Differential distributions in rare four-leptonic B-decays.

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Introduction

Nowadays remarkably growing attention is being devoted to rare decays of B-mesons. These decays are investigated at such experiments at the LHC as LHCb, CMS and ATLAS. Branching ratios of helicity suppressed decays $B_{d,s} \to \mu^+\mu^-$ were measured at the CMS and LHCb experiments, and upper limits on the branching ratios for the decays $B_{d,s} \to \mu^+\mu^-\mu^+\mu^-$ were obtained at the LHCb. Japanese Belle – II Collaboration has plan to research leptonic decays of B-meson like $B^- \to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu$. The analysis of $B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu$ decay is very advanced with LHCb expecting too. Thus, a theoretical study of the rare leptonic decays of B-meson is of great interest for further investigations on the LHC and other experiments.

Theoretical review of $B^- \to \mu^+ \mu^- e^- \bar{\nu}_e$

The Hamiltonian for the $B^- \to \ell^+ \ell^- \bar{\nu}_{\ell'} \ell'^-$ leptonic decays can be represented in the form

$$\mathcal{H}_{eff}(x) = \mathcal{H}_W(x) + \mathcal{H}_{em}(x)\,. \tag{1}$$

The Hamiltonian for the $b \to uW^- \to u\ell^-\bar{\nu}_\ell$ transitions is given by

$$\mathcal{H}_W(x) = \frac{G_F}{\sqrt{2}} V_{ub} \left(\bar{u}(x)\,\gamma^\mu(1-\gamma^5)\,b(x)\right) \left(\bar{\ell}(x)\,\gamma_\mu(1-\gamma^5)\nu_\ell(x)\right) + h.c.,$$

where $u(x)$ and $b(x)$ – are quark fields, $\ell(x)$ and $\nu_\ell(x)$ – are lepton fields. The Hamiltonian for electromagnetic interaction has the form

$$\mathcal{H}_{em}(x) = e \sum_f Q_f \left(\bar{f}(x)\,\gamma^\mu f(x)\right) A_\mu(x),$$

where Q_f – is the charge of the fermion of flavor f in elementary-charge units, $f(x)$ – is the field of such fermions f и $A_\mu(x)$ – is the 4-potential of the electromagnetic field.

