Bounds on scalar leptoquark masses from $S, T, U$ parameters in the minimal four-color quark-lepton symmetry model

A.D. Smirnov*

Division of Theoretical Physics, Department of Physics,
Yaroslavl State University, Sovietskaya 14,
150000 Yaroslavl, Russia.

Abstract

The contributions into radiative correction parameters $S, T, U$ from the scalar leptoquarks are calculated in the minimal gauge model with the four-color quark-lepton symmetry. It is shown that the contributions into $T$ and $U$ from the scalar leptoquark doublets are not positive definite. Using the current experimental data on $S, T, U$ the bounds on the scalar leptoquark masses are obtained. In particular, the existence of the relatively light scalar leptoquark with electric charge $2/3$ is shown to be compatible with the current experimental data on $S, T, U$.

*E-mail: asmirnov@univ.uniyar.ac.ru
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 possible variants of the new physics beyond the SM can turn out to be the variant induced by the possible four-color symmetry\cite{1} between quarks and leptons. The investigation of the possible manifestations of this symmetry at attainable energies is of a certain interest now.

The main feature of the four-color gauge symmetry is the prediction of the vector leptoquarks the masses of which are expected to be of about the mass scale $M_c$ of the four-color symmetry breaking. There are many models dealing with the four-color gauge symmetry now. Some of them are induced by the grand unification ideas and regard the four-color symmetry as an intermediate stage of the symmetry breaking. The mass scale $M_c$ in these models is usually very high. For instance, in $SO(10)$ model it is of about $M_c \sim 10^{12}\, GeV$\cite{2}, but it can be essentially lowered up to $M_c \sim 10^5 - 10^6\, GeV$ by appropriate scheme of the symmetry breaking\cite{3}. The other models\cite{4, 5, 6, 7, 8} regard the four-color symmetry as a primary symmetry with the mass scale $M_c$ determined mainly by the low energy experimental data. At such approach the lower limit on $M_c$ can be about $1000\, TeV$\cite{4} or about $100\, TeV$ or slightly less\cite{5, 6} or even can be lowered up to $1\, TeV$ by the appropriate arrangement of the fermions in the SU(4)-multiplets\cite{7, 8}.

It should be noted that the four-color symmetry can manifest itself not only by the vector leptoquark physics but also due to the scalar leptoquarks. Because of their $SU(2)-$doublet structure the scalar leptoquarks can manifest themselves in the oblique radiative corrections, in particular, affecting the $S, T, U$ parameters of Peskin and Takeuchi\cite{9}. It is interesting to know the effect of the scalar leptoquarks on $S, T, U$ in some simple gauge model predicting these particles.

In this work the contributions into $S, T, U$ parameters from the scalar leptoquarks are calculated using the minimal quark-lepton symmetry model (MQLS-model)\cite{4} as a minimal extension of the SM containing the four-color quark-lepton symmetry. Taking the current experimental values of $S, T, U$ into account the bounds on scalar leptoquark masses are obtained and discussed.

The MQLS-model to be used here is based on the $SU_V(4) \times SU_L(2) \times U_R(1)$-group and predicts the new gauge particles (vector leptoquarks $V_{\alpha \mu}^\pm$ with electric charge $\pm 2/3$ and an extra neutral $Z'$-boson) as well as the new
The scalar sector of the model contains in general the four multiplets

\[
(4, 1, 1) : \Phi^{(1)} = \left( \begin{array}{c} S_a^{(1)} \\ \eta_1 + \chi^{(1)} + i\omega^{(1)} \end{array} \right),
\]

\[
(1, 2, 1) : \Phi_a^{(2)} = \delta_a \frac{\eta_2}{\sqrt{2}} + \phi_a^{(2)},
\]

\[
(15, 2, 1) : \Phi_a^{(3)} = \left( \begin{array}{c} (F_a)_{a\beta} S_{a\alpha}^{(+)} \\ S_{a\alpha}^{(-)} \end{array} \right) + \Phi_{15,a} t_{15},
\]

