Naturalness reconsidered

M. Fabbrichesi, INFN Trieste, Italy

SUSY 2014, 21-26 July 2013, Manchester

- protect the Higgs boson mass,
  no matter what the physics at shorter distances is

- make assumptions on the short-distance physics
  that may render it compatible with naturalness

- accept the fine tuning

R.Barbieri, arXiv:1309.3437

- protect the Higgs boson mass,
no matter what the physics at shorter distances is

(from the textbooks)

$$\delta m_h^2 = \frac{\Lambda^2}{8\pi^2 v_W^2}\left[3m_h^2 + 3m_Z^2 + 6m_W^2 - 12m_t^2\right]$$

troublesome points w/ cutoff regularization

- mixing of UV and IR terms
- integrating over vs. integrating out

even though it has been the motivation for SUSY in the past 40 years

- accept the fine tuning

naturalness is about decoupling

■ make assumptions on the short-distance physics that may render it compatible with naturalness

no new physics beyond SM → no problem

a tale of two scales

SM all the way

new physics at scale M_χ →

$$\delta\mu_H^2(\mu) = \frac{1}{(2\pi)^2}\left[M_\chi^2 + M_\chi^2 \ln\frac{M_\chi^2}{\mu^2}\right]$$

IR sensitivity: one-loop finite

W. A. Bardeen, FERMILAB-CONF-95-391-T, 1995
K.A. Meissner and H. Nicolai, 2008
M. Shaposhnikov and D. Zenhausern, 2009

F. Bazzocchi and M.F., 2012
M. Farina, D. Pappadopulo and A. Strumia, 2013
J. Lykken, 2013
M.F., 2013

I see a hand rising…   What about the Planck mass?

- only what I can compute can give me a problem
- quantum gravity: is there a Planck mass in the loop?

model building requires guiding principles

let new physics enter in such a way that
IR finite contributions to the Higgs boson mass cancel

$O(m_h)$

one loop: solution to the little hierarchy problem

physics at the new scale decouples from lower scale

Low-scale seesaw mechanism and scalar dark matter

An example at work

M.F. and S. Petcov, 2013

neutrino masses and seesaw mechanism

$$\mathcal{L} = -y^{\nu}_{a\ell}\bar{N}_{aR}\tilde{H}^{\dagger}L_{\ell} - \frac{1}{2}\bar{N}^{c}_{aL}M_{Nab}N_{bR} + H.c.$$

$$\hat{y}^{\nu}_{j\ell} = M_{N_j}(RV)^{T}_{j\ell}/v_W$$

3 RH Majorana neutrinos (singlets)

couplings to LH leptons and neutrinos

$$|(RV)_{e1}|^2, |(RV)_{\mu 1}|^2, |(RV)_{\tau 1}|^2 \lesssim 10^{-3}$$

$$\left|\sum_k (RV)^{*}_{\ell' k} M_k (RV)^{\dagger}_{k\ell}\right| = |(m_v)_{\ell'\ell}| \lesssim 1\ \text{eV}$$

D.N. Dinh *et al*, 2012
Akhmedov *et al*, 2013

$$\alpha = |(RV)_{e1}|^2 + |(RV)_{\mu 1}|^2 + |(RV)_{\tau 1}|^2$$

traditional see-saw $\alpha \simeq 10^{-12}$

low-scale see-saw $\alpha \simeq 10^{-3}$

Ibarra *et al,* JHEP 1009 (2011) 013005

Higgs boson mass renormalization

$$\delta\mu_H^2(\mu) = \frac{4y^2}{(4\pi)^2} M_N^2 \left(1 - \log\frac{M_N^2}{\mu^2}\right)$$

