Higgs Portal

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New physics in the Higgs sector

modified couplings to known fields

couplings to new fields

$y_0 \rightarrow y_0 + y_1 \bar{H}H / \Lambda^2$

$\bar{H}H S^2$

$$(\partial H)^2 \longrightarrow (\partial H)^2 \;(1 + H^2/\Lambda^2 + \dots)$$

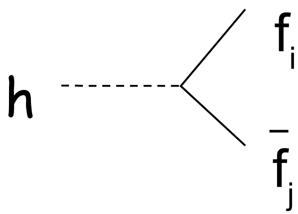
$$y_0 H \bar{f} f \longrightarrow H \bar{f} f \;(y_0 + y_1 H^2/\Lambda^2 + \dots)$$

$\Rightarrow$ main effect: modified Yukawas

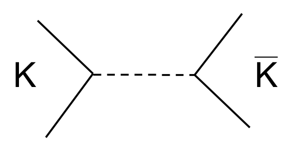
Higgs-induced flavor violation:

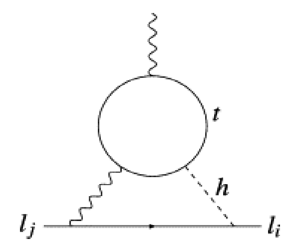
$$\begin{cases} M_{ij} = v\ Y_{ij} \\ y_{ij} = a_{ij}\, Y_{ij} \end{cases} \Rightarrow$$

not diagonalizable simultaneously



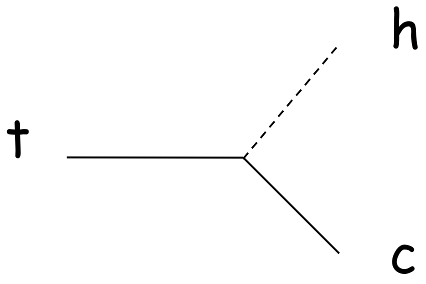
Constraints :



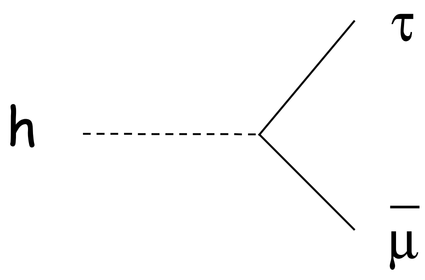


...

LHC :



BR ~ 10^{-2}



BR ~ 0.1

The Higgs key to the hidden sector

Motivation :

✓ $\boxed{E_8}$ X $\boxed{E_8}$ strings

observable hidden

✓ dark matter

✓ ...

Lowest order operators ("Higgs Portal") :

$$\bar{H}H\, S^2 \;+\; \ldots$$

$$\bar{H}H\, V_\mu V^\mu \;+\; \ldots$$

$$\bar{H}H\, \bar{\chi}\chi / \Lambda \;+ \ldots$$

"Portal" due to Patt,Wilczek'06 (earlier : Silveira,Zee'85; Shabinger,Wells'05;...)

Special role of the Higgs :

Silveira, Zee '85
Veltman, Yndurain '89
...

$|H|^2$ = the only gauge and Lorentz-inv. dim-2 operator

$$L = a\,|H|^2\,S^2 + b\,|H|^2\,S$$

(S = "hidden" scalar)

b=0 (S has hidden charge):

$$\boxed{L = a\,|H|^2\,S^2}$$

"S" is stable and couples weakly to SM --> DARK MATTER (?)

Vector Higgs portal:

OL, Lee, Mambrini '11

$$L = a\,|H|^2\; V_\mu V^\mu \;+\; b\,(\,\bar{H} i D_\mu H\, V^\mu + \text{h.c.})$$

(V_μ = "hidden" vector)

b=0 (V^μ <--> $-V^\mu$ symmetry):

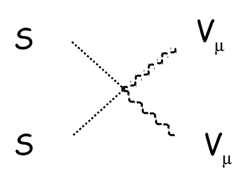
$$\boxed{L = a\,|H|^2\; V_\mu V^\mu}$$

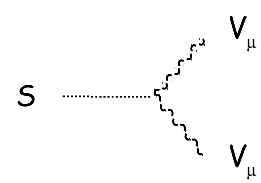
V^μ = DM (?)

