Minimal Dilaton Model

Kin-ya Oda (Kyoto)

arXiv: 1209.4544

with

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Finally we see "the scalar"?

1967, birth of SM.

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[11] In obtaining the expression (11) the mass difference between the charged and neutral has been ignored.

[12] M. Ademollo and R. Gatto, Nuovo Cimento 44A, 282 (1966); see also J. Pasupathy and R. E. Marshak, Phys. Rev. Letters 17, 888 (1966).

[13] The predicted ratio [eq. (12)] from the current algebra is slightly larger than that (0.23 %) obtained from the ρ-dominance model of Ref. 2. This seems to be true also in the other case of the ratio $\Gamma(\eta \to \pi^+\pi^-\gamma)/\Gamma(\gamma\gamma)$ calculated in Refs. 12 and 14.

[14] L. M. Brown and P. Singer, Phys. Rev. Letters 8, 460 (1962).

A MODEL OF LEPTONS*

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(Received 17 October 1967)

Leptons interact only with photons, and with the intermediate bosons that presumably mediate weak interactions. What could be more natural than to unite[1] these spin-one bosons into a multiplet of gauge fields? Standing in the way of this synthesis are the obvious differences in the masses of the photon and intermediate meson, and in their couplings. We might hope to understand these differences by imagining that the symmetries relating the weak and electromagnetic interactions are exact symmetries of the Lagrangian but are broken by the vacuum. However, this raises the specter of unwanted massless Goldstone bosons.[2] This note will describe a model in which the symmetry between the electromagnetic and weak interactions is spontaneously broken, but in which the Goldstone bosons are avoided by introducing the photon and the intermediate-boson fields as gauge fields.[3] The model may be renormalizable.

We will restrict our attention to symmetry groups that connect the observed electron-type leptons only with each other, i.e., not with muon-type leptons or other unobserved leptons or hadrons. The symmetries then act on a left-handed doublet

and on a right-handed singlet

$$R = [\tfrac{1}{2}(1-\gamma_5)]e. \quad (2)$$

The largest group that leaves invariant the kinematic terms $-\bar{L}\gamma^\mu\partial_\mu L - \bar{R}\gamma^\mu\partial_\mu R$ of the Lagrangian consists of the electronic isospin $\vec{T}$ acting on L, plus the numbers N_L, N_R of left- and right-handed electron-type leptons. As far as we know, two of these symmetries are entirely unbroken: the charge $Q = T_3 - N_R - \frac{1}{2}N_L$, and the electron number $N = N_R + N_L$. But the gauge field corresponding to an unbroken symmetry will have zero mass,[4] and there is no massless particle coupled to N,[5] so we must form our gauge group out of the electronic isospin $\vec{T}$ and the electronic hyperchange $Y = N_R + \frac{1}{2}N_L$.

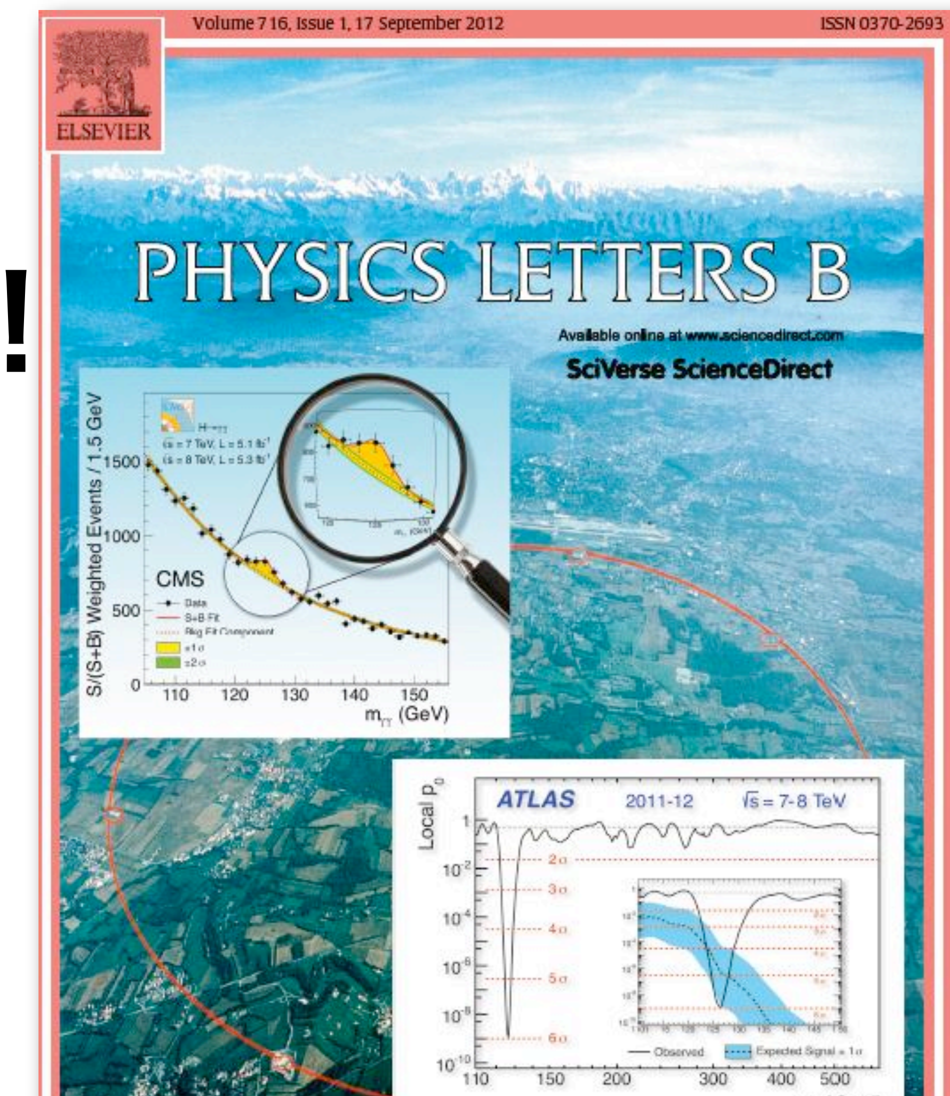
Therefore, we shall construct our Lagrangian out of L and R, plus gauge fields $\vec{A}_\mu$ and B_μ coupled to $\vec{T}$ and Y, plus a spin-zero doublet

$$\varphi = \begin{pmatrix} \varphi^0 \\ \varphi^- \end{pmatrix} \quad (3)$$

whose vacuum expectation value will break $\vec{T}$

45 years!

2012, its completion?

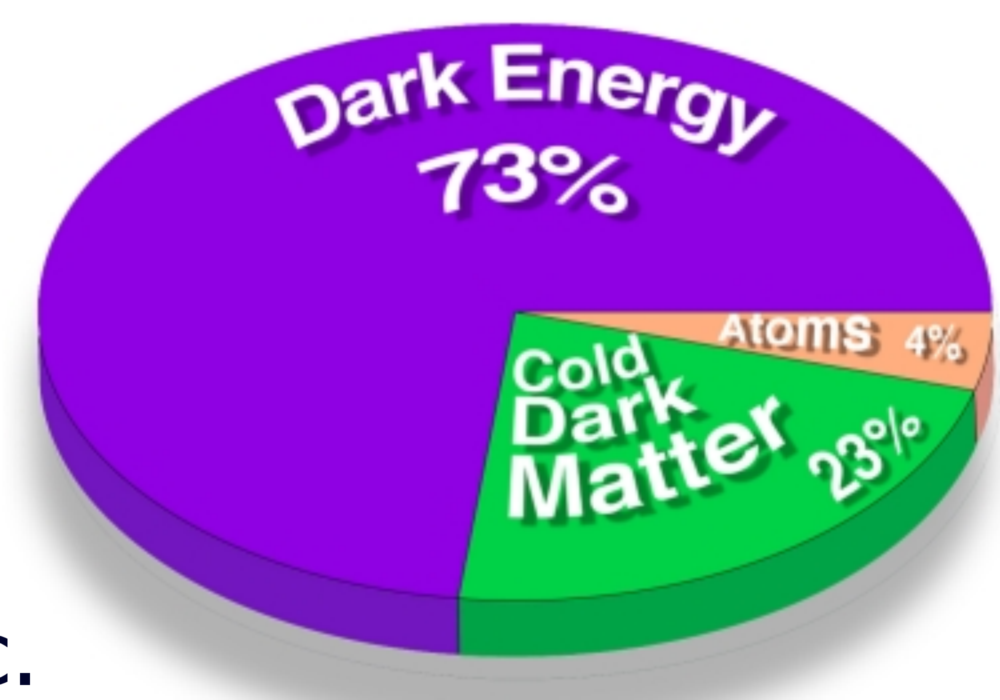


Is it the end of the story?

(Should students quit joining particle physics community?)

Of course not!

- We **know** that SM is **not** enough.
  - ★ With experimental support:
    - ✳ <u>**DM**</u> **must** exist.
    - ✳ CP violation in CKM is **not** sufficient for <u>baryogenesis</u>.
  - ★ Also theoretically:
    - ✳ Strong CP "problem,"
    - ✳ Hierarchy "problem,"
    - ✳ U(1) charge quantization, etc.



[Fig. from web]

Possible directions

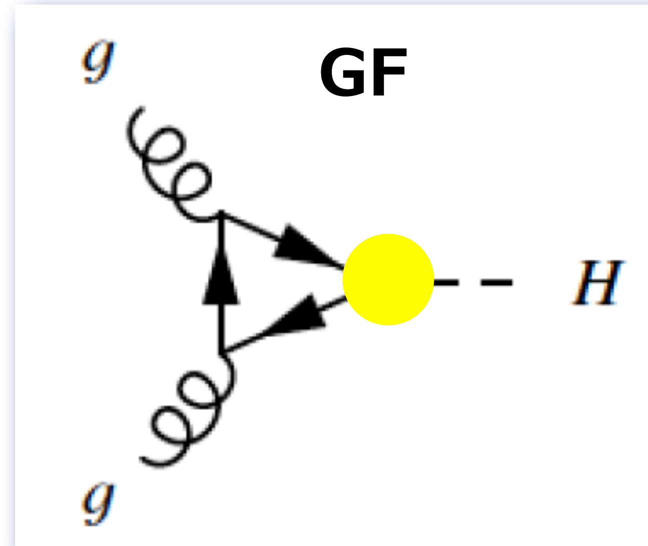
- What we see today may turn out to be...
  - ★ Non-Higgs: Today’s talk.
  - ★ SM-Higgs: [w/Hamada & Kawai, arXiv:1210.????].
  - ★ Higgs+UED: [w/(Kakuda,) Nishiwaki, Okuda & Watanabe, PLB, 2012; PRD, 2012; (arXiv:1210.????)]
- It’s an experimentalists’ era.
  - ★ Exciting to see the forthcoming data!!