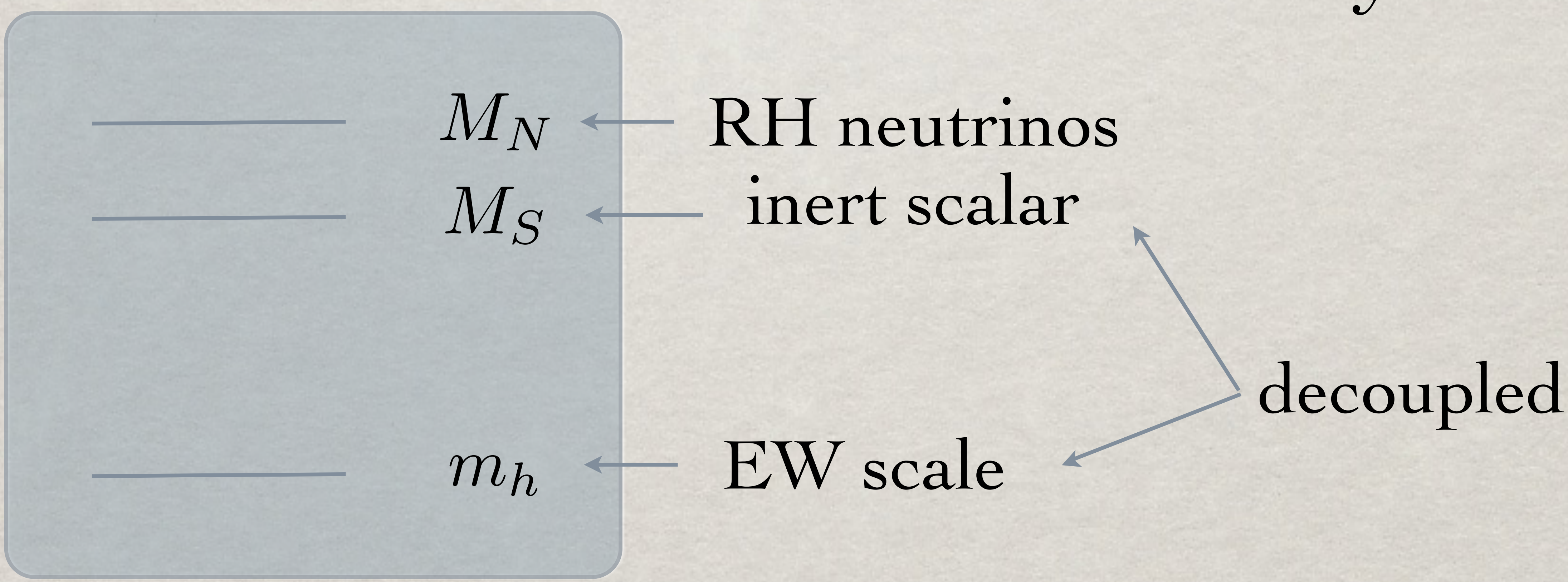
largest Yukawa coupling

$$y^2 v_W^2 = 2M_N^2 \left[|(RV)_{e1}|^2 + |(RV)_{\mu1}|^2 + |(RV)_{\tau1}|^2\right]$$

simplest choice: <u>add an inert scalar</u>

$$V(H,S) = \mu_H^2 (H^\dagger H) + \mu_S^2 S^2 + \lambda_1 (H^\dagger H)^2 + \lambda_2 S^4 + \lambda_3 (H^\dagger H) SS$$

Z_2 symmetry



one-loop renormalization

$$\delta\mu_H^2(M_S) = \frac{1}{(4\pi)^2}\left[\lambda_3 M_S^2 - 4y^2 M_N^2\left(1-\log\frac{M_N^2}{M_S^2}\right)\right]$$

new inert scalar

heavy RH neutrinos

controlling the one-loop renormalization

$$\lambda_3 = \frac{4y^2 M_N^2}{M_S^2}\left(1-\log\frac{M_N^2}{M_S^2}\right)$$

$O(m_h)$

still a bit ugly (fine tuning at the level of 10%)

a better way: find a symmetry

(work in progress)

