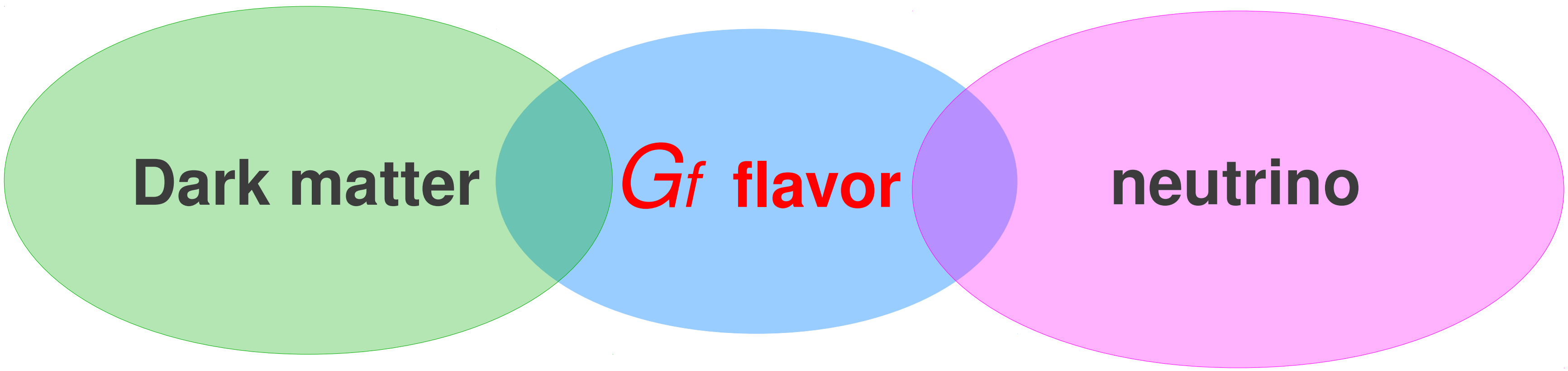
Stability of the dark matter from non-abelian discrete flavor symmetry

Stefano Morisi
AHEP group, University of Valencia (Spain), IFIC/CSIC

Hirsch, Morisi, Peinado, Valle, ***PRD 82 (2010)***
Meloni, Morisi, Peinado, ***PLB697 (2011)***
Boucenna,Hirsch,Morisi,Peinado,Taoso,Valle, ***JHEP1105 (2011)***
Meloni,Morisi,Peinado *1104.0178*
Adelhart,Bazzocchi,Morisi *1104.5676*

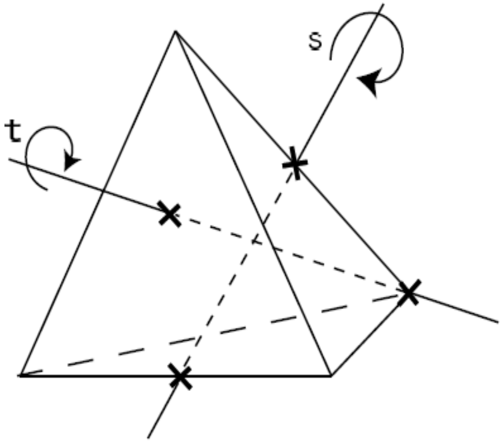
Introduction



The flavor symmetry

A4

Discrete group
even permutations
four objects



tetrahedron

Z2 , Z3 subgroups

See also Feruglio, Hagedorn, Varzielas, Merlo, Luhn,....

Stability of DM from A4

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

triplet of A4 $\langle \eta \rangle \sim (1,0,0)$

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

$S^2 = 1$ generator of Z_2 subgroup of A_4

The Model

Hirsch, Morisi, Peinado, Valle, ***PRD 82 (2010)***

	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

Quarks are singlets of A4

4 R-nu

4 Higgs

$$\eta = (\eta_1, \eta_2, \eta_3)$$

The lagrangian

3 3

$$\begin{aligned}\mathcal{L} \;=\; & y_e L_e l^c_e \hat{H} + y_\mu L_\mu l^c_\mu \hat{H} + y_\tau L_\tau l^c_\tau \hat{H} + \\ & + y_1^\nu L_e (N_T \eta)_1 + y_2^\nu L_\mu (N_T \eta)_{1''} + y_3^\nu L_\tau (N_T \eta)_{1'} + \\ & + y_4^\nu L_e N_4 \hat{H} + M_1 N_T N_T + M_2 N_4 N_4 + \text{h.c.}\end{aligned}$$

