Search for new physics in the $B \to K^{(*)} l^+ l^-$ decays at BABAR

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Abstract Based on a data sample of 384 million $B\overline{B}$ pairs collected with the BABAR detector at the PEP-II asymmetric e^+e^- storage ring, we measure branching fractions, direct CP, isospin and lepton-flavor asymmetries for the rare decays $B \to K^{(*)} l^+ l^-$ in two di-lepton mass bins above and below the J/ψ resonance. For the $B \to K^* l^+ l^-$ decay, we also measure the K^* longitudinal polarization fraction and the di-lepton forward-backward asymmetry.

Key words rare B decay, branching fraction, direct CP asymmetry, lepton flavor ratio, isospin asymmetry, K^* longitudinal polarization fraction, lepton forward-backward asymmetry

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1 Introduction

The decays $B^+ \to K^+ l^+ l^-$ and $B \to K^* l^+ l^-$, where l^+l^- is either an e^+e^- or $\mu^+\mu^-$ pair, arise from flavor-changing neutral-currents (FCNC). In the Standard Model (SM), the $b \to s l^+ l^-$ FCNC transitions are fobidden at tree level, and proceed at the lowest order through photon or Z penguin and W^+W^- box diagrams. For these diagrams, the amplitudes can be expressed in terms of effective Wilson coefficients for the electromagnetic penguin, C_7, and the vector and axial-vector electroweak contributions, C_9 and C_{10} respectively, arising from the interference of the Z penguin and W^+W^- diagrams [1]. Non-SM physics at the electroweak scale may contribute at the same order as the SM and cause sizable deviations of the Wilson coefficients C_7, C_9 and C_{10} from their expected SM values [2].

Many observables in $B \to K^{(*)} l^+ l^-$ decays are useful for the probe of possible new physics due to their sensitivitity to changes in the Wilson coefficients. Since the form factors in $B \to K^{(*)} l^+ l^-$ are poorly known, the theoretical calculations for the decay rates possess large uncertainties. However the ratios of these rates, in which form factor dependencies largly cancel, and the dilepton forward-backward asymmetry, are better known theoretically, thus provide more sensitive tools in the new physics searches [3]. We perform the measurements of these observables in two bins of dilepton mass squared ($q^2 \equiv m_{ll}^2$) below and above the J/ψ resonance.

2 Experimental details

In our measurements, we collect data events with the BABAR detector [4] at the PEP-II asymmetric-energy e^+e^- collider located at the SLAC National Accelerator Laboratory. The data sample comprises of 384 million $B\overline{B}$ pairs collected at the $\Upsilon(4S)$ resonance. The selection of charged and neutral particles, as well as reconstruction of π^0, K_S^0 candidates is described in Ref. [5]. We reconstruct $B \to K^{(*)} l^+ l^-$ signal events in ten final states with an e^+e^- or $\mu^+\mu^-$ pair and a K_S^0, K^+, or K^* candidate, where a K^* candidate is reconstructed in $K^+\pi^-$, $K^+\pi^0$, or $K_S^0\pi^+$ final state with an invariant mass $0.82 < m_{K\pi} < 0.97$ GeV$/c^2$. To characterize the reconstructed B candidates, we define the kinematic variables $m_{ES} = \sqrt{s/4 - p_B^{*2}}$ and $\Delta E = E_B^* - \sqrt{s}/2$, where p_B^* and E_B^* are the B momentum and energy in the center-of-mass (CM) frame, and $\sqrt{s}$ is the total CM energy. We define a fit region with stringent requirements on m_{ES} and ΔE as described in Ref. [5]. Further suppression on the random combinatorial background re-

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lies on the use of neural networks with inputs such as event shape variables, vertexing information and missing energy. For background events in which both pions are mis-identified as muons, they are either vetoed (for $B\to D(\to K^{(*)}\pi)\pi$ events) or estimated from dedicated data samples (for $B\to K^{(*)}\pi^+\pi^-$ events). The events with dilepton mass close to the nominal J/ψ and $\psi(2S)$ masses are rejected to suppress the charmonium backgrounds.

3 Measurements

We perform $m_{\rm ES}$ fits to extract signal and background yields. These yields are used to derive the branching fractions and rate asymmetries. We measure the total branching fractions for decays $B\to Kl^+l^-$ and $B\to K^*l^+l^-$ at $(0.394^{+0.073}_{-0.069}\pm0.020)\times10^{-6}$ and $(1.11^{+0.19}_{-0.18}\pm0.07)\times10^{-6}$ respectively, by assuming isospin and lepton-flavor symmetry. For these results, the first uncertainty is statistical, and the second is systematic. These results agree well with other measurements [6, 7].

