Available online at www.sciencedirect.com

ScienceDirect

ELSEVIER

PHYSICS LETTERS B

Physics Letters B 661 (2008) 360–364

www.elsevier.com/locate/physletb

Unparticle physics and Higgs phenomenology

Tatsuru Kikuchi [a,*], Nobuchika Okada [a,b]

[a] Theory Division, KEK, 1-1 Oho, Tsukuba 305-0801, Japan

[b] Department of Physics, University of Maryland, College Park, MD 20742, USA

Received 3 February 2008; accepted 16 February 2008

Available online 26 February 2008

Editor: T. Yanagida

Abstract

Recently, conceptually new physics beyond the Standard Model has been proposed, where a hidden conformal sector provides "unparticle" which couples to the Standard Model sector through higher dimensional operators in low energy effective theory. Among several possibilities, we focus on operators involving unparticle, the Higgs doublet and the gauge bosons. Once the Higgs doublet develops the vacuum expectation value, the conformal symmetry is broken and as a result, the mixing between unparticle and Higgs boson emerges. We find that this mixing can cause sizable shifts for the couplings between Higgs boson and a pair of gluons and photons, because these couplings exist only at the loop level in the Standard Model. These Higgs couplings are the most important ones for the Higgs boson search at the CERN Large Hadron Collider, and the unparticle physics effects may be observed together with the discovery of Higgs boson.

In spite of the success of the Standard Model (SM) in describing all the existing experimental data, the Higgs boson, which is responsible for the electroweak symmetry breaking, has not yet been directly observed, and is one of the main targets at the CERN Large Hadron Collider (LHC). At the LHC, the main production process of Higgs boson is through gluon fusion, and if Higgs boson is light, say $m_h \lesssim 150$ GeV, the primary discovery mode is through its decay into two photons. In the SM, these processes occur only at the loop level and Higgs boson couples with gluons and photons very weakly.

A certain class of new physics models includes a scalar field which is singlet under the SM gauge group. In general, such a scalar field can mix with the Higgs boson and also can directly couple with gluons and photons through higher dimensional operators with a cutoff in effective low energy theory. Even if the cutoff scale is very high, say, 100–1000 TeV, the couplings with gluons and photons can be comparable to or even larger than those of the Higgs boson induced only at the loop level in the SM. This fact implies that if such a new physics exists, it potentially has an impact on Higgs boson phenomenology at the LHC. In other words, such a new physics may be observed together with the discovery of Higgs boson.

As one of such models, in this Letter, we investigate a new physics recently proposed by Georgi [1], which is described in terms of "unparticle" provided by a hidden conformal sector in low energy effective theory. A concrete example of unparticle staff was proposed by Banks–Zaks [2] many years ago, where providing a suitable number of massless fermions, theory reaches a non-trivial infrared fixed point and a conformal theory can be realized at a low energy. Various phenomenological considerations on the unparticle physics have been developed in the literature [3–5].

Basic structure of the unparticle physics is as follows. First, we introduce a coupling between the new physics operator ($\mathcal{O}_{\rm UV}$) with dimension $d_{\rm UV}$ and the Standard Model one ($\mathcal{O}_{\rm SM}$) with dimension n,

$$\mathcal{L} = \frac{c_n}{M^{d_{\rm UV}+n-4}} \mathcal{O}_{\rm UV} \mathcal{O}_{\rm SM}, \tag{1}$$

where c_n is a dimension-less constant, and M is the energy scale characterizing the new physics. This new physics sector is assumed to become conformal at a energy $\Lambda_{\mathcal{U}}$, and the operator $\mathcal{O}_{\rm UV}$ flows to the unparticle operator $\mathcal{U}$ with dimension $d_{\mathcal{U}}$. In

* Corresponding author.
E-mail address: tatsuru@post.kek.jp (T. Kikuchi).

