DARK MATTER
From
A4 Flavor Symmetry

Sofiane Boucenna
IFIC/Universidad de Valencia

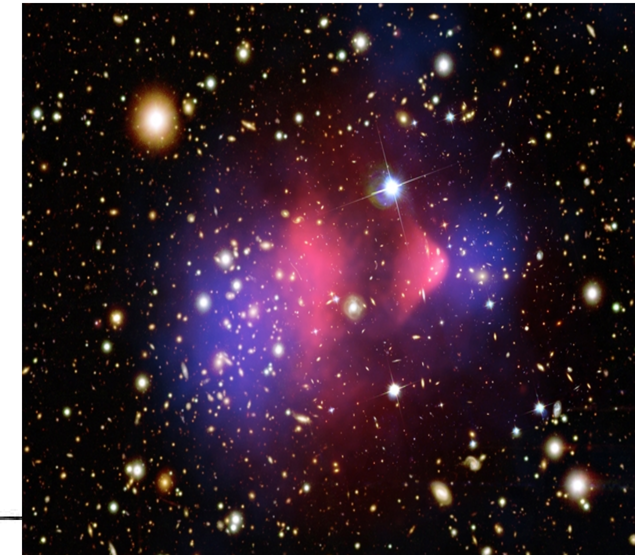
Based on :
1007.0871 [M.Hirsch, S.Morisi, E.Peinado, J.W.F.Valle] *Phys.Rev. D82 (2010) 116003*
1101.2874 [SB, M. Hirsch, S. Morisi, E. Peinado, M. Taoso, J.W.F. Valle] *JHEP 1105 (2011) 037*

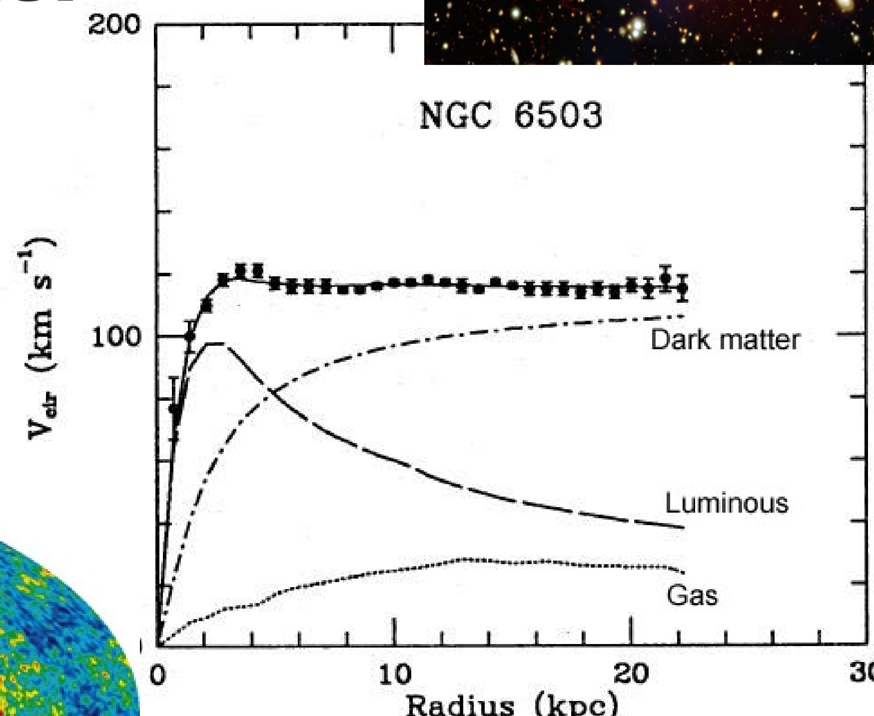
Cosmology & Astronomy :

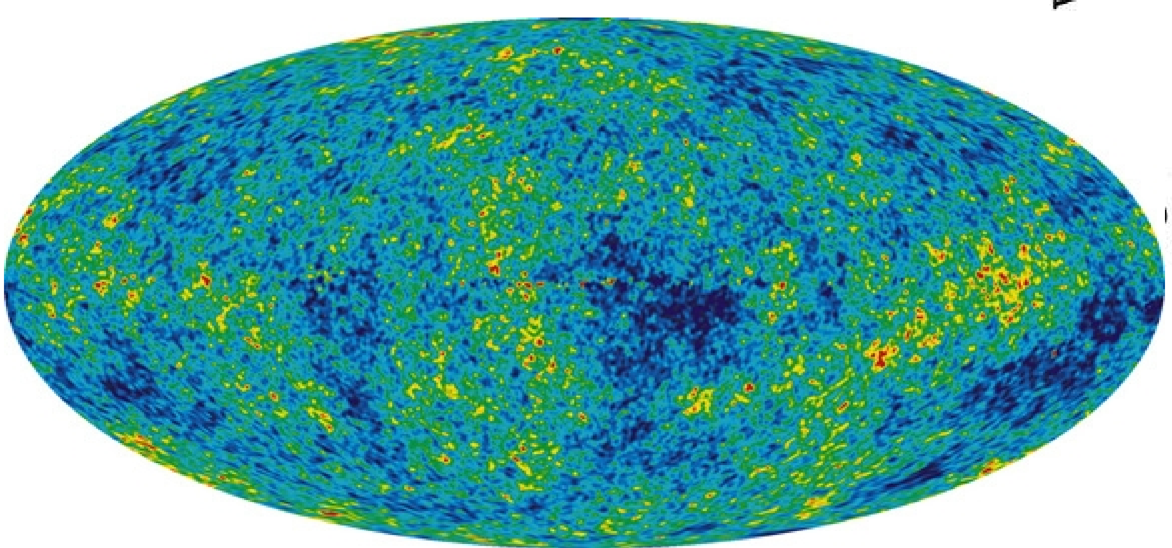
... 04% Ordinary Matter

... 23% Dark Matter

... 73% Dark Energy







We know that a DM particle must be :

... Neutral

... Cold

... “Non-interactingish”

... Long lived ... Stable

Bertone et. al. 040417, ***Phys.Rept. 405 (2005) 279-390***

Taoso et. al. 0711.4996, ***JCAP 0803 (2008) 022***

Neutrinos are massive & show mixing patterns, we need :

