Techni-dilaton at 125 GeV

Shinya Matsuzaki[1,*] and Koichi Yamawaki[2,†]

[1]*Maskawa Institute for Science and Culture, Kyoto Sangyo University, Motoyama, Kamigamo, Kita-Ku, Kyoto 603-8555, Japan*
[2]*Kobayashi-Maskawa Institute for the Origin of Particles and the Universe (KMI), Nagoya University, Nagoya 464-8602, Japan*

Walking technicolor predicts a light composite scalar, techni-dilaton, arising as a pseudo-Nambu-Goldstone boson for the approximate scale symmetry spontaneously broken by techni-fermion condensation. We show that a light techni-dilaton with a mass of around 125 GeV can explain presently observed excesses particularly in the di-photon decay channel at the LHC.

I. INTRODUCTION

The origin of mass is one of the most intriguing quests in particle physics. It is explained in the standard model (SM) by the presence of the Higgs boson. The LHC has now started searching for the SM Higgs and recently reported the first hint toward discovery of a Higgs-like object around the mass of 125 GeV [1,2]. Thus we are now coming into an exciting period of particle physics.

The ATLAS [1] and CMS [2] experiments reported the observation of some excesses at around 125 GeV in di-photon and weak gauge boson decay channels by ~ 5 fb^{-1} data, corresponding to the statistical significance of about 2.5σ in total. In the weak gauge boson channels ($WW^* \to 2l2\nu$ and $ZZ^* \to 4l$) the excessive signals around 125 GeV are compatible with the expected backgrounds [3,4]. In the di-photon channel, on the other hand, the excess around 125 GeV is about 3σ in the local significance level, and the signatures denoted by $\sigma \times$ BR (cross section times branching ratio) are about 4 times larger than those of the SM Higgs resonance at around 125 GeV, i.e., $(\sigma \times \text{BR})_{\text{obs}} \simeq 4(\sigma \times \text{BR})_{\text{SM-Higgs}}$ [5], which would imply new physics beyond the SM.

Technicolor (TC) [6,7] is an attractive idea to explain the origin of mass without introduction of the fundamental Higgs boson, in a way that the electroweak symmetry is broken by the techni-fermion condensation just like the quark condensation in QCD. Although the original TC was ruled out a long time ago by the excessive flavor-changing neutral currents (FCNC), the walking TC (WTC) is a viable model beyond the SM, solving the FCNC problem by a large anomalous dimension $\gamma_m \simeq 1$ in the approximately scale/conformal-invariant dynamics [8]. (See also similar works [9] subsequently done without concept of anomalous dimension and the scale/conformal invariance.) In sharp contrast to the original TC of a simple QCD-scale-up version, the WTC predicts a relatively light composite scalar, techni-dilaton (TD) [8,10] arising as a pseudo-Nambu-Goldstone boson associated with the spontane-

ously broken approximate scale symmetry. Since the TD mass is expected to be somewhat lighter than those of other techni-hadrons of order $\mathcal{O}(\text{TeV})$, the TD is anticipated to be discovered at the LHC instead of the SM Higgs.[1]

Recently the TD signatures of TD at the LHC were actually studied in Ref. [11], focusing on the heavy mass range above 200 GeV, the region extensively searched at the LHC before the recent report at the end of the last year [1,2]. In Ref. [11] it was concluded that in the typical one-family WTC model [7] the heavy TD with mass around ~ 600 GeV[2] will be seen through the decays to WW/ZZ or $\gamma\gamma$, along with the gigantic enhancement clearly distinguishable from the SM Higgs signatures.[3]

In this article, we simply extend the previous analysis [11] down to the lower mass region and explore a light TD with mass of around 125 GeV and compare its signatures with the present LHC data on this low mass region. Surprisingly, we find that the light TD in the one-family WTC models actually should have predicted the excesses around 125 GeV particularly in the di-photon decay channel before the observation reports [1,2] came out.

The weak boson decay channels turn out to be as much as the expected backgrounds consistent with the present LHC results: The gluon-fusion production cross section gets enhanced by about a factor of 10, $\sigma_{\text{TD}}/\sigma_{h_{\text{SM}}} \sim (g_{\text{TD}}/g_{h_{\text{SM}}})^2|1 + 2N_{\text{TC}}|^2 \sim \mathcal{O}(10)$, involving

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[1]As to the notorious TC problem of S and T parameters, possible solutions were already suggested [11,12]. Particularly, the issue on the S parameter may be resolved in the case of walking [13,14]. Even if WTC in isolation cannot overcome this problem, there still exists a possibility that the problem may be resolved in the combined dynamical system including the SM fermion mass generation such as the extended TC (ETC) dynamics [15], in much the same way as the solution ("ideal fermion delocalization") [16] in Higgsless models.