Diagrams of $B^- \to \mu^+\mu^- e^- \bar{\nu}_e$ decay

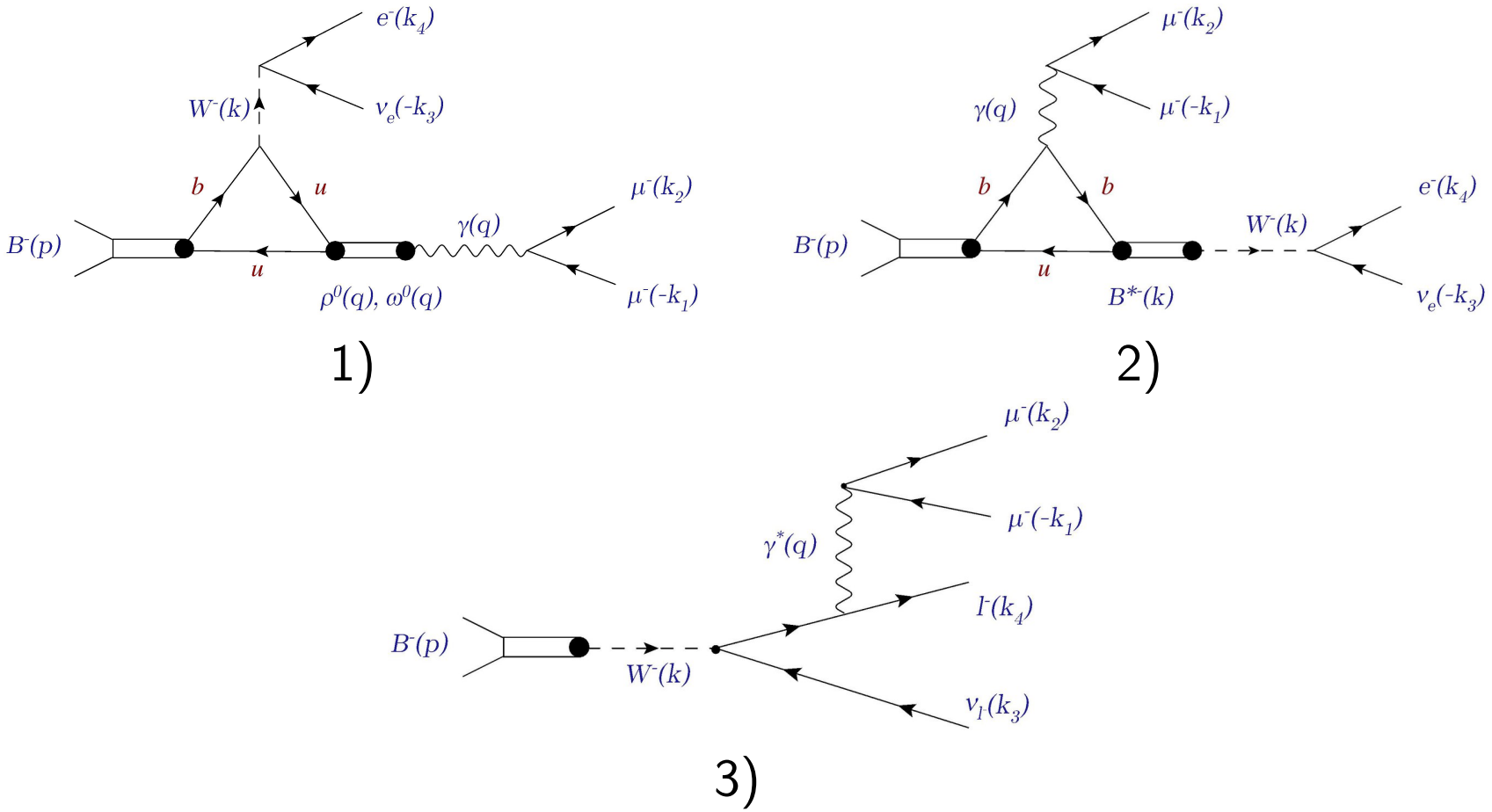


Рис.: 1) Virtual-photon emitted from the light quark; 2) Virtual-photon emitted from the heavy quark; 3) bremsstrahlung.

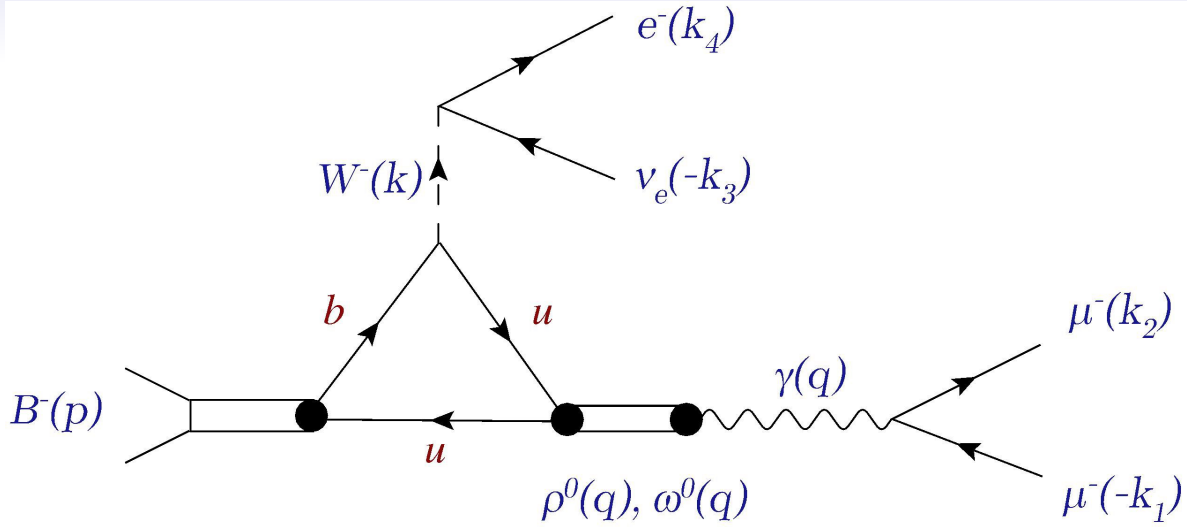


Fig.2 Virtual-photon emission from the light quark is described on the basis of the VMD model.

