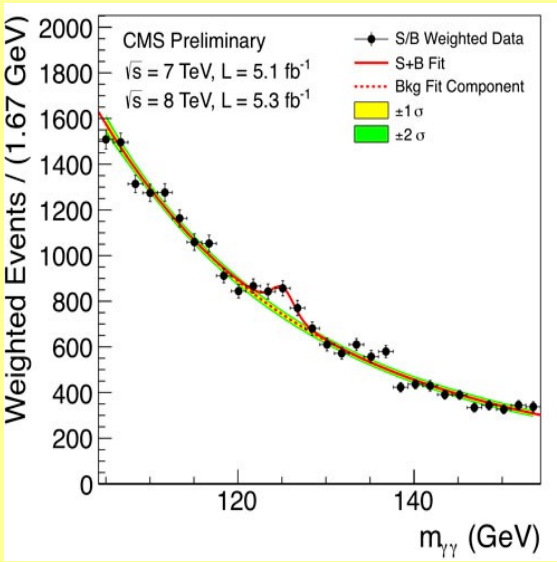
Neutrinos as Pathfinders

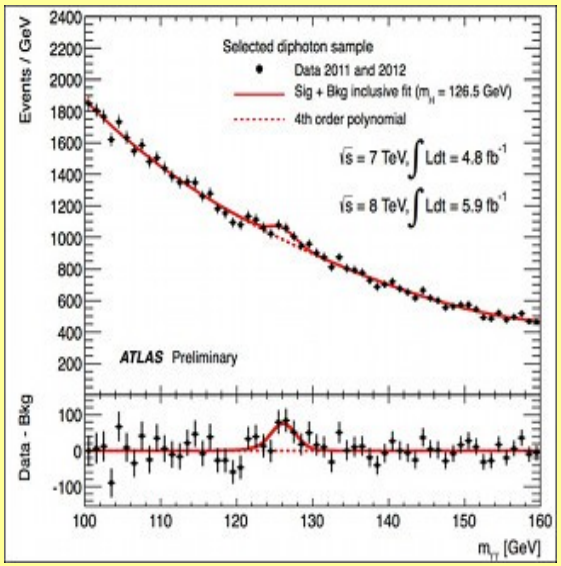
José W F Valle

IFIC AHEP on facebook

November 2015

HISTORIC DISCOVERY 1





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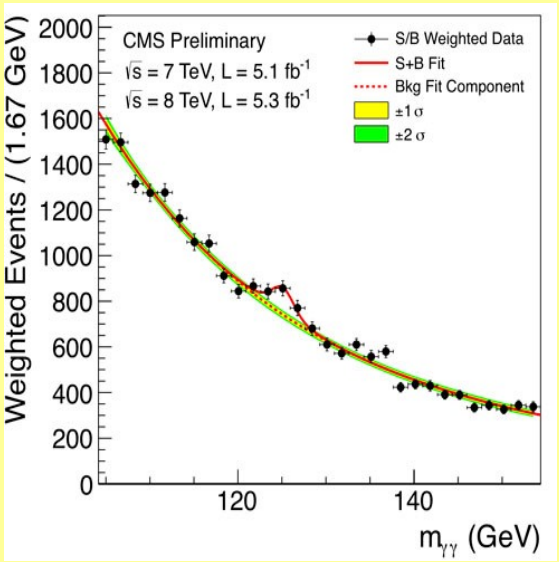
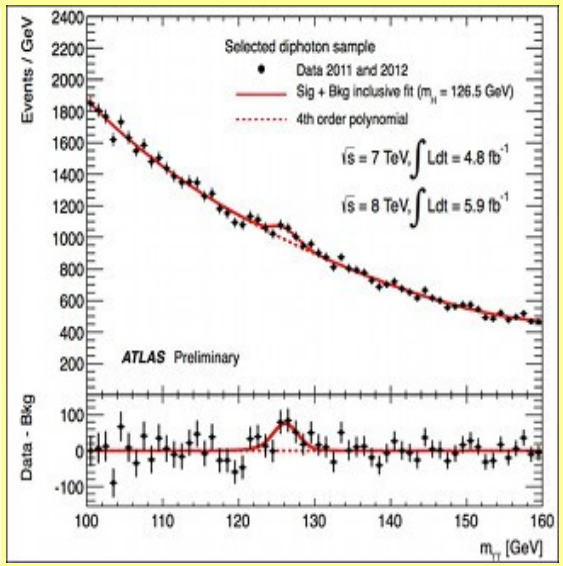
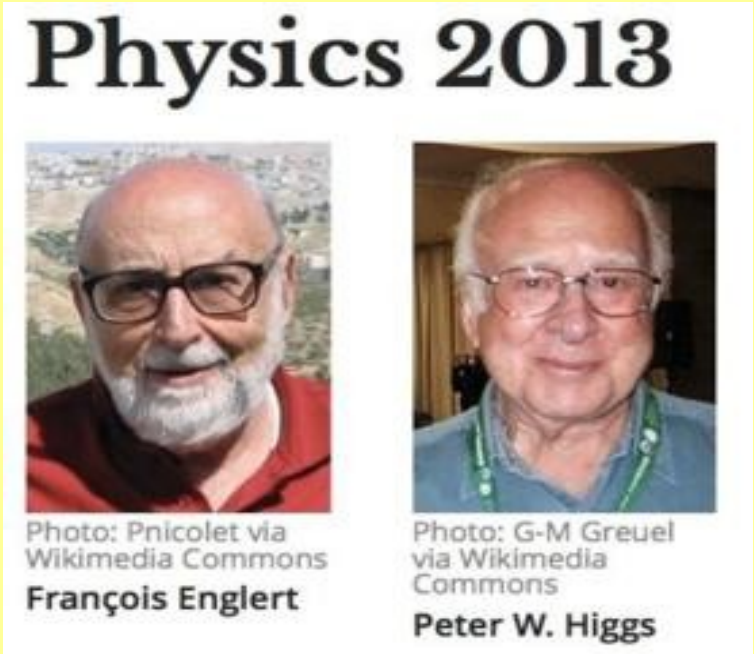


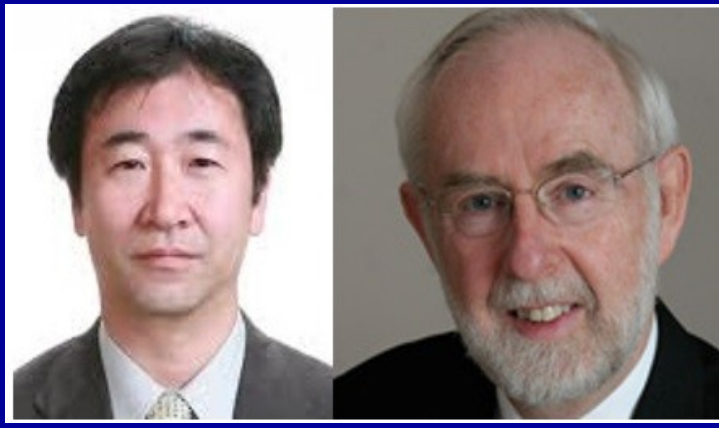


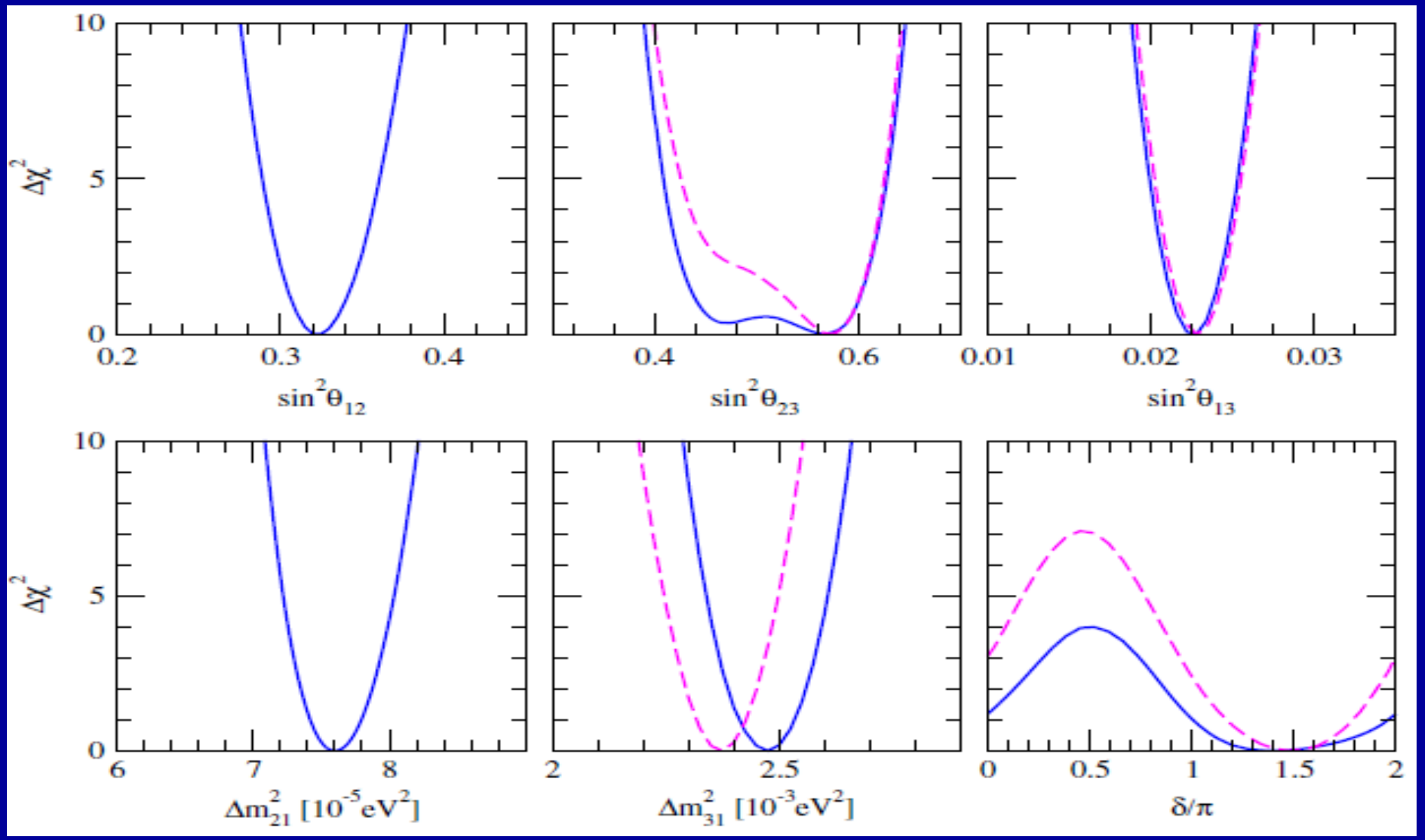


Last stone ...

HISTORIC DISCOVERY 2

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





THE PRECISION ERA ...

Schechter & JV PRD22 (1980) 2227 & PDG

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

PHYSICAL REVIEW D 90, 093006 (2014)

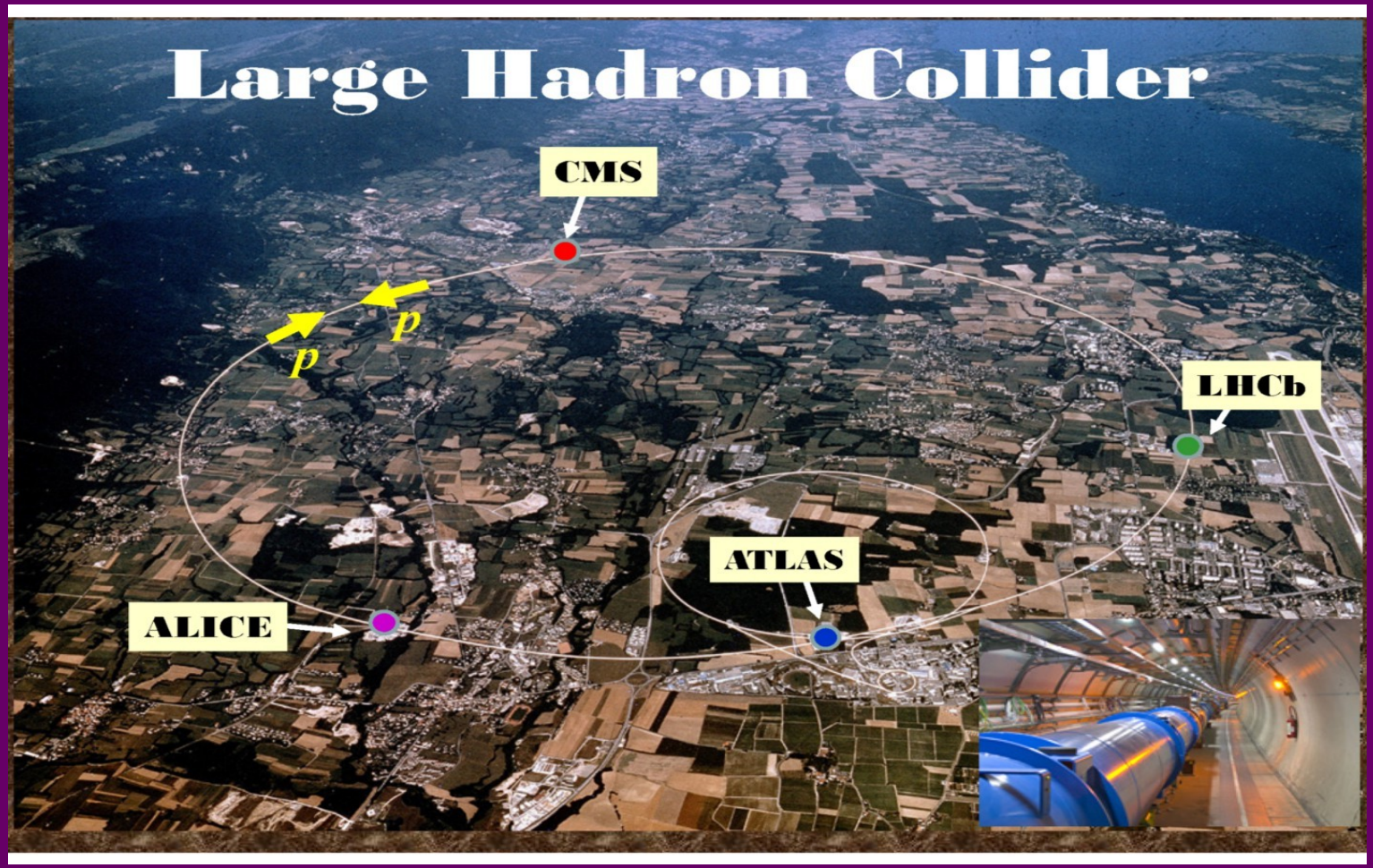
TABLE II. Neutrino oscillation parameters summary from the global analysis updated after Neutrino 2014 conference.

Parameter	Best fit $\pm$ 1σ	2σ range	3σ range
$\Delta m^2_{21}\,[10^{-5}\ \mathrm{eV}^2]$	$7.60^{+0.19}_{-0.18}$	7.26–7.99	7.11–8.18
$\lvert\Delta m^2_{31}\rvert\,[10^{-3}\ \mathrm{eV}^2]$ (NH)	$2.48^{+0.05}_{-0.07}$	2.35–2.59	2.30–2.65
$\lvert\Delta m^2_{31}\rvert\,[10^{-3}\ \mathrm{eV}^2]$ (IH)	$2.38^{+0.05}_{-0.06}$	2.26–2.48	2.20–2.54
$\sin^2\theta_{12}/10^{-1}$	3.23 ± 0.16	2.92–3.57	2.78–3.75
$\theta_{12}/^\circ$	34.6 ± 1.0	32.7–36.7	31.8–37.8
$\sin^2\theta_{23}/10^{-1}$ (NH)	$5.67^{+0.32\,a}_{-1.24}$	4.14–6.23	3.93–6.43
$\theta_{23}/^\circ$	$48.9^{+1.8}_{-7.2}$	40.0–52.1	38.8–53.3
$\sin^2\theta_{23}/10^{-1}$ (IH)	$5.73^{+0.25}_{-0.39}$	4.35–6.21	4.03–6.40
$\theta_{23}/^\circ$	$49.2^{+1.5}_{-2.3}$	41.3–52.0	39.4–53.1
$\sin^2\theta_{13}/10^{-2}$ (NH)	2.26 ± 0.12	2.02–2.50	1.90–2.62
$\theta_{13}/^\circ$	$8.6^{+0.3}_{-0.2}$	8.2–9.1	7.9–9.3
$\sin^2\theta_{13}/10^{-2}$ (IH)	2.29 ± 0.12	2.05–2.52	1.93–2.65
$\theta_{13}/^\circ$	8.7 ± 0.2	8.2–9.1	8.0–9.4
δ/π (NH)	$1.41^{+0.55}_{-0.40}$	0.0–0.2.0	0.0–2.0
$\delta/^\circ$	254^{+99}_{-72}	0–360	0–360
δ/π (IH)	1.48 ± 0.31	0.00–0.09 & 0.86–2.0	0.0–2.0
$\delta/^\circ$	266 ± 56	0–16 & 155–360	0–360

[a]There is a local minimum in the first octant, at $\sin^2\theta_{23} = 0.473$ with $\Delta\chi^2 = 0.36$ with respect to the global minimum

BEYOND UNITARITY : Miranda et al, http://dx.doi.org/10.1103/PhysRevD.92.053009

HISTORIC DISCOVERY 3 ???