0370-2693/$ – see front matter
doi:10.1016/j.physletb.2008.02.041

low energy effective theory, we have the operator of the form,

$$\mathcal{L} = c_n \frac{\Lambda_{\mathcal{U}}^{d_{\mathrm{UV}}-d_{\mathcal{U}}}}{M^{d_{\mathrm{UV}}+n-4}} \mathcal{U}\mathcal{O}_{\mathrm{SM}} \equiv \frac{\lambda_n}{\Lambda^{d_{\mathcal{U}}+n-4}} \mathcal{U}\mathcal{O}_{\mathrm{SM}}, \tag{2}$$

where the dimension of the unparticle $\mathcal{U}$ have been matched by $\Lambda_{\mathcal{U}}$ which is induced the dimensional transmutation, λ_n is an order one coupling constant and Λ is the (effective) cutoff scale of low energy effective theory. In this Letter, we consider only the scalar unparticle. It was found in Ref. [1] that, by exploiting scale invariance of the unparticle, the phase space for an unparticle operator with the scale dimension $d_{\mathcal{U}}$ and momentum p is the same as the phase space for $d_{\mathcal{U}}$ invisible massless particles,

$$d\Phi_{\mathcal{U}}(p) = A_{d_{\mathcal{U}}} \theta(p^0)\theta(p^2)(p^2)^{d_{\mathcal{U}}-2} \frac{d^4 p}{(2\pi)^4}, \tag{3}$$

where

$$A_{d_{\mathcal{U}}} = \frac{16\pi^{\frac{5}{2}}}{(2\pi)^{2d_{\mathcal{U}}}} \frac{\Gamma(d_{\mathcal{U}}+\frac{1}{2})}{\Gamma(d_{\mathcal{U}}-1)\Gamma(2d_{\mathcal{U}})}. \tag{4}$$

Also, based on the argument on the scale invariance, the (scalar) propagator for the unparticle was suggested to be

$$\frac{A_{d_{\mathcal{U}}}}{2\sin(\pi d_{\mathcal{U}})} \frac{i}{(p^2)^{2-d_{\mathcal{U}}}} e^{-i(d_{\mathcal{U}}-2)\pi}. \tag{5}$$

Interestingly, $d_{\mathcal{U}}$ is not necessarily integral, it can be any real number or even complex number. In this Letter we consider the scale dimension in the range, $1 < d_{\mathcal{U}} < 2$, for simplicity.

Among several possibilities, we focus on the operators between the unparticle and the Higgs sector,

$$\mathcal{L} = \frac{\lambda_n}{\Lambda^{d_{\mathcal{U}}+n-4}} \mathcal{U}\mathcal{O}_{\mathrm{SM}}(H^\dagger H), \tag{6}$$

where H is the Standard Model Higgs doublet and $\mathcal{O}_{\mathrm{SM}}(H^\dagger H)$ is the Standard Model operator as a function of the gauge invariant bi-linear of the Higgs doublet. Once the Higgs doublet develops the vacuum expectation value (VEV), the tadpole term for the unparticle operator is induced,

$$\mathcal{L}_{\mathcal{U}} = \Lambda_{\mathcal{U}}^{4-d_{\mathcal{U}}} \mathcal{U}, \tag{7}$$

and the conformal symmetry in the new physics sector is broken [4]. Here, $\Lambda_{\mathcal{U}}^{4-d_{\mathcal{U}}} = \lambda_n \langle \mathcal{O}_{\mathrm{SM}} \rangle / \Lambda^{d_{\mathcal{U}}+n-4}$ is the conformal symmetry breaking scale. At the same time, we have the interaction terms between the unparticle and the physical Standard Model Higgs boson (h) such as (up to $\mathcal{O}(1)$ coefficients)

$$\mathcal{L}_{\mathcal{U}\text{-Higgs}} = (\Lambda_{\mathcal{U}}^{4-d_{\mathcal{U}}}/v)\mathcal{U}h + (\Lambda_{\mathcal{U}}^{4-d_{\mathcal{U}}}/v^2)\mathcal{U}h^2 + \cdots, \tag{8}$$

where $v = 246$ GeV is the Higgs VEV. In order not to cause a drastic change or instability in the Higgs potential, the scale of the conformal symmetry breaking should naturally be smaller than the Higgs VEV, $\Lambda_{\mathcal{U}} \lesssim v$.

