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A Search for the Decay $B^- \rightarrow K^- \nu\overline{\nu}$

The *BABAR* Collaboration

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Abstract

We present a search for the rare flavour-changing neutral-current decay $B^- \rightarrow K^- \nu\overline{\nu}$ based on a sample of $(86.9 \pm 1.0) \times 10^6$ $\Upsilon(4S) \rightarrow B\overline{B}$ events collected in the *BABAR* experiment at the SLAC B-factory. Signal candidate events are selected by fully reconstructing a $B^+ \rightarrow \overline{D}^0 X^+$ decay, where X^+ represents a combination of up to three charged pions or kaons and up to two π^0 candidates. The charged tracks and calorimeter clusters not used in the B^+ reconstruction are required to be compatible with a $B^- \rightarrow K^- \nu\overline{\nu}$ decay. We observe a total of three signal candidate events with an expected background of 2.7 ± 0.8, resulting in a preliminary limit of $\mathcal{B}(B^- \rightarrow K^- \nu\overline{\nu}) < 1.05 \times 10^{-4}$ at the 90% confidence level. This search is combined with the results of a previous and statistically independent preliminary *BABAR* search for $B^- \rightarrow K^- \nu\overline{\nu}$ to give a limit of $\mathcal{B}(B^- \rightarrow K^- \nu\overline{\nu}) < 7.0 \times 10^{-5}$ at the 90% confidence level.

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1 INTRODUCTION

The quark level process $b \to s\nu\overline{\nu}$ represents a rare flavour-changing neutral-current (FCNC) decay which proceeds at the one-loop level in the Standard Model (SM) via "penguin" and "box" diagrams such as those shown in Fig. 1. The inclusive $b \to s\nu\overline{\nu}$ process is nearly free from theoretical uncertainties associated with strong interaction effects, permitting a fairly precise prediction of the SM branching fraction. The inclusive branching fraction, summed over the three neutrino flavours, is estimated to be $(4.1^{+0.8}_{-1.0}) \times 10^{-5}$ [1]. Since additional heavy particles would also contribute additional loop diagrams, various "New Physics" scenarios can potentially lead to significant enhancements to the SM branching fraction [2]. Unfortunately, an experimental search for the inclusive $b \to s\nu\overline{\nu}$ process is extremely difficult in a B-factory environment due to the presence of two unobserved neutrinos which limit the available kinematic constraints that can be exploited in order to suppress other B decay backgrounds.

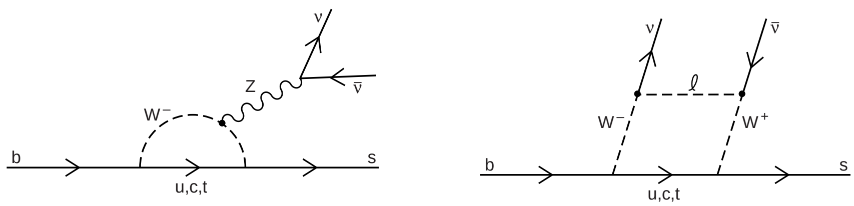

Figure 1: Electroweak penguin (left) and box (right) Feynman diagrams for the process $b \to s\nu\overline{\nu}$ predicted by the SM. In both cases the amplitudes are expected to be dominated by the heavy t quark contribution.

Instead, we search for the exclusive $B^- \to K^-\nu\overline{\nu}$ decay mode, which proceeds via the $b \to s\nu\overline{\nu}$ process. The SM branching fraction for $B^- \to K^-\nu\overline{\nu}$ is estimated to be $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) \simeq 4 \times 10^{-6}$ [3, 4]. The best published limit on the exclusive branching fraction is from CLEO [5] with a limit of $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) \leq 2.4 \times 10^{-4}$ at the 90% confidence level. *BABAR* has already reported a preliminary upper limit $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) \leq 9.4 \times 10^{-5}$ [6] based on 50.7 fb^{-1} data. The two *BABAR* analyses use reconstruction methods which produce mutually exclusive data samples, permitting the two statistically independent results to be combined to obtain an improved limit.

2 THE *BABAR* DETECTOR AND DATASET

The data used in this analysis were collected with the *BABAR* detector at the PEP-II storage ring during the period from 2000 – 2002, corresponding to a total integrated luminosity of 80.06 fb^{-1} collected at the $\Upsilon(4S)$ resonance. This "onpeak" sample is estimated to contain $(86.9 \pm 1.0) \times 10^6$ $B\overline{B}$ pairs. This data set is supplemented by a sample of 9.6 fb^{-1} of "offpeak" data collected approximately 40 MeV below the $\Upsilon(4S)$ resonance, which is used to study continuum background sources due to $e^+e^- \to f\overline{f}$ where $f = u, d, s, c, e, \mu, \tau$.

