

## DISTINGUISHING INDIRECT SIGNATURES ARISING FROM NEW PHYSICS AT THE NLC <sup>a</sup>

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Many sources of new physics can lead to shifts in the Standard Model predictions for cross sections and asymmetries at the NLC below their direct production thresholds. In this talk we discuss some of the tools that are useful for distinguishing amongst these new physics scenarios.  $R$ -parity violation and extensions of the Standard Model gauge structure are two typical non-minimal realizations of supersymmetry which provide us with an important test case to examine.

While the MSSM provides a simplified framework in which to work, most would agree that the MSSM is itself inadequate due to the very large number of free parameters it contains. In going beyond the MSSM there are many possible paths to follow. In this talk we discuss two of the simplest of these scenarios: an extension of the SM gauge group by an additional  $U(1)$  factor broken near the TeV scale and  $R$ -parity violation, both of which are well-motivated by string theory. Although these two alternatives would appear to have little in common they can lead to similar phenomenology at future linear colliders and may be easily confused in certain regions of the parameter space for each class of model. This is a particular example of a more general situation wherein various distinct classes of new physics models can lead to similar experimental signatures at colliders that differ only in detail. The purpose of the present analysis is to explore the tools that can be used to distinguish these scenarios at  $e^+e^-$  colliders<sup>1</sup> which can be then applied to other more complex scenarios<sup>2</sup>.

If  $R$ -parity is violated it is possible that the exchange of sparticles can contribute significantly to SM processes and may even be produced as bumps<sup>3</sup> in cross sections if they are kinematically accessible. Below threshold, these new spin-0 exchanges may make their presence known via indirect effects on cross sections and other observables even when they occur in the  $t$ - or  $u$ -channels. Here we will address the question of whether the effects of the exchange of such particles can be differentiated from those conventionally associated with a  $Z'$  below threshold at linear colliders. If just the  $R$ -parity violating  $\lambda LLE^c$  terms of the superpotential are present it is clear that only the observables associated with leptonic processes will be affected

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by the exchange of  $\tilde{\nu}$ 's in the (i)  $t$ - or (ii)  $s$ -channels (in the case of  $e^+e^- \rightarrow \mu^+\mu^-/\tau^+\tau$ ) or (iii) both (for the case of Bhabha scattering). [The generalization to include hadronic final states is reasonably straightforward.] In making the  $Z'$  vs  $\tilde{\nu}$  comparison it is important to remember that in the  $Z'$  case, for the  $\mu^+\mu^-$  and  $\tau^+\tau$  final states, the angular distributions retain their SM forms,  $\sim A(1+z)^2 + B(1-z)^2$ , where  $z = \cos\theta$ , but with the  $s$ -dependent constants  $A, B$  get shifted from their SM values. In the case  $\tilde{\nu}$  exchange the angular distribution is modified in a more complex manner. It is also important to remember that we must in principle allow the  $Z'$  couplings to fermions,  $g_{L,R}^{f'}$ , to be completely arbitrary in our discussion below in order to avoid any model dependence. We note that in all cases the single beam polarization asymmetry,  $A_{LR}$ , does not help to separate these two new physics sources when only leptonic final states are involved.

In case (i) the  $\tilde{\nu}$  exchange leaves the SM value of  $A$  unchanged while adding a  $z$ -dependent contribution to  $B$ . By contrast a generic  $Z'$  will modify both  $A$  and  $B$  leading to distortions in the angular distribution in both the forward and backward directions depending upon the details of the  $Z'$  couplings. Fig. 1 shows the resulting change in the distribution for  $\tilde{\nu}$  exchange; note that the cross section in the forward direction is left unaltered. Fig. 2 shows the corresponding  $Z'$  induced shifts for comparison. Fig. 1 also shows that fits to  $A, B$  should be able to isolate the  $\tilde{\nu}$  scenario except in conspiratorial parameter space regions with suitably chosen  $Z'$  couplings. With luminosities of  $150 \text{ fb}^{-1}$ , except for these conspiratorial cases, the two scenarios remain separable up to  $m_{\tilde{\nu}} \simeq (7-8)\lambda \text{ TeV}$ . We note that with only low statistics the  $z$ -dependence of  $B$  may not be visible and only a general average shift in its value is obtained from the fit. At some point however, enough statistics can be accumulated such that fits with  $B$  constant give bad  $\chi^2$ 's. For a luminosity of  $200 \text{ fb}^{-1}$  at a TeV collider we estimate that this occurs when  $m_{\tilde{\nu}} \leq 2.4\lambda \text{ TeV}$ . Though the reach is much smaller, in this case there is no confusion with the  $Z'$  scenario.

