Neutrino physics and implications

José W F Valle

Lecture II

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

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INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

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Summer School and Workshop on Standard Model and Beyond – Corfu 2016

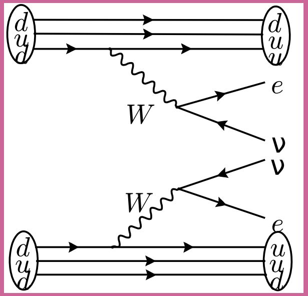
Outline

Lecture II

- Neutrinoless double beta decay
- Flavor predictions for neutrinoless double beta decay
- Long versus short range mechanisms
- Black-box theorem
- Neutrinos and electroweak vacuum
- Stability & perturbativity
- Invisible Higgs decays
- Gravity and the Standard Model
- Extra dimensions & unification
- Neutrino predictions from warped flavor
- String completion of SU(3)c⊗SU(3)L⊗U(1) model
- Neutrinos in cosmology

A.S. Barabash arXiv:1104.2714

Neutrinoless double beta decay



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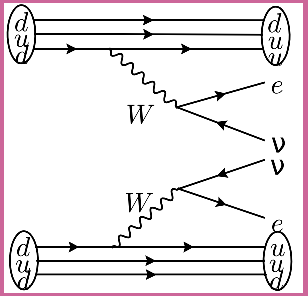

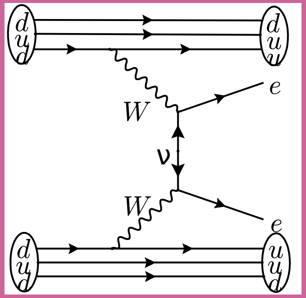

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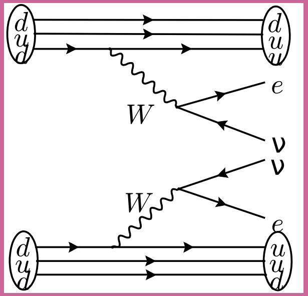

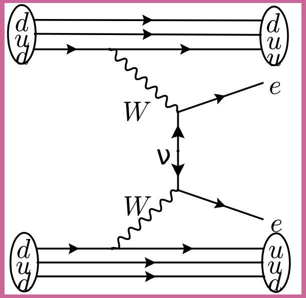

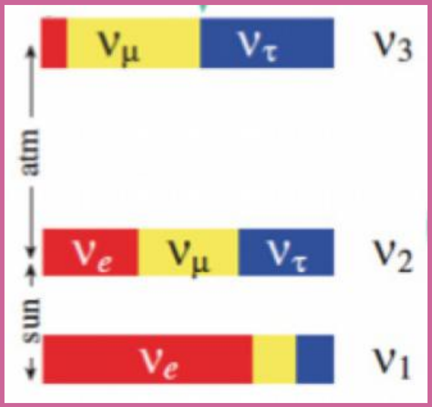

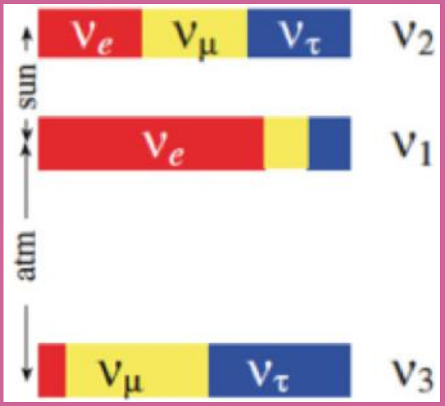

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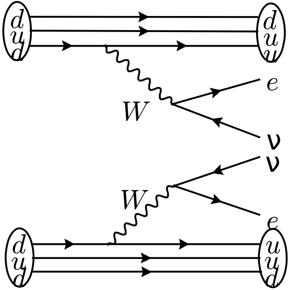
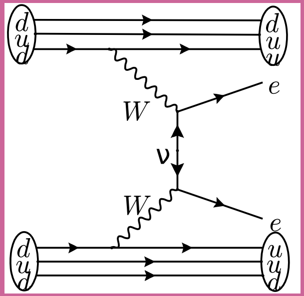
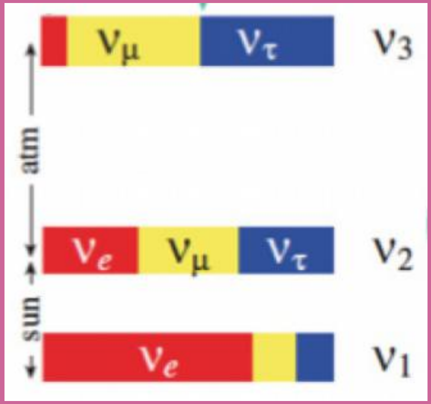
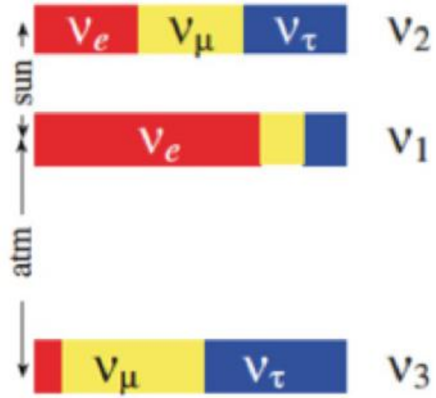
Neutrinoless double beta decay

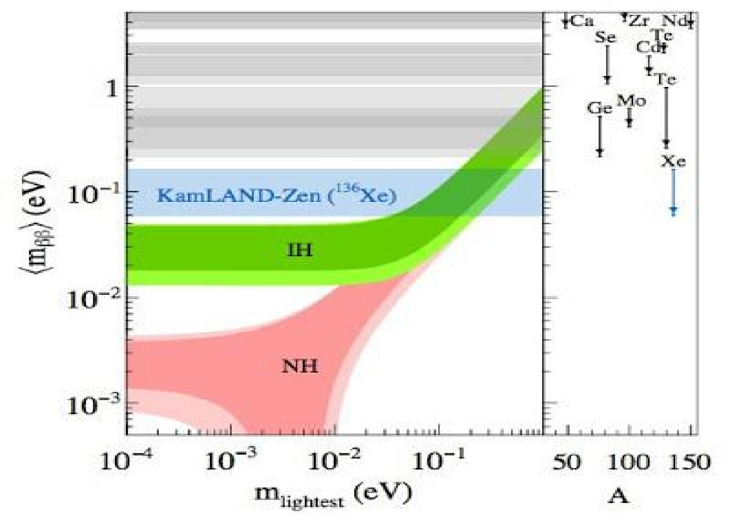
1605.02889











Neutrinoless double beta decay

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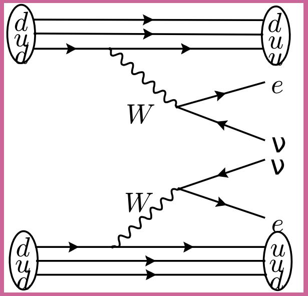

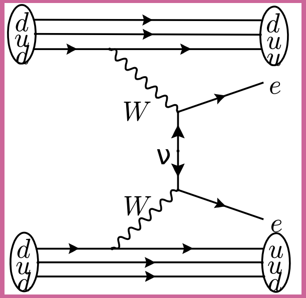

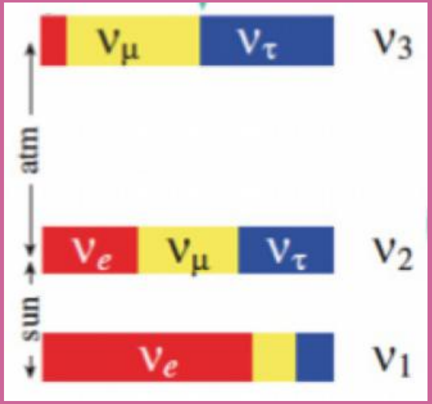

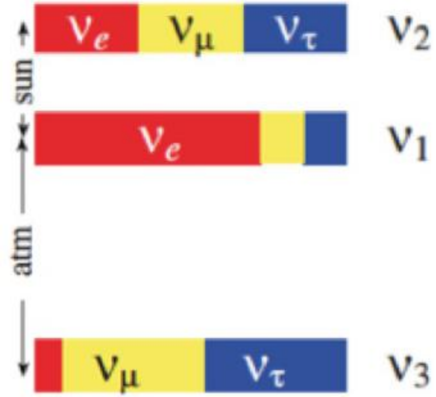

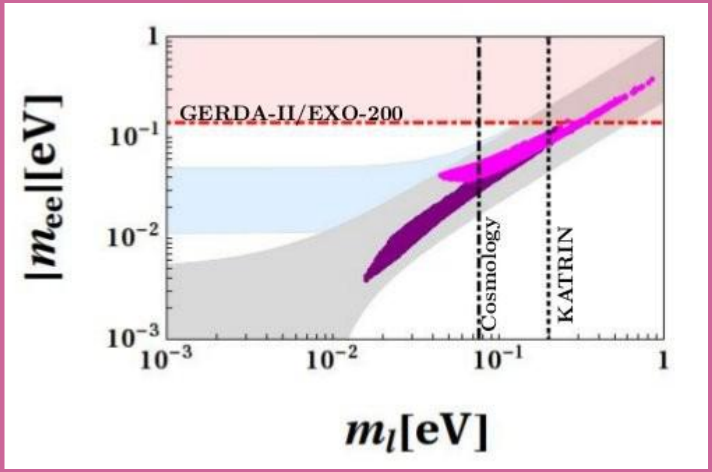

Flavor Sensitivity

Bonilla et al arXiv:1411.4883

Neutrinoless double beta decay

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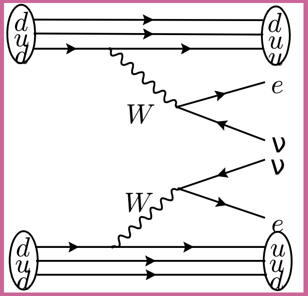

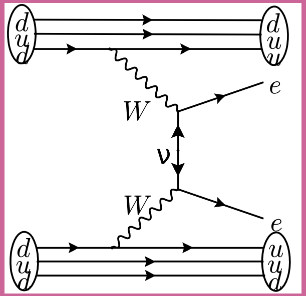

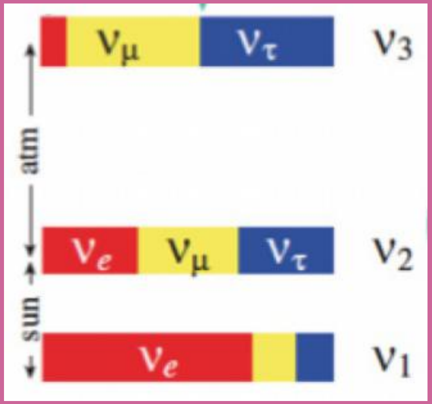

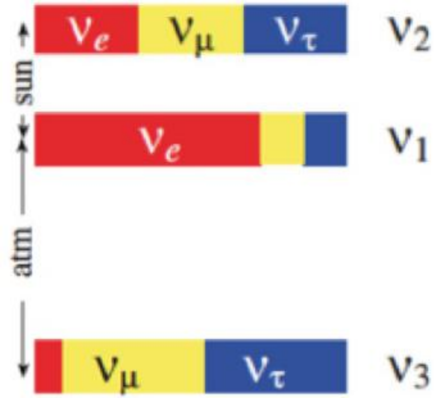

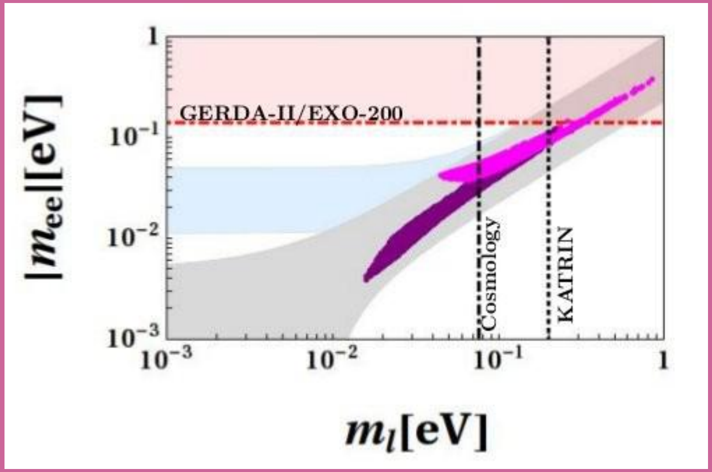

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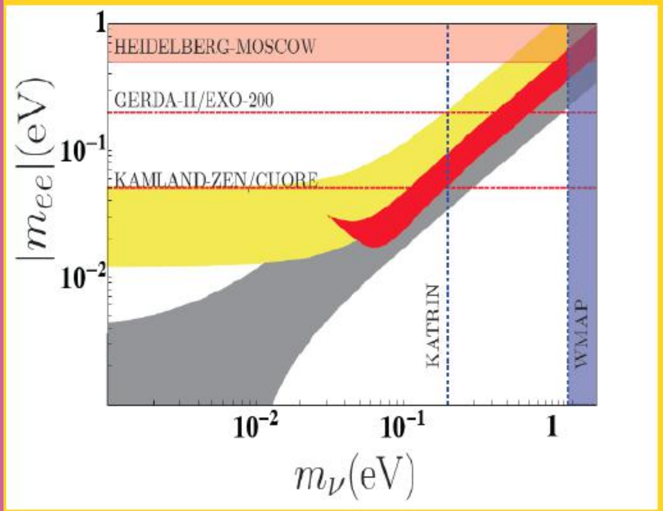
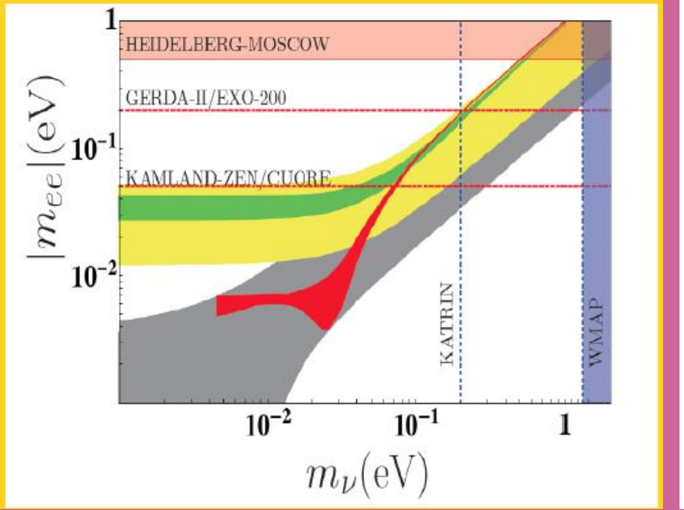
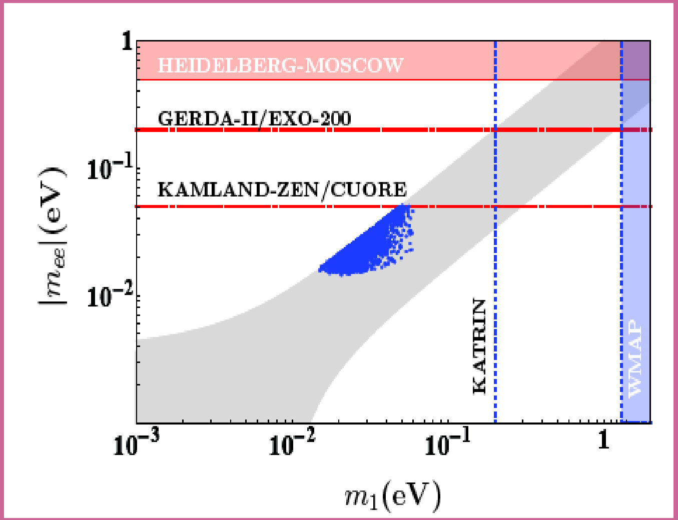






