Measurement of the Branching Fraction and $\bar{\Lambda}$ Polarization in $B^0 \to \bar{\Lambda}p\pi^-$

B. Aubert, Y. Karyotakis, J. P. Lees, V. Poireau, E. Prencipe, X. Prudent, and V. Tisserand
Laboratoire d’Annecy-le-Vieux de Physique des Particules (LAPP),
Université de Savoie, CNRS/IN2P3, F-74941 Annecy-Le-Vieux, France

J. Garra Tico and E. Grauges
Universitat de Barcelona, Facultat de Física, Departament ECM, E-08028 Barcelona, Spain

M. Martinelli$^a$, A. Palano$^{ab}$, and M. Pappagallo$^{ab}$
INFN Sezione di Bari$^a$; Dipartimento di Fisica, Università di Bari$^a$, I-70126 Bari, Italy

G. Eigen, B. Stugu, and L. Sun
University of Bergen, Institute of Physics, N-5007 Bergen, Norway

M. Battaglia, D. N. Brown, L. T. Kerth, Yu. G. Kolomensky, G. Lynch, I. L. Osipenkov, K. Tackmann, and T. Tanabe
Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA

C. M. Hawkes, N. Soni, and A. T. Watson
University of Birmingham, Birmingham, B15 2TT, United Kingdom

H. Koch and T. Schroeder
Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany

D. J. Asgeirsson, B. G. Fulsom, C. Hearty, T. S. Mattison, and J. A. McKenna
University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1

M. Barrett, A. Khan, and A. Randle-Conde
Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom

V. E. Blinov, A. D. Bukin$^c$, A. R. Buzykaev, V. P. Druzhinin, V. B. Golubev, A. P. Onuchin, S. I. Serednyakov, Yu. I. Skovpen, E. P. Solodov, and K. Yu. Todyshev
Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

M. Bondioli, S. Curry, I. Eschrich, D. Kirkby, A. J. Lankford, P. Lund, M. Mandelkern, E. C. Martin, J. Schultz, and D. P. Stoker
University of California at Irvine, Irvine, California 92697, USA

H. Atmacan, J. W. Gary, F. Liu, O. Long, G. M. Vitug, Z. Yasin, and L. Zhang
University of California at Riverside, Riverside, California 92521, USA

V. Sharma
University of California at San Diego, La Jolla, California 92093, USA

C. Campagnari, T. M. Hong, D. Kovtunskyi, M. A. Mazur, and J. D. Richman
University of California at Santa Barbara, Santa Barbara, California 93106, USA

T. W. Beck, A. M. Eisner, C. A. Heusch, J. Kroseberg, W. S. Lockman, A. J. Martinez, T. Schalk, B. A. Schumm, A. Seiden, L. Wang, and L. O. Winstrom
University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA

C. H. Cheng, D. A. Doll, B. Echenard, F. Fang, D. G. Hitlin, I. Narinsky, T. Piatenko, and F. C. Porter
California Institute of Technology, Pasadena, California 91125, USA

R. Andreassen, G. Mancinelli, B. T. Meadows, K. Mishra, and M. D. Sokoloff
University of Cincinnati, Cincinnati, Ohio 45221, USA

P. C. Bloom, W. T. Ford, A. Gaz, J. F. Hirschauer, M. Nagel, U. Nauenberg, J. G. Smith, and S. R. Wagner
We present a measurement of the $B^0 \to \bar{\Lambda}p\pi^-$ branching fraction performed using the BABAR detector at the PEP-II asymmetric $e^+e^-$ collider. Based on a sample of $467 \times 10^6 B\bar{B}$ pairs we measure $B(B^0 \to \bar{\Lambda}p\pi^-) = (3.07 \pm 0.31(\text{stat.}) \pm 0.23(\text{syst.})) \times 10^{-6}$. The measured differential spectrum as a function of the dibaryon invariant mass $m(\bar{\Lambda}p)$ shows a near-threshold enhancement similar to that observed in other baryonic $B$ decays. We study the $\bar{\Lambda}$ polarization as a function of $\bar{\Lambda}$ energy in the $B^0$ rest frame ($E^*_{\bar{\Lambda}}$) and compare it with theoretical expectations of fully longitudinally right-polarized $\bar{\Lambda}$ at large $E^*_{\bar{\Lambda}}$.