The *BABAR* detector is an hermetic detector optimized to provide precision vertexing, charged and neutral particle reconstruction and particle identification in an asymmetric B-factory environment. Tracking is provided by a five-layer double-sided silicon vertex tracker (SVT), surrounded by a 40-layer drift chamber (DCH) filled with a mixture of helium and isobutane. The SVT and DCH are situated within a 1.5 T solenoidal field. K/π separation is provided by a quartz ringimaging Cherenkov detector (DIRC) located immediately outside of the DCH. The electromagnetic calorimeter (EMC) is used to measure energy and position of photons and electrons. Muon identification is achieved through segmentation and instrumentation of the iron of the magnetic flux return (IFR) using resistive plate chambers. A more detailed description of the *BABAR* detector can be found in [7].

A GEANT4 [8] based Monte Carlo (MC) simulation is used to model the signal efficiency and physics backgrounds. MC samples equivalent to approximately three times the data luminosity were used to model $B\bar{B}$ events, and samples equivalent to approximately 1.5 times the data luminosity were used to model continuum events.

3 ANALYSIS METHOD

Due to the presence of two unobserved neutrinos, the $B^- \to K^- \nu \overline{\nu}$ decay mode [7] lacks the kinematic constraints which are usually exploited in B decay searches in order to reject both continuum and $B\overline{B}$ backgrounds. Consequently, the approach which is used in this analysis is to first reconstruct the accompanying "tag" B^+, which is produced in association with the signal B^- through the process $\Upsilon(4S) \to B^+B^-$, and then search for evidence of a $B^- \to K^- \nu \overline{\nu}$ decay among the tracks and clusters not associated with the reconstructed tag B. In order to avoid experimenter bias, the signal region in data is not examined ("blinded") until the cuts are finalized.

We reconstruct the tag B^+ in a set of decay modes $B^+ \to \overline{D}^0 X^+$ where X^+ is a hadronic system composed of up to three charged mesons (either π or K) and up to two π^0 candidates. The $\overline{D}^0$ candidate is reconstructed in one of the three decay modes $\overline{D}^0 \to K^+\pi^-$, $\overline{D}^0 \to K^+\pi^-\pi^0$ or $\overline{D}^0 \to K^+\pi^-\pi^+\pi^-$. Candidate B^+ decays are identified by combining $\overline{D}^0$ candidates with sets of charged tracks and π^0 candidates until the combination yields a B candidate consistent with the kinematics expected for a true B meson decay. We use the two kinematic variables $m_{\rm ES}$ and ΔE, defined by $m_{ES} \equiv \sqrt{{E_{\rm beam}}^2 - {\vec{p}_{\rm B}}^2}$ where $\vec{p}_{\rm B}$ is the momentum vector of the B candidate and $E_{\rm beam}$ is the beam energy, and $\Delta E \equiv E_B - E_{\rm beam}$, where E_B is the energy of the B candidate. All these quantities are evaluated in the center of mass (CM) frame. If multiple B candidates are identified within the kinematic region $m_{\rm ES} > 5.2$ GeV$/c^2$ and -1.8 GeV $< \Delta E < 0.6$ GeV, only the candidate for which ΔE is closest to zero is retained.

Combinatorial backgrounds from continuum processes are significantly reduced by requiring the thrust, computed using all tracks and clusters in the event, be less than 0.925 and that $|\cos\theta_T|$, the magnitude of the cosine of the angle between the thrust axis defined by tracks and clusters used to reconstruct the tag B candidate and the thrust axis defined by all other tracks and clusters in the event, be less than 0.8. Correctly reconstructed B meson candidates produce a peak in the $m_{\rm ES}$ distribution above a combinatorial background at the nominal B mass as shown in Fig. 2. The tag B yield is determined directly from data by determining the peaking component of the m_{ES} distribution. Tag B candidates which are reconstructed in MC events containing a true $B^- \to K^- \nu \overline{\nu}$ decay are found to possess very little combinatoric background, since there are few additional tracks and clusters in the event which can be randomly combined to produce combinatoric tag B candidates. Events with tag B candidates lying within a signal region defined by 5.272 GeV$/c^2$ $< m_{\rm ES} < 5.288$ GeV$/c^2$ are retained for use in the search for $B^- \to K^- \nu \overline{\nu}$ decays. Events in the region 5.225 GeV$/c^2$ $< m_{\rm ES} < 5.265$ GeV$/c^2$ are retained for use in background

[7]Charge conjugate modes are implied throughout this paper, however the signal mode will always be denoted as a B^- decay, while the fully reconstructed tag B will be denoted as a B^+ decay to avoid confusion.

