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The branching fractions of the exclusive decays $B^0 \to K^0 \gamma$ and $B^+ \to K^{++} \gamma$ are measured from a sample of $(22.74 \pm 0.36) \times 10^6$ $B \bar{B}$ decays collected with the BABAR detector at the PEP II asymmetric $e^+e^-$ collider. We find $\mathcal{B}(B^0 \to K^0 \gamma) = (4.23 \pm 0.40\text{(stat.)} \pm 0.22\text{(sys.)}) \times 10^{-5}$, $\mathcal{B}(B^+ \to K^{++} \gamma) = (3.83 \pm 0.62\text{(stat.)} \pm 0.22\text{(sys.)}) \times 10^{-5}$ and constrain the CP-violating charge asymmetry to be $-0.170 < A_{CP}(B \to K^{*+} \gamma) < 0.082$ at 90\% C.L.

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In the Standard Model (SM) the exclusive decays $B \to K^{*} \gamma$ proceed dominantly by the electromagnetic loop “penguin” transition $b \to s \gamma$. Many extensions of the SM provide new virtual high-mass fermions and bosons that can appear in the loop, causing deviations in the inclusive rate for $b \to s \gamma$ [1]. The sensitivity of the exclusive rates to these effects is limited by the uncertainty in the SM calculation. However, there has been considerable progress recently [2]. The precision measurement of the exclusive branching fractions $\mathcal{B}(B^0 \to K^*\gamma)$, $\mathcal{B}(B^+ \to K^{*+} \gamma)$ is needed to test and improve these calculations. The non-SM processes can also interfere with the SM decay to cause CP-violating charge asymmetries at a level as high as 20\% [3]. The CP-violating charge asymmetry from SM contributions alone is expected to be < 1\%.

In this letter, measurements of the exclusive branching fractions, $\mathcal{B}(B^0 \to K^*\gamma)$ in the $K^{*0} \to K^+\pi^-$, $K^{*0}\pi^0$ modes, and $\mathcal{B}(B^+ \to K^{*+} \gamma)$ in the $K^{*+} \to K^+\pi^0$, $K^{*+}\pi^+\pi^-$ modes with $K^{*0} \to \pi^+\pi^-$, are presented. Here $K^*$ refers to the $K^*(892)$ resonance and the charge conjugate decays are implied unless otherwise stated. The $K^{*0} \to K^+\pi^-$ and $K^{*+} \to K^+\pi^0$, $K^{*+}\pi^+\pi^-$ modes are used to search for CP-violating charge asymmetries.

The data were collected with the BABAR detector [4] at the PEP-II asymmetric $e^+e^-(3.1 \text{ GeV}) - e^- (9 \text{ GeV})$ storage ring [5]. The results in this paper are based upon an integrated luminosity of 20.7 fb$^{-1}$ of data corresponding to $(22.74 \pm 0.36) \times 10^6$ $B \bar{B}$ meson pairs recorded at the $\Upsilon(4S)$ resonance (“on-resonance”), and 2.6 fb$^{-1}$ at 40 MeV below this energy (“off-resonance”).

We use Monte Carlo simulations of the BABAR detector based on GEANT 3.21 [6] to optimize our selection criteria and to determine signal efficiencies. Events taken from random triggers are used to measure the beam backgrounds. These simulations take account of varying detector conditions and beam backgrounds.

The selection criteria for this analysis are optimized to maximize $S/(S+B)$ where $S$ is the number of signal candidates expected, assuming the central values of the previous measurement $\mathcal{B}(B^0 \to K^{*+}\gamma)$, $\mathcal{B}(B^+ \to K^{*+}\gamma) = (4.53^{+0.72}_{-0.68}\text{(stat.)} \pm 0.34\text{(sys.)}, 3.76^{+0.83}_{-0.83}\text{(stat.)} \pm 0.28\text{(sys.)}) \times 10^{-5}$ [7], and $B$ is the expected number of background candidates determined from Monte Carlo and confirmed with off-resonance data. Quantities are computed in both the laboratory frame and the center-of-mass frame of the $e^+e^-$ system. Those computed in the center-of-mass frame are denoted by an asterisk; e.g., $E_{beam}^* = 5.29 \text{ GeV}$. We require $1.5 < E_\gamma < 4.5 \text{ GeV}$ in the laboratory frame and $2.0 < E_\gamma^* < 2.85 \text{ GeV}$ in the center-of-mass frame. A photon candidate is defined as a localized energy maximum [4] in the calorimeter acceptance $0.74 < \cos \theta < 0.93$, where $\theta$ is the polar angle to the detector axis. It must be isolated by 25 cm from any other photon candidate or track and have a lateral energy profile consistent with a photon shower. We veto photons from a $s^q(\eta)$ by requiring that the invariant mass of the combination with any other photon of energy greater than 50 (250) MeV not be within the range $115(508) < M_{\gamma\gamma} < 155(588) \text{ MeV}/c^2$.