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I. INTRODUCTION

Observations of charmless three-body baryonic $B$ decays have been reported recently by both the Belle and BABAR collaborations. A common feature of these decay modes is the peaking of the baryon-antibaryon mass spectrum near threshold. This feature has stimulated considerable interest among theorists as a key element in the explanation of the unexpectedly high branching fractions for these decays.

In the standard model, the $B^0 \to \bar{\Lambda}p\pi^-$ decay proceeds through tree level $b \to u$ and penguin $b \to s$ amplitudes. It is of interest to study the structure of the decay amplitude in the Dalitz plane to test theoretical expectations. The weak decay $\bar{\Lambda} \to \bar{p}\pi^+$ is spin self-analyzing. Since
the $\bar{s}$ quark carries the $\bar{\Lambda}$ spin, the V-A transition $b \to s$ leads to the expectation that the $\Lambda$ is fully longitudinally right-polarized at large $\Lambda$ energy in the $B^0$ rest frame. This channel may also be used to search for direct $CP$ violation.

II. DATASET AND SELECTION

The data sample consists of $467 \times 10^6$ $BB$ pairs, corresponding to an integrated luminosity of $426$ fb$^{-1}$, collected at the $T(4S)$ resonance with the $BABAR$ detector. The detector is described in detail elsewhere. Charged-particle trajectories are measured in a tracking system consisting of a five-layer double-sided silicon vertex tracker (SVT) and a 40-layer central drift chamber (DCH), both operating in a 1.5-T axial magnetic field. A ring-imaging Cherenkov detector (DIRC) is used to detect and identify photons and electrons, while muons and hadrons are identified in the instrumented flux return of the magnet (IFR). A $BABAR$ detector Monte Carlo simulation based on GEANT4 is used to optimize selection criteria and determine selection efficiencies.

We reconstruct $\bar{\Lambda}$ candidates in the $\bar{\Lambda} \to \bar{p}\pi$ decay mode as combinations of oppositely charged tracks, assign the proton and pion mass hypotheses, and fit to a common vertex. Combinations with invariant mass in the range $1.111 - 1.121$ GeV$/c^2$ are refit requiring the track pairs to originate from a common vertex and constraining the mass to the world-average $\Lambda$ mass. Candidate $B^0$ mesons are formed by combining $\bar{\Lambda}$ candidates with two additional oppositely charged tracks, each with momentum transverse to the beam greater than 50 MeV$/c$.

Measurements of the average energy loss $(dE/dx)$ in the tracking devices, the angle of the Cherenkov cone in the DIRC, and energies deposited in the EMC and IFR are combined to give a likelihood estimator $L_\alpha$ for a track to be consistent with a given particle hypothesis $\alpha$. We require that the $\bar{\Lambda}$-decay proton candidates satisfy the particle-identification criteria $L_p/L_K > 0.33$ and $L_p/L_\pi > 1$ to discriminate from kaons and pions, respectively. The candidate protons, which are assumed to originate from the $B^0$ decay vertex, are analyzed with a selection algorithm based on bagged decision trees which provide efficient particle discrimination, retaining 96.4% of the signal candidates and 17.8% of the background. The candidate pions from the $B^0$ vertex are required to pass a similar selection algorithm, tuned to discriminate pions, that retains 98.8% of the signal and 66.8% of the background. A Kalman fit to the full decay sequence is used to reconstruct the $B^0$ vertex using the position of the beam spot and the total beam energy as kinematic constraints. Only candidates with a fit probability $P_{\text{rec}} > 10^{-6}$ are considered, a requirement that retains 94.4% of the signal and 58.2% of the background.

