Minimal Dilaton Model

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(to be published PRD)

Tomohiro Abe
(Tsinghua U.)

In collabollations with
Ryuichiro Kitano (Tohoku U.)
Yasufumi Konishi (Saitama U.)
Kin-ya Oda (Kyoto U.)
Joe Stato (Saitama)
Shohei Sugiyama (ICRR)

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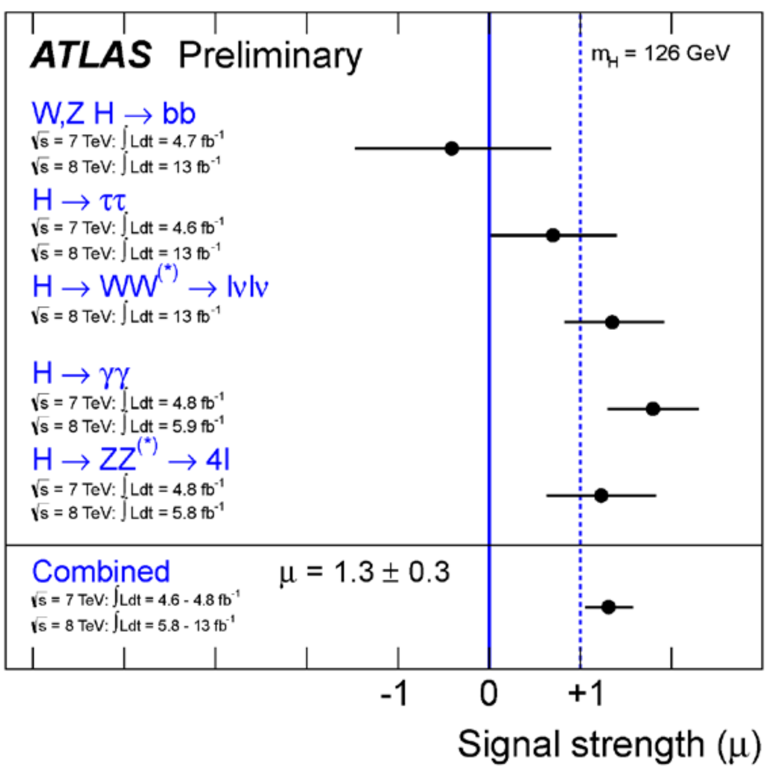
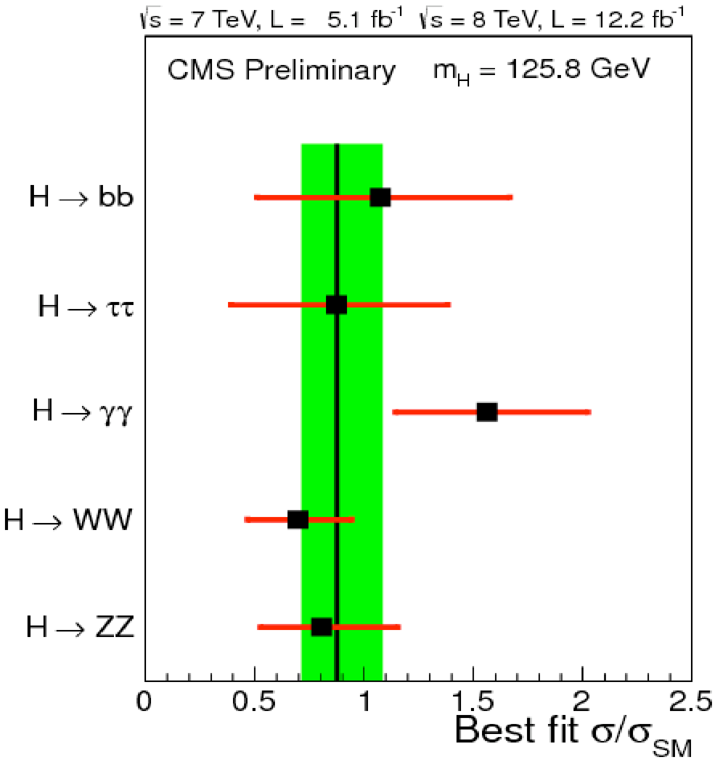
Introduction

- LHC found a new particle around 125 GeV!
- Is this really SM Higgs boson?
- It can be other particles such as **Dilaton**





Dilaton and EWSB

If there is a dilaton, who breaks electroweak symmetry breaking?