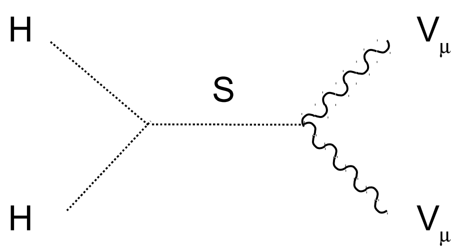
Higgs mechanism in the hidden sector :

$$L = -1/4\, F_{\mu\nu} F^{\mu\nu} + D_\mu S^* D^\mu S - V(S) + \lambda/4\; H^*H\, S^*S$$

$$S \longrightarrow \text{VEV}$$







$\Rightarrow$ $H^*H\, V_\mu V^\mu$ vertex

(Z_2 parity)

gauge invariance (+ minimal field content)

$$\Downarrow$$

Z_2

OL, Lee, Mambrini '11

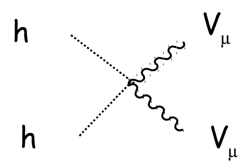
Unitarity:

$$L = \tfrac{1}{4}\lambda\,|H|^2\, V_\mu V^\mu + \tfrac{1}{2} m^2\, V_\mu V^\mu$$

Physical mass :

$$m^2_V = m^2 + \tfrac{1}{2}\lambda v^2$$

Cutoff :



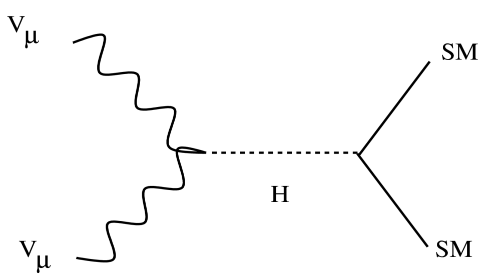
$$+ \quad \ldots \qquad \sim \; E^2$$

$$\boxed{E \sim m^2_V / m}$$

$$(\cdot \sqrt{16\pi/\lambda} \;)$$

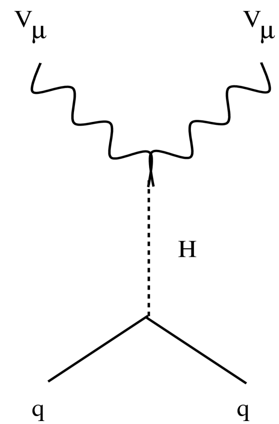
Important processes :