\[
(15, 1, 0) : \Phi^{(4)} = \left( \begin{array}{c} F_{\alpha\beta}^{(4)} \frac{1}{\sqrt{2}} S_{a}^{(4)} \\ S_{a}^{(4)} \end{array} \right) + (\eta_4 + \chi^{(4)}) t_{15},
\]

transforming according to the \((4,1,1)-(1,2,1)-(15,2,1)-(15,1,0)-\) representations of the \(SU_V(4) \times SU_L(2) \times U_R(1)\)-group respectively. Here \(\Phi_{15,a}^{(3)} = \delta a_2 \eta_3 + \phi_{15,a}^{(3)}\), \(\eta_1, \eta_2, \eta_3, \eta_4\) are the vacuum expectation values, \(t_{15}\) is the 15-th generator of \(SU_V(4)\)-group, \(a = 1, 2\) is the \(SU_L(2)\) index and \(\alpha, \beta = 1, 2, 3\) are the \(SU_c(3)\) color indexes.

As regards the \(S, T, U\) parameters the most interesting of these multiplets is the multiplet \(\Phi^{(3)}\) which has been introduced to split the masses of quarks and leptons. This multiplet contains fifteen doublets which can be arranged into two scalar leptoquark doublets \(S_a^{(+)}\) and \(S_a^{(-)}\) with the SM hypercharge \(Y^{(SM)} = 7/3\) and \(-1/3\) respectively, eight scalar gluon doublets \(F_{ja}, j=1,2,...,8\) with \(Y^{(SM)} = 1\) and the doublet \(\Phi_{15,a}^{(3)}\) which in admixture with \(\Phi_a^{(2)}\) gives the SM doublet

\[
\Phi^{(SM)} = \left( \begin{array}{c} \Phi_1^{(SM)} \\ \eta + \chi^{(1)} + i\omega_1 \end{array} \right)
\]

with SM VEV \(\eta = \sqrt{\eta_2^2 + \eta_3^2} = (\sqrt{2}G_F)^{-\frac{1}{2}} \approx 250 \text{ GeV}\) and an additional scalar doublet \(\Phi'\).

All these scalar doublets contribute into \(S, T, U\) parameters. We have calculated these contributions neglecting the effect of the small \(Z-Z'\)-mixing.

The contributions into \(S, T, U\) from the doublets \(\Phi_a^{(2)}\) and \(F_{ja}\) have the usual form of those from a single scalar doublet \(\Phi\) and can be written as

\[
S^{(\Phi)} = -k_{\Phi} \frac{Y^{SM}}{12\pi} \ln \frac{m_1^2}{m_2^2}, \tag{1}
\]
\[ T(\Phi) = k_\Phi \frac{1}{16\pi c_W^2 s_W^2 m_Z^2} f_1(m_1, m_2), \]  
\[ U(\Phi) = k_\Phi \frac{1}{12\pi} f_2(m_1, m_2), \]

where

\[ f_1(m_1, m_2) = m_1^2 + m_2^2 - \frac{2m_1^2 m_2^2}{m_1^2 - m_2^2} \ln \frac{m_1^2}{m_2^2}, \]  
\[ f_2(m_1, m_2) = -\frac{5m_1^4 + 5m_2^4 - 22m_1^2 m_2^2}{3(m_1^2 - m_2^2)^2} \]  
\[ + \frac{m_1^6 - 3m_1^4 m_2^2 - 3m_1^2 m_2^4 + m_2^6 \ln \frac{m_1^2}{m_2^2}}{(m_1^2 - m_2^2)^3} \]

and \( m_1, m_2 \) are the masses of the up and down components of the doublet \( \Phi \). Here \( k_{\Phi'} = 1, \ m_a = m_{\Phi'_a} \) and \( k_F = 8, \ m_a = m_{F_a} \) for multiplets \( \Phi' \) and \( F \) respectively.

