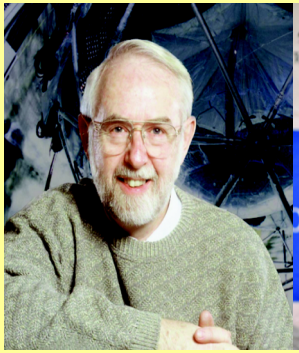
neutrino mass and new physics at the energy frontier

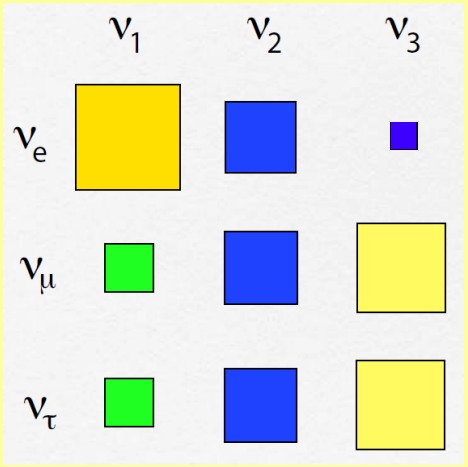
José W F Valle

https://www.facebook.com/ific.ahep/

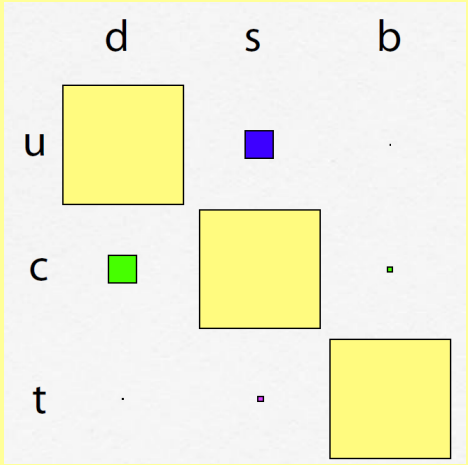
ACFI Neutrino Workshop, Amherst, July 18, 2017



neutrino oscillations



vs



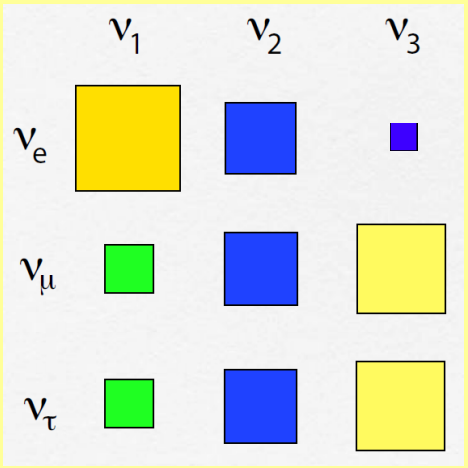
Why large?

Cabbibo as seed?

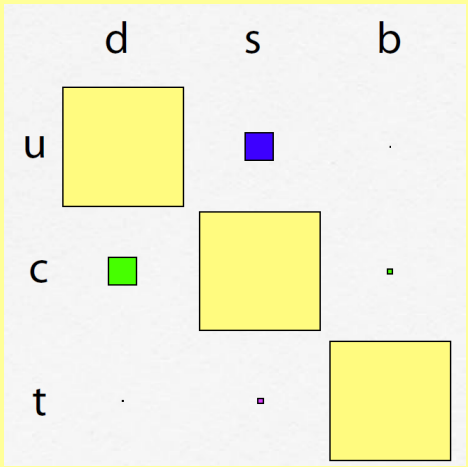
Phys.Rev. D86 (2012) 051301

Phys.Lett. B748 (2015) 1-4

neutrino oscillations



vs



Why large?

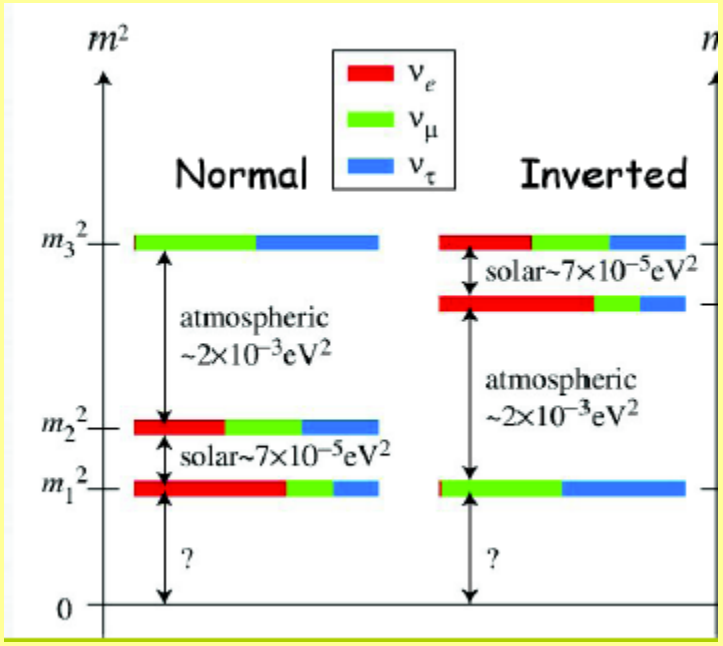
Cabbibo as seed?

Phys.Rev. D86 (2012) 051301

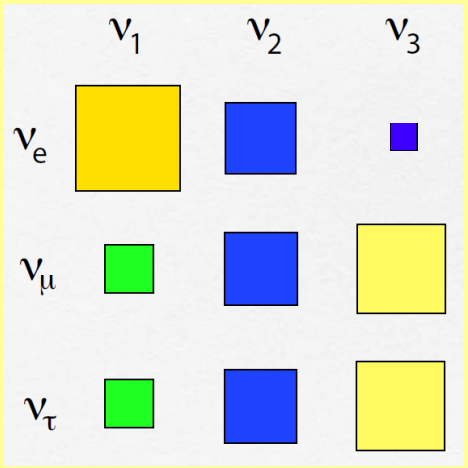
Phys.Lett. B748 (2015) 1-4

http://arxiv.org/abs/arXiv:1706.00210

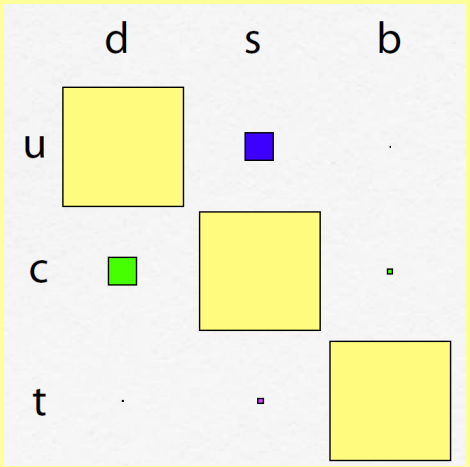
spectrum predictions



neutrino oscillations



vs



CP predictions

http://dx.doi.org/10.1007/JHEP01(2016)007

http://arxiv.org/abs/arXiv:1705.06320

Why large?

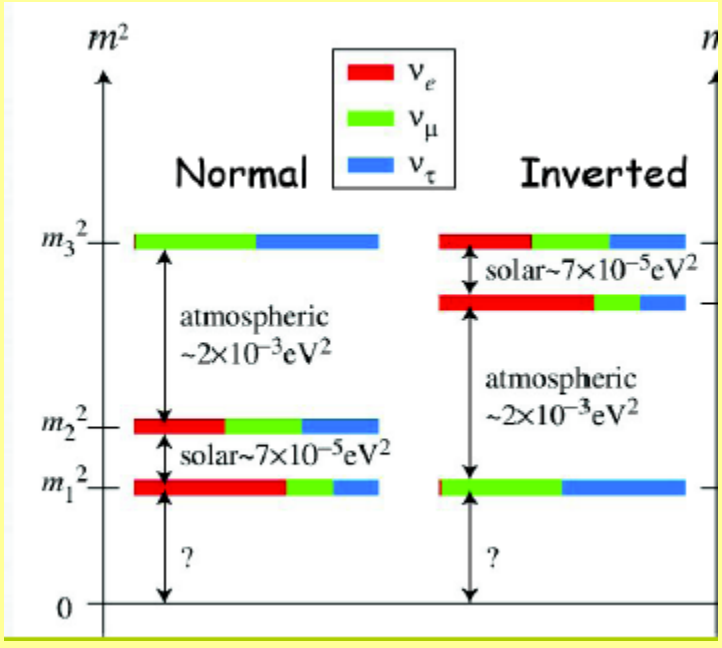
Cabbibo as seed?

Phys.Rev. D86 (2012) 051301

Phys.Lett. B748 (2015) 1-4

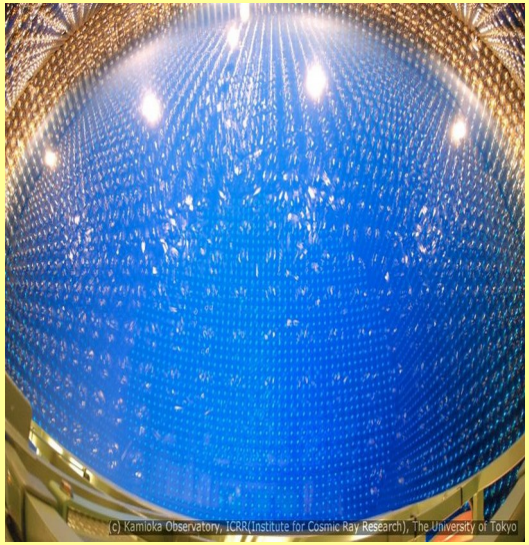
http://arxiv.org/abs/arXiv:1706.00210

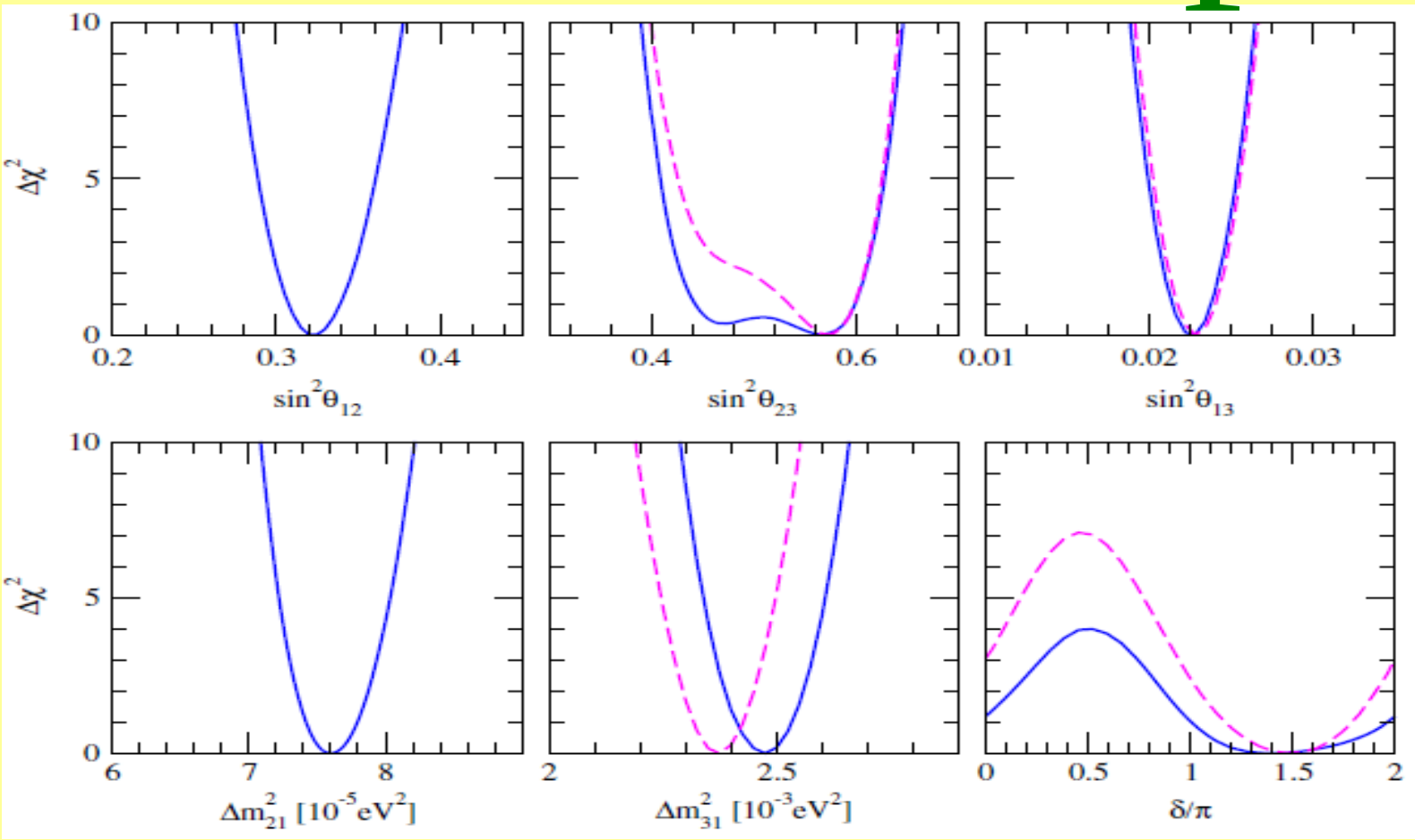
spectrum predictions



the oscillation map

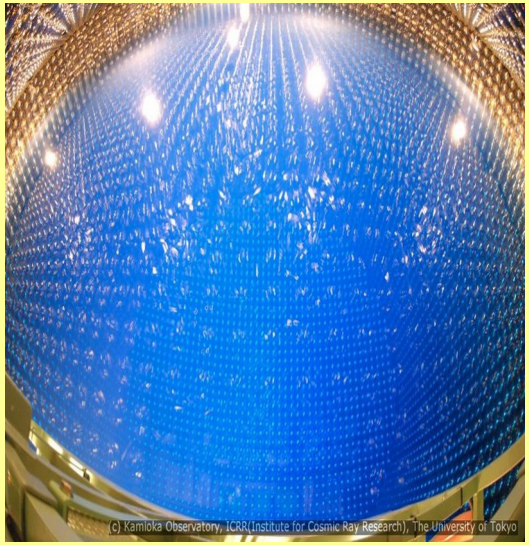
PRD90 (2014) 093006



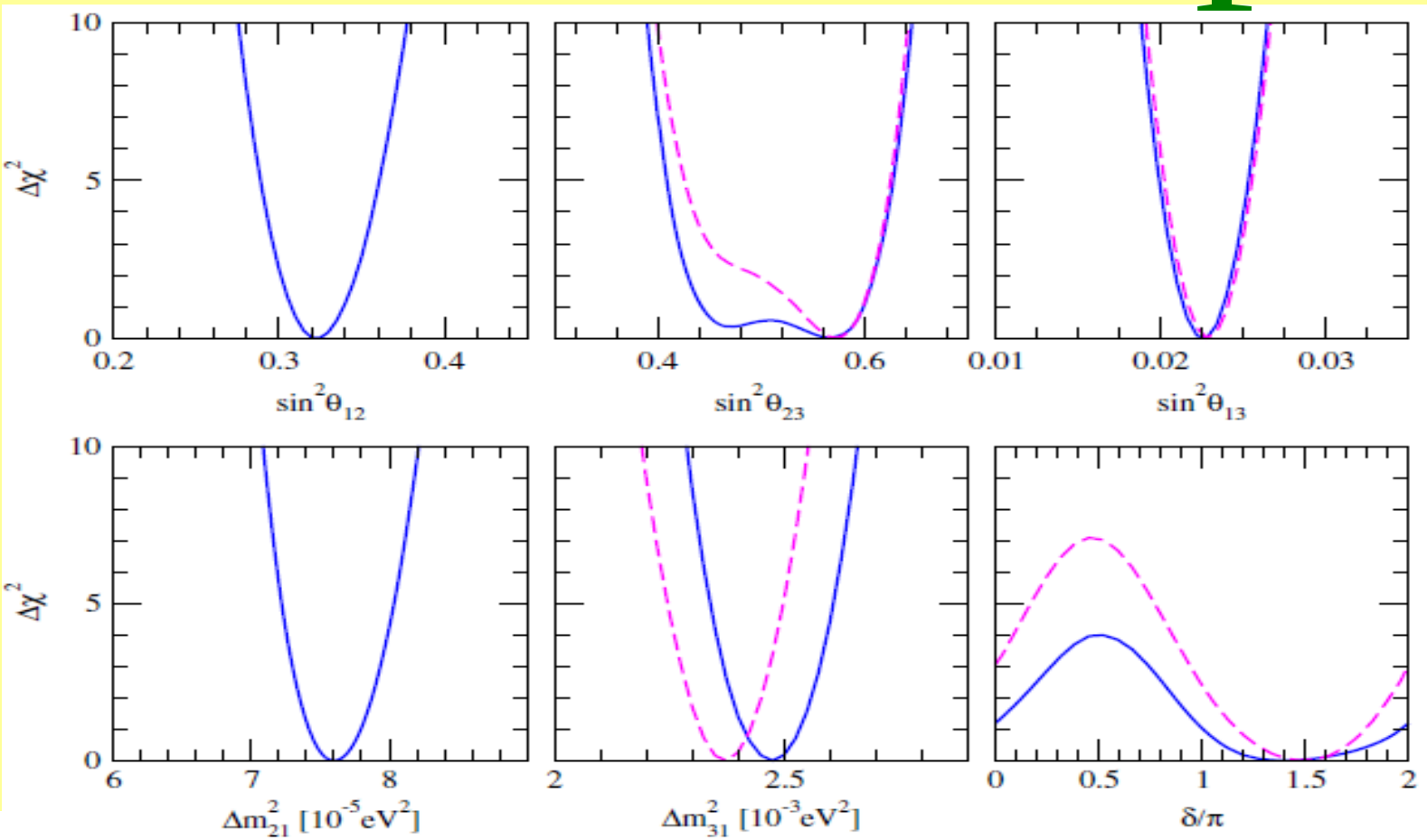


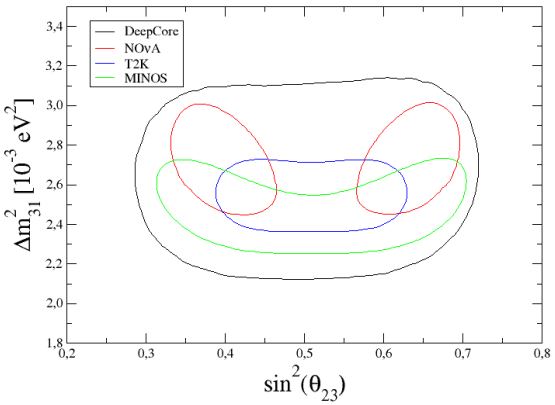
the oscillation map

PRD90 (2014) 093006



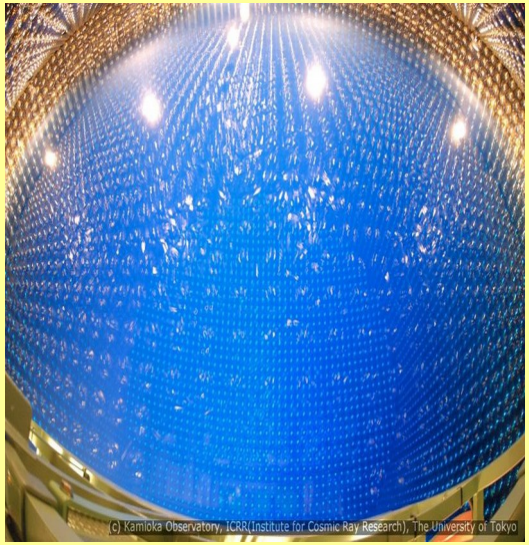
Good agreement,
update in progress for TAUP,
Consistency with
IceCube/DeepCore, etc



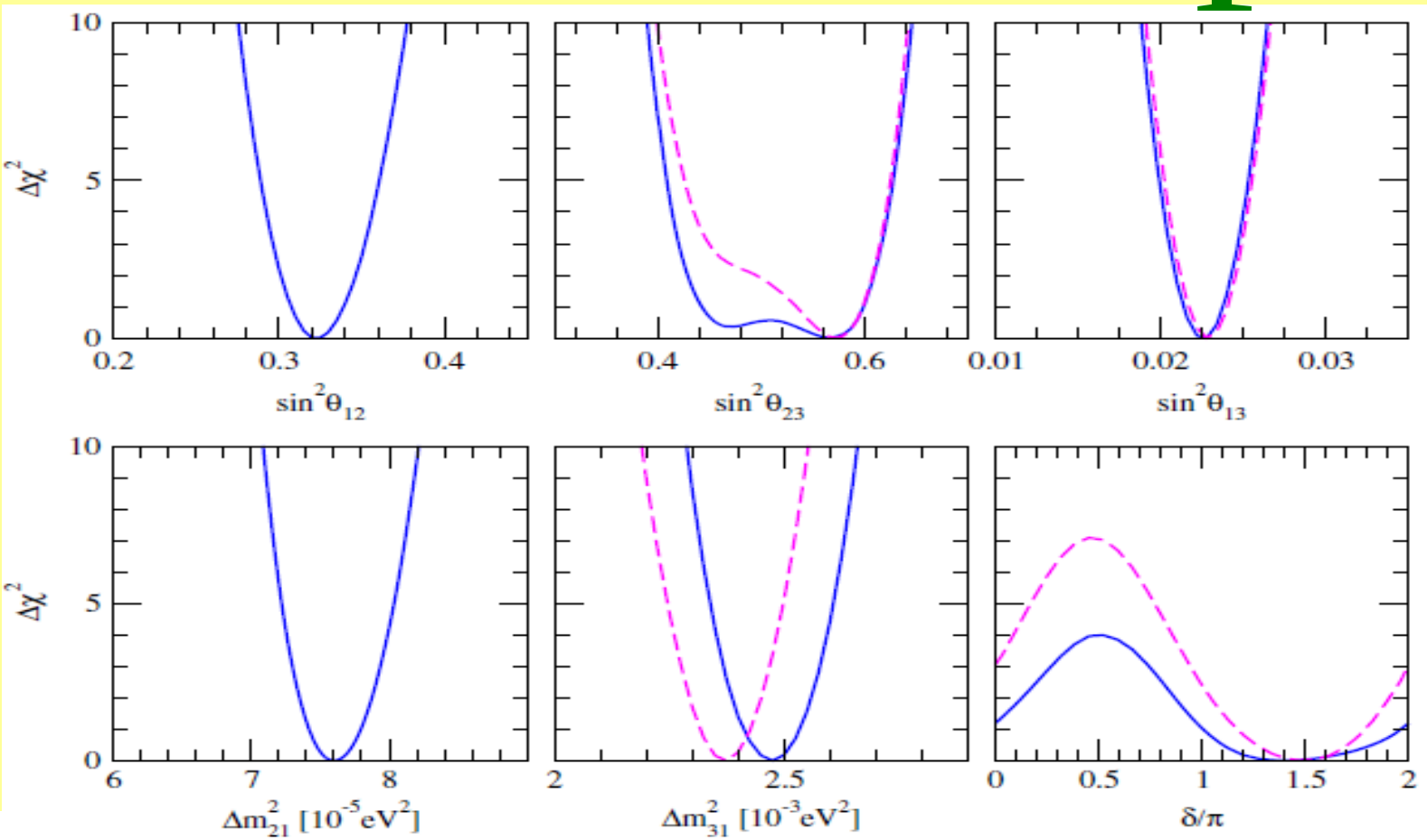


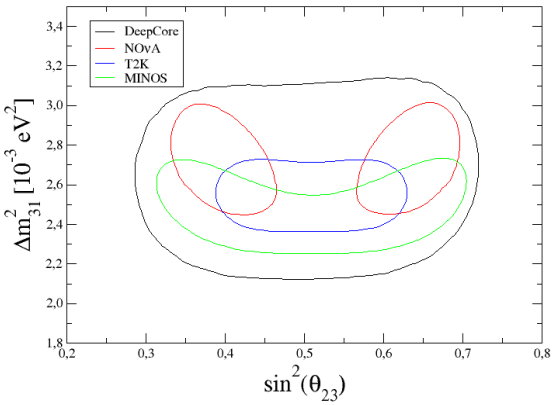
the oscillation map

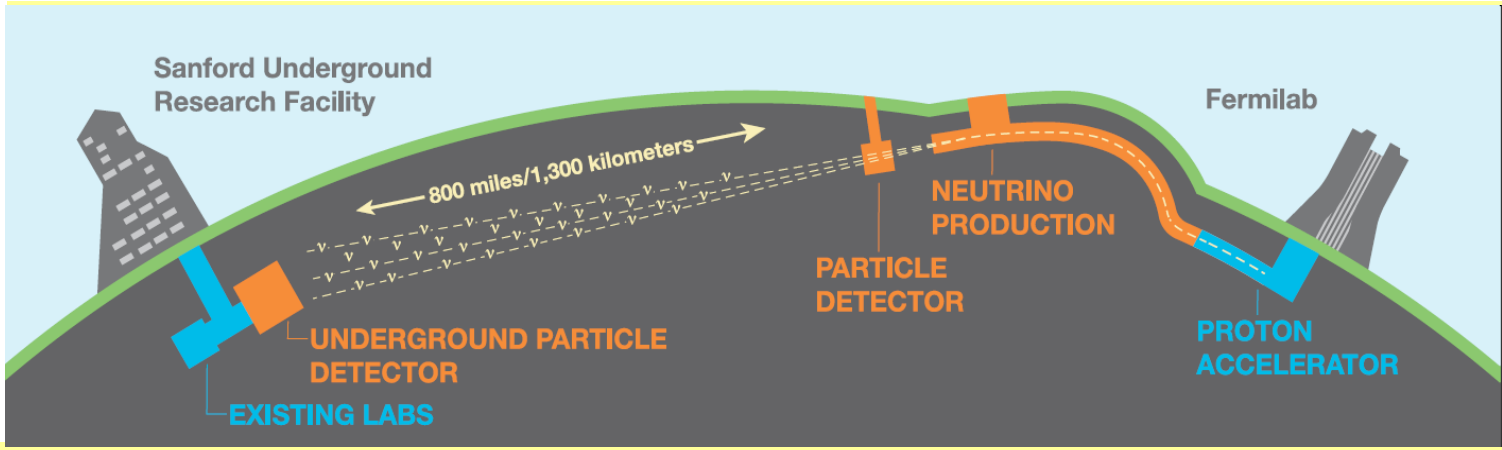
PRD90 (2014) 093006



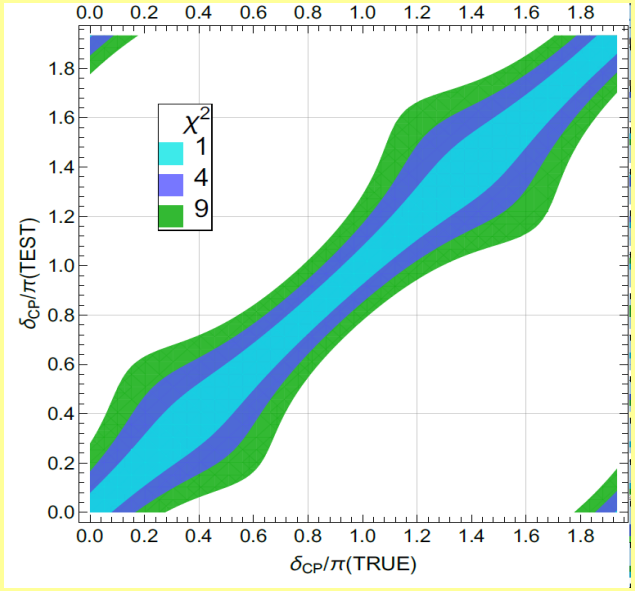
Good agreement,
update in progress for TAUP,
Consistency with
IceCube/DeepCore, etc







