Implications of LHC data on 125 GeV Higgs-like boson for the SM and its various extensions

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Based on arXiv:1307.3948, JHEP (2013)
with Suyong Choi and Sunghoon Jung

What can we learn about BSM from Higgs properties ?

- Higgs signal strength ~ SM like
- ATLAS diphoton rate may require new charged particles at EW scale
- Important to measure Higgs couplings to the SM particles as precisely as possible
- Most works EFT approach assuming New Physics scale is high enough

- However this needs not be true
- There could be an additional singlet scalar "S" at EW scale that mixes with the SM Higgs boson (especially motivated by hidden sector DM with Higgs portal or singlet portal)
- Then we cannot integrate out "S"
- We include "S" explicitly

Assumptions

- Impose the full SM gauge symmetry, not just its unbroken subgroup
- Assume there is an additional SM singlet scalar, extra vector-like fermions, hDM etc
- "S" could be a remnant of the spontaneous breaking of extra gauge symmetry such as dark gauge symmetry or $U(1)_{B-L}$
- Our assumptions encompass a large class of BSMs

(3,2,1) or SU(3)cXU(1)em ?

- Well below the EW sym breaking scale, it may be fine to impose SU(3)c X U(1)em
- At EW scale, better to impose (3,2,1) which gives better description in general after all
- Majorana neutrino mass is a good example
- For example, in the Higgs + dilaton (radion) system, and you get different results
- Singlet mixing with SM Higgs

Issue here is whether we use

$$\mathcal{L}_{\text{int}} \simeq -\frac{\phi}{f_\phi} T^\mu_{\ \mu} = -\frac{\phi}{f_\phi}\left[m_H^2 H^\dagger H - 2m_W^2 W^+ W^- - m_Z^2 Z_\mu Z^\mu + \sum_f m_f \bar{f} f + \sum_G \frac{\beta_G}{g_G} G_{\mu\nu} G^{\mu\nu}\right], \quad (1)$$

OR

$$T^\mu_{\ \mu}(\text{SM}) = 2\mu_H^2 H^\dagger H + \sum_G \frac{\beta_G}{g_G} G_{\mu\nu} G^{\mu\nu}.$$

arXiv:1401.5586 with D.W.Jung
Phys.Lett. B (2014)

In the usual earlier approach, one has

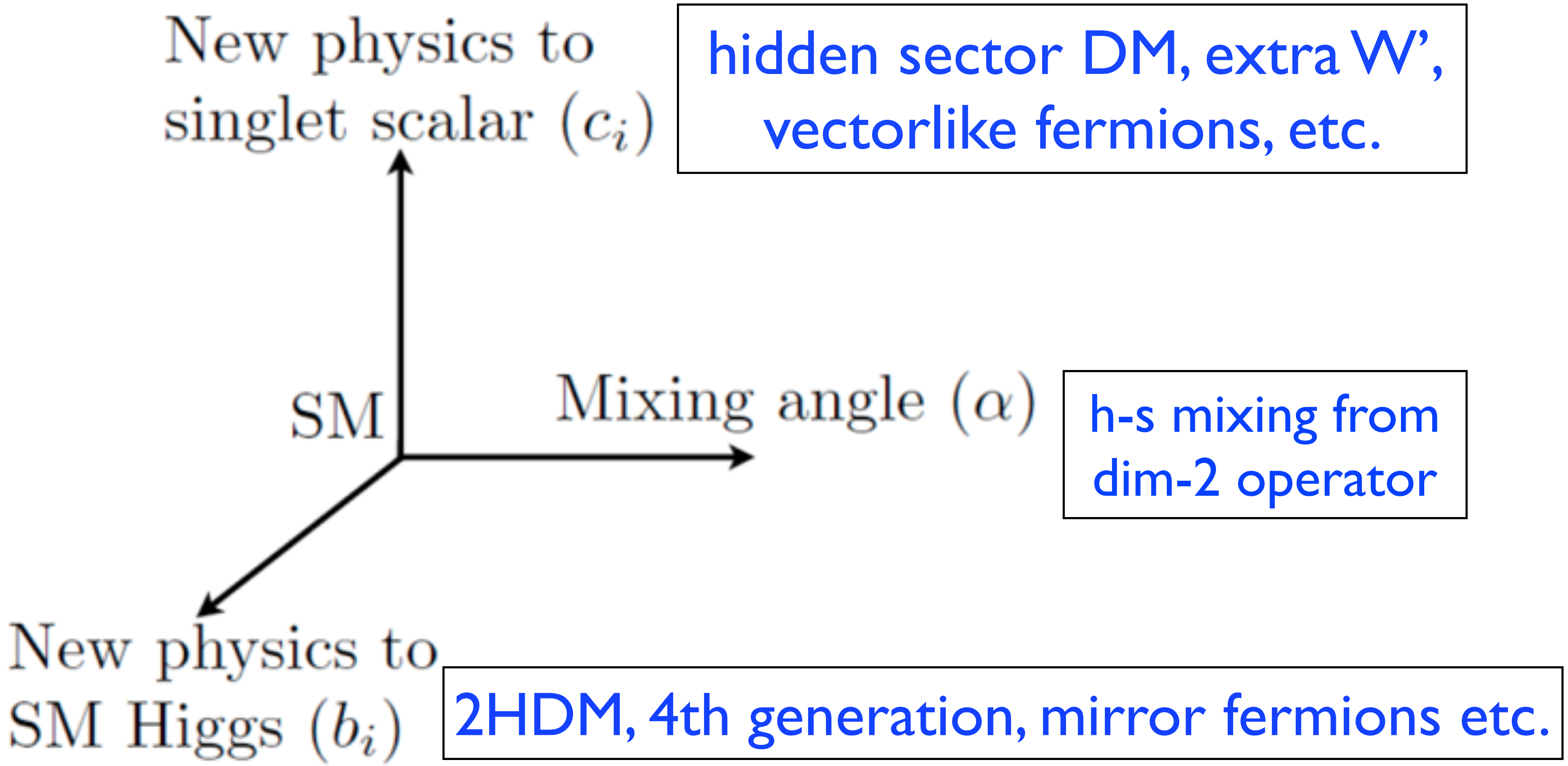
$$\mathcal{L}(f,\bar{f},\phi) = -\frac{m_f}{f_\phi}\bar{f}f\phi\, \mathrm{e}^{-\bar{\phi}/f_\phi}.$$

In the new approach, one has

$$\mathcal{L}(f,\bar{f},H_{i=1,2}) = -\frac{m_f}{v}\overline{f}fh = -\frac{m_f}{v}\overline{f}f(H_1 c_\alpha + H_2 s_\alpha),$$

These two lead to very different predictions for Higgs phenomenology at the LHC, especially for H to diphoton, and gg fusion for H productions (see the paper for the details)

Back to the main issue



- Orthogonal ways to modify the same observable.
- Our framework is suitable to get insight on singlet mixing, singlet couplings as well as Higgs couplings.

