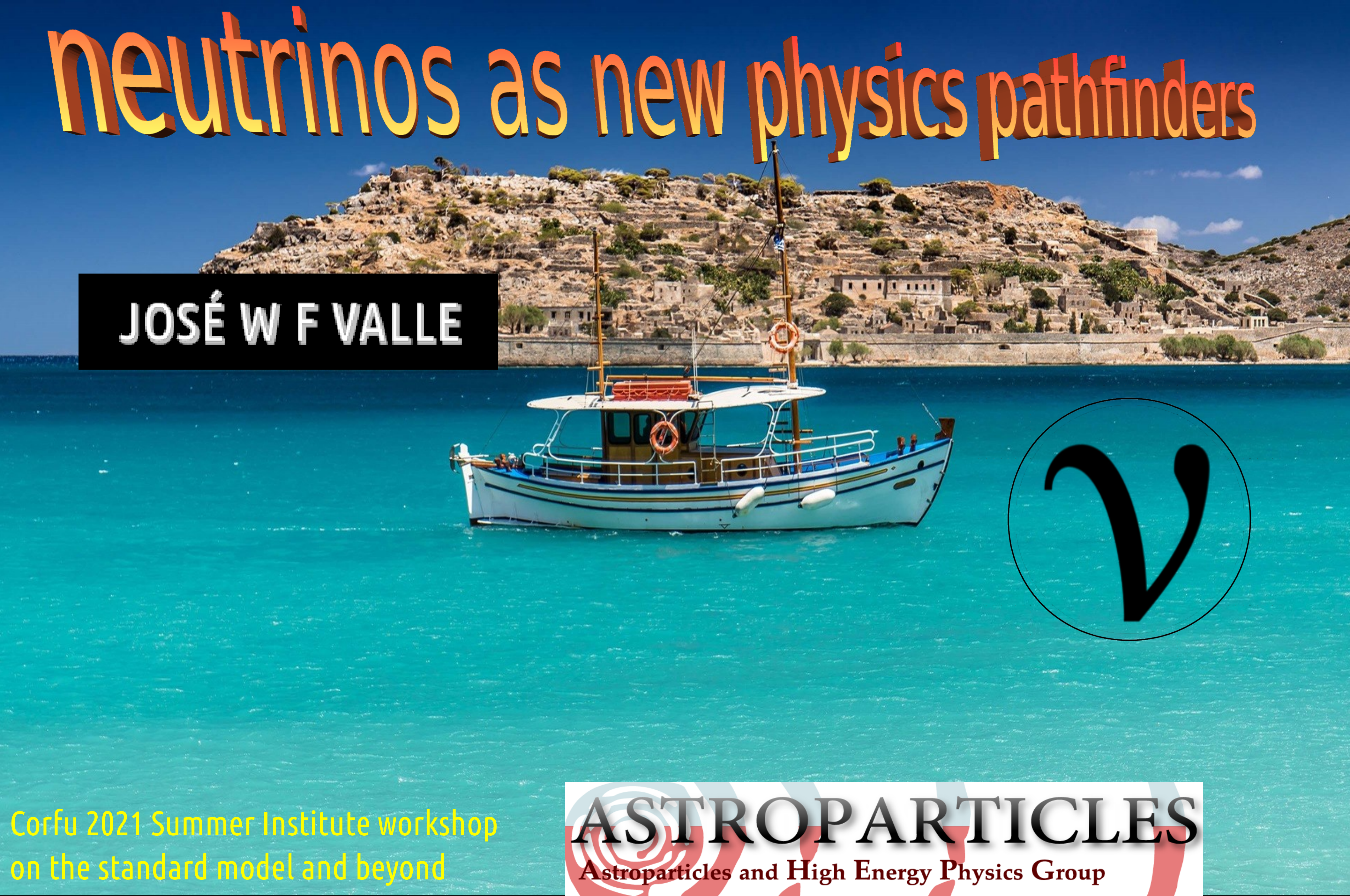
neutrinos as new physics pathfinders



JOSÉ W F VALLE

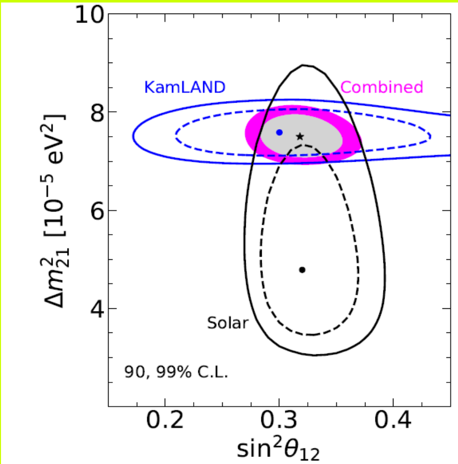
ν

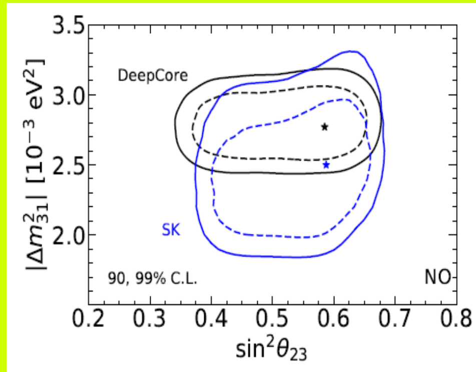
Corfu 2021 Summer Institute workshop
on the standard model and beyond

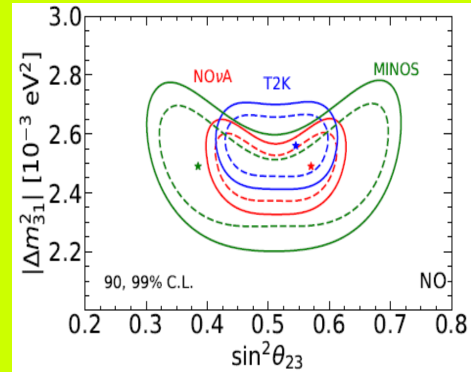
ASTROPARTICLES
Astroparticles and High Energy Physics Group

