Dark Matter carriers from vector-like Technicolor model

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Dynamical EWSB (Higgsless models):

- TC was introduced as the mechanism for DEWSB via a condensate of technifermions (techniquarks) $\langle \bar{F} F \rangle$
- Technifermions are charged under $SU(N)_{\rm TC}$
- TC condensate breaks symmetry $SU(2)_W \otimes U(1)_Y$ to $U(1)_{em}$ without fundamental Higgs.

(Susskind 1979, Weinberg 1979, Farhi and Jackiw 1982 etc)

New dynamics with strong coupling – new confinement scale – composite(?) Higgs – extra T-hadron states – composite(?) Dark Matter

QCD: hadrons and constituent quarks

TC: T-hadrons and constituent T-quarks

Linear σ (T- σ) Model:
constituent quark (T-quark) – meson (T-meson) interactions

$N,\, Q,\, \sigma,\, \pi,\, \omega,\, \rho,\, f,\, a,\, \ldots$ $\Rightarrow$ $\tilde{N},\, \tilde{Q},\, \tilde{\sigma},\, \tilde{\pi},\, \tilde{\omega},\, \tilde{\rho},\, \tilde{f},\, \tilde{a},\, \ldots$

QCD ⟷ **TC**

QCD

$\Lambda_{\rm QCD} \sim 200~{\rm MeV}$

Static properties of light hadrons can be completely determined by two dimensionful vacuum parameters:

gluon condensate:

$$\langle 0|\frac{\alpha_s}{\pi}\hat{G}_{\mu\nu}\hat{G}^{\mu\nu}|0\rangle = (365 \pm 20\,{\rm MeV})^4 \simeq (2\Lambda_{\rm QCD})^4\,,$$

light quark condensate:

$$\langle 0|\bar{u}u|0\rangle = \langle 0|\bar{d}d|0\rangle = -l_g\langle 0|\frac{\alpha_s}{\pi}\hat{G}_{\mu\nu}\hat{G}^{\mu\nu}|0\rangle = -(235 \pm 15\,{\rm MeV})^3$$

QCD – T-QCD analogy

"T-QCD"

$\Lambda_{\rm TC} \gtrsim v \sim 200~{\rm GeV}$

Spectrum of light composites (incl. Higgs) is governed by

$$\langle 0|\frac{\alpha_{\rm TC}}{\pi}\hat{F}_{\mu\nu}\hat{F}^{\mu\nu}|0\rangle \sim (2\Lambda_{\rm TC})^4\,,$$

$$\langle 0|\bar{U}U|0\rangle = \langle 0|\bar{D}D|0\rangle \sim -l_{\rm TC}(2\Lambda_{\rm TC})^4$$

New strong coupling scale, $\Lambda_{\rm TC}$ =
the T-quarks – T-gluons condensate scale

Consider the following case:

$$SU(N_{\rm TC})_{\rm TC} \qquad \tilde{Q} = \begin{pmatrix} U \\ D \end{pmatrix}, \qquad Y_{\tilde{Q}} = \begin{cases} 0, & \text{if } N_{\rm TC} = 2\,, \\ 1/3, & \text{if } N_{\rm TC} = 3\,. \end{cases}$$

Simplest scenario: two-color bosonic TC with two generations of chiral fields

left-chiral TC-quark bidoublet as matrix $Q_L^{a\alpha}$

Fundamental rep.

a,α =1, 2 $\rightarrow$ $SU_L(2)$ and $SU_{TC}(2)$

Left chiral quark doublet charges: $q_{U,D}$ = ±1/2

Electro-weak singlets hypercharges: Y = ±1/2

Right chiral TC-field are SU(2)$_L$ singlets

Left bidoublet transformation:

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

Right field transformation:

$$\left(U^{\alpha}_{R}\right)' = U^{\alpha}_{R} + \frac{i}{2} g_1 \theta U^{\alpha}_{R} + \frac{i}{2} g_{TC} \varphi_k \tau_k^{\alpha\beta} U^{\beta}_{R};$$

$$\left(D^{\alpha}_{R}\right)' = D^{\alpha}_{R} - \frac{i}{2} g_1 \theta D^{\alpha}_{R} + \frac{i}{2} g_{TC} \varphi_k \tau_k^{\alpha\beta} D^{\beta}_{R}$$

$SU(2)_L \times SU(2)_R \times L(T)\sigma M$

1-st TC-quark generation

$$Q_{L(1)} = (U_{L(1)}, D_{L(1)}), U_{R(1)}, D_{R(1)}$$

2-nd TC-quark generation

Charge conjugation $$\hat{C} Q^{a\alpha}_{L(2)} = Q^{Ca\alpha}_{L(2)}$$

Now the field transforms as

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

New right-handed weak doublet

$$\boxed{Q^{a\alpha}_{R(2)} = \epsilon^{ab} \epsilon^{\alpha\beta} Q^{Cb\beta}_{L(2)}, \quad \epsilon = i\sigma_2}$$

