Mass limits for chiral and scalar leptoquarks from $K_L^0 \to e^\mp \mu^\pm$, $B^0 \to e^\mp \tau^\pm$ decays.

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Abstract

The chiral and the scalar leptoquark contributions into widths of the $K_L^0 \to e^\mp \mu^\pm$, $B^0 \to e^\mp \tau^\pm$ decays are calculated in MQLS model with Higgs mechanism of the quark-lepton mass splitting and the resulted leptoquark mass limits are investigated. It is shown that the chiral leptoquark mass limits are essentially weaker than those for vector leptoquarks and that the account of scalar leptoquark contribution gives the further decreasing the mass limits. The search for leptonic decays of B^0-meson $B^0 \to l_i^+ l_j^-$ is pointed to be interesting for further setting the leptoquark mass limits.

1 Introduction.

The search for a new physics beyond the Standard Model is now one of the aims of the high energy physics. One of the possible variants of such new physics can be the variant induced by the possible four color symmetry [1] between quarks and leptons. The main feature of the four-color gauge

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symmetry is the prediction of the vector leptoquarks the masses of which are expected to be of about the mass scale of the four-color symmetry breaking. At the present time the most stringent experimental limits on the mass of the vector leptoquarks are resulted from $K_L^0 \to e^\mp\mu^\pm$ decay. The branching ratio of $K_L^0 \to e^\mp\mu^\pm$ decay inducing by the vector leptoquark has the form [3, 4]:

$$Br(K_L^0 \to e^\mp\mu^\pm) = \frac{\pi\alpha_{st}^2(m_V)m_{K_L^0}^3 f_k^2}{16 m_V^4 \Gamma_{K_L^0}^{tot}}(1-(\frac{m_\mu}{m_{K_L^0}})^2)^2 \\ (\frac{m_\mu}{m_{K_L^0}} - \frac{2m_{K_L^0}}{m_d+m_s})^2 Q^2(\mu)k_{mix}; \\ Q(\mu) = (\frac{\alpha_{st}(\mu)}{\alpha_{st}(m_V)})^{\frac{4}{b}},\ b = 11 - \frac{2}{3}n_f; \quad (1)$$

where α_{st} is the effective QCD coupling constant at the hadron mass μ scale, n_f is the number of the quark flavors at the scale μ, k_{mix} is the possible fermion mixing factor ($|k_{mix}| \leq 1$). One can see that main contribution to this branching ratio is given by the K_L^0 meson mass term. The branching ratio (1) gives the lower limit on the vector leptoquark mass of about $m_V > 10^3$ TeV with possible reducing this limit by the fermion mixing factor k_{mix}. In this talk I will discuss the mass limits which can be extracted from $K_L^0 \to e^\mp\mu^\pm$ and $B^0 \to e^\mp\tau^\pm$ decays for chiral and scalar leptoquarks.

2 Branching ratios of $K_L^0 \to e^\mp\mu^\pm$, $B^0 \to e^\mp\tau^\pm$ decays

We are starting from the lagrangians of the interactions of the chiral and scalar leptoquark with down quarks and charged leptons in the form (2,3).

$$L_{V^{L,R}} = (\bar{d_{i\alpha}} g_{ij}^L \gamma^\mu P_L l_j)V_{\alpha\mu}^L + (\bar{d_{i\alpha}} g_{ij}^R \gamma^\mu P_R l_j)V_{\alpha\mu}^R + h.c. \quad (2)$$

$$L_{S^{L,R}} = (\bar{d_{i\alpha}} h_{ij}^L P_L l_j)S_\alpha^L + (\bar{d_{i\alpha}} h_{ij}^R \gamma^\mu P_R l_j)S_\alpha^R + h.c. \quad (3)$$

where $g_{ij}^{L,R}$ and $h_{i,j}^{L,R}$ are the gauge and Yukawa coupling constants accounting the possible fermion mixing, $P_{L,R} = (1 \pm \gamma_5)/2$; $\alpha = 1, 2, 3$ are $SU(3)$ indexes, and $i, j = 1, 2, 3$,... are the generation indexes.

