# Differential distributions in rare four-leptonic B-decays.

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QUARKS-2018
XXth International Seminar on High Energy Physics
The XXIII International Workshop
Valday, Russia
27 May - 2 June, 2018.

# 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 $B_{d,s} \; ! \; \mu^+\mu$ were measured at the CMS and LHCb experiments, and upper limits on the branching ratios for the decays $B_{d,s} \; ! \; \mu^+\mu \; \mu^+\mu$ were obtained at the LHCb. Japanese Belle – II Collaboration has plan to research leptonic decays of B-meson like $B \; ! \; \mu^+\mu \; \nu_\mu\bar{\nu}_\mu$. The analysis of $B \; ! \; \mu^+\mu \; \mu \; \bar{\nu}_\mu$ 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 $B \to \ell^+ \ell \bar{\nu}_{\ell^0} \ell^0$ leptonic decays can be represented in the form

$$H_e(x) = H_W(x) + H_{em}(x). \tag{1}$$

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

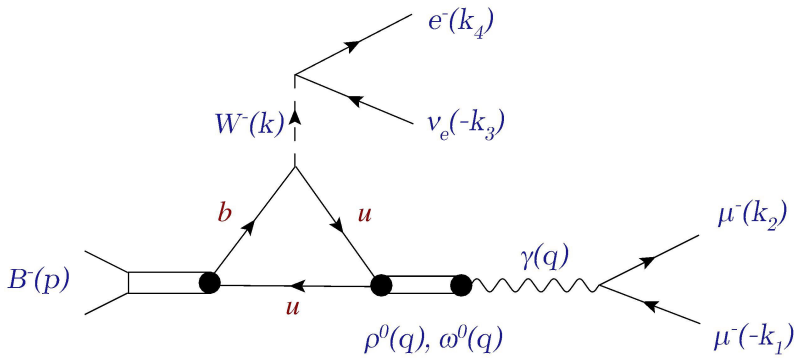
$$H_W(x) = \frac{G_F}{\sqrt{2}} V_{ub} \left(\bar{u}(x)\gamma^\mu(1 - \gamma^5) b(x)\right) \left(\bar{\ell}(x)\gamma_\mu(1 - \gamma^5)\nu_\ell(x)\right) + h.c.,$$

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

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

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

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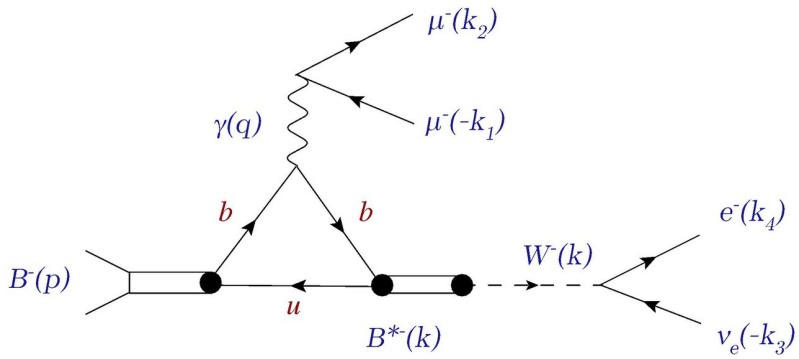


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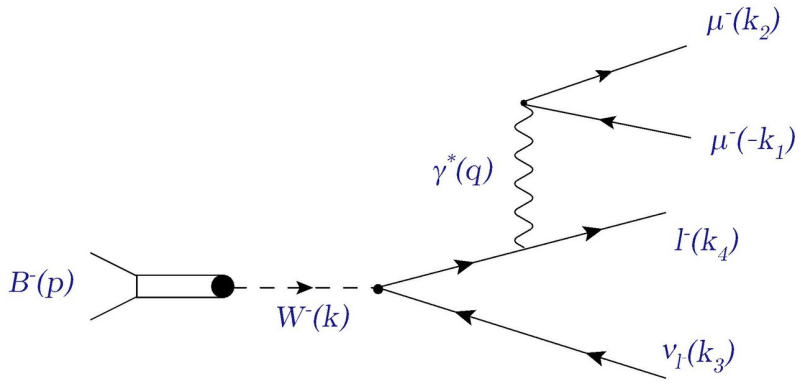



