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

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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\cite{1}. 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)\cite{2} 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 $e^-NW_R$ 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
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 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 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 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 $L = 100 - 200 fb^{-1}$ 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 $e^-e^- \rightarrow W_L^{-}W_L^-\nu\bar{\nu}$, 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
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. 1: Event rates per $100 fb^{-1}$ for $W_R + jj$ production at a 1 TeV $e^-e^-$ collider assuming $\kappa = 1$ (a) as a function of $M_R$ for $M_N = M_\Delta = 1$ TeV (dots), $M_\Delta = 1.2$ TeV and $M_N = 0.4$ TeV (dashes), $M_\Delta = 0.3$ and $M_N = 0.1$ TeV (dash-dots), $M_\Delta = 2$, $M_N = 0.6$ TeV (solid), or $M_\Delta = 1.8$ and $M_N = 0.6$ TeV (square dots); (b) with $M_R = 700$ GeV fixed as a function of $M_N$ for $M_\Delta = 0.3(0.6,1.2,1.5,2)$ TeV corresponding to the dotted(dashed, dash-dotted, solid, square-dotted) curve; (c) as a function of $M_\Delta$ for $M_N = 0.2(0.5,0.8,1.2,1.5)$ TeV corresponding to the dotted(dashed, dash-dotted, solid, square-dotted) curve.

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.
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