Electroweak Vacuum Stability from extended Higgs portal Dark matter and type-I seesaw

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based on work: Purusottam Ghosh, Abhijit Kumar Saha and A.S.
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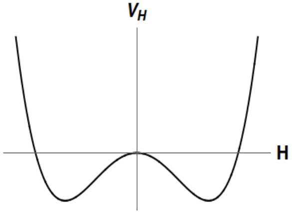
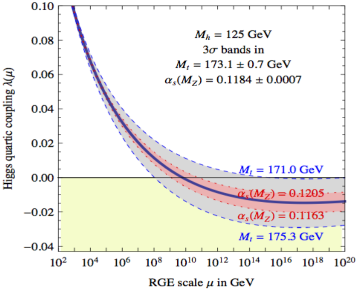


SM Higgs potential: $V(H)=\frac{\lambda_H}{4}(H^2-v^2)^2$,
where $\lambda_H = \frac{m_H^2}{2v^2}$.

One loop β function of λ_H:

$$\beta^{\rm SM}_{\lambda_H} = 24\lambda_H^2+\frac{3}{4}g_1^2g_2^2-3g_1^2\lambda_H+\frac{3}{8}g_1^4-9g_2^2\lambda_H+\frac{9}{8}g_2^4+12y_t^2\lambda_H-6y_t^4.$$



SM Higgs: $m_H \simeq 125$ GeV, $\lambda_H \sim 0.13$ and $y_t \sim 1$.

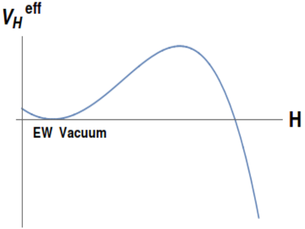
λ_H becomes negative at $\Lambda_I^{\rm SM}{\sim}10^{9-11}$ GeV ($m_t \simeq 172 - 174$ GeV)

$\lambda_H(M_P){\simeq}{-0.013}$ for $m_t{\simeq}173.2$ GeV.

Very sensitive to top mass (m_t).

G. Degrassi, S. Di Vita, J. Elias-Miro, J. R. Espinosa, G. F. Giudice, G. Isidori and A. Strumia, JHEP 1208 (2012)

- **RG improved effective potential at** $H \gg v$: $V_H^{\rm eff} = \frac{\lambda_H}{4} H^4 + \Delta V^{\rm 1\text{-}loop}$



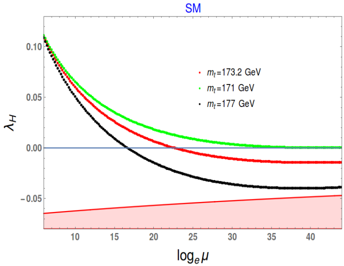
$V_H^{\rm eff} = \frac{\lambda_H^{\rm eff}}{4} H^4$

Coleman, Weinberg PRD 1888 (1973)

- EW minimum may not be the global one $\Rightarrow$ **Stability not ensured**.
- Tunneling probability: $\mathcal{P} = T_U^4 \mu_B^4 e^{-\frac{8\pi^2}{3|\lambda_H(\mu_B)|}}$,
  T_U: age of the universe. μ_B: the scale where $\beta_{\lambda_H}(\mu_B) = 0$.
  If $\mathcal{P} < 1 \Rightarrow \lambda_H(\mu_B) > \frac{-0.065}{1 - 0.01 \ln\left(\frac{v}{\mu_B}\right)}$; metastable otherwise instable.

G. Isidori, G. Ridolfi, A. Strumia Nucl. Phys. B 2001

Evolution of λ_H in SM:



EW vacuum is metastable!

Outlook

- So far we have not considered any new physics between $\Lambda_I^{\rm SM}$ and M_P.

  However we do need an extension of SM.
  - Neutrino mass,
  - Dark matter.

