particle landscape 2016

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Consejo Superior de Investigaciones Científicas

IFIC
Institut de Física Corpuscular

Universitat de València

EXCELENCIA SEVERO OCHOA

ASTROPARTICLES
Astroparticles and High Energy Physics Group

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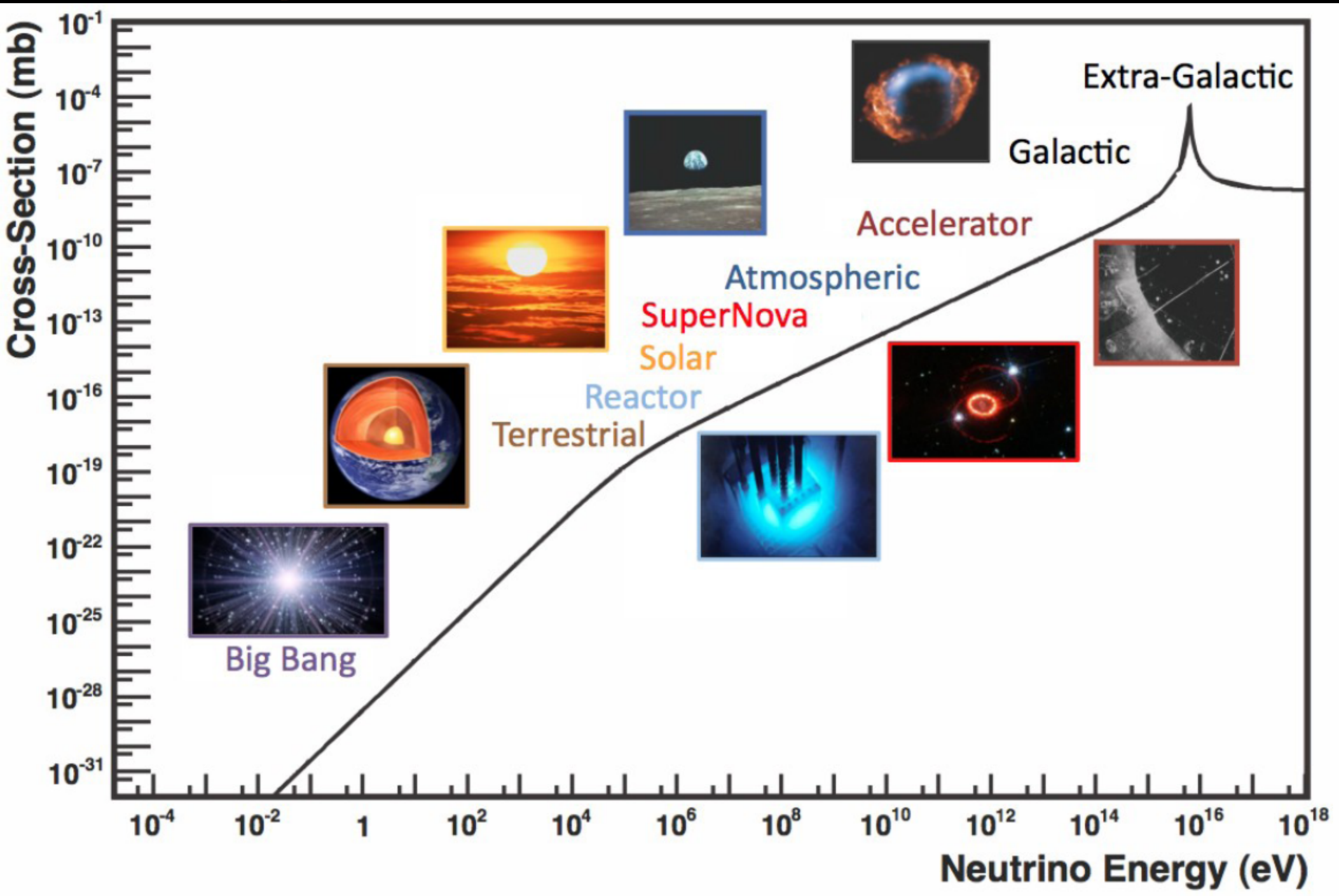
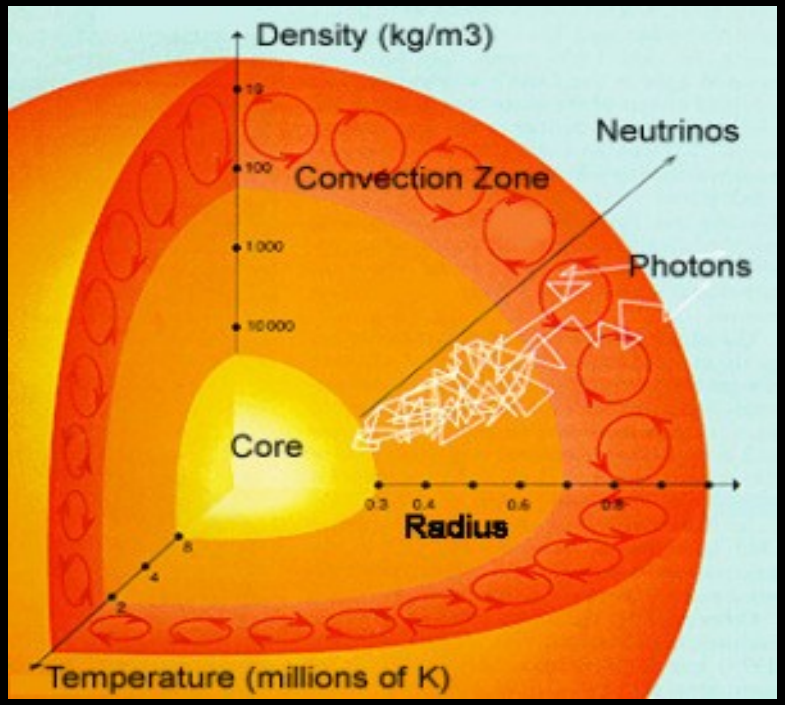
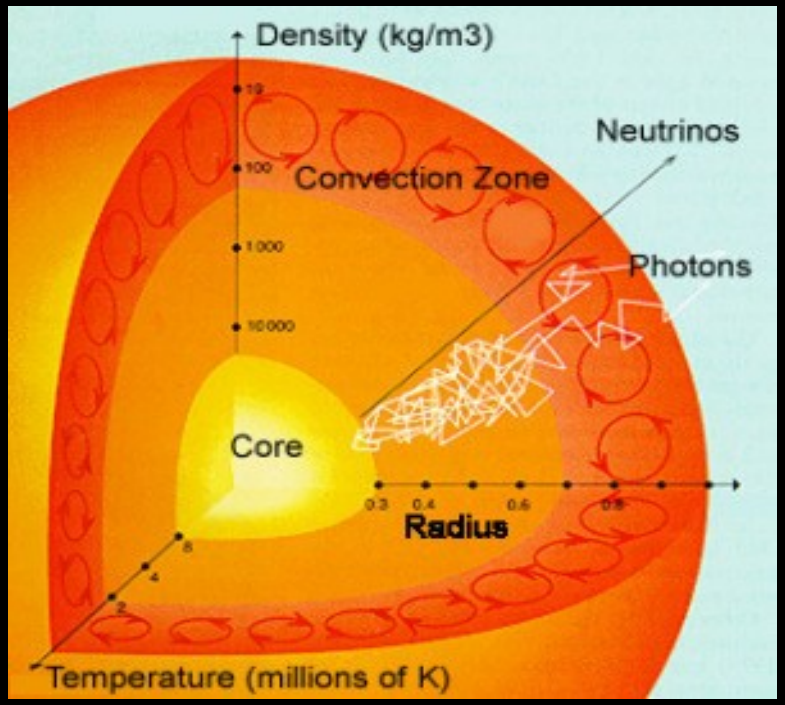
FLASY 2016 Valparaiso 28-30 septiembre 2016

Neutrino sources & cross sections




Density (kg/m3)
10
100
1 000
10 000
Neutrinos
Convection Zone
Photons
Core
0.3
0.4
0.6
0.8
Radius
6
4
2
Temperature (millions of K)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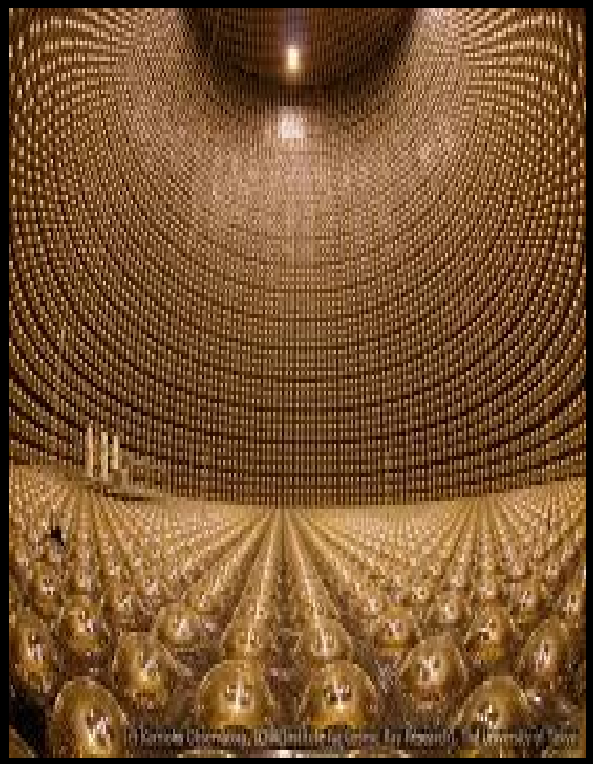

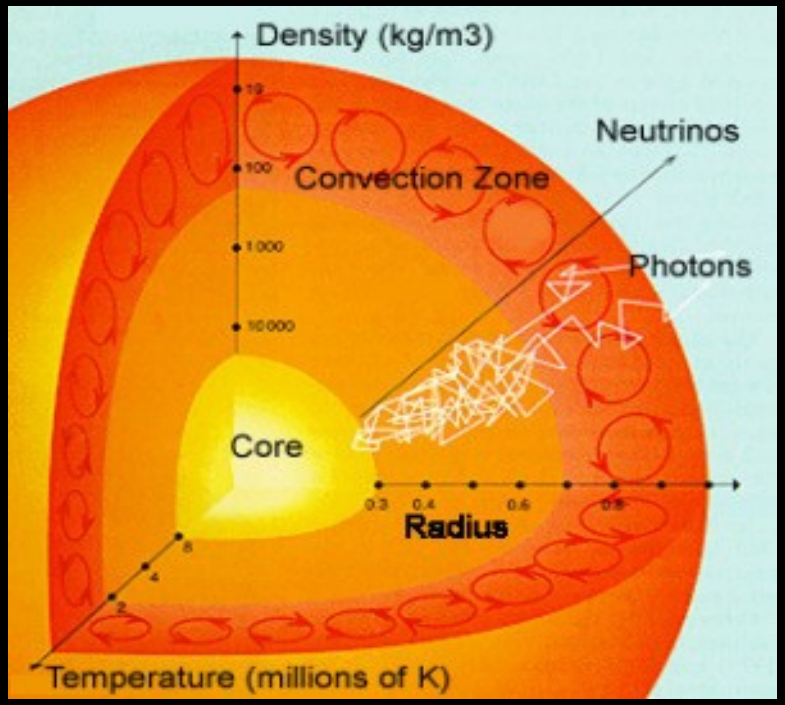
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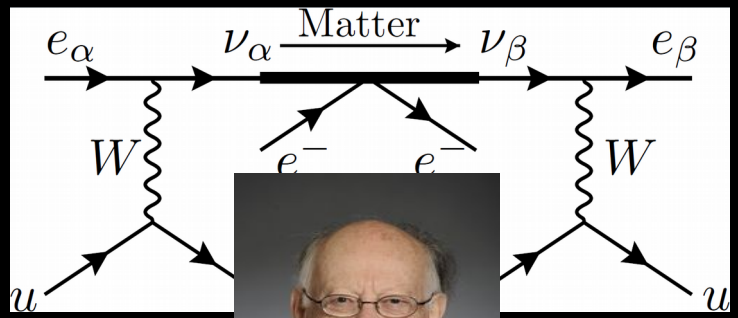
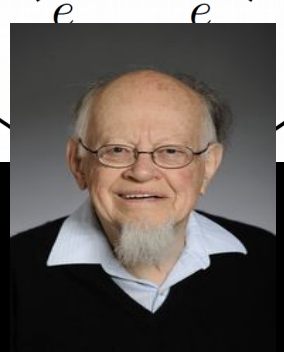
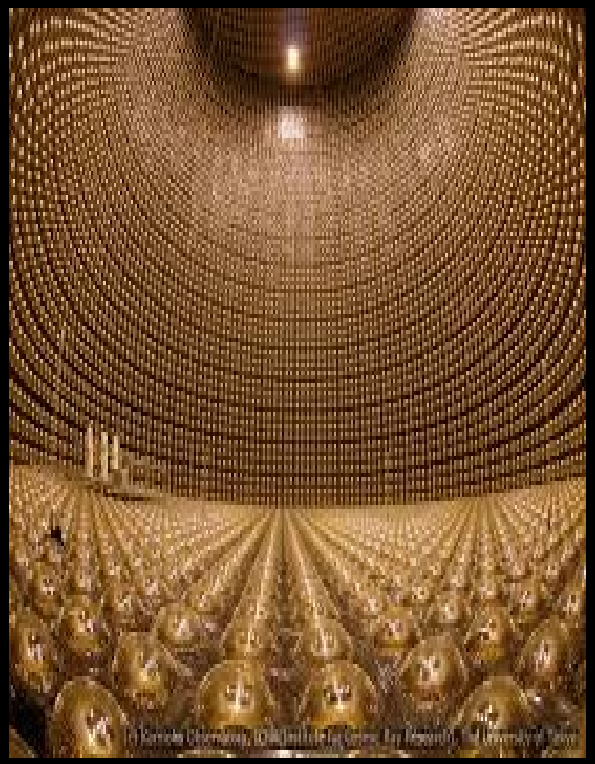
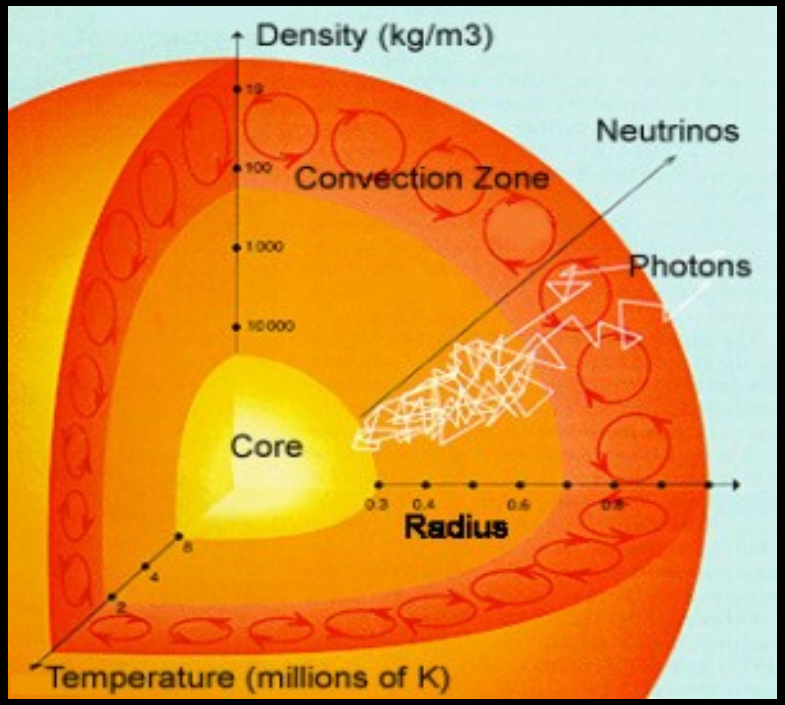

e_α
ν_α
Matter
ν_β
e_β
W
e^-
e^-
W
u
u






Density (kg/m3)
Neutrinos
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Core
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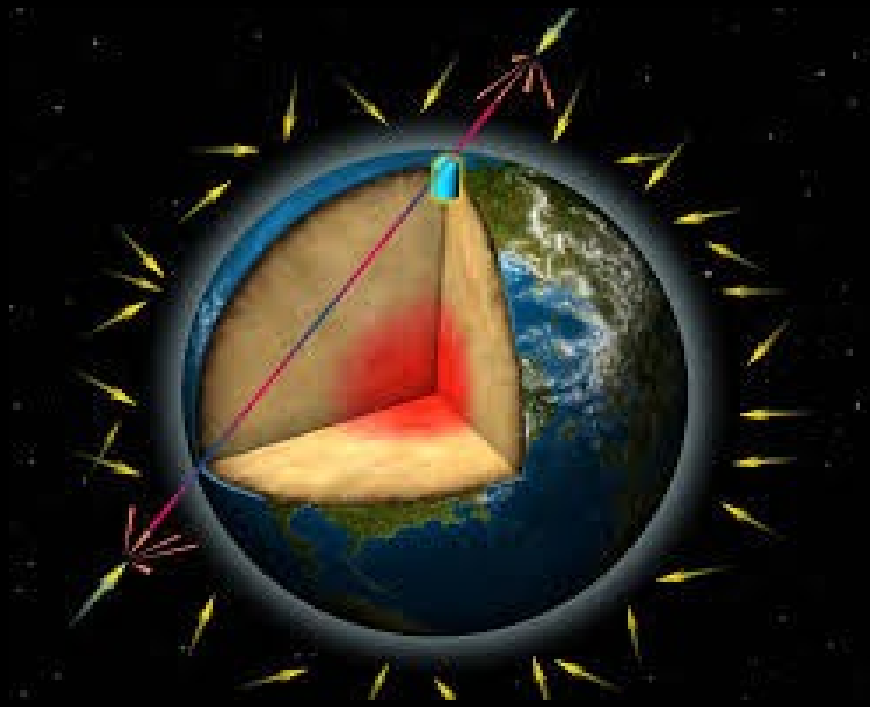
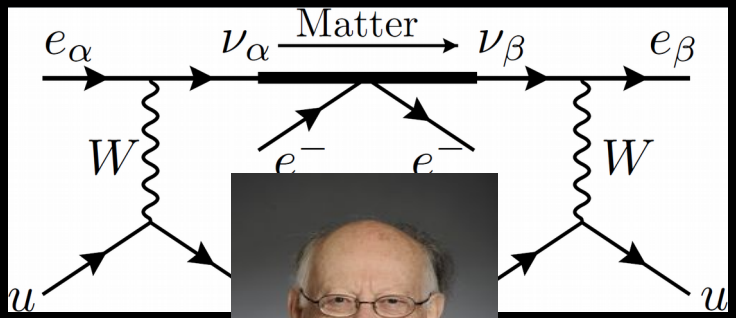
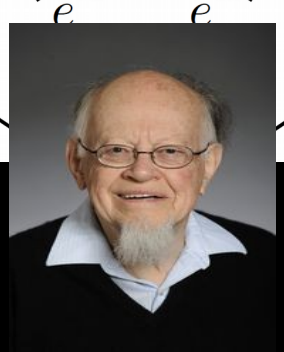
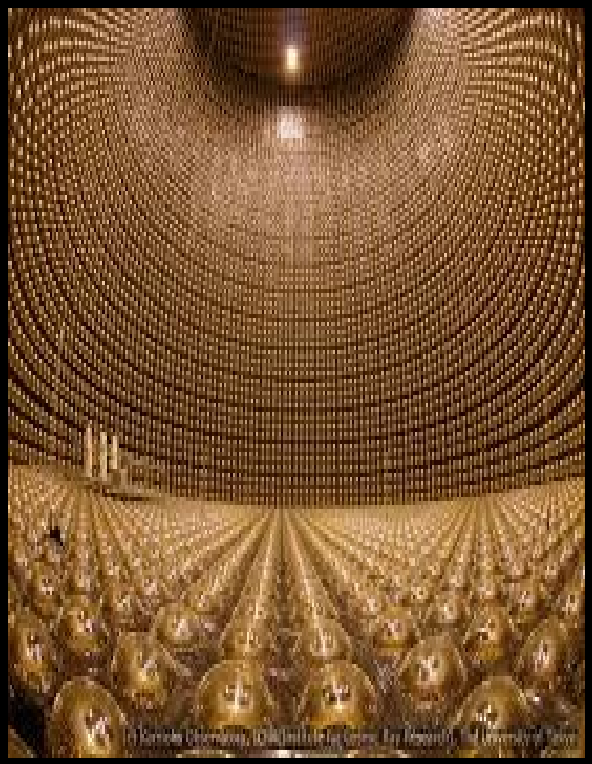
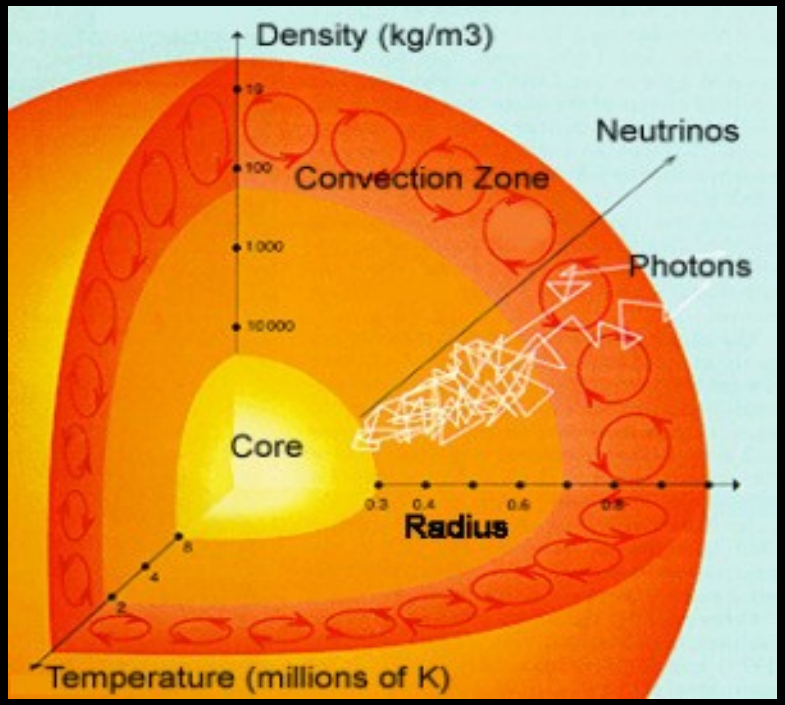
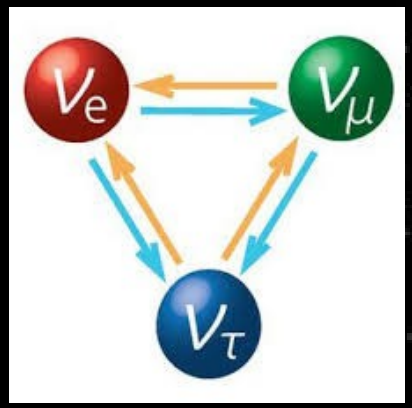


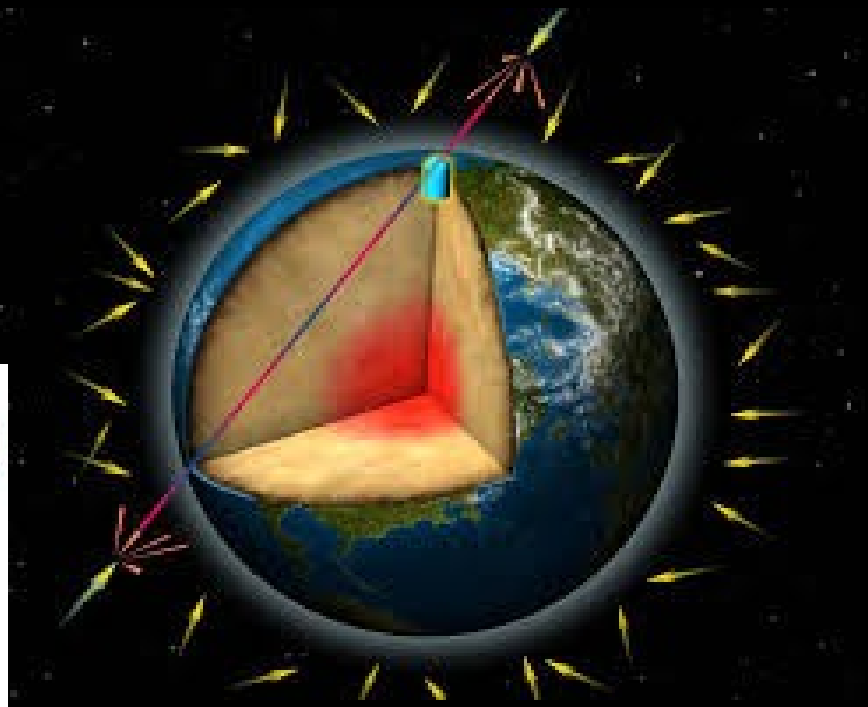

e_α
ν_α
Matter
ν_β
e_β
W
e^-
e^-
W
u
u



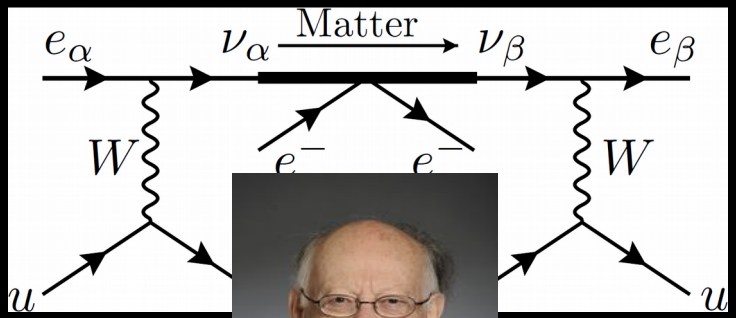


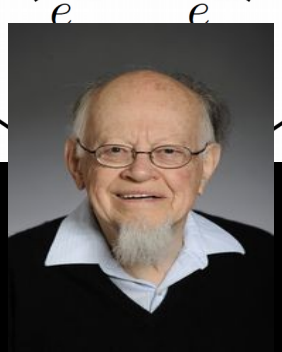


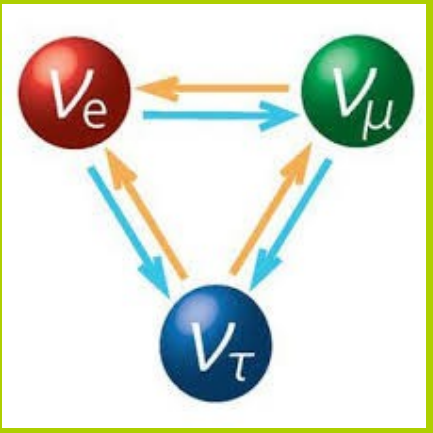




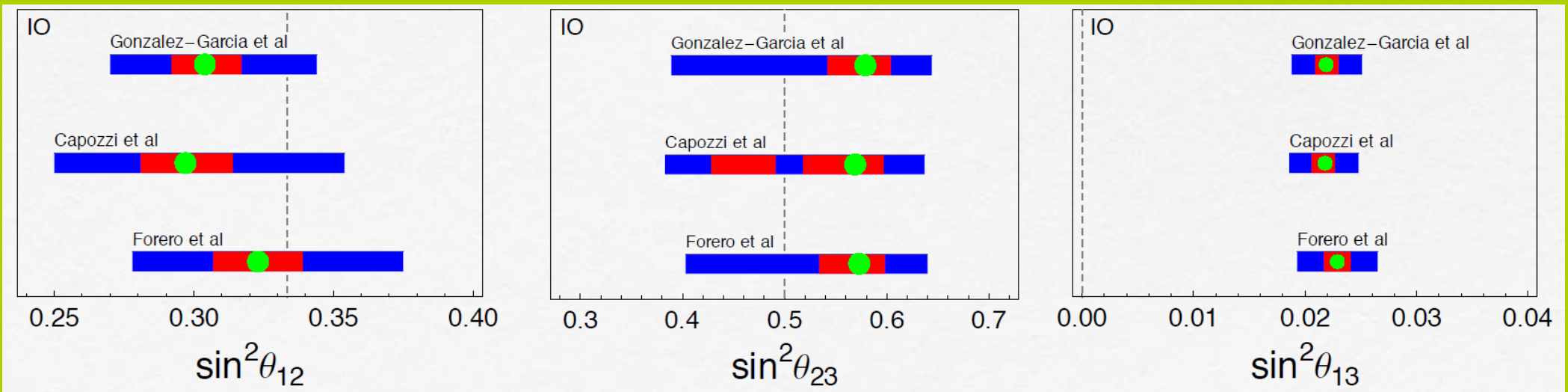
"for the discovery of neutrino oscillations, which shows that neutrinos have mass"

