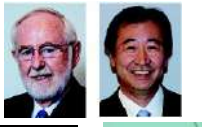
Dark matter as the source of neutrino mass: a case for WIMPS

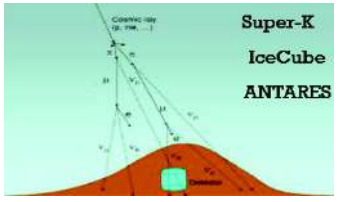
JOSÉ W F VALLE

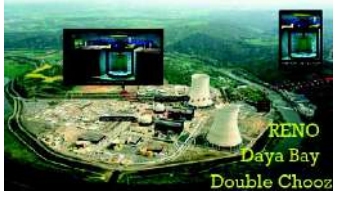
IFIC, CSIC-Universitat de València

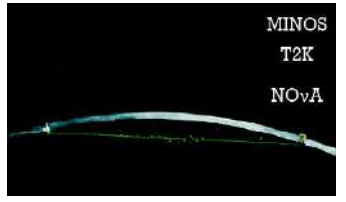
IBS-IFT Workshop, dark matter and particle physics, Daejeon, Nov 5-8, 2024

current status



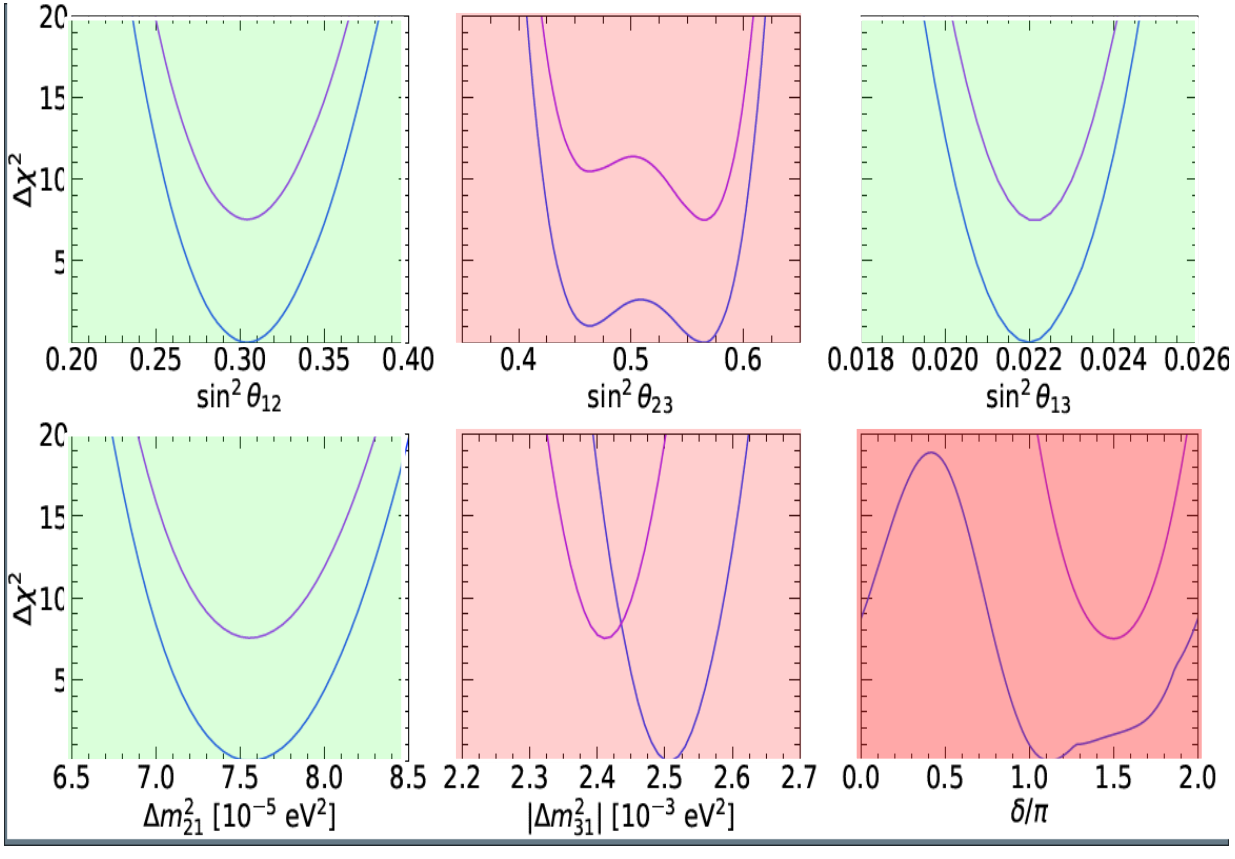


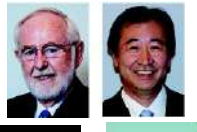


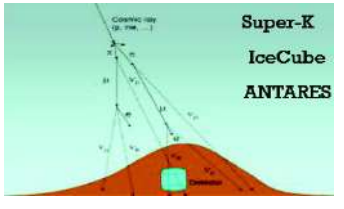


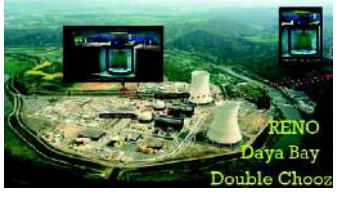
current status

PF de Salas et al JHEP02(2021)071



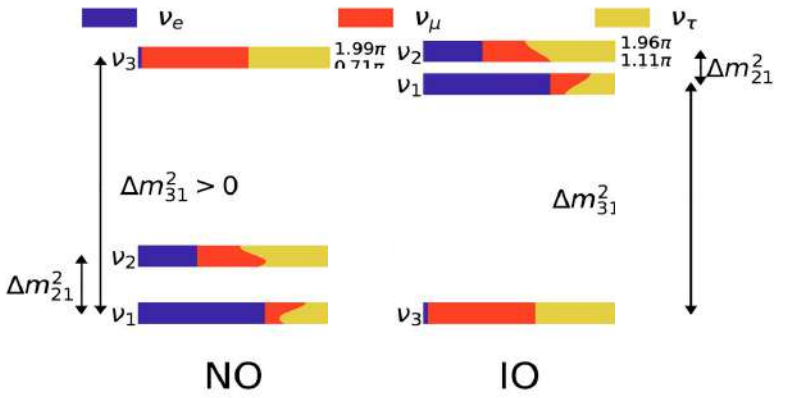


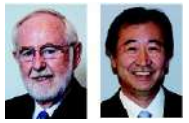


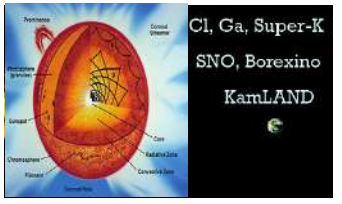


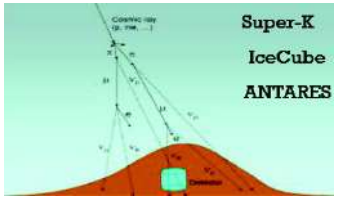
current status

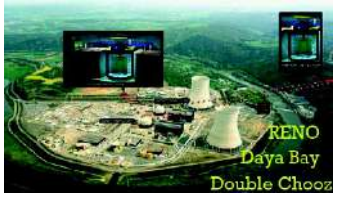
Mass ordering problem

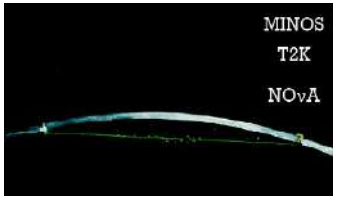




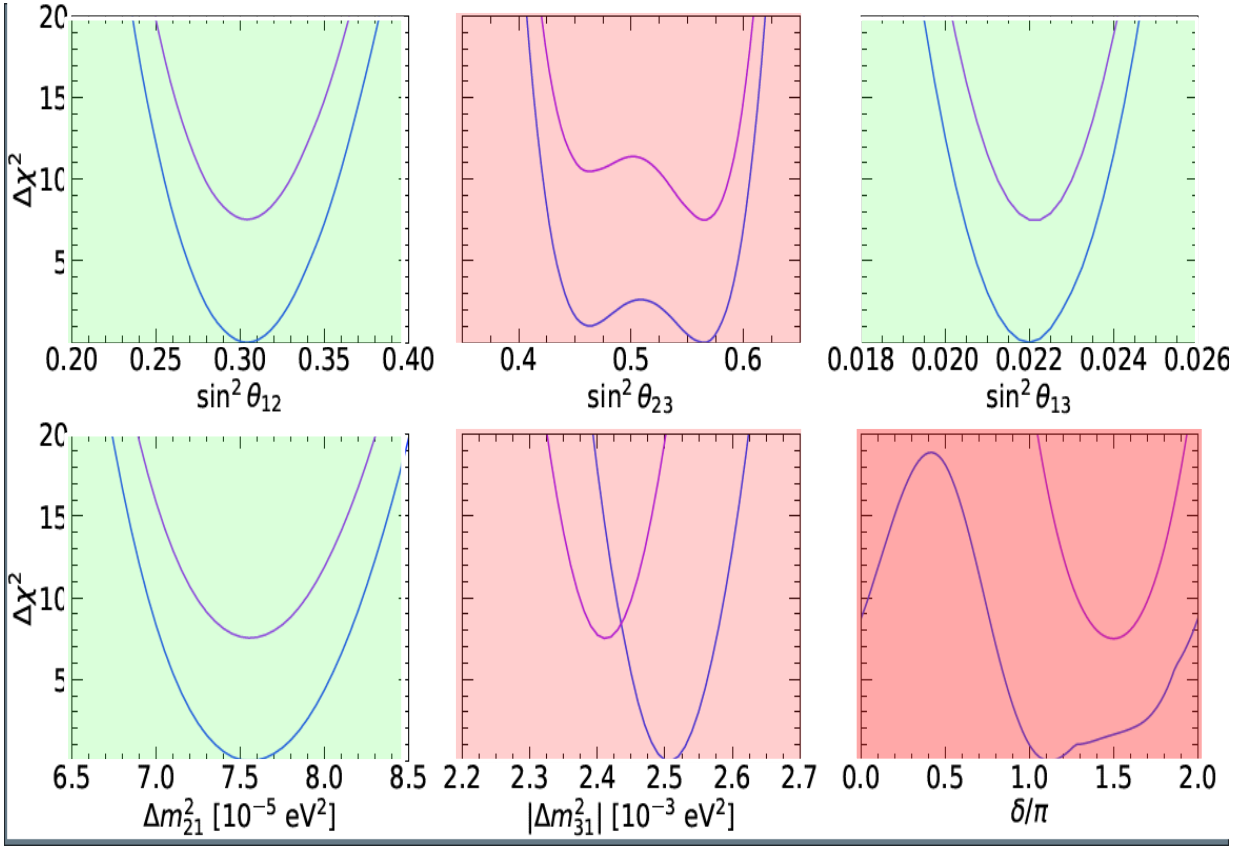








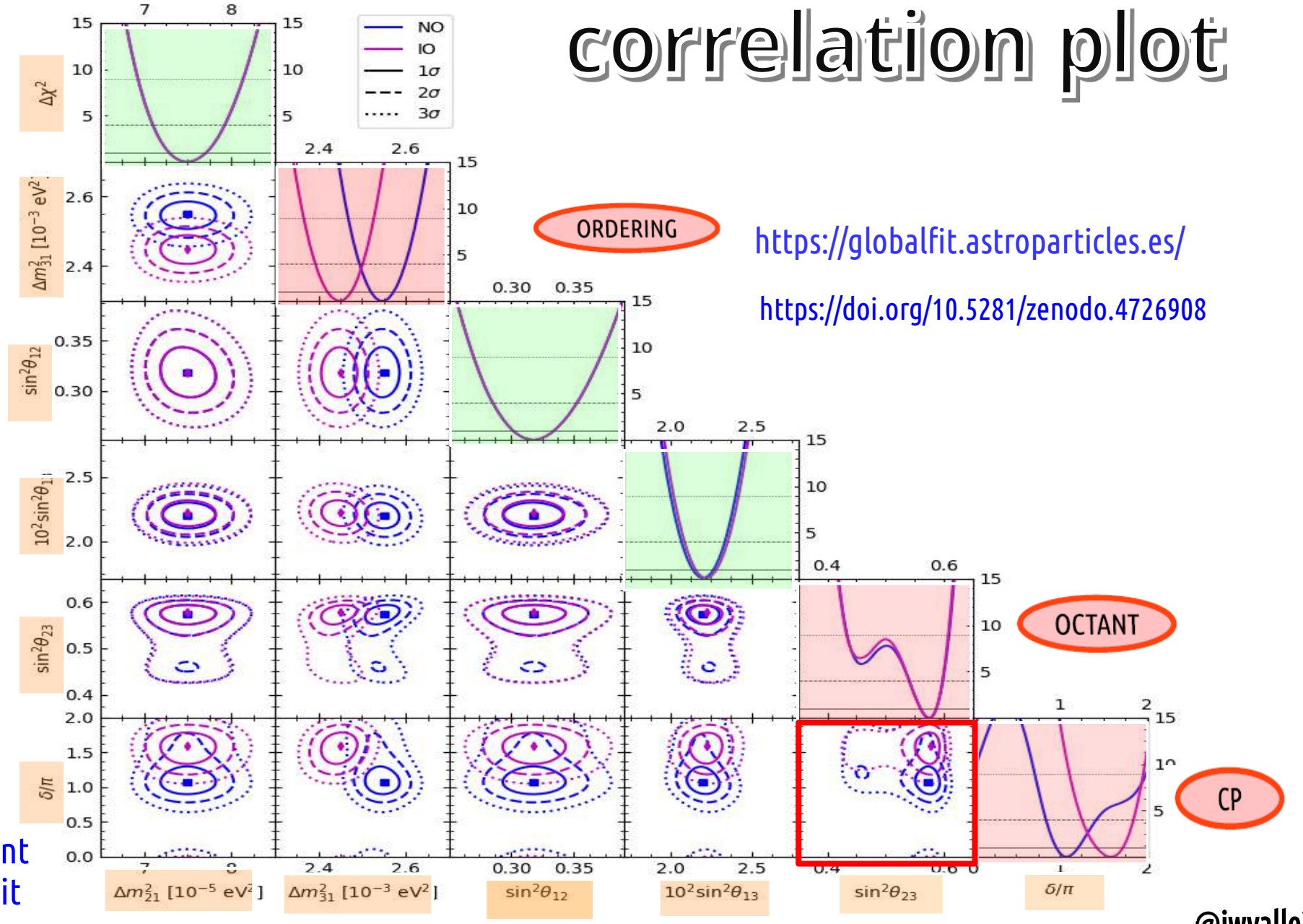
PF de Salas et al JHEP02(2021)071



post Nu2024 results, from Mariam Tórtola

@jwvalle2

correlation plot



https://globalfit.astroparticles.es/

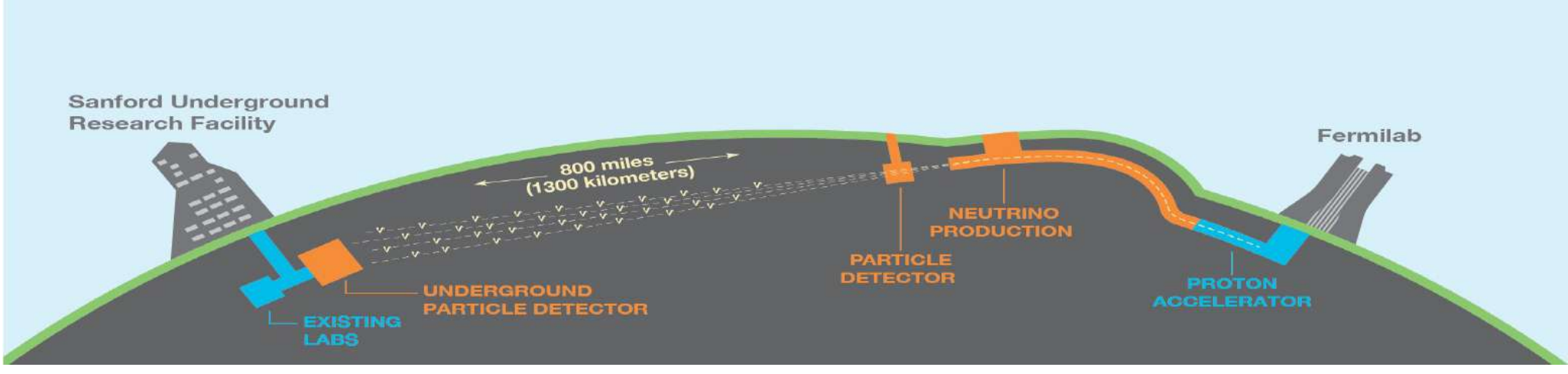
https://doi.org/10.5281/zenodo.4726908

PF de Salas et al JHEP02(2021)071

Agreement with NuFit and Bari

@jwvalle3

DUNE 2008.12769
Hyper-K
ESSnuSB



CPV

PhysRevLett117(2016)061804
New J.Phys. 19 (2017) 9, 093005
PhysRevD97 (2018) 095026