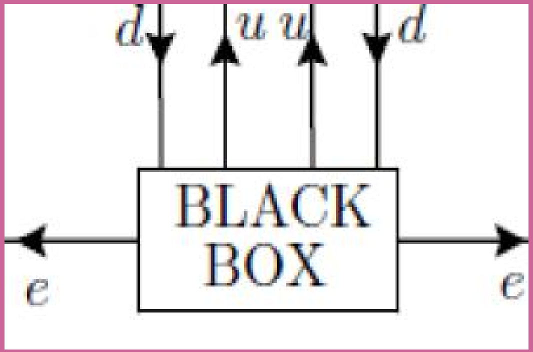
Dorame et al

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

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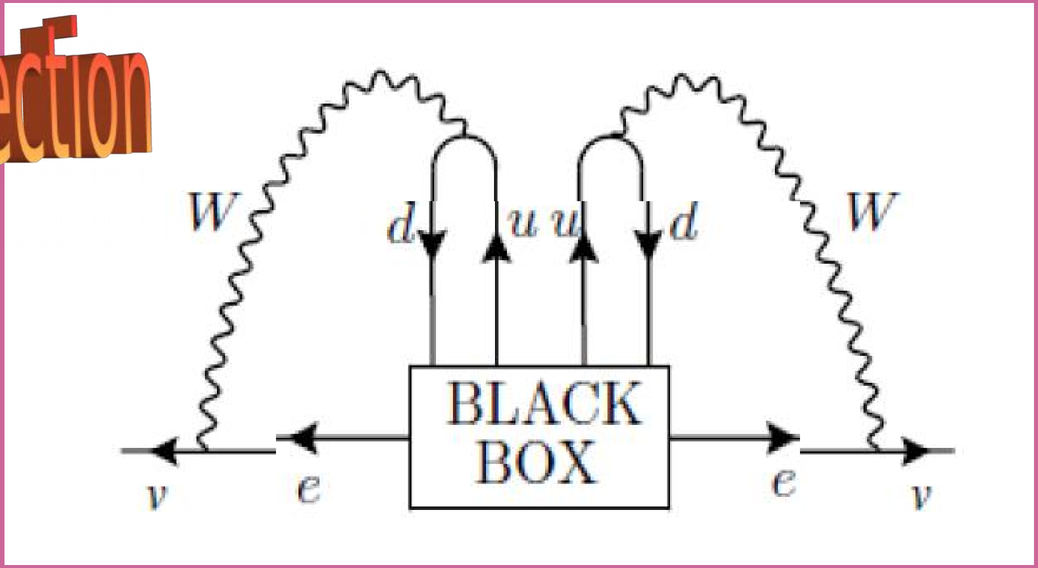

Even if mediated by short-range mechanism …

Schechter, JWFV 82
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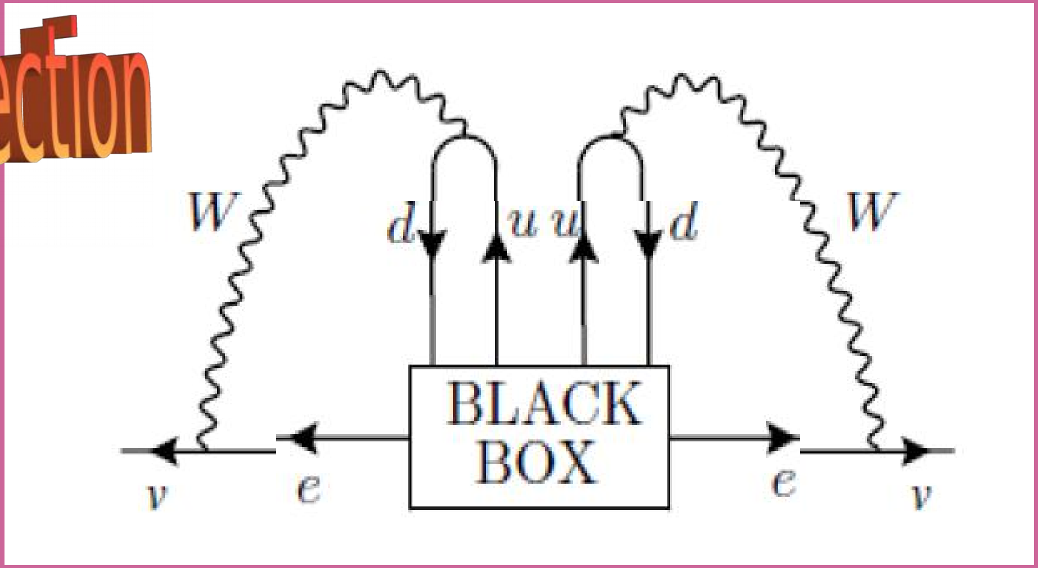

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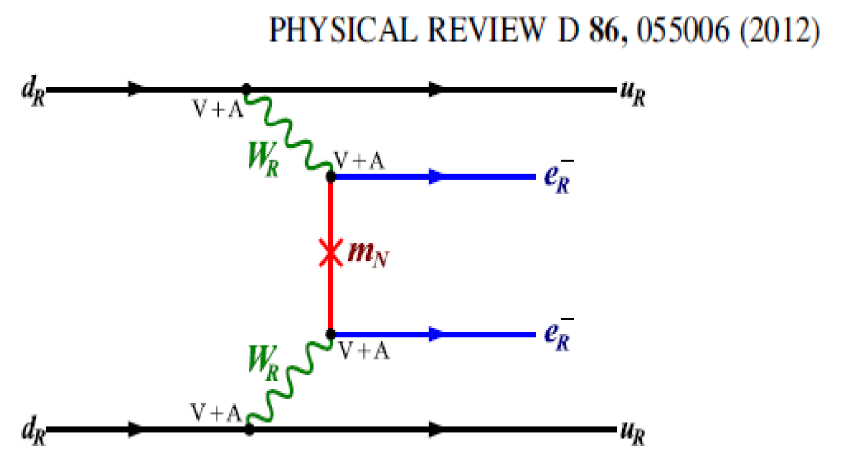
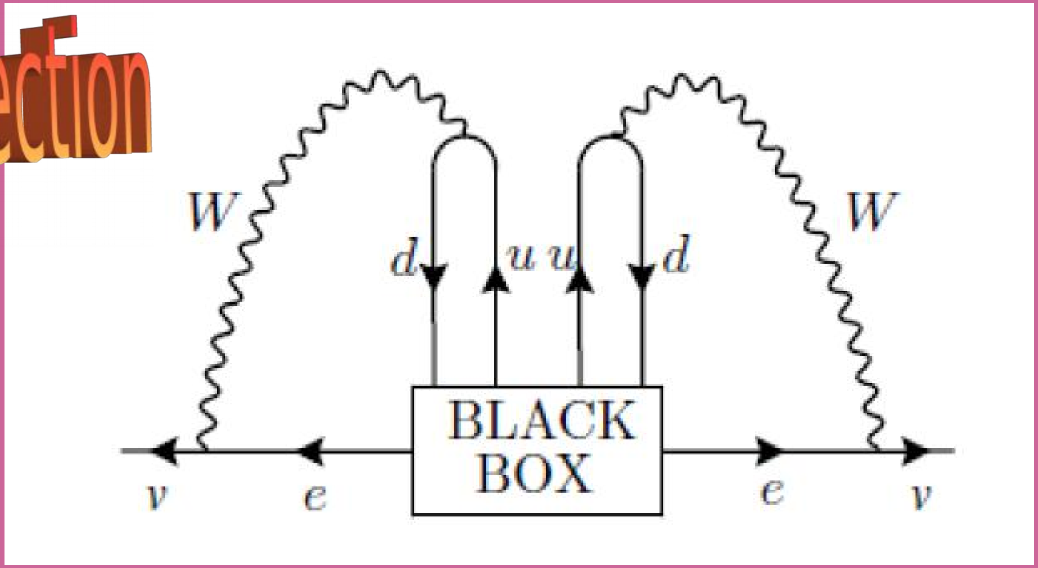
Heavy mediators



PHYSICAL REVIEW D **86,** 055006 (2012)

The Majorana connection



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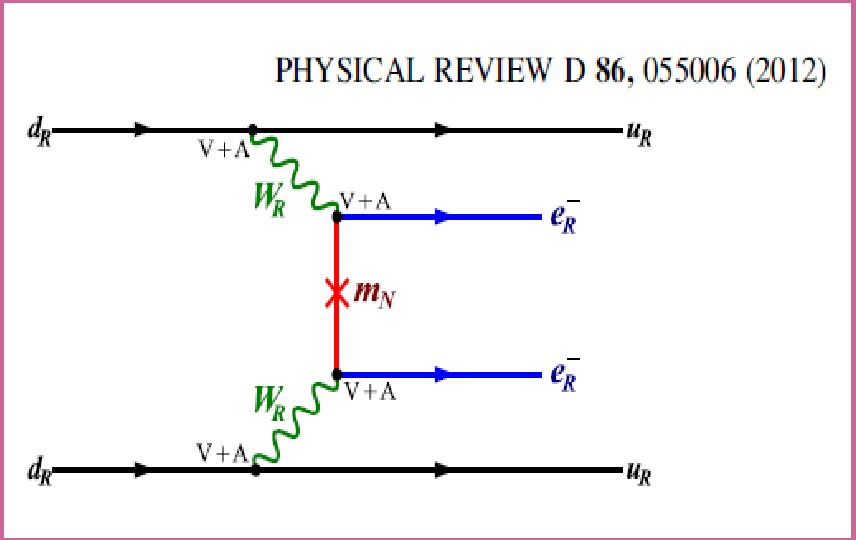
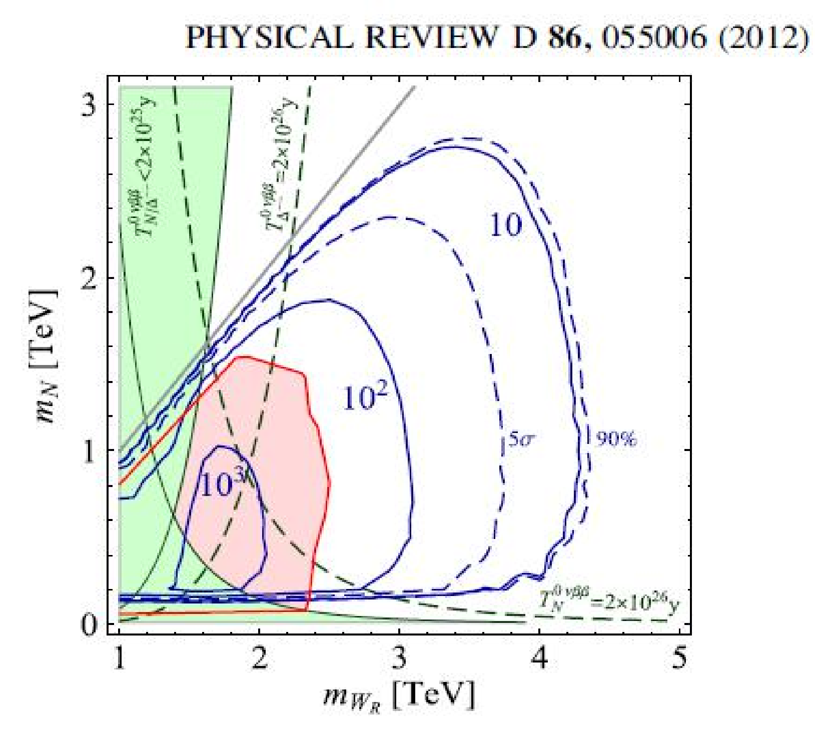
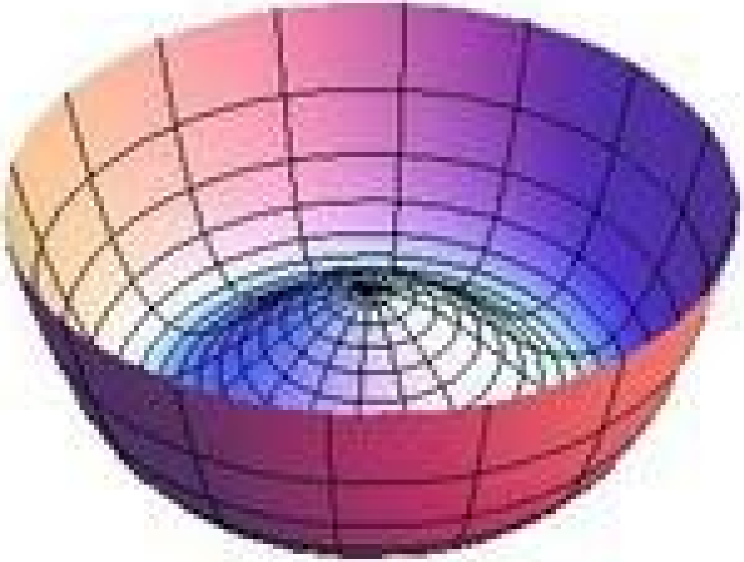


PHYSICAL REVIEW D 86, 055006 (2012)



PHYSICAL REVIEW D 86, 055006 (2012)

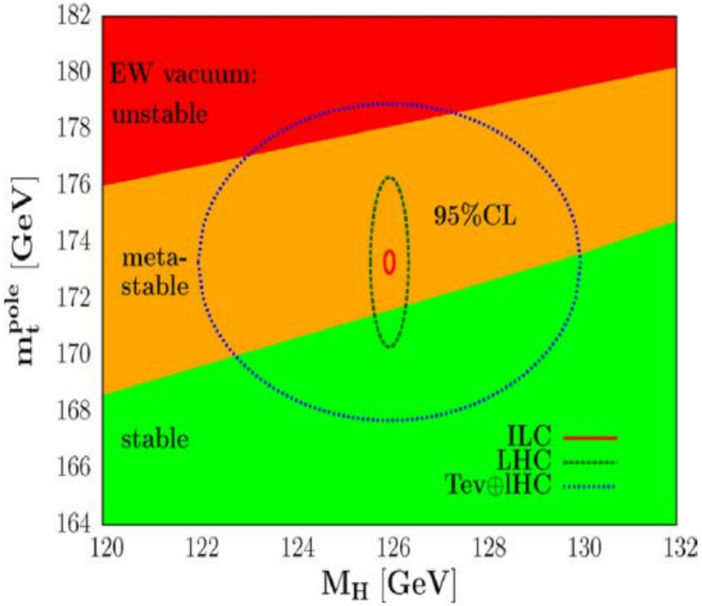
Spontaneous electroweak symmetry breaking
The role of neutrino mass generation



SM vacuum

SM vacuum

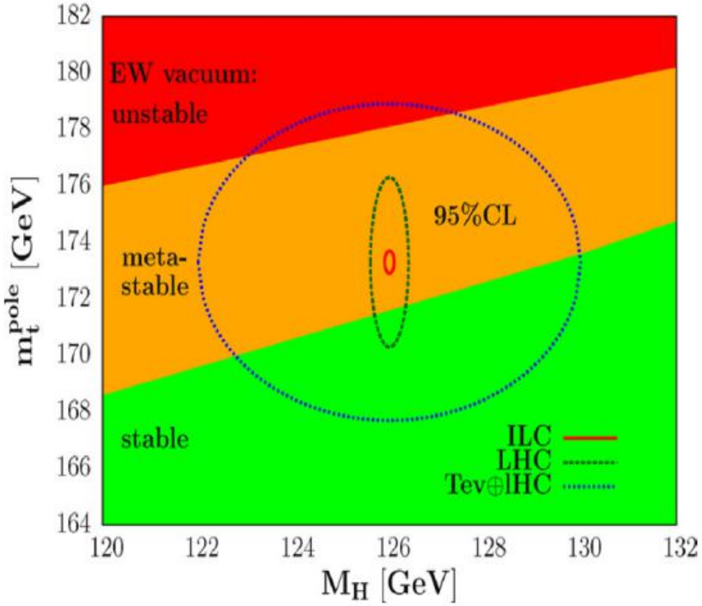
Physics Letters B 716 (2012) 214–219

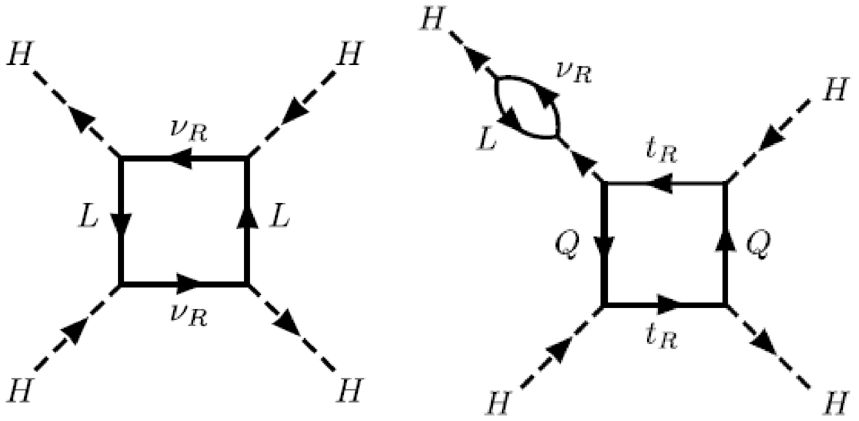


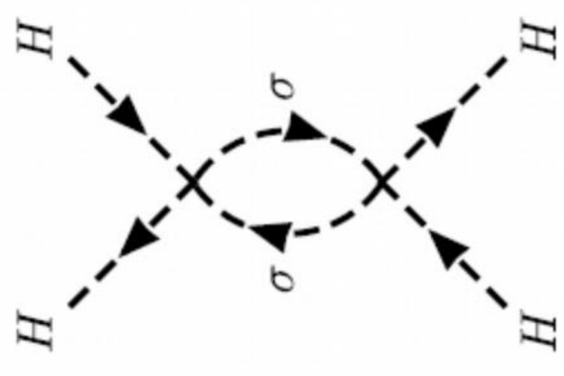
SM vacuum and neutrinos

Physics Letters B 756 (2016) 345–349

Physics Letters B 716 (2012) 214–219







Stability from neutrinos

Physics Letters B 756 (2016) 345–349

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

$$(4\pi)^2 \frac{dg_i}{dt} = b_i g_i^3 \text{ with } b_i = \left(\frac{41}{10}, -\frac{19}{6}, -7\right),$$

$$(4\pi)^2 \frac{dY_t}{dt} = \left(-\frac{17}{20}g_1^2 - \frac{9}{4}g_2^2 - 8g_3^2 + \frac{9}{2}Y_t^2 + Y_\nu^2\right) Y_t\,,$$

$$(4\pi)^2 \frac{dY_\nu}{dt} = \left(-\frac{9}{20}g_1^2 - \frac{9}{4}g_2^2 + 3Y_t^2 + \frac{5}{2}Y_\nu^2\right) Y_\nu\,,$$

