Mass limits for scalar leptoquark and scalar gluon doublets from current data on S, T, U

Alexander D. Smirnov
Yaroslavl State University, Russia

15th International Seminar QUARKS-2008, Sergiev Posad, Russia
May 23–29, 2008

Contents

1.Introduction

The search for a new physics beyond the Standard Model (SM) is now one of the aims of the high energy physics. One of the new physics can be induced by the possible four color symmetry treating leptons as quarks of the fourth color[J. C. Pati, A. Salam. PRD, 1974]. This symmetry can be unified with the SM by the gauge group

$$G_{new} = G_c \times SU_L(2) \times U_R(1)$$

where G_c is the group of the four color symmetry.

New gauge fields:

$$G_c = SU_V(4) \;\; \Rightarrow \;\; V,\; Z',$$
$$G_c = SU_L(4) \times SU_R(3) \;\; \Rightarrow \;\; V^L,\; G^{(A)},\; Z',$$
$$G_c = SU_L(3) \times SU_R(4) \;\; \Rightarrow \;\; V^R,\; G^{(A)},\; Z',$$
$$G_c = SU_L(4) \times SU_R(4) \;\; \Rightarrow \;\; V^L,\; V^R,\; G^{(A)},\; Z'_1,\; Z'_2.$$

1.Introduction

The most stringent lower mass limits for the gauge leptoquarks are the indirect mass limits resulted from $K_L^0 \to e^{\mp}\mu^{\pm}$ decay which in the case of zero fermion mixing are [G. Valencia, S. Willenbrock. PRD, 1994; A. V. Kuznetsov, N. V. Mikheev. PLB, 1994, YaF, 1995; A. D. Smirnov. MPLA, 2007, YaF, 2008, in print]

$$m_V^{lower} = 2000\ TeV,$$
$$m_{V^L}^{lower} = 260\ TeV.$$

1.Introduction

New scalar fields: scalar leptoquarks, scalar gluons

It should be noted however that the four color symmetry allows also the existence of scalar leptoquarks and such particles have been phenomenologically introduced in ref. [W. Buchmüller, R. Rückl, D. Wyler. PLB, 1987] and have been discussed in a number of papers.

The experimental lower mass limits for the scalar leptoquarks from their direct search are [PDG. W.-M. Yao et al., J. Phys.,2006]

1st generation	2nd generation	3rd generation	
$m_{LQ} > 256\,\text{GeV},$	$251\,\text{GeV},$	$148\,\text{GeV},$	$153\,\text{GeV}\ [*)]$
$Br(eq) = 1,$	$Br(\mu q) = 1,$	$Br(\nu b) = 1,$	$Br(\tau b) = 1;$
$m_{LQ} > 234\,\text{GeV},$	$204\,\text{GeV}$		
$Br(eq) = 0.5,$	$Br(\mu q) = 0.5.$		

[*) T.Aaltonen et.al. (CDF), hep-ex//0802.3887.]

The indirect mass limits for the scalar leptoquarks $\rightarrow$ h/m_S.

1.Introduction

Minimal Quark - Lepton Symmetry model (MQLS - model):

MQLS - model $= \begin{cases} G_{new} = SU_V(4) \times SU_L(2) \times U_R(1) \ + \\ \text{the Higgs mechanism of fermion mass generation} \\ \text{(including the quark–lepton mass splittings)} \end{cases}$

MQLS - model $\Rightarrow \begin{pmatrix} S^{(+)}_{1\alpha} \\ S^{(+)}_{2\alpha} \end{pmatrix}, \begin{pmatrix} S^{(-)}_{1\alpha} \\ S^{(-)}_{2\alpha} \end{pmatrix}, \begin{pmatrix} F_{1k} \\ F_{2k} \end{pmatrix}, \begin{pmatrix} \Phi'_1 \\ \Phi'_2 \end{pmatrix}, \begin{pmatrix} \Phi^{(SM)}_1 \\ \Phi^{(SM)}_2 \end{pmatrix},$

$\alpha = 1, 2, 3, \ k = 1, 2, ..., 8$ – $SU_c(3)$–color indices.

$$Q_{em}: \qquad \begin{pmatrix} 5/3 \\ 2/3 \end{pmatrix}, \begin{pmatrix} 1/3 \\ -2/3 \end{pmatrix}, \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 \\ 0 \end{pmatrix}.$$

$$h \sim m_f/\eta,$$

The indirect mass limits for the scalar leptoquarks from $K^0_L \to e^{\mp}\mu^{\pm}$ decays are of order of the direct mass limits. [A. D. Smirnov. MPLA, 2007, YaF, 2008, in print]