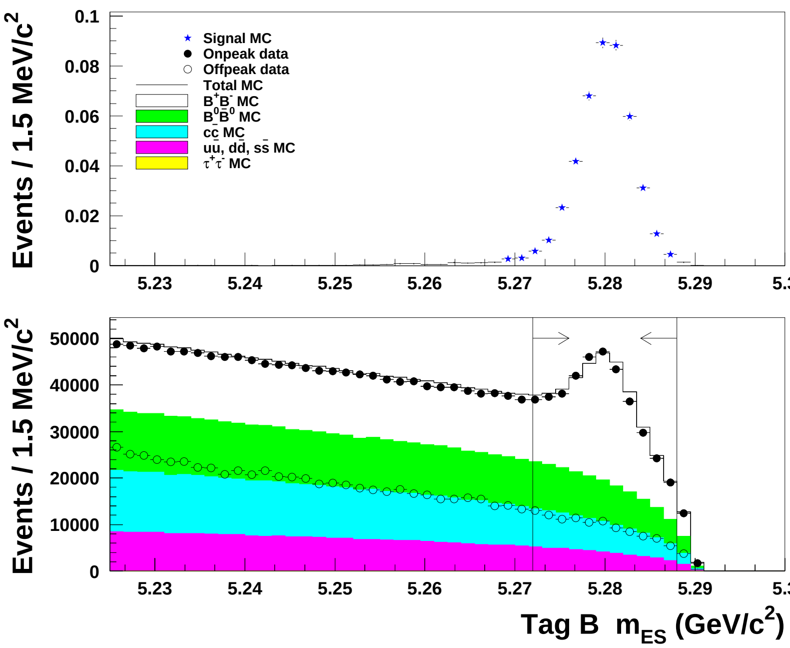

Figure 2: The distribution $m_{\rm ES}$ for $B^+ \to \overline{D}^0 X^+$ candidates in the $B^- \to K^- \nu\overline{\nu}$ signal MC (top), and in the data (bottom). The bottom plot also shows the expected contributions from continuum and $B\bar{B}$ MC. No signal-side selection cuts have been applied. Signal MC is shown scaled to the data luminosity assuming $\mathcal{B}(B^- \to K^- \nu\overline{\nu}) = 4 \times 10^{-6}$; inclusive background MC and offpeak data are shown scaled to the onpeak data luminosity of 80.06 fb^{-1}.

studies as discussed below. A discrepancy of approximately 25% between the observed yield in data and the predicted yield in MC is corrected by scaling the peaking component of the MC simulation. Good agreement between data and MC is obtained once this correction is applied. The same scale factor, $(75 \pm 7)\%$, is used to correct the tag B yield in signal MC as well as MC estimates of peaking backgrounds. The quoted error of 7% is due to the uncertainty in the estimation of the peaking component of the data and due to the discrepancy between MC and data in the shape of the non-peaking background component.

Once a reconstructed tag B candidate has been identified, $B^- \to K^- \nu\overline{\nu}$ signal candidates are selected by considering all tracks and clusters in the event which are not used in the tag B reconstruction. This set of tracks and clusters is referred to in the following as the "signal-side" of the event. Candidate events are required to possess exactly one signal-side reconstructed charged track with a charge which is opposite that of the tag B. The signal-side charged track multiplicity is plotted for signal MC and data in Fig. 3. The signal candidate track is required to satisfy particle identification criteria for charged kaons based on information from the tracking system and the DIRC. The kaon candidate is boosted into the CM frame assuming a kaon mass hypothesis, and the CM momentum, p^*_K, is required to be greater than 1.5 GeV/c. The average particle identification efficiency in the momentum range of interest is $\sim 85\%$ and the typical $\pi \to K$ misidentification rate is $\sim 2\%$. The p^*_K of signal candidate tracks is plotted in Fig. 4. We assume the kaon momentum spectrum is described by the decay model of reference [3] and correct the signal MC distribution

