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Search for the rare decay $B^- \to \Lambda \overline{p} \nu \overline{\nu}$

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We present a search for the rare, flavour-changing-neutral-current decay $B^- \to \Lambda \overline{p} \nu \overline{\nu}$ at the BABAR experiment. We see no evidence for signal decays and set an upper limit of $\mathscr{B}(B^- \to \Lambda \overline{p} \nu \overline{\nu}) < 3.0 \times 10^{-5}$ at the 90% confidence level. This result is the first experimental limit on this decay mode.

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1. Introduction

The process $B^- \to \Lambda \bar{p} \nu \bar{\nu}$[1] is a flavour-changing neutral-current (FCNC) decay. Such decays are heavily suppressed in the Standard Model and appear, at lowest order, at the one-loop level. The predicted branching fraction in the Standard Model is $\mathscr{B}(B^- \to \Lambda \bar{p} \nu \bar{\nu}) = (7.9 \pm 1.9) \times 10^{-7}$ [1].

Due to the rare nature of FCNC decays, they can be used as sensitive probes for new physics. A new particle contributing to the decay signal at the one-loop level could lead to a branching fraction different from that predicted by the Standard Model. Furthermore, by searching for new physics particles indirectly at the one-loop level, we are sensitive to particles with masses beyond the energy of our colliders. $B^- \to \Lambda \bar{p} \nu \bar{\nu}$ is the baryonic equivalent of the FCNC decay $B \to K^{(*)} \nu \bar{\nu}$, both decays proceeding via the same $b \to s \nu \bar{\nu}$ process. $B \to K^{(*)} \nu \bar{\nu}$ has been previously studied at both BABAR [2] and Belle [3].

This analysis uses data collected by the BABAR experiment, which recorded e^+e^- collisions produced by the PEP-II collider. The BABAR experiment is described in detail in Refs [4, 5]. At BABAR, e^+e^- collisions at a centre-of-mass energy of 10.58 GeV were used to produce $\Upsilon(4S)$ resonances which subsequently decayed almost exclusively to $B\bar{B}$ pairs. The BABAR dataset at the $\Upsilon(4S)$ energy has an integrated luminosity of 424 fb^{-1}, equivalent to $(471 \pm 3) \times 10^6$ $B\bar{B}$ pairs [6].

Monte Carlo (MC) simulations are generated for $B\bar{B}$ events, as well as for background processes $e^+e^- \to q\bar{q}$ $(q = u, d, s, c)$ and $e^+e^- \to \tau^+\tau^-$, collectively known as 'continuum' events. Event simulation is performed using EvtGen [7] and JETSET [8], while BABAR detector response is simulated using GEANT4 [9]. We additionally generate a signal sample of $B^- \to \Lambda \bar{p} \nu \bar{\nu}$ events, where we require $\Lambda \to p\pi^-$ and where the B^+ decays generically according to known branching fractions [10].

2. Analysis

In an ideal signal event, a B^+B^- pair is produced via $e^+e^- \to \Upsilon(4S) \to B^+B^-$, with the B^- decaying via $B^- \to \Lambda \bar{p} \nu \bar{\nu}$ and the B^+ decaying generically. Since $B^- \to \Lambda \bar{p} \nu \bar{\nu}$ has two neutrinos in its final state, the B^- cannot be fully reconstructed. We therefore use a technique known as hadronic tag reconstruction [2, 11, 12] to reconstruct B decays using known exclusive hadronic decay modes of the form $B \to SX_{had}$, where S is either $D^{(*)}_{(s)}$ or J/ψ and X_{had} is a combination of kaons and pions. We reconstruct approximately 1,100 exclusive B^0 and B^+ decay modes, although for this analysis only B^+ candidates are kept. B decay modes are also required to pass reconstruction quality cuts relating to: the difference in energy of the reconstructed B meson from that expected based on the known centre-of-mass energy of the e^+e^- collision system, reconstructed B meson mass, and reconstruction efficiency based on MC studies.

By performing a full reconstruction of the B^+ (hereafter referred to as the 'tag B', or B_{tag}), we can take advantage of the clean e^+e^- collision conditions to completely define the kinematics of the B^- (hereafter referred to as the 'signal B', or B_{sig}). Since the B_{tag} is fully reconstructed, all remaining final state particles in the event can be assumed to originate from the B_{sig}. In addition, any missing momentum in the event can be assumed to originate from the B_{sig} decay.

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[1] CP conjugates are implied throughout this paper unless stated otherwise.

$B_{\rm tag}$ candidates are required to have a reconstructed mass satisfying $5.20 < m_{Btag} < 5.30\,{\rm GeV}/c^2$. We search for our signal in the region $5.27 < m_{Btag} < 5.30\,{\rm GeV}/c^2$, referred to as the 'signal region', and perform background studies in the region $5.20 < m_{Btag} < 5.26\,{\rm GeV}/c^2$, referred to as the 'sideband region'.

Continuum backgrounds are suppressed using a multivariate likelihood method comprising several event-shape variables which discriminate between relatively isotropic $B\overline{B}$ events and more jet-like continuum events. The reconstructed mass of the $B_{\rm tag}$ after hadronic tag reconstruction and continuum suppression is shown in Fig 1.

