Fermion-mixing parameters and search limit on the mass leptoquark.

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Outline

Introduction

Vector Leptoquarks V_α predicted in “four color” symmetry– J.C.Pati and A.Salam, PRD 10 1974

The restriction on the mass of the vector leptoquark from decays type

$$K_L^0 \to \mu^\pm e^\mp$$

are strong [order 10^3 TeV](excluding fermion mixing).

- G. Valencia and S. Willenbrock, PRD 50,1994
- A .V. Kuznetsov and N.V. Mikheev, PLB 329, 1994; YaF 58, 1995

The fermion mixing can be this restriction weak

- A. Povarov and A. Smirnov, ITEPh-talk, 2011
- A .V. Kuznetsov, N.V. Mikheev, A.V.Serghienko Int.J.Mod.Phys A27, 2012

Minimal Quark-Lepton Symmetry Model

$$SU_V(4) \times SU_L(2) \times U_R(1)$$

A. D. Smirnov, Phys. Lett. B 346, (1995); YaF 58, (1995).

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

where $i, j = 1,\ 2,\ 3$ – fermion generation indexes, $a = 1, 2$ and $\alpha = 1, 2, 3$ – indexes $SU_L(2)$ and $SU_c(3)$.

$$A^{L,R}_{Q_a}, \quad A^{L,R}_{l_a}$$

- unitary matrices describe the fermion mixing and diagonalize the mass matrices of quarks and leptons, which appear after spontaneous symmetry breaking

$$C_Q = (A^L_{Q_1})^+ A^L_{Q_2} = V_{CKM}, \quad C_l = (A^L_{l_1})^+ A^L_{l_2} = U^+_{PMNS}$$

$$K^{L,R}_a = (A^{L,R}_{Q_a})^+ A^{L,R}_{l_a}$$

Minimal Quark-Lepton Symmetry Model

The lagrangian interaction vector leptoquarks with down fermions can be written in the following form

$$L_{Vdl} = \frac{g_4}{\sqrt{2}}(\bar{d}_{p\alpha}[(K_2^L)_{pi}\gamma^\mu P_L + (K_2^R)_{pi}\gamma^\mu P_R]l_i)V_{\alpha\mu} + h.c.,$$

where $g_4 = g_{st}(M_c)$ is the $SU_V(4)$ gauge coupling constant, related to the strong coupling consnant at the mass scale M_c of the $SU_V(4)$ symmetry breaking, $p, i = 1, 2, 3$,... are the quark and lepton generation indexes, $\alpha = 1, 2, 3$ – $SU(3)$ colour index, $P_{L,R} = (1 \pm \gamma_5)/2$.

Decays K^0-meson

A. D. Smirnov, Mod.Phys. Lett. A 22, (2007); YaF 71, (2008).

$$BR(K_L^0 \to l_i^+ l_j^-) = \frac{m_{K^0} \pi \alpha_{st}^2 f_{K^0}^2 \bar{m}_{K^0}^2 (R_{K^0}^V)^2}{4 m_V^4 \Gamma_K^{total}} \, |k_{ij}^{(K^0)}|^2,$$

where $\bar{m}_{K^0} = m_{K^0}^2/(m_s + m_d)$, Γ_K^{total} – total width decay K_L^0-meson, $f_{K^0} = 0.16$ GeV – form factor K_L^0-meson, factor $R_{K^0}^V = R_{K^0}(\mu_{K^0}, M_c)$ incorporate gluonic corrections, mixing factors incorporate fermionic mixing in general form

$$k_{ij}^{(K^0)} = \sqrt{(|\varkappa_{ij}^L|^2 + |\varkappa_{ij}^R|^2)/2}$$

$$\varkappa_{ij}^{L,R} = (K_2^{L,R})_{2i} (\overset{*}{K}{}_2^{R,L})_{1j} + (K_2^{L,R})_{1i} (\overset{*}{K}{}_2^{R,L})_{2j}.$$

Decays K^0-meson

PDG: C. Patrignani et al., Chin. Phys. C, 40, 100001 (2016) and 2017.

