LNV versus neutrino masses

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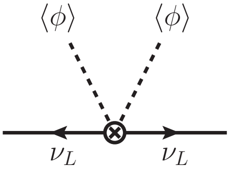
Neutrinos: The quest for a new physics scale
CERN, 27-31 March 2017

$0\nu\beta\beta$ and Majorana m_ν

Majorana $m_\nu \Longrightarrow 0\nu\beta\beta$



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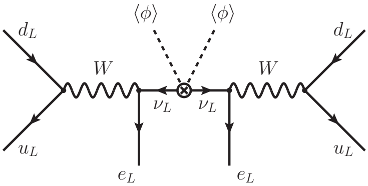

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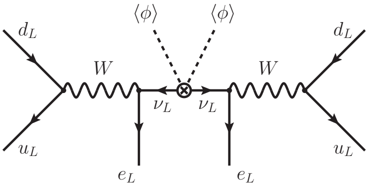

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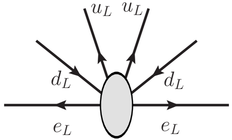

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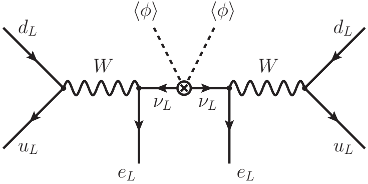

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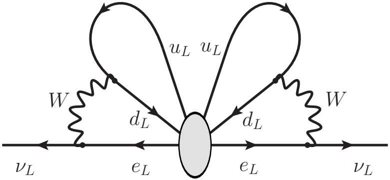

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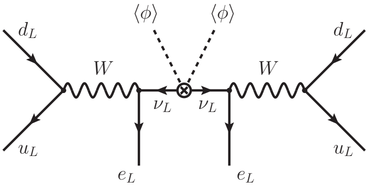

How tight is this connection?

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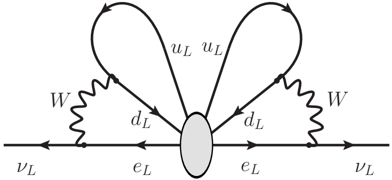

What if $(M_\nu)_{ee} < 10^{-3}$ eV?

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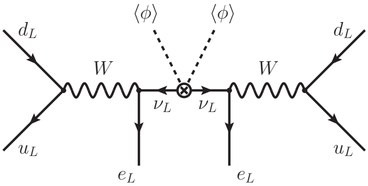

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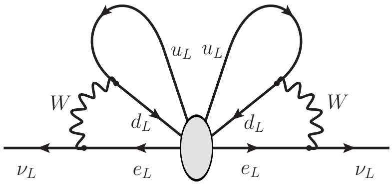


What if $(M_\nu)_{ee} < 10^{-3}$ eV?

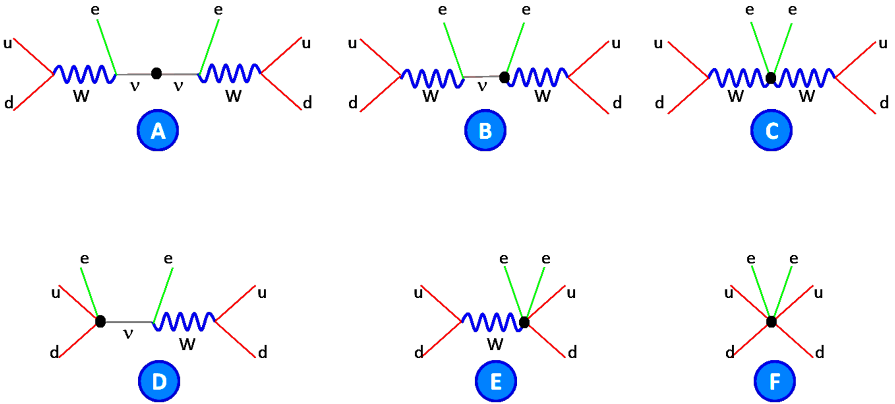
Chiral lepton number

$$\text{Majorana}\,\nu: \quad \nu_L\nu_L\,, \qquad 0\nu\beta\beta: \begin{cases} e_L e_L \\ e_L e_R \\ e_R e_R \end{cases}$$