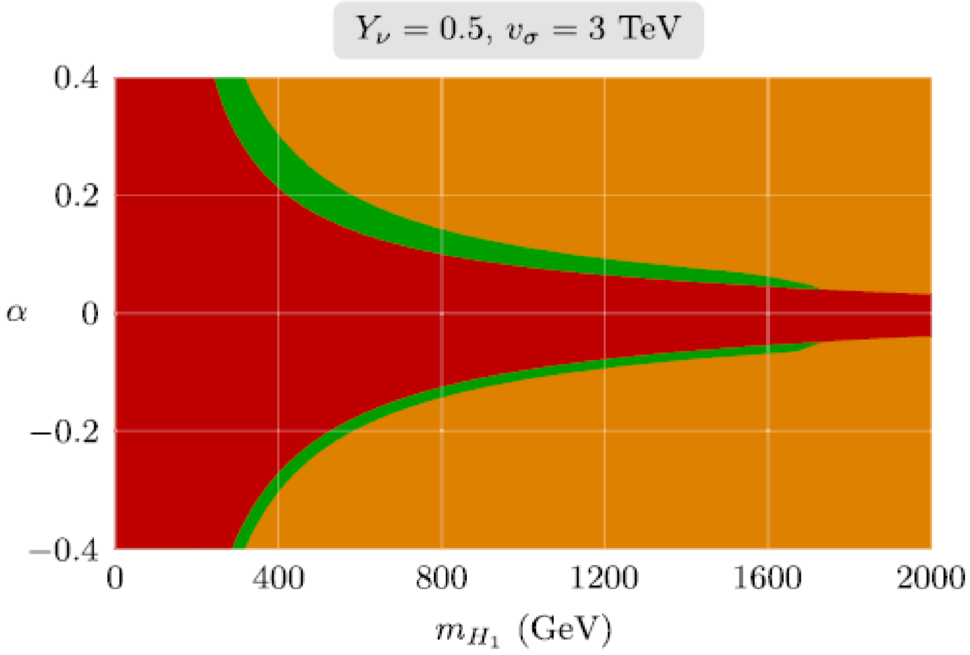
$$(4\pi)^2 \frac{dY_S}{dt} = 6Y_S^3\,,$$

$$(4\pi)^2 \frac{d\lambda_1}{dt} = 20\lambda_1^2 + 2\lambda_{12}^2 + 8\lambda_1 Y_S^2 - 16Y_S^4\,,$$

$$\begin{aligned}(4\pi)^2 \frac{d\lambda_2}{dt} &= \frac{27}{200}g_1^4 + \frac{9}{20}g_1^2 g_2^2 + \frac{9}{8}g_2^4 \\ &- \left(\frac{9}{5}g_1^2 + 9g_2^2\right)\lambda_2 + 24\lambda_2^2 + \lambda_{12}^2 \\ &+ \lambda_2\left(12Y_t^2 + 4Y_\nu^2\right) - \left(6Y_t^4 + 2Y_\nu^4\right),\end{aligned}$$

$$\begin{aligned}(4\pi)^2 \frac{d\lambda_{12}}{dt} &= \Big[-\left(\frac{9}{10}g_1^2 + \frac{9}{2}g_2^2\right) + 6Y_t^2 + 2Y_\nu^2 \\ &+ 4Y_S^2 + 8\lambda_1 + 12\lambda_2 + 4\lambda_{12}\Big]\lambda_{12}\,.\end{aligned}$$

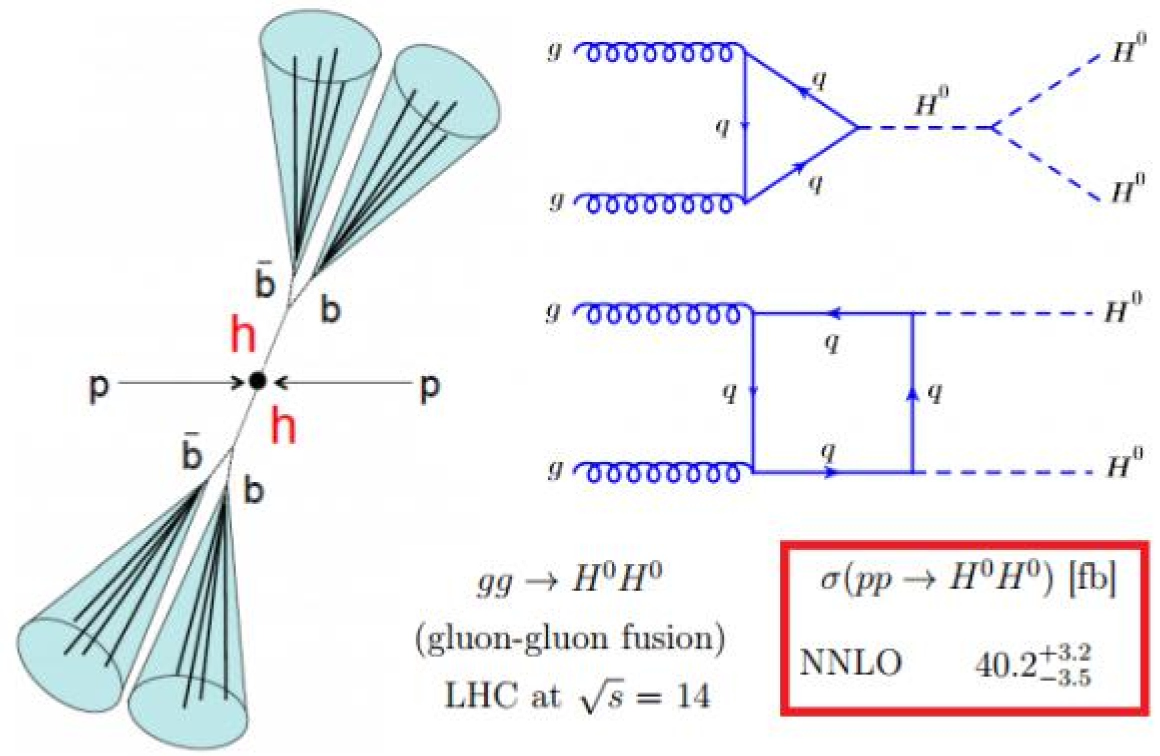
$$\begin{aligned}V(\sigma, H) &= \mu_1^2|\sigma|^2 + \mu_2^2 H^\dagger H + \lambda_1|\sigma|^4 \\ &+ \lambda_2\left(H^\dagger H\right)^2 + \lambda_{12}\left(H^\dagger H\right)|\sigma|^2\,.\end{aligned}$$



Neutrino as
higgs benchmark

Where is the New physics?

Higgs production & decay

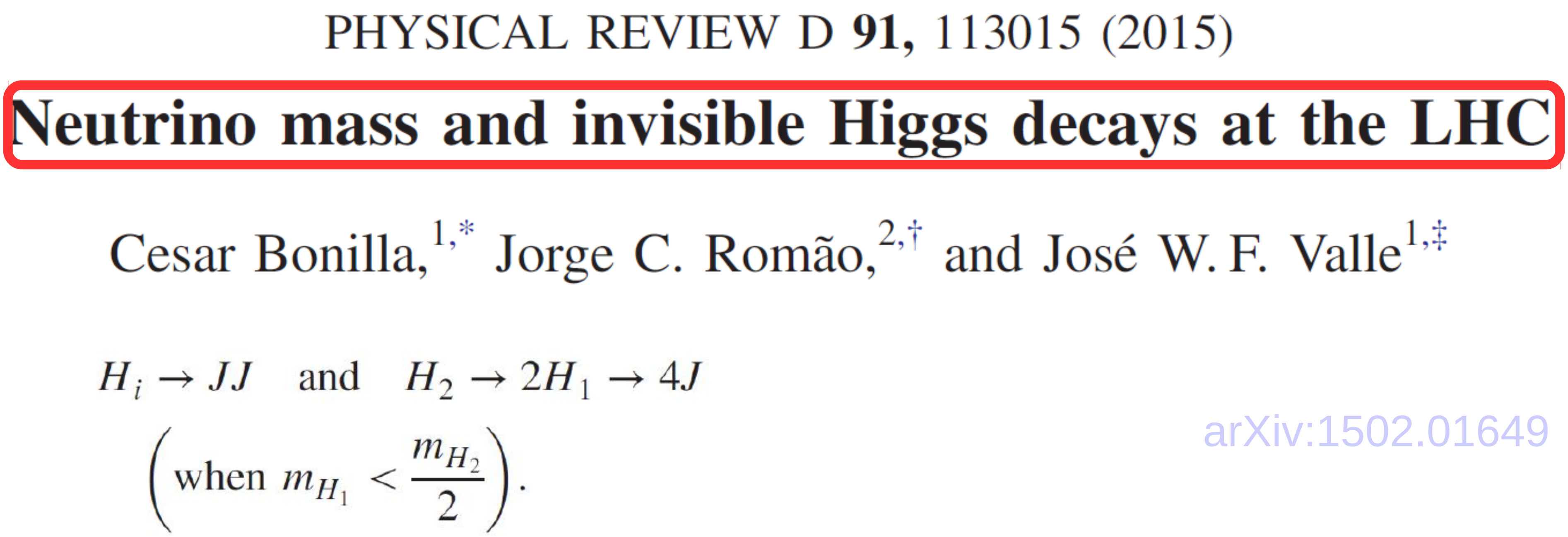


$gg \to H^0H^0$
(gluon-gluon fusion)
LHC at $\sqrt{s} = 14$

$\sigma(pp \to H^0H^0)$ [fb]
NNLO $40.2^{+3.2}_{-3.5}$

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

Joshipura & J.V. Nucl.Phys. B397 (1993) 105-122



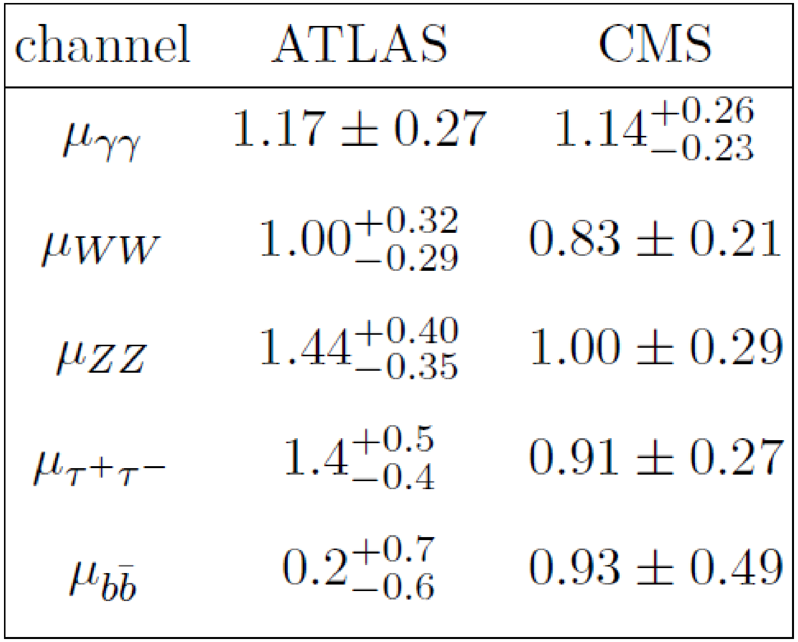
PHYSICAL REVIEW D **91,** 113015 (2015)

Neutrino mass and invisible Higgs decays at the LHC

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

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

arXiv:1502.01649



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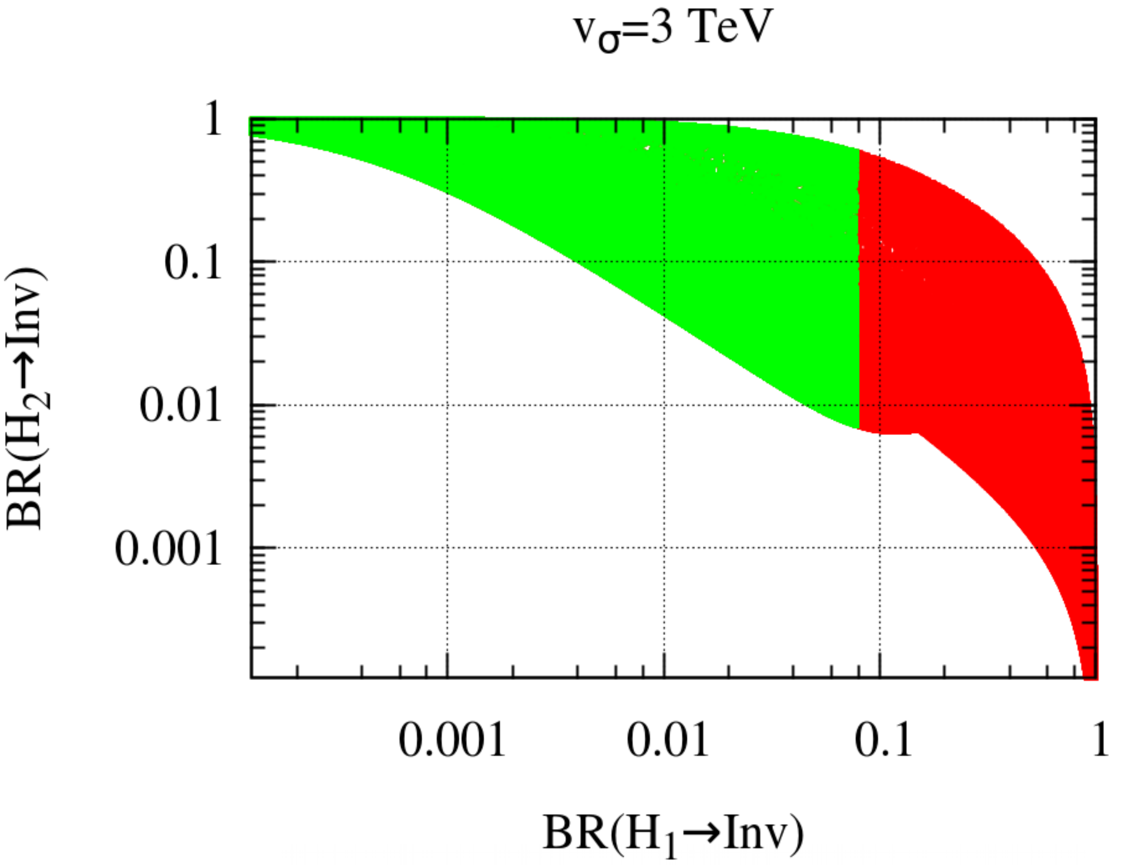
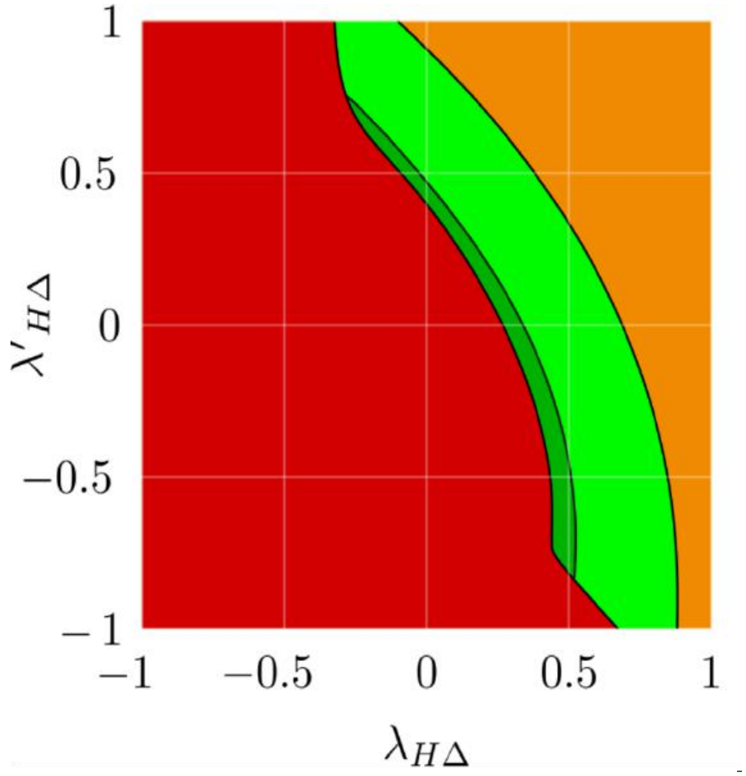