DUNE 2008.12769
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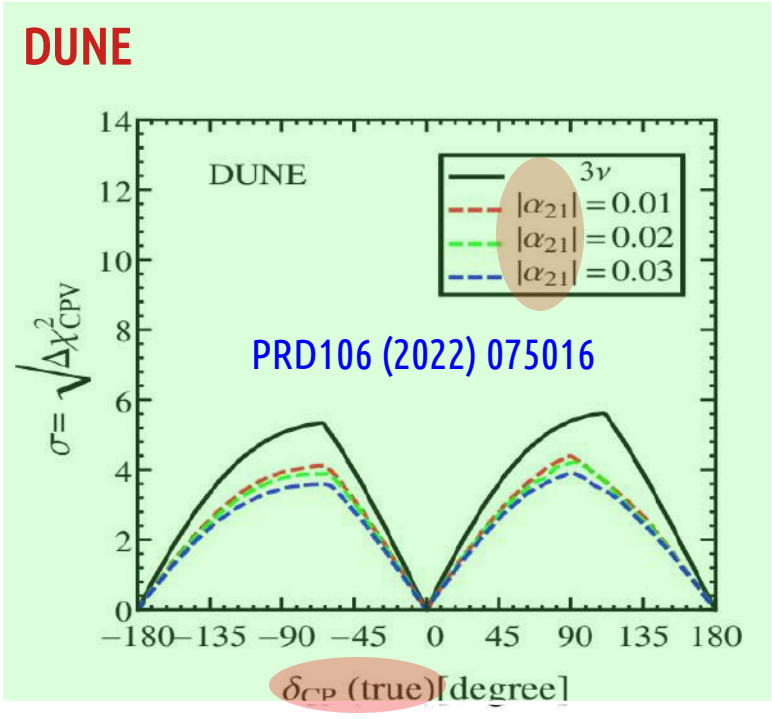
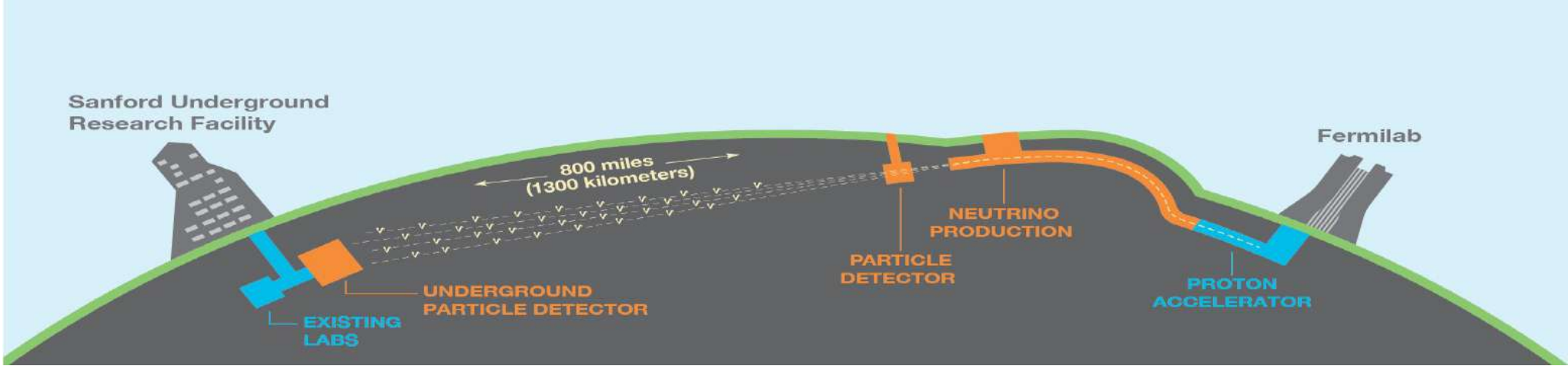


Expected CP discovery Sensitivity: standard 3-nu vs Unitarity violation



CPV

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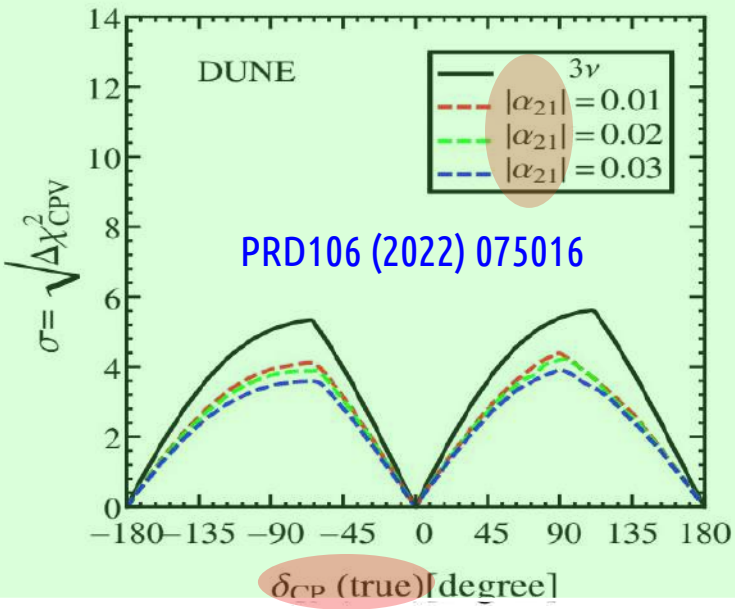
DUNE



mass ordering

JUNO combined with LBL

NovA and **T2K** 2008.11280

Or DUNE and Hyper-K

or neutrino telescopes

KM3NET/ORCA

S. Aiello et al JHEP03(2022)055

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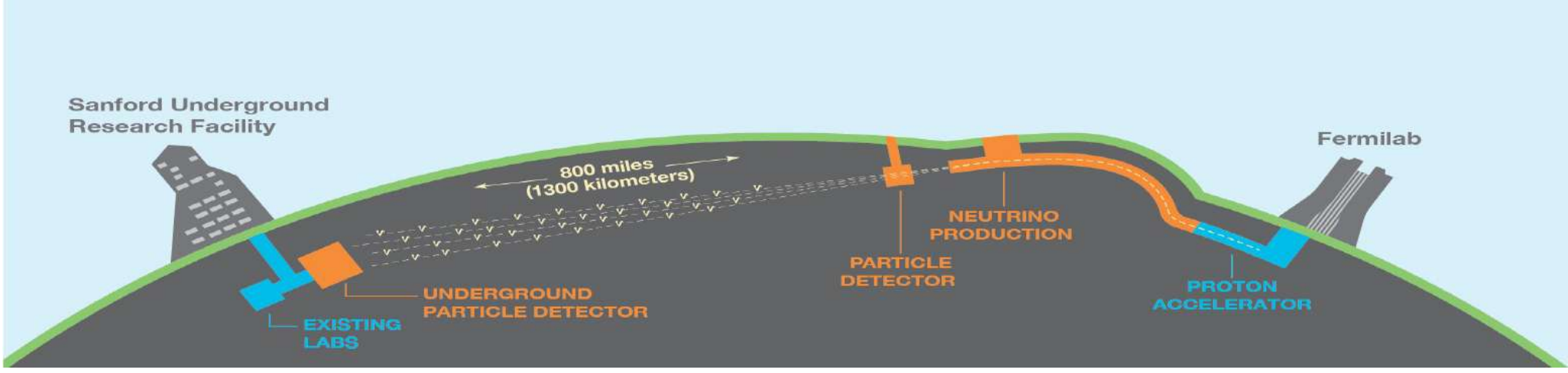

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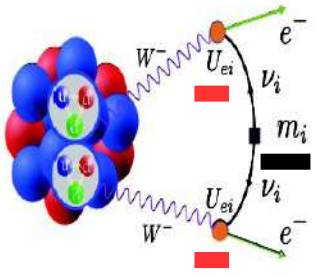
neutrinoless doublebeta decay

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



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

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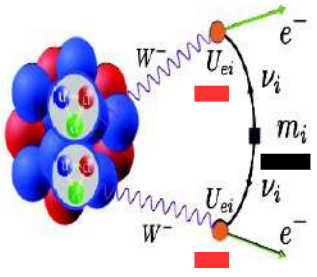

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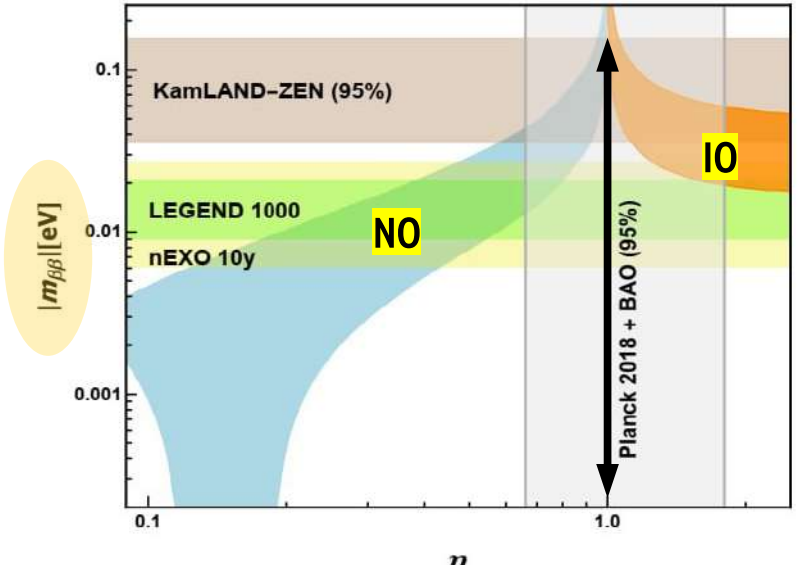

Lattanzi et al JHEP 10 (2020) 213

Nearly degenerate

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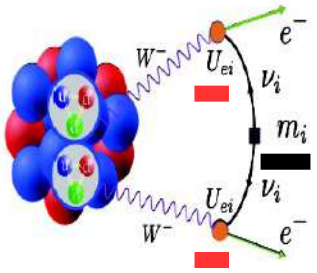

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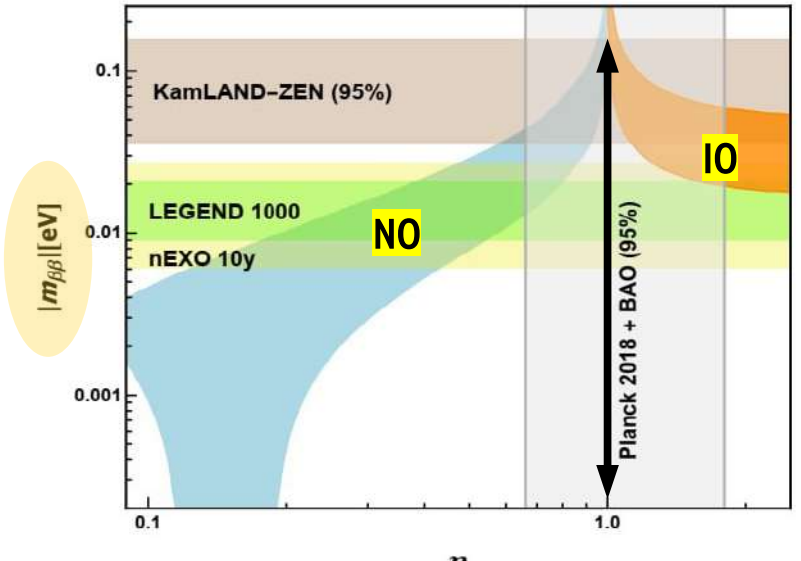
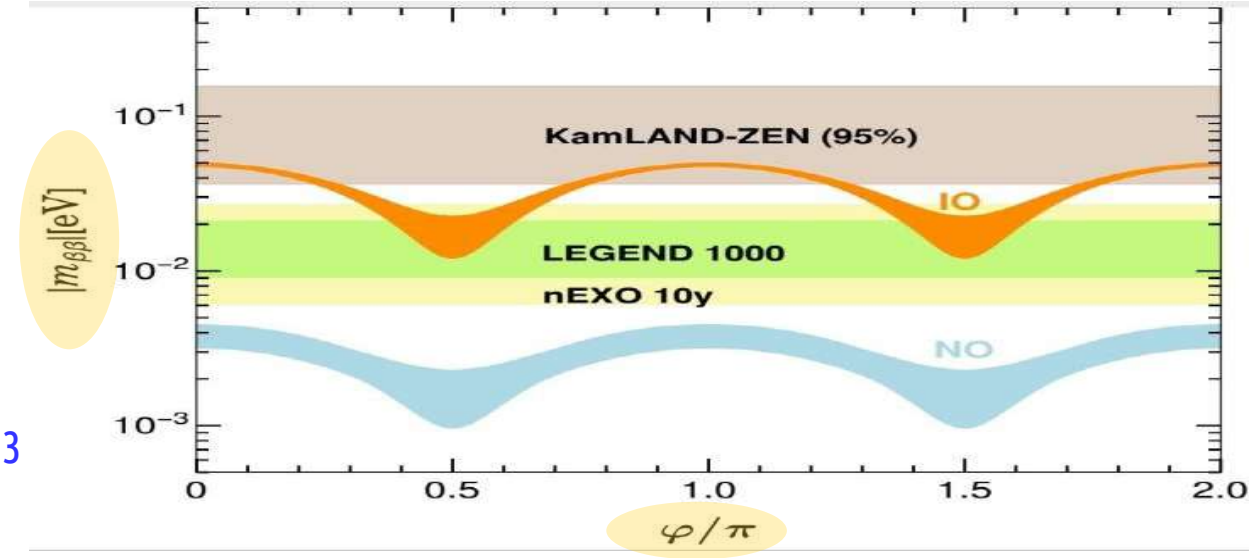


Lattanzi et al JHEP 10 (2020) 213

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

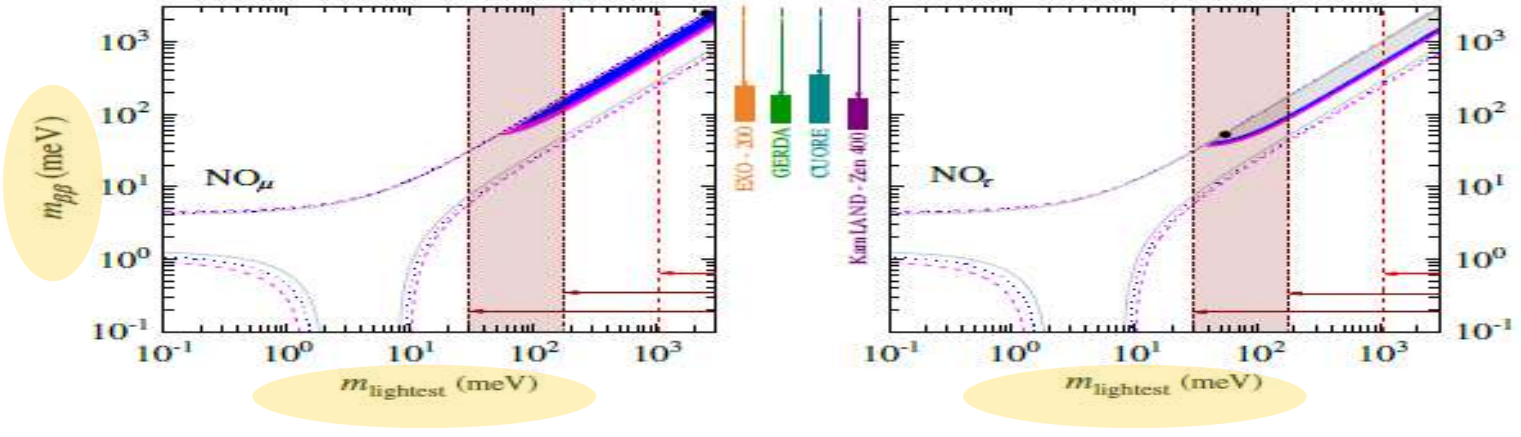
@jwvalle5

- **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



3-massive case

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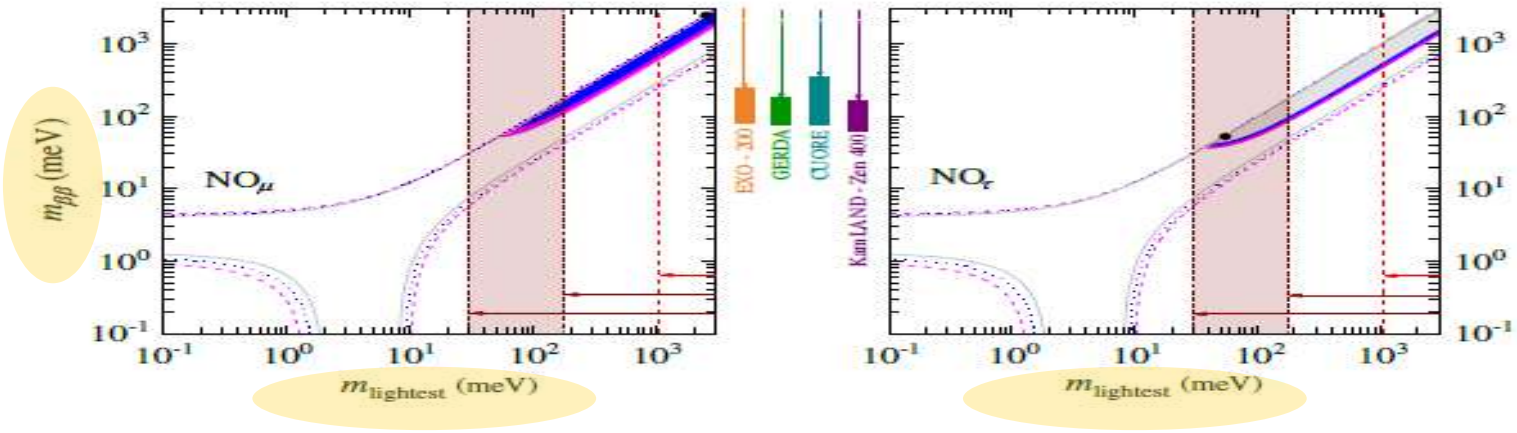
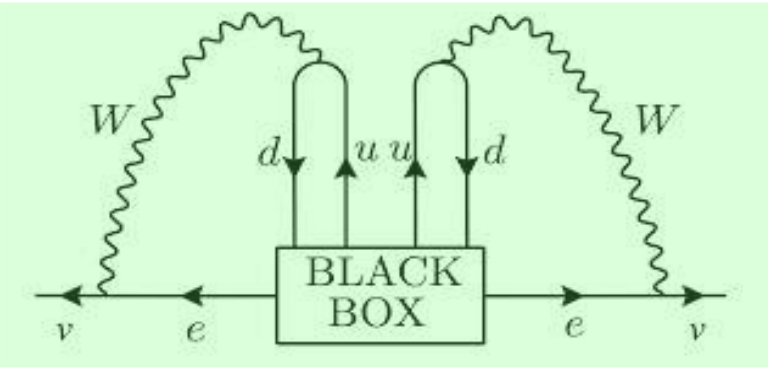