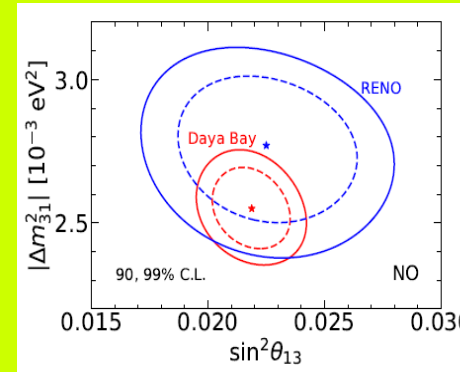
IFIC INSTITUT DE FÍSICA CORPUSCULAR
VNIVERSITAT DE VALÈNCIA
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
GENERALITAT VALENCIANA
Conselleria d'Educació, Investigació, Cultura i Esport

neutrino oscillations status









consistent global picture
good determination of lepton mixing

$$U^{\rm NO} = \begin{pmatrix} 0.7838 \to 0.8442 & 0.5133 \to 0.6004 & (-0.1568 \to 0.1489) + i(-0.1182 \to 0.1520) \\ (-0.4831 \to -0.2394) + i(-0.0749 \to 0.0963) & (0.4635 \to 0.6749) + i(-0.0521 \to 0.0668) & 0.6499 \to 0.7719 \\ (0.3068 \to 0.5391) + i(-0.0643 \to 0.0933) & (-0.6897 \to -0.4821) + i(-0.0446 \to 0.0644) & 0.6161 \to 0.7434 \end{pmatrix}$$

$$U^{\rm IO} = \begin{pmatrix} 0.7835 \to 0.8440 & 0.5133 \to 0.6005 & (-0.1423 \to 0.1490) + i(0.0191 \to 0.1553) \\ (-0.4806 \to -0.2682) + i(0.0114 \to 0.0990) & (0.4546 \to 0.6395) + i(0.0074 \to 0.0695) & 0.6493 \to 0.7711 \\ (0.3102 \to 0.5133) + i(0.0094 \to 0.0947) & (-0.6956 \to -0.5248) + i(0.0057 \to 0.0654) & 0.6171 \to 0.7436 \end{pmatrix}$$

Apart from loose ends ... octant CP ordering

P.F. de Salas et al **JHEP 02 (2021) 071**

https://www.astroparticles.es/

https://zenodo.org/record/4593330#.YFoBVWNKjIo latest update see Ternes talk@Lomonosov **@jwvalle 2**

revamping TBM

Harrison, Scott & Perkins 2002

$$\begin{bmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{bmatrix}$$

θ_{13}

CP

predicting solar

$$\sin^2\theta_{12} = \frac{\cos^2\theta}{\cos^2\theta + 2},$$

$$\sin^2\theta_{13} = \frac{\sin^2\theta}{3},$$

$$\sin^2\theta_{23} = \frac{1}{2} + \frac{\sqrt{6}\sin 2\theta \sin\sigma}{2\cos^2\theta + 4}$$

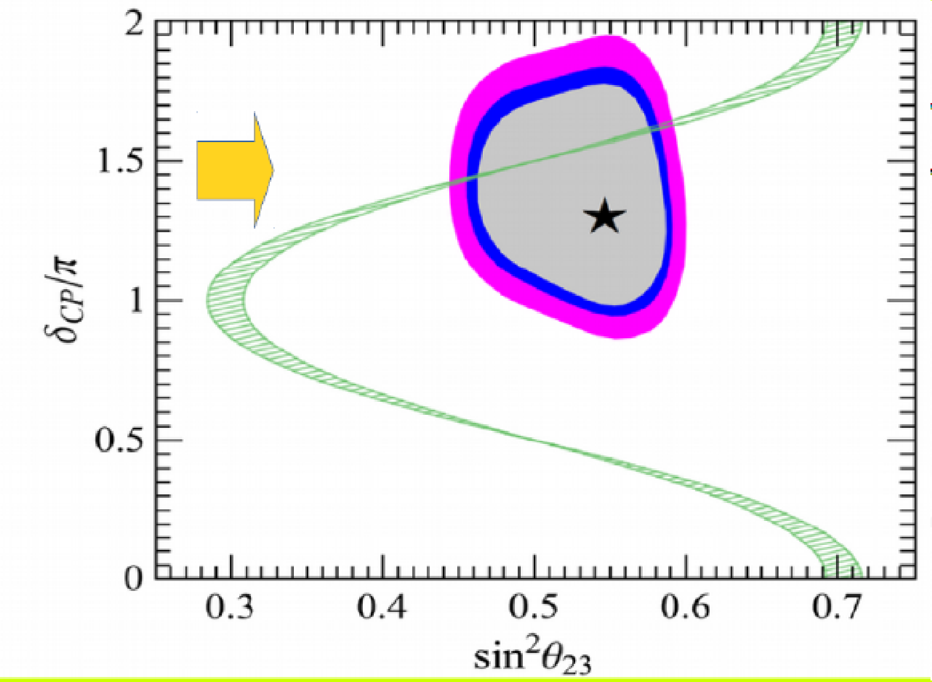
$$\tan\delta_{CP} = \frac{(\cos^2\theta + 2)\cot\sigma}{5\cos^2\theta - 2},$$

PHYSICAL REVIEW D **98,** 055019 (2018)

systematic

Chen et al
Phys.Lett. B753 (2016) 644
Phys.Rev. D94 (2016) 033002
JHEP 1807 (2018) 077
Phys.Lett. B792 (2019) 461
Phys.Rev. D99 (2019) 075005

predicting CP



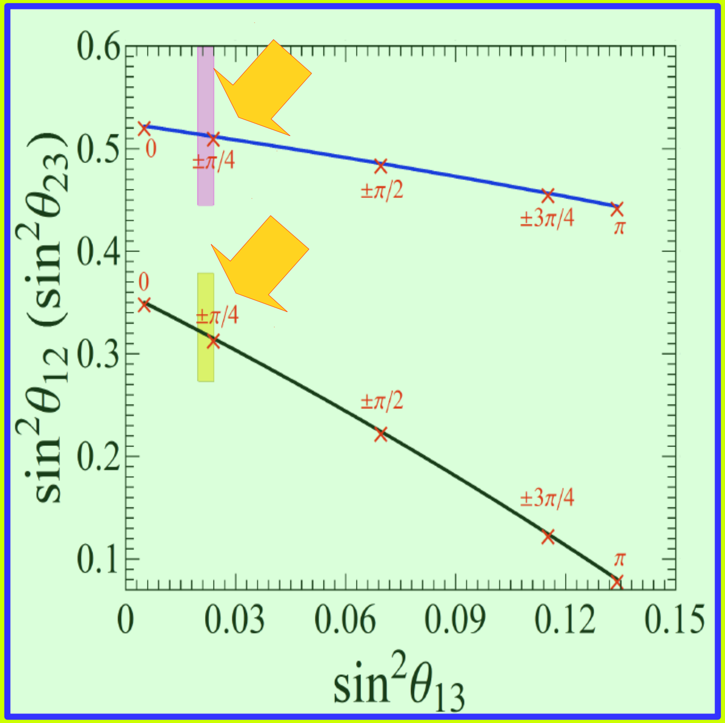
Bi-Large lepton mixing pattern

Largest Q-mixing similar to smallest L-mixing
Cabibbo angle as universal seed for flavor mixing