Break **different quantum numbers**, only linked by m_e

Vertices contributing to $0\nu\beta\beta$

Classification of possible $0\nu\beta\beta$ contributions



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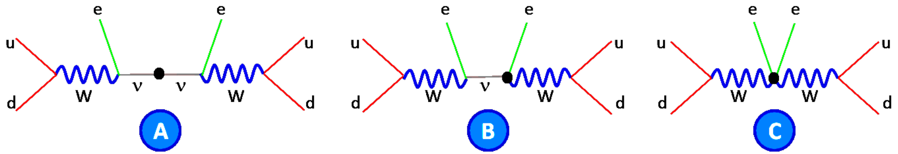
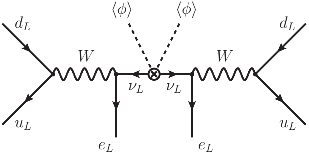


Operators with quarks and/or no derivatives widely considered:

K. Babu & C.N. Leung; K. Choi, K.S. Jeong & W.Y. Song;
J. Engel & P. Vogel; A. de Gouvea & J. Jenkins;
F. Bonnet, M. Hirsch, T. Ota, W. Winter;
J. C. Helo, M. Hirsch, T. Ota, F. A. Pereira dos Santos
P.W. Angel, N.L. Rodd, R.R. Volkas

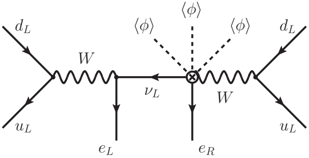
Contributions to $0\nu\beta\beta$

(del Aguila, Aparici, Bhattacharya, AS, Wudka ’12)



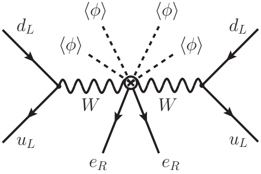
$$\mathcal{O}^{(5)} = \left(\overline{\tilde{L}_L}\Phi\right)\left(\tilde{\Phi}^\dagger L_L\right)$$

$$\mathcal{A}^{(5)}_{0\nu2\beta} \sim \frac{C^{(5)}_{ee}}{\Lambda p^2_{\mathrm{eff}} v^2}$$



$$\mathcal{O}^{(7)} = \left(\Phi^\dagger D_\mu \tilde{\Phi}\right)\left(\Phi^\dagger \overline{e_{\mathrm{R}}}\gamma^\mu \tilde{L}_L\right)$$

$$\mathcal{A}^{(7)}_{0\nu2\beta} \sim \frac{C^{(7)}_{ee}}{\Lambda^3 p_{\mathrm{eff}} v}$$

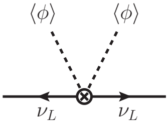


$$\mathcal{O}^{(9)} = \overline{e_{\mathrm{R}}} e^c_{\mathrm{R}} \left(\Phi^\dagger D_\mu \tilde{\Phi}\right)\left(\Phi^\dagger D^\mu \tilde{\Phi}\right)$$

$$\mathcal{A}^{(9)}_{0\nu2\beta} \sim \frac{C^{(9)}_{ee}}{\Lambda^5}$$

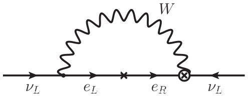
Contributions to ν Masses

$\mathcal{O}^{(5)}$



$$(M_\nu)_{ab} \sim \frac{v^2}{\Lambda} C^{(5)}_{ab}$$

$\mathcal{O}^{(7)}$



$$\frac{v}{16\pi^2\Lambda}\left(m_a C^{(7)}_{ab} + m_b C^{(7)}_{ba}\right)$$

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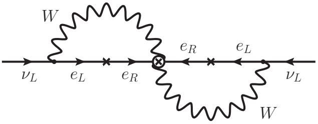

$$\frac{1}{(16\pi^2)^2\Lambda} m_a C^{(9)}_{ab} m_b$$

Contributions to ν Masses

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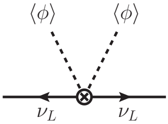

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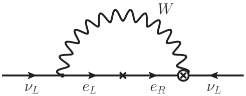

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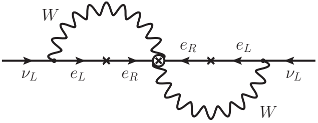

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Need models: C.S. Chen, C.Q. Geng, J.N. Ng, J.M.S. Wu; del Aguila, Aparici, Bhattacharya, AS, Wudka; M. Gustafsson, J.M. No, M.A. Rivera

A model for 1loop $0\nu\beta\beta$, 3loop m_ν with DM
(J. Alcaide, D. Das, A.S. '17)

3 new scalars $\kappa^{++} \sim (1,2,+)$, $\chi \sim (3,1,-)$,$\sigma \sim (1,0,-)$ with Z_2

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- The DM requirement (small mixings large singlet-triplet splittings)

