neutrino landscape

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Astroparticles and High Energy Physics Group

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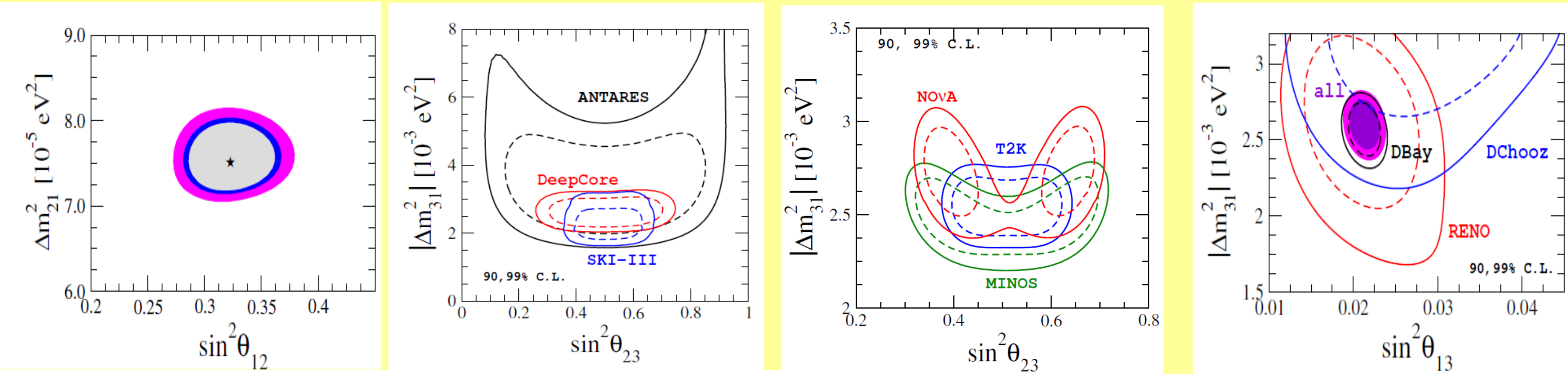
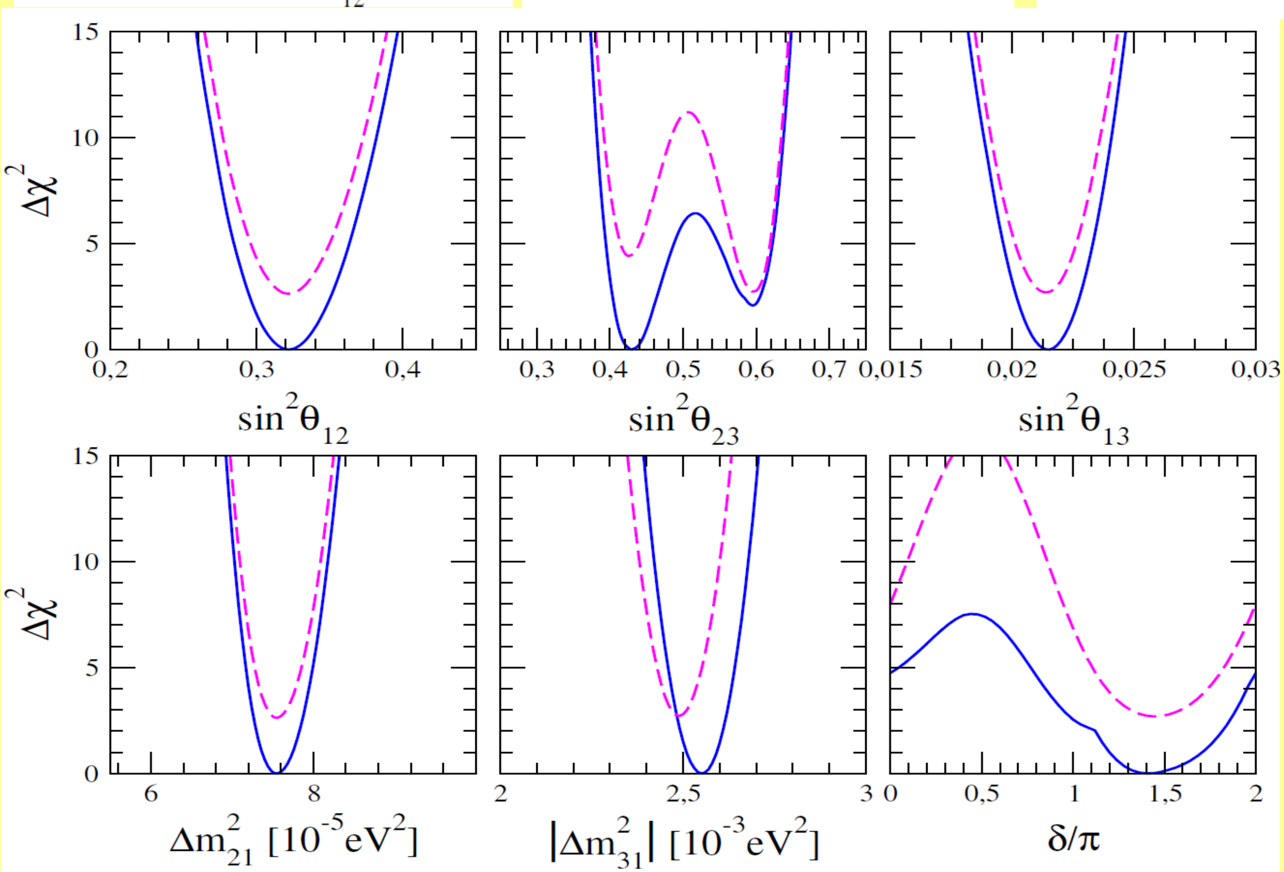
https://www.facebook.com/ific.ahep/

