

10/3-95751  
2-3-95751

Conf-940816-80

SLAC-PUB-6591

July 1994

T/E

## EXTENDING THE KINEMATIC RANGE FOR $W_R$ SEARCHES IN $e^-e^-$ COLLISIONS AT THE NLC

Thomas G. Rizzo

*Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, USA*

### ABSTRACT

While the much discussed lepton-number violating process  $e^-e^- \rightarrow W_R^- W_R^-$  provides an excellent probe of both the Majorana nature of the right-handed neutrino and the symmetry breaking sector of the Left-Right Symmetric Model, it is likely that  $W_R$ 's are too massive to be pair produced at the NLC with  $\sqrt{s}$  in the 1-1.5 TeV range. We are thus lead to consider the single  $W_R$  production process  $e^-e^- \rightarrow W_R^-(W_R^-)^* \rightarrow W_R^- + jj$  in order to expand the collider's kinematic reach. After pointing out that  $W_R$ 's with masses of order 1 TeV may be missed by future hadron collider searches, we demonstrate that this three-body process possesses a significant cross section, of order several fb, at the NLC with  $\sqrt{s}$  in the range above. The angular distribution of the produced  $W_R$ 's is shown to be essentially flat and the potential backgrounds from standard model processes are shown to be small.

The possibility of producing like sign pairs of  $W$  bosons in  $e^-e^-$  collisions has been discussed for some time<sup>1</sup>. Such a process, if it exists, signals the existence of new  $|\Delta L| = 2$  interactions which may manifest themselves as Majorana masses for neutrinos. Within the Standard Model(SM) gauge group, it is difficult to generate a large cross section for this reaction while simultaneously satisfying the constraint of tree-level unitarity at large values of the center of mass energy,  $s$ , and the bounds on the effective neutrino mass arising from the lack of observation of neutrinoless double beta decay. These difficulties can be easily circumvented by extending the gauge group to that of the Left-Right Symmetric Model(LRM)<sup>2</sup> and considering instead the reaction  $e^-e^- \rightarrow W_R^- W_R^-$ , where  $W_R$  is the right-handed charged gauge boson. This process occurs quite naturally in the LRM as a result of the see-saw mechanism used to generate small masses for the ordinary 'left-handed' neutrinos.

The amplitude for  $e^-e^- \rightarrow W_R^- W_R^-$  gets both  $t$ - and  $u$ -channel contributions from the exchange of heavy 'right-handed' neutrinos( $N$ ), with mass  $M_N$ , as well as an  $s$ -channel contribution from the exchange of a doubly-charged Higgs boson( $\Delta$ ), with mass  $M_\Delta$ . (Any mixing between the SM  $W$  and  $W_R$  will be neglected in what follows.) Since the  $e^-e^- \Delta$  coupling is proportional to  $M_N$  and the  $e^- N W_R$  coupling is chiral, the total amplitude is found to be proportional to  $M_N$ . Thus, as the Majorana mass of  $N$  vanishes so does the amplitude, which is just what we would expect since

\*Work supported by the Department of Energy, contract DE-AC03-76SF00515.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Presented at the Meeting of the American Physical Society, Division of Particles and Fields(DPF'94), Albuquerque, NM, August 2-6, 1994

MASTER

it is this Majorana mass term which generates the  $|\Delta L| = 2$  interaction. At NLC energies, *i.e.*,  $\sqrt{s} = 0.5 - 1.5$  TeV, the cross section for  $e^-e^- \rightarrow W_R^-W_R^-$  is quite large, of order a few  $pb$ , fairly sensitive to the values of  $M_N$  and  $M_\Delta$ , and has a rather flat angular distribution. The  $s$ -channel  $\Delta$  may appear as a resonance depending upon the value of  $\sqrt{s}$ . Unfortunately, the ‘reach’ is rather limited since we are restricted to  $W_R$  masses less than  $\sqrt{s}/2$  and there are substantial reasons to believe<sup>3</sup> that  $W_R$ ’s are relatively heavy with masses  $M_R \geq 0.5$  TeV. It is reasonable to contemplate that  $W_R$  pair production may not be kinematically accessible at these center of mass energies. This forces us to consider<sup>4</sup> the possibility of *singly* producing  $W_R$ ’s via the reaction  $e^-e^- \rightarrow W_R^-(W_R^-)^* \rightarrow W_R^-jj$ . We limit ourselves to this  $jj$  mode to allow for the possibility that  $M_N > M_R$  in which case  $W_R$  can only decay to  $jj$  barring the existence of exotics. It is interesting to note that all collider searches for  $W_R$  rely on it’s leptonic decay as a trigger; if  $M_N > M_R$  it is quite possible that  $W_R$ ’s may not be observable at the Tevatron or LHC<sup>5</sup> and may be missed until the NLC turns on.

