A Higgs Portal Update

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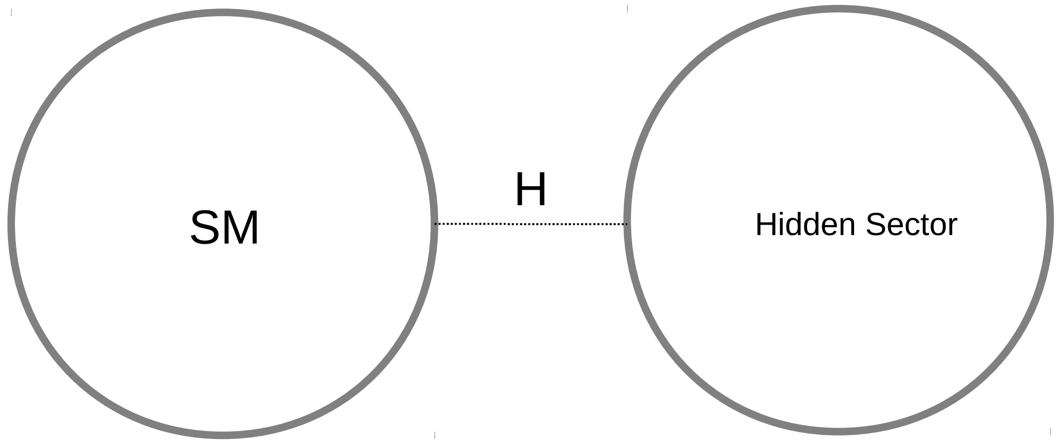
- the Higgs and the hidden sector

- 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

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

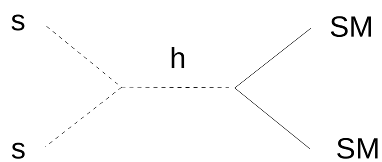
(S = "hidden" scalar)

b=0 (S has hidden charge):

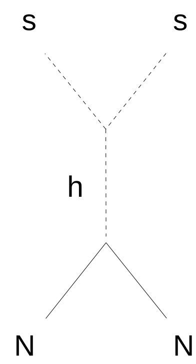
$$L = a\,|H|^2 S^2$$

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

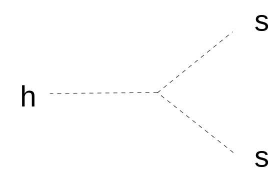
Dark matter:



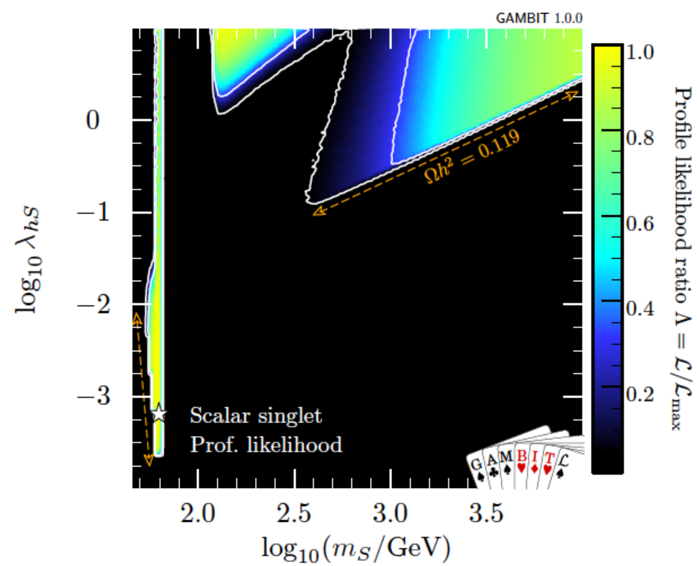
DM annihilation



DM direct detection



Higgs decay



GAMBIT collaboration
1705.07931

white contour = 2 σ bound

(Pseudo) Goldstone dark matter

Add a complex scalar *S* , require softly broken U(1) symmetry:

