systematic error, and the detection efficiency is reduced by its systematic uncertainty in calculating the branching fraction upper limit. The statistical significance of a given channel is determined by fixing the yield to zero, repeating the fit and recording the change in $-2\ln\mathcal{L}$.

We have made a preliminary measurement of the *CP* asymmetry in Eq. 2.1 of $\mathcal{A}_{\rm phys} = -0.04 \pm 0.18 \pm 0.02$, which is consistent with zero. Imperfect knowledge of the PDF shapes, of the detection efficiencies and of the background subtraction (counting method) are the main sources of systematic uncertainties on the branching fraction measurements. Uncertainties in the PDF parameterizations are estimated either by varying the PDF parameters within 1σ of their measured uncertainties or by substituting alternative PDFs from independent control samples and recording the variations in the fit results.

mode	$\epsilon(\%)$	$N_S \pm$ (stat) $\pm$ (syst)	Stat. Sig. (σ)	$\mathcal{B}(10^{-6})$
$\rho^\pm(770)\pi^\mp$	13.5 ± 1.6	$89 \pm 16 \pm 6$	5.0	$28.9 \pm 5.4 \pm 4.3$
$\rho^0(770)\pi^0$	7.4 ± 0.9	$6.1 \pm 5.8 \pm 2.8$	1.0	< 10.6
$\pi^+\pi^-\pi^0$ (NR)	7.5 ± 1.0	$-4.2 \pm 7.3 \pm 3.8$	N/A	< 7.3
$a_0(\eta\pi)\pi$	32.8 ± 2.4	$18.1^{+8.7}_{-7.4} \pm 1.6$	3.7	< 11.5
$K^0\bar{K}^0$	36.6 ± 4.6	$3.4^{+3.4}_{-2.4} \pm 3.5$	1.5	< 7.3

Table 1: Summary of results for detection efficiencies (ϵ), signal yields (N_S), statistical significances and measured branching fractions ($\mathcal{B}$). Upper limits are at 90% CL.

4. Summary

We have measured branching fractions for the rare charmless decay $B^0 \to \rho^{\pm}(770)\pi^{\mp}$ with its asymmetry $\mathcal{A}_{\rm phys}$ and set upper limits on $B^0 \to \rho^0(770)\pi^0$, non-resonant $B^0 \to \pi^+\pi^-\pi^0$, $B^0 \to a_0^{\pm}(\to \eta\pi^{\pm})\pi^{\mp}$ and $B^0 \to K^0\bar{K}^0$.

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