- **Q1. What happens to EW vacuum stability while considering the new physics related to neutrino and DM (seperately)**

  (i) SM + RH neutrinos via type-I seesaw

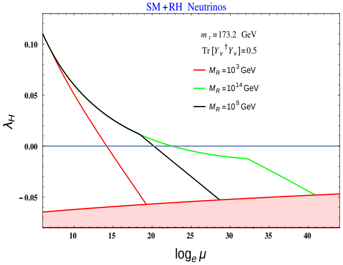
  $$\mathcal{L}_\nu = Y_\nu \bar{l}_L \tilde{H} N + \frac{1}{2} M_{N_{ij}} N_i N_j$$

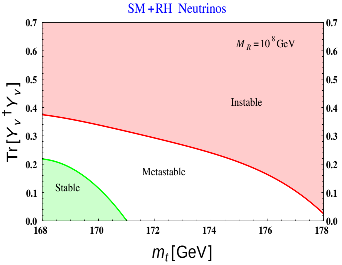
  For simplicity we consider $M_N = {\rm diag}\{M_R, M_R, M_R\}$. Light neutrino mass: $m_\nu = \frac{v^2 Y_\nu^T Y_\nu}{2M_R}$.

  For $\mu > M_R$:

  $$\beta_{\lambda_H} = \{\beta_{\lambda_H}^{SM} + 4\lambda_H {\rm Tr}[Y_\nu^\dagger Y_\nu] - 2{\rm Tr}[(Y_\nu^\dagger Y_\nu)^2]\}$$

- Presence of large Yukawa:
- Lighter M_R allows significant running:





S Khan, S Goswami, S. Roy PRD 2014; J.N. Ng, A de la Puente EPJC 2012;
M Lindner, H H. Patel, B Radovčić PRD 2016; L Rose, C Mazro, A Urbano 2015;

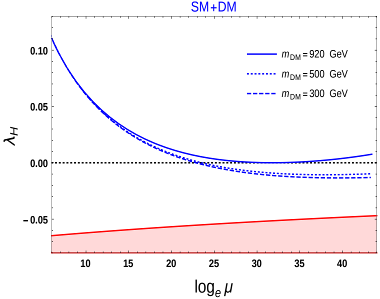
R Mohapatra, Y Zhang JHEP 2014.
J Chakrabortty, M Das, S Mohanty MP. A 2013; W Rodejohann, H Zhang JHEP 2012;
A Dutta, A Elsayed, S Khalil, A Moursy PRD 2013; A Kobakhidze, A S Smith JHEP 2013;

C Bonilla, Fonseca, Valle PLB 2016.

(ii) Effect of inclusion of scalar Higgs portal DM: ϕ, SM singlet scalar.

$$V_{\rm DM} = m_\phi^2 \phi^2 + \frac{\lambda_\phi}{4!}\phi^4 + \frac{\lambda_{\phi H}}{4}\phi^2 H^2$$

β **function:** $(\mu > m_{\rm DM})$ $\beta_{\lambda_H} = \beta_{\lambda_H}^{SM} + \{\frac{\lambda_{\phi H^2}}{2}\}$



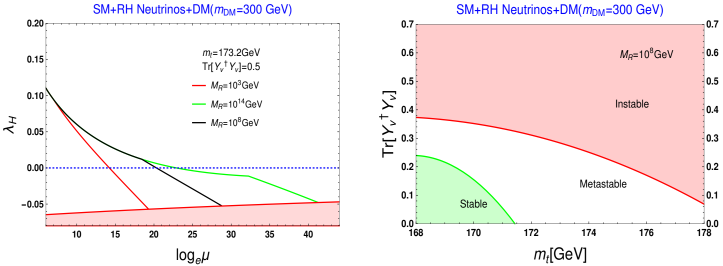
For $m_{\rm DM} > 920$ GeV, EW vacuum is stable with $m_t = 173.2$ GeV.

M Gonderinger et al JHEP 2010; A Eichhorn, M M. Scherer PRD 2014; N Khan, S Rakshit PRD 2014.

- $m_{\rm DM} < 500$ GeV is ruled out in context of present data. XENON Collaboration PRL 2017.

- **Q2. What if both DM and RH neutrinos are present!**

W Chao, M Gonderinger, M J R Musolf PRD 2012; I Garg, N Khan, S Goswami PRD 2018; C Chen, Y Tang JHEP 2012.



For $m_{\mathrm{DM}} = 300$ GeV, Not much improvement observed, EW vacuum is still unstable.

