neutrino theory

JOSÉ W F VALLE

Double Beta Decay: the road to normal hierarchy sensitivity

ASTROPARTICLES
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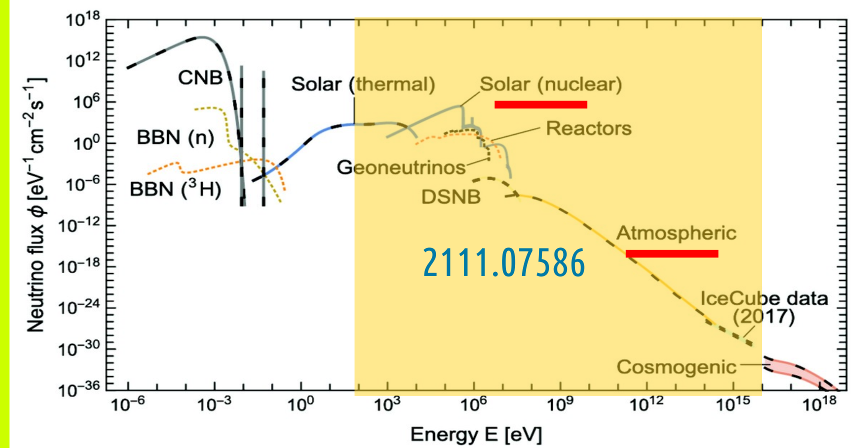
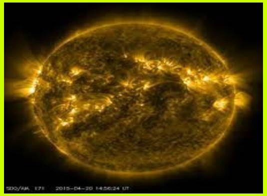
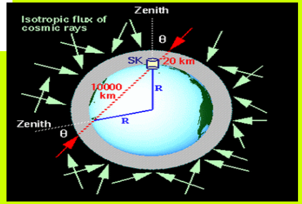
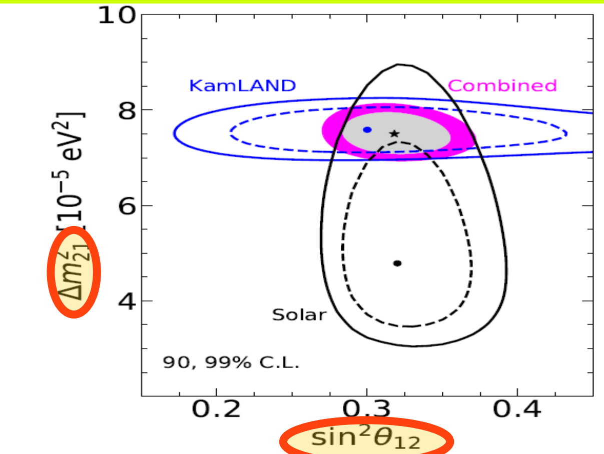
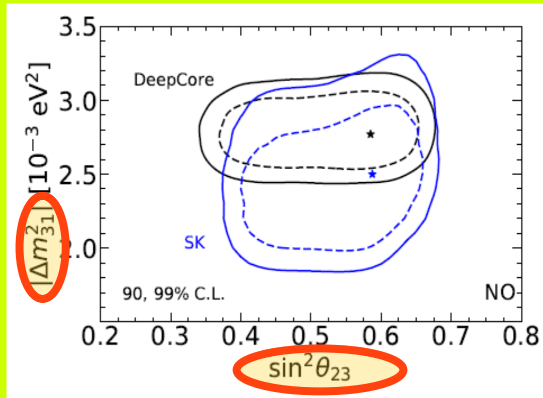
oscillations





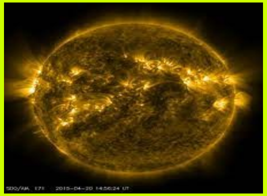


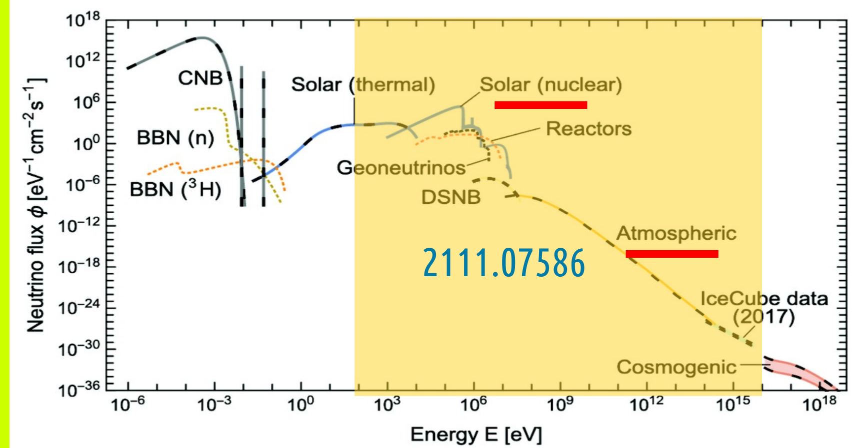


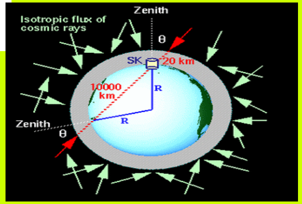


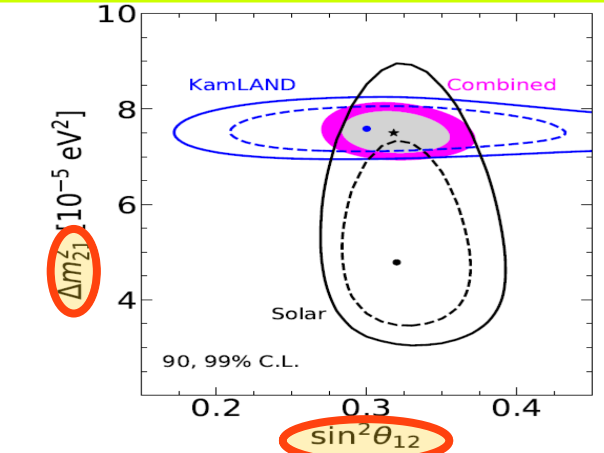
P.F. de Salas et al **JHEP 02 (2021) 071**

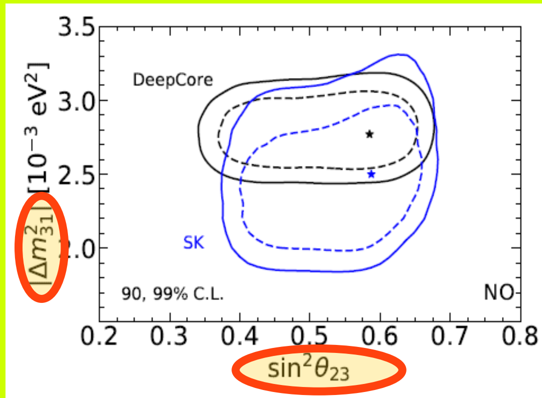
oscillations











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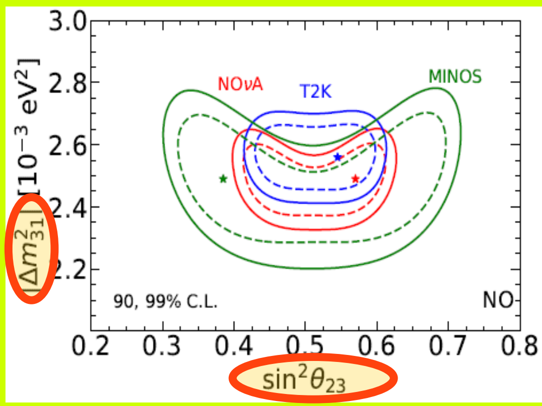
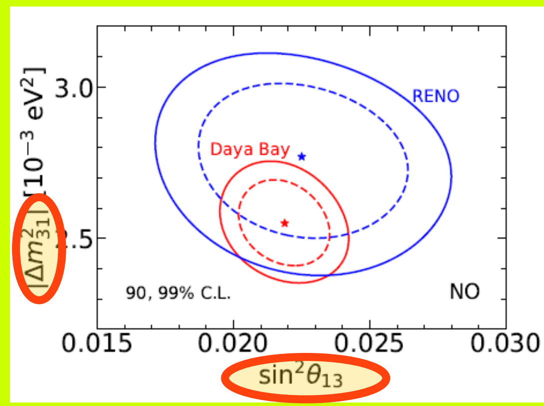
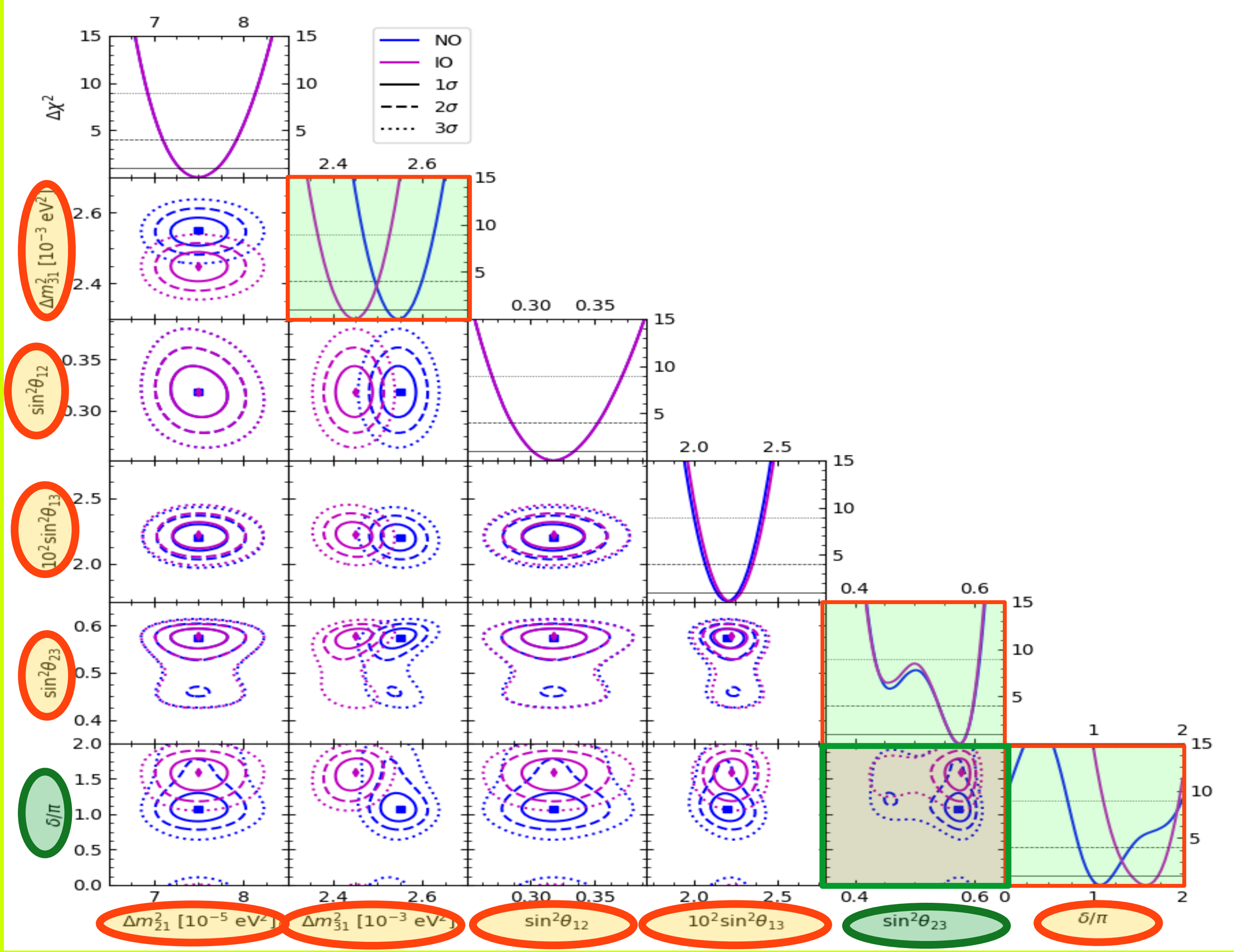




Updates from nu2022
Tortola's talk

@jwvalle2

neutrino oscillation maps

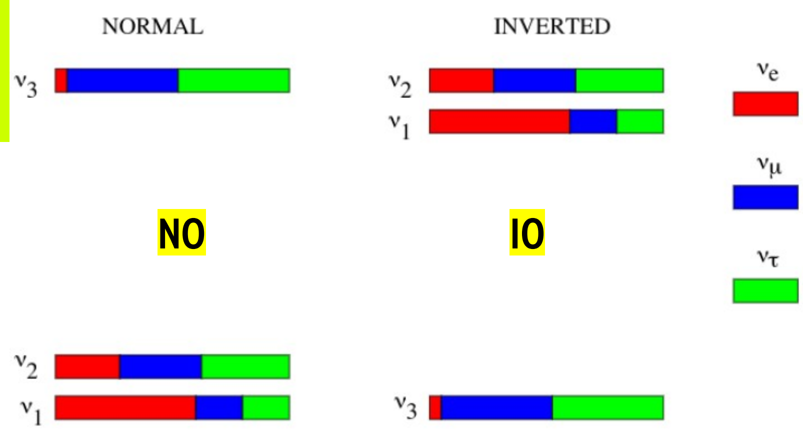


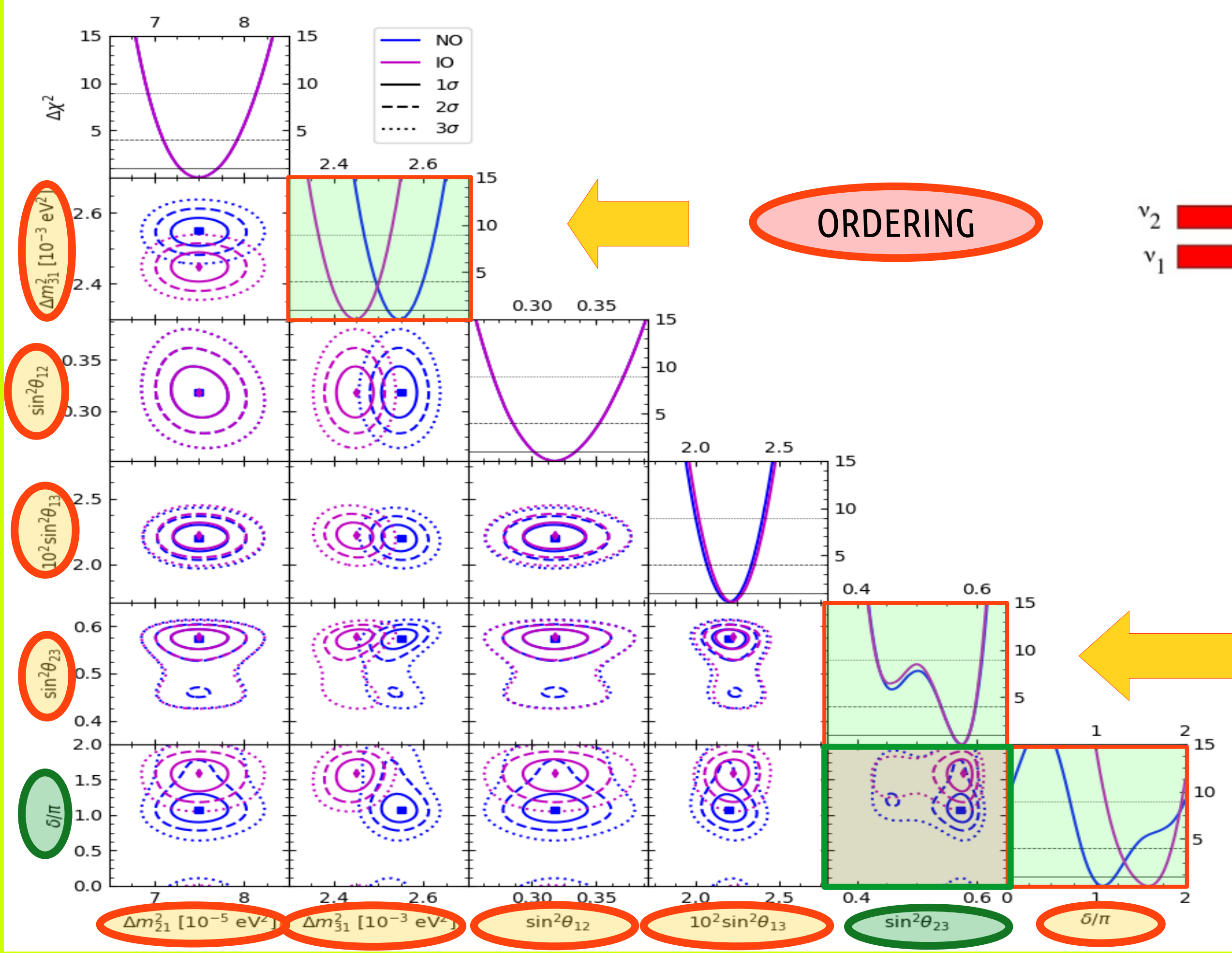
P.F. de Salas et al **JHEP 02 (2021) 071**