The primary background arises from light-quark continuum events $e^+e^- \to q\bar{q} (q = u,d,s,c)$, which are characterized by collimation of final-state particles with respect to the quark direction, in contrast to the more spherical $BB$ events. Exploiting this shape difference, we increase the signal significance using event-shape variables computed from the center-of-mass (CM) momenta of charged and neutral particles in the event. For each event, we combine the sphericity, the angle between the $B^0$ thrust axis and detector longitudinal axis, and the zeroth and second-order Legendre polynomial moments of the tracks not associated with the reconstructed $B$ candidate, into a Fisher discriminant, where the coefficients are chosen to optimize the separation between signal and continuum-background Monte Carlo samples. We find that the selection using the optimal cut on the Fisher discriminant retains 72% of the candidates from the signal Monte Carlo sample and 8% from the continuum-background Monte Carlo sample.

To further reduce the combinatoric background, we take advantage of the long mean lifetime of $\Lambda$ particles and require that the separation of the $\Lambda$ and $B^0$ vertices, divided by its measurement error, computed on a per-candidate basis by the fit procedure, exceeds 20. This criterion is optimized on Monte Carlo events and is effective in rejecting 42% of combinatoric background that survives all other selection requirements, while retaining 90% of the signal candidates. The only sizable $B^0$ background is from the process $B^0 \to \Lambda_c^- p \to \Lambda_c \pi^-$, which we suppress by removing candidates with an invariant mass $m(\Lambda_c^- \pi^-)$ within 5 standard deviations (20 MeV/$c^2$) of the nominal $\Lambda_c$ mass.

The kinematic constraints on $B^0$ mesons produced at the $T(4S)$ allow further background discrimination from the variables $m_{\text{ES}}$ and $\Delta E$. We define $m_{\text{ES}} = \sqrt{(\vec{r} + \vec{p}_B)^2 / E_i^2 - \vec{p}_B^2}$, where $(E_i, \vec{p}_i)$ is the four momentum of the initial $e^+e^-$ system and $\vec{p}_B$ is the momentum of the reconstructed $B^0$ candidate, both measured in the laboratory frame, and $s$ is the square of the total energy in the $e^+e^-$ center-of-mass frame. We define $\Delta E = E_B - \sqrt{s}$, where $E_B$ is the $B^0$ energy in the $e^+e^-$ center-of-mass frame. Signal candidates have $m_{\text{ES}}$ close to the $B^0$ mass and $\Delta E$ near zero. Candidates satisfying $|\Delta E| < 100$ MeV and $5.20 < m_{\text{ES}} < 5.29$ GeV/$c^2$ are used in the maximum-likelihood fitting process.

III. BRANCHING FRACTION

We measure the branching fraction with a maximum-likelihood fit on the $m_{\text{ES}}$-$\Delta E$ observables of reconstructed $B^0$ candidates. The $\chi^2$-plot technique is then used to determine the $m(\Lambda\bar{p})$ distribution and, after correcting for the nonuniform reconstruction efficiency, measure the $m(\Lambda\bar{p})$-dependent differential branching fraction.
candidates in which all particles are correctly assigned in the decay chain. By self-cross-feed, we refer to events in which \( B^0 \) mesons decay to \( \bar{A}p\pi \) and are reconstructed as signal candidates in which one or more particles are not correctly assigned in the decay chain. An example of such a misreconstruction is where the protons from the signal \( B^0 \) and \( \Lambda \) decays are interchanged. We define the probability density function (PDF) in the \( \Delta E-m_{\text{ES}} \) plane as the sum of signal, self-cross-feed, and background components. The likelihood function is given by

\[
\mathcal{L} = \frac{1}{N!} e^{-(N_S+N_{\text{scf}}+N_B)} \prod_{e=1}^{N} \left\{ N_S \mathcal{P}_S(y_e) + N_{\text{scf}} \mathcal{P}_{\text{scf}}(y_e) + N_B \mathcal{P}_B(y_e) \right\},
\]