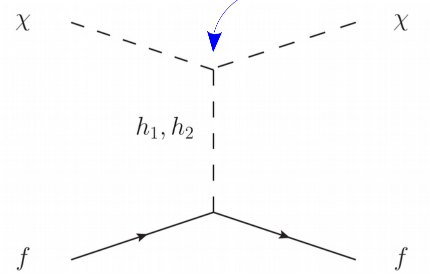
$$V = V_0 + V_{\rm soft} \; ,$$
$$V_0 = -\frac{\mu_H^2}{2} |H|^2 - \frac{\mu_S^2}{2} |S|^2 + \frac{\lambda_H}{2}|H|^4 + \lambda_{HS}|H|^2|S|^2 + \frac{\lambda_S}{2}|S|^4 \; ,$$
$$V_{\rm soft} = -\frac{\mu_S'^2}{4} S^2 + {\rm h.c.}$$

All parameters are real ⇨ $\langle S \rangle$ = real , $S \to S^*$ symmetry

Im S = Dark Matter ~ Goldstone boson

Direct detection:

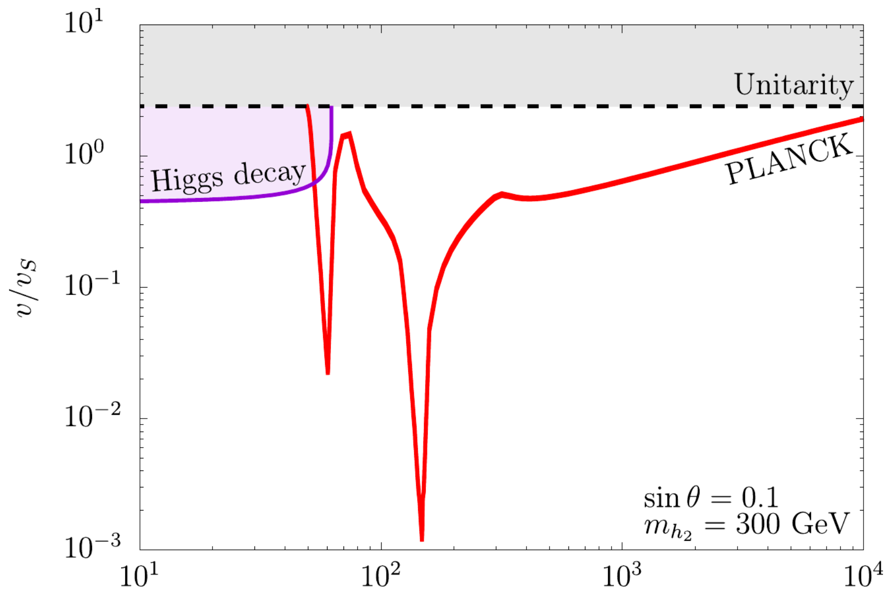
coupling$_i$ ~ m_i^2



Tree level:

$$\mathcal{A}_{dd}(t) \propto \sin\theta\cos\theta\left(\frac{m_2^2}{t-m_2^2} - \frac{m_1^2}{t-m_1^2}\right) \longrightarrow 0$$

Perfect cancellation for any parameter choice !



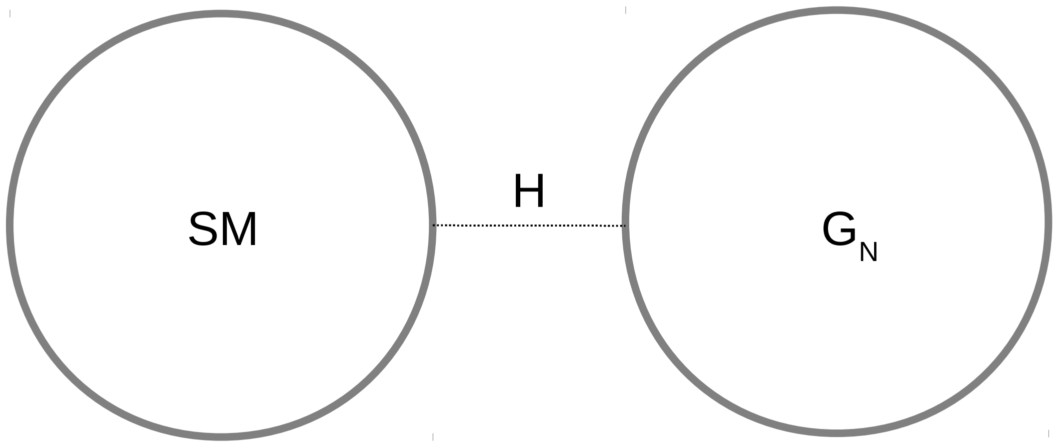
Direct detection = loop-suppressed

Annihilation = unsuppressed

Excellent WIMP

(from 60 GeV to 10 TeV)

