Contribution of charm to rare radiative leptonic B-decays

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Introduction

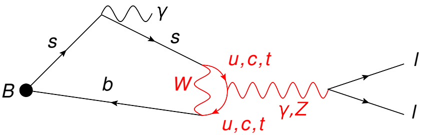
Rare radiative leptonic decays $B_{d,s} \to \gamma \ell^+ \ell^-$:

- Induced by weak flavour changing neutral currents (FCNCs)
- Forbidden at tree level in the Standard Model and occur only via loop diagrams
- Have small branching ratios of order $10^{-8} - 10^{-10}$
- New particles can contribute to the loops

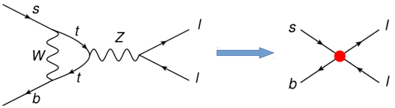
Similar B-decays are actively studied experimentally ($B \to K^{(*)} \ell^+ \ell^-$ and others), and 2-3 σ deviations from the Standard Model have been observed.

Effective Hamiltonian

Penguin diagram as an example:



In the loop u,c,t quarks are possible



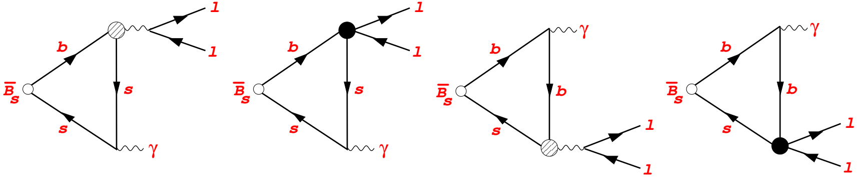
Exchange of heavy virtual particles (t,W,Z) can be reduced to effective quasilocal interactions

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} V_{tb} V_{tq}^* \sum_i C_i(\mu) O_i(\mu),$$

$C_i(\mu)$ - Wilson coefficients,

$O_i(\mu)$ - set of basis operators

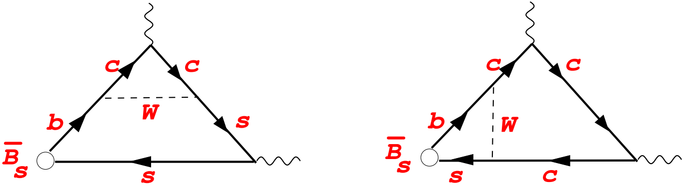
t-quark contribution



- Diagrams containing top-quarks in the loops. The loops with t-quarks are reduced to the effective vertices (black and shaded circles)
- The diagrams are described in terms of meson-to-photon transition formfactors.
- The formfactors were calculated in the wide range of momentum transfer via relativistic quark model

  The parameters of the model (quark masses and parameters of the hadron wave functions) were fixed by the requirement to reproduce weak decay constants.
- Comparison with other approaches (lattice QCD, sum rules) showed the accuracy of 10%.

c-quark contribution

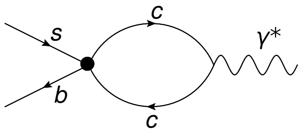


(a) (b)

- c-quark is dynamical
- When the W boson line is reduced to a point ($M_W >> M_B$), diagram (a) produces the penguin diagram, diagram (b) produces the diagram of weak annihilation (the contribution is small compared to others)
- In diagram (a) we have contribution of the c-quark loop for $0 < q^2 < M_B^2$, that means charmonia appear in the kinematical region of the process. This leads to uncertainties in theoretical predictions.

Penguin with c-quark

Factorizable contribution



Takes into account factorizable gluon exchanges only

$$A_{\mu\nu} \sim \frac{3C_1 + C_2}{3} \Pi^{cc}_{\mu\nu}(k) * (Rest)$$

Perturbative QCD + results of the measurements

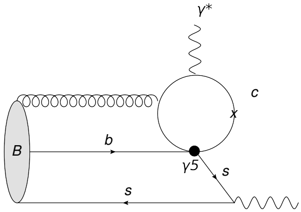
$$\Pi^{cc}_{\mu\nu}(k') = i \int dx e^{ikx} \langle 0 | T\{\bar{c}\gamma_\mu c(x), \bar{c}\gamma_\nu c(0)\} | 0 \rangle = \left(-g_{\mu\nu}k^2 + k_\mu k_\nu\right) \Pi^{cc}(k^2).$$

Factorizable contribution can be represented as an addition to Wilson coefficient C_9:

$$C_{9V} \to C^{\mathrm{eff}}_{9V}(q^2) = C_{9V} + \frac{16\pi^2}{9} \left(3C_1 + C_2\right) \Pi_{\bar{c}c}(q^2)$$

