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Right-Handed Majorana Neutrinos at a e^+e^- collider

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We consider a gauged $(B-L)$ (Baryon number minus Lepton number) extension of the Standard Model (SM), which implies the existence of three SM-singlet Right Handed Neutrinos (RHNs). The RHNs acquire Majorana masses through $U(1)_{(B-L)}$ gauge symmetry breaking, and tiny Majorana masses for the SM-like neutrinos are generated by the seesaw mechanism. The high-mass eigenstates, mostly composed of the RHNs, obtain suppressed electroweak interactions through small mixings with the SM neutrinos.

We study the pair production of heavy Majorana neutrinos at the International Linear Collider (ILC) at 500 GeV. Considering the current and prospective future bounds on $(B-L)$ model parameters from the search for resonant Z' boson production at the Large Hadron Collider (LHC), we focus on a smoking-gun signature of the Majorana nature of the heavy neutrinos: a final state with a pair of same-sign, same-flavor leptons, small missing momentum, and hadronic jets. We estimate the projected significance of the signature at the ILC.

This work was carried out in the framework of the ILD Concept Group

1 Introduction

The type I seesaw mechanism, in which the Standard Model (SM) is augmented by three SM-gauge-singlet Right Handed Neutrinos (RHNs), is probably the simplest way to explain the origin of tiny neutrino masses. RHNs are naturally introduced in the minimal $(B-L)$ (Baryon minus Lepton number) model in which the SM's accidental global $U(1)_{(B-L)}$ symmetry is gauged [1]. Breaking of the $U(1)_{(B-L)}$ gauge symmetry induces masses of the RHNs and the associated Z' boson.

We report on a study to estimate the sensitivity to this class of models, using full simulation of the ILD concept at the ILC. More details of the analysis can be found in [2].

2 Signal and Backgrounds

We focus on RHN pair production $e^+e^- \to NN$ at ILC-500. If the RHN mass is sufficient, RHN can decay to $(l^\pm W^\mp), (Z\nu)$, and/or $(H\nu)$. In this study, we assume that the lightest RHN decays to the first lepton generation and consider the decay $N \to e^\pm W^\mp$. We consider benchmark points with the lightest RHN mass between 100 and 225 GeV, Z' mass $M_{Z'} = 7$ TeV, coupling constant $g'_{(B-L)} = 1$, and mixing angle $|V_{eN}| = 0.03$. Model parameters are chosen to avoid experimental constraints.

We utilise a final state with two isolated same-sign leptons and hadronic jets, which has no irreducible backgrounds from SM processes. Some backgrounds do arise when a lepton originating from hadron decay is mis-identified as an isolated primary lepton, and is paired with a charged lepton, for example from the decay of an associated W boson. All SM processes leading to 4- and 6-fermion final states with at least one electron and two quarks are considered in the background estimation.

3 Simulation Setup and Cut Based Analysis

Signal events were generated using the WHIZARD event generator 2.8.5 [3]. SM samples were prepared by the ILD software group using WHIZARD 1.9.5. Both signal and background events included the effect of beam energy spread and Initial State Radiation (ISR). Events were full simulated and reconstructed using the standard tools developed for the ILD concept.

The ILC is foreseen to have longitudinally polarised beams, 80% for the e^- and 30% for the e^+ beams. We assumed two data sets with opposite polarisations, each of $1600\ \mathrm{fb}^{-1}$, as envisioned in the current ILC run plan.

