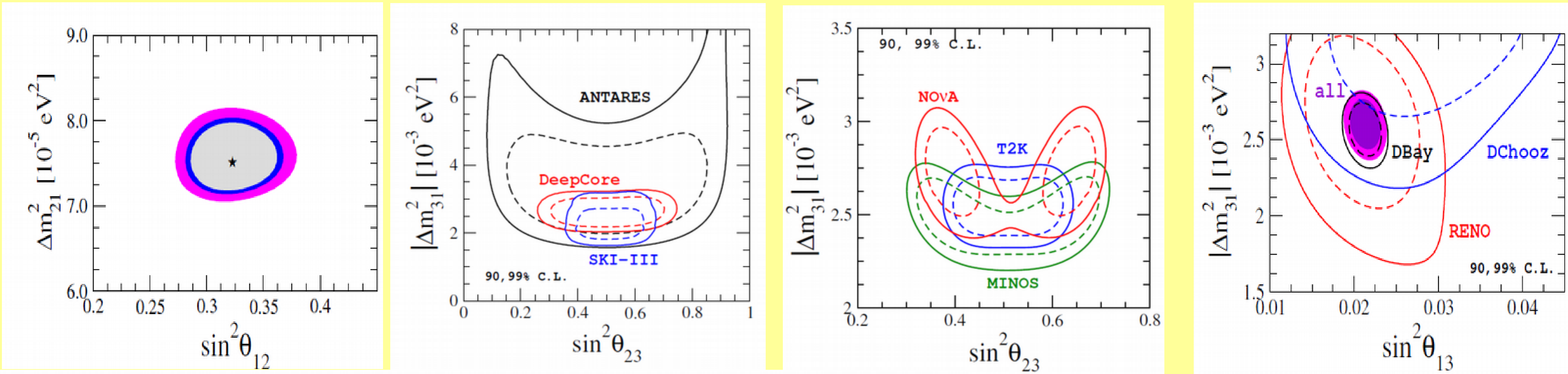
neutrinos and the new physics landscape

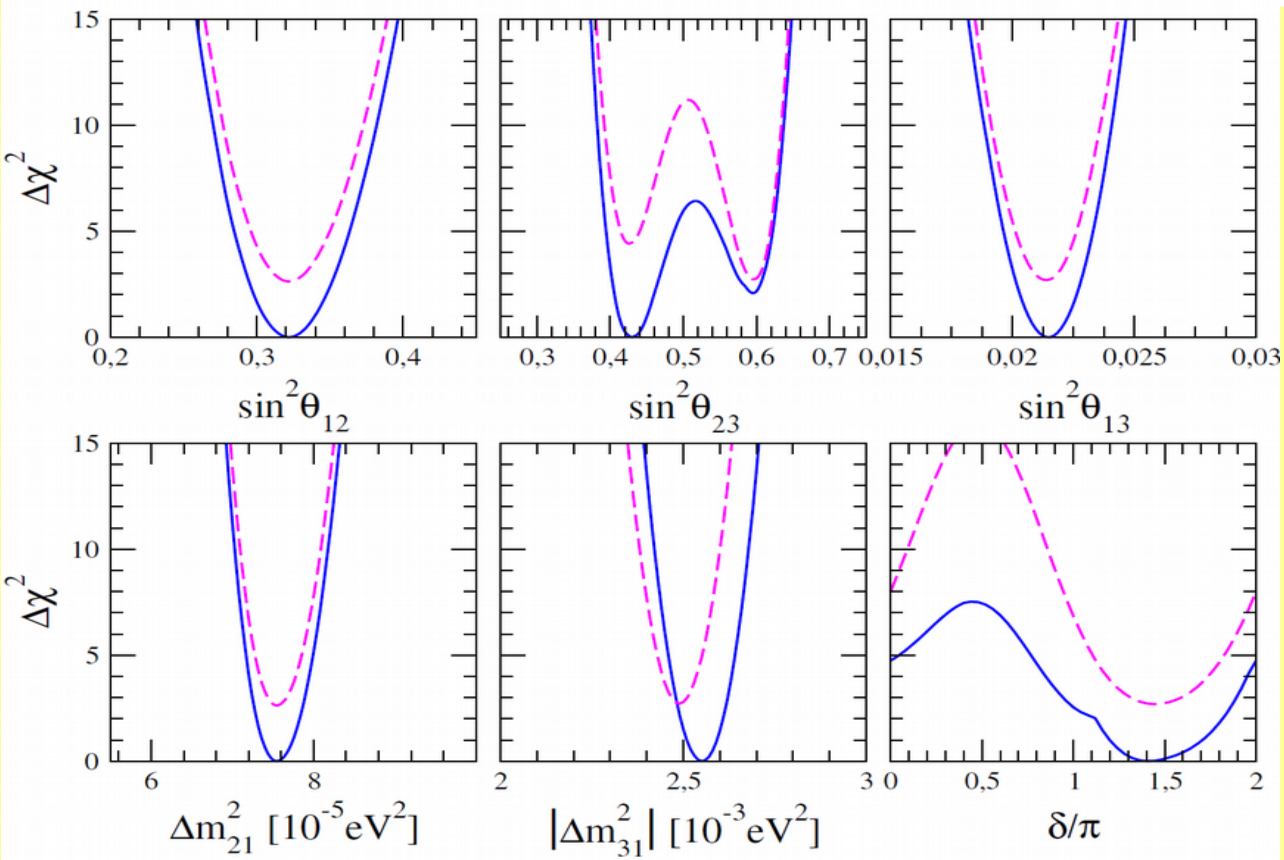
José W F Valle

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

XXIV Cracow Epiphany Conference on Advances in Heavy Flavour Physics

status of neutrino oscillations 2017





P.F. de Salas et al,
http://arxiv.org/abs/arXiv:1708.01186

Consistent global picture
Good agreement

current hints

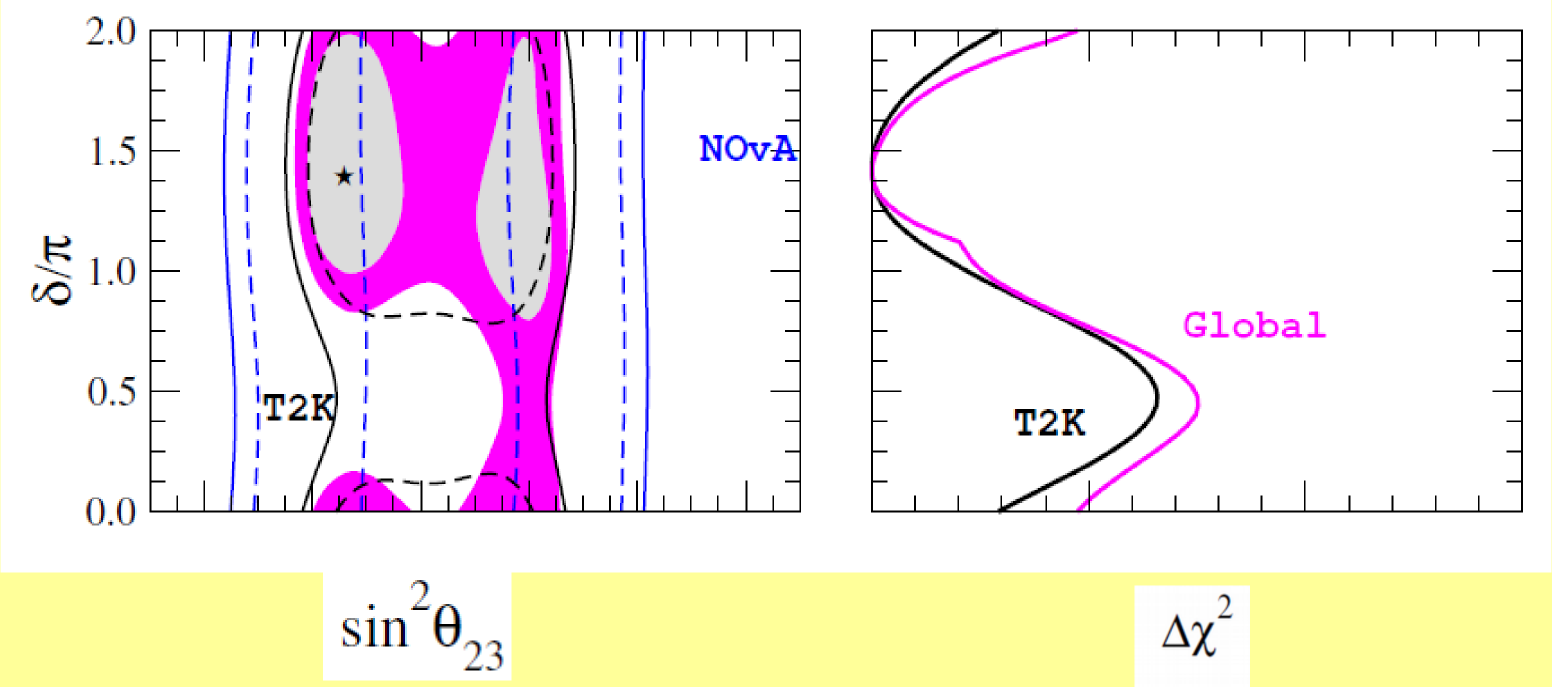
normal ordering is preferred

for normal mass ordering the lower atmospheric octant is now preferred by $\Delta\chi^2 = 2.1$