In case (ii) where the  $\tilde{\nu}$  is exchanged in the  $s$ -channel, the angular distribution gets modified to  $\sim A(1+z)^2 + B(1-z)^2 + C$  with  $A, B$  taking on their SM values and  $C$  being a constant for fixed  $s$ . While  $Z'$  exchange will lead to a good fit for some values of  $A, B$ , this will not happen in the  $\tilde{\nu}$  case. The result of this analysis is shown in Fig. 3 where we see that the fit fails when  $m_{\tilde{\nu}} \simeq (3.3-4.0)\lambda \text{ TeV}$ . In the case where  $\tau$  pairs are produced further sensitivity can be gained by constructing the spin-spin correlation,  $B_{zz}$ , as introduced by Bar-Shalom, Eilam and Soni<sup>3</sup>. This quantity is unity in the SM as well as in extended gauge models but can be substantially smaller when  $s$ -channel scalars are present as shown in Fig. 3. Given the small statistical error anticipated at future colliders,  $B_{zz}$  offers sensitivity to  $\tilde{\nu}$  mass as large as  $(4-6)\lambda \text{ TeV}$  from the  $\tau$  pair channel. In the case of the  $\mu$  pair final state a similar asymmetry can be constructed provided both  $e^\pm$  beams can be polarized:

$$A_{double} = \frac{\sigma(+,+) + \sigma(-,-) - \sigma(-,+) - \sigma(+,-)}{\sigma(+,+) + \sigma(-,-) + \sigma(-,+) + \sigma(+,-)}. \quad (1)$$

where  $\pm$  refer to the incoming  $e^-$  and  $e^+$  polarizations.  $A_{double}$  takes on a fixed value in both the SM and in all  $Z'$  models which is determined by the available beam

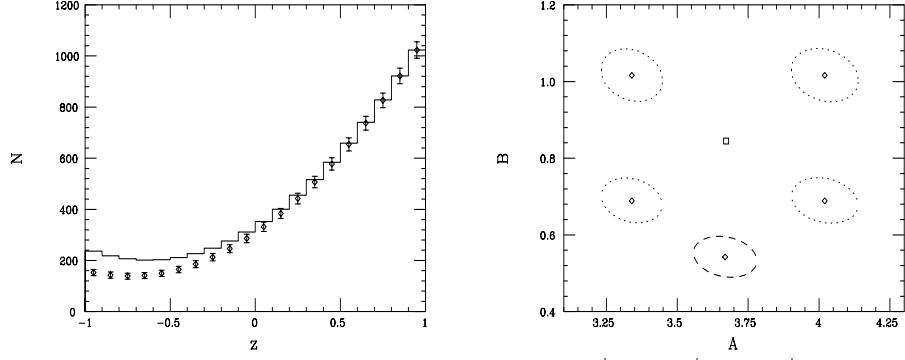


Figure 1: (Left) Binned angular distribution for the process  $e^+e^- \rightarrow \mu^+\mu^-$  or  $\tau^+\tau^-$  at a 1 TeV NLC in the SM (histogram) and for the case where a 3 TeV  $\tilde{\nu}$  with  $\lambda = 0.5$  exchanged in the  $t$ -channel also contributes assuming an integrated luminosity of  $L = 150 \text{ fb}^{-1}$ . (Right) 95% CL fits to the values of  $A$  and  $B$  for the data generated with  $\tilde{\nu}$  exchange(dashed region) and for the data generated for the four typical choices of  $Z'$  couplings(dots) employed in Fig. 2. The SM result is represented by the square in the center of the figure while the diamonds are the locations of the best fits.

