The Higgs Portal

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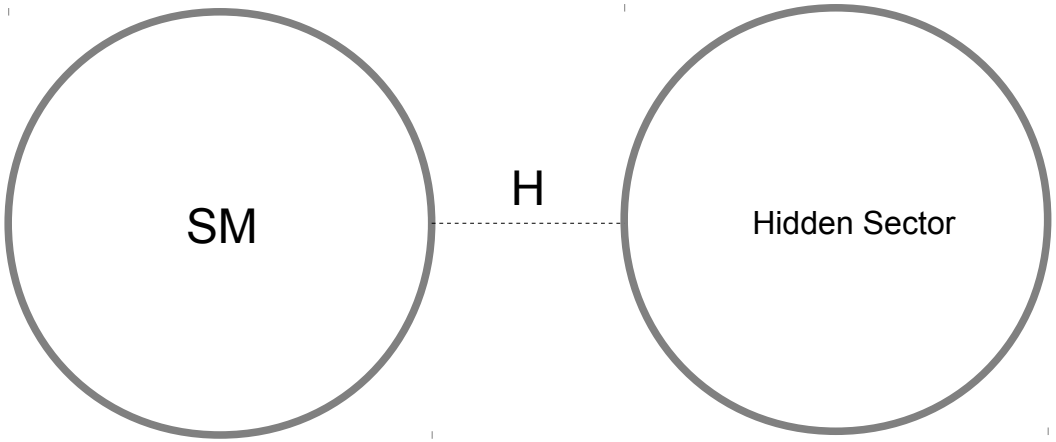
The Higgs and the hidden sector



Lowest order operators ("Higgs Portal") :

$\overline{H}H\, S^2 \quad + \quad \ldots$ (scalar)

$\overline{H}H\, V_\mu V^\mu \quad + \quad \ldots$ (vector)

$\overline{H}H\, \overline{\chi}\chi / \Lambda \quad + \quad \ldots$ (fermion)

"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):

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

"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):

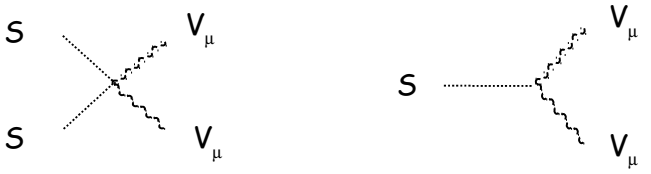
$$L = a\,|H|^2\; V_\mu V^\mu$$

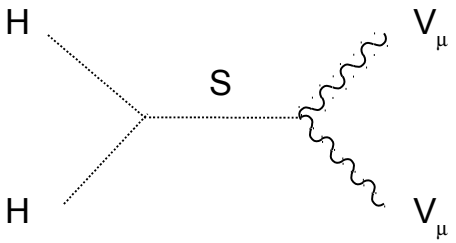
V^μ = DM (?)

Higgs mechanism in the hidden sector :

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

$$S \longrightarrow VEV$$

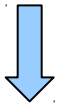




$\Rightarrow$ $H^*H\, V_\mu V^\mu$ vertex

(Z_2 parity)

gauge invariance (+ minimal field content)



Z_2

OL, Lee, Mambrini '11

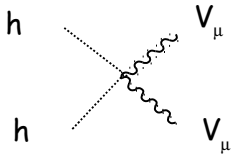
Unitarity:

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

Physical mass :

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

Cutoff :