η has Dirac couplings only through heavy right-handed neutrino

The Model: the DM candidate

Z2:

$$
\begin{aligned}
N_1 &\to +N_1\,, & \eta_1 &\to +\eta_1\,, \\
N_2 &\to -N_2\,, & \eta_2 &\to -\eta_2\,, \\
N_3 &\to -N_3\,, & \eta_3 &\to -\eta_3\,,
\end{aligned}
$$

$$
\eta_2 = \begin{pmatrix} H_2'^{+} \\ (H_2' + iA_2')/\sqrt{2} \end{pmatrix}, \qquad \eta_3 = \begin{pmatrix} H_3'^{+} \\ (H_3' + iA_3')/\sqrt{2} \end{pmatrix}
$$

the lightest is the DM candidate

Neutrino phenomenology

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

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

IH : $m_3 = 0$

0.03 eV< 0nubb <0.05 eV

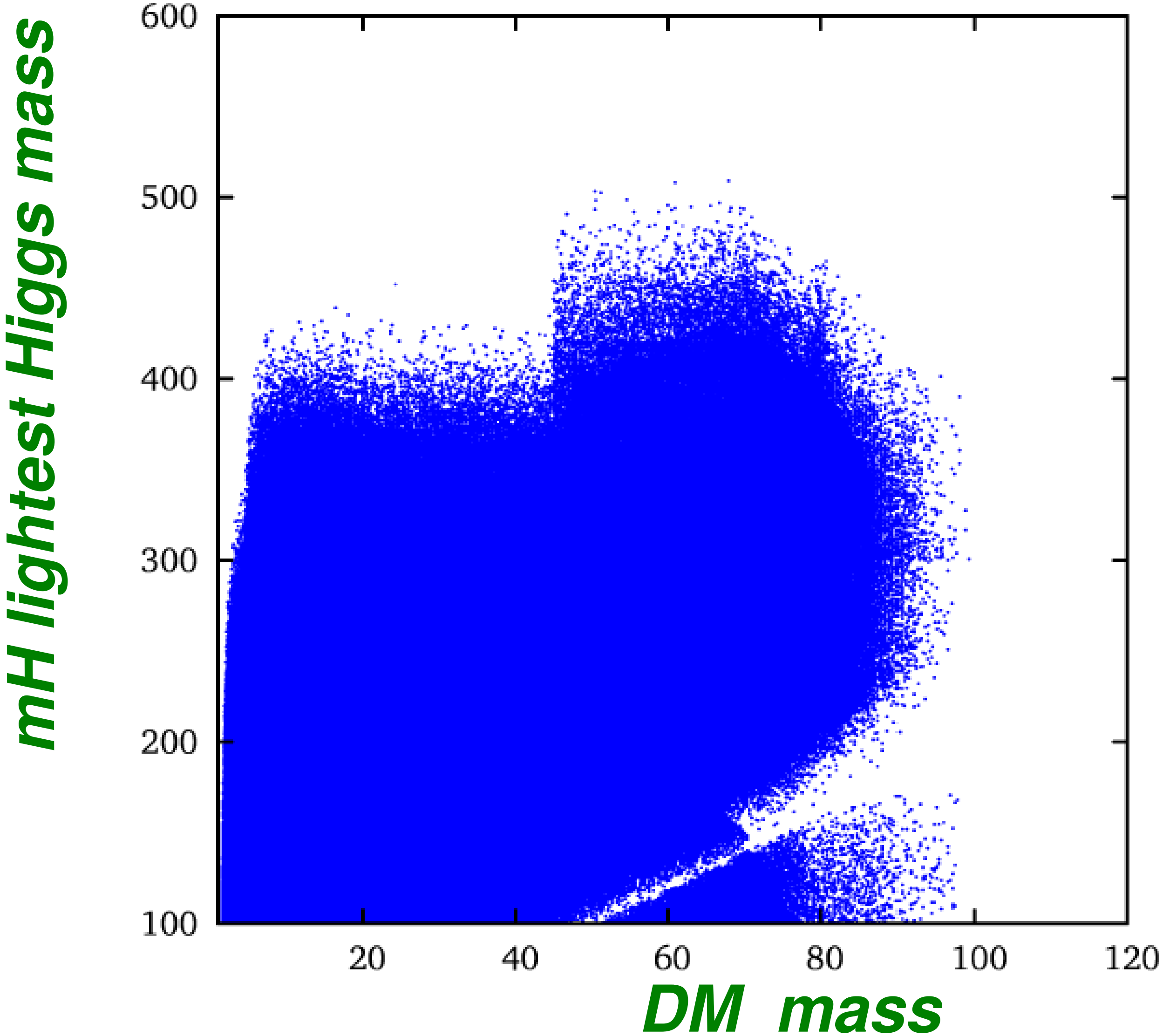
$$V_3 \sim \begin{pmatrix} 0 \\ -b/c \\ 1 \end{pmatrix}$$