The $K^*$ is reconstructed from $K^{*0}, K^{*+}, K^{*-}$ and $\pi^0$ candidates through the four modes $K^{*0} \to K^+\pi^-, K^{*0}\pi^0$ and $K^{*+} \to K^+\pi^0, K^{*+}\pi^+\pi^-$. The $K^+$ and $\pi^-$ track candidates are required to be well reconstructed in the drift chamber and to originate from a vertex consistent with the $e^+e^-$ interaction point (IP). The $K^{*0}$ candidates are reconstructed from two oppositely-charged tracks coming from a common vertex displaced from the IP by at least 0.2 cm in the transverse plane and having an invariant mass $489 < M_{\pi^+\pi^-} < 507 \text{ MeV}/c^2$. A track is identified as a kaon if it is projected to pass through the fiducial volume of the particle identification detector, an internally-refracting ring-imaging Cherenkov detector (DIRC) [4], and the cone of Cherenkov light is consistent in time and angle with a kaon of the measured track momentum. A charged pion is identified as a track that is not a kaon. The $\pi^0$ candidates are reconstructed from pairs of photons, each with energy greater than 30 MeV, and are required to have $115 < M_{\gamma\gamma} < 150 \text{ MeV}/c^2$ and $E_{\gamma\gamma} > 200 \text{ MeV}$. A mass-constraint fit to the nominal $\pi^0$ mass is used to improve the resolution of its momentum. The $K^*$ reconstruction is completed by requiring the invariant mass of the candidate pairs to be within $100 \text{ MeV}/c^2$ of the $K^{*0}/K^{*+}$ mass.

The $B$ meson candidates are reconstructed from the $K^*$ and $\gamma$ candidates. The background is predominantly from continuum $q\bar{q}$ production, with the high-energy photon originating from initial-state radiation or from $\tau^\pm$ and $\eta$ decays. The background from other $B$ meson decays is found to be negligible from Monte Carlo simu-
$K^+\pi^0$ modes, and $100 < \Delta E^* < 300$ MeV in the $K^+\pi^-$ and $K^0_S\pi^+$ modes. The signal yields with statistical errors from the fit are given in Table I.

<table>
<thead>
<tr>
<th>Mode</th>
<th>K$^+\pi^-$ events</th>
<th>K$^+\pi^0$ events</th>
<th>K$^0_S\pi^+$ events</th>
<th>K$^+\pi^0$ events</th>
<th>K$^+\pi^0$ events</th>
<th>K$^+\pi^0$ events</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>14.0</td>
<td>135.7</td>
<td>73.3</td>
<td>0.4 ± 0.1</td>
<td>0.6 ± 0.1</td>
<td>4.2 ± 0.4 ± 0.22</td>
</tr>
<tr>
<td>10%</td>
<td>1.4</td>
<td>14.8</td>
<td>5.6</td>
<td>0.4 ± 0.1</td>
<td>1.0 ± 0.2</td>
<td>4.1 ± 0.7 ± 0.42</td>
</tr>
<tr>
<td>3%</td>
<td>3.9</td>
<td>28.1</td>
<td>6.6</td>
<td>0.7 ± 0.2</td>
<td>1.2 ± 0.2</td>
<td>3.0 ± 0.7 ± 0.21</td>
</tr>
<tr>
<td>4.3%</td>
<td>57.6</td>
<td>104.4</td>
<td>1.2 ± 0.2</td>
<td>0.4 ± 0.4</td>
<td>5.3 ± 0.7 ± 0.38</td>
<td></td>
</tr>
</tbody>
</table>