$$\begin{bmatrix} 1-\frac{1}{2}\lambda^2 & -\lambda e^{i\phi} & A\lambda^3 e^{i\phi} \\ \lambda e^{-i\phi} & 1-\frac{1}{2}\lambda^2 & -A\lambda^2 \\ 0 & A\lambda^2 & 1 \end{bmatrix} \quad \begin{bmatrix} 1-\frac{5\lambda^2}{2} & 2\lambda & -\lambda \\ -2\lambda+3\lambda^2 & 1-\frac{13\lambda^2}{2} & 3\lambda \\ \lambda+6\lambda^2 & -3\lambda+2\lambda^2 & 1-5\lambda^2 \end{bmatrix}$$

Phys.Rev. D86 (2012) 051301
Phys.Rev.D87 (2013) 053013
Phys.Lett. B748 (2015) 1-4

$\sin\theta_{12}^{\rm CKM} = \lambda$ and $\sin\theta_{23}^{\rm CKM} = A\lambda^2$, where $\lambda = 0.22453 \pm 0.00044,\ A = 0.836 \pm 0.015$



From
Phys.Lett. B792 (2019) 461

predicting
solar + atm
from reactor

for “softer” version of Bi-Large see

Phys.Lett.B 796 (2019) 162

$0\nu\beta\beta$

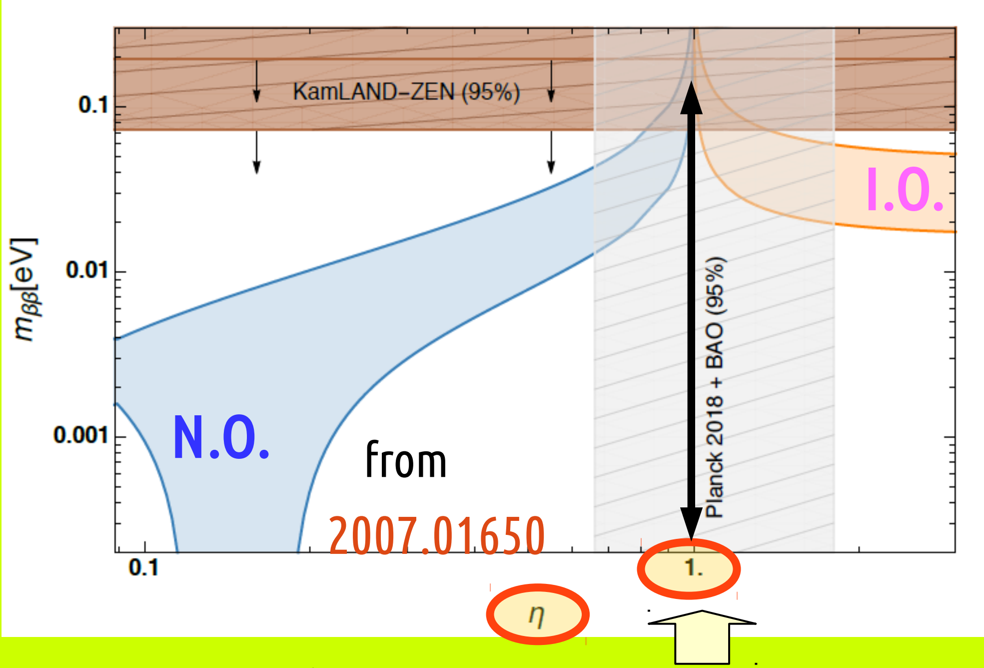
$$\left|m_{\beta\beta}\right| = \left|c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 m_2 e^{2\phi_{12}} + s_{13}^2 m_3 e^{2\phi_{13}}\right|$$

