Bounds
on scalar leptoquark and scalar gluon masses
from S, T, U in the minimal four color
symmetry model

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Abstract

The contributions into radiative correction parameters S, T, U from scalar leptoquark and scalar gluon doublets are investigated in the minimal four color symmetry model. It is shown that the current experimental data on S, T, U allow the scalar leptoquarks and the scalar gluons to be relatively light (with masses of order of 1 TeV or less), the lightest particles are preferred to lie below 400 GeV. In particular, the lightest scalar leptoquarks with masses below 300 GeV are shown to be compatible with the current data on S, T, U at $\chi^2 < 3.1(3.2)$ for $m_H = 115(300)$ GeV in comparison with $\chi^2 = 3.5(5.0)$ in the Standard Model. The lightest scalar gluon in this case is expected to lie below $850(720)$ GeV. The possible significance of such particles in the t-quark physics at LHC is emphasized.

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The search for a new physics beyond the Standard Model (SM) is one of the aims of high energy physics now. One of the possible variants of such new physics can be the variant induced by the possible four color symmetry between quarks and leptons. This symmetry predicts the vector leptoquarks with the lower limit on their masses of order 100 TeV or less and allows the scalar leptoquarks with the more undefined masses, some other colored particles are also allowed.

In addition to the vector leptoquarks the four color symmetry with the Higgs mechanism of splitting the masses of quarks and leptons (MQLS-model) predicts the scalar leptoquarks and the scalar gluons of the doublet structure under the electroweak \( SU_L(2) \)-group. In this approach these doublets are responsible for splitting the masses of quarks from those of leptons and they are the partners of the standard Higgs doublet. What can we say about the masses of these scalar doublets? The first analysis of the masses of the scalar leptoquark doublets by the formalism of the radiative corrections showed that some of these particles can be relatively light.

In the present paper we calculate and discuss the contributions into \( S, T, U \) from both the scalar leptoquark and the scalar gluon doublets, accounting the Higgs mechanism of generating the masses of these particles from the scalar potential of their interactions with the standard Higgs doublet. This is the most reasonable way of generating the masses of scalar particles and it reduces the region of the fitting parameters of the model and gives the possibility to obtain the new bounds on the masses of the scalar leptoquarks and of the scalar gluons from current experimental data on \( S, T, U \).

The scalar leptoquark and scalar gluon doublets \( S^{(±)}_{\alpha a} \) and \( F_{ja} \) to be discussed here belong to the \((15,2,1)\)-multiplet \( \Phi_{(3)}^{(3)} \) of the \( SU_V(4) \times SU_L(2) \times U_R(1) \)-group of the MQLS-model with VEV \( \eta_3 \), here \( a = 1,2 \) and \( i = 1,2...15 \) are the \( SU_L(2) \) and \( SU_V(4) \) indexes and \( \alpha = 1,2,3 \) and \( j = 1,2...8 \) are the indexes of the ordinary color \( SU_c(3) \) group. This multiplet together with \((1,2,1)\)-multiplet \( \Phi_{(2)}^{(2)} \) with VEV \( \eta_2 \) generates the fermion masses by Higgs mechanism and splits the masses of quarks from those of leptons.

Below we consider the scalar leptoquark doublets in the case of the simplest scalar leptoquark mixing and with neglect of the small parameter \( \xi^2 = \frac{2}{3} g_1^2 \eta_3^2 / m_V^2 \ll 1 \) of the model. In this case the scalar leptoquark doublets
can be written as

\[
S^{(+)} = \left( \begin{array}{c}
S_1^{(+)} \\
S_2 \\
\end{array} \right), S^{(-)} = \left( \begin{array}{c}
S_1^{(-)} \\
-S_1^* + c S_2^* \\
\end{array} \right),
\]

(1)

where \( S_1, S_2 \) are the mass eigen states of the scalar leptoquarks with electric charge 2/3 and \( c = \cos \theta, \ s = \sin \theta, \ \theta \) is the scalar leptoquark mixing angle.