The contributions into \( S, T, U \) from the scalar leptoquarks are more complicated mainly owing to the existence of the Goldstone mode \( S_0 \) among the scalar leptoquark fields. Indeed, in addition to the SM Goldstone modes \( \Phi_1^{(SM)} \) and \( \omega_1 \) the model has the Goldstone modes \( \omega^{(2)} \) and

\[ S_0 = \left[ \frac{\eta_1}{2} S^{(1)} + \sqrt{\frac{2}{3}} \left( \eta_3 S_2^{(+)} + \eta_4 S_2^{(-)} \right) / \sqrt{2} + \eta_4 S^{(4)} \right] / \sqrt{\frac{\eta_1^2}{4} + \frac{2}{3} (\eta_3^2 + \eta_4^2)} . \]

Because the Goldstone field \( S_0 \) is constructed from the fields \( S^{(1)}, S_2^{(+)} \), \( S_2^{(-)} \), \( S^{(4)} \) with electric charge 2/3 the mixing between these fields is required and they must be expressed as the superpositions of \( S_0 \) and of the orthogonal to it the mass eigenstate leptoquark fields \( S_1, S_2, S_3 \). In general these superpositions can be written as

\[ S_2^{(+)} = \sum_k C_k^{(+)} S_k, \quad S_2^{(-)} = \sum_k C_k^{(-)} S_k, \]  
\[ S^{(1)} = \sum_k C_k^{(1)} S_k, \quad S^{(4)} = \sum_k C_k^{(4)} S_k, \]

where \( C_k^{(\pm)}, C_k^{(1)}, C_k^{(4)} \) are the elements of a unitary mixing matrix, \( k = 0, 1, 2, 3 \).
In the unitary gauge the Goldstone fields are eliminated

$$\Phi^{(S)}_1 = 0, \omega_1 = 0, \omega^{(1)}_1 = 0, S_0 = 0$$

and the physical scalar leptoquarks contributing into $S, T, U$ are two colored triplets of up scalar leptoquarks $S^{(+, -)}_{1a}, S^{(-)}_{1a}$ with electric charge $5/3$ and $1/3$ respectively and three scalar leptoquarks $S_{ka}, k = 1, 2, 3$ with electric charge $2/3$. The contribution into $S, T, U$ from the SM Higgs particle is the usual form and the other scalar fields $\chi^{(1)}, \chi^{(4)}$ and $F_j^{(4)}, j = 1, 2, ...8$ as well as the new gauge fields $Z'$ and $V^{(\pm)}_1$ do not contribute into $S, T, U$.

The self energy diagrams contributing into $S, T, U$ from the leptoquarks are shown in Fig.1. The coupling constants $g_{XsS}, g_{XS_{1}^{(\pm)}S_{1}^{(\pm)}}, g_{WS_{1}^{(\pm)}S_{k}}, g_{XV_{s}}, g_{WV_{S_{1}^{(\pm)}}}$ ($X$ is the photon $A$ and $Z$-boson) are defined by the model and depend on the gauge coupling constants and on the matrix elements of the mixing matrix with $g_{ZV_{s}}, g_{WV_{S_{1}^{(\pm)}}}$ depending also on the VEV $\eta_3$ ($g_{AV_{S_{k}}} = 0$ in the unitary gauge).

We have calculated the contributions $S^{(LQ)}$, $T^{(LQ)}$, $U^{(LQ)}$ into $S$, $T$, $U$-parameters from the leptoquarks. The result can be presented in the form

$$S^{(LQ)} = \frac{n_c}{12\pi} \left\{ -\sum_{k} \left[ C_{k}^{(\pm)} \right] Y_{SM}^{2} \ln \frac{m^{2}_{k}}{m^{2}_{V}} + \frac{1}{2} \sum_{k} \sum_{l} B_{kl} f_{2}(m_{k}, m_{l}) \right\}$$

