NONOBLIQUE EFFECTS AND WEAK-ISOSPIN BREAKING FROM EXTENDED TECHNICOLOR

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ABSTRACT

Several aspects of the flavor-diagonal extended technicolor (ETC) gauge boson are reviewed. Among them are an increase of R_b that could explain the LEP R_b excess, a sizable, positive correction to the τ asymmetry parameter A_τ, and a contribution to the weak-isospin breaking ρ parameter that is just barely acceptable by present data.

1. Introduction

In extended technicolor[1] models, the low ETC scale for the third family often implies large corrections to the standard model physics involving the third family of quarks and leptons. Indeed, the third-family flavor physics could be the key to understanding the origin of top quark mass generation and possibly of electroweak symmetry breaking[2]. As the electroweak measurements have reached a precision at the one percent level (as in $R_b \equiv \Gamma_b/\Gamma_{\text{had}} = 0.2202 \pm 0.0020$ measured at LEP) or better (as in $\Delta\rho_{new} = \alpha T \leq 0.4\%$), severe constraints can be imposed on models of dynamical electroweak symmetry breaking[3]. It is therefore both timely and important to examine various models of new physics and to see what we can learn from experiments.

In this talk, we review the non-oblique effects in a standard ETC[4,5,6,7,8,9] where the ETC bosons are standard model singlets.[a] We will especially note that flavor-diagonal ETC exchange could explain the LEP R_b excess,[b] however the same dynamics gives a positive contribution to the weak-interaction ρ parameter which seems just barely consistent with global fits to data.

2. The $Zb\bar{b}$ Vertex

We consider a one-family TC model with technifermions belonging to the fundamental representation of an $SU(N)_{\text{TC}}$ technicolor group and carrying the same color and electroweak quantum numbers as their standard model counterparts. The sideways ETC bosons mediate transitions between technifermions and ordinary fermions, and the diagonal ETC boson couples technifermions (and ordinary fermions) to them-

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[a] Corresponding analysis for non-commuting ETC models has also be performed[10].
[b] A new gauge boson[2] existing in other models of dynamical symmetry breaking plays a similar role.

selves. The traceless diagonal ETC generator commutes with TC and is normalized as diag$\frac{1}{\sqrt{2N(N+1)}}(1,\cdots,1,-N)$. The effective ETC lagrangian can thus be written as

$$\mathcal{L}_{\rm ETC} \;=\; -\frac{1}{\sqrt{2}}\sum_{i=1}^{N}(X_S^{i,\mu}J_{S,i,\mu}+X_{S,i,\mu}J_S^{i,\mu})-X_{D,\mu}J_D^{\mu}, \qquad (1)$$

where i is the technicolor index, and $X_S^{i,\mu}$ and $X_{D,\mu}$ stand for the sideways and diagonal ETC bosons respectively. The sideways and diagonal ETC currents are given by

$$\begin{aligned} J_{S,i,\mu} &= g_{E,L}\bar{Q}_{iL}\gamma_\mu\psi_L+g_{E,R}^U\bar{U}_{iR}\gamma_\mu t_R+g_{E,R}^D\bar{D}_{iR}\gamma_\mu b_R, & (2)\\ J_S^{i,\mu} &= (J_{S,i}^{\mu})^\dagger, & \\ J_D^{\mu} &= \frac{1}{\sqrt{2N(N+1)}}g_{E,L}(\bar{Q}_L\gamma^\mu Q_L-N\bar{\psi}_L\gamma^\mu\psi_L) & (3)\\ &\quad+\frac{1}{\sqrt{2N(N+1)}}g_{E,R}^U(\bar{U}_R\gamma^\mu U_R-N\bar{t}_R\gamma^\mu t_R) & \\ &\quad+\frac{1}{\sqrt{2N(N+1)}}g_{E,R}^D(\bar{D}_R\gamma^\mu D_R-N\bar{b}_R\gamma^\mu b_R), & \end{aligned}$$

where $Q\equiv(U,D)$ is the techniquark doublet, $\psi\equiv(t,b)$ is the quark doublet, and summation over color (and technicolor) indices is implied.

To further simplify our analysis, we assume a technifermion mass spectrum[11] where the weak scale is dominated by the nearly degenerate techniquarks, and where the splitting between the lighter technileptons gives a negative contribution to the S parameter. We therefore have $v^2\simeq N_C f_Q^2\simeq(250\mathrm{GeV})^2$, where $N_C=3$ is the number of colors, and f_Q is the Goldstone boson (GB) decay constant for the techniquark sector. ETC corrections to the $Zb\bar{b}$ vertex are similarly dominated by techniquarks. For an estimate of the ETC correction to R_b, we only need to consider its contribution to the left-handed Zbb coupling g_L^b.