pairwise correlations

Chi2 maps downloadable from https://globalfit.astroparticles.es/

neutrino oscillation maps





ORDERING

OCTANT

CP

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

pairwise correlations

Chi2 maps downloadable from
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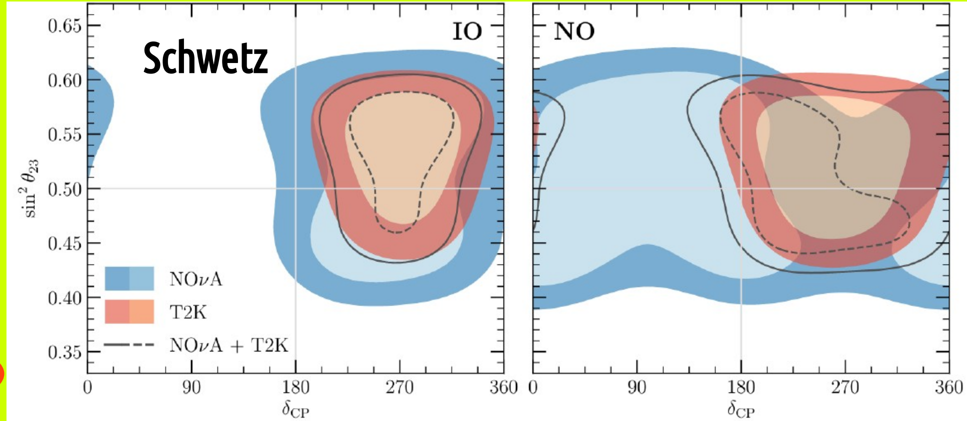
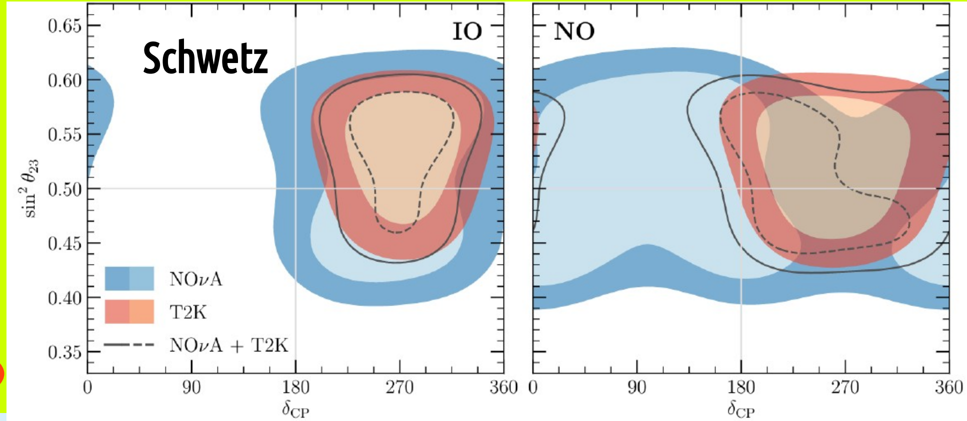
CP

ORDERING



Schwetz
IO
NO
$\sin^2\theta_{23}$
0.65
0.60
0.55
0.50
0.45
0.40
0.35
NOνA
T2K
NOνA + T2K
0
90
180
270
360
δ_{CP}



CP

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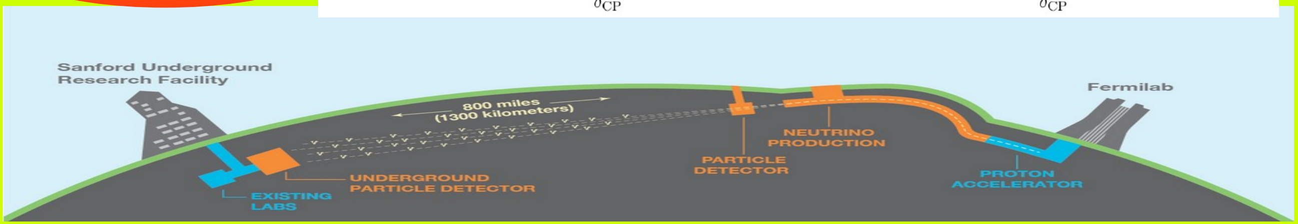
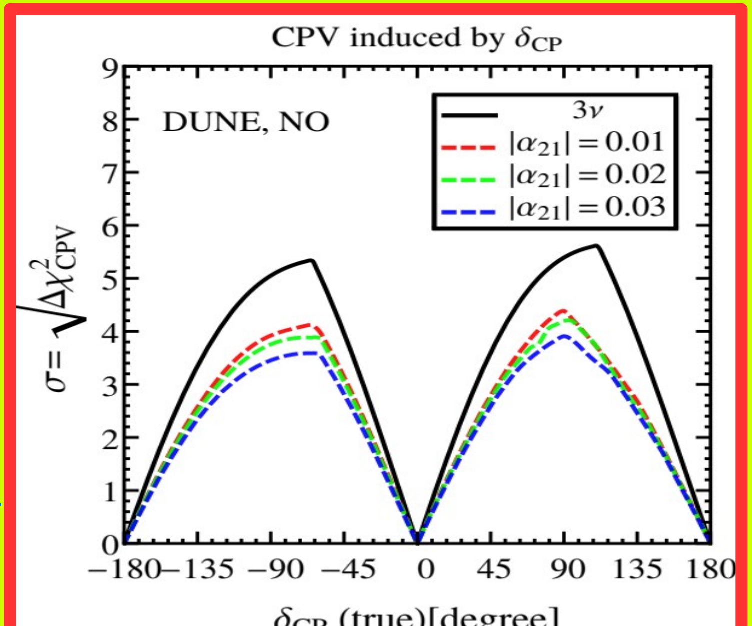


DUNE

Expected Sensitivity: 3nu vs Unitarity violation



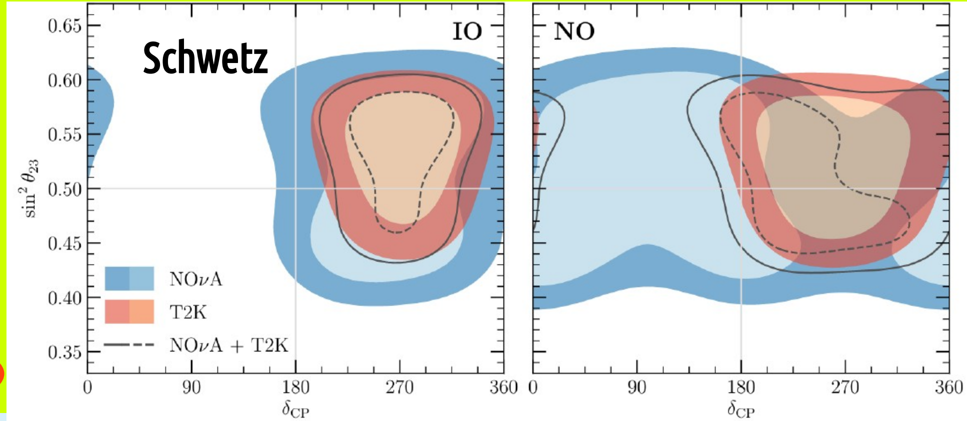
Phys.Rev.Lett.117 (2016) 061804

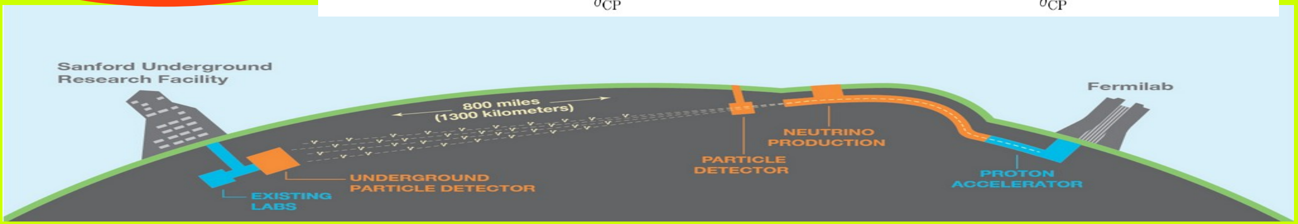
New J.Phys. 19 (2017) 9, 093005

PhysRevD97 (2018) 095026

CP

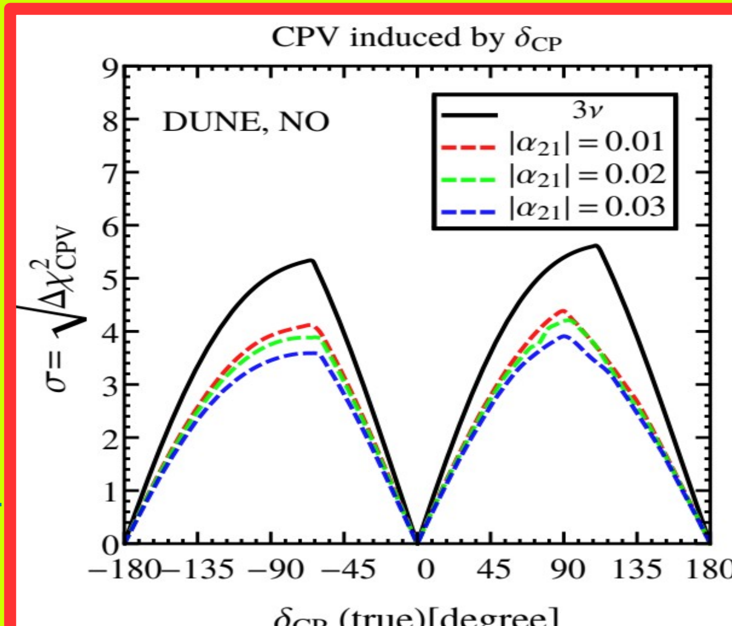
ORDERING

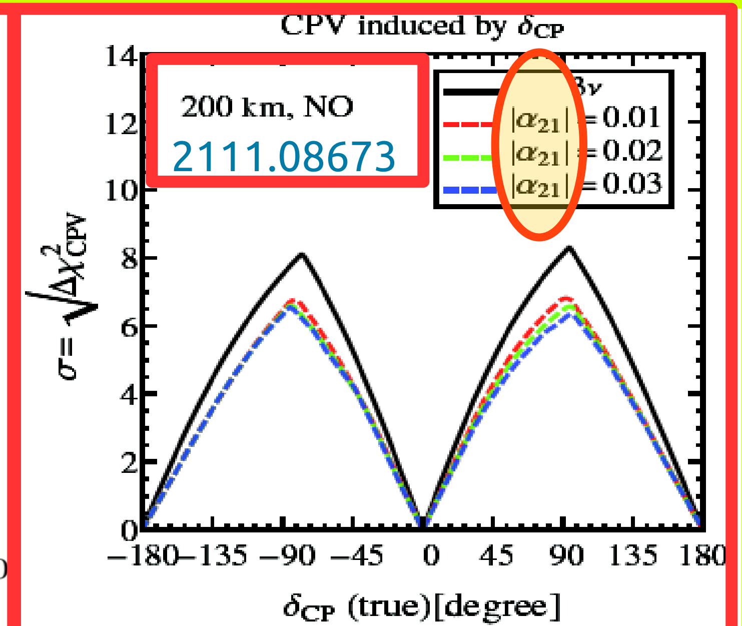




DUNE

ESSnuSB





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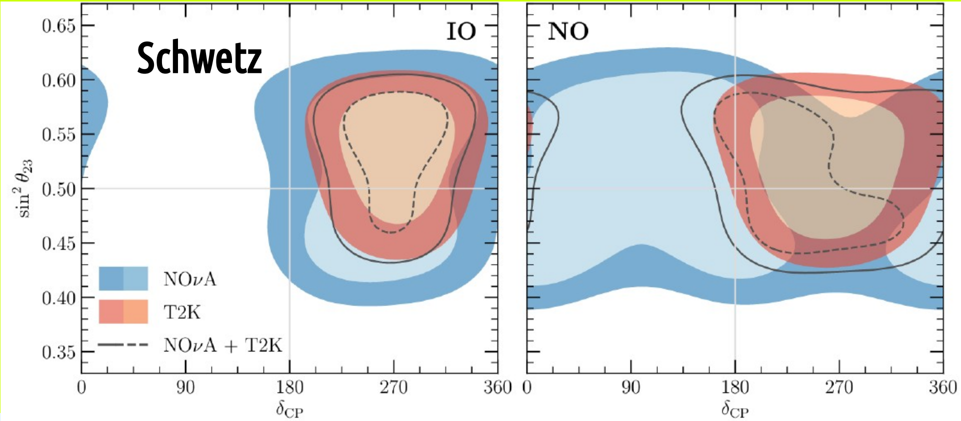