where \( y_e = (m_{\text{ES},e}, \Delta E_e) \), the product is over the \( N \) fitted candidates with \( N_S \) and \( N_B \) representing the numbers of signal and background events, and \( N_{\text{scf}} = N_S - N_B \) representing the self-cross-feed contribution. The three PDFs are taken as products of one-dimensional \( \Delta E \) and \( m_{\text{ES}} \) PDFs. We are justified in this simplification by the small correlation between these two variables in our Monte Carlo sample. The \( m_{\text{ES}} \) PDF is taken as a sum of two Gaussians for the signal and an ARGUS function \cite{17} for the background. The \( \Delta E \) PDF is taken as a sum of two Gaussians for the signal and a first-order polynomial for the background. Finally, the self-cross-feed contribution shows a peaking component that is modeled as the product of a sum of two Gaussians in \( \Delta E \), and a single Gaussian in \( m_{\text{ES}} \). We determine \( f_{\text{scf}} = 0.006 \) and the other parameters that characterize this background from fits to simulated events.

We fit the means of the narrow \( \Delta E \) and \( m_{\text{ES}} \) signal Gaussians, the coefficient in the exponential of the Argus function, the linear coefficient of the \( \Delta E \) background distribution, and the event yields \( N_S \) and \( N_B \). The means of the wide Gaussians are determined by applying Monte Carlo-determined offsets to the means of the narrow ones, such that only an overall shift of the fixed PDF shape is allowed. All other parameters used in the likelihood definition are fixed to values determined from fits to Monte Carlo-simulated events.

Once the maximum-likelihood fit provides the best estimates of the PDF parameters, we use the \( s\mathcal{P}\) plot technique to reconstruct the efficiency-corrected \( m(\bar{A}p) \) distribution and measure the branching fraction. The PDF is used to compute the s-weight for the \( n \)th component of event \( e \) as

\[
s\mathcal{P}_n(y_e) = \frac{\sum_{j=1}^{n_c} V_{nj} \mathcal{P}_j(y_e)}{\sum_{k=1}^{n_c} N_k \mathcal{P}_k(y_e)},
\]

where the indices \( n, j, \) and \( k \) run over the \( n_c = 3 \) signal, background, and self-cross-feed components. The symbol \( V_{nj} \) is the covariance matrix of the event yields as measured from the fit to the data sample. An important property of the \( s\mathcal{P}\) plot is that the sum of the \( s\)-weights for the signal or background component equals the corresponding number of fitted signal or background events.

We have demonstrated with simulated experiments that the \( s\mathcal{P}\) plot is an unbiased and nearly optimal estimator of the \( m(\bar{A}p) \) distribution. To retrieve the efficiency-corrected number of signal events in a given \( m(\bar{A}p) \) bin \( J \), we use the s-weight sum

\[
\tilde{N}_{S,J} = \sum_{e \in J} \frac{s\mathcal{P}_s(y_e)}{\varepsilon(x_e)},
\]

where the per-event efficiency \( \varepsilon(x_e) \) depends on the position \( x_e = (m_{\bar{A}p}, \cos \Theta_{\bar{A}p}) \) in the square Dalitz plane. Here \( \Theta_{\bar{A}p} \) is the angle between the momenta of the pion and the \( \Lambda \) candidate in the \( \bar{A}p \) rest frame, and the efficiency is determined over a \( 20 \times 20 \) grid in the Dalitz plane, using fully reconstructed signal-Monte Carlo events. The error \( \sigma[\tilde{N}_{S,J}] \) in \( \tilde{N}_{S,J} \) is given by

\[
\sigma^2[\tilde{N}_{S,J}] = \sum_{e \in J} \left( \frac{s\mathcal{P}_s(y_e)}{\varepsilon(x_e)} \right)^2 .
\]

