neutrino pathways to dark matter

José W F Valle

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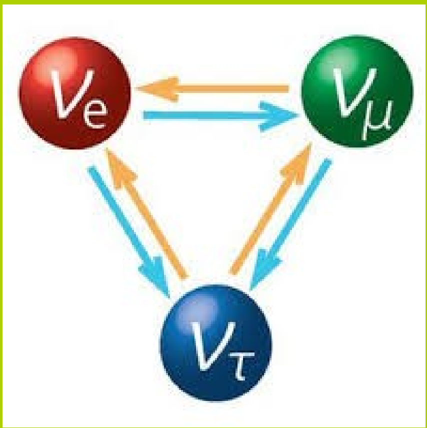
ASTROPARTICLES — Astroparticles and High Energy Physics Group

https://www.facebook.com/ific.ahep/

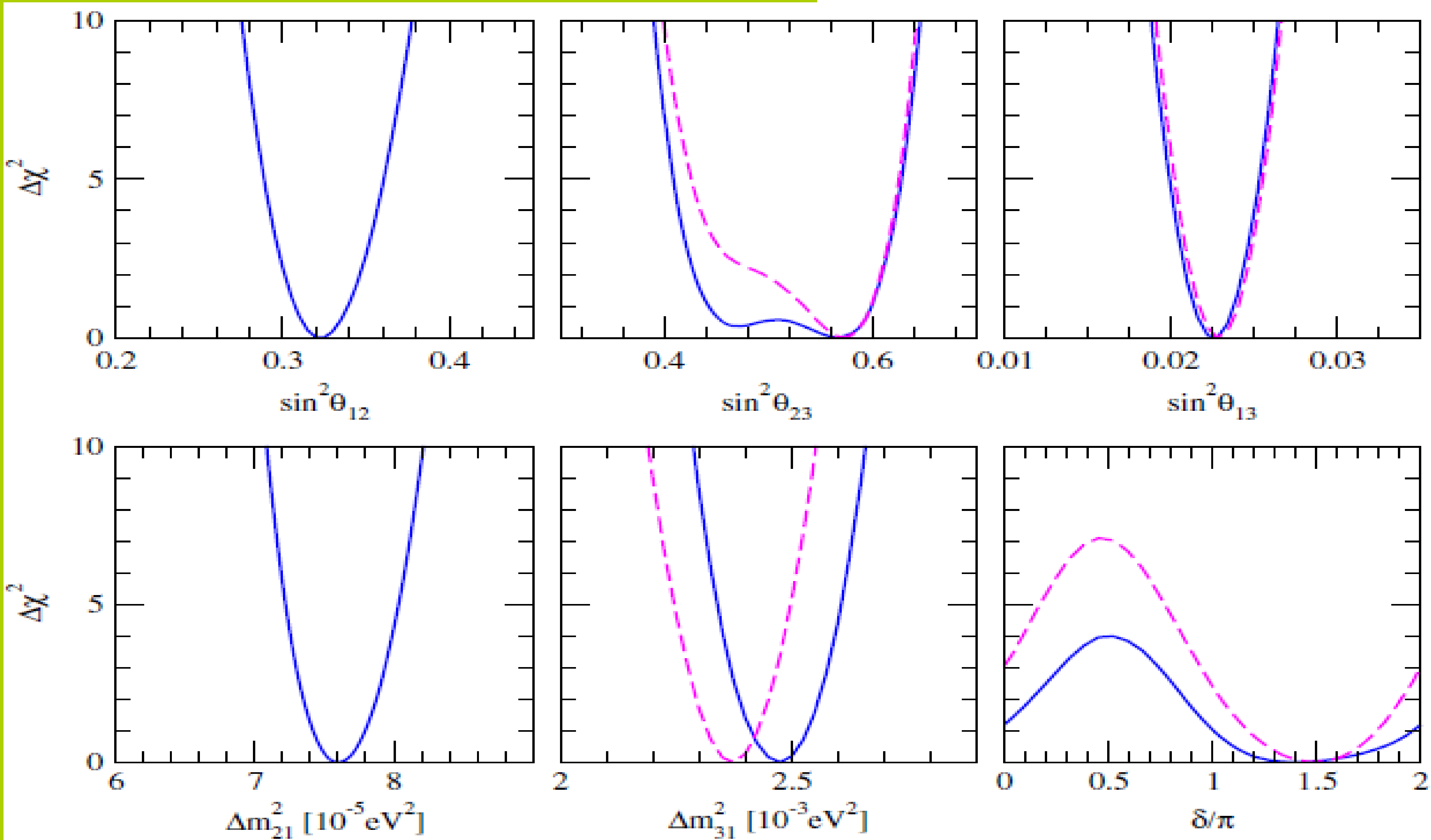
3rd IBS-MultiDark-IPPP workshop

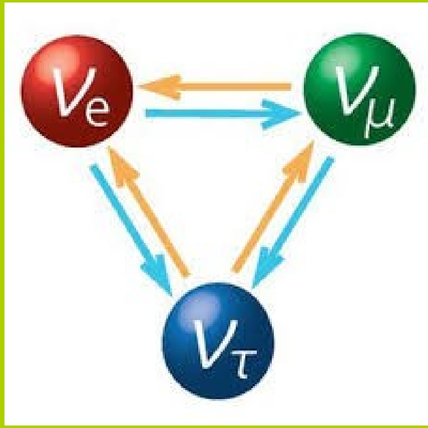


Oscillation parameters

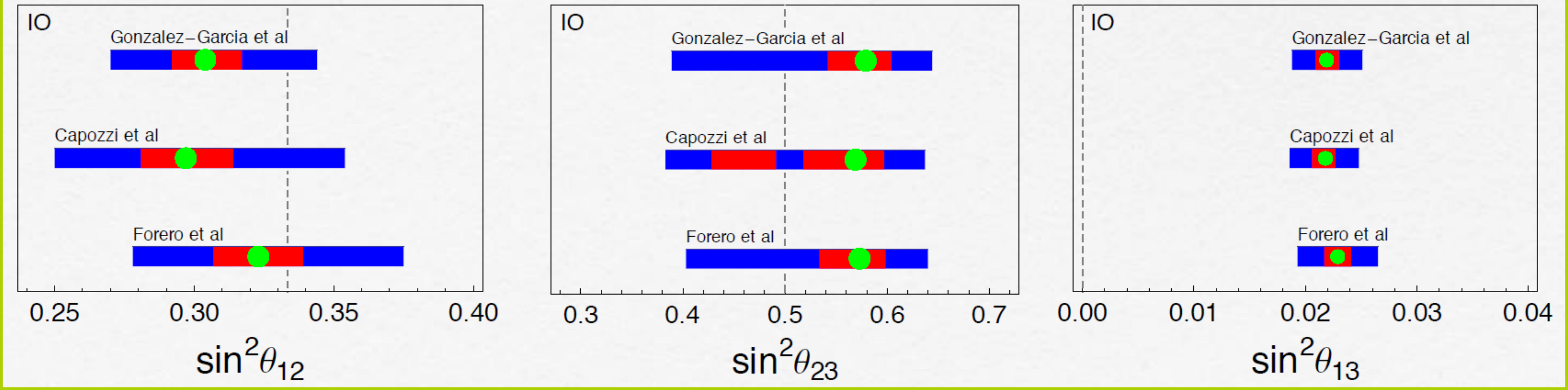
Precision era starts

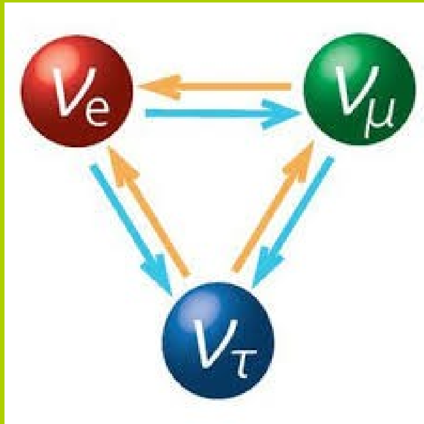
PHYSICAL REVIEW D **90**, 093006 (2014)





neutrino oscillation parameters

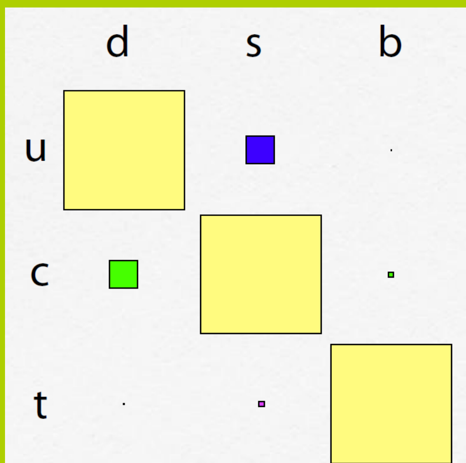




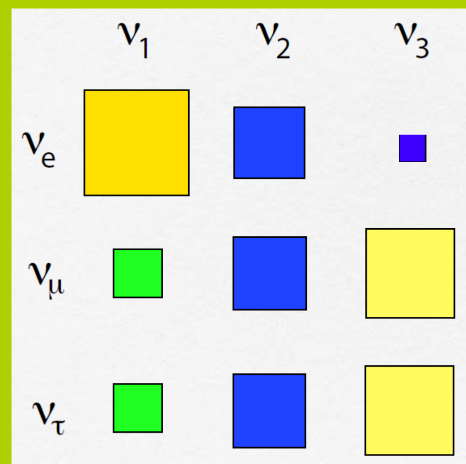
neutrino oscillation parameters

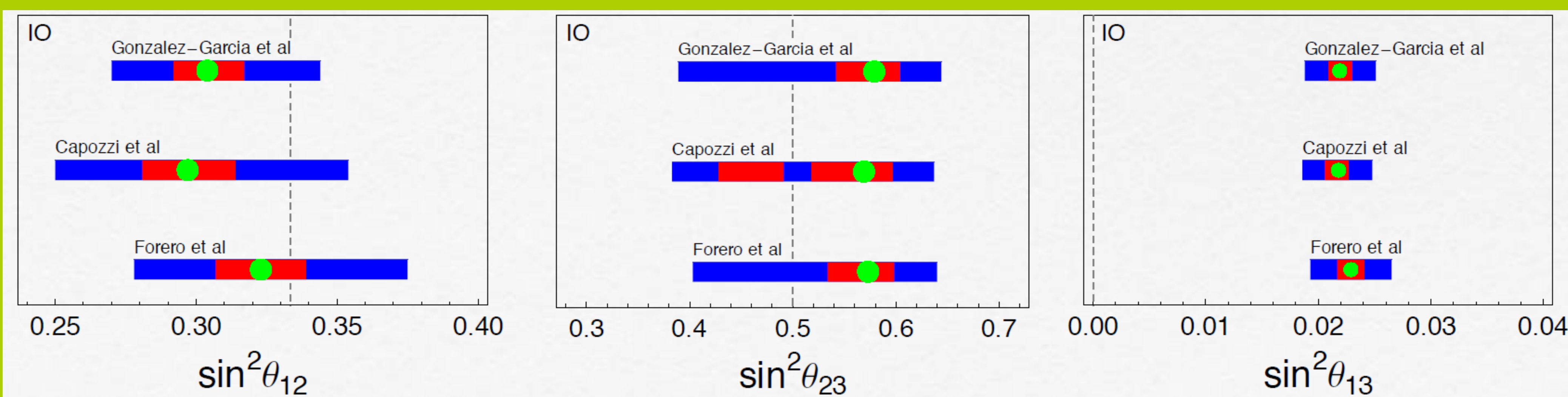
Phys.Lett. B748 (2015) 1-4

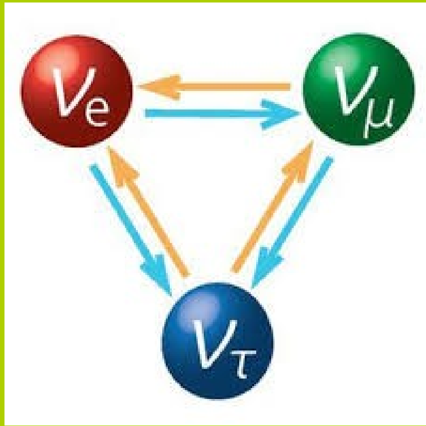
Phys.Rev. D86 (2012) 051301



vs







neutrino oscillation parameters

Phys.Lett. B748 (2015) 1-4

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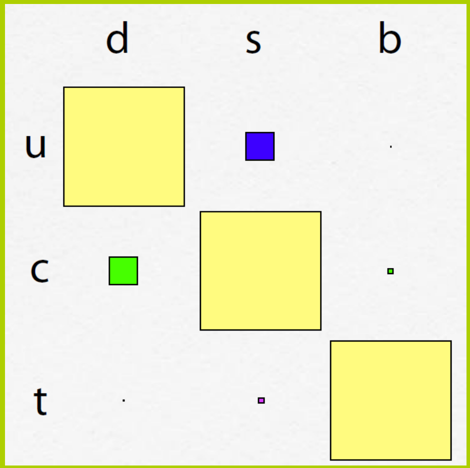

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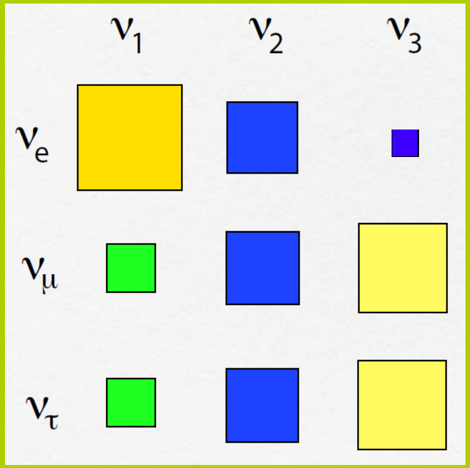
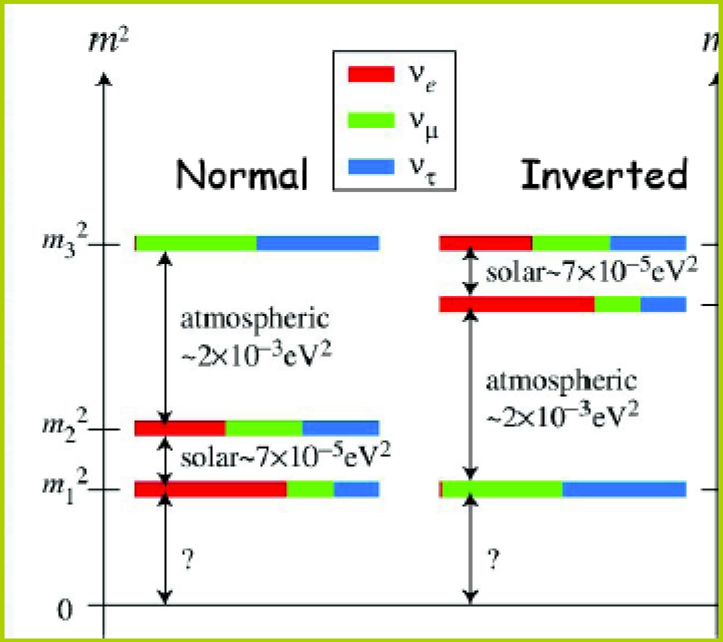
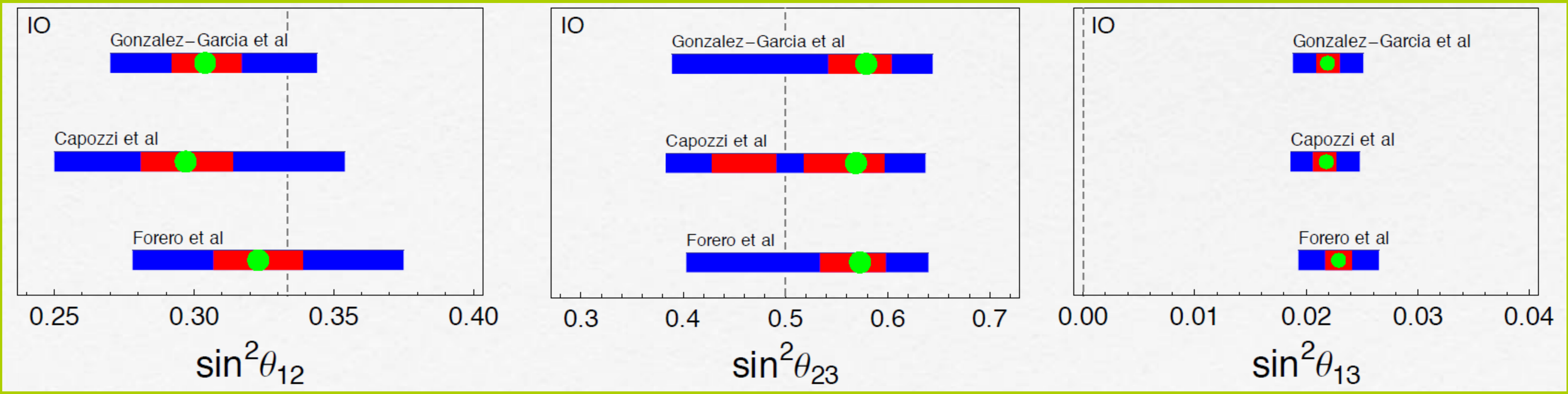


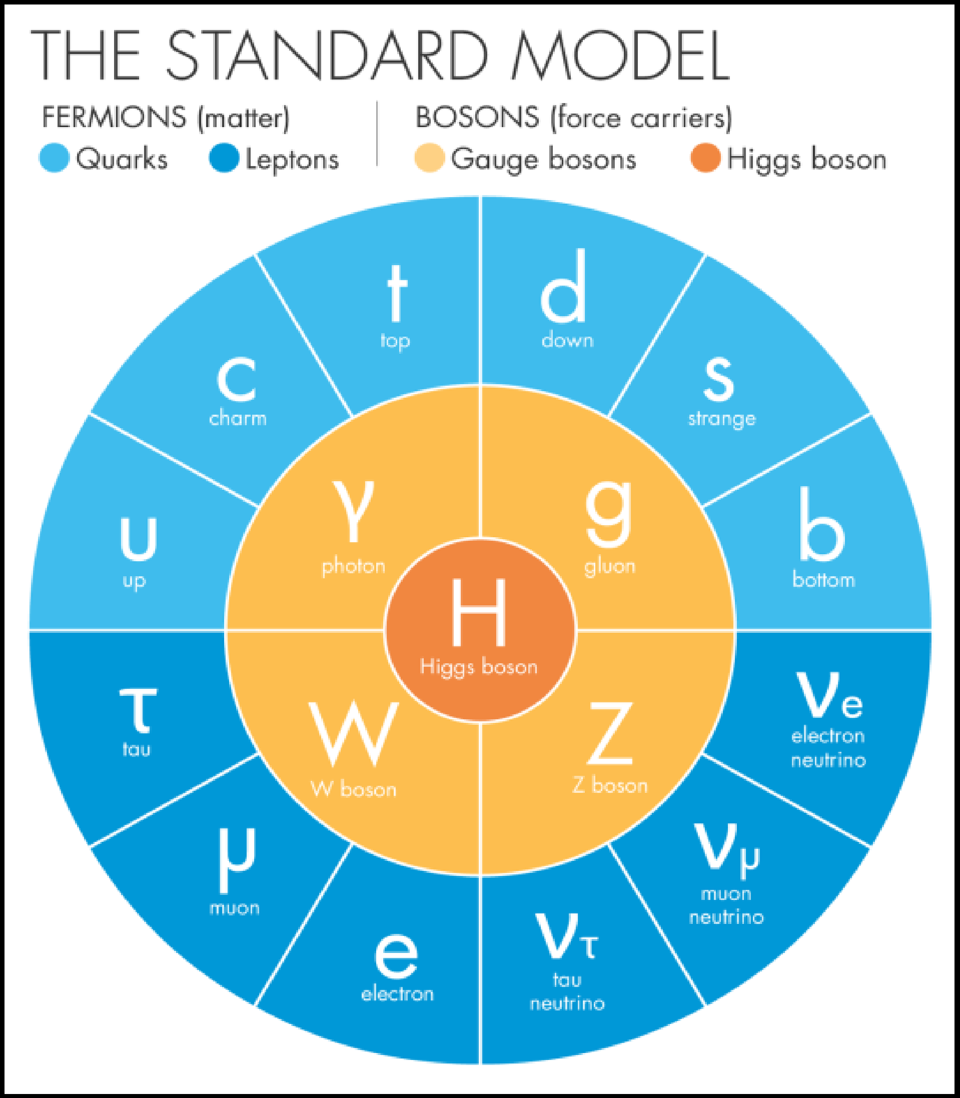




However exciting ...

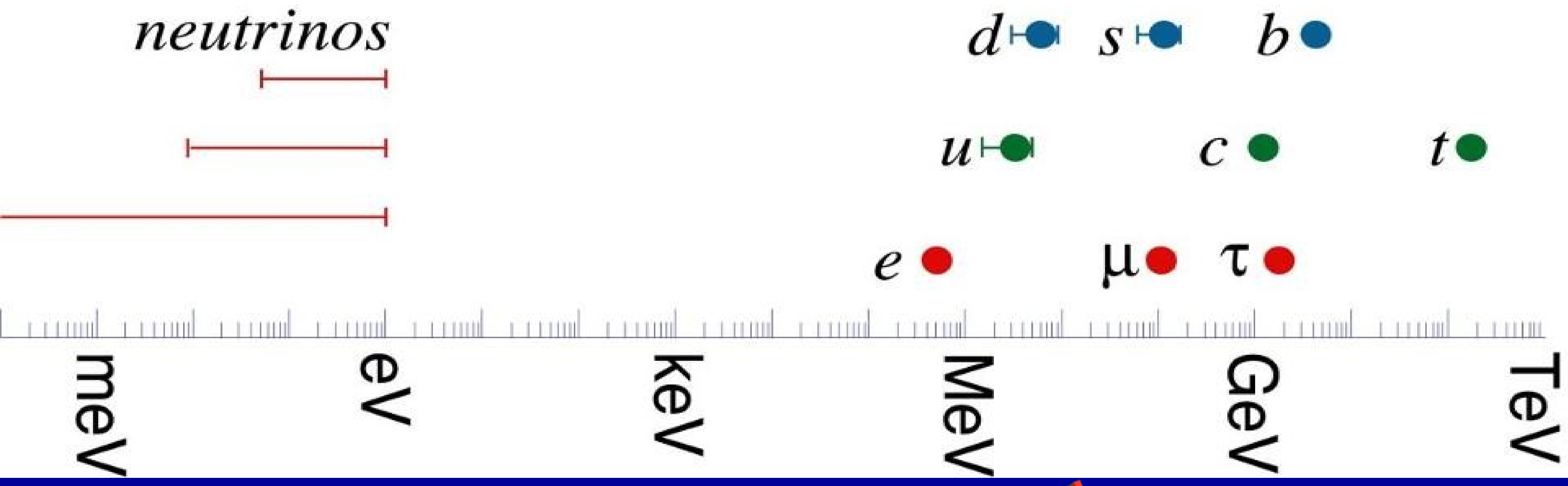
Higgs not the last brick !