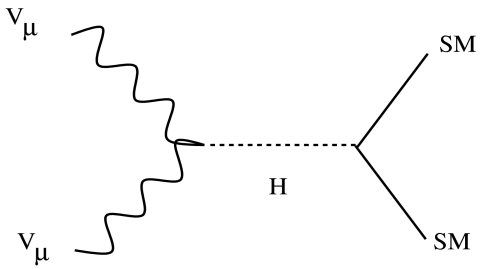


$+ \quad \ldots \quad \sim E^2$

$$E \sim m^2_V / m \qquad (\cdot \sqrt{16\pi/\lambda}\ )$$

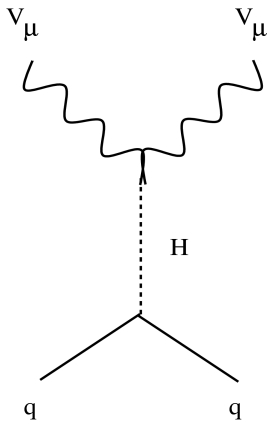
Important processes :

annihilation



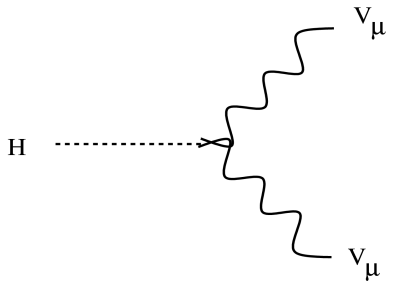
$< \sigma v >$

DM-nucleon scattering



σ^{SI}_{S-P}

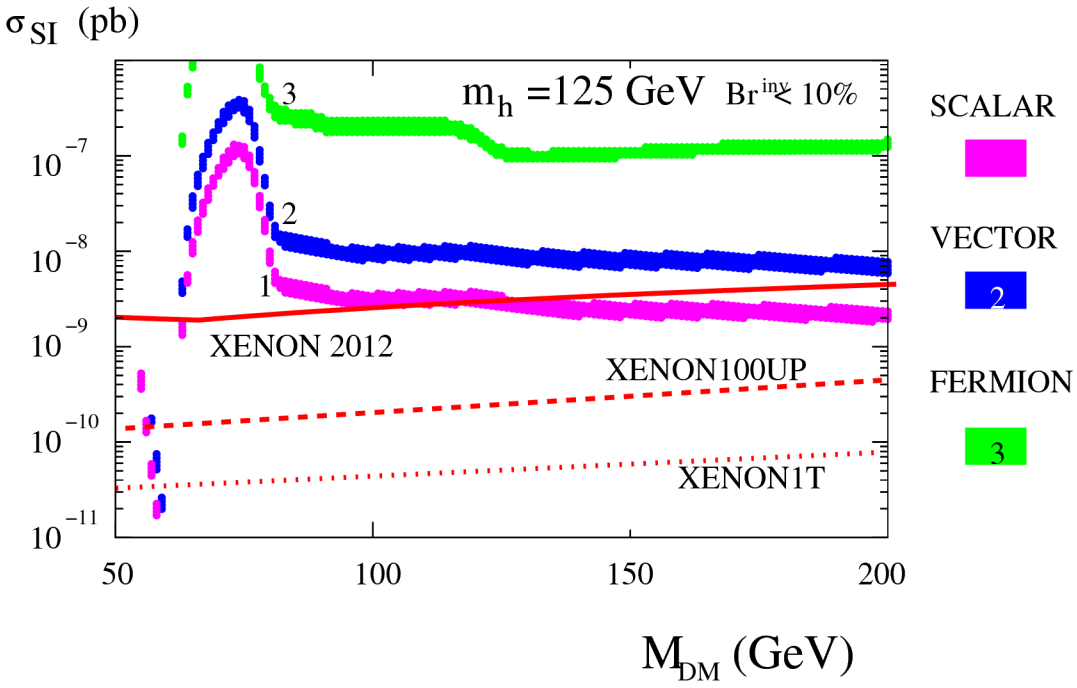
invisible Higgs decay



Γ_H^{inv}

Prediction :

Djouadi, OL , Mambrini , Quevillon '11



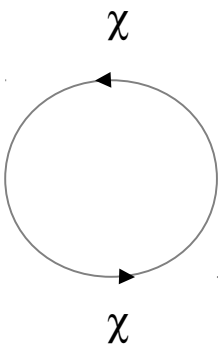
DM direct detection with $\sigma \sim 10^{-8} - 10^{-10}$ pb

