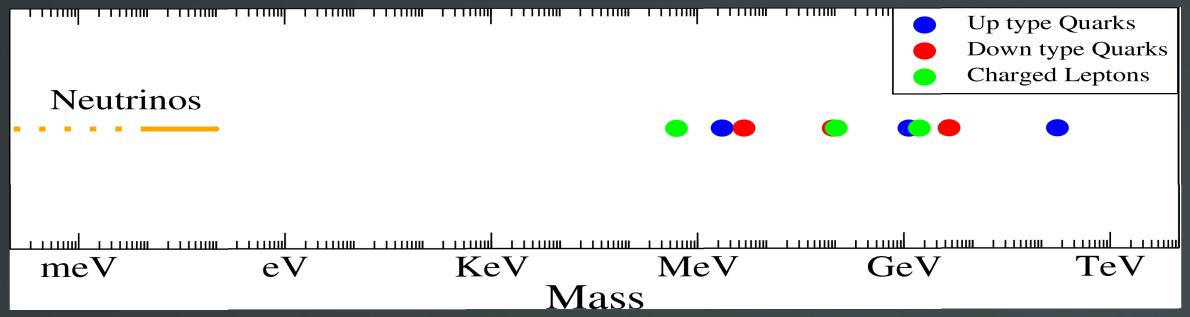
Radiative Neutrino Masses Linked to $0\nu\beta\beta$ Decay

Jose Miguel No (Sussex U.)

FLASY14, Sussex, June 18th 2014

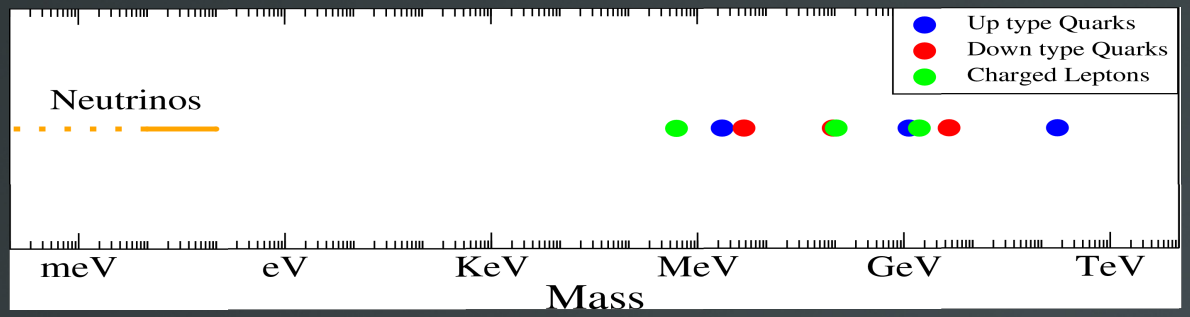
(Naturally small) Neutrino Masses



$m_\nu < 0.1\,\text{eV}$ ***Why So Small?***

Suggests Alternative Mechanism for Neutrino Mass Generation

(Naturally small) Neutrino Masses



Suggests Alternative Mechanism for Neutrino Mass Generation

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⇨ See-Saw Mechanism

⇨ Radiative Neutrino Masses

Loop suppression

Symmetry (e.g. Z_2) Connection to DM

Ma, Aoki, Kanemura, Morisi, Valle, Nasri, Peinado, Lineros, Okada, Kajiyama, Lindner, Suematsu, Watanabe, Seto, Pilafsis, Gustafsson, No, Kubo, Hirsch, McDonald, Farzan, Schmidt, Sugiyama...

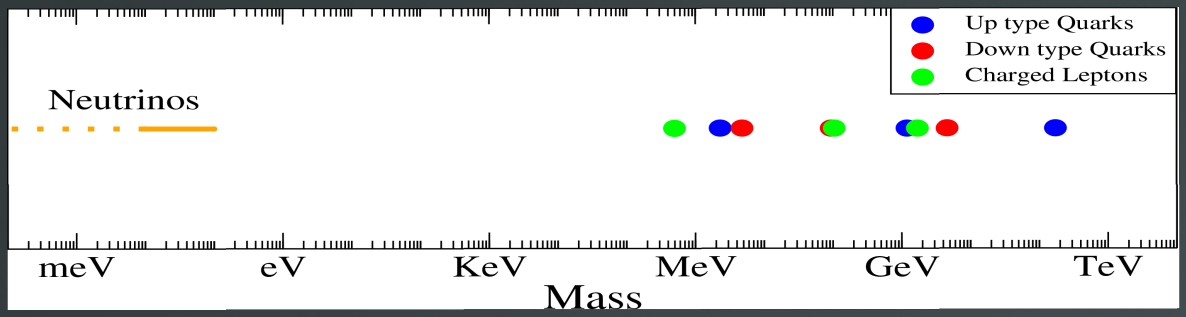
(⊃ ***Radiative See-Saw***)

***New* EW *States* (+ Lepton Number Violation)**

*A. Zee, Phys. Lett. B **93** (1980) 389*
*K. S. Babu, Phys. Lett. B **203** (1988) 132*
...

Connection to EW Physics

(Naturally small) Neutrino Masses



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...

Connection to EW Physics

Rich Phenomenology:

➔ ***Possible Collider Signatures at* LHC & ILC** (Potential LNV!)

➔ ***Potentially large Lepton Flavour Violation signals***

➔ ***Potentially large $0\nu\beta\beta$ decay signals***

Radiative ν-Masses & 0νββ (& Neutrino Mixing)

(A Systematic Approach to Structure)

A Systematic Approach to 0νββ?

