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On mass limits for vector leptoquarks from $K_L^0, B^0, B_s \to l_i^+ l_j^-$ decays with account of fermion mixing

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Abstract. The contributions of the vector leptoquarks to branching ratios of $K_L^0, B^0, B_s \to l\,l'$ decays are calculated with account of fermion mixing in leptoguark currents of the general type and the corresponding mass limit for the vector leptoquarks resulting from the current data on these decays is obtained and analysed. It is found that the vector leptoquarks with masses $m_V > 78\ TeV$ are consistent with current data on these decays. The branching ratios of $K_L^0, B^0, B_s \to l\,l'$ decays at the possible lower mass $m_V = 78\ TeV$ are presented and the decays $B^0 \to \mu^+\mu^-$, $B_s \to e\mu$, $B_s \to \mu^+\mu^-$ are shown to be the most perspective ones for setting the new more stringent mass limits for the vector leptoquarks.

1 Introduction

The search for a new physics beyond the Standard Model (SM) is one of the aims of the current experiments at the LHC. There is a lot of models predicting new physics effects at LHC energies (such as models based on the supersymmetry, on the left-right symmetry, two Higgs models, extended dimension models, etc.).

One of such possible variants of new physics can be based on the well known idea of J.C. Pati and A. Salam on the possible four color symmetry between quarks and leptons regarding lepton number as the fourth color [1]. The four color symmetry can be unified with the SM in the minimal way by the gauge group [2, 3]

$$G_{MQLS} = SU_V(4) \times SU_L(2) \times U_R(1), \tag{1}$$

where $SU_V(4)$ is the vectorlike group of the four color symmetry [1–3], $SU_L(2)$ is the electroweak group for the left-handed fermions and $U_R(1)$ is the hypercharge factor for the right-handed ones (the minimal quark-lepton-symmetric model - $MQLS$-model [2, 3]). The four color symmetry of the vectorlike type predicts the new gauge particles - vector leptoquarks which form the color triplet $V_\alpha, \alpha = 1, 2, 3$ of the usual $SU_c(3)$ color group.

The lower mass limits for vector leptoquarks from their direct searches are of about 1 TeV. The essentially more stringent lower mass limits for vector leptoquarks are resulting from the rare decays of pseudoscalar mesons. The most stringent of them are given by data on the $K_L^0 \to e^\mp\mu^\pm$ decay and with neglect of fermion mixing in leptoquark currents achieve the order of 2 000 TeV [4–8].

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It should be noted however that the fermion mixing in leptoquark currents is natural. It is as natural as the fermion mixing in the week currents which are described by the well known matrices V_{CKM} and U_{PMNS} in the quark and lepton sectors respectively. The fermion mixing in the leptoquark currents and that in the week currents have a common origin and are resulting from the fact that the mass eigenstates of left- and right-handed quarks and leptons $Q^{L,R}_{pa\alpha}$, $l^{L,R}_{ia}$ can enter to interactions with gauge and scalar fields in general case through the superpositions

$$Q'^{L,R}_{pa\alpha} = \sum_q (A^{L,R}_{Q_a})_{pq}\, Q^{L,R}_{qa\alpha}, \quad l'^{L,R}_{ia} = \sum_j (A^{L,R}_{l_a})_{ij}\, l^{L,R}_{ja},$$

where $A^{L,R}_{Q_a}$ and $A^{L,R}_{l_a}$ are unitary matrices describing the fermion mixing and diagonalizing the mass matrices of quarks and leptons, $p, q, i, j = 1, 2, 3,...$ are the quark and lepton generation idexes, $a = 1, 2$ and $\alpha = 1, 2, 3$ are the $SU_L(2)$ and $SU_c(3)$ indexes, $Q_{q1} \equiv u_q = (u, c, t)$, $Q_{q2} \equiv d_q = (d, s, b)$ are the up and down quarks, $l_{j1} \equiv \nu_j$ are the mass eigenstates of neutrinos and $l_{j2} \equiv l_j = (e^-, \mu^-, \tau^-)$ are the charged leptons.

