Hidden QCD at leading-order scale-symmetry limit: probed as enhanced diHiggs signal

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references: R. Ouyang (NICPB, Talinn), and S.M., 1809.10009 [hep-ph]

0. Introduction

☆ Discovery of Higgs boson in 2012

--- last piece of particles predicted in SM

--- very successful SM pheno. so far

--- but, NOT the end of the story!

still lots of stuff left needed to account for

e.g. neutrino masses (mixing),
dark matter, baryon asymmetry, etc

No clear BSM signal seen yet, though…
(2012 was already 7 years ago….)

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☆ In particular,
SM involves unsatisfactory stuff on theoretical ground:

--- origin of mass is given "by hand"

--- why mH^2 <0 (dynamical origin?) and O(100 GeV)^2?
(related to gauge hierarchy problem)

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= scale symmetry (classical scale-inv.(CSI))

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→ dimensional transmutation That's what we call "scalegenesis"

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☆ "Dynamical scalegenesis" -- one candidate: hsQCD

Extension w/ Higgs portal term $V = \kappa |\phi|^2 (H^\dagger H)$

* κ <O(1), and <0
* Φ = a SM singlet scalar, strongly coupled to hidden/dark QCD

$$\langle \phi^\dagger \phi \rangle \simeq \Lambda^2_{\rm dQCD} \longrightarrow V = -|\kappa| \Lambda^2_{\rm dQCD} (H^\dagger H)$$

below the dynamical scale, hidden scalar QCD generates scalar condensation

F.Wilczek (2008); T.Hur, et al(2011); M.Holthausen, et al (2013); J.Kubo, et al(2014); (2015); (2016); (2017); (2018); R.Ouyang and S.M, (2018)

☆Other merits on hsQCD

J.Kubo, et al (2015); (2016); (2017); (2018)

* Predicted hsQCD hadrons (e.g. $\phi_i^\dagger \phi_j$ mesons) = can be stable, to be DM

* Higgs portal coupling κ = nonzero, but <O(1);

$$V = \kappa|\phi|^2(H^\dagger H)$$

-- possibly strong 1st order PT;
-- could be linked to a baryo(lepto)genesis
-- sensitive to GWs detections

So, hsQCD provides

i) the dynamical EW scalegenesis, origin of mass
ii) rich related phenomenological consequences accessible in future exps.

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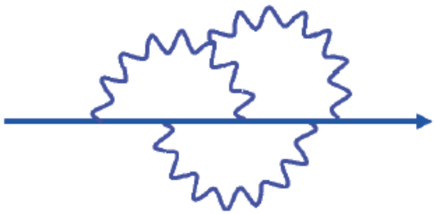
☆ nonperturvative analyses for sQCD with Nc=3 & Ns=1



Refs.

-- Lattice simulations

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-- Schwinger-Dyson analyses
(on diquark mass generation in fermionic QCD)

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Dynamical mass generation w/o chiral symmetry

* Colored-scalar quarks get the dynamical mass by nonper. gluon-dressing effects i.e. gluon condensate (NP scale anomaly)

* The estimated size of m_{dyn} = $\mathcal{O}(\Lambda_{\rm sQCD})$

as well as mass of the scalar meson bound state $\phi^\dagger \phi$ due to the sizable gluon condensate effect (NP scale anomaly)

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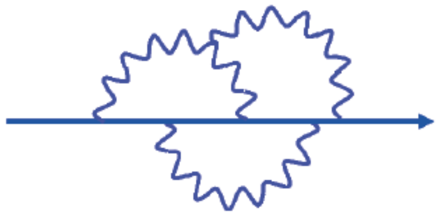

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So, NP gluonic scale anomaly is essential for the mass generation!

$$\langle T^\mu_\mu \rangle = \frac{\beta_{\rm sQCD}(\alpha_{\rm sQCD})}{4\alpha_{\rm sQCD}} \langle G^2_{\mu\nu} \rangle$$

disregarded so far in literature…

☆ In this talk, it is shown that

the **significant impact** of the **gluonic-scale anomaly** in s-hQCD on the Higgs portal physics, **accessible at LHC**

To access the LHC pheno.,

work in an effective $\phi^\dagger\phi$ meson description

1. Leading order scale symmetry

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* Lesson from fermionic QCD

Y.L.Li, et al (2017)

☆ Leading order scale symmetry (LOSS)

* scale-inv. linear sigma model with the SI explicitly broken only by the "dilaton" potential

