Unparticle Physic and Higgs Phenomenology

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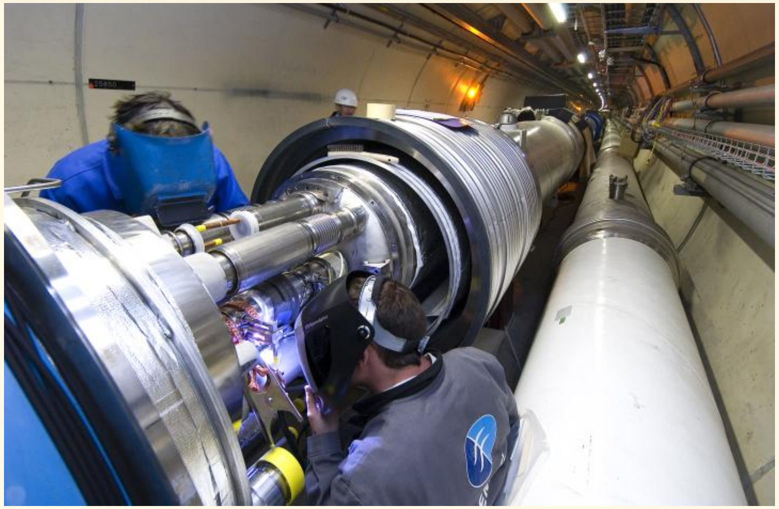
Introduction

Large Hadron Collider (LHC) is coming soon!



Hadron collider: pp

$\sqrt{s} = 14$ TeV

Initial states: $gg,\ gq(\bar{q}),\ q\bar{q}$

Purpose

Discovery of Higgs boson ← the last particle in the SM to be observed

New Physics beyond the SM

Many New Physics models have been proposed

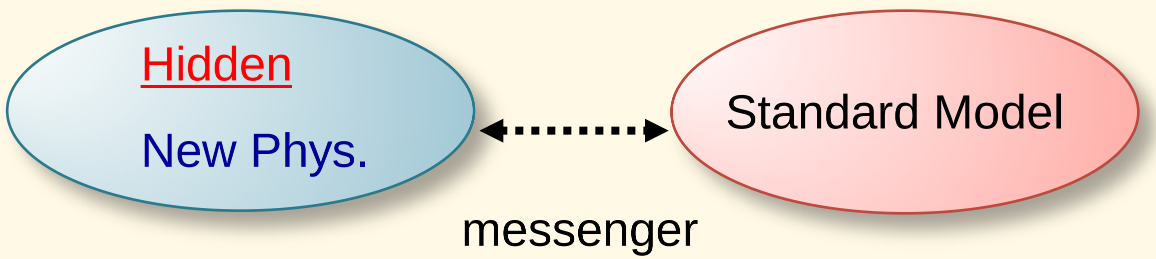
SUSY, Extra dim, Little Higgs, etc….

My topic today: ``Hidden New Physics Sector''

A class of New Physics Models

→ Singlet under the SM gauge group: hidden

Weakly couples to the SM sector



After integrating out heavy ``messenger''

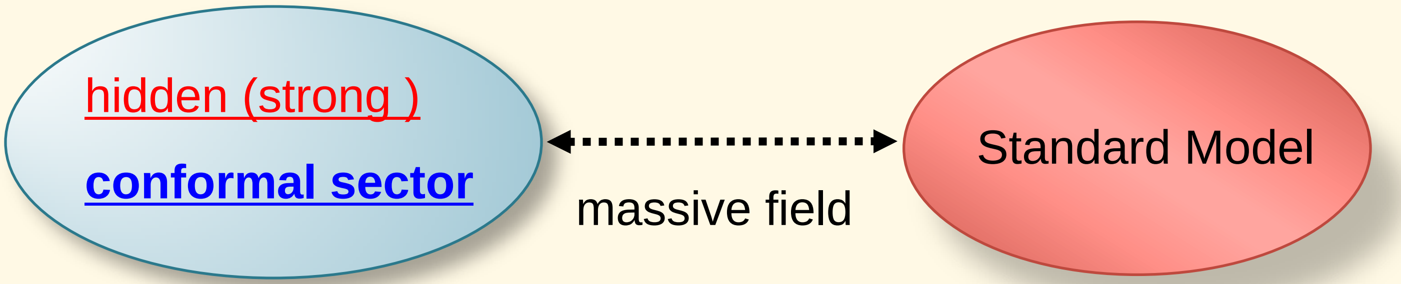
(or messenger can be just an effective cutoff)

$$\mathcal{L} = \frac{c_n}{\Lambda^n} \mathcal{O}_{\rm NP} \mathcal{O}_{\rm SM}$$

