Search for the Rare Decays B → K+π and B → K+π'}
We present results from a search for the avor-changing neutral current decays B \to K^{\pm} e^{\mp} \nu and B \to K^{\pm} \nu e^{\mp}, where \nu is either an e or \mu pair. The data sample comprises 22.7 \times 10^{6} (45\%) B \to B \nu \nu decays collected with the BABAR detector at the PEP-II B Factory. We obtain the 90\% C.L. upper limits B(B \to K^{\pm} e^{\mp}) < 0.50 \times 10^{-6} and B(B \to K^{\pm} \nu e^{\mp}) < 2.9 \times 10^{-6}, close to Standard Model predictions for these branching fractions. We have also obtained limits on the lepton-fam by-violating decays B \to K e^{\pm} and B \to K \nu e^{\pm}. PACS numbers: 13.25.Hw, 13.20.Jr

The avor-changing neutral current decays B \to K^{\pm} e^{\mp} and B \to K^{\pm} \nu e^{\mp}, where \nu is a charged lepton, are highly suppressed in the Standard Model, with branching fractions predicted to be of order $10^{-7}$ 10^{-5} [4,5]. The dominant contributions arise at the one-boson level and are known as electroweak penguins.
Besides probing Standard Model loop effects, these rare decays are important because their rates and kinematic distributions are sensitive to new, heavy particles such as those predicted by supersymmetric models that can appear virtually in the loop.  

The Standard Model predictions for \( B \to K^{(*)} \) include three main contributions: the electromagnetic (EM) penguin, the \( Z \) penguin, and the \( W^+W^- \) box diagram. Evidence for the EM penguin amplitude has been obtained from the observation of \( B \to K \) and inclusive \( B \to X_{s} \gamma \) where \( X_{s} \) is any hadronic system with strangeness.

Calculations of decay rates for \( B \to K^{(*)} \) based on the Standard Model have significant uncertainties due to strong interactions. For example, Ali et al. predict \( B \to K^{(*)} \) = \((0.57 \pm 0.15) \times 10^{-6} \) for both \( e^+e^- \) and \( \pi^+\pi^- \) states, \( B \to K^{(*)} \) = \((2.3 \pm 0.7) \times 10^{-6} \), and \( B \to K^{(*)} \) = \((1.9 \pm 0.5) \times 10^{-6} \). The contribution of the EM penguin amplitude to \( B \to K^{(*)} \) is particularly strong at low values of \( Q^2 \), giving a larger rate for \( B \to K^{(*)} \) than for \( B \to K \).

We search for the following decays: \( B^+ \to K^{(*)} \), \( B^0 \to K^{(*)} \), \( B^+ \to K^{(*)} \), \( B^0 \to K^{(*)} \), \( K^0 \to K^{(*)} \), \( K^0 \to K^{(*)} \), \( K^0 \to K^{(*)} \), and \( K^0 \to K^{(*)} \). We also search for the lepton-flip violating decays \( B \to K^{(*)} \).

The data used in the analysis were collected with the BABAR detector at the PEP-II storage ring at the Stanford Linear Accelerator Center during 1999-2000. We analyzed a data sample taken on the (4S) resonance consisting of \((22.7 \times 10^6) \) \( B \to X_{s} \gamma \) events.

This search relies primarily on the charged-particle tracking and particle-identification capabilities of the BABAR detector. Charged particle tracking is provided by a \( 1 \) layer silicon vertex tracker (SVT) and a \( 40 \) layer drift chamber (DCH). The DRC, a Cherenkov ring imaging particle-identification system, is used for charged hadron identification. Electrons are identified using the electromagnetic calorimeter (EMC), which consists of 6580 thallium-doped CsI crystals. These systems are mounted inside a 1.5 T solenoidal superconducting magnet. Muons are identified in the instrum ented \( 1 \) or \( 2 \) return (IFR), in which resistive plate chambers are interleaved with the iron return of the magnet return (IFR).

We extract the signal using the kinematic variables:

\[
m_{ES} = E_\text{beam}^2 \cdot \left(1 + P_1 \right)^2 \quad P_i = m_i^2 + P_{i+}^2 \quad E_i = m_i^2 + P_{i+}^2 \]

where \( E_\text{beam} \) is the beam energy in the c.m. frame; \( \cos \theta \) is the cosine of the angle between the \( B \) candidate and the beam axis in the c.m. frame; \( \cos \phi \) is the cosine of the angle between the thrust axis of the candidate B meson and the rest of the particles in the c.m. frame. The \( m_{ES} \) distribution, with a resolution of about 2.5 MeV-cm\(^2\) and \( E \) peaks near zero, indicating that the candidate system of particles has total energy consistent with the beam energy in the c.m. frame.