Right-handed field of 2-nd generation transforms as corresponding left handed field

$$\left(Q^{a\alpha}_{R(2)}\right)' = Q^{a\alpha}_{R(2)} + \frac{i}{2} g_w \theta_k \tau_k^{ab} Q^{b\alpha}_{R(2)} + \frac{i}{2} g_{TC} \varphi_k \tau_k^{\alpha\beta} Q^{a\beta}_{R(2)}$$

Composing these fields → **Dirac weak doublet**

$$\boxed{Q^{a\alpha} = Q^{a\alpha}_{L(1)} + Q^{a\alpha}_{R(2)} = Q^{a\alpha}_{L(1)} + \epsilon^{ab}\epsilon^{\alpha\beta} Q^{Cb\beta}_{L(2)}}$$

Having two right-handed fields $U^{\alpha}_{R}\ D^{\alpha}_{R}$ $\longrightarrow$ $\boxed{D^{\alpha}_{L} = -\epsilon^{\alpha\beta} U^{C\beta}_{R}}$

$$\left(D^{\alpha}_{L}\right)' = D^{\alpha}_{L} - \frac{i}{2} g_1 \theta D^{\alpha}_{L} + \frac{i}{2} g_{TC} \varphi_k \tau_k^{\alpha\beta} D^{\beta}_{L}$$

Dirac TC-field, SU(2)L scalar

$$\boxed{S^{\alpha} = D^{\alpha}_{L} + D^{\alpha}_{R} = -\epsilon^{\alpha\beta} U^{C\beta}_{R} + D^{\alpha}_{R}}$$

Simplest vector-like TC SU(2)$_L$ X SU(2)$_R$ Lagrangian (with extra weak singlet quark S for composite scalar "Higgs boson")

$$L(T,Q,S) = -\frac{1}{4}T^n_{\mu\nu}T^{\mu\nu}_n + i\bar{Q}\gamma^\mu(\partial_\mu - \frac{i}{2}g_W W^a_\mu \tau_a - \frac{i}{2}g_{TC}T^n_\mu \tau_n)Q - m_Q\bar{Q}Q$$
$$+i\bar{S}\gamma^\mu(\partial_\mu + \frac{i}{2}g_1 B_\mu - \frac{i}{2}g_{TC}T^n_\mu \tau_n)S - m_S\bar{S}S.$$

LTσM – σ-field interaction with T-degrees of freedom (cf. low-energy quark-meson interactions)

$$\bar{Q}Q \to \langle\bar{Q}Q\rangle + \bar{Q}Q$$

Scalar real field S' = <S'>+σ (non-zero v.e.v.),
<S'> ≡ u gives masses for T-quarks

$$-g_{\rm TC}\Big(\langle\bar{Q}Q\rangle S + \bar{Q}(S + i\gamma_5 P^a\tau^a)Q\Big)$$

scalar T-sigma (singlet rep.)

pseudoscalar T-pions (adjoint rep.)

T-σ-meson – lightest T-glueball?
T-pions – T-quark condensate excitation?

(Constituent) quark-meson, Λ_{QCD}

$$\boxed{N,\ Q,\ \sigma,\ \pi,\ \omega,\ \rho,\ f,\ a,\ \ldots}$$

(Constituent) T-quark - T-meson, Λ_{TC}

$$\boxed{\tilde{N},\ \tilde{Q},\ \tilde{\sigma},\ \tilde{\pi},\ \tilde{\omega},\ \tilde{\rho},\ \tilde{f},\ \tilde{a},\ \ldots}$$

Both u and v v.e.v.'s are induced by T-quark condensate

$$\mathbf{u}\,,\,\mathbf{v} \sim \sqrt[3]{\langle \bar{Q} Q \rangle}$$

Vacuum potential energy

$$\frac{1}{2}\mu_{\rm S}^2(S^2+P^2)+\mu_{\rm H}^2\mathcal{H}^2-\frac{1}{4}\lambda_{\rm TC}(S^2+P^2)^2-\lambda_{\rm H}\mathcal{H}^4+\lambda\mathcal{H}^2(S^2+P^2)$$

some h – σ mixing is due to

Possible deviations from the SM for $\lambda \neq 0$?