* dilaton $= \chi$, w/ VEV $\langle\chi\rangle = \eta$

$$V(H,\chi) = -\lambda_{H\chi}(H^\dagger H)\chi^2 + \lambda_H(H^\dagger H)^2 + \lambda_\chi\chi^4 \;\underbrace{+\lambda_a\eta^4\left(\frac{\chi}{\eta}\right)^{4+a}}_{\text{breaks SI}}$$

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* Trace of energy momentum tensor detects the scale-anomaly

$$T^\mu_\mu = \partial_\mu D^\mu = \delta_D \mathcal{L} = -(a\cdot\lambda_a)\cdot\eta^4\left(\frac{\chi}{\eta}\right)^{4+a}$$

PCDC w/ anomalous dim. "a"

Since χ gets a mass by nonzero "a"

$$m_\chi^2 = (a\cdot\lambda_a)(4+a)\eta^2 \longrightarrow \langle T^\mu_\mu\rangle = -\frac{m_\chi^2\eta^2}{4+a} \qquad d[T^\mu_\mu] = d[(G_{\mu\nu})^2] = 4+a$$

☆ LOSS predictions: i) a light dilaton

$$V(H,\chi) = -\lambda_{H\chi}(H^\dagger H)\chi^2 + \lambda_H (H^\dagger H)^2 + \lambda_\chi \chi^4 \; + \lambda_a \eta^4 \left(\frac{\chi}{\eta}\right)^{4+a}$$

stationary condition

$$v^2 = \frac{\lambda_{H\chi}}{\lambda_H}\eta^2$$

$$\lambda_a + \lambda_\chi = \frac{{\lambda_{H\chi}}^2}{4\lambda_H} \, .$$

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mixing w/ Higgs "h" allowed

$$\chi' = \chi\cos\theta - h\sin\theta$$
$$h' = \chi\sin\theta + h\cos\theta.$$

Physical χ' dilaton mass

$$m_{\chi'}^2 = 2\left(\frac{\cos^2\theta}{\cos 2\theta}\lambda_{H\chi} - \frac{\sin^2\theta}{\cos 2\theta}\lambda_H\right)\cdot v^2 + 7\left(\frac{\cos^2\theta}{\cos 2\theta}(a\cdot\lambda_a)\frac{\lambda_H}{\lambda_{H\chi}}\right)\cdot v^2$$
$$\equiv 2\left(\frac{\cos^2\theta}{\cos 2\theta}\lambda_{H\chi} - \frac{\sin^2\theta}{\cos 2\theta}\lambda_H\right)\cdot v^2 + \Delta m_{\chi'}^2$$

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$$\chi' = \chi\cos\theta - h\sin\theta$$
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$$\equiv 2\left(\frac{\cos^2\theta}{\cos 2\theta}\lambda_{H\chi} - \frac{\sin^2\theta}{\cos 2\theta}\lambda_H\right)\cdot v^2 + \Delta m^2_{\chi'}$$

Take $v = 246$ GeV, $m_{h'} = 125$ GeV, and

$\eta = m_{\chi'}$: "simple-minded ansatz"

$\cos^2\theta = 0.9$: current limit on Higgs coupling measurement

$a = 0.1$: typical small breaking size, controlling scale anomaly

$$\lambda_{H\chi} \simeq 0.138\,, \qquad \lambda_H \simeq 0.182$$
$$\lambda_a \simeq 1.014\,, \qquad \lambda_\chi \simeq -0.987\,.$$

