THEORETICAL ANALYSIS OF $B^0 \to \phi\ell^+\ell^-$ DECAY

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PROBLEM

In the Standard Model (SM), the $b \to s\,(d)$ flavor-changing neutral currents (FCNC), being loop-induced, are standard experimental channels for testing the SM precisely and searching for possible physics beyond the SM. Purely annihilation decays of B-mesons originating by these currents are of significant interest as in the SM they are extremely suppressed and New Physics effects can increase substantially their decay widths.

Radiative and semileptonic decays with the ϕ-meson production are typical examples of annihilation-type processes. The upper limit on the radiative decay branching fraction, $\mathcal{B}(B^0 \to \phi\gamma) < 1.0 \times 10^{-7}$, by the Belle collaboration [1] was the only one for quite some time. This year, the LHCb collaboration obtained the upper limit on its semileptonic counterpart, $\mathcal{B}(B^0 \to \phi\mu^+\mu^-) < 3.2 \times 10^{-9}$ [2]. It would be desirable to obtain the SM predictions for the later one.

CONTRIBUTIONS

Theoretical analysis of radiative annihilation-type decays $B^0 \to \phi\gamma$ and $B_s \to \rho^0(\omega)\gamma$, including the $\omega - \phi$ mixing effect was undertaken in [3].

For semileptonic annihilation-type $B^0 \to \phi\ell^+\ell^-$ decay we present Standard model predictions, so far, without taking into account $\omega - \phi$ mixing. We estimate also the dependence on the choice of theoretical models for B-meson distribution amplitudes entering through first inverse moments.

THEORETICAL ANALYSIS

Calculatons are done in the Effective Electroweak Hamiltonian approach. The effective Lagrangian density is derived from the Standard Model (SM) by integrating out heavy particles — the top quark, W-, Z- and Higgs bosons:

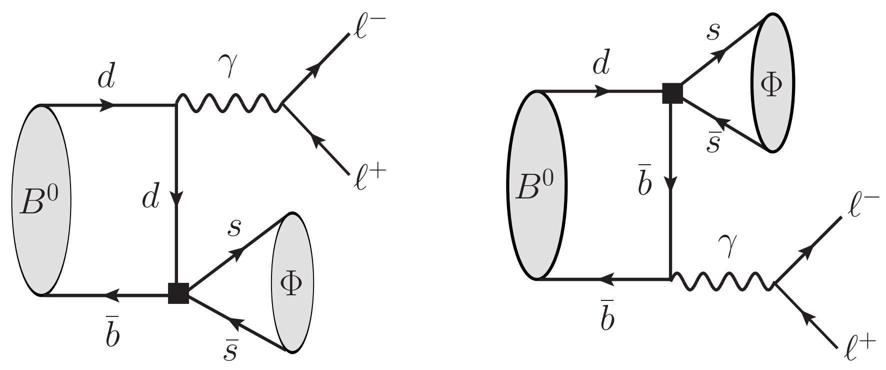
$$\mathcal{L}_{\rm eff}(x) = \mathcal{L}_{\rm QED}(x) + \mathcal{L}_{\rm QCD}(x) + \mathcal{L}_{\rm weak}^{b\to d}(x) + \mathcal{L}_{\rm weak}^{b\to s}(x).$$

Flavor-changing neutral current (FCNC) term $\mathcal{L}_{\rm weak}^{b\to d}$ describes the $b \to d$ transition:

$$\mathcal{L}_{\rm weak}^{b\to d} = -\frac{4G_F}{\sqrt{2}} \sum_{p=u,c} V_{pd}^* V_{pb} \sum_j C_j(\mu)\mathcal{P}_j(\mu) + \text{h. c.}.$$

The standard basis of four-fermion operators for the $b \to d$ transition includes 10 operators. The leading-order contribution to the decay amplitude is given by Penguin operators $\mathcal{P}_3 = (\bar{d}\gamma_\mu L b)\sum_q(\bar{q}\gamma^\mu q)$ and $\mathcal{P}_5 = (\bar{d}\gamma_\mu\gamma_\nu\gamma_\rho L b)\sum_q(\bar{q}\gamma_\mu\gamma_\nu\gamma_\rho q)$.