3)

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

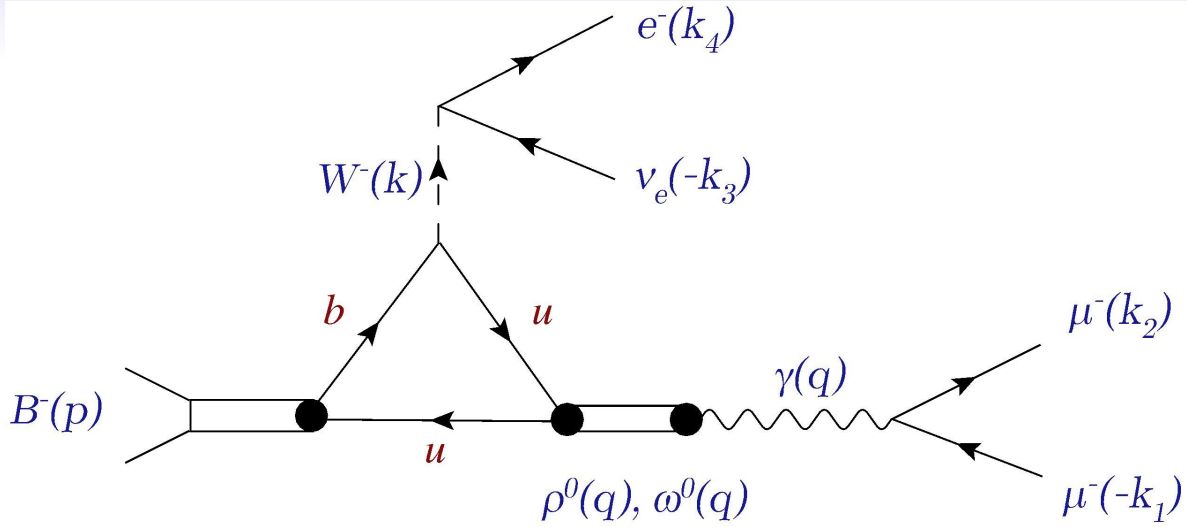



Fig.2 Virtual-photon emission from the light quark is described on the basis of the VMD model.