The Higgs and "secluded" dark matter



$$V_{portal} \sim \bar{H} H \bar{S} S$$

Gross,OL, Mambrini '15

Minimal SU(N) breaking

⇓

automatic vector dark matter

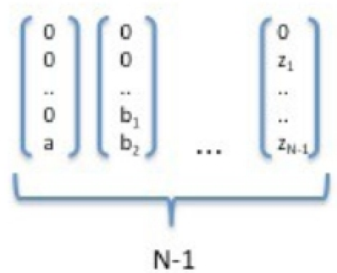
E.g. SU(2) gauge field DM

Hambye '08

Gross,OL, Mambrini '15

Minimal SU(N) Higgsing:

Need N-1 fundamentals, gauge them to



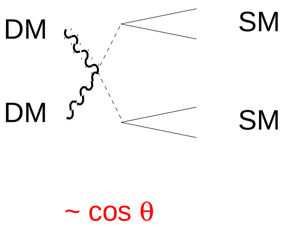
Unbroken symmetry: $U_1 = \textit{const} \;\times\; \mathrm{diag}(e^{iq}, 1, \ldots, 1)$

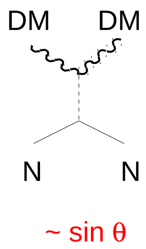
Lightest gauge fields transforming under U_1 are **stable**

For SU(3) and larger groups,

$$m_{DM} > m_{unstable}$$ if CP is broken

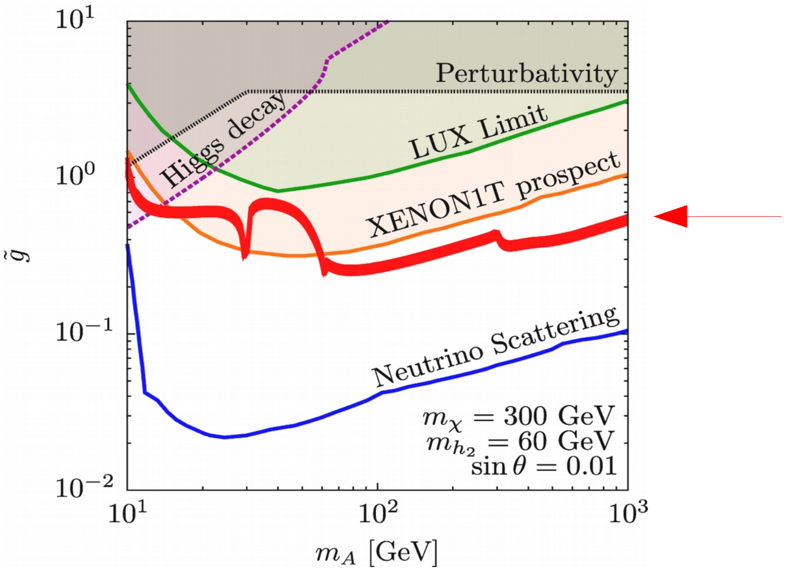
"secluded" DM *à la Pospelov et al.'07* (also Hambye' 08)





Arcadi, Gross, OL, Pokorski, Toma '16

SU(3):