$\mathcal{H}$ - scalar Higgs doublet

Here we consider the simplest TC model variant: $N_C = 2$, $q_{U,D} = \pm 1/2$

The model Lagrangian

T-quark – vector bosons interaction

$$L(Q,G) = \frac{1}{\sqrt{2}} g \bar{U} \gamma^\mu D W_\mu^+ + \frac{1}{\sqrt{2}} g \bar{D} \gamma^\mu U W_\mu^-$$
$$\frac{1}{2} g (\bar{U} \gamma^\mu U - \bar{D} \gamma^\mu D)(c_w Z_\mu + s_w A_\mu)$$

T-pions – vector bosons interaction

$$L(\pi, G) = ig W^{\mu +}(\pi^0 \pi^-_{,\mu} - \pi^- \pi^0_{,\mu}) + ig W^{-\mu}(\pi^+ \pi^0_{,\mu} - \pi^0 \pi^+_{,\mu})$$
$$+ig(c_w Z_\mu + s_w A_\mu) * (\pi^- \pi^+_{,\mu} - \pi^+ \pi^-_{,\mu}) + g^2 W^+_\mu W^{-\mu}(\pi^0 \pi^0 + \pi^+ \pi -)$$
$$+g^2 (c_w Z_\mu + s_w A_\mu)^2 * \pi^+ \pi^- + \ldots$$

T-quarks – (pseudo-) scalar field interaction

$$L(Q, \sigma, h) = - g_{TC}(c_\theta \sigma + s_\theta h) * (\bar{U} U + \bar{D} D) - i\sqrt{2} g_{TC} \pi^+ \bar{U} \gamma_5 D$$
$$-i\sqrt{2} g_{TC} \pi^- \bar{D} \gamma_5 U - i\sqrt{2} g_{TC} \pi^0 (\bar{U} \gamma_5 U - \bar{D} \gamma_5 D).$$

Oblique corrections (Peskin – Takeuchi parameters) – New Physics should not drastically change EW observables!

$$M_Z^2 = M_{Z0}^2 \frac{1-\widehat{\alpha}(M_Z)T}{1-G_F M_{Z0}^2 S/2\sqrt{2}\pi}$$

$$M_W^2 = M_{W0}^2 \frac{1}{1-G_F M_{W0}^2 (S+U)/2\sqrt{2}\pi}$$

$$\Gamma_Z = \frac{M_Z^3 \beta_Z}{1-\widehat{\alpha}(M_Z)T}$$

Precision exp. constraints

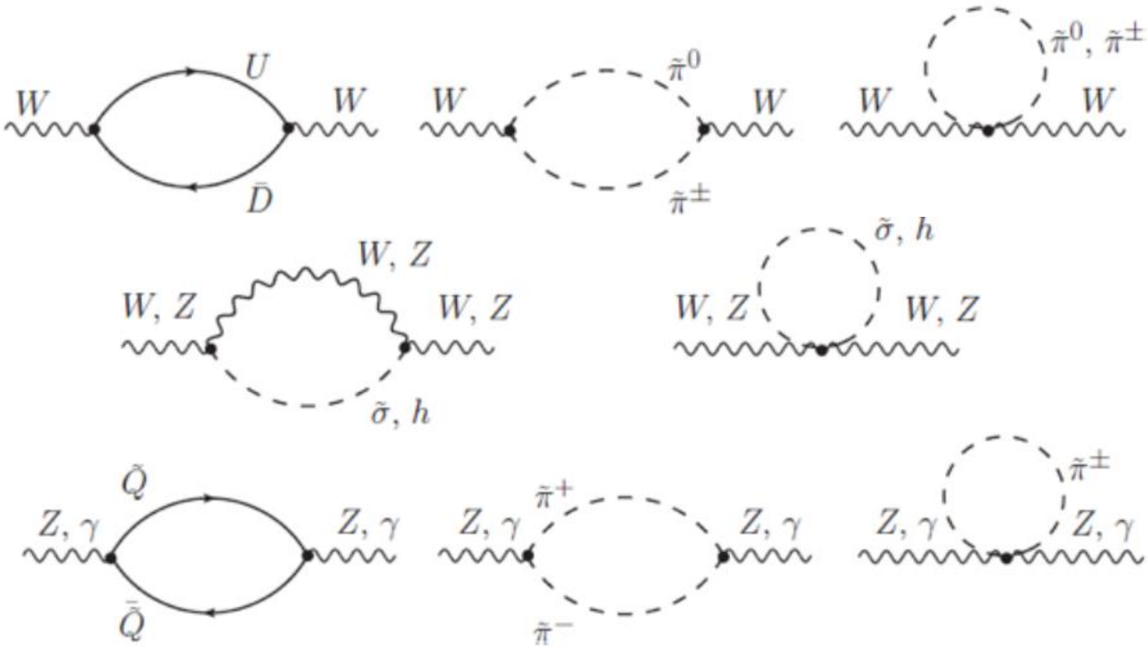
$$S = 0.00^{+0.11}_{-0.10} \qquad T = 0.02^{+0.11}_{-0.12} \qquad U = 0.08 \pm 0.11$$