Schechter & JV PRD22 (1980) 2227

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

- **Quasi-degenerate strongly-disfavored**

Lattanzi, Gerbino, Freese, Kane, Valle
JHEP 10 (2020) 213



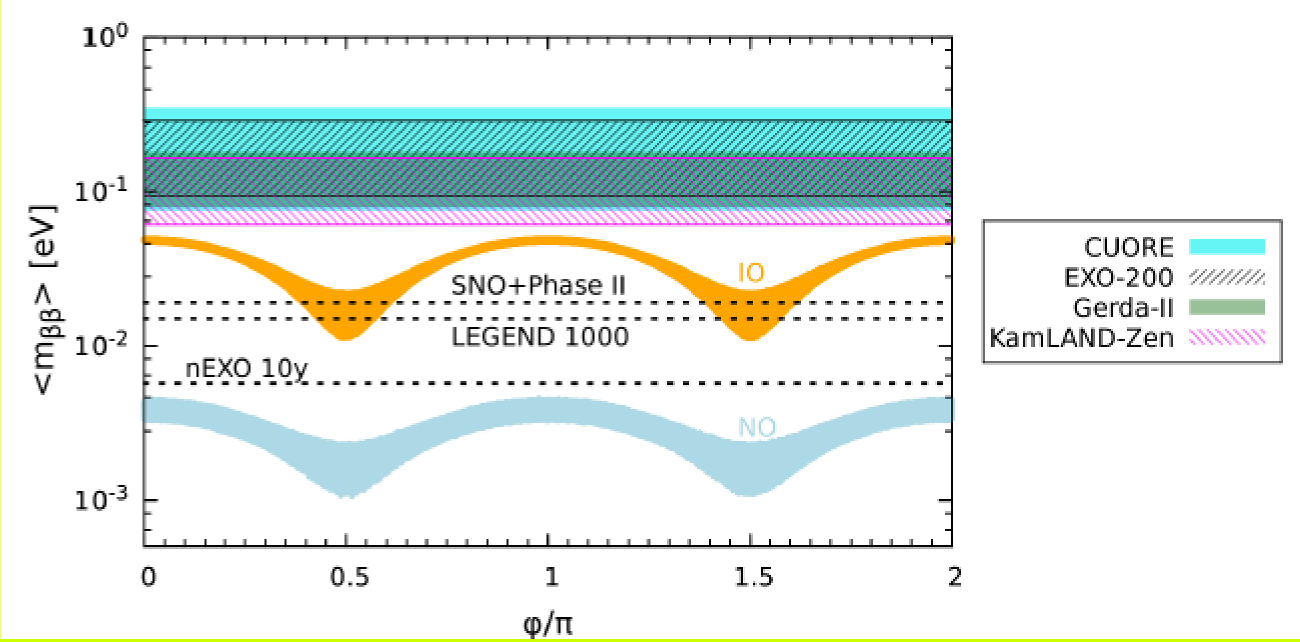
degeneracy parameter

- **one-massless**

Reig et al Phys.Lett. B790 (2019)303

Barreiros, Felipe & Joaquim JHEP (2019)

Avila et al Eur.Phys.J.C 80 (2020) 10, 908

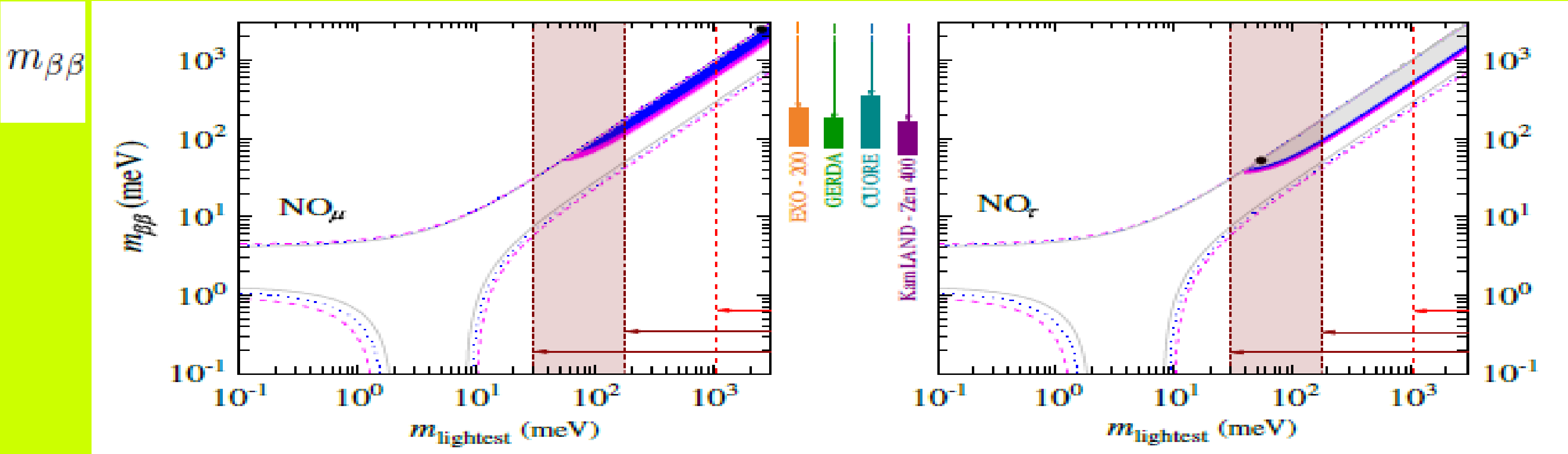


majorana phase

neutrinoless doublebeta decay

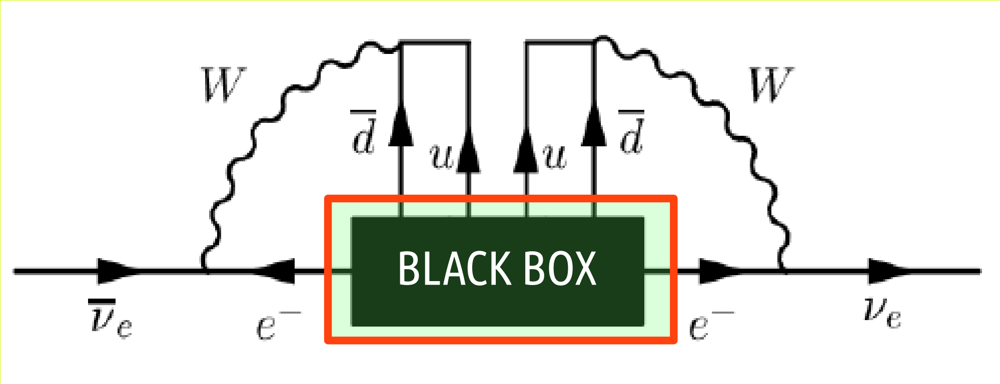
Lower bounds from family symmetries

Dorame et al 10.1103/PhysRevD.86.056001
Dorame et al 10.1016/j.nuclphysb.2012.04.003
King et al 10.1016/j.physletb.2013.05.067 etc

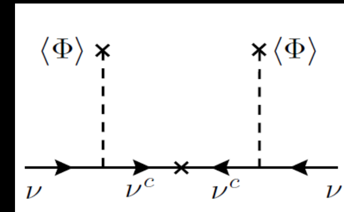


From Barreiros et al
https://doi.org/10.1007/JHEP04(2021)249

Schechter, Valle 10.1103/PhysRevD.25.2951
Duerr, Lindner, Merle 10.1007/JHEP06(2011)091
B.J.P. Jones 2108.09364 (TASI2020)

