neutrinos as gateways to new physics

José W F Valle

CSIC
Consejo Superior de Investigaciones Científicas

IFIC
Institut de Física Corpuscular

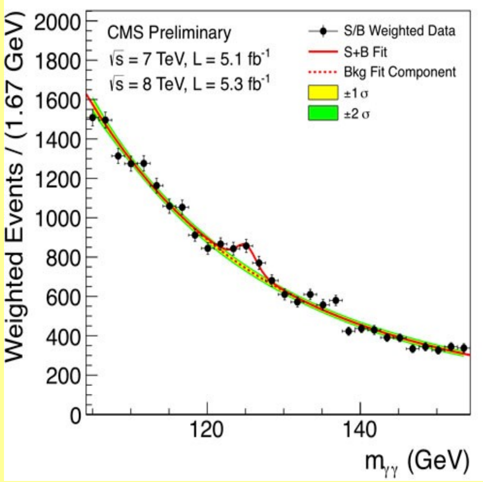
Vniversitat de València

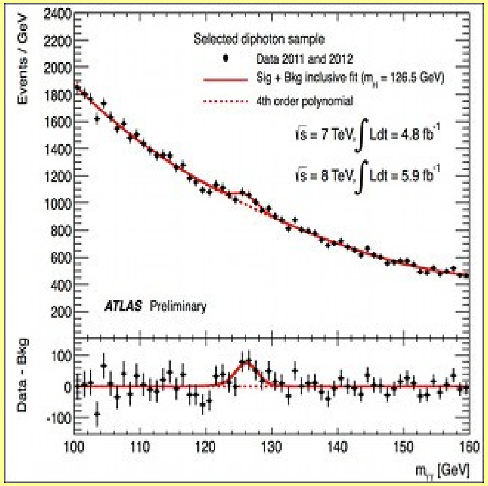
ASTROPARTICLES
Astroparticles and High Energy Physics Group

IFIC AHEP on facebook

Manzanillo, July 2015, Mexico

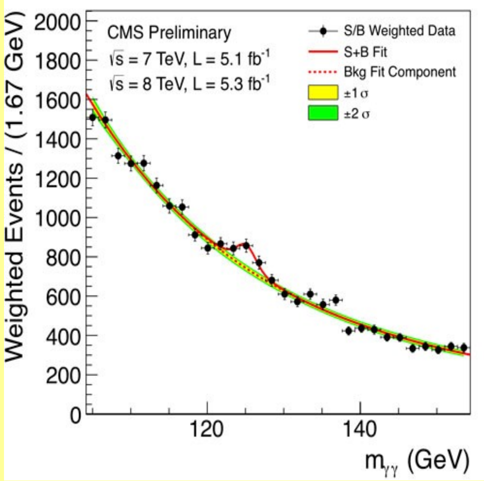
the historic Higgs discovery

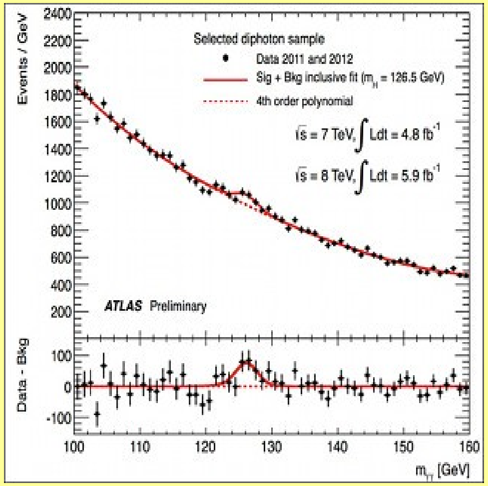




SM is complete

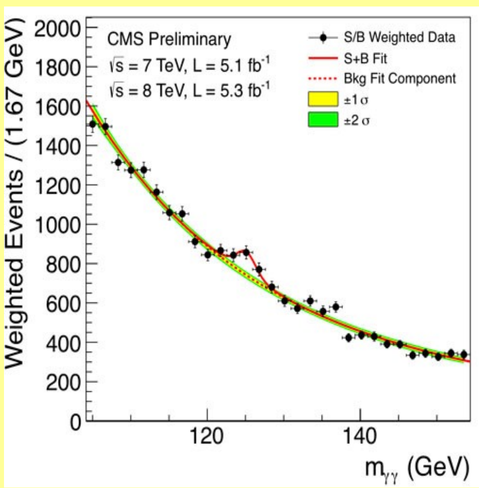
the historic Higgs discovery

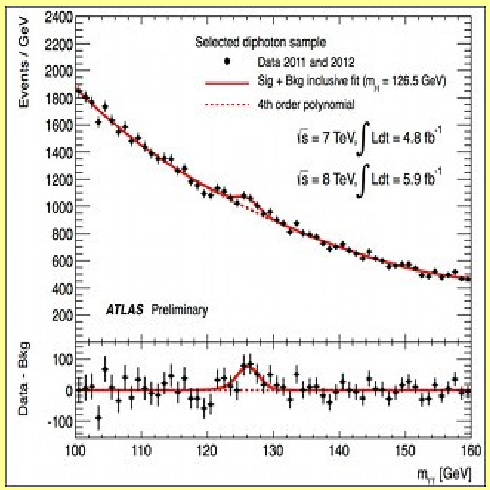




complete
were it not for
neutrinos & cosmology

the historic Higgs discovery

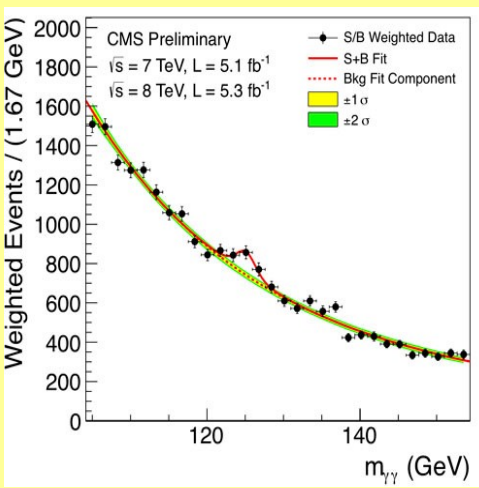


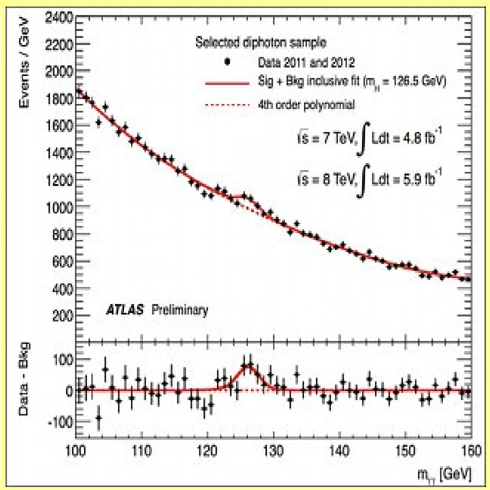


no neutrino masses
no dark matter
no baryon asymmetry
no inflation
no gauge coupling unification
consistency of vacuum ?
……

complete
were it not for
neutrinos & cosmology

the historic Higgs discovery





no neutrino masses
no dark matter
no baryon asymmetry
no inflation
no gauge coupling unification
consistency of vacuum ?
......

complete
were it not for
neutrinos & cosmology

SM vacuum

Physics Letters B 716 (2012) 214–219

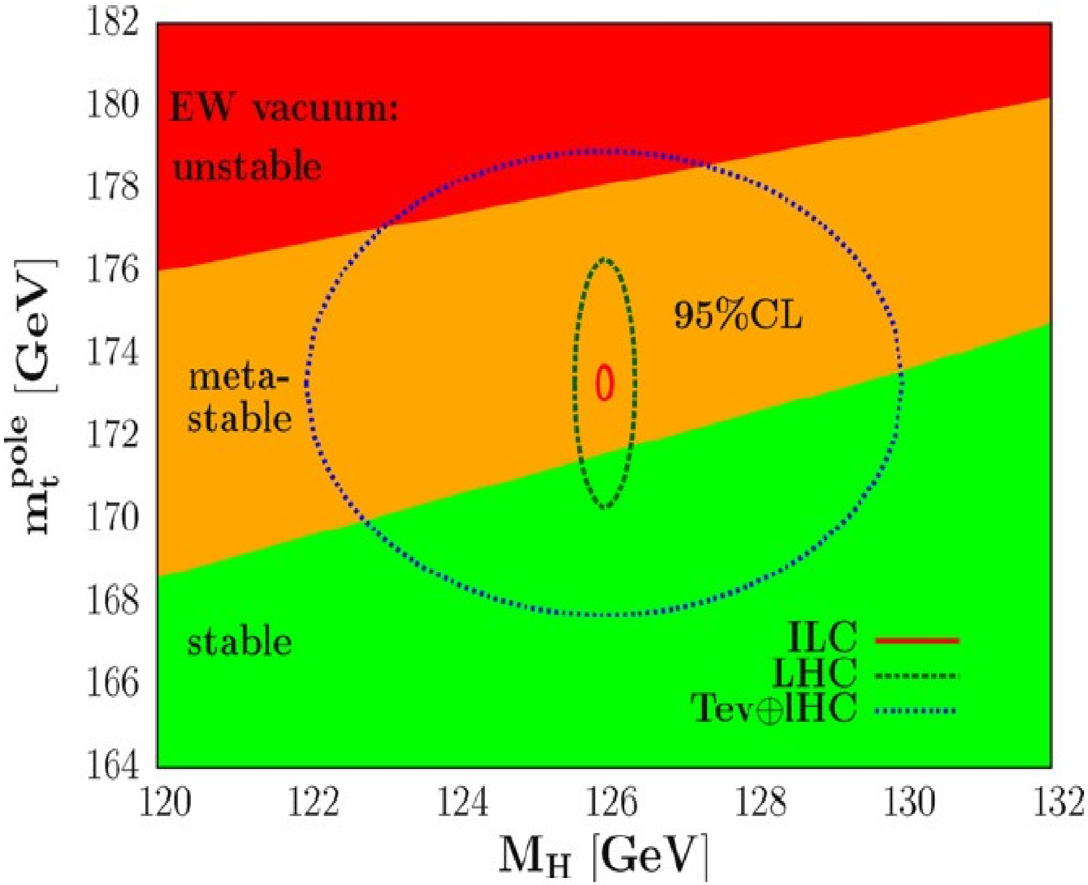


Fig. 1. The 2σ ellipses in the $[M_H, m_t^{pole}]$ plane that one obtains from the current top quark and Higgs mass measurements at the Tevatron and LHC and which can be expected in future measurements at the LHC and at the ILC, when confronted with the areas in which the SM vacuum is absolutely stable,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

SM vacuum ... Can Neutrinos bring Stability?

Physics Letters B 716 (2012) 214–219

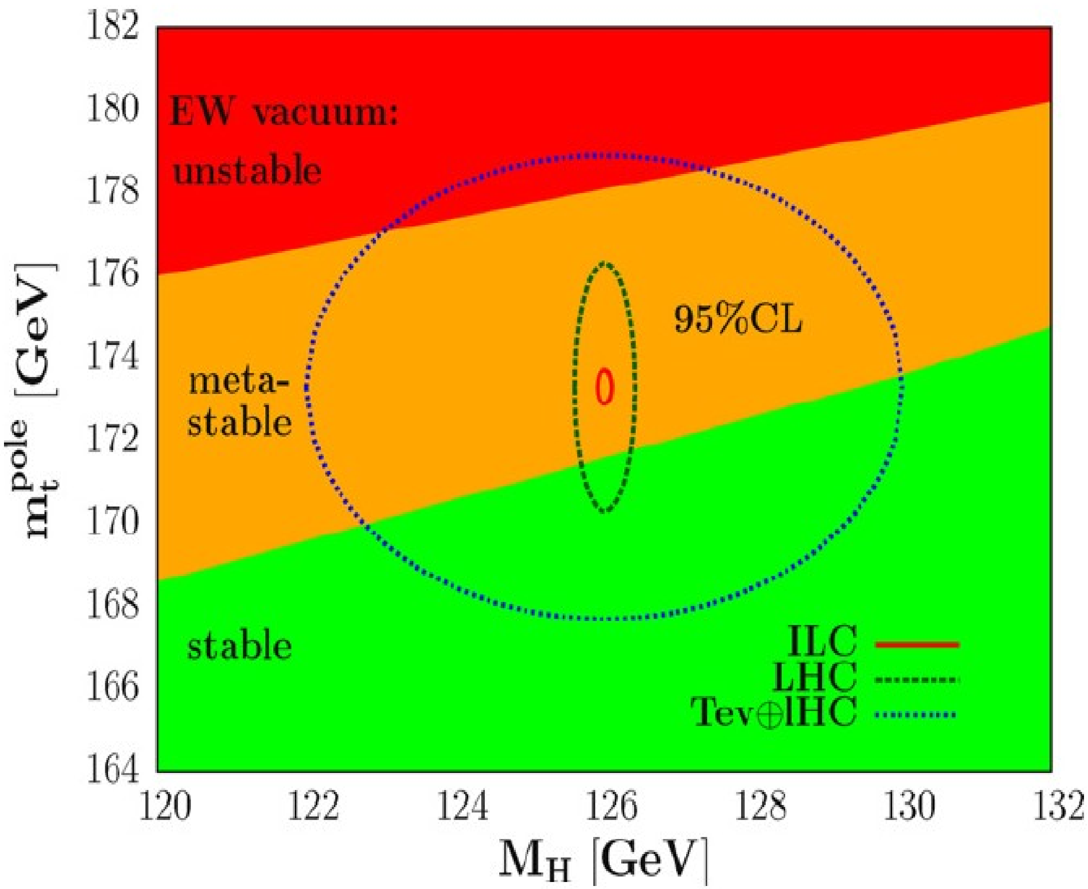
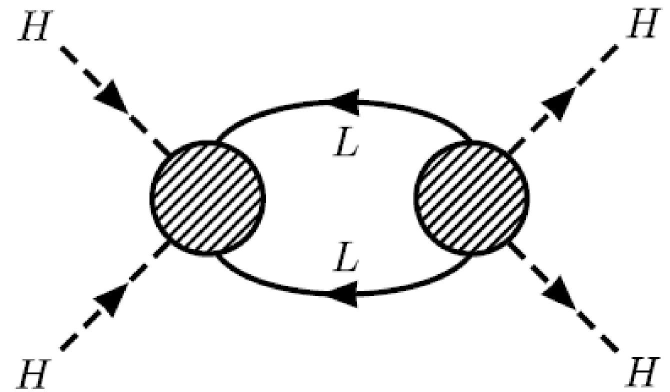


Fig. 1. The 2σ ellipses in the $[M_H, m_t^{pole}]$ plane that one obtains from the current top quark and Higgs mass measurements at the Tevatron and LHC and which can be expected in future measurements at the LHC and at the ILC, when confronted with the areas in which the SM vacuum is absolutely stable,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



arXiv:1506.04031

Neutrinos & Stability

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

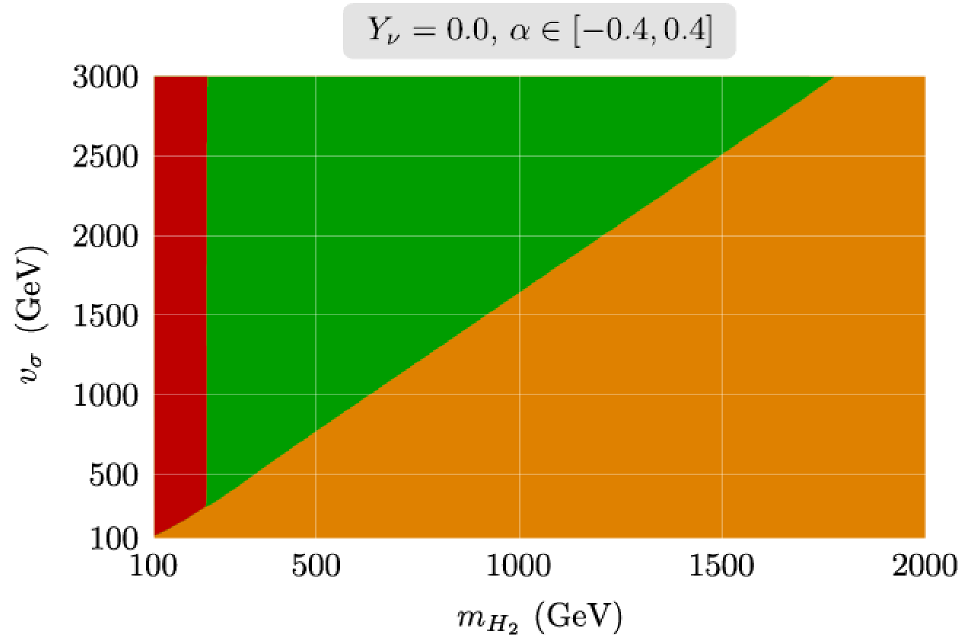
Vacuum stability with spontaneous violation of lepton number

Cesar Bonilla, Renato M. Fonseca and José W. F. Valle

AHEP Group, Institut de Física Corpuscular – C.S.I.C./Universitat de València, Parc Cientific de Paterna.
C/ Catedratico Jose Beltran, 2 E-46980 Paterna (Valencia) - SPAIN

(Dated: June 15, 2015)