SM Higgs

$$
\begin{aligned}
-\mathcal{L}_{\rm h,int} =& \sum_f b_f \frac{m_f}{v} h\bar{f}f - \left\{2b_W\frac{h}{v} + b_W^{'}\left(\frac{h}{v}\right)^2\right\} m_W^2 W_\mu^+ W^{-\mu} - \left\{b_Z\frac{h}{v} + \frac{1}{2}b_Z^{'}\left(\frac{h}{v}\right)^2\right\} m_Z^2 Z_\mu Z^\mu \\
&+ \frac{\alpha}{8\pi} r_{\rm sm}^{\gamma}\left\{b_\gamma\frac{h}{v} + \frac{1}{2}b_\gamma^{'}\left(\frac{h}{v}\right)^2\right\} F_{\mu\nu}F^{\mu\nu} + \frac{\alpha_s}{16\pi} r_{\rm sm}^{g}\left\{b_g\frac{h}{v} + \frac{1}{2}b_g^{'}\left(\frac{h}{v}\right)^2\right\} G_{\mu\nu}^a G^{a\mu\nu} \\
&+ \frac{\alpha_2}{\pi}\left\{2b_{dW}\frac{h}{v} + b_{dW'}\left(\frac{h}{v}\right)^2\right\} W_{\mu\nu}^+ W^{-\mu\nu} + \frac{\alpha_2}{\pi}\left\{2b_{dZ}\frac{h}{v} + b_{dZ'}\left(\frac{h}{v}\right)^2\right\} Z_{\mu\nu}Z^{\mu\nu} \\
&+ \frac{\alpha_2}{\pi}\left\{2\widetilde{b_{dW}}\frac{h}{v} + \widetilde{b_{dW'}}\left(\frac{h}{v}\right)^2\right\} W_{\mu\nu}^+ \widetilde{W^{-\mu\nu}} + \frac{\alpha_2}{\pi}\left\{2\widetilde{b_{dZ}}\frac{h}{v} + \widetilde{b_{dZ'}}\left(\frac{h}{v}\right)^2\right\} Z_{\mu\nu}\widetilde{Z^{\mu\nu}} \\
&+ \frac{\alpha}{\pi}\left\{2b_{Z\gamma}\frac{h}{v} + b_{Z\gamma'}\left(\frac{h}{v}\right)^2\right\} F_{\mu\nu}Z^{\mu\nu} \qquad (2.1)
\end{aligned}
$$

Singlet Scalar S

$$
\begin{aligned}
-\mathcal{L}_{\rm s,int} =& \sum_f c_f \frac{m_f}{v} s\bar{f}f - \left\{2c_W\frac{s}{v} + c_W^{'}\left(\frac{s}{v}\right)^2\right\} m_W^2 W_\mu^+ W^{-\mu} - \left\{c_Z\frac{s}{v} + \frac{1}{2}c_Z^{'}\left(\frac{s}{v}\right)^2\right\} m_Z^2 Z_\mu Z^\mu \\
&+ \frac{\alpha}{8\pi} r_{\rm sm}^{\gamma}\left\{c_\gamma\frac{s}{v} + \frac{1}{2}c_\gamma^{'}\left(\frac{s}{v}\right)^2\right\} F_{\mu\nu}F^{\mu\nu} + \frac{\alpha_s}{16\pi} r_{\rm sm}^{g}\left\{c_g\frac{s}{v} + \frac{1}{2}c_g^{'}\left(\frac{s}{v}\right)^2\right\} G_{\mu\nu}^a G^{a\mu\nu} \qquad (2.10) \\
&+ \frac{\alpha_2}{\pi}\left\{2c_{dW}\frac{s}{v} + c_{dW'}\left(\frac{s}{v}\right)^2\right\} W_{\mu\nu}^+ W^{-\mu\nu} + \frac{\alpha_2}{\pi}\left\{2c_{dZ}\frac{s}{v} + c_{dZ'}\left(\frac{s}{v}\right)^2\right\} Z_{\mu\nu}Z^{\mu\nu} \\
&+ \frac{\alpha_2}{\pi}\left\{2\widetilde{c_{dW}}\frac{s}{v} + \widetilde{c_{dW'}}\left(\frac{s}{v}\right)^2\right\} W_{\mu\nu}^+ \widetilde{W^{-\mu\nu}} + \frac{\alpha_2}{\pi}\left\{2\widetilde{c_{dZ}}\frac{s}{v} + \widetilde{c_{dZ'}}\left(\frac{s}{v}\right)^2\right\} Z_{\mu\nu}\widetilde{Z^{\mu\nu}} \\
&+ \frac{\alpha}{\pi}\left\{2c_{Z\gamma}\frac{s}{v} + c_{Z\gamma'}\left(\frac{s}{v}\right)^2\right\} F_{\mu\nu}Z^{\mu\nu} \quad - \mathcal{L}_{nonSM} \qquad (2.11)
\end{aligned}
$$

Typical Sizes of b,c's

$$b_i \sim \text{“1”} + \frac{g^2 m^2}{(4\pi)^2 M^2}, \quad \text{or} \quad \text{“1”} + \frac{g^2 m^2}{M^2}$$