$$\eta \equiv m_{\chi'} \simeq 282\ \mathrm{GeV}$$

as low as EW scale v

$$\frac{\Delta m^2_{\chi'}}{m^2_{\chi'}} \simeq 0.798$$

NP scale-anomaly dominant

W/ $v = 246$ GeV, $m_{h'} = 125$ GeV, and

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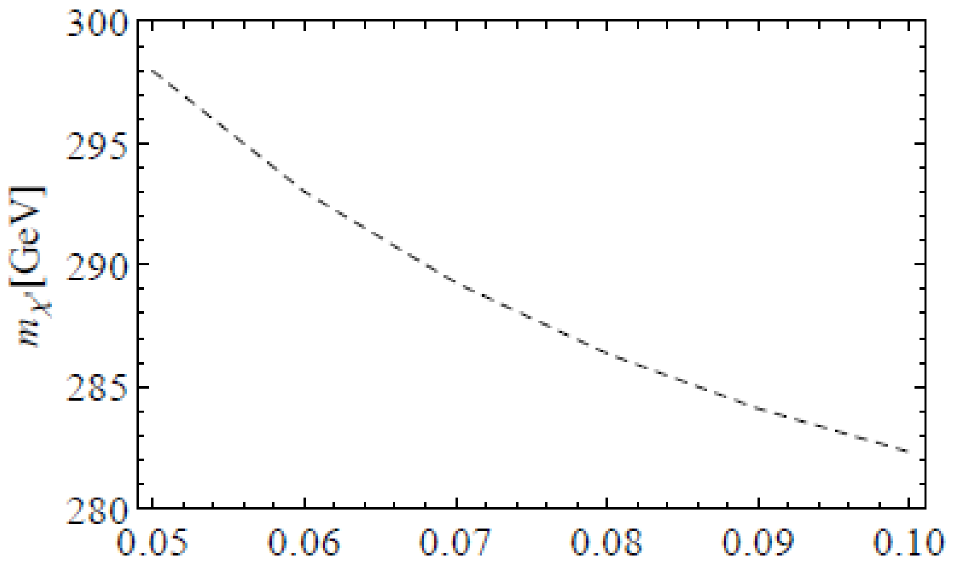
Light enough dilaton w/ mass around 280 - 300 GeV



HL-LHC prospect
L=3000/fb
← $\sin^2\theta$ →
current limit
L=36.1/fb

☆ LOSS predictions: ii) effect on Higgs trilinear coupling

$$\lambda_{h'h'h'} = -4\sin^3\theta\left[\lambda_\chi + \left(1+\frac{13}{12}a\right)\lambda_a\right]\eta$$
$$+\cos^3\theta\lambda_H v$$
$$-\sin\theta\cos\theta\lambda_{H\chi}\left(v\sin\theta - \eta\cos\theta\right)$$

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$$\frac{\lambda_{h'h'h'}}{v}\Big|_{\rm LOSS} \simeq 1.01 \ \text{ for } \cos\theta > 0$$
$$\simeq -0.702 \ \text{ for } \cos\theta < 0$$

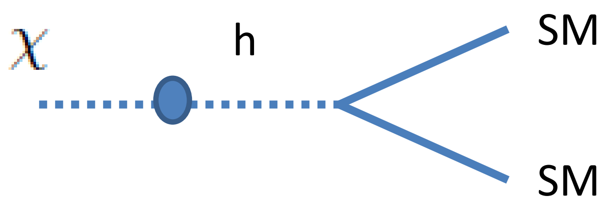
Compared to SM prediction

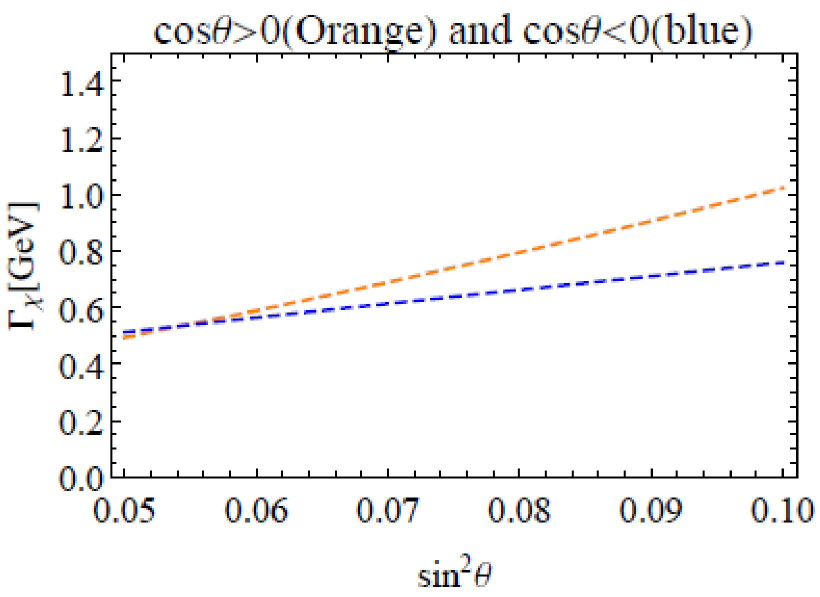
$$\frac{\lambda_{hhh}}{v}\Big|_{\rm SM} \simeq 0.75$$

