Discrete Dark Matter and reactor mixing angle

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M. Hirsch, S. Morisi, E. P. and J. W. F. Valle, Phys. Rev. D 82 (2010) 116003
M. Lamprea and EP, in preparation

HEP2016, Universidad Técnica Federico Santa María, Valparaiso, Chile

Plan of the talk

- DM stability from a FS
- The reactor mixing angle problem
- Solving RMA problem
- Summary

Flavour symmetries

FS has been used to reduce
# of Yukawa couplings

Correlations among observables
masses, mixings and CP phases

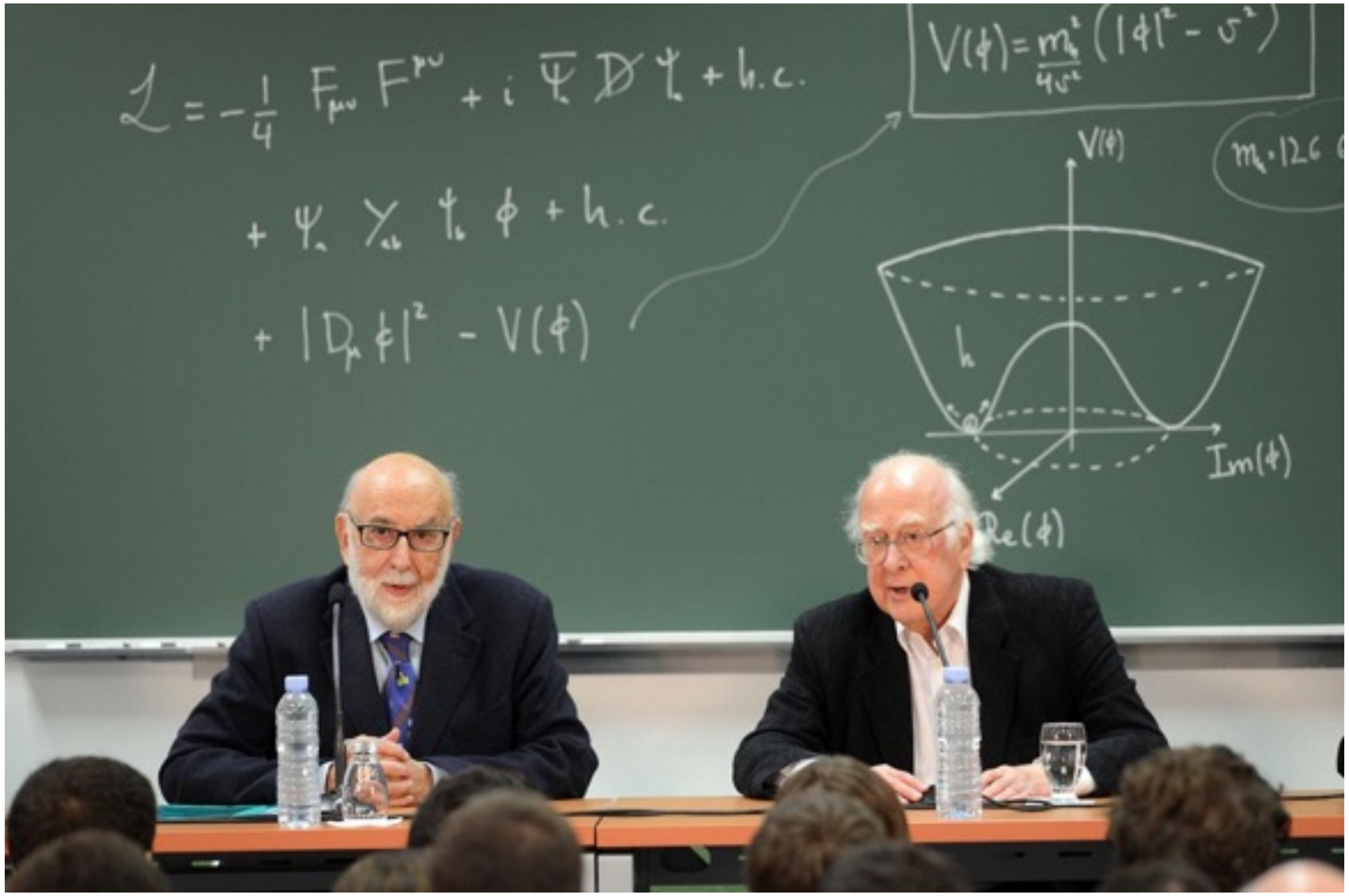
Sometimes predictions
such as TBM mixing