As other operators between the unparticle and the Standard Model sector, we consider

$$\mathcal{L}_{\mathcal{U}} = -\frac{\lambda_g}{4} \frac{\mathcal{U}}{\Lambda^{d_{\mathcal{U}}}} G^A_{\mu\nu} G^{A\mu\nu} - \frac{\lambda_\gamma}{4} \frac{\mathcal{U}}{\Lambda^{d_{\mathcal{U}}}} F_{\mu\nu} F^{\mu\nu}, \tag{9}$$

where we have neglected $\mathcal{O}(1)$ coefficients, but taken into account of the two possible relative signs of the coefficients, $\lambda_g = \pm 1$ and $\lambda_\gamma = \pm 1$. We will see that these operators are the most important ones relevant to the Higgs phenomenology.

Now let us focus on effective couplings between the Higgs boson and the gauge bosons (gluons and photons) of the form,

$$\mathcal{L}_{\text{Higgs-gauge}} = \frac{1}{v} C_{gg} h G^A_{\mu\nu} G^{A\mu\nu} + \frac{1}{v} C_{\gamma\gamma} h F_{\mu\nu} F^{\mu\nu}. \tag{10}$$

As is well known, in the Standard Model, these operators are induced through loop corrections in which fermions and W-boson are running [6]. For the coupling between the Higgs boson and gluons, the contribution from top quark loop dominates and is described as[1]

$$C_{gg}^{\mathrm{SM}} = \frac{\alpha_s}{16\pi} F_{1/2}(\tau_t), \tag{11}$$

where α_s is the QCD coupling, and $\tau_t = 4m_t^2/m_h^2$ with the top quark mass m_t and the Higgs boson mass m_h. For the coupling between the Higgs boson and photons, there are two dominant contributions from loop corrections through top quark and W-boson,

$$C_{\gamma\gamma}^{\mathrm{SM}} = \frac{\alpha}{8\pi} \left(\frac{4}{3} F_{1/2}(\tau_t) + F_1(\tau_W) \right), \tag{12}$$

where $\tau_W = 4M_W^2/m_h^2$ with the W-boson mass M_W. In these expressions, the structure functions are given by

$$F_{1/2}(\tau) = 2\tau\left[1 + (1-\tau) f(\tau)\right],$$
$$F_1(\tau) = -\left[2 + 3\tau + 3(2-\tau) f(\tau)\right] \tag{13}$$

with

$$f(\tau) = \begin{cases} [\sin^{-1}(1/\sqrt{\tau})]^2 & (\text{for } \tau \geqslant 1), \\ -\frac{1}{4}[\ln(\frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}}) - i\pi]^2 & (\text{for } \tau < 1). \end{cases}$$

Note that even though the effective couplings are loop suppressed in the Standard Model, they are the most important ones for the Higgs boson search at the LHC. In the wide range of the Higgs boson mass $m_h < 1$ TeV, the dominant Higgs boson production process at the LHC is the gluon fusion channel through the first term in Eq. (10). If the Higgs boson is light, $m_h < 2M_W$, the primary discovery mode of the Higgs boson is on its decay into two photons, in spite of this branching ratio is $\mathcal{O}(10^{-3})$ at most. Therefore, a new physics will have a great impact on the Higgs phenomenology at LHC if it can provide sizable contributions to the effective couplings in Eq. (10). Furthermore, the fact that the Standard Model contributions are loop-suppressed implies that it is relatively easier to obtain sizable (or sometimes big) effects from new physics.

