Rare radiative leptonic B-decays as a tool to study New Physics

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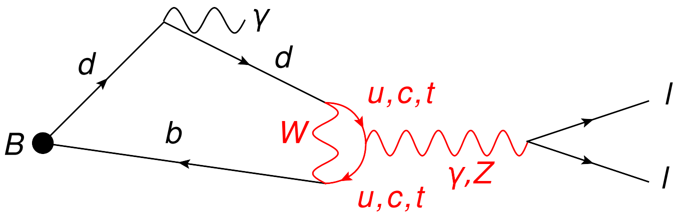
Introduction

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

- Have a small branching ratio (of order 10^{-8}-10^{-10})
- No tree diagrams, only loop diagrams
- May contain contribution of new particles in the loops (possibility to study New Physics)



Motivation

Discrepancies concerning $b \to s l^+ l^-$ transitions:

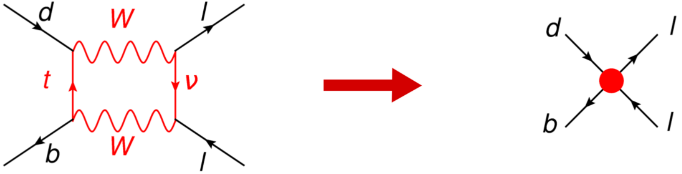
- $\mathcal{R}_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ e^+ e^-)} = 0.745^{+0.090}_{-0.074}(\mathrm{stat}) \pm 0.036(\mathrm{syst})$ (2.6σ)
- $\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)_{\mathrm{SM}} = (1.75^{+0.60}_{-0.29}) \times 10^{-7}$
  $\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)_{\mathrm{exp}} = (1.19 \pm 0.03 \pm 0.06) \times 10^{-7}$
- $\mathcal{R}_{K^{*0}} = 0.69\,^{+\,0.11}_{-\,0.07}\,(\mathrm{stat}) \pm 0.05\,(\mathrm{syst})$ for $1.1 < q^2 < 6.0\ \mathrm{GeV}^2/c^4$
- Same for $\mathcal{B}(B^+ \to \phi \mu^+ \mu^-)$ $(> 3\sigma)$

- $\frac{\mathcal{B}(B_s^0 \to \mu^+ \mu^-)_{\mathrm{exp}}}{\mathcal{B}(B_s^0 \to \mu^+ \mu^-)_{\mathrm{SM}}} = 0.76^{+0.20}_{-0.18}$ (1.2σ)

- $\frac{\mathcal{B}(B_s^0 \to \ell^+ \ell^- \gamma)}{\mathcal{B}(B_s^0 \to \ell^+ \ell^-)} \sim \left(\frac{M_{B^0}}{m_\ell}\right)^2 \frac{\alpha_{em}}{4\pi}$
  $(M_{B^0}/m_\mu)^2 \sim 2.5 \times 10^3 \sim 4\pi/\alpha_{em} \Longrightarrow \mathcal{B}(B_s \to \mu^+ \mu^- \gamma) \sim \mathcal{B}(B_s \to \mu^+ \mu^-)$

Effective theory

- At low energies, the exchange of heavy, virtual particles (M»E) leads into quasi-local effective interactions
- select a cut-off $\Lambda \leq M$, where M - some fundamental scale, and divide the fields into those significant at low energies and at high energies



Wilson expension

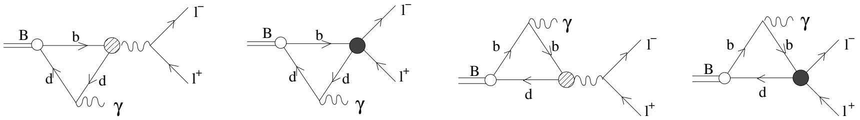
$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} V_{tb} V_{tq}^* \sum_i C_i(\mu) O_i(\mu),$$

$C_i(\mu)$ - wilson coefficients,
$O_i(\mu)$ - basis operators

- W, t are integrated out
- u, c-quarks are dinamical

Buras,1995.