the future

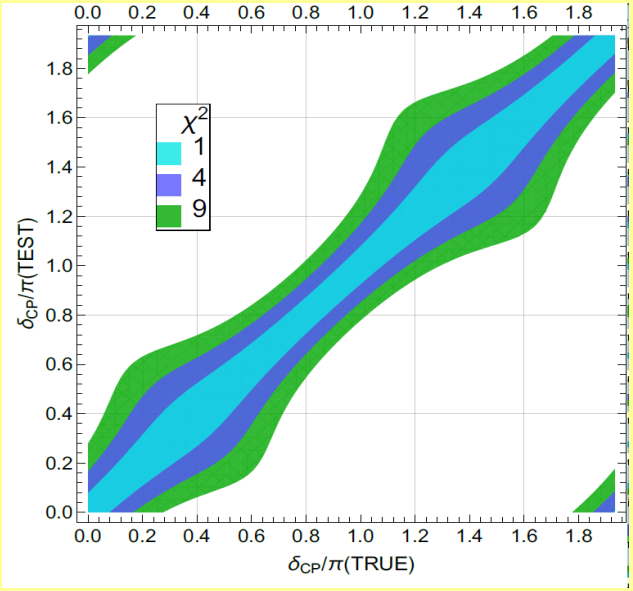


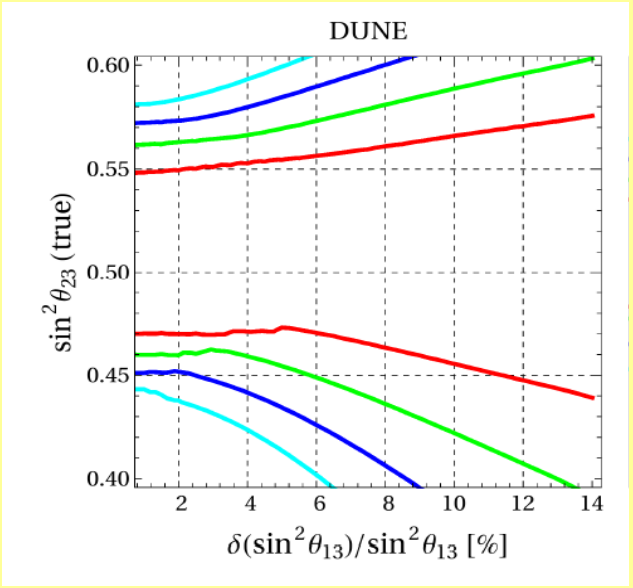
10.1016/j.physletb.2017.05.080

https://arxiv.org/pdf/1703.03435.pdf

dune

the future



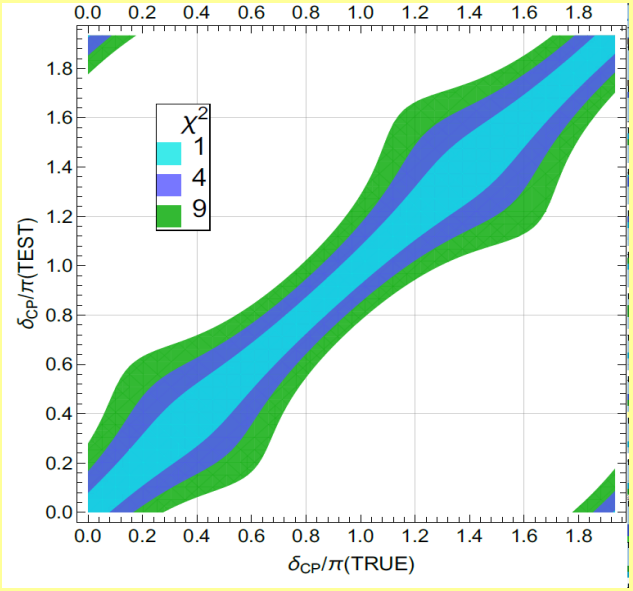


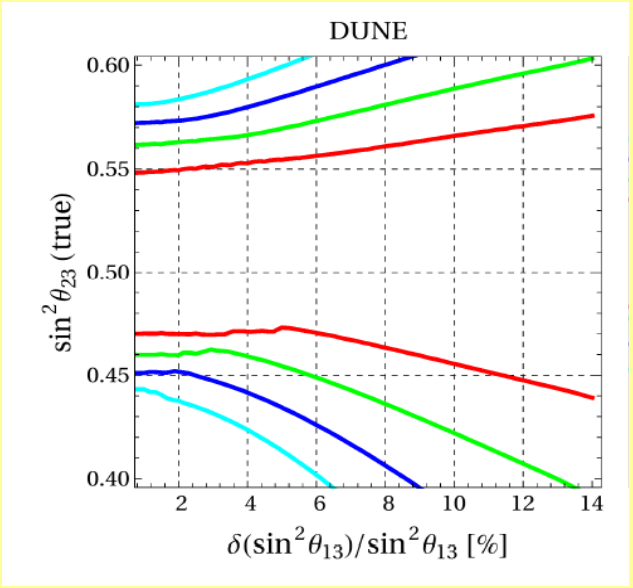
10.1016/j.physletb.2017.05.080

https://arxiv.org/pdf/1703.03435.pdf

dune

the future





10.1016/j.physletb.2017.05.080

https://arxiv.org/pdf/1703.03435.pdf

dune

oscillation robustness

Miranda & JV, Nucl.Phys. B908 (2016) 436
Escrihuela, et al PhysRevD.92.053009
MTV, PhysRevLett.117.061804

non unitarity & seesaw scale

nsi

http://dx.doi.org/10.1103/PhysRevD.95.033005

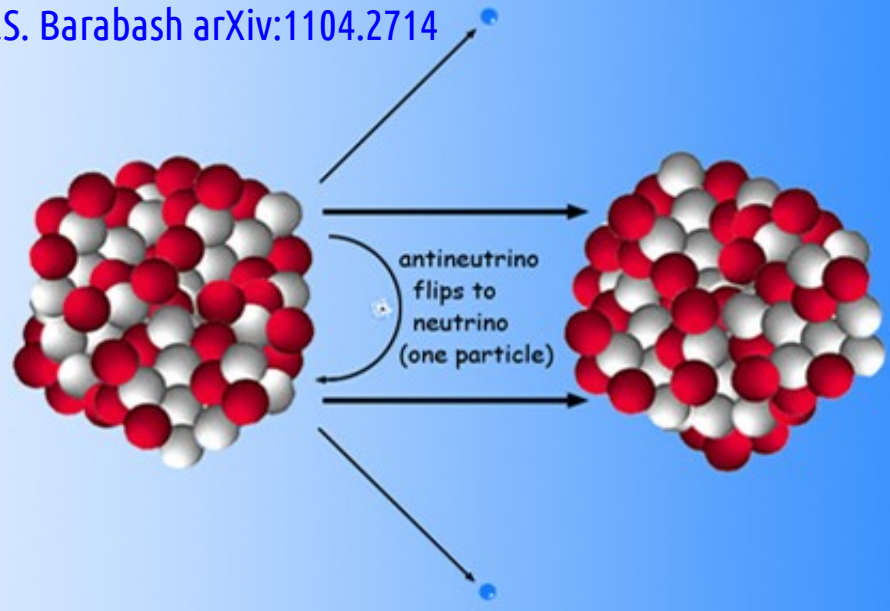
implications for future

http://arxiv.org/abs/arXiv:1612.07377

the neutrino mass scale

Neutrinoless Double Beta Decay

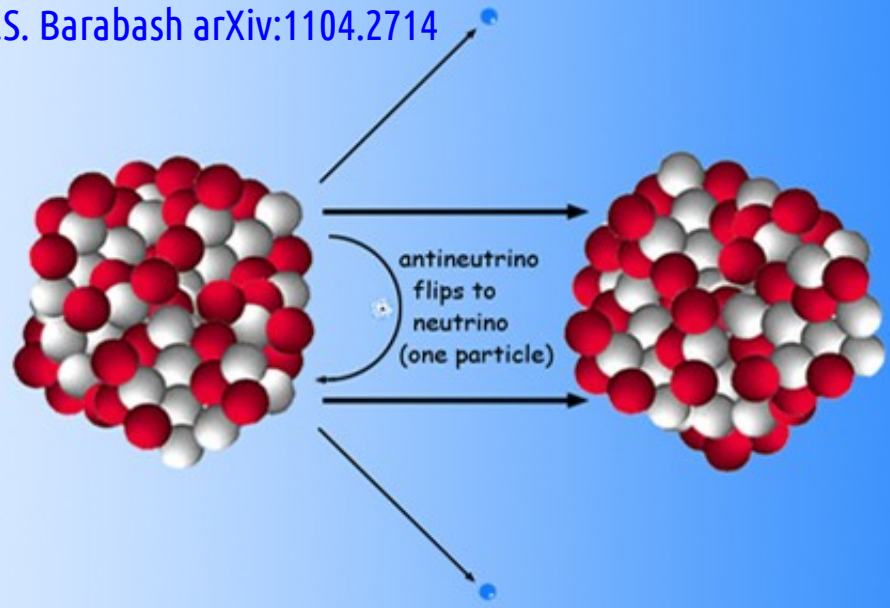
A.S. Barabash arXiv:1104.2714



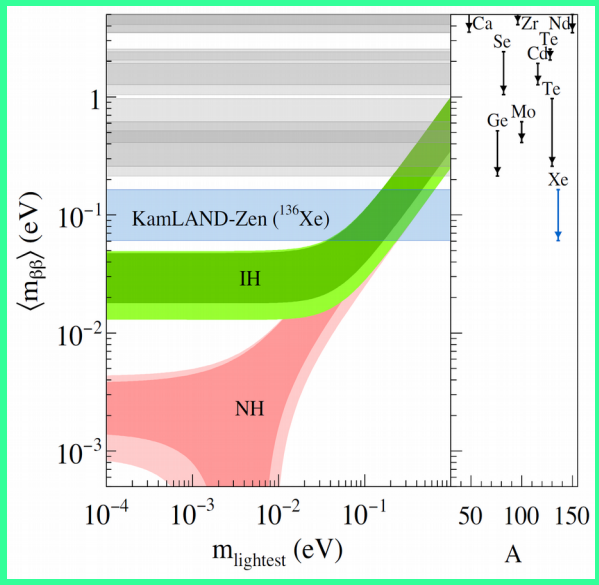
the neutrino mass scale

Neutrinoless Double Beta Decay

A.S. Barabash arXiv:1104.2714



nEXO, CUORE , LEGEND (nGERDA/Majorana) ….



KamLAND-Zen PRL117 (2016)

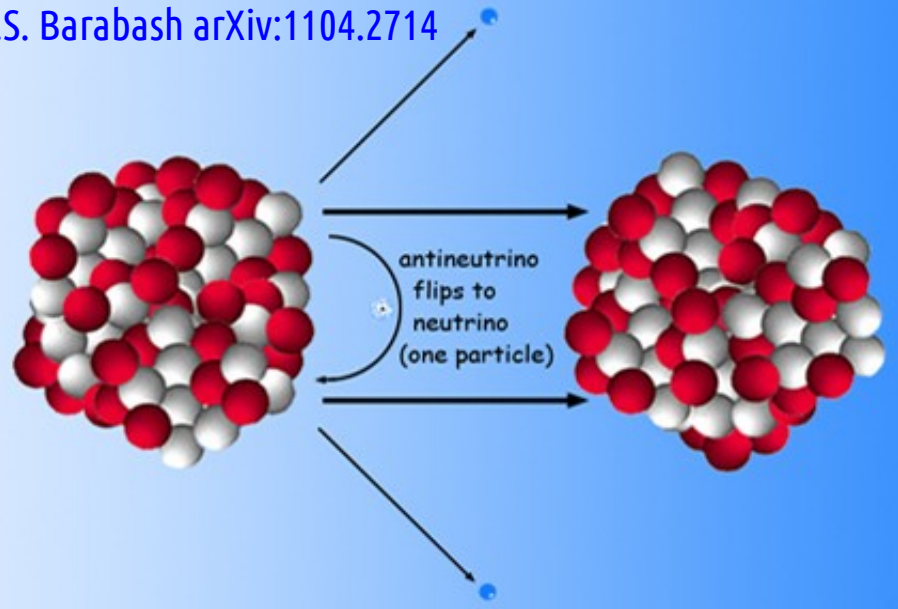
the neutrino mass scale

Majorana phases in lepton mixing matrix …
Original symmetric form
versus PDG

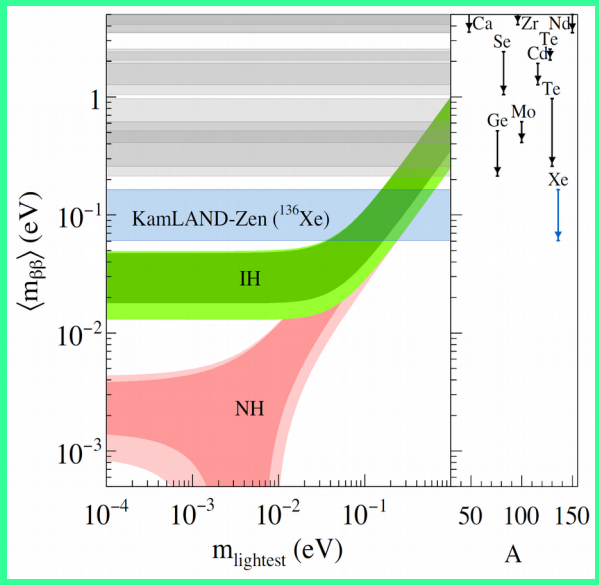
Schechter & JV PRD22 (1980) 2227 & PDG
Rodejohann, JV Phys.Rev. D84 (2011) 073011

Neutrinoless Double Beta Decay

A.S. Barabash arXiv:1104.2714



nEXO, CUORE , LEGEND (nGERDA/Majorana) ….



KamLAND-Zen PRL117 (2016)

the neutrino mass scale

A.S. Barabash arXiv:1104.2714

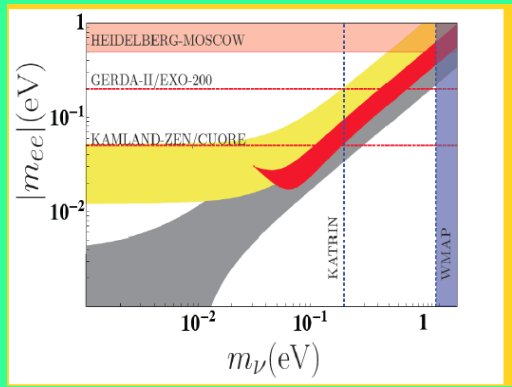
Majorana phases in lepton mixing matrix …
Original symmetric form
versus PDG

Schechter & JV PRD22 (1980) 2227 & PDG
Rodejohann, JV Phys.Rev. D84 (2011) 073011

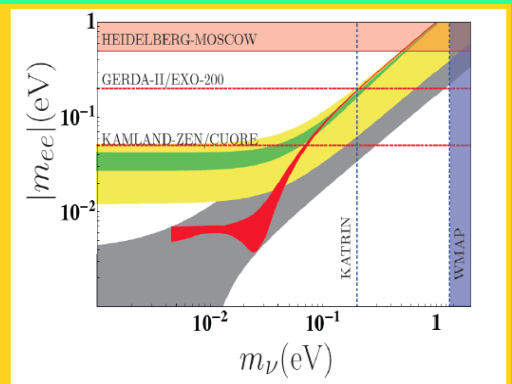
Lower bounds even for NH …

nEXO, CUORE , LEGEND (nGERDA/Majorana) ….

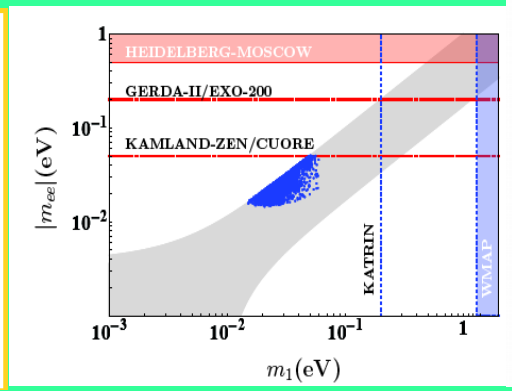
Dorame et al
NPB861 (2012) 259-270

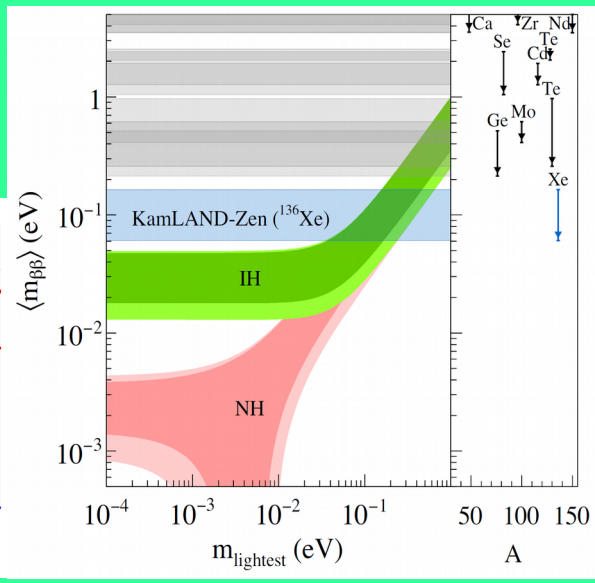


Dorame et al
PhysRevD.86.056001



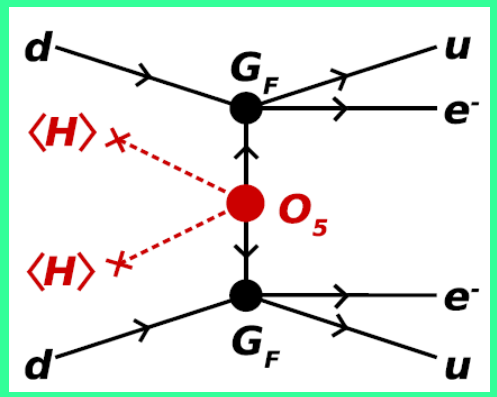
King et al
Phys. Lett. B 724 (2013) 68



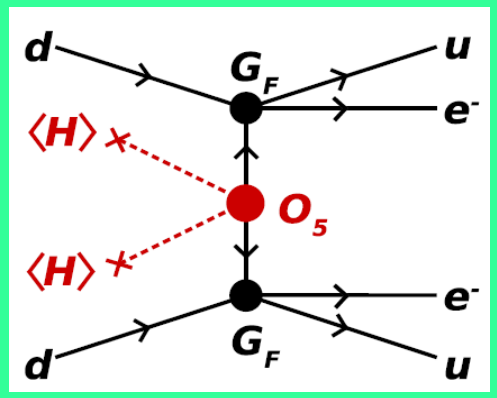


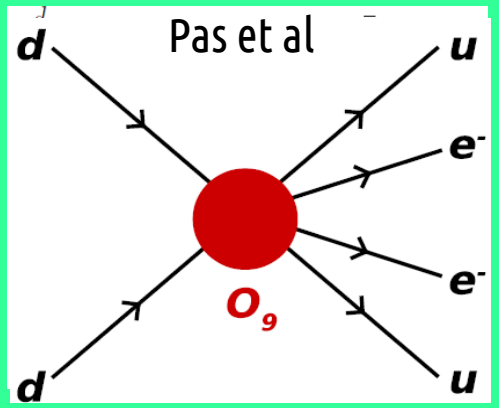
KamLAND-Zen PRL117 (2016)