annihilation



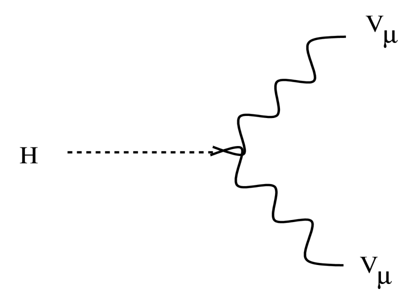
$< \sigma v >$

DM-nucleon scattering



σ^{SI}_{S-P}

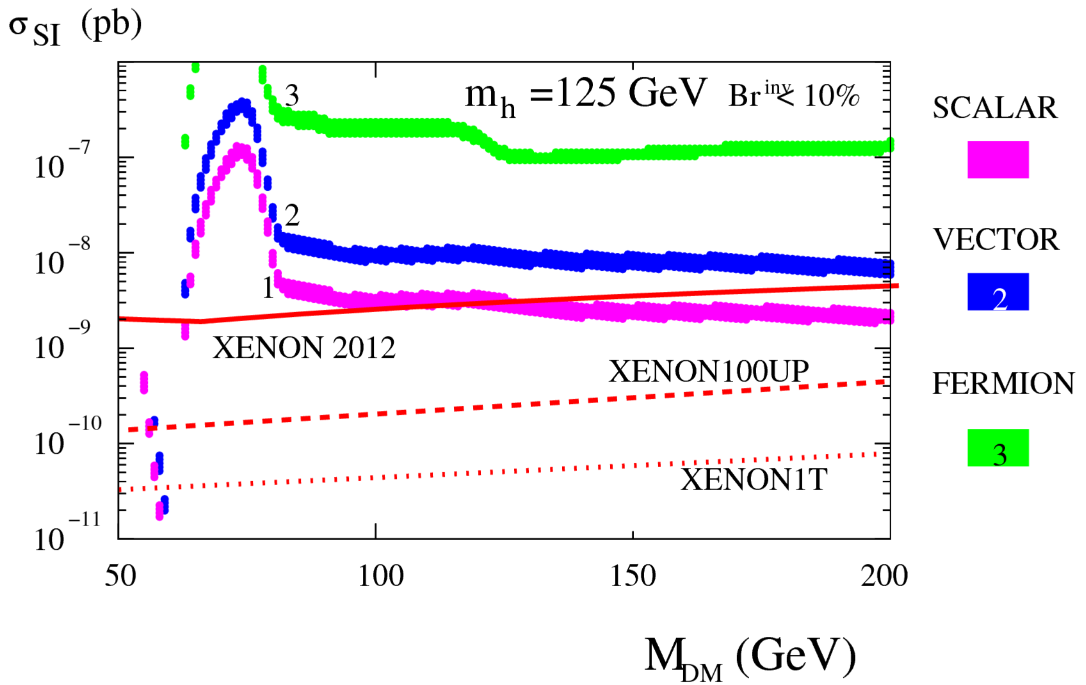
invisible Higgs decay



Γ_H^{inv}

Prediction :

Djouadi, OL , Mambrini , Quevillon '11



DM direct detection with $\sigma \sim 10^{-8} - 10^{-10}$ pb

Scalar vs Vector DM :

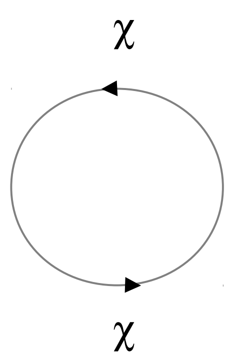
annihilation **:** $g^2_{vector} = 3\, g^2_{scalar}$ (3 species)

direct detection **:** same (Higgs exchange)

Higgs decay **:** $\Gamma_{vector} \sim m_h^4 / m_V^4 \; \Gamma_{scalar}$ (Goldstone production)

Fermion DM :

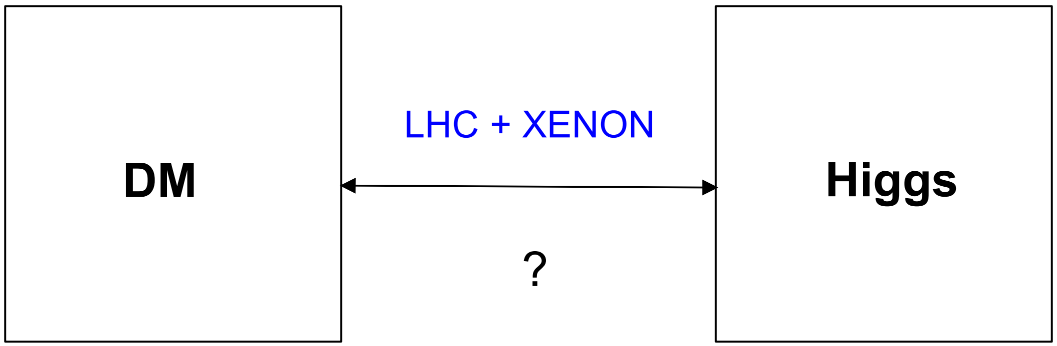
suppressed annihilation



$P = (-1)^{l+1} = -1$, $P(h)=+1$

Lopez-Honorez et al.'12

Note: CP violation can solve the problem $\bar{H}H\ \bar{\chi}\gamma_5\chi$


DM
LHC + XENON
?
Higgs

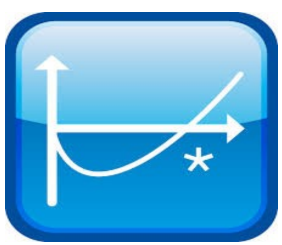
Gabrielli, Heikinheimo, Kannike, Racioppi, Raidal, Spethmann'13

Dimensional transmutation and DM :