2.1. Sideways ETC Exchange

The sideways ETC effects on R_b have been discussed previously[4,5,6], and we briefly review the estimate for our one-family TC model. The relevant four-fermion operator can be first Fierz-transformed into the product of a quark-current and a techniquark-current,

$$\begin{aligned} \mathcal{L}_{4f}^S &= -\frac{g_{E,L}^2}{2m_{X_S}^2}(\bar{Q}_L\gamma^\mu\psi_L)(\bar{\psi}_L\gamma_\mu Q_L)\\ &\longrightarrow -\frac{g_{E,L}^2}{2m_{X_S}^2}\frac{1}{2N_C}\sum_{a=1}^{3}(\bar{\psi}_L\gamma_\mu\tau_a\otimes 1_3\psi_L)(\bar{Q}_L\gamma^\mu\tau_a\otimes 1_3 Q_L)+\cdots, \qquad (4)\end{aligned}$$

where τ_a's are the Pauli matrices, 1_3 denotes the unit matrix in color space, and the other pieces do not contribute to the $Zb\bar{b}$ vertex.

The techniquark current can then be replaced by the corresponding sigma model current[12] below the TC chiral symmetry breaking scale,

$$\bar{Q}_L\gamma^\mu\tau_a\otimes 1_3 Q_L \to i\frac{f_Q^2}{2}\mathrm{Tr}(\Sigma^\dagger\tau_a\otimes 1_3 D^\mu\Sigma) \stackrel{\Sigma\equiv 1}{=} -\frac{g}{c}Z^\mu N_C f_Q^2\frac{\delta^{3a}}{2} + W^{\pm,\mu} \text{ piece}, \quad (5)$$

where Σ is the $2N_C$ by $2N_C$ exponentiated Goldstone boson matrix transforming as $\Sigma \to L\Sigma R^\dagger$ under $SU(2N_C)_L\otimes SU(2N_C)_R$, $D_\mu\Sigma$ is its electroweak covariant derivative, g is the $SU(2)_L$ gauge coupling, and $c = \cos\theta_W$ (θ_W is the Weinberg angle). The sideways ETC correction to g_L^b is obtained after substituting Eq. (5) into Eq. (4),

$$\delta g_L^b(\text{sideways}) \;=\; \frac{g_{E,L}^2 f_Q^2}{8m_{X_S}^2}. \quad (6)$$

As this is opposite in sign to the standard model tree level value $g_L^b = -\frac{1}{2}+\frac{1}{3}s^2$, sideways ETC exchange decreases Γ_b relative to the standard model prediction. Note that Eq. (6) is directly related to the TC dynamics contributing to the weak scale, and is not dependent on the low energy effective lagrangian approximation. The same is true for Eq. (9).

2.2. Diagonal ETC Exchange

The diagonal ETC effect can be similarly analysed. We start with the dominant four-fermion operator induced by flavor-diagonal ETC boson exchange,

$$\mathcal{L}_{4f}^D = \frac{1}{4m_{X_D}^2}\frac{1}{N+1}g_{E,L}(g_{E,R}^U - g_{E,R}^D)(\bar{Q}_R\tau_3\gamma^\mu Q_R)(\bar{\psi}_L\gamma_\mu\psi_L), \quad (7)$$

where color and technicolor summation is implied. Below the TC chiral symmetry breaking scale, the right-handed techniquark current is replaced by the corresponding sigma model current

$$\bar{Q}_R\tau_3\otimes 1_3\gamma^\mu Q_R \to i\frac{f_Q^2}{2}\mathrm{Tr}(\Sigma\tau_3\otimes 1_3(D^\mu\Sigma)^\dagger) \stackrel{\Sigma\equiv 1}{=} \frac{g}{c}Z^\mu\frac{N_C f_Q^2}{2}. \quad (8)$$

Substituting Eq. (8) into Eq. (7), we get the diagonal ETC correction to g_L^b,

$$\delta g_L^b(\text{diagonal}) \;\simeq\; -\frac{f_Q^2}{8m_{X_D}^2}\frac{N_C}{N+1}g_{E,L}(g_{E,R}^U - g_{E,R}^D). \quad (9)$$

In extended technicolor, masses of the t and b are given by $m_t \sim g_{E,L}g_{E,R}^U < \bar{U}U >$ and $m_b \sim g_{E,L}g_{E,R}^D < \bar{D}D >$ respectively. We conclude from $m_t > m_b$ that

$g_{E,L}(g^U_{E,R} - g^D_{E,R}) > 0$. Contrary to a previous estimate[7], diagonal ETC exchange gives a negative correction to g^b_L and increases Γ_b[9].

