Flavor violation and New Physics in Rare decays

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The paper which I studied for this workshop

1. Inclusive $\bar{B} \to X_s l^+ l^-$; complete analysis and a thorough study of colliner photons.
   T. Huber, T. Hurth, and E. Lunghi.
   (JHEP06(2015)176, Arxiv:1503.04849)

1-1. In this paper, the effects of the collinear photons (QED corrections) to Rare B decays $\bar{B} \to X_s l^+ l^- (l = e, \mu)$ are included.

1-2. The structure of the double differential decay rate is modified compared with the case without collinear photons and various observables are affected due to thecollinear photons.

1-3. Including the effect, branching fractions for the modes $\bar{B} \to X_s e^+ e^-$ and $\bar{B} \to X_s \mu^+ \mu^-$ are predicted.

Issue of lepton universality of Rare B decay

Branching ratios in unit (10^{-6}) (Inclusive rates)

Babar,J.P.Lees et.al. PRL112(2014)211802

Low dilepton invariant mass region $(q^2 = M^2_{l^+l^-})$

$1 < q^2(\mathrm{GeV}^2) < 6$.

$$Br(B \to X_s \mu^+ \mu^-) = 0.66^{+0.82+0.30}_{-0.76-0.24} \pm 0.07$$

$$Br(B \to X_s e^+ e^-) = 1.93^{+0.47+0.21}_{-0.45-0.16} \pm 0.07$$

$$Br(B \to X_s l^+ l^-) = 1.60^{+0.41+0.17}_{-0.39-0.13} \pm 0.07 (l = e, \mu)$$

High invariant mass region(Babar,J.P.Lees et.al. PRL112(2014)211802)

$\mathbf{14.2 < q^2(GeV^2)}$

$$Br(B \to X_s \mu^+ \mu^-) = 0.60^{+0.31+0.05}_{-0.29-0.04} \pm 0.00$$

$$Br(B \to X_s e^+ e^-) = 0.56^{+0.19+0.03}_{-0.18-0.03} \pm 0.00$$

$$Br(B \to X_s l^+ l^-) = 0.57^{+0.16+0.03}_{-0.15-0.02} \pm 0.00$$

Branching fractions for regions $M_{l^+l^-} > 0.2$(GeV)
Belle, Iwasaki et.al. PRD72(2005)092005,

$$Br(B \to X_s e^+ e^-) = (4.04 \pm 1.30^{+0.87}_{-0.83}) \times 10^{-6}$$

$$Br(B \to X_s \mu^+ \mu^-) = (4.13 \pm 1.05^{+0.85}_{-0.81}) \times 10^{-6}$$

$$Br(B \to X_s l^+ l^-) = (4.11 \pm 0.83^{+0.85}_{-0.81}) \times 10^{-6}$$

Belle: Low and High invariant mass regions.

(lepton-flavor-averaged) Branching fractions;

Iwasaki et.al.PRD72(2005)092005 Low invariant mass region:

$(1 < q^2(\mathrm{GeV}^2) < 6)$

$$Br(B \to X_s l^+ l^-) = 1.493 \pm 0.504^{+0.411}_{-0.321}.$$

High invariant mass region:

$(14.44 < q^2(\mathrm{GeV}^2) < 25)$

$$Br(B \to X_s l^+ l^-) = 0.418 \pm 0.117^{+0.061}_{-0.068}.$$

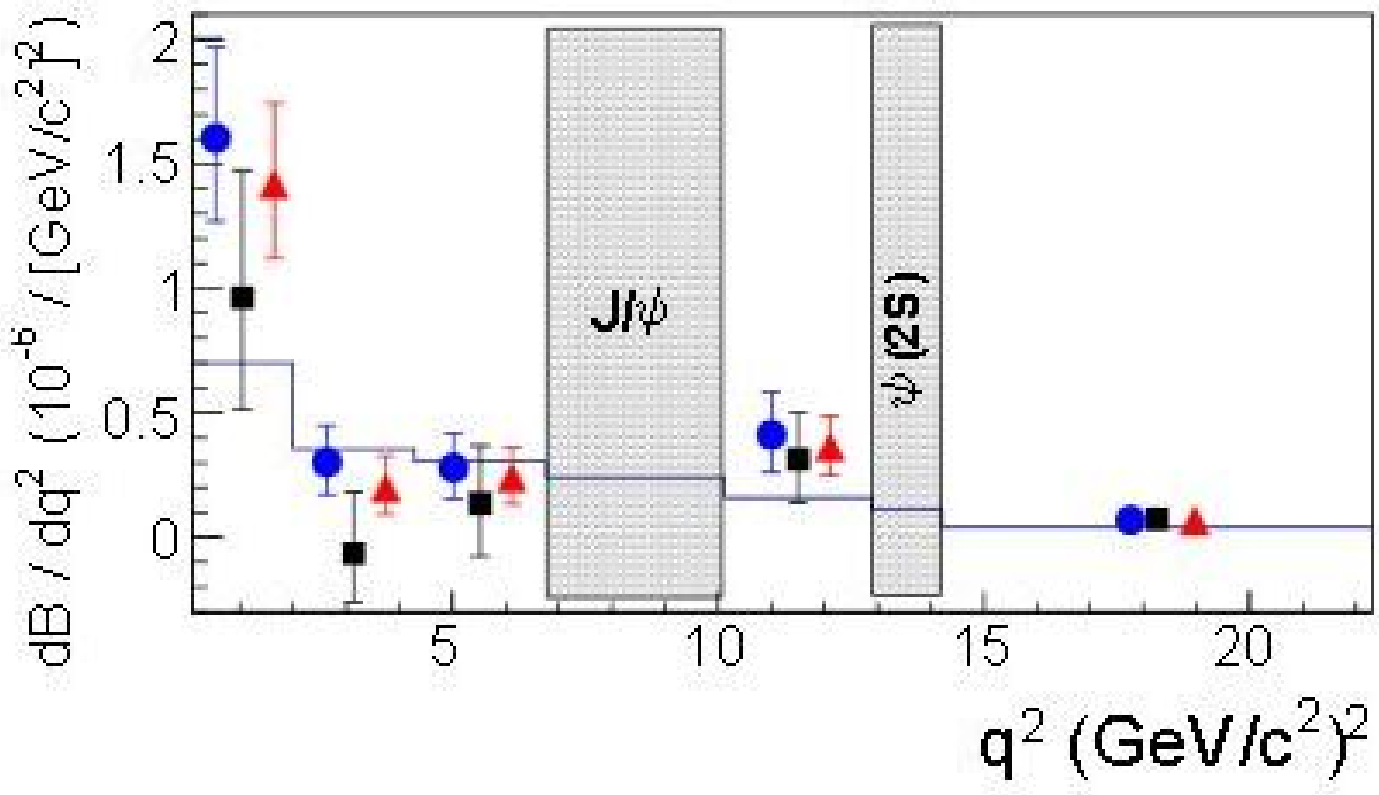


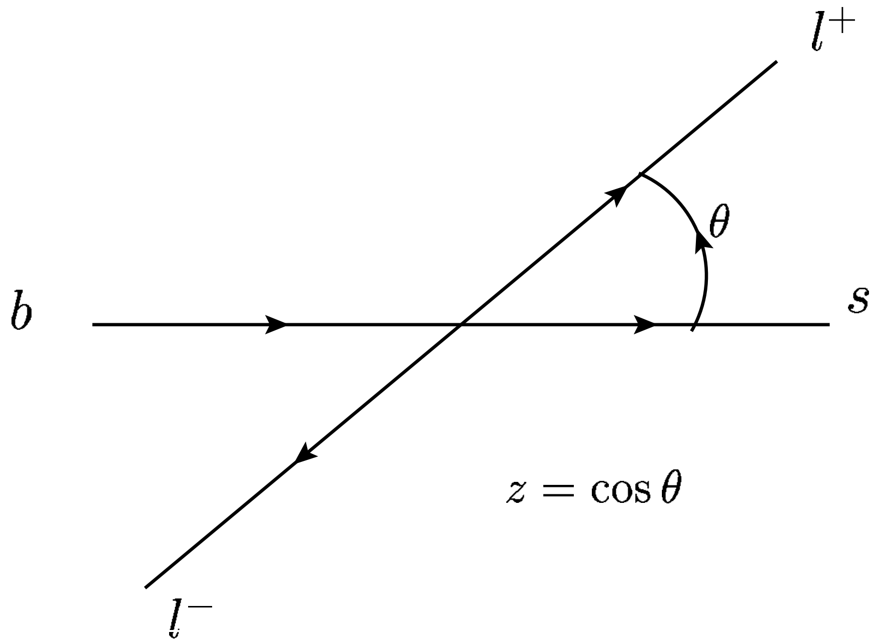
Figure 1: Differential Branching fractions. (electron) blue circles. (muon) black squares. (lepton-flavor-averaged) red triangles. The histogram is SM expectation without QED corrections. The figure is taken from Babar, J.P.Lees et.al. PRL112(2014).

Amplitude for $\bar{B} \to X_s l^+ l^-$

$$M(b \longrightarrow s l^+ l^-)$$
$$= \frac{G_F \alpha}{\sqrt{2}\pi} V_{ts}^* V_{tb} [(C_{9eff} \bar{s_L} \gamma_\mu b_L \bar{l} \gamma^\mu l$$
$$+ C_{10} \bar{s_L} \gamma_\mu b_L \bar{l} \gamma^\mu \gamma_5 l)$$
$$- 2 C_7 (\bar{s_L} i \sigma_{\mu\nu} \frac{q^\nu}{q^2} b_R m_b) \bar{l} \gamma^\mu l]$$

Kinematical variables

In cm frame of dileptons, the angle θ is defined as an angle bet. incoming momentum of b and outgoing l^+.