LAUNCH 17 14-15 September 2017, MPIK Heidelberg

status of neutrino oscillations 2017





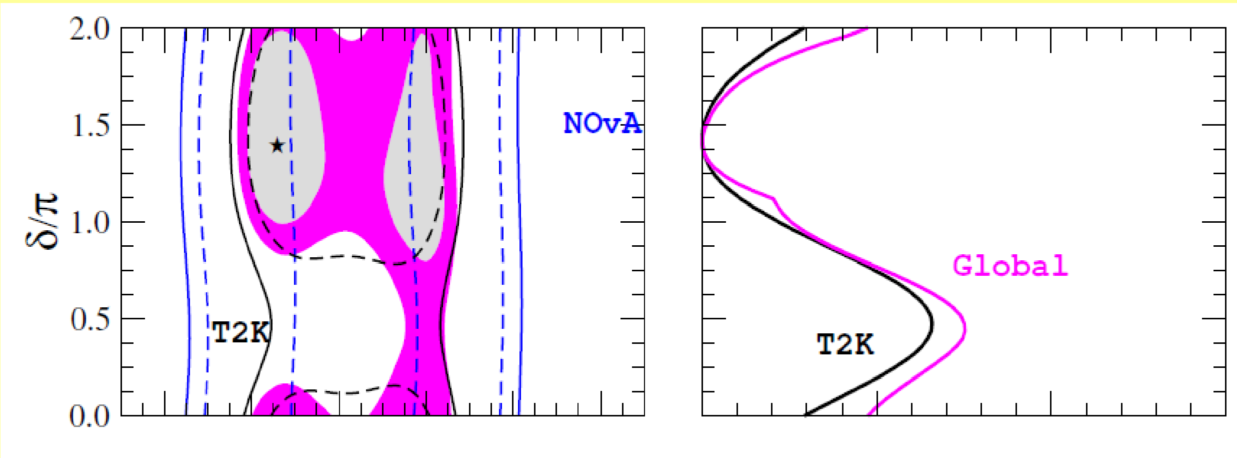
P.F. de Salas et al,
http://arxiv.org/abs/arXiv:1708.01186

Consistent global picture
Good agreement w/ NuFit & Bari

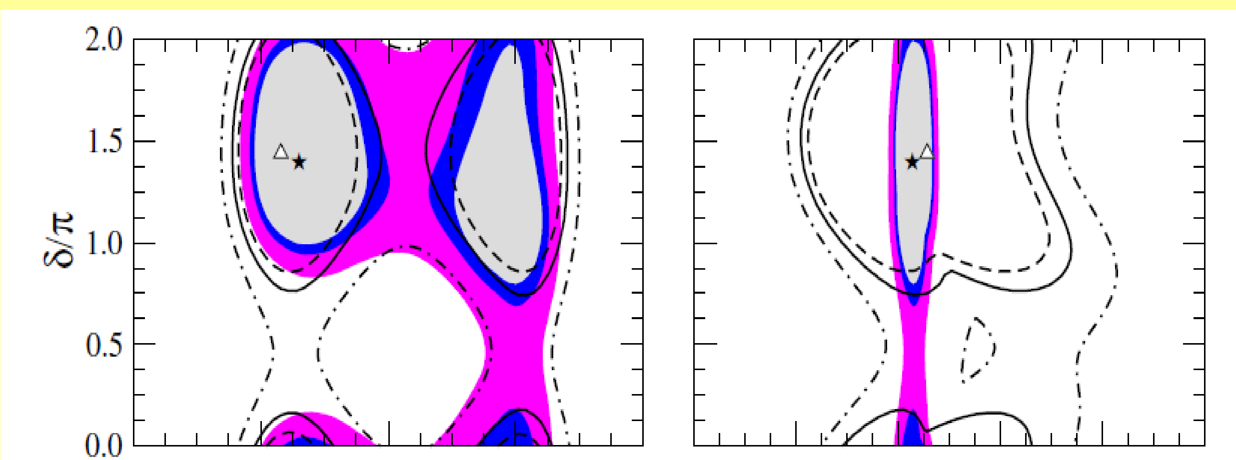
current hints

normal ordering is preferred by $\Delta\chi^2 = 2.7$

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



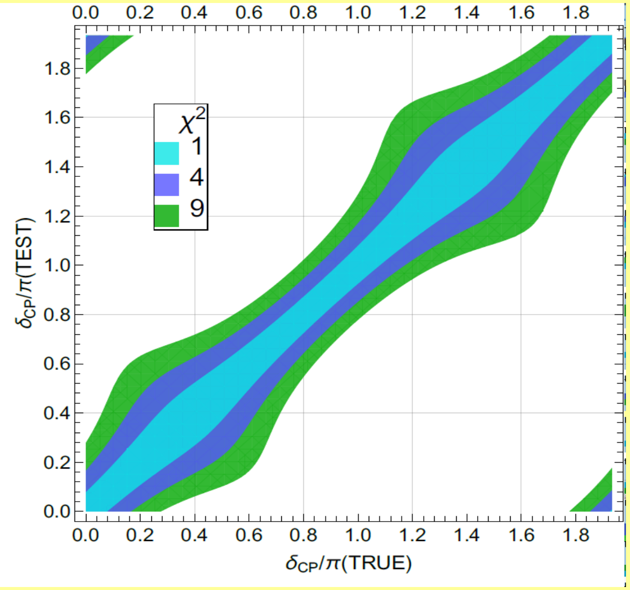
here we hide our ignorance

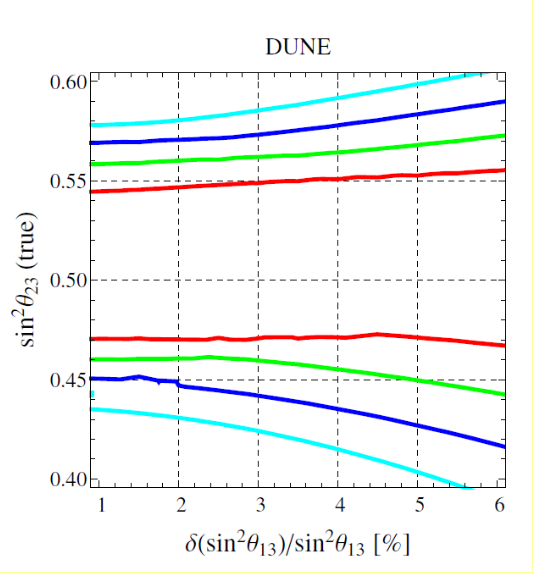


$\sin^2\theta_{23}$

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

the future





10.1016/j.physletb.2017.05.080

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

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 opportunities 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 …