Barring confirmation or other surprises ...

consistency of vacuum
flavour
coupling unification
gravity

neutrino
masses

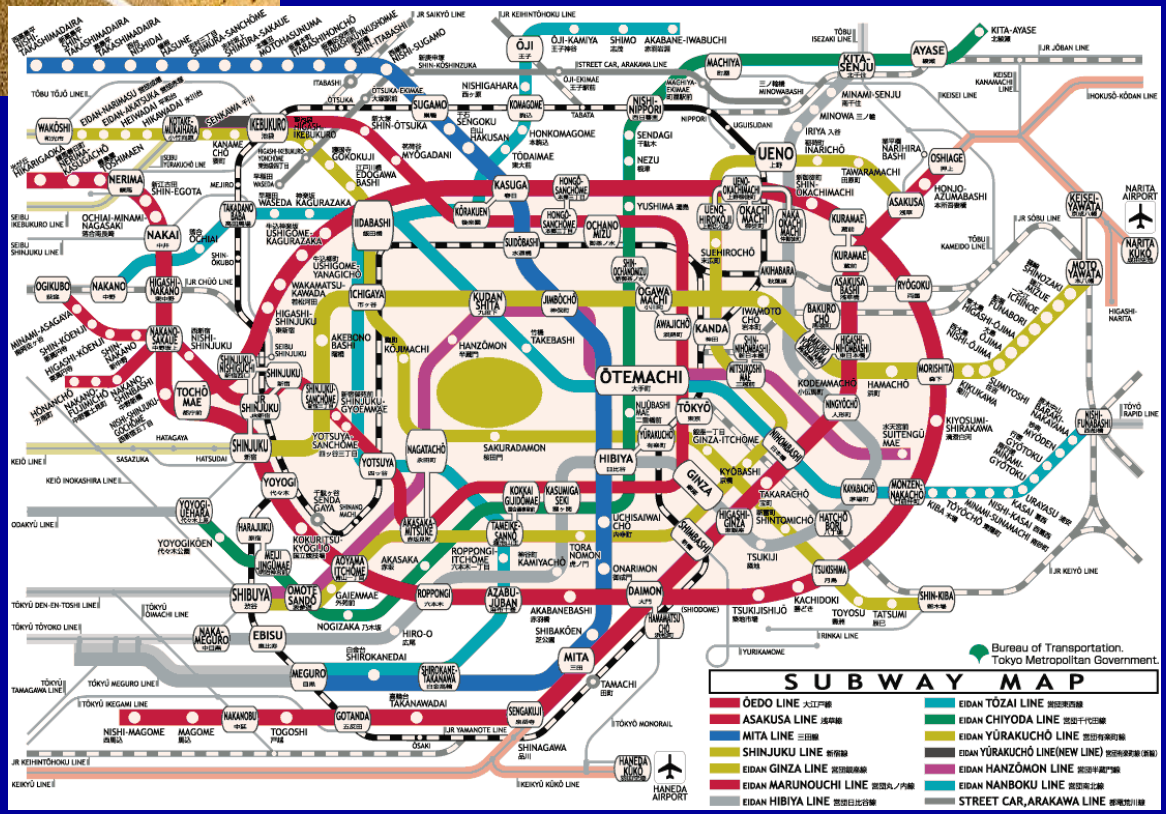
dark matter
baryon asymmetry
Inflation

If so ...

It's a looooong

It's a loooong

And winding Road...



JWF Valle

SM vacuum …

Physics Letters B 716 (2012) 214–219

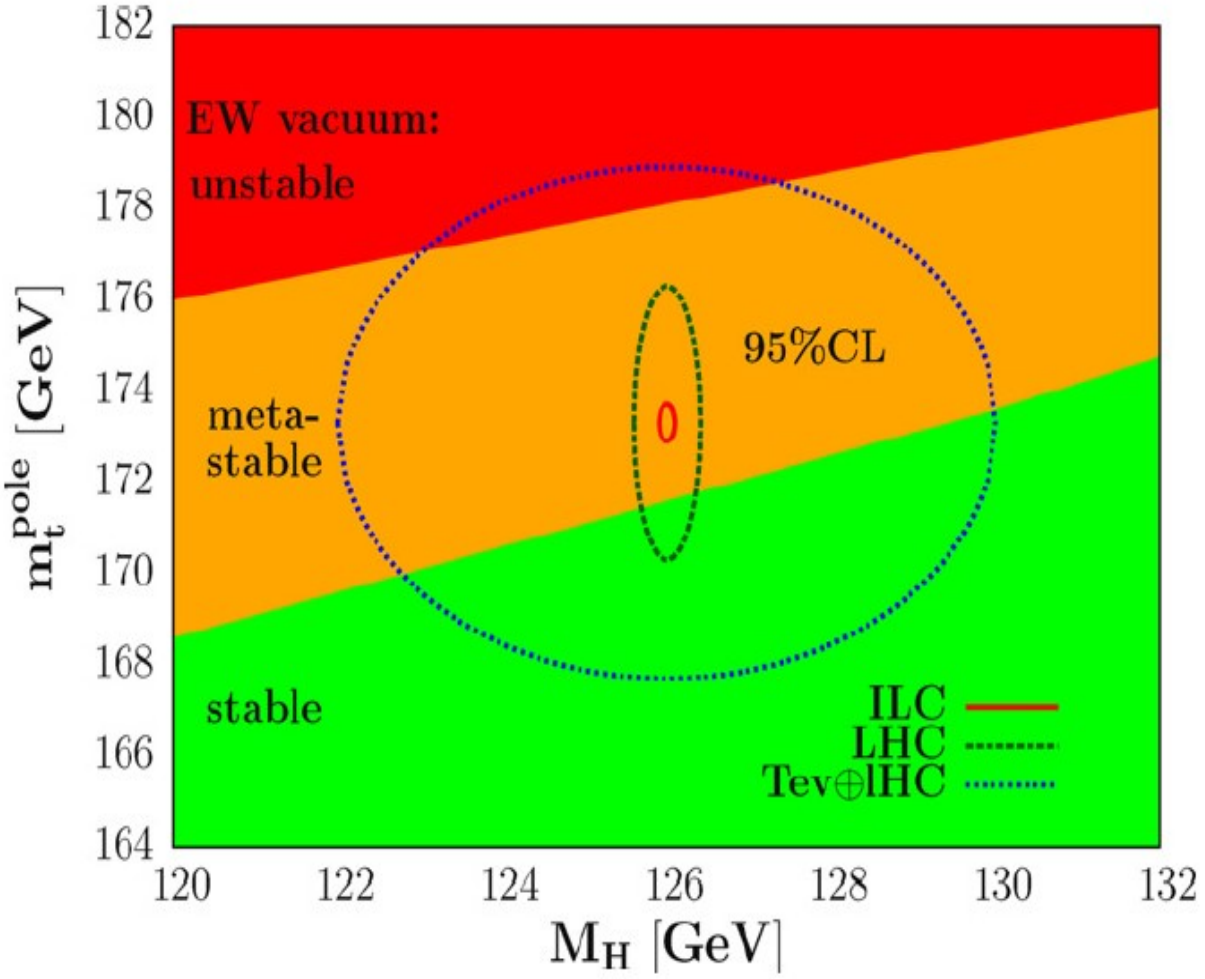


Fig. 1. The 2σ ellipses in the $[M_H, m_t^{pole}]$ plane that one obtains from the current top quark and Higgs mass measurements at the Tevatron and LHC and which can be expected in future measurements at the LHC and at the ILC, when confronted with the areas in which the SM vacuum is absolutely stable, metastable and unstable up to the Planck scale.

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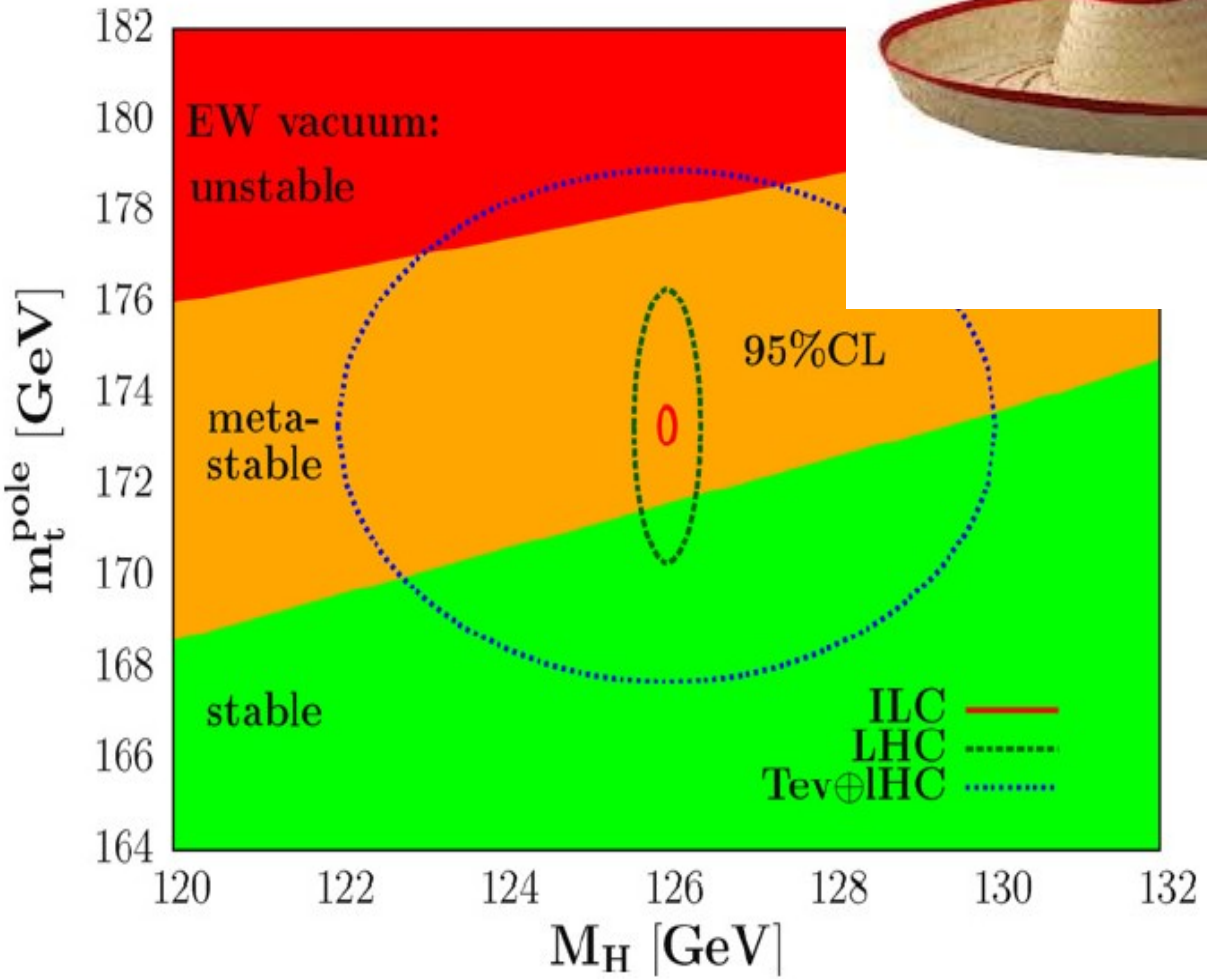

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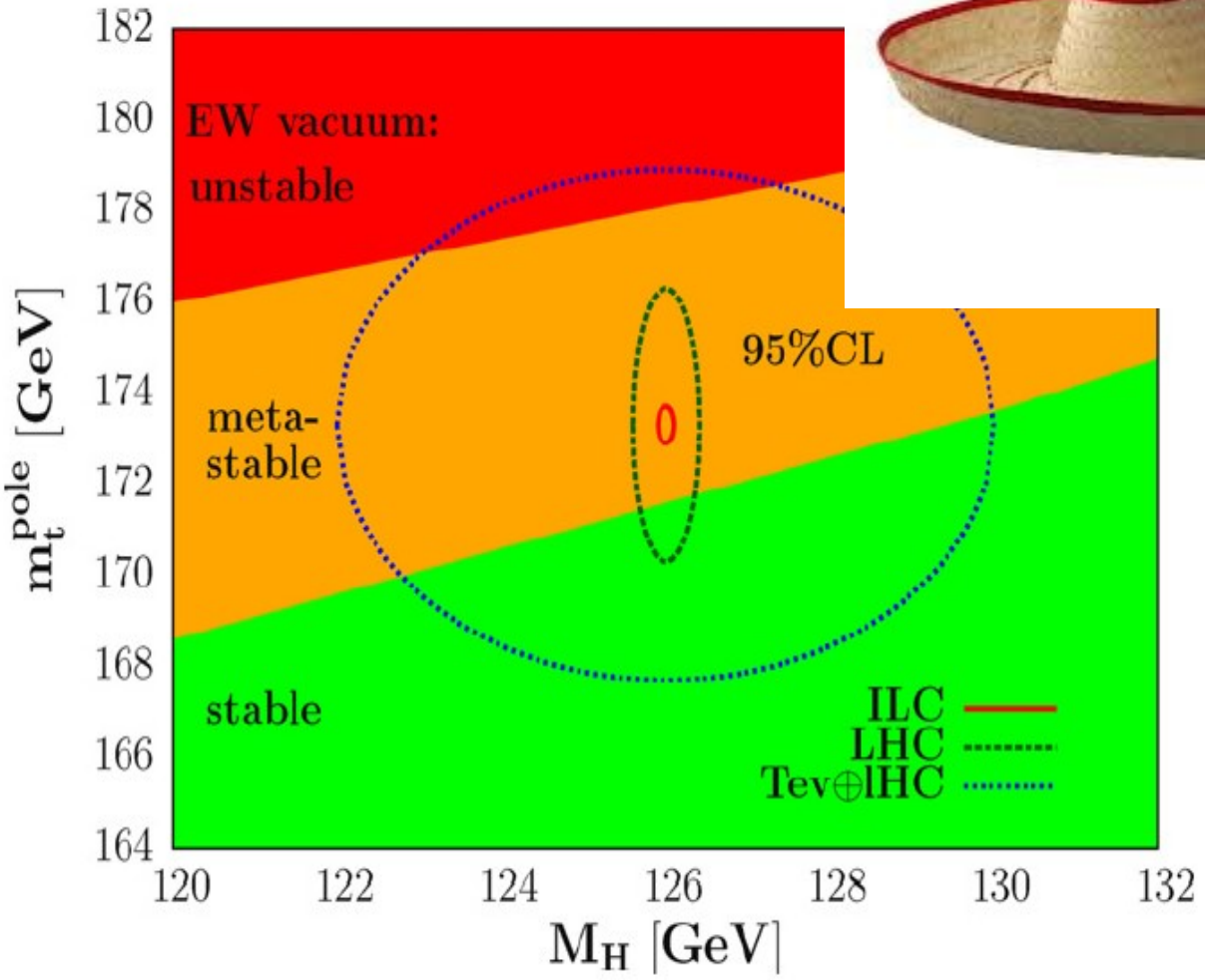

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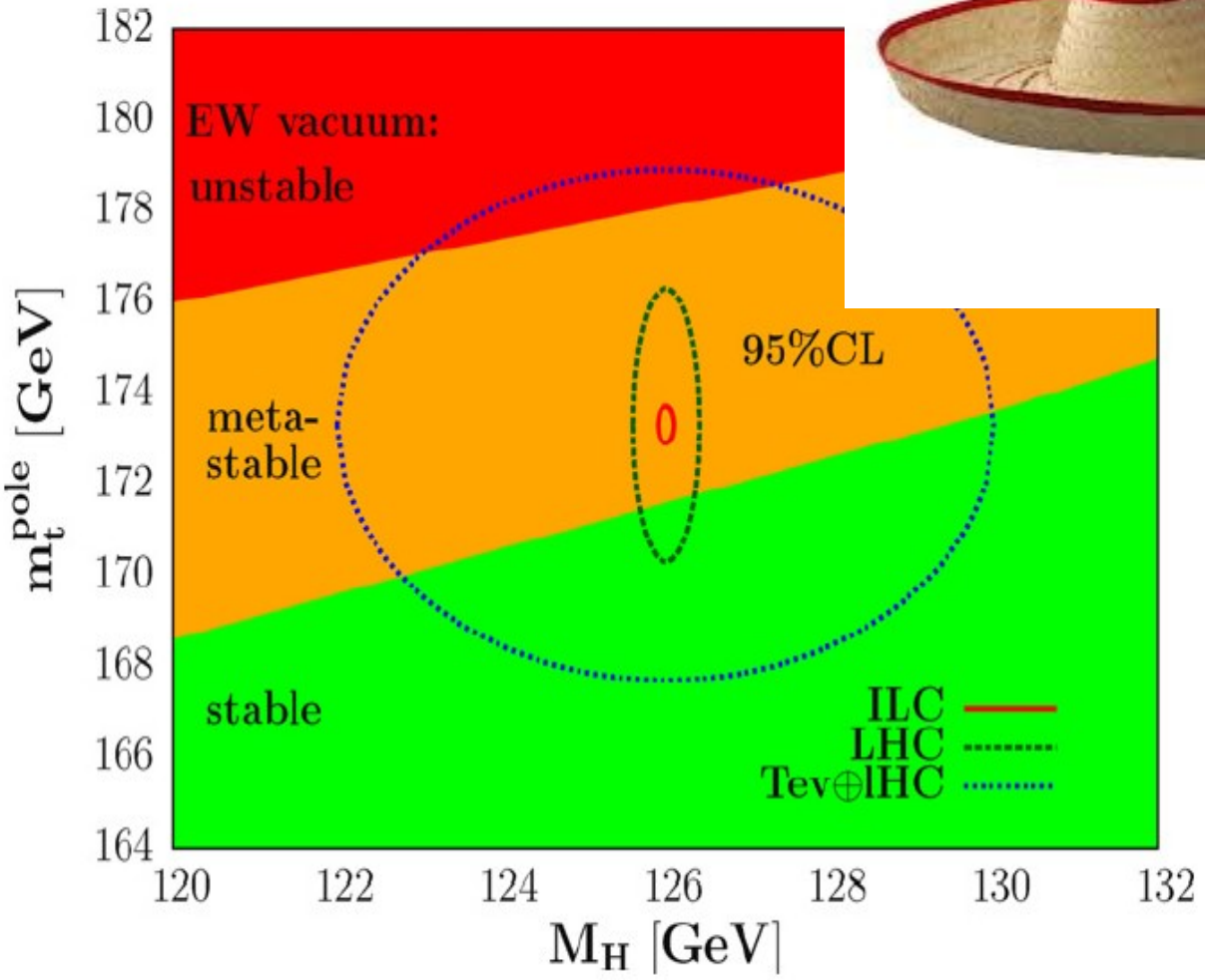

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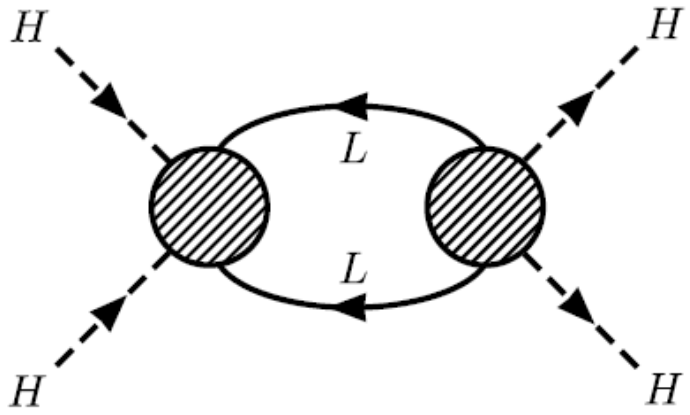
Neutrinos & Stability?

arXiv:1506.04031



PHYSICAL REVIEW D 92, 075028 (2015)

Consistency of the triplet seesaw model revisited

Cesar Bonilla,* Renato M. Fonseca,† and J. W. F. Valle‡
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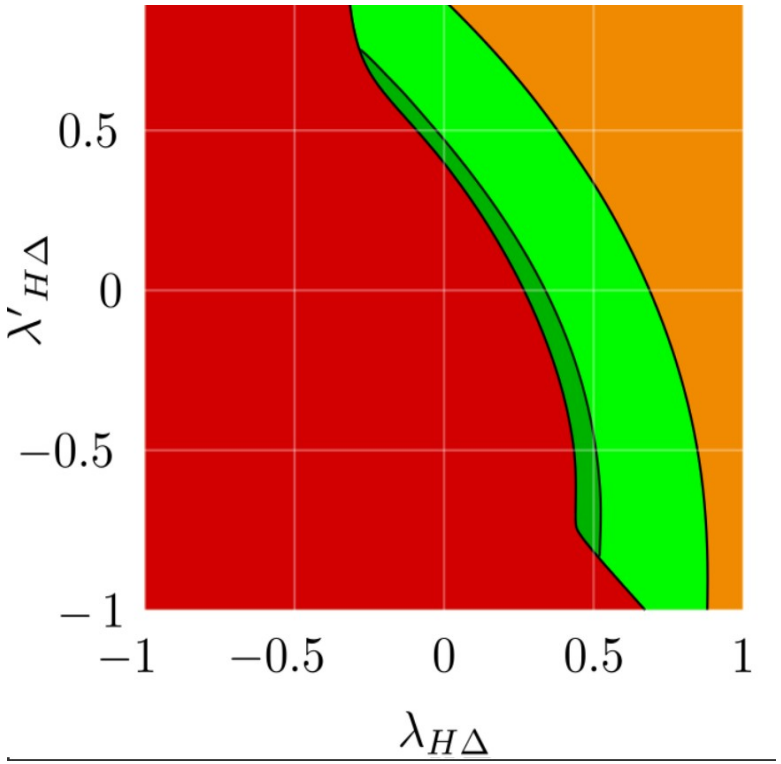
(Received 17 August 2015; published 21 October 2015)



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In addition to SM gauge invariance must break lepton number to give Masses to neutrinos ..

