A note on the coupling of the techni-dilaton to the weak bosons

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In this note, we study the coupling of the techni-dilaton to the weak bosons. We consider two cases: (1) The dilaton directly couples to the weak bosons similarly to the SM. (2) The coupling in question is effectively induced only through the techni-fermion loops. In both cases, we find that the coupling is essentially determined by the mass-squared of the weak bosons over the dilaton decay constant.

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One of the most important aims at the Tevatron and at the CERN Large Hadron Collider (LHC) is to discover the Higgs boson. The direct searches of the standard model (SM) Higgs boson at the LEP have set limits on the Higgs mass to be larger than 114.4 GeV [1]. Recently, the mass ranges of the SM Higgs boson from 114 GeV to 600 GeV have been narrowed down to several windows and slits [2–4]. The fourth generation model [5–7] are also constrained [2, 8]. Besides, these results impact on several classes of the top condensate models [9].

A heavy Higgs boson can be a signal of the existence of models beyond the SM (BSM), because non-standard contributions to the $S$ and $T$ parameters [10] are required for consistency with the LEP precision measurements [1]. Such a class of the models contains the walking technicolor (WTC) scenario [11–14].

It is believed that in the WTC, there appears a scalar particle, so-called the techni-dilaton (TD), which is the pseudo Nambu-Goldstone (NG) boson associated with the scale symmetry breaking [12, 15]. The TD mass near the critical point has been suggested as $M_{TD} \sim \sqrt{2} m$ in the context of the gauged Nambu-Jona-Lasinio (NJL) model [16], where $m$ represents the dynamically generated fermion mass. The TD mass in the criticality limit is discussed recently in Refs. [17, 18].

In the previous work [19], we have studied the yukawa couplings of the SM fermions in the WTC, because the gluon fusion process, which is important in the heavy Higgs searches, depends on the magnitude of the yukawa coupling in addition to the trivial factor arising from the number of the extra heavy colored particles.

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The axial current correlator in the momentum space is

$$F.T. i(x)J_A^\mu(x)J_A^\nu(0)|0\rangle = \left(g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}\right)\Pi_A(q^2).$$

The vacuum polarization function $\Pi_A$ is characterized by

$$\Pi_A(0) = F_\pi^2.$$  \hspace{1cm} (4)

This relation plays an important role in our approach. The $\sigma_T$ coupling to $J_A^\mu$ at the zero momentum transfer is just like the mass insertion: Note that the identity holds

$$\frac{1}{f-m} y_T \frac{1}{f-m} = y_T \frac{1}{\partial m} \frac{1}{f-m},$$

where $m$ and $y_T$ are the dynamically generated TF mass and the Yukawa coupling, respectively. We can then obtain the coupling of $\sigma_T$ to $J_A^\mu$ at zero momentum simply by

$$g_{\sigma_T AA}(0) = y_T \frac{\partial \Pi_A(0)}{\partial m}.$$  \hspace{1cm} (6)

Because $F_\pi$ is generated through the TF loop effects, $F_\pi$ should be proportional to $m$, i.e., $F_\pi = \kappa m$, when we take the infinite limit of the ETC scale. Even in a realistic situation with a finite ETC scale $\sim \mathcal{O}(1000 \text{ TeV})$, we expect that $F_\pi$ does not strongly depend on the ETC scale. One could find the numerical factor $\kappa$ in Ref. [19], $\kappa \equiv \kappa_F \sqrt{N_{TC}/(2\pi)}$ with $\kappa_F \simeq 1.4 - 1.5$ and $N_{TC}$ being the number of the color of the TC gauge group, where the Pagels-Stokar formula \cite{24} is employed. Then Eq. (6) yields

$$g_{\sigma_T AA}(0) = \frac{2F_\pi^2}{m}. \hspace{1cm} (7)$$

Attaching $W^\mu$ to $J_A^\mu$, we finally obtain the coupling of the TD to the weak bosons at zero momentum,

$$g_{\sigma_T WW}(0) = \frac{2M_W^2}{m}. \hspace{1cm} (8)$$

The two cases are conceptually different. However, when the yukawa coupling is like the SM, $y_T = m/F_\sigma$, Eq. (8) formally agrees with Eq. (2). The yukawa coupling was also estimated as $y_T = (3 - \gamma_m)m/F_\sigma$ with the anomalous dimension $\gamma_m (\simeq 1)$ for the model in Ref. [15], where the four-fermion interactions were incorporated, $\mathcal{L} = \mathcal{L}_{TC} + G_1(TT)^2 + G_2(TT)(f f) + G_3(f f)^2$ with $\mathcal{L}_{TC}$ standing for the TC gauge theory, and $T$ and $f$ being the TF’s and the SM fermions, respectively. If so, this suggests that $g_{\sigma_T WW}$ is changed by the additional factor $(3 - \gamma_m)$ from Eq. (2). Therefore we conclude that the coupling of the TD to the weak bosons is essentially determined by the mass-squared of the weak bosons over the TC decay constant.

Although we have estimated the coupling $g_{\sigma_T WW}$ at zero momentum, one might expect that the on-shell one is not so far from these estimates. Strictly speaking, the TF mass function in the internal line is not a constant $m$. In sufficiently low energy, however, this would not affect the estimate so much.

The results derived in this note mean that the (effectively induced) operator $\bar{f}LW_{\mu\nu}W^{\mu\nu}$ yields the coupling between the TD and the weak bosons, similarly to the SM. The earlier argument in Ref. [25] contradicted ours, i.e., they argued that the higher dimensional operator $\bar{f}L W_{\mu\nu} W^{\mu\nu}$ gave the $\sigma_T - W-W$ coupling when the TD couples to $W$ only through the TF-loop. In the end they have revised it, following our results \cite{26}.

In any case, the Higgs boson might be revealed soon. What exciting data will be supplied at the LHC and the Tevatron?

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