Our proposal

- **Aim:** Can we achieve absolute vacuum stability or metastability while incorporating light neutrino mass and DM ($m_{\rm DM} < 500$ GeV)?
- **Proposal**: [Extension of SM with three RH neutrinos + ϕ (as DM)] + χ (another singlet scalar with non-zero vev)

Interaction of ϕ with χ and H leads to rich DM phenomenology. ($m_{\rm DM} < 500$ GeV can be accomodated)

← $\langle\chi\rangle \neq 0$ →

EW vacuum stability can be improved through the threshold correction.

J Elias-Miroe et al JHEP 2012; O Lebedev EPJC 2012.

Symmetry imposed: SM gauge group $\times Z_2 \times Z_2'$. SM fields and N's transform trivially. ϕ and χ are singlet under SM gauge group.

Fields	Z_2	Z_2'
ϕ	-1	1
χ	1	-1

$$V_{\rm POT} = V_H + \left[\tfrac{1}{2}\mu_\phi^2\phi^2 + \tfrac{1}{4!}\lambda_\phi\phi^4 + \tfrac{1}{2}\lambda_{\phi H}\phi^2 H^\dagger H\right] + \left[-\tfrac{1}{2}\mu_\chi^2\chi^2 + \tfrac{\lambda_\chi}{4!}\chi^4 + \tfrac{\lambda_{\chi H}}{2}\chi^2|H|^2\right] + \tfrac{1}{4}\lambda_{\chi\phi}\phi^2\chi^2.$$

$$-\mathcal{L}_\nu = Y_{\nu_{ij}}\bar{l}_{L_i}\tilde{H}N_j + \tfrac{1}{2}M_{N_{ij}}N_iN_j.$$

$Z_2 \times Z_2'$ forbids linear term of χ and ϕ in $V_{\rm POT}$.

Mixing between H and χ characterised by angle θ

$$\tan 2\theta = \frac{\lambda_{\chi H} v v_\chi}{-\lambda_H v^2 + \frac{\lambda_\chi v_\chi^2}{6}}$$

$$H_1 = H^0\cos\theta - \chi\sin\theta$$

$$H_2 = H^0\sin\theta + \chi\cos\theta.$$

$$\lambda_H = \frac{m_{H_1}^2}{2v^2}\cos^2\theta + \frac{m_{H_2}^2}{2v^2}\sin^2\theta,$$

$$\lambda_\chi = \frac{3m_{H_1}^2}{v_\chi^2}\sin^2\theta + \frac{3m_{H_2}^2}{v_\chi^2}\cos^2\theta,$$

$$\lambda_{\chi H} = \sin 2\theta\left(\frac{m_{H_2}^2 - m_{H_1}^2}{2vv_\chi}\right).$$

Mass of the physical fields:

$$m_{\rm DM}^2 = \mu_\phi^2 + \tfrac{1}{2}\lambda_{\chi H}v^2 + \tfrac{1}{2}\lambda_{\chi\phi}v_\chi^2,$$

$$m_{H_1}^2 = \frac{\lambda_\chi}{6}v_\chi^2(1-\sec 2\theta) + \lambda_H v^2(1+\sec 2\theta),$$

$$m_{H_2}^2 = \frac{\lambda_\chi}{6}v_\chi^2(1+\sec 2\theta) + \lambda_H v^2(1-\sec 2\theta).$$

$v_\chi \neq 0 \Rightarrow Z_2 \times Z_2' \to Z_2$. Remnant Z_2 stabilizes the DM.

Constraints on the model

- Theoretical Constraints:
  - **Copositivity criteria:** Conditions for stability of the entire scalar potential: J. Chakrabortty, P. Konar and T. Mondal, PRD 2014

$$\mathbf{ST}_{1,2,3}\textbf{:}\ \lambda_H>0,\quad \lambda_\chi>0,\quad \lambda_\phi>0$$

$$\mathbf{ST}_{4,5,6}\textbf{:}\ \lambda_{\chi H}+\sqrt{\tfrac{2}{3}\lambda_H\lambda_\chi}>0,\quad \lambda_{\phi H}+\sqrt{\tfrac{2}{3}\lambda_H\lambda_\phi}>0,\quad 3\lambda_{\chi\phi}+\sqrt{\lambda_\chi\lambda_\phi}>0$$

$$\mathbf{ST}_{7}\textbf{:}\ \sqrt{\lambda_H\lambda_\chi\lambda_\phi}+\lambda_{\chi H}\sqrt{\tfrac{3}{2}\lambda_\chi}+3\lambda_{\phi H}\sqrt{\lambda_H}+3\lambda_{\chi\phi}\sqrt{\lambda_H}+ 3\left[\left(\lambda_{\chi H}+\sqrt{\tfrac{2}{3}\lambda_H\lambda_\chi}\right)\left(\lambda_{\phi H}+\sqrt{\tfrac{2}{3}\lambda_H\lambda_\phi}\right)\left(\lambda_{\chi\phi}+\tfrac{1}{3}\sqrt{\lambda_\phi\lambda_\chi}\right)\right]^{1/2}>0$$

