Majorana and pseudo-Dirac Neutrinos at the ILC

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1. Abstract

In the extension of the standard model with two right hand neutrinos and considering an approximate lepton number symmetry, we can have these neutrinos with masses in the scale of the GeV and large mixing. We found that splitting in the masses of the right handed neutrinos could be connected to a lepton number violation (LNV) parameter, and that therefore we will have important contributions from LNV processes. We consider the production of heavy neutrinos in electron-positron colliders, where its displaced vertex can be a golden signal for experimental searches. We analyze a forward-backward asymmetry that will depend on the mass splitting of heavy neutrinos. With this asymmetry, we can put restrictions on the mass difference, and found that they can be much lower than the known limits.

2. Current Constraints on Mass Splittings

The mass splitting of the heavy neutrinos is connected primarily to μ' in the region of interest and LNV processes such as neutrinoless double beta decay $(0\nu\beta\beta)$. In addition, loop corrections to the light neutrino masses have also been shown to be sensitive to μ'. In the Fig. 1 , Any point above a given contour would require more degeneracy than that corresponding to the contour label. The shaded blue region is ruled out by direct searches, taken from [1], while the red region is ruled out by LFV experiments [2].

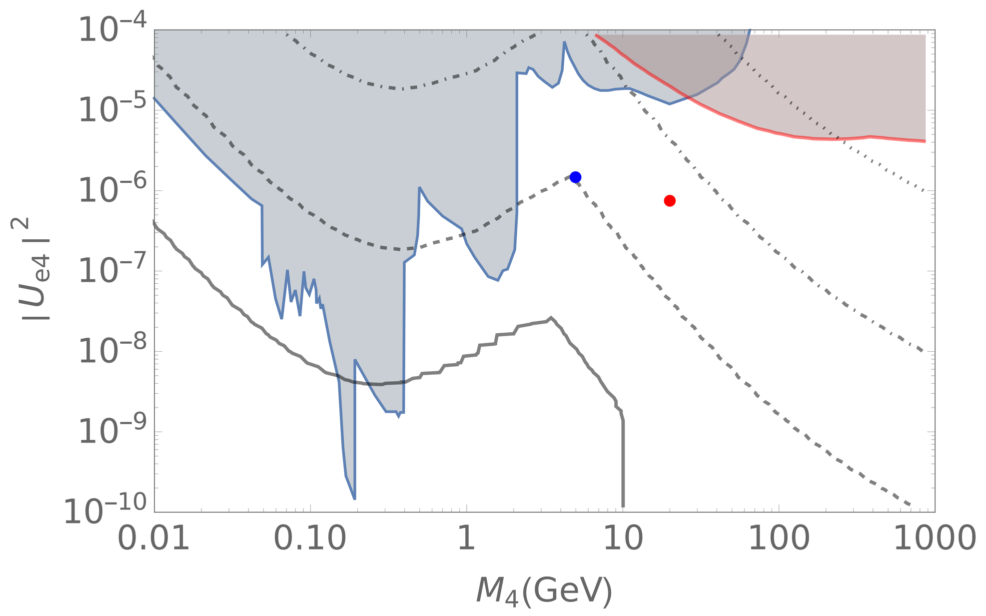


Figura 1: We show contours for Max$(\delta M/M_4)$ = $1, 10^{-2}, 10^{-4}, 10^{-6}$ in solid, dashed, dash-dotted and dotted lines.

3. Pseudo-Dirac Neutrinos at e^+e^- Colliders.

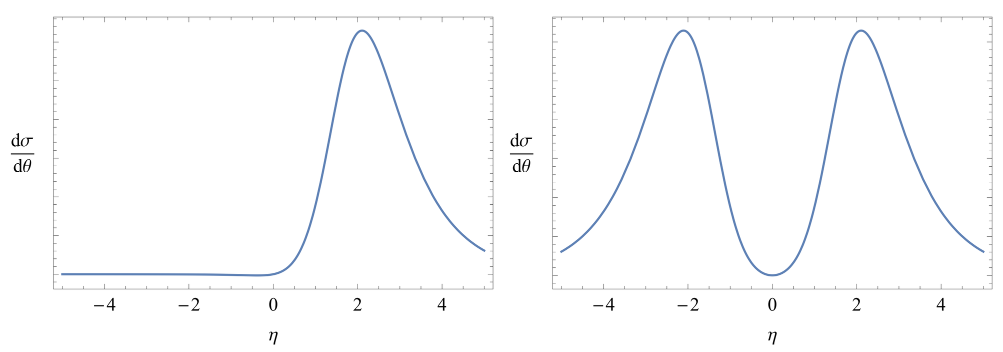


Figura 2: Pseudo-rapidity distribution of $N_{4,5}$ in the W-exchange process involving a $\bar{\nu}$ (left) and both a $\bar{\nu}$ and a ν (right).