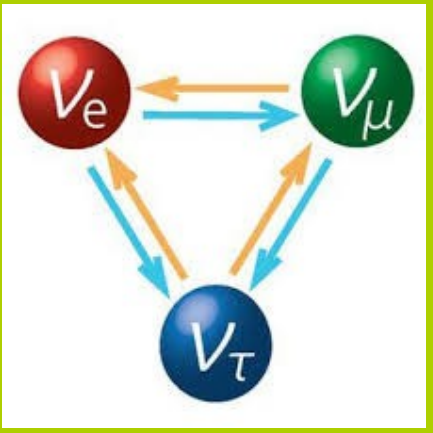






Neutrino oscillation parameters

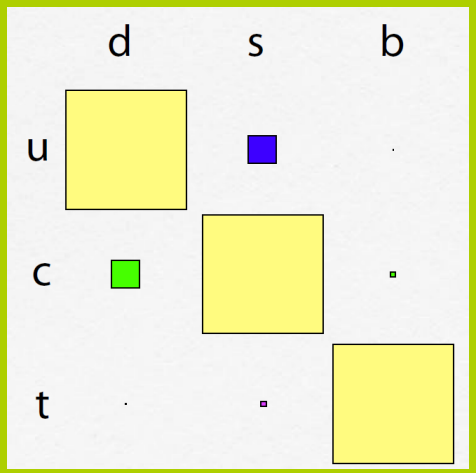




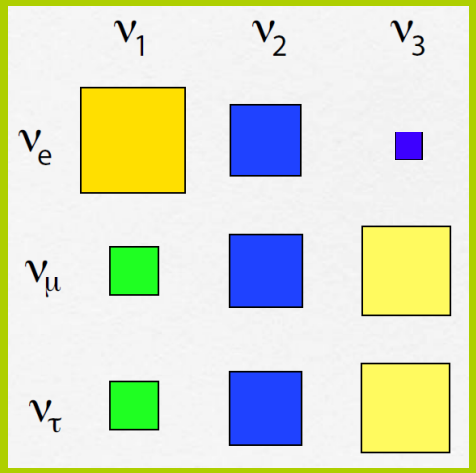
Neutrino oscillation parameters

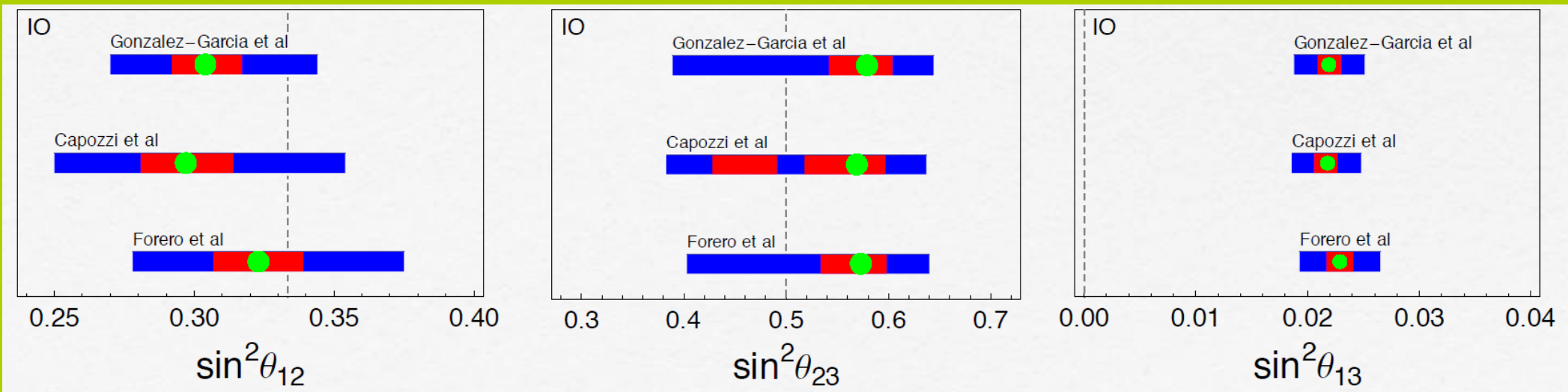
Phys.Lett. B748 (2015) 1-4

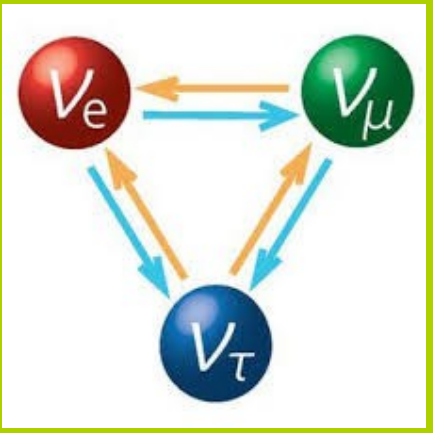
Phys.Rev. D86 (2012) 051301



vs







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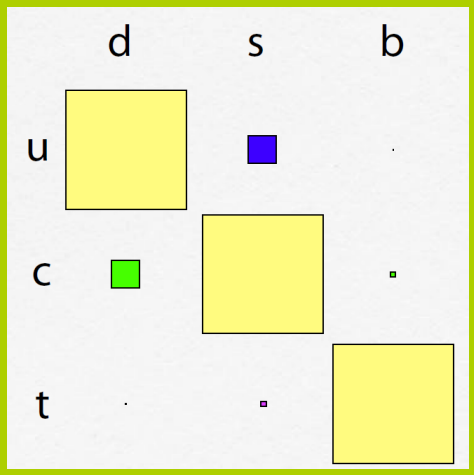
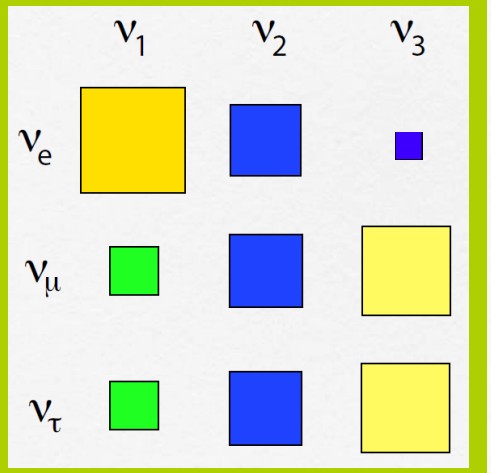
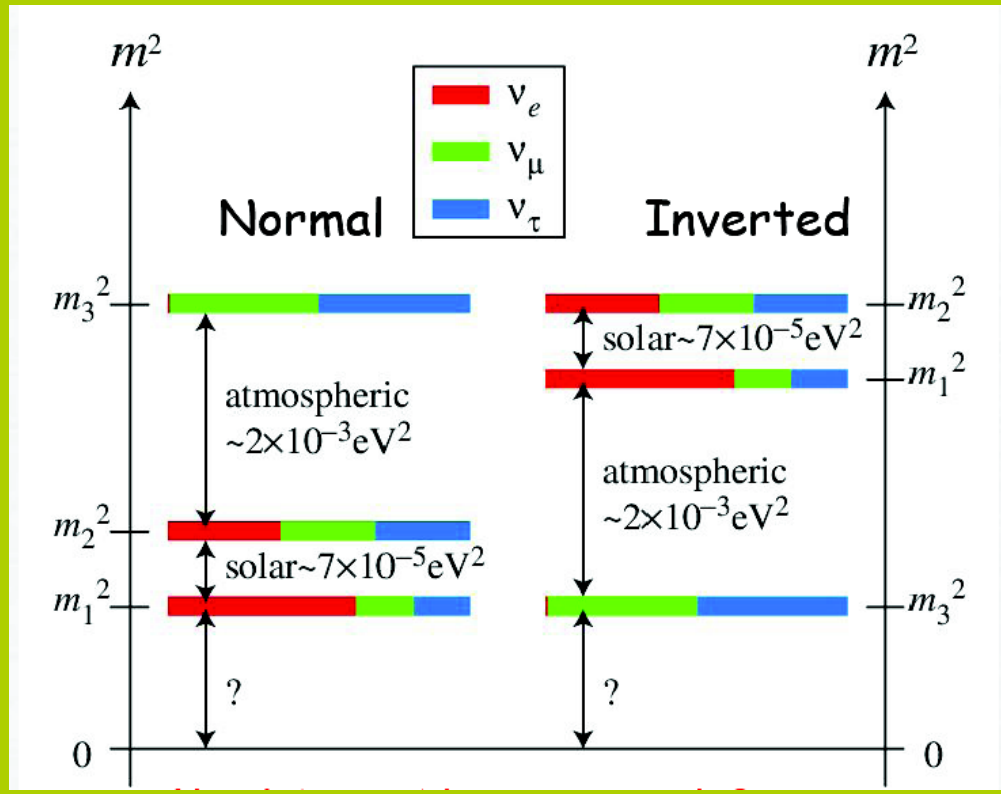
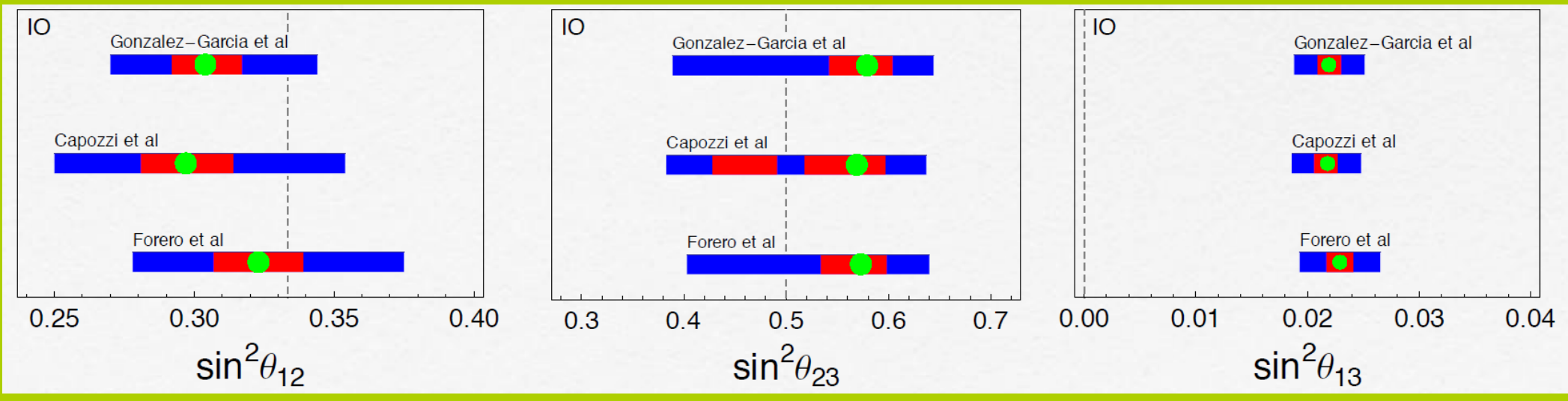
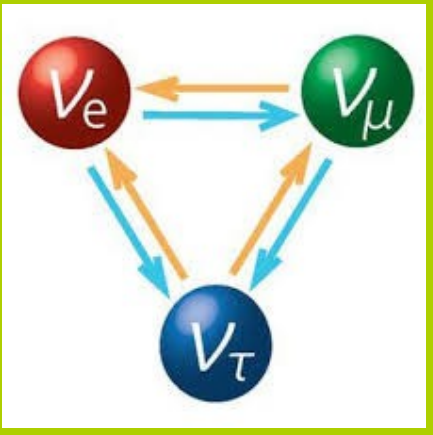


vs





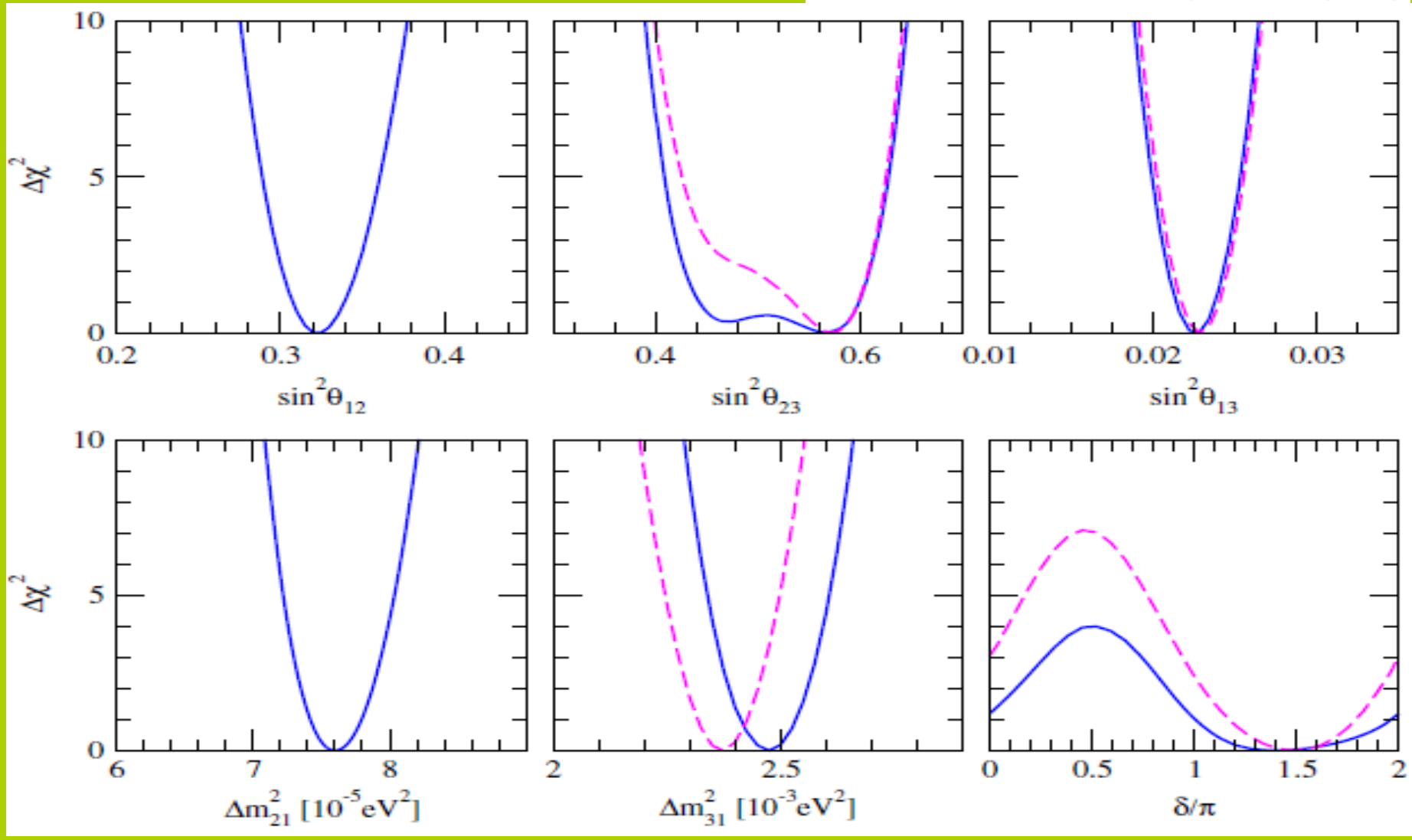




Oscillation parameters

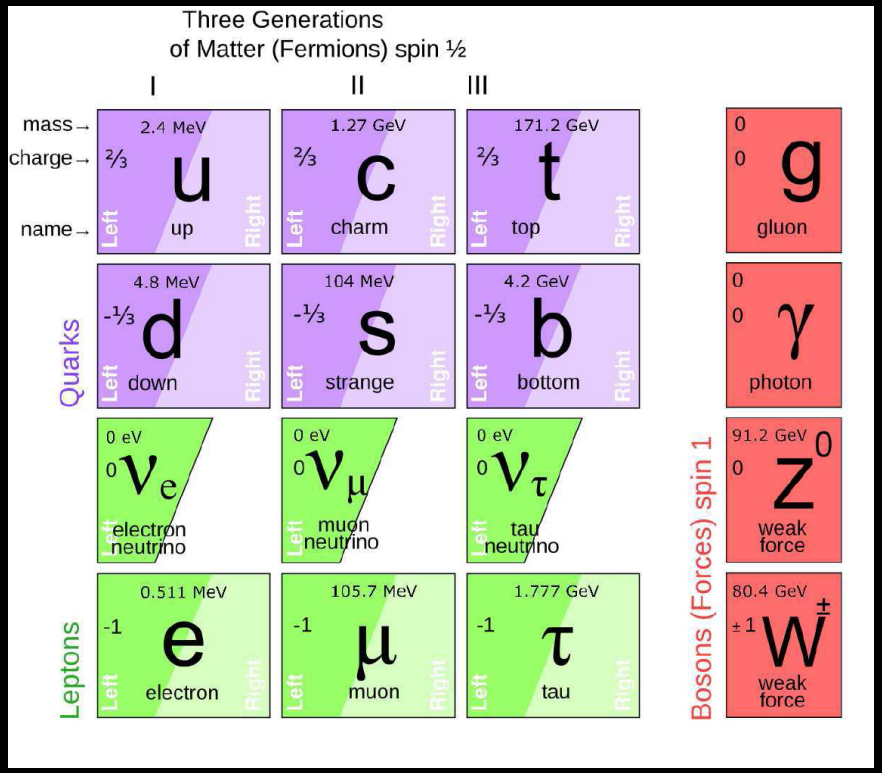
Precision era starts

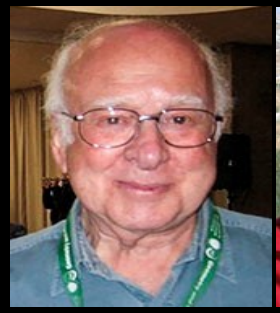
PHYSICAL REVIEW D 90, 093006 (2014)

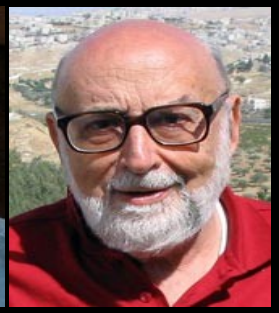


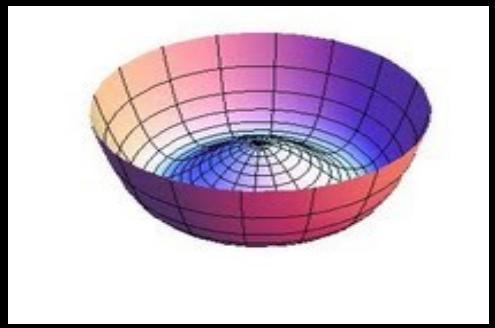
Standard model

$$\mathrm{SU(3)_c} \otimes \mathrm{SU(2)_L} \otimes \mathrm{U(1)_Y}$$









Standard model

$$\mathrm{SU(3)_c \otimes SU(2)_L \otimes U(1)_Y}$$

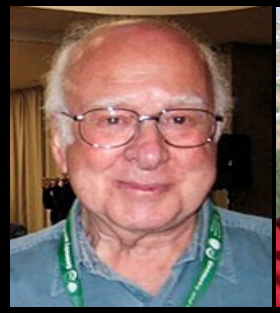
125 GeV
0
0
H
Higgs boson

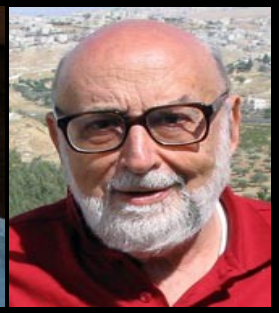
spin 0

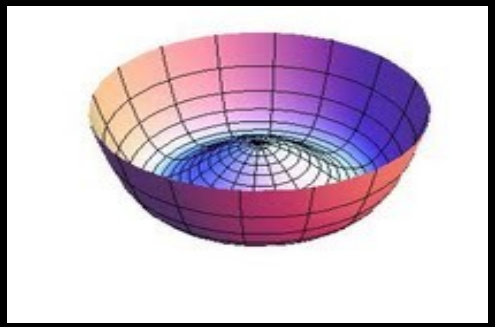
Three Generations of Matter (Fermions) spin ½

	I	II	III	
mass →	2.4 MeV	1.27 GeV	171.2 GeV	0
charge →	⅔	⅔	⅔	0
name →	u up	c charm	t top	g gluon
	4.8 MeV	104 MeV	4.2 GeV	0
Quarks	-⅓ d down	-⅓ s strange	-⅓ b bottom	0 γ photon
	0 eV	0 eV	0 eV	91.2 GeV
	0 ν_e electron neutrino	0 ν_μ muon neutrino	0 ν_τ tau neutrino	0 Z^0 weak force
Leptons	0.511 MeV	105.7 MeV	1.777 GeV	80.4 GeV
	-1 e electron	-1 μ muon	-1 τ tau	±1 $W^\pm$ weak force

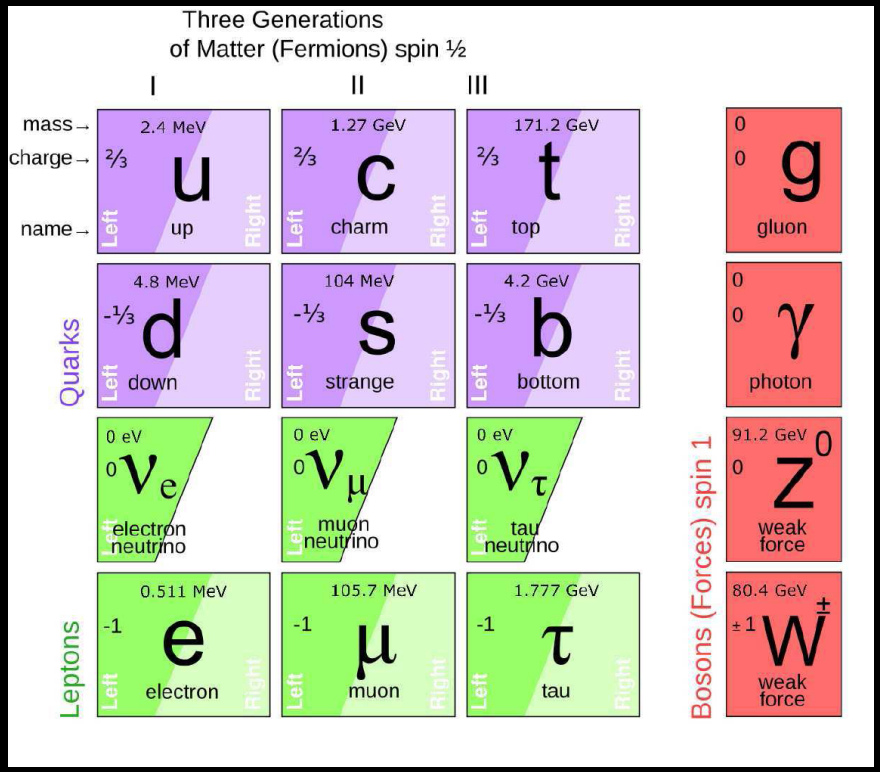
Bosons (Forces) spin 1

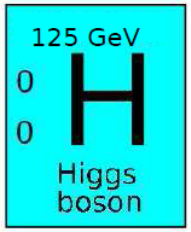






Standard model



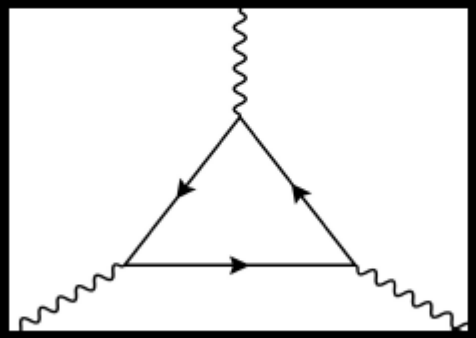


spin 0

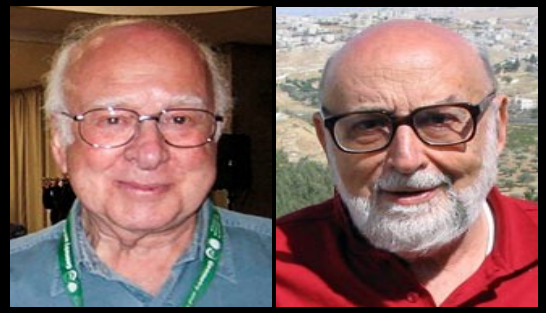
$$\mathrm{SU(3)_c} \otimes \mathrm{SU(2)_L} \otimes \mathrm{U(1)_Y}$$