In the case (1) the contributions \( S^{(LQ)}, T^{(LQ)}, U^{(LQ)} \) into \( S, T, U \) from the scalar leptoquark doublets can be obtained by simplifying the general expressions of ref. [11] and take the form

\[
S^{(LQ)} = \frac{n_c}{12\pi} \left\{ -Y_{SM}^+ \left[ c^2 \ln \frac{m_+^2}{m_1^2} + s^2 \ln \frac{m_+^2}{m_2^2} \right] - Y_{SM}^- \left[ s^2 \ln \frac{m_-^2}{m_1^2} + c^2 \ln \frac{m_-^2}{m_2^2} \right] + 4c^2 s^2 f_2(m_1, m_2) \right\},
\]

(2)

\[
T^{(LQ)} = \frac{n_c}{16\pi s_W^2 c_W m_Z^2} \left\{ c^2 \left[ f_1(m_+^2, m_1^2) + f_1(m_-^2, m_1^2) \right] + s^2 \left[ f_1(m_+^2, m_2^2) + f_1(m_-^2, m_2^2) \right] - 4c^2 s^2 f_1(m_1, m_2) \right\},
\]

(3)

\[
U^{(LQ)} = \frac{n_c}{12\pi} \left\{ c^2 \left[ f_2(m_+^2, m_1^2) + f_2(m_-^2, m_1^2) \right] + s^2 \left[ f_2(m_+^2, m_2^2) + f_2(m_-^2, m_2^2) \right] - 4c^2 s^2 f_2(m_1, m_2) \right\},
\]

(4)

where

\[
f_1(m_1, m_2) = \frac{m_1^2}{m_2^2} + \frac{m_2^2}{m_1^2} - \frac{2m_1^2 m_2^2}{m_1^2 - m_2^2} \ln \frac{m_1^2}{m_2^2},
\]

(5)

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

(6)

\( n_c = 3, \ Y^+_{SM} = 1 \pm 4/3, \ m_+ = m_{s_1^{(+)}} = m_{5/3}, \ m_- = m_{s_1^{(-)}} = m_{1/3}, \ m_{1,2} = m_{s_1,s_2} = m_{2/3,2/3'} \). Here indexes 5/3, 1/3, 2/3 of the masses denote the
electric charges of the corresponding scalar leptoquarks. Notice that the contributions $T^{(LQ)}$ and $U^{(LQ)}$ from the scalar leptoquark doublets are not positive definite due to the $S_1 - S_2$ mixing and can be negative if $m_+, m_-$ are between $m_1$ and $m_2$.

The scalar gluon doublets can be written as

$$F_j = \left( \frac{F_{1j}}{(\phi_{1j} + i\phi_{2j})/\sqrt{2}} \right),$$  \hspace{1cm} \text{(7)}$$

where the charged fields $F_{1j}$ and the neutral fields $\phi_{1j}, \phi_{2j}, j = 1, 2, ..., 8$ are the mass eigen state fields (in general case the real and imaginary parts $\phi_{1j}, \phi_{2j}$ of the down component of the doublet $F_j$ can be splitted in the mass). The scalar gluon doublets (7) give the contributions into $S, T, U$ of the form

$$S^{(F)} = -\frac{k_F}{24\pi} \left\{ \ln \frac{m_{F_1}^2}{m_{\phi_1}^2} + \ln \frac{m_{F_2}^2}{m_{\phi_2}^2} - f_2(m_{\phi_1}, m_{\phi_2}) \right\},$$  \hspace{1cm} \text{(8)}$$

$$T^{(F)} = \frac{k_F}{32\pi c_W^2 s_W^2 m_Z^2} \left\{ f_1(m_{F_1}, m_{\phi_1}) + f_1(m_{F_1}, m_{\phi_2}) - f_1(m_{\phi_1}, m_{\phi_2}) \right\},$$  \hspace{1cm} \text{(9)}$$

$$U^{(F)} = \frac{k_F}{24\pi} \left\{ f_2(m_{F_1}, m_{\phi_1}) + f_2(m_{F_1}, m_{\phi_2}) - f_2(m_{\phi_1}, m_{\phi_2}) \right\},$$  \hspace{1cm} \text{(10)}$$

where $k_F = 8$ and $f_1(m_1, m_2)$ and $f_2(m_1, m_2)$ are defined by eqs. (5), (6). The contributions $T^{(F)}$ and $U^{(F)}$ are not positive definite and they are negative if $m_{F_1}$ is between $m_{\phi_1}$ and $m_{\phi_2}$.

