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RH sneutrino DM and non-standard seesaws

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OUTLINE

(1) Introduction

(2) The models

(3) Phenomenological constraints

(4) Right-Handed sneutrino Dark Matter

(5) Results

1. INTRODUCTION

DARK MATTER

Requirements:

- Stable on cosmological time scales
- Reproduce the correct relic abundance
- Not excluded by direct or indirect searches
- No conflicts with BBN or stellar evolution

Many candidates in Particle Physics:

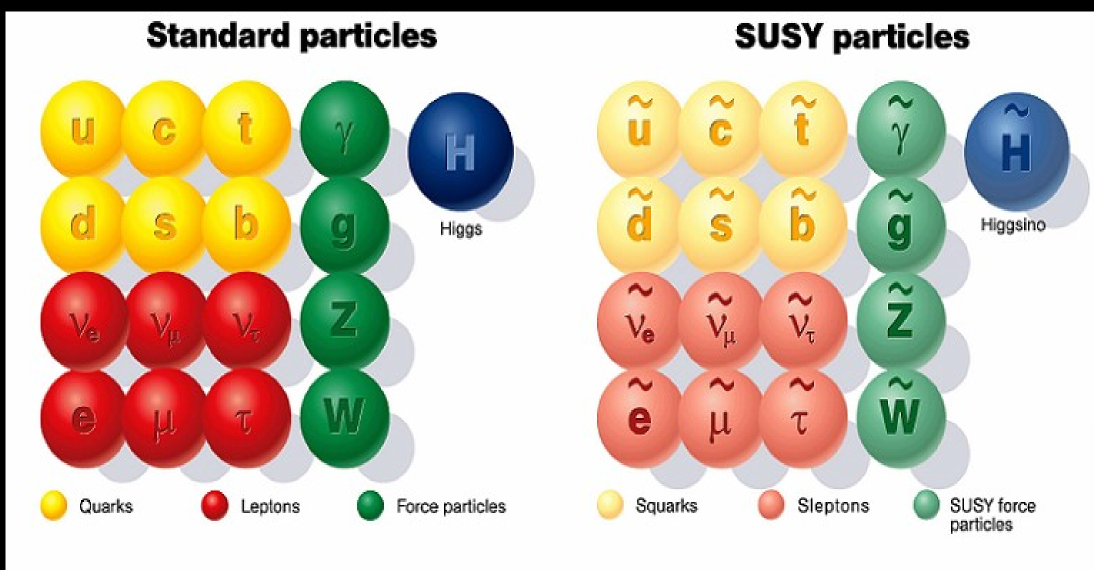
- Weakly-Interacting massive particles: WIMPs
- Axions
- SuperWIMPs (gravitino, axino)
- … many others

Cold Dark Matter content in the Universe:

$$\Omega_{CDM} h^2 \simeq 0.112 \pm 0.006$$ (WMAP, PDG 2011)

DM in the Minimal supersymmetric extension of the Standard Model

The LSP is stable in SUSY theories with R-parity. Thus, it will exist as a relic from the early universe and may account for the observed Dark Matter.



Lightest sneutrino:

annihilates very quickly and the regions where the correct relic density is obtained are experimentally excluded

(Ibañez 1984, Ellis et al. 1984, Hegelin et al. 1984, Freese 1986 ….)

mSUGRA framework just 5 parameters: m_0, $M_{1/2}$, A_0, tan β, sign μ

2. THE MODELS

Model Ia : MSSM with Inverse Seesaw

(Mohapatra, Valle 1986)

Simple extension of the MSSM

Three pairs of MSSM singlets, ν^c and S

$$W = Y_u \hat{u}\,\hat{q}\,\hat{H}_u - Y_d \hat{d}\,\hat{q}\,\hat{H}_d - Y_e \hat{e}\,\hat{l}\,\hat{H}_d + \mu\,\hat{H}_u \hat{H}_d + Y_\nu \hat{\nu}\,\hat{l}\,\hat{H}_u + M_R \hat{\nu}\,\hat{S} + \frac{1}{2}\mu_S \hat{S}\,\hat{S}$$

$$\boldsymbol{M}_\nu = \begin{pmatrix} 0 & M_D & 0 \\ M_D^T & 0 & M_R \\ 0 & M_R^T & \mu_S \end{pmatrix}$$

$$m_\nu = -v_u^2 Y_\nu \left(M_R^T\right)^{-1} \mu_S M_R^{-1} Y_\nu^T$$

Model Ib: MSSM with Linear Seesaw

(Akhmedov et al. 1996)

$$W = Y_u \hat{u}\,\hat{q}\,\hat{H}_u - Y_d \hat{d}\,\hat{q}\,\hat{H}_d - Y_e \hat{e}\,\hat{l}\,\hat{H}_d + \mu\,\hat{H}_u \hat{H}_d$$

$$+ Y_\nu \hat{\nu}\,\hat{l}\,\hat{H}_u + M_R \hat{\nu}\,\hat{S} + Y_{SL} \hat{S}\,\hat{l}\,\hat{H}_u$$

$$\boldsymbol{M}_\nu = \begin{pmatrix} 0 & M_D & M_L \\ M_D^T & 0 & M_R \\ M_L^T & M_R^T & 0 \end{pmatrix} \qquad m_\nu = M_D (M_L M_R^{-1})^T + (M_L M_R^{-1}) M_D^T$$