  - **Perturbative Unitarity:**
    $2\rightarrow 2$ scattering amplitude for eleven neutral combination of two paricle states and four singly charged two particle states is bounded by $|\mathcal{M}|<8\pi$. J. Horejsi and M. Kladiva, EPJC (2006)

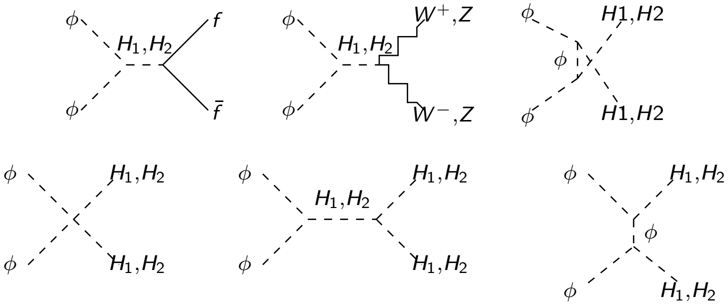
    This provides,

    $\lambda_H<4\pi,\quad \lambda_{\phi H}<8\pi,\quad \lambda_{\chi H}<8\pi,\quad \lambda_{\chi\phi}<8\pi$ and $x_{1,2,3}<16\pi$ where x_i are the combinations of other quartic couplings.

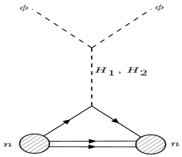
Constraints on the model contd.

- **Perturbativity of the couplings:** $\lambda_H < \frac{2}{3}\pi$, $\lambda_\chi, \lambda_\phi, \lambda_{\chi H}, \lambda_{\phi H}, \lambda_{\chi\phi} < 4\pi$.
- **Experimental constraints:**
  - Measured Higgs signal strength at LHC gives constraint on $\sin\theta \lesssim 0.36$.
  - For $m_{H_2} <$ 250 GeV Higgs searches at LHC provides stronger bound on $\sin\theta$. T. Robens and T. Stefaniak, EPJC 2016.
  - For 250 GeV $\leq m_{H_2} <$ 800 singlet induced W boson mass correction restricts $\sin\theta$ more. D. Lpez-Val and T. Robens, PRD 2014.
  - DM relic density and direct detection constraints will be applicable.
  - Lepton flavor violating decays will restrict the RH neutrino mass and neutrino Yukawa coupling as well.

Dominant anhilation channels of DM:



Direct detection DM and nucleon scattering:



Choice of parameters

- We have the following parameters in our set-up,

$$\{m_{H_2}, m_{\rm DM}, \sin\theta, \lambda_{\chi\phi}, \lambda_{\phi H}, \tan\beta, \lambda_\phi\}.$$

  - First we fix mass of heavy higgs, m_{H_2}=300 GeV. Then strongest upper limit on $\sin\theta \lesssim 0.3$ comes from W mass correction. We take $\sin\theta \sim 0.2$.
  - Once we fix m_{H_2}, $\lambda_\chi < 1$ demands $v_\chi > 620$ GeV. We chose $v_\chi = 800$ GeV $\Rightarrow \tan\beta = \frac{v}{v_\chi} \sim 0.301$.

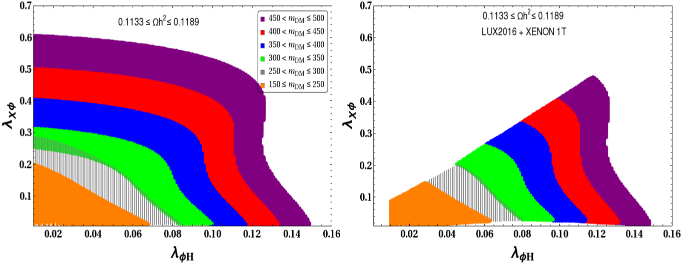
Note: $\lambda_H,\ \lambda_\chi,\ \lambda_{\chi H}$ are function of only $m_{H_2},\ v_\chi$ and $\sin\theta$.