The $K_L^0 \to e^-\mu^+$ decay amplitude can be written with account of (2), (3) as

$$M = \frac{i}{\sqrt{2}} f_K p_\mu (\bar{u}_e(p_1)(G^L\gamma^\mu P_L + G^R\gamma^\mu P_R)u_\mu(-p_2)) \quad (4)$$

$$G^{L,R} = \mp\frac{1}{2}\Big(\frac{{g_{11}^*}^{R,L}{g_{22}}^{R,L} + {g_{21}^*}^{R,L}{g_{12}}^{R,L}}{m^2_{V^{R,L}}} - \frac{{h_{11}^*}^{L,R}{h_{22}}^{L,R} + {h_{21}^*}^{L,R}{h_{12}}^{L,R}}{2m^2_{S^{L,R}}}\Big); \quad (5)$$

where the decay constant f_K is defined by the standard way: $< 0|\bar{s}\gamma_\mu\gamma_5 d|K^0(p) >= if_K p_\mu$, u_e, u_μ are bispinors, here the relations $K^0 = \bar{s}d$, $K_L^0 = (\bar{s}d - \bar{d}s)/\sqrt{2}$ have been taken into account. Because the last term in (5) has on opposite sign relatively to the first one the amplitude (4) has the possibility of the partial cancelation of the chiral and scalar leptoquark contributions.

Using the (4), (5) and the analogous formulas for $B^0(= \bar{b}d)$ meson we obtain the branching ratios for $K_L^0 \to e^\mp\mu^\pm$ and $B^0 \to e^\mp\tau^\pm$ decays in the form

$$Br(K_L^0 \to e^\mp\mu^\pm) = \frac{m_{K_L^0} f_K^2 m_\mu^2}{64\pi\Gamma^{tot}_{K_L^0}}(1 - (\frac{m_\mu}{m_{K_L^0}})^2)^2 \times \quad (6)$$
$$\times \quad \{|\frac{{g_{11}^*}^L{g_{22}}^L + {g_{21}^*}^L{g_{12}}^L}{m^2_{V^L}} - \frac{{h_{11}^*}^R{h_{22}}^R + {h_{21}^*}^R{h_{12}}^R}{2m^2_{S^R}}|^2 + |L \longleftrightarrow R|^2\},$$

$$Br(B^0 \to e^\mp\tau^\pm) = \frac{m_{B^0} f_B^2 m_\tau^2}{32\pi\Gamma^{tot}_{B^0}}(1 - (\frac{m_\tau}{m_{B^0}})^2)^2 \times \quad (7)$$
$$\times \quad \{|\frac{{g_{11}^*}^L{g_{33}}^L}{m^2_{V^L}} - \frac{{h_{11}^*}^R{h_{22}}^R}{2m^2_{S^R}}|^2 + |L \longleftrightarrow R|^2\},$$

where $m_e, m_\mu, m_{K_L^0}$ are the masses of the electron, muon and K_L^0 meson, $m_{V^{L,R}}, m_{S^{L,R}}$ are the masses of the chiral and scalar leptoquarks and the relations $(m_e/m_\mu)^2$ and $(m_e/m_\tau)^2$ have been neglected. Here and below $Br(K_L^0 \to e^\mp\mu^\pm)$ denotes the sum over the charge modes of final particles, i.e. $Br(K_L^0 \to e^\mp\mu^\pm) \equiv Br(K_L^0 \to e^-\mu^+) + Br(K_L^0 \to e^+\mu^-)$ and we use the same notation for $Br(B^0 \to e^\mp\tau^\pm)$.

There are three possibilities for reducing of the leptoquark mass limit from K_L^0 (B_0) decays. Firstly, the account of the chirality decreases the branching ratio of the K_L^0 decay by 30 times as compared with vector leptoquark case (the term $2m_K/(m_d+m_s)$ presented in (1) is absent in the chiral cases (6),(7)). Secondly, there is the partial cancelation of the chiral and the scalar leptoquark contributions. Thirdly, the fermion mixing effects can decrease this limit too.

The Yukawa coupling constants of the scalar leptoquarks are usually thought to be arbitrary parameters. It should be noted however that in the case of the Higgs mechanism of the quark-lepton mass splitting the four color symmetry of quark and leptons predicts the scalar leptoquarks with the Yukawa coupling constants which are (due to their Higgs origin) proportional to ratios m_f/η of the fermion mass to SM VEV η, hence they are known (up to mixing parameters). In particular, the minimal extension of the Standard Model (SM) containing the four color symmetry with Higgs quark-lepton mass splitting (MQLS model [5]) predicts such scalar leptoquarks with doublet $SU(2)_L$- structure [7]

$$S_{a\alpha}^{(\pm)} = \begin{pmatrix} S_{1\alpha}^{(\pm)} \\ S_{2\alpha}^{(\pm)} \end{pmatrix}. \tag{8}$$