Of course, allowing one of the  $W_R$ ’s to be off-shell we are forced to pay the price of an additional gauge coupling as well as three-body phase space. This results in a substantial reduction in the cross section from the on-shell case to the level of a few  $fb$ . This implies machine luminosities in the range of  $\mathcal{L} = 100 - 200 fb^{-1}$  are required to make use of this channel. The complete expression for the cross section is given in Ref. 4. The total event rates for  $e^-e^- \rightarrow W_R^-(W_R^-)^* \rightarrow W_R^-jj$  are found in Figs. 1 and 2, in which we have set  $\kappa = 1$  and scaled by an integrated luminosity of  $100 fb^{-1}$ . ( $\kappa = g_R/g_L$  is the ratio of the two gauge couplings in the LRM.) Fig. 1a shows the number of expected  $W_R+jj$  events, as a function of  $M_R$ , at a  $\sqrt{s} = 1$  TeV  $e^-e^-$  collider for different choices of  $M_N$  and  $M_\Delta$ . The results are seen to be quite sensitive to the values of these mass parameters even when  $M_R$  is fixed. In Fig. 1b(c), we fix  $M_R = 700$  GeV and plot the event rate as a function of  $M_N(M_\Delta)$  for various values of  $M_\Delta(M_N)$ . Typically, we see event rates of order several hundred/yr except near the  $\Delta$  resonance (where very large rates are obtained) or when  $M_N$  is small (as the cross section vanishes for massless  $N$  since it probes the  $N$ ’s Majorana nature). Increasing  $\sqrt{s}$  to 1.5 TeV, as shown in Fig. 2a, we see substantial cross sections are obtainable even assuming  $W_R$ ’s in the 1-1.2 TeV mass range for some parameter choices. Fixing  $M_R = 1$  TeV in Figs. 2b and c, we again see reasonable event rates for most choices of  $M_N$  and  $M_\Delta$  assuming  $\sqrt{s} = 1.5$  TeV. The exact rate is, however, a sensitive probe of both the  $N$  and  $\Delta$  masses. For most choices of the input masses we obtain extremely flat distributions, however, when  $N$  is light a significant angular dependence is observed. This is simply a result of the  $t$ - and  $u$ - channel poles which develop as  $M_N$  tends to zero. Of course, small  $M_N$  also leads to a small cross section, as shown in Figs. 1 and 2, as might be expected since the matrix element vanishes in this massless limit.

Potential backgrounds to the process  $e^-e^- \rightarrow W_R^-(W_R^-)^* \rightarrow W_R^- + jj$  at the NLC are easily controlled and/or removed. For example, there may be some contamination from the SM process  $e^-e^- \rightarrow W_L^-W_L^-\nu\nu$ , but this can be easily eliminated by using missing energy cuts and demanding that the  $W_R$  final state be reconstructed from either the  $jj$  or  $eN \rightarrow eejj$  decay modes. (Since the on-shell  $W_R$  decays to either  $jj$  or  $eN \rightarrow eejj$  there is no missing energy in the signal process.) In addition, with polarized beams, we can take advantage of the fact that  $W_R$  couples via right-handed