- Hence DM analysis effectively depends on:

$$\{m_{\rm DM}, \lambda_{\chi\phi}, \lambda_{\phi H}\}.$$

DM phenomenology:

Benchmark points: $m_{H_2} = 300$ GeV, $v_\chi = 800$ GeV, $\sin\theta = 0.2$.



Note: DM $<$ 500 GeV is allowed.

When $\lambda_{\chi\phi} \gg \lambda_{\phi H}$ the channels with Higgses in the final states contribute dominantly.

For low values of $\lambda_{\chi\phi}$, the model resembles the usual Higgs portal dark matter scenario.

DM phenomenology contd.

- **Main anhilation channels at different mass ranges of DM:**

Mass range	Active processes
150 $\mathbf{GeV}$ < $m_{\rm DM}$ < 212.5 $\mathbf{GeV}$	$\phi\phi \to$ SM,SM
212.5 $\mathbf{GeV}$ < $m_{\rm DM}$ < 300 $\mathbf{GeV}$	$\phi\phi \to$ SM,SM $\phi\phi \to H_1 H_2$
300 $\mathbf{GeV}$ < $m_{\rm DM}$ < 500 $\mathbf{GeV}$	$\phi\phi \to$ SM,SM $\phi\phi \to H_1 H_2$ $\phi\phi \to H_2 H_2$

Neutrino parameters and Type I Seeasaw

- **Evaluation of Tr$[Y_\nu^\dagger Y_\nu]$:**
  Let us assume RH neutrino mass matrix as diagonal with uniform entry M_R. Hence type I seesaw: $m_\nu = Y_\nu^T Y_\nu \frac{v^2}{2M_R}$.

  $$Y_\nu = \sqrt{2}\frac{\sqrt{M_R}}{v}\mathcal{R}\sqrt{m_\nu^d}\ U_{\rm PMNS}^\dagger.$$ J. A. Casas and A. Ibarra, Nucl. Phys. B 2001.

  Where $\mathcal{R} = O\exp(i\mathcal{A})$, $\mathcal{R}$: complex orthogonal matrix,

  O: real orthogonal matrix,

  $\mathcal{A}$: real antisymmetric matrix. Say $\mathcal{A}=\begin{pmatrix} 0 & a & a \\ -a & -0 & a \\ -a & -a & 0 \end{pmatrix}$.

  W. Rodejohann and H. Zhang, JHEP 2012.

- Therefore,

  $$\mathrm{Tr}[Y_\nu^\dagger Y_\nu] = \frac{2M_R}{v^2}\mathrm{Tr}\left[\sqrt{m_\nu^d}e^{2i\mathcal{A}}\sqrt{m_\nu^d}\right].$$

  example: for $M_R = 10^3$ GeV and $a = 8.1$, Tr$[Y_\nu^\dagger Y_\nu] \simeq 1$.

  Note: $\mathcal{A}$ does not appear in m_ν

- β **functions:** $(\mu > M_R)$

$$\beta_{\lambda_H}=\beta^{SM}_{\lambda_H}+\left\{4\lambda_H\mathrm{Tr}[Y_\nu^\dagger Y_\nu]-2\mathrm{Tr}[(Y_\nu^\dagger Y_\nu)^2]+\frac{\lambda^2_{\phi H}}{2}+\frac{\lambda^2_{\chi H}}{2}\right\}.$$

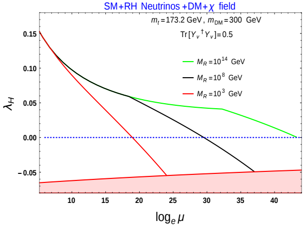
With large a, one can safely assume $\mathrm{Tr}[(Y_\nu^\dagger Y_\nu)^2] \simeq \mathrm{Tr}[Y_\nu^\dagger Y_\nu]^2$.