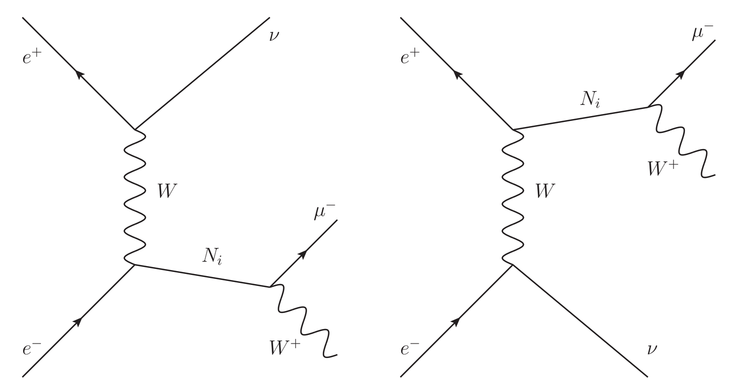


Figura 3: Diagram A (Left) conserves lepton number, Diagram B (Right) does not.

We analize the $e^-e^+ \longrightarrow \nu N^* \longrightarrow \nu \ell W^* \longrightarrow \nu \ell jj$. Since the N_i has a significant boost, the decay products follow the same angular distribution.

$$|\mathcal{M}_A|^2 = \frac{1}{4}\left(\frac{g}{\sqrt{2}}\right)^6 \sum_{j,k=4}^{5} \Omega_{Aj}\Omega^*_{Ak} G_A^{\lambda\delta}\, \epsilon^*_\lambda(p_4)\, \epsilon_\delta(p_4)$$

$$|\mathcal{M}_B|^2 = \frac{1}{4}\left(\frac{g}{\sqrt{2}}\right)^6 \sum_{j,k=4}^{5} \frac{M_j M_k}{q^2} \Omega_{Bj}\Omega^*_{Bk} G_B^{\lambda\delta}\, \epsilon^*_\lambda(p_4)\, \epsilon_\delta(p_4)$$

We compare the two contributions.

$$\left(\frac{\Phi_B}{\Phi_A}\right)_{\text{on-shell}} \xrightarrow{LNC} \left(1+\frac{\Gamma_4^2}{4M_4^2}\right)\left(\frac{\delta M}{\Gamma_4}\right)^2$$

4. Forward-Backward Asymmetry and Results

The heavy neutrino production is expected to have a very large background coming from the SM process $e^-e^+ \longrightarrow W^*W^*$. In order to avoid this background, We require the heavy neutrino to be nearly on-shell,with a large enough life time in order to decay far from the interaction point. This conditions are in L_T , L_z and d_ℓ (transverse and longitudinal coordinates, and impact parameter.)[3].

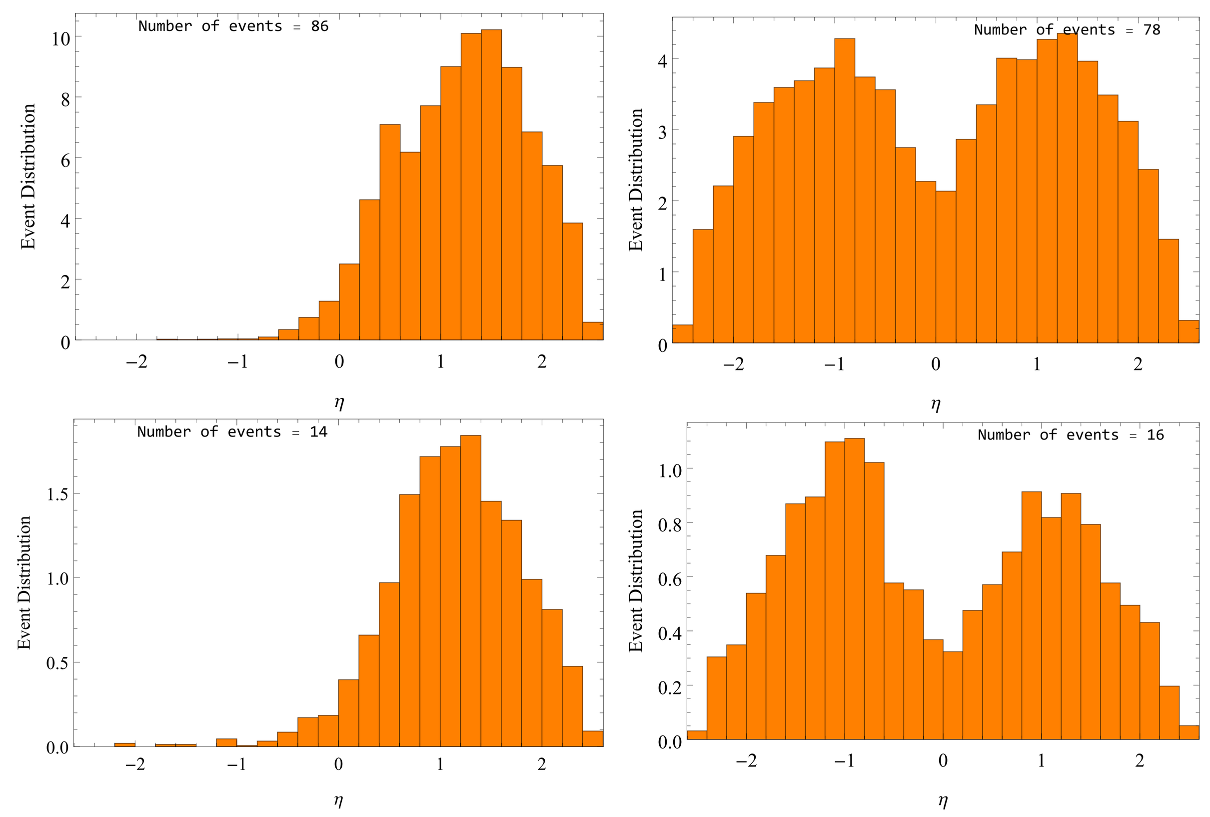
In this work we have two scenarios:

Name	Mass (GeV)	$\lvert U_{\mu 4}\rvert^2$	Γ_4 (meV)	$c\,\tau_4$ (mm)
Light	5	$1{,}0\times 10^{-5}$	0,02	10
Heavy	20	$5{,}0\times 10^{-6}$	20	0.01

The pseudorapidity distribution of the charged lepton in $e^-e^+ \to \nu N^* \to \nu + \ell + jets$ matches our expectations. We can see an asymmetry in the lepton pseudorapidity distribution when $\delta M < \Gamma$, in this case there are important contributions from diagram A (LNC process), when $\delta M > \Gamma$ we have contributions from the diagram A and B (LNV process) .

$\delta M < \Gamma$ $\quad$ $\delta M > \Gamma$

M= 5 GeV



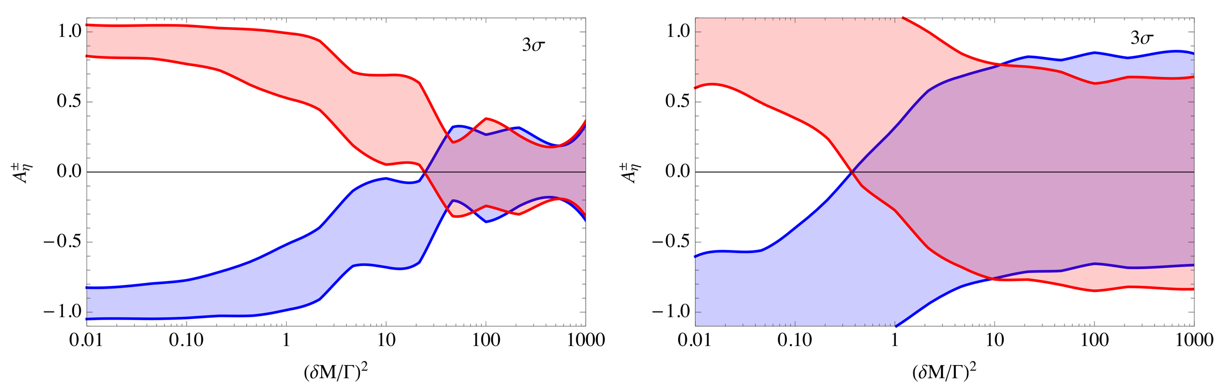


Figura 4: Forward - backward asymmetry as a function of $(\delta M/\Gamma)^2$. We show the 3σ region for A^-_η (A^+_η) in red (blue).

M = 20 GeV

The asymmetry was quantified as: $A^{\pm}_\eta = \frac{N^{\pm}(\eta>0)-N^{\pm}(\eta<0)}{N^{\pm}_{\text{tot}}}$

$A^{\pm} \to 0$ when $(\delta M/\Gamma_4)^2 \to \infty$ (LNV limit) and $A^{\pm} \to 1$ for $(\delta M/\Gamma_4)^2 \to 0$ (LNC limit)

5. Conclusions

- For M = 5 GeV, the critical region where the asymmetry disappears is around $\delta M/M_4 \sim \mathcal{O}(10^{-14})$, and for M = 20 GeV, the region is around $\delta M/M_4 \sim \mathcal{O}(10^{-12})$.
- We can probe the nature of the neutrinos by the observing or not in the η distribution of the lepton.

6. References

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