[2]$M_{\text{TD}} \simeq 500$–600 GeV for the typical one-family model was suggested [17], based on various explicit calculations that are not conclusive, however, due to the respective uncertainties in those computations. More reliable calculations such as the lattice simulations will yield a conclusive answer.

[3]Phenomenological arguments on the TD in comparison with the recent LHC data were also done in slightly different contexts [12,18]. See also [19].

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*synya@cc.kyoto-su.ac.jp
†yamawaki@kmi.nagoya-u.ac.jp

the enhancement from extra techni-quark loop contributions which are somewhat compensated by the overall suppression by TD coupling at 125 GeV (see Table I), where we study $N_{TC} = 3, 4, 5, 6$ for $SU(N_{TC})$ WTC. Moreover, the techni-quark loop corrections make relatively larger the branching ratios for TD $\to gg$ so that the branching fraction for other modes becomes about 10% of the SM Higgs case at 125 GeV (see Tables II and III). Accordingly, the cross section times branching ratio turns out to be of order of the SM Higgs one.

This mechanism is operative for the di-photon channel as well, though it gets enhanced more from electromagnetically-charged techni-fermion loops (see Table IV). Thus the di-photon signal becomes larger than the SM Higgs case, to be comparable with the current ATLAS and CMS data.[4] This enhancement will be even more eminent only in the di-photon channel, when N_{TC} is increased, a clear distinction from the SM Higgs. For the explicit formula see Ref. [11].

II. TECHNI-DILATON COUPLING

As was discussed previously in Ref. [11], the TD couplings to the SM particles are almost identical to those of the SM Higgs, except for two ingredients: The scale set by the TD decay constant F_{TD} instead of the electroweak scale v_{EW} for the SM Higgs and the gluon, and photon couplings depending highly on particle contents of models of WTC. The essential discrepancy between the TD and SM couplings is therefore set by the ratio,

$$\frac{g_{TD}}{g_{h_{SM}}} = \frac{(3 - \gamma_m)v_{EW}}{F_{TD}}, \tag{1}$$

where the electroweak scale is $v_{EW} \simeq 246$ GeV and γ_m stands for the anomalous dimension of techni-fermion bilinear and $\gamma_m \simeq 1$ for WTC.

The TD decay constant F_{TD} and TD mass M_{TD} are related to the vacuum energy density $\mathcal{E}_{vac} = \langle \theta_\mu^\mu \rangle / 4$ through partially conserved dilatation current for the trace anomaly:

$$F_{TD}^2 M_{TD}^2 = -4\langle \theta_\mu^\mu \rangle = -16\mathcal{E}_{vac}, \tag{2}$$

where $\theta_{\mu\nu}$ is the energy-momentum tensor. The vacuum energy density $\mathcal{E}_{vac}$ is dominated by the techni-gluon condensation induced by the loop of the techni-fermion with dynamical mass m_F, which can be written in a generic manner as

$$\langle \theta_\mu^\mu \rangle = 4\mathcal{E}_{vac} = -\kappa_V \left(\frac{N_{TC}N_{TF}}{2\pi^2}\right)m_F^4, \tag{3}$$

with κ_V being the overall coefficient which is in principle calculable by the nonperturbative analysis. N_{TF} denotes the flavor number of techni-fermions.

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[4]Similar enhancement on the di-photon channel was discussed in Ref. [20] in terms of radion.

The dynamical techni-fermion mass m_F can, on the other hand, be related to the techni-pion decay constant F_π:

$$F_\pi^2 = \kappa_F^2 \frac{N_{TC}}{4\pi^2} m_F^2, \tag{4}$$

with the overall coefficient κ_F and the property of N_{TC} scaling taken into account. The scale of F_π is set by the electroweak scale v_{EW} along with N_D as $F_\pi = v_{EW}/\sqrt{N_D}$, where N_D denotes the number of electroweak doublet techni-fermions. With these combined, one can express $F_{TD}M_{TD}$ in Eq. (2) in terms of N_{TC}, N_{TF} and $\kappa_{V,F}$, once $F_\pi = v_{EW}/\sqrt{N_D}$ is fixed.