To prevent bias in the analysis, we optimized the event-selection criteria using Monte Carlo samples; we did not look at the data in the signal region or in the sidesbands that were used to measure the background until these criteria were xed. Signal e ciencies were determined using the Ali et al. model.

We select events that have at least four charged tracks, the ratio \( R_2 \) of the second and zeroth Fox-Wolfram moments less than 0.5, and two oppositely charged leptons with \( m_{lepton} > 0.5 (1.0) \) GeV for \( e ( \mu ) \) leptons. Electron-positron pairs consistent with photon conversions in the detector material are vetoed. We require charged kaon candidates to be identified as kaons and the charged pion in \( K \) to be identified as a kaon. For \( B \to K^{(*)} \), we require the mass of the K candidate to be within 75 MeV/c\(^2\) of the mean K mass. K candidates are reconstructed from two oppositely charged tracks that form a good vertex displaced from the primary vertex by at least 1 mm.

The decays \( B \to J=1 \) and \( B \to 2S(1)^{(*)}(1)^{(*)} \) have identical topologies to signal events. These backgrounds are suppressed by applying a veto in the \( \phi \) vs. \( m_{es} \) plane. This veto removes kaon-remnants events not only with reconstructed \( m_{es} \) values near the nominal kaon mass, but also events that lie further away in \( m_{es} \) due to photon radiation (in one pronounced in electron channels) or tracks that seem to be events. Removing all of these events simplifies the description of the background shape. In the nominal events can, however, pass this veto if one of the leptons (typically a muon) and the kaon are misidentified with each other. If, in addition, any other particle types results in a dilepton mass consistent with the J=0 or 2S mass, the candidate is vetoed. There is also a significant background from \( B \to K^{(*)} \) and \( B \to 2S \) into \( B \to K^{(*)} \), since energy lost due to bremsstrahlung in \( B \) to \( J=K \) can be compensated for by including a random pion. If the decay is in a \( B \to K^{(*)} \) candidate is kinematically consistent with \( B \to J=1 \) or \( B \to 2S \), assuming that the photon (which is not directly observed) was radiated along the direction of either lepton, the candidate is vetoed. A part from the chaim onium vetoes, we analyze the full \( m_{es} \) range.

Continuum background from non-resonant \( e^{+}e^{-} \) or \( \gamma \) production is suppressed using a Fisher discriminant, a linear combination of the input variables with optimized coefficients. The variables are \( R_2; \cos \phi \) and \( \cos \theta \).

The variable \( m_{ES} \) helps discriminate against background from...
strong discrimination against evet in t he c.m. frame. The variable pressed using a signal-to-

FIG. 1: Charm onium veto in the E vs. m plane for (a) B ! K (1) e e and (b) B ! K (0) . Hatched regions are vetoed. The dots correspond to a Monte Carlo simulation of B ! J= (! e ) K and B ! (ZS)(! e ) K . Most signal events would lie in the E region between the horizontal lines.

semileptonic D decays, for which m _K < m _D .

Combinatorial background from BB events is sup-
pressed using a signal-to-B _B likelihood ratio that com-

ines candidate B and dilepton vertex probabilities; the signi cance of the dilepton separation along the beam direction; cos _ and the m missing energy, E _miss , of the event in the c.m. frame. The variable E _miss provides the strongest discrimination against BB background, since events with semileptonic decays usually have signi cant unobserved energy due to neutrinos. For each m state, we select at most one combina tion of particles per event as a B signal candidate. If multiple candidates occur, we select the candidate with the greatest number of drift chamber and SVT hits on the charged tracks.

We use the known charm onium decays B ! J= K (1) and B ! (ZS)K (0) to check the e ciency of our analy-
sis cuts. Figure 2 compares the E distributions (abso-

olutely normalized) of these charm onium samples in M onte Carlo with data. We nd good agreement in both the renormalization and the shape.

We extract the signal and background yields in each channel using a two-dimensional extended un-
binned maximum likelihood t in the region de ned by m _ES > 5.2 GeV/c^2 and t E < 0.25 GeV. The signal shapes, including the e ects of radiation on the E dis-

tribution and the correlation between m _ES and E , are obtained by parametrizing the GEANT3 M onte Carlo [3] simulation of the signal. The background is described by a function with two param eters that are deter-

ined in our t to the data. Backgrounds from BB that peak in the signal region are suppressed to less than 0.2 events in each m mode. Although we allow the signal yield to be negative, we have imposed a lower cut-off such that the total t function is positive. The t results are shown in Fig. 2 and summarized in Table 1. We observe no signi cant signals.