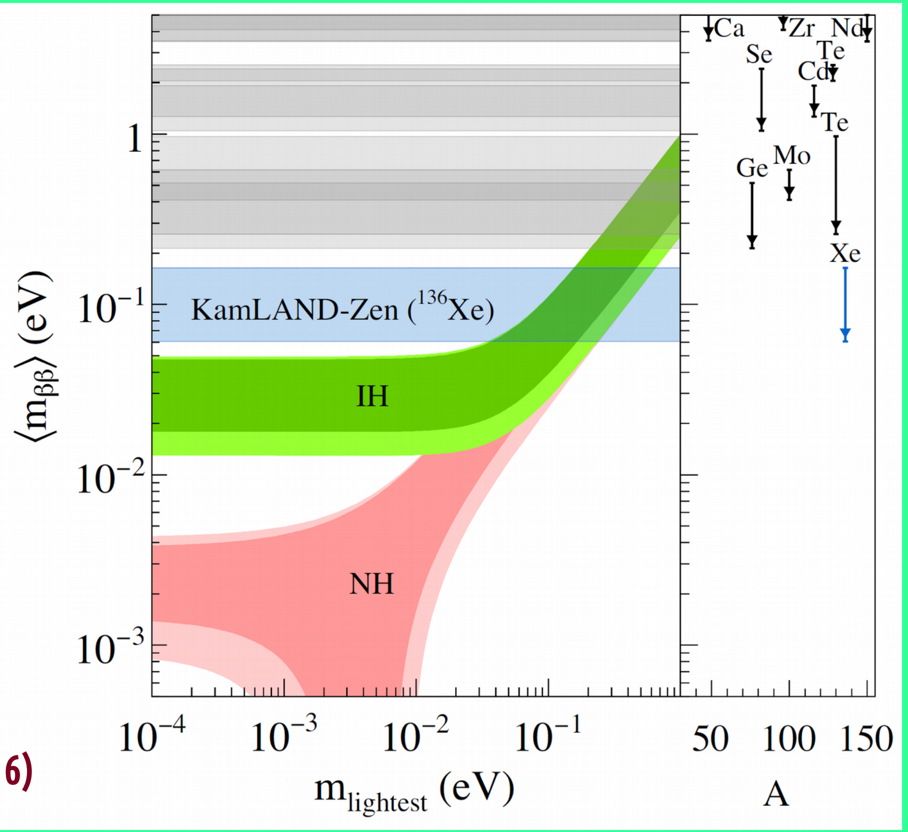
the neutrino mass scale

beta decay
0dbd & 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



KamLAND-Zen PRL117 (2016)

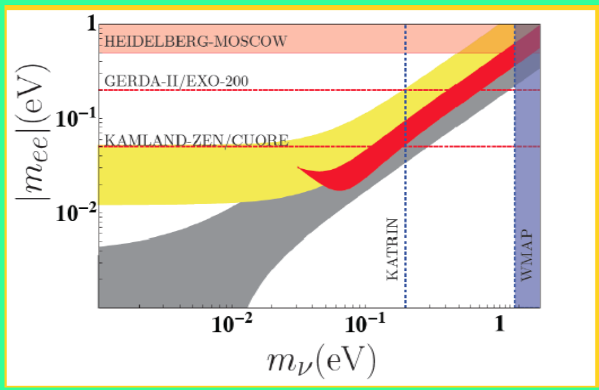
nEXO, CUORE , LEGEND (nGERDA/Majorana) ...

