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Topcolor Assisted Technicolor

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Abstract

A condensate, $\bar{t}t$, arising from $O(TeV)$ scale "topcolor," in addition to technicolor (and ETC) may naturally explain the gauge hierarchy, the large top quark mass, and contains a rich system of testable consequences. A triplet of strongly coupled pseudo–Nambu–Goldstone bosons, "top-pions," near the top mass scale is a generic prediction of the models. A new class of technicolor schemes and associated phenomenology is suggested in this approach.

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I. Introduction and Synopsis

The large top quark mass is suggestive of new dynamics associated with electroweak symmetry breaking (ESB). Top quark condensation models try to identify all of the ESB with the formation of a dynamical top quark mass. In the fermion–loop approximation one can write a simple Pagels–Stokar formula which connects the Nambu–Goldstone boson (longitudinal W and Z) decay constant, f_π, to the dynamical mass, m_c [1] (we fix the normalization of f_π in eq.(7) below):

$$f_\pi^2 = \frac{N_c}{16\pi^2} m_c^2 (\log \frac{\Lambda^2}{m_c^2} + k) \tag{1}$$

Here m_c is the dynamical mass, k a constant of $O(1)$, and Λ the cut-off scale at which the dynamical mass is rapidly going to zero. If electroweak symmetries are broken dynamically by the top quark mass, then $f_\pi = v_{wk} = (2\sqrt{2}G_F)^{-1/2} \approx 175$ GeV, and taking the cut–off $\Lambda \sim 1.5$ TeV, and $k \approx 1$, we would predict too large a top mass, $m_c \sim 900$ GeV. Ergo, top condensation models must either allow $\Lambda/m_t >> 1$ with drastic fine-tuning, or invoke new dynamical mechanisms to try to obtain a natural scheme.[2]

In this letter we wish to sketch another possibility, which seems to carry some intriguing implications. We consider the possibility that: (i) electroweak interactions are indeed broken by technicolor (TC) [3] with an extended technicolor (ETC) (yet, one could replace these elements of our discussion with Higgs scalars, either as an

[2] In theories, such as SUSY schemes, in which the scale of new physics may be large, $\Lambda \sim 10^{15}$ GeV, the top quark mass surprisingly saturates the Pagels–Stokar formula. In this case m_t is precisely determined by the infra-red quasi-fixed point [2], which subsumes all corrections to eq.(1).

approximation to the TC/ETC dynamics, or as a fundamental structure as in SUSY); **(ii)** the top quark mass is large because it is a combination of a *dynamical condensate component*, $(1-\epsilon)m_t$, generated by a new strong dynamics, together with a small *fundamental component*, ϵm_t (i.e, $\epsilon << 1$, generated by the extended technicolor (ETC) or Higgs); **(iii)** the new strong dynamics is assumed to be chiral–critically strong but spontaneously broken by TC at the scale $\sim$ 1 TeV, and it is coupled preferentially to the third generation. The new strong dynamics therefore occurs primarily in interactions that involve $\bar{t}t\bar{t}t$, $\bar{t}t\bar{b}b$, and $\bar{b}b\bar{b}b$, while the ETC interactions of the form $\bar{t}t\overline{Q}Q$, where Q is a techniquark, are relatively feeble.

Our basic assumptions, (i)-(iii), leave little freedom of choice in the new dynamics: We require a new class of technicolor models incorporating "topcolor" (TopC) [4].[3] In TopC the dynamics at the $\sim$ 1 TeV scale involves the following structure (or a generalization thereof):

$$SU(3)_1 \times SU(3)_2 \times U(1)_{Y1} \times U(1)_{Y2} \times SU(2)_L \rightarrow SU(3)_{QCD} \times U(1)_{EM} \qquad (2)$$

where $SU(3)_1 \times U(1)_{Y1}$ ($SU(3)_2 \times U(1)_{Y2}$) generally couples preferentially to the third (first and second) generations. The $U(1)_{Yi}$ are just strongly rescaled versions of electroweak $U(1)_Y$. Hence we are advocating a kind of gauge group "replication" which is generation sensitive. $SU(3)_1 \times U(1)_{Y1}$ is assumed strong enough to form chiral condensates which will naturally be tilted in the top quark direction by the $U(1)_{Y1}$ couplings. This strong interaction is non-confining, since the theory spontaneously breaks down to ordinary QCD$\times U(1)_{EM}$ at the TEV scale by the technicolor gauge

