Evidence for Charged $B$ Meson Decays to $a_1^{\pm}(1260)\pi^0$ and $a_0^{0}(1260)\pi^\pm$

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The branching fraction is measured as $\mathcal{B}(B^\pm \rightarrow a_{1}^{0}(1260)\pi^{\pm}) = (13.2 \pm 2.9 \pm 2.1) \times 10^{-6}$ with a significance of $4.2\sigma$, and the branching fraction $\mathcal{B}(B^\pm \rightarrow a_{1}^{0}(1260)\pi^{\pm}) = (20.4 \pm 4.7 \pm 3.4) \times 10^{-6}$ with a significance of $3.8\sigma$, where the first error quoted is statistical and the second is systematic.
The rare decays of $B$ mesons to two-body final states with an $a_1(1260)$ and a $\pi^+\pi^-$, $\pi^0K^+$, or $K_S^0$ are important processes for testing theoretical factorization model predictions for branching fractions, branching fraction ratios, and CP-violation parameters. The measurements can be combined with assumptions about SU(3) symmetries to form upper bounds on $\Delta \alpha = |\alpha - \alpha_{\text{eff}}|$, where $\alpha$ is the weak interaction phase $\alpha = \arg[-V_{ud}V_{ub}^*/V_{ud}V_{ub}]$ of the Unitarity Triangle [1] and $\alpha_{\text{eff}}$ is the measured phase. The difference $\Delta \alpha$ is a measure of the poorly known strength of the penguin amplitudes in the decay and can be used to improve our understanding of the CP-violating mechanism.

The rare decays $B^+ \to a_1^+(1260)\pi^0$ and $B^+ \to a_1^0(1260)\pi^\pm$ are expected to be dominated by $b \to u\bar{d}d$ contributions. The branching fraction for $B^0 \to a_1^0\pi^0$ has been measured to be $(33.2 \pm 3.8 \pm 3.0) \times 10^{-6}$ [2], and this agrees well with the calculation of Bauer, Stech, and Wirbel [3] within the framework of naive factorization and assuming $|V_{ub}/V_{cb}| = 0.08$. A more recent analysis using naive factorization and measured form factors predicts branching fractions in the range $(5 - 11) \times 10^{-6}$ and $(4 - 9) \times 10^{-6}$ for $B^+ \to a_1^+\pi^0$ and $B^+ \to a_1^0\pi^\pm$, respectively [4]. Previous measurements have placed 90% confidence level upper limits of $1.7 \times 10^{-3}$ and $9 \times 10^{-4}$ on the branching fractions for $B^+ \to a_1^+\pi^0$ and $B^+ \to a_1^0\pi^\pm$, respectively [5], and recently the BABAR collaboration reported the first measurements of the CP-violating asymmetries in the decay $B^0 \to a_1^+\pi^\mp$ [6].

We present measurements of the branching fractions for the two charmless $B$ meson decays $B^+ \to a_1^+\pi^0$ and $B^+ \to a_1^0\pi^\pm$ where the final state contains one neutral and three charged pions. The $a_1 \to 3\pi$ decay proceeds mainly through the intermediate states $(\pi \pi\pi)_{\rho}$ and $(\pi \pi\pi)_{\sigma}$ [7]. We do not distinguish between the dominant $P$-wave $(\pi \pi)_{\rho}$ and the $S$-wave $(\pi \pi)_{\sigma}$ in the channel $\pi^+\pi^-$. Possible background contributions from $B \to a_1^-(1320)\pi$ are investigated. Charge conjugate modes are implied throughout this Letter.

The data were collected with the BABAR detector [8] at the PEP-II asymmetric $e^+e^-$ collider. An integrated luminosity of 211 fb$^{-1}$, corresponding to $232 \times 10^9 \bar{B}\bar{B}$ pairs, was recorded at the $Y(4S)$ resonance (“on-resonance”) at a center-of-mass (c.m.) energy $\sqrt{s} = 10.58$ GeV. An additional 20 fb$^{-1}$ were taken about 40 MeV below this energy (“off-resonance”) for the study of the continuum background in which a charm or lighter quark pair is produced.