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

where

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

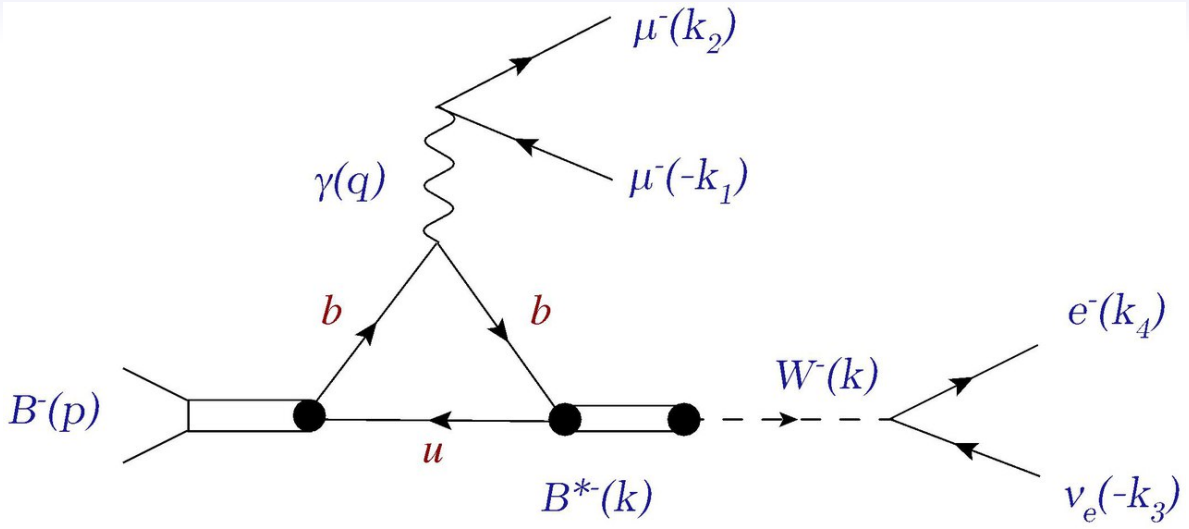



Fig.2 Crossing channel of the $B \;\; ! \;\; B\gamma$ decay of a heavy vector meson to a heavy pseudoscalar meson and a virtual photon.

$$i\,M^b \;=\; i\,\frac{G_F}{\overline{p}\overline{2}}\,jV_{ub}j\;4\pi\alpha_{em}\,\frac{1}{q^2}\,\frac{M_B\;\;f_B}{k^2 \quad M_B^2 \;\; + i\Gamma_B\;\;M_B}$$

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

where

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

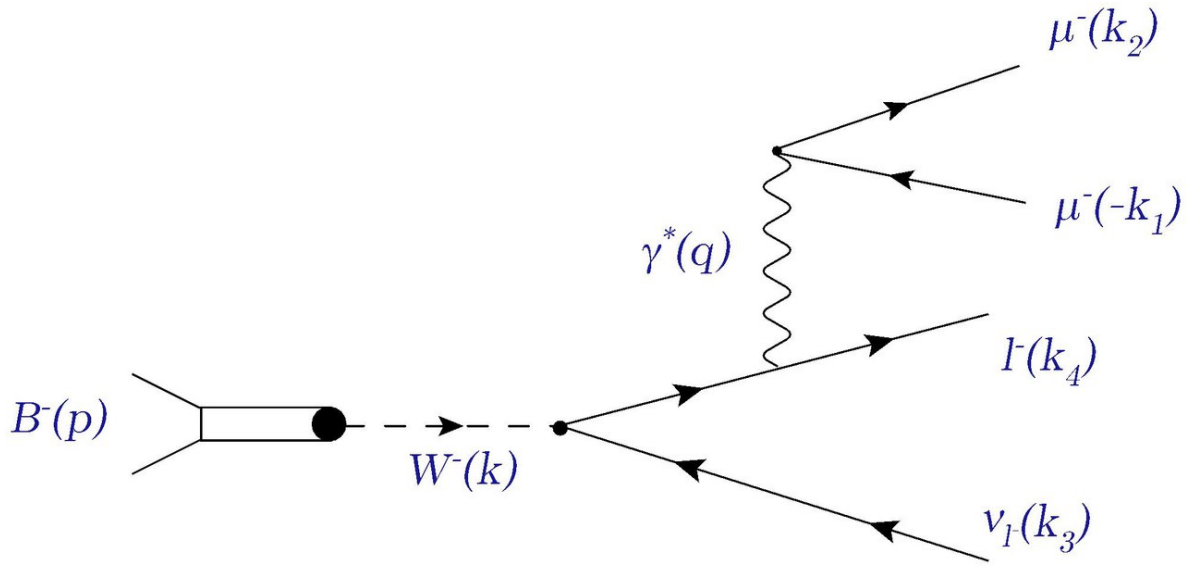



Fig.4 Diagram for calculating the bremsstrahlung amplitude

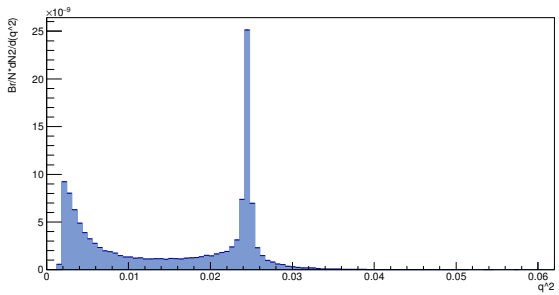
$$i\,M^{(brm)} = i\,\frac{G_F}{\sqrt{2}}\,|V_{ub}|\,4\pi\,\alpha_{em}\,\frac{i\,f_{B_u}}{q^2}\,g_{\mu\nu} \left(\bar{\mu}(k_2)\gamma^\nu\mu(k_1)\right)\left(\bar{\mu}(k_4)\gamma^\mu(1-\gamma^5)\nu(k_3)\right).$$