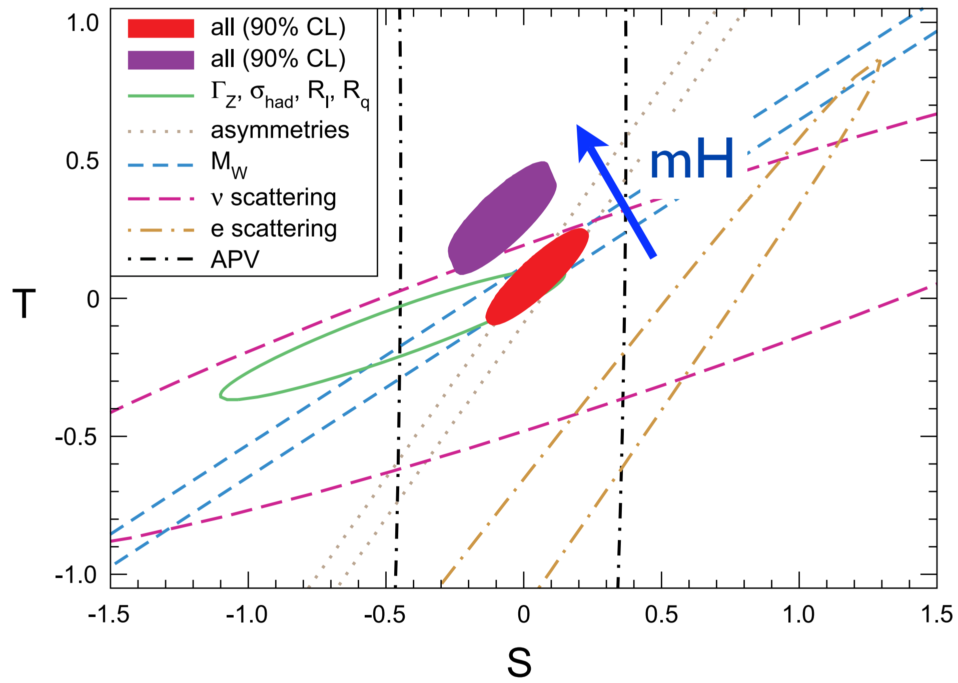
- Strong dynamics
  - ⋆ Walking/Conformal TC

- A Heavy Higgs doublet gets VEV
  - ⋆ effective discription of some (unknown) strong dynamics
  - ⋆ or believe in the elementaly scalar

Heavy Higgs and precision data

If there is a Heavy Higgs, how about S and T parameters?

- Heavy Higgs prefer Large positive T parameter
- We need new particles to satisfy the ST constraint
- Top partner will help



Who is top partner

- vector-like and $SU(2)_L$ singlet (to give positive T param.)
- We needed top partner to get T parameter in dilaton + Heavy Higgs system
- If we do not consider such situation, we do not need it
- Then it is natural to consider that the top partner related with scale invariance sector

The Goal of this talk

- Construct an effective and calculable model with
  - ⋆ dilaton
  - ⋆ Heavy Higgs
  - ⋆ top partner
  - ⋆ SM particles, which does not respect scale invariance
- Care about ST parameters
- See what happen the signal strength of 125 GeV particle

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Model : top and scalar sector

- Guage symmetry:

$$\mathrm{SU(3)} \times \mathrm{SU(2)_L} \times \mathrm{U(1)_Y}$$

- Matter contents:

Dilaton	$\phi \sim (1,1)_0$
Higgs	$H \sim (1,2)_{-1/2}$
left-handed 'top' quark	$q_{3L} \sim (3,2)_{1/6}$
right-handed 'top' quark	$t_R \sim (3,1)_{2/3}$
top partners	$T_{L,R} \sim (3,1)_{2/3}$

and other SM particles are there.

