neutrino pathways to new physics

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Astroparticles and High Energy Physics Group

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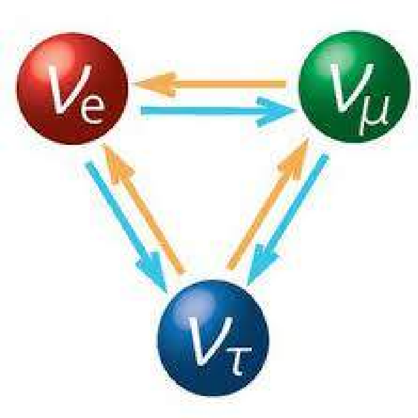
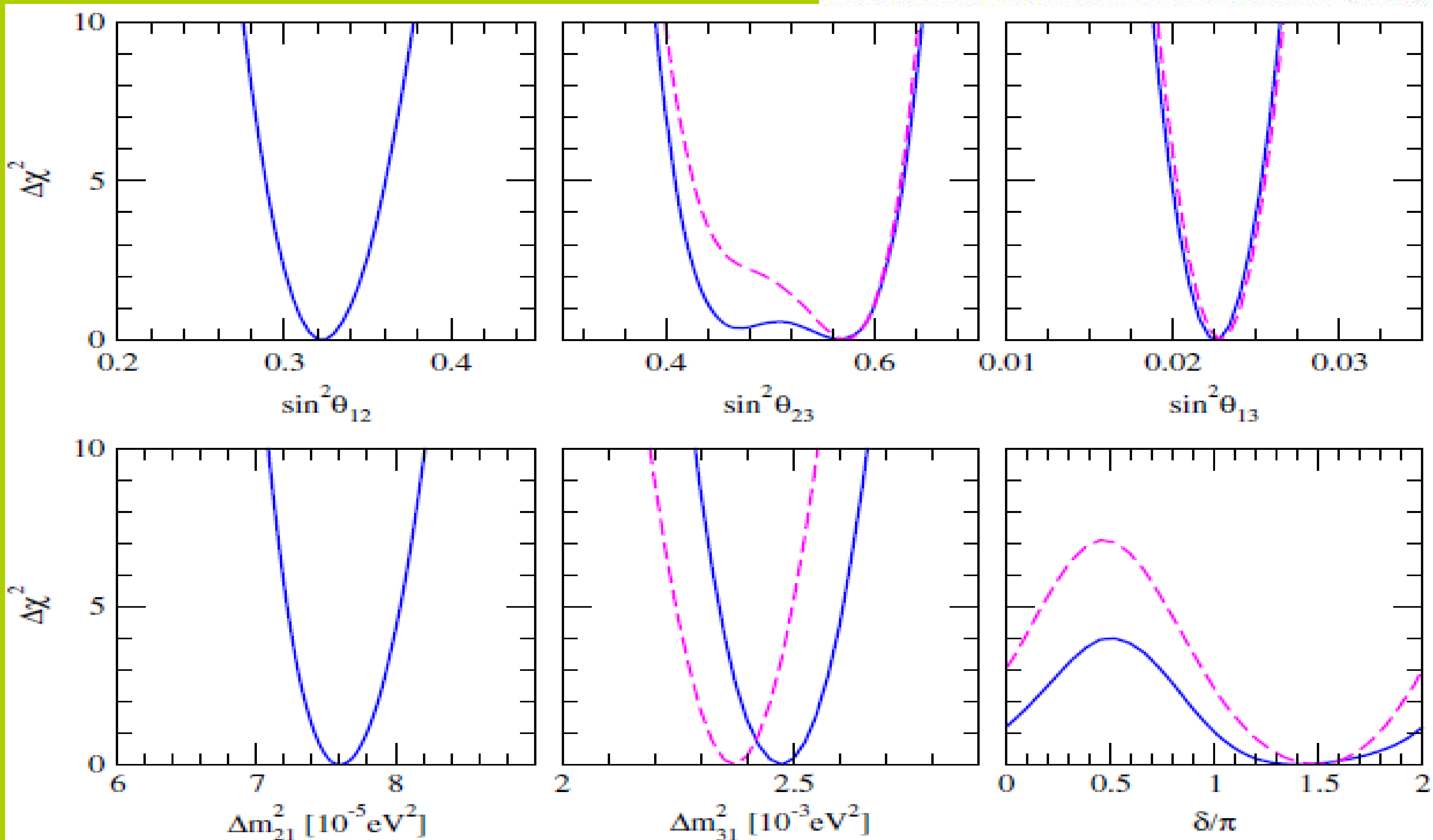
NCTS Annual Theory Meeting. 2016 Hsinchu, Taiwan

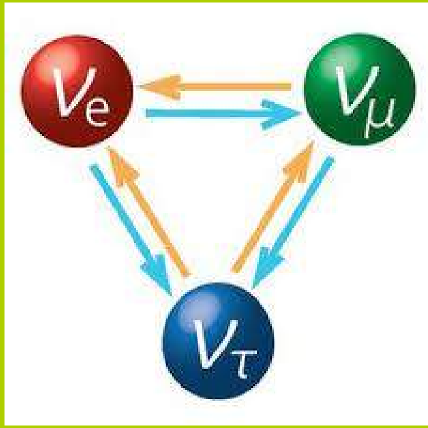


Oscillation parameters

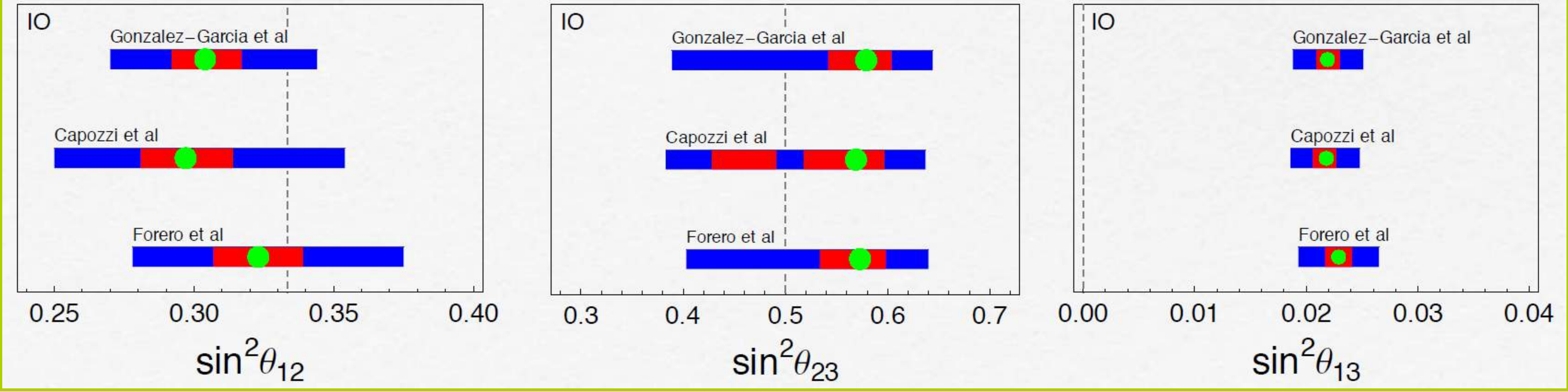
Precision era starts

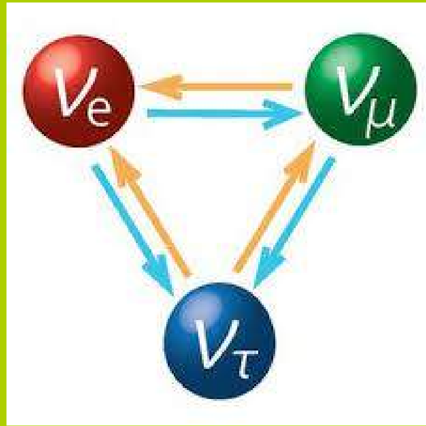
PHYSICAL REVIEW D **90**, 093006 (2014)





neutrino oscillation parameters

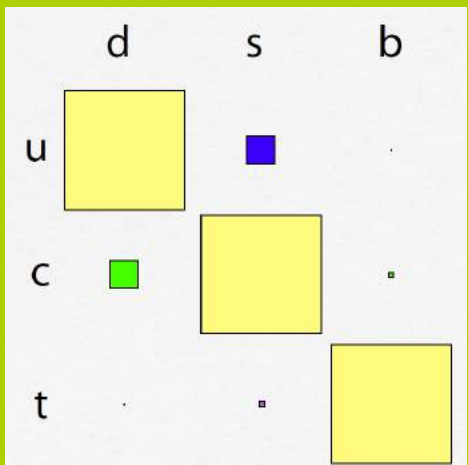




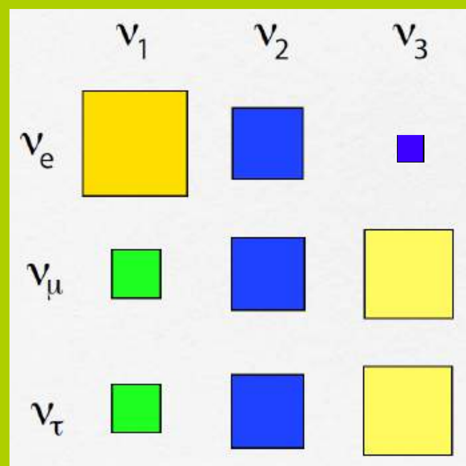
neutrino oscillation parameters

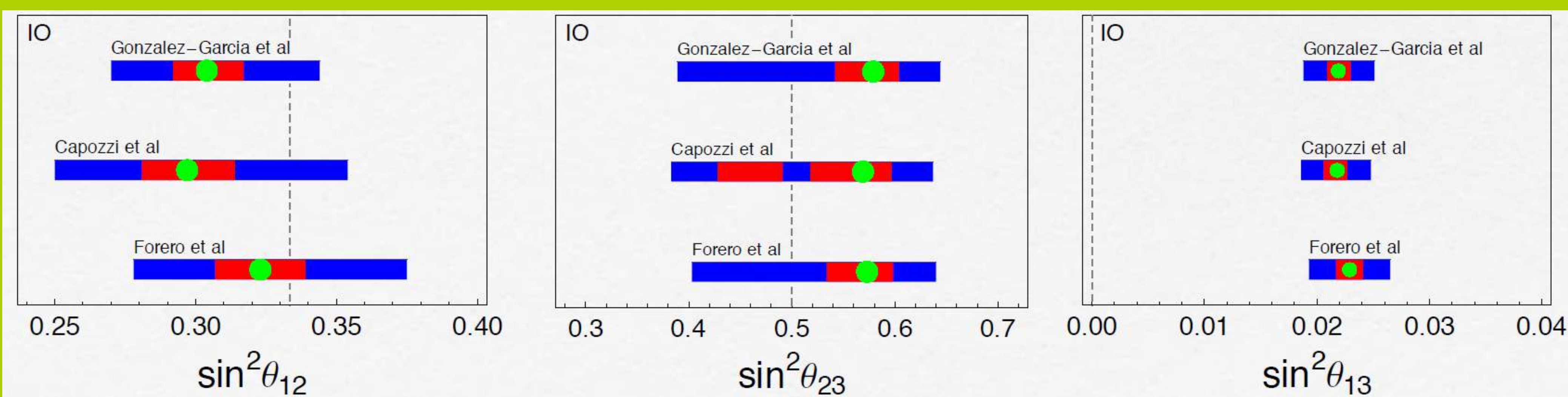
Phys.Lett. B748 (2015) 1-4

Phys.Rev. D86 (2012) 051301

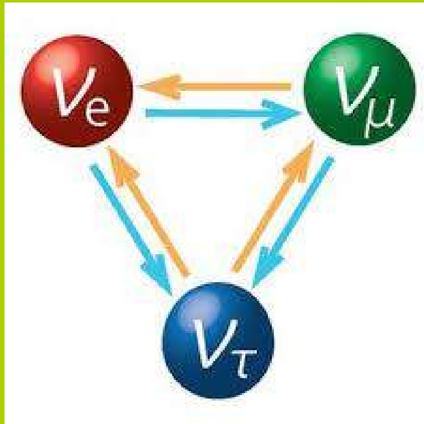


vs





neutrino oscillation parameters



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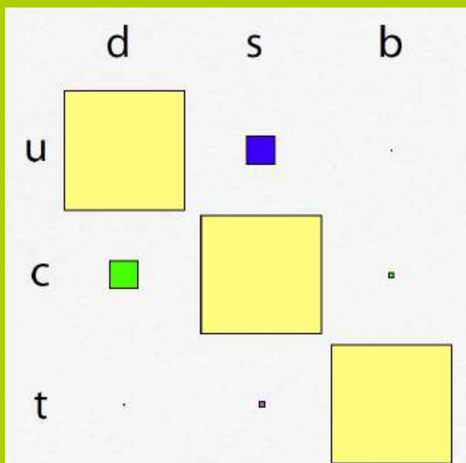
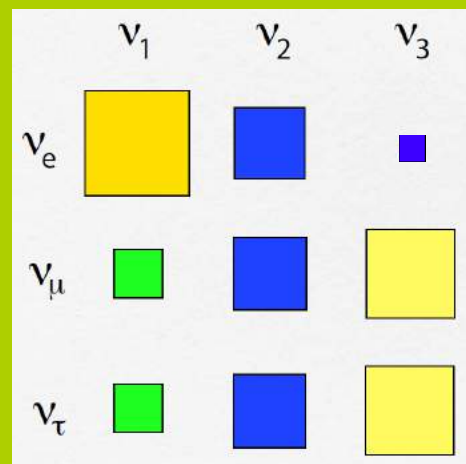
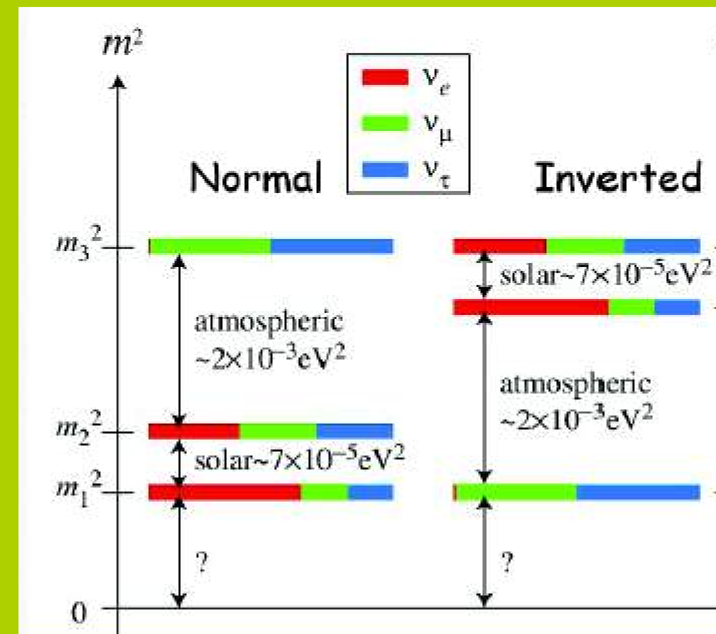
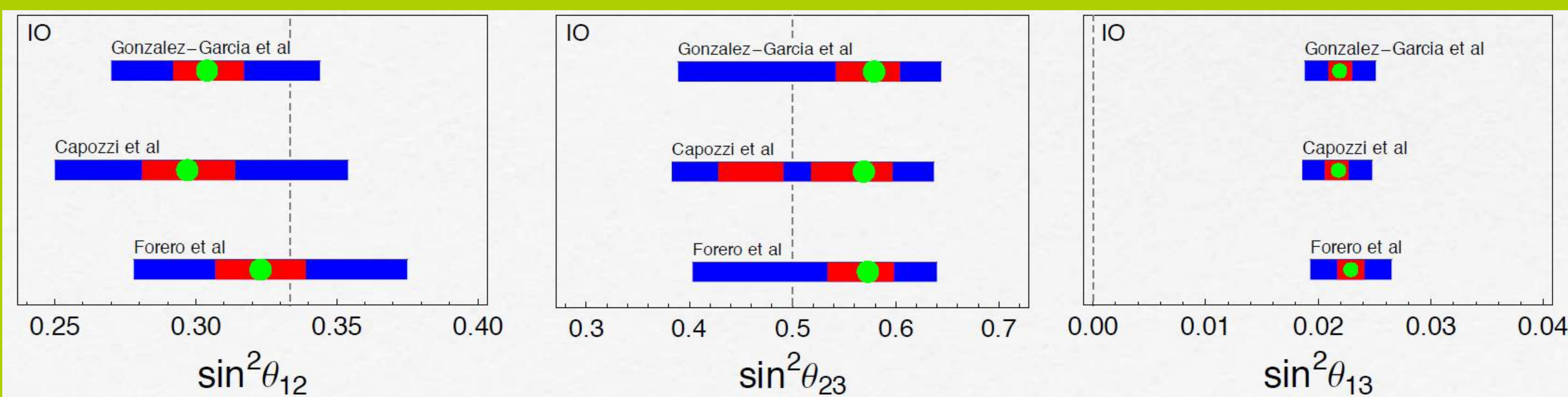


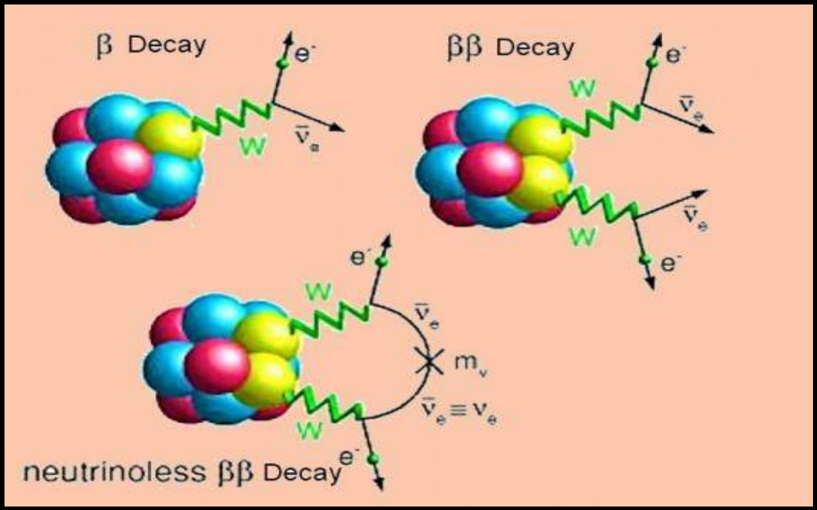
vs





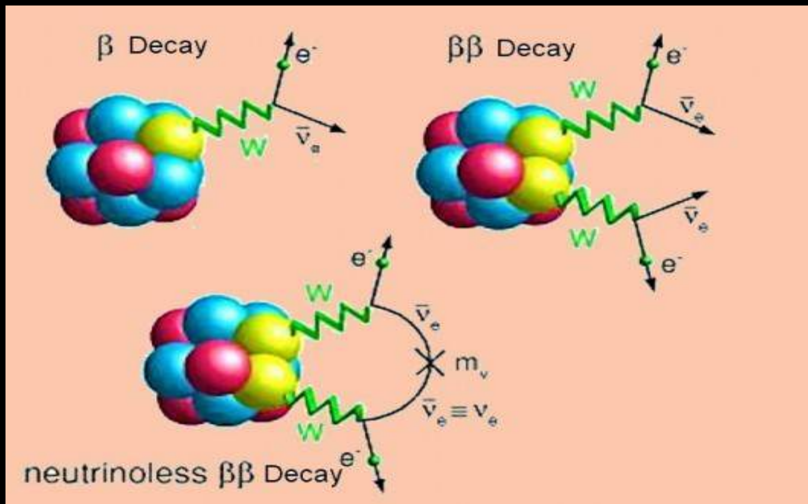


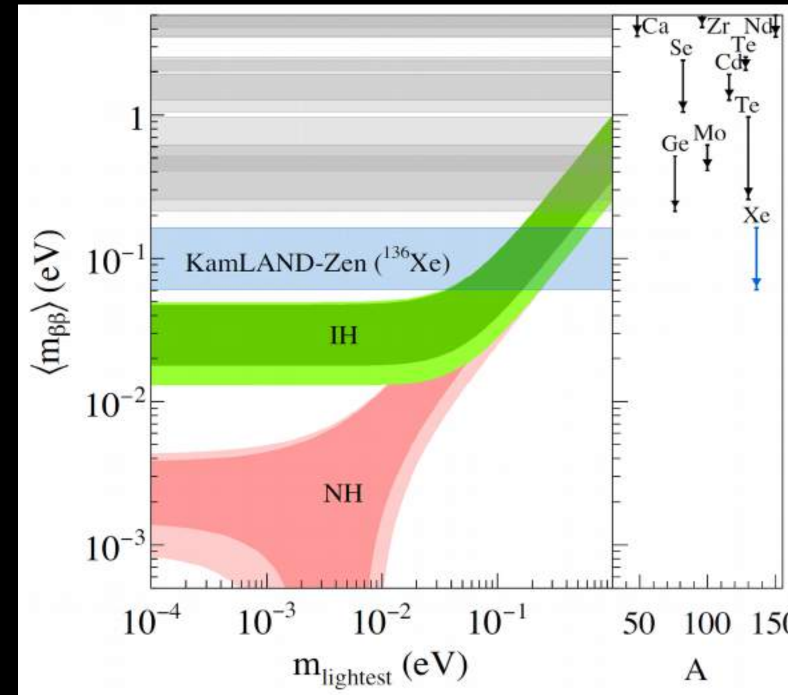
beta & double beta decay



A.S. Barabash arXiv:1104.2714

beta & double beta decay





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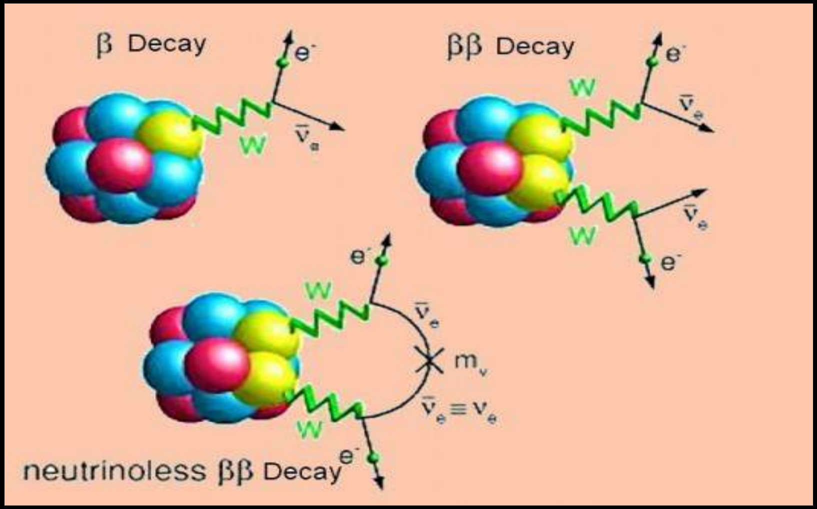

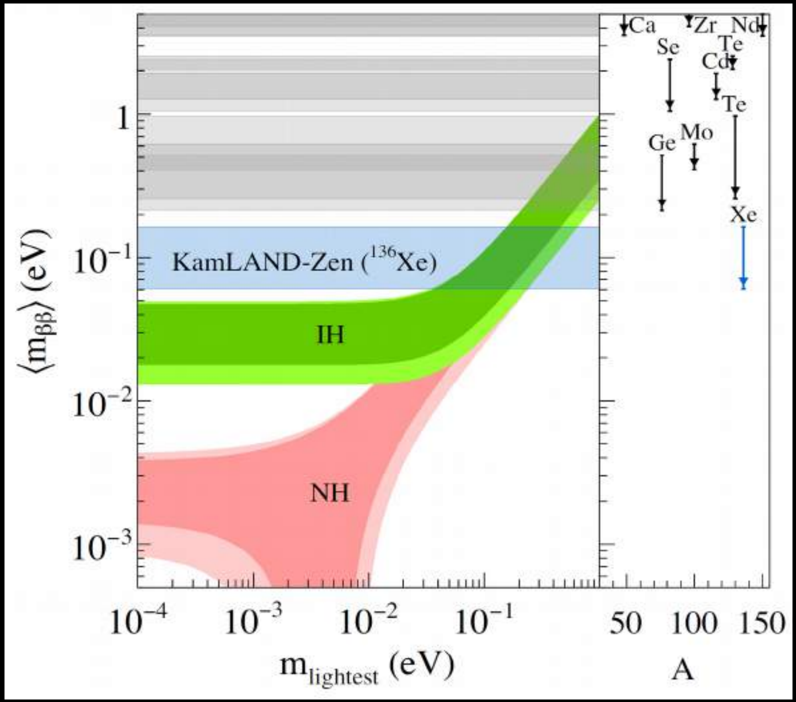

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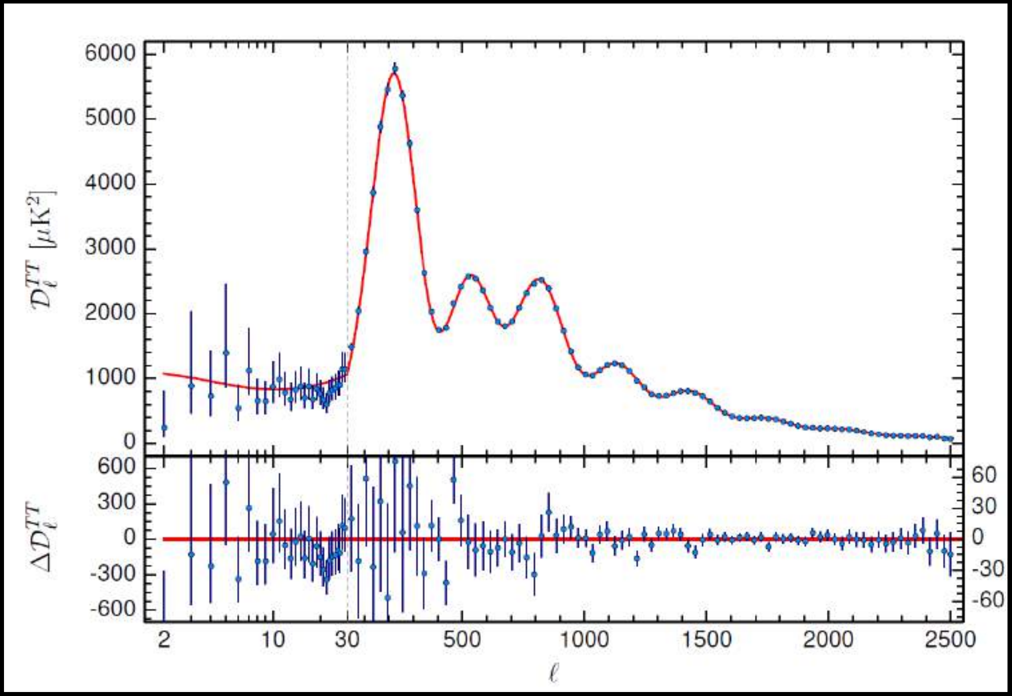