Standard model



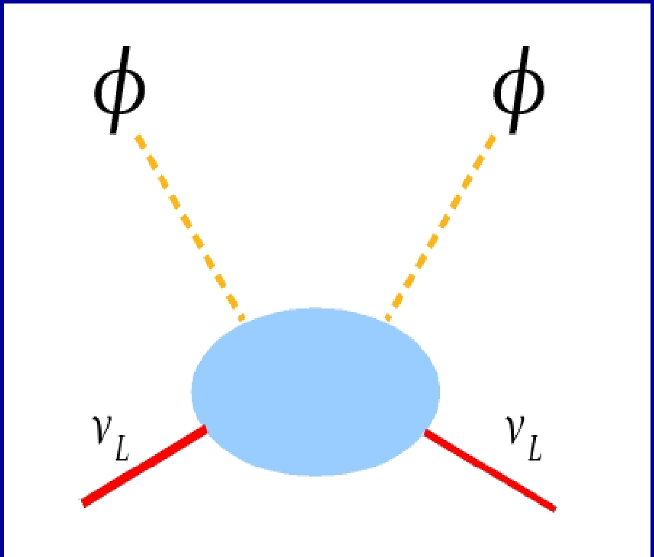
Despite its great success
SM can not explain neutrinos

... *nor dark matter*



need to generate
tiny masses for neutrinos

The origin of neutrino mass

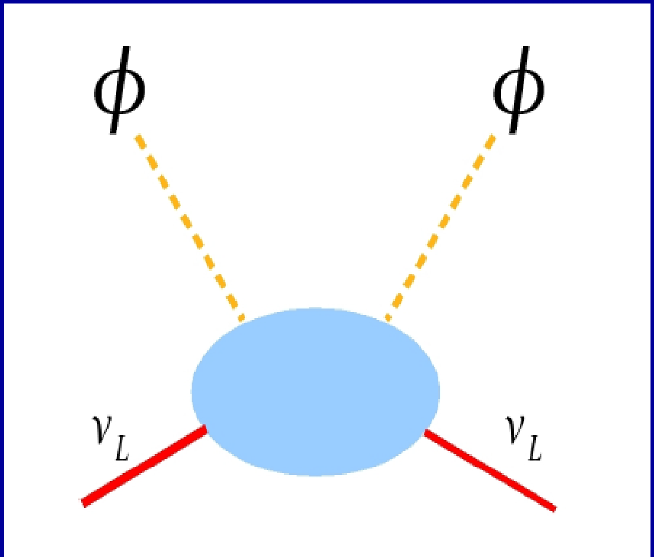


MECHANISM

SCALE

FLAVOR STRUCTURE

The origin of neutrino mass



MECHANISM

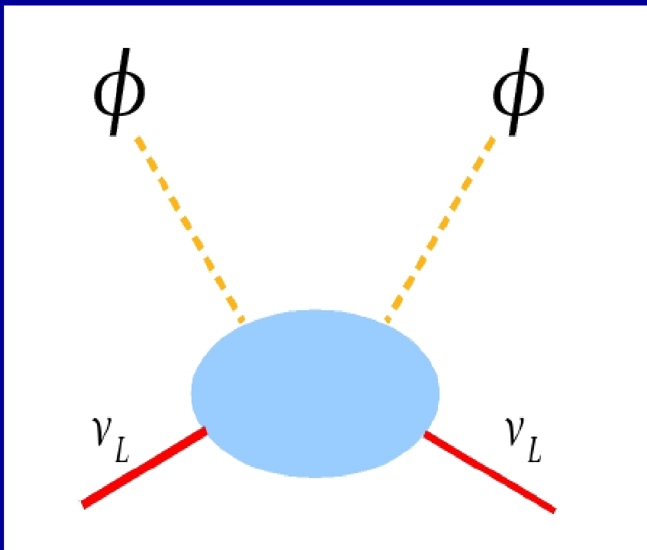
SCALE

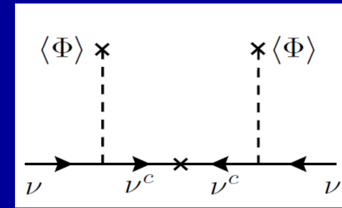
FLAVOR STRUCTURE

Seesaw

$$v_3 v_1 \sim {v_2}^2$$

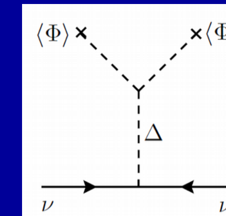
The origin of neutrino mass





TYPE I

Minkowski 77
Gellman Ramond Slansky 80
Glashow, Yanagida 79
Mohapatra Senjanovic 80
Lazarides Shafi Weterrich 81
Schechter-Valle, 80 & 82



TYPE II

Schechter-Valle 80/82

Seesaw

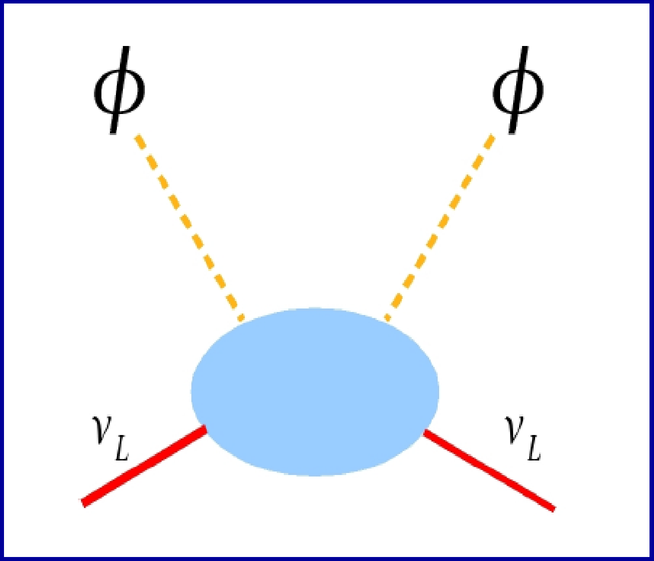
$$v_3 v_1 \sim {v_2}^2$$

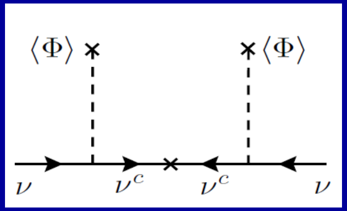
MECHANISM

SCALE

FLAVOR STRUCTURE

The origin of neutrino mass





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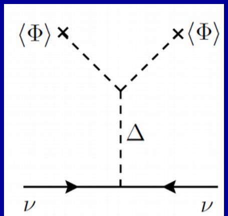


TYPE II

Schechter-Valle 80/82

Seesaw

$$v_3 v_1 \sim {v_2}^2$$

MECHANISM

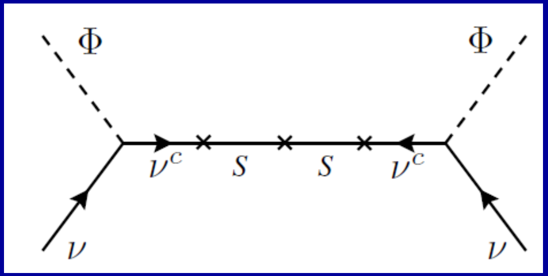
SCALE

FLAVOR STRUCTURE

Number & properties of messengers

LOW-SCALE SEESAW

Mohapatra-Valle 86
Akhmedov et al PRD53 (1996) 2752
Malinsky et al PRL95(2005)161801
Bazzocchi et al, PRD81 (2010) 051701



Why large neutrino mixing?

$$\begin{pmatrix}\nu_e \\ e\end{pmatrix}_L \quad \begin{pmatrix}\nu_\mu \\ \mu\end{pmatrix}_L \quad \begin{pmatrix}\nu_\tau \\ \tau\end{pmatrix}_L$$

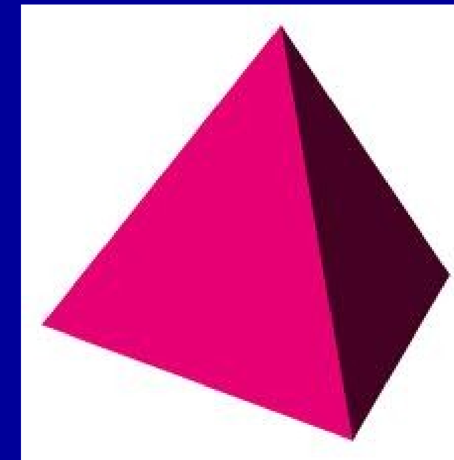
$$e_R \quad \mu_R \quad \tau_R$$

$$\begin{pmatrix}u \\ d\end{pmatrix}_L \quad \begin{pmatrix}c \\ s\end{pmatrix}_L \quad \begin{pmatrix}t \\ b\end{pmatrix}_L$$

$$u_R \quad c_R \quad t_R$$

$$d_R \quad s_R \quad b_R$$

Flavor Symmetry



A4

Babu-Ma-Valle PLB552 (2003) 207
Hirsch et al PRD69 (2004) 093006

$$\sin^2\theta_{23} = 0.5$$

$$\sin^2\theta_{13} = 0$$

Flavor Symmetry

$$\begin{pmatrix}\nu_e\\ e\end{pmatrix}_L \quad \begin{pmatrix}\nu_\mu\\ \mu\end{pmatrix}_L \quad \begin{pmatrix}\nu_\tau\\ \tau\end{pmatrix}_L$$

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$$\begin{pmatrix}u\\ d\end{pmatrix}_L \quad \begin{pmatrix}c\\ s\end{pmatrix}_L \quad \begin{pmatrix}t\\ b\end{pmatrix}_L$$

$$u_R \quad c_R \quad t_R$$

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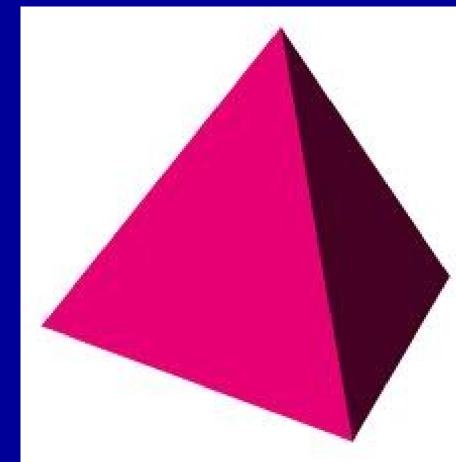

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Babu-Ma-Valle PLB552 (2003) 207

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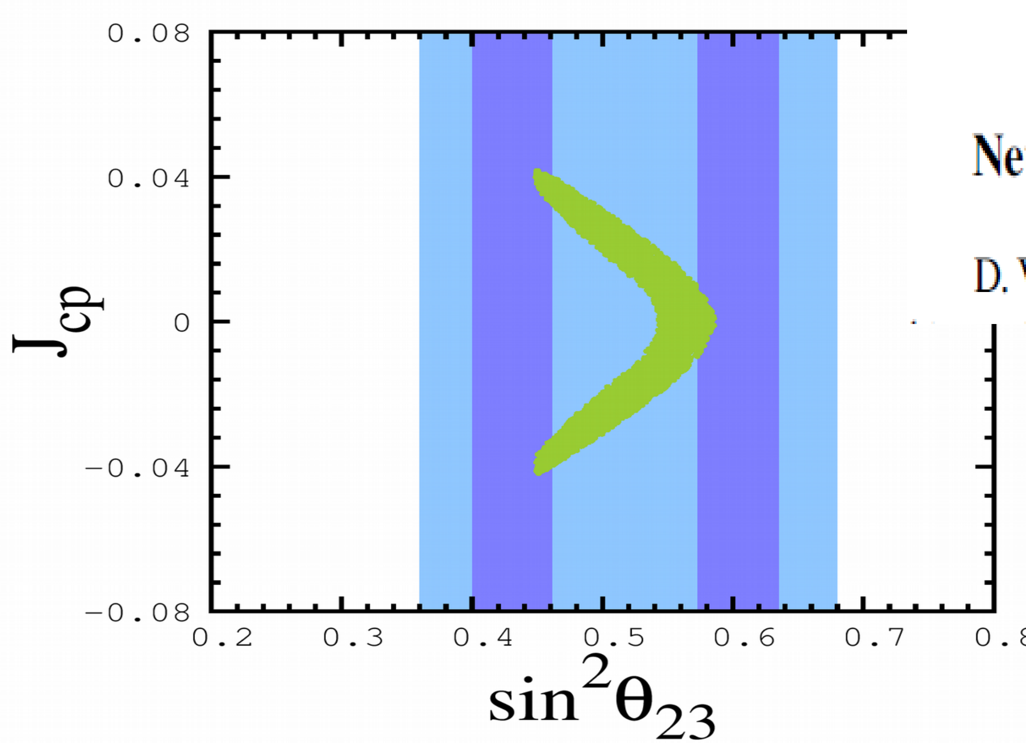


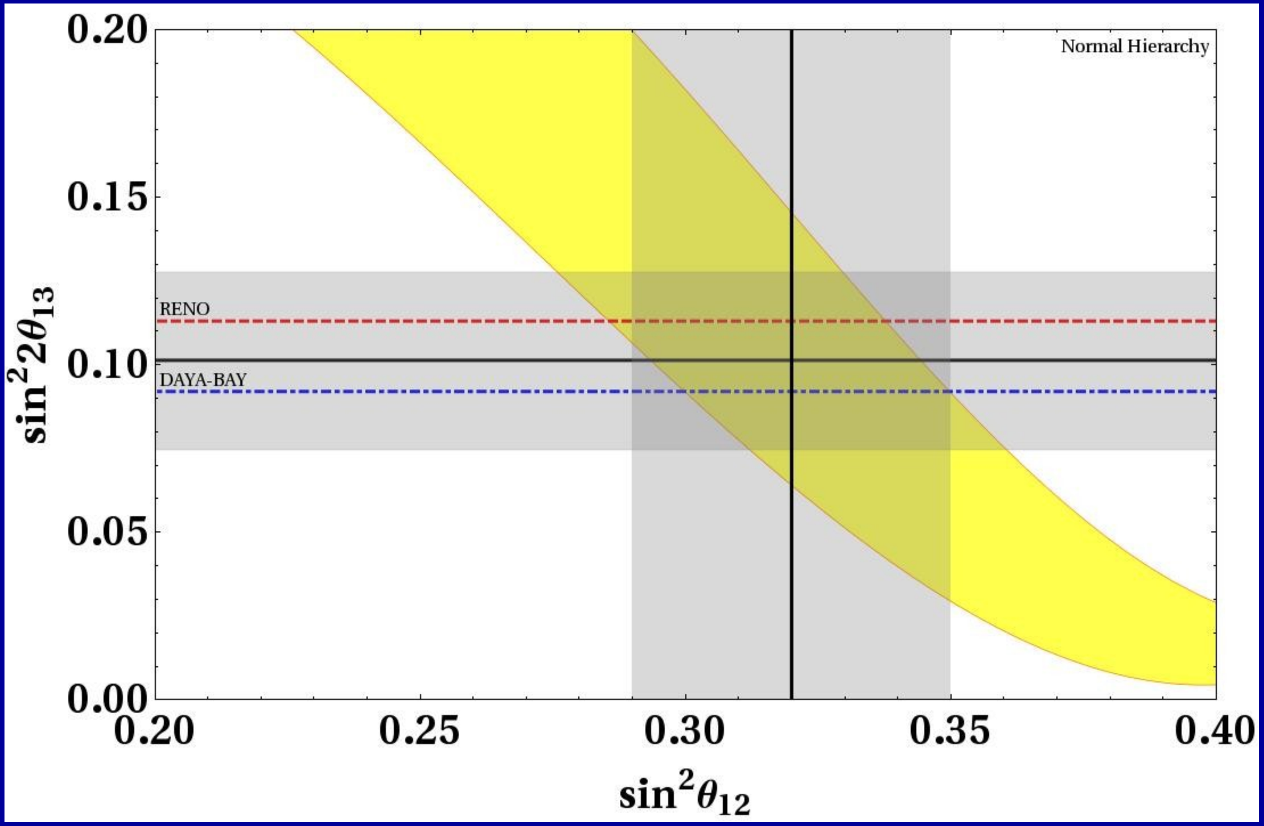
PHYSICAL REVIEW D 88, 016003 (2013)

