Polarization signatures from effective interactions of Majorana neutrinos

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Outline

The SM picture: massless neutrinos

- Leptons: $SU(2)_L$ doublet
  $L_i = \begin{pmatrix} \nu_i \\ \ell_i \end{pmatrix}_L$
- ℓ acquires a mass interacting with the Higgs v.e.v. after EWSB:
  $\langle \Phi \rangle = \begin{pmatrix} 0 \\ \frac{v}{\sqrt{2}} \end{pmatrix}$
- Dirac mass: $m_D \ell_L \ell_R$

$$-\mathcal{L}_{Yukawa} \supset Y_\ell^{ij} \overline{L^i} \Phi \ell_R^j \to \frac{Y_l^{ij} v}{\sqrt{2}} \ell_L^i \ell_R^j$$

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- But...
- Neutinos change flavor as they propagate: they have masses $m_\nu \sim 0.01 eV$
- One has to go beyond the SM to get massive neutrinos.

Type I "vanilla" seesaw: neutrino mixing and N decoupling

$$\mathcal{L}_\nu = \mathcal{L}_{SM} - Y_{\alpha i}\overline{L^\alpha}\tilde{\Phi}N_{Ri} - \sum_{i,j=1}^{3}\frac{M_{N_{ij}}}{2}\overline{N^c_{iL}}N_{jR} + h.c.$$

- Mixing with Majorana massive states: lepton number violation (LNV)
  $\nu_{\ell L} = U_{\ell m}\nu_m + U_{\ell N}N$

$$\mathcal{L}_W = -\frac{g}{\sqrt{2}}U_{\ell N}\overline{N}^c\gamma^\mu P_L \ell W^+_\mu$$
$$\mathcal{L}_Z = -\frac{g}{2c\theta_W}\overline{\nu_\ell}\gamma^\mu U_{\ell N}P_L N Z_\mu$$

- $U_{\ell N} \simeq \sqrt{\frac{m_\nu}{M_N}} \lesssim 10^{-6}\sqrt{\frac{100GeV}{M_N}}$

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- The observation of LNV depends only on $\nu_L - N$ mixing $U_{\ell N}$.
  So the N decouples (if no textures applied to mass matrix...)
- What kind of New Physics could lead to observable LNV ?

(e.g. in colliders)

Outline

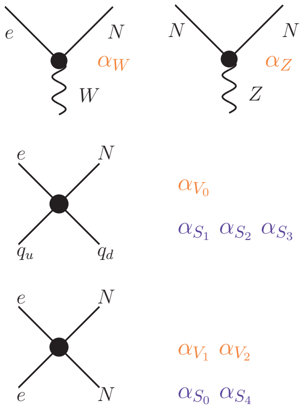
Effective approach [1]

- SM $+$ one heavy Majorana N, $m_N < \Lambda$ (not integrated out...)
- Neglect the $\nu_L - N$ $U_{\ell N}$ mixing
- NP parameterized with a lagrangian constructed with effective operators inolving the N and the standard fields, preserving the $SU(2)_L \times U(1)_Y$ symmetry
- Low-energy limit of some unknown ultraviolet theory: suppressed by inverse powers of the new physics scale Λ:

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_{n=6}^{\infty} \frac{1}{\Lambda^{n-4}} \sum_{\mathcal{J}} \alpha_{\mathcal{J}} \mathcal{O}_{\mathcal{J}}^{(n)}$$

[1] F. del Aguila, S. Bar Shalom, A. Soni y J. Wudka. Phys. Lett. B 670, 399 (2009), 0806.0876

Effective operators



The (dim = 6) operators are [1] (tree-level-generated):

$$\mathcal{O}^{(i)}_{LN\Phi} = (\Phi^\dagger\Phi)(\bar{L}_i N\tilde{\Phi})$$
$$\mathcal{O}_{NN\Phi} = \imath(\Phi^\dagger D_\mu \Phi)(\bar{N}\gamma^\mu N)$$
$$\mathcal{O}^{(i)}_{Ne\Phi} = \imath(\Phi^T \epsilon D_\mu \Phi)(\bar{N}\gamma^\mu e_i)$$