Charged particles are detected and their momenta measured by the combination of a silicon vertex tracker, consisting of five layers of double-sided silicon detectors, and a 40-layer central drift chamber, both operating in the 1.5-T magnetic field of a solenoid. The tracking system covers 92% of the solid angle in the c.m. frame. 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. A $K/\pi$ separation of better than 4 standard deviations ($\sigma$) is achieved for momenta below 3 GeV/c, decreasing to $2.5\sigma$ at the highest momenta in the $B$ decay final states.

The off-resonance data together with the Monte Carlo (MC) simulations of the signal decay modes, continuum, $\bar{B}\bar{B}$ backgrounds, and detector response [9] are used to establish the event selection criteria and reconstruction efficiency. The MC signal events are simulated as $B^+$ decays to $a_1 \pi$ with $a_1 \to \rho \pi$. The $a_1$ and $a_2$ line shapes are generated with EVTGEN [10], where we use mass and width parameters from Refs. [2,7].

Two photons with a minimum energy of 30 MeV (100 MeV for $B^+ \to a_1^0\pi^0$) and an invariant mass of $120 < m_{\gamma\gamma} < 150$ MeV/$c^2$ are used to reconstruct the $\pi^0$. The intermediate dipion states $(\pi^+\pi^-)$ or $(\pi^+\pi^0)$ are required to have an invariant mass of $0.46 < m_{\pi\pi} < 1.1$ GeV/$c^2$. We impose PID requirements to cleanly identify the charged pions and to suppress contamination from $a_1 K$. We require the invariant mass reconstructed for candidate $a_1^+ \to \pi^+\pi^+\pi^-$ and $a_1^0 \to \pi^+\pi^-\pi^0$ decays to be $0.8 < m_{a_1} < 1.8$ GeV/$c^2$.

A $B$ meson candidate is characterized kinematically by the energy-substituted mass $m_{ES} = \sqrt{(s/2 + p_0 \cdot p_B)^2/E_0^2 - p_B^2}$ and energy difference $\Delta E = E_B^0 - \sqrt{s}/2$, where the subscripts 0 and $B$ refer to the initial $Y(4S)$ and to the $B$ candidate in the lab frame, respectively, and the asterisk denotes the $Y(4S)$ frame. The resolutions in $m_{ES}$ and in $\Delta E$ are about 3.0 MeV/$c^2$ and 20 MeV, respectively. Candidates are required to have $5.25 \leq m_{ES} \leq 5.29$ GeV/$c^2$ and $|\Delta E| \leq 0.2$ GeV. To reduce fake $B$ meson candidates we require a $B$ vertex $\chi^2$ probability $> 0.01$. The absolute value of the cosine of the angle between the direction of the $\pi$ meson from $a_1 \to \rho \pi$ with respect to the flight direction of the $B$ in the $a_1$ meson rest frame is required to be less than 0.85 to suppress misreconstructed candidates. The distribution of this variable is flat for signal and peaks near $\pm 1$ for misreconstructed candidates.

To reject continuum background, we use the angle $\theta_\rho$ between the thrust axis of the $B$ candidate’s decay products and that of the rest of the tracks and neutral clusters in the event, calculated in the c.m. frame. The distribution of $\cos \theta_\rho$ is sharply peaked near $\pm 1$ for combinations drawn from jetlike $q\bar{q}$ pairs and is nearly uniform for the isotropic $B$ meson decays; we require $|\cos \theta_\rho| < 0.65$.

The decay mode $B \to a_2 \pi$ can also give background contributions. It is suppressed by using the angular variable $A_x$, defined as the cosine of the angle between the normal to the plane of the $3\pi$ resonance and the flight direction of the $a_2$.
the bachelor pion evaluated in the $3\pi$ resonance rest frame. Since the $a_1$ and $a_2$ have spins of 1 and 2, respectively, the distributions of $\mathcal{A}$ for these two resonances differ. We require $|\mathcal{A}| < 0.6$, which reduces the $a_2$ background by more than a factor of 2 in both decay channels.