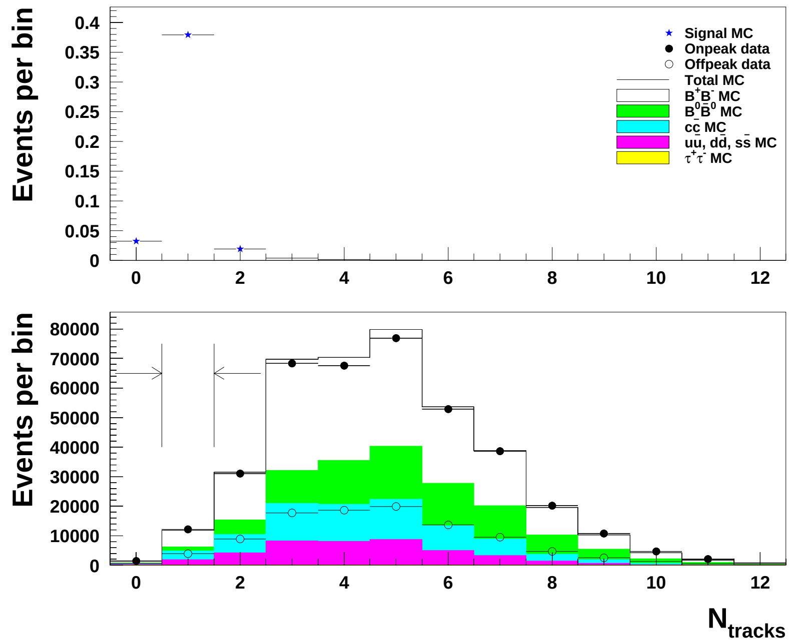

Figure 3: The distribution of the number, N_{tracks}, of signal-side charged tracks is plotted for the $B^- \to K^-\nu\overline{\nu}$ signal MC (top), and for onpeak data and generic MC (bottom) for events which pass the tag B selection. No signal-side selection cuts have been applied. Signal MC is shown scaled to the data luminosity assuming $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) = 4 \times 10^{-6}$, and generic MC and offpeak data are shown scaled to the onpeak data luminosity of 80.06 fb^{-1}.

(which is generated with a phase-space model) accordingly.

Constraints are also imposed on signal-side EMC clusters to reject events with significant neutral energy deposition in the calorimeter. $B^- \to K^-\nu\overline{\nu}$ events possess an average of two additional signal-side clusters. These are generally attributable to hadronic split-offs in the EMC, usually from pions or kaons associated with the tag B side of the event, or to beam related backgrounds. Events possessing one or more π^0 candidates, composed of combinations of two EMC clusters with lab frame energy greater than 30 MeV which combine to produce an invariant mass in the range 122 MeV$/c^2 < m_{\gamma\gamma} < 145$ MeV$/c^2$, are rejected. In addition to this π^0 veto, a restriction is imposed on the total "extra" signal-side neutral energy, E_{extra}, that is present in the event. E_{extra} is computed by summing the CM-frame energies of all signal-side EMC clusters with lab frame energy greater than 30 MeV. Signal candidate events are required to possess $E_{\mathrm{extra}} < 300$ MeV. The E_{extra} distribution obtained from signal MC is compared to data in Fig. 5.

The requirement that signal candidate events possess low signal-side track multiplicity and relatively little additional neutral energy in the EMC also tends to select B^+B^- events in which the tag B^+ has been correctly reconstructed, but the opposing B^- has one or more unreconstructed particles which have passed outside the detector acceptance in either the forward or backward directions. An additional cut is therefore imposed on the direction of the missing momentum vector in the CM-frame, p^*_{miss}, which is required to satisfy $|\cos\theta_{p^*_{\mathrm{miss}}}| < 0.8$.

Due to the low signal-side multiplicity, there is almost no tag B reconstruction mode-dependence