Contributions to $\mathcal{H}_{eff}$ for $B^0 \to \ell^+\ell^-\gamma$



$$\mathcal{H}_{\text{eff}}^{b\to d\ell^+\ell^-} = \frac{G_F}{\sqrt{2}}\frac{\alpha_{\text{em}}}{2\pi}V_{tb}V_{tq}^*\Big[-2im_b\frac{C_{7\gamma}(\mu)}{q^2}\cdot\bar{d}\sigma_{\mu\nu}q^\nu\,(1+\gamma_5)\,b\cdot\bar{\ell}\gamma^\mu\ell +$$
$$+C_{9V}^{\text{eff}}(\mu,q^2)\cdot\bar{d}\gamma_\mu\,(1-\gamma_5)\,b\cdot\bar{\ell}\gamma^\mu\ell + C_{10A}(\mu)\cdot\bar{d}\gamma_\mu\,(1-\gamma_5)\,b\cdot\bar{\ell}\gamma^\mu\gamma_5\ell\Big]$$

The operators contain nonperturbative contribution

Form Factors

$$\langle\gamma(k,\,\epsilon)|\bar{d}\gamma_\mu\gamma_5 b|B(p)\rangle \;=\; i\,e\,\epsilon^*_\alpha\,\left(g_{\mu\alpha}\,pk - p_\alpha k_\mu\right)\,\frac{F_A(q^2)}{M_B},$$

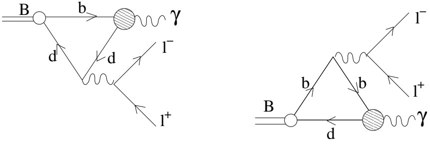
$$\langle\gamma(k,\,\epsilon)|\bar{d}\gamma_\mu b|B(p)\rangle \;=\; e\,\epsilon^*_\alpha\,\epsilon_{\mu\alpha\xi\eta}p_\xi k_\eta\,\frac{F_V(q^2)}{M_B},$$

$$\langle\gamma(k,\,\epsilon)|\bar{d}\sigma_{\mu\nu}\gamma_5 b|B(p)\rangle\,(p-k)^\nu \;=\; e\,\epsilon^*_\alpha\,\left[g_{\mu\alpha}\,pk - p_\alpha k_\mu\right]\,F_{TA}(q^2,0),$$

$$\langle\gamma(k,\,\epsilon)|\bar{d}\sigma_{\mu\nu} b|B(p)\rangle\,(p-k)^\nu \;=\; i\,e\,\epsilon^*_\alpha\epsilon_{\mu\alpha\xi\eta}p_\xi k_\eta\,F_{TV}(q^2,0).$$

Contributions to Effective Hamiltonian

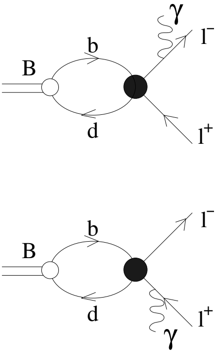
The virtual photon is emitted from the valence quark



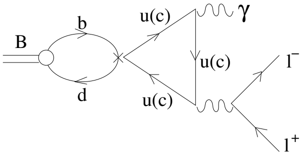
$$F_{TV,TA}(0,q^2) \;=\; F_{TV,TA}(0,0) \;-\; \sum_V \; 2\, f_V\, g_+^{B\to V}(0)\,\frac{q^2/M_V}{q^2 - M_V^2 + iM_V\Gamma_V}$$

Contributions to Effective Hamiltonian

Bremsstrahlung:



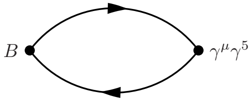
Weak annihilation diagrams:



Relativistic Quark Model

We make use of dispersion approach based on constituent quark picture: All hadron observables are given by dispersion representations in terms of the hadron relativistic wave functions and the spectral densities of Feynman diagrams with constituent quarks in the loops.