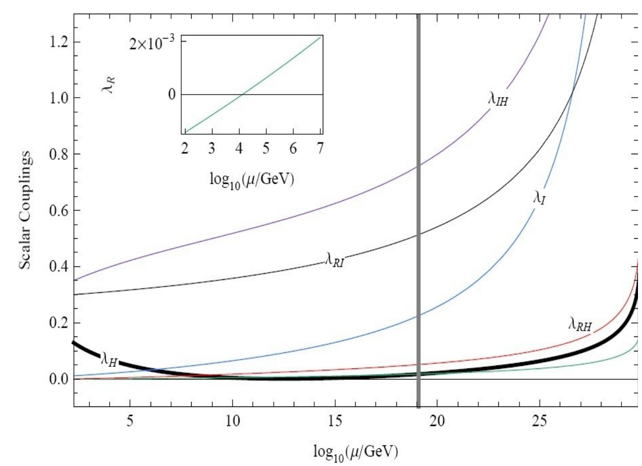
"Dimensionless" Higgs portal with a complex scalar (s_R + is_I) and Z_2 :

$$V = \frac{1}{4}\lambda_H \phi^4 + \frac{1}{4}\lambda_I s_I^4 + \frac{1}{4}\lambda_{RI} s_I^2 s_R^2 + \frac{1}{4}\lambda_R s_R^4 + \frac{1}{4}\lambda_{IH}\phi^2 s_I^2 + \frac{1}{4}\lambda_{RH}\phi^2 s_R^2$$

Coleman-Weinberg symmetry breaking due to s_R (s_I=DM) :



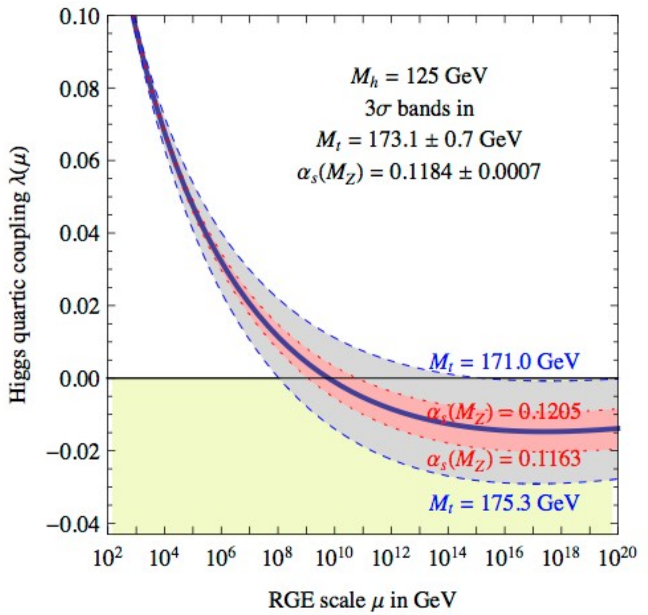
$\lambda_R < 0 \, , \, \lambda_{RH} < 0$



Higgs and inflation

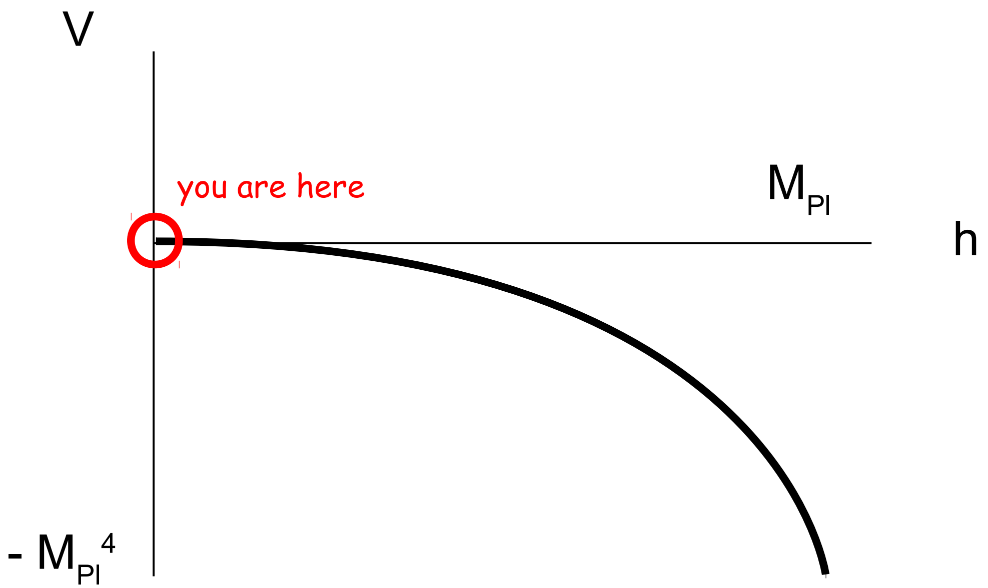
Degrassi et al.'12

SM stability bound: $m_h >$ 126 GeV at 98% CL



(not settled : Alekhin et al. '12
Bezrukov et al. '12)

