The EvtGen-based Model for the Monte-Carlo Generation of the Rare Radiative Leptonic $B$-decays

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Introduction

The main goal of this talk is to present the new Monte-Carlo model for the simulation of the rare radiative leptonic $B$-mesons decays in the framework of the program package $\text{EvtGen}$. This model is based on the thorough theoretical calculations of these decays in the SM with $CP$-violation effects. In addition, in this model it is possible to easily change all the input parameters (including CKM-matrix elements in the Wolfenstein parametrization).
Program package EvtGen

- The EvtGen package has been created for the simulation of the $b$-hadrons decays at $B$-factories. Now this package is used by LHC Collaborations (LHCb, ATLAS, CMS).

- The basic idea of EvtGen is that each decay is described in terms of helicity amplitudes which are forming a density matrix. So EvtGen makes it possible to correctly simulate the angular and spin correlations in the entire decay chain.

- The EvtGen package provides a service in which new decays can be simply added as new modules. These modules, which perform the simulation of decays, are called models in EvtGen.
Rare radiative leptonic $B$-decays

Rare radiative leptonic $\mathcal{B}^0_{d,s} (\bar{\mathcal{B}}^0_{d,s}) \to \gamma \ell^+\ell^-$ decays are induced by flavor changing neutral currents (FCNC) $b \to d, s$, which are forbidden at the tree level in the framework of the SM and occur starting from the lowest order only through the one-loop "penguin" and "box" diagrams.

Lowest order SM contributions to the $\mathcal{B}^0_s \to \gamma \ell^+\ell^-$ decays.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Branching</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{B}^0_d \to \gamma \mu^+\mu^-$</td>
<td>$4.0 \times 10^{-10}$</td>
</tr>
<tr>
<td>$\mathcal{B}^0_s \to \gamma \mu^+\mu^-$</td>
<td>$1.9 \times 10^{-8}$</td>
</tr>
</tbody>
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The $b\to q$ transitions $q=\{d,s\}$ are described using the effective Hamiltonian in the Wilson expansion form with CP-violation effects:

$$
H_{\text{eff}}^{b\to q} = \frac{G_F}{\sqrt{2}} V_{tb} V_{tq}^* \left[ \left( 1 + \lambda_u^{(q)} \right) \left( C_1(\mu) O_1^c(\mu) + C_2(\mu) O_2^c(\mu) \right) - \lambda_u^{(q)} \left( C_1(\mu) O_1^{(u)}(\mu) + C_2(\mu) O_2^{(u)}(\mu) \right) + \sum_{i=3}^{\infty} C_i(\mu) O_i(\mu) \right] + (\bar{b} \to \bar{q})
$$

where $G_F$ is the Fermi constant, $V_{tq}$ and $V_{tb}$ are the CKM matrix elements, $\lambda_u^{(q)} = V_{ub} V_{uq}^*/V_{tb} V_{tq}^*$. The set of Wilson coefficients $C_i(\mu)$ depends on the chosen model. The scale parameter $\mu$ (approximately equal to the $b$-quark mass $\sim 5 \text{ GeV}$) separates the perturbative and nonperturbative contributions of the strong interactions. $O_i(\mu)$ is the set of basic operators. The nonperturbative contributions of the strong interactions are contained in the matrix elements of this operators:

$$
\langle \text{final states} | O_i(\mu) | \text{initial states} \rangle
$$

It can be described in terms of Lorentz-invariant form factors and structures composed of 4-momenta of the initial and final particles, metrical tensor $g^{\mu\nu}$ and Levi-Civita symbol $\varepsilon^{\alpha\beta\mu\nu}$.
EvtGen model for rare radiative leptonic B-decays

We prepare the new EvtGen model BSTOGLLMNT for rare radiative leptonic B-mesons decays. In this model:

- decay channels of $B_d$- and $B_s$-mesons are included:

  $$ B_{d(s)} \rightarrow \gamma l^+ l^- $$ where $l=\{e,\mu,\tau\}$;

- the form factors are calculated using the dispersion relation of the QM and the vector-meson dominance approach;

- the $\mu$-dependence of the Wilson coefficients $C_i$ and the contribution from $\rho$, $\omega$, $\psi$ etc. vector resonances in the SM are included;

- the $CP$-violation effects are included.
There are 9 input parameters specified in BSTOGLLMNT model:

- **mu** is the scale parameter $\mu \sim 5 \text{ GeV}$;
- **Nf** is the number of “effective” quark flavours, used for calculation of the strong interaction running constant $\alpha_S(M_Z)$ ($\text{Nf}=5$ by default);
- **Res_swch** is the parameter of switching on/off the resonant contribution (with resonances by default). The area of J/$\psi$ and $\psi'$-resonances is excluded in the matrix element;
- **ias** defines a choice of the strong interaction running constant $\alpha_S(M_Z)$ value.
- **Egamma** is the photon energy cut (20 MeV by default) in the $B$-meson rest frame.
- **A**, **lambda**, **barrho** and **bareta** are the CKM matrix parameters corresponding the Wolfenstein parametrisation: $A$, $\lambda$, $\rho$, and $\eta$. 

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Classes structure of BSTOGLLMNT

EvtDecayBase

EvtDecayAmp

EvtbsIIGammaMNT
EvtbsIIGammaMNT.cpp
EvtbsIIGammaMNT.hh

public:
void getName();
void init();
void initProbMax();
void decay;
private:
EvtbsIIGammaFF *_mntffmodel;
EvtbTosIIWilsCoeffNLO *_wilscoeff;
EvtbsIIGammaAmp *_calcamp;

EvtbsIIGammaFF
EvtbsIIGammaFF.hh

public:
virtual void getPhotonFF;
virtual double getQuarkMass;

EvtbsIIGammaFFMNT
EvtbsIIGammaFFMNT.cpp
EvtbsIIGammaFFMNT.hh

public:
EvtbsIIGammaFFMNT();
void getPhotonFF;
double getQuarkMass;

evtbTosIIWilsCoeffNLO

evtbTosIIWilsCoeffNLO

EvtbsIIGammaAmp
EvtbsIIGammaAmp.cpp
EvtbsIIGammaAmp.hh

public:
void CalcAmp;
double CalcMaxProb;
double lambda;

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Example of the $q^2$-distribution

The normalized $\hat{s} = q^2/M_1^2$ distribution for the BSTOGLLMNT (left) and the theoretical prediction from Phys.Rev. D70, 114028 (2004) (right) for the decays $B_s^0(B_s^0) \to \gamma \mu^+\mu^-$. 

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Example of the $A_{FB}$-distribution

The $A_{FB}$-distributions for the BSTOGLLMNT (left) and the theoretical prediction from Phys.Rev. D81, 054024 (2010) (right) for the decay $\bar{B}^0_d \rightarrow \gamma \mu^+ \mu^-$. 
Conclusion

We have prepared the EvtGen-based Monte-Carlo generator model for the description of the rare radiative leptonic decays $B_{d,s} \rightarrow \gamma \ell^+\ell^-$, which includes the resonant contribution and the CP-violation effects.

We have found a good agreement between the theoretical predictions and the MC results.