$$\mathcal{O}^{(i,j)}_{duNe} = (\bar{d}_i\gamma^\mu u_i)(\bar{N}\gamma_\mu e_j)$$
$$\mathcal{O}^{(i,j)}_{LNQd} = (\bar{L}_i N)\epsilon(\bar{Q}_j d_j)$$
$$\mathcal{O}^{(i,j)}_{QuNL} = (\bar{Q}_i u_i)(\bar{N} L_j)$$
$$\mathcal{O}^{(i,j)}_{QNLd} = (\bar{Q}_i N)\epsilon(\bar{L}_j d_j)$$

$$\mathcal{O}^{(i)}_{fNN} = (\bar{f}_i\gamma^\mu f_i)(\bar{N}\gamma_\mu N)$$
$$\mathcal{O}^{(i,j)}_{LNLe} = (\bar{L}_i N)\epsilon(\bar{L}_j e_j)$$
$$\mathcal{O}^{(i)}_{LN} = |\bar{N} L_i|^2$$

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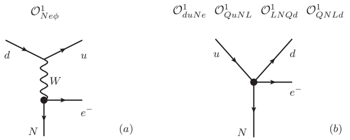
Bounds on the couplings $\alpha_{\mathcal{J}}^{(i,j)}$

We exploit the existing bounds for the $U_{\ell N}$ mixings taking $U_{\ell N} \simeq \frac{\alpha v^2}{2\Lambda^2}$ (for $\Lambda = 1\,TeV$)

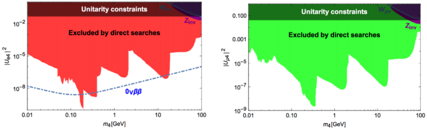
- Neutrinoless double beta decay (KamLAND-Zen)

$$\alpha_{0\nu\beta\beta}^{bound} \lesssim 3.2\times10^{-2}\left(\frac{m_N}{100\,GeV}\right)^{1/2}$$



- Electroweak precision data (low energy LFV: $\mu \to e\gamma$)

$$\alpha_{EWPD}^{bound} \lesssim 0.32$$



[*] Abada et.al. JHEP02(2018)169, 1712.03984

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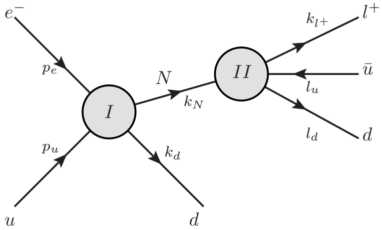
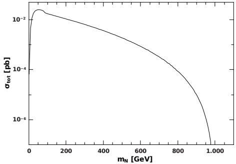
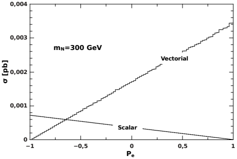
$e^- p \to l_j^+ + 3jets\ (l_j \equiv e, \mu)$ [2]



- Vectorial or Scalar contribution to σ depends on initial polarization P_{e^-}





LHeC $E_p = 7\ TeV$, $E_e =$, $\mathcal{L} = 100\ fb^{-1}$

[2] L.Duarte, G. Zapata and O.A. Sampayo, Eur. Phys. J. C (2018) 78:352, 1802.07620

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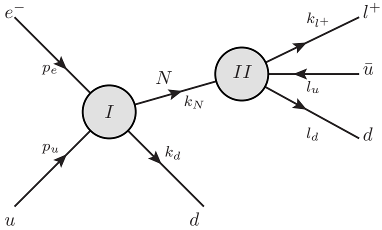
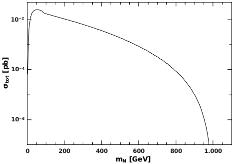
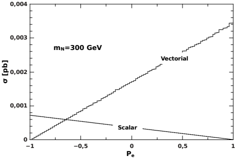
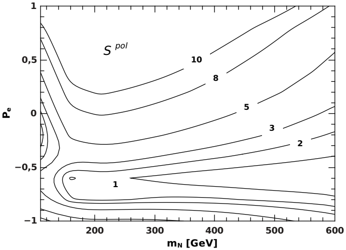


- Vectorial or Scalar contribution to σ depends on initial polarization P_{e^-}
- Standard deviation $\mathcal{S}^{pol} = \frac{N^{vec} - N^{sca}}{\sqrt{N^{vec}} + \sqrt{N^{sca}}}$