$$\begin{aligned} BR(K_L^0 \to e^\pm \mu^\mp) &< 4.7 \times 10^{-12} \\ BR(K_L^0 \to \mu^+ \mu^-) &= (6.8 \pm 0.11) \times 10^{-9} \\ BR(K_L^0 \to e^+ e^-) &= (9^{+6}_{-4}) \times 10^{-12}. \end{aligned}$$

$$K_2^{L,R} =$$

$$\begin{bmatrix} c_{12}^{L,R} c_{13}^{L,R} & s_{12}^{L,R} c_{13}^{L,R} & s_{13}^{L,R} e^{-i\delta_{L,R}} \\ s_{12}^{L,R} c_{23}^{L,R} - c_{12}^{L,R} s_{23}^{L,R} s_{13}^{L,R} e^{i\delta_{L,R}} & c_{12}^{L,R} c_{23}^{L,R} - s_{12}^{L,R} s_{23}^{L,R} s_{13}^{L,R} e^{i\delta_{L,R}} & s_{23}^{L,R} c_{13}^{L,R} \\ s_{12}^{L,R} s_{23}^{L,R} - c_{12}^{L,R} c_{23}^{L,R} s_{13}^{L,R} e^{i\delta_{L,R}} & c_{12}^{L,R} s_{23}^{L,R} - s_{12}^{L,R} c_{23}^{L,R} s_{13}^{L,R} e^{i\delta_{L,R}} & c_{23}^{L,R} c_{13}^{L,R} \end{bmatrix}.$$

$$s_{ij}^{L,R} = \sin \Theta_{ij}^{L,R}, c_{ij}^{L,R} = \cos \Theta_{ij}^{L,R}$$

$$M_{V\,ij} = f(BR(K^0 \to l_i l_j), \Theta_{ij}^{L,R}, \delta_{L,R})$$

Decays K^0-meson

Joint calculation of mass vector leptoquark from the three decay K_L^0 - meson taking into account additional fermion mixing give the lower bounds to 0.

In particular, the choice of parameters in next values: $\Theta_{12}^L = \Theta_{13}^L = \Theta_{23}^L = \Theta_{12}^R = \Theta_{13}^R = \Theta_{23}^R = \pi/2$, with correspondent matrix

$$K_2^L = K_2^R = \begin{bmatrix} 0 & 0 & 1 \\ 0 & -1 & 0 \\ 1 & 0 & 0 \end{bmatrix},$$

obtain $k_{21}^{(K^0)} = k_{11}^{(K^0)} = k_{22}^{(K^0)} = 0$, and experimental limits performed for all values m_V.

Decays K^0- and B^0-mesons

$$BR(B^0 \to l_i^+ l_j^-) = \frac{m_{B^0}\pi\alpha_{st}^2 f_{B^0}^2 \bar{m}_{B^0}^2 (R_{B^0}^V)^2}{4 m_V^4 \Gamma_B^{total}} \; |k_{ij}^{(B^0)}|^2,$$

where $\bar{m}_{B^0} = m_{B^0}^2/(m_b + m_d)$, $f_{B^0} = 0.229$ GeV – form factor B^0-meson, factor $R_{B^0}^V = R_{B^0}(\mu_{B^0}, M_c)$ incorporate gluonic corrections, $\mu_{l_i^\pm} = m_{l_i^\pm}/(m_{B^0} R_{B^0}^V)$

$$|k_{ij}^{(B^0)}|^2 = \Big[(|\beta_{ij}^L|^2 + |\beta_{ij}^R|^2)(1 - \mu_{l_i}^2 - \mu_{l_j}^2) + 2(\overset{*}{\beta}{}_{ij}^L \beta_{ij}^R + \beta_{ij}^L \overset{*}{\beta}{}_{ij}^R)\mu_{l_i}\mu_{l_j}\Big] \times \sqrt{[1 - (\mu_{l_i} + \mu_{l_j})^2][1 - (\mu_{l_i} - \mu_{l_j})^2]}, \quad (1)$$

$$\beta_{ij}^{L,R} = k_{ij}^{L,R} - (\mu_{l_j^-} k_{ij}'^{L,R} + \mu_{l_i^+} k_{ij}'^{R,L})/2$$

$$k_{ij}^{L,R} = (K_2^{L,R})_{3i}(\overset{*}{K}{}_2^{R,L})_{1j}, \qquad k_{ij}'^{L,R} = (K_2^{L,R})_{3i}(\overset{*}{K}{}_2^{L,R})_{1j}$$