… New Particles

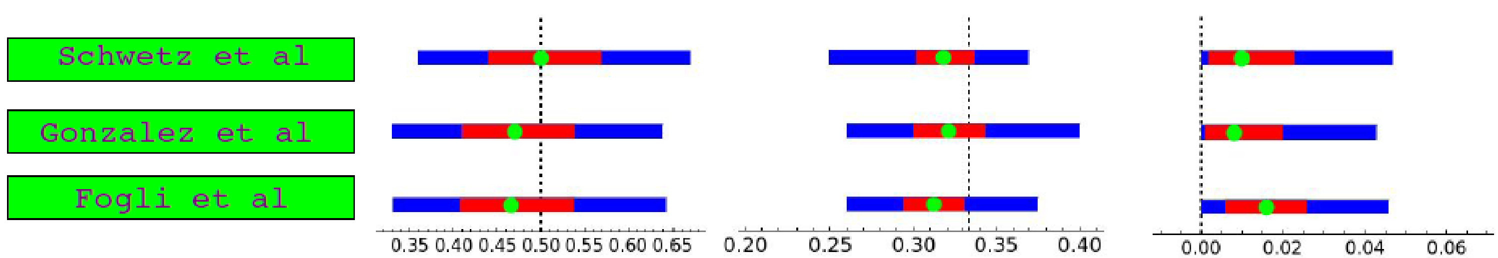
… New Symmetry

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

Tribimaximal ansatz

Harrison, Perkins & Scott

$\sin^2\theta_{23} = 0.5$ $\sin^2\theta_{12} = 1/3$ $\sin^2\theta_{13} = 0$



Schwetz et. al. 1103.0734, ***New J.Phys. 13 (2011) 063004***

Dark Matter & Neutrino Masses :

... Well established

... Need BSM mechanisms

Can we build a model

unifying them in a somehow minimal

way ?

DM Stability

Common ways to stabilize DM :

... discrete Z_2 of gauged $U(1)_{B-L}$ **(R parity, GUT)**

... accidentally **(minimal DM, hidden vector DM)**

... from gauged symmetries

... "hands"

T.Hambye 1012.4587

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T.Hambye 1012.4587

$$S = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \quad T = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$

A_4 is :

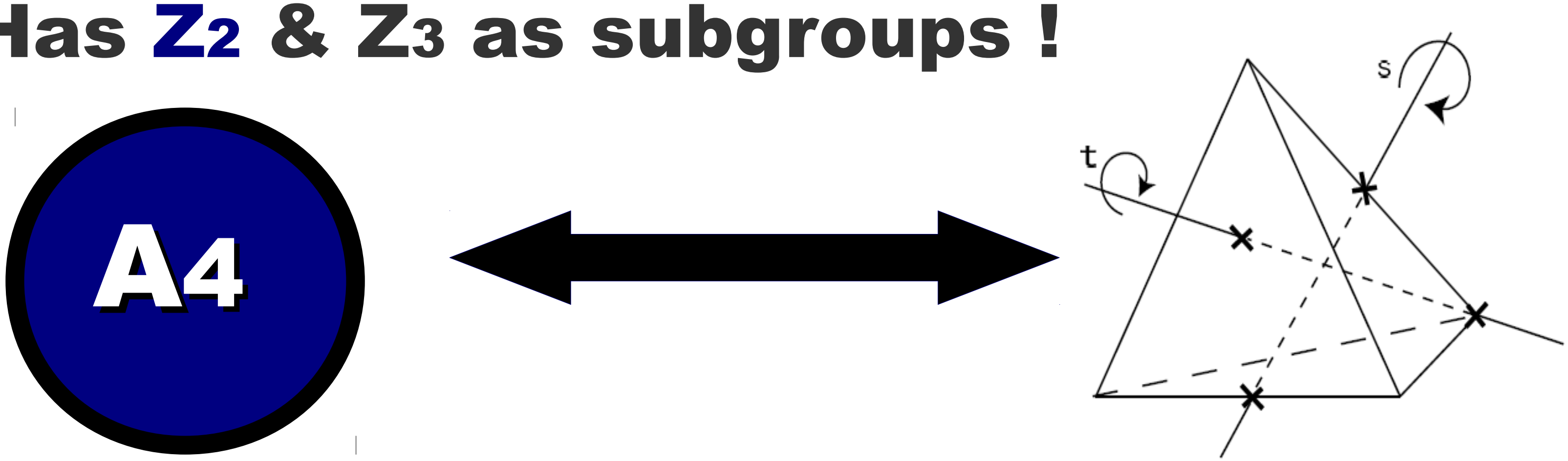
... Group of even perms. of 4 objects

... Non-Abelian

... Discrete (No Goldstones/Gauge bosons)

... Minimal (3D irrep. , TBM)

... Has Z_2 & Z_3 as subgroups !