2.3. R_b Constraint

The total ETC correction is obtained by combining Eqs. (6) and (9),

$$\begin{aligned} \delta g^b_{L,\mathrm{ETC}} &\simeq -\frac{f_Q^2}{8}[\frac{g_{E,L}(g^U_{E,R}-g^D_{E,R})}{m^2_{X_D}}\frac{N_C}{N+1} - \frac{g^2_{E,L}}{m^2_{X_S}}] \\ &\overset{N=2}{\simeq} -\frac{v^2}{24 m^2_{X_S}}[\frac{m^2_{X_S}}{m^2_{X_D}} g_{E,L}(g^U_{E,R}-g^D_{E,R}) - g^2_{E,L}]. \end{aligned} \tag{10}$$

The two contributions are seen to be comparable, and we have taken $N = 2$ above as suggested by the experimental value of the S parameter. There are of course corrections from pseudo-Goldstone-bosons (PGB's) that need to be taken into account. These have been estimated for QCD-like TC[8], and could be neglected in ETC models with strong high momentum enhancement[13].

A strong constraint can be obtained by simply requiring that the diagonal ETC effect be as large as the effect seen at LEP. Denoting the generic ETC couplings by g_E and ETC boson masses by m_{ETC}, we have $\delta g^b_{L,\mathrm{ETC}} \sim -\frac{v^2}{24}\frac{g^2_E}{m^2_{\mathrm{ETC}}}$ from diagonal ETC. This gives a positive correction to R_b,

$$\frac{\delta R_b}{R_b} \simeq (1-R_b)\frac{2 g^b_L \delta g^b_L}{{g^b_L}^2 + {g^b_R}^2} \sim 0.9\% \times \frac{g^2_E}{(m_{\mathrm{ETC}}/\mathrm{TeV})^2}, \tag{11}$$

where the value $s^2 = 0.232$ has been used. For this to agree with LEP measurement, we need the ETC scale to be

$$g^2_E/m^2_{\mathrm{ETC}} \;\sim\; (2\pm 1)/\mathrm{TeV}^2. \tag{12}$$

In strong ETC, this corresponds to $m_{\mathrm{ETC}} \sim 3 - 6$ TeV assuming $g^2_E/4\pi^2 \simeq 1$, and unlike QCD-like TC models[4] there is no simple relation between R_b and m_t[6].

3. The τ Asymmetry

Due to the $1/(1-4s^2)$ enhancement, A_τ is particularly sensitive to new physics. For the assumed technifermion mass spectrum, the sideways ETC effect is negligible compared to the diagonal ETC effect, and the ETC correction to the $Z\tau\tau$ couplings can be simply estimated,

$$\delta g^\tau_{L,\mathrm{ETC}} \simeq -\frac{f_Q^2}{8}\frac{g^\tau_{E,L}(g^U_{E,R}-g^D_{E,R})}{m^2_{X_D}}\frac{N_C}{N+1} \tag{13}$$

$$\delta g^\tau_{R,\mathrm{ETC}} \simeq -\frac{f_Q^2}{8}\frac{g^\tau_{E,R}(g^U_{E,R}-g^D_{E,R})}{m^2_{X_D}}\frac{N_C}{N+1} \tag{14}$$

where $g^\tau_{E,L}$ and $g^\tau_{E,R}$ are the ETC couplings for τ_L and τ_R respectively.

Assuming the ETC couplings are comparable (the fermion mass spectrum could partly arise from the hierarchy in the technifermion condensates), and taking $N=2$ and $g_E^2/m_{\rm ETC}^2 \sim (2\pm1)/{\rm TeV}^2$, we have $\delta g^\tau_{L,{\rm ETC}} \sim \delta g^\tau_{R,{\rm ETC}} \sim -(5.0\pm2.5)\times10^{-3}$. The ETC correction to A_τ is then

$$\delta A_\tau/A_\tau({\rm ETC}) \;\; \sim \;\; 0.28\pm0.14 \tag{15}$$

Note that this could be significantly reduced if τ couples to the technifermion sector at a higher ETC scale than the t quark. Assuming e, μ universality, the experimental value for $\delta A_\tau/A_\tau$ can be extracted[2] from lepton asymmetry measurements at LEP[14],

$$\delta A_\tau/A_\tau({\rm exp}) \;\; = \;\; 0.14\pm0.10. \tag{16}$$

It is seen that future lepton asymmetry measurements can have nontrivial implications for the lepton sector in ETC.