Now we consider new contributions to the Higgs effective couplings induced through the mixing between the unparticles and the Higgs boson (the first term in Eq. (8)) and Eq. (9), in other words, through the process $h \to \mathcal{U} \to gg$ or $\gamma\gamma$. We can easily evaluate them by using the vertex among the unparticle,

[1] In our numerical analysis, we take all fermion contributions into account, for completeness.

the Higgs boson and gauge bosons and the unparticle propagator as

$$C^{\mathcal{U}}_{gg,\gamma\gamma} = \Lambda_{\mathcal{U}}^{4-d_{\mathcal{U}}} \times \left(\frac{A_{d_{\mathcal{U}}}}{2\sin(\pi d_{\mathcal{U}})} \frac{e^{-i(d_{\mathcal{U}}-2)\pi}}{(m_h^2)^{2-d_{\mathcal{U}}}}\right) \times \left(\frac{\lambda_{g,\gamma}}{\Lambda^{d_{\mathcal{U}}}}\right)$$
$$= \lambda_{g,\gamma} \frac{A_{d_{\mathcal{U}}} e^{-i(d_{\mathcal{U}}-2)\pi}}{2\sin(\pi d_{\mathcal{U}})} \left(\frac{\Lambda_{\mathcal{U}}}{m_h}\right)^{4-d_{\mathcal{U}}} \left(\frac{m_h}{\Lambda}\right)^{d_{\mathcal{U}}}, \qquad (14)$$

where we replaced the momentum in the unparticle propagator into the Higgs mass, $p^2 = m_h^2$. The unparticle contributions become smaller as m_h and Λ ($\Lambda_{\mathcal{U}}$) become larger (smaller) for a fixed $1 < d_{\mathcal{U}} < 2$. Note that in the limit $d_{\mathcal{U}} \to 1$, the unparticle behaves as a real scalar field and the above formula reduces into the one obtained through the mass-squared mixing $\Lambda_{\mathcal{U}}^3/v$ between the real scalar and the Higgs boson.

Let us first show the partial decay width of the Higgs boson into two gluons and two photons. Here we consider the ratio of the sum of the Standard Model and unparticle contributions to the Standard Model one,

$$R = \frac{\Gamma^{\text{SM}+\mathcal{U}}(h \to gg, \gamma\gamma)}{\Gamma^{\text{SM}}(h \to gg, \gamma\gamma)} = \frac{|C^{\text{SM}}_{gg,\gamma\gamma} + C^{\mathcal{U}}_{gg,\gamma\gamma}|^2}{|C^{\text{SM}}_{gg,\gamma\gamma}|^2}. \qquad (15)$$

Using Eqs. (11), (12) and (14) we evaluate the ratio of the partial decay widths as a function of $d_{\mathcal{U}}$. The results are shown in Figs. 1 and 2, for $\Lambda_{\mathcal{U}} = v$ and $m_h = 120$ GeV, and different choices of $\Lambda = 100$ and 1000 TeV. Even for $\Lambda = \mathcal{O}(1000\ \text{TeV})$, we can see a sizable deviation of $\mathcal{O}(10\%)$ from the Standard Model one with $d_{\mathcal{U}} \sim 1$. Here, it is shown that the relative sign $\lambda_{g,\gamma}$ plays an important role in the interference between the unparticle and the Standard Model contributions.

Assuming $m_h < 2M_W$, it is interesting to evaluate the Higgs boson signal events through $gg \to h \to \gamma\gamma$ at the LHC, in the presence of the unparticle effects. We consider the ratio of two photon events including unparticle effects to those in the Standard Model. For $\Lambda \gtrsim 100$ TeV, we will approximately evaluate the event number ratio. Note that the branching ratio into $h \to gg, \gamma\gamma$ is small in the Standard Model and the unparticle contributions are comparable to or smaller than the Standard Model ones (see Figs. 1 and 2). Thus, the deviation of the total decay width due to the unparticle effects is negligible, and we arrive at the approximation formula for the event number ratio (r),