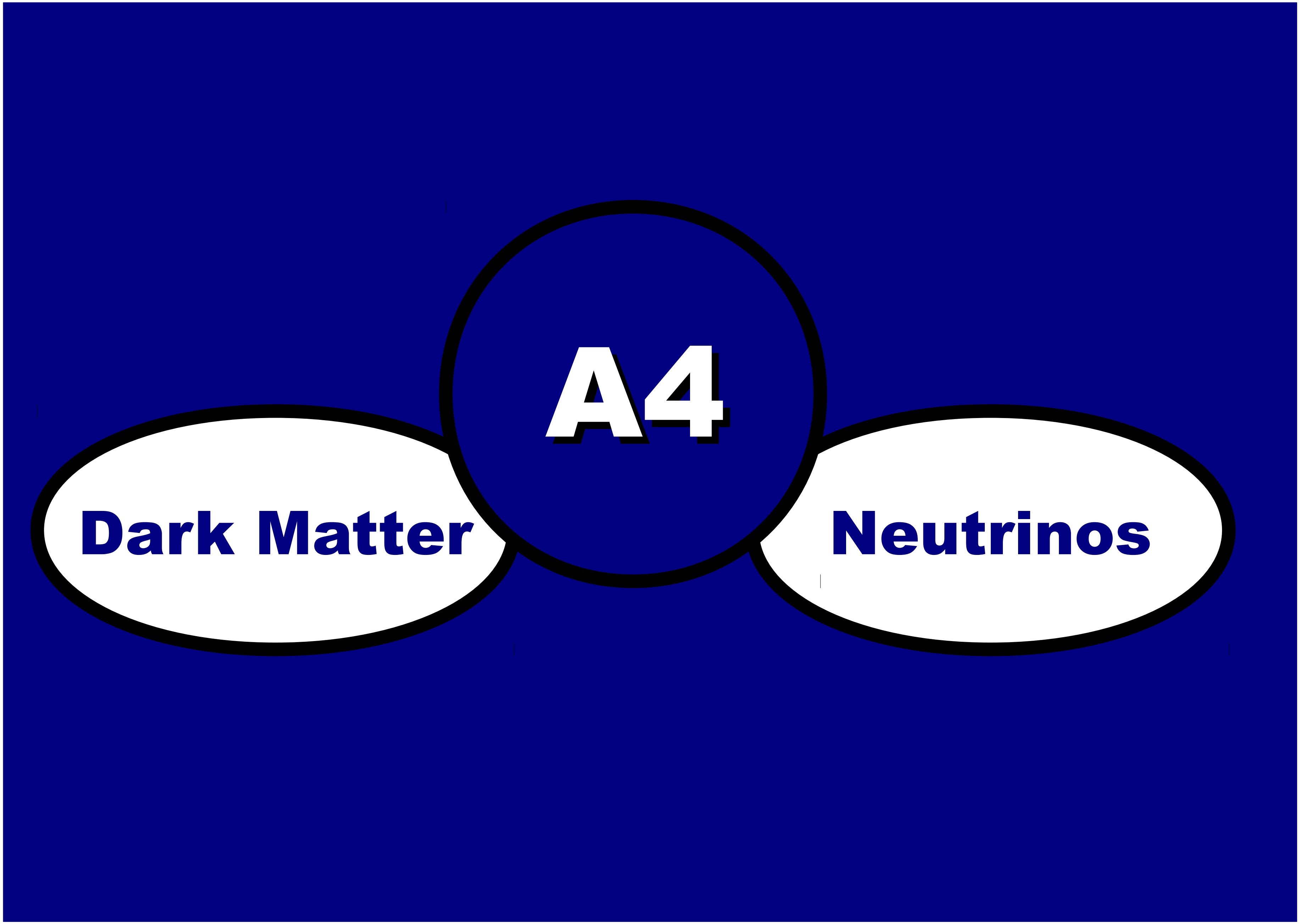


$$A_4 \xrightarrow{\text{Spontaneously}} Z_2$$

$\langle \eta \rangle \sim (1, 0, 0)$ **Triplet of A_4**

$$S\Psi = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} = \begin{pmatrix} a_1 \\ -a_2 \\ -a_3 \end{pmatrix}$$

... 'S' generator of the Z_2 subgroup


A4
Dark Matter
Neutrinos

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

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	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.

Neutrino phenomenology

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

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

M3 =0 (IH) , Theta13 = 0

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

... Z2 residual symmetry

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

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

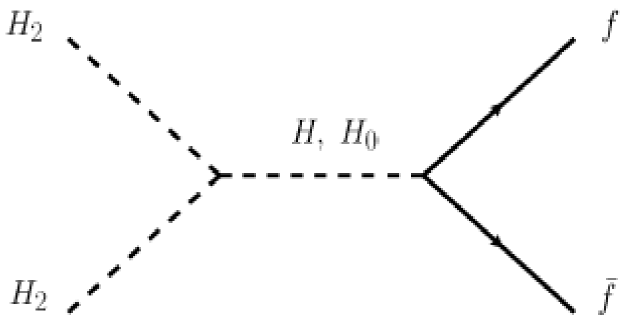
→ **Z2 even**

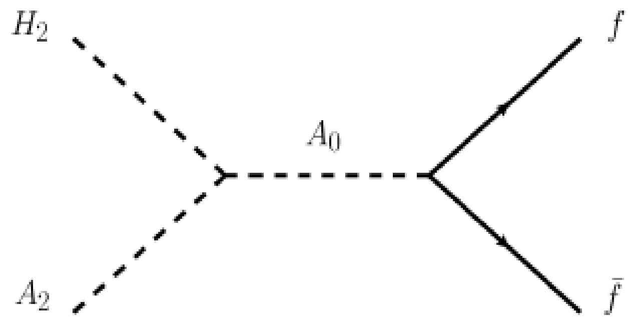
$$\eta_2 = \begin{pmatrix} \tilde{H}_2^+ \\ (\tilde{H}_2 + i\tilde{A}_2)/\sqrt{2} \end{pmatrix}, \qquad \eta_3 = \begin{pmatrix} \tilde{H}_3^+ \\ (\tilde{H}_3 + i\tilde{A}_3)/\sqrt{2} \end{pmatrix}$$

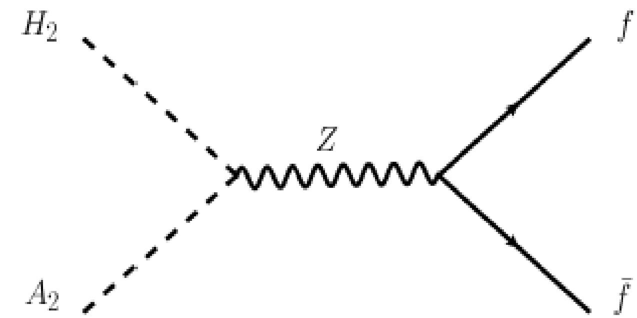
→ **Z2 odd** → **Dark Matter Stability**

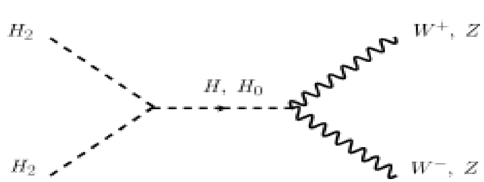
$$
\begin{aligned}
V &= \mu_\eta^2 \eta^\dagger \eta + \mu_H^2 H^\dagger H \\
&+\lambda_1 [H^\dagger H]^2 + \lambda_2 [\eta^\dagger \eta]_1^2 + \\
&+\lambda_3 [\eta^\dagger \eta]_{1'} [\eta^\dagger \eta]_{1''} \\
&+\lambda_4 [\eta^\dagger \eta^\dagger]_{1'} [\eta\eta]_{1''} + \lambda_{4'} [\eta^\dagger \eta^\dagger]_{1''} [\eta\eta]_{1'} \\
&+\lambda_5 [\eta^\dagger \eta^\dagger]_1 [\eta\eta]_1 \\
&+\lambda_6 ([\eta^\dagger \eta]_{3_1} [\eta^\dagger \eta]_{3_1} + h.c.) \\
&+\lambda_7 [\eta^\dagger \eta]_{3_1} [\eta^\dagger \eta]_{3_2} \\
&+\lambda_8 [\eta^\dagger \eta^\dagger]_{3_1} [\eta\eta]_{3_2} \\
&+\lambda_9 [\eta^\dagger \eta]_{1'} [H^\dagger H] \\
&+\lambda_{10} [\eta^\dagger H][H^\dagger \eta] \\
&+\lambda_{11} ([\eta^\dagger \eta^\dagger]_1 H H + h.c.) \\
&+\lambda_{12} ([\eta^\dagger \eta^\dagger]_{3_1} [\eta H] + h.c.) \\
&+\lambda_{13} ([\eta^\dagger \eta^\dagger]_{3_2} [\eta H] + h.c.) \\
&+\lambda_{14} ([\eta^\dagger \eta]_{3_1} \eta^\dagger H + h.c.) \\
&+\lambda_{15} ([\eta^\dagger \eta]_{3_2} \eta^\dagger H + h.c.)
\end{aligned}
$$