Significance

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



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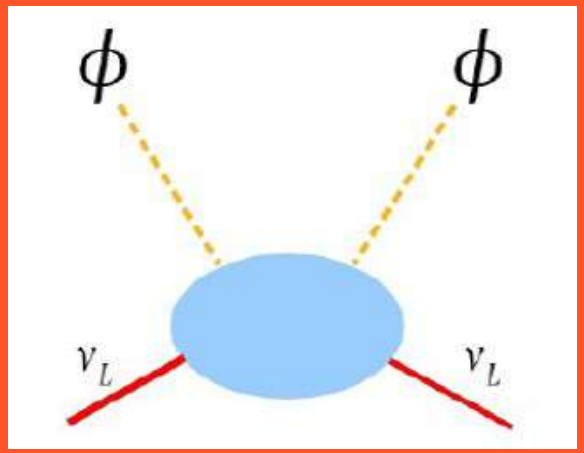
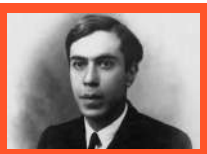
Origin of neutrino mass



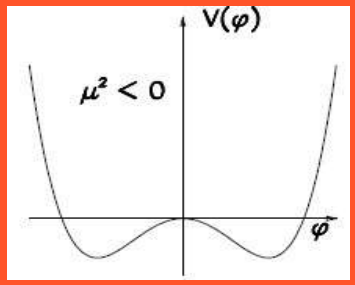


Origin of neutrino mass

stability

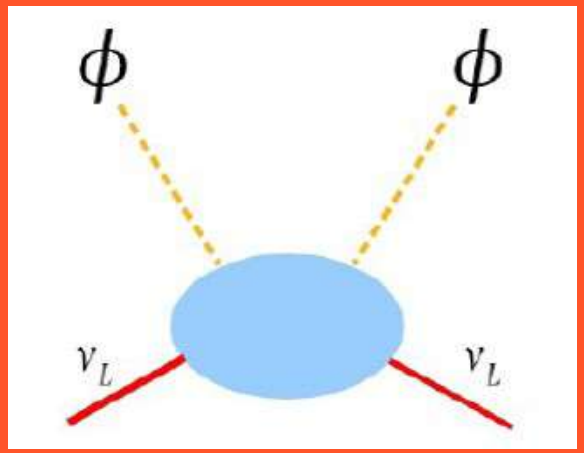
SEESAW dynamics

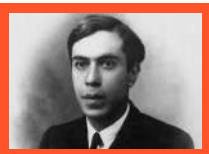
$$v_3 v_1 \sim v_2{}^2$$



Mandal et al PRD101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029





Origin of neutrino mass

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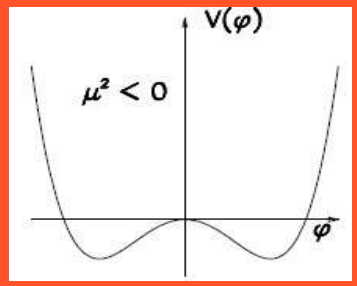

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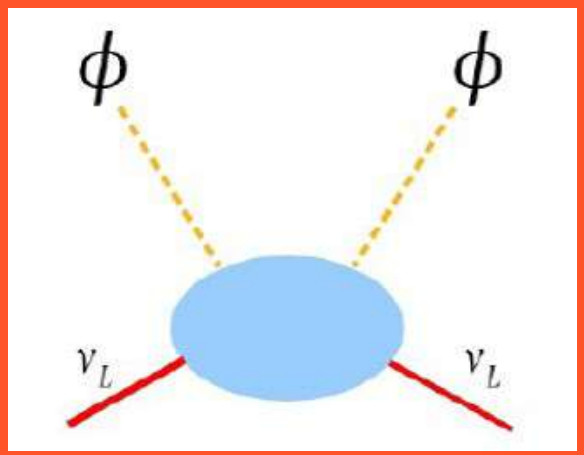
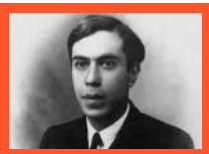
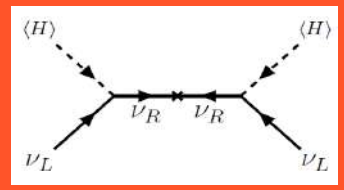






TYPE I

Minkowski 77

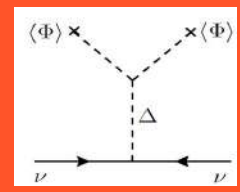
Gellman Ramond Slansky 80

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

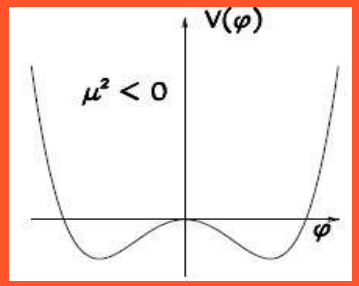
PRD105 (2022) 095020

Origin of neutrino mass

SEESAW dynamics

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

stability



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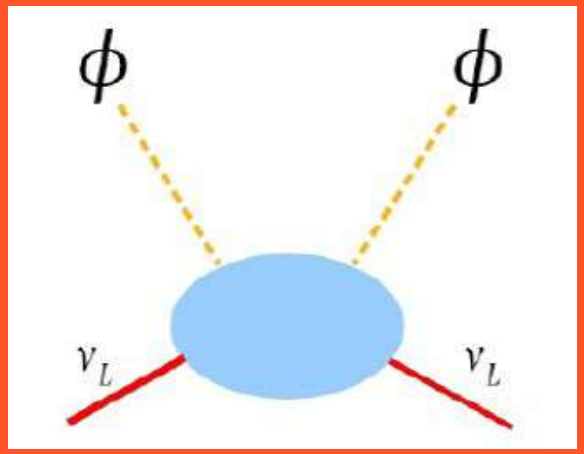

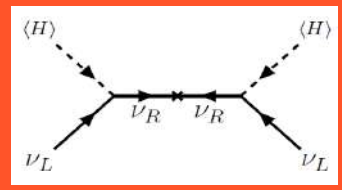

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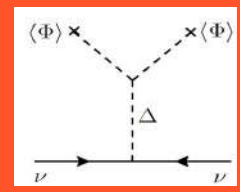


TYPE II

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

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

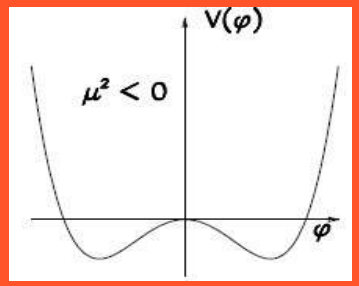
SM seesaw any # of singlets (3,m)

Origin of neutrino mass

SEESAW dynamics

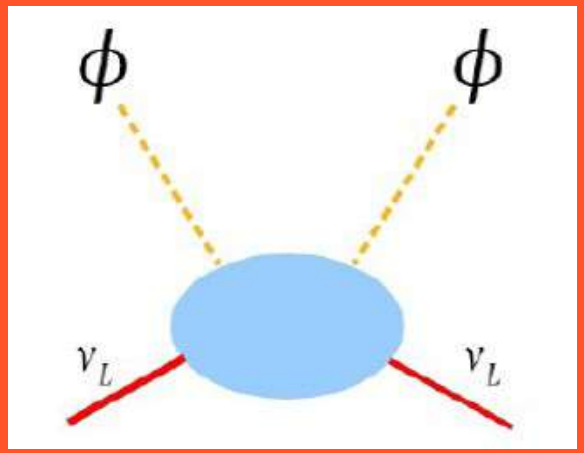
$$v_3 v_1 \sim v_2^{\,2}$$

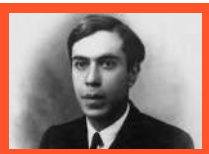
stability

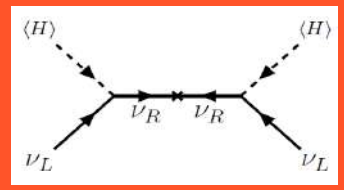


Mandal et al PRD101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029







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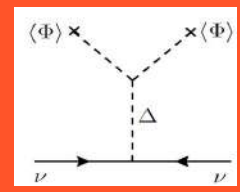
Lazarides Shafi Weterrich 81
Schechter-Valle 80 & 82



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

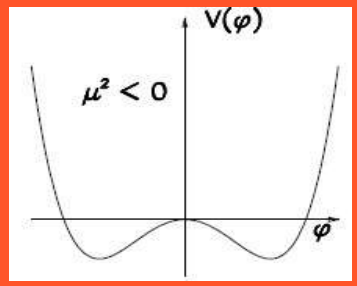
SEESAW dynamics

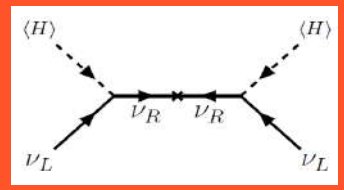
$$v_3 v_1 \sim v_2^{\,2}$$

Mandal et al PRD101 (2020) 115030

JHEP03(2021)212 & JHEP07(2021) 029

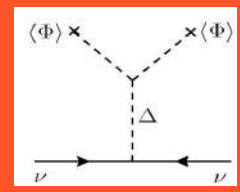
stability





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

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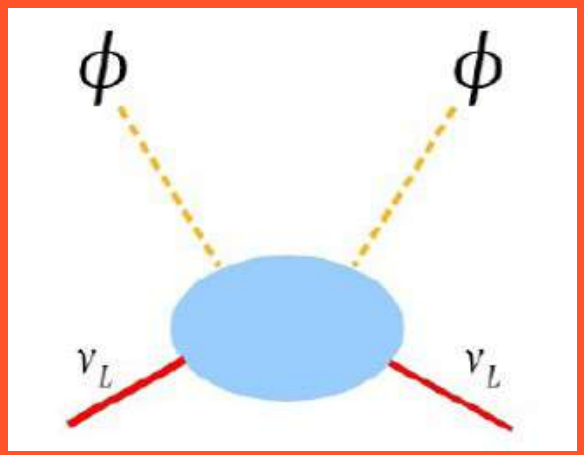
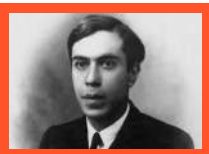
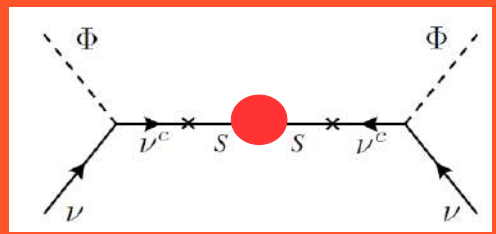




- **MISSING PARTNER** (3,2) min viable type1 seesaw
  (3,1) scoto-seesaw template

$m_{\beta\beta}$

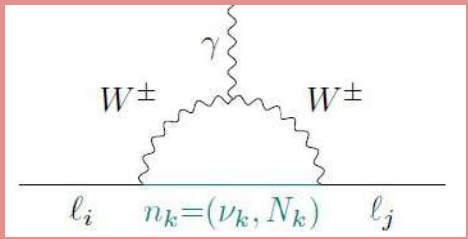
- **LOW-SCALE Type1 SEESAW (3,6) ISS & LSS**

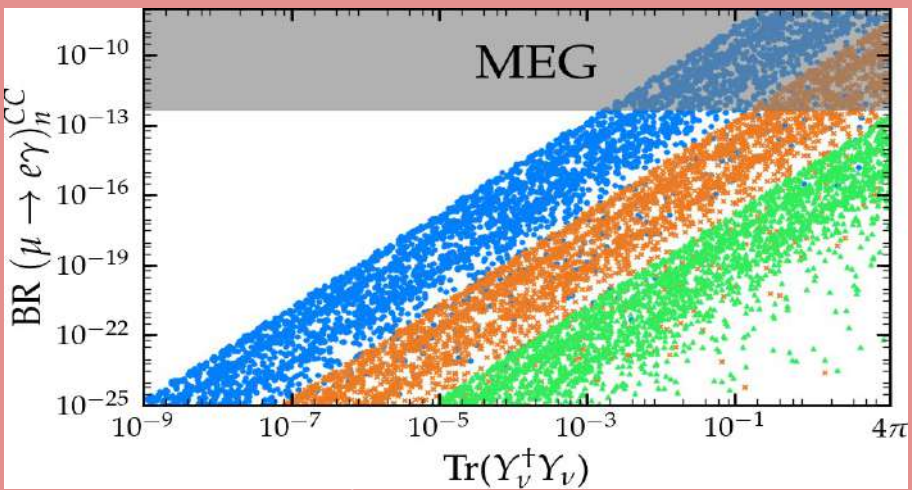


Mohapatra,Valle 86
Akhmedov et al Phys.Rev.D53 (1996) 2752
PhysLettB368 (1996) 270
Malinsky et al PhysRevLett95(2005)161801

@jwvalle7

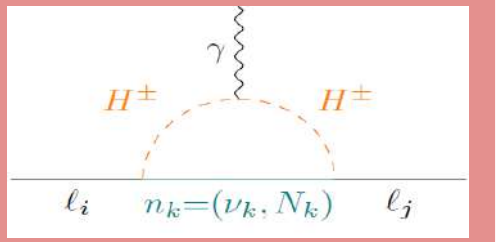
CC Lepton Flavor Violation In low-scale seesaw

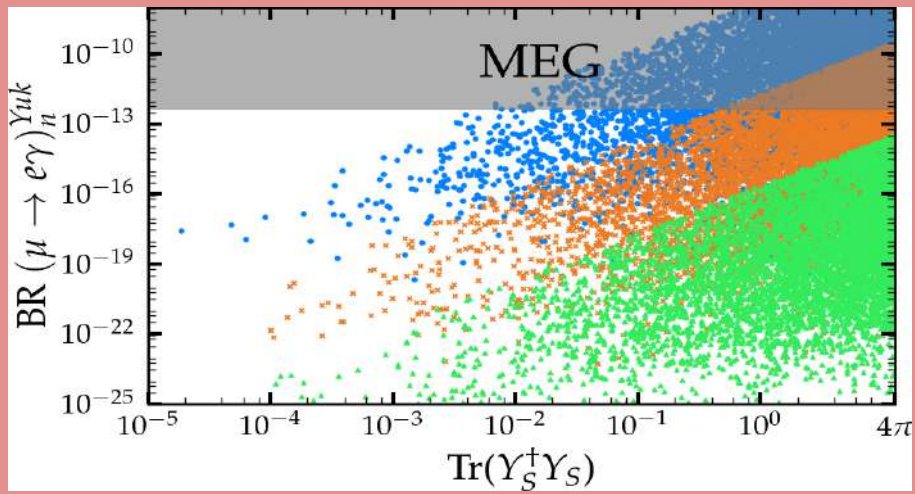




From Batra et al 2305.00994

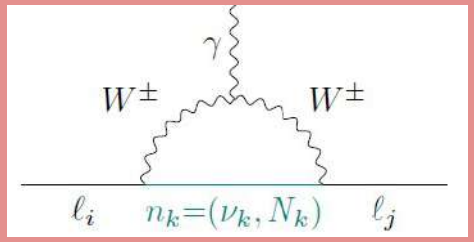
Leptophilic Higgs linear seesaw cLFV

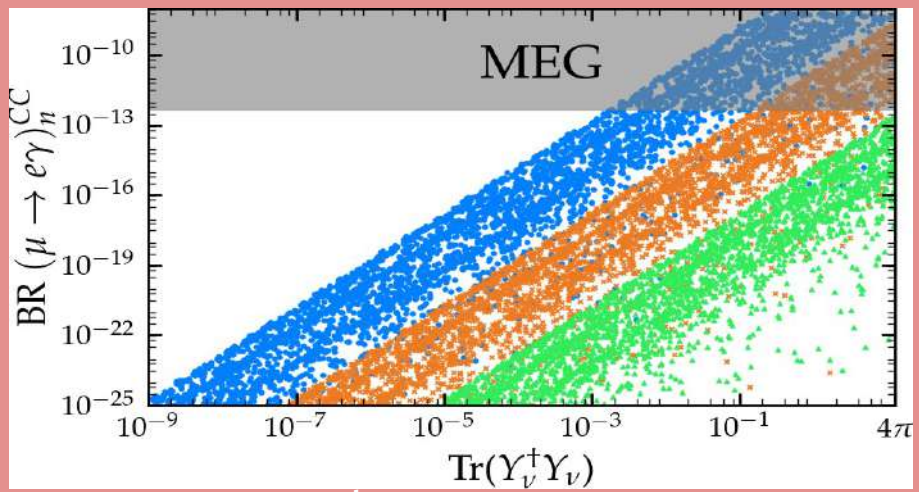




@jwvalle9

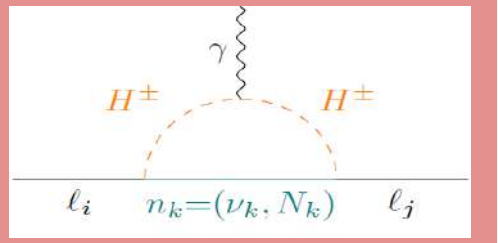
CC Lepton Flavor Violation In low-scale seesaw

