Test of lepton flavor universality in $B \to K\ell^+\ell^-$ decays

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We present measurements of the branching fractions for the decays $B \rightarrow K\mu^+\mu^-$ and $B \rightarrow K\ell^+\ell^-$, and their ratio ($R_K$), using a data sample of 711 fb$^{-1}$ that contains $772 \times 10^6$ $BB$ events. The data were collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy $e^+e^-$ collider. The ratio $R_K$ is measured in four bins of dilepton invariant-mass squared, $q^2$; the results are

$$R_K = \begin{cases} 
0.95 \pm 0.27 \pm 0.06 & q^2 \in (0.1, 1.4) \text{ GeV}^2/c^4, \\
0.81 \pm 0.28 \pm 0.05 & q^2 \in (4.0, 8.1) \text{ GeV}^2/c^4, \\
0.98 \pm 0.27 \pm 0.06 & q^2 \in (10.6) \text{ GeV}^2/c^4, \\
1.11 \pm 0.29 \pm 0.07 & q^2 > 14.18 \text{ GeV}^2/c^4.
\end{cases}$$

The first uncertainties listed are statistical, and the second uncertainties are systematic. The $R_K$ value in the whole $q^2$ range is found to be $1.06^{+0.15}_{-0.14} \pm 0.07$. We also measure $CP$-averaged isospin asymmetries in the same $q^2$ bins; the results are consistent with a null asymmetry with the largest difference of 2.7 standard deviations found in the $q^2 \in (10.6) \text{ GeV}^2/c^4$ bin in the mode with muon final states. The measured branching fractions are $B(B \rightarrow K\mu^+\mu^-) = (5.5 \pm 0.5 \pm 0.3) \times 10^{-7}$ and $B(B \rightarrow K\ell^+\ell^-) = (5.1 \pm 0.5 \pm 0.3) \times 10^{-7}$. These results are compatible with standard model expectations.

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The decays $B \rightarrow K\ell^+\ell^-$ ($\ell = e, \mu$), which are mediated by the $b \rightarrow s\ell^+\ell^-$ quark-level transition, constitute a flavor-changing neutral current process. Such processes are forbidden at tree level in the standard model (SM) but can proceed via suppressed loop-level diagrams, and are therefore sensitive to particles predicted in a number of new physics models $[1, 2]$. A robust observable $\delta$ to test the SM is the lepton-flavor-universality ratio,

$$R_H = \frac{\int dq^2 \frac{\Gamma(B \rightarrow H\ell^+\ell^-)}{\Gamma(B \rightarrow H\ell^+\ell^-)} dq^2}{\int dq^2 \frac{\Gamma(B \rightarrow H\ell^+\ell^-)}{\Gamma(B \rightarrow H\ell^+\ell^-)} dq^2},$$

where $H$ is a $K$ or $K^*$ meson and the decay rate $\Gamma$ is integrated over a range of the dilepton invariant-mass squared, $q^2 \equiv M^2(\ell^+\ell^-)$. For $R_K$, recent LHCb $[6, 7]$ reported hints of deviations from SM expectations, while Belle $[6]$ results were consistent with the SM. LHCb also measured $R_K$ $[6]$, reporting a difference of about 2.5 standard deviations ($\sigma$) from the SM prediction in the $q^2 \in (1.1, 6.0) \text{ GeV}^2/c^4$ bin. Previous measurement of the same quantity was performed by Belle $[6]$ in the whole $q^2$ range with a data sample of 657 $\times 10^6$ $BB$ events. The result presented here is obtained from a multi-dimensional fit performed on the full Belle data sample, and supercedes our previous result.