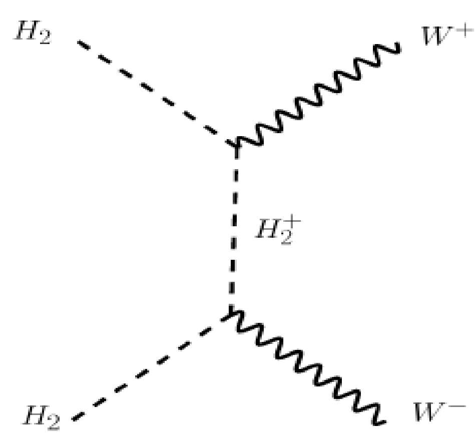
… Relevant Diagrams

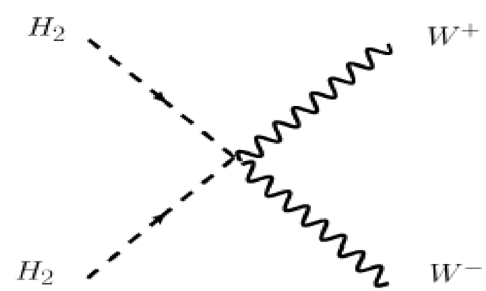


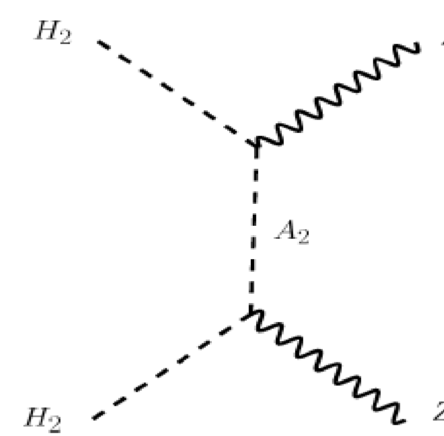












Constraints :