An estimate of the efficiency-corrected number of signal events in the sample is given by the sum of the efficiency-corrected \( s\)-weights, or

\[
\tilde{N}_S = \sum_J \tilde{N}_{S,J} ,
\]

and the branching fraction is obtained from

\[
B(B^0 \to \bar{A}p\pi^-) = \frac{\tilde{N}_S}{N_{\bar{B}\bar{B}}} \cdot B(\Lambda \to p\pi) ,
\]

where \( N_{\bar{B}\bar{B}} \) is the total number of \( B\bar{B} \) pairs and \( B(\Lambda \to p\pi) = 0.639 \pm 0.005 \) \cite{10}. Using a collection of Monte Carlo pseudoexperiments, in which signal candidates, generated and reconstructed with a complete detector simulation, were mixed with background candidates, generated according to the background PDF, we confirm that this procedure provides a measurement of the branching fraction with negligible biases and accurate errors.

We can measure the CP-violating branching-fraction asymmetry by tagging the flavor of the \( B^0 (\bar{B}^0) \) meson with the charge of its daughter proton (antiproton). We repeat the maximum-likelihood fit described above including the partial rate asymmetry

\[
A = \frac{B(B^0 \to \bar{A}p\pi^+)-B(B^0 \to \bar{A}p\pi^-)}{B(B^0 \to \bar{A}p\pi^+)+B(B^0 \to \bar{A}p\pi^-)}
\]

as a free parameter. We reduce the effect of systematic differences in particle-identification efficiencies between protons and antiprotons, and between positive and negative pions, by performing the fit on a sample of reconstructed candidates, where protons and pions that originate from the \( \Lambda \) decay satisfy the same particle-identification criteria as those imposed on the protons and pions that originate from the \( B^0 \) vertex.
IV. $\Lambda$ POLARIZATION MEASUREMENT

We study the three orthogonal components of the polarization of $\Lambda$ candidates reconstructed in the $B^0 \rightarrow \Lambda p \pi^-$ decay as a function of $E^*_\Lambda$, the $\Lambda$ energy in the $B^0$ rest frame [10]. The distribution of the helicity angle $\theta_H$ for the $\Lambda$ decay is given by

$$\frac{1}{\Gamma} \frac{d\Gamma}{d\cos \theta_H} = \frac{1}{2} \left[ 1 + \alpha_\Lambda P \left( E^*_\Lambda \right) \cos \theta_H \right],$$

(8)

where $\theta_H$ is the angle between the antiproton direction, in the $\Lambda$ rest frame, and either $L$, the unit vector in the direction of the $\Lambda$ in the $B^0$ rest frame, of the proton and the $\Lambda$; or (2) $T = L \times T$, the unit vector along the direction of the cross product between the momenta, in the $B^0$ rest frame, of the proton and the $\Lambda$; if (3) $N = L \times T$. The symbol $P \left( E^*_\Lambda \right)$ is the component of the $\Lambda$ polarization in the $L$, $T$, or $N$ direction as a function of $E^*_\Lambda$, and $\alpha_\Lambda$ is the $\Lambda$ decay-asymmetry parameter [10]. $CP$ conservation in $B^0 \rightarrow \Lambda p \pi^-$ decays implies that

$$\alpha_\Lambda P_{[L,N]} \left( B^0 \rightarrow \Lambda p \pi^- \right) \left( E^*_\Lambda \right) = \alpha_\Lambda P_{[L,N]} \left( B^0 \rightarrow \bar{\Lambda} p \pi^- \right) \left( E^*_\bar{\Lambda} \right),$$

(9)

while the product $\alpha_\Lambda P_T$ changes sign under $CP$ conjugation. We use these relations to fit the $B^0$ and $\bar{B}^0$ candidate samples together.

