neutrinos, flavor and dark matter

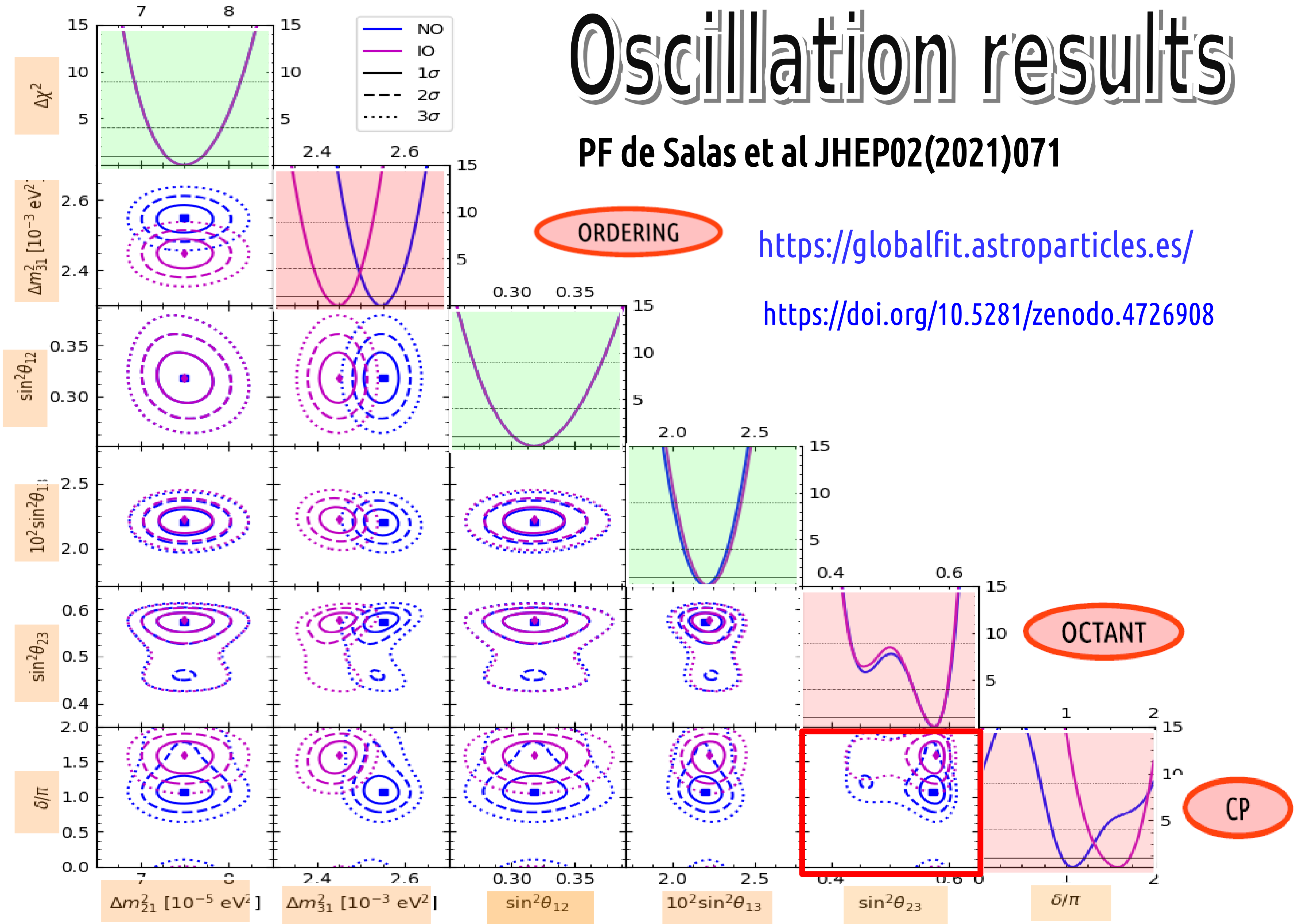
JOSÉ W F VALLE

IFIC, CSIC-UV, Spain

12th Workshop on Flavor Symmetries and Consequences in Accelerators and Cosmology - FLASY 2026 - Gyeongju, August 17 - 22, 2026

Oscillation results

PF de Salas et al JHEP02(2021)071



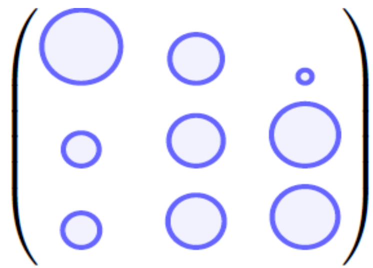
https://globalfit.astroparticles.es/

https://doi.org/10.5281/zenodo.4726908

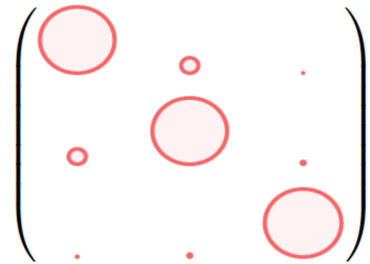
NuFit & Bari

flavor legacy of oscillations

Q/L mixing pattern

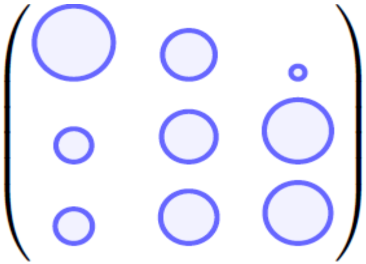


versus

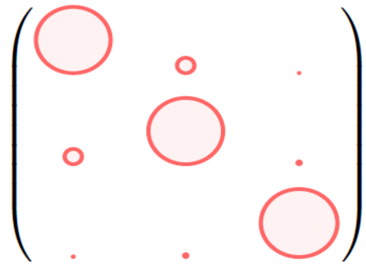


flavor legacy of oscillations

Q/L mixing pattern



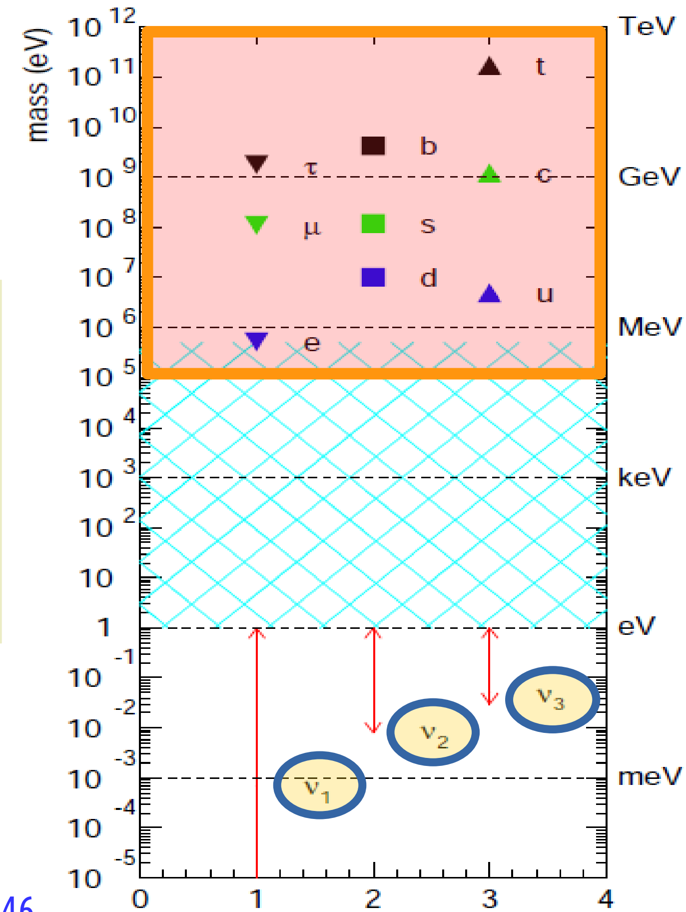
versus



Q/L mass hierarchies

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

from family sym	Morisi et al	PRD84 (2011) 036003
	King et al	PLB 724 (2013) 68
	Morisi et al	PRD88 (2013) 036001
	Bonilla et al	PLB742 (2015) 99
modular sym	Chen, King, Medina, Valle	JHEP 02 (2024) 160
	Centelles, Li, Liu, Medina, Penedo	2606.25027
from PQ sym	Reig, JV, Wilczek	PRD98 (2018) 095008
from orbifolds	De Anda et al	PRD105 (2022) 055030 , JHEP10 (2020) 190, PLB 801 (2020) 135195, PRD 101 (2020) 11, 116012 PRD 108 (2023) 3, 035046

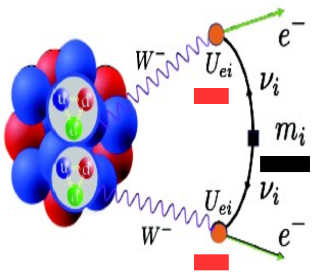


Gui-Jun Ding and JV

Phys.Rept. 1109 (2025) 1-105

neutrinoless doublebeta decay

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



Original symmetrical parametrization

Schechter & JV PRD22 (1980) 2227

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

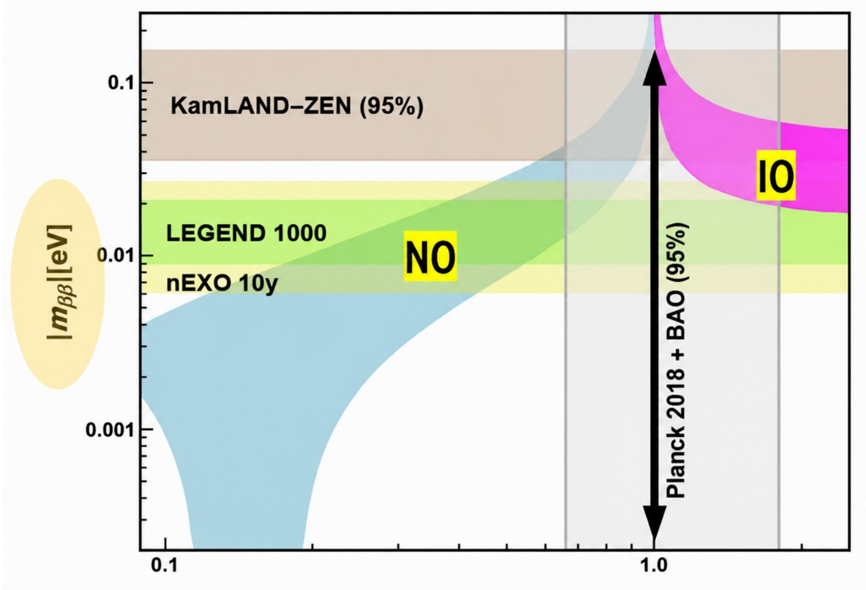
Versus PDG phase convention

KamLAND-Zen 2203.02139 GERDA 2009.06079

C Adams et al 2212.11099

Agostini et al. Science 365 (2019) 1445

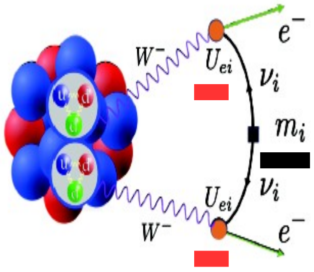
Nearly degenerate



Lattanzi et al JHEP10(2020)213

neutrinoless doublebeta decay

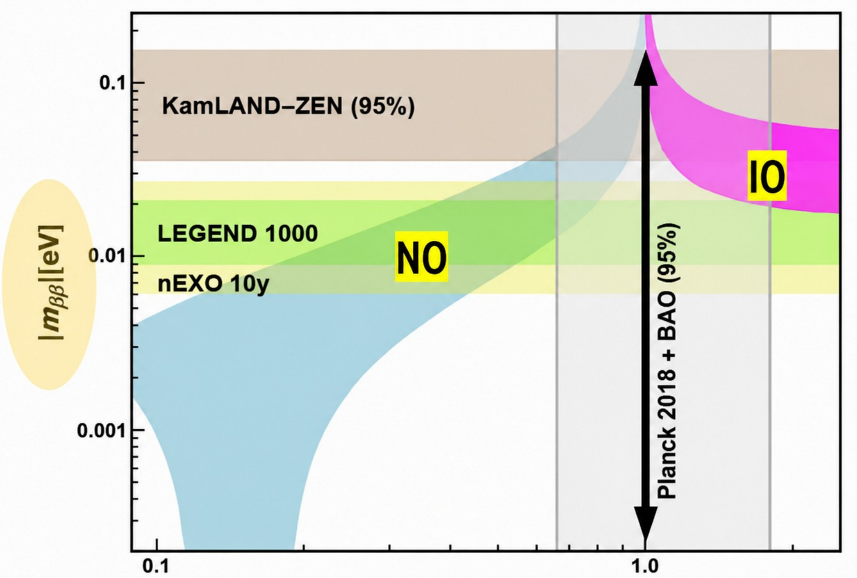
$$\left|\sum_j U_{ej}^2 m_j\right| = \left|c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 m_2 e^{2i\phi_{12}} + s_{13}^2 m_3 e^{2i\phi_{13}}\right|$$



Original symmetrical parametrization
Schechter & JV PRD22 (1980) 2227
Rodejohann, JV Phys.Rev. D84 (2011) 073011
Versus PDG phase convention

KamLAND-Zen 2203.02139 GERDA 2009.06079

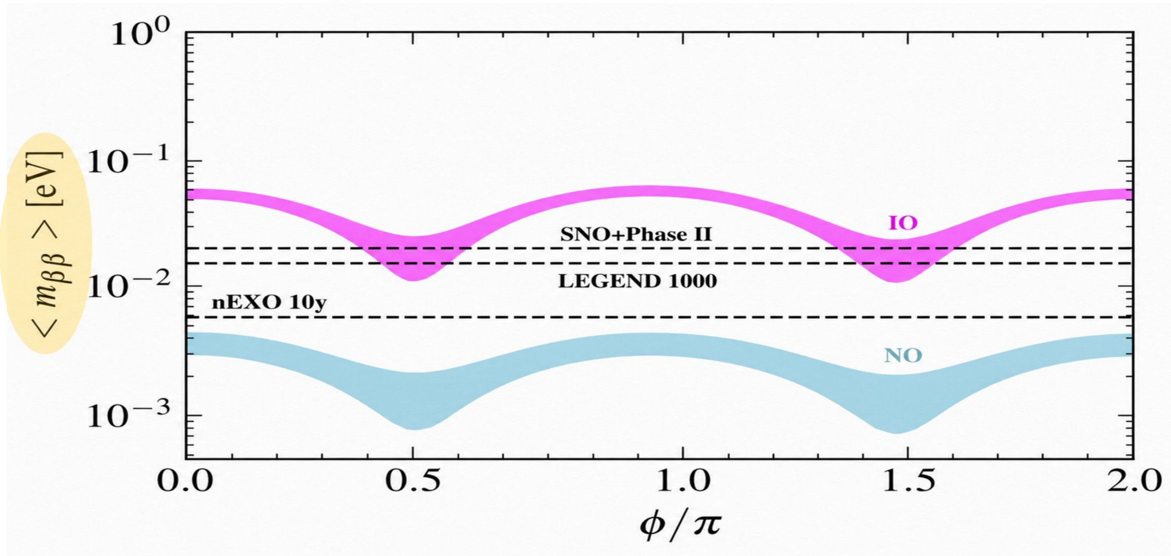
C Adams et al 2212.11099
Agostini et al. Science 365 (2019) 1445