$$+ \xi^{2} \left[ \sum_{k} \left| C_{k} \right|^{2} \left( -12 \frac{m^{2}_{V} f_{1}(m_{k}, m_{V})}{(m^{2}_{k} - m^{2}_{V})^{2}} + f_{2}(m_{V}, m_{k}) \right) + \frac{1}{2} \sum_{k} \sum_{l} \ln \frac{m^{2}_{k}}{m^{2}_{l}} - \frac{2}{3} \ln \frac{m^{2}_{k}}{m^{2}_{l}} \right]$$

$$T^{(LQ)} = \frac{n_c}{16\pi s^{2}_{w} c^{2}_{w} m^{2}_{Z}} \left\{ \sum_{k} \sum_{l} \left| C_{k}^{(\pm)} \right|^{2} f_{1}(m_{k}, m_{l}) - \frac{1}{2} \sum_{k} \sum_{l} B_{kl} f_{1}(m_{k}, m_{l}) \right\}$$

$$+ \xi^{2} \sum_{k} \sum_{l} \left| C_{2k} \right|^{2} \left[ \frac{1}{2} \left( f_{1}(m_{k}, m_{V}) - f_{1}(m_{k}, m_{l}) \right) + 4m^{2}_{V} f_{3}(m_{k}, m_{l}) \right]$$

$$U^{(LQ)} = \frac{n_c}{12\pi} \left\{ \sum_{k} \sum_{l} \left| C_{k}^{(\pm)} \right|^{2} f_{2}(m_{k}, m_{l}) - \frac{1}{2} \sum_{k} \sum_{l} B_{kl} f_{2}(m_{k}, m_{l}) \right\}$$

$$+ \xi^{2} \sum_{k} \sum_{l} \left| C_{2k} \right|^{2} \left[ \frac{1}{2} \left( f_{2}(m_{k}, m_{V}) - f_{2}(m_{k}, m_{l}) \right) \right]$$

$$- 6m^{2}_{V} \left( \frac{f_{1}(m_{k}, m_{V}) - f_{1}(m_{k}, m_{l})}{(m^{2}_{k} - m^{2}_{V})^{2}} \right)$$

}
where $f_1(m_1, m_2), f_2(m_1, m_2)$ are defined by eqs.(4,5) and 

$$f_3(m_1, m_2; m_V) = \frac{m_1^2 m_2^2 \ln(m_1^2/m_2^2) + m_V^2 (-m_1^2 \ln(m_1^2/m_2^2) + m_2^2 \ln(m_2^2/m_V^2))}{(m_1^2 - m_V^2)(m_2^2 - m_V^2)}.$$ 

Here

$$B_{kl} = |C_k^{(+)} C_l^{(+)} - C_k^{(-)} C_l^{(-)}|^2, C_k^{(\pm)} = \frac{1}{\sqrt{2}}(\sqrt{1 - \xi^2} C_{1k} \pm C_{2k}), k, l = 1, 2, 3$$

$$\xi^2 = \frac{2}{3} \eta_3^2/(\eta_1^2/4 + 2/3(\eta_3^2 + \eta_4^2)) = \frac{2}{3} g_4^2 \eta_3^2/m_V^2,$$

$Y_{SM}^{\pm} = 1 \pm 4/3, n_c = 3, m_k = m_{S_k}, m_{\pm} = m_{S_{\pm}}, g_4$ is the $SU_V(4)$ - coupling constant. $C_{1k}, C_{2k}$ are two unit mutually orthogonal complex vectors. In general, the vectors $C_{1k}, C_{2k}$ can be parametrized by means of three mixing angles and three phases, for example, as

$$C_{1k} = \left\{ c_{13} c_{12}, c_{13} s_{12} e^{i\delta_{12}}, s_{13} e^{i\delta_{13}} \right\},$$

$$C_{2k} = \left\{ -c_{23} s_{12} e^{-i\delta_{12}} - s_{23} s_{13} c_{12} e^{i(-\delta_{13} + \delta_{23})},
-c_{23} s_{12} e^{i(-\delta_{13} - \delta_{12} + \delta_{23})}, s_{23} c_{13} e^{i\delta_{23}} \right\},$$

where $c_{ij} = \cos \theta_{ij}, s_{ij} = \sin \theta_{ij}, \theta_{ij}, \delta_{ij}$ are the mixing angles and phases.

