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Measurement of the Branching Fraction for $B^+ \to K^{*0}\pi^+$

The *BABAR* Collaboration

Abstract

We present a preliminary result of the branching fraction for the B meson decay to the final state $K^+\pi^-\pi^+$ via an intermediate K^{*0} resonance using the sample of approximately 23 million $B\overline{B}$ mesons produced at the $\Upsilon(4S)$ resonance with the *BABAR* detector at the PEP II e^+e^- collider. The K^{*0} was detected through the decay to the final state $K^+\pi^-$. The result of this analysis is $\mathcal{B}(B^+ \to K^{*0}\pi^+) = (15.5 \pm 3.4 \pm 1.8) \times 10^{-6}$ where the first error is statistical and the second is systematic.

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1 Introduction

Charmless hadronic B meson decays to pseudoscalar-vector final states have contributions from tree and penguin diagrams that are of similar magnitudes. It is expected that the interference between the tree and the penguin contributions may lead to direct CP violation. The measurement of the branching fractions of these charmless decays is an important first step in our understanding of the sizes of the various contributions. Recent measurements of the decays of B mesons to the pseudoscalar-pseudoscalar states involving pions and kaons hint at larger penguin contributions than expected [1].

In this paper we report a preliminary measurement of the branching fraction for the decay $B^+ \to K^{*0}\pi^+$ where the K^{*0} resonance is detected through its decay to the $K^+\pi^-$ final state. Inclusion of charge conjugate states is assumed throughout the paper.

2 The *BABAR* Detector and Dataset

The data used in these analyses were collected with the *BABAR* detector at the PEP-II storage ring [2]. The *BABAR* detector, described in detail elsewhere [3], consists of five active sub-detectors. Surrounding the beam-pipe is a silicon vertex tracker (SVT) to track particles of momentum less than $\sim$120 MeV/c and to provide precision measurements of the positions of charged particles of all momenta as they leave the interaction point. A beam-support tube surrounds the SVT. Outside this is a 40-layer drift chamber (DCH), filled with an 80:20 helium-isobutane gas mixture to minimize multiple scattering, providing measurements of track momenta in a 1.5 T magnetic field. It also provides energy-loss measurements that contribute to charged particle identification. Surrounding the drift chamber is a novel detector of internally reflected Cherenkov radiation (DIRC) that provides charged hadron identification in the barrel region. The DIRC consists of quartz bars of refractive index $\sim$1.42 in which Cherenkov light is produced by relativistic charged particles. The light is internally reflected and collected by an array of photomultiplier tubes, which enable Cherenkov rings to be reconstructed and associated with the charged tracks in the DCH, providing a measurement of particle velocities. Outside the DIRC is a CsI(Tl) electromagnetic calorimeter (EMC) which is used to detect photons and neutral hadrons, and to provide electron identification. The EMC is surrounded by a superconducting coil which provides the magnetic field for tracking. Outside the coil, the flux return is instrumented with resistive plate chambers interspersed with iron (IFR) for the identification of muons and long-lived neutral hadrons.

The data sample used for the analyses contains approximately 23 million $B\overline{B}$ pairs, corresponding to 20.7 fb^{-1} taken near the $\Upsilon(4S)$ resonance. An additional 2.6 fb^{-1} of data were taken approximately 40 MeV below the $\Upsilon(4S)$ resonance to validate the contribution to backgrounds resulting from e^+e^- annihilation into light $q\overline{q}$ pairs. These data have all been processed with reconstruction software to determine the three-momenta and positions of charged tracks and the energies and positions of photons.

3 Analysis Method

3.1 Candidate Selection

The B candidates are reconstructed from three charged tracks. Charged tracks are required to have a transverse momentum greater than 0.1 GeV/c, at least 12 hits in the DCH and to originate close to the beam-spot. A good quality vertex of the three tracks is also required which is 96% efficient for signal.

One of the tracks is required to pass a tight kaon selection based on Cherenkov angle information from the DIRC combined with energy-loss information from the DCH. The track that passes the kaon selection is assigned the kaon mass. The other two tracks, which are candidate pions, are required to fail the kaon selection and are assigned the pion mass. The kaon selection passes 79% of signal kaons and 96% of signal pions pass the pion identification.