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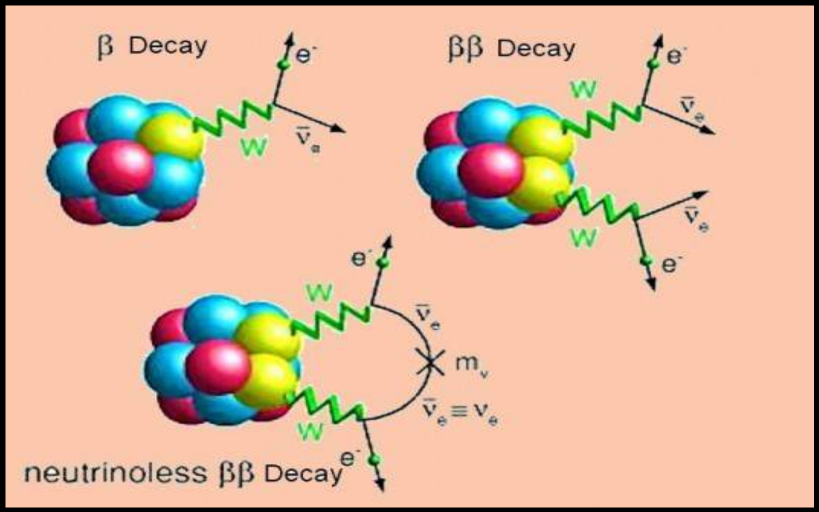

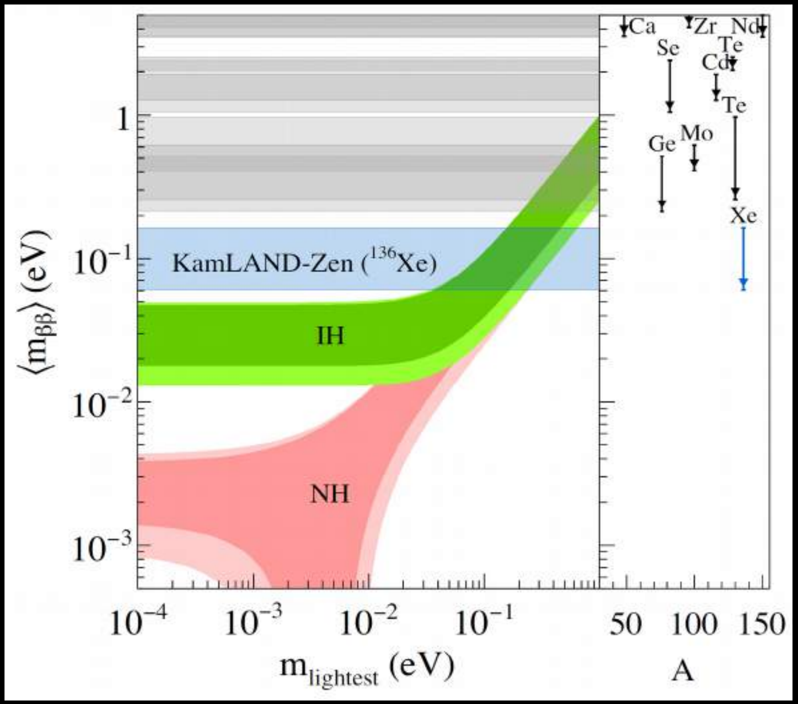

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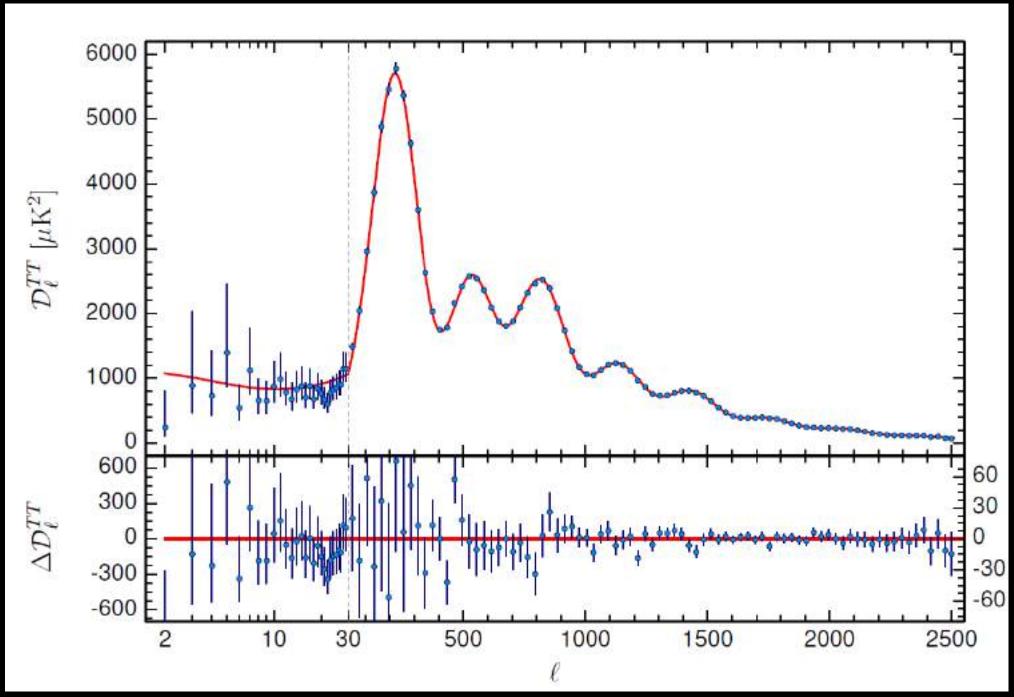
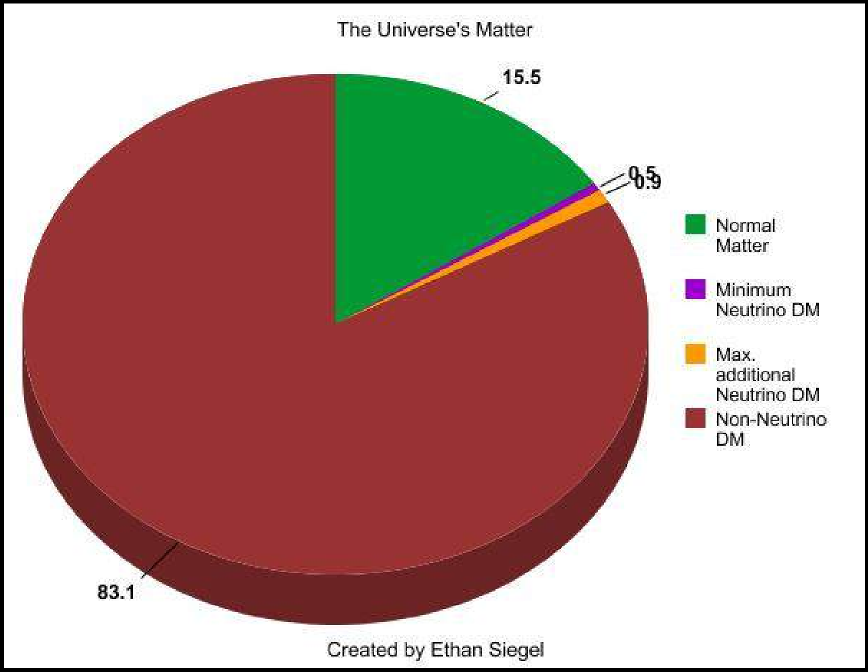
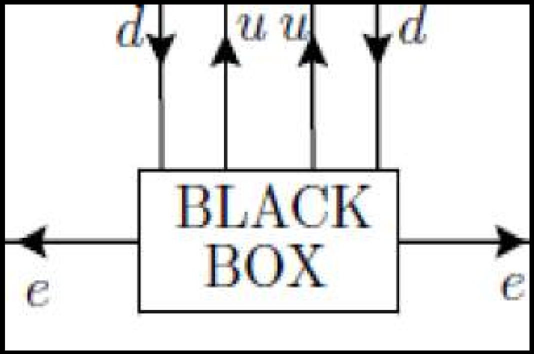


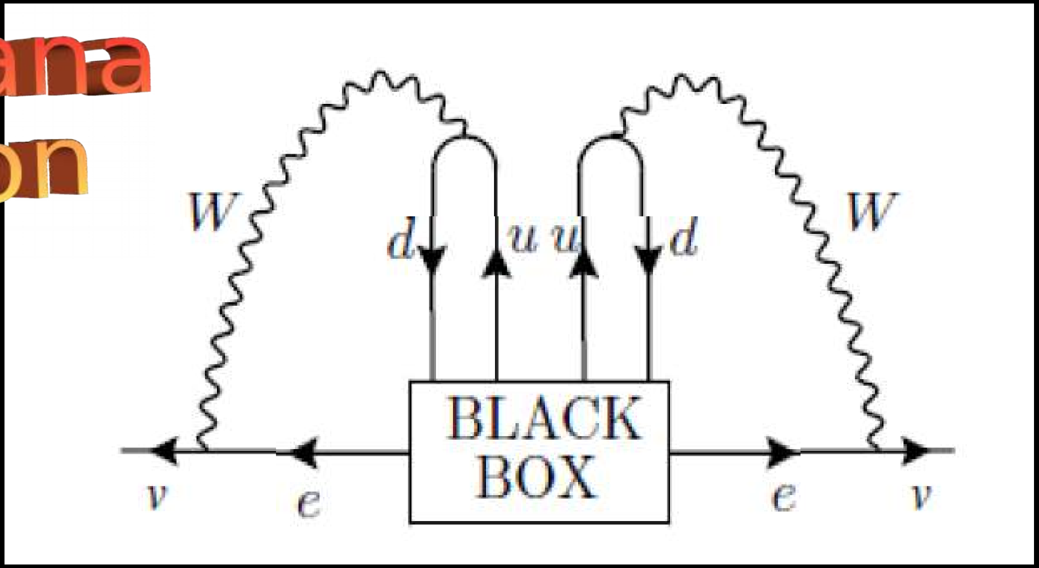


The Majorana connection



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

The Majorana connection

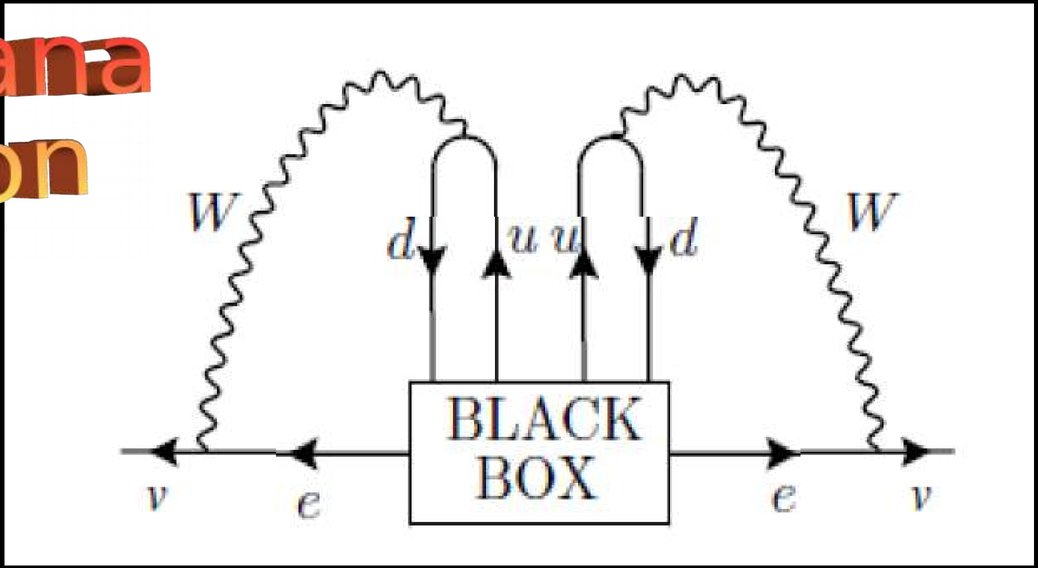


Even if mediated by short-range mechanism ...

Heavy mediators

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

The Majorana connection



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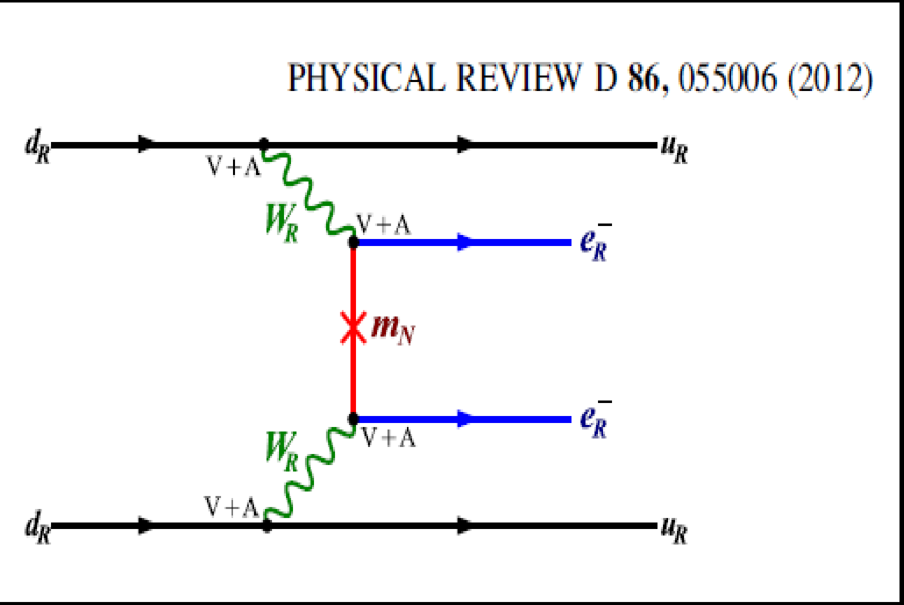
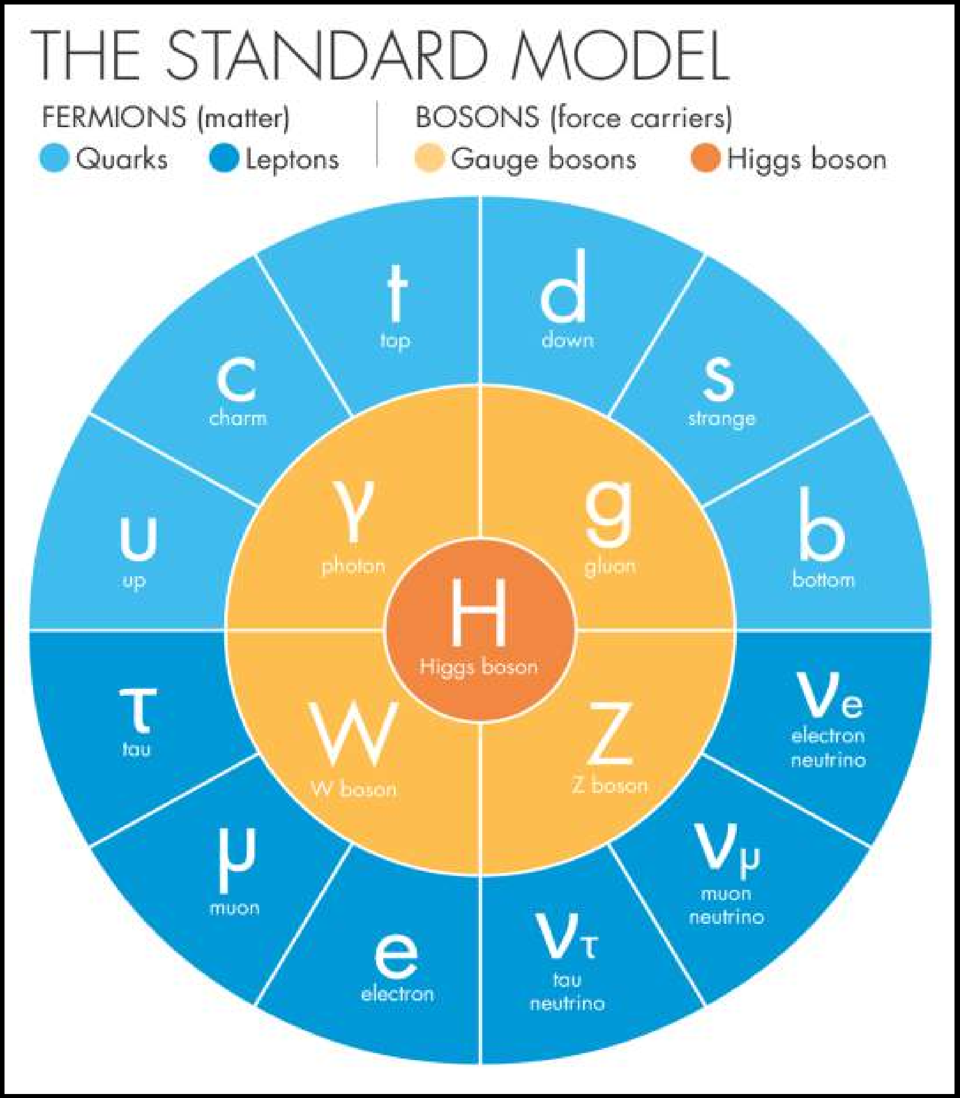
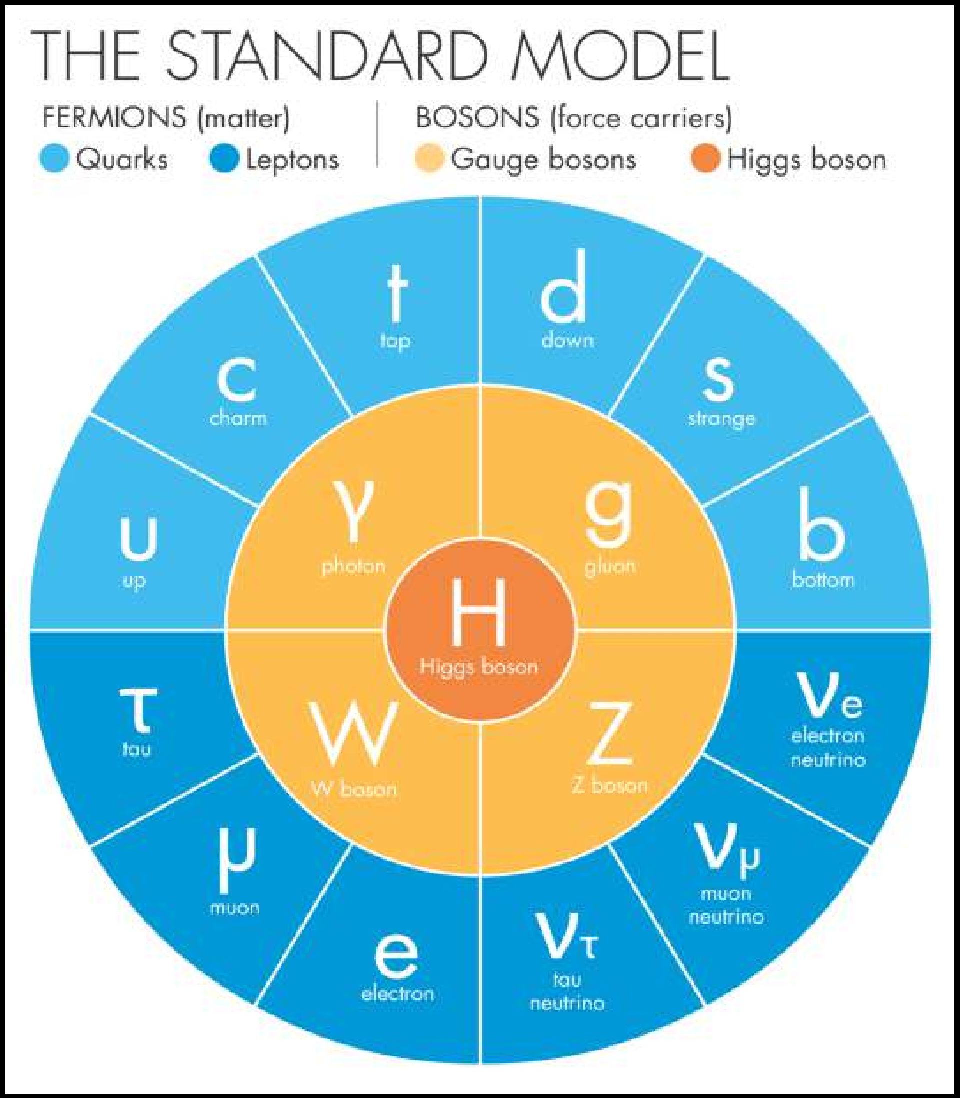


Standard model



However exciting ...



Higgs not the last brick !

Standard model

- Anomalies,
- unification,
- consistency of SSB,
- Gravity
- Flavor

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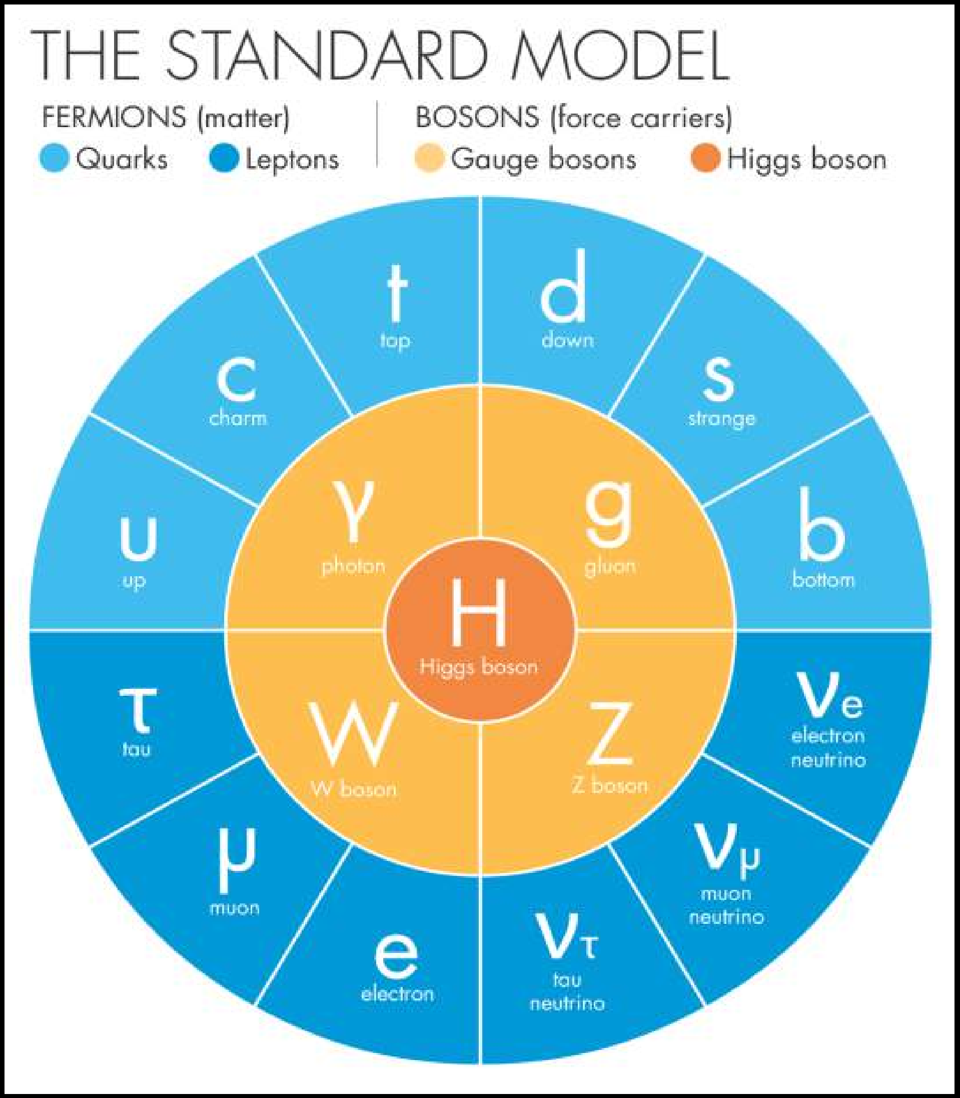
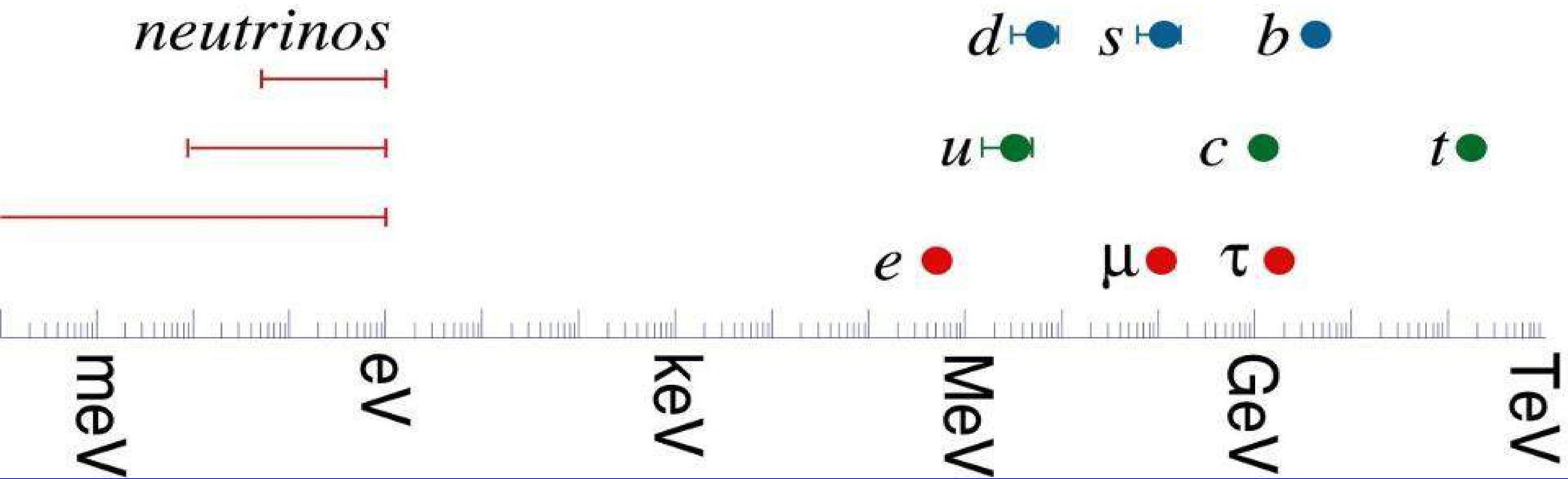