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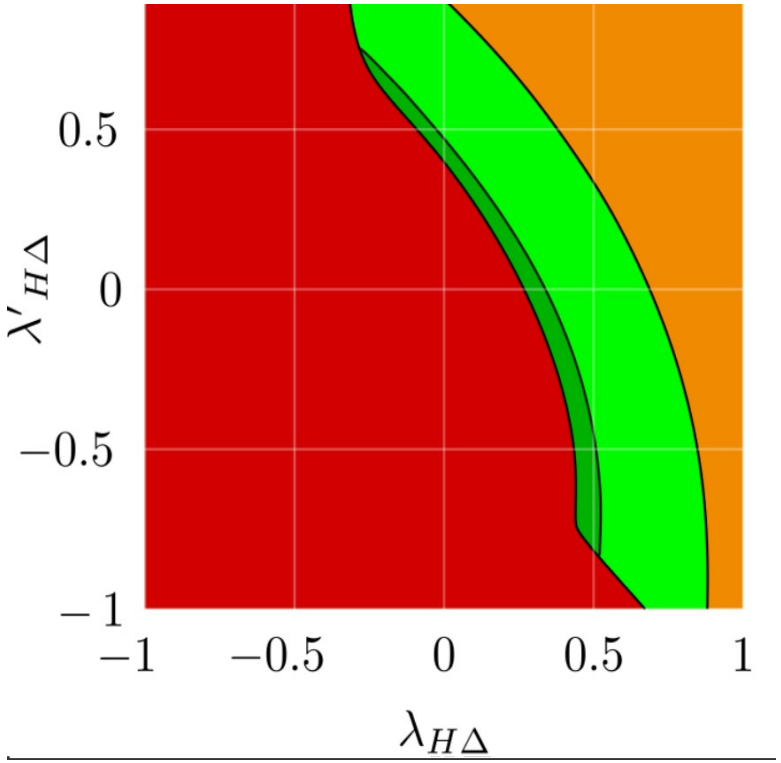

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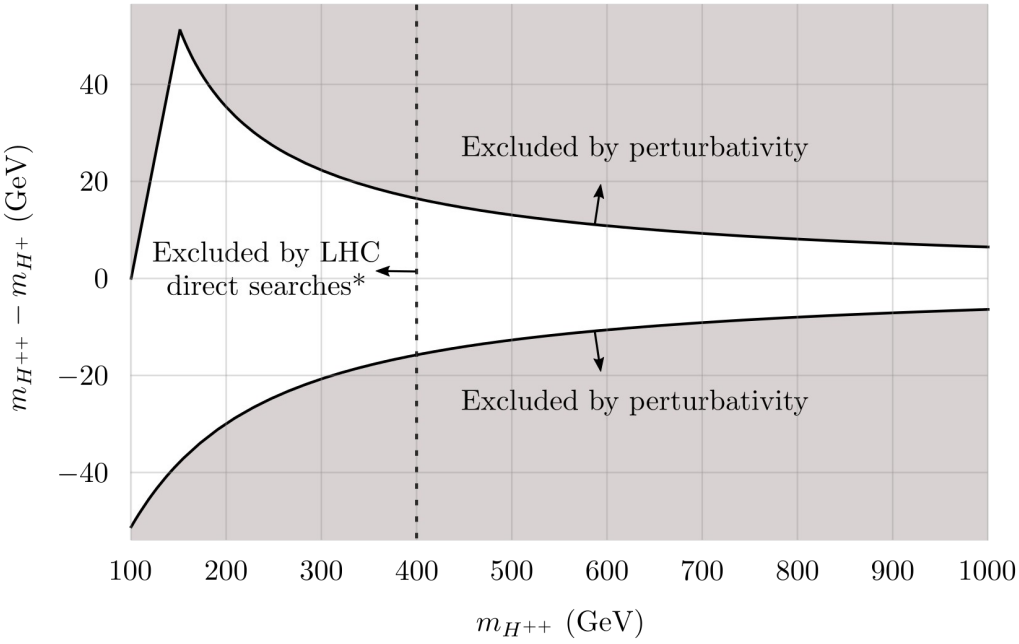

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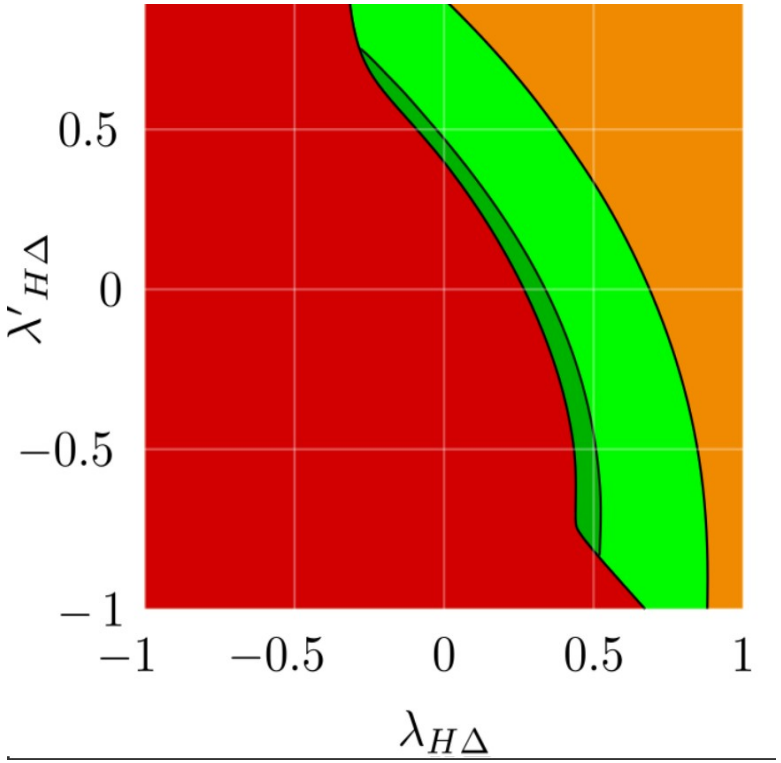

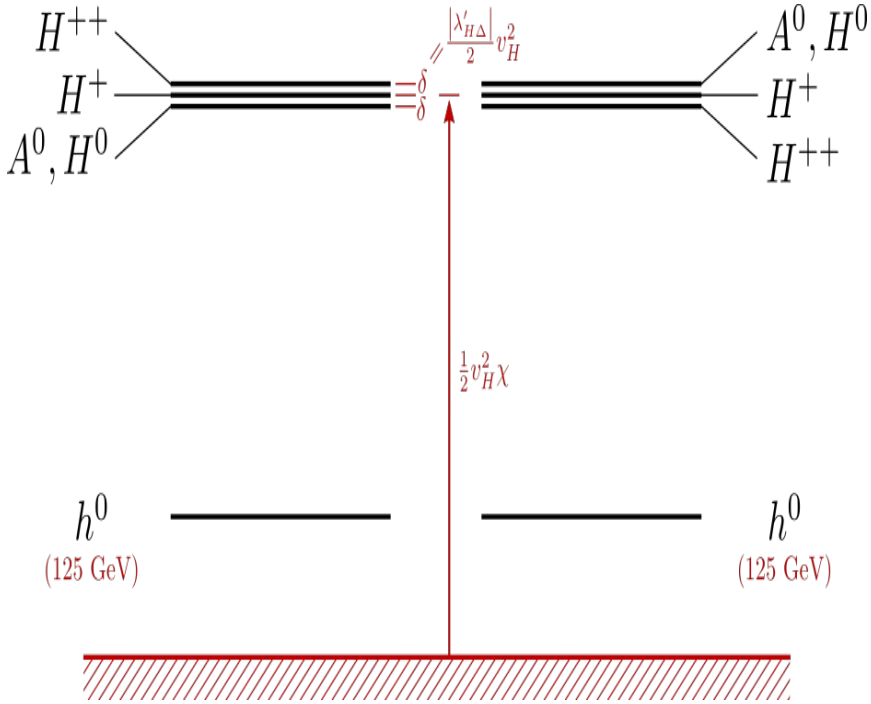

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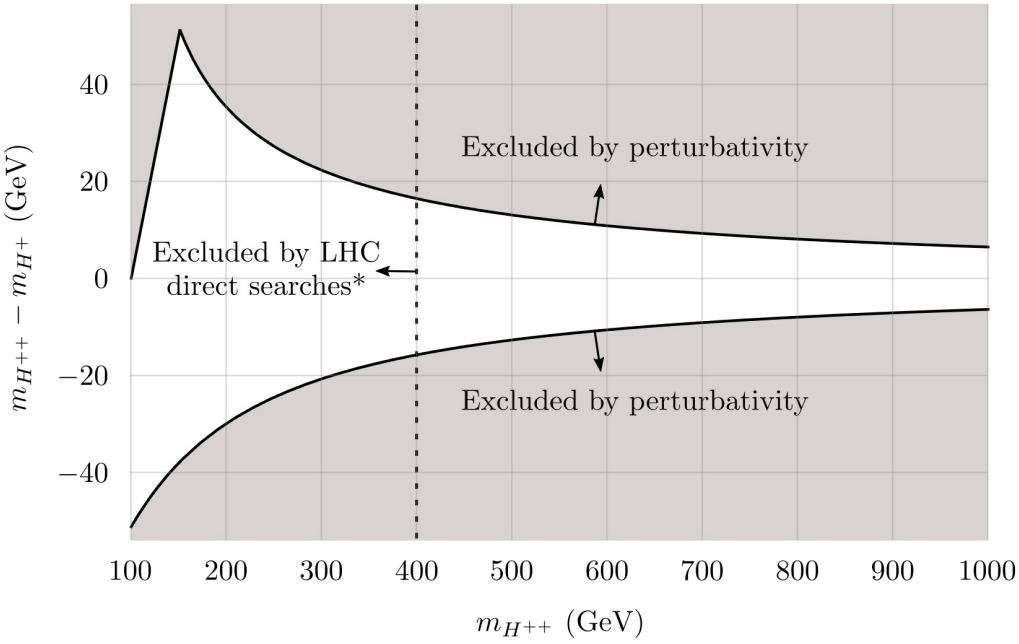

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Vacuum stability with spontaneous violation of lepton number

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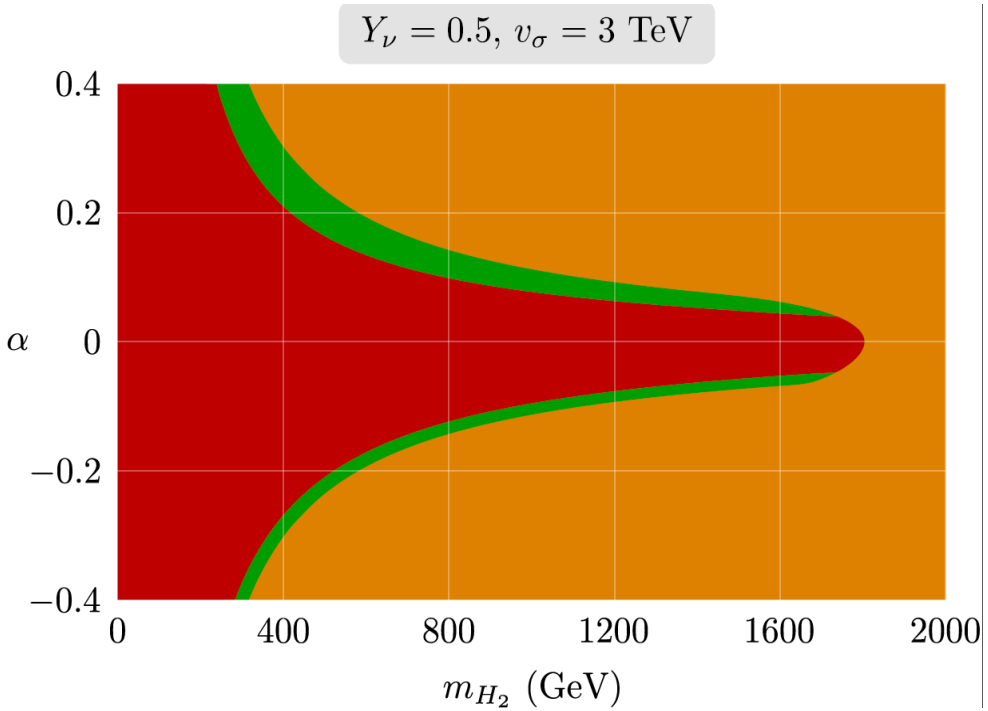

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Neutrinos & Invisible Higgs

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,‡]

$$\Gamma(H_i \to JJ) = \frac{1}{32\pi} \frac{g^2_{H_i JJ}}{m_{H_i}}$$

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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

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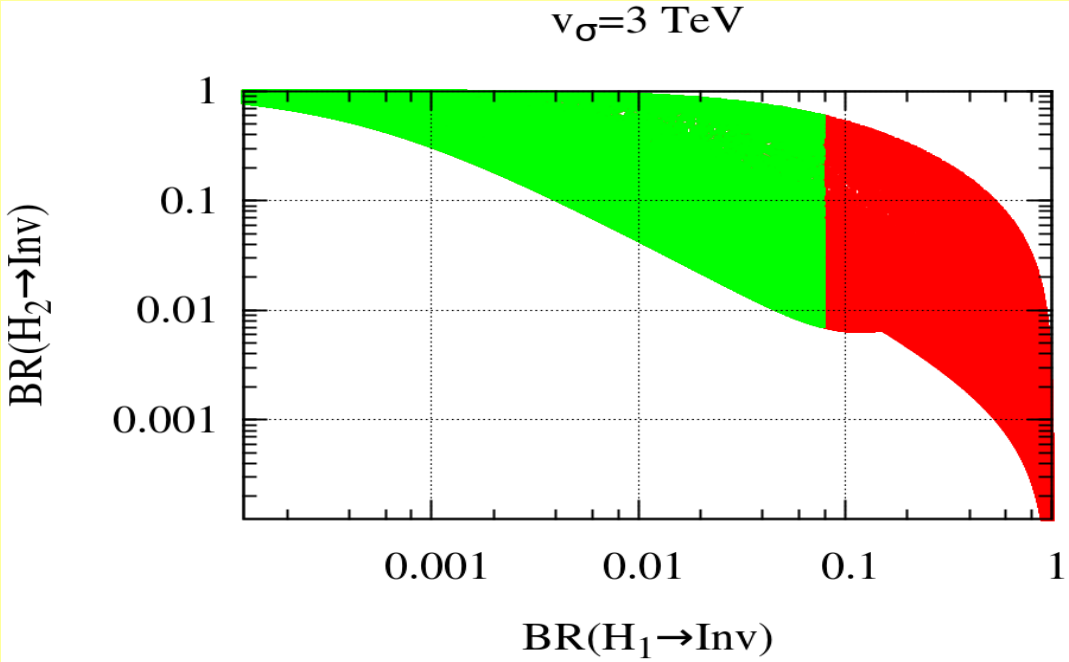
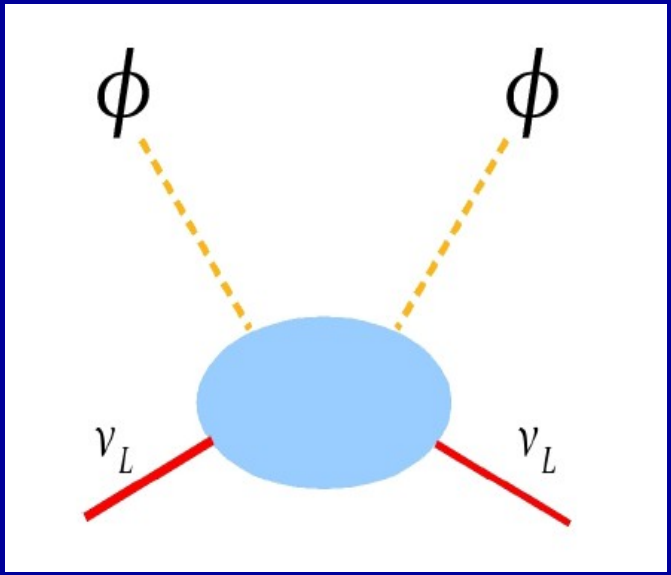