The B candidates are required to satisfy kinematic constraints appropriate for B mesons produced by the decay of an $\Upsilon(4S)$. We use two kinematic variables: the energy-substituted B mass $m_{\rm ES} = \sqrt{(s/2 + \mathbf{p}_0 \cdot \mathbf{p}_B)^2/E_0^2 - p_B^2}$, where the subscripts 0 and B refer to the e^+e^- system and the B candidate, respectively; and $\Delta E = E_B^* - \sqrt{s}/2$, where E_B^* is the B candidate energy in the center-of-mass frame. For signal events, the former has a value close to the B meson mass and the latter should be close to zero. In the Monte Carlo simulation of $B^+ \to K^{*0}\pi^-$ the ΔE and m_{ES} distributions are Gaussian and have have resolutions of 18 MeV and 2.4 MeV/c^2 respectively. The requirements on these variables, $\mid \Delta E \mid < 60$ MeV and $\mid m_{ES} - 5279.5 \mid < 7.5$ MeV/c^2, form the signal region in the m_{ES}-ΔE plane. The bounds of the signal region are over three times the Monte Carlo predicted resolutions so that uncertanties in the ΔE and m_{ES} distributions do not contribute significant systematic errors.

The K^{*0} candidate is formed by adding the 4-momenta of the kaon and oppositely charge pion candidates. A window of $0.816 - 0.976$ GeV/c^2 is allowed for the mass of the $K^+\pi^-$ pair, ± 1.6 times the width of the K^{*0} resonance. For B decays to final states formed from a pseudoscalar and a vector meson, the vector meson is longitudinally polarized. The angular distribution of K^{*0} decay products is used to suppress background. The helicity angle, θ_H, is defined as the angle of the K momentum in the K^{*0} rest frame with respect to the momentum of the K^{*0} in the lab frame. The distribution of θ_H follows a $\cos^2\theta_H$ functional form for signal and is essentially flat for background. A requirement of $\mid \cos\theta_H \mid > 0.2$ is used in this analysis.

To avoid bias, the on-resonance events in the signal region were not counted or studied until the analysis method and selection criteria were finalised. Many of the selection criteria were optimized for statistical significance to an assumed branching fraction, as the signal region was blinded. The criteria that were optimized are the mass window on the K^* candidates, $\cos\theta_H$, the criteria on the particle identification and the requirements on event shape discussed in the following section.

3.2 Background Suppression and Characterization

There are two contributions to the background. The dominant background is random combinatorial background but there is also a small contribution from specific B decay channels.

Charmless hadronic modes suffer large amounts of background from random combinations of tracks, mostly from light quark and charm continuum production. Such backgrounds may be reduced by selection requirements on the event topologies computed in the $\Upsilon(4S)$ rest frame. As the B mesons are almost at rest in this frame, they decay spherically, whereas continuum events are jet–like. We use $\cos\theta_T$, the cosine of the angle θ_T between the thrust axis of the B meson decay and the thrust axis of the rest of the event (all tracks and neutral clusters in the event except those that form the B candidate). For continuum-related backgrounds, these two directions tend to be aligned because the fake reconstructed B candidate daughters lie in the same jets as the remaining particles in the event. By contrast, in B events, the decay products from one B meson are independent of those in the other, making the distribution of this angle isotropic. A requirement on the maximum size of $|\cos\theta_T|$ strongly suppresses continuum background. This requirement was optimised to give the greatest significance to the branching fraction. $|\cos\theta_T| < 0.7$ was optimum which is 67% efficient for signal and rejects 90% of continuum events.

Other event shape variables also help to discriminate between $b\bar{b}$ and continuum events. We form a linear combination of 11 variables in a Fisher discriminant $\mathcal{F}$ [4]. The coefficients for each variable are chosen to maximize the separation between training samples of signal and background events. The variables contained in $\mathcal{F}$ are the cosine of the angle between the B momentum and the beam axis, the cosine of the angle between the thrust axis of the B candidate and the beam axis, and the summed momentum of the rest of the event in nine cones coaxial with the thrust axis of the B candidate. The $\mathcal{F}$ requirement is 80% efficient on signal and rejects 60% of continuum events after the $\cos\theta_T$ cut has been applied.