We measure the direct CP asymmtry $A_{\rm CP}^{K^{(*)}}$

$$A_{\rm CP}^{K^{(*)}}\equiv\frac{\mathcal{B}(\overline{B}\to\overline{K}^{(*)}l^+l^-)-\mathcal{B}(B\to K^{(*)}l^+l^-)}{\mathcal{B}(\overline{B}\to\overline{K}^{(*)}l^+l^-)+\mathcal{B}(B\to K^{(*)}l^+l^-)},\quad(1)$$

which is expected to be very small of $\mathcal{O}(10^{-3})$ in the SM. New physics at the electroweak scale may increase $A_{\rm CP}^{K^{(*)}}$ significantly [8]. For the measurements of $A_{\rm CP}^{K^{(*)}}$ integrated over the entire q^2 region, we find $A_{\rm CP}^{K}=-0.18^{+0.18}_{-0.18}\pm0.01$ averaged over two $K^{\pm}l^+l^-$ final states, and $A_{\rm CP}^{K^*}=+0.01^{+0.16}_{-0.15}\pm0.01$ averaged over six $K^*l^+l^-$ final states. The statistical and systematic uncertainties of these results are given out sequentially. Our results are consistent with the SM expectation of negligible direct CP asymmetry.

In the SM, the lepton flavor ratios

$$R_{K^{(*)}}\equiv\frac{\mathcal{B}(B\to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B\to K^{(*)}e^+e^-)},\quad(2)$$

differ from unity by only a few percent for $q^2>(2m_\mu)^2$ [9], while according to two-Higgs-doublet models, the presence of a neutral Higgs boson at large $\tan\beta$ might increase these ratios by $\sim$10% [10]. Our results of $R_K=0.96^{+0.44}_{-0.34}\pm0.05$ and $R_{K^*}=1.37^{+0.53}_{-0.40}\pm0.09$ integrated over the entire q^2 region are consistent with unity, as expected in the SM, where the statistical and systematic uncertainties are presented sequentially.

We measure the CP-average isospin asymmetry

$$A_I^{K^{(*)}}\equiv\frac{\mathcal{B}(B^0\to K^{(*)0}l^+l^-)-r\mathcal{B}(B^{\pm}\to K^{(*)\pm}l^+l^-)}{\mathcal{B}(B^0\to K^{(*)0}l^+l^-)+r\mathcal{B}(B^{\pm}\to K^{(*)\pm}l^+l^-)},\quad(3)$$

with $\tau=\tau_0/\tau_+$ as the ratio of the B^0 and B^+ lifetimes [11]. In the SM, the values of $A_I^{K^{(*)}}$ integrated over the low q^2 region are expected to be very close to zero [12]. In the high q^2, these asymmetries may receive contributions from charmonium states. Since the isospin asymmetry measured in $B\to J/\psi K^{(*)}$ [11] is small, these contributions can be neglected.

We measure $A_I^{K^{(*)}}$ integrated over the entire q^2 region as $A_I^{K}=-0.37^{+0.27}_{-0.34}\pm0.04$ and $A_I^{K^*}=-0.12^{+0.18}_{-0.16}\pm0.04$, where the statistical and systematic uncertainties are shown sequentially. These results are in reasonable agreement with the SM expectation of small values. We also find $A_I^{K^{(*)}}$ in the high q^2 region ($q^2>10.24$ GeV$^2/c^4$) consistent with the SM expectation. However, in the low q^2 ($0.1<q^2<7.02$ GeV$^2/c^4$), our observations of $A_I^{K,\,\rm low}=-1.41^{+0.49}_{-0.69}\pm0.04$ and $A_I^{K^*,\,\rm low}=-0.56^{+0.17}_{-0.15}\pm0.04$ show large negative values. By using the change in log likelihood $\sqrt{2\Delta\ln\mathcal{L}}$ between the nominal fit to the data and a fit with $A_I^{K^{(*)}}$ fixed at 0, we calculate the statistic significance of $A_I^{K,\,\rm low}$ and $A_I^{K^*,\,\rm low}$ with which a null isospin asymmetry hypothesis is rejected. By taking into account the systematic effects, we find the significances for $A_I^{K,\,\rm low}$ and $A_I^{K^*,\,\rm low}$ different from 0 are 3.2σ and 2.7σ, respectively. The likelihood curves from the Kl^+l^- and $K^*l^+l^-$ fits are shown in Fig. 1. From the $\Delta\ln\mathcal{L}$ for the combined $K^{(*)}l^+l^-$ modes, we obtain $A_I^{K^{(*)},\,\rm low}=-0.64^{+0.15}_{-0.14}\pm0.03$. Including systematic effects, the significance for $A_I^{K^{(*)},\,\rm low}$ from 0 is 3.9σ.

