Dark Matter carriers from vector-like Technicolor model. Part I.

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It is shown that Technicolor model can be formulated having vector-like interaction of Techniquarks with the Standard Model bosons and Dirac mass term. Oblique corrections values for the case agree with experimental restrictions. The model Lagrangian is based on $\sigma-$model scheme introducing Techni-meson and Techni-baryon states. Neutral component of a "triplet" of heavy scalar Techni-baryons can be considered as Dark Matter particle. Small mixing between scalar states $h-\tilde{\sigma}$ is in accordance with experiment and is provided by strong relation between masses of Techni-$\tilde{\sigma}$ and Techni-$\tilde{\pi}$.

1 Introduction

Two years ago a scalar state (Higgs boson?) which is predicted by the Standard Model (SM) has been discovered at the LHC [1,2]. This achievement, however, can not help to solve other immanent problems of the SM, namely, come up to understanding of the mass hierarchy, the Dark Matter (DM) source or the Electro-Weak Symmetry Breaking (EWSB) origin. Attempts to extend the SM were covered, for example, in the framework of Supersymmetry (SUSY) [3,4], left-right symmetry [5–7] or Technicolor (TC) [8–10].

Introducing a number of (s)particles and their interactions the SUSY, however, uses "standard" Higgs mechanism to provide symmetry breaking via vacuum condensates.

Recent data from the LHC do not reject ideas of the SUSY, but all its manifestations are shifted up to $\sim 5-10$ TeV scale due to parameter space restriction [11–13].

$B-L$ models [14,15] and/or multi-higgs schemes [16–18] are interesting ways to the SM extensions too. Question on the SM generalization type, content and symmetry is especially intriguing due to recent LHC data on $\gamma-\gamma$ signal at approximately 750 GeV energy (a bulk of papers in ArXiv confirms expectations and readiness of scientists to see New Physics).

As to the DM origin (it is also one of the SM problems) there are a variety of DM carriers which are suggested and discussed [19–28], for example, the DM can originated from the Higgs sector too [31,32]. Technicolor (TC) models suggest one again origin of the DM provided by TC particles (Techni (T)-fermions) and their bound states (see, for example, Refs. [29,30]). Dynamics of these fields is governed by a "Technistrong interaction" at some high-energy scale duplicating "standard" QCD and its confinement. Probably, low-energy meson physics is reproduced for TC bound states too - this possibility is contributed by $\sigma-$model scheme at TC scale. Aside from fundamental scalar Higgs scheme, the electro-weak (EW) symmetry breaking (EWSB) can be realized in a dynamical manner by TC-fields. A "Higgs scalar boson" emerges in this case as T-quark bound state in the framework of so called higgsless models [33–38]. Thus, TC-models

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introduce a new fundamental object - T-quark condensate following from complex structure of physical vacuum which is considered as an interacting set of field excitations at different energy scales.

TC-model with vector-like interaction (in the case T-fermion fields have Dirac form with the corresponding mass term and Lagrangian) is an interesting scenario which has been studied for the first time without composite Higgs boson (it corresponds to "bosonic TC" [39–42]). However, due to extra singlet T-quark, S, a possibility to consider composite "Higgs boson" and more complicate set of additional T-quark states appears (it will be analyzed later).

It is well known that TC-contributions to precision EW parameters are crucial for TC-models constraining variety of them [33]. Values of Peskin-Takeuchi (PT) parameters [42–47] are criteria of the model feasibility - their calculation and comparison with experiments allows to see the reason of the model inconsistency with data. As a rule, contributions of some new degrees of freedom contradict to S, T, U parameter values. To provide a minimal contribution of TC-generations to PT parameters, a minimal TC-model of a special type was also suggested earlier (see Ref.

In this paper some main features of the vector-like TC-model are considered in the simplest case when $N_{TC} = 2$, $N_{TC}-$ number of T-quark colors, Higgs-like scalar state appears in the model from the very beginning. It is demonstrated a procedure which was used for the model formulation, calculations of the PT parameters are considered too. Note, a set of T-baryons that are generated by T-quark currents in the framework of T-$\sigma-$ model involves neutral heavy triplet of scalar T-baryons - the lightest neutral component of it can be identified with the DM particle.

So, we describe main operation to construct the vector-like TC-model and present some parts of the model Lagrangian. We also discuss briefly analytical and numerical results for oblique corrections in the case. Analysis of the mass splitting in the scalar T-baryon triplet and the DM relic abundance calculation is presented in the next report.