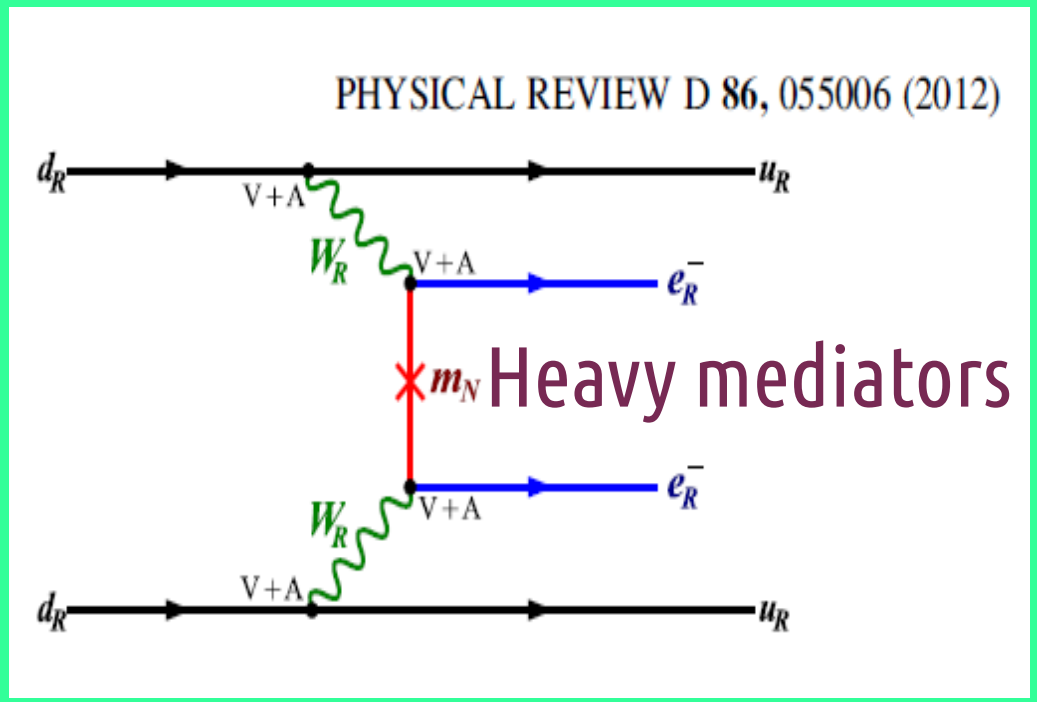
the Majorana connection



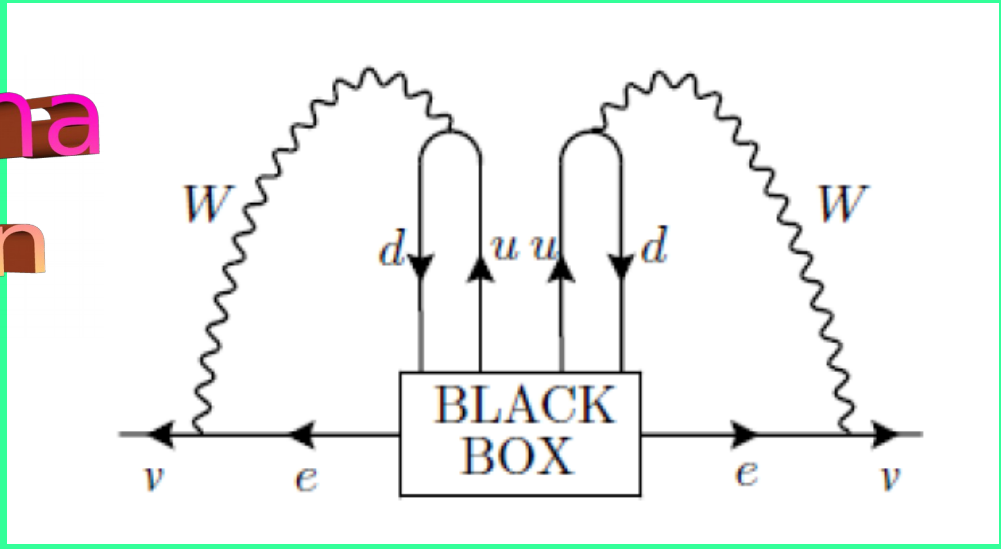
the Majorana connection





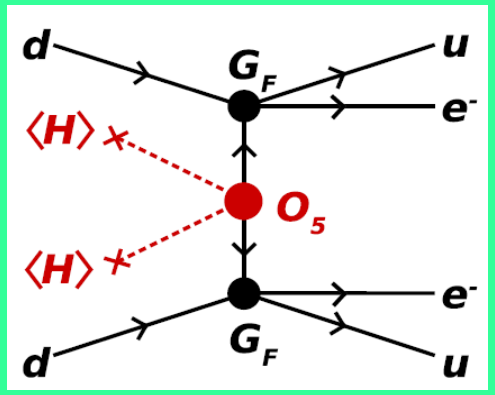


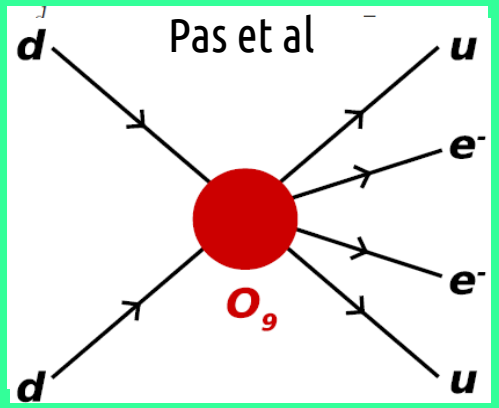
the Majorana connection

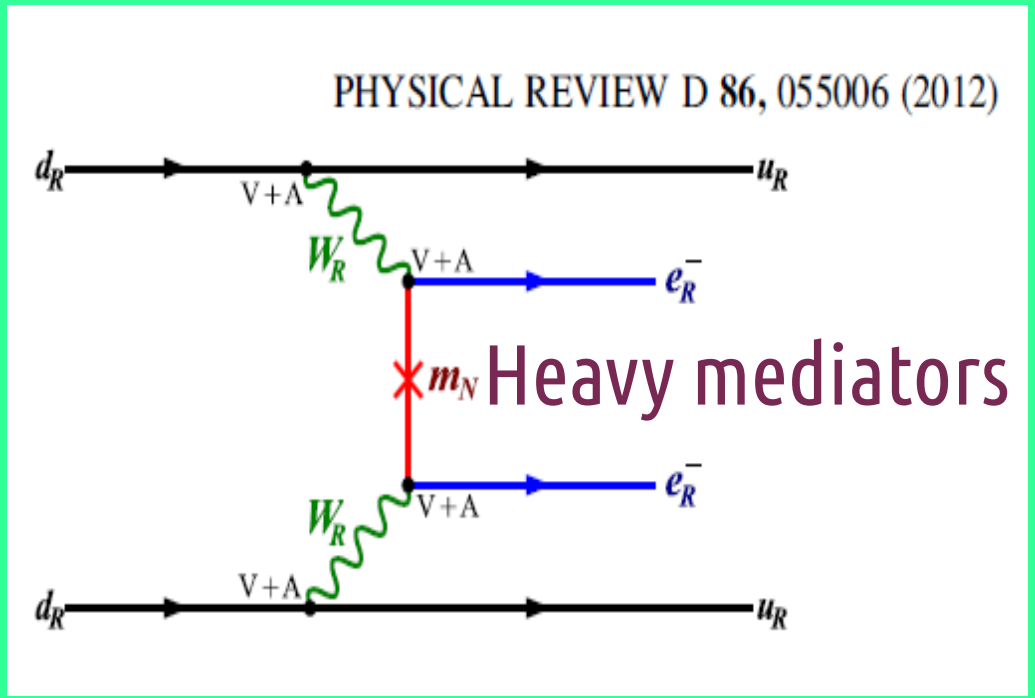


Schechter, Valle 82

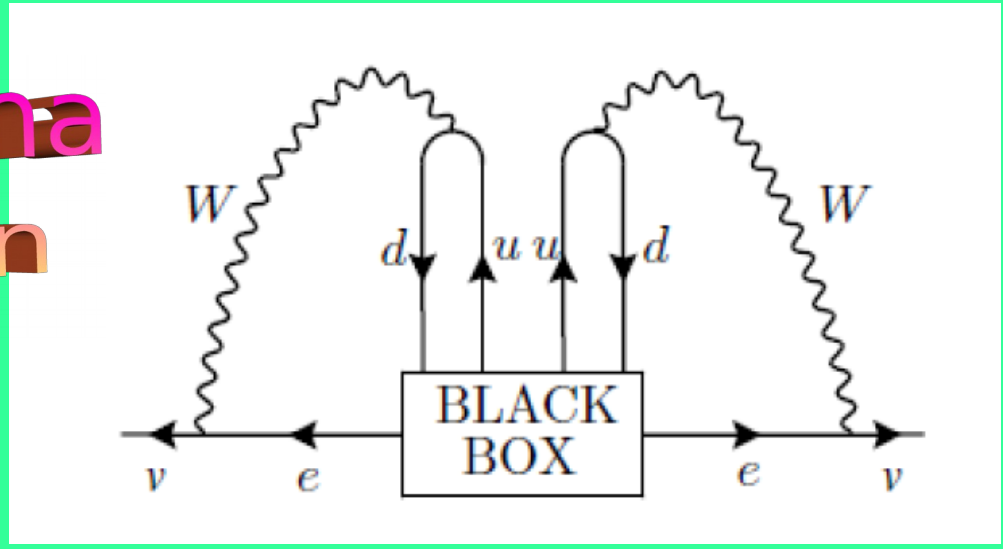
Lindner et al JHEP 1106 (2011) 091





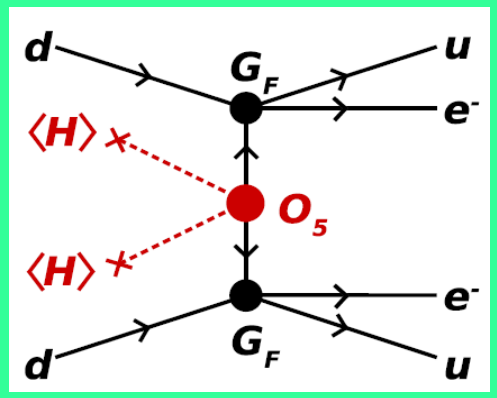


the Majorana connection

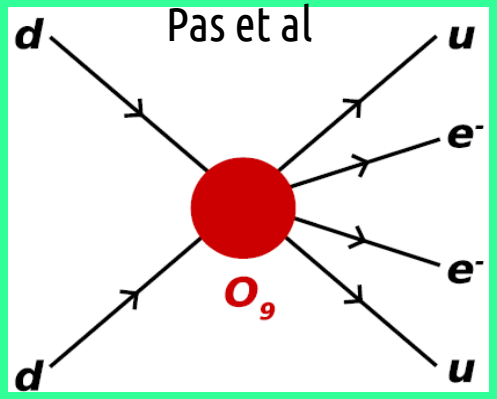


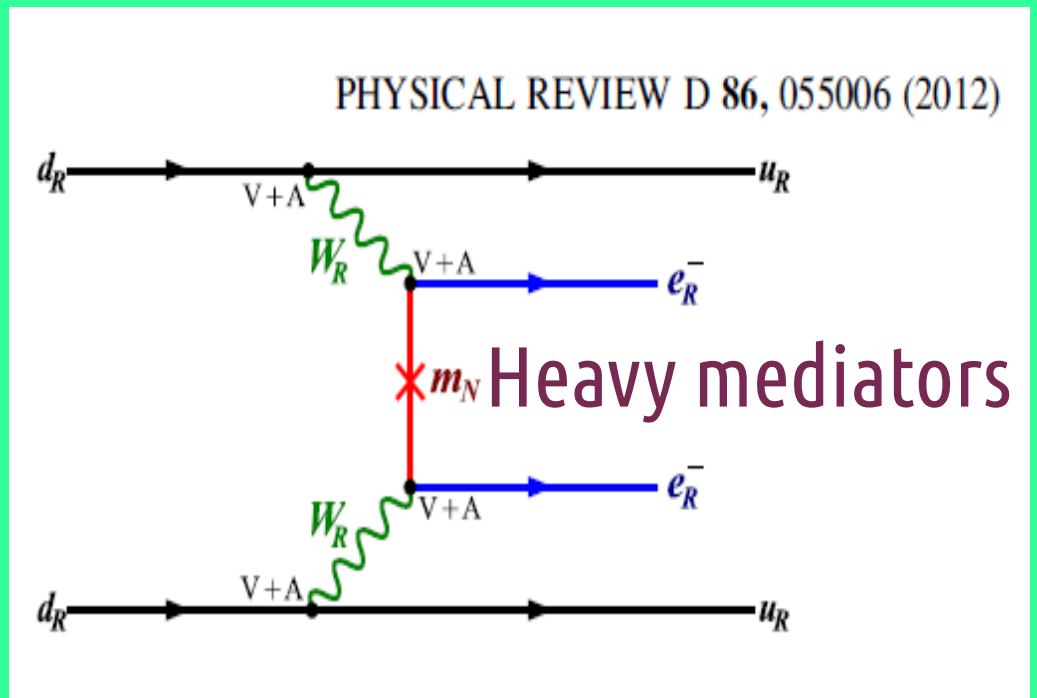
Schechter, Valle 82

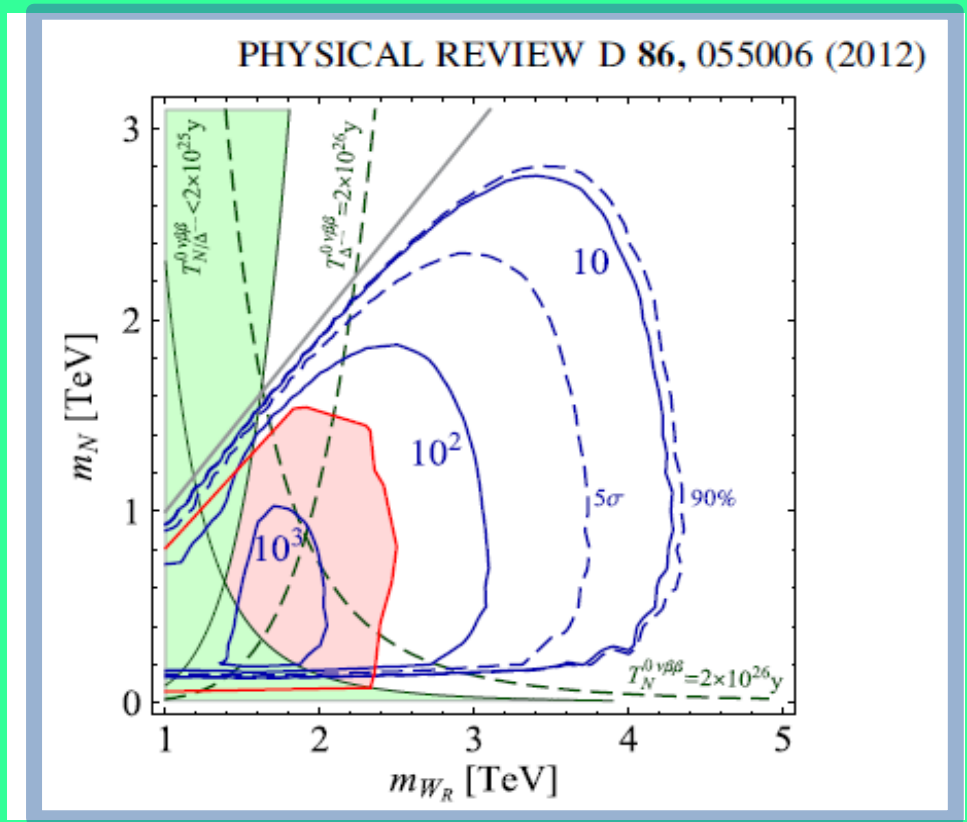
Lindner et al JHEP 1106 (2011) 091



Pas et al







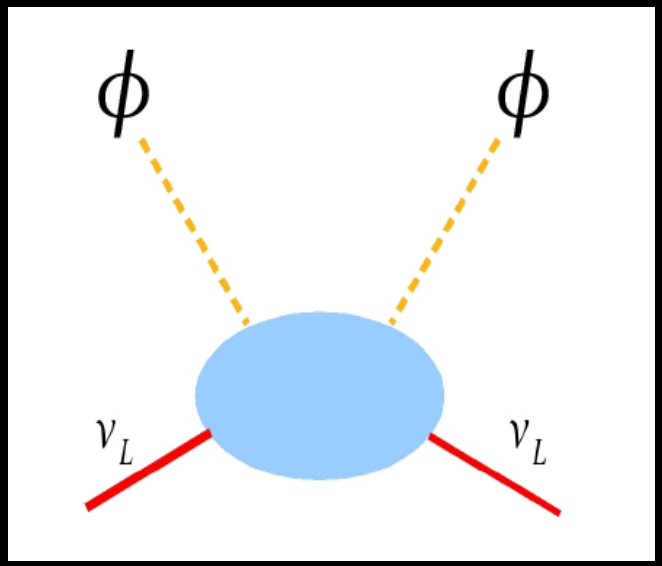
nearly all SM drawbacks
may involve neutrinos

anomalies,
unification,
flavor,
consistency of EW breaking

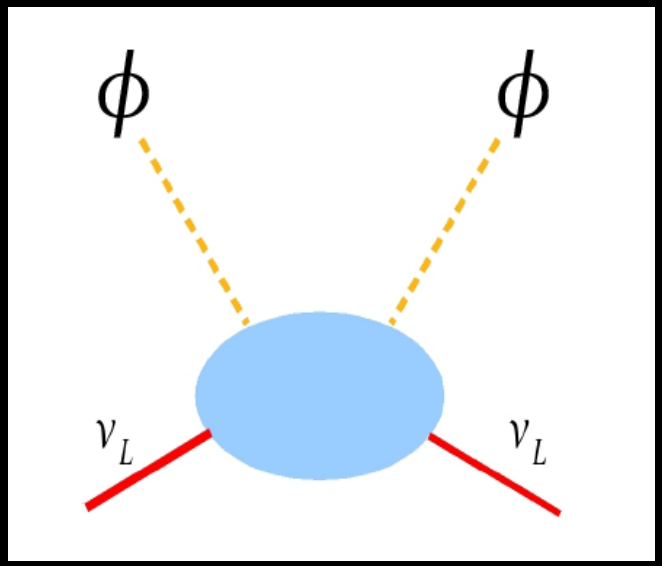
Gravity & cosmo:

dark matter, inflation,
EW baryogenesis, LG
dark energy, ...

origin of neutrino mass

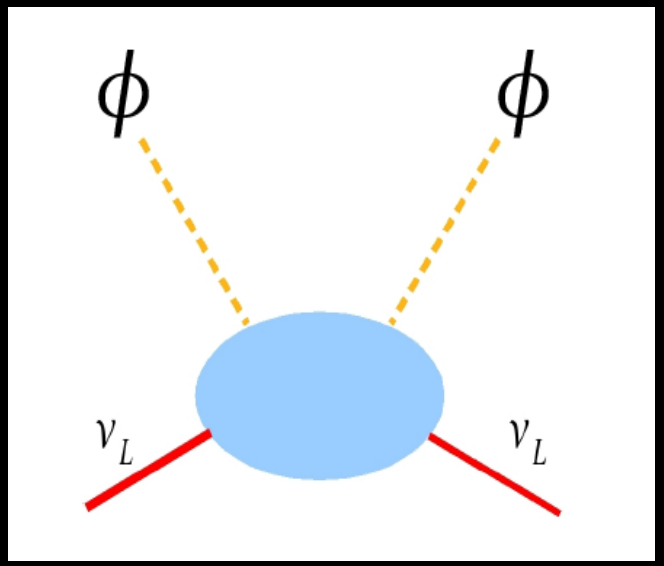


origin of neutrino mass



coefficient
mechanism
scale
flavor structure

origin of neutrino mass

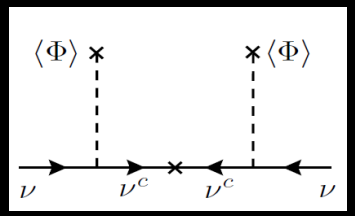


seesaw

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

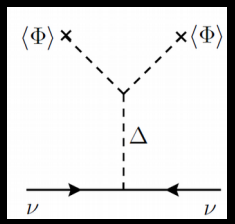
coefficient
mechanism
scale
flavor structure

origin of neutrino mass



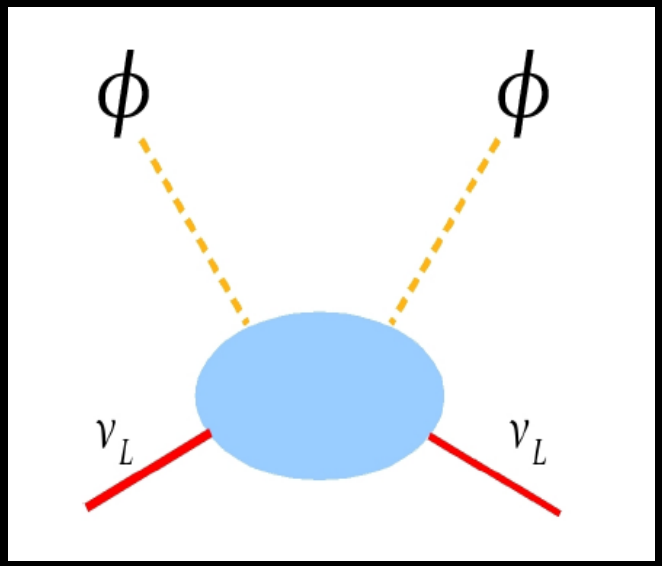
TYPE I

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

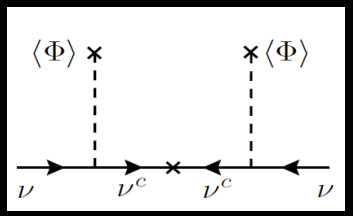


seesaw

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

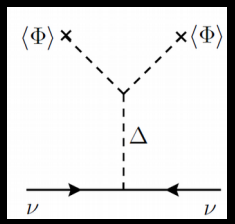
coefficient
mechanism
scale
flavor structure

origin of neutrino mass



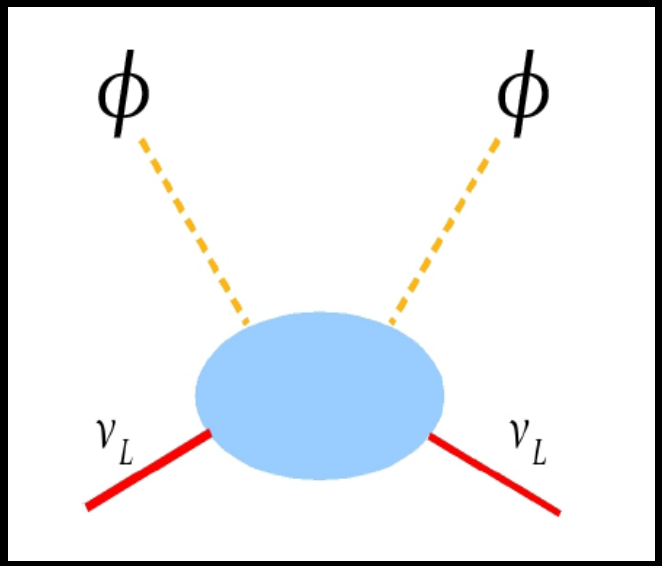
TYPE I

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

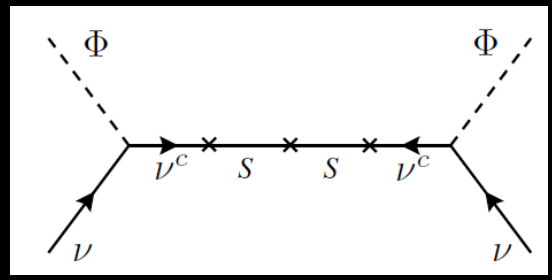
$$v_3 v_1 \sim v_2^{\,2}$$

coefficient
mechanism
scale
flavor structure

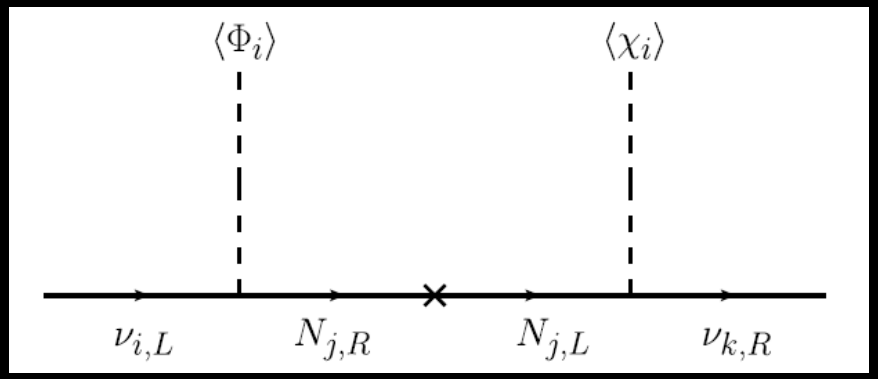
number & properties of singlet messengers

LOW-SCALE SEESAW

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



seesawing a la Dirac

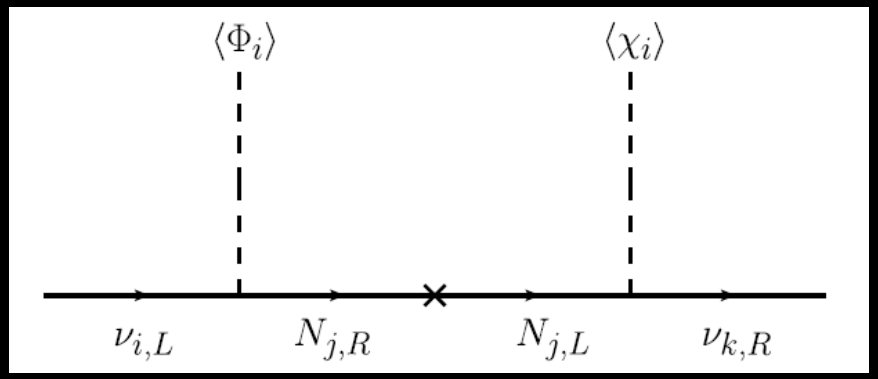


type1

Phys.Lett. B761 (2016) 431-436

Phys.Lett. B767 (2017) 209-213

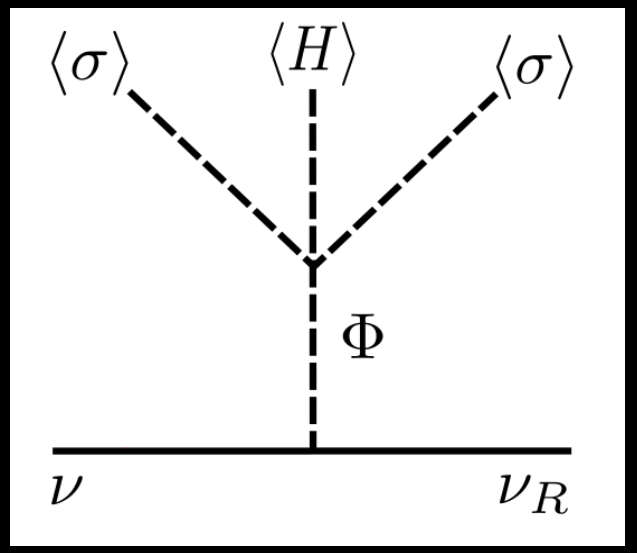
Seesawing a la Dirac



type1

Phys.Lett. B761 (2016) 431-436

Phys.Lett. B767 (2017) 209-213

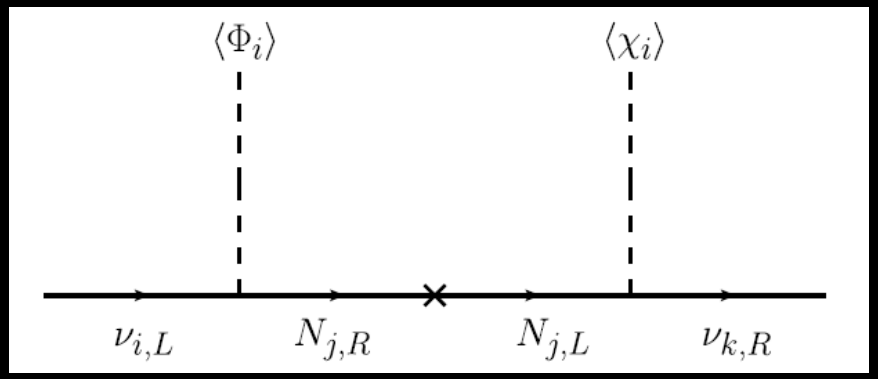


type2

Phys.Lett. B762 (2016) 162-165

Phys.Rev. D94 (2016) 033012

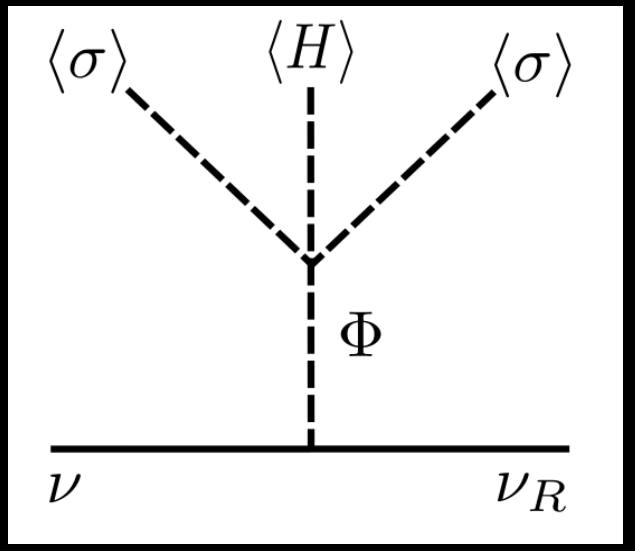
Seesawing a la Dirac



type1

Phys.Lett. B761 (2016) 431-436

Phys.Lett. B767 (2017) 209-213



type2

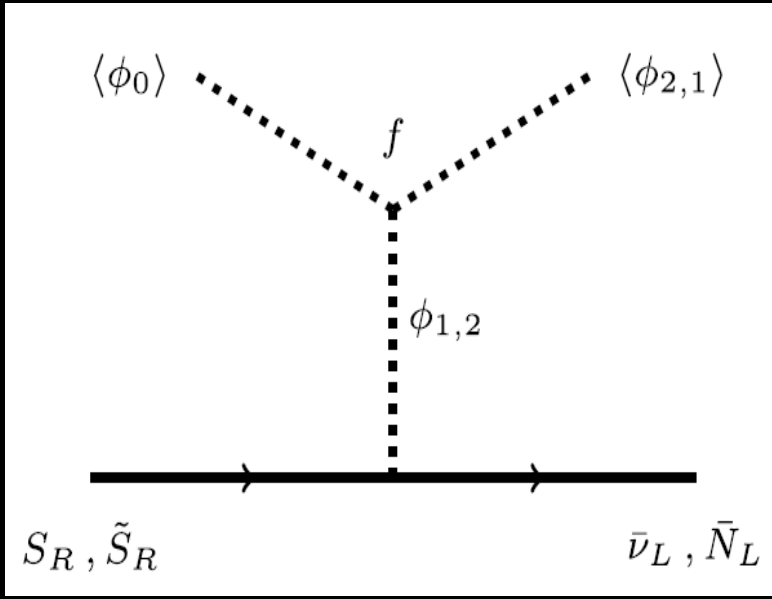
Phys.Lett. B762 (2016) 162-165

Phys.Rev. D94 (2016) 033012

symmetry violation

RH neutrino & theory completion

Dirac seesaw

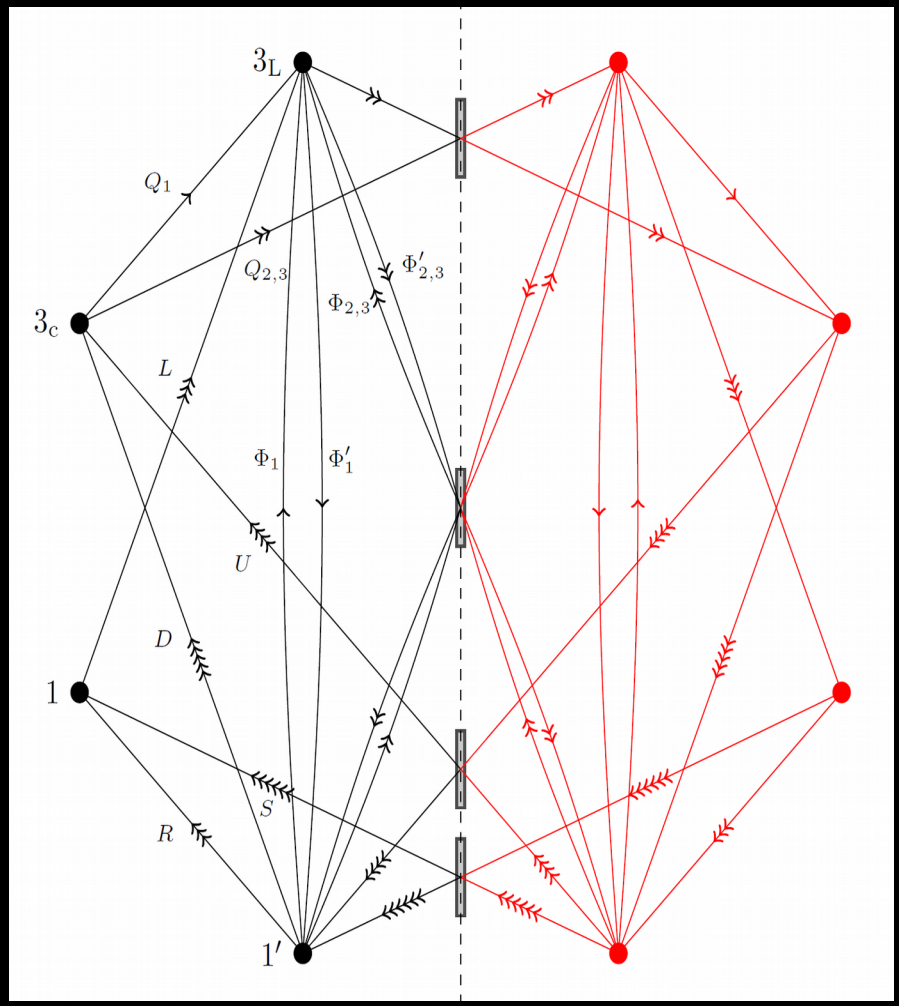


Physics Letters B 755 (2016) 363–366

10.1016/j.physletb.2016.10.002

String EW completion

10.1016/j.physletb.2016.06.015



Quiver consistency requires RH neutrino

Radiative neutrino mass

many low-scale neutrino mass schemes ...

arXiv:1404.3751

Radiative neutrino mass

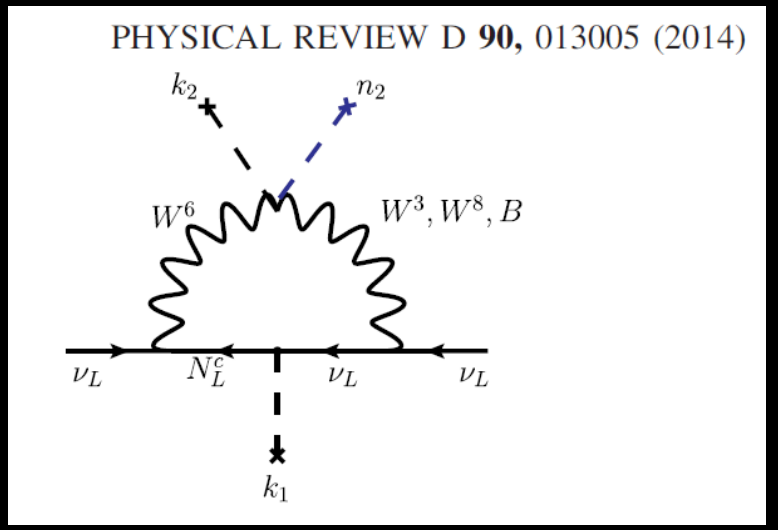
many low-scale neutrino mass schemes ...

arXiv:1404.3751

331 EW theory # families = # colours

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

Gauge vs Higgs



Boucenna, Morisi, JV Phys.Rev. D90 (2014) 013005

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

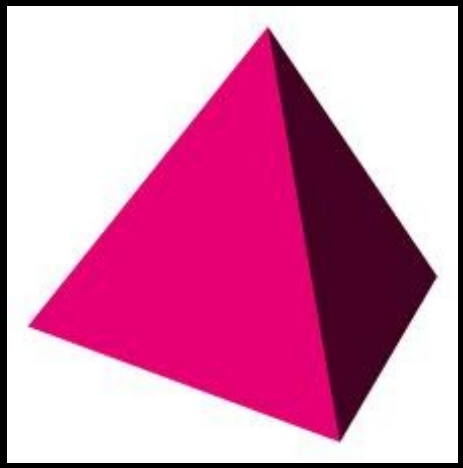
$$e_R \qquad \mu_R \qquad \tau_R$$

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

$$u_R \qquad c_R \qquad t_R$$

$$d_R \qquad s_R \qquad b_R$$

Flavor Symmetry



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

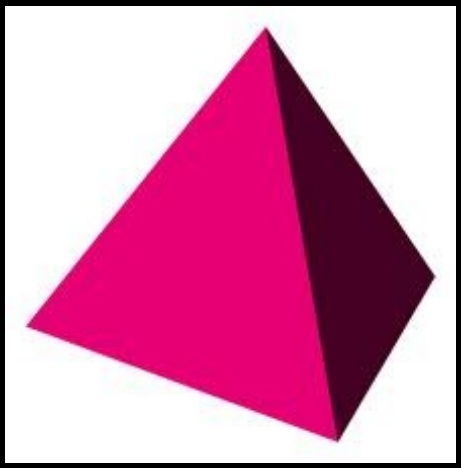
$$e_R \qquad \mu_R \qquad \tau_R$$

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

$$u_R \qquad c_R \qquad t_R$$

$$d_R \qquad s_R \qquad b_R$$

Flavor Symmetry



A4

PLB552 (2003) 207
PRD69 (2004) 093006

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

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

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

$$e_R \qquad \mu_R \qquad \tau_R$$

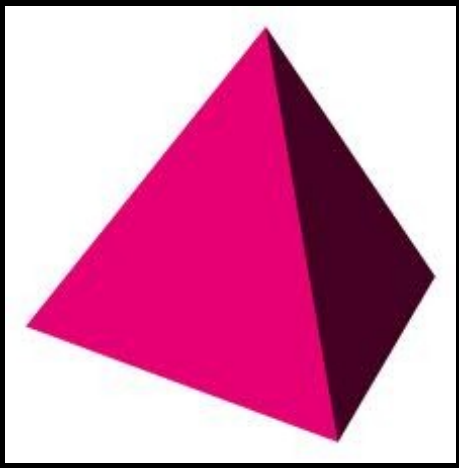
$$\begin{pmatrix} u \\ d \end{pmatrix}_L \quad \begin{pmatrix} c \\ s \end{pmatrix}_L \quad \begin{pmatrix} t \\ b \end{pmatrix}_L$$

$$u_R \qquad c_R \qquad t_R$$

$$d_R \qquad s_R \qquad b_R$$

flavor symmetry

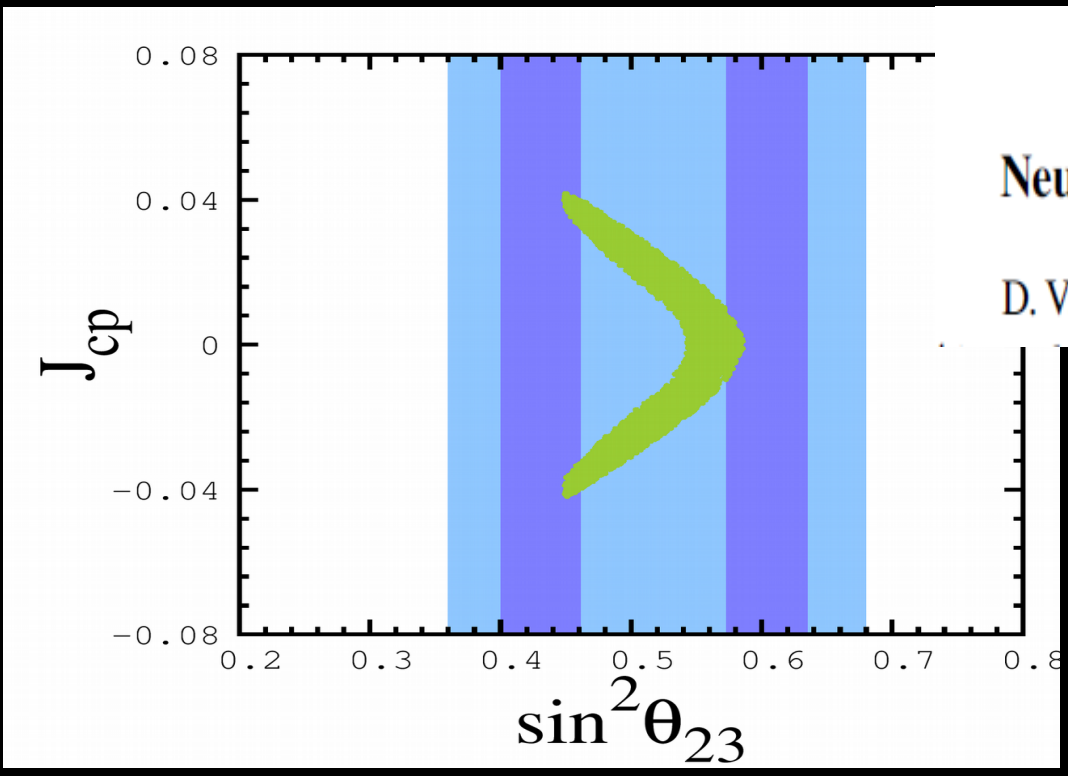
A4



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

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

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



PHYSICAL REVIEW D 88, 016003 (2013)