Let the masses of the scalar leptoquark and scalar gluon doublets are generated from the scalar potential of their interactions with the standard Higgs doublet by the Higgs mechanism of the symmetry breaking. In general case the terms of the scalar potential contributing into the scalar leptoquark and scalar gluon masses can be written as

$$V(\Phi^{(SM)}, S) = \sum_{+, -} \left[ m_{\pm}^0 (\hat{S}^{(\pm)} S^{(\pm)}) + \beta_{\pm} (\hat{\Phi}^{(SM)} \Phi^{(SM)}) (\hat{S}^{(\pm)} S^{(\pm)}) + \right]$$

$$\gamma_{\pm} (\hat{\Phi}^{(SM)} S^{(\pm)})(S^{(\pm)} \Phi^{(SM)}) \right\} + \left[ \delta_S (\hat{\Phi}^{(SM)} S^{(\pm)})(\hat{\Phi}^{(SM)} S^{(-)}) + h.c. \right],$$  \hspace{1cm} \text{(11)}$$

$$V(\Phi^{(SM)}, F) = m_F^0 \sum_j (\hat{F}_j F_j) + \beta_F (\hat{\Phi}^{(SM)} \Phi^{(SM)}) \sum_j (\hat{F}_j F_j) +$$

$$\gamma_F \sum_j (\hat{\Phi}^{(SM)} F_j)(\hat{\Phi}^{(SM)} F_j) \right\} + \left[ \delta_F \sum_j (\hat{\Phi}^{(SM)} F_j)(\hat{\Phi}^{(SM)} F_j) + h.c. \right],$$  \hspace{1cm} \text{(12)}$$
where $m_{F}^{(0)2}$ and $m_{S}^{(0)2}$ are the parameters of squared mass dimension and $\beta_{\pm}$, $\gamma_{\pm}$, $\delta_{S}$, $\beta_{F}$, $\gamma_{F}$, $\delta_{F}$ are the dimensionless coupling constants. After symmetry breaking the potentials \((11), (12)\) give the mass matrix of the down scalar leptoquarks $\left(S_{2}^{(+)}; \delta_{2}^{(-)}\right)$

\[
M = \begin{pmatrix}
M_{11} & M_{12} \\
M_{21} & M_{22}
\end{pmatrix} = \begin{pmatrix}
m_{+}^{2} + \gamma_{+}\eta^{2}/2 & \delta_{S}\eta^{2}/2 \\
\delta_{S}\eta^{2}/2 & m_{-}^{2} + \gamma_{-}\eta^{2}/2
\end{pmatrix}
\]

and the relations for the masses of the scalar gluons

\[
m_{\phi_{1}, \phi_{2}}^{2} = m_{F_{1}}^{2} + \gamma_{F}\eta^{2}/2 \pm \delta_{F}\eta^{2},
\]

where $\eta = \sqrt{\eta_{2}^{2} + \eta_{3}^{2}}$ is the Standard Model VEV.

For the case of real $\delta_{S}$ from the mass matrix \((13)\) we have the masses of the scalar leptoquarks with electric charge $2/3$ and mixing angle in the form

\[
m_{1,2}^{2} = M_{11,22} \pm \left[2M_{12}\cos\theta \sin\theta + (M_{11} - M_{22})\sin^{2}\theta\right],
\]

\[
\tan 2\theta = -2M_{12}/(M_{11} - M_{22}).
\]

For the stability of the vacuum the coupling constants in the scalar potential are supposed below to satisfy some conditions ensuring the positiveness of the total scalar potential

\[
V(\Phi^{(SM)}; S) + V(\Phi^{(SM)}; F) + \lambda_{SM}(\Phi^{(SM)}\Phi^{(SM)})^{2} + \sum_{\pm,} \lambda_{\pm}(S^{(\pm)}S^{(\pm)})^{2} + \lambda_{F}(\sum_{j}(F_{j}^{2})j)^{2} > 0.
\]