$$\alpha S = 4 s_w^2 c_w^2 \left[\frac{\Pi_{ZZ}(M_Z^2)}{M_Z^2} - \frac{c_w^2 - s_w^2}{s_w c_w}\Pi'_{Z\gamma}(0) - \Pi'_{\gamma\gamma}(0)\right];$$

$$\alpha U = 4 s_w^2 \left[\frac{\Pi_{WW}(M_W^2)}{M_W^2} - c_w^2 \frac{\Pi_{ZZ}(M_Z^2)}{M_Z^2} - 2 s_w c_w \Pi'_{Z\gamma}(0) - s_w^2 \Pi'_{\gamma\gamma}(0)\right];$$

$$\alpha T = \frac{\Pi_{WW}(0)}{M_W^2} - \frac{\Pi_{ZZ}(0)}{M_Z^2}.$$

SU(2)L x SU(2)R: oblique corrections diagrams



Structure of P-T parameters in the model

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

$$X, Y = W, Z, \gamma.$$

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

$$\boxed{S = \frac{2c_w^4}{3\pi}\{\frac{1}{3} - \beta_\pi^Z(1 - \sqrt{\beta_\pi^Z}\,\mathrm{arctg}\,\frac{1}{\sqrt{\beta_\pi^Z}}) + N_C[-\frac{1}{3} + (3+\beta_Q^Z) * (1 - \sqrt{\beta_Q^Z}\,\mathrm{arctg}\,\frac{1}{\sqrt{\beta_Q^Z}})]\}}$$

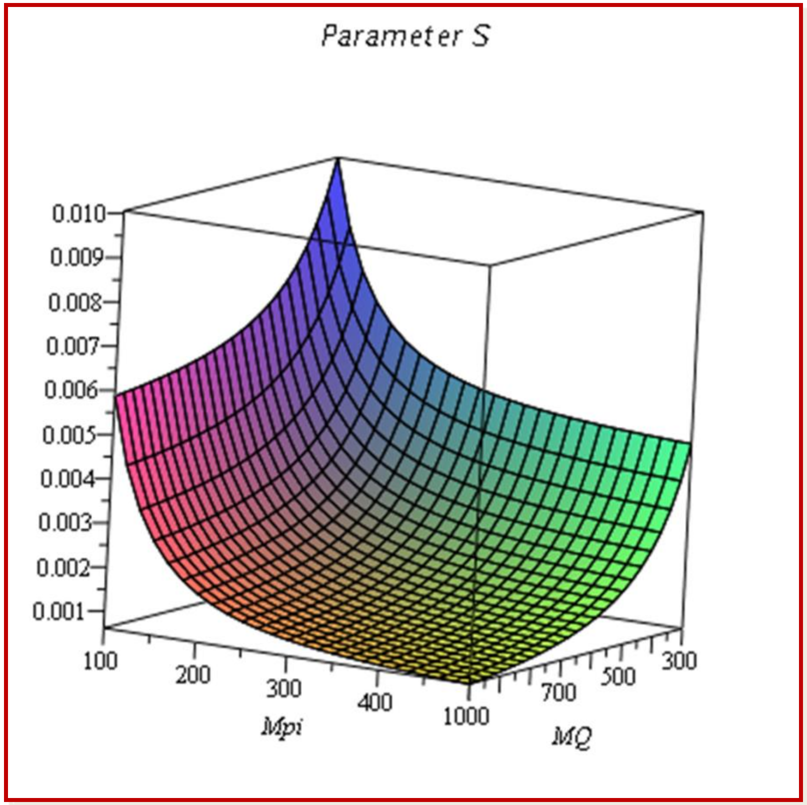
$$\begin{aligned} U =& \frac{2}{3\pi}\{\frac{1}{3}(1 - c_w^4) * (1 - N_C) - \beta_\pi^W(1 - \sqrt{\beta_\pi^W}\,\mathrm{arctg}\,\frac{1}{\sqrt{\beta_\pi^W}} \\ &+ N_C[(3+\beta_Q^W) * (1 - \sqrt{\beta_Q^W}\,\mathrm{arctg}\,\frac{1}{\sqrt{\beta_Q^W}}) + c_w^4\beta_Q^Z(1 - \sqrt{\beta_Q^Z})\,\mathrm{arctg}\,\frac{1}{\sqrt{\beta_Q^Z}} \\ &- c_w^4(3+\beta_Q^Z) * (1 - \sqrt{\beta_Q^Z}\,\mathrm{arctg}\,\frac{1}{\sqrt{\beta_Q^Z}})]\} \end{aligned}$$