- Initial values of the relevant SM couplings ($\alpha_S = 0.1184$, $m_{H_1} = 125.09$ GeV and $m_t = 173.2$ GeV):

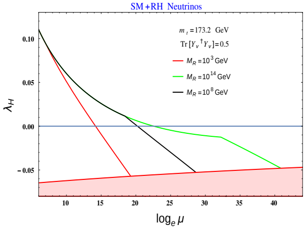
Scale	y_t	g_1	g_2	g_3	λ_H
$\mu = m_t$	0.93610	0.357606	0.648216	1.16655	0.125932

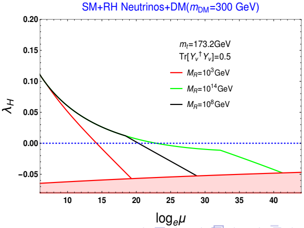
D. Buttazzo, G. Degrassi, P. P. Giardino, G. F. Giudice, F. Sala, A. Salvio and A. Strumia, JHEP 2013.

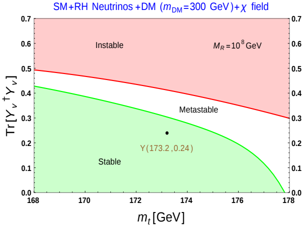
Benchmark points: $\sin\theta = 0.2$, $m_{H_2} = 300\text{GeV}$ $v_\chi = 800\ \text{GeV}$, $m_{\text{DM}} = 300\text{GeV}$, $\lambda_{\phi_H} = 0.06$, $\lambda_{\chi\phi} = 0.135$



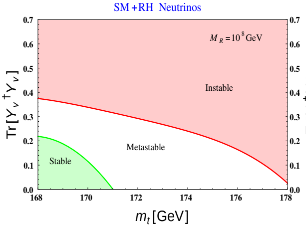
Comparison with cases without χ field!!!!.

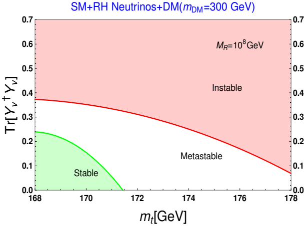






Comparison with cases without χ field!!!!.





Stability region increases significantly in presence of χ field

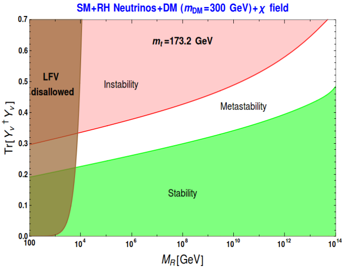
Connection with other observable

The branching ratio of $\mu \to e\gamma$ decay process: A. Ilakovac and A. Pilaftsis, Nucl. Phys. B 437, 491 (1995).

$$\mathrm{Br}(\mu\to e\gamma)=\frac{3\alpha_e v^4}{16\pi M_R^4}|Y_{\nu_{ei}}^\dagger Y_{\nu_{i\mu}} f(x_i)|^2,$$

where $\alpha_e = \frac{e^2}{4\pi}$, the fine sructure constant, i=1-3, $x = \frac{M_R^2}{m_W^2}$ and $f(x)=\frac{x\left(2x^3+3x^2-6x-6x^2\ln x+1\right)}{2(1-x)^4}$. **Present limit:** $\mathrm{Br}(\mu\to e\gamma)<5.7\times10^{-13}$.

K. A. Olive et al. [Particle Data Group], Chin. Phys. C 38, 090001 (2014).



Conclusions

- Presence of χ field ensures that $m_{\mathrm{DM}<500}$ GeV is allowed.
- The non-zero mixing angle between ϕ and χ can make the EW vacuum stable till M_P even with large Y_ν.
- LFV: $\mathrm{Br}(\mu \to e\gamma)$ gives strong constarint for $M_R < 10^4$ GeV.

Thank you

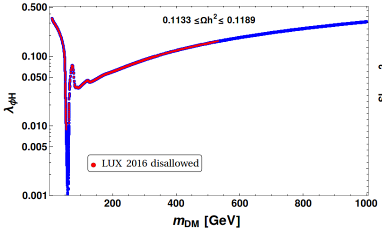
Backup Slides:Singlet scalar DM

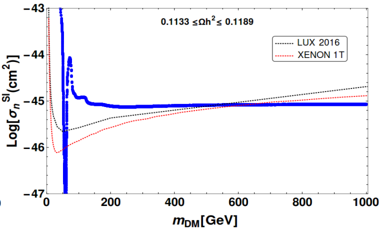
- Higgs portal DM: $V(\phi, H) = \frac{\lambda_{\phi H}}{4}\phi^2 H^2$.