[3] Else, we could try to use the $SU(2)$ degrees of freedom of the third generation, a possibility which we will not consider presently.

group G_{TC}. $U(1)_{Y1}$ and $U(1)_{Y2}$ are stronger than the usual $U(1)_Y$, and there need occur no significant fine-tuning to arrange a $\langle \bar{t}t \rangle$ condensate, but not a $\left\langle \bar{b}b \right\rangle$ condensate, by the simultaneous effects of $SU(3)_1$ and $U(1)_{Y1}$ in the gap equation. The b-quark mass is then an interesting issue, involving a combination of ETC effects and instantons in $SU(3)_1$. The θ-term in $SU(3)_1$ may ultimately be the origin of CKM CP-violation in these schemes. Above all, the new spectroscopy of such a system should begin to materialize indirectly in the third generation (e.g., in $Z \to \bar{b}b$) or perhaps at the Tevatron in top and bottom quark production. A triplet of strongly coupled pseudo-Nambu-Goldstone bosons (PNGB's), $\tilde{\pi}^a$, we dub "top-pions," near the top mass scale is a generic prediction of the models. The top-pions will have a decay constant of $f_\pi \approx 50$ GeV, and a strong coupling given by a Goldberger-Trieman relation, $g_{tb\pi} \approx m_t/\sqrt{2} f_\pi \approx 2.5$, potentially observable in $\tilde{\pi}^+ \to t + \bar{b}$ if $m_{\tilde{\pi}} > m_t + m_b$[4].

II. Topcolor Dynamics

We are relaxing the requirement that a top condensate account for the full ESB and we are generalizing the structure in the interest in naturalness. ESB can be primarily driven by a technicolor group G_{TC}, and/or TC can also provide condensates which generate the breaking of topcolor to QCD and $U(1)_Y$. The coupling constants (gauge fields) of $SU(3)_1 \times SU(3)_2$ are respectively h_1 and h_2 ($A^A_{1\mu}$ and $A^A_{2\mu}$) while for $U(1)_{Y1} \times U(1)_{Y2}$ they are respectively q_1 and q_2, ($B_{1\mu}, B_{2\mu}$). The $U(1)_{Yi}$ couplings

[4]Or the top quark may disappear into a dominant decay mode $t \to b + (\tilde{\pi}^+ \to c + \bar{b})$ if $m_t > m_{\tilde{\pi}} + m_b$ in which case top has not been detected at the Tevatron.

are then $q_i\frac{Y}{2}$, where Y is usual electroweak hypercharge. A $(3,\overline{3}) \times (q_1, \overline{q}_2)$ techni-condensate breaks $SU(3)_1 \times SU(3)_2 \times U(1)_{Y1} \times U(1)_{Y2} \rightarrow SU(3)_{QCD} \times U(1)_Y$ at a scale $\Lambda \gtrsim 240$ GeV, or it fully breaks $SU(3)_1 \times SU(3)_2 \times U(1)_{Y1} \times U(1)_{Y2} \times SU(2)_L \rightarrow SU(3)_{QCD} \times U(1)_{EM}$ at the scale $\Lambda_{TC} = 240$ GeV. This typically leaves a *residual global symmetry*, $SU(3)' \times U(1)'$, implying a degenerate, massive color octet of "colorons," B^A_μ, and a singlet heavy Z'_μ. The gluon A^A_μ and coloron B^A_μ (the SM $U(1)_Y$ field B_μ and the $U(1)'$ field Z'_μ), are then defined by orthogonal rotations with mixing angle θ $[\theta']$:

$$
\begin{array}{llll}
h_1 \sin\theta = g_3; & h_2 \cos\theta = g_3; & \cot\theta = h_1/h_2; & \dfrac{1}{g_3^2} = \dfrac{1}{h_1^2} + \dfrac{1}{h_2^2}; \\
q_1 \sin\theta' = g_1; & q_2 \cos\theta' = g_1; & \cot\theta' = q_1/q_2; & \dfrac{1}{g_1^2} = \dfrac{1}{q_1^2} + \dfrac{1}{q_2^2};
\end{array} \tag{3}
$$

