Phenomenological Aspects of Discrete Dark Matter

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Based on :

1101.2874 [SMB, M. Hirsch, S. Morisi, E. Peinado, M. Taoso, J.W.F. Valle] *JHEP 1105 (2011) 037*
1204.4733 [SMB, S. Morisi, E. Peinado, Y. Shimizu, J.W.F. Valle]
1204.2576 [SMB, R. Lineros, J.W.F. Valle]

FLASY'12. Dortmund, July 1st.

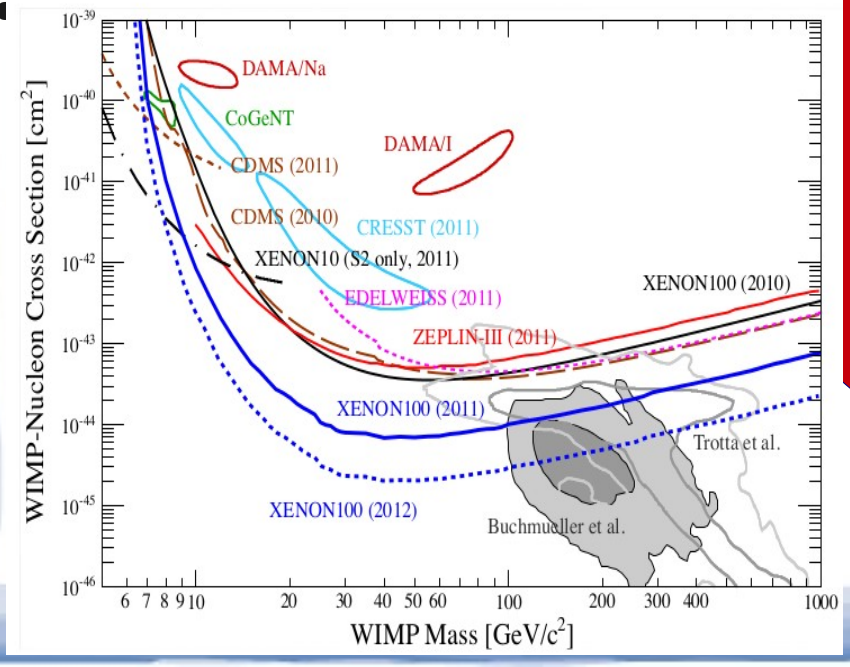
The amount of evidence for Dark Matter is consistently growing since the 30's ... but we still don't know its precise nature !

however, we do know some of its aspects :

- Non-relativistic @ onset of galaxy formation (Cold)
- Very Weakly interacting with photons (dark!)
- Reproduces the non-baryonic matter density
- Fits Rotation curves of galaxies
- OK with BBN
- Stable or Very long lived

The Dark Matter 'Landscape'

- Primordial Black Holes
- Sterile Neutrinos
- PNGBs (Axion, Majoron)
- Gravitinos
- Q-Balls
- WIMPs



- Known and well tested physics
- Thermal Production
- "Miraculous"

$$\Omega_{\rm CDM}h^2 \simeq 0.1\,\frac{3\times10^{-26}\ {\rm cm^3 s^{-1}}}{\langle\sigma v\rangle_{\rm f.o.}}$$

Testable !

Dark Connections ?

- Baryogenesis
- Inflation
- Strong CP problem
- GUT
- Dark energy
- Neutrinos
- …

- Very well measured parameters!
- At the heart of SM conceptual edifice.

- Testable !

Discrete Dark Matter

A mechanism to stabilize the DM by means of a flavor symmetry.

Previous Talk (S. Morisi)


SM +
Neutrinos masses & angles
Extras
Z_N

What is the Nature of the DDM ?

- Scalar / Fermion
- Singlet / Doublet / …
- Neutral
- Absolutely Stable
- WIMP !

We'll focus on scalar SU(2)-doublet WIMP dark matter

- Thermal Production via Higgs/Gauge portal.
- Rich (in)direct detection prospects.
- Multi-Higgs models appeal.

The Multi-Higgs Variations

DDM mechanism offers a well motivated framework of (constrained) multi-higgs extensions of the SM. We can distinguish four phenomenological classes :

- 1 Bright + 1 Dark
- 1 Bright + 2 Dark
- 2 Bright + 1 Dark
- 2 Bright + 2 Dark

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- Inert Higgs model
- Single Higgs (SM)
- Limited coannihilations
- Very constrained

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- '2 Inert Higgs' model
- Single Higgs (SM)
- Strong coannihilations
- Extra channels with charged dark scalars

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- Extra diagrams with charged scalars

An archetype of (2+2) DDM

The Model :

... SM

... + 3 SU(2) doublets + (3+1) right handed neutrinos

	L_e	L_μ	L_τ	l_e^c	l_μ^c	l_τ^c	N_T	N_4	H	η
$SU(2)$	2	2	2	1	1	1	1	1	2	2
A_4	1	$1'$	$1''$	1	$1''$	$1'$	3	1	1	3

$$1 \times 1_i = 1_i$$
$$1' \times 1'' = 1$$
$$1' \times 1' = 1''$$
$$1'' \times 1'' = 1'$$

... Diagonal charged leptons, Quarks are A4 blind.

An archetype of (2+2) DDM

$$\langle \eta \rangle \sim (1,0,0) \qquad S = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

$$H = \begin{pmatrix} \tilde{H}_0^+ \\ (v_h + \tilde{H}_0 + i\tilde{A}_0)/\sqrt{2} \end{pmatrix}, \quad \eta_1 = \begin{pmatrix} \tilde{H}_1^+ \\ (v_\eta + \tilde{H}_1 + i\tilde{A}_1)/\sqrt{2} \end{pmatrix}$$