Radiative corrections $\rightarrow \ m_S, m_F \sim \ ?$

2. S, T, U parameters of Peskin - Takeuchi

$$m_{new} \gg m_Z$$

The S-, T-, U- parameters of Peskin and Takeuchi are defined as [M.E. Peskin, T. Takeuchi. PRD, 1992]

$$\begin{aligned}
\alpha S &= 4 s_W c_W [s_W c_W (\Pi'_{ZZ}(0) - \Pi'_{AA}(0)) - ({c_W}^2 - {s_W}^2)\Pi'_{ZA}(0)], \\
\alpha T &= \frac{1}{{c_W}^2 {m_Z}^2}[\Pi_{WW}(0) - {c_W}^2 \Pi_{ZZ}(0)], \\
\alpha U &= 4 {s_W}^2 [\Pi'_{WW}(0) - {c_W}^2 \Pi'_{ZZ}(0) - {c_W}^2 \Pi'_{AA}(0) - 2 c_W s_W \Pi'_{ZA}(0)],
\end{aligned}$$

where $\Pi^{\mu\nu}_{XY}(k^2) = g^{\mu\nu}\Pi_{XY}(k^2) + (k^\mu k^\nu - terms)$ are the self energy functions of X-, Y-fields, $\Pi_{XY}(k^2) = \Pi_{XY}(0) + k^2 \Pi'_{XY}(0) + ...$, X, Y are A_μ-,Z_μ- and $W^{\pm}_\mu$-fields.

2. S, T, U parameters of Peskin - Takeuchi

The S, T, U parameters are normalized so that in the SM (i.e. in the case of absence of any New Physics) S, T, U must be equal to zero:

$$S_{new} = 0, T_{new} = 0, U_{new} = 0.$$

The current experimental data on S, T, U are

$$\begin{aligned} S^{exp}_{new} &= -0.13 \pm 0.10(-0.08), \\ T^{exp}_{new} &= -0.13 \pm 0.11(+0.09), \\ U^{exp}_{new} &= 0.20 \pm 0.12(+0.01), \end{aligned}$$

where the central values assume $m_H = 117\ GeV$ and the change for $m_H = 300\ GeV$ is shown in parentheses [PDG. W.-M. Yao et al., J. Phys.,2006].