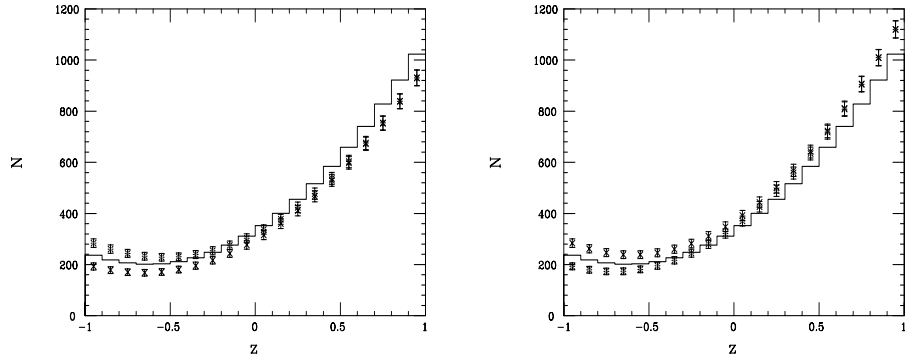


Figure 2: Same as the left panel of the previous figure but now including a 3 TeV  $Z'$  exchange in the  $s$ -channel. The magnitude of all  $Z'$  couplings is taken to be the same value, *i.e.*,  $|g_{L,R}^{e',f'}| = 0.3c$ , for purposes of demonstration. In the left panel, the relative signs of  $(g_L^{e'}, g_R^{e'}, g_L^{f'}, g_R^{f'})$  are chosen to be  $(+, -, +, -)[(+, +, +, +)]$  for the upper[lower] series of data points, while in the right panel they correspond to the choices  $(+, -, -, +)[(+, +, -, -)]$  for the upper[lower] series, respectively.

polarizations. For example at a 1 TeV collider with  $P_{e-} = 90\%$  and  $P_{e+} = 65\%$ , one finds  $A_{double} = 0.585$ . However in the case of  $\tilde{\nu}$  exchange the value of  $A_{double}$  can be significantly reduced. The reach in this variable is found to be very comparable to that obtained from  $B_{zz}$ , *i.e.*,  $m_{\tilde{\nu}} \simeq (4 - 6)\lambda$  TeV.

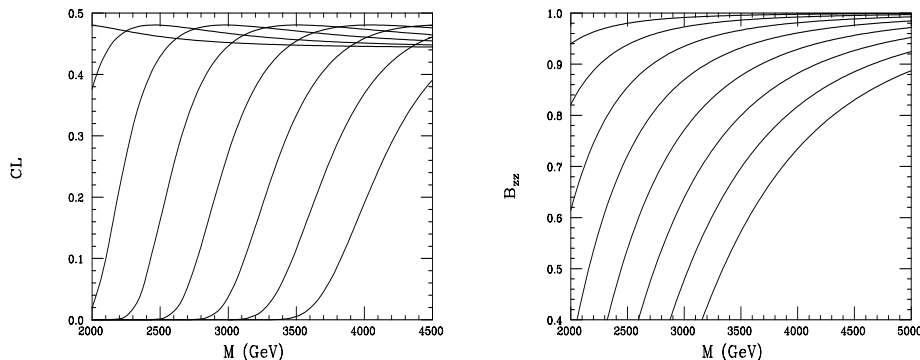


Figure 3: (Left) Average confidence level of the best fit to the parameters  $A$  and  $B$  as a function of the  $\tilde{\nu}$  mass in the case of  $s$ -channel  $\tilde{\nu}$  exchange for various values of the Yukawa coupling  $\lambda$  in the range 0.3 to 1.0 in steps of 0.1 from top left to lower right. (Right) Double  $\tau$  spin asymmetry at a 1 TeV NLC as a function of the  $\tilde{\nu}$  mass for different values of the Yukawa coupling  $\lambda$ . From left to right,  $\lambda$  varies from 0.3 to 1.0 in steps of 0.1 as in the left panel. In the case of either the SM or a  $Z'$ ,  $B_{zz} = 1$ .