Decay distribution $\hat{s} = q^2/m^2_{\rm bpole}, z = \cos\theta$.

$$\frac{d\Gamma}{dq^2 dz} = \frac{3}{8}[(1+z^2)H_T(q^2) + 2(1-z^2)H_L(q^2) + 2zH_A(q^2)]$$

$$H_T = \frac{G_F^2 m^5_{\rm bpole}|V_{tb}V^*_{ts}|^2}{48\pi^3} 2\hat{s}(1-\hat{s})^2[|C_9 + \frac{2C_7}{\hat{s}}|^2 + |C_{10}|^2]$$

$$H_L = \frac{G_F^2 m^5_{\rm bpole}|V_{tb}V^*_{ts}|^2}{48\pi^3} (1-\hat{s})^2[|C_9 + 2C_7|^2 + |C_{10}|^2]$$

$$H_A = -4\frac{G_F^2 m^5_{\rm bpole}|V_{tb}V^*_{ts}|^2}{48\pi^3} \hat{s}(1-\hat{s})^2 \mathrm{Re}\{C_{10}(C_9^* + \frac{2}{\hat{s}}C_7^*)\}$$

$H_T \sim H_A$ are functions of dilepton mass squared q^2.

Decay distribution and Forward backward Asymmetry

$$\frac{d\Gamma}{dq^2} = \int_{-1}^{1} dz \frac{d^2\Gamma}{dq^2 dz} = \frac{8}{3}(H_T(q^2) + H_L(q^2)),$$

$$\frac{dA_{FB}}{dq^2} = \int_{-1}^{1} dz \frac{d^2\Gamma}{dq^2 dz} \mathrm{sign}(z) = \frac{3}{4} H_A(q^2).$$

(A_{FB} A.Ali, T.Mannel and T.Morozumi,1991)

Dimensionless $\mathcal{H}_I$.

$$H_I(q^2) = \frac{G_F^2 m_{\mathrm{bpole}}^5 |V_{tb}V_{ts}^*|^2}{48\pi^3} \Phi_{ll}^I(\hat{s})$$

$$\mathcal{H}_I(q^2) \equiv \frac{H_I(q^2)}{\Gamma[\bar{B}]} = \frac{H_I(q^2)}{\Gamma[\bar{B} \to X_c e \bar{\nu}_e]} Br(\bar{B} \to X_c e \bar{\nu}_e)$$

$$= \frac{4}{C} \frac{|V_{tb}V_{ts}|^2}{|V_{cb}|^2} \frac{\Phi_{ll}^I(\hat{s})}{\Phi_u} Br(\bar{B} \to X_c e \bar{\nu}_e)\Big|_{\mathrm{exp.}}$$

$$\frac{1}{\Gamma[\bar{B} \to X_c e \bar{\nu_e}]} = \frac{|V_{ub}|^2}{|V_{cb}|^2 C} \frac{1}{\Gamma[\bar{B} \to X_u e \bar{\nu_e}]}, C = 0.574 \pm 0.019,$$

$$\Gamma[\bar{B^0} \to X_u l \bar{\nu_l}] = \frac{G_F^2 m_{\mathrm{bpole}}^5 |V_{ub}|^2}{192\pi^3} \Phi_u.(\tilde{\alpha_s} = \frac{\alpha_s}{4\pi}, \kappa = \frac{\alpha_{em}(\mu_b)}{\alpha_s(\mu_b)})$$

$$\Phi_u = 1 + \tilde{\alpha_s}\varphi^{(1)} + O(\kappa) + O(\tilde{\alpha_s}^2) + O(1/m_b^2) + .., .$$

Including QED corrections and the results In the paper, T. Huber, T. Hurth, and E. Lunghi, the log-enhanced QED bremsstrahlung effect are included and the sizable corrections to Branching fractions are found.

	$\frac{O_{[1,6]}}{B_{[1,6]}}$	$\frac{\Delta O_{[1,6]}}{B_{[1,6]}}$	$\frac{\Delta O_{[1,6]}}{O_{[1,6]}}$
$\mathcal{B}$	100	5.1	5.1
$\mathcal{H}_T$	19.5	14.1	72.5
$\mathcal{H}_L$	80.0	-8.7	-10.9
$\mathcal{H}_A$	-3.3	1.4	-43.6

Table 1: The size of the QED corrections within the low dilepton invariant mass regions $q^2 \in [1, 6]$(GeV^2) (e^+e^- case). The data is taken from the table 2 of T. Huber et.al. JHEP1506(2015)176.