2 TC-model with vector-like interaction

TC-sector is a high-energy confined substructure which reproduces "low-energy" QCD at a some scale $\Lambda_{TC} \geq 1$ TeV to provide dynamical EWSB due to non-zero vacuum condensates of Techni-fields. T-quarks and T-gluons can be considered as an analog of QCD at Techni-scale, T-fermions and their bound states interact with the "standard" particles via EW bosons and (elementary or composite) scalar states. TC gauge group, $SU(N_{TC})_{TC}$, can have both odd and even dimension, we are focused here on the simplest $N_{TC} = 2$ case.

Here we present some possibility to formulate TC-model with vector-like interaction of T-quarks with Z and W-bosons. It is a minimal model with $N_{TC} = 2$ and two T-quark generations transformed under global chiral symmetry $SU(2)_L \otimes SU(2)_R$; in this case we avoid too large S parameter value [47, 49–51].

In the simplest scenario with two generations ($A = 1, 2$) of left-handed T-quarks, the T-bidoublet is the matrix $Q^{a\alpha}_{L(A)}$, where $a = 1, 2$ and $\alpha = 1, 2$ are indices of $SU(2)_L$ and $SU(2)_{TC}$ fundamental representations; essentially, T-quark doublet hypercharge equals zero.

Under $SU(2)_L \otimes SU(2)_{TC}$ the bidoublet transforms as the following

$$(Q^{a\alpha}_{L(A)})' = Q^{a\alpha}_{L(A)} + \frac{i}{2} g_W \theta_k \tau_k^{ab} Q^{b\alpha}_{L(A)} + \frac{i}{2} g_{TC} \varphi_k \tau_k^{\alpha\beta} Q^{a\beta}_{L(A)}. \tag{1}$$

Here

$$Q = \begin{pmatrix} U \\ D \end{pmatrix}$$

and $q_{U,D} = \pm 1/2$. For right-handed T-singlets (with respect to electro-weak $SU(2)_L$ group) having fixed hypercharges, $Y_{U,D} = \pm 1/2$, group transformations are:

$$\begin{aligned}(U_R^\alpha)' =& U_R^\alpha + \frac{i}{2} g_1 \theta U_R^\alpha + \frac{i}{2} g_{TC} \varphi_k \tau_k^{\alpha\beta} U_R^\beta;\\ (D_R^\alpha)' =& D_R^\alpha - \frac{i}{2} g_1 \theta D_R^\alpha + \frac{i}{2} g_{TC} \varphi_k \tau_k^{\alpha\beta} D_R^\beta.\end{aligned} \tag{2}$$

Now, keeping the first generation of T-quarks unchanged, we use charge conjugation operation, $\hat{\mathbf{C}}$, to define the second generation fields as

$$Q_{L(2)}^{Ca\alpha} = \hat{\mathbf{C}} Q_{L(2)}^{a\alpha}, \tag{3}$$

and group transformations have the form (the fermion chirality is unchanged by this operation):

$$(Q_{L(2)}^{Ca\alpha})' = Q_{L(2)}^{Ca\alpha} - \frac{i}{2} g_W \theta_k (\tau_k^{ab})^* Q_{L(2)}^{Cb\alpha} - \frac{i}{2} g_{TC} \varphi_k (\tau_k^{\alpha\beta})^* Q_{L(2)}^{Ca\beta}. \tag{4}$$

So, we get for the T-fermion field:

$$Q_{R(2)}^{a\alpha} = \epsilon^{ab} \epsilon^{\alpha\beta} Q_{L(2)}^{Cb\beta}, \;\; \epsilon^{ab} = \epsilon^{\alpha\beta} = i\sigma_2. \tag{5}$$

Using the following property of $SU(2)$ group matrices $\epsilon^{ac}\epsilon^{bc} = \delta^{ab}$, their asymmetry $\epsilon^{ab} = -\epsilon^{ba}$ and the identities

$$\epsilon^{ab} (\tau_k^{bc})^* \epsilon^{cf} = \tau_k^{af}, \;\; \epsilon^{\alpha\beta} (\tau_k^{\beta\gamma})^* \epsilon^{\gamma\mu} = \tau_k^{\alpha\mu}, \tag{6}$$

we have

$$(Q_{R(2)}^{a\alpha})' = Q_{R(2)}^{a\alpha} + \frac{i}{2} g_w \theta_k \tau_k^{ab} Q_{R(2)}^{b\alpha} + \frac{i}{2} g_{TC} \varphi_k \tau_k^{\alpha\beta} Q_{R(2)}^{a\beta}. \tag{7}$$

It is obviously coincides with transformation (1).