JWF Valle

origin of neutrino mass and seesaw



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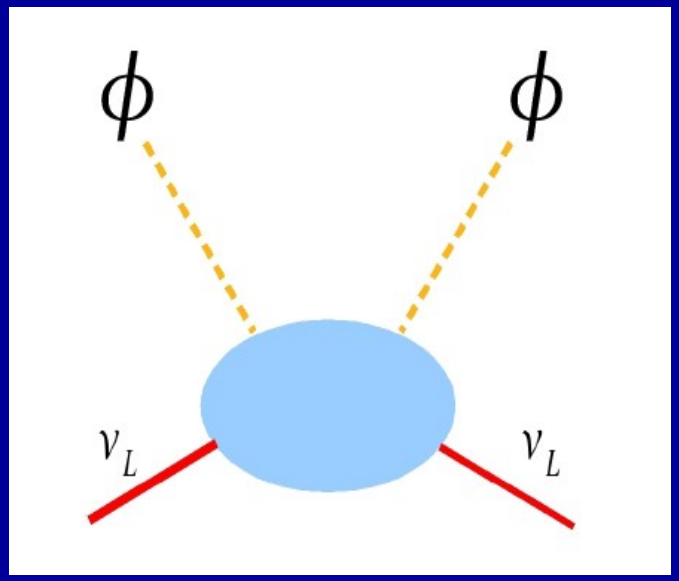
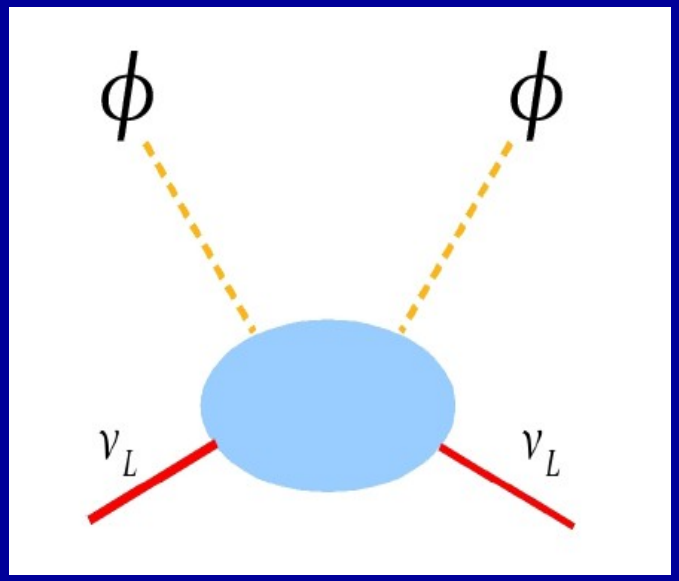


SCALE

MECHANISM

FLAVOR STRUCTURE

origin of neutrino mass and seesaw



SCALE

MECHANISM

FLAVOR STRUCTURE

$$v_3 v_1 \sim v_2^{\,2} \quad \text{with} \quad v_1 \gg v_2 \gg v_3$$

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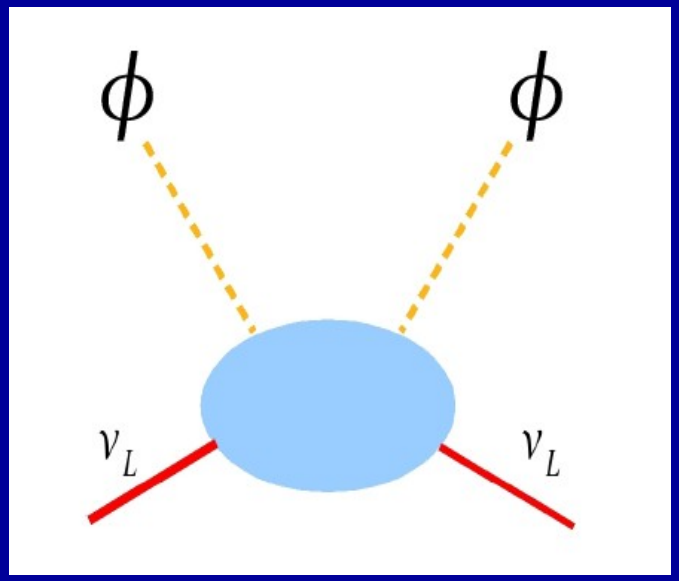

SCALE

MECHANISM

FLAVOR STRUCTURE

fermion exchange

TYPE I

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

$$v_3 v_1 \sim v_2^{\,2} \quad \text{with} \quad v_1 \gg v_2 \gg v_3$$

Scalar-exchange

TYPE II

Schechter-Valle 80/82

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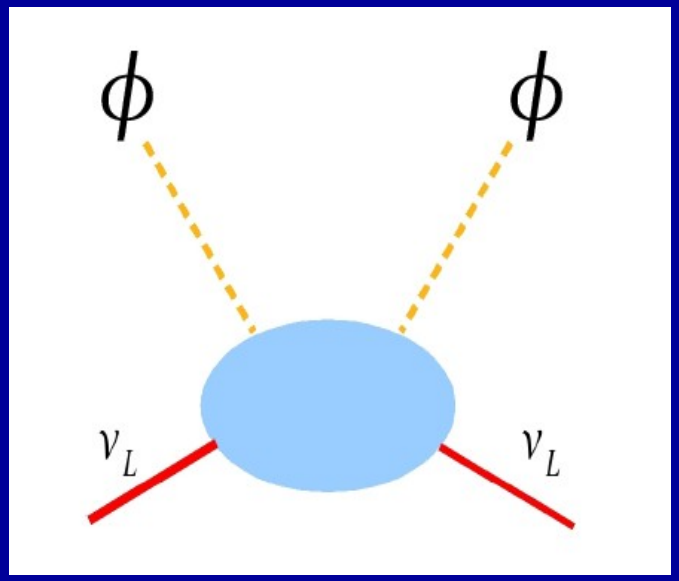

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SCALE

MECHANISM

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

Radiative neutrino mass

many low-scale neutrino mass schemes ...

arXiv:1404.3751

3L3C1 scheme # generations = # colours

Singer, Valle, Schechter, Phys.Rev. D22 (1980) 738

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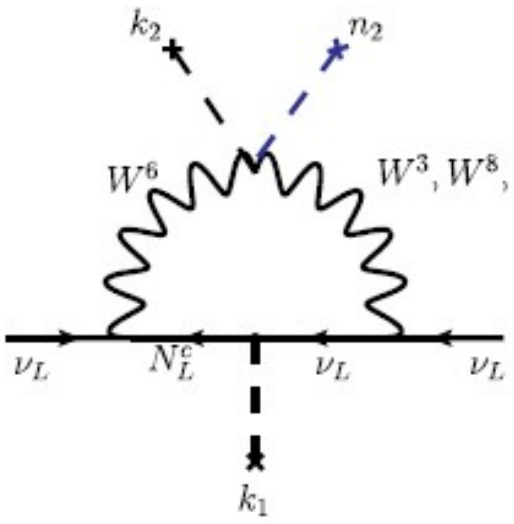
PHYSICAL REVIEW D **90,** 013005 (2014)

Radiative neutrino mass in 3-3-1 scheme

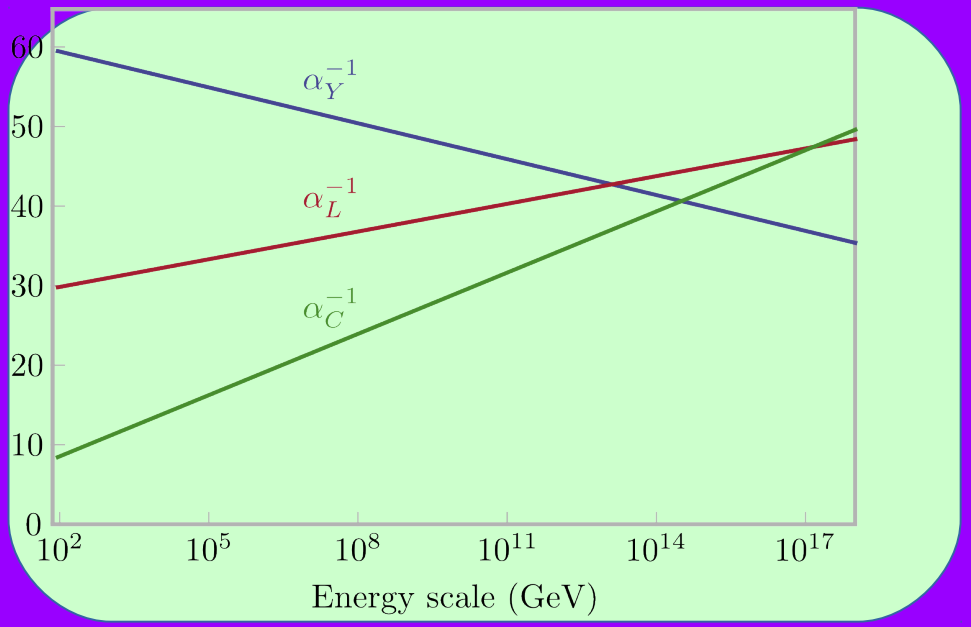
PHYSICAL REVIEW D **90,** 013005 (2014)



Gauge vs Higgs

gauge coupling unification :

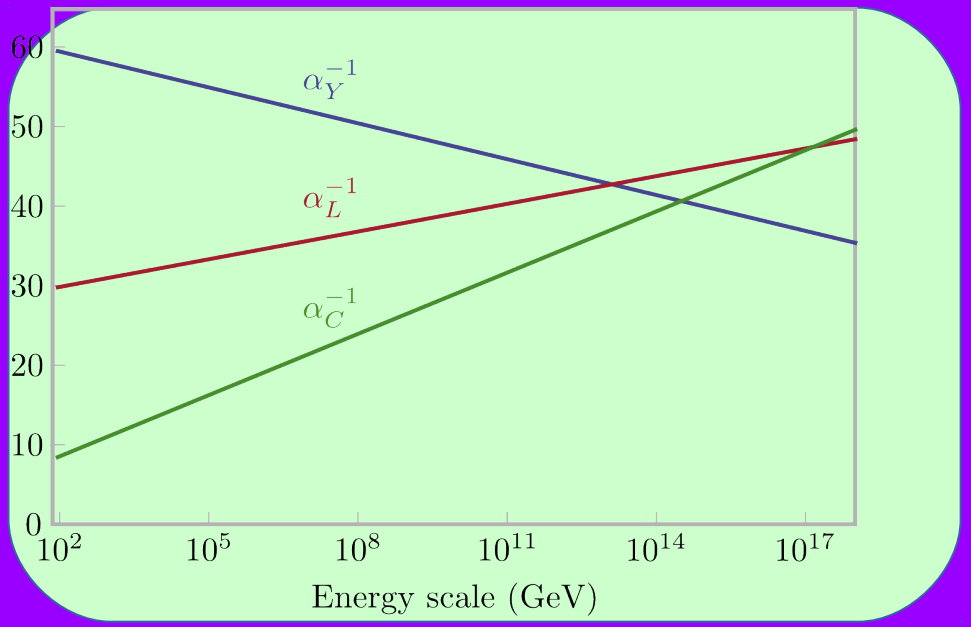
a near miss ...



What makes the gauge couplings unify?

gauge coupling unification :

a near miss ...



What makes the gauge couplings unify? **GUT (p decay)**

SUSY

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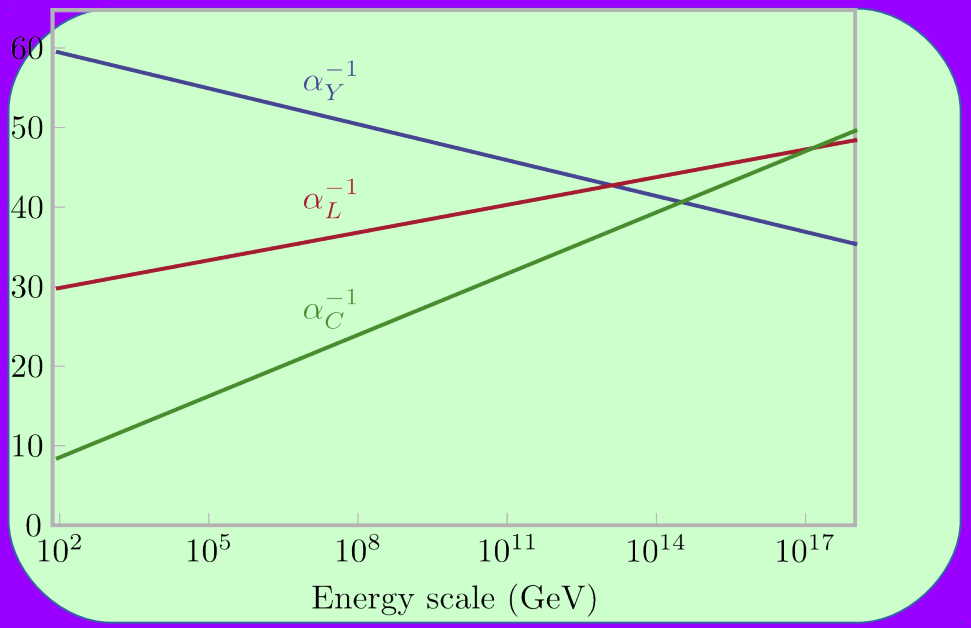

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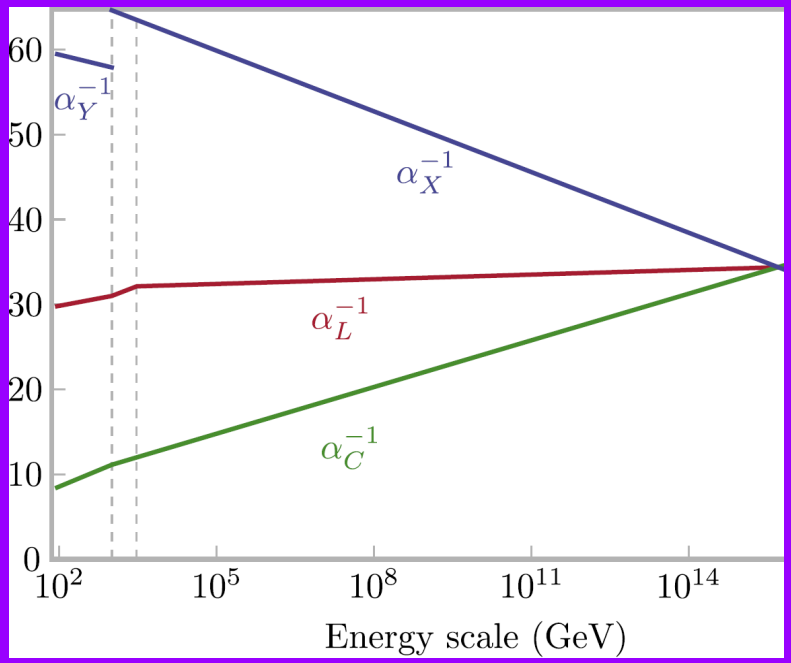
NEUTRINO



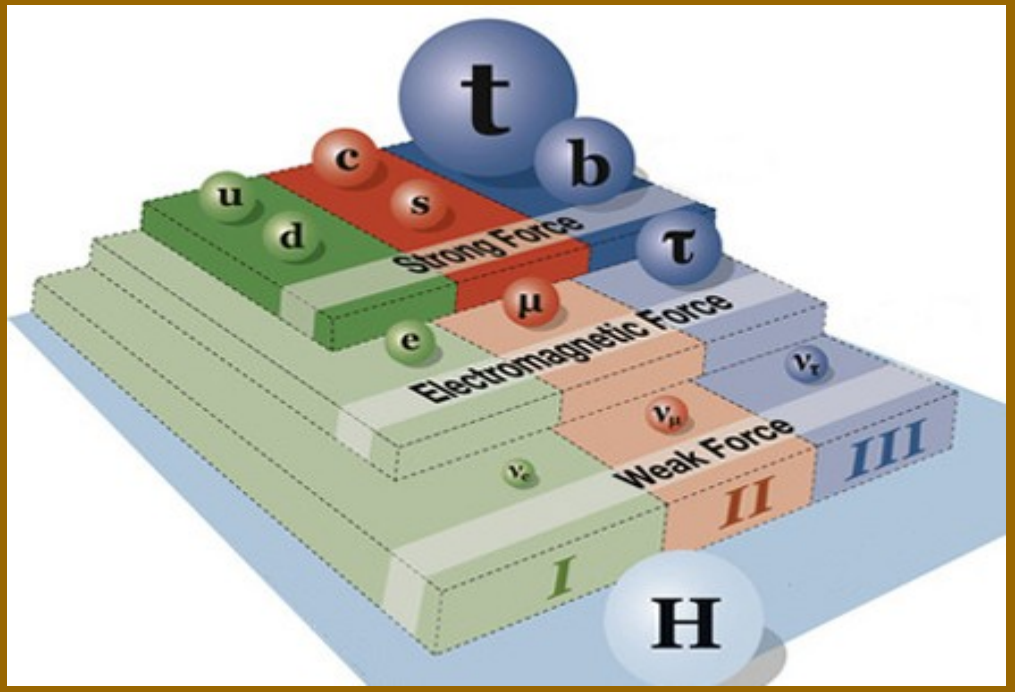
The physics responsible for gauge coupling unification may also induce small neutrino masses

Phys. Rev. D 91, 031702 (2015)

Boucenna, Fonseca, Gonzalez-Canales, JV

JWF Valle

Flavor problem



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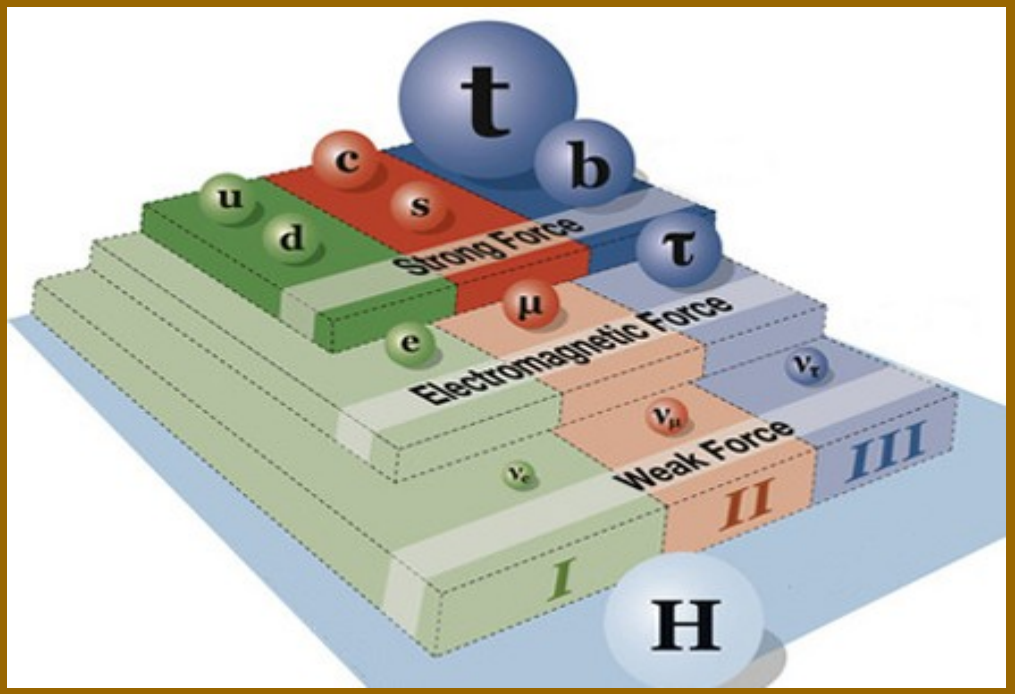

pattern of masses...