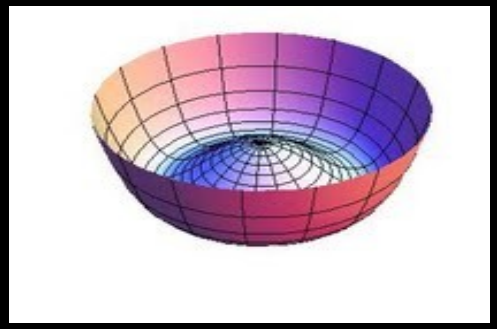
$$-\frac{1}{2} \quad -\frac{1}{2} \quad \frac{1}{6} \quad \frac{1}{6} \quad -1 \quad \frac{2}{3} \quad -\frac{1}{3}$$

anomalies

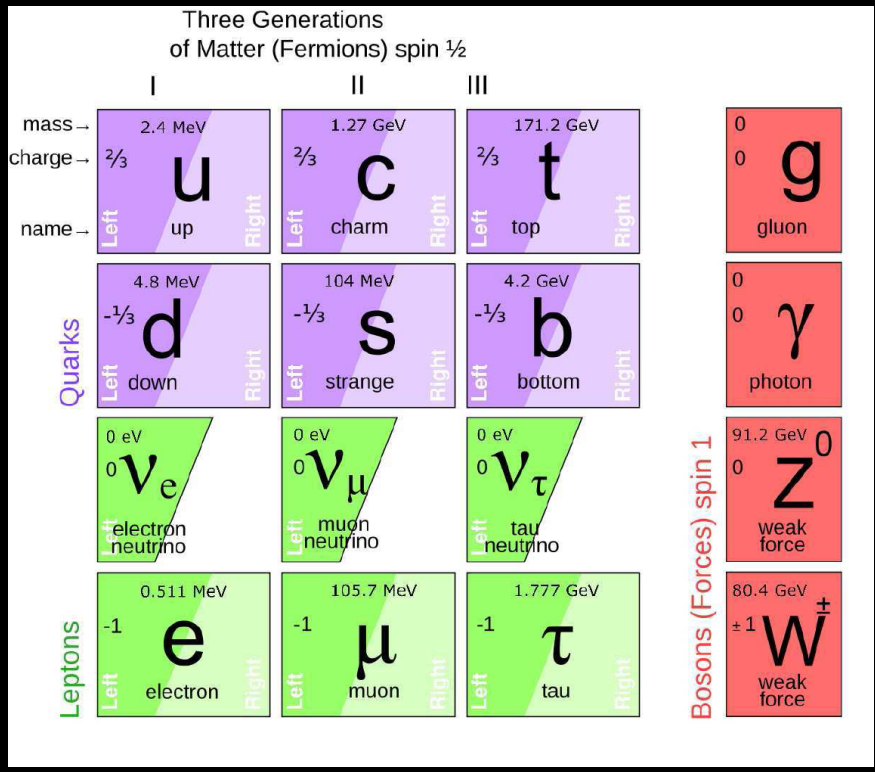


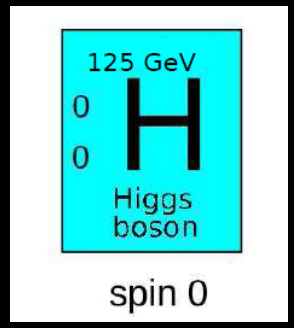
Charge quantization





Standard model

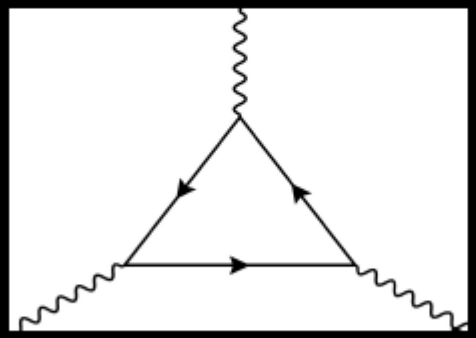




$$\mathrm{SU(3)_c} \otimes \mathrm{SU(2)_L} \otimes \mathrm{U(1)_Y}$$

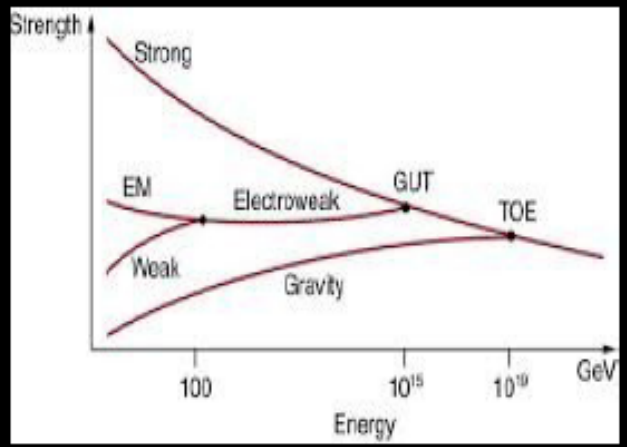
$$-\frac{1}{2} \quad -\frac{1}{2} \quad \frac{1}{6} \quad \frac{1}{6} \quad -1 \quad \frac{2}{3} \quad -\frac{1}{3}$$

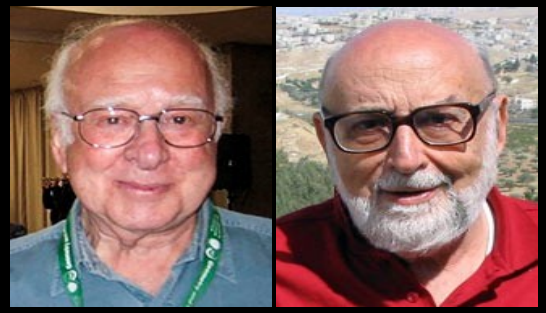
anomalies

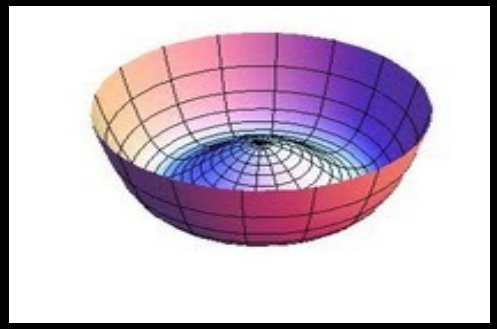


Charge quantization

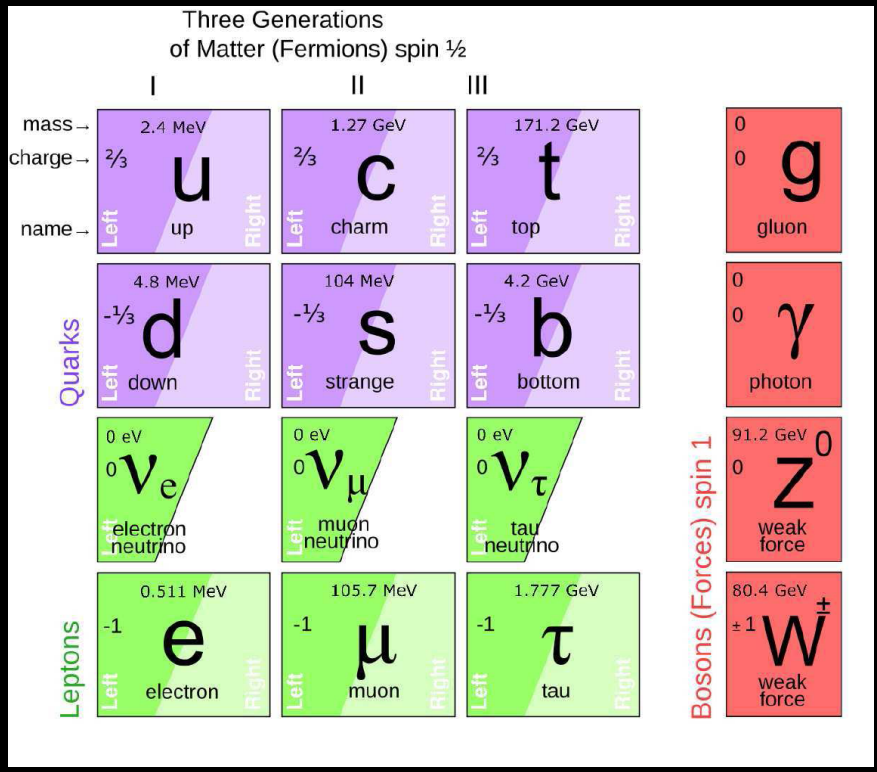
coupling unification

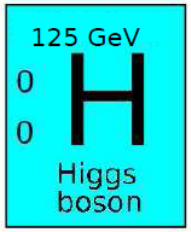






Standard model



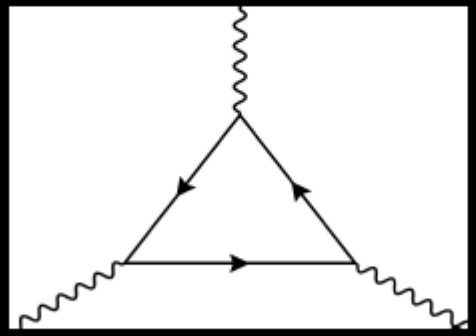


spin 0

$$\mathrm{SU(3)_c \otimes SU(2)_L \otimes U(1)_Y}$$

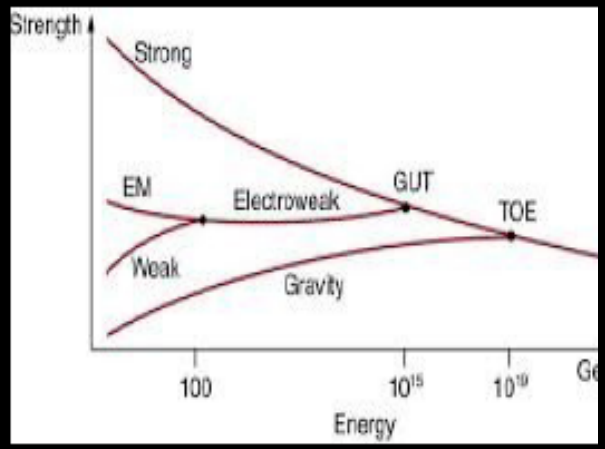
$$-\frac{1}{2} \quad -\frac{1}{2} \quad \frac{1}{6} \quad \frac{1}{6} \quad -1 \quad \frac{2}{3} \quad -\frac{1}{3}$$

anomalies

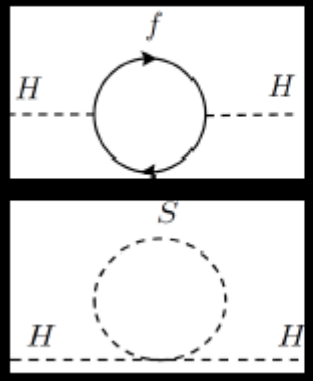


Charge quantization

coupling unification



Consistency of SSB



Gravity ...

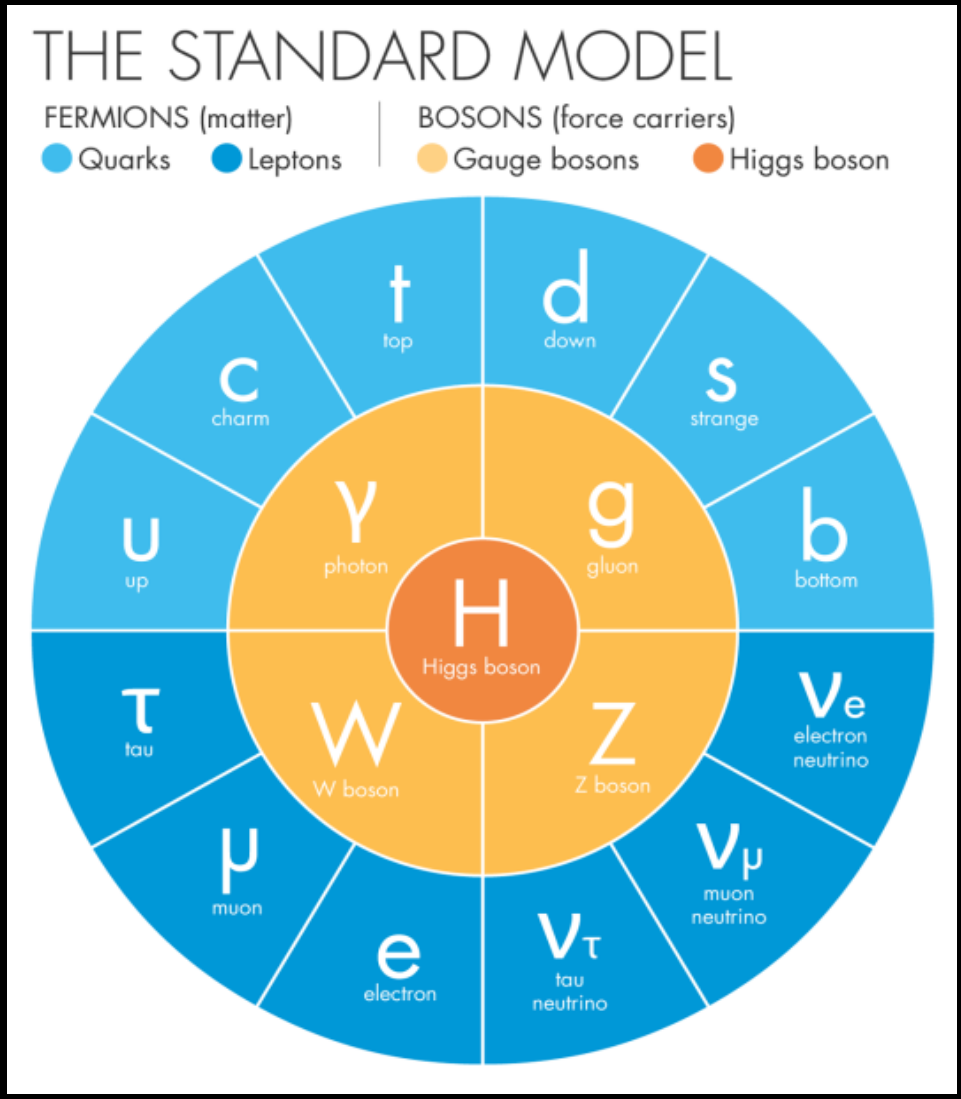
Neutrino mass

Why 3 families ...

However exciting …

Higgs not the last brick !

Standard model

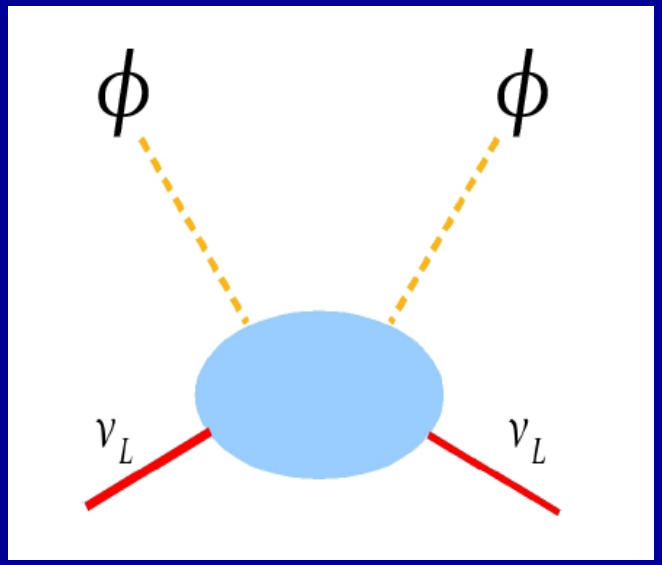


Despite its great success
SM can not explain neutrinos

… A key building block of the Standard Model

need to generate
tiny masses for neutrinos

The origin of neutrino mass

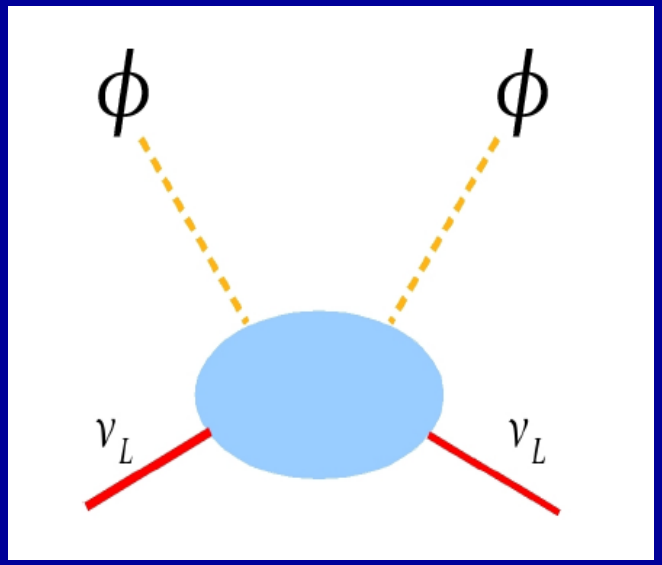


MECHANISM

SCALE

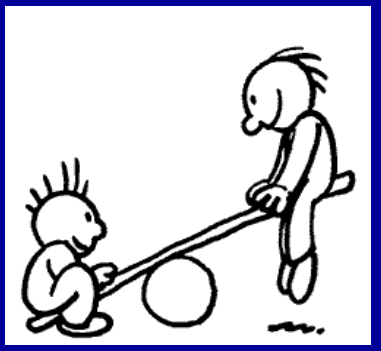
FLAVOR STRUCTURE

The origin of neutrino mass



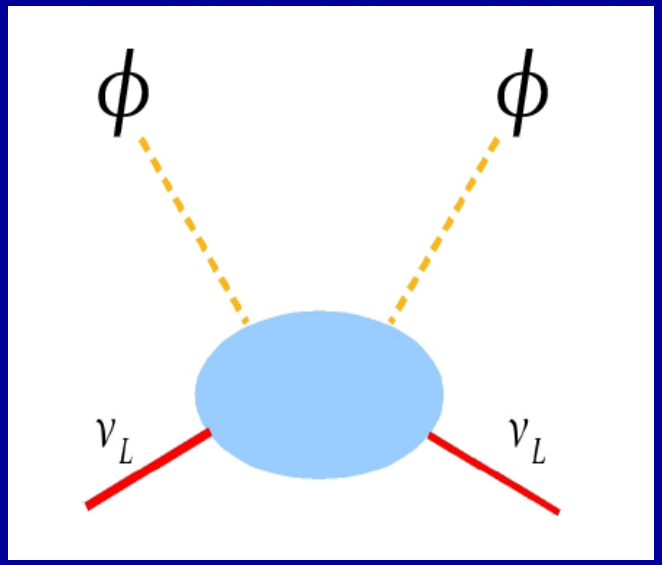
Seesaw

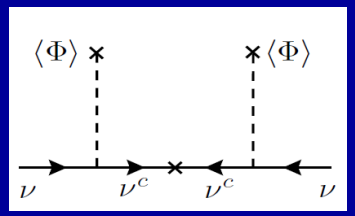
$$v_3 v_1 \sim {v_2}^2$$



- MECHANISM
- SCALE
- FLAVOR STRUCTURE

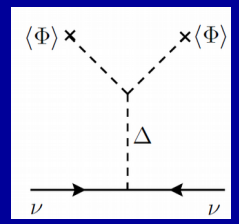
The origin of neutrino mass





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

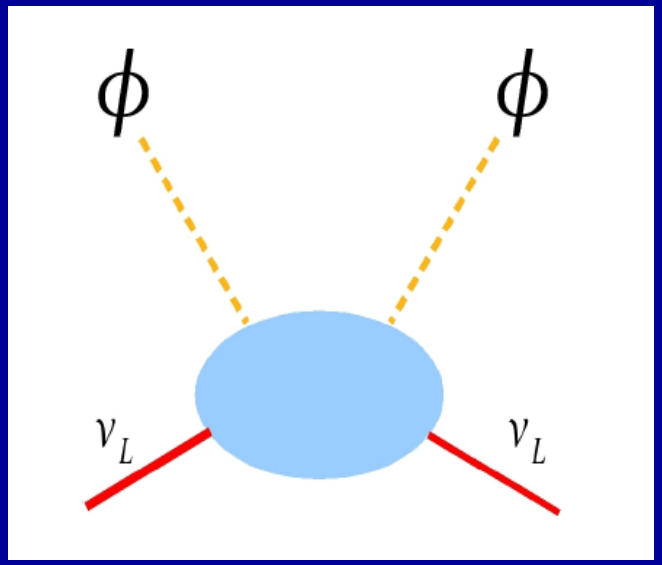
$$v_3 v_1 \sim v_2{}^2$$

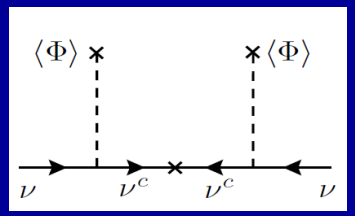
MECHANISM

SCALE

FLAVOR STRUCTURE

The origin of neutrino mass





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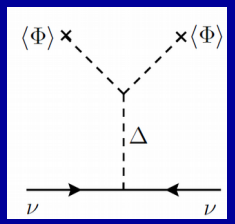

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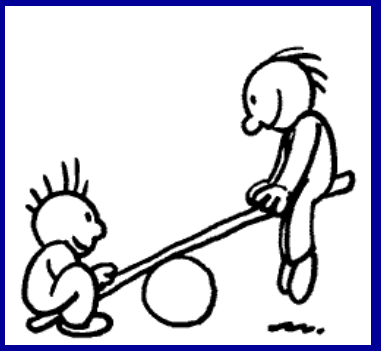


MECHANISM

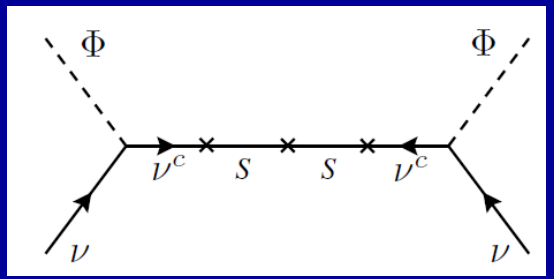
SCALE

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



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

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(relatively low–mass) type-I seesaw
messenger responsible for inducing neutrino mass

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non-unitary propagation hints associated
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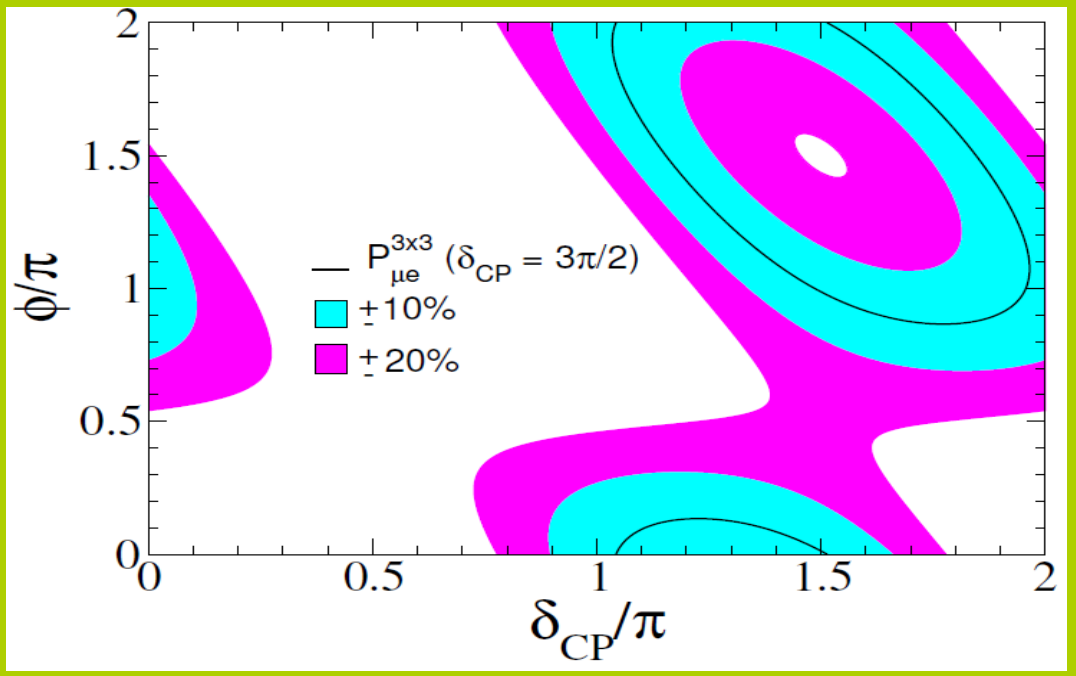
$$P_{\mu e} = \alpha_{11}^2 \alpha_{22}^2 P_{\mu e}^{3\times 3} + \alpha_{11}^2 \alpha_{22} |\alpha_{21}| P_{\mu e}^{I} + \alpha_{11}^2 |\alpha_{21}|^2$$