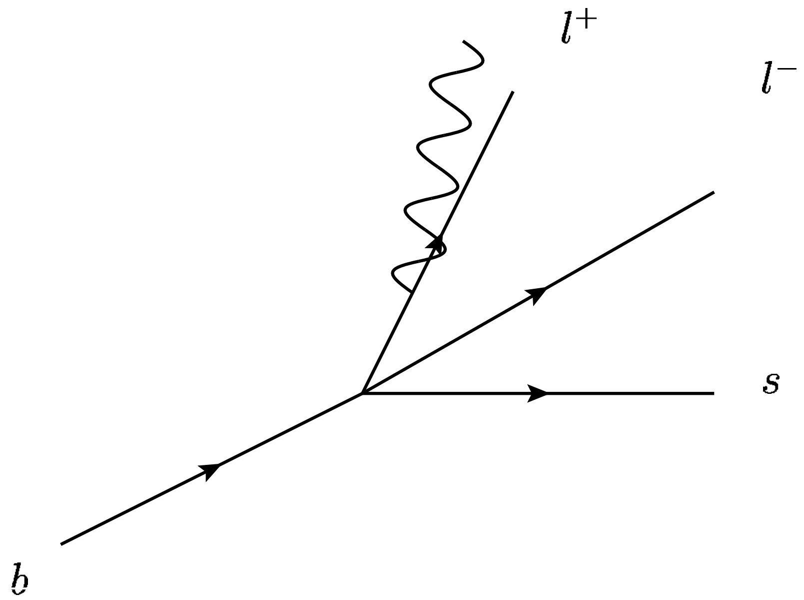


Figure 2: Feynman diagram for emission of collinear photon (collinear to l^+).

The observation within the analysis $q^2 \in [1, 6]$

- The large QED corrections to $\mathcal{H}_T$ is found. There is a suppression for H_T and H_A without QED effect.

$$H_T \sim \hat{s}(|C_9 + \frac{2C_7}{\hat{s}}|^2 + |C_{10}|^2)$$

$$H_L \sim (|C_9 + 2C_7|^2 + |C_{10}|^2)$$

$$H_A \sim -\hat{s}Re.(C_9 + \frac{2C_7}{\hat{s}})(C_{10}^*)$$

Flavor dependence of the standard model predictions

$B_{ee[1,6]}$	$B_{\mu\mu[1,6]}$
1.67 ± 0.10	1.62 ± 0.09

Table 2: Branching fractions for e^+e^- mode and $\mu^+\mu^-$ mode.) in the unit of 10^{-6}. The data is taken from Eqs(5.13-5.14) of T. Huber et.al. JHEP1506(2015)176.

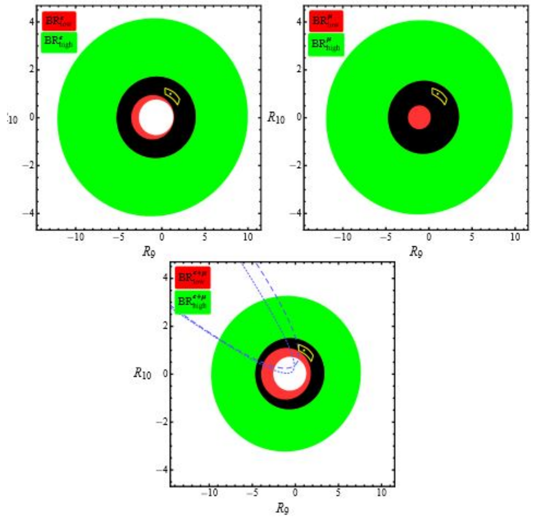


Figure 3: New Physics Constraints on new physics (R_9, R_{10}), $R_i = C_i/C_{iSM}$ The figure is taken from Fig.4 of T. Huber et.al. JHEP1506(2015)176. The black regions are overlapping regions for high and low q^2 branching fraction constraints from Belle and Babar. The bottom figure is the constraints from the data in which electron and muon modes are added. The regions outside the parabola lines are allowed region obtained from the normalized forward backward asymmetry measured by Belle. For the details, see the original paper,T. Huber et.al. JHEP1506(2015)176.

Summary

Recent new calculation of FCNC modes $b \to s e^+ e^-$ and $b \to s \mu^+ \mu^-$ taking into account of the QED bremsstrahlung effect does not give rize to large charged lepton flavor dependence for partially integrated ($q^2 \in [1, 6]$(GeV^2)) branching fraction. The theoretical calculation does not lead to the difference found for the central values of the Babar data for e and μ mode at low invariant mass regions. Since the statistical errors are still large, we should wait until the experimental data will be improved.