Neutrinos & Stability



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

Vacuum stability with spontaneous violation of lepton number

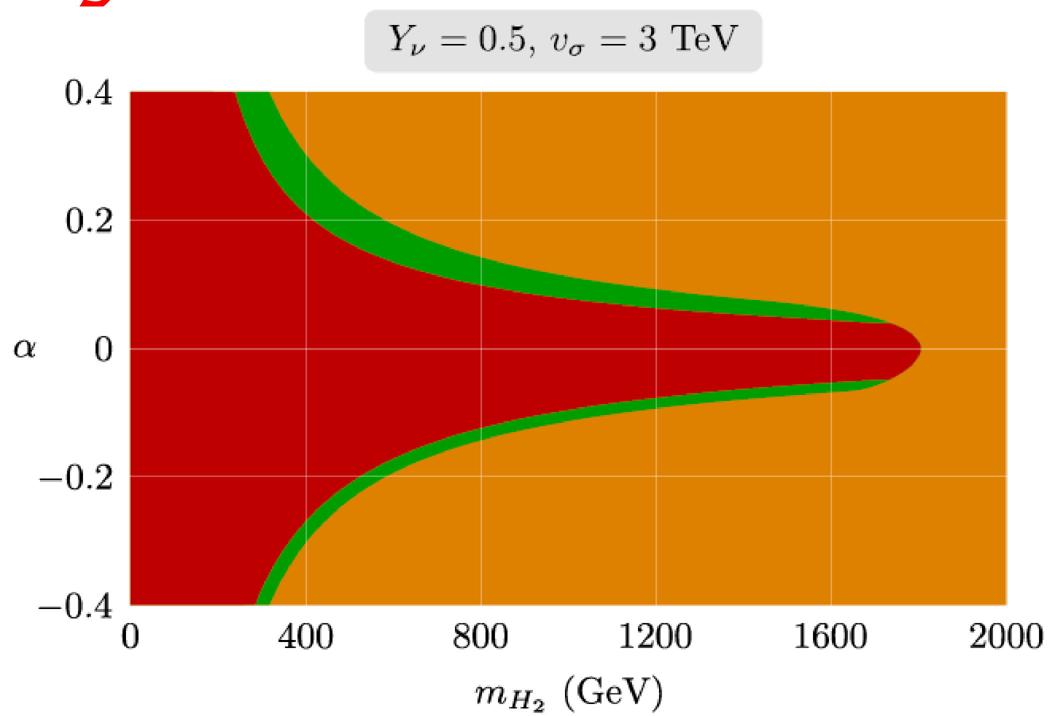
Cesar Bonilla, Renato M. Fonseca and José W. F. Valle

AHEP Group, Institut de Física Corpuscular – C.S.I.C./Universitat de València, Parc Científic de Paterna. C/ Catedratico Jose Beltran, 2 E-46980 Paterna (Valencia) - SPAIN

(Dated: June 15, 2015)

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

Neutrinos & Stability



Vacuum stability with spontaneous violation of lepton number

Cesar Bonilla, Renato M. Fonseca and José W. F. Valle

AHEP Group, Institut de Física Corpuscular – C.S.I.C./Universitat de València, Parc Científic de Paterna.
C/ Catedratico Jose Beltran, 2 E-46980 Paterna (Valencia) - SPAIN

(Dated: June 15, 2015)

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,‡]

$$\Gamma\left(H_2 \to H_1 H_1\right) = \frac{g^2_{H_2 H_1 H_1}}{32\pi m_{H_2}} \left(1 - \frac{4m^2_{H_1}}{m^2_{H_2}}\right)^{1/2}$$

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

arXiv:1502.01649

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,‡]

$$\Gamma\left(H_2 \to H_1 H_1\right) = \frac{g^2_{H_2 H_1 H_1}}{32\pi m_{H_2}} \left(1 - \frac{4 m^2_{H_1}}{m^2_{H_2}}\right)^{1/2}$$

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

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

arXiv:1502.01649

Neutrinos & Invisible Higgs

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

Neutrino mass and invisible Higgs decays at the LHC

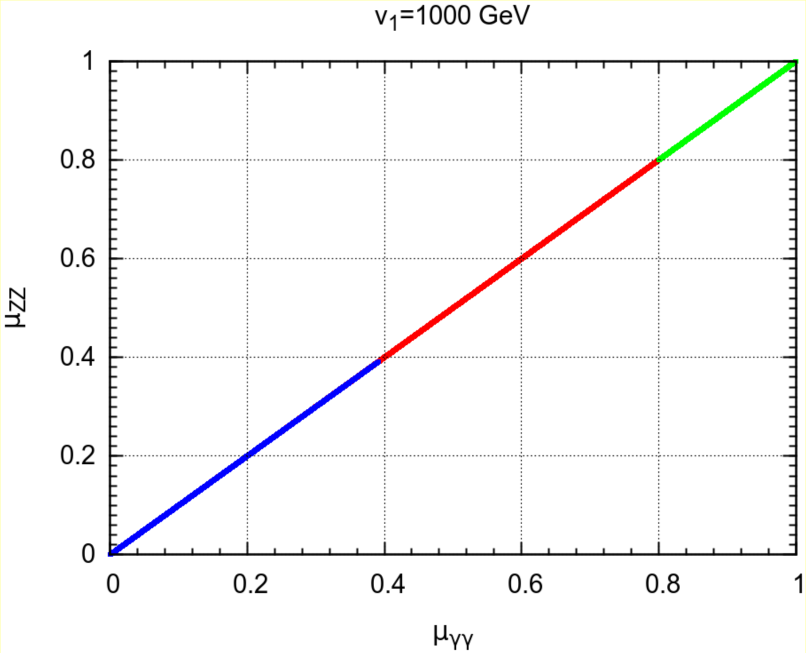
Cesar Bonilla,[1,*] Jorge C. Romão,[2,†] and José W. F. Valle[1,‡]

$$\Gamma\left(H_2 \to H_1 H_1\right) = \frac{g^2_{H_2 H_1 H_1}}{32\pi m_{H_2}} \left(1 - \frac{4m^2_{H_1}}{m^2_{H_2}}\right)^{1/2}$$

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

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

arXiv:1502.01649



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,‡]

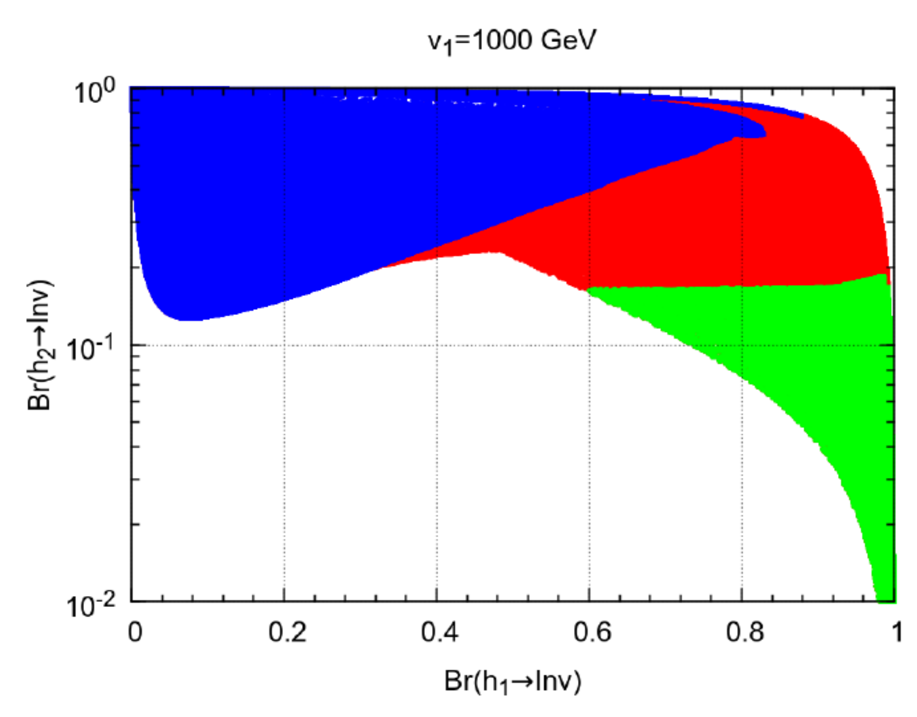
$$\Gamma\left(H_2 \to H_1 H_1\right) = \frac{g^2_{H_2 H_1 H_1}}{32\pi m_{H_2}} \left(1 - \frac{4m^2_{H_1}}{m^2_{H_2}}\right)^{1/2}$$

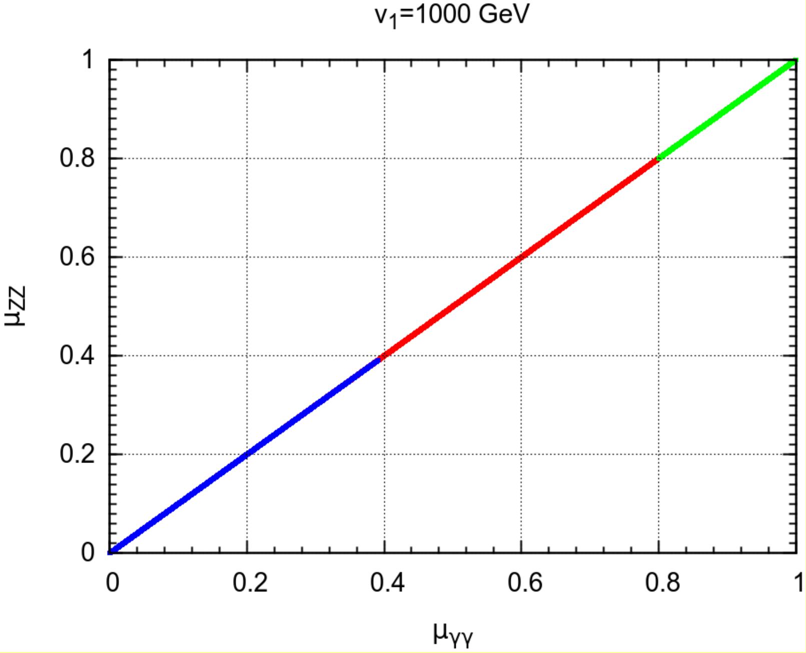
$$\Gamma(H_i \to JJ) = \frac{1}{32\pi} \frac{g^2_{H_i JJ}}{m_{H_i}} .$$

SM

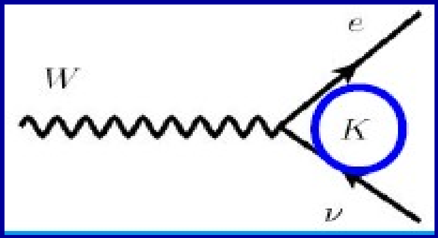
channel	ATLAS	CMS
$\mu_{\gamma\gamma}$	1.17 ± 0.27	$1.14^{+0.26}_{-0.23}$
μ_{WW}	$1.00^{+0.32}_{-0.29}$	0.83 ± 0.21
μ_{ZZ}	$1.44^{+0.40}_{-0.35}$	1.00 ± 0.29
$\mu_{\tau^+\tau^-}$	$1.4^{+0.5}_{-0.4}$	0.91 ± 0.27
$\mu_{b\bar{b}}$	$0.2^{+0.7}_{-0.6}$	0.93 ± 0.49

arXiv:1502.01649





NEUTRINO MIXING



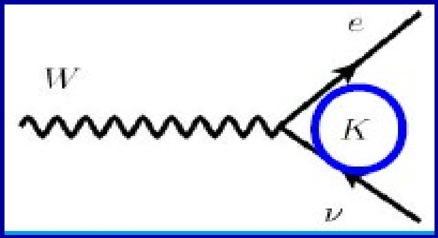
Schechter & JV PRD22 (1980) 2227 & PDG

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

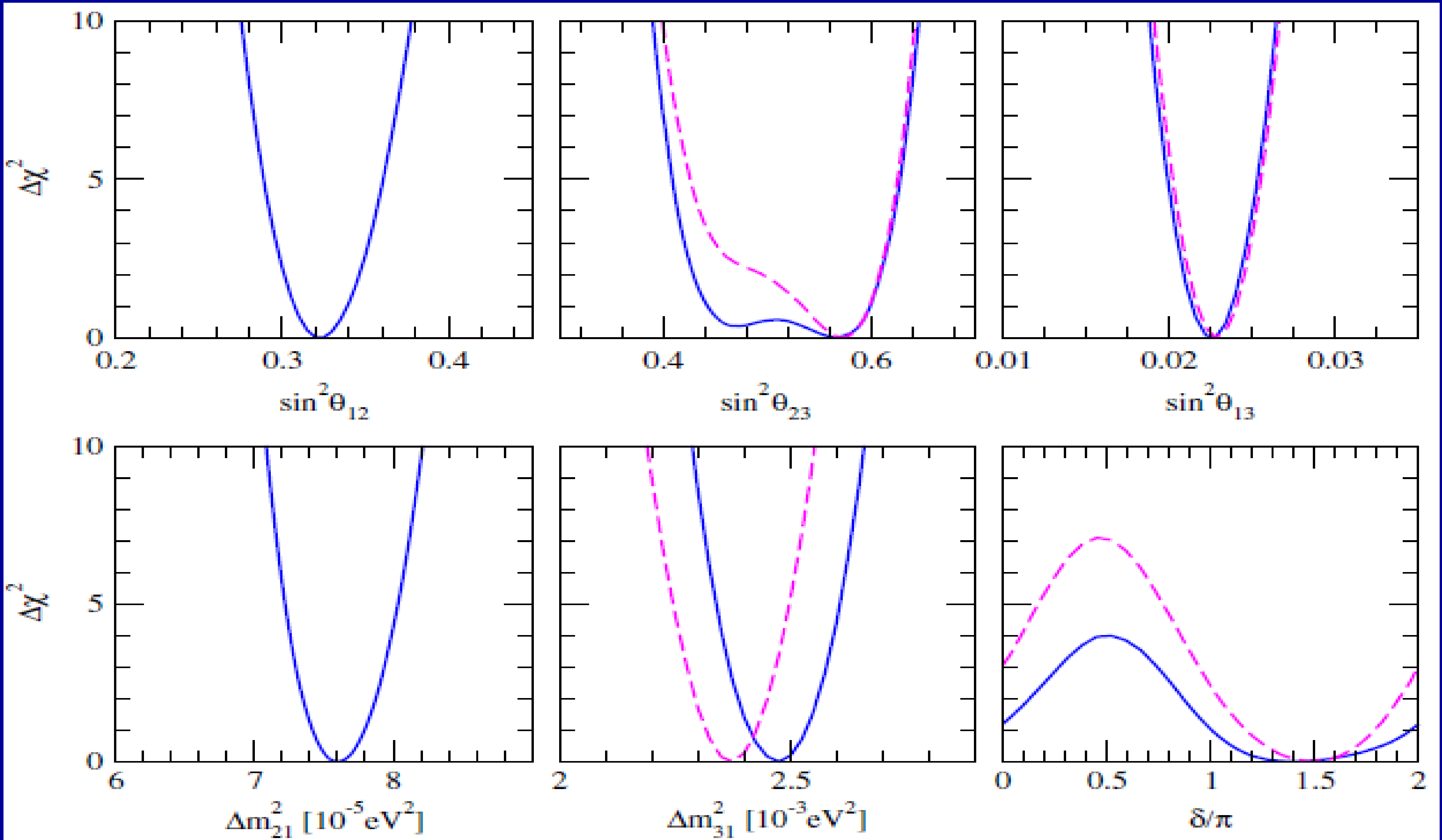
NEUTRINO MIXING & OSCILLATIONS

Schechter & JV PRD22 (1980) 2227 & PDG

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



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



The precision era ...

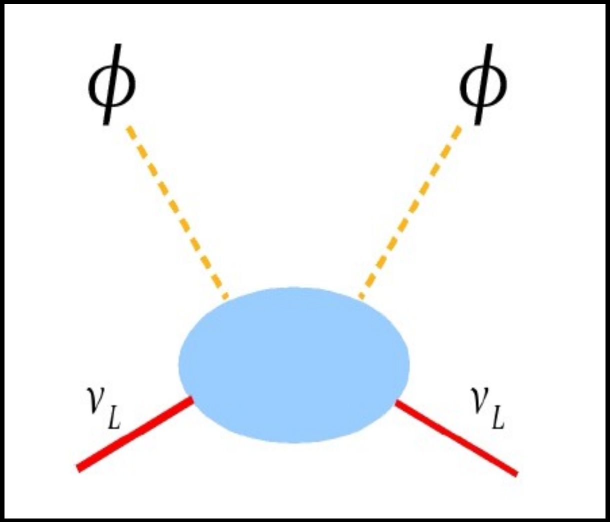
PHYSICAL REVIEW D **90**, 093006 (2014)