⇨ Classify LNV Non-Renormalizable SM Operators ($\Delta L = 2$)

*K. S. Babu, C. N. Leung, Nucl. Phys. B **619** (2001) 667*
*A. de Gouvea, J. Jenkins, Phys. Rev. D **77** (2008) 013008*
*F. Bonnet, M. Hirsch, T. Ota, W. Winter, JHEP **1303** (2013) 055*
*P. W. Angel, N. L. Rodd, R. R. Volkas, Phys. Rev. D **87** (2013) 7, 073007*

$N_{operators} > 20$ $(D \leq 9)$ $\quad$ $N_{operators} > 75$ $(D \leq 11)$

Radiative ν-Masses & 0νββ (& Neutrino Mixing)

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Assume:

⇨ LNV New (BSM) Physics Only Couples Directly to Leptons (not to quarks)

⇨ No New Gauge Symmetries (below a few TeV)

Construct Lowest Order LNV SM Operator (O_{SM}) → Lepton Chirality

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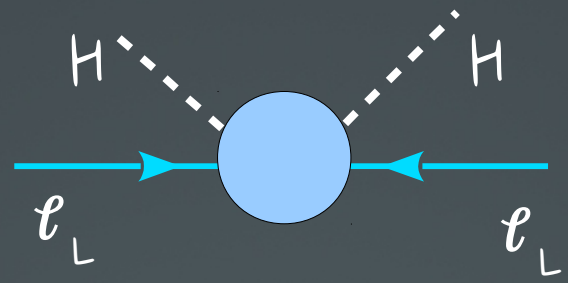
❶ If O_{SM} Involves 2 ℓ_L: D = 5 Weinberg Operator



➔ No Structure in Neutrino Mass Matrix m^{ν}_{ab}

➔ 0νββ Dominated by Light Neutrino Exchange

*J. Lopez-Pavon, S. Pascoli, C. Wong, Phys. Rev. D **87** (2013) 9, 093007*

Radiative ν-Masses & 0νββ (& Neutrino Mixing)

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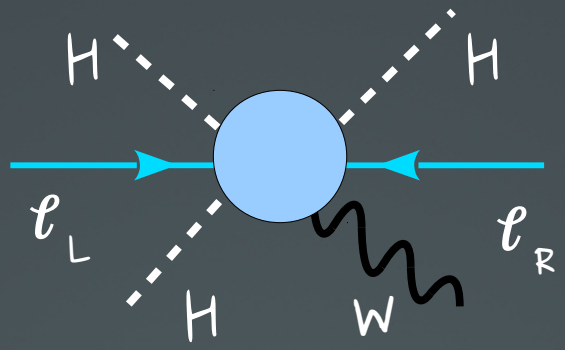
Construct Lowest Order LNV SM Operator (O_{SM}) → Lepton Chirality

❷ If O_{SM} Involves 1 ℓ_R and 1 ℓ_L : $D = 7$

*F. del Aguila, A. Aparici, S. Bhattacharya, A. Santamaria, J. Wudka, JHEP **1206** (2012) 146*



$$(H^\dagger D_\mu \tilde{H})(H^\dagger \bar{\ell}_R \gamma_\mu \tilde{\ell}_L)$$

Radiative ν-Masses & 0νββ (& Neutrino Mixing)

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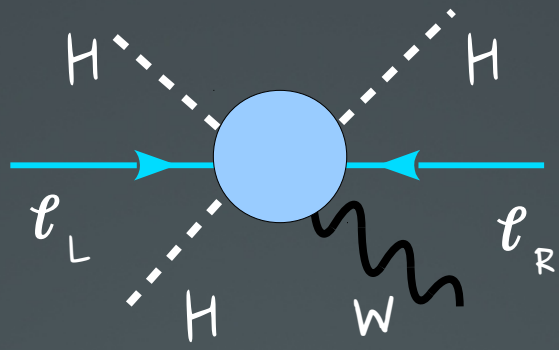
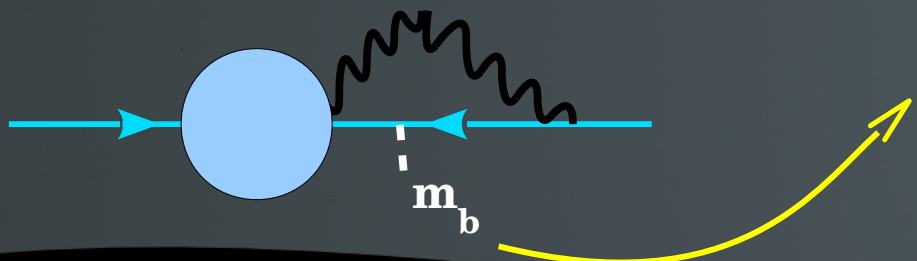


➔ Structure in Neutrino Mass Matrix m^{ν}_{ab} → $(m^{\nu}_{ee} \simeq 0)$



$$m^{\nu}_{ab} \sim \frac{v\, C_{ab}\, (m_a + m_b)}{(16\pi^2)\,\Lambda}$$

Radiative ν-Masses & 0νββ (& Neutrino Mixing)

(A Systematic Approach to Structure)

Assume:

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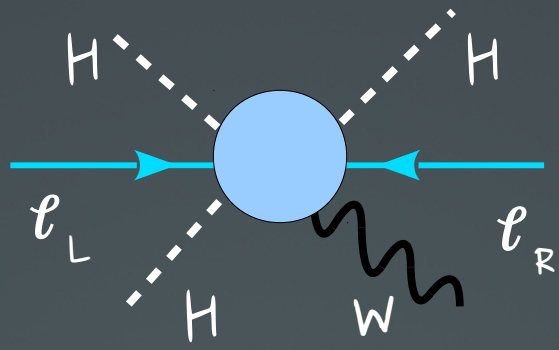
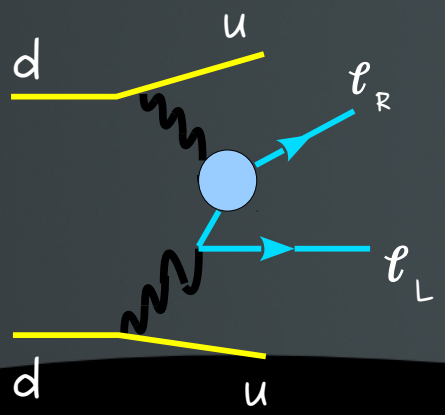