V. Silvera and A. Zee, 1985
J. McDonald, 1994
C.P. Burgess *et al*, 2001
R. Dick *et al*, 2008
C.E. Yaguna, 2009
K. Cheung *et al*, 2012

inert scalar as cold dark matter

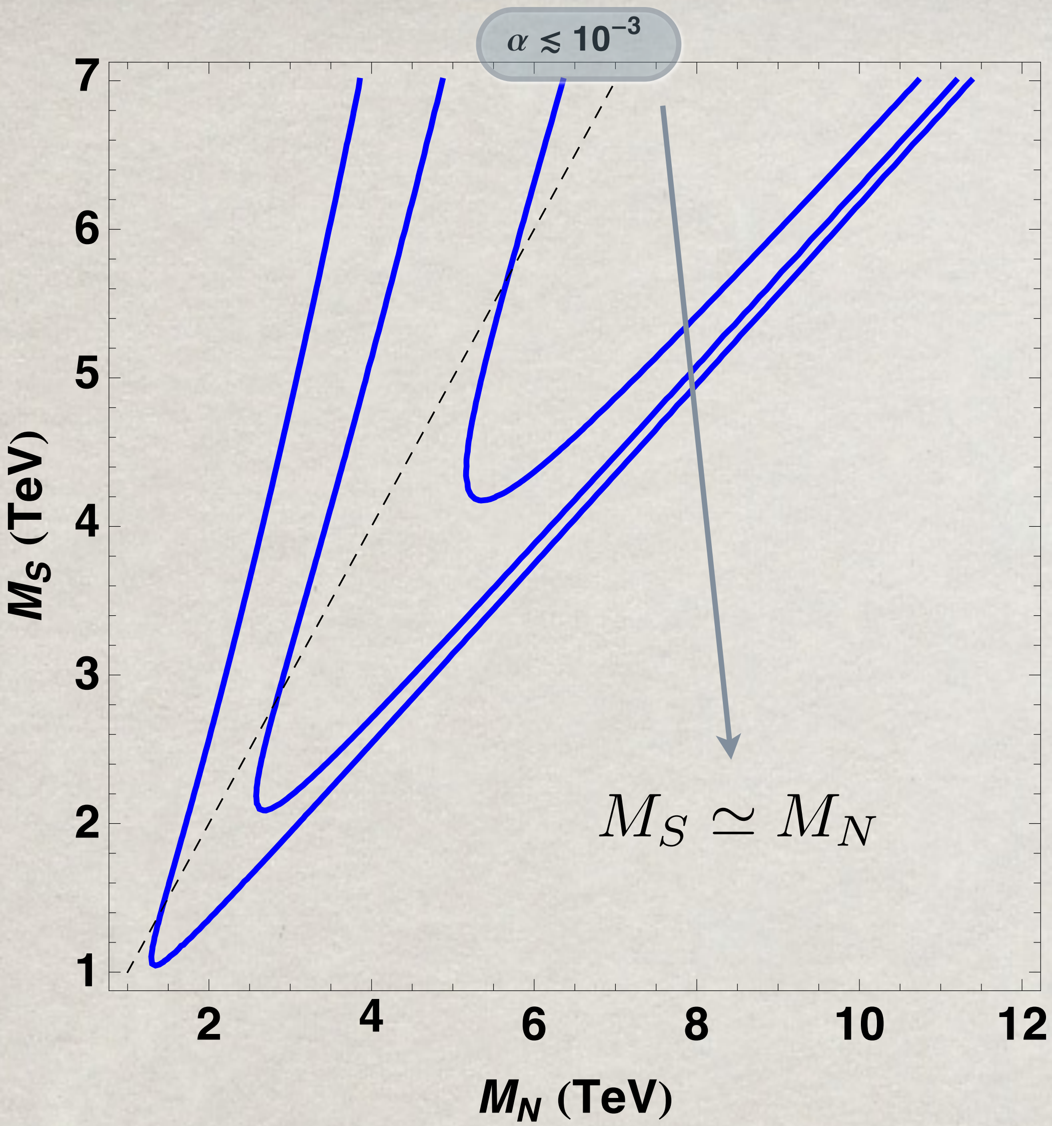
$$\Omega_S h^2 \simeq 8.41 \times 10^{-11} \frac{M_S}{T_f} \sqrt{\frac{45}{\pi g_*}} \frac{\mathrm{GeV}^{-2}}{\langle \sigma v \rangle}$$