Neutrino as higgs benchmark

PHYSICAL REVIEW D **92,** 075028 (2015)

Consistency of the triplet seesaw model revisited



IOP Publishing *New J. Phys.* **18** (2016) 033033

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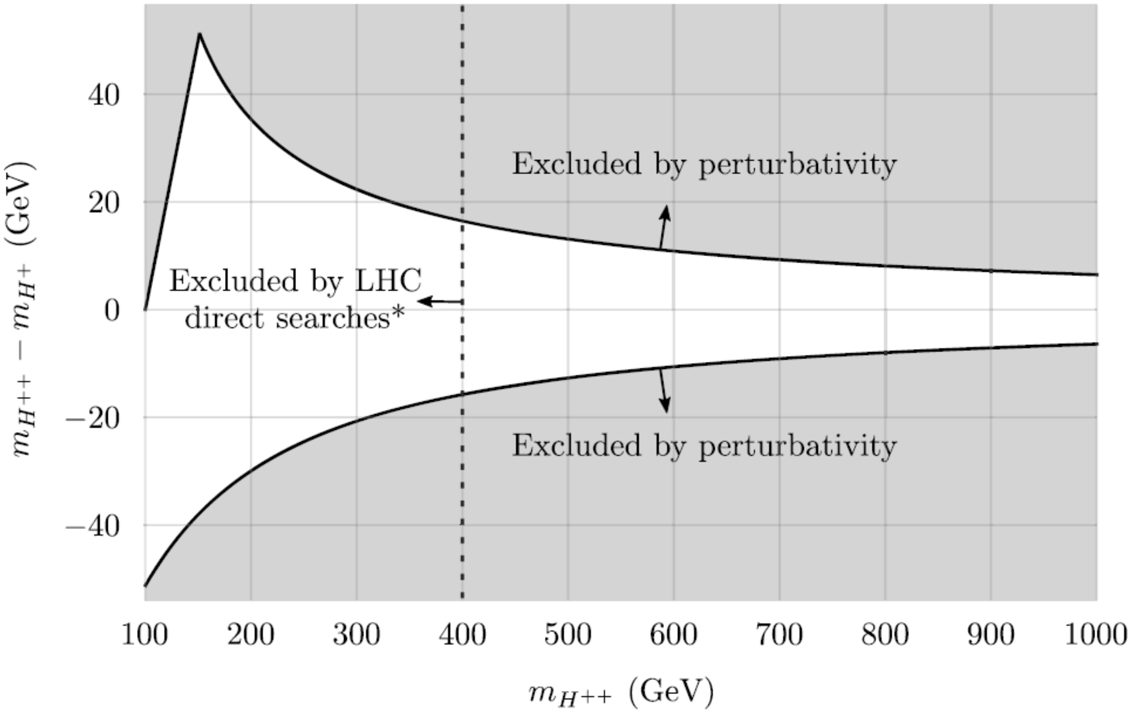
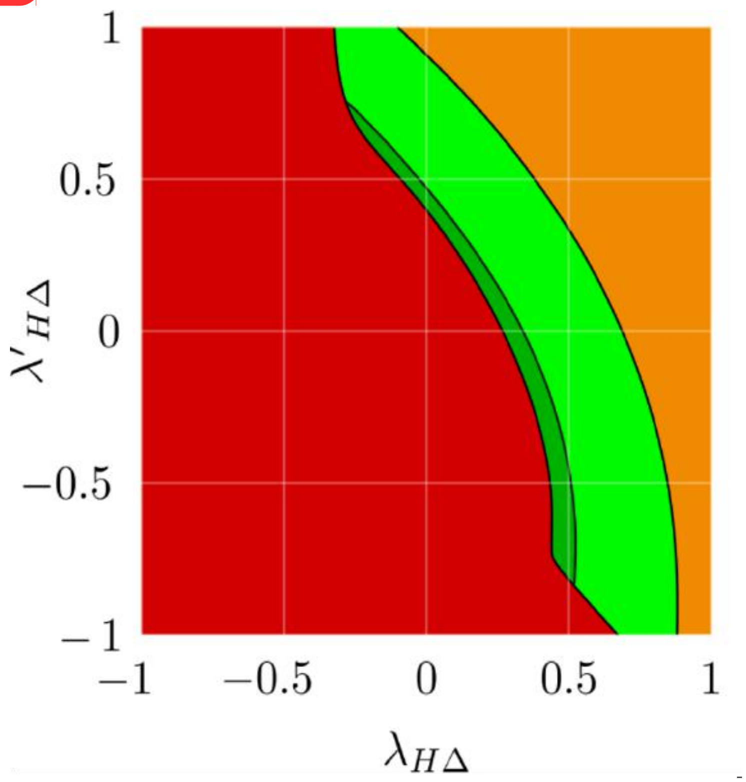
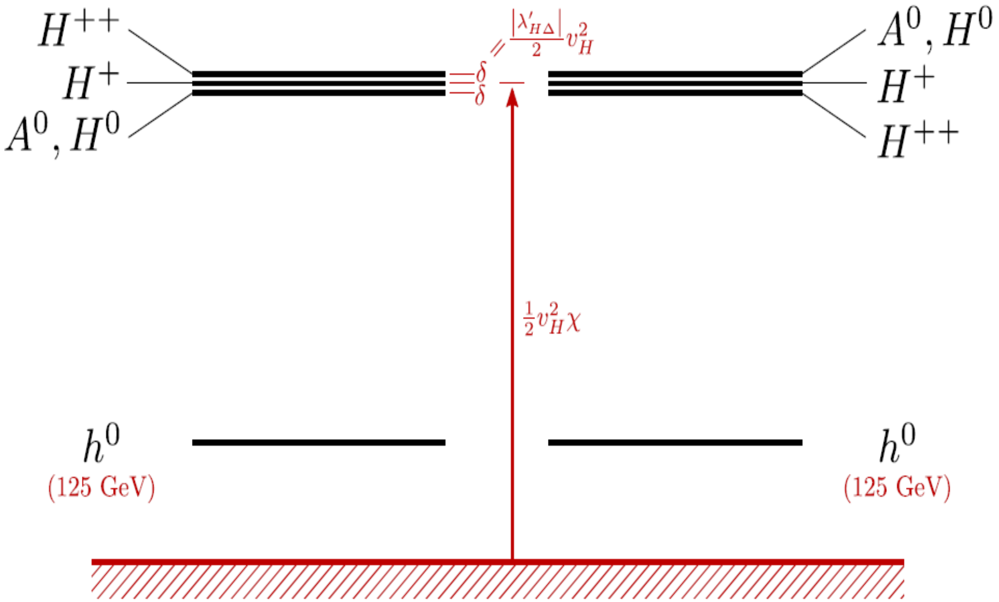


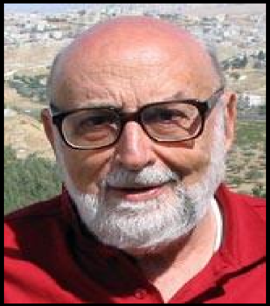




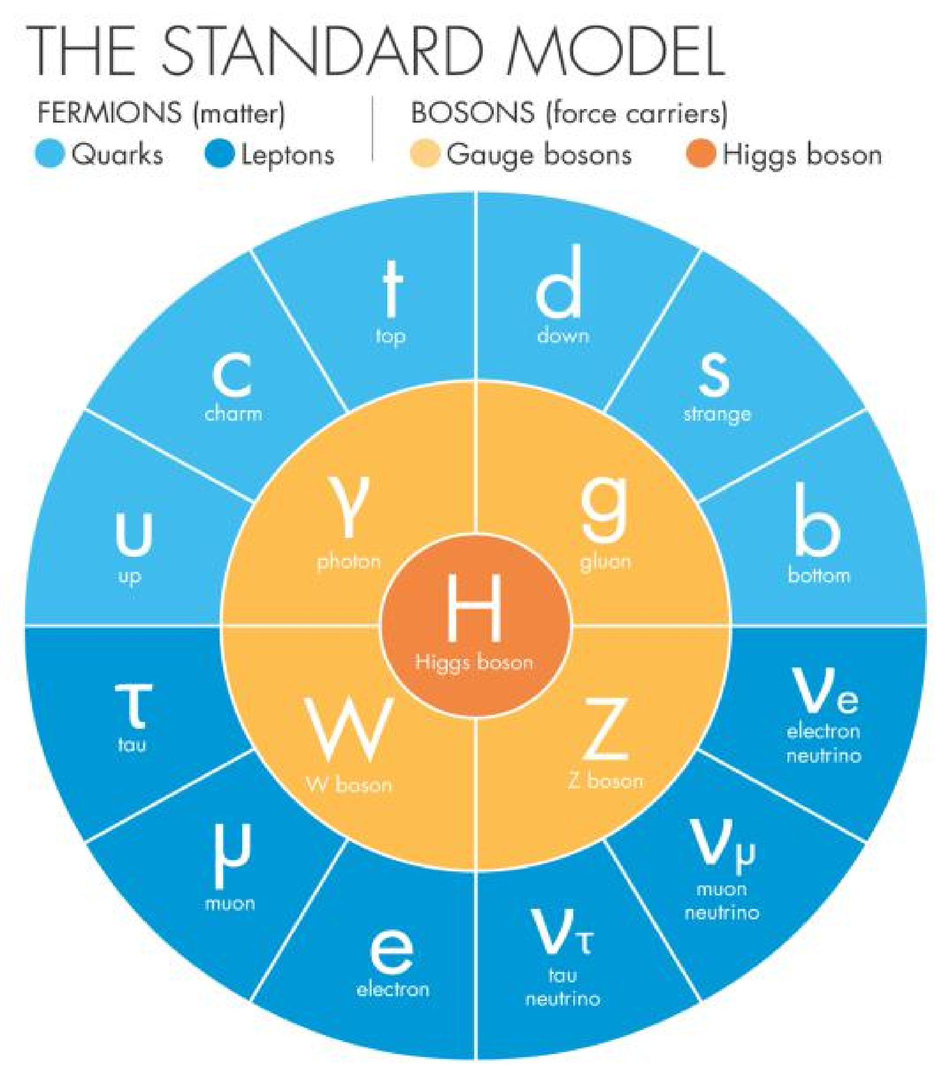
IOP Publishing *New J. Phys.* 18 (2016) 033033

Neutrino as
higgs benchmark

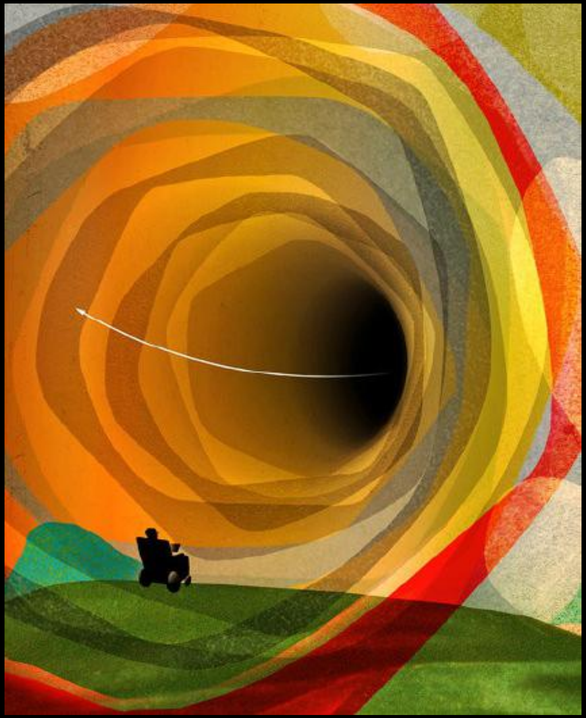
How about gravity?