## **DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

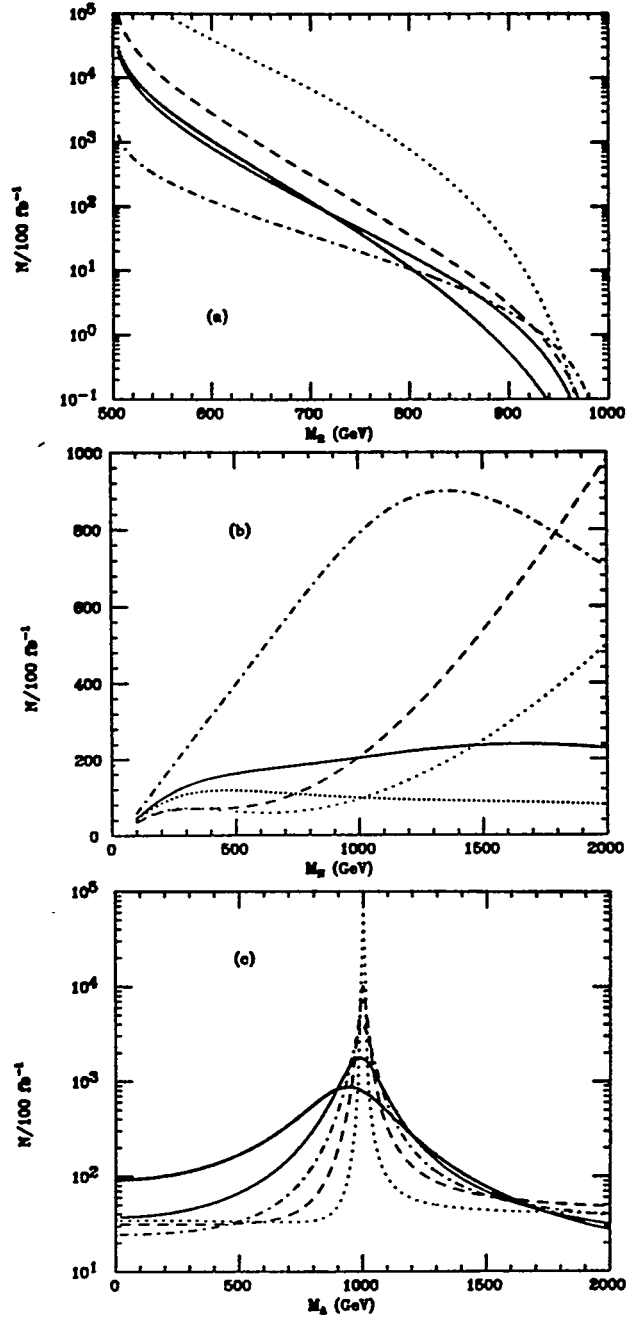


Fig. 1: Event rates per  $100 \text{ fb}^{-1}$  for  $W_R + jj$  production at a  $1 \text{ TeV } e^-e^-$  collider assuming  $\kappa = 1$  (a) as a function of  $M_R$  for  $M_N = M_\Delta = 1 \text{ TeV}$  (dots),  $M_\Delta = 1.2 \text{ TeV}$  and  $M_N = 0.4 \text{ TeV}$  (dashes),  $M_\Delta = 0.3$  and  $M_N = 0.1 \text{ TeV}$  (dash-dots),  $M_\Delta = 2$ ,  $M_N = 0.6 \text{ TeV}$  (solid), or  $M_\Delta = 1.8$  and  $M_N = 0.6 \text{ TeV}$  (square dots); (b) with  $M_R = 700 \text{ GeV}$  fixed as a function of  $M_N$  for  $M_\Delta = 0.3(0.6, 1.2, 1.5, 2) \text{ TeV}$  corresponding to the dotted(dashed, dash-dotted, solid, square-dotted) curve; (c) as a function of  $M_\Delta$  for  $M_N = 0.2(0.5, 0.8, 1.2, 1.5) \text{ TeV}$  corresponding to the dotted(dashed, dash-dotted, solid, square-dotted) curve.

currents while any SM background must arise only via left-handed currents. Within the LRM itself a possible background could arise from a similar lepton-number conserving processes such as  $e^-e^- \rightarrow W_R^- W_R^- N N$ . Even if such a final state could be produced, in comparison to the process we are considering, the subsequent  $N$  decays would lead to a final state with too many charged leptons and/or jets.

In this talk the following points have been addressed: (i) While  $e^-e^- \rightarrow W_R^- W_R^-$  is an excellent probe of both the Majorana nature of  $N$  and the symmetry breaking sector of the Left-Right Symmetric Model, it is more than likely that  $W_R$ 's are too massive to be pair produced at the NLC if  $\sqrt{s} = 1 - 1.5$  TeV forcing us to consider the production of a single on-shell  $W_R$  via the process  $e^-e^- \rightarrow W_R^- (W_R^-)^* \rightarrow W_R^- + jj$ . (ii) Since the pair of on-shell  $W_R$ 's cross section was generally very large, we would expect that the single  $W_R$  rate would be significant if integrated luminosities in the  $100 fb^{-1}$  range were available. From the explicit calculations we found that these expectations were realized for most of the model parameter space with cross sections of order  $1 - 10 fb^{-1}$ . (iii) For values of the input parameters that lead to significant rates, the  $W_R$  angular distribution was found to be rather flat implying that angular cuts will not significantly reduce the cross sections. The rates themselves were found to be quite sensitive to the particular values of the masses of  $N$  and  $\Delta$ . Masses for both these particles beyond the kinematic reach of the NLC were found to be probed by the single  $W_R$  production process.

$e^-e^-$  collisions allow us to probe the Majorana nature of the heavy neutrinos in the LRM even when they are too massive to be directly produced.