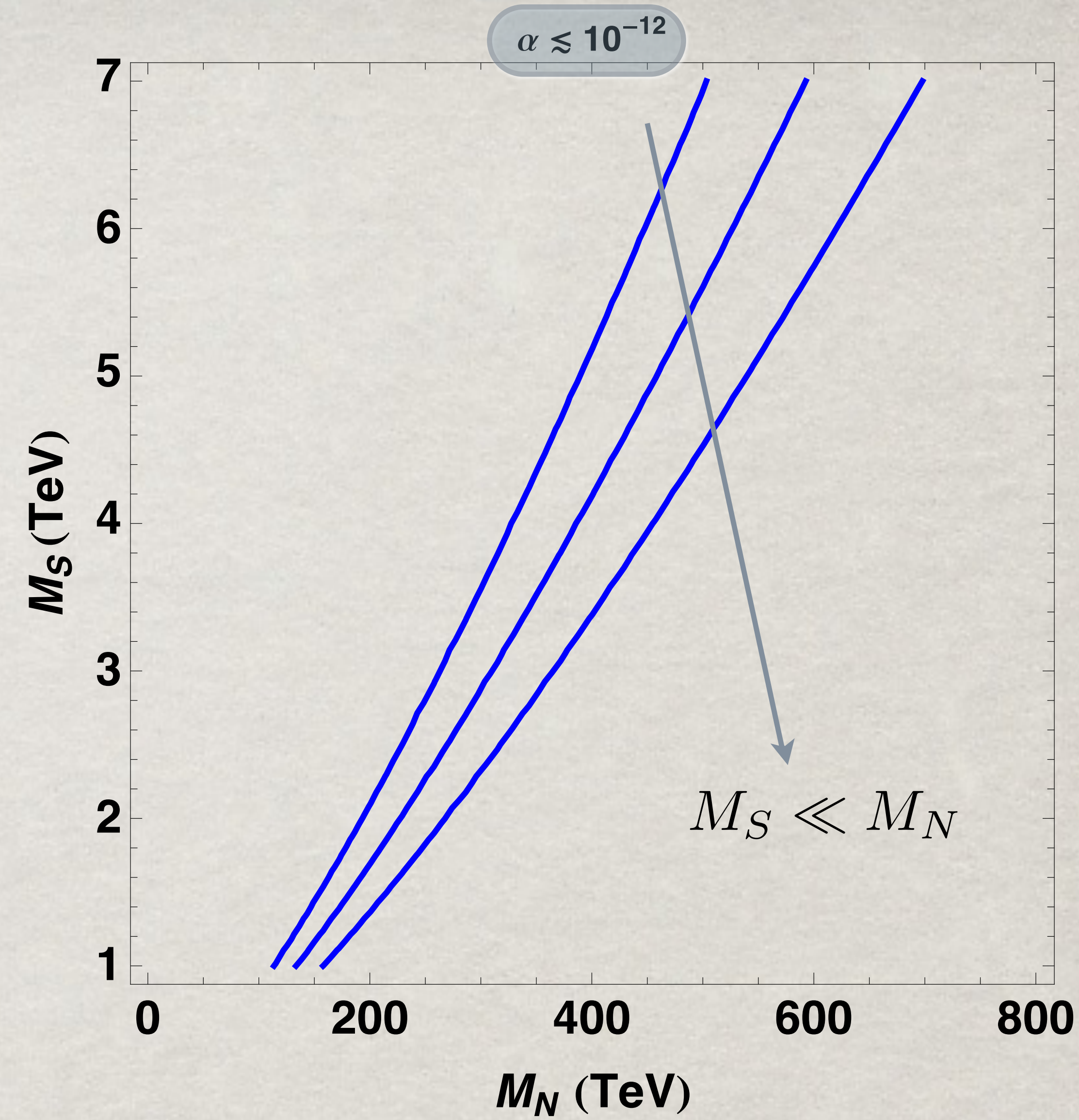
$$\langle \sigma v \rangle \simeq \frac{1}{4\pi} \frac{\lambda_3^2}{M_S^2} \sqrt{1 - \frac{m_h^2}{m_S^2}}$$