and g_3 (g_1) is the QCD $(U(1)_Y)$ coupling constant at Λ_{TC}. We ultimately demand $\cot\theta \gg 1$ and $\cot\theta' \gg 1$ to select the top quark direction for condensation. The masses of the degenerate octet of colorons and Z' are given by $M_B \approx g_3\Lambda/\sin\theta\cos\theta$ $M_{Z'} \approx g_1\Lambda/\sin\theta'\cos\theta'$. The usual QCD gluonic ($U(1)_Y$ electroweak) interactions are obtained for any quarks that carry either $SU(3)_1$ or $SU(3)_2$ triplet quantum numbers (or appropriately scaled $U(1)_i$ couplings). Integrating out B and Z' we obtain an effective low energy four-fermion interaction:

$$
\mathcal{L}' = -\frac{4\pi\kappa}{M_B^2}\left[\bar{t}\gamma_\mu\frac{\lambda^A}{2}t + \bar{b}\gamma_\mu\frac{\lambda^A}{2}b\right]^2 - \frac{4\pi\kappa_{Y1}}{M_{Z'}^2}\left[\frac{1}{3}\bar{\psi}_L\gamma_\mu\psi_L + \frac{4}{3}\bar{t}_R\gamma_\mu t_R - \frac{2}{3}\bar{b}_R\gamma_\mu b_R\right]^2 \tag{4}
$$

where $\psi_{L,R} = \frac{1}{2}(1 \pm \gamma^5)\psi$, $\kappa = g_3^2\cot^2\theta/4\pi$ and $\kappa_{Y1} = g_1^2\cot^2\theta'/4\pi$, with cut-offs of M_B and $M_{Z'}$.

The symmetry breaking leading to the top mass is triggered by the interactions of eq.(4) and can be estimated in the Nambu-Jona-Lasinio (NJL) approximation. For sufficiently large κ the attractive four-fermion TopC interaction would alone trigger formation of a condensate, $\left\langle \bar{t}t + \bar{b}b \right\rangle$, which is globally custodially $SU(2)$ symmetric. However, the $U(1)_{Y1}$ force is attractive in the $\bar{t}t$ channel and repulsive in the $\bar{b}b$ channel. Thus, one obtains the pair of gap equations for m_t and m_b ($M_{Z'} \approx M_B$ for simplicity here):

$$
\begin{aligned}
m_t &= \frac{3}{2\pi}(\kappa + \frac{8}{27}\kappa_{Y1})m_t \left(1 - \frac{m_t^2}{M_B^2}\ln(M_B^2/m_t^2)\right) \\
m_b &= \frac{3}{2\pi}(\kappa - \frac{4}{27}\kappa_{Y1})m_b \left(1 - \frac{m_b^2}{M_B^2}\ln(M_B^2/m_t^2)\right)
\end{aligned}
\qquad (5)
$$

Demanding nonvanishing m_t and vanishing m_b, we require critical and subcritical combinations:

$$
\kappa + \frac{8}{27}\kappa_{Y1} > \kappa_{crit}; \qquad \kappa_{crit} > \kappa - \frac{4}{27}\kappa_{Y1}; \qquad (\kappa_{crit} = \frac{2\pi}{3} \text{ in NJL}). \qquad (6)
$$

We can readily satisfy eqs.(6) without fine-tuning. Note that in the color singlet channels the $U(1)_{Y1}$ effects are actually $1/N_c$. If $M_{Z'} << M_B$ then we should treat the $U(1)_{Y1}$ as a radiative enhancement (suppression) of the $\bar{t}t$ ($\bar{b}b$) channel. Moreover, an analysis of the full effective Lagrangian reveals that one obtains a composite 2 Higgs-doublet model. One doublet, H_1, couples to t_R and develops the VEV; the other, H_2, couples to b_R and remains a massive (non tachyonic) boundstate. In the limit of switching off κ_{Y1}, H_1 and H_2 form a (custodial) $SU(2)_c$ doublet and the effective Lagrangian is $SU(2)_c$ invariant. The techniquarks (Q_i), which have condensed by the confining TC interactions, have acquired constituent masses of order 500 GeV and can be neglected on the scales $\mu \sim m_t$ as well. Thus, $\left\langle \overline{Q}t \right\rangle$ condensates, which would break technicolor, do not form. Of course, the NJL approximation is crude, but as long as the associated phase transitions of the full strongly coupled theory are approximately second order, then analogous rough–tuning in the full theory should be possible.