Lattanzi et al JHEP10(2020)213

Nearly degenerate

- **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

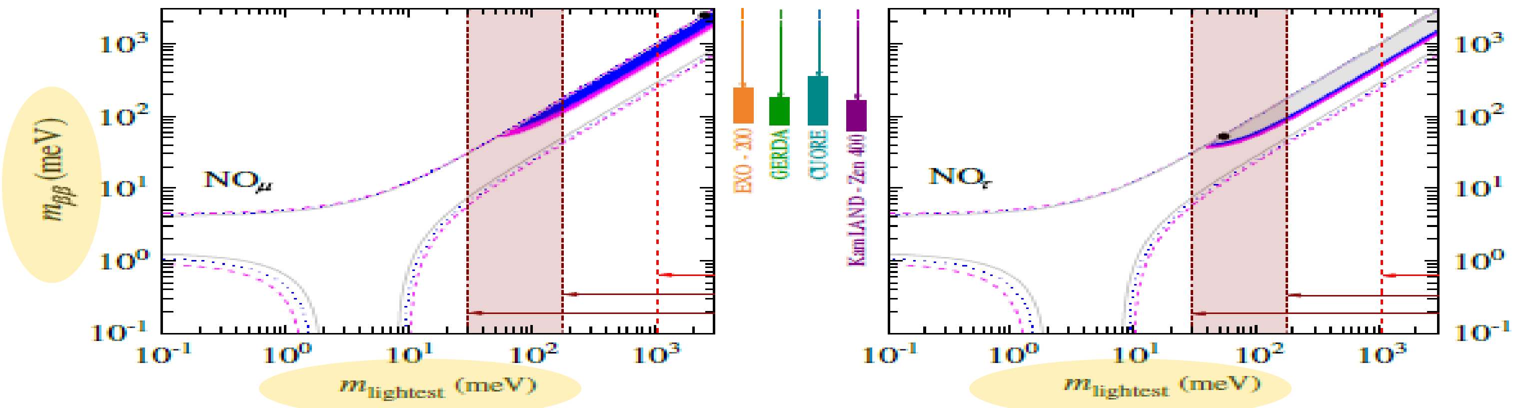
majorana phase

➢ **3-massive case**

Lower bounds from oscil. legacy + family symmetries

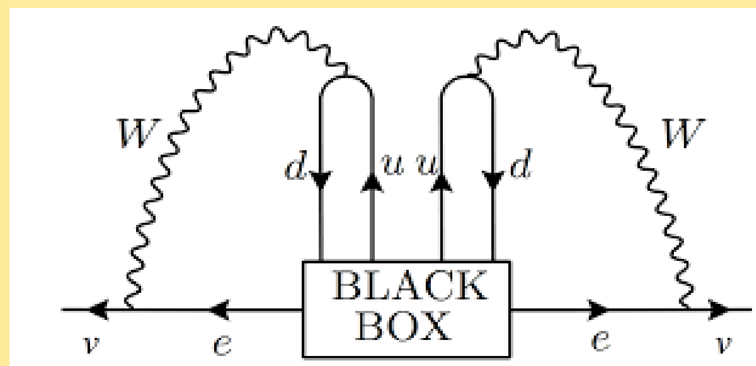
Dorame et al PhysRevD86(2012)056001
Dorame et al Nucl.Phys.B861 (2012) 259-270
King et al Phys.Lett. B724 (2013) 68-72 etc

From Barreiros et al JHEP04(2021)249

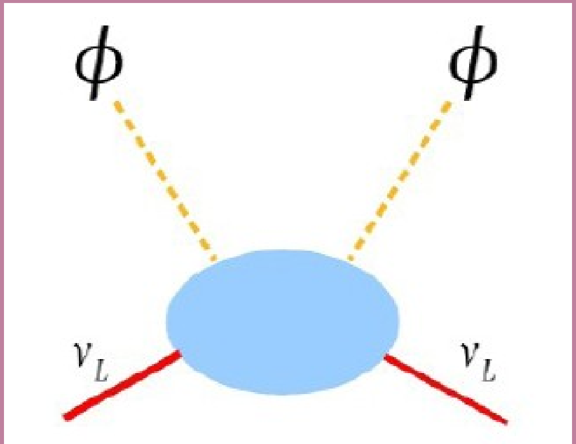


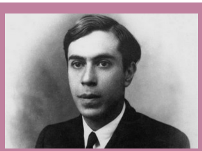
Significance

Schechter, Valle Phys.Rev.D25 (1982) 2951
Duerr, Lindner, Merle JHEP06(2011)091
Oliver Scholer, 2024
B.J.P. Jones 2108.09364 (TASI 2020)



Origin of neutrino mass



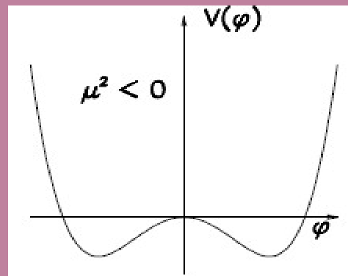


Origin of neutrino mass

stability

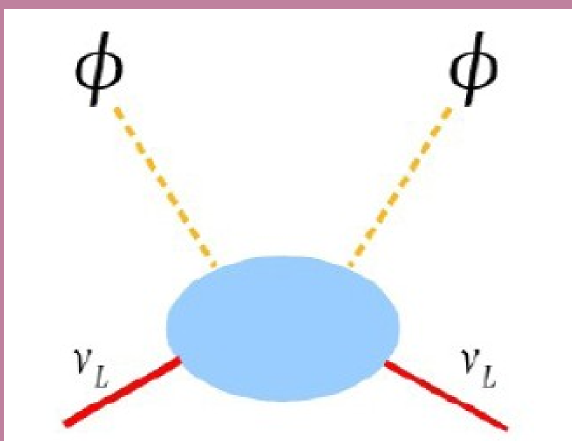
SEESAW dynamics

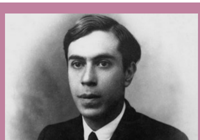
$$v_3 v_1 \sim {v_2}^2$$



Mandal et al PRD101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029



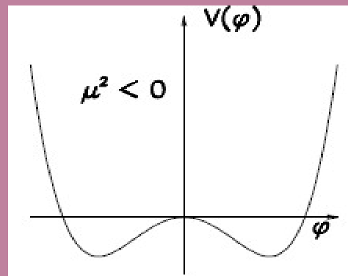


Origin of neutrino mass

SEESAW dynamics

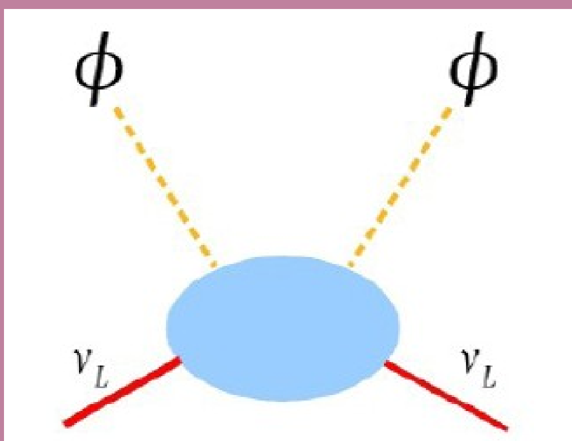
$$v_3 v_1 \sim v_2{}^2$$

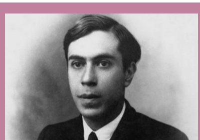
stability

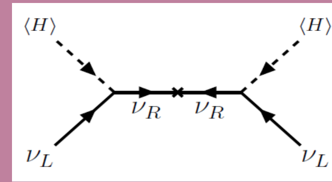


Mandal et al PRD101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029







TYPE I

Minkowski 77

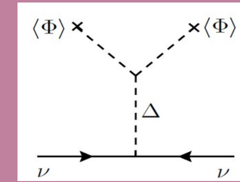
Gellman Ramond Slansky 80

Glashow, Yanagida 79

Mohapatra Senjanovic 80

Lazarides Shafi Weterrich 81

Schechter-Valle 80 & 82



TYPE II

Schechter-Valle 80 & 82

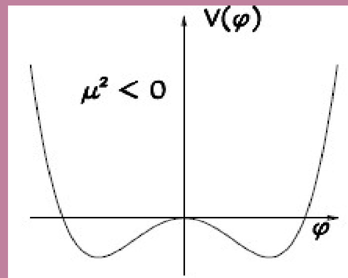
Miranda et al

PLB829 (2022) 137110

PRD105 (2022) 095020

Origin of neutrino mass

stability

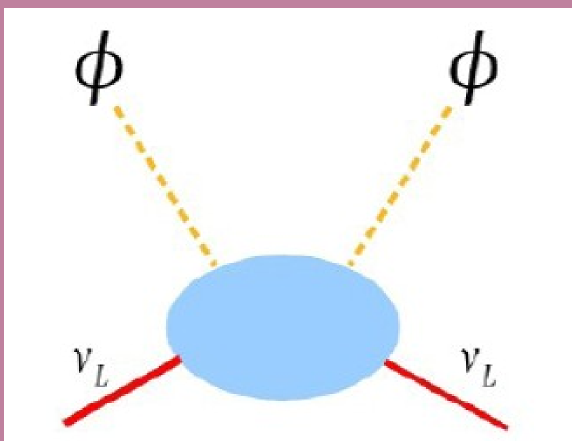


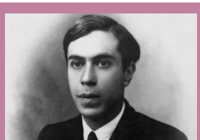
SEESAW dynamics

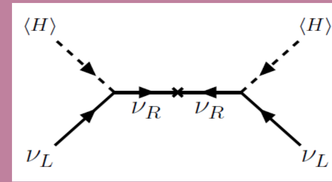
$$v_3 v_1 \sim v_2^{\,2}$$

Mandal et al PRD101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029







TYPE I

Minkowski 77

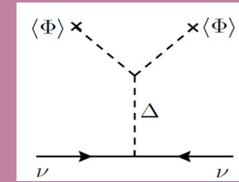
Gellman Ramond Slansky 80

Glashow, Yanagida 79

Mohapatra Senjanovic 80

Lazarides Shafi Weterrich 81

Schechter-Valle 80 & 82



TYPE II

Schechter-Valle 80 & 82

Miranda et al

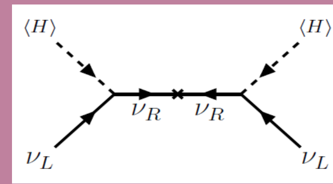
PLB829 (2022) 137110

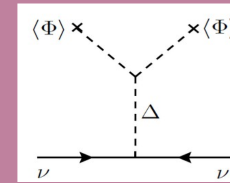
PRD105 (2022) 095020

L-R seesaw # of Rs = # Ls (3,3)

SM seesaw any # of singlets (3,m)

Origin of neutrino mass

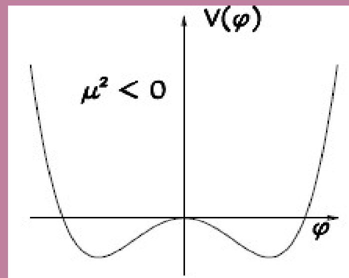




stability

SEESAW dynamics

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



Mandal et al PRD101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029

TYPE I

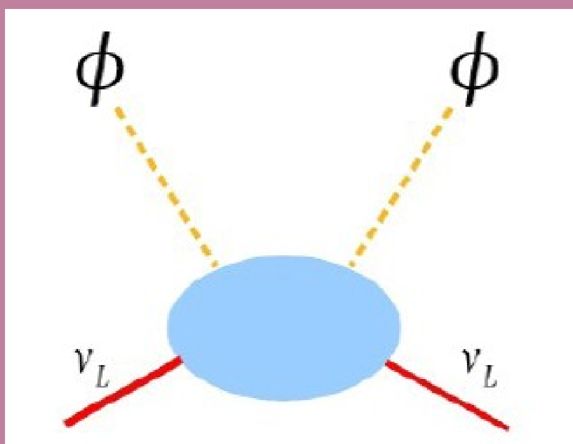
Minkowski 77
Gellman Ramond Slansky 80
Glashow, Yanagida 79
Mohapatra Senjanovic 80
Lazarides Shafi Weterrich 81
Schechter-Valle 80 & 82

TYPE II

Schechter-Valle 80 & 82
Miranda et al
PLB829 (2022) 137110
PRD105 (2022) 095020

L-R seesaw # of Rs = # Ls (3,3)

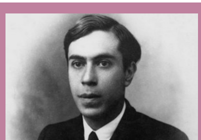
SM seesaw any # of singlets (3,m)



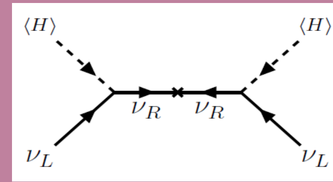
- MISSING PARTNER

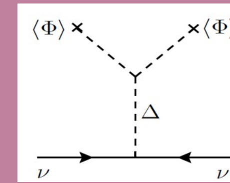
(3,2) min viable type1 seesaw
(3,1) scoto-seesaw template

$m_{\beta\beta}$



Origin of neutrino mass

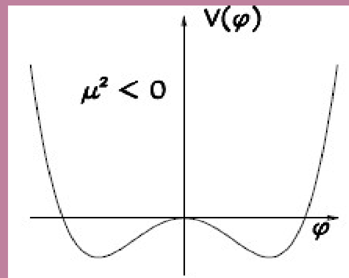




SEESAW dynamics

stability

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



Mandal et al PRD101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029

TYPE I

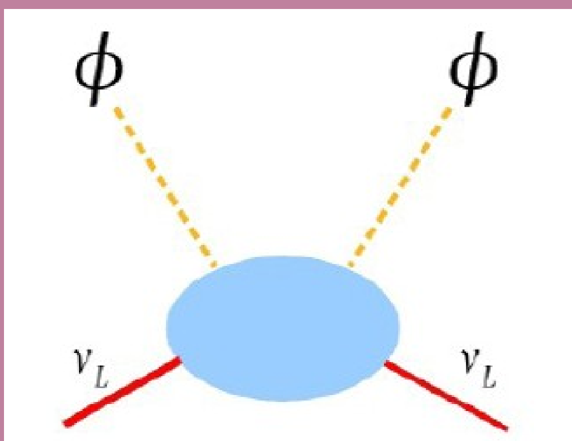
Minkowski 77
Gellman Ramond Slansky 80
Glashow, Yanagida 79
Mohapatra Senjanovic 80
Lazarides Shafi Weterrich 81
Schechter-Valle 80 & 82

TYPE II

Schechter-Valle 80 & 82
Miranda et al
PLB829 (2022) 137110
PRD105 (2022) 095020

L-R seesaw # of Rs = # Ls (3,3)

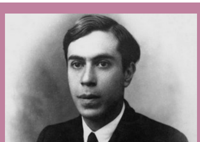
SM seesaw any # of singlets (3,m)

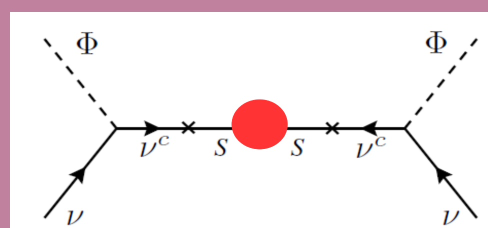


- MISSING PARTNER (3,2) min viable type1 seesaw
  (3,1) scoto-seesaw template

$m_{\beta\beta}$

- LOW-SCALE Type1 SEESAW (3,3,3) 3,1,1



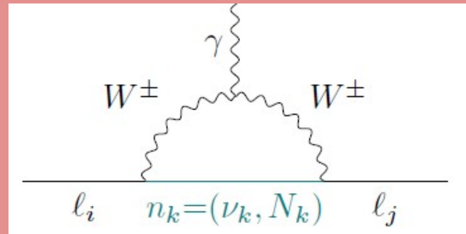


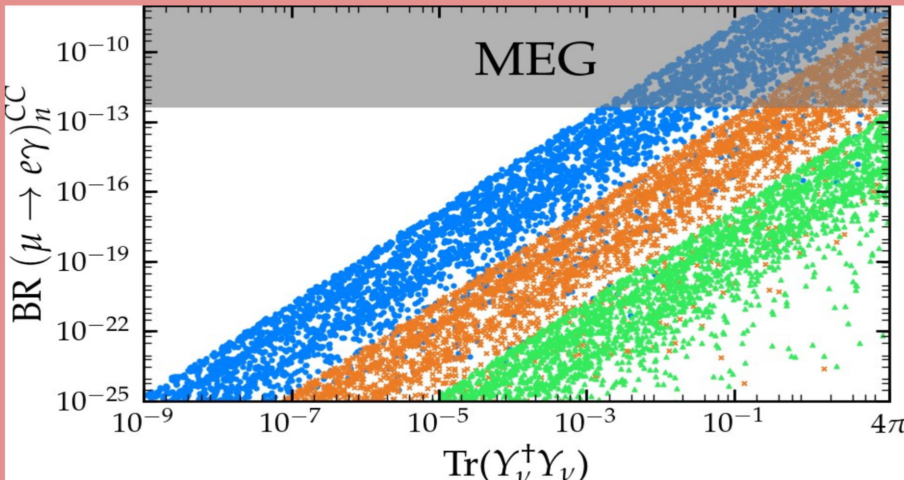
Mohapatra,Valle 86
Akhmedov et al Phys.Rev.D53 (1996) 2752
PhysLettB368 (1996) 270
Malinsky et al PhysRevLett95(2005)161801

low-scale seesaw

inverse versus linear seesaw

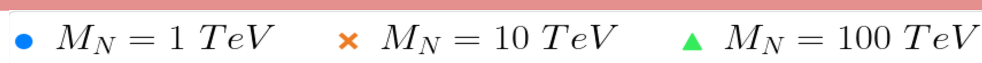
CC Lepton Flavor Violation In low-scale seesaw



