

# Invisible Higgs and Dark Matter – A Technicolor inspired scenario

Matti Heikinheimo

Department of Physics and Astronomy, York University and LAPTh, Annecy

GDR Terascale meeting, Clermont, April 2012

# Contents

1 Introduction

2 The Model

3 Results

# Invisible Higgs

- If the Higgs boson is not found<sup>1</sup> in the usual searches for  $b\bar{b}$ ,  $\gamma\gamma$ ,  $WW$ ,  $ZZ$  etc., it does not necessarily mean it's not there.
- The production cross section could be suppressed, mainly by suppressing the loop-induced coupling to gluons.
- Or the branching ratios of the decay channels that are searched for could be suppressed.

---

<sup>1</sup>It has **not** been found yet!

# $H \rightarrow$ Invisible

- A presence of an invisible decay channel with a large width can suppress the branching ratios of the visible decay channels.
- This can be achieved by introducing a new, stable, weakly interacting particle  $\chi$  with mass  $m_b \ll m_\chi < \frac{1}{2}m_H < m_W$ .
- This particle is a WIMP (weakly interacting massive particle) DM-candidate by construction.
- $\chi$  could be a boson<sup>2</sup> or a fermion<sup>3</sup>.

---

<sup>2</sup>see e.g. M. Raidal and A. Strumia, arXiv:1108.4903 [hep-ph], Y. Mambrini, arXiv:1112.0011 [hep-ph], X. G. He and J. Tandean, arXiv:1109.1277 [hep-ph], I. Low et.al., arXiv:1110.4405 [hep-ph].

<sup>3</sup>O. Lebedev et.al., arXiv:1111.4482 [hep-ph], S. Baek et.al., arXiv:1112.1847 [hep-ph]

# MWT

- A particle like  $\chi$  is naturally present in the Minimal Walking Technicolor (MWT) model.
- The model contains two flavors of techniquarks in the adjoint representation of  $SU(2)_{TC}$ .
- This introduces a global anomaly, which must be cancelled by introducing a new weak doublet.
- A natural solution is to add a fourth generation of SM-like leptons.
- The 4th generation neutrino must be heavier than  $\frac{1}{2}m_Z$  to not affect the invisible decay width of the  $Z$ .
- This neutrino is then a natural candidate to play the role of  $\chi^4$ .

---

<sup>4</sup>For previous work on  $H \rightarrow$  heavy neutrinos see e.g. R. E. Shrock and M Suzuki, Phys. Lett. B 110, K. Belotsky et.al., arXiv:hep-ph/0210153, W. Y. Keung and Schwaller, arXiv:1103.3765 [hep-ph]

# Contents

1 Introduction

2 The Model

3 Results

# The Model

The lepton mass Lagrangian:

$$\begin{aligned}\mathcal{L}'_{\text{Mass}} = & (y \bar{L}_L H E_R + \text{h.c.}) + C_D \bar{L}_L \tilde{H} N_R \\ & + \frac{C_L}{\Lambda} (\bar{L}^c \tilde{H})(\tilde{H}^T L) + \frac{C_R}{\Lambda} (H^\dagger H) \bar{N}_R^c N_R + \text{h.c.} \quad (1)\end{aligned}$$

Leads to the neutrino mass term:

$$-\frac{1}{2} \bar{n}_L^c \begin{pmatrix} M_L & m_D \\ m_D & M_R \end{pmatrix} n_L + \text{h.c.} \quad (2)$$

where  $n_L = (N_L, N_R^c)^T$ ,  $m_D = C_D v / \sqrt{2}$  and  
 $M_{L,R} = C_{L,R} v^2 / 2\Lambda$

# Neutrino masses

- The neutrino mass-eigenstates are two Majorana neutrinos, with mass eigenvalues

$$\lambda_{1,2} = \frac{1}{2} \left( M_L + M_R \pm \sqrt{(M_L - M_R)^2 + 4m_D^2} \right). \quad (3)$$

- The eigenvalues may be negative or positive, so the positivity of the masses is ensured by a phase rotation parameter  $\rho_{1,2} = \pm 1$ :

$$m_{1,2} = \rho_{1,2} \lambda_{1,2} = |\lambda_{1,2}|. \quad (4)$$

- There are two physically different scenarios, identified by the sign of  $\rho_{12} = \rho_1 \rho_2 = \pm 1$ .
- The limits of a pure Dirac Neutrino or a purely left- or right-handed neutrino are contained in the  $\rho_{12} = -1$ -part.