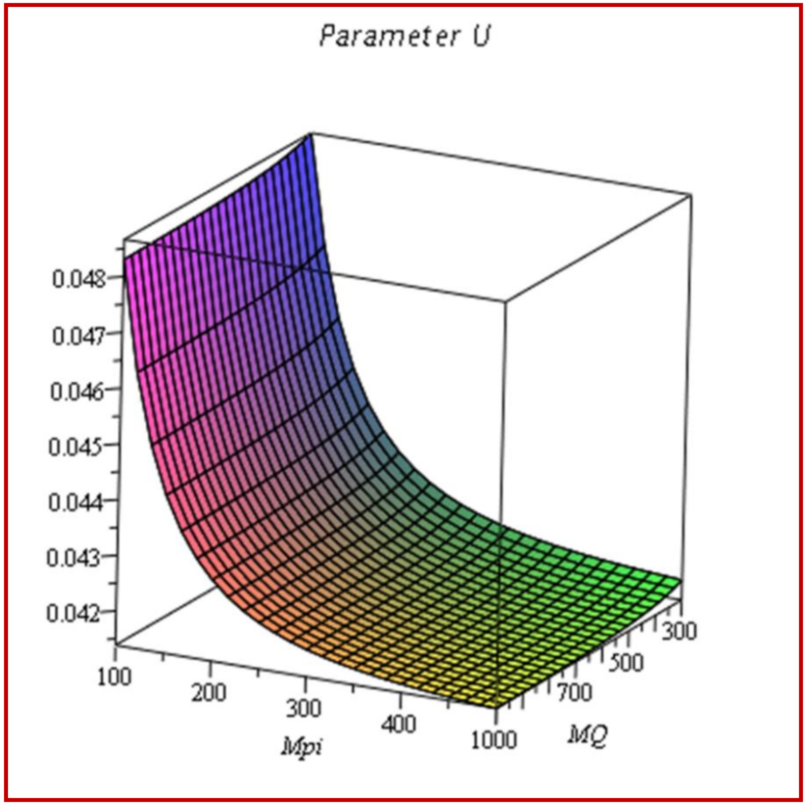
$$\boxed{\Pi_{WW}(0) = \Pi_{ZZ}(0) = 0} \Longrightarrow \boxed{T = 0}$$

In the case of zero “higgs – T-sigma” mixing!

P-T parameters S and U as functions of T-pion mass and T-quark mass

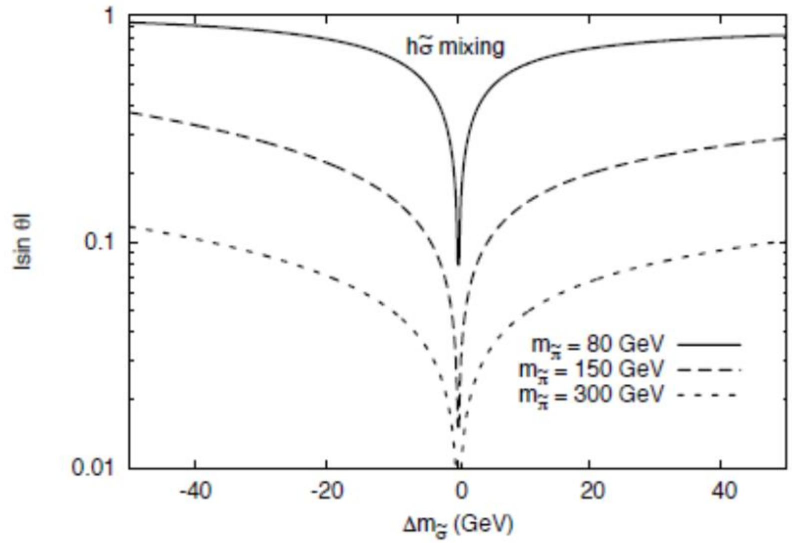
Remind that $S = 0.00^{+0.11}_{-0.10} \quad T = 0.02^{+0.11}_{-0.12} \quad U = 0.08 \pm 0.11$

