The Higgs and Cosmology

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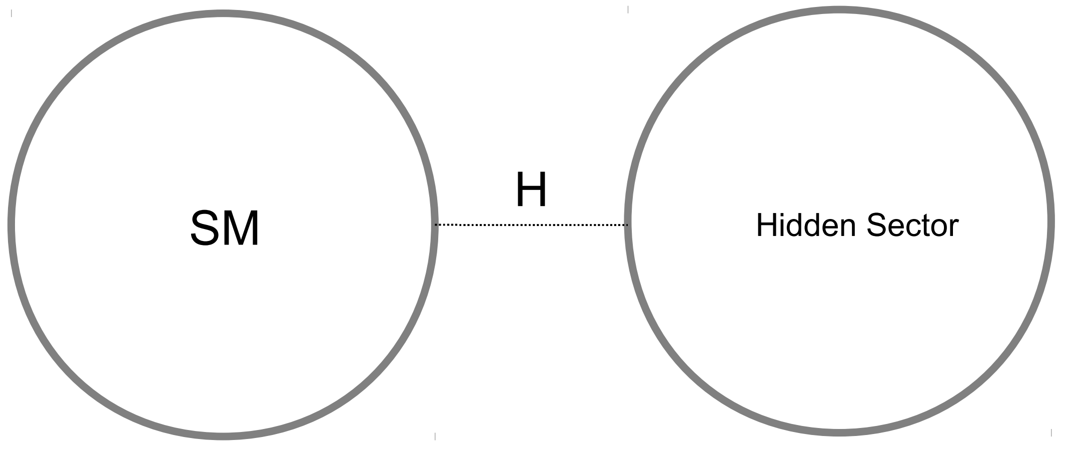
- the Higgs and the hidden sector
- the Higgs and dark matter
- the Higgs and inflation

The Higgs and the hidden sector



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):

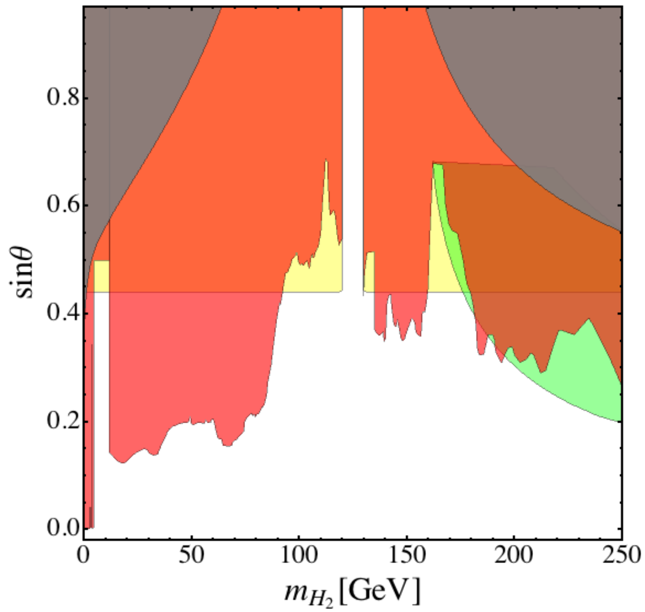
$$\boxed{L = a\,|H|^2 S^2}$$

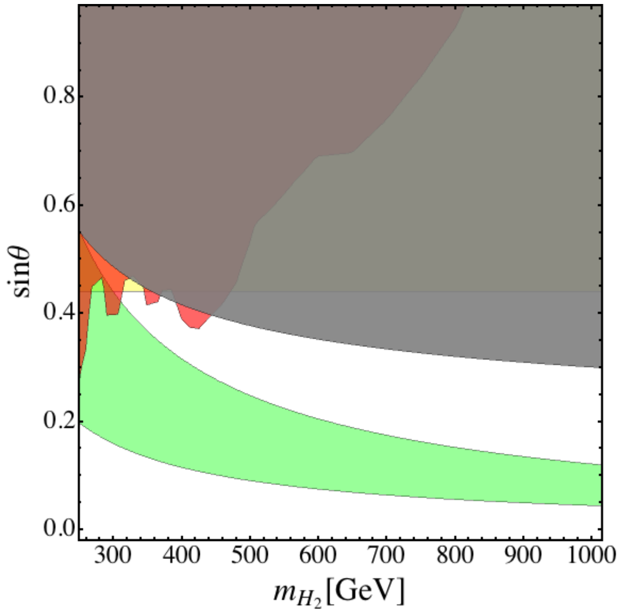
"S" is stable and couples weakly to SM --> DARK MATTER (?)