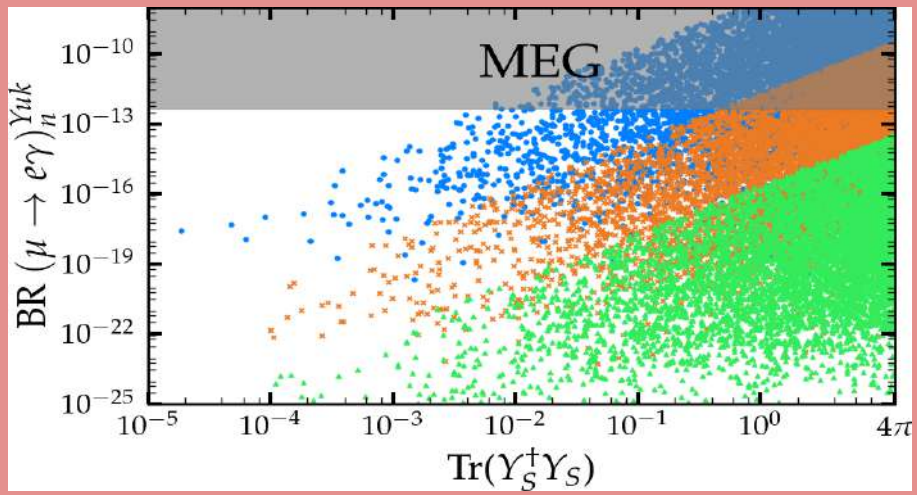




From Batra et al 2305.00994

Leptophilic Higgs linear seesaw cLFV





Genuine (3,6) low-scale seesaw

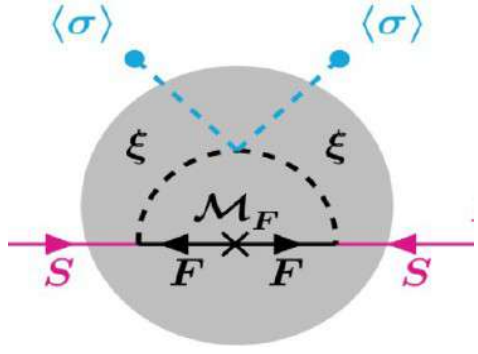
$M_N = 1\ TeV$ $M_N = 10\ TeV$ $M_N = 100\ TeV$

cLFV persists in the massless neutrino limit

Bernabeu et al B187 (1987) 303-308

@jwvalle8

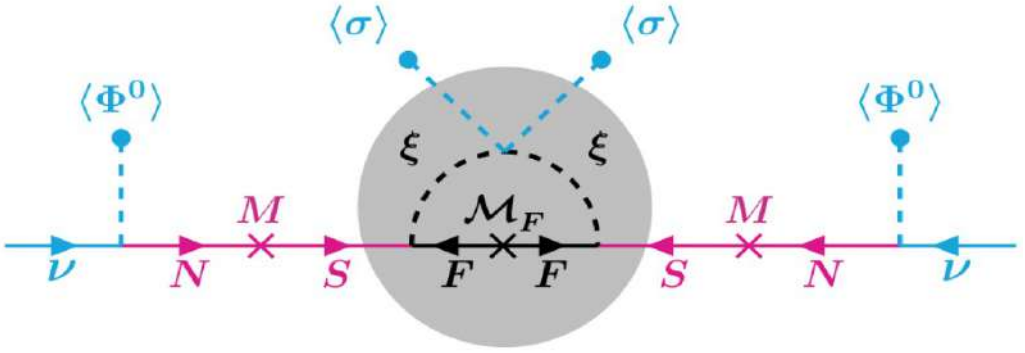

DARK MATTER
PROTON
PHOTON
e⁻
NEUTRINO
NEUTRON
MUON
QUARK
VISIBLE MATTER
e
e
DARK ELECTRONS
DARK NEUTRON
NEUTRALINO
AXION
AXION
GRAVITINO
Wimp



is dark matter the radiative seed of neutrino mass?

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

dark inverse seesaw



Dark loop+seesaw/symmetry protection

is dark matter the radiative seed of neutrino mass?

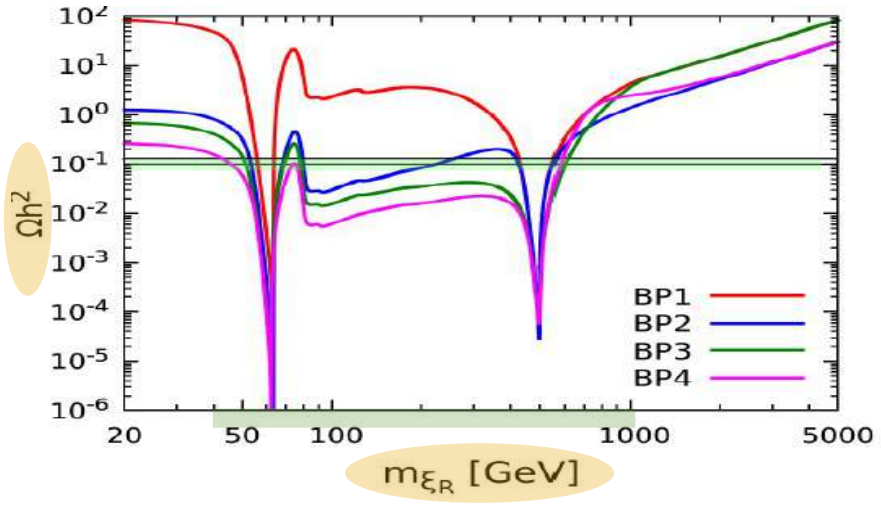
Mandal et al
Phys.Lett.B821 (2021) 136609

low-scale type-1

dark inverse seesaw

LambdaCDM

Phys.Lett.B821 (2021) 136609

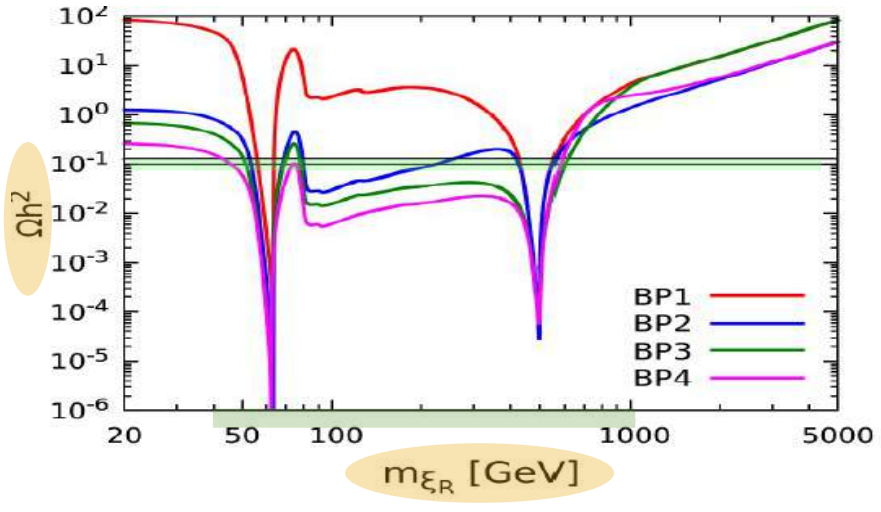


low-scale type-1

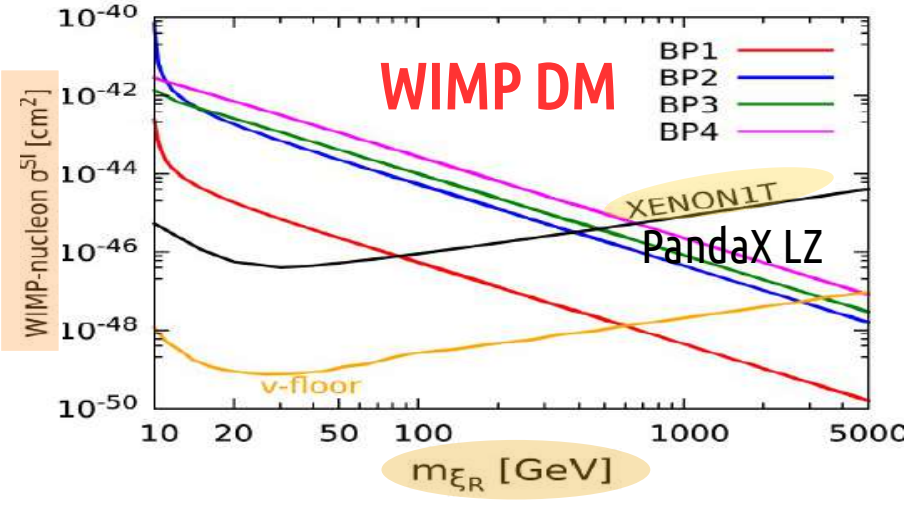
dark inverse seesaw

LambdaCDM

Phys.Lett.B821 (2021) 136609



Xenon1T PhysRevLett.121.111302
PandaX Lux-Zepellin

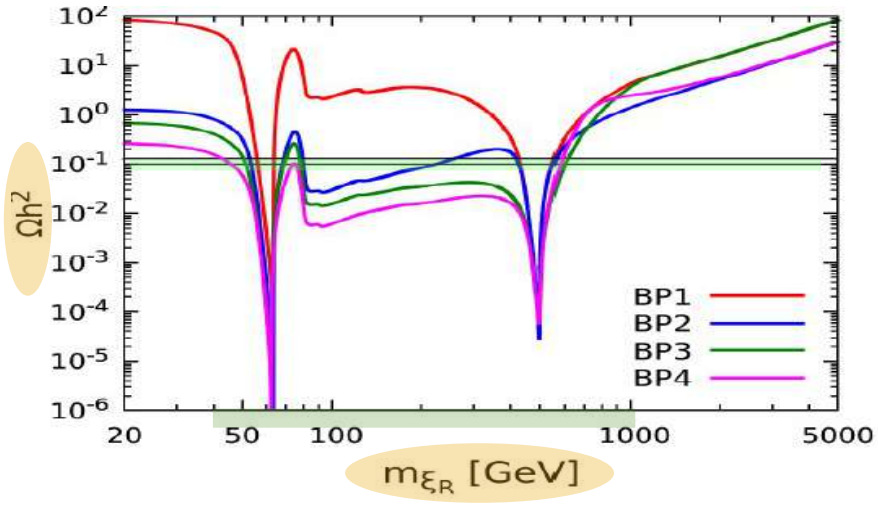


low-scale type-1

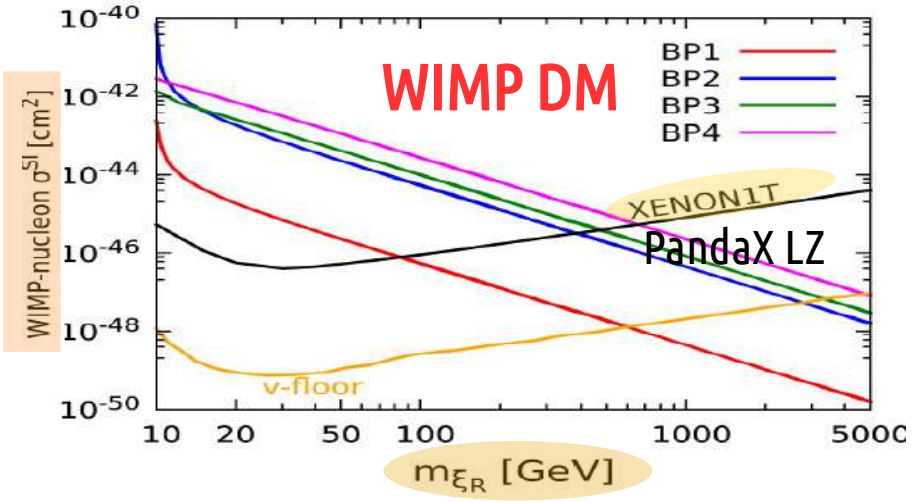
dark inverse seesaw

LambdaCDM

Phys.Lett.B821 (2021) 136609



Xenon1T PhysRevLett.121.111302
PandaX Lux-Zepellin

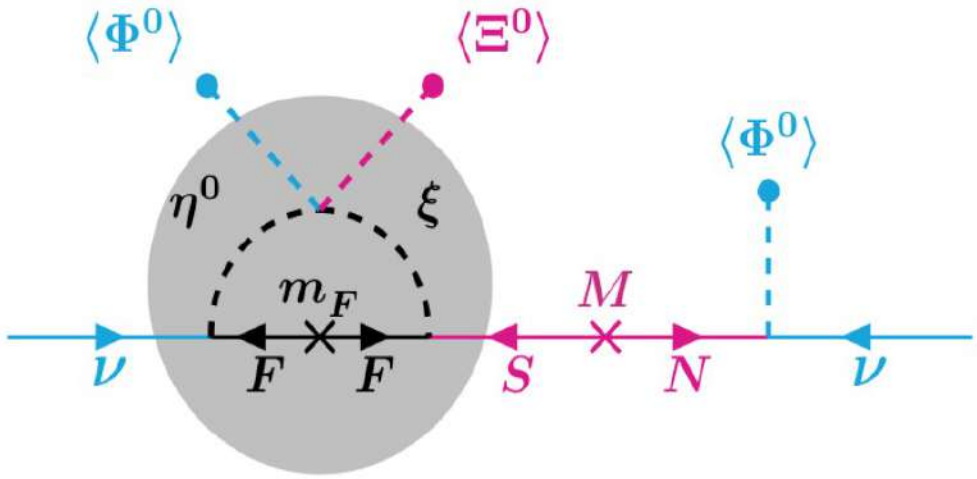


+ charged lepton flavor violation

@jwvalle11

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

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



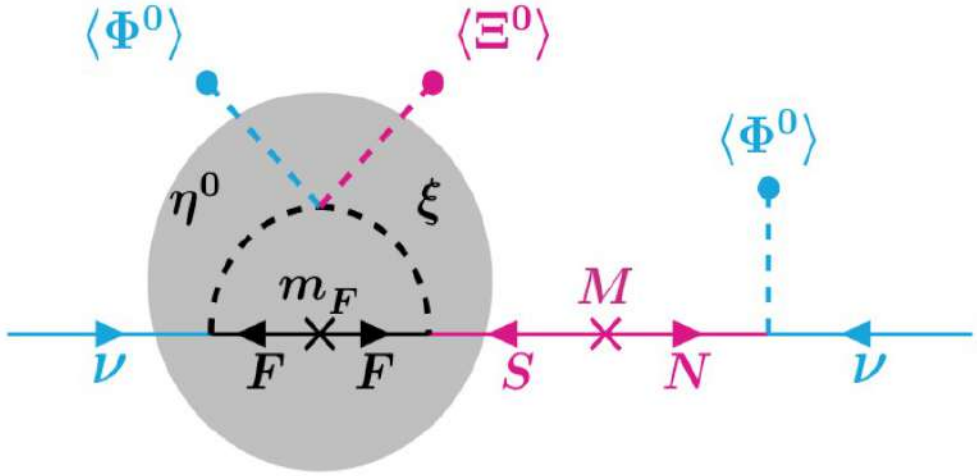
Carcamo, Vishnudath, J.V. JHEP 09 (2023) 046

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

(Also Batra, Camara, Joaquim, 2305.01687)

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

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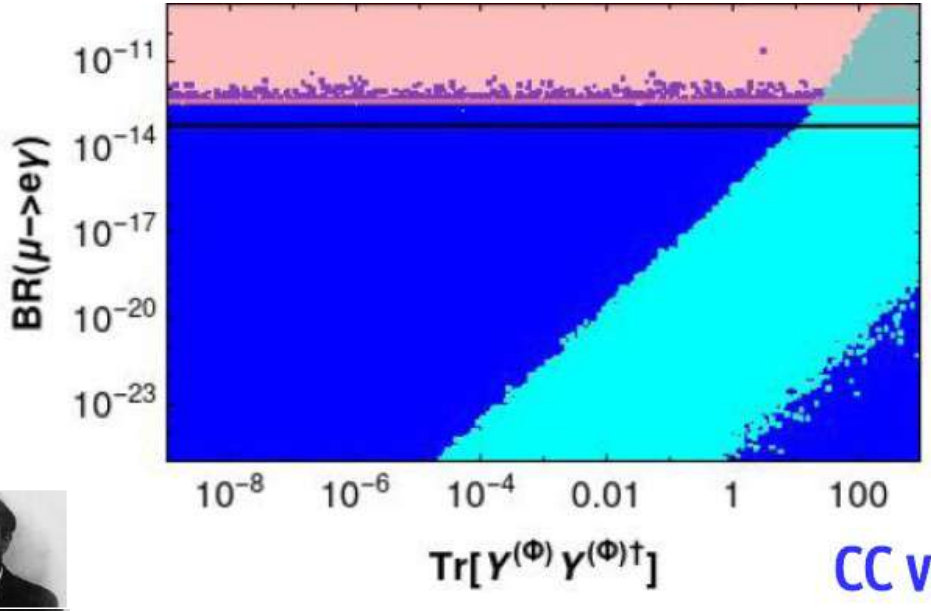
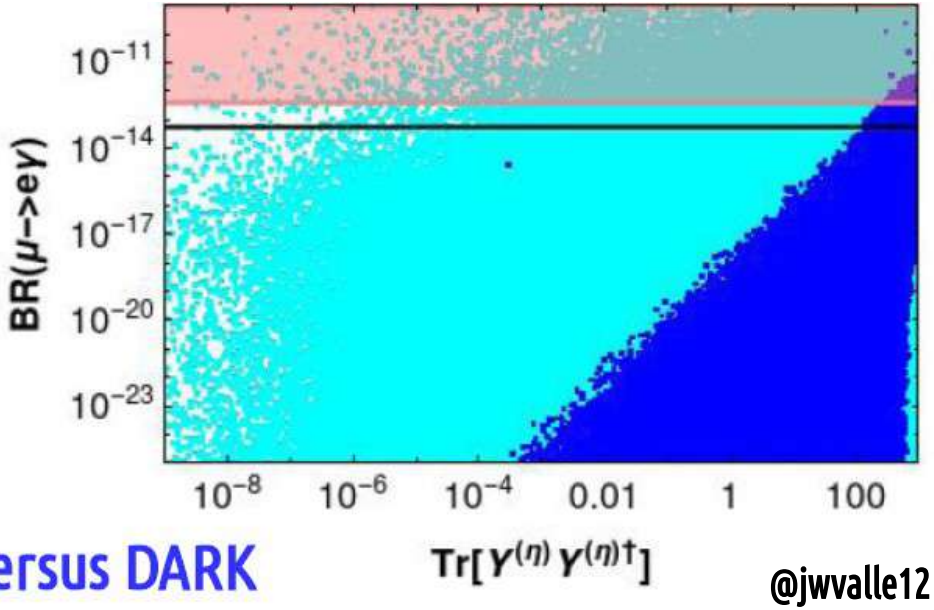
(Also Batra, Camara, Joaquim, 2305.01687)