Model : Lagrangian

$$
\begin{aligned}
\mathcal{L} =& \mathcal{L}_{\text{SM}} \\
&+ \frac{e^{-2\phi/f}}{2}\partial_\mu\phi\partial^\mu\phi && \text{Dilaton kinetic term} \\
&+ \overline{T}\left(\not{D} + Me^{-\phi/f}\right)T && \text{Top partner kinetic term} \\
&- [y'\overline{q}_{3L}HT_R + (h.c.)] && \text{top - top partner coupling} \\
&- V(\phi, H) && \text{scalar potential}
\end{aligned}
$$

- Top partner mass respects scale invariance
- H has VEV through the scalar potential: $\langle H \rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$

Model : Linearization

- Redefine dilaton field

$$S = f e^{-\phi/f}$$

- Then the Lagrangian rewriten as

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu S \partial^\mu S + \overline{T}\left(\not{D} + \frac{M}{f} S \right) T - [y' \overline{q}_{3L} H T_R + (h.c.)] - \tilde{V}(S, H)$$

- This Lagrangian looks like renormalizable/calculable
- We proporse this is a minimal effective description of an approximately scale invariant theory of EWSB involing the only top and Higgs sector.

Model : mass eigenstates

After diagonalizing mass matricies for top and scalar sector, we find the mass eigenstates:

$$(s, h), \quad (t_{L,R}, t'_{L,R})$$

The relations between mass and gauge eigenstates are given by

$$S = f + s\cos\theta_H - h\sin\theta_H ,$$

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v + s\sin\theta_H + h\cos\theta_H \end{pmatrix}$$

$$\begin{pmatrix} t_{3L} \\ T_L \end{pmatrix} = \begin{pmatrix} \cos\theta_L & \sin\theta_L \\ -\sin\theta_L & \cos\theta_L \end{pmatrix}\begin{pmatrix} t_L \\ t'_L \end{pmatrix} \qquad \begin{pmatrix} t_{3R} \\ T_R \end{pmatrix} = \begin{pmatrix} \cos\theta_R & \sin\theta_R \\ -\sin\theta_R & \cos\theta_R \end{pmatrix}\begin{pmatrix} t_R \\ t'_R \end{pmatrix}$$

- We assume *s* is 125 GeV, and *h* is 600 GeV
- s is dilatonic in small θ_H region
- The mixing angle play an important role in phenomenology

Model : some couplings

s couplings to gauge bosons

$$g_{WWs} = \sin\theta_H g_{WWh}^{\mathrm{SM}}$$

$$g_{ZZs} = \sin\theta_H g_{ZZh}^{\mathrm{SM}}$$

s couplings to fermions (*f* stands for fermions except *t* and *t'*)

$$g_{ffs} = \sin\theta_H g_{ffh}^{\mathrm{SM}}$$

$$g_{tts} = \left(-\eta\sin^2\theta_L\cos\theta_H + \cos^2\theta_L\sin\theta_H\right) g_{tth}^{\mathrm{SM}}$$

$$g_{t't's} = \left(-\eta\cos^2\theta_L\cos\theta_H + \sin^2\theta_L\sin\theta_H\right)\frac{m_{t'}}{v}$$

$$\eta = \frac{v}{f}$$

- $\theta_H = 0$ is dilaton limit
- $(\theta_H, \theta_L) = (\pi/2, 0)$ is SM limit

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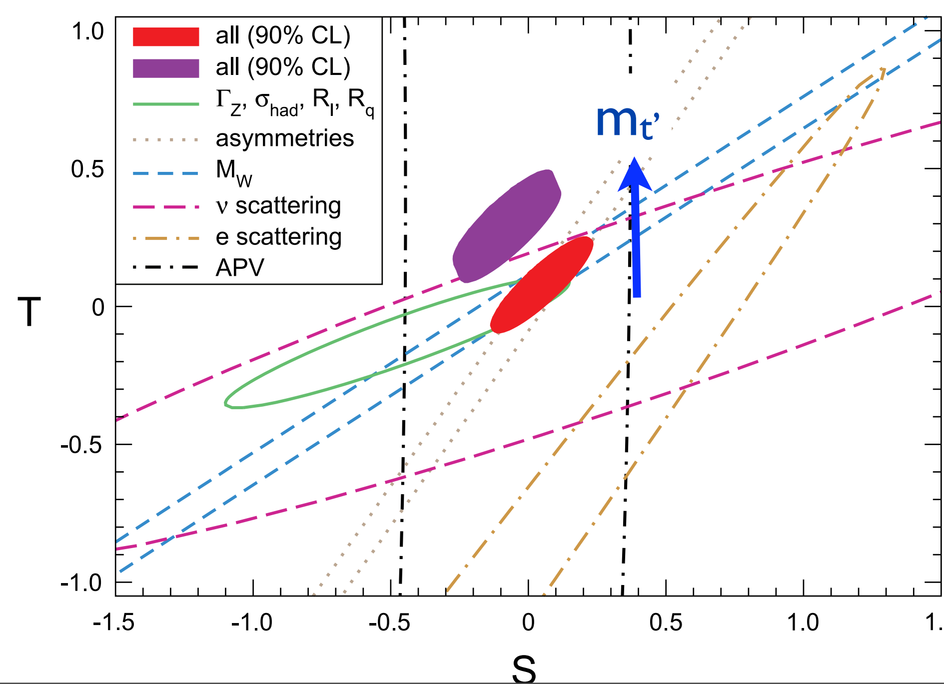
ST parameters