The SM is complete

The SM is complete

Standard Model & Physics BSM

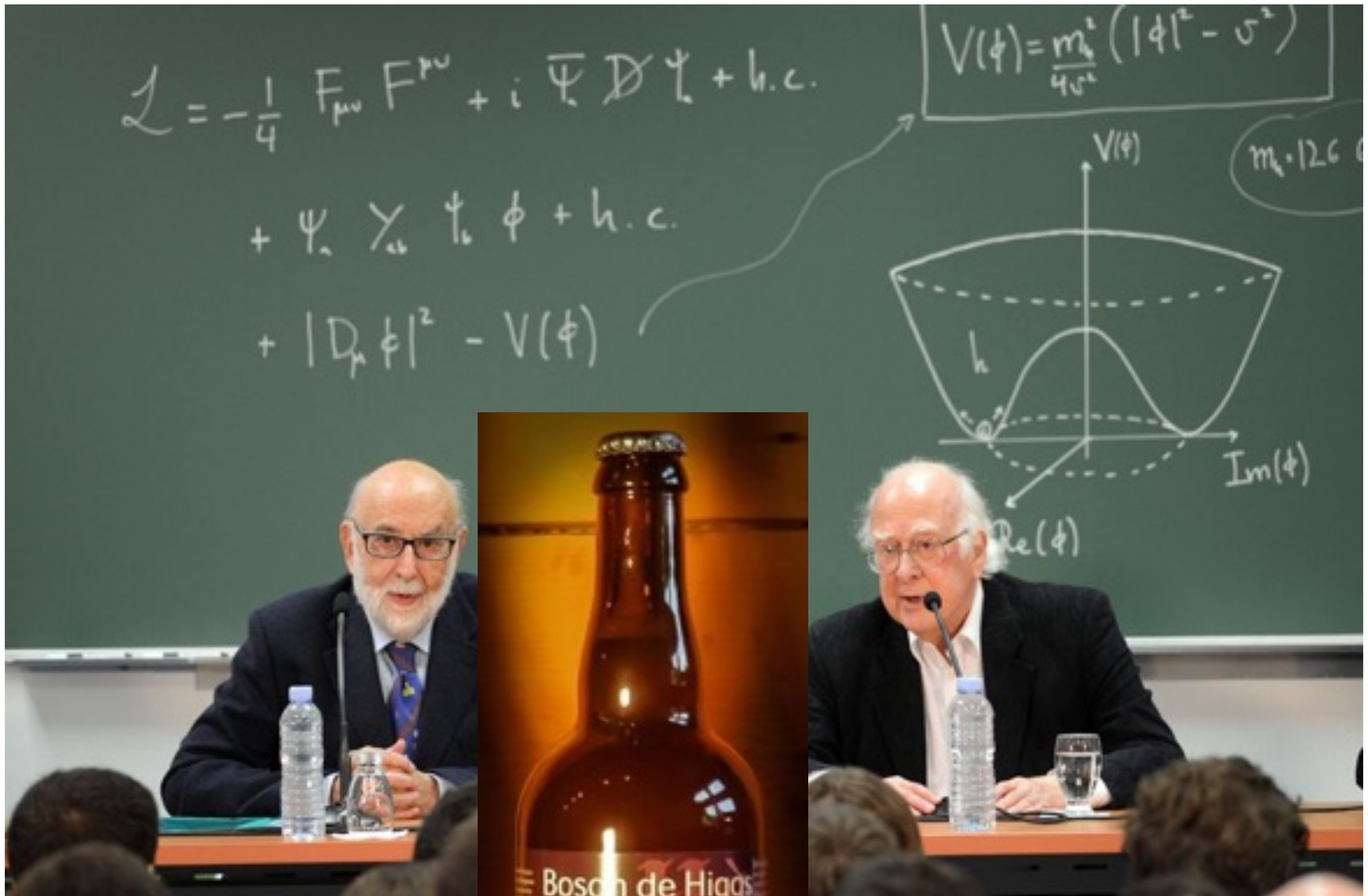
The SM



Fundación principe de Asturias

Cern Higgs Discovery

The SM

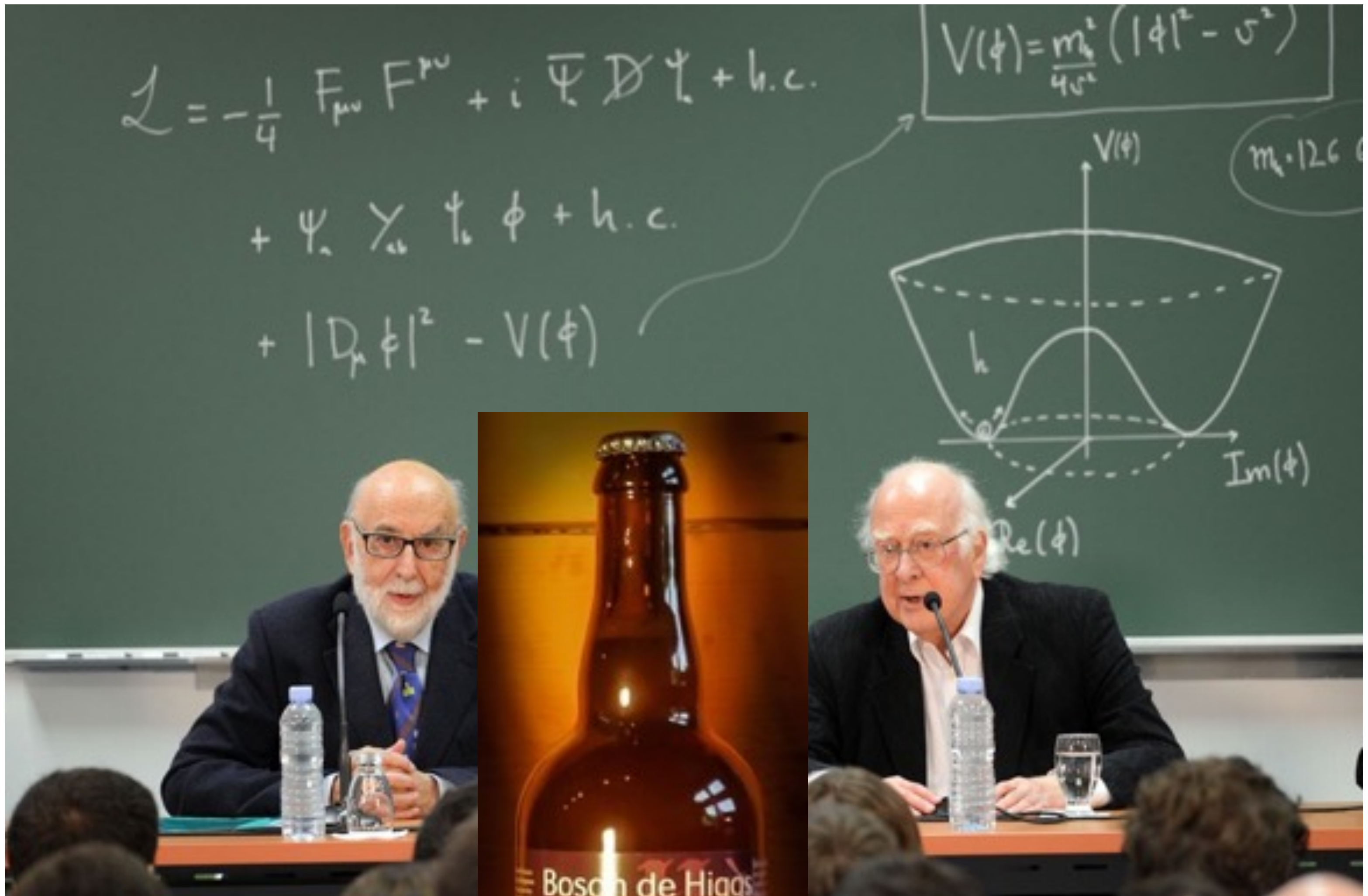


Fundación principe de Astu

Cern Higgs Discovery

What about