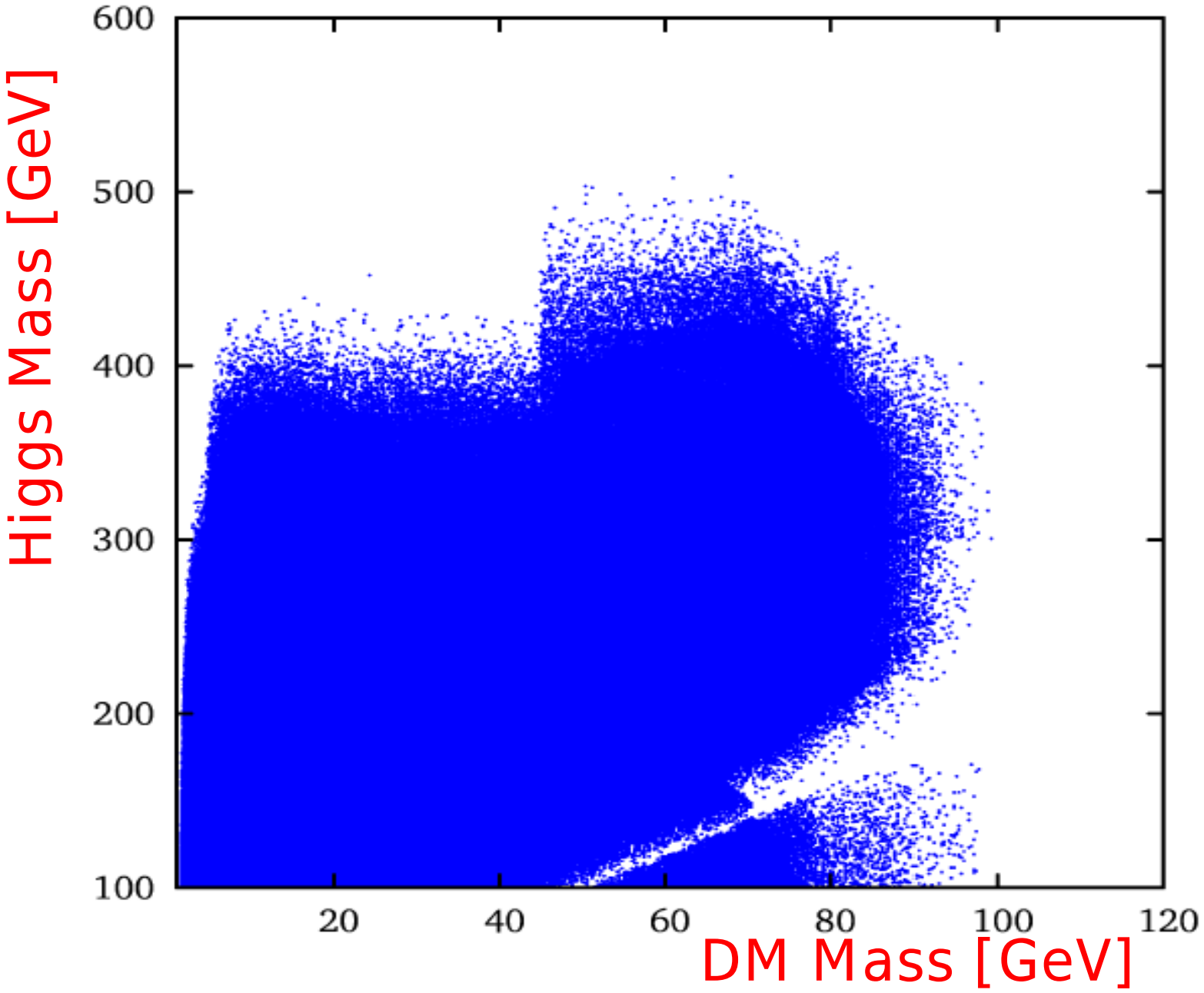
Z2 even

$$\eta_2 = \begin{pmatrix} \tilde{H}_2^+ \\ (\tilde{H}_2 + i\tilde{A}_2)/\sqrt{2} \end{pmatrix}, \qquad \eta_3 = \begin{pmatrix} \tilde{H}_3^+ \\ (\tilde{H}_3 + i\tilde{A}_3)/\sqrt{2} \end{pmatrix}$$

Z2 odd

Dark Matter Stability

. . RELIC DENSITY



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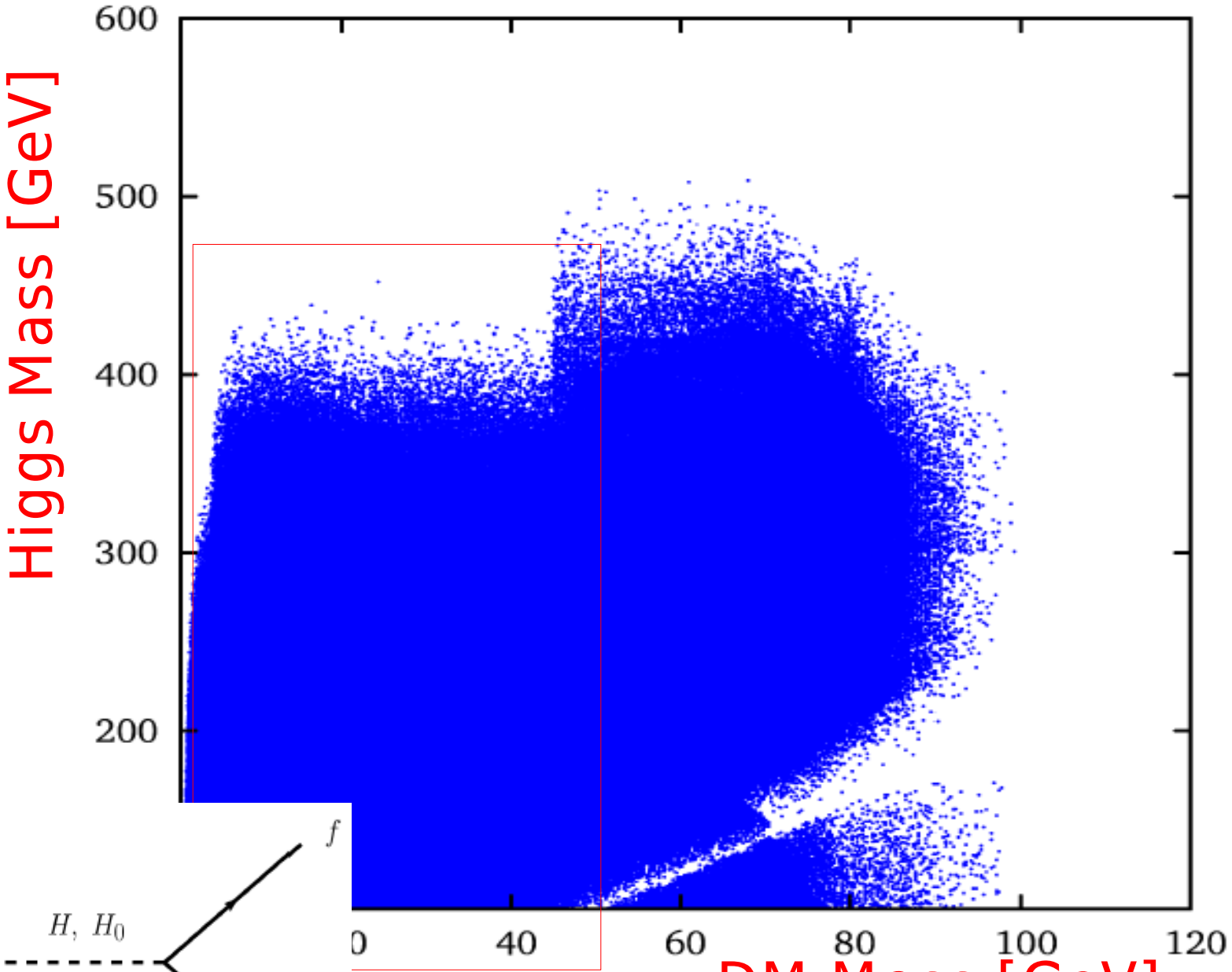