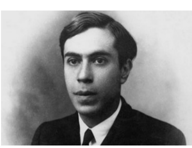


From Batra et al 2305.00994

(3,3,3) low-scale seesaw

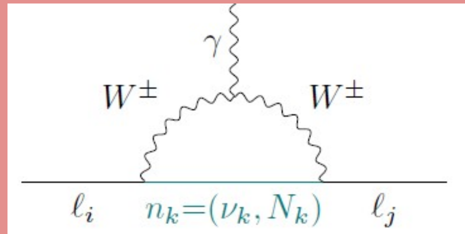


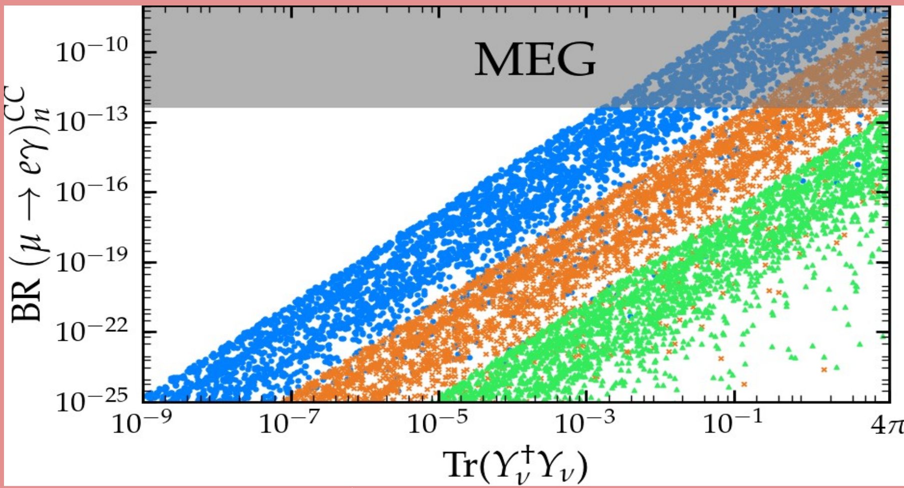
cLFV with massless neutrinos



Bernabeu et al B187 (1987) 303-308

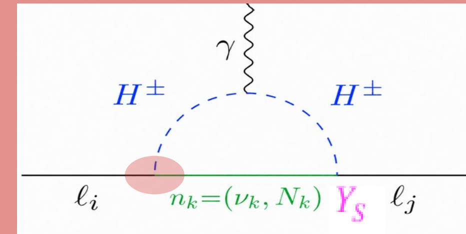
CC Lepton Flavor Violation In low-scale seesaw

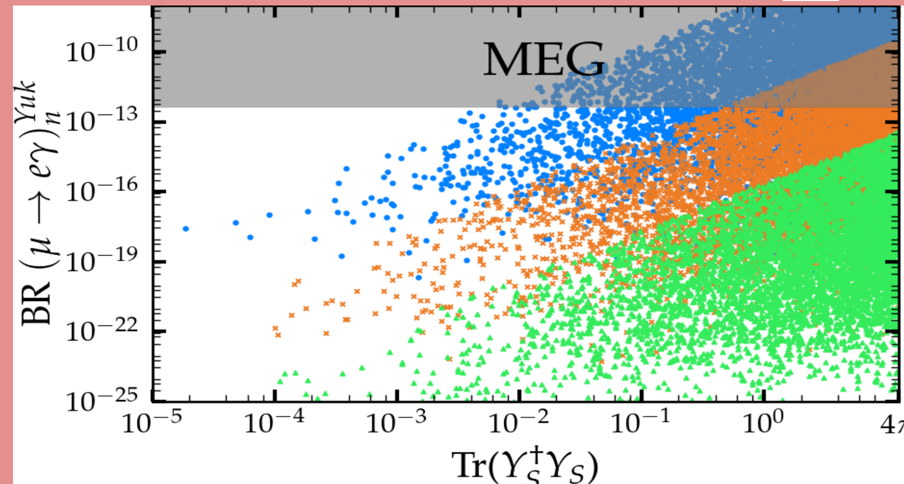




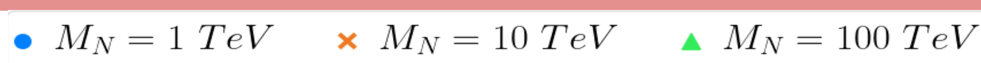
From Batra et al
2305.00994

Leptophilic Higgs linear seesaw cLFV

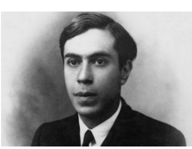




(3,3,3) low-scale seesaw

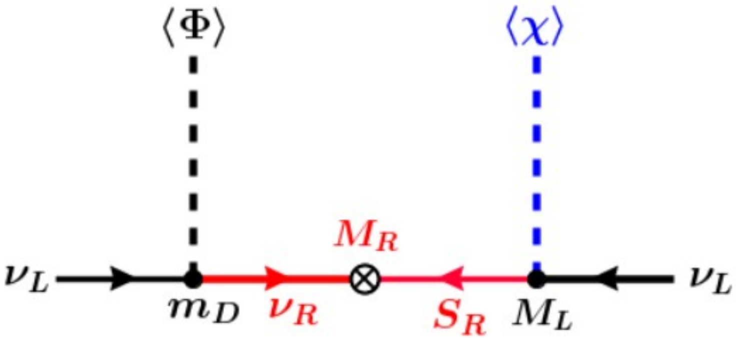


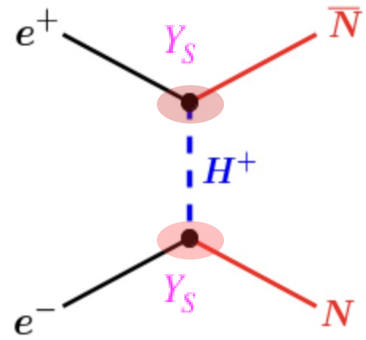
cLFV with massless neutrinos

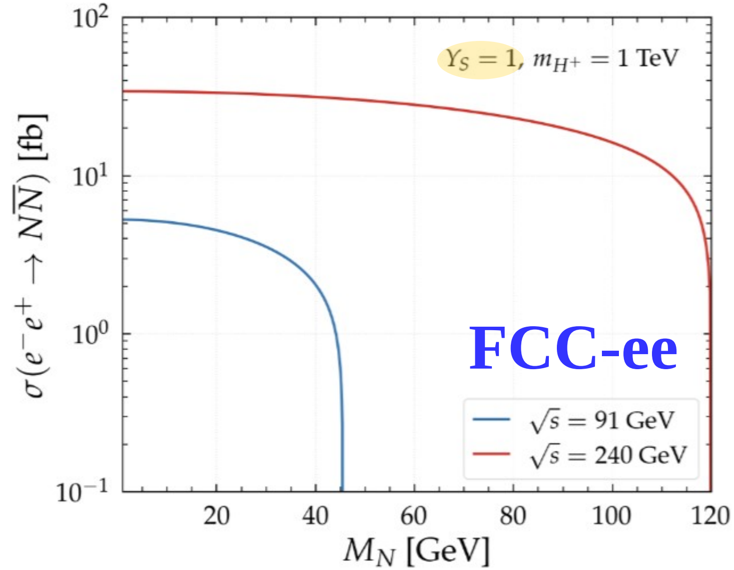


Bernabeu et al B187 (1987) 303-308

Batra et al, Phys.Lett.B 834 (2022) 137408
JHEP 07 (2023) 221
Phys.Lett.B 860 (2025) 139204
Majoron version JHEP 10 (2019) 245

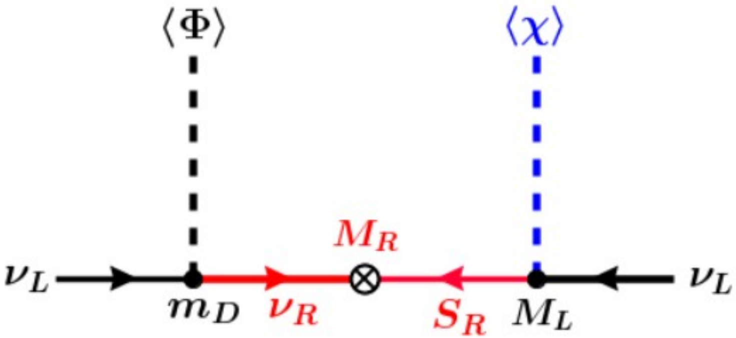


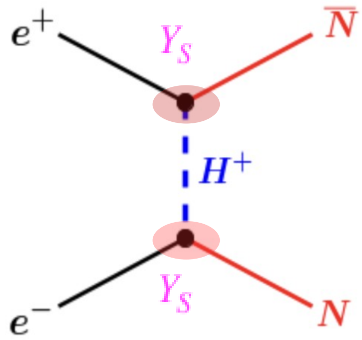


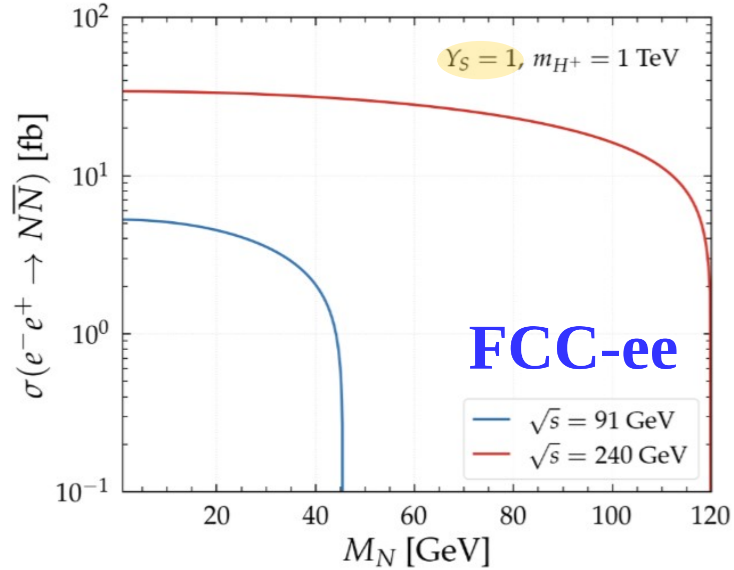


probing lepton number violation at colliders

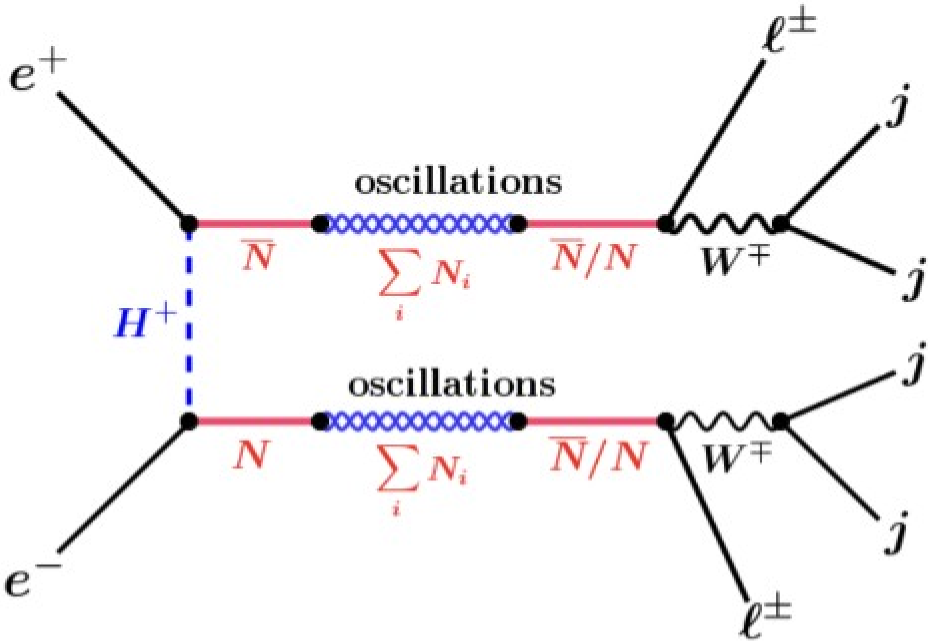
Minimal
T1 seesaw
3,1,1 LSS
2606.09993

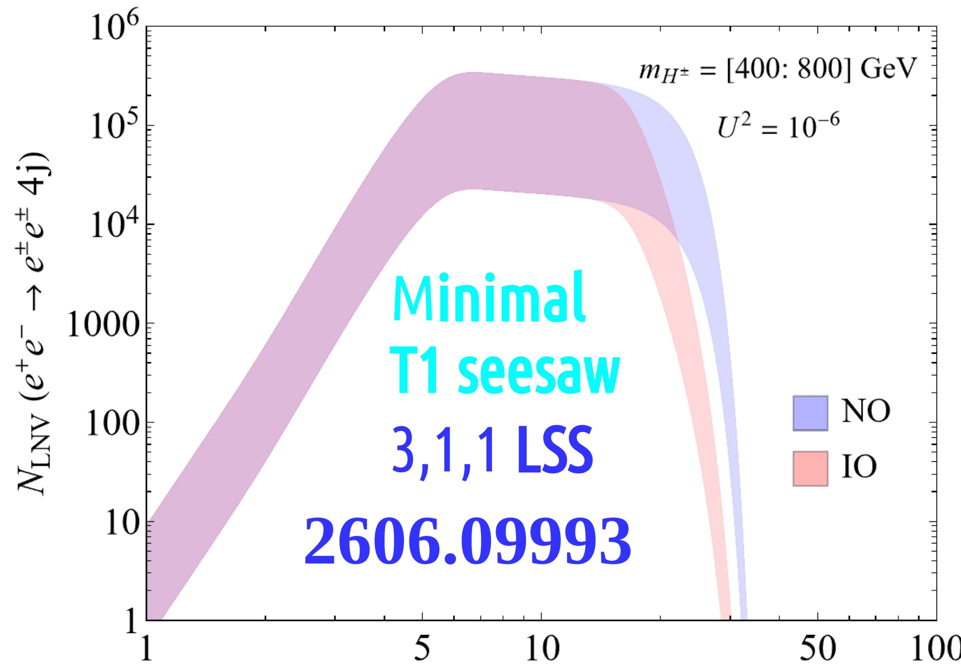






probing lepton number violation at colliders





Antusch, Hajer, Rosskopp; Anamiati, Hirsch, Nardi

GrWaves 2606.15316


DARK MATTER
VISIBLE MATTER
PROTON
PHOTON
e-
NEUTRINO
MUON
NEUTRON
QUARK
NEUTRALINO
GRAVITINO
AXION
AXION
Wimp
DARK ELECTRONS
e
e
DARK NEUTRON

Scotogenic paradigm

minimal versus revamped

Ma hep-ph/0601225
Tao hep-ph/9603309

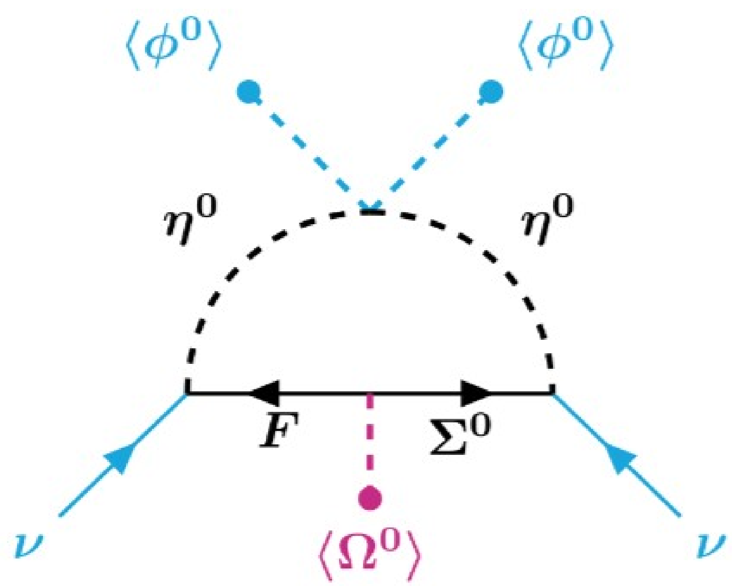
Avila et al Phys.Rept. 1173 (2026) 1-81

revamped scoto DM

PHYS. REV. D **112**, 055007 (2025)

	Standard Model			Fermions		Scalars	
Fields	L_i	e_i	Φ	Σ	F	η	Ω
Multiplicity	3	3	1	1	1	1	1
$\mathrm{SU(2)_L}$	2	1	2	3	1	2	3
$\mathrm{U(1)_Y}$	$-1/2$	-1	$1/2$	0	0	$1/2$	0
$\mathbb{Z}_2$	$+$	$+$	$+$	$-$	$-$	$-$	$+$