Candidate of New Particles: scalar, fermion, vector, tensor

Unparticle: an example of hidden New Physics which have "conformal symmetry"

H. Georgi, PRL98, 221601 (2007)



$$\mathcal{L}_{\rm int} = \frac{c_n}{M^{d_{\rm NP}+d_{\rm SM}-4}} \mathcal{O}_{\rm NP}\, \mathcal{O}_{\rm SM}$$

Assume: IR fixed point → New Physics sector becomes conformal at $\Lambda_{\mathcal{U}}$

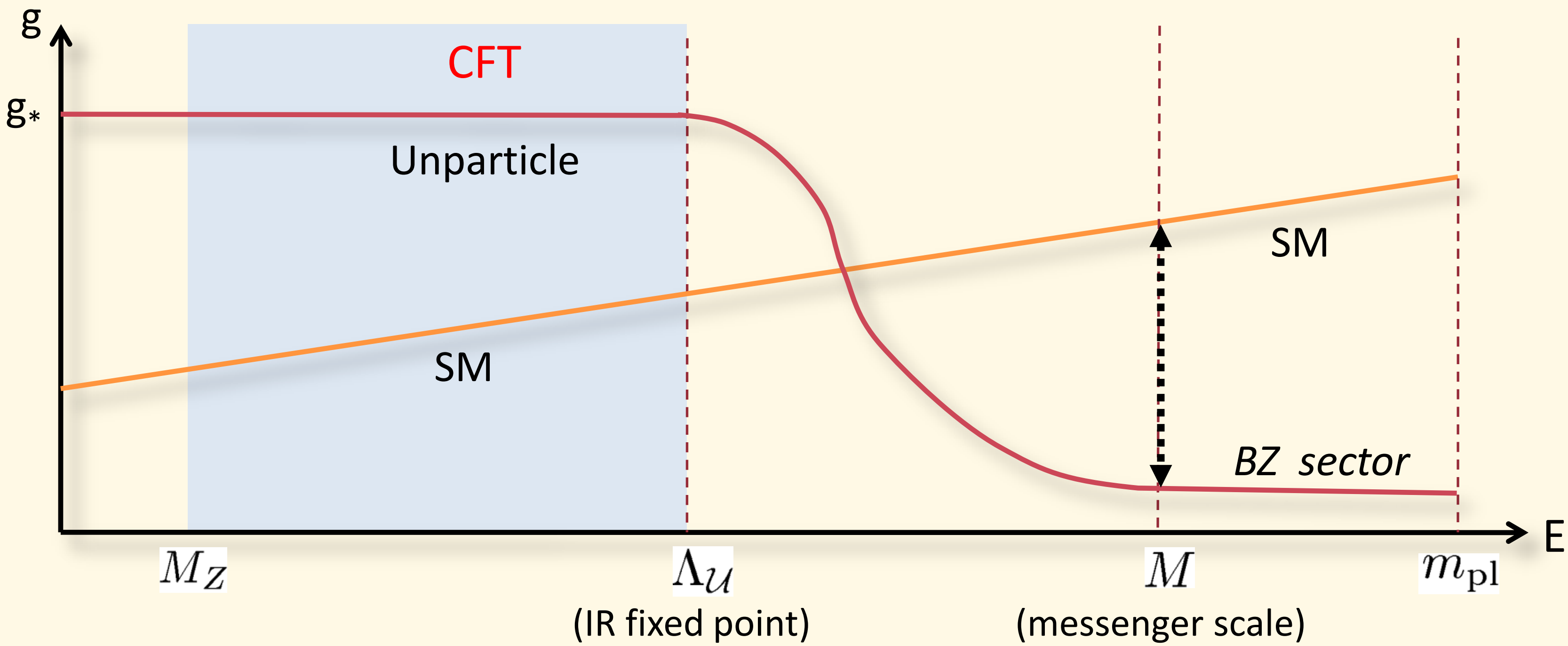
Then, the NP operator flows to $\mathcal{O}_{\rm NP} \to \Lambda_{\mathcal{U}}^{d_{\rm NP}-d_{\mathcal{U}}} \mathcal{U}$