$\theta_{13} = 0$

Relic density

$$0.09 \leq \Omega h^2 \leq 0.13$$

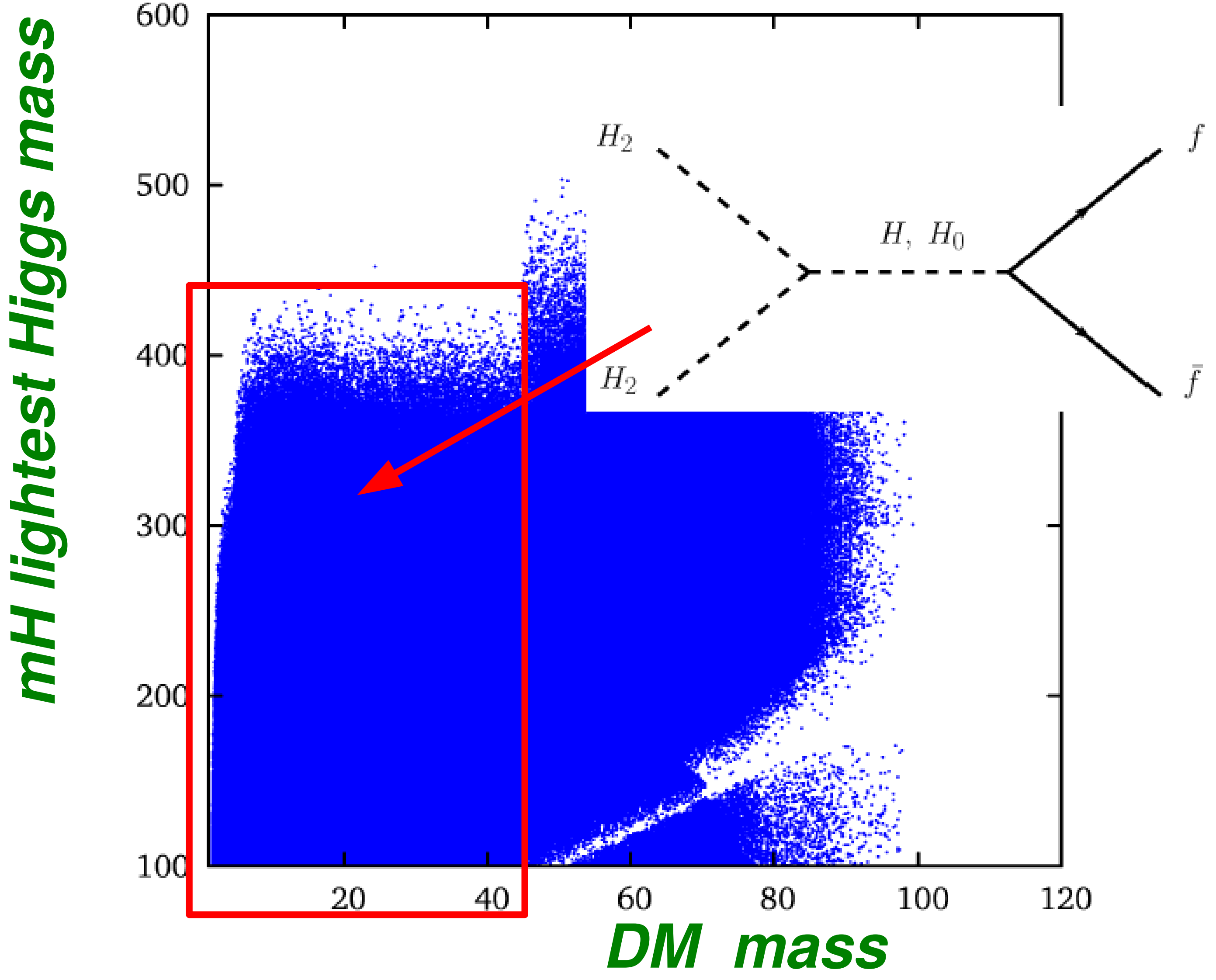
Boucenna *et al.*, ***JHEP1105 (2011)***