## References

1. T.G. Rizzo, *Phys. Lett.* B116, 23 (1982); D. London, G. Belanger, and J.N. Ng, *Phys. Lett.* B188, 155 (1987); J. Maalampi, A. Pietilä, and J. Vuori, *Phys. Lett.* B297, 327 (1992) and Turku University report FL-R9 (1992); M.P. Worah, Enrico Fermi Institute report EFI 92-65 (1992); C.A. Heusch and P. Minkowski, CERN report CERN-TH-6606-92 (1993); see also T.G. Rizzo in, *Proceedings of the Workshop on Physics and Experiments with Linear  $e^+e^-$  Colliders*, Waikoloa, Hawaii, April 1993, edited by F.A. Harris *et al.*, (World Scientific, Singapore, 1993).
2. For a review of the LRM and original references, see R.N. Mohapatra, *Unification and Supersymmetry*, (Springer, New York, 1986).
3. P. Langacker and S.U. Sankar, *Phys. Rev.* D40, 1569 (1989); F. Abe *et al.*, CDF Collaboration, *Phys. Rev. Lett.* 67, 2609 (1991) and *Phys. Rev. Lett.* 68, 1464 (1992); see also the CDF and D0 Collaboration talks given at the *9th Topical Workshop on Proton-Antiproton Collider Physics*, Tsukuba, Japan, October 1993. For an overview, see T.G. Rizzo, *Phys. Rev.* D50, 325 (1994).
4. T.G. Rizzo, SLAC report SLAC-PUB-6475, 1994.
5. A. Datta, M. Guchait, and D.P. Roy, *Phys. Rev.* D47, 961 (1993); D. Gingrich *et al.*, ATLAS Collaboration Letter of Intent, CERN report LHCC/12, (1992); A. Henriques and L. Poggioli, ATLAS Collaboration Note PHYS-NO-010, (1992); T.G. Rizzo, *Phys. Rev.* D48, 4236 (1993).

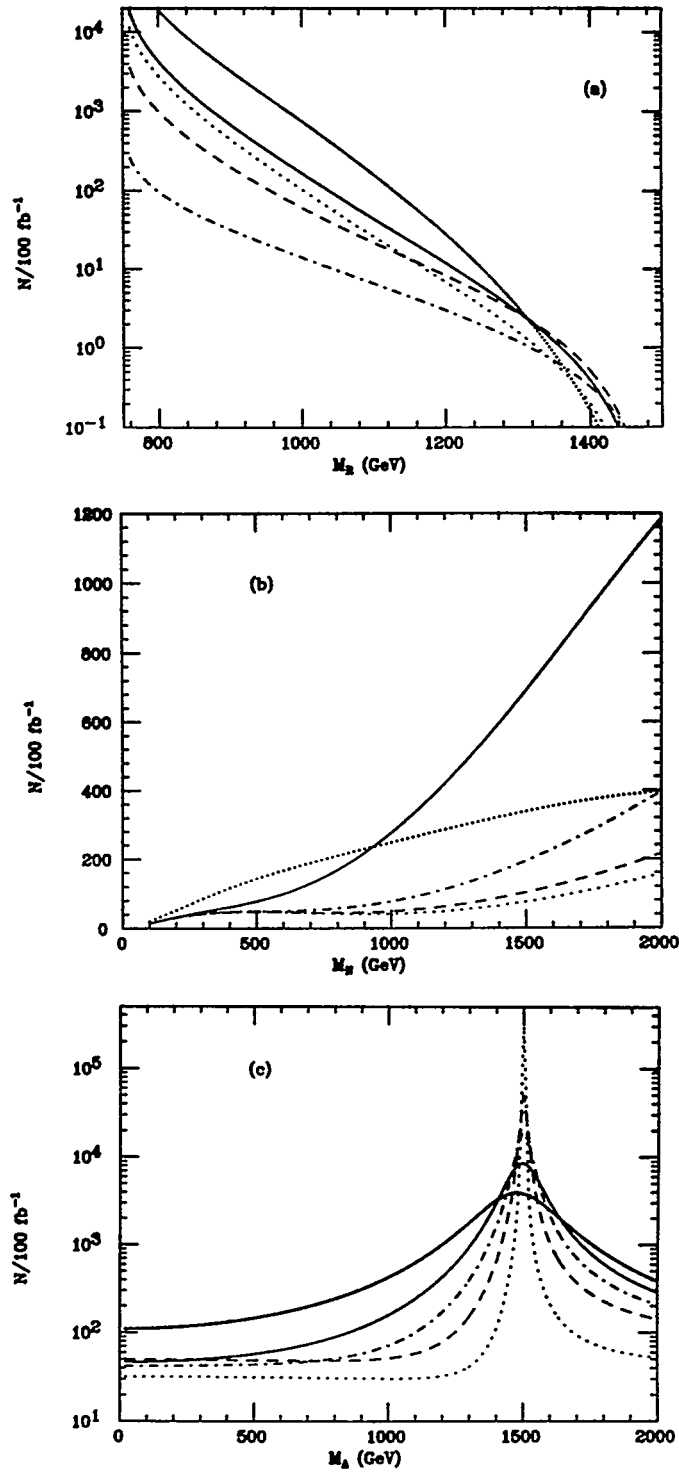


Fig. 2: Same as Fig. 1, but for a 1.5 TeV  $e^-e^-$  collider. In (b) and (c), a  $W_R$  mass of 1 TeV is assumed.