Unparticle: $\mathcal{U}$ provided by the hidden conformal sector in low energy effective theory with a scaling dimension $d_{\mathcal{U}}$

$$\mathcal{L}_{\rm int} = \frac{c_n}{M^{d_{\rm NP}+d_{\rm SM}-4}} \mathcal{O}_{\rm NP}\, \mathcal{O}_{\rm SM} \to \frac{\lambda}{\Lambda^{d_{\mathcal{U}}+d_{\rm SM}-4}} \mathcal{U}\, \mathcal{O}_{\rm SM}$$

Unparticle

- There are lots of candidates which provides an origin of the hidden conformal sector (*unparticle*). One example is given by Banks-Zaks. [Banks and Zaks, NPB 196, 189 (1982)]



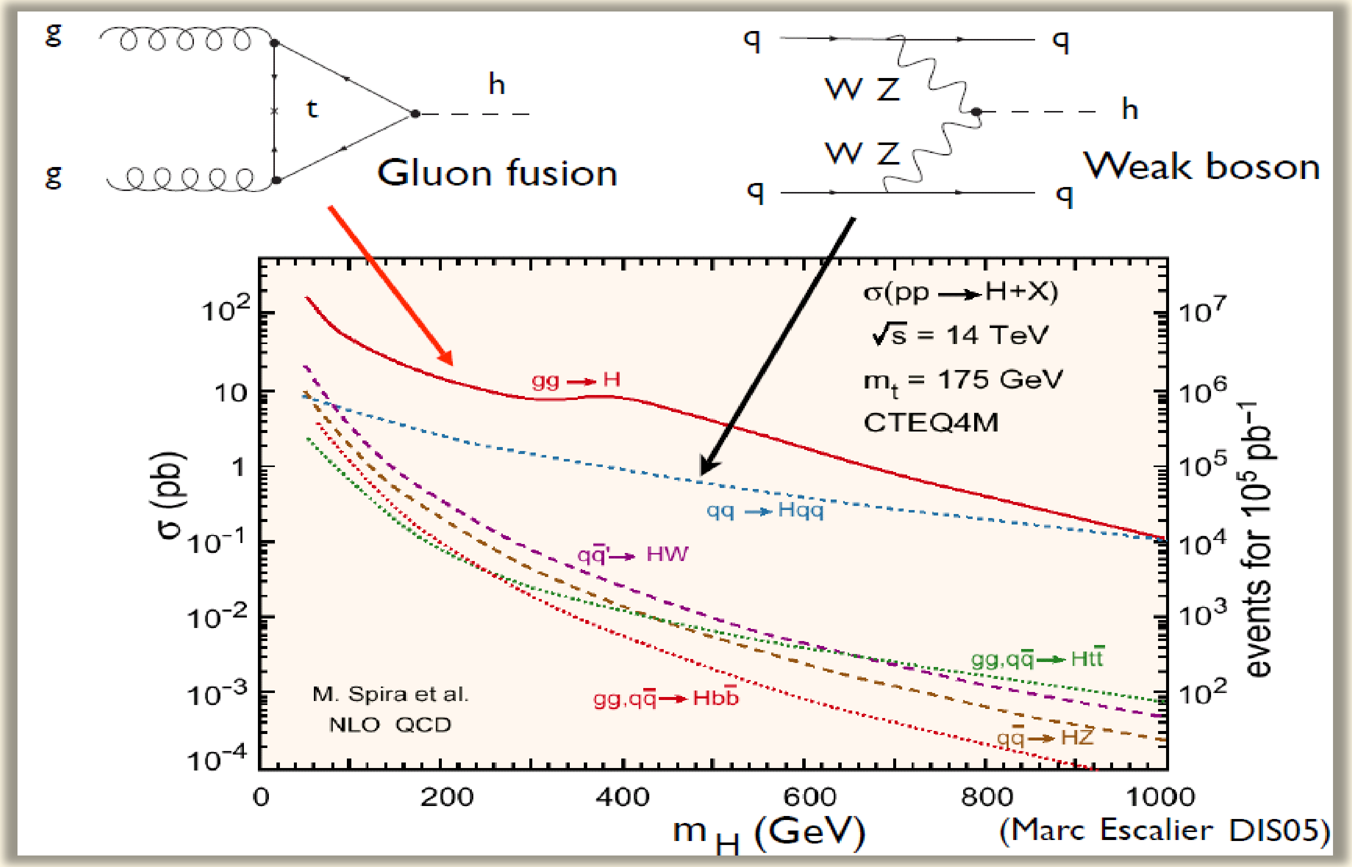
- BZ sector and SM particles interact with each other though the exchange of massive states at a scale M.