In the weak interaction the matrices $A^{L,R}_{Q_a}$ and $A^{L,R}_{l_a}$ form the CKM and PMNS matrices as

$$C_Q = (A^L_{Q_1})^+ A^L_{Q_2} = V_{CKM}, \qquad C_\ell = (A^L_{\ell_1})^+ A^L_{\ell_2} = U^+_{PMNS}.$$

In analogous way in the interaction of quarks and leptons with leptoquarks the matrices $A^{L,R}_{Q_a}$ and $A^{L,R}_{l_a}$ led to the four specific matrices

$$K^{L,R}_a = (A^{L,R}_{Q_a})^+ A^{L,R}_{\ell_a} \tag{2}$$

of the fermion mixing in leptoquark currents for up ($a = 1$), doun ($a = 2$) left (L)- and right (R)-handed fermions. The fermion mixing in leptoquark currents can lower the mass limits on leptoquark masses.

The responsible for the leptonic decays

$$P = K^0_L, B^0, B_s \to l^+_i l^-_j \tag{3}$$

of neutral pseudoscalar mesons interaction of the vector leptoquarks with down fermions in general case can be written as

$$L_{Vdl} = \frac{g_4}{\sqrt{2}} \{(\bar{d}_{p\alpha}[(K^L_2)_{pi}\gamma^\mu P_L + (K^R_2)_{pi}\gamma^\mu P_R] l_i) V_{\alpha\mu} + h.c.\}, \tag{4}$$

where $g_4 = g_{st}(M_c)$ is the $SU_V(4)$ gauge coupling constant related to the strong coupling constant at the mass scale M_c of the $SU_V(4)$ symmetry breaking, $P_{L,R} = (1 \pm \gamma_5)/2$ are the left and right operators of fermions and $K^{L,R}_2$ are the mixing matrices (2) for down fermions. It should be noted that in general case of $K^L_2 \neq K^R_2$ the interaction (4) of vector leptoquarks with quarks and leptons is not purely vectorlike. The mixing matrices $K^{L,R}_2$ in (4) can lower the mass limits on leptoquark masses resulting from the decays (3) and now the current experimental data on the decays (3) give the possibility to obtain new lower mass limits for the leptoquarks from these decays with account of the fermion mixing in leptoquark currents. The results of the first attempt to account the fermion mixing in leptoquark currents in the rare decays of type (3) was published in [9].

In the present paper the results of the calculations and analysis of the contributions of the vector leptoquarks into decays (3) with account of the fermion mixing in leptoquark currents of general form and the corresponding new lower mass limit for the vector leptoquarks are presented and discussed. With account of this lower mass limit the expected branching ratios of the decays (3) are also presented.

2 Branching ratios of $P \to l\,l'$ decays

Omitting the details of calculations (some details can be found in [7, 8]) the induced by the vector leptoquarks V branching ratios $Br_V(P \to l_i^+ l_j^-)$ of the decays of pseudoscalar meson P into lepton-antilepton pairs $l_i^+ l_j^-$ with $l_i^\pm = (e^\pm, \mu^\pm, \tau^\pm)$ can be written as

$$Br_V(P \to l_i^+ l_j^-) = B_P \; r_P(\mu_{l_i}, \mu_{l_j}) \; b_{P,ij}\,, \tag{5}$$

where

$$B_P = \frac{m_P\, \pi\, \alpha_{st}^2(M_c)\, f_P^2\, \bar{m}_P^2\, (R_P^V)^2}{2\, m_V^4\, \Gamma_P^{tot}} \tag{6}$$

is the typical branching ratio of these decays, $r_P(\mu_{l_i}, \mu_{l_j})$ are the root factors

$$r_P(\mu_{l_i}, \mu_{l_j}) = \sqrt{[1 - (\mu_{l_i} + \mu_{l_j})^2][1 - (\mu_{l_i} - \mu_{l_j})^2]}$$