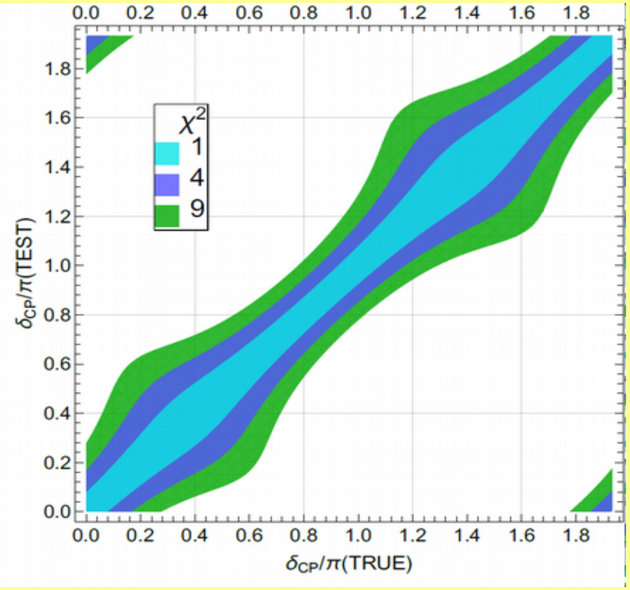
4 well measured parameters + 2 poorly determined ones

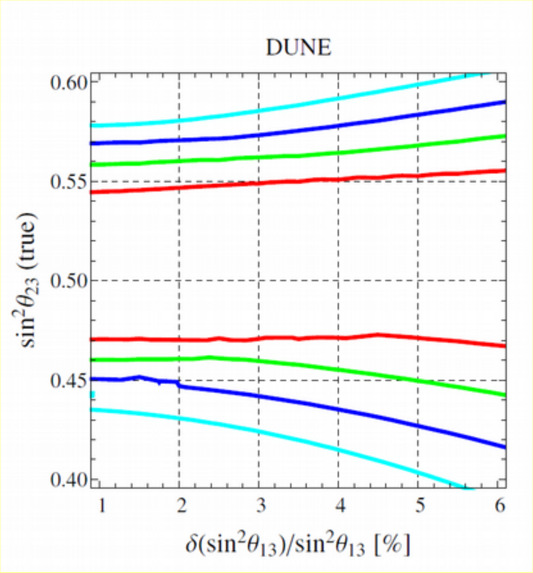
P.F. de Salas et al,
http://arxiv.org/abs/arXiv:1708.01186

N.O.



the future





10.1016/j.physletb.2017.05.080

https://journals.aps.org/prd/abstract/
10.1103/PhysRevD.96.011303

dune

robustness

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

non unitarity

CP confusion

new ways to probe seesaw scale

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

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

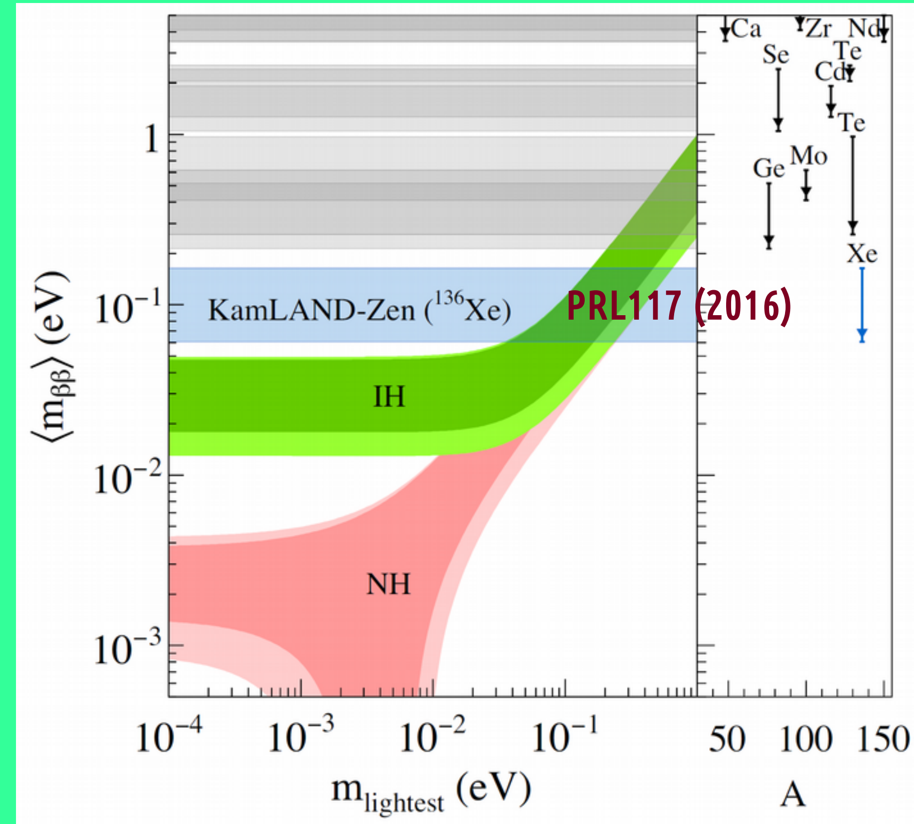
new window into BSM physics e.g. nsi

Coloma, Huber et al, Miranda et al,
de Gouvea et al, Goswami et al, Kopp et el
UAM group, many others ...

the neutrino mass scale

beta decay
0nu-dbd & CMB

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

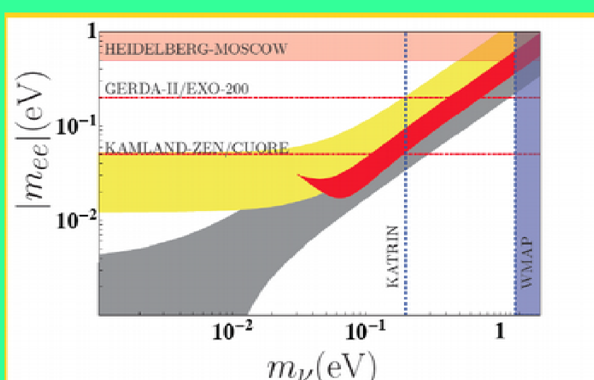
$$m_{\beta\beta} < (140 - 400)\ \text{meV},$$

$$T^{0\nu}_{1/2}(^{130}\text{Te}) > 1.5 \times 10^{25}\ \text{yr}\ (90\%\ \text{C.L.}),$$

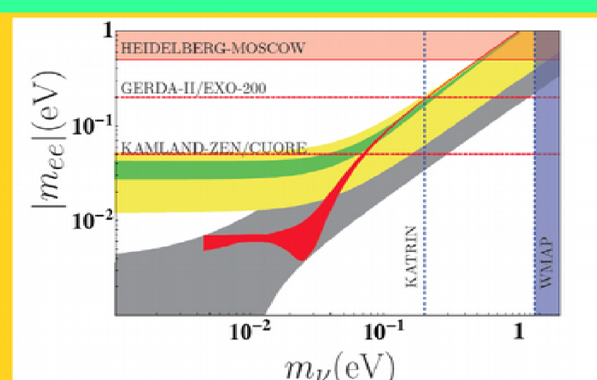
nEXO, **CUORE** , LEGEND (nGERDA/Majorana) ...