➔ Short-Distance Contribution from O_{SM} Important for 0νββ



➔ ***Light Neutrino Exchange Contribution Supressed*** ($m^{\nu}_{ee} \simeq 0$)

... but SD contribution has $16\pi^2\ v/m_e$ "enhancement"

➔ ***Electrons of Opposite Chirality***

Radiative ν-Masses & 0νββ (& Neutrino Mixing)

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Assume:

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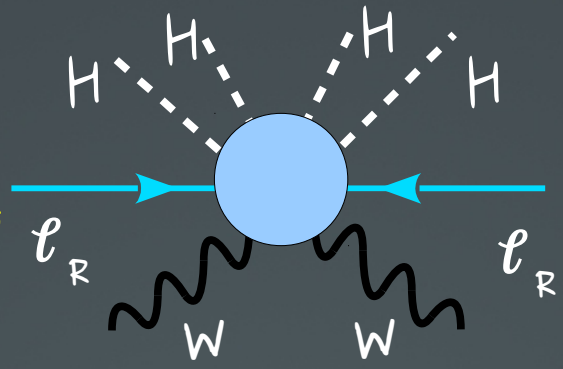
Construct Lowest Order LNV SM Operator (O_{SM}) → Lepton Chirality

❸ If O_{SM} Involves 2 ℓ_R: $D = 9$

*F. del Aguila, A. Aparici, S. Bhattacharya, A. Santamaria, J. Wudka, JHEP **1206** (2012) 146*
M. Gustafsson, J.M.N, M. Rivera, arXiv:1402.0515



$$\bar{\ell}_R \ell^c_R (H^\dagger D_\mu \tilde{H})^2$$

Radiative ν-Masses & 0νββ (& Neutrino Mixing)

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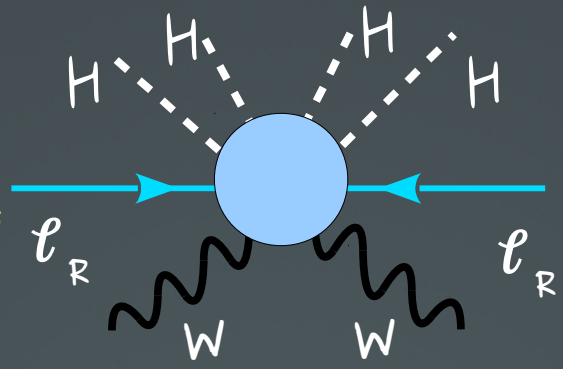
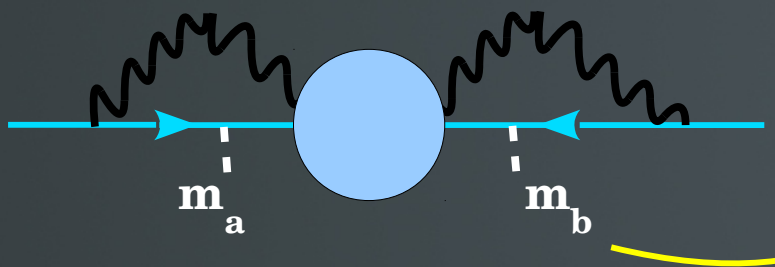


➔ Structure in Neutrino Mass Matrix m^ν_{ab} → $(m^\nu_{ee} \simeq 0,\ m^\nu_{e\mu} \simeq 0?)$



$$m^\nu_{ab} \sim \frac{C_{ab}\, m_a\, m_b}{(16\pi^2)^2\, \Lambda}$$

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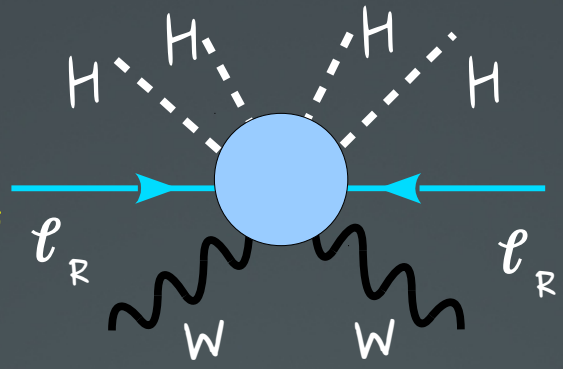
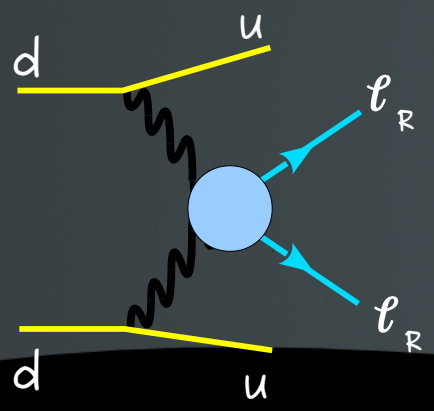


➔ Short-Distance Contribution from O_{SM} Crucial for 0νββ



➔ ***Light Neutrino Exchange Contribution Negligible*** ($m^{\nu}_{ee} \simeq 0$)