$h >> \Lambda \sim 10^{10}$ GeV $\Rightarrow$ $V \sim \frac{1}{4}\lambda(h)\, h^4$, $\lambda(h) < 0$



$\Lambda = 10^{-8} M_{Pl}$, barrier $= 10^{-32}\ M_{Pl}^4$

Problems :

- how did the Universe end up at $h \sim 0$?

- why did it stay there during inflation ?

Possible solution :

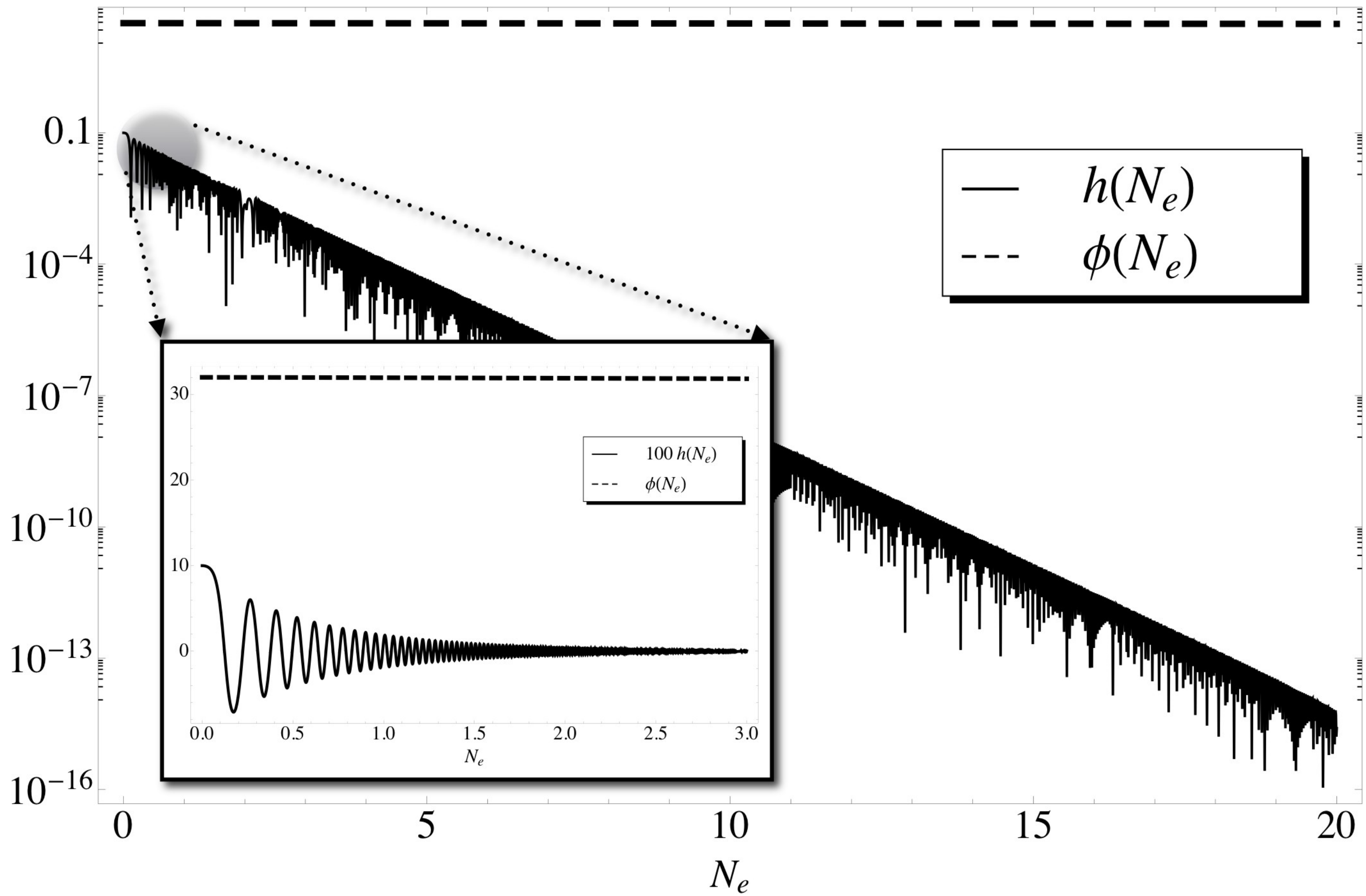
Higgs-inflaton coupling $\boxed{\Delta V = \frac{1}{2}\, \xi\, h^2 \phi^2}$ (simplest choice)