Thus, for the first T-quark generation we get right-handed field using the second generation of left-handed fields in two steps: charge conjugation and transposition. Therefore, composing these fields we have for the T-quark generation:

$$Q^{a\alpha} = Q_{L(1)}^{a\alpha} + Q_{R(2)}^{a\alpha} = Q_{L(1)}^{a\alpha} + \epsilon^{ab} \epsilon^{\alpha\beta} Q_{L(2)}^{Cb\beta}, \tag{8}$$

and there appear Dirac T-quarks interacting with EW vector bosons as chiral symmetric fields.

Analogously, taking right-handed field U_R^α and conjugate it

$$\hat{\mathbf{C}} U_R^\alpha = U_R^{C\alpha} \tag{9}$$

let's define the field

$$D_L^\alpha = -\epsilon^{\alpha\beta} U_R^{C\beta}. \tag{10}$$

This redefined field is transformed as right-handed structure (cf. with 2):

$$(D_L^\alpha)' = D_L^\alpha - \frac{i}{2} g_1 \theta D_L^\alpha + \frac{i}{2} g_{TC} \varphi_k \tau_k^{\alpha\beta} D_L^\beta, \tag{11}$$

so we can introduce chiral symmetric Dirac T-quark which is singlet with respect to $SU(2)_L$:

$$S^{\alpha} = D_L^{\alpha} + D_R^{\alpha} = -\epsilon^{\alpha\beta} U_R^{C\beta} + D_R^{\alpha}. \tag{12}$$

This extra singlet $S-$quark can be added to construct a composite "Higgs-like" scalar, $H = (\overline{Q}S)$, such possibility will be considered in a forthcoming paper.

This representation of Technicolor fields generate Dirac mass term for T-quarks after the fields mixing. The simplest way is the using of singlet real scalar, s, which has non-zero v.e.v., $s = \tilde{\sigma} + u$, where $u =< s >$. Just interaction of T-quarks with this scalar field provides Dirac type mass term for T-quarks. Hereafter, it is used linear $\sigma-$ model as most simple and conventional way to introduce and analyze effective interactions of bounded states of Techni-fermions - T-mesons, T-diquark states, T-baryons besides maintenance of T-quark mass term (see for detail Refs. TC12,DMou1).

As to the model Lagrangian, Techni-QCD part of it has usual form for gauge interactions (including singlet S-quark and T-gluon field $T_\mu \equiv T_\mu^n \tau_n$):

$$\begin{aligned} L(Q,S) = &-\frac{1}{4} T^n_{\mu\nu} T_n^{\mu\nu} + i\overline{Q}\gamma^\mu (\partial_\mu - \frac{i}{2} g_W W_\mu^a \tau_a - \frac{i}{2} g_{TC} T_\mu^n \tau_n) Q - m_Q \overline{Q} Q \\ &+ i\overline{S}\gamma^\mu(\partial_\mu + \frac{i}{2} g_1 B_\mu - \frac{i}{2} g_{TC} T_\mu^n \tau_n) S - m_S \overline{S} S. \end{aligned} \tag{13}$$

In the framework of linear $\sigma-$model with singlet scalar field, s, "surplus" degrees of freedom arise as adjoint triplet of T-pion states. Phenomenological interactions of the Dirac (constituent) T-quarks and the lightest T-hadrons - T-pions and T-sigma field - are described by the following Lagrangian:

$$\begin{aligned} L(Q,\sigma,h) = &- g_{TC}(c_\theta \tilde{\sigma} + s_\theta h) * (\overline{U}U + \overline{D}D) - i\sqrt{2} g_{TC} \tilde{\pi}^+ \overline{U}\gamma_5 D \\ &- i\sqrt{2} g_{TC} \tilde{\pi}^- \overline{D}\gamma_5 U - i\sqrt{2} g_{TC} \tilde{\pi}^0 (\overline{U}\gamma_5 U - \overline{D}\gamma_5 D). \end{aligned} \tag{14}$$