The final and most difficult case to examine is *(iii)* Bhabha scattering since  $s$ - and  $t$ -channels exchanges are simultaneously present for both the  $Z'$  and  $\tilde{\nu}$  cases. To examine this cross section in any detail angular cuts are necessary to remove the photon pole; a cut  $|z| < 0.95$  will be assumed here which also removes a large SM background. Fig. 4 shows the contributions to Bhabha scattering from either a  $Z'$  or  $\tilde{\nu}$  exchange assuming an integrated luminosity of  $150 \text{ fb}^{-1}$  at a 1 TeV collider. Note that the  $\tilde{\nu}$  exchange leads to an increase in the cross section in the backwards direction while  $Z'$  exchange may either increase or decrease the cross section there. The distribution in the forward direction is little influenced by either type of new physics. In Fig. 4 we see that if the product of the left- and right-handed couplings to the  $Z'$  is  $> 0$  we will not be able to separate a  $Z'$  from  $\tilde{\nu}$  contribution. This result remains true even if the double polarization asymmetry,  $A_{double}$ , is employed and this ambiguity remains.

In this talk we have considered the problem of how to distinguish two potential new physics scenarios from each other below the threshold for direct production of new particles at the NLC:  $R$ -parity violation and an extension of the SM gauge group by an additional  $U(1)$  factor. Both kinds of new physics can lead to qualitatively similar alterations in SM cross sections, angular distributions and various asymmetries but differ in detail. These detailed differences provide the key to the two major weapons that are useful in accomplishing our task: *(i)* the angular distribution of the final state fermion and *(ii)* an asymmetry formed by polarizing both beams in the initial state,  $A_{double}$ . The traditional asymmetry,  $A_{LR}$ , formed when only a single beam is polarized, was shown<sup>1</sup> not to be useful for the case of purely

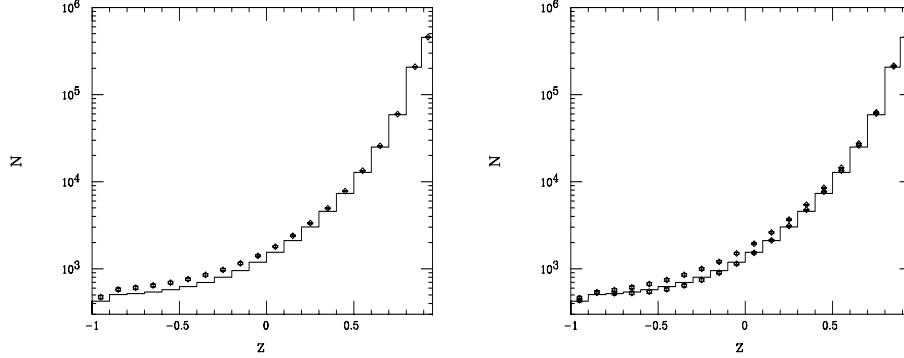


Figure 4: (Left) Same as left panel in Fig.1 but now for the case of Bhabha scattering. Angular cuts as described in the text have been employed to render the cross section finite in the forward direction. (Right) Same as the left panel but now for a 3 TeV  $Z'$  in comparison to the SM. The upper(lower) set of data points corresponds to  $g_L^{e'} = g_R^{e'} = 0.5c(g_L^{e'} = -g_R^{e'} = 0.5c)$ .

leptonic processes we considered, but will be useful in an extension of the analysis to hadronic final states. This same analysis employed above can be easily extended to other new physics scenarios which involve the exchange on new particles<sup>2</sup> as in the case of massive graviton exchange in theories with compactified dimensions.

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