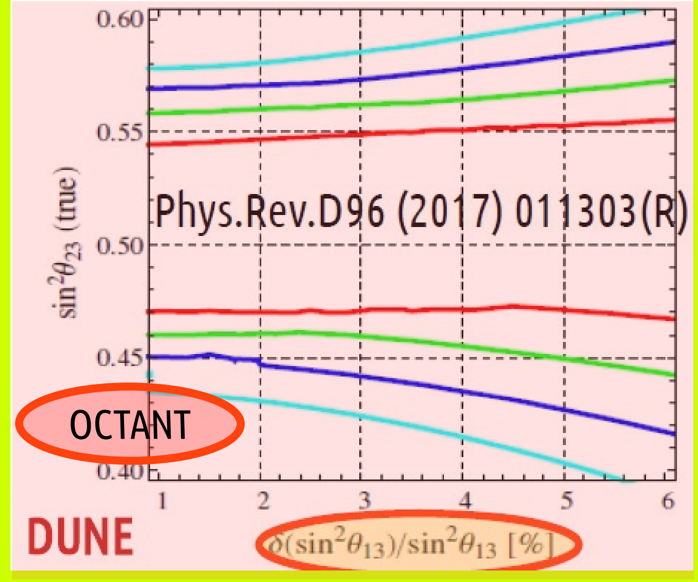

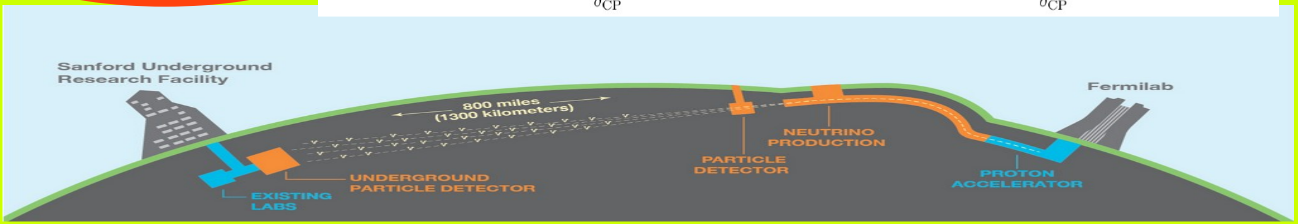

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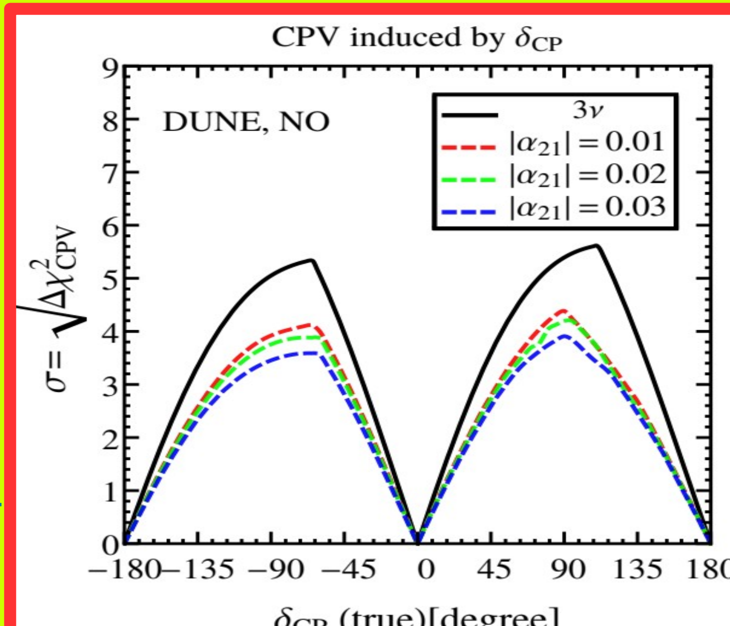

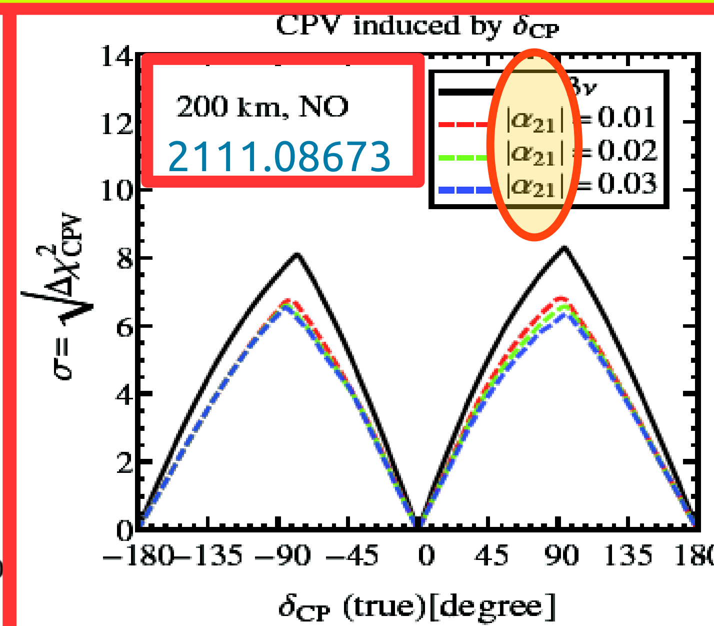

Phys.Rev.Lett.117 (2016) 061804

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PhysRevD97 (2018) 095026

@jwvalle4

neutrino properties from colliders

current oscillation data
can reconstruct m_nu
so that it can be tested
at high-energies

Miranda et al Phys.Rev.D105 (2022) 095020

seesaw mediator produced in
@ e+e- / pp collisions

Miranda et al PLB 829 (2022) 137110

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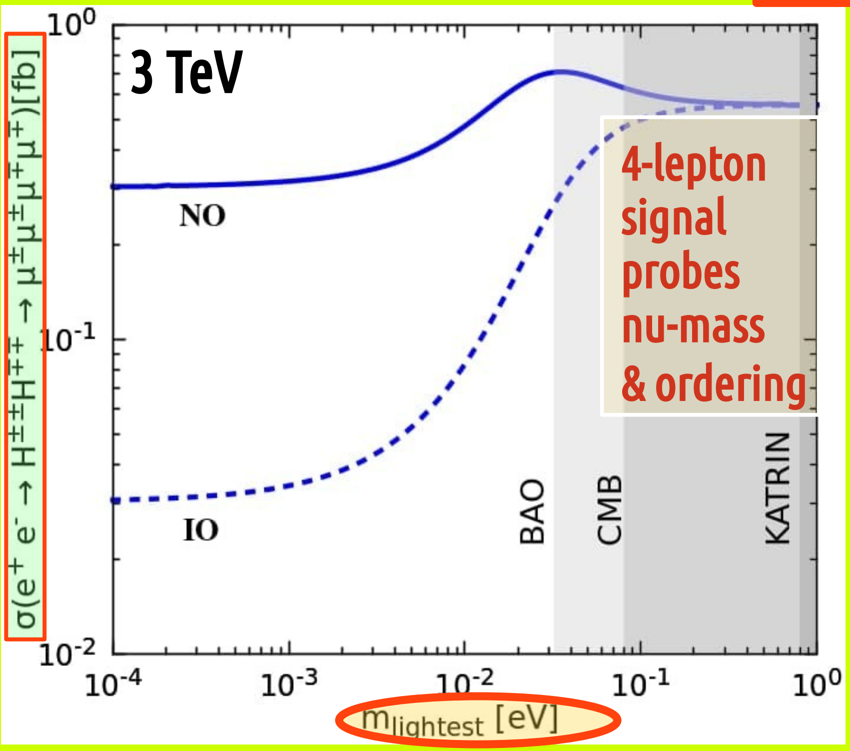

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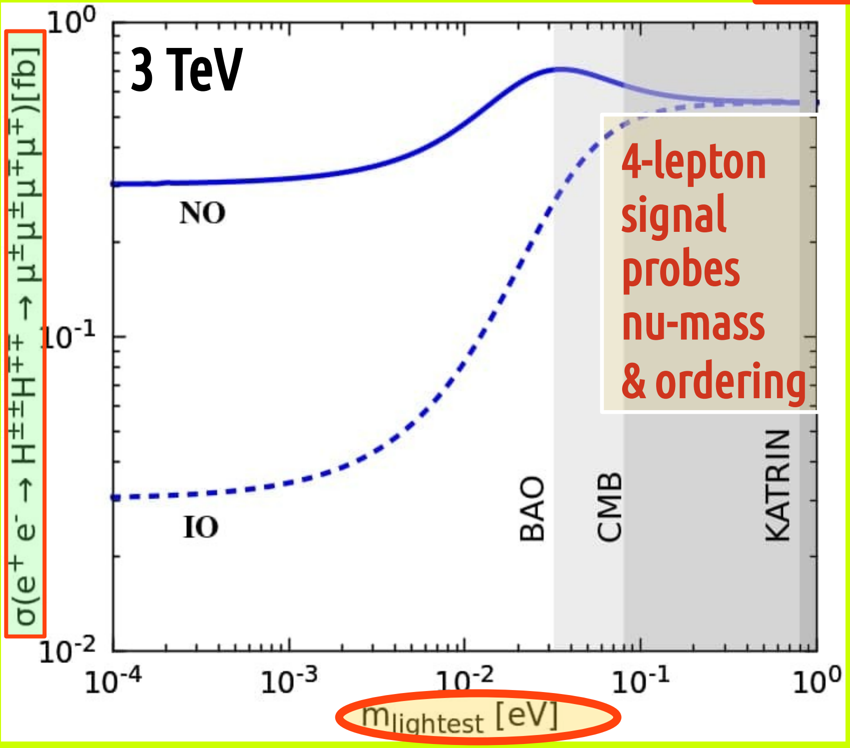

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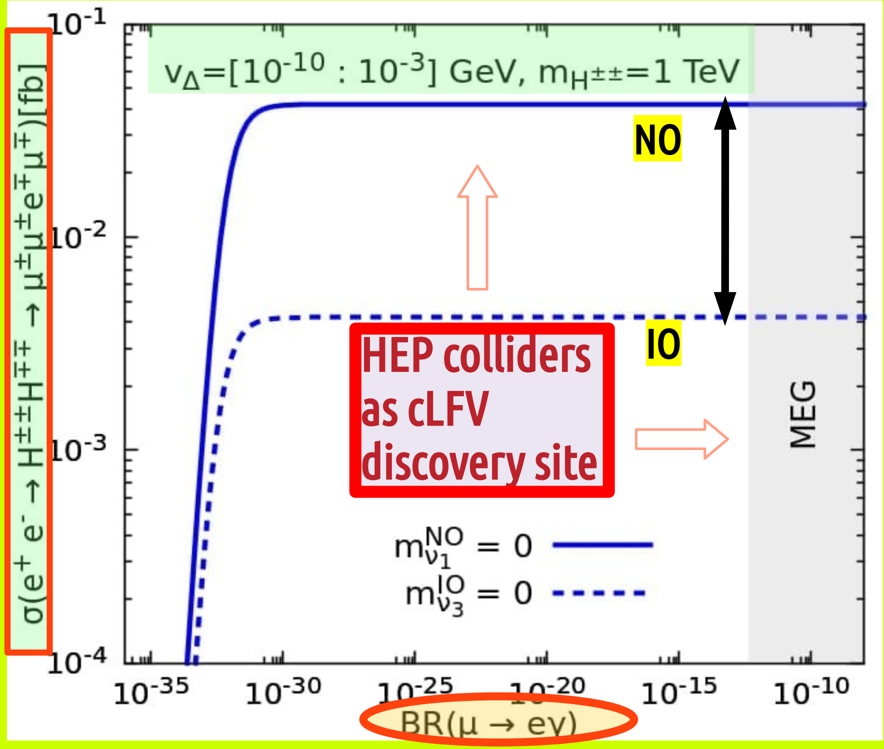

TBM interpretation

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

systematic revamping

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

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Θ_{13}

CP

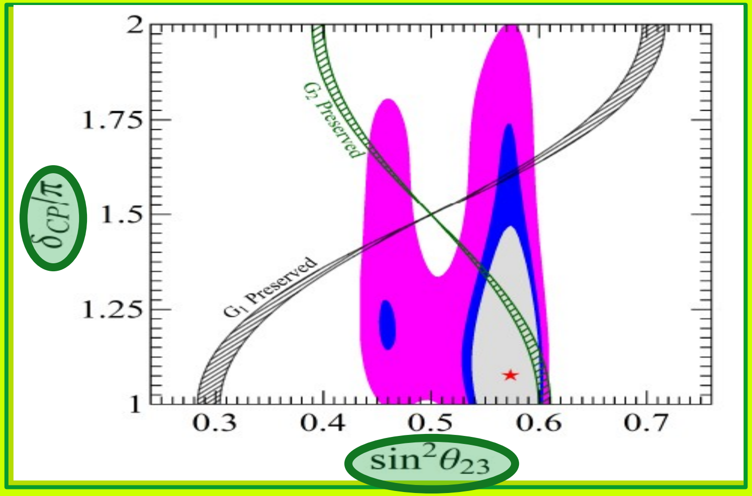
Phys.Rev.D98(2018)055019

$$\sin^2\theta_{12}\cos^2\theta_{13} = \frac{1}{3}$$

$$\tan 2\theta_{23}\cos\delta_{CP} = \frac{\cos 2\theta_{13}}{\sin\theta_{13}\sqrt{2-3\sin^2\theta_{13}}}$$

systematic revamping

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



many examples

Bi-Large lepton mixing pattern

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

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

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

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

predicting solar & atm

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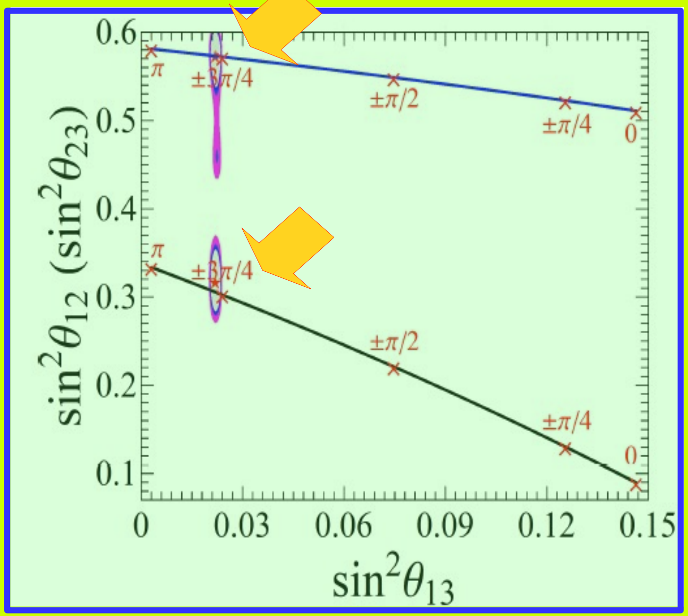


many probes of neutrino mixing hypotheses e.g. at DUNE

e.g. Phys.Rev.D97(2018)095025

From
Phys.Lett. B792 (2019) 461

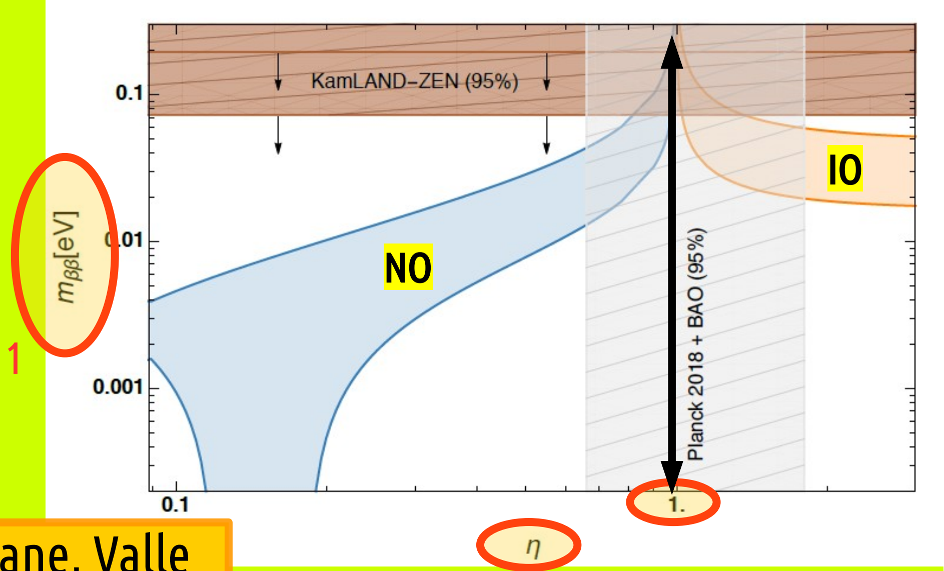
Less tight realization
Phys.Lett.B 796 (2019) 162

neutrinoless doublebeta decay

$$\left|\sum_j U_{ej}^2 m_j\right| = \left|c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 m_2 e^{2i\phi_{12}} + s_{13}^2 m_3 e^{2i\phi_{13}}\right|$$