$$i\,M_{fi}^{(VMD)} = -i\,\frac{G_F}{\sqrt{2}}|V_{ub}|4\pi\alpha_{em}\sum_{i=\{\rho\},\{\omega\}}\frac{1}{f_V^i}\frac{1}{q^2-M_{2i}^2+i\Gamma_{2i}M_{2i}}F_{\mu\nu}^{(i)}(k^2)$$
$$\Big(\overline{\mu}(k_2)\gamma^\nu\mu(-k_1)\Big)\Big(\overline{\mu}(k_4)\gamma^\mu(1-\gamma^5)\nu(-k_3)\Big),$$

where

$$F_{\mu\nu}^{(i)}(k^2) = \frac{2V(k^2)}{M_1+M_{2i}}\epsilon_{\mu\nu kq} - i(M_1+M_{2i})A_1^{(i)}(k^2)g_{\mu\nu} + 2i\frac{A_2^{(i)}(k^2)}{M_1+M_{2i}}q_\mu k_\nu.$$

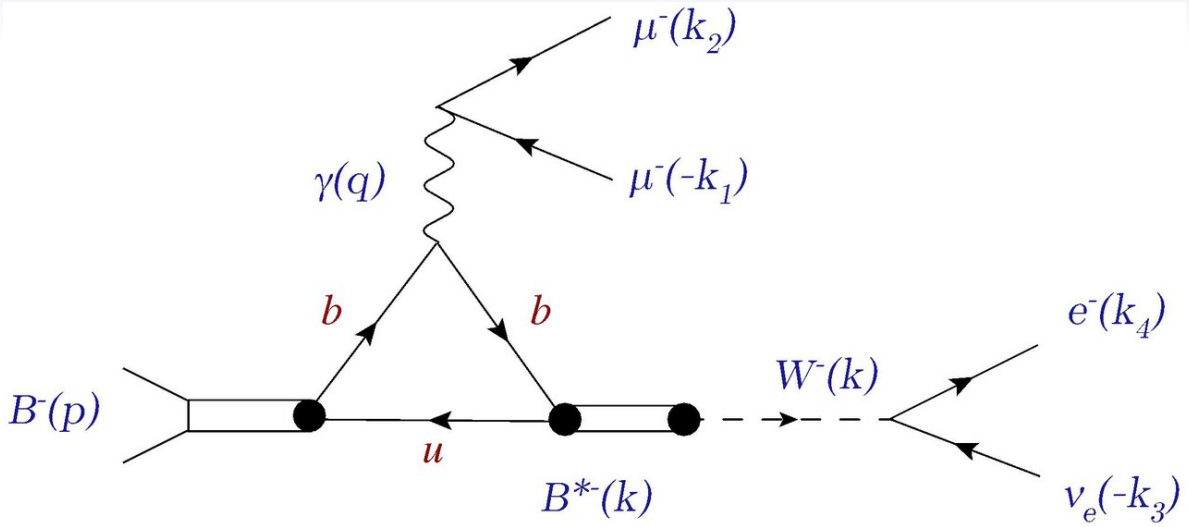


Fig.2 Crossing channel of the $B^* \to B\gamma^*$ decay of a heavy vector meson to a heavy pseudoscalar meson and a virtual photon.

$$i\,M_{fi}^{b} = -\,i\,\frac{G_F}{\sqrt{2}}\,|V_{ub}|\,4\pi\alpha_{em}\,\frac{1}{q^2}\,\frac{M_{B^*}\,f_{B^*}}{k^2 - M_{B^*}^2 + i\Gamma_{B^*}\,M_{B^*}}$$

$$\frac{1}{3}\,\frac{2V_b(q^2)}{M_1 + M_{B^*}}\,\epsilon_{\mu\nu pq}\left(\overline{\mu}(k_2)\gamma^{\mu}\mu(-k_1)\right)\left(\overline{\mu}(k_4)\gamma^{\nu}(1-\gamma^5)\nu(-k_3)\right),$$

where

$V_b(q^2) = \dfrac{1.044}{\left(1 - \frac{q^2}{M_\Upsilon^2}\right)\left(1 - 0.81\,\frac{q^2}{M_\Upsilon^2}\right)}$ - is the electromagnetic form factor.