Most of dim-6 operators lead to the definite relation, $b_i = b_i^{'}$, since they involve $H^\dagger H$ which yields $(v+h)^2$. But this is not the case for b_f and $b_f^{'}$. For example, the following operators ($q_L \equiv (t_L, b_L)$), which are invariant under the full SM gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$,

$$\overline{q_L} D_\mu b_R D^\mu H, \quad \overline{q_L} D_\mu t_R D^\mu \widetilde{H},$$

$$c_i \sim \text{“0”} + \frac{g^2 m^2}{(4\pi)^2 M^2}, \quad \text{“0”} + \frac{g^2 m^2}{M^2},$$

All the c_i's from nonrenormalizable operators

- 125GeV Higgs (mass-eigenstate) is

$$H = h\cos\alpha - s\sin\alpha$$

h: SU(2) doublet interaction eigenstate
s: SU(2) singlet interaction eigenstate
alpha: mixing angle (alpha=0 means SM-like)

- h and s effective couplings are parameterized by {b_i}, {c_i}. Some terms are shown below.

$$-\mathcal{L}_{\rm h,int} = \sum_f b_f \frac{m_f}{v} h\bar{f}f - \left(2b_W\frac{h}{v} + b'_W\left(\frac{h}{v}\right)^2\right) m_W^2 W_\mu^+ W^{-\mu} - \left(b_Z\frac{h}{v} + \frac{1}{2}b'_Z\left(\frac{h}{v}\right)^2\right) m_Z^2 Z_\mu Z^\mu$$
$$+ \frac{\alpha}{8\pi} r^\gamma_{\rm sm}\left(b_\gamma\frac{h}{v} + \frac{1}{2}b'_\gamma\left(\frac{h}{v}\right)^2\right) F_{\mu\nu}F^{\mu\nu} + \frac{\alpha_s}{16\pi} r^g_{\rm sm}\left(b_g\frac{h}{v} + \frac{1}{2}b'_g\left(\frac{h}{v}\right)^2\right) G^a_{\mu\nu}G^{a\mu\nu} \qquad (2.2)$$

NB: b_i=1, c_i=0 mean SM-like

- Models are ubiquitous, and singlet scalar is versatile:
- If Hidden fermion is DM, s is needed for correct thermal relic density.

Model	Nonzero c_F's
Pure Singlet Extension	c_{h^2}
Hidden Sector DM	c_χ, c_{h^2}
Dilaton	$c_g, c_W, c_Z, c_\gamma, c_{h^2}$
Vectorlike Quarks	$c_g, c_\gamma, c_{Z\gamma}, c_{h^2}$
Vectorlike Leptons	$c_\gamma, c_{Z\gamma}, c_{h^2}$
New Charged Vector bosons	c_γ, c_{h^2}
Extra charged scalar bosons	

$$\mathcal{L}_{\text{hidden}} = \mathcal{L}_S + \mathcal{L}_\psi - \lambda S \overline{\psi}\psi,$$

$$\mathcal{L}_{\text{portal}} = -\mu_{HS} S H^\dagger H - \frac{\lambda_{HS}}{2} S^2 H^\dagger H,$$

- If an extra vector exists, "s" may result from spontaneous gauge symmetry breaking. Gauge symmetry may needed for various reasons: just another force, or ensuring DM stability, etc...

- Singlet-Higgs mixing is just gauge invariant, renormalizable.

$$\mathcal{L}_{\rm portal} = -\mu_{HS} S H^\dagger H - \frac{\lambda_{HS}}{2} S^2 H^\dagger H,$$

- S and Mixing eventually modify Higgs properties!
- Many interesting examples are built to enhance Higgs-to-diphoton rate.

$$l_4 = \begin{pmatrix} \nu_4 \\ e_4 \end{pmatrix} \sim (1, 2, -1/2),\ e_4^c \sim (1, 1, 1),$$
$$\tilde{l}_4 = \begin{pmatrix} \tilde{e}_4 \\ \tilde{\nu}_4 \end{pmatrix} \sim (1, \bar{2}, 1/2),\ \ \tilde{e}_4^c \sim (1, 1, -1),$$

$$\begin{aligned} -\mathcal{L} &= M_l l_4 \tilde{l}_4 + M_e e_4^c \tilde{e}_4^c + M \\ &+ y_e H l_4 e_4^c + \tilde{y}_e \tilde{l}_4 H^\dagger \tilde{e}_4^c - \\ &+ \frac{x_l}{\sqrt{2}} S l_4 \tilde{l}_4 + \frac{x_e}{\sqrt{2}} S e_4^c \tilde{e}_4^c \end{aligned}$$

$$\mathcal{M}'_e = \begin{pmatrix} M_l + x_l w/\sqrt{2} & \tilde{y}_e v/\sqrt{2} \\ y_e v/\sqrt{2} & M_e + x_e w/\sqrt{2} \end{pmatrix} \quad \mathcal{L} \supset \frac{\alpha}{16\pi v} b_{EM} \left(\frac{\partial}{\partial \log v} \log\det \mathcal{M}\mathcal{M}^\dagger \right) h F_{\mu\nu} F^{\mu\nu}$$

- Production times BR is measured: signal strength. So hard to extract info on individual couplings.

$$R\left(\sigma(i \to h)\frac{\Gamma(h \to j)}{\Gamma^{tot}}\right) = \frac{\kappa_i^2 \kappa_j^2}{\kappa_H^2} \qquad \kappa_i^2 = \frac{\Gamma(h \to i)}{\Gamma(h \to i)_{SM}} \quad \kappa_H^2 = \frac{\Gamma^{tot}}{\Gamma^{tot}_{SM}}$$

- Unknown width leaves overall normalization undetermined.

$$\frac{\kappa_i^2 \kappa_j^2}{\kappa_H^2} \equiv \hat{\kappa}_i^2 \hat{\kappa}_j^2,$$

- If nonSM decay width exists, generally no unique solution of global fit is found. But statistically useful info can still be obtained, and built-in restrictions may further provide info.

- Higgs is produced via several channel. They are properly weighted-summed by couplings and density.

$$R(\sigma(pp \to h)) = \kappa_g^2 \mathcal{A}_g + \kappa_W^2 \mathcal{A}_W + \kappa_Z^2 \mathcal{A}_Z$$

$$\mathcal{A}_g = \frac{\sigma(ggF)}{(\sigma(ggF) + \sigma(VBF))} \simeq 0.925,$$

$$R(\sigma(pp \to Vh)) = \kappa_W^2 \mathcal{A}'_W + \kappa_Z^2 \mathcal{A}'_Z$$

How to parameterize modifications to loop-induced gg fusion will be discussed later.