Neutrino mixing with revamped A_4 flavor symmetry

D. V. Forero,[1,2,*] S. Morisi,[3,†] J.C. Romão,[1,‡] and J.W.F. Valle[2,§]

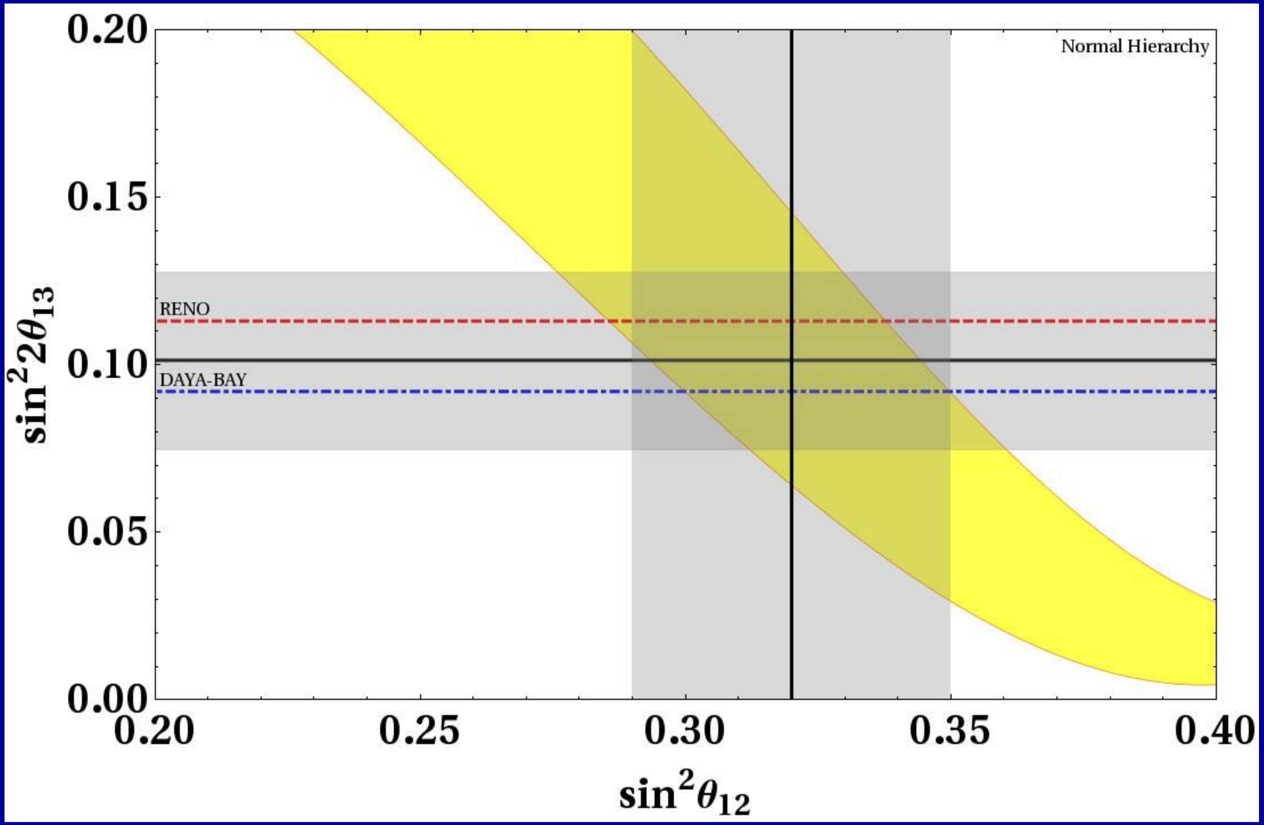
Flavor correlations

Boucenna et al
PhysRevD.86.073008



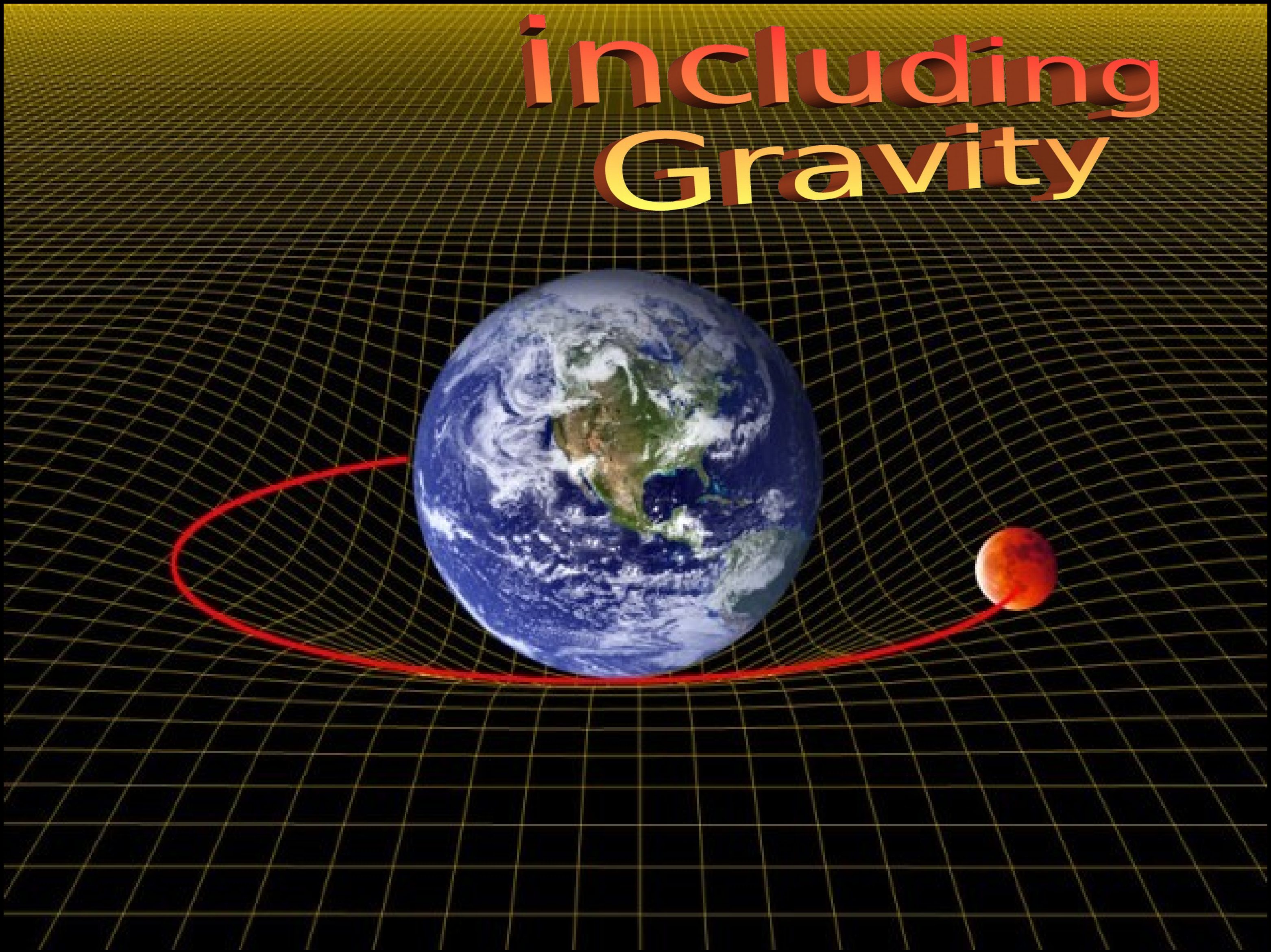
Flavor correlations

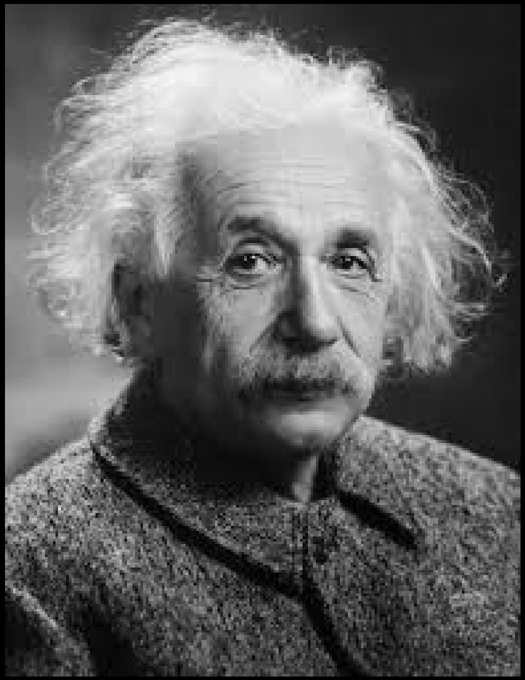
Boucenna et al
PhysRevD.86.073008



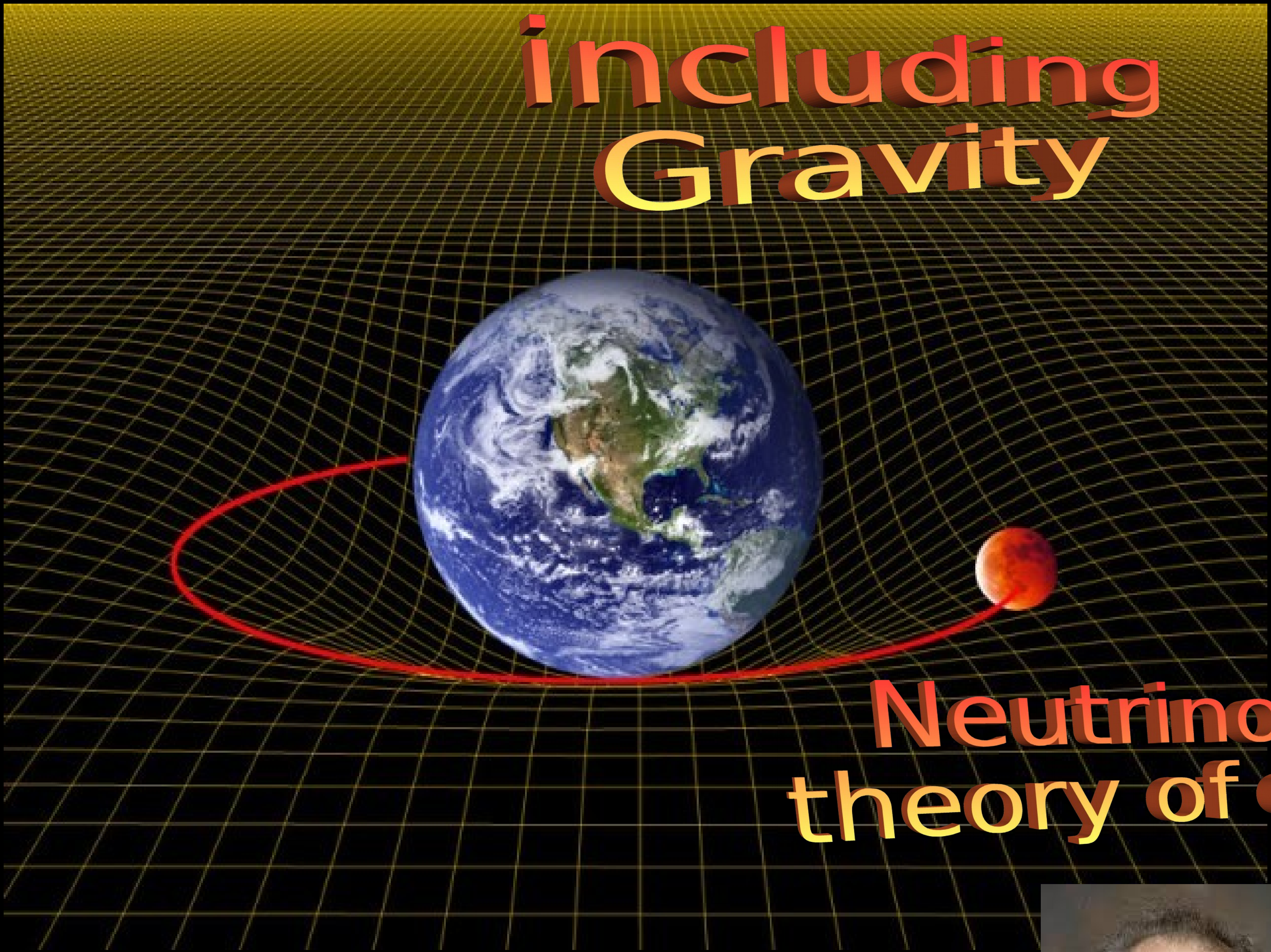
P Chen et al
Phys.Lett. B753 (2016) 644-652
Phys.Rev. D94 (2016) no.3, 033002

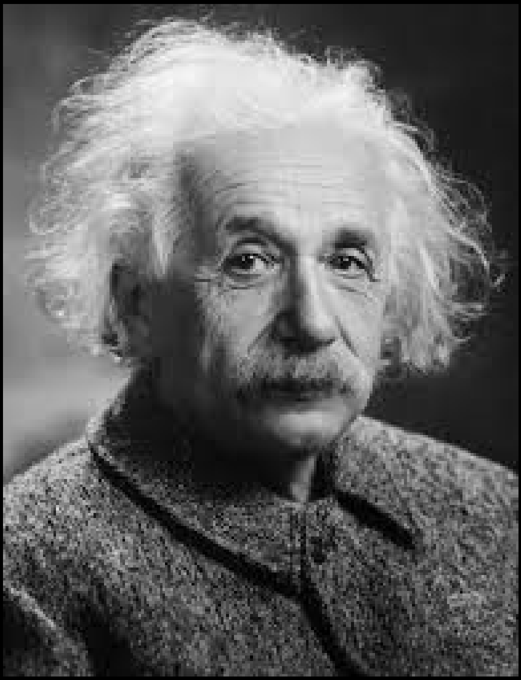
Model-independent flavor approach


including
Gravity



including Gravity





Neutrinos in the theory of everything

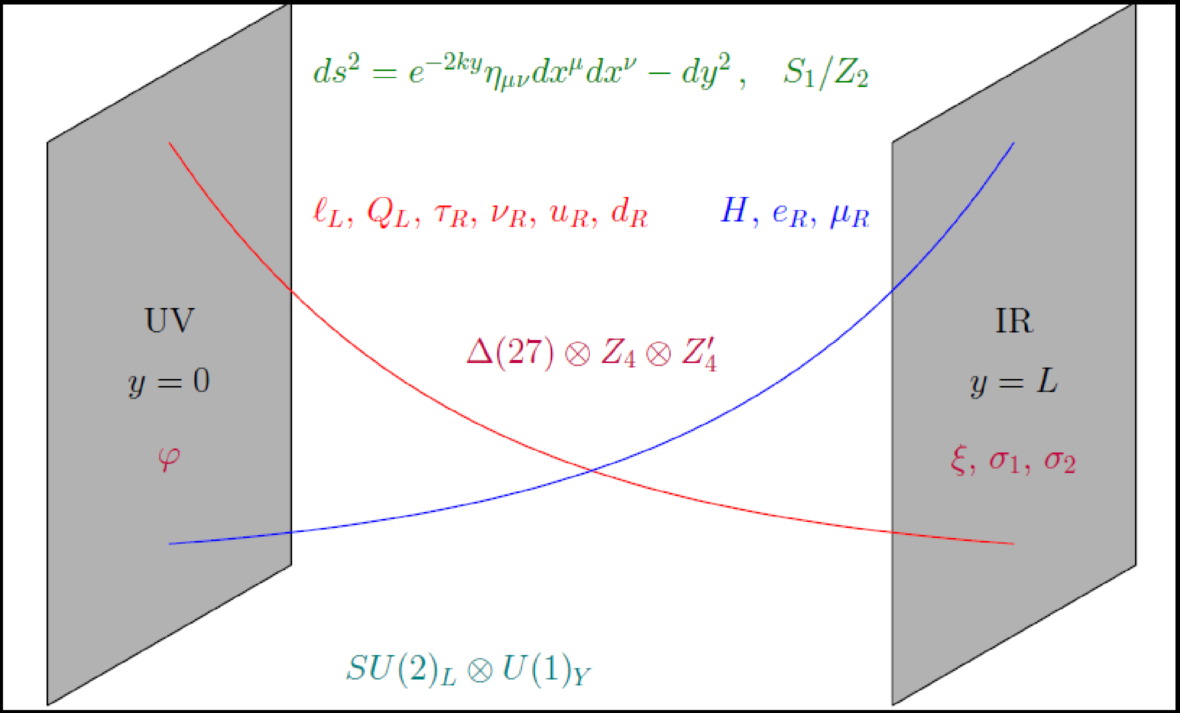
: Chen et al arXiv:1509.06683
JHEP01(2016)007

Addazi et al

Phys.Lett. B759 (2016) 471-478

Warped flavor predictions

: Chen et al arXiv:1509.06683
JHEP01(2016)007



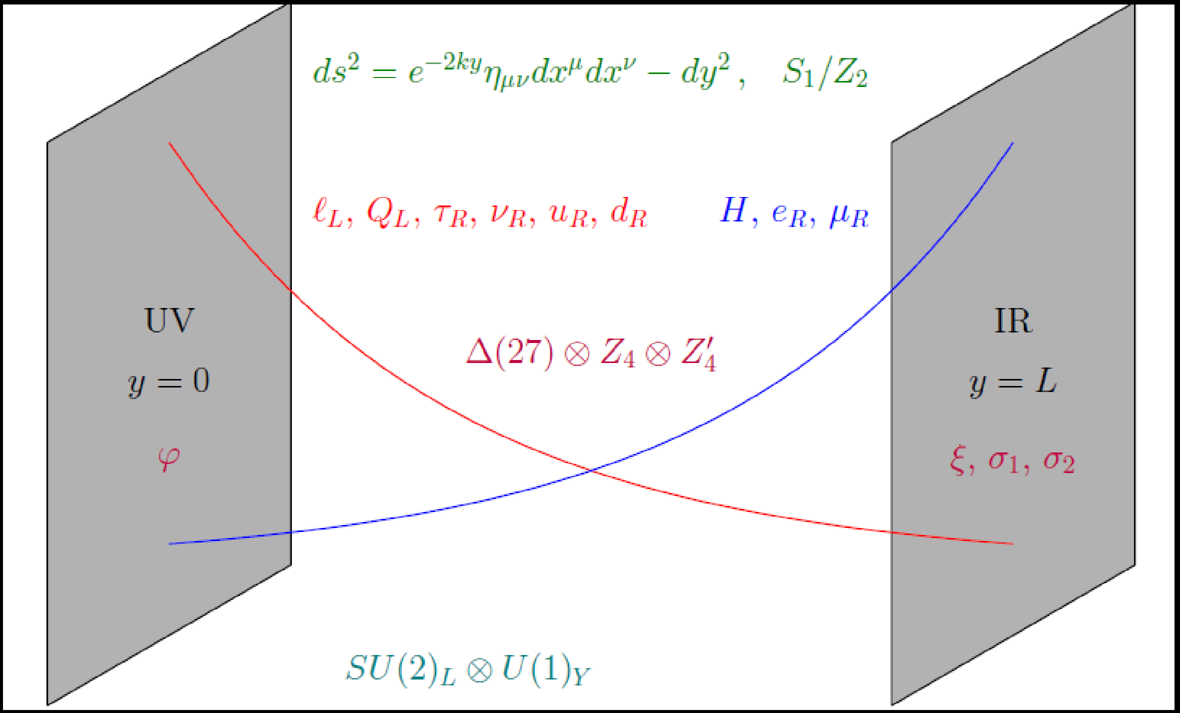
Masses explained by choices

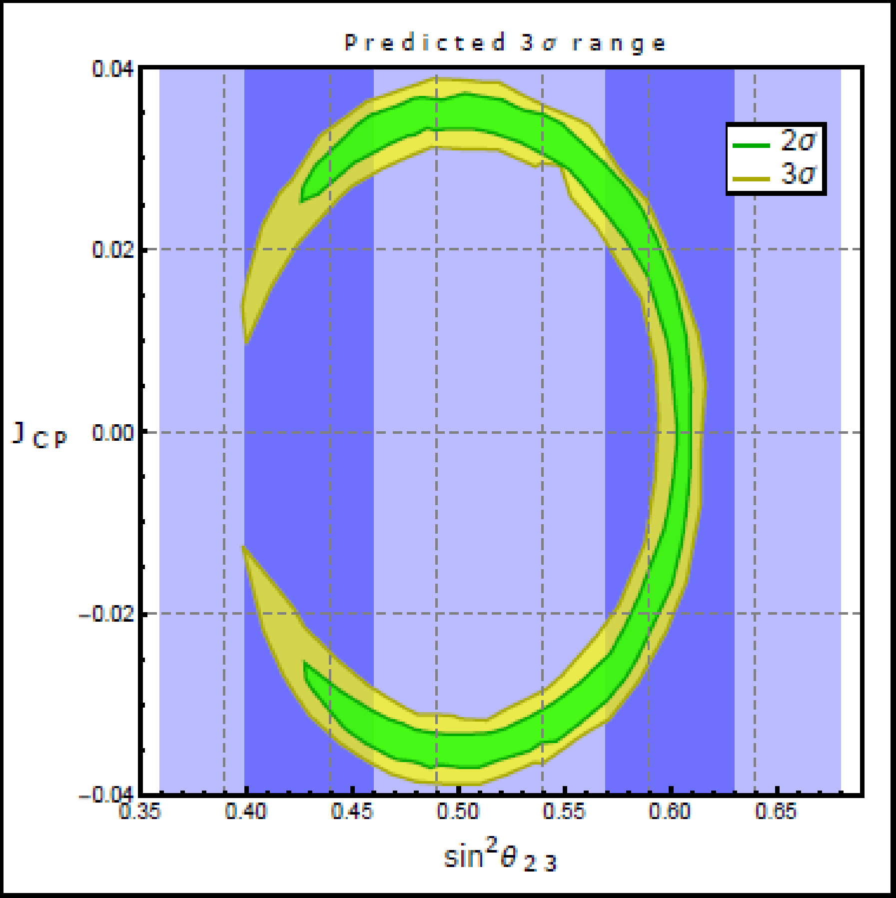
of the bulk parameters

http://arxiv.org/abs/arXiv:1610.05962

Warped flavor predictions

: Chen et al arXiv:1509.06683
JHEP01(2016)007





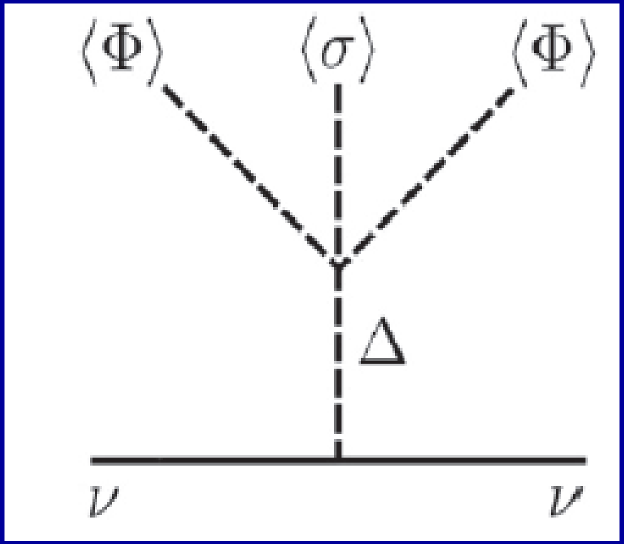
Masses explained by choices of the bulk parameters

http://arxiv.org/abs/arXiv:1610.05962


new states in neutrino mass
models may play the role of
Dark matter

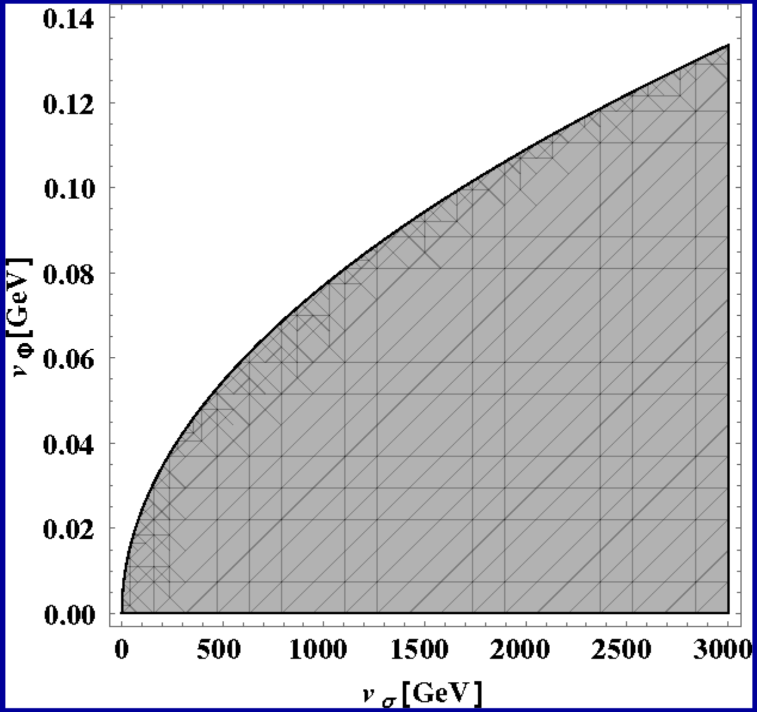
type-II seesaw with spont U(1) violation