CC versus DARK

@jwvalle12

Solar scale from SCOTOGENIC

Atm scale from SEESAW

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

Dark-mediated nu-mass loop

LOOP
TREE

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

Solar scale from SCOTOGENIC

Atm scale from SEESAW

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

Dark-mediated nu-mass loop

LOOP
TREE

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

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

@jwvalle13

atm scale from seesaw

Leite, Sadhukhan, Valle

Phys.Rev.D 109 (2024) 3, 035023

Scoto-seesaw with Gauged lepton

LOOP

TREE

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

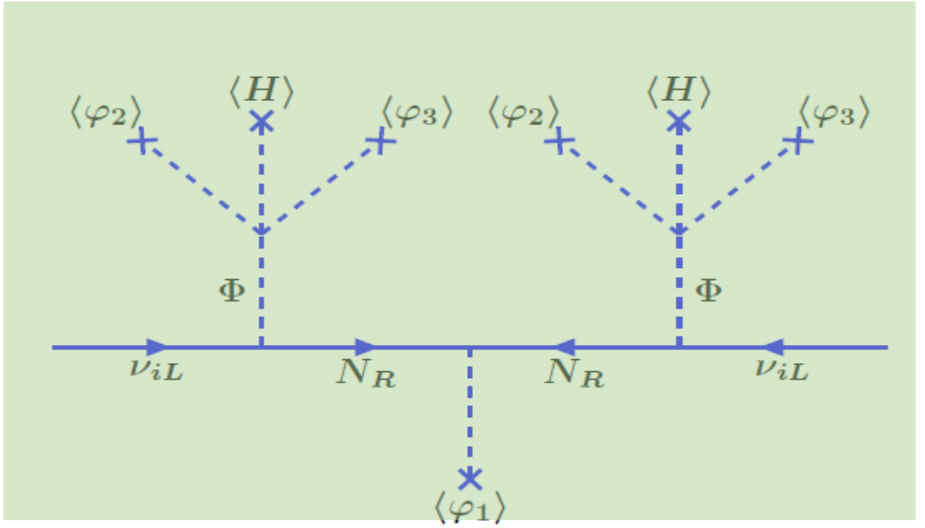
solar scale from scoto

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

atm scale from seesaw

Leite, Sadhukhan, Valle

Phys.Rev.D 109 (2024) 3, 035023



Scoto-seesaw with Gauged lepton

LOOP

TREE

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

solar scale from scoto

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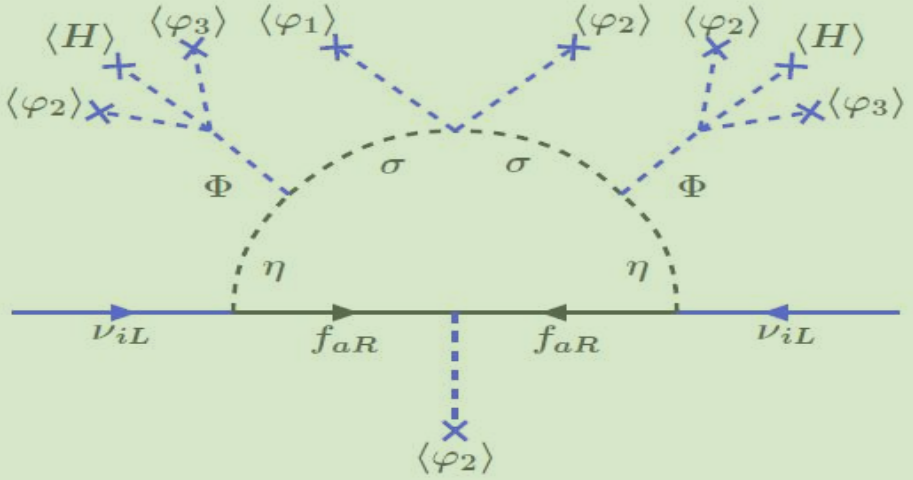
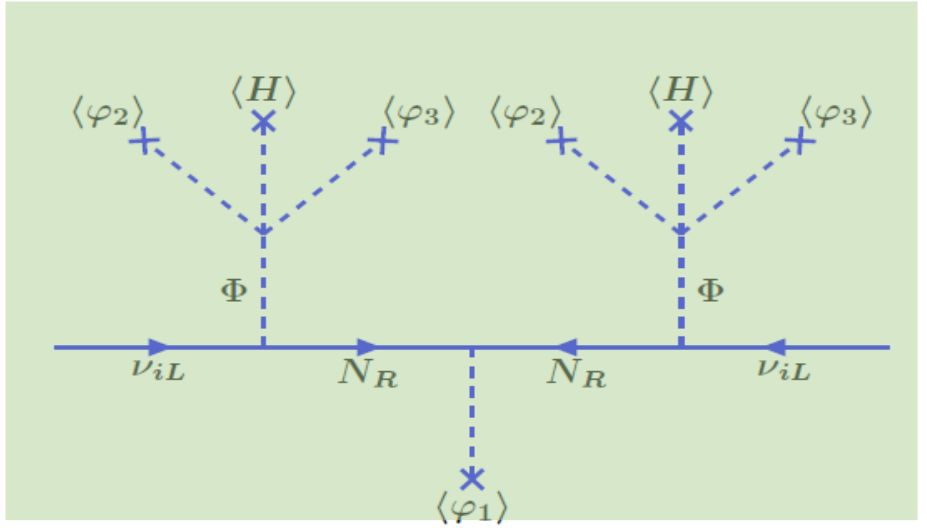


atm scale from seesaw

Leite, Sadhukhan, Valle

Phys.Rev.D 109 (2024) 3, 035023



Scoto-seesaw with Gauged lepton

GENUINE LOW-SCALE (3,3) SEESAW

tiny induced leptophilic Φ vev

Drell-Yan mediator N-pair production from TeV scale Z'

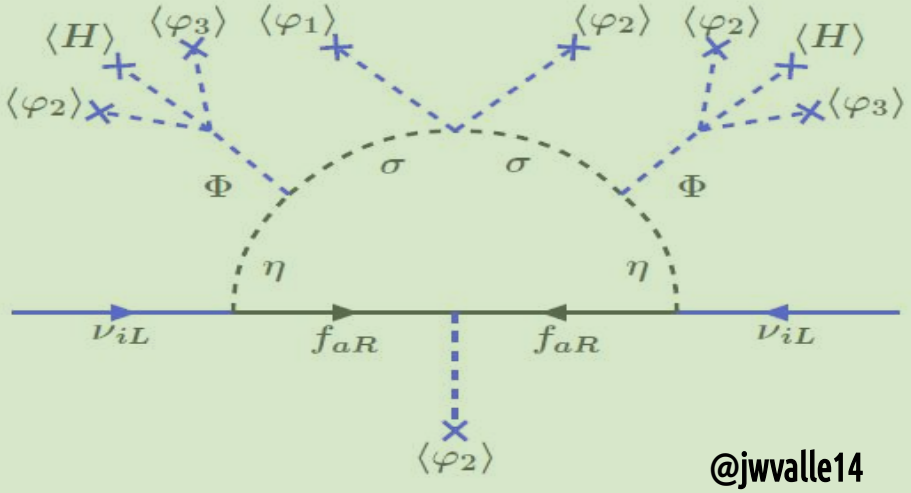
LOOP

TREE

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

solar scale from scoto

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

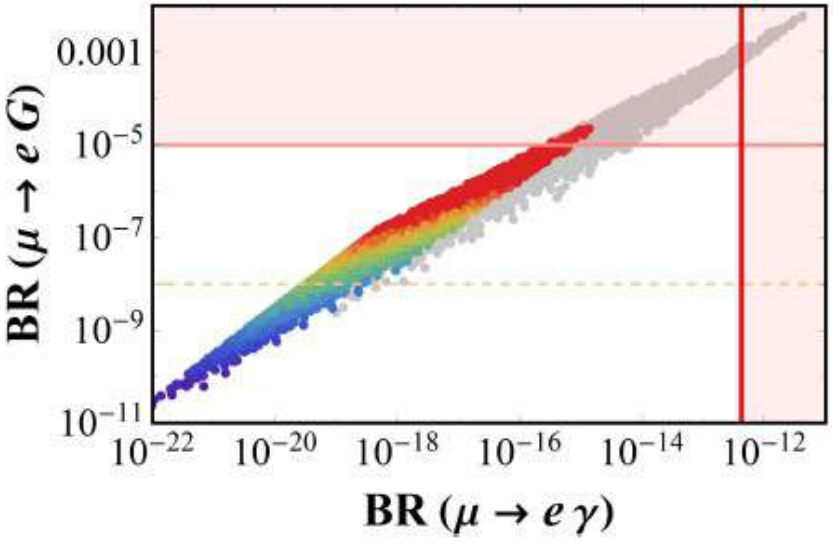


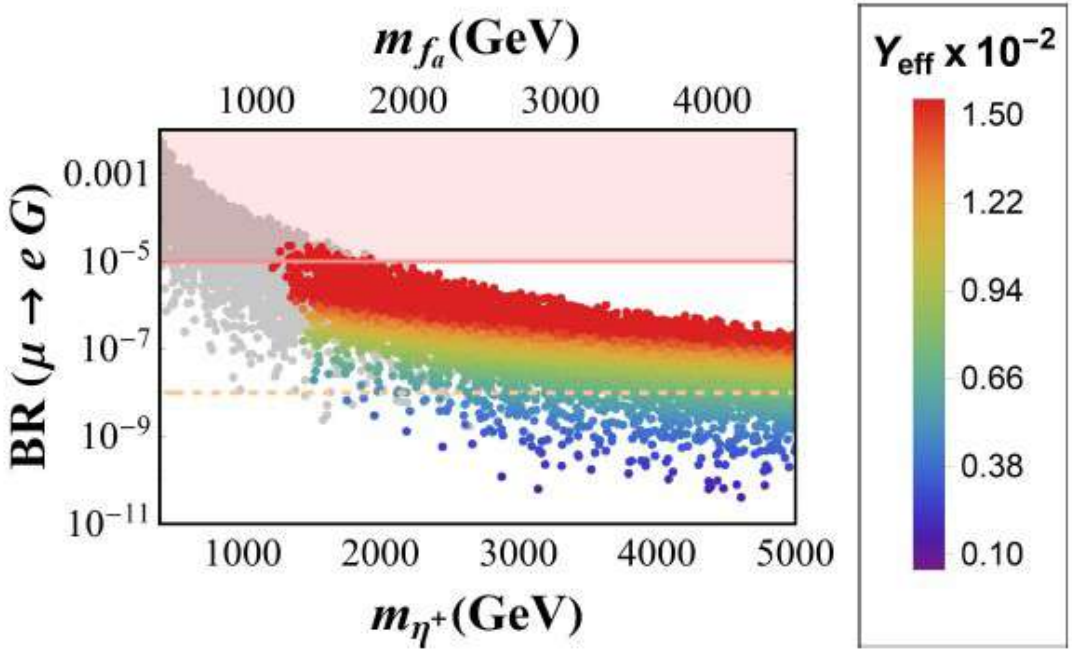
@jwvalle14

+ charged lepton flavor violation

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

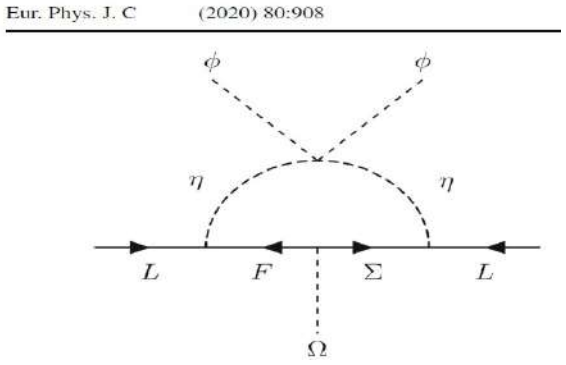
$$G \simeq \frac{1}{\sqrt{14}}\left(5\frac{v_\Phi^2}{v_H v_\varphi}A_H - 5\frac{v_\Phi}{v_\varphi}A_\Phi + A_{\varphi_1} - 2A_{\varphi_2} + 3A_{\varphi_3}\right)$$



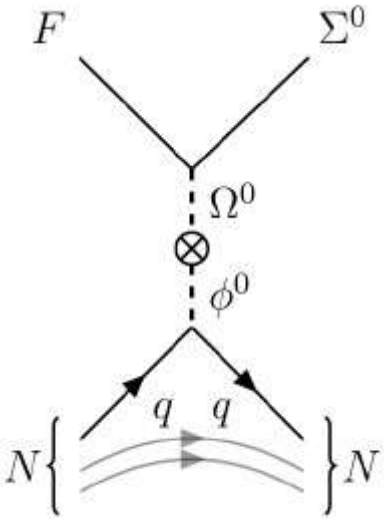


@jwvalle15

revamped scoto DM

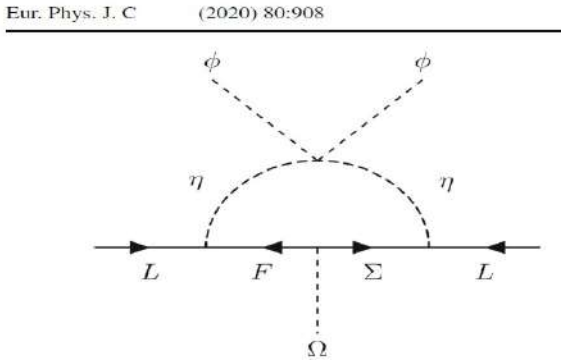


M. Hirsch et al JHEP 10 (2013) 149
A. Merle et al JHEP 07 (2016) 013
Rocha-Moran, Vicente JHEP 07 (2016) 078
Restrepo, Rivera JHEP 04 (2020) 134

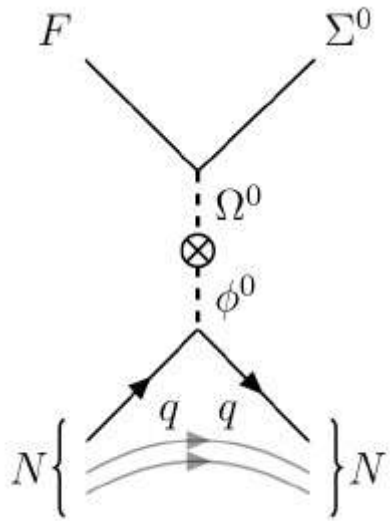


Avila et al Eur.Phys.J.C 80 (2020) 10, 908
Karan, Sadhukhan, Valle JHEP12 (2023) 185

revamped scoto DM

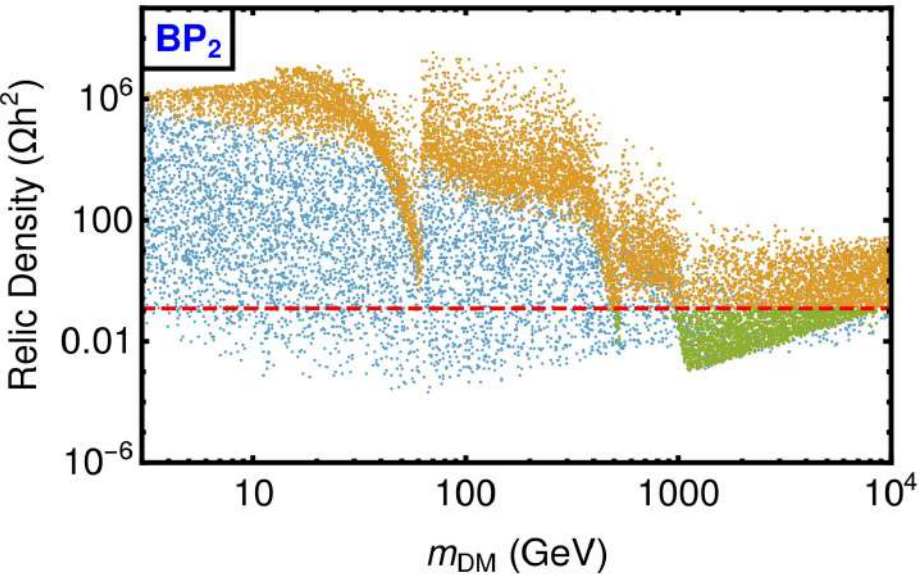


M. Hirsch et al JHEP 10 (2013) 149
A. Merle et al JHEP 07 (2016) 013
Rocha-Moran, Vicente JHEP 07 (2016) 078
Restrepo, Rivera JHEP 04 (2020) 134