Arranging that the couplings are simultaneously large at ~ 1 TeV is a further issue having to do with a GUT scale boundary condition. It suggests that low energy couplings are small because of the familiar imbedding relations of eq.(3), and GUT scale couplings are larger than usually assumed, perhaps $O(1)$. Further strong dynamics probably occurs in the "desert" (e.g. imbedding involving $SU(2)_L$, etc.). Of course, without knowing the ETC theory $\sim 10^5$ GeV, we cannot imagine reliable extrapolations to the GUT scale. In a theory like this we are clearly *a priori* abandoning the few "successful predictions" of perturbative (SUSY) unification.

ETC interactions (or fundamental Higgs) generate the light fermion masses, and give small contributions to the t and b quark masses as well. The ETC masses are potentially subject to resonant enhancements in the full theory, [5], and without significant fine–tuning we expect that the largest fermion mass scale that ETC need provide is $O(m_c) \sim 1.0$ GeV to $O(m_s) \sim 0.1$ GeV. As described below the b quark receives instanton contributions in the gauge group $SU(3)_1$. Since ETC is required to generate $O(1.0)$ to $O(0.1)$ GeV masses, it may need to be a walking ETC [6].

Since the top condensation is a spectator to the TC (or Higgs) driven ESB, there must occur a multiplet of top-pions. A chiral Lagrangian can be written:

$$L = i\overline{\psi}\partial\!\!\!/\,\psi - m_t(\overline{\psi}_L \Sigma P \psi_R + h.c.) - \epsilon m_t \overline{\psi} P \psi, \qquad P = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \tag{7}$$

and $\psi = (t, b)$, $\Sigma = \exp(i\tilde{\pi}^a \tau^a/\sqrt{2}f_\pi)$. When $\epsilon = 0$, eq.(7) is invariant under $\psi_L \to e^{i\theta^a\tau^a/2}\psi_L$, $\tilde{\pi}^a \to \tilde{\pi}^a + \theta^a f_\pi/\sqrt{2}$. Hence, the relevant currents are left-handed, $j^a_\mu = \psi_L \gamma_\mu \frac{\tau^a}{2}\psi_L$, and $< \tilde{\pi}^a | j^b_\mu | 0 >= \delta^{ab} f_\pi p_\mu/\sqrt{2}$. The Pagels-Stokar relation, eq.(1), then follows by demanding that the $\tilde{\pi}^a$ kinetic term is generated by integrating out the fermions. The top-pion decay constant estimated from eq.(1) using $\Lambda = M_B$ and $m_t = 175$ GeV is $f_\pi \approx 50$ GeV. The couplings of the top-pions to t and b take the form:

$$\frac{m_t}{\sqrt{2}f_\pi}\left[i\bar{t}\gamma^5 t\tilde{\pi}^0 + \frac{i}{\sqrt{2}}\bar{t}(1-\gamma^5)b\tilde{\pi}^+ + \frac{i}{\sqrt{2}}\bar{b}(1+\gamma^5)t\tilde{\pi}^- \right] \tag{8}$$

and the coupling strength is governed by the relation $g_{bt\tilde{\pi}} \approx m_t/\sqrt{2}f_\pi$.

The small ETC mass component of the top quark implies that the masses of the top-pions will depend upon ϵ and Λ. Estimating the induced top-pion mass from the fermion loop yields [7]:

$$m^2_{\tilde{\pi}} = \frac{N\epsilon m_t^2 M_B^2}{8\pi^2 f_\pi^2} = \frac{\epsilon M_B^2}{\log(M_B/m_t)} \tag{9}$$

where the Pagels-Stokar formula is used for f^2_π (with $k = 0$) in the last expression. For $\epsilon = (0.03,\ 0.1)$, $M_B \approx (1.5,\ 1.0)$ TeV, and $m_t = 180$ GeV this predicts $m_{\tilde{\pi}} = (180,\ 240)$ GeV. The bare value of ϵ, ϵ_0, generated at the ETC scale Λ_{ETC}, is subject to very large radiative enhancements by topcolor and $U(1)_{Y1}$ by factors of order $(\Lambda_{ETC}/M_B)^\gamma \sim 10^1$. Thus, we expect that a bare value of $\epsilon_0 \sim 0.005$ can produce sizeable $m_{\tilde{\pi}} > m_t$. Note that $\tilde{\pi}$ will generally receive gauge contributions to its mass; these are at most electroweak in strength, and therefore of order ~ 10 GeV.