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

b-tau unification without GUTS...

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

JWF Valle

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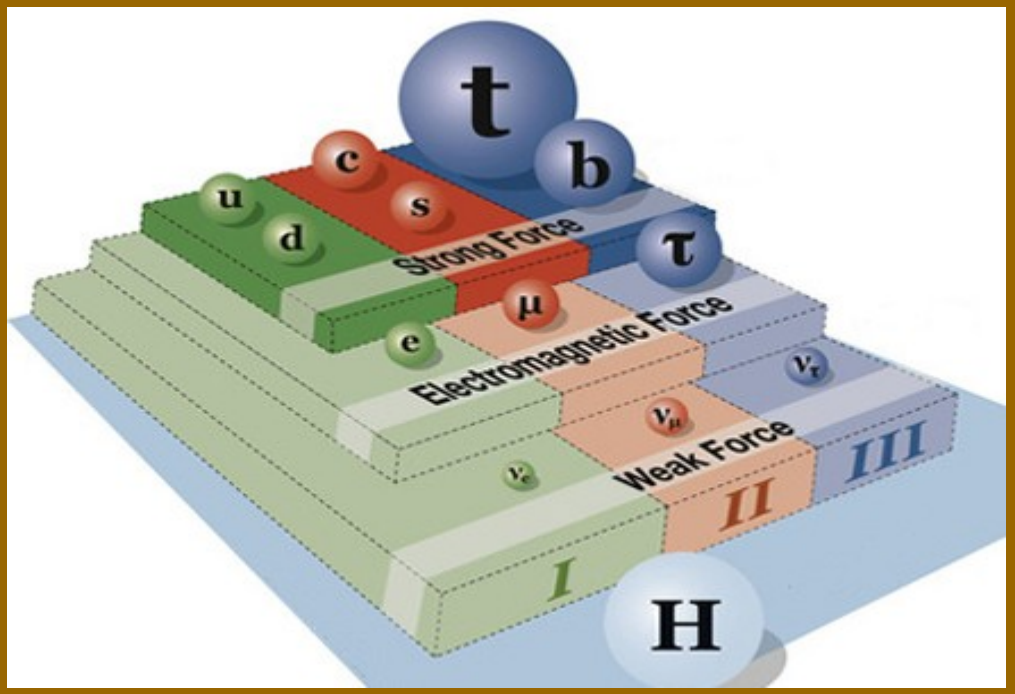


pattern of masses…

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

pattern of mixing parameters …

Anarchy ?

Donoghue et al PRD73
Hall,Murayama,Weiner,PRL
Altarelli, Feruglio,Masina,JHEP

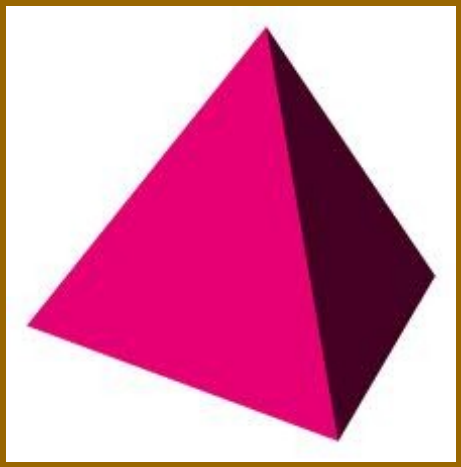
b-tau unification without GUTS…

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

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L$$
$$e_R \qquad \mu_R \qquad \tau_R$$
$$\begin{pmatrix} u \\ d \end{pmatrix}_L \quad \begin{pmatrix} c \\ s \end{pmatrix}_L \quad \begin{pmatrix} t \\ b \end{pmatrix}_L$$
$$u_R \qquad c_R \qquad t_R$$
$$d_R \qquad s_R \qquad b_R$$

FLAVOR SYMMETRY

A4



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

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

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

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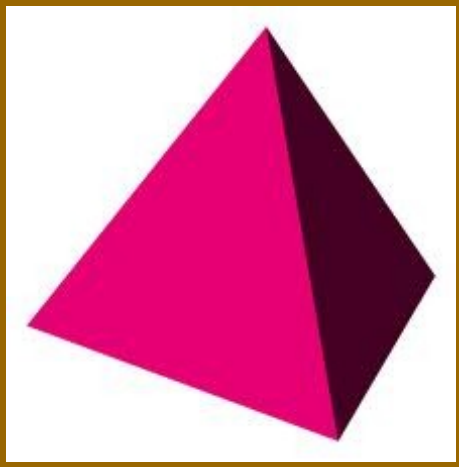

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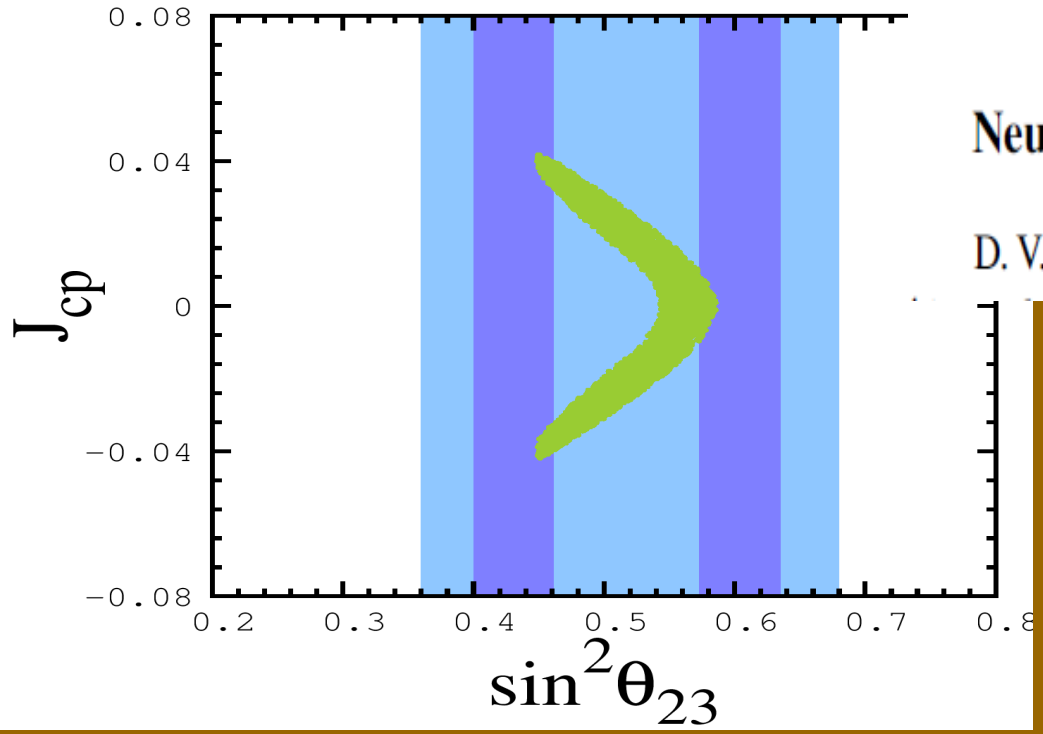


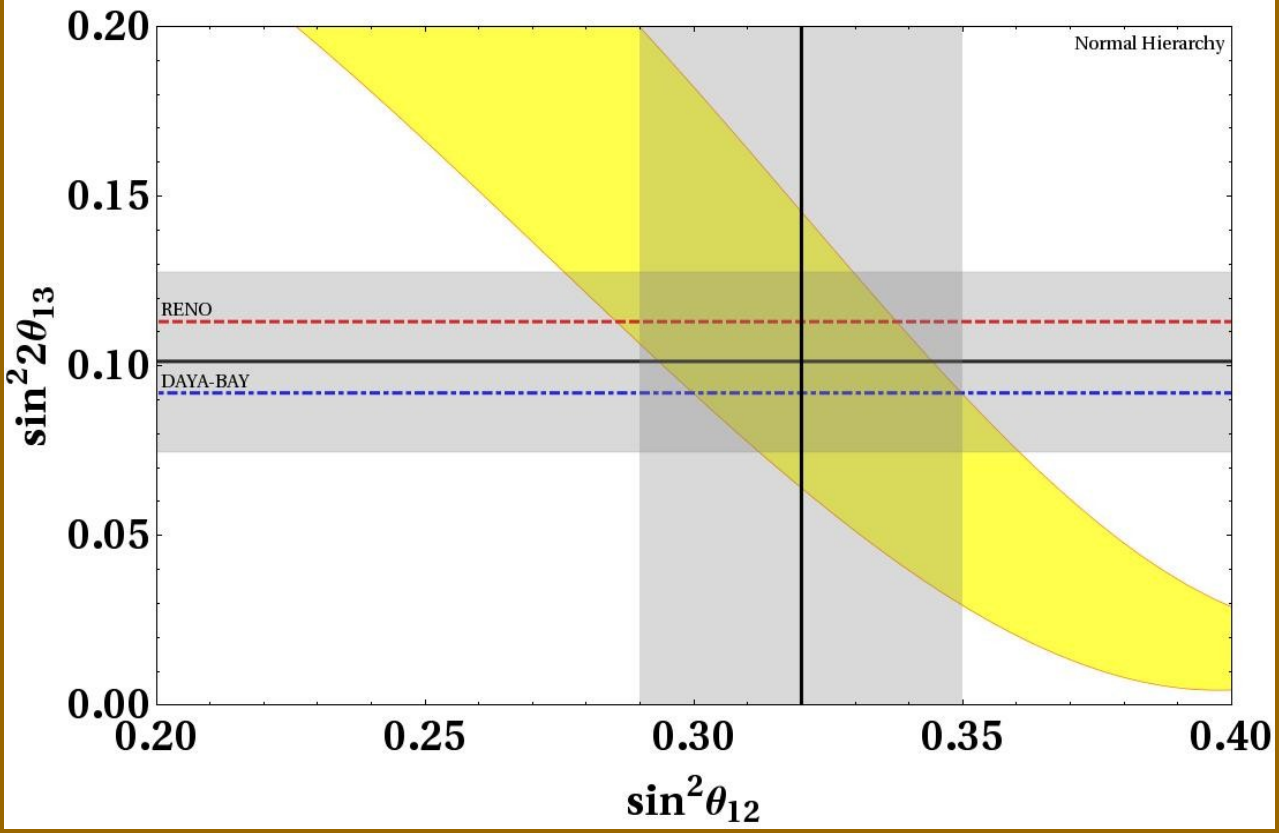
PHYSICAL REVIEW D 88, 016003 (2013)

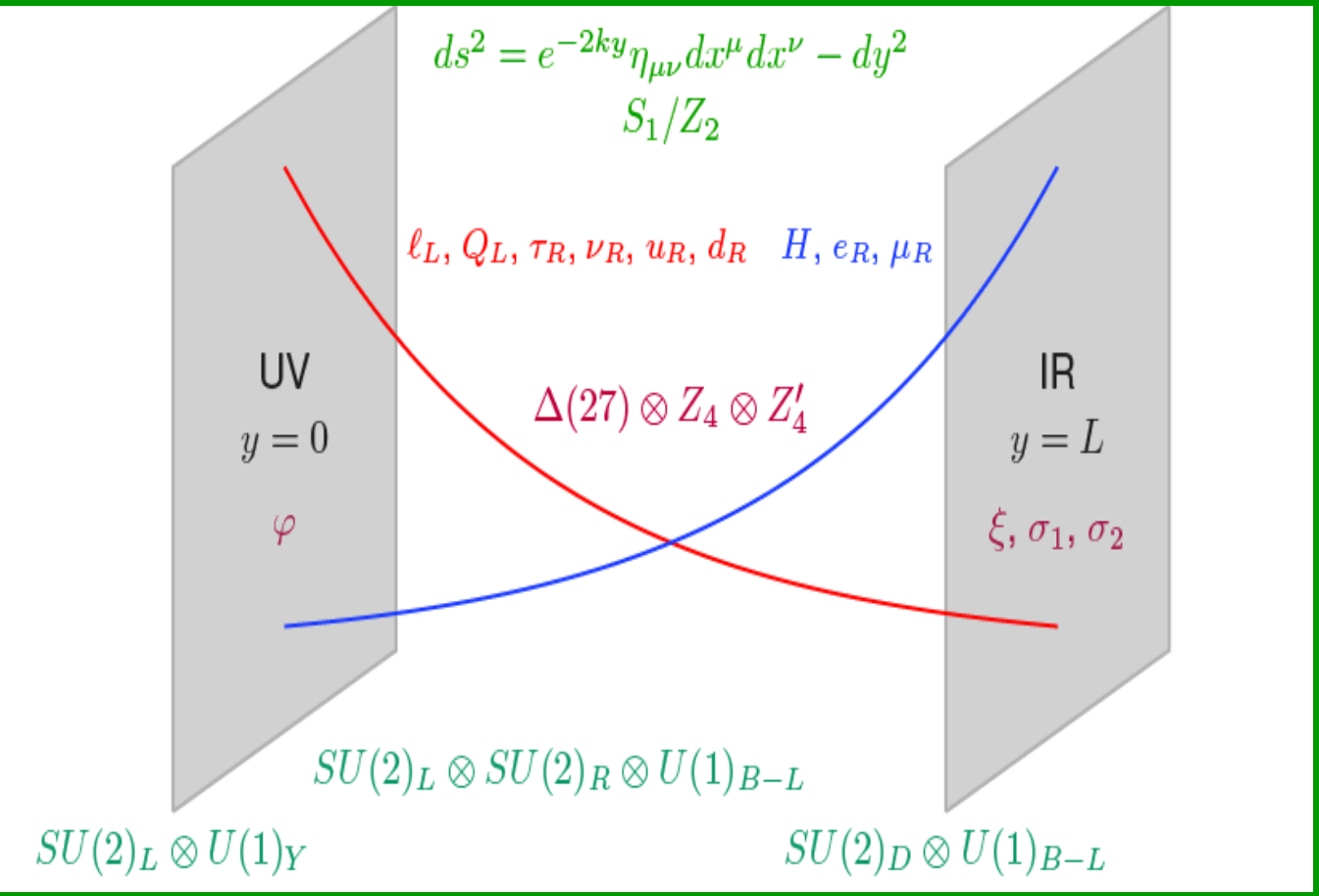
Neutrino mixing with revamped A_4 flavor symmetry

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

OSCILLATION PARAMETER CORRELATIONS

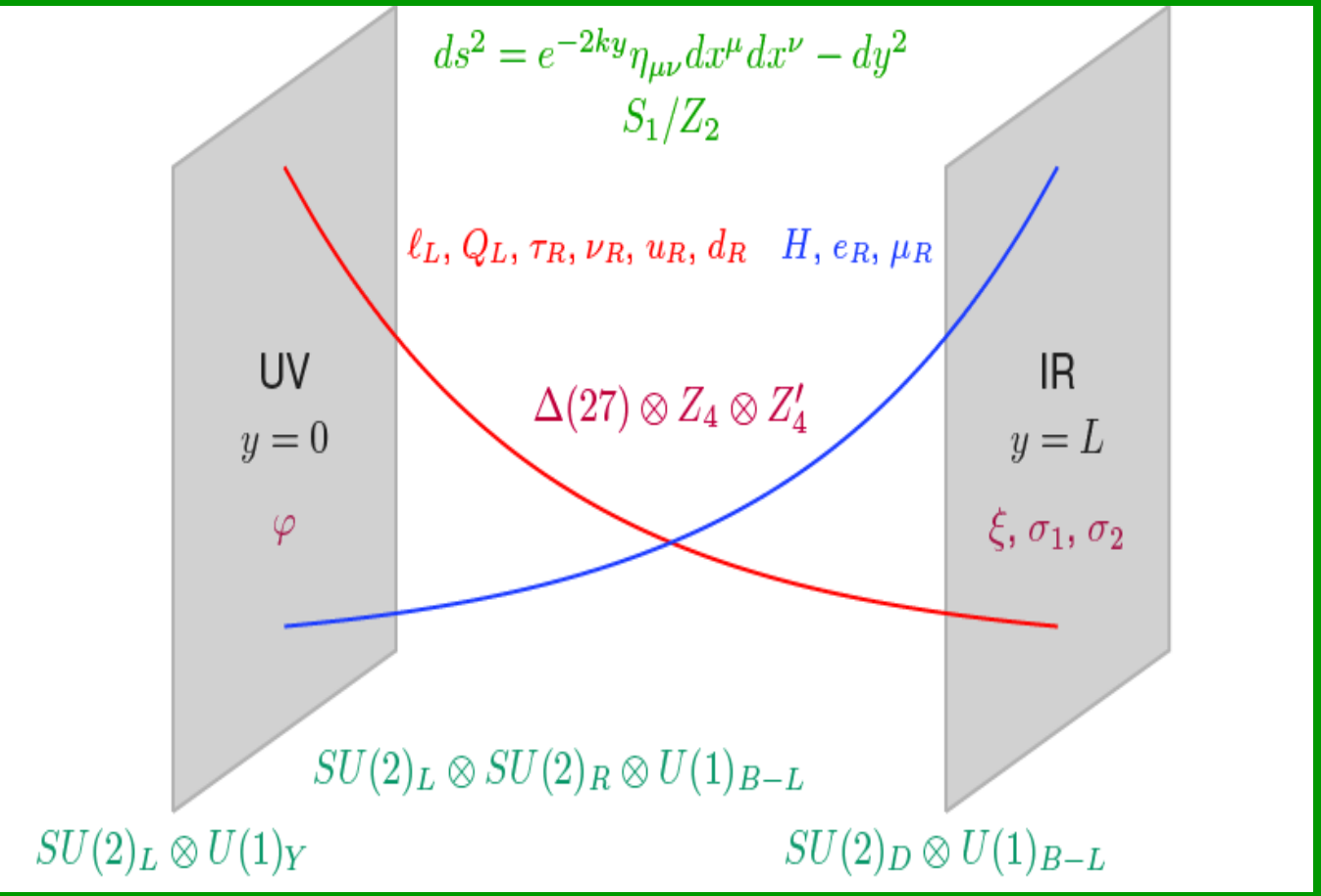
Boucenna et al
PhysRevD.86.073008





: Chen et al arXiv:1509.06683

Mass hierarchies in principle be accounted for by judicious choices of the bulk mass parameters