Interplay with oscillation physics
lower bounds even for normal ordering

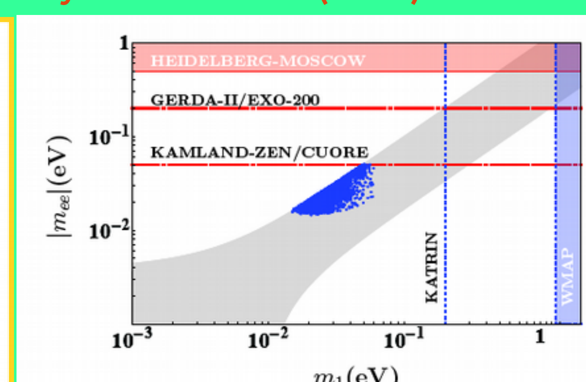
Dorame et al
NPB861 (2012) 259-270



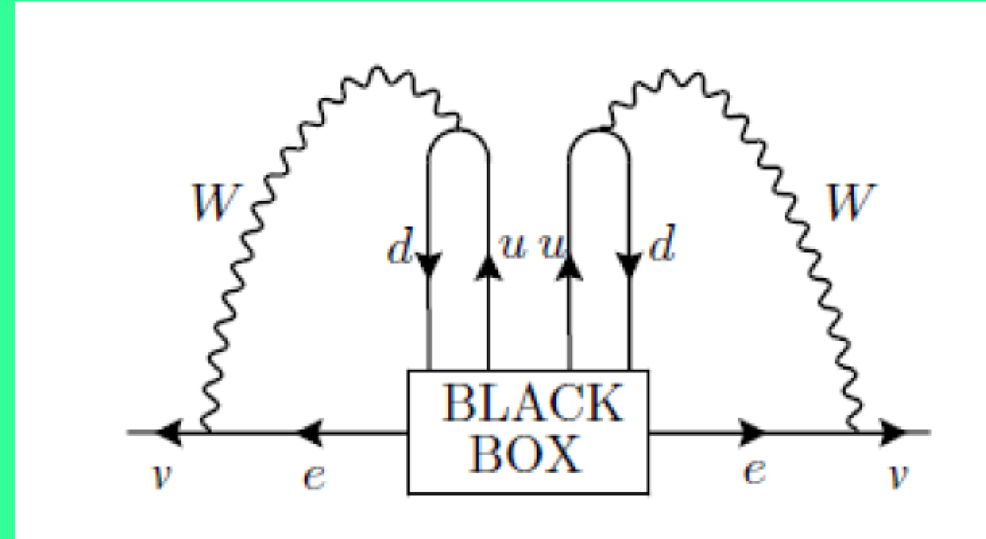
Dorame et al
PhysRevD.86.056001



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

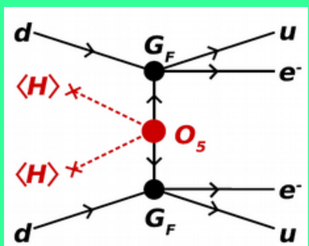


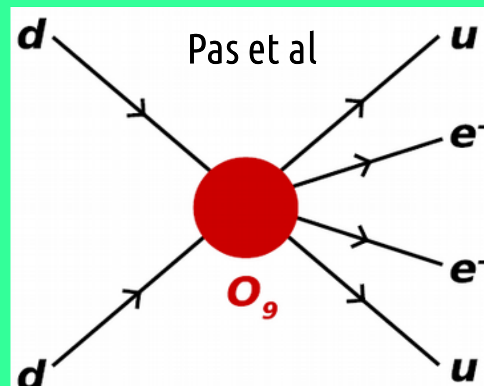
Significance



Schechter, Valle 82

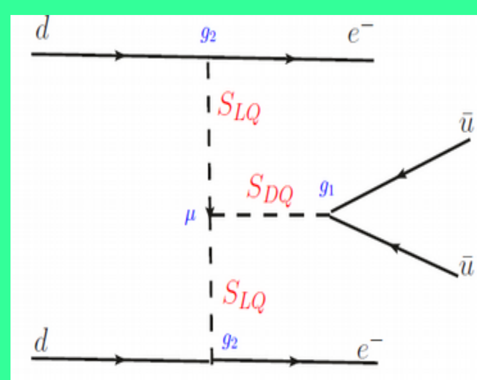
Lindner et al JHEP 1106 (2011) 091

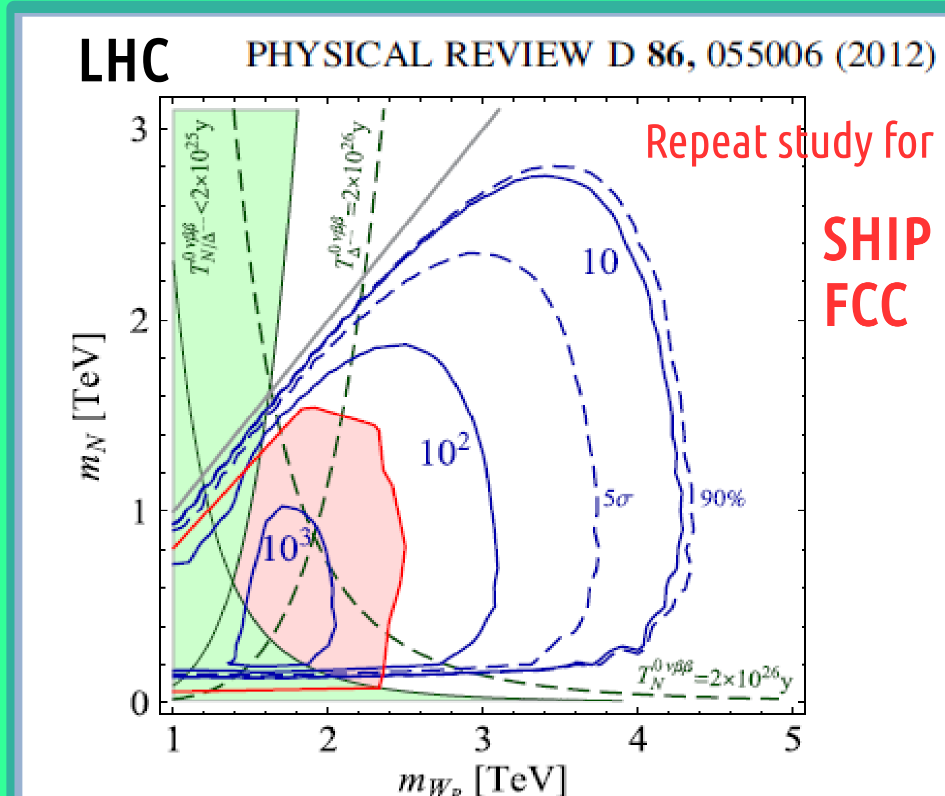




Heavy mediators

Hirsch et al





Can one ever prove that neutrinos are Dirac particles?

J. Heeck and W. Rodejohann, https://arxiv.org/abs/1306.0580

Centelles-Chulia et al Phys.Lett.

10.1016/j.physletb.2017.01.070

http://arxiv.org/abs/arXiv:1711.10318

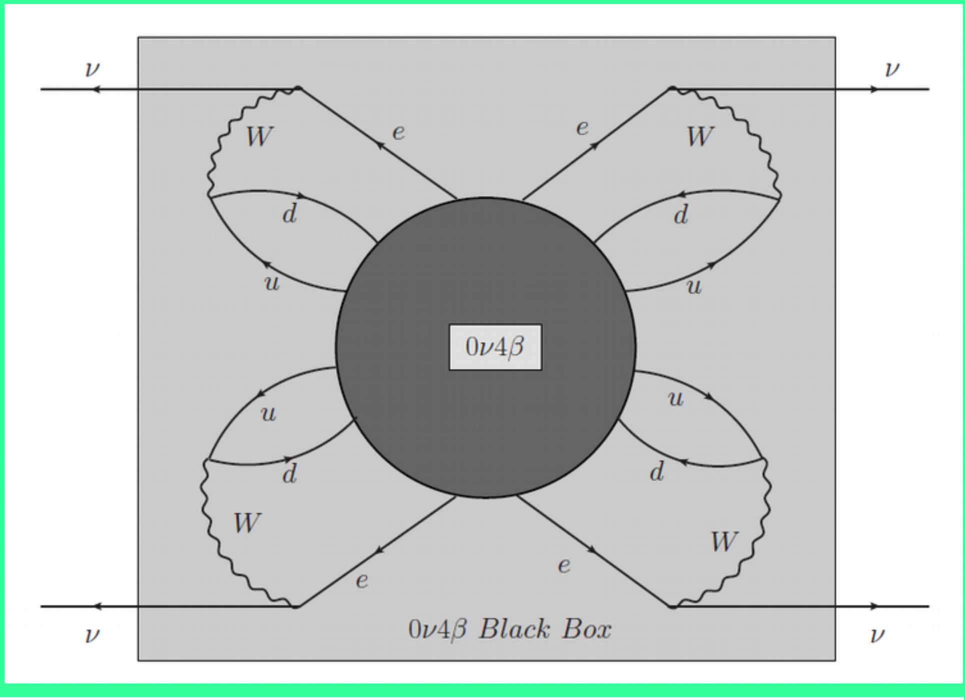


Figure 3. The quadruple beta decay process is allowed by a residual Z_4 symmetry irrespective of the nature of neutrinos.

Criterium for Diracness

the questions

why lepton mixing
Special?

why large w.r.t. CKM?

Cabbibo angle as
a common seed?

Phys.Rev. D86 (2012) 051301

Phys.Lett. B748 (2015) 1-4

Is there a flavor symmetry?

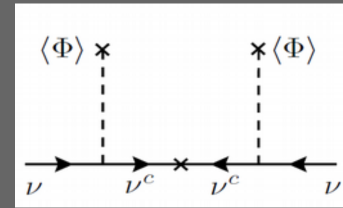
Is it common for leptons & quarks?

Can one predict angles & phases?

Dirac or Majorana?

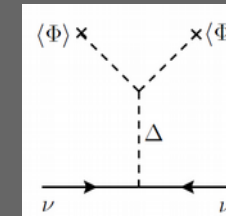
why so light?