Radiative DM-mediated neutrino mass



Potential

Avila et al Phys.Rept. 1173 (2026) 1-81

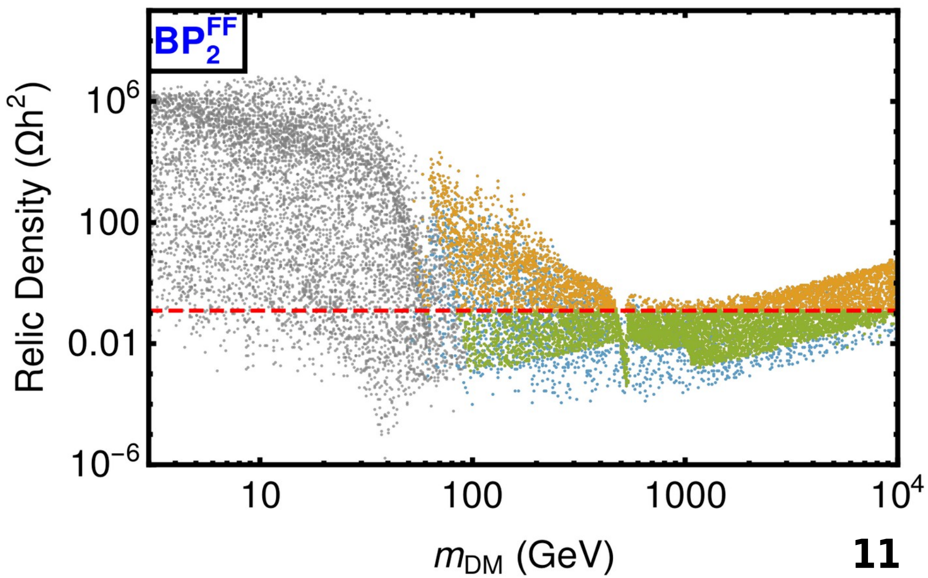
$$V = -m_\phi^2\phi^\dagger\phi + m_\eta^2\eta^\dagger\eta - \frac{m_\Omega^2}{2}\mathrm{Tr}(\Omega^\dagger\Omega) + \frac{\lambda_1}{2}(\phi^\dagger\phi)^2 + \frac{\lambda_2}{2}(\eta^\dagger\eta)^2 + \frac{\lambda_3}{2}(\phi^\dagger\phi)(\eta^\dagger\eta)$$
$$+\lambda_4(\phi^\dagger\eta)(\eta^\dagger\phi) + \frac{\lambda_5}{2}[(\phi^\dagger\eta)^2 + (\eta^\dagger\phi)^2] + \mu_1\phi^\dagger\Omega\phi + \mu_2\eta^\dagger\Omega\eta$$
$$+\frac{\lambda_1^\Omega}{2}(\phi^\dagger\phi)\mathrm{Tr}(\Omega^\dagger\Omega) + \frac{\lambda_2^\Omega}{4}[\mathrm{Tr}(\Omega^\dagger\Omega)]^2 + \frac{\lambda_\eta^\Omega}{2}(\eta^\dagger\eta)\mathrm{Tr}(\Omega^\dagger\Omega),$$

revamped scoto DM

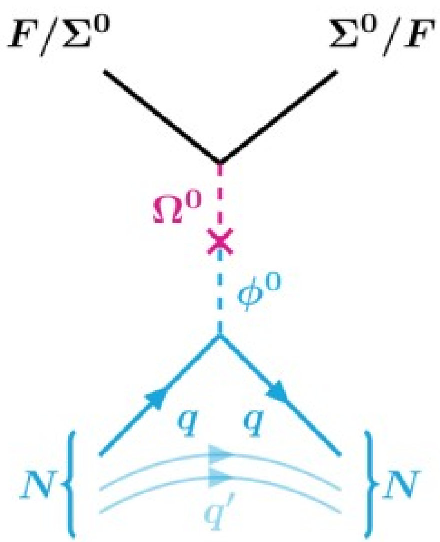
M. Hirsch et al JHEP 10 (2013) 149
A. Merle et al JHEP 07 (2016) 013
Rocha-Moran, Vicente JHEP 07 (2016) 078
Restrepo, Rivera JHEP 04 (2020) 134

Avila et al Eur.Phys.J.C 80 (2020) 10, 908
Karan, Sadhukhan, Valle JHEP12 (2023) 185

DM coannihilation



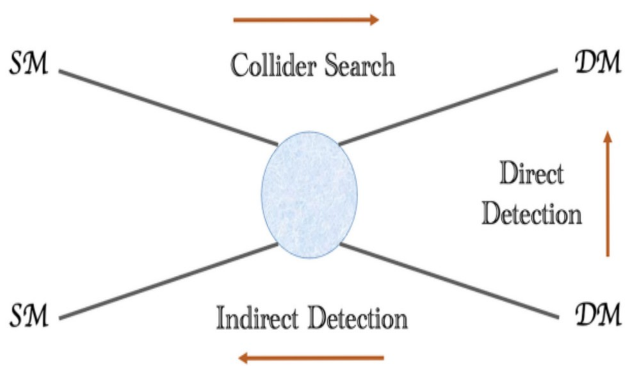
revamped scoto DM

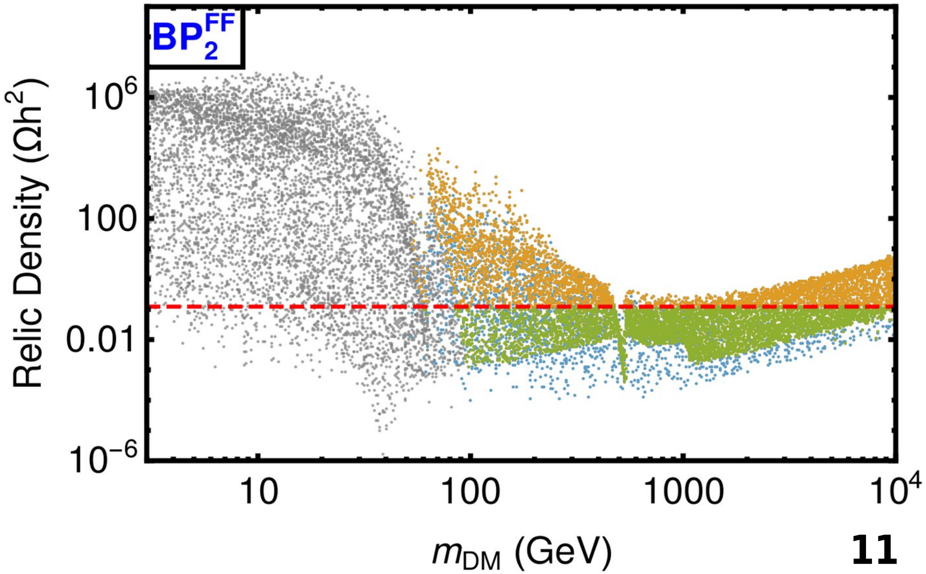


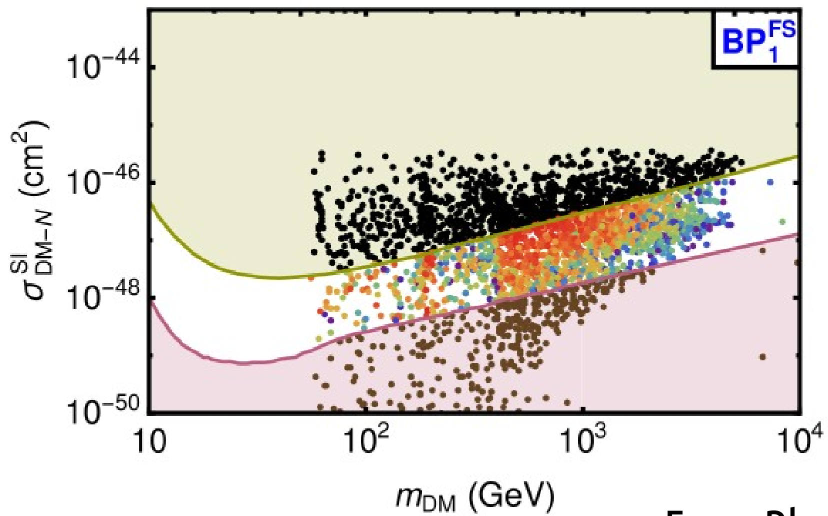
M. Hirsch et al JHEP 10 (2013) 149
A. Merle et al JHEP 07 (2016) 013
Rocha-Moran, Vicente JHEP 07 (2016) 078
Restrepo, Rivera JHEP 04 (2020) 134

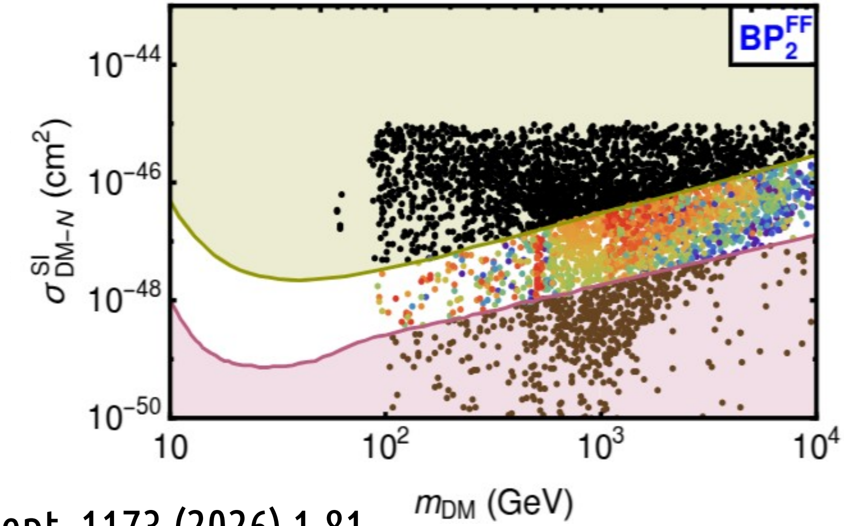
Avila et al Eur.Phys.J.C 80 (2020) 10, 908
Karan, Sadhukhan, Valle JHEP12 (2023) 185

DM coannihilation







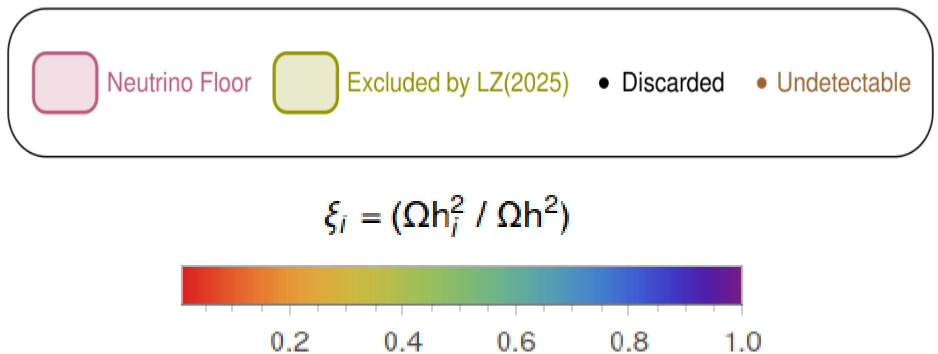


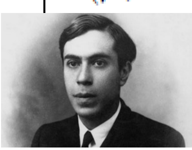
From Phys.Rept. 1173 (2026) 1-81

Higher v_Ω (4 GeV): Fermion-Scalar Coannihilation

Lower v_Ω (1.5 GeV): Fermion-Fermion Coannihilation

LFV Process	Current Bound	Future Sensitivity
$\mathcal{B}(\mu \to e\gamma)$	4.2×10^{-13} [44]	6.0×10^{-14} [45]
$\mathcal{B}(\mu \to 3e)$	1.0×10^{-12} [46]	$\sim 10^{-16}$ [47, 48]
$\mathcal{C}(\mu, Au \to e, Au)$	7.0×10^{-13} [49]	–
$\mathcal{C}(\mu, Ti \to e, Ti)$	4.3×10^{-12} [49]	$\sim 10^{-18}$ [50]
$\mathcal{C}(\mu, Pb \to e, Pb)$	4.6×10^{-11} [49]	–
$\mathcal{C}(\mu, Al \to e, Al)$	–	$\sim 10^{-17}$ [51, 52]



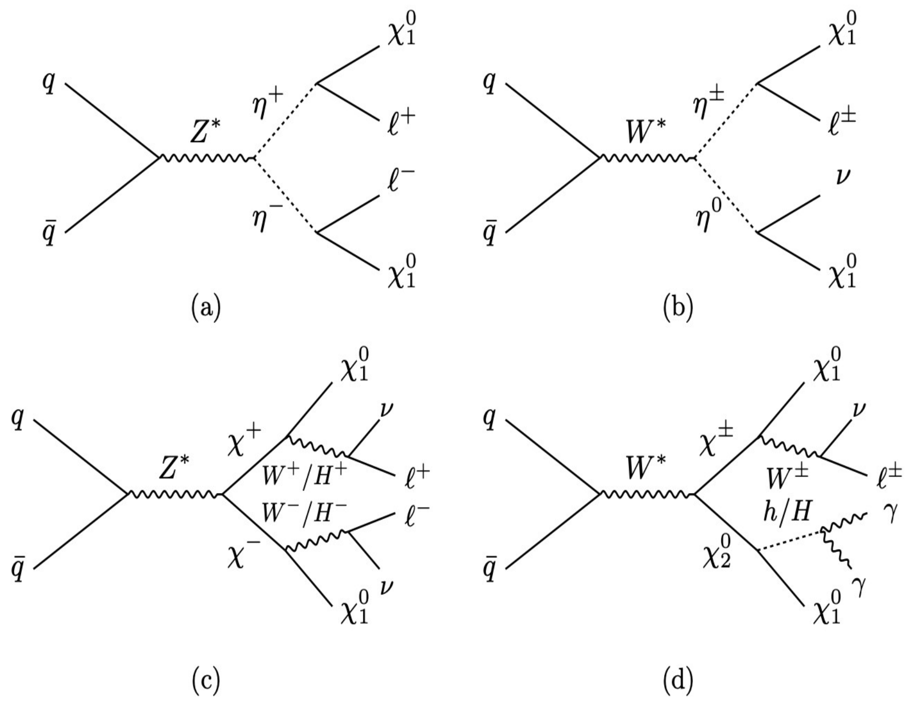


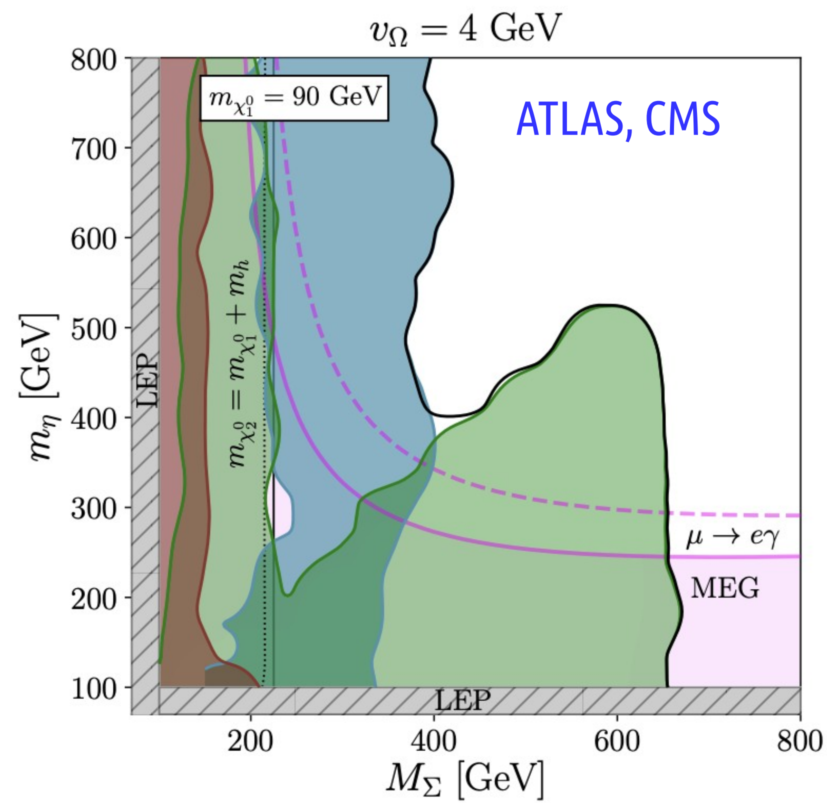
LNV .... DBD lower bound

revamped scoto DM at colliders

Light dark sector $M_F < m_\eta \simeq M_\Sigma.$

Dominant diagrams:



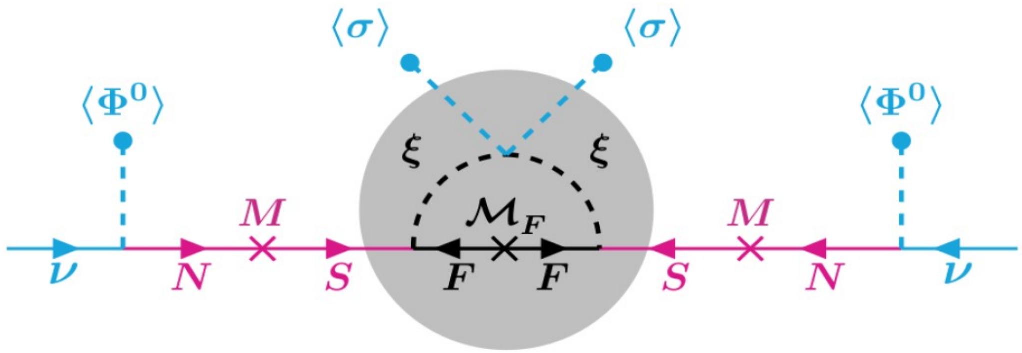


Lozano, Sanchez-Garcia, JV
Phys.Rev.D 112 (2025) 5

dark seeded low-scale seesaw

inverse versus linear

dark inverse seesaw



Dark loop+seesaw/symmetry protection

is dark matter the radiative seed of neutrino mass?