Unparticle physics and Higgs phenomenology

Higgs boson search at LHC

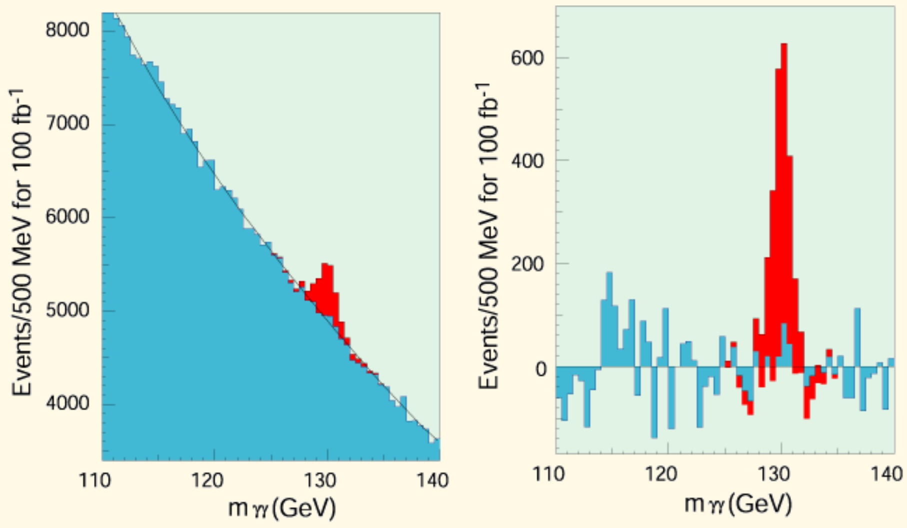
Higgs boson production dominantly by gluon fusion,

followed by week boson fusion



Gold plated Higgs decay mode: Higgs → γγ

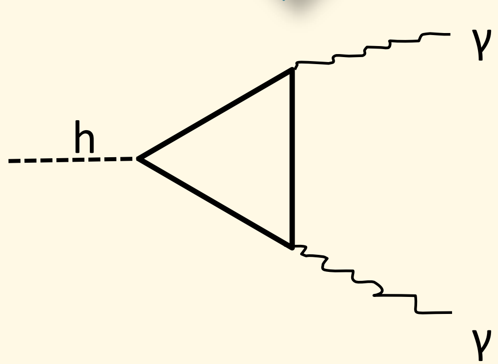
- Branching ratio of h→γγ is so small, BR = 2×10^{-3}.
- However, the resolution of both energy and position for photon is excellent at ATLAS, and we can see the narrow γγ invariant mass as a clear peak!
- **h→γγ is one of the most promising channel to discover the Higgs boson!**



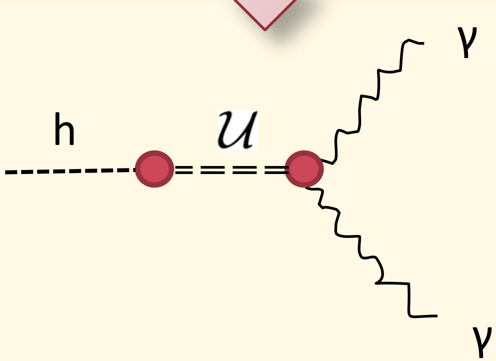
Higgs sector as a prove of New Physics

- SM Higgs can decay into γγ **only at the loop level**, and the branching ratio BR(h → γγ) is always loop suppressed.
- However, if some New Physics directly couple to γγ and gg, then, even if the cutoff scale is very high (∼10 TeV) we can explore New Physics from Higgs decay into γγ because Standard Model background for this process is always loop suppressed!