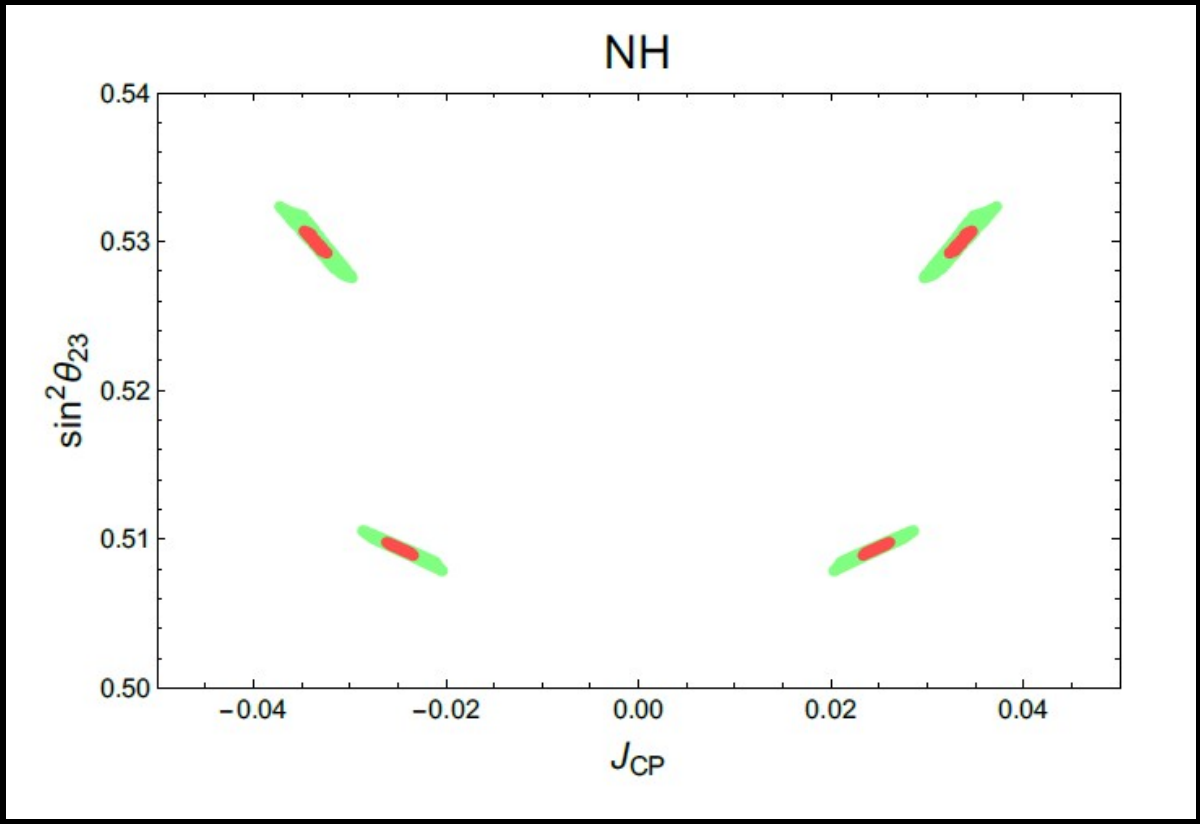
Neutrino mixing with revamped A_4 flavor symmetry

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

testable

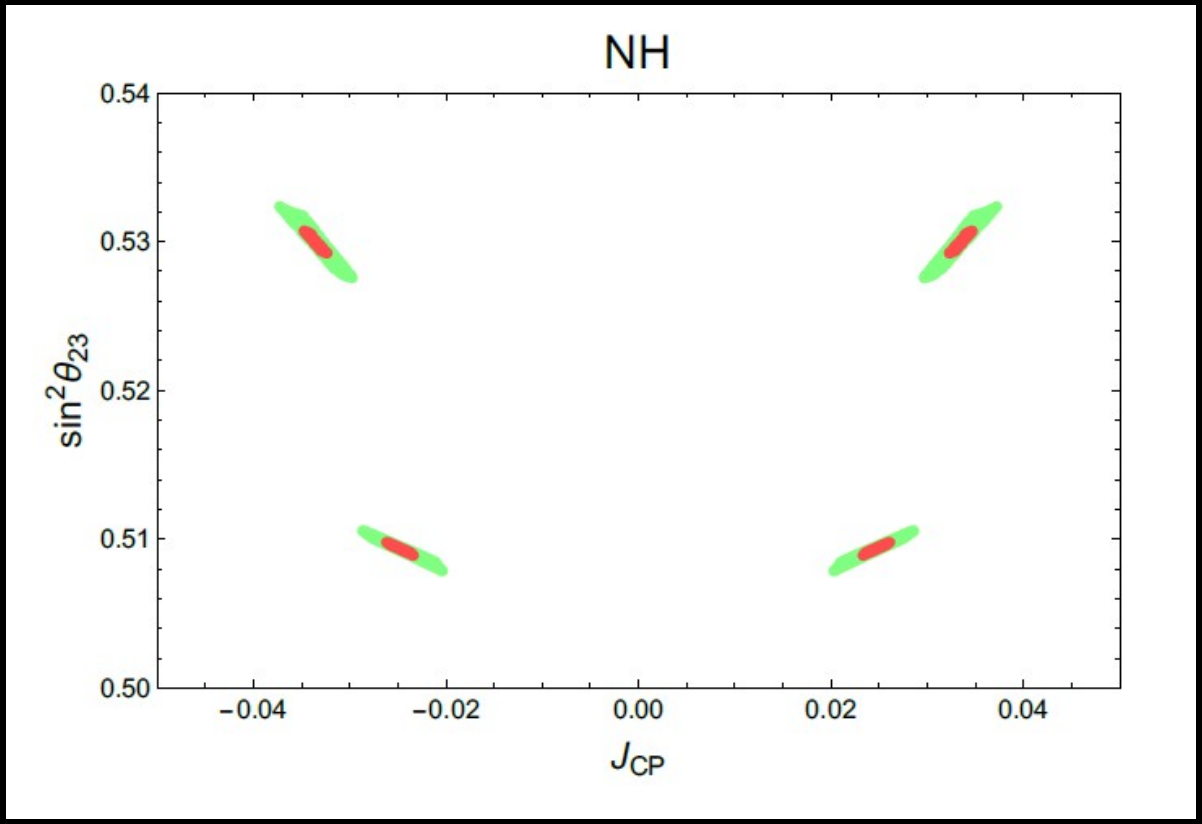
Flavored Pati Salam

Cárcamo Hernández, et al JHEP
http://arxiv.org/abs/arXiv:1705.06320



Flavored Pati Salam

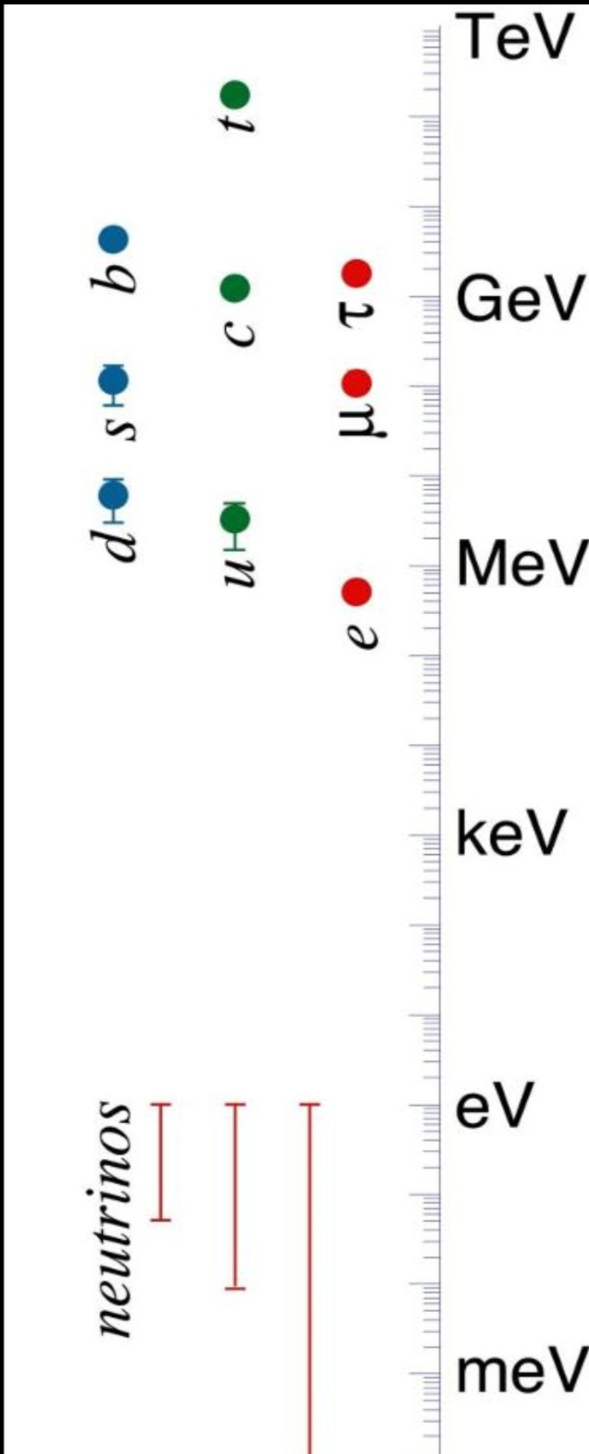
Cárcamo Hernández, et al JHEP
http://arxiv.org/abs/arXiv:1705.06320

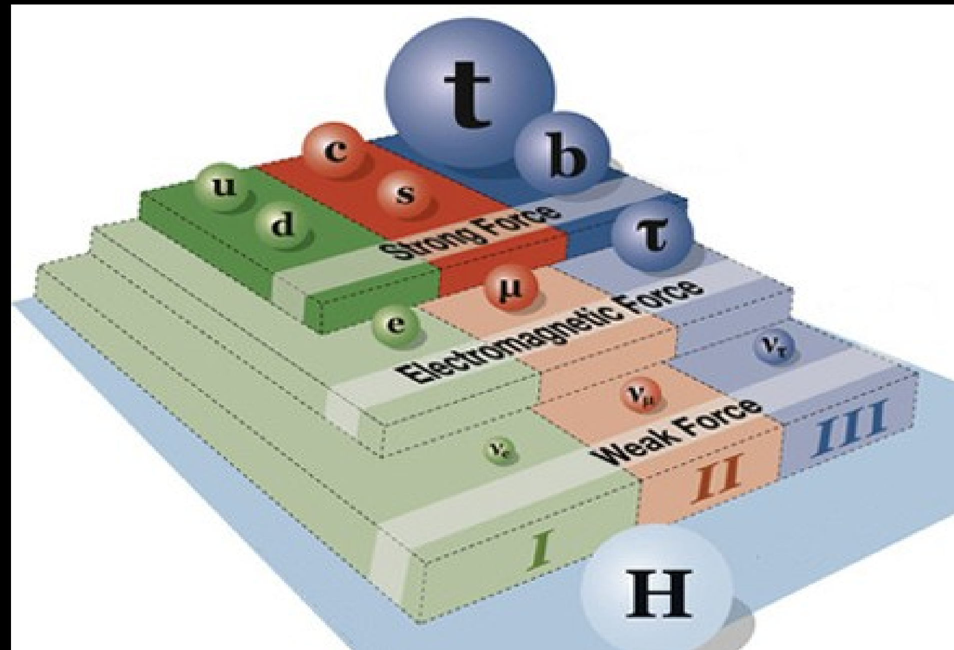


$$\mathbf{X}^T \mathbf{m}_\nu \mathbf{X} = \mathbf{m}_\nu^*$$

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

residual CP


TeV
GeV
MeV
keV
eV
meV
t
b
c
τ
s
μ
d
u
e
neutrinos


t
b
c
u
s
d
Strong Force
τ
μ
e
Electromagnetic Force
Weak Force
III
II
I
H

charged fermion masses

Flavor dependent b-tau unification

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

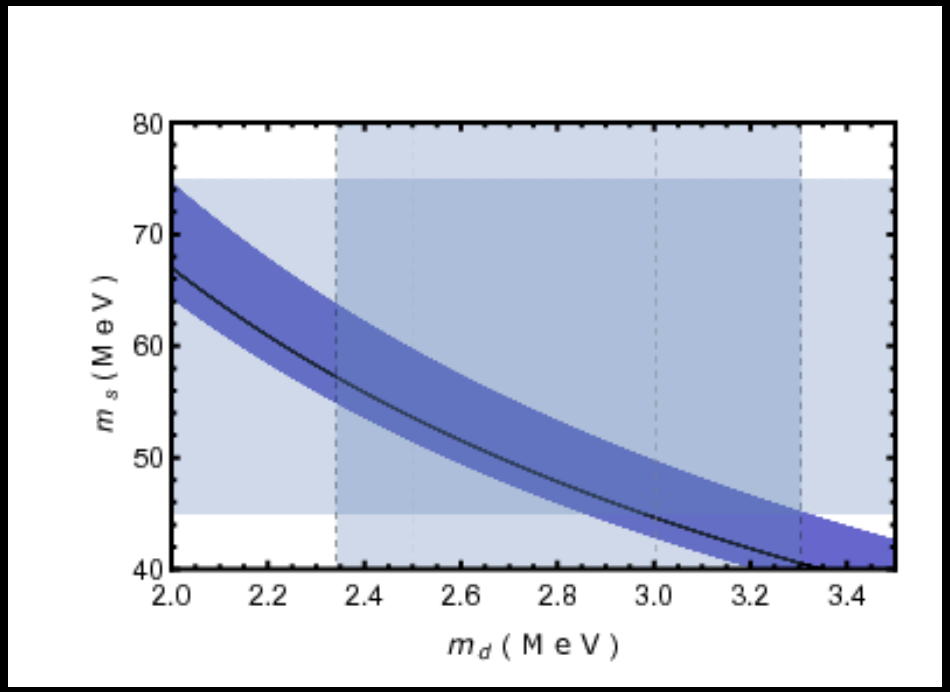
Morisi et al Phys.Rev. D84 (2011) 036003

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

charged fermion masses



http://arxiv.org/abs/arXiv:1706.00210

Flavor dependent b-tau unification

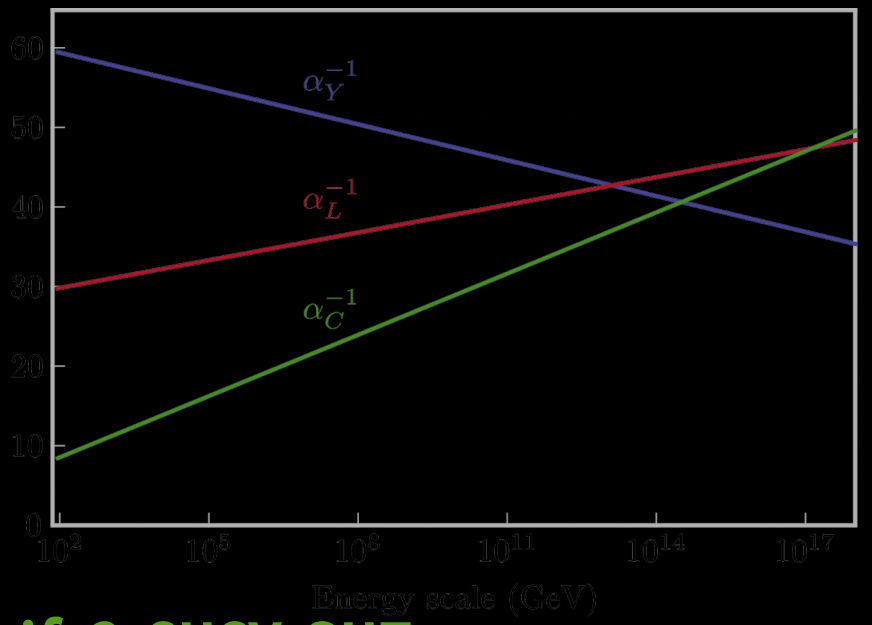
$$\frac{m_\tau}{\sqrt{m_e m_\mu}} \approx \frac{m_b}{\sqrt{m_d m_s}}$$

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

from same symmetry explaining oscillations

gauge coupling unification

a near miss ...

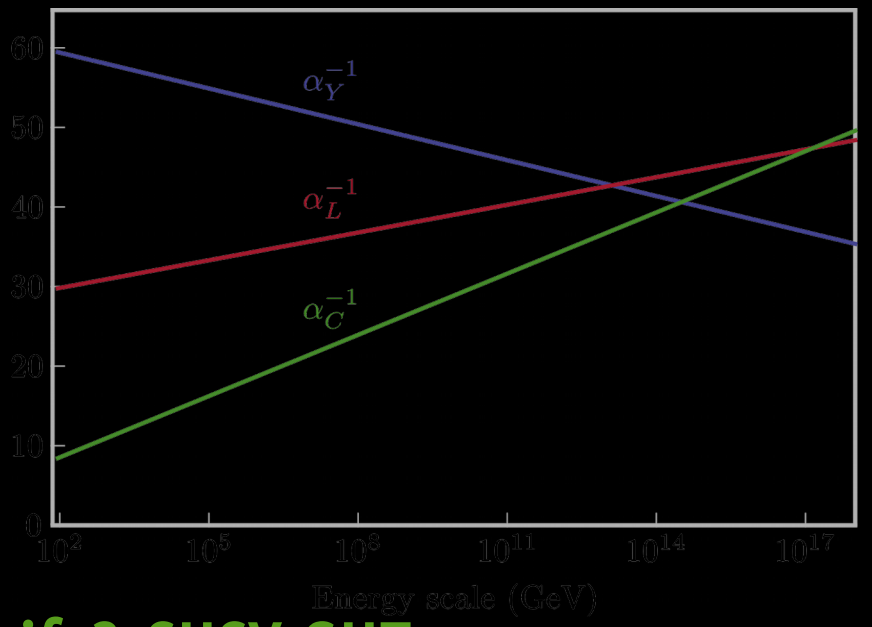


What makes the gauge couplings unify? SUSY-GUT

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

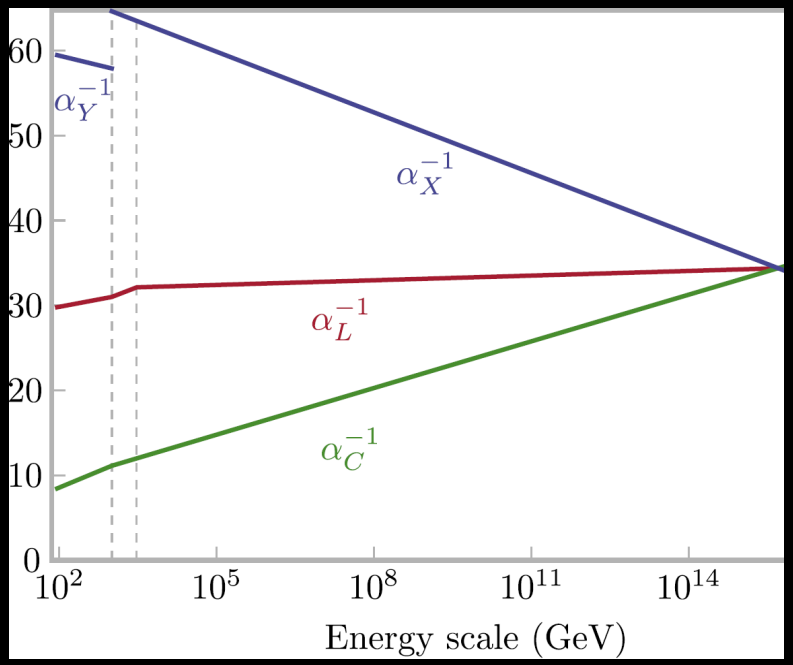
gauge coupling unification

a near miss ...



What makes the gauge couplings unify? SUSY-GUT

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

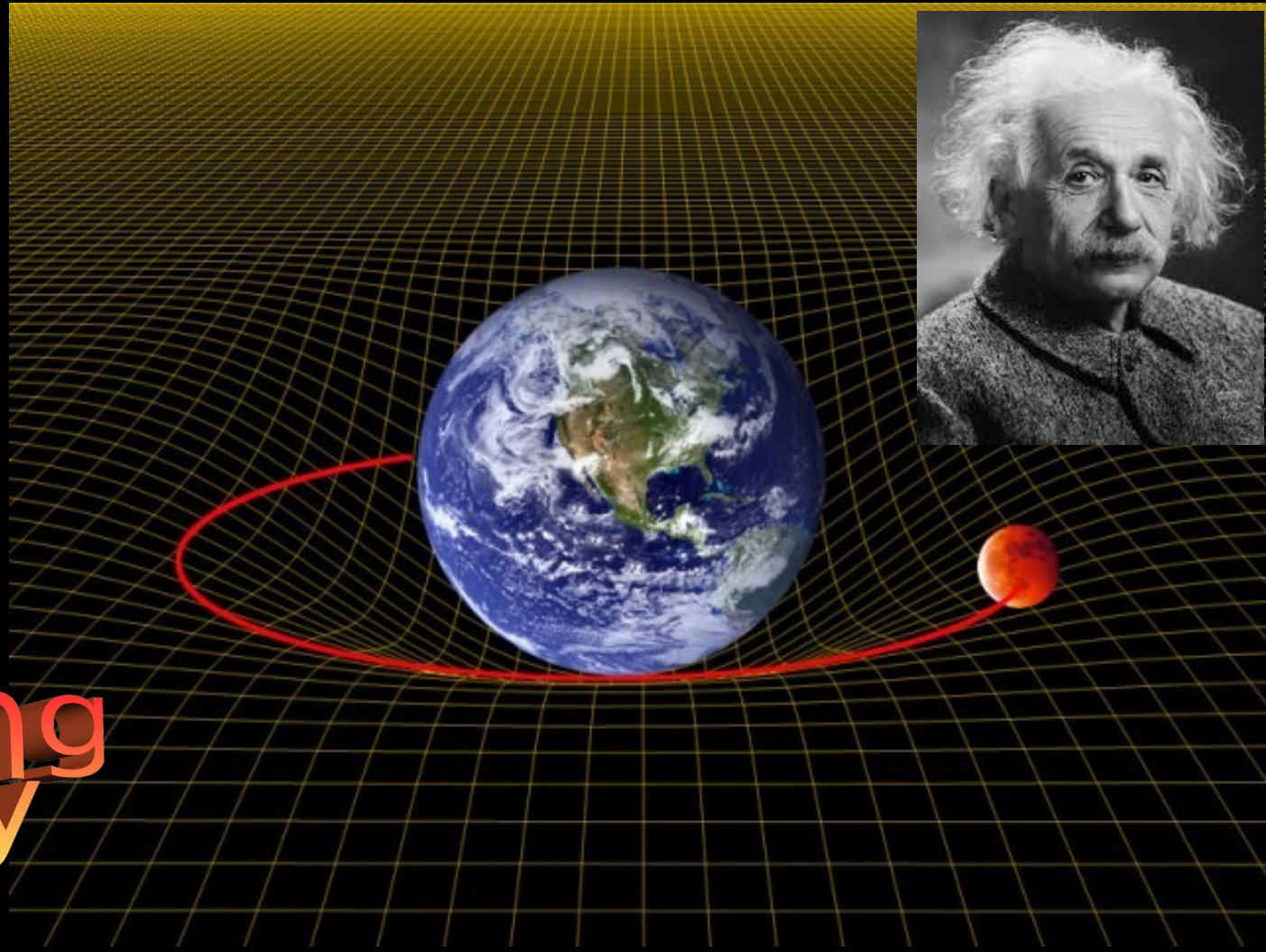


neutrinos & unification

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

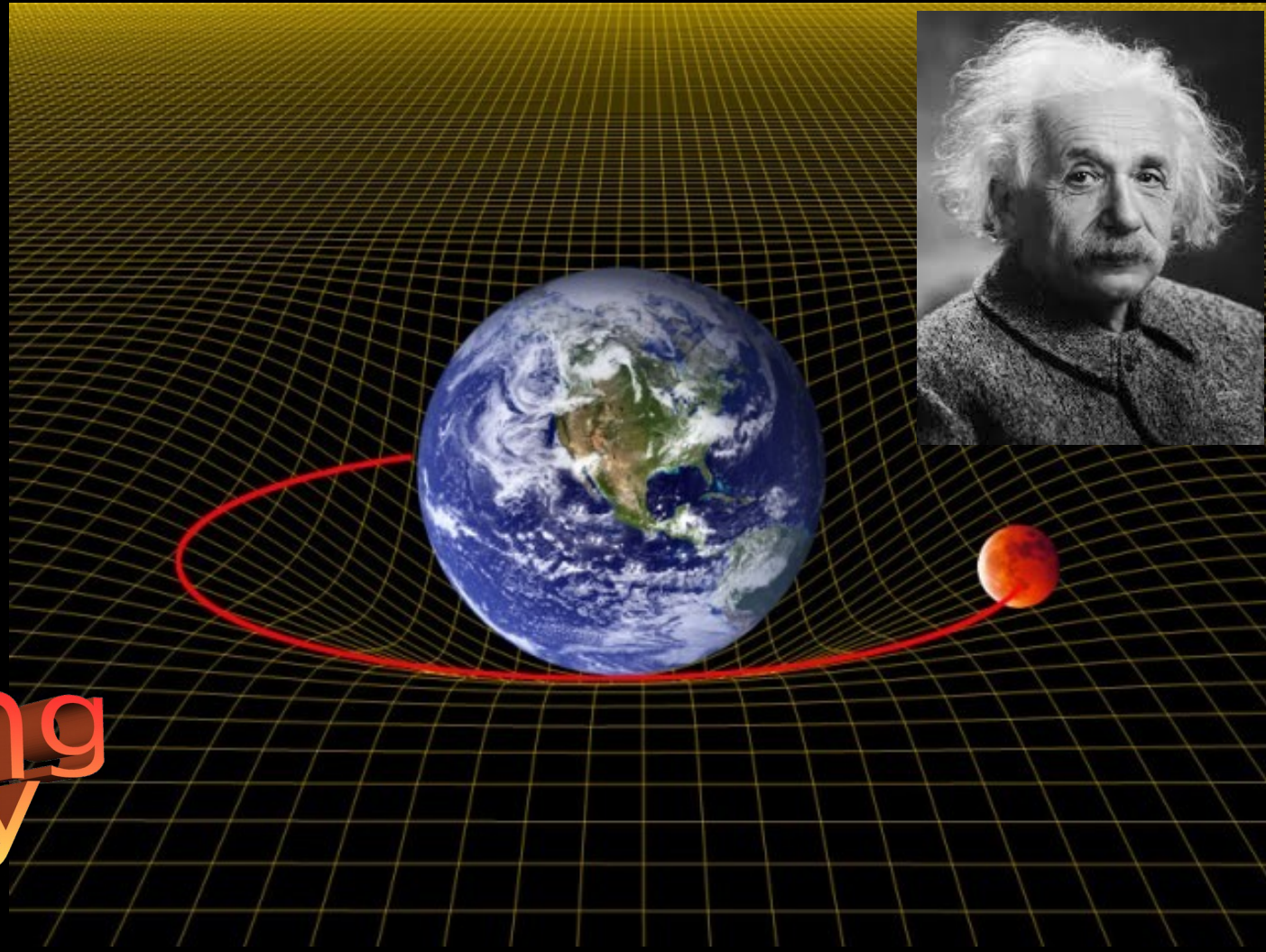
Boucenna et al Phys. Rev. D 91, 031702 (2015)