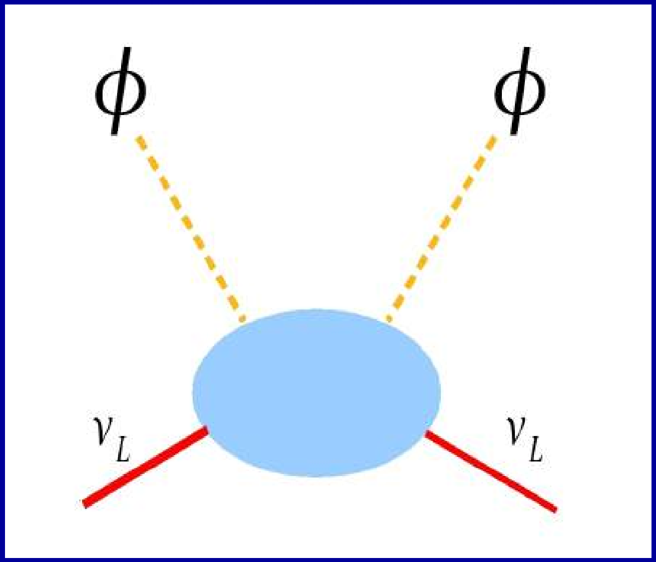
Despite its great success
SM does not explain neutrinos

... nor cosmo: dark matter, inflation, LG, dark energy



Why tiny neutrino masses

The origin of neutrino mass

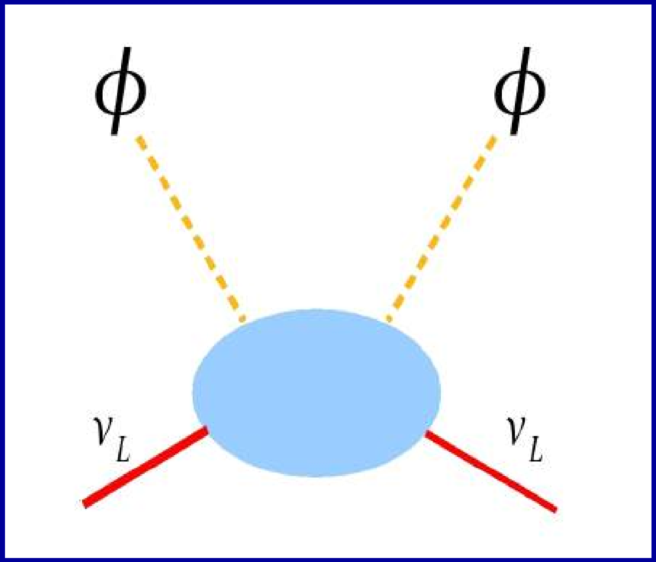


MECHANISM

SCALE

FLAVOR STRUCTURE

The origin of neutrino mass



Seesaw

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

MECHANISM

SCALE

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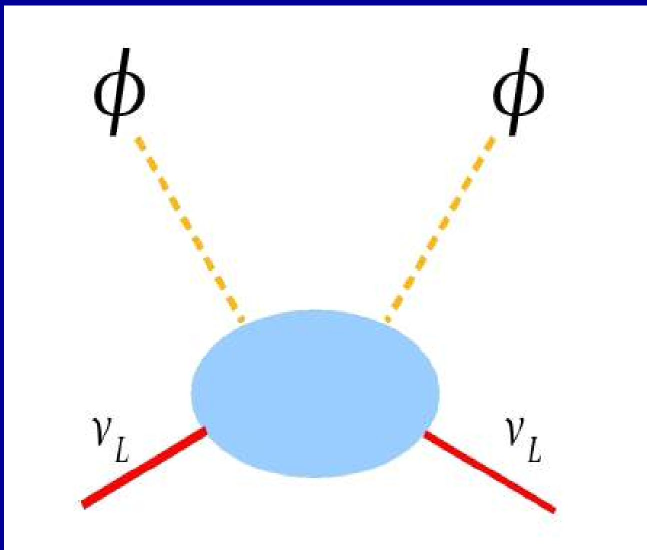
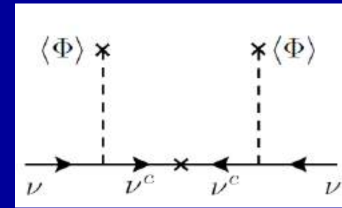
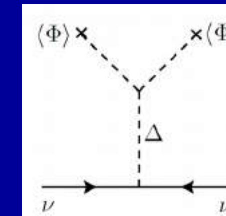




TYPE I

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

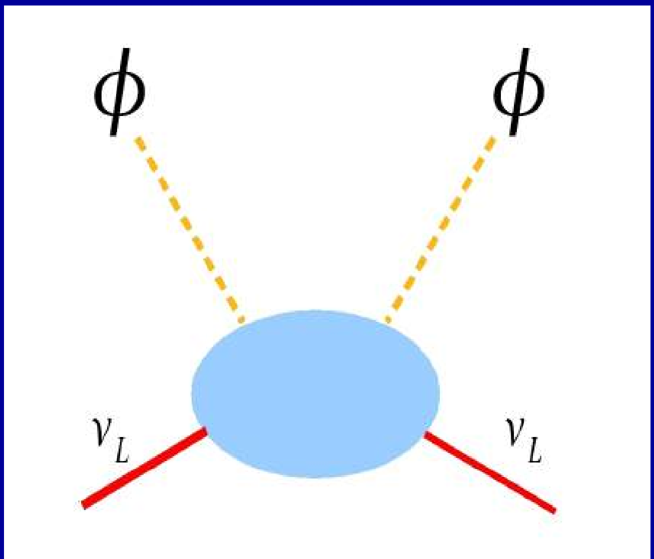
$$v_3 v_1 \sim {v_2}^2$$

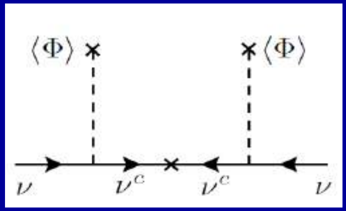
MECHANISM

SCALE

FLAVOR STRUCTURE

The origin of neutrino mass





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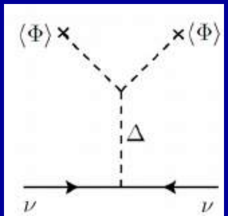


TYPE II

Schechter-Valle 80/82

MECHANISM

Seesaw

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

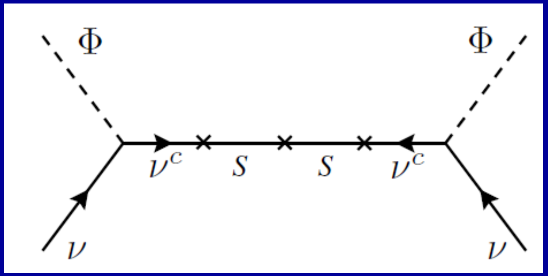
SCALE

Number & properties of messengers

FLAVOR STRUCTURE

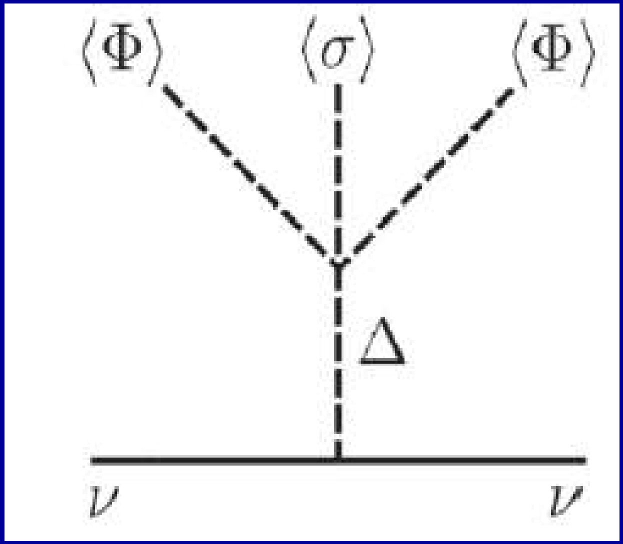
LOW-SCALE SEESAW

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

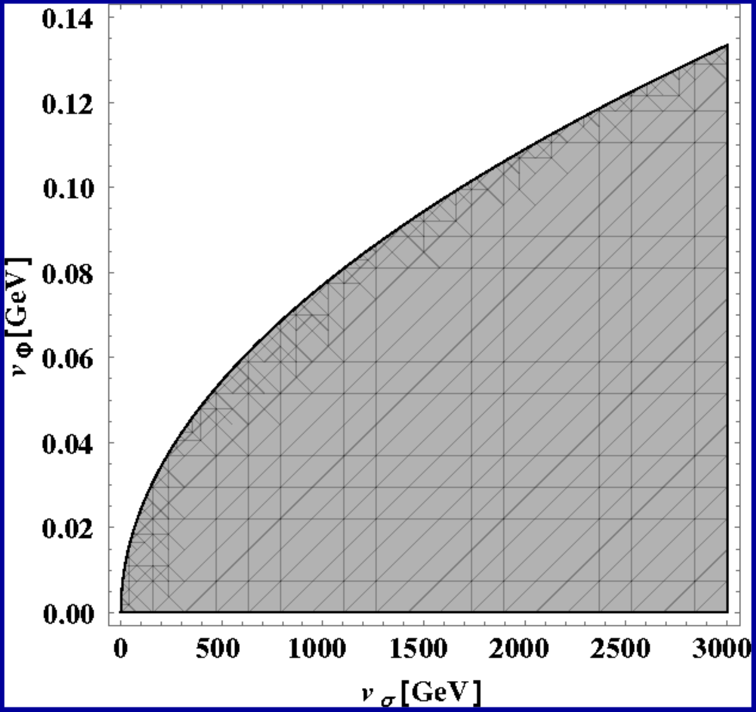


type-II seesaw with spont U(1) violation

Phys.Rev. D25 (1982) 774



Astrophysical limit



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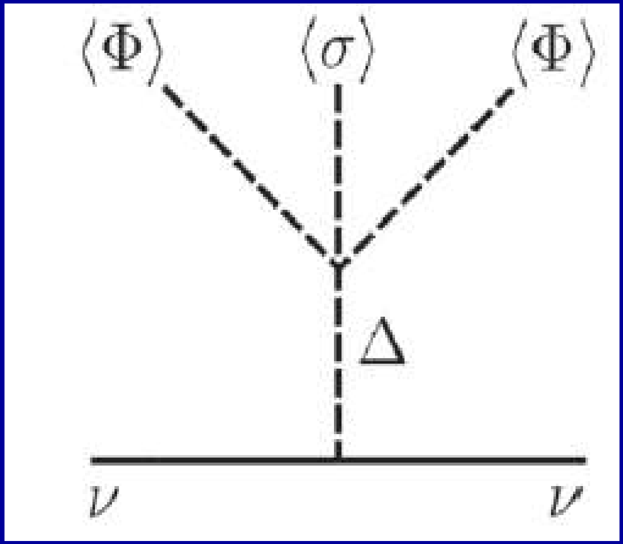
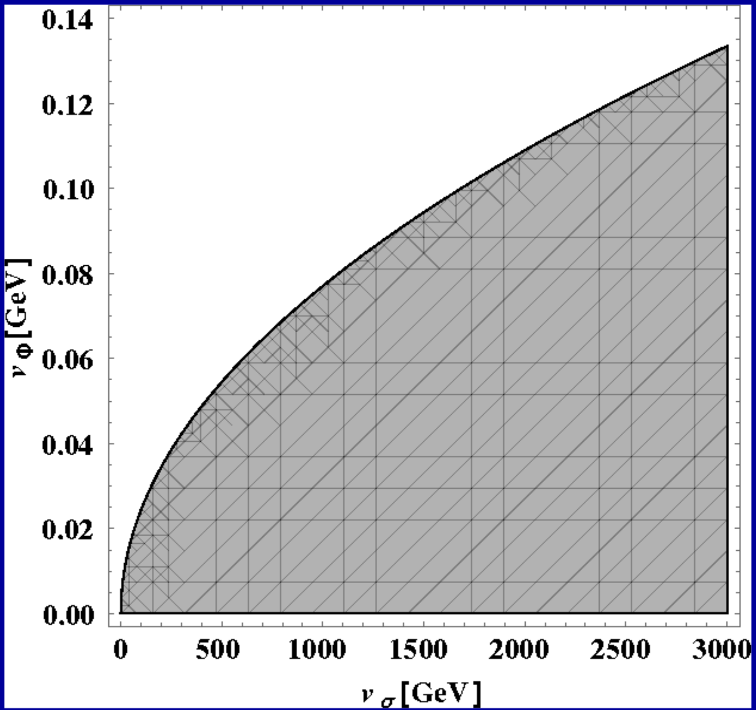


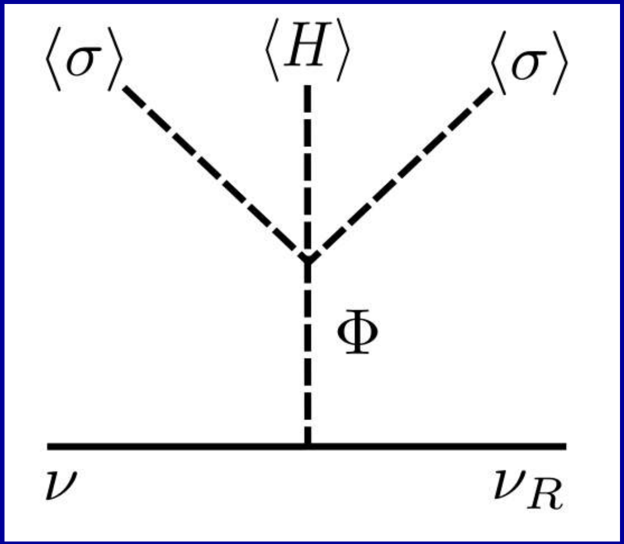
naturally small induced vev

Majoron
vs
Diracon

Astrophysical limit



accidental global U(1)



ArXiv:1605.08362 PLB

Why large neutrino mixing?

Flavor Symmetry

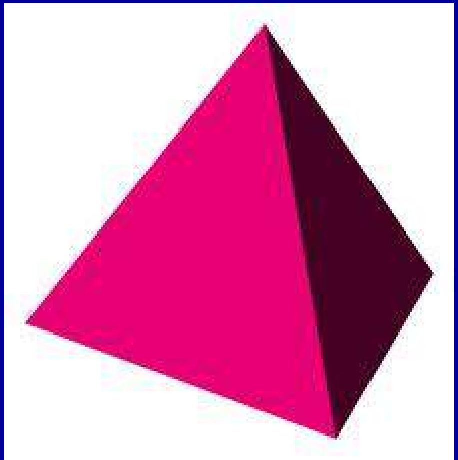
$$\begin{pmatrix}\nu_e\\ e\end{pmatrix}_L \quad \begin{pmatrix}\nu_\mu\\ \mu\end{pmatrix}_L \quad \begin{pmatrix}\nu_\tau\\ \tau\end{pmatrix}_L$$

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

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

$$u_R \quad c_R \quad t_R$$

$$d_R \quad s_R \quad b_R$$

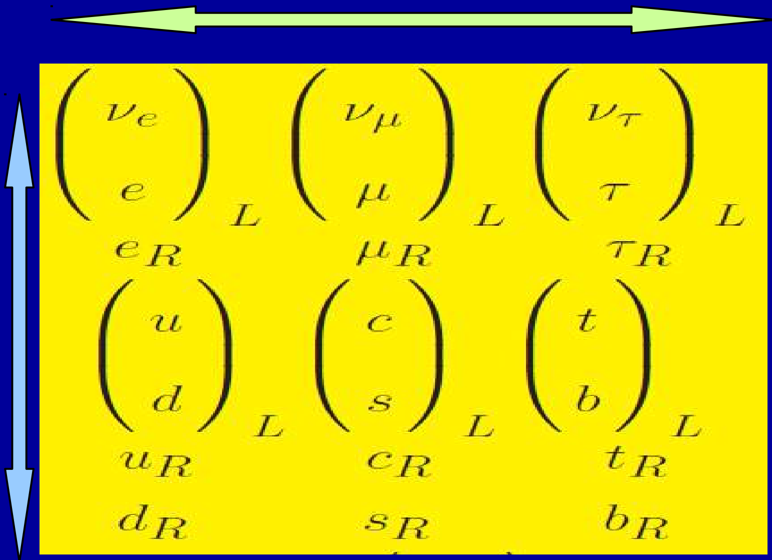


A4

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

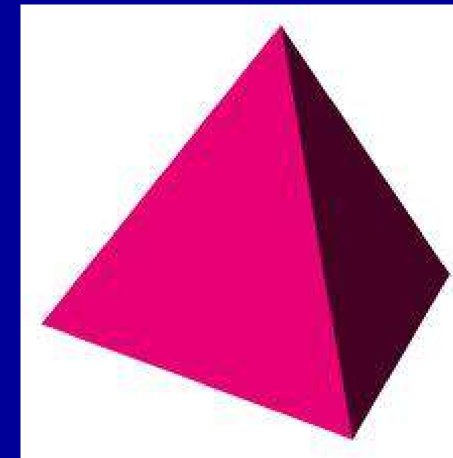
$$\sin^2\theta_{23} = 0.5$$

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



Flavor Symmetry

A4



Babu-Ma-Valle PLB552 (2003) 207
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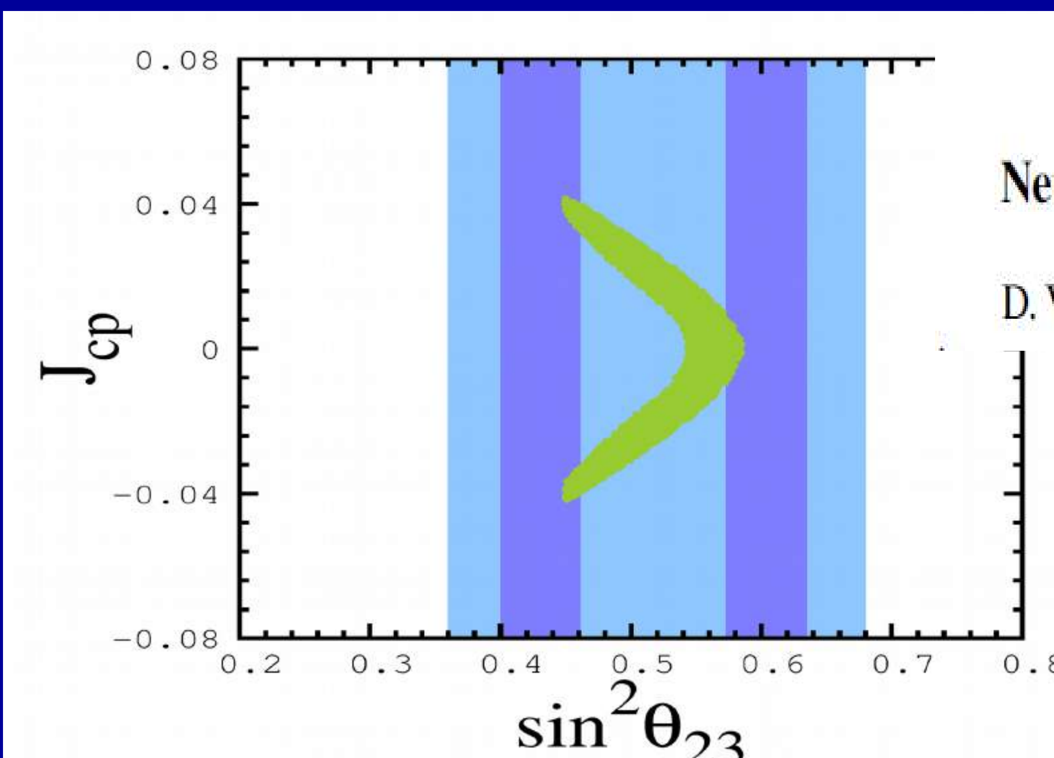


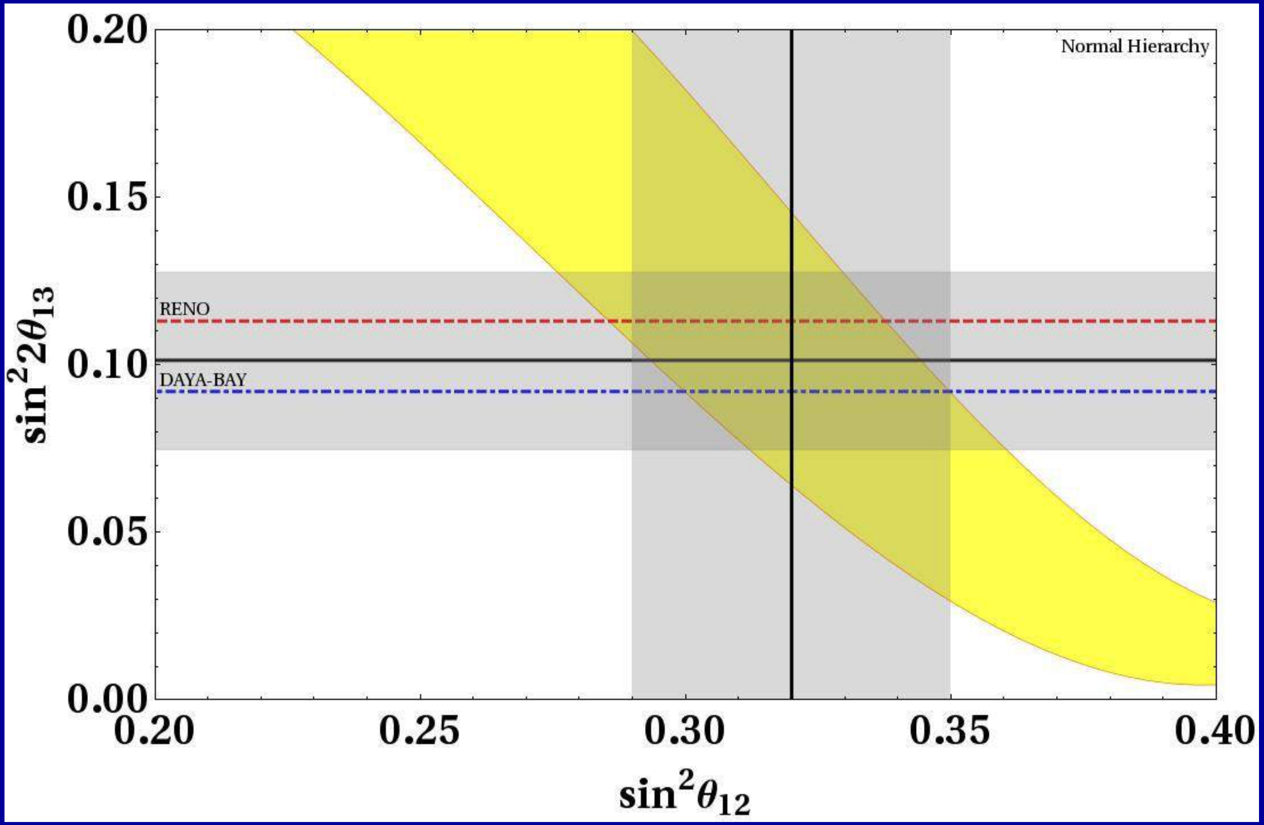
PHYSICAL REVIEW D 88, 016003 (2013)