Model II: SUSY SO(10) GUT with Inverse Seesaw

$$SO(10) \Rightarrow SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \Rightarrow SU(3)_c \times SU(2)_L \times U(1)_R \times U(1)_{B-L}$$

(Malinsky,Romao,Valle 2005)

	Superfield	$SU(3)_c \times SU(2)_L \times U(1)_R \times U(1)_{B-L}$	Generations
Matter	$\hat{Q}$	$(\mathbf{3}, \mathbf{2}, 0, +\frac{1}{6})$	3
	$\hat{d}^c$	$(\overline{\mathbf{3}}, \mathbf{1}, +\frac{1}{2}, -\frac{1}{6})$	3
	$\hat{u}^c$	$(\overline{\mathbf{3}}, \mathbf{1}, -\frac{1}{2}, -\frac{1}{6})$	3
	$\hat{L}$	$(\mathbf{1}, \mathbf{2}, 0, -\frac{1}{2})$	3
	$\hat{e}^c$	$(\mathbf{1}, \mathbf{1}, +\frac{1}{2}, +\frac{1}{2})$	3
	$\hat{\nu}^c$	$(\mathbf{1}, \mathbf{1}, -\frac{1}{2}, +\frac{1}{2})$	3
	$\hat{S}$	$(\mathbf{1}, \mathbf{1}, 0, 0)$	3
Higgs	$\hat{H}_u$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2}, 0)$	1
	$\hat{H}_d$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, 0)$	1
	$\hat{\chi}_R$	$(\mathbf{1}, \mathbf{1}, +\frac{1}{2}, -\frac{1}{2})$	1
	$\hat{\bar{\chi}}_R$	$(\mathbf{1}, \mathbf{1}, -\frac{1}{2}, +\frac{1}{2})$	1

New gauge boson Z'

$$W = Y_u \hat{u} \hat{q} \hat{H}_u - Y_d \hat{d} \hat{q} \hat{H}_d + Y_\nu \hat{\nu} \hat{l} \hat{H}_u - Y_e \hat{e} \hat{l} \hat{H}_d + Y_{SL} \hat{\nu} \hat{\chi}_R \hat{S} + \frac{1}{2} \mu_S \hat{S} \hat{S} + \mu \hat{H}_u \hat{H}_d - \mu_R \hat{\bar{\chi}}_R \hat{\chi}_R$$

3. PHENOMENOLOGICAL CONSTRAINTS

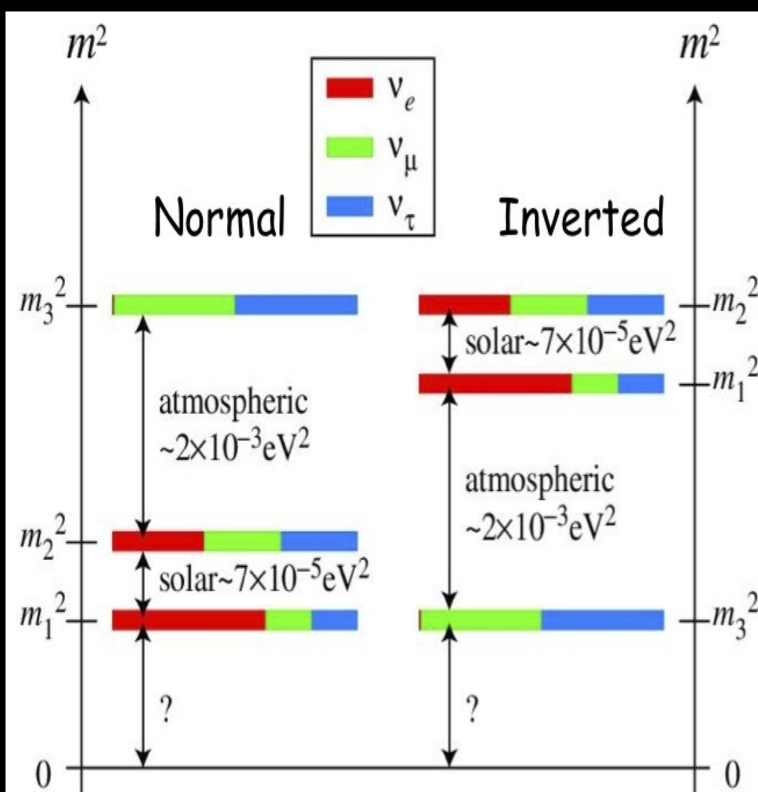
1) Neutrino masses

$$U_{TBM}=\begin{pmatrix} \sqrt{2/3} & 1/\sqrt{3} & 0 \\ -1/\sqrt{6} & 1/\sqrt{3} & 1/\sqrt{2} \\ -1/\sqrt{6} & 1/\sqrt{3} & 1/\sqrt{2} \end{pmatrix}$$