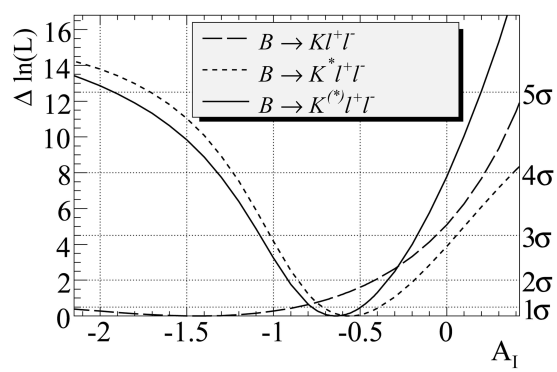

Fig. 1. Likelihood curves for the $K^{(*)}l^+l^-$ A_I fits in the low q^2 region.

In the decay $B\to K^*l^+l^-$, we also measure the K^* logitudinal polarization fraction $F_{\rm L}$ and the lepton forward-backward asymmetry $A_{\rm FB}$. The q^2 dependency of $F_{\rm L}$ and $A_{\rm FB}$ expected in the SM is shown in Fig. 2 together with new physics scenarios in which the Wilson coefficients take opposite-sign values. Due to the dominance of C_7 at low q^2, the SM value of $A_{\rm FB}$ is expected to be negative at very small q^2 and crosses zero at $q^2 \sim 4$ GeV$^2/c^4$ with the increase of q^2 [3, 13]. The magnitude of C_7 is experimentally constrained by measuring the branching fraction for $b \rightarrow s\gamma$ [11, 13], which corresponds to the limit of $q^2 \rightarrow 0$, while the choice of C_7 sign different from the SM prediction is allowed. At high q^2, A_{FB} is expected to be kept positive in the SM. However an opposite C_9 C_{10} from right-handed weak currents would yield a negative A_{FB} in this region.

The measurements of F_L and A_{FB} rely on the angular observables θ_K and θ_l, which are defined respectively as the angle between the K and the B directions in the K* rest frame, and the angle between the $l^+(l^-)$ and the $B(\overline{B})$ directions in the l^+l^- rest frame. Successively, we obtain F_L by fitting to $\cos\theta_K$ of the form [14]

$$\frac{3}{2}F_L\cos^2\theta_K+\frac{3}{4}(1-F_L)(1-\cos^2\theta_K), \qquad (4)$$

and obtain A_{FB} by fitting to $\cos\theta_l$ of the form [14]

$$\frac{3}{4}F_L(1-\cos^2\theta_l)+\frac{3}{8}(1-F_L)(1+\cos^2\theta_l)+A_{FB}\cos\theta_l. \qquad (5)$$

For the measurements of F_L and A_{FB}, in the low q^2 region ($0.1 < q^2 < 6.25$ GeV$^2/c^4$), we find $F_L = 0.35 \pm 0.16 \pm 0.04$ and $A_{FB} = 0.24^{+0.18}_{-0.23} \pm 0.05$, while the SM predicts $F_L^{SM} = 0.63$ and $A_{FB}^{SM} = -0.03$. In the high q^2 region ($q^2 > 10.24$ GeV$^2/c^4$), we find $F_L = 0.71^{+0.20}_{-0.22} \pm 0.04$ and $A_{FB} = 0.76^{+0.52}_{-0.32} \pm 0.07$, while the SM predicts $F_L^{SM} = 0.38$ and $A_{FB}^{SM} = 0.40$. The statistical and systematic uncertainties of these results are presented sequentially. Our F_L and A_{FB} results are summarized in Fig. 2, along with the predictions from the SM, and new physics models with flipped signs of Wilson coefficients. Our A_{FB} results are also consistent with the Belle measurements [7].