neutrino masses?
DM?
BAU?
etc…

The SM



Fundación principe de Astu

with flavor?

Cern Higgs Discovery

What about

neutrino masses?

DM?

BAU?

etc…

Some hints

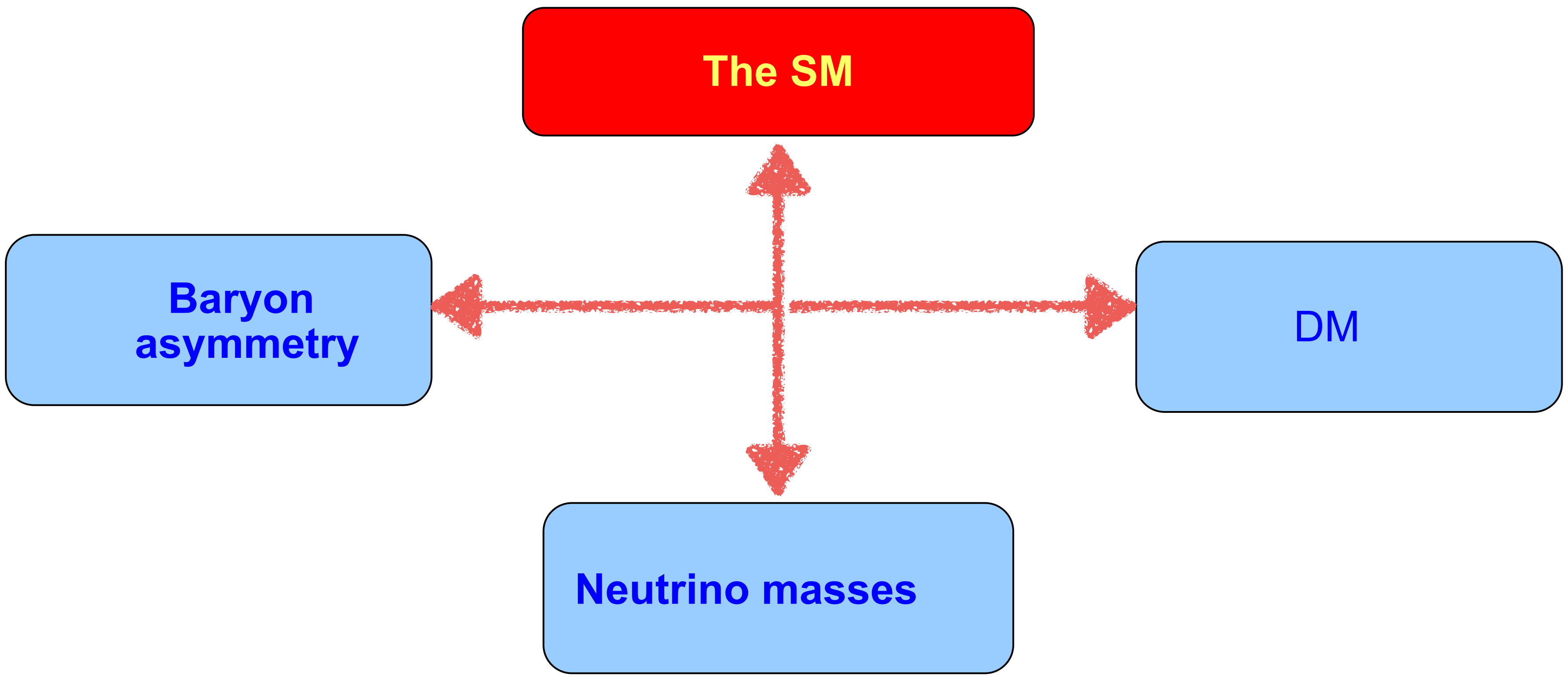
LHC puts some limits on PBSM

Now we have some “hints”, W´s? new scalars?
LFV Higgs ➞ mu tau?