Penguin with c-quark

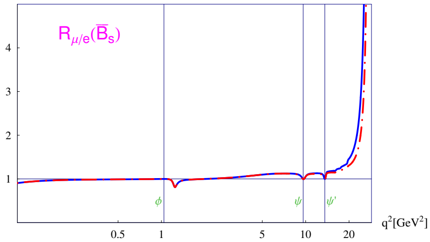
Nonfactorizable contribution

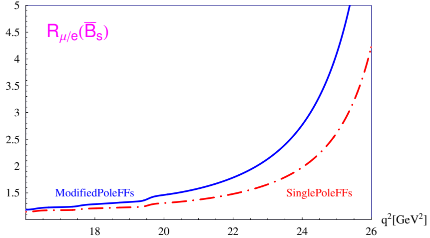


- Nonfactorizable and factorizable contributions are of the same order (experimental data)
- It is impossible to calculate the charm contribution in the region of cc-resonances
- Nonfactorizable contributions are not universal and depend on concrete processes

- We used the results for $B \to V\ell\ell$, combined with the concept of vector meson dominance to obtain predictions for $B \to \gamma\ell\ell$

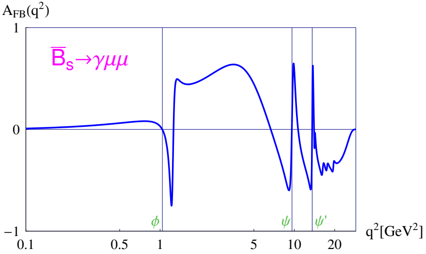
The ratio $R_{\mu/e} = \Gamma(B_s \to \mu\mu\gamma)/\Gamma(B_s \to ee\gamma)$

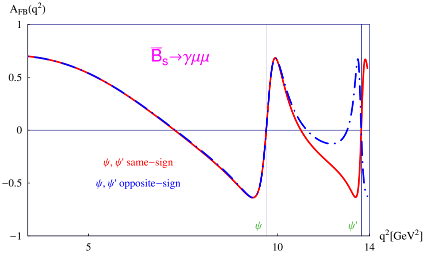




- Test of lepton universality: possibility to study New Physics effects?
- For small q^2 visible effect of $\phi(\rho,\omega)$-resonance
- For large q^2 the ratio strongly depends on hadron formfactors

Forward-backward asymmetry





- Forward-backward asymmetry has the standard form and contains cc-resonances in the kinematical region

Conclusions

We performed a detailed theoretical analysis of the nonperturbative decays $B_{d,s} \to \gamma\ell^+\ell^-$ in the Standard Model:

- Formfactors which parametrize the amplitudes of the processes were calculated via relativistic quark model including the constraints obtained from gauge invariance. These formfactors satisfy restrictions from QCD in the heavy quark limit. Comparing our results with the results from lattice QCD and sum rules we obtained that the accuracy of our results is about 10%

Conclusions

- We analyzed the charm contribution and obtained restrictions for this contribution obtained from gauge invariance. The contribution of $B \to V\ell\ell$ is similar to that of $B \to \gamma\ell\ell$ so the sum rules results for the latter were used to take into account the contribution of $B \to \gamma\ell\ell$. We demonstrated that the results of the nonfactorizable contribution in the region of small q^2 do not provide any conclusions about the phases of the cc-resonances. The experimental measurement of the forward-backward asymmetry in the region between the ψ and ψ' resonances will clarify the situation with the relative contribution of the narrow cc-resonances?

Conclusions

- We obtained numerical predictions for different differential distributions of the decays $B \to \gamma \ell^+ \ell^-$. In particular, we demonstrated that the measurement of the ratio $R_{\mu/e}(q^2)$ in the region of large q^2 will clarify the q^2 dependence of the transition formfactors $B \to \gamma$ if the lepton universality is established from the data for small q^2.
- We calculated the branching ratios for the region $q^2 \in [1, 6]\mathrm{GeV}^2$, where the formfactors are reliably known and the contribution of charm is at the level of few percent:

$$\mathcal{B}(\bar{B}_s \to \gamma l^+ l^-)|_{q^2 \in [1,6]\ \mathrm{GeV}^2} = (6.01 \pm 0.08 \pm 0.70)10^{-9},$$
$$\mathcal{B}(\bar{B}_d \to \gamma l^+ l^-)|_{q^2 \in [1,6]\ \mathrm{GeV}^2} = (1.02 \pm 0.15 \pm 0.05)10^{-11}$$

- The results of our work were published

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