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

neutrinoless doublebeta decay

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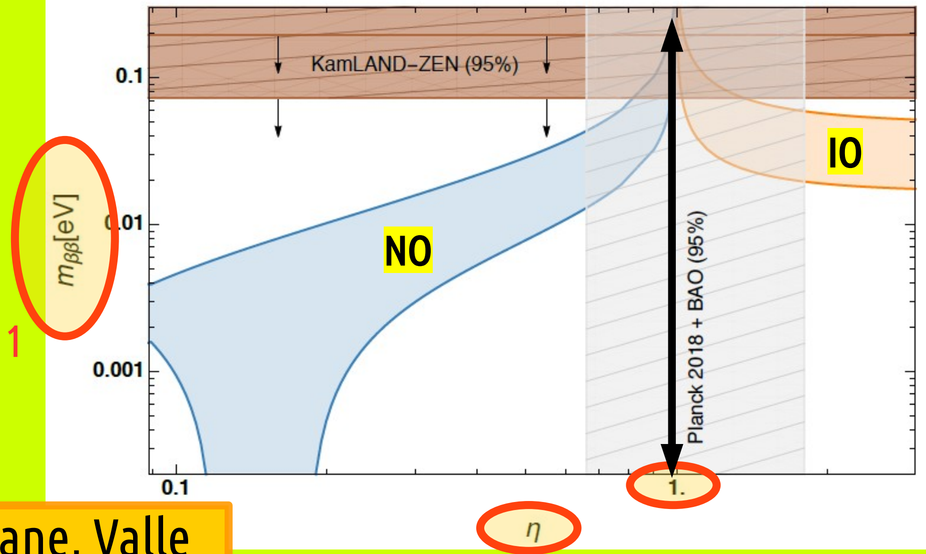


- **Quasi-degenerate strongly-disfavored**

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

degeneracy parameter

- **One-massless neutrino**

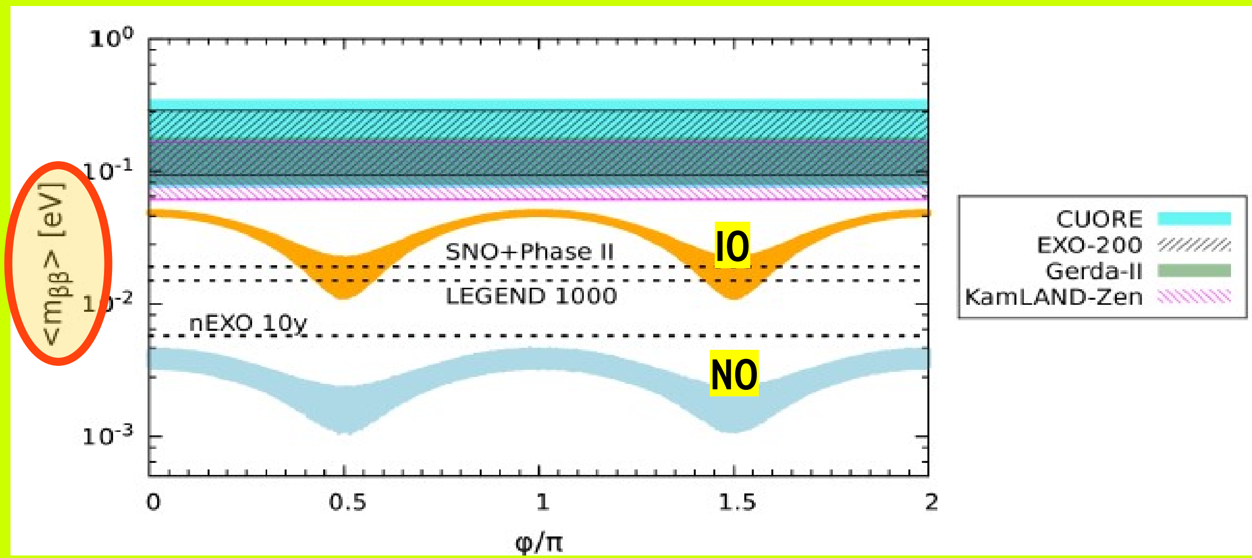
Reig et al Phys.Lett. B790 (2019)303

Barreiros, Felipe & Joaquim JHEP (2019) 223

Mandal et al PLB789 (2019) 132

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

Agostini et al. Science 365 (2019) 1445
Final Gerda … 2009.06079

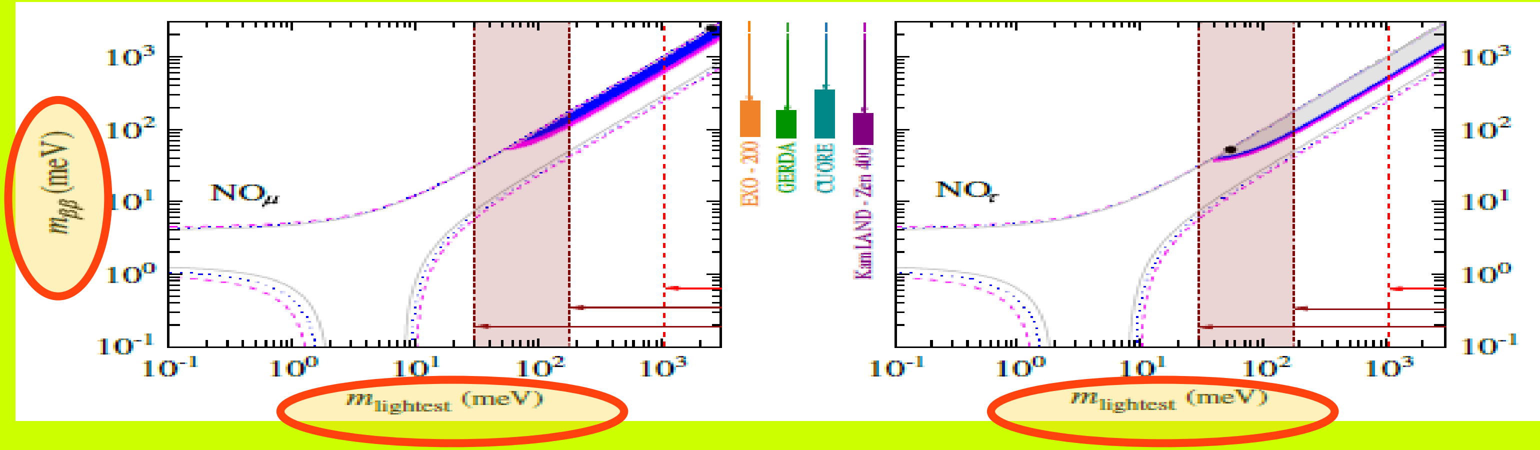


majorana phase

neutrinoless doublebeta decay

Lower bounds from family symmetries

Dorame et al PhysRevD86(2012)056001
Dorame et al Nucl.Phys.B 861 (2012) 259-270
King et al Phys.Lett. B 724 (2013) 68-72 etc



From Barreiros et al JHEP04(2021)249

neutrinoless doublebeta decay

Lower bounds from family symmetries

Dorame et al PhysRevD86(2012)056001
Dorame et al Nucl.Phys.B 861 (2012) 259-270
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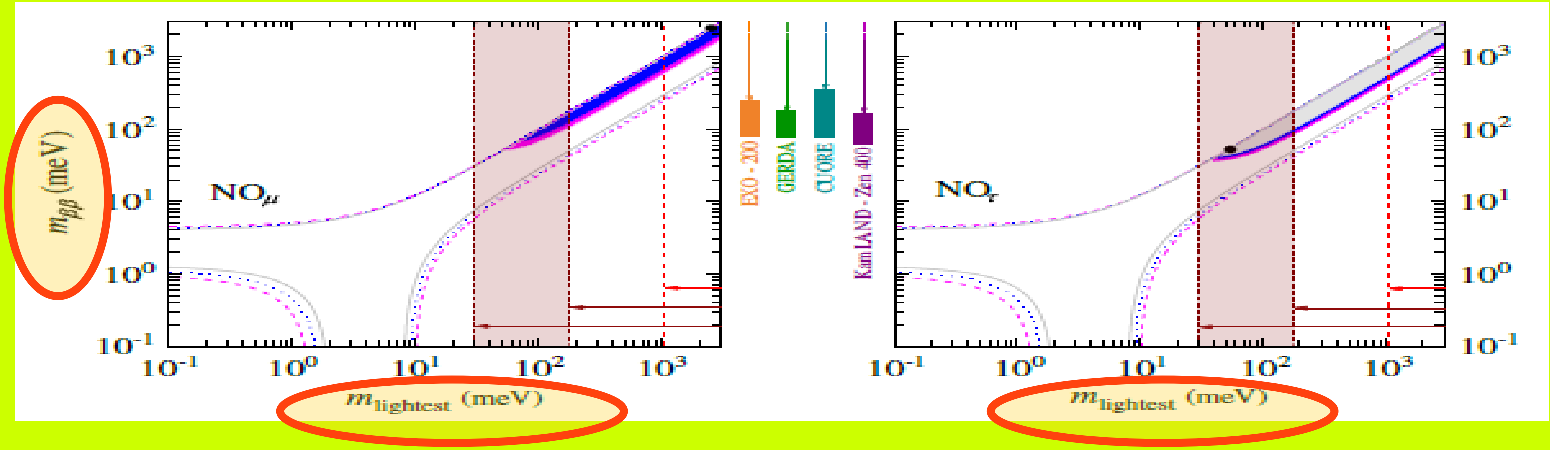
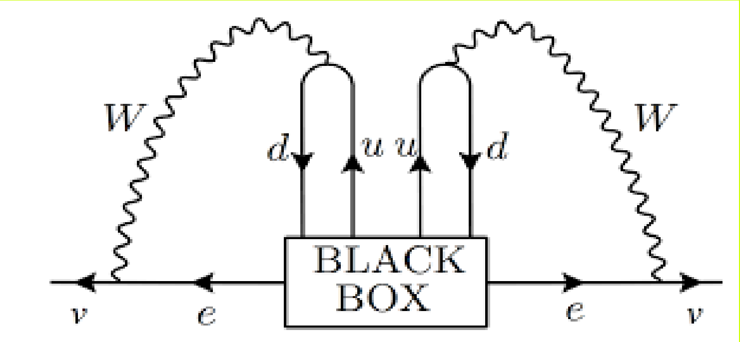
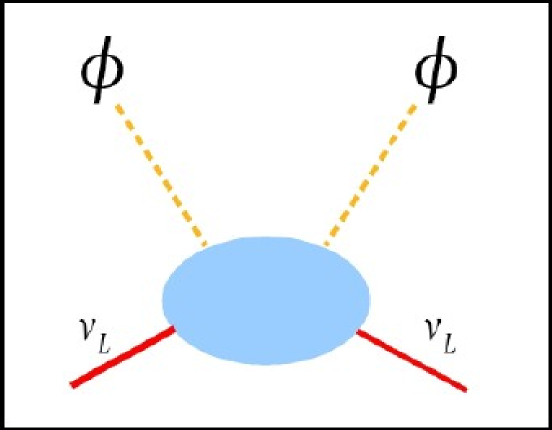


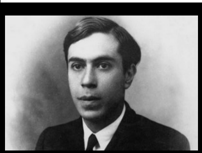
From Barreiros et al JHEP04(2021)249

Schechter, Valle PhysRev D25 (1982) 2951
Duerr, Lindner, Merle JHEP06(2011)091
B.J.P. Jones 2108.09364 (TASI 2020)



Origin of neutrino mass

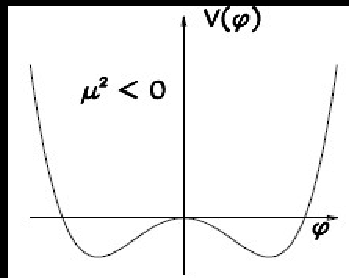




Origin of neutrino mass

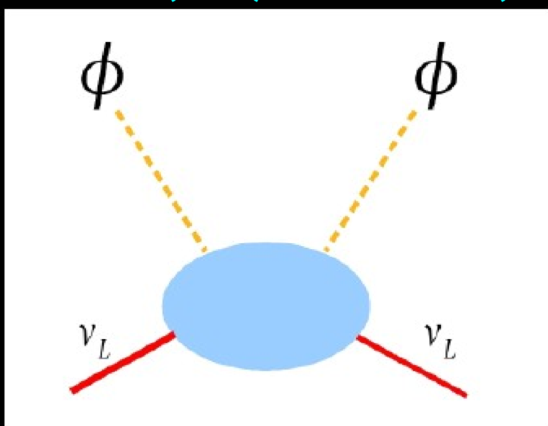
SEESAW dynamics

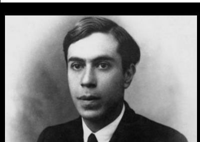
$$v_3 v_1 \sim v_2{}^2$$



Phys.Rev.D 101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029





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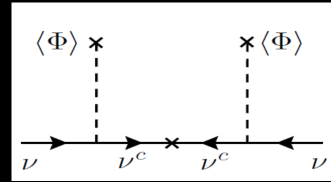