- How is decay width ratio, kappa, parameterized in terms of {alpha, b_i, c_i}?

- Tree-level decay to WW, ZZ, ff:

$$\kappa_i^2 = \frac{\Gamma(h \to i)}{\Gamma(h \to i)_{SM}} = (b_i c_\alpha - c_i s_\alpha)^2$$

- Loop induced decay to gg, gamma gamma:

$$\kappa_g^2 = (b_g c_\alpha - c_g s_\alpha)^2 = (\, c_\alpha(b_t \mathcal{C}_t + \Delta b_g) - c_g s_\alpha \,)^2$$

$$\kappa_\gamma^2 = (b_\gamma c_\alpha - c_\gamma s_\alpha)^2 = (\, c_\alpha(b_W \mathcal{B}_W + b_t \mathcal{B}_t + \Delta b_\gamma) - c_\gamma s_\alpha \,)^2$$

Scalar mixing — modification of W, top coupling — modification of diphoton coupling — inherit from singlet

- NB: b, Delta b, c are norm. to SM coupling.

$$\mathcal{B}_W = \frac{A_1(\tau_W)}{A_1(\tau_W) + N_c Q_t^2 A_{1/2}(\tau_t)} \simeq 1.283,$$

	channel	luminosity (fb^{-1})	μ	ref.
CMS	$\gamma\gamma$	24.7	$0.78^{+0.28}_{-0.26}$	[15]
	ZZ	24.7	$0.91^{+0.30}_{-0.24}$	[16]
	WW	24.7	$0.76^{+0.21}_{-0.21}$	[17]
	$\tau\tau$	24.3	$1.1^{+0.4}_{-0.4}$	[18]
	$b\bar{b}$	17	$1.3^{+0.7}_{-0.6}$	[19]
ATLAS	$\gamma\gamma$	25	$1.65^{+0.35}_{-0.30}$	[20]
	ZZ	25	$1.7^{+0.50}_{-0.40}$	[21]
	WW	25	$1.01^{+0.31}_{-0.31}$	[22]
	$\tau\tau$	18	$0.7^{+0.7}_{-0.7}$	[23]
	$b\bar{b}$	18	$-0.4^{+1.06}_{-1.06}$	[24]

- Moriond 2013 data used (to be updated after ICHEP)
- Best fit values of each channel is used. The minimum of each channel occurs at slightly different mh.

- Preliminaries without singlet mixing:
New effects are now multiplicatively rescaling SM Higgs effective Lagrangian by {b_i}. (ex: composite Higgs analysis)

	both	CMS	ATLAS
SM	$\chi^2/\nu = 12.01/10 = 1.20$	$2.33/5 = 0.466$	$9.69/5 = 1.94$
(Δb_γ)	(0.090) 11.19/9=1.24	(-0.117) 1.71/4=0.428	(0.28) 4.99/4=1.25
$(\Delta b_g, \Delta b_\gamma)$	(-0.018, 0.107) $11.13/8 = 1.39$	(-0.078, -0.048) $0.859/3 = 0.286$	(0.11, 0.17) $4.14/3 = 1.38$
(b_V, b_f)	(1.031, 0.962) $11.74/8 = 1.47$	(0.898, 1.021) 0.808/3=0.27	(1.345, 0.808) 4.52/3=1.51

- CMS and ATLAS indicate different directions. They are about 2sigma away each other (even most other below).

bi's only

	both	CMS	ATLAS
SM	$\chi^2/\nu = 12.01/10 = 1.20$	$2.33/5 = 0.466$	$9.69/5 = 1.94$
(Δb_γ)	(0.090) 11.19/9=1.24	(-0.117) 1.71/4=0.428	(0.28) 4.99/4=1.25
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(b_V, b_f)	(1.031, 0.962) $11.74/8 = 1.47$	(0.898, 1.021) 0.808/3=0.27	(1.345, 0.808) 4.52/3=1.51
$(b_V \leq 1, b_u, b_d)$	(1.0, 0.969, 0.938) $11.86/7 = 1.69$		
$(\Delta b_g, \Delta b_\gamma, b_V, b_f)$	(0.041, 0.117, 0.941, 0.961) $11.07/6 = 1.85$		

Table 5. Best-fit results using b_i only from both CMS and ATLAS data as well as individual. Errors are shown in text.

- All signal strengths are *universally modified* if just scalar mixing(alpha) and/or non-SM width(kappa_H).

$\{\alpha,\ BR_{nonSM}\}$: In this case,

$$\kappa_{univ}^2 = c_\alpha^2, \qquad \kappa_H^2 = \frac{c_\alpha^2}{1 - BR_{nonSM}}.$$

- Data is parameterized by one while theory has two.