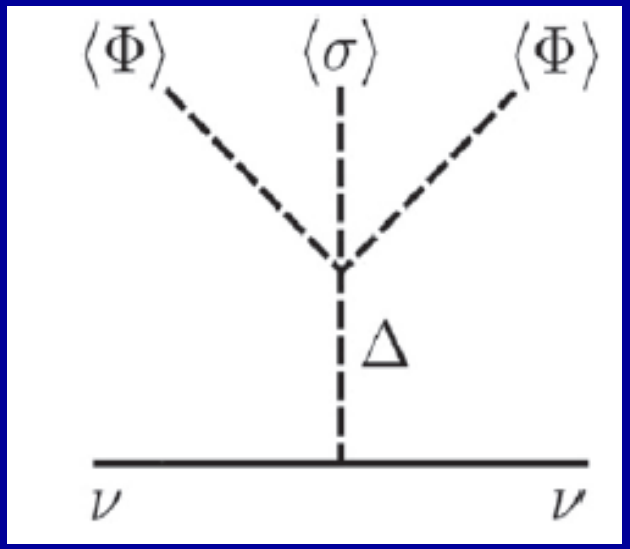
PhysRevLett.117.061804

CP confusion

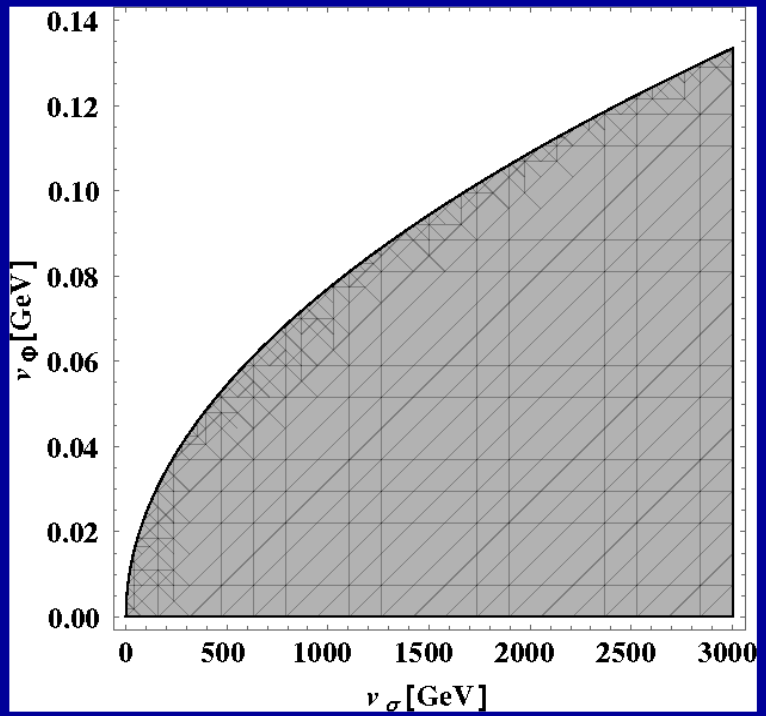


type-II seesaw with spont U(1) violation

Phys.Rev. D25 (1982) 774



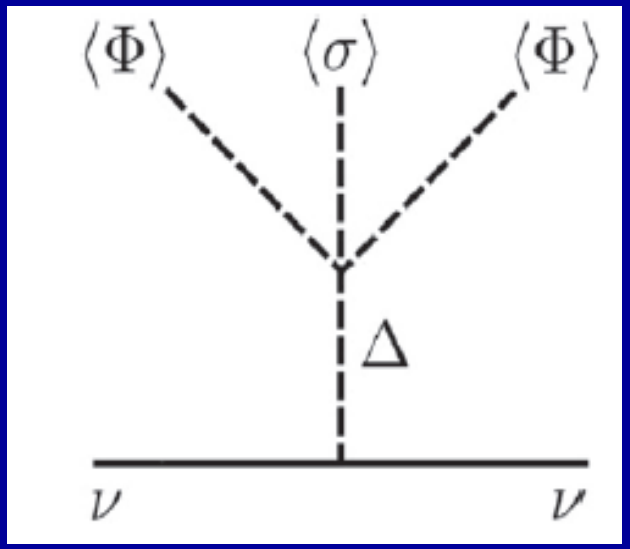
Astrophysical limit



type-II seesaw with spont U(1) violation

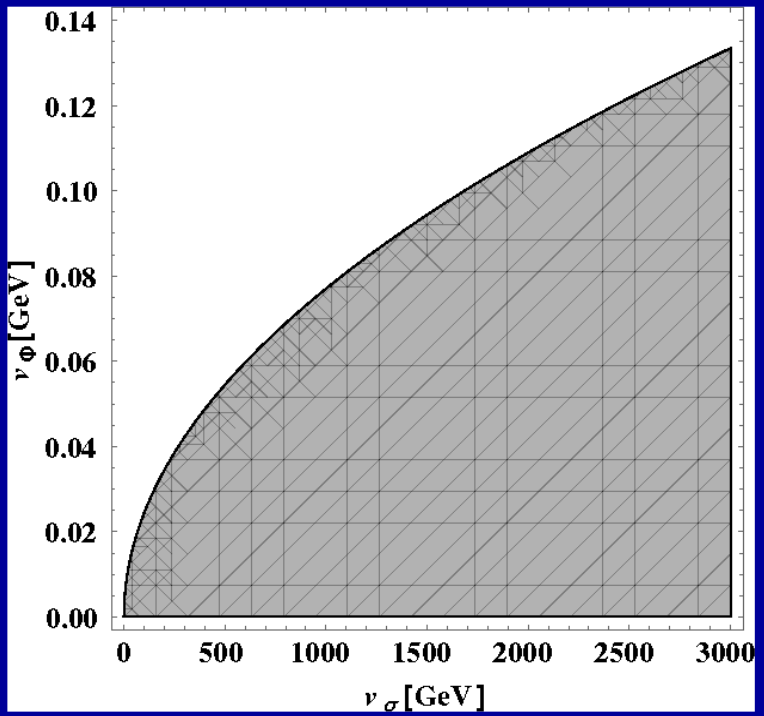
Phys.Rev. D25 (1982) 774

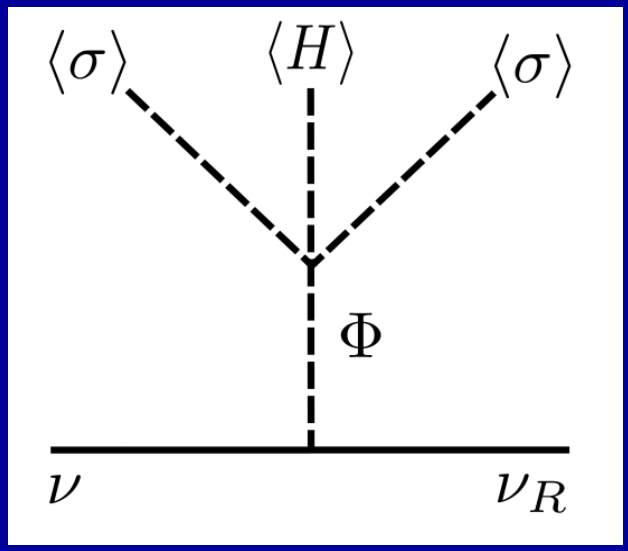
- **Lepton # from accidental global U(1)**
- **Naturally small induced vev**



Majoron
vs
Diracon

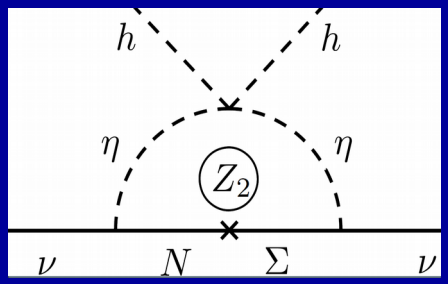
Astrophysical limit





ArXiv:1605.08362 PLB

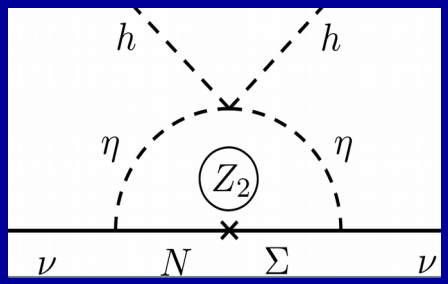
Another approach to tiny neutrino masses



Radiative neutrino mass

many low-scale neutrino mass schemes ...

arXiv:1404.3751



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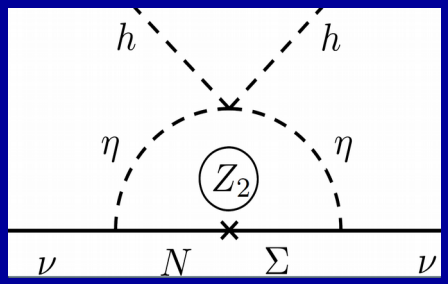
331 electroweak theory # generations = # colours

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



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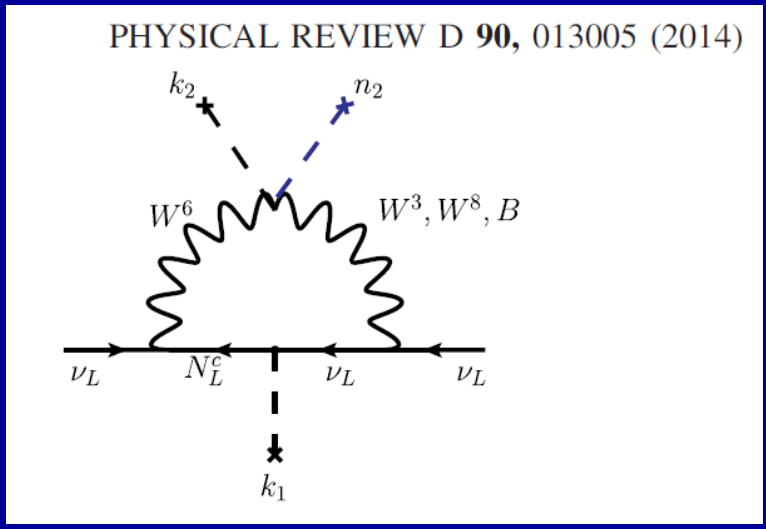
Gauge vs Higgs



BOUCENNA, MORISI, AND VALLE

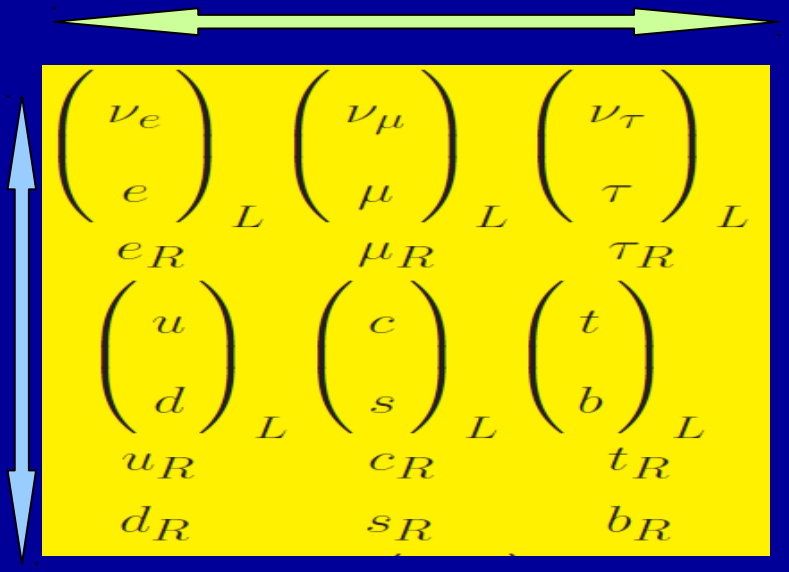
TABLE I. Matter content of the model, where $\hat{u}_R \equiv (u_R, c_R, t_R, t'_R)$ and $\hat{d}_R \equiv (d_R, s_R, b_R, d'_R, s'_R)$ (see text).

	ψ_L^ℓ	ℓ_R	$Q_L^{1,2}$	Q_L^3	$\hat{u}_R$	$\hat{d}_R$	S	ϕ_1	ϕ_2	ϕ_3
$SU(3)_c$	**1**	**1**	**3**	**3**	**3**	**3**	**1**	**1**	**1**	**1**
$SU(3)_L$	$\mathbf{3}^*$	**1**	**3**	$\mathbf{3}^*$	**1**	**1**	**1**	$\mathbf{3}^*$	$\mathbf{3}^*$	$\mathbf{3}^*$
$U(1)_X$	$-\frac{1}{3}$	-1	0	$+\frac{1}{3}$	$+\frac{2}{3}$	$-\frac{1}{3}$	0	$+\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$
$\mathcal{L}$	$-\frac{1}{3}$	-1	$-\frac{2}{3}$	$+\frac{2}{3}$	0	0	1	$+\frac{2}{3}$	$-\frac{4}{3}$	$+\frac{2}{3}$

$$Q = T_3 + \frac{1}{\sqrt{3}} T_8 + X, \qquad (2)$$

$$L = \frac{4}{\sqrt{3}} T_8 + \mathcal{L}. \qquad (3)$$

try to explain
neutrino mixing angles
And fermion mass hierarchies
with flavor symmetries



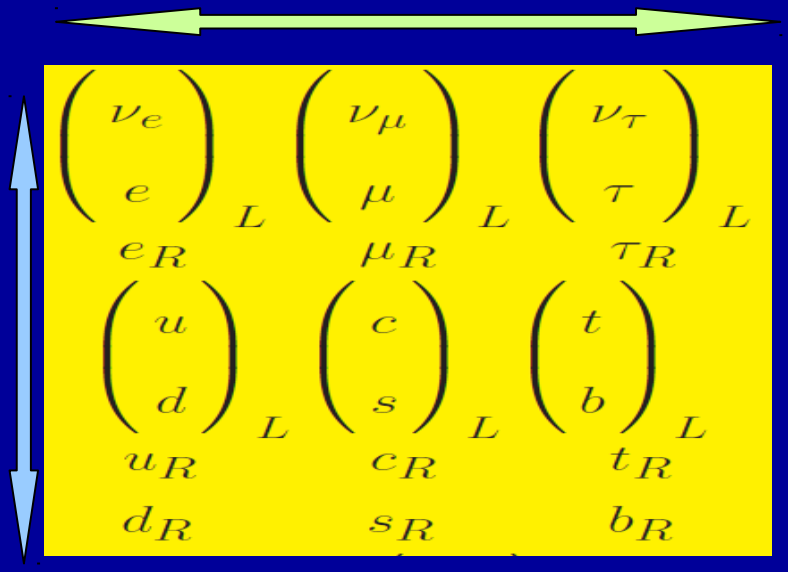
Flavor Symmetry

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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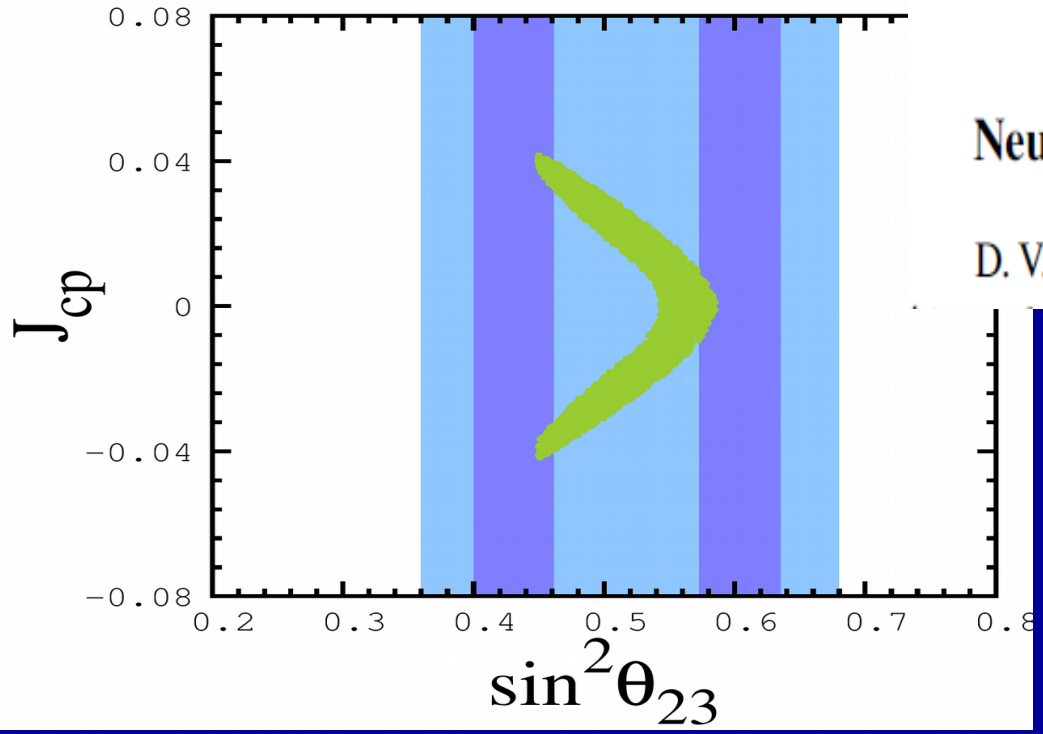


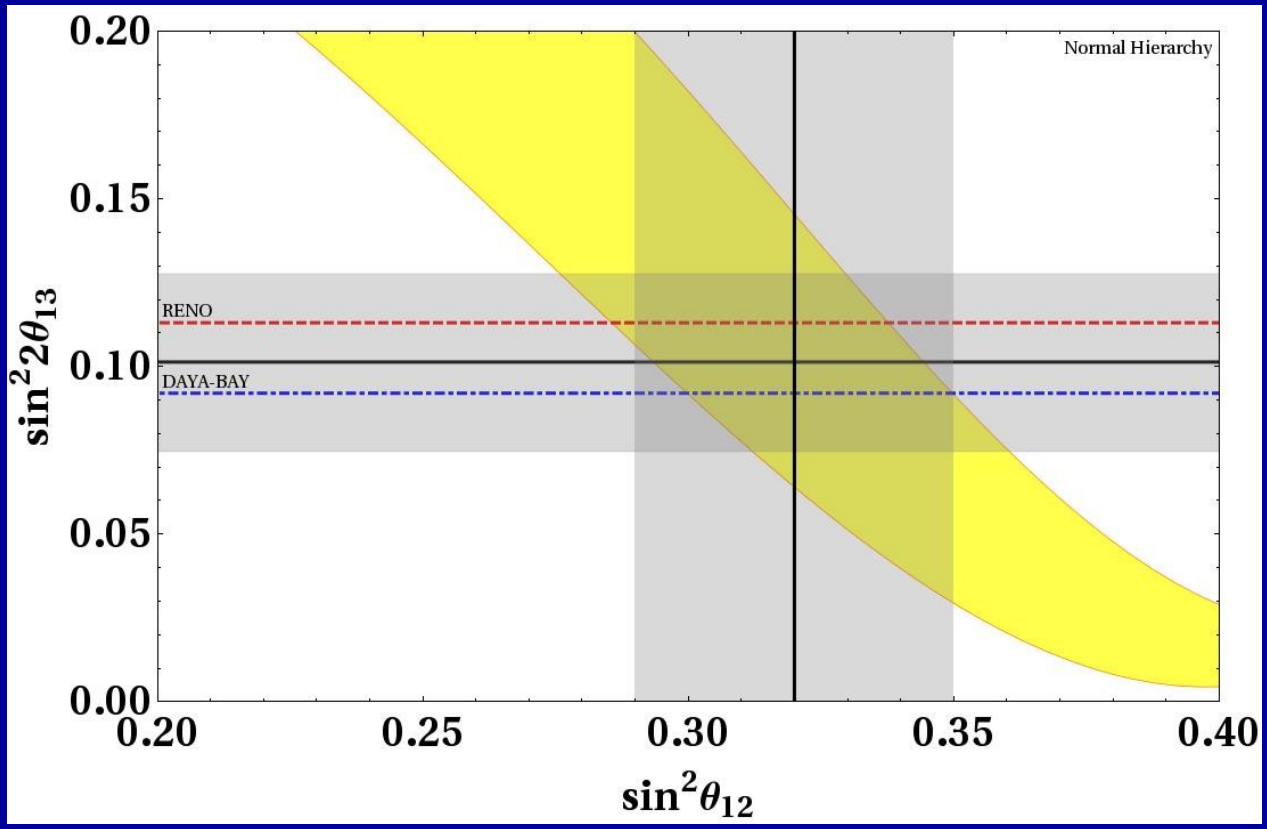
PHYSICAL REVIEW D 88, 016003 (2013)

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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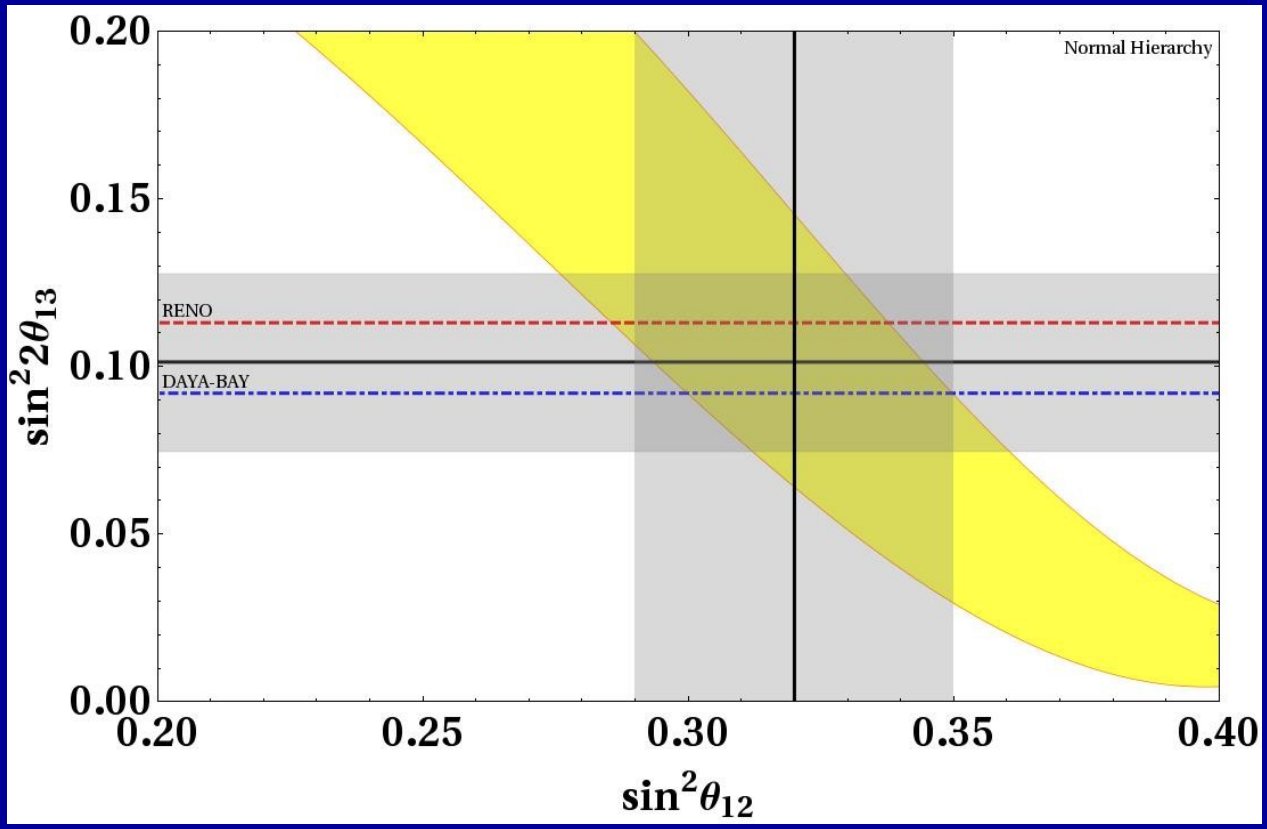
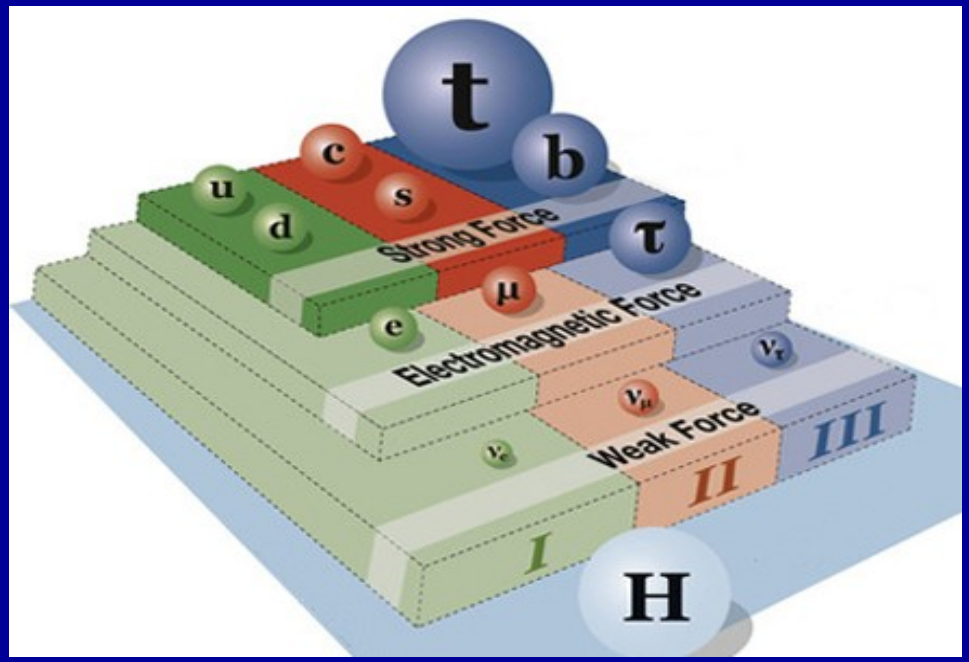


Model-independent flavor approach

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

Can neutrinos shed light on charged fermion masses?

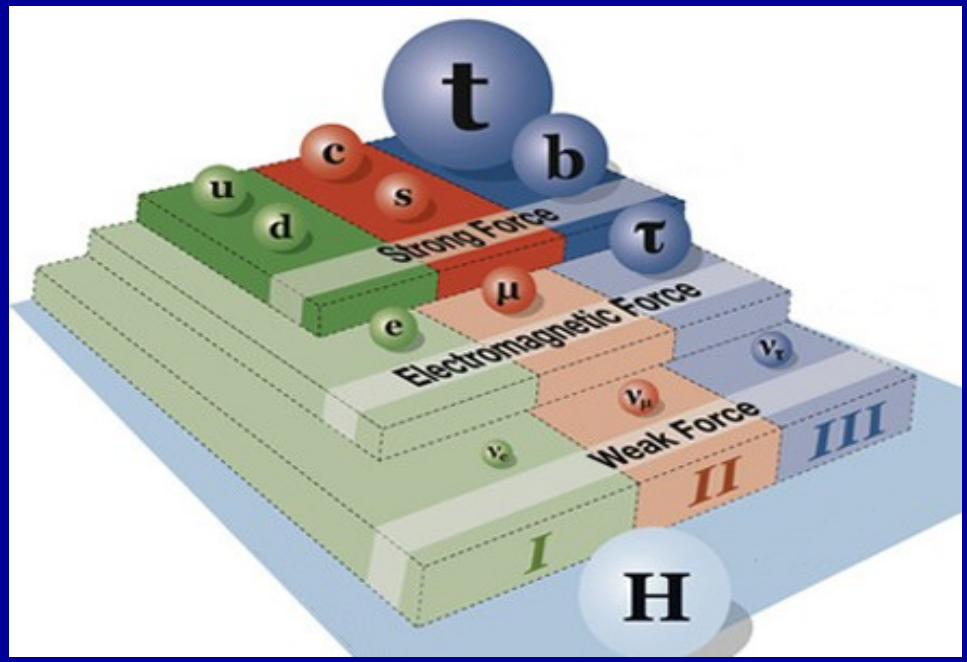


Neutrinos : Lepton number?