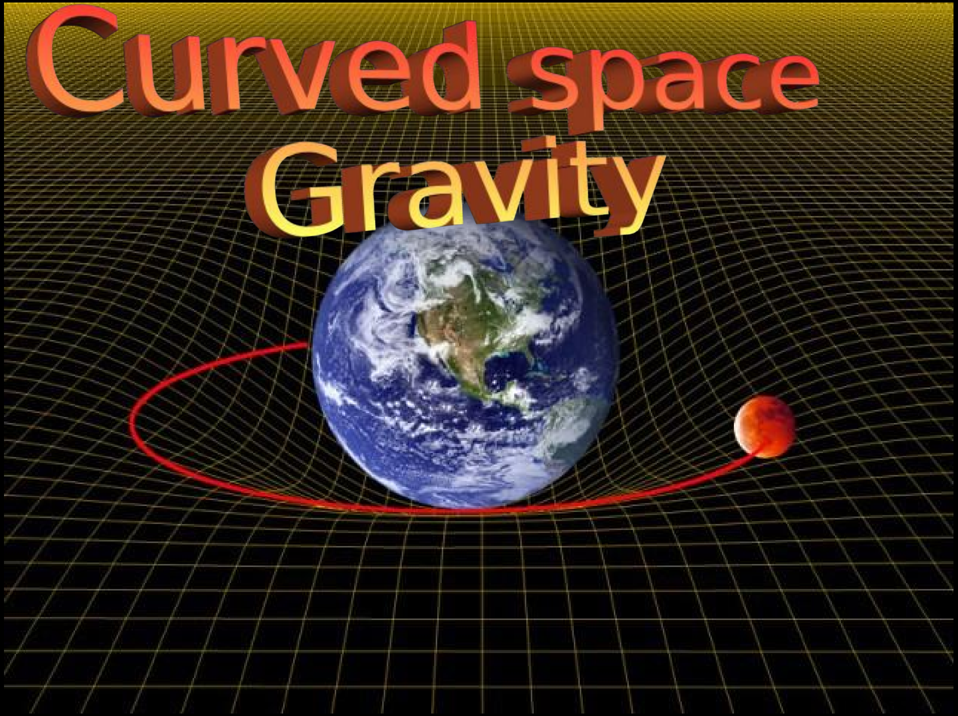


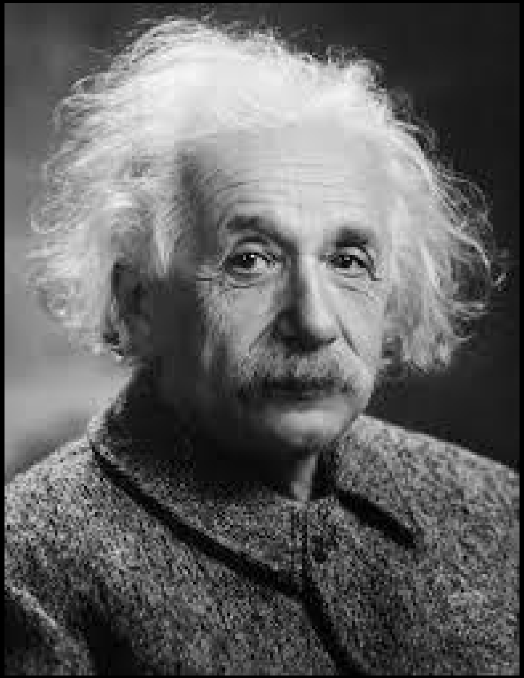
Higgs not the last brick ! …

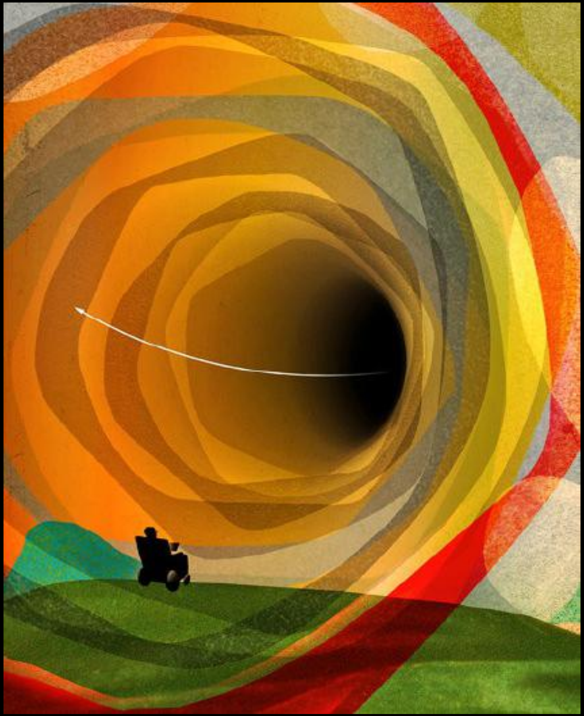


does not include gravity




Curved space
Gravity





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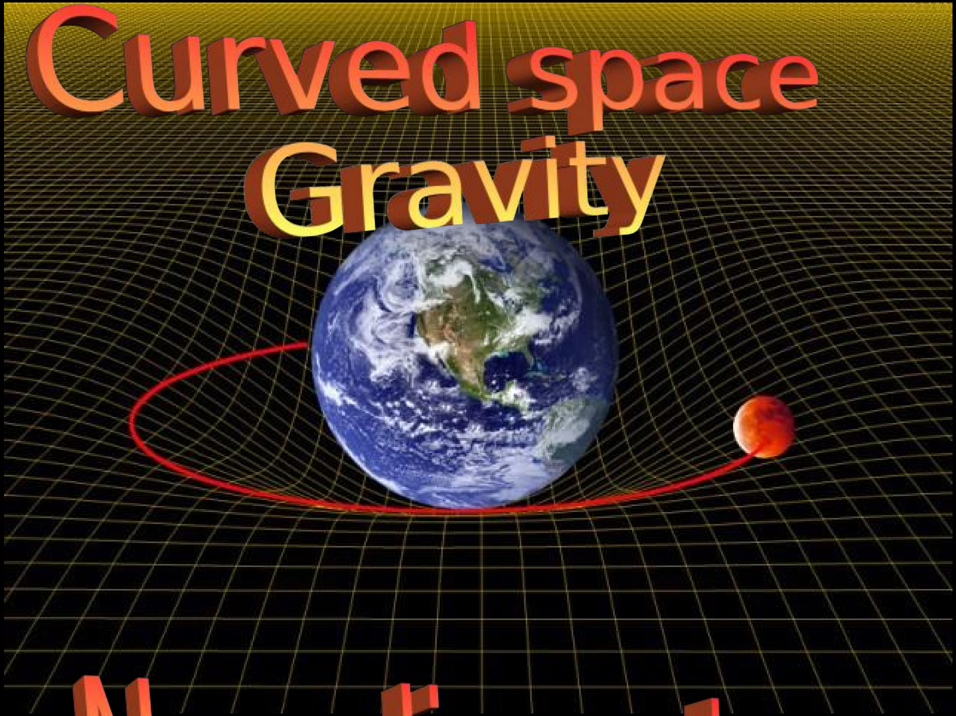
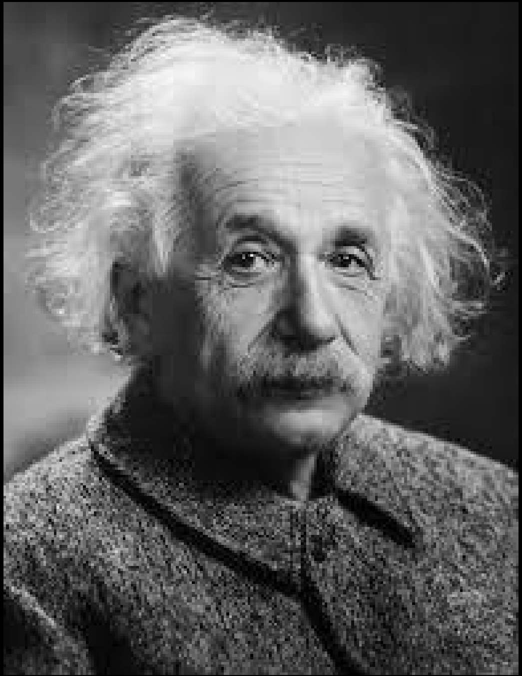
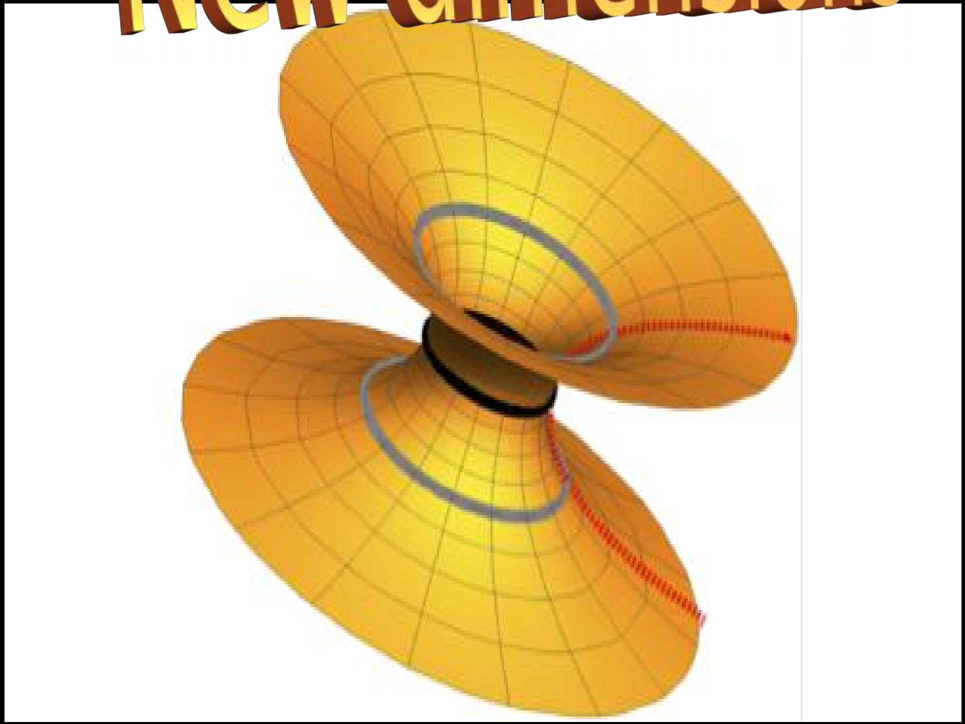
Gravity





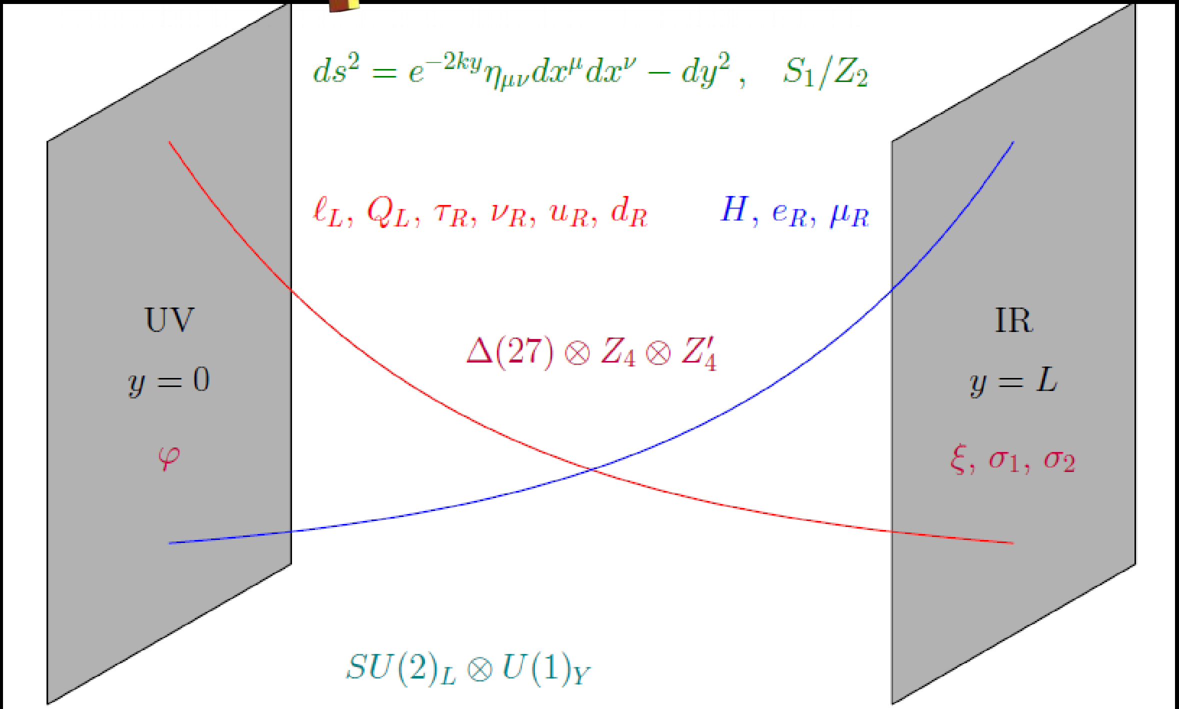
New dimensions



Warped flavor

: Chen et al arXiv:1509.06683

JHEP01(2016)007



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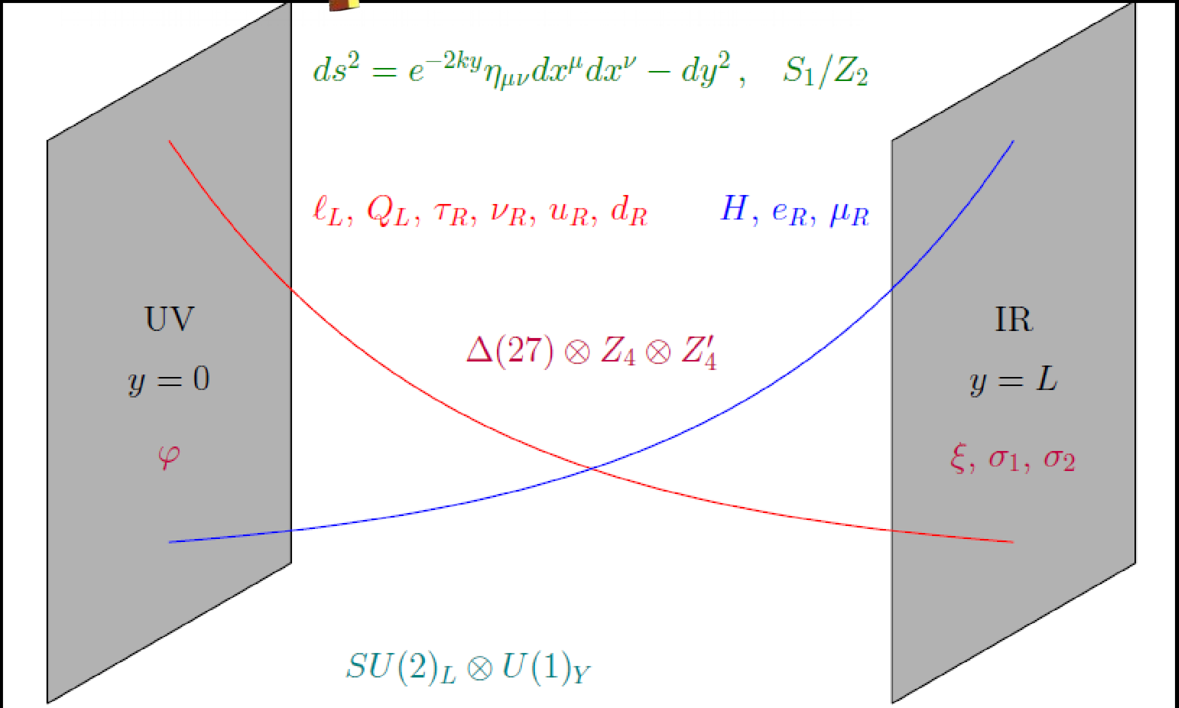

Mass hierarchies in principle explained by judicious choices of the bulk parameters

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

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

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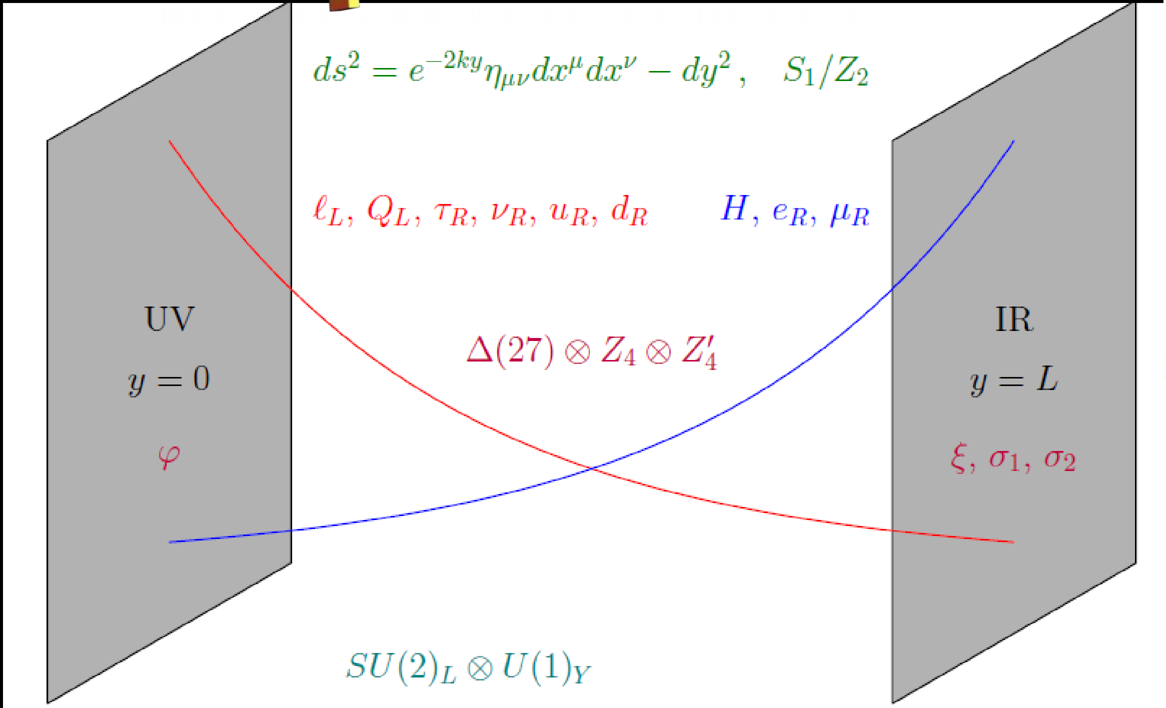