Below we regard the parameters

\[
m_{1}, m_{2}, m_{\phi_{2}}, \gamma_{+}, \gamma_{-}, \delta_{S}, \gamma_{F}, \delta_{F}
\]

as the fitting parameters and find the masses $m_{+}, m_{-}, m_{\phi_{1}}, m_{F_{1}}$ and the mixing angle from \((13) - (16)\) and then calculate the contributions \((2) - (4), (8) - (10)\) of the scalar doublets into $S, T, U$. Notice that for validity of the perturbation theory the coupling constants in the potentials \((11), (12), (17)\) cannot be too large and this circumstance bounds the allowed region of the fitting masses and mixing angle in the formulas \((2) - (4), (8) - (10)\). We
suppose below that all the coupling constants in (11), (12), (17) do not exceed some maximal value $\lambda_{\text{max}}$ ensuring the validity of perturbation theory. In the further numerical analysis we restrict ourselves by the values of $\lambda_{\text{max}}$ from the region $\lambda_{\text{max}} = 1.0 - 4.0$ which give the reasonable values of the perturbation theory expansion parameter of order $\lambda_{\text{max}}/4\pi = 0.1 - 0.3$.

We have carried out the numerical analysis of the contributions (2) - (4), (8) - (10) using the current experimental values of $S$, $T$, $U$ induced by a new physics [13, 14]

\begin{align*}
S_{\text{exp}}^{\text{new}} &= -0.03 \pm 0.11 (-0.08), \\
T_{\text{exp}}^{\text{new}} &= -0.02 \pm 0.13 (+0.09), \\
U_{\text{exp}}^{\text{new}} &= 0.24 \pm 0.13 (+0.01),
\end{align*}

where the central values assume $m_H = 115$ GeV and the change for $m_H = 300$ GeV is shown in parentheses.

Varying the fitting parameters (18) we minimize $\chi^2$ defined as

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

where $S = S^{(LQ)} + S^{(F)}$, $T = T^{(LQ)} + T^{(F)}$, $U = U^{(LQ)} + U^{(F)}$ and $S^{(LQ)}$, $T^{(LQ)}$, $U^{(LQ)}$ and $S^{(F)}$, $T^{(F)}$, $U^{(F)}$ are the contributions (2) - (4) and (8) - (10). $\Delta S, \Delta T, \Delta U$ are the experimental errors in (19).

To clear up the possible effect of the scalar leptoquark and scalar gluon doublets on $S$, $T$, $U$ we vary the masses of these particles so that

\[
m_1, m_2, m_{\pm}, m_{F_1}, m_{\phi_1}, m_{\phi_2} \geq m_{\text{lower scalar}},
\] (20)

where $m_{\text{lower scalar}}$ is a lower limit on the masses of these particles. After minimization of $\chi^2$ under condition (20) we have analysed the dependence of $\chi^2_{\text{min}}$ on this lower limit $m_{\text{lower scalar}}$ and on upper limit $\lambda_{\text{max}}$ on the coupling constants of the scalar potential.

The Fig.1 and Fig.2 show $\chi^2_{\text{min}}(m_{\text{lower scalar}}, \lambda_{\text{max}})$ as a function of the lower limit $m_{\text{lower scalar}}$ for $m_H = 115$ GeV and for $m_H = 300$ GeV respectively by the curves $a(b)$ for $\lambda_{\text{max}} = 1.0(4.0)$ for the case without scalar leptoquark mixing ($\theta = 0$, this case is slightly preferred by $\chi^2$ minimum ). The horizontal lines denote $\chi^2_{SM} = 3.5$ and $\chi^2_{SM} = 5.0$ of the compatibility of the SM zero values of $S$, $T$, $U$ with the experimental data [13] at $m_H = 115$ GeV and $m_H = 300$ GeV respectively.
As seen from the Figs. 1, 2 the lower limit $m_{\text{scalar}}^{\text{lower}}$ on the masses of the scalar leptoguarks and of the scalar gluons is allowed by data (19) to vary within wide limits from high values when the contributions from these particles into $S, T, U$ are negligibly small to values of order of 1 TeV or less. It is interesting that in both cases the more light particles agree with the data (19) even slightly better than in the SM. For $m_H = 115$ GeV (Fig. 1) such slight improvement of the agreement takes place for $m_{\text{scalar}}^{\text{lower}} < 400$ GeV whereas in the case of $m_H = 300$ GeV (Fig. 2) such improvement is seen in all the region of the lightest masses of order of 1 TeV or less and it is more appreciable also for $m_{\text{scalar}}^{\text{lower}} < 400$ GeV. In particular the scalar leptoguarks with the lightest masses of order of $m_{\text{scalar}}^{\text{lower}} < 300$ GeV (and for $\lambda_{\text{max}} = 4.0$) are compatible with the data (19) at $\chi^2 < 3.1(3.2)$ for $m_H = 115(300)$ GeV in comparison with $\chi^2_{\text{SM}} = 3.5(5.0)$ in the SM. The mass of the lightest scalar gluon in this case is expected to be $m_{\phi_2} < 850(720)$ GeV.