As a consistency check we plot in Figure 3a the $\Delta E^*$ projection for the $K^+\pi^-$ mode after requiring $5.27 < m_{ES} < 5.29$ GeV/c$^2$. A comparison of the observed $\Delta E^*$ distribution with Monte Carlo shows good agreement. We also plot $M_{K^+\pi^-}$ in Figure 3b after requiring $5.27 < m_{ES} < 5.29$ GeV/c$^2$. $-200 < \Delta E^* < 100$ MeV and 0.7 < $M_{K^+\pi^-} < 1.1$ GeV/c$^2$. We fit with a relativistic Breit-Wigner plus linear background shape and determine that the signal is consistent with coming from the $K^*(892)$.

![Figure 3](image-url)  
(a) $\Delta E^*$ projection for $B^0 \rightarrow K^*\gamma$, $K^0 \rightarrow K^+\pi^-$ candidates. The curve is the Monte Carlo expectation with a linear background. (b) The $M_{K^+\pi^-}$ projection for $B^0 \rightarrow K^*\gamma$, $K^0 \rightarrow K^+\pi^-$ candidates with the $M_{K^+\pi^-}$ mass cut relaxed. The curve is a fit to a relativistic Breit-Wigner function with linear background.

The efficiency for the selection of $B \rightarrow K^*\gamma$ candidates is given in Table I. The branching fraction is determined from the yield, the efficiency and the total number of $B\overline{B}$ events in the sample. The cross-feed from the other $B \rightarrow K^\gamma$ modes and the down-feed from $B \rightarrow K^\gamma$ are estimated with Monte Carlo assuming the measured branching fractions from the CLEO collaboration [7, 8] for each mode and subtracted from the signal yield.

The total systematic error is the sum in quadrature of the components shown in Table II. The systematic uncertainty in the signal yield derives from uncertainties in the signal line shape, and cross-feed and down-feed contributions. The uncertainty in the signal line shape results from the $m_{ES}$ width difference described above. To gain statistics in the off-resonance data sample used to fit the background function for the $K^+\pi^-$ and $K^+\pi^0$ modes we relax the kaon identification requirement and consequently assign a systematic uncertainty to the assumption that the background shape is unaffected. The error in the assumed branching fractions and final-state modeling for $B \rightarrow X\gamma$ [8] gives a systematic error in the estimated down-feed from these modes. The tracking efficiency is computed by identifying tracks in the silicon vertex detector and observing the fraction that is well reconstructed in the drift chamber. We estimate the $K^0_S$ efficiency uncertainty by comparing the momenta and flight-distance distributions in data and Monte Carlo. The kaon identification efficiency in the DIRC is derived from a sample of $D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K^-\pi^+$ decays. The photon and $\pi^0$ efficiencies are measured by comparing the ratio of events $N(\pi^+ \rightarrow h^+ \pi^-)/N(\pi^0 \rightarrow h^+ \pi^-)$ to the previously measured branching ratios [11]. The photon isolation and $\pi^0/\eta$ veto efficiency are dependent on the event multiplicity and are tested by "embedding" Monte Carlo-generated photons into both an exclusively reconstructed $B$ meson data sample and a generic $B$ meson Monte Carlo sample. The $\Delta E^*$ resolution is dominated by the photon-energy resolution so that uncertainties in the calorimeter energy resolution and overall energy-scale cause an uncertainty in the efficiency of the $\Delta E^*$ requirement. The photon-energy resolution is measured in data using $\pi^0$ and $\eta$ meson decays and $e^+ e^- \rightarrow e^+ e^-\gamma$ events. The energy scale uncertainty is estimated by using a sample of $\eta$ meson decays with symmetric energy photons; the deviation in the reconstructed $\eta$ mass from the nominal $\eta$ mass provides an estimate of the uncertainty in the measured single photon energy.