4. The ρ Parameter

For the assumed technifermion mass spectrum in the one-family TC model, there are contributions to the weak-interaction ρ parameter from the TC sector[11], namely from the technileptons and the PGBs. ETC interactions could also give a sizable correction, and the most important ETC effect comes from the diagonal-ETC-induced four-techniquark operator,

$$\mathcal{L}^{\Delta\rho}_{4f} \;\; = \;\; -\frac{1}{16N(N+1)}\frac{(g^U_{E,R}-g^D_{E,R})^2}{m^2_{X_D}}(\bar{Q}_R\tau_3\gamma^\mu Q_R)(\bar{Q}_R\tau_3\gamma_\mu Q_R), \tag{17}$$

The leading contribution from this operator can be easily gotten by use of Eq. (8),

$$\Delta\rho_{\rm ETC} \simeq \frac{v^2}{8N(N+1)}\frac{(g^U_{E,R}-g^D_{E,R})^2}{m^2_{X_D}} \simeq 0.13\% \times \frac{(g^U_{E,R}-g^D_{E,R})^2}{(m_{X_D}/{\rm TeV})^2}. \tag{18}$$

And for $(g^U_{E,R}-g^D_{E,R})^2/m^2_{X_D} \sim g_E^2/m^2_{\rm ETC} \sim (2\pm1)/{\rm TeV}^2$, this gives a correction

$$\Delta\rho_{\rm ETC} \;\; \sim \;\; (0.26\pm0.13)\% \tag{19}$$

which is barely consistent with recent global fits to data[16]. The ETC effect on the S parameter is however, negligible compared to the TC contributions. We refer the reader to ref. [3] for a more complete review on weak-isospin breaking in dynamical electroweak symmetry breaking.

5. Conclusion

An ETC scale as low as $g_E^2/m^2_{\rm ETC} \sim (2\pm1)/{\rm TeV}^2$ is required for diagonal ETC to result in a correction to R_b as large as seen at LEP. This makes the diagonal ETC contribution to the ρ parameter barely acceptable. Diagonal ETC could also give a large and positive correction to A_τ if the τ couples at the same low ETC scale as the top quark.

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1. S. Dimopoulos and L. Susskind, *Nucl. Phys.* **B155** (1979) 237; E. Eichten and K. Lane, *Phys. Lett.* **B90** (1980) 125.
2. B. Holdom, these proceedings and *Phys. Lett.* **B339** (1994) 114.
3. R.S. Chivukula, B.A. Dobrescu, and J. Terning, these proceedings, hep-ph/9506450.
4. R.S. Chivukula, S.B. Selipsky, and E.H. Simmons, *Phys. Rev. Lett.* **69** (1992) 575.
5. R.S. Chivukula, E. Gates, E.H. Simmons, and J. Terning, *Phys. Lett.* **B311** (1993) 157.
6. N. Evans, *Phys. Lett.* **B331** (1994) 378.
7. N. Kitazawa, *Phys. Lett.* **B313** (1993) 395.
8. Z. Xiao *et al.*, *Phys. Rev.* **D49** (1994) 5949.
9. G.-H. Wu, *Phys. Rev. Lett.* **74** (1995) 4137.
10. R.S. Chivukula, E.H. Simmons, and J. Terning, *Phys. Lett.* **B331** (1994) 383.
11. T. Appelquist and J. Terning, *Phys. Lett.* **B315** (1993) 139.
12. H. Georgi, *Weak Interactions and Modern Particle Theory*, Benjamin-Cummings, Menlo Park, 1984.
13. T. Appelquist, M. Einhorn, T. Takeuchi, and L.C.R. Wijewardhana, *Phys. Lett.* **B220** (1989) 223; V.A. Miransky and K. Yamawaki, *Mod. Phys. Lett.* **A4** (1989) 129;
14. A. Kounine, talk presented at the Third Workshop on Tau Lepton Physics, Montreux, Switzerland, Sept. 19-22, 1994.
15. T. Appelquist, M. Bowick, E. Cohler, and A. Hauser, *Phys. Rev. Lett.* **53** (1984) 1523.
16. See for example, J. Erler and P. Langacker, University of Pennsylvania report number UPR-0632T, hep-ph/9411203, 1994.