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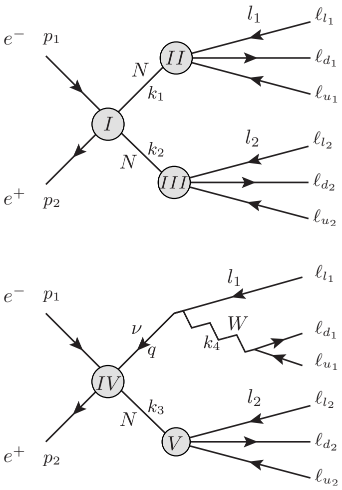

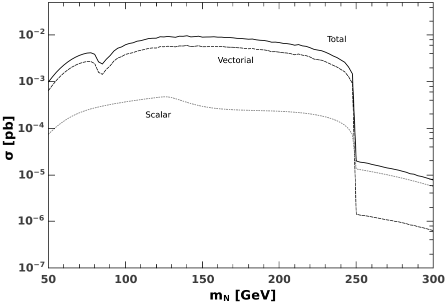

$\sqrt{s} = 500\ GeV$

[3] L.Duarte, G. Zapata and O.A. Sampayo, 1812.XXXXX

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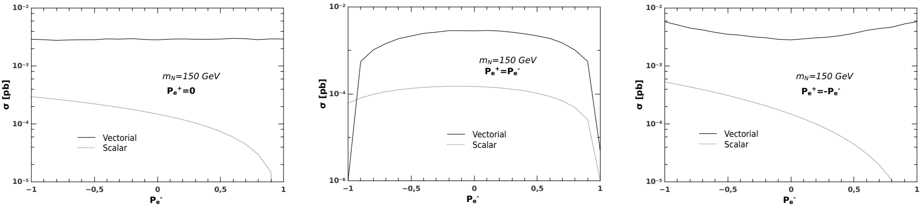
Initial polarization: distinguish Vectorial and Scalar behavior for σ:



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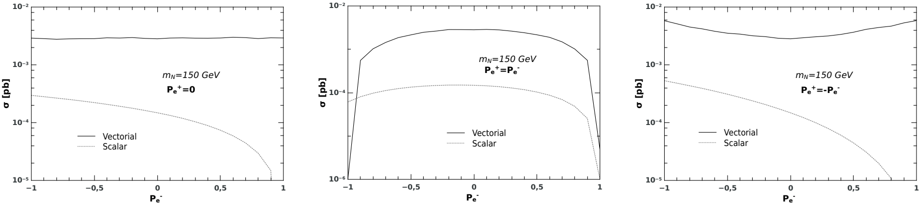
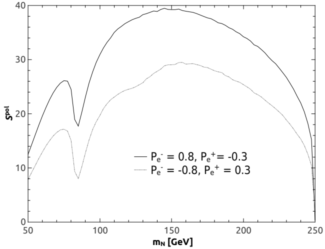


- Counting events:
  $\sqrt{s} = 500\ GeV$, $\mathcal{L} = 500 fb^{-1}$ (ILC)
- Standard deviation
  $\mathcal{S}^{pol} = \frac{N^{vec} - N^{sca}}{\sqrt{N^{vec}} + \sqrt{N^{sca}}}$



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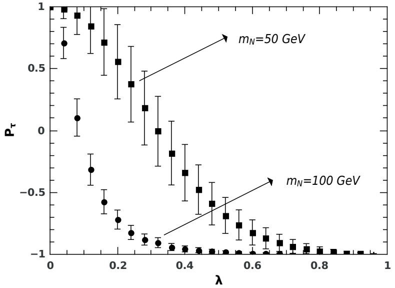
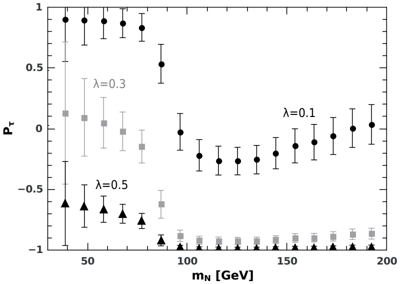
- Final $\tau^+\tau^+$ polarizations: $$P_\tau = \frac{N_{++} + N_{+-} - N_{-+} - N_{--}}{N_{++} + N_{+-} + N_{-+} + N_{--}}$$
- $\lambda \in [0,1]$ weights contributions: $\lambda\,Vectorial + (1-\lambda)\,Scalar$





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Thank you,
and the
XII SILAFAE
organizers.