... **Relic density**

... **Collider bounds**

... **EW precision tests**

... **Vacuum stability**

... **Perturbativity**

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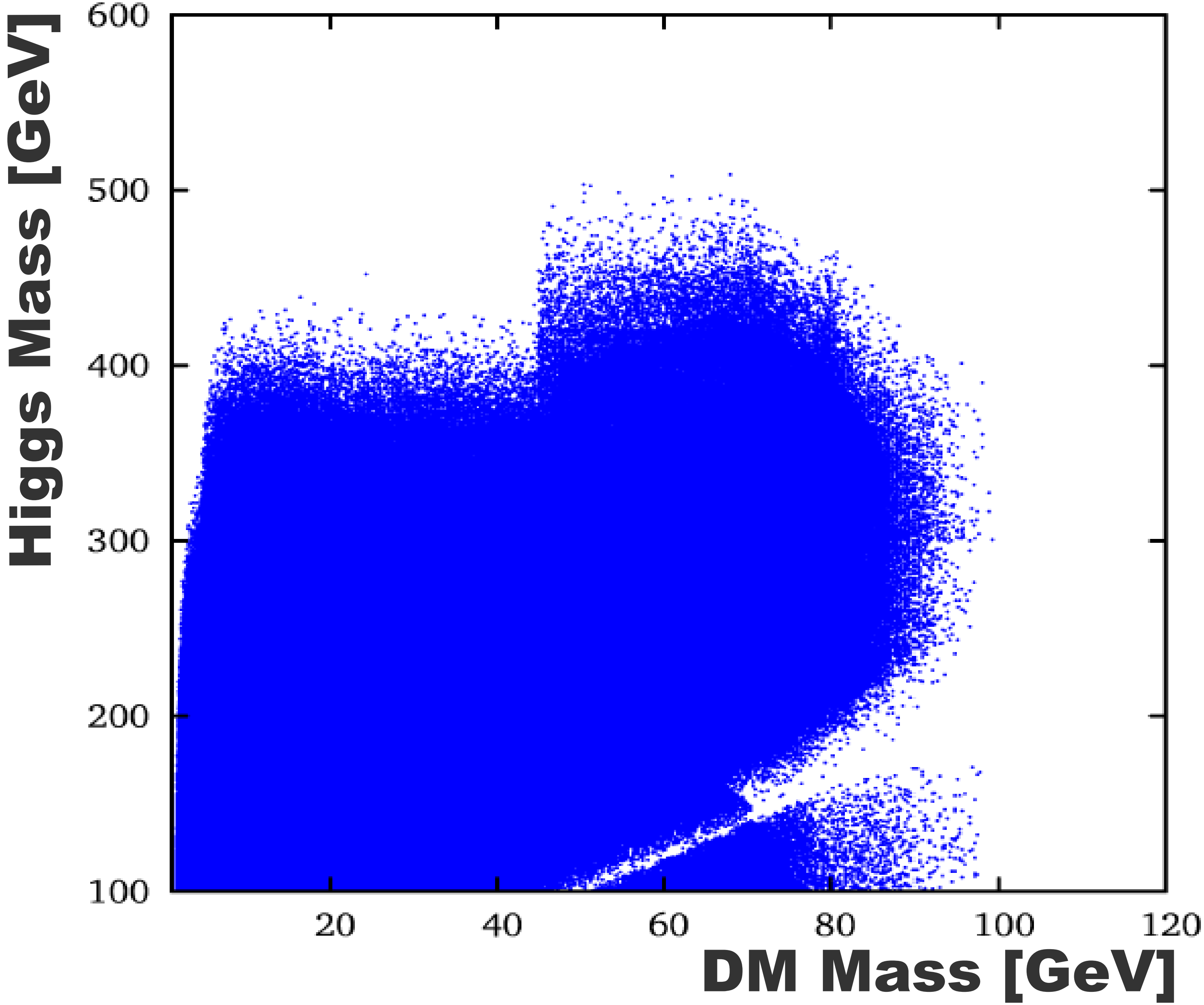
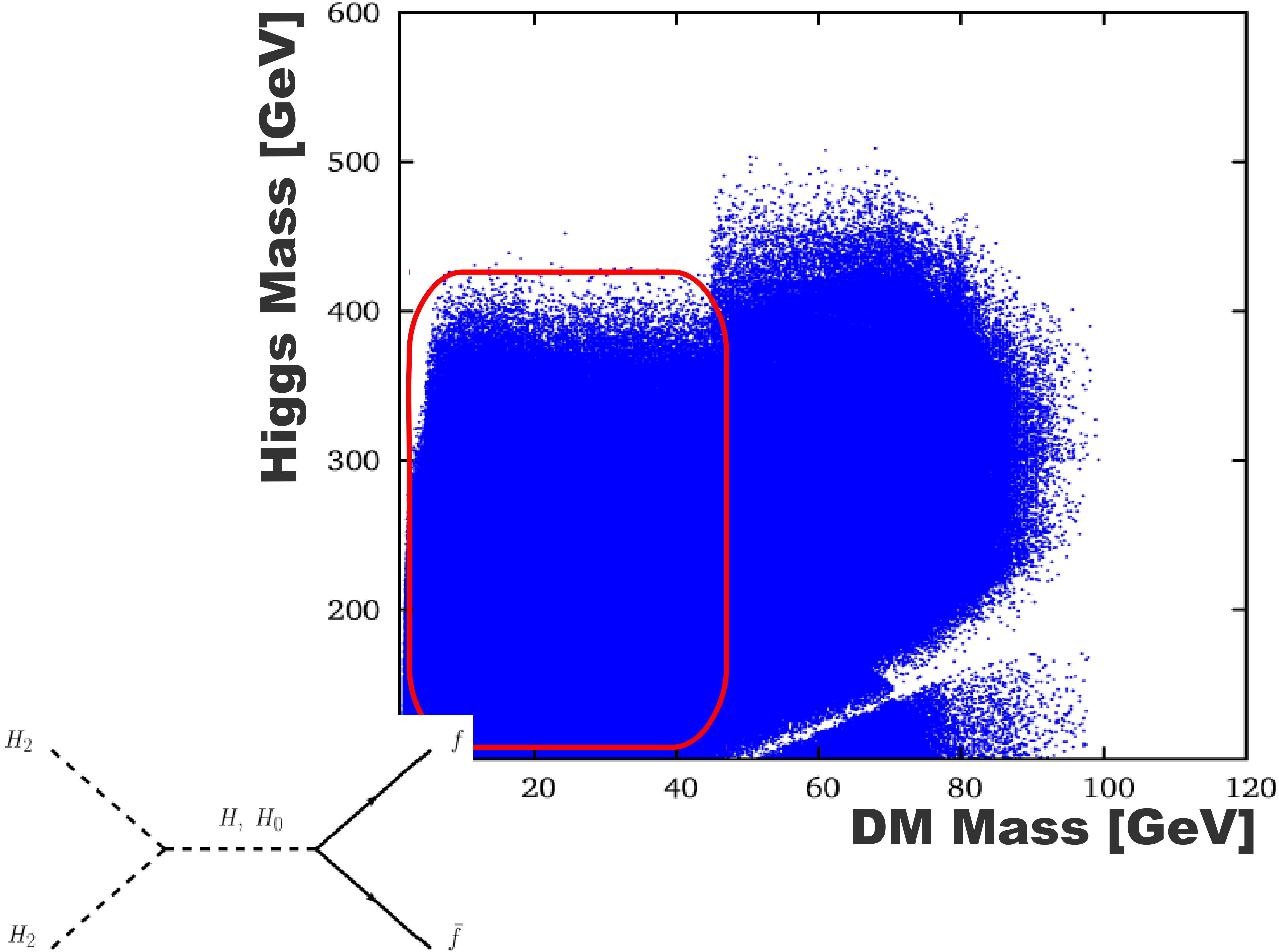
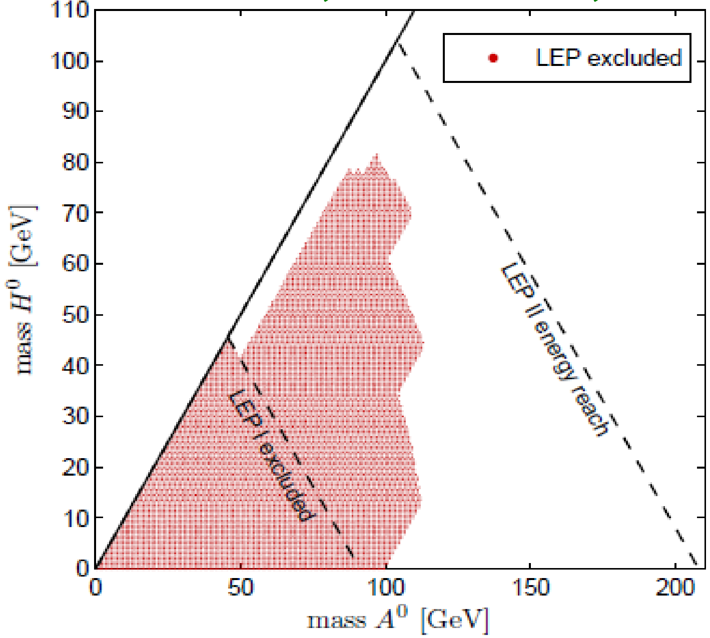
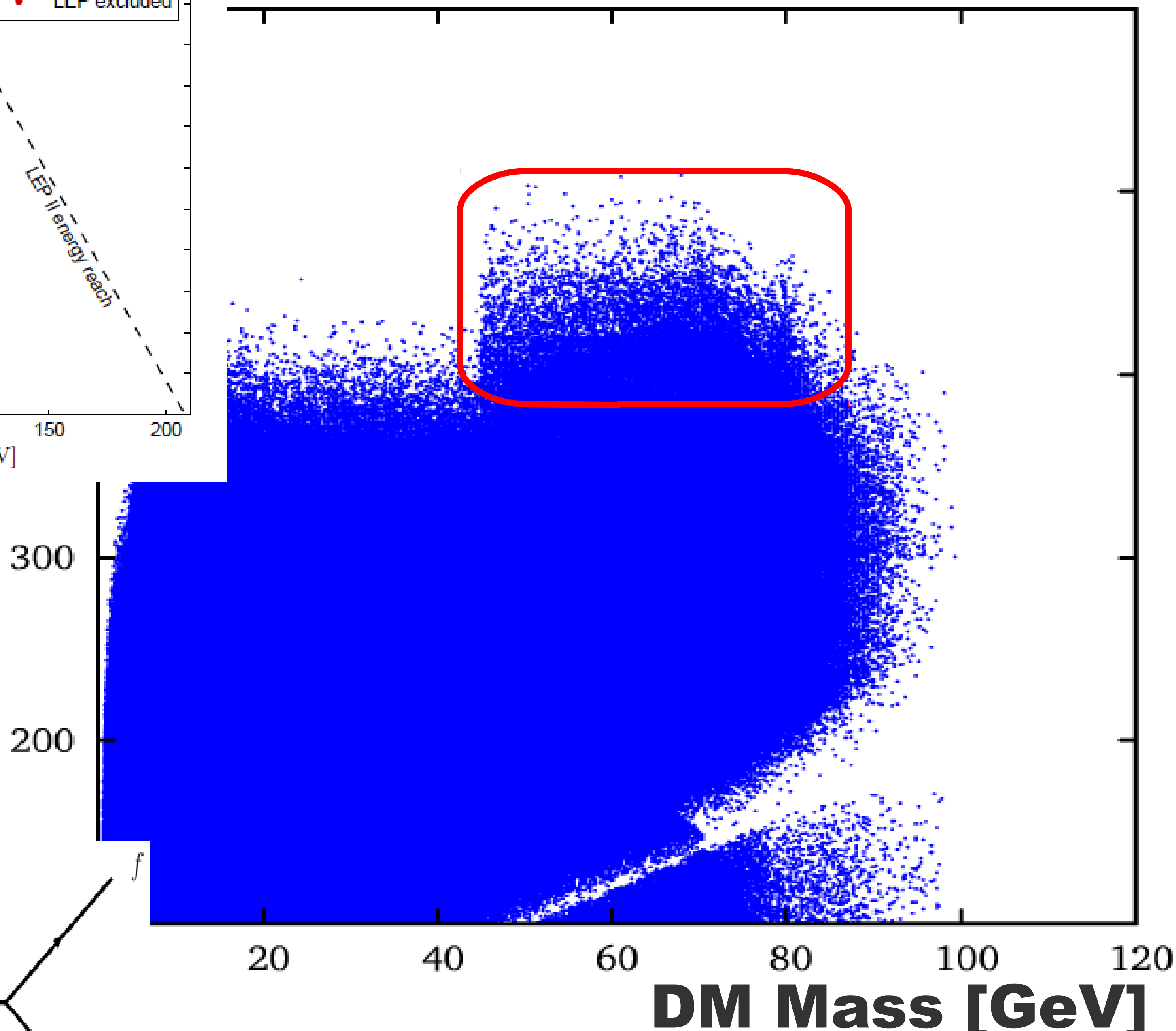
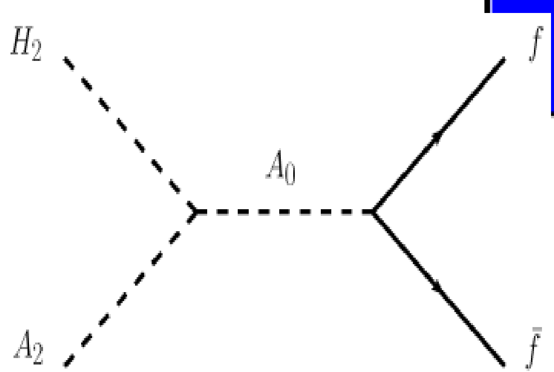