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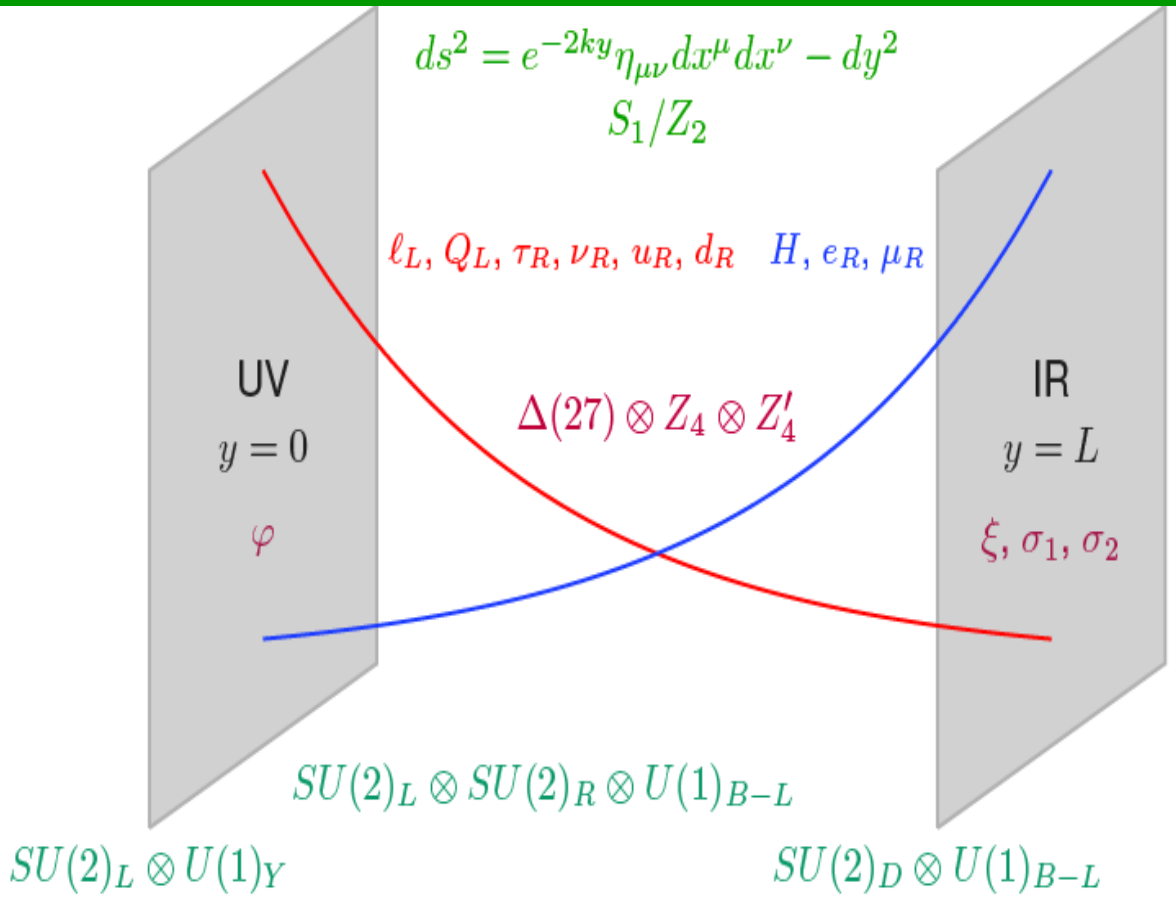
Mass hierarchies in principle be accounted for by judicious choices of the bulk mass parameters

Particle content and transformation properties

Field	Ψ_ℓ	Ψ_e	Ψ_μ	Ψ_τ	Ψ_{ν_1}	Ψ_{ν_2}	Ψ_{ν_3}	H	φ	ξ	σ_1	σ_2
$\Delta(27)$	$\mathbf{3}$	$\mathbf{1}_{0,0}$	$\mathbf{1}_{1,0}$	$\mathbf{1}_{2,0}$	$\mathbf{1}_{0,0}$	$\mathbf{1}_{0,0}$	$\mathbf{1}_{0,0}$	$\mathbf{1}_{0,0}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{1}_{0,1}$	$\mathbf{1}_{0,0}$
Z_4	1	1	1	1	-1	i	-1	1	1	-1	1	i
Z_4'	1	i	i	i	-1	-1	-1	1	$-i$	1	-1	-1



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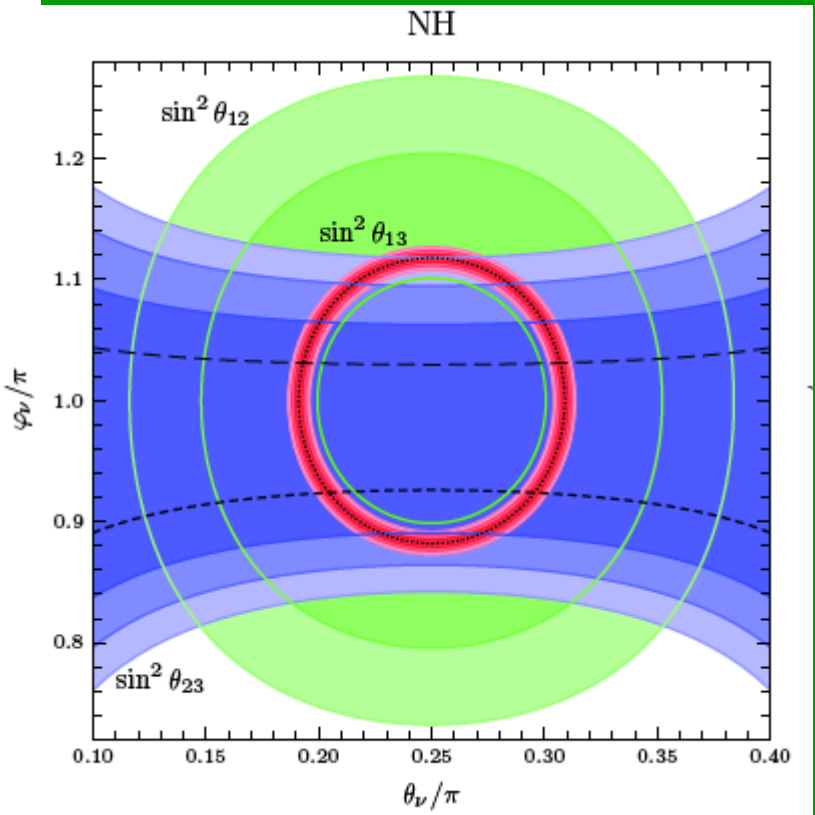

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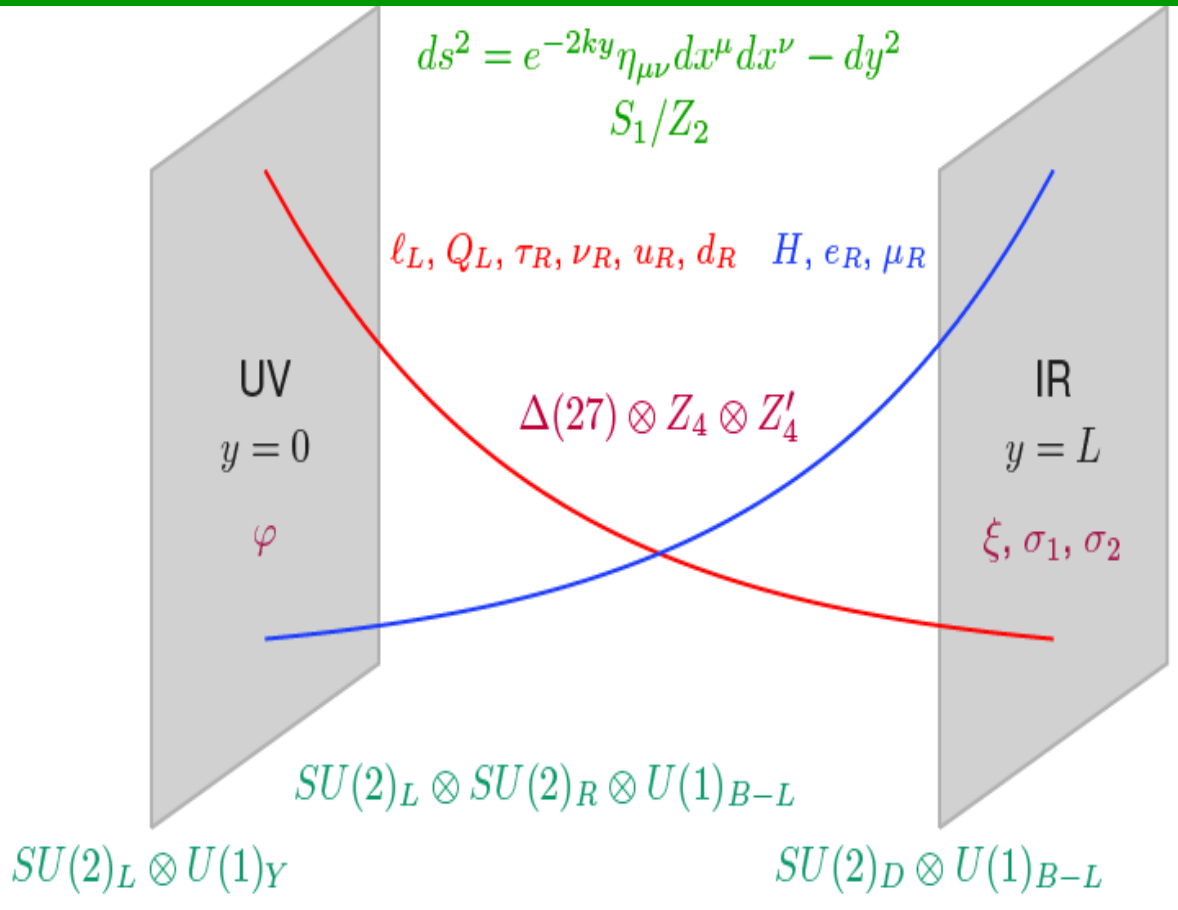

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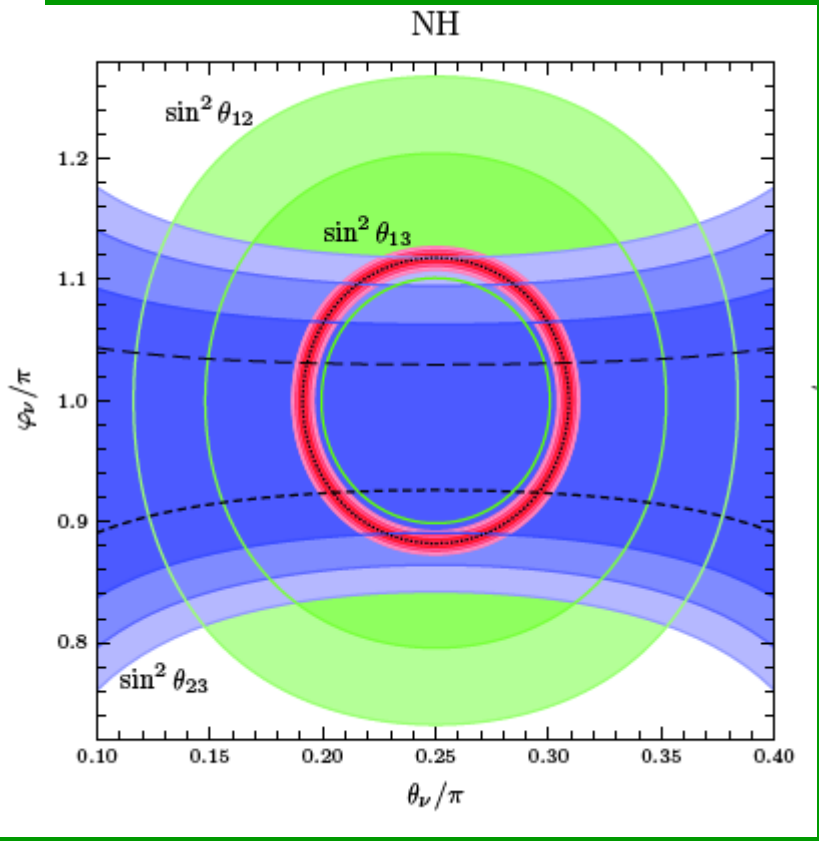

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$$\sin^2\theta_{12}\cos^2\theta_{13} = \frac{1}{3}.$$

B ANOMALIES

$$R_K = \frac{\mathrm{BR}(B \to K\mu^+\mu^-)}{\mathrm{BR}(B \to Ke^+e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

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where

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The violation of lepton universality usually comes together with the violation of lepton flavor. Based on symmetry arguments, Glashow, Guadagnoli and Lane [19] recently argued that the observation of universality violation in the lepton flavor conserving (LFC) $B \to K\ell_i^+\ell_i^-$ decays implies the existence of the lepton flavor violating (LFV) processes $B \to K\ell_i^+\ell_j^-$ (with $i \neq j$).

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Physics Letters B 750 (2015) 367–371

Here we raise the following question: can the leptonic mixing matrix provide the required lepton flavor structure in $\mathcal{O}_9$ and $\mathcal{O}_{10}$?

Boucenna, Vicente JWF Valle

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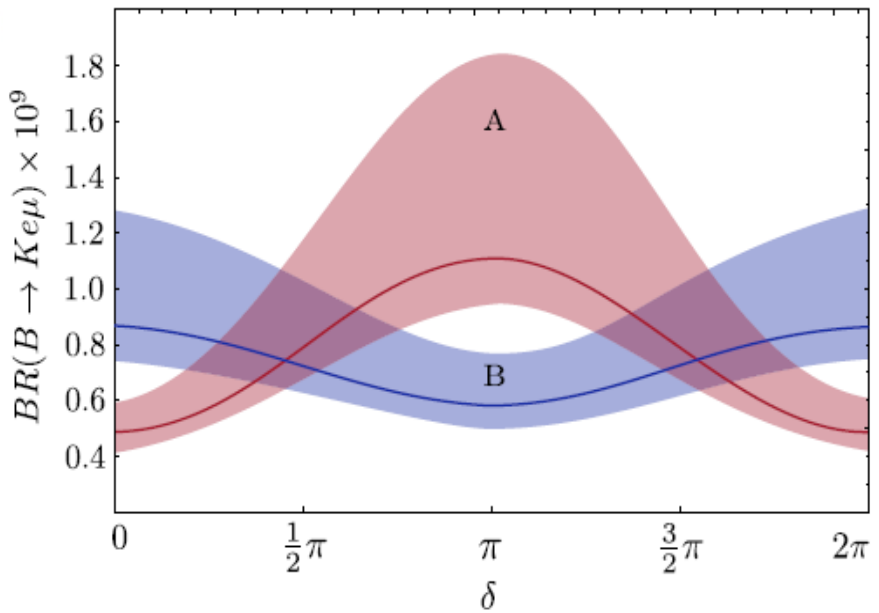
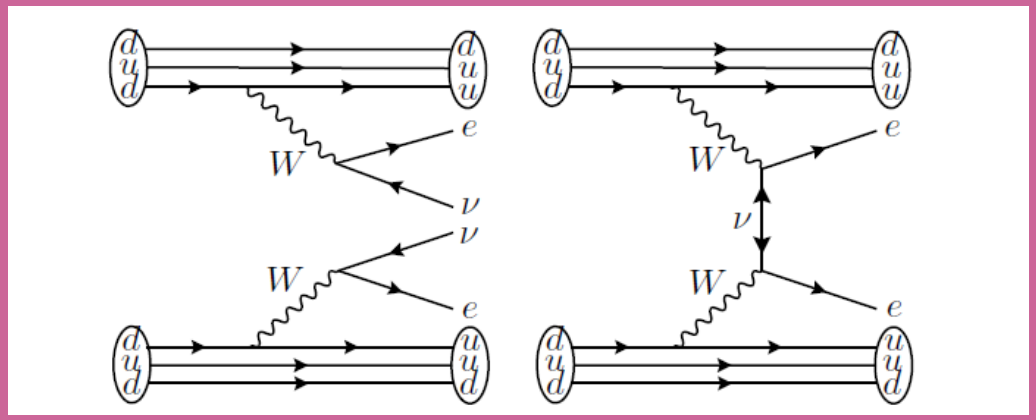


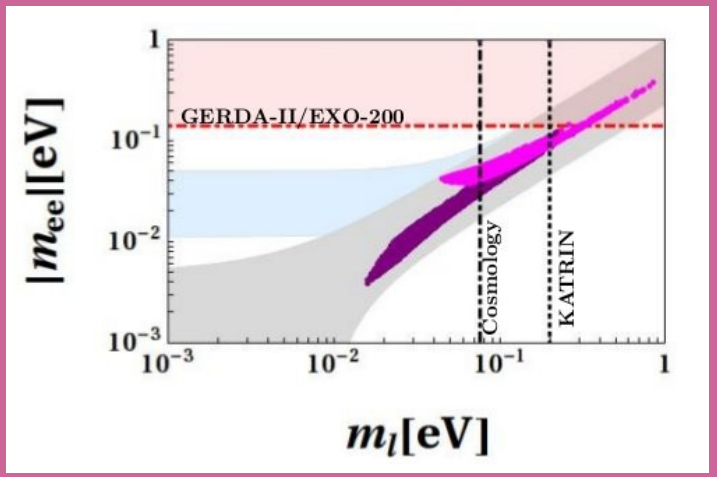
Boucenna, Vicente JWF Valle

Neutrinoless Double Beta Decay and flavor

A.S. Barabash arXiv:1104.2714



Family symmetry dependent lower bound



Bonilla et al arXiv:1411.4883

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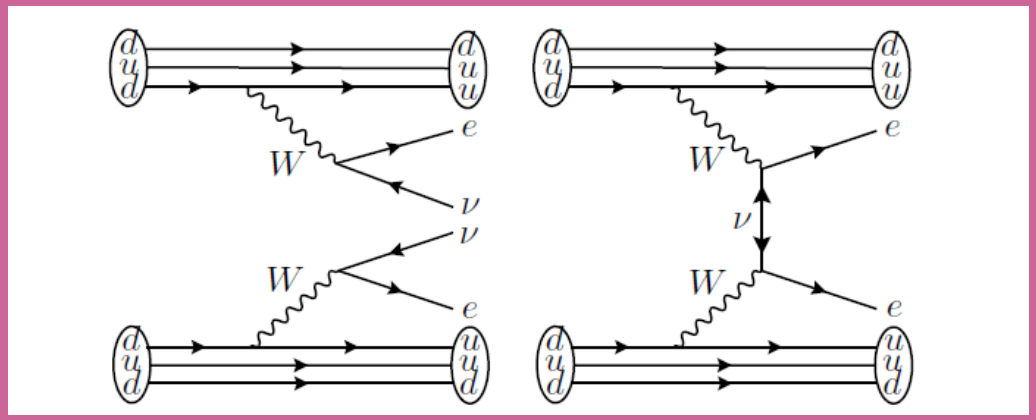