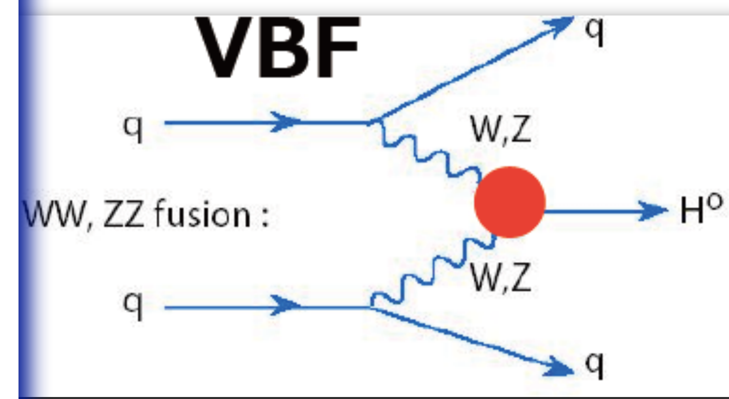
Outline

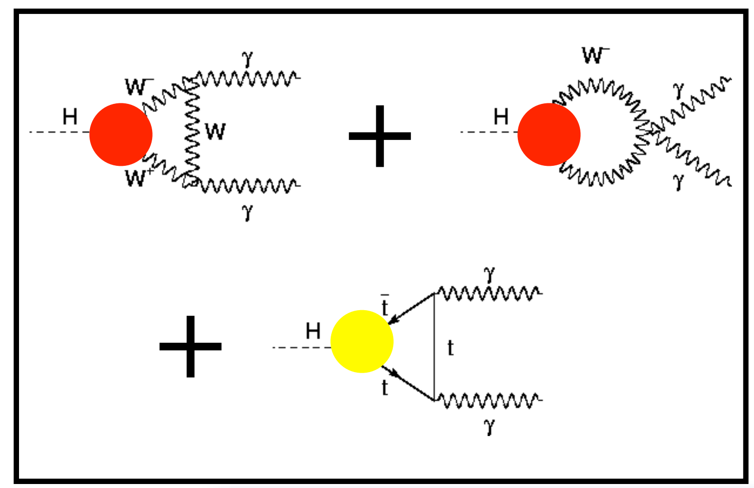
1. "Higgs" may not be a Higgs
2. Minimal Dilaton Model
3. Model predictions
4. Confronting LHC data

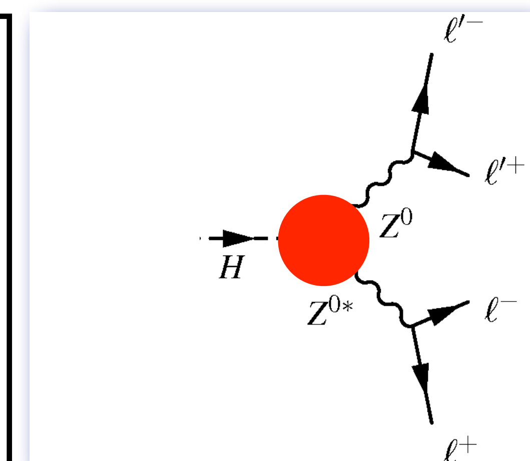
Higgs at LHC

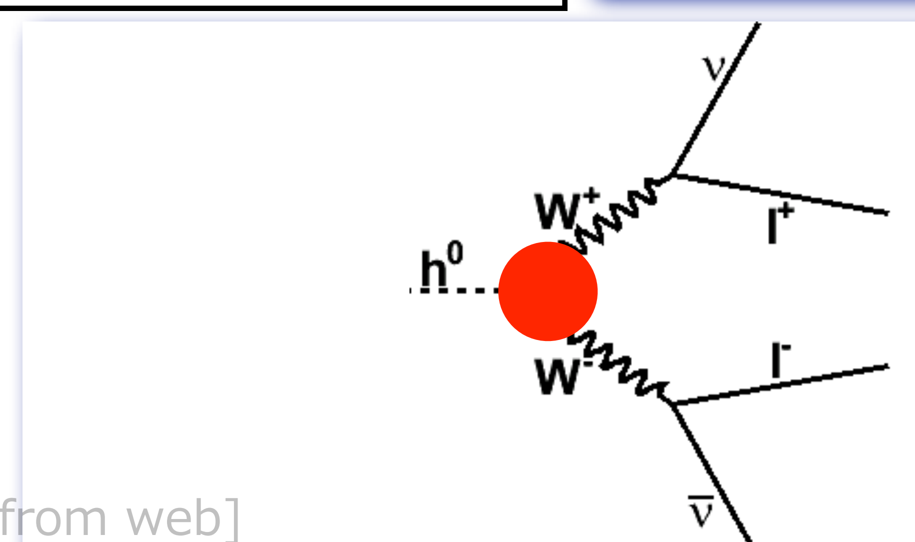
- If SM Higgs,
  - ★ Production mainly via gluon fusion.
    - ✳ VBF 10 times smaller but cleaner.
  - ★ Resonance observed in:
    - ✳ “H” → γγ (di-photon),
    - ✳ “H” → ZZ → llll.
  - ★ Which is consistent with (non-resonant)
    - ✳ “H” → WW → lνlν.





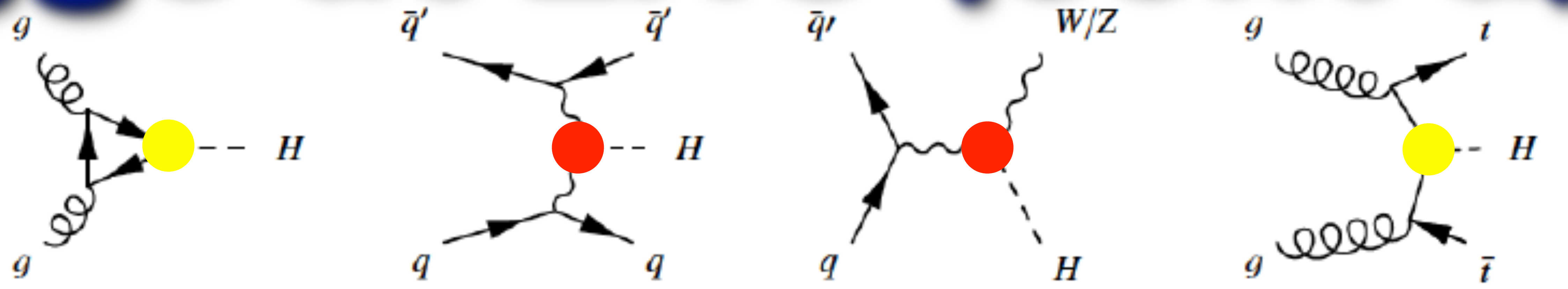






[Figs. from web]

Higgs at LHC (cont'd)

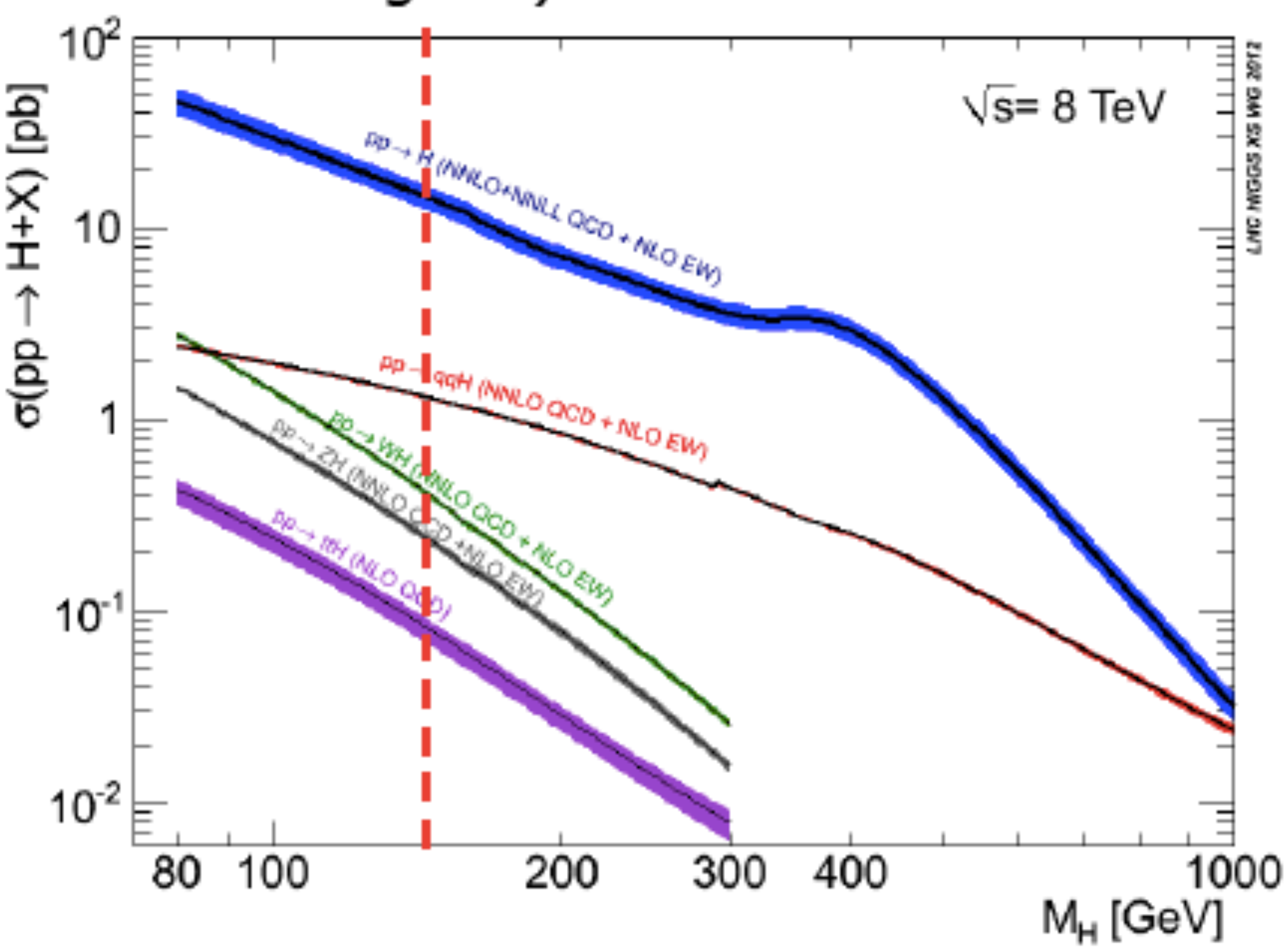


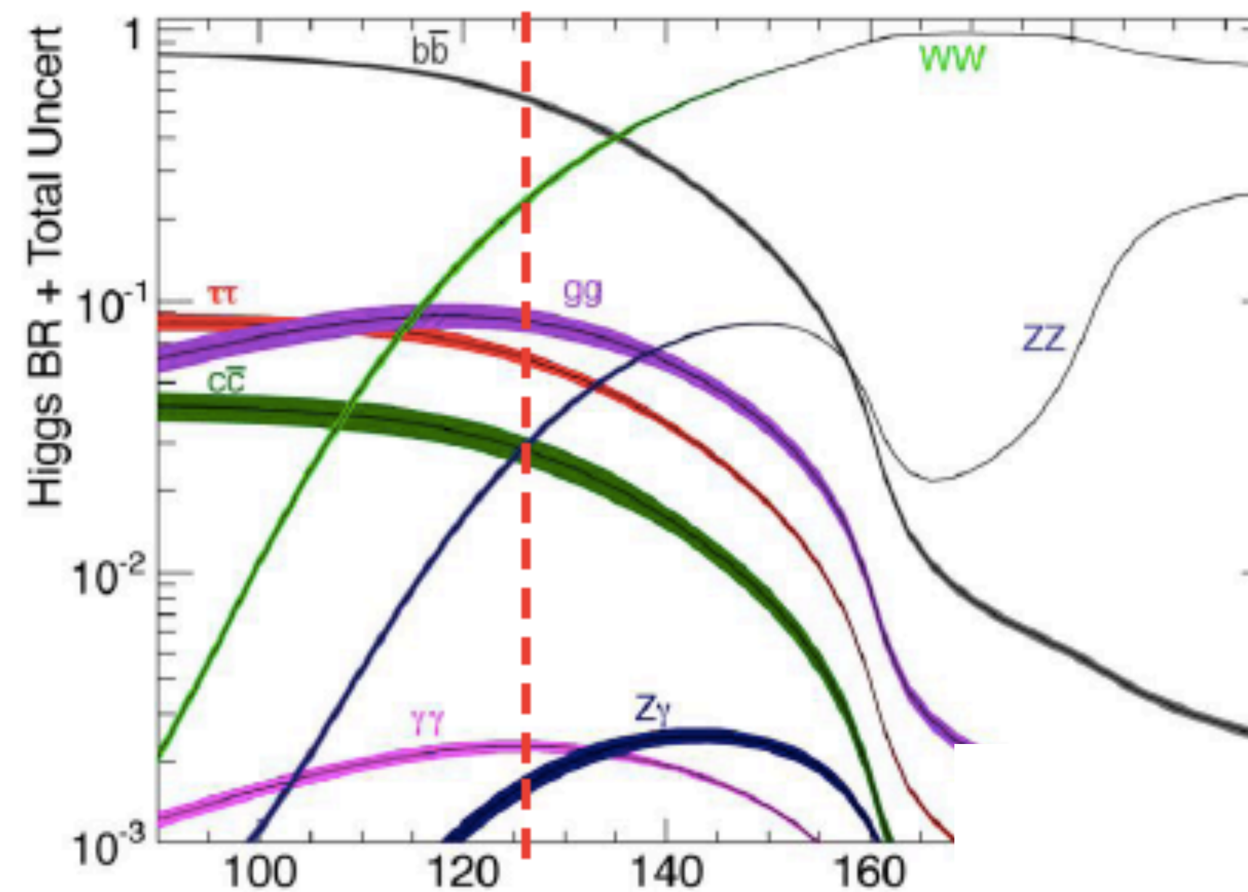
(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$