The b quark receives mass contributions from ETC of $O(0.1)$ to $O(1.0)$ GeV, but also an induced mass from instantons in $SU(3)_1$ which may be dominant. The instanton effective Lagrangian may be approximated by the 't Hooft flavor determinant (we place the cut-off at M_B):

$$L_{eff} = \frac{k}{M_B^2} e^{i\theta_1} \det(\overline{q}_L q_R) + h.c. = \frac{k}{M_B^2} e^{i\theta_1} [(\overline{b}_L b_R)(\overline{t}_L t_R) - (\overline{t}_L b_R)(\overline{b}_L t_R)] + h.c. \quad (10)$$

where θ_1 is the $SU(3)_1$ strong CP-violation phase. θ_1 cannot be eliminated because of the ETC contribution to the t and b masses. It can lead to induced scalar couplings of the neutral top-pion, as in ref.[7], and an induced CKM CP-phase, however, we will presently neglect the effects of θ_1 (these effects will be small, of order ϵ [7]).

We generally expect $k \sim 1$ to 10^{-1} as in QCD. Bosonizing in fermion bubble approximation $\overline{q}^i_L t_R \sim \frac{N}{8\pi^2} m_t M_B^2 \Sigma^i_1$, where $\Sigma^i_j = \exp(i\tilde{\pi}^a \tau^a/\sqrt{2} f_\pi)^i_j$ yields:

$$L_{eff} \to \frac{Nkm_t}{8\pi^2} e^{i\theta} [(\overline{b}_L b_R)\Sigma^1_1 + (\overline{t}_L b_R)\Sigma^2_1 + h.c.] \quad (11)$$

This implies an instanton induced b-quark mass:

$$m_b^\star \approx \frac{3km_t}{8\pi^2} \sim 6.6\ k\ GeV \quad (12)$$

This is not an unreasonable estimate of the observed b quark mass as we might have feared it would be too large. Expanding Σ^i_j, there also occur induced top-pion couplings to b_R proportional to $m_b^\star$:

$$\frac{m_b^\star}{\sqrt{2} f_\pi} (i\overline{b}\gamma^5 b\tilde{\pi}^0 + \frac{i}{\sqrt{2}}\overline{t}(1+\gamma^5)b\tilde{\pi}^+ + \frac{i}{\sqrt{2}}\overline{b}(1-\gamma^5)t\tilde{\pi}^-) \quad (13)$$

III. Some Observables

The t and b quarks appearing in, e.g., eq.(8), are current-basis quarks. The combination of TopC masses and ETC masses yields a general fermion mass matrix. Diagonalization leads to the CKM matrix. For the up-type (down-type) quarks we take the field redefinition to be given by unitary matrices $U_{L,R}$ and $D_{L,R}$, where the CKM matrix is $V = U_L^\dagger D_L$. The leading flavor changing interactions involve then mixing to the 2nd generation:

$$\frac{m_t}{\sqrt{2}f_\pi}\left[i\tilde{\pi}^0(\bar{t}_R c_L U_{L,tc} + \bar{c}_R t_L U^*_{R,tc}) + i\sqrt{2}\tilde{\pi}^+(\bar{t}_R s_L D_{L\,bs} + \bar{c}_R b_L U^*_{Rtc}) + h.c.\right] \quad (14)$$

Exchange of top-pions (as well as topgluons, Z', and the deeply bound H_2) generates flavor changing effects. By and large we find that these can be tolerably small in the low lying states, up to the B mesons, but may show up in processes like $Z \to \bar{b}b$.

(i) $b \to s + \gamma$: The top–pion interactions lead in principle to contributions to the process $b \to s+\gamma$. We estimate the ratio to the SM result (we expect QCD corrections to largely cancel):

$$\frac{B_{\tilde{\pi}}(s \to \gamma b)}{B_{SM}(s \to \gamma b)} \approx (1+\omega)^2 \qquad \omega \approx \left(\frac{D_{Lbs}v_{wk}}{V_{bs}f_\pi}\right)^2 \frac{A(m_t^2/m_{\tilde{\pi}}^2)}{3A(m_t^2/M_W^2)} \quad (15)$$