defined by the ratios $\mu_{l_i} = m_{l_i}/m_P$ of lepton m_{l_i} and meson m_P masses and $b_{P,ij}$ are the mixing factors depending on the matrices K_2^L, K_2^R. The enterring into (6) form factors f_P parametrize the matrix elements of the axial and pseudoscalar quark currents as

$$\langle 0|\bar{b}\gamma^\mu\gamma^5 d|P(p)\rangle = i f_P p^\mu, \quad \langle 0|\bar{b}\gamma^5 d|P(p)\rangle = -\,i\,\bar{m}_P f_P,$$

where p_μ is 4-momentum of the decaying meson, $\bar{m}_P = m_P^2/(m_{d_p} + m_{d_q})$, the factors $R_P^V = R_P(\mu_P, M_c)$ accounts the gluonic corrections to the pseudoscalar quark current and depend on mass scale M_c of the four color symmetry breaking and on mass scales μ_P at which the decays occur, Γ_P^{tot} is the total width of P meson and m_{d_p}, m_{d_q} are the masses of its valency quarks, m_V is the mass of the vector leptoquark.

The mixing factors $b_{P,ij}$ in (5) can be presented in the form [7, 8]

$$b_{P,ij} = \frac{1}{2}(|\beta_{P,ij}^L|^2 + |\beta_{P,ij}^R|^2)(1 - \mu_{l_i}^2 - \mu_{l_j}^2) + (\overset{*}{\beta}{}_{P,ij}^L \beta_{P,ij}^R + \beta_{P,ij}^L \overset{*}{\beta}{}_{P,ij}^R)\, \mu_{l_i}\, \mu_{l_j}, \tag{7}$$

where

$$\beta_{K_L^0,ij}^{L,R} = (\beta_{21,ij}^{L,R} + \beta_{12,ij}^{L,R})/\sqrt{2}, \qquad \beta_{B^0,ij}^{L,R} = \beta_{31,ij}^{L,R}, \qquad \beta_{B_s,ij}^{L,R} = \beta_{32,ij}^{L,R}$$

for $P = K_L^0 = ((\tilde{s}d) + (\tilde{d}s))/\sqrt{2}$, $P = B^0 = (\tilde{b}d)$, $P = B_s = (\tilde{b}s)$ respectively and

$$\beta_{pq,ij}^{L,R} = k_{pq,ij}^{L,R} - (\bar{\mu}_{l_j^-} k'^{L,R}_{pq,ij} + \bar{\mu}_{l_i^+} k'^{R,L}_{pq,ij})/2$$

with

$$k_{pq,ij}^{L,R} = (K_2^{L,R})_{pi}\, (\overset{*}{K}{}_2^{R,L})_{qj},$$
$$k'^{L,R}_{pq,ij} = (K_2^{L,R})_{pi}\, (\overset{*}{K}{}_2^{L,R})_{qj}$$

and $\bar{\mu}_{l_i^\pm} = m_{l_i^\pm}/(\bar{m}_P R_P^V)$.

Denoting the sums of the branching ratios of charge conjugated final states as

$$Br_V(P \to e\mu) = Br_V(P \to e^+\mu^-) + Br_V(P \to \mu^+ e^-), \tag{8}$$
$$Br_V(P \to e\tau) = Br_V(P \to e^+\tau^-) + Br_V(P \to \tau^+ e^-), \tag{9}$$
$$Br_V(P \to \mu\tau) = Br_V(P \to \mu^+\tau^-) + Br_V(P \to \tau^+\mu^-) \tag{10}$$

the branching ratios (5) can be rewritten as

$$Br_V(P \to l\,l') = B_P\ r_P(\mu_l, \mu_{l'})\ b_{P,ll'}\ , \tag{11}$$

with

$$b_{P,e^+e^-} = b_{P,11}, \qquad b_{P,\mu^+\mu^-} = b_{P,22}, \qquad b_{P,e\mu} = b_{P,12} + b_{P,21}, \tag{12}$$