Despite the power of such topological variables to reduce the combinatorial backgrounds, it is necessary to make a background subtraction in measuring the branching fraction. In order to do this, the background in the signal region is estimated from the number of on-resonance data events in a sideband region and extrapolated into the signal region. The sideband region is a larger area than the signal region at lower $m_{\rm ES}$ and is specified by $5.22 < m_{\rm ES} < 5.26\,{\rm GeV}/c^2$, $|\Delta E| < 0.3\,{\rm GeV}$. In order to extrapolate from the sideband region to the signal region the shape of the background in the ΔE-m_{ES} plane must be characterised. This is done using on-resonance data (avoiding the signal region), off-resonance data and Monte Carlo continuum events in the region $5.20 < m_{ES} < 5.29\,{\rm GeV}/c^2$, $|\Delta E| < -0.3\,{\rm GeV}$. The shape of the distribution of the background as a function of $m_{\rm ES}$ is parameterized using the ARGUS function [5] which has one shape parameter, ξ. The background ΔE distribution is quadratic and the integrals over the signal region and sideband depend only on the quadratic coefficient. The quadratic coefficient and ξ values measured for on- and off-resonance data and continuum Monte Carlo (which are consistent) are averaged and used along with the ΔE and m_{ES} requirements to calculate $\mathcal{R}$, the ratio of the number of candidates in the signal region to the number in the sideband region. For this analysis, $\mathcal{R} = 0.0647 \pm 0.00029$.

In order not to underestimate the background, the selection criteria optimisation is done using only half the on-resonance events (every alternative event) and the final number of events in the sideband is measured on the other half of the events.

The B background is supressed by the particle identification, and the K^*, ΔE, and m_{ES} requirements. The remaining B background is then estimated with Monte Carlo events and subtracted from the number of events in the signal region. Possible sources of B-related backgrounds include events with low-multiplicity decays to charm and other charmless decays. Background channels were identified by running over generic $b\bar{b}$ Monte Carlo and a dedicated charmless B decay simulation with loosened analysis requirements. For each background, Monte Carlo events exclusively of that type were studied to predict feed-through. Current branching fractions [6] are used to calculate the number of events expected in the signal region. Three channels have potential contributions, $B^+ \to K^{*0}K$, $B^+ \to \rho^0 K^+$ and $B^+ \to \rho^0\pi^+$ though they are all small. The total amount of B-related background expected in the signal region is only 1.0 ± 0.6 events, the error is from the errors on the branching fractions and is systematic.

Non-resonant $B^+ \to K^+\pi^-\pi^+$ decays and decays to a $K^+\pi^-\pi^+$ final states proceeding through higher $K^+\pi^-$ resonances are expected to be negligable in the signal region (less than one event). Although backgrounds from channels with the same final state are small the possible interference of the amplitudes of these processes may affect the branching fraction in the area of the Dalitz plot under study. This effect is not considered in the the branching fraction calculation but could be as large as 30%. With more data this interference can be studied.

3.3 Branching Fraction Analysis

The branching fraction is calculated using

$$\mathcal{B} = \frac{N_1 - 2\mathcal{R}N_2 - N_{Bbg}}{N_{B\overline{B}} \times \epsilon} \tag{1}$$

where N_1 is the number of candidates in the signal region for on-resonance data; N_2 is the number of candidates in half the on-resonance data observed in the sideband region, so that $2\mathcal{R}N_2$ is the estimated number of background candidates in the signal region; N_{Bbg} is the number of B-related background expected in the signal region; $N_{B\overline{B}}$ is the number of $B\overline{B}$ pairs produced and ϵ is the signal efficiency multiplied by $\mathcal{B}(K^{*0} \to K^+\pi^-) = 2/3$.