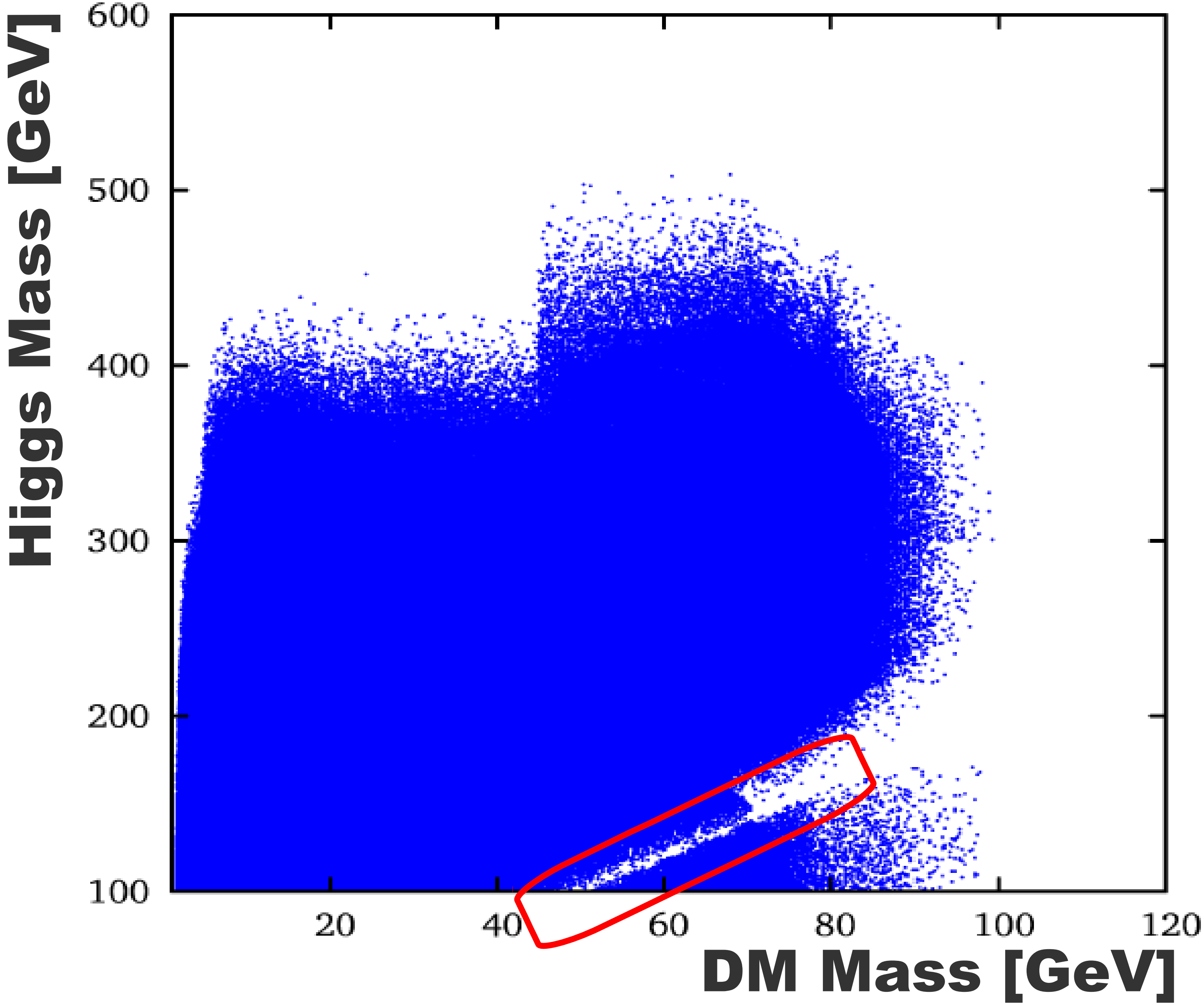

Higgs Mass [GeV]
600
500
400
300
200
20
40
60
80
100
120
DM Mass [GeV]
H_2
H_2
$H,\ H_0$
f
$\bar{f}$