Phys.Rev. D25 (1982) 774



Majoron

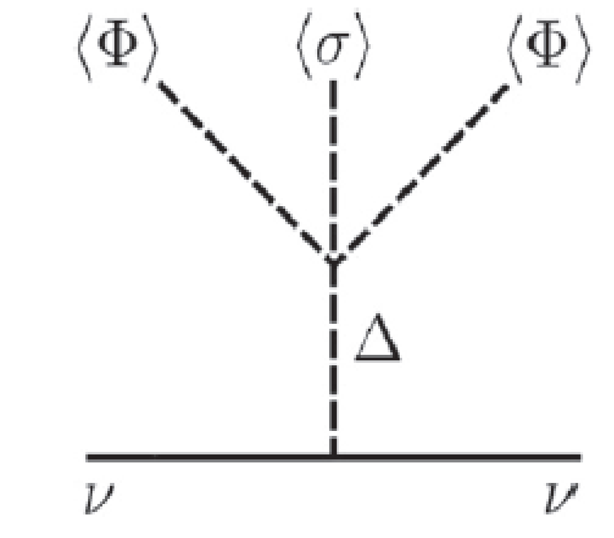
Astrophysical limit



type-II seesaw with spont U(1) violation

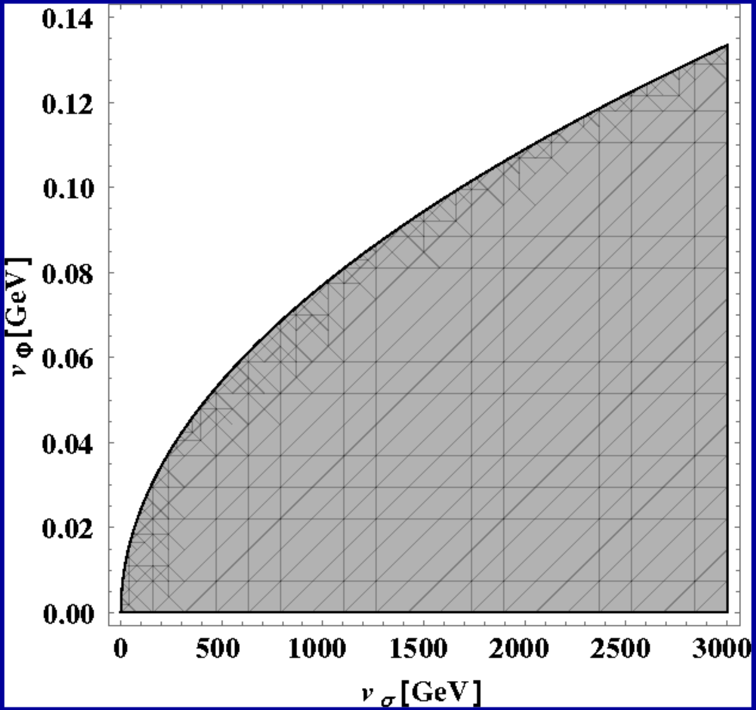
Phys.Rev. D25 (1982) 774

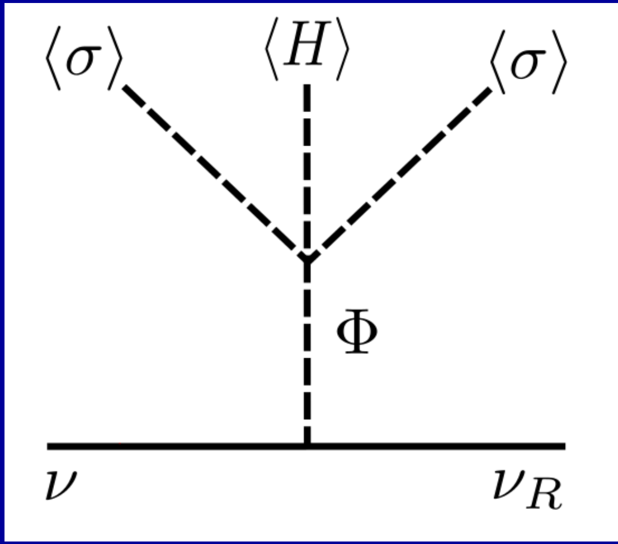
Naturally small induced vev



Majoron
vs
Diracon

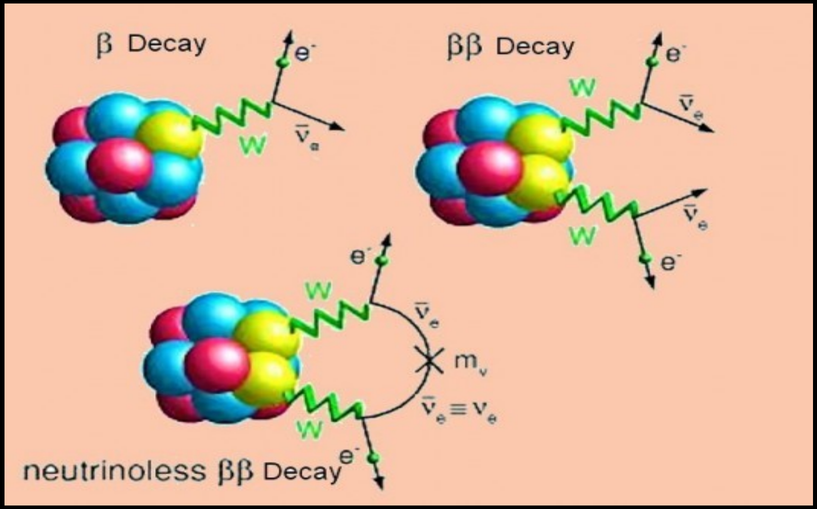
Astrophysical limit





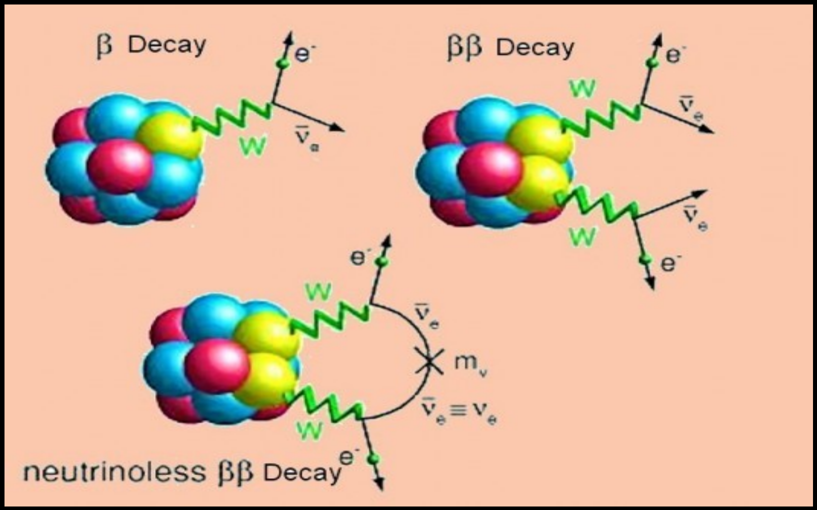
ArXiv:1605.08362 PLB

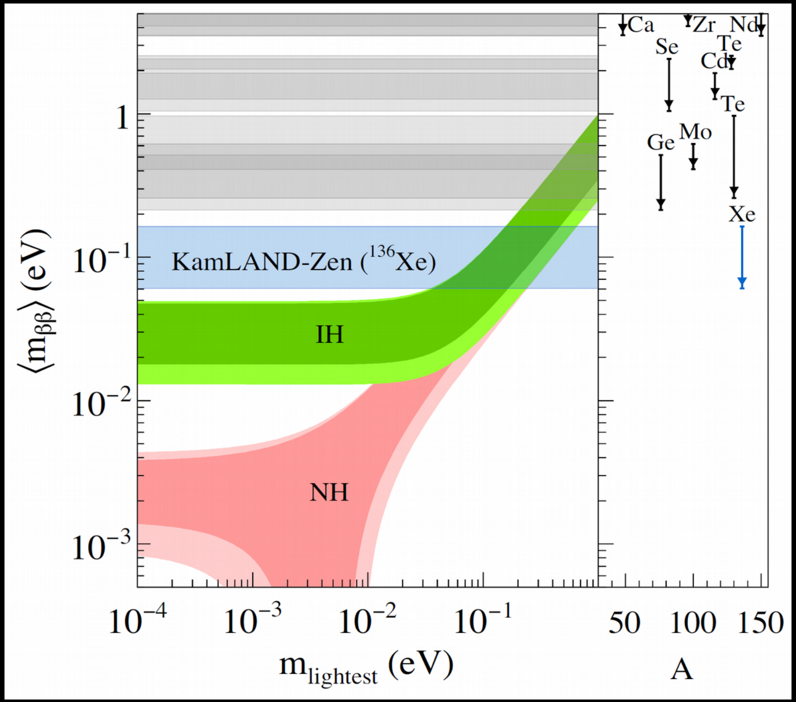
beta & double beta decay



A.S. Barabash arXiv:1104.2714

beta & double beta decay





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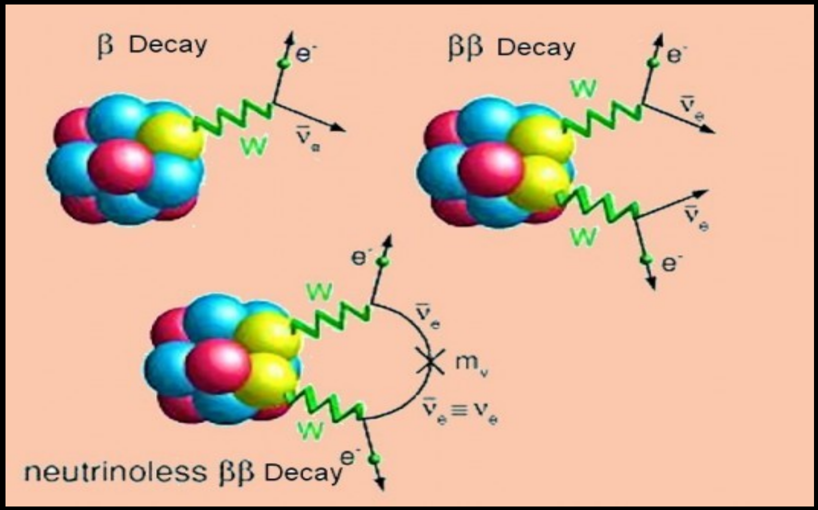

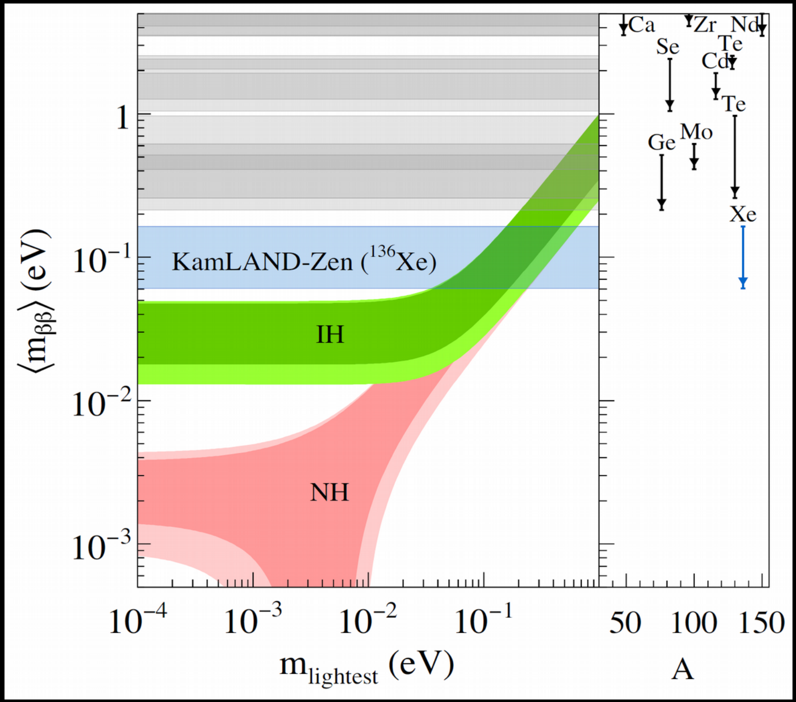

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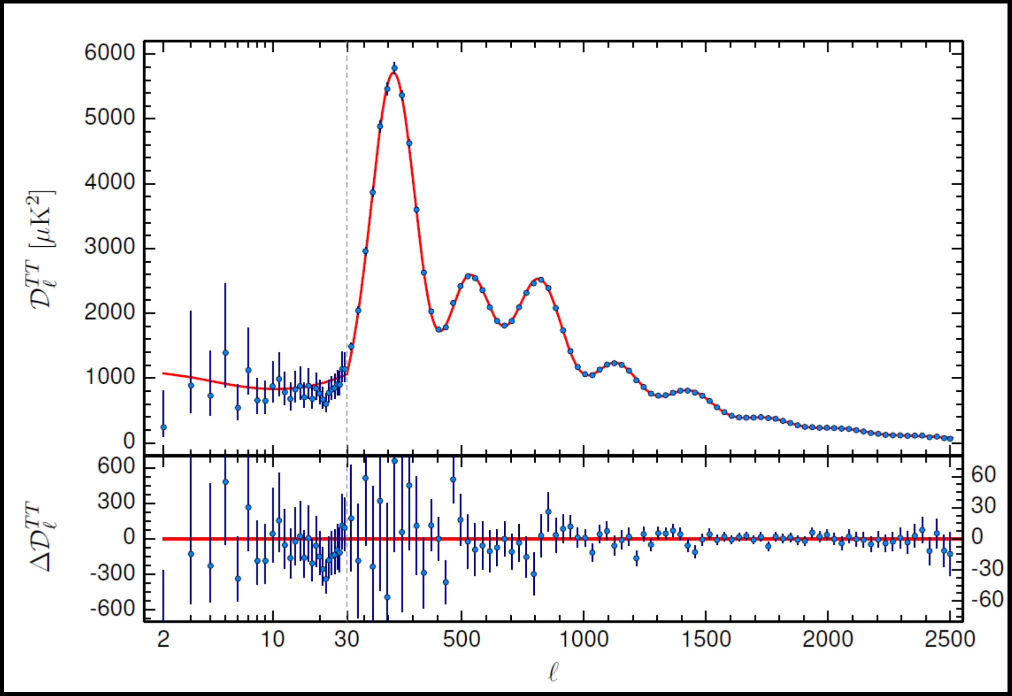

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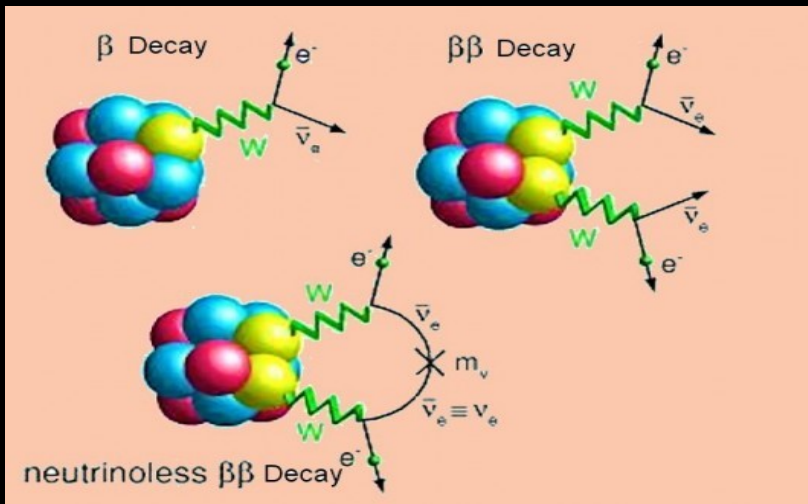
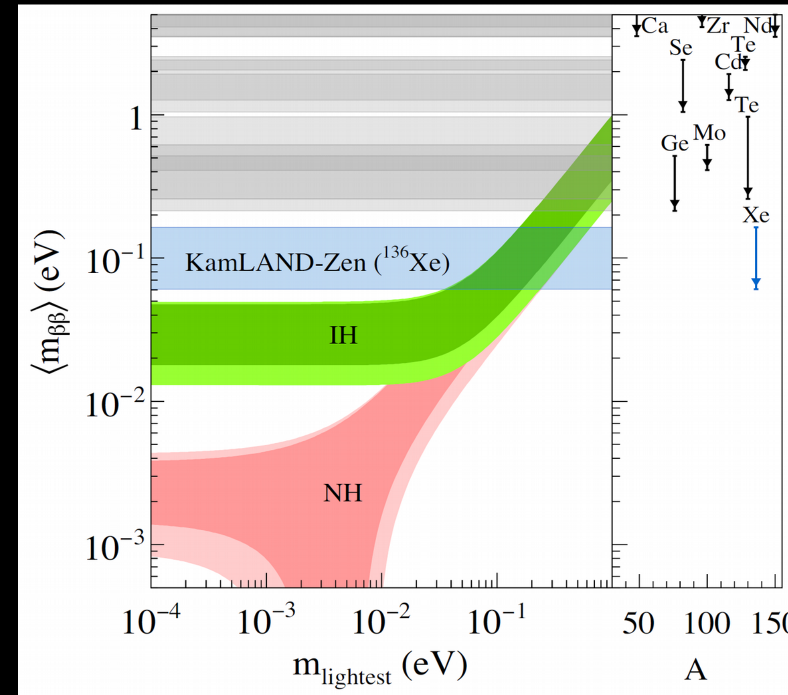
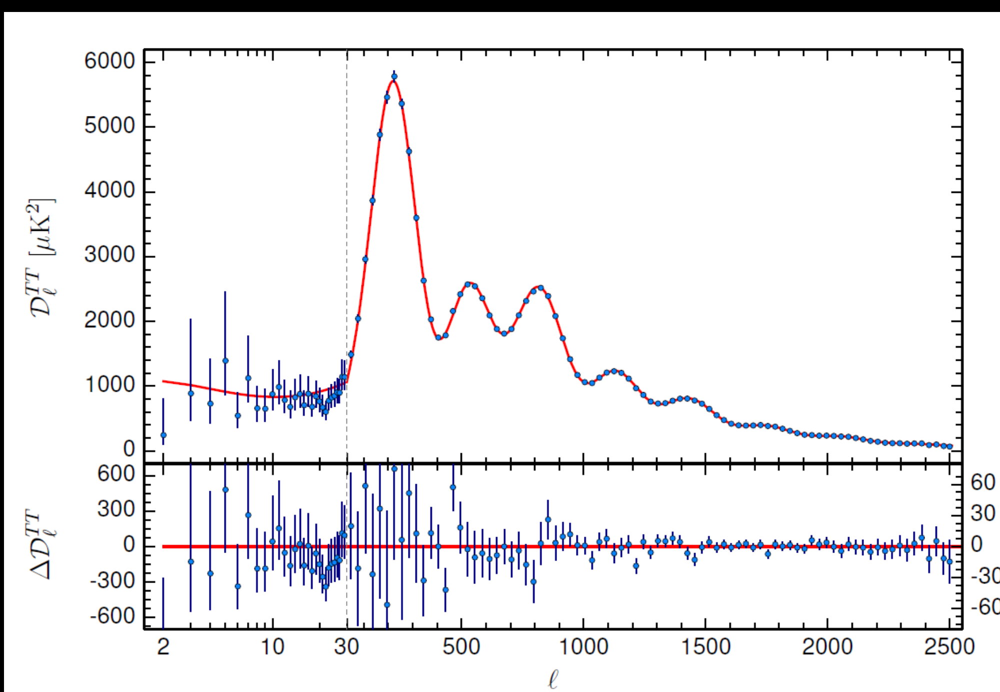
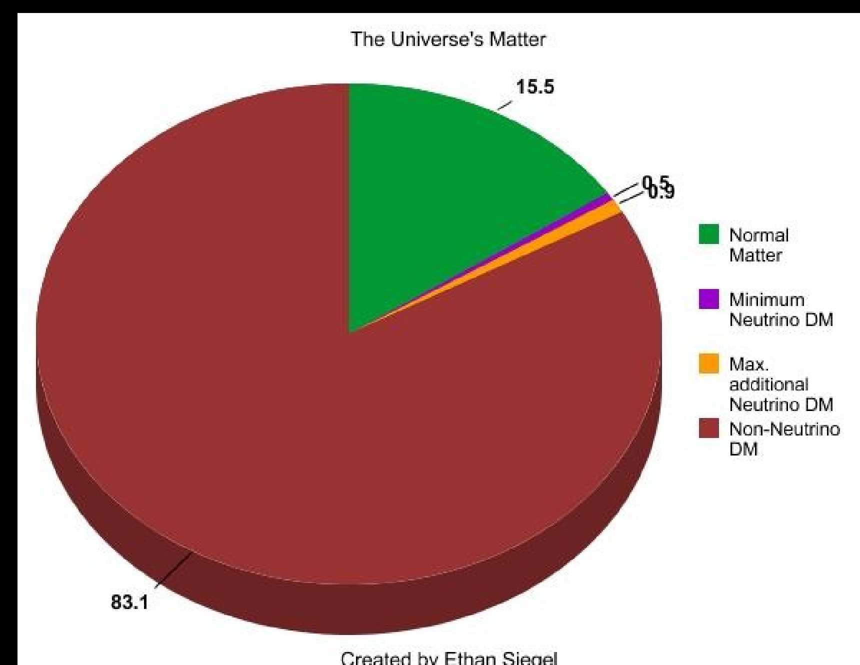




A.S. Barabash arXiv:1104.2714





The keV majoron as a dark matter particle

PLB318 (1993) 360

dark matter majorons

V. Berezinsky [1]

INFN, Laboratori Nazionali del Gran Sasso, I-67010, Assergi (AQ), Italy and Institute for Nuclear Research, Moscow, Russia

and

J.W.F. Valle [2]

Instituto de Fisica Corpuscular - IFIC/CSIC, Dept. de Fisica Teòrica, Universitat de València, 46100 Burjassot, València, Spain

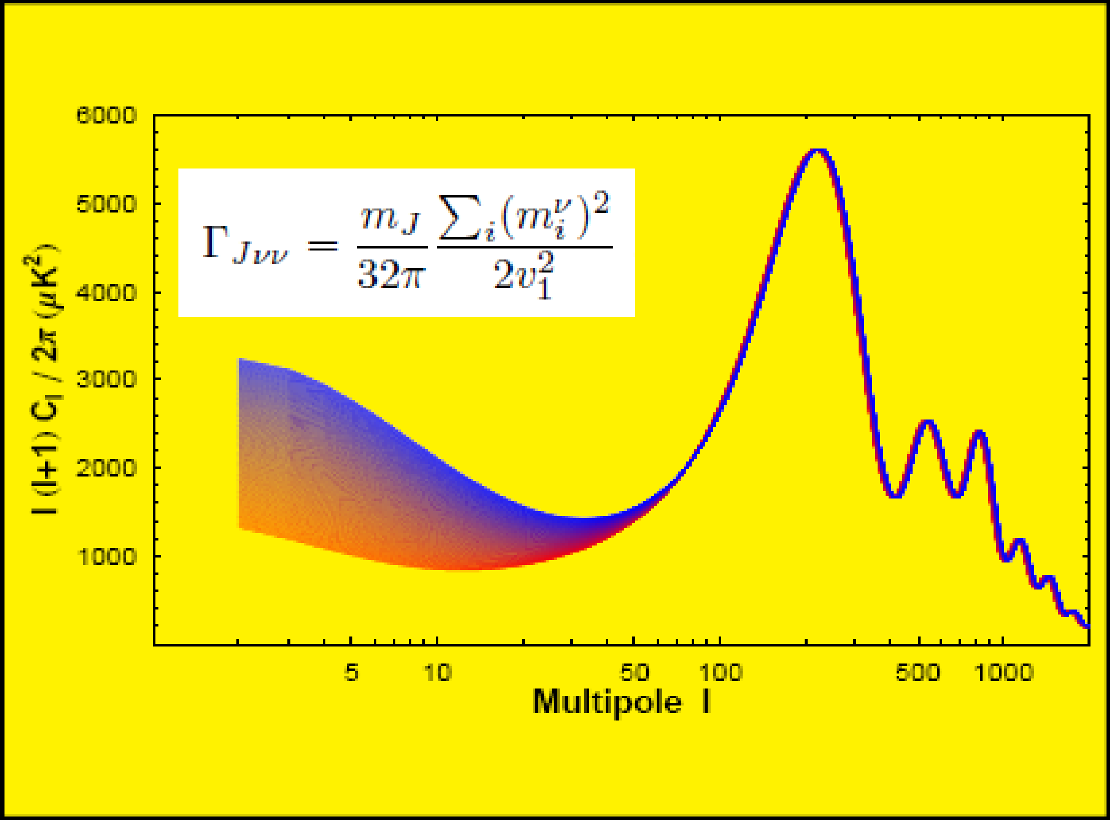
Received 23 August 1993
Editor: R. Gatto

We consider a very weakly interacting keV majoron as a dark matter particle (DMP), which provides both the critical density $\rho_{cr} = 1.88 \times 10^{-29} h^2$ g/cm^3 and the galactic scale $M_{gal} \sim m_{Pl}^3/m_J^2 \sim 10^{12} M_\odot (m_J/1\,\text{keV})^{-2}$ for galaxy formation. The majoron couples to the leptons only through some new "directly interacting particles", called DIPs, and this provides the required smallness of its coupling constants. If the masses of these DIPs are greater than the scale V_s characterizing the spontaneous violation of the global lepton symmetry they are absent at the corresponding phase transition ($T \sim V_s$) and the majorons are produced during the phase transition, never being in thermal equilibrium during the history of the universe. In the alternative case $m_{DIP} < V_s$ the majorons can be for a short period in thermal equilibrium. This scenario is not forbidden by nucleosynthesis and gives a reasonable growth factor for the density fluctuations compatible with the recent restrictions from the COBE experiment. It also provides as a possible signature the existence of an X-ray line at $E_\gamma = m_J/2$, produced by the decay $J \to \gamma + \gamma$. A particle physics model which provides the required smallness of the majoron couplings is described. It realizes the possibility of the keV majoron as a DMP in a consistent way and may also lead to observable rates for flavour violating decays such as $\mu \to e\gamma$ and $\mu \to 3e$, testable in the laboratory.