The $B \rightarrow K^*\gamma$ samples, except for the $K^0_S\pi^0$ sample, are used to search for $CP$-violating charge asymmetries $A_{CP}$, defined by

$$A_{CP} = \frac{\Gamma(B \rightarrow \overline{K}^*\gamma) - \Gamma(B \rightarrow K^*\gamma)}{\Gamma(B \rightarrow \overline{K}^*\gamma) + \Gamma(B \rightarrow K^*\gamma)}.$$  

The flavor of the underlying $b$ quark is tagged by the charge of the $K^\pm$ or $K^{*\pm}$ in the decay. The on-resonance sample for each mode is divided into two $CP$-conjugate samples and the signal yield for each is extracted with the same fitting technique as for the branching fraction measurements. In the fit the background shape and normalization, as well as the signal peak and width are constrained to be the same for both $CP$-conjugate samples. The measured asymmetries and the asymmetry of the background in the sideband regions defined by $-200 < \Delta E^* < 100$ MeV, $5.2 < m_{ES} < 5.27$ GeV/c$^2$ are given in Table III.

The systematic uncertainty in the asymmetry is due to possible detector effects that cause a different reconstruction efficiency for the two $CP$ conjugate decays. This un-
TABLE II: The systematic uncertainties in the measurement of $B(B \to K^{*}\gamma)$.

<table>
<thead>
<tr>
<th>Source</th>
<th>$K^{+}\pi^{-}$</th>
<th>$K_{S}^{0}\pi^{0}$</th>
<th>$K_{S}^{0}\pi^{0}$</th>
<th>$K^{+}\pi^{0}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{EB}$, line shape</td>
<td>-5.4</td>
<td>1.7</td>
<td>1.9</td>
<td>-</td>
</tr>
<tr>
<td>Background shape</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>3.8</td>
</tr>
<tr>
<td>Down-feed modeling</td>
<td>1.0</td>
<td>1.5</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>$K^{+}/\pi^{0}$ tracking efficiency</td>
<td>2.4</td>
<td>-</td>
<td>-</td>
<td>1.2</td>
</tr>
<tr>
<td>$K_{S}^{0}$ efficiency</td>
<td>-</td>
<td>4.5</td>
<td>4.5</td>
<td>-</td>
</tr>
<tr>
<td>Kaon identification</td>
<td>0.7</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>Photon efficiency</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Photon distance cut</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>$\pi^{0}/\eta$ veto</td>
<td>-</td>
<td>2.5</td>
<td>-</td>
<td>2.5</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Energy scale</td>
<td>1.0</td>
<td>1.4</td>
<td>1.5</td>
<td>2.1</td>
</tr>
<tr>
<td>MC statistics</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>$B$ counting</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Total</td>
<td>5.3</td>
<td>10.3</td>
<td>6.7</td>
<td>7.0</td>
</tr>
</tbody>
</table>

TABLE III: The measured $A_{CP}$ in signal and background samples.

<table>
<thead>
<tr>
<th>Mode</th>
<th>$A_{CP}$(signal)</th>
<th>$A_{CP}$(background)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^{+}\pi^{-}$</td>
<td>$-0.049 \pm 0.094 \pm 0.012$</td>
<td>$+0.011 \pm 0.104$</td>
</tr>
<tr>
<td>$K_{S}^{0}\pi^{0}$</td>
<td>$-0.190 \pm 0.210 \pm 0.012$</td>
<td>$-0.080 \pm 0.080$</td>
</tr>
<tr>
<td>$K^{+}\pi^{0}$</td>
<td>$0.044 \pm 0.155 \pm 0.021$</td>
<td>$-0.022 \pm 0.105$</td>
</tr>
</tbody>
</table>

* Also with Università di Perugia, Perugia, Italy
* Also with Università della Basilicata, Potenza, Italy


[9] The signal for the $K^{+}\pi^{0}$ and $K_{S}^{0}\pi^{0}$ modes is fit with the function $dN/dm_{EB} = A_{2}\exp\left[-0.5\left(\ln^{2}(1 + \tau m_{EB} - m_{0})/\mu^{2} + \tau^{2}\right)\right]$ where $A = \sinh(\mu/\tau)$, the peak position is $m_{0}$, the width is $\sigma$, and $\tau$ is the tail parameter. The $K^{+}\pi^{-}$ and $K_{S}^{0}\pi^{0}$ modes are fitted with a Gaussian distribution.

[10] The background for each mode is fit with: $dN/dm_{EB} = A_{2}\exp\left[-0.5\left(1 - m_{EB}^{2}/F_{kba}^{2}\right)\right]$, a function introduced by the ARGUS Collaboration, H. Albrecht et al., Z. Phys. C 48, 543 (1990).