(Harrison, Perkins, Scott 2002)

parameter	best fit $\pm 1\sigma$	2σ	3σ
Δm^2_{21} $[10^{-5}\mathrm{eV}^2]$	7.62 ± 0.19	7.27–8.01	7.12–8.20
Δm^2_{31} $[10^{-3}\mathrm{eV}^2]$	$2.53^{+0.08}_{-0.10}$ $-(2.40^{+0.10}_{-0.07})$	$2.34-2.69$ $-(2.25-2.59)$	$2.26-2.77$ $-(2.15-2.68)$
$\sin^2\theta_{12}$	$0.320^{+0.015}_{-0.017}$	0.29–0.35	0.27–0.37
$\sin^2\theta_{23}$	$0.49^{+0.08}_{-0.05}$ $0.53^{+0.05}_{-0.07}$	0.41–0.62 0.42–0.62	0.39–0.64
$\sin^2\theta_{13}$	$0.026^{+0.003}_{-0.004}$ $0.027^{+0.003}_{-0.004}$	0.019–0.033 0.020–0.034	0.015–0.036 0.016–0.037
δ	$(0.83^{+0.54}_{-0.64})\,\pi$ 0.07π [a]	$0-2\pi$	$0-2\pi$

(Forero, Tortola, Valle 2012)

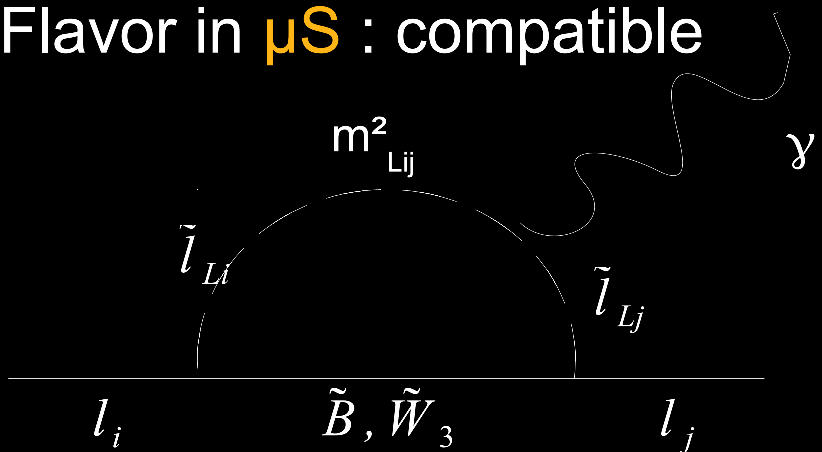


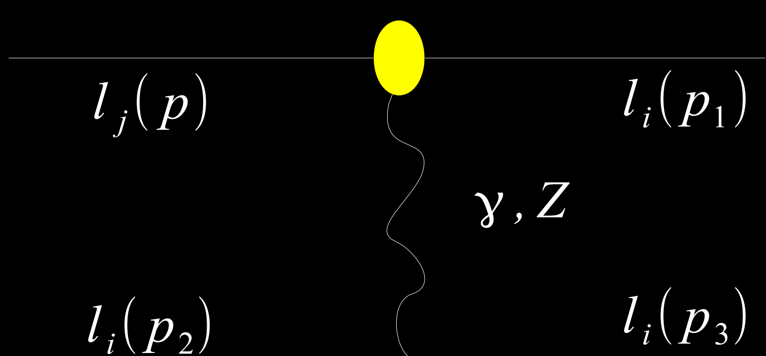
$$M_\nu^{TBM}=\frac{m_{sol}}{3}\begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}+\frac{m_{atm}}{2}\begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & -1 & 1 \end{pmatrix}$$

2) Lepton Flavor Violation

MSSM INVERSE SEESAW:

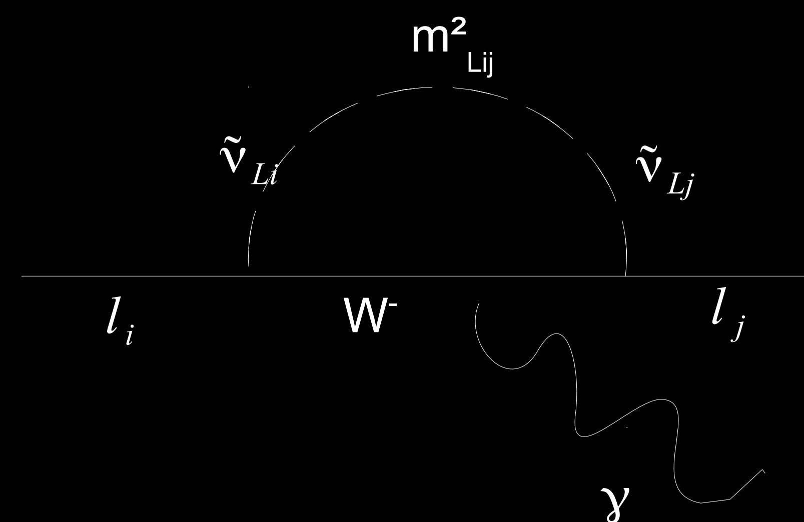
Flavor in Yv : ruled out
Flavor in MR : ruled out
Flavor in μS : compatible