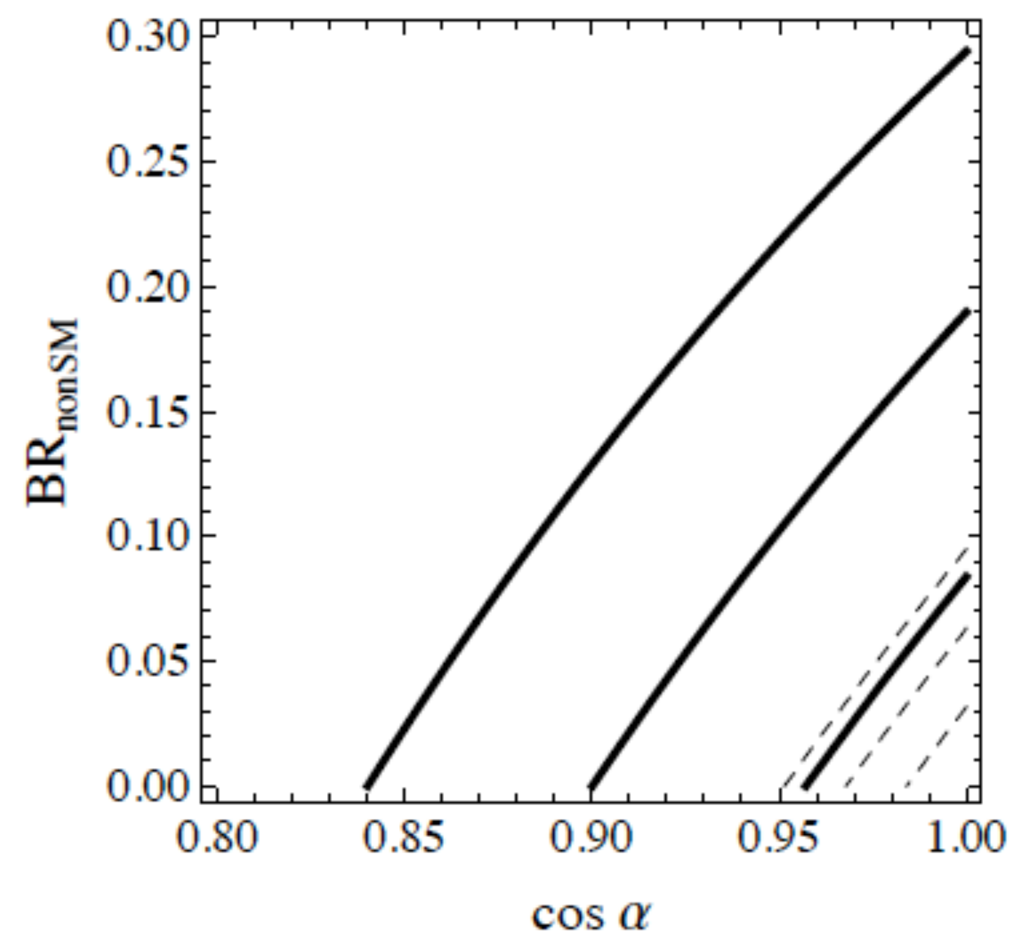
$$\mu_i = \kappa_{univ}^2 \frac{\kappa_{univ}^2}{\kappa_H^2} = \hat{\kappa}_{univ}^2 \hat{\kappa}_{univ}^2.$$

- Overall, enhancement is slightly preferred although not significant

$$\hat{\kappa}_{univ}^2 = 1.012^{+0.0517}_{-0.0549},$$

$BR_{nonSM} \leq 18.8\%$ at 95%C.L. if $c_\alpha = 1$ fixed

$c_\alpha \geq 0.904$ at 95%C.L. if $BR_{nonSM} = 0$ fixed



- Models with extra leptons or W' which couple to singlet scalar : {alpha, c_gamma}

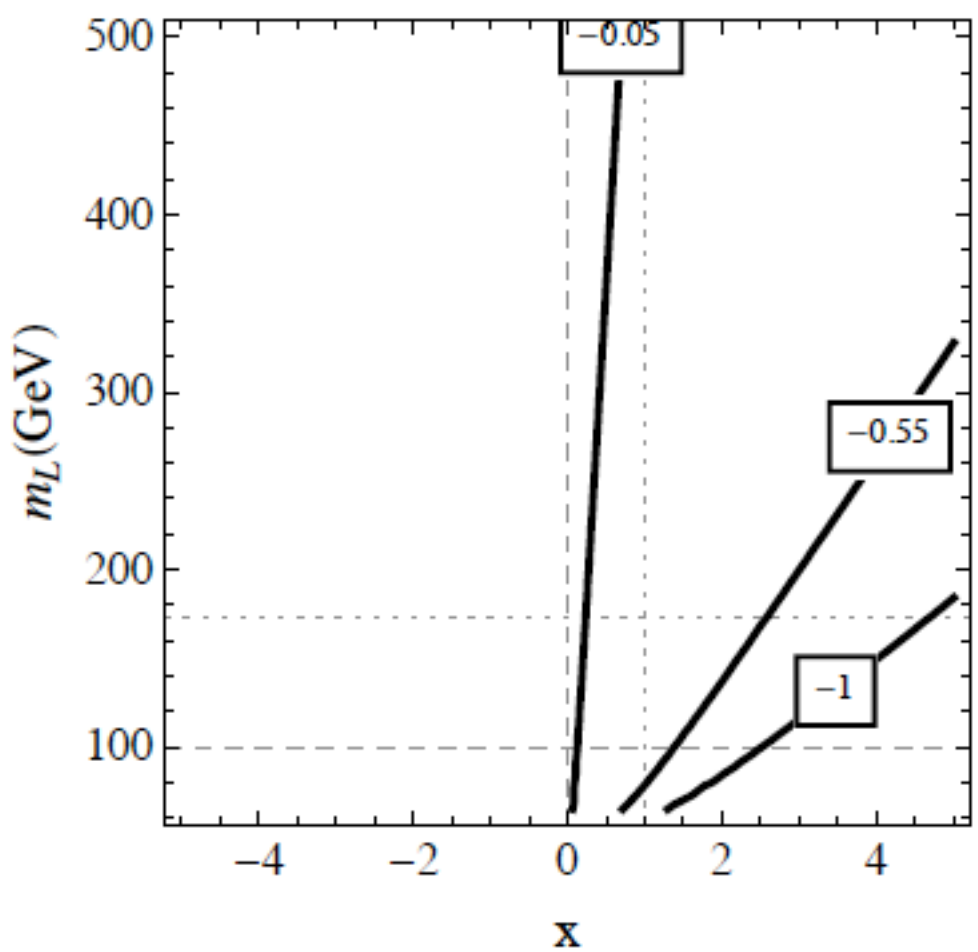
$$\kappa_\gamma^2 = (c_\alpha - c_\gamma s_\alpha)^2, \quad \kappa_g^2 = \kappa_{mix}^2 = c_\alpha^2, \quad \kappa_H^2 \simeq c_\alpha^2$$

$$c_\alpha = 0.98_{-0.056}, \quad c_\gamma = -0.55^{+0.50}_{-0.45},$$

- Constraints on singlet parameter space

$$c_\gamma = \frac{v}{\sqrt{2} A_\gamma^{SM}} \frac{x A_{1/2}(m_{H_1}^2/4m_L^2)}{m_L}.$$

x: singlet coupling to extra lepton L



- Interestingly, by having nonSM width in global fit,
  { alpha, c_gamma, BR(nonSM) },
  we can generically set upper bound on it.