NNLO+NNLL(QCD soft-gluon)+NLO EW

NNLO+NLO EW

NLO

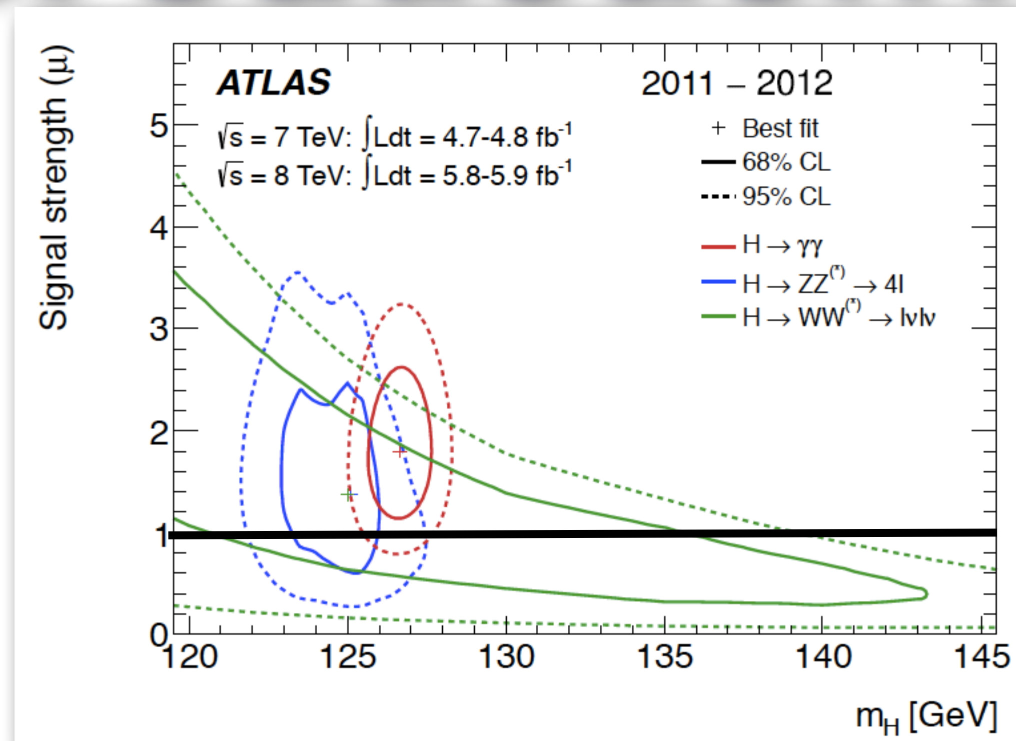


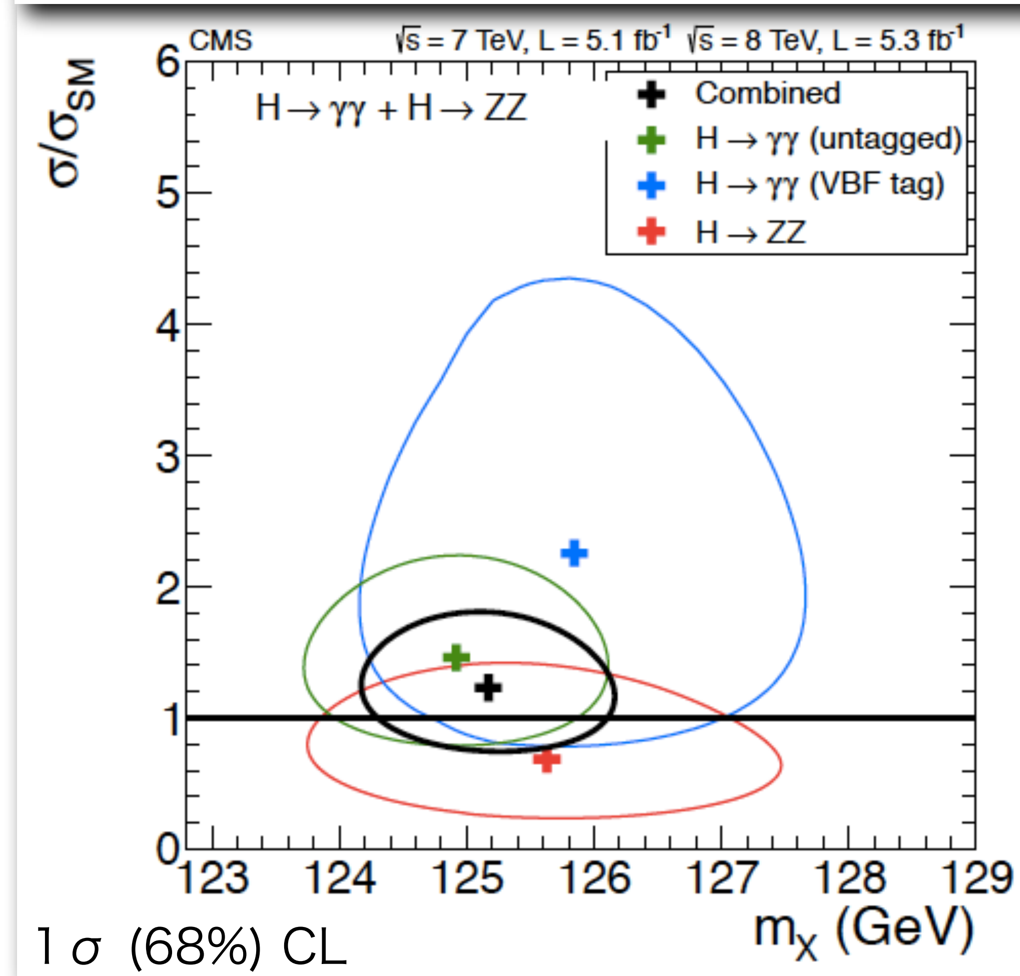


[This slide from Junichi Tanaka, JSPS meeting 2012]

Enhanced Higgs production?

- Seems to be **enhanced** in γγ-channels both in ATLAS & CMS.
- Currently WW & ZZ are
  - ★ less effective for **signal strength** determination.
  - ★ Consistent with both 0 (w/~3σ) & 1.

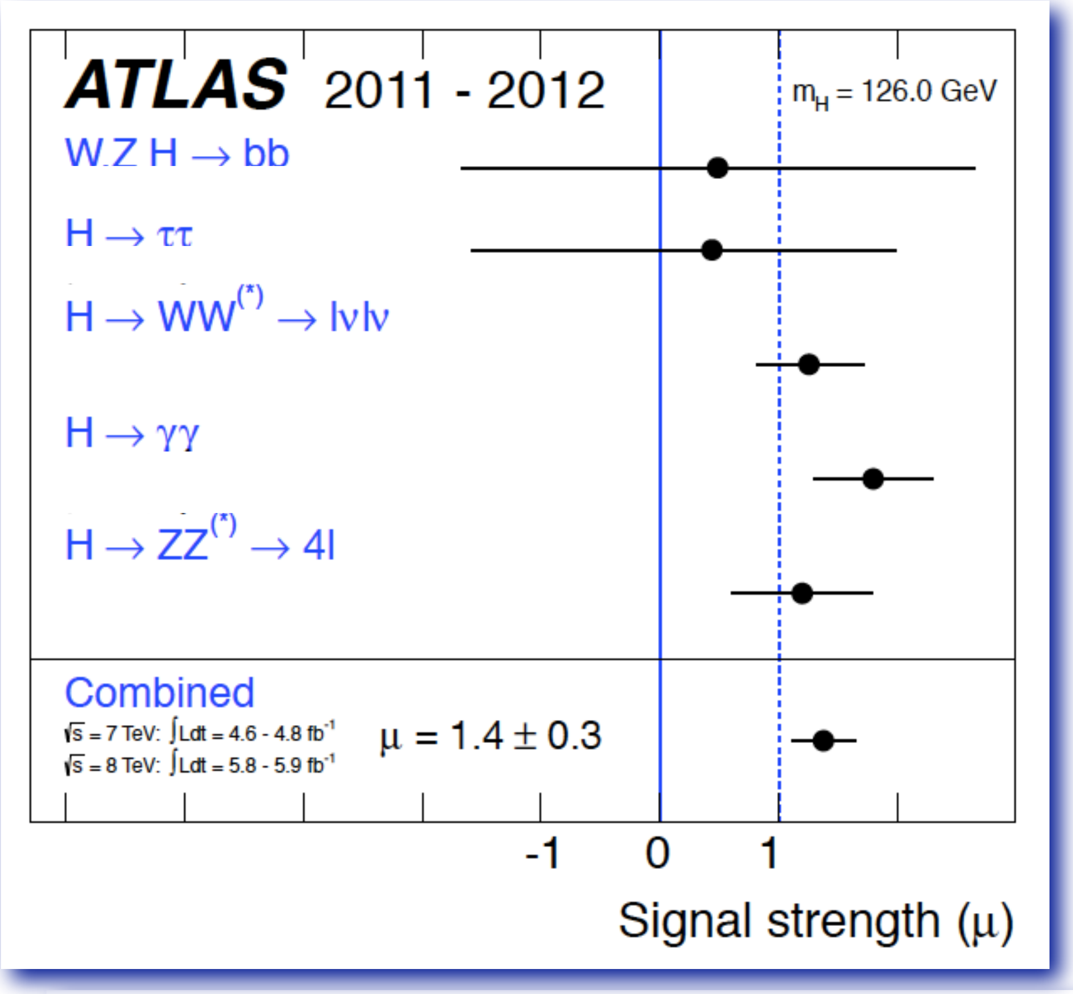


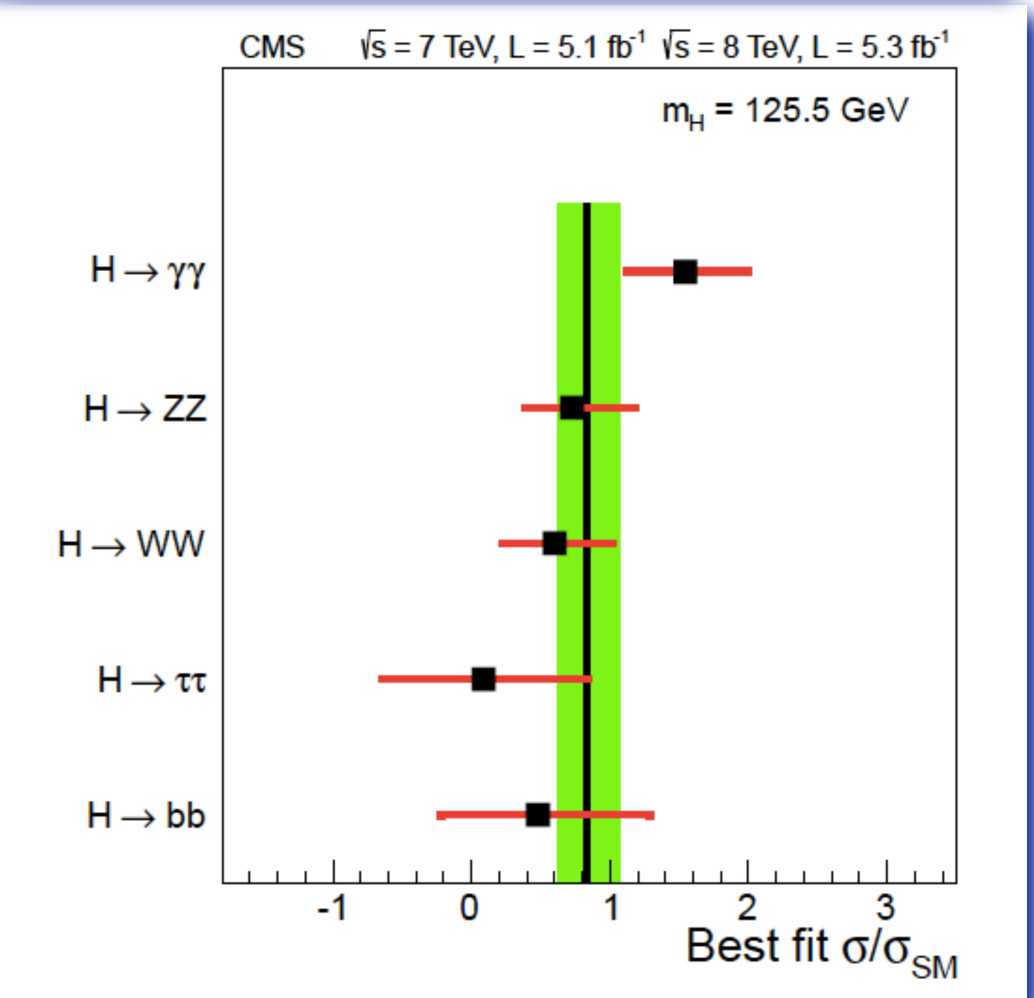


[Figs. from ATLAS & CMS]

Signal strengths

- More **diphoton (γγ)** than in SM, at both ATLAS & CMS.
- Slightly fewer **bb** & **ττ** at both ATLAS & CMS.
- Slightly more (less) for **ZZ** & **WW** at ATLAS (CMS).