... but SD contribution has $(16\pi^2)^2\ v^2/m_e^2$ "enhancement"

❶ O_7 & O_9 ***give Tree-Level*** $0\nu\beta\beta$ vs ***Loop-Level*** m^ν

F. del Aguila, A. Aparici, S. Bhattacharya, A. Santamaria, J. Wudka, JHEP ***1206*** *(2012) 146*
M. Gustafsson, J.M.N, M. Rivera, arXiv:1402.0515

(Known to be possible for Effective Operators involving Quarks)

K. S. Babu, R. N. Mohapatra, Phys. Rev. Lett. ***75*** *(1995) 2276*
K. S. Babu, C. N. Leung, Nucl. Phys. B ***619*** *(2001) 667*

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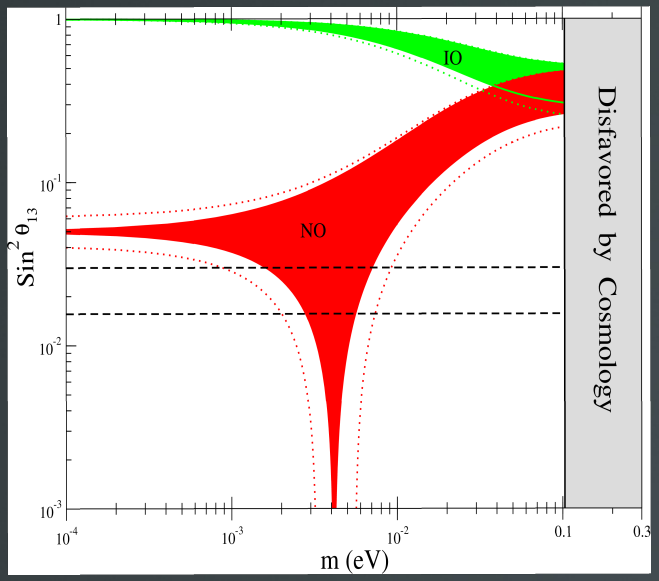
M. Gustafsson, J.M.N, M. Rivera, arXiv:1402.0515

❷ O_7 & O_9 give structure to m^ν $\rightarrow$ $m^\nu_{ee} \simeq 0$

(A Word on Neutrino Mixing...)



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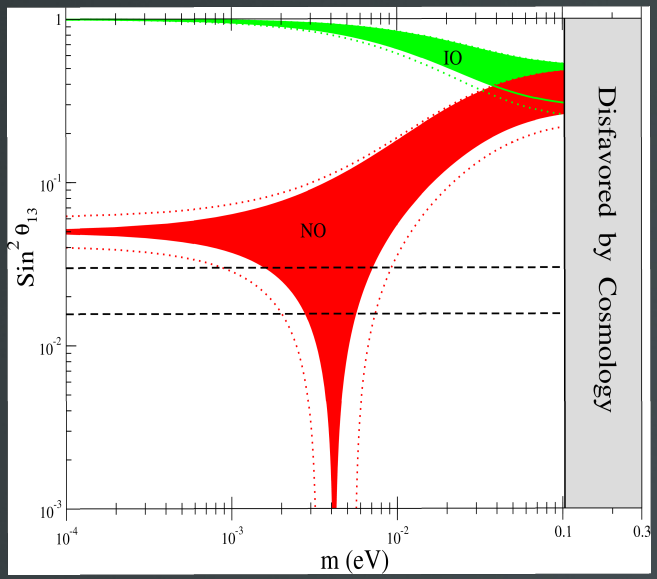
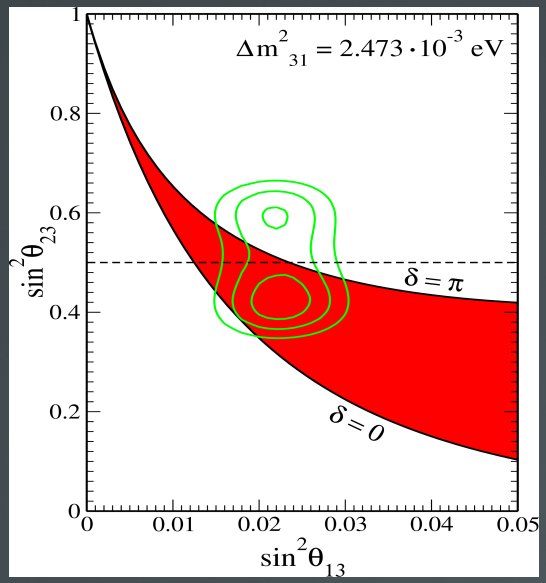
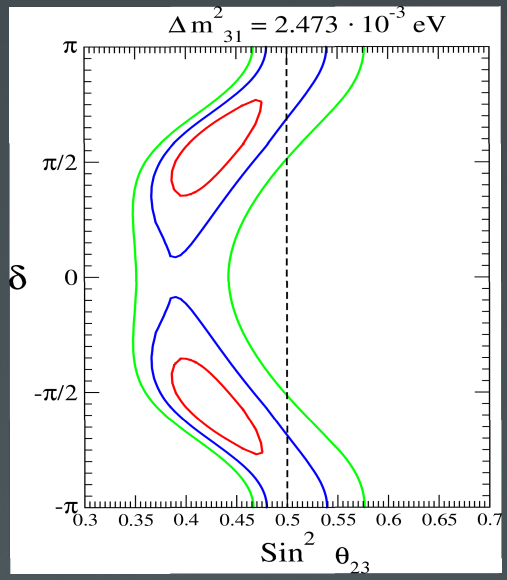






Compatible with Current Oscillation Data

Predictive (NO, θ_{23} Octant, δ_{CP})