Neutrinoless double beta decay

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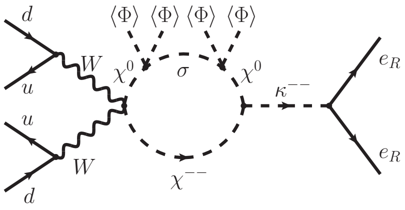
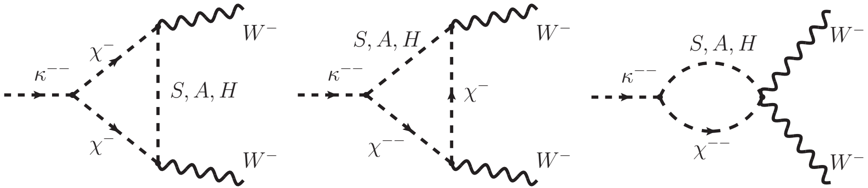


Neutrinoless double beta decay

The effective $\kappa^{--} WW$ vertex



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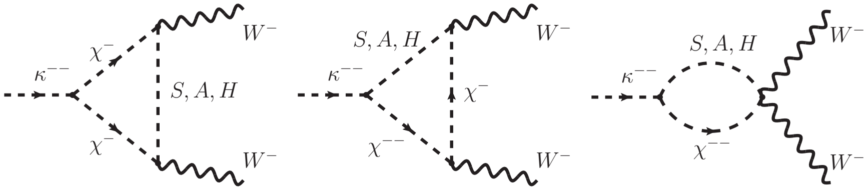


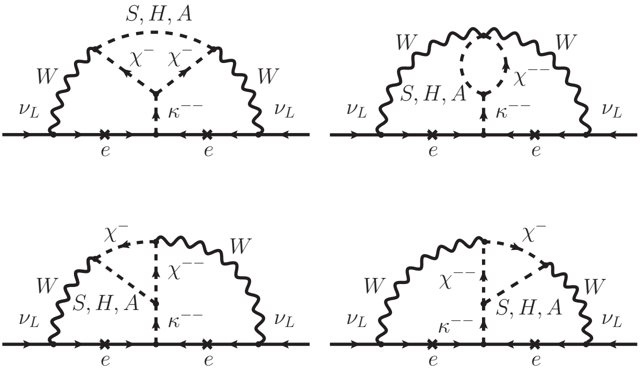
The amplitude

$$\mathscr{L}_{0\nu\beta\beta} = 2\frac{f_{ee}^*}{16\pi^2}\frac{\mu_\kappa\lambda_6^2}{m_\kappa^2 m_A^4} I_\beta \left(\overline{u_L}\gamma^\mu d_L\right)\left(\overline{u_L}\gamma_\mu d_L\right)\overline{e_R}e_R^c$$

$$4\times 10^{-10} < \frac{m_p}{2G_F^2}\frac{f_{ee}^*}{16\pi^2}\frac{\mu_\kappa\lambda_6^2}{m_\kappa^2 m_A^4} I_\beta < 4\times 10^{-9}$$

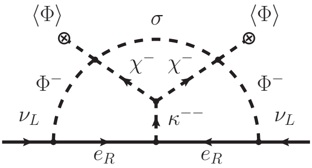
The neutrino masses

Neutrino mass in the unitary gauge



The neutrino masses

Mass insertion approximation



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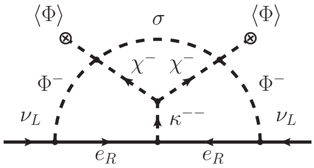

The neutrino mass matrix

$$M_{ab} = \frac{8\mu_\kappa \lambda_6^2}{(4\pi)^6 m_\kappa^2} I_\nu \, m_a f_{ab} m_b = U D_\nu U^T$$

Structure of the ν Mass Matrix

- M_{ee} highly suppressed by the factor m_e^2
- $M_{e\mu}$ also suppressed because the $\mu \to 3e$ bound on $f_{e\mu}$
- $M_{ee}, M_{e\mu} \ll M_{e\tau}, M_{\mu\mu}, M_{\mu\tau}, M_{\tau\tau} \sim 0.02\,\mathrm{eV}$

M_ν strongly constrained

$$M_\nu = \begin{pmatrix} < 10^{-4} & < 10^{-4} & \sim 0.01 \\ < 10^{-4} & \sim 0.02 & \sim 0.02 \\ \sim 0.01 & \sim 0.02 & \sim 0.02 \end{pmatrix} \mathrm{eV}$$