Constraints on Higgs-singlet mixing :

H_1 = 125 GeV Higgs ; H_2 = extra Higgs ; θ = mixing angle

Falkowski, Gross, OL '15

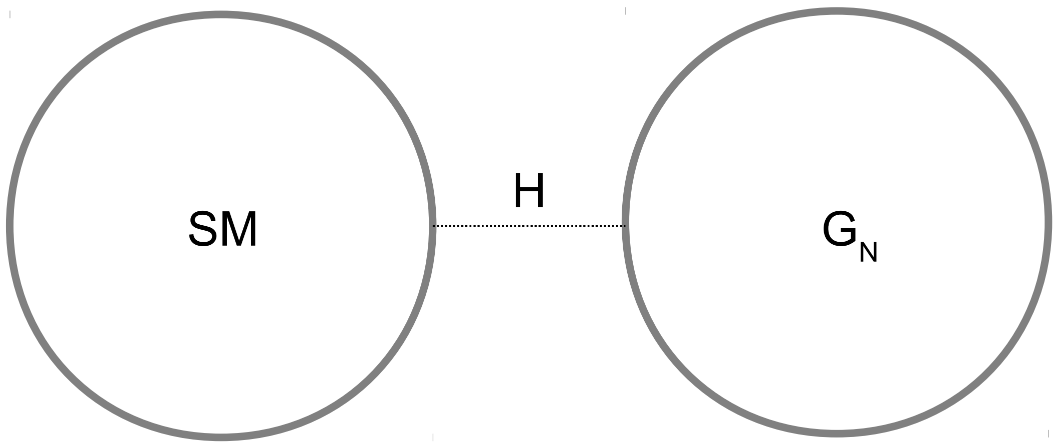




Grey = EW precision data , Yellow = LHC Higgs couplings , Reddish = B-physics, LEP, LHC

Green (optional) = Higgs potential stability/perturbativity up to M_{Pl}

The Higgs and dark matter



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

Gross,OL, Mambrini '15

Lie groups possess discrete symmetries

gauge fields as dark matter

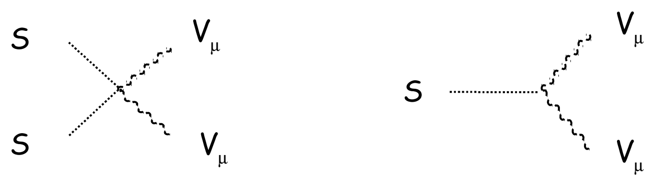
E.g. U(1) : $A_\mu \rightarrow -A_\mu$

Lee, OL, Mambrini '11

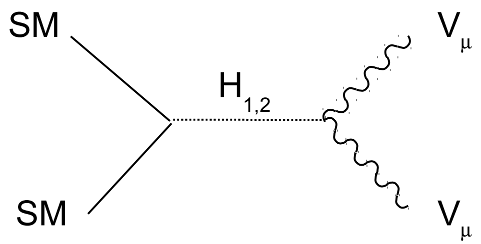
Higgs mechanism in the hidden sector :

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

$S \longrightarrow$ VEV



SM couplings:



$\Rightarrow$ Z_2

gauge invariance (+ minimal field content)

↓

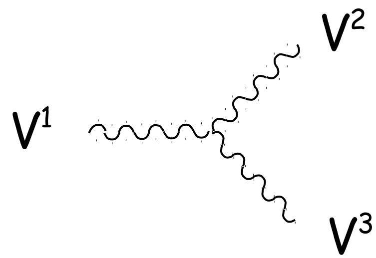
Z_2

↓

gauge fields are natural DM candidates

Hambye '08
Gross, OL, Mambrini '15

Non-abelian case:



$\Rightarrow$ Z_2 odd

But there are 2 Z_2's:

$$V^{1,2} \rightarrow -V^{1,2} \,, \quad V^3 \rightarrow V^3$$

$$V^{1,3} \rightarrow -V^{1,3} \,, \quad V^2 \rightarrow V^2$$

$\Rightarrow$ V^a = stable

hidden Higgs $= \begin{pmatrix} 0 \\ v \end{pmatrix}$

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}; \quad \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}; \quad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}.$$

Z_2 : reflects real generators

complex (or "charge") conjugation = outer automorphism

Z_2' : reflects off-diagonal generators with non-zero elements in the first row

gauge transformation

Arcadi, Gross, OL, Pokorski, Toma '16

minimal SU(N): $Z_2 \times Z_2$

⇩

two stable components

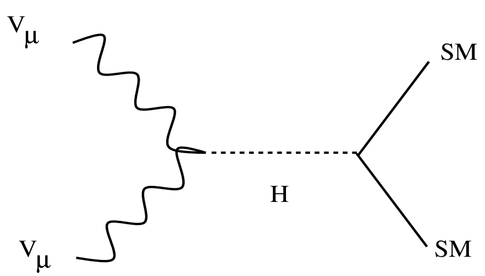
E.g. spin1 + spin 0 DM

DM phenomenology :