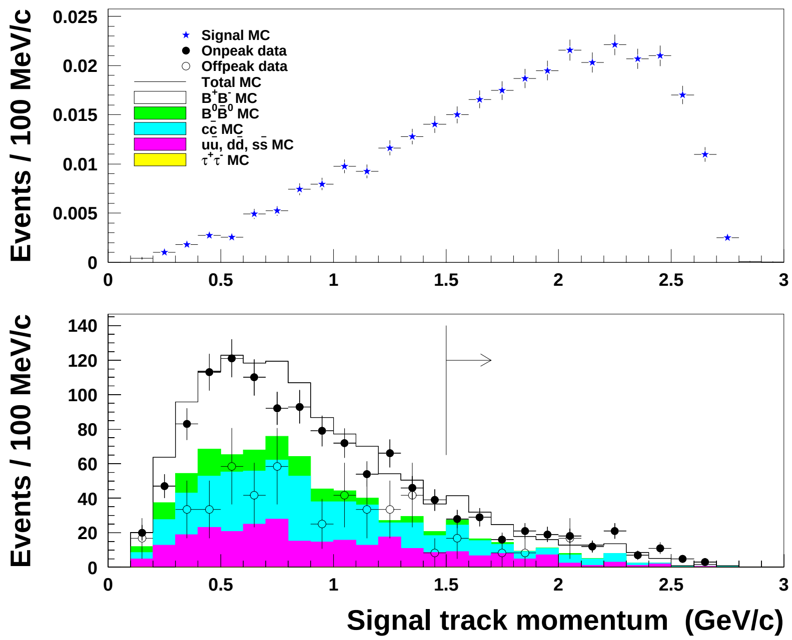

Figure 4: The CM momentum distribution of signal-side kaons candidates is plotted for the $B^- \to K^-\nu\overline{\nu}$ signal MC (top), and for onpeak data and generic MC (bottom). Plotted events are required to possess exactly one signal-side track satisfying kaon identification criteria and having a charge opposite that of the tag B. Signal MC is shown scaled to the data luminosity assuming $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) = 4 \times 10^{-6}$, and generic MC and offpeak data are shown scaled to the onpeak data luminosity of 80.06 fb^{-1}.

of the measured signal-side efficiency. The overall selection efficiency, ϵ_{tot}, can therefore be expressed as the product of the tag B selection efficiency, ϵ_{tag}, and the signal-side efficiency ϵ_{sig}. The overall efficiency is estimated to be $\epsilon_{\mathrm{tot}} = (0.046 \pm 0.005)\%$, while the ϵ_{sig} is estimated to be $(35 \pm 1)\%$. The uncertainties on the efficiencies are due to both statistics and systematics.

Monte Carlo modeling of the signal efficiency and background estimates is validated by comparing the yields obtained in a number of data control samples. These samples include 9.6 fb^{-1} of offpeak data, an m_{ES} sideband region defined by 5.225 GeV/c^2 $< m_{\mathrm{ES}} <$ 5.265 GeV/c^2 , an E_{extra} sideband defined by 0.5 GeV $< E_{\mathrm{extra}} <$ 1.5 GeV, and a “large m_{ES}” sideband spanning the entire region defined by 5.225 GeV/c^2 $< m_{\mathrm{ES}} <$ 5.265 GeV/c^2 and $E_{\mathrm{extra}} <$ 1.5 GeV. In addition, we retain samples of events which pass all of the nominal signal selection requirements except that they are required to have a total of two or three charged tracks associated with the signal side of the event instead of only one. All data control samples were found to be in good agreement with the MC predictions, as shown in Table 1.

Backgrounds consist primarily of B^+B^- events in which the tag B^+ has been correctly reconstructed but in which the accompanying B^- decays to a high-momentum kaon and additional particles which are not reconstructed by the tracking detectors or calorimeter. Typically these events contain one or more K_L^0 and/or neutrinos, and frequently also one or more additional charged or neutral particles which pass outside of the tracking or calorimeter acceptance. This

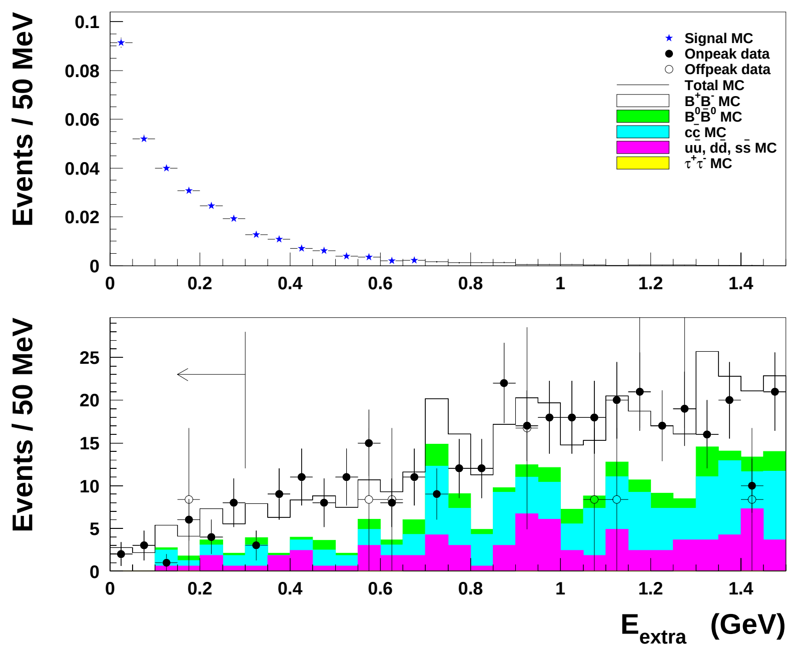

Figure 5: The total extra neutral energy distribution, $E_{\rm extra}$ is plotted for the $B^- \to K^-\nu\overline{\nu}$ signal MC (top), and for onpeak data and generic MC (bottom). Plotted events are required to possess exactly one signal-side track satisfying kaon identification criteria and having a charge opposite that of the tag B. Signal MC is shown scaled to the data luminosity assuming $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) = 4 \times 10^{-6}$, and generic MC and offpeak data are shown scaled to the onpeak data luminosity of 80.06 fb^{-1}.