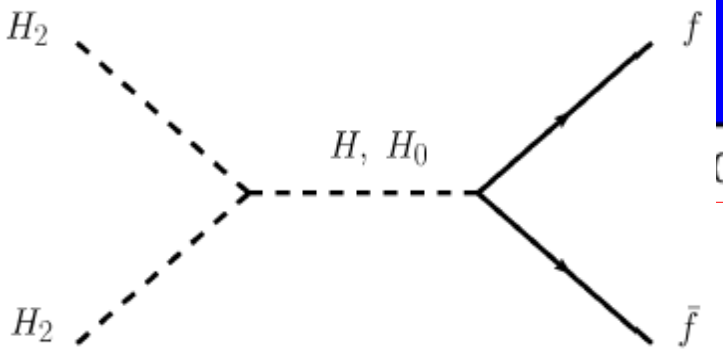

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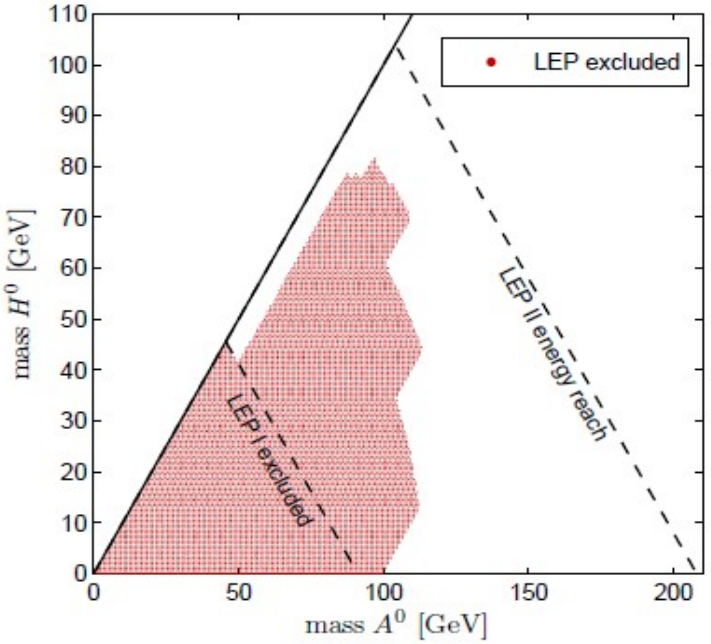