As was done in Ref. [11], the values of κ_V and κ_F may be quoted from the latest result [21] on a ladder Schwinger-Dyson analysis for a modern version of WTC [22–24]:

$$\kappa_V \simeq 0.7, \qquad \kappa_F \simeq 1.4. \tag{5}$$

In that case N_{TF} is fixed by the criticality condition for the walking regime as [23]

$$N_{TF} \simeq 4N_{TC}, \tag{6}$$

where $N_{TF} = 2N_D + N_{EW-singlet}$, with $N_{EW-singlet}$ being the number of the electroweak/color-singlet techni-fermions, ''dummy'' techni-fermions introduced in order to fulfill the criticality condition, which serve to reduce the TD coupling g_{TD} by enhancing F_{TD} through Eqs. (2) and (3). Taking the original one-family model [7] with $N_D = 4$ as a definite benchmark, we thus evaluate m_F, F_{TD} and $g_{TD}/g_{h_{SM}}$ in Eq. (1) to get

$$m_F \simeq 319 \text{ GeV} \sqrt{\frac{3}{N_{TC}}},$$

$$F_{TD} \simeq 1836 \text{ GeV}\left(\frac{125 \text{ GeV}}{M_{TD}}\right) \tag{7}$$

$$\frac{g_{TD}}{g_{h_{SM}}} \simeq 0.27\left(\frac{M_{TD}}{125 \text{ GeV}}\right).$$

Note that F_{TD} and hence the TD coupling is independent of N_{TC} when $N_{TF} \simeq 4N_{TC}$ is used. The plot of $g_{TD}/g_{h_{SM}}$ as a function of M_{TD} is shown in Fig. 1.[5]

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[5]At this point we may remark on stability of the light TD mass against radiative corrections. As a pseudo-Nambu-Goldstone boson of scale invariance the quadratic divergence is suppressed by the scale invariance for the walking energy region $m_F < \mu < \Lambda$, where Λ is the intrinsic scale of the walking TC, roughly taken as the order of the ETC scale Λ_{ETC}. The scale symmetry breaking in the ultraviolet region $\mu > \Lambda$ has no problem for the naturalness as usual like in the QCD and the QCD-scale-up TC where the theory has only logarithmic divergences. The only possible source of the scale symmetry violation is from $\mu < m_F$, giving rise to the quadratically divergent corrections $\delta M_{TD}^2 \sim \mu^2/(4\pi)^2 < m_F^2/(4\pi)^2$, which are evaluated from Eq. (7) as only 2 percent corrections to $M_{TD}(\simeq 125$ GeV). Higher loop corrections are even more dramatically suppressed by powers of $(m_F/(4\pi F_{TD}))^2$.

One−family model with $N_{TF}=4N_{TC}$
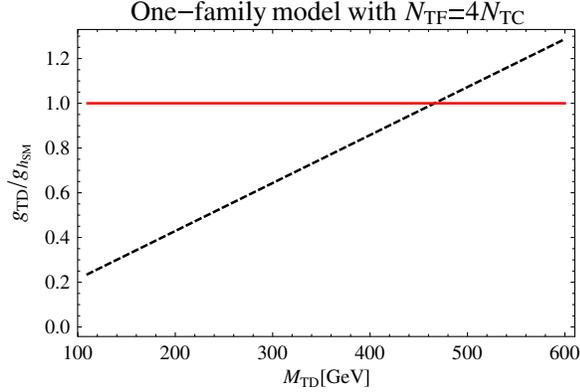

FIG. 1 (color online). $g_{TD}/g_{h_{SM}} = (3 - \gamma_m)v_{EW}/F_{TD}$ with $\gamma_m \simeq 1$, with respect to the TD mass M_{TD} in a range from 110 to 600 GeV for one-family models with $N_{TF} = 4N_{TC}$ fixed.

TABLE I. The estimated numbers at $M_{TD} = 125$ GeV relevant to the TD LHC production processes at 7 TeV, compared with the corresponding ones for the SM Higgs. GF and VBF label gluon and vector boson fusions, respectively.