- t and t' loop give the dominant contributions

$$S \simeq \sin^2\theta_L \frac{N_c}{6\pi}\left(\frac{1}{3} - \cos^2\theta_L\right)\ln\frac{m_t^2}{m_{t'}^2} - \frac{\cos^2\theta_H}{12\pi}\ln\frac{m_{\rm href}^2}{m_h^2} - \frac{\sin^2\theta_H}{12\pi}\ln\frac{m_{\rm href}^2}{m_s^2}$$

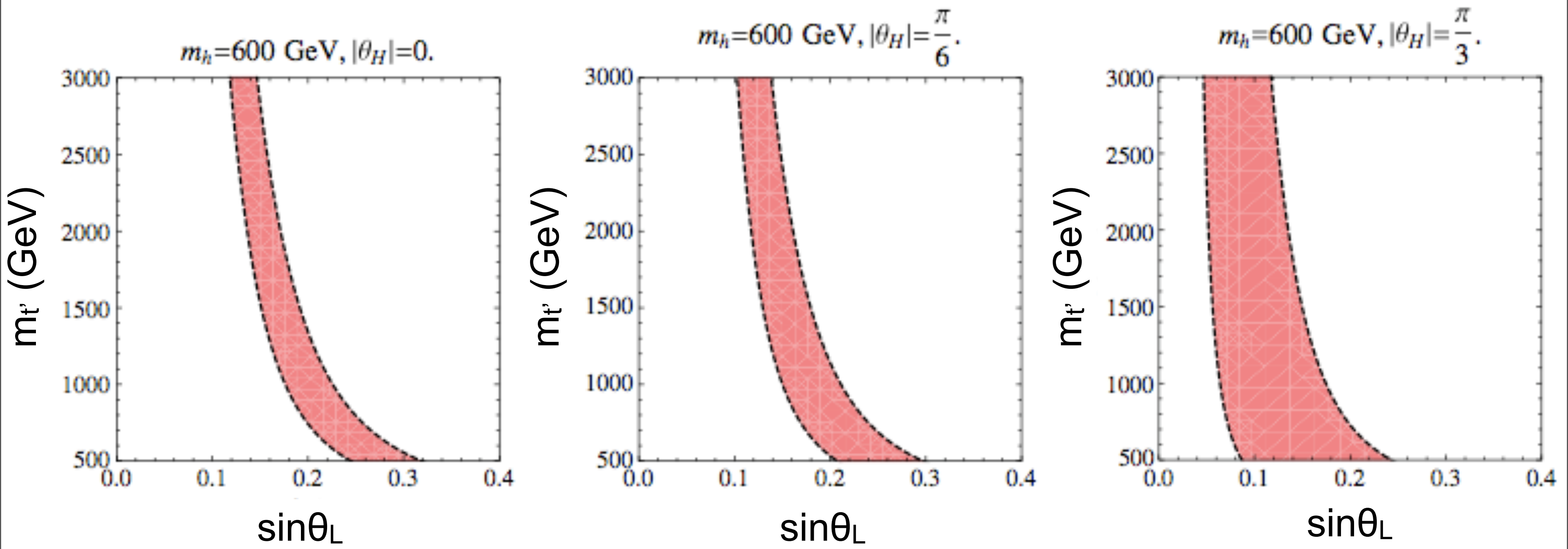
$$T \simeq \sin^4\theta_L \frac{N_c}{16\pi}\frac{1}{s_W^2 c_W^2}\frac{m_{t'}^2}{m_Z^2} + \frac{3\cos^2\theta_H}{16\pi c_W^2}\ln\frac{m_{\rm href}^2}{m_h^2} + \frac{3\sin^2\theta_H}{16\pi c_W^2}\ln\frac{m_{\rm href}^2}{m_s^2}$$