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



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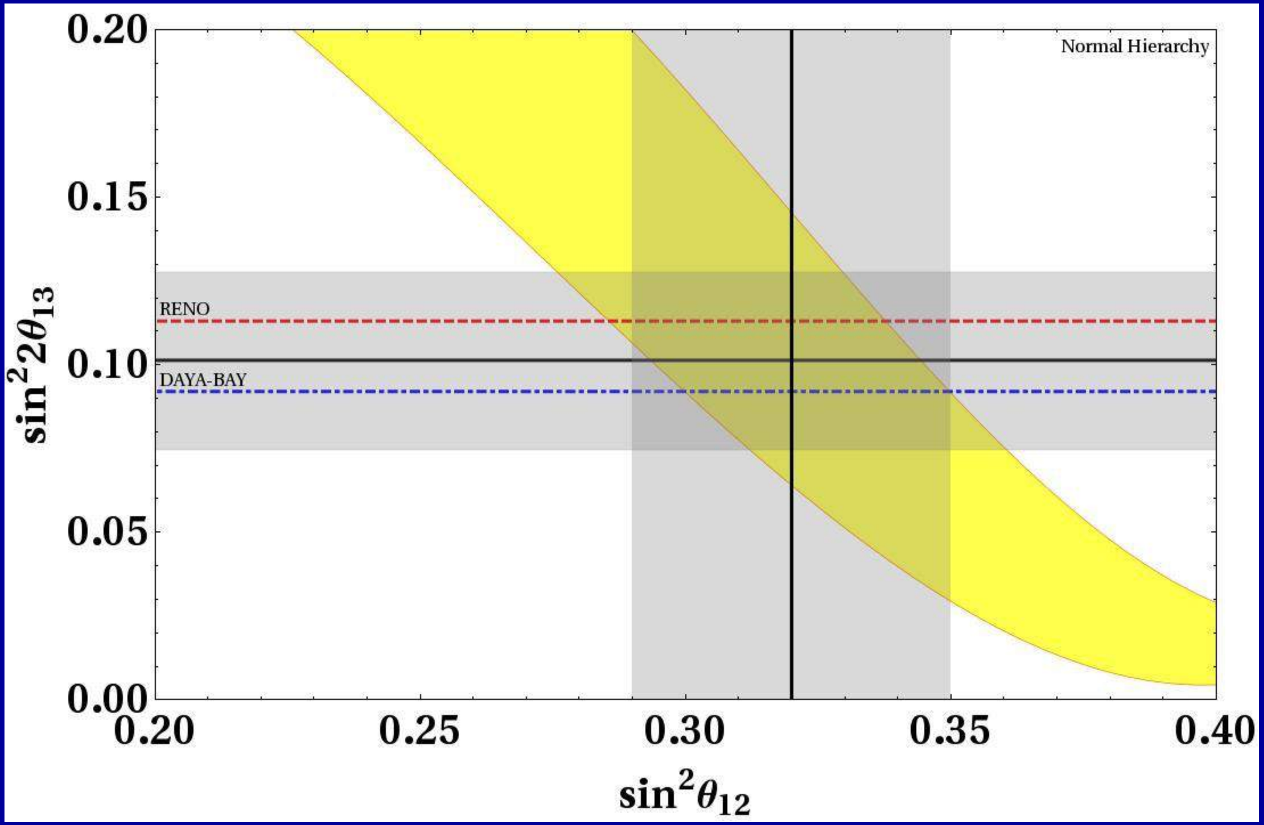
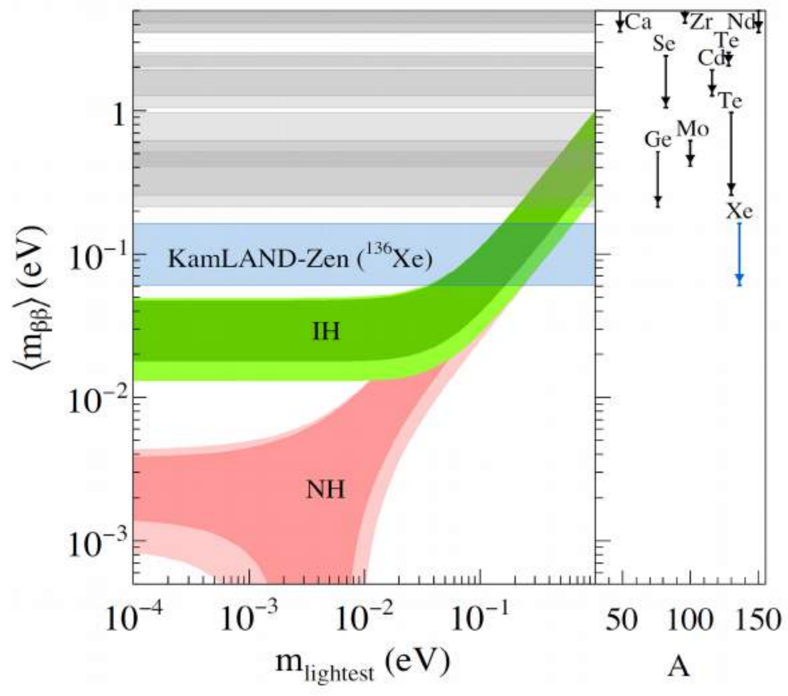


P Chen et al
Phys.Lett. B753 (2016) 644-652
Phys.Rev. D94 (2016) no.3, 033002

Model-independent flavor approach

Flavor Sensitivity in neutrinoless double beta decay



A.S. Barabash arXiv:1104.2714

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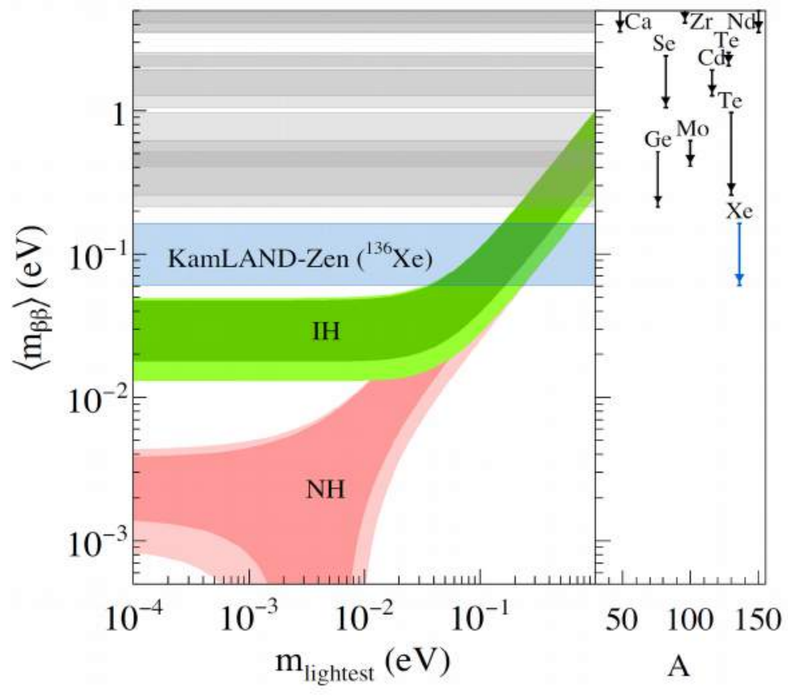
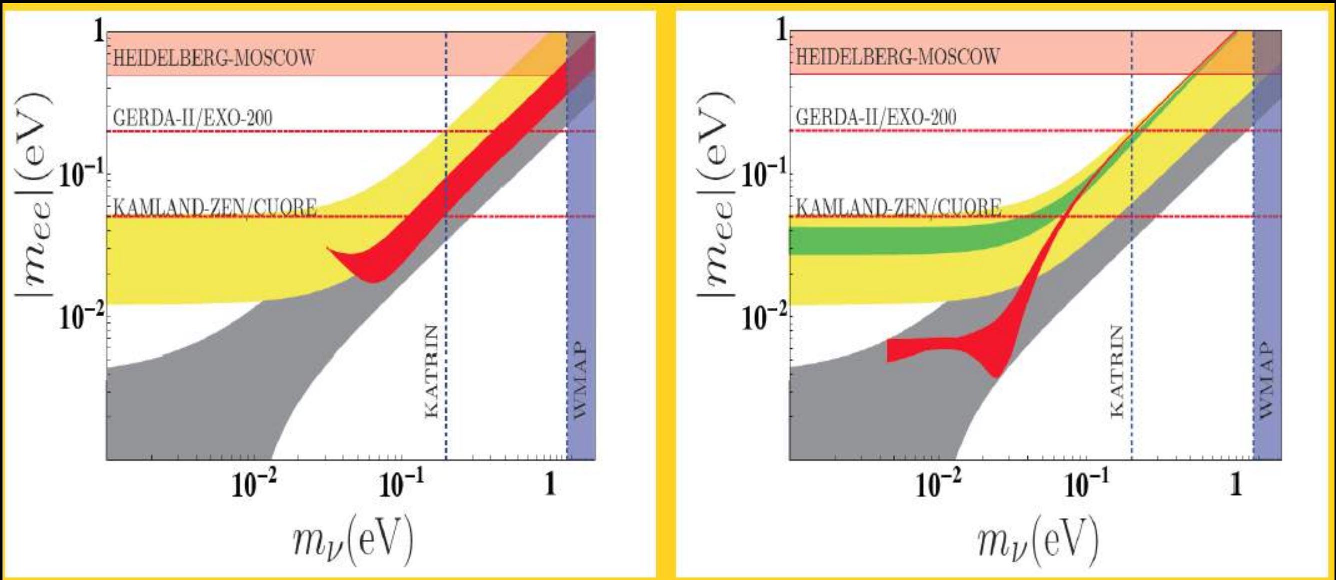
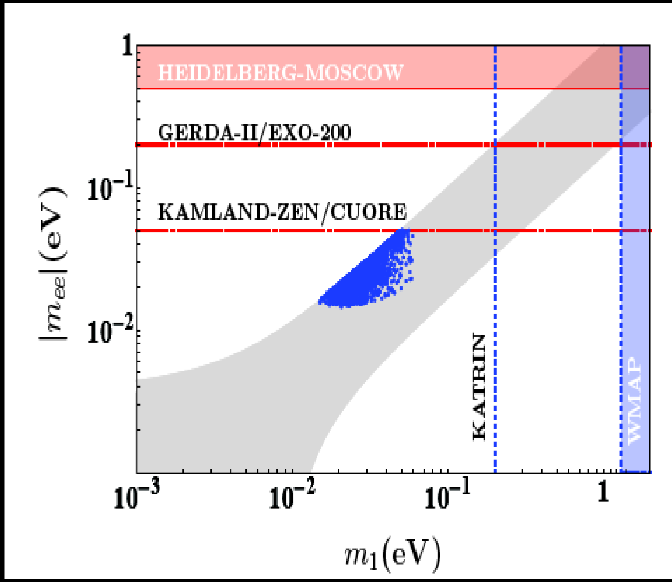


Lower bounds ...

A.S. Barabash arXiv:1104.2714



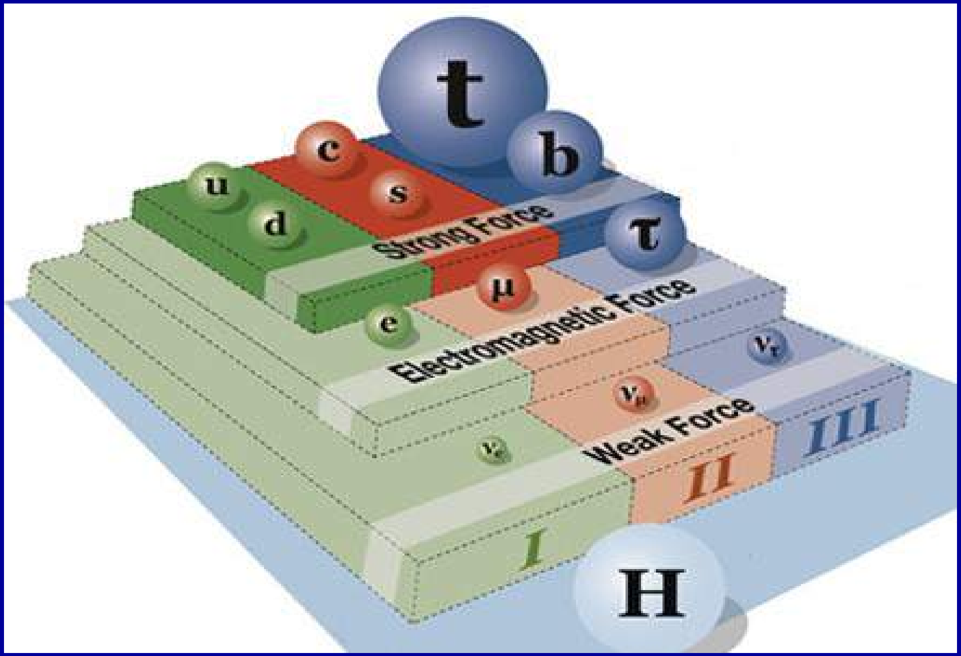


Dorame et al
NPB861 (2012) 259-270

PhysRevD.86.056001

King et al Phys. Lett. B 724 (2013) 68

Can neutrinos shed light on charged fermion masses?

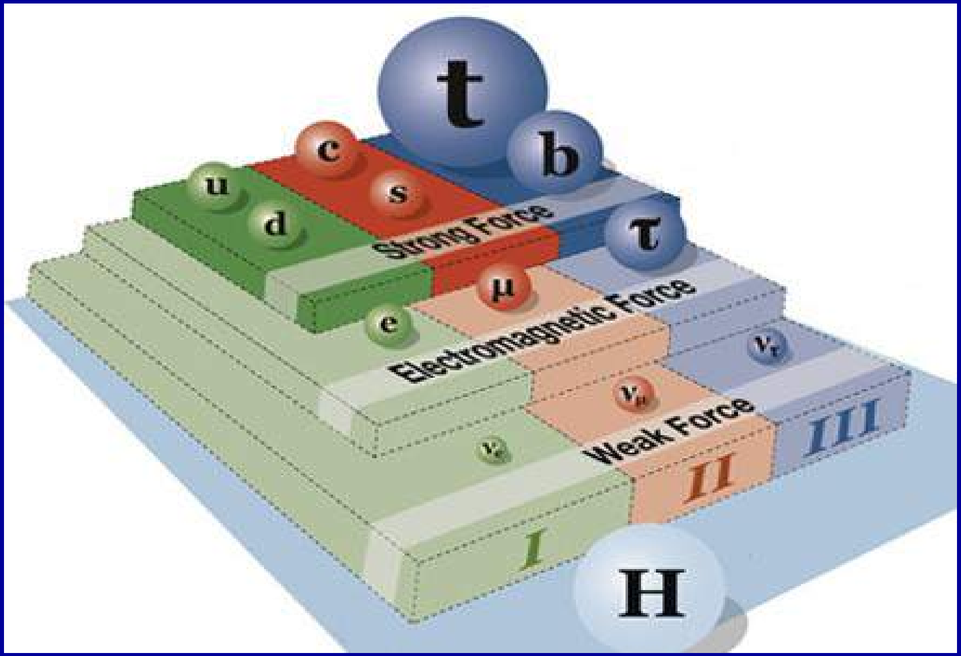


Neutrinos : Lepton number?

Can neutrinos shed light on charged fermion masses?

Flavor dependent b-tau unification

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

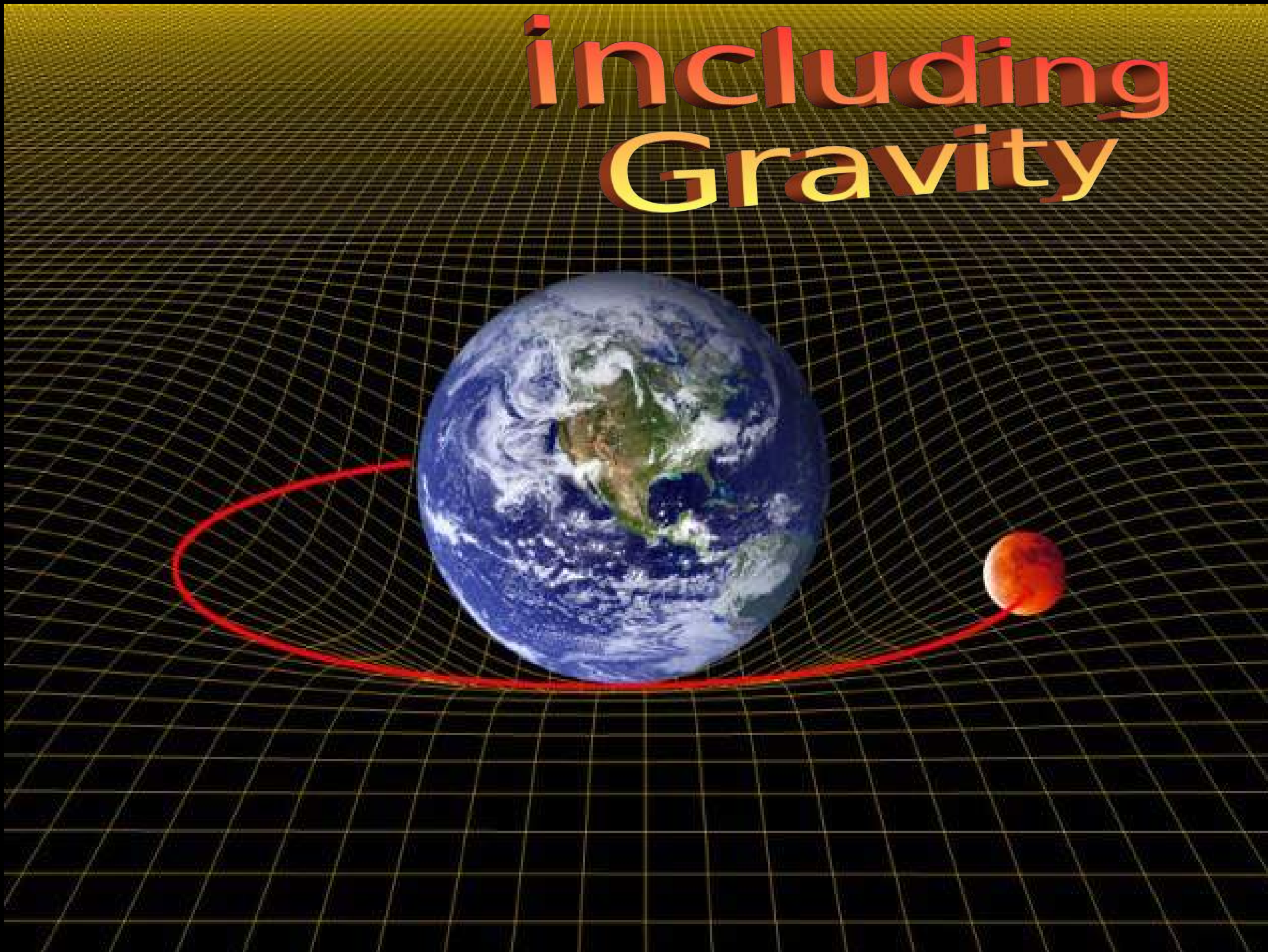
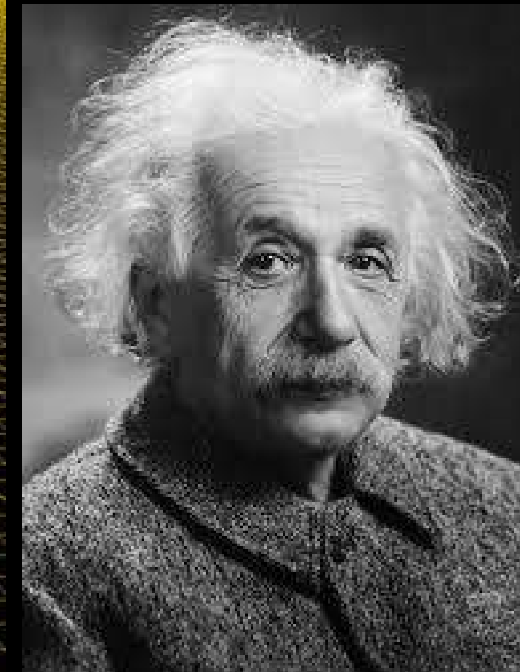


Morisi et al Phys.Rev. D84 (2011) 036003

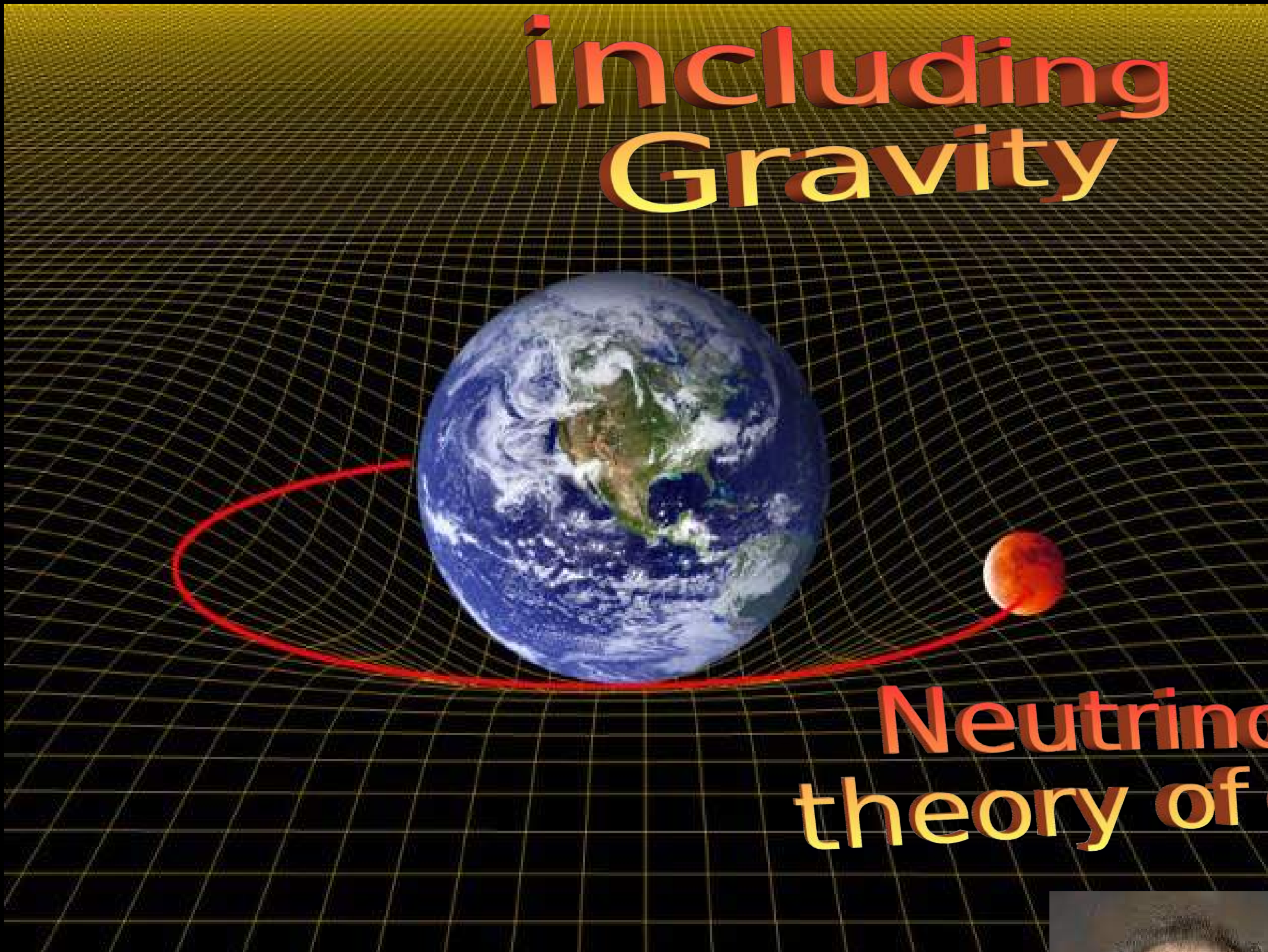
King et al Phys. Lett. B 724 (2013) 68

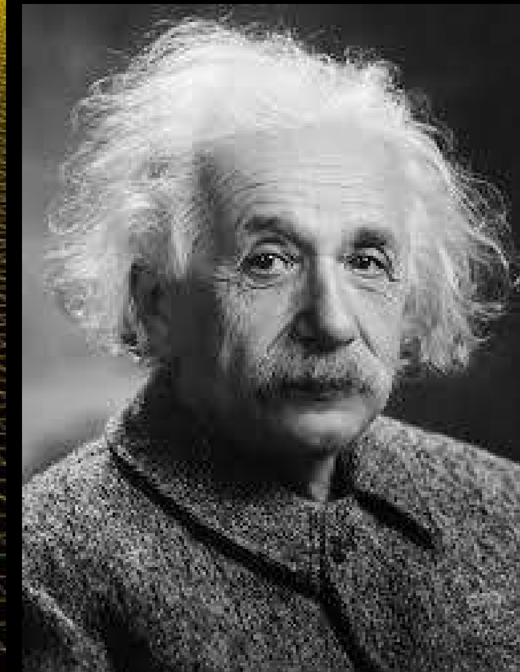
Morisi et al Phys.Rev. D88 (2013) 036001

Bonilla et al Phys.Lett. B742 (2015) 99


including
Gravity


including Gravity





Neutrinos in the theory of everything

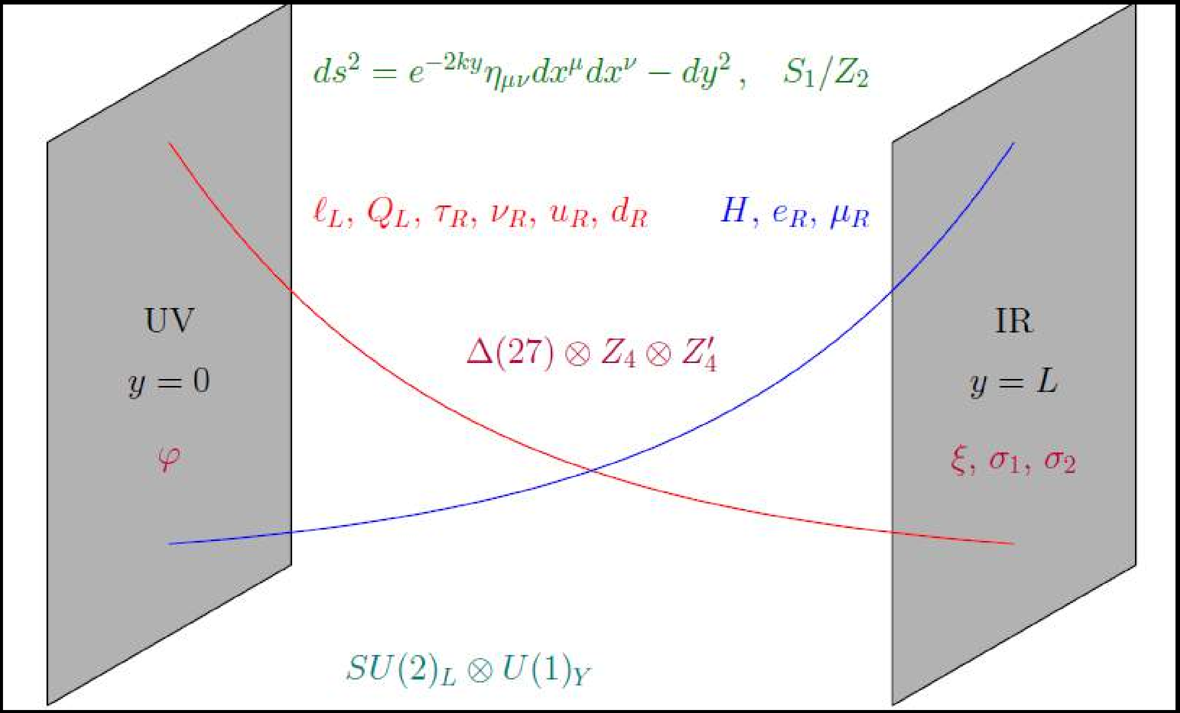
: Chen et al arXiv:1509.06683
JHEP01(2016)007