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

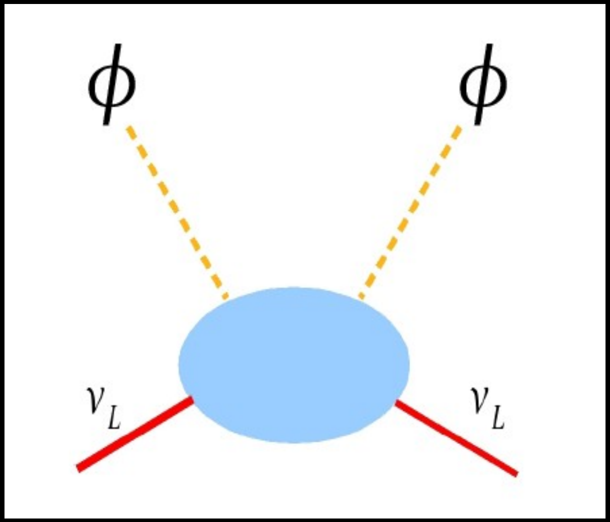
Parameter	Best fit $\pm$ 1σ	2σ range	3σ range
Δm^2_{21} [10^{-5} eV^2]	$7.60^{+0.19}_{-0.18}$	7.26–7.99	7.11–8.18
$\lvert\Delta m^2_{31}\rvert$[$10^{-3}$ eV^2] (NH)	$2.48^{+0.05}_{-0.07}$	2.35–2.59	2.30–2.65
$\lvert\Delta m^2_{31}\rvert$[$10^{-3}$ eV^2] (IH)	$2.38^{+0.05}_{-0.06}$	2.26–2.48	2.20–2.54
$\sin^2\theta_{12}/10^{-1}$	3.23 ± 0.16	2.92–3.57	2.78–3.75
$\theta_{12}/°$	34.6 ± 1.0	32.7–36.7	31.8–37.8
$\sin^2\theta_{23}/10^{-1}$ (NH)	$5.67^{+0.32}_{-1.24}$[a]	4.14–6.23	3.93–6.43
$\theta_{23}/°$	$48.9^{+1.8}_{-7.2}$	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
$\theta_{23}/°$	$49.2^{+1.5}_{-2.3}$	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
$\theta_{13}/°$	$8.6^{+0.3}_{-0.2}$	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
$\theta_{13}/°$	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
$\delta/°$	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
$\delta/°$	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

origin of neutrino mass



origin of neutrino mass

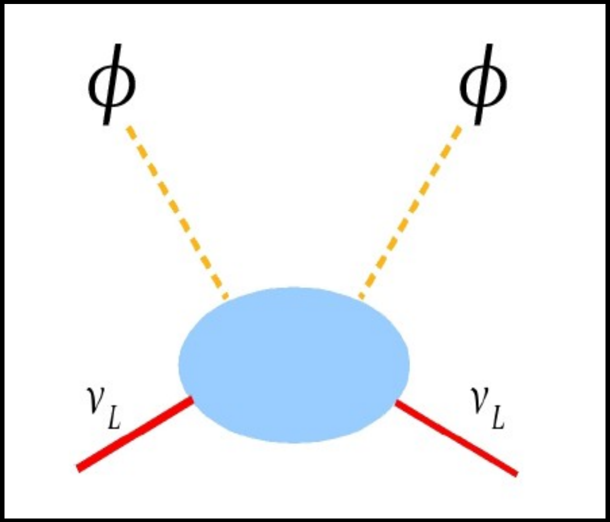


SCALE

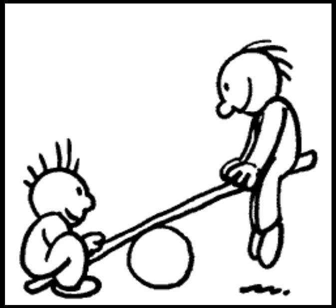
MECHANISM

FLAVOR STRUCTURE

origin of neutrino mass and seesaw



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

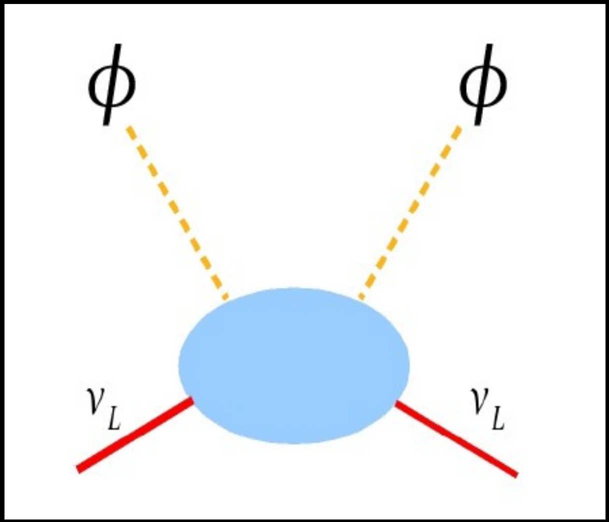


SCALE

MECHANISM

FLAVOR STRUCTURE

origin of neutrino mass and seesaw

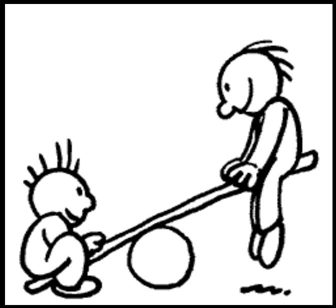


fermion exchange

TYPE I

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

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

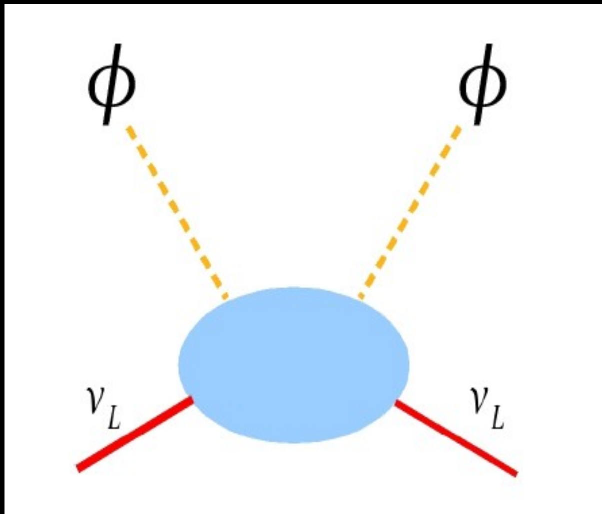


SCALE

MECHANISM

FLAVOR STRUCTURE

origin of neutrino mass and seesaw



fermion exchange

TYPE I

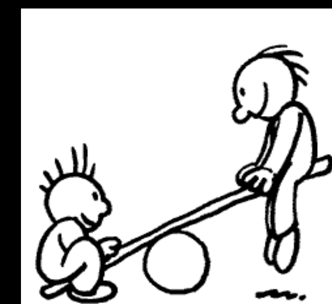
Minkowski 77
Gellman Ramond Slansky 80
Glashow, Yanagida 79
Mohapatra Senjanovic 80
Lazarides Shafi Weterrich 81
Schechter-Valle, 80 & 82

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

Scalar-exchange

TYPE II

Schechter-Valle 80/82

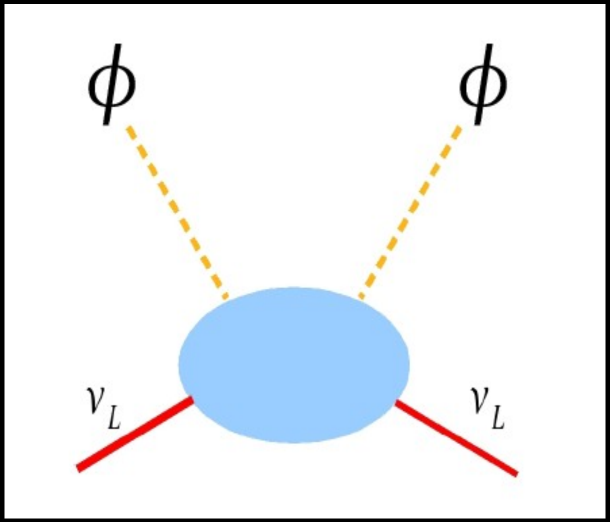


SCALE

MECHANISM

FLAVOR STRUCTURE

origin of neutrino mass and seesaw



fermion exchange

TYPE I

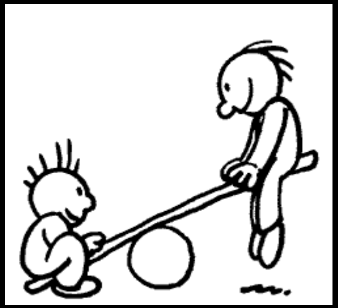
Minkowski 77
Gellman Ramond Slansky 80
Glashow, Yanagida 79
Mohapatra Senjanovic 80
Lazarides Shafi Weterrich 81
Schechter-Valle, 80 & 82

Scalar-exchange

TYPE II

Schechter-Valle 80/82

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



SCALE

MECHANISM

Number & properties of messengers

FLAVOR STRUCTURE

LOW-SCALE SEESAW

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

Radiative neutrino mass

many low-scale neutrino mass schemes ... arXiv:1404.3751

Radiative neutrino mass

many low-scale neutrino mass schemes ...

arXiv:1404.3751

331 scheme # generations = # colours

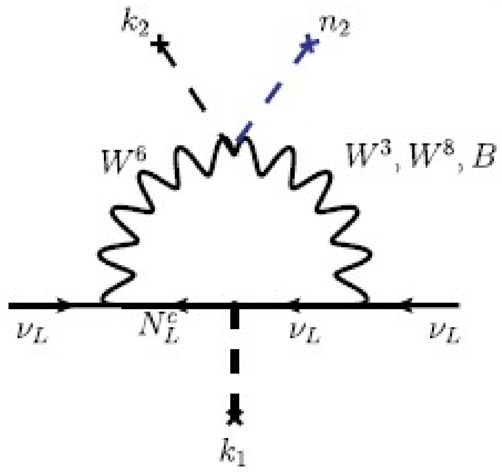
Gauge vs Higgs

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

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

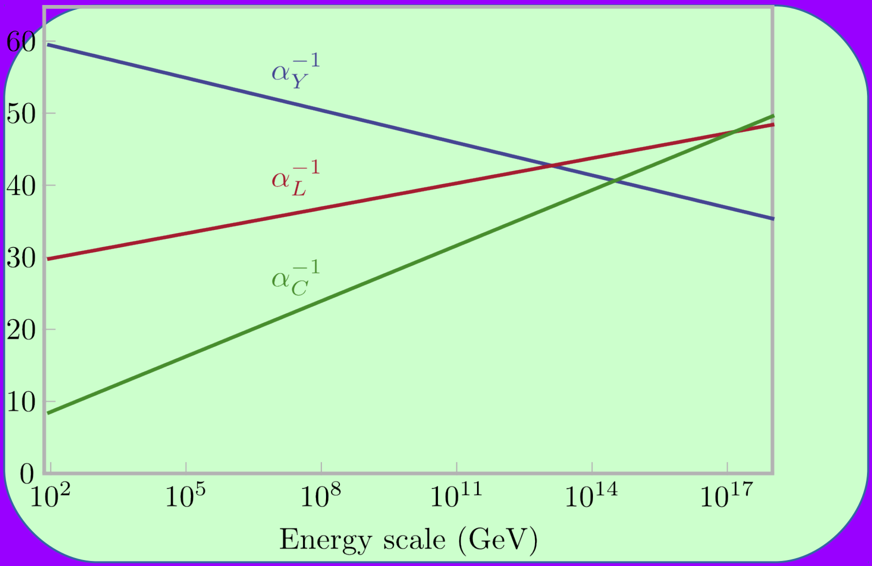
Radiative neutrino mass in 3-3-1 scheme

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

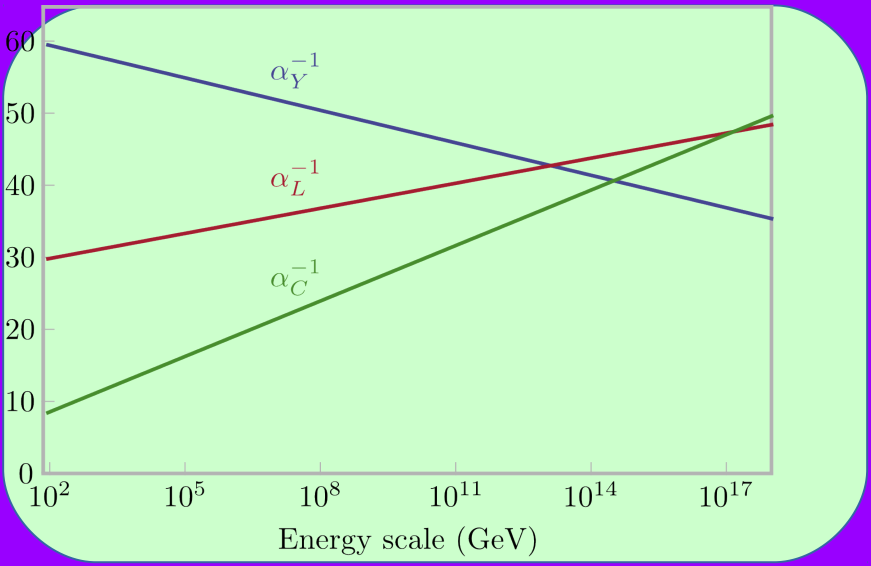


gauge coupling unification :

a near miss ...

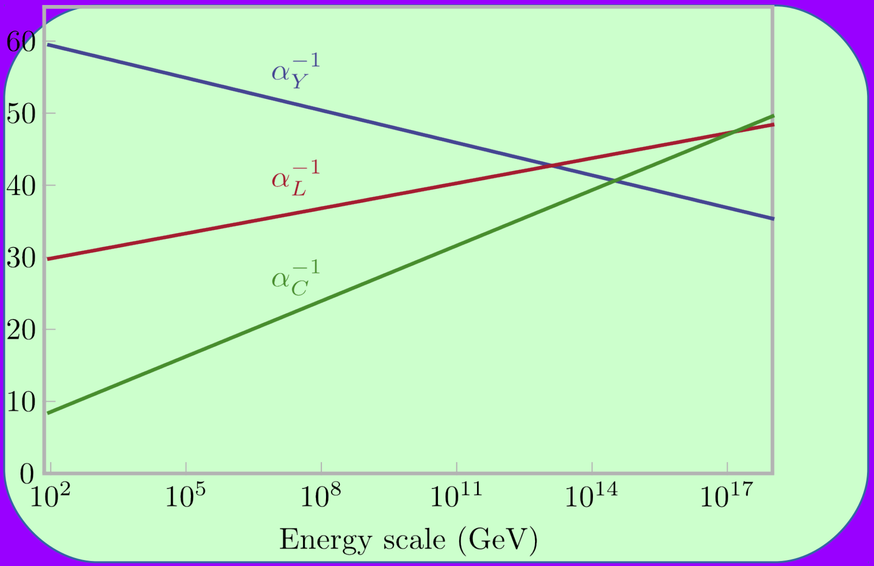


gauge coupling unification :
a near miss ...



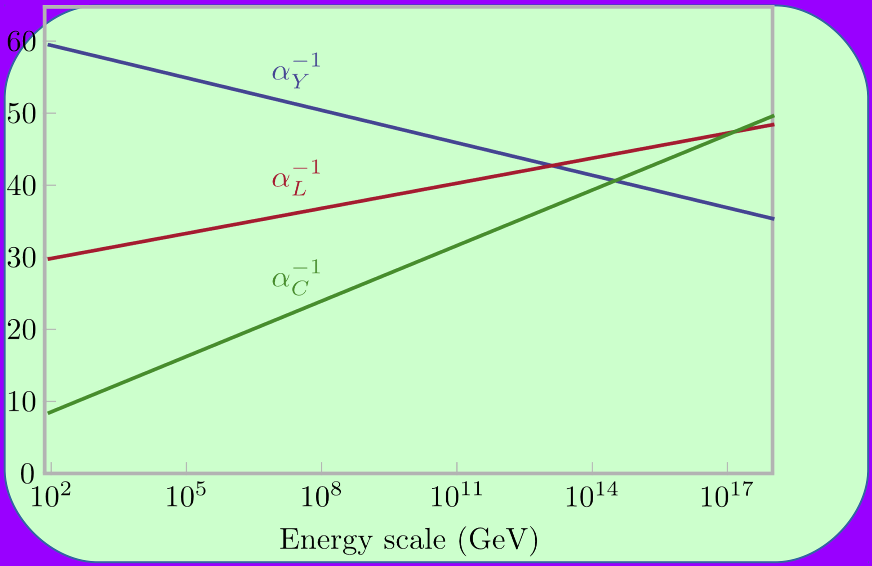
What makes the gauge couplings unify? – A GUT (p decay)

gauge coupling unification : a near miss ...

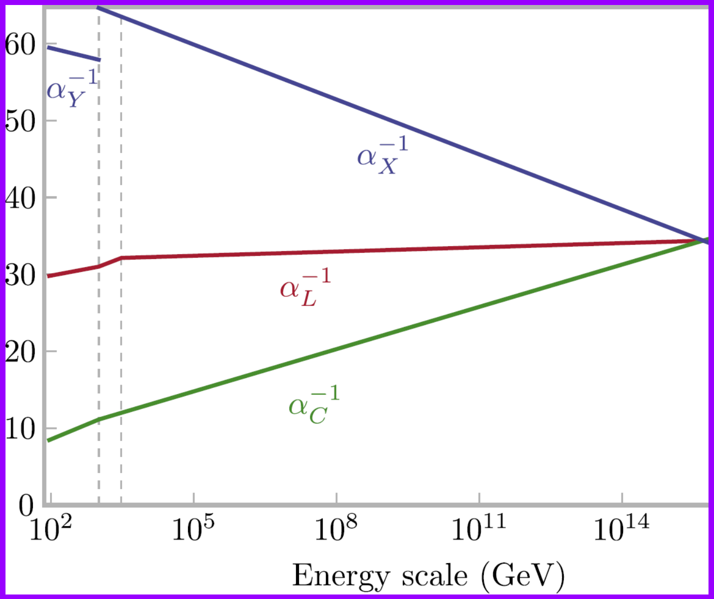


What makes the gauge couplings unify?
- A GUT (p decay)
- SUSY (LHC13)

gauge coupling unification :
a near miss ...