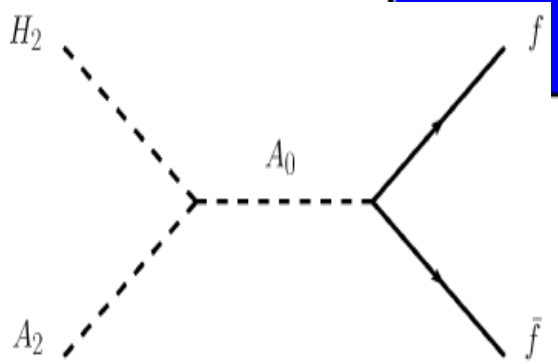

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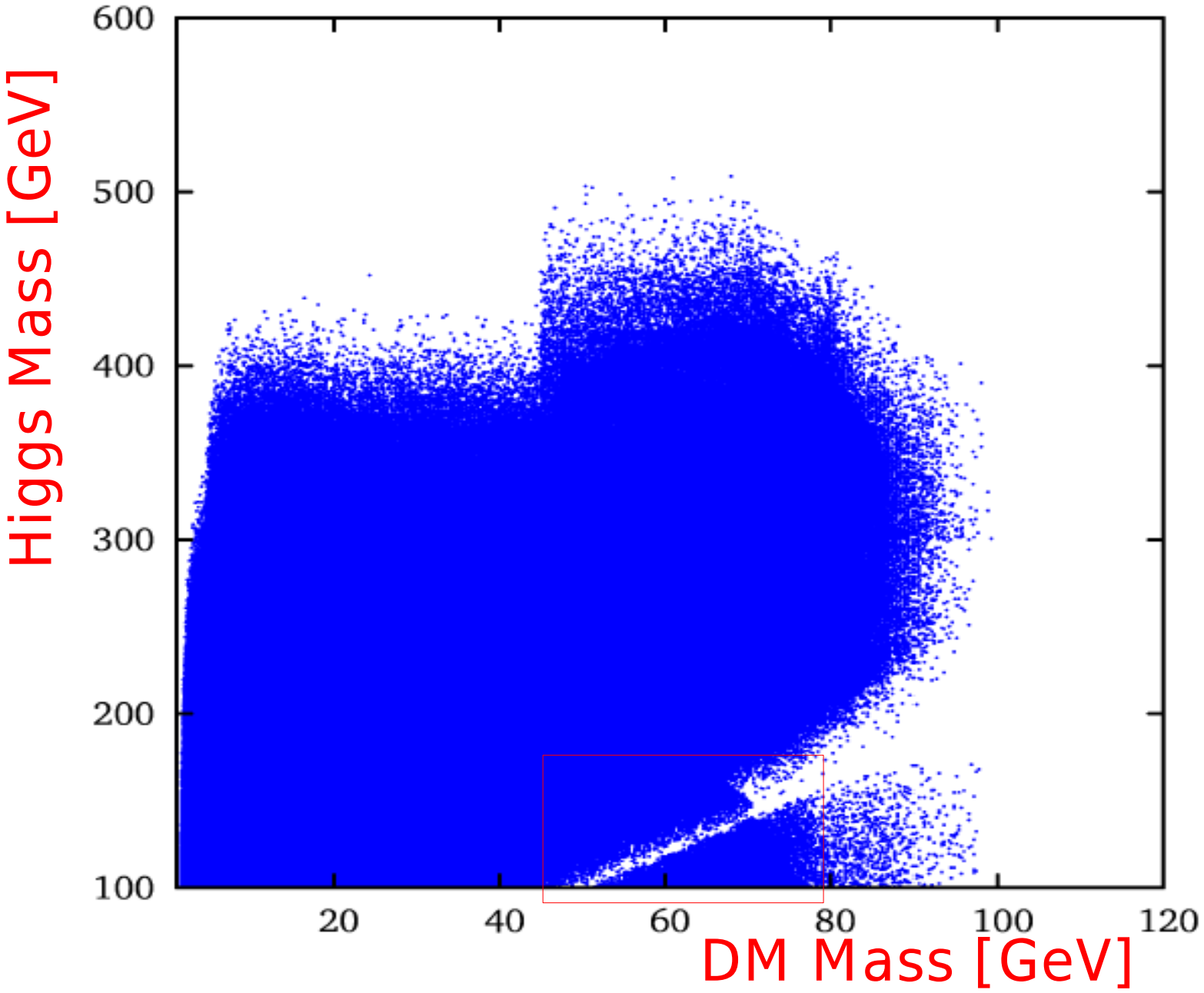