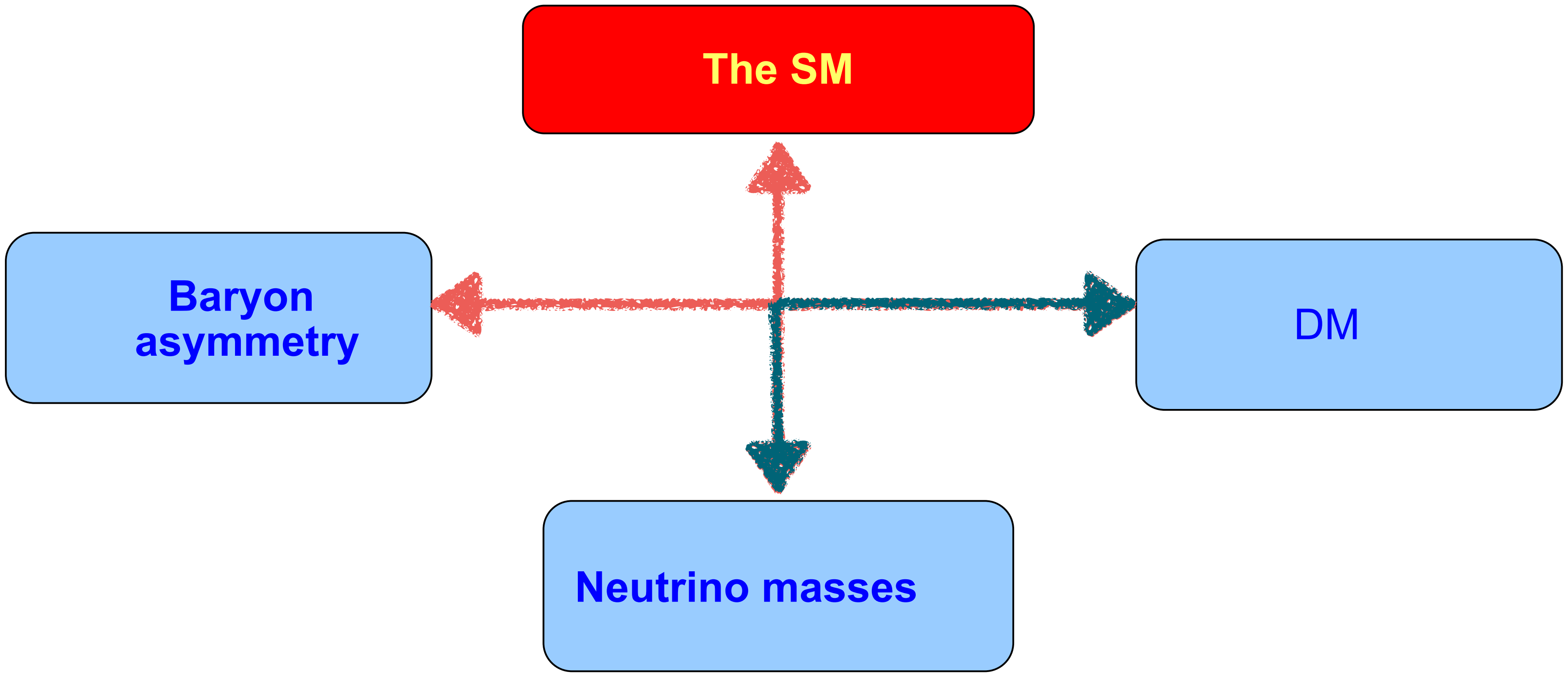
Connection of neutrinos with DM

The SM

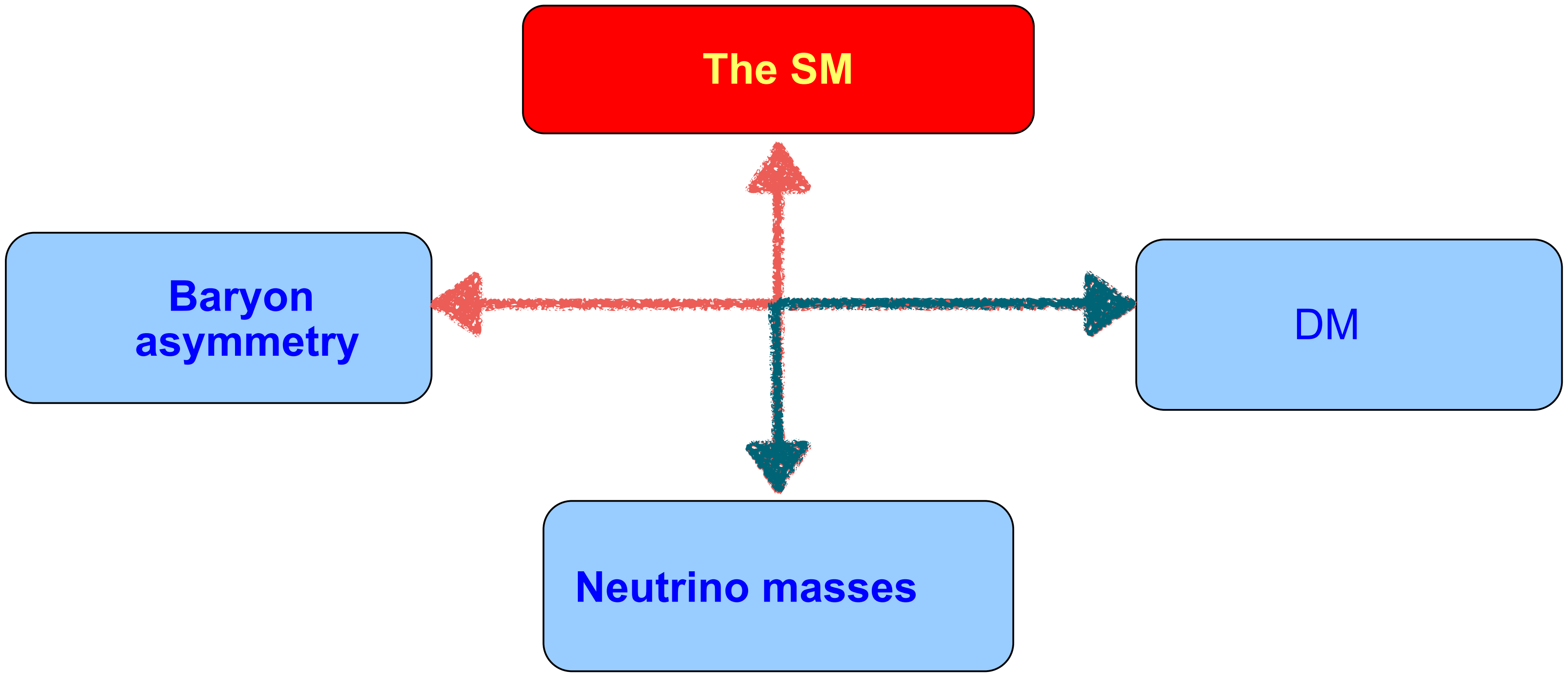
Connection of neutrinos with DM



Connection of neutrinos with DM



Connection of neutrinos with DM



Majoron

Inert+loops

DDM

loops with higher Higgs representations

KeV sterile neutrinos

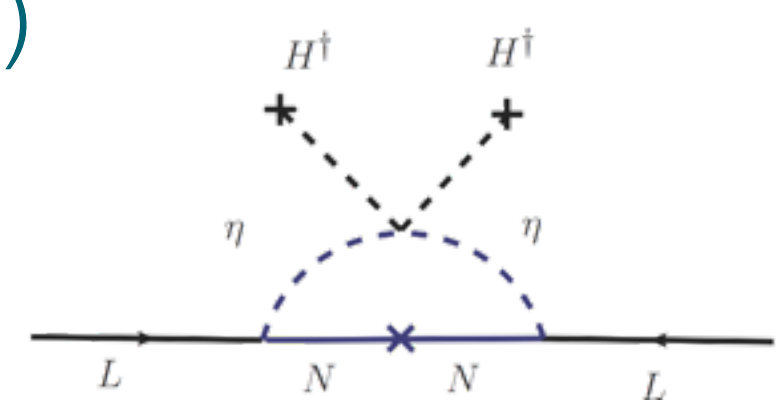
etc...

Scalar DM

One of the simplest way is to add a stable scalar field

If it is really stable we need a symmetry
(inert DM)
simplest symmetry → Z_2

Connection with Neutrinos is also possible
if RH neutrinos also transform with Z_2
(Ma's Scotogenic)



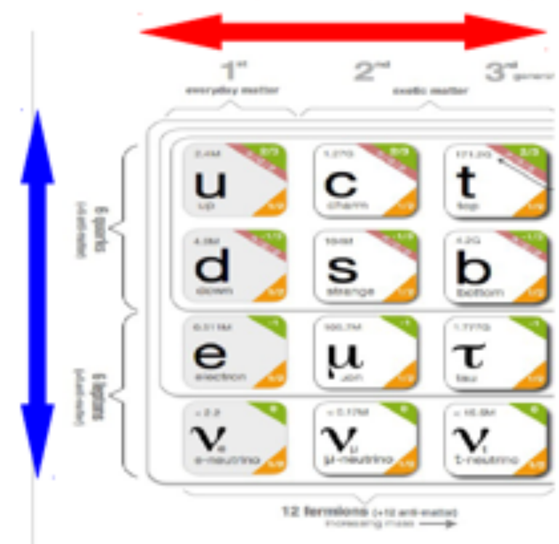
Flavor symmetries

Frampton and Kephart, PRD64 (01)

order	groups
6	$S_3 \equiv D_3$
8	$D_4, Q = Q_4$
10	D_5
12	$D_6, Q_6, T \equiv A_4$
14	D_7
16	$D_8, Q_8, Z_2 \times D_4, Z_2 \times Q$
18	$D_9, Z_3 \times D_3$
20	D_{10}, Q_{10}
22	D_{11}
24	$D_{12}, Q_{12}, Z_2 \times D_6, Z_2 \times Q_6, Z_2 \times T, Z_3 \times D_4, Z_3 \times Q, Z_4 \times D_3, S_4$
26	D_{13}
28	D_{14}, Q_{14}
30	$D_{15}, D_5 \times Z_3, D_3 \times Z_5$

horizontal symmetry like *SU(3)* – *triplets*

vertical gauge symmetry



Abelian, non-abelian
continuous, discrete,
global, local