Addazi et al

Phys.Lett. B759 (2016) 471-478

Warped standard model

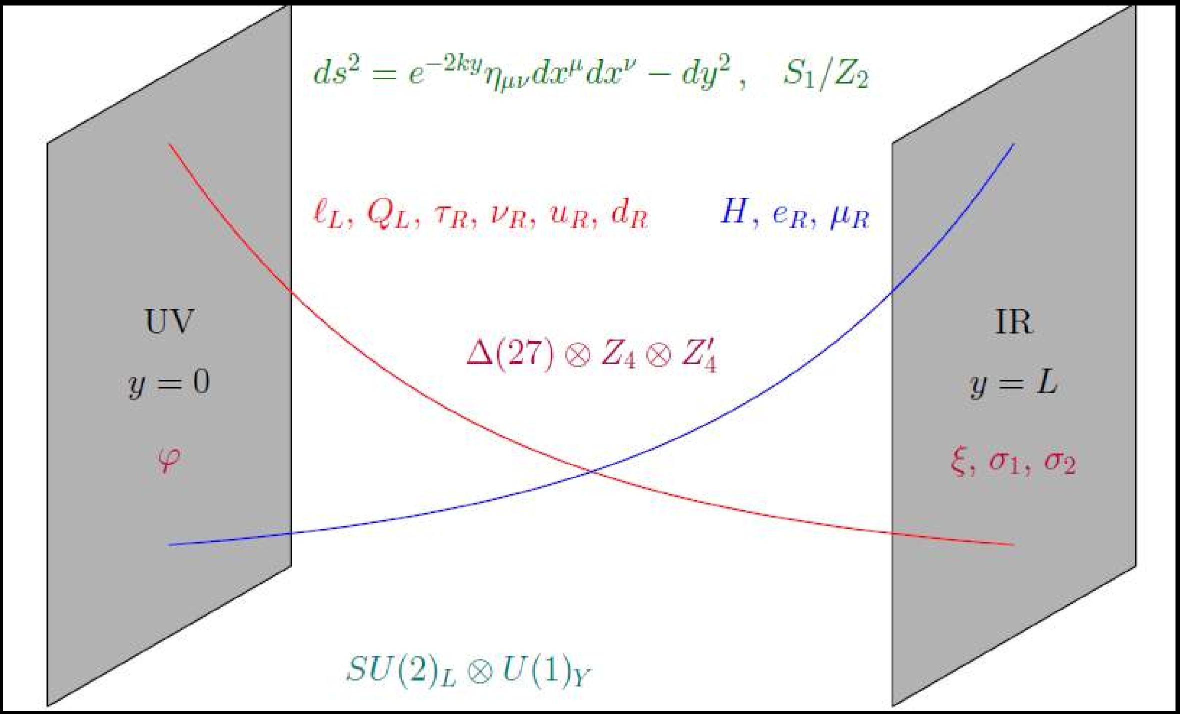
: Chen et al arXiv:1509.06683
JHEP01(2016)007

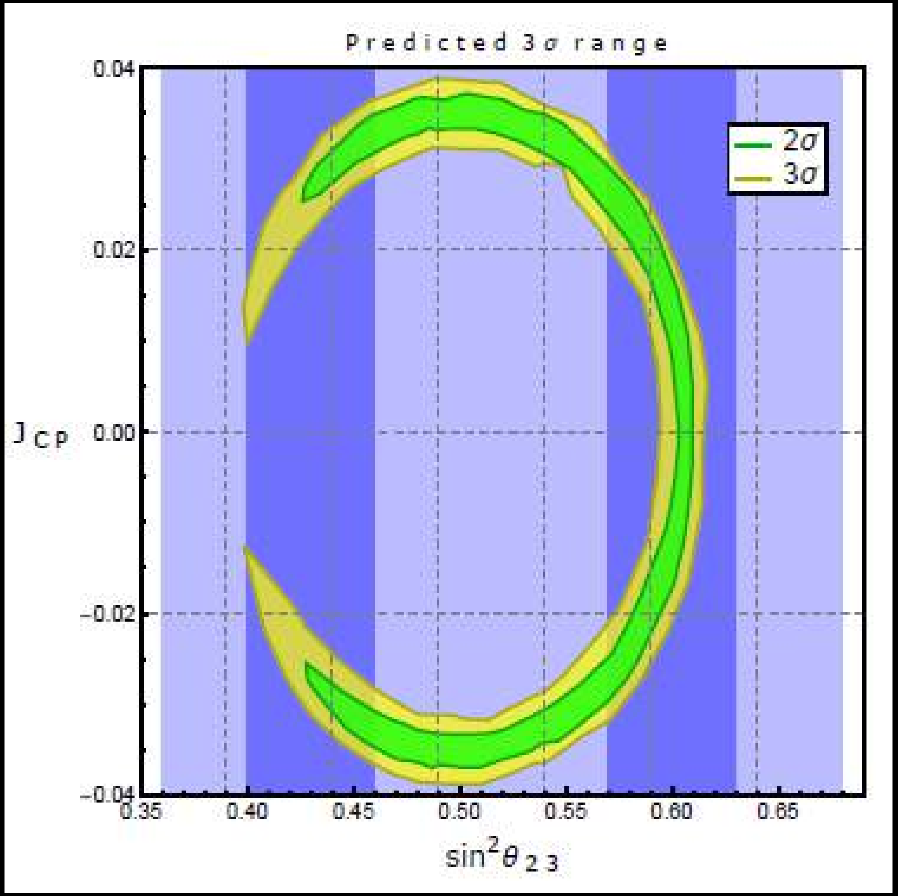


Masses explained by choices
of the bulk parameters

Warped standard model

: 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

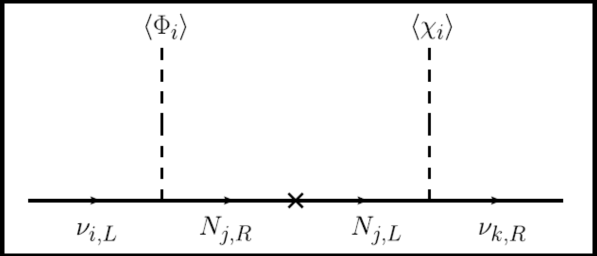

even if neutrinos form only
tiny DM fraction
they can hold the key
to Dark matter problem

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

arXiv:1606.04543
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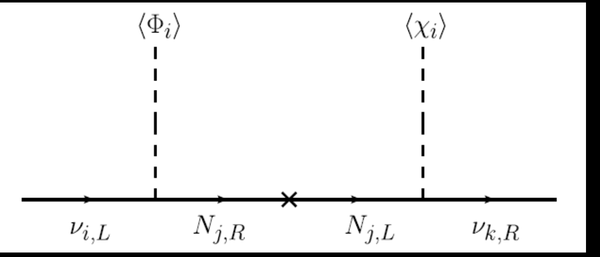


Lepton Quarticity vs Lepton number

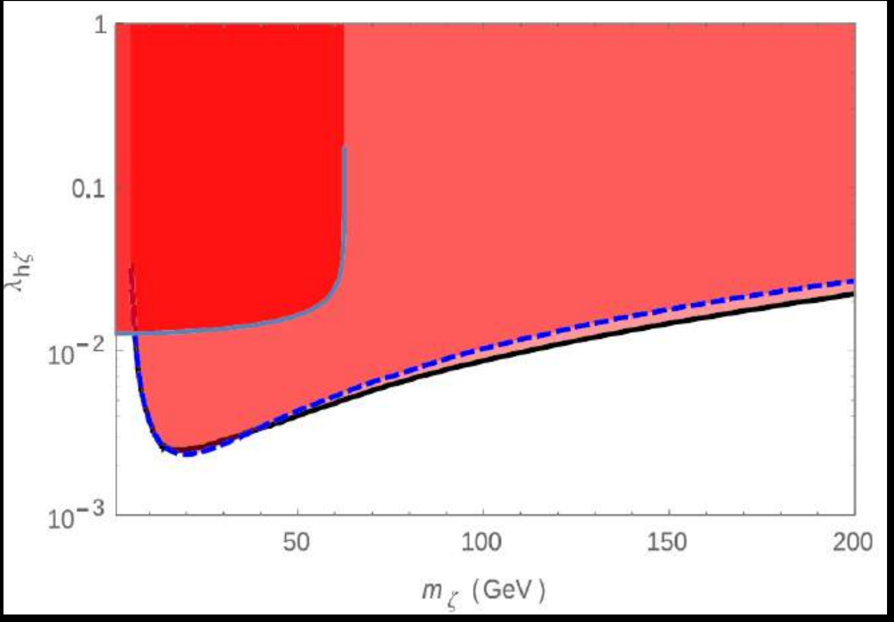
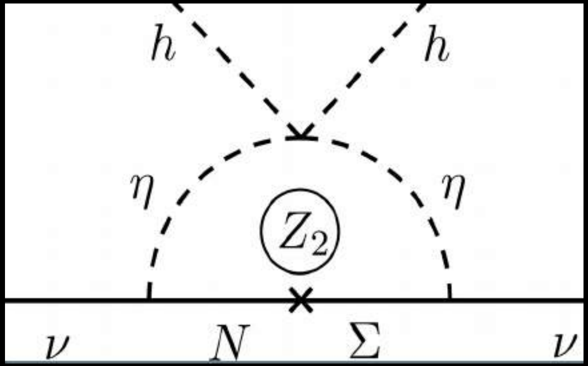


Fig. 5. The experimental sensitivity of our WIMP scalar dark matter candidate to invisible Higgs decay and direct detection. The light shaded region is ruled out by LUX (black continuous line) [34] and PandaX (blue dashed line) [35] data whereas the dark shaded region is ruled out by the bound on the Higgs invisible decay width from the LHC [36].

non SUSY scalar WIMP



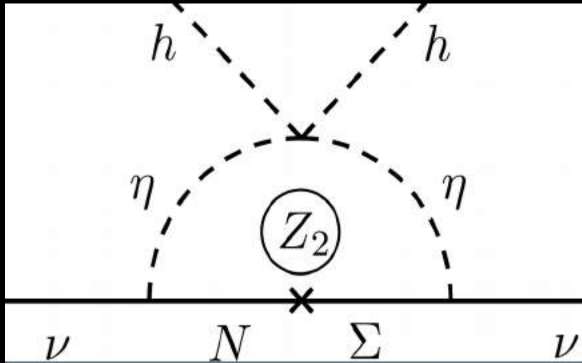
scotogenic dark matter

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
$SU(2)_L$	2	1	2	3	1	2	3
$U(1)_Y$	-1/2	-1	1/2	0	0	1/2	0
$\mathbb{Z}_2$	+	+	+	−	−	−	+

WIMP dark Matter as radiative neutrino mass messenger

scotogenic dark matter



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

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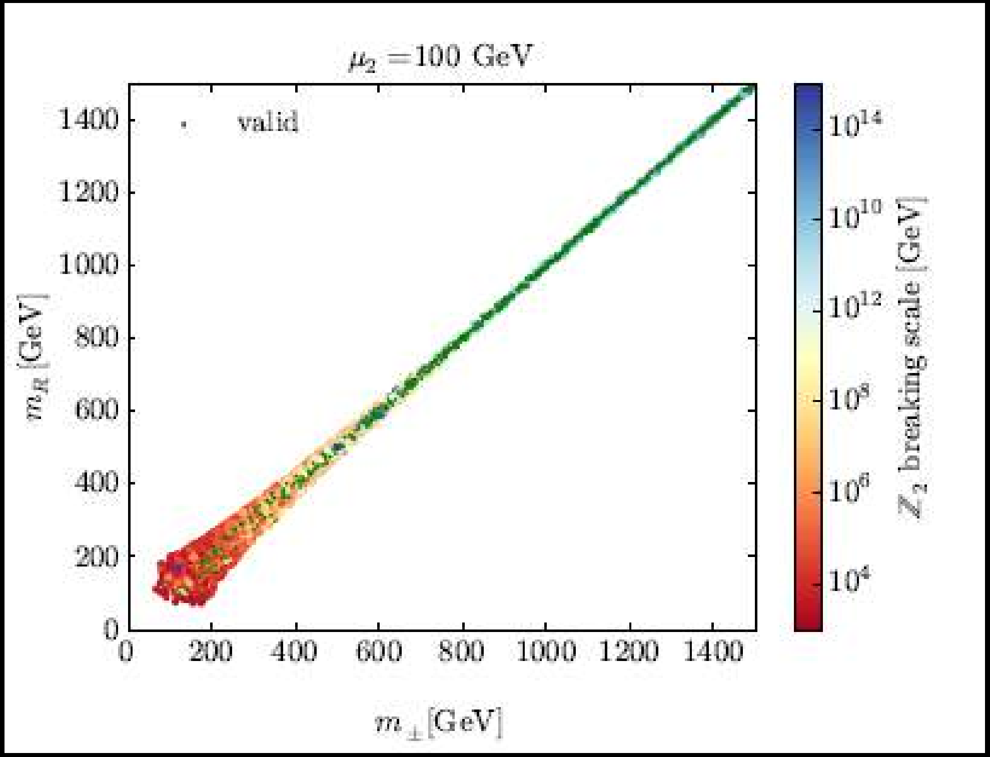
WIMP dark Matter as radiative neutrino mass messenger

Merle et al JHEP 1607 (2016) 013



Either scalar or fermion messenger

"susy" without susy

Phys.Lett. B762 (2016) 214-218

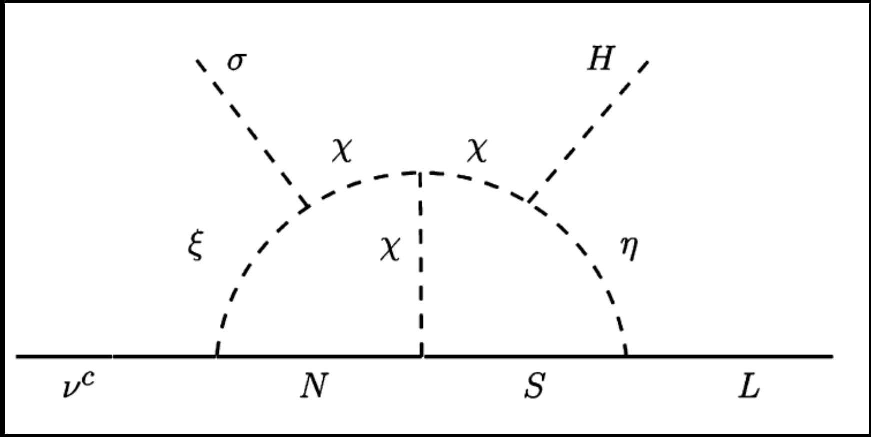
Scotogenic dark matter stability from Diracness

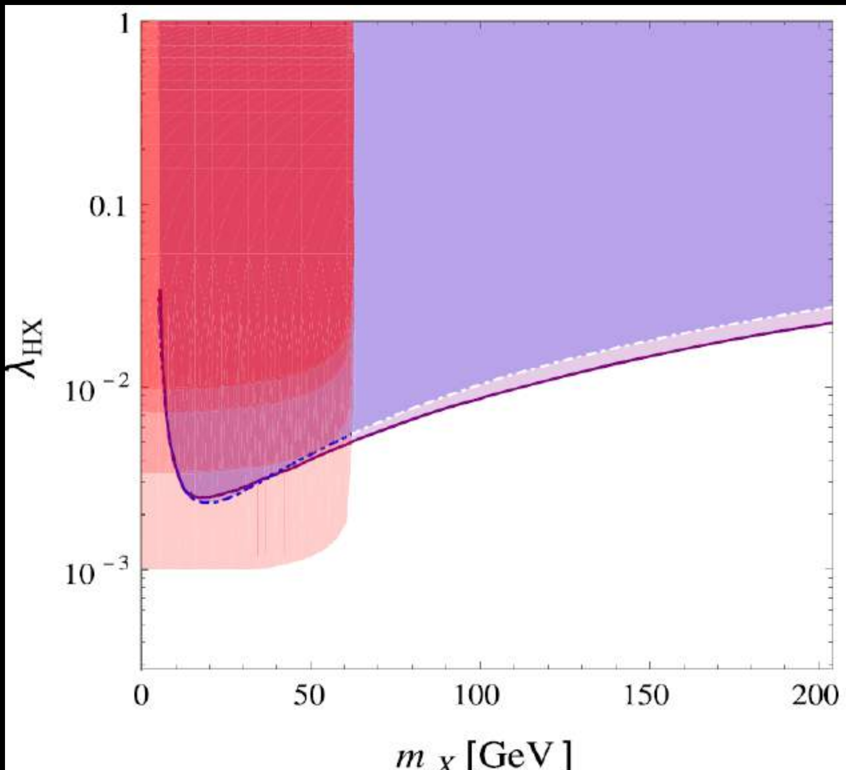
Lepton triality vs Lepton number

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





Phys.Lett. B762 (2016) 214-218

non SUSYscalar WIMP

Scotogenic dark matter stability from Diracness

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

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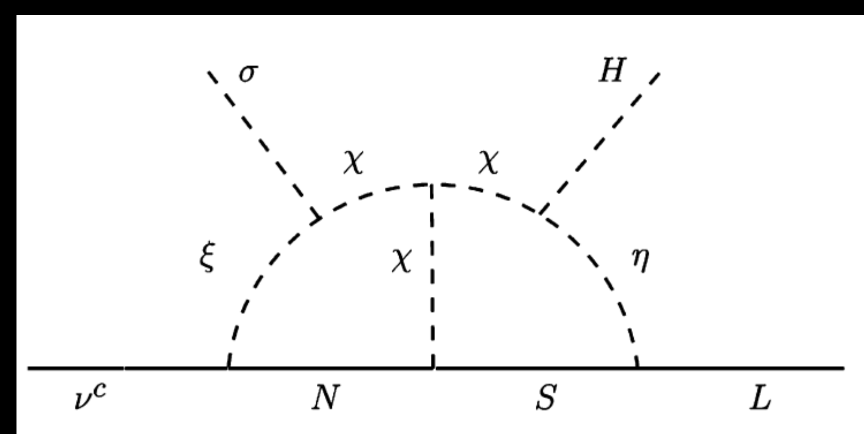

Physics Letters B 318 (1993) 360–366
North-Holland

PHYSICS LETTERS B

The keV majoron as a dark matter particle

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 Física Teòrica, Universitat de València,
46100 Burjassot, València, Spain

Physics Letters B 318 (1993) 360–366
North-Holland

PHYSICS LETTERS B

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Decaying Warm Dark Matter and Neutrino Masses

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.

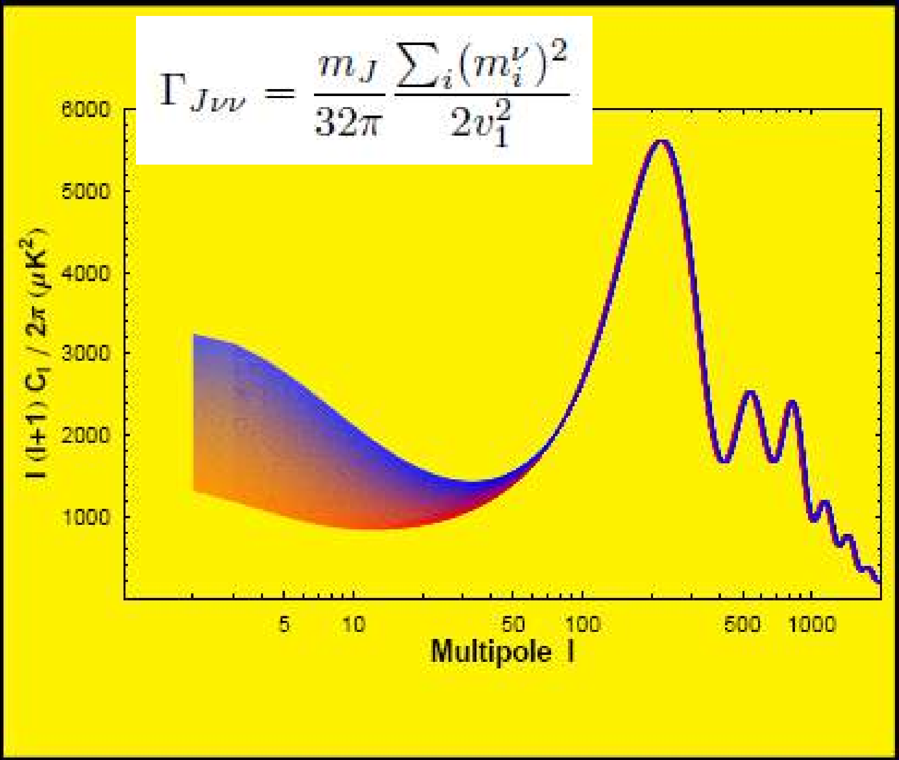
Lattanzi & Valle, PRL99 (2007) 121301

Consistency with CMB

dark matter majorons

Lattanzi & Valle, PRL99 (2007) 121301

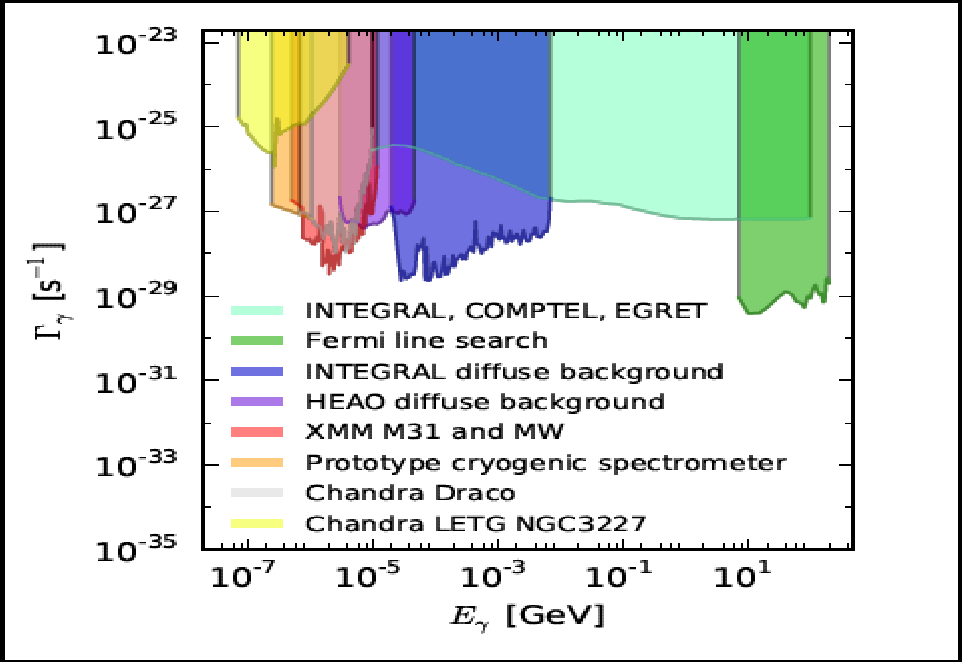
$$\Gamma_{J\nu\nu} = \frac{m_J}{32\pi}\frac{\sum_i (m_i^\nu)^2}{2v_1^2}$$



Bazzocchi & al JCAP 0808 (2008) 013

Esteves et al, PRD 82, 073008 (2010)