Deppisch et al Phys.Lett. B762 (2016) 432



including gravity

including gravity



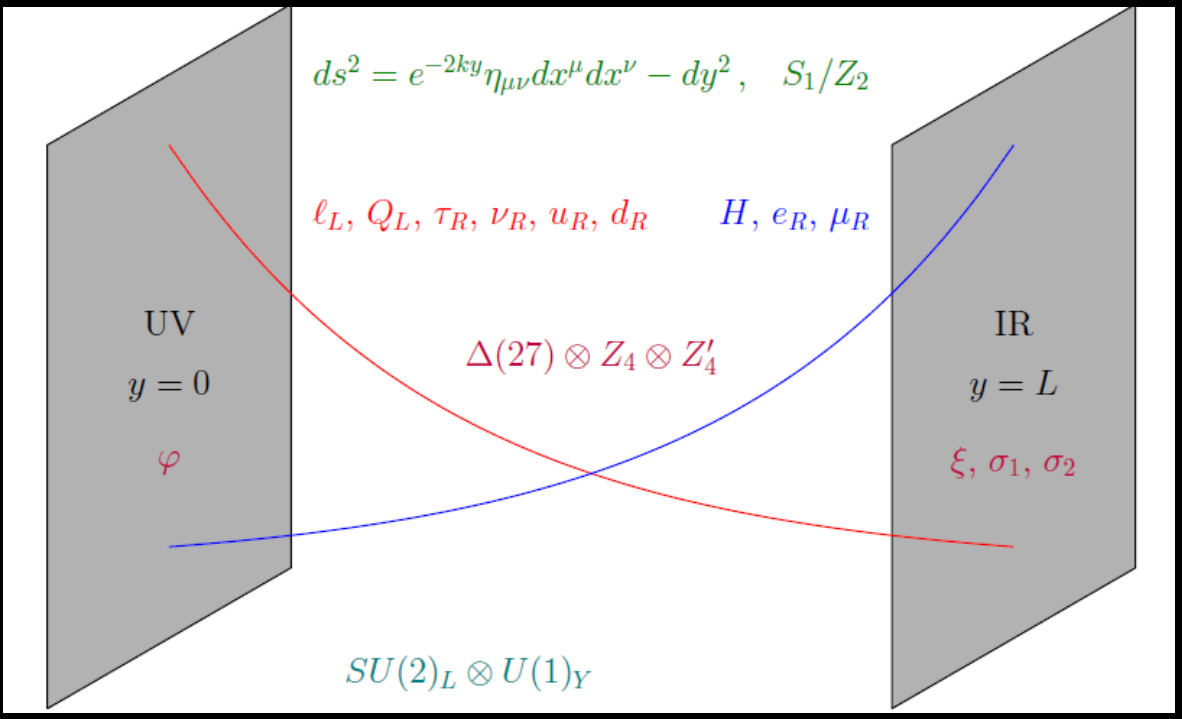
Chen et al arXiv:1509.06683
JHEP01(2016)007

Addazi et al

Phys.Lett. B759 (2016) 471-478

Warped flavor predictions

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

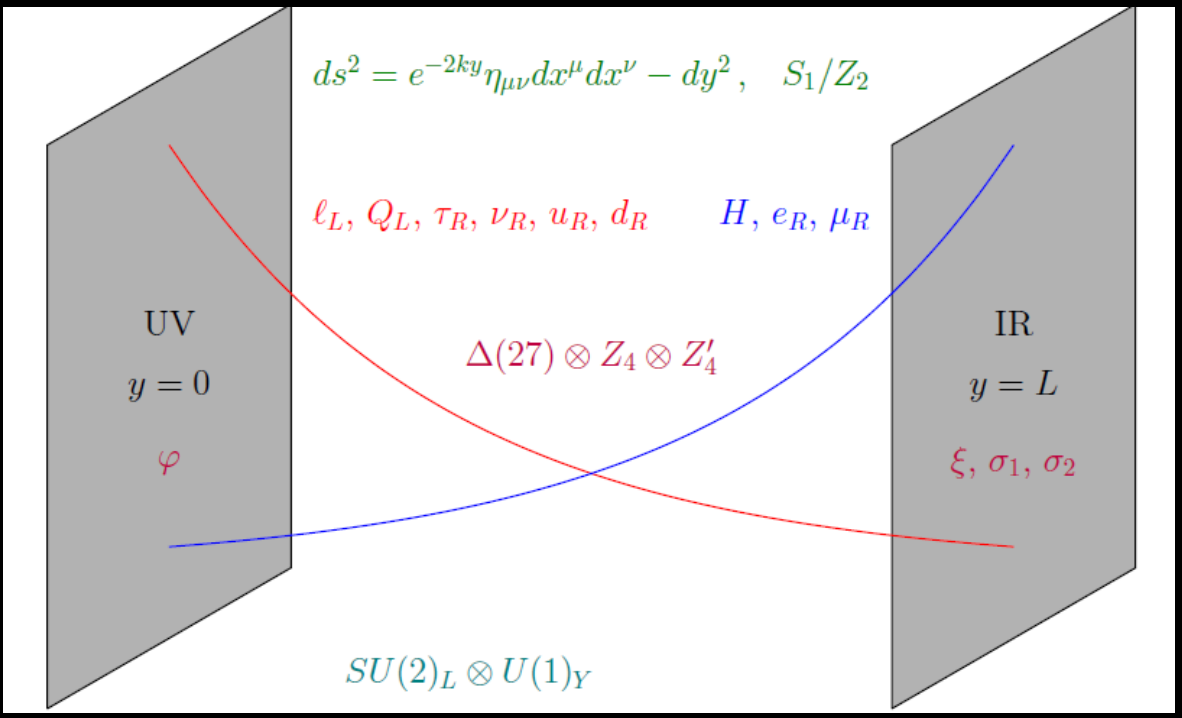


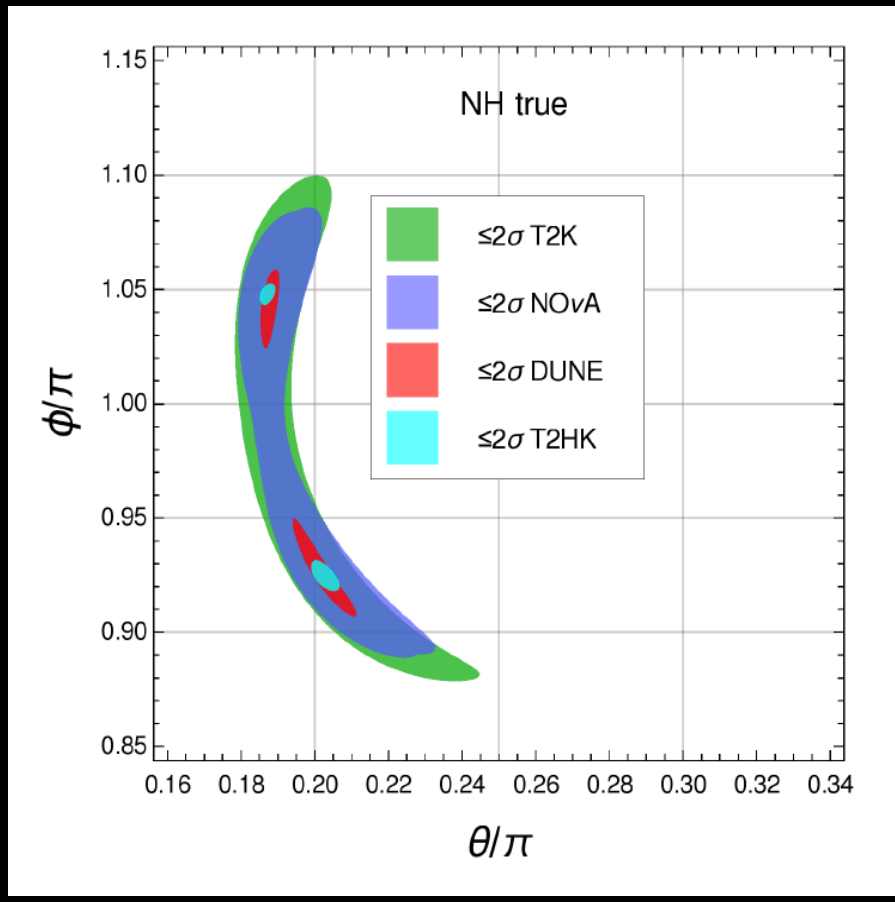
masses explained by bulk profile choices

mixings from
flavor symmetry

Warped flavor predictions

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





masses explained by bulk profile choices

mixings from flavor symmetry

$$\sin^2\theta_{12} = \frac{1}{2 - \sin 2\theta_\nu \cos\phi_\nu}$$

$$\sin^2\theta_{13} = \frac{1}{3}(1 + \sin 2\theta_\nu \cos\phi_\nu)$$

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

$$J_{CP} = -\frac{1}{6\sqrt{3}}\cos 2\theta_\nu$$

Phys. Rev. D 95, 095030 (2017)

Phys.Lett. B771 (2017) 524

neutrino oscillations in warped SM model

neutrinos in TOE

forces + families : recent revival of old idea

$$\begin{aligned}\mathbf{16} \rightarrow &(\mathbf{3},\mathbf{2},1/6) + (\mathbf{1},\mathbf{2},-1/2) + (\bar{\mathbf{3}},\mathbf{1},1/3) \\ &+ (\bar{\mathbf{3}},\mathbf{1},-2/3) + (\mathbf{1},\mathbf{1},1) + (\mathbf{1},\mathbf{1},0)\,,\end{aligned}$$

neutrinos in TOE

forces + families : recent revival of old idea

$$\begin{aligned}\mathbf{16} \rightarrow &(\mathbf{3},\mathbf{2},1/6)+(\mathbf{1},\mathbf{2},-1/2)+(\bar{\mathbf{3}},\mathbf{1},1/3)\\ &+(\bar{\mathbf{3}},\mathbf{1},-2/3)+(\mathbf{1},\mathbf{1},1)+(\mathbf{1},\mathbf{1},0)\,,\end{aligned}$$

$SO(2n+2m)$ spinors split as

$$\mathbf{2}^{n+m-1} \rightarrow 2^m \times \mathbf{2}^{n-1}$$

$$SO(2n+2m) \rightarrow SO(2n)$$

Chirality problem

neutrinos in TOE

forces + families : recent revival of old idea

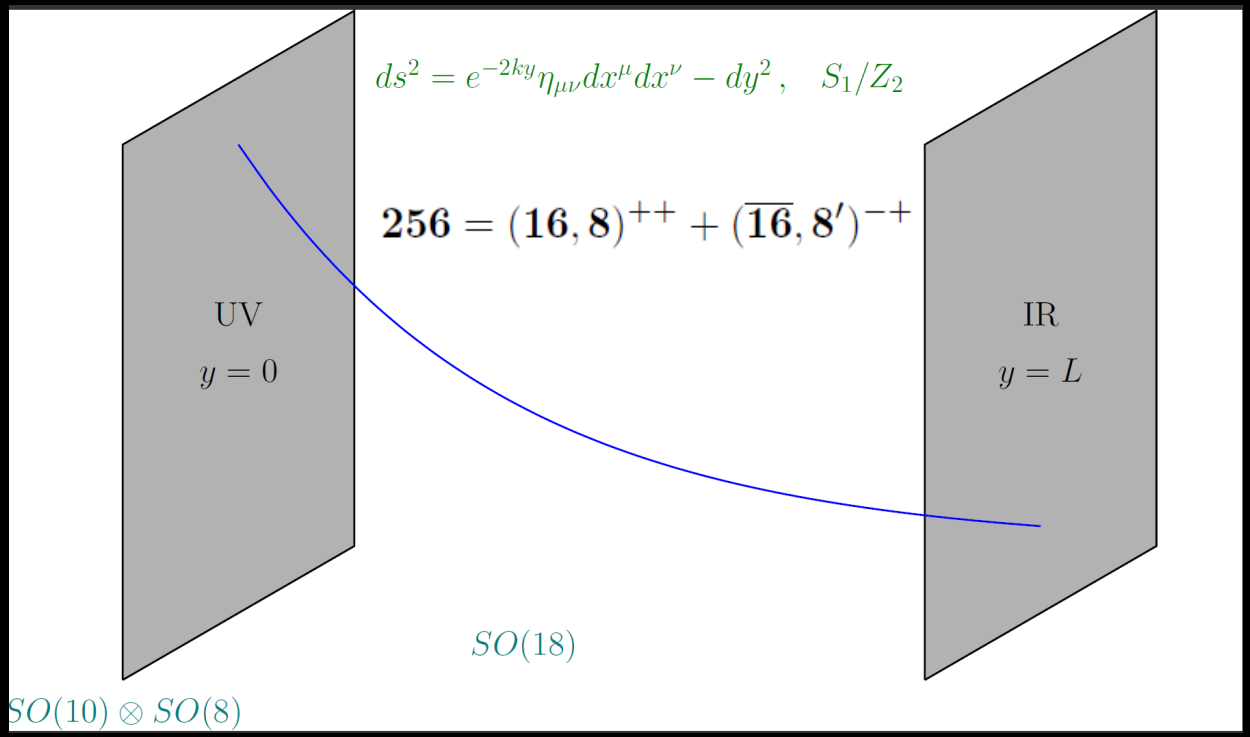
$$\mathbf{16} \to (\mathbf{3},\mathbf{2},1/6) + (\mathbf{1},\mathbf{2},-1/2) + (\bar{\mathbf{3}},\mathbf{1},1/3) + (\bar{\mathbf{3}},\mathbf{1},-2/3) + (\mathbf{1},\mathbf{1},1) + (\mathbf{1},\mathbf{1},0)\,,$$

$SO(2n+2m)$ spinors split as

$$\mathbf{2}^{n+m-1} \to 2^m \times \mathbf{2}^{n-1}$$

$$SO(2n+2m) \to SO(2n)$$

Chirality problem



Promote M4 to AdS5 & use orbifold BC to decouple mirros

Reig, Valle, Vaquera-Araujo, Wilczek

http://arxiv.org/abs/arXiv:1706.03116

neutrinos in TOE

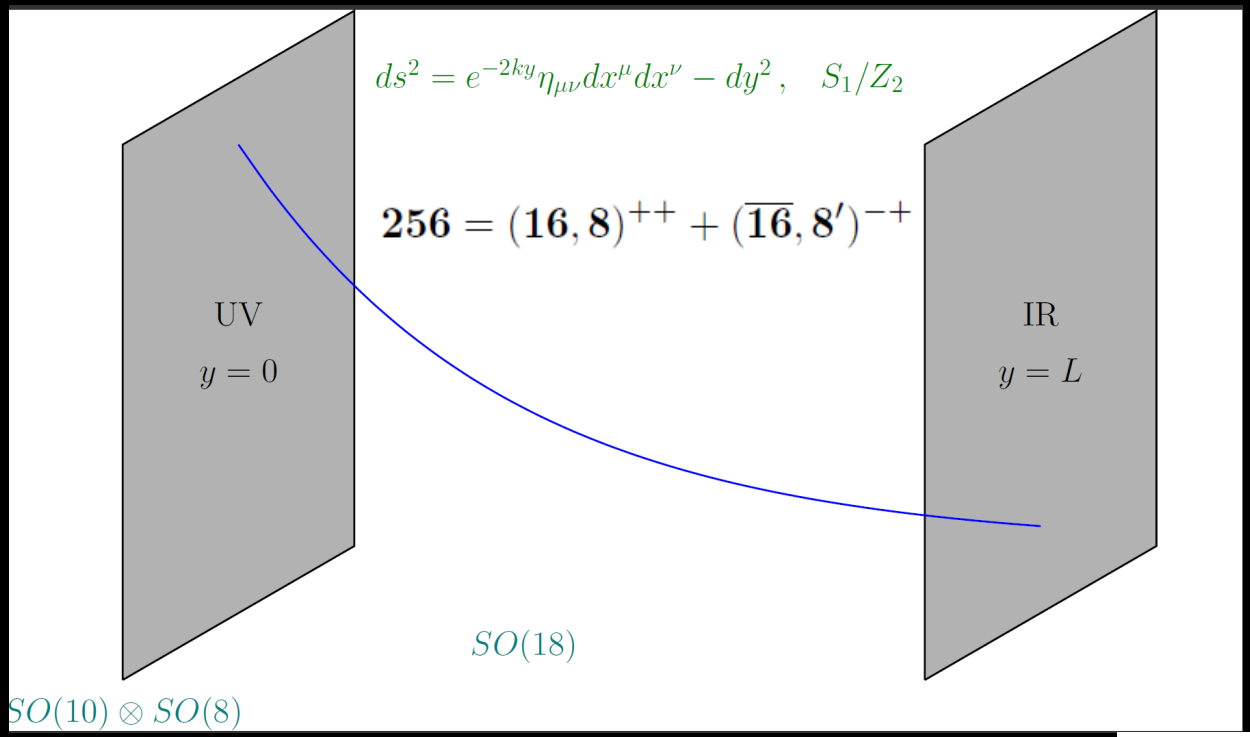
forces + families : recent revival of old idea

$$16 \to (3,2,1/6) + (1,2,-1/2) + (\bar{3},1,1/3) + (\bar{3},1,-2/3) + (1,1,1) + (1,1,0)\,,$$

$SO(2n+2m)$ spinors split as

$$2^{n+m-1} \to 2^m \times 2^{n-1}$$
$$SO(2n+2m) \to SO(2n)$$

Chirality problem



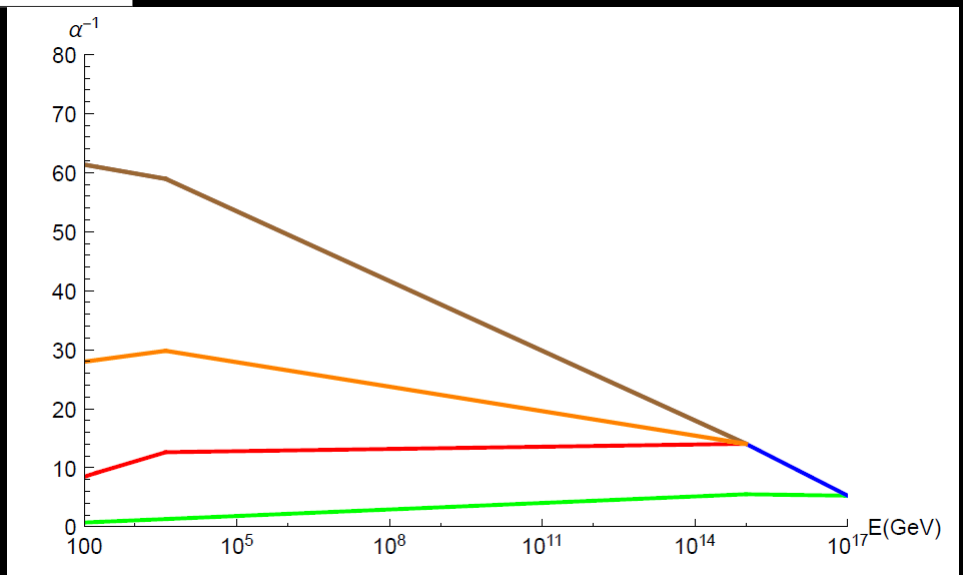
further reduction from a new Hypercolor @ few TeV ??

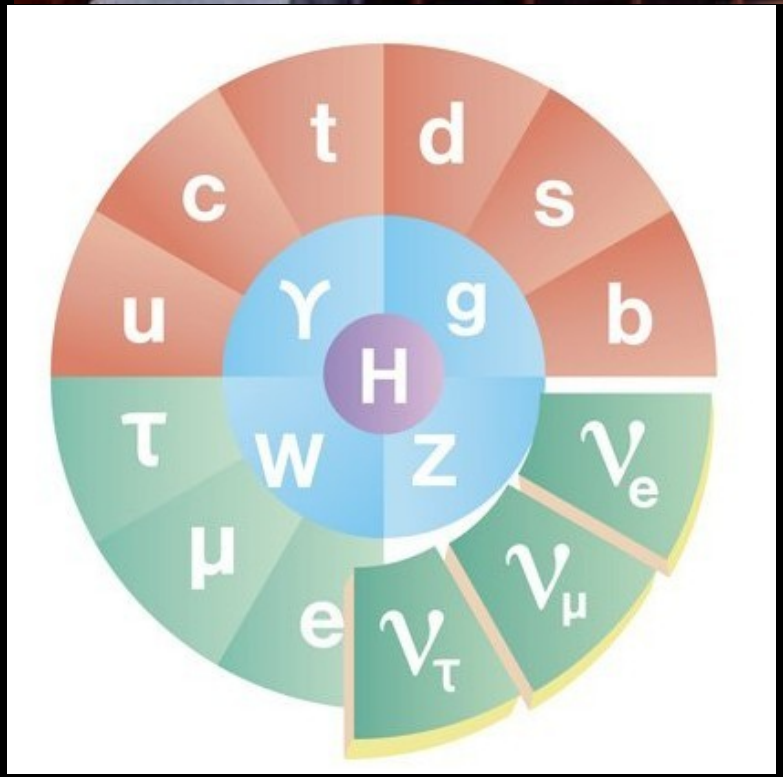
Promote M4 to AdS5 & use orbifold BC to decouple mirros

Reig, Valle, Vaquera-Araujo, Wilczek

http://arxiv.org/abs/arXiv:1706.03116

$$SO(10) \times SO(8) \to SO(10) \times SO(5)_{HC}$$

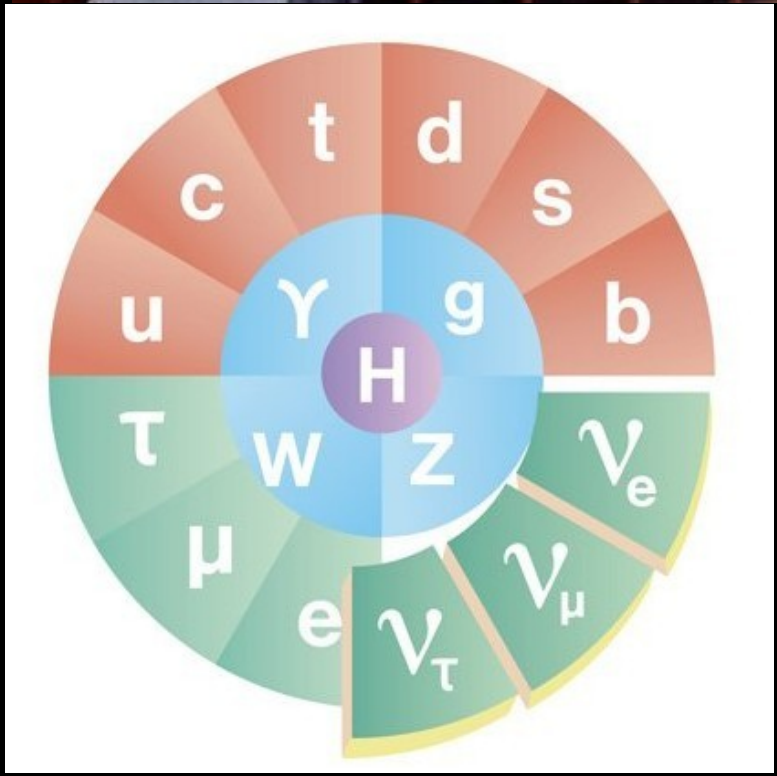


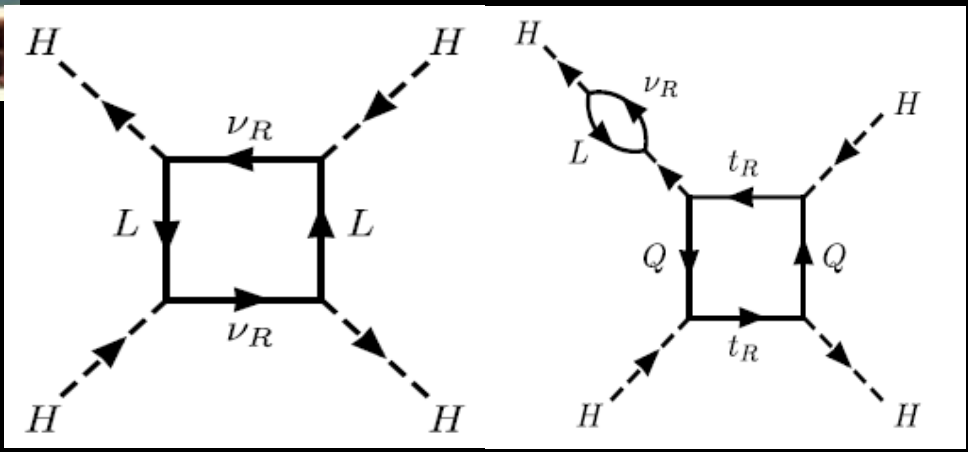

t
d
c
s
u
γ
g
b
H
τ
W
Z
ν_e
μ
ν_μ
e
ν_τ

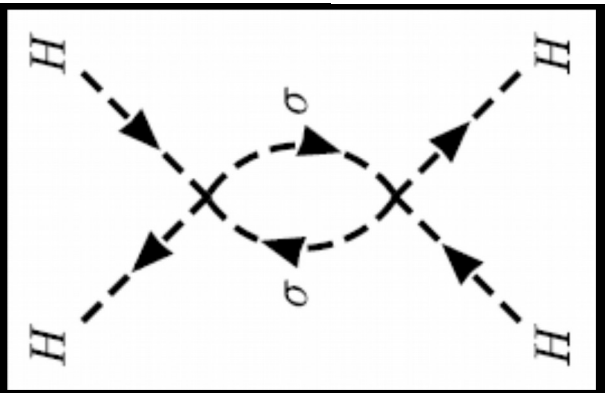
neutrinos make the EW vacuum stable again

http://dx.doi.org/10.1103/PhysRevD.92.075028

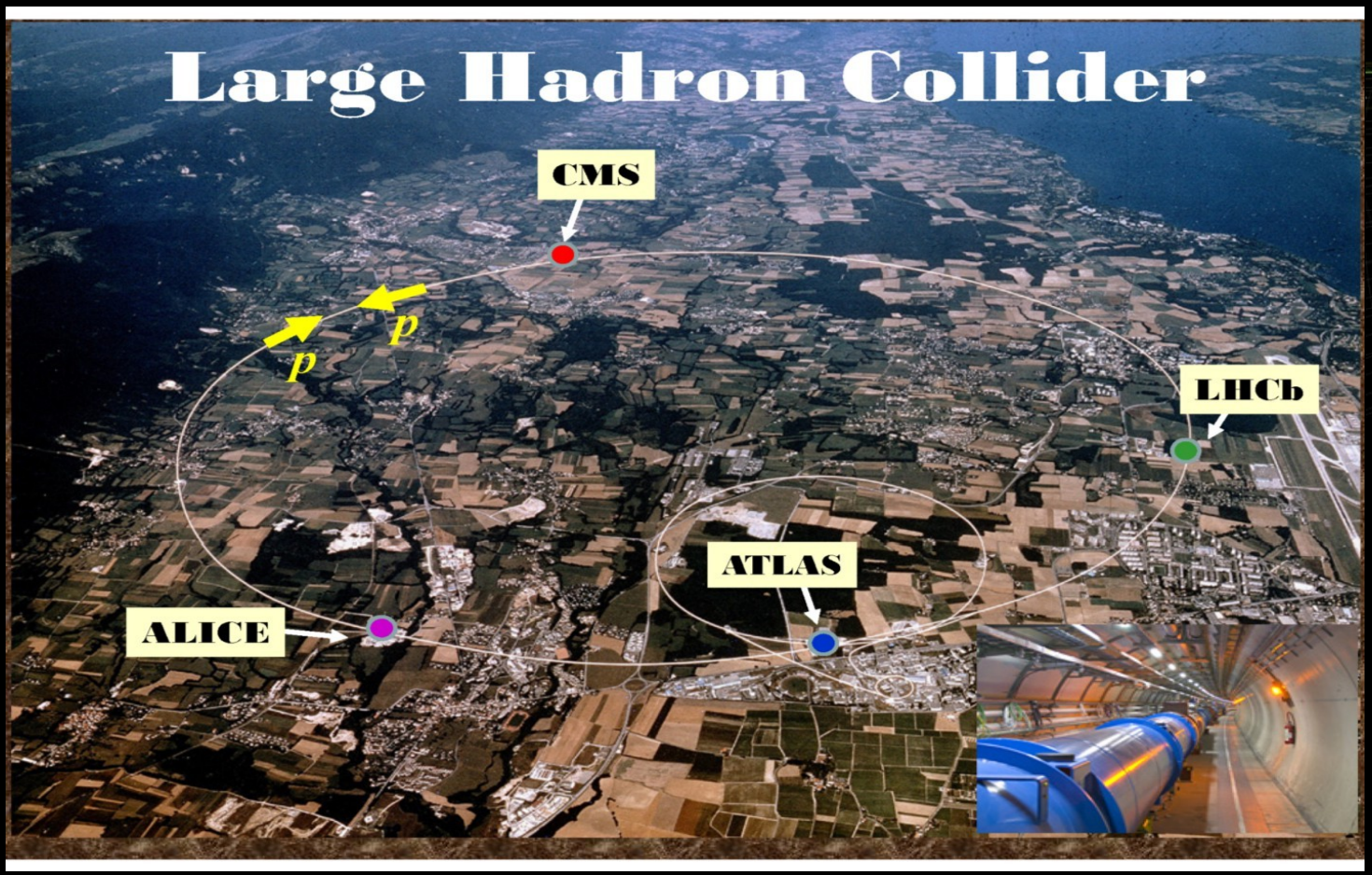
http://dx.doi.org/10.1103/PhysRevD.92.075028