see for instance talks by
E. Nardi
C. Arbelaes
A. Carcamo

Z_N already in these symmetries

A4

Ma and Rajasekaran 2001
Babu, Ma, Valle 2003
Altarelli, Feruglio 2005
...

The generators are :

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

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

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

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

A4 and TBM

$\langle \phi \rangle = (1,1,1)$

$\langle \phi' \rangle = (1,0,0)$

Z_3

Altarelli Feruglio (2005)

Z_2

$$m = \begin{pmatrix} x & y & y \\ y & x+v & y-v \\ y & y-v & x+v \end{pmatrix}$$

M_l

M_ν

A4 completely broken

$$V_{lep} = U_l^+ U_\nu = TBM$$

Large neutrino mixing

$\phi \neq \phi'$

Misalignment

How to use it to stabilise DM

Instead of **breaking A4** in two different directions

$$\langle\phi\rangle = (1,0,0)$$

Preserves "S" (Z_2)

$$\langle\phi\rangle = (1,1,1)$$

Preserves "T" (Z_3)

How to use it to stabilise DM

Instead of **breaking A4** in two different directions

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No TBM, but Z2

How to use it to stabilise DM

Instead of **breaking A4** in two different directions

$\langle\phi\rangle = (1,0,0)$

Preserves "S" (Z_2)