$$\Omega_{\mathrm{DM}} h^2 = 0.1187 \pm 0.0017$$

Planck Collaboration, 2013

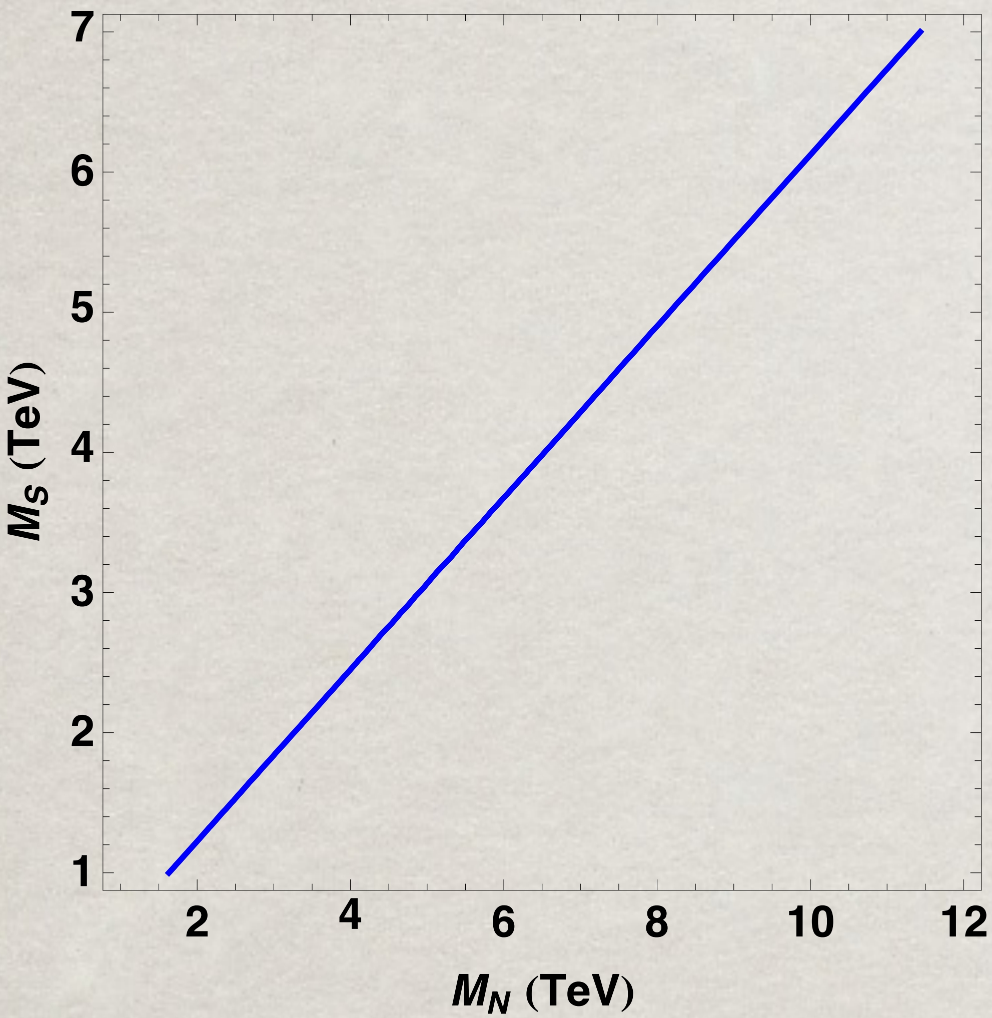
$$\Rightarrow \quad |\lambda_3| \simeq 0.15 \frac{M_S}{\mathrm{TeV}}$$





$$0.15\, M_S^3 = 8\,\alpha\,\frac{M_N^4}{v_W^2}\left(1 - \log\frac{M_N^2}{M_S^2}\right)$$