3. Contributions into S, T, U from scalar leptoquark doublets

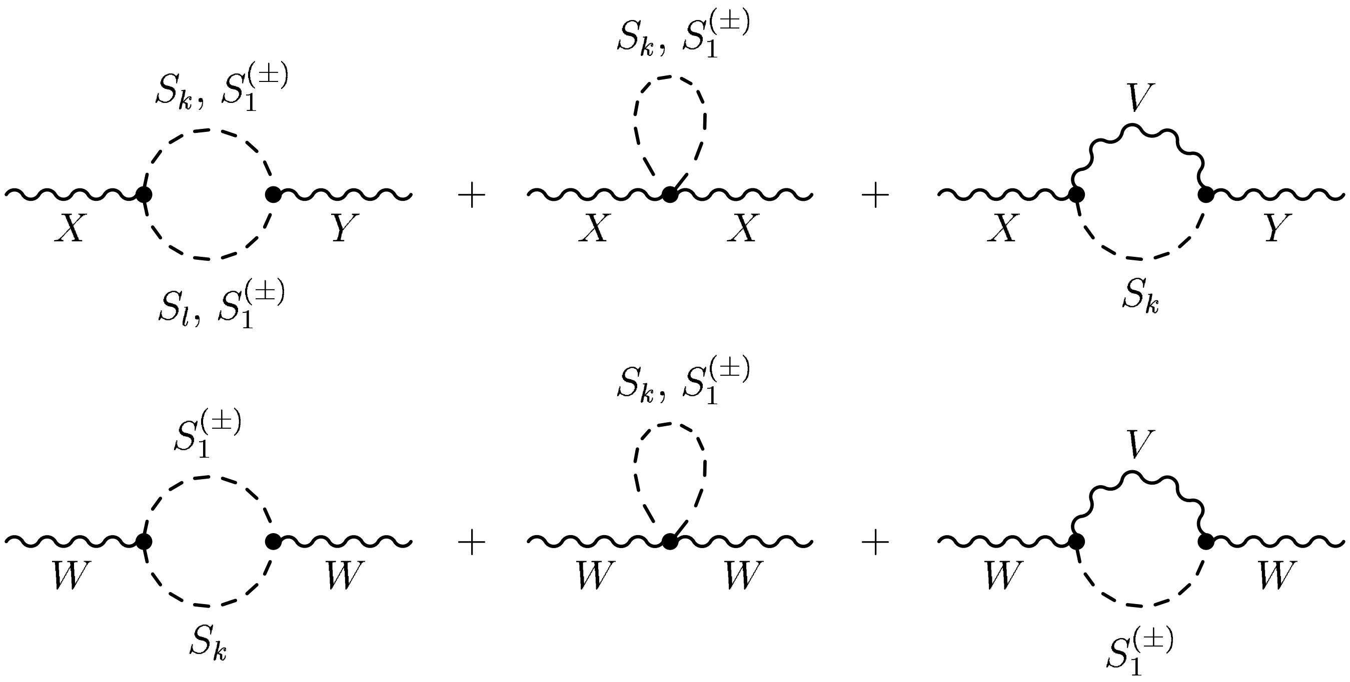

Figure 1: The self energy diagramms contributing into S, T, U from the scalar leptoquarks $S_1^{(\pm)}$, S_k, $k = 1, 2, 3$ (V is the vector leptoquark, X, Y are the photon and Z-boson).

3. Contributions into S, T, U from scalar leptoquark doublets

The contribution of scalar leptoquark and scalar gluon doublets into S, T, U in general case have been calculated in refs: [A.D. Smirnov. PLB, 1998; YaF, 2001; PLB, 2002; A.V. Povarov, A.D. Smirnov. YaF, 2003] In general case the scalar leptoquark contributions into S, T, U are rather complicated because of the possible scalar leptoquark mixing

$$S_{2\alpha}^{(+)} = \sum_{m=0}^{3} c_m^{(+)} S_m, \qquad \overset{*}{S}{}_2^{(-)} = \sum_{m=0}^{3} c_m^{(-)} S_m$$

and because of existence of the goldstone mode S_0.

Below we consider the case of zero scalar leptoquark mixing and with neglect of the small parameter $\xi^2 = \frac{2}{3} g_4^2 \eta_3^2 / m_V^2 \ll 1$ of the model. In this case the scalar leptoquark doublets

$$S^{(+)} = \begin{pmatrix} S_1^{(+)} \\ S_2^{(+)} \end{pmatrix}, S^{(-)} = \begin{pmatrix} S_1^{(-)} \\ S_2^{(-)} \end{pmatrix}$$

are the physical states and their contributions into S, T, U take the simplest form:

3. Contributions into S, T, U from scalar leptoquark doublets

$$S^{(LQ)} = \frac{n_c}{12\pi}\left\{ -Y_+^{SM}\ln\frac{m_+^2}{m_1^2} - Y_-^{SM}\ln\frac{m_-^2}{m_2^2}\right\},$$

$$T^{(LQ)} = \frac{n_c}{16\pi s_W^2 c_W^2 m_Z^2}\left\{ f_1(m_+, m_1) + f_1(m_-, m_2)\right\} > 0,$$

$$U^{(LQ)} = \frac{n_c}{12\pi}\left\{ f_2(m_+, m_1) + f_2(m_-, m_2)\right\} > 0,$$

where

$$f_1(m_1, m_2) = {m_1}^2 + {m_2}^2 - \frac{2m_1^2 m_2^2}{{m_1}^2 - {m_2}^2}\ln\frac{m_1^2}{m_2^2} > 0\,,$$

$$f_2(m_1, m_2) = -\frac{5{m_1}^4 + 5{m_2}^4 - 22{m_1}^2{m_2}^2}{3({m_1}^2 - {m_2}^2)^2} + \frac{{m_1}^6 - 3{m_1}^4{m_2}^2 - 3{m_1}^2{m_2}^4 + {m_2}^6}{({m_1}^2 - {m_2}^2)^3}\ln\frac{m_1^2}{m_2^2} > 0\,,$$

$n_c = 3$, $Y_\pm^{SM} = 1 \pm 4/3$ and $m_+ = m_{S_1^{(+)}}$, $m_- = m_{S_1^{(-)}}$, $m_{1,2} = m_{S_2^{(+)}, S_2^{(-)}}$ are the scalar leptoquark masses.