[In lowest order we have the standard model contribution plus the top-pion contribution $C_7 = -\frac{1}{2}A(m_t^2/M_W^2) - (c)^2 A(m_t^2/m_{\tilde{\pi}}^2)/6$ where $c = D_{Lbs}v_{wk}/V_{bs}f_\pi$, comparing eq.(14) to Grinstein *et al.* [8] eqs.(2.3, 2.29b); c is essentially $\cot\beta$ in model I, and there is no $B(y)$ in the present case.] For us, $A(m_t^2/m_{\tilde{\pi}}^2)/3A(m_t^2/M_W^2) \approx 0.15$. The SM result with QCD saturates the observed branching ratio. However, the QCD corrections are very large, and one cannot assume the NNLO QCD effects are not also significant. Conservatively, we might require, $\omega \lesssim 0.1$, hence, $D_{L\,bs}/V_{bs} \lesssim 0.2$ using $v_{wk}/f_\pi \sim 3.5$. Since $D_{L\,bs}$ is not measured (only the CKM element is) this constraint is not strictly binding. Identifying, however, $D_{L\,bs}$ with the corresponding element in the square root of the CKM matrix would favor $\frac{D_{L\,bs}}{V_{bs}} \sim \frac{1}{2}$, the constraint becomes slightly binding. We note that the situation is not completely settled [8]. There are, of course, other apparently smaller effects due to Z', b–coupled top-pions from instantons, and the deeply bound Higgs, H_1 and H_2.

(ii) $\Delta S = 2$ and $\Delta C = 2$ Effects: There occur FCNC effects induced by the CKM mixing in the mass basis to the current basis third generation. In the current basis, we have the neutral top–pion coupled to the t and b quarks as $i(m_t\bar{t}\gamma^5 t + m_b^*\bar{b}\gamma^5 b)\pi^0/\sqrt{2}f_\pi$. Exchange of these neutrals will induce $\Delta C = 2$ and $\Delta S = 2$ effective interactions when we rotate the t and b quarks to their mass eigenbases, $t \to t + O(\lambda^2)c + O(\lambda^3)u$ and $b \to b + O(\lambda^2)s + O(\lambda^3)d$. Thus, we obtain effective $\Delta C = 2$ and $\Delta S = 2$ interactions:

$$\frac{m_t^2 O(\lambda^{10})}{2m_{\tilde{\pi}}^2 f_\pi^2}\bar{c}\gamma^5 u\bar{c}\gamma^5 u + \frac{m_b^2 O(\lambda^{10})}{2m_{\tilde{\pi}}^2 f_\pi^2}\bar{s}\gamma^5 d\bar{s}\gamma^5 d + ... \tag{16}$$

With $\lambda \sim O(10^{-1})$, $m_{\tilde{\pi}} \gtrsim m_t$, these are of an acceptable strength, e.g., in comparison to $(m_c^2\lambda^2/128\pi^2 v_{wk}^4)\bar{s}\gamma^\mu d\bar{s}\gamma_\mu d$. Charged top–pions give box diagrams of a similar strength.

(iii) $t \to \tilde{\pi}^+ + b$: The mode $t \to \tilde{\pi}^+ + b$, if kinematically allowed, is ruled out if the top is seen to have the conventional rate $t \to W^+ + b$, because the $\tilde{\pi}$ coupling is very strong. Small $m_{\tilde{\pi}}$ is disfavored by $b \to s + \gamma$ in any case. From our perspective the observation of a strongly coupled $\tilde{\pi}^+ \to t + \bar{b}$ is a natural consequence of new strong dynamics associated with the generation of the top quark mass. The $\tilde{\pi}^+$ is expected

to be a broad state and may be difficult to detect; the $\tilde{\pi}^0$ may be narrow if $m_{\tilde{\pi}} < 2m_t$ and would decay through anomalies to gg and $\gamma\gamma$, (and to $\bar{b}b$ through eq.(13)) and imitates some effects of states in two-scale technicolor (in contrast to [9] we do not expect color octet PNGB's associated with the $f_\pi \sim 50$ GeV scale).

(v) R_b, $\sigma_{\bar{b}b}$, $\sigma_{\bar{t}t}$: It is particularly intriguing that, while ETC interactions generally lead to a suppression [10], *TopC schemes can contain significant enhancements of $R_b = \Gamma(Z \to \bar{b}b)/\Gamma(Z \to \overline{hadrons})$ [11].* In the models we have described both the topgluons and the Z' will enhance R_b. This is a desirable feature, because when the observed LEP central value for R_b is fit topgluons alone give too much enhancement to top production at the Tevatron [12, 11]. On the other hand Z' can enhance R_b with smaller impact upon $\sigma_{\bar{t}t}$. In our present schemes we might expect $M_{Z'}, M_B \sim 500-1000$ GeV to accomodate acceptable observable effects in top production and R_b. The Z' may then be observable in $\sigma_{\bar{b}b}$ at the Tevatron. These potentially important effects, as well as S, T and U, will be discussed in greater detail elsewhere.