Berezinsky, Valle PLB318 (1993) 360

Consistency with CMB

dark matter majorons



Decaying Warm Dark Matter and Neutrino Masses

PRL99 (2007) 121301

M. Lattanzi[1,*] and J. W. F. Valle[2,†]

[1] *Oxford Astrophysics, Denis Wilkinson Building, Keble Road, OX1 3RH, Oxford, United Kingdom*

[2] *Instituto de Física Corpuscular-C.S.I.C./Universitat de València Campus de Paterna, Apt 22085, E-46071 València, Spain*

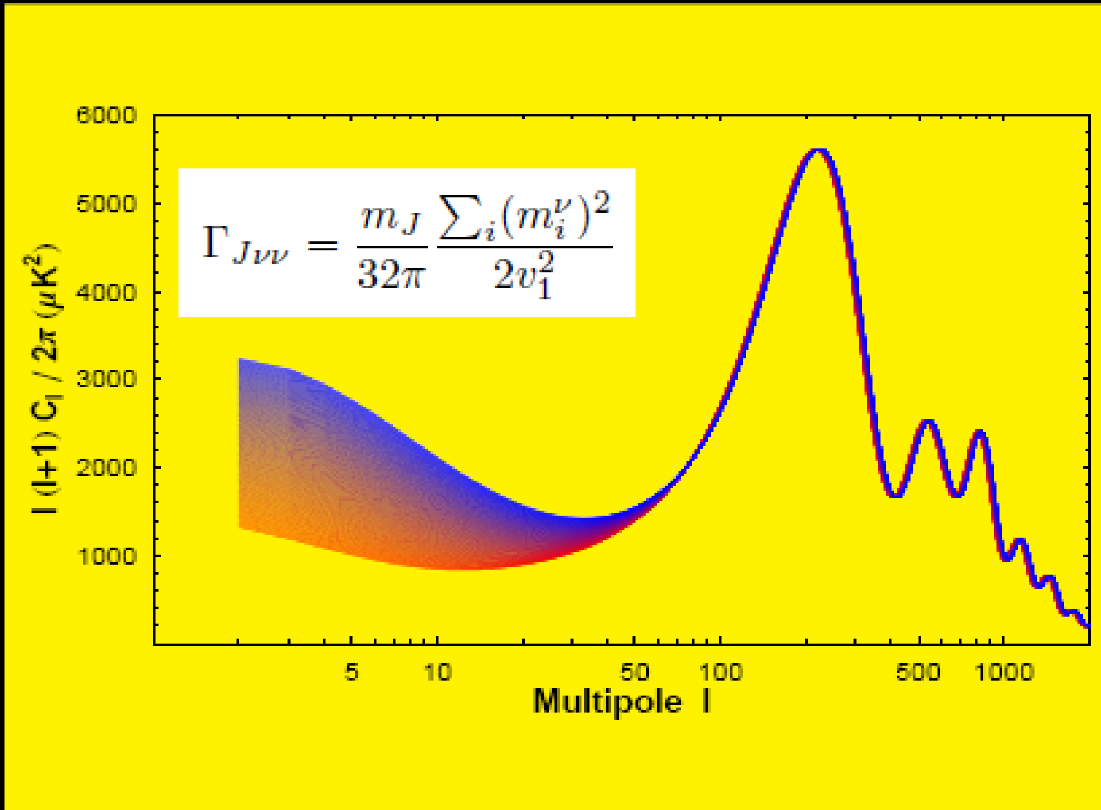
(Received 27 May 2007; published 20 September 2007)

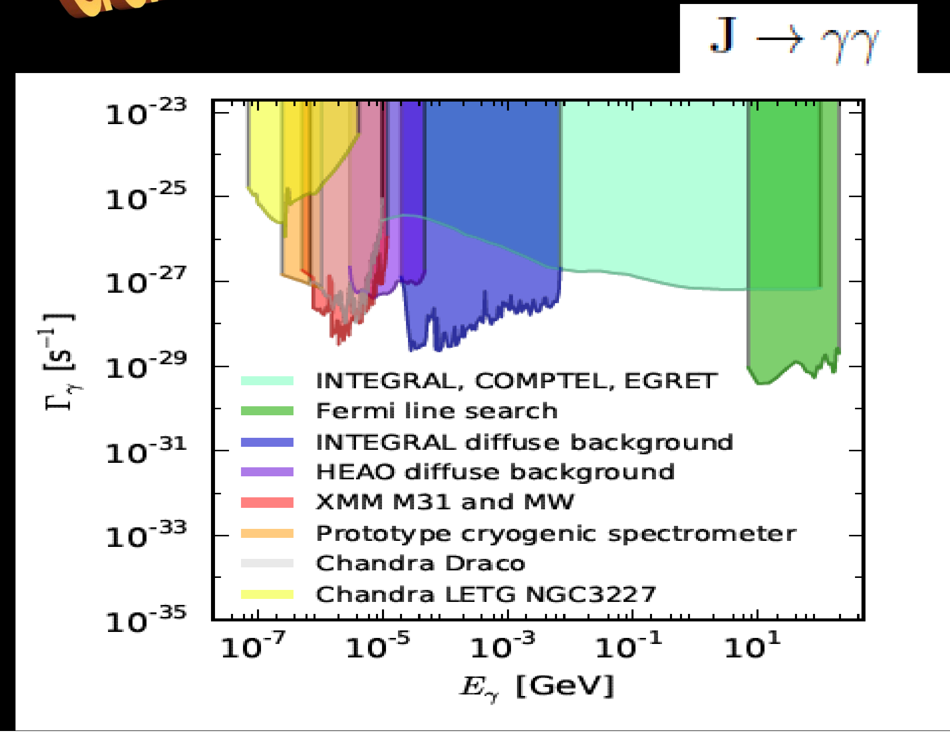
Neutrino masses may arise from spontaneous breaking of ungauged lepton number. Because of quantum gravity effects the associated Goldstone boson—the majoron—will pick up a mass. We determine the lifetime and mass required by cosmic microwave background observations so that the massive majoron provides the observed dark matter of the Universe. The majoron decaying dark matter scenario fits nicely in models where neutrino masses arise via the seesaw mechanism, and may lead to other possible cosmological implications.

Berezinsky, Valle PLB318 (1993) 360

Consistency with CMB

dark matter majorons





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M. Lattanzi[1,*] and J. W. F. Valle[2,†]

[1]*Oxford Astrophysics, Denis Wilkinson Building, Keble Road, OX1 3RH, Oxford, United Kingdom*

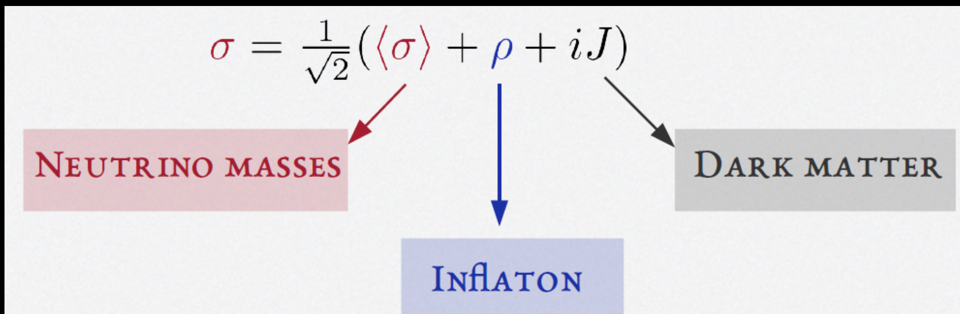
[2]*Instituto de Física Corpuscular-C.S.I.C./Universitat de València Campus de Paterna, Apt 22085, E-46071 València, Spain*

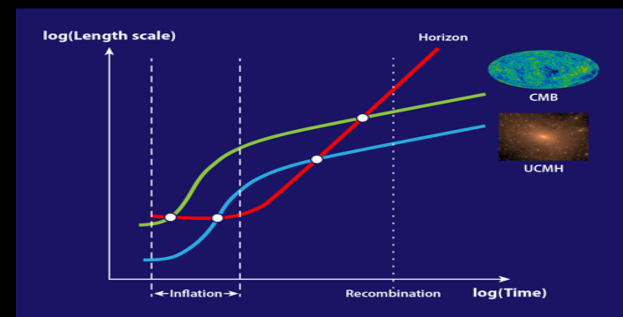
(Received 27 May 2007; published 20 September 2007)

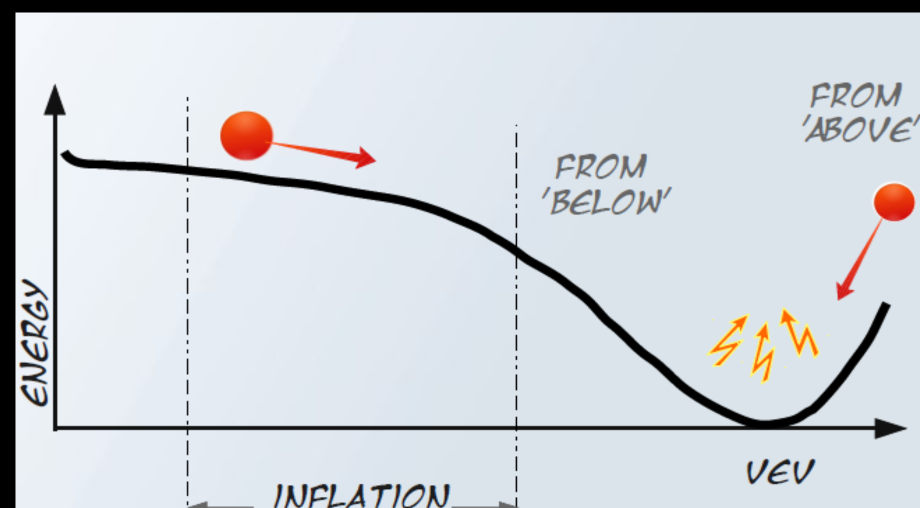
Neutrino masses may arise from spontaneous breaking of ungauged lepton number. Because of quantum gravity effects the associated Goldstone boson—the majoron—will pick up a mass. We determine the lifetime and mass required by cosmic microwave background observations so that the massive majoron provides the observed dark matter of the Universe. The majoron decaying dark matter scenario fits nicely in models where neutrino masses arise via the seesaw mechanism, and may lead to other possible cosmological implications.

majoron dark matter & seesaw inflation

Boucenna, Morisi, Shafi, Valle
PRD90 (2014) 055023







http://arxiv.org/pdf/1502.00612v1

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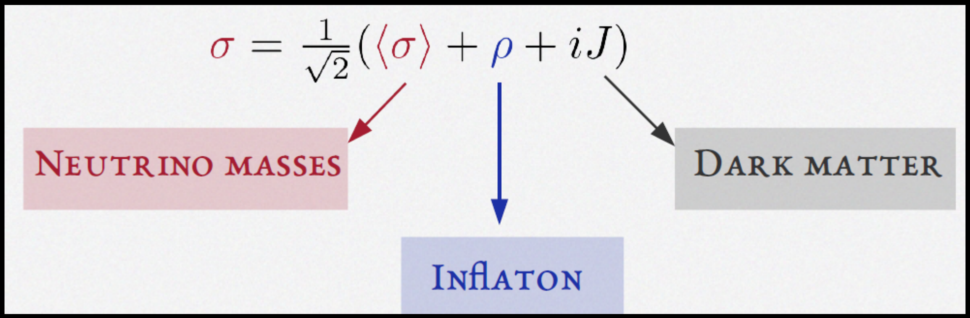
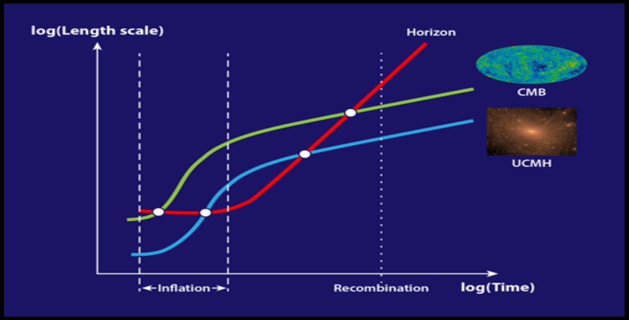
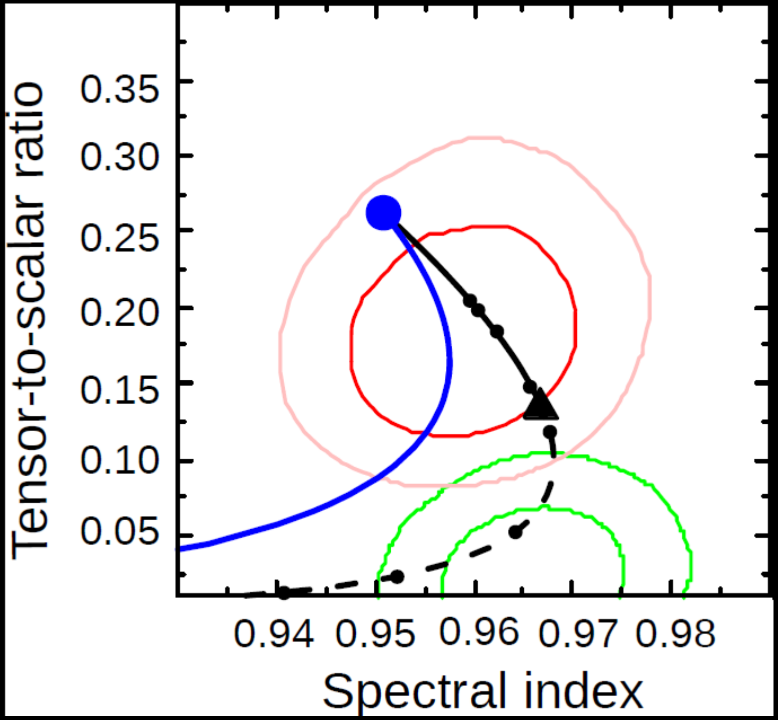
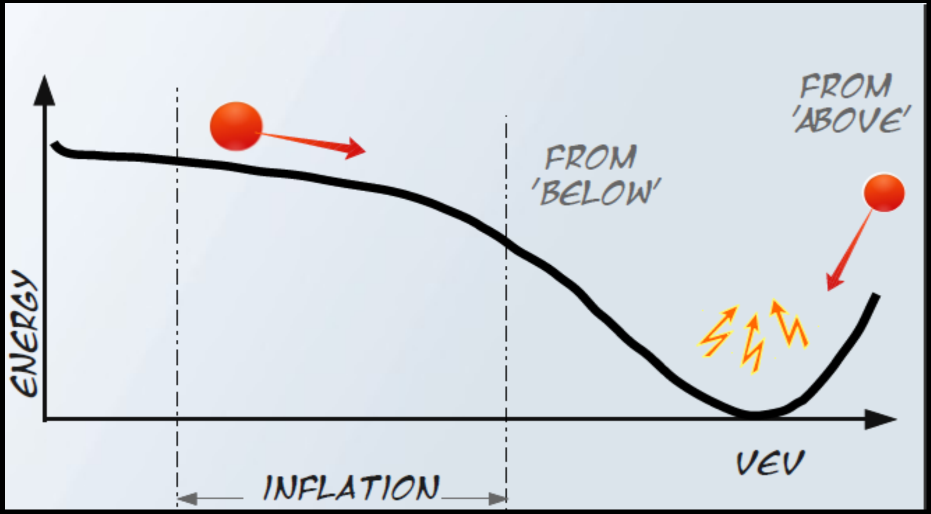
Boucenna, Morisi, Shafi, Valle
PRD90 (2014) 055023





Quartic versus *Higgs Inflation*





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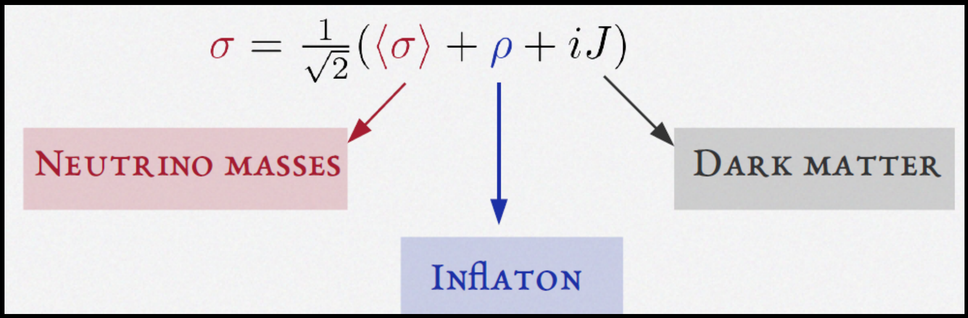
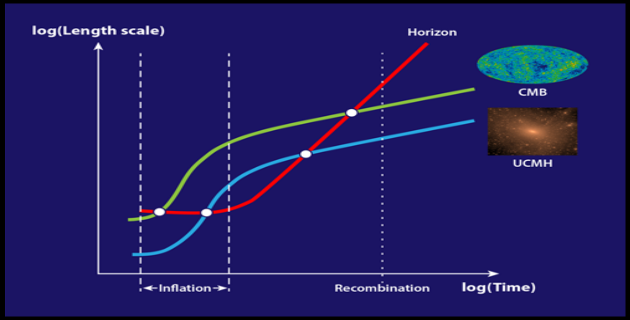


type-I seesaw **Leptogenesis**

Aristizabal et al JCAP 1407 (2014) 052



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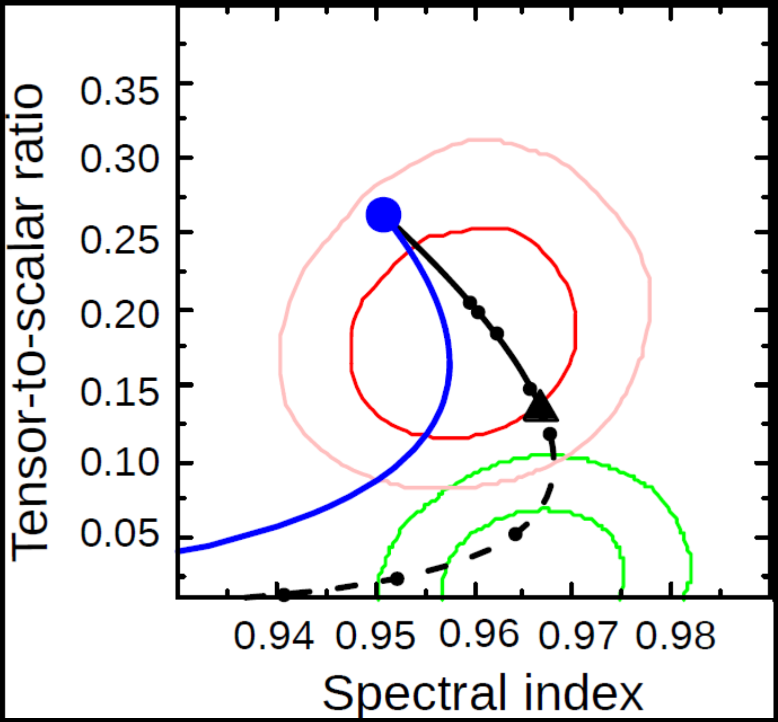

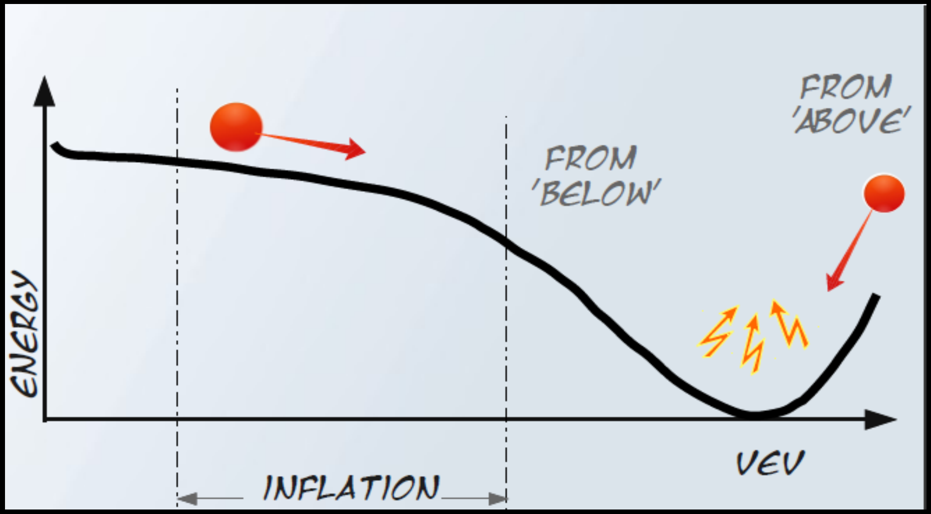

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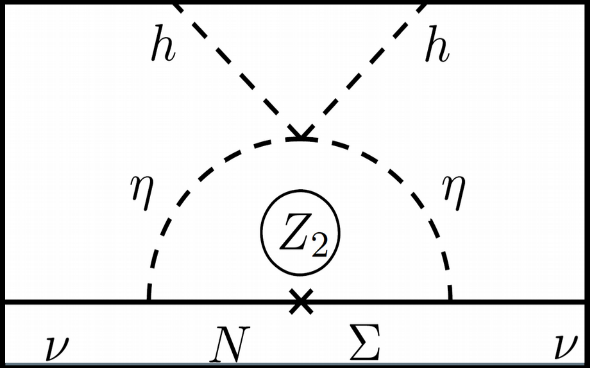
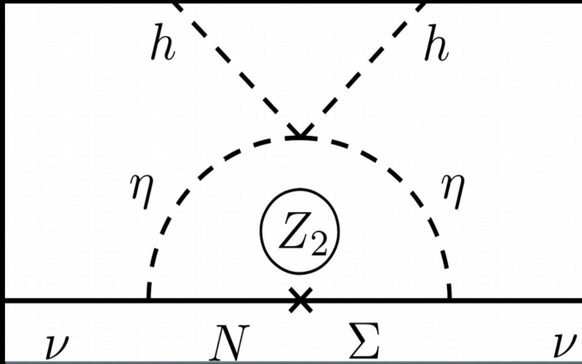


scotogenic dark matter

E Ma, Hirsch et al JHEP 1310 (2013) 149

	Standard Model			Fermions		Scalars	
	L	e	ϕ	Σ	N	η	Ω
Generations	3	3	1	1	1	1	1
$\mathrm{SU(2)_L}$	2	1	2	3	1	2	3
$\mathrm{U(1)_Y}$	-1/2	-1	1/2	0	0	1/2	0
$\mathbb{Z}_2$	+	+	+	−	−	−	+

scotogenic dark matter



E Ma, Hirsch et al JHEP 1310 (2013) 149

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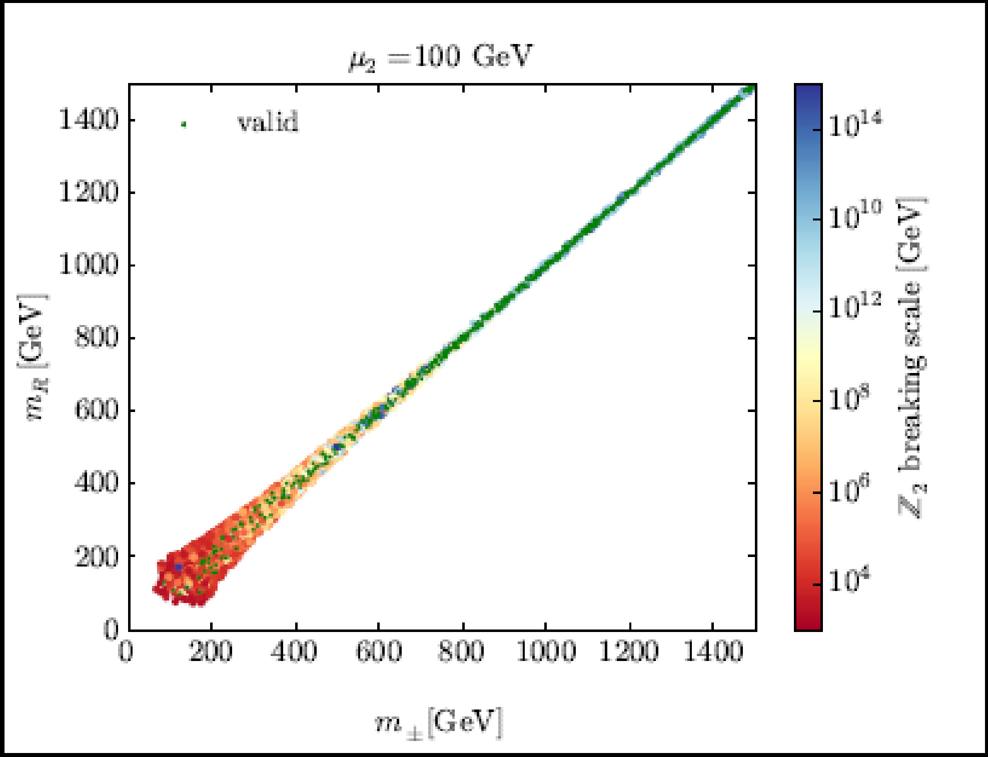
WIMP dark Matter as radiative neutrino mass messenger