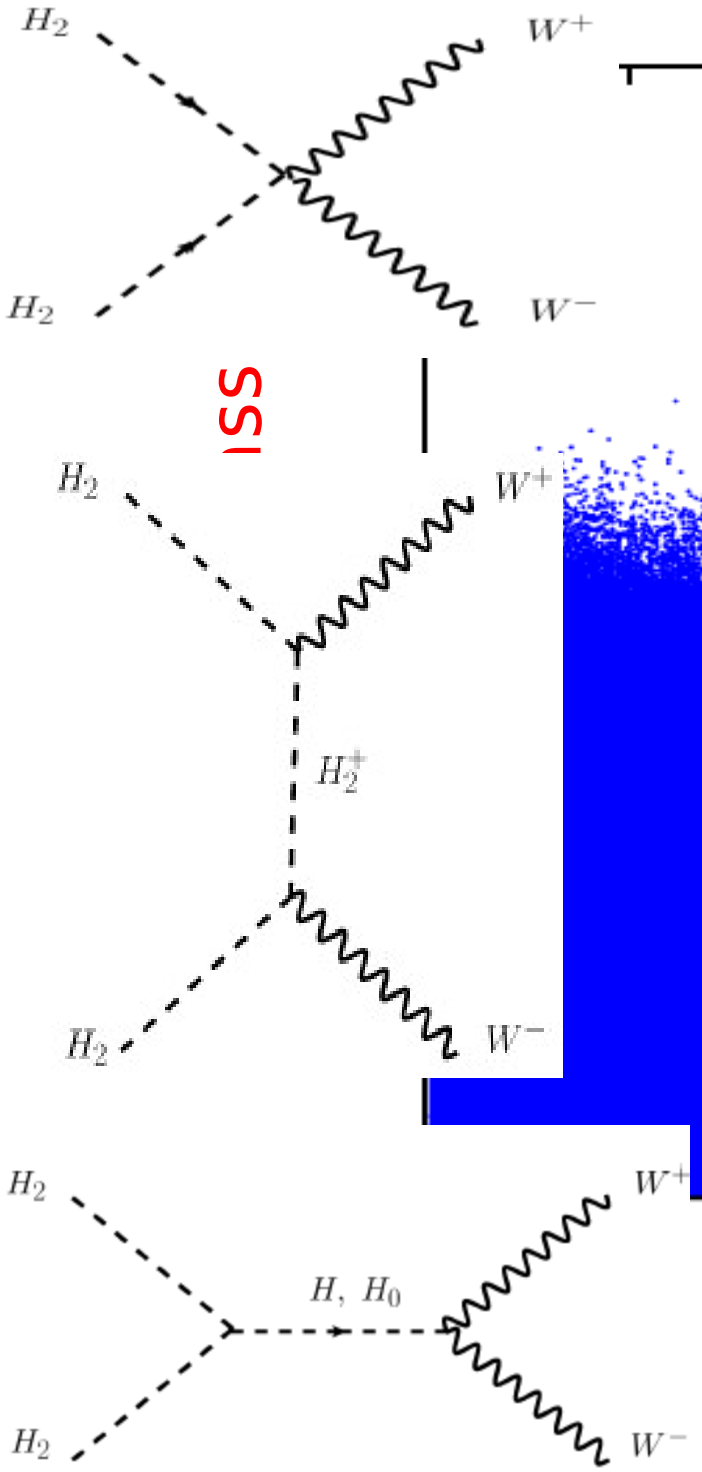
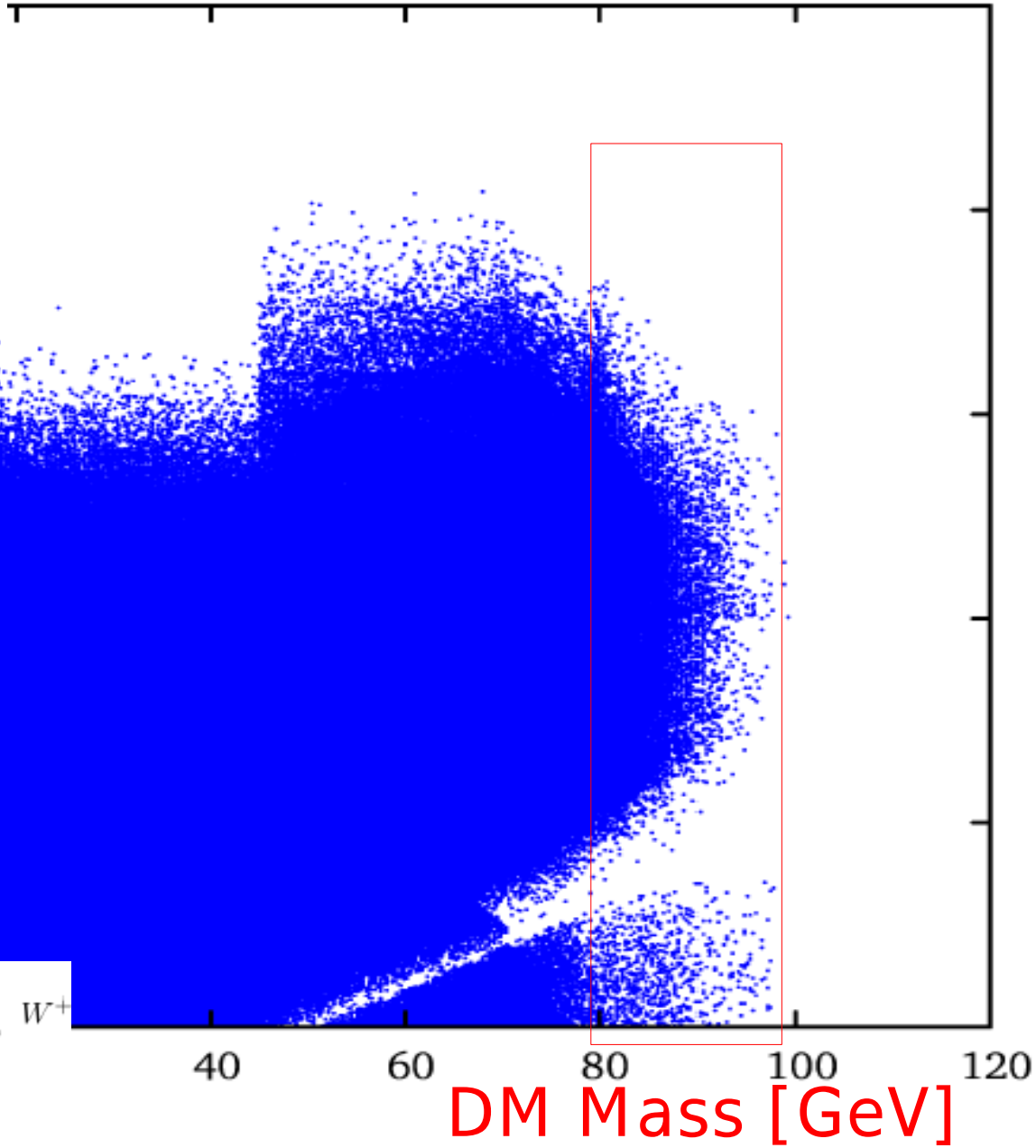
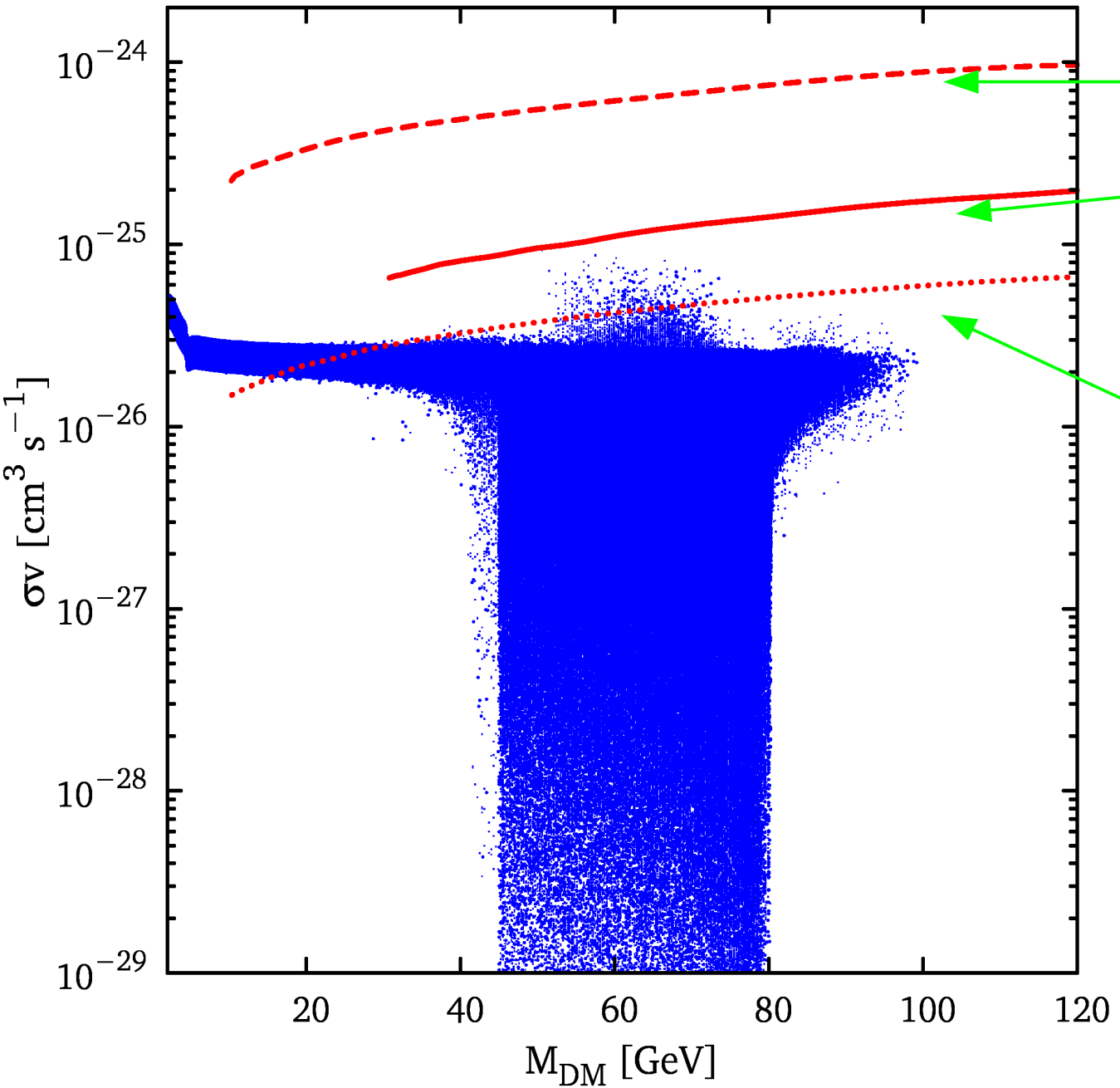