# 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: $B \;\; ! \;\; \mu^+\mu \;\; e \;\; \bar{\nu}_e$, $B^+ \;\; ! \;\; \mu \;\; \mu^+ e^+ \nu_e$;
- 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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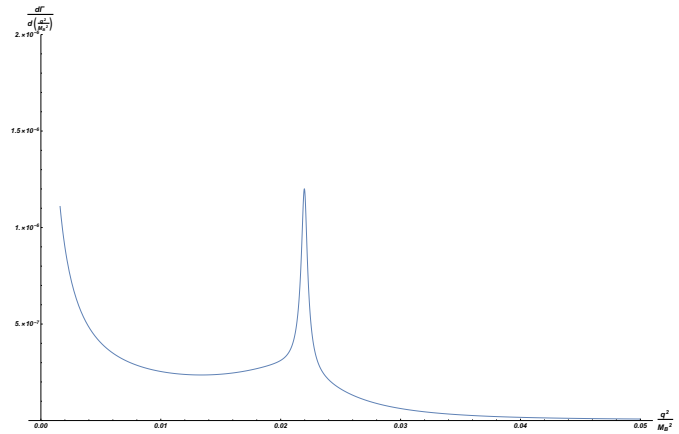

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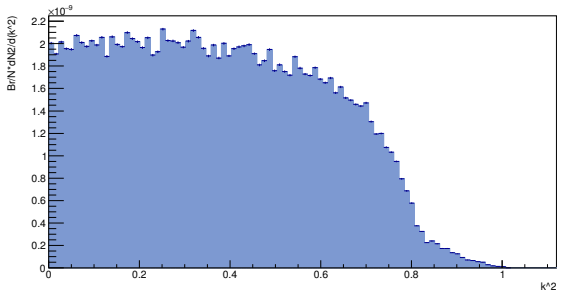