$\Delta V + V_{Higgs} > 0 \quad \Rightarrow \quad \phi_0 \sim 20\, M_{Pl} \;,\quad \xi \sim 10^{-6}$

Large effective mass term $\Rightarrow$ $h(t) \sim h(0)\, \exp(- 3/2\, Ht\;)$

Higgs field is driven to zero during inflation !

Higgs/inflaton evolution (in M_{Pl}):



Another option:

stabilize the EW vacuum

$$\Delta L = \tfrac{1}{4}\,\lambda_{hs}|H|^2 S^2 + \tfrac{1}{2} m^2 S^2 + \tfrac{1}{4}\,\lambda_s S^4$$

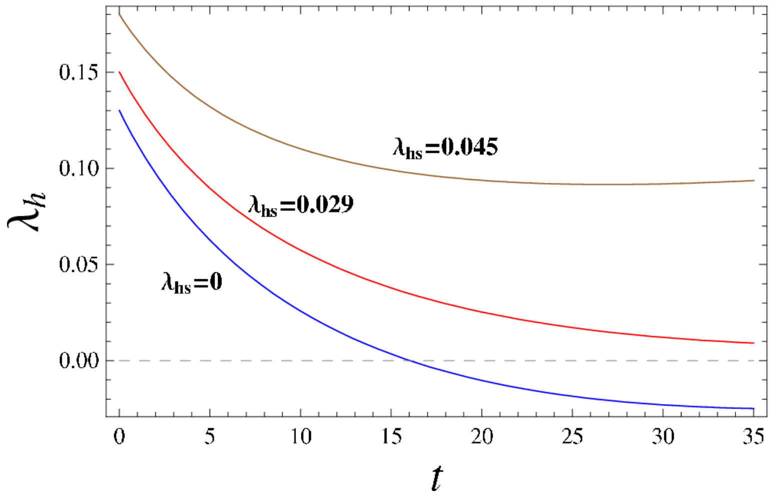
Low energy states :

$$\begin{cases} H_1 = H\cos\theta + S\sin\theta \\ H_2 = H\sin\theta - S\cos\theta \end{cases}$$

If $\langle S\rangle \gg 246$ GeV ,

$$\begin{cases} \theta \to 0 & \text{(SM—like Higgs)} \\ m_h^2 = 2v^2\,[\,\lambda_h - \lambda^2_{hs}/(4\lambda_s)\,] \end{cases}$$

OL '12
Elias-Miro et al.'12

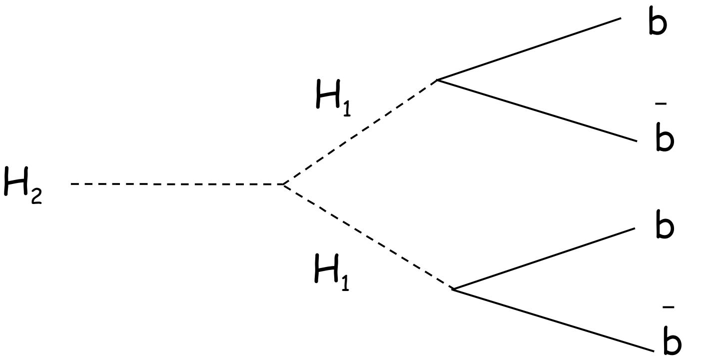


$\lambda_s = 0.01$
$t = \ln(\mu/m_t)$

Higgs-portal coupling favored by cosmology

Possible low-energy signatures :

- 2 Higgs-like states
- suppressed couplings
- cascades



Higgs potential reconstruction :

Englert et al. '11

m_1 , m_2 , θ , $H_2 \to H_1 H_1$ ⇨ 4 parameters of the scalar potential

Conclusion

- Higgs sector is special
- key to the hidden sector / DM / inflation
- LHC/direct detection are crucial