- Built-in restriction in this framework, cos alpha<1; the upper bound on cos alpha and best-fit range of kappa_H give the upper bound on BR(nonSM).

$$\kappa_H^2 = \frac{c_\alpha^2}{1 - BR_{nonSM}}$$

- BR(nonSM) < 0.15(1sigma), 0.24(95%CL).
  (For most other cases, BR(nonSM)<10-25%(1sigma)).

General Cases

Models	Best-fit results	χ^2/ν
SM		$12.01/10 = 1.20$
universal modification $(\hat{\kappa}^2_{univ})$ (BR_{nonSM}) $(\cos\alpha)$	 (1.012) $\leq 18.8\%$ at 95%CL ≥ 0.904 at 95%CL	 $11.96/9 = 1.33$
VL lepton, W', S' (c_α, c_γ)	 (0.98, -0.55)	 $11.1/8 = 1.39$
VL quark $(c_\alpha, c_g, c_\gamma)$	 (0.947, -0.128, -0.313)	 $11.1/7 = 1.58$
$(c_\alpha, c_\gamma, Br_{nonSM})$	$BR_{nonSM} \leq 24\%$ at 95%CL	$11.1/8 = 1.39$
$(c_\alpha, c_g, c_\gamma, Br_{nonSM})$	$BR_{nonSM} \leq 39\%$ at 95%CL	$11.1/7 = 1.58$
singlet mixed-in $\hat{\kappa}$ $(\hat{\kappa}^2_g, \hat{\kappa}^2_\gamma, \hat{\kappa}^2_{mix})$	 (1.03, 1.15, 0.942)	 $11.1/7 = 1.58$
singlet mixed-in theory $(\hat{c}_g, \hat{c}_\gamma, \hat{c}_\alpha)$	 (-0.176, -0.432, 0.971)	 $11.1/7 = 1.58$

Table 7. Summary of best-fit results with scalar mixing. If BR_{nonSM} is included in fit, no unique solution is found, and its upper bound at 95%CL is presented. Only central values of best-fit are shown, and errors can be found in text.

Results

- Although it is premature to say definitely due to large uncertainties, the SM gives the best fit in terms of the chi^2/d.o.f.
- Even if we include more parameters with new physics, it does not improve the overall fit very much (small decrease in total chi^2)
- Mixing with an extra singlet scalar is slightly disfavored now, but the CMS data alone favors such a scenario

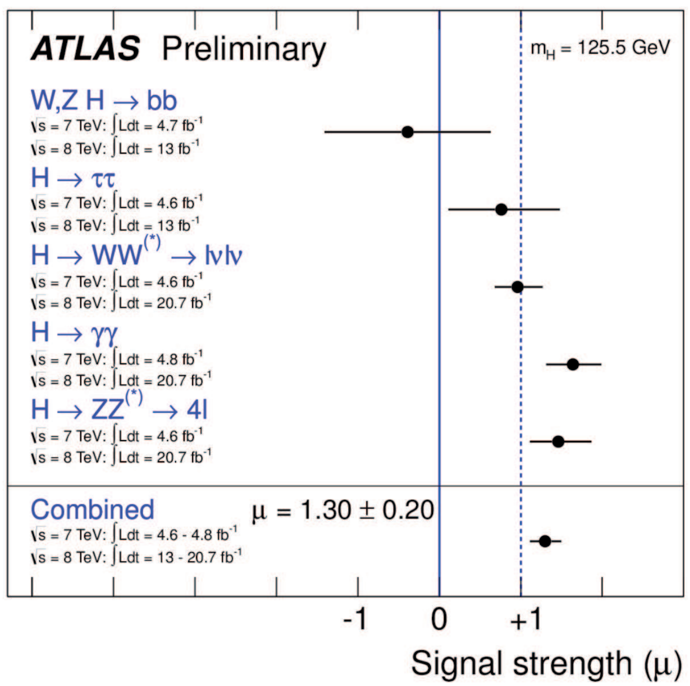
Important to seek for

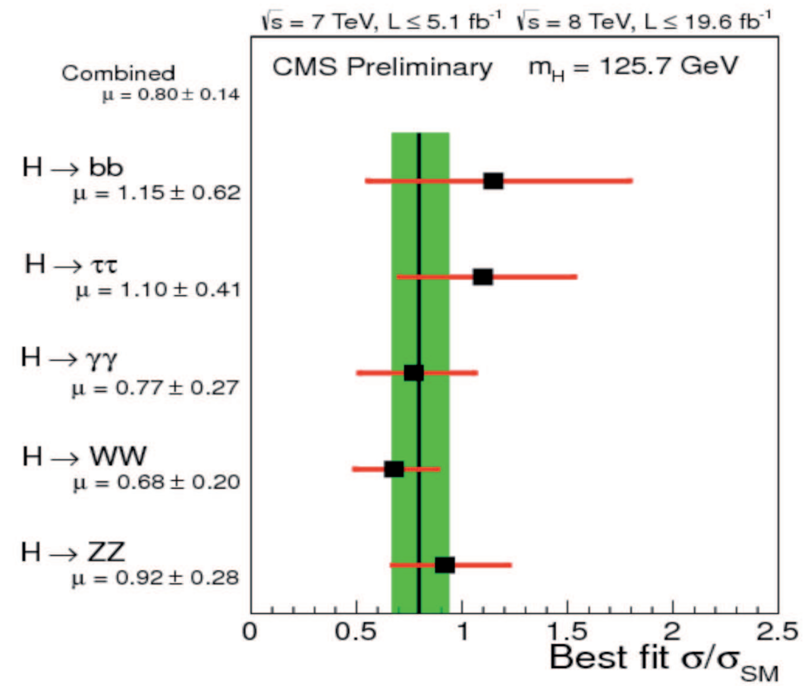
- The 2nd singlet-like scalar boson (which might couple to the DM) is very generic in any DM models with hidden sector (with local dark gauge symmetries) where DM is stabilized by local dark gauge symmetry
- Can solve some puzzles in CDM models with DM self-interaction from light mediator (2nd scalar or dark gauge boson)
- Additional singlet S improves EW Vac stability, and Higgs inflation with larger "r"