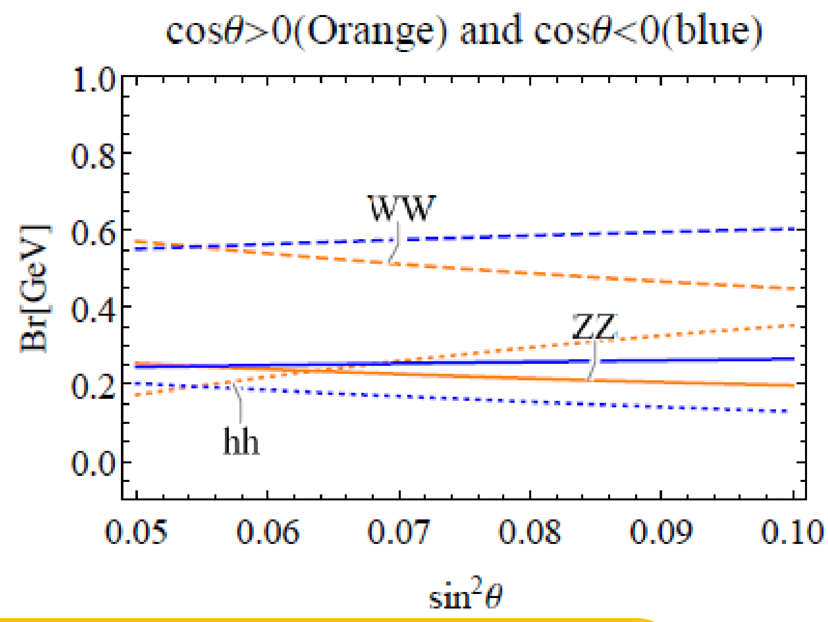
34% enhancement ,or nearly the same, in magnitude

☆ LOSS predictions: iii) dilaton decay properties

* Dilaton couples to SM only through mixing w/ Higgs “h”



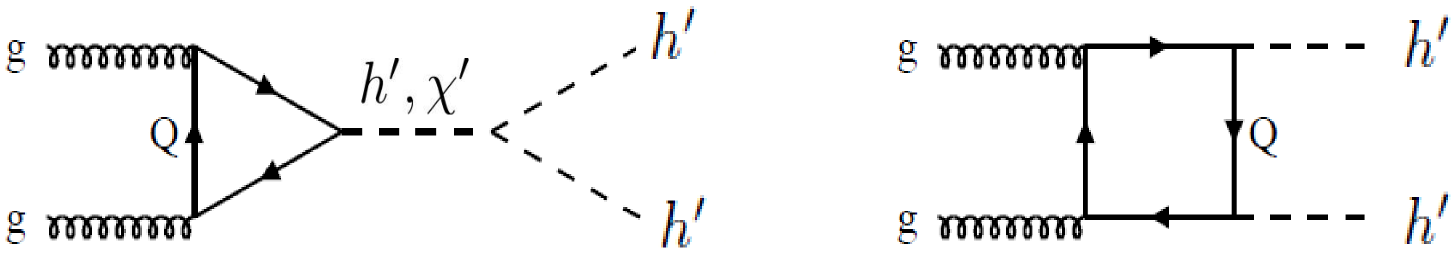




* narrow resonance w/ width-to-mass ~ 10^-4 – 10^-3 (around the mass 280 -300 GeV)