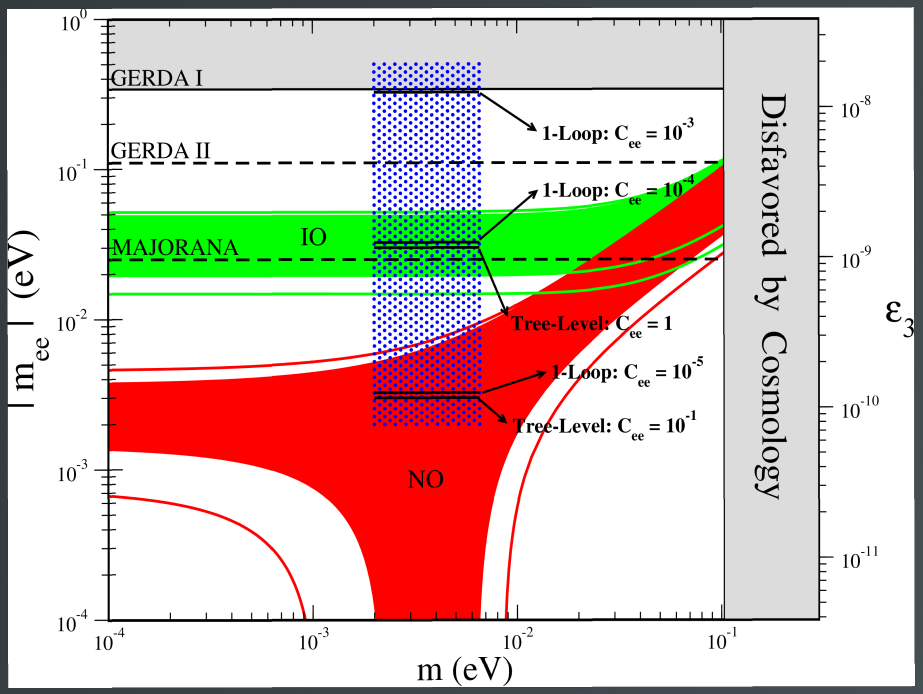
❶ O_7 & O_9 give Tree-Level 0νββ vs Loop-Level m^ν

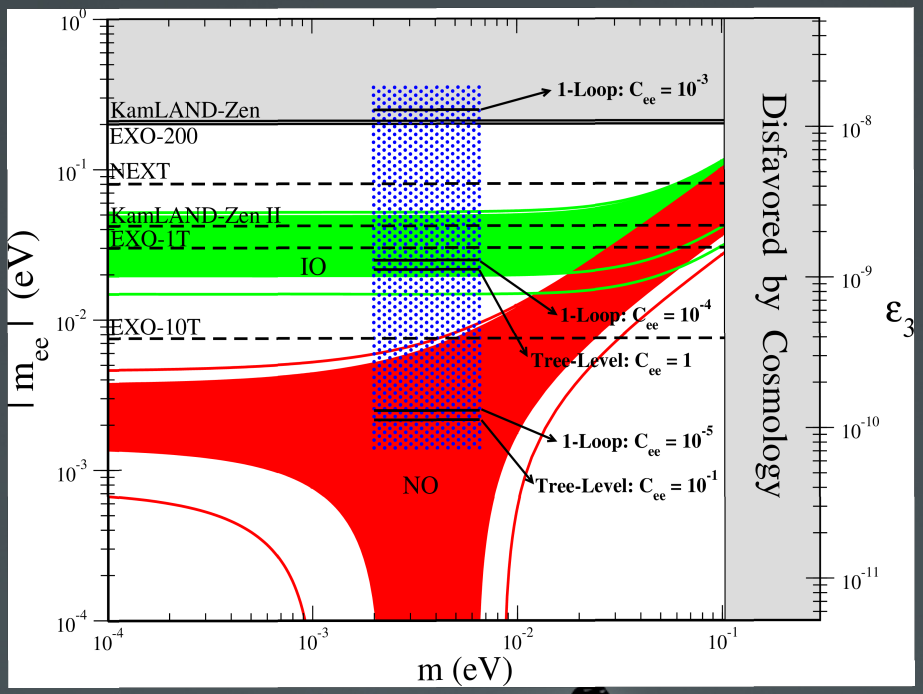
F. del Aguila, A. Aparici, S. Bhattacharya, A. Santamaria, J. Wudka, JHEP **1206** (2012) 146

M. Gustafsson, J.M.N, M. Rivera, arXiv:1402.0515

Short-Distance

$$\mathcal{L}_{0\nu\beta\beta} = \frac{G_F^2}{2\,m_p}\,\epsilon_3\,J^\mu\,J_\mu\,\bar{e}(1-\gamma_5)e^c$$