Origin of neutrino mass



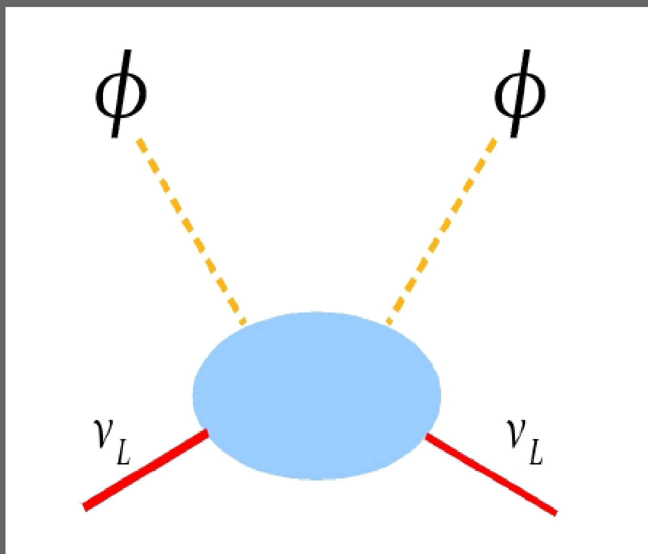
TYPE I

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

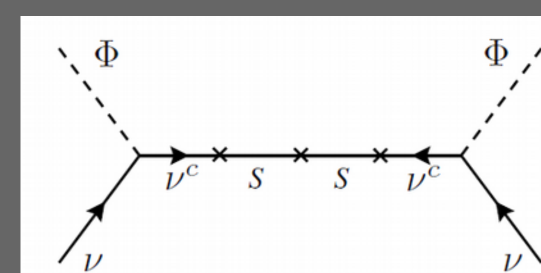
$$v_3 v_1 \sim {v_2}^2$$

coefficient
mechanism
scale
flavor structure

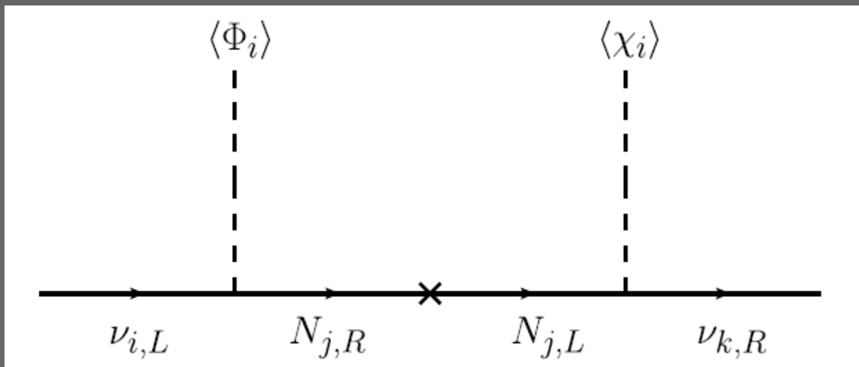
Arbitrary number of singlet messengers

LOW-SCALE SEESAW

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



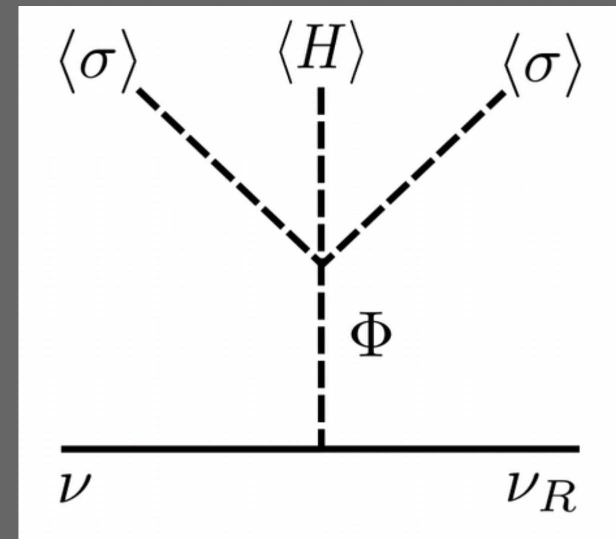
Seesawing a la Dirac



type1

Phys.Lett. B761 (2016) 431-436

Phys.Lett. B767 (2017) 209-213



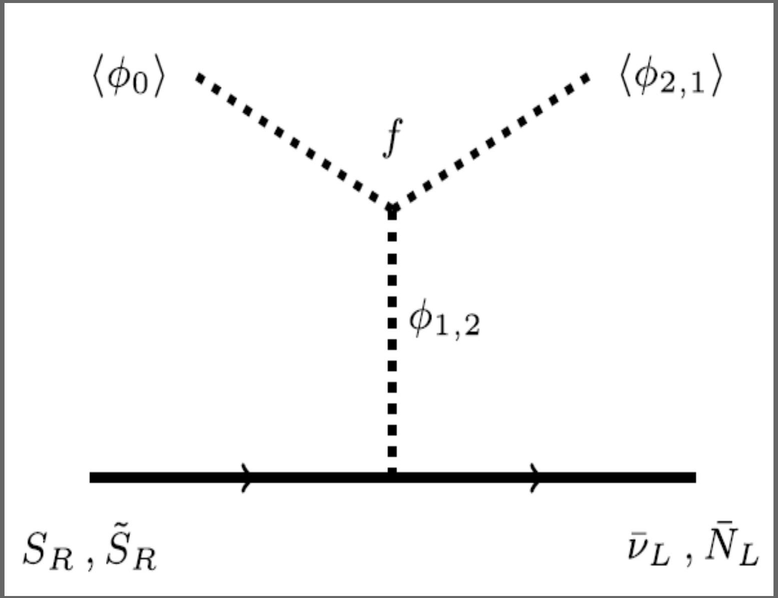
type2

Phys.Lett. B762 (2016) 162-165

Phys.Rev. D94 (2016) 033012

Symmetry protects small neutrino mass

Addazi et al Phys.Lett. B759 (2016) 471-478



Physics Letters B 755 (2016) 363–366

RH from HE completion

extra dim theories

larger gauge symmetry

Quiver consistency requires RH neutrino

Radiative neutrino mass

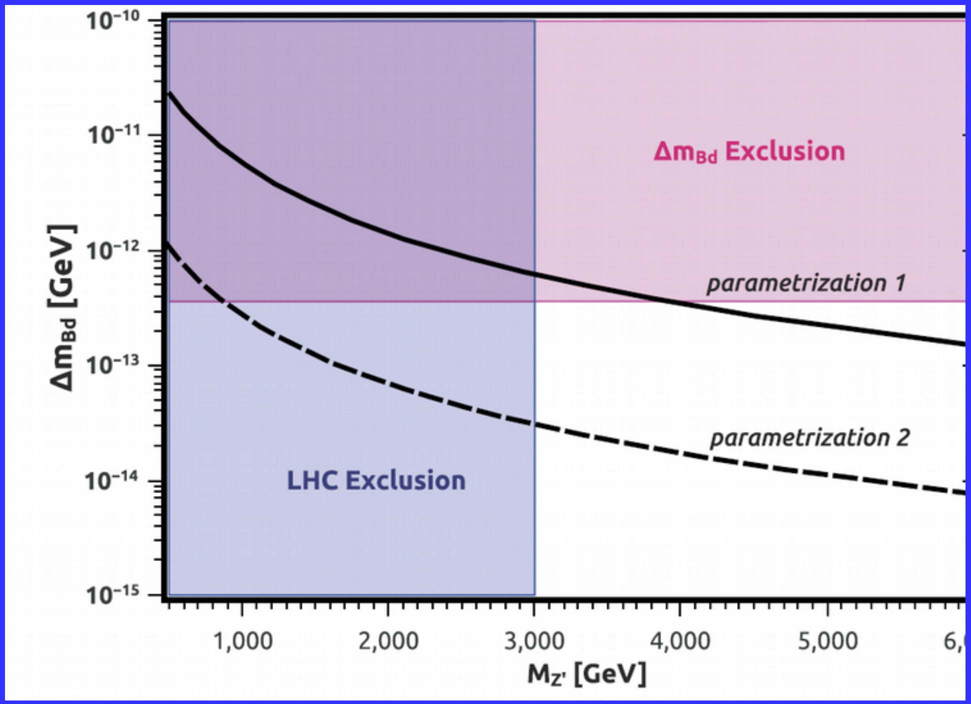
many low-scale neutrino mass schemes ...

arXiv:1404.3751

331 EW theory # families = # colours

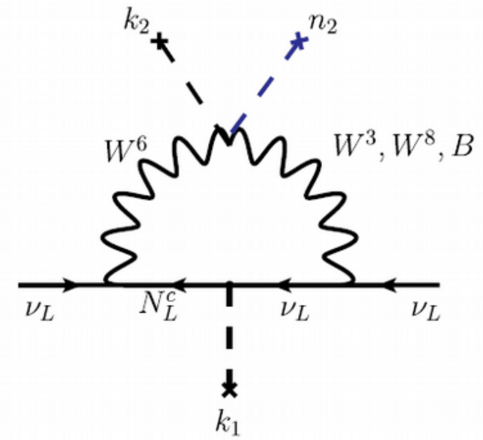
Singer, Valle, Schechter, Phys.Rev. D22 (1980) 738

F.S. Queiroz et al. / Physics Letters B 763 (2016) 269–274



Gauge vs Higgs

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



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

Simplest flavor symmetry

A4

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

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

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

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

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

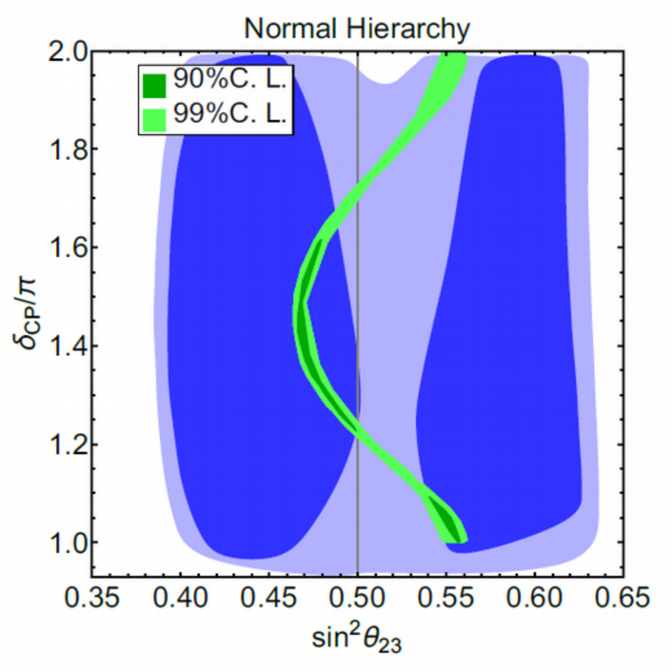
$$u_R \quad c_R \quad t_R$$

$$d_R \quad s_R \quad b_R$$

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

Revamping ...
Morisi et al, Phys.Rev. D88 (2013) 016003

Constrained global
fit 1708.03290
Phys.Lett. B774 (2017) 179-182



prefers for NO, LO, max CPV, as hinted

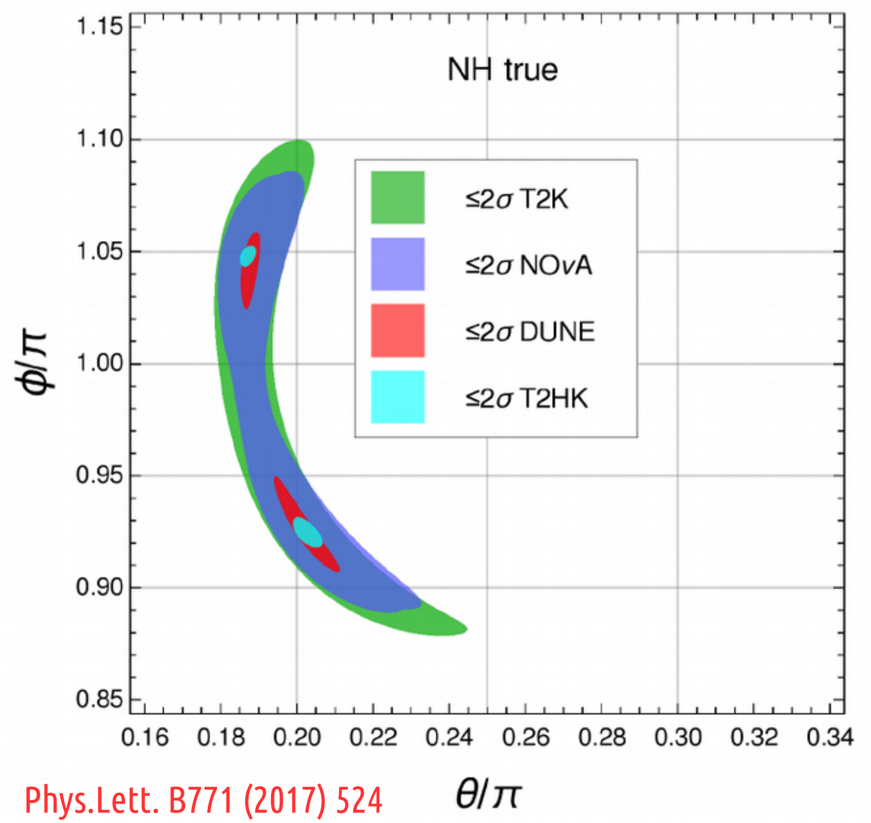
BUT

will it survive DUNE?