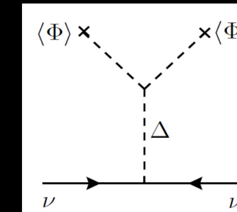


Origin of neutrino mass



TYPE I

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

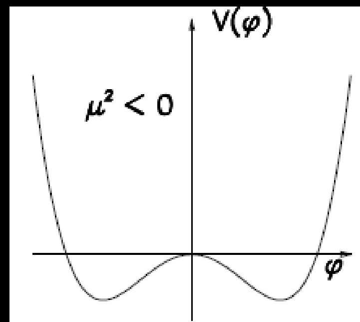


TYPE II

Schechter-Valle 80 & 82

SEESAW dynamics

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

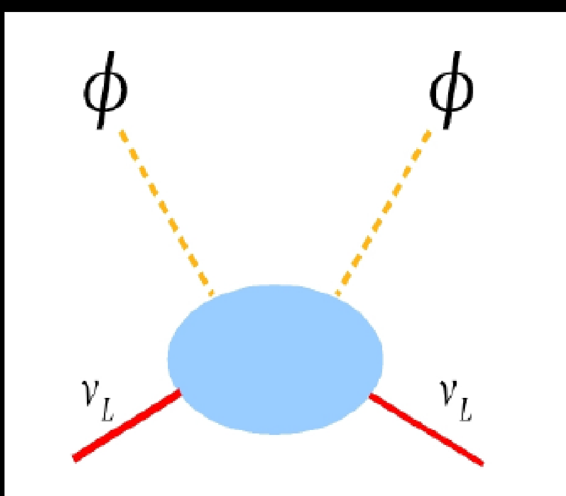


Phys.Rev.D 101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029

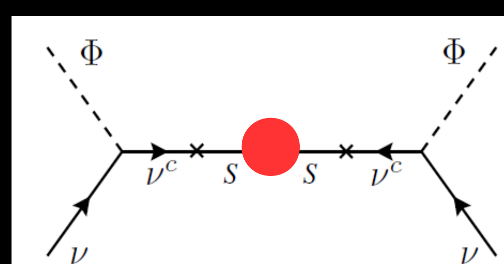
L-R Type1 seesaw ➡ **# of Rs = # Ls**

SM Type1 seesaw ➡ **# of singlets arbitrary**



- **MISSING PARTNER SEESAW** (3,2) min viable type1 seesaw; (3,1) scoto-seesaw template

- **LOW-SCALE Type1 SEESAW** (3,6) low-scale seesaw template

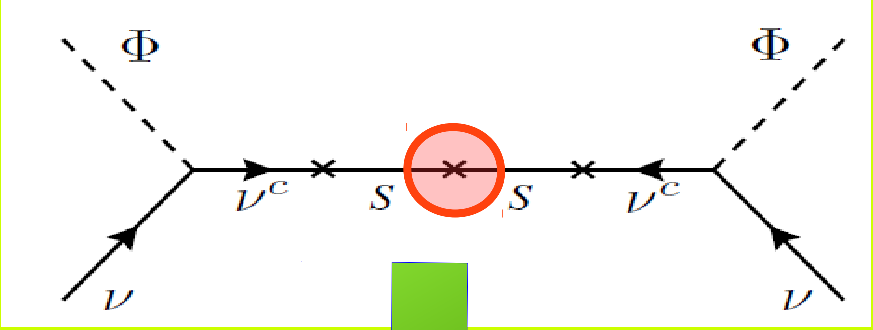


Mohapatra,Valle 86

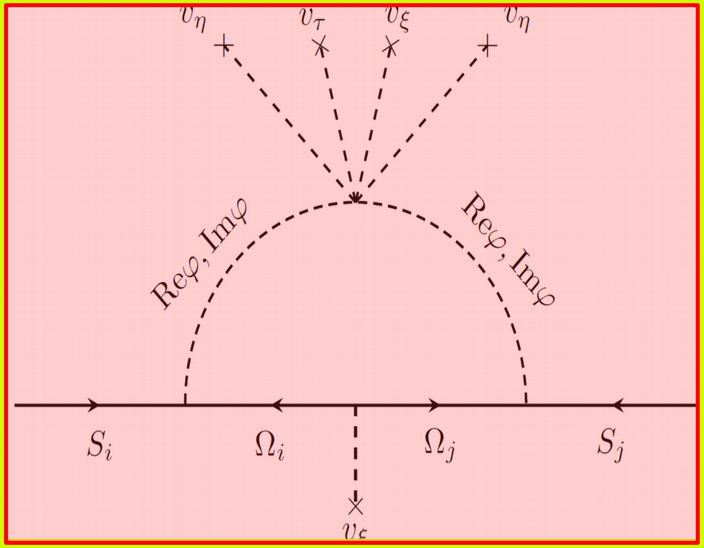
Akhmedov et al — PRD53 (1996) 2752; PLB368 (1996) 270

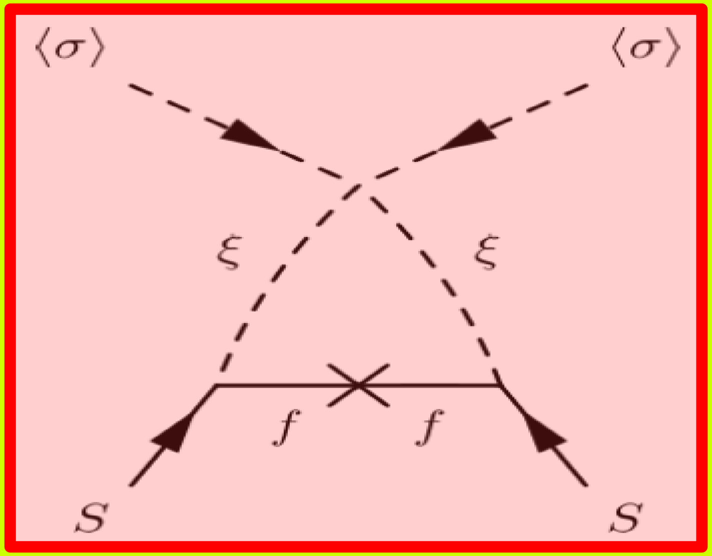
Malinsky,Romao,Valle — PRL95(2005)161801

doubly protected low scale seesaw



radiative
inverse seesaw





L-R flavored scheme

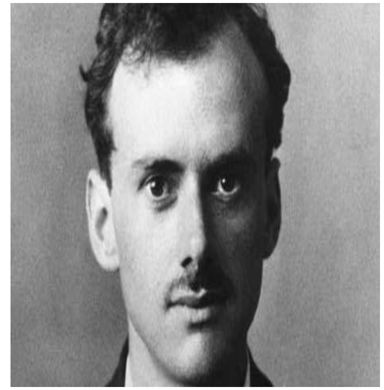
:Cárcamo Hernández et al JHEP 1902 (2019) 065