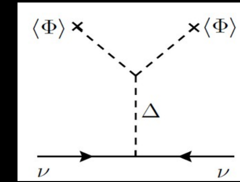

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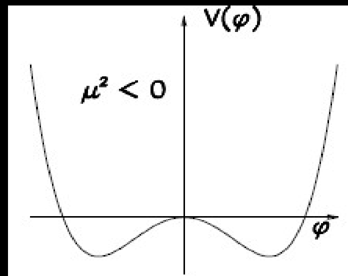
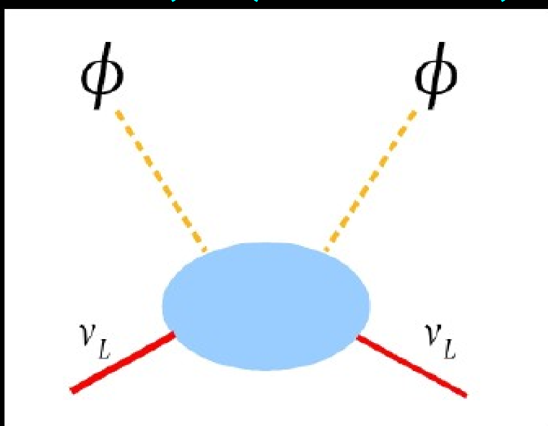
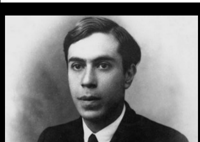


Phys.Rev.D 101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029





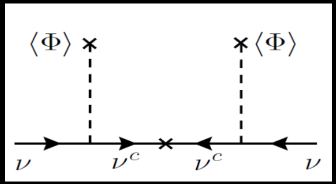
TYPE I

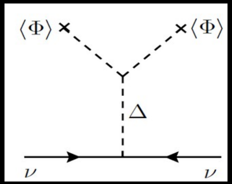
Minkowski 77
Gellman Ramond Slansky 80
Glashow, Yanagida 79
Mohapatra Senjanovic 80
Lazarides Shafi Weterrich 81
Schechter-Valle 80 & 82

TYPE II

Schechter-Valle 80 & 82

Origin of neutrino mass





TYPE I

Minkowski 77

Gellman Ramond Slansky 80

Glashow, Yanagida 79

Mohapatra Senjanovic 80

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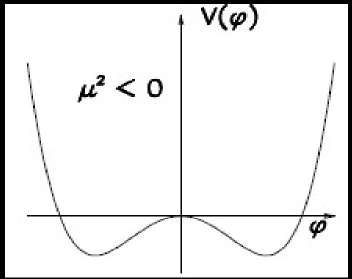
TYPE II

Schechter-Valle 80 & 82

SEESAW dynamics

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

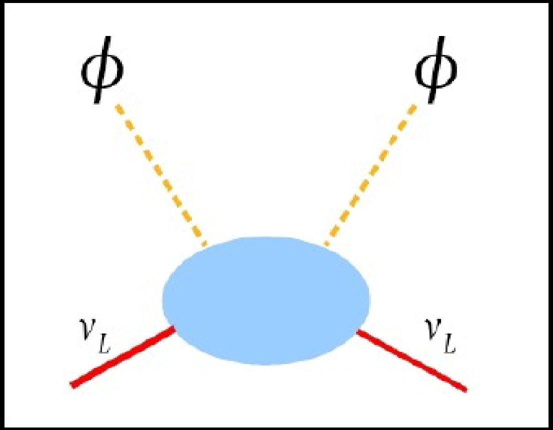


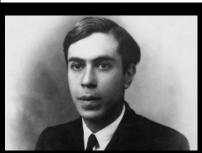
Phys.Rev.D 101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029

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

SM Type1 seesaw **# of singlets arbitrary**





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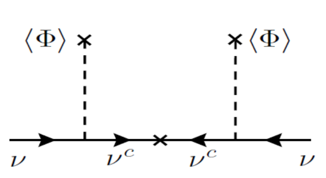

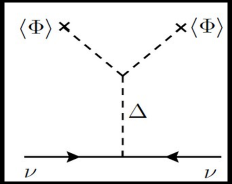

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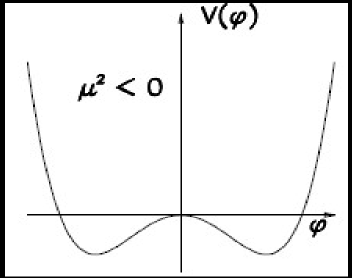

Phys.Rev.D 101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029

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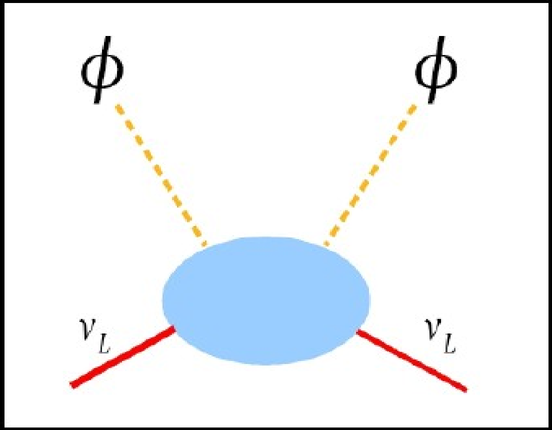
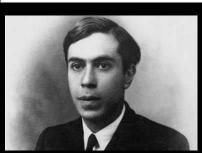
(3,1) scoto-seesaw template





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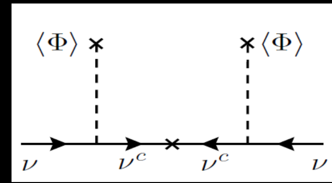

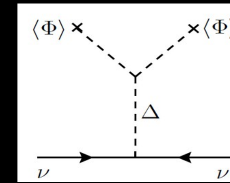

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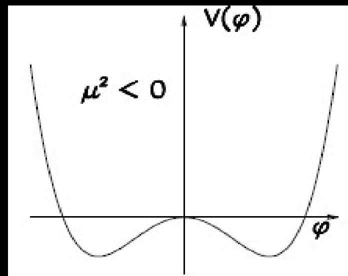

Phys.Rev.D 101 (2020) 115030

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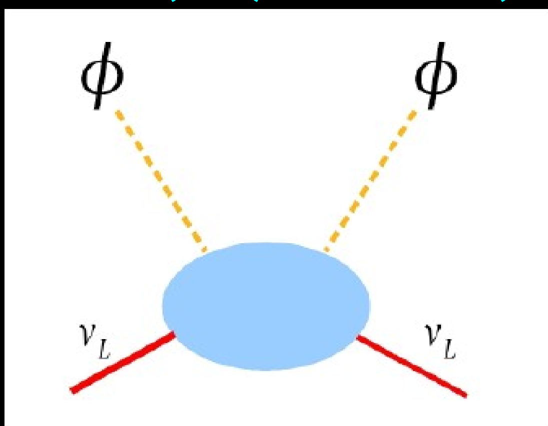

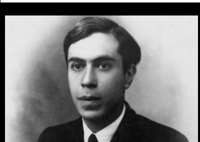

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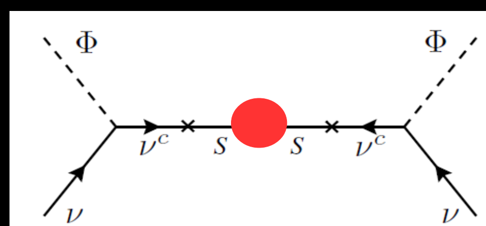
  (3,1) scoto-seesaw template
- **LOW-SCALE Type1 SEESAW (3,6) ISS & LSS**

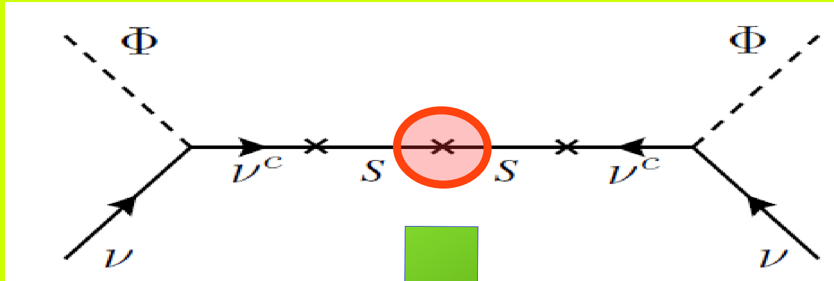


Mohapatra,Valle 86

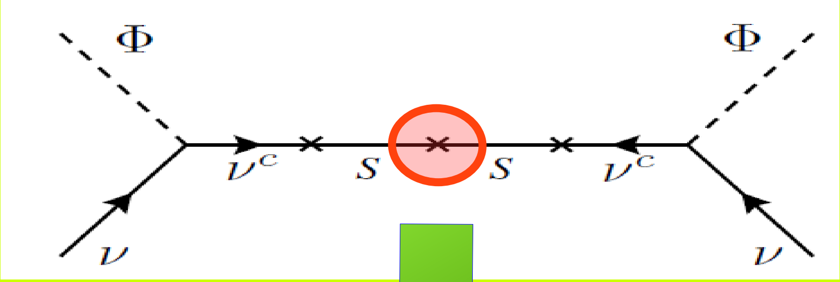
Akhmedov et al Phys.Rev.D53 (1996) 2752
PhysLettB368 (1996) 270

Malinsky et al PhysRevLett95(2005)161801

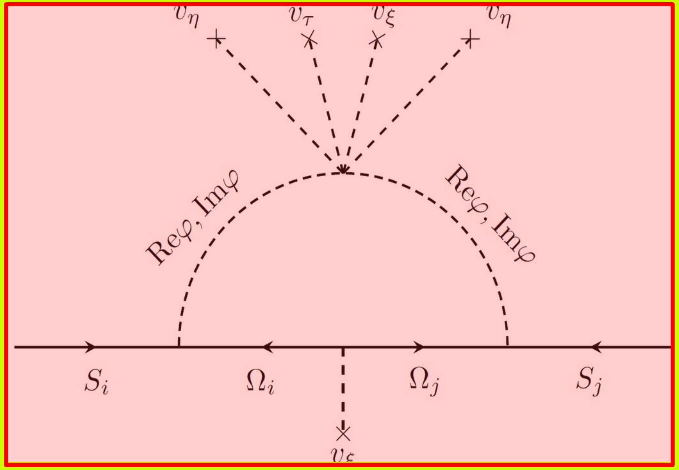
doubly protected inverse seesaw

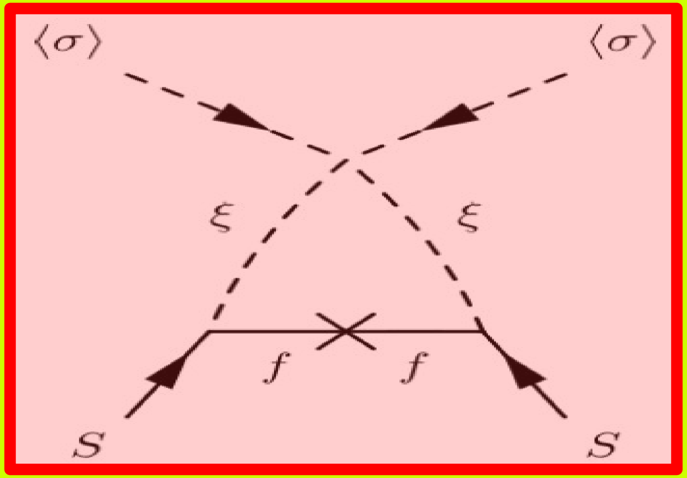


doubly protected inverse seesaw



radiative inverse seesaw





L-R scheme

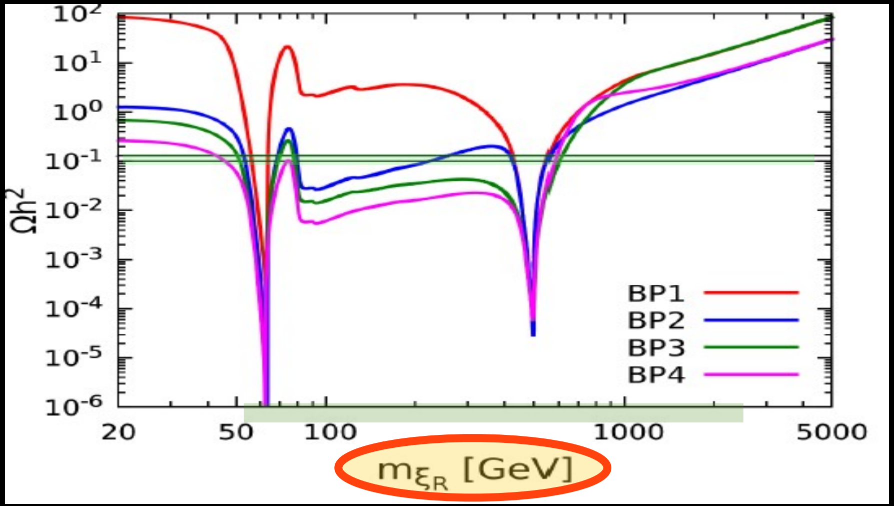
:Cárcamo Hernández et al JHEP 1902 (2019) 065

dark inverse seesaw

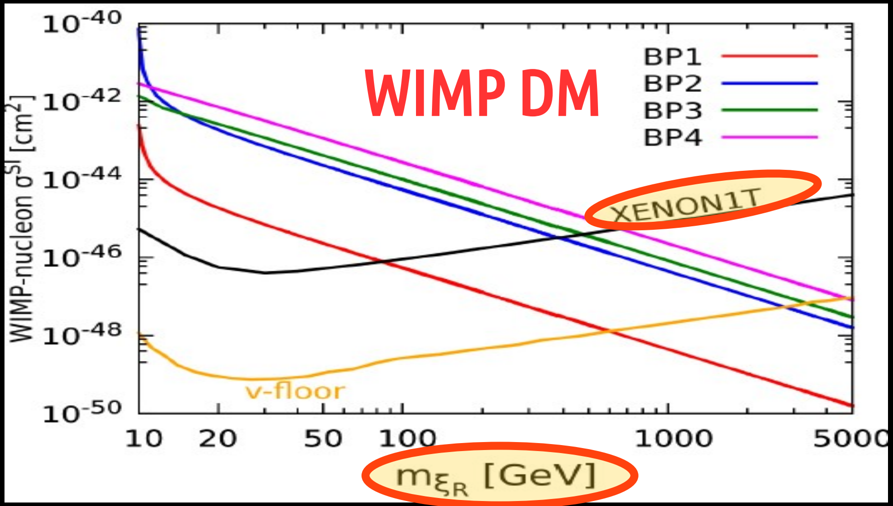
Mandal et al Phys.Lett.B821 (2021) 136609