$$b_{P,e\tau} = b_{P,13} + b_{P,31},\ b_{P,\mu\tau} = b_{P,23} + b_{P,32},\ b_{P,\tau^+\tau^-} = b_{P,33} \tag{13}$$

for $l\,l' = e^+e^-,\ \mu^+\mu^-,\ e\mu,\ e\tau,\ \mu\tau,\ \tau^+\tau^-$. With account of notations (8)–(10) the branching ratios (11)–(13) can be immediately compared with the experimental data on the decays (3).

3 Minimization of branching ratios of $P \to l\,l'$ decays

In the further analysis we use the general expressions

$$K_2^{L,R} = K_2^{L,R}(\theta_{12}^{L,R}, \theta_{13}^{L,R}, \theta_{23}^{L,R}, \delta^{L,R}, \varepsilon^{L,R}, \varphi_0^{L,R}, \varphi_1^{L,R}, \varphi_2^{L,R}, \varphi_3^{L,R}) \tag{14}$$

for the mixing matrices $K_2^{L,R}$. Each of the matrices (14) as the unitary 3×3 matrix depends on three angles $\theta_{12}^{L,R}$, $\theta_{23}^{L,R}$, $\theta_{13}^{L,R}$ and six phases $\delta^{L,R}$, $\varepsilon^{L,R}$, $\varphi_0^{L,R}$, $\varphi_1^{L,R}$, $\varphi_2^{L,R}$, $\varphi_3^{L,R}$.

In the case of neglecting the electron and muon masses

$$m_e, m_\mu \ll m_\tau, m_{K^0}, m_{B^0}, m_{B_s} \tag{15}$$

the mixing factors (12), (13) can be presented as the functions

$$b_{K_L^0,ll'} = b_{K_L^0,ll'}(\theta_{12}^{L,R}, \theta_{13}^{L,R}, \theta_{23}^{L,R}, \delta^{L,R}, \varepsilon^{L,R}), \tag{16}$$

$$b_{B^0,ll'} = b_{B^0,ll'}(\theta_{12}^{L,R}, \theta_{13}^{L,R}, \theta_{23}^{L,R}, \delta^{L,R}, \varepsilon^{L,R}, \chi_1^{L,R}, \chi_2^{L,R}), \tag{17}$$

$$b_{B_s,ll'} = b_{B_s,ll'}(\theta_{12}^{L,R}, \theta_{13}^{L,R}, \theta_{23}^{L,R}, \delta^{L,R}, \varepsilon^{L,R}, \chi_1^{L,R}, \chi_2^{L,R}) \tag{18}$$

with $b_{K_L^0,ll'}$ depending on the mixing angles $\theta_{12}^{L,R}$, $\theta_{23}^{L,R}$, $\theta_{13}^{L,R}$ and the phases $\delta^{L,R}$, $\varepsilon^{L,R}$ and with $b_{B^0,ll'}$, $b_{B_s,ll'}$ depending also on the phases $\varphi_0^{L,R}$, $\varphi_1^{L,R}$, $\varphi_2^{L,R}$, $\varphi_3^{L,R}$ through the phases

$$\chi_1^{L,R} = \varphi_0^{L,R} - \varphi_1^{L,R} - \varphi_2^{L,R}, \qquad \chi_2^{L,R} = \varphi_0^{L,R} + \varphi_3^{L,R}.$$

With fixed values of mixing angles $\theta_{12}^{L,R}$, $\theta_{23}^{L,R}$, $\theta_{13}^{L,R}$ and phases $\delta^{L,R}$ the mixing factors (17), (18) can be minimized over phases $\chi_1^{L,R}$, $\chi_2^{L,R}$, $\varepsilon^{L,R}$ by the conditions

$$\chi_1^L - \varepsilon^L - \chi_1^R + \varepsilon^R = 0, \qquad \chi_2^L - \chi_2^R = 0, \qquad \delta^L + \varepsilon^L - \delta^R - \varepsilon^R = 0. \tag{19}$$