[Figs. from ATLAS & CMS]

Suppose CMS tendency grows

- Namely, if we confirm:
  - ★ More diphoton ($\gamma\gamma$),
  - ★ Less others (ZZ, WW, bb, $\tau\tau$).
- What we see is **not** a Higgs!

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If What we see is NOT a Higgs

- We are observing another scalar field φ.
- Especially, PNGB coupling to violation of scale invariance gives: $(\varphi/\Lambda)\, F_{\mu\nu}F^{\mu\nu}$.

★ Radion [Cheung & Yuan, 2011; Kubota & Nojiri, 2012]

★ Techi-dilation [Matsuzaki & Yamawaki, 2012]

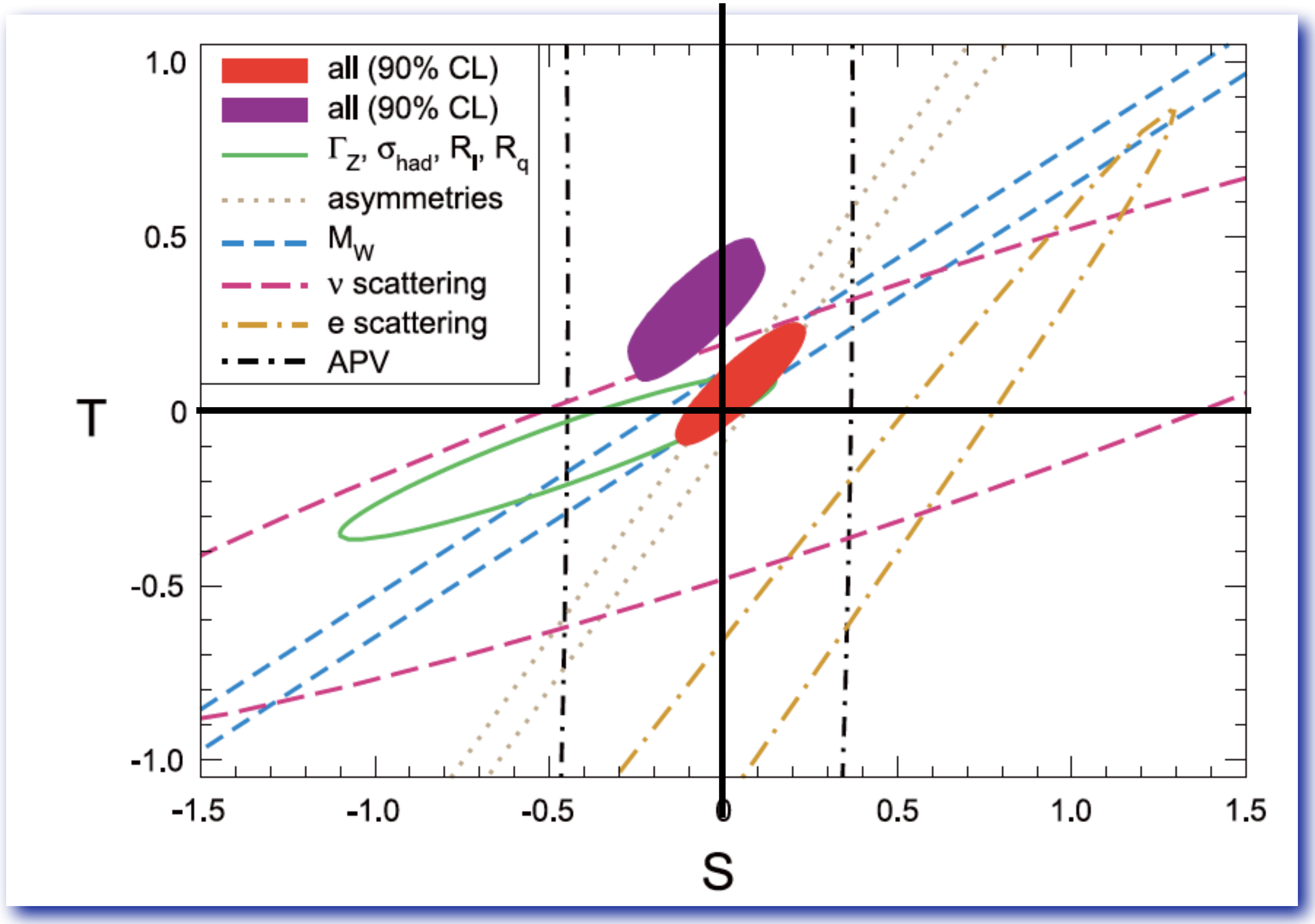
- In such models, the Higgs triggering EWSB must be heavy: $\mathbf{m_H > 600GeV}$. → T becomes too negative.

★ Radion: T becomes too negative.

★ Techni-dilaton: un-calculable due to strong dynamics.

Peskin-Takeuchi S&T

- **m_H<127GeV:**
  - ★ Consistent with SM.
- **m_H>600GeV:**
  - ★ Needs extra positive ΔT.
  - ★ With small ΔS.



[PDG2012]

We propose

- **Simplest** model that
  - ★ keeps track of essence of radion & techni-dilaton, and
  - ★ solves Peskin-Takeuchi S&T simultaneously.
- Other than φ, we introduce fermion t′ contributing to S&T.
  - ★ Must be colored & charged.
    - ✳ To generate φGG & φFF through loops.
  - ★ We put t′ vector-like in order not to have large ΔS.
  - ★ To generate large ΔT, Let t′
    - ✳ Acquire mass from H too.
  - ★ To avoid stable t′, let it mix with top by
    - ✳ SU(2) singlet and Y = 2/3. **Simplest!**

In other words,

- We assume that **only top and Higgs sector** involves in quasi scale invariant dynamics behind.

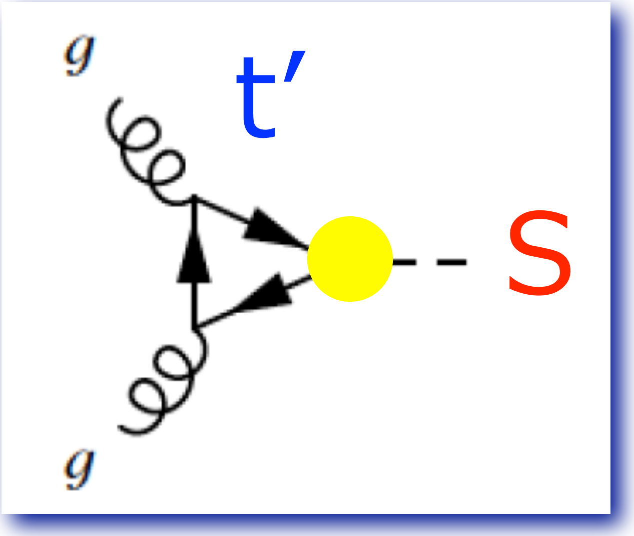
  ★ Since **only top** has large (Yukawa) coupling to **Higgs**, hence to EWSB sector.

- That is, we assume that **only top and Higgs** are composite in a UV completion.

  ★ Minimal model in this sense.

To summarize,

- The **minimal dilaton model** is
- SM with $M_H > 600\text{GeV}$ plus

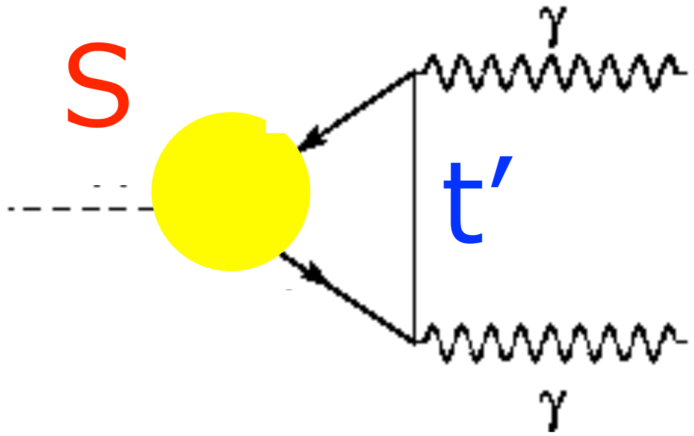


★ Top-partner t′.

✳ Vector-like but same gauge charge as t_R.

✳ ($SU(2)_W$ singlet and $Y = 2/3$.)

★ Extra singlet Higgs S.



✳ $S := f\, e^{-\varphi/f}$.

✳ SGG & SFF via t′ loop.

[Figs. from web]

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Model parameters

- $\eta = \dfrac{v}{f}$ ($f = \langle S \rangle$: dilaton decay constant)

- θ_H : mixing between Higgs and dilaton.

  ★ $\theta_H \to 0$, purely dilatonic. ($\theta_H \to \pm\pi/2$, SM.)

- (θ_L: small mixing between top and its partner.

  ✳ Turns out to be irrelevant for Higgs physics. S&T gives an allowed θ_L.)

Production

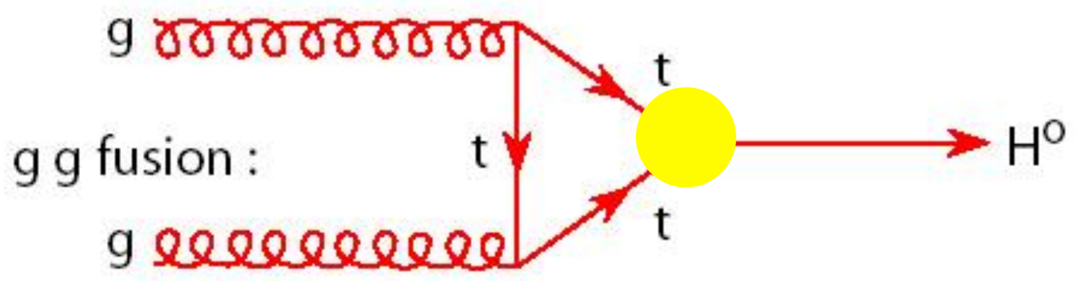
$$R_{\mathrm{GF}} = (\eta \cos\theta_H + \sin\theta_H)^2\,,$$

$$R_{\mathrm{VBF}} = R_{\mathrm{VH}} = \sin^2\theta_H\,,$$ ←suppressed

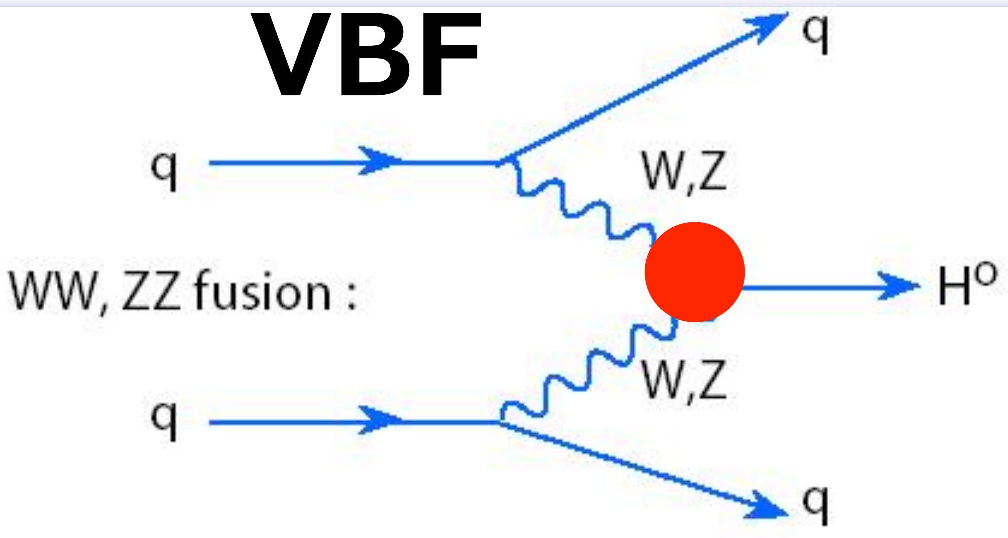
$$R_X := \frac{\sigma_X}{\sigma_X^{\mathrm{SM}}}$$