$$M_{DM} \sim M_H/2$$

..RELIC DENSITY





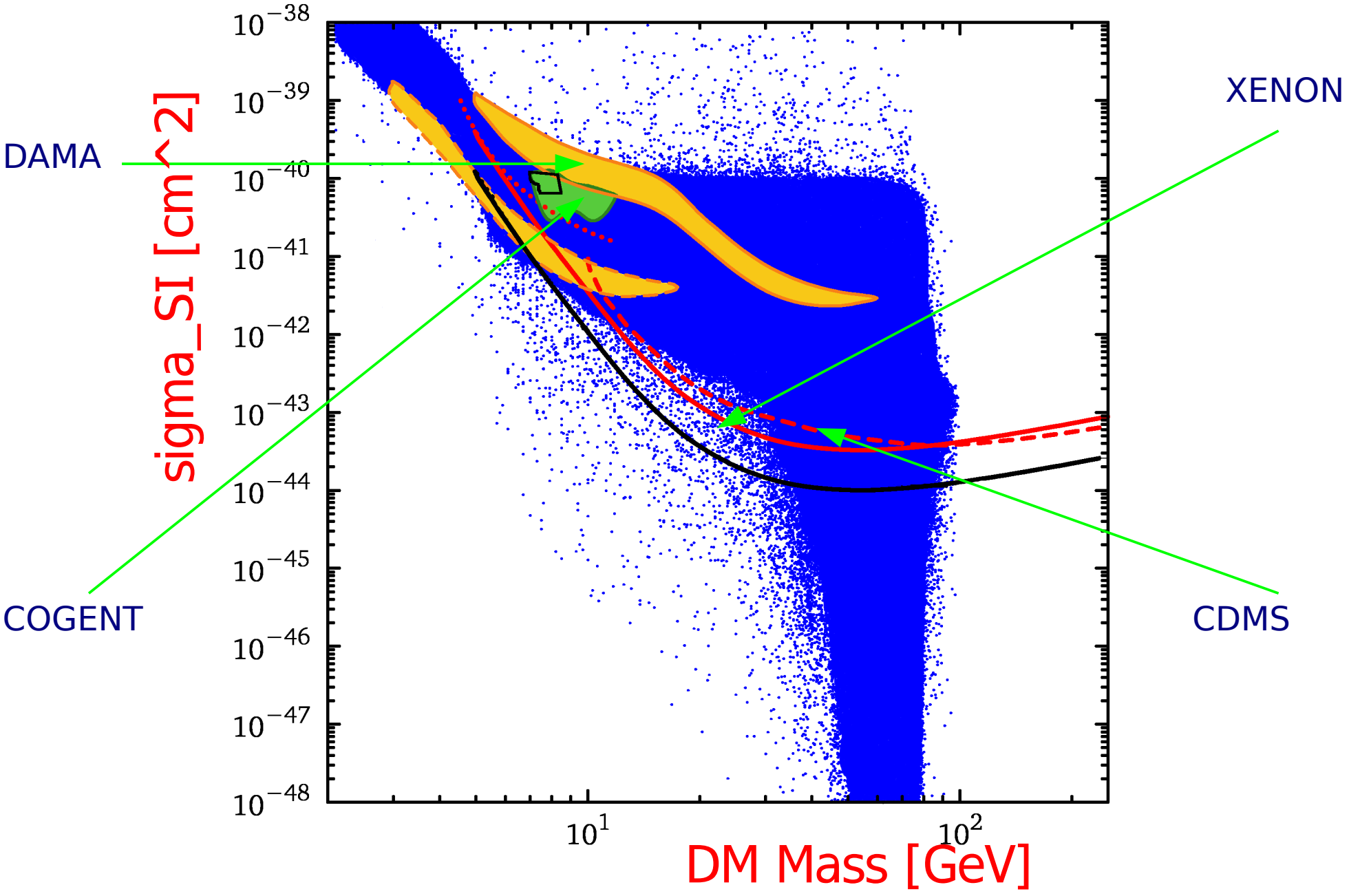


FERMI, Isotropic Diffuse G-ray emission.

FERMI, DRACO Dsph.

Projected 5 years sensitivity from measurements of the IDGE

... Indirect Detection



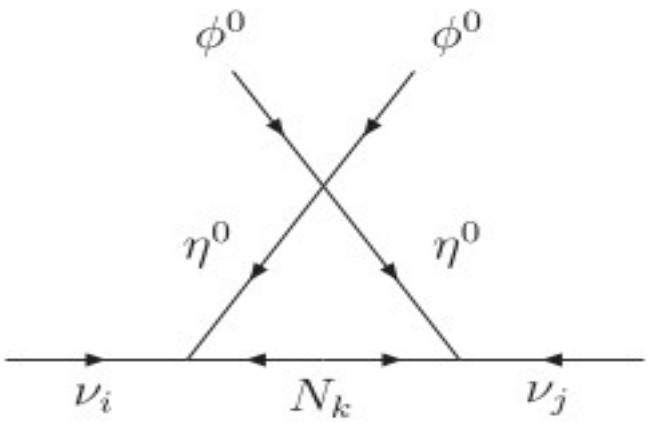
... Direct Detection

Beyond (N+M) models

- So far, the link with neutrinos was essentially conceptual.. (although the discrete group was constraining the Higgs sector hence the DDM phenomenology.)
- Can we go farther and tightly link DM to Neutrinos ?
  - Link through the mass mechanism
  - Link through the mixing angles

Radiative Neutrino masses

- "Scotogenic" DM is a very attractive and successful model linking dark matter to neutrinos.



- DM can be either a scalar or a fermion.
- An imposed parity is required to stabilize the DM.