Higgs signal strengths

Signal Strengths

$$\mu \equiv \frac{\sigma \cdot \mathrm{Br}}{\sigma_{\mathrm{SM}} \cdot \mathrm{Br}_{\mathrm{SM}}}$$





Decay Mode	**ATLAS** ($M_H = 125.5$ GeV)	**CMS** ($M_H = 125.7$ GeV)
$H \to bb$	-0.4 ± 1.0	1.15 ± 0.62
$H \to \tau\tau$	0.8 ± 0.7	1.10 ± 0.41
$H \to \gamma\gamma$	1.6 ± 0.3	0.77 ± 0.27
$H \to WW^*$	1.0 ± 0.3	0.68 ± 0.20
$H \to ZZ^*$	1.5 ± 0.4	0.92 ± 0.28
Combined	$\mathbf{1.30 \pm 0.20}$	$\mathbf{0.80 \pm 0.14}$

$$\langle \mu \rangle = \mathbf{0.96 \pm 0.12}$$

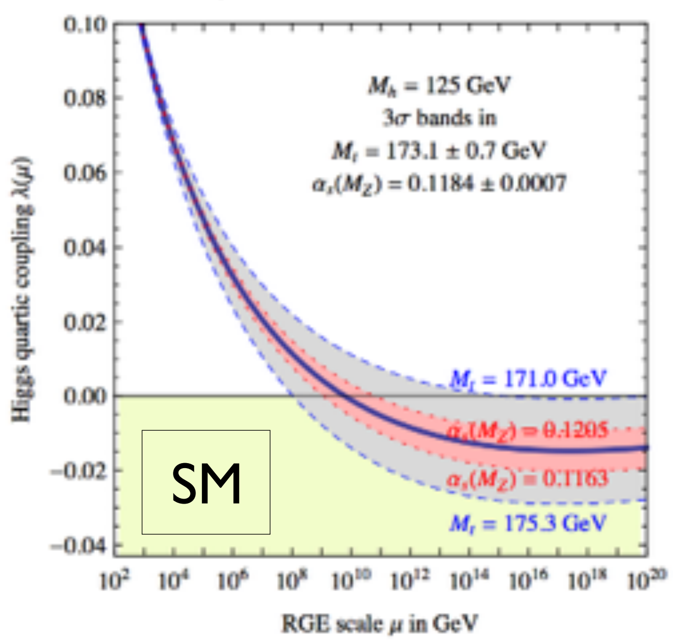
Getting smaller

Low energy phenomenogy

- Universal suppression of collider SM signals
  [See 1112.1847, Seungwon Baek, P. Ko & WIPark]
- If "m_h > 2 m_ϕ", non-SM Higgs decay!
- Tree-level shift of $\boldsymbol{\lambda}_{H,SM}$ (& loop correction)

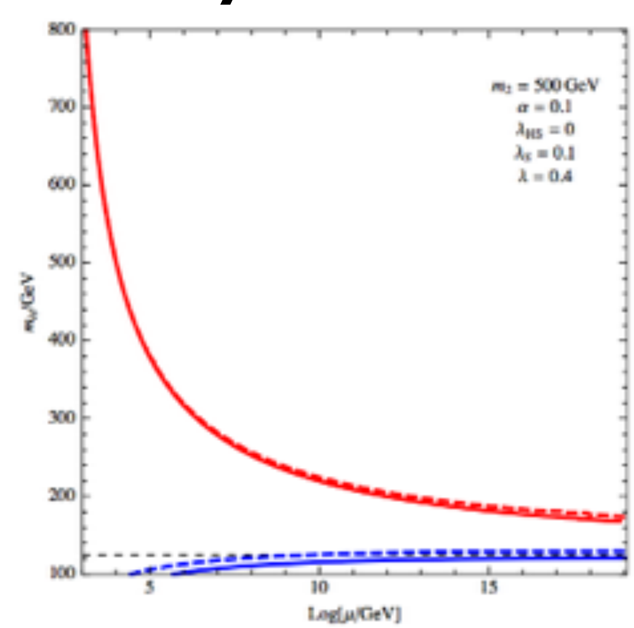
$$\lambda_{\Phi H} \Rightarrow \lambda_H = \left[1 + \left(\frac{m_\phi^2}{m_h^2} - 1 \right) \sin^2 \alpha \right] \lambda_H^{SM}$$

⇨ If "m_ϕ> m_h", vacuum instability can be cured.



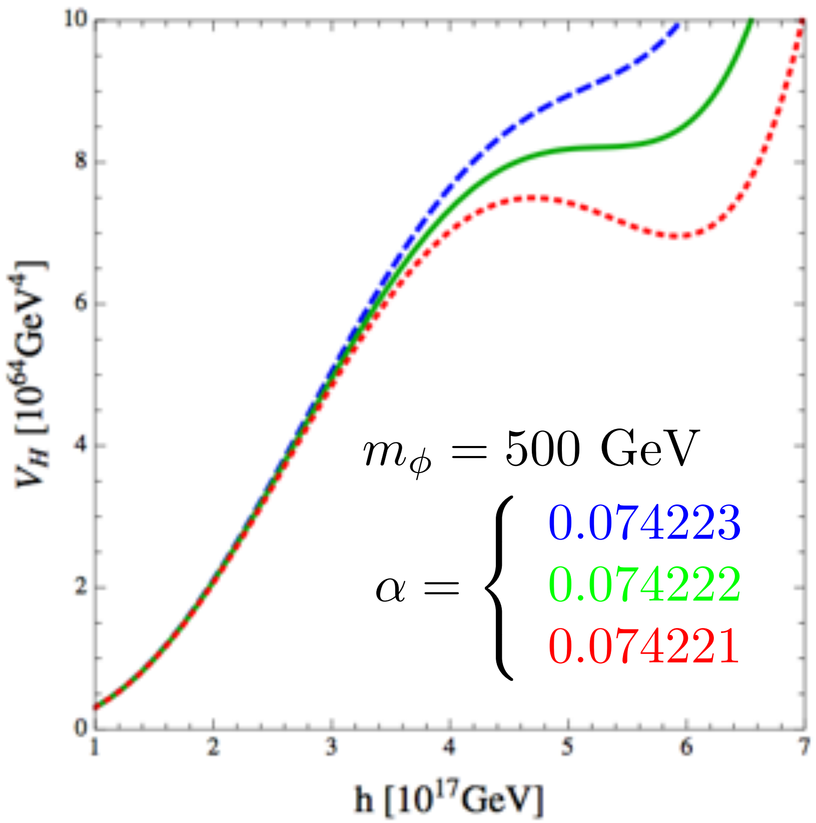
[G. Degrassi et al., 1205.6497]