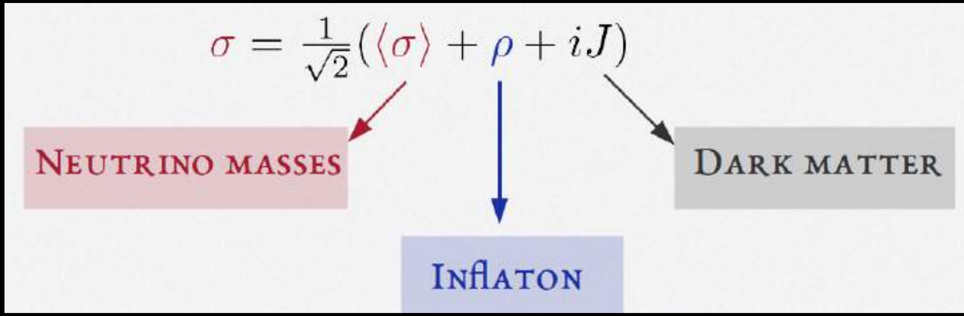
$J \to \gamma\gamma$

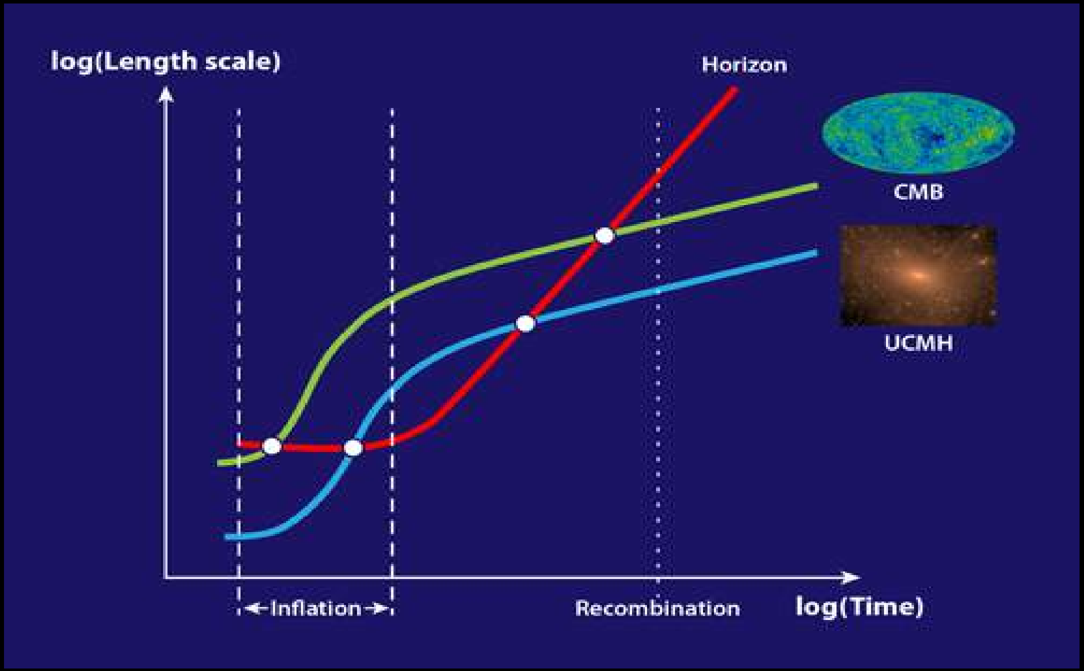


Lattanzi et al PRD88 (2013) 063528

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
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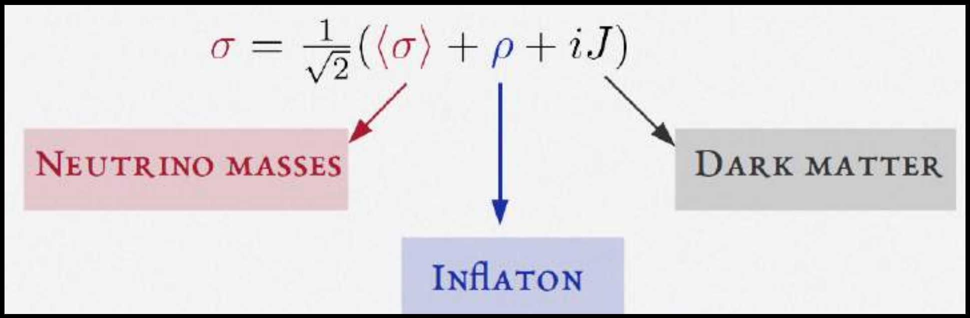
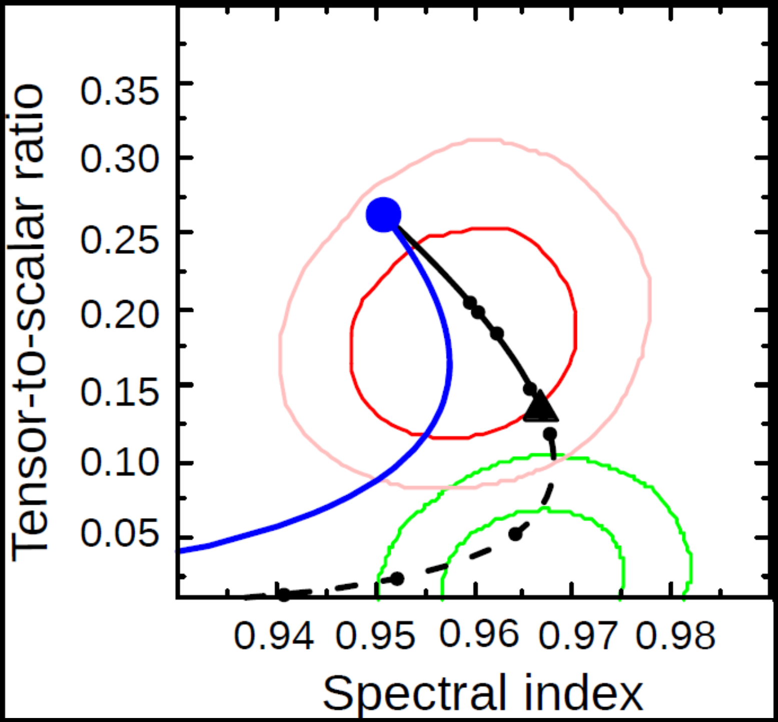
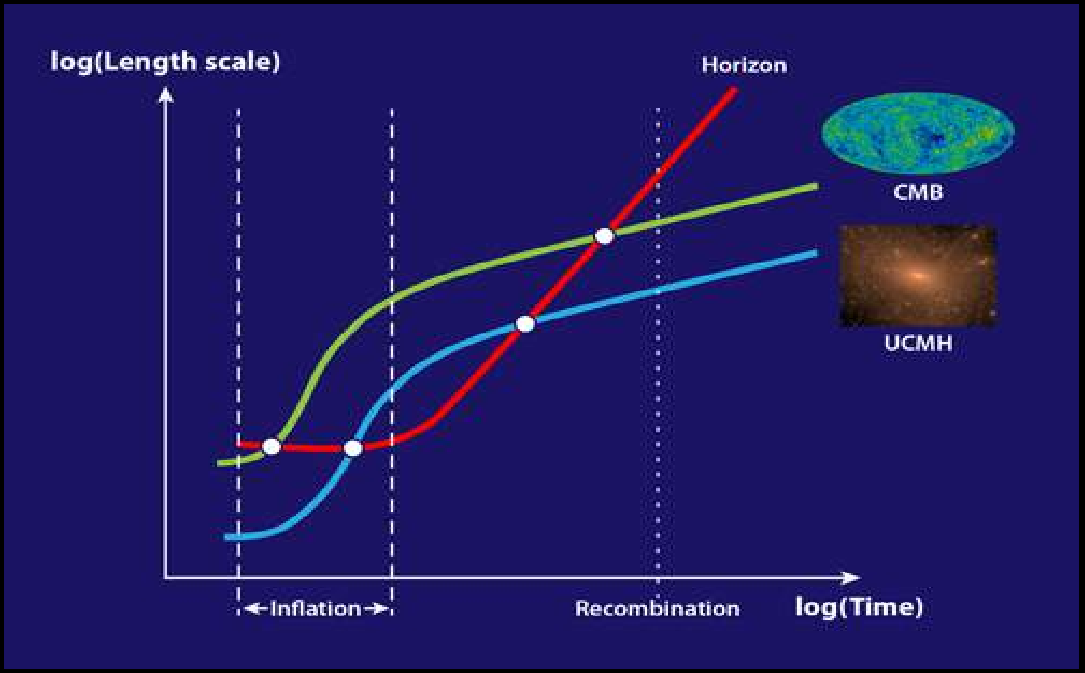


Quartic versus Higgs Inflation





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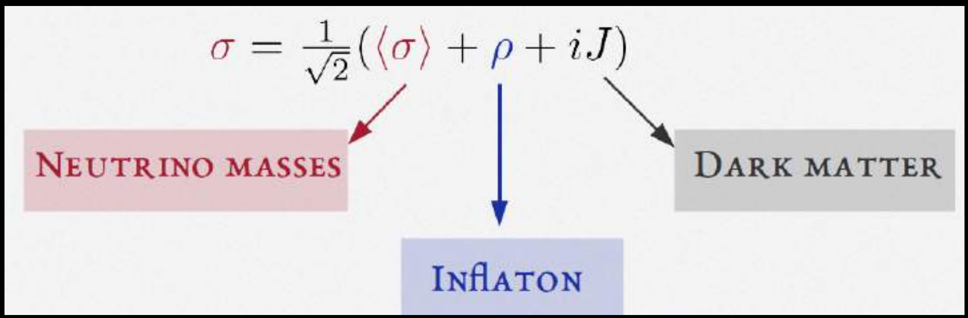
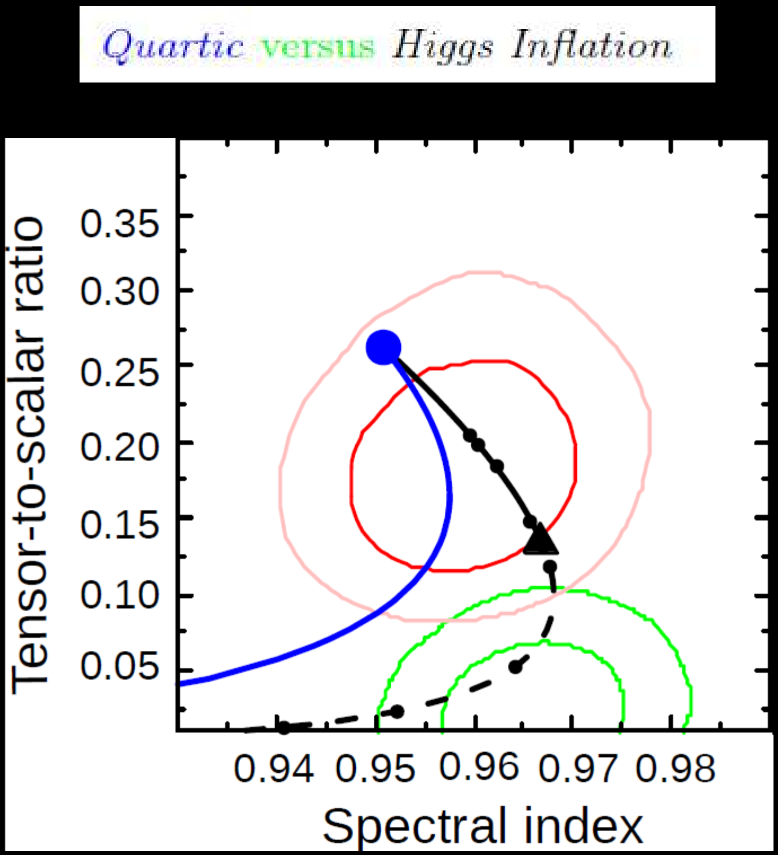
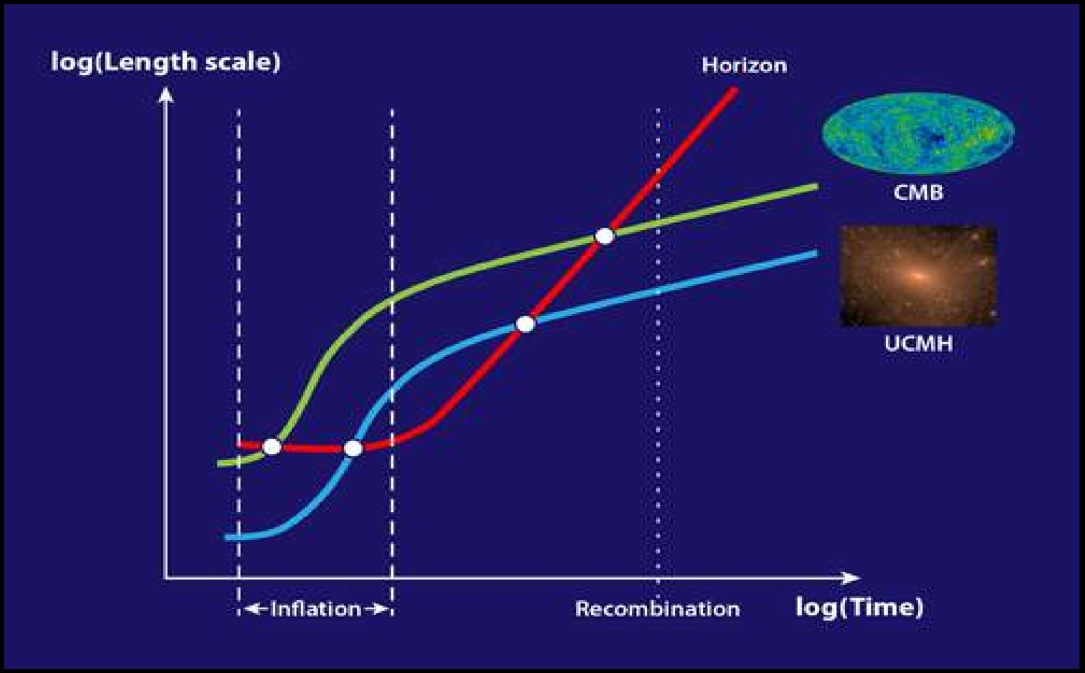


type-I seesaw **Leptogenesis**

Aristizabal et al JCAP 1407 (2014) 052





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

DARK MATTER FROM FLAVOR SYMMETRY

- ***Accidental ?***

Lavoura, Morisi, JV JHEP 1302(2013) 118

DARK MATTER FROM FLAVOR SYMMETRY

- ***Accidental ?***

Lavoura, Morisi, JV JHEP 1302(2013) 118

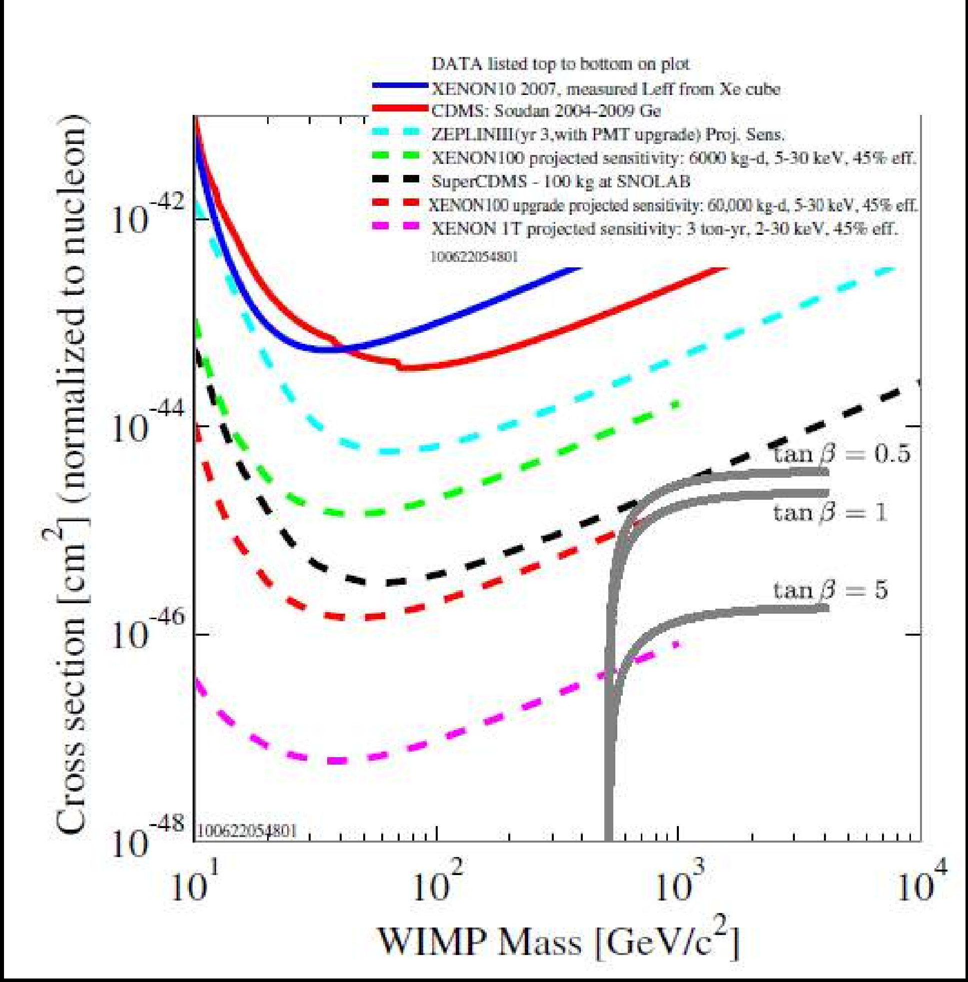
- ***unbroken subgroup***

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

many choices

more possibilities

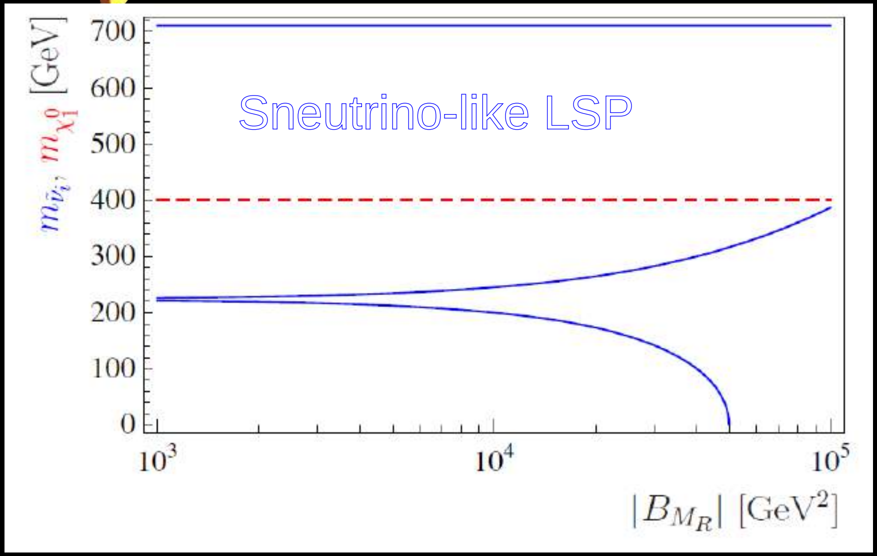
HIGGS PORTAL
DIRECT DETECTION



susy wimp dark matter

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

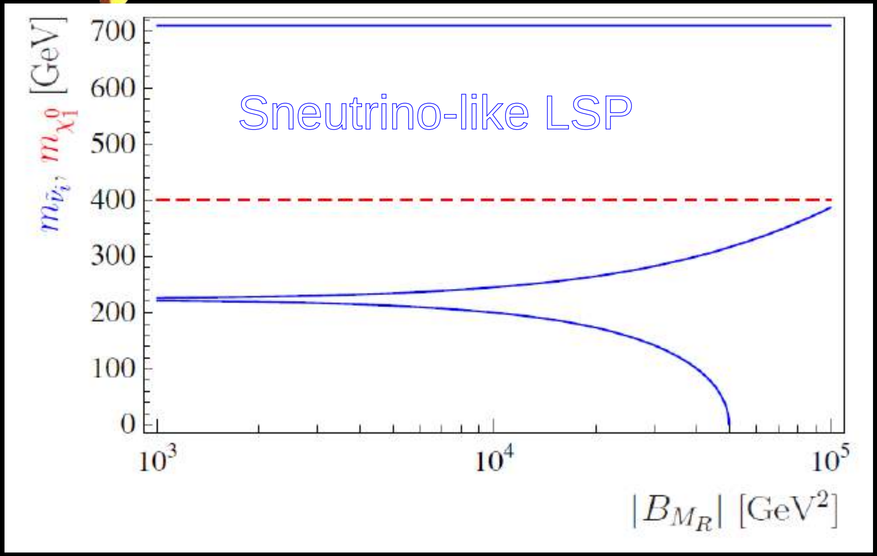
De Romeri, Hirsch, JHEP 1212 (2012) 106



susy low-scale seesaw ...

susy wimp dark matter

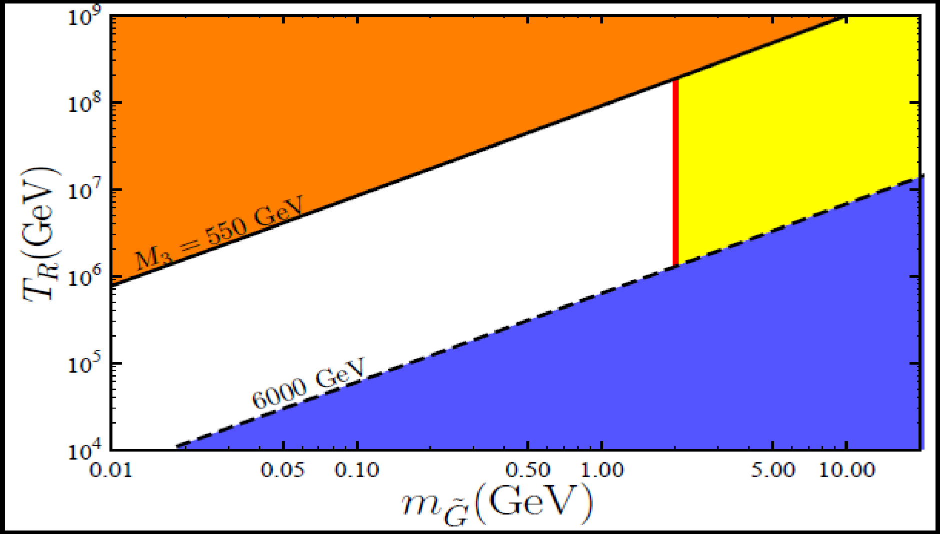
Arina et al PRL101 (2008) 161802
Bazzocchi, Cerdeno, Munoz, J.V., PRD81 (2010) 051701
De Romeri, Hirsch, JHEP 1212 (2012) 106



susy inverse seesaw ...

decaying Gravitino dark matter

Restrepo et al PRD85 (2012) 023523



doubly suppressed decays

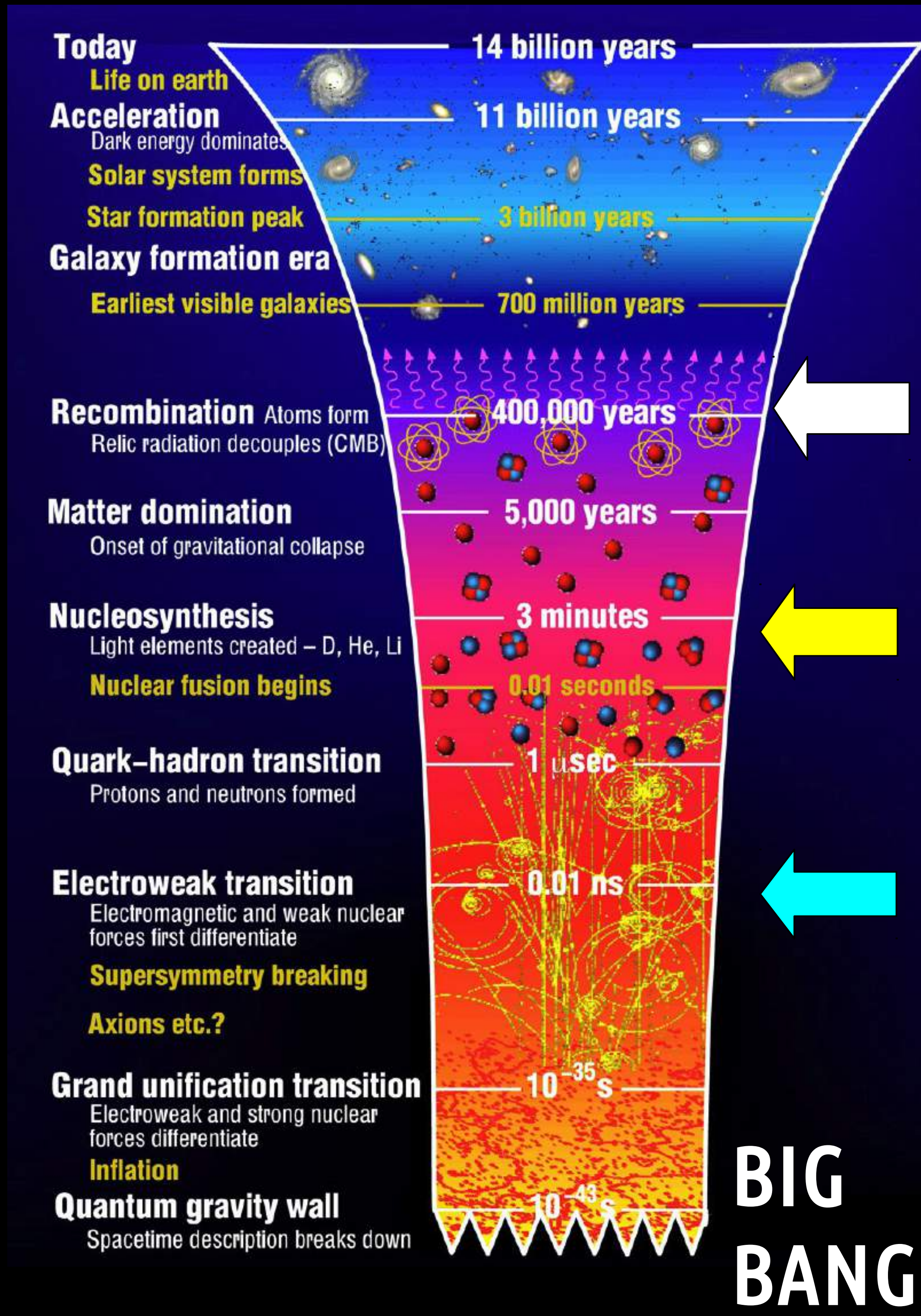
$$\Gamma = \Gamma(\tilde{G} \to \sum_i \nu_i \gamma) \simeq \frac{1}{32\pi} |U_{\tilde{\gamma}\nu}|^2 \frac{m_{\tilde{G}}^3}{M_P^2}$$

chosen to fit neutrino osc. data

conclusions

a most ubiquitous particle in the Universe

neutrinos may explain WDM or CDM
through an emergent theory …



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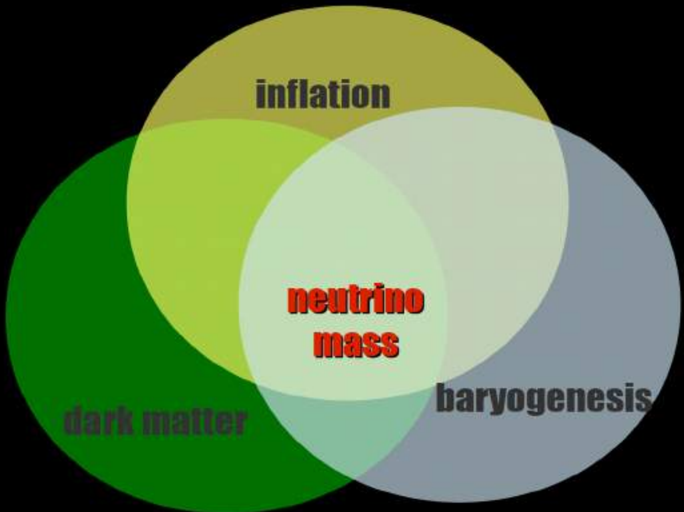