Another theoretically robust observable $\zeta$, where the dominant form-factor-related uncertainties cancel, is the $CP$-averaged isospin asymmetry, that measures the difference in partial widths,

$$A_I = \frac{(\tau_{B-D}/\tau_{B-S}) B(B^0 \rightarrow K^0\ell^+\ell^-) - B(B^+ \rightarrow K^+\ell^+\ell^-)}{(\tau_{B^+}/\tau_{B^0}) B(B^0 \rightarrow K^0\ell^+\ell^-) + B(B^+ \rightarrow K^+\ell^+\ell^-)},$$

where $\tau_{B-D}/\tau_{B-S} = 1.076$ is the lifetime ratio of $B^+ \rightarrow B^0$. The $A_I$ value is close to zero in the SM $[10]$. Earlier, BaBar $[11]$, Belle $[6]$ and LHCb $[12]$ had reported $A_I$ to be significantly below zero, especially in the $q^2$ region below the $J/\psi$ resonance.

We report here a measurement of the decay branching fractions of $B \rightarrow K\ell^+\ell^-$, and $R_K$ and $A_I$ in the whole $q^2$ range as well as in four $q^2$ bins $[(0, 1, 4.0), (4.0, 8.12), (1.0, 6.0), > 14.18 \text{ GeV}^2/c^4]$. The analysis uses 711 fb$^{-1}$ data sample containing $(772 \pm 11) \times 10^6$ $BB$ events. The data were collected by the Belle experiment running near the $\Upsilon(4S)$ resonance at the KEKB $e^+e^-$ collider $[13]$. An 89 fb$^{-1}$ data sample recorded 60 MeV below the $\Upsilon(4S)$ peak (off-resonance) is used to calculate the contribution of continuum background in the analysis.

The Belle detector is a large-solid-angle magnetic spectrometer composed of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like ar-
rangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) comprising CsI(Tl) crystals. All these are located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux return yoke placed outside the coil is instrumented with resistive plate chambers (KLM) to detect $K_0^0$ mesons and muons. Further details about the detector can be found in Ref. [13]. Two inner detector configurations were used: a 2.0 cm radius beam-pipe and a three-layer SVD for the first sample of 140 fb$^{-1}$; and a 1.5 cm radius beam-pipe, a four-layer SVD, and a small-cell inner CDC for the remaining 571 fb$^{-1}$ [15].

To study properties of signal events and optimize selection criteria, we use samples of Monte Carlo (MC) simulated events. These are generated with the EvtGen package [10] based on a model described in Ref. [17]. PHOTOS [18] is used to incorporate final state radiation. The detector response is simulated with GEANT3 [19].

We reconstruct $B \rightarrow K^+\ell^−\nu$ ($K = K^+, K_0^0$) decays by selecting charged particles that originate from the vicinity of the $e^+e^−$ interaction point (IP), except for those originating from $K_0^0$ decays. We require impact parameters less than 1.0 cm in the transverse plane and less than 4.0 cm along the $z$ axis (opposite the $e^+$ beam). To reduce backgrounds from low-momentum particles, we require that tracks have a minimum transverse momentum of 100 MeV/c.

From selected tracks, we identify $K^±$ candidates using a likelihood ratio $R_{K/π} = L_K/(L_K + L_π)$, where $L_π$ and $L_K$ are the likelihoods for charged kaons and pions, respectively, calculated based on the number of photoelectrons in the ACC, the specific ionization in the CDC, respectively, calculated based on the number of photoelectrons in the ACC, the specific ionization in the CDC, and the two track helices at their closest approach, the flight length in the $x−y$ plane, the angle between the $K_0^0$ momentum and the vector joining the IP to the $K_0^0$ decay vertex, the angle between the pion momentum and the laboratory-frame direction in the $K_0^0$ rest frame, the distance of closest approach in the $x−y$ plane between the IP and the two pion helices, and the total number of hits (in the CDC and SVD) for each pion track.

Muon candidates are identified based on information from the KLM. We require that candidates have a momentum greater than 0.8 GeV/c, and a penetration depth and degree of transverse scattering consistent with those of a muon [21]. A criterion on the normalized muon likelihood, $R_μ > 0.9$, is used to select muon candidates. For this requirement, the average muon detection efficiency is 89%, with a pion misidentification rate of 1.5% [22].