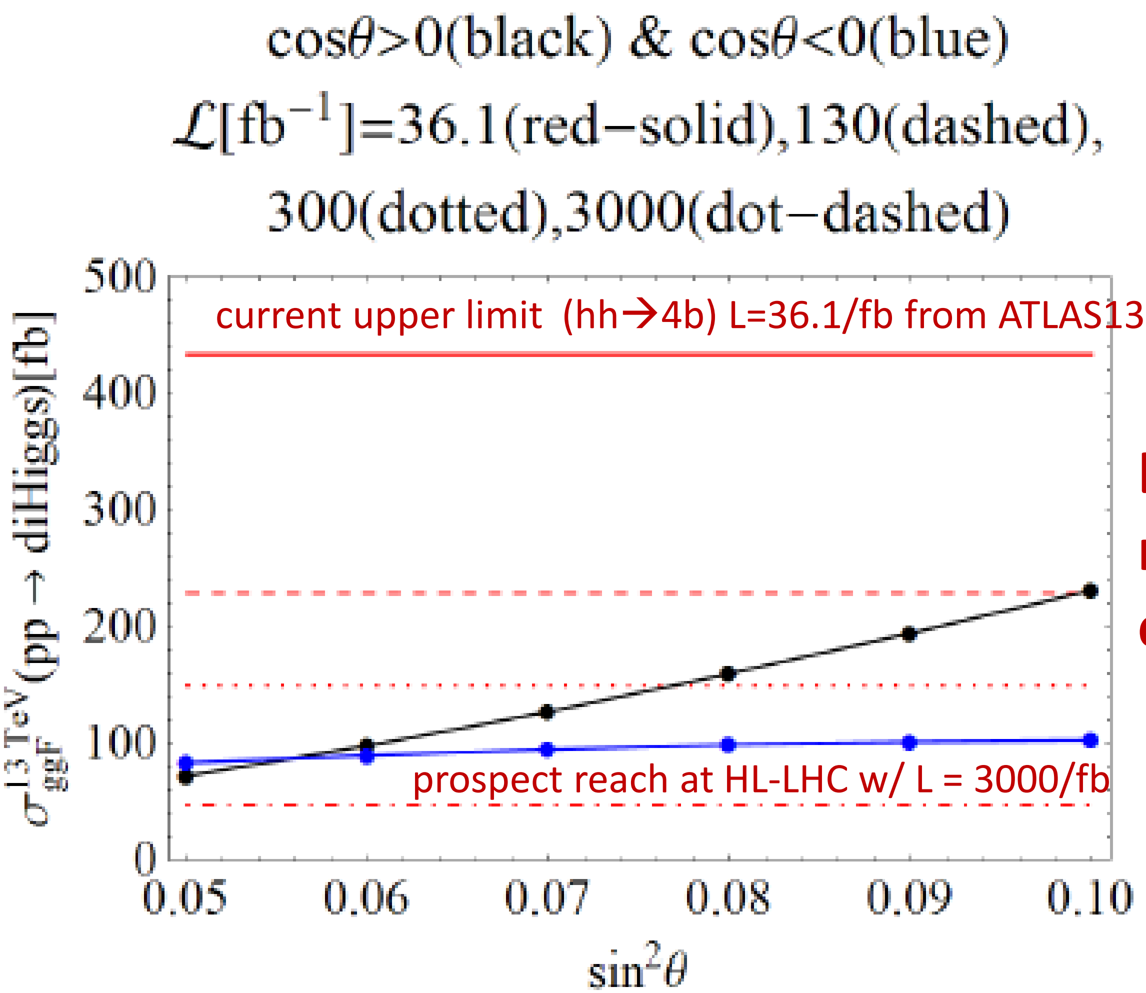
* predominantly decays to diboson (WW, ZZ, hh)