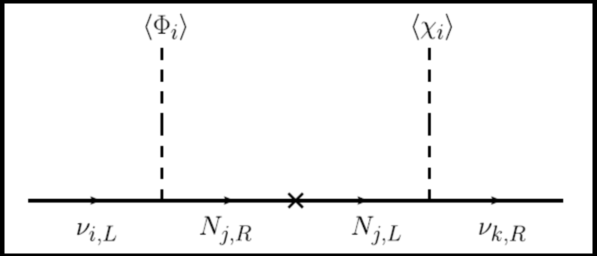
Merle et al JHEP 1607 (2016) 013



Dark Matter Stability from Diracness

Chiulia et al
arXiv:1606.04543
Phys.Lett. B761 (2016) 431

Fields	Z_4	Z_2	Fields	Z_4	Z_2
$\bar{L}_{i,L}$	$\mathbf{z}^3$	$\mathbf{1}$	$\nu_{i,R}$	$\mathbf{z}$	$-\mathbf{1}$
$l_{i,R}$	$\mathbf{z}$	$\mathbf{1}$	$\bar{N}_{i,L}$	$\mathbf{z}^3$	$\mathbf{1}$
$N_{i,R}$	$\mathbf{z}$	$\mathbf{1}$			
Φ	$\mathbf{1}$	$\mathbf{1}$	χ	$\mathbf{1}$	$-\mathbf{1}$
ζ	$\mathbf{z}$	$\mathbf{1}$	η	$\mathbf{z}^2$	$\mathbf{1}$



Lepton Quarticity vs Lepton number

Dark Matter Stability from Diracness

Chiulia et al

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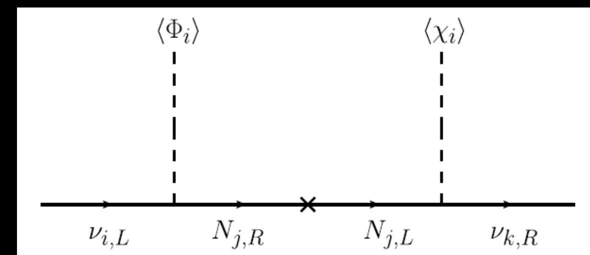


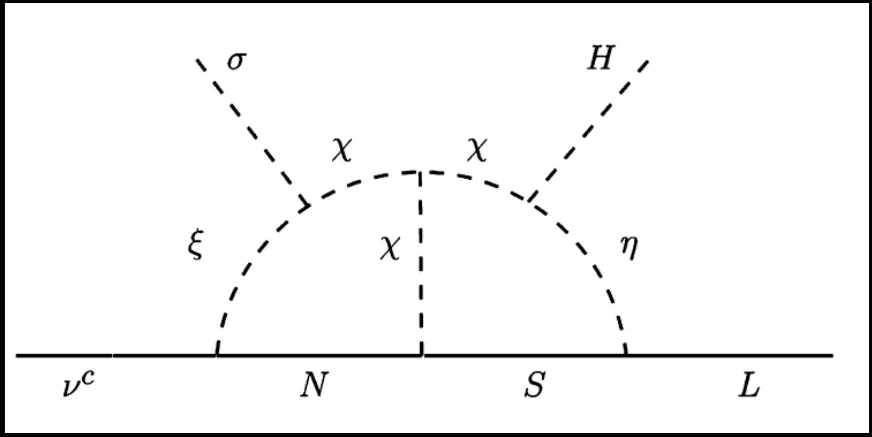
Lepton Quarticity vs Lepton number

Scotogenic dark matter stability from Diracness

C. Bonilla et al. / Physics Letters B 762 (2016) 214–218

Table 1
Relevant particle content and quantum numbers of the model.

	$\bar{L}$	ν^c	H	η	N	S	σ	ξ	χ
$SU(2)_L$	2	1	2	2	1	1	1	1	1
$U(1)_D$	−1	3	0	0	−1	1	2	−2	0
Z_3^{DM}	1	1	1	α	α	α	1	α^2	α
Z_3	ω	ω^2	1	1	ω	ω^2	1	1	1



Dark Matter Stability from Diracness

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$N_{i,R}$	$\mathbf{z}$	$\mathbf{1}$			
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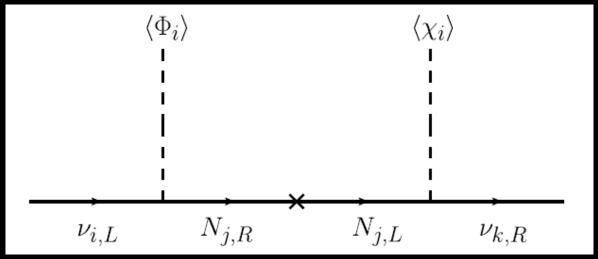
ζ	$\mathbf{z}$	$\mathbf{1}$	η	$\mathbf{z}^2$	$\mathbf{1}$



Lepton Quarticity vs Lepton number

non SUSY WIMP

Scotogenic dark matter stability from Diracness

C. Bonilla et al. / Physics Letters B 762 (2016) 214–218

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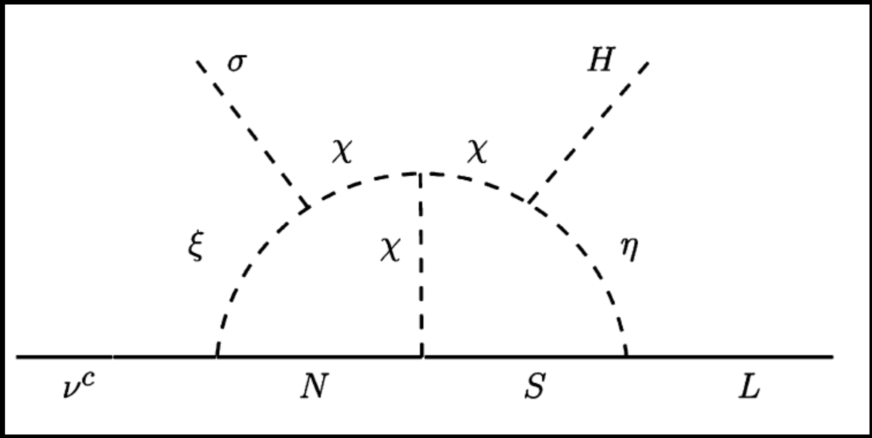
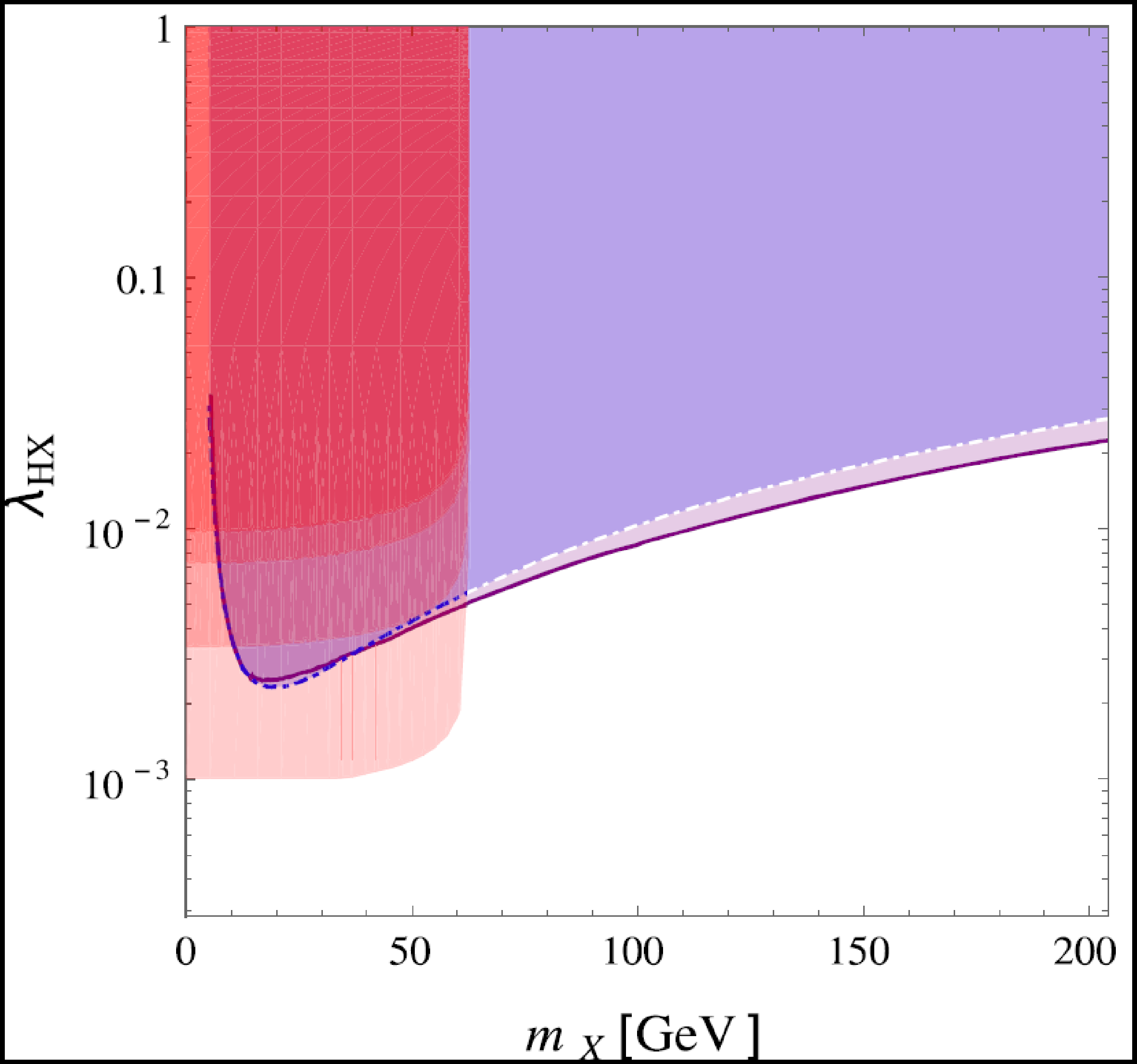


dark matter stability from Diracness



non SUSY WIMP

DARK MATTER FROM FLAVOUR SYMMETRY

- *Accidental ?*
- *unbroken subgroup*

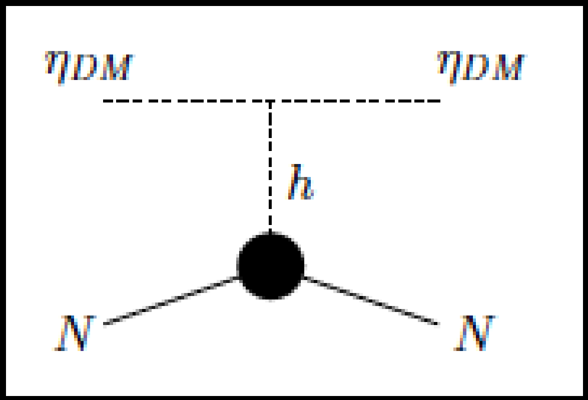
Lavoura, Morisi, JV JHEP 1302(2013) 118

Boucenna, et al JHEP 1105 (2011) 037
Hirsch, et al Phys.Rev. D82 (2010) 116003

many choices

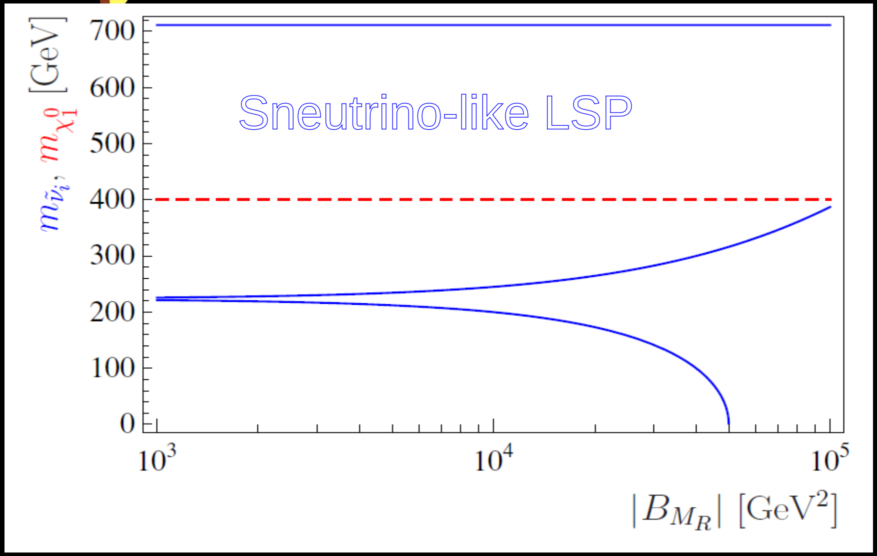
more possibilities

HIGGS PORTAL
DIRECT DETECTION

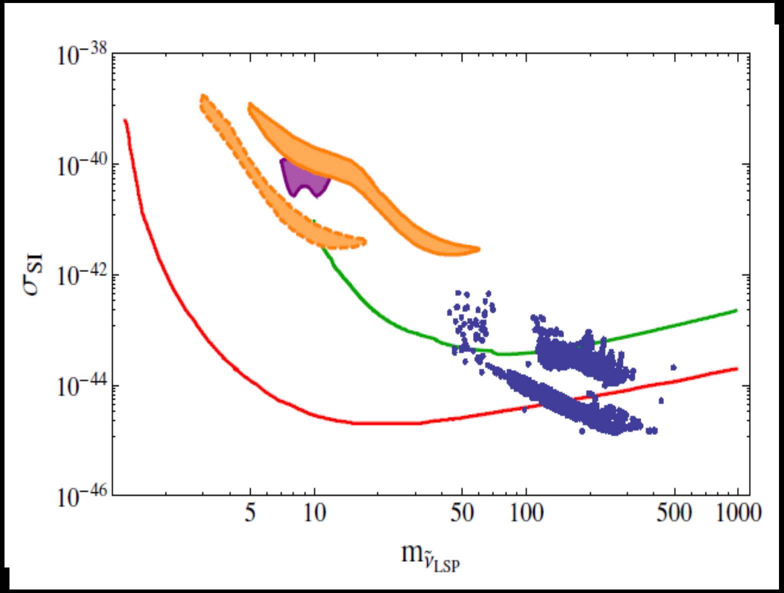


susy wimp dark matter

Arina et al PRL101 (2008) 161802
Bazzocchi, Cerdeno, Munoz, J.V., PRD81 (2010) 051701



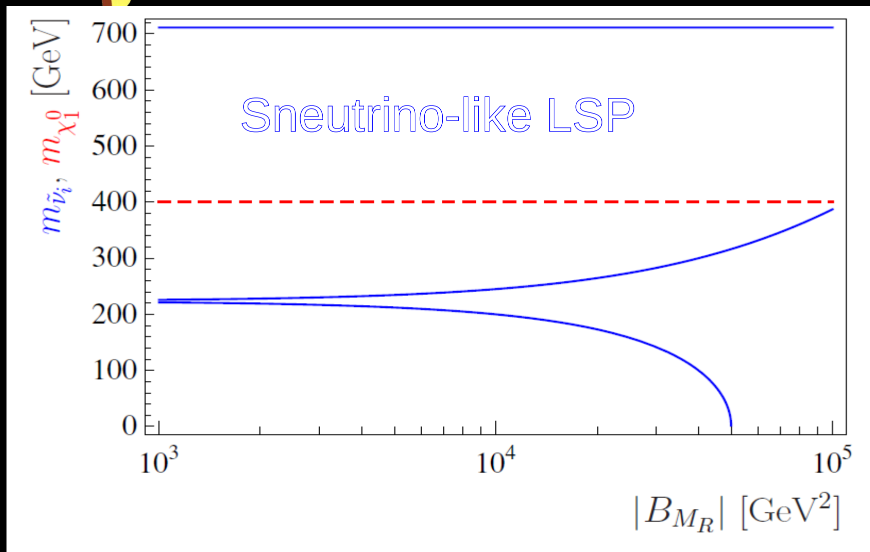
susy inverse seesaw ...

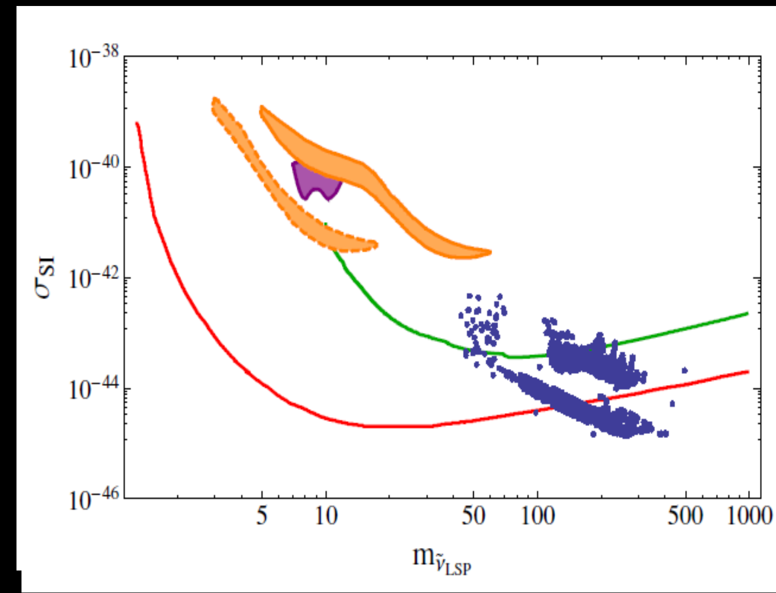


De Romeri, Hirsch, JHEP 1212 (2012) 106

susy wimp dark matter

Arina et al PRL101 (2008) 161802
Bazzocchi, Cerdeno, Munoz, J.V., PRD81 (2010) 051701



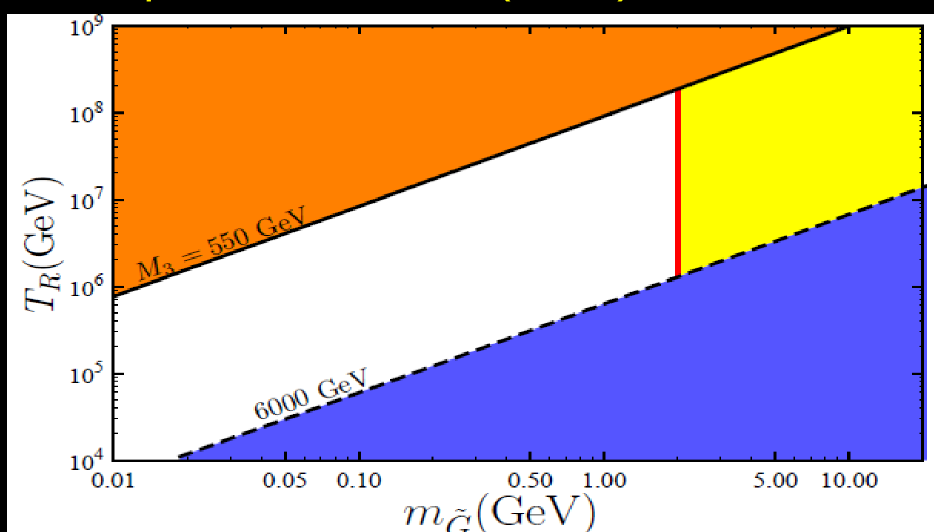


susy inverse seesaw ...