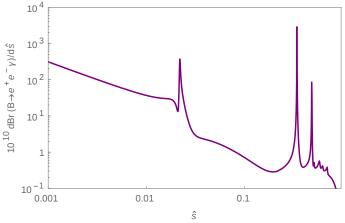
- Decay constants: $f_B = \int ds \phi_B(s) \rho(s)$

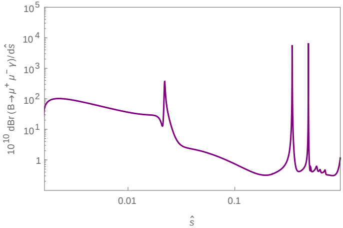


- Meson-meson form factors: $F_{M_1 \to M_2}(q^2) = \int ds_1 \phi_1(s_1) ds_2 \phi_2(s_2) \Delta(s_1, s_2, q^2)$
- Meson-photon transition form factors: $F(q^2, k^2) = \int ds \phi(s) \frac{ds' \Delta(s, s', q_2^2)}{s' - q_1^2}$
- Wave function ($\phi(s) \sim e^{-\frac{k^2}{2\beta^2}}$) is normalized by the condition that electromagnetic form factor is 1 at $q^2 = 0$: $F_{el}(q^2 = 0) = 1$

Numerical Estimates

	this work	[1]
$Br\,(B \to e^+e^-\gamma)\ \times\ 10^{10}$	4.84	3.95
$Br\,(B \to \mu^+\mu^-\gamma)\ \times\ 10^{10}$	1.60	1.31
$Br\,(B_s \to e^+e^-\gamma)\ \times\ 10^{9}$	18.8	24.6
$Br\,(B_s \to \mu^+\mu^-\gamma)\ \times\ 10^{9}$	12.2	18.8





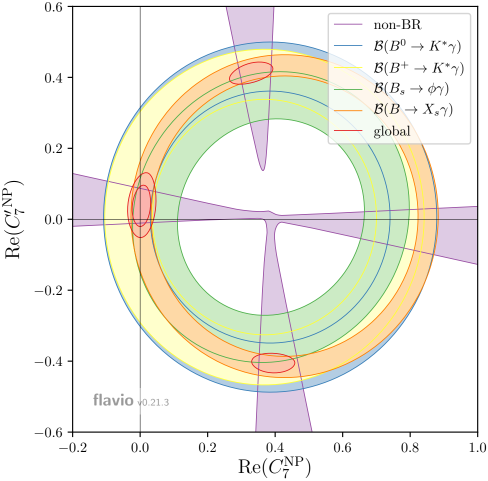
D. Melikhov and N. Nikitin, Phys. Rev. D **70**, 114028 (2004)

New Physics contributions?

Experimental constraints on wilson coefficients:

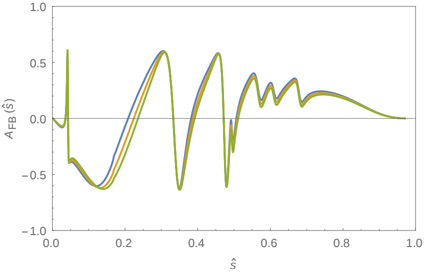
- Peter Strangl,"Constraints on the Wilson coefficients C7 and C7"' June, 2017, https://doi.org/10.5281/zenodo.804453
- A. Paul and D. M. Straub, "Constraints on new physics from radiative B decays," JHEP **1704**, 027 (2017)
- W. Altmannshofer, P. Stangl and D. M. Straub, arXiv:1704.05435 [hep-ph].
- B. Capdevila, A. Crivellin, S. Descotes-Genon, J. Matias and J. Virto, arXiv:1704.05340 [hep-ph].

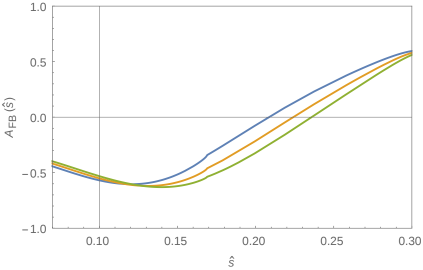
Experimental limits on C_7



Experimental limits on C_7

Forward-Backward Asymmetry for $B_s \to \gamma\mu^+\mu^-$:





Summary

- We obtained predictions for the branching ratios of $B_{d,s} \to \gamma l^+ l^-$ decays in the Standard Model
- We used reliable form factors that satisfy all known QCD constraints.
- We took into account contributions of light vector resonances.
- We are analyzing the sensitivity of the forward-backward asymmetry to wilson coefficients.