We use a maximum-likelihood fit in $m_{ES}$, $\Delta E$, $E^*_\Lambda$, and cos$\theta_H$ to measure the polarization as a function of $E^*_\Lambda$ along each of the three axes defined above. We divide the $E^*_\Lambda$ range into three bins with boundaries 1.10, 1.53, 1.80, and 2.40 GeV, chosen in order to have similar numbers of signal events in each bin. We define a PDF as the sum of signal and background components. The likelihood is

$$\mathcal{L} = \frac{1}{N!} \prod_{k=1}^{3} \prod_{e=1}^{N_k} e^{-\left(N_{k,s}+N_{k,b}\right)} \prod_{e=1}^{N_k} \left[ N_{k,S} P'_{k,S}(z_e) \mathcal{P}_S(y_e) + N_{k,B} P'_{k,B}(z_e) \mathcal{P}_B(y_e) \right],$$

(10)

where we have divided the observables into two sets $y_e = (m_{ES}, \Delta E)$ and $z_e = (\cos \theta_H, E^*_\Lambda)$, and the products are over the three bins in $E^*_\Lambda$ and over the $N_k$ events that populate the $k$th bin, where $N_{k,S}$ and $N_{k,B}$ represent the numbers of fitted signal and background events. The $\mathcal{P}_{S,B}(y_e)$ PDFs are the same functions used in the branching-fraction measurement. However the self-cross-feed component is not included since it corresponds to a negligible fraction of the signal events. For the $k$th bin in $E^*_\Lambda$, the signal (cos$\theta_H, E^*_\Lambda$) PDF is written as the product of the differential branching fraction of Eq. 8 times the signal-reconstruction efficiency $\epsilon(\theta_H, E^*_\Lambda)$:

$$P'_{k,S} \left( \theta_H, E^*_\Lambda \right) = \frac{1}{2} \left[ \epsilon \left( \theta_H, E^*_\Lambda \right) \left( 1 + \alpha_\Lambda P \right) \right],$$

(11)

where the $\{\alpha_\Lambda P\}_k$ are fit parameters. The signal-selection efficiency is measured with a sample of reconstructed signal-Monte Carlo events that pass the same selection criteria as those used to define the data sample. We bin the signal efficiency in $20 \times 20$ rectangular boxes that cover the allowed region of the $E^*_\Lambda$ cos$\theta_H$ plane (Fig. 1).

The background $\theta_H$ distribution is modeled as a linear combination of Chebyshev polynomials up to fourth order. The four coefficients that define the linear combination are fitted independently for each of the three bins in $E^*_\Lambda$. We study the $\theta_H$ distribution of background events using candidates in the sideband region $m_{ES} < 5.27$ GeV/$c^2$, and find it to be nearly independent of $m_{ES}$. We consider this insensitivity as an indication that the shape of the background $\theta_H$ distribution is the same for events in and out of the signal region.

We have confirmed that this PDF representation does not bias the polarization measurement by performing pseudoexperiments in which signal candidates, generated and reconstructed with a complete detector simulation, were mixed with background candidates generated according to the observed helicity distribution in the $m_{ES} < 5.27$ GeV/$c^2$ sideband. The number of signal and background candidates are chosen to match the characteristics of the data.

V. SYSTEMATIC UNCERTAINTIES

Systematic uncertainties in the branching-fraction measurement are listed in Table I and classified as overall uncertainties, uncertainties associated with event selection, and uncertainties associated with fitting the event distribution. We study the uncertainty due to tracking efficiency by comparing data and Monte Carlo for a sample of $\tau$-pair events, in which one $\tau$ decays to one charged track and the other $\tau$ decays to three charged tracks. We separately study the tracking efficiency of $\Lambda$ decay products using an inclusive sample of $\Lambda \rightarrow p\pi$ candi-
TABLE I: Systematic uncertainties on the branching-fraction measurement. “Total” is the sum in quadrature of all the individual contributions.

| Source                        | Uncertainty (%) |
|-------------------------------|-----------------|
| Overall                       | 2.4             |
| Tracking efficiency           | 1.4             |
| PID efficiency                | 0.4             |
| MC statistics                 | 1.1             |
| $BB$ counting                 | 3.2             |
| $B^0\bar{B}^0/BB$ fraction   | 0.8             |
| $\Lambda \to \pi\tau$ branching fraction |              |
| Event selection requirements  | 1.0             |
| Event shape                   | 1.0             |
| Fit probability               | 2.8             |
| $\Lambda$ flight length       | 2.4             |
| $\Lambda_c$ veto             | 0.5             |
| Fit procedure                 | 3.9             |
| Likelihood parameters         | 1.7             |
| $\Delta E$ resolution         | 0.8             |
| Self cross-feed fraction      | 0.6             |
| $P$-Plot bias                 | 7.4             |