flavor predictions from warped SM

:Chen et al
JHEP01(2016)007

constrained global fitting



Phys.Lett. B771 (2017) 524

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

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

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

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

can be projected into physical osc parameters used to make predictions for dune, etc

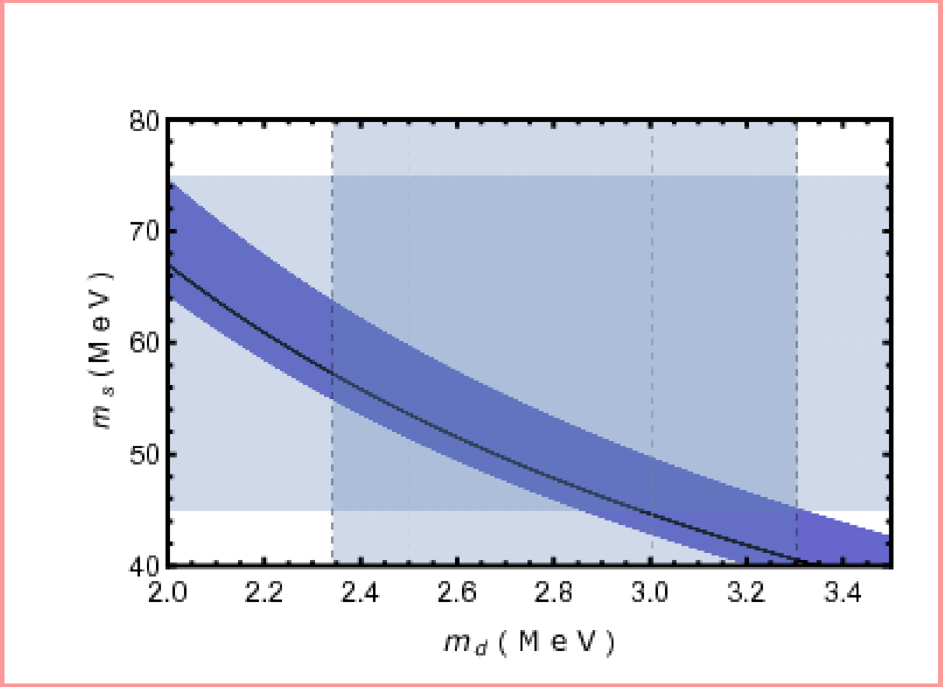
Phys. Rev. D95 (2017) 095030

neutrinos and new physics landscape

from oscillations to charged fermion masses

Golden Q-L unification

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



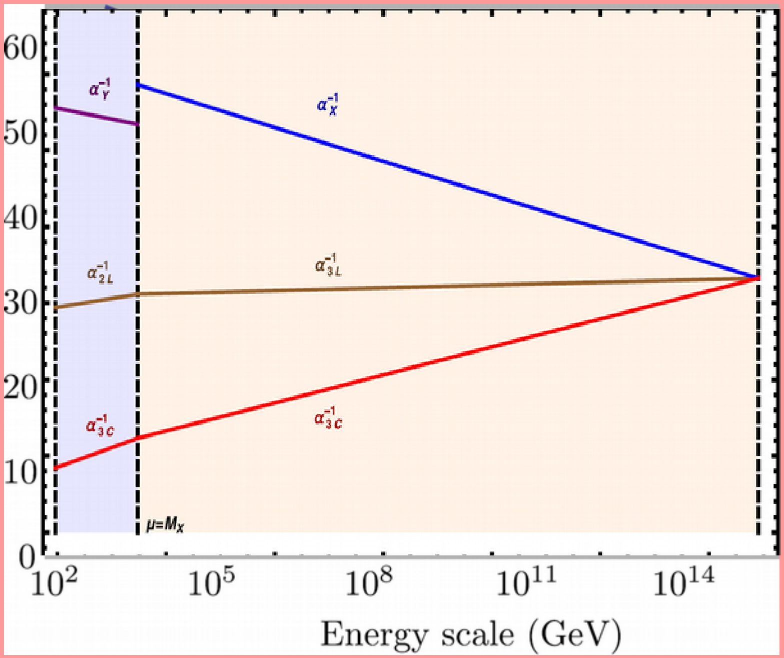
Morisi et al Phys.Rev. D84 (2011) 036003

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

neutrino mass as the cause of unification?



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

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

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

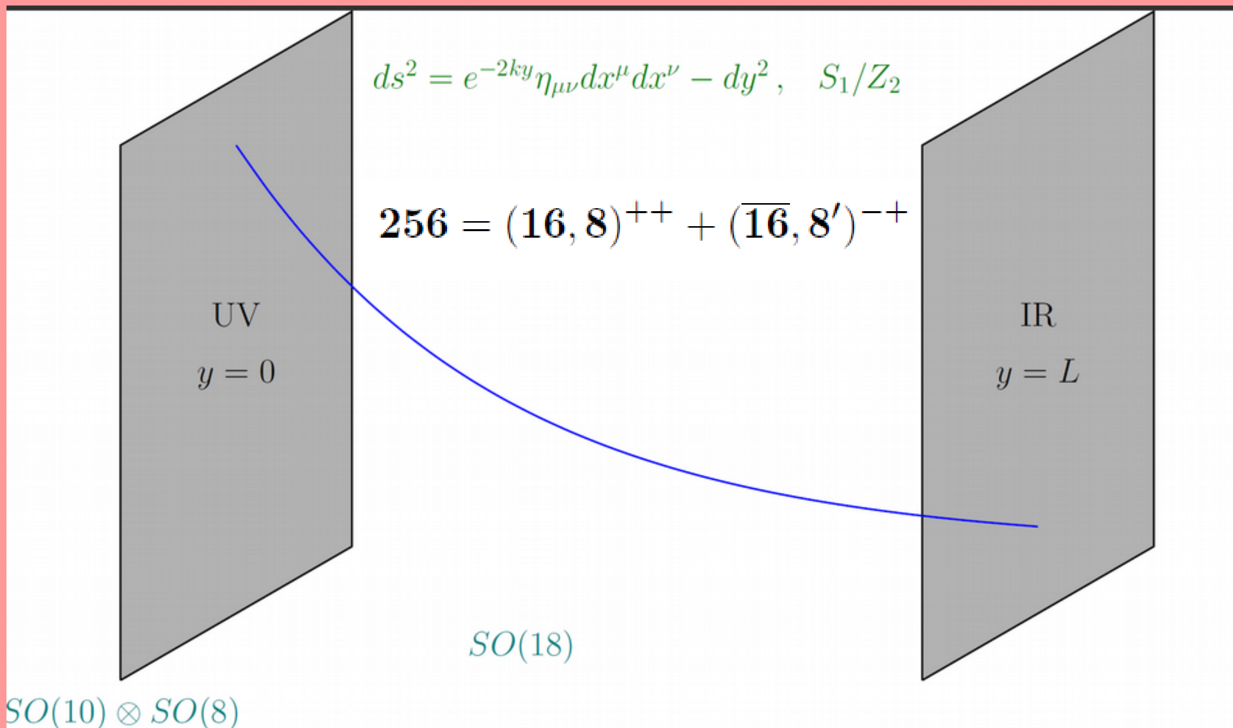
Unifying forces & families

Inspired by beauty of neutrinos in SO10

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

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

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



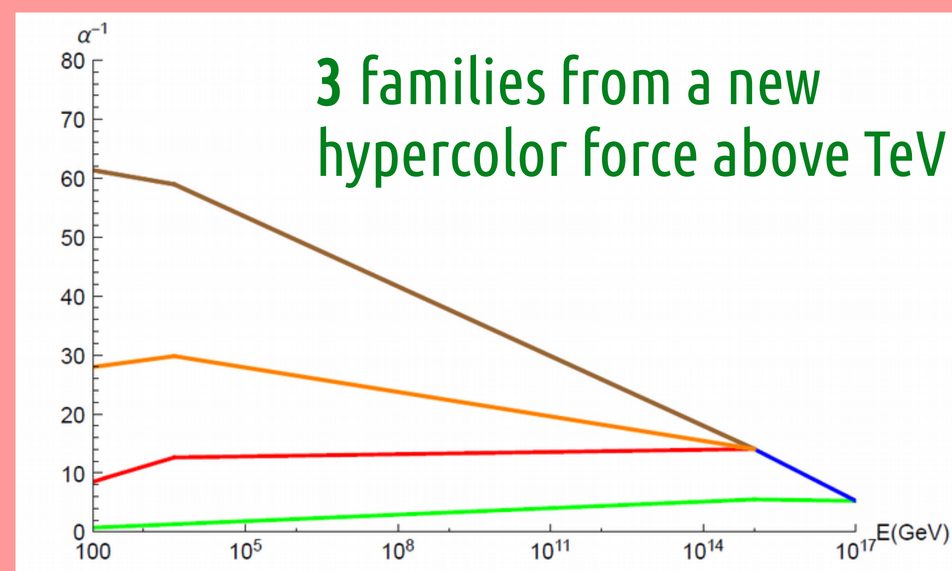
warping is the way

promote M4 to AdS5 & use orbifold BC to decouple mirrors

Reig, Valle, Vaquera-Araujo, Wilczek

Phys.Lett. B774 (2017) 667-670

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



neutrinos make the particle landscape very rich

many new Phenomena @ the high energy & high intensity frontier

- Understanding small m-nu may restore EW consistency,
- bring in new higgses, new decays
- new gauge bosons & fermions : 331 vs LR symmetry
- novel pathways to unification ..
- Novel aspects of LFV/CPV (e.g. mainly at high energies, w/o neutrino mass)
- LNV @ high energies (short-range 0nuββ decay)
- Even some input for B anomalies