❶ O_7 & O_9 *give Tree-Level* $0\nu\beta\beta$ vs *Loop-Level* m^ν

F. del Aguila, A. Aparici, S. Bhattacharya, A. Santamaria, J. Wudka, JHEP ***1206*** *(2012) 146*

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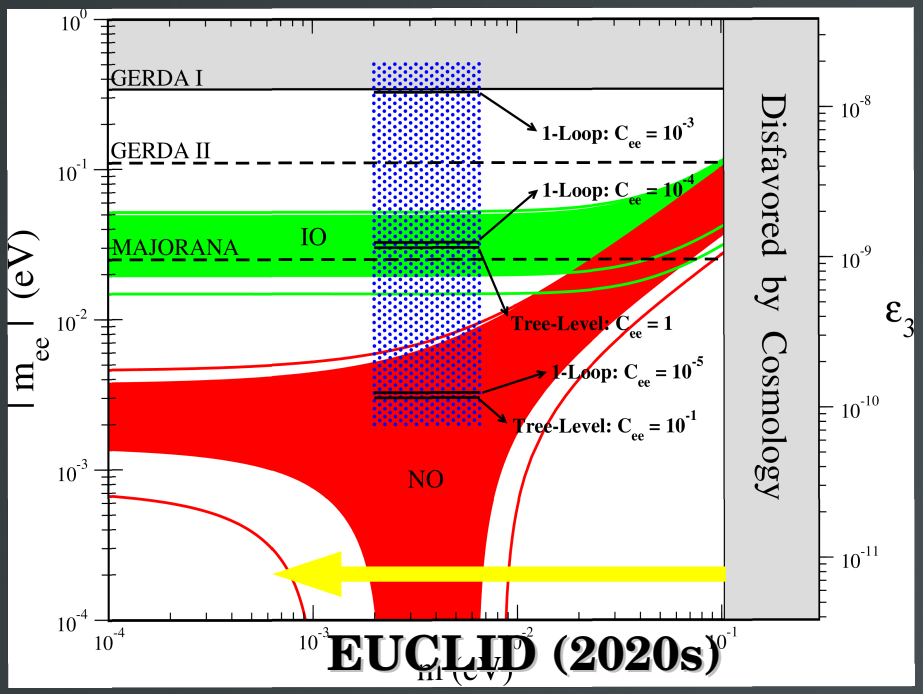
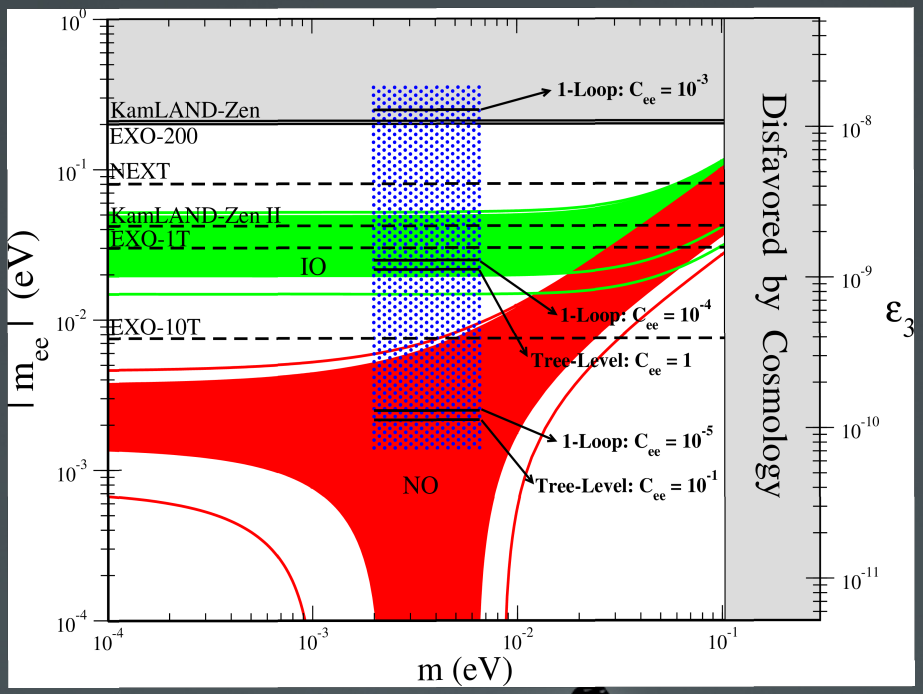


EUCLID (2020s)



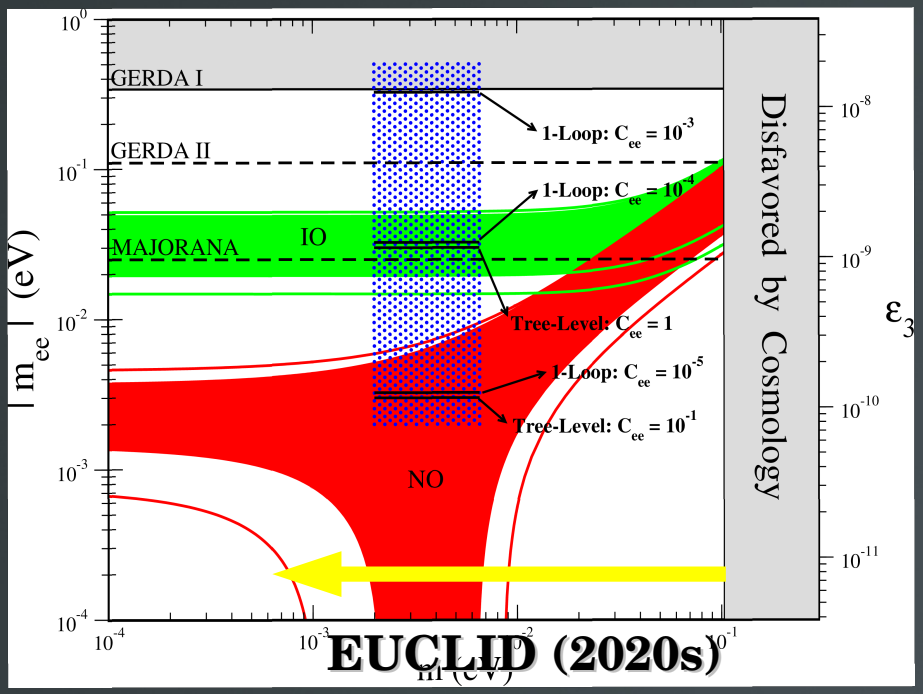
Positive Signal in $0\nu\beta\beta$ combined with NO (hierarchical) as a way to test O_7/O_9