  V. Silveira and A. Zee, Phys. Lett. 161B, 136 (1985).

  Anhilation process: $\phi\phi \rightarrow \mathrm{SM}, \mathrm{SM}$.

  $\Omega_{\rm CDM} h^2 = 0.1186 \pm 0.0020$ P. A. R. Ade et al. [Planck Collaboration] (2014)





- $m_{\rm DM} \lesssim 500$ GeV is ruled out by XENON 1T direct detection cross section bound. E. Aprile et al. [XENON Collaboration]

$H_1 f\bar{f},\ H_2 f\bar{f}\ :\ \frac{m_f}{v}\cos\theta, \frac{m_f}{v}\sin\theta;\quad H_1 ZZ,\ H_2 ZZ\ :\ \frac{2m_Z^2}{v}\cos\theta g^{\mu\nu}, \frac{2m_Z^2}{v}\sin\theta g^{\mu\nu}$

$H_1 W^+W^-,\ H_2 W^+W^-\ :\ \frac{2m_W^2}{v}\cos\theta g^{\mu\nu}, \frac{2m_W^2}{v}\sin\theta g^{\mu\nu},$

$\phi\phi H_1\ :\ -v_\chi\lambda_{\chi\phi}\sin\theta + v\lambda_{\phi H}\cos\theta \equiv \lambda_1;\quad \phi\phi H_2\ :\ v_\chi\lambda_{\chi\phi}\cos\theta + v\lambda_{\phi H}\sin\theta \equiv \lambda_2,$

$\phi\phi H_1 H_1\ :\ \lambda_{\phi H}\cos^2\theta + \lambda_{\chi\phi}\sin^2\theta;\quad \phi\phi H_2 H_2\ :\ (\lambda_{\phi H} - \lambda_{\chi\phi})\sin\theta\cos\theta,$

$\phi\phi H_1 H_2\ :\ (\lambda_{\phi H} - \lambda_{\chi\phi})\sin\theta\cos\theta,$

$H_1 H_1 H_1\ :\ [6v\lambda_H\cos^3\theta - 3v_\chi\lambda_{\chi H}\cos^2\theta\sin\theta + 3v\lambda_{\chi H}\cos\theta\sin^2\theta - v_\chi\lambda_\chi\sin^3\theta],$

$H_2 H_2 H_2\ :\ [6v\lambda_H\sin^3\theta + 3v_\chi\lambda_{\chi H}\cos\theta\sin^2\theta + 3v\lambda_{\chi H}\cos^2\theta\sin\theta + v_\chi\lambda_\chi\cos^3\theta],$

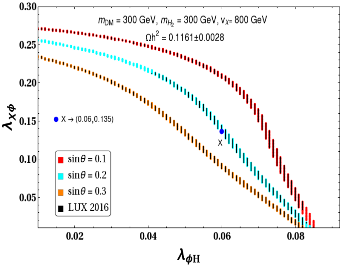
$H_1 H_1 H_2\ :\ [2v(3\lambda_H - \lambda_{\chi H})\cos^2\theta\sin\theta + v\lambda_{\chi H}\sin^3\theta + v_\chi(\lambda_\chi - 2\lambda_{\chi H})\cos\theta\sin^2\theta + v_\chi\lambda_{\chi H}\cos^3\theta],$

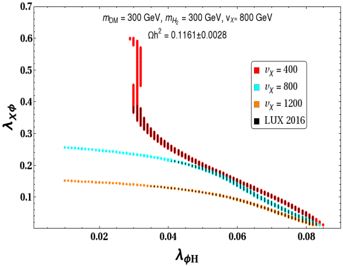
$H_1 H_2 H_2\ :\ [2v(3\lambda_H - \lambda_{\chi H})\cos\theta\sin^2\theta + v\lambda_{\chi H}\cos^3\theta - v_\chi(\lambda_\chi - 2\lambda_{\chi H})\cos^2\theta\sin\theta - v_\chi\lambda_{\chi H}\sin^3\theta].$