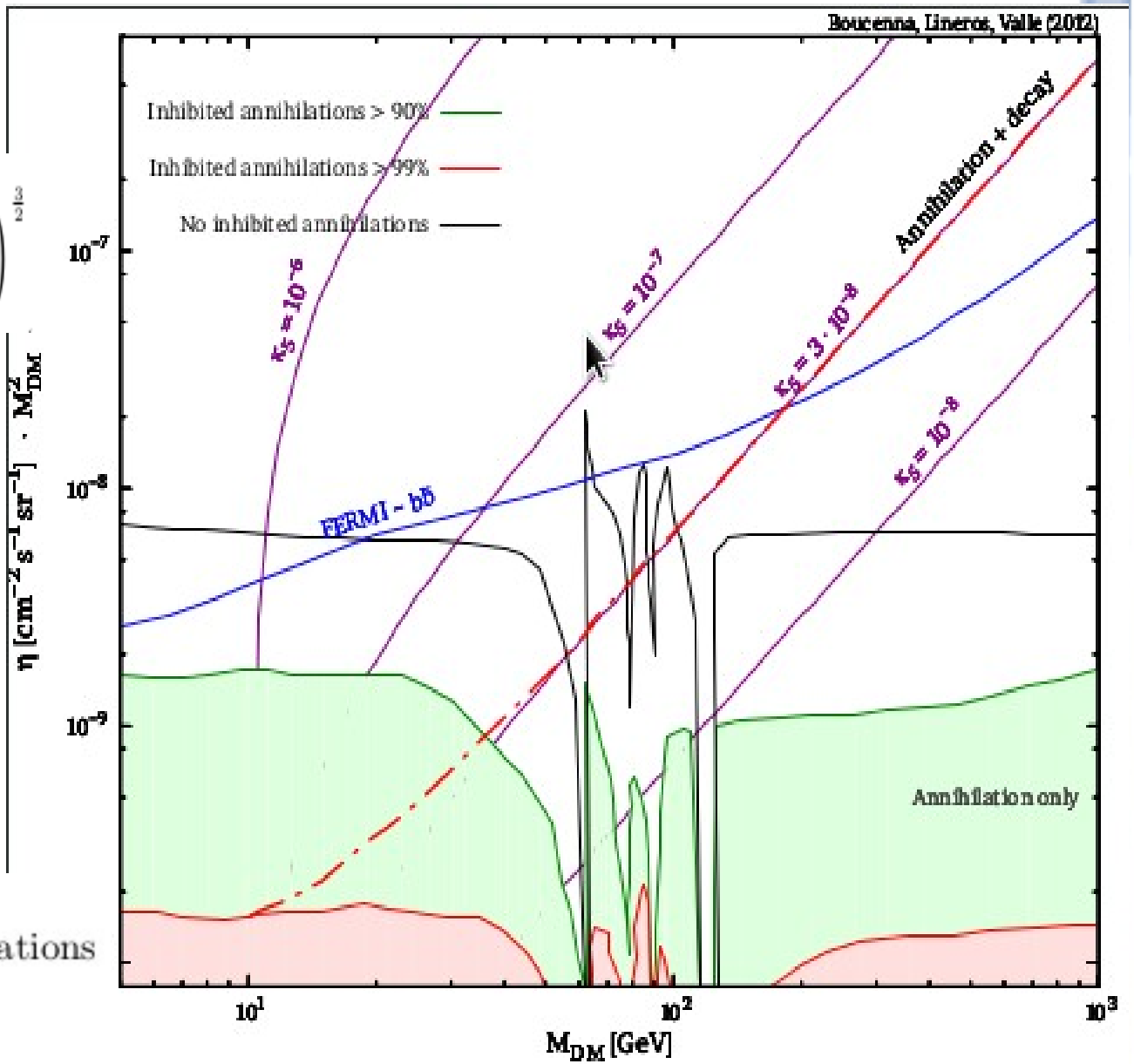
- *DDM philosophy* : Embed the model into a flavor group to motivate the stability and predict the mixing angles.

WORK IN PROGRESS

Gravity Rules !

$$\mathcal{V}_{\rm non-sym} = \sum_{n>4} \frac{\kappa_n}{M_{pl}^{n-4}} \hat{\mathcal{O}}_n \,,$$

$$\Gamma^{ll}(M_{\rm DM}) = \sum_f \frac{3}{8\pi^2} \left(\frac{\kappa_5 Y_f v}{M_{pl}}\right)^2 M_{\rm DM} \left(1 - \frac{4m_f^2}{M_{\rm DM}^2}\right)^{\frac{3}{2}}$$



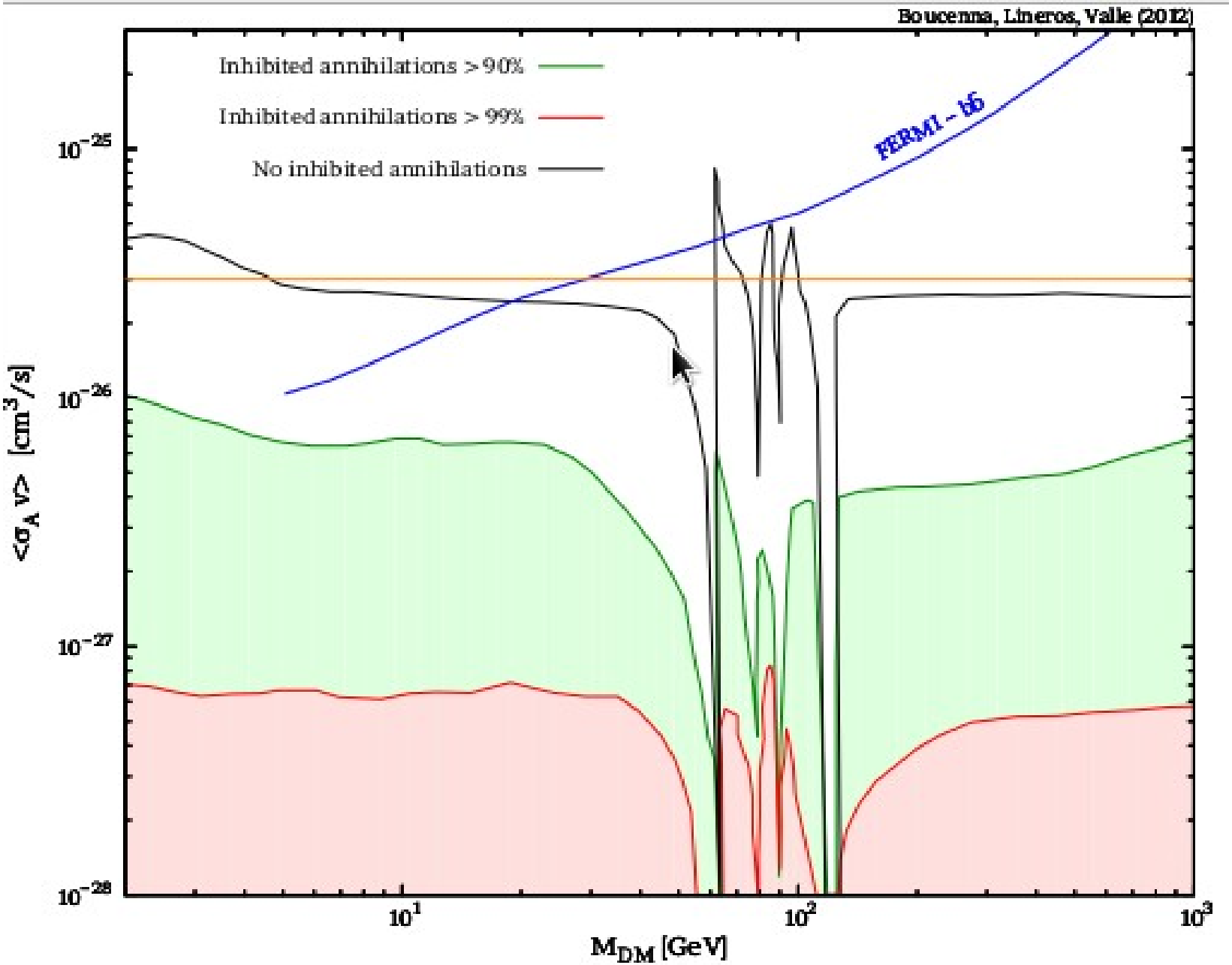
$$\eta(M_{\rm DM}) = \begin{cases} \dfrac{1}{4\pi} \dfrac{\langle \sigma_A v \rangle J_{\Delta\Omega}^{\rm ann}}{2M_{\rm DM}^2} & \text{for annihilations} \\ \dfrac{1}{4\pi} \dfrac{J_{\Delta\Omega}^{\rm dec}}{2\tau_{\rm DM} M_{\rm DM}} & \text{for decays} \end{cases}$$