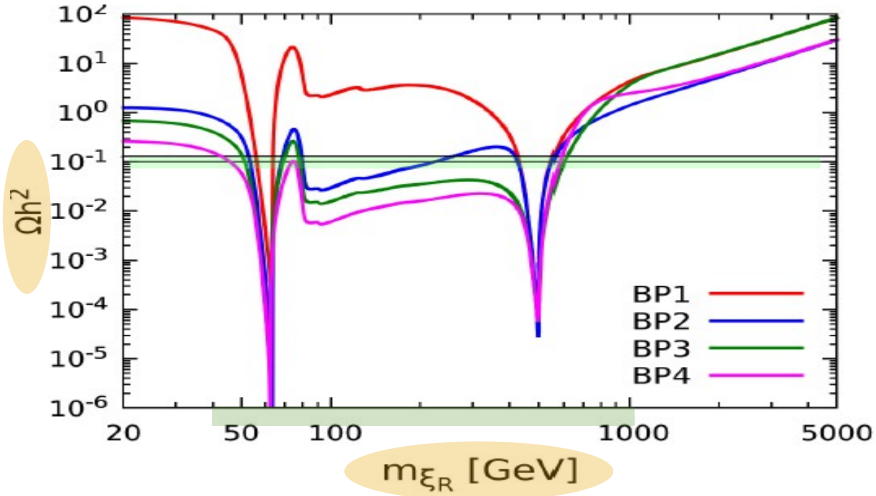
Mandal et al
Phys.Lett.B821 (2021) 136609

low-scale type-1

dark inverse seesaw

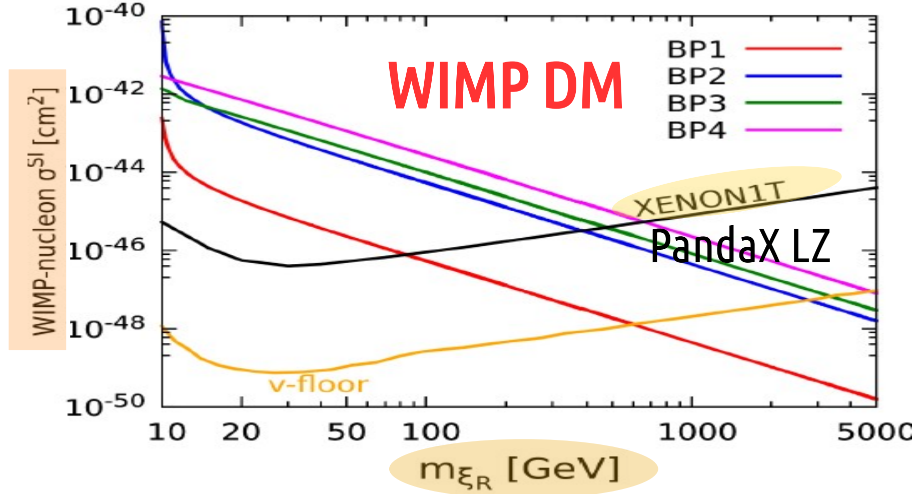
LambdaCDM

Phys.Lett.B821 (2021) 136609



Xenon1T PhysRevLett.121.111302

PandaX Lux-Zepellin



+ charged lepton flavor violation

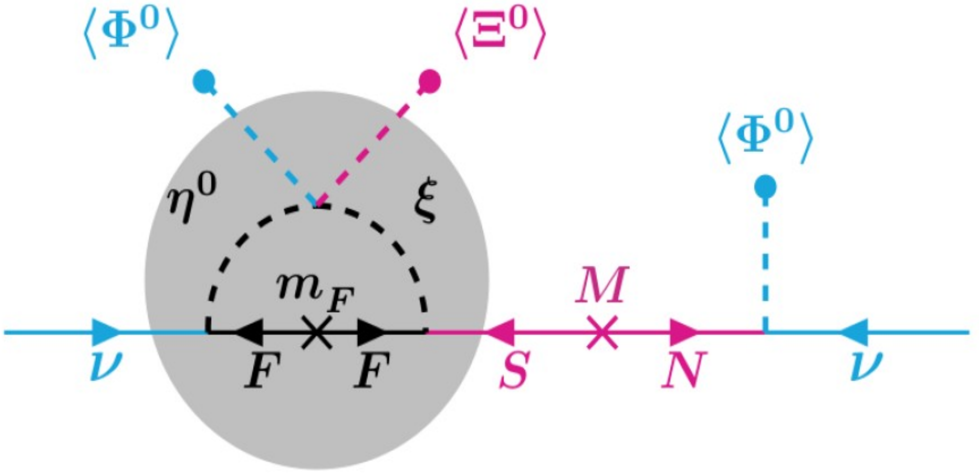
low-scale type-1 **dark linear seesaw** (3,6)

$$M_\nu = \begin{pmatrix} 0_{3\times3} & m_D & \varepsilon \\ m_D^T & 0_{3\times3} & M \\ \varepsilon^T & M & 0_{3\times3} \end{pmatrix}$$

Carcamo, Vishnudath, J.V. JHEP 09 (2023) 046

$$m_{\rm light} = -\left[m_D M^{-1}\varepsilon^T + \varepsilon M^{-1} m_D^T\right]$$

(Also Batra, Camara, Joaquim, 2305.01687)



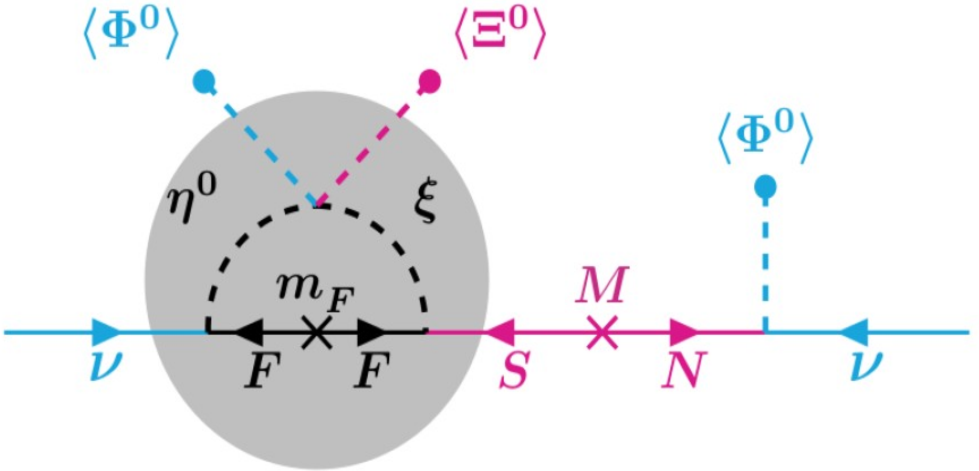
low-scale type-1 **dark linear seesaw** (3,6)

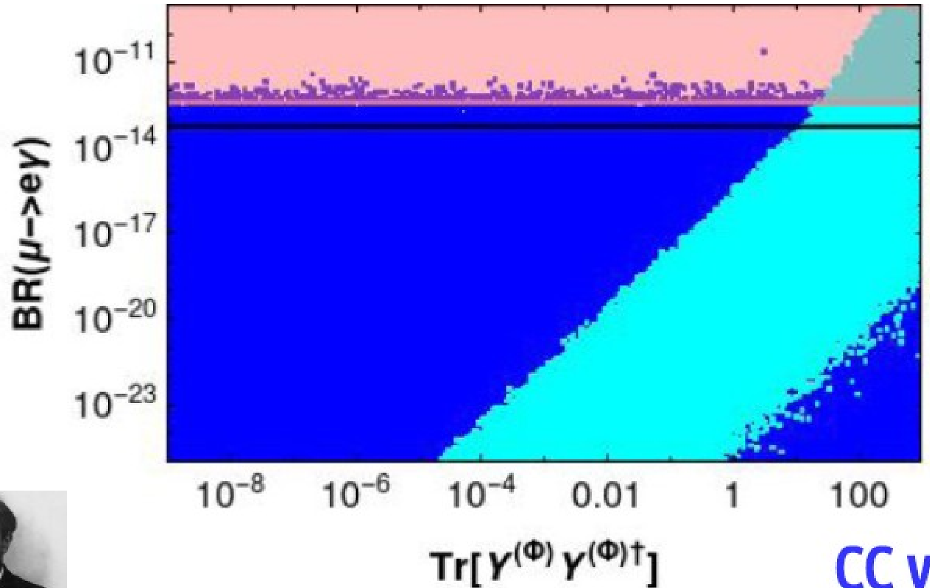
$$M_\nu = \begin{pmatrix} 0_{3\times3} & m_D & \varepsilon \\ m_D^T & 0_{3\times3} & M \\ \varepsilon^T & M & 0_{3\times3} \end{pmatrix}$$

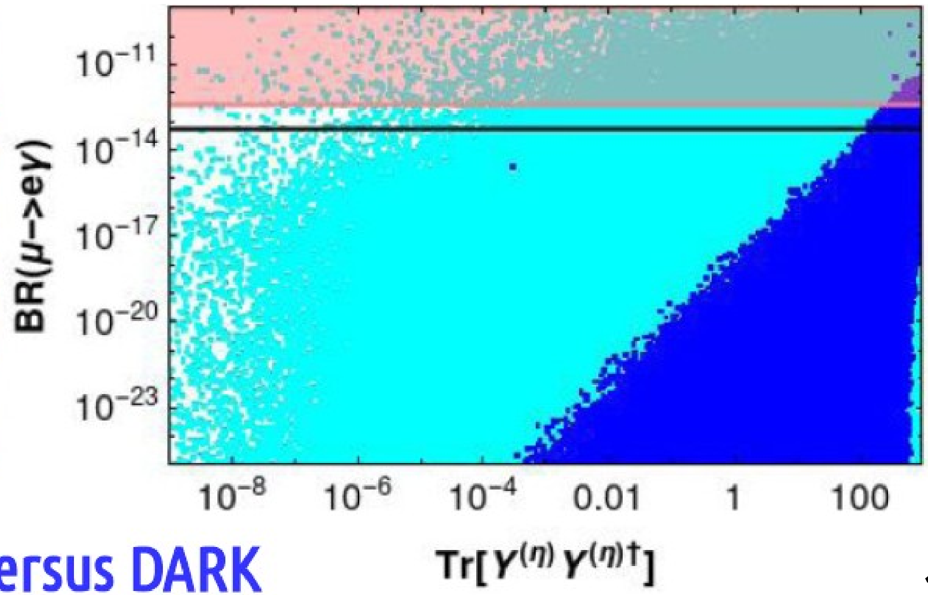
Carcamo, Vishnudath, J.V. JHEP 09 (2023) 046

$$m_{\text{light}} = -\left[m_D M^{-1}\varepsilon^T + \varepsilon M^{-1} m_D^T\right]$$

(Also Batra, Camara, Joaquim, 2305.01687)







CC versus DARK

scoto-seesaw

LOOP

TREE

$$\frac{\Delta m^2_{\text{SOL}}}{\Delta m^2_{\text{ATM}}} = 0.0302^{+0.0012}_{-0.0010}$$

Atm scale from SEESAW

Solar scale from SCOTO-LOOP

scoto-seesaw

LOOP
TREE

$$\frac{\Delta m^2_{\rm SOL}}{\Delta m^2_{\rm ATM}} = 0.0302^{+0.0012}_{-0.0010}$$

Atm scale from SEESAW

Solar scale from SCOTO-LOOP

	Standard Model			Fermions		Scalar
Fields	L_i	e_i	Φ	N	F	η
Multiplicity	3	3	1	1	1	1
$\mathrm{SU(2)_L}$	2	1	2	1	1	2
$\mathrm{U(1)_Y}$	$-1/2$	-1	$1/2$	0	0	$1/2$
$\mathbb{Z}_2$	$+$	$+$	$+$	$+$	$-$	$-$

Simplest UV-complete model with Global lepton #
Phys.Lett.B 789 (2019) 132-136
Phys.Lett.B 819 (2021) 136458

Scoto-seesaw with gauged lepton number

atm scale from seesaw

Leite, Sadhukhan, Valle
Phys.Rev.D 109 (2024) 3, 035023

$B-L$ charges $(f_{1R}, f_{2R}, N_R) \sim (-4, -4, 5)$

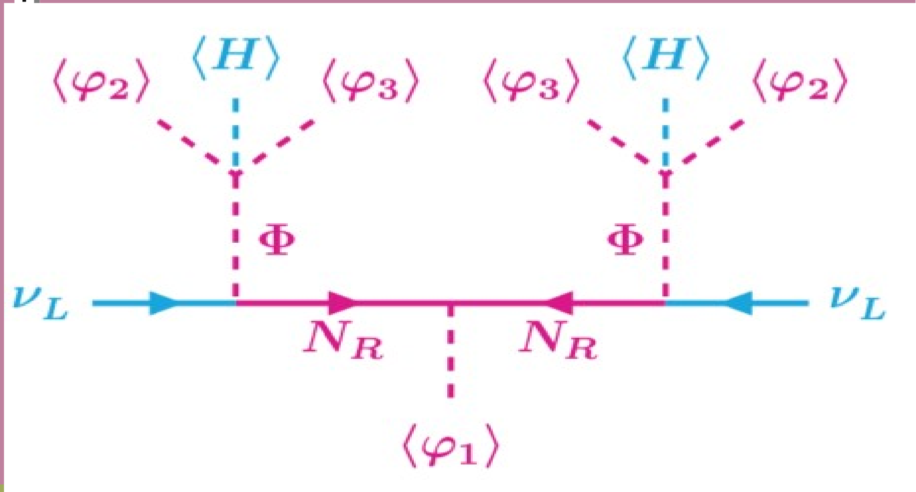
solar scale from scoto

Scoto-seesaw with gauged lepton number

atm scale from seesaw

Leite, Sadhukhan, Valle
Phys.Rev.D 109 (2024) 3, 035023

$B-L$ charges $(f_{1R}, f_{2R}, N_R) \sim (-4,-4,5)$

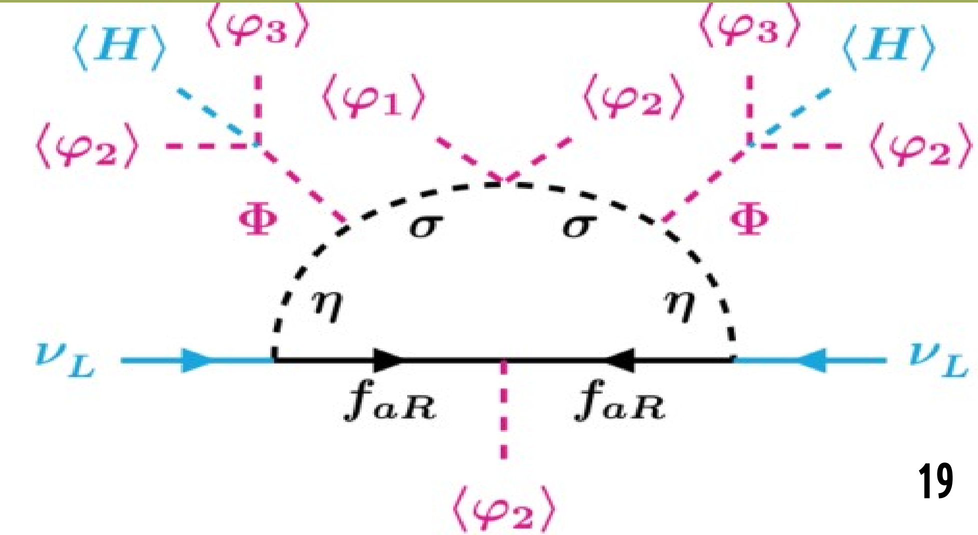


LOW-SCALE (3,3) Type1 SEESAW from
tiny induced leptophilic Φ vev
Drell-Yan mediator N-pair production from TeV scale Z'