Decays K^0- and B^0-mesons

$$
\begin{aligned}
BR(B^0 \to e^{\pm}\mu^{\mp}) &< 2.8 \times 10^{-9} \\
BR(B^0 \to e^{\pm}\tau^{\mp}) &< 2.8 \times 10^{-5} (*) \\
BR(B^0 \to \mu^{\pm}\tau^{\mp}) &< 2.2 \times 10^{-5} (*) \\
BR(B^0 \to \mu^{+}\mu^{-}) &< 3.4 \times 10^{-10} \\
BR(B^0 \to e^{+}e^{-}) &< 8.3 \times 10^{-8} \\
BR(B^0 \to \tau^{+}\tau^{-}) &< 2.1 \times 10^{-3}.
\end{aligned}
$$

LHCb collaboration: R. Aaij et al, Phys.Rev.Lett. 118 (2017)

The restriction on the mass VLQ obtained from decays K_L^0 and B^0 mesons together are 10 TeV

Decays K^0-, B^0- and B_s-mesons

$$
\begin{aligned}
BR(B_s \to e^{\pm}\mu^{\mp}) &< 1.1 \times 10^{-8} (*) \\
BR(B_s \to \mu^{+}\mu^{-}) &= (3.0^{+0.67}_{-0.63}) \times 10^{-10} (*) \\
BR(B_s \to e^{+}e^{-}) &< 8.3 \times 10^{-8} \\
BR(B_s \to \tau^{+}\tau^{-}) &< 6.8 \times 10^{-3}
\end{aligned}
$$

LHCb collaboration: R. Aaij et al, Phys.Rev.Lett. 118 (2017)

For example if set parameters as

$\Theta^L_{12} = \Theta^R_{12} = 9\pi/50, \quad \Theta^L_{13} = \Theta^R_{13} = \pi/2, \quad \Theta^L_{23} = \Theta^R_{23} = 0,$

$$
K^L_2 = K^R_2 = \begin{pmatrix} 0 & 0 & 1 \\ -0.54 & 0.84 & 0 \\ -0.84 & -0.54 & 0 \end{pmatrix}. \tag{2}
$$

Decays K^0-, B^0- and B_s-mesons

$$k_{ij}^{(K^0)} = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix},$$

$$k_{ij}^{(B^0)} = \begin{pmatrix} 0 & 0 & 0.87 \\ 0 & 0 & 0.35 \\ 0 & 0 & 0 \end{pmatrix},$$

$$k_{ij}^{(B_s)} = \begin{pmatrix} 0.41 & 0.99 & 0 \\ 0.16 & 0.4 & 0 \\ 0 & 0 & 0 \end{pmatrix}.$$

The restriction on the mass vector leptoquark obtained from decays K_L^0, B^0 and B_s mesons together are 85 TeV

Conclusions

- Accounting fermion mixing in leptonic decays of K_L^0, B^0 and B_s mesons leads to a significant weakening of restrictions on mass vector leptoquark. The current limit is about 85 TeV, it is essentially weaker, than restriction without taking into account fermion mixing.

Conclusions

- Accounting fermion mixing in leptonic decays of K_L^0, B^0 and B_s mesons leads to a significant weakening of restrictions on mass vector leptoquark. The current limit is about 85 TeV, it is essentially weaker, than restriction without taking into account fermion mixing.

$$M_V : 2200\, TeV \to 85\, TeV$$

We hope that the “Grand Desert” will not.