SM Higgs coupling to γγ is always loop suppressed!



New Physics may have tree level coupling to γγ



Unparticle-Higgs mixing

We introduce interactions between unparticle & Higgs doublet

$$\mathcal{L} = \frac{1}{\Lambda^{d_\mathcal{U}+n-4}} \mathcal{U} \mathcal{O}_{\mathrm{SM}} (H^\dagger H)$$

→

- EW symmetry breaking induces a tadpole term

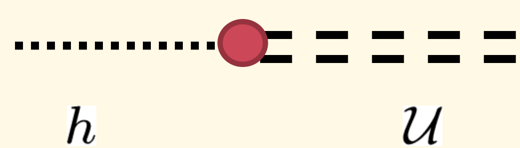
  $$\mathcal{L}_{\mathcal{U}} = \Lambda_{\mathcal{U}}^{4-d_\mathcal{U}} \mathcal{U}$$ → conformal symmetry is broken

  Not to change Higgs VEV → $\Lambda_{\mathcal{U}} \lesssim v$

- Interaction terms between unparticle & Higgs boson

  $$\mathcal{L}_{\mathcal{U}-\mathrm{Higgs}} = \frac{\Lambda_{\mathcal{U}}^{4-d_\mathcal{U}}}{v} \mathcal{U} h + \frac{\Lambda_{\mathcal{U}}^{4-d_\mathcal{U}}}{v^2} \mathcal{U} h^2 + \cdots$$

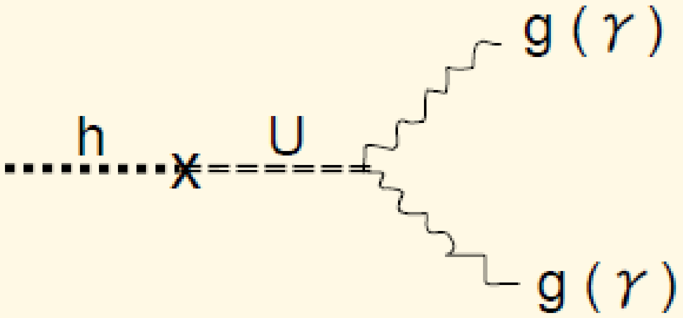
Mixing occurs:



We also introduce interactions between unparticle & gluons, photons

$$\mathcal{L}_{\mathcal{U}} = -\frac{\lambda_g}{4}\frac{\mathcal{U}}{\Lambda^{d_{\mathcal{U}}}}G^A_{\mu\nu}G^{A\mu\nu} - \frac{\lambda_\gamma}{4}\frac{\mathcal{U}}{\Lambda^{d_{\mathcal{U}}}}F_{\mu\nu}F^{\mu\nu} \quad (\lambda_{g,\gamma} = \pm 1)$$

→ Higgs boson obtains additional effective couplings with gluons & photons through the mixing with unparticle



Effective couplings:

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

SM contributions:

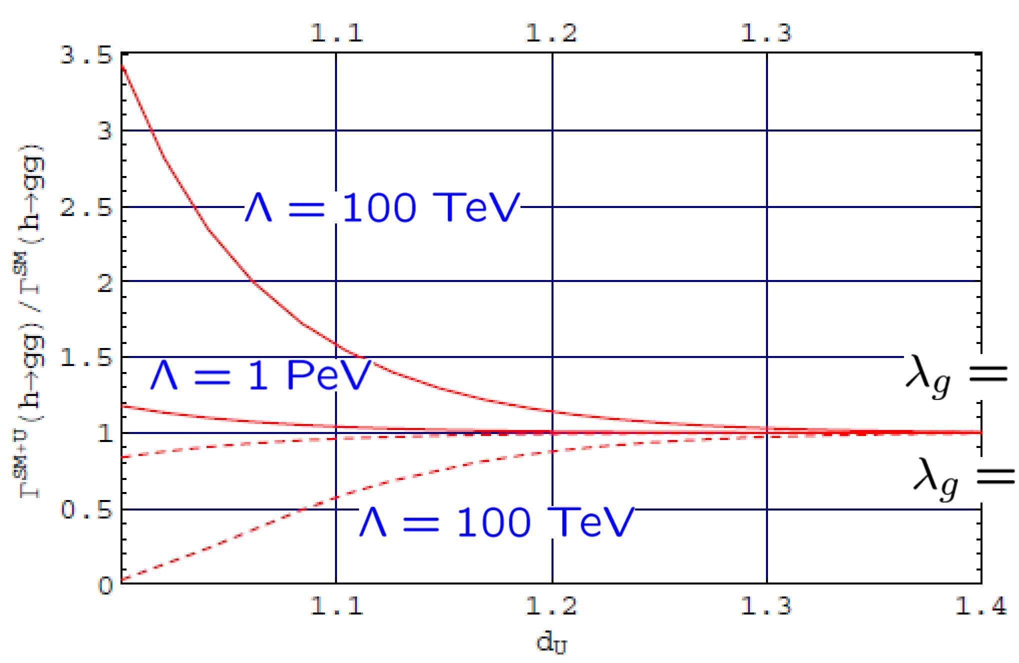
$$C^{\rm SM}_{gg} = \frac{\alpha_s}{16\pi} F_{1/2}(\tau_t) \quad \leftarrow +\mathcal{O}(1)$$

$$C^{\rm SM}_{\gamma\gamma} = \frac{\alpha}{8\pi} \left(\frac{4}{3} F_{1/2}(\tau_t) + F_1(\tau_W) \right) \quad \leftarrow -\mathcal{O}(1)$$

Unparticle effect:

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

Even for $\Lambda \gg 1$ TeV, the unparticle effect is significant!