MSSM LINEAR SEESAW:

Flavor in Yv : ruled out
Flavor in MR : ruled out
Flavor in Y_{SL} : compatible



$BR(\mu \rightarrow e\gamma) = 2.4 \times 10^{-12}$
$BR(\mu \rightarrow eee) = 1.0 \times 10^{-12}$

(90% C.L.) (MEG collab 2012)

4. RH SNEUTRINO AS DARK MATTER CANDIDATE

Scanning over the parameter space

- Write the model file for SARAH

- Start from mSUGRA boundary conditions and run the RGE equation low to the EW scale with Spheno

- Select the points where the RH sneutrino is the LSP

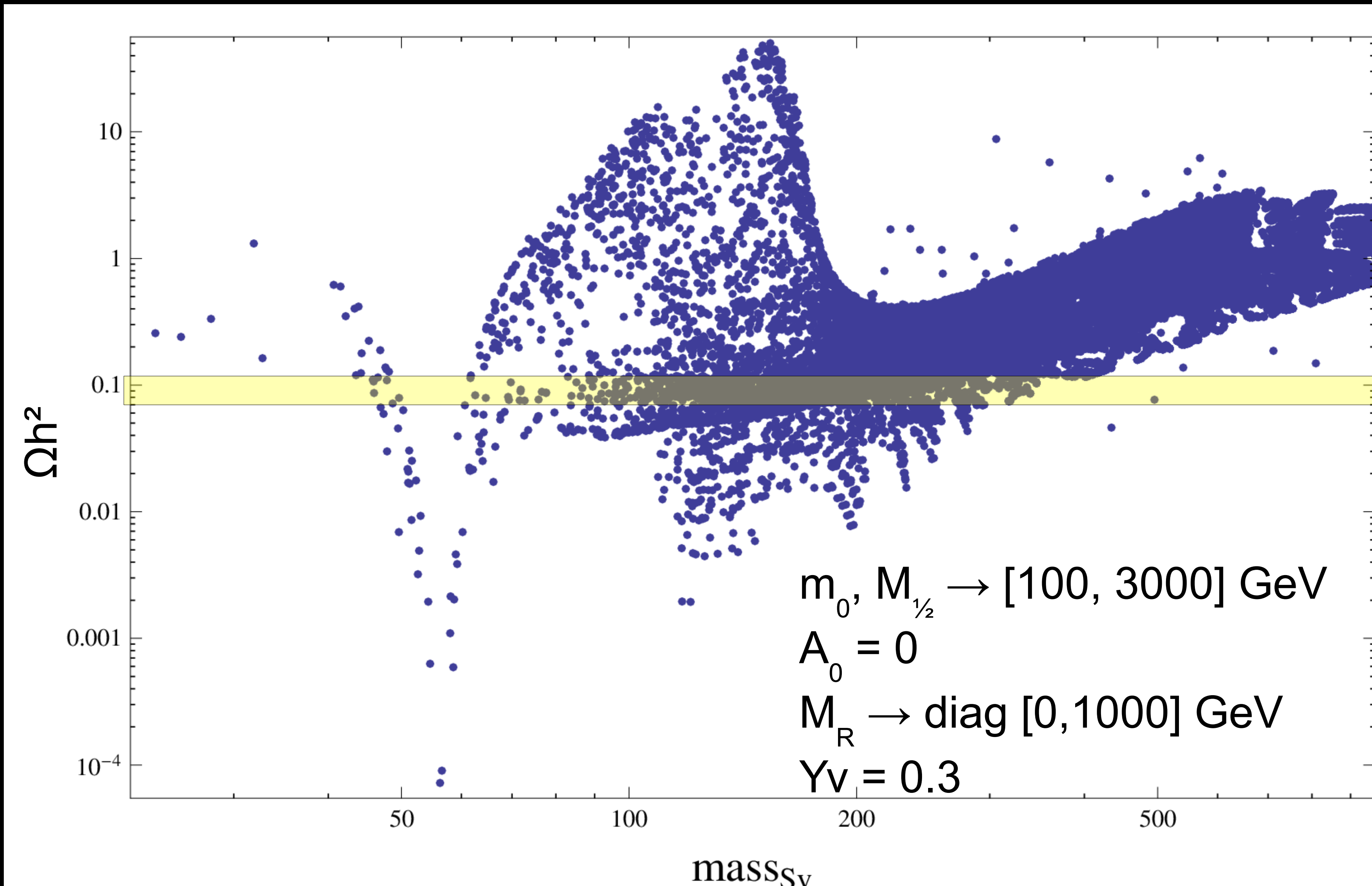
- Evaluate the Relic Abundance and the direct detection cross section using MicrOmegas