Lundstrom et al, 0810.3924, *PRD79*



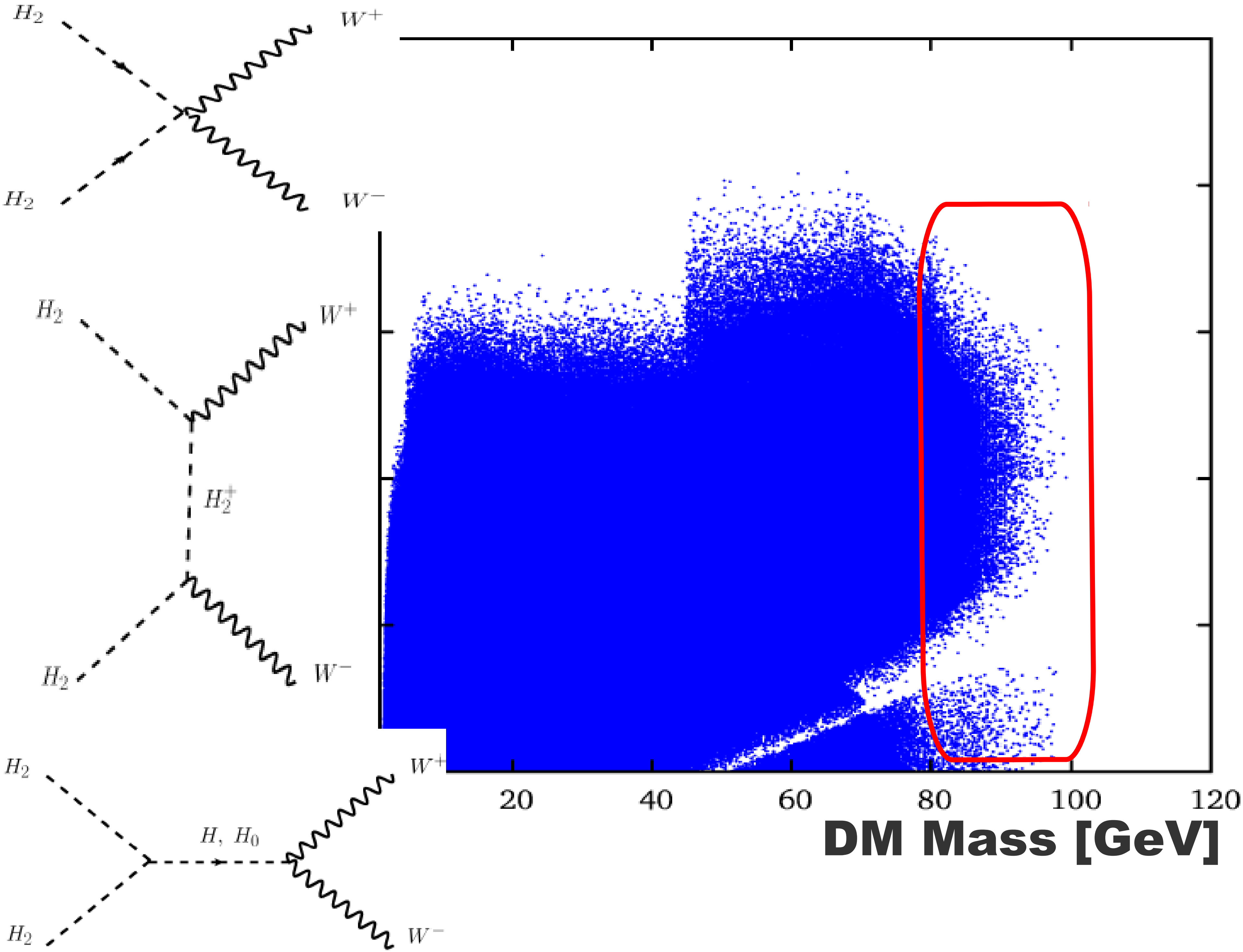




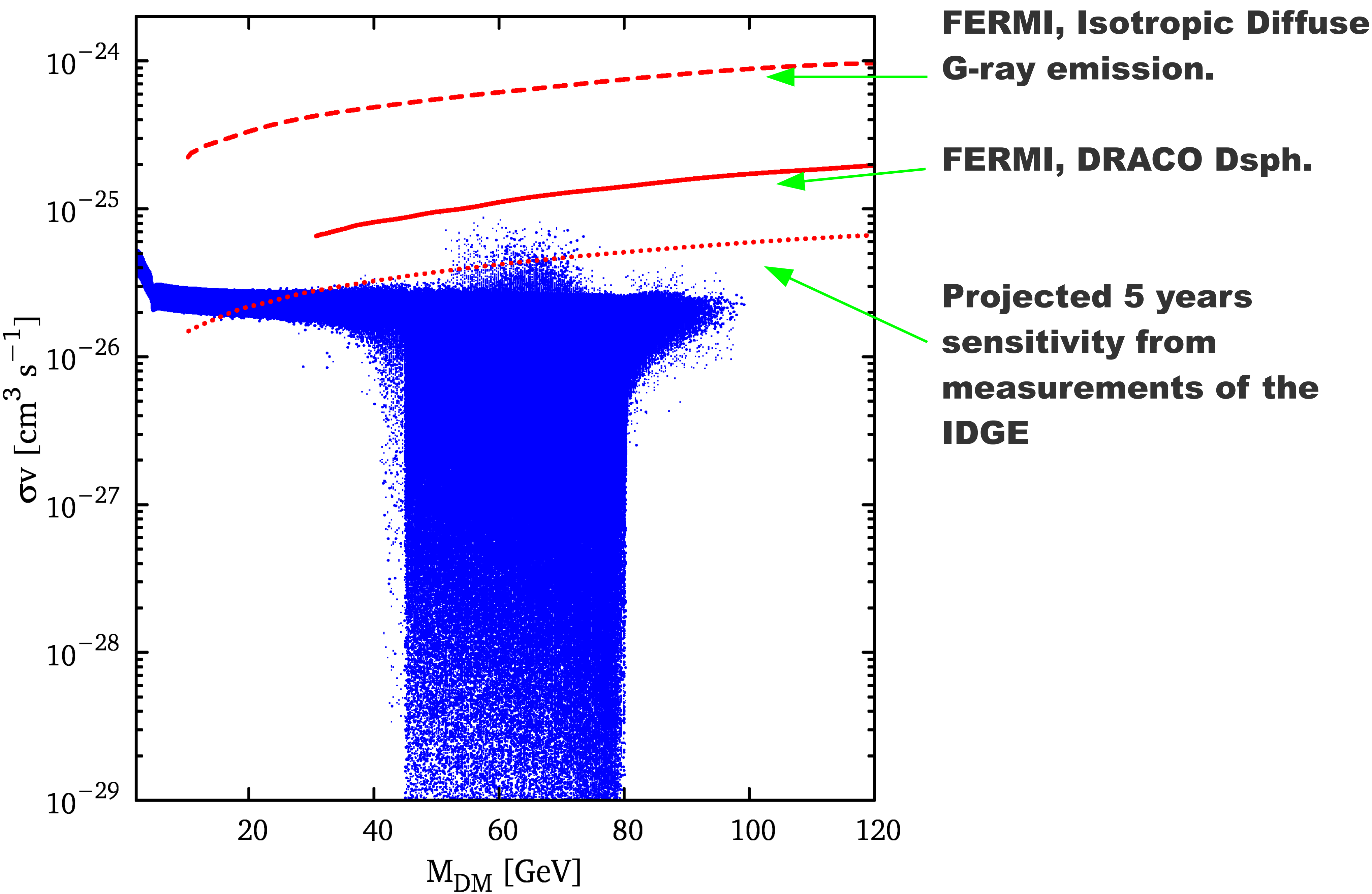


Higgs Mass [GeV]
600
500
400
300
200
100
20
40
60
80
100
120
DM Mass [GeV]