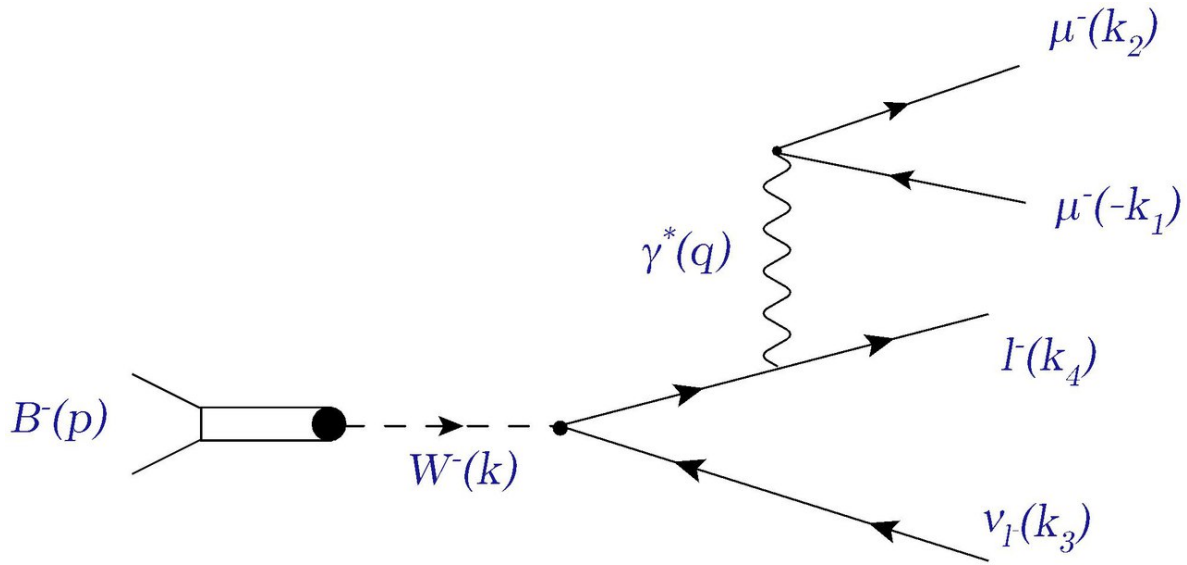


Fig.4 Diagram for calculating the bremsstrahlung amplitude

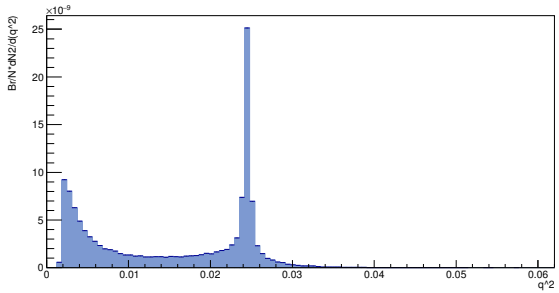
$$i\,M_{fi}^{(brm)} = -i\,\frac{G_F}{\sqrt{2}}\,|V_{ub}|\,4\,\pi\,\alpha_{em}\,\frac{i\,f_{B_u}}{q^2}\,g_{\mu\nu} \left(\overline{\mu}(k_2)\gamma^\nu\mu(-k_1)\right)\left(\overline{\mu}(k_4)\gamma^\mu(1-\gamma^5)\nu(-k_3)\right).$$

EvtGen model for rare four-leptonic B-decays

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

- decay channels of B^- and B^+ mesons are included: $B^- \to \mu^+\mu^- e^- \bar{\nu}_e$, $B^+ \to \mu^-\mu^+ e^+ \nu_e$;
- the form factors are calculated using dispersion formulation of the relativistic constituent quark model;
- contribution of two vector $\rho^0(770)$, $\omega(782)$ resonances in the SM are taking into account;
- charged lepton in the final state are massless $m_{\mu^\pm} = m_{e^\pm} = 0$.