$$r = \frac{\sigma^{\text{SM}+\mathcal{U}}(gg \to h) \times \text{BR}^{\text{SM}+\mathcal{U}}(h \to \gamma\gamma)}{\sigma^{\text{SM}}(gg \to h) \times \text{BR}^{\text{SM}}(h \to \gamma\gamma)}$$
$$\simeq \frac{\Gamma^{\text{SM}+\mathcal{U}}(h \to gg) \times \Gamma^{\text{SM}+\mathcal{U}}(h \to \gamma\gamma)}{\Gamma^{\text{SM}}(h \to gg) \times \Gamma^{\text{SM}}(h \to \gamma\gamma)}$$
$$= \frac{|C^{\text{SM}}_{gg} + C^{\mathcal{U}}_{gg}|^2 \times |C^{\text{SM}}_{\gamma\gamma} + C^{\mathcal{U}}_{\gamma\gamma}|^2}{|C^{\text{SM}}_{gg}|^2 \times |C^{\text{SM}}_{\gamma\gamma}|^2}. \qquad (16)$$

The event number ratio as a function of $d_{\mathcal{U}}$ are depicted in Figs. 3 and 4 for $\Lambda = 100$ and 1000 TeV, respectively, with $\Lambda_{\mathcal{U}} = v$ and $m_h = 120$ GeV. As discussed before, once the Higgs doublet develops the VEV, the conformal symmetry is broken in the new physics sector, providing the tadpole term in Eq. (7). Once such a tadpole term is induced, the unparticle

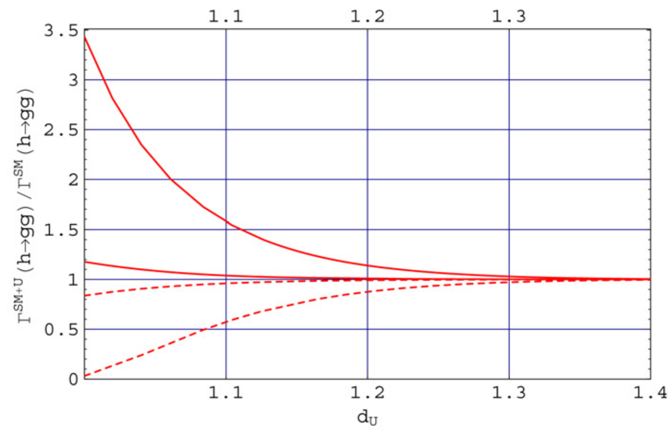

Fig. 1. The ratio of the partial decay width for the mode $h \to gg$ as a function of $d_{\mathcal{U}}$ for $\Lambda = 100$ and 1000 TeV, with $\Lambda_{\mathcal{U}} = v$ and $m_h = 120$ GeV. The solid and dashed lines correspond to $\lambda_g = +$ and $\lambda_g = -$, respectively. Each solid or dashed line with larger deviations corresponds to $\Lambda = 100$ TeV.

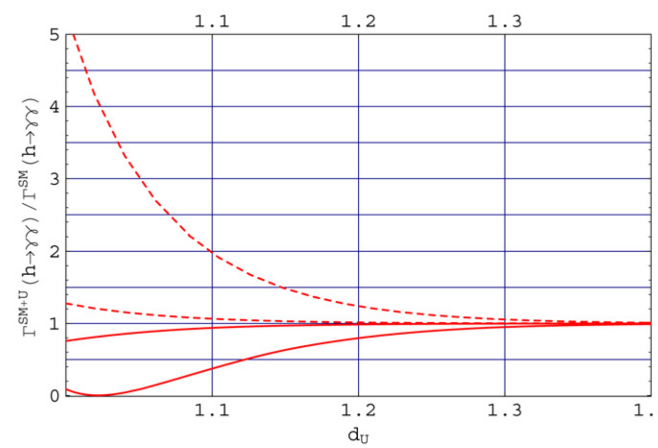

Fig. 2. The ratio of the partial decay width for the mode $h \to \gamma\gamma$ as a function of $d_{\mathcal{U}}$ for $\Lambda = 100$ and 1000 TeV. The solid line and dashed line correspond to $\lambda_\gamma = +$ and $\lambda_\gamma = -$, respectively. Each solid or dashed line with larger deviations corresponds to $\Lambda = 100$ TeV.