- *Cosmology from neutrino mass generation (another talk)*

Back-ups

status of neutrino oscillations 2017

P.F. de Salas et al,
http://arxiv.org/abs/arXiv:1708.01186

the numbers

parameter	best fit ± 1σ	2σ range	3σ range
Δm^2_{21} $[10^{-5}\text{eV}^2]$	7.56±0.19	7.20–7.95	7.05–8.14
$\|\Delta m^2_{31}\|$ $[10^{-3}\text{eV}^2]$ (NO)	2.55±0.04	2.47–2.63	2.43–2.67
$\|\Delta m^2_{31}\|$ $[10^{-3}\text{eV}^2]$ (IO)	2.49±0.04	2.41–2.57	2.37-2.61
$\sin^2\theta_{12}/10^{-1}$	$3.21^{+0.18}_{-0.16}$	2.89–3.59	2.73–3.79
$\theta_{12}/^\circ$	$34.5^{+1.1}_{-1.0}$	32.5–36.8	31.5–38.0
$\sin^2\theta_{23}/10^{-1}$ (NO)	$4.30^{+0.20}_{-0.18}$ [a]	3.98–4.78 & 5.60–6.17	3.84–6.35
$\theta_{23}/^\circ$	41.0±1.1	39.1–43.7 & 48.4–51.8	38.3–52.8
$\sin^2\theta_{23}/10^{-1}$ (IO)	$5.96^{+0.17}_{-0.18}$ [b]	4.04–4.56 & 5.56–6.25	3.88–6.38
$\theta_{23}/^\circ$	50.5±1.0	39.5–42.5 & 48.2–52.2	38.5–53.0
$\sin^2\theta_{13}/10^{-2}$ (NO)	$2.155^{+0.090}_{-0.075}$	1.98–2.31	1.89–2.39
$\theta_{13}/^\circ$	$8.44^{+0.18}_{-0.15}$	8.1–8.7	7.9–8.9
$\sin^2\theta_{13}/10^{-2}$ (IO)	$2.140^{+0.082}_{-0.085}$	1.97–2.30	1.89–2.39
$\theta_{13}/^\circ$	$8.41^{+0.16}_{-0.17}$	8.0–8.7	7.9–8.9
δ/π (NO)	$1.40^{+0.31}_{-0.20}$	0.85–1.95	0.00–2.00
$\delta/^\circ$	252^{+56}_{-36}	153–351	0–360
δ/π (IO)	$1.44^{+0.26}_{-0.23}$	1.01–1.93	0.00–0.17 & 0.79–2.00
$\delta/^\circ$	259^{+47}_{-41}	182–347	0–31 & 142–360

local minimum in the second octant, at $\sin^2\theta_{23}$=0.596 with $\Delta\chi^2 = 2.08$ with respect to the global minimum.
local minimum in the first octant, at $\sin^2\theta_{23}$=0.426 with $\Delta\chi^2 = 1.68$ with respect to the global minimum for IO

Are the B decay anomalies related to neutrino oscillations?

Sofiane M. Boucenna [a], José W.F. Valle [b], Avelino Vicente [b,c,*]

Phys.Lett. B750 (2015) 367-371

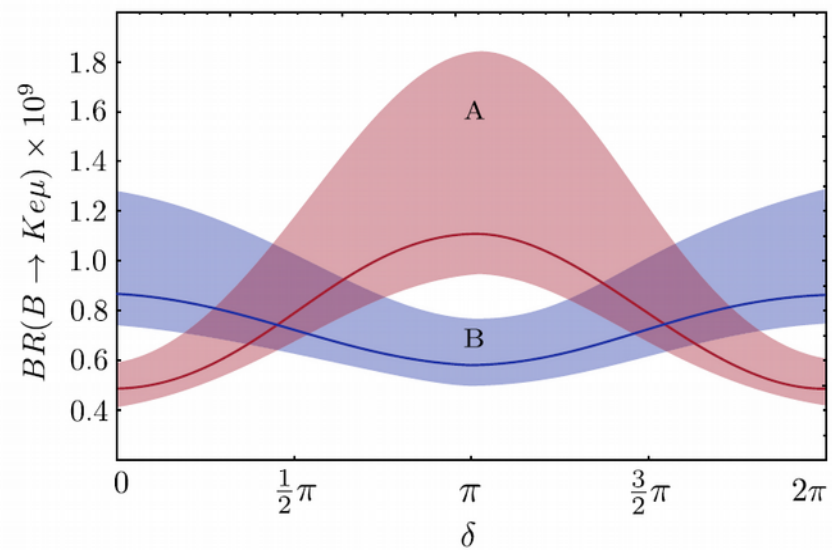
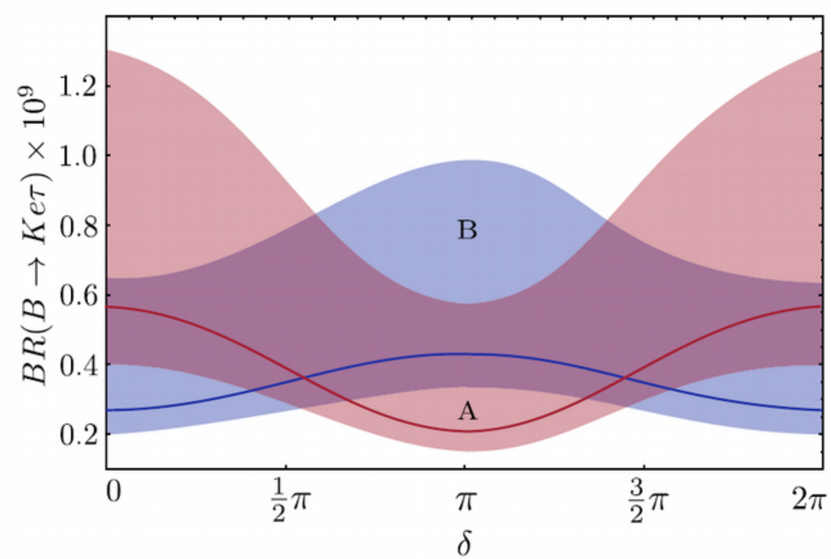
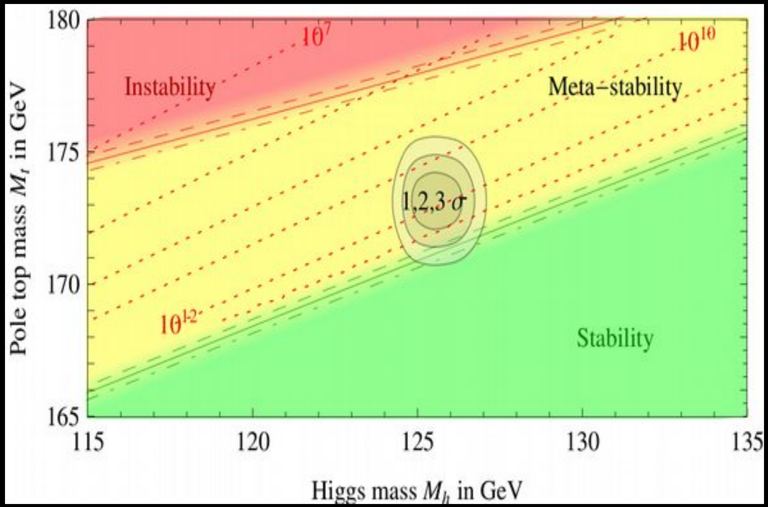


Fig. 1. The branching ratio of the decay $B \to Ke\mu$ versus the CP violating phase δ in scenarios A and B. The bands are obtained by taking the leptonic mixing angles within their 1σ range w.r.t. the best-fit value (solid line) [26].