Example of the q^2-,the k^2- distribution from EvtGen and WM



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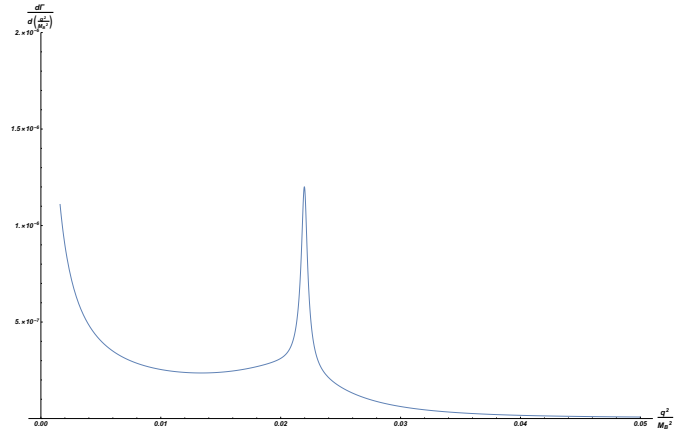

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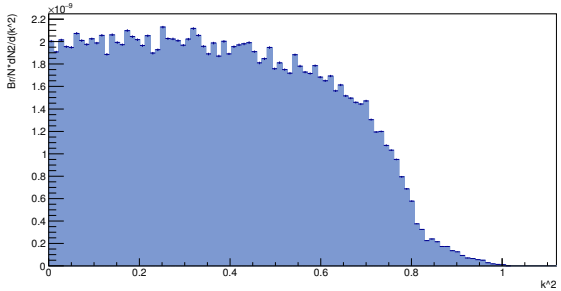

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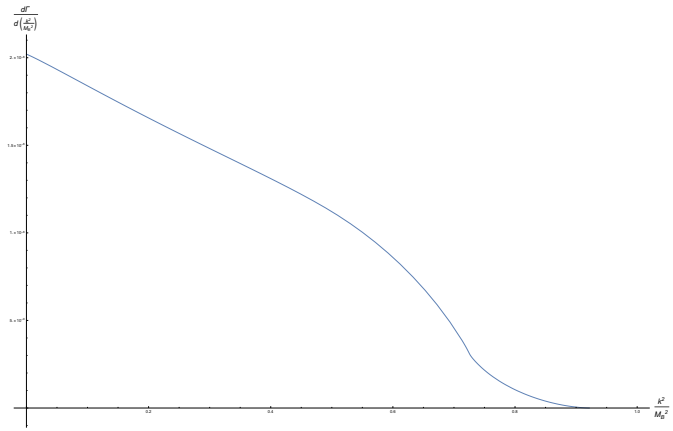
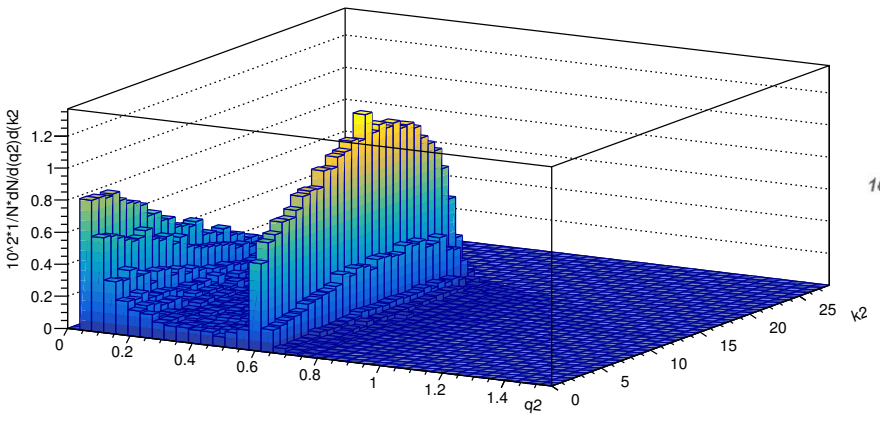
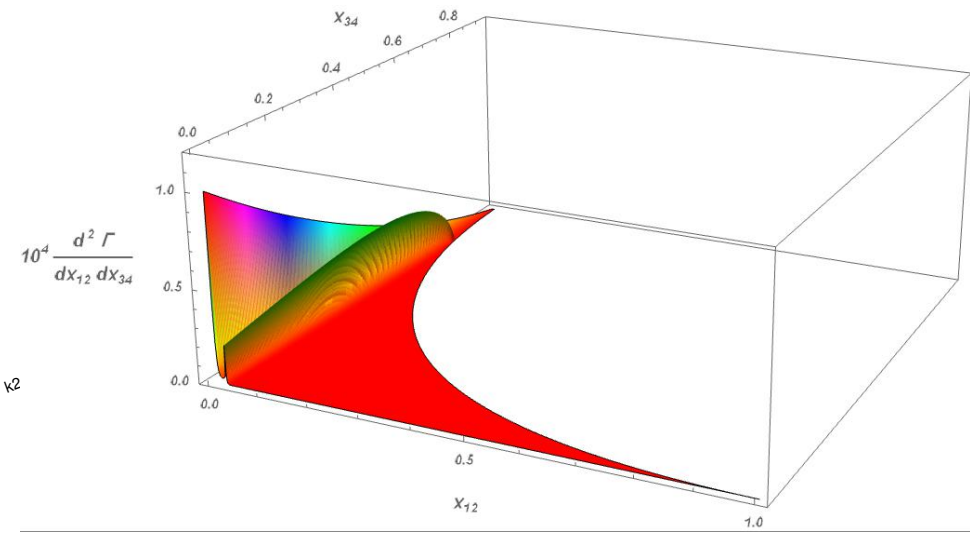