De Romeri, Hirsch, JHEP 1212 (2012) 106

decaying Gravitino dark matter

Restrepo et al PRD85 (2012) 023523



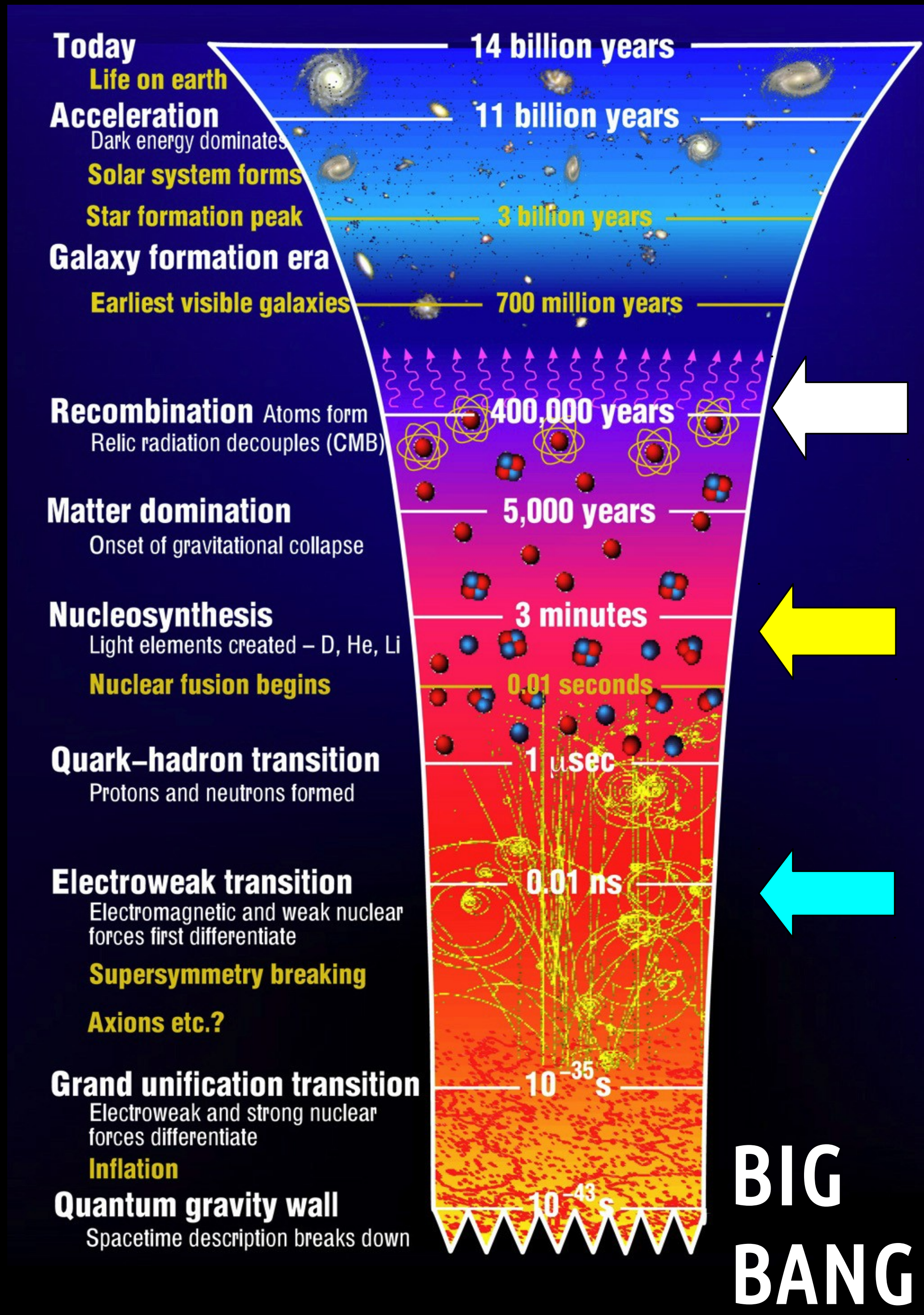
doubly suppressed decays

$$\Gamma = \Gamma(\tilde{G} \to \sum_i \nu_i \gamma) \simeq \frac{1}{32\pi} |U_{\tilde{\gamma}\nu}|^2 \frac{m_{\tilde{G}}^3}{M_P^2}$$

chosen to fit neutrino osc. data

conclusions

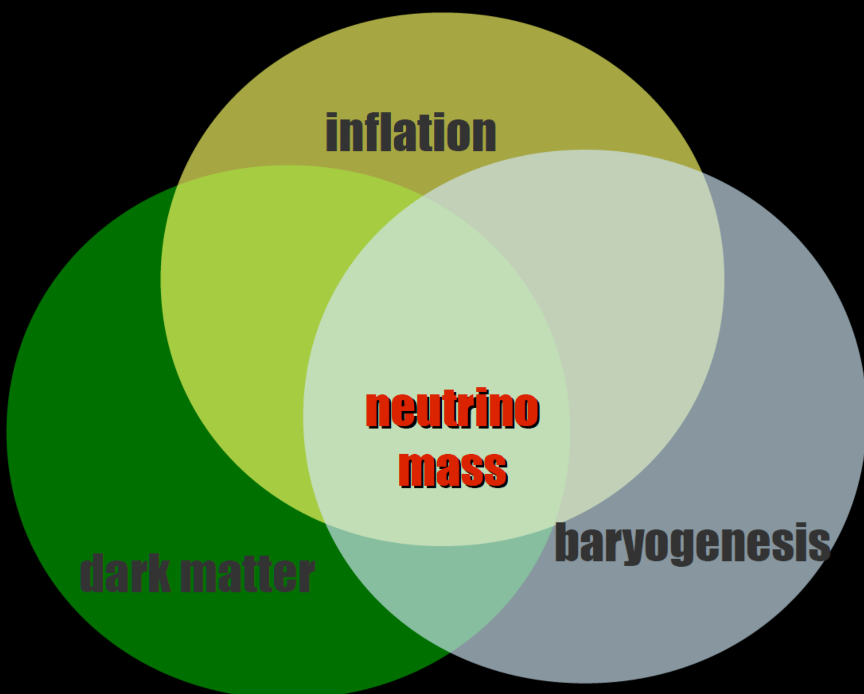
a most ubiquitous
particle in the Universe



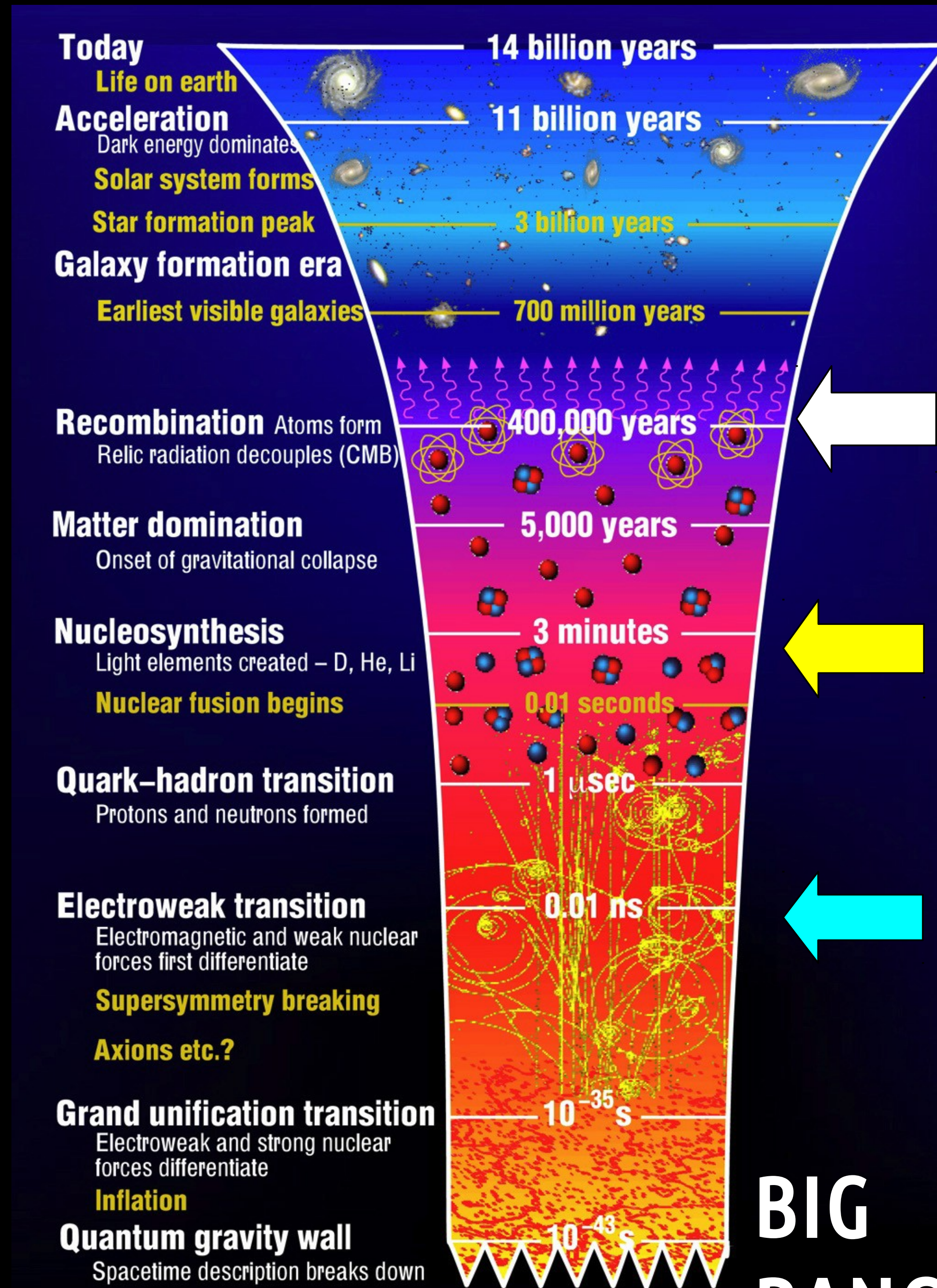
conclusions

a most ubiquitous particle in the Universe

neutrinos may explain DM through an emergent theory …



e.g. Warm or Cold DM majoron



BIG BANG

Thank you

Neutrinos in High Energy and Astroparticle Physics

Jose Wagner Furtado Valle,
Jorge Romao

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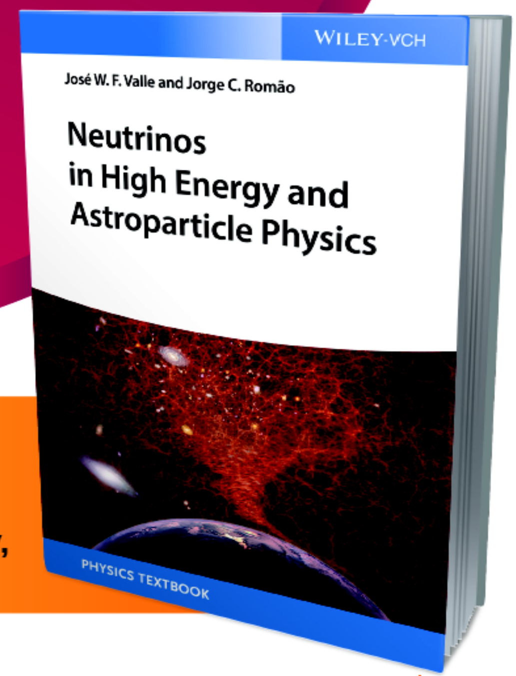
February 2015



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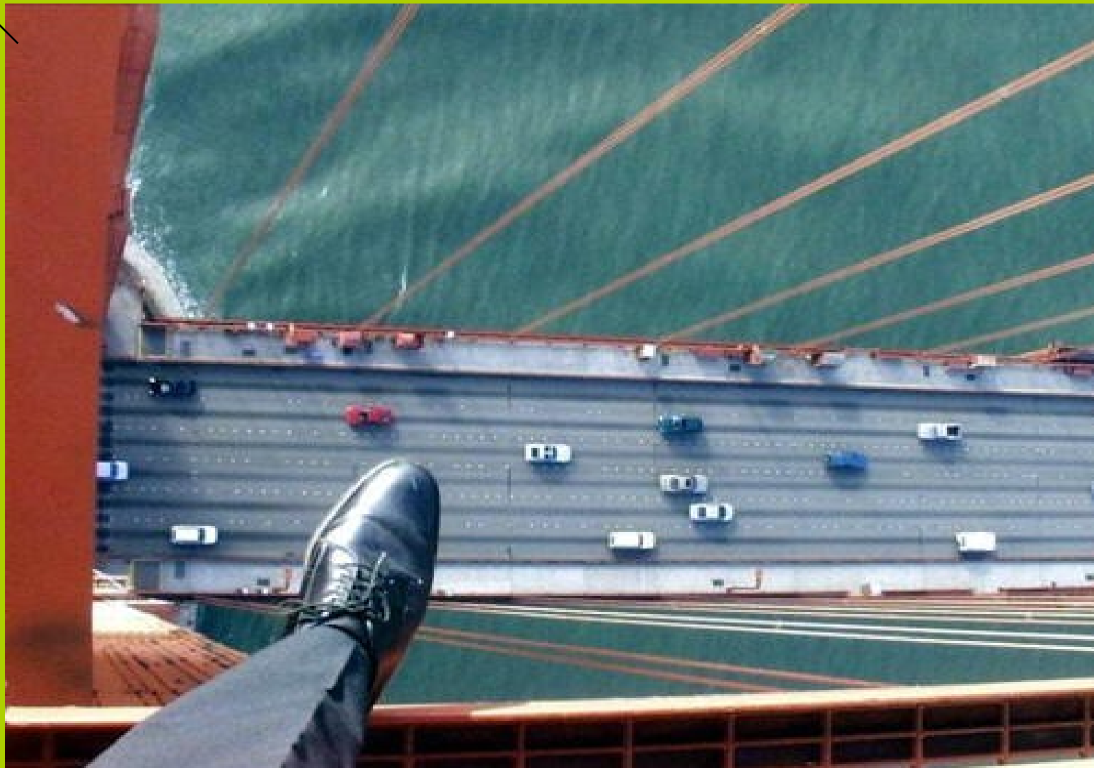
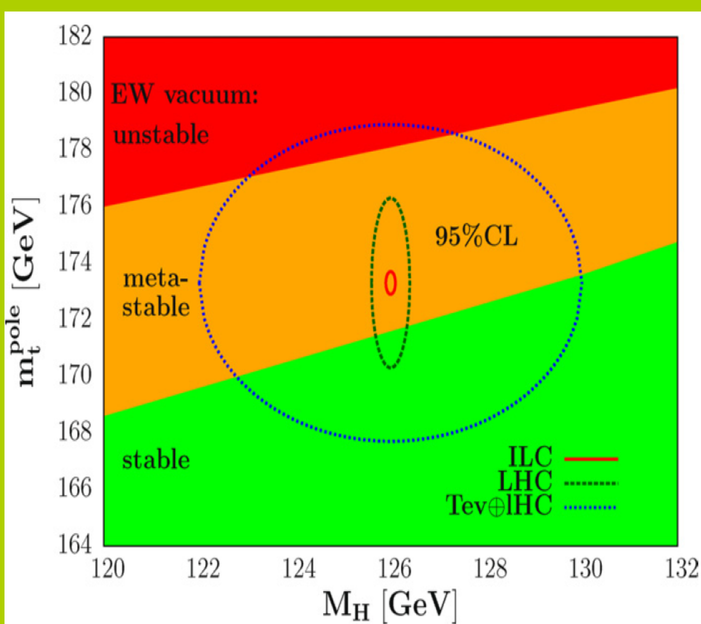
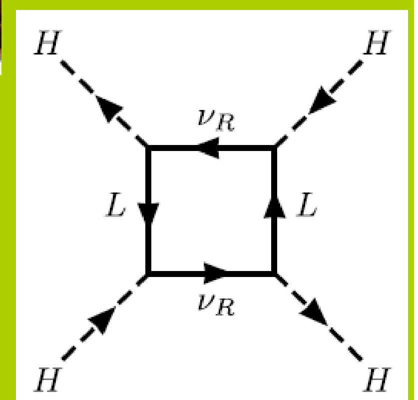
Back up

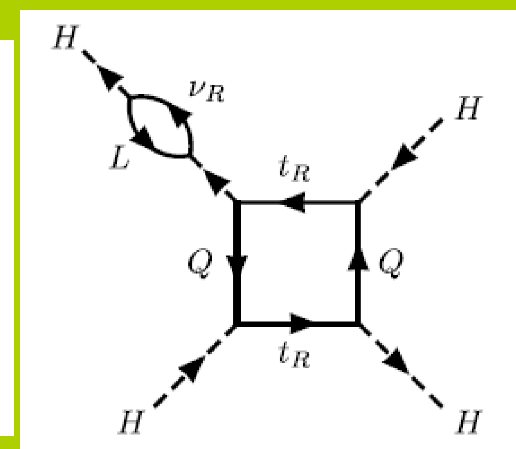
SM vacuum and neutrinos

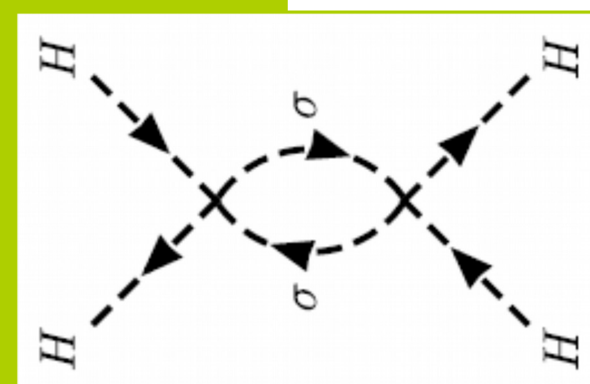
Physics Letters B 756 (2016) 345–349



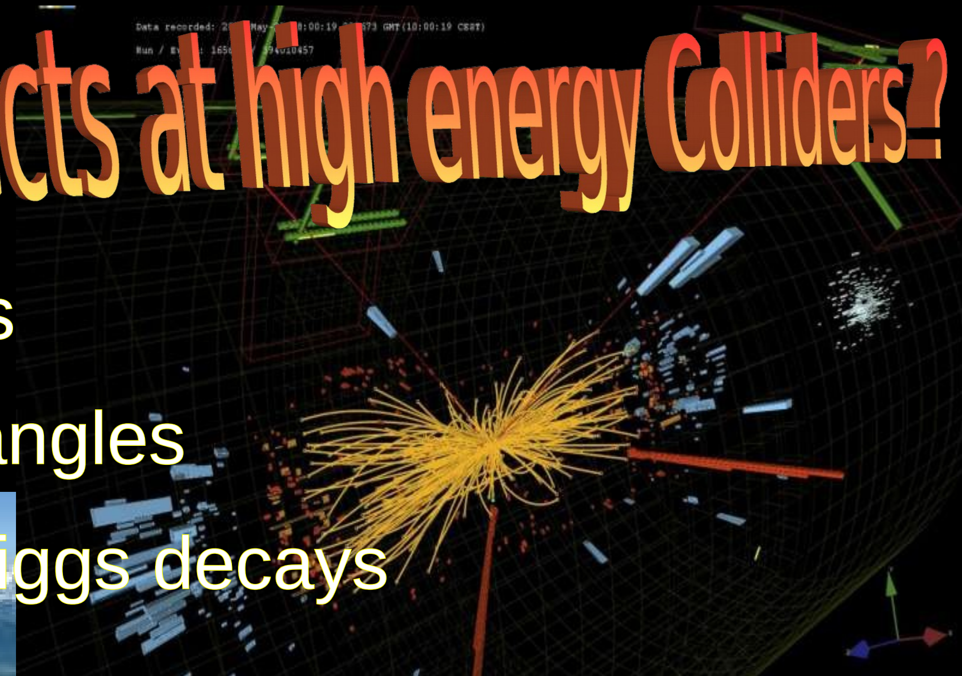




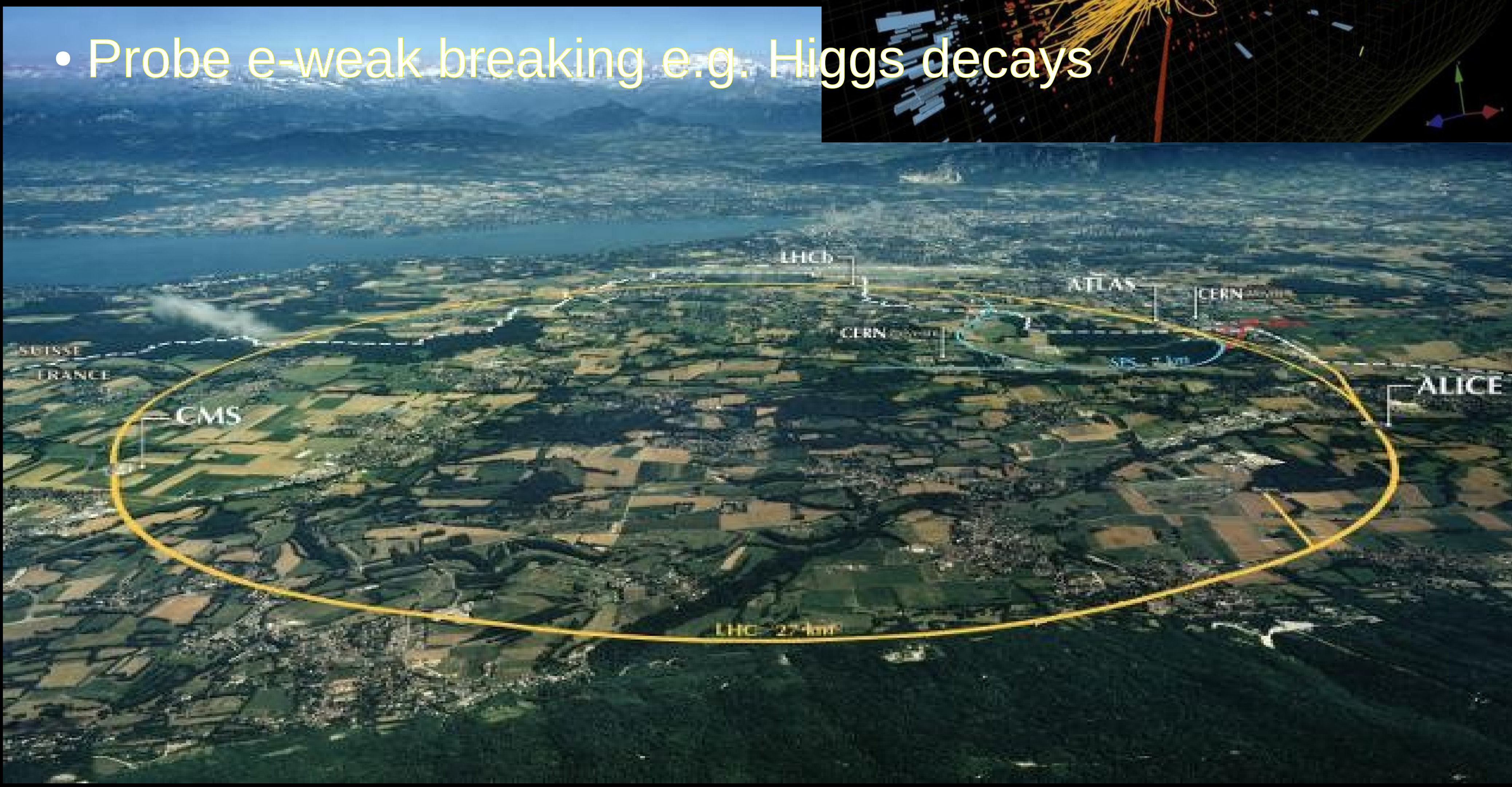




Neutrino effects at high energy Colliders?