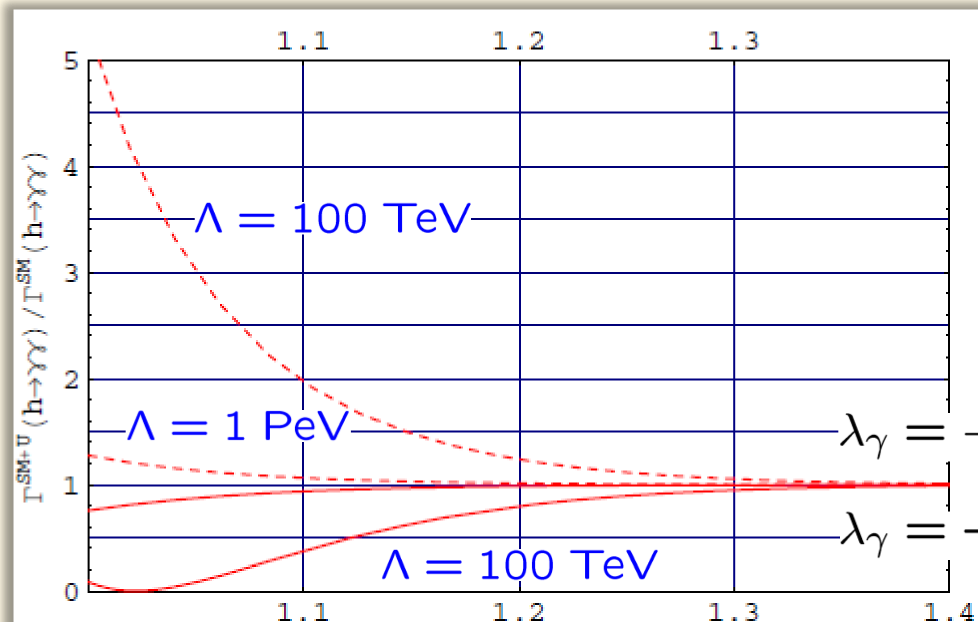


$$\frac{\Gamma^{SM+U}(h \to gg)}{\Gamma^{SM}(h \to gg)}$$

$m_h = 120$ GeV

$\lambda_g = +1$: constructive

$\lambda_g = -1$: subtractive



$$\frac{\Gamma^{SM+U}(h \to \gamma\gamma)}{\Gamma^{SM}(h \to \gamma\gamma)}$$

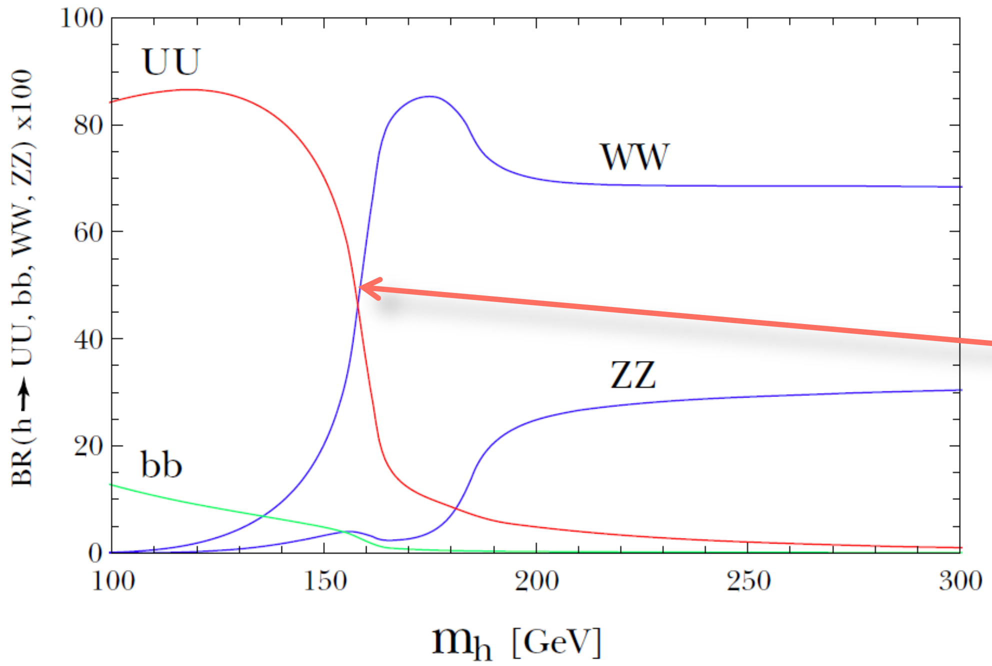
$m_h = 120$ GeV

$\lambda_\gamma = -1$: subtractive

$\lambda_\gamma = +1$: constructive

Invisible Higgs boson decay

T.K. and N. Okada, arXiv:0711.1506 [hep-ph]