The contributions (8)-(9) into $S, T, U$ from the scalar leptoquarks differ essentially from those arising from ordinary scalar doublets and having the form (1)-(3). Firstly, the contributions (8), (9) from the scalar leptoquarks into $T$ and $U$ are not positive definite due to the mixing between the scalar leptoquarks with electric charge $2/3$. The mixing of the components of two scalar doublets as a possible mechanism for obtaining the negative $T$ and $U$ was pointed out in Ref.[10]. But in our case the $S_1 - S_2 - S_3$ -mixing is caused by the presence of Goldstone mode in the scalar leptoquark sector and this mixing is an intrinsic feature of the model. Our results (8)-(9) differ from those of Ref.[10] due to the account of the Goldstone mode and due to the more general form of the scalar leptoquark mixing.

Secondly, in the case of the degenerated scalar leptoquark masses $m_k = m_+ = m_- \equiv m_S$ the expressions (8)-(9) give

$$S^{(LQ)} = \frac{n_c \xi^2}{12\pi} \left[ -12 m_V^2 \frac{f_1(m_S, m_V)}{(m_S^2 - m_V^2)^2} + f_2(m_S, m_V) + \ln \frac{m_V^2}{m_S^2} \right] \quad (10)$$

6
and

\[ T^{(LQ)} = 0, U^{(LQ)} = 0, \]

whereas the contributions of type (1)-(3) into \( S, T, U \) from the ordinary scalar doublets in the case of all degenerated masses are equal to zero. It should be noted, however, that the contribution (10) is small because of the smallness of the parameter \( \xi \). In the particular cases of \( m_S \gg m_V, m_S = m_V, \) and \( m_S \ll m_V \) the contribution (10) takes the values \( S^{(LQ)} = -5n_c\xi^2/36\pi, S^{(LQ)} = -n_c\xi^2/3\pi \) and \( S^{(LQ)} = -(n_c\xi^2/12\pi)(41/3 + 2\ln(m_V^2/m_S^2)) \) respectively.

The splitting of the scalar leptoquark masses varies the situation essentially. Because the scalar leptoquark masses are defined by Yukawa coupling constants and by the VEV’s including the large VEV’s \( \eta_1 \) and \( \eta_4 \) their splitting can be rather large giving the possibility for \( S \) and \( T \) to take the large values, positive or negative in dependence on the mass splitting and the mixing parameters.

We have carried out the numerical analysis of the contributions (7)-(9) and (1)-(3) using the responsible for a new physics experimental values of \( S_{\text{exp}}^{\text{new}}, T_{\text{exp}}^{\text{new}}, U_{\text{exp}}^{\text{new}} \)

\[ S_{\text{exp}}^{\text{new}} = -0.28 \pm 0.19, T_{\text{exp}}^{\text{new}} = -0.20 \pm 0.26, U_{\text{exp}}^{\text{new}} = -0.31 \pm 0.54 \quad (11) \]

by minimizing \( \chi^2 \) 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 \( S, T, U \) are the leptoquark contributions (1)-(3) or the sum of the contributions (7)-(9) and (1)-(3) and \( \Delta S, \Delta T, \Delta U \) are the experimental errors in (11).

In following, we assume for simplicity that the fields \( S_2^{(+)} \) and \( S_2^{(-)} \) in (7) contain (in addition to the Goldstone mode \( S_0 \)) only two physical fields \( S_1 \) and \( S_2 \), that is, we assume that \( \theta_{13} = \theta_{23} = 0 \). In this case the contributions (7)-(9) depend on the vector leptoquark mass \( m_V \), parameter \( \xi \) and on the four scalar leptoquark masses \( m_+ = m_{5/3}, m_- = m_{1/3}, m_1 = m_{2/3}, m_2 = m_{2/3}' \) and one mixing angle \( \theta_{12} \). Here indexes 5/3, 1/3, 2/3 of the mass denote the electric charges of the corresponding scalar leptoquarks.