LOOP
TREE

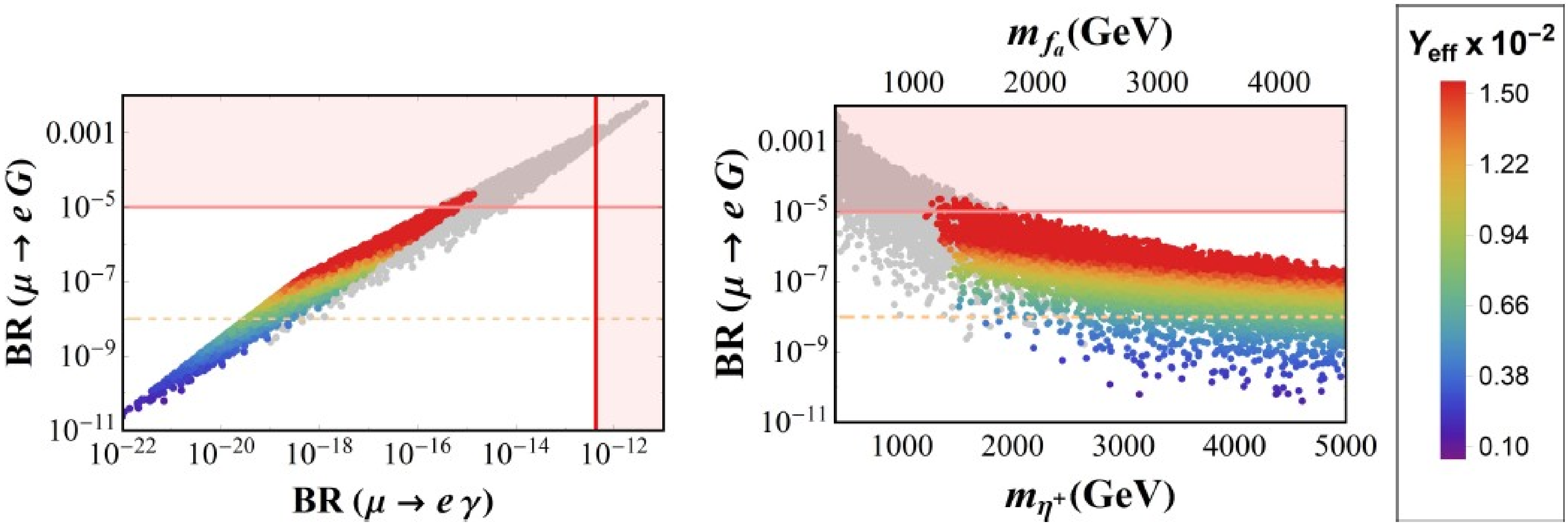
$$\frac{\Delta m^2_{\text{SOL}}}{\Delta m^2_{\text{ATM}}} = 0.0302^{+0.0012}_{-0.0010}$$

solar scale from scoto

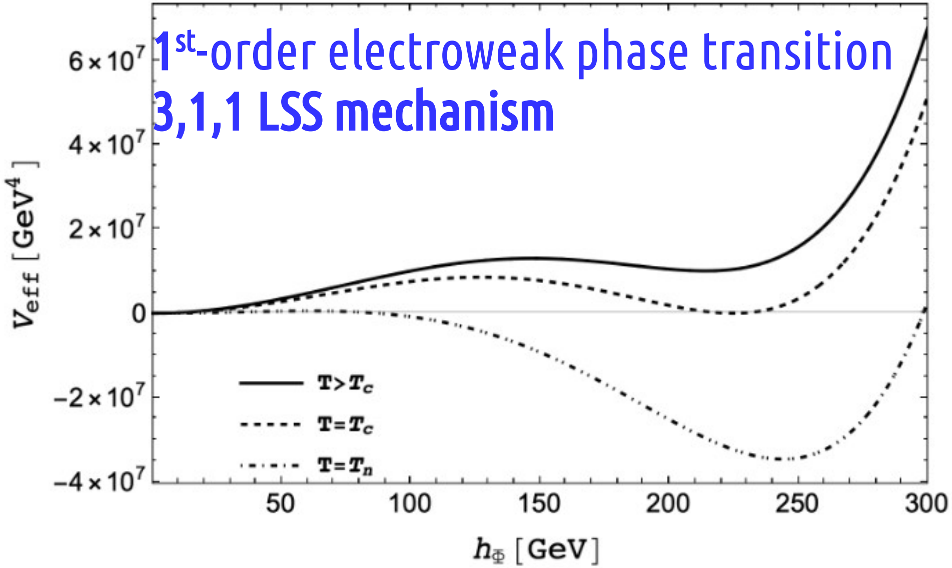


Leite, Sadhukhan, Valle
Phys.Rev.D 109 (2024) 3, 035023

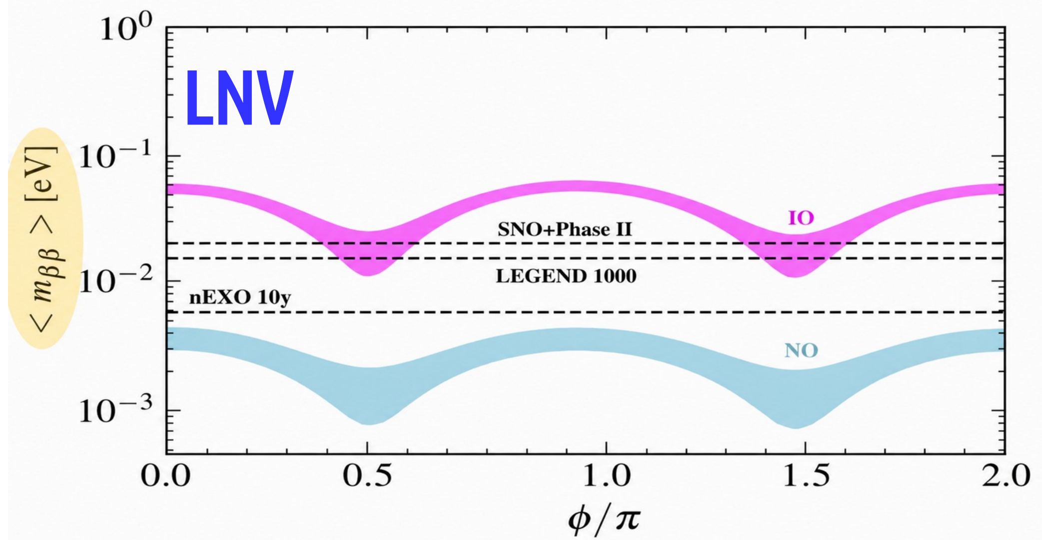
$$G \simeq \frac{1}{\sqrt{14}}\left(5\frac{v_\Phi^2}{v_H v_\varphi}A_H - 5\frac{v_\Phi}{v_\varphi}A_\Phi + A_{\varphi_1} - 2A_{\varphi_2} + 3A_{\varphi_3}\right)$$



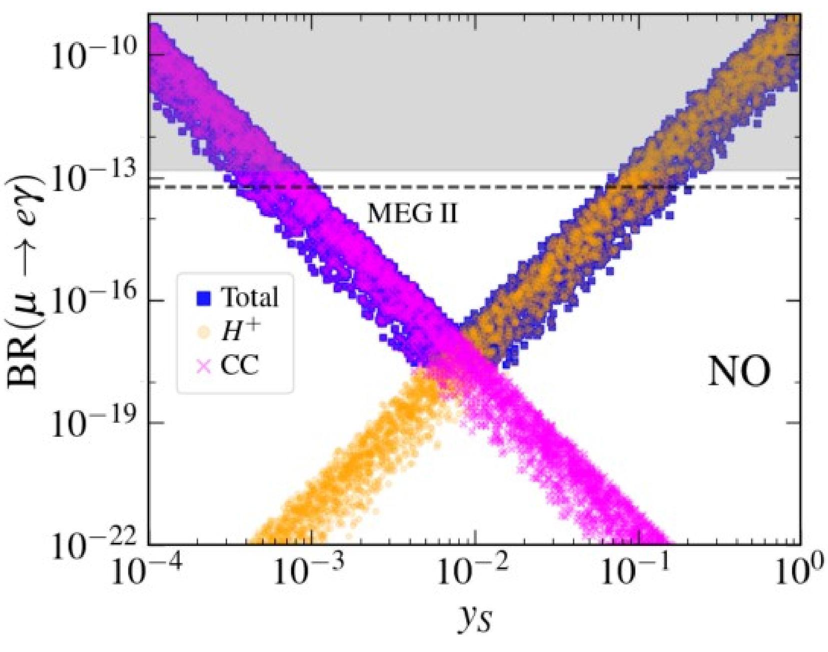
Back-ups



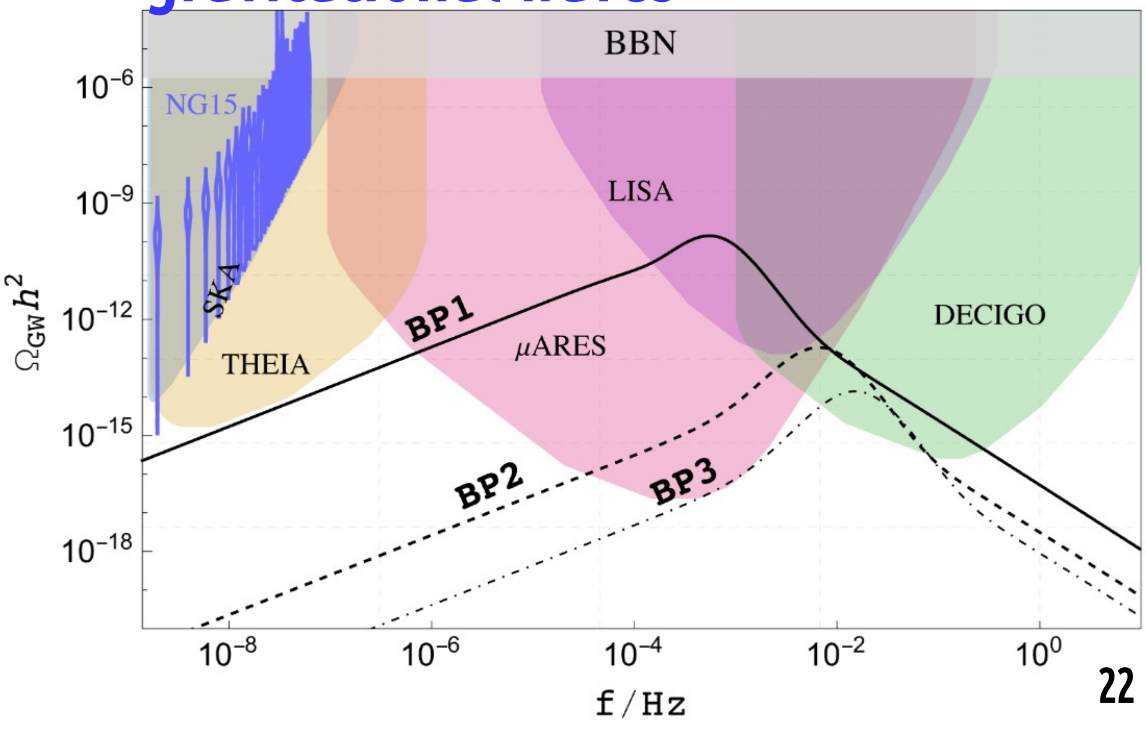
LNV



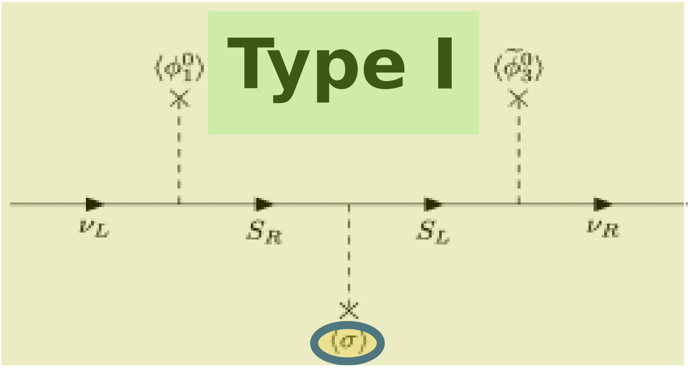
cLFV

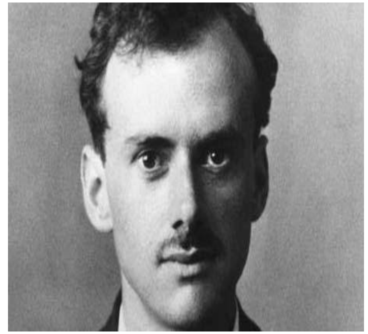


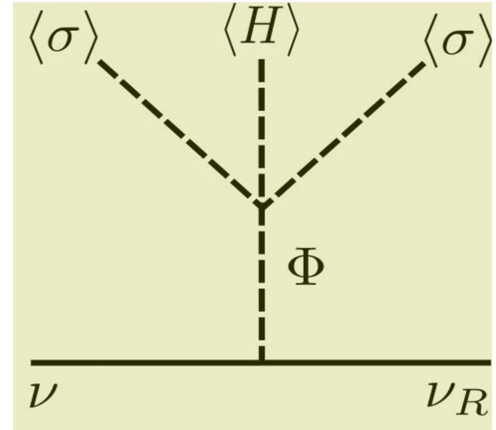
gravitational waves 2606.15316



seesawing a la



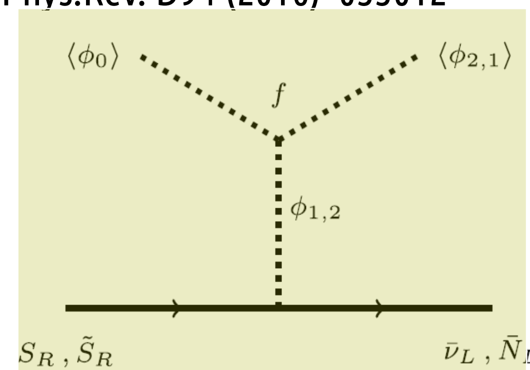




Type II

Phys.Lett. B762 (2016) 162-165

Phys.Rev. D94 (2016) 033012



Phys.Lett. B761 (2016) 431-436

Phys.Lett. B767 (2017) 209-213

Phys.Rev. D98 (2018) 035009

Phys.Lett. B781 (2018) 122-128

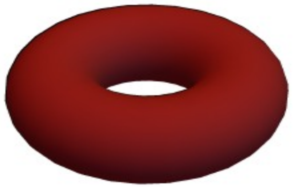
Addazi et al Phys.Lett. B759 (2016) 471-478

Phys.Lett. B755 (2016) 363-366

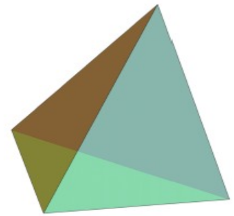
family symmetry from 6D orbifold

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

Phys.Lett.B 801 (2020) 135195
Phys.Rev.D 101 (2020) 11, 116012
Phys.Rev.D 105 (2022) 055030

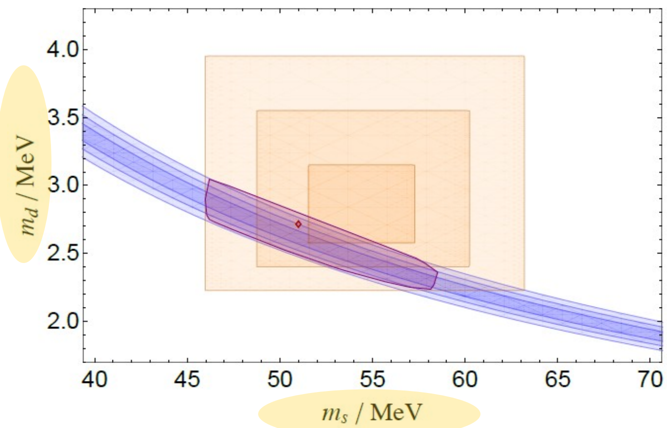


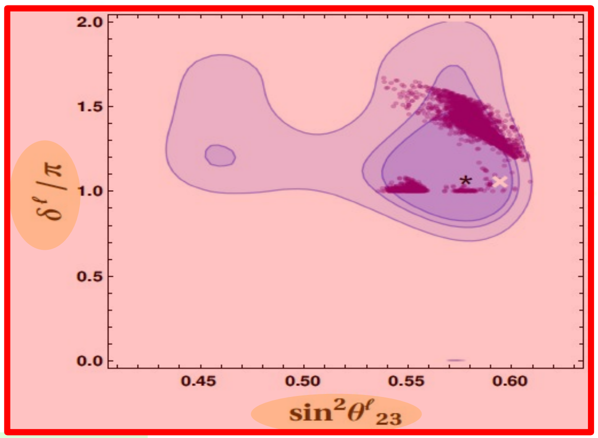
A4 family symmetry “derived”