After all the above selections, we have on average 1.20 and 1.56 candidates per event in events where there is at least one candidate, for $B^+ \rightarrow a_1^+ \pi^0$ and $B^+ \rightarrow a_0^0 \pi^+$, respectively, and we select the $B$ candidate with the $(\pi\pi)$ mass nearest to the nominal $\rho$ mass [7]. From the simulation, we find that this algorithm selects the correct-combination candidate in $B^+ \rightarrow a_1^+ \pi^0$ and $B^+ \rightarrow a_0^0 \pi^+$ in 65% and 55% of events containing multiple candidates, respectively.

We use an unbinned maximum-likelihood fit using five variables to extract the background and signal yields of $B^+ \rightarrow a_1^+ \pi^0$ and $B^+ \rightarrow a_0^0 \pi^+$. We describe the $B$ decay kinematics with the two variables $\Delta E$ and $m_{ES}$. We also include the invariant mass of the $3\pi$ system ($m_{a_1}$), the variable $\mathcal{A}$ and a Fisher discriminant $\mathcal{F}$. This discriminant combines four variables: the angles with respect to the beam axis of the $B$ momentum and $B$ thrust axis in the c.m. frame, and the zeroth and second angular moments of the energy flow around the $B$ thrust axis [2].

The extended likelihood function is

$$\mathcal{L} = \frac{1}{N!} \exp \left( -\sum_j n_j \right) \prod_i \left[ \sum_j n_j P_j (\vec{x}_i; \vec{\alpha}_j) \right],$$

where $n_j$ is the yield of events for hypothesis $j$ (signal, $a_2$, $B\bar{B}$ charmless, $B\bar{B}$ charm, or continuum) and $N$ is the number of events in the sample. The probabilities $P_j$ are products of probability density functions (PDF) for each of the independent variables $\vec{x}_i = \{m_{ES}, \Delta E, m_{a_1}, \mathcal{F}, \mathcal{A}\}$ evaluated for each event $i$. The $\vec{\alpha}_j$ are the parameters of the distributions in $\vec{x}_i$. By minimizing the quantity $-\ln \mathcal{L}$ in two separate fits, we determine the yields for $B^+ \rightarrow a_1^+ \pi^0$ and $B^+ \rightarrow a_0^0 \pi^+$. To take into account the relatively large number of misreconstructed signal events, the signal is separated into two components, representing the correctly reconstructed (true) and the self-cross-feed (SCF) candidates, with proportions fixed in the fit for each mode. SCF occurs when a track from an $a_1^+ \pi^0$ or $a_0^0 \pi^+$ is exchanged with a track from the rest of the event. The fraction of SCF, determined from MC, is 35% and 44% for $B^+ \rightarrow a_1^+ \pi^0$ and $B^+ \rightarrow a_0^0 \pi^+$, respectively.

In addition to the $a_2$, there are three main categories of backgrounds: $B\bar{B}$ charmless, $B\bar{B}$ charm, and continuum. $B\bar{B}$ backgrounds are studied using MC simulations of $B^0\bar{B}^0$ and $B^+\bar{B}^-$ decays, using a large sample equivalent to $-0.8$ ab$^{-1}$. There are $17 B\bar{B}$ charmless decays for $B^+ \rightarrow a_1^+ \pi^0$ and 20 for $B^+ \rightarrow a_0^0 \pi^+$ that contribute as background. Those decays with similar distributions are grouped to form 13 and 10 hypotheses, respectively, and are included in the fit with a fixed yield as determined from MC. The total $B\bar{B}$ charmless yields are $368 \pm 92$ and $755 \pm 164$ for $B^+ \rightarrow a_1^+ \pi^0$ and $B^+ \rightarrow a_0^0 \pi^+$, respectively. These are dominated by $B \rightarrow \rho \rho$, $B \rightarrow a_1 \rho$, and the other $B \rightarrow a_1 \pi$ mode under study. The $B\bar{B}$ charm backgrounds are included as a single hypothesis, with the normalization of the $B\bar{B}$ charm yield as a free parameter. Continuum events come from light quark production. We establish the functional forms and parameter values of the PDFs for $B\bar{B}$ charm and $B\bar{B}$ charmless backgrounds from MC simulations. For continuum, we use off-resonance data for the Fisher, on-resonance data with $|\Delta E| > 0.1$ GeV for $m_{ES}$, and on-resonance data with $5.25 < m_{ES} < 5.27$ GeV$/c^2$ for the other variables.