For the signal efficiency in Eq. 1, we used simulated signal events, applied the same selection criteria as used for data, and corrected for discrepancies between Monte Carlo and data. The efficiencies due to tracking, particle identification, vertex quality and $\mathcal{F}$ selection criteria are determined from independent control samples derived from the data.

Any discrepancy between the measured track-finding efficiency and that obtained in our simulation is taken into account with a momentum, azimuthal angle, and track multiplicity dependent weight per track. The $\pi^{\pm}$ and $K^{\pm}$ particle identification efficiency was measured in data using a control sample of $D^+ \to \overline{D}^0\pi^+, \overline{D}^0 \to K^+\pi^-$. The efficiency was measured as a function of particle momentum and polar and azimuthal angle.

The efficiency of the $\mathcal{F}$ requirement was measured using the control sample $B^+ \to \overline{D}^0\pi^+, \overline{D}^0 \to K^+\pi^-$ which has the same final state and similar kinematics to the signal mode. The vertex quality requirement efficiency was not measured on this channel as the D^0 may fly before decaying. Instead the control sample $B^+ \to J/\psi K^+, J/\psi \to \mu^+\mu^-$ was used.

4 Treatment of Experimental Uncertainties

The systematic errors associated with branching fraction measurement arise from uncertainties in the background subtraction, in the overall signal efficiency and in the number of $B\overline{B}$ pairs produced as this is only known to 1.6%.

The estimate of the combinatoric background is given as the product of the number of events in the sideband region and the factor $\mathcal{R}$. The number of events observed in the sideband has only a statistical error. The factor $\mathcal{R}$ has a systematic error given by the error in the fitted ARGUS shape parameter, ξ. The contribution from the error in the ΔE characterization is negligible. A systematic uncertainty on $\mathcal{R}$ is estimated from the range of values of ξ measured in different data and different ΔE regions. The error on $\mathcal{R}$ contributes a 2.5% systematic uncertainty to the branching fraction. The error on N_{Bbg} the number of B-related events expected in the signal region, is from the errors on the branching ratios used in the calculation. This contributes 1.8% to the systematic error.

Some uncertainty arises from the limited statistics of the signal Monte Carlo used to estimate the efficiency. The fractional error from this source is 2.3%. The accuracy of the simulation is subject to systematic uncertainties leading to uncertainties in the efficiencies of selection requirements. At present the dominant uncertainties are in the the efficiencies of the particle identification (6.4%), vertex quality cut (6.0%), $\mathcal{F}$ cut (4.1%) and tracking (3.6%). These systematic errors come from the methods used to to calculate the efficiencies in data, explain above.

The uncertainty on the particle identification data efficiency is taken as 5.0% per kaon and 2.0% per pion. The particle identification efficiency errors for the two pions are added coherently but the

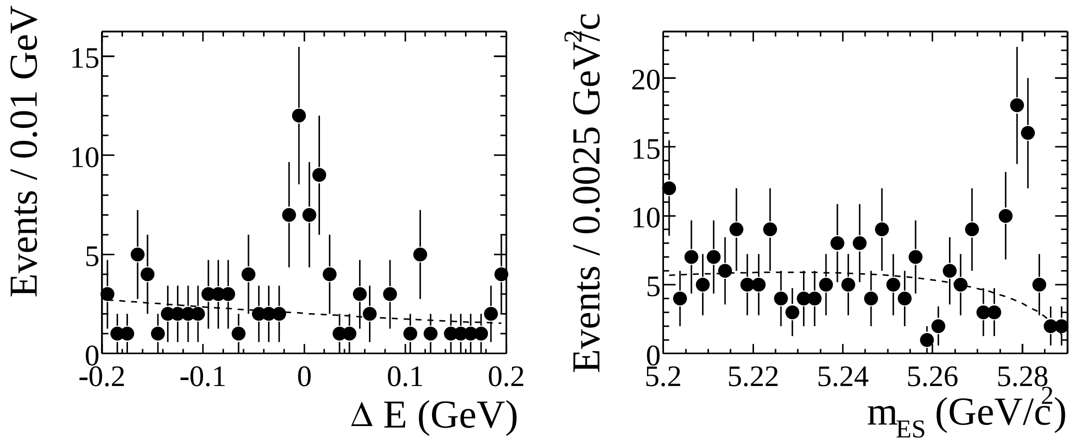

Figure 1: ΔE and m_{ES} distributions for $B^+ \to K^{*0}\pi^+, K^{*0} \to K^+\pi^-$. The lines are the background distributions used in the background subtraction.

pion and kaon identification efficiencies have little correlation and so are added in quadrature. The uncertainty in the determination of the tracking efficiency in data leads to an uncertainty in the tracking efficiency of 1.2% per track, added coherently for all charged tracks in the B candidate.