The down components of these doublets interact with down quarks and leptons according (3) under notations $S_2^{(+)} \equiv S^R$, $S_2^{*(-)} \equiv S^L$ with coupling constants

$$h_{i,j}^{L,R} \;=\; -\sqrt{\frac{3}{2}}\frac{1}{\eta\sin\beta}(m_{Q_i}K_{i,j}^{L,R} - K_{i,j}^{R,L}m_{l_j}), \tag{9}$$

where m_{f_i} $(f = Q, l)$ are the mass of quark or lepton of the i(j) generation, $K^{L,R}$ are the new matrixes specific for the model with the four color quark-lepton symmetry, β is the angle of the mixing of the 15th scalar doublet of the (15, 2, 1)– multiplet $\Phi^{(3)}$ with the (1,2,1)-doublet $\Phi^{(2)}$ of the MQLS-model, $\tan\beta = \eta_3/\eta_2$, η_2, and η_3 are the VEVs of the $\Phi^{(2)}$ and $\Phi^{(3)}$ multiplets, $\eta = \sqrt{\eta_2^2+\eta_3^2}$ is the SM VEV [7].

For simplicity we neglect below the fermion mixing (believing $g_{i,j}^{L,R} = g^{L,R}\delta_{ij}$, $K_{i,j}^{L,R} = \delta_{i,j}$) and assume that $m_{S^L}, m_{V^R} \gg m_{S^R}, m_{V^L}$ and $g^L = g^R$ $(= g_{st}(m_{V^L})$ where g_{st} is QCD coupling constant at the chiral leptoquark mass).

In this case after account of only lightest leptoquarks V^L and S^R the branching ratio (6), (7) take the form

$$Br(K_L^0 \to e^\mp \mu^\pm) = \frac{m_{K_L^0} f_k^2 m_\mu^2}{64\pi \Gamma^{tot}_{K_L^0}} (1 - (\frac{m_\mu}{m_{K_L^0}})^2)^2 \times \times \{\frac{4\pi\alpha_{st}}{m_{V^L}^2} - \frac{3m_d(m_s - m_\mu)}{4\eta^2 m_{S^R}^2 \sin^2\beta}\}^2, \quad (10)$$

$$Br(B^0 \to e^\mp \tau^\pm) = \frac{m_{B^0} f_B^2 m_\tau^2}{32\pi \Gamma^{tot}_{B^0}} (1 - (\frac{m_\tau}{m_{B^0}})^2)^2 \times \times \{\frac{4\pi\alpha_{st}}{m_{V^L}^2} - \frac{3m_d(m_b - m_\tau)}{4\eta^2 m_{S^R}^2 \sin^2\beta}\}^2. \quad (11)$$

3 Numerical results.

Let us consider the numerical results.

$Br(K_L^0 \to e^\mp \mu^\pm)$

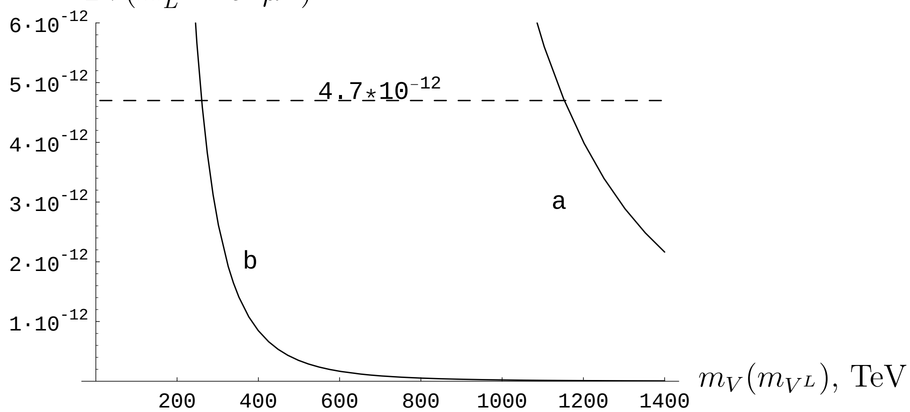

Figure 1: Branching ratio of $K_L^0 \to e^\mp \mu^\pm$ decay via a) vector and b) chiral leptoquark in dependence on the leptoquark mass.

Fig.1 describes the case of the gauge leptoquark contribution into K_L^0 (without gluon correction). The dashed line shows the experimental limit $Br(K_L^0 \to e^\mp \mu^\pm) < 4.7 \cdot 10^{-12}$ [2]. The curve a) shows the branching ratio of $K_L^0 \to e^\mp \mu^\pm$ decay via one vector leptoquark . In this case the low mass limit on the vector leptoquark is of order of $m_V > 1150$ TeV. (The account of the gluon corrections increases the low mass limit up to 1400 TeV [6].) The curve b) shows the branching ratio of $K_L^0 \to e^{\mp}\mu^{\pm}$ decay in the case of one chiral leptoquark as function of the chiral leptoquark mass. In this case the low mass limit for the chiral leptoquark is of order of $m_{V^L} > 260$ TeV.