will subsequently develop the VEV [4,5] whose order is naturally the same as the scale of the conformal symmetry breaking,

$$\langle \mathcal{U} \rangle = (c\Lambda_{\mathcal{U}})^{d_{\mathcal{U}}}. \qquad (17)$$

Here we have introduced a numerical factor c, which can be $c = \mathcal{O}(0.1) - \mathcal{O}(1)$, depending on the naturalness criteria. Through this conformal symmetry breaking, parameters in the model are severely constrained by the current precision measurements. We follow the discussion in Ref. [5]. From Eq. (9), the VEV of the unparticle leads to the modification of the photon kinetic term,

$$\mathcal{L} = -\frac{1}{4}\left[1 \pm \frac{\langle \mathcal{U} \rangle}{\Lambda^{d_{\mathcal{U}}}}\right] F_{\mu\nu} F^{\mu\nu}, \qquad (18)$$

which can be interpreted as a threshold correction in the gauge coupling evolution across the scale $\langle \mathcal{U} \rangle^{1/d_{\mathcal{U}}}$. The evolution of the fine structure constant from zero energy to the Z-pole is consistent with the Standard Model prediction, and the largest uncertainty arises from the fine structure constant measured at

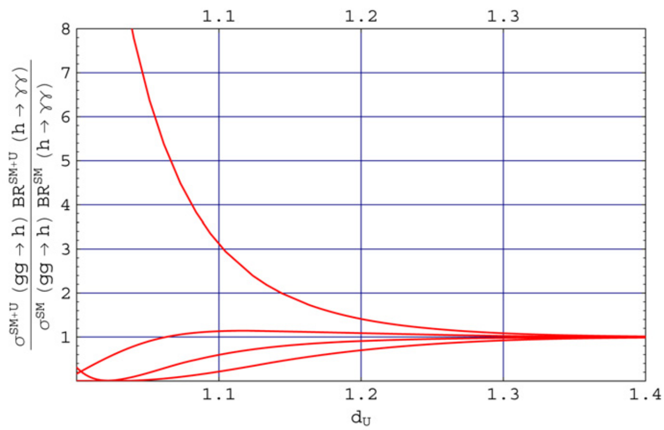

Fig. 3. The ratio of the two photon evens as a function of $d_{\mathcal{U}}$ for $\Lambda = 100$ TeV, with $\Lambda_{\mathcal{U}\!\!\!/} = v$ and $m_h = 120$ GeV. Each line from top to bottom at $d_{\mathcal{U}} = 1.1$ corresponds to $(\lambda_g, \lambda_\gamma) = (+,-)$, $(-,-)$, $(+,+)$ and $(-,+)$, respectively.

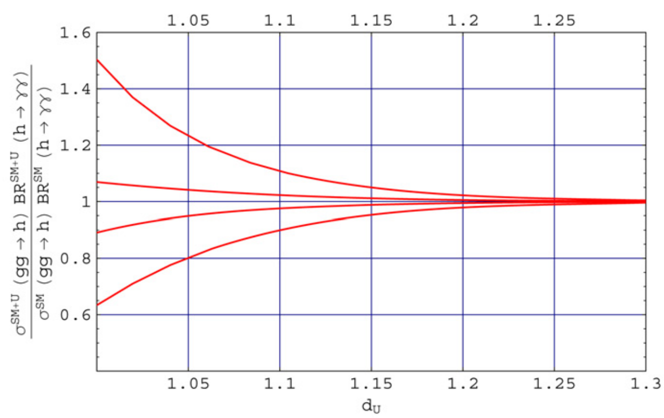

Fig. 4. The same figure as Fig. 3 but for $\Lambda = 1000$ TeV.

the Z-pole [7],

$$\hat{\alpha}^{-1}(M_Z) = 127.918 \pm 0.019.$$

This uncertainty (in the $\overline{\text{MS}}$ scheme) can be converted to the constraint,

$$\epsilon = \langle \mathcal{U} \rangle / \Lambda^{d_{\mathcal{U}}} \lesssim 1.4 \times 10^{-4}. \tag{19}$$

This provides a lower bound on the effective cutoff scale. For $d_{\mathcal{U}} \simeq 1$ and $\Lambda_{\mathcal{U}\!\!\!/} \simeq v$ we find

$$\Lambda \gtrsim c \times 1000 \text{ TeV}.$$

This is a very severe constraint on the scale of new physics, for example, $\Lambda \gtrsim 100$ TeV for $c \gtrsim 0.1$.