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

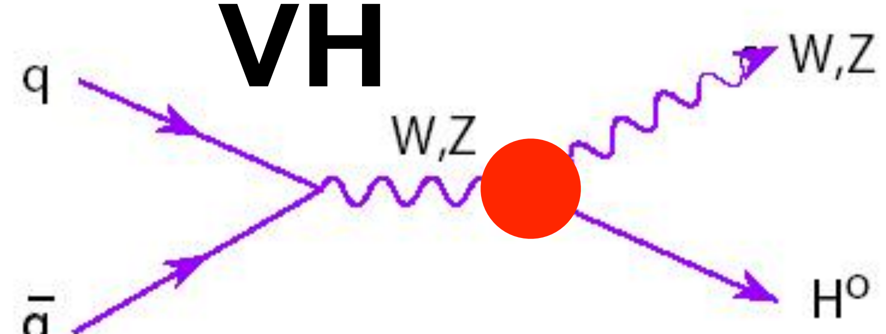
GF



VBF



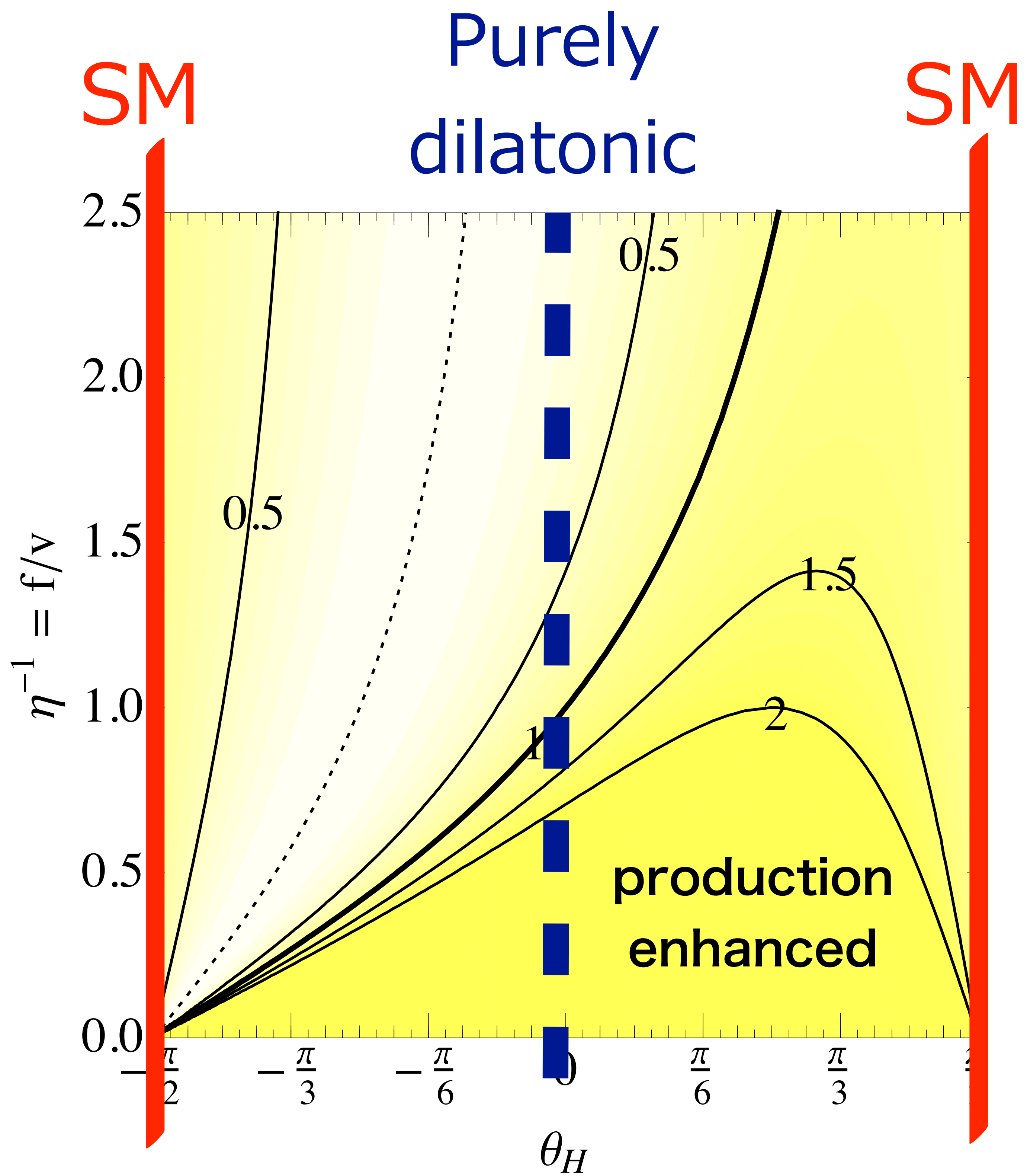
VH



[Figs. from web]

Result: GF cross section

Dilaton
decay
constant
(in units of
v=246GeV)



Higgs-dilaton mixing

Decay

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

$$R(s \to \text{others}) = \sin^2\theta_H$$

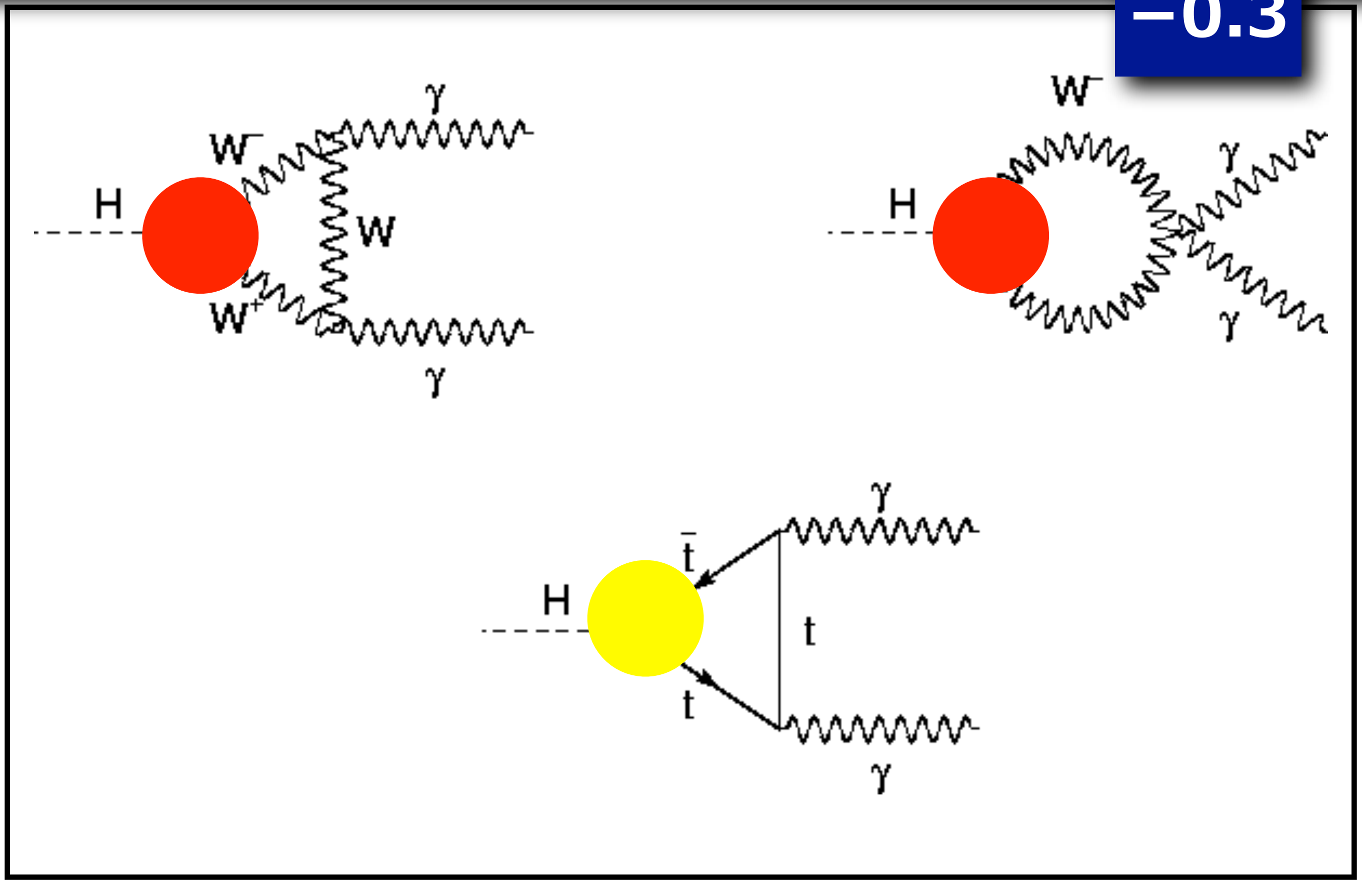
($\sim\Gamma_{\rm total}$) suppressed:

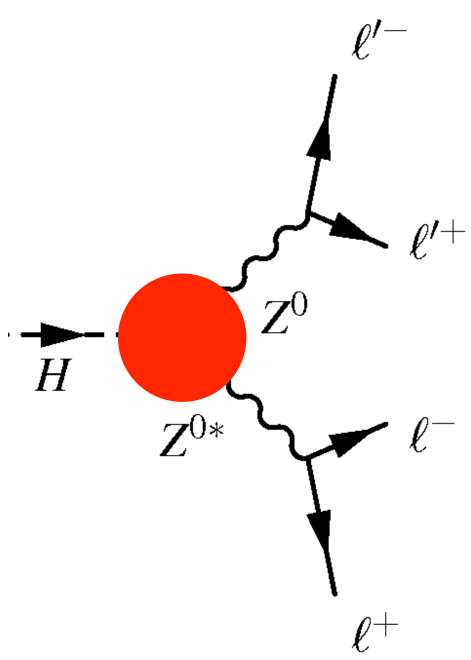
leading to an enhanced $BR_{s\to\gamma\gamma}$

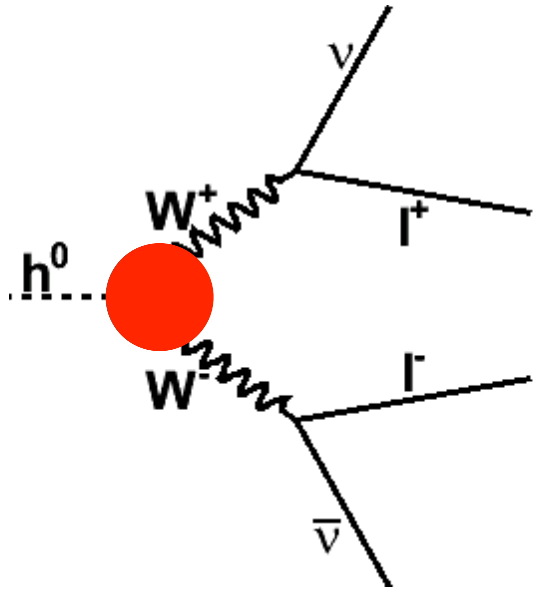
$$R(s \to \gamma\gamma) = \left(\eta \frac{A_{t'}}{A_{\rm SM}} \cos\theta_H + \sin\theta_H\right)^2$$