# scenario II

- We also investigate another type of mass Lagrangian for the leptons.
- Here the right-handed neutrino mass is generated by an additional scalar SM-singlet field  $S$ .

$$\begin{aligned}\mathcal{L}_{\text{Mass}}^{II} = & (y \bar{L}_L H E_R + \text{h.c.}) + C_D \bar{L}_L \tilde{H} N_R \\ & + \frac{C_L}{\Lambda} (\bar{L}^c \tilde{H})(\tilde{H}^T L) + C_R S \bar{N}_R^c N_R + \text{h.c.} \quad (5)\end{aligned}$$

- We label this model *scenario II* and the previous model is *scenario I*.

$$H \rightarrow \nu\nu$$

- The invisible decay width is given by:

$$\Gamma_{H \rightarrow N_2 N_2} = \frac{G_F (m_2 C_{22}^h)^2 m_H}{2\pi\sqrt{2}} \left(1 - \left(\frac{2m_2}{m_H}\right)^2\right)^{\frac{3}{2}}, \quad (6)$$

where  $C_{22}^h = 1 - \frac{1}{4} \sin^2 2\theta (1 - \rho_{12} \frac{m_1}{m_2})$  in scenario I and  $C_{22}^h = \sin^2 \theta (1 - \rho_{12} \frac{m_1}{m_2})$  in scenario II.

- The invisible branching ratio is defined as

$$R_{\text{invisible}} = \frac{\Gamma_{H \rightarrow N_2 N_2}}{\Gamma_{H \rightarrow N_2 N_2} + \Gamma_H^{\text{SM}}}, \quad (7)$$

# Contents

**1** Introduction

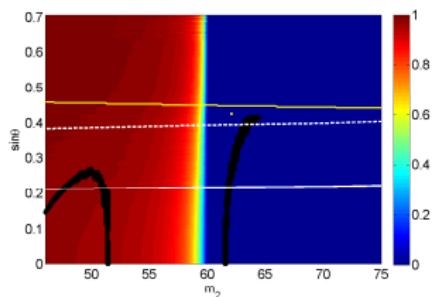
**2** The Model

**3** Results

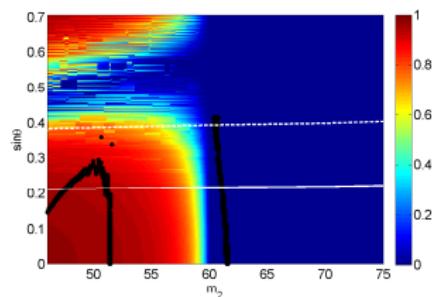
# $R_{\text{invisible}}$ for $m_H = 120$ GeV

Scenario I

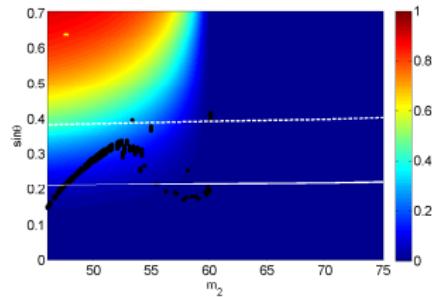
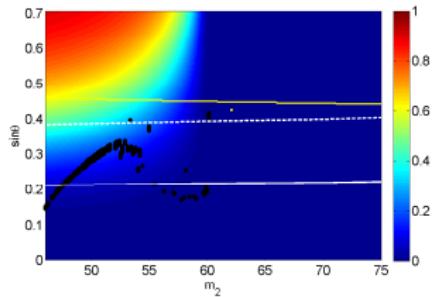
$\rho_{12} = -1$



$\rho_{12} = +1$



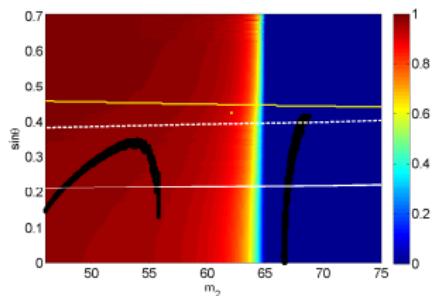
Scenario II



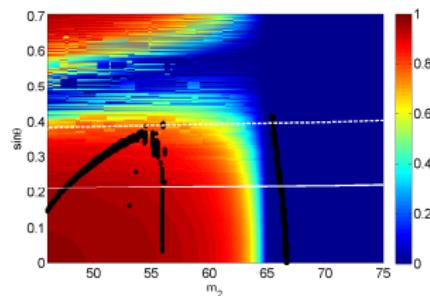
# $R_{\text{invisible}}$ for $m_H = 130$ GeV