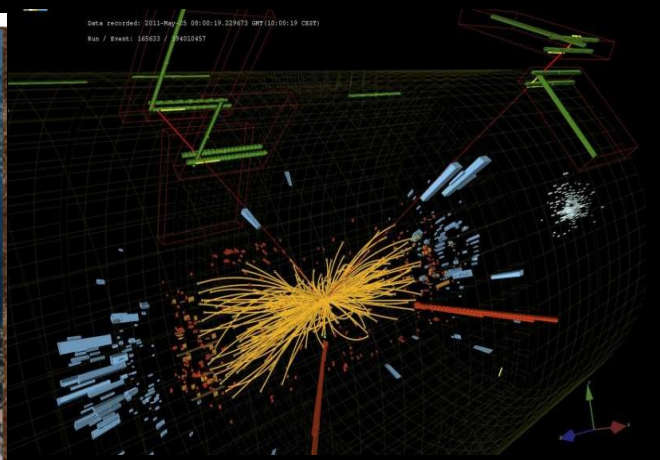




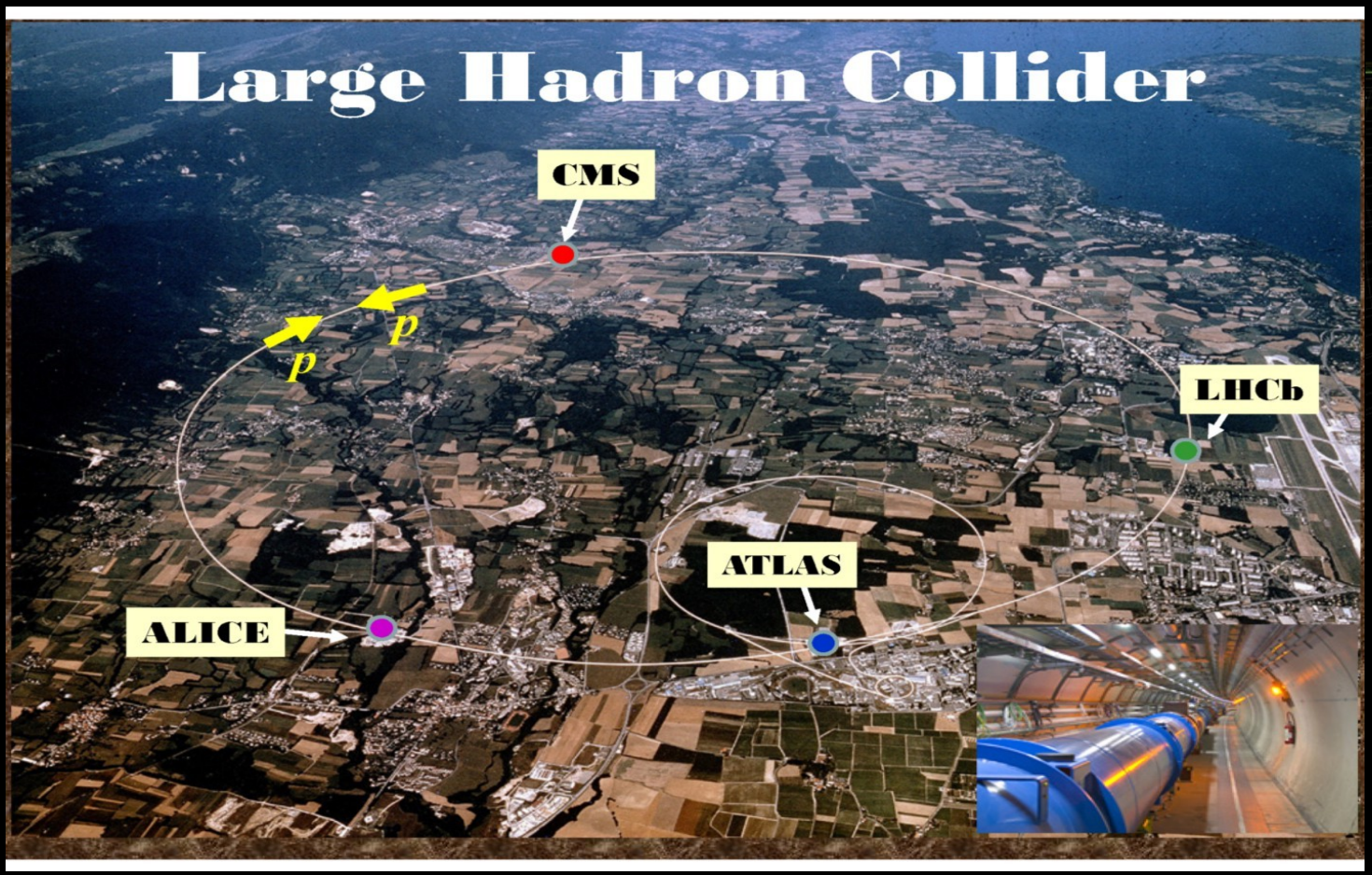


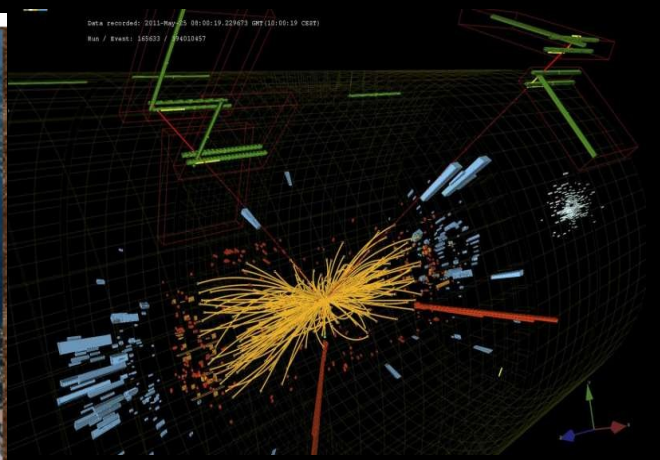
theories of neutrino as EW breaking benchmarks at high energy colliders





theories of neutrino as EW breaking benchmarks at high energy colliders



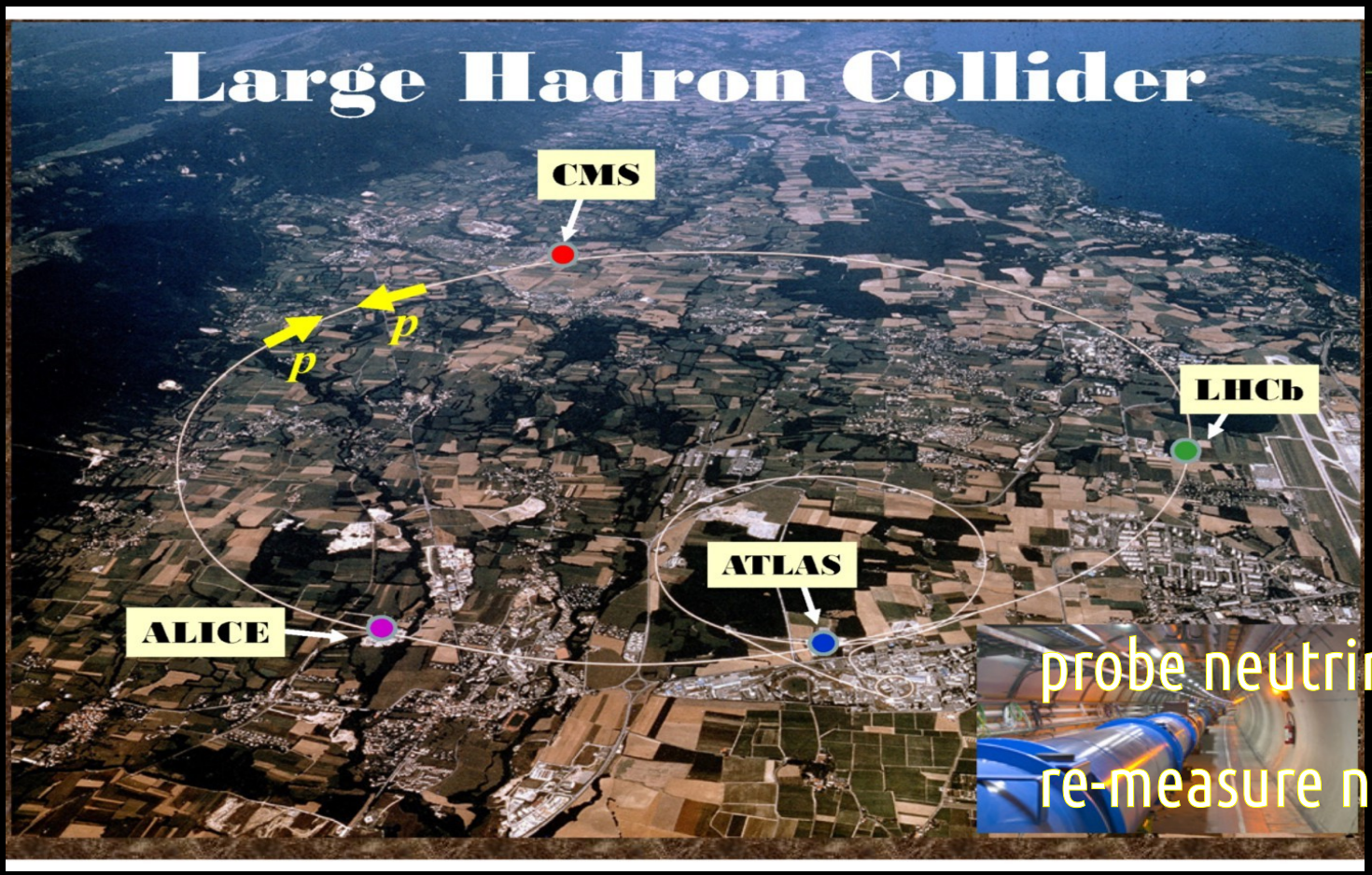


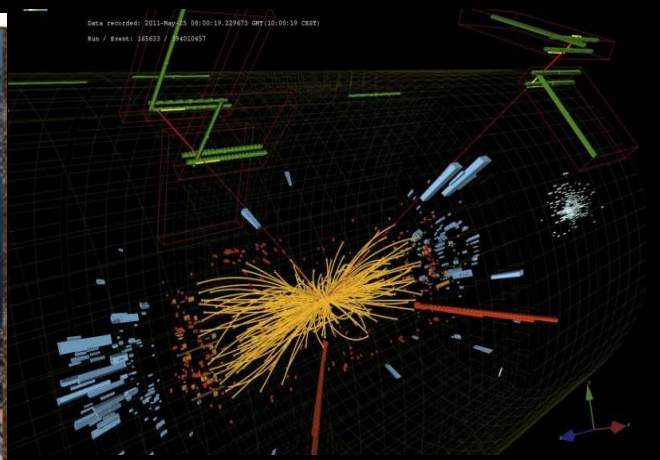
Higgs searches **Bonilla et al** http://dx.doi.org/10.1016/j.physletb.2016.03.037

http://dx.doi.org/10.1088/1367-2630/18/3/033033

http://dx.doi.org/10.1103/PhysRevD.91.113015 ...

theories of neutrino as EW breaking benchmarks at high energy colliders





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

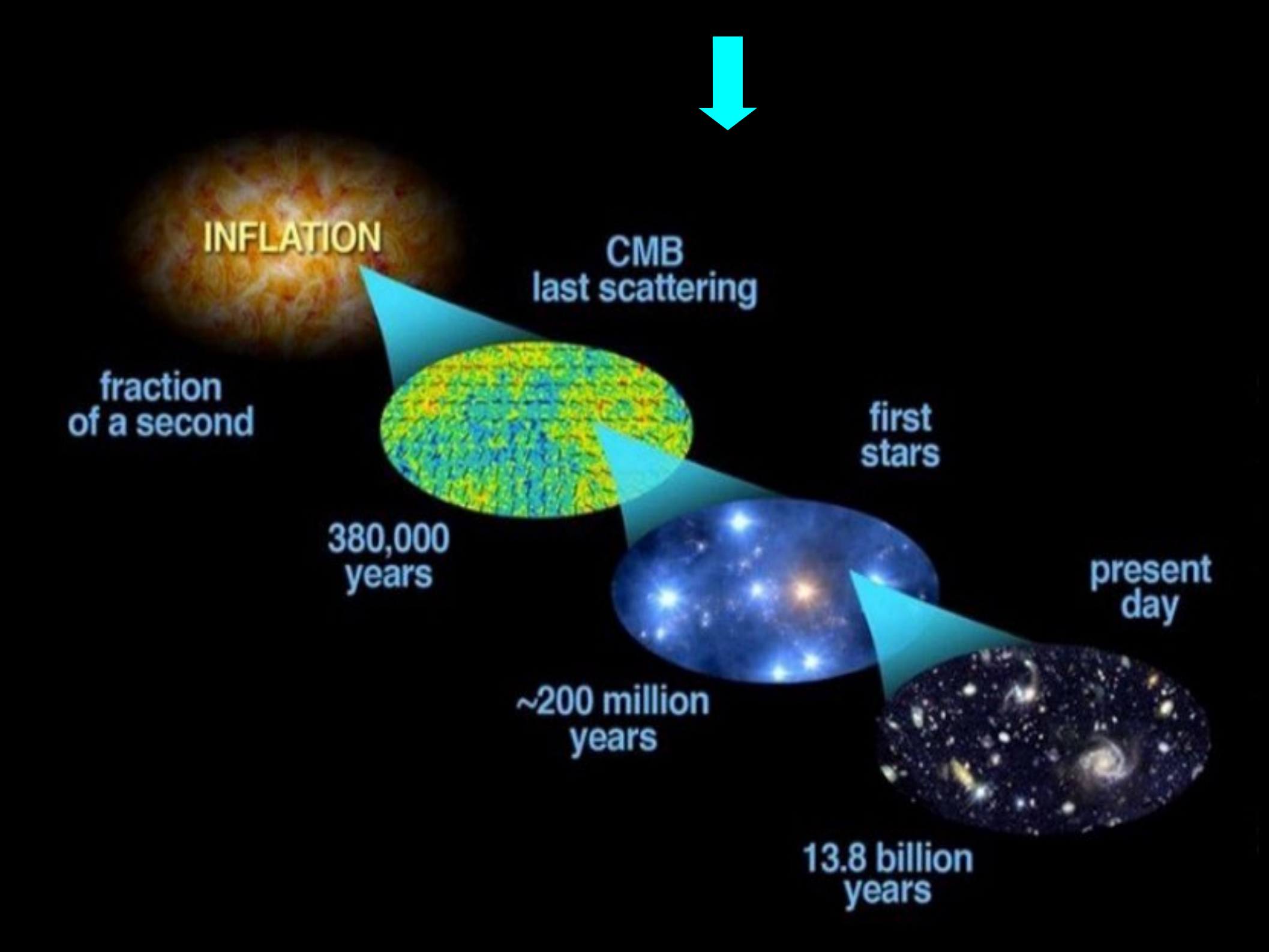
probe neutrino messengers

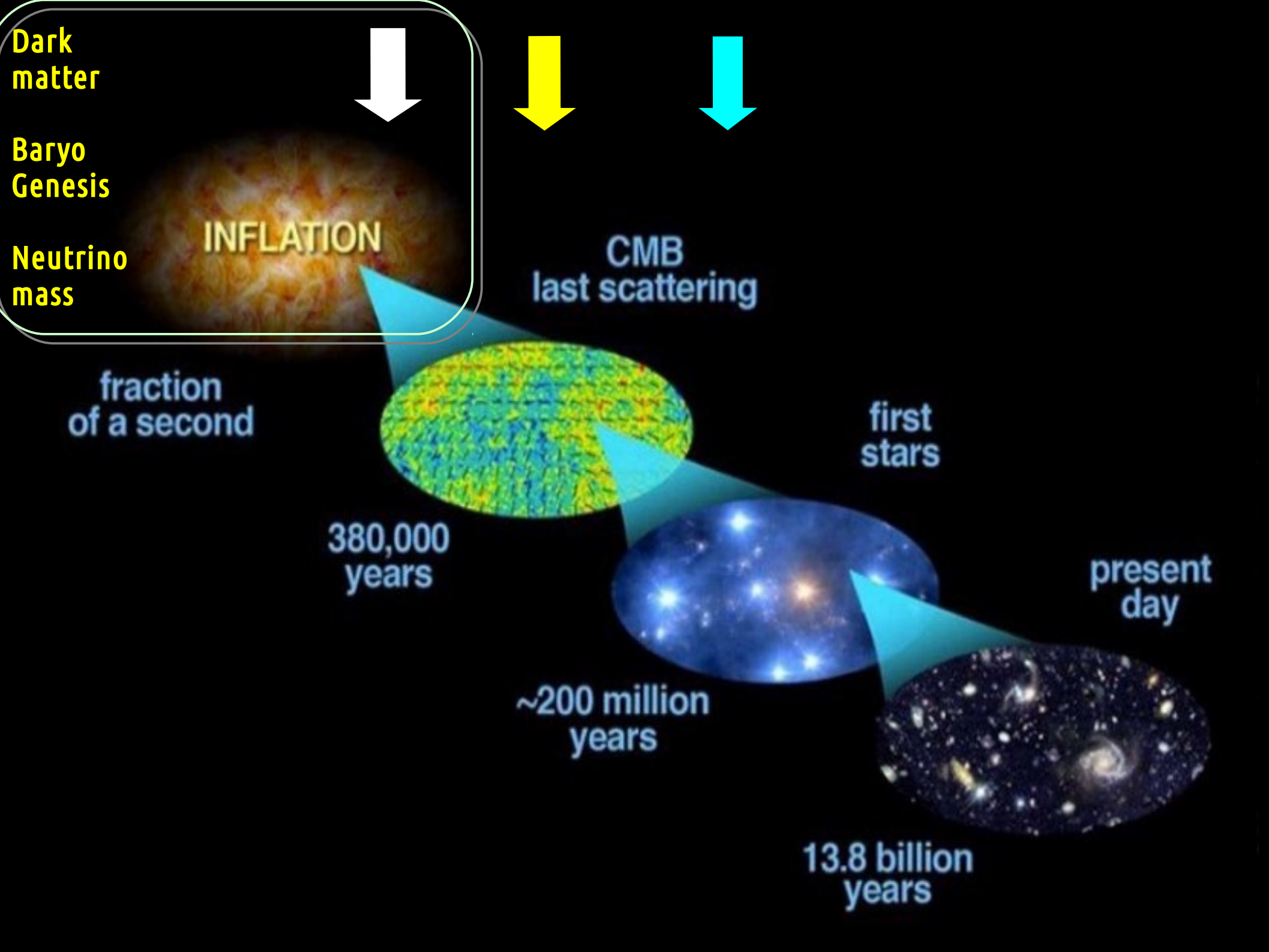
re-measure neutrino mixing angles ..

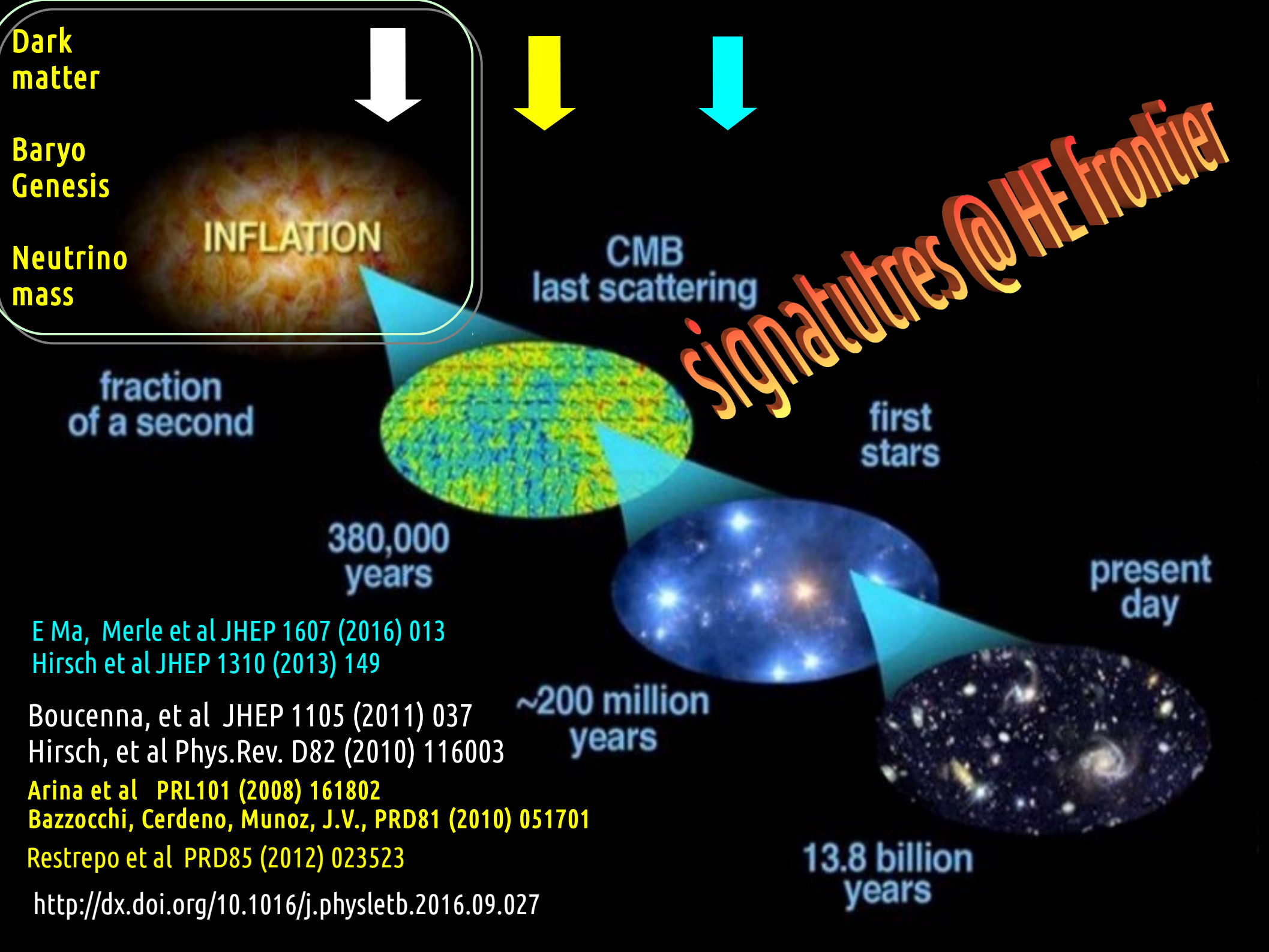
Higgs searches **Bonilla et al** http://dx.doi.org/10.1016/j.physletb.2016.03.037

http://dx.doi.org/10.1088/1367-2630/18/3/033033

http://dx.doi.org/10.1103/PhysRevD.91.113015 ...


INFLATION
CMB
last scattering
fraction
of a second
first
stars
380,000
years
present
day
~200 million
years
13.8 billion
years

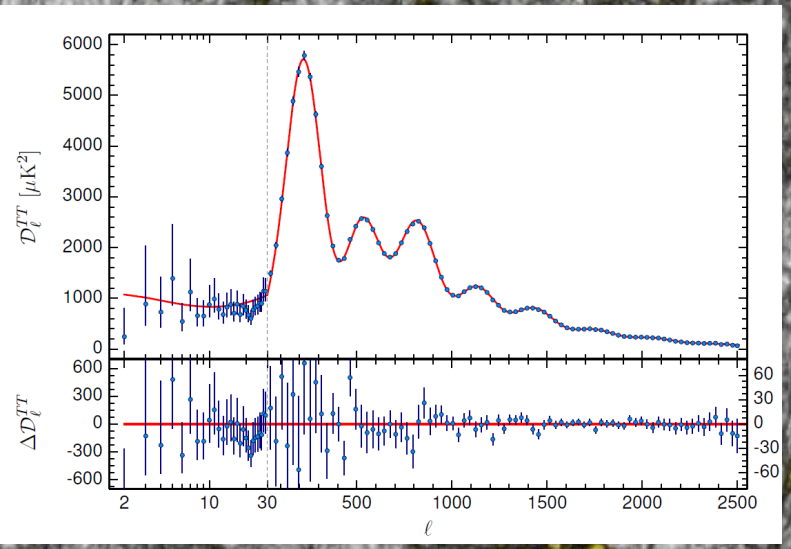

Dark matter
Baryo Genesis
Neutrino mass
INFLATION
CMB last scattering
fraction of a second
380,000 years
first stars
~200 million years
present day
13.8 billion years

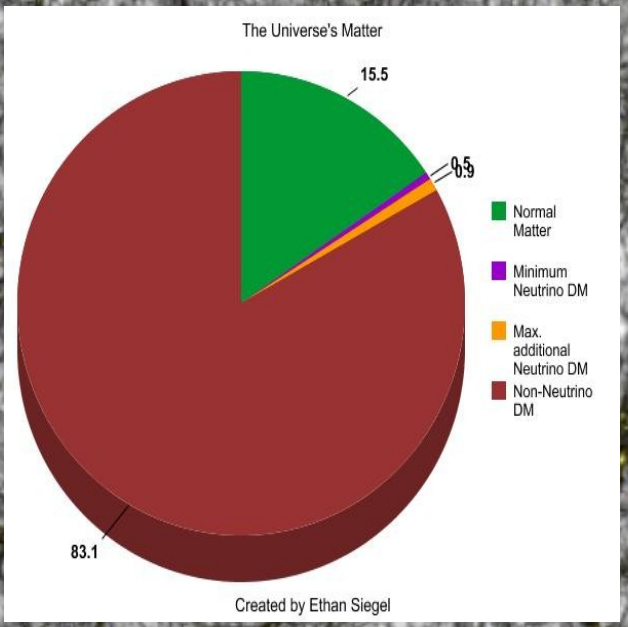


E Ma, Merle et al JHEP 1607 (2016) 013
Hirsch et al JHEP 1310 (2013) 149

Boucenna, et al JHEP 1105 (2011) 037
Hirsch, et al Phys.Rev. D82 (2010) 116003
Arina et al PRL101 (2008) 161802
Bazzocchi, Cerdeno, Munoz, J.V., PRD81 (2010) 051701
Restrepo et al PRD85 (2012) 023523

http://dx.doi.org/10.1016/j.physletb.2016.09.027



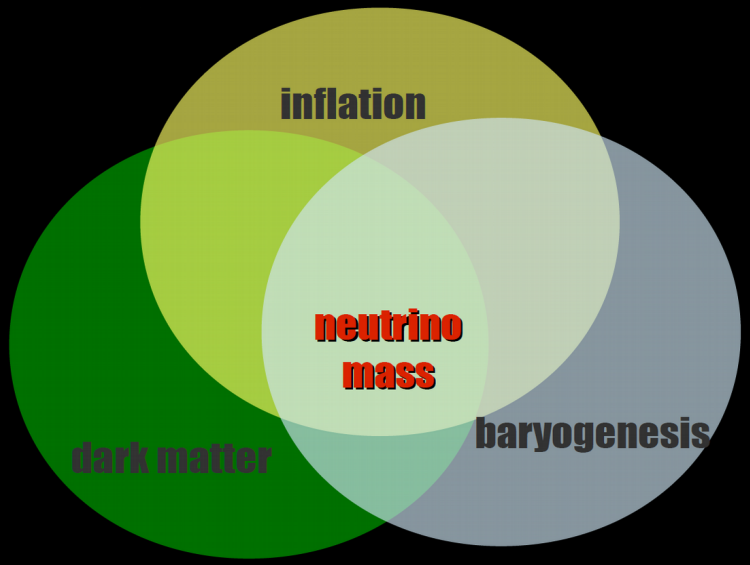


While from CMB neutrinos form only tiny DM fraction they can hold the key to dark matter problem

signatures @ HF frontier

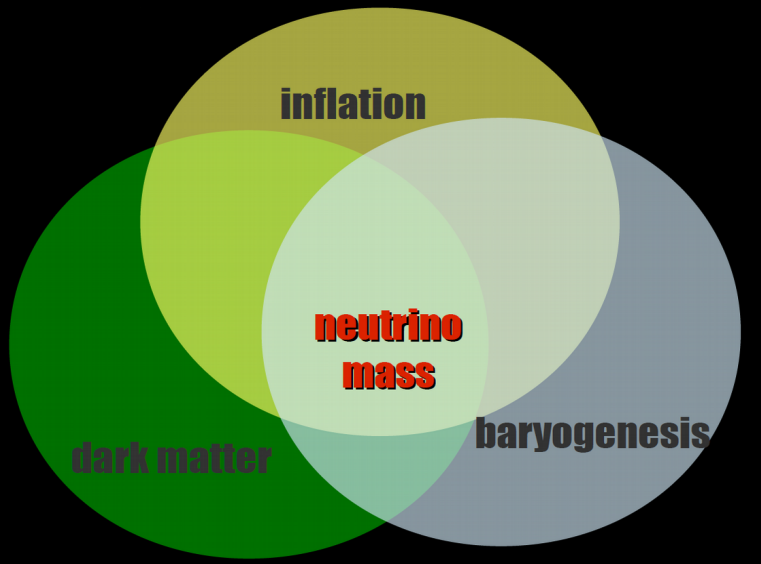
cosmology as an emergent theory of neutrino mass generation

conclusions



cosmology as an emergent theory of neutrino mass generation

conclusions



new phenomena @ high energy frontier

- non-unitarity => new CPV in neutrino oscillations
- EW consistency, new higgses, new decays
- new gauge boson & fermion messengers
- reconciling 331 with LR symmetry
- novel HE completion & unification
- LFV mainly at high energies
- LFV/CPV with no neutrino mass
- LNV @ high energies (short-range 0nuββ decay)
- B anomalies ...