IV. An Example of a New Model

We note that a number of new models is suggested by this approach. In model building we have several options: (I) TC breaks both the EW interactions and the TopC interactions; (II) TC breaks EW, and something else breaks TopC; (III) TC breaks only TopC and something else drives ESB (e.g., a fourth generation condensate driven by TopC). We presently show an example of a very skeletal model in category (I) in Table I.

For simplicity we choose $G_{TC} = SU(3)_{TC1} \times SU(3)_{TC2}$ and we have indicated the $U(1)_i$ hypercharge assignments. The leptons and other techni–fields that are required to cancel anomalies are not shown. The techniquark condensate $\left\langle \overline{Q}Q \right\rangle$, breaks $SU(3)_1 \times SU(3)_2 \times U(1)_{Y1} \times U(1)_{Y2} \to SU(3) \times U(1)_Y$, but does not break $SU(2)_L \times U(1)_Y$. $SU(2)_L \times U(1)_Y \to U(1)_{EM}$ occurs through the condensate of techniquarks $T_{L,R}$ which feel the weaker $SU(3)_{TC2} \times U(1)_2$ interactions, thus $\left\langle \overline{T}T \right\rangle$ is approximately custodially $SU(2)$ invariant. The third generation develops the tilted condensate through the $SU(3)_1 \times U(1)_1$ interaction with rough tuning of the tilting. We have also assigned the second generation (c, s) to the stronger $U(1)_1$ perhaps permitting a resonant enhancement of the ETC mass scale for charm and strange, so we assume that the $U(1)_1$ coupling is subcritical by itself. The pattern suggests a further "$SU(3)_3$" replication for the first generation.

We believe these models offer new insights into the dynamical origin of fermion masses and electroweak symmetry breaking, and merit further study. Further model studies and phenomenological applications will be presented elsewhere. Our key result is that, if the top mass arises by a dynamical chiral symmetry breaking, together with some additional mechanism leading to the light quark masses and electroweak breaking (TC/ETC or Higgs), then there will necessarily occur a triplet of top-pions. This result is generic to all such models and possibly testable in the foreseeable future.

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field	$SU(3)_{TC1}$	$SU(3)_{TC2}$	$SU(3)_1$	$SU(3)_2$	$SU(2)_L$	$U(1)_{Y1}$	$U(1)_{Y2}$
Q_L	3	1	3	1	1	1	0
Q_R	3	1	1	3	1	0	1
$T_L = (T,B)_L$	1	3	1	1	2	0	$\frac{1}{3}$
$T_R = (T,B)_R$	1	3	1	1	1	0	$(\frac{4}{3},\ -\frac{2}{3})$
$t_L = (t,b)_L$	1	1	3	1	2	$\frac{1}{3}$	0
$t_R = (t,b)_R$	1	1	3	1	1	$(\frac{4}{3},\ -\frac{2}{3})$	0
$c_L = (c,s)_L$	1	1	1	3	2	$\frac{1}{3}$	0
$c_R = (c,s)_R$	1	1	1	3	1	$(\frac{4}{3},\ -\frac{2}{3})$	0
$u_L = (u,d)_L$	1	1	1	3	2	0	$\frac{1}{3}$
$u_R = (u,d)_R$	1	1	1	3	1	0	$(\frac{4}{3},\ -\frac{2}{3})$

Table I: Gauge charge assignments of quarks in a schematic model $SU(3)_{TC1}\times SU(3)_{TC2}\times SU(3)_1\times SU(3)_2\times SU(2)_L\times U(1)_{Y1}\times U(1)_{Y2}$. Additional fields (such as leptons) required for anomaly cancellation and are not shown. $\langle\overline{Q}Q\rangle$ breaks $SU(3)_1 \times SU(3)_2 \times U(1)_{Y1} \times U(1)_{Y2} \to SU(3) \times U(1)_Y$, and $\langle\overline{T}T\rangle$ breaks $SU(2)_L \times U(1)_Y \to U(1)_{EM}$. $\langle\bar{t}t\rangle$ forms via $SU(3)_1 \times U(1)_{Y1}$.