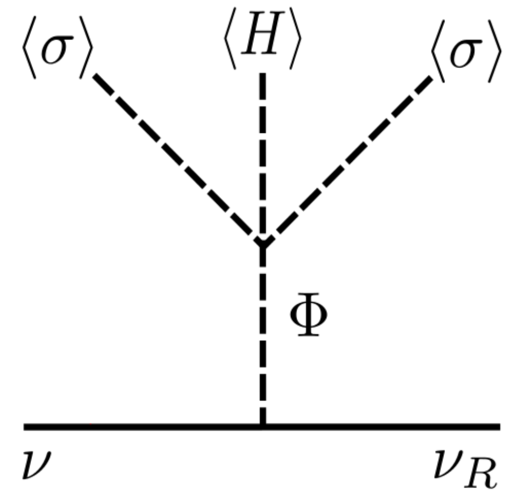
dark inverse seesaw

Mandal et al PLB (2021)

See also Ernest Ma 0904.4450, Bazzocchi et al 0907.126, Baldes, Bell, Petraki, Volkas 1304.6162

Seesawing a la

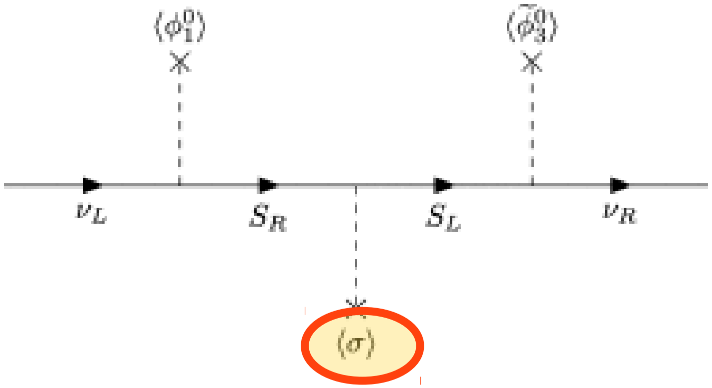




Type II

Phys.Lett. B762 (2016) 162-165

Phys.Rev. D94 (2016) 033012



Type I

symmetry protects small neutrino mass + Diracness

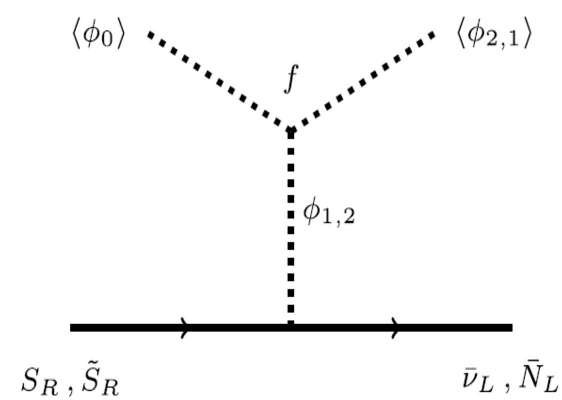
Peccei-Quinn symmetry

$$m_\nu^D \simeq \frac{y^{\nu_1}(y^S)^{-1}(y^{\nu_2})^T}{\sqrt{2}} \frac{v_W}{v_\sigma}.$$

SU3L

PQ

Physics Letters B 810 (2020) 135829



Phys.Lett. B761 (2016) 431-436

Phys.Lett. B767 (2017) 209-213

Phys.Rev. D98 (2018) 035009

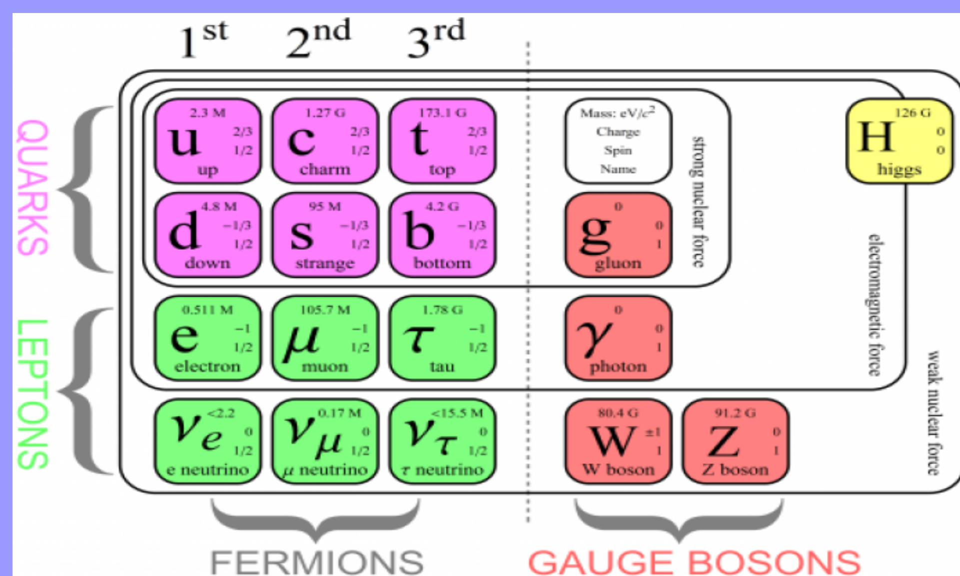
Phys.Lett. B781 (2018) 122-128

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

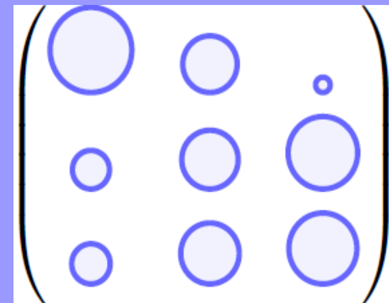
Phys.Lett. B755 (2016) 363-366

Flavors

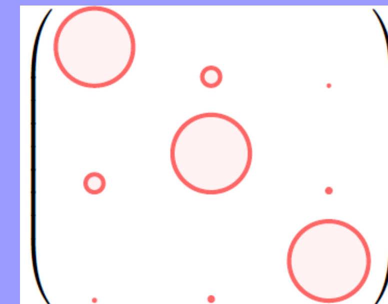
SM lacks an organizing principle to understand flavor