Here Higgs field h and scalar $\tilde{\sigma}$ originate from Higgs doublet H and singlet field s in the following manner

$$H = v + hc_\theta - \tilde{\sigma} s_\theta, \qquad s = u + hs_\theta + \tilde{\sigma} c_\theta,$$

where c_θ and s_θ are cosine and sine of mixing angle θ, vev's $v \simeq 246\,\mathrm{GeV}$ and $u > v$ break dynamically the EW and chiral symmetry. We also add the Lagrangian part which describes scalar and pseudo-scalar fields self-interaction (it contains Higgs doublet, H):

$$\begin{aligned} L_U = &g_{TC} < \overline{Q}Q > s - \frac{1}{4}\lambda_{TC}(s^2 + \tilde{\pi}_a \tilde{\pi}^a)^2 - \frac{1}{4}\lambda_H (H^+ H)^2 \\ &+ \frac{1}{2}\lambda (s^2 + \tilde{\pi}_a \tilde{\pi}^a)(H^+ H) + \frac{1}{2}\mu_1 (H^+ H) + \frac{1}{2}\mu_2 (s^2 + \tilde{\pi}_a \tilde{\pi}^a). \end{aligned} \tag{15}$$

Here, the first term containing singlet field is an external source, which is proportional to T-quark vacuum condensate; parameter λ governs the mixing of TC-and Higgs scalars; the field h is identified with the standard Higgs boson having mass $\approx 125\,\mathrm{GeV}$. As it is known at the moment, there are no significant discrepancies with the SM predictions for this state. So, effects of the $h - \tilde{\sigma}$ mixing should not be large, and we consider the small mixing case when $\mu-$ terms can be safely omitted (for details see Ref. TC12).

Further, T-quarks interact with vector bosons as chiral symmetric fields, and corresponding Lagrangian is

$$\begin{aligned} L(Q,G) = &\frac{1}{\sqrt{2}} g \overline{U}\gamma^\mu D W_\mu^+ + \frac{1}{\sqrt{2}} g \overline{D}\gamma^\mu U W_\mu^- \\ &+ \frac{1}{2} g (\overline{U}\gamma^\mu U - \overline{D}\gamma^\mu D)(c_w Z_\mu + s_w A_\mu) \end{aligned} \tag{16}$$

and T-pions - SM bosons interactions have the form

$$
\begin{aligned}
L(\tilde{\pi},G) =& igW^{\mu +}(\tilde{\pi}^0\tilde{\pi}^-_{,\mu} - \tilde{\pi}^-\tilde{\pi}^0_{,\mu}) + igW^{-\mu}(\tilde{\pi}^+\tilde{\pi}^0_{,\mu} - \tilde{\pi}^0\tilde{\pi}^+_{,\mu}) \\
&+ig(c_w Z_\mu + s_w A_\mu) * (\tilde{\pi}^-\tilde{\pi}^+_{,\mu} - \tilde{\pi}^+\tilde{\pi}^-_{,\mu}) + g^2 W^+_\mu W^{-\mu}(\tilde{\pi}^0\tilde{\pi}^0 + \tilde{\pi}^+\tilde{\pi}-) \\
&+g^2(c_w Z_\mu + s_w A_\mu)^2 * \tilde{\pi}^+\tilde{\pi}^- + ...
\end{aligned} \tag{17}
$$

The model contains a set of scalar T-quark states with conserving baryon number (T-baryons), more exactly they are diquark-like bound states of T-quarks with $M_Q = M_U = M_D \sim \Lambda_{TC}$ at tree level due to chiral symmetry:

$$B^+ = (UU), \quad B^- = (DD), \quad B^0 = (UD).$$

Note, $B^0 \neq \overline{B}^0$, $B^+ \neq \overline{B}^-$ because these states have opposite baryon numbers. We consider them as EW triplet with $J = 0$ and it is proved by direct calculations that B^0 is the lightest state of the triplet (see the report of M. Bezuglov). This triplet interacts with other fields, and corresponding Lagrangian is:

$$L_B = L_{VB\overline{B}} + L_{VVB\overline{B}} + L_{Bs\tilde{\pi}}$$

where

$$
\begin{aligned}
L_{VB\overline{B}} =& ig[W^-_\mu(B^0_{,\mu}\overline{B}^- - B^0\overline{B}^-_{,\mu} + \overline{B}^0_{,\mu}B^+ - \overline{B}^0 B^+_{,\mu}) \\
&+(s_w A_\mu + c_w Z_\mu)(B^+_{,\mu}\overline{B}^+ + \overline{B}^-_{,\mu}B^-)] + \text{c. c.},
\end{aligned} \tag{18}
$$