$$\alpha = |(RV)_{e1}|^2 + |(RV)_{\mu 1}|^2 + |(RV)_{\tau 1}|^2$$

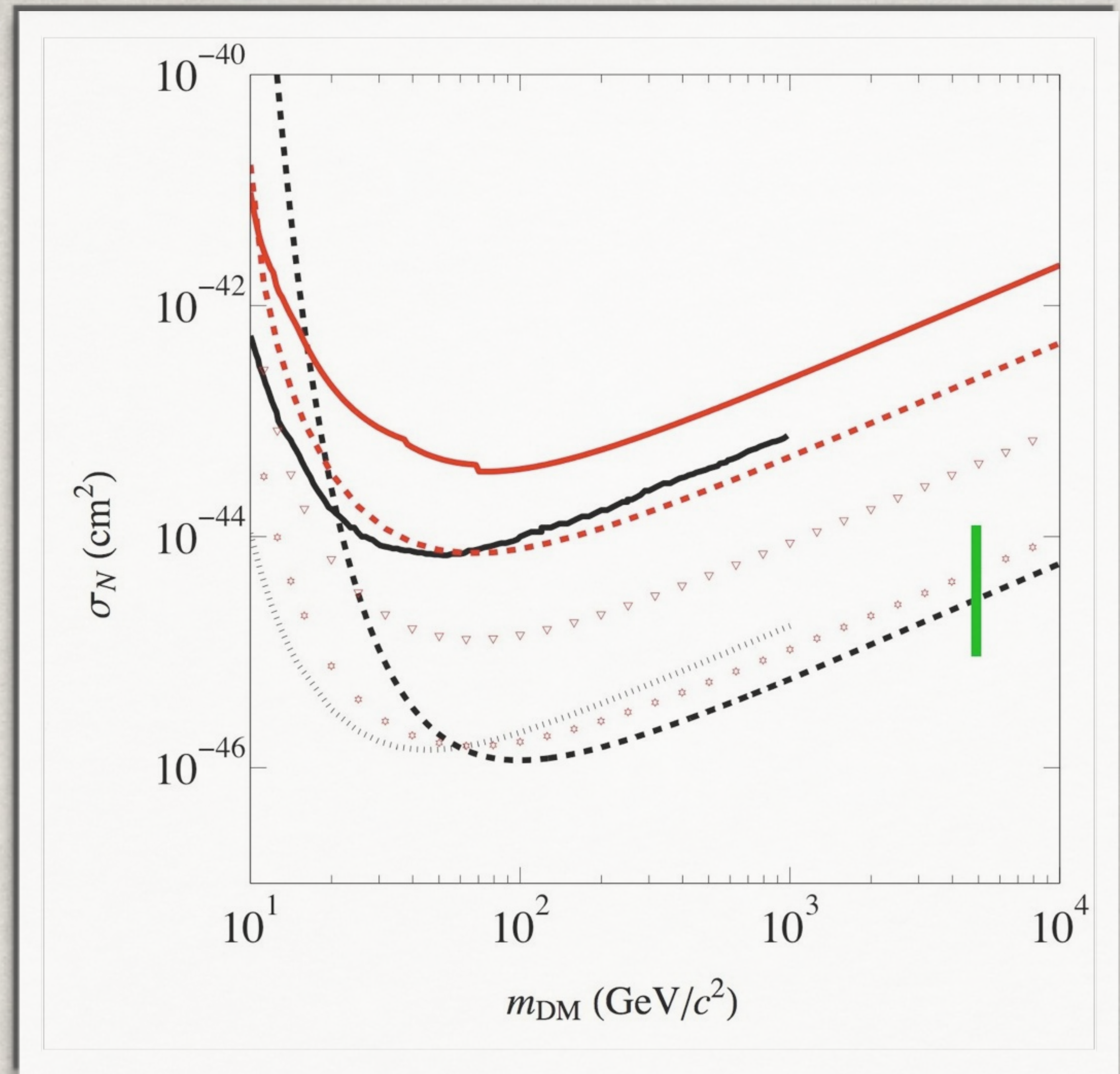


feebly interacting massive particle (FIMP)

$\lambda_3 \ll 1$

does not thermalize,
abundance very small,
no annihilations
(usual result does not apply)

$\lambda_3 \simeq 10^{-11}$ $\alpha \simeq 10^{-12}$



XENON100
http://dmtools.brown.edu

$$\sigma_N = f_N^2 m_N^2 \frac{\lambda_3^2}{4\pi}\left(\frac{m_r}{m_S m_h^2}\right)^2$$