~~$\langle\phi\rangle = (1,1,1)$~~

~~Preserves "T" (Z_3)~~

No TBM, but Z2

→ DM Stability

Discrete Dark Matter

- We need a non-abelian flavor group
- Scalar fields in a non-trivial irrep
- This scalar only couples with leptons
- not connected with quarks
- The vev of the scalar breaks the flavor into a Z_N subgroup of the FS
- This breaking dictates the Neutrino pheno

The model

SM + 3 Higgs SU(2) doublets , 4 right handed neutrinos

Hirsch, Morisi, Peinado and Valle
Phys. Rev. D 82, 116003 (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

$\langle \eta_{2,3}^0 \rangle = 0$

$\langle \eta \rangle \sim (1,0,0)$

$\langle \eta_1^0 \rangle = v_\eta$

$\langle H^0 \rangle = v_h$

$$m_D = \begin{pmatrix} x_1 & 0 & 0 & y_1 \\ x_2 & 0 & 0 & 0 \\ x_3 & 0 & 0 & 0 \end{pmatrix}$$

$$M_R = \mathrm{diag}(M_1, M_1, M_1, M_2)$$

inert part

Rank 2 matrix

Neutrino Pheno

Scaling matrix,
Rodejohan and Mohapatra

$$\begin{pmatrix} y^2 & ab & ac \\ ab & b^2 & bc \\ ac & bc & c^2 \end{pmatrix}$$

$$m_3 = 0 \qquad \begin{pmatrix} 0 \\ -c/b \\ 1 \end{pmatrix}$$

Inverse mass Hierarchy

$$\left\{ m_{ee} \sim 0.03 - 0.05\ eV \right\}$$

Neutrino Pheno

Scaling matrix,
Rodejohan and Mohapatra

$$\begin{pmatrix} y^2 & ab & ac \\ ab & b^2 & bc \\ ac & bc & c^2 \end{pmatrix} \rightarrow m_3 = 0 \quad \begin{pmatrix} 0 \\ -c/b \\ 1 \end{pmatrix}$$

$\sin^2\theta_{13}/10^{-2}$ (NH)	2.34±0.20	1.95–2.74	1.77–2.94

Inverse mass Hierarchy

$$\{\, m_{ee} \sim 0.03 - 0.05\ eV \,\}$$

Some attempts with the idea

- We modify the model but it was not enough
- Use other groups, the reactor mixing angle remains a problem
- All these models are at the EW scale
- What if we break the FS at the see saw scale?

Meloni, Morisi and Peinado, Phys.Lett. B697 (2011) 339-342
Meloni, Morisi and Peinado, Phys.Lett. B703 (2011) 281-287
Boucena, Morisi, Peinado, Shimizu and Valle, Phys.Rev. D86 (2012) 073008

The path to θ_{13}

Let’s couple a scalar field with RH neutrinos

The path to θ_{13}

Let’s couple a scalar field with RH neutrinos

↓

This scalar field breaks the FS at the see-saw scale

The path to θ_{13}

Let's couple a scalar field with RH neutrinos

↓

This scalar field breaks the FS at the see-saw scale

↓

At EW we have a Z_2 (like in the inert case)

The model(s)

M. Lamprea and E. Peinado, in preparation

	L_e	L_μ	L_τ	l_e^c	l_μ^c	l_τ^c	N_T	N_4	N_5	H	η	ϕ
SU(2)	2	2	2	1	1	1	1	1	1	2	2	1
A_4	1	$1'$	$1''$	1	$1''$	$1'$	3	1	$1'$	1	3	3

$$\langle\phi\rangle = (1,0,0)$$

$$A_4 \longrightarrow Z_2$$

In order to preserve the Z_2, only η_1 acquire vev

$$\begin{aligned}\mathcal{L}_{\mathrm{Y}}^{(\mathrm{A})} &= y_e L_e l_e^c H + y_\mu L_\mu l_\mu^c H + y_\tau L_\tau l_\tau^c H \\ &+ y_1^\nu L_e [N_T\,\eta]_1 + y_2^\nu L_\mu [N_T\,\eta]_{1''} + y_3^\nu L_\tau [N_T\,\eta]_{1'} + y_4^\nu L_e\, N_4\, H + y_5^\nu L_\tau\, N_5\, H \\ &+ M_1\, N_T N_T + M_2\, N_4 N_4 + y_1^N [N_T\,\phi]_{3_i} N_T + y_2^N [N_T\,\phi]_1 N_4 + y_3^N [N_T\,\phi]_{1''} N_5\end{aligned}$$

Neutrino masses

$$m_{\mathrm{D}}^{(\mathrm{A})} = \begin{pmatrix} y_1^\nu v_\eta & 0 & 0 & y_4^\nu v_h & 0 \\ y_2^\nu v_\eta & 0 & 0 & 0 & 0 \\ y_3^\nu v_\eta & 0 & 0 & 0 & y_5^\nu v_h \end{pmatrix}$$

$$M_{\mathrm{R}} = \begin{pmatrix} M_1 & 0 & 0 & y_2^N v_\phi & y_3^N v_\phi \\ 0 & M_1 & y_1^N v_\phi & 0 & 0 \\ 0 & y_1^N v_\phi & M_1 & 0 & 0 \\ y_2^N v_\phi & 0 & 0 & M_2 & 0 \\ y_3^N v_\phi & 0 & 0 & 0 & 0 \end{pmatrix}$$

Neutrino masses

$$m_{\rm D}^{(\rm A)} = \begin{pmatrix} y_1^\nu v_\eta & 0 & 0 & y_4^\nu v_h & 0 \\ y_2^\nu v_\eta & 0 & 0 & 0 & 0 \\ y_3^\nu v_\eta & 0 & 0 & 0 & y_5^\nu v_h \end{pmatrix}$$

$$M_{\rm R} = \begin{pmatrix} M_1 & 0 & 0 & y_2^N v_\phi & y_3^N v_\phi \\ 0 & M_1 & y_1^N v_\phi & 0 & 0 \\ 0 & y_1^N v_\phi & M_1 & 0 & 0 \\ y_2^N v_\phi & 0 & 0 & M_2 & 0 \\ y_3^N v_\phi & 0 & 0 & 0 & 0 \end{pmatrix}$$