What makes the gauge couplings unify?
- A GUT (p decay)
- SUSY (LHC13)
- NEUTRINO PHYSICS

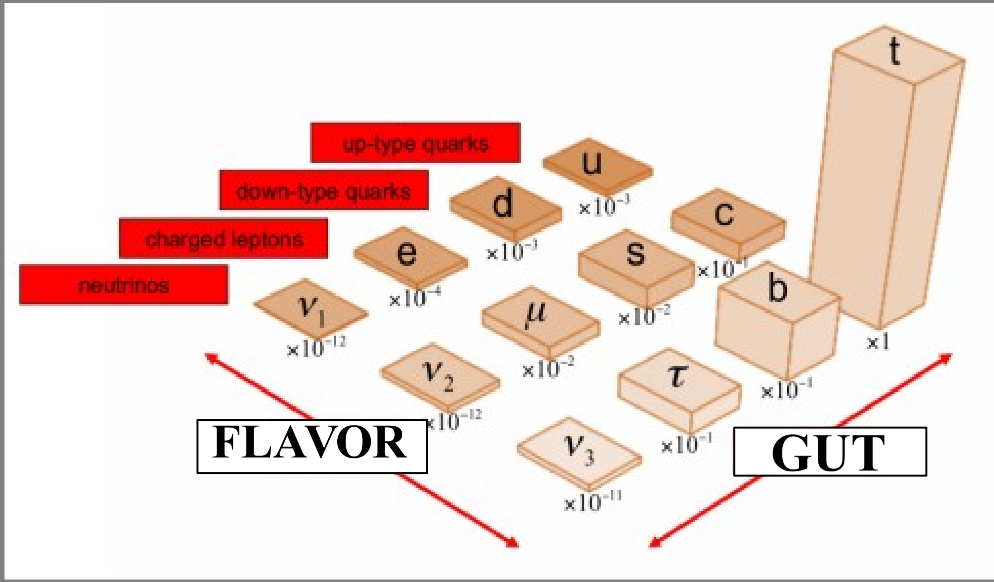


The physics responsible for gauge coupling unification may also induce small neutrino masses

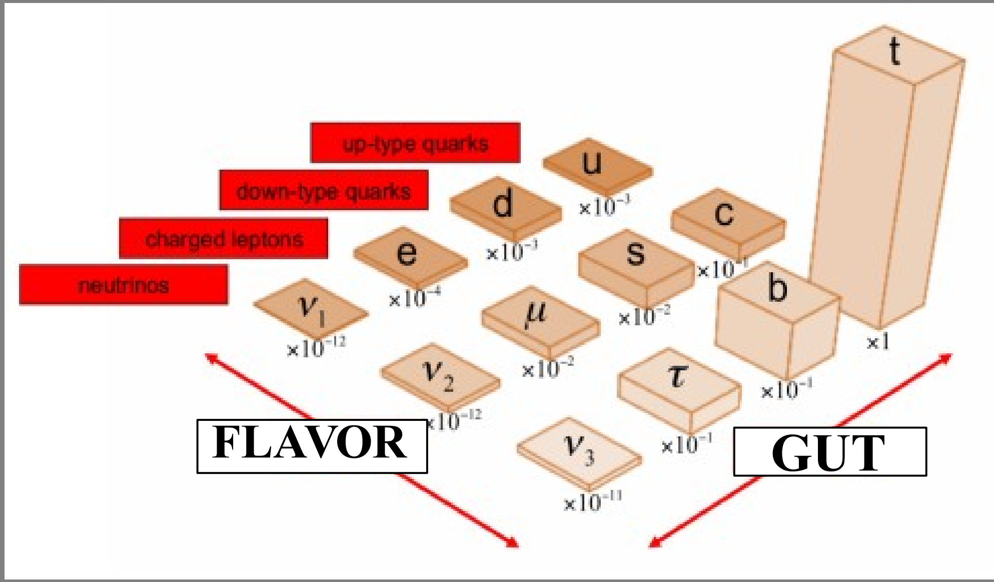
Boucenna, Fonseca, Gonzalez-Canales, JV

Phys. Rev. D 91, 031702 (2015)

Flavor problem



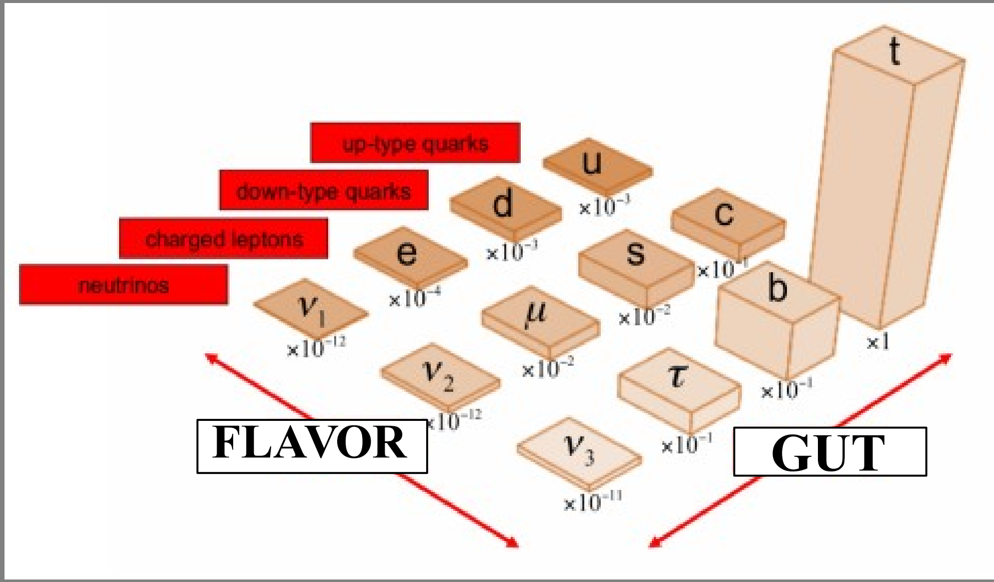
Flavor problem



pattern of charged fermion masses…

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

Flavor problem



pattern of charged fermion masses…

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

b-tau unification without GUTS…

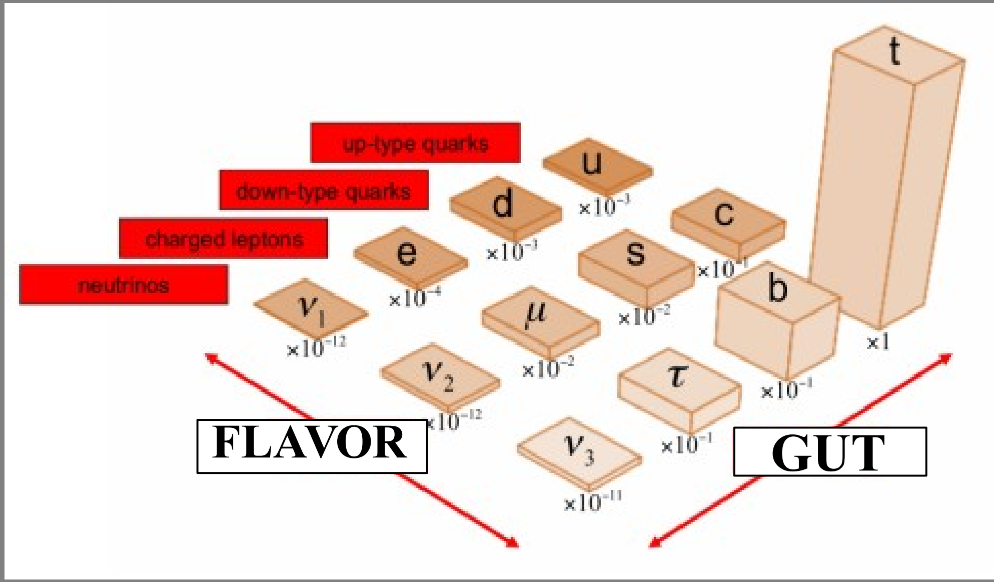
Morisi et al Phys.Rev. D84 (2011) 036003

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

Flavor problem



pattern of oscillation parameters ...

pattern of charged fermion masses...

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

b-tau unification without GUTS...

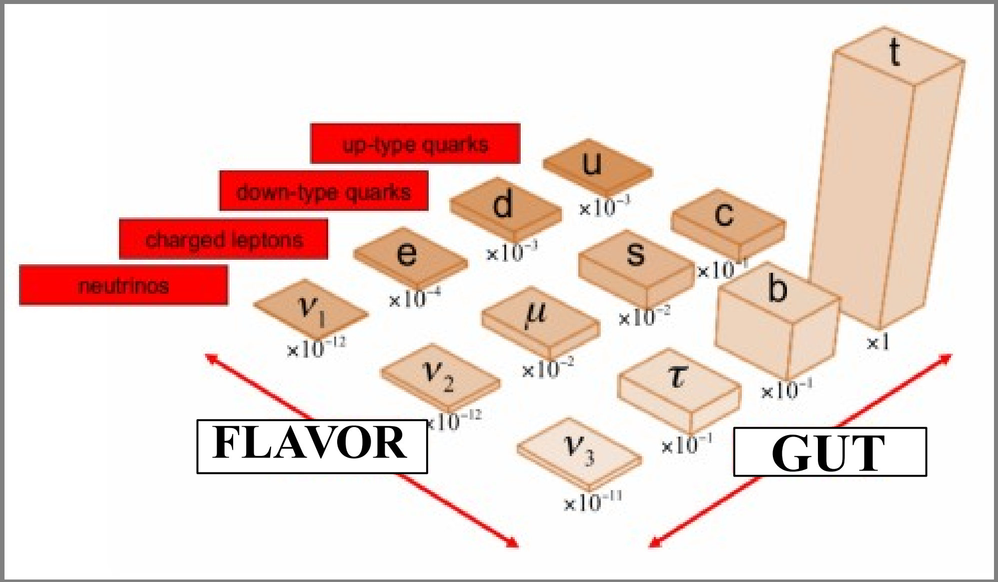
Morisi et al Phys.Rev. D84 (2011) 036003

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

Flavor problem



pattern of oscillation parameters ...

Anarchy?

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

pattern of charged fermion 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

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

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

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

$$
u_R \quad c_R \quad t_R
$$

$$
d_R \quad s_R \quad b_R
$$

FLAVOR SYMMETRY

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

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

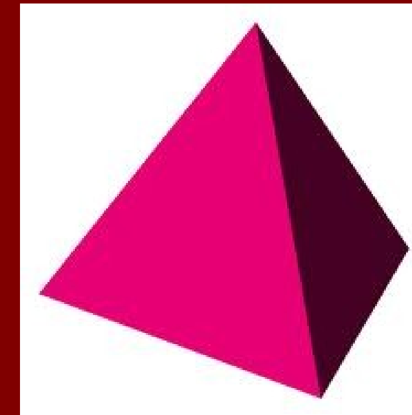
$$\begin{pmatrix}u\\ d\end{pmatrix}_L \quad \begin{pmatrix}c\\ s\end{pmatrix}_L \quad \begin{pmatrix}t\\ b\end{pmatrix}_L$$

$$u_R \quad c_R \quad t_R$$

$$d_R \quad s_R \quad b_R$$

FLAVOR SYMMETRY

A4



Babu-**Ma**-Valle PLB552 (2003) 207

Hirsch et al PRD69 (2004) 093006

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

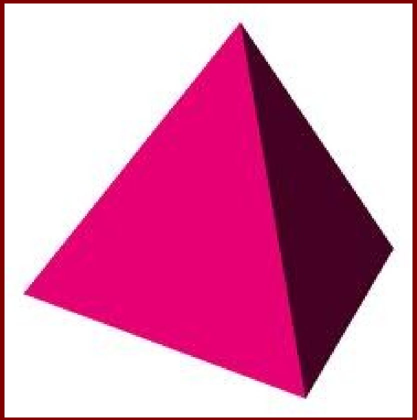
$$e_R \quad \mu_R \quad \tau_R$$

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

$$u_R \quad c_R \quad t_R$$

$$d_R \quad s_R \quad b_R$$

FLAVOR SYMMETRY



A4

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

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

Babu-**Ma**-Valle PLB552 (2003) 207

Hirsch et al PRD69 (2004) 093006

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

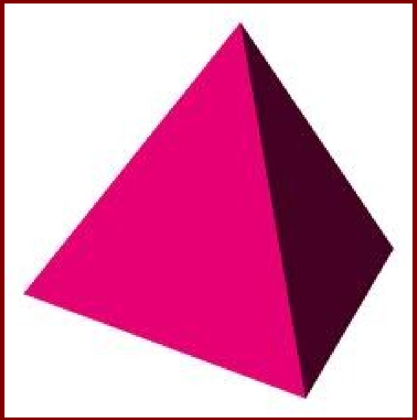
$$e_R \quad \mu_R \quad \tau_R$$

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

$$u_R \quad c_R \quad t_R$$

$$d_R \quad s_R \quad b_R$$

FLAVOR SYMMETRY



A4

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

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

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

Flavor roadmap

Ishimori.etal ProgTheor Phys Suppl 183 (2010) 1

Holthausen et al 1212.2411

Morisi, JV **Fortsch.Phys. 61 (2013) 466-492**

King, Merle, Morisi, Shimizu, Tanimoto NJP

arXiv:1305.6774

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,§]

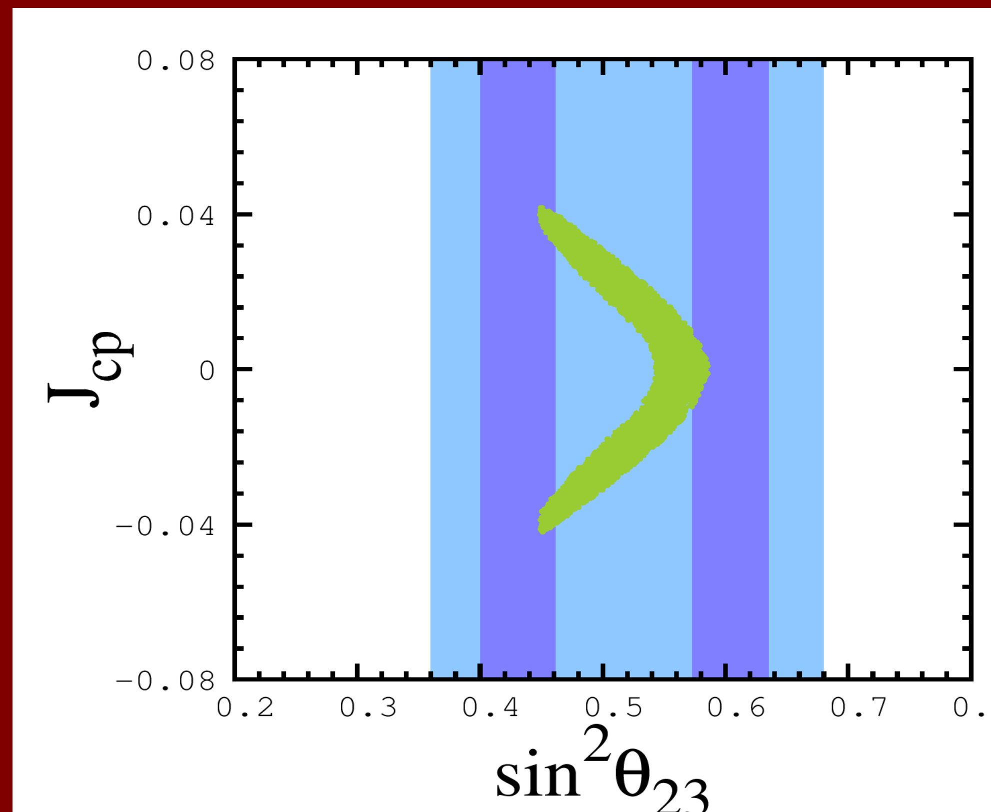
arXiv:1305.6774

PHYSICAL REVIEW D 88, 016003 (2013)

Neutrino mixing with revamped A_4 flavor symmetry

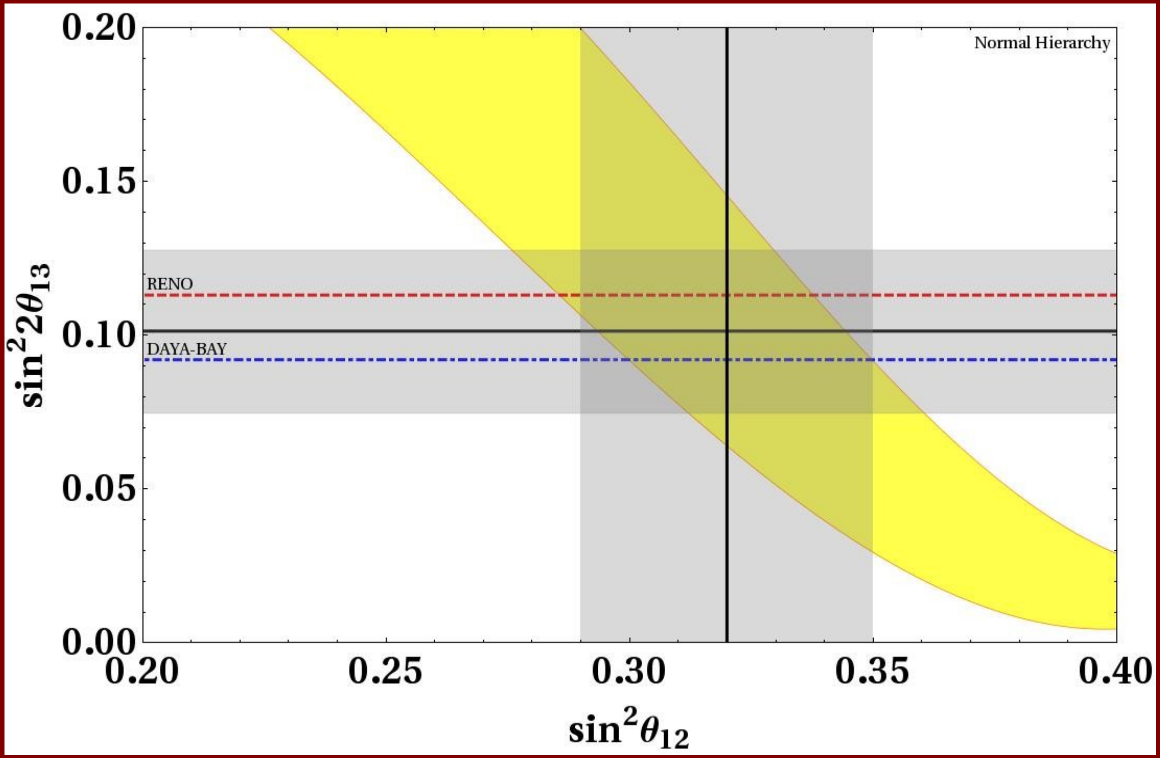
D. V. Forero,[1,2,*] S. Morisi,[3,†] J.C. Romão,[1,‡] and J. W. F. Valle[2,§]

STRIKING CORRELATION



OSCILLATION PARAMETER CORRELATIONS

Boucenna et al
PhysRevD.86.073008



Bi-large mixing & Cabibbo angle

Boucenna et al, Phys. Rev. D 86, 051301(R)