4)

The normalized to unity q^2-(1,2), k^2-(3,4) and distributions in the BUTOMMENU model(left) and from WM(right) for the $B^- \to \mu^+ \mu^- e^- \bar{\nu}_e$ decay.

$B^- \to \mu^+\mu^- e^- \bar{\nu}_e$ – two resonances contributions ($\rho^0(770)$,$\omega(782)$)

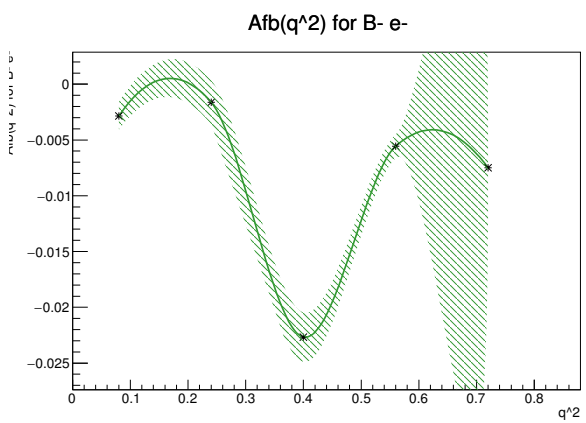




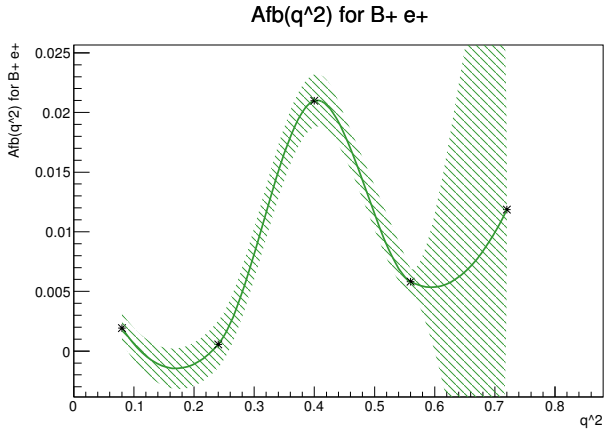
The normalized double distribution $\frac{d^2N}{N\,dx_{12}\,dx_{34}}$ from EvtGen for the BUTOMMEN (left) and the theoretical prediction for $\frac{d^2Br}{dx_{12}\,dx_{34}}$ from WM [Phys.of Nucl. (2018)](right) for the decay $B^- \to \mu^+\mu^- e^- \bar{\nu}_e$. The integration cutoff lower bound is taken at the at double muon mass: $x_{12}^{min} = (2m_\mu/M_1)^2 \approx 0.0016$ After the integration and taking into account all contributions and interference terms, we got the following branching ratio for $B^- \to \mu^+\mu^- e^- \bar{\nu}_e$ decay:

$$Br(B^- \to \mu^+\mu^- e^- \bar{\nu}_e) \approx (1,3 \pm 0.3) * 10^{-7}.$$

Example of the A_{FB} -distribution



1)