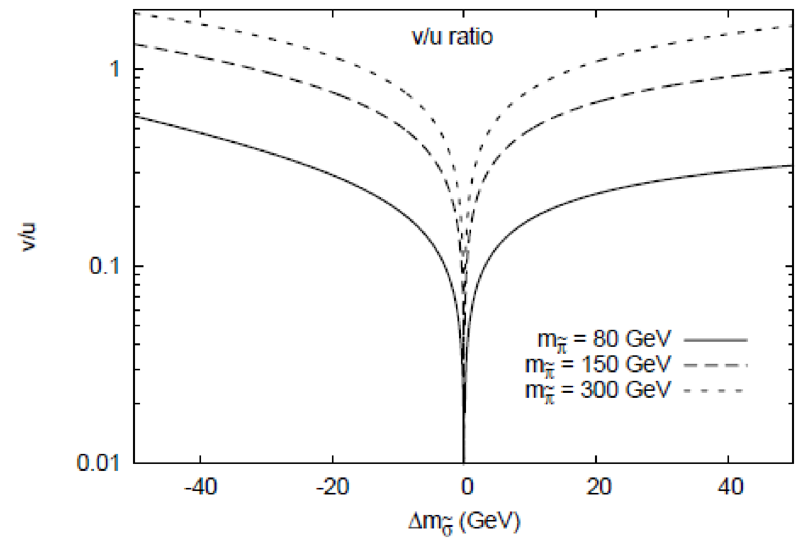




T-sigma – T-pion parameter

$\Delta m_\sigma = m_\sigma - \sqrt{3}\, m_\pi$





$m_{\tilde{\pi}},\ m_{\tilde{\sigma}}$ **are free parameters of the model**

Should Δm_σ be small?

Deviations of the Higgs properties from the SM are so much the less, the smaller is the Δm_σ

Diquark-like bound states with conserved T-baryonic number, T_B

$$\boxed{\begin{array}{llll} B^+ = UU\,, & B^- = DD\,, & B^0 = UD\,, & T_B = +1\,, \\ \bar{B}^+ = \bar{U}\bar{U}\,, & \bar{B}^- = \bar{D}\bar{D}\,, & \bar{B}^0 = \bar{U}\bar{D}\,, & T_{\bar{B}} = -1\,. \end{array}}$$

T-baryon interactions with the SM vector bosons

no vector interactions of type $\bar{B}^0 B^0 Z$

$$\mathcal{L}_{\mathrm{VB\bar{B}}} = ig\Big[W^-_\mu(B^0_{,\mu}\bar{B}^- - B^0\bar{B}^-_{,\mu} + \bar{B}^0_{,\mu}B^+ - \bar{B}^0 B^+_{,\mu}) \\ + (s_W A_\mu + c_W Z_\mu)(B^+_{,\mu}\bar{B}^+ + \bar{B}^-_{,\mu}B^-)\Big] + c.c.$$

$$\mathcal{L}_{\mathrm{VVBB}} = g^2\Big[(\bar{B}^0 B^0 + \bar{B}^+ B^+)W^+_\mu W^{\mu-} \\ + \bar{B}^+ B^+(s_W A_\mu + c_W Z_\mu)^2 - \bar{B}^+ B^- W^+_\mu W^{\mu+} \\ - (\bar{B}^+ B^0 + \bar{B}^0 B^-)(s_W A_\mu + c_W Z_\mu)W^{\mu+}\Big] + c.c.$$

+ T-baryons interactions with Higgs boson, T-pions, T-sigma

⇓

Lightest state of B-triplet -> scalar T-baryon DM?

(see report of M.Bezuglov)

Intermediate conclusions

- Dynamical EWSB in VLTC provides an effective Higgs mechanism, induced by T-fermion condensate at high-energy TC-scale ;
- It is shown how TC-model can be rearranged as the model with vector-like interaction of T-quarks with SM vector bosons;
- Such vector-like two-boson TC model with SU(2) symmetry has no problems with the EW (and FCNC) precision constraints, conserving standard Higgs mechanism;
- Light T-pions and T-sigma as a carriers of new strong TC-dynamics can emerge at the LHC energies through their creation and decays; the amplitude of Higgs – T-sigma mixing drive possible non-SM Higgs behavior; +T-loops contributions!
- TC-model can be formulated as higgsless too – due to extra weak singlet T-quark, keeping all important features: safety for P-T parameters, a rich phenomenology of (pseudo)scalar states, small deviations from the SM “Higgs state” and so on;
- In all variants TC- model contains some lightest neutral states, which are good candidates for the CDM description – here it is one of the component of triplet of bounded di(T)quark states with conserved T-baryon number.

Analysis of this possibility will be presented in the report of M.Bezuglov.

Thank you for attention!