To select events with same-sign isolated electrons and hadronically decaying W bosons, the following selection cuts were applied:

1. exactly two same-sign isolated $e^\pm$, and no isolated muons or photons.
2. energy of both isolated $e^\pm$ should be < 200 GeV
3. both isolated electron polar angles $|\cos\theta_{isoe}| < 0.95$.
4. the "IsolatedLeptonTagging parameter", the output of a multi-variate analysis designed to identiy isolated leptons, of both electrons > 0.9.
5. jet clustering parameter with Durham $\log_{10}(y_{12}) > -1$.
6. magnitude of the missing momentum $P_{miss} < 100$ GeV, and ($P_{miss} < 40$ GeV or $|\cos\theta_{P_{miss}}| > 0.95$)

In this study we consider RHN pair decays with two hadronically decaying W bosons. After removing isolated $e^\pm$, remaining particles are clustered into 4 jets. To reconstruct the RHN mass, we search for the best jet pairing. We assume that the jet pair masses M_{jj} should be consistent with the W mass, and choose the jet pairing which minimizes

$$F_1 = (M_{jj1} - M_W)^2 + (M_{jj2} - M_W)^2. \tag{1}$$

We also assume that the two reconstructed RHN masses M_{jje1}, M_{jje2} should be equal, so we choose the electron–jet-pair combination which minimizes

$$F_2 = (M_{jje1} - M_{jje2})^2. \quad (2)$$

The chosen jet-lepton pairing was used to reconstruct the average RHN mass M_N.

A mass window from -10 GeV to $+15$ GeV around each tested RHN mass was then applied. The background is consistent with a flat distribution in M_N. Only 3 (20) SM background events remain in 1600 fb^{-1} with $e_R^{80} p_L^{30}$ ($e_L^{80} p_R^{30}$) beam polarisation.

4 Results and Summary

The signal significance ($N_S/\sqrt{N_B+N_S}$) and expected 95% confidence upper limits on the partial cross-section $\sigma = \sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{NN}) \times BR(\mathrm{N} \to \mathrm{e}^\pm \mathrm{W}^\mp)^2$ were calculated using the number of selected signal and background events N_S, N_B. Figure 1 shows the calculated limits graphically. The expected cross-section upper limits are up to 10 times smaller than those of the chosen benchmarks, depending on the RHN mass. The cross-section limits are significantly stronger for the $e_R^{80} p_L^{30}$ polarization, a result of both a larger signal cross-section and smaller SM background for this polarisation.

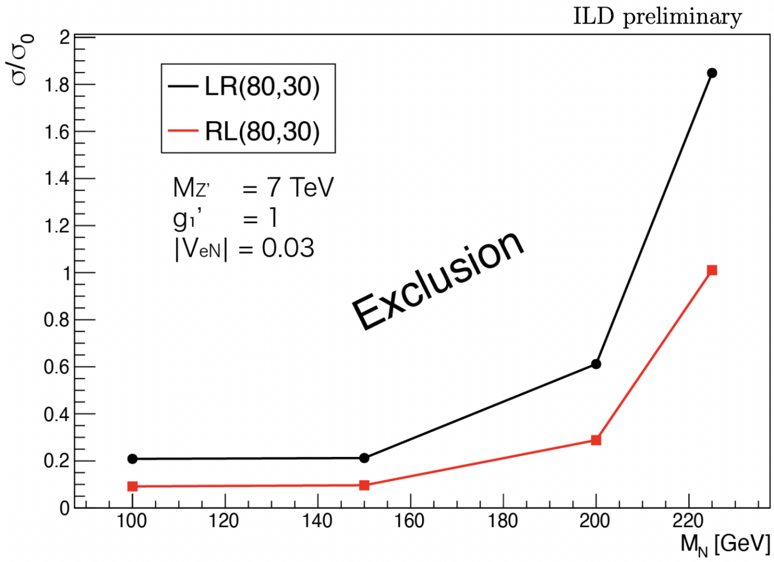

Figure 1: The obtained 95% upper limits on the partial cross-section $\sigma = \sigma(ee \to NN) \times (BR(N \to e^\pm W^\mp))^2$ normalised to the benchmark points' cross-sections σ_0, as a function of M_N. 1600 fb^{-1} of data at ILC-500 in beam polarizations $e_L^{80} p_R^{30}$ (black) and $e_R^{80} p_L^{30}$ (red) are assumed.

This study will be expanded to the di-muon final state, which probes different mixings between the lightest RHN and the SM leptons. The SM backgrounds are expected to be significantly reduced in this case.

References

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