-0.3

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

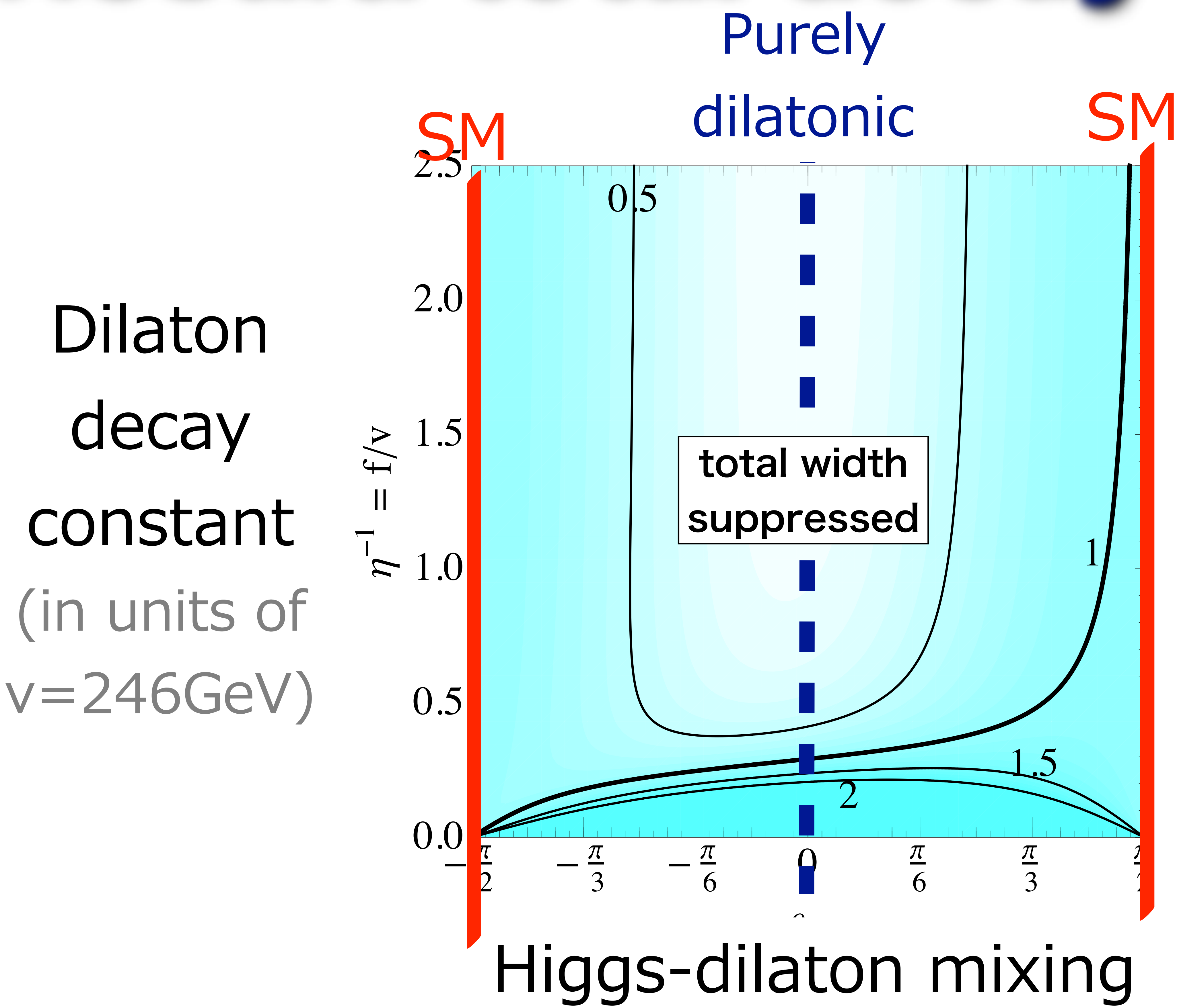






[Figs. from web]

Result: total decay width

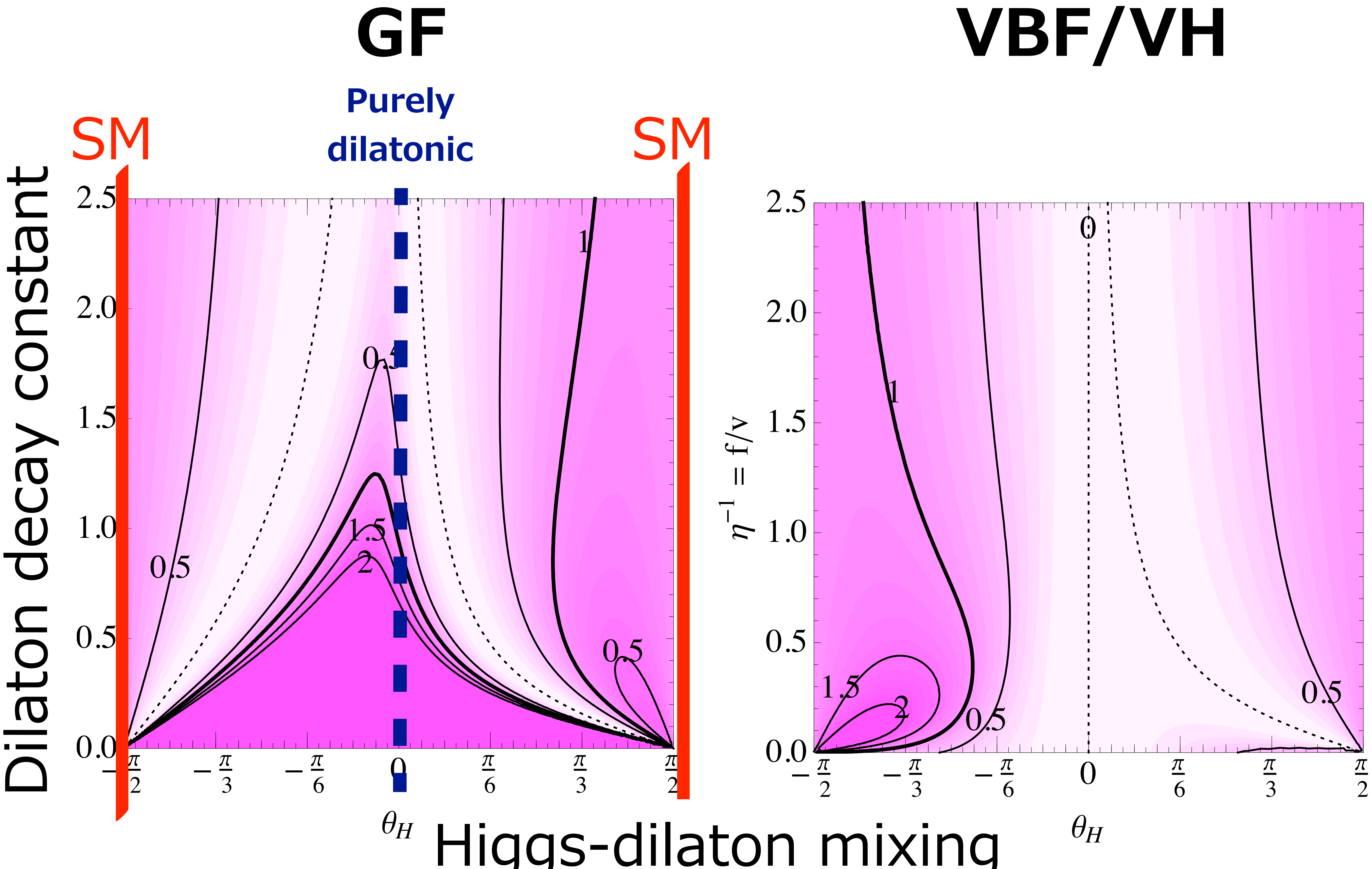


Prediction summary

- Production:
  - ★ GF can be enhanced.
  - ★ **Suppressed VBF** (&VH).
- Decay:
  - ★ BR($s \to \gamma\gamma$) can be enhanced:
    - ✳ Γ_{total} can be suppressed: BR($s \to \gamma\gamma$) = $\Gamma_{s \to \gamma\gamma}$ / Γ_{total}.

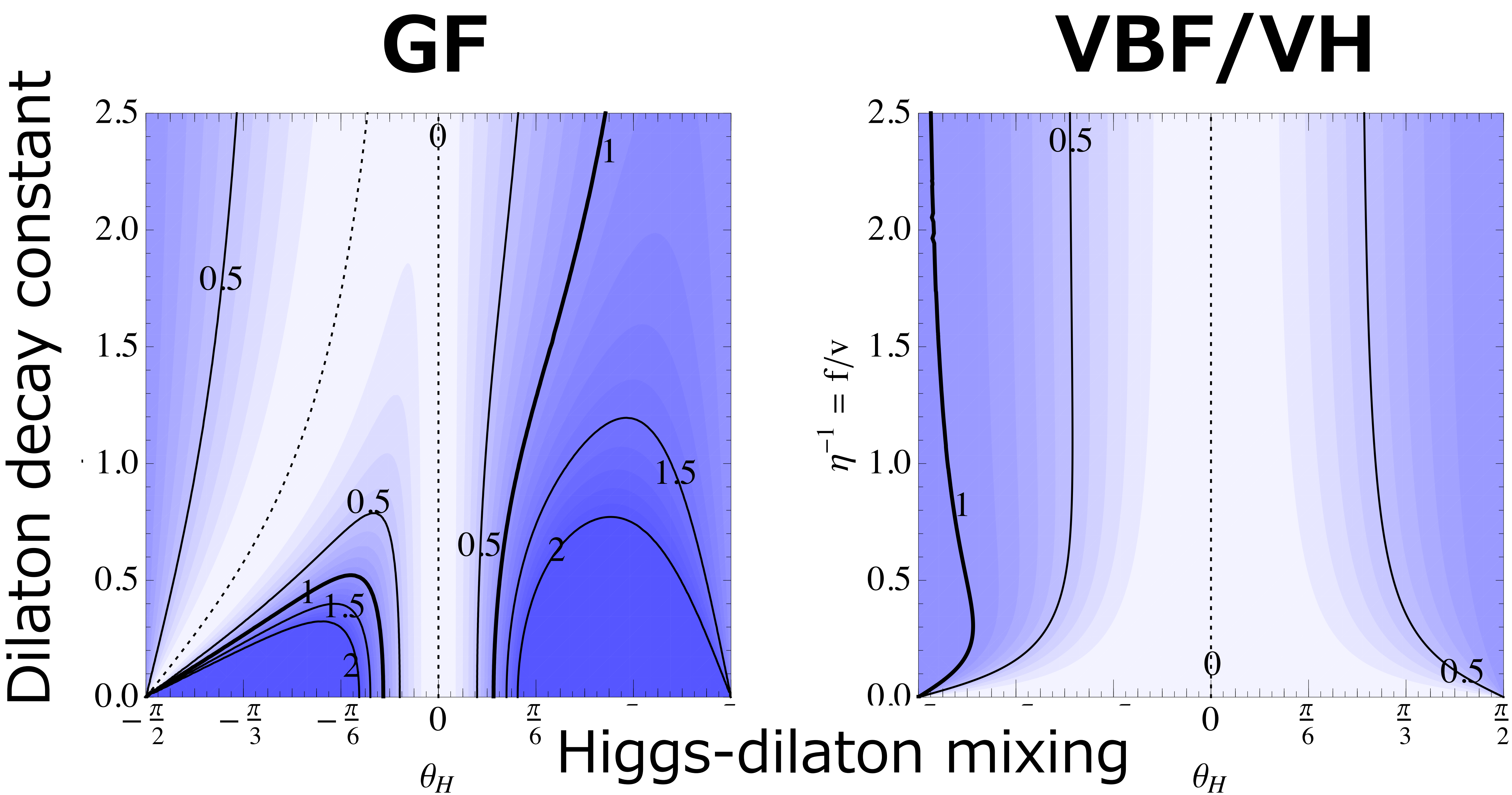
$\sigma \times$BR for each channel

Diphton can be enhanced



WW, ZZ, bb, $\tau\tau$

- GF production can be both suppressed and enhanced.
- VBF/VH production suppressed for dilatonic $\theta_H \sim 0$.