- Only NH allowed
- $\sin^2\theta_{13}$ cannot be zero
- Predicction for $m_{\mathrm{light}} \sim 0.005\,\mathrm{eV}$
- Prediction for Majorana phases: fixed by δ

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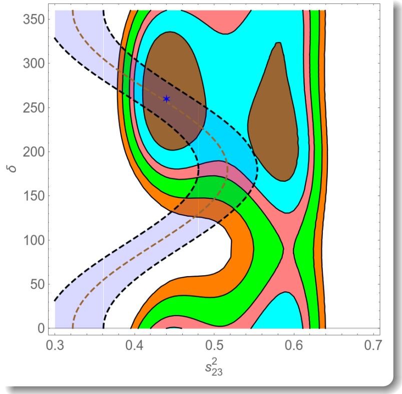

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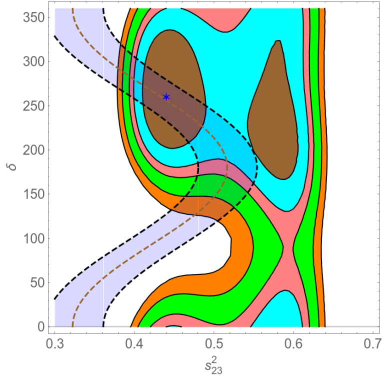
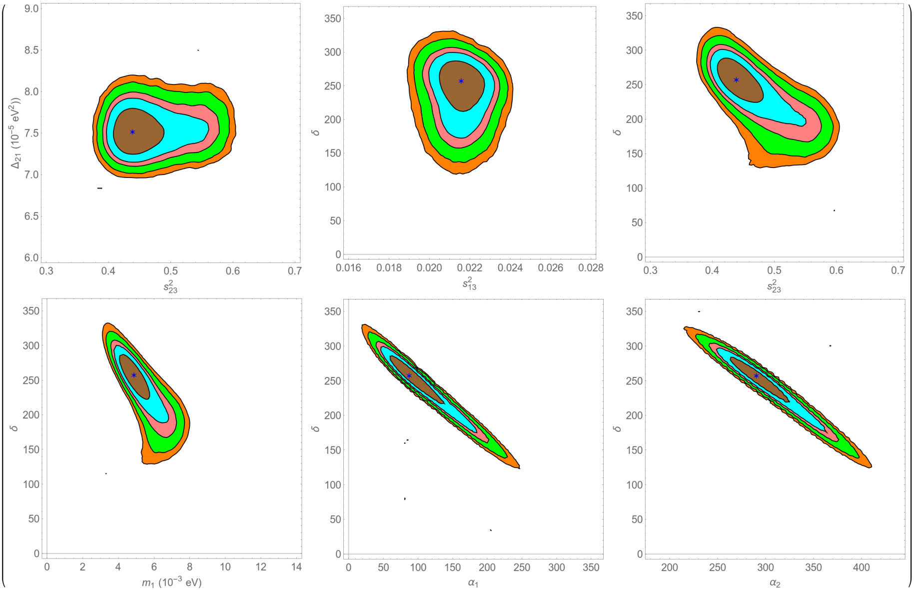


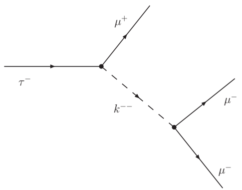
$\delta \sim 260^\circ$ and $s^2_{23} \sim 0.44$

The fit (preliminary)



LFV and LHC

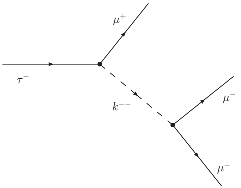
LFV ($\ell_a^- \to \ell_b^+ \ell_c^- \ell_d^-$, $\ell_a^- \to \ell_b^- \gamma$, ...): limits on f_{ab}