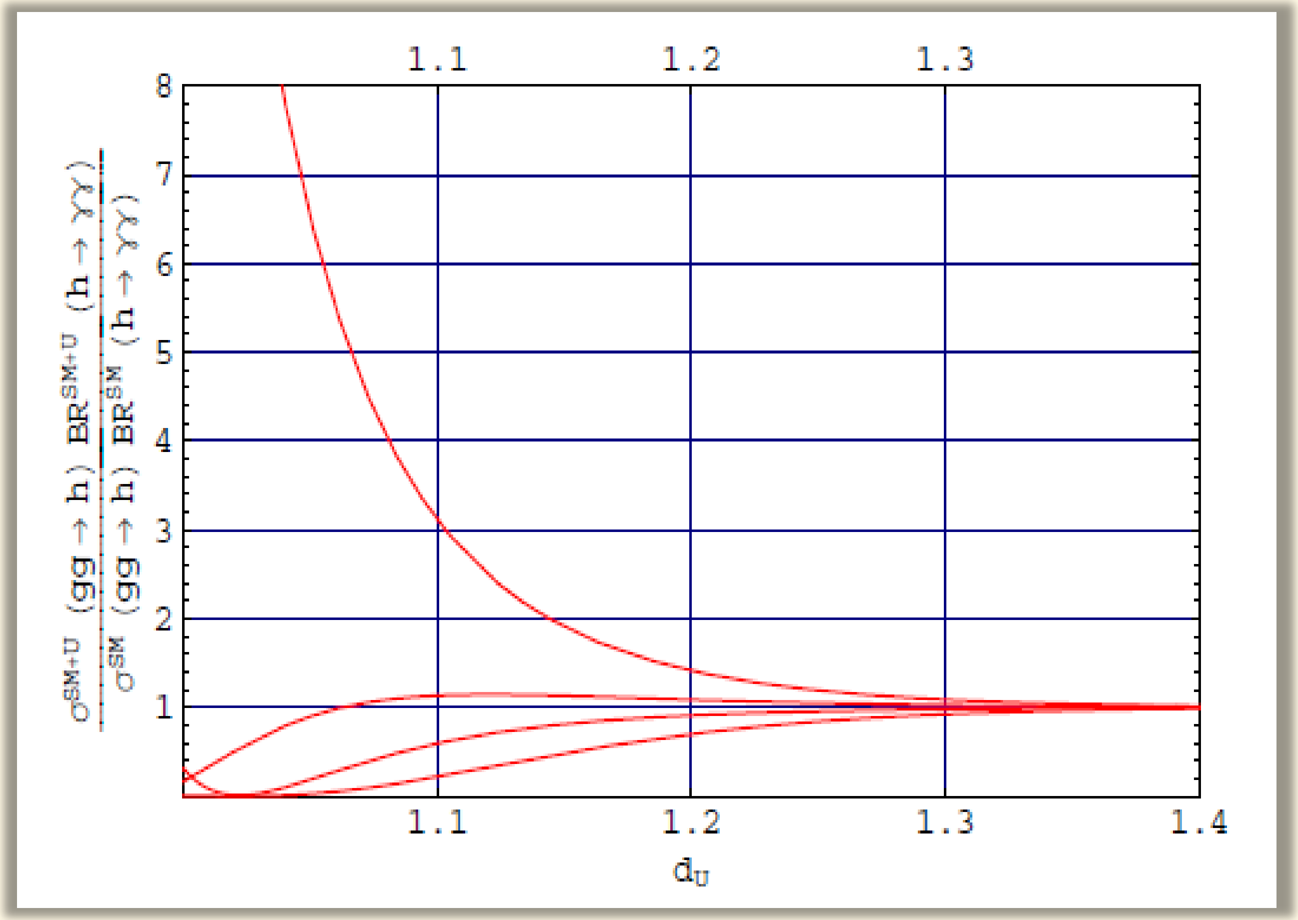


For m_h = 160 GeV, the branching ratio of invisible Higgs boson is *50%!* This is extraordinary thing and should be checked at future collider experiments.

For m_h < 160 GeV, Higgs boson dominantly decays into the unparticle dark matters. Even for m_h = 200 GeV, the branching ratio of invisible Higgs boson decay is sizable, BR(h → UU) ~ 8.5 %.

Ratio of two events

$$\frac{\sigma^{\mathrm{SM}+\mathcal{U}}(gg \to h) \times \mathrm{BR}^{\mathrm{SM}+\mathcal{U}}(h \to \gamma\gamma)}{\sigma^{\mathrm{SM}}(gg \to h) \times \mathrm{BR}^{\mathrm{SM}}(h \to \gamma\gamma)}$$



$m_h = 120$ GeV

$\Lambda = 100$ TeV

$(\lambda_g, \lambda_\gamma) = (+,-)$
$(-,-)$
$(+,+)$
$(-,+)$

Great impact on Higgs boson search at LHC even for 100 TeV!

Summary

- **We have considered the unparticle physics focusing on the Higgs phenomenology.** The mixing between the unparticle and Higgs boson make the Higgs phenomenology much more interesting.
- ***Unparticle can develop the VEV after the EW symmetry breaking***, which indicates the conformal symmetry breaking will be broken after EW symmetry breaking!
- ***Unparticle can decay into γγ even at the tree level*** while in the SM Higgs boson can decay into γγ only at the loop level. As a result, there is a factor enhancement for the branching ratio $h \to \gamma\gamma$ compared to the SM which can be measured at the LHC!