As can be seen in Fig 1, the MC and data match in shape but not in yield. This phenomenon has been seen in previous BABAR analyses [2, 11, 12] and is understood to primarily be caused by discrepancies between between MC and data in branching fractions and in hadronic tag reconstruction efficiencies. We correct for this by extrapolating the combinatorial shape of the data in the sideband region into the signal region, which allows us to estimate the combinatorial component of backgrounds in the signal region, and correcting for any remaining discrepancy by scaling non-combinatorial (or 'peaking') MC in the signal region to match the data yield. The same scaling is also applied to signal MC. Once the data-MC agreement has been corrected, the analysis is conducted with the signal region blinded until the signal selection is finalised.

Candidate $B^- \to \Lambda\overline{p}\nu\overline{\nu}$ events are selected by requiring that the final state particles assigned to the $B_{\rm sig}$ comprise three charged tracks with a total charge opposite that of the $B_{\rm tag}$. Since a $B^- \to \Lambda\overline{p}\nu\overline{\nu}$ event should contain no neutral final state particles assigned to the $B_{\rm sig}$, events with a high neutral energy deposits in BABAR's electromagnetic calorimeter not originating from the $B_{\rm tag}$ are excluded.

We additionally employ particle identification selectors to select events with two oppositely-charged protons originating from the $B_{\rm sig}$, and the third charged track is assumed to be the pion. With the daughters of the Λ identified, we reconstruct Λ candidates from the identified tracks and impose a fit on the Λ and it's daughters. The mass of reconstructed Λ candidates is shown in Fig 2. Λ candidates satisfying $1.112 < m_\Lambda < 1.120\,{\rm GeV}/c^2$ are kept; in events with more than one Λ candidate, the candidate with the highest vertex significance is kept.

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3. Results

Systematic uncertainties are evaluated on signal MC kinematic distributions (resulting in a 9.6% uncertainty on signal efficiency), background estimation (16% uncertainty on signal efficiency, 17% uncertainty on background yield), particle identification (1.4% on signal efficiency, 1.3% on background yield), Λ reconstruction and selection (13% on signal efficiency, 13% on background yield), and neutral cluster energy calibration (1.9% on signal efficiency, 11% on background yield). The signal efficiency is $\varepsilon = (3.42 \pm 0.08({\rm stat.}) \pm 0.80({\rm sys.})) \times 10^{-4}$, and total background is estimated as $N_{\rm bg} = 2.3 \pm 0.7({\rm stat.}) \pm 0.6({\rm sys.})$.

After unblinding the data we observe $N_{\rm data} = 3$ events in the signal region, consistent with our background estimate. We thus calculate a branching fraction central value consistent with zero of $\mathscr{B}(B^- \to \Lambda\overline{p}\nu\overline{\nu}) = (0.4 \pm 1.1\ ({\rm stat.}) \pm 0.6\ ({\rm sys.})) \times 10^{-5}$. We also calculate a branching fraction upper limit at the 90% confidence level, using the Barlow method [13], of $\mathscr{B}(B^- \to \Lambda\overline{p}\nu\overline{\nu}) < 3.0 \times 10^{-5}$. This analysis is the first time an experimental limit has been placed on $B^- \to \Lambda\overline{p}\nu\overline{\nu}$.

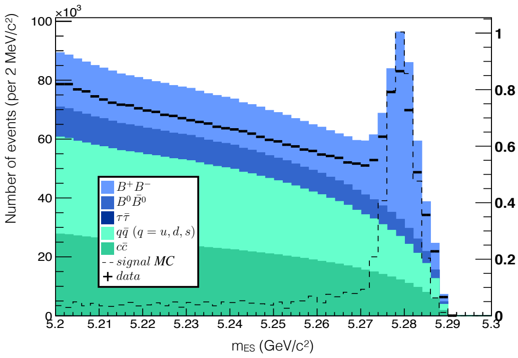

Figure 1: Mass of the reconstructed B_{tag} after hadronic tag reconstruction and continuum suppression for data (points) and MC (shaded). Signal MC (dashed line) for $B^- \to \Lambda\bar{p}\nu\bar{\nu}$ is overlaid using an assumed branching fraction of 0.4×10^{-5}, with the yield given on the right-hand y-axis.

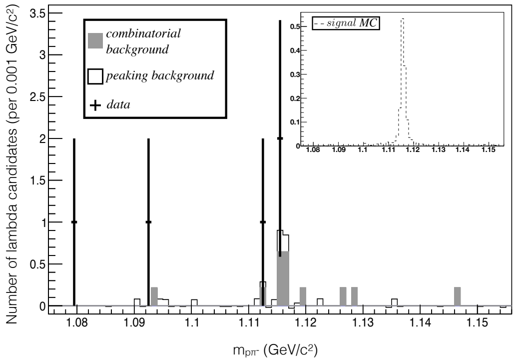

Figure 2: Mass of reconstructed Λ candidates at the end of the signal selection for data (points) and MC (grey and white histograms); negative entries in some bins are an artefact of the background estimation procedure. Inset: signal MC for $B^- \to \Lambda\bar{p}\nu\bar{\nu}$ with assumed branching fraction of 0.4×10^{-5}.

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