We estimate possible biases associated with the determination of yields with the $P$-Plot technique, using an ensemble of Monte Carlo experiments. Signal events, generated and reconstructed with a complete detector simulation, were mixed with background events, generated according to the background PDF. The numbers of events were chosen according to the expected yields in the data sample under study. We estimate an uncertainty of 0.6%.

The main systematic uncertainty in the polarization measurement is associated with the limited statistics of the Monte Carlo sample used to measure the signal-reconstruction efficiency in the $(\cos\theta_{\bar{P}}, E_{\Lambda^*})$ plane, which results in $\sigma_{\Lambda^* P_L(E_{\Lambda^*})}$ uncertainties of 0.05, 0.07, and 0.04 for the three $E_{\Lambda^*}$ bins. Variation of parameters fixed in the likelihood fit within their uncertainties provides additional contributions of 0.004, 0.03, and 0.03 in the three bins, respectively. We correct the fit result for the small biases we observe in a sample of Monte Carlo experiments, where background candidates were generated with the helicity distribution observed in $m_{ES} < 5.27$ GeV/$c^2$ sideband data, and conservatively take these shifts as contributions to the systematic uncertainty.

VI. BRANCHING-FRACTION RESULTS

We select a total of 6360 candidates in the region $|\Delta E| < 100$ MeV, $m_{ES} > 5.2$ GeV/$c^2$, $|m(\Lambda\tau) - m(\Lambda_c)| > 20$ MeV/$c^2$. Table II reports the fitted values of the two-dimensional $m_{ES}\Delta E$ PDF parameters, while Fig. 2 shows projections of the two-dimensional PDF on the $m_{ES}$ and $\Delta E$ axes. Figure 3 shows the efficiency-corrected signal-$P$-Plot distribution of candidates as a function of $m(\bar{P})$, demonstrating a near-threshold enhancement similar to that observed in other baryonic $B$ decays. Summing the content of the efficiency-corrected $P$-Plot bins, we obtain $916 \pm 92$ signal events, where the uncertainty is statistical. Using Eq. 6 we measure the
branching fraction:

\[ B(B^0 \rightarrow \bar{A}p\pi^-) = [3.07 \pm 0.31 \text{(stat.)} \pm 0.23 \text{(syst.)}] \times 10^{-6}. \]

This measurement, which is compatible with a previous measurement by the Belle collaboration [2], confirms the peaking of the baryon-antibaryon mass spectrum near threshold, a feature that plays a key role in the explanation of the larger branching fractions of three-body baryonic B decays compared to two-body decays [5]. From the maximum-likelihood fit to the branching-fraction asymmetry we obtain:

\[ \mathcal{A} = -0.10 \pm 0.10 \text{(stat.)} \pm 0.02 \text{(syst.)}, \]

which is compatible with zero asymmetry.

VII. POLARIZATION RESULTS

Only 3994 candidates populate the \( E_A^* \) range [1.1, 2.4] GeV. Signal candidates are absent in the region with \( E_A^* > 2.4 \) GeV (Fig. 3) as a kinematical consequence of the near-threshold peaking of the baryon-antibaryon mass spectrum.

We plot in Fig. 4 the values of the longitudinal polarization product \( \alpha_A P_L (E_A^*) \) obtained from the maximum-likelihood fit. Table III displays the longitudinal, transverse, and normal polarization measurements in each of the three \( E_A^* \) bins, assuming \( \alpha_A = -0.642 \pm 0.013 \) for the \( \bar{A} \) decay-asymmetry parameter [10]. The results are consistent with full longitudinal right-polarization of \( \bar{A} \)'s from \( B^0 \rightarrow \bar{A}p\pi^- \) decays at large \( E_A^* \) (\( A \)'s would be oppositely polarized). The transverse polarization is not expected to be zero because of the presence of strong final-state interactions.