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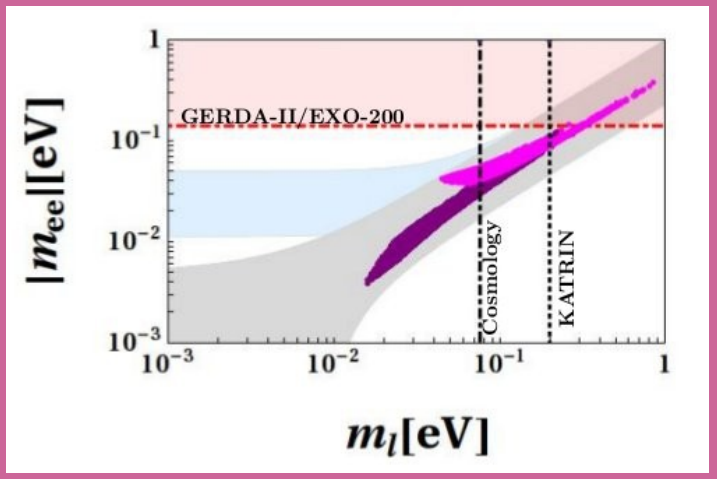
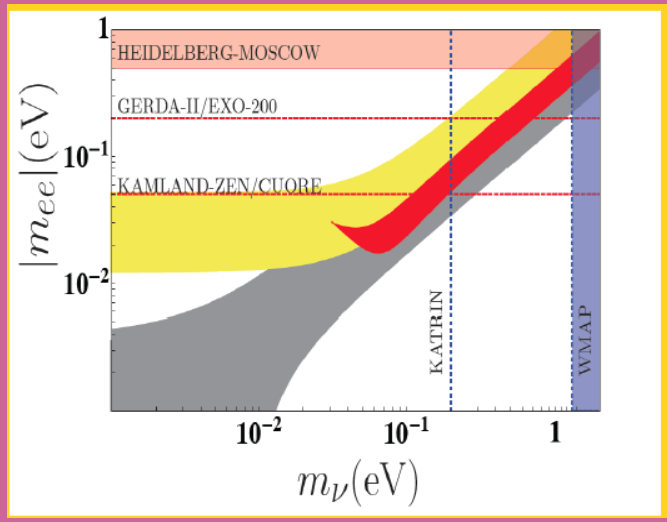
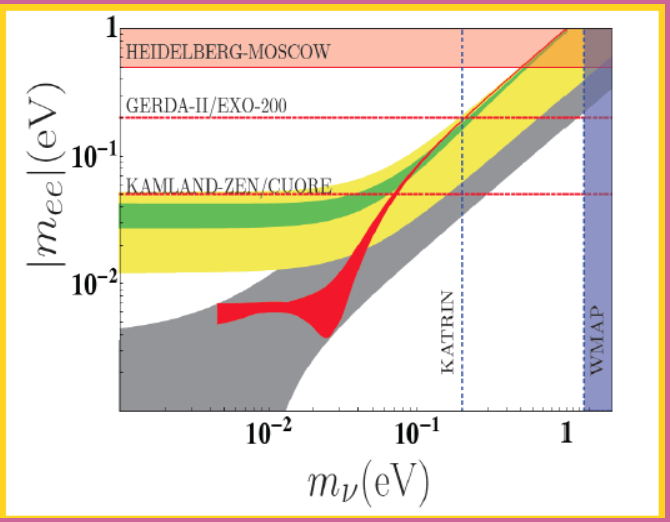


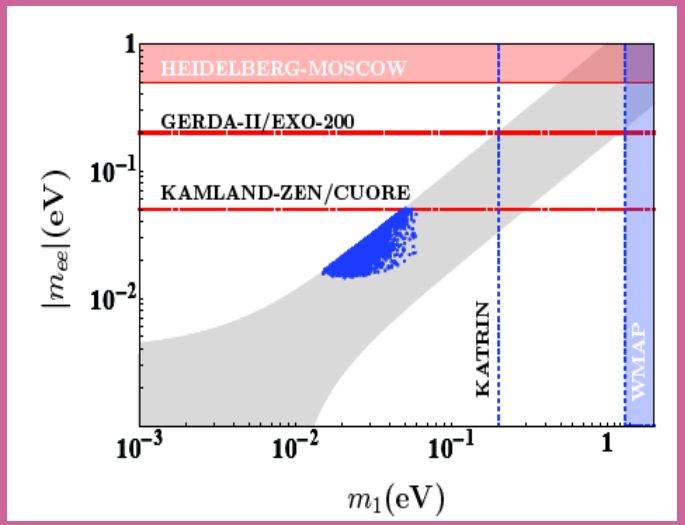
Bonilla et al arXiv:1411.4883



Dorame et al
NPB861 (2012) 259-270

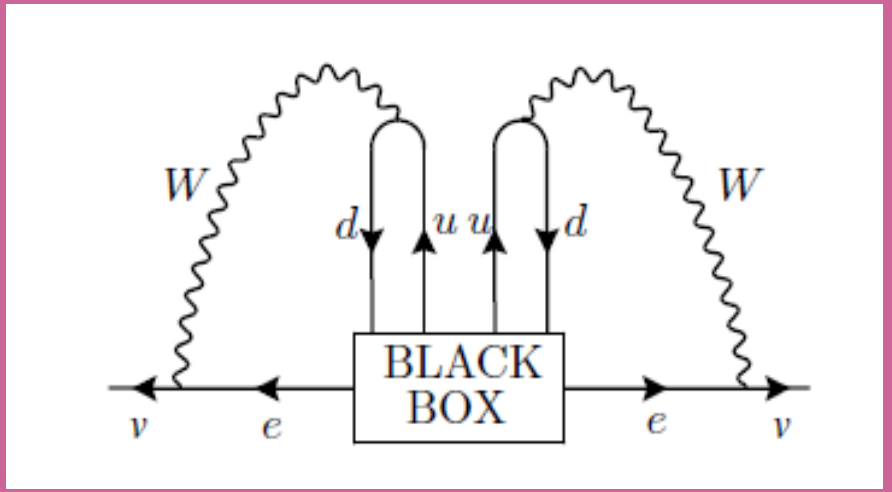


PhysRevD.86.056001
JWF Valle



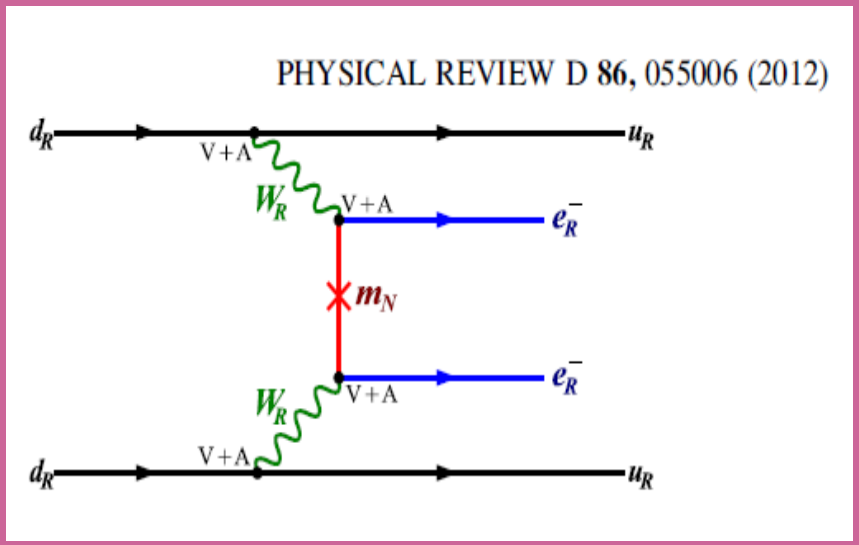
King et al Phys. Lett. B 724 (2013) 68

Neutrinoless Double Beta Decay and COLLIDERS

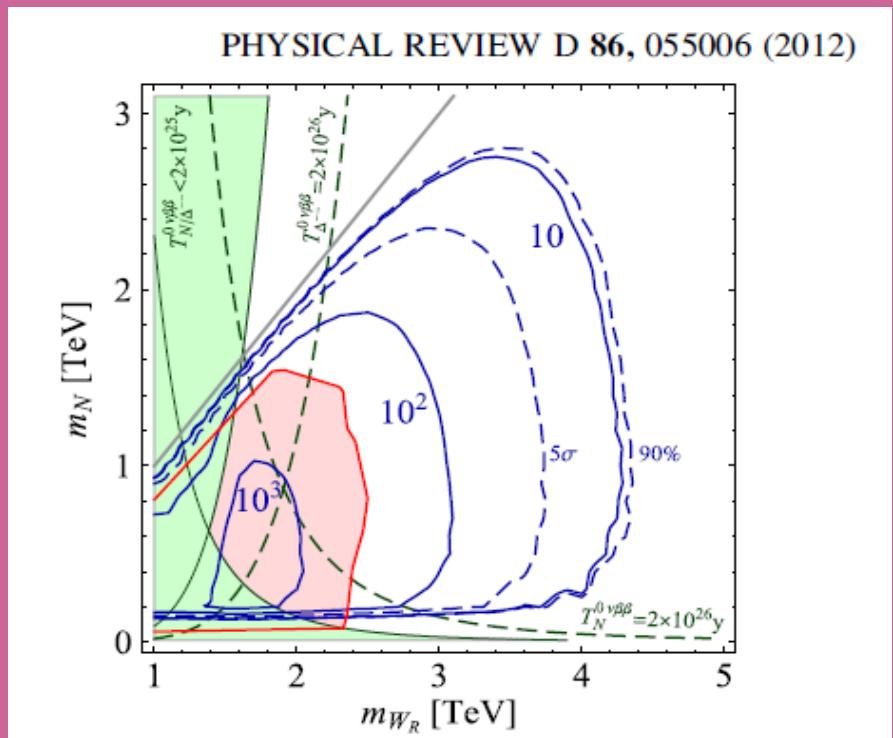


Schechter, JWFV 82
Lindner et al JHEP 1106 (2011) 091

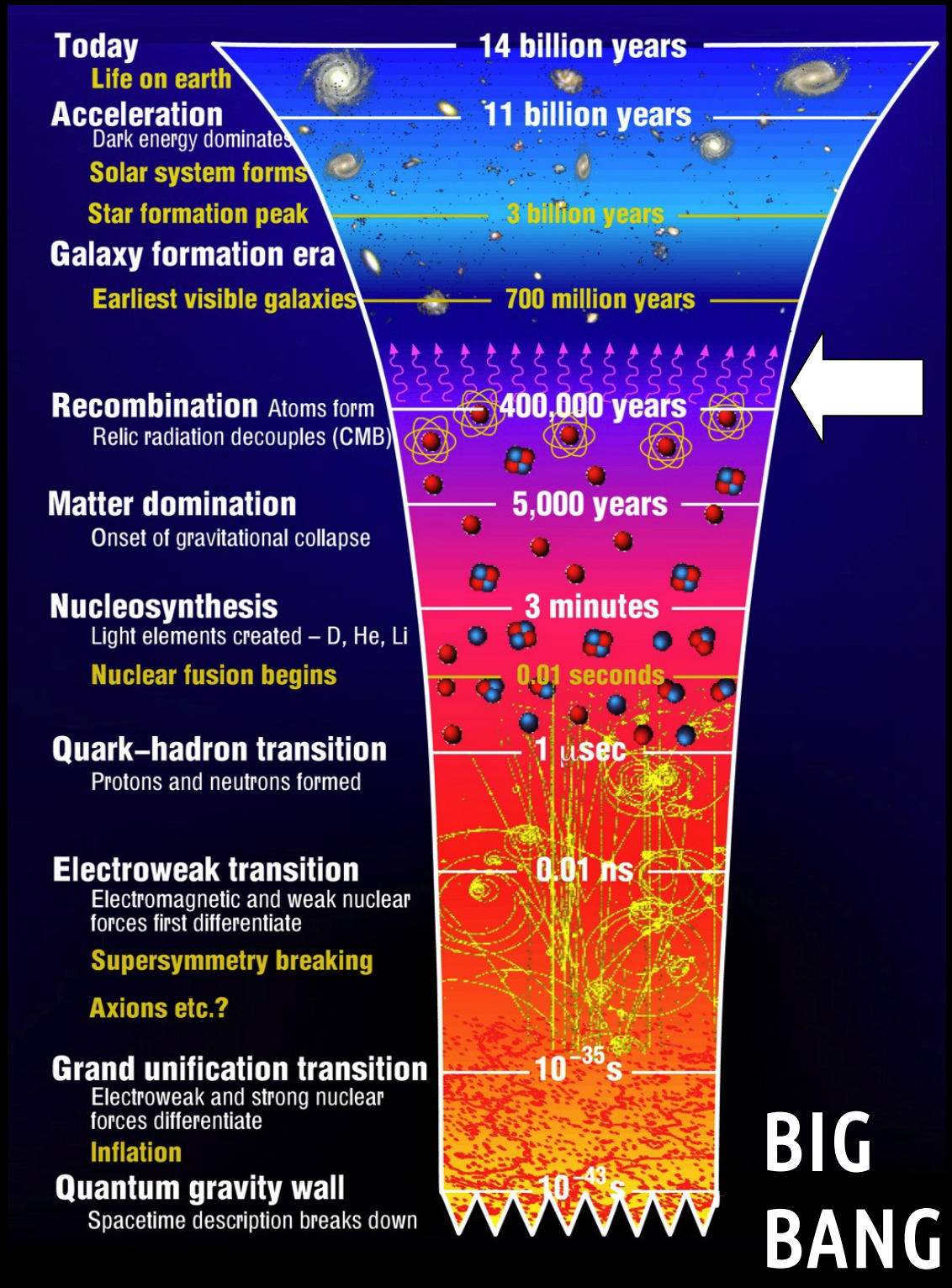
Short versus long-range and the LHC



JWF Valle



Neutrinos affect the CMB and large scale structure in the Universe …



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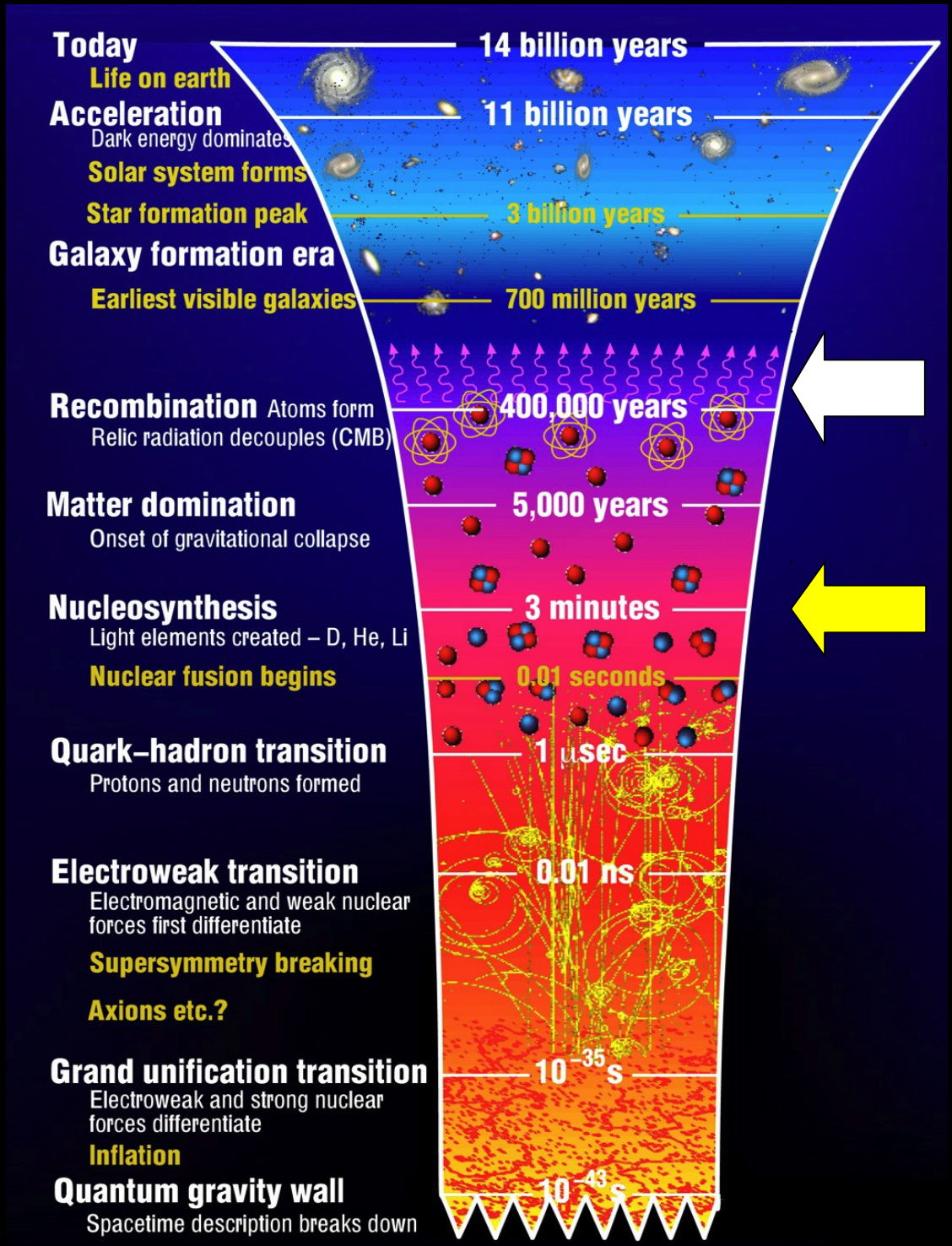
are key in the synthesis of light elements