The slight improvement for $400$ GeV $\leq m_{\text{scalar}}^{\text{lower}} \leq 1$ TeV is caused by the sufficient contributions which are given by the scalar leptoquark and scalar gluon doublets into $S$ and $T$, the contributions into $U$ in this case are negligibly small. For the more light particles ($m_{\text{scalar}}^{\text{lower}} < 400$ GeV) the light scalar leptoquark doublets give the more noticeable contribution into $U$ with the simultaneous cancellation of their relatively large contributions into $S$ and $T$ with those from the scalar gluon doublets. As a result the more appreciable agreement with the data (19) is achieved.

For example the scalar leptoquarks and gluons with the masses

\[ m_{5/3} = 330 \text{ GeV}, \; m_{1/3} = 430 \text{ GeV}, \; m_{F_1} = 850 \text{ GeV}, \]
\[ m_{2/3} = 250 \text{ GeV}, \; m_{2/3}^{\prime} = 250 \text{ GeV}, \; m_{\phi_1} = 1040 \text{ GeV}, \; m_{\phi_2} = 770 \text{ GeV}, \;
\]

give the contributions

\[
S^{(\text{LQ})} = -0.07, \; T^{(\text{LQ})} = 2.03, \; U^{(\text{LQ})} = 0.02, \\
S^{(F)} = 0.03, \; T^{(F)} = -2.05, \; U^{(F)} = -3 \cdot 10^{-3}, \\
S = -0.04, \; T = -0.02, \; U = 0.02,
\]

which agree with (19) for $m_H = 115$ GeV with $\chi^2 = 2.9$ (in comparison with $\chi^2 = 3.5$ of the SM).

In a similar way for the masses

\[ m_{5/3} = 430 \text{ GeV}, \; m_{1/3} = 430 \text{ GeV}, \; m_{F_1} = 650 \text{ GeV}, \]
\[ m_{2/3} = 250 \text{ GeV}, \; m_{2/3}^{\prime} = 250 \text{ GeV}, \; m_{\phi_1} = 890 \text{ GeV}, \; m_{\phi_2} = 550 \text{ GeV}, \]

(22)
we obtain the contributions

\[
\begin{align*}
S^{(LQ)} &= -0.17, & T^{(LQ)} &= 3.39, & U^{(LQ)} &= 0.04, \\
S^{(F)} &= 0.05, & T^{(F)} &= -3.32, & U^{(F)} &= -0.01, \\
S &= -0.12, & T &= 0.07, & U &= 0.03,
\end{align*}
\]

which agree with the data \((19)\) for \(m_H = 300 \, GeV\) with \(\chi^2 = 2.9\) (in comparison with \(\chi^2 = 5.0\) of the SM).

The lightest scalar leptoquark masses in \((21), (22)\) are compatible with the experimental limits resulting from the direct search for the leptoquarks. The most stringent of these limits are resulted from the pair production and for the scalar leptoquarks of the first generation they give \([14]\)

\[
m_{LQ} > 225 \, GeV, \ 204 \, GeV, \ 79 \, GeV
\]

(23)

under assuming the branching ratios \(B(eq) = 1, \ 0.5, \ 0\) respectively.