☆ LOSS predictions: iv) **DiHiggs enhancement**



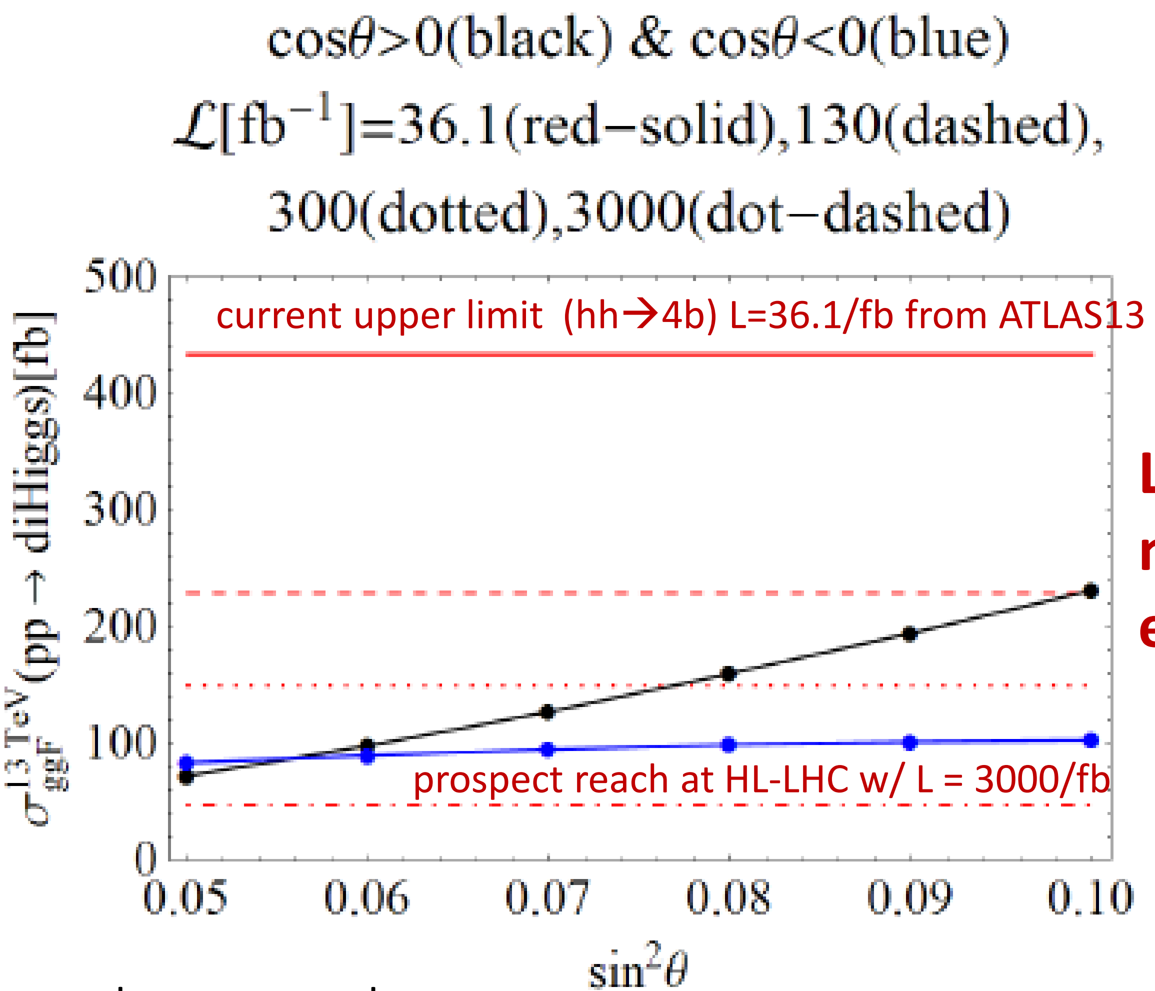
* Sizable enhancement is expected to happen due to the narrow dilaton resonance (~280 GeV – 300 GeV) near threshold for on-shell diHiggs production (~250 GeV)

(* w/ QCD-NLO included)



LOSS can be tested until near future high lumi-exps ~ 130/fb – 3000/fb

(* w/ QCD-NLO included)



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e.g. at the current edge

$\sin^2\theta = 0.1$

$$\sigma_{ggF}^{13\mathrm{TeV}}(pp \to h'h')\Big|_{\sin^2\theta=0.1} \simeq 231\ \mathrm{fb}$$

maximally
about 6.8 times
larger than SM prediction!!!

☆ LOSS predictions: v) other dilaton resonance signatures at LHC

Via ggF production

$\sin^2\theta$	$\cos\theta$	$m_{\chi'}$ [GeV]	$\sigma(\chi' \to h'h')$ [fb]	$\sigma(\chi' \to \gamma\gamma)$ [fb]	$\sigma(\chi' \to ZZ)$ [fb]	$\sigma(\chi' \to WW)$ [fb]	$\sigma(\chi' \to b\bar{b}b\bar{b})$ [fb]
0.1	+	282	307	0.0066	158	361	0.764
0.1	-	282	112	0.0088	213	486	1.029
0.05	+	298	71.9	0.0037	97.9	220	0.400
0.05	-	298	84.2	0.0035	94.4	213	0.385

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Current bound on di-EW boson (ATLAS13 w/ L=36.1/fb; arXiv:1808.02380)

σ[WW or ZZ] ~ 300fb @ resonant mass = 300 GeV

--- close to the LOSS predictions

--- probed by upcoming data in near future,
in significant correlation w/ deviation on Higgs coupling,
and excessive diHiggs signal!!!

2. Summary

☆ **Dynamical scalegenesis** gives the elegant explanation for the EW symmetry breaking, in place of the SM
--- candidate scenarios include SI-Hidden scalar QCD:

☆ The **LOSS** limit was analyzed, including crucial gluonic-scale anomaly effect into a low-energy description

--- **LOSS** predicts light enough (~280 GeV), narrow dilaton, at diboson channels at LHC

--- remarkably, gives **diHiggs enhancement** to be maximally about 6.8 times large compared to the SM Higgs, to be tested up until HL-LHC, w/ significant correlation w/ deviation on Higgs coupling measurements

☆ Applications to other dynamical scalegenesis scenarios easily doable, and LOSS predictions to other physics as well (in progress)