References

1. Chiral-Symmetric Technicolor with Standard Model Higgs boson. Phys. Rev. D 88, 075009 (2013)

2. Vector-like technineutron Dark Matter: is a QCD-type Technicolor ruled out by XENON100? Eur.Phys.J.C (2014) 74 2728

3.Scalar technibaryon Dark Matter from vector-like SU(2) Technicolor , arXiv: 1407.2392

Receipt of right-handed component

$$\epsilon^{ab}\epsilon^{\alpha\beta}(Q^{Cb\beta}_{L(2)})' = \epsilon^{ab}\epsilon^{\alpha\beta}Q^{Cb\beta}_{L(2)} - \frac{i}{2}g_W\theta_k\epsilon^{ab}(\tau^{bc}_k)^*\epsilon^{\alpha\beta}Q^{Cc\beta}_{L(2)} - \frac{i}{2}g_{TC}\varphi_k\epsilon^{\alpha\beta}(\tau^{\beta\gamma}_k)^*\epsilon^{ab}Q^{Cb\gamma}_{L(2)}.$$

$$\epsilon^{\gamma\mu}\epsilon^{\lambda\mu} = \delta^{\gamma\lambda} \qquad \epsilon^{cf}\epsilon^{df} = \delta^{cd}$$

$$\epsilon^{ab}\epsilon^{\alpha\beta}(Q^{Cb\beta}_{L(2)})' = \epsilon^{ab}\epsilon^{\alpha\beta}Q^{Cb\beta}_{L(2)} - \frac{i}{2}g_W\theta_k\epsilon^{ab}(\tau^{bc}_k)^*\epsilon^{\alpha\beta}Q^{Cc\beta}_{L(2)} - \frac{i}{2}g_{TC}\varphi_k\epsilon^{\alpha\beta}(\tau^{\beta\gamma}_k)^*\epsilon^{ab}Q^{Cb\gamma}_{L(2)}.$$

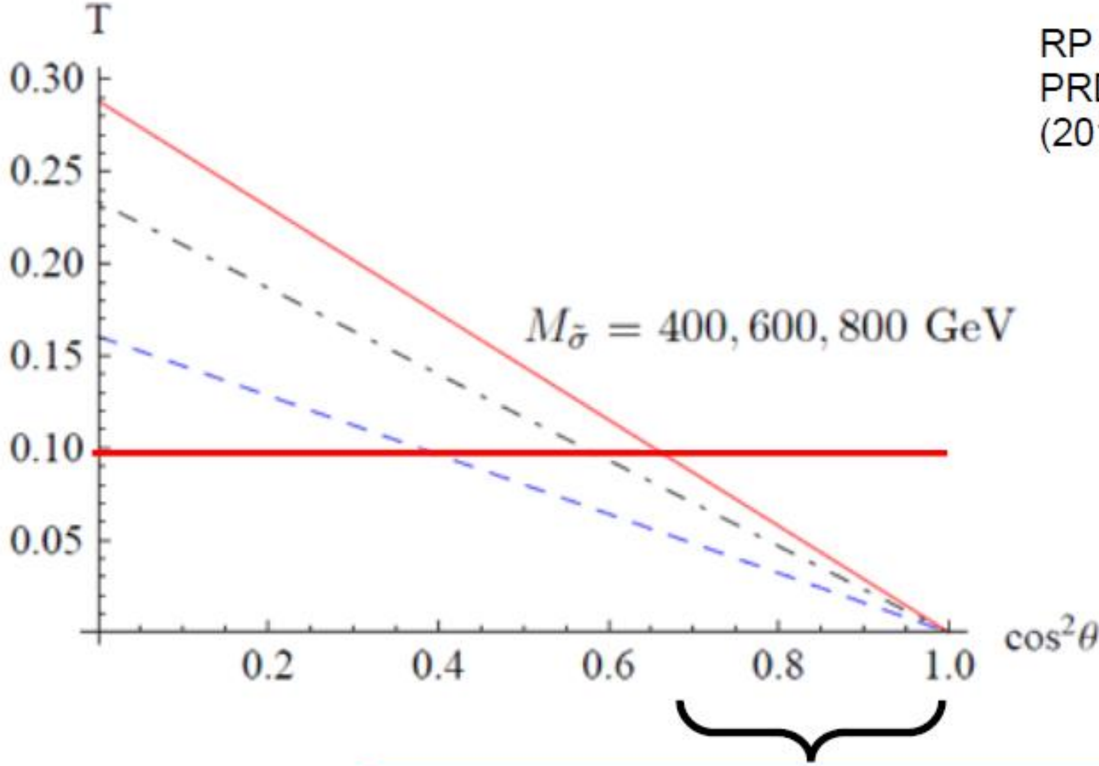
$$\epsilon^{ab}(\tau^{bc}_k)^*\epsilon^{cf} = \tau^{af}_k, \quad \epsilon^{\alpha\beta}(\tau^{\beta\gamma}_k)^*\epsilon^{\gamma\mu} = \tau^{\alpha\mu}_k.$$