Relic density

$$0.09 \leq \Omega h^2 \leq 0.13$$

Boucenna *et al.*, ***JHEP1105 (2011)***



Relic density

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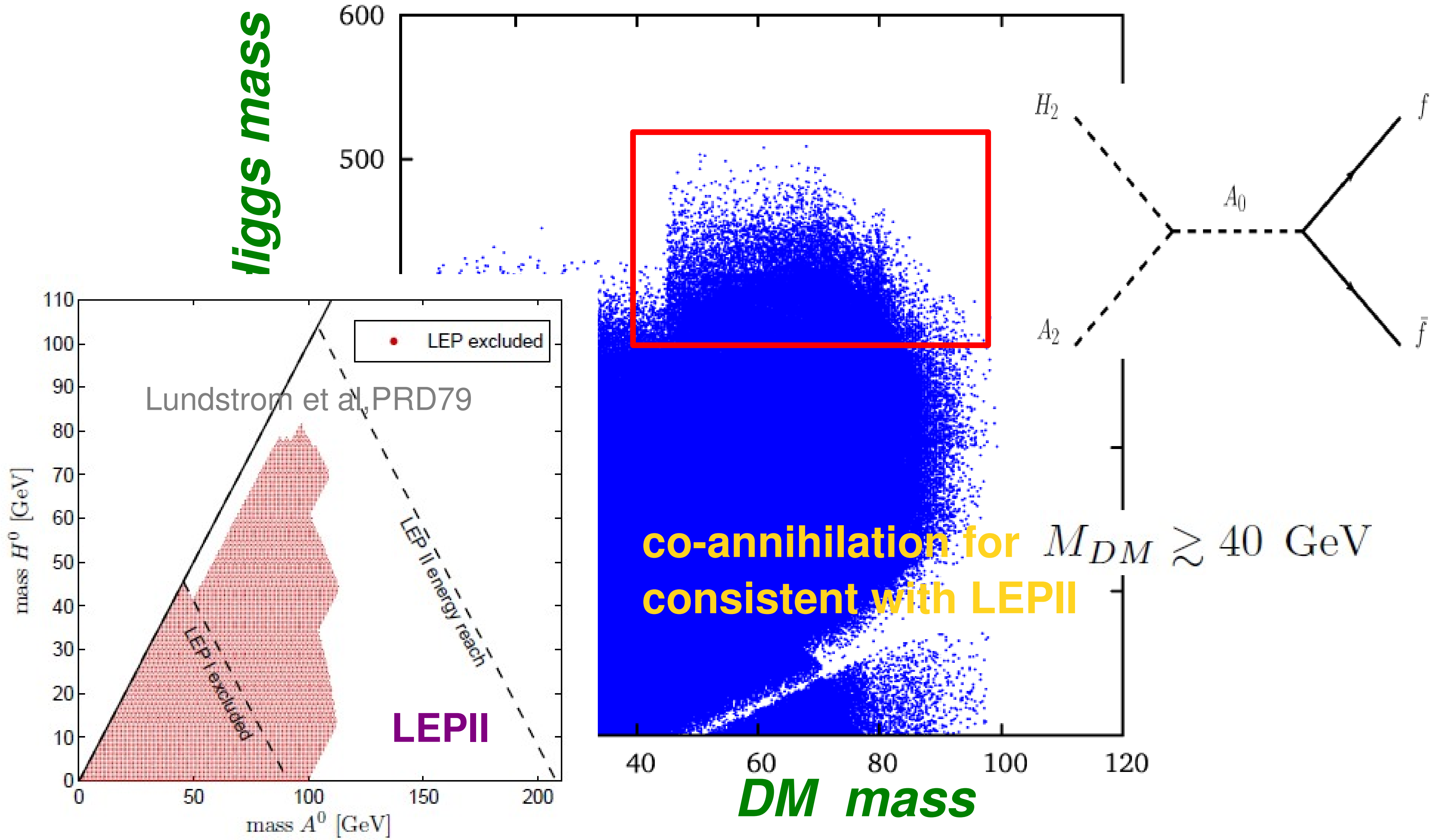
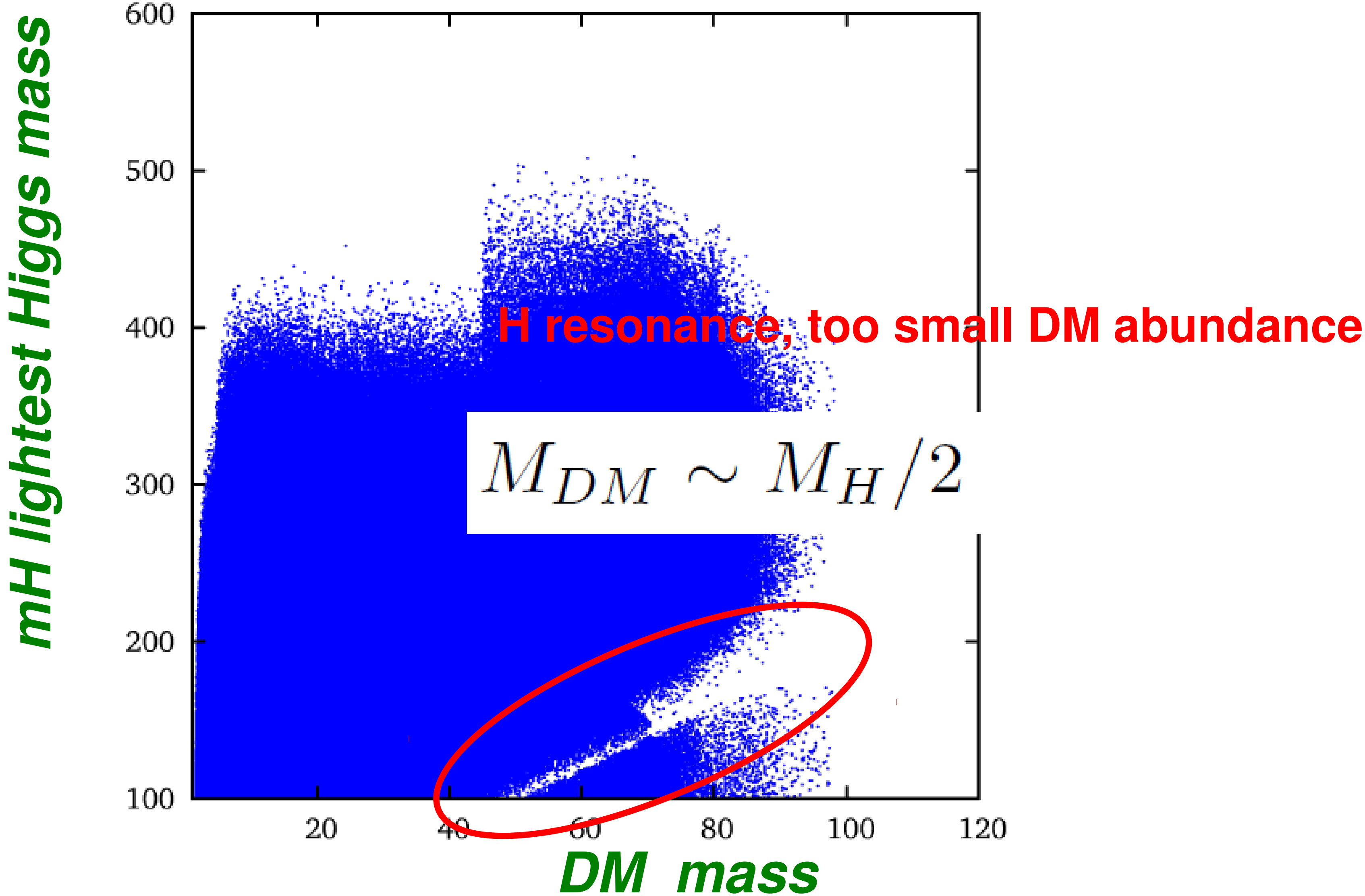
Boucenna *et al.*, ***JHEP1105 (2011)***