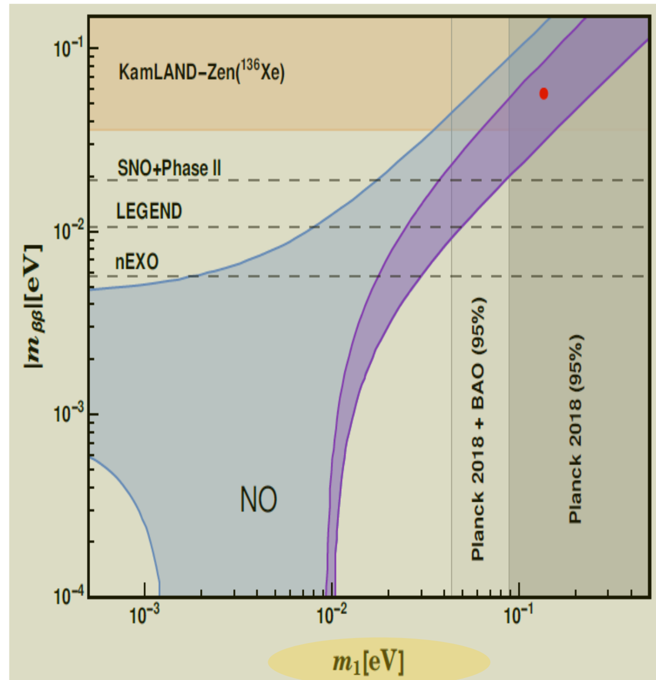


Golden Q-L relation

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







Good global fit of flavor observables

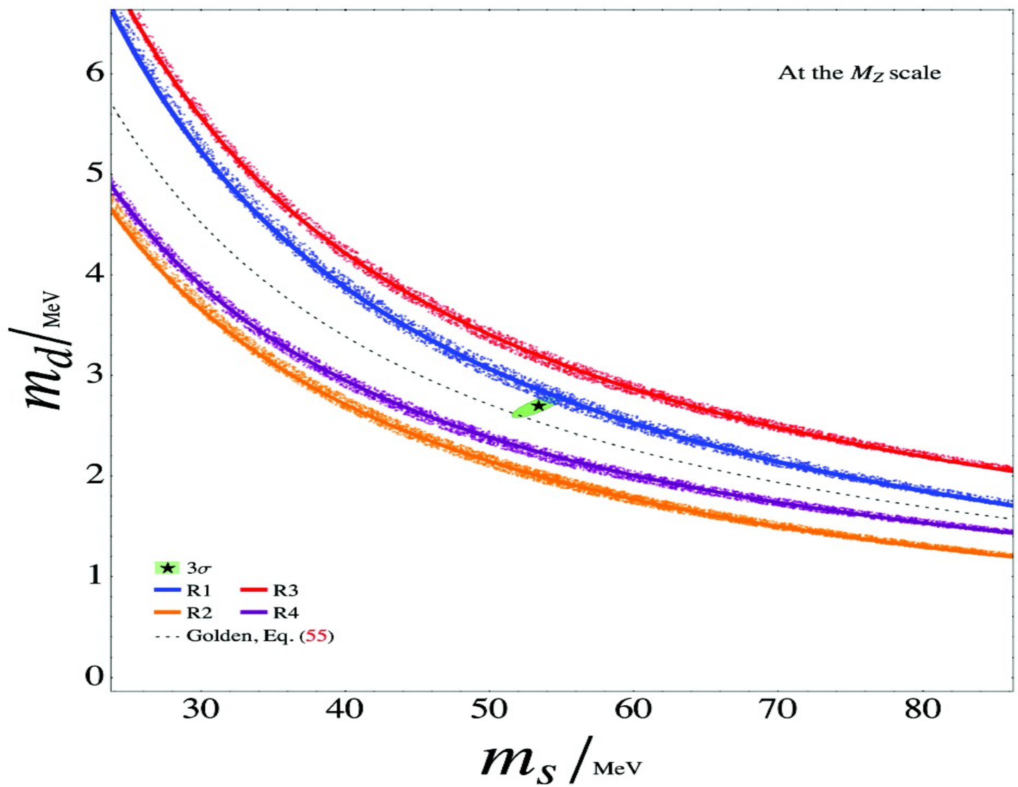
R1

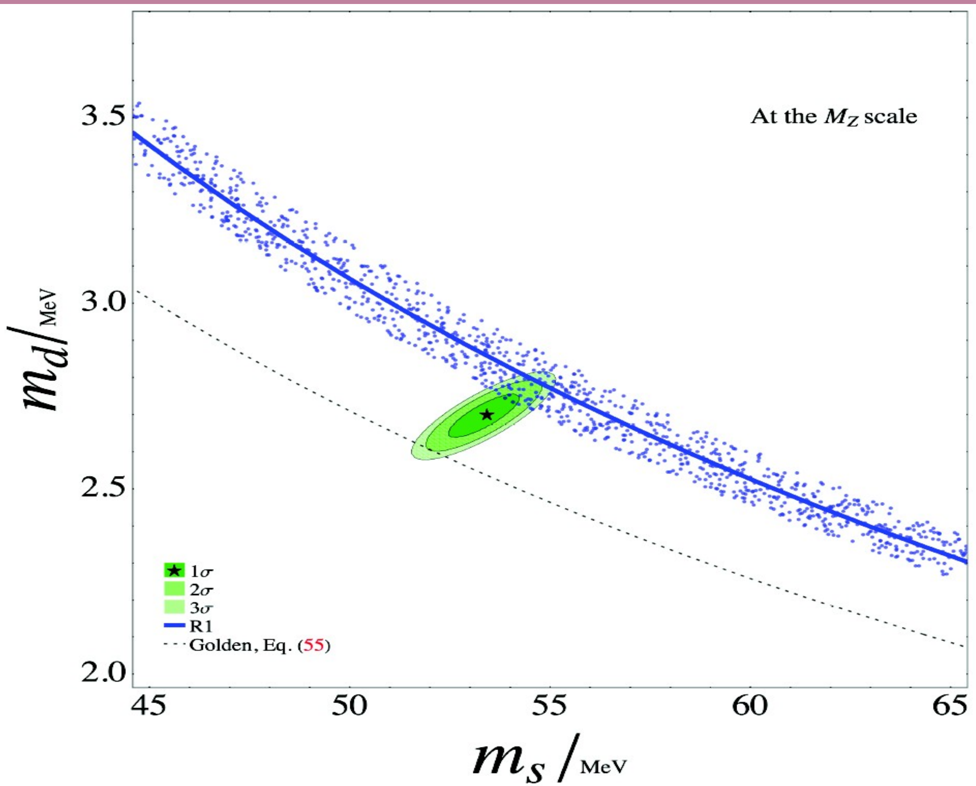
modular symmetry corrections

Chen, King, Medina, Valle
JHEP 02 (2024) 160

$$\frac{m_d m_s}{m_b(m_b - 3m_s)} \approx \frac{m_e m_\mu}{m_\tau(m_\tau - 3m_\mu)}$$

modified golden mass relation

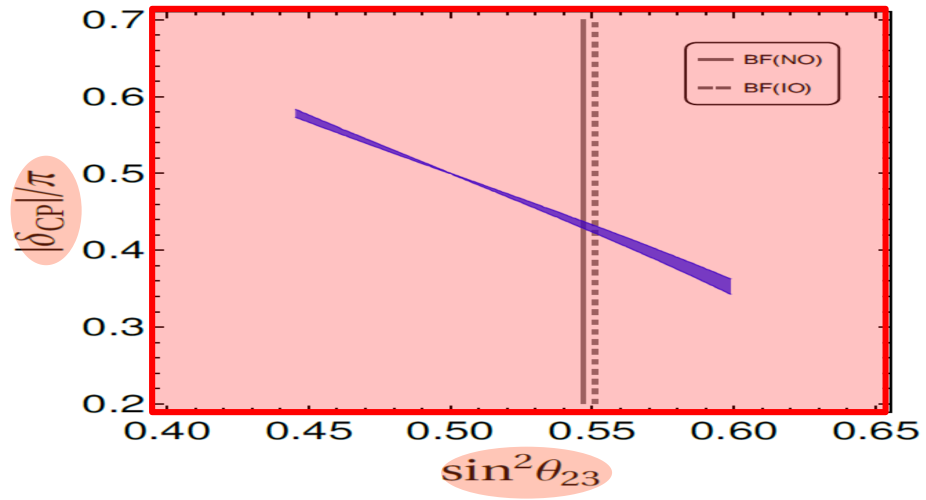




5D warped flavor dynamics

Randall-Sundrum Phys.Rev.Lett. 83 (1999) 3370
Arkani-Hamed & Schmaltz hep-ph/9903417

- mass hierarchies from geometry
- mixing angles from family symmetry



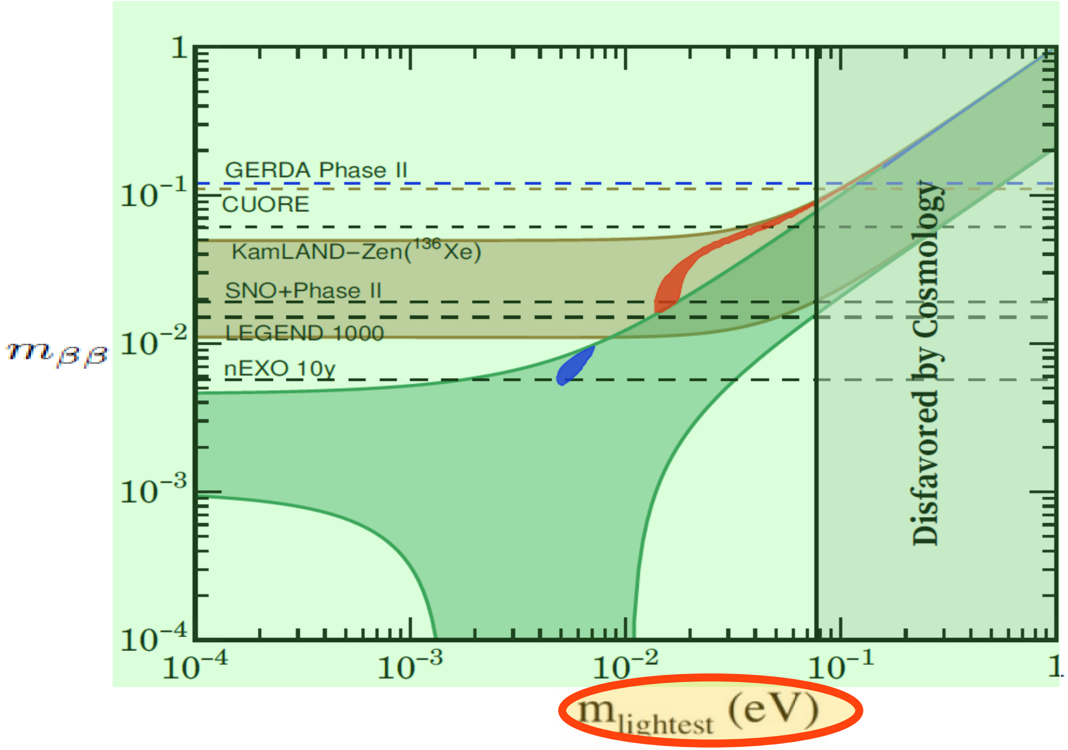
TM1

TM mixing pattern predicted from T'

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

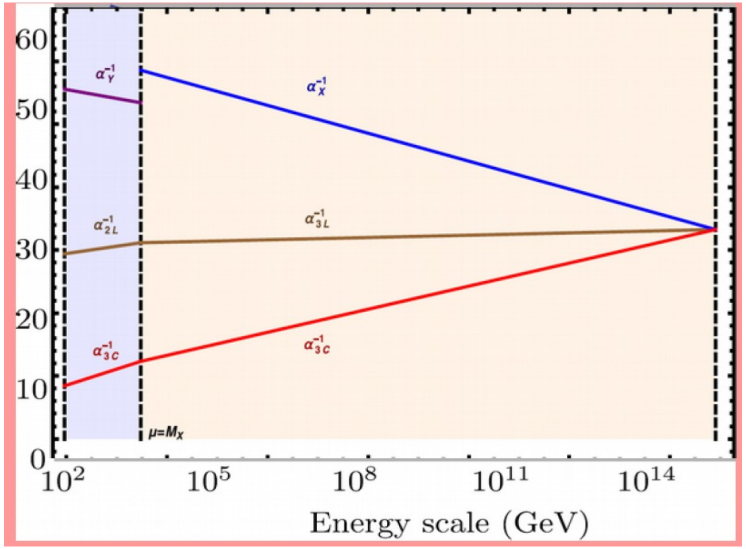
$$\cos\delta_{CP} = \frac{(3\cos 2\theta_{12} - 2)\cos 2\theta_{23}}{3\sin 2\theta_{23}\sin 2\theta_{12}\sin\theta_{13}}$$

Chen et al Phys. Rev. D 102, 095014 (2020)



TM2 pattern

Dirac neutrino alternative
Chen et al JHEP01(2016)007
Phys. Rev. D95 (2017) 095030
Phys.Lett. B771 (2017) 524



neutrino path to unification

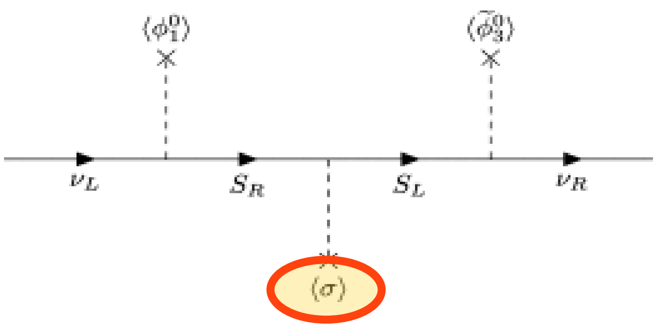
the physics responsible for neutrino masses may also induce gauge coupling unification

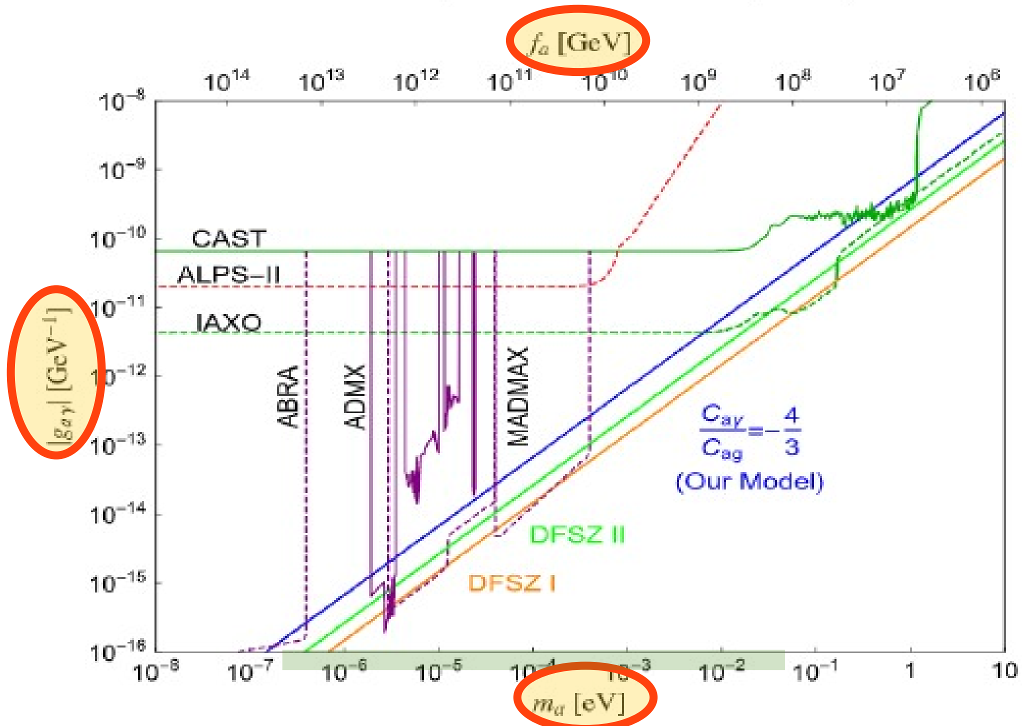
Boucenna et al PRD91, 031702 (2015)