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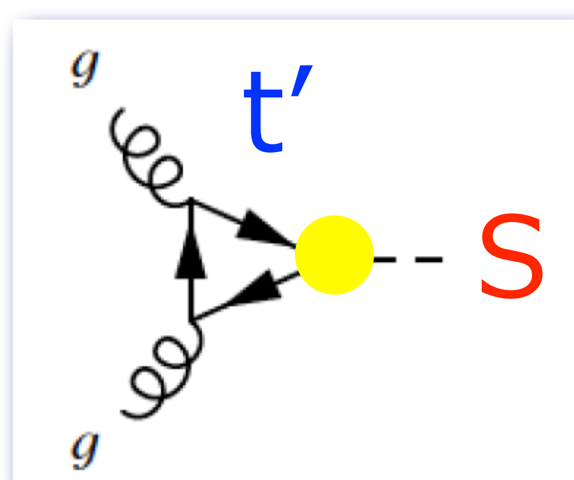
Signal Strength

- $\mu := [\sigma_{pp\to S} BR_{S\to\gamma\gamma}] / [\sigma_{pp\to H} BR_{H\to\gamma\gamma}]_{SM}$

★ $BR_{S\to\gamma\gamma} = \Gamma_{S\to\gamma\gamma} / \Gamma_{S\to all}$

E.g., $\mu_{gg\to\gamma\gamma}$ =



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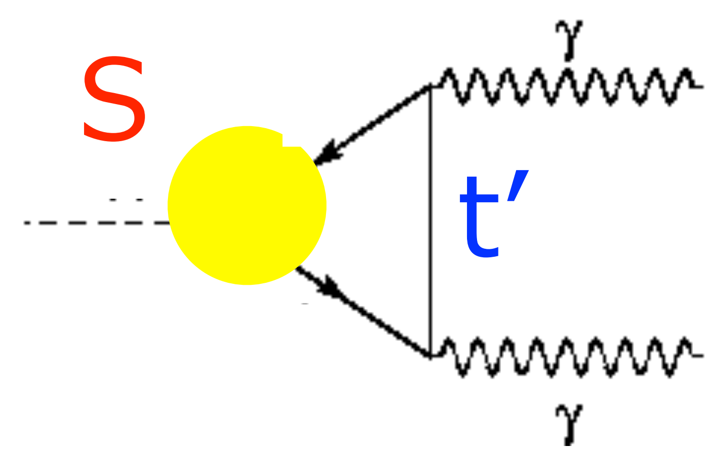
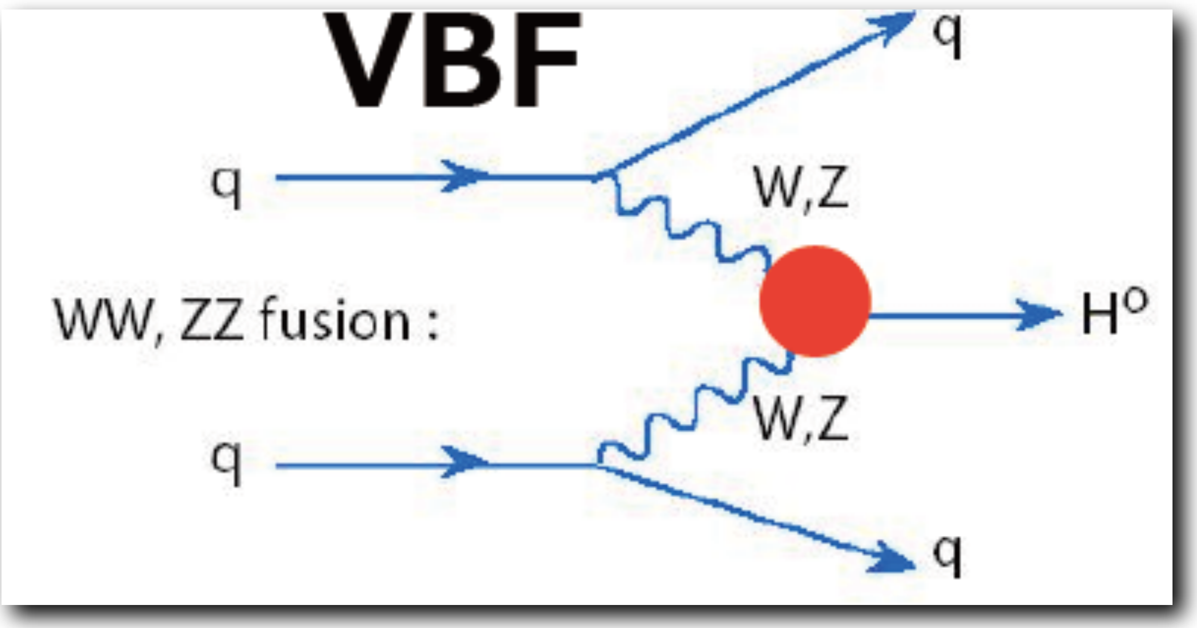


[Figs. from web]

How to verify VBF suppression?

- Look for events with diget (jj) in foward/ backward region.
- Problem: We never get <u>purely VBF event</u>.



[Figs. from web]

What experimentalists really give:

$\sqrt{s}$	Category	Events	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	ttH [%]
7 TeV	Inclusive	79.3	87.8	7.3	2.9	1.6	0.4
	Unconverted central, low p_{Tt}	10.4	92.9	4.0	1.8	1.0	0.2
	Unconverted central, high p_{Tt}	1.5	66.5	15.7	9.9	5.7	2.4
	Unconverted rest, low p_{Tt}	21.6	92.8	3.9	2	1.1	0.2
	Unconverted rest, high p_{Tt}	2.7	65.4	16.1	10.8	6.1	1.8
	Converted central, low p_{Tt}	6.7	92.8	4.0	1.9	1.0	0.2
	Converted central, high p_{Tt}	1.0	66.6	15.3	10	5.7	2.5
	Converted rest, low p_{Tt}	21.0	92.8	3.8	2.0	1.1	0.2
	Converted rest, high p_{Tt}	2.7	65.3	16.0	11.0	5.9	1.8
	Converted transition	9.5	89.4	5.2	3.3	1.7	0.3
	2-jets	2.2	22.5	76.7	0.4	0.2	0.1
8 TeV	Inclusive	111.6	88.5	7.4	2.7	1.6	0.5
	Unconverted central, low p_{Tt}	14.4	92.9	4.2	1.7	1.0	0.2
	Unconverted central, high p_{Tt}	2.5	72.5	14.1	6.9	4.2	2.3
	Unconverted rest, low p_{Tt}	31.4	92.5	4.1	2.0	1.1	0.2
	Unconverted rest, high p_{Tt}	5.3	72.1	13.8	7.8	4.6	1.7
	Converted central, low p_{Tt}	9.1	92.8	4.3	1.7	1.0	0.3
	Converted central, high p_{Tt}	1.6	72.7	13.7	7.1	4.1	2.3
	Converted rest, low p_{Tt}	27.3	92.5	4.2	2.0	1.1	0.2
	Converted rest, high p_{Tt}	4.6	70.8	14.4	8.3	4.7	1.7
	Converted transition	13.0	88.8	6.0	3.1	1.8	0.4
	2-jets	2.9	30.4	68.4	0.4	0.2	0.2

↑ i ↓

[ATLAS-CONF-2012-091]

← x →

What experimentalists really give:

$\sqrt{s}$	Category	Events	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	ttH [%]
7 TeV	Inclusive	79.3	87.8	7.3	2.9	1.6	0.4
	Unconverted central, low p_{Tt}	10.4	92.9	4.0	1.8	1.0	0.2
	Unconverted central, high p_{Tt}	1.5	66.5	15.7	9.9	5.7	2.4
	Unconverted rest, low p_{Tt}	21.6	92.8	3.9	2	1.1	0.2
	Unconverted rest, high p_{Tt}	2.7	65.4	16.1	10.8	6.1	1.8
	Converted central, low p_{Tt}	6.7	92.8	4.0	1.9	1.0	0.2
	Converted central, high p_{Tt}	1.0	66.6	15.3			
	Converted rest, low p_{Tt}	21.0	92.8	3.8			
	Converted rest, high p_{Tt}	2.7	65.3	16.0			
	Converted transition	9.5	89.4	5.2			
	2-jets	2.2	22.5	76.7			
8 TeV	Inclusive	111.6	88.5	7.4			
	Unconverted central, low p_{Tt}	14.4	92.9	4.2			
	Unconverted central, high p_{Tt}	2.5	72.5	14.1			
	Unconverted rest, low p_{Tt}	31.4	92.5	4.1			
	Unconverted rest, high p_{Tt}	5.3	72.1	13.8			
	Converted central, low p_{Tt}	9.1	92.8	4.3			
	Converted central, high p_{Tt}	1.6	72.7	13.7			
	Converted rest, low p_{Tt}	27.3	92.5	4.2			
	Converted rest, high p_{Tt}	4.6	70.8	14.4			
	Converted transition	13.0	88.8	6.0			
	2-jets	2.9	30.4	68.4			

[ATLAS-CONF-2012-091]

Expected signal and estimated backg

Event classes		SM Higgs boson		
		Total	ggH	VBF
7 TeV 5.1 fb^{-1}	Untagged 0	3.2	61%	17%
	Untagged 1	16.3	88%	6%
	Untagged 2	21.5	91%	4%
	Untagged 3	32.8	91%	4%
	Dijet tag	2.9	27%	73%
8 TeV 5.3 fb^{-1}	Untagged 0	6.1	68%	12%
	Untagged 1	21.0	88%	6%
	Untagged 2	30.2	92%	4%
	Untagged 3	40.0	92%	4%
	Dijet tight	2.6	23%	77%
	Dijet loose	3.0	53%	45%

← X →

[HIG-12-015-pas]

Confronting experiment

- a^i_{GF}, a^i_{VBF}: **acceptance** of GF, VBF events for i-th bin (by given cuts).
- **Signal fraction** (given by experimentalists in previous slide):
  - ★ $\varepsilon^i_{VBF} = (a^i_{VBF}\,\sigma^{SM}_{VBF}) / (\Sigma_X\, a^i_X\, \sigma^{SM}_X)$.
    - ✳ Because #(events in i-th bin) $\propto \Sigma_X\, a^i_X\, \sigma^{SM}_X$.
- We put mild assumption that only acceptance, not signal fraction, remains the same as in SM.
  - ★ Then we get **signal strength** for i-th bin:

$$\hat{\mu}_i(h \to \gamma\gamma) = \frac{\sum_X a^i_X\, \sigma_X}{\sum_Y a^i_Y\, \sigma^{SM}_Y} \frac{\mathrm{BR}(s \to \gamma\gamma)}{\mathrm{BR}(h \to \gamma\gamma)_{\mathrm{SM}}} = \sum_X \varepsilon^i_X R_X \frac{R(s \to \gamma\gamma)}{R(s \to \mathrm{all})}$$

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already obtained in closed form

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To summarize,

- Only assuming unchanged acceptance,
- we get **signal strength** for i-th bin as
  - ★ summation over production modes X,
  - ★ with given signal fractions being multiplied as coefficients.

$$\hat{\mu}_i(h \to \gamma\gamma) = \frac{\sum_X a_X^i \, \sigma_X}{\sum_Y a_Y^i \, \sigma_Y^{\rm SM}} \frac{{\rm BR}(s \to \gamma\gamma)}{{\rm BR}(h \to \gamma\gamma)_{\rm SM}} = \sum_X \varepsilon_X^i R_X \frac{R(s \to \gamma\gamma)}{R(s \to {\rm all})}$$