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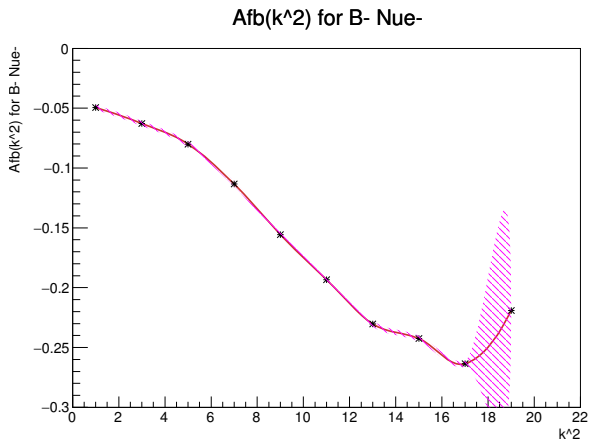

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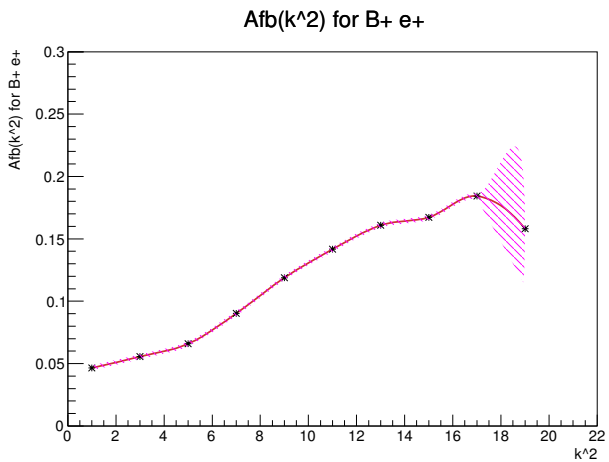
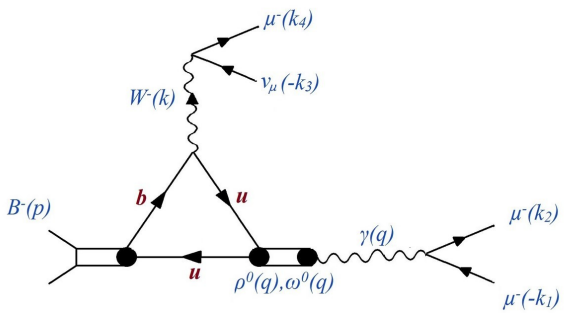


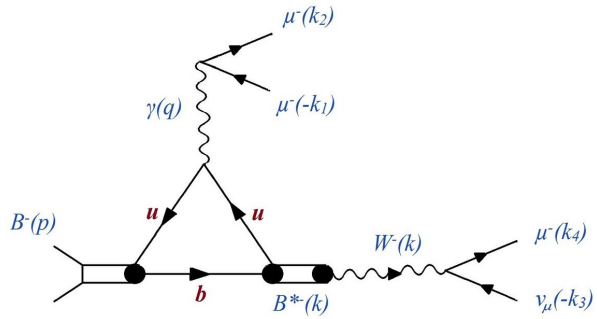
4)

The $A_{FB}(q^2)$ (top)and $A_{FB}(k^2)$(down) -distributions for the BTOMUMUENU for the $B^- \to \mu^+\mu^- e^- \bar{\nu}_e$(left) and $B^+ \to \mu^-\mu^+ e^+ \nu_e$ (right) decays.

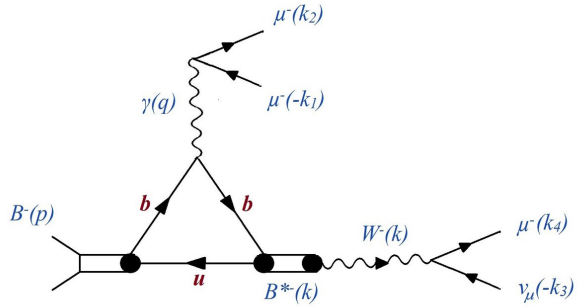
Diagrams of $B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu$ decay



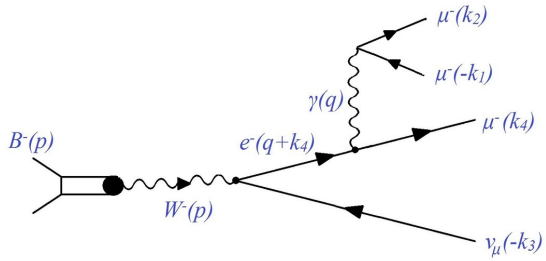
1a)