We model the distributions using appropriate functions. The $\mathcal{A}$ distributions are modeled with polynomials. For the true signal component, the remaining distributions are fitted using modified Gaussians [11], and a relativistic Breit-Wigner line shape with a mass-dependent width [12], as necessary. The SCF component and the $a_2$ have similar shapes to the true signal but have broader or more asymmetric distributions and shifted means. The $B\bar{B}$ backgrounds and continuum distributions are modeled with modified Gaussians, polynomials, nonparametric functions [13], and, for $m_{ES}$, a phase-space-motivated empirical function [14]. The PDF variables are assumed to be independent except for $B^+ \rightarrow a_1^+ \pi^+$, where a two-dimensional nonparametric PDF [13] in $m_{a_1}$ and $\Delta E$ accounts for observed correlations in the MC for both true signal events and SCF.

In the fit there are six free parameters: four yields (signal, continuum, $a_2$, and $B\bar{B}$ charm background), and two continuum background parameters ($|\Delta E|$ polynomial coefficient and $m_{ES}$ shape coefficient $\xi$ [14]).

For $B^+ \rightarrow a_1^+ \pi^0$, there are 24,608 events in the data sample. We measure the raw signal yield to be $459 \pm 78$ events with a reconstruction efficiency of $12.5\% \pm 0.1\%$, corrected for differences in tracking and neutral particle reconstruction between data and MC. The yield of the decay $B^+ \rightarrow a_1^+ \pi^0$ is $28 \pm 65$ events. For $B^+ \rightarrow a_0^0 \pi^+$, there are 33,375 events in the data sample, and we measure the raw signal yield to be $382 \pm 79$ events with a corrected reconstruction efficiency of $7.2\% \pm 0.1\%$. The yield of the decay $B^+ \rightarrow a_0^0 \pi^+$ is $107 \pm 65$ events.

We confirm our fitting procedure by generating and fitting MC samples containing signal and background populations using the yields as found from data. We identify a signal yield bias for $B^+ \rightarrow a_1^+ \pi^0$ and $B^+ \rightarrow a_0^0 \pi^+$ of $16.8\% \pm 0.1\%$ and $10.9\% \pm 0.1\%$, respectively. We fit for the branching fractions taking into account the fitted signal yield, the yield bias, the corrected reconstruction efficiency, daughter branching fractions, and the number of produced $B$ mesons, assuming equal production rates of $B^0\bar{B}^0$ and $B^+\bar{B}^-$ pairs. The statistical significance is taken as the square root of the difference between the value of
measure the branching fraction correction. The effect of possible interference between errors are statistical.

independent background component. The fitted branching

B
tions for B and thus do not show all events in the data sample.

with a requirement on the signal likelihood to enhance the signal,

2\ln L for zero signal and the value at its minimum. We measure the branching fraction \( \mathcal{B}(B^+ \to a_1^+ \pi^0) \times \mathcal{B}(a_1^+ \to \pi^- \pi^+ \pi^0) = (13.2 \pm 2.7) \times 10^{-6} \) with a statistical significance of 5.3\( \sigma \) and the branching fraction \( \mathcal{B}(B^+ \to a_1^0 \pi^+) \times \mathcal{B}(a_1^0 \to \pi^- \pi^+ \pi^0) = (20.4 \pm 4.7) \times 10^{-6} \) with a statistical significance of 4.7\( \sigma \), where the errors are statistical.