Bi-large mixing & Cabibbo angle

Boucenna et al, Phys. Rev. D 86, 051301(R)

reactor seeds solar & atm

$$\sin\theta_{13} = \lambda\,;$$
$$\sin\theta_{12} = s\,\lambda\,;$$
$$\sin\theta_{23} = a\,\lambda\,,$$

Bi-large mixing & Cabibbo angle

Boucenna et al, Phys. Rev. D 86, 051301(R)

reactor seeds solar & atm

$$\sin\theta_{13} = \lambda;$$
$$\sin\theta_{12} = s\,\lambda;$$
$$\sin\theta_{23} = a\,\lambda\,,$$

Abelian Flavor Models

Ding, et al Phys.Rev. D87 (2013) 053013

Bi-large mixing & Cabibbo angle

Boucenna et al, Phys. Rev. D 86, 051301(R)

reactor seeds solar & atm

$$\sin\theta_{13} = \lambda;$$
$$\sin\theta_{12} = s\,\lambda;$$
$$\sin\theta_{23} = a\,\lambda\,,$$

Abelian Flavor Models

Ding, et al Phys.Rev. D87 (2013) 053013

The Cabibbo angle as a universal seed for quark and lepton mixings

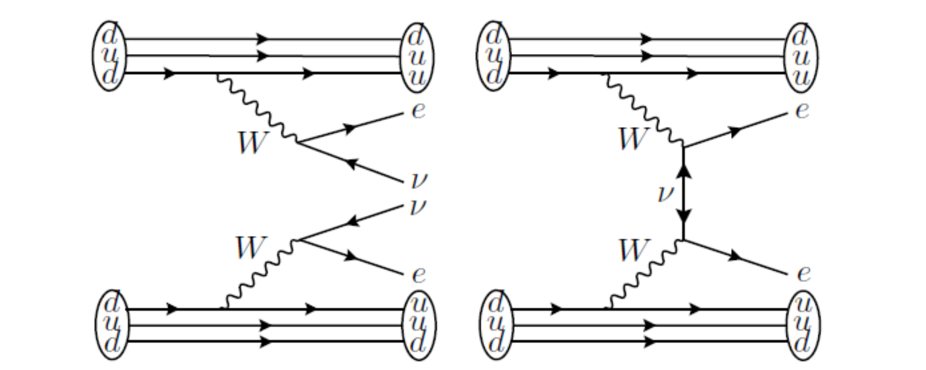
S. Roy et al. / Physics Letters B 748 (2015) 1–4

$\sin^2\theta_{23}$	δ_{CP}/π
$0.4585^{+0.08543}_{-0.08646}$	$1.2308^{+0.0692}_{-0.0717}$,
$0.4174^{+0.0921}_{-0.0937}$	$1.2159^{+0.0754}_{-0.0733}$,
$0.4585^{+0.0855}_{-0.08641}$	$1.2303^{+0.0717}_{-0.0713}$
$0.4996^{+0.0927}_{-0.0935}$	$1.2303^{+0.0717}_{-0.0713}$

*Predicting **octant** and **CPV***

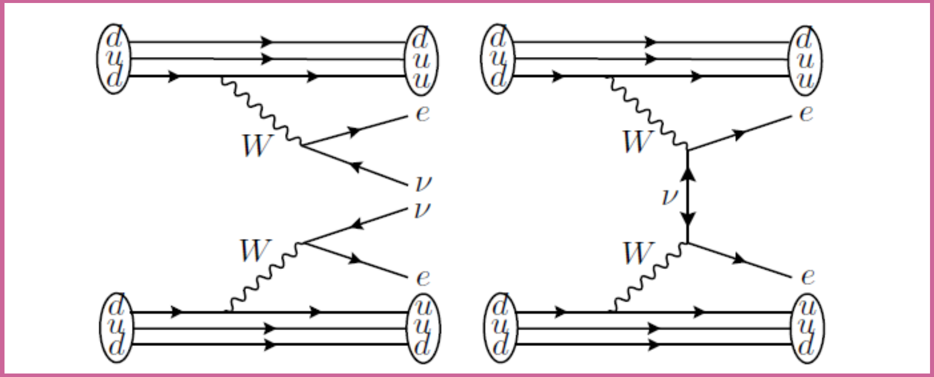
Neutrinoless Double Beta Decay

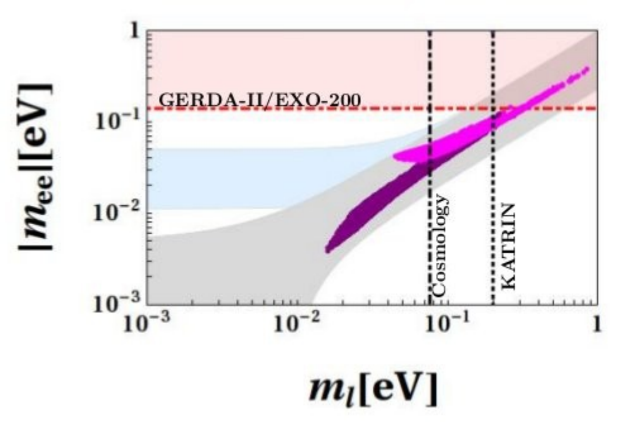
A.S. Barabash arXiv:1104.2714



Neutrinoless Double Beta Decay and flavor

A.S. Barabash arXiv:1104.2714



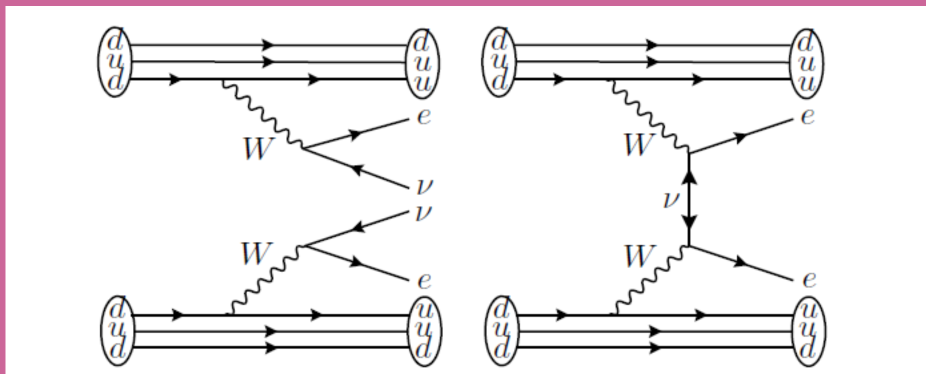


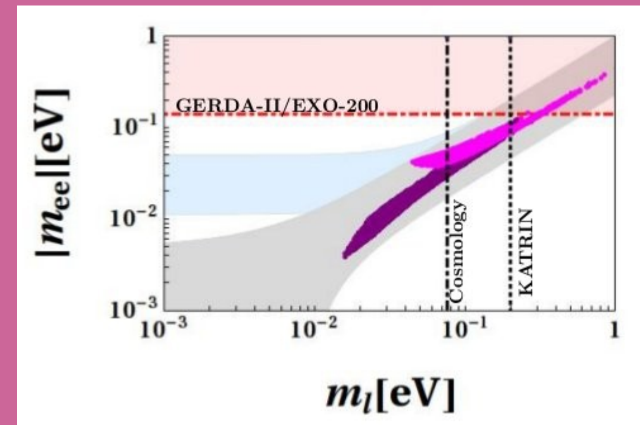
Family symmetry dependent lower bound

Bonilla et al arXiv:1411.4883

Neutrinoless Double Beta Decay and flavor

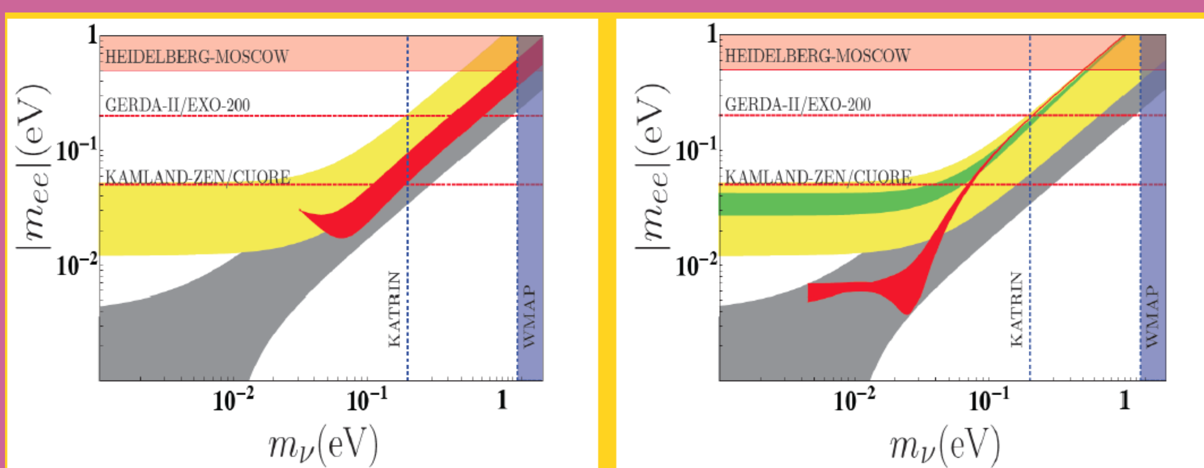
A.S. Barabash arXiv:1104.2714

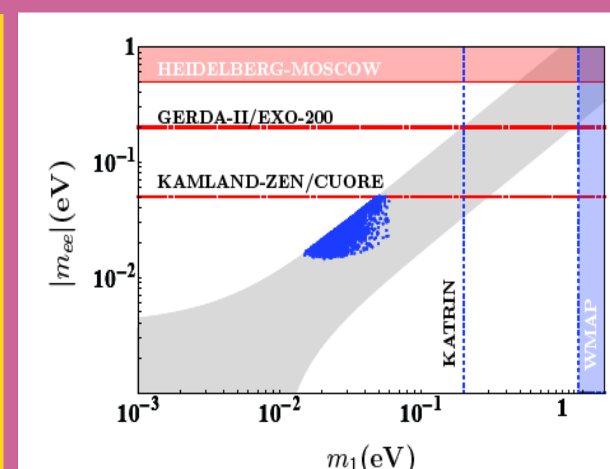




Family symmetry dependent lower bound

Bonilla et al arXiv:1411.4883





Dorame et al
NPB861 (2012) 259-270

PhysRevD.86.056001

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

Neutrinoless Double Beta Decay

Flavor predictions

Probing flavor models with ^{76}Ge-based experiments on neutrinoless double-β decay

Matteo Agostini,[1,2,*] Alexander Merle,[3,†] and Kai Zuber[4,‡]

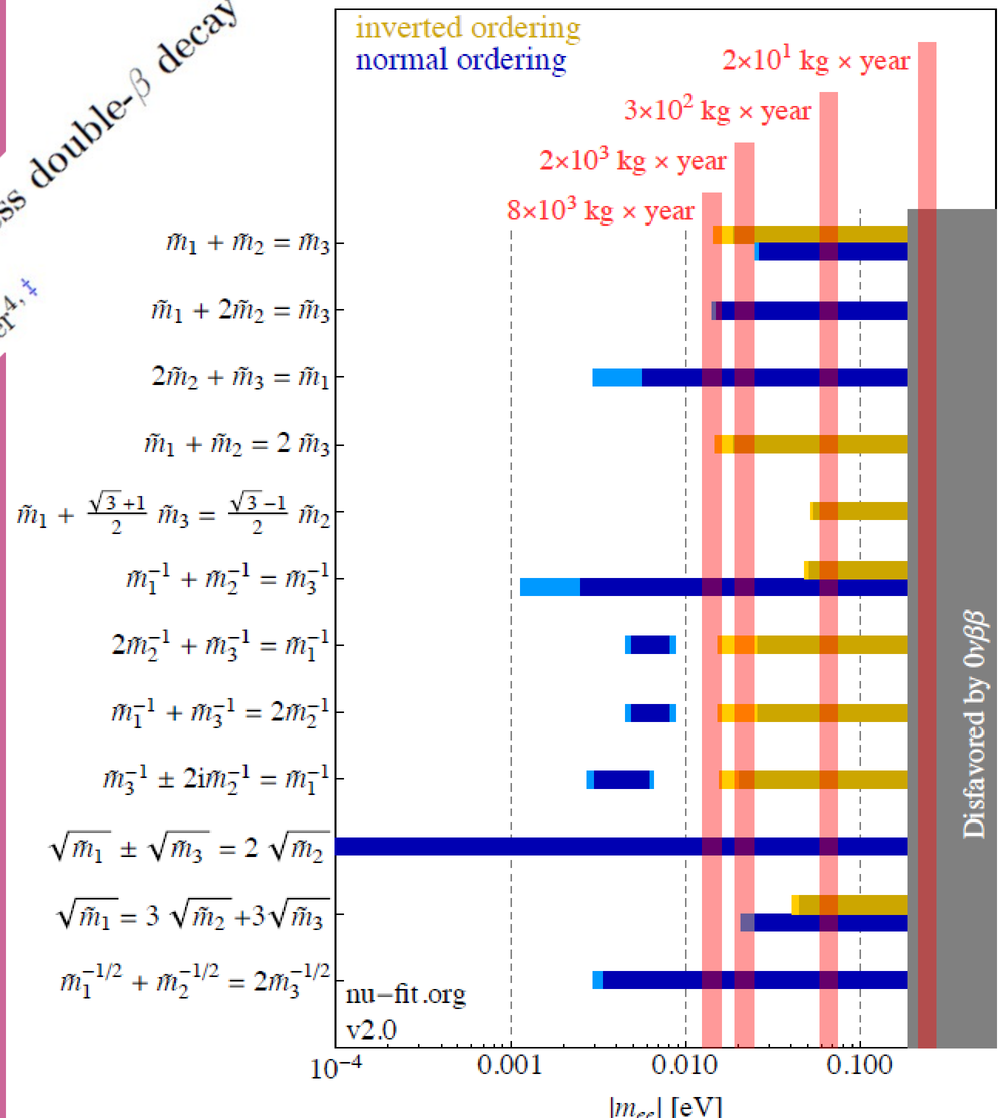
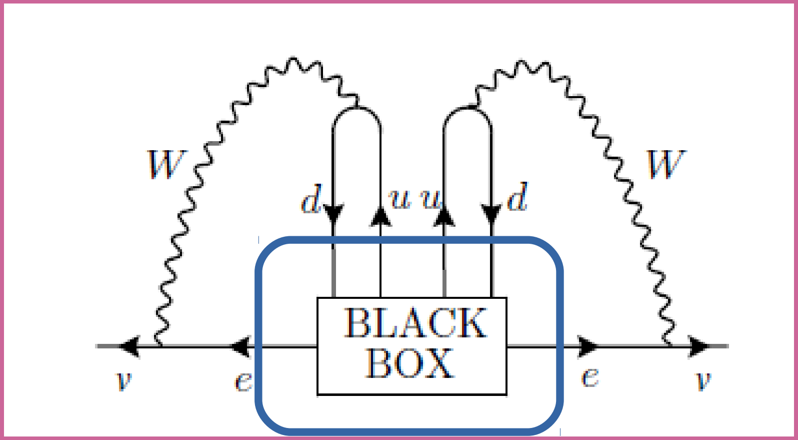


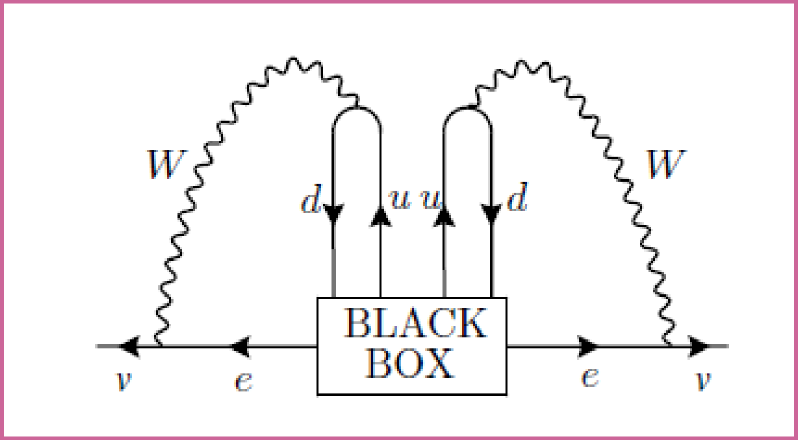
FIG. 2. Range of the $0\nu\beta\beta$ effective mass allowed for different classes of neutrino flavor models that are characterized by respective sum rules. The sensitivity for different stages of ^{76}Ge-based experiments considered in the text is also displayed.