Under conditions (19) the mixing factors (17), (18) depend only on the mixing angles $\theta_{12}^{L,R}$, $\theta_{23}^{L,R}$, $\theta_{13}^{L,R}$ and phases $\delta^{L,R}$ as

$$b_{B^0,ll'} = b_{B^0,ll'}(\theta_{12}^{L,R}, \theta_{13}^{L,R}, \theta_{23}^{L,R}, \delta^{L,R}), \tag{20}$$

$$b_{B_s,ll'} = b_{B_s,ll'}(\theta_{12}^{L,R}, \theta_{13}^{L,R}, \theta_{23}^{L,R}, \delta^{L,R}). \tag{21}$$

Keeping in mind that the most stringent lower mass limits for vector leptoquark are resulting from the experimental data $Br(K_L^0 \to l\,l')^{exp}$ on the branching ratios of the decays $K_L^0 \to l\,l'$ the mixing factors $b_{K_L^0,ll'}$ for the more small masses m_V must be very small (close to zero). In the further analysis the factors (16) for $l\,l' = e^+e^-$, $\mu^+\mu^-$, $e\mu$ can be assumed to be equal to zero

$$b_{K_L^0,ll'} = 0. \tag{22}$$

There are two solutions of the equations (22):

$$\text{solution A:} \qquad \theta^L_{23} = \theta^R_{23} = \pi/2, \quad \theta^L_{13} = \theta^R_{13} \equiv \theta_{13}, \quad \delta^L + \varepsilon^L + \delta^R + \varepsilon^R = \pi \tag{23}$$

and

$$\text{solution B:} \qquad \theta^L_{13} = \theta^R_{13} = \pi/2. \tag{24}$$

In the case (23) each of the matrices (14) K^L_2 (K^R_2) contains two angles θ_{13} and θ^L_{12} (θ^R_{12}) and the corresponding phases with $\delta^{L,R}$, $\varepsilon^{L,R}$ satisfying the last equation in (23). In the case (24) each of the matrices (14) K^L_2 (K^R_2) is defined by the unitary 2×2 matrix $U^L(2)$ ($U^R(2)$) and hence contains only one effective mixing angle. In the further analysis we use the matrices (14) of the case (23) as of the more general one because this case results in two mixing angles in each of the matrices K^L_2 (K^R_2).

In the case (23) the mixing factors (20), (21) take the form

$$b_{B^0,ll'} = b_{B^0,ll'}(\theta^L_{12}, \theta^R_{12}, \theta_{13}), \tag{25}$$

$$b_{B_s,ll'} = b_{B_s,ll'}(\theta^L_{12}, \theta^R_{12}, \theta_{13}) \tag{26}$$

of the functions on three angles θ^L_{12}, θ^R_{12}, θ_{13}.

The branching ratios (11) with mixing factors (22), (25), (26) have been numericaly analysed with account of experimental data on the decays (3) by varying the mixing angles θ^L_{12}, θ^R_{12}, θ_{13} to find the minimal vector leptoquark mass m_V satisfying these data.

4 Numerical results and discussion

In the numerical analysis we use from ref. [10] the data on the masses m_{l_i}, m_{d_i} of leptons and quarks, the data on the masses m_P, life times τ_P ($\tau_P \to \Gamma^{tot}_P$) and the form factors f_P

$$f_{K^0_L} = f_{K^-} = 155.72\, MeV, \;\; f_{B^0} = 190.9\, MeV, \;\; f_{B_s} = 227.2\, MeV$$

of mesons $P = (K^0_L,\, B^0,\, B_s)$ as well as the experimental data on the branching ratios $Br(P \to l\, l')^{exp}$ except the branching ratios