Electron candidates are required to have a momentum greater than 0.4 GeV/c and are identified using the following information: the ratio of ECL energy to the CDC track momentum; the ECL shower shape; the position matching of the CDC track with the ECL cluster; and the specific ionization in the CDC [23]. A requirement on the normalized electron likelihood $R_e > 0.9$ is imposed. This requirement has an efficiency of 92% and a pion misidentification rate below 1% [22]. To recover energy loss due to possible bremsstrahlung, we search for photons inside a cone of radius 50 mrad centered around the electron momentum. If a photon is found within the cone, its four-momentum is added to that of the electron.

Charged (neutral) $B$ candidates are reconstructed by combining $K^±$ ($K_0^0$) with suitable $μ^±$ or $e^±$ candidates. To distinguish signal from background events, two kinematic variables are used: the beam-energy-constrained mass $M_{bc} = \sqrt{(E_{beam}/c^2)^2 − (p_{B}/c)^2}$, and the energy difference $ΔE = E_B − E_{beam}$, where $E_{beam}$ is the beam energy, and $E_B$ and $p_{B}$ are the energy and momentum, respectively, of the $B$ candidate. All these quantities are calculated in the $e^+e^−$ center-of-mass (CM) frame. For signal events, the $ΔE$ distribution peaks at zero, and the $M_{bc}$ distribution peaks near the $B$ mass. We retain events satisfying the requirements $−0.1 < ΔE < 0.25$ GeV and $M_{bc} > 5.2$ GeV/c$^2$.

With the above selection criteria applied, about 2% of events are found to have more than one signal $B$ candidate. We retain the candidate having the smallest $χ^2$ value from a vertex fit of the $B$ daughter candidates. From MC simulation, we find that this criterion identifies the correct signal decay 78-85% of the time, depending on the decay mode. The decays $B \rightarrow J/ψ(→$ $ℓ^+ℓ^−)K$ and $B \rightarrow ψ(2S)(→$ $ℓ^+ℓ^−)K$, later used as control samples, are suppressed in the signal selection via a set of vetoes $8.75 < q^2 < 10.2$ GeV$^2/c^4$ and $13.0 < q^2 < 14.0$ GeV$^2/c^4$ with the dimuon; $8.5 < q^2 < 10.2$ GeV$^2/c^4$ and $12.8 < q^2 < 14.0$ GeV$^2/c^4$ with the dielectron final states for $B \rightarrow J/ψK$ and $B \rightarrow ψ(2S)K$, respectively. An additional veto of the low $q^2$ region ($< 0.05$ GeV$^2/c^4$) is applied in the case of $B \rightarrow K^−e^+$ to suppress possible contaminations from $γ^* \rightarrow e^+e^−$ and $a^0 \rightarrow γe^+e^−$.

At this stage of the analysis, there is significant background from $e^+e^− → q\bar{q}$ ($q = u, d, s, c$) continuum events and other $B$ decays. As lighter quarks are produced with large kinetic energy, the former events tend to consist of two back-to-back jets of pions and kaons. In contrast, $BB$ events are produced almost at rest in the CM frame, resulting in more spherically distributed daughter particles. We thus distinguish $BB$ events from $q\bar{q}$ background based on event topology.

Background arising from $B$ decays mostly has two un-
correlated leptons in the final state. Such background falls into three categories: (a) both $B$ and $\bar{B}$ decay semileptonically; (b) a $B \to D^{(*)} X e^+\nu$ decay is followed by $D^{(*)} \to X e^-\bar{\nu}_e$; and (c) hadronic $B$ decays where one or more daughter particles are misidentified as leptons.