Neutrinoless Double Beta Decay significance



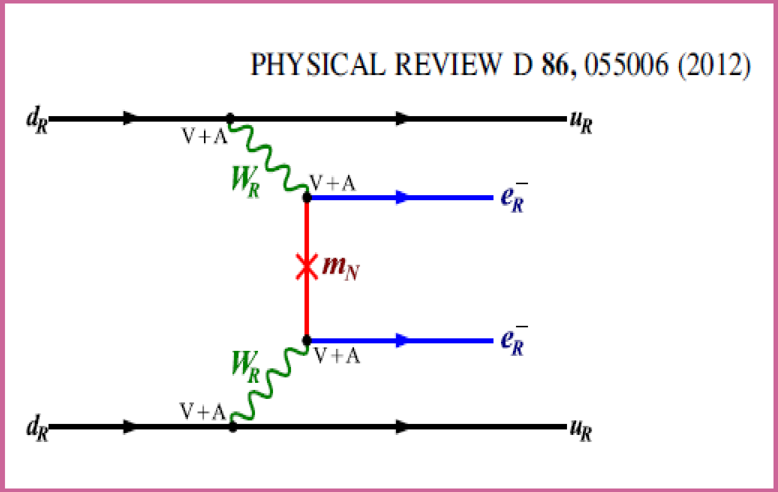
Schechter, JWFV 82
Lindner et al JHEP 1106 (2011) 091

Neutrinoless Double Beta Decay significance

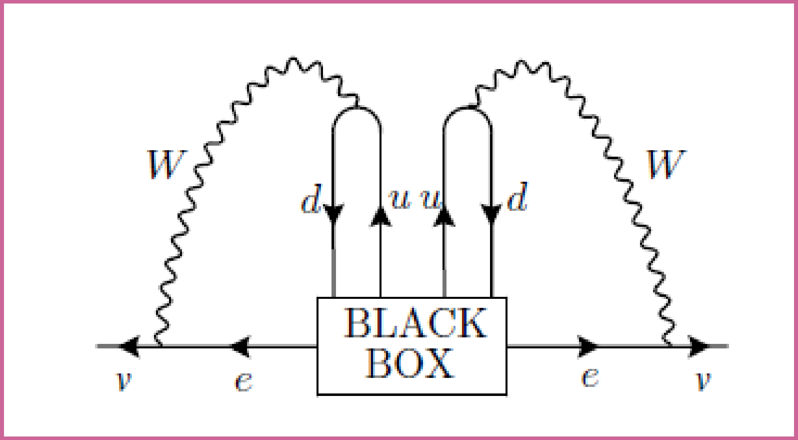


Schechter, JWFV 82
Lindner et al JHEP 1106 (2011) 091

Short versus long-range and the LHC

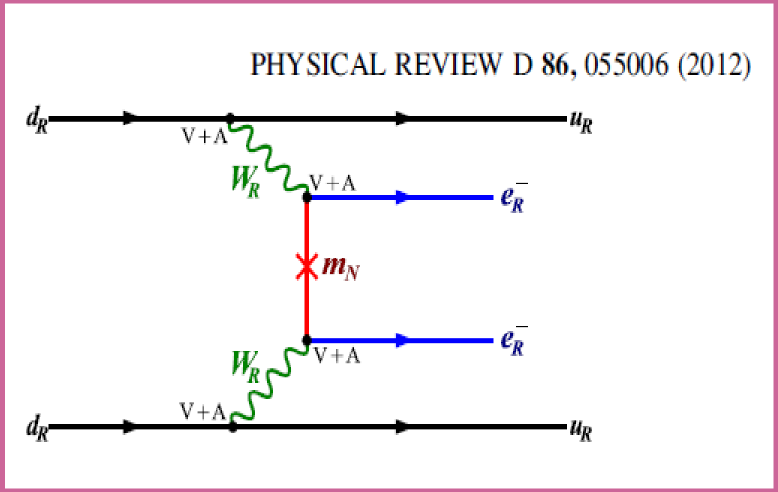


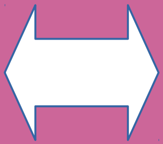
Neutrinoless Double Beta Decay and colliders

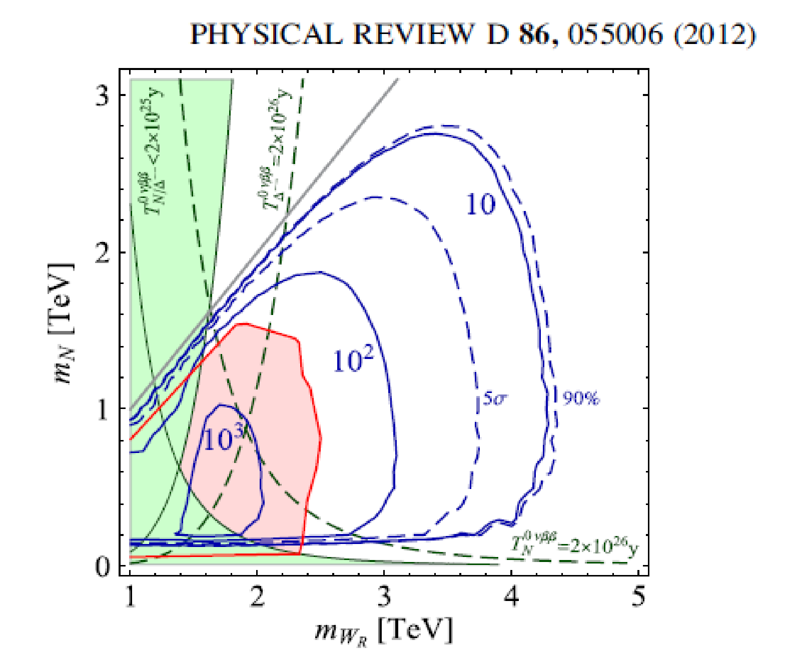


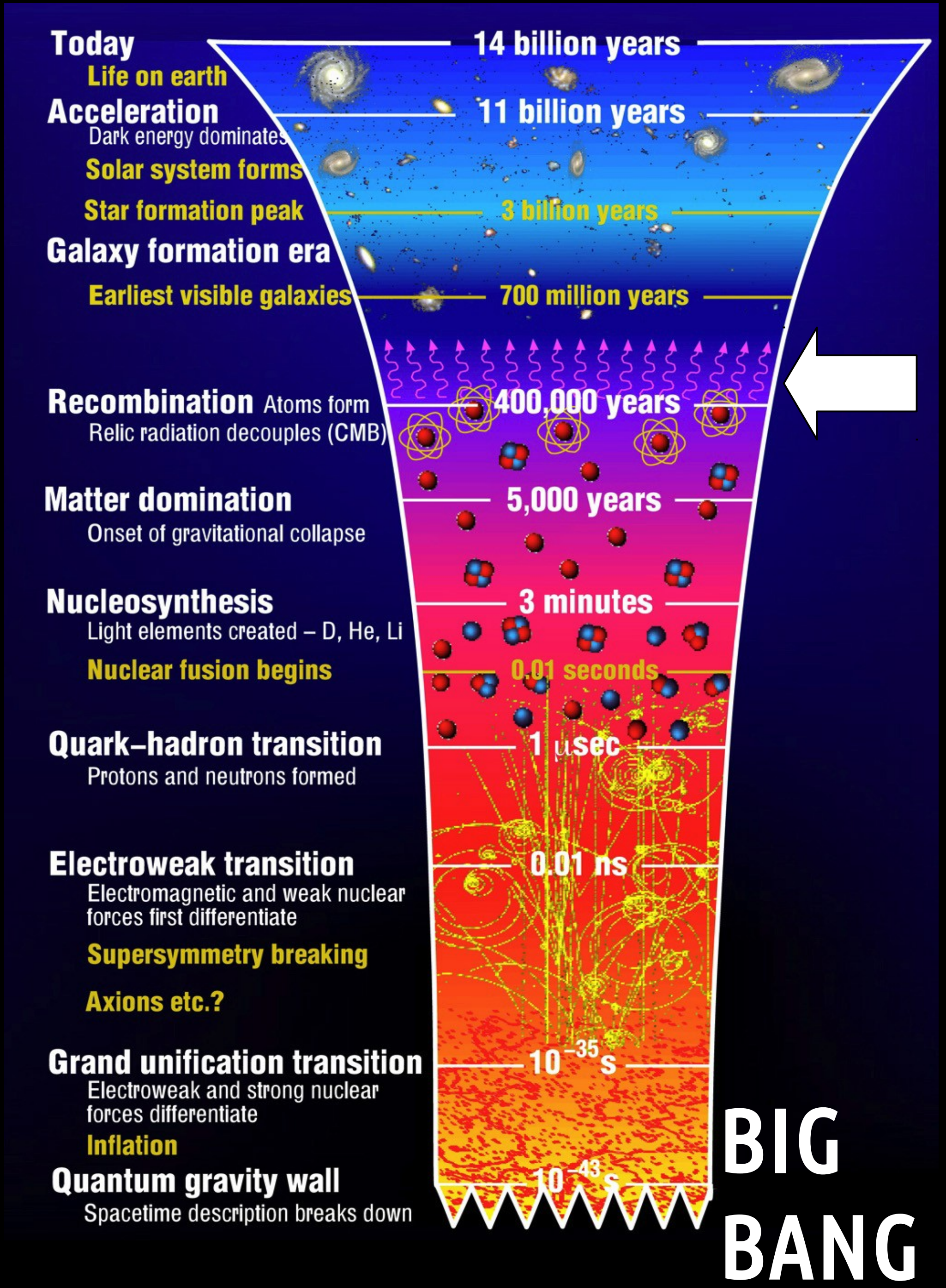
Schechter, JWFV 82
Lindner et al JHEP 1106 (2011) 091

Short versus long-range and the LHC

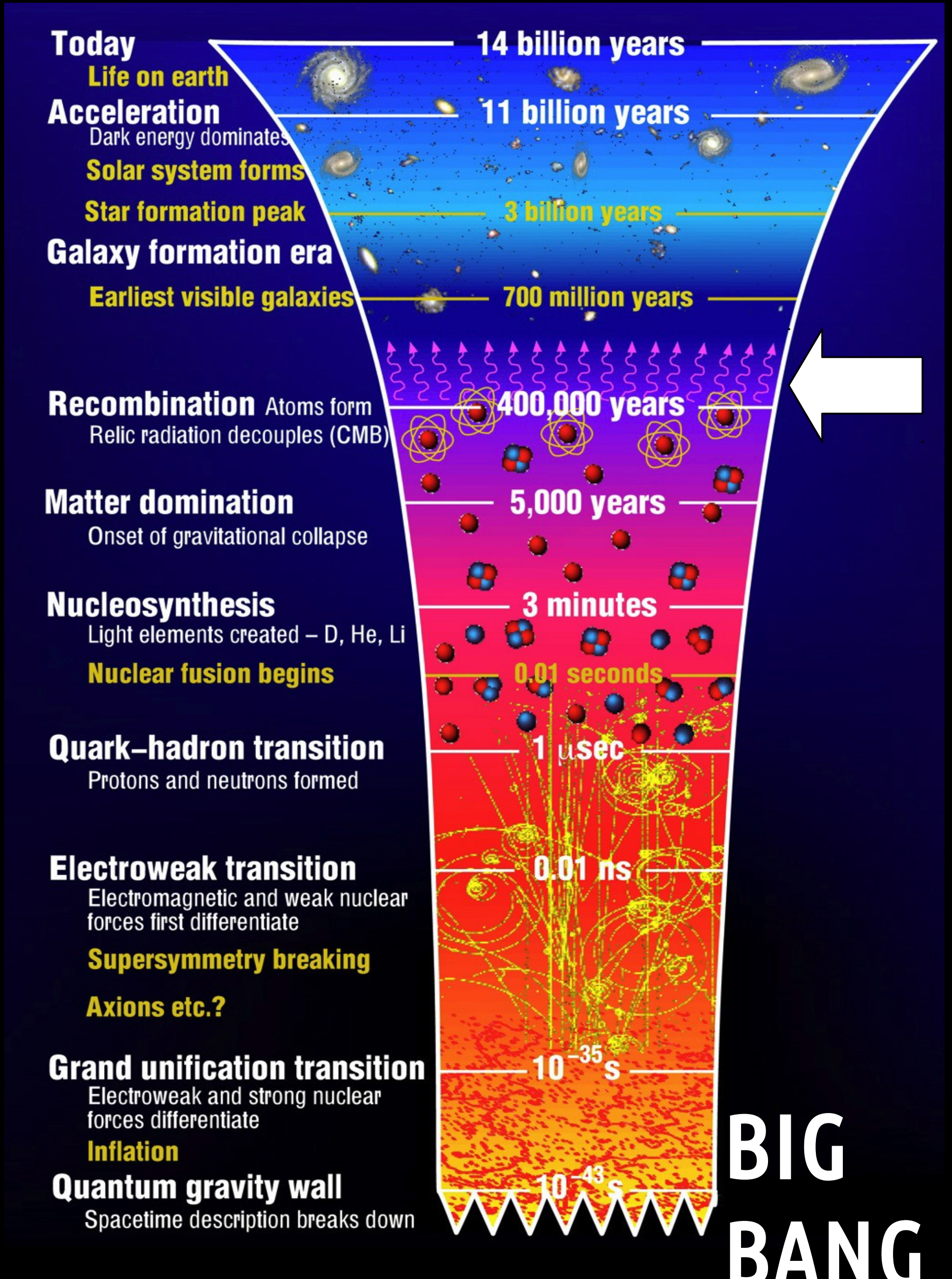






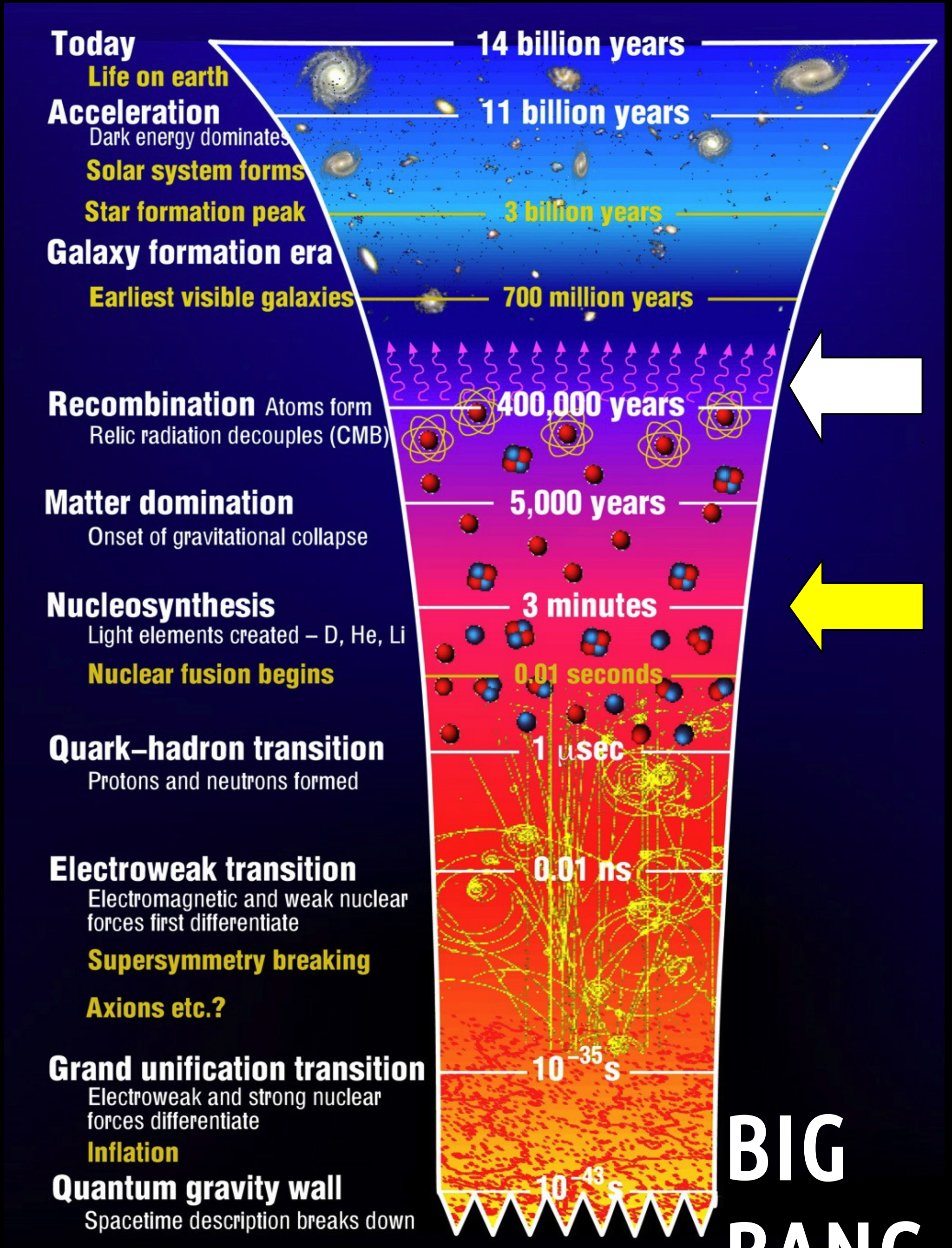

Today
Life on earth
Acceleration
Dark energy dominates
Solar system forms
Star formation peak
Galaxy formation era
Earliest visible galaxies
Recombination Atoms form
Relic radiation decouples (CMB)
Matter domination
Onset of gravitational collapse
Nucleosynthesis
Light elements created – D, He, Li
Nuclear fusion begins
Quark–hadron transition
Protons and neutrons formed
Electroweak transition
Electromagnetic and weak nuclear forces first differentiate
Supersymmetry breaking
Axions etc.?
Grand unification transition
Electroweak and strong nuclear forces differentiate
Inflation
Quantum gravity wall
Spacetime description breaks down
14 billion years
11 billion years
3 billion years
700 million years
400,000 years
5,000 years
3 minutes
0.01 seconds
1 μsec
0.01 ns
10^{-35} s
10^{-43} s
BIG BANG