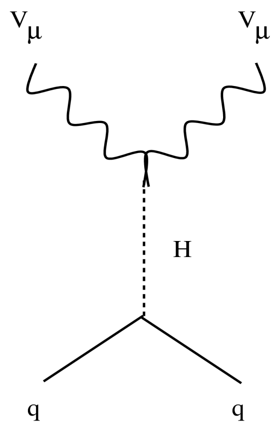
DM-nucleon scattering

invisible Higgs decay

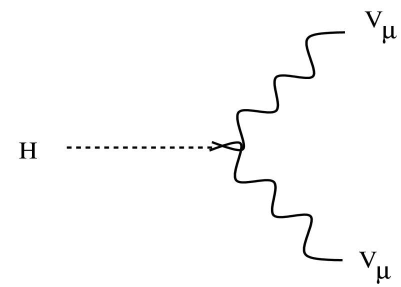
annihilation



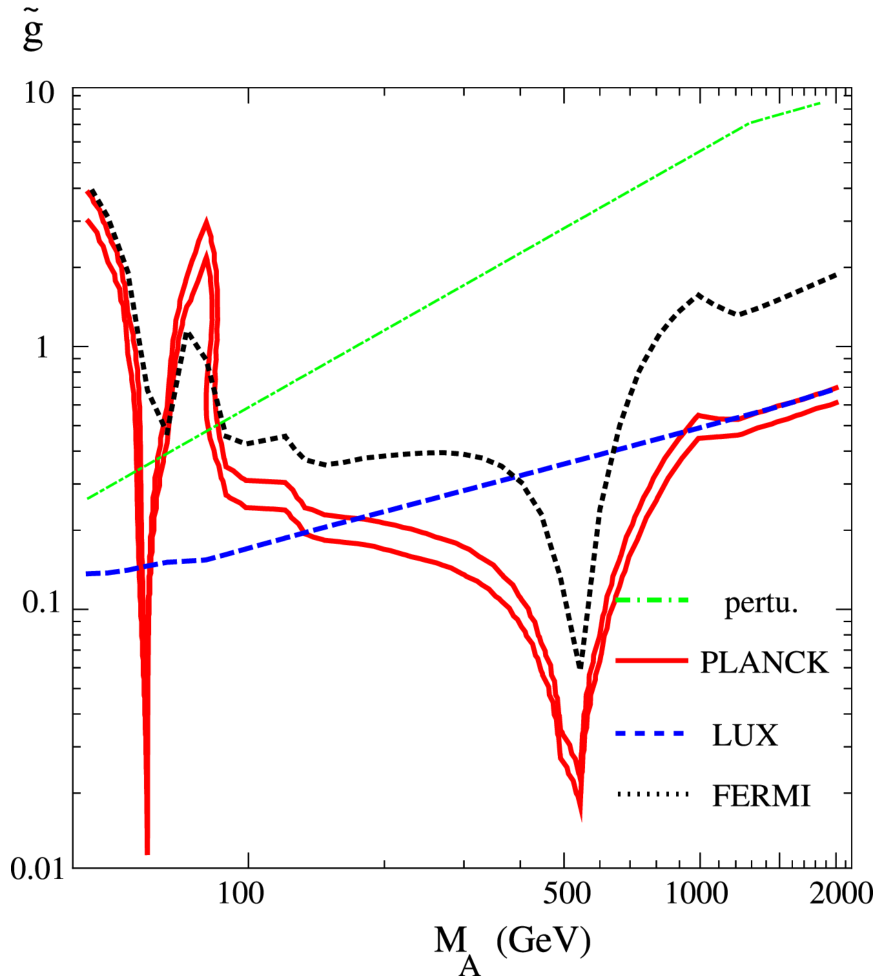
$< \sigma v >$



σ^{SI}_{S-P}



Γ^{inv}_{H}



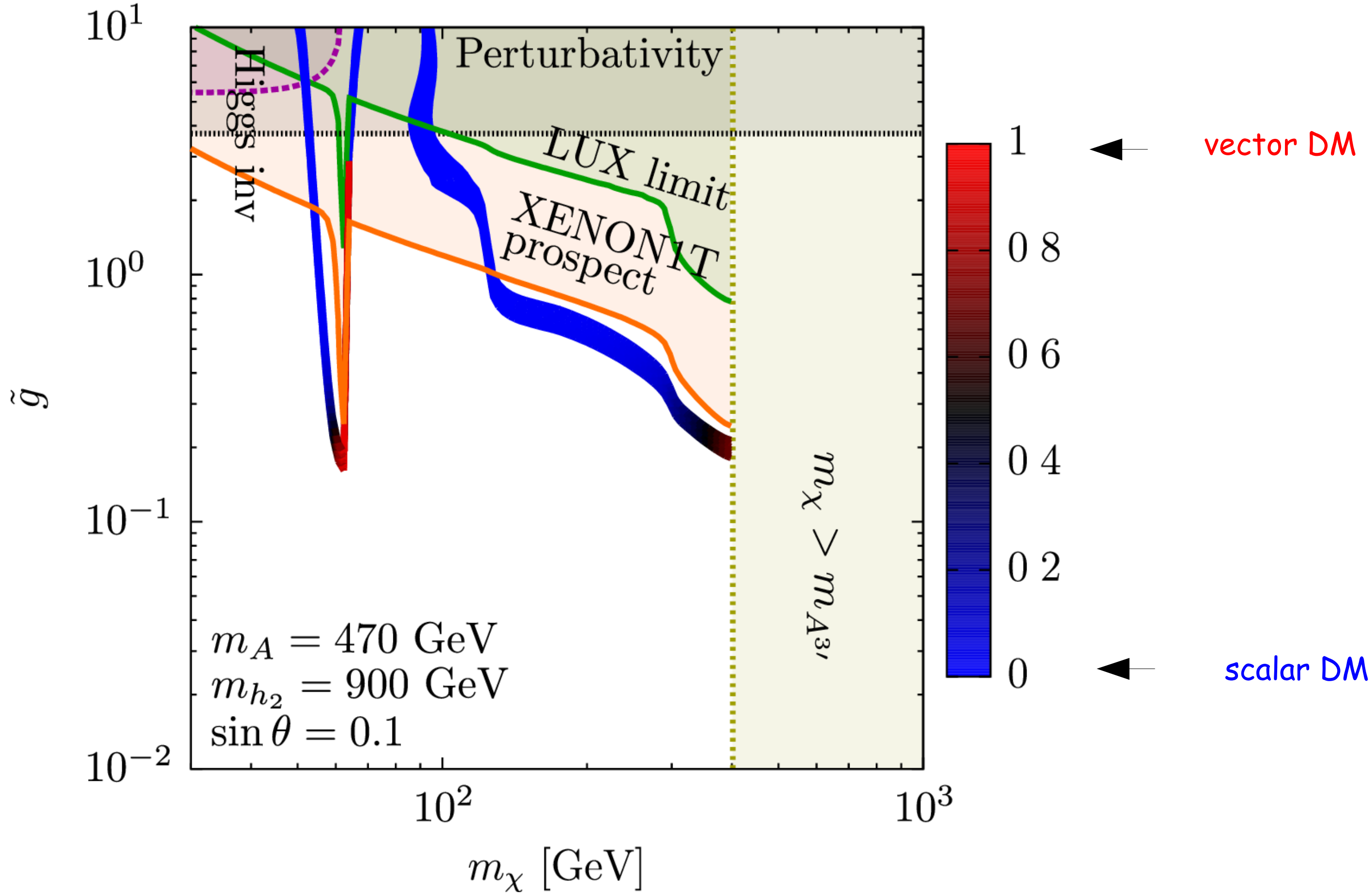
U(1)