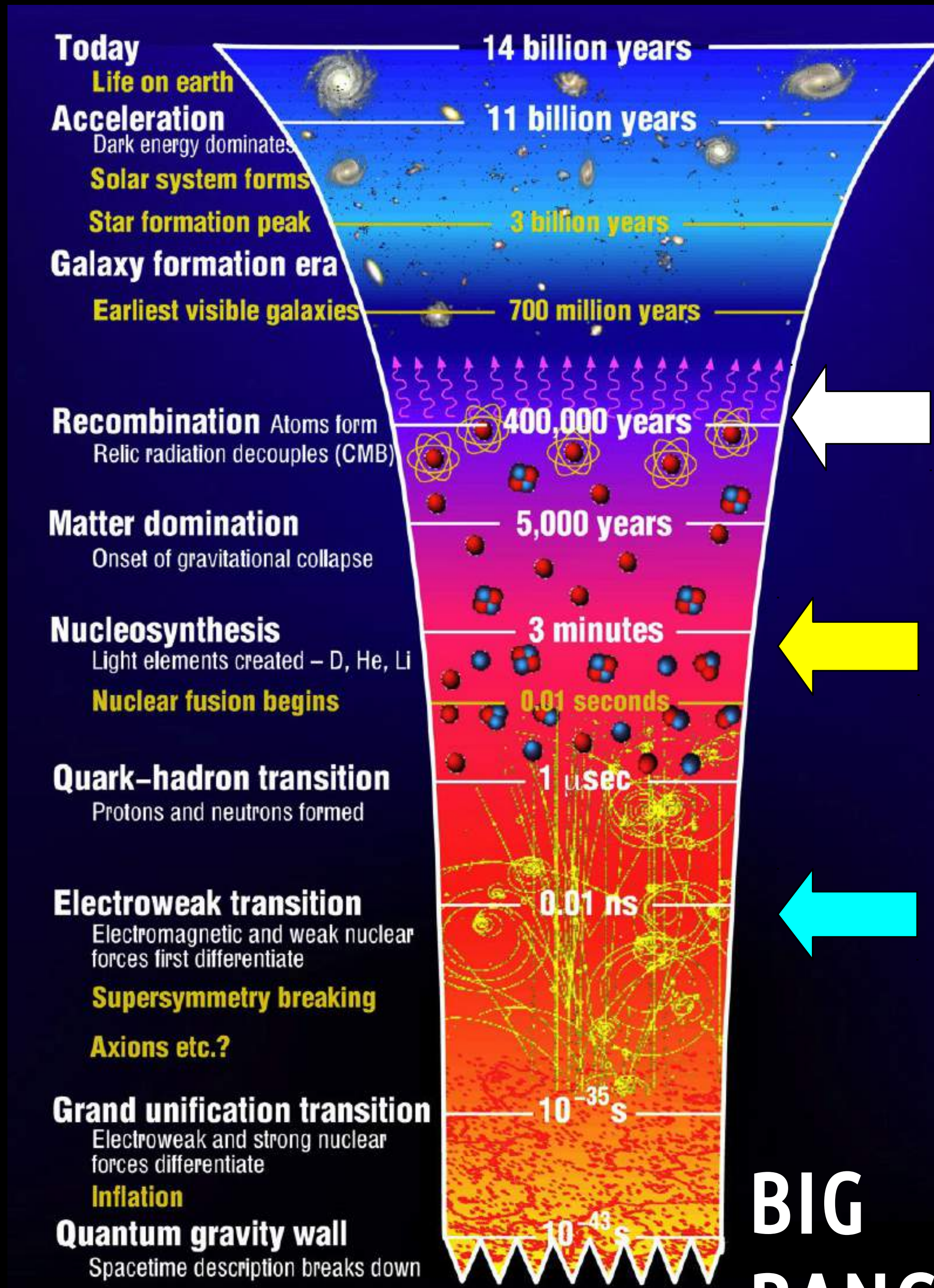

BIG
BANG

conclusions

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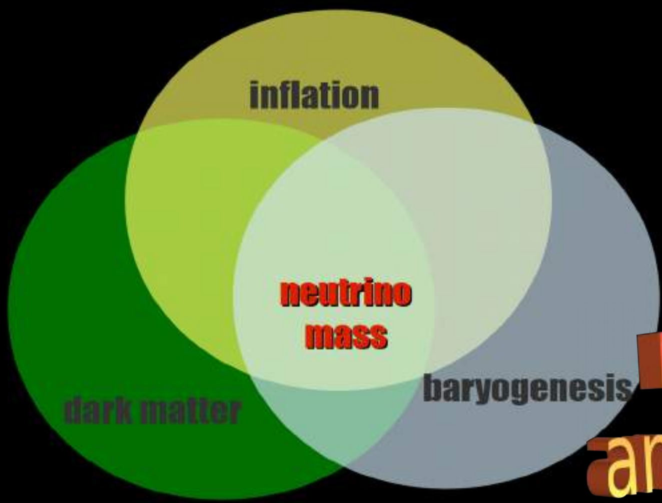
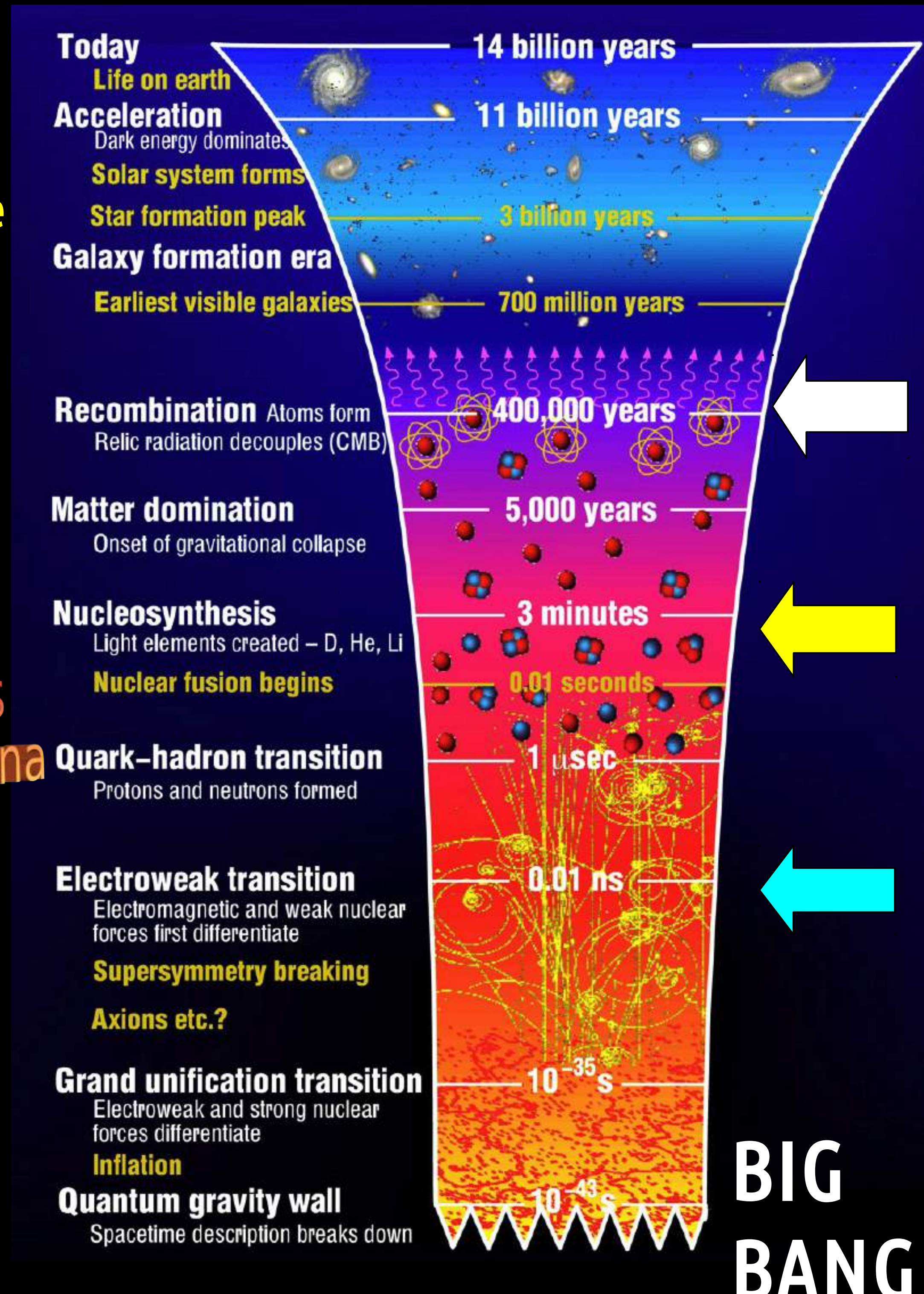


new features and phenomena

- SSB consistency, new higgses, new decay modes
- unification without GUT embedding
- new gauge boson & fermion messengers @ LHC
- non-unitarity => new CPV in neutrino oscillations
- LFV mainly at HE colliders
- LFV/CPV unsupressed by neutrino mass
- LNV either short or long-range

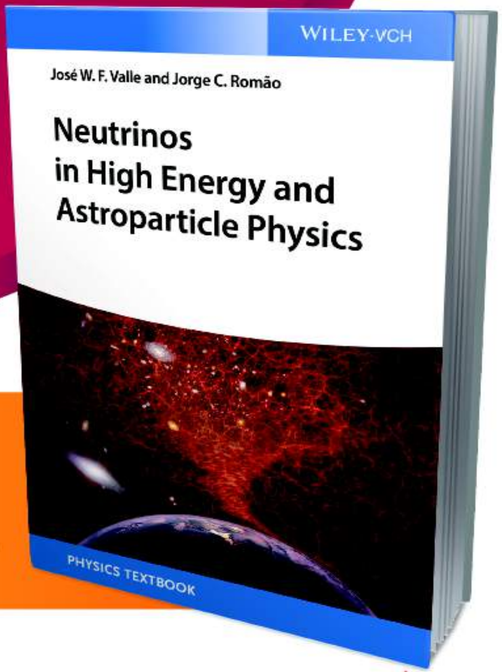


Thank you

Neutrinos in High Energy and Astroparticle Physics

Jose Wagner Furtado Valle, Jorge Romao

ISBN: 978-3-527-41197-9
448 pages
February 2015



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Back up

Type I & non-unitarity of lepton mixing

$$\begin{pmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} U$$

$$\alpha_{11}^2 \geq 0.989\,, \quad \alpha_{22}^2 \geq 0.999\,, \quad |\alpha_{21}|^2 \leq 6.6 \times 10^{-4}$$

Schechter & JV PRD22 (1980) 2227 & PDG

Rodejohann, JV Phys.Rev. D84 (2011) 073011

PLB199, 432 (1987)

PhysRevD.92.053009

non-unitary propagation hints associated
(relatively low–mass) type-I seesaw
messenger responsible for inducing neutrino mass

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PLB199, 432 (1987)

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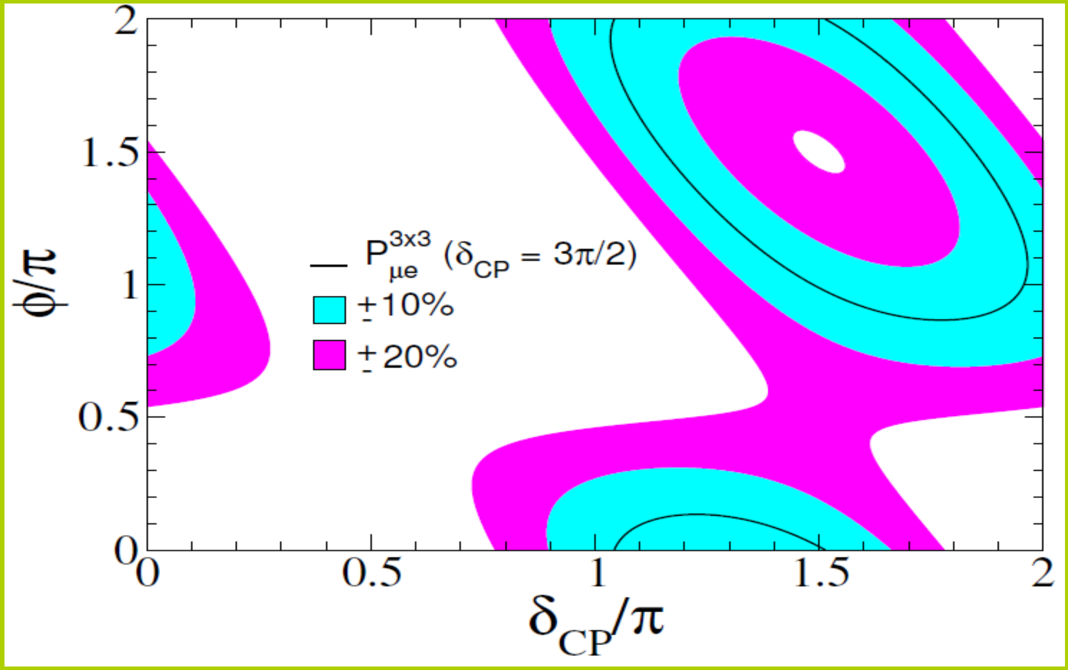
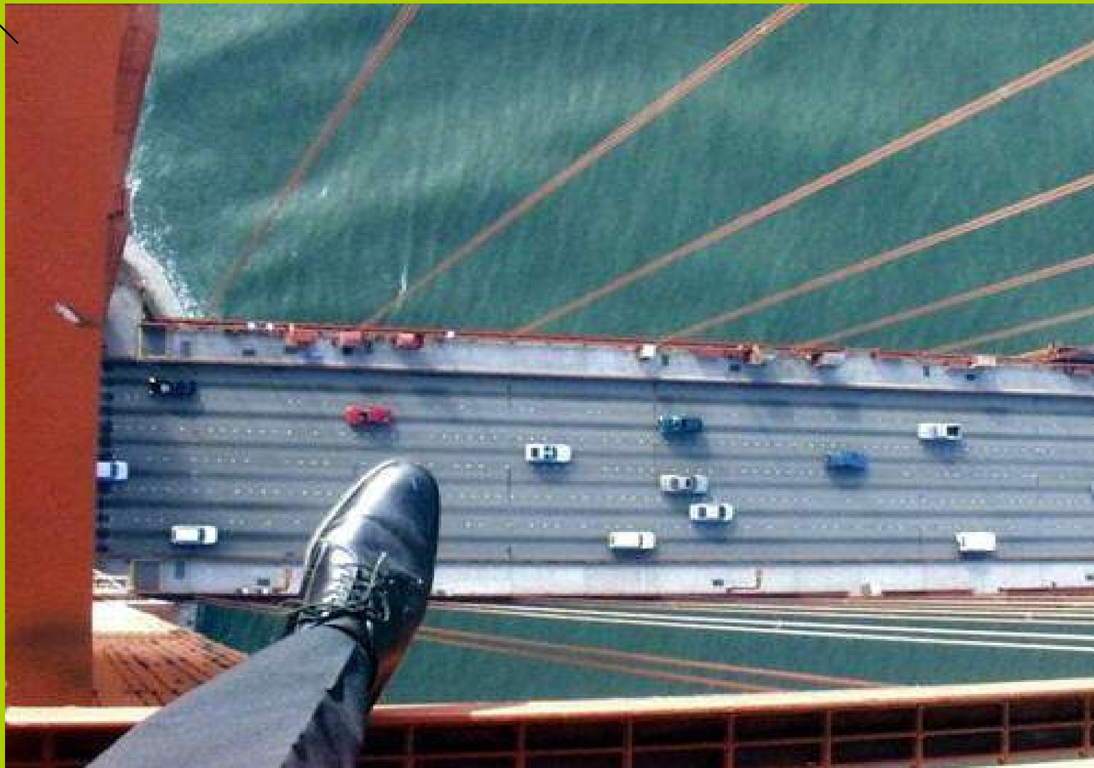
non-unitary propagation hints associated
(relatively low–mass) type-I seesaw
messenger responsible for inducing neutrino mass

$$P_{\mu e} = \alpha_{11}^2 \alpha_{22}^2 P_{\mu e}^{3\times 3} + \alpha_{11}^2 \alpha_{22} |\alpha_{21}| P_{\mu e}^{I} + \alpha_{11}^2 |\alpha_{21}|^2$$

PhysRevLett.117.061804

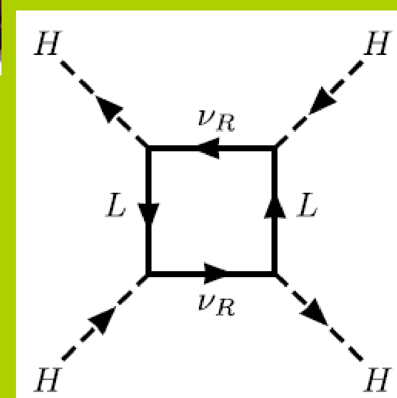
CP confusion

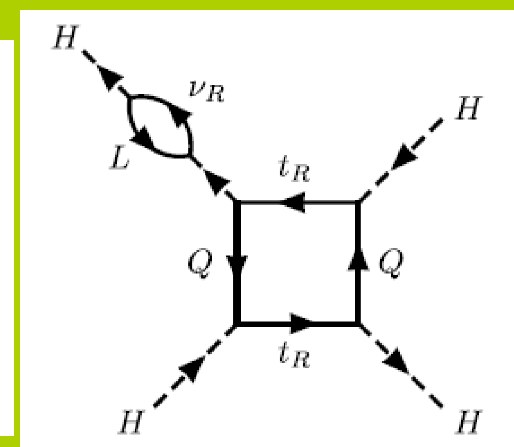


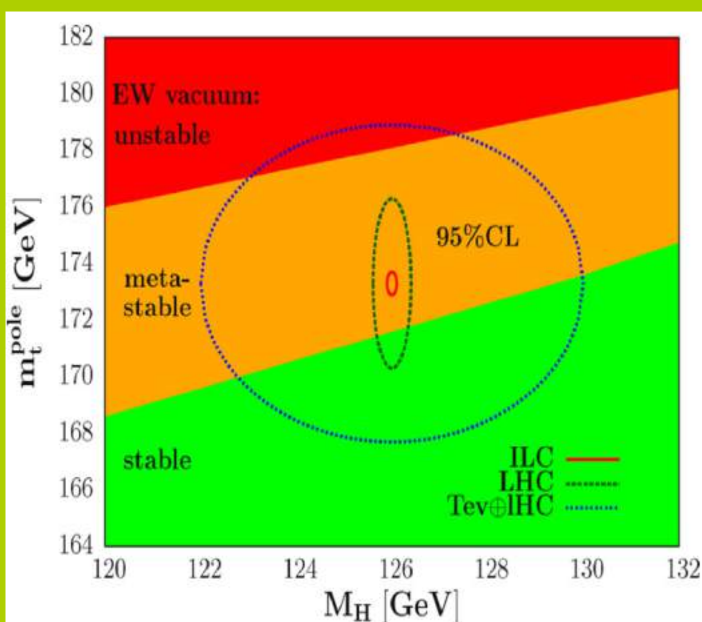


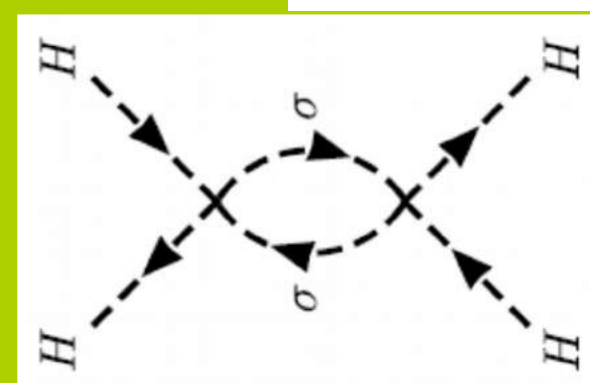
SM vacuum and neutrinos

Physics Letters B 756 (2016) 345–349



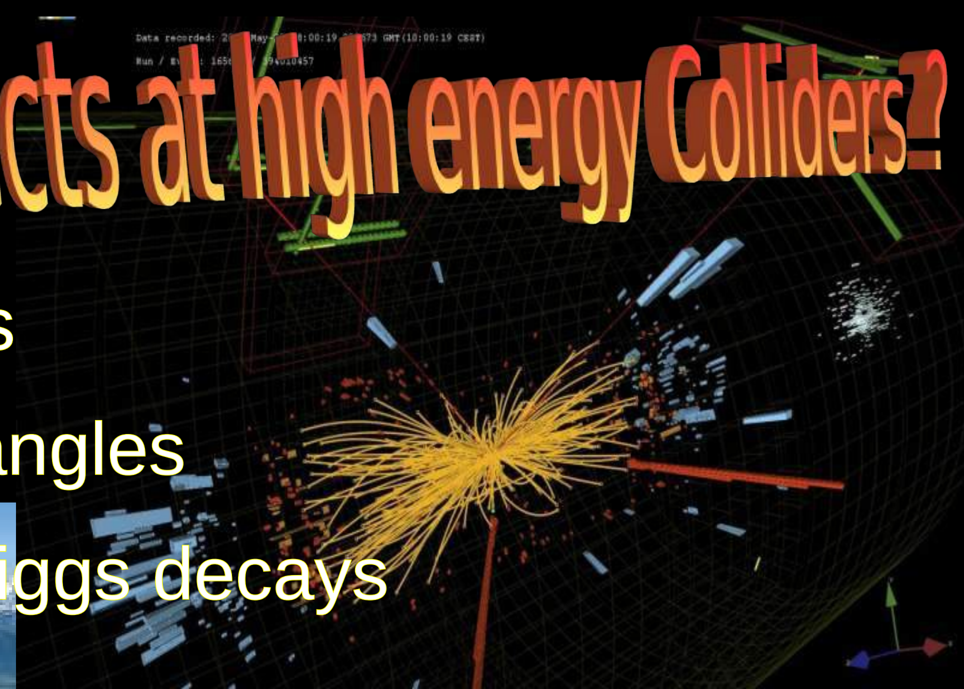






Neutrino effects at high energy Colliders?

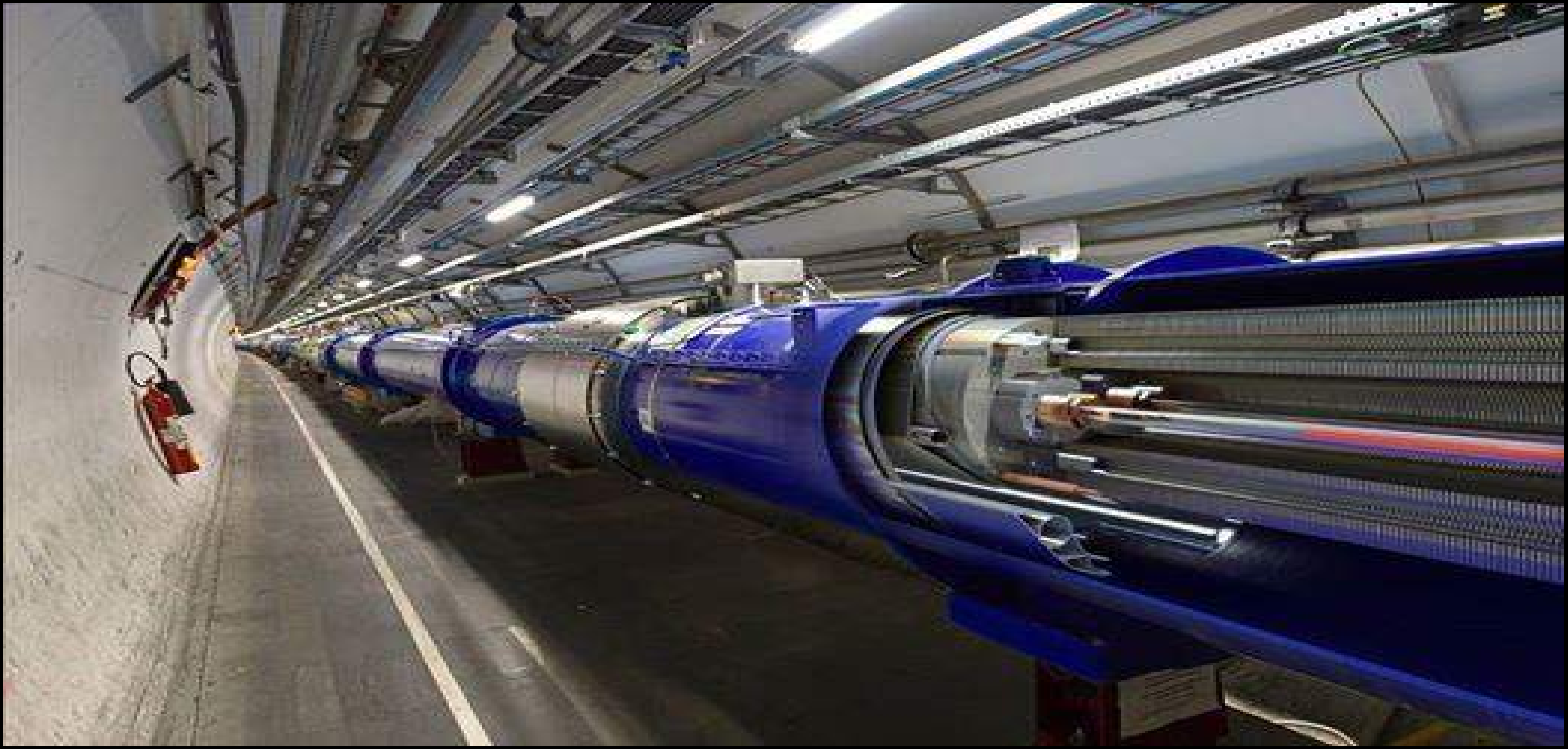
- Discover neutrino messengers
- Re-measure neutrino mixing angles
- Probe e-weak breaking e.g. Higgs decays



Invisible Higgs decays

Joshipura & J.V.

Nucl.Phys. B397 (1993) 105-122



Higgs searches 2016

Bonilla Fonseca & J.V.