- T parameter is larger than S parameter
- We can easily satisfy the constraint



ST parameters

- ST constraint on (mt' , sinθ$_L$)
- Red region is allowd at 95% CL



- This model is consistent with EWPT

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σ/SM for *s* production process

- production cross section ratio to the SM via process X

$$R_X = \frac{\sigma_X}{\sigma_X^{SM}}$$

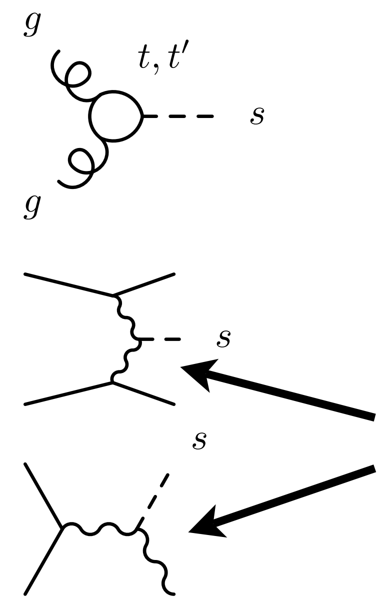
- main production processes are

$$R_{\mathrm{GF}} \simeq (\eta \cos\theta_H + \sin\theta_H)^2$$

$$R_{\mathrm{VBF}} = \sin^2\theta_H$$

$$R_{\mathrm{VH}} = \sin^2\theta_H$$

$$\eta = \frac{v}{f}$$



top partner also works in GF

couplings are suppressed by $\sin\theta_H$

Γ/SM for s

- partial decay width ratio to the SM

$$R(s \to X) = \frac{\Gamma(s \to X)}{\Gamma(h \to X)^{\rm SM}}$$

- Results are

$$R(s \to ff) = \sin^2\theta_H$$

$$R(s \to WW) = \sin^2\theta_H$$

$$R(s \to ZZ) = \sin^2\theta_H$$

$$R(s \to gg) \simeq (\eta\cos\theta_H + \sin\theta_H)^2$$

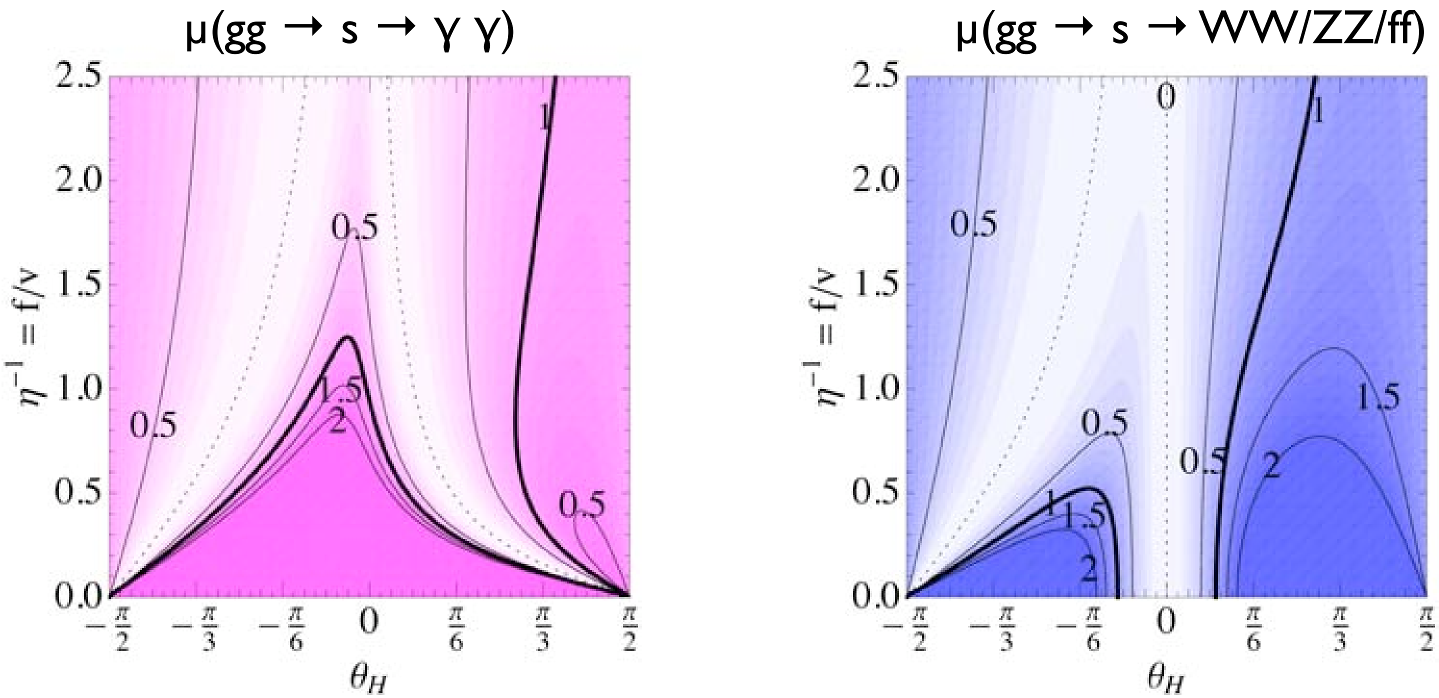
$$R(s \to \gamma\gamma) \simeq \left(\eta\frac{A_{t'}}{A_{\rm SM}}\cos\theta_H + \sin\theta_H\right)^2$$