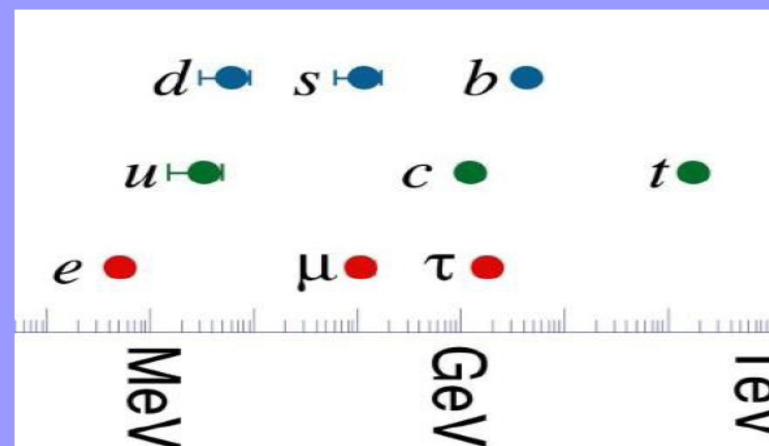
Q/L mixing pattern



versus



Q/L mass hierarchies



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

Reig, JV, Wilczek Phys.Rev. D98 (2018) 095008

Golden Q-L mass relation

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

warped flavour dynamics

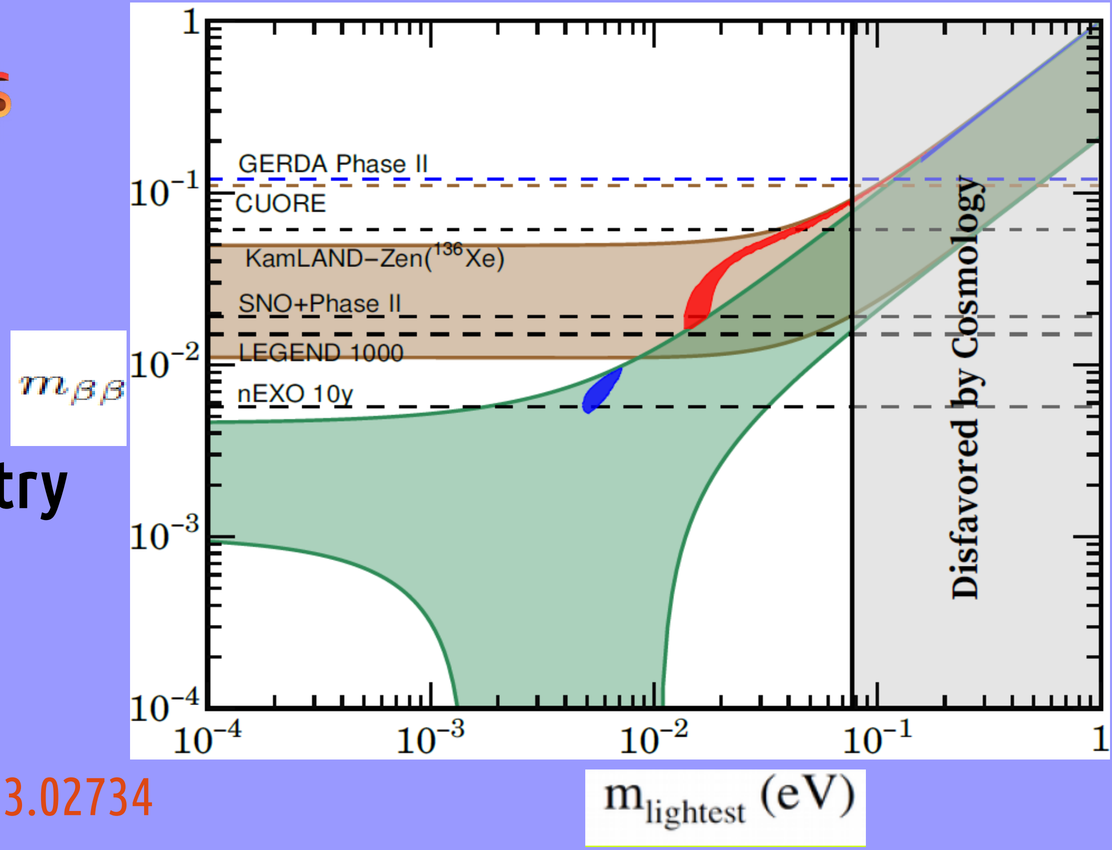
Randall-Sundrum Phys.Rev.Lett. 83 (1999) 3370

- **mass hierarchies from geometry**

  Arkani-Hamed & Schmaltz hep-ph/9903417

- **mixing angles from family symmetry**

T' predictions

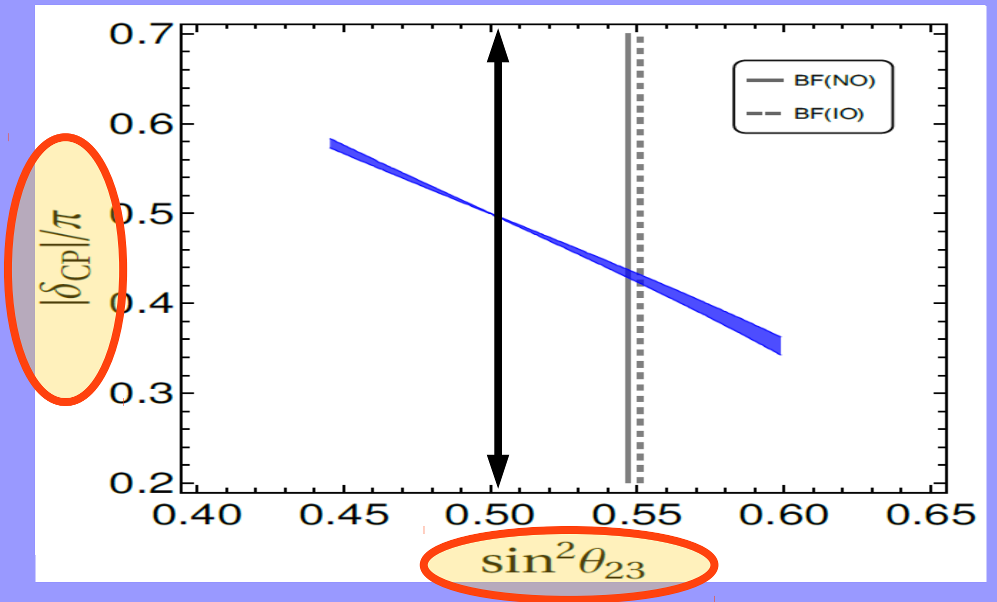


$$\cos^2\theta_{12}\cos^2\theta_{13} = \frac{2}{3}$$

from Chen et al 2003.02734

Phys. Rev. D 102, 095014 (2020)

$$\cos\delta_{CP} = \frac{(3\cos 2\theta_{12} - 2)\cos 2\theta_{23}}{3\sin 2\theta_{23}\sin 2\theta_{12}\sin\theta_{13}}$$