The dependence of \( S^{(LQ)}, T^{(LQ)}, U^{(LQ)} \) on the large \( m_V \) (of order of hundreds TeV) is slight because of the smallness of the parameter \( \xi \). For definiteness we assume further that \( m_V \sim 100 \text{ TeV} \) and \( \xi \sim 10^{-4} \). The numerical
analysis of the contributions (7)-(9) by minimizing $\chi^2$ at these values of $m_V$ and $\xi$ shows that, firstly, $S^{(LQ)}, T^{(LQ)}, U^{(LQ)}$ and $\chi^2$ depend on the ratios of scalar leptoquark masses and, secondly, the value of the mixing angle $\theta_{12} = 0$ is favored. $\chi^2_{\text{min}}$ as a functions of each of the independent mass ratios $\mu_{2/3} = m_{2/3}/m_{5/3}$, $\mu_{1/3} = m_{1/3}/m_{5/3}$ and $\mu'_{2/3} = m'_{2/3}/m_{5/3}$ in the case of degenerated doublets $\Phi'$ and $F_j$ are shown in Fig.2 at $\theta_{12} = 0$. Here we denote by $\chi^2_{\text{min}}(\mu)$ the minimal value of $\chi^2$ obtained at fixed value $\mu$ of one of the mass ratios by minimizing $\chi^2$ over two other mass ratios.

It is seen from Fig.2 that experimental values (11) favor one scalar leptoquark $S_1$ with electric charge 2/3 to be the lightest one the scalar leptoquark $S_1^{(-)}$ with electric charge 1/3 to be slightly heavier whereas the other scalar leptoquarks $S_2$ and $S_1^{(+)}$ with electric charges 2/3 and 5/3 respectively to be the heaviest ones.

The Fig.3 shows the regions in the plane of the lightest masses $\mu_{2/3}$ and $\mu_{1/3}$ compatible with the data (11) at 95% CL and 90% CL (the inner regions bounded by the solid and bold lines respectively).

It is interesting to note that the scalar leptoquarks improve the agreement of the experimental values (11) with the theory so that $\chi^2$ can be reduced from the value $\chi^2 = 3.1$ (i.e. 38% CL) of the SM to the value $\chi^2 \approx 0.22$ (i.e. 97% CL) in the model under consideration. For example, at the mass ratios near the values $\mu_{2/3} = 0.01$, $\mu_{1/3} = 0.10$, $\mu'_{2/3} = 0.96$ the formulas (7)-(9) give the values

$$S^{(LQ)} = -0.27, T^{(LQ)} = -0.20, U^{(LQ)} = -0.06$$

(12)

which agree with (11) with $\chi^2 = 0.22$ (i.e. at 97% CL). It should be noted, however, that attainment of the values (11) demands a fine mutual fitting of the mass ratios near the values mentioned above as if there were some relation between the masses of the scalar leptoquarks. Possibly, such mass relation can arise as a result of the broken four-color symmetry implied here.

The account of the mass splitting of the doublets $\Phi'$ and $F_j$ modifies the result not essentially preferring slightly the down neutral components of these doublets to be lighter than the up charged ones. For example, at $m_{\Phi_2}/m_{\Phi_1} = 0.5$ the deviations of $\chi^2_{\text{min}}$ and of the boundaries of regions from those shown in Figs.2,3 do not exceed 10%. It should be noted that with the existence of the scalar leptoquark doublets the mass splittings of other doublets are allowed to be rather large. The arising in this case large
positive contribution into $T$ from these doublets can be absorbed by the large negative contribution from the scalar leptoquark, which results in the values compatible with the experimental ones.

Recently a new analysis of the current electroweak data has been carried out in Ref. [12]. Using the results of Ref. [12] one can obtain

$$S_{new}^{exp} = -0.11 \pm 0.13, \quad T_{new}^{exp} = -0.03 \pm 0.14, \quad U_{new}^{exp} = 0.03 \pm 0.38$$

(13)

at $m_t = 175 \, GeV$, $m_{H^0} = 300 \, GeV$.

