Fourth generation Majorana neutrinos

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Dario Schalla*
in collaboration with Heinrich Päs* and Alexander Lenz**

* Technische Universität Dortmund, Department of Physics
** Technische Universität München, Physik Department

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technische universität dortmund

Introduction

What do we mean by "fourth generation" neutrinos?

a complete sequential fermion generation (quarks and leptons):

$$S.M. + \begin{pmatrix} t' \\ b' \end{pmatrix}_L \quad t'_R \quad b'_R \quad \begin{pmatrix} \nu_4 \\ \ell_4 \end{pmatrix}_L \quad \ell_{4R} \quad \nu_{4R}$$

No change in gauge or Higgs sector

State of the art:

Eberhardt, Lenz & Rohrwild (Phys.Rev. D82 (2010) 095006)

$$|m_{t'} - m_{b'}| < 80\,\mathrm{GeV}$$

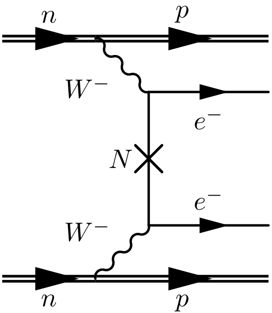
$$|m_{l_4} - m_{\nu_4}| < 140\,\mathrm{GeV}$$

Lacker & Menzel (JHEP 1007 (2010) 006):

2σ fit of several processes with $SM4$ neutrino parameters:

$$U_{PMNS} = \begin{pmatrix} * & * & * & {}^{<0.089}_{>0.021} \\ * & * & * & < 0.029 \\ * & * & * & < 0.085 \\ < 0.115 & < 0.115 & < 0.115 & {}^{<0.9998}_{>0.9934} \end{pmatrix}$$

Neutrinoless double beta decay



$T_{1/2}^{\text{Ge}} > 1.57 \cdot 10^{25}\,\mathrm{y}$

IGEX, Phys. Rev. D65, 092007 (2002)

fermion propagator: $\frac{\not{p}+m}{p^2-m^2}$
nuclear momentum $\mathcal{O}(100\,\mathrm{MeV})$
light (SM) neutrino $\rightarrow m$

$$\Rightarrow \langle m_\nu \rangle = \sum_{\ell=e,\mu,\tau} U_{e\ell}^2 m_{\nu_\ell}$$

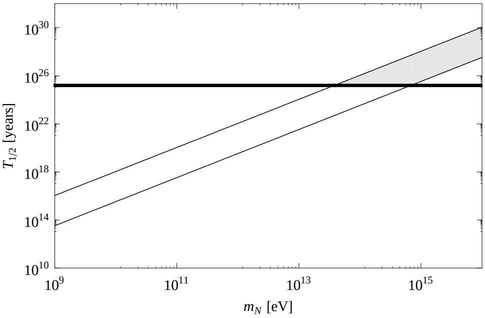
heavy (BSM) neutrino $\rightarrow \frac{1}{m}$

$$\Rightarrow \langle m_N \rangle^{-1} = \sum_N U_{eN}^2 m_N^{-1}$$

M. Hirsch *et al.* (Phys. Lett. B374, 7 (1996)):

$$\left[T_{1/2}^{0\nu\beta\beta}\right]^{-1} = \left(\frac{\langle m_\nu\rangle}{m_e}\right)^2 C_{mm}^{LL} + \left(\frac{m_p}{\langle m_N\rangle}\right)^2 C_{mm}^{NN} + \left(\frac{\langle m_\nu\rangle}{m_e}\right)\left(\frac{\langle m_p\rangle}{\langle m_N\rangle}\right) C_{mm}^{NL}$$

pure heavy contribution



$$U_{e4}^{max} = 0.089$$

$$\Rightarrow \; m_4^{max} = 6.8 \cdot 10^5 \,\mathrm{GeV}$$

$$U_{e4}^{min} = 0.021$$

$$\Rightarrow \; m_4^{min} = 3.8 \cdot 10^4 \,\mathrm{GeV}$$

$$m_4 >> \mathcal{O}(100\,\mathrm{GeV})$$

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Not necessarily.

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3. neutrinos are pseudo-Dirac particles

We focus on the latter alternative.

pseudo-Dirac neutrino:

$$\text{Majorana mass} \ << \ \text{Dirac mass}$$

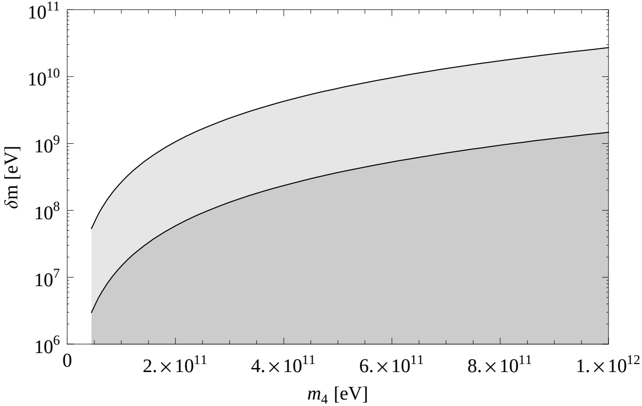
$\Rightarrow$ mass eigenstates are nearly degenerate
Active and sterile state mix maximal:

$$\tan 2\theta \approx \frac{2m_D}{m_1 - m_2}$$

Mass splitting of "light" and "heavy" eigenstate δm is small compared to absolute mass scale
pseudo-Dirac half-life:

$$\left[T_{1/2}^{0\nu\beta\beta}\right]^{-1} = \left(\frac{m_p}{\langle m_-\rangle} - \frac{m_p}{\langle m_+\rangle}\right)^2 C_{mm}^{NN}$$

maximal mass splitting to hide neutrino in $0\nu\beta\beta$

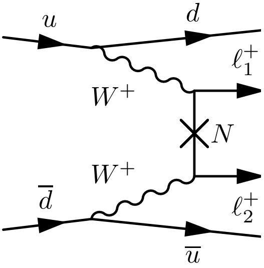


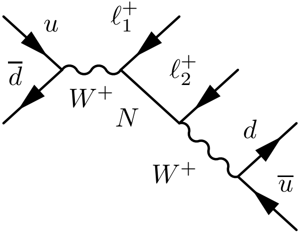
$$m_- = 45\,\mathrm{GeV} \quad \Rightarrow \quad \delta m \leq 54\,\mathrm{MeV}$$

$$m_- = 1000\,\mathrm{GeV} \quad \Rightarrow \quad \delta m \leq 27\,\mathrm{GeV}$$

Like-sign dilepton production

$$pp \to \ell_1^+ \ell_2^+ X$$





single heavy Majorana neutrino:

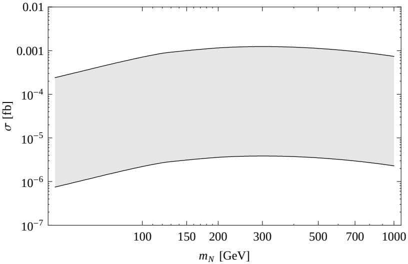
$$\sigma_{single}\left(pp \to \ell_1^+ \ell_2^+ X\right) = \frac{G_F^4 m_W^6}{8\pi^5}\left(1 - \frac{1}{2}\delta_{\ell_1\ell_2}\right)\left|U_{\ell_1 N} U_{\ell_2 N}\right|^2 F\left(E, m_N\right)$$

Ali, Eur. Phys. J. C21. 123 (2001)

Δ_{pD} reduces like-sign dilepon production drastically

like-sign dielectron production

Majorana neutrino
(w/o $0\nu\beta\beta$ constraints)



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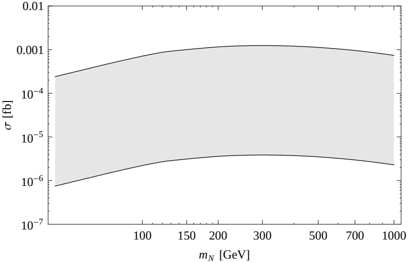
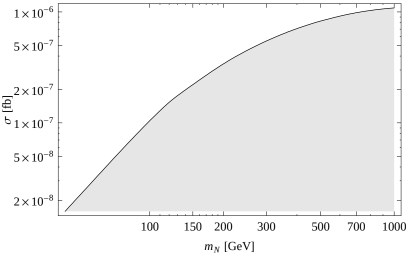


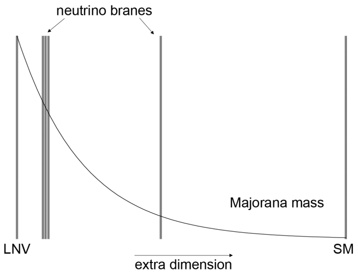
pseudo-Dirac neutrino
(with $0\nu\beta\beta$ constraints)



$\Rightarrow$ observation from $0\nu\beta\beta$ gives hard constraints on collider experiments

An extradimensional model

large mass of ν_4 $\rightarrow$ hierarchy problem
ansatz: introduce a brane with maximal LNV in an extra dimension and locate each right handed neutrino on a different brane along this axis $\Rightarrow$ each generation gains a different amount of LNV in terms of Majorana mass.



bulk field: $\langle\chi\rangle \propto e^{-mr}$
Majorana mass:
$M_{Ri} = \Lambda_{LNV} e^{-\alpha_i}$

i	α_i	m_i [GeV]	M_i [GeV]
4	~ 43.7	246	247
3	9.6	$5.0 \cdot 10^{-11}$	$6.7 \cdot 10^{14}$
2	8.7	$9.1 \cdot 10^{-12}$	$1.7 \cdot 10^{15}$
1	≤ 7.9	$\leq 4.1 \cdot 10^{-12}$	$\geq 3.7 \cdot 10^{15}$

Arkani-Hamed *et al.* Phys.Rev. D65 (2002) 024032

Summary

- fourth generation neutrinos not yet excluded
- $0\nu\beta\beta$ gives hard constraints on Majorana nature of EWS neutrinos
- pseudo-Dirac scenario can hide the Majorana nature of neutrinos
- extra dimensions can soften hierarchy problem

reference: arXiv:1104.2465