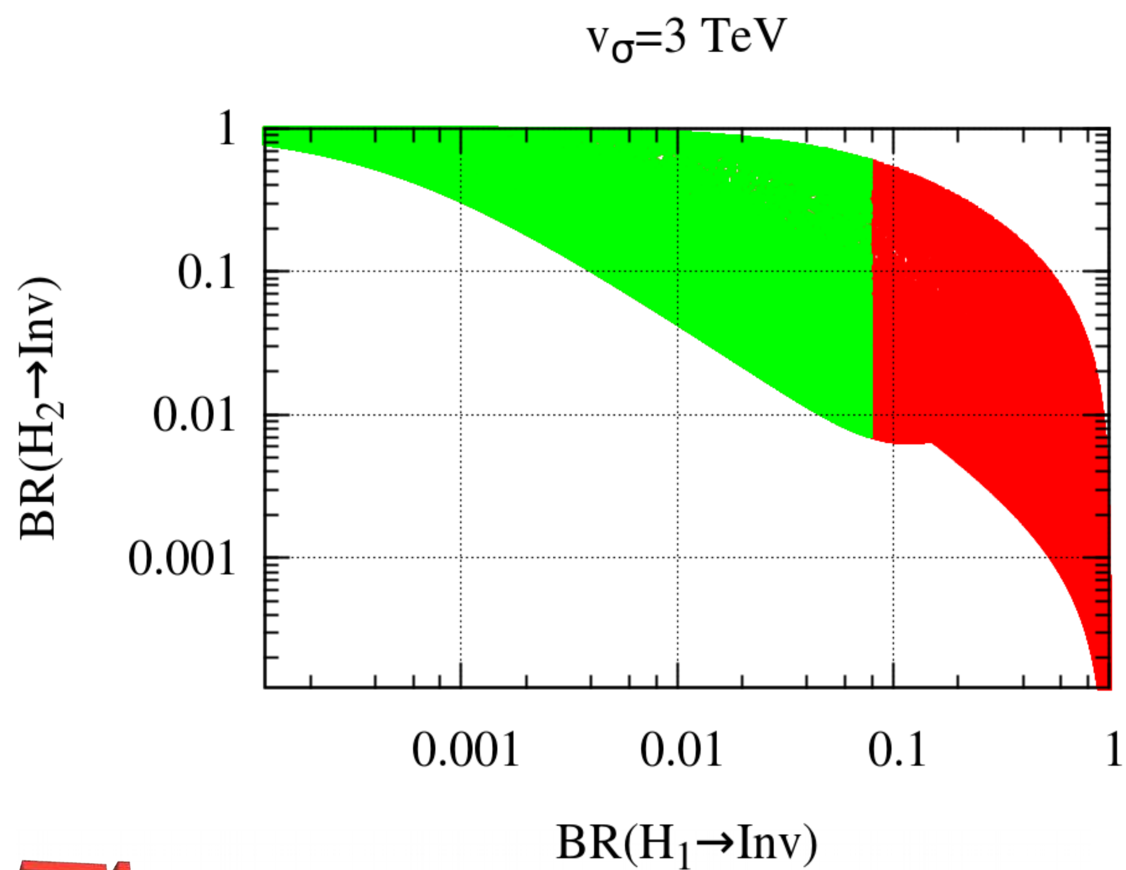
Phys.Lett. B756 (2016) 345-349 ...

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,‡]

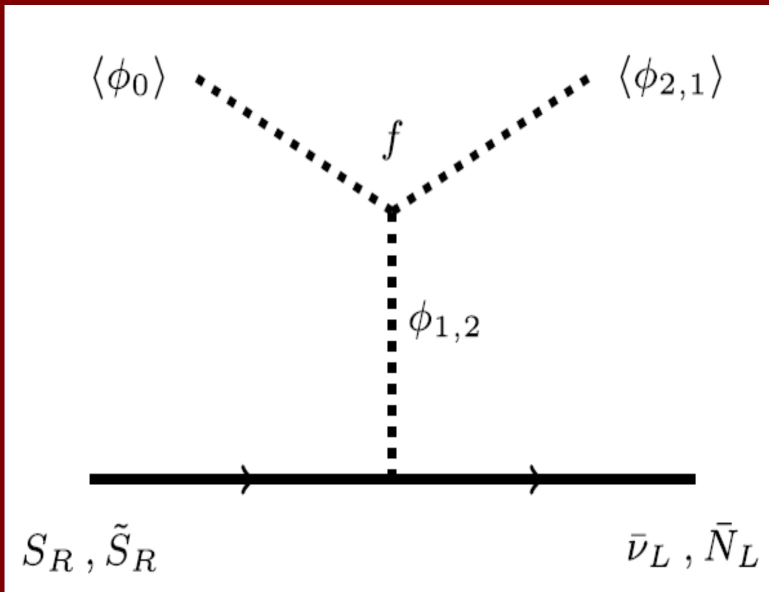
channel	ATLAS	CMS
$\mu_{\gamma\gamma}$	1.17 ± 0.27	$1.14^{+0.26}_{-0.23}$
μ_{WW}	$1.00^{+0.32}_{-0.29}$	0.83 ± 0.21
μ_{ZZ}	$1.44^{+0.40}_{-0.35}$	1.00 ± 0.29
$\mu_{\tau^+\tau^-}$	$1.4^{+0.5}_{-0.4}$	0.91 ± 0.27
$\mu_{b\bar{b}}$	$0.2^{+0.7}_{-0.6}$	0.93 ± 0.49

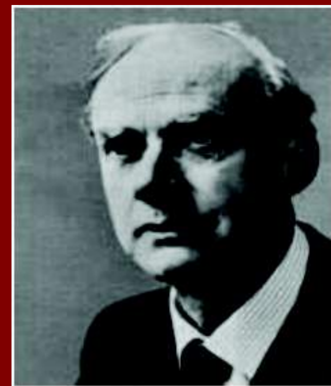


$$H_i \to JJ \quad \text{and} \quad H_2 \to 2H_1 \to 4J \left(\text{when } m_{H_1} < \frac{m_{H_2}}{2}\right).$$

Theories of neutrino as attractive higgs search benchmarks

Dirac seesaw





Physics Letters B 755 (2016) 363–366

No conventional GUT embedding :

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

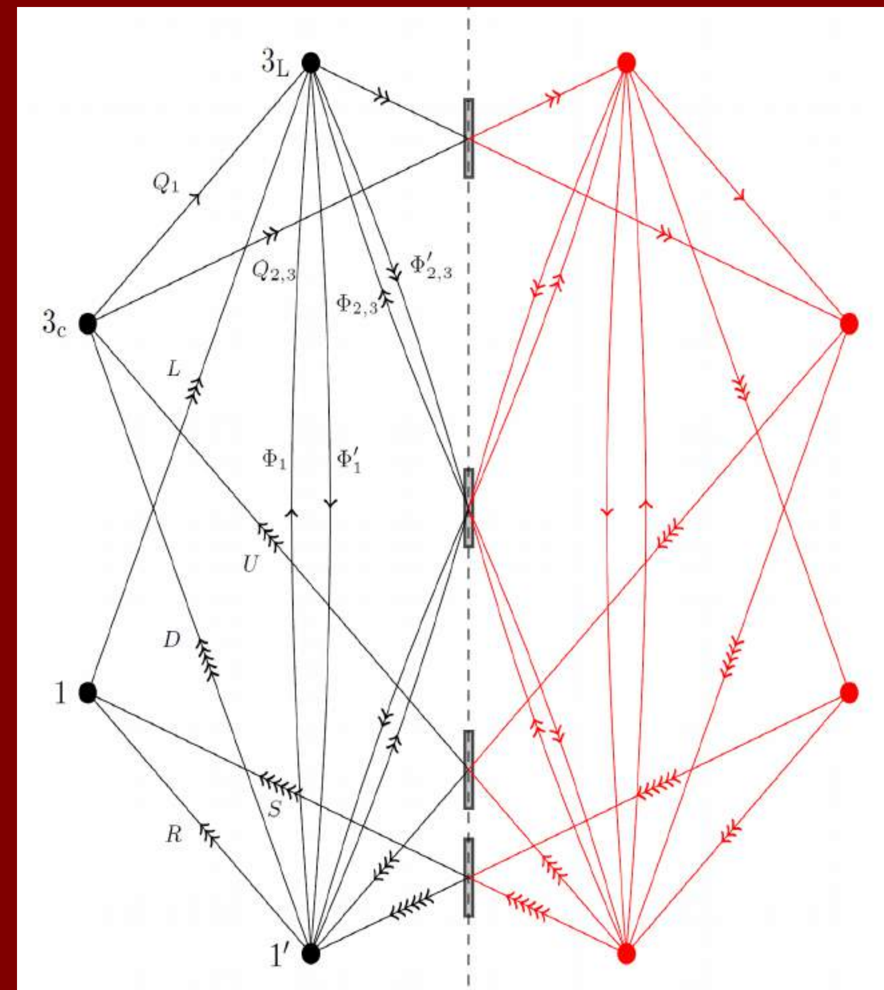
string completion Quiver setup

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

Addazi et al arXiv:1604.02117

331 from strings

10.1016/j.physletb.2016.06.015

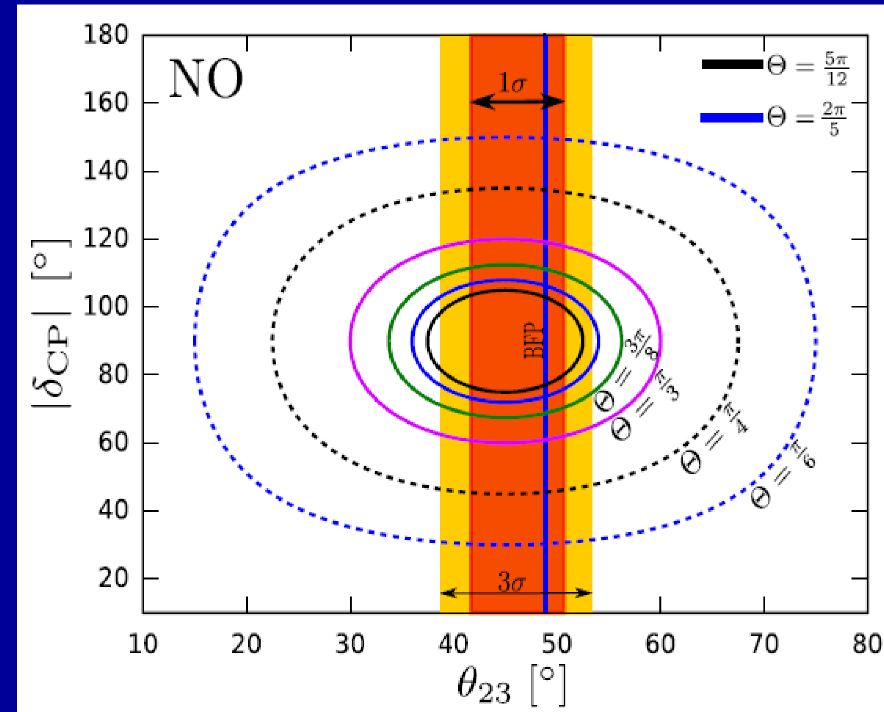


neutron-antineutron oscillations from exotic instantons

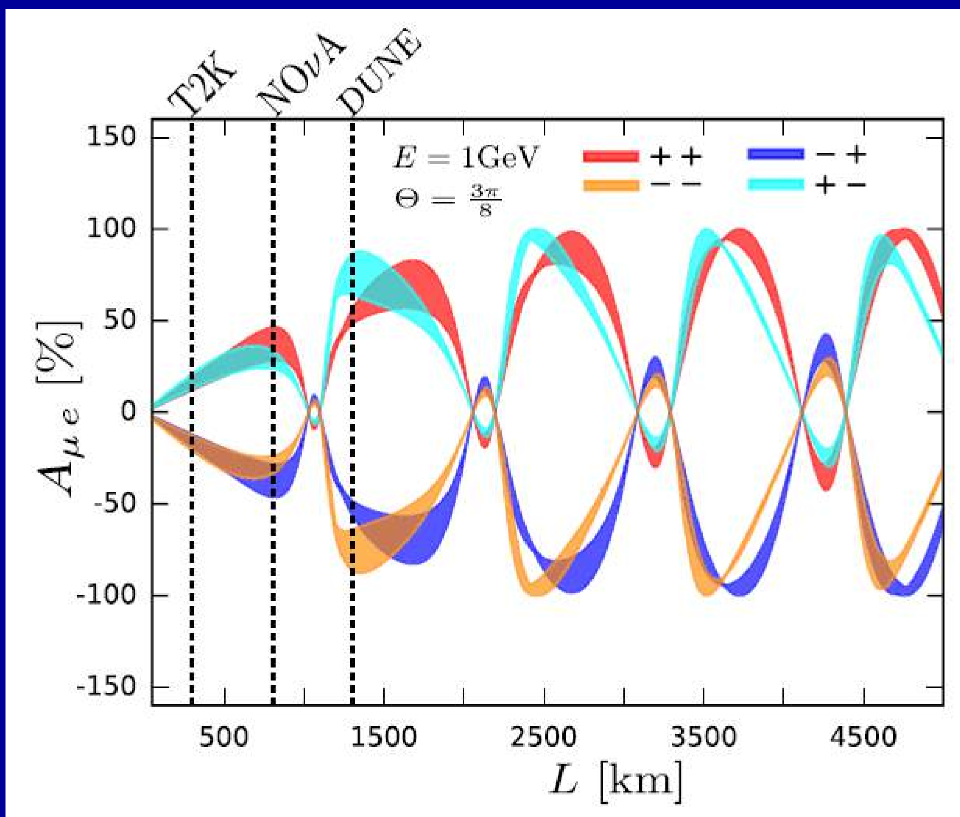
Model-independent flavor approach

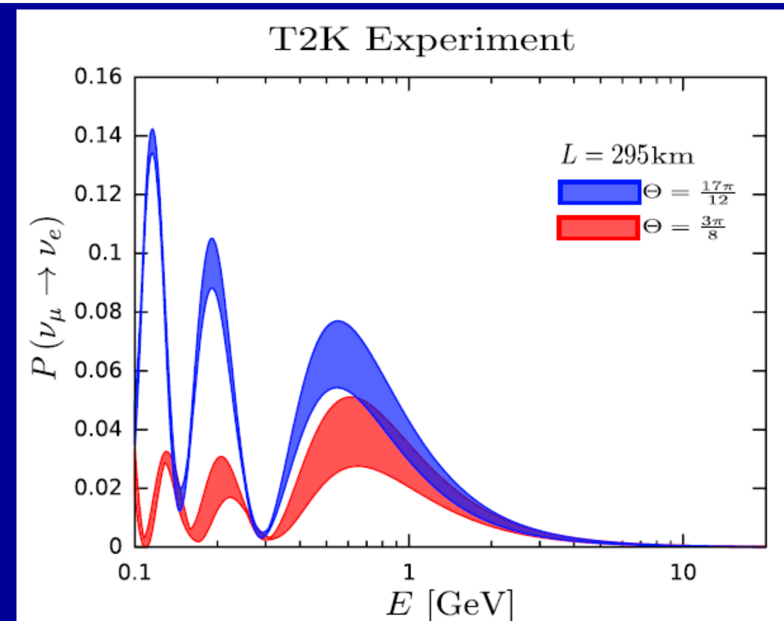
$$\mathbf{X}^T \mathbf{m}_\nu \mathbf{X} = \mathbf{m}_\nu^*$$

Predicting neutrino mixing from residual CP symmetries

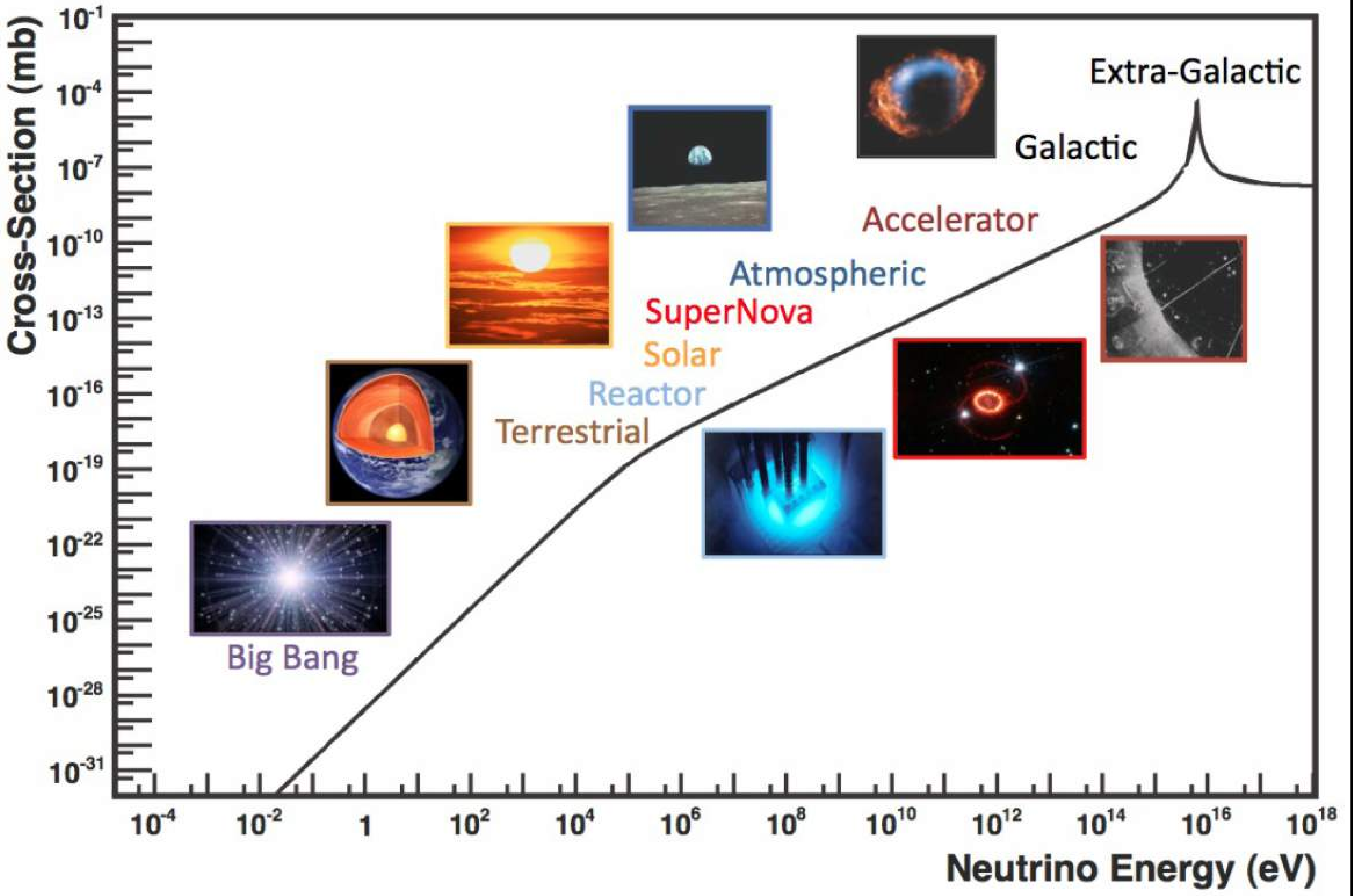


P. Chen et al. / Physics Letters B 753 (2016) 644–652

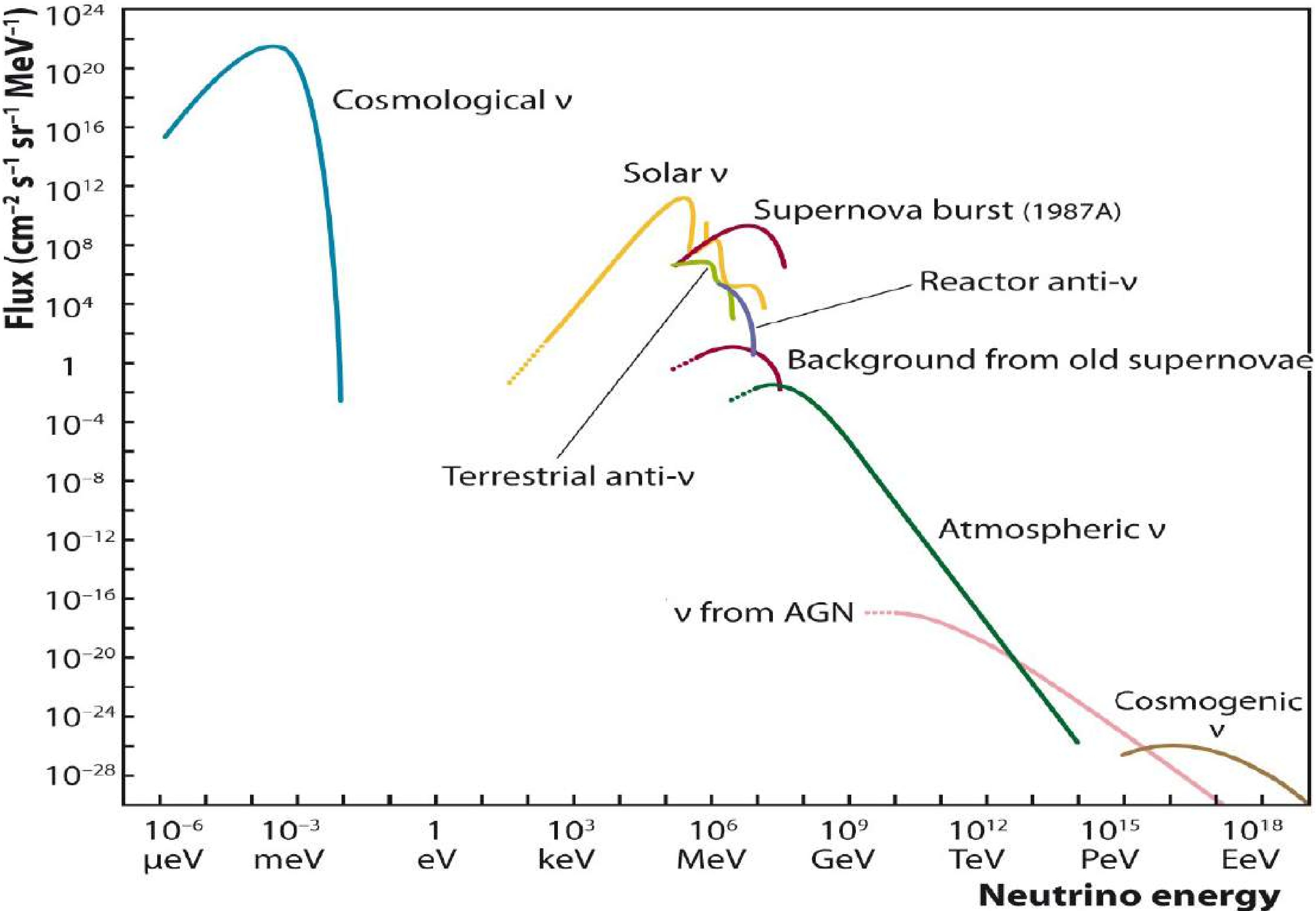




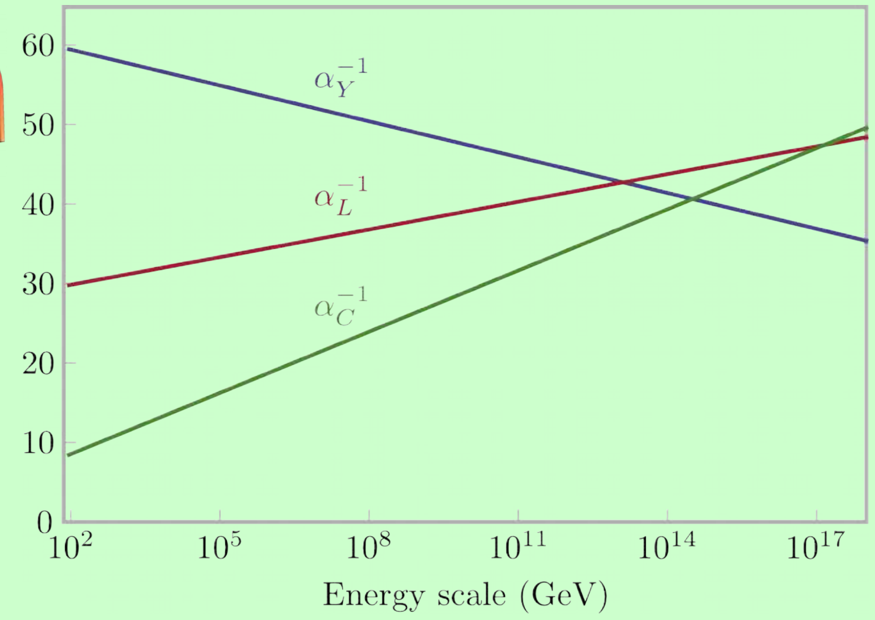
Neutrino sources & cross sections



neutrino sources & fluxes



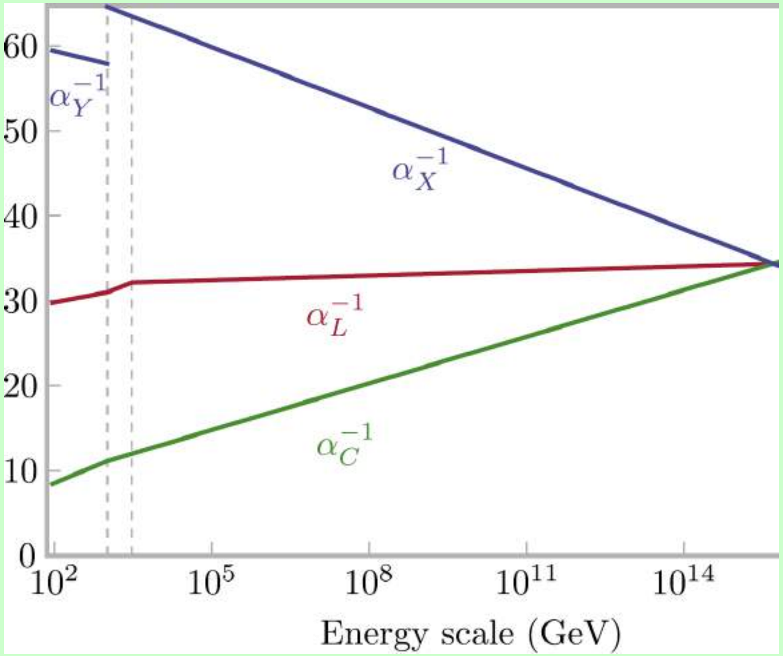
neutrinos may help unification



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