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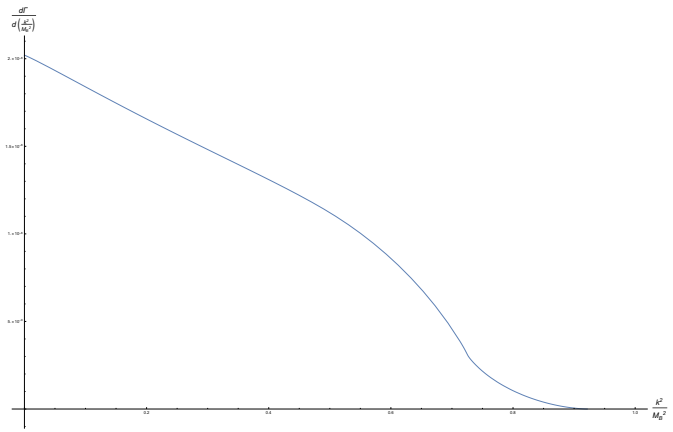
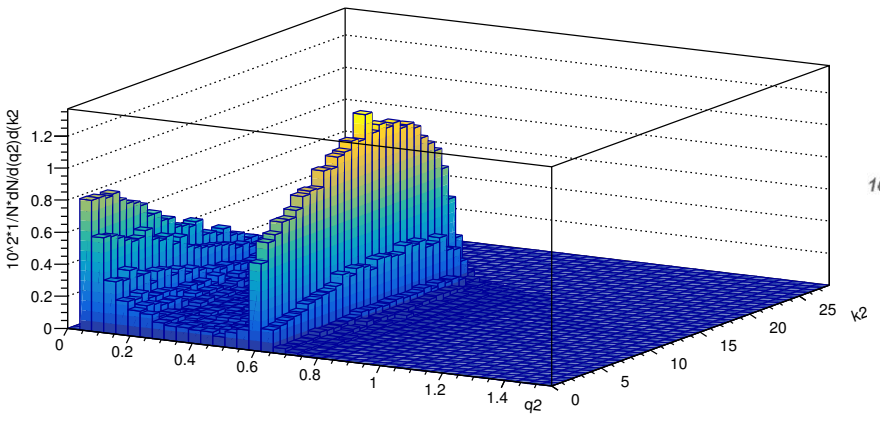
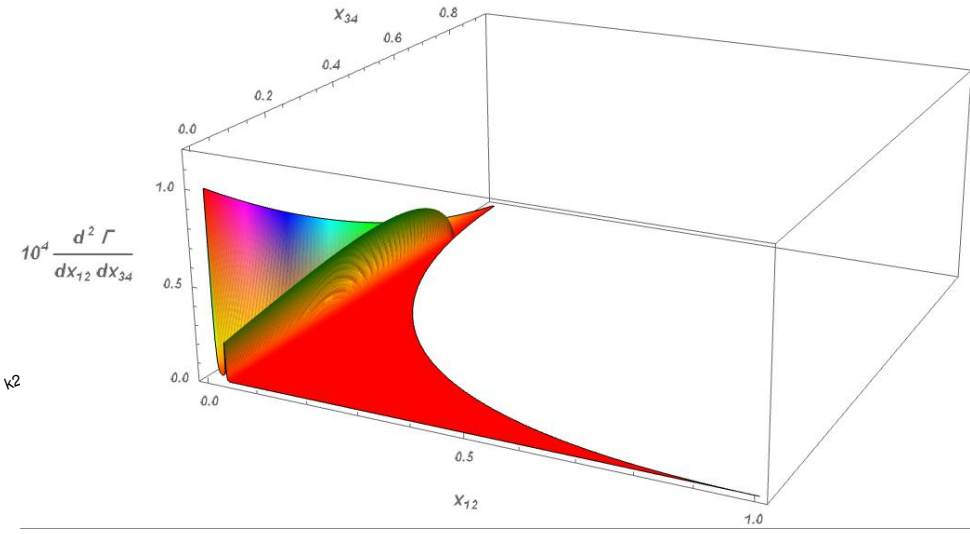


4)

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 $B \;\; ! \;\; \mu^+ \mu \;\; e \;\; \bar{\nu}_e$ 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

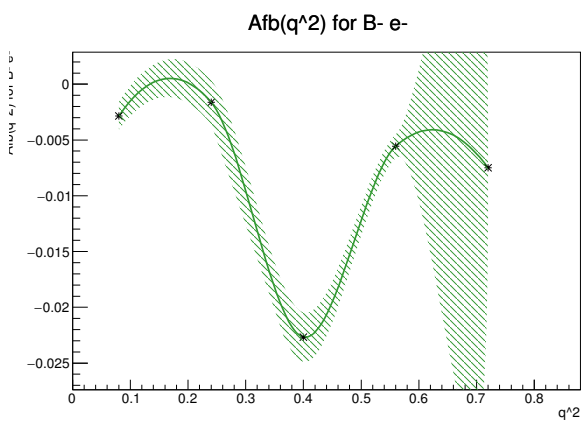
(left) and the theoretical prediction for $\frac{d^2Br}{dx_{12}\,dx_{34}}$ from WM [Phys.of Nucl.

