PHYSICAL REVIEW D **84,** 111901(R) (2011)

# Note on the coupling of the technidilaton to the weak bosons

Michio Hashimoto*

*Chubu University, 1200 Matsumoto-cho, Kasugai-shi, Aichi, 487-8501, Japan*

(Received 16 September 2011; published 27 December 2011)

In this note, we study the coupling of the technidilaton to the weak bosons. We consider two cases: (1) The dilaton directly couples to the weak bosons in a similar way as in the standard model. (2) The coupling in question is effectively induced only through the technifermion 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.

DOI: 10.1103/PhysRevD.84.111901 PACS numbers: 11.15.Tk, 12.60.Nz, 12.60.Rc, 14.80.Ec

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 to 600 GeV have been narrowed down to several windows and slits [2–4]. The fourth generation model [5–7] is 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, because nonstandard 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, the so-called technidilaton (TD), which is the pseudo-Nambu-Goldstone boson associated with the scale symmetry breaking [12,15]. The TD mass near the critical point has been suggested as $M_{\rm TD} \sim \sqrt{2}m$ in the context of the gauged Nambu-Jona-Lasinio model [16], where $m$ represents the dynamically generated fermion mass. The TD mass in the criticality limit was discussed recently in Refs. [17,18].

In a previous work [19], we 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.

In this note, we briefly analyze the coupling of the TD to the weak bosons.

Let us first consider the case where the dilaton $\sigma$ directly couples to $W$. This situation is similar to the SM. Owing to the nature of the energy-momentum tensor, we formally obtain the following relation [20]:

$$\langle W(p)|\theta^\lambda_\lambda(0)|W(p)\rangle = 2M_W^2. \tag{1}$$

Assuming the $\sigma$ dominance at the zero momentum transfer as shown in Fig. 1, we can read the $g^{\mu\nu}$ part of the $\sigma - W^\mu - W^\nu$ form factor $\Gamma^{\mu\nu}_{\sigma WW}$ as

$$g_{\sigma WW}(0) = \frac{2M_W^2}{F_\sigma}, \tag{2}$$

where $F_\sigma$ represents the dilaton decay constant being $\langle 0|\theta^\lambda_\lambda(0)|\sigma(q)\rangle = F_\sigma M_\sigma^2$ with the dilaton mass $M_\sigma$. The expression (2) agrees with the result in Refs. [21,22]. For a generalization of Refs. [21,22], see also Ref. [23].

Next, we study the so-called technidilaton $\sigma_T$ which couples to $W$ only through the technifermions (TF's). The axial current $J^\mu_A$ of the TF's yields the decay constant $F_\pi$, $\langle 0|J^\mu_A(0)|\pi(q)\rangle = -iq^\mu F_\pi$, and the weak boson mass is provided by $F_\pi$. We thus consider the coupling between $\sigma_T$ and $J^\mu_A$.

The axial current correlator in the momentum space is

$$\text{F.T.}\, i\langle 0|J^\mu_A(x)J^\nu_A(0)|0\rangle = \left(g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}\right)\Pi_A(q^2). \tag{3}$$

The vacuum polarization function $\Pi_A$ is characterized by

$$\Pi_A(0) = F_\pi^2. \tag{4}$$

This relation plays an important role in our approach.

The $\sigma_T$ coupling to $J^\mu_A$ at the zero momentum transfer is just like the mass insertion: Note that the identity holds

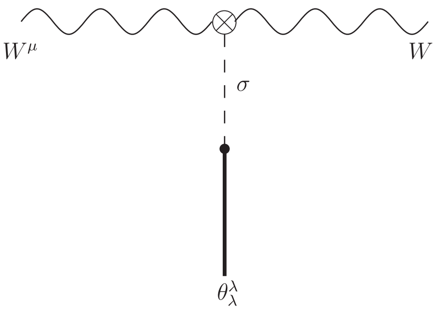

FIG. 1. The $\sigma WW$ coupling in the case where the $\sigma$ directly couples to $W$.

---

*michioh@isc.chubu.ac.jp

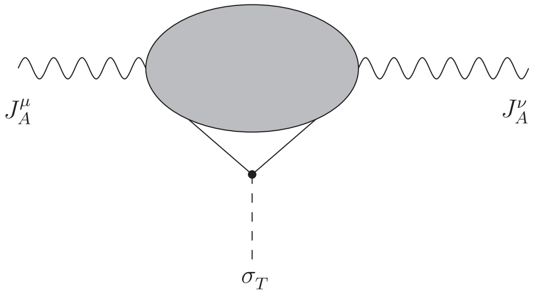

FIG. 2. Coupling of the TD to the axial currents of the TF's. The TD $\sigma_T$ couples to $J_A^\mu$ only through the internal TF lines.

$$\frac{1}{\ell - m} y_T \frac{1}{\ell - m} = y_T \frac{\partial}{\partial m} \frac{1}{\ell - m}, \tag{5}$$

where $m$ and $y_T$ are the dynamically generated TF mass and the Yukawa coupling, respectively. See also Fig. 2. We can then obtain the coupling of $\sigma_T$ to $J_A^\mu$ at zero momentum simply by

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

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 extended technicolor (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], $\kappa \equiv \kappa_F \sqrt{N_{\rm TC}}/(2\pi)$ with $\kappa_F \simeq$ 1.4–1.5 and $N_{\rm TC}$ being the number of the color of the TC gauge group, where the Pagels-Stokar formula [24] is employed. Then Eq. (6) yields

$$g_{\sigma_T AA}(0) = y_T \frac{2F_\pi^2}{m}. \tag{7}$$

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

$$g_{\sigma_T WW}(0) = y_T \frac{2M_W^2}{m}. \tag{8}$$

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, $\mathcal{L} = \mathcal{L}_{\rm TC} + G_1(\bar{T}T)^2 + G_2(\bar{T}T)(\bar{f}f) + G_3(\bar{f}f)^2$ with $\mathcal{L}_{\rm TC}$ 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 TD 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 $\frac{\sigma_T}{F_\sigma} W_\mu W^\mu$ yields the coupling between the TD and the weak bosons, in a similar way as in the SM. The earlier argument in Ref. [25] contradicted ours. However, the authors have revised it, following our results [26].