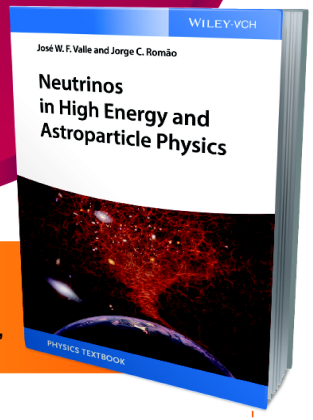
Thank you

Back-ups

Neutrinos in High Energy and Astroparticle Physics

Jose Wagner Furtado Valle, Jorge Romao

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



A self-contained modern advanced textbook on the role of neutrinos in astrophysics and cosmology, and high energy physics

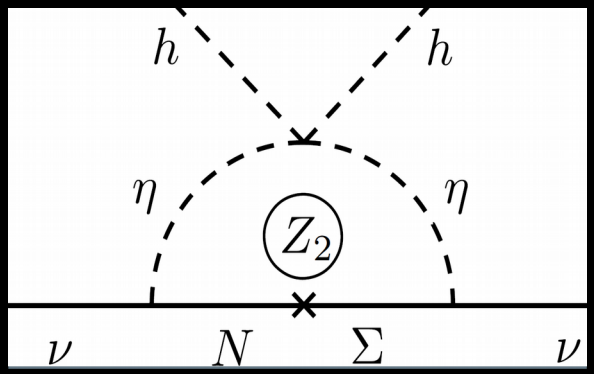
- Written by two renowned and well-established authors in the field.
- Bridges the gap between neutrino theory and supersymmetric model building, so far missing in the current literature.
- Includes a thorough discussion of varieties of seesaw mechanism, with or without supersymmetry.
- Each chapter includes chapter summaries and further reading lists.
- Full problem sets throughout and appendices with useful tables and equations.

$ 124.00 | £ 73.50 | € 99.90

Please note that all prices are correct at time of going to press but are subject to change without notice

241216

WILEY-VCH WILEY

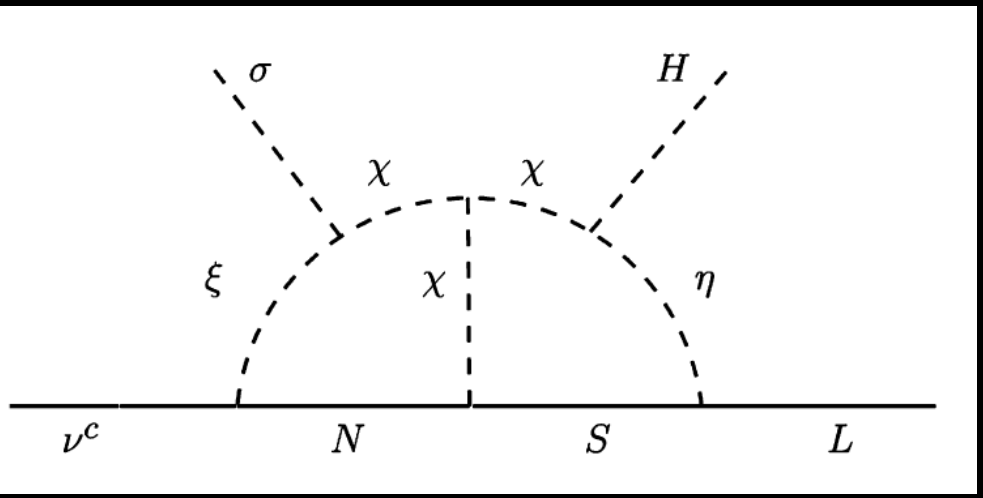


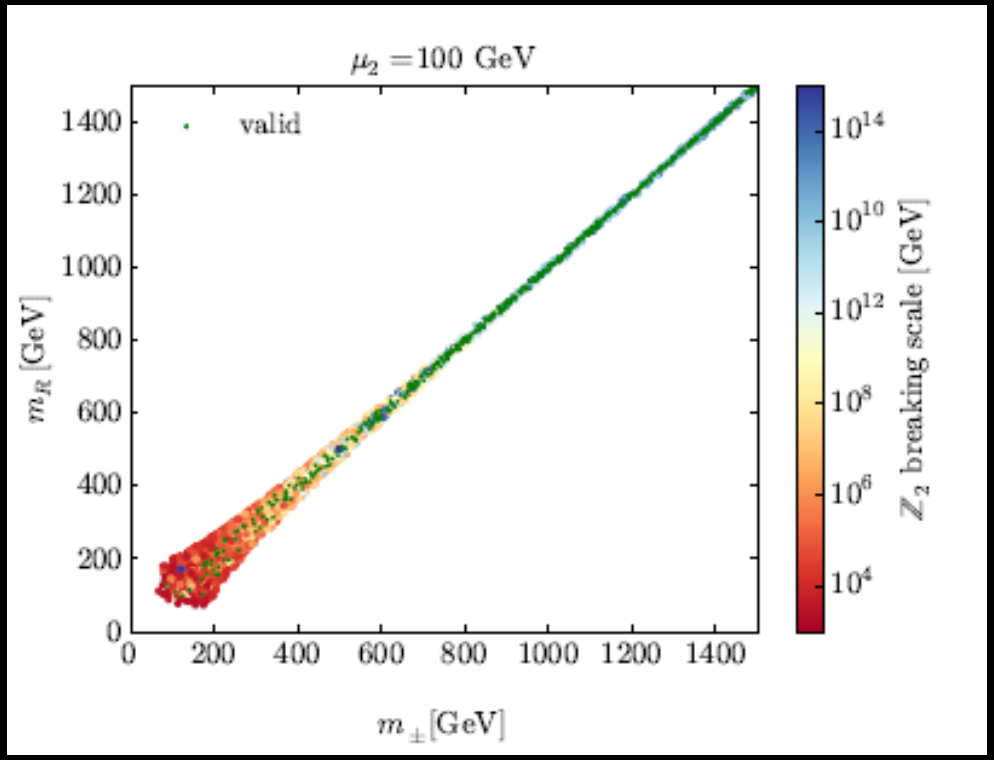
scotogenic dark matter

	Standard Model			Fermions		Scalars	
	L	e	ϕ	Σ	N	η	Ω
Generations	3	3	1	1	1	1	1
$SU(2)_L$	2	1	2	3	1	2	3
$U(1)_Y$	-1/2	-1	1/2	0	0	1/2	0
$\mathbb{Z}_2$	+	+	+	−	−	−	+

E Ma, Merle et al JHEP 1607 (2016) 013
Hirsch et al JHEP 1310 (2013) 149

dark matter as radiative fermion or scalar neutrino mass messenger

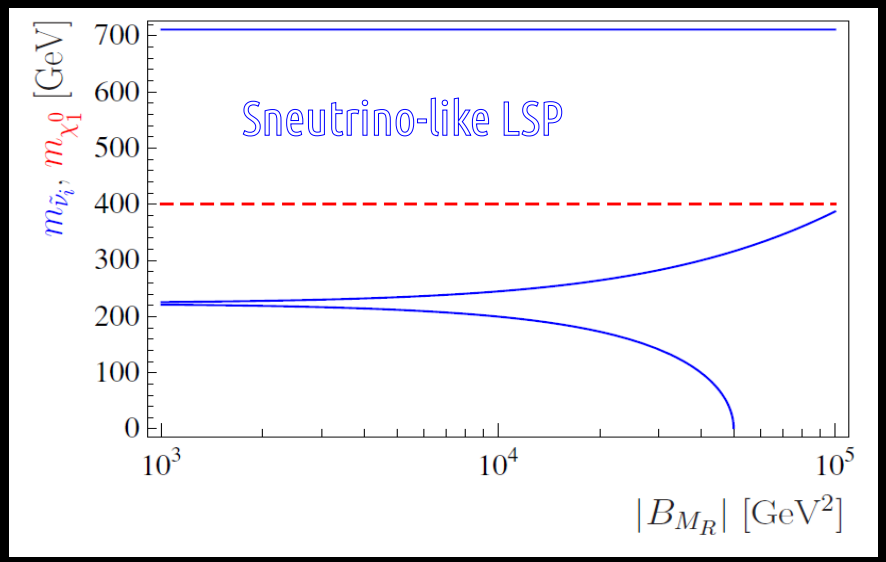




http://dx.doi.org/10.1016/j.physletb.2016.09.027

susy dark matter

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

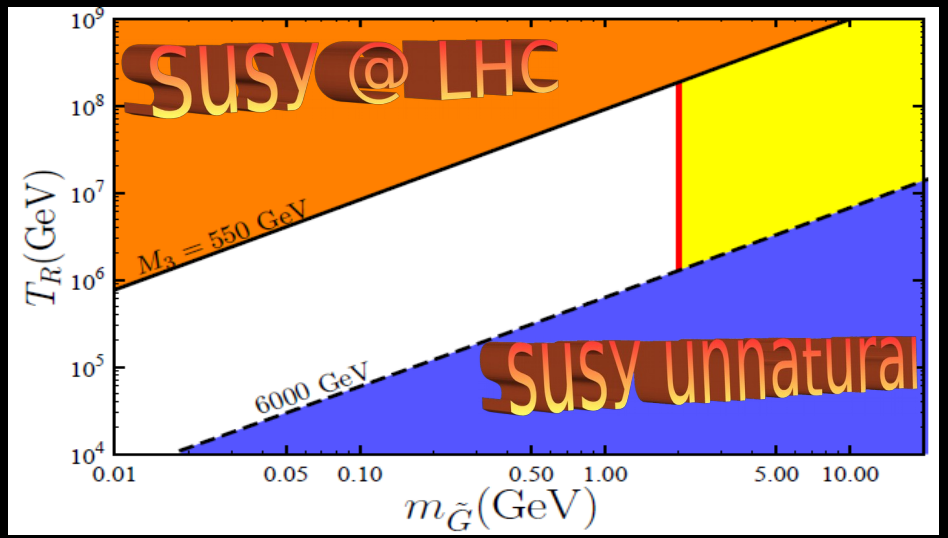


wimp signals also @ colliders

susy inverse seesaw ...

decaying gravitino dark matter

Restrepo et al PRD85 (2012) 023523



doubly suppressed decays

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

chosen to fit neutrino osc. data

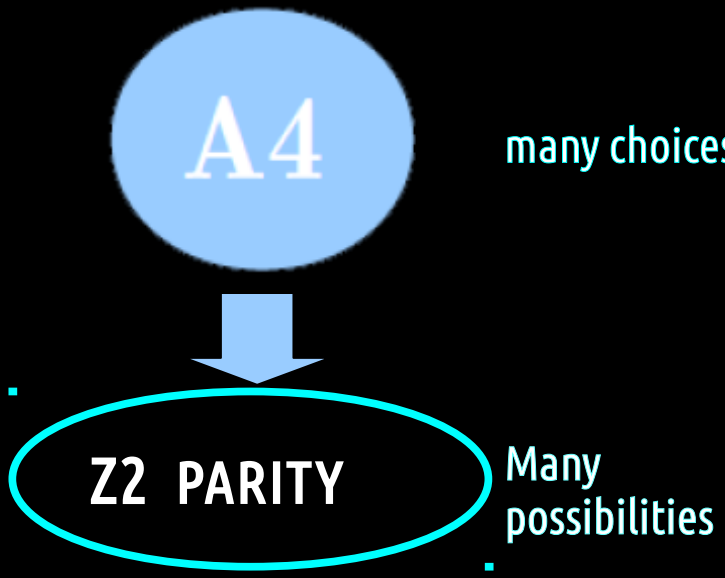
DARK MATTER FROM FLAVOR SYMMETRY

Accidental ?

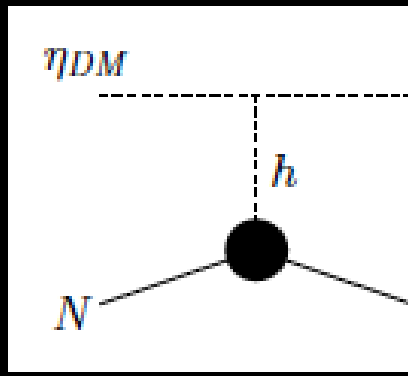
Lavoura, Morisi, JV JHEP 1302(2013) 118

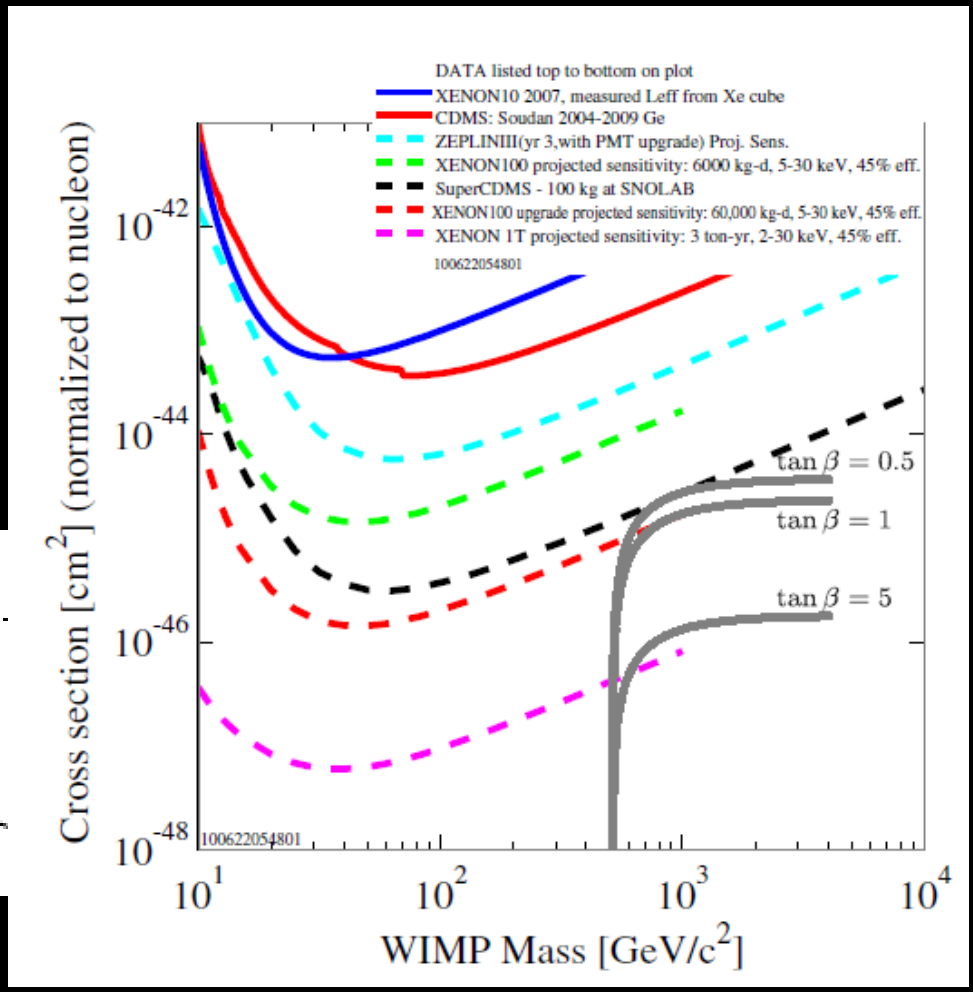
As remnant symmetry

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

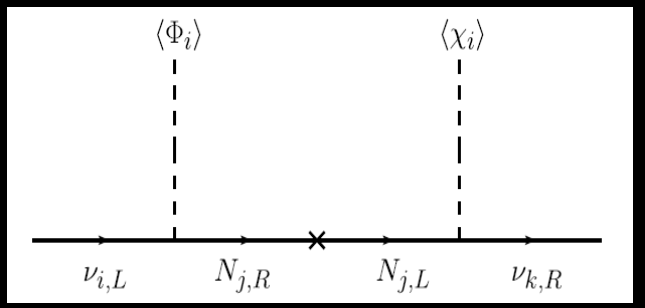


HIGGS PORTAL DIRECT DETECTION





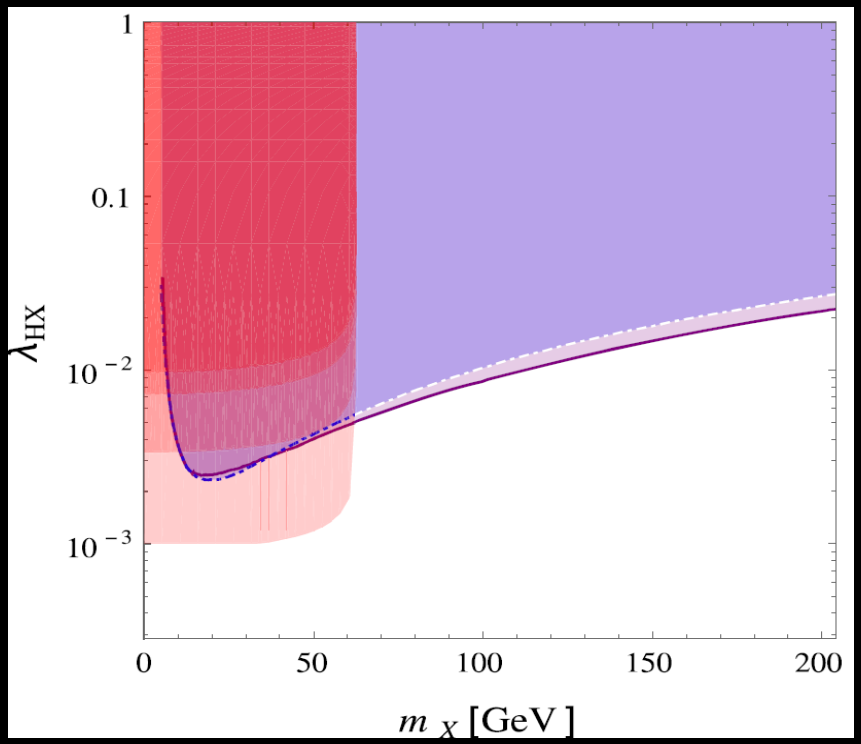
DM Stability from Diracness



Chiulia et al arXiv:1606.04543
Phys.Lett. B761 (2016) 431

http://inspirehep.net/record/1602168

non susy wimp



No neutrinoless ββ decay

Search for neutrinoless quadruple-β decay

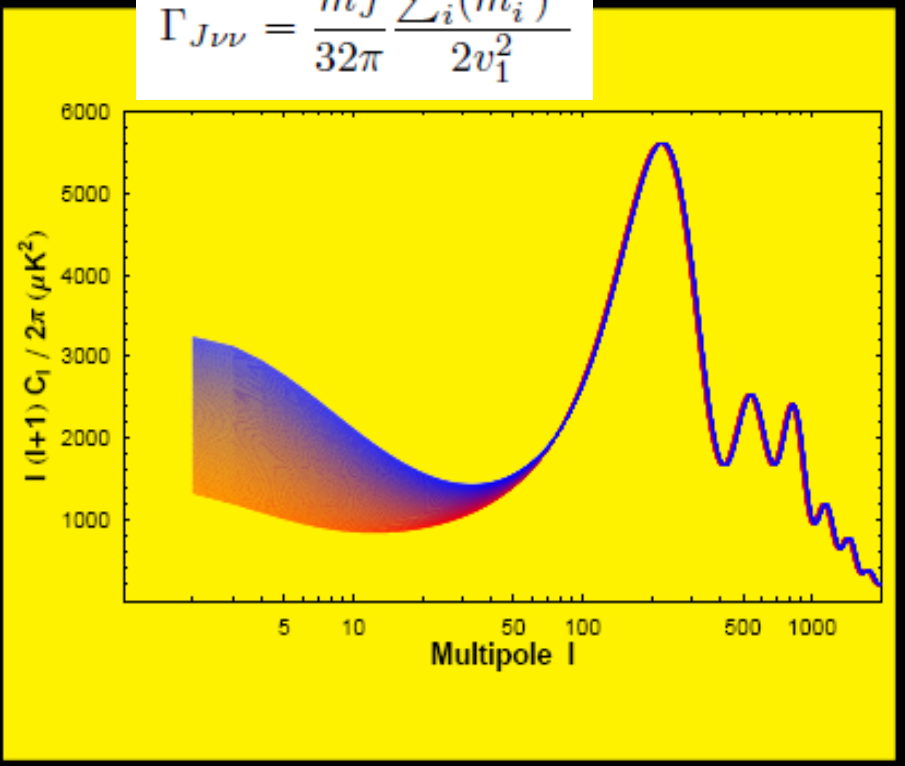
NEMO3

http://arxiv.org/abs/arXiv:1705.08847

majoron decaying dark matter versus CMB

Lattanzi & Valle, PRL99 (2007) 121301

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



Bazzocchi & al JCAP 0808 (2008) 013

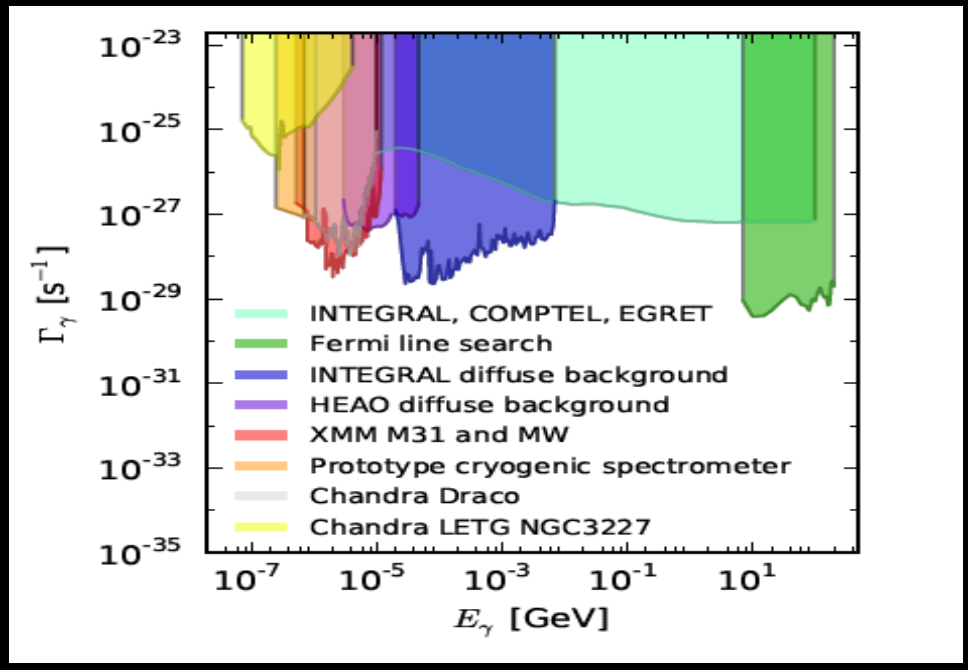
Esteves et al, PRD 82, 073008 (2010)

dark matter majorons

Gelmini, Schramm, Valle Phys.Lett. 146B (1984) 31110.1016/0370-2693(84)91703-9

Berezinsky, Valle PLB318 (1993) 360 http://dx.doi.org/10.1016/0370-2693(93)90140-D

$$J \to \gamma\gamma$$



Lattanzi et al PRD88 (2013) 063528

majoron DM & seesaw inflation

Boucenna, Morisi, Shafi, Valle
PRD90 (2014) 055023

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

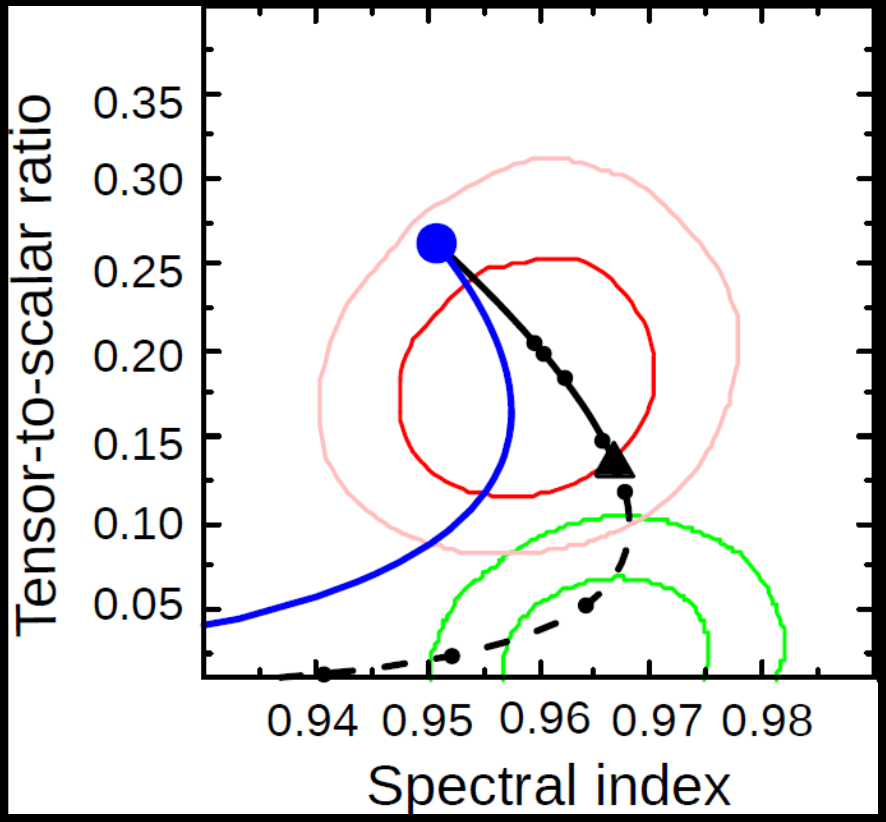
NEUTRINO MASSES

INFLATON

DARK MATTER

type-I seesaw **Leptogenesis**

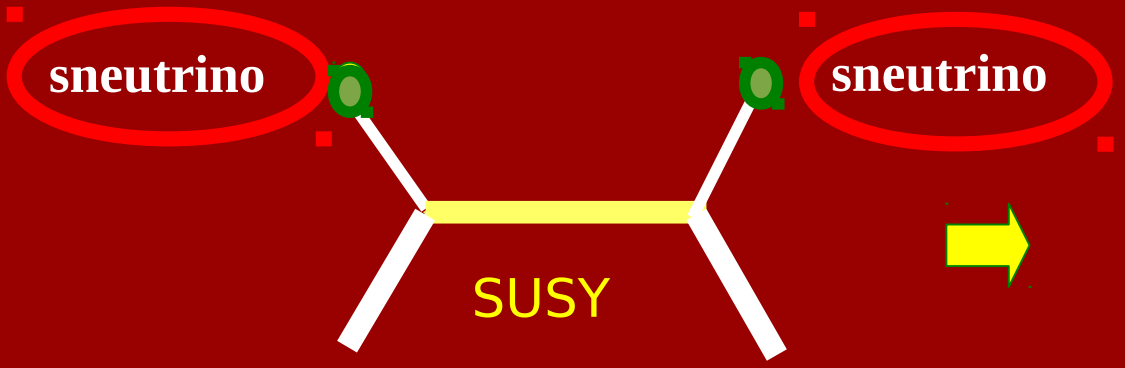
Aristizabal et al JCAP 1407 (2014) 052



Quartic versus Higgs Inflation

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

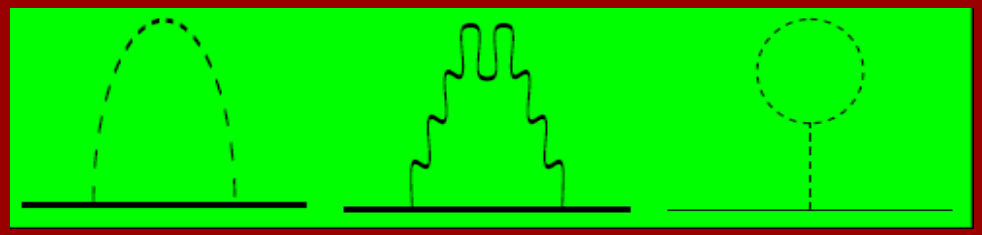
SUSY ORIGIN OF NEUTRINO MASS



Masiero & Valle, PLB251 (1990) 273
Bhattacharyya & Pal, PRD82 (2010) 055013

EFF. BILINEAR RPV

ATM SCALE
SUSY-SEESAW



SOLAR SCALE
RADIATIVE

Diaz et al PRD68 (2003) 013009, PRD62 (2000) 113008

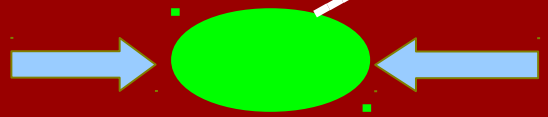
Bazzocchi et al JHEP 01 (2013) 033 arXiv:1202.1529