Experimental Data (90% CL)	Bounds (90% CL)	Bounds assuming Eq. (28)
$\mathrm{BR}(\mu^- \to e^+e^-e^-) < 1.0 \times 10^{-12}$	$\lvert f_{e\mu} f^*_{ee}\rvert < 2.3 \times 10^{-5} \left(\frac{m_{\kappa^{++}}}{\mathrm{TeV}}\right)^2$	
$\mathrm{BR}(\tau^- \to e^+e^-e^-) < 2.7 \times 10^{-8}$	$\lvert f_{e\tau} f^*_{ee}\rvert < 0.009 \left(\frac{m_{\kappa^{++}}}{\mathrm{TeV}}\right)^2$	$\lvert f^*_{ee} f_{\tau\tau}\rvert \lesssim 7.8 \times 10^{-6} \left(\frac{m_{\kappa^{++}}}{\mathrm{TeV}}\right)^2$
$\mathrm{BR}(\tau^- \to e^+e^-\mu^-) < 1.8 \times 10^{-8}$	$\lvert f_{e\tau} f^*_{e\mu}\rvert < 0.005 \left(\frac{m_{\kappa^{++}}}{\mathrm{TeV}}\right)^2$	$\lvert f^*_{e\mu} f_{\tau\tau}\rvert \lesssim 4.3 \times 10^{-6} \left(\frac{m_{\kappa^{++}}}{\mathrm{TeV}}\right)^2$
$\mathrm{BR}(\tau^- \to e^+\mu^-\mu^-) < 1.7 \times 10^{-8}$	$\lvert f_{e\tau} f^*_{\mu\mu}\rvert < 0.007 \left(\frac{m_{\kappa^{++}}}{\mathrm{TeV}}\right)^2$	$\lvert f_{\tau\tau}\rvert \lesssim 1.4 \times 10^{-4} \left(\frac{m_{\kappa^{++}}}{\mathrm{TeV}}\right)$
$\mathrm{BR}(\mu \to e\gamma) < 5.7 \times 10^{-13}$	$\lvert f^*_{ee} f_{e\mu} + f^*_{e\mu} f_{\mu\mu} + f^*_{e\tau} f_{\mu\tau}\rvert^2 < 1 \times 10^{-7} \left(\frac{m_{\kappa^{++}}}{\mathrm{TeV}}\right)^4$	$\lvert f_{\tau\tau}\rvert \lesssim 1.2 \times 10^{-4} \left(\frac{m_{\kappa^{++}}}{\mathrm{TeV}}\right)$

LFV and LHC

LFV ($\ell_a^- \to \ell_b^+ \ell_c^- \ell_d^-$, $\ell_a^- \to \ell_b^- \gamma$, ...): limits on f_{ab}



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Corrrelations of BR fixed by ν oscillation data

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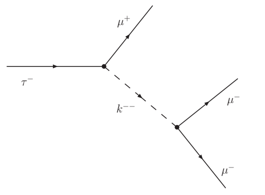

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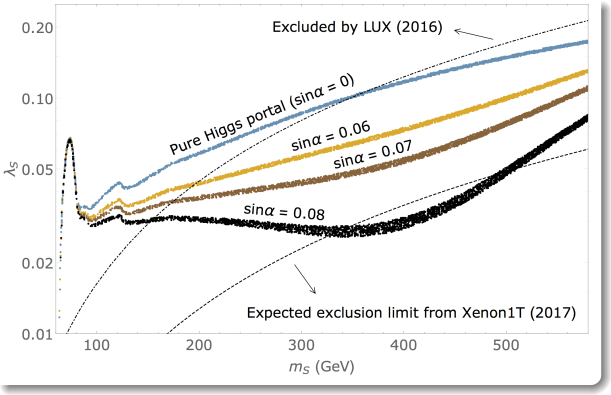
Corrrelations of BR fixed by ν oscillation data

LHC

- $\kappa^{--} \to \ell_a \ell_b$ Easily produced and detected.
  BR fixed by ν oscilaton data
- χ^{--}, χ^- easily produced.
  Interesting phenomenology because the discrete symmetry; have to decay into DM.

Dark Matter (Singlet-triplet scalar Higgs portal)



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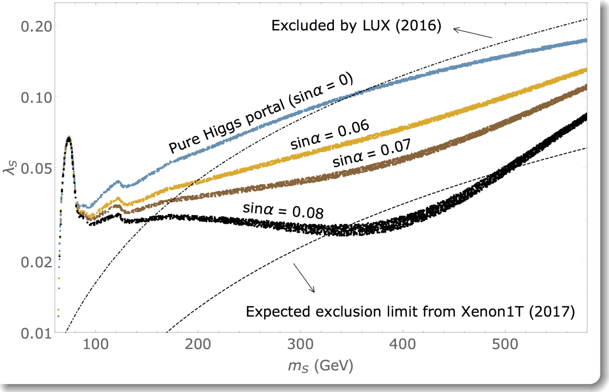

- Adjust the relic density with the mixing singlet-triplet
- Connection with neutrino masses

$$\lambda_6 = \frac{\sin 2\alpha}{\sqrt{2}v^2}\left(m_H^2 - m_S^2\right)$$

Conclusions

Radiative neutrino mass models also interesting for $0\nu\beta\beta$ and DM

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- Predictions of ν masses and mixings without symmetries

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Can be tested NOW!

The higher the loops the sooner we will see or discard them!