Effectively only 3 RHN participate in the see-saw

Neutrino masses

$$m_{\rm D}^{(\rm A)} = \begin{pmatrix} y_1^\nu v_\eta & 0 & 0 & y_4^\nu v_h & 0 \\ y_2^\nu v_\eta & 0 & 0 & 0 & 0 \\ y_3^\nu v_\eta & 0 & 0 & 0 & y_5^\nu v_h \end{pmatrix}$$

$$M_{\rm R} = \begin{pmatrix} M_1 & 0 & 0 & y_2^N v_\phi & y_3^N v_\phi \\ 0 & M_1 & y_1^N v_\phi & 0 & 0 \\ 0 & y_1^N v_\phi & M_1 & 0 & 0 \\ y_2^N v_\phi & 0 & 0 & M_2 & 0 \\ y_3^N v_\phi & 0 & 0 & 0 & 0 \end{pmatrix}$$

Effectively only 3 RHN participate in the see-saw

$$m_\nu^{(\rm A)} \equiv \begin{pmatrix} a & 0 & b \\ 0 & 0 & c \\ b & c & d \end{pmatrix}$$

Two zero-texture B3

Frampton, Glashow ,Marfatia
Merle, Rodejohan
Xing, Fritsch
Ludl, Morisi, Peinado
Meroni, Meloni, Peinado
…

Neutrino masses

$$m_D^{(A)} = \begin{pmatrix} y_1^\nu v_\eta & 0 & 0 & y_4^\nu v_h & 0 \\ y_2^\nu v_\eta & 0 & 0 & 0 & 0 \\ y_3^\nu v_\eta & 0 & 0 & 0 & y_5^\nu v_h \end{pmatrix}$$

$$M_R = \begin{pmatrix} M_1 & 0 & 0 & y_2^N v_\phi & y_3^N v_\phi \\ 0 & M_1 & y_1^N v_\phi & 0 & 0 \\ 0 & y_1^N v_\phi & M_1 & 0 & 0 \\ y_2^N v_\phi & 0 & 0 & M_2 & 0 \\ y_3^N v_\phi & 0 & 0 & 0 & 0 \end{pmatrix}$$

Effectively only 3 RHN participate in the see-saw

$$m_\nu^{(A)} \equiv \begin{pmatrix} a & 0 & b \\ 0 & 0 & c \\ b & c & d \end{pmatrix}$$

tex

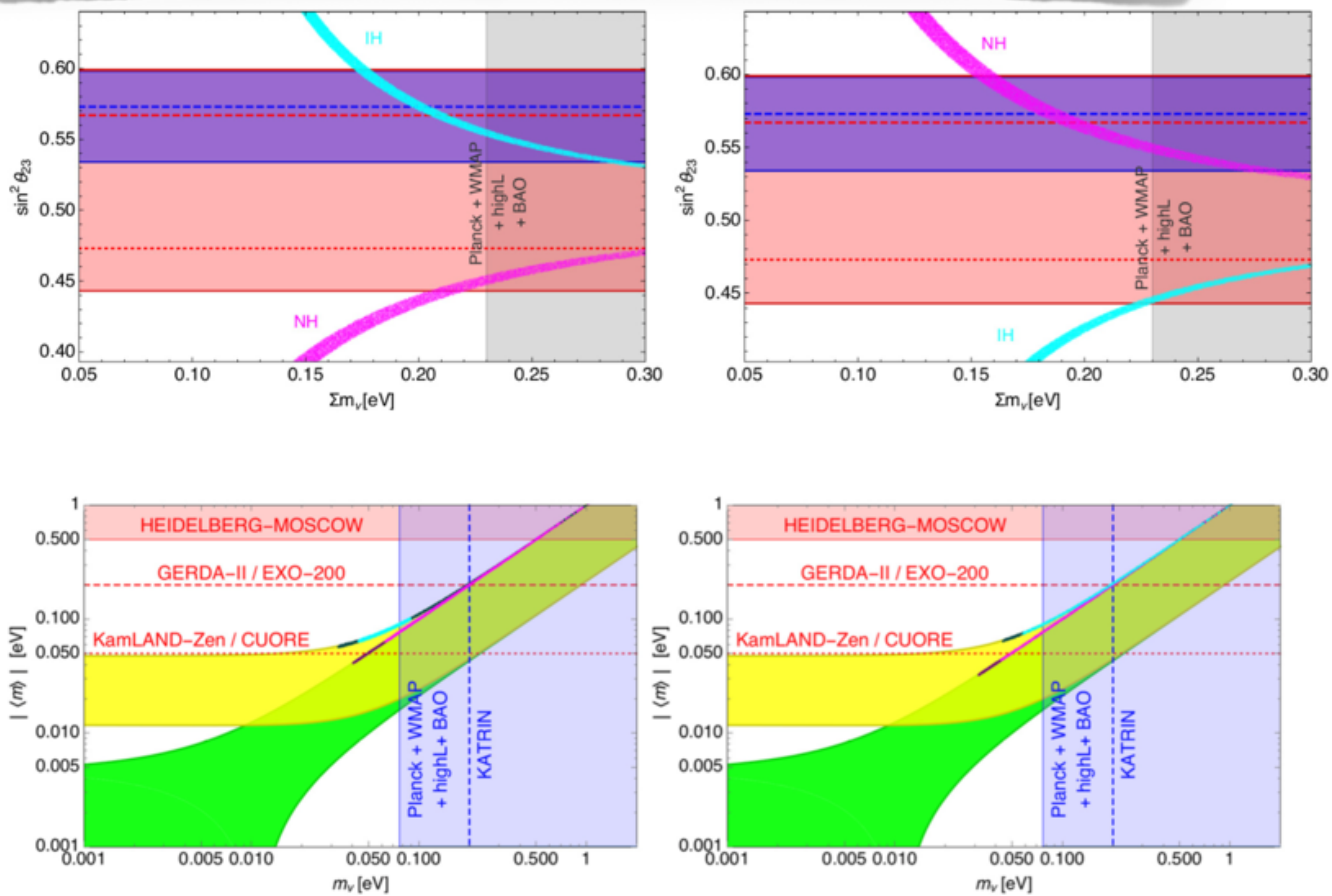
If N5 is 1''