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

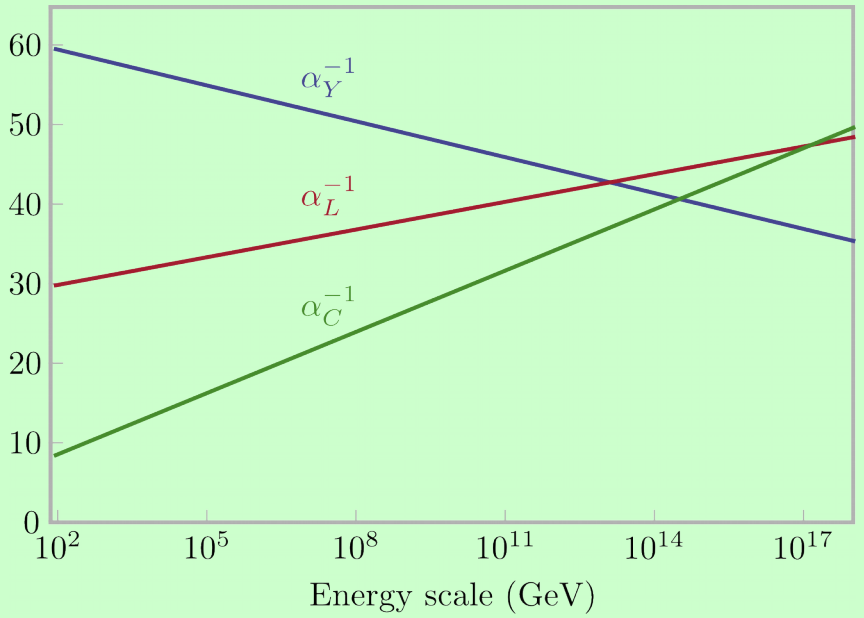
King et al Phys. Lett. B 724 (2013) 68

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

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

Neutrinos : Lepton number?

neutrinos may help unification

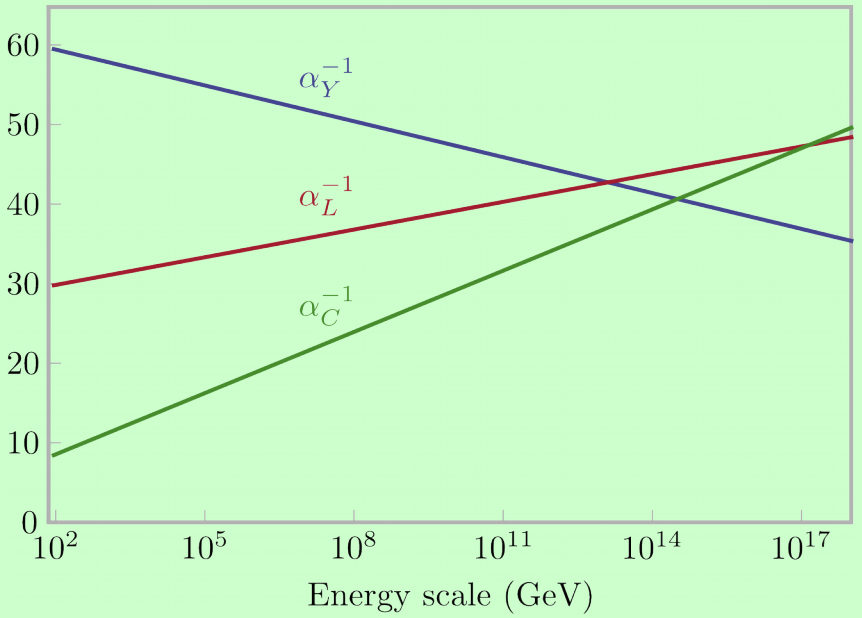


a near miss ...

What makes the gauge couplings unify? SUSY-GUT

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

neutrinos may help unification



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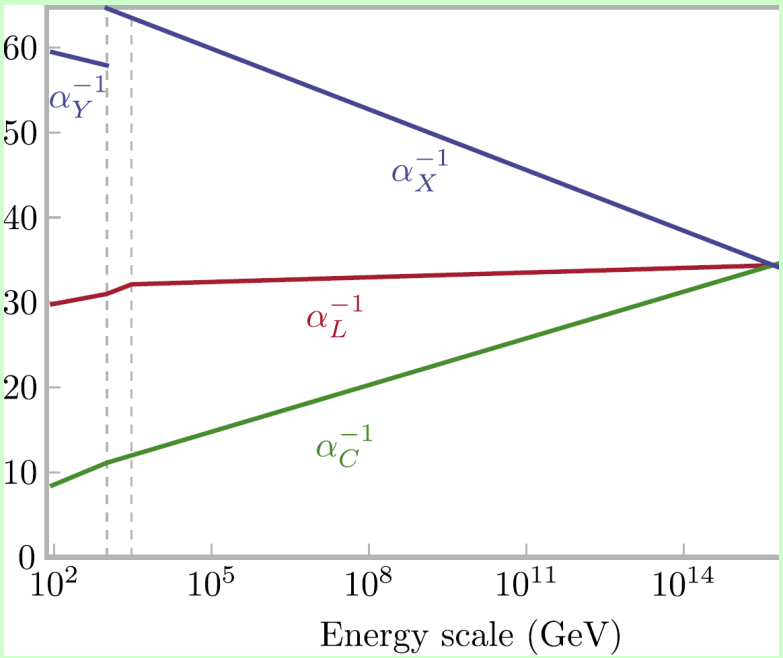
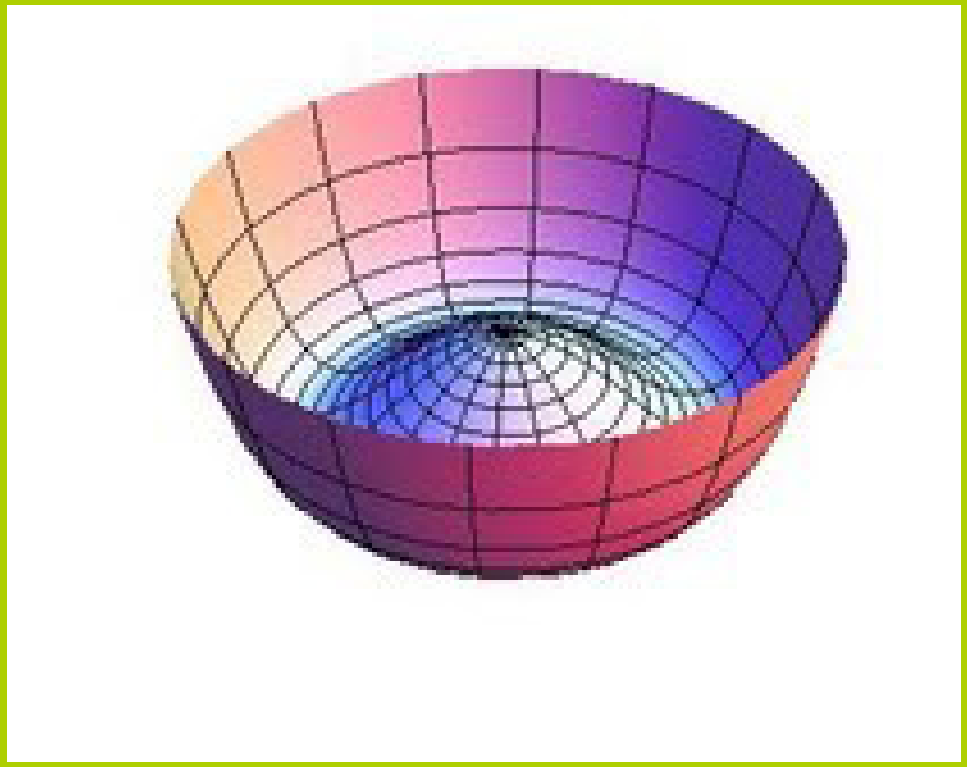


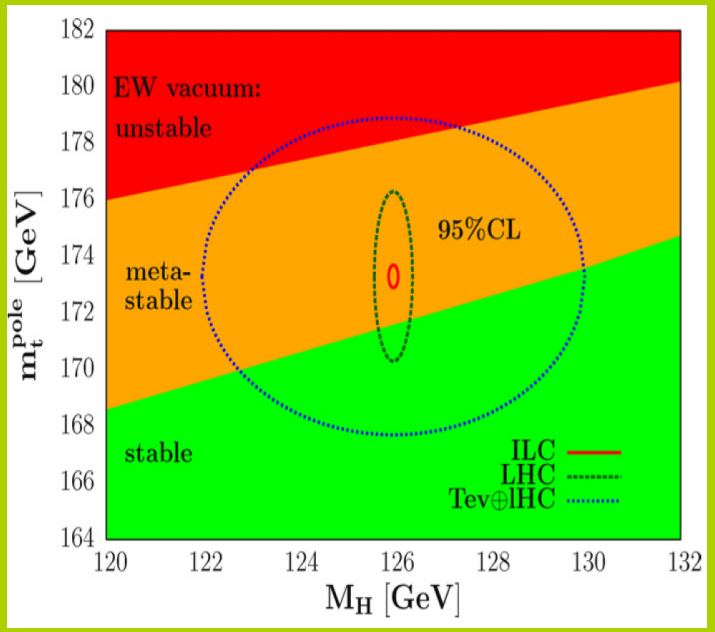
The physics responsible for gauge coupling unification may also induce neutrino masses

Boucenna et al Phys. Rev. D 91, 031702 (2015)
Deppisch et al 1608.05334

neutrinos may help electroweak breaking

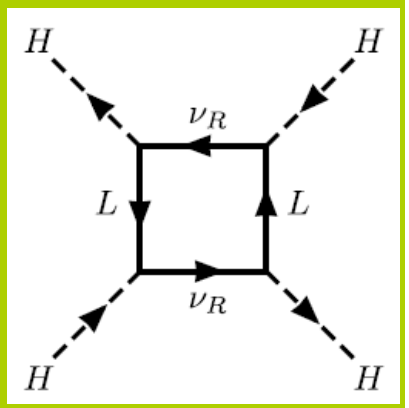


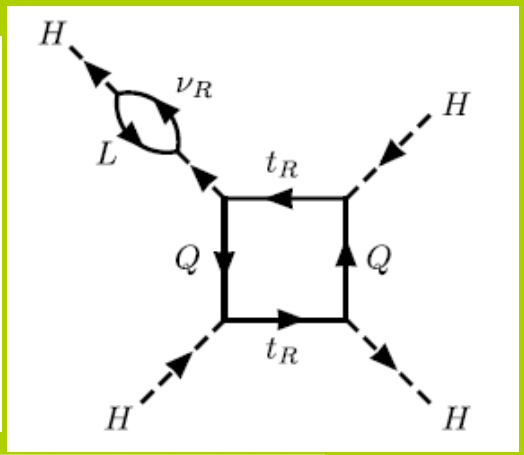
SM vacuum

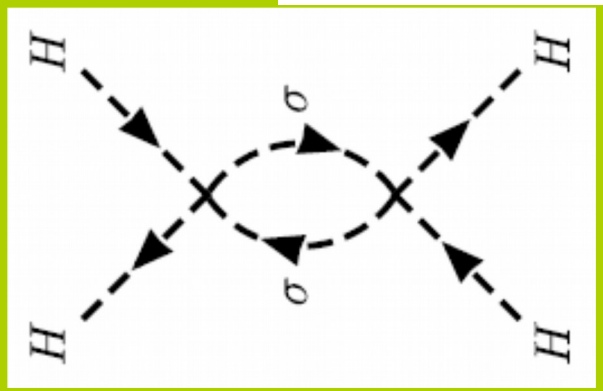

EW vacuum:
unstable
meta-
stable
stable
95%CL
0
ILC
LHC
Tev⊕lHC
m_t^{pole} [GeV]
M_H [GeV]
182
180
178
176
174
172
170
168
166
164
120
122
124
126
128
130
132

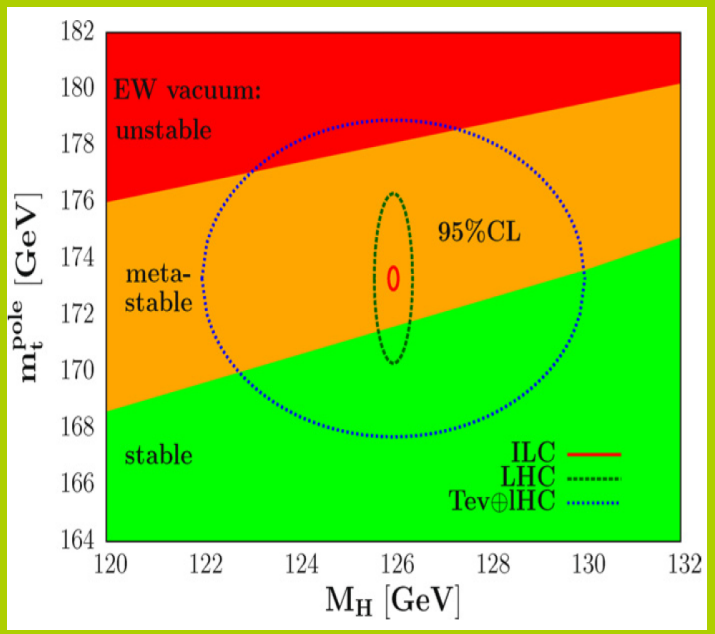
SM vacuum and neutrinos

Physics Letters B 756 (2016) 345–349



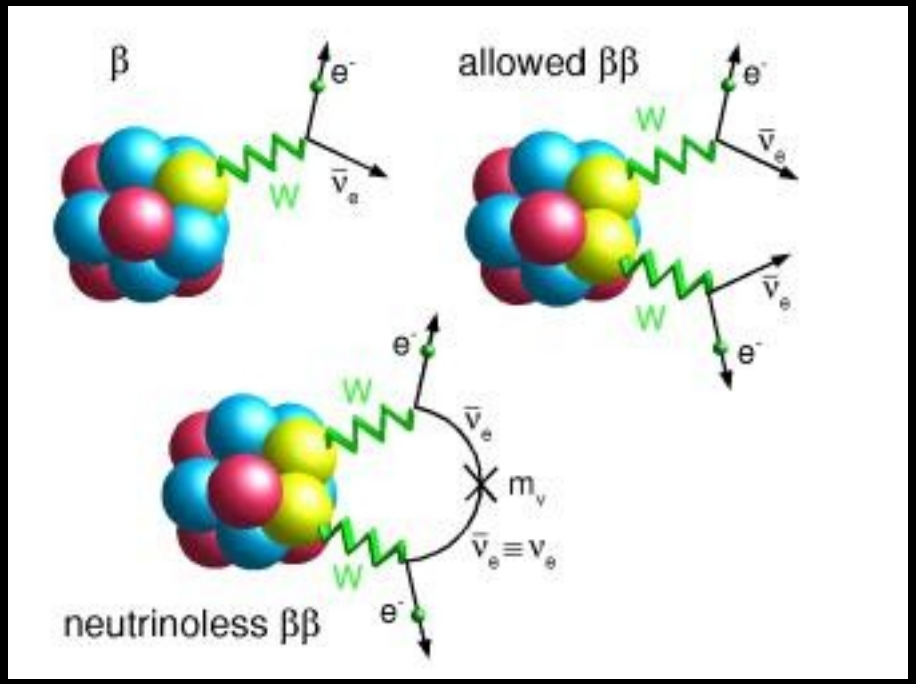


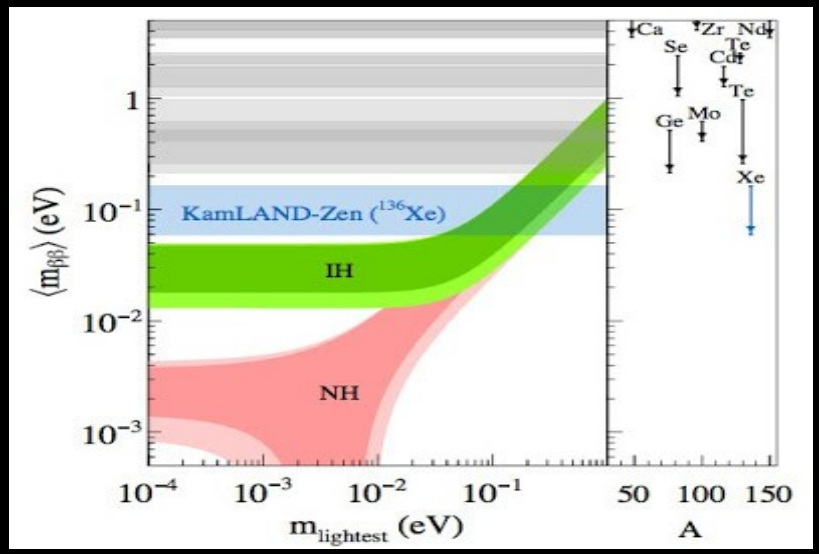




A.S. Barabash arXiv:1104.2714

Neutrinoless double beta decay





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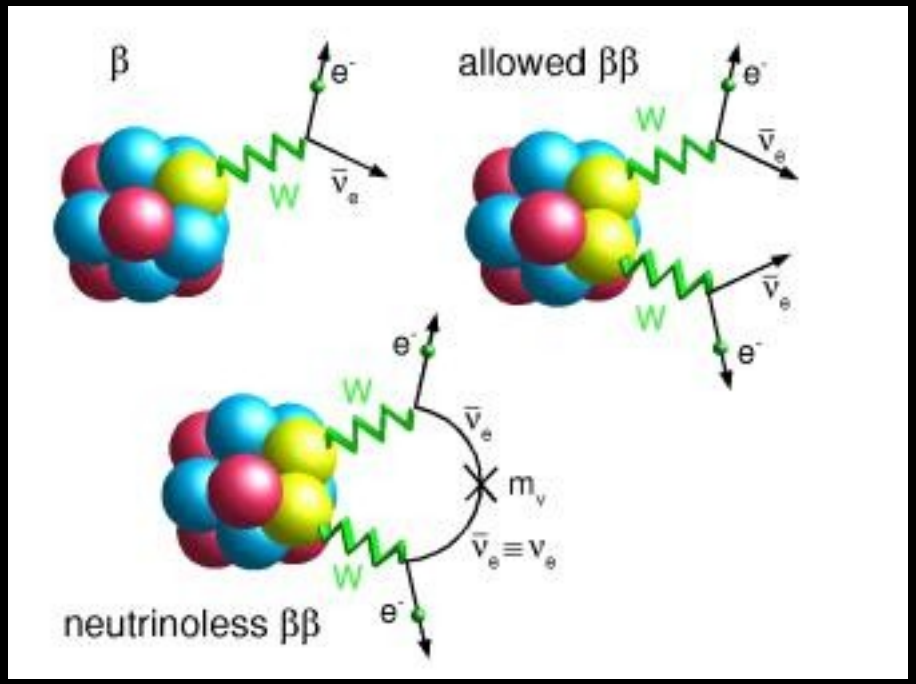
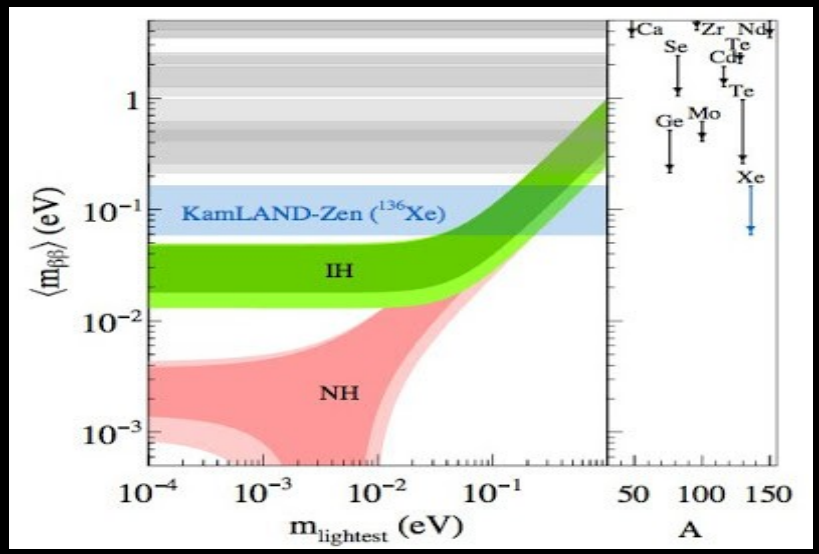
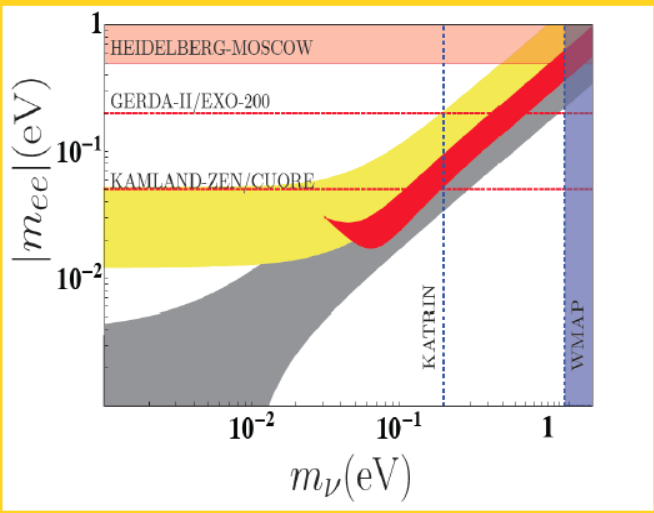
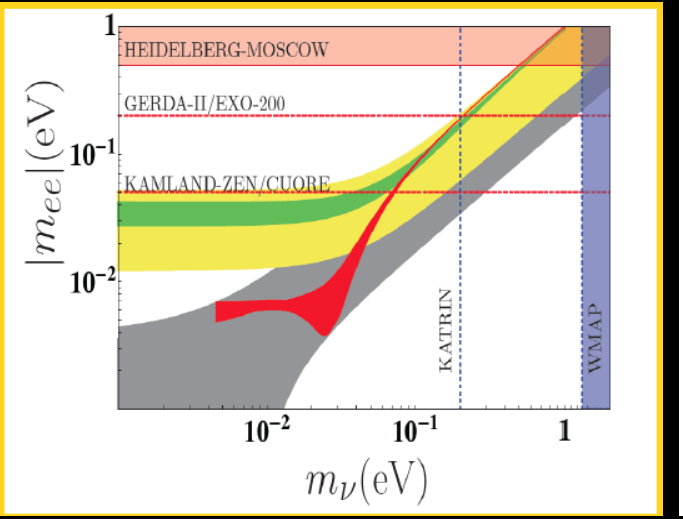
Neutrinoless double beta decay

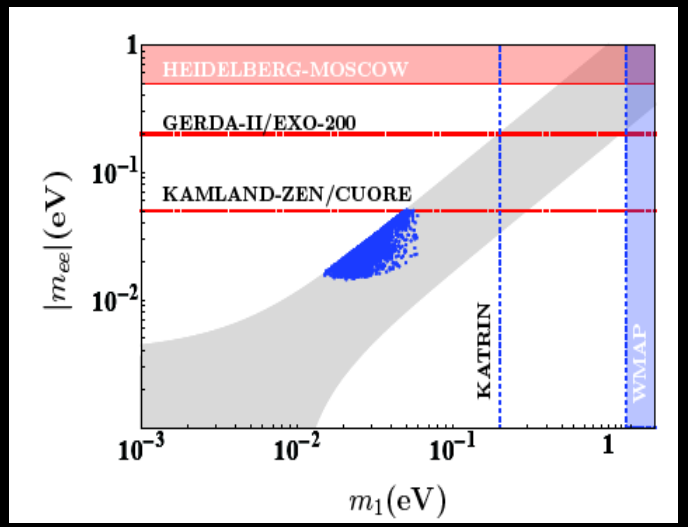




Lower bounds ... Flavor Sensitive





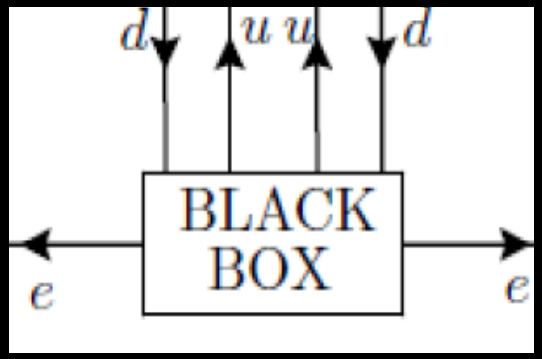


Dorame et al
NPB861 (2012) 259-270

PhysRevD.86.056001

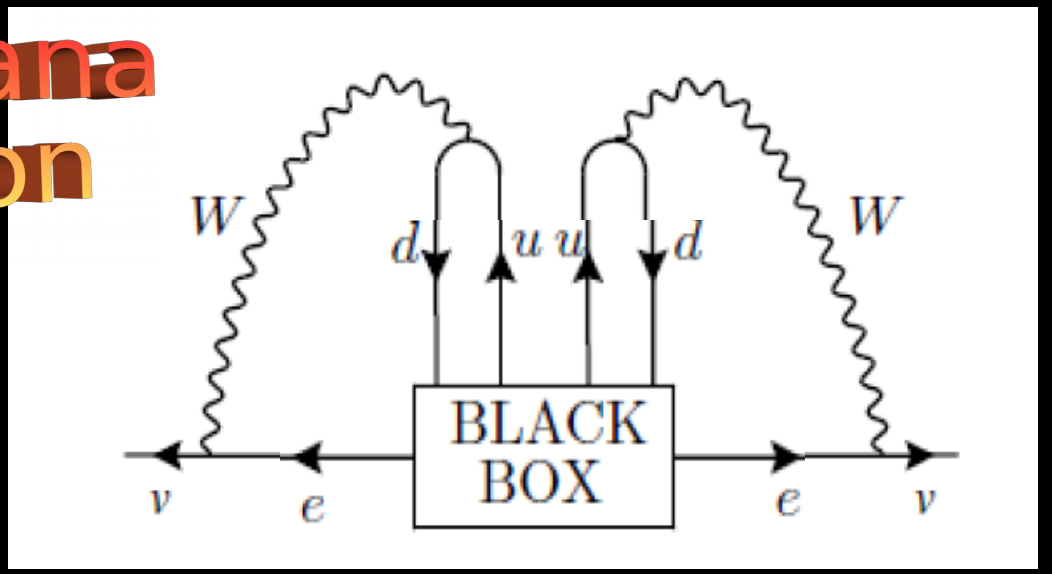
King et al Phys. Lett. B 724 (2013) 68

The Majorana connection



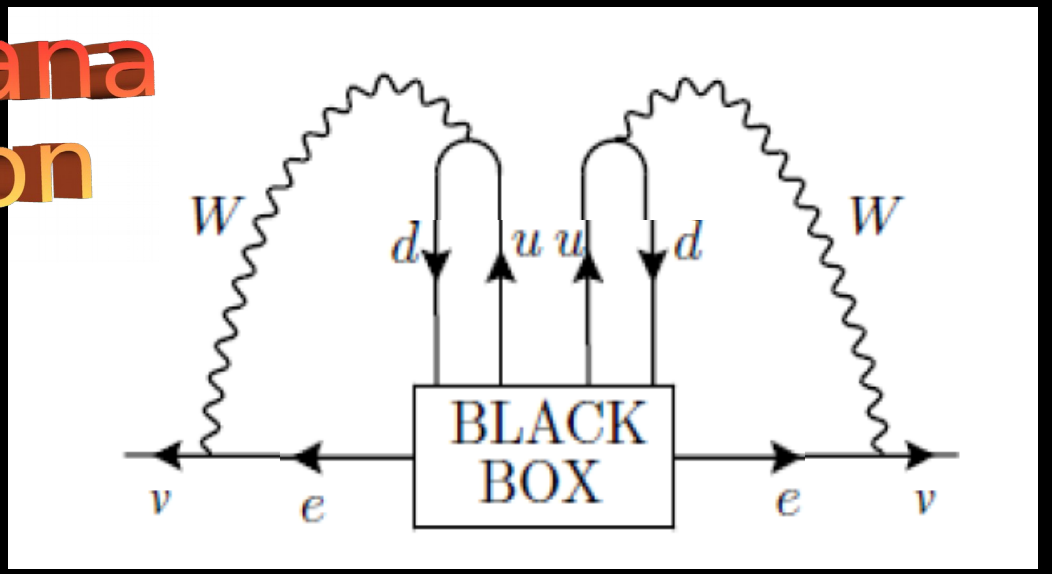
Schechter, JWFV 82
Lindner et al JHEP 1106 (2011) 091