❶ O_7 & O_9 *give Tree-Level* $0\nu\beta\beta$ vs *Loop-Level* m^ν

F. del Aguila, A. Aparici, S. Bhattacharya, A. Santamaria, J. Wudka, JHEP ***1206*** *(2012) 146*

M. Gustafsson, J.M.N, M. Rivera, arXiv:1402.0515

Short-Distance → $\mathcal{L}_{0\nu\beta\beta} = \dfrac{G_F^2}{2\,m_p}\,\epsilon_3\,J^\mu\,J_\mu\,\bar{e}(1-\gamma_5)e^c$



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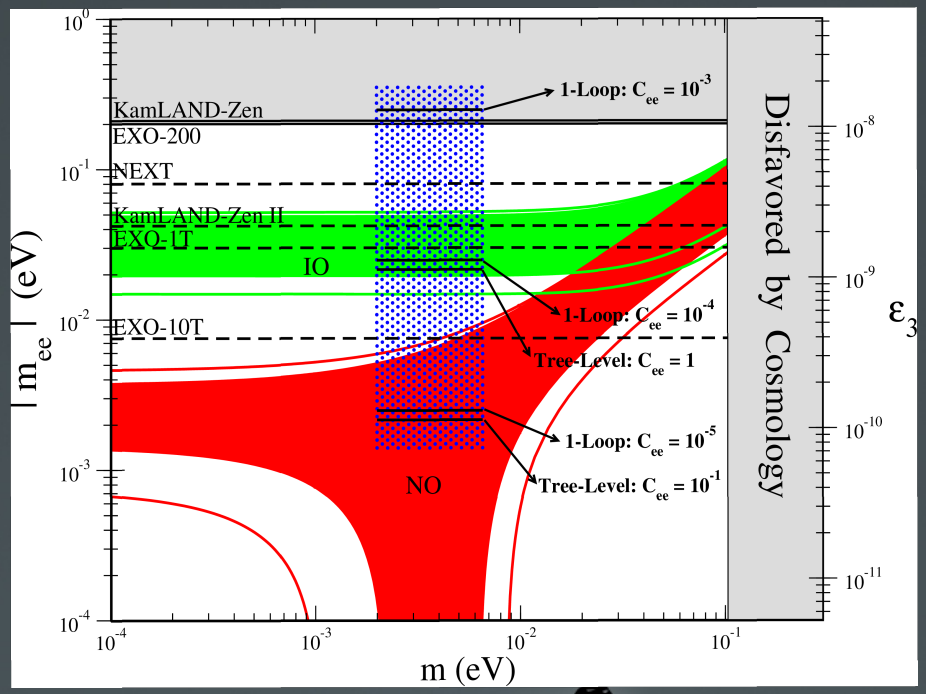


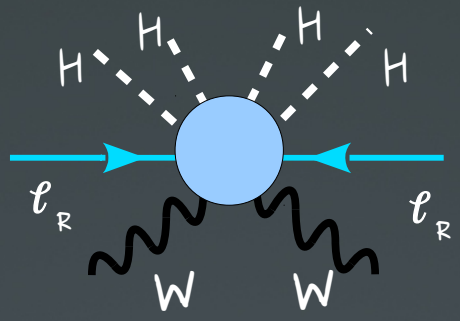
Positive Signal in $0\nu\beta\beta$ combined with NO (hierarchical) as a way to test O_7/O_9

Angular Distribution in SuperNEMO? ← ***Electrons of Opposite Chirality***

A Word for the Model Builder...

A Word for the Model Builder…

Renormalizable Completions of O_9



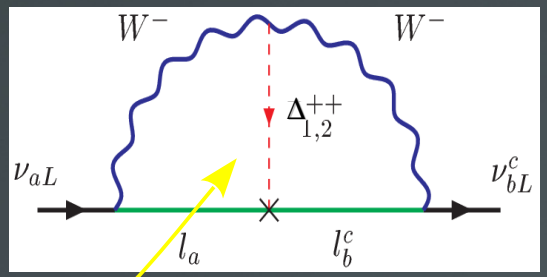
***Tree-Level* (2-Loop Neutrino Masses)**

*C. S. Chen, C. Q. Geng, J. N. Ng, Phys. Rev. D **75** (2007) 053004*

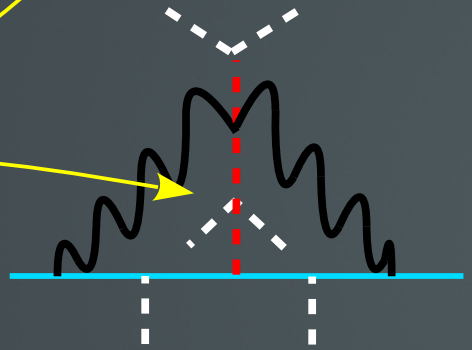
*F. del Aguila, A. Aparici, S. Bhattacharya, A. Santamaria, J. Wudka, JHEP **1205** (2012) 133*

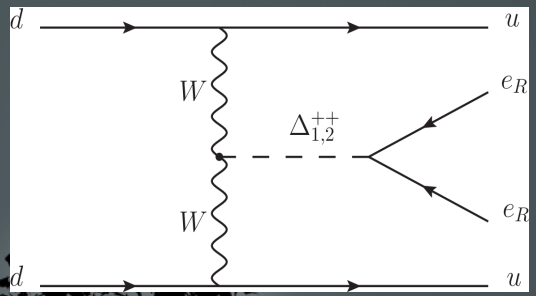
$C_{ab}\,\bar{\ell}_{Ra}\,\ell^{c}_{Rb}\,\rho^{--}$

(+ Complex SU(2) Triplet Δ)



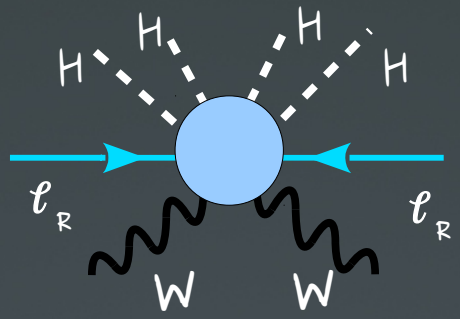
ρ^{++} and Δ^{++} Mix





A Word for the Model Builder...