Direct detection cross section:

$$\sigma_n^{SI} = \frac{f_n^2\mu_n^2 m_n^2}{4\pi v^2 m_{\rm DM}^2}\left[\frac{\lambda_1\cos\theta}{m_{H_1}^2} + \frac{\lambda_2\sin\theta}{m_{H_2}^2}\right]^2;\quad \mu_n = \frac{m_n m_{\rm DM}}{m_n + m_{\rm DM}},\ f_n = 0.284.$$

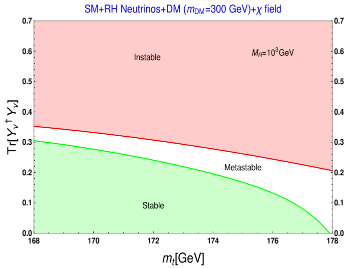
Backup slides, DM analysis for different benchmark points:

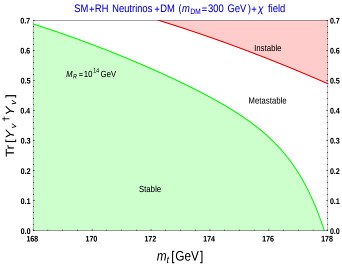




Benchmark points:

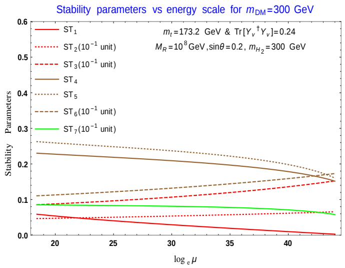
$\sin\theta = 0.2$, $m_{H_2} = 300\text{GeV}$ $v_\chi = 800$ GeV, $m_{\rm DM} = 300\text{GeV}$, $\lambda_{\phi_H} = 0.06$, $\lambda_{\chi\phi} = 0.135$

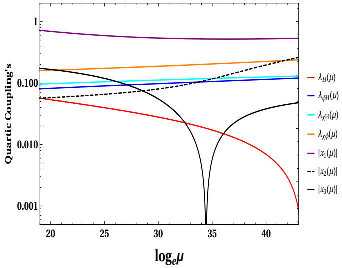




Benchmark points:

$\sin\theta = 0.2$, $m_{H_2} = 300\text{GeV}$ $v_\chi = 800$ GeV, $m_{\text{DM}} = 300\text{GeV}$, $\lambda_{\phi_H} = 0.06$, $\lambda_{\chi\phi} = 0.135$, $Tr[Y_\nu^\dagger Y_\nu] \simeq 0.24$, $M_R = 10^8$ GeV, $m_t = 173.2$ GeV.





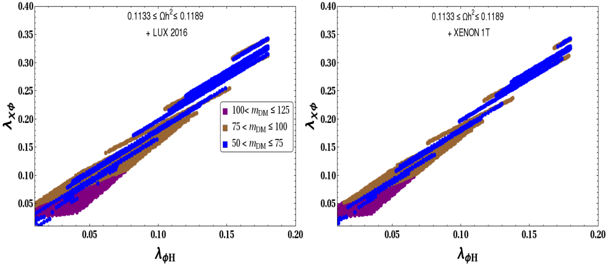
Perturbative unitarity constraints

Perturbativity unitarity conditions:

$\lambda_H < 4\pi, \quad \lambda_{\phi H} < 8\pi, \quad \lambda_{\chi H} < 8\pi, \quad \lambda_{\chi\phi} < 8\pi \quad \text{and} \quad x_{1,2,3} < 16\pi$. where

$$x^3 + x^2(-12\lambda_H - \lambda\chi - \lambda\phi) + x\left(12\lambda_H\lambda_\chi + 12\lambda_H\lambda_\phi - 4\lambda^2_{\chi H} - \lambda^2_{\chi_\phi} + \lambda_\chi\lambda_\phi - 4\lambda^2_{\phi H}\right)$$
$$+12\lambda_H\lambda^2_{\chi\phi} - 12\lambda_H\lambda_\chi\lambda_\phi + 4\lambda^2_{\chi H}\lambda_\phi + 4\lambda_\chi\lambda^2_{\phi H} - 8\lambda_{\chi H}\lambda_{\chi\phi}\lambda_{\phi H} = 0$$

- In this mass range of DM only $\phi\phi \to {\rm SM,SM}$ process is present.



- Benchmark points: $m_{H_2} = 300$ GeV, $v_\chi = 800$ GeV, $\sin\theta = 0.2$.