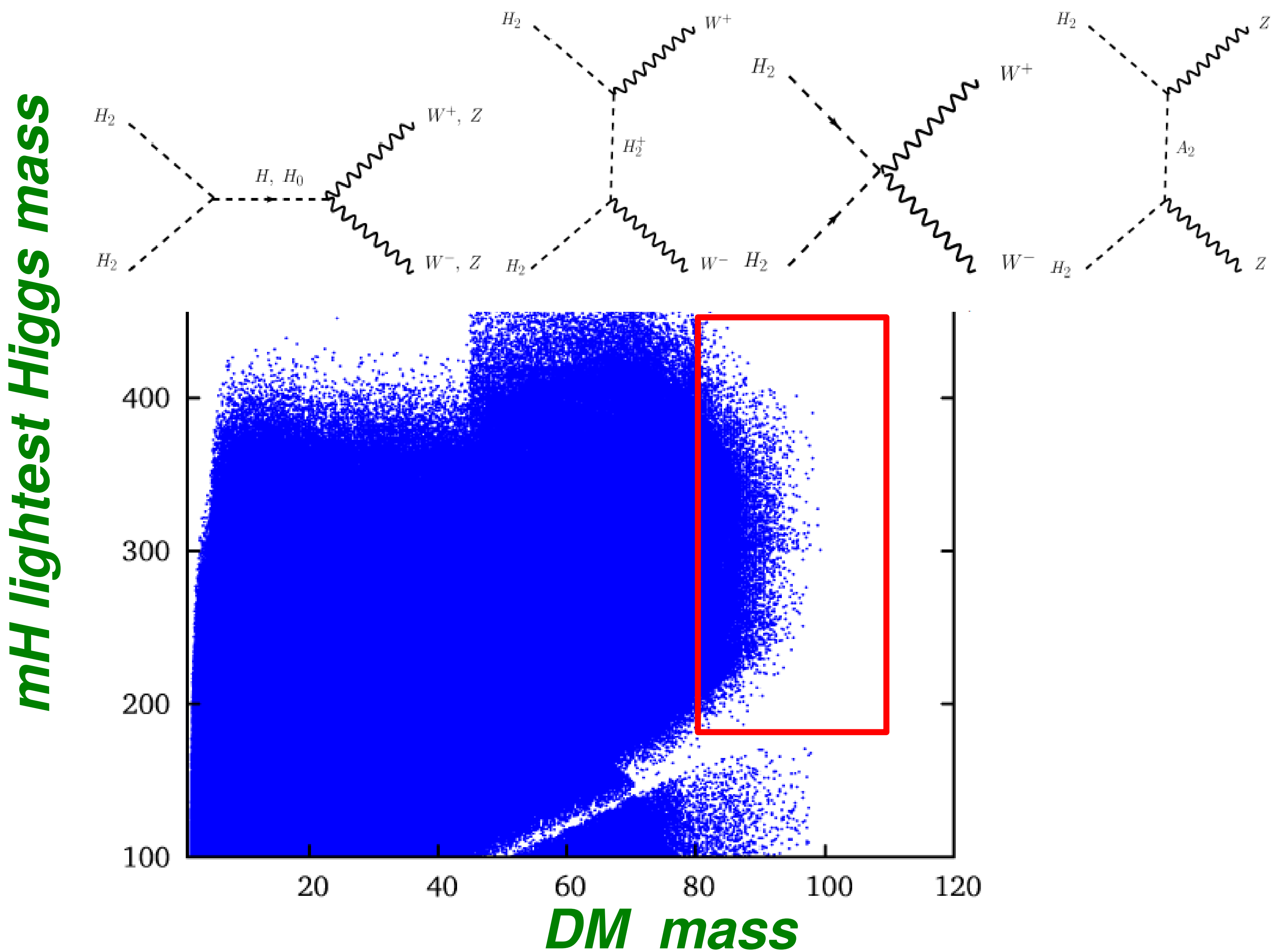


Relic density $0.09 \leq \Omega h^2 \leq 0.13$

Boucenna *et al.*, ***JHEP1105 (2011)***

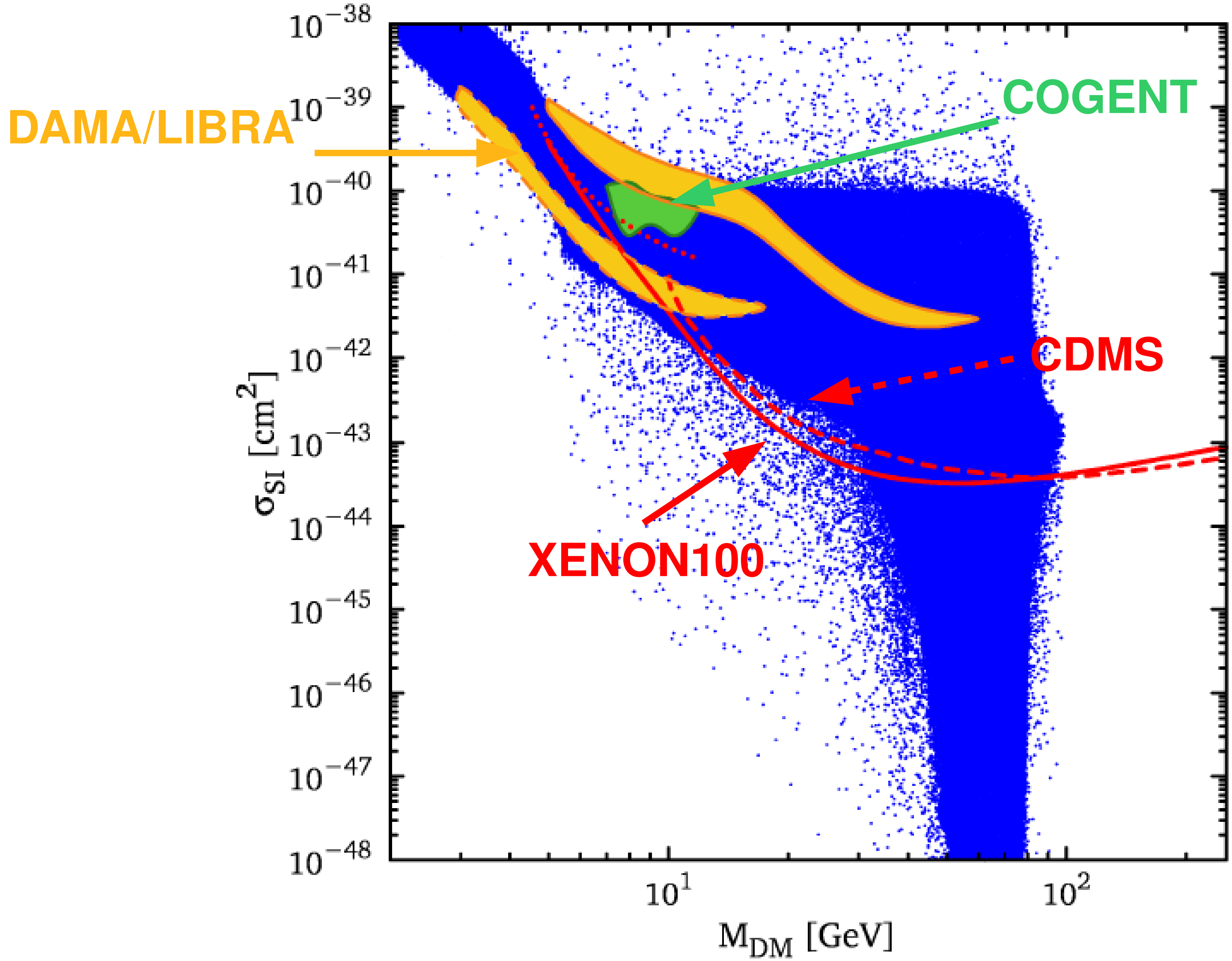


Relic density $0.09 \leq \Omega h^2 \leq 0.13$



Direct detection

Boucenna *et al.*, ***JHEP1105 (2011)***



Quarks

Adelhart,Bazzocchi,Morisi *1104.5676*

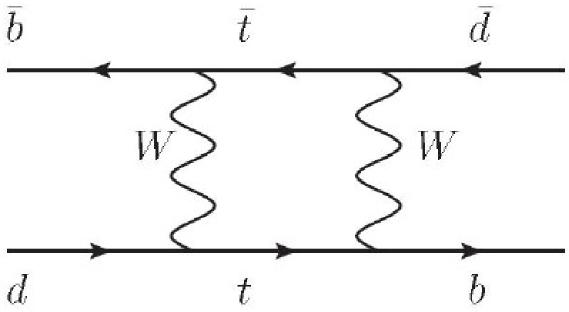
$$\sum \frac{f_{ij}}{\Lambda^2}(\overline{Q}_i\hat{H})d_j(\eta^\dagger\eta) + \frac{f'_{ij}}{\Lambda^2}(\overline{Q}_i\eta)d_j(\eta^\dagger\hat{H}) + \frac{f''_{ij}}{\Lambda^2}(\overline{Q}_i\eta)d_j(\hat{H}^\dagger\eta)$$