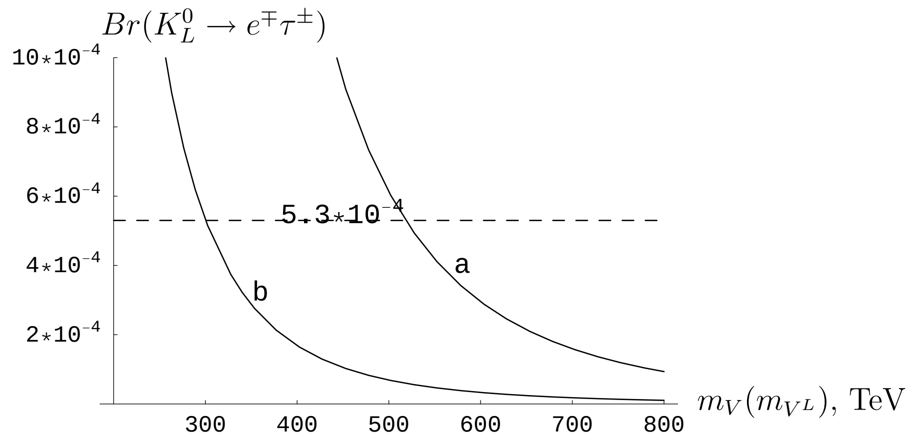

Figure 2: Branching ratio $B^0 \to e^{\mp}\tau^{\pm}$ decay via a) vector and b) chiral leptoquark in dependence on the leptoquark mass.

Fig.2 describes the branching ratio $Br(B^0 \to e^{\mp}\tau^{\pm})$ via vector leptoquark (curve a)) and via chiral leptoquark (curve b)). The resulted from the experimental limit $Br(B^0 \to e^{\mp}\tau^{\pm}) < 5.3 \cdot 10^{-4}$ [2] the mass limits are of order of $m_V > 520$TeV, $m_{V^L} > 300$TeV.

Fig.3 describes the allowed region in chiral leptoquark mass – scalar leptoquark mass plane from $K_L^0 \to e^{\mp}\mu^{\pm}$ decay. Yukawa coupling constants of the scalar leptoquarks depend on quark's masses. We present here two curves a) and b) for the running quark masses a) $m_d(1GeV) = 11$MeV, $m_s(1GeV) = 210$MeV, b) $m_d(750MeV) = 14$MeV, $m_s(750MeV) = 260$MeV corresponding to the mass scale a) 1GeV and b) 750 MeV. For scalar leptoquark mass 250 GeV we obtain the chiral leptoquark low mass limits a) $m_{V^L} > 205$TeV, b) $m_{V^L} > 180$TeV.

Strictly speeking one should to use the quark masses at the mass of K_L^0-meson but this is a nonpertubative region and we can not calculate them. Nevertheless one can hope that the quark masses at $m_{K_L^0}$ are larger that those at 750 MeV and, hence the contribution of the scalar leptoquark is also larger. To illustrate how such large contribution could affect mass limits

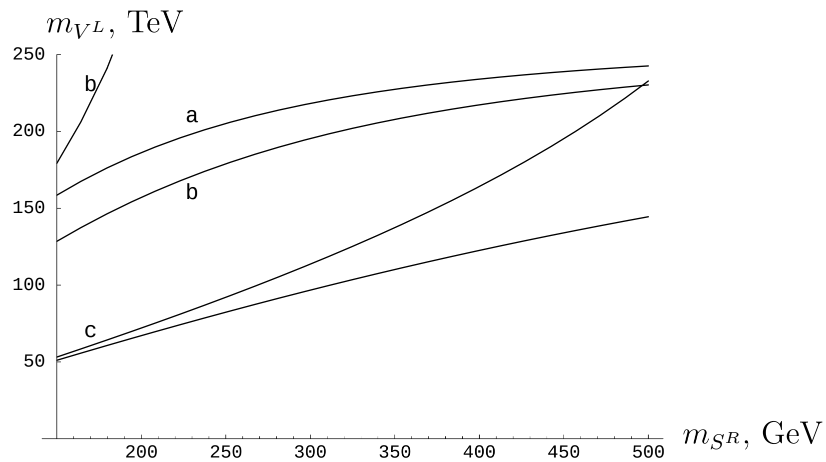

Figure 3: The allowed region in chiral leptoquark mass – scalar leptoquark mass plane from $Br(K_L^0 \to e^{\mp}\mu^{\pm}) < 4.7 \cdot 10^{-12}$ [2].

we present also the curve c) for $m_d = 34$MeV, $m_s = 620$MeV. In this case we obtain the lower and the upper limits on the chiral leptoquark mass, for example for $m_S = 250$ GeV we obtain 80 TeV $< m_{V^L} < 90$ TeV.