The Majorana connection



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

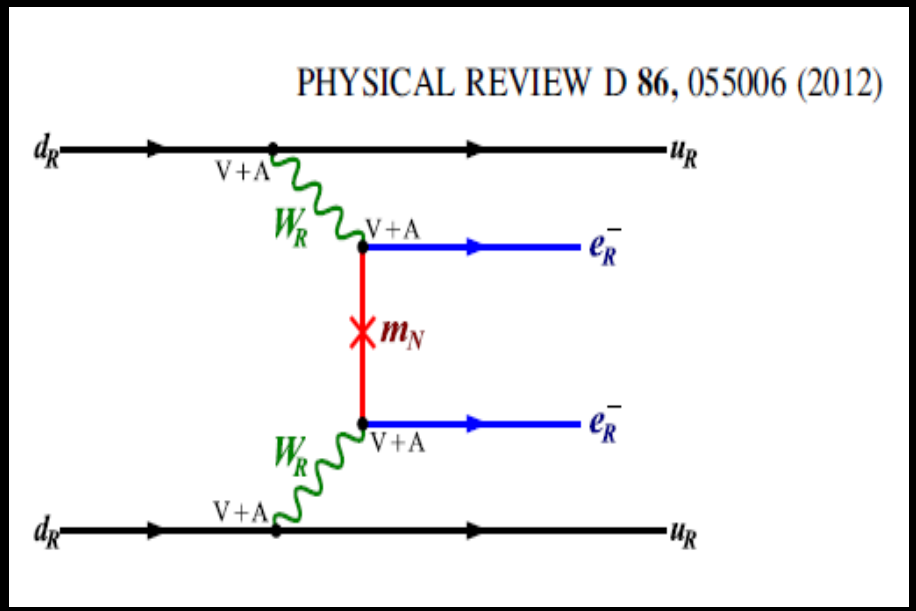
The Majorana connection



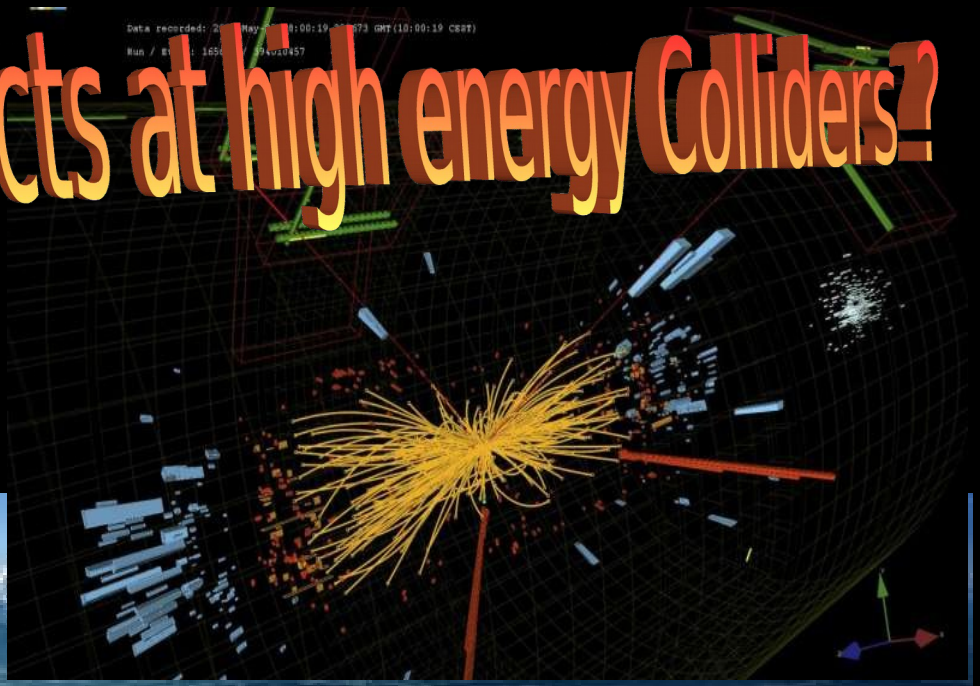
Schechter, JWFV 82
Lindner et al JHEP 1106 (2011) 091

Even if mediated by short-range mechanism …

Heavy mediators

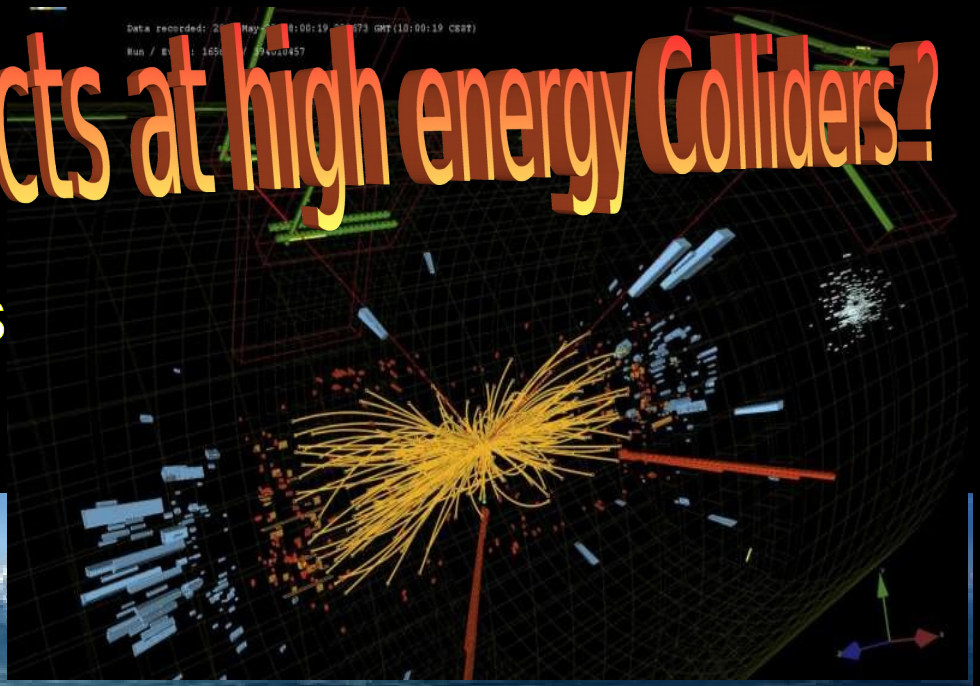


Neutrino effects at high energy Colliders?



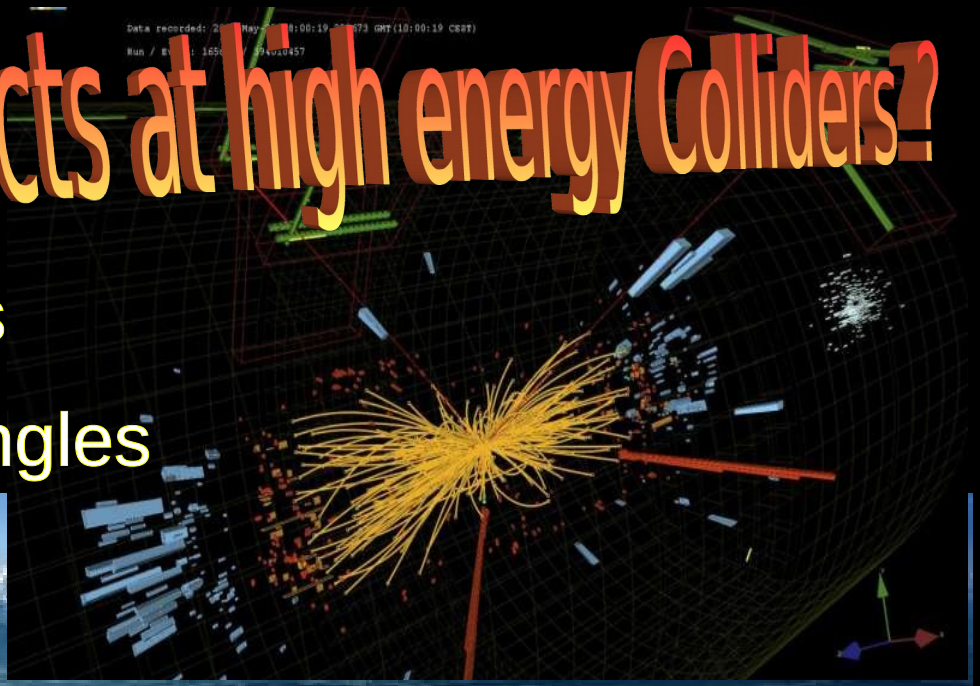
Neutrino effects at high energy Colliders?

- Discover neutrino messengers



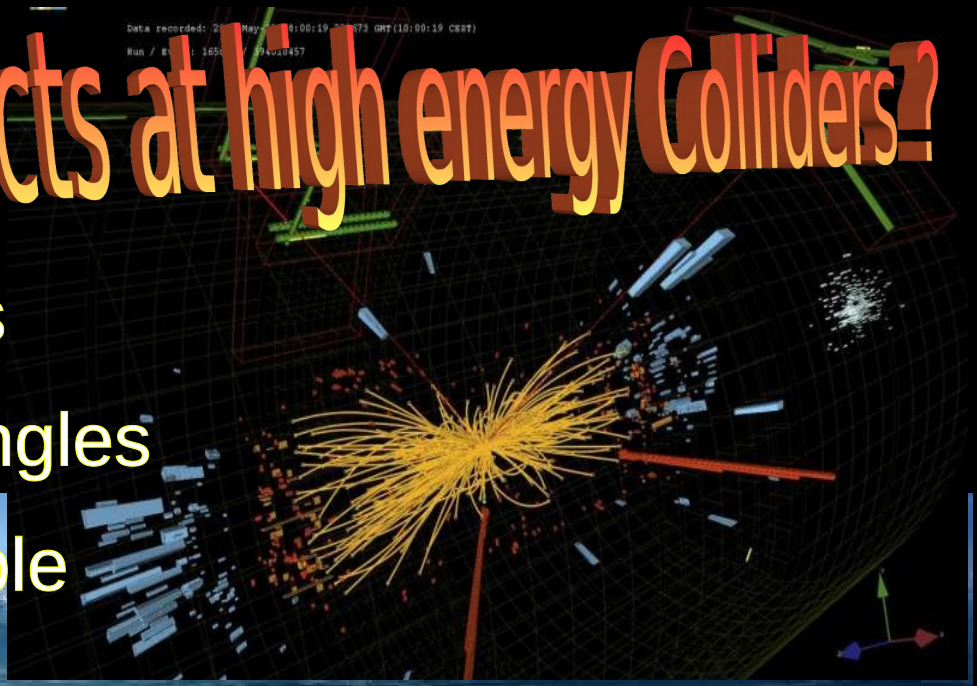
Neutrino effects at high energy Colliders?

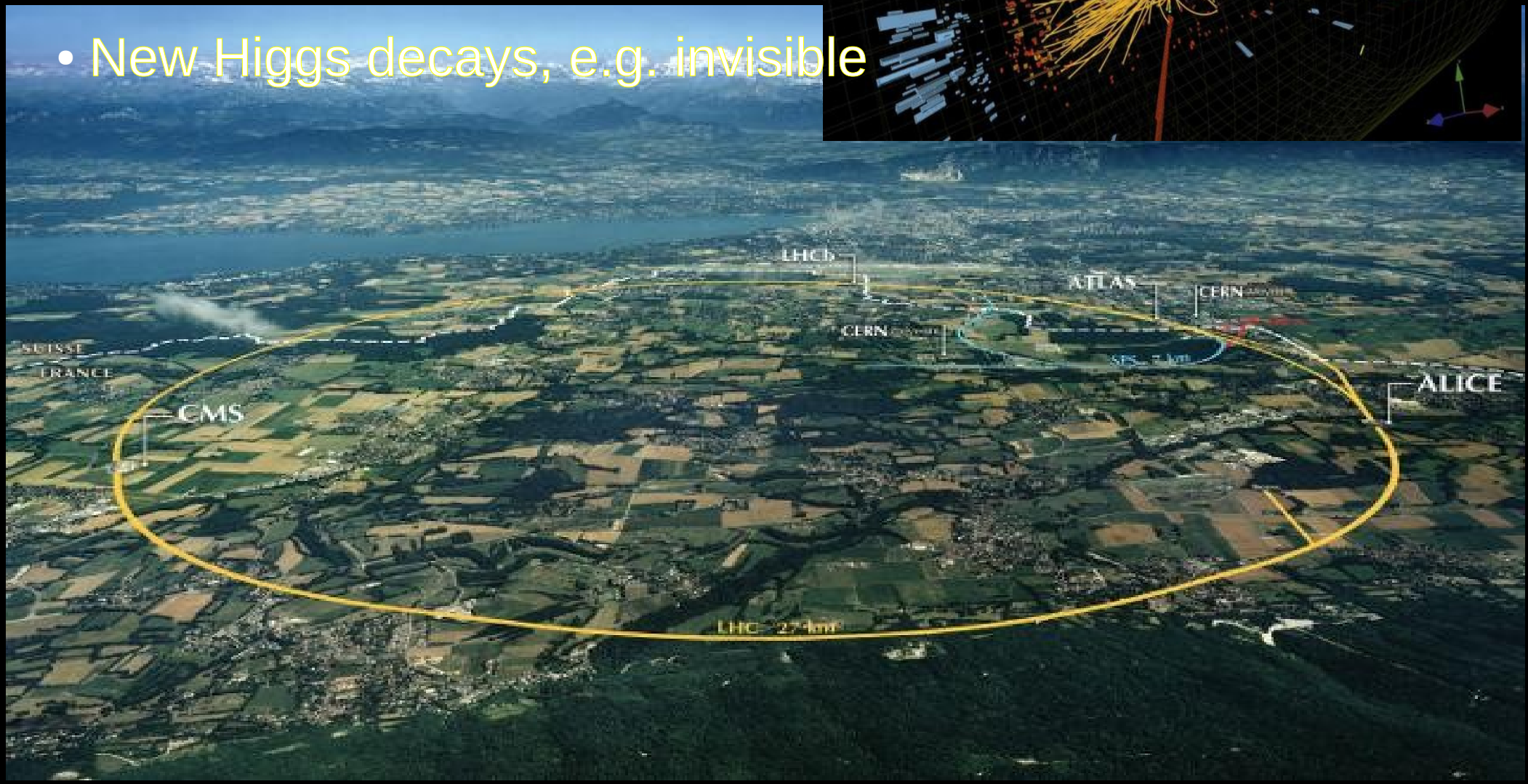
- Discover neutrino messengers
- Remeasure neutrino mixing angles



Neutrino effects at high energy Colliders?

- Discover neutrino messengers
- Remeasure neutrino mixing angles
- New Higgs decays, e.g. invisible

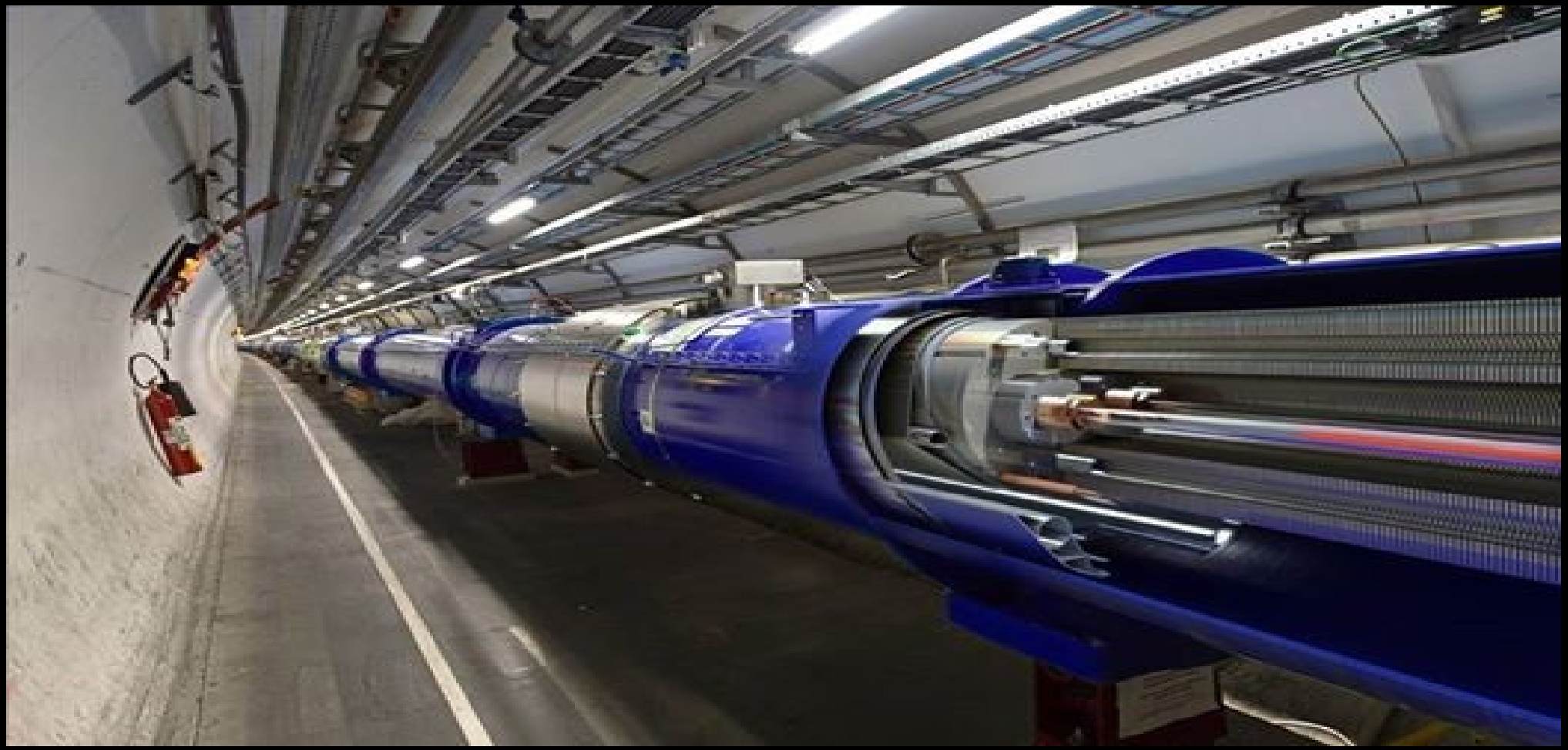




New Higgs decay channels

Joshipura & J.V.

Nucl.Phys. B397 (1993) 105-122



New Higgs decay channels

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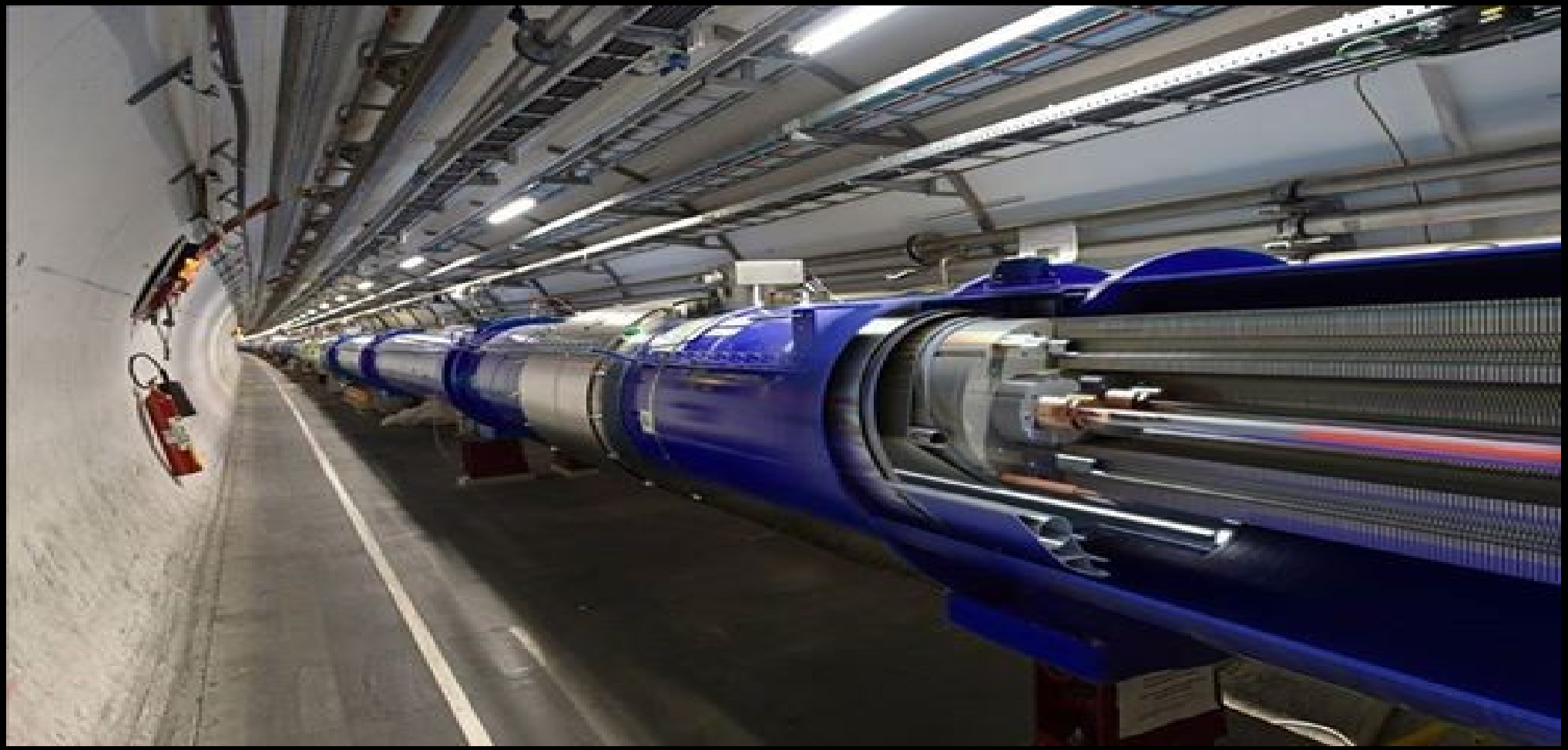
Nucl.Phys. B397 (1993) 105-122

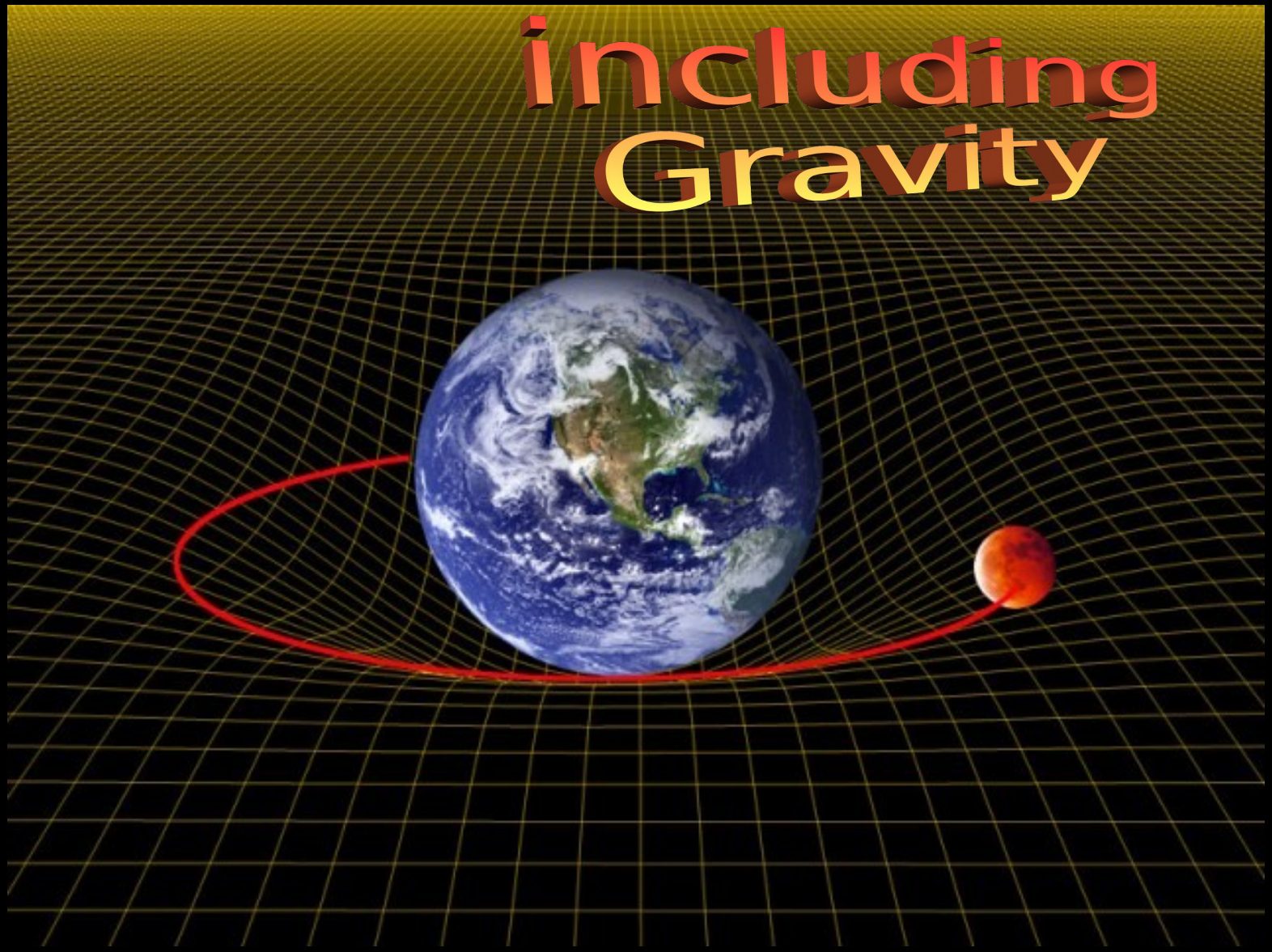


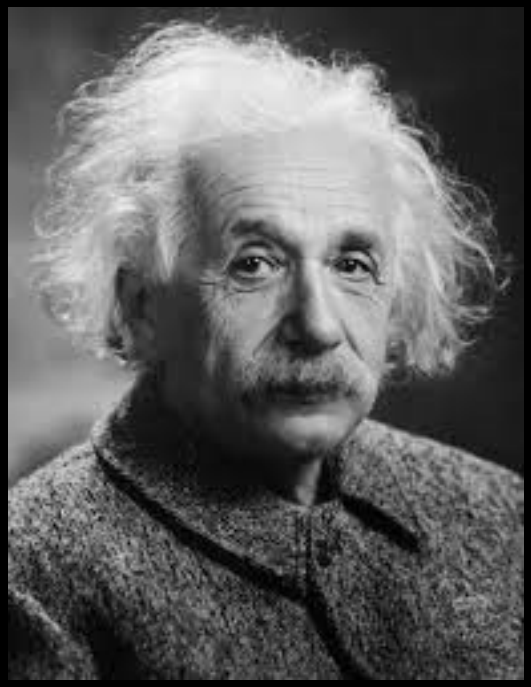
Higgs searches 2016

Bonilla Fonseca & J.V.