VIII. CONCLUSIONS

Based on \( 467 \times 10^6 B\bar{B} \) pairs collected by the \( BaBar \) detector at PEP-II, we present a measurement of the \( B^0 \rightarrow \bar{A}p\pi^- \) branching fraction and confirm the peaking of the baryon-antibaryon mass spectrum near threshold, characteristic of three-body baryonic B decays. In ad-
TABLE II: Branching-fraction results. $N_S$ and $N_B$ are the numbers of fitted signal and background events, respectively. The symbol $\mu(\Delta E)$ is the mean for the narrow Gaussian of the $\Delta E$ signal-PDF component, while $c_1(\Delta E)$ is the slope of the linear $\Delta E$ background PDF. $\mu(m_{ES})$ is the mean for the Gaussian of the $m_{ES}$ signal PDF, and $c_{ARGUS}(m_{ES})$ is the coefficient of the exponent in the background $m_{ES}$ Argus function [18]. The uncertainties are statistical.

| Parameter | Value |
|-----------|-------|
| $N_S$     | $183.9^{+19.2}_{-18.5}$ |
| $N_B$     | $6176 \pm 80$ |
| $\mu(\Delta E)$ | $-2.65 \pm 1.84$ MeV |
| $c_1(\Delta E)$ | $-3.5 \pm 0.4$ GeV$^{-1}$ |
| $\mu(m_{ES})$ | $5.2797 \pm 0.0003$ GeV/c$^2$ |
| $c_{ARGUS}(m_{ES})$ | $-14.6 \pm 1.45$ |

TABLE III: Polarization results. $N_S$ and $N_B$ are the numbers of fitted signal and background candidates in each $E_A^p$ bin. We report the values of the longitudinal, transverse, and normal $\Lambda$ polarizations in each of the three $E_A^p$ bins.

| $E_A^p$ range (GeV) | $N_S$ | $N_B$ | $P_L$ | $P_T$ | $P_N$ |
|---------------------|-------|-------|-------|-------|-------|
| 1.10 – 1.53         | 63 \pm 9 | 51 \pm 9 | $-0.08^{+0.47}_{-0.40} \pm 0.09$ | $0.64^{+0.73}_{-0.65} \pm 0.12$ | $0.97^{+0.62}_{-0.62} \pm 0.08$ |
| 1.53 – 1.80         | 519 \pm 23 | 643 \pm 26 | $0.25^{+0.53}_{-0.58} \pm 0.09$ | $0.56^{+0.42}_{-0.48} \pm 0.12$ | $0.05^{+0.61}_{-0.60} \pm 0.08$ |
| 1.80 – 2.40         | 2663 \pm 52 | 2663 \pm 52 | $-0.64^{+0.34}_{-0.33} \pm 0.09$ | $-0.78^{+0.39}_{-0.36} \pm 0.12$ | $0.26^{+0.53}_{-0.53} \pm 0.08$ |

FIG. 4: The product of $\Lambda$ longitudinal polarization and $\alpha_A$ as a function of $E_A^p$. Horizontal bars represent bin ranges.

FIG. 5: $\alpha_B(E_A^p)$ as a function of $E_A^p$. Horizontal bars represent bin ranges.

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$$B(B^0 \to \Lambda p\pi^-) = [3.23^{+0.33}_{-0.29}\text{(stat.)} \pm 0.29\text{(syst.})] \times 10^{-6}.$$  

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The zeroth and second-order Legendre polynomial moments are defined as follows: $L_0 = \sum_i p_i^\ast$ and $L_2 = \sum_i \frac{1}{2}p_i^\ast (3 \cos^2 \theta_i^\ast - 1)$, where $p_i^\ast$ are the magnitudes of the momenta of the tracks and neutral clusters not associated with the reconstructed $B^0$ candidate and $\theta_i^\ast$ are the angles between the momenta and the $B^0$ thrust axis.