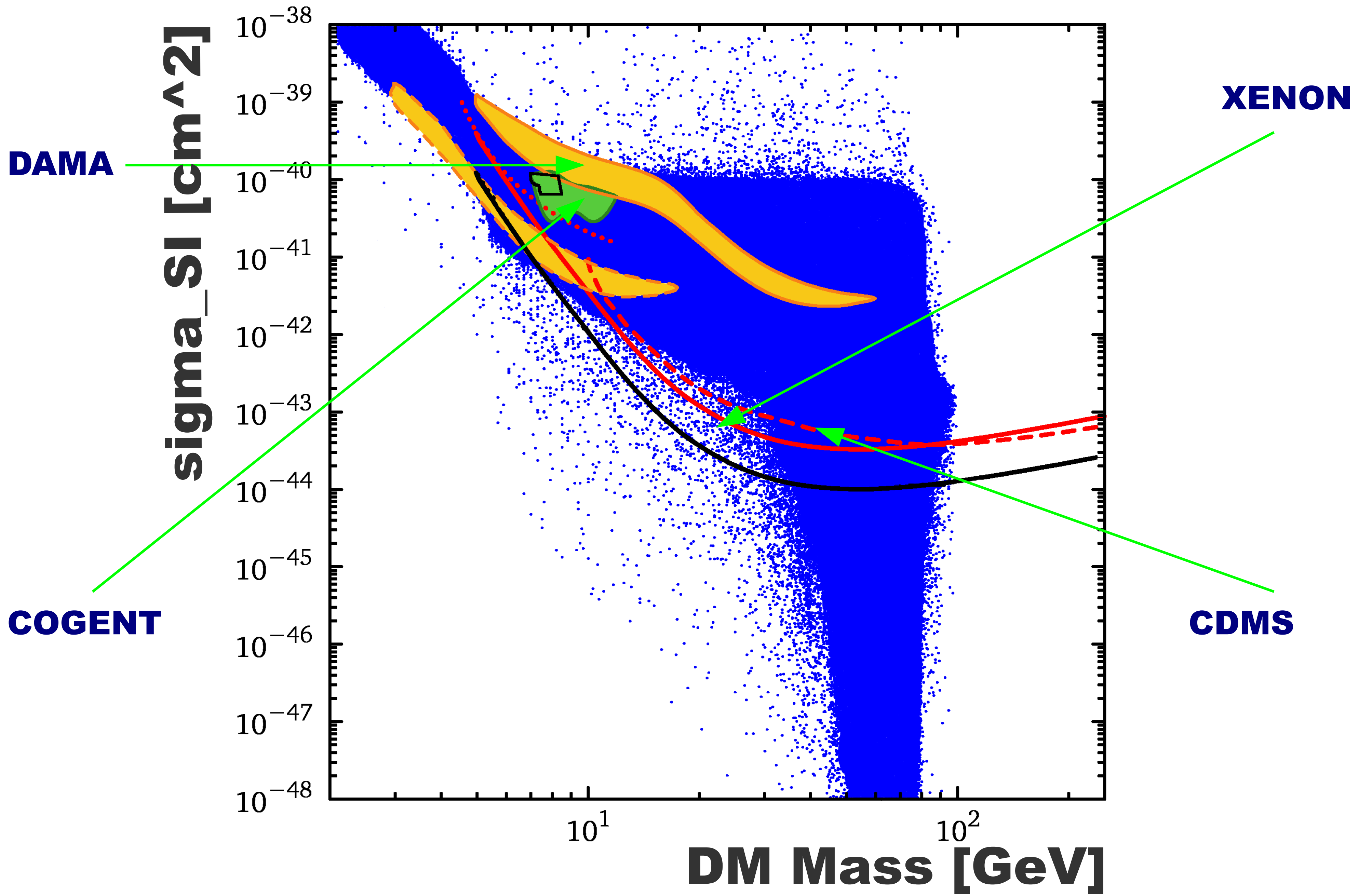
$$M_{DM} \sim M_H/2$$



H_2
H_2
W^+
W^-
H_2
H_2
H_2^+
W^+
W^-
H_2
H_2
$H,\ H_0$
W^+
W^-
20
40
60
80
100
120
DM Mass [GeV]



... Indirect Detection



... Direct Detection

The Model offers a stable DM candidate due to a residual symmetry arising from a discrete non-Abelian flavor symmetry.

... It is consistent with Neutrino Phenomenology

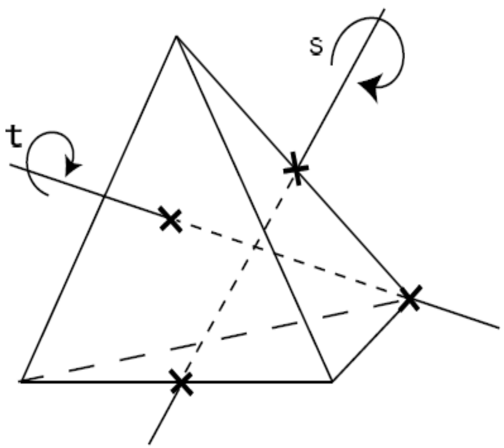
... Predicts IH & vanishing theta13 $m_3 = 0$ $\theta_{13} = 0$

... We found Regions compatible with Cosmology

... Direct detection possibilities.

... T2K $\rightarrow$ **Meloni, Morisi, Peinado, 1011.1371,** ***Phys.Lett. B697 (2011) 339-342***

... Thanks



A4

Irrep: three singlets 1, 1’, 1” and one triplet 3

smallest discrete group with triplet irrep

$$1' \times 1' = 1'', \; 1' \times 1'' = 1, \; 1'' \times 1'' = 1' \text{ etc.}$$

$$3 \times 3 = 1 + 1' + 1'' + 3 + 3$$

A4 Symmetry

… The Generators are :

S and T $\qquad$ $S^2 = T^3 = (ST)^3 = \mathcal{I}.$

$1,\ 1',\ 1''$ and 3

1	$S = 1$	$T = 1$
$1'$	$S = 1$	$T = e^{i4\pi/3} \equiv \omega^2$
$1''$	$S = 1$	$T = e^{i2\pi/3} \equiv \omega$

$$S = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \quad T = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$