Scenario I

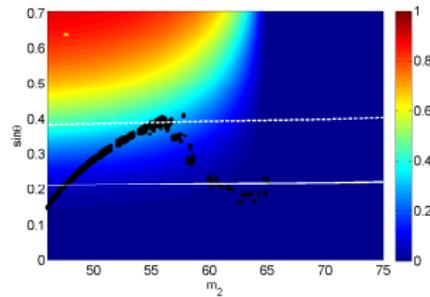
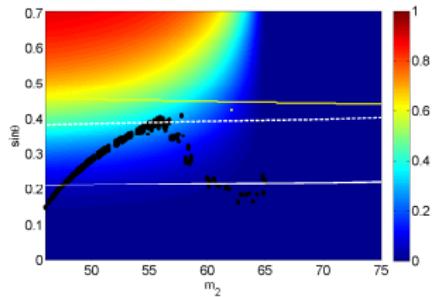
$\rho_{12} = -1$



$\rho_{12} = +1$



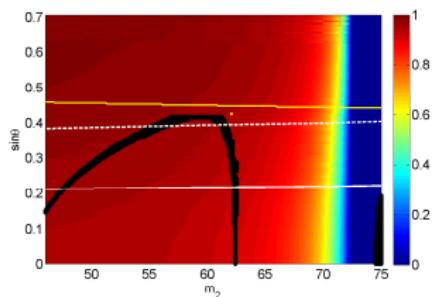
Scenario II



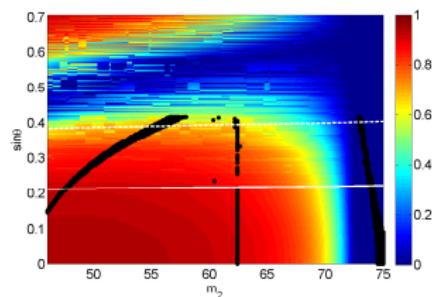
# $R_{\text{invisible}}$ for $m_H = 145 \text{ GeV}$

Scenario I

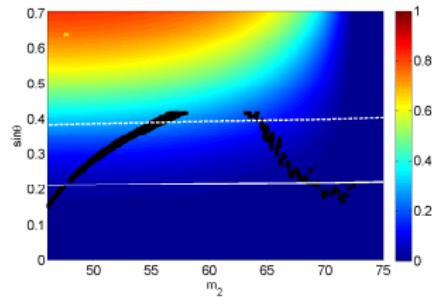
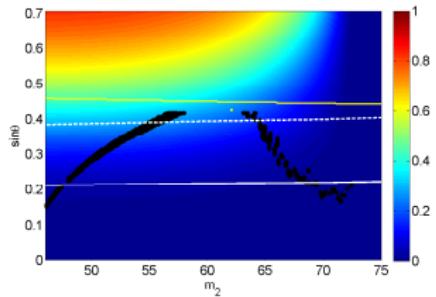
$\rho_{12} = -1$