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

---

[1] K. Nakamura *et al.* (Particle Data Group), J. Phys. G **37**, 075021 (2010).

[2] ATLAS Collaboration, Report No. ATLAS-CONF-2011-135, 2011.

[3] CMS Collaboration, Report No. CMS PAS HIG-11-022, 2011.

[4] CDF and D0 Collaborations, Tevatron New Phenomena, and Higgs Working Group, arXiv:1107.5518.

[5] H. J. He, N. Polonsky, and S. f. Su, Phys. Rev. D **64**, 053004 (2001); G. D. Kribs, T. Plehn, M. Spannowsky, and T. M. P. Tait, Phys. Rev. D **76**, 075016 (2007); M. Hashimoto, Phys. Rev. D **81**, 075023 (2010); J. Erler and P. Langacker, Phys. Rev. Lett. **105**, 031801 (2010).

[6] For a dynamical model, see, e.g., M. Hashimoto and V. A. Miransky, Phys. Rev. D **80**, 013004 (2009); **81**, 055014 (2010).

[7] For reviews, see, e.g., P. H. Frampton, P. Q. Hung, and M. Sher, Phys. Rep. **330**, 263 (2000); B. Holdom, W. S. Hou, T. Hurth, M. L. Mangano, S. Sultansoy, and G. Unel, PMC Phys. A **3**, 4 (2009).

[8] CMS Collaboration, Report No. CMS PAS HIG-11-011, 2011; Report No. CMS PAS EXO-11-051, 2011;

[9] For a comprehensive review, see, e.g., C. T. Hill and E. H. Simmons, Phys. Rep. **381**, 235 (2003); **390**, 553(E) (2004). for a dynamical model with extra dimensions, see, e.g., M. Hashimoto, M. Tanabashi, and K. Yamawaki, Phys. Rev. D **64**, 056003 (2001); **69**, 076004 (2004); V. Gusynin, M. Hashimoto, M. Tanabashi, and K. Yamawaki, Phys. Rev. D **65**, 116008 (2002); for a recent analysis of the top-Higgs, see, e.g., R. S. Chivukula, B. Coleppa, H. E. Logan, A. Martin, and E. H. Simmons, Phys. Rev. D **84**, 095022 (2011).

[10] M. E. Peskin and T. Takeuchi, Phys. Rev. Lett. **65**, 964 (1990); B. Holdom and J. Terning, Phys. Lett. B **247**, 88 (1990); M. Golden and L. Randall, Nucl. Phys. **B361**, 3 (1991).

[11] B. Holdom, Phys. Rev. D **24**, 1441 (1981).

[12] K. Yamawaki, M. Bando, and K. Matumoto, Phys. Rev. Lett. **56**, 1335 (1986); M. Bando, T. Morozumi, H. So, and K. Yamawaki, Phys. Rev. Lett. **59**, 389 (1987).

[13] T. Akiba and T. Yanagida, Phys. Lett. **169B**, 432 (1986).

[14] T. W. Appelquist, D. Karabali, and L. C. R. Wijewardhana, Phys. Rev. Lett. **57**, 957 (1986); T. Appelquist and L. C. R. Wijewardhana, Phys. Rev. D **36**, 568 (1987).

[15] M. Bando, K. Matumoto, and K. Yamawaki, Phys. Lett. B **178**, 308 (1986).

[16] S. Shuto, M. Tanabashi, and K. Yamawaki, in *Proc. 1989 Workshop on Dynamical Symmetry Breaking*, edited by T. Muta and K. Yamawaki (Nagoya University, Nagoya, 1990), p. 115; M. S. Carena and C. E. M. Wagner, Phys. Lett. B **285**, 277 (1992); M. Hashimoto, Phys. Lett. B **441**, 389 (1998).

[17] M. Hashimoto and K. Yamawaki, Phys. Rev. D **83**, 015008 (2011).

[18] D. D. Dietrich, F. Sannino, and K. Tuominen, Phys. Rev. D **72**, 055001 (2005); T. Appelquist and Y. Bai, Phys. Rev. D **82**, 071701 (2010); L. Vecchi, J. High Energy Phys. 04 (2011) 127.

[19] M. Hashimoto, Phys. Rev. D **83**, 096003 (2011).

[20] For a textbook, see, e.g., J. F. Donoghue, E. Golowich, and B. R. Holstein, *Dynamics of the Standard Model* (Cambridge University Press, Cambridge, England, 1994).

[21] W. D. Goldberger, B. Grinstein, and W. Skiba, Phys. Rev. Lett. **100**, 111802 (2008).

[22] J. Fan, W. D. Goldberger, A. Ross, and W. Skiba, Phys. Rev. D **79**, 035017 (2009).

[23] L. Vecchi, Phys. Rev. D **82**, 076009 (2010).

[24] H. Pagels and S. Stokar, Phys. Rev. D **20**, 2947 (1979).

[25] S. Matsuzaki and K. Yamawaki, arXiv:1109.1742, withdrawn by the authors.

[26] S. Matsuzaki and K. Yamawaki, arXiv:1109.5448.