- **DM annihilation efficient**
- **Direct detection suppressed**

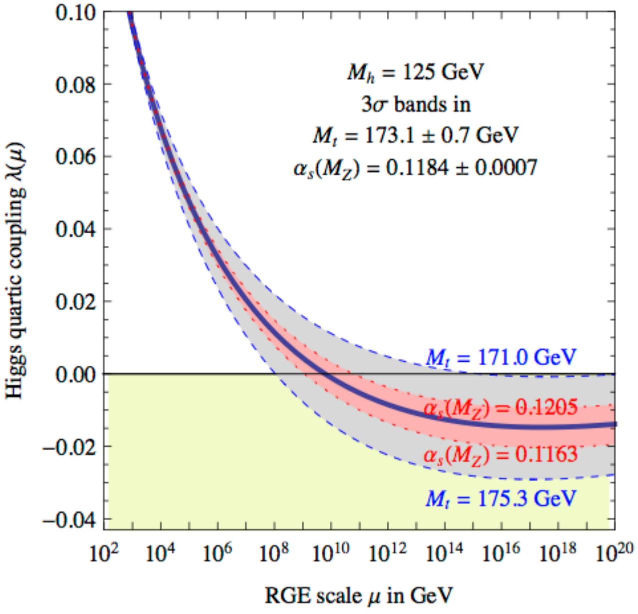
Higgs portal DM = viable WIMP

(especially if there's more than one state in the hidden sector)

The Higgs and inflation

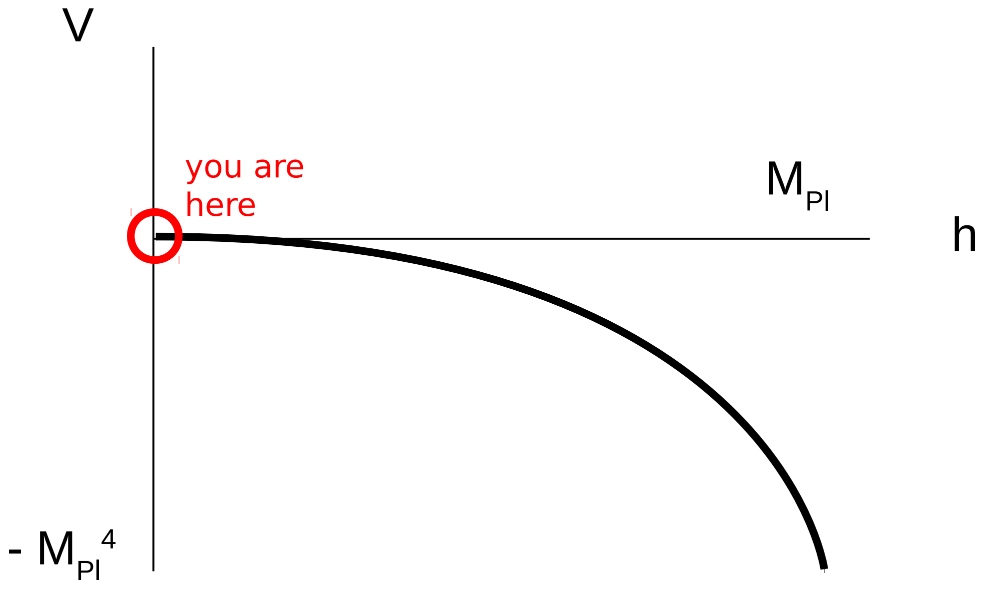
Buttazzo et al.'13

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



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

$h \gg \Lambda \sim 10^{10}$ 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

Ema, Karciauskas, OL, Rusak, Zatta '17

Vacuum stabilization via **Higgs-inflaton mixing**

Renormalizable Higgs–inflaton/gravity interactions:

$$-\mathcal{L}_{h\phi} = \lambda_{h\phi} H^\dagger H \phi^2 + 2\sigma H^\dagger H \phi \,,$$
$$-\mathcal{L}_{hR} = \xi_h H^\dagger H \hat{R} \,.$$

always leads to Higgs-inflaton mixing

Two mass eigenstates $h_{1,2}$ with mixing angle θ :

$$2\lambda_h v^2 \quad = \quad m_1^2 \cos^2\theta + m_2^2 \sin^2\theta$$

⇓

λ_h increases for $m_2 > m_1$!