3. Contributions into S, T, U from scalar gluon doublets

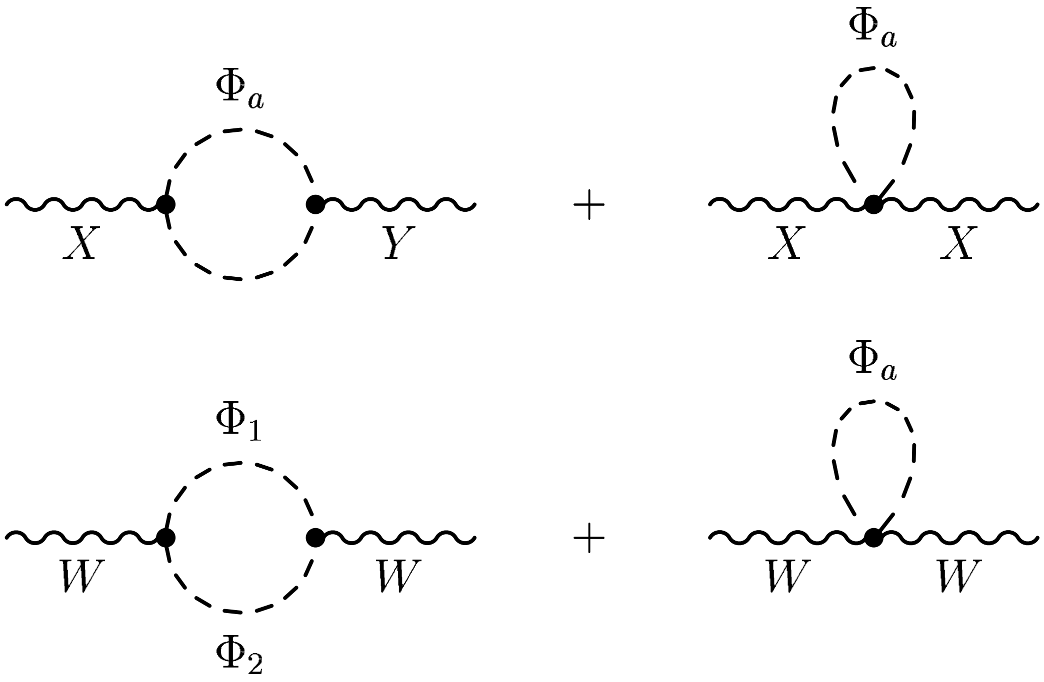

Figure 2: The self energy diagramms contributing into S, T, U from the scalar gluons F_j and from additional scalar doublet Φ' ($\Phi_a = \Phi'_a$, F_{ja}, $a = 1, 2$, $j = 1, 2, \ldots, 8$, X, Y are the photon and Z-boson).

4. Contributions into S, T, U from scalar gluon doublets

The scalar gluon doublets can be written as

$$F_j = \begin{pmatrix} F_{1j} \\ (\phi_{1j} + i\phi_{2j})/\sqrt{2} \end{pmatrix},$$

where the charged fields F_{1j} and the neutral fields $\phi_{1j}, \phi_{2j}, j = 1, 2, ..., 8$ are the mass eigen state fields.

The scalar gluon doublets give the next contributions into S, T, U

$$S^{(F)} = -\frac{k_F}{24\pi}\left\{ \ln\frac{m_{F_1}^2}{m_{\phi_1}^2} + \ln\frac{m_{F_1}^2}{m_{\phi_2}^2} - f_2(m_{\phi_1}, m_{\phi_2}) \right\},$$

$$T^{(F)} = \frac{k_F}{32\pi {c_W}^2 {s_W}^2 {m_Z}^2}\left\{ f_1(m_{F_1}, m_{\phi_1}) + f_1(m_{F_1}, m_{\phi_2}) - f_1(m_{\phi_1}, m_{\phi_2}) \right\},$$

$$U^{(F)} = \frac{k_F}{24\pi}\left\{ f_2(m_{F_1}, m_{\phi_1}) + f_2(m_{F_1}, m_{\phi_2}) - f_2(m_{\phi_1}, m_{\phi_2}) \right\},$$

where $k_F = 8$. The contributions $T^{(F)}$ and $U^{(F)}$ are not positive definite and they are negative if m_{F_1} is between m_{ϕ_1} and m_{ϕ_2}.