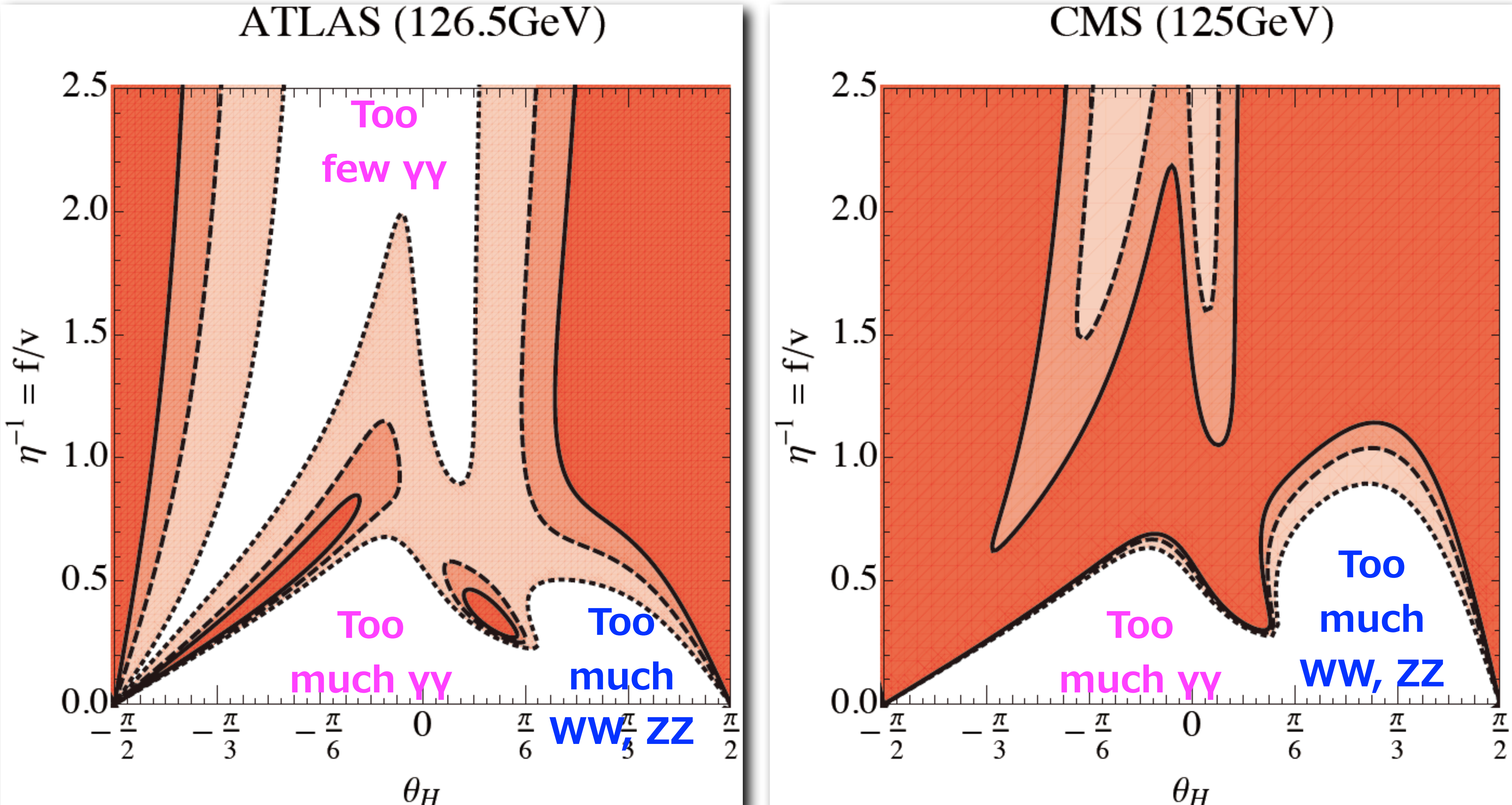
Resultant constraint on Higgs sector

Constraint from Higgs

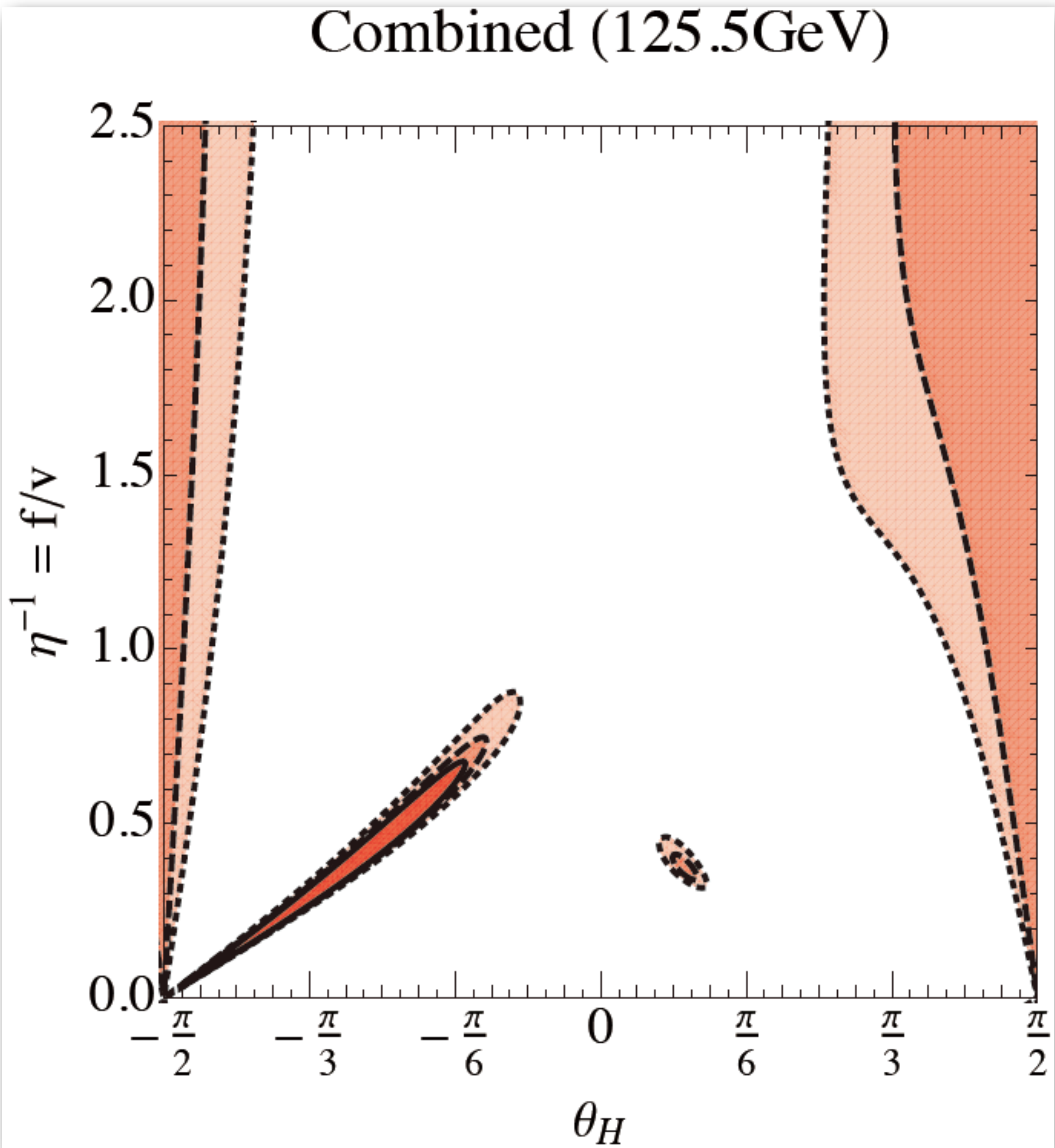
90%CL

95%CL

99%CL



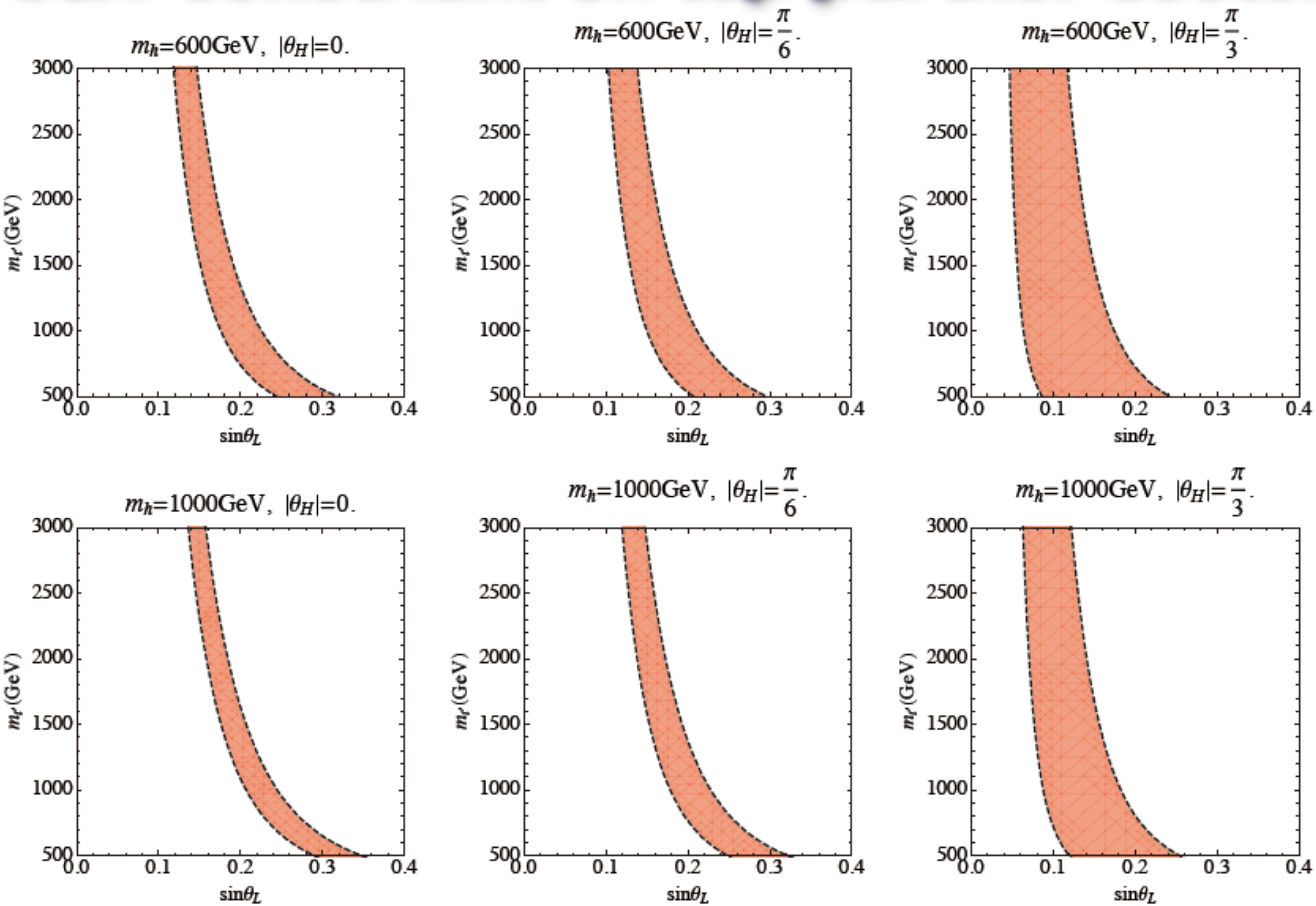
A "theorist" combination



- Just for fun, we plot from
- Unofficial world average [Giardino, Kannike, Raidal & Strumia, 2012]
- Assuming:
  - ★ Pure GF for **WW, ZZ, γγ,**
  - ★ Pure VBF for **bbV, WWV, ττ,**
  - ★ 30% GF & 70% VBF for **γγjj.**

おまけ
(giveaway)

S&T constriant on top partner sector



Summary

- If diphoton signal remains **larger** than in SM.
  - ★ And others remain/become smaller.
  - ★ Then what we are observing **cannot** be Higgs.
- We propose calculable model grabbing essence of radion/techni-dilaton.
  - ★ Quasi scale invariant top seesaw behind?
- t′ may be observed soon!


Thank you!