The set-up :

$$S = \int d^4x \sqrt{-\hat{g}} \left[\frac{1}{2}\Omega^2 \hat{R} - \frac{1}{2}\hat{g}^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi - \frac{1}{2}\hat{g}^{\mu\nu}\partial_\mu h\,\partial_\nu h - V(\phi,h) \right]$$

$$\Omega^2 = 1 + \xi_\phi \phi^2 + \xi_h h^2 \,,$$

$$V(\phi,h) = \frac{\lambda_h}{4}h^4 - \frac{\mu_h^2}{2}h^2 + \frac{\lambda_{h\phi}}{2}h^2\phi^2 + \sigma h^2\phi + \frac{\lambda_\phi}{4}\phi^4 + \frac{b_3}{3}\phi^3 - \frac{\mu_\phi^2}{2}\phi^2 + b_1\phi \,,$$

Inflation is driven by ϕ with $\xi_\phi \gg 1$ (à la Bezrukov-Shaposhnikov) :

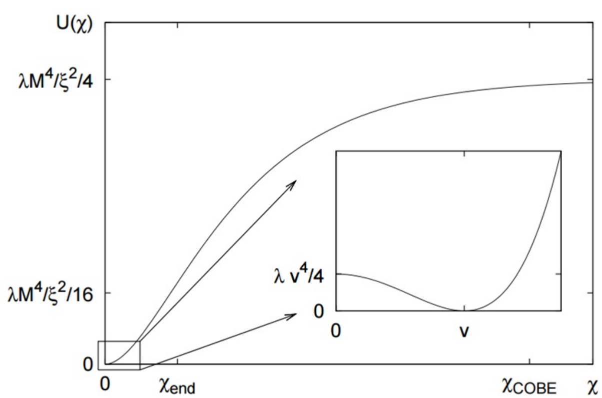


Fig. 1. Effective potential in the Einstein frame.

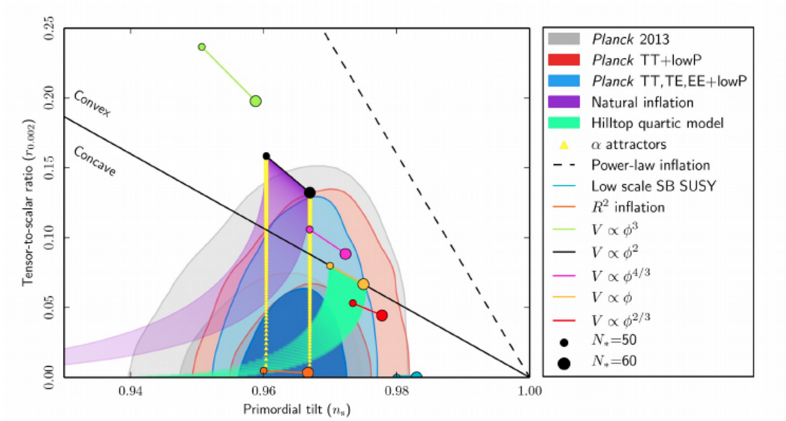


Fig. 12. Marginalized joint 68 % and 95 % CL regions for n_s and $r_{0.002}$ from *Planck* in combination with other data sets, compared to the theoretical predictions of selected inflationary models.

High energy constraints :

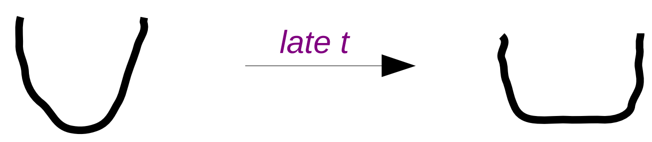
$\lambda_{\phi} < 10^{-5}$ ⇨ no unitarity issues

$\lambda_{h\phi} < 10^{-2}$ ⇨ no large rad. corrections

(also assume a single scale ⇨ TeV dimensionful parameters)

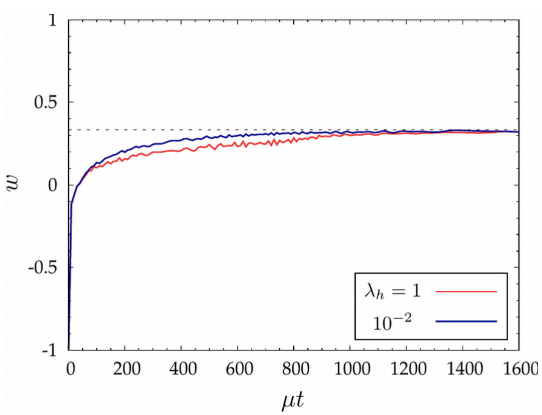
Preheating :

V_{inflaton} :