$$\eta = \frac{v}{f}$$

$$A_{t'} \simeq \frac{16}{9}$$

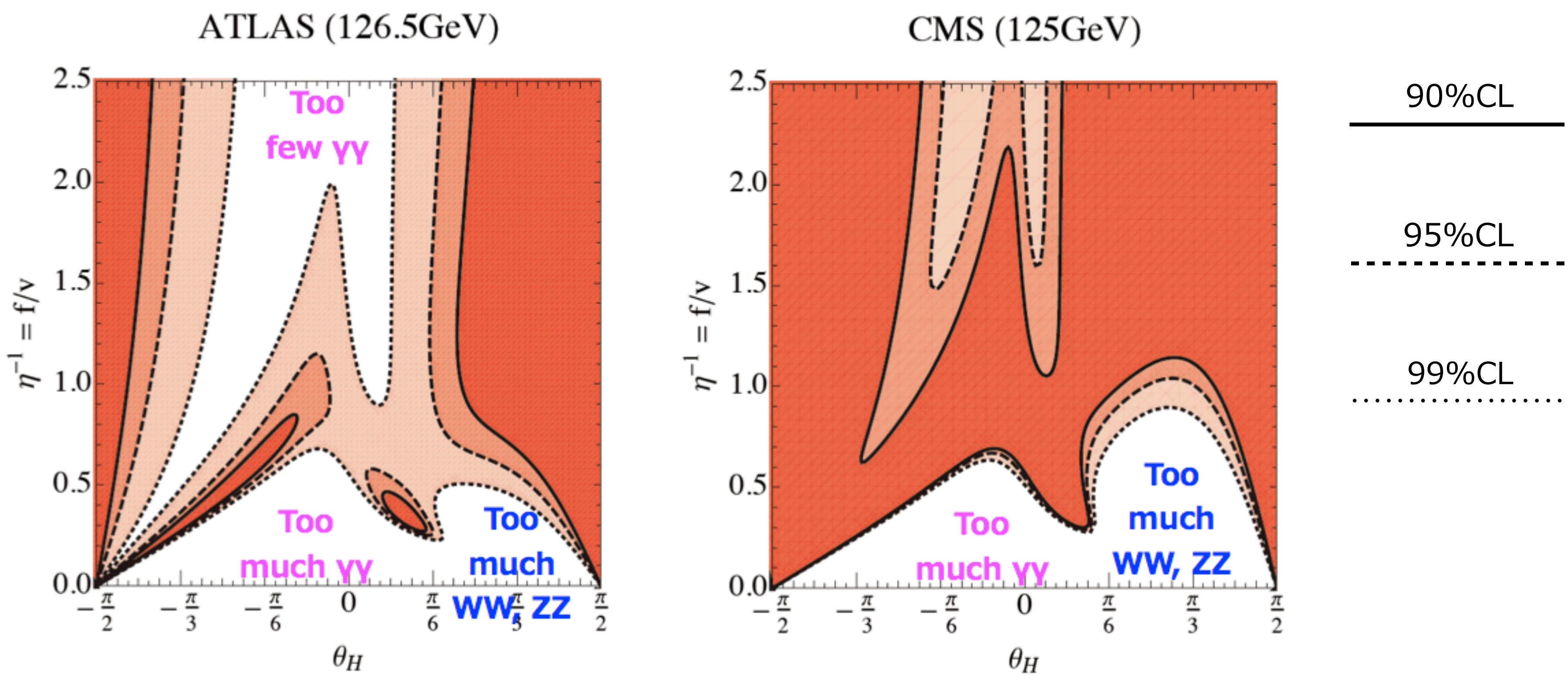
$$A_{\rm SM} \simeq -6.5$$

signal strength



- μ(gg → s → WW) = μ(gg → s → ZZ) = μ(gg → s → bb) = μ(gg → s → ττ)
- At small θ_H (s ~ pure dilatonic), γ γ is enhanced but WW/ZZ is suppressed.
- At large θ_H (s ~ dilaton + Higgs), WW/ZZ is compatible with the data but γ γ is not enhanced.
- chi-squre fit is needed to find the compatible region with data.

vs ATLAS and CMS



- combined analysis by using chi square fit
- we used experimental data given at July 4th
- In large θ_H region, model is compatible with data but *s* is not purely dilaton
- In the small θ_H region (*s* ~ dilaton), f should be smaller than v.

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Summary

- We Construct an effective and calculable model with
  - ⋆ dilaton
  - ⋆ Heavy Higgs
  - ⋆ top partner
  - ⋆ SM particles
- The constraints from ST parameters are satisfied thanks to top partner
- We study the signal strength of 125 GeV particle and find this model is compatible with current experiments
  - ⋆ θ_H is not small, namely s = dilaton + Higgs
  - ⋆ θ_H is small, and f is smaller than v