Neutrinos affect the CMB and large scale structure in the Universe …

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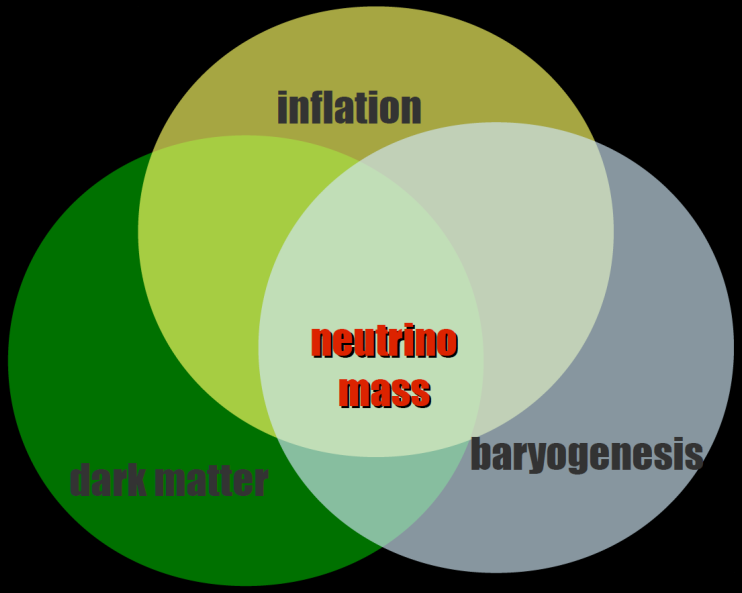
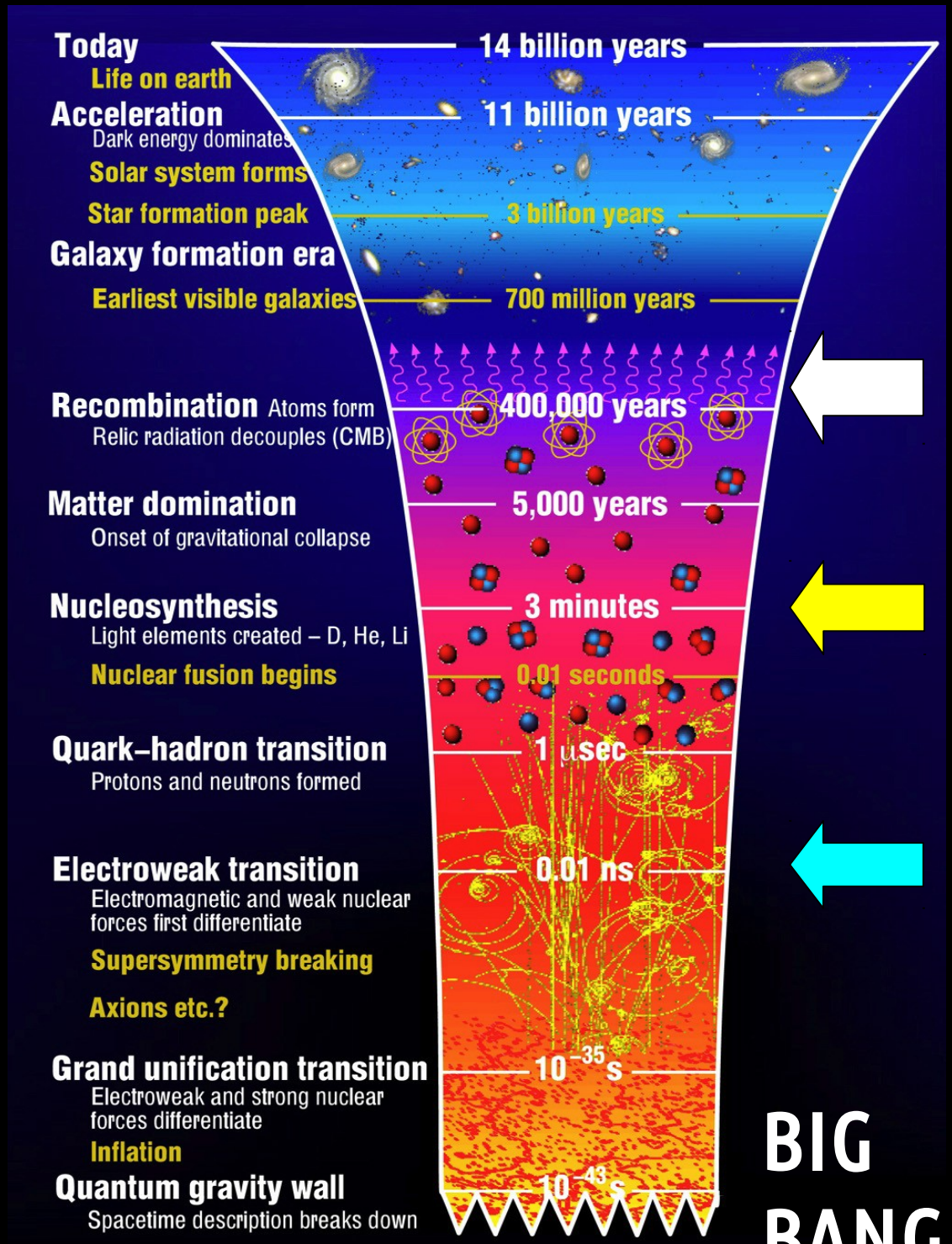
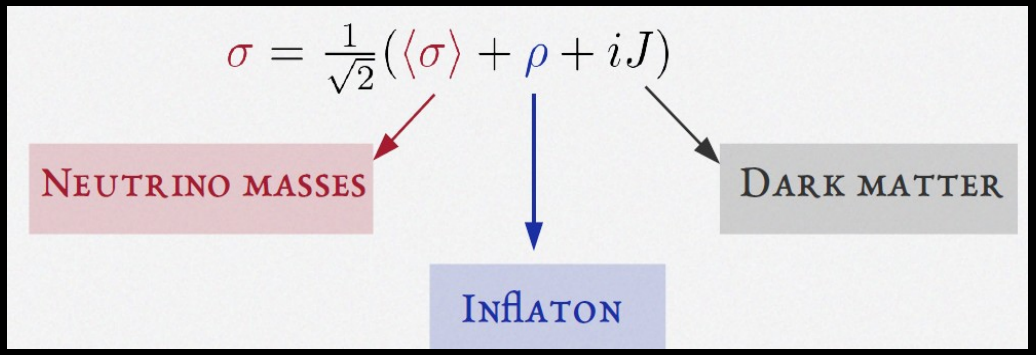
can "probe" the Universe earlier than photons …

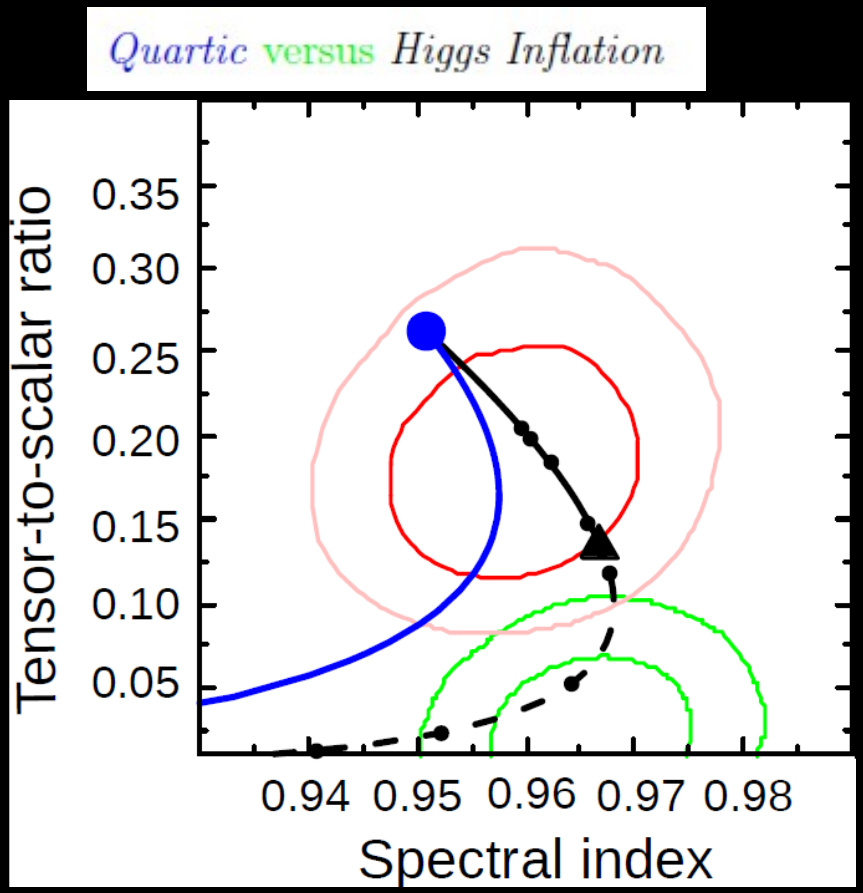




SEESAW INFLATION & MAJORON DARK MATTER

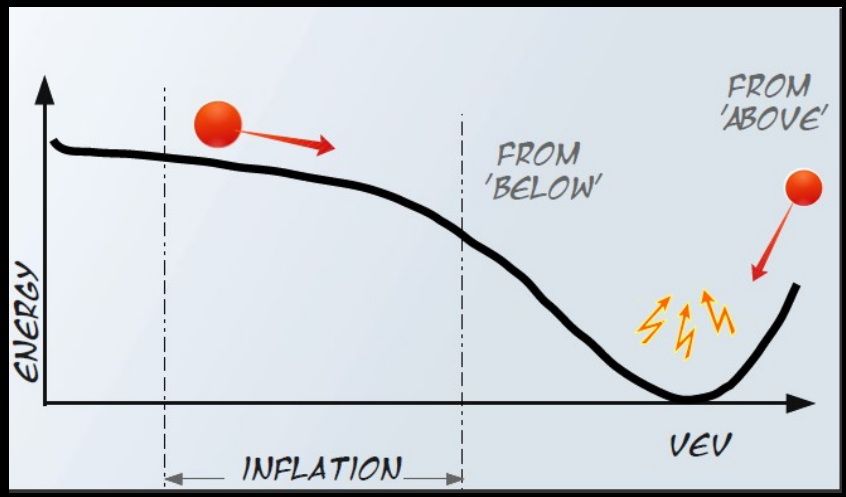


Boucenna et al arXiv:1405.2332 PRD90 (2014) 055023



type-I seesaw Leptogenesis

Aristizabal et al arXiv:1405.4706



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

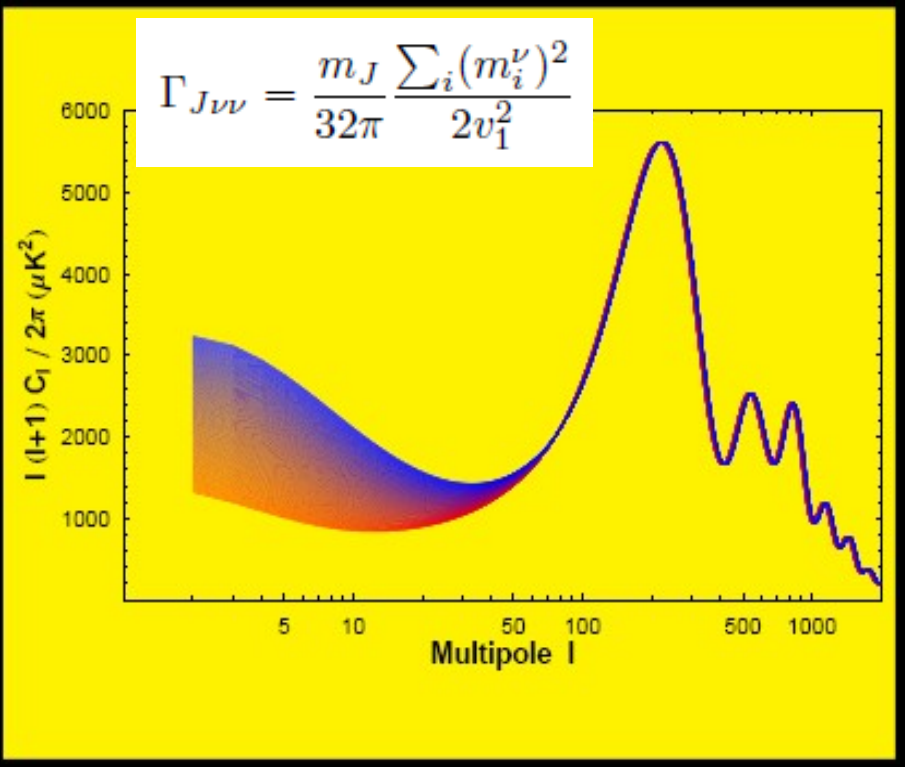
DARK MATTER MAJORONS

Berezinsky, Valle PLB318 (1993) 360

Consistency with CMB

Lattanzi & Valle, PRL99 (2007) 121301

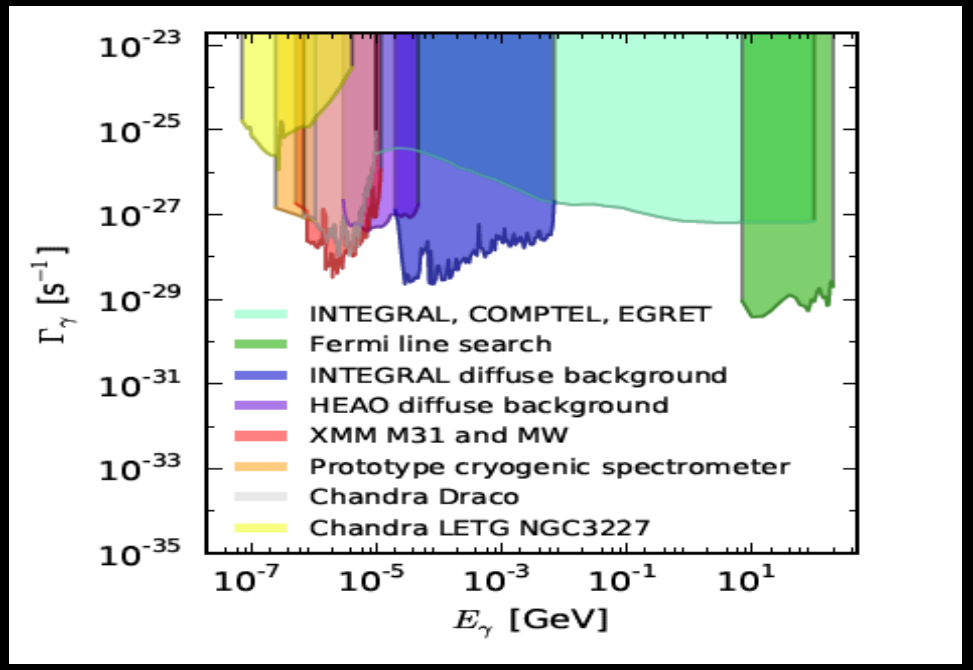
$$\Gamma_{J\nu\nu} = \frac{m_J}{32\pi} \frac{\sum_i (m_i^\nu)^2}{2v_1^2}$$



Esteves et al, PRD 82, 073008 (2010)

Bazzocchi & al JCAP 0808 (2008) 013

$$J \to \gamma\gamma$$



Lattanzi et al PRD88 (2013) 063528

consistency of vacuum
flavour
coupling unification
gravity

neutrino
masses

dark matter
baryon asymmetry
Inflation

First nail ???

neutrino as pathfinder

Thank you

Apart from Miranda and his Group at CINVESTAV ...

Alfredo Aranda
Cesar Bonilla
Luis Dorame
Felix Gonzalez
Eduardo Peinado
Alma Rojas
Carlos Vaquera

Thank you

Apart from Miranda and his Group at CINVESTAV ...

Alfredo Aranda
Cesar Bonilla
Luis Dorame
Felix Gonzalez
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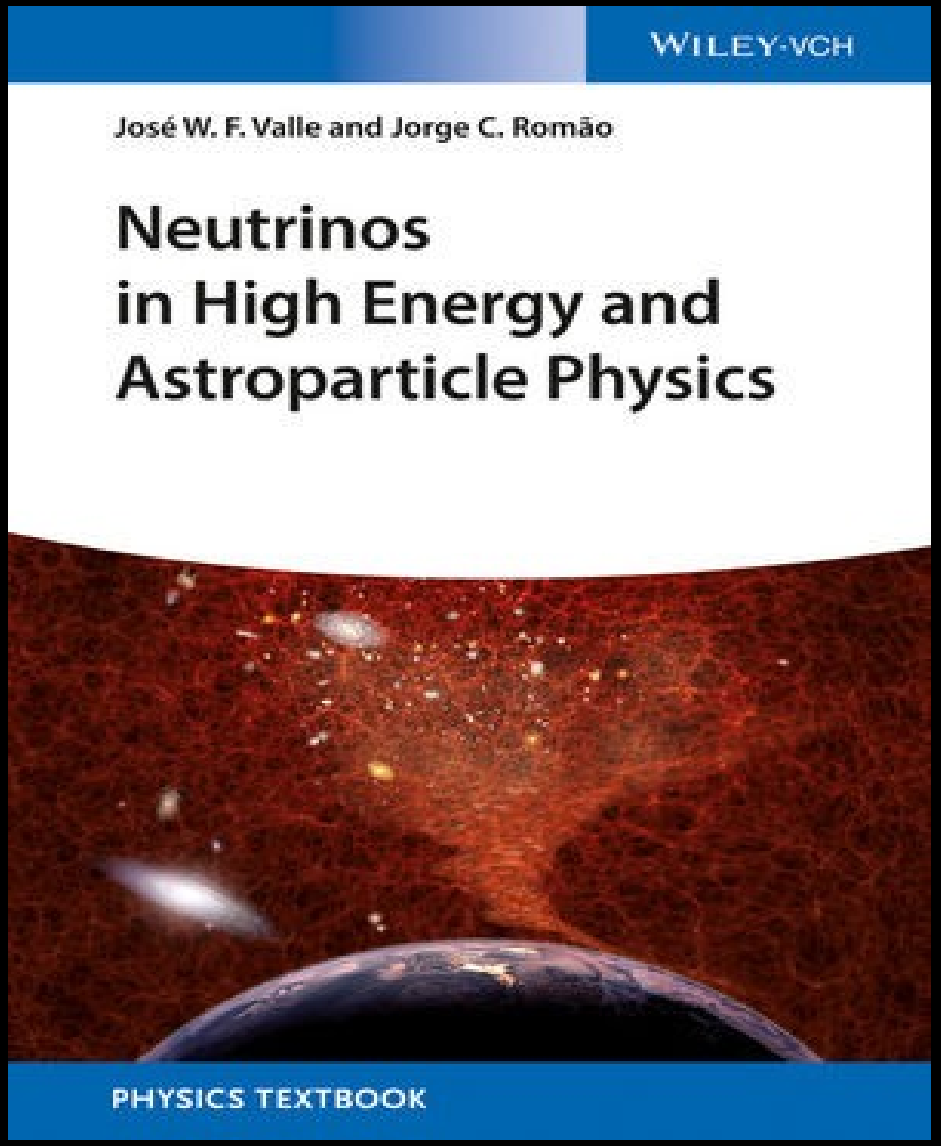

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