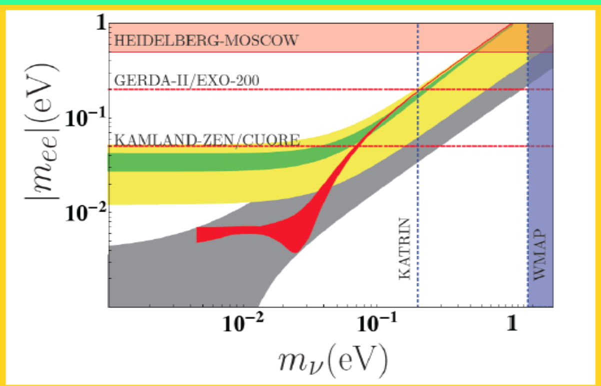
lower bounds even for normal ordering

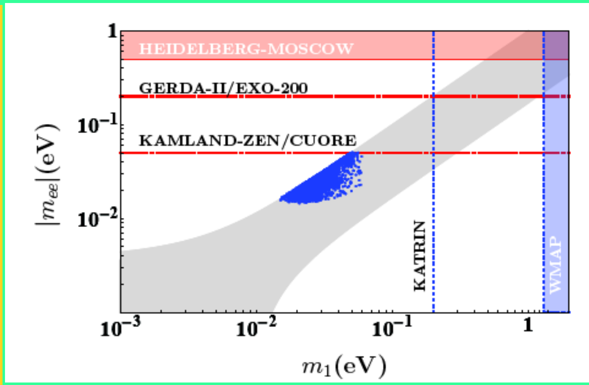
Dorame et al
NPB861 (2012) 259-270

Dorame et al
PhysRevD.86.056001

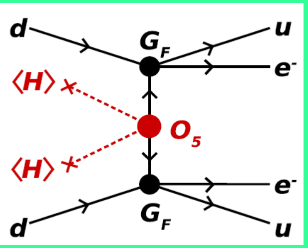
King et al
Phys. Lett. B 724 (2013) 68



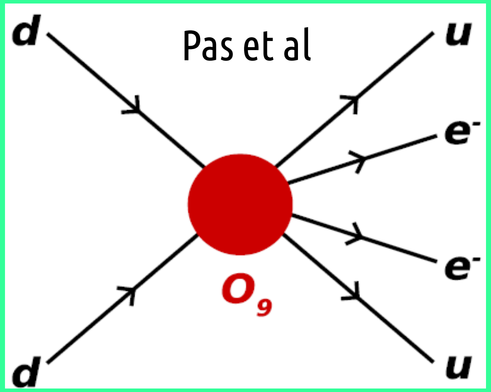


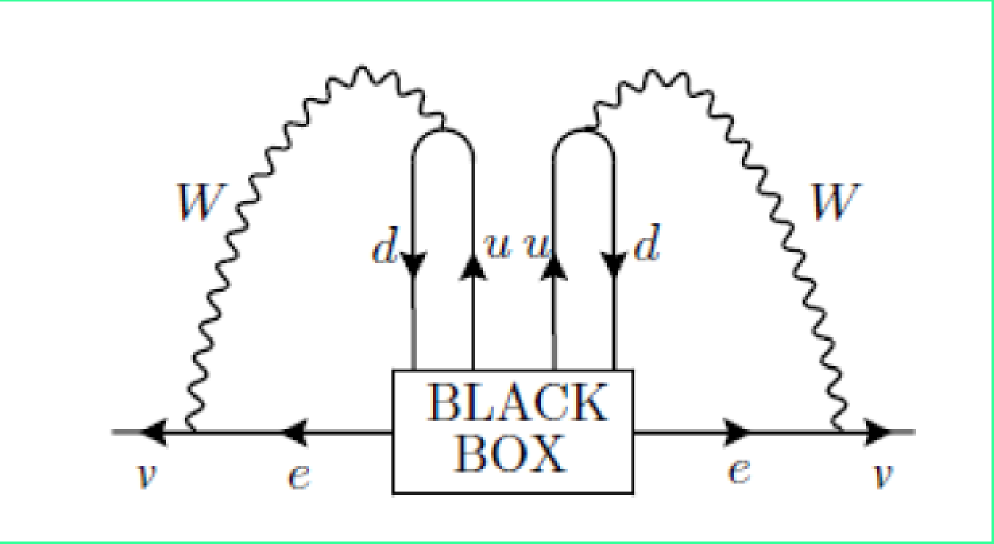


Significance



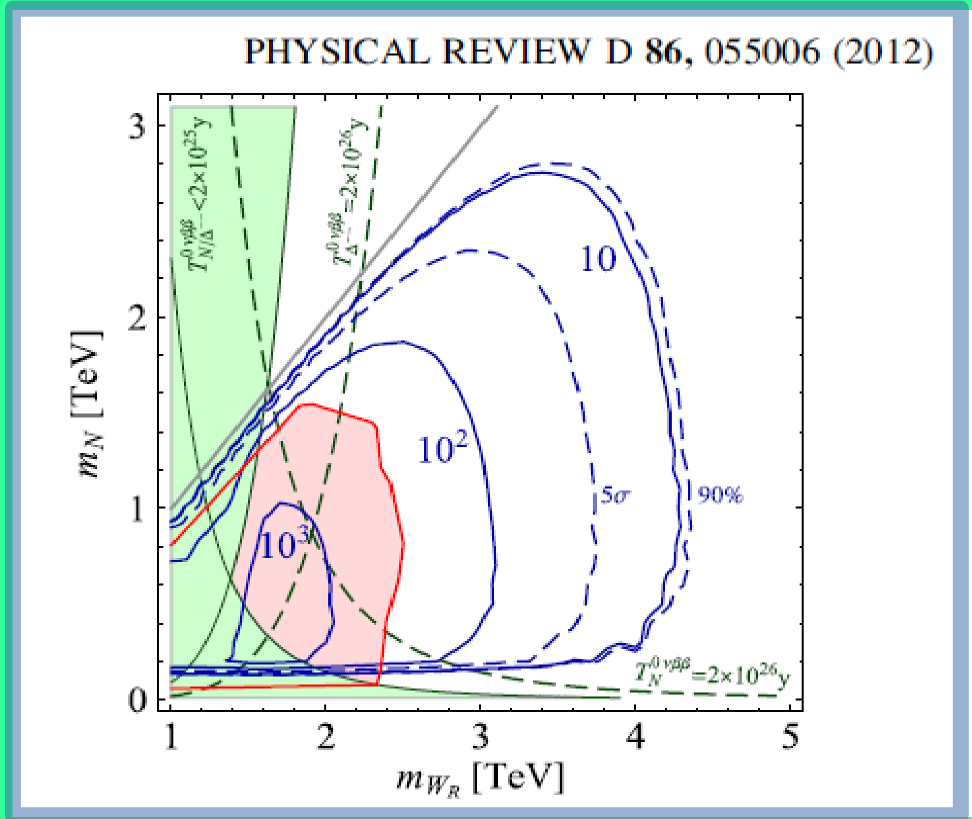
Pas et al





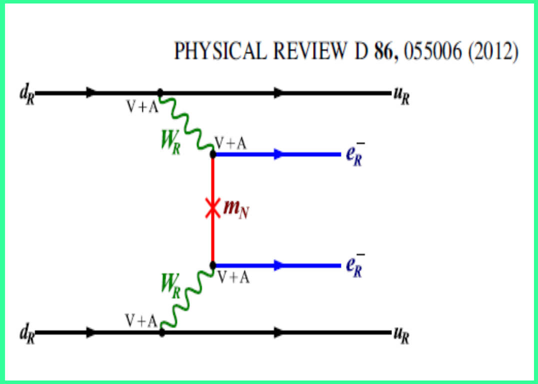
Schechter, Valle 82

Lindner et al JHEP 1106 (2011) 091

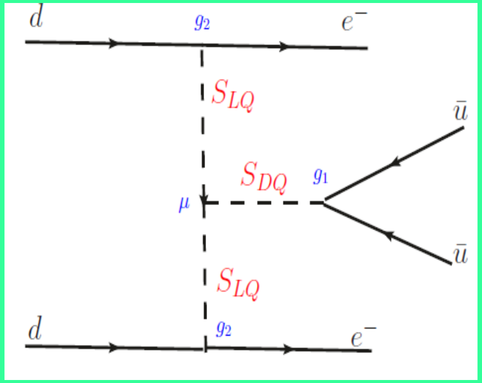


Heavy mediators

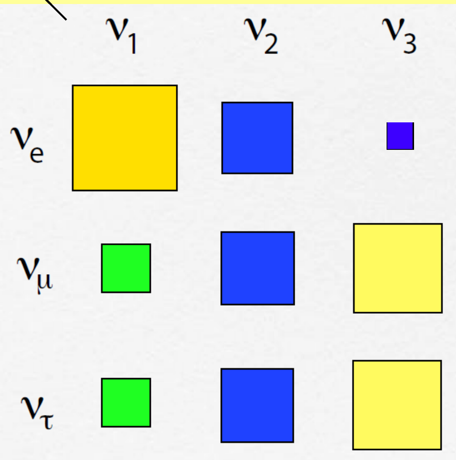
Deppisch et al



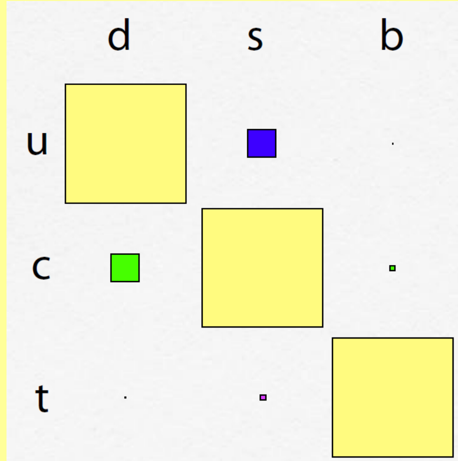
Hirsch et al



the questions



vs



why lepton mixing is large w.r.t. CKM?

flavor symmetry? is it common with quarks?