N_{TC}	$g_{TD}/g_{h_{SM}}$	$\sigma_{TD}/\sigma_{h_{SM}}|_{GF}$	$\sigma_{TD}/\sigma_{h_{SM}}|_{VBF}$
3	0.27	3.8	0.072
4	0.27	6.3	0.072
5	0.27	9.4	0.072
6	0.27	13	0.072

III. THE LHC SIGNATURES AT 125 GEV

Using the values in Eq. (7) and formulas[6] previously reported in Ref. [11], we compute the TD LHC production cross section times branching ratios normalized to the corresponding quantities for the SM Higgs. Here we focus on the one-family model with $N_{TC} = 3, 4, 5, 6$. The SM Higgs branching ratios and LHC production cross sections at 7 TeV are read off from Ref. [26].

The production cross section is highly dominated by the gluon-fusion process since the TD couplings to the weak bosons and fermions are suppressed just by amount of $(g_{TD}/g_{h_{SM}})^2 = \mathcal{O}(10^{-2})$ for the mass region we are interested in, around 125 GeV (see Eq. (7) and Table I). The gluon-fusion production, on the other hand, gets enhanced due to the presence of techni-quarks carrying the QCD color.

The same argument is applicable to the branching fraction as well: The di-gluon decay channel becomes fairly enhanced in the branching fraction to highly exceed the $b\bar{b}$ channel (see Table II), so that the other decay channels are relatively suppressed compared to the SM Higgs case (see Table III). The total width of TD at around 125 GeV is however as small as the SM Higgs one $\Gamma_{tot}^{TD}(125 \text{ GeV}) \sim$ a few MeV.

The result on the TD signatures at 125 GeV is summarized in Table IV. We see that the di-photon signal is fairly sensitive to the number of N_{TC}: When $N_{TC} = 6$ it is close to the amount of the presently observed excess $\sim 4 \times \sigma_{h_{SM}} \times$ BR$(h_{SM} \to \gamma\gamma)$ [5], while it exceeds the present observation for $N_{TC} \geq 7$. One can understand this feature by considering a ratio $R_{2\gamma}/R_{WW/ZZ}$ whose N_{TC}-dependence can be roughly described numerically

TABLE II. The TD branching fraction at $M_{TD} = 125$ GeV.

N_{TC}	BR$_{gg}$	BR$_{b\bar{b}}$	others
3	82%	10%	8%
4	88%	7%	5%
5	92%	5%	3%
6	94%	4%	2%

TABLE III. The TD branching fraction at $M_{TD} = 125$ GeV compared with the SM Higgs, $r_{BR}^X \equiv$ BR(TD $\to X$)/ BR($h_{SM} \to X$). The label "others" denotes other decaying particles relevant to this mass range, such as WW^*, ZZ^*, $b\bar{b}$, $c\bar{c}$, $\tau^+\tau^-$.

N_{TC}	$r_{BR}^{2\gamma}$	r_{BR}^{2g}	r_{BR}^{others}
3	0.079	10	0.19
4	0.18	10	0.12
5	0.26	11	0.086
6	0.33	11	0.063

TABLE IV. The TD signatures at $M_{TD} = 125$ GeV normalized to those of the SM Higgs, $R_X \equiv \sigma_{TD} \times$ BR(TD $\to X$)/ $[\sigma_{h_{SM}} \times$ BR($h_{SM} \to X$)], where $\sigma_i = \sigma_i|_{GF} + \sigma_i|_{VBF}$ ($i =$ TD, h_{SM}). The label "others" means the same as in Table III.

N_{TC}	$R_{2\gamma}$	R_{2g}	R_{others}
3	0.28	35	0.67
4	1.0	63	0.72
5	2.3	99	0.75
6	4.1	142	0.77