2a)

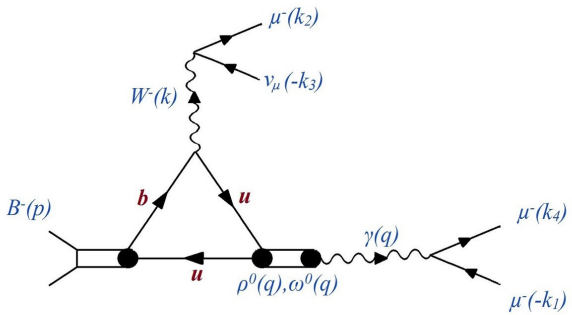


3a)

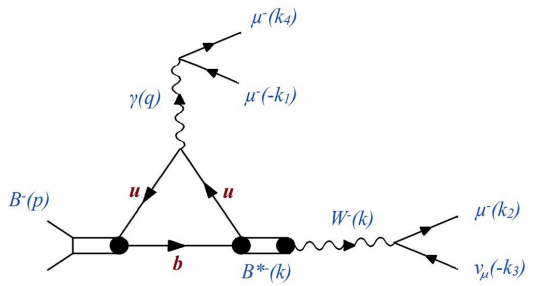


4a)

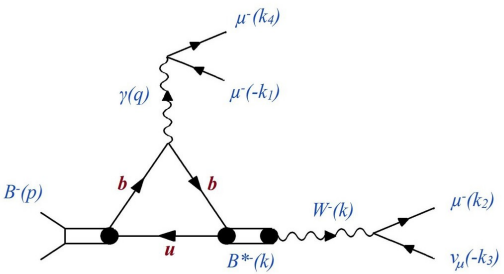
Diagrams of $B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu$ decay



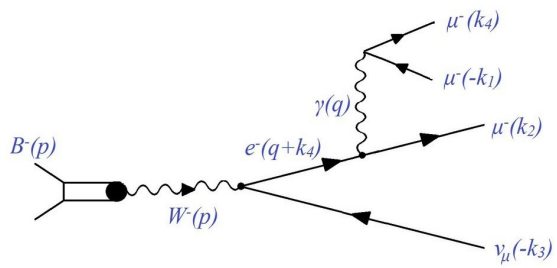
1b)



2b)



3b)



4b)

$Br(B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu)$ estimation

For the $Br(B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu)$ estimation the basic problem was calculation of interference part in the matrix element.
And branching ratio for this decay we can represent as

$$Br(B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu) = Br(B^- \to \mu^+\mu^- e^-\bar{\nu}_e) - Br^{(interf)}(B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu).$$

Numerically

$$Br^{(interf)}(B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu) \approx -2.1 * 10^{-9}.$$

$$Br(B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu) \approx (1 \pm 0.2) * 10^{-7}.$$

Summary and future work

- We get the following results for branching ratio of $B^- \to \mu^+\mu^- e^- \bar{\nu}_e$ and $B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu$:

$$Br(B^- \to \mu^+\mu^- e^- \bar{\nu}_e) \approx (1,3 \pm 0.3) * 10^{-7};$$

$$Br(B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu) \approx (1 \pm 0.2) * 10^{-7};$$

- We have prepared the EvtGen-based Monte-Carlo generator model for the description of the four-leptonic decays, which includes the resonant contribution;
- We have found a good agreement between the theoretical predictions and the MC results;
- We have plan to research leptonic decay of B -mesons like $B_{d,s} \to \mu^+\mu^- e^+ e^-$ and $B_{d,s} \to \mu^+\mu^-\mu^+\mu^-$, where the contribution of new physics can be identified;
- More detail investigation of $B^- \to \mu^+\mu^- e^- \bar{\nu}_e$ and $B^- \to e^+ e^-\mu^-\bar{\nu}_\mu$,$B^- \to \mu^+\mu^-\mu^-\bar{\nu}_\mu$ and $B^- \to e^+ e^- e^-\bar{\nu}_e$ may be used for probing violations of the lepton universality.

Literature

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