FIG. 1 (color online). Projections of (a) \( \Delta E \), (b) \( m_{ES} \), (c) \( m_{a_1} \), and (d) \( \mathcal{F} \) for \( B^+ \to a_1^+ \pi^0 \). Points represent on-resonance data, dashed lines the signal, dotted lines the continuum, dash-dotted lines the BB charm background, the filled region the \( a_2 \) background, and solid lines the full fit function. These plots are made with a requirement on the signal likelihood to enhance the signal, and thus do not show all events in the data sample.

\[-2\ln L \text{ for zero signal and the value at its minimum. We measure the branching fraction } \mathcal{B}(B^+ \to a_1^+ \pi^0) \times \mathcal{B}(a_1^+ \to \pi^- \pi^+ \pi^0) = (13.2 \pm 2.7) \times 10^{-6} \text{ with a statistical significance of 5.3} \sigma \text{ and the branching fraction } \mathcal{B}(B^+ \to a_1^0 \pi^+) \times \mathcal{B}(a_1^0 \to \pi^- \pi^+ \pi^0) = (20.4 \pm 4.7) \times 10^{-6} \text{ with a statistical significance of 4.7} \sigma \text{, where the errors are statistical.}

Figures 1 and 2 show the \( \Delta E \), \( m_{ES} \), \( m_{a_1} \), and \( \mathcal{F} \) projections for \( B^+ \to a_1^+ \pi^0 \) and \( B^+ \to a_1^0 \pi^+ \) made by selecting events with a signal likelihood (computed without the variable shown in the figure) exceeding a threshold that optimizes the expected sensitivity.

The systematic errors are summarized in Table I. We determine the sensitivity to the parameters of the signal and background PDF components by varying these within their uncertainties. The effect of varying the mass and width of the \( a_1 \) by the errors as reported in Ref. [2] is included in the PDF parameters’ variation systematic. The uncertainty in the fit bias correction is taken as half of the fit bias correction. The effect of possible interference between \( a_2 \) and \( a_1 \) is estimated by adding the \( a_2 \) and \( a_1 \) amplitudes together with a varying phase difference and using half the maximum change in yield as an uncertainty. The uncertainty in SCF is investigated by varying the SCF fraction. We also perform a separate fit treating the SCF as an independent background component. The fitted branching fraction is compatible with the nominal fit within the increased statistical uncertainty, but the statistical significance is reduced to 3.5\( \sigma \) and 3.0\( \sigma \) for \( B^+ \to a_1^+ \pi^0 \) and \( B^+ \to a_1^0 \pi^+ \), respectively. A systematic uncertainty of 1.6\( \% \) is estimated for the difference in reconstruction efficiency in the decay modes through the dominant P-wave (\( \pi \pi \)) and the S-wave (\( \pi \pi \)). An error is assigned for the uncertainty in the fixed charmless BB background yields and possible interference effects by varying the individual components by the reported error on the branching fractions [7]. The systematic errors for the flight direc-

\begin{table}[h]
\centering
\caption{Summary of systematic errors for the \( a_1^+ \pi^0 \) and \( a_1^0 \pi^+ \) branching fraction measurements.}
\begin{tabular}{|c|c|c|}
\hline
Systematic & \( a_1^+ \pi^0 \) & \( a_1^0 \pi^+ \) \\
\hline
PDF Parameter Variation & 8.6\% & 8.8\% \\
Fit Bias & 8.4\% & 5.5\% \\
\( a_1-a_2 \) Interference & 6.6\% & 7.4\% \\
SCF Variation & 4.4\% & 8.2\% \\
Tracking Efficiency & 3.9\% & 3.9\% \\
\( \pi^0 \) Efficiency & 3.0\% & 3.0\% \\
Flight Direction Criteria & 2.0\% & 2.0\% \\
P-wave and S-wave Reconstruction & 1.6\% & \ldots \\
Charmless BB Background & 1.4\% & 3.1\% \\
Number of BB Pairs & 1.1\% & 1.1\% \\
\cos\theta_2 \ Selection Criteria & 1.1\% & 1.8\% \\
Track Multiplicity & 1.0\% & 1.0\% \\
\( p \pi \pi, 4\pi \) Cross Feed & 0.9\% & 0.5\% \\
\( a_1, K \) Cross Feed & \ldots & 0.4\% \\
Total & 16\% & 16\% \\
\hline
\end{tabular}
\end{table}