Cabbibo angle as a common seed?

Phys.Rev. D86 (2012) 051301

Phys.Lett. B748 (2015) 1-4

can one predict mass ordering?

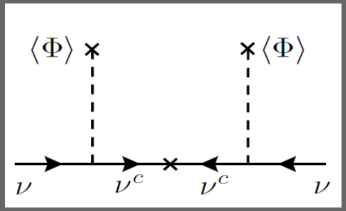
can we predict the leptonic CP phase?

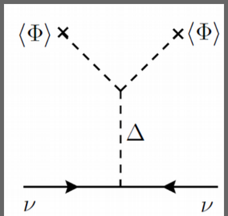
http://arxiv.org/abs/arXiv:1706.00210
http://arxiv.org/abs/arXiv:1705.06320

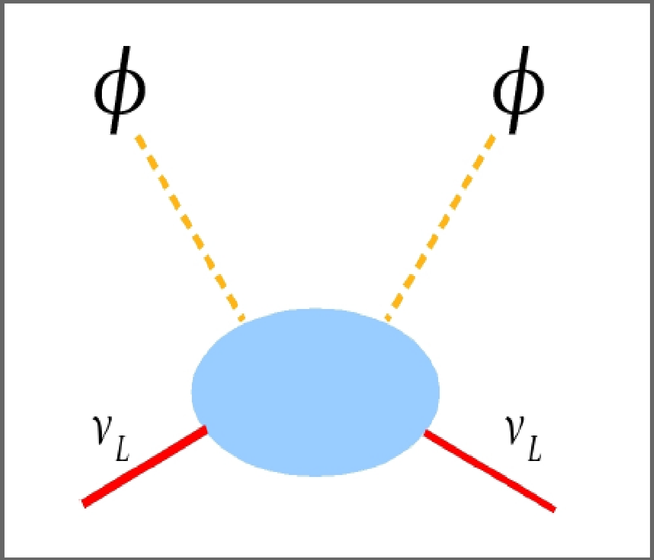
Dirac or Majorana?