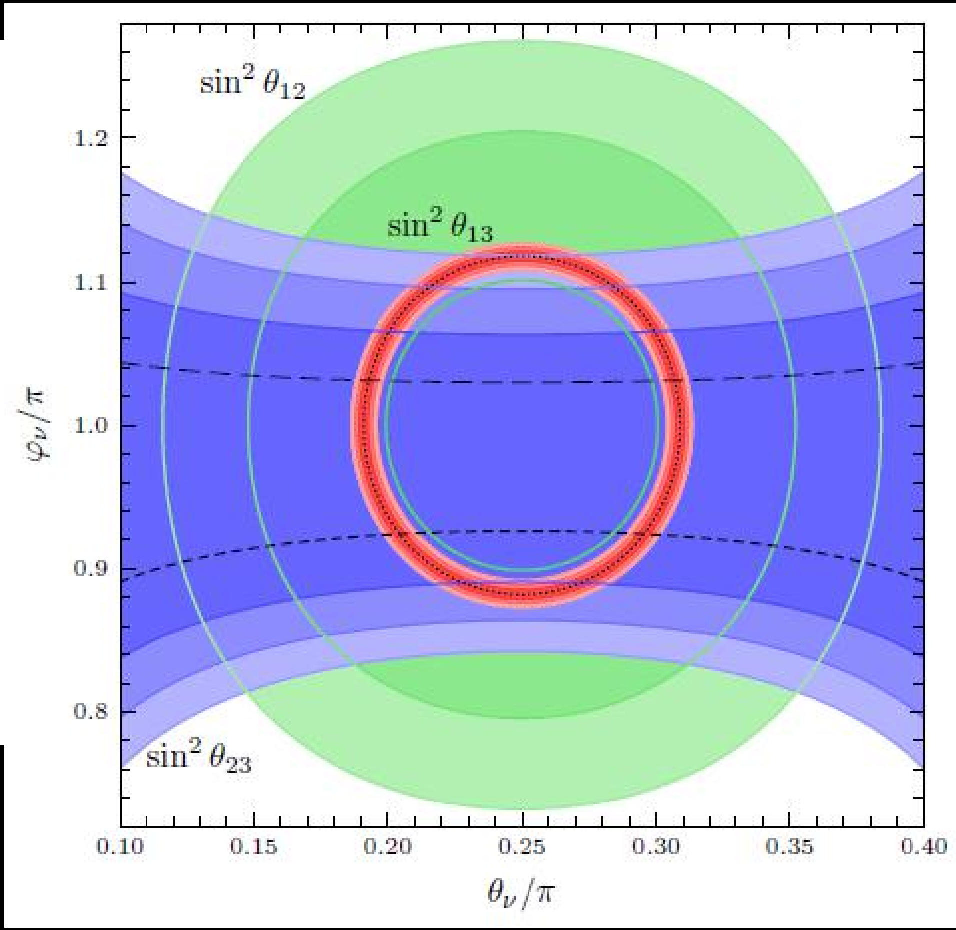

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Addazi et al arXiv:1604.02117

331 from strings

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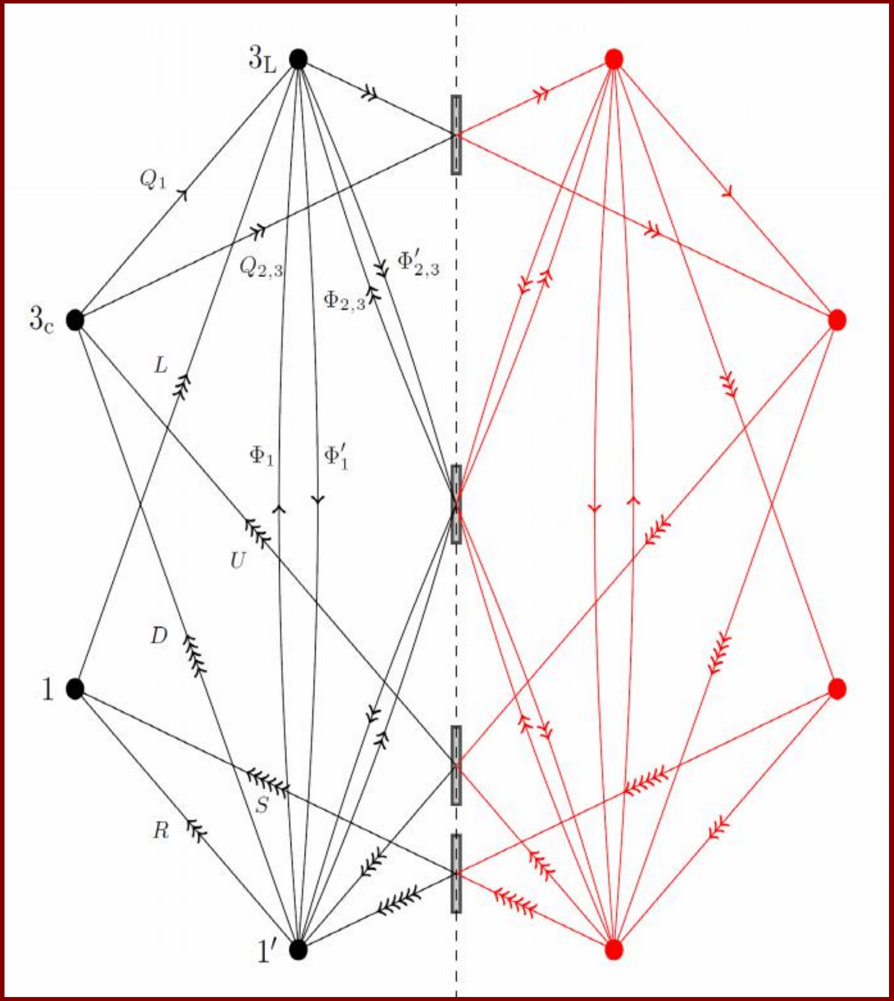

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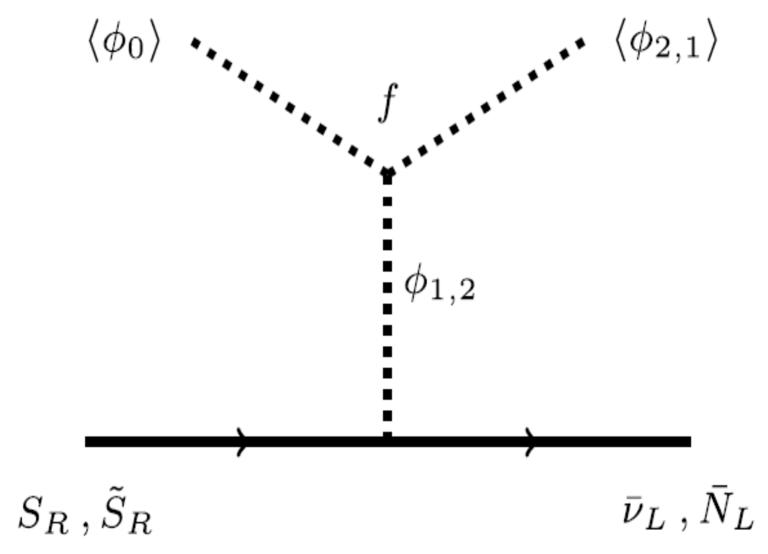


Physics Letters B 755 (2016) 363–366

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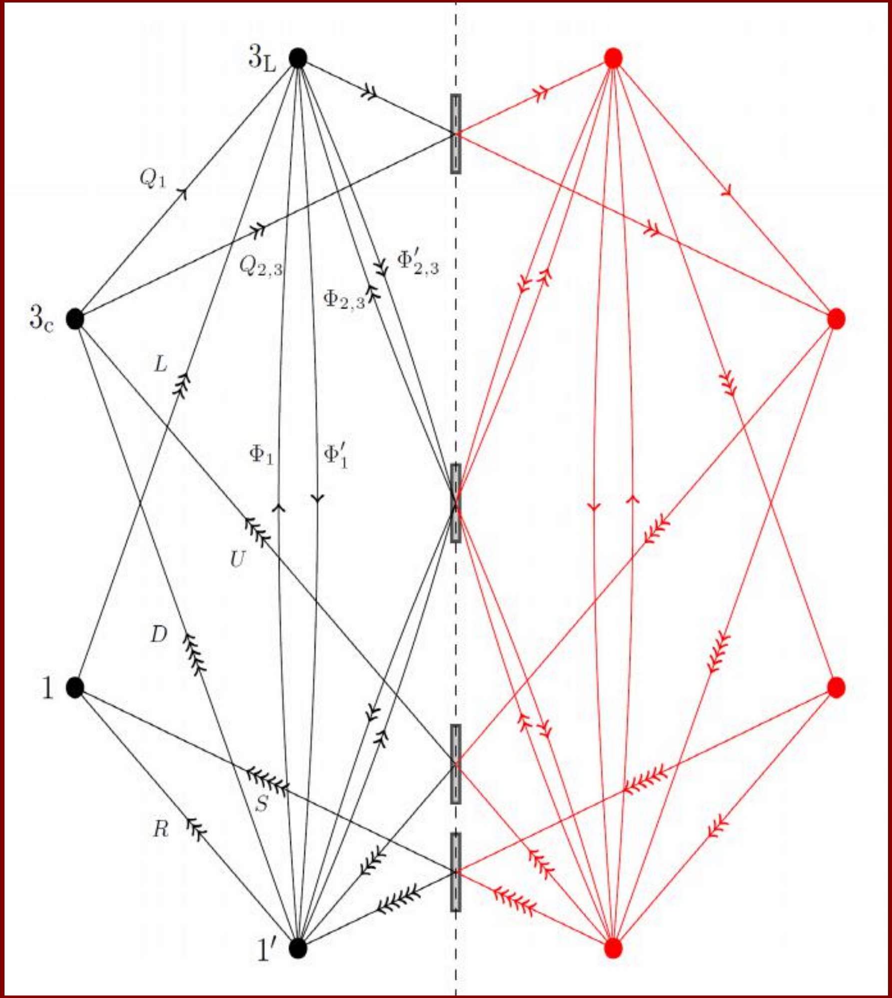

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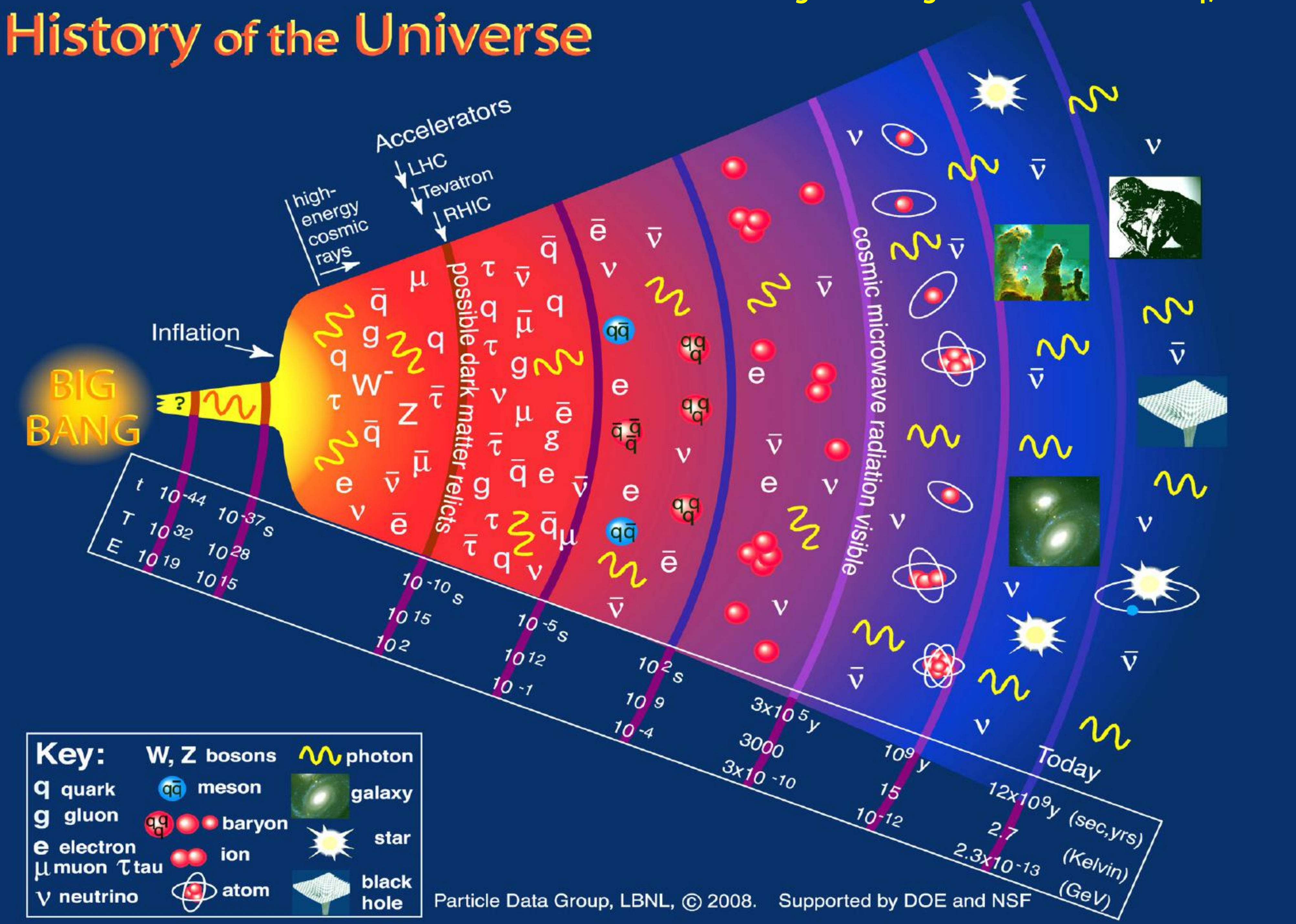
How about cosmology?

understanding the largest from the SM q, l ...



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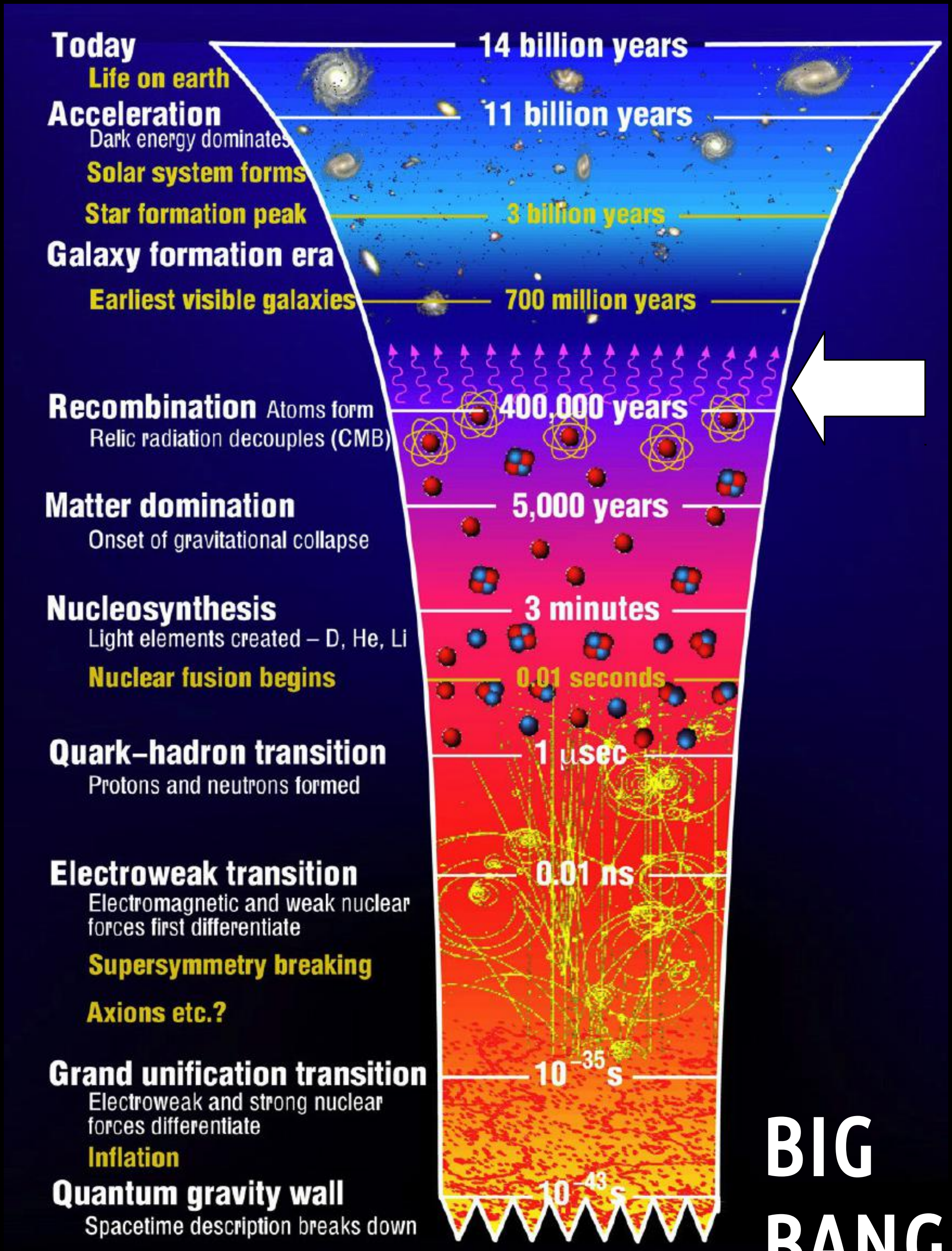
Neutrinos affect the CMB and large scale structure in the Universe …