To suppress continuum as well as $BB$ background, we use an second NN. This NN is trained using the following input variables:

1. A likelihood ratio constructed from modified Fox-Wolfram moments $[24, 25]$. 
2. The angle $\theta_B$ between the $B$ flight direction and the $z$ axis in the CM frame for $BB$ events, $dN/d\cos\theta_B \propto 1 - \cos^2 \theta_B$, whereas for continuum events, $dN/d\cos\theta_B \approx \text{constant}$.
3. The angle $\theta_T$ between the thrust axes calculated from final state particles for the candidate $B$ and for the rest of the event (the thrust axis is the direction that maximizes the sum of the longitudinal momenta for all particles). For signal events, the $\cos \theta_T$ distribution is flat, whereas for continuum events it peaks near $\pm 1$.
4. Flavor-tagging information from the tag-side recoiling $B$ decay. The flavor-tagging algorithm $[20]$ outputs two variables: the flavor $q$ of the tag-side $B$, and the tag quality $r$. The latter ranges from zero for no flavor information to one for unambiguous flavor assignment.
5. The confidence level of the $B$ vertex fitted from all daughter particles.
6. The separation in $z$ between the signal $B$ decay vertex and that of the tag-side $B$.
7. The separation between the two leptons along the $z$-axis divided by the uncertainties in the transverse plane.
8. The sum of the ECL energy of tracks and clusters not associated with the signal $B$ decay.
9. A set of variables developed by CLEO $[27]$ that characterize the momentum flow into concentric areas around the thrust axis of a reconstructed $B$ candidate.

The NN outputs a single variable $O$, for which larger values correspond to more signal-like events. To facilitate modeling the distribution of $O$ with an analytic function, we transform $O$ to a new variable:

$$O' = \log \left[ \frac{O - O_{\text{min}}}{O_{\text{max}} - O} \right],$$

where $O_{\text{min}}$ and $O_{\text{max}}$ are the lower and upper boundaries, respectively, of $O$. The value of $O_{\text{max}}$ depends on the decay modes and is determined from the signal MC sample. The criteria on $O > -0.6$ ($= O_{\text{min}}$) reduces the background events by more than 75%, with a signal loss of about 4-5%.

We study the remaining background events using MC simulation for individual modes, with special attention paid to those that can mimic signal decays. Candidates arising from $B^0 \to J/\psi(\ell^+\ell^-)K^0$ populate towards the negative side in $\Delta E$ and are suppressed with the requirement $\Delta E > -0.1$ GeV. The decay $B^+ \to D^0(K^+\pi^-)\pi^+\pi^-$ mimics $B^+ \to K^+\mu^+\mu^-$ with pions being misidentified as muons, and to suppress it a veto is applied on the invariant mass formed from $K^+$ and $\mu^-$ candidates: $M[K^+\mu^-] \notin (1.85, 1.88)$ GeV/$c^2$. The contribution from other $B$ to charm decays is negligible. Events originating from the decays $B^+ \to J/\psi(\mu^+\mu^-)K^+$ in which one of the muons is misidentified as a kaon, and the kaon is misidentified as a muon, contributes as a peaking background to $B^+ \to K^+\mu^+\mu^-$ signal. Such events are suppressed by applying a veto on the invariant mass $M[K^+\mu^-] \notin (3.06, 3.13)$ GeV/$c^2$. When calculating invariant masses for these vetoes, the mass hypothesis for the misidentified particle is used. There is small background from $B \to K\pi^+\pi^-$ decays in the $B^+ \to K^+\mu^+\mu^-$ (1.37 $\pm$ 0.01 events) and $B^0 \to K^0_S\mu^+\mu^-$ (0.17 $\pm$ 0.01 events) samples. In the corresponding $B^+ \to K^+e^+e^-$ and $D^0 \to K^0_Se^+e^-$ samples, background from charmless $B$ decays is negligible. The mentioned yields of peaking charmless background are estimated by considering all known intermediate resonances. To avoid biasing our results, all selection criteria are determined in a “blind” manner, i.e., they are finalized before looking at data events in the signal region.