It should be noted that in the model under consideration the coupling constants of the scalar leptoquark doublets with the fermions ( and those of the scalar gluon doublets ) are proportional to the ratios of the fermion masses to the SM VEV \(\eta = 246 \, GeV\) ( the general form of this interaction can be found in ref. \([15]\) ) and for ordinary quarks these coupling constants are small. The dominant decay modes of such leptoquarks are the modes with heavy quarks ( predominantly with t-quark ) whereas the branching ratio for the first generation is small \(0 < B(eq) \ll 0.5\). So the lower experimental limit on the masses of such scalar leptoquarks can be near the lowest value in \((23)\), the masses \(m_{1/3}, \ m_{5/3}\) of the other scalar leptoquarks are in this case compatible with other experimental limits ( including those for the second and for the third generations ) resulting from the direct search for leptoquarks.

It should be noted also that the light scalar leptoquarks can be also compatible with the indirect leptoquark mass limits resulting from the rare decays of \(K^0_L \rightarrow \mu e\) type. Due to the smallness of the coupling constants of the scalar leptoquark interaction with d- and s- quarks the contributions of the scalar leptoquarks into \(K^0_L \rightarrow \mu e\) width can be sufficiently small to satisfy the stringent experimental limit \(Br(K^0_L \rightarrow \mu e) < 4.7 \cdot 10^{-12}\) \([14]\) on the branching ratio of this decay, even for the relatively light masses of the scalar leptoquarks.

Thus, the current direct and indirect mass limits for leptoquarks do not exclude the relative light scalar leptoquark doublets considered here
whereas the experimental data on $S, T, U$ not only allow the existence of such particles but even slightly prefer them to have the masses of order of $m_{\text{scalar}}^{\text{lower}} < 400 \text{ GeV}$. The search for such scalar leptoquarks and scalar gluons in the processes with heavy quarks (predominantly with t-quark) at LHC is of interest.

It should be noted that the presence of the so light new particles can also affect the new physics at high energies. In particular these particles can affect the gauge coupling constant unification in GUT approaches. As known the SM without any new physics up to the GUT mass scale $M_{\text{GUT}}$ ("grand desert") do not unify three coupling constants at any mass scale. But such a unification can be possible if an intermediate new physics below $M_{\text{GUT}}$ (such as the four color symmetry physics with mass scale $M_c$) is assumed. For example in the model under consideration in the case of the scalar sector containing, for simplicity, only the standard Higgs doublet and the $(4,1,1)$ multiplet with VEV $\eta_1 \sim M_c \sim 10^{11} \div 10^{12} \text{ GeV}$ all three coupling constants do converge in one point at $M_{\text{GUT}} \sim 10^{14} \div 10^{15} \text{ GeV}$ with $\alpha_3(M_{\text{GUT}}) = \alpha_2(M_{\text{GUT}}) = \alpha_1(M_{\text{GUT}}) \equiv \alpha_{\text{GUT}} \sim 0.023$. The account of the scalar leptoquark and scalar gluon doublets gives the additional contributions $\Delta b_3 = 8/3, \Delta b_2 = 7/3, \Delta b_1 = 37/15$ into the factors $b_i$ which define the mass scale evolution of the running coupling constants $\alpha_i(\mu)$ through the beta functions $\beta_i$ of the one loop approximation, $i = 3, 2, 1$. These contributions together with the SM factors $b_3^{\text{SM}} = -7, b_2^{\text{SM}} = -19/6, b_1^{\text{SM}} = 41/10$ and with the corresponding contributions (for $M_c < \mu < M_{\text{GUT}}$) from the $(4,1,1)$ scalar and from the vector leptoquarks determine the mass scale evolution of $\alpha_i(\mu)$ from $\mu \sim 1 \text{ TeV}$ to $\mu \sim M_{\text{GUT}}$. The analysys shows that in this case all three coupling constants $\alpha_i(\mu)$ do also converge in one point if $M_c \sim 10^{10} \div 10^{11} \text{ GeV}$ and $M_{\text{GUT}} \sim 10^{14} \div 10^{15} \text{ GeV}$ with $\alpha_{\text{GUT}} \sim 0.029$. As seen the presence of the relatively light scalar leptoquark and scalar gluon doublets (with masses below 1 TeV) lowers the four color symmetry mass scale $M_c$ and increases the value of the unified coupling constant $\alpha_{\text{GUT}}$, leaving the GUT mass scale $M_{\text{GUT}}$ practically unchanged.