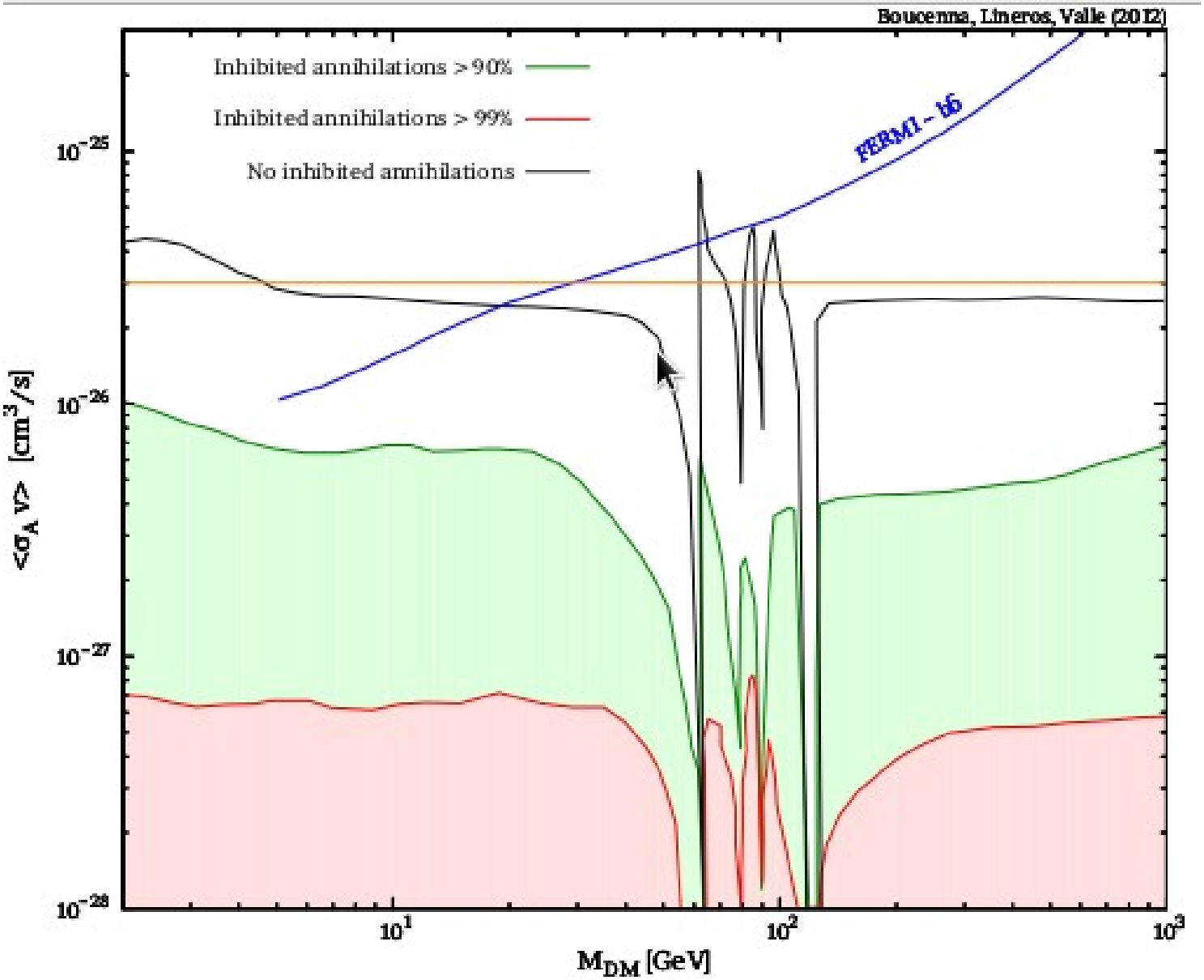
To conclude ...

- Linking the Dark Matter problematic to other BSM sectors is very appealing and conceptually enriching !
- The basic discrete dark matter mechanism motivates well the multi-higgs extensions of the SM but fails to strongly link DM to neutrinos observables.
- An implementation of the idea based on the Scotogenic DM would allow us to go further.
- Approximate discrete symmetries are as interesting as exact ones !

- Thanks.

… Backup slides.


Boucenna, Lineros, Valle (2012)
Inhibited annihilations > 90%
Inhibited annihilations > 99%
No inhibited annihilations
FERMI - 86
10^{-25}
10^{-26}
10^{-27}
10^{-28}
$<\sigma_A v>$ [cm^3/s]
10^1
10^2
10^3
M_{DM} [GeV]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$<\sigma_A v>$ [cm^3/s]
10^1
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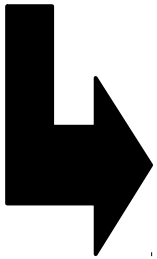
10^3
M_{DM} [GeV]

The Do-it-yourself DDM kit

- Write down the Lagrangian of the model.
- Calculate the mass spectrum then re-parametrize.
- Convert everything to a CalcHEP model file.
- Scan over the parameter space and implement the following cuts : *Bounded-below, LEP limits & oblique parameters, LHC, FCNC, perturbativity, neutrinos + model-dependent stuff.*
- Calculate with Micromegas the relic density of the surviving population of points.
- Calculate the (in)direct detection cross-sections.
- Plot !

Neutrino phenomenology

$$m_D = \begin{pmatrix} x_1 & 0 & 0 & x_4 \\ x_2 & 0 & 0 & 0 \\ x_3 & 0 & 0 & 0 \end{pmatrix}, \quad M_R = \begin{pmatrix} M_1 & 0 & 0 & 0 \\ 0 & M_1 & 0 & 0 \\ 0 & 0 & M_1 & 0 \\ 0 & 0 & 0 & M_2 \end{pmatrix}$$



$$m_\nu = -m_{D_{3\times4}} M^{-1}_{R_{4\times4}} m^T_{D_{3\times4}} \equiv \begin{pmatrix} y^2 & ab & ac \\ ab & b^2 & bc \\ ac & bc & c^2 \end{pmatrix}$$

$M_3 = 0$ (IH) , $\text{Theta}_{13} = 0$

$$V_3 \sim \begin{pmatrix} 0 \\ -b/c \\ 1 \end{pmatrix}$$