+antisymmetry of epsilon matrices

$$\downarrow$$

$$(Q^{a\alpha}_{R(2)})' = Q^{a\alpha}_{R(2)} + \frac{i}{2}g_w\theta_k\tau^{ab}_kQ^{b\alpha}_{R(2)} + \frac{i}{2}g_{TC}\varphi_k\tau^{\alpha\beta}_kQ^{a\beta}_{R(2)}.$$

T-parameter: constraint on σh-mixing and σ-mass



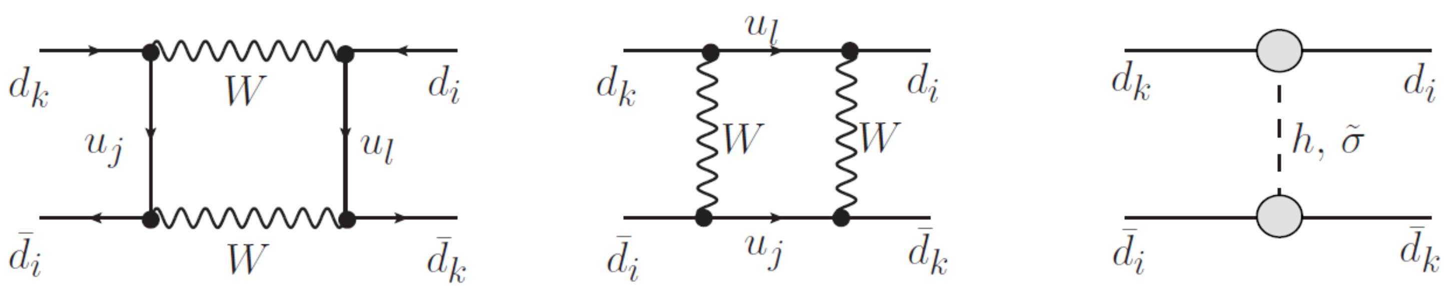
RP et al,
PRD88, 075009
(2013)

a small mixing angle and/or small
σ-mass are preferable!

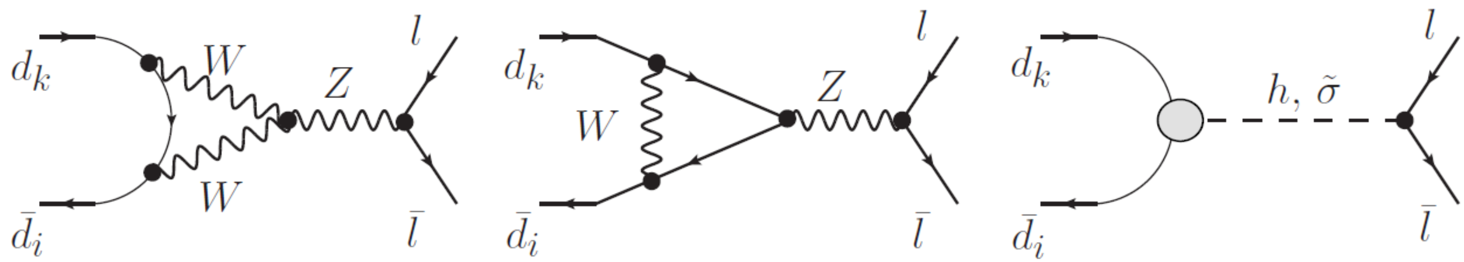
Constraints on 2BTCM: FCNC processes

One-loop SM part | **Extra contributions**

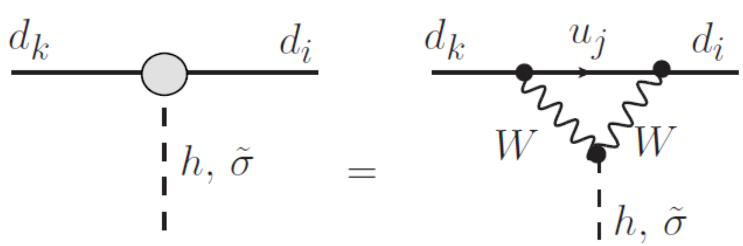
$M^0 - \bar{M}^0$ mixing



$M \to l\bar{l}$ rare leptonic decay



Loop-induced vertex



New TC contributions to FCNC's are strongly suppressed:

- Two-loop FCNC effects
- heavy **σ** –mass in denominators
- double suppression by a small **σ-Higgs mixing**