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



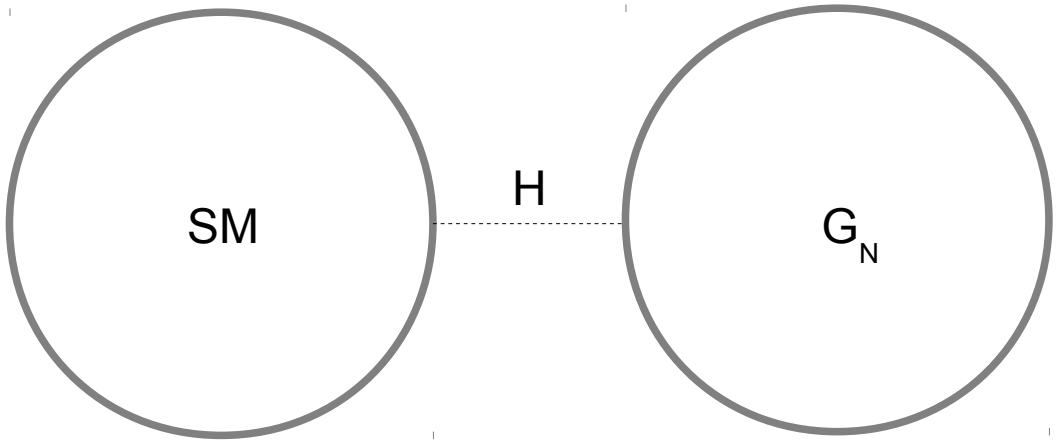
$P = (-1)^{l+1} = -1$, $P(h)=+1$

Lopez-Honorez et al.'12

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

Kim, OL ,Schmeier '15

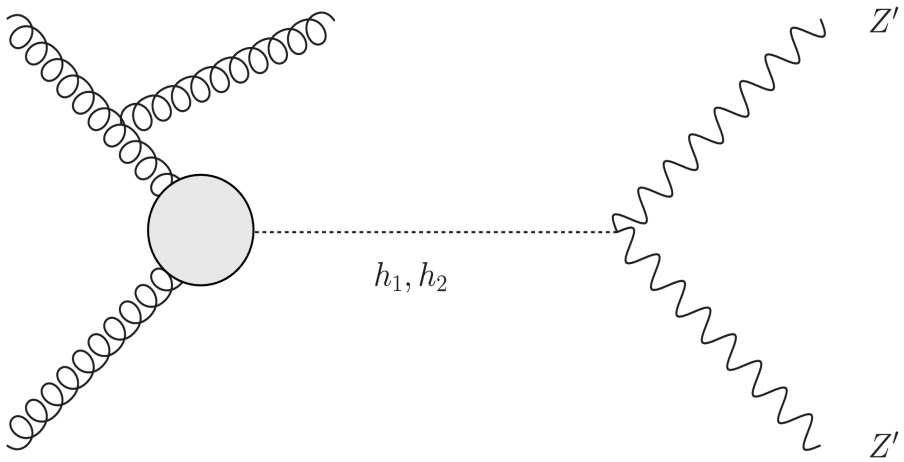
Probing gauge fields of the hidden sector



$V \sim \bar{H}H\,\bar{S}S$ ⇨ H-S mixing ⇨ **h couples to G_N**

Kim, OL ,Schmeier '15

Monojet + missing E_T :