5. Numerical results and discussion

$$S = S^{(LQ)} + S^{(F)}, \ \ T = T^{(LQ)} + T^{(F)}, \ \ U = U^{(LQ)} + U^{(F)}$$

$$V(\Phi^{(SM)}, S^{(+)}), S^{(-)}, F) \ > \ 0,$$

$$\lambda_i \le \lambda_{max}$$

$$m_1, m_2, m_{\pm}, m_{F_1}, m_{\phi_1}, m_{\phi_2} \ge m_{scalar}^{lower}.$$

$$\lambda_{max} = 1.0 - 4.0, \ \ (\lambda_{max}/4\pi = 0.1 - 0.3.)$$

$$\chi^2 = \frac{(S - S_{new}^{exp})^2}{(\Delta S)^2} + \frac{(T - T_{new}^{exp})^2}{(\Delta T)^2} + \frac{(U - U_{new}^{exp})^2}{(\Delta U)^2},$$

$\Delta S, \Delta T, \Delta U$ are the experimental errors in $S_{new}^{exp}, T_{new}^{exp}, U_{new}^{exp}$.

5. Numerical results and discussion

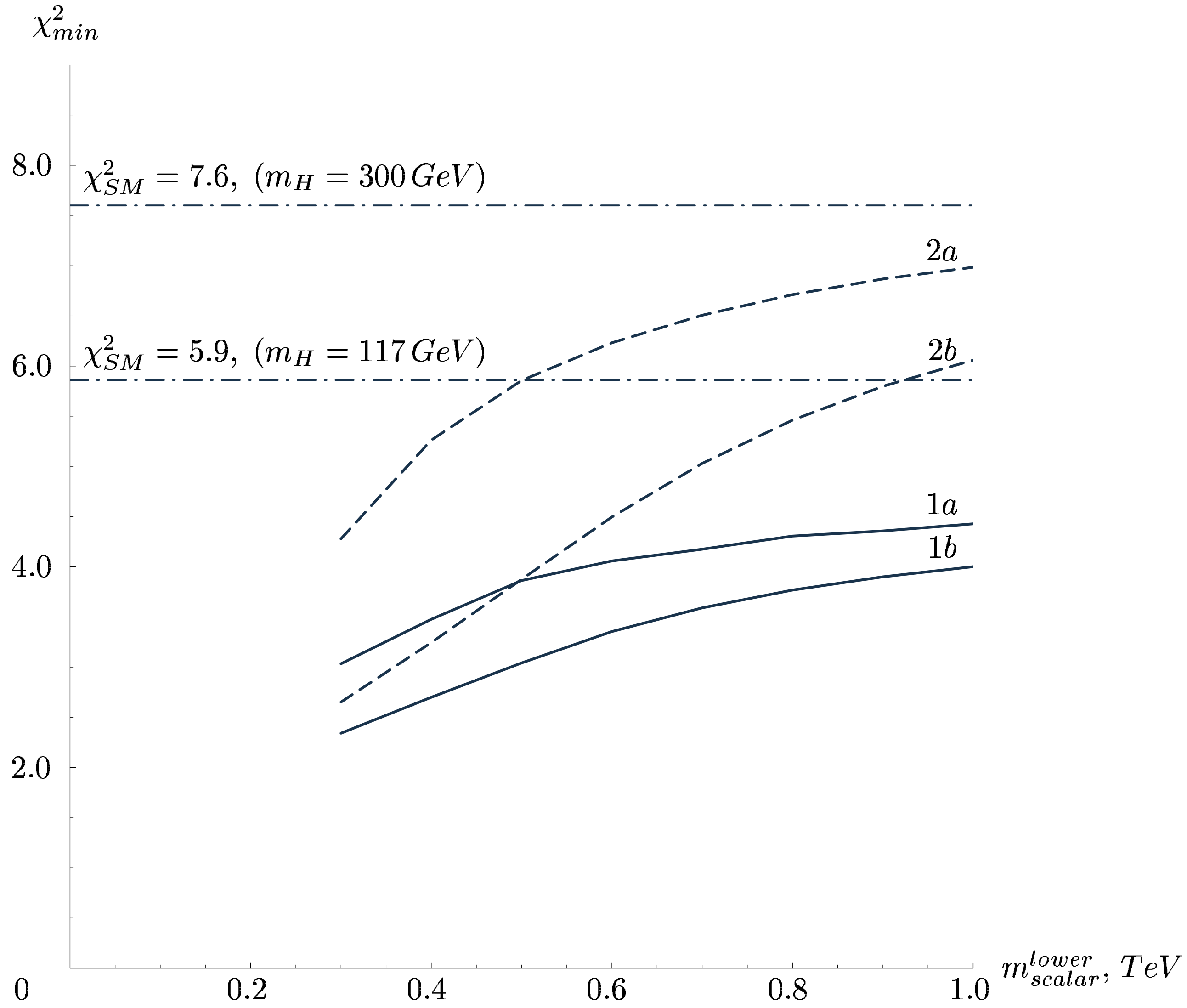

Figure 3: $\chi^2_{min}(m^{lower}_{scalar}, \lambda_{max})$ as a function of the lower limit m^{lower}_{scalar} on the scalar doublet masses for $1)\, m_H = 117\ GeV$, $2)\, m_H = 300\ GeV$ at $a)\, \lambda_{max} = 1.0$, $b)\, \lambda_{max} = 4.0$.

5. Numerical results and discussion

For example for $\lambda_{max} = 1.0$, $m^{lower}_{scalar} = 400\ GeV$ the scalar leptoquarks and gluons with the masses

$$m_{S_1^{(+)}} = 440\,GeV, \quad m_{S_1^{(-)}} = 400\,GeV, \quad m_{F_1} = 460\,GeV,$$

$$m_{S_2^{(+)}} = 400\,GeV, \quad m_{S_2^{(-)}} = 420\,GeV, \quad m_{\phi_1} = 480\,GeV, \quad m_{\phi_2} = 400\,GeV$$

give the contributions

$$\begin{aligned} S^{(LQ)} &= -0.03, \quad T^{(LQ)} = 0.08, \quad U^{(LQ)} = 5.5 \cdot 10^{-4}, \\ S^{(F)} &= -0.01, \quad T^{(F)} = -0.21, \quad U^{(F)} = -1.2 \cdot 10^{-3}, \\ S &= -0.05, \quad T = -0.13, \quad U = 6.6 \cdot 10^{-4}, \end{aligned}$$

which agree with

$$S^{exp}_{new} = -0.13 \pm 0.10, \; T^{exp}_{new} = -0.13 \pm 0.11, \; U^{exp}_{new} = 0.20 \pm 0.12$$