We determine the signal yield by performing a three dimensional unbinned extended maximum-likelihood fit to the $M_{bc}, \Delta E$ and $O'$ distributions in different $q^2$ bins. The fits are performed for each mode separately. The probability density functions (PDF) used to model signal decays are as follows: for $M_{bc}$ we use the sum of a Gaussian and a Crystal Ball function $[28]$, whereas for $\Delta E$ we use a single Gaussian and for $O'$ we use the sum of an asymmetric Gaussian and a regular Gaussian with a common mean. All signal shape parameters are obtained from MC simulation. To account for small differences observed between data and MC simulations, we introduce a small offset in the mean positions and scaling factors for the width. The values of these parameters are obtained from fitting the control sample $B \to J/\psi(\to \ell^+\ell^-)K$ decays and kept fixed. The shape of $M_{bc}, \Delta E$ and $O'$ distributions for background arising from $B-$decays are parameterized with an ARGUS function $[24]$, an exponential, and a Gaussian PDF, respectively. Similarly, the continuum background is modeled using an ARGUS, a first-order polynomial and a Gaussian function for $M_{bc}, \Delta E$ and $O'$, respectively. The shape of $BB$ and continuum backgrounds are very similar in two of the fit variables,
FIG. 1: Signal enhanced $M_{bc}$ (left), $\Delta E$ (middle), and $O'$ (right) projections of three-dimensional unbinned extended maximum-likelihood fits to the data events that pass the selection criteria for $B^+ \rightarrow K^+ \mu^+ \mu^-$ (top), and $B^+ \rightarrow K^+ e^+ e^-$ (bottom). Points with error bars are the data; blue solid curves are the fitted results for the signal-plus-background hypothesis; red dashed curves denote the signal component; cyan big dashed, green dashed-dotted, and black dashed curves represent continuum, $B\bar{B}$ background, and $B \rightarrow$ charmless decays, respectively.

FIG. 2: Signal enhanced $M_{bc}$ (left), $\Delta E$ (middle), and $O'$ (right) projections of three-dimensional unbinned extended maximum-likelihood fits to the data events that pass the selection criteria for $B^0 \rightarrow K^0_S \mu^+ \mu^-$ (top), and $B^0 \rightarrow K^0_S e^+ e^-$ (bottom). The legends are the same as in Fig. 1.
and this makes it difficult to independently vary the yields of both backgrounds. Hence, the continuum yields are obtained for each mode in each $q^2$ bin from the off-resonance data sample. These yields are consistent with those of the high-statistics off-resonance MC sample and kept fixed during the fits. The results of the fit projected in a signal-enhanced region $[M_{bc} \in (5.27, 5.29)\, \text{GeV}/c^2, |\Delta E| < 0.05\, \text{GeV} \text{ and } O' \in (1.0, 8.0)]$ for $M_{bc}$, $\Delta E$ and $O'$ distributions in the data sample are shown in Figs. 1 and 2.

The fit is also performed in the aforementioned four $q^2$ bins including the bin $1 < q^2 < 6\, \text{GeV}^2/c^4$, where LHCb result has deviation, and $R_K$ and $A_I$ are calculated from Eqs. 1 and 2, respectively. The results are listed in Table 1. The results for $R_K$ and $A_I$ are also shown in Figs. 3 and 4, respectively.

![FIG. 3: $R_K$ in bins of $q^2$, for $B^+ \rightarrow K^+\ell^+\ell^-$ (top-left), $B^0 \rightarrow K_0^0\ell^+\ell^-$ (top-right), and combining both modes (bottom). The red marker represents the bin of $1 < q^2 < 6\, \text{GeV}^2/c^4$, and the blue markers are for $0.1 < q^2 < 4, 4 < q^2 < 8.12$ and $q^2 > 14.18\, \text{GeV}^2/c^4$ bins. The green marker denotes the whole $q^2$ region excluding the charmonium resonances.](image)