BIG BANG

Neutrinos affect the CMB
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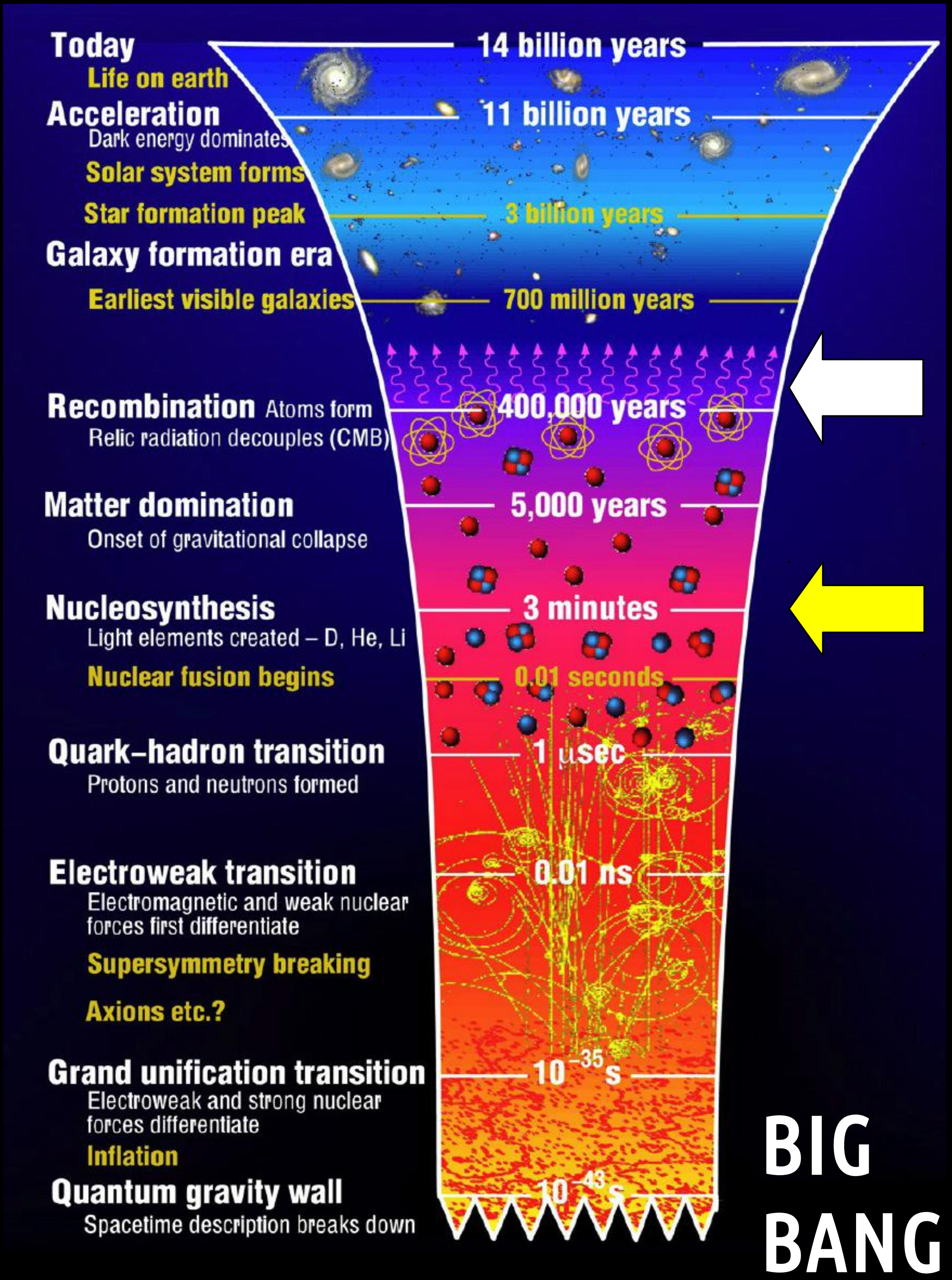
are key in the synthesis of light elements



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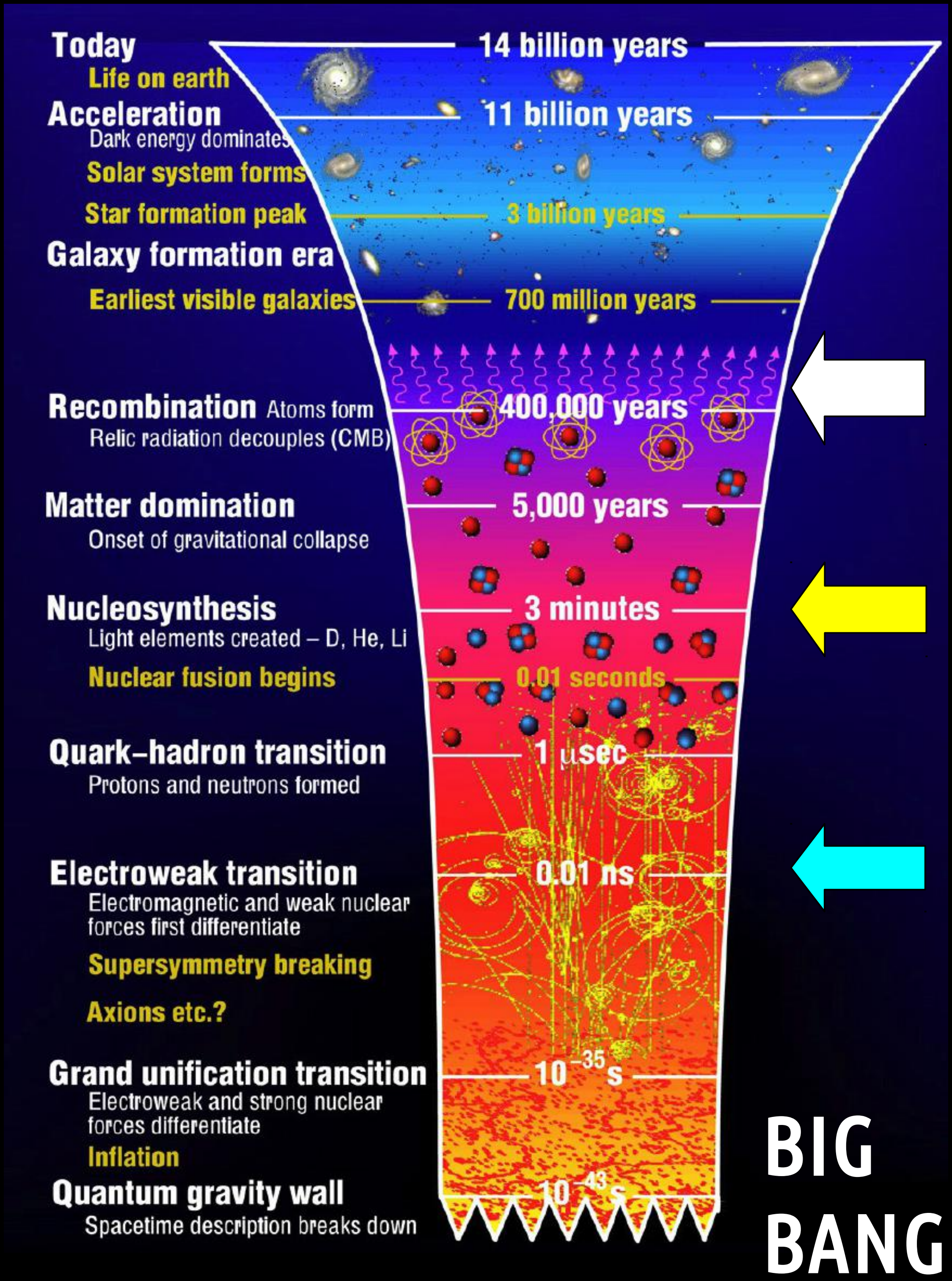

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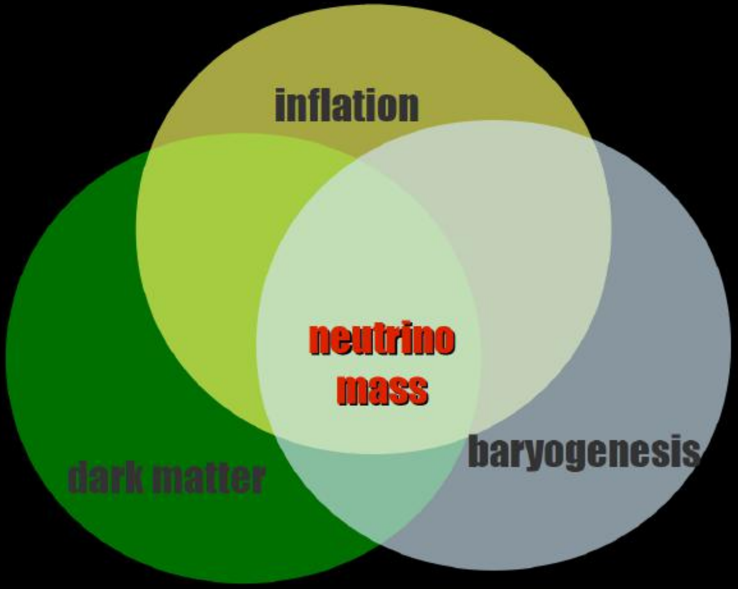

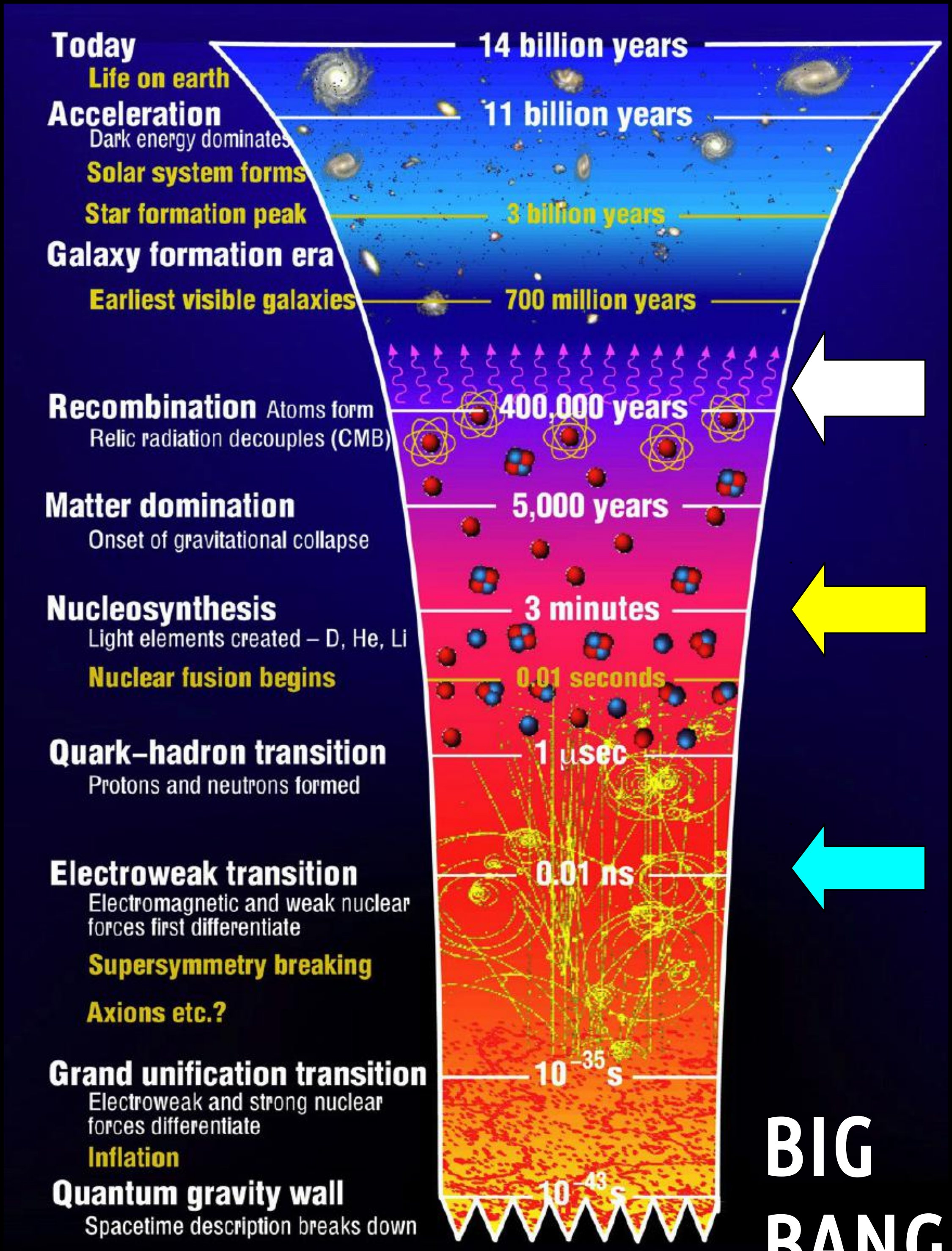

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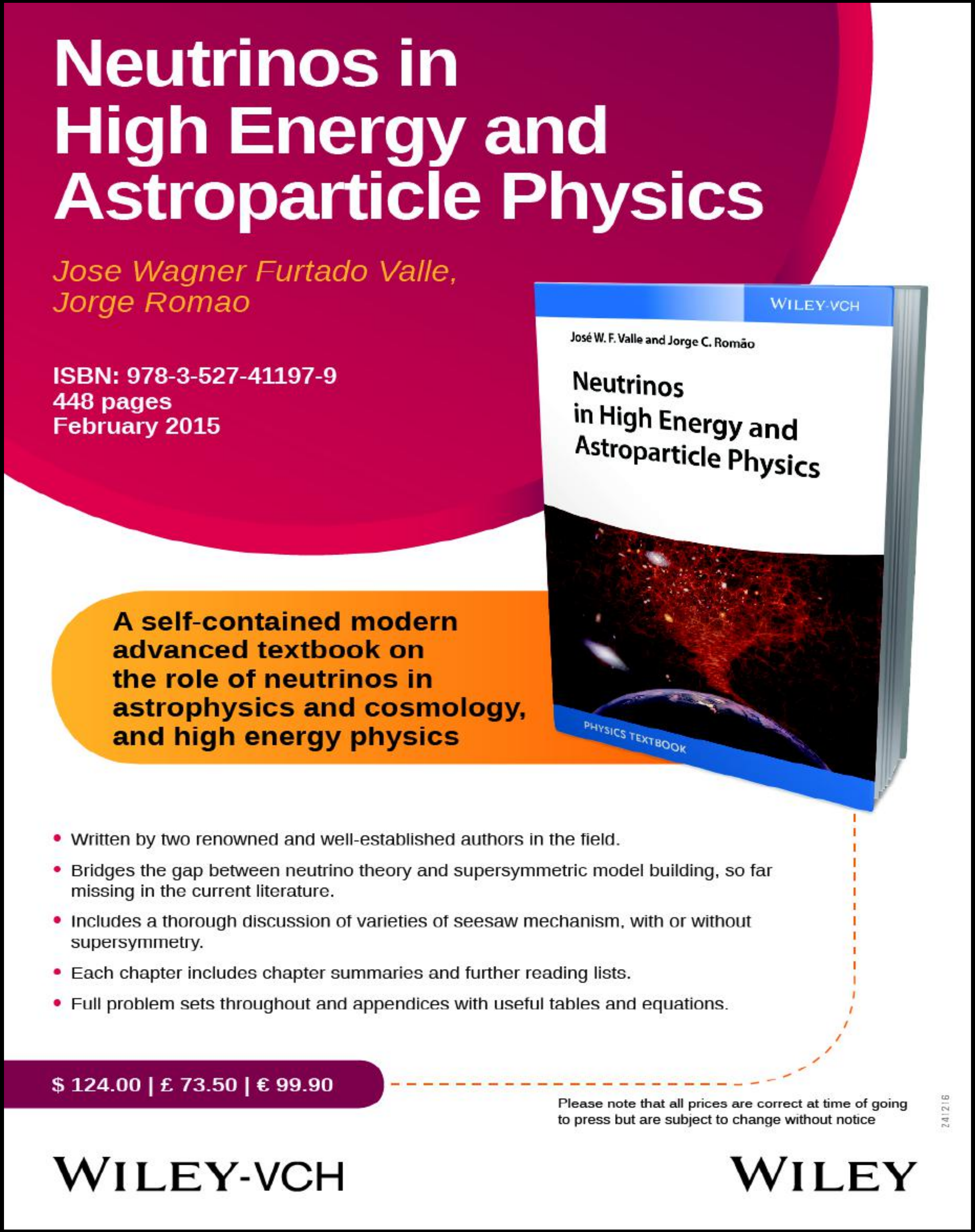
The road to new physics

neutrino masses

dark matter
baryon asymmetry
Inflation
Dark energy

Thank you



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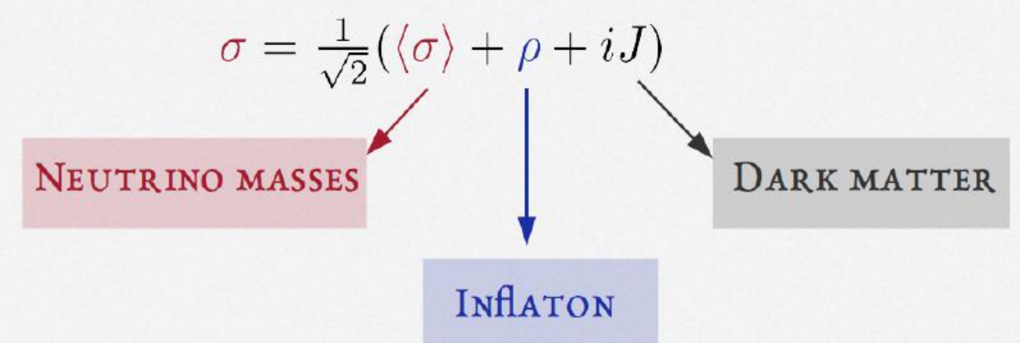
Seesaw inflation & majoron dark matter