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

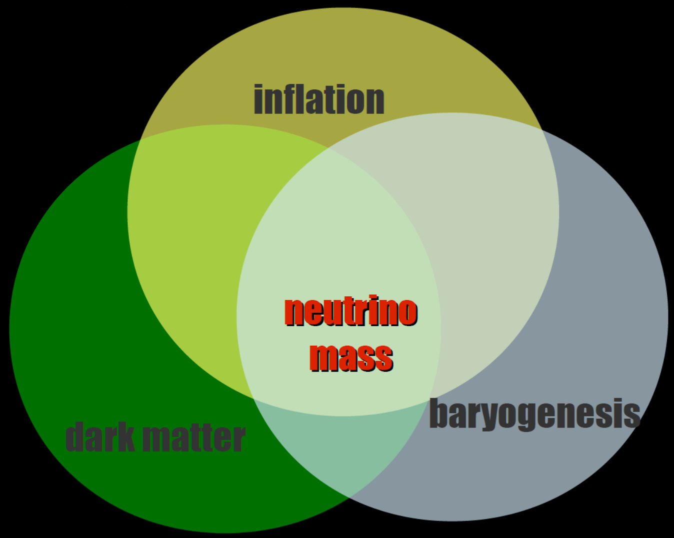


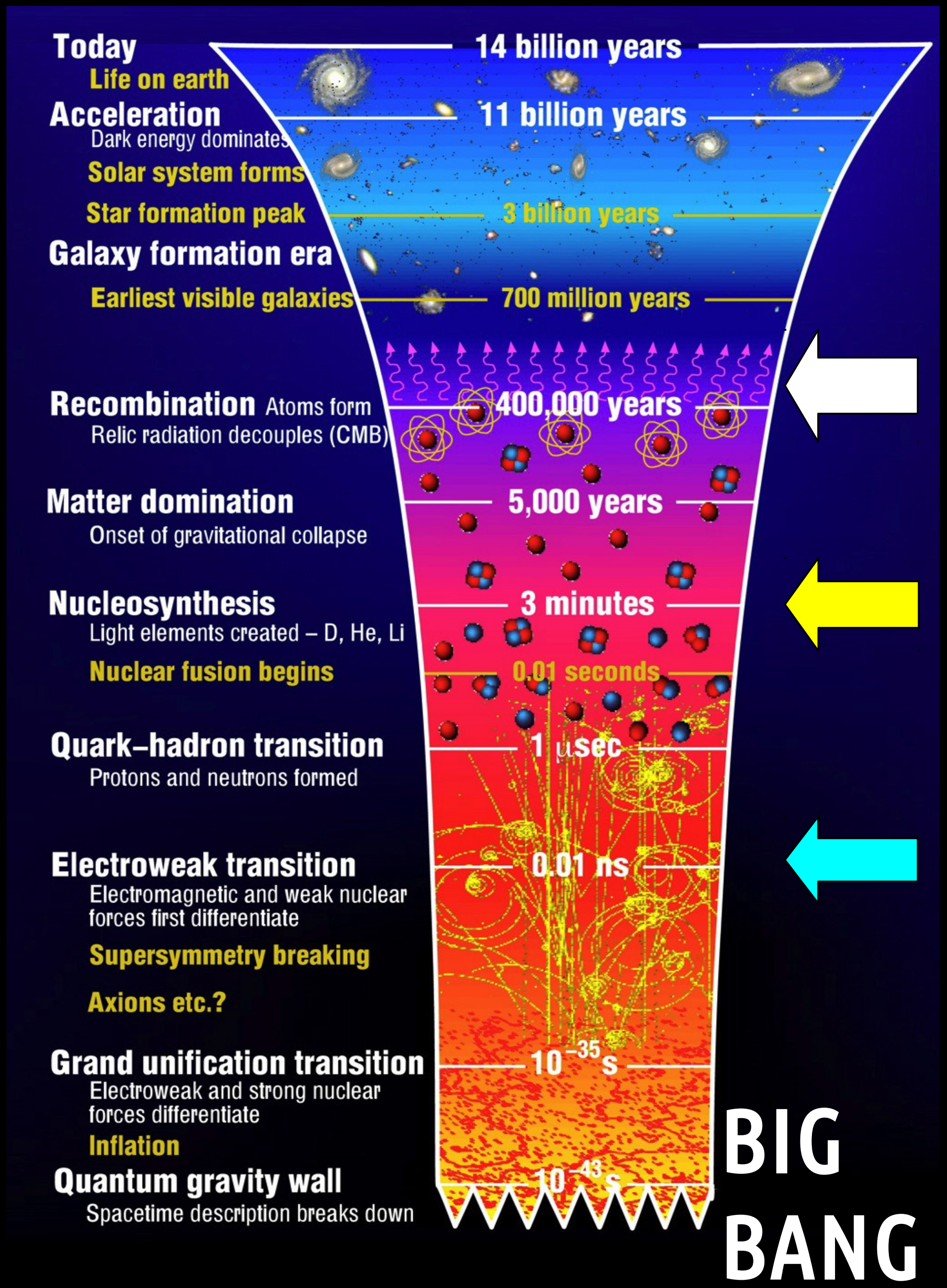
BIG BANG

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

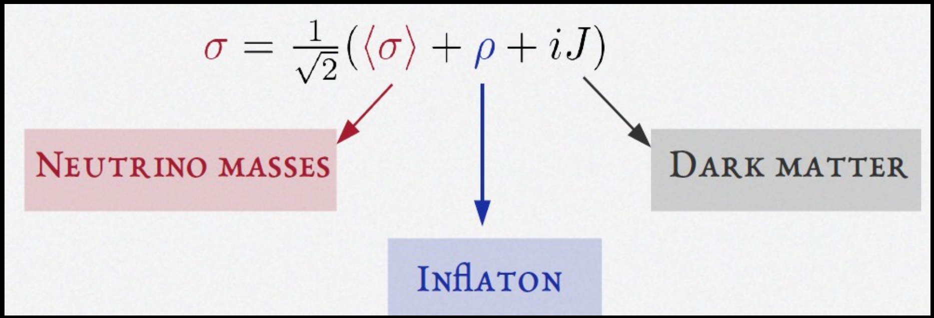
are key in the synthesis of light elements

can "probe" the Universe earlier than photons …



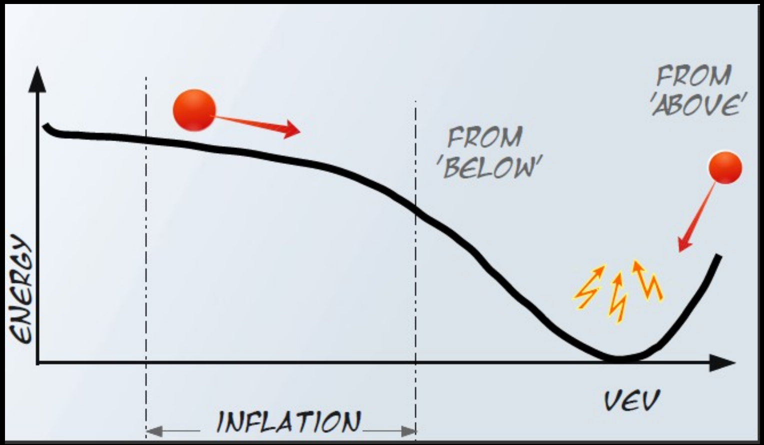


seesaw inflation & *majoron dark matter*

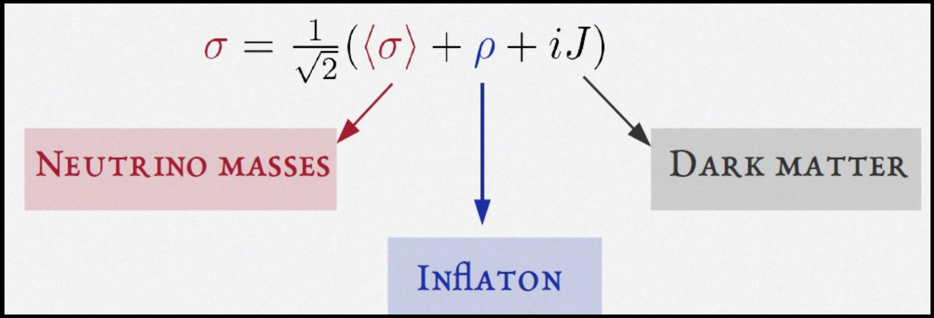


Boucenna et al arXiv:1405.2332 PRD90 (2014) 055023

type-I seesaw **Leptogenesis**

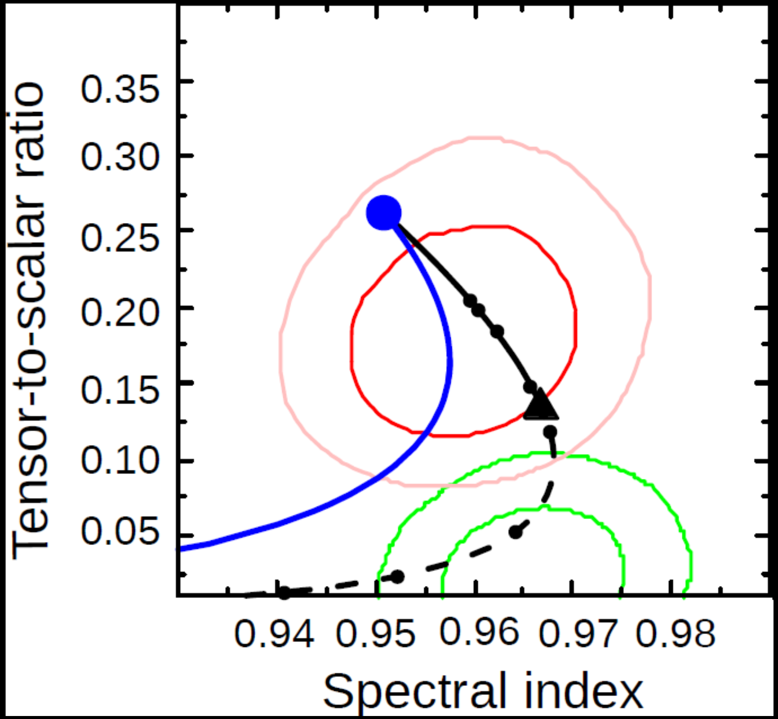


seesaw inflation & *majoron dark matter*



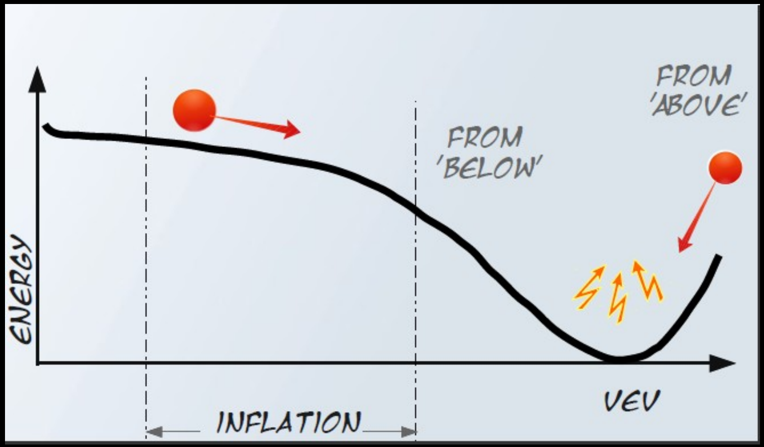
Boucenna et al arXiv:1405.2332 PRD90 (2014) 055023

Quartic versus *Higgs Inflation*



type-I seesaw **Leptogenesis**

Aristizabal et al arXiv:1405.4706



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

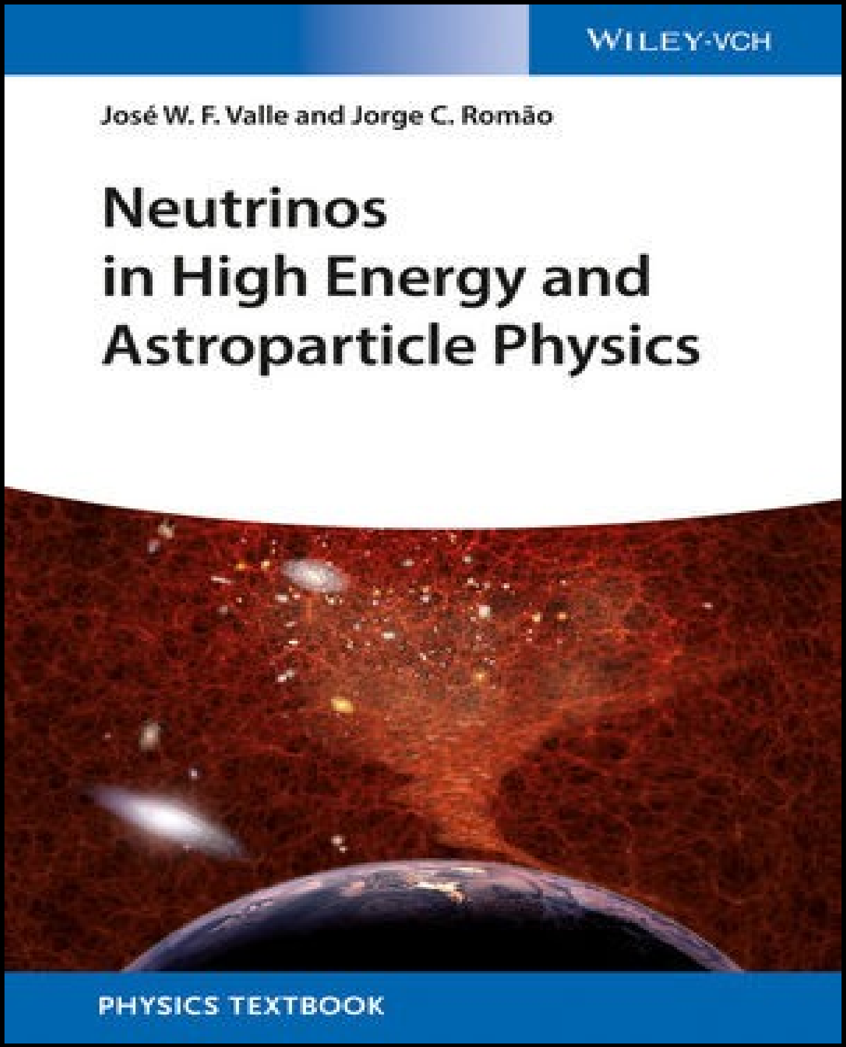
Thank you ...

Thank you Ernest !!

All you ever Wanted to know About neutrinos

http://t.co/yUSLiF1cGX

fb.me/2ZAD7khZf



ISBN: 978-3-527-41197-9
458 pages
April 2015

Now the back up slides

dark matter majorons

Berezinsky, Valle PLB318 (1993) 360

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

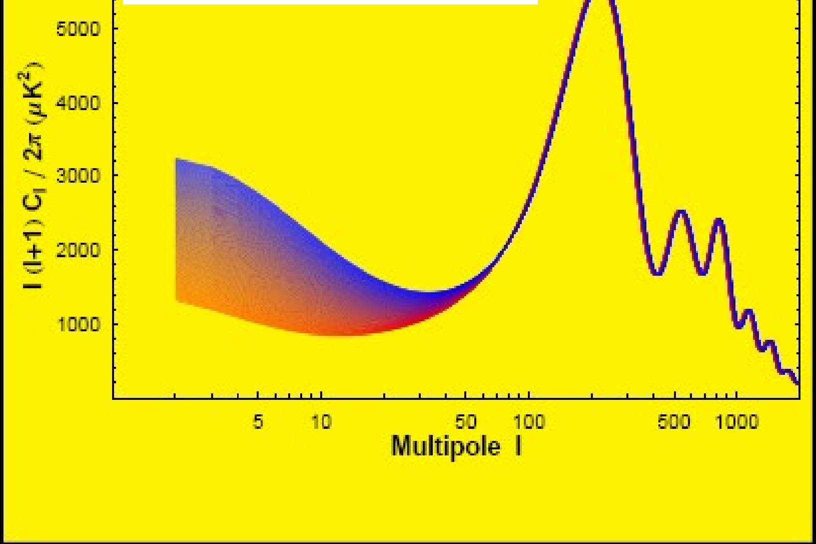
dark matter majorons

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

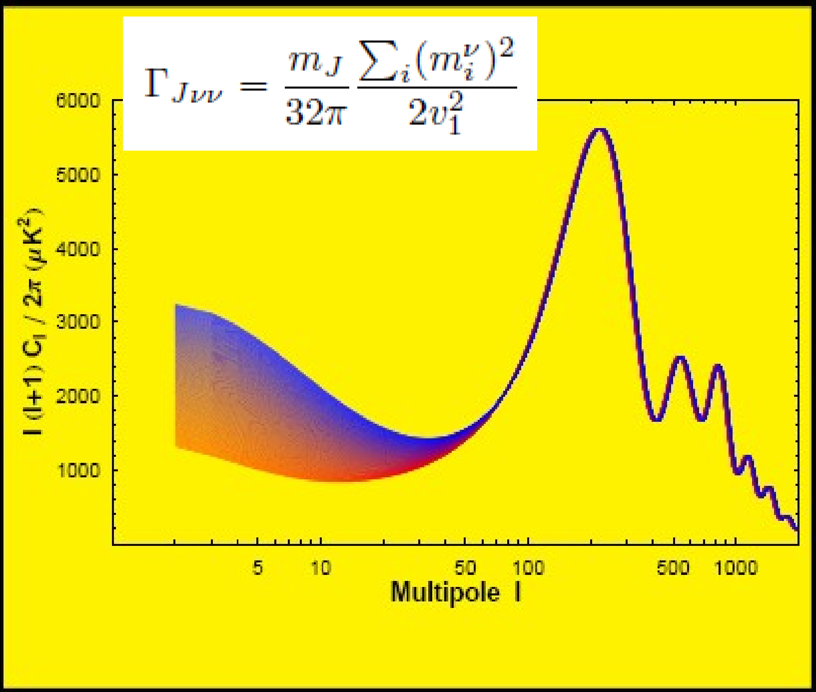
dark matter majorons

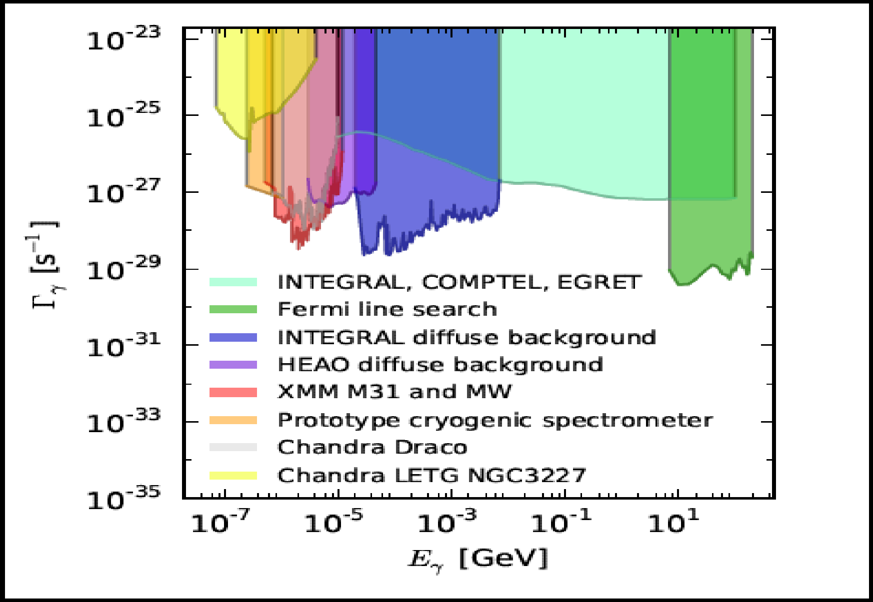
Berezinsky, Valle PLB318 (1993) 360

Consistency with CMB

Lattanzi & Valle, PRL99 (2007) 121301

$$J \to \gamma\gamma$$





Lattanzi et al PRD88 (2013) 063528

Esteves et al, PRD 82, 073008 (2010)