Systematic uncertainties in the branching fraction arise mainly from lepton identification: about $2\%$ ($1.6\%$) for muon (electron) identification for each lepton. Uncertainty due to hadron identification is about $0.8\%$ for $K^\pm$ and $1.6\%$ for $K_0^0$. The systematic uncertainty due to charged track reconstruction is $0.35\%$ per track. These uncertainties related to detector performance are determined from dedicated control samples. The uncertainty in efficiency due to limited MC statistics is about $0.2\%$, and the uncertainty in the number of $BB$ events is $1.4\%$. Systematic uncertainty in the branching fraction ratio, $B[Y(4S) \rightarrow B^+B^-]/B[Y(4S) \rightarrow B^0\bar{B}^0] = 1.058 \pm 0.024$ is $1.2\%$. We compare the efficiency of the $O > O_{\text{min}}$ criterion between data and MC samples for the control channel $B \rightarrow J/\psi K, J/\psi \rightarrow \ell^+\ell^-$, and the corresponding uncertainty is estimated as $1.5\%$. The uncertainty due to PDF shapes is evaluated by varying the fixed shape parameters by $\pm 1\sigma$ and repeating the fit; the change in the central value of $N_{\text{sig}}$ is taken as the systematic uncertainty, which ranges from $0.1\%$ to $0.6\%$. The uncertainty due to the fixed yield of continuum events is estimated by varying the yield by $\pm 1\sigma$ in the fit; the resulting variation in $N_{\text{sig}}$ is found to be less than $1\%$. In the case of $R_K$, systematic uncertainties due to charged track reconstruction, hadron identification, number of $BB$ events, and the ratio $B[Y(4S) \rightarrow B^+B^-]/B[Y(4S) \rightarrow B^0\bar{B}^0]$ cancel, while for the $A_I$ measurement lepton identification and the number of $BB$ events cancel.