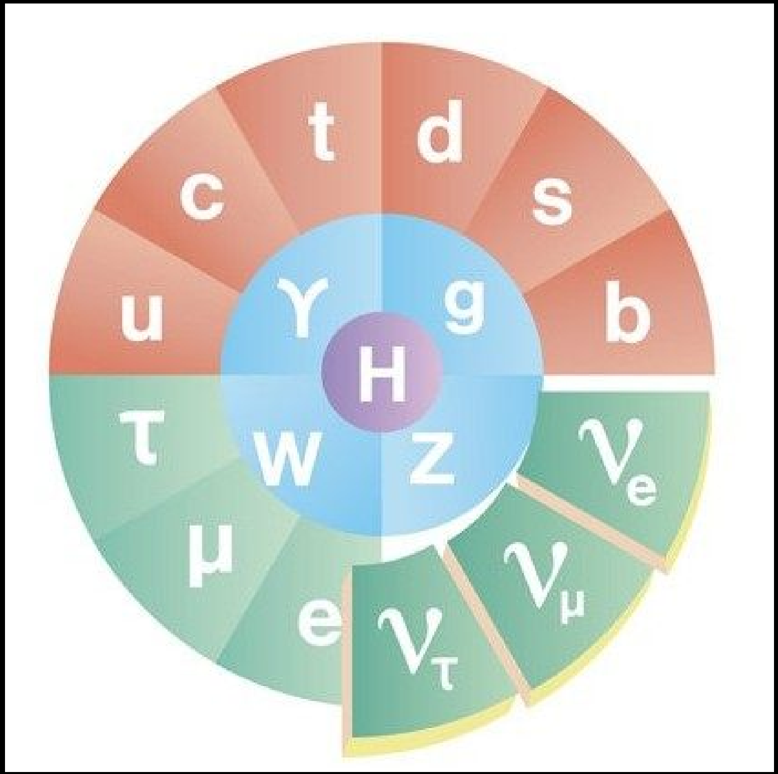


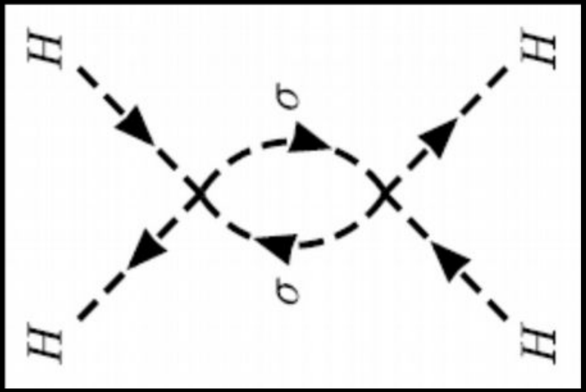


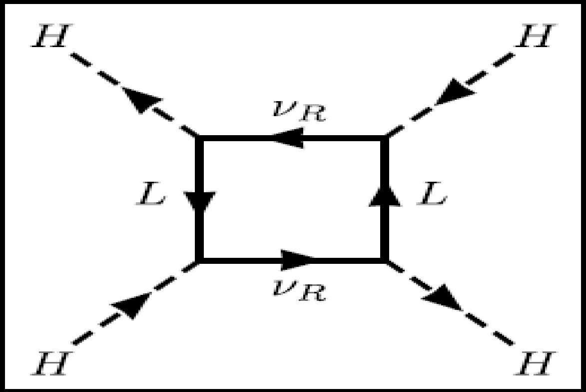
From Degrassi et al:
JHEP 1208 (2012) 098

neutrinos make the EW vacuum stable again

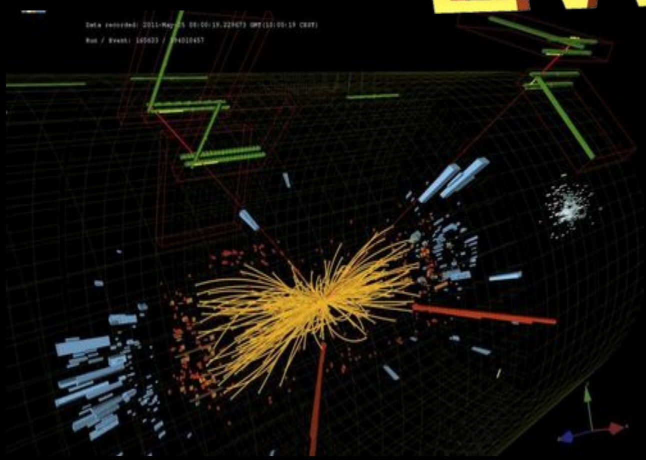
http://dx.doi.org/10.1103/PhysRevD.92.075028







theories of neutrino as EW breaking benchmarks



probe neutrino messengers

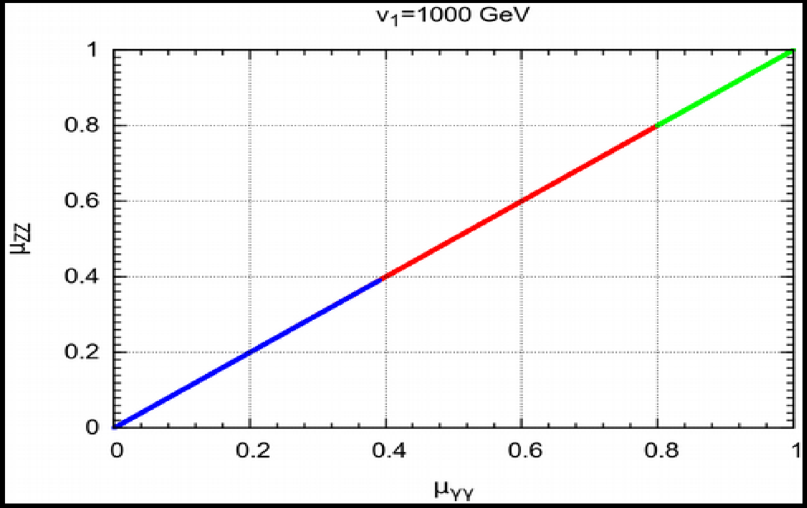
re-measure neutrino mixing angles ...

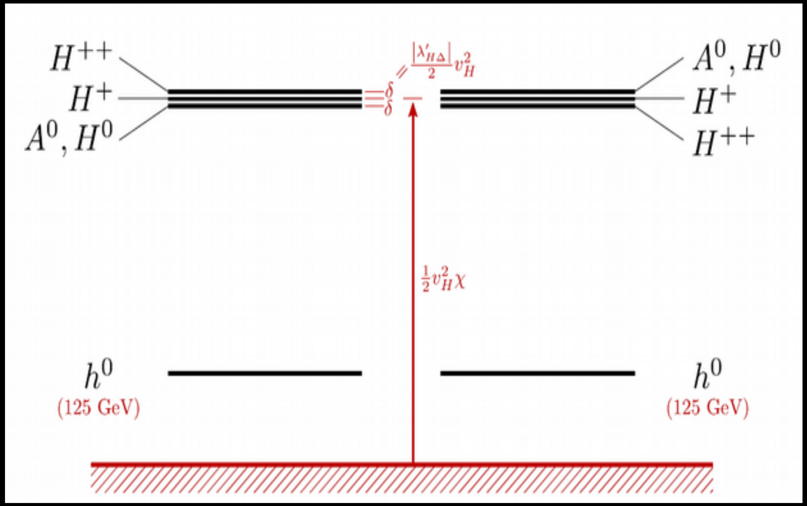
Higgs searches **Bonilla et al**

http://dx.doi.org/10.1016/j.physletb.2016.03.037

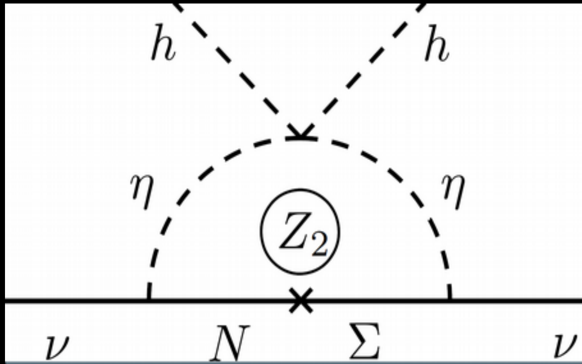
http://dx.doi.org/10.1088/1367-2630/18/3/033033