sin θ = 0.3

mixed spin DM

SU(3)

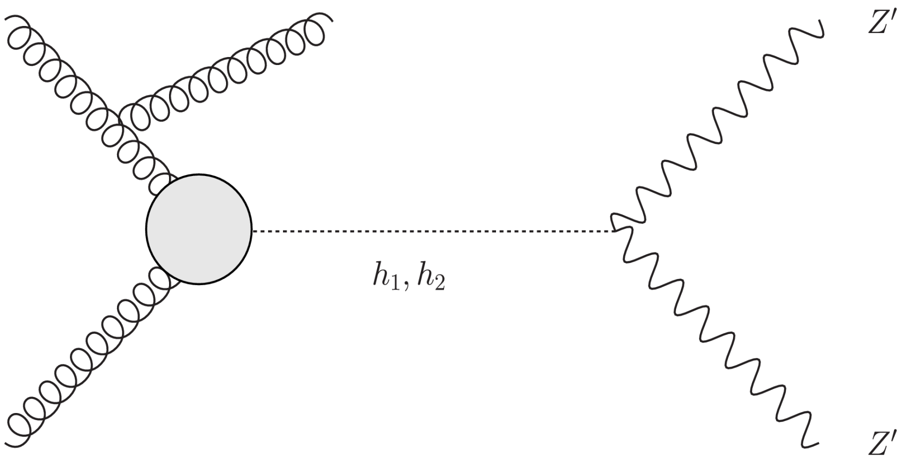
sin θ = 0.1



Kim, OL ,Schmeier '15

Higgsophilic gauge bosons at the LHC:

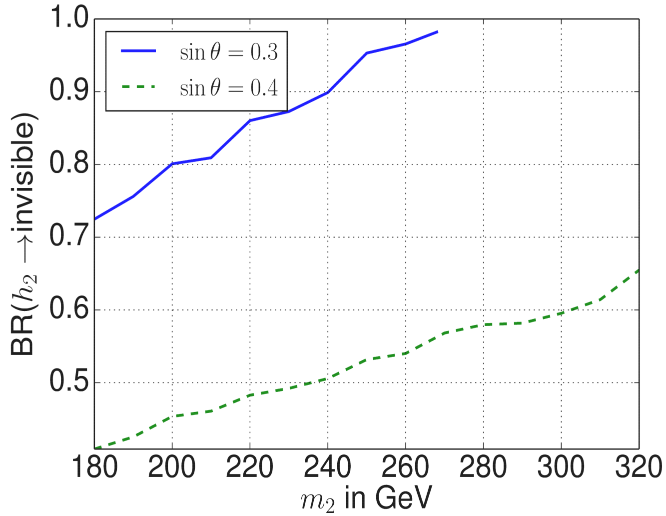
monojets (or VBF) + missing E_T

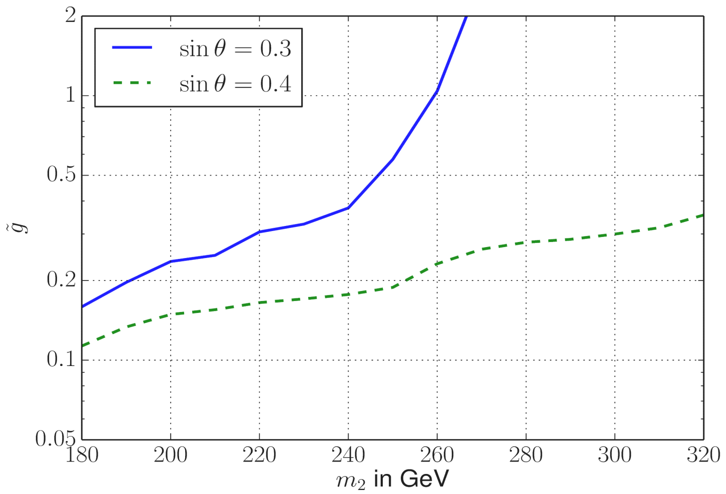


efficient for $m_2 > 2\, m_{Z'}$

Kim, OL ,Schmeier '15

Monojet results with 600 fb^{-1} :