(SARAH: F. Staub arxiv 0806.0538)

(SPHENO: W. Porod 2003)

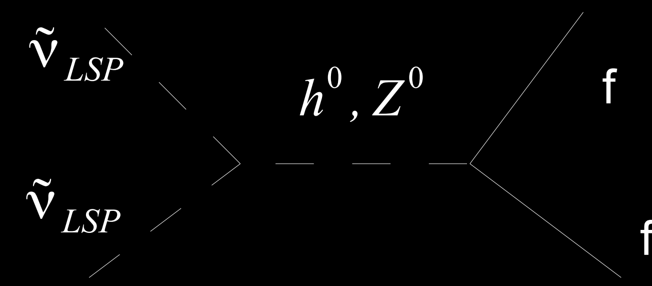
(MICROMEGAS: G. Belanger et al.)

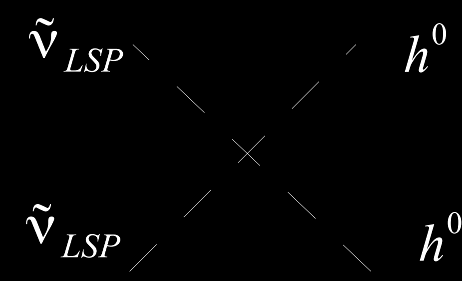
Model Ia: General Scan

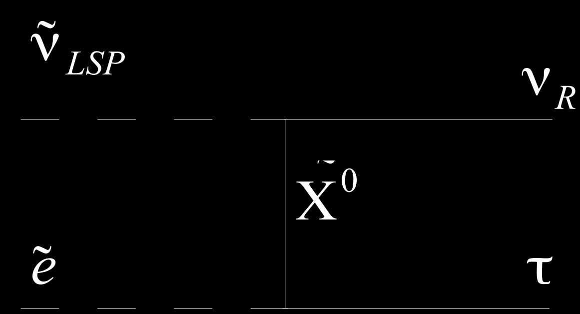


Main annihilation channels

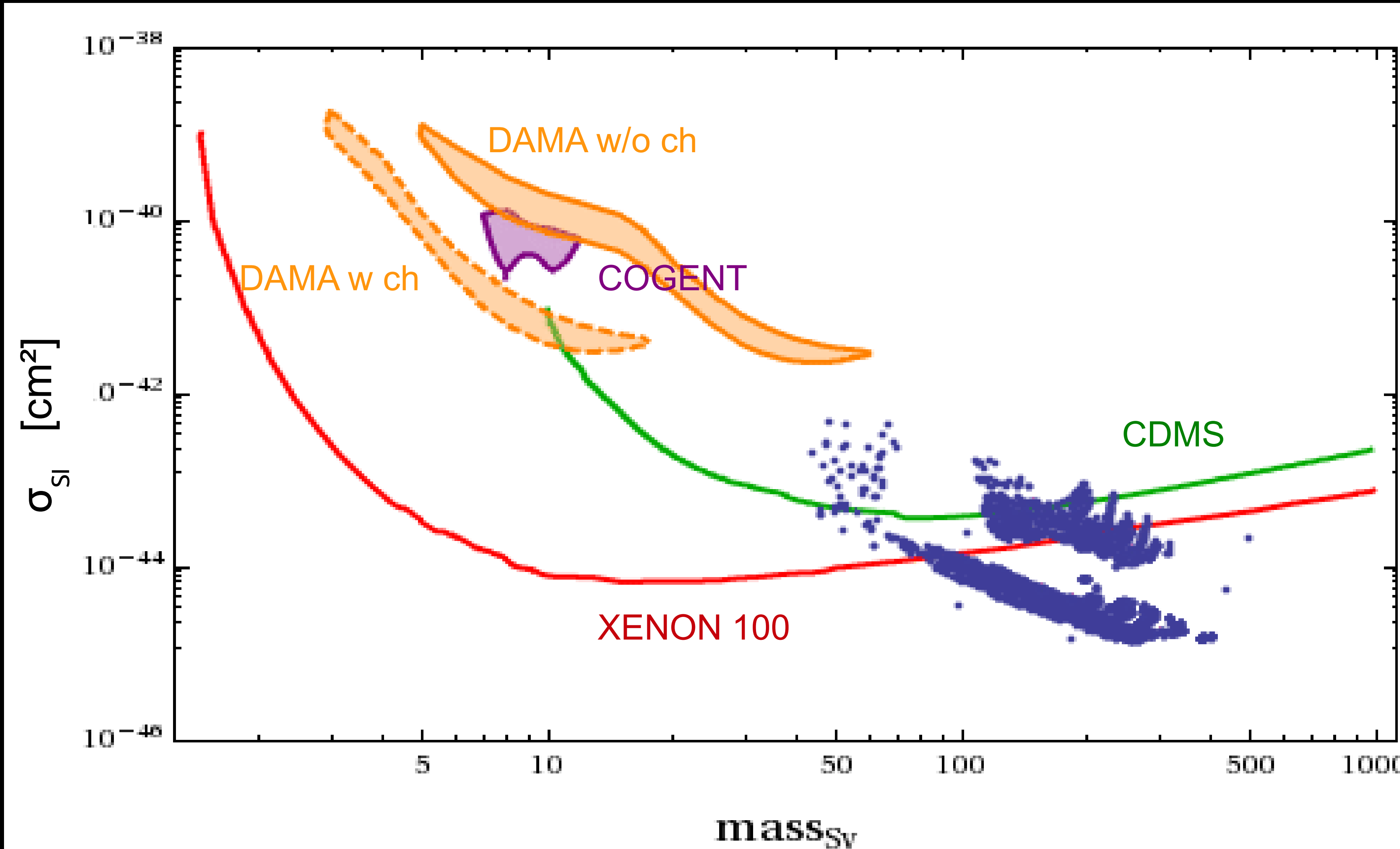
- The channel through the Higgs is the main one;
- Shows a resonance at half the Higgs mass;
- The annihilation into tops is quite efficient (for masses larger than top mass);
- Once the quartic coupling channel opens, it is also quite efficient;
- Coannihilations are possible.