Table 1: A comparison of data yields and MC predictions in the signal region and in various control samples. Quoted uncertainties reflect MC statistics only.

MC type	Signal Region	$m_{\rm ES}$	large $m_{\rm ES}$	$E_{\rm extra}$	$N_{\rm tracks} = 2$	$N_{\rm tracks} = 3$
B^+B^-	1.7 ± 0.6	1.1 ± 0.5	7.0 ± 1.4	3.3 ± 0.9	17.4 ± 1.9	54.6 ± 3.4
$B^0\overline{B^0}$	0	0	1.4 ± 0.6	0.6 ± 0.4	0.9 ± 0.5	3.5 ± 1.0
$u\bar{u}, d\bar{d}, s\bar{s}$	0	1.8 ± 1.0	14.0 ± 2.9	2.4 ± 1.2	0.6 ± 0.6	1.2 ± 0.9
$c\overline{c}$	0	1.8 ± 1.0	11.1 ± 2.6	2.4 ± 1.2	1.9 ± 1.0	3.1 ± 1.4
$\tau^+\tau^-$	0	0	0	0	0	0
Onpeak data Total MC ($\mathcal{L} = 80.06$ fb^{-1})	3 1.7 ± 0.6	7 4.8 ± 1.7	31 33.5 ± 4.2	10 8.8 ± 2.0	21 20.7 ± 2.3	55 62.4 ± 3.9
Offpeak data Continuum MC ($\mathcal{L} = 9.6$ fb^{-1})	0 0.11 ± 0.05	0 0.4 ± 0.2	1 3.0 ± 0.5	0 0.6 ± 0.2	0 0.3 ± 0.1	1 0.5 ± 0.2

"peaking" background component is evaluated directly from B^+B^- MC and estimated to yield 1.7 ± 0.6 events in 80.06 fb^{-1} of data. This estimate is validated by comparison with the data in the $E_{\rm extra}$, $N_{\rm tracks} = 2$ and $N_{\rm tracks} = 3$ sideband, all of which have large contributions from peaking B^+B^- backgrounds. Due to the limited MC statistics, a smaller combinatorial component of the background is estimated by scaling the observed yield in the MC $m_{\rm ES}$ sideband into the signal region. This scaling assumes an "Argus function" shape for the $m_{\rm ES}$ distribution of the combinatorial component which is obtained from data using a "wrong-sign" tag B sample in which the charge of the D^0 daughter kaon is inconsistent with the charge of the tag B candidate, resulting in no significant peaking component in the $m_{\rm ES}$ distribution. Scaling the $m_{\rm ES}$ sideband into the signal region yields an additional background of 1.0 ± 0.4 events, leading to an estimated total background of 2.7 ± 0.7, where the quoted uncertainties are due to MC statistics.

4 SYSTEMATIC STUDIES

Estimates of systematic uncertainties are summarized in Table 2. Systematic uncertainties in the branching ratio determination are dominated by the statistical uncertainty on the background estimate, and by the uncertainty on the determination of the tag B yield in data using $(75 \pm 7)\%$ scaling correction determined from the comparison of $B^+ \to \overline{D}^0 X^+$ yields in data and MC. Since the tag B yield is determined directly from data, no other systematic uncertainties associated with the tag B need to be assigned. The signal track reconstruction and kaon identification procedure yield comparatively small uncertainties on the efficiency and background estimates. Uncertainties also arise from the MC modeling of the energy and multiplicity of low energy clusters in the EMC which would potentially produce a bias in the $E_{\rm extra}$ distribution. These uncertainties are estimated by evaluating the change in the MC efficiency and background estimates when low energy clusters are selectively removed from the MC until data and MC multiplicity distributions are in agreement. An additional systematic uncertainty is assigned to the efficiency estimate as a result of the reweighting procedure used to correct the MC kaon momentum spectrum to be consistent with that predicted by reference [3]. Note however that this uncertainty does not account for variations in the momentum spectrum which would result from the use of other theoretical models. A small uncertainty also enters the branching ratio limit calculation from the estimation of the number of B^+B^- events present in the data sample.