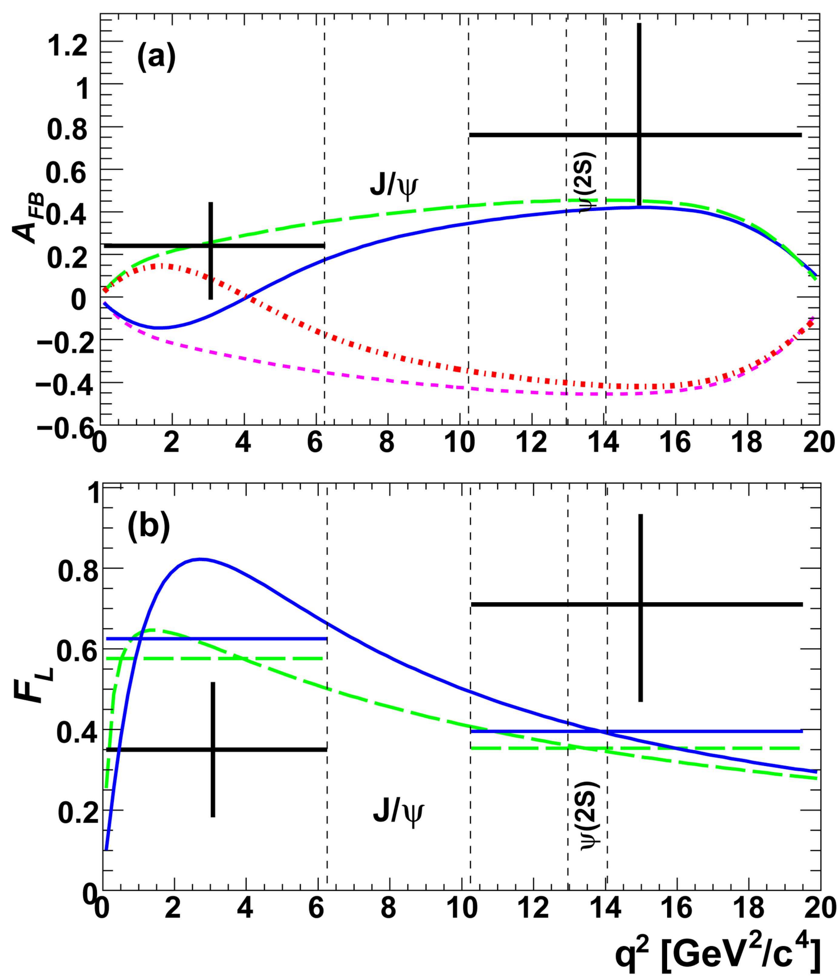

Fig. 2. (color online). Plots of our results (points with error bars) for (a) A_{FB} and (b) F_L for the decay $B \rightarrow K^*l^+l^-$ showing comparisons with SM (solid); $C_7 = -C_7^{SM}$ (long dash); $C_9C_{10} = -C_9^{SM}C_{10}^{SM}$ (short dash); $C_7 = -C_7^{SM}, C_9C_{10} = -C_9^{SM}C_{10}^{SM}$ (dash-dot). Expected F_L values integrated over each q^2 region are also shown.

The results reported here have been published in Ref. [15] for $A_{CP}^{K^{(*)}}$, $R_{K^{(*)}}$, and $A_I^{K^{(*)}}$, and in Ref. [5] for F_L and A_{FB} in the decay $B\to K^*l^+l^-$.

4 Conclusion

We have measured the branching fractions, direct CP asymmetries, lepton flavor ratios, and isospin asymmetries in the decays $B\to Kl^+l^-$ and $B\to K^*l^+l^-$. Our results on the branching fractions, direct CP asymmetries and lepton flavor ratios are in good agreement with the SM expectations. For the isospin asymmetries, our results in the high and combined q^2 region are consistent with zero as expected in the SM. However, we observe large negative isospin asymmetries in the low q^2 region for both $B\to Kl^+l^-$ and $B\to K^*l^+l^-$. By combining the $K^{(*)}l^+l^-$ results, we measure $A_I^{K^{(*)}}=-0.64^{+0.15}_{-0.14}\pm0.03$, which rejects the $A_I=0$ hypothesis with 3.9σ significance, including systematic effects.

Furthermore, we measure the K^* longitudinal polarization fraction and lepton forward-backward asymmetry in the low and high q^2 regions for the decay $B\to K^*l^+l^-$. Our results are generally consistent with the SM predictions.

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