The overall systematic uncertainty is the sum in quadrature of the contributions from all sources giving a systematic error on the branching fraction of 11%.

5 Physics Results and Conclusion

Our preliminary measurement result of the branching fraction is summarized in Table 1. Figure 1 shows the ΔE and m_{ES} distributions in the signal region with lines showing the background distributions used in the background subtraction. Figure 2 shows the background subtracted K^{*0} candidate mass and $\cos\theta_H$. The lines on the plots are the expected $B^+ \to K^{*0}\pi^+$ distributions. The data is consistent with being polarised K^{*0} mesons as the χ^2 per degree of freedom is less than unity for both distributions.

Events in signal region	55
Events in sideband	148
Ratio, $\mathcal{R}$	0.0647 ± 0.0029
Combinatoric background	$19.1 \pm 1.6 \pm 0.9$
B-related background	1.0 ± 0.6
signal yield	$34.8 \pm 7.6 \pm 1.1$
signal efficiency	$(0.149 \pm 0.004 \pm 0.013) \times 2/3$
Stat. Signif. (σ)	6.0
$\mathcal{B}$ ($\times 10^{-6}$)	$15.5 \pm 3.4 \pm 1.8$

Table 1: A summary of the branching fraction measurement analysis for the decay mode $B^+ \to K^{*0}\pi^+$. The factor of 2/3 in the signal efficiency is the branching fraction of $K^{*0} \to K^+\pi^-$.

In summary, we have measured the branching fraction for B meson decay to the final state

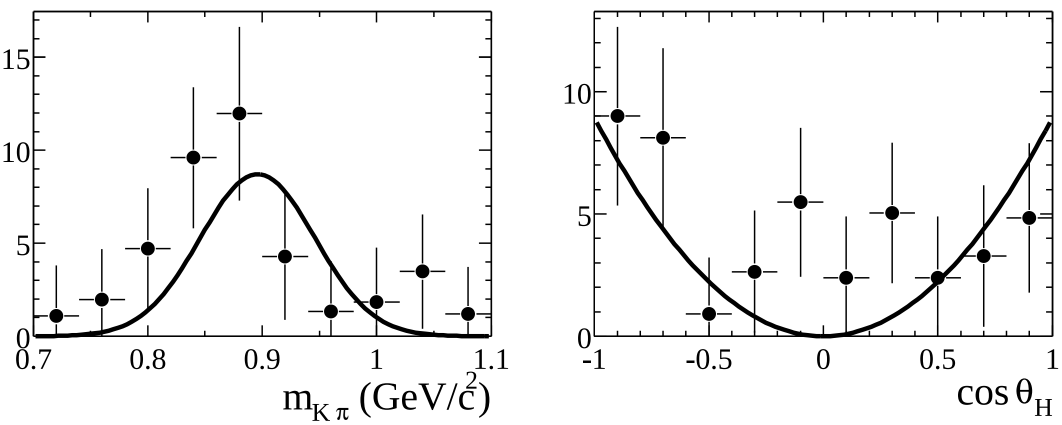

Figure 2: The mass of the K^{*0} candidate and $\cos\theta_H$ for on-resonance data in the signal region with background subtracted. The lines are the expexted $B^+ \to K^{*0}\pi^+$ distributions.

$K^+\pi^-\pi^+$ via an intermediate K^{*0} resonance with a statistical significance of 6.0σ. Our preliminary result is $\mathcal{B}(B^+ \to K^{*0}\pi^+) = (15.5 \pm 3.4 \pm 1.8) \times 10^{-6}$.

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