To determine 90% C.L. upper limits on the signal

yields, we generate a series of M onte Carlo samples in which the background probability density function is taken from our t to the data, but the mean number of signal events is varied. We generate ten thousand samples for each mean value, increasing the mean until 90% of the ts to a set of samples gives a signal yield greater than that obtained by t ing the data. To give a measure of the sensitivity of the analysis we list in Table 2 an effective background yield. This quantity is de ned as the square of the error on the signal yield from a t to a toy M onte Carlo sample drawn from the background probability function, with no signal contribution.

Table 2 lists the systematic uncertainties from the t, ( B=B ) t , expressed according to their effect on the limits. The sensitivity of the limits to the values used for signal-shape parameters is determined by performing alternative ts using parameters from the B ! J= K ( ) control samples. Form odes with electrons, we also varied the fraction of signal events in the tail of the E distribution.

to determine whether a more general background shape would lead to di erent results, we introduced additional parameters and allowed for a correlation between m _ES and E . This procedure shifted the upper limits by 2% to 5%, depending on the m mode. Most of the uncertainty associated with the background shape is incorporated in the statistical error on the yield because the background shape is deter mined from the t.

![Figure 1: Charm onium veto in the E vs. m plane for (a) B ! K (1) e e and (b) B ! K (0) . Hatched regions are vetoed. The dots correspond to a Monte Carlo simulation of B ! J= (! e ) K and B ! (ZS)(! e ) K . Most signal events would lie in the E region between the horizontal lines.](image1)

![Figure 2: Comparison of event yields and E shapes between data and Monte Carlo for the charm onium control samples. The points with error bars show the data, and the solid histograms show the prediction of the charm onium Monte Carlo. A list of the analysis selection criteria have been applied except for the charm onium veto, which is reversed. The large tails in the e e modes are due to photon radiation. All shifts between data and Monte Carlo are taken into account as systematic uncertainties on the signal yields.](image2)
TABLE I: Results from the tt to B ! K ( e ) e and B ! K e m odes. The columns from left to right are: tt signal yield (I); upper limit on the signal yield; the contribution of the background to the error on the signal yield, expressed as an effective background yield (see text); the signal efficiency, (not including the branching fractions for K , K e, and K e decays); the systematic error on the selection efficiency, (B=B); the systematic error from the t , (B=B), the branching fraction central value (I); and the upper limit on the branching fraction, including systematic errors.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Signal yield</th>
<th>Effective background (%)</th>
<th>(B=B) (%)</th>
<th>(B=B) (%)</th>
<th>B=10⁻³</th>
<th>B=10⁻⁴</th>
<th>90% C.L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>B⁻⁺K⁺e⁻e</td>
<td>0.03 ±0.02</td>
<td>3.1</td>
<td>0.7</td>
<td>17.5</td>
<td>7.5</td>
<td>4.0</td>
<td>0.0</td>
</tr>
<tr>
<td>B⁺⁺K⁺e⁺e</td>
<td>0.03 ±0.02</td>
<td>2.6</td>
<td>0.7</td>
<td>10.5</td>
<td>7.5</td>
<td>4.0</td>
<td>0.0</td>
</tr>
<tr>
<td>B⁺⁺K⁰e⁺e</td>
<td>3.0 ±0.1</td>
<td>8.8</td>
<td>1.4</td>
<td>10.2</td>
<td>8.8</td>
<td>11.9</td>
<td>2.5</td>
</tr>
<tr>
<td>B⁺⁺K⁺e⁺e</td>
<td>1.1 ±0.2</td>
<td>3.5</td>
<td>0.7</td>
<td>8.0</td>
<td>10.8</td>
<td>3.0</td>
<td>0.0</td>
</tr>
<tr>
<td>B⁺⁺K⁺e⁺e</td>
<td>0.05 ±0.02</td>
<td>4.2</td>
<td>0.2</td>
<td>15.7</td>
<td>8.8</td>
<td>9.5</td>
<td>0.0</td>
</tr>
<tr>
<td>B⁺⁺K⁺e⁺e</td>
<td>0.04 ±0.02</td>
<td>1.2</td>
<td>0.1</td>
<td>9.6</td>
<td>8.8</td>
<td>3.0</td>
<td>0.0</td>
</tr>
<tr>
<td>B⁺⁺K⁺e⁺e</td>
<td>1.2 ±0.2</td>
<td>3.8</td>
<td>0.1</td>
<td>8.5</td>
<td>11.0</td>
<td>5.0</td>
<td>0.0</td>
</tr>
<tr>
<td>B⁺⁺K⁺e⁺e</td>
<td>0.04 ±0.02</td>
<td>0.3</td>
<td>0.1</td>
<td>5.8</td>
<td>13.0</td>
<td>7.0</td>
<td>0.0</td>
</tr>
<tr>
<td>B⁺⁺K⁺e⁺e</td>
<td>0.04 ±0.02</td>
<td>2.9</td>
<td>1.3</td>
<td>16.5</td>
<td>5.7</td>
<td>4.0</td>
<td>0.0</td>
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<tr>
<td>B⁺⁺K⁺e⁺e</td>
<td>1.1 ±0.2</td>
<td>5.3</td>
<td>2.1</td>
<td>11.9</td>
<td>7.1</td>
<td>10.6</td>
<td>0.0</td>
</tr>
<tr>
<td>B⁺⁺K⁺e⁺e</td>
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<td>4.2</td>
<td>0.5</td>
<td>14.6</td>
<td>7.3</td>
<td>11.2</td>
<td>0.0</td>
</tr>
<tr>
<td>B⁺⁺K⁺e⁺e</td>
<td>0.04 ±0.02</td>
<td>3.5</td>
<td>1.1</td>
<td>9.0</td>
<td>9.5</td>
<td>3.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