The last grafic (fig.4) describes the allowed region in chiral leptoquark mass – scalar leptoquark mass plane from $B^0 \to e^{\mp}\tau^{\pm}$ decay. One can see that this mass region is compatible with that of case c) in the Fig.3. In particular for $m_S = 250$ GeV we also obtain 80 TeV $< m_{V^L} < 90$ TeV.

One should to note that the discussed mass limits should be regarded rather qualitatively than quantitatively becouse we do not account the gluonic corrections. These corrections can be essential for $K_L^0 \to e^{\mp}\mu^{pm}$ decays and possibly they even can not be exactly calculated in the perturbative approach.

In spite of this case the gluonic correction for the B^0 decays can be accounted with sufficient accuracy. Further, in the case of B^0 meson the decays $B^0 \to l_i^+ l_j^-$ into all lepton-antilepton pairs are allowed. The measurement of $Br(B^0 \to l_i^+ l_j^-)$ will give the possibility to set leptoquark mass limits with the total account of the fermion mixing. So, the search for leptonic decays of B^0 meson $B^0 \to l_i^+ l_j^-$ seems to be interesting and useful for further setting the leptoquark mass limits.

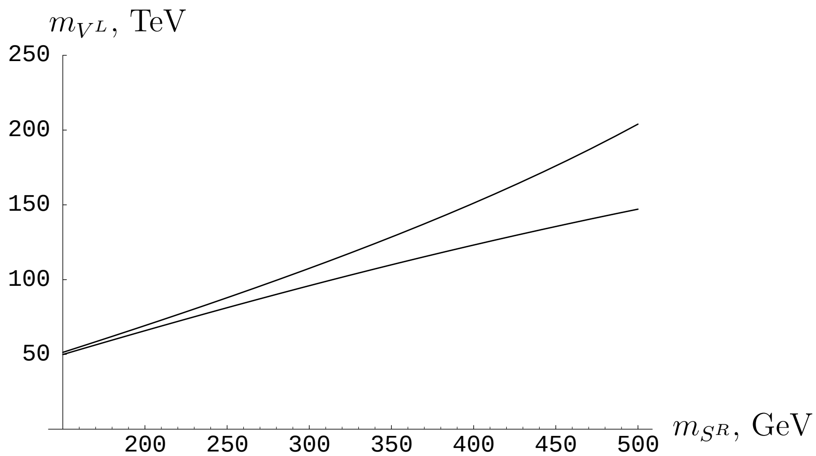

Figure 4: The allowed region in chiral leptoquark mass – scalar leptoquark mass plane from $Br(B^0 \to e^{\mp}\tau^{\pm}) < 5.3 \cdot 10^{-4}$ [2].

4 Conclusion

1) The chiral and the scalar leptoquark contributions into widths of the $K_L^0 \to e^{\mp}\mu^{\pm}$, $B^0 \to e^{\mp}\tau^{\pm}$ decays are calculated in MQLS model with Higgs mechanism of the quark-lepton mass splitting and the resulted from these decays mass limits for the leptoquarks are investigated.

2) The chiral leptoquark mass limits are shown to be weaker than those for vector leptoquark

$$K_L^0 \to e^{\mp}\mu^{\pm} \Rightarrow \; m_{V^L} > 260\text{TeV}(m_V > 1150\text{TeV})*)$$

$$B^0 \to e^{\mp}\tau^{\pm} \Rightarrow \; m_{V^L} > 300\text{TeV}(m_V > 520\text{TeV})*)$$

*)without account of the gluonic corrections.

3) The account the scalar leptoquarks in $B^0 \to e^{\mp}\tau^{\pm}$ decay reduces the lower limit and gives the upper limit on the chiral leptoquark masses

$$B^0 \to e^{\mp}\tau^{\pm} \Rightarrow \; 80\text{TeV} < m_{V^L} < 90\text{TeV}$$

for $m_S = 250$GeV. The $K_L^0 \to e^-\mu^+$ decays is expected to be strongly affected by the gluonic corrections.

4) For obtaining the more correct leptoquark mass limits it is perspective to investigate experimentaly the leptonic decays $B^0 \to l_i^+ l_j^-$ of B^0 meson.

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