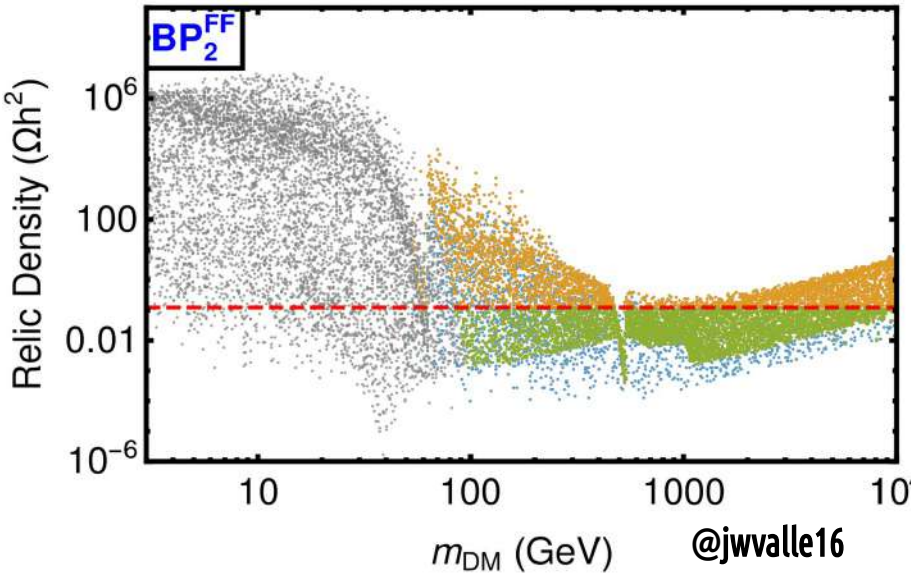


Avila et al Eur.Phys.J.C 80 (2020) 10, 908
Karan, Sadhukhan, Valle JHEP12 (2023) 185

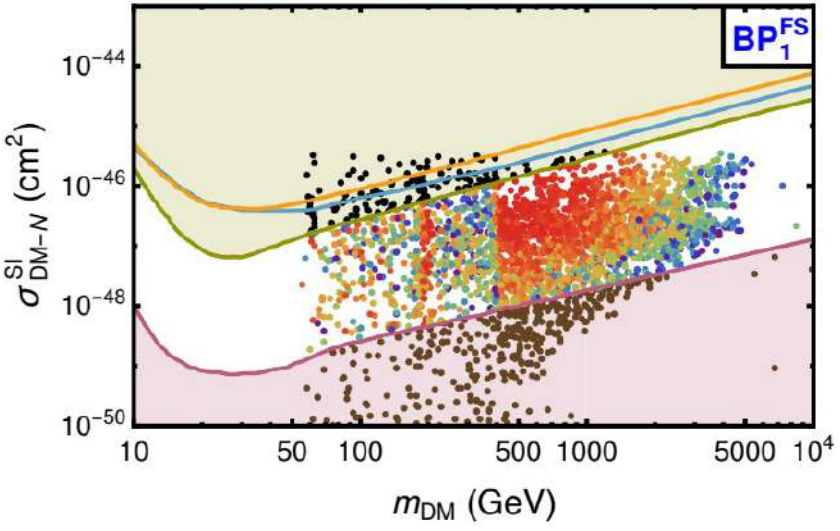
No DM coannihilation:



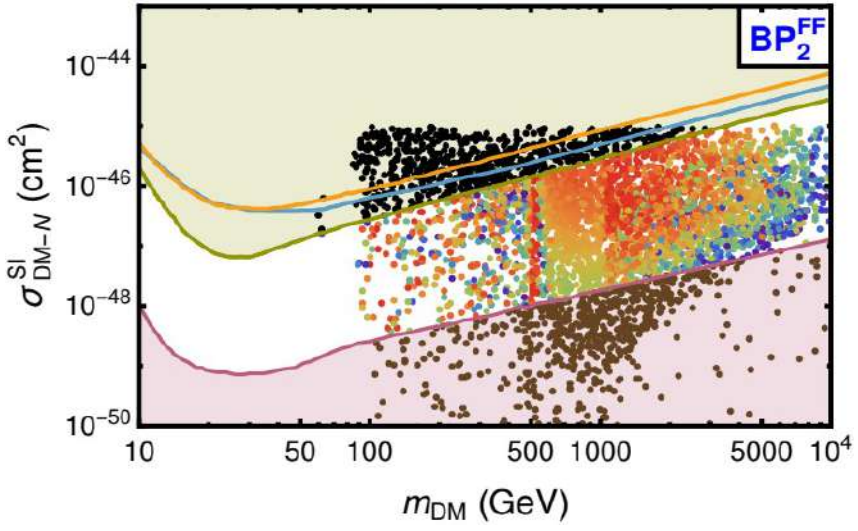
With DM coannihilations



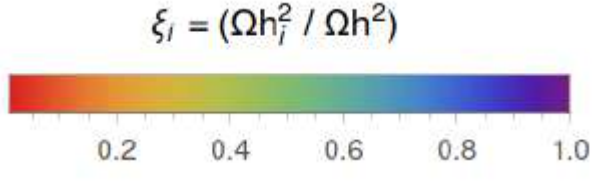
@jwvalle16



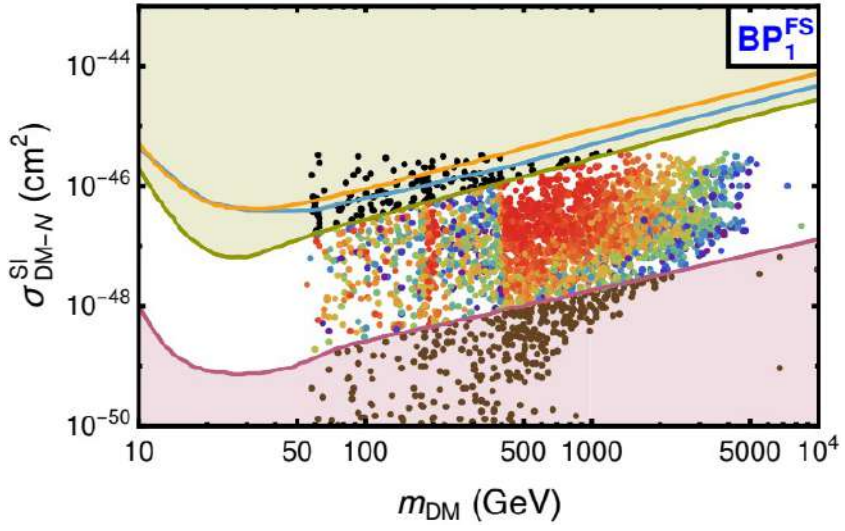
Higher v_Ω (4 GeV): Fermion-Scalar Coannihilation



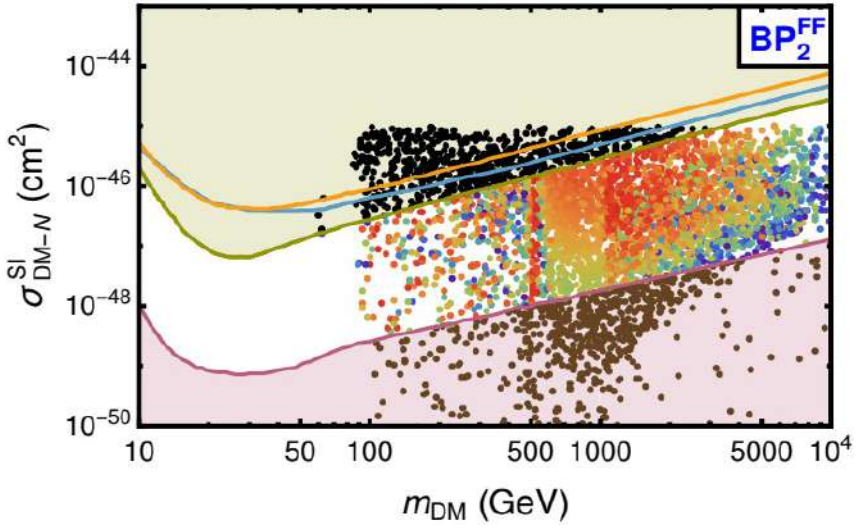
Lower v_Ω (1.5 GeV): Fermion-Fermion Coannihilation



Karan, Sadhukhan, Valle 2308.09135

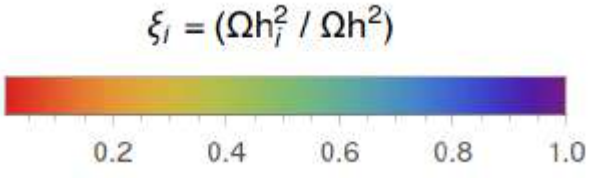


Higher v_Ω (4 GeV): Fermion-Scalar Coannihilation



Lower v_Ω (1.5 GeV): Fermion-Fermion Coannihilation

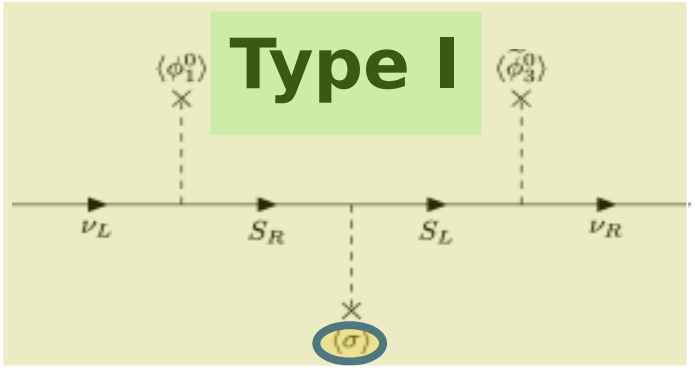
LFV Process	Current Bound	Future Sensitivity
$\mathcal{B}(\mu \to e\gamma)$	4.2×10^{-13} [44]	6.0×10^{-14} [45]
$\mathcal{B}(\mu \to 3e)$	1.0×10^{-12} [46]	$\sim 10^{-16}$ [47, 48]
$\mathcal{C}(\mu, Au \to e, Au)$	7.0×10^{-13} [49]	–
$\mathcal{C}(\mu, Ti \to e, Ti)$	4.3×10^{-12} [49]	$\sim 10^{-18}$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

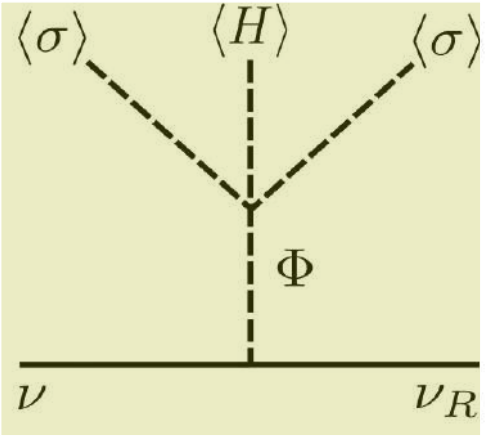


Karan, Sadhukhan, Valle 2308.09135

LNV .... DBD lower bound

seesawing a la

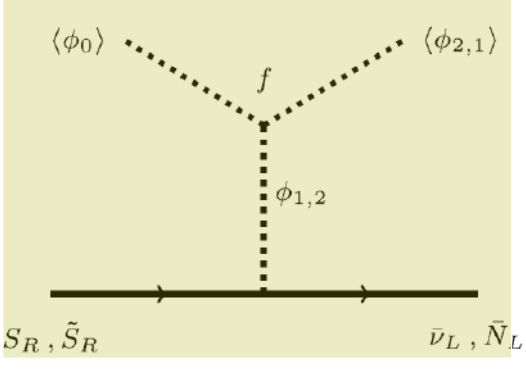




Type II

Phys.Lett. B762 (2016) 162-165

Phys.Rev. D94 (2016) 033012



Phys.Lett. B761 (2016) 431-436

Phys.Lett. B767 (2017) 209-213

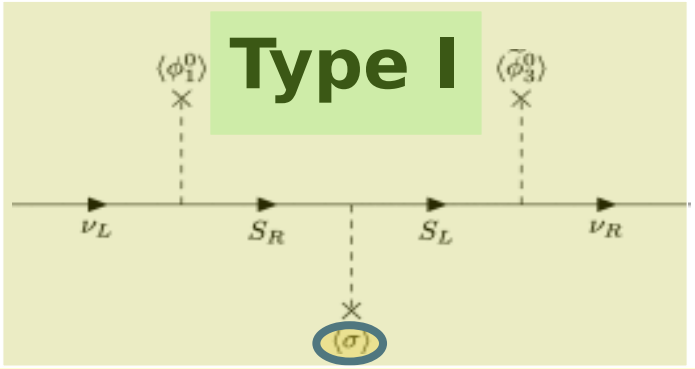
Phys.Rev. D98 (2018) 035009

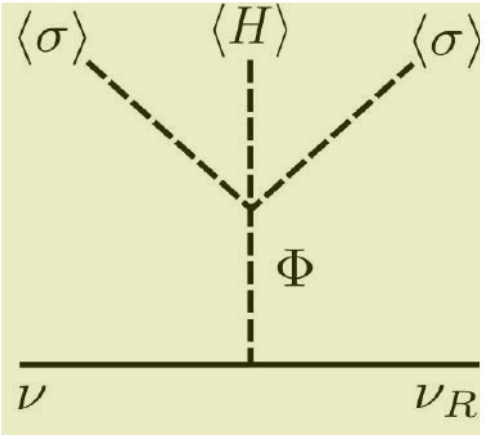
Phys.Lett. B781 (2018) 122-128

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

Phys.Lett. B755 (2016) 363-366

seesawing a la





Type II

symmetry protecting small neutrino mass

+ Diracness

Peccei-Quinn symmetry

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

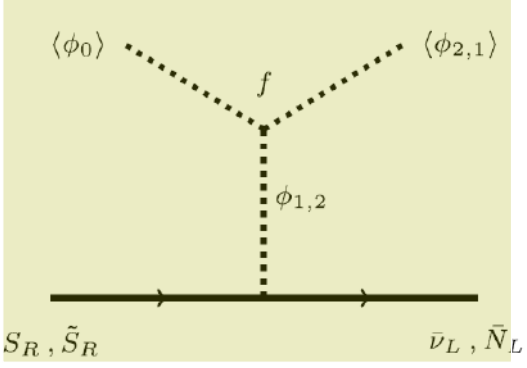
SU3L

PQ

Phys.Lett.B 810 (2020) 135829

Phys.Lett. B762 (2016) 162-165

Phys.Rev. D94 (2016) 033012



Phys.Lett. B761 (2016) 431-436

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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

@jwvalle18

ILC: 1506.07830, **CLIC**: 1812.06018,
CEPC: 1811.10545
FCC-ee
Eur.Phys.J.ST 228 (2019) 2, 261-623