LIGHTEST NEUTRALINO DECAYS: PROBING NUs @ LHC

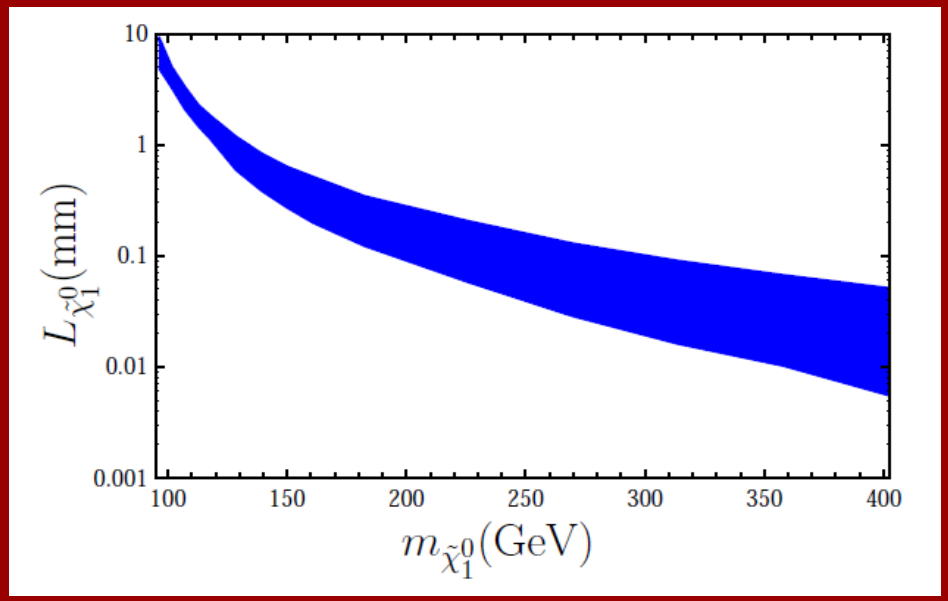
De Campos et al
Phys.Rev. D86 (2012) 075001

$$\tilde{\chi}_1^0 \to W^{\pm} l_i^{\mp}$$

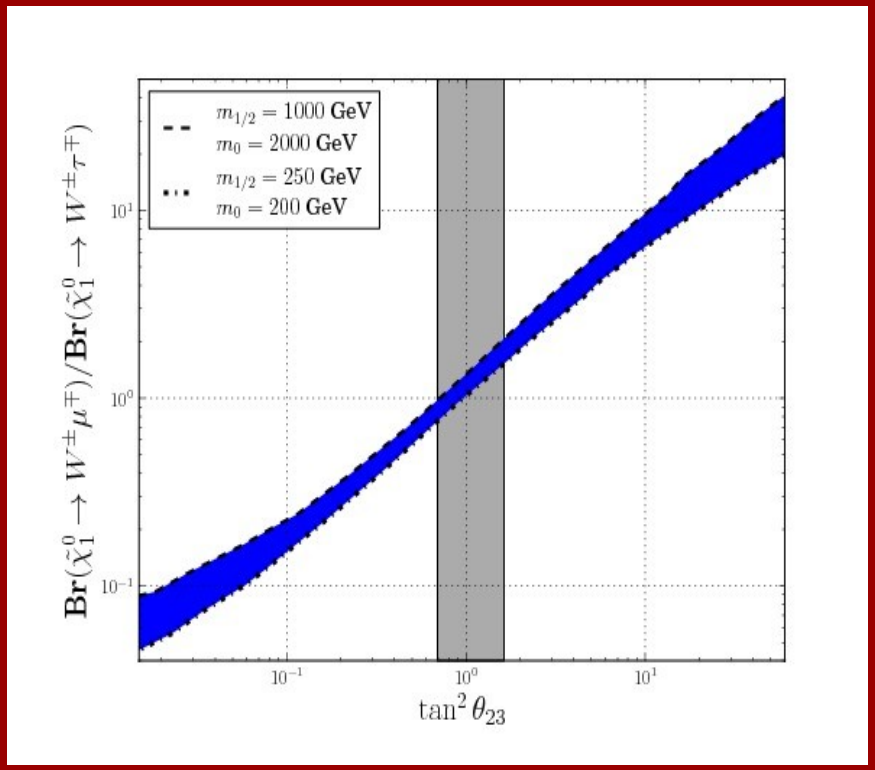
$$\tilde{\chi}_1^0 \to Z^0 \nu_i$$

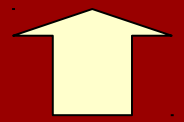


Lightest neutralino decay length



Lightest neutralino decay correlates with atm angle





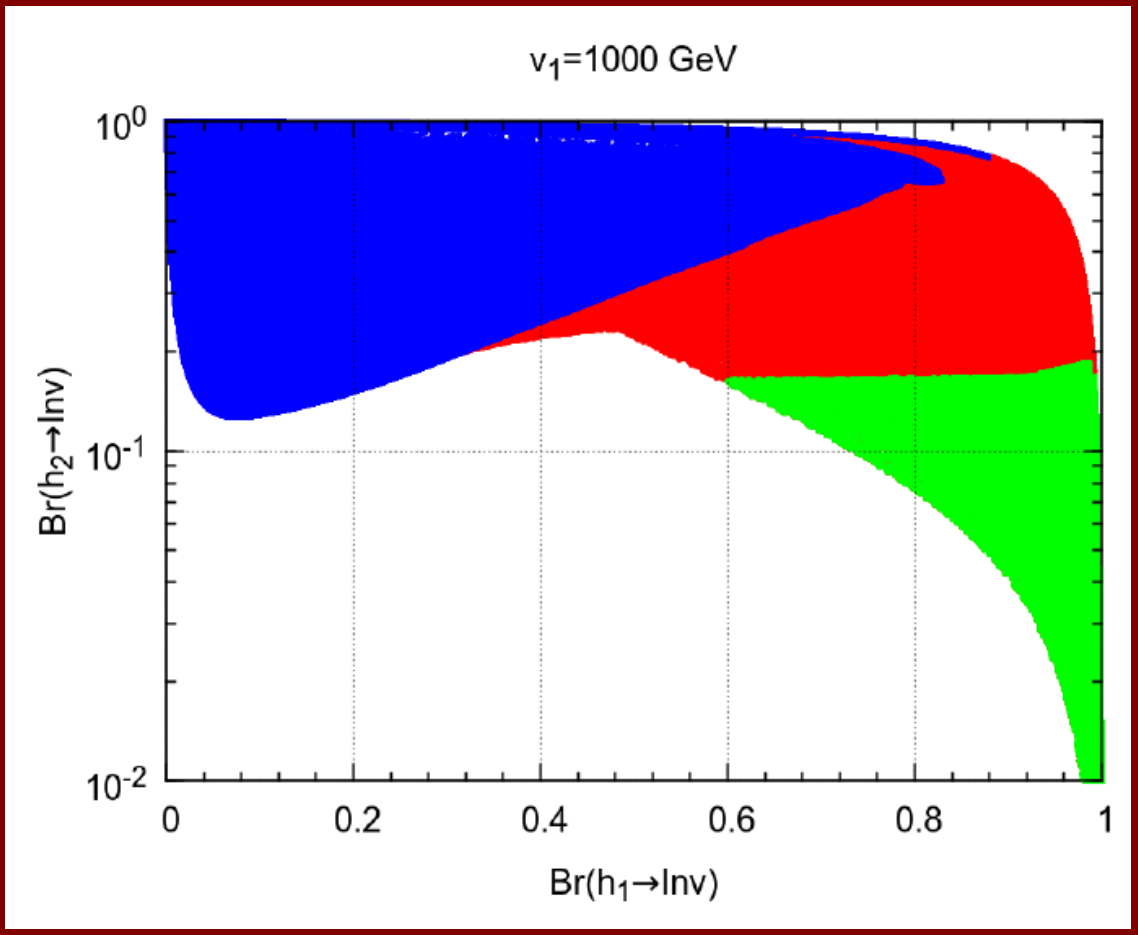
neutrino mass and invisible Higgs decays at the LHC

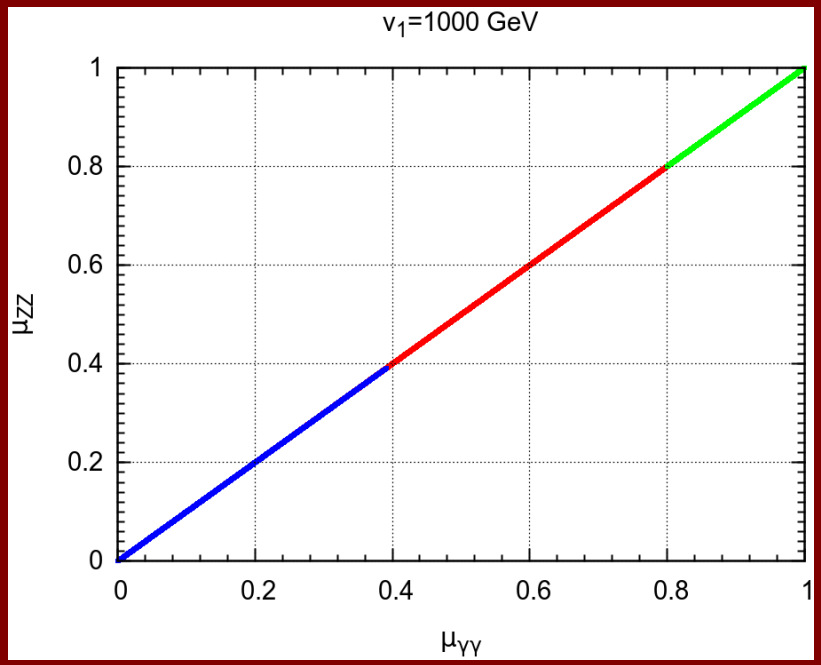
$$\Gamma\left(H_2 \to H_1 H_1\right) = \frac{g^2_{H_2 H_1 H_1}}{32\pi m_{H_2}} \left(1 - \frac{4m^2_{H_1}}{m^2_{H_2}}\right)^{1/2}$$

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

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

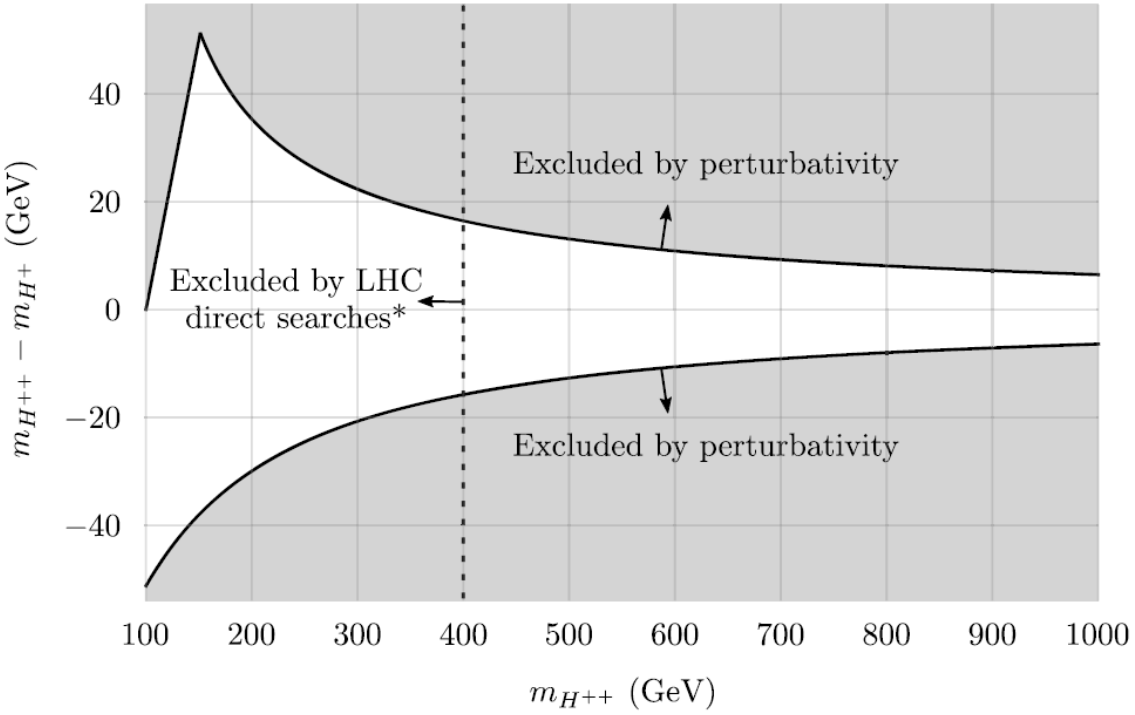
Phys.Rev. D91 (2015) no.11, 113015

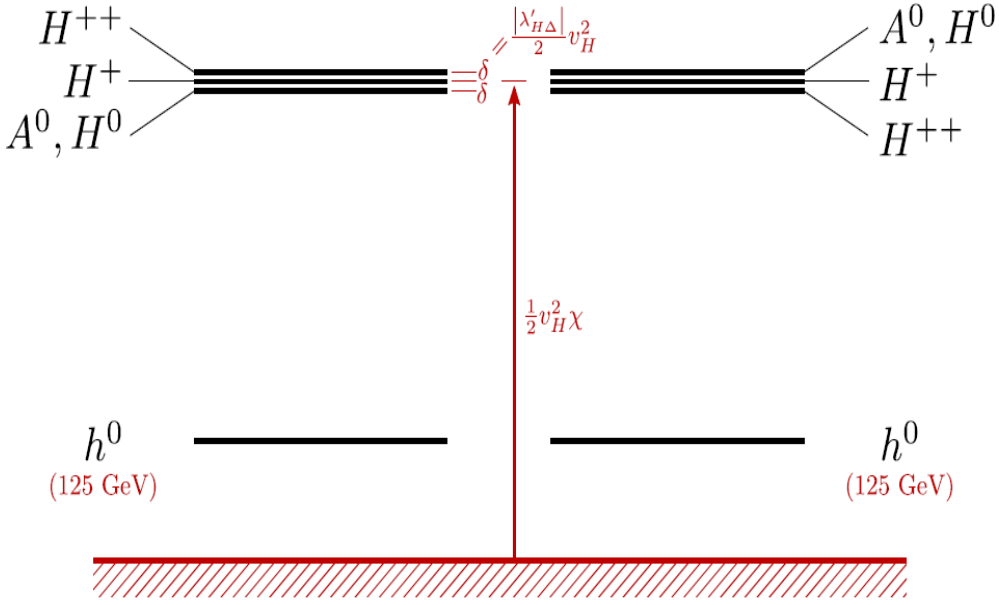




PHYSICAL REVIEW D **92,** 075028 (2015)

Consistency of the triplet seesaw model revisited



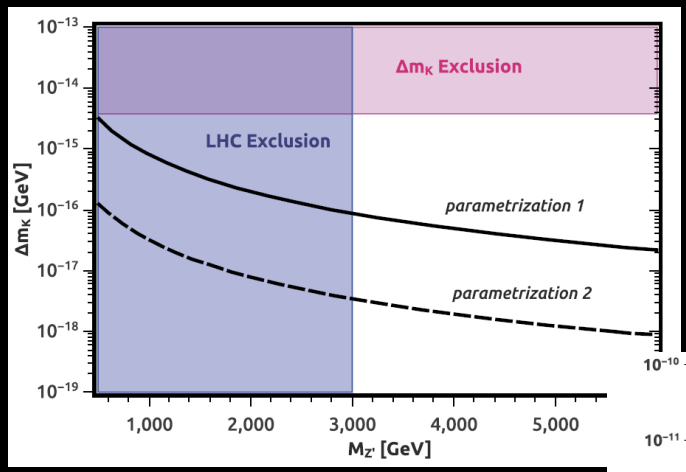


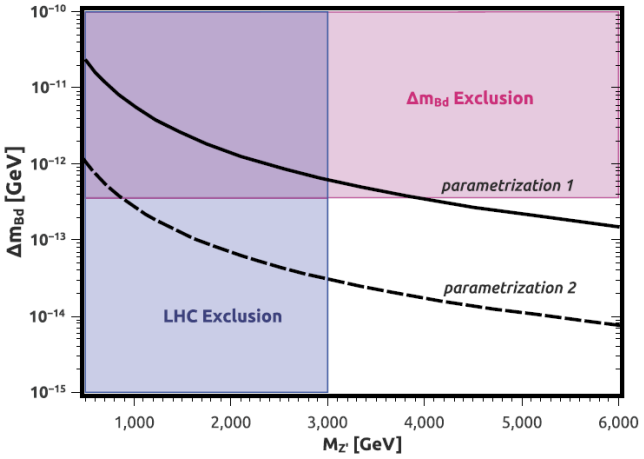
IOP Publishing *New J. Phys.* **18** (2016) 033033

Neutrino as higgs benchmark

new gauge bosons

Phys.Lett. B763 (2016) 269-274





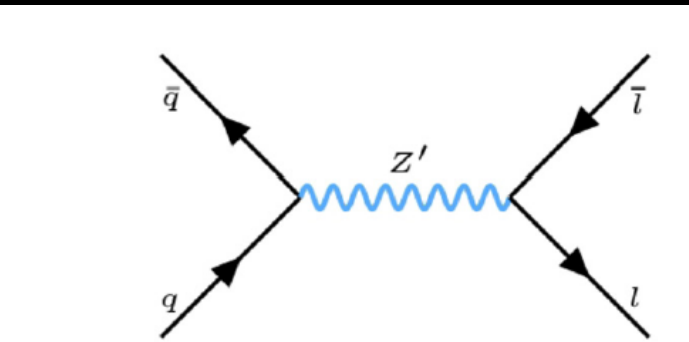
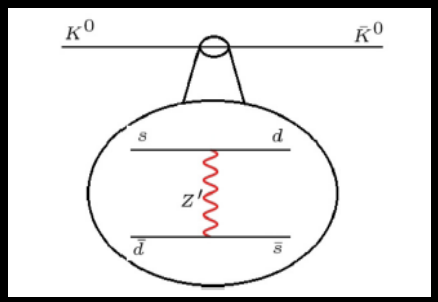
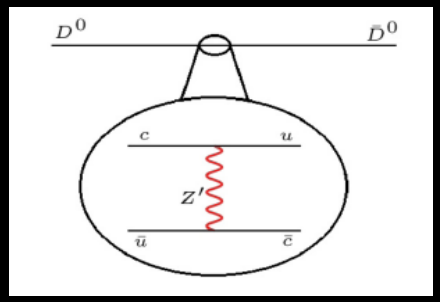
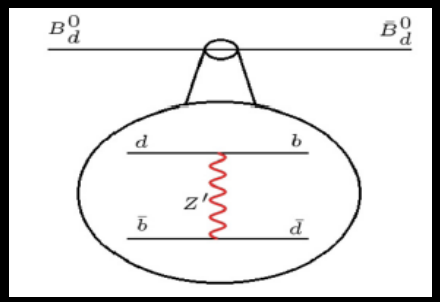
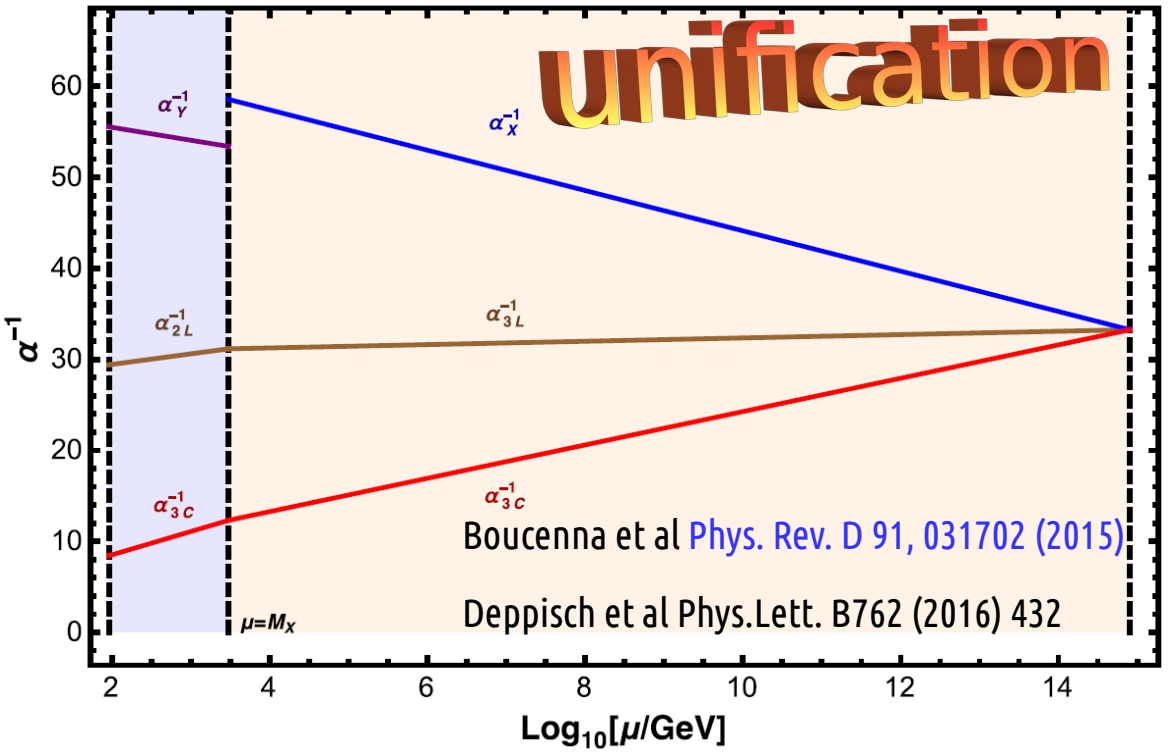


Fig. 1. Feynman diagram relevant for dilepton production at the LHC.









Rp as residual gauge symmetry in 3311

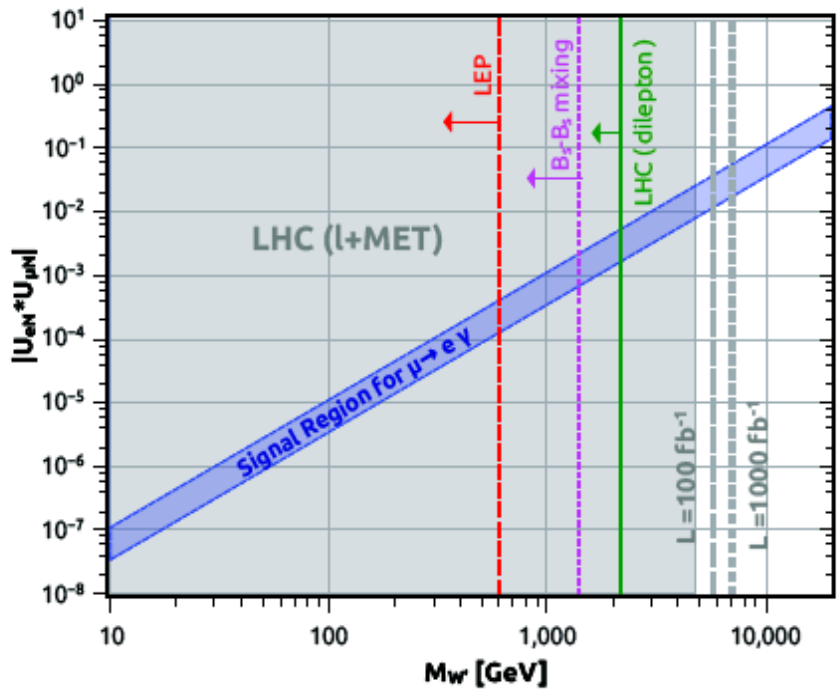


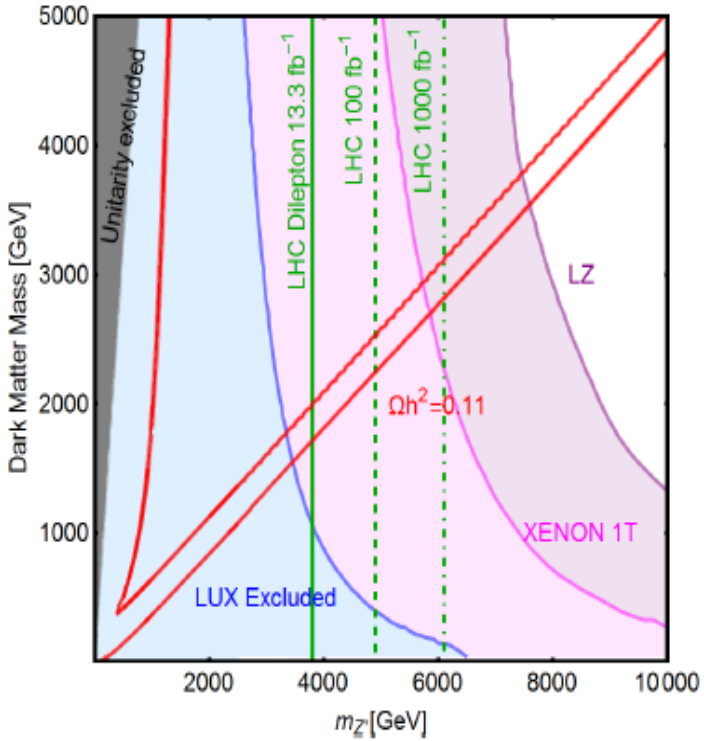
FIG. 1. Region of parameters yielding $4.2 \times 10^{-13} < \mathrm{Br}(\mu \to \mathrm{e}\gamma) < 4 \times 10^{-14}$ in blue, overlaid with bounds from LEP (dashed red), $B_s^0 - \bar{B}_s^0$ mixing (dashed pink), dilepton data from LHC (solid green), and l+MET data from LHC in gray. The upper blue line in the region represents the current limit $\mathrm{Br}(\mu \to \mathrm{e}\gamma) < 4.2 \times 10^{-13}$.

The model.– Our non-supersymmetric model is based on the $\mathrm{SU(3)_c \otimes SU(3)_L \otimes U(1)_X \otimes U(1)_N}$ gauge group, in which the matter generations are arranged in the fundamental representation of $SU(3)_L$ as follows,

Leptons	1-2nd Generations	3th Generation
$l_{aL} = \begin{pmatrix} \nu_a \\ e_a \\ N_a \end{pmatrix}_L$	$q_{\alpha L} = \begin{pmatrix} d_\alpha \\ -u_\alpha \\ D_\alpha \end{pmatrix}_L$	$q_{3L} = \begin{pmatrix} u_3 \\ d_3 \\ U \end{pmatrix}_L$
ν_{aR}, e_{aR}, N_{aR}	$u_{\alpha R}, d_{\alpha R}, D_{\alpha R}$	u_{3R}, d_{3R}, U_R

Scalars

$$\eta = \begin{pmatrix} \eta_1^0 \\ \eta_2^- \\ \eta_3^0 \end{pmatrix} \quad \rho = \begin{pmatrix} \rho_1^+ \\ \rho_2^0 \\ \rho_3^+ \end{pmatrix} \quad \chi = \begin{pmatrix} \chi_1^0 \\ \chi_2^- \\ \chi_3^0 \end{pmatrix}, \quad \phi$$



Non-susy wimp Dirac DM