5 PHYSICS RESULTS

Unblinding the analysis revealed a total of $N_{\rm sel} = 3$ events in the signal region, with an expected background, $N_{\rm bg}$, of 2.7 ± 0.8 where the additional systematic uncertainties from table 2 have been combined with the MC statistical uncertainty. The $m_{\rm ES}$ distribution and signal kaon candidate momentum spectrum are shown in Fig. 6 and Fig. 7 respectively. The $B^- \to K^- \nu\overline{\nu}$ branching ratio is computed as follows:

$$\mathcal{B}(B^- \to K^- \nu\overline{\nu}) = \frac{(N_{\rm sel} - N_{\rm bg})}{2 \cdot N_{B^+B^-} \cdot \epsilon_{\rm tot}} \qquad (1)$$

where $\epsilon_{\rm tot} = (0.046 \pm 0.005)\%$ is the overall signal selection efficiency, and $N_{B^+B^-}$ is the number of $\Upsilon(4S) \to B^+B^-$ events in the data. $N_{B^+B^-} = (43.5 \pm 0.5) \times 10^6$ is obtained by assuming equal branching fractions for $\Upsilon(4S)$ decays into charged and neutral B mesons. The central value of the branching ratio is determined to be $\mathcal{B}(B^- \to K^- \nu\overline{\nu}) = (0.8 \pm 2.0) \times 10^{-5}$ where the quoted

Table 2: Systematic uncertainties

Source	Relative uncertainty
Signal efficiency:	
Signal MC statistics $\epsilon_{\rm sig}$	1%
Signal MC statistics $\epsilon_{\rm tag}$	5%
Tag B yield	7%
Signal track reconstruction efficiency	1%
K particle ID efficiency	2%
$E_{\rm extra}$	2%
Kaon momentum correction	3%
Total $\sigma\epsilon/\epsilon$	10%
Background estimate:	
Generic MC statistics	27%
Tag B correction	7%
Track efficiency	5%
$E_{\rm extra}$	8%
Total background estimate uncertainty	29%
B^+B^- yield	1.2%

uncertainty is from systematics only. The significance of the central value is somewhat less than 1σ and we therefore quote a 90% confidence level limit. The branching ratio limit is computed using a frequentist approach based on reference [9]. The confidence level for a given branching fraction limit "guess" is obtained by generating a large number of experiments in which the systematic uncertainties in the inputs to equation 1 are modeled by Gaussian distributions and the signal statistics are modeled by a Poisson distribution. The limit is set at the value of the branching fraction at which 10% of the generated experiments produce a yield which is less than the observed data yield of three events. This procedure results in a limit of $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) < 1.05 \times 10^{-4}$ at the 90% confidence level assuming the central model of reference [3]. This limit is weakly model dependent, since the signal efficiency depends on the kaon momentum spectrum. Varying the model within the range specified in [3] results in a variation in the limit in the range $(1.02 - 1.10) \times 10^{-4}$. Alternatively, the model of reference [4] yields a limit of 9.5×10^{-5}. Sensitivity to new physics will also be model dependent, however it should be noted that this analysis has an efficiency which is relatively uniform as a function of kaon momentum above the 1.5 GeV/c cut. The efficiency is zero for kaon momenta below 1.5 GeV/c, which may effect the limit interpretation for exotic New Physics modes with significantly different kaon momentum spectra.

This analysis can be combined with the result of a preliminary *BABAR* search for $B^- \to K^-\nu\overline{\nu}$ reported previously [6], based on a sample of 50.7 fb^{-1} of data. This analysis yielded a limit of $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) \leq 9.4 \times 10^{-5}$ at the 90% confidence level assuming the model of reference [3]. In this analysis, the tag B was reconstructed in a set of semileptonic B decay modes of the form $B^+ \to \overline{D}^0\ell^+\nu X^0$ were X^0 can be either nothing, or one or more photons which are consistent with the decay products of higher mass open charm states such as $\overline{D}^{*0} \to \overline{D}^0\gamma/\pi^0$. Two events were observed, and were treated as signal for the limit determination (i.e. no background subtraction was performed). Because this previous analysis required an identified high momentum lepton for

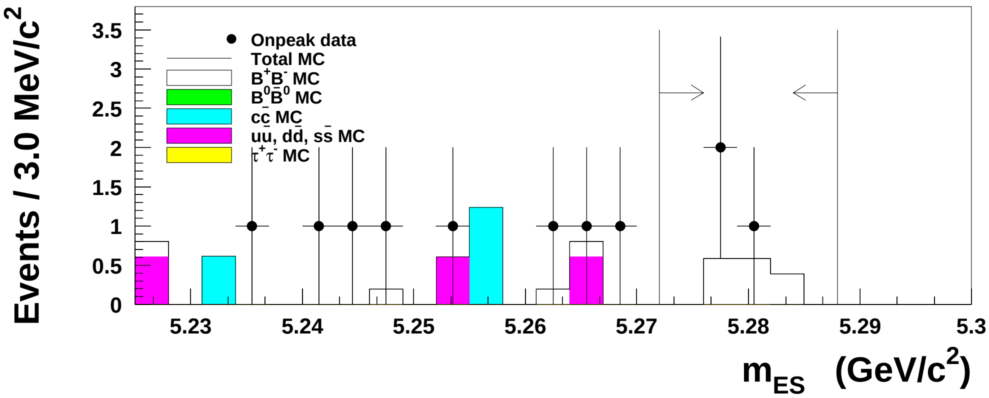

Figure 6: The $m_{\rm ES}$ distribution of events passing all other $B^- \to K^-\nu\overline{\nu}$ selection cuts, showing the three selected events in the signal region.