On the tree level, $B^0 \to \phi\ell^+\ell^-$ amplitude is represented by 8 diagrams. The largest contribution is from diagrams with emmiting the ϕ-meson from a quark line (shown on right hand side). The diagram with emmiting from a b-quark line is $1/m_b$ supressed compared to the left one. Contributions of other 6 diargrams are supressed by α_s and α_s/m_b.



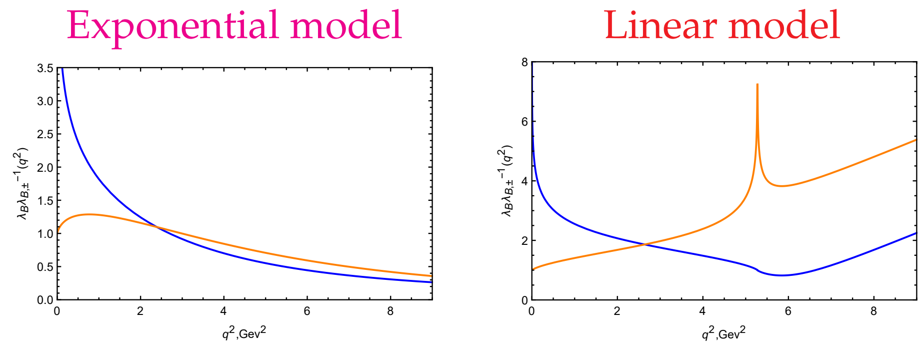
The most significant contribution diagrams for $B^0 \to \phi\ell^+\ell^-$ on the tree level

$B^0 \to \phi\ell^+\ell^-$ Differential Branching Fraction:

$$\frac{d\mathcal{B}}{dq^2} = \tau_B \frac{G_F^2|V_{td}^* V_{tb}|^2\alpha^2}{216\pi} M_B f_B^2 f_\phi^2 Q_d^2 \lambda^3(1, m_\phi/M_B, \sqrt{q^2}/M_B)\,|C_3 + 4C_5|^2 \times \left[\left|\frac{1}{\lambda_-^B(q^2)}\right|^2 + \frac{m_\phi^2}{q^2\left(1-q^2/M_B^2\right)^2}\left|\frac{1}{\lambda_+^B(q^2)}\right|^2\right]$$

It depends on the first inverse moments (FIMs) $[\lambda_\pm^B(q^2)]^{-1}$ of the B-meson distribution amplitudes (DAs), $\phi_\pm^B(\omega)$, which are non-perturbative quantities. A momentum-dependence of them is determined by the choice of DAs theoretical models.

We use two models of the DAs — Exponential model [4] and Linear model [5], and the corresponding q^2-dependence, where q^2 is the momentum squared of the lepton pair, of the FIMs is shown in the plots below.



NUMERICAL RESULTS

Theoretical predictions for a partially integrated branching fraction are estimated in the region $q^2 \in [1\ \text{GeV}^2, 8\ \text{GeV}^2]$.

Exponential model:

$$\Delta\mathcal{B}(1\ \text{GeV}^2 < q^2 < 8\ \text{GeV}^2) = (2.14^{+1.57}_{-0.96}) \times 10^{-13}$$

Linear model:

$$\Delta\mathcal{B}(1\ \text{GeV}^2 < q^2 < 8\ \text{GeV}^2) = (3.88^{+2.85}_{-1.75}) \times 10^{-13}$$

The difference in the model predictions of the order of the factorization scale uncertainty.
Estimation of the total branching fraction $\mathcal{B}(B^0 \to \phi\ell^+\ell^-) \sim 10^{-12}$ consistent with the upper limit by LHCb [2].

REFERENCES

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[5] H. Kawamura, J. Kodaira, et al. B-Meson Light-Cone Distribution Amplitudes in the Heavy-Quark Limit. PLB 523 (2001) 111.

CONCLUSIONS AND FUTURE PROSPECTS

We present the theoretical analysis of the $B^0 \to \phi\ell^-\ell^+$ decay in the leading order. The branching fraction is calculated perturbatively in the region of small q^2 and its dependence on the theoretical model of the B-mesom DAs is demonstrated numerically. Theoretical prediction for the total branching fraction agrees with the experimental limit by LHCb Collaboration. This analysis should be extended by taking into account all the tree-level amplitudes. A more precise prediction for the total branching fraction which cover the entire kinematically allowed region is under derivation. As a next step, an impact of the $\omega - \phi$ mixing on the decay considered should be worked out.