$$
\begin{aligned}
L_{VVB\overline{B}} =& g^2[W^+_\mu W^{\mu -}(\overline{B}^0 B^0 + \overline{B}^+ B^+) - W^+_\mu W^{\mu +}\overline{B}^+ B^- + (s_w A_\mu + c_w Z_\mu)^2 \overline{B}^+ B^+ \\
&-W^{+\mu}(s_w A_\mu + c_w Z_\mu)(\overline{B}^+ B^0 + \overline{B}^0 B^-)] + \text{c. c.},
\end{aligned} \tag{19}
$$

and

$$
\begin{aligned}
L_{Bs\tilde{\pi}} =& (\overline{B}B)\{g_{Bs}(s_1^2 + 2us_1 + \tilde{\pi}^2) + \frac{1}{2}g_{BH}(s_2^2 + 2vs_2)\} + g_{B\tilde{\pi}}[\overline{B}^0 B^0\tilde{\pi}^0\tilde{\pi}^0 \\
&+(\overline{B}^+ B^+ + \overline{B}^- B^-)\tilde{\pi}^+\tilde{\pi}^- + (\overline{B}^-\tilde{\pi}^- + \overline{B}^+\tilde{\pi}^+)B^0\tilde{\pi}^0 \\
&+(B^+\tilde{\pi}^- + B^-\tilde{\pi}^+)\overline{B}^0\tilde{\pi}^0 + \overline{B}^- B^+\tilde{\pi}^-\tilde{\pi}^- + \overline{B}^+ B^-\tilde{\pi}^+\tilde{\pi}^+].
\end{aligned} \tag{20}
$$

We specify here $s_1 = s_\theta h + c_\theta\tilde{\sigma}, \quad s_2 = c_\theta h - s_\theta\tilde{\sigma}$.

It is this B-triplet will be studied henceforth as possible origin of the DM.

3 Oblique corrections in the vector-like TC-model

Experimental restrictions are known only for S, T, U Peskin-Takeuchi parameters. In the framework of the model we calculate them and present as functions of new particles contributions to Z, W polarizations. Initially, they take the form:

$$\begin{aligned}
\alpha S =& 4s_w^2c_w^2[\frac{\Pi_{ZZ}(M_Z^2)}{M_Z^2} - \frac{c_w^2 - s_w^2}{s_w c_w}\Pi^{'}_{Z\gamma}(0) - \Pi^{'}_{\gamma\gamma}(0)];\\
\alpha U =& 4s_w^2[\frac{\Pi_{WW}(M_W^2)}{M_W^2} - c_w^2\frac{\Pi_{ZZ}(M_Z^2)}{M_Z^2} - 2s_w c_w \Pi^{'}_{Z\gamma}(0) - s_w^2\Pi^{'}_{\gamma\gamma}(0)];\\
\alpha T =& \frac{\Pi_{WW}(0)}{M_W^2} - \frac{\Pi_{ZZ}(0)}{M_Z^2}.
\end{aligned} \tag{21}$$

Polarization functions $\Pi_{XY}(p^2)$, where $X, Y = W, Z, \gamma$, can be written as:

$$\Pi_{XY}(p^2) = \frac{g^2}{24\pi^2}K_{XY}[F_\pi(p^2) + N_C F_Q(p^2)], \tag{22}$$

here $N_C = 2$ and coefficients K_{XY}, where we denote $(XY) = (WW, ZZ, \gamma\gamma, Z\gamma)$, are:

$$K_{XY} = (1,\, c_w^2,\, s_w^2,\, c_w s_w). \tag{23}$$

For T-pions, $F_\pi(p^2)$, and T-quarks, $F_Q(p^2)$, we get following expressions:

$$\begin{aligned}
F_\pi(p^2) =& \frac{1}{3}p^2 - 2m_\pi^2 - 2A_0(m_\pi^2) + \frac{1}{2}(p^2 - 4m_\pi^2)B_0(p^2; m_\pi^2, m_\pi^2);\\
F_Q(p^2) =& -\frac{1}{3}M_Q^2 + 2A_0(M_Q^2) + (p^2 - 2M_Q^2)B_0(p^2; M_Q^2, M_Q^2).
\end{aligned} \tag{24}$$