Renormalizable Completions of O_9



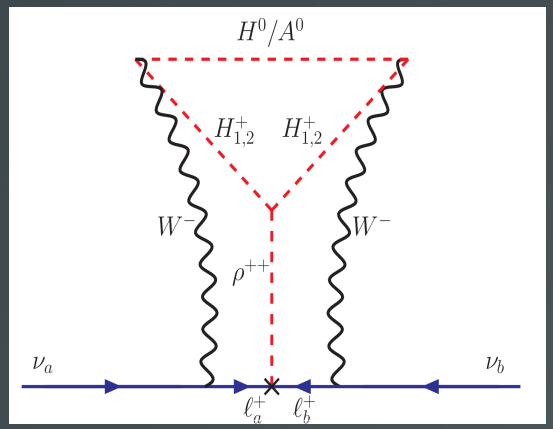
1-Loop *(3-Loop Neutrino Masses)*

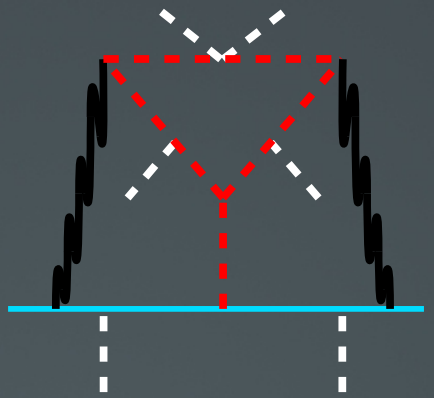
M. Gustafsson, J. M. N., M. Rivera, Phys. Rev. Lett ***110*** *(2013) 211802*

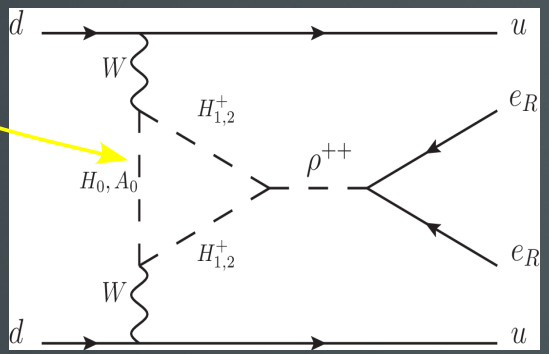
The "Cocktail" Model

$$C_{ab}\,\bar{\ell}_{Ra}\,\ell^{c}_{Rb}\,\rho^{--}$$

(+ DM Running in the Loop)







Conclusions

$0\nu\beta\beta$ Decay → ***Standard Mechanism*** **(Light-neutrino Exchange)**

$0\nu\beta\beta$ Decay → ***New Particles*** **(Short-Distance Physics)**

Effective Operators

If LNV New Physics Couples Only to Leptons (not Quarks), few Operators (e.g. O_7 & O_9)

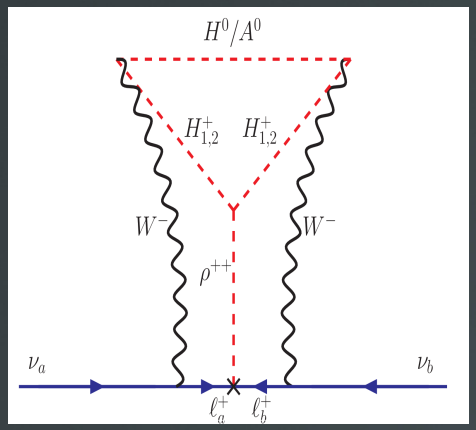
There exist attractive ways to connect Radiative Neutrino Mass Generation to $0\nu\beta\beta$ Decay Probes of the Majorana Nature of Neutrinos

Ultimate Answer: $0\nu\beta\beta$ + LHC + Cosmology

Thanks!

The "Cocktail" Model

Inert Doublet Model "&" inspired by Zee/Babu



$$\Phi_1 = \begin{pmatrix} G^+ \\ \frac{h+i\,G_0}{\sqrt{2}} \end{pmatrix} + \begin{pmatrix} 0 \\ v \end{pmatrix} \qquad \Phi_2 = \begin{pmatrix} \Lambda^+ \\ \frac{H_0+i\,A_0}{\sqrt{2}} \end{pmatrix} \qquad S^+ \qquad \rho^{++}$$

$$-\Delta\mathcal{L} = C_{ab}\,\overline{l^c_{R_a}}\,l_{R_b}\,\rho^{++} + V(|\Phi_1|^2, |\Phi_2|^2, |S|^2, |\rho|^2) + \lambda_4 \left|\Phi_1^\dagger \Phi_2\right|^2 + \frac{\lambda_5}{2}\left(\Phi_1^\dagger \Phi_2\right)^2$$

$$+\kappa_1\,\Phi_1^T i\sigma_2 \Phi_2\,S^- + \lambda_{\rho S}\,\Phi_1^T i\sigma_2 \Phi_2\,S^+\rho^{--} + \kappa_2\,S^- S^-\rho^{++} + \text{h.c.}$$

Lepton Number Breaking

Need $C_{ab} \neq 0$, $\lambda_5 \neq 0$, $(\kappa_1 \neq 0)$ Need $\lambda_{\rho S}$ or $\kappa_2 \neq 0$