for $m_H = 117\ GeV$ with $\chi^2 = 3.5$ (in comparison with $\chi^2_{SM} = 5.9$).

5. Numerical results and discussion

In a similar way for $\lambda_{max} = 1.0$, $m^{lower}_{scalar} = 400\ GeV$ the scalar leptoquarks and gluons with the masses

$$m_{S_1^{(+)}} = 440\,GeV, \quad m_{S_1^{(-)}} = 400\,GeV, \quad m_{F_1} = 520\,GeV,$$
$$m_{S_2^{(+)}} = 400\,GeV, \quad m_{S_2^{(-)}} = 440\,GeV, \quad m_{\phi_1} = 540\,GeV, \quad m_{\phi_2} = 440\,GeV$$

give the contributions

$$\begin{aligned} S^{(LQ)} &= -0.04, \quad T^{(LQ)} = 0.14, \quad U^{(LQ)} = 9.5 \cdot 10^{-4}, \\ S^{(F)} &= -0.03, \quad T^{(F)} = -0.20, \quad U^{(F)} = -9.5 \cdot 10^{-4}, \\ S &= -0.06, \quad T = -0.06, \quad U = 3.4 \cdot 10^{-6}, \end{aligned}$$

which agree with

$$S^{exp}_{new} = -0.21 \pm 0.10, \; T^{exp}_{new} = -0.04 \pm 0.11, \; U^{exp}_{new} = 0.21 \pm 0.12$$

for $m_H = 300\ GeV$ with $\chi^2 = 5.3$ (in comparison with $\chi^2_{SM} = 7.6$).

6. Conclusion

- The contributions into radiative correction parameters S, T, U from the scalar leptoquark and scalar gluon doublets predicted by the four color symmetry with Higgs mechanism of the quark–lepton mass splitting are discussed in comparision with the curent experimental data on S, T, U . It is shown that the existence of the relatively light scalar leptoquark and scalar gluon doublets (with masses below 1 TeV)
- is consistent with current experimental data on S, T, U (this conclusion is stable under variations of the experimental values of S, T, U),
- gives the negative values to S and T parameters with improving (in comparision with the SM) the agreement of the model with the current experimental data on S, T, U and
- can relax the SM upper limit on the mass of Higgs boson.