Exploring the Quantum Universe

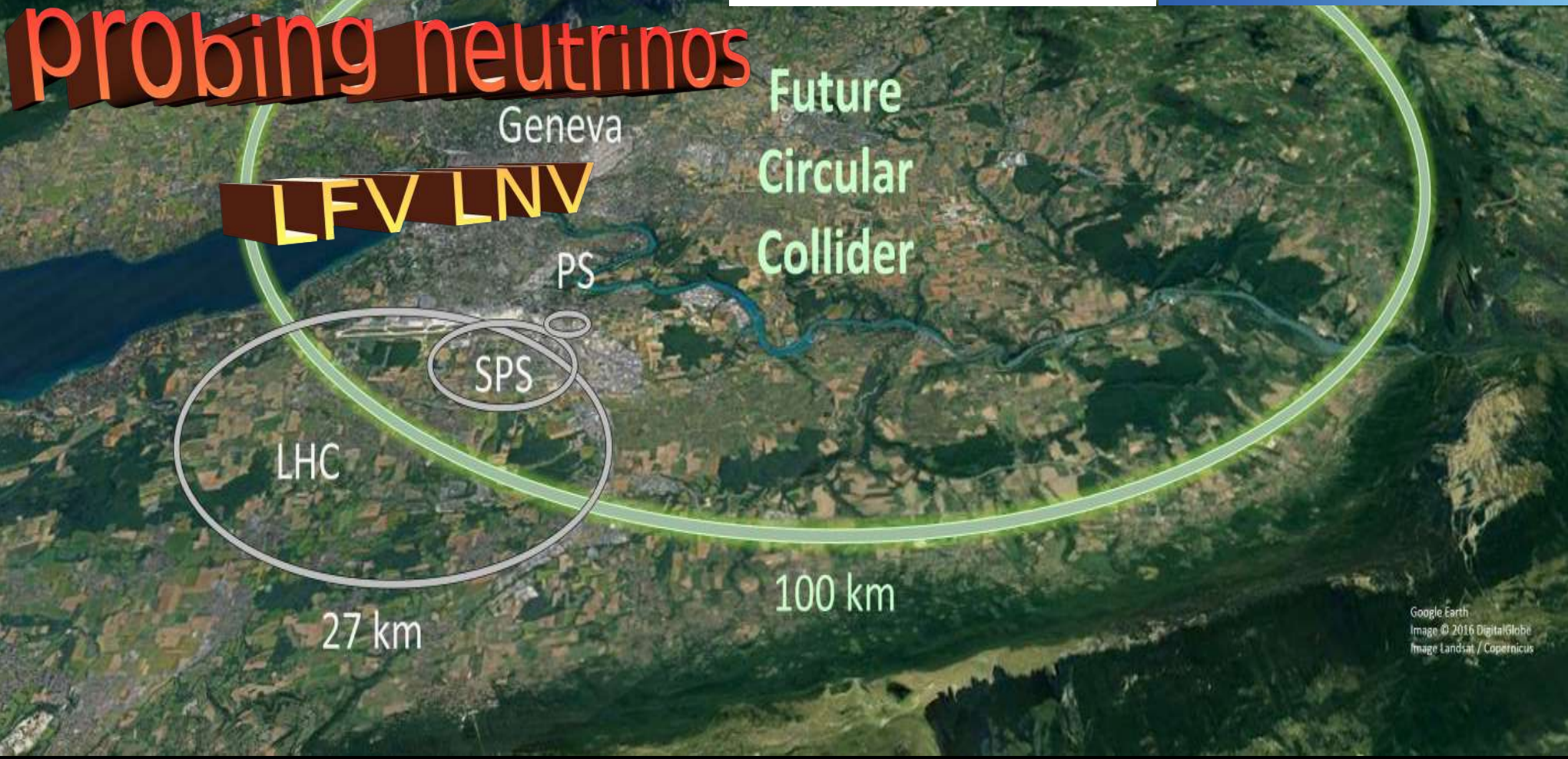
The future of European competitiveness

Part A | A competitiveness strategy for Europe

SEPTEMBER 2024

probing neutrinos

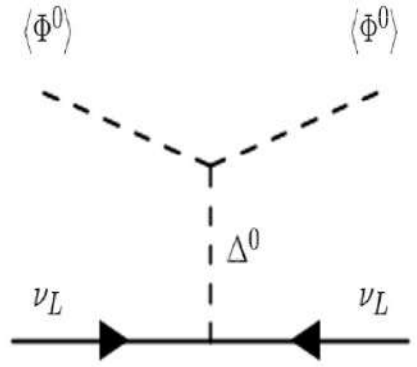
LFV LNV



low-scale type-2

triplet seesaw

Schechter & JV PRD22 (1980) 2227
PRD25 (1982) 774



Can be reconstructed from data leading to high-energy tests

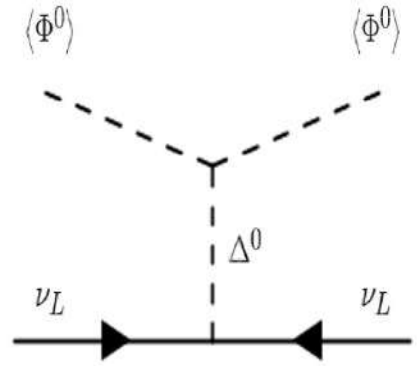
Miranda et al Phys.Rev.D105 (2022) 095020

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

Miranda et al PLB 829 (2022) 137110

low-scale type-2

triplet seesaw

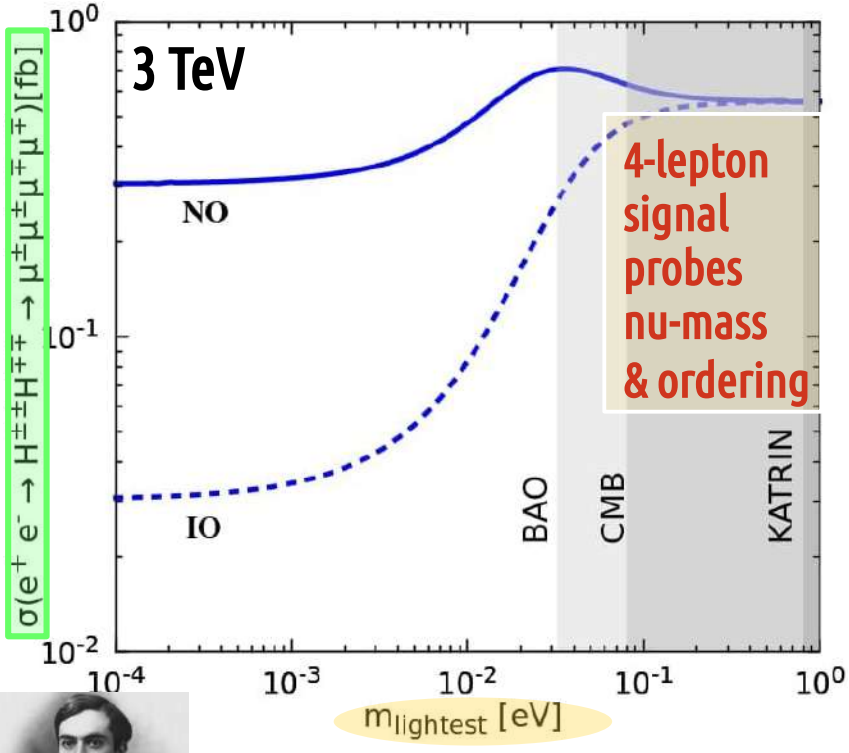


Can be reconstructed from data leading to high-energy tests

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

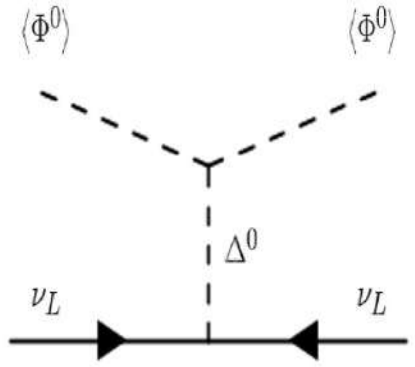
Miranda et al Phys.Rev.D105 (2022) 095020

Miranda et al PLB 829 (2022) 137110



low-scale type-2

triplet seesaw



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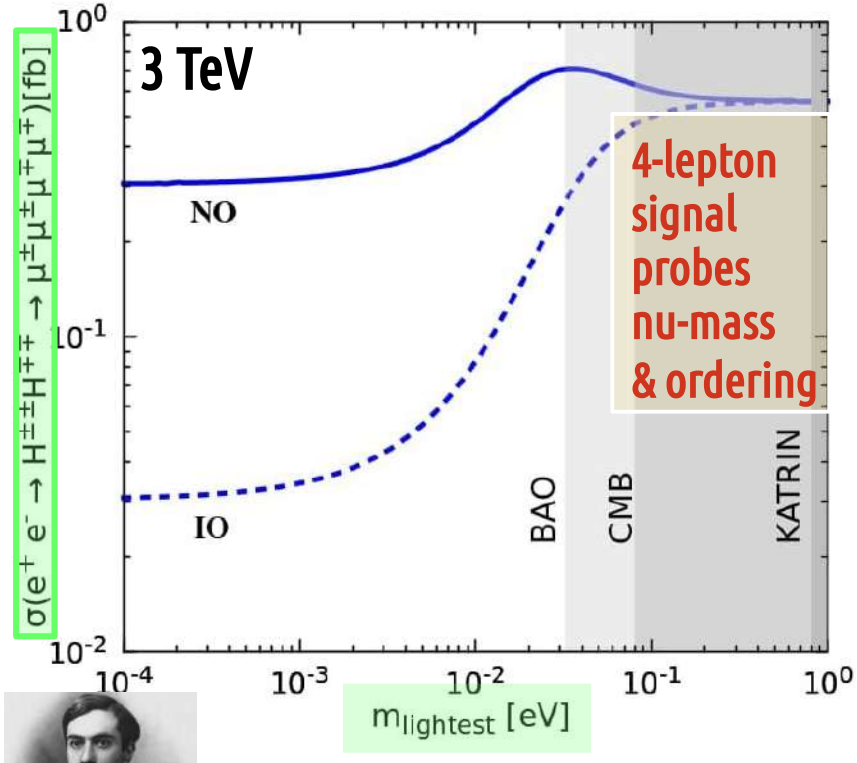
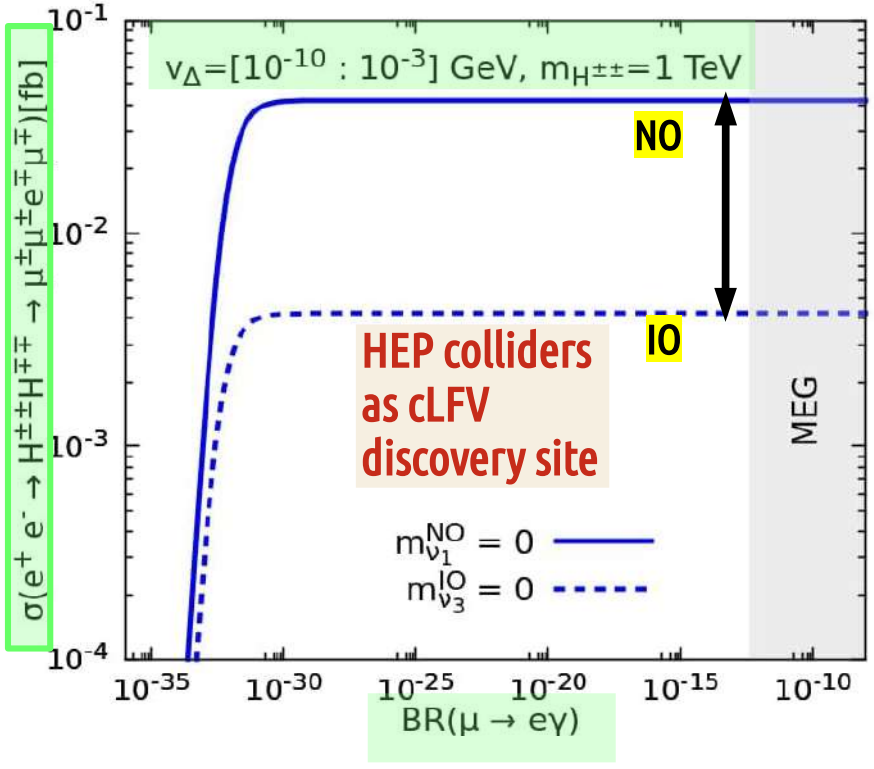
Miranda et al Phys.Rev.D105 (2022) 095020

Miranda et al PLB 829 (2022) 137110

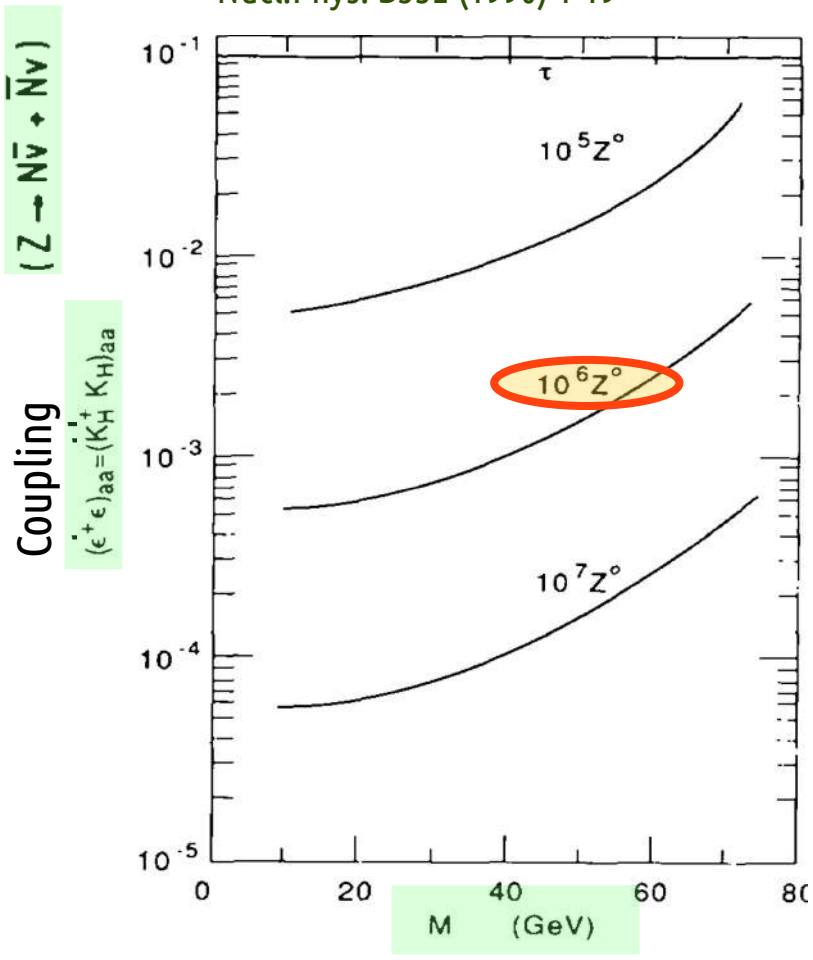




@jwvalle20

Single NHL production via SM Z portal

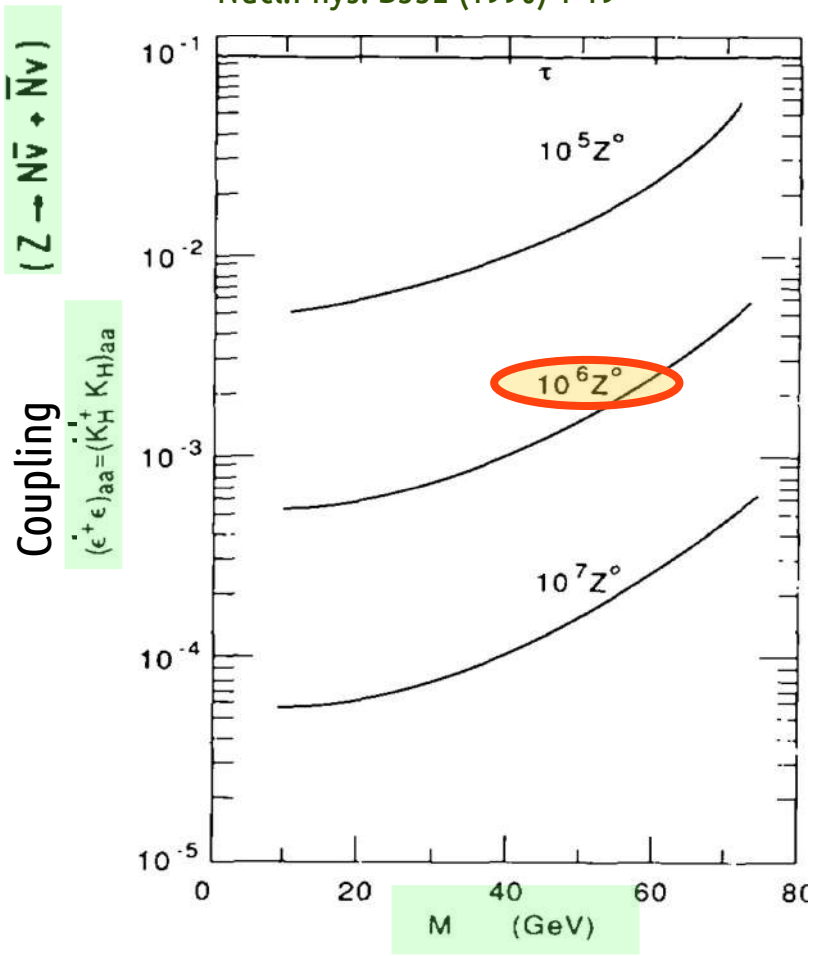
From Dittmar et al
Nucl.Phys. B332 (1990) 1-19



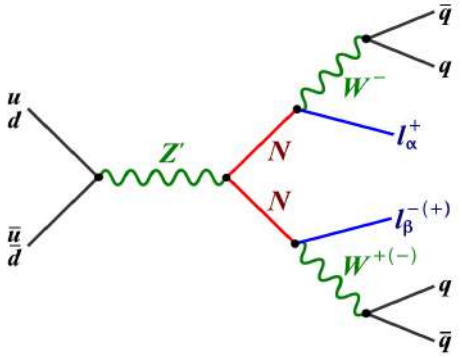
Colliders as test bed for LFV in type I seesaw