(2018)](right) for the decay $B \to \mu^+\mu\, e\, \bar{\nu}_e$. The integration cuto lower bound is taken at the at double muon mass: $x_{12}^{min} = (2m_\mu/M_1)^2$ 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:

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

# Example of the $A_{FB}$ -distribution

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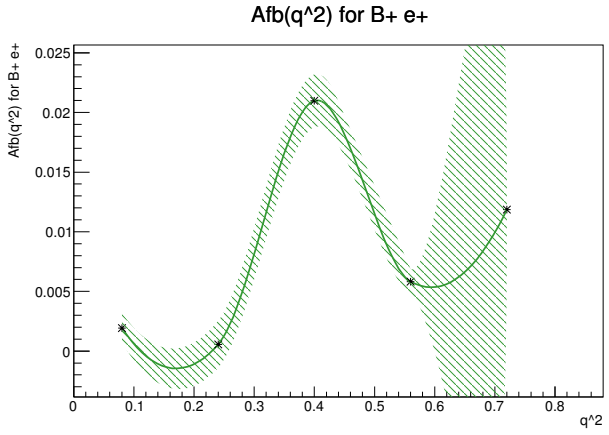


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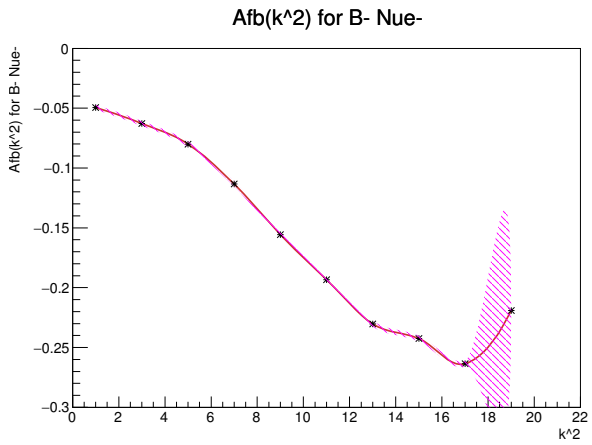


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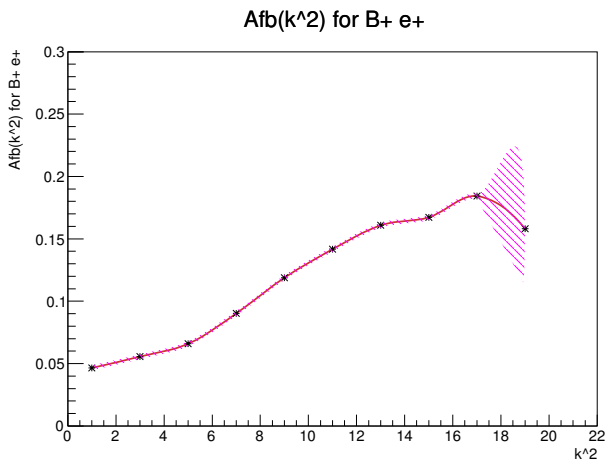
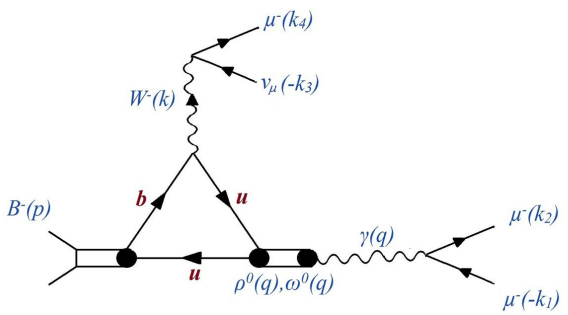


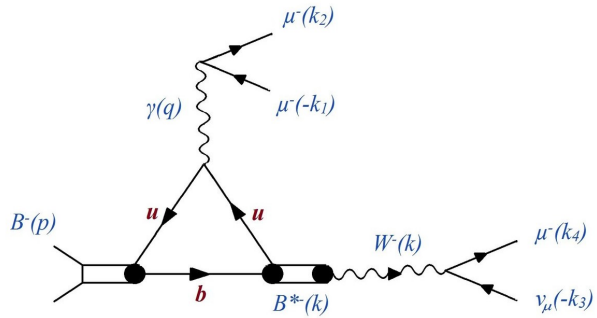

4)