dark inverse typeI seesaw mechanism

Phys.Lett.B 821 (2021) 136609

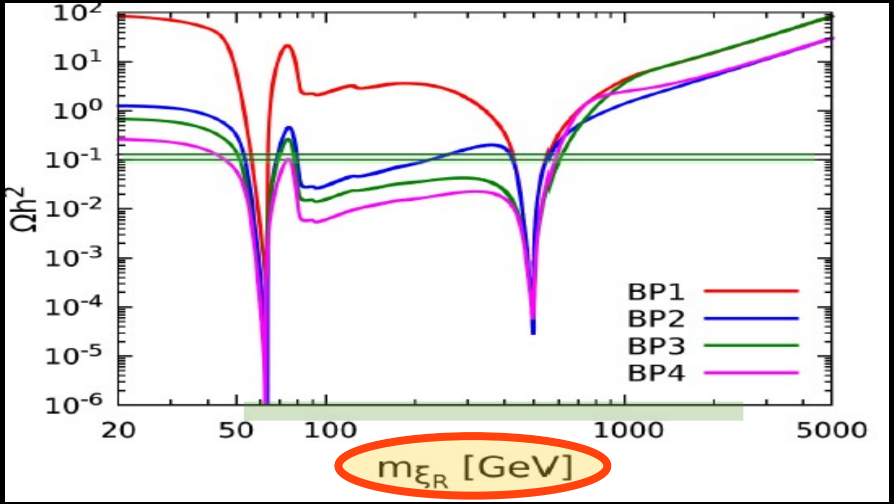


Xenon1T PhysRevLett.121.111302

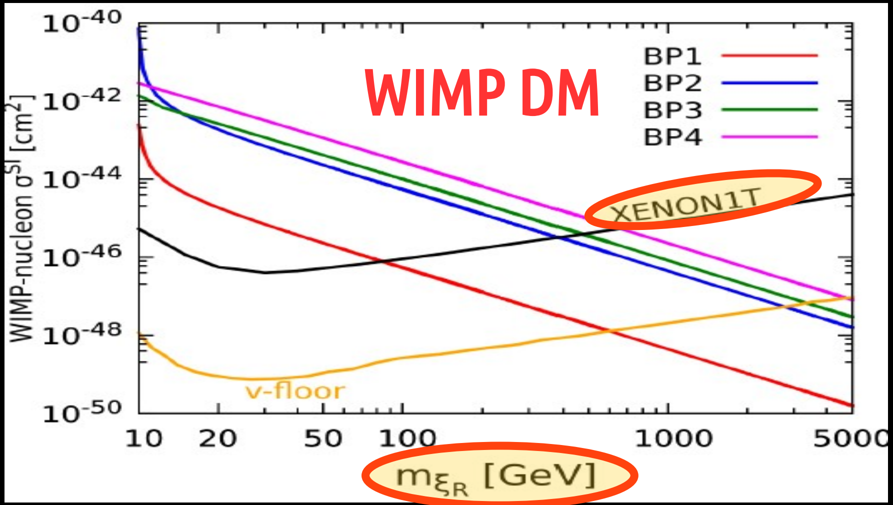


dark inverse typeI seesaw mechanism

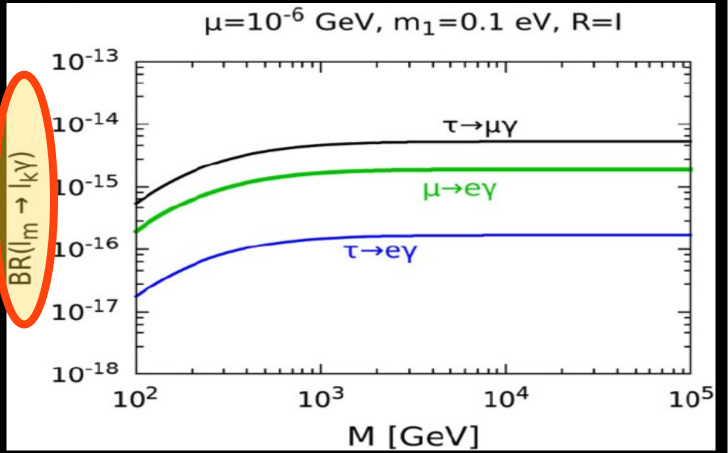
Phys.Lett.B 821 (2021) 136609



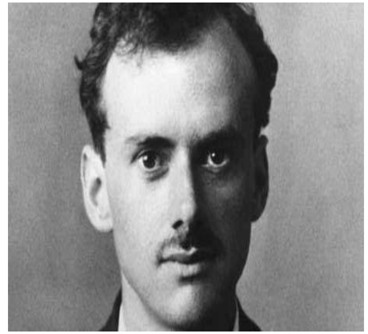
Xenon1T PhysRevLett.121.111302



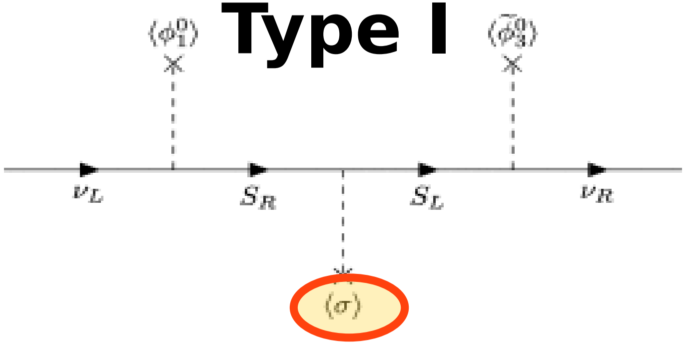
large cLFV from inverse type I seesaw
Mandal et al
Phys.Lett.B 821 (2021) 136609

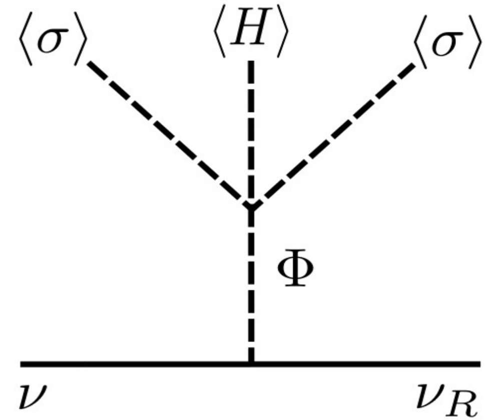


seesawing a la



Type I

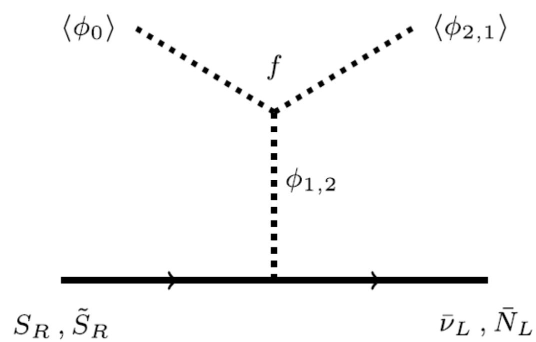




Type II

Phys.Lett. B762 (2016) 162-165

Phys.Rev. D94 (2016) 033012



Phys.Lett. B761 (2016) 431-436

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

Phys.Lett. B755 (2016) 363-366

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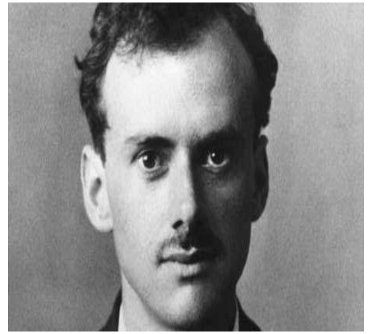

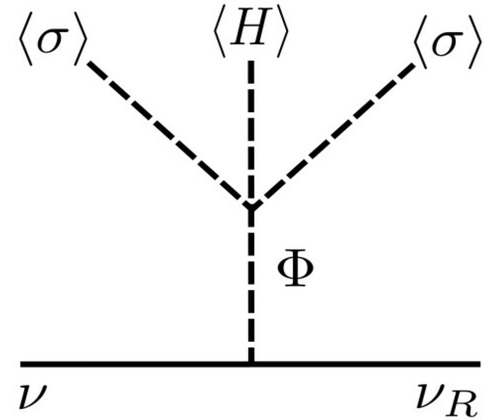

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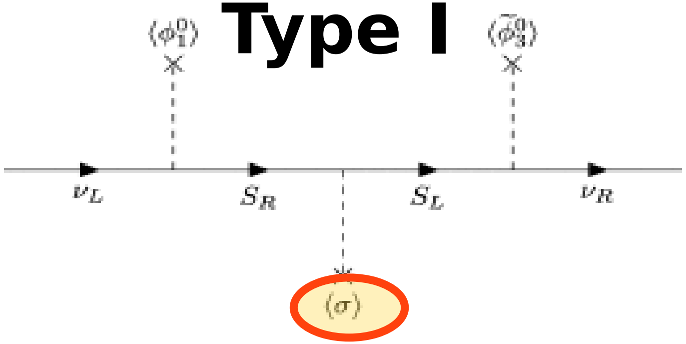

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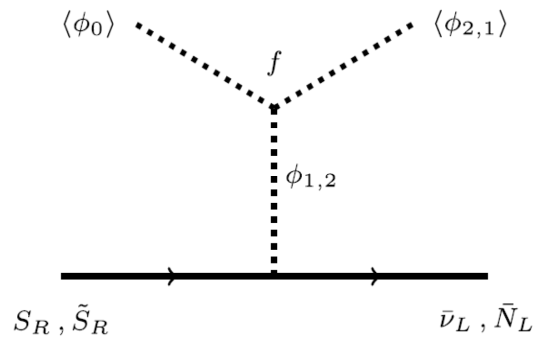


symmetry protecting small neutrino mass

+ Diracness

Peccei-Quinn symmetry Phys.Lett.B 810 (2020) 135829

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

SU3L

PQ

Phys.Lett. B761 (2016) 431-436

Phys.Lett. B767 (2017) 209-213

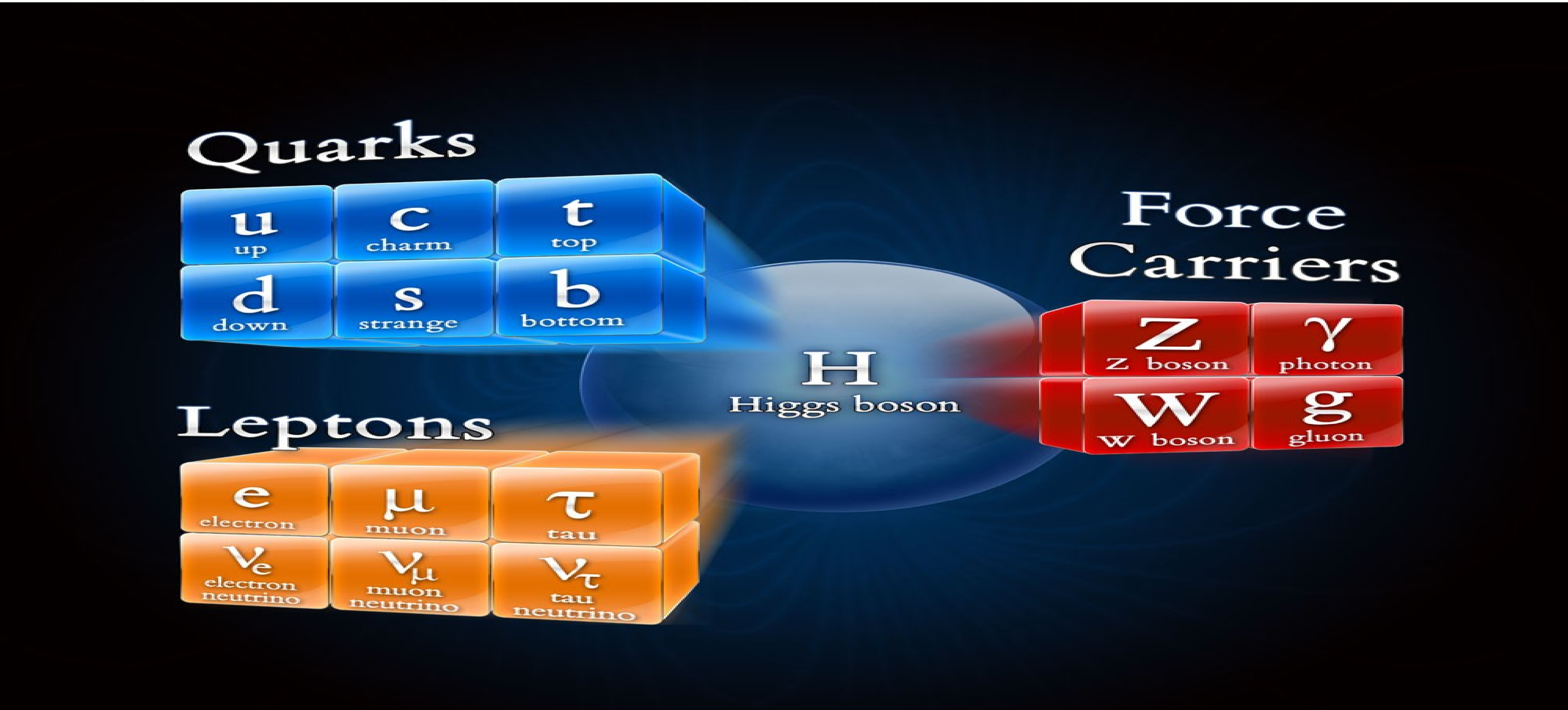
Phys.Rev. D98 (2018) 035009

Phys.Lett. B781 (2018) 122-128

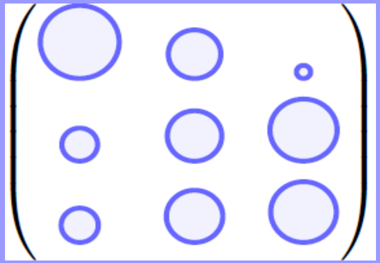
Addazi et al Phys.Lett. B759 (2016) 471-478

Phys.Lett. B755 (2016) 363-366

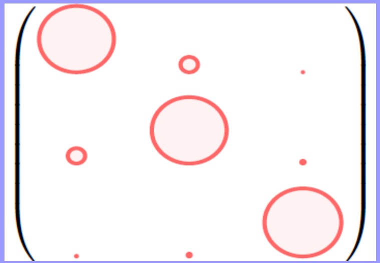
SM lacks an organizing principle to understand Flavor



Q/L mixing pattern



versus



flavour legacy of oscillations

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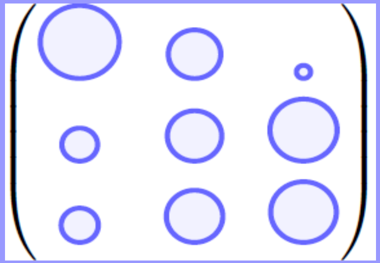