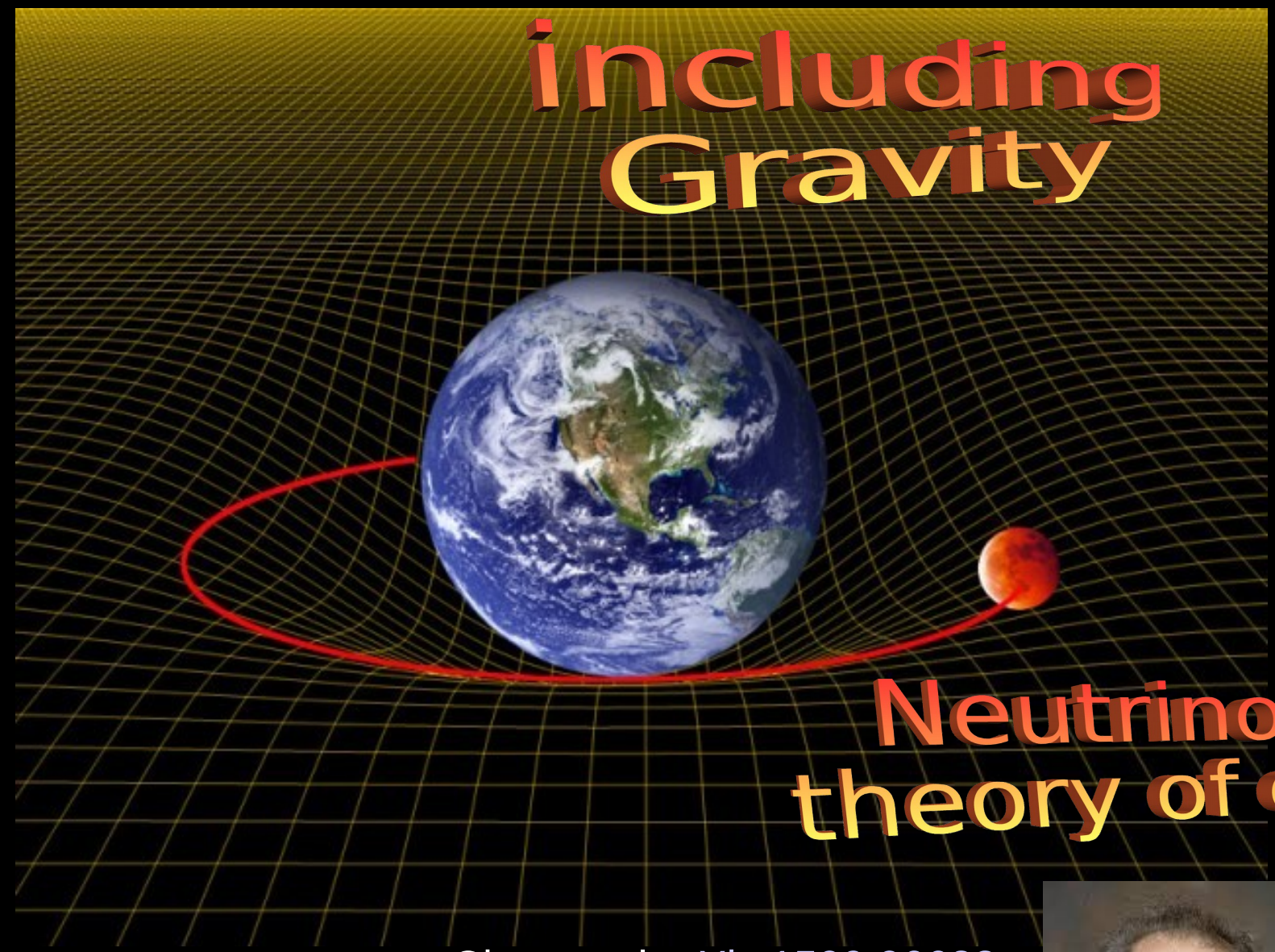
Phys.Lett. B756 (2016) 345-349 ...

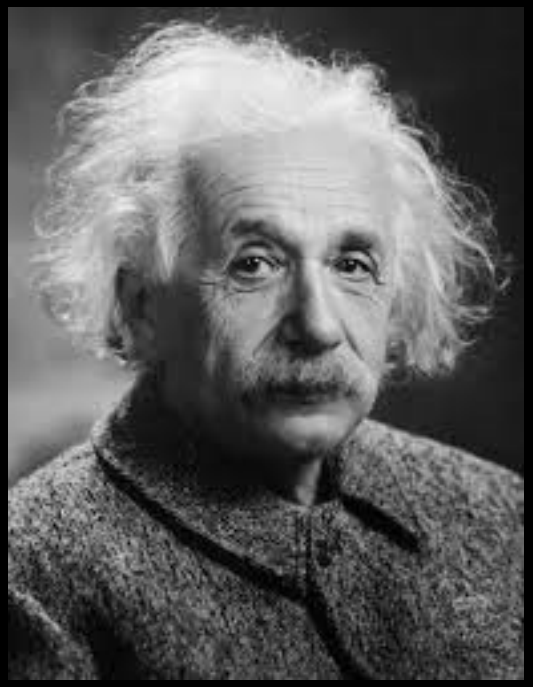
including Gravity





including Gravity





Neutrinos in the theory of everything

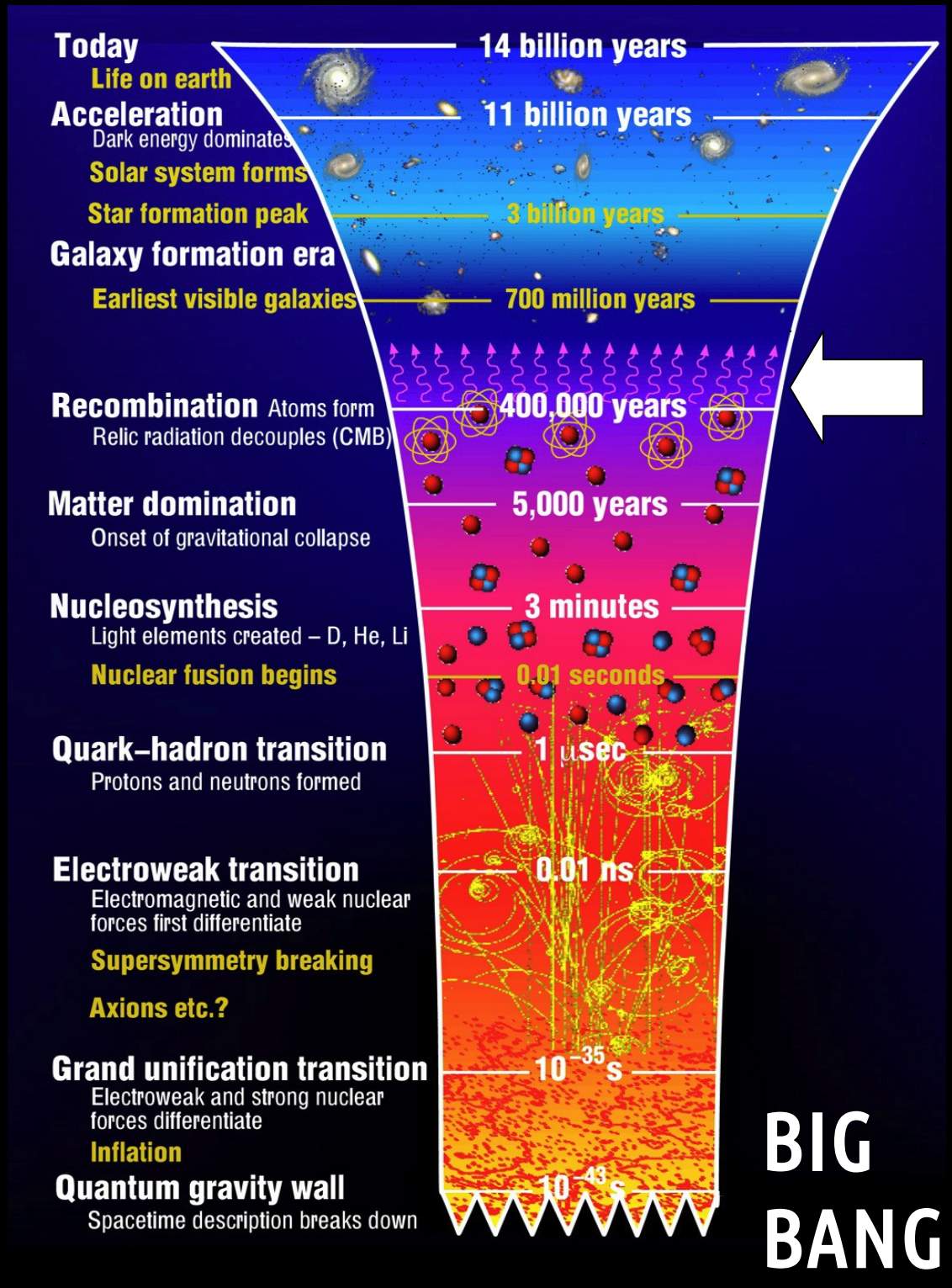
: Chen et al arXiv:1509.06683
JHEP01(2016)007

Addazi et al

Phys.Lett. B759 (2016) 471-478

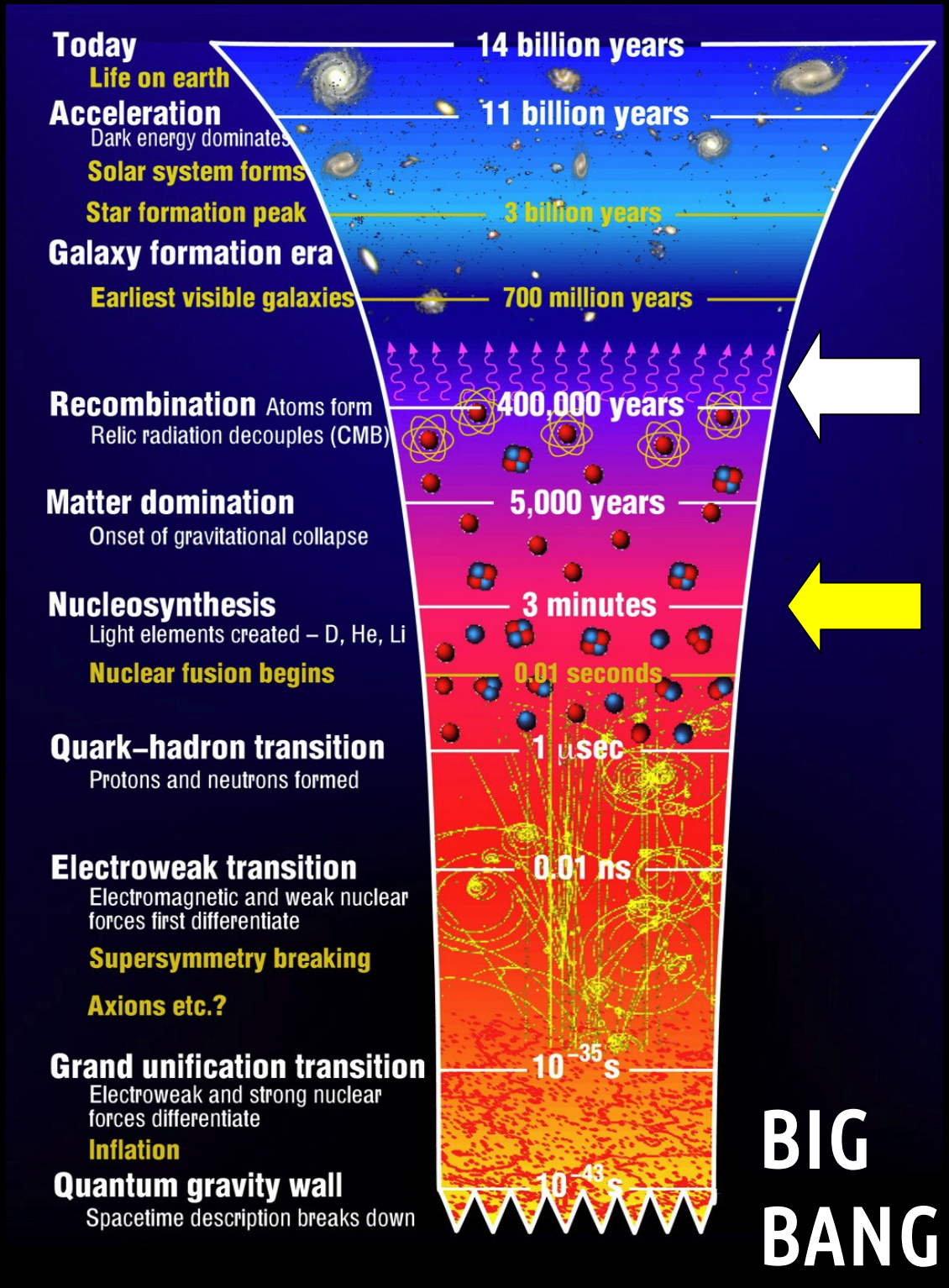

Neutrinos in cosmology
Can not do without neutrinos
Basic cosmogical and astro probe

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



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

are key in the synthesis of light elements

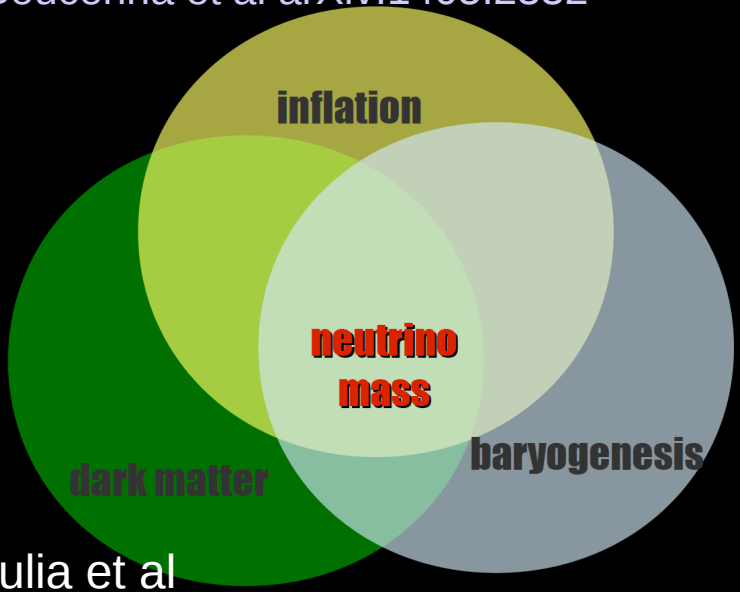


Neutrinos affect the CMB and large scale structure in the Universe …

are key in the synthesis of light elements

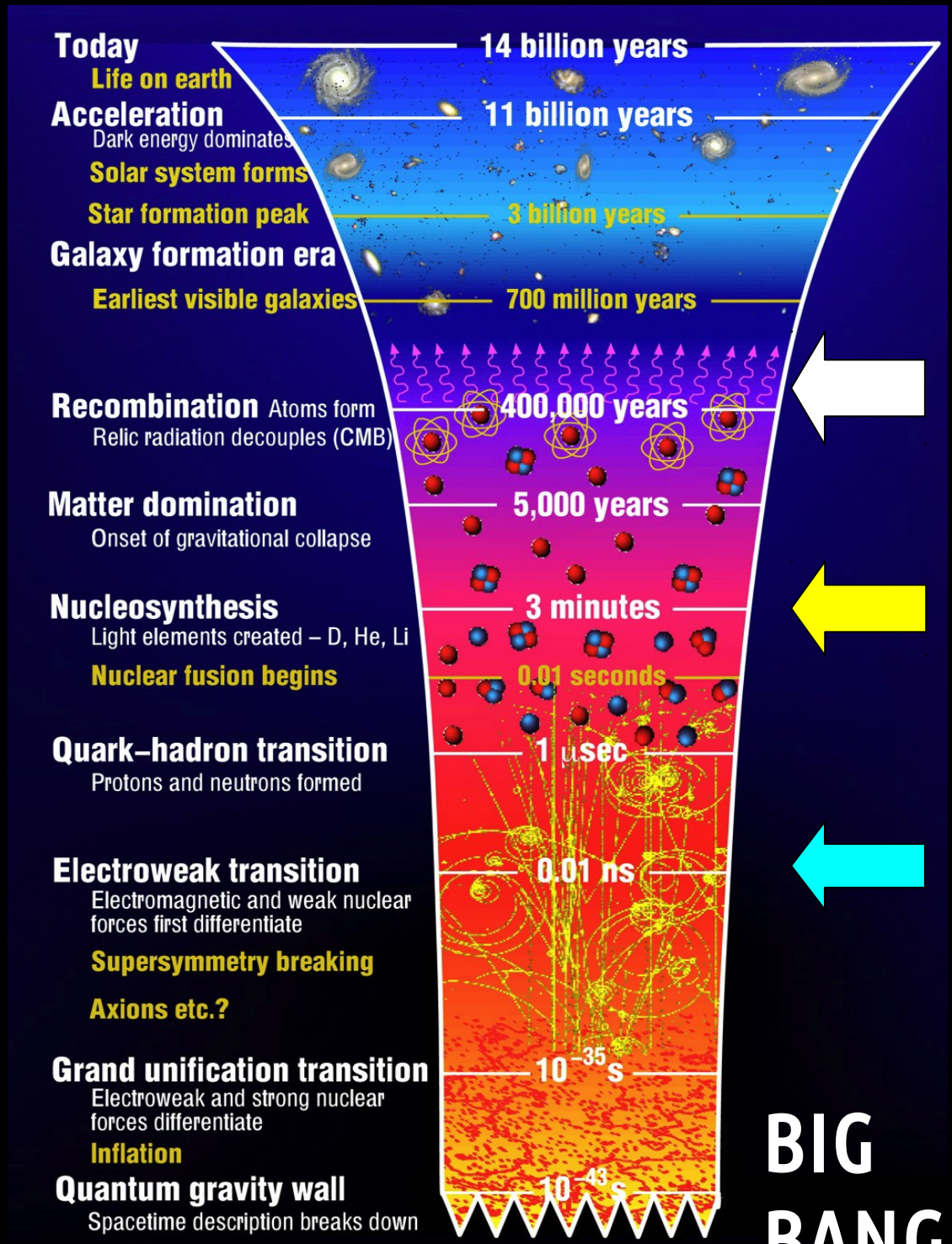
can "probe" the Universe earlier than photons …

Boucenna et al arXiv:1405.2332



Chiulia et al

1606.04543 & Phys.Lett. B761 (2016) 431-436



neutrino masses

dark matter

baryon asymmetry

Inflation

Dark energy

neutrino masses

dark matter

baryon asymmetry

Inflation

Dark energy

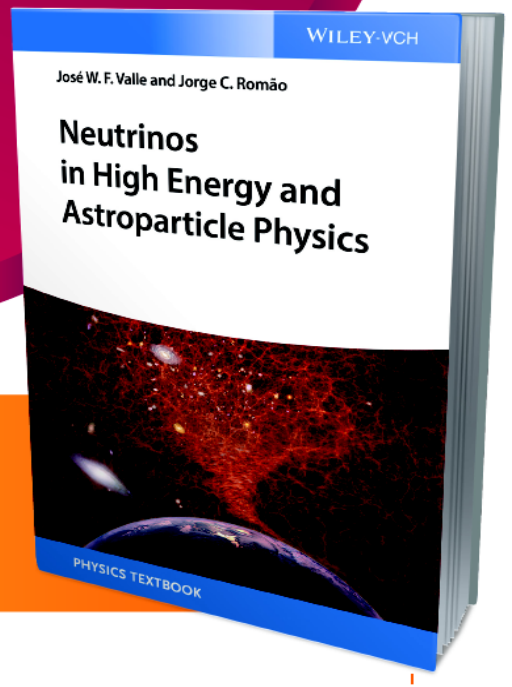
The road to new physics

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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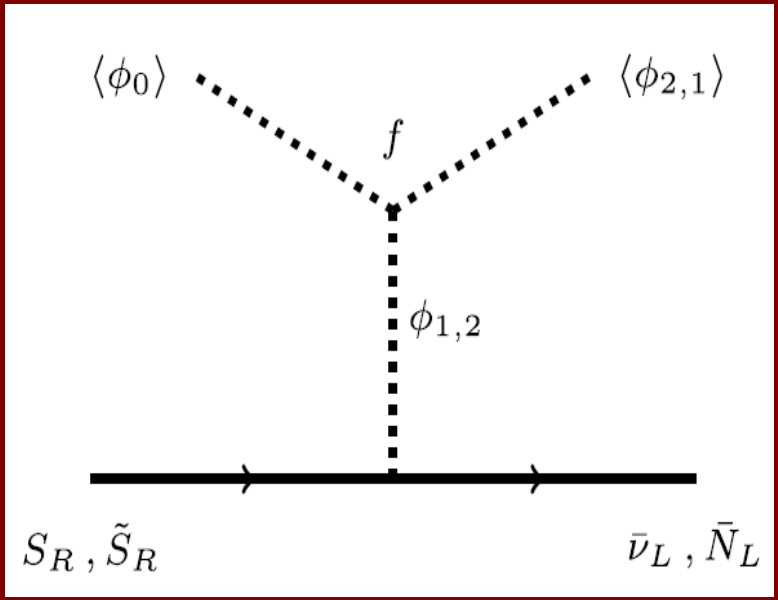
Back up

Dirac seesaw



Physics Letters B 755 (2016) 363–366

No conventional GUT embedding :