$$Br(B^0 \to \mu^+\mu^-)^{exp} < 3.4 \cdot 10^{-10} \quad [11],$$
$$Br(B^0 \to \tau^+\tau^-)^{exp} < 2.1 \cdot 10^{-3} \quad [12],$$
$$Br(B_s \to \mu^+\mu^-)^{exp} = (3.0 \pm 0.6^{+0.3}_{-0.2}) \cdot 10^{-9} \quad [11],$$
$$Br(B_s \to \tau^+\tau^-)^{exp} < 6.8 \cdot 10^{-3} \quad [12]$$

for which we use the current data of refs.[11, 12]. For the mass scale M_c of the $SU_V(4)$ symmetry we use the value $M_c = 100\, TeV$.

In the case of vectorlike mixing ($\theta^L_{12} = \theta^R_{12} \equiv \theta_{12}$) minimizing the vector leptoquark mass m_V over mixing angles θ_{12}, θ_{13} with satisfying the experimental values of $Br(P \to l\, l')^{exp}$ we find for vector leptoquark the mass limit

$$m_V > 78\ TeV. \tag{27}$$

The further analysis showed that the chiral mixing ($\theta^L_{12} \neq \theta^R_{12}$) does not change this mass limit for vector leptoquark. The additional analysis showed that in the case (24) the vector leptoquark mass limit exceeds the limit (27).

The mass limit (27) is essentially lower than that of order of 2 000 TeV obtained with neglect of the fermion mixing [4–8] at the same time it noticeably exceeds the mass limit of order of 1 TeV

resulting from the current direct searches for vector leptoquarks. It should be noted however that the mass limit (27) can be further lowered by the possible destructive interference of the vector leptoquark contributions discussed in this paper with those from the scalar leptoquarks which are also predicted (in addition to the vector leptoquarks) by the gauge group (1). The simultaneous account of the contributions of the vector and scalar leptoquarks to decays (3) needs the special consideration and we restrict ourselves here only by account of the vector leptoquark contributions. The mass limit (27) exceeds the mass limit $m_V > 38\ TeV$ declared in ref.[9] (mainly due to the difference of mixing factors (12), (13) from those of ref.[9]).

Keeping in mind the mass limit (27) we have calculated the contributions $Br_V(P \to l\,l')$ of vector leptoquarks to branching ratios of $P \to l\,l'$ decays with account of fermion mixing for $m_V = 78\ TeV$ with corresponding mixing angles. The results of calculations are presented in the second column of the table (1). In the third column of the table (1) we present for comparision the current experimental data on these decays.

Table 1. Contributions $Br_V(P \to l\,l')$ of vector leptoquarks to branching ratios of $P \to l\,l'$ decays with account of fermion mixing for $m_V = 78\ TeV$

$Br(P \to l\,l')$	$Br_V(P \to l\,l')$	$Br(P \to l\,l')^{exp}$
$Br(K_L^0 \to e^+e^-)$	0	$(9^{+6}_{-4}) \cdot 10^{-12}$
$Br(K_L^0 \to \mu^+\mu^-)$	0	$(6.84 \pm 0.11) \cdot 10^{-9}$
$Br(K_L^0 \to e\mu)$	0	$< 4.7 \cdot 10^{-12}$
$Br(B^0 \to e^+e^-)$	$3.3 \cdot 10^{-10}$	$< 8.3 \cdot 10^{-8}$
$Br(B^0 \to \mu^+\mu^-)$	$3.3 \cdot 10^{-10}$	$< 3.4 \cdot 10^{-10}$ *)
$Br(B^0 \to e\mu)$	$1.3 \cdot 10^{-9}$	$< 2.8 \cdot 10^{-9}$
$Br(B^0 \to e\tau)$	$2.0 \cdot 10^{-9}$	$< 2.8 \cdot 10^{-5}$
$Br(B^0 \to \mu\tau)$	$6.9 \cdot 10^{-9}$	$< 2.2 \cdot 10^{-5}$
$Br(B^0 \to \tau^+\tau^-)$	0	$< 2.1 \cdot 10^{-3}$
$Br(B_s \to e^+e^-)$	$2.9 \cdot 10^{-9}$	$< 2.8 \cdot 10^{-7}$
$Br(B_s \to \mu^+\mu^-)$	$2.9 \cdot 10^{-9}$	$(3.0 \pm 0.6^{+0.3}_{-0.2}) \cdot 10^{-9}$ *)
$Br(B_s \to e\mu)$	$1.09 \cdot 10^{-8}$	$< 1.1 \cdot 10^{-8}$ *)
$Br(B_s \to e\tau)$	$5.0 \cdot 10^{-10}$	-
$Br(B_s \to \mu\tau)$	$1.7 \cdot 10^{-9}$	-
$Br(B_s \to \tau^+\tau^-)$	0	$< 6.8 \cdot 10^{-3}$