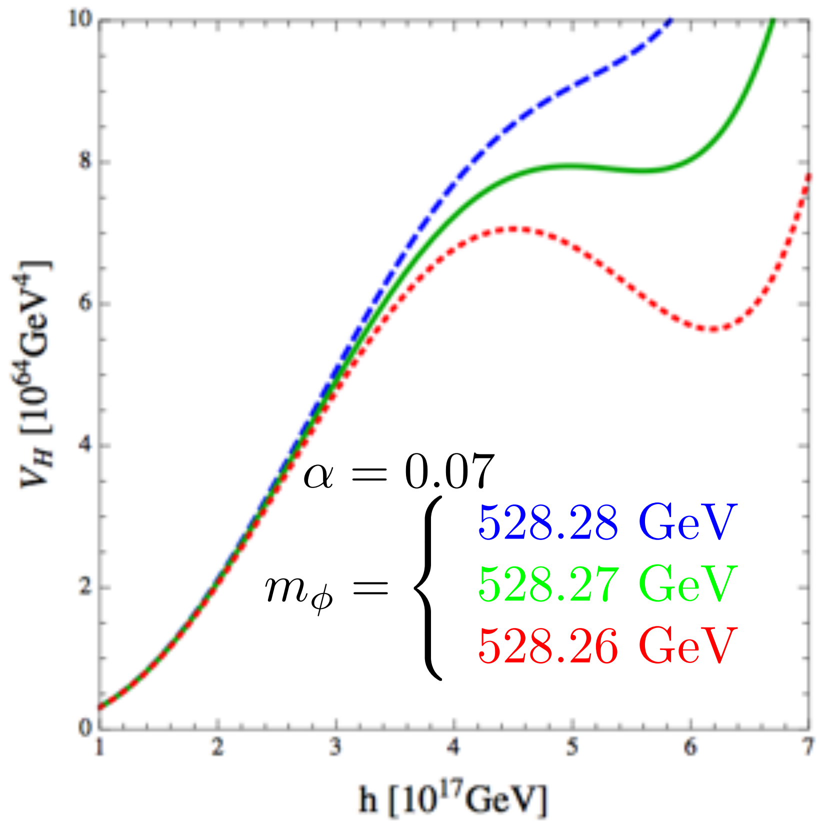
α ⇨



[S. Baek, P. Ko, WIP & E. Senaha, JHEP(2012)]

Higgs-portal Higgs inflation



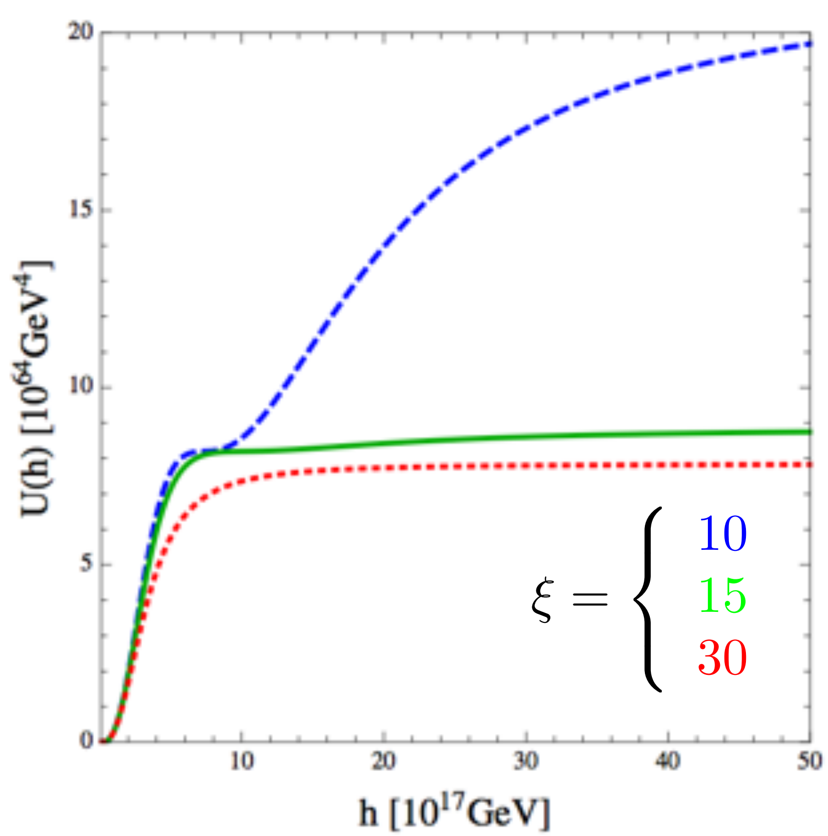


$m_t = 173.2$ GeV

$M_h = 125.5$ GeV

* Inflection point control

(α, m_ϕ) & $\lambda_{\Phi H}$



Result of numerical analysis

$k_* \times$ Mpc	N_e	$h_*/M_{\rm Pl}$	ϵ_*	η_*	$10^9 P_S$	n_s	r
0.002	59	0.83	0.00448	−0.02465	2.2639	0.9238	0.0717
0.05	56	0.72	0.00525	−0.00190	2.1777	0.9647	0.0840

\- Result depends very sensitively on α, m_Φ and $\lambda_{\Phi H}$ -

H.P.H.I allows Higgs inflation matching to BICEP2 result without resorting to m_t and M_h.