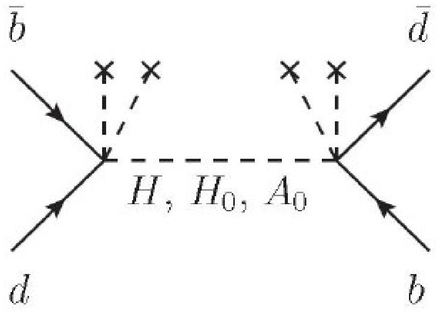
$$M_d = \begin{pmatrix} m_d & 0 & 0 \\ 0 & m_s & 0 \\ 0 & 0 & m_b \end{pmatrix} + \frac{v_H v_\eta^2}{\Lambda^2}\begin{pmatrix} h_{dd} & h_{ds} & h_{db} \\ h_{sd} & h_{ss} & h_{sb} \\ h_{bd} & h_{bs} & h_{bb} \end{pmatrix} + \mathcal{O}(1/\Lambda^4)\,,$$

$$h_{ds}\frac{v_H v_\eta^2}{\Lambda^2} = \lambda_C m_s$$

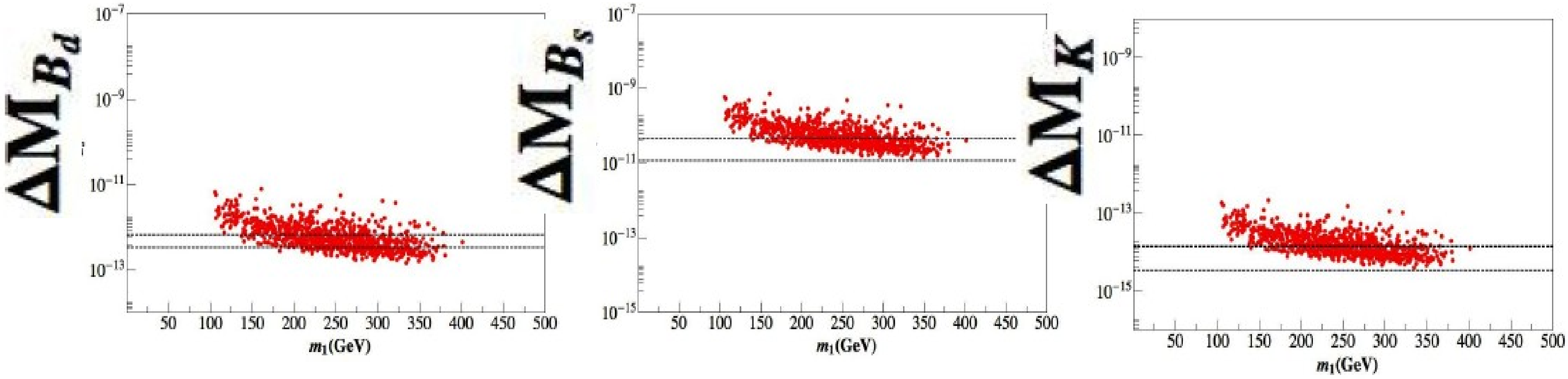
1-10 TeV

Quarks: FCNC





CKM mostly from down sector



lightest Higgs mass

Outlook: embedding into GUT

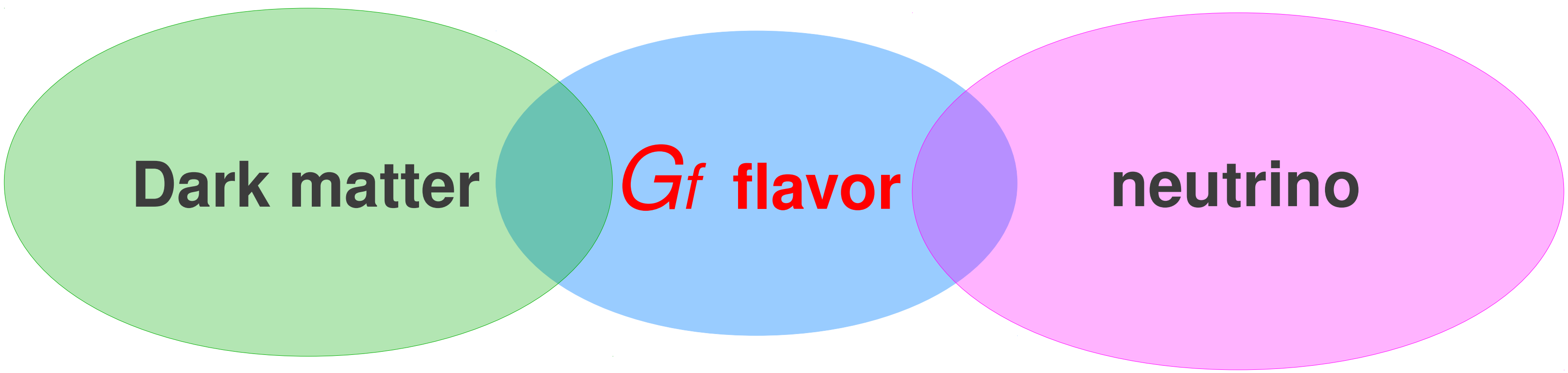
	T_1	T_2	T_3	F_1	F_2	F_3	N_T	N_4
SU(5)	10	10	10	$\bar{5}$	$\bar{5}$	$\bar{5}$	1	1
A_4	1	$1'$	$1''$	1	$1''$	$1'$	3	1