Bazzocchi & al JCAP 0808 (2008) 013

DARK MATTER STABILITY FROM FLAVOUR SYMMETRY

DARK MATTER STABILITY FROM FLAVOUR SYMMETRY

- ***accidental?*** Lavoura, Morisi, JV JHEP 1302(2013) 118
- ***unbroken subgroup*** Hirsch, Morisi, Peinado, Valle PRD82 116003 (2010)

DARK MATTER FROM FLAVOUR SYMMETRY

- *accidental?*
- *unbroken subgroup*

Lavoura, Morisi, JV JHEP 1302(2013) 118

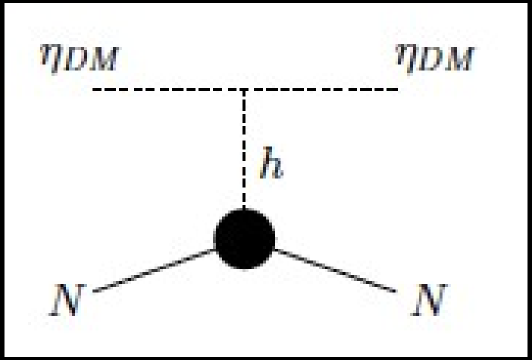
Hirsch, Morisi, Peinado, Valle
PRD82 116003 (2010)

A4

Boucenna et al JHEP 1105 037 (2011)

Z2 PARITY

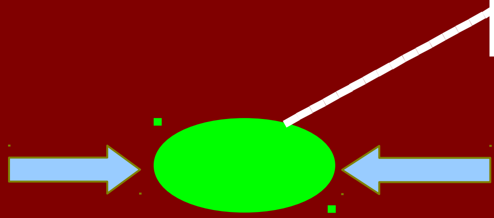
HIGGS PORTAL
DIRECT DETECTION



LIGHTEST NEUTRALINO DECAYS: *probing neutrinos @ lhc13*

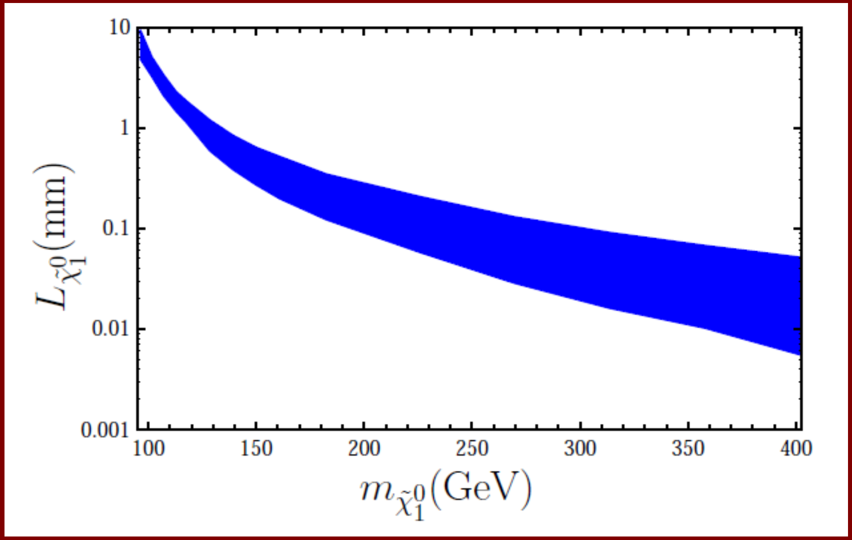
De Campos et al
Phys.Rev. D86 (2012) 075001

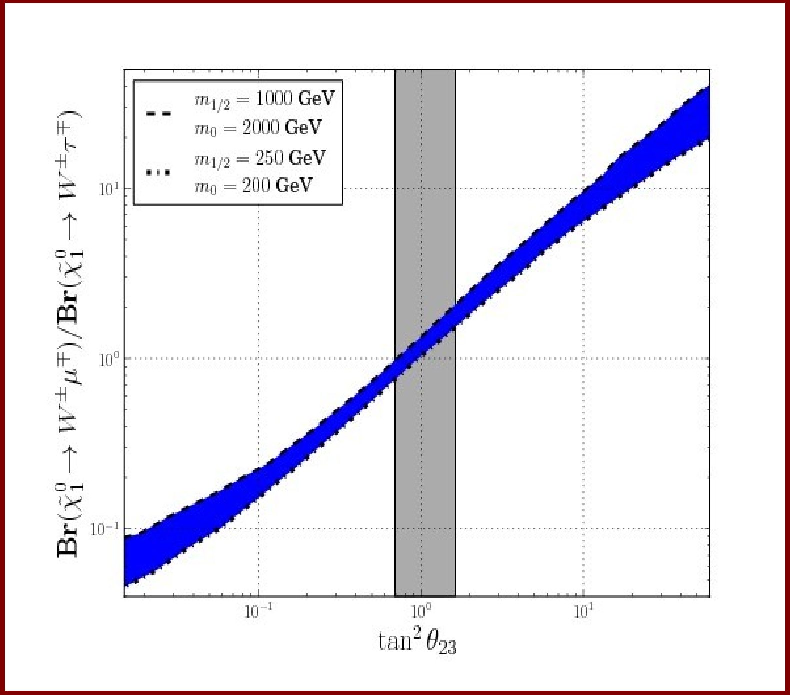
$\tilde{\chi}_1^0 \rightarrow W^{\pm} l_i^{\mp}$ $\tilde{\chi}_1^0 \rightarrow Z^0 \nu_i$



Lightest neutralino decay correlates with atm angle

Lightest neutralino decay length





decaying Gravitino dark matter

decays suppressed by Planck mass & smallness of m-nu

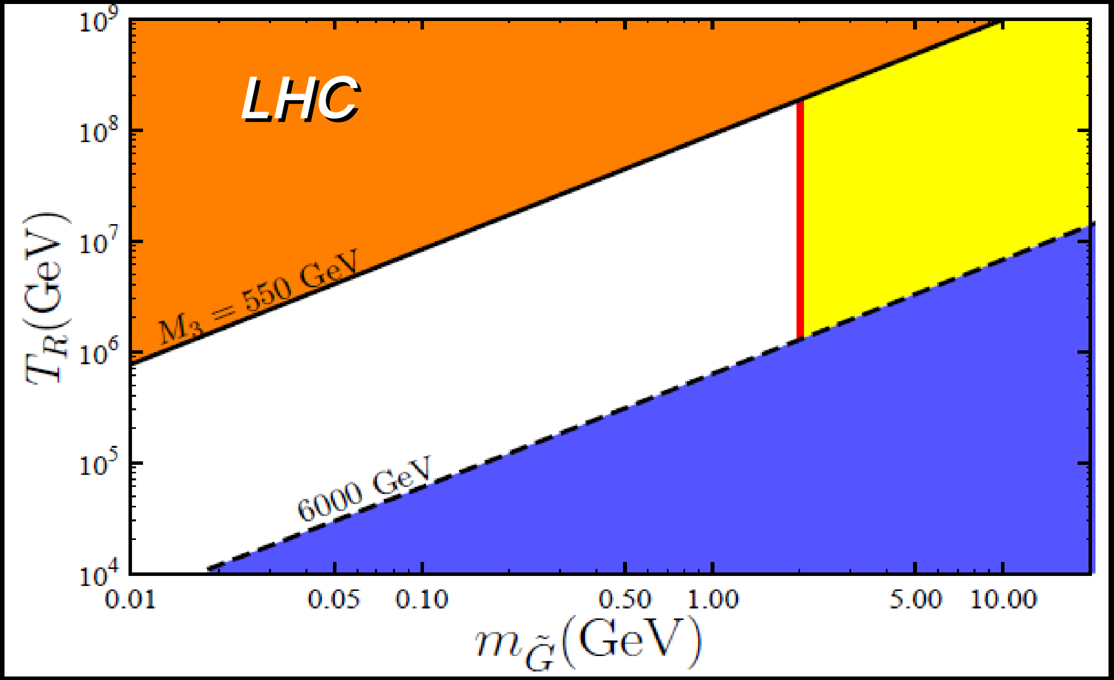
$$\Gamma = \Gamma(\tilde{G} \to \sum_i \nu_i \gamma) \simeq \frac{1}{32\pi} |U_{\tilde{\gamma}\nu}|^2 \frac{m_{\tilde{G}}^3}{M_P^2}$$

chosen to fit neutrino osc. data

Restrepo et al
PRD85 (2012) 023523

relic abundance
+ LHC searches

excluded by gamma
line searches @
Egret & Fermi-LAT



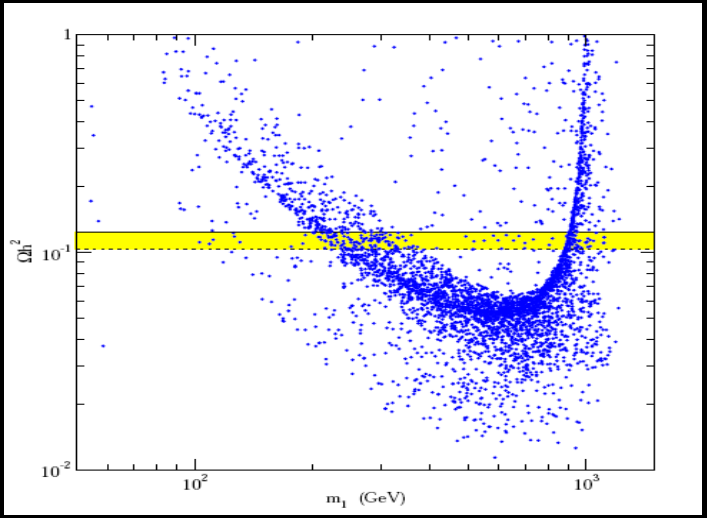
wimp dark matter

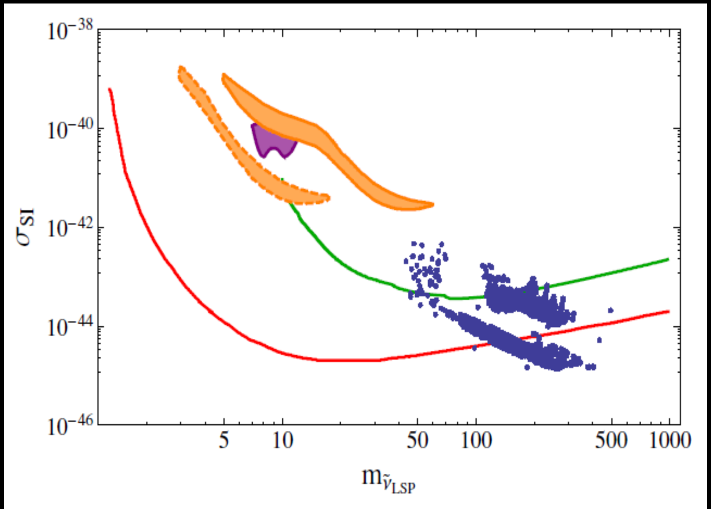
If neutrinos get mass a la Inverse seesaw susy Spectrum can change so …

LSP is SNEUTRINO-like

instead of neutralino ..

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

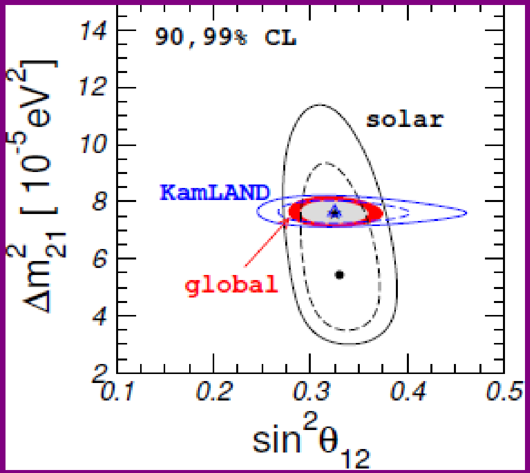


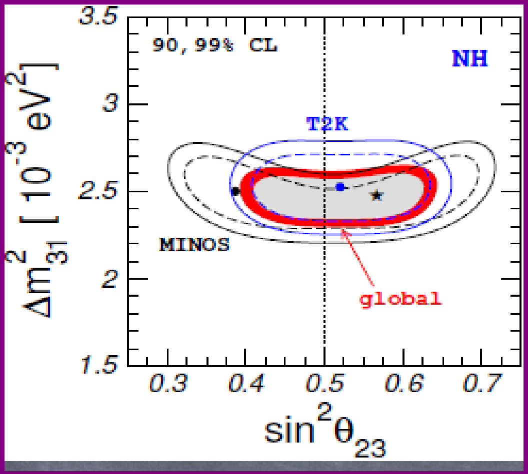


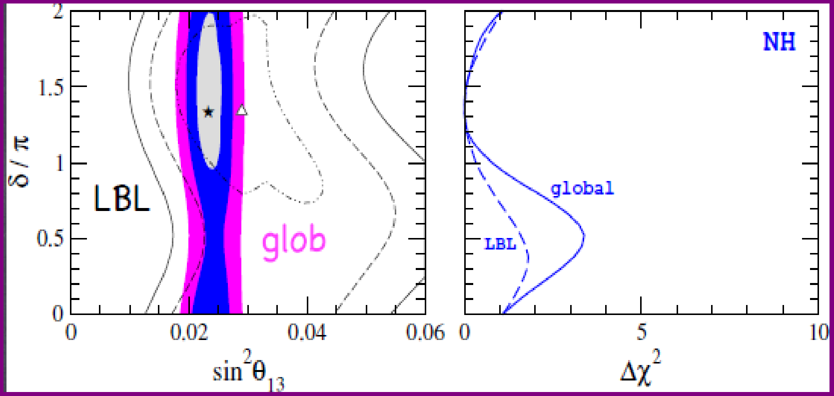
Oscillations after nu2014

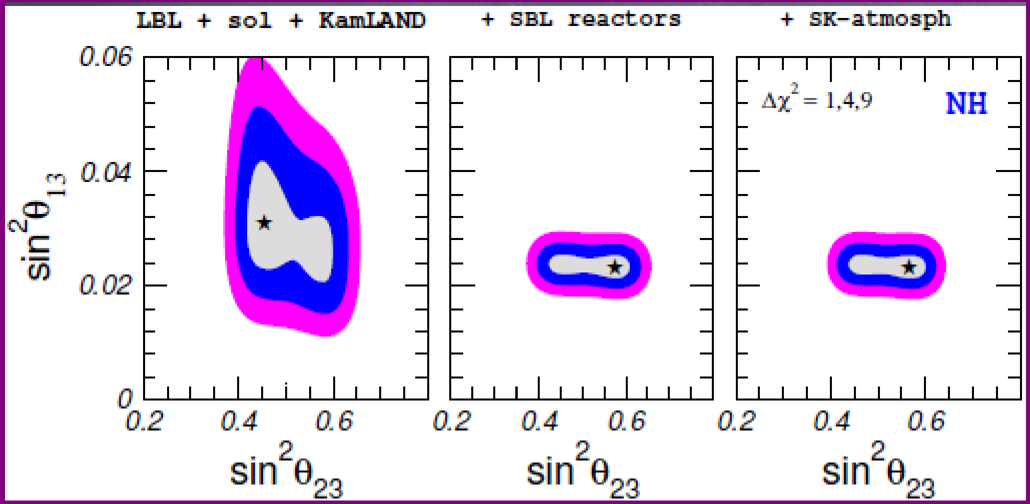
Forero, Tortola, JWFV arXiv:1405.7540

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









Double Chooz: 467.9 days [arXiv:1406.7763]
RENO: 800 days [talk by Seon-Hee Seo@ICHEP2014]
Daya Bay: 621 days of data (6AD + 8AD) [Talk by Chao Zhang@ICHEP2014]

Flavor problem

Table 2
Experimental and predicted quark masses and mixing parameters from our fit. Quark masses (at the scale of the M_Z) have been taken from [18], while quark mixing angles have been taken from [19]. The third column displays our predicted values from Eqs. (27) which are in very good agreement with the experimental data.

Observable	Experimental value	Model prediction
m_d [MeV]	$2.9\pm^{0.5}_{0.4}$	2.93
m_s [MeV]	$57.7^{+16.8}_{-15.7}$	62
m_b [MeV]	2820^{+90}_{-40}	2830
m_u [MeV]	$1.45^{+0.56}_{-0.45}$	1.63
m_c [MeV]	635 ± 86	640
m_t [GeV]	$172.1 \pm 0.6 \pm 0.9$	172.1
$\|V_{us}\|$	0.22534 ± 0.00065	0.2253
$\|V_{ub}\|$	$0.00351^{+0.00015}_{-0.00014}$	0.00347
$\|V_{cb}\|$	$0.0412^{+0.0011}_{-0.0005}$	0.0408
J	$2.96^{+0.20}_{-0.16}$	2.93

pattern of charged fermion masses
B-tau unification without GUTS ...

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