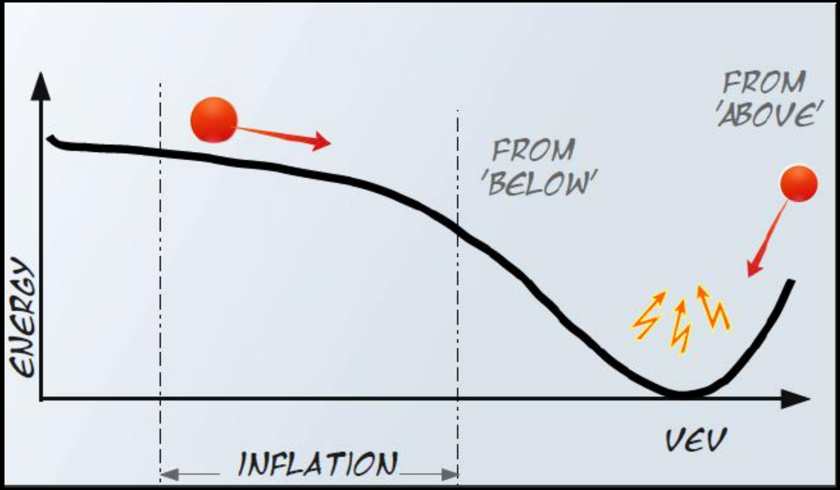


$$\sigma = \frac{1}{\sqrt{2}}(\langle\sigma\rangle + \rho + iJ)$$

Boucenna et al arXiv:1405.2332 PRD90 (2014) 05502

type-I seesaw Leptogenesis

Aristizabal et al arXiv:1405.4706



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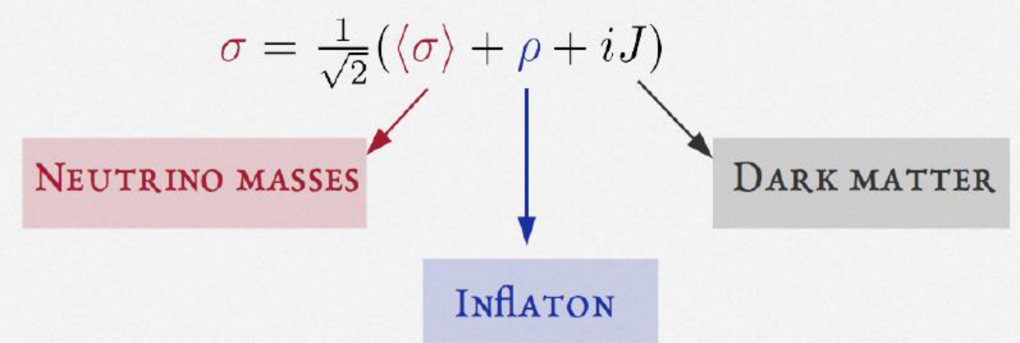
Seesaw inflation & majoron dark matter



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Neutrino masses

Inflaton

Dark matter

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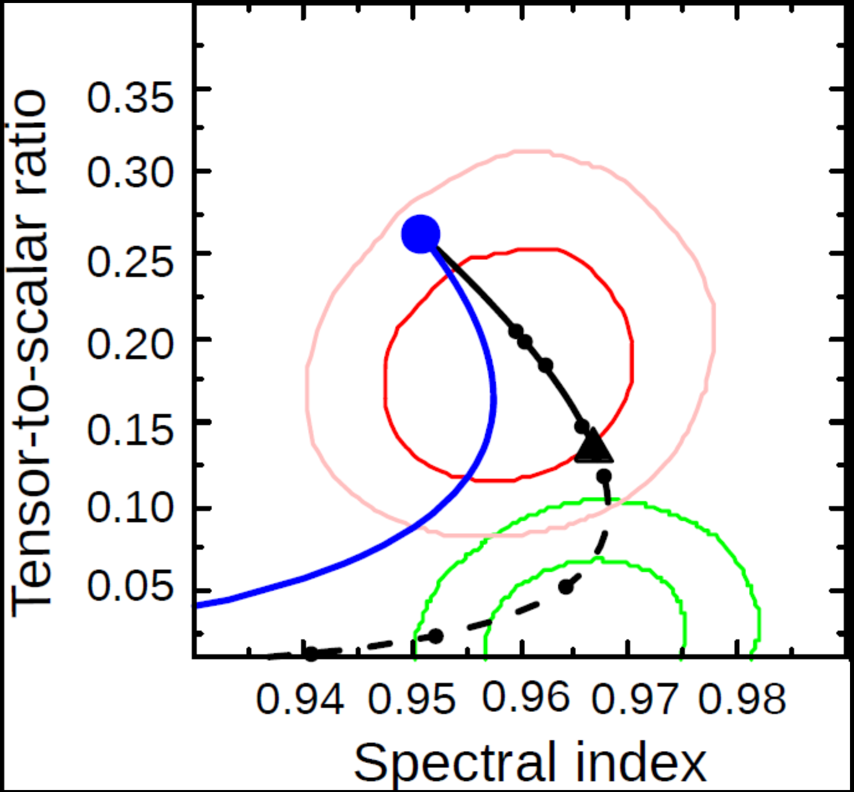
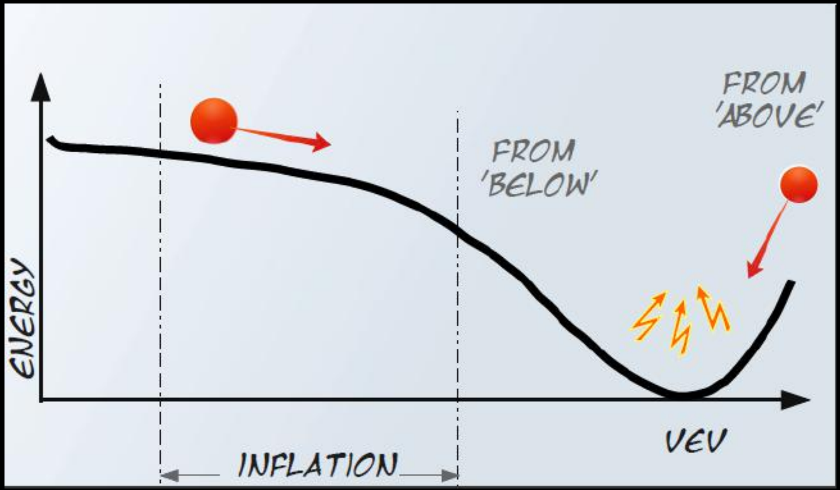
Quartic versus *Higgs Inflation*





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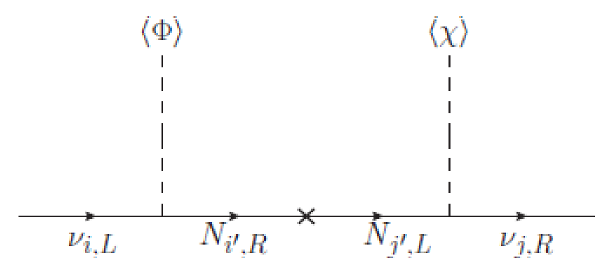
Dark Matter Stability from Dirac nature of neutrinos



Chiulia et al arXiv:1606.04543

arXiv:1606.06904

Lepton Quarticity vs Lepton number

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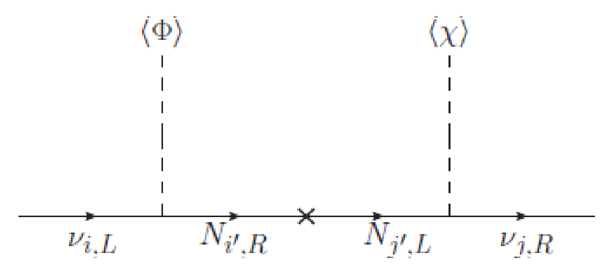

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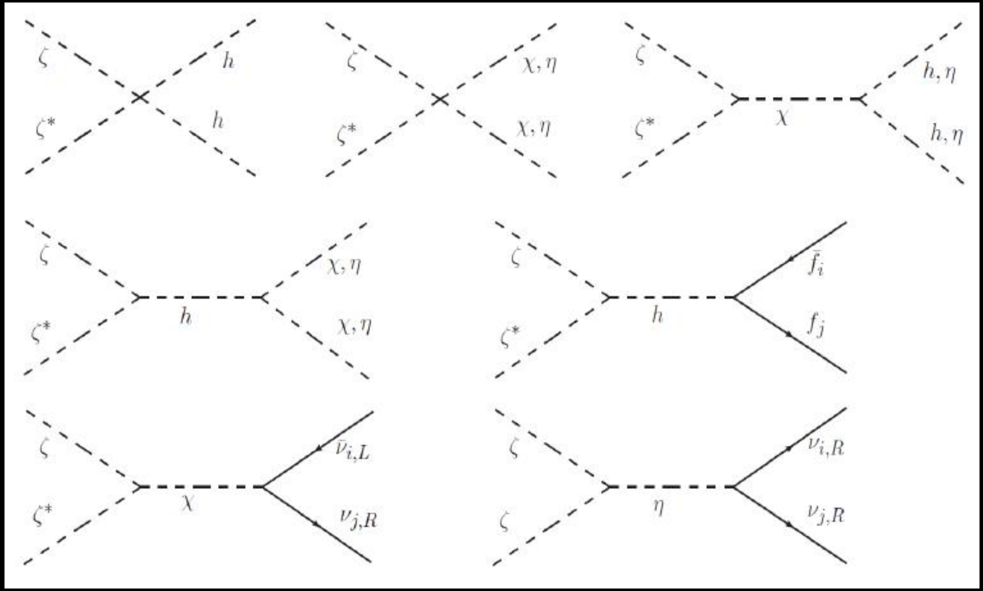

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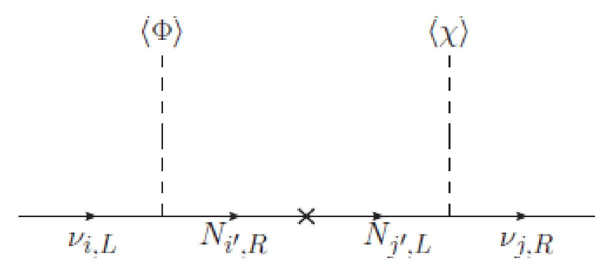

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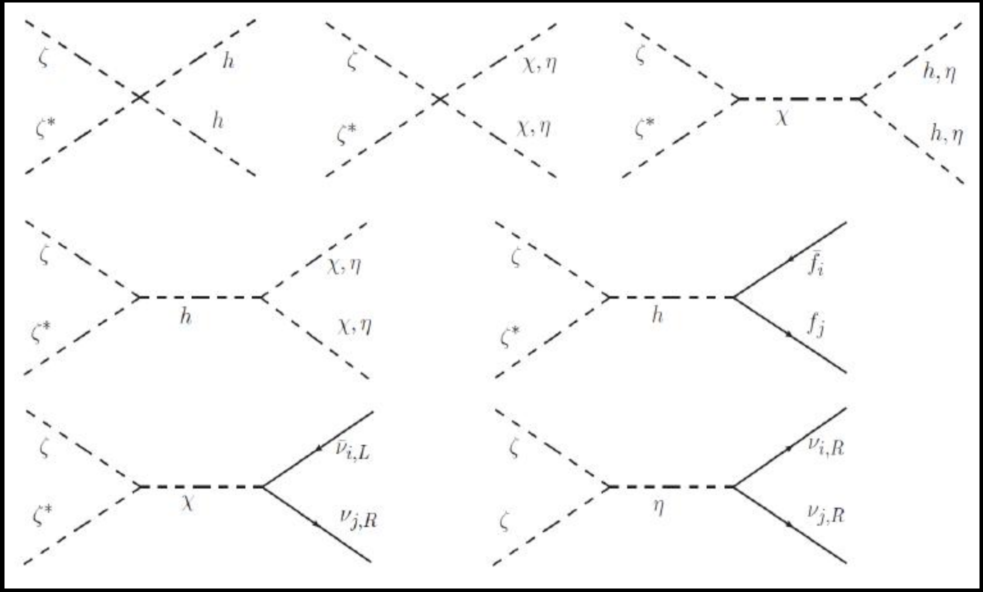

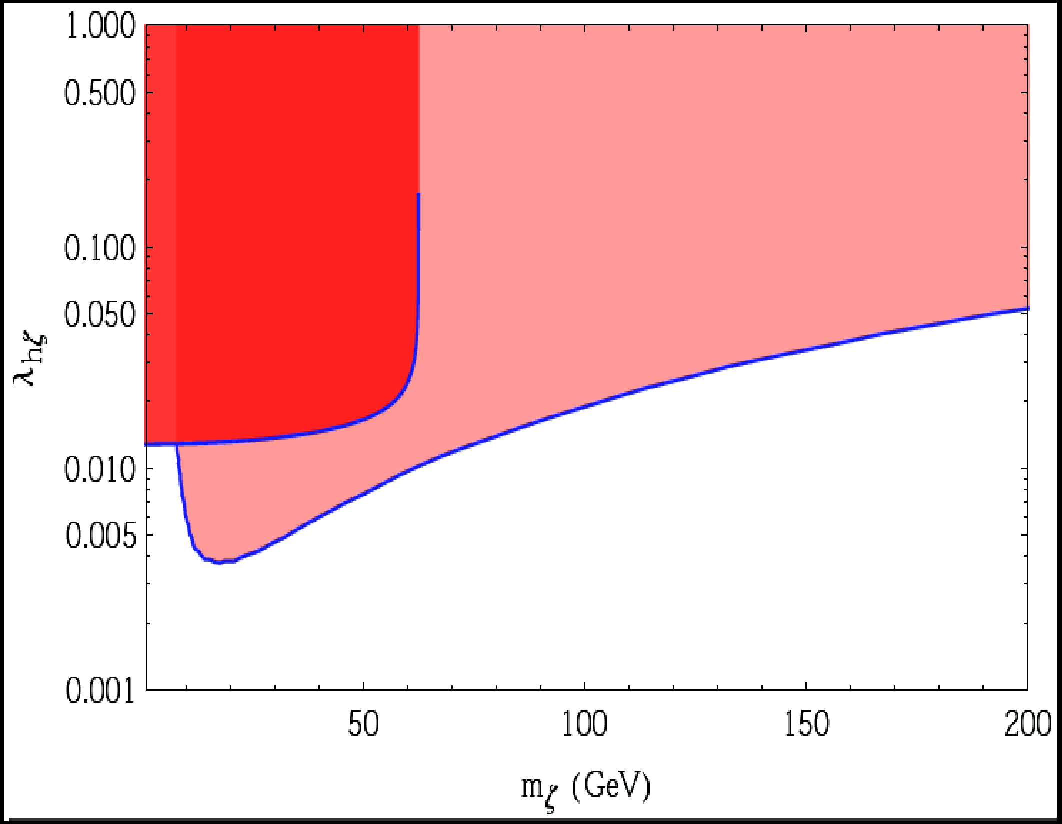

Di-photon anomaly As a flavon

PhysRevD93, 073009 (2016)