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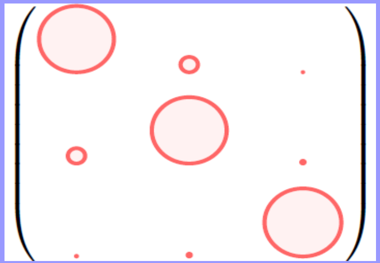
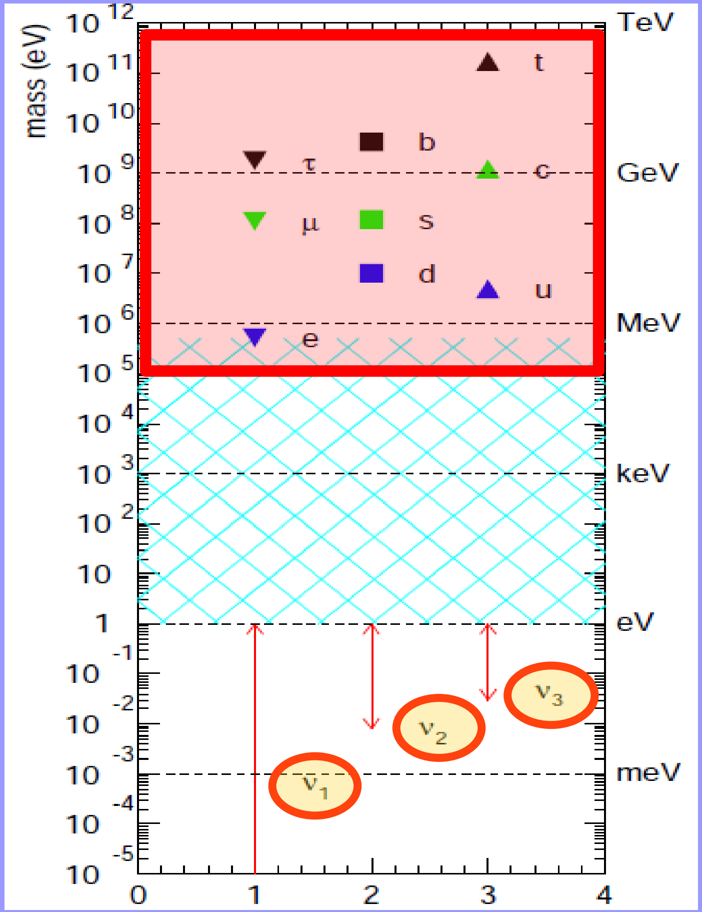


Q/L mass hierarchies



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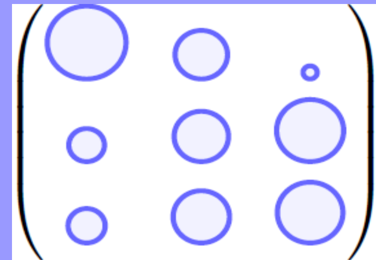

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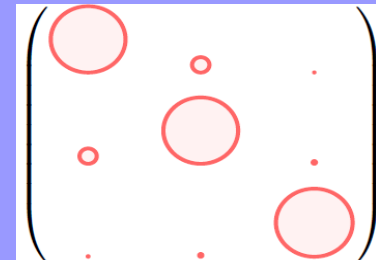
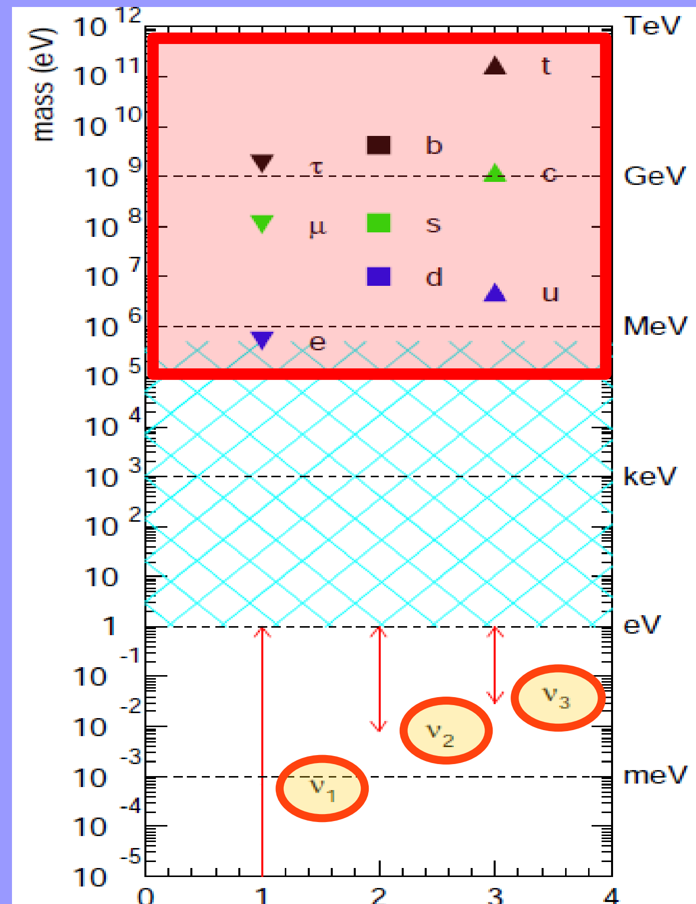


Q/L mass hierarchies

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

Golden Q-L mass relation

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



@jwvalle 15

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**

warped flavour dynamics

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TM mixing pattern predicted from T'

$$\cos^2\theta_{12}\cos^2\theta_{13} = \frac{2}{3}$$ TM1

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

Chen et al

Phys. Rev. D 102, 095014 (2020)

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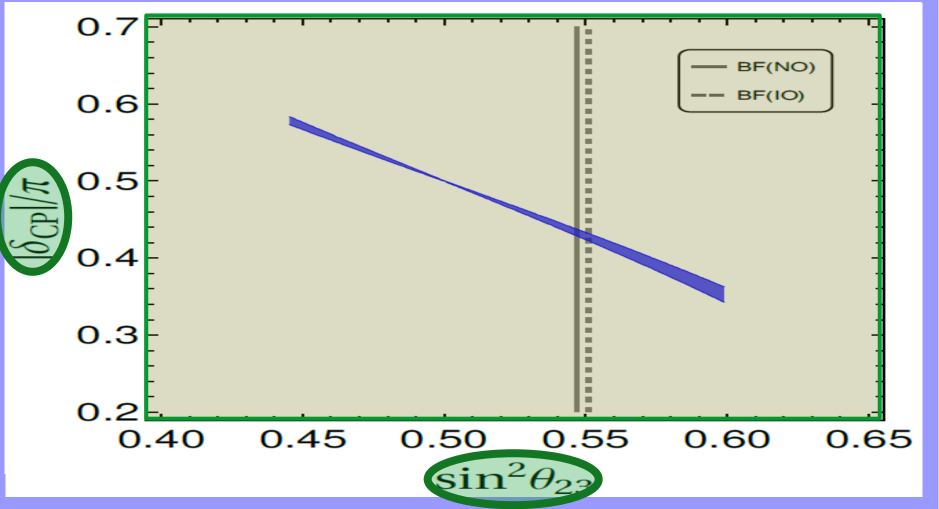

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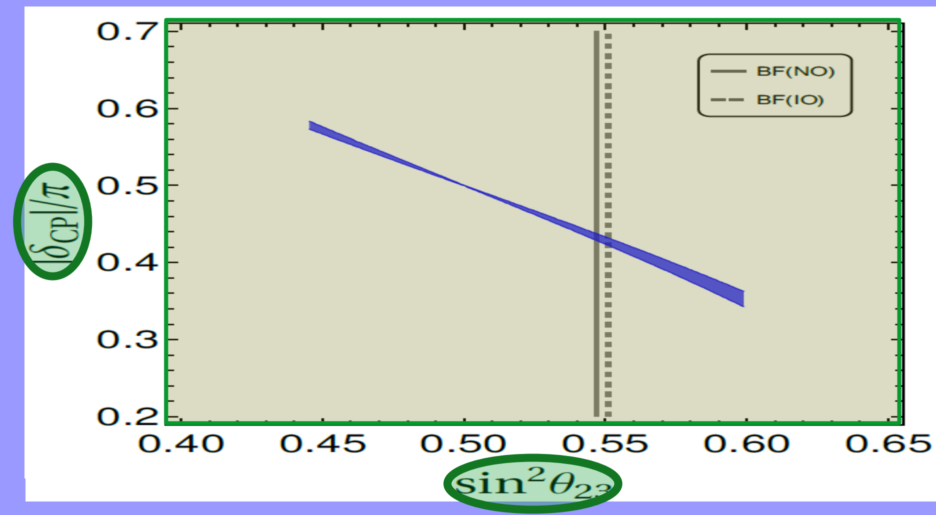

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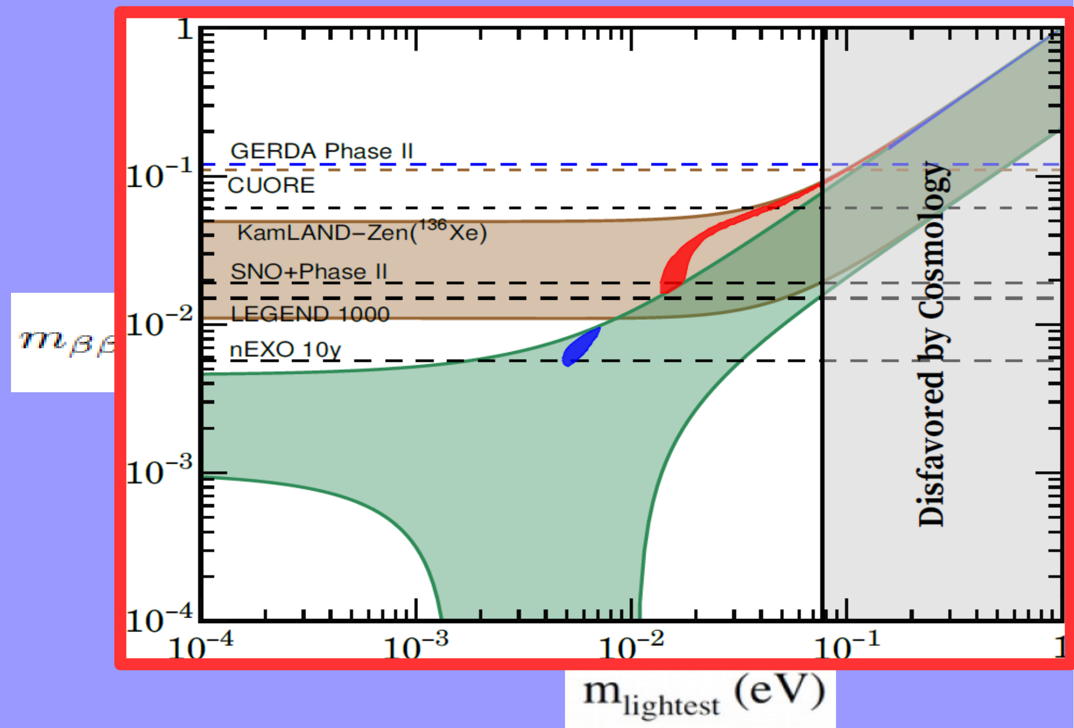

Chen et al

Phys. Rev. D 102, 095014 (2020)

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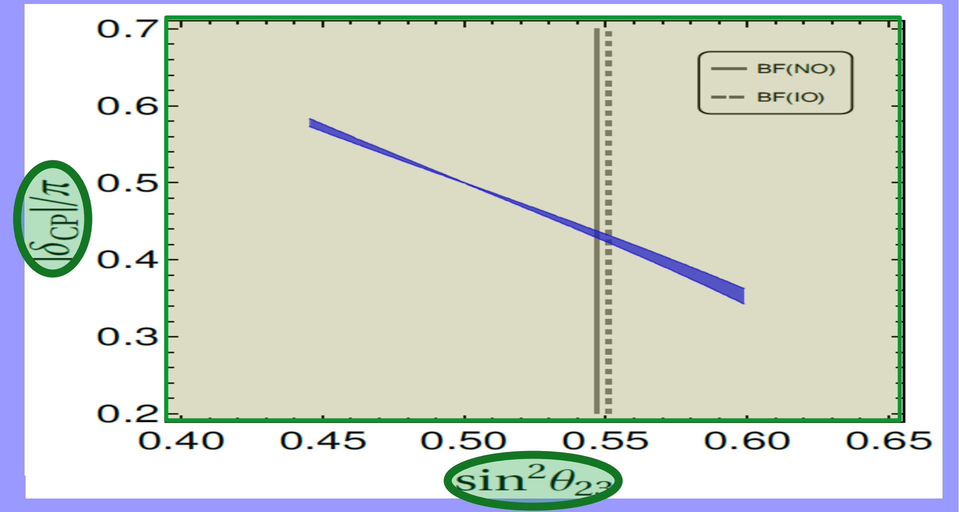
Chen et al

Phys. Rev. D 102, 095014 (2020)

For an alternative see also Chen et al
JHEP01(2016)007

TM2 Phys. Rev. D95 (2017) 095030
Phys.Lett. B771 (2017) 524



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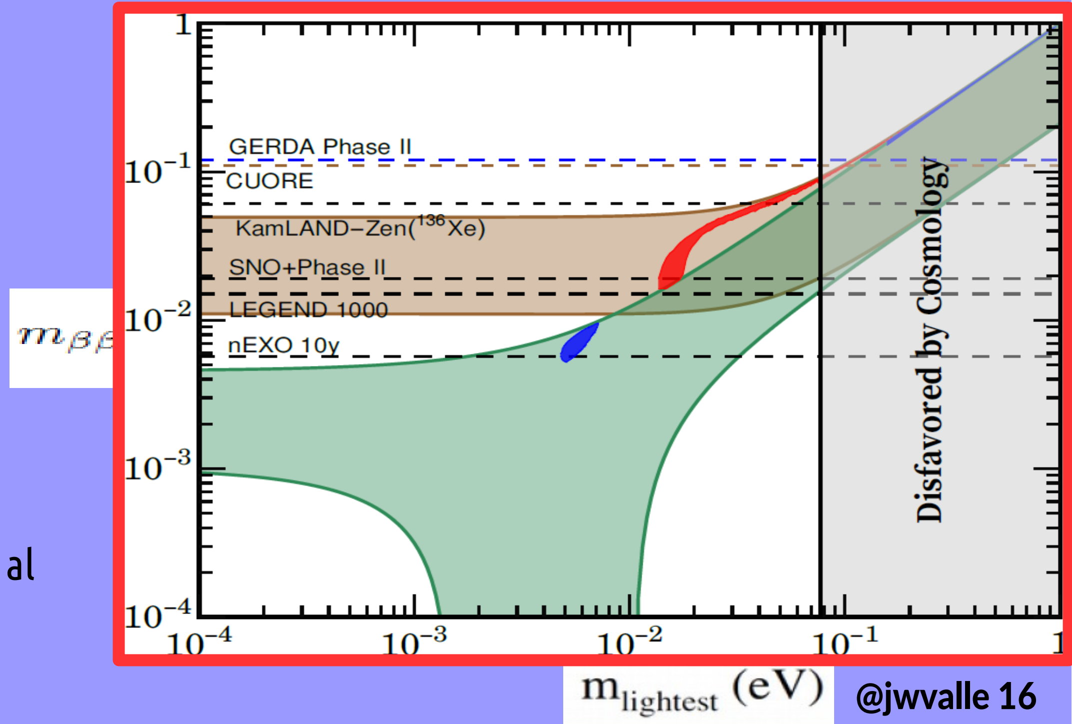
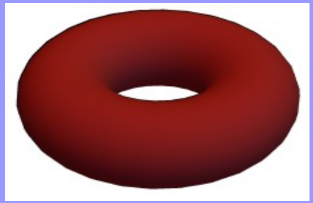