FIG. 3: Projections from individual maximum likelihood fits onto m ES for the E signal regions: 0.01 < E < 0.05 GeV (electrons) and 0.07 < E < 0.05 GeV (muons). The dotted lines show the background component, and the solid lines show the sum of background and signal components.

The systematic uncertainties on the efficiency, (B=B), are listed in Table I and arise from charged-particle tracking (1.2% per lepton, 2.0% for the pion from K ! K , and 1.3% per track for other charged hadrons), particle identification (1.4% per electron, 1.0% per muon, 2.0% per track for kaons and pions), and the continuum suppression cut (2.0%), the B suppression cut (3.0%), K ² selection (4.0%), M onte Carlo signal statistics (3.0% to 5.0%), the theoretical model dependence of the efficiency (4.0% to 7.0%, depending on the mode), and the number of B events (1.6%). The uncertainties due to model dependence of four factors are taken to be the full range of variation obtained from different theoretical models. In setting the upper limit, the systematic uncertainties from the efficiency, (B=B), and from the t , (B=B), are added in quadrature, and the limit is increased by this factor.

Table I also includes the results for the lepton-flavoured-violating decays B ! K e, where the signal efficiencies were determined from phase-space Monte Carlo simulations. We observe no evidence for these decays.

We determine the branching fractions B ! K e and B ! K e averaged over both B meson charge and lepton type (e and ) by performing a simultaneous maximum likelihood fit to the four contributing channels in each case. In combining the B ! K e m odes, the ratio of branching fractions B ! K e = B ! K e is used to weight the yield in the muon channel relative to that in the electron channel. The extracted yield corresponds to the electron mode. The combined fit gives

B ! K e = (0.06 ±0.04 ±0.03) 10⁻⁶;
B ! K e = (0.09 ±0.08 ±0.09) 10⁻⁶;

where the first error is statistical and the second is systematic. We evaluate the upper limits on these combined modes and obtain

B ! K e < 0.50 10⁻⁶ at 90% C.L.;
B ! K e < 2.0 10⁻⁶ at 90% C.L.;
These limits represent an improvement over previously published results from CDF [11] and CLEO [12]. The Belle [13] experiment has also recently obtained results on these modes. We see no evidence for a signal, and our limits are close to many of the predictions based on the Standard Model. With the rapidly increasing size of our data sample, we expect to have significantly better sensitivity to these modes in the future.

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues. The collaborating institutions wish to thank SLAC for its support and kind hospitality. This work is supported by DOE and NSF (USA), NSERC (Canada), IHEP (China), CEA and CNRS-IN2P3 (France), BM BF (Germany), INFN (Italy), NFR (Norway), M IST (Russia), and PPARC (United Kingdom). Individuals have received support from the Swiss NSF, A.P. Sloan Foundation, Research Corporation, and Alexander von Humboldt Foundation.

A. Ali with Universita di Perugia, Perugia, Italy
A. Ali with Universita della Basilicata, Potenza, Italy
[8] \textsc{Geant} (Detector Description and Simulation Tool), CERN Program Library Long Writeup W 5013 (1995).
[9] We parameterize the background shape using

$$f(m_{ES}; E) = N e^{s E_{ES} - \frac{E_{ES}^2}{2 s^2}} e^{\frac{-E}{b}};$$

where $N$ is a normalization factor and $s$ and $b$ are free parameters determined from the data.
[10] Whenever possible, we report two-sided 68\% central confidence intervals. For channels constrained by the requirement that the total $t$ function be non-negative, we quote a single-sided 68\% confidence interval and set the lower statistical error to zero.