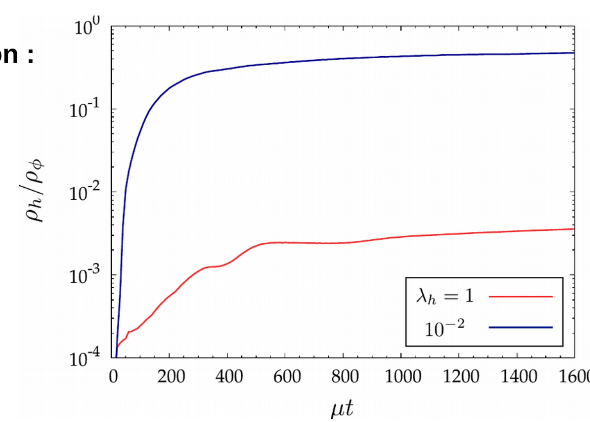


quadratic quartic

Equation of state:



Higgs production :

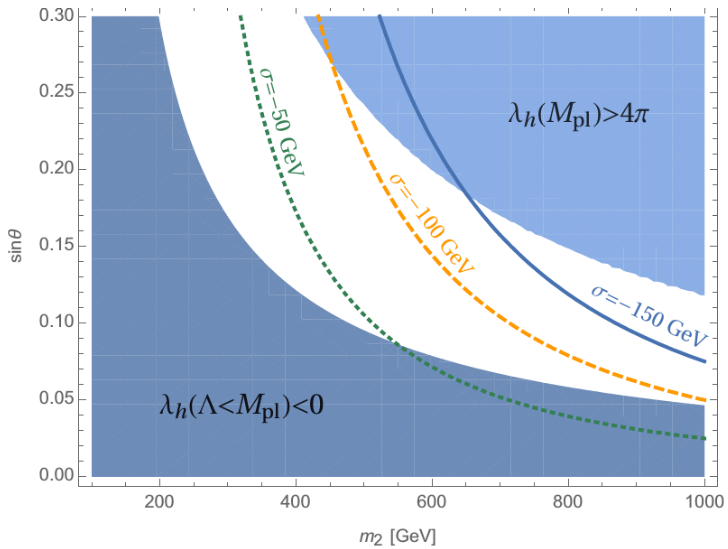


Reheating :

$\phi + \phi \rightarrow h + h$ ⇨ $T_{reh} > 10^{12}$ GeV

ϕ freezes-out and decays $\phi \rightarrow h + h$

Vacuum stability :



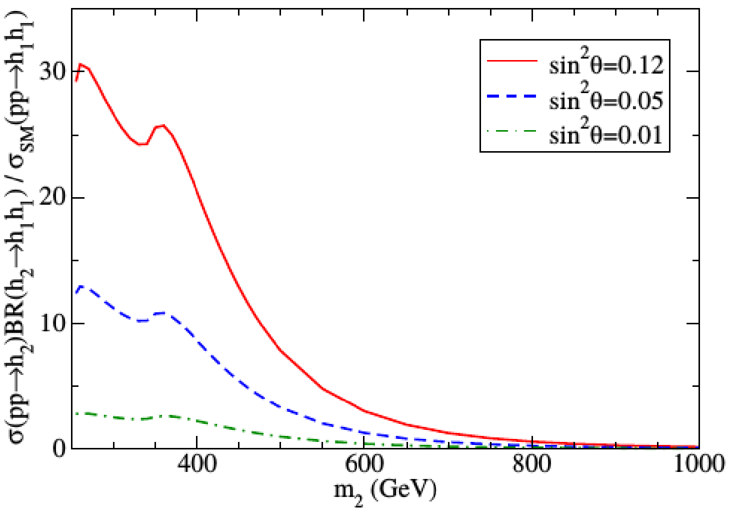
$$\sigma' v = \frac{\sin 2\theta}{4}\left(m_1^2 - m_2^2\right)$$

the trilinear interaction is crucial for the mixing

Inflaton search at LHC :

- Universal Higgs coupling reduction
- Heavy Higgs–like resonance
- Resonant decay $h_2 \rightarrow h_1 h_1$

Lewis, Sullivan '17



Conclusion

- Higgs portal WIMP DM is viable:
  - *Goldstone DM*
  - *Secluded DM*
- Higgs—inflaton mixing
  - *vacuum stability*
  - *inflaton at LHC*