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

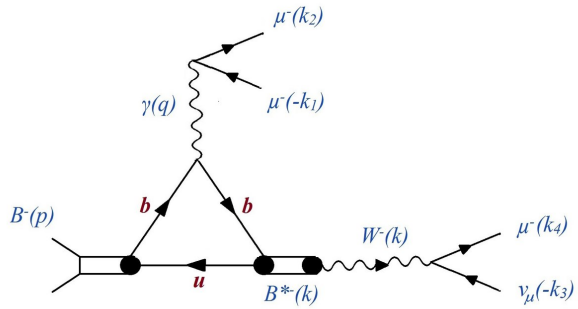
# Diagrams of $B \to \mu^+\mu\ \mu\ \bar{\nu}_\mu$ decay



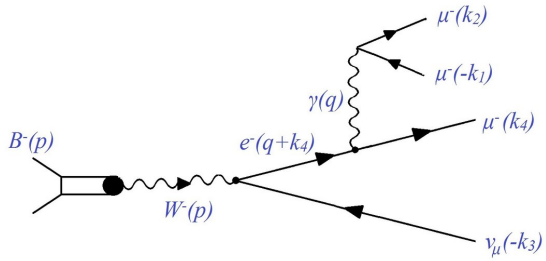

1a)




2a)

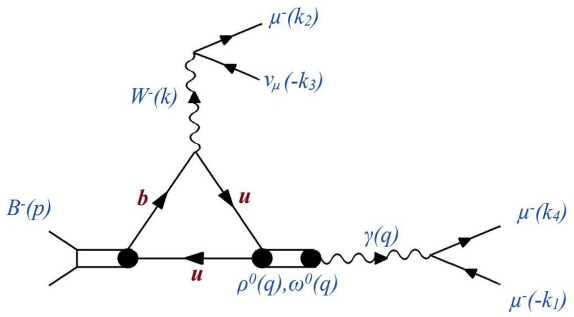



3a)

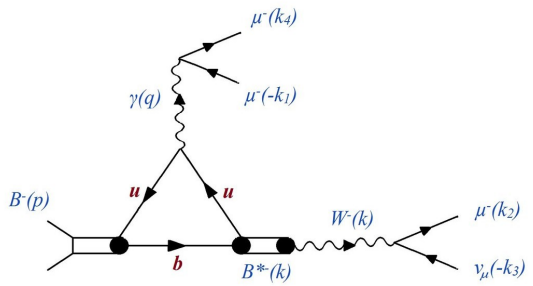



4a)

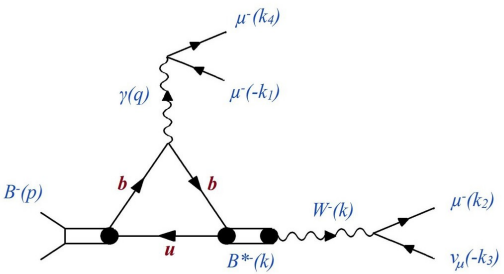
# Diagrams of $B \to \mu^+\mu\ \mu\ \bar{\nu}_\mu$ decay



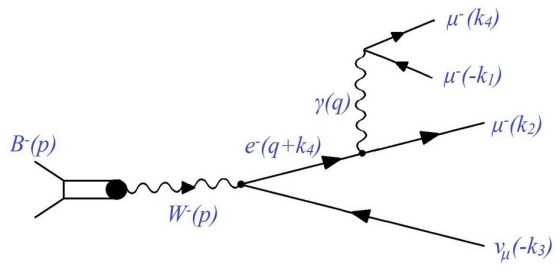

1b)




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

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

Numerically

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

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

# Summary and future work

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

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

$$Br(B \to \mu^+\mu\, \mu\, \bar{\nu}_\mu) \quad (1 \quad 0.2) \quad 10^{\ 7};$$

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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