In summary, we have measured the branching fractions, their ratios ($R_K$) and the $CP$-averaged isospin...
| $q^2$ (GeV$^2$/c$^4$) | Mode | $\varepsilon$ (\%) | $N_{\text{sig}}$ (10$^{-7}$) | $A_I$ (individual) | $A_I$ (combined) | $R_K$ (individual) | $R_K$ (combined) |
|-----------------|-------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| B$^+$ $\rightarrow$ K$^+$ $\mu^+ \mu^-$ | 0.1,4.0 | 20.8 | 28.4 | 1.72$^{+0.4}_{-0.4}$ | $A_I(\mu\mu) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0$ $\mu^+ \mu^-$ | 14.7 | 6.8$^{+3.3}_{-2.6}$ | 0.62$^{+0.30}_{-0.23}$ | $-0.10^{+0.20}_{-0.17}$ | $-0.22^{+0.14}_{-0.12}$ | $0.92^{+0.27}_{-0.24}$ | $0.95^{+0.27}_{-0.24}$ |
| B$^+$ $\rightarrow$ K$^+e^+e^-$ | 27.8 | 41.5$^{+7.7}_{-7.0}$ | 1.88$^{+0.35}_{-0.31}$ | $A_I(ee) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0e^+e^-$ | 18.4 | 5.5$^{+3.6}_{-2.2}$ | 0.40$^{+0.26}_{-0.21}$ | $-0.35^{+0.21}_{-0.17}$ | $1.5^{+1.2}_{-1.0}$ |
| B$^+$ $\rightarrow$ K$^+e^+e^-$ | 0.4,8.12 | 29.2 | 28.4$^{+6.4}_{-5.7}$ | 1.2$^{+0.3}_{-0.2}$ | $A_I(\mu\mu) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0e^+e^-$ | 20.8 | 4.2$^{+4.2}_{-3.5}$ | 0.27$^{+0.18}_{-0.13}$ | $-0.33^{+0.23}_{-0.19}$ | $-0.08^{+0.15}_{-0.12}$ | $1.22^{+0.42}_{-0.37}$ | $0.81^{+0.28}_{-0.25}$ |
| B$^+$ $\rightarrow$ K$^+e^+e^-$ | 33.9 | 26.9$^{+6.9}_{-6.1}$ | 1.00$^{+0.26}_{-0.23}$ | $A_I(ee) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0e^+e^-$ | 22.8 | 9.3$^{+3.7}_{-3.0}$ | 0.54$^{+0.22}_{-0.18}$ | $0.11^{+0.19}_{-0.16}$ | $0.50^{+0.39}_{-0.30}$ | $0.03^{+0.27}_{-0.22}$ |
| B$^+$ $\rightarrow$ K$^+e^+e^-$ | 0.1,6.0 | 23.5 | 42.3$^{+7.6}_{-6.9}$ | 2.3$^{+0.4}_{-0.4}$ | $A_I(\mu\mu) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0e^+e^-$ | 16.7 | 3.9$^{+2.9}_{-2.7}$ | 0.31$^{+0.16}_{-0.12}$ | $-0.52^{+0.20}_{-0.17}$ | $-0.30^{+0.13}_{-0.11}$ | $1.31^{+0.34}_{-0.31}$ | $0.98^{+0.27}_{-0.25}$ |
| B$^+$ $\rightarrow$ K$^+e^+e^-$ | 30.4 | 41.7$^{+8.0}_{-7.2}$ | 1.74$^{+0.33}_{-0.30}$ | $A_I(ee) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0e^+e^-$ | 20.1 | 8.9$^{+4.2}_{-3.2}$ | 0.59$^{+0.27}_{-0.23}$ | $-0.12^{+0.18}_{-0.15}$ | $0.53^{+0.44}_{-0.33}$ | $0.03^{+0.27}_{-0.22}$ |
| B$^+$ $\rightarrow$ K$^+e^+e^-$ | > 14.18 | 45.3 | 47.9$^{+8.6}_{-7.8}$ | 1.34$^{+0.24}_{-0.22}$ | $A_I(\mu\mu) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0e^+e^-$ | 25.3 | 9.6$^{+4.2}_{-3.5}$ | 0.51$^{+0.22}_{-0.18}$ | $-0.07^{+0.17}_{-0.15}$ | $-0.13^{+0.14}_{-0.12}$ | $1.08^{+0.30}_{-0.27}$ | $1.11^{+0.29}_{-0.26}$ |
| B$^+$ $\rightarrow$ K$^+e^+e^-$ | 44.2 | 43.2$^{+9.1}_{-8.3}$ | 1.24$^{+0.26}_{-0.24}$ | $A_I(ee) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0e^+e^-$ | 23.6 | 5.9$^{+4.0}_{-3.1}$ | 0.33$^{+0.23}_{-0.18}$ | $-0.24^{+0.23}_{-0.19}$ | $1.52^{+1.23}_{-0.97}$ | $0.10^{+0.29}_{-0.26}$ |
| B$^+$ $\rightarrow$ K$^+e^+e^-$ | whole $q^2$ | 27.8 | 137.0$^{+14.2}_{-13.5}$ | 6.24$^{+0.65}_{-0.61}$ | $A_I(\mu\mu) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0e^+e^-$ | 18.2 | 27.3$^{+6.6}_{-5.9}$ | 2.0$^{+0.5}_{-0.4}$ | $-0.15^{+0.09}_{-0.08}$ | $-0.19^{+0.07}_{-0.06}$ | $1.04^{+0.15}_{-0.13}$ | $1.06^{+0.15}_{-0.14}$ |
| B$^+$ $\rightarrow$ K$^+e^+e^-$ | 29.1 | 135.0$^{+15.5}_{-14.7}$ | 6.00$^{+0.6}_{-0.5}$ | $A_I(ee) = \ldots$ | $R_K = \ldots$ |
| B$^0$ $\rightarrow$ K$^0e^+e^-$ | 18.2 | 21.8$^{+7.0}_{-6.1}$ | 1.60$^{+0.52}_{-0.45}$ | $-0.24^{+0.11}_{-0.09}$ | $1.25^{+0.50}_{-0.44}$ | $0.08^{+0.27}_{-0.24}$ |
asymmetry ($A_f$) for the decays $B \rightarrow K \ell^+\ell^-$ as a function of $q^2$. The $R_K$ values for different $q^2$ bins are consistent with the SM prediction. Our result for the bin of interest, $q^2 \in (1.0, 6.0) \text{GeV}^2/c^4$, is consistent with the LHCb R [30] result, which has a deviation of 2.5$\sigma$, as well as the SM expectation. The $A_f$ for almost all the bins for different channels have negative asymmetry. For the bin $q^2 \in (1.0, 6.0) \text{GeV}^2/c^4$, the obtained $A_f$ value deviates from zero by 2.7$\sigma$ for the mode with muon final states.

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