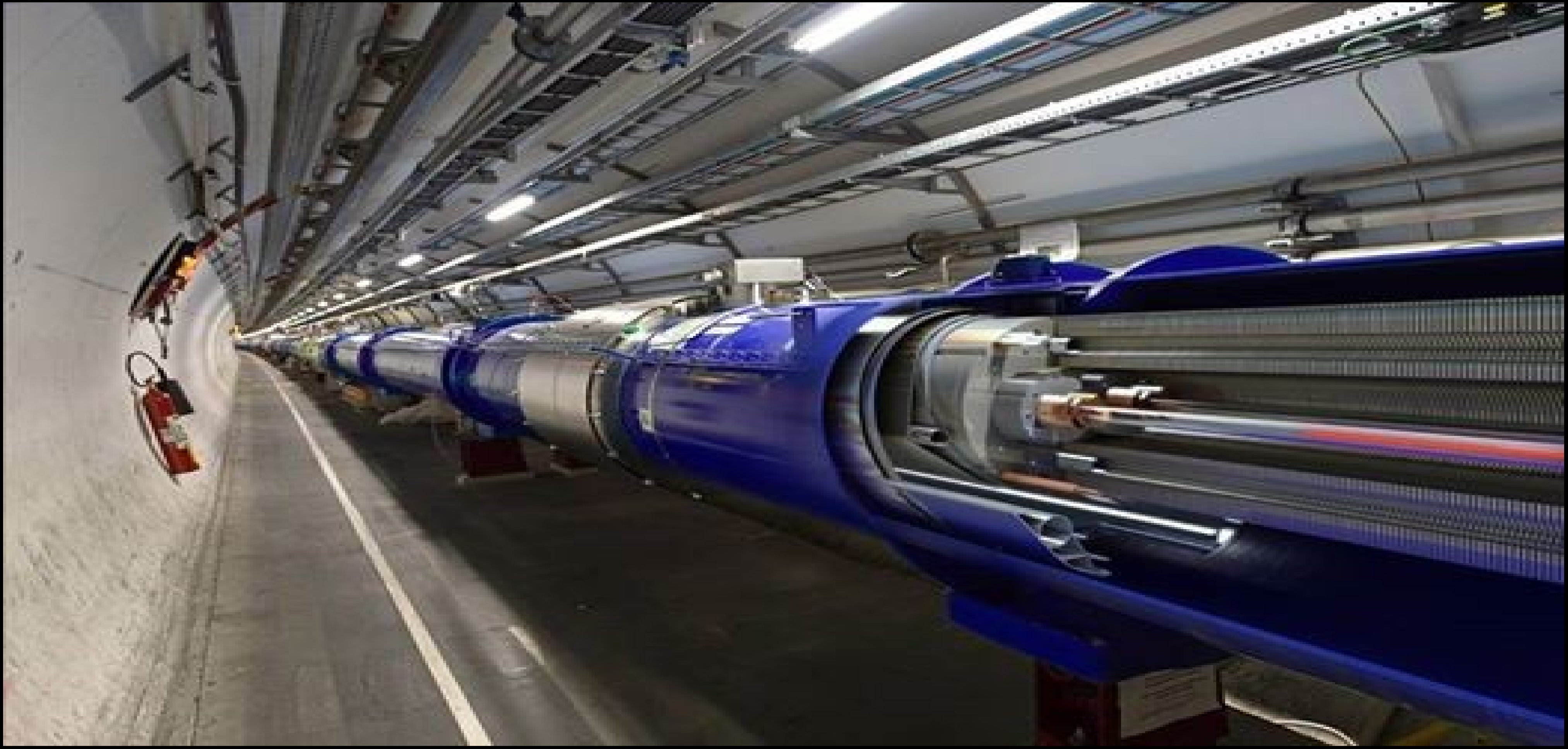
- Discover neutrino messengers
- Re-measure neutrino mixing angles
- Probe e-weak breaking e.g. Higgs decays



Invisible Higgs decays

Joshipura & J.V.

Nucl.Phys. B397 (1993) 105-122



Higgs searches 2016

Bonilla Fonseca & J.V.

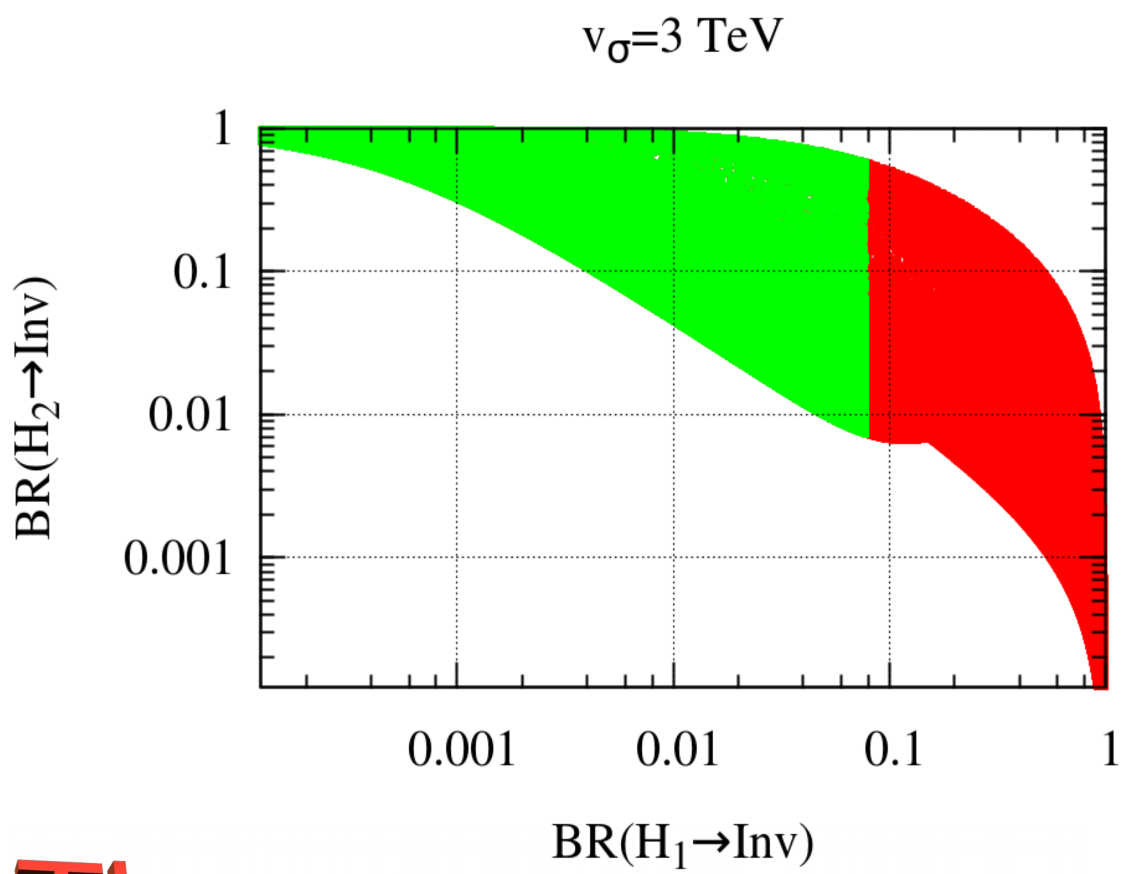
Phys.Lett. B756 (2016) 345-349 ...

PHYSICAL REVIEW D **91,** 113015 (2015)

Neutrino mass and invisible Higgs decays at the LHC

Cesar Bonilla,[1,*] Jorge C. Romão,[2,†] and José W. F. Valle[1,‡]

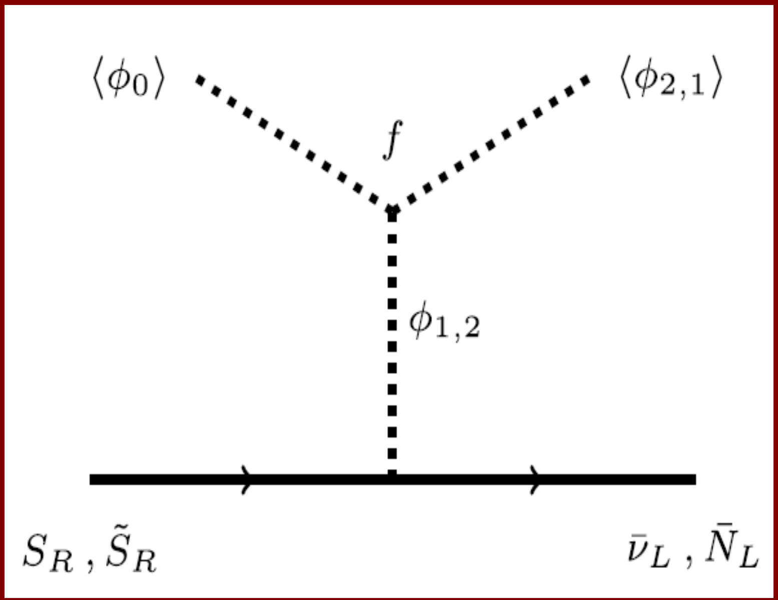
channel	ATLAS	CMS
$\mu_{\gamma\gamma}$	1.17 ± 0.27	$1.14^{+0.26}_{-0.23}$
μ_{WW}	$1.00^{+0.32}_{-0.29}$	0.83 ± 0.21
μ_{ZZ}	$1.44^{+0.40}_{-0.35}$	1.00 ± 0.29
$\mu_{\tau^+\tau^-}$	$1.4^{+0.5}_{-0.4}$	0.91 ± 0.27
$\mu_{b\bar{b}}$	$0.2^{+0.7}_{-0.6}$	0.93 ± 0.49

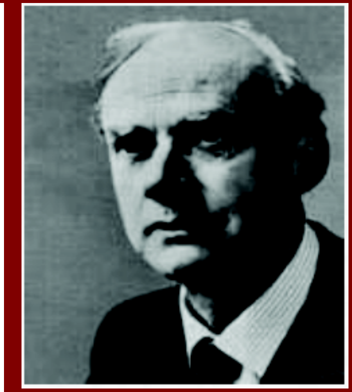


$$H_i \to JJ \quad \text{and} \quad H_2 \to 2H_1 \to 4J \quad \left(\text{when } m_{H_1} < \frac{m_{H_2}}{2}\right).$$

Theories of neutrino as attractive higgs search benchmarks

Dirac seesaw



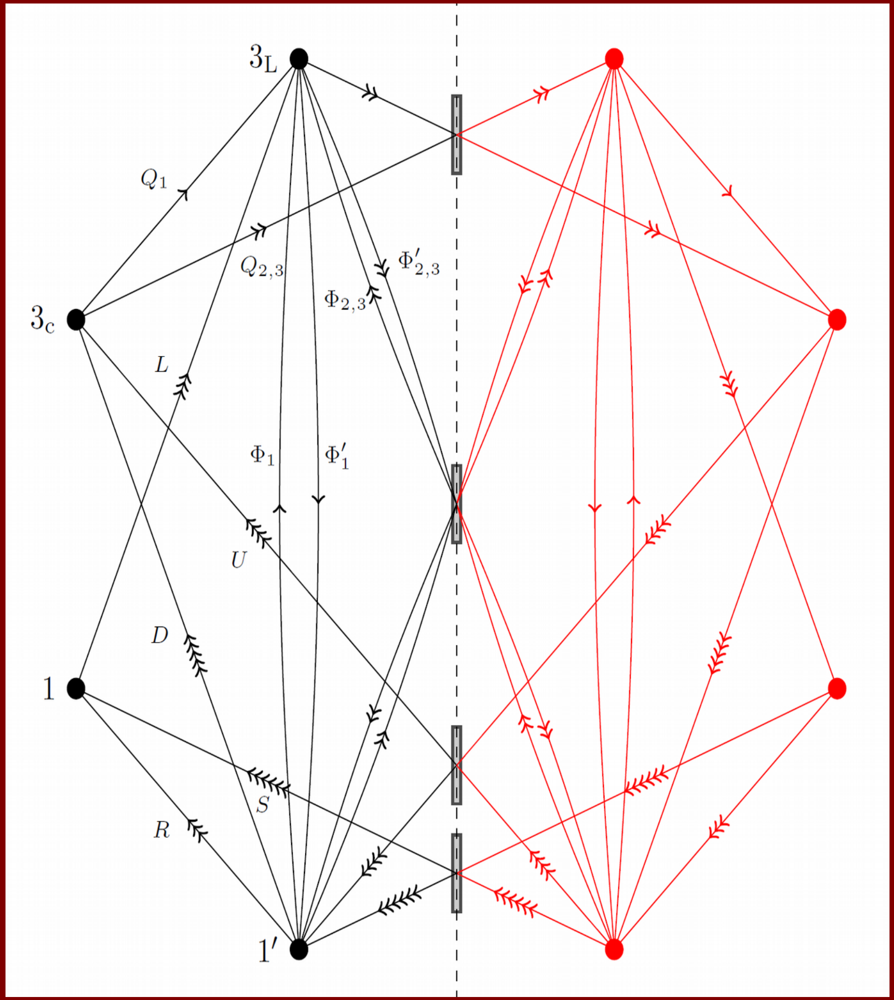


Physics Letters B 755 (2016) 363–366

Addazi et al arXiv:1604.02117

331 from strings

10.1016/j.physletb.2016.06.015



No conventional GUT embedding :

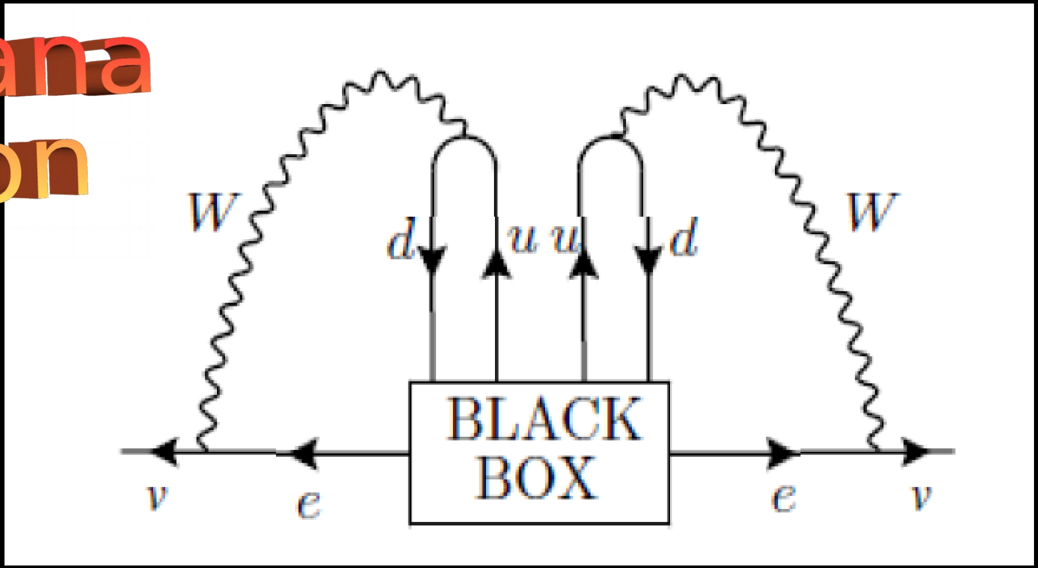
http://arxiv.org/abs/arXiv:1608.05334

string completion Quiver setup

L and B conserved : no proton decay, no RPV …

neutron-antineutron oscillations from exotic instantons

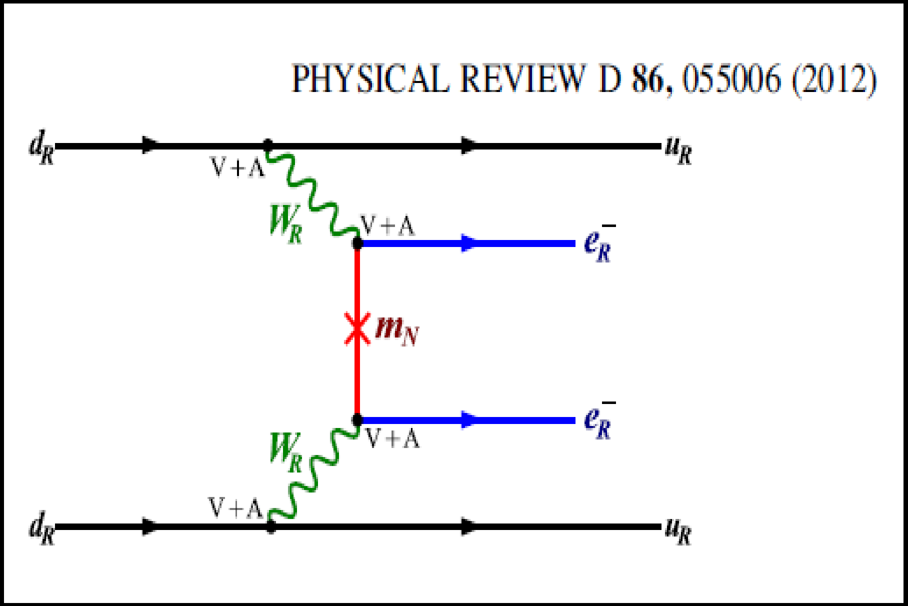
The Majorana connection



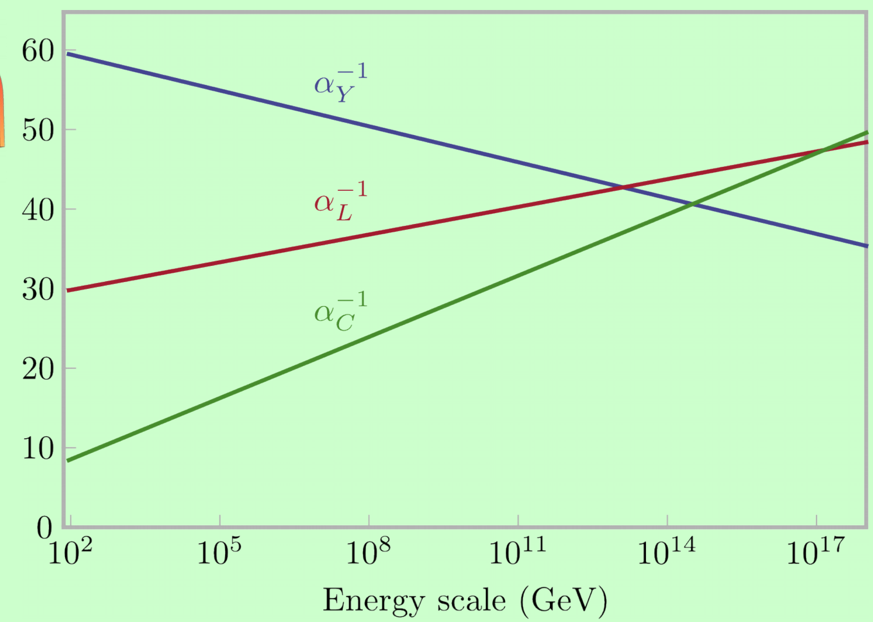
Even if mediated by short-range mechanism …

Heavy mediators

Schechter, JWFV 82
Lindner et al JHEP 1106 (2011) 091



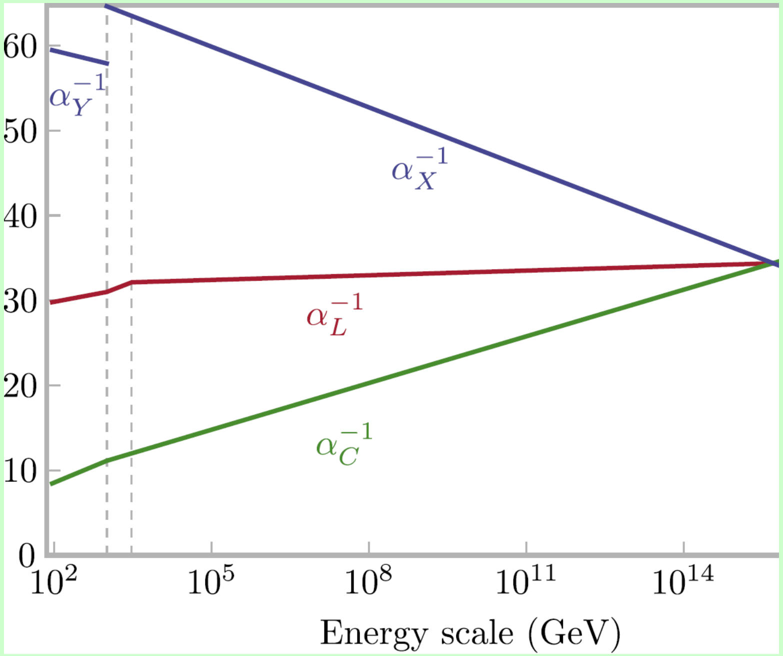
neutrinos may help unification



a near miss ...

What makes the gauge couplings unify? SUSY-GUT

But ... p decay, super-particles ...



The physics responsible for gauge coupling unification may also induce neutrino masses

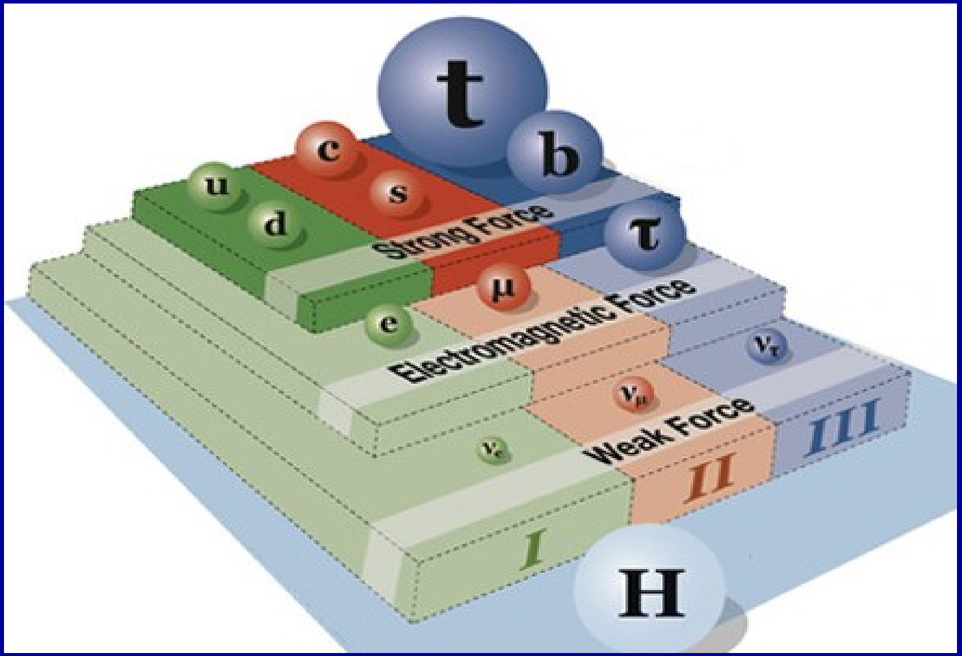
Boucenna et al Phys. Rev. D 91, 031702 (2015)

Deppisch et al Phys.Lett. B762 (2016) 432

Can neutrinos shed light on charged fermion masses?

Flavor dependent b-tau unification

$$\frac{m_\tau}{\sqrt{m_e m_\mu}} \approx \frac{m_b}{\sqrt{m_d m_s}},$$



Morisi et al Phys.Rev. D84 (2011) 036003

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Neutrinos : Lepton number?