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

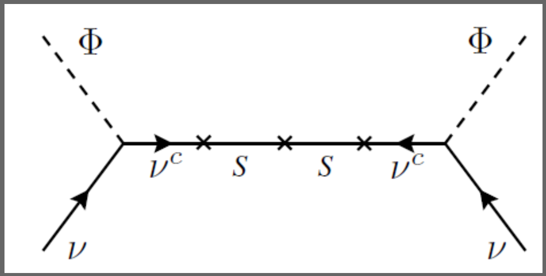
$$v_3 v_1 \sim {v_2}^2$$

coefficient
mechanism
scale
flavor structure

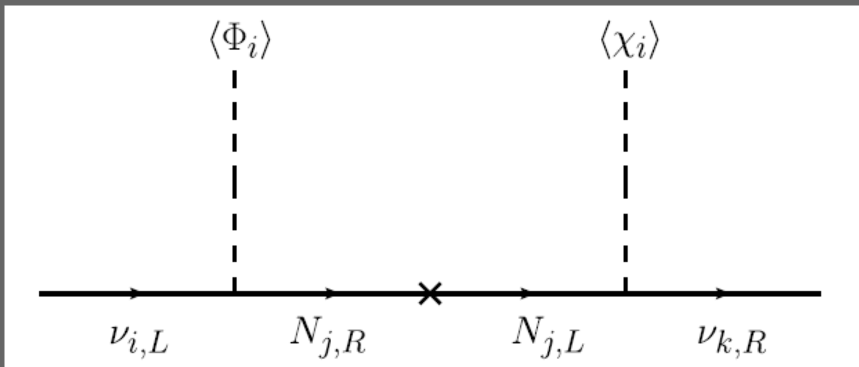
Arbitrary number of singlet messengers

LOW-SCALE SEESAW

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



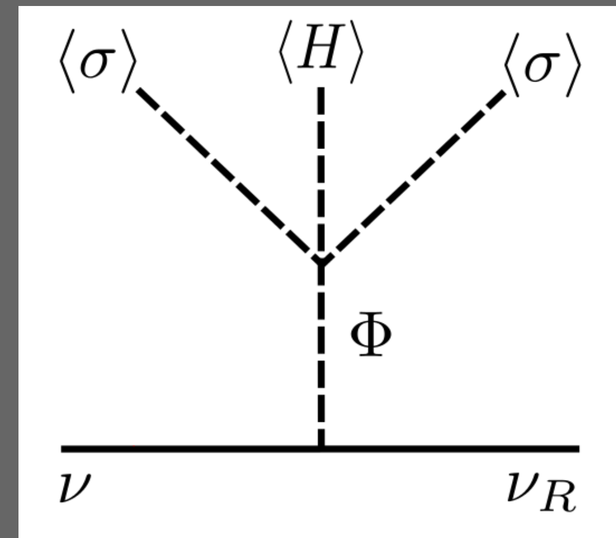
Seesawing a la Dirac



type1

Phys.Lett. B761 (2016) 431-436

Phys.Lett. B767 (2017) 209-213



type2

Phys.Lett. B762 (2016) 162-165

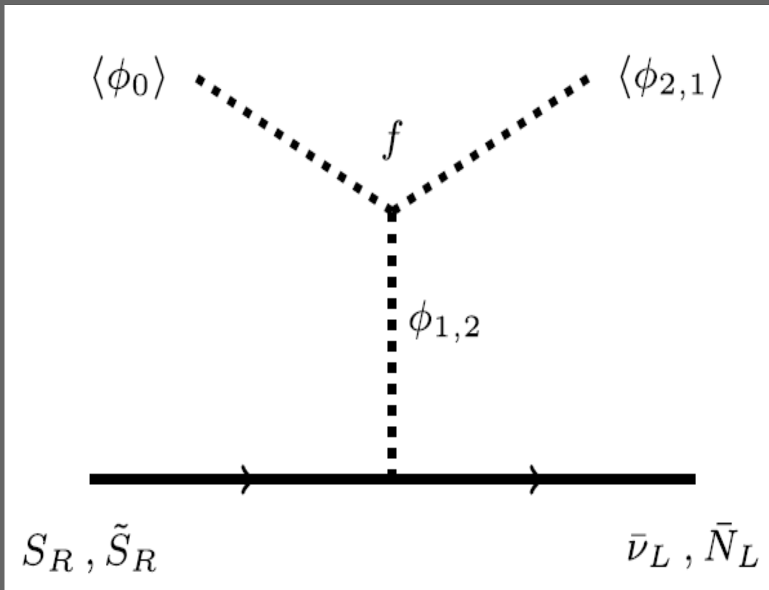
Phys.Rev. D94 (2016) 033012

symmetry protects small neutrino mass

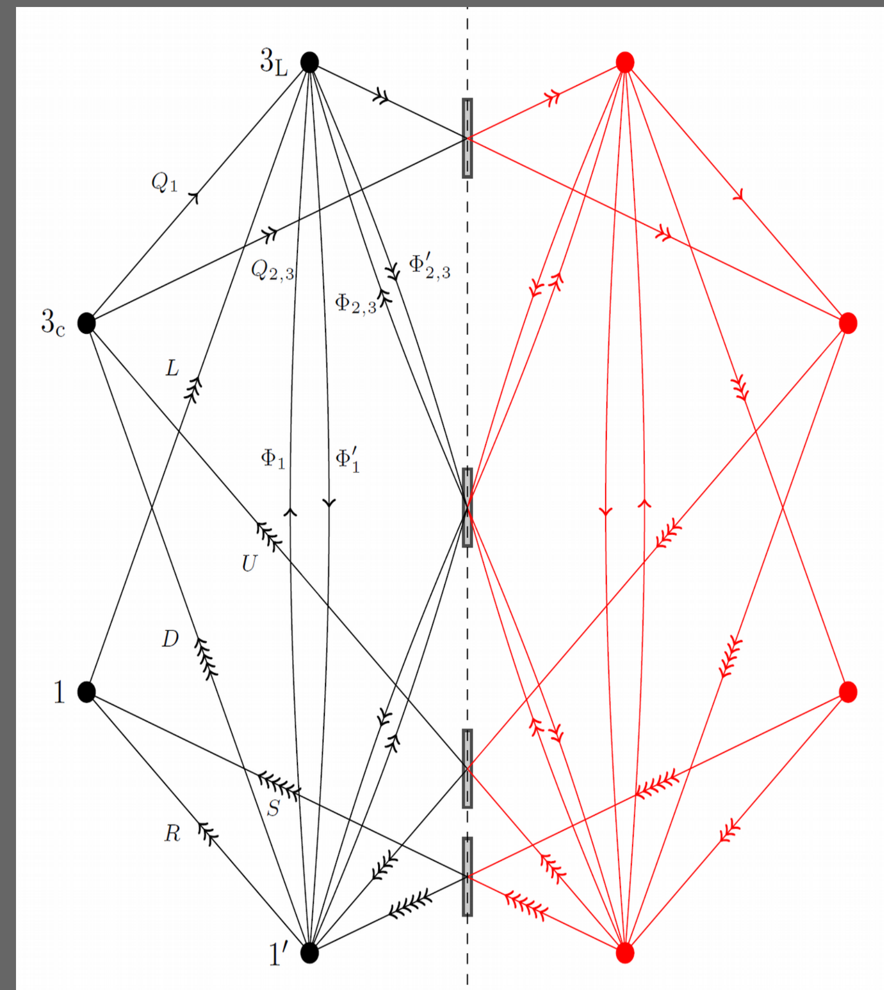
as in LR majorana seesaw

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

RH nu needed for completion



Physics Letters B 755 (2016) 363–366



Quiver consistency requires RH neutrino

some extra dim theories

Simplest flavor symmetry

A4

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

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

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

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

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

$$u_R \quad c_R \quad t_R$$

$$d_R \quad s_R \quad b_R$$

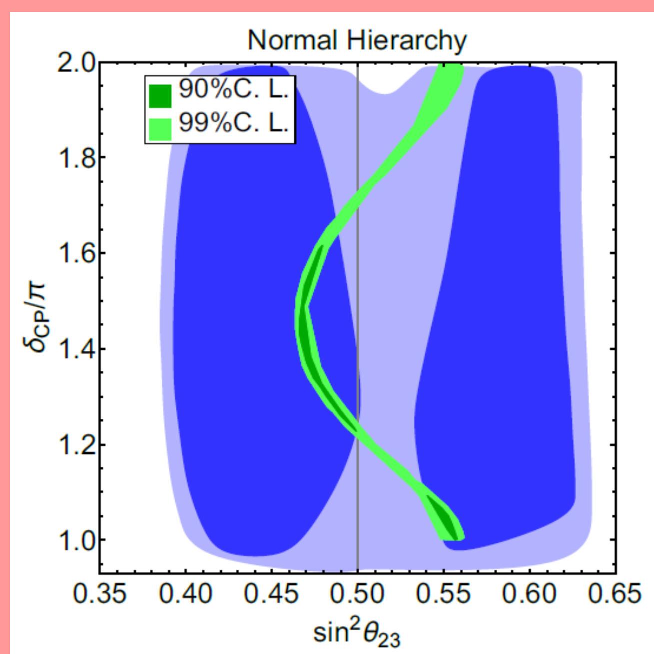
Babu-Ma-Valle PLB552 (2003) 207

Hirsch et al PRD69 (2004) 093006

Revamping ...