$A_0(m^2)$ and $B_0(p^2; m^2, m^2)$ -are corresponding Veltman functions. Now, for PT-parameters we obtain:

$$\begin{aligned}
S =& \frac{2c_w^4}{3\pi}\{\frac{1}{3} - \beta_\pi^Z(1 - \sqrt{\beta_\pi^Z}\frac{1}{\sqrt{\beta_\pi^Z}}) + N_C[-\frac{1}{3} + (3 + \beta_Q^Z) * (1 - \sqrt{\beta_Q^Z}\frac{1}{\sqrt{\beta_Q^Z}})]\};\\
T =& 0, \text{ because of } \Pi_{WW}(0) = \Pi_{ZZ}(0) = 0;\\
U =& \frac{2}{3\pi}\{\frac{1}{3}(1 - c_w^4) * (1 - N_C) - \beta_\pi^W(1 - \sqrt{\beta_\pi^W}\frac{1}{\sqrt{\beta_\pi^W}}\\
&+ N_C[(3 + \beta_Q^W) * (1 - \sqrt{\beta_Q^W}\frac{1}{\sqrt{\beta_Q^W}}) + c_w^4\beta_Q^Z(1 - \sqrt{\beta_Q^Z})\frac{1}{\sqrt{\beta_Q^Z}}\\
&- c_w^4(3 + \beta_Q^Z) * (1 - \sqrt{\beta_Q^Z}\frac{1}{\sqrt{\beta_Q^Z}})]\}.
\end{aligned} \tag{25}$$

Following denotations were used here:

$$\beta_\pi^{W,Z} = \frac{4m_\pi^2}{M_{W,Z}^2} - 1 > 0, \;\; \beta_Q^{W,Z} = \frac{4m_Q^2}{M_{W,Z}^2} - 1 > 0. \tag{26}$$

In the approximation $\beta \gg 1$ all parameters are equal zero up to second order terms. Exact dependencies of S, U on M_π and M_Q values in a wide intervals are shown in Fig. 1 and 2. Obviously, values of PT parameters in the vector-like model are in agreement with experimental corridors $S^{exp} = 0.00 \pm 0.10$ and $U^{exp} = 0.08 \pm 0.11$.

4 Conclusions

It is presented in brief some way to realize vector-like interaction in the framework of Technicolor. With two generations of T-quarks (having zero hypercharge of T-doublet) in hands, it is possible to introduce some combinations of T-fermions and redefine so as to get Dirac T-quark fields. After these fields mixing, we can provide mass term of Dirac type for these T-fields using v.e.v. of real scalar field s. So, it leads to the model physical Lagrangian which contain interaction of T-pions, T-quarks, T-gluons, self-interaction of scalars and pseudo-scalars an so on. In the model there are some (possibly heavy) T-baryon states, which are, in fact, di-T-quarks, forming a "triplet". As it will be shown, the lightest component of it, B^0, can be identified with the Dark Matter particle. Importantly, in the model considered oblique corrections prove to be sufficiently small in comparison with experimental data.

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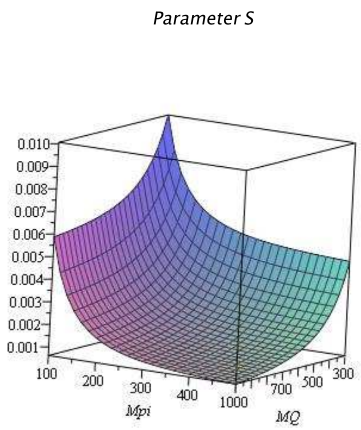

Figure 1: Peskin-Takeuchi S parameter as function of T-pion and T-quark masses.

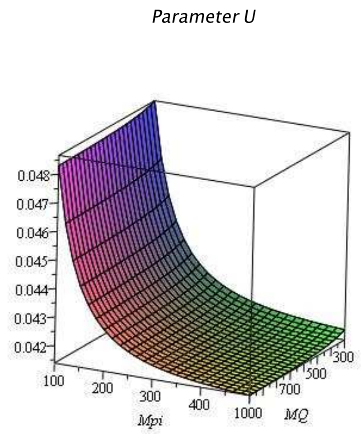

Figure 2: Peskin-Takeuchi U parameter as function of T-pion and T-quark masses.