A similar bound can be obtained by the results on Higgs boson search through two photon decay mode at the Tevatron. With the integrated luminosity 1 fb^{-1} and the Higgs boson mass around $m_h = 120$ GeV for example, the ratio in Eq. (16) is constrained to be $r \lesssim 50$ [8]. For $d_{\mathcal{U}} \simeq 1$, this leads to the bound, $\Lambda \gtrsim 60$ TeV, which is, as far as we know, the strongest constraint on the cutoff scale by the current collider experiments.

In conclusion, we have considered the unparticle physics focusing on the Higgs phenomenology. Once the electroweak symmetry breaking occurs, the conformal symmetry is also broken and this breaking leads to the mixing between the unparticle and the Higgs boson. Providing the operators among the unparticle and the gauge bosons (gluons and photons), the unparticle brings the sizable deviation into effective couplings between the Higgs boson and the gauge bosons, that can be measured at the LHC through the discovery of the Higgs boson. The conformal symmetry breaking induces threshold corrections for the gauge coupling evolutions, and the current precision measurements on the fine structure constant require the effective cutoff scale far above the electroweak scale. The similar bound on the cutoff scale can be obtained from the Tevatron experiments. When we naively assume the common cutoff scale for operators between the unparticle and the Standard Model sector, it seems very hard to measure unparticle effects in any processes. However, as have been shown in this Letter, there exist sizable effects in the Higgs phenomenology. This is the point of this Letter. The unparticle physics makes Higgs phenomenology more interesting.

Finally, we give several comments. In Eq. (9), we can in general introduce the coupling involving the weak gauge bosons and also discuss the unparticle effects on couplings between the Higgs bosons and the weak gauge bosons. However, such effects are negligible, because the Higgs boson couples to the weak gauge boson at tree level and the effective cutoff is required to be very high by the current experiments. In this sense, we can neglect several operators through which the unparticle cause additional contributions to the couplings existing in the Standard Model at tree level.

If there exists a coupling between the unparticle and Yukawa sectors in the Standard Model, the unparticle VEV gives an additional contribution to fermion masses. In order for such a fermion mass contribution to be consistent with the observed fermion masses, the coefficient of the coupling involving light fermions should be very small. As a result, the Yukawa coupling constant of the interactions term $\mathcal{U}\bar{\Psi}_f\Psi_f$ is at most m_f/v, where m_f is the fermion mass, and negligibly small for light fermions.

There are other new physics models which can cause the similar effects in Higgs phenomenology as what we have investigated in this Letter. A well-studied example is two Higgs doublet model (2HDM) where the SM Higgs sector is simply modified. In fact, there has been a study on a comparison between the 2HDM and the SM results in the effective Higgs coupling to two photons [9]. It is worth investigating how to distinguish the unparticle physics from 2HDM. A clear difference is that the unparticle is singlet under the SM gauge group, while the charged Higgs bosons appears in 2HDM. However, in the part involving only (CP-even) neutral Higgs bosons, 2HDM has many free parameters enough to produce the same results we have obtained, by choosing a special parameter set.

Once the unparticle develops the VEV, the unparticle may acquire a "mass" term characterized by the scale $\Lambda_{\mathcal{U}\!\!\!/}$ [4]. If this is the case, it is interesting to investigate the unparticle production at the LHC. Through Eq. (9), it is produced via gluon fusion and subsequently decays into two gluons and photons. Therefore, the unparticle behaves like the Higgs boson at the

LHC. However, counting the degrees of freedom of the gluons and photons, the branching ratio into photon will be $1/9 \sim 0.1$, so that we can expect two photon events from the unparticle production much larger than those from the Higgs boson. This unparticle phenomenology is similar to the one investigated in Ref. [10], where the scalar particle in the supersymmetry breaking sector plays the similar role of the unparticle in the limit $d_{\mathcal{U}} \to 1$.