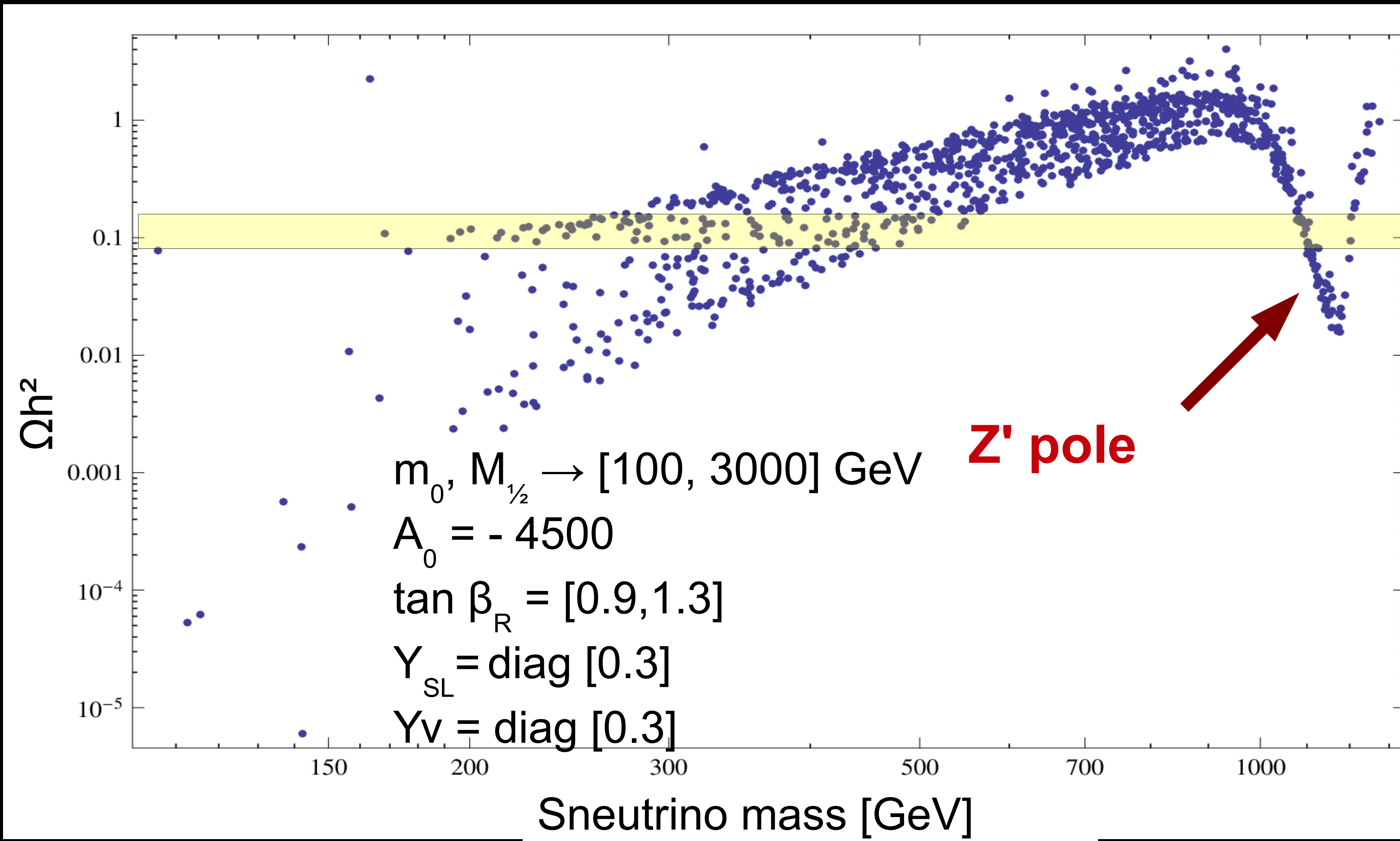




Direct Detection Cross Section

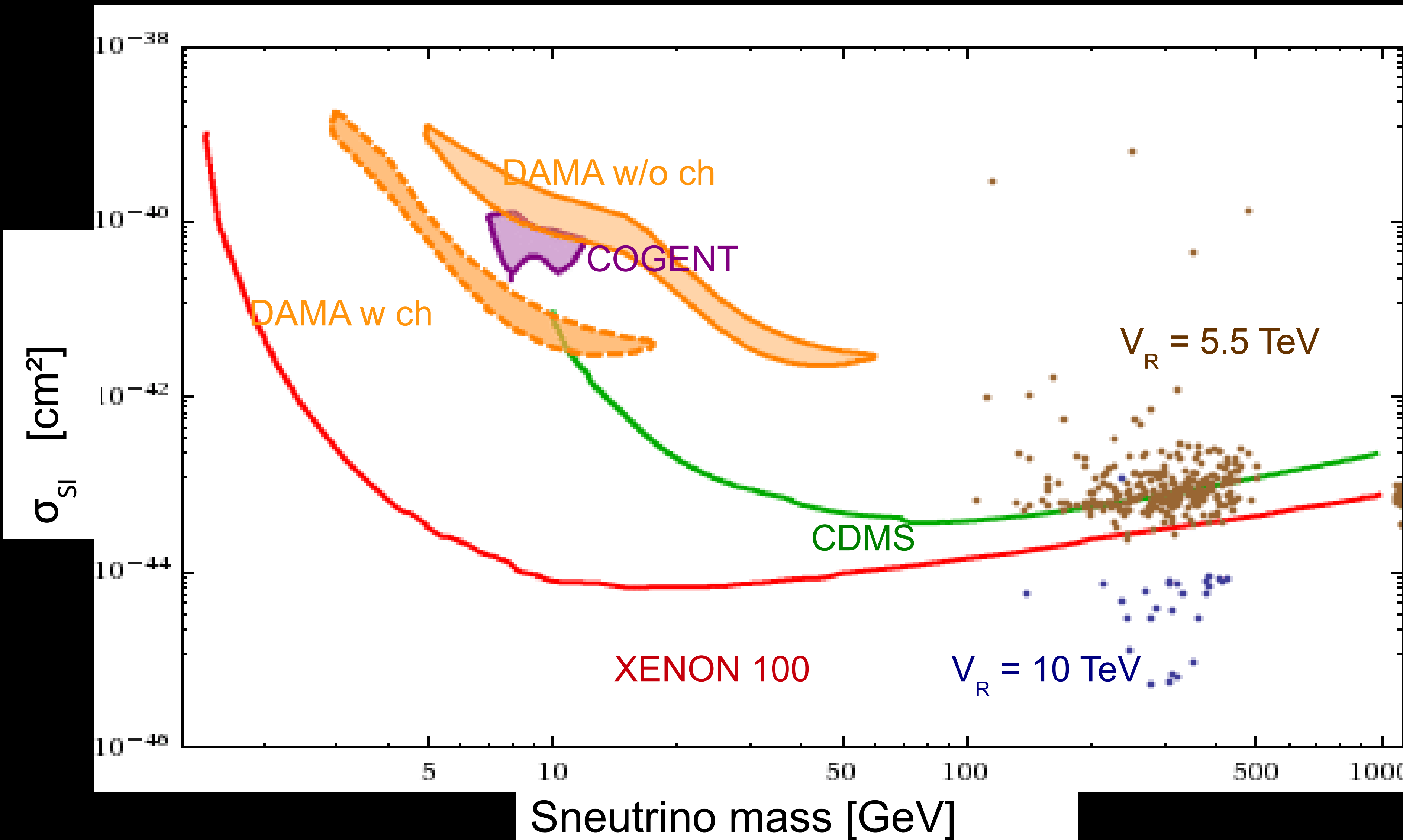


Model II



1
0.1
0.01
0.001
10^{-4}
10^{-5}
Ωh^2
150
200
300
500
700
1000
Sneutrino mass [GeV]
m_0, $M_{½}$ → [100, 3000] GeV
A_0 = - 4500
tan β_R = [0.9,1.3]
Y_{SL} = diag [0.3]
Yv = diag [0.3]
Z' pole

Direct Detection Cross Section



Conclusions

- We can obtain the correct Relic Abundance for the RH sneutrino dark matter in all the models;
- Inverse and Linear seesaw give very similar results (as to DM);
- LFV decays into three leptons are very constraining;
- In Model I the annihilation through the h^0 is the main channel, very efficient close to the resonance;
- Effect of the presence of the new gauge boson Z' in model II, especially in the DD cross section.


Thanks for your attention!