BACKUP SLIDES

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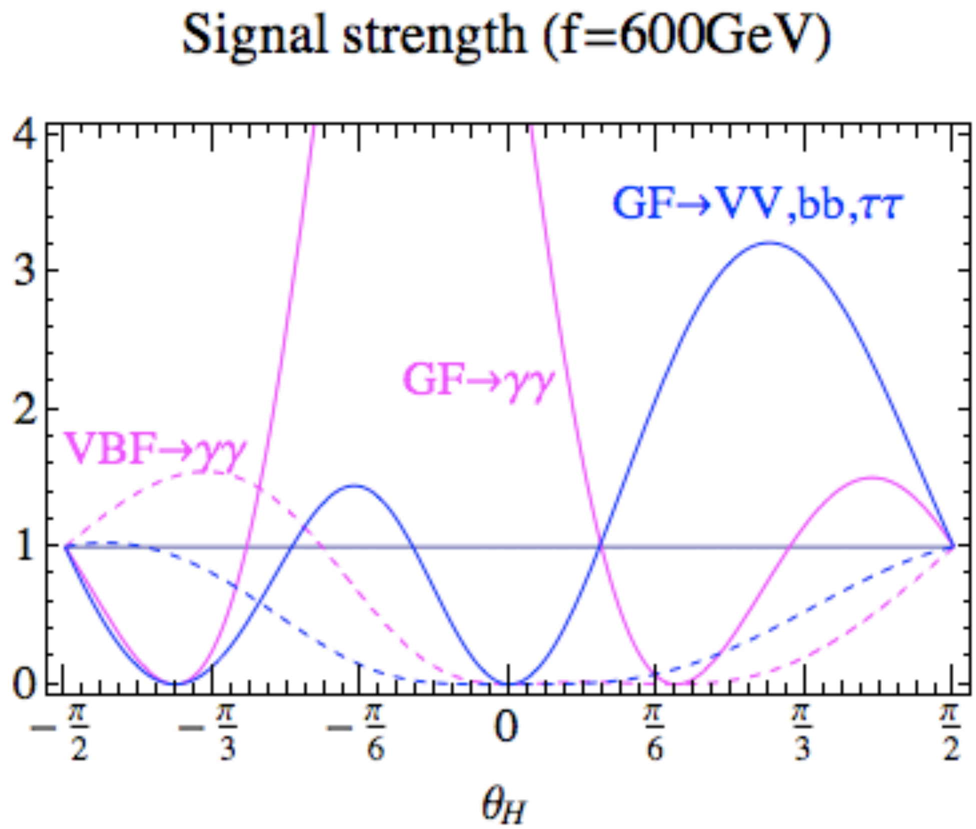
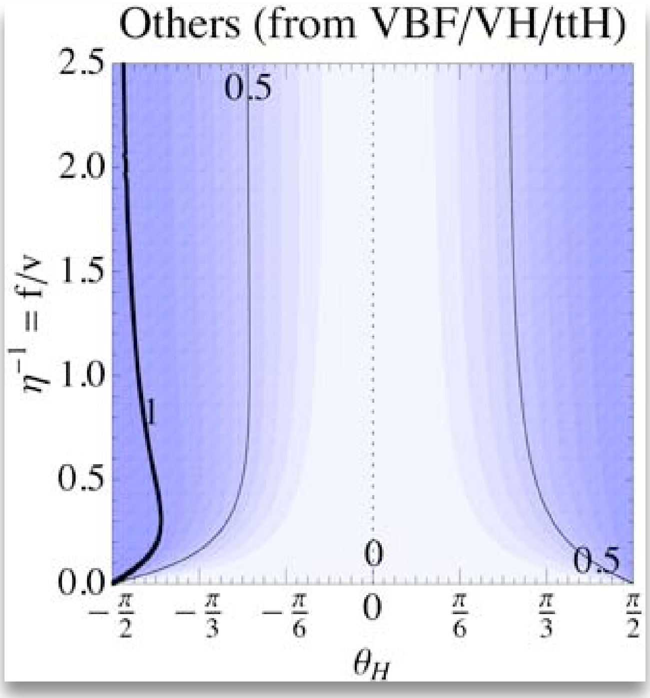
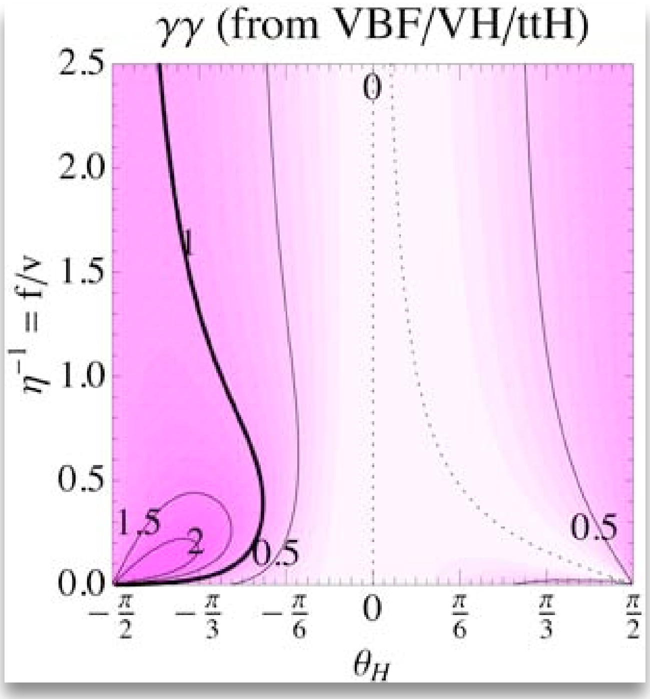


Signal strength (f=600GeV)
4
3
2
1
0
GF→VV,bb,ττ
GF→γγ
VBF→γγ
$-\frac{\pi}{2}$
$-\frac{\pi}{3}$
$-\frac{\pi}{6}$
0
$\frac{\pi}{6}$
$\frac{\pi}{3}$
$\frac{\pi}{2}$
θ_H

title



Others (from VBF/VH/ttH)
$\eta^{-1} = f/v$
θ_H
0.5
1
0
0.5



$\gamma\gamma$ (from VBF/VH/ttH)
$\eta^{-1} = f/v$
θ_H
0
1
1.5
2
0.5
0.5