As mentioned above the scalar multiplets $(1,2,1,)$ and $(15,2,1)$ were introduced to give the Dirac masses to the fermions and to split the masses of the quarks from those of the leptons by the Higgs mechanism. The general form of Yukawa interaction of these doublets with the fermions makes the fermion masses to be arbitrary as they are in the SM. The lightness of neutrinos can be ensured by the smallness of their Dirac masses due to the smallness of the corresponding Yukawa coupling constants or, more naturally, by the
smallness of their Majorana masses due to the seesaw mechanism. In the latter case the necessary large Majorana mass term of the right neutrinos can be generated by the interaction of the right fermions with an additional $(10, 1, -2)$ scalar multiplet with the large VEV of order of $M_c$.

In conclusion we resume the results of the work.

The contributions into radiative correction $S$-, $T$-, $U$- parameters from the scalar leptoquark and scalar gluon doublets are investigated in the minimal model with the four color symmetry, accounting the Higgs mechanism of generating the masses of these particles. It is shown that the current experimental data on $S$, $T$, $U$ allow the existence of the relatively light scalar leptoquarks and scalar gluons (with masses of order of 1 TeV or less), the more light particles (with masses below 400 GeV) are preferred and agree with these data better than in the Standard Model.

In particular the scalar leptoquarks with the masses of order of $m_{\text{lower}}^{\text{scalar}} < 300 \text{ GeV}$ are shown to be compatible with current data on $S$, $T$, $U$ for $m_H = 115(300) \text{ GeV}$ with $\chi^2 < 3.1(3.2)$ (in comparison with $\chi^2 = 3.5(5.0)$ of the SM). The lightest scalar gluon in this case is expected to lie below 850(720) GeV.

We emphasize the possible significance of such particles in the top-quark physics at LHC.

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References

[1] J.C. Pati and A. Salam, Phys. Rev. D10 (1974) 275.

[2] A.D. Smirnov, Phys. Lett. B346 (1995) 297.

[3] A.D. Smirnov, Yad. Fiz. 58 (1995) 2252, Phys. At. Nucl. 58 (1995) 2137.

[4] R. Foot, Phys. Lett. B420 (1998) 333.

[5] R. Foot, G. Filewood, Phys. Rev. D60 (1999) 115002.

[6] T.L. Yoon, R. Foot, hep-ph/0105101, Phys. Rev. D65 (2002) 015002.

[7] A. Blumhofer, B. Lampe, Eur. Phys. J. C7 (1999), 141.

[8] W. Buchmüller, R. Rückl, D. Wyler, Phys. Lett. B191 (1987) 442.

[9] J.L. Hewett, T.G. Rizzo, Phys. Rev. D56 (1997) 5709.

[10] M.E. Peskin and T. Takeuchi, Phys. Rev. D46 (1992) 381.

[11] A.D. Smirnov, Phys. Lett. B431 (1998) 119.

[12] A.D. Smirnov, Yad. Fiz. 64 (2001) 367, Phys. At. Nucl. 64 (2001) 318.

[13] P.Langacker, hep-ph/0110129.

[14] Particle Data Group, D.E. Groom et al., Eur. Phys. J. C15 (2000), 1 and 2001 partial update for edition 2002 (URL http://pdg.lbl.gov).

[15] A.V. Povarov, A.D. Smirnov, Yad. Fiz. 64 (2001) 78, Phys. At. Nucl. 64 (2001) 74.
Figure captions

Fig. 1. $\chi^2_{\text{min}}(m_{\text{scalar}}^{\text{lower}}, \lambda_{\text{max}})$ as a function of the lower limit $m_{\text{scalar}}^{\text{lower}}$ on the masses of the scalar particles for $m_H = 115 \text{ GeV}$ at $\lambda_{\text{max}} = 1.0(a)$ and $\lambda_{\text{max}} = 4.0(b)$.

Fig. 2. $\chi^2_{\text{min}}(m_{\text{scalar}}^{\text{lower}}, \lambda_{\text{max}})$ as a function of the lower limit $m_{\text{scalar}}^{\text{lower}}$ on the masses of the scalar particles for $m_H = 300 \text{ GeV}$ at $\lambda_{\text{max}} = 1.0(a)$ and $\lambda_{\text{max}} = 4.0(b)$. 
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Fig. 1