$\rho_{12} = +1$



Scenario II

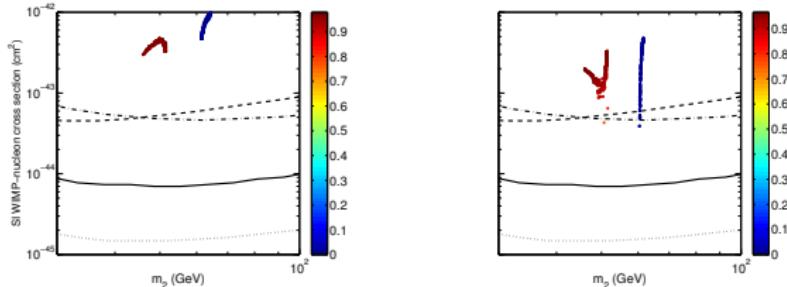


# Spin-Independent Limits, $m_H = 120$ GeV

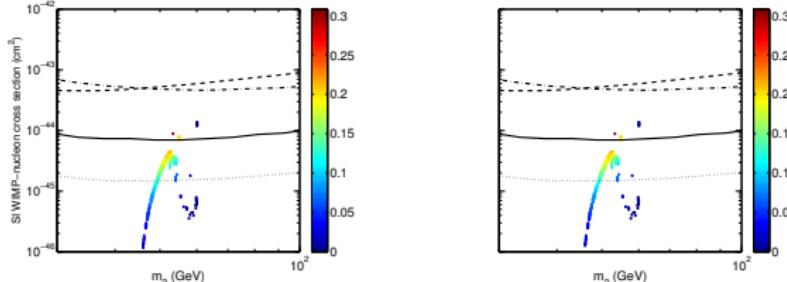
Scenario I

$\rho_{12} = -1$

$\rho_{12} = +1$



Scenario II

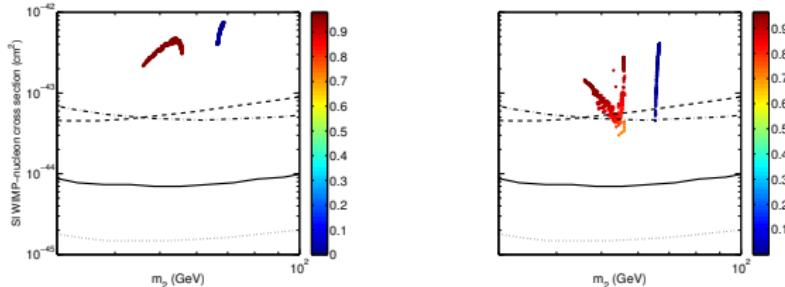


# Spin-Independent Limits, $m_H = 130$ GeV

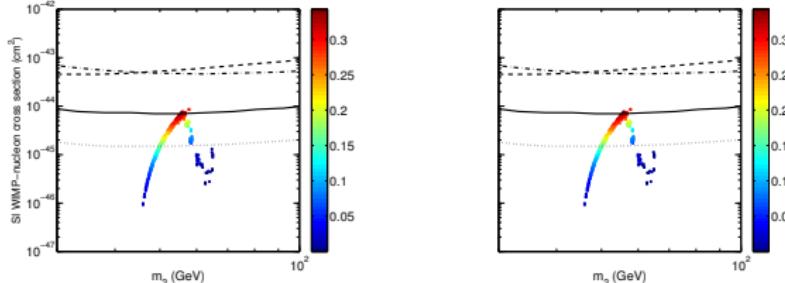
Scenario I

$\rho_{12} = -1$

$\rho_{12} = +1$



Scenario II

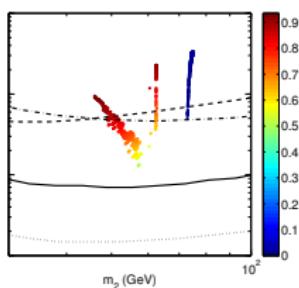
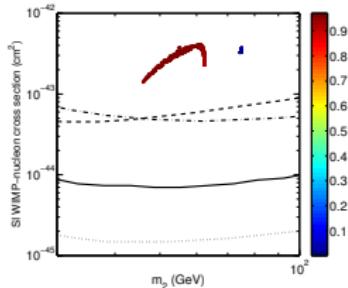


# Spin-Independent Limits, $m_H = 145$ GeV

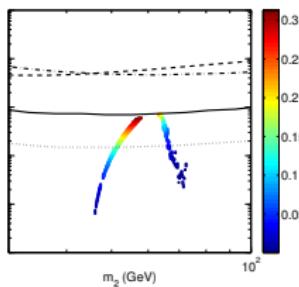
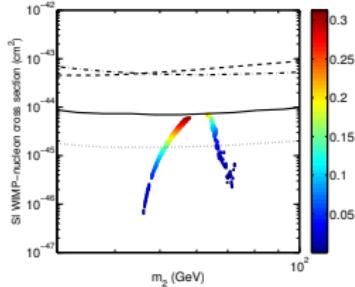
Scenario I

$\rho_{12} = -1$

$\rho_{12} = +1$



Scenario II



# Conclusions

- A neutrino with a suitable mass could be the dominant decay channel of the Higgs.
- In scenario I the neutrino is ruled out as a dark matter candidate.
- In scenario II (right-handed neutrino mass given by an SM-singlet scalar field) the neutrino is a plausible dark matter candidate.
- In this case the invisible branching ratio  $\Gamma_{H \rightarrow \text{DM}} / \Gamma_H^{\text{tot}}$  is of the order of  $\lesssim 0.1$ .