Acknowledgements

T.K. would like to thank K.S. Babu and R.N. Mohapatra for their hospitalities at Oklahoma State University and University of Maryland, respectively. The work of N.O. is supported in part by the Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture of Japan (#18740170). The work of T.K. was supported by the Research Fellowship of the Japan Society for the Promotion of Science (#1911329).

References

[1] H. Georgi, Phys. Rev. Lett. 98 (2007) 221601, hep-ph/0703260.
[2] T. Banks, A. Zaks, Nucl. Phys. B 196 (1982) 189.
[3] H. Georgi, Phys. Lett. B 650 (2007) 275, arXiv: 0704.2457 [hep-ph];
K. Cheung, W.Y. Keung, T.C. Yuan, arXiv: 0704.2588 [hep-ph];
M. Luo, G. Zhu, arXiv: 0704.3532 [hep-ph];
C.H. Chen, C.Q. Geng, arXiv: 0705.0689 [hep-ph];
G.J. Ding, M.L. Yan, arXiv: 0705.0794 [hep-ph];
Y. Liao, arXiv: 0705.0837 [hep-ph];
T.M. Aliev, A.S. Cornell, N. Gaur, arXiv: 0705.1326 [hep-ph];
X.Q. Li, Z.T. Wei, arXiv: 0705.1821 [hep-ph];
M. Duraisamy, arXiv: 0705.2622 [hep-ph];
C.D. Lu, W. Wang, Y.M. Wang, arXiv: 0705.2909 [hep-ph];
M.A. Stephanov, arXiv: 0705.3049 [hep-ph];
N. Greiner, arXiv: 0705.3518 [hep-ph];
H. Davoudiasl, arXiv: 0705.3636 [hep-ph];
D. Choudhury, D.K. Ghosh, Mamta, arXiv: 0705.3637 [hep-ph];
S.L. Chen, X.G. He, arXiv: 0705.3946 [hep-ph];
T.M. Aliev, A.S. Cornell, N. Gaur, arXiv: 0705.4542 [hep-ph];
P. Mathews, V. Ravindran, arXiv: 0705.4599 [hep-ph];
S. Zhou, arXiv: 0706.0302 [hep-ph];
G.J. Ding, M.L. Yan, arXiv: 0706.0325 [hep-ph];
C.H. Chen, C.Q. Geng, arXiv: 0706.0850 [hep-ph];
Y. Liao, J.Y. Liu, arXiv: 0706.1284 [hep-ph];
T.G. Rizzo, arXiv: 0706.3025 [hep-ph];
K. Cheung, W.Y. Keung, T.C. Yuan, arXiv: 0706.3155 [hep-ph];
H. Goldberg, P. Nath, arXiv: 0706.3898 [hep-ph];
S.L. Chen, X.G. He, H.C. Tsai, arXiv: 0707.0187 [hep-ph].
[4] P.J. Fox, A. Rajaraman, Y. Shirman, arXiv: 0705.3092 [hep-ph].
[5] M. Bander, J.L. Feng, A. Rajaraman, Y. Shirman, arXiv: 0706.2677 [hep-ph].
[6] J.F. Gunion, H.E. Haber, G.L. Kane, S. Dawson, The Higgs Hunter's Guide, Addison–Wesley, Redwood City, CA, 1989.
[7] W.M. Yao, et al., Particle Data Group, J. Phys. G 33 (2006) 1.
[8] S. Mrenna, J.D. Wells, Phys. Rev. D 63 (2001) 015006, hep-ph/0001226.
[9] I.F. Ginzburg, M. Krawczyk, P. Osland, Nucl. Instrum. Methods A 472 (2001) 149, hep-ph/0101229.
[10] H. Itoh, N. Okada, T. Yamashita, Phys. Rev. D 74 (2006) 055005, hep-ph/0606156.