matter

SU(5)	5_H	$\bar{5}_H$	5_η	45_H
A_4	1	1	3	1

scalar

conclusion



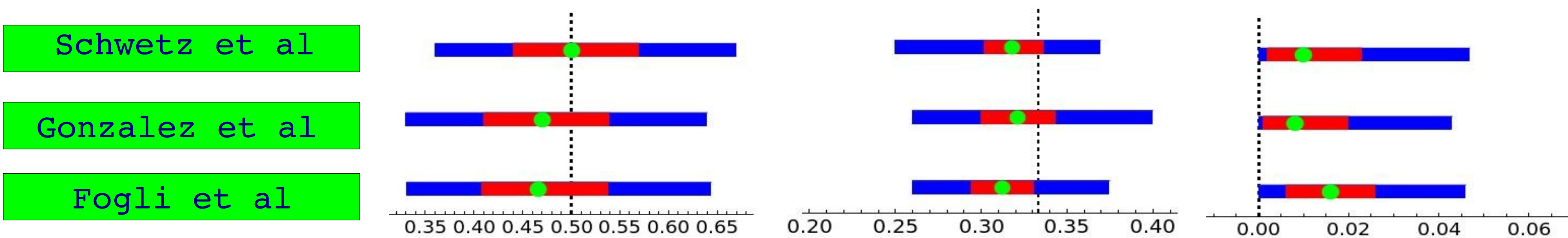
stability of DM

reactor angle = 0
inverse hierarchy
m3=0

In a specific model

Tri-bimaximal neutrino mixing (TBM)

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



$$U_{\mathrm{HPS}} = \begin{pmatrix} \sqrt{2/3} & 1/\sqrt{3} & 0 \\ -1/\sqrt{6} & 1/\sqrt{3} & -1/\sqrt{2} \\ -1/\sqrt{6} & 1/\sqrt{3} & 1/\sqrt{2} \end{pmatrix} \longleftrightarrow \textbf{A4}$$

Harrison, Perkins & Scott

Babu, Ma, Valle PLB552
Altarelli, Feruglio NPB720

See also Hagedorn, Varzielas, Merlo, Luhn,....

Outlook: embedding into GUT

	T_1	T_2	T_3	F_1	F_2	F_3	N_T	N_4
SU(5)	10	10	10	$\bar{5}$	$\bar{5}$	$\bar{5}$	1	1
A_4	1	$1'$	$1''$	1	$1''$	$1'$	3	1

matter

SU(5)	5_H	$\bar{5}_H$	5_η	45_H
A_4	1	1	3	1

scalar

$$\begin{aligned}
\mathcal{L}_{down} &= y_1^{l,d} T_1 F_1 \bar{5}_H + y_2^{l,d} T_2 F_2 \bar{5}_H + y_3^{l,d} T_3 F_3 \bar{5}_H \quad + y_1'^{l,d} T_1 F_1 45_H + y_2'^{l,d} T_2 F_2 45_H + y_3'^{l,d} T_3 F_3 45_H; \\
\mathcal{L}_{up} &= y_1^u T_1 T_1 5_H + y_2^u T_2 T_3 5_H + y_1'^u T_1 T_1 45_H + y_2'^u T_2 T_3 45_H; \\
\mathcal{L}_\nu &= y_1^\nu T_1 N_4 5_H + y_2^\nu T_2 N_4 5_H + y_3^\nu T_3 N_4 5_H + y_1^\nu T_1 N_T 5_\eta + M_1\, N_T N_T + M_2\, N_4 N_4.
\end{aligned}$$

it is possible to fit the masses

$$m_e = y_1^{l,d}\langle 5_H\rangle - 3y_1'^{l,d}\langle 45_H\rangle;\ \ m_\mu = y_2^{l,d}\langle 5_H\rangle - 3y_2'^{l,d}\langle 45_H\rangle;\ \ m_\tau = y_3^{l,d}\langle 5_H\rangle - 3y_3'^{l,d}\langle 45_H\rangle;$$

$$m_d = y_1^{l,d}\langle 5_H\rangle + y_1'^{l,d}\langle 45_H\rangle; \quad m_s = y_2^{l,d}\langle 5_H\rangle + y_2'^{l,d}\langle 45_H\rangle; \quad m_b = y_3^{l,d}\langle 5_H\rangle + y_3'^{l,d}\langle 45_H\rangle;$$

$$m_u = y_1^u\langle 5_H\rangle; \qquad m_c = y_2^u\langle 5_H\rangle - y_2'^u\langle 45_H\rangle; \qquad m_t = y_2^u\langle 5_H\rangle + y_2'^u\langle 45_H\rangle.$$

CKM?