As seen from the table (1) the contributions of vector leptoquarks with $m_V = 78\ TeV$ to branching ratios $Br(B^0 \to \mu^+\mu^-)$, $Br(B_s \to e\mu)$ are close their current experimental limits (marked by stars) and the corresponding contribution to $Br(B_s \to \mu^+\mu^-)$ is compatible with its current experimental value (also marked by the star). It means that the further search for these decays can immediately give new more stringent limits on the vector leptoquark mass m_V.

The contribution of the vector leptoquarks to branching ratio $Br(B^0 \to e\mu)$ is about twice lower than its current experimental limit and the search for this decay looks also as perspective for setting new mass limit for vector leptoquarks.

As concerns the branching ratios $Br(B^0 \to e^+e^-), Br(B^0 \to e\tau), Br(B^0 \to \mu\tau), Br(B_s \to e^+e^-)$ the contributions of the vector leptoquarks to these decays are essentially (by order of $2 \div 4$) less than their current experimental limits, the corresponding contributions to branching ratios $Br(B^0 \to \tau^+\tau^-)$, $Br(B_s \to \tau^+\tau^-)$ are very small (under assumptions (22) they are equal to zero).

The contributions of the vector leptoquarks to branching ratios $Br(B_s \to e\tau)$ and $Br(B_s \to \mu\tau)$ are expected to be of order of 10^{-10} and 10^{-9} respectively, which can be kept in mind in the future experimental searches for these decays.

5 Conclusion

1. The contributions of the vector leptoquarks to branching ratios of $K_L^0, B^0, B_s \to l\,l'$ decays are calculated with account of fermion mixing in leptoguark currents of the general type and the corresponding mass limit for the vector leptoquarks resulting from the current experimental data on these decays are obtained and analysed.

2. It is found that the vector leptoquarks with masses

$$m_V > 78\ TeV$$

are consistent with current data on the branching ratios of $K_L^0, B^0, B_s \to l\,l'$ decays.

3. It is shown that the contributions of the vector leptoquarks with $m_V = 78\ TeV$ to branching ratios of the decays

$$B^0 \to \mu^+\mu^-, \quad B_s \to e\mu, \quad B_s \to \mu^+\mu^-$$

are close to the current experimental data on these decays and the further searches for these decays look as the most perspective ones for setting the new more stringent mass limits for the vector leptoquarks.

4. The contribution of the vector leptoquarks to branching ratio $Br(B^0 \to e\mu)$ is shown to be about twice lower than its current experimental limit and the search for this decay looks also as perspective for obtaining new mass limit for vector leptoquarks.

5. The contributions of the vector leptoquarks to branching ratios $Br(B_s \to e\tau)$ and $Br(B_s \to \mu\tau)$ are snown to be of order or less than 10^{-10} and 10^{-9} respectively.

6. The contributions of the vector leptoquarks to branching ratios of the others decays of $K_L^0, B^0, B_s \to l\,l'$ type are shown to be essentially lower (by order 2 or greater) than their current experimental limits.

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