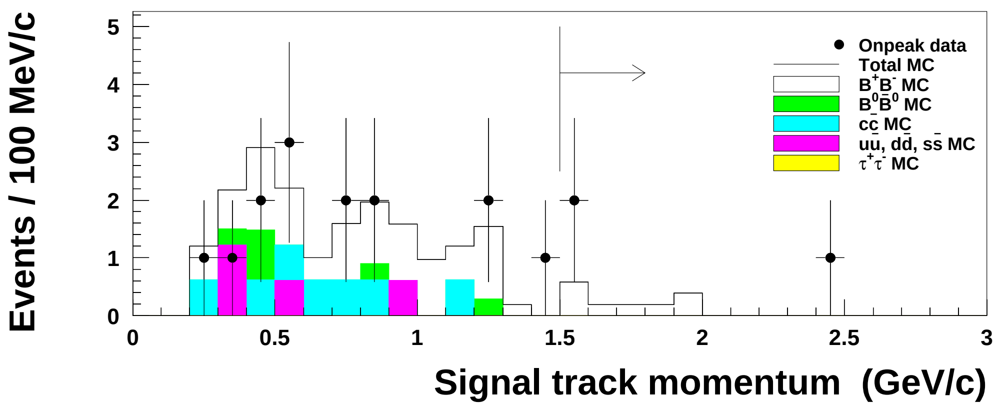

Figure 7: The CM momentum distribution of signal kaon candidates which pass all other $B^- \to K^-\nu\overline{\nu}$ selection cuts, showing the three data events above the 1.5 GeV/c cut.

the tag B reconstruction, while in the present work the tag B modes are purely hadronic, the two analyses are by construction statistically independent and can be readily combined. Using the same frequentist method as described above and ignoring correlated systematic uncertainties which are expected to be small, we obtain a combined limit of $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) < 7.0 \times 10^{-5}$ at the 90% confidence level.

6 SUMMARY

We have performed a search for the rare FCNC decay $B^- \to K^-\nu\overline{\nu}$ using a method in which the accompanying tag B meson is reconstructed into a set of hadronic final states. Using a data sample corresponding to an integrated luminosity of 80.06 fb^{-1}, we observe a total of three signal candidate events, consistent with the background expectation of 2.7 ± 0.8. We determine a preliminary limit of the branching fraction $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) < 1.05 \times 10^{-4}$ at the 90% confidence level. Combining our result with the result from a previous and independent *BABAR* search for $B^- \to K^-\nu\overline{\nu}$ yields a combined preliminary limit of $\mathcal{B}(B^- \to K^- \nu\overline{\nu}) < 7.0 \times 10^{-5}$. The result is consistent with the SM expectation of $\mathcal{B}(B^- \to K^- \nu\overline{\nu}) \simeq 4 \times 10^{-6}$.

7 ACKNOWLEDGMENTS

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References

[1] The *BABAR* collaboration, P. F. Harrison and H. R. Quinn ed., "The *BABAR* Physics Book: Physics at an Asymmetric B Factory", SLAC-R-0504.

[2] Y. Grossman, Z. Ligeti and E. Nardi, Nucl. Phys. **B465** 369-398, (1996); *ibid.* **B480** 753-754, (1996) (E).

[3] G. Buchalla, G. Hiller and G. Isidori, Phys. Rev. D **63** 014015 (2001).

[4] A. Faessler, Th. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij, Eur. Phys. J. direct **C4**, 18, (2002).

[5] The CLEO Collaboration, T. E. Browder *et al.*, Phys. Rev. Lett. **86** 2950-2954, (2001).

[6] The *BABAR* Collaboration, B. Aubert *et al.*, hep-ex/0207069, *BABAR*-CONF-02/027.

[7] The *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instrum. Methods **A479**, 1-116 (2002).

[8] GEANT4 Collaboration, "*GEANT4* – a simulation toolkit", submitted Nucl. Instrum. Methods, CERN-IT-2002-003.

[9] R. D. Cousins and P. L. Highland, Nucl. Inst. Meth. **A320**, 331 (1992).