Deppisch et al PLB762 (2016) 432

why 3 families

Physics Letters B 810 (2020) 135829





Dirac type-1 seesaw neutrino mass

Peccei-Quinn symmetry

tree-level quark FCNC

Axion completions

Phys.Rev.Lett. 132 (2024) 5, 051801
Phys.Lett.B 868 (2025) 139629

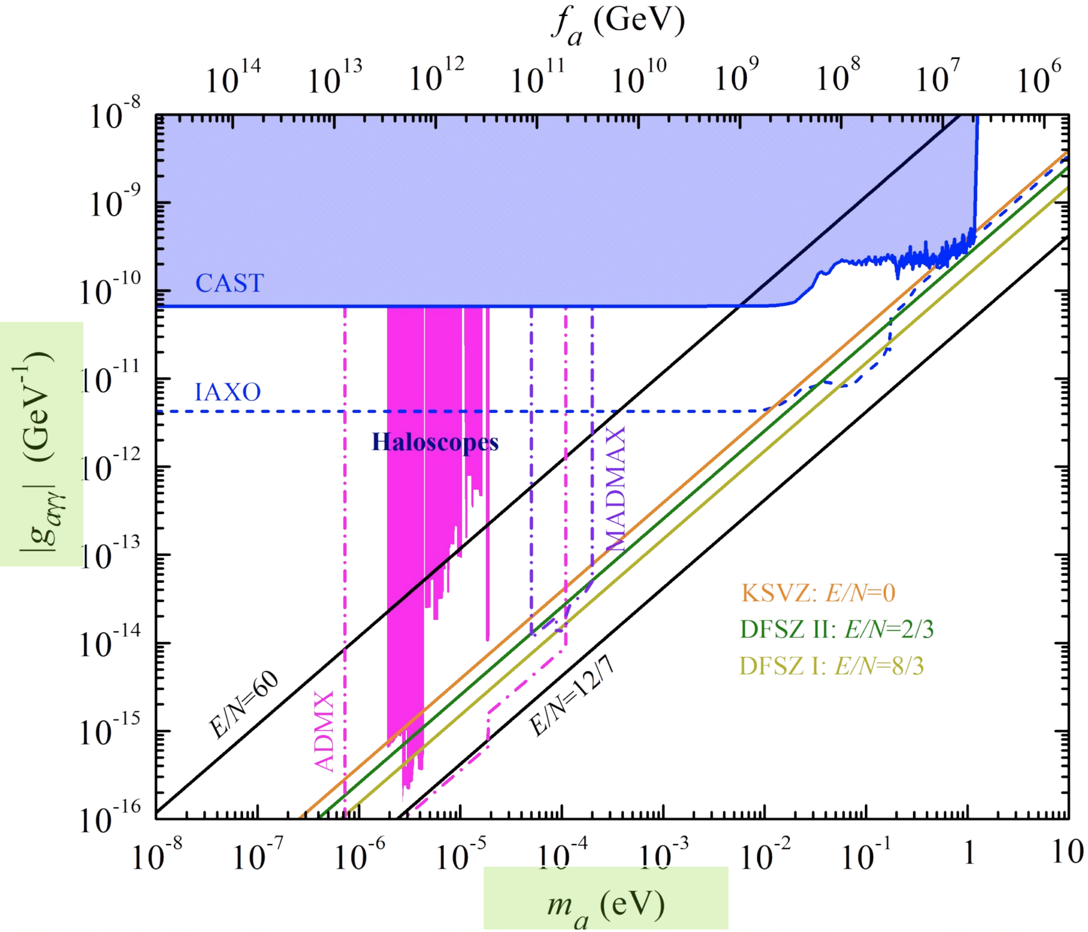
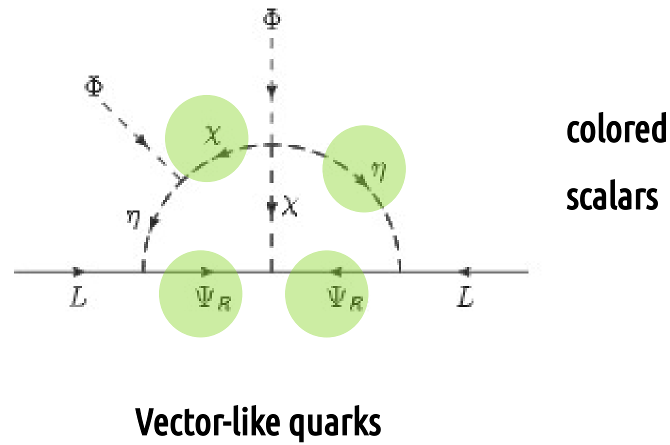


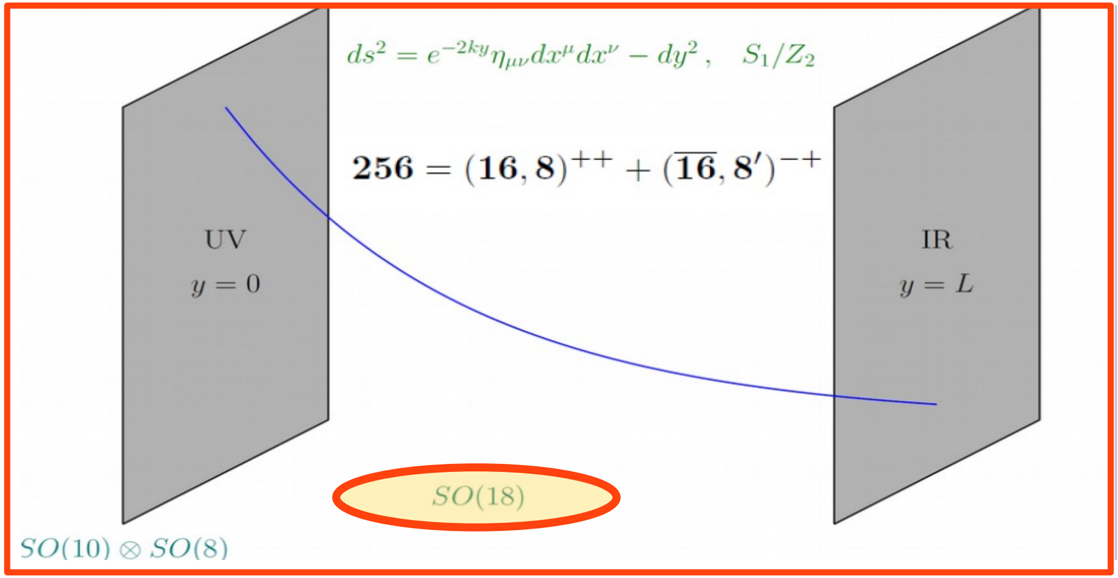
FIG. 2. $|g_{a\gamma\gamma}|$ versus m_a (bottom axis) and f_a (top axis) [see Eqs. (4) and (8)]. The black lines correspond to E/N values leading to maximum and minimum $|g_{a\gamma\gamma}|$ for the representations shown in Table II. The KSVZ and DFSZ I and II predictions are indicated by the orange, light green, and dark green lines, respectively. Shaded regions are presently excluded, while dash-dotted lines delimit projected sensitivities of several helio-scope and haloscope experiments—see text for details.



$$(m_\nu)_{\alpha\beta} \sim 0.1 \text{ eV} \left(\frac{\tilde{Y}^j_{a\alpha} (\tilde{Y}_\chi)^k_{ab} \tilde{Y}^l_{b\beta}}{10^{-3}} \right) \left(\frac{\tilde{\mu}_{jkl}}{10^8 \text{ GeV}} \right)$$

color-mediated neutrino masses

new path to family unification



promote M4 to AdS5

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

- viable SO3 family symmetry
- golden Q-L mass formula
- PQ symmetry & axion

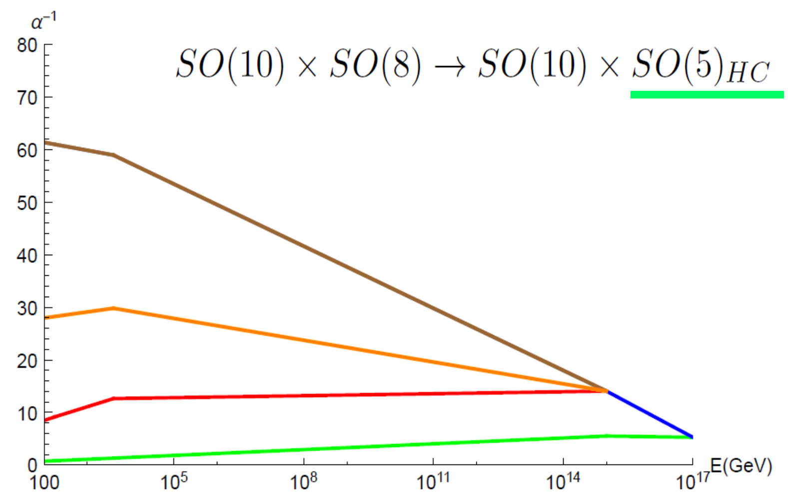
inspired by beauty of SO10

Reig, Valle, Vaquera-Araujo, Wilczek
Phys.Lett. B774 (2017) 667-670

use orbifold BC to decouple mirrors

unwanted chiral families bound
by new hypercolor force above TeV

new spectroscopy

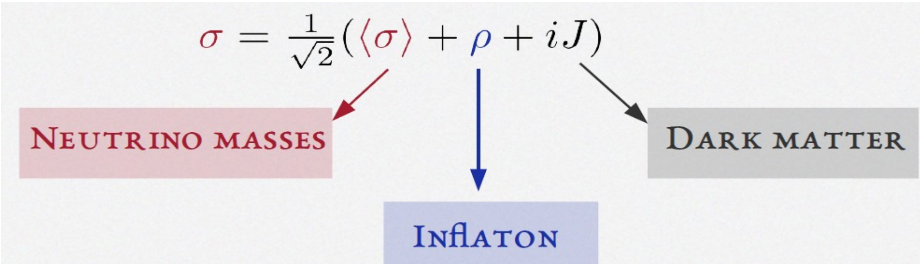


majoron warm dark matter

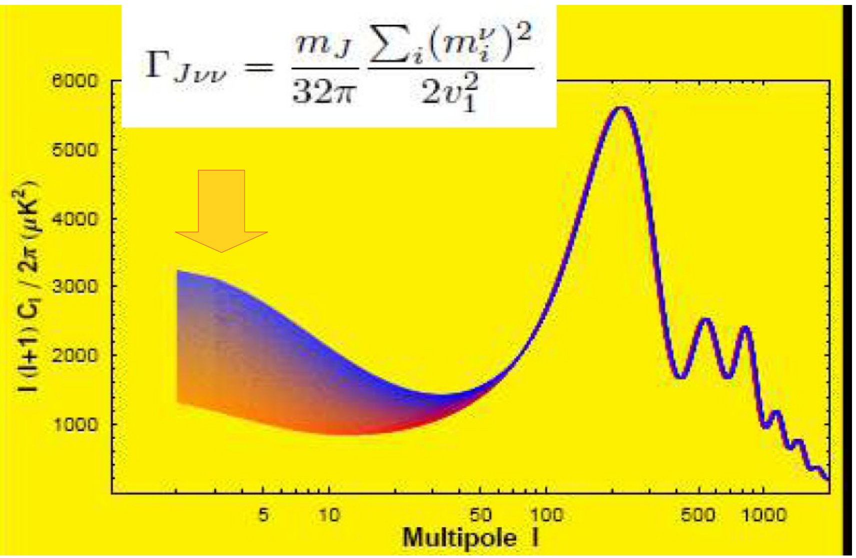
DM Berezinsky, Valle PLB318 (1993) 360

Inflation Boucenna, Morisi, Shafi, Valle Phys.Rev. D90 (2014) 055023

LG Aristizabal et al JCAP 1407 (2014) 052



Consistency with CMB
Lattanzi & Valle, PRL99 (2007) 121301



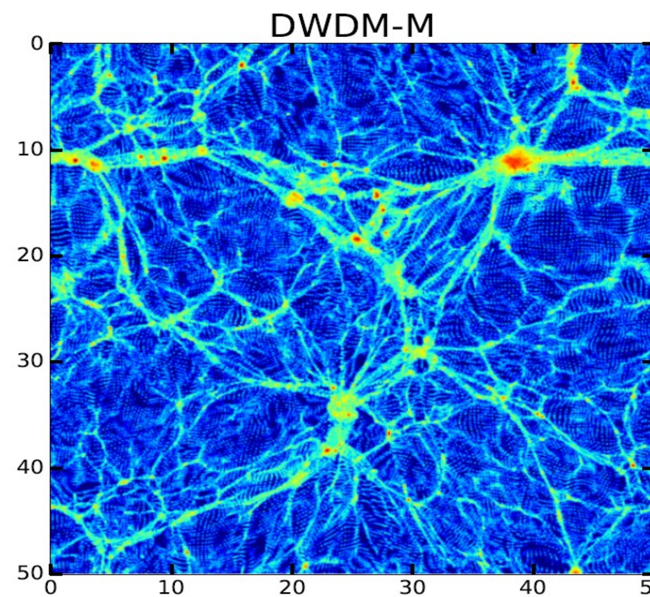
large scale structure

Kuo et al JCAP 1812 (2018) 026

X-rays from DM decay

$J \to \gamma\gamma$

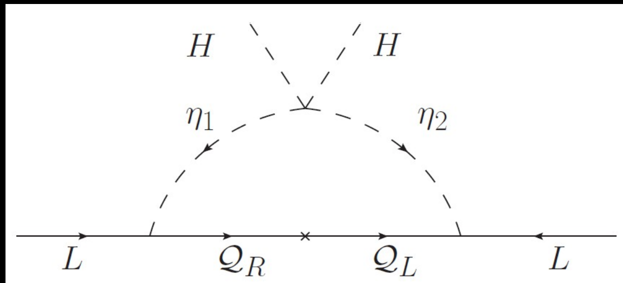
Lattanzi et al PRD88 (2013) 063528

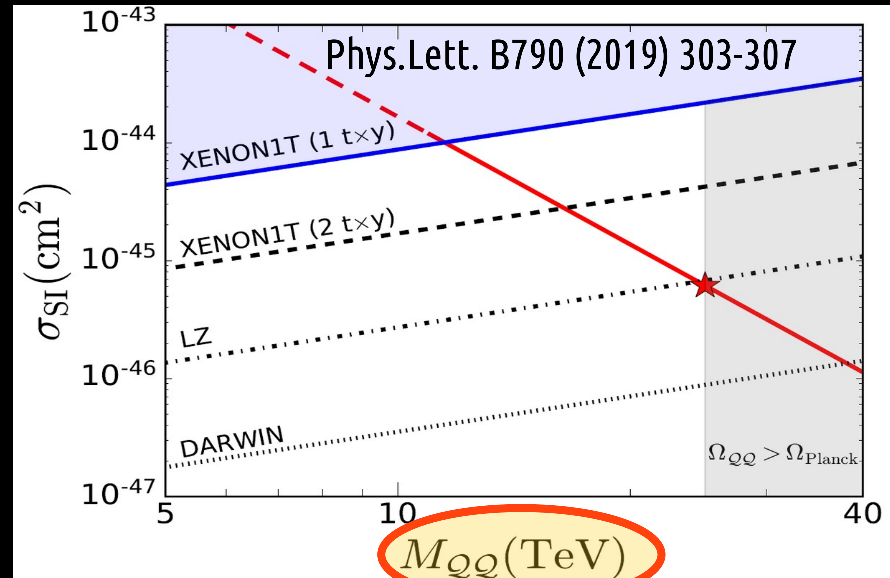


DWDM picture leads to a viable alternative to the ΛCDM

See also Light majoron CDM Reig, Yamada, JV **JCAP09 (2019) 029**

Bound-state scoto DM





Bound-state dark matter with Majorana neutrinos

M. Reig, D. Restrepo, J.W. F. Valle, O. Zapata
Phys.Lett.B 790 (2019) 303-307

$$(\mathcal{M}_\nu)_{ij} \sim 0.04\,\text{eV}\left(\frac{M_Q}{12.5\,\text{TeV}}\right)\left(\frac{\lambda_{\eta_1\eta_2 H}v^2}{0.1\,\text{GeV}^2}\right)\left(\frac{15\,\text{TeV}}{\mu_{\eta_1}}\right)^2\left(\frac{h_i y_j}{10^{-6}}\right)$$

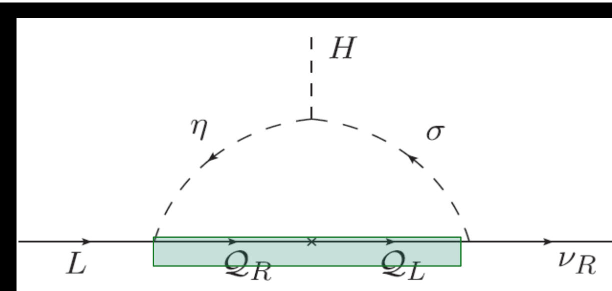
diracness & DM stability

Bonilla et al — Phys.Lett.B 762 (2016) 214 - quarticity

Centelles-Chuliá et al — Phys.Lett.B 767 (2017) 209 – dim5 ops

Leite et al — Phys.Lett.B 807 (2020) 13553 – Phys.Lett.B 817 (2021) 136292

Phys.Rev.D 102 (2020) 1, 015022 - automatic Mp



From Reig et al
Phys.Rev. D97 (2018) 115032