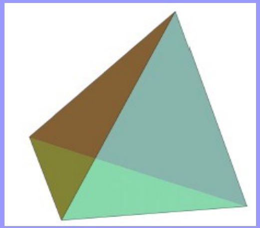
family symmetry from orbifolding

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

Phys.Lett.B 801 (2020) 135195
Phys.Rev.D 105 (2022) 055030



A4 family symmetry as emergent



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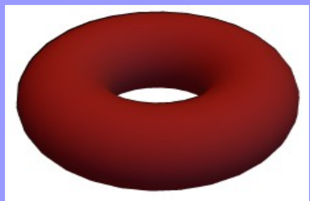
Phys.Lett.B 801 (2020) 135195
Phys.Rev.D 105 (2022) 055030



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Golden Q-L relation

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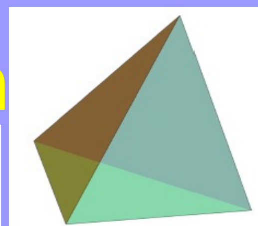
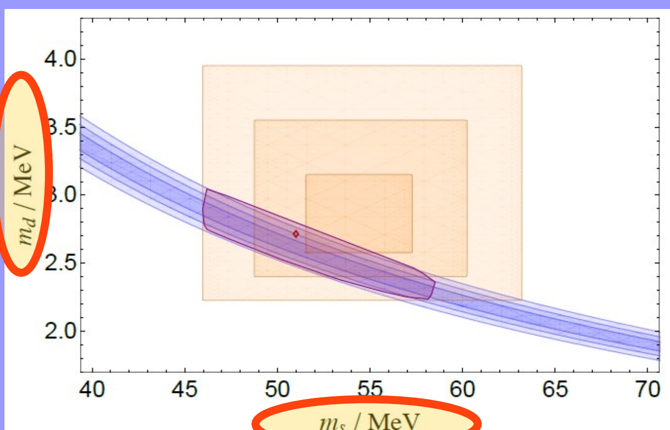


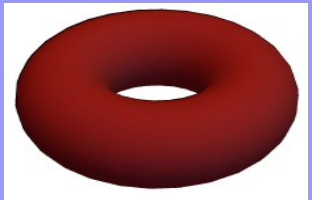


Good global fit of flavor observables

family symmetry from orbifolding

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

Phys.Lett.B 801 (2020) 135195
Phys.Rev.D 105 (2022) 055030



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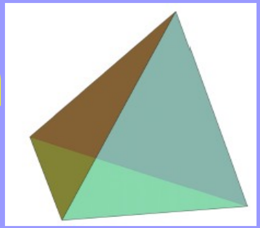
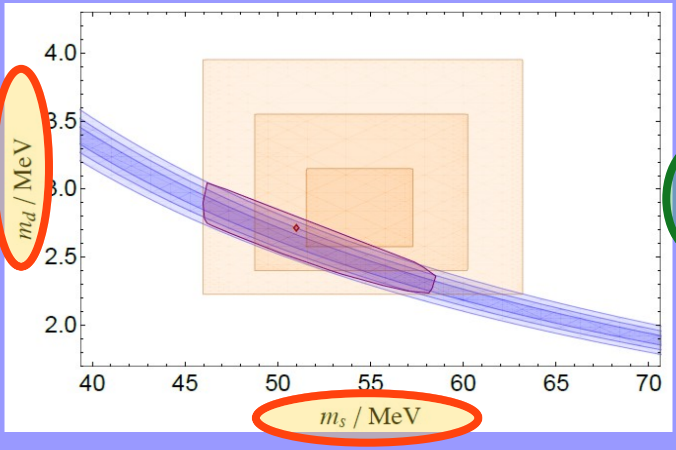
Golden Q-L relation

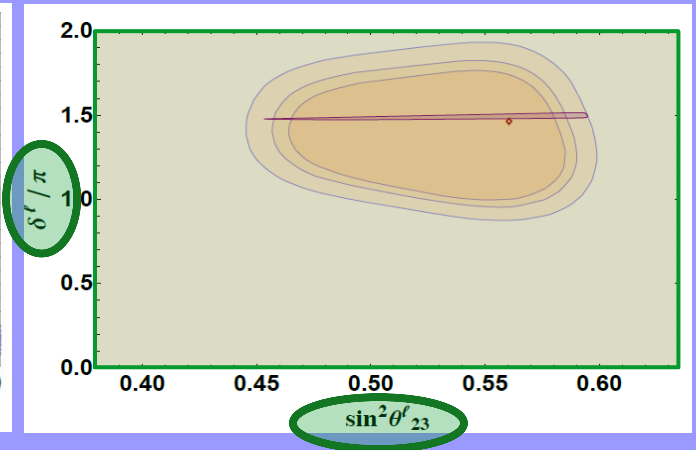
$$\frac{m_\tau}{\sqrt{m_\mu m_e}} \approx \frac{m_b}{\sqrt{m_s m_d}}$$



Sign of CP phase!

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





Dark Matter incorporated

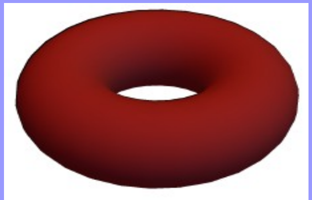
Anda, Antoniadis et al

Good global fit of flavor observables

family symmetry from orbifolding

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

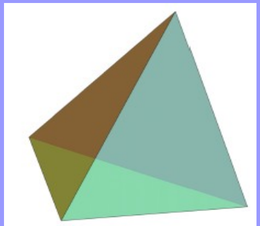
Phys.Lett.B 801 (2020) 135195
Phys.Rev.D 105 (2022) 055030



A4 family symmetry as emergent

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!

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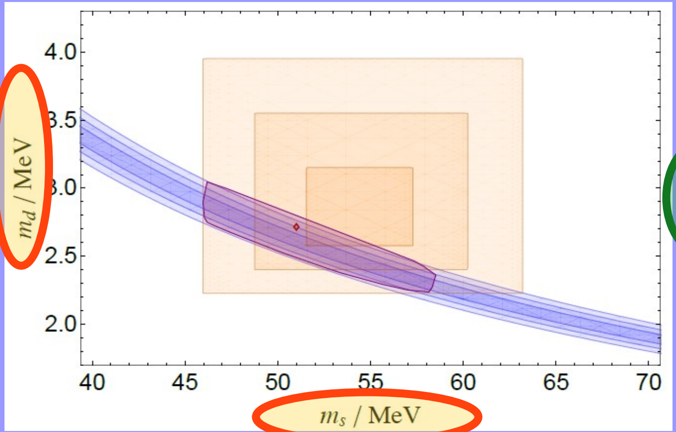
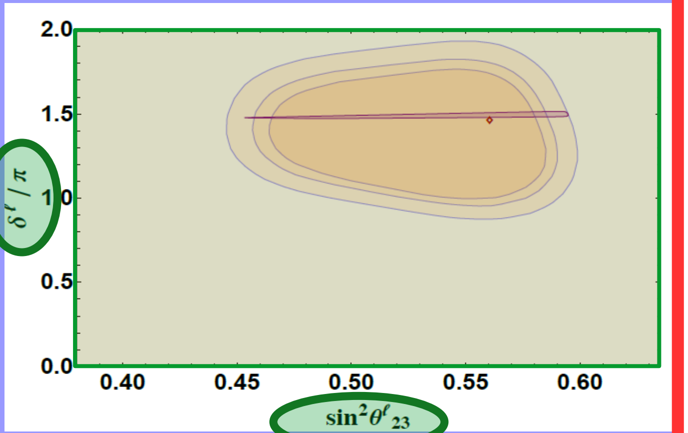
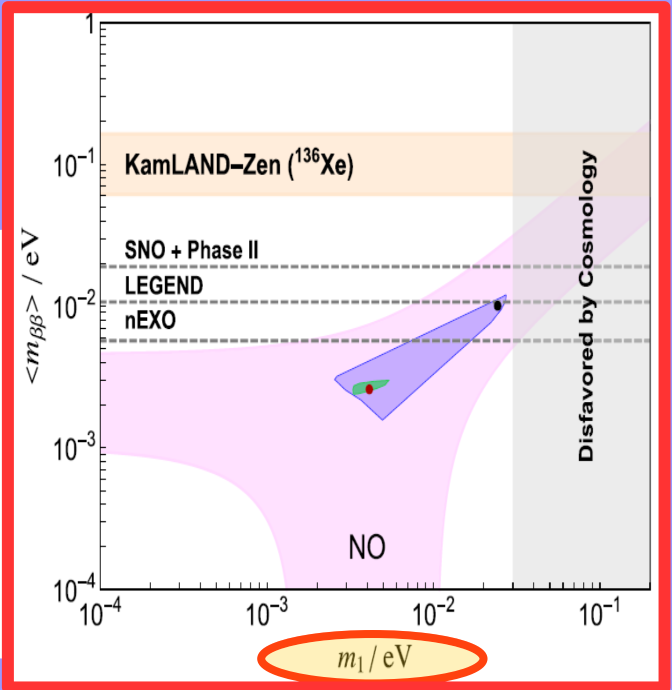






Good global fit of flavor observables

Dark Matter incorporated

Anda, Antoniadis et al JHEP10(2020)190

neutrinos at the spotlight

oscillation program, CP, octant, ordering, unitarity/NSI **CEvNS** ......

0nuDBD

other searches at HE

& **cLFV**

neutrinos at the spotlight

oscillation program, CP, octant, ordering, unitarity/NSI CEvNS ......

0nuDBD

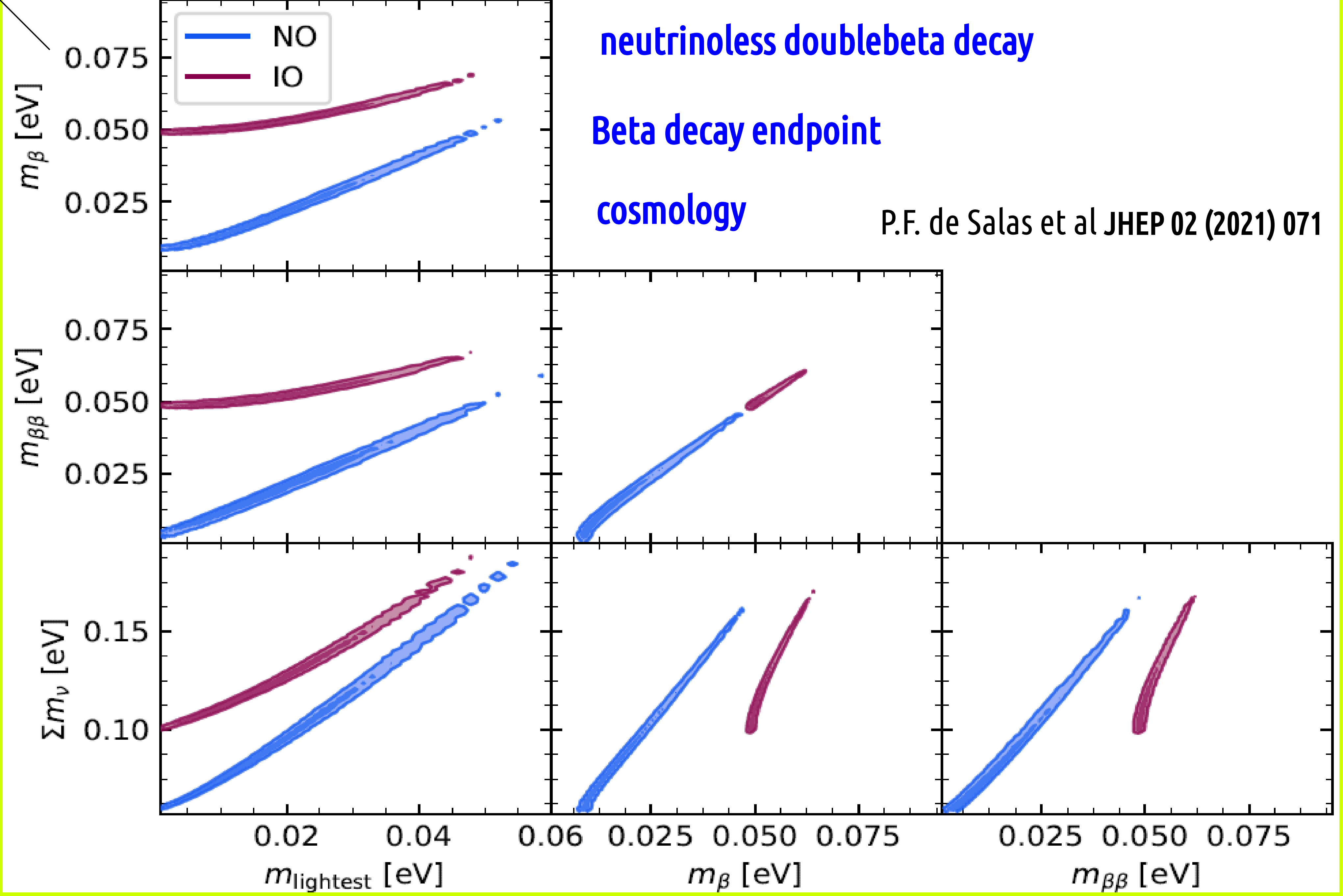
other searches at HE
& cLFV

EW vacuum
flavor puzzle & unification
strong CP problem

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

baryon asymmetry from neutrinos, GWs from lepton # violation..

@jwvalle 18


neutrinoless doublebeta decay
Beta decay endpoint
cosmology
P.F. de Salas et al JHEP 02 (2021) 071
NO
IO
m_β [eV]
$m_{\beta\beta}$ [eV]
Σm_ν [eV]
0.025
0.050
0.075
0.10
0.15
0.02
0.04
0.06
m_{lightest} [eV]
m_β [eV]
$m_{\beta\beta}$ [eV]