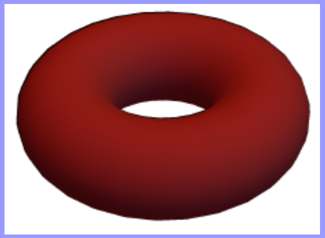


See also Chen et al
JHEP01(2016)007
Phys. Rev. D95 (2017) 095030
Phys.Lett. B771 (2017) 524

family symmetry from orbifolding

Phys.Lett.B 801 (2020) 135195

$$\mathcal{M} = \mathbb{M}^4 \times (\mathbb{T}^2/\mathbb{Z}_2)$$



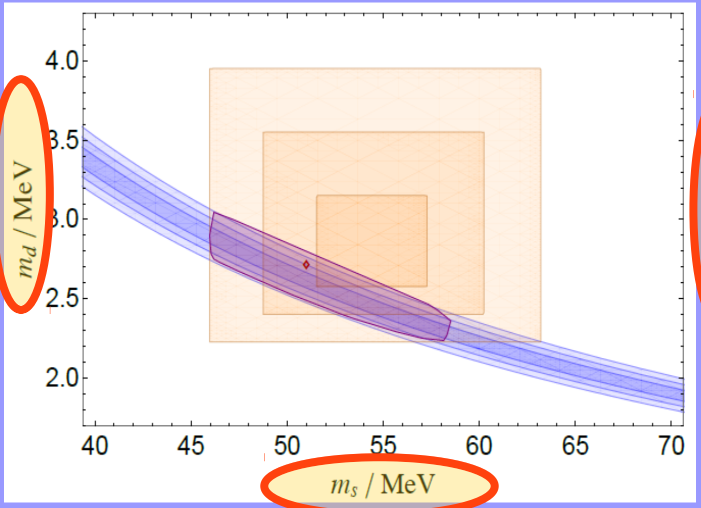
A4 family symmetry
inherited from extra-dim

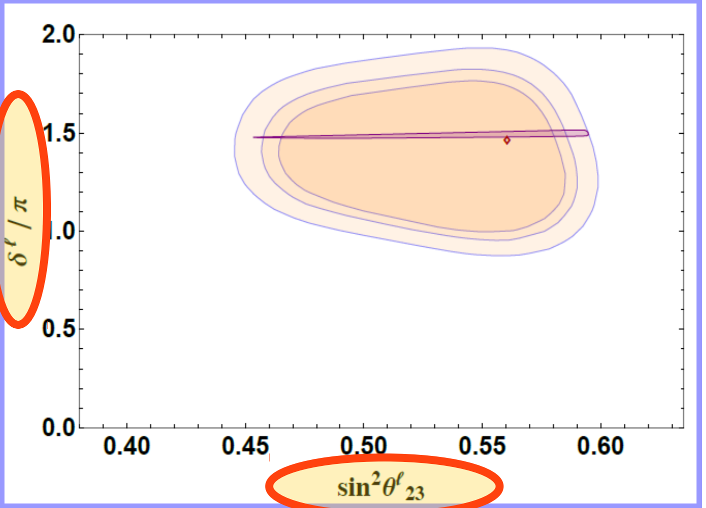
Golden Q-L relation

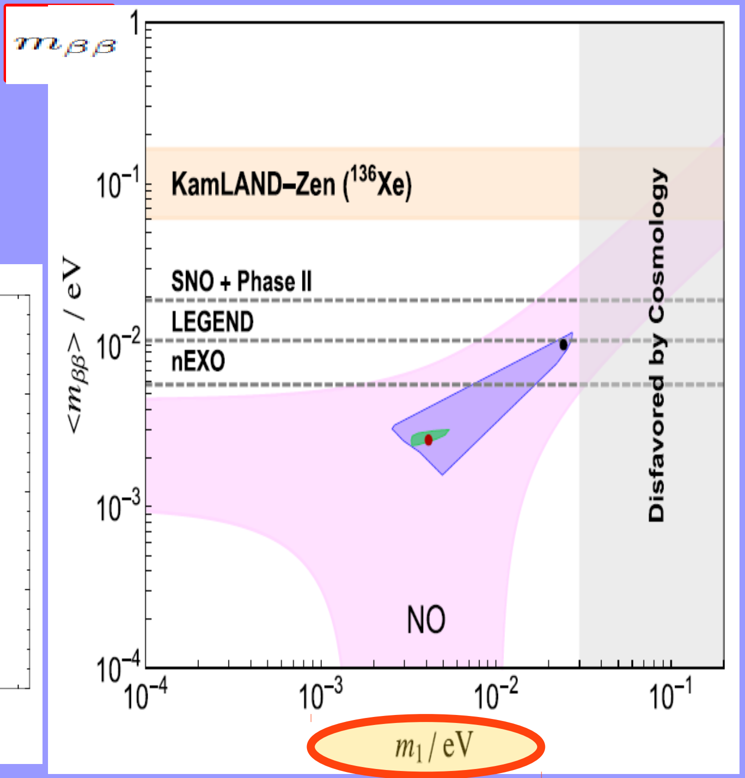
$$\frac{m_\tau}{\sqrt{m_\mu m_e}} \approx \frac{m_b}{\sqrt{m_s m_d}}$$

Sign of CP phase!

Phys.Rev.D 101 (2020) 11, 116012







Good global fit of all flavor observables

Dark Matter incorporated

Anda, Antoniadis et al JHEP 10 (2020) 190

neutrinos at the spotlight

oscillation program, CP, octant, ordering, unitarity/NSI …

0nuDBD, **CEvNS** …

ν

seesaw mediators via cLFV signatures

neutrinos and EW vacuum stability

flavor puzzle

unification & strong CP problem

WIMP DM as neutrino-mass mediator, DM stability from Diracness …

baryon asymmetry ..

Back-ups