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

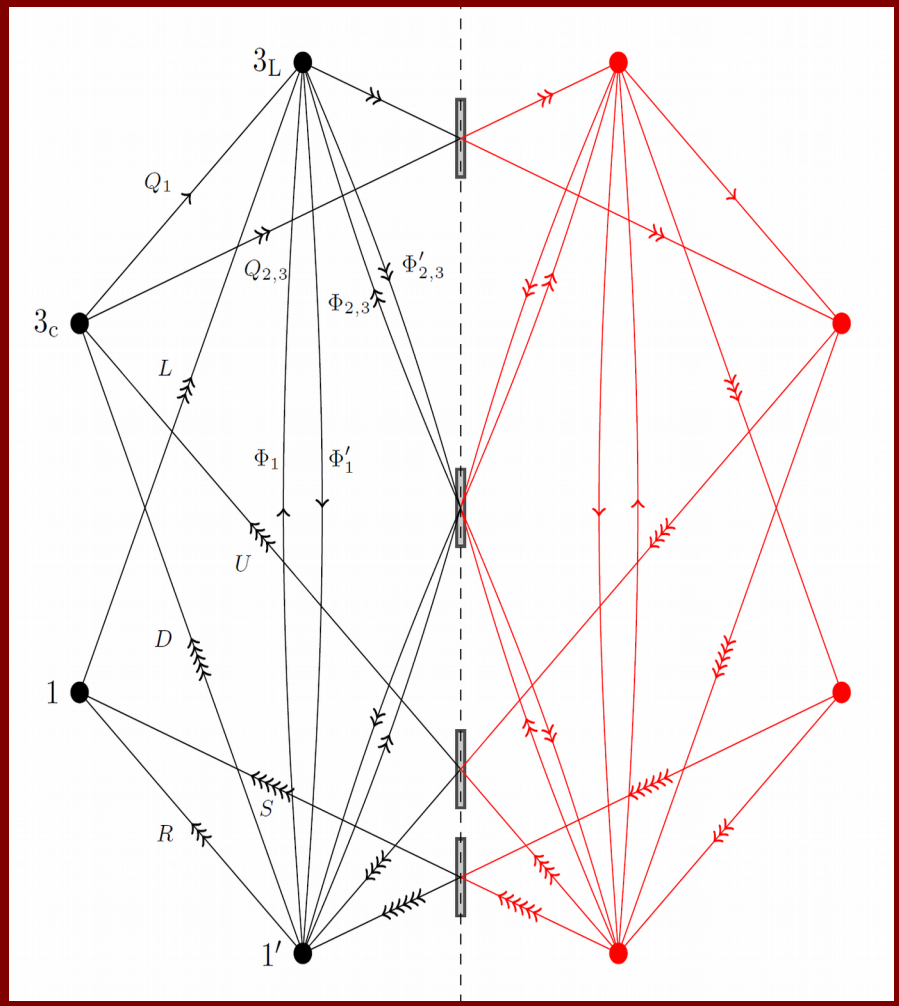
string completion Quiver setup

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

Addazi et al arXiv:1604.02117

331 from strings

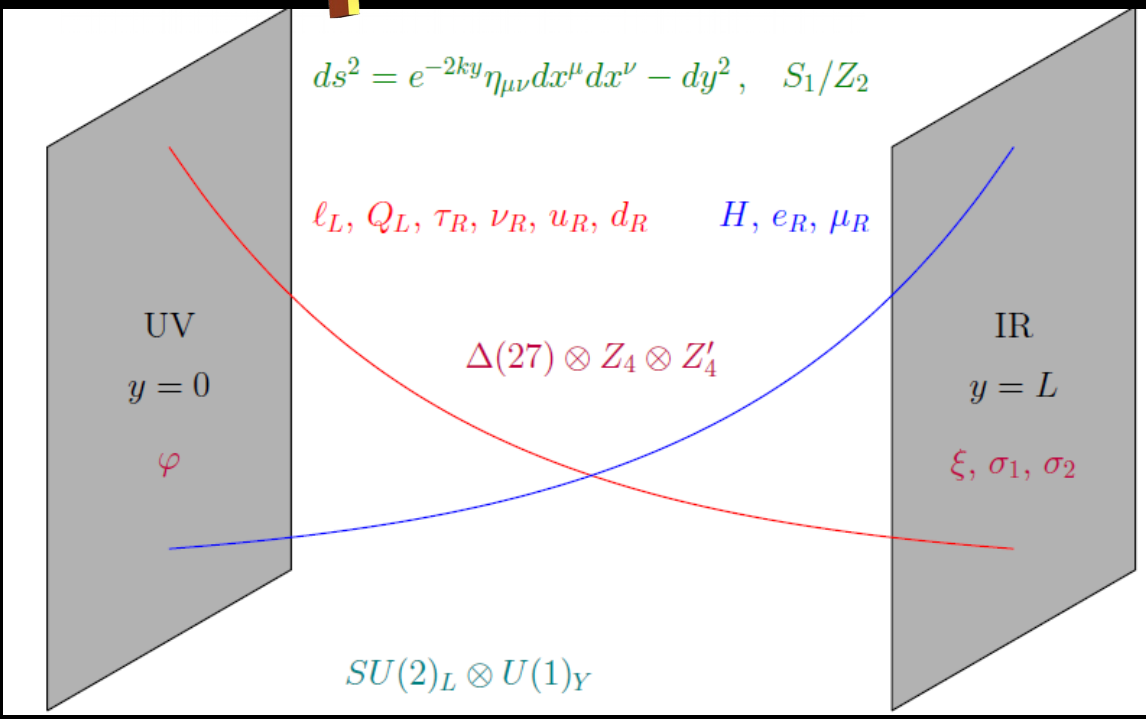
10.1016/j.physletb.2016.06.015

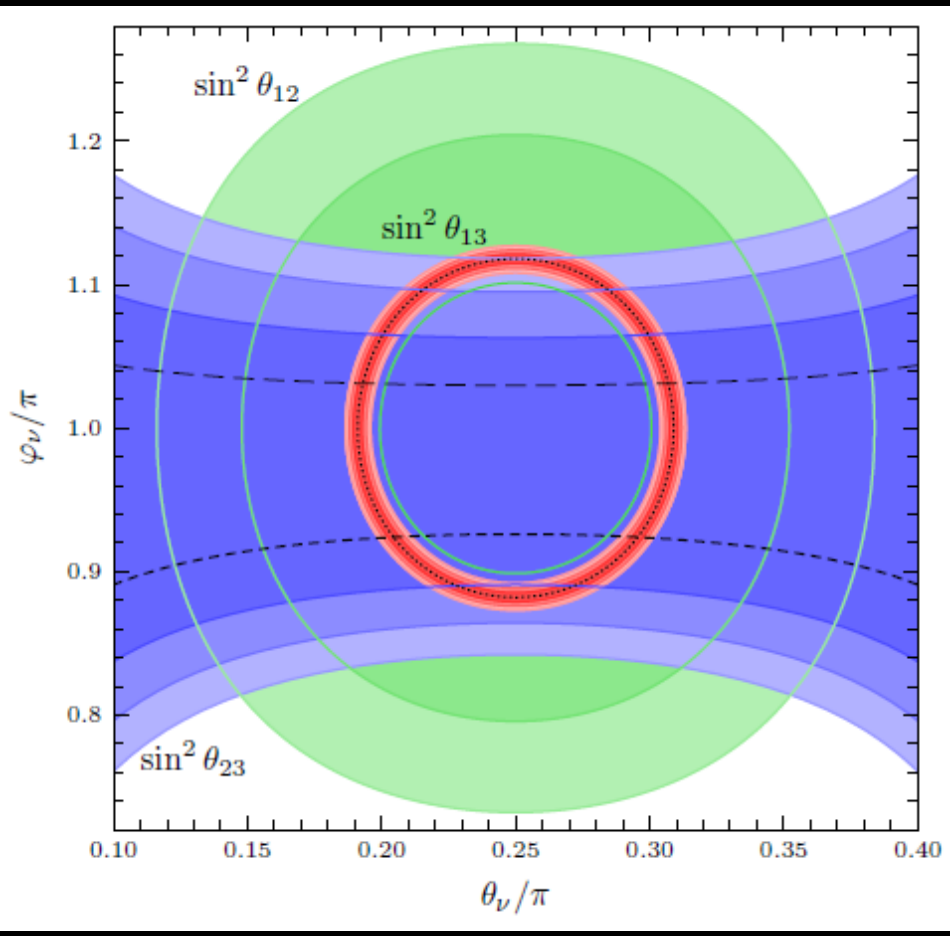


neutron-antineutron oscillations from exotic instantons

Warped flavor

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





Mass hierarchies in principle explained by judicious choices of the bulk parameters

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

4 neutrino mixing angles & CP phase predicted in terms of **2**

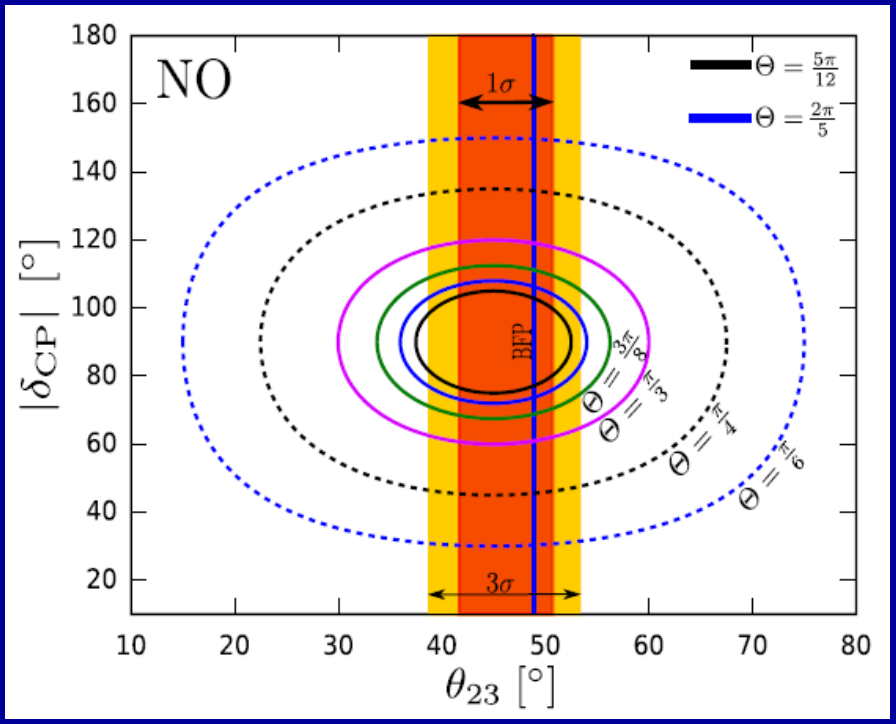
$$\sin^2\theta_{12} = (2 - \sin 2\theta_\nu \cos\varphi_\nu)^{-1}\,, \qquad \sin^2\theta_{23} = \frac{1-\sin 2\theta_\nu \sin(\pi/6-\varphi_\nu)}{2-\sin 2\theta_\nu \cos\varphi_\nu}$$

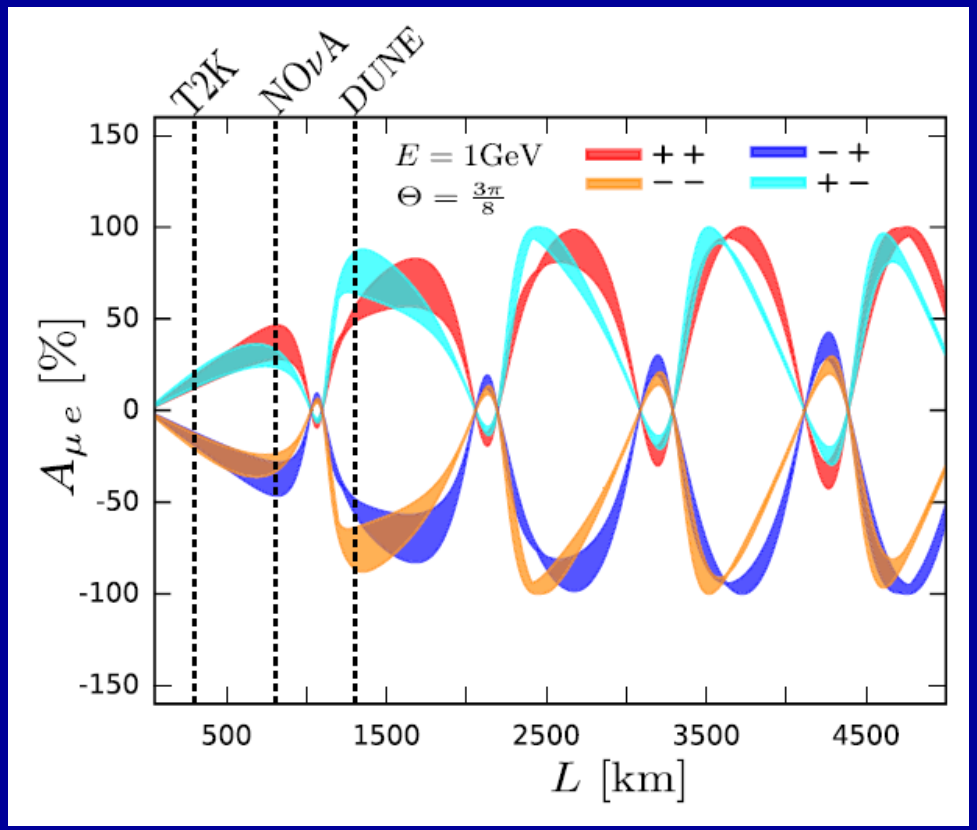
$$\sin^2\theta_{13} = \frac{1}{3}\left(1 + \sin 2\theta_\nu \cos\varphi_\nu\right)\,, \qquad J_{\rm CP} = -\frac{1}{6\sqrt{3}}\cos 2\theta_\nu\,.$$

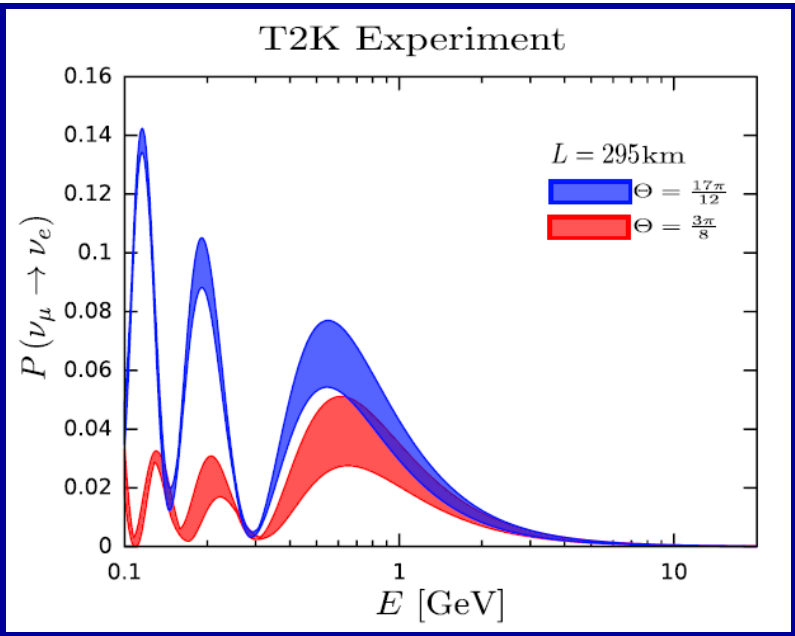
Model-independent flavor approach

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

Predicting neutrino mixing from residual CP symmetries







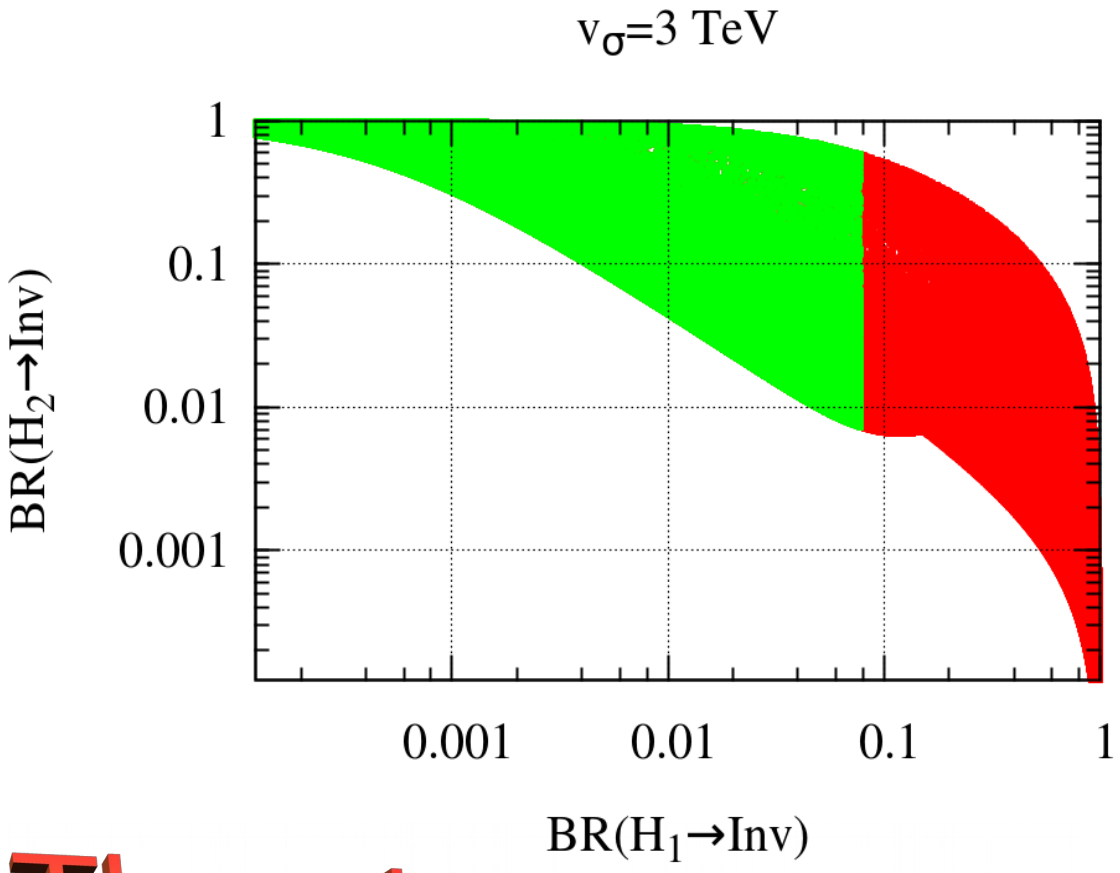
P. Chen et al. / Physics Letters B 753 (2016) 644–652

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

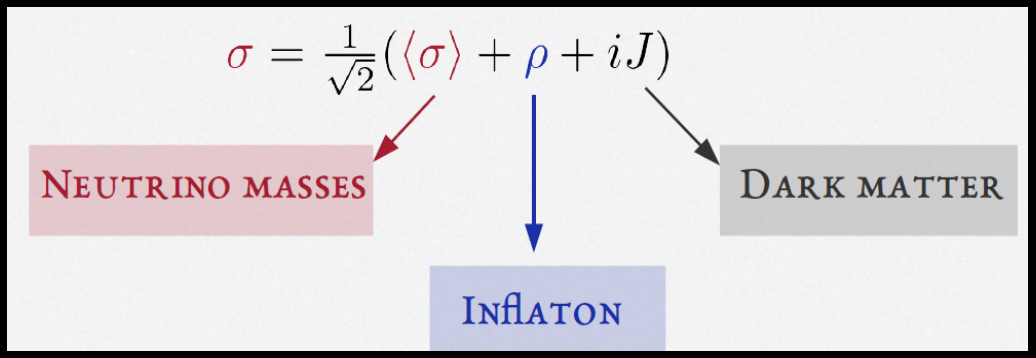


$$H_i \to JJ \quad \text{and} \quad H_2 \to 2H_1 \to 4J$$

$$\left(\text{when } m_{H_1} < \frac{m_{H_2}}{2}\right).$$

Theories of neutrino as attractive higgs search benchmarks

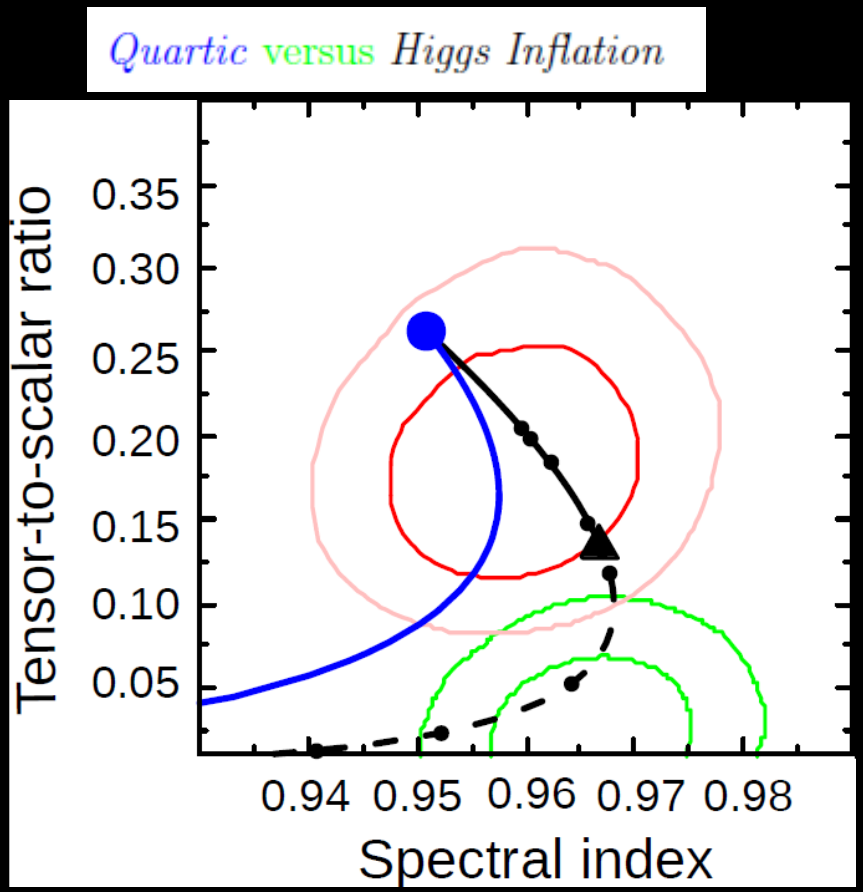
Seesaw inflation & majoron dark matter

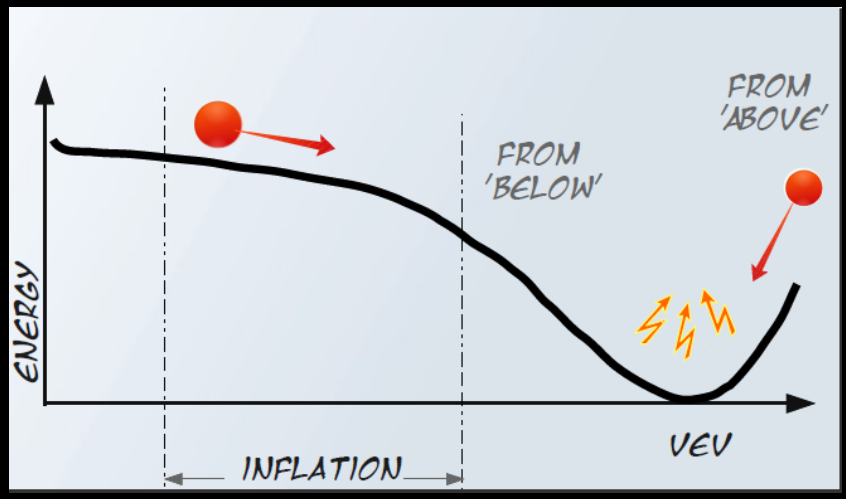


Boucenna et al arXiv:1405.2332 PRD90 (2014) 05502

type-I seesaw Leptogenesis

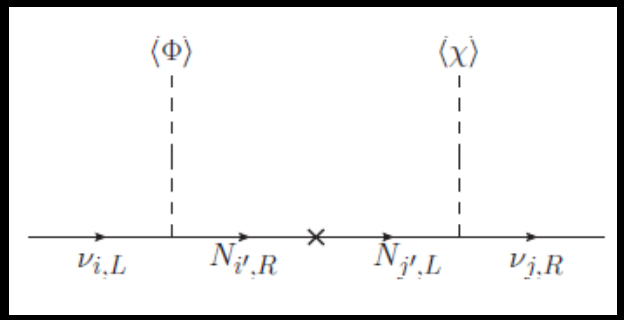
Aristizabal et al arXiv:1405.4706





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

Dark Matter Stability from Dirac nature of neutrinos

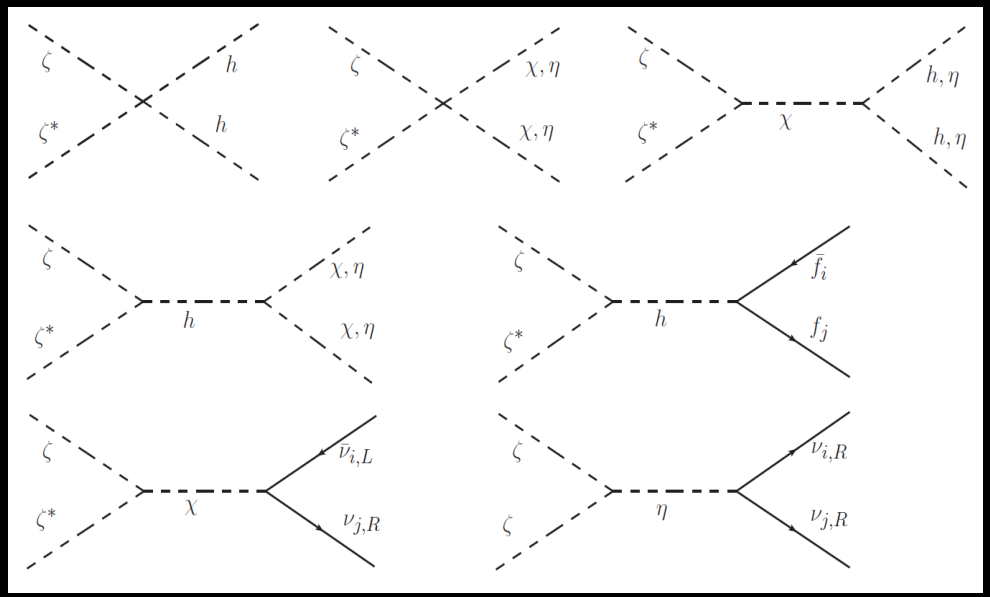


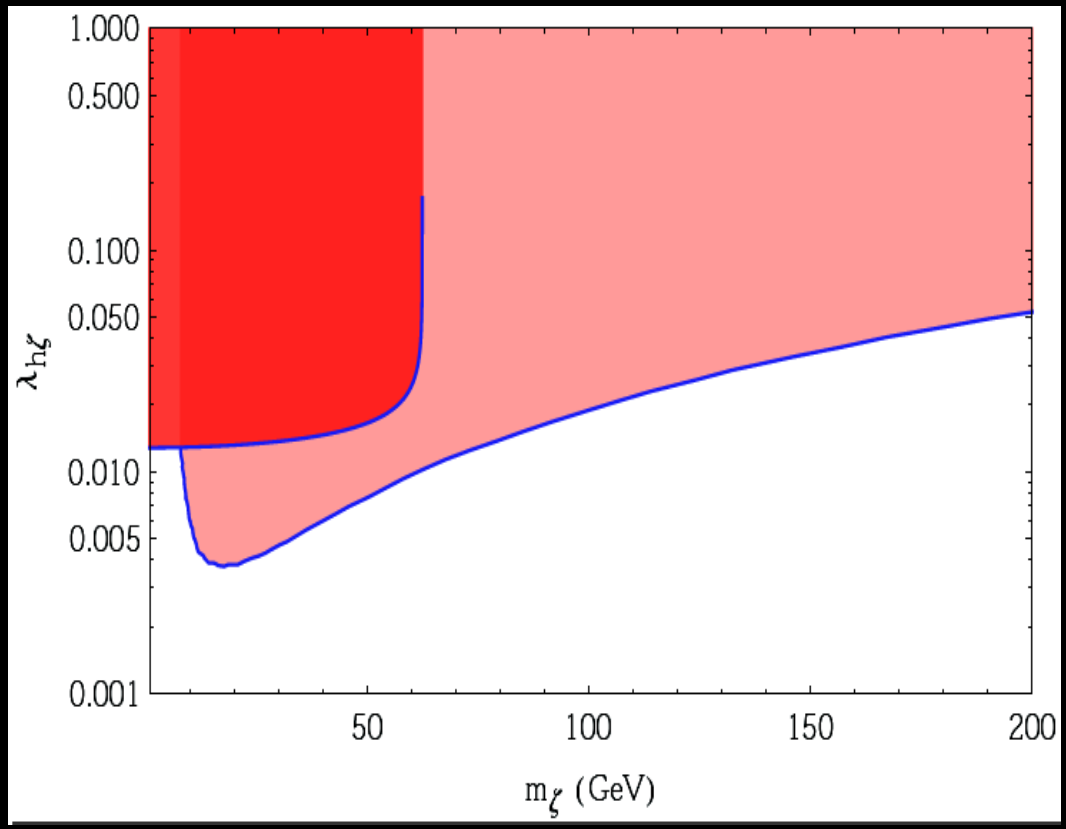
Chiulia et al arXiv:1606.04543

arXiv:1606.06904

Lepton Quarticity vs Lepton number

Non SUSY WIMP





neutrino sources & fluxes