Single NHL production via SM Z portal

From Dittmar et al
Nucl.Phys. B332 (1990) 1-19



new Z' gauge portal

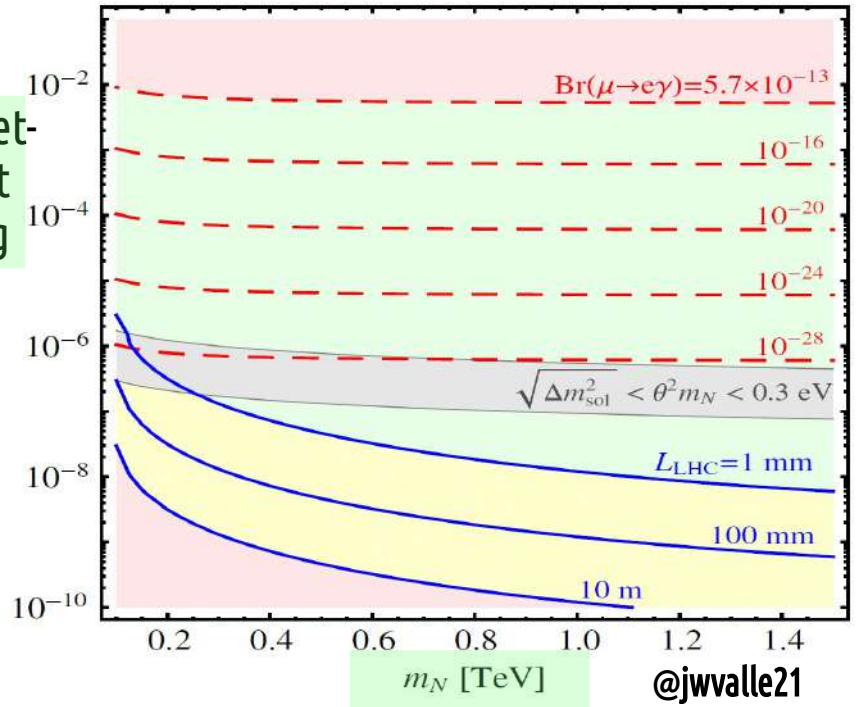


Leite, Sadhukhan, Valle
Phys.Rev.D 109 (2024) 3, 035023

cLFV at HE

From Phys.Rev. D89 (2014) 051302
L-R symmetry Phys.Rev. D86 (2012) 055006

doublet-singlet mixing



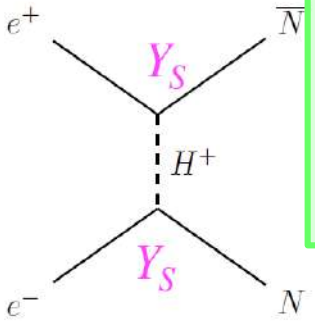
cLFV discovery first at high energies

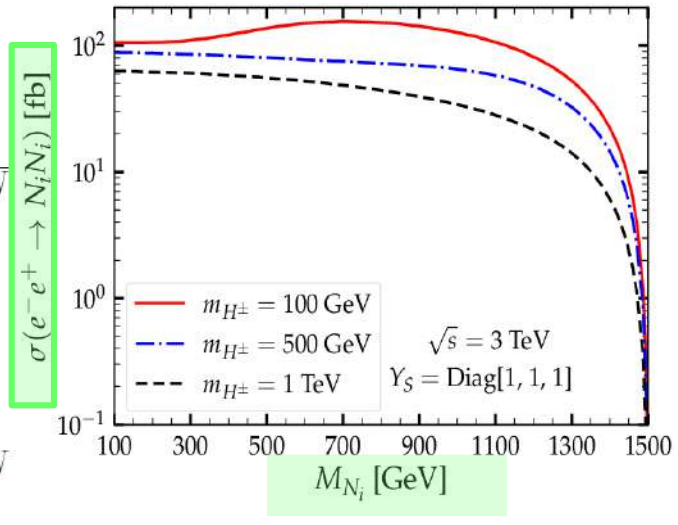
@jwvalle21

type I linear seesaw

Batra et al, Phys.Lett.B 834 (2022) 137408
JHEP 07 (2023) 221 , 2304.06080

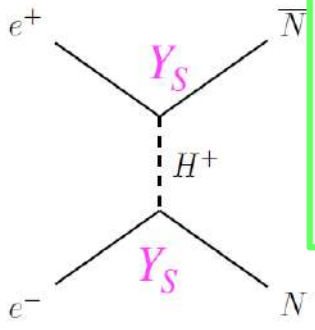
Pair production

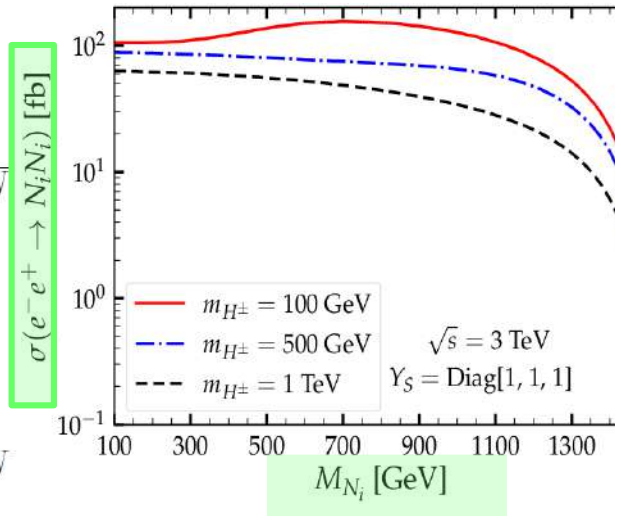


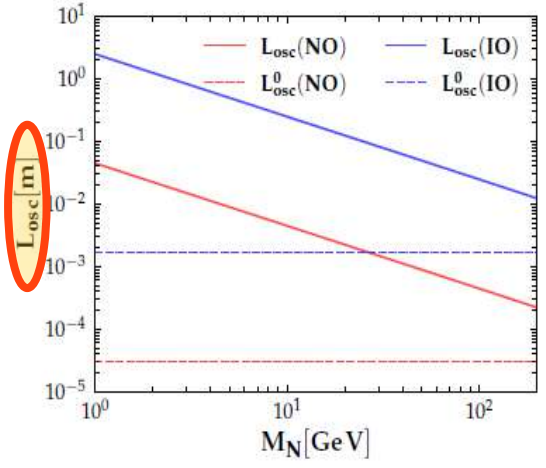


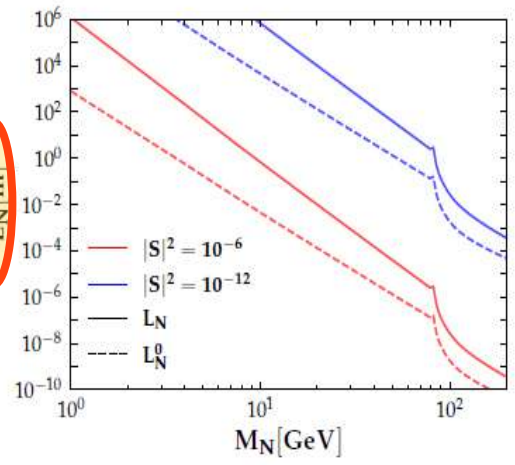
type I linear seesaw

Batra et al, Phys.Lett.B 834 (2022) 137408
JHEP 07 (2023) 221 , 2304.06080









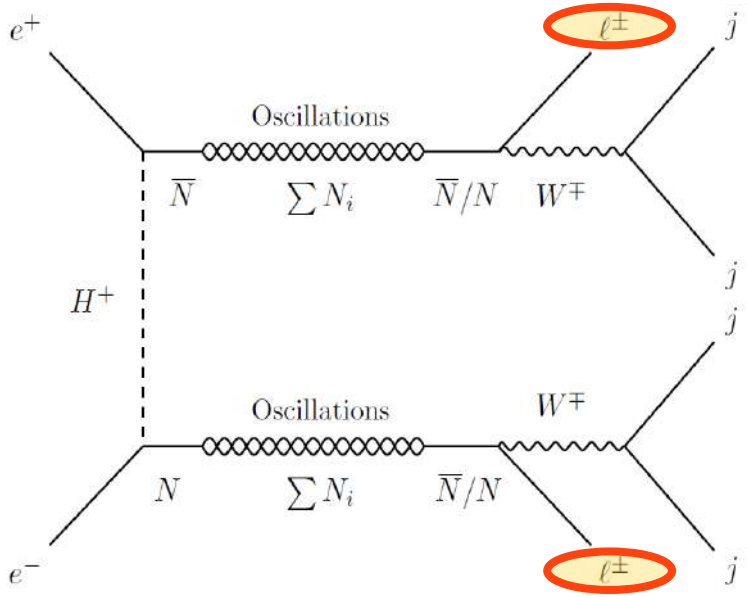
Anamiati et al, Antusch et al,

leptophilic portal

(3,1,1)

$$\Delta M^{\mathrm{IO}} = \Delta m_{21}$$

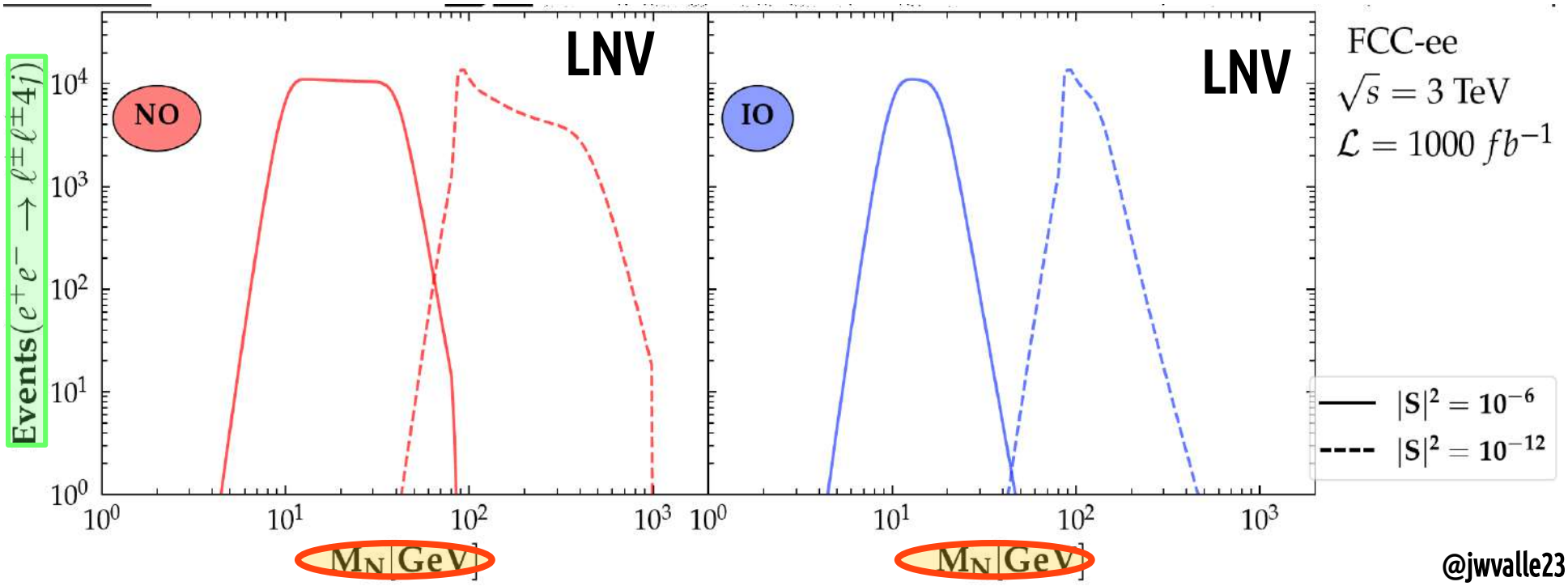
$$\Delta M^{\mathrm{NO}} = \Delta m_{32}$$



@jwvalle22

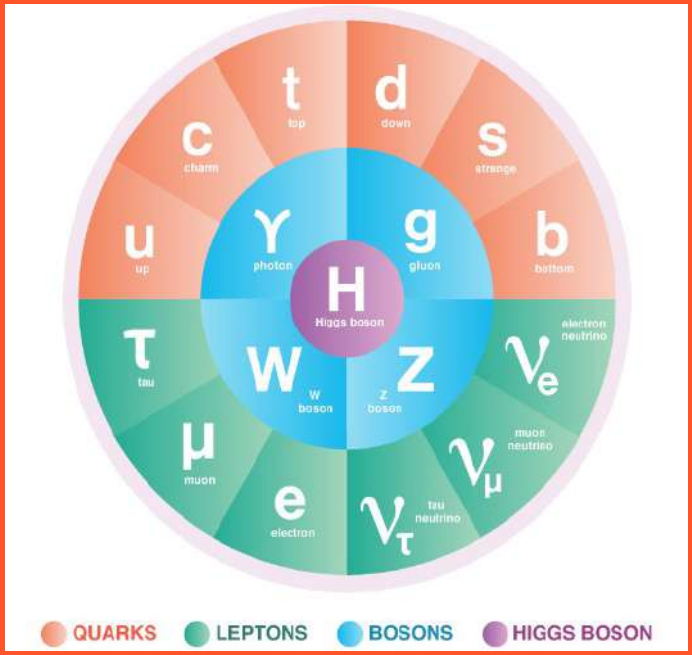
LNV first discovered at HE? eg FCC-ee

Batra et al, Phys.Lett.B 834 (2022) 137408
JHEP 07 (2023) 221 , 2304.06080



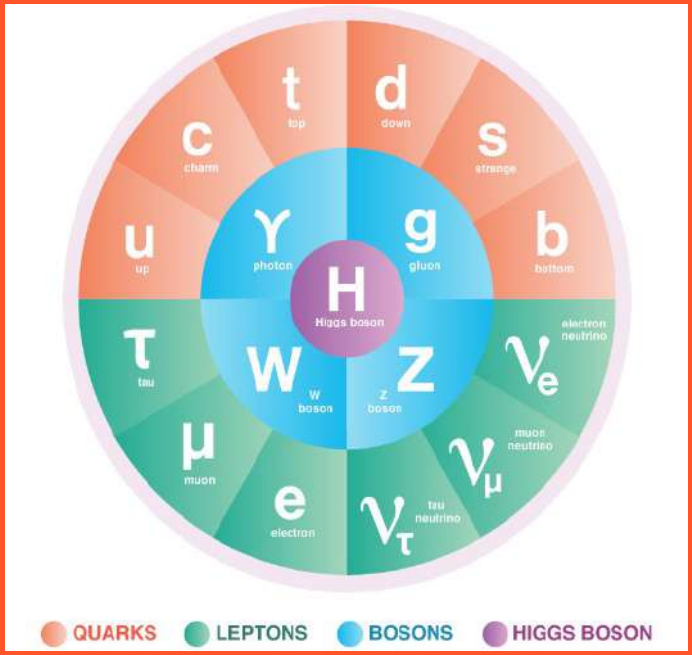
@jwvalle23

HIGGS DISCOVERY DOES NOT CLOSE THE SM



precision neutrino program,
CP, octant, ordering,
NSI,unitarity,
0nuDBD, **CEvNS** …
Fierce effort on **DM identification**

HIGGS DISCOVERY DOES NOT CLOSE THE SM



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Fierce effort on **DM identification**

neutrino mass and dark matter puzzle

- **they may be closely related, e.g.**
- **DM may source neutrino mass**

a new reason for the WIMP CDM paradigm with pheno imprints at colliders, I.e. cLFV, LNV ..

HIGGS DISCOVERY DOES NOT CLOSE THE SM

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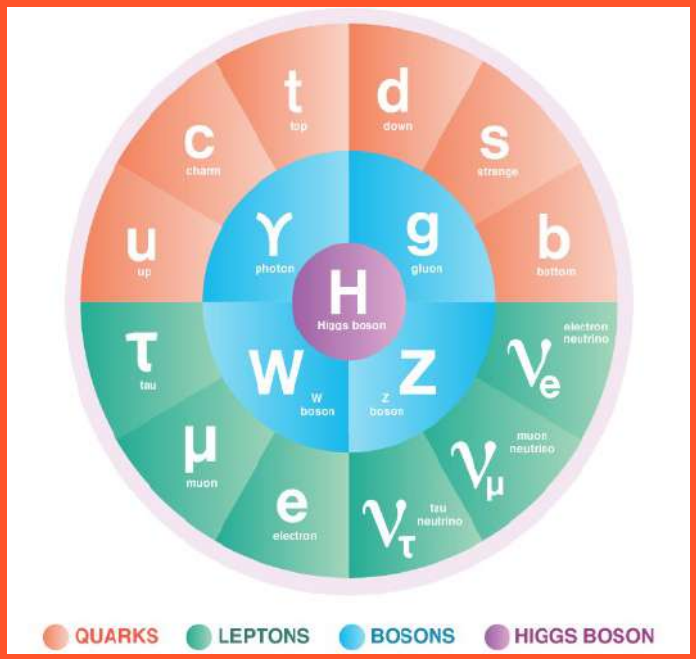

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- **they may be closely related, e.g.**
- **DM may source neutrino mass**

a new reason for the WIMP CDM paradigm with pheno cLFV imprints and colliders, LFV/LNV

@jwvalle24

HIGGS DISCOVERY DOES NOT CLOSE THE SM

precision neutrino program,
CP, octant, ordering,
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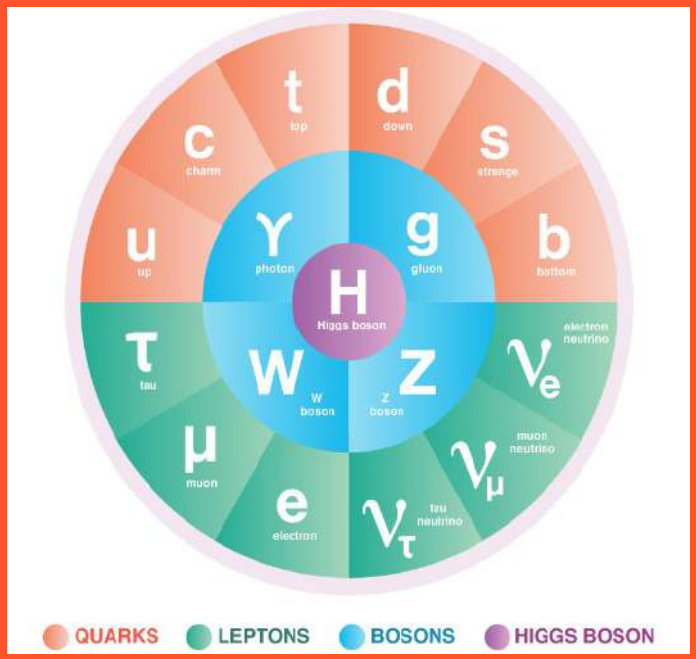
Fierce effort on **DM identification**



neutrino mass and dark matter puzzle

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a new reason for the WIMP CDM paradigm with pheno cLFV imprints and colliders, LFV/LNV

neutrinos and **flavor**
neutrinos and **unification**
neutrinos and strong CP problem
neutrinos and SM anomalies

@jwvalle24