\[
\begin{align*}
\text{FIG. 2 (color online). Projections of (a) } \Delta E, \text{ (b) } m_{ES}, \text{ (c) } m_{a_1}, \text{ and (d) } \mathcal{F} \text{ for } B^+ \to a_1^0 \pi^+, \text{ using the same criteria and line styles as Fig. 1.}
\end{align*}
\]
tion criteria, number of $B\bar{B}$ pairs, $\cos\theta_T$ selection criteria, track multiplicity, potential backgrounds from $\rho\pi\pi$ and $4\pi$, and $a_iK$ cross feed are small. The total systematic error for both modes is 16%. The significance of the branching fractions, combining both statistical and systematical errors, is $4.2\sigma$ for $B^+ \rightarrow a_1^+\pi^0$ and $3.8\sigma$ for $B^+ \rightarrow a_1^0\pi^+$. In conclusion, we have measured the branching fractions $\mathcal{B}(B^\pm \rightarrow a_1^\pm (1260)\pi^0) \times \mathcal{B}(a_1^\pm (1260) \rightarrow \pi^-\pi^+\pi^\pm) = (13.2 \pm 2.7 \pm 2.1) \times 10^{-6}$ and $\mathcal{B}(B^\pm \rightarrow a_1^0 (1260)\pi^\pm) \times \mathcal{B}(a_1^0 (1260) \rightarrow \pi^-\pi^+\pi^0) = (20.4 \pm 4.7 \pm 3.4) \times 10^{-6}$. Neglecting isoscalar contributions to the two-pion state, we assume $\mathcal{B}(a_1^+ (1260) \rightarrow \pi^-\pi^+\pi^\pm)$ is equal to $100\%$ [7], resulting in $\mathcal{B}(B^\pm \rightarrow a_1^+ (1260)\pi^0) = (26.4 \pm 5.4 \pm 4.1) \times 10^{-6}$. We measure $\mathcal{B}(B^\pm \rightarrow a_1^0 (1260)\pi^\pm) = (20.4 \pm 4.7 \pm 3.4) \times 10^{-6}$, assuming $\mathcal{B}(a_1^0 (1260) \rightarrow \pi^-\pi^+\pi^0)$ is equal to 100%. The first errors quoted are statistical and the second are systematic. The signals are seen with significances of $4.2\sigma$ and $3.8\sigma$, respectively, and are in agreement with factorization model predictions [3]. We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues, and for the substantial dedicated effort from the computing organizations that support BABAR. The collaborating institutions thank SLAC for its support and kind hospitality. This work is supported by DOE and NSF (USA), NSERC (Canada), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MIST (Russia), MEC (Spain), and STFC (United Kingdom). Individuals have received support from the Marie Curie EIF (European Union) and the A.P. Sloan Foundation.

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[1] B. Aubert et al. (BABAR Collaboration), arXiv:hep-ex/0703008.
[2] B. Aubert et al. (BABAR Collaboration), Phys. Rev. Lett. 97, 051802 (2006).
[3] M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C 34, 103 (1987).
[4] V. Laporta, G. Nardulli, and T.N. Pham, Phys. Rev. D 74, 054035 (2006); arXiv:hep-ph/0602243v4 [Phys. Rev. D (to be published)].
[5] H. Albrecht et al. (ARGUS Collaboration), Phys. Lett. B 241, 278 (1990).
[6] B. Aubert et al. (BABAR Collaboration), Phys. Rev. Lett. 98, 181803 (2007).
[7] S. Eidelman et al., Phys. Lett. B 592, 1 (2004).
[8] B. Aubert et al. (BABAR Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A 479, 1 (2002).
[9] S. Agostinelli et al., Nucl. Instrum. Methods Phys. Res., Sect. A 506, 250 (2003).
[10] D. J. Lange, Nucl. Instrum. Methods Phys. Res., Sect. A 462, 152 (2001).
[11] J. E. Gaiser et al., Phys. Rev. D 34, 711 (1986).
[12] T. A. Armstrong et al. (WA76 Collaboration), Z. Phys. C 48, 213 (1990).
[13] K. S. Cranmer, Comput. Phys. Commun. 136, 198 (2001).
[14] With $x \equiv m_{ES}/E_b$ and $\xi$ a parameter to be fit, $f(x) \propto x\sqrt{1-x^2}\exp[-\xi(1-x^2)]$. See Ref. [5].