BACKUP SLIDES

Model Ia: Sneutrino Mass matrix

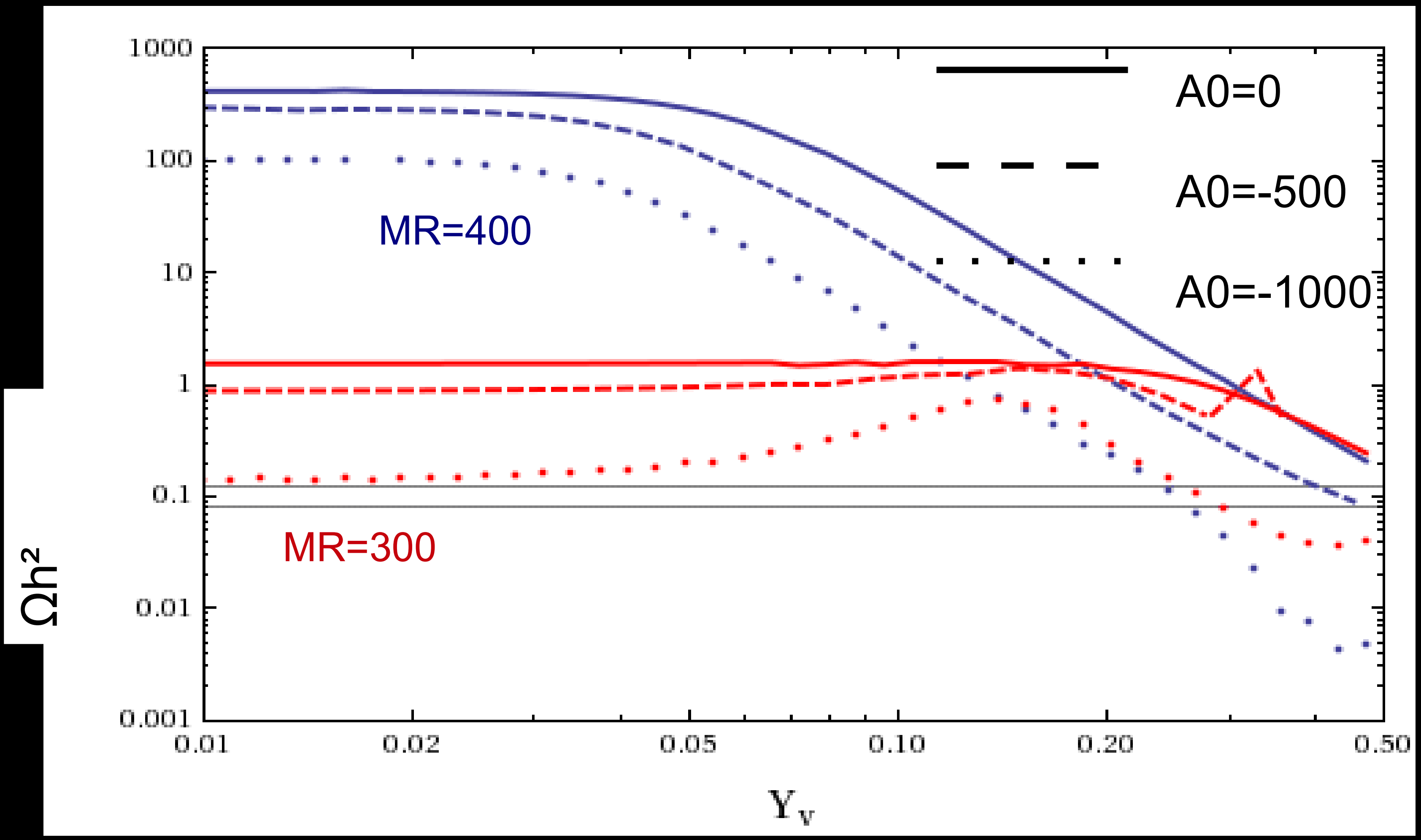
$$M^2_{\tilde{\nu}} = \begin{pmatrix} M_P^2 & 0 \\ 0 & M_M^2 \end{pmatrix}$$

separated into CP-even and CP-odd blocks

$$M^2_{P,M} = \begin{pmatrix} m_L^2 + 1/2\, m_Z^2 \cos 2\beta + m_D^2 & T_{Y_\nu} v_u - \mu\, m_D\, cotg\, \beta & m_D M_R \\ T_{Y_\nu} v_u - \mu\, m_D\, cotg\, \beta & m_{\nu_R}^2 + M_R^2 + m_D^2 & \mu_S M_R + B_{M_R} \\ m_D M_R & \mu_S M_R + B_{M_R} & m_S^2 + \mu_S^2 + M_R^2 \pm B_{\mu_S} \end{pmatrix}$$

$$\tilde{\nu}_{LSP} = -\sin\theta\, \tilde{\nu}_L + \cos\theta \left(-\sin\alpha\, \tilde{\nu}_R + \cos\alpha\, \tilde{S} \right)$$

Yv dependence of the Relic Abundance



Annihilation final states