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

Constrained global fit 1708.03290



prefers for NO, LO, max CPV, as hinted

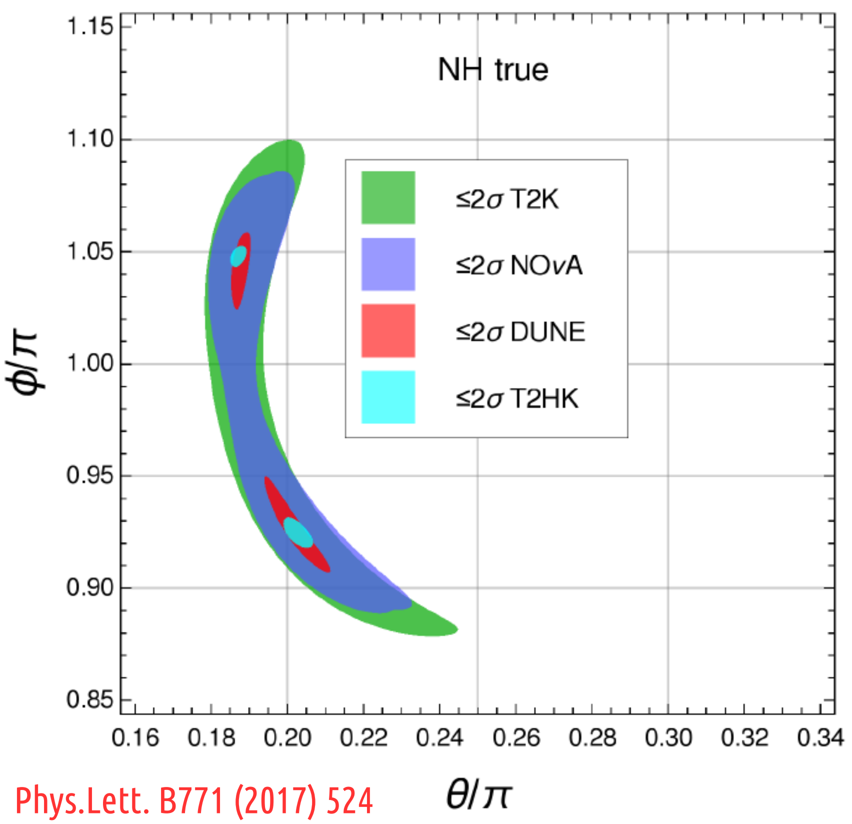
BUT

will it survive DUNE?

flavor correlations from warped SM

:Chen et al JHEP01(2016)007

constrained global fitting



Phys.Lett. B771 (2017) 524

can be projected in the ignorance plane
used to make predictions for dune, etc

Phys. Rev. D 95, 095030 (2017)