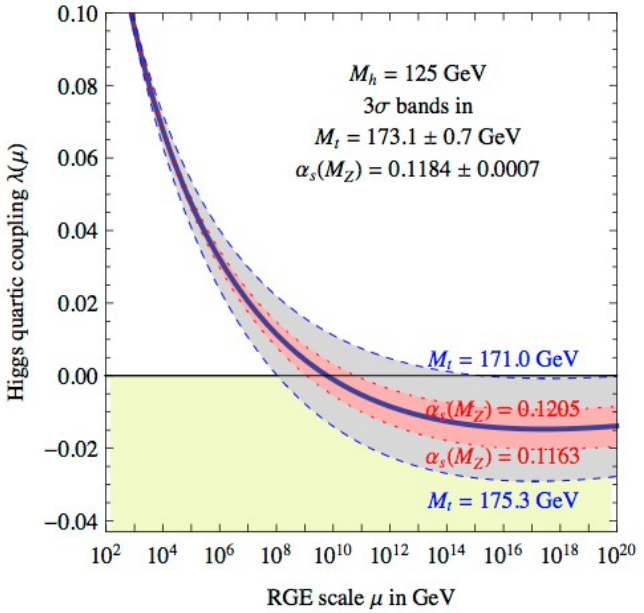


Gauge bosons = DM *or* decay into DM

Higgs potential and cosmology

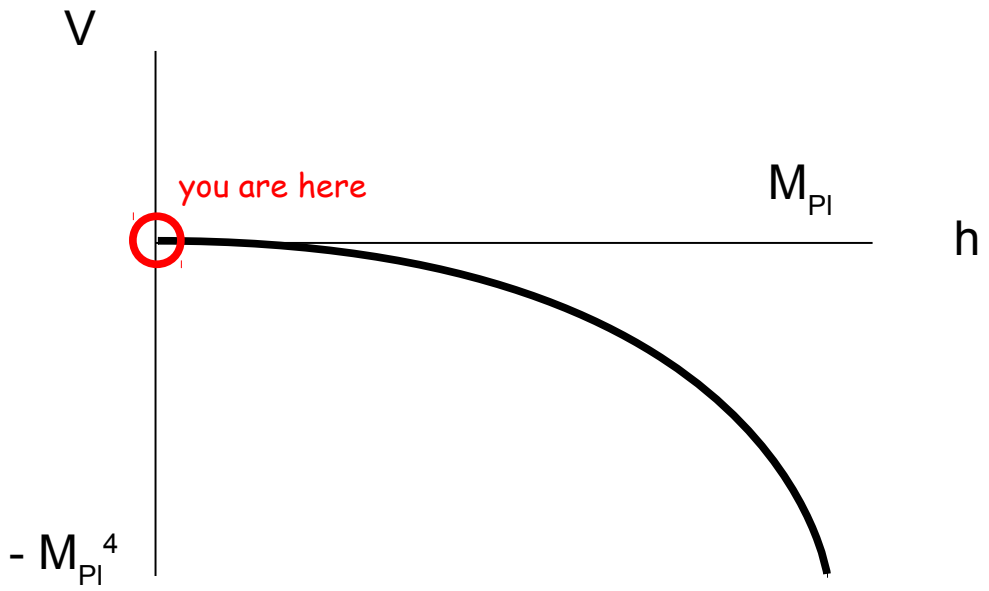
Degrassi et al.'12

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



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

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



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

Problems :

- how did the Universe end up at h ~ 0 ?

- why did it stay there during inflation ?

Solutions :

- modify the Higgs potential during inflation

- just modify the Higgs potential

Solution 1:

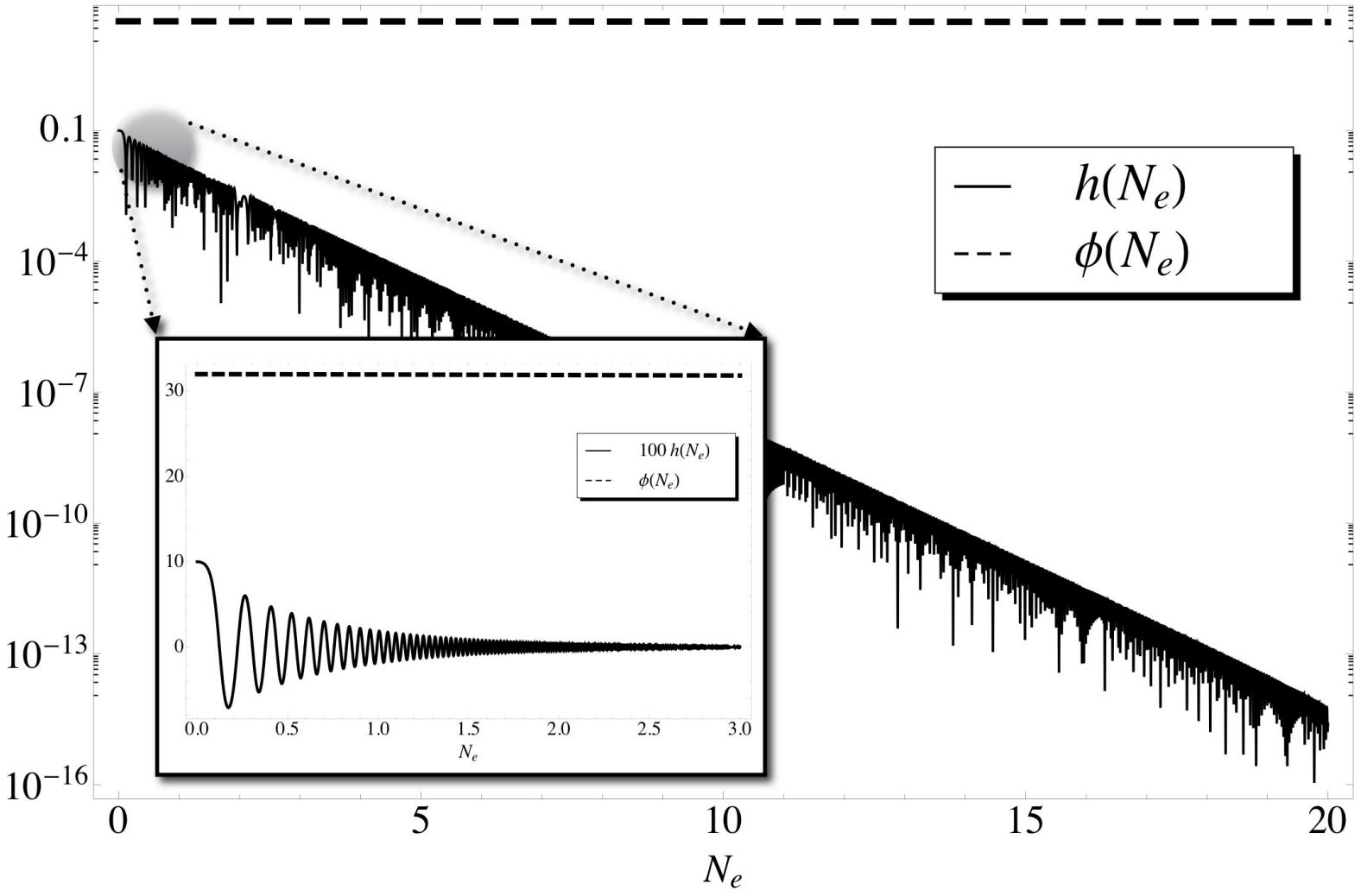
Higgs-inflaton coupling $\quad \boxed{\Delta V = \tfrac{1}{2}\, \xi\, h^2 \phi^2}$ ("Higgs portal" coupling)

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

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}):



Solution 2:

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

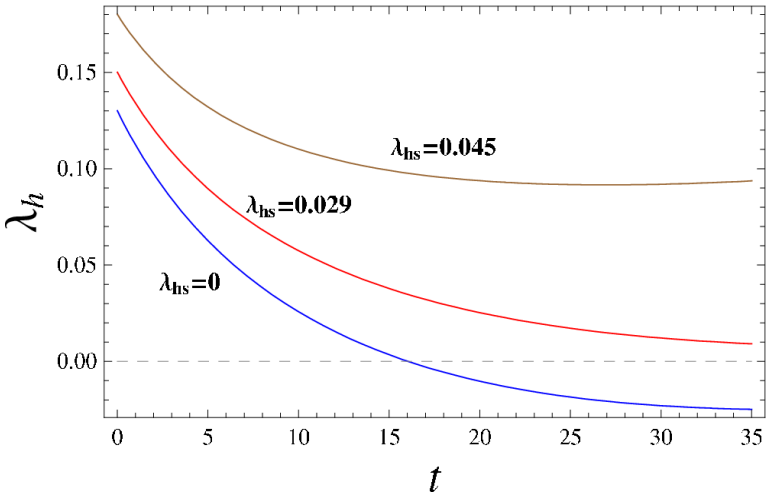
Low energy states :

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

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

$$\begin{cases} \theta \to 0 \qquad \text{(SM—like Higgs)} \\ m_h^2 = 2v^2\left[\lambda_h - \lambda_{hs}^2/(4\lambda_s)\right] \end{cases}$$

OL '12
Elias-Miro et al.'12



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

Solution 2':

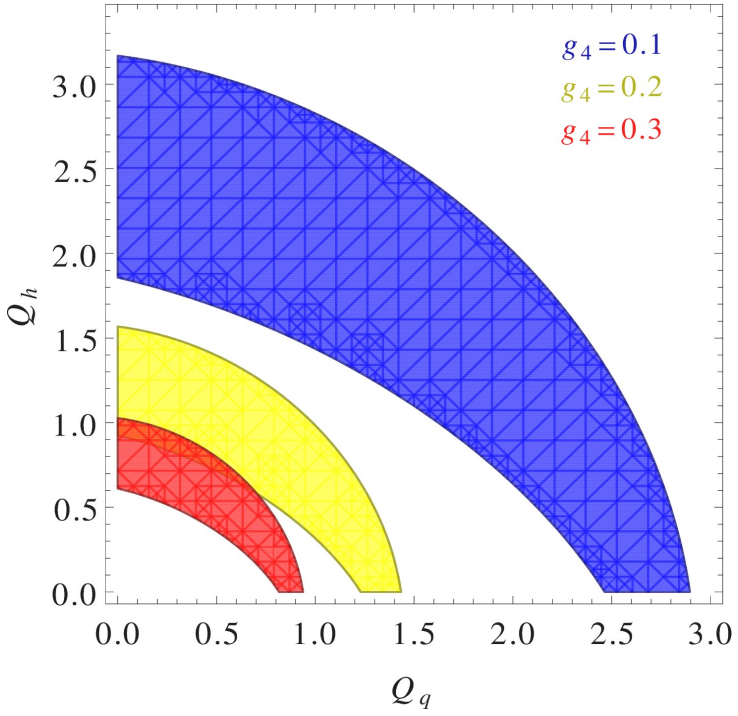
extra U(1)

$$\Delta L = g_4^2 Q_h^2 |H|^2 Z'^2$$

General features :

λ_h ↑

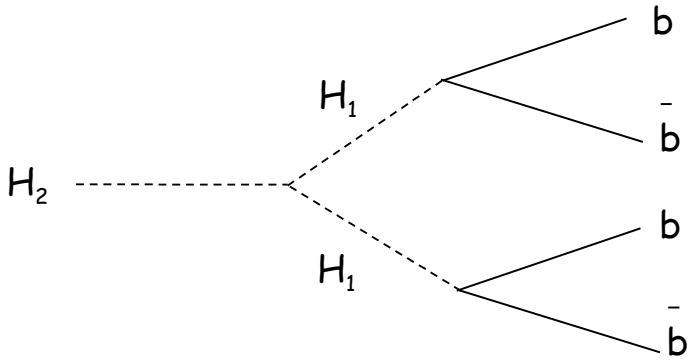
y_t ↓



Higgs portal at the LHC

Possible low-energy signatures :

- 2 Higgs-like states
- suppressed couplings
- cascades



Higgs potential reconstruction :

Englert et al. '11

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

Conclusion

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