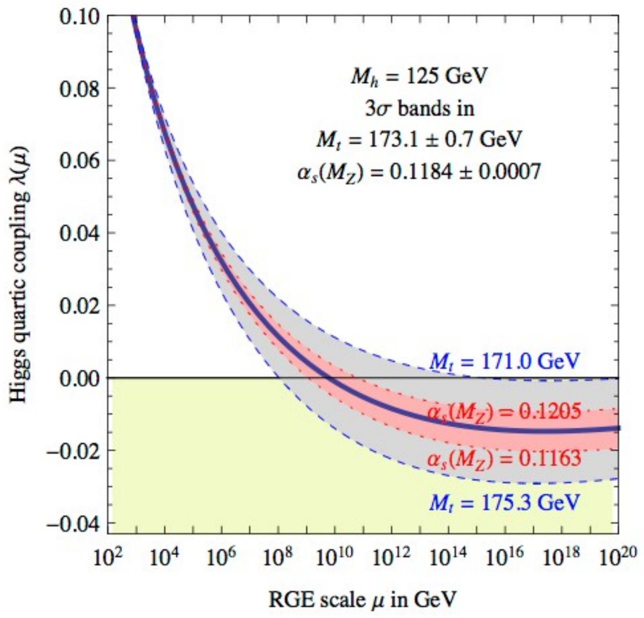


+ similar results for VBF with already 300 fb^{-1}

The Higgs and inflation

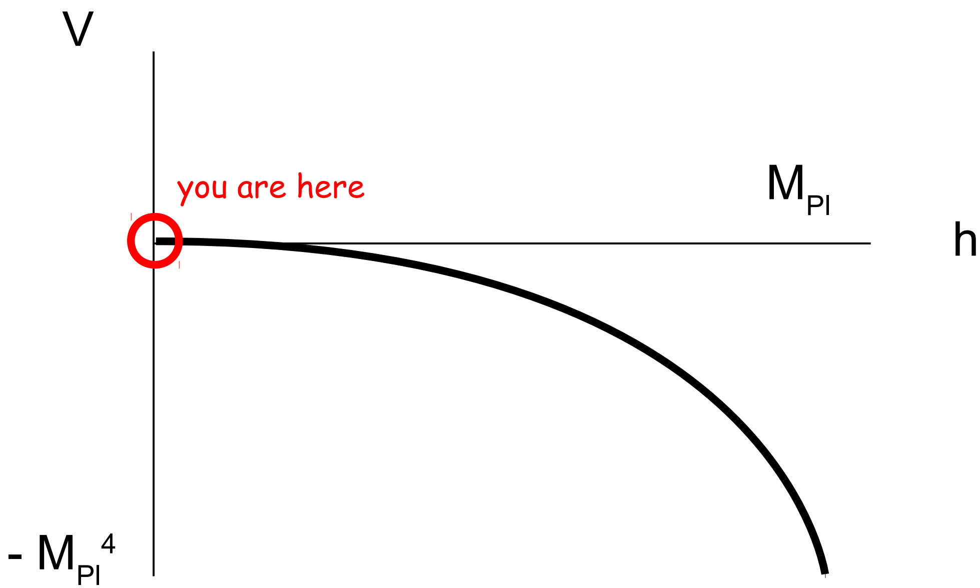
Buttazzo et al.'13

SM stability bound: $m_h > (129.6 \pm 1.5)$ GeV



(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 ~ 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 $\Delta V = \frac{1}{2} \lambda_{h\phi} h^2 \phi^2$ ("Higgs portal" coupling)

$\Delta V + V_{Higgs} > 0$ ⇒ $\phi_0 \sim 20\, M_{Pl}$, $\lambda_{h\phi} \sim 10^{-6}$

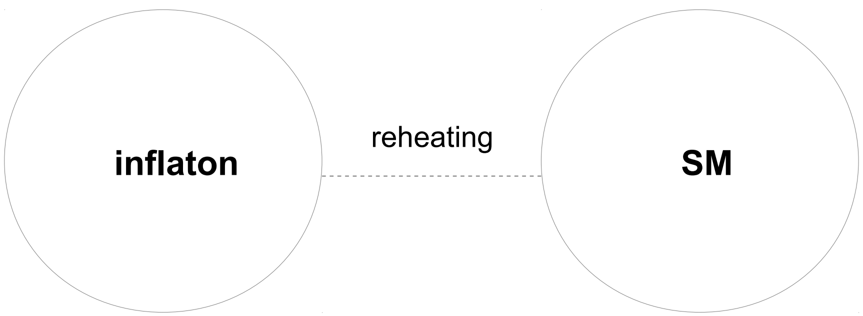
Large effective mass term ⇒ $h(t) \sim h(0) \exp(-3/2\, Ht)$

Higgs field is driven to zero during inflation !

Gross, OL, Zatta '15

The Higgs-inflaton coupling is

- generated radiatively
- required by renormalizability
- important if greater than $\mathbf{10^{-10}}$

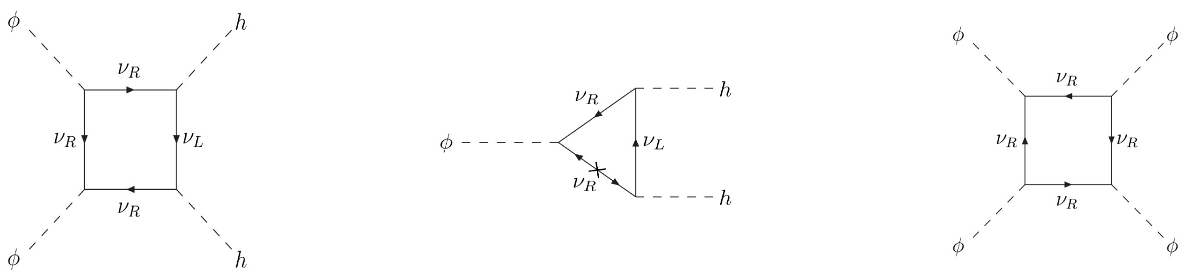


Gross, OL, Zatta '15

Example 1:

reheating through RH neutrinos

$$\Delta L = \lambda \, \phi \, \nu_R \, \nu_R$$



divergent, renormalize at M_{Pl} : $\lambda_i (M_{Pl})=0$

⇨ $\lambda_{h\phi}(H) < 2 \times 10^{-7}$

The Higgs-inflaton coupling is essential for the Higgs evolution

$$m_h^2 \sim \lambda_{h\phi}\, \phi^2 > H^2$$

Issues: Higgs behavior during preheating

Conclusion

- Higgs sector is special
- key to the hidden sector / DM / inflation
- need precise Higgs data