Ludl, Morisi, Peinado
Meroni, Meloni, Peinado
…

$$m_\nu^{(B)} \equiv \begin{pmatrix} a & b & 0 \\ b & d & c \\ 0 & c & 0 \end{pmatrix}$$

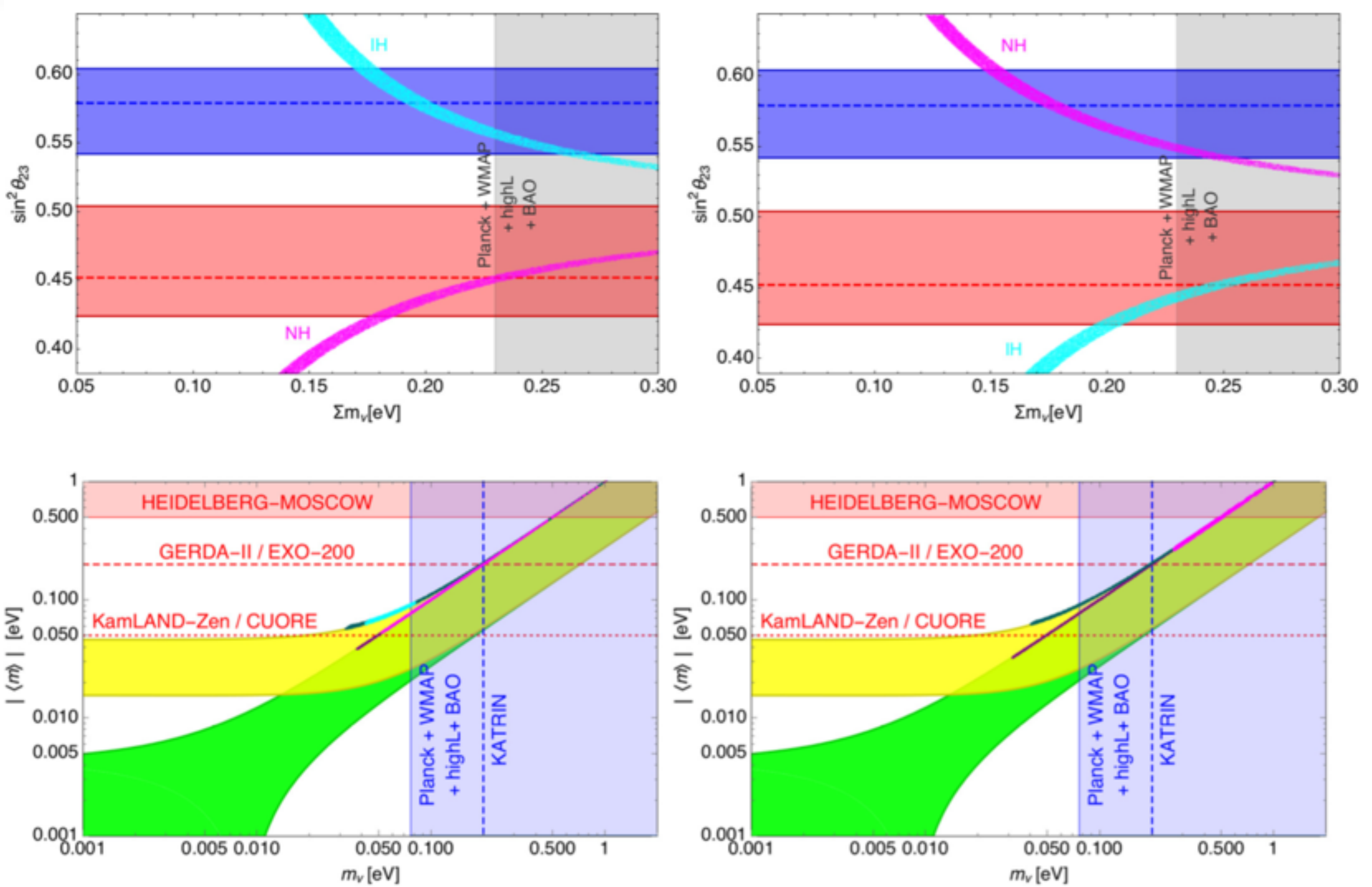
Neutrino Phenomenology

Fits from D.V.Forero,M.Tortola and J.W.F.Valle,Phys.Rev.D90(2014)9,093006



Neutrino Phenomenology

Fits from M. C. Gonzalez-Garcia, M. Maltoni and T. Schwetz, arXiv:1512.06856 [hep-ph]



Summary

- It is possible to conciliate the DDM with the neutrino phenomenology
- It will be falsifiable in the near future with the $0\nu\beta\beta$ decay experiments
- Open the possibility of Leptogenesis if the breaking scale is above the see-saw scale
- compatibility of neutrino-DM-BAU in the same framework