The contributions (7)-(9) have a large mass region compatible with these data at high CL. As an example the dotted curve in Fig.3 shows the region in plane of $\mu_2/3, \mu_1/3$ compatible with the data (13) at 99% CL.

It should be pointed out that both data (11) and (13) do not impose any lower limit on the mass $m_{2/3}$ of the scalar leptoquark $S_1$ with electric charge $2/3$ (see Figs.2,3), which gives the possibility for this mass (in contrast, for example, to $m_{5/3}$) to be light, perhaps to lie even not far from the SM mass scale. In this case the scalar leptoquark $S_1$ could manifest itself in experiments at a moderate energies, in particular, through the $e^+d \, S_1^*-\, coupling in e^+p - collisions.

In conclusion we resume the results of the work. The contributions into radiative correction parameters $S, T, U$ from the scalar leptoquarks are calculated in the minimal gauge model with four-color quark-lepton symmetry.

It is shown that the contributions into $T$ and $U$ from the scalar leptoquark doublets are not positive definite due to the mixing between the scalar leptoquark fields with electric charge $2/3$, which is caused by the existence of the Goldstone mode among these fields.

Using the current experimental limits on $S, T, U$ the numerical analysis of these contributions is carried out and the bounds on the scalar leptoquark masses are obtained. In particular, it is shown that the current experimental data on $S, T, U$ allow the existence of the relatively light scalar leptoquark with electric charge $2/3$.

Acknowledgment

The author is grateful to A.V. Povarov for the help in the work.
References

[1] J.C. Pati and A. Salam, Phys. Rev. D10 (1974) 275.
[2] E.M. Freire, Phys. Rev. D43 (1991) 209.
[3] G. Senjanovic, A. Sokorac, Z.Phys. C20 (1983) 255.
[4] A.D. Smirnov, Phys. Lett. B346 (1995) 297.
[5] A.D. Smirnov, Yad. Fiz. 58 (1995) 2252, Phys. of At. Nucl. 58 (1995) 2137.
[6] R.R. Volkas, Phys. Rev. D53 (1996) 2681.
[7] R. Foot, UM-P-97/48, RCHEP-97/08, hep-ph/9708205.
[8] A. Blumhofer, B. Lampe, MPI-PhT/97-37, LMU-07/97, hep-ph/9706454.
[9] M.E. Peskin and T. Takeuchi, Phys. Rev. D46 (1992) 381.
[10] L. Lavoura and L.F. Li, Phys. Rev. D48 (1993) 234.
[11] Particle Data Group, R.M. Barnet et al., Phys. Rev. D54 (1996) part 1, 7.
[12] K. Hagivara, D. Haidt, S. Matsumoto, DESY preprint DESY 96-192 (1997), KEK preprint KEK-TH-512(1997), hep-ph/9706331.
Figure captions

Fig. 1. The self energy diagrams 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).

Fig. 2. $\chi^2_{min}$ as a function of the scalar leptoquark mass ratios $\mu_{2/3} = m_{2/3}/m_{5/3}$ (the solid line), $\mu_{1/3} = m_{1/3}/m_{5/3}$ (the bold line), and $\mu_{2/3}' = m_{2/3}'/m_{5/3}$ (the dotted line).

Fig. 3. The regions in plane of mass ratios $\mu_{2/3} = m_{2/3}/m_{5/3}$, $\mu_{1/3} = m_{1/3}/m_{5/3}$ compatible with the data (11) at 95% CL (the solid line), at 90% CL (the bold line) and with the data (13) at 99% CL (the dotted line).
$S_k, S_1^{(\pm)}$

\[ + 
\]

$S_k, S_1^{(\pm)}$

\[ + 
\]

$S_k, S_1^{(\pm)}$

\[ + 
\]

$S_k, S_1^{(\pm)}$

\[ + 
\]

A.D. Smirnov, Physics Letters B

Fig. 1
A.D. Smirnov, Physics Letters B
Fig. 3