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[6]For the WW^* and ZZ^* decays we have quoted the corresponding formulas for the SM Higgs given in Ref. [25] just simply by replacing v_{EW} with $F_{TD}/2$.
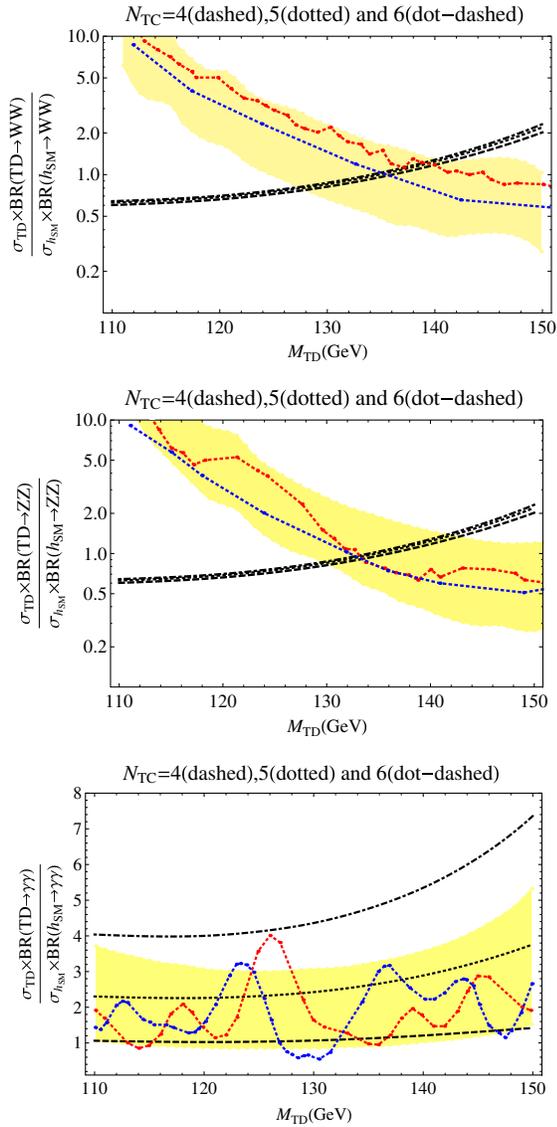
FIG. 2 (color online). The TD LHC cross section at 7 TeV times branching ratios for WW^* (top panel), ZZ^* (middle panel) and di-photon (bottom panel) decay channels normalized to the corresponding quantities for the SM Higgs, in comparison with the current ATLAS (red curves) and CMS (blue curves) data [3–5] at 95% C.L. for the low Higgs mass range. The yellow band denotes the expected backgrounds within the 2σ level.

$(R_{2\gamma}/R_{WW/ZZ})|_{N_{TC}} \sim (1 + 0.3 N_{TC})^2$ at $M_{TD} = 125$ GeV. The di-photon excess therefore grows even more as N_{TC} is increased. It is sharply contrasted to other channels

including the weak boson decay channels which are almost insensitive to N_{TC}, staying in the range consistent with the present data on the weak boson decay channels [3,4] as well as the fermionic modes [27].

To be more explicit, in Fig. 2 we plot the TD signatures as a function of M_{TD} varied from 110 to 150 GeV, along with the current ATLAS and CMS 95% C.L. upper limits on WW^*, ZZ^*, $\gamma\gamma$ channels and their expected backgrounds [3–5].

The estimated signals for the weak boson channels can be pulled up by about 30% ($R_{WW/ZZ} \simeq 0.77 \to 1.0$ at 125 GeV when $N_{TC} = 6$) to be within a range consistent with the expected backgrounds for the weak boson channels [3,4]: This error comes from a theoretical uncertainty associated with the estimate of κ_V and κ_F in Eq. (5), arising from the deviation of the criticality condition [21]: $\kappa_F \simeq 1.4 \to 1.49$ (shift by about 6%), $\kappa_V \simeq 0.7 \to 0.81$ (shift by about 14%) at the criticality. The expected uncertainty about $(g_{TD}/g_{h_{SM}})^2$ will be about 30%. Similar improvement can be made for the fermionic modes [27] as well, so that all the signatures other than the di-photon channel will be consistent with the expected backgrounds at about the 2σ level. Thus the excess of only the di-photon channel will be a salient feature of the TD discriminated from the SM Higgs.

IV. CONCLUSION

To conclude, we have explored a light TD with mass of around 125 GeV and compare its signatures with the present LHC data available for this low mass region. We showed that the light TD in the one-family WTC models actually gives the signals consistent with the presently observed excesses around 125 GeV particularly in the di-photon channel. The main results in Fig. 2 show that when N_{TC} increases, only the di-photon channel excess grows, while the other channel stays unchanged. This is a clear distinction from the SM Higgs. Then, if the excessive di-photon signals develop at the upcoming experiments to reach the desired significance level, while other channels like the weak boson signals essentially stay at the present significance, it would imply the discovery of the 125 GeV TD.

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