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






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

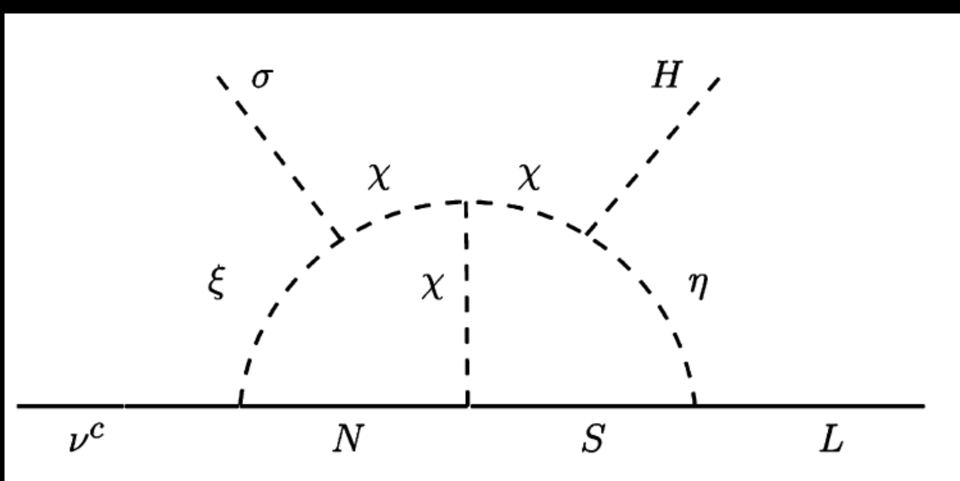


Scotogenic dark matter

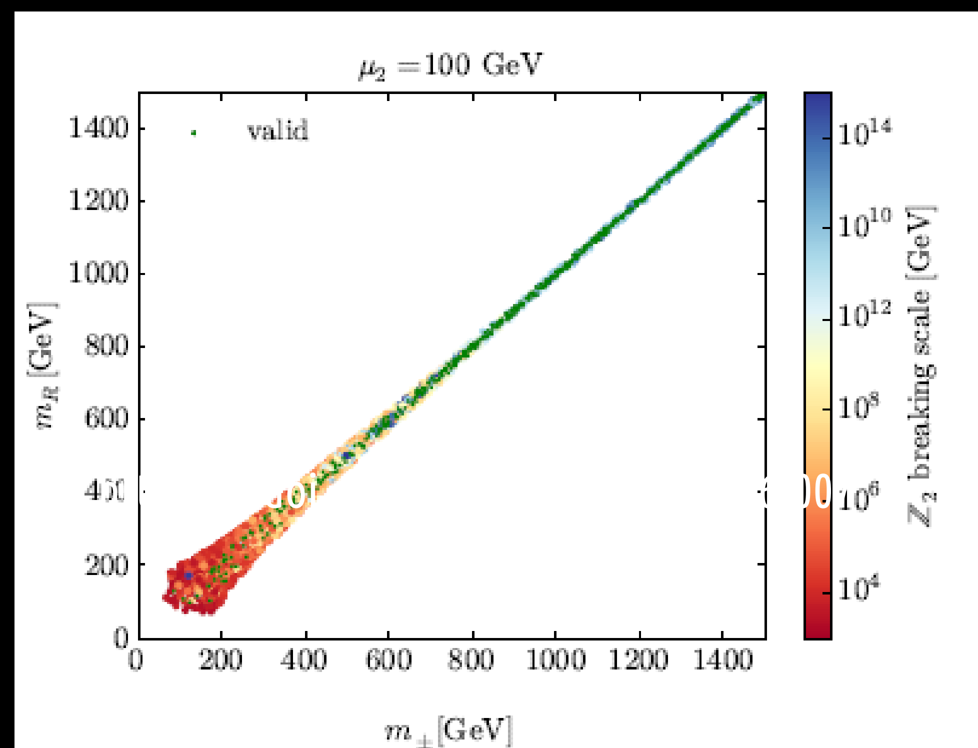
	Standard Model			Fermions		Scalars	
	L	e	ϕ	Σ	N	η	Ω
Generations	3	3	1	1	1	1	1
$SU(2)_L$	2	1	2	3	1	2	3
$U(1)_Y$	-1/2	-1	1/2	0	0	1/2	0
$\mathbb{Z}_2$	+	+	+	−	−	−	+

E Ma, Merle et al JHEP 1607 (2016) 013
Hirsch et al JHEP01(2016)007
Diaz et al http://dx.doi.org/10.1007/JHEP01(2016)007

dark matter as radiative neutrino mass messenger



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

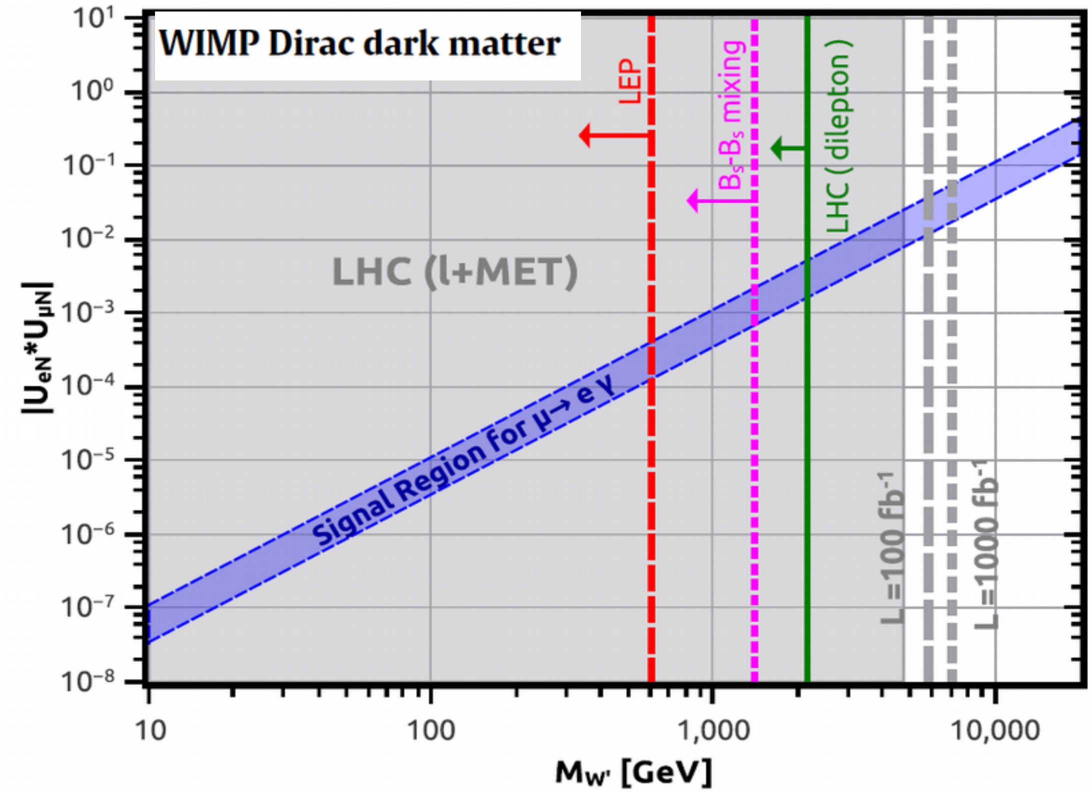


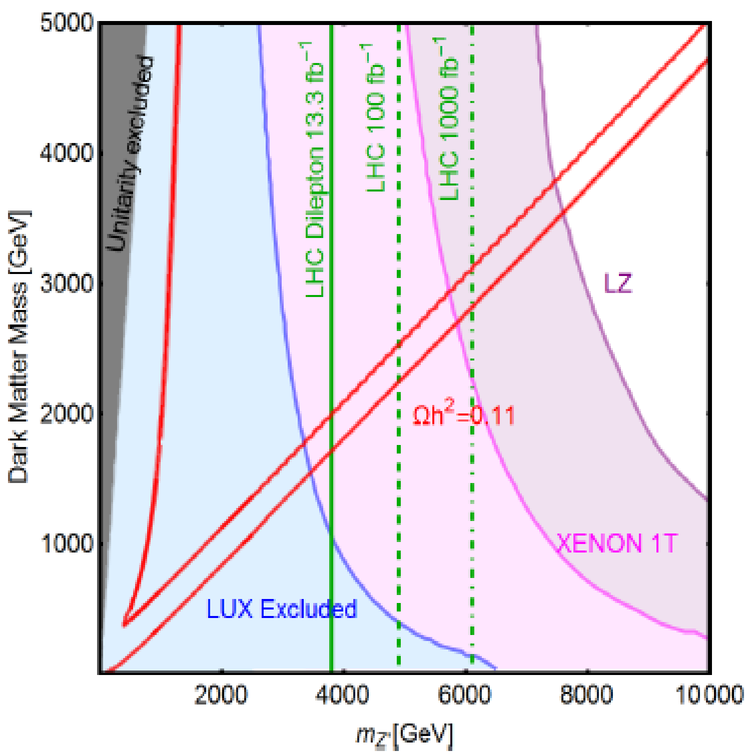
Matter-parity as a residual gauge symmetry: Probing a theory of cosmological dark matter

Alexandre Alves [a], Giorgio Arcadi [b], P.V. Dong [c], Laura Duarte [d], Farinaldo S. Queiroz [b,*], José W.F. Valle [e]

Phys.Lett. B772 (2017) 825–831

dark matter & neutrinos



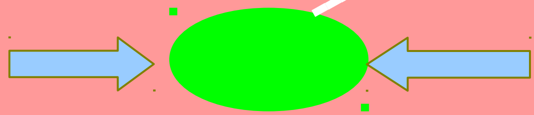


LIGHTEST NEUTRALINO DECAYS: PROBING NUs @ LHC

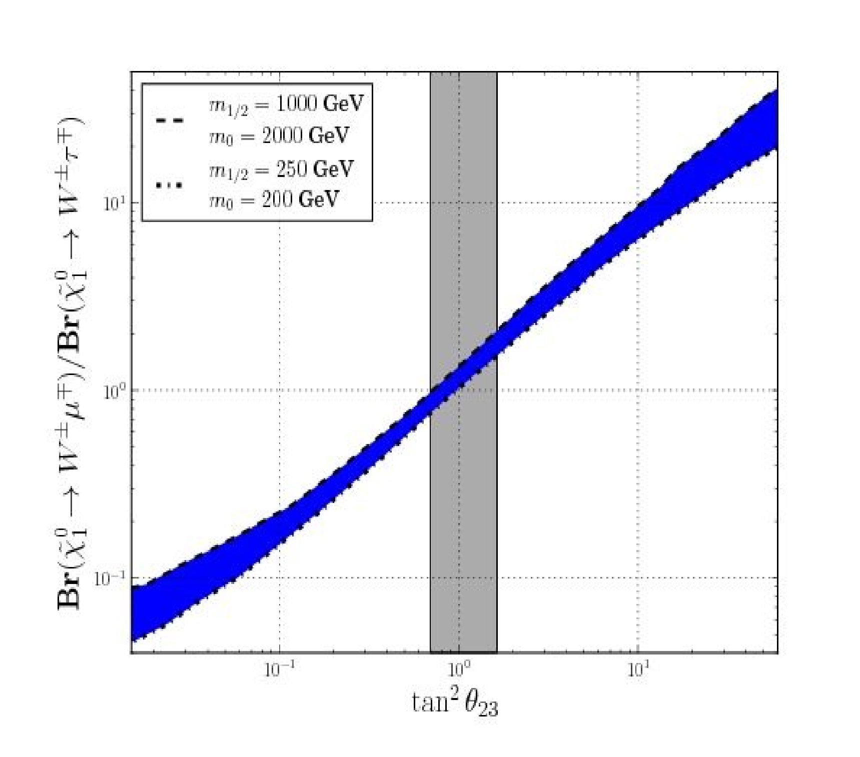
De Campos et al
Phys.Rev. D86 (2012) 075001

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

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



Lightest neutralino decay correlates with atm angle



Lightest neutralino decay length