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

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

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

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

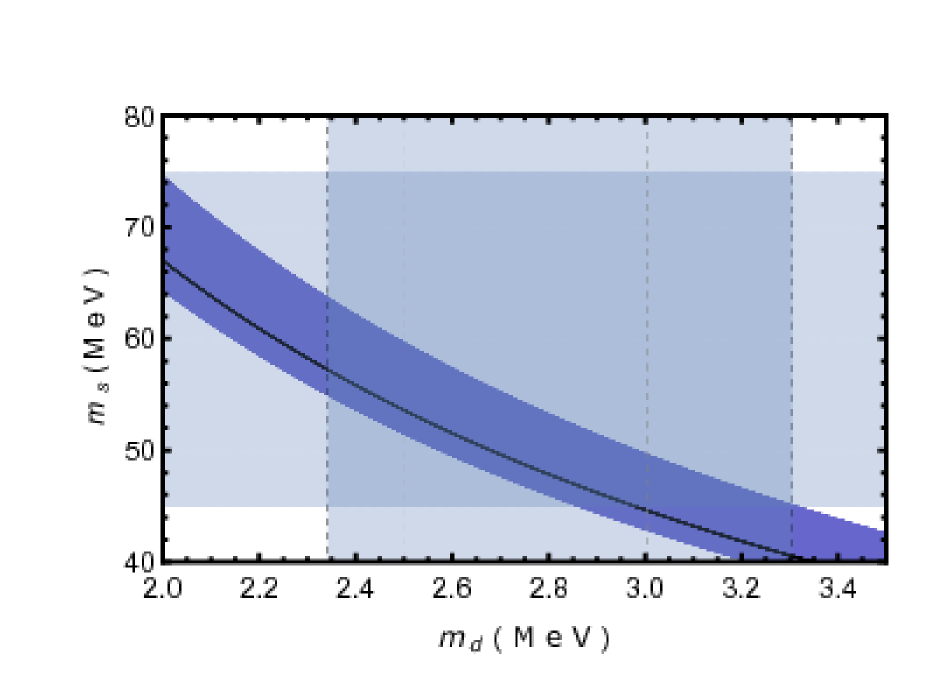
breaking taboos with neutrinos

breaking taboos with neutrinos - 1

relating quark & lepton masses without GUTS

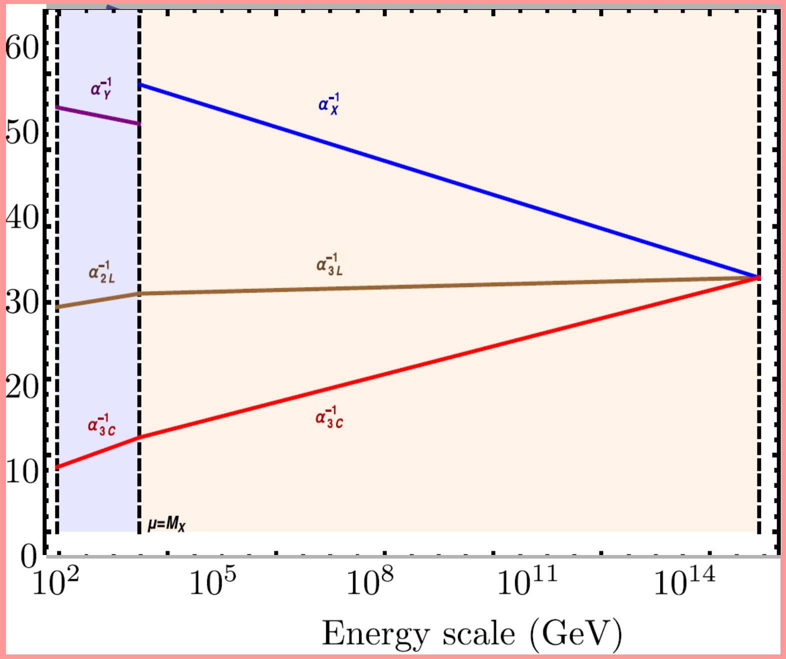
flavor dependent b-tau unification

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



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

breaking taboos with neutrinos - 2



neutrinos causing unification

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

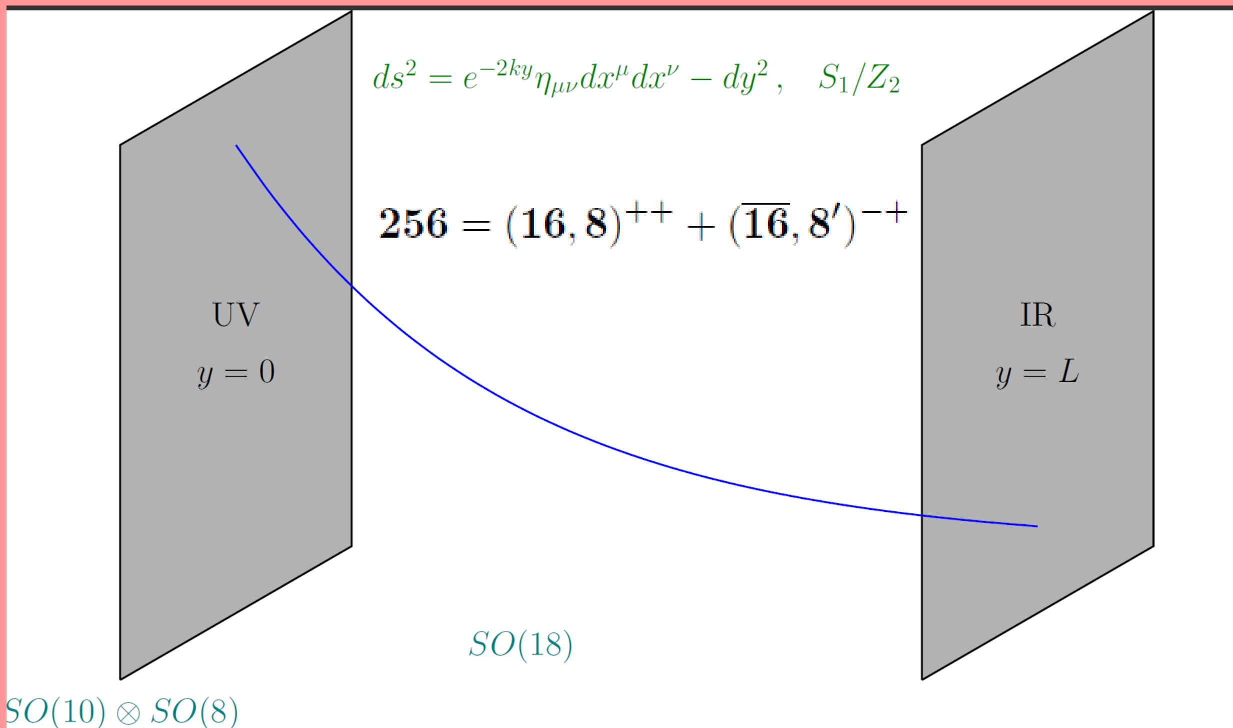
Boucenna et al Phys. Rev. D 91, 031702 (2015)

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

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

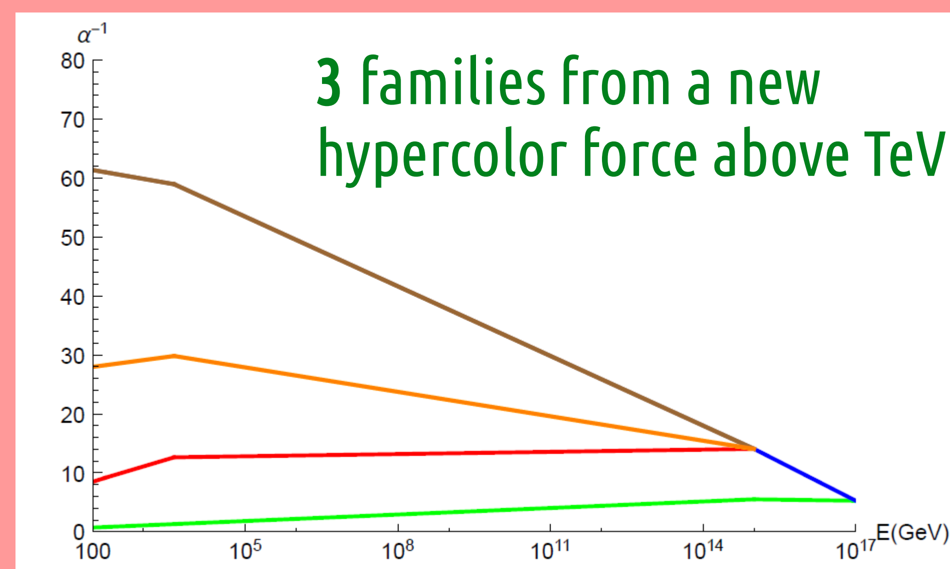
warping is the way

promote M4 to AdS5 & use orbifold BC to decouple mirrors

Reig, Valle, Vaquera-Araujo, Wilczek

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

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



conclusions

plethora of new phenomena @ the high energy & high intensity frontier

- non-unitarity => new CPV in neutrino oscillations
- EW consistency, new higgses, new decays
- new gauge boson & fermions : 331 vs LR symmetry
- novel HE completion & unification .. B anomalies ..
- LFV mainly at high energies
- LFV/CPV with no neutrino mass
- LNV @ high energies (short-range 0nuββ decay)
- *Cosmology as an emergent theory of neutrino mass generation…*

Congratulations Manfred for your dynamical career!

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}eV^2]	7.56±0.19	7.20–7.95	7.05–8.14
$\|\Delta m^2_{31}\|$ [10^{-3}eV^2] (NO)	2.55±0.04	2.47–2.63	2.43–2.67
$\|\Delta m^2_{31}\|$ [10^{-3}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
$\theta_{12}/°$	$34.5^{+1.1}_{-1.0}$	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
$\theta_{23}/°$	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
$\theta_{23}/°$	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
$\theta_{13}/°$	$8.44^{+0.18}_{-0.15}$	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
$\theta_{13}/°$	$8.41^{+0.16}_{-0.17}$	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
$\delta/°$	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
$\delta/°$	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