

Sneutrino Identification in Lepton Pair Production at ILC with Polarized Beams

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Numerous non-standard dynamics are described by contact-like effective interactions that can manifest themselves in electron-positron collisions only through deviations of the observables (cross sections, asymmetries) from the Standard Model predictions. If such a deviation were observed, it would be important to identify the actual source among the possible non-standard interactions as many different new physics scenarios may lead to very similar experimental signatures. We study the possibility of uniquely identifying the indirect effects of s -channel sneutrino exchange, as predicted by supersymmetric theories with R -parity violation, against other new physics scenarios in high-energy e^+e^- annihilation into lepton pairs at the International Linear Collider. These competitive models are interactions based on gravity in large and in TeV-scale extra dimensions, anomalous gauge couplings, Z' vector bosons and compositeness-inspired four-fermion contact interactions. To evaluate the identification reach on sneutrino exchange, we use as basic observable a double polarization asymmetry, that is particularly suitable to directly test for such s -channel sneutrino exchange effects in the data analysis. The availability of both beams being polarized plays a crucial rôle in identifying the new physics scenario.

1 Introduction

Numerous new physics (NP) scenarios, candidates as solutions of Standard Model (SM) conceptual problems, are characterized by novel interactions mediated by exchanges of very heavy states with mass scales significantly greater than the electroweak scale. In many cases, theoretical considerations as well as current experimental constraints indicate that the new objects may be too heavy to be directly produced even at the highest energies of the CERN Large Hadron Collider (LHC) and at foreseen future colliders, such as the e^+e^- International Linear Collider (ILC). In this situation the new, non-standard, interactions would only be revealed by indirect, virtual, effects manifesting themselves as deviations from the predictions of the SM. In the case of indirect discovery the effects may be subtle since many different NP scenarios may lead to very similar experimental signatures and they may easily be confused in certain regions of the parameter space for each class of models.

At the available energies provided by the accelerators, where we study reactions among the familiar SM particles, effective contact interaction Lagrangians represent a convenient theoretical tool to physically parameterize the effects of the above-mentioned non-standard interactions and, in particular, to test the corresponding virtual high-mass exchanges. There are many very different NP scenarios that predict new particle exchanges which can lead to contact interactions (CI) which may show up below direct production thresholds. These are compositeness [1], a Z' boson from models with an extended gauge sector [2–5], scalar or vector leptoquarks [6], R -parity violating sneutrino ($\tilde{\nu}$) exchange [7, 8], bi-lepton boson exchanges [9], anomalous gauge boson couplings (AGC) [10], virtual Kaluza–Klein (KK) graviton exchange in the context of gravity propagating in large extra dimensions, exchange of KK gauge boson towers or string excitations [11–16], *etc.* Of course, this list is not exhaustive, because other kinds of contact interactions may be at play.

If R -parity is violated it is possible that the exchange of sparticles can contribute significantly to SM processes and may even produce peaks or bumps [7, 8] in cross sections if they are kinematically accessible. Below threshold, these new spin-0 exchanges may make their manifestation known via indirect effects on observables (cross sections and asymmetries), including spectacular decays [17]. Here we will address the question of whether the effects of the exchange of scalar (spin-0) sparticles can be differentiated at linear colliders from those associated with the wide class of other contact interactions mentioned above.

For a sneutrino in an R -parity-violating theory, we take the basic couplings to leptons and quarks to be given by

$$\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k. \quad (1)$$

Here, L (Q) are the left-handed lepton (quark) doublet superfields, and \bar{E} (\bar{D}) are the corresponding left-handed singlet fields. If just the R -parity violating $\lambda L L \bar{E}$ terms of the superpotential are present it is clear that observables associated with leptonic processes

$$e^+ + e^- \rightarrow \mu^+ + \mu^- \quad (\text{or } \tau^- + \tau^+), \quad (2)$$

will be affected by the exchange of $\tilde{\nu}$'s in the t - or s -channels [7, 8]. For instance, in the case only one nonzero Yukawa coupling is present, $\tilde{\nu}$'s may contribute to, e.g. $e^+e^- \rightarrow \mu^+\mu^-$ via t -channel exchange. In particular, if λ_{121} , λ_{122} , λ_{132} , or λ_{231} are nonzero, the $\mu^+\mu^-$ pair production proceeds via additional t -channel sneutrino exchange mechanism. However, if only the product of Yukawa, e.g. $\lambda_{131}\lambda_{232}$, is nonzero the s -channel $\tilde{\nu}_\tau$ exchange would contribute to the $\mu^+\mu^-$ pair final state. Below we denote by λ the relevant Yukawa coupling from the superpotential (1) omitting the subscripts.

In this note, we discuss the deviations induced by the s -channel sneutrino exchange and contact interactions in electron-positron annihilation into lepton pairs (2) at the planned ILC. In particular, we use as a basic observable a double polarization asymmetry that will unambiguously identify s -channel sneutrino exchange effects in the data, relying on its spin-0 character and by *filtering* out contributions of other NP interactions.¹ The availability of both beams being polarized plays a crucial rôle in identifying that new physics scenario [18]. On the other hand, we note that if only single (electron) beam polarization is available, the left-right asymmetry does not help to unambiguously identify an s -channel sneutrino exchange signature.²

The R -parity violating s -channel sneutrino exchange in the process (2) requires a non-zero coupling λ_{131} (λ_{121}). This would necessarily induce non-standard contributions to Bhabha scattering,

$$e^+ + e^- \rightarrow e^+ + e^-, \quad (3)$$

which we also study, in order to compare the sensitivities in these channels.

We also compare the capability of the ILC to distinguish effects of s -channel sneutrino exchange in the lepton pair production process from other NP interactions with the corresponding potential of the Drell-Yan process ($l = e, \mu$) [19]

$$p + p \rightarrow l^+ + l^- + X \quad (4)$$

at the LHC.

For completeness, we will in Sec. 2 recall a minimum of relevant formulae defining the basic observables used in our analysis. In Sec. 3 we perform the numerical analysis, evaluating discovery and identification reaches on sneutrinos. Finally, Sec. 4 contains some concluding remarks.

2 Observables and NP parametrization

We concentrate on the process $e^+ + e^- \rightarrow \mu^+ + \mu^-$. With P^- and P^+ denoting the longitudinal polarizations of the electrons and positrons, respectively, and θ the angle between the incoming electron and the outgoing muon in the c.m. frame, the differential cross section in the presence of contact interactions can be expressed as ($z \equiv \cos \theta$) [20, 21]:

$$\frac{d\sigma^{\text{CI}}}{dz} = \frac{3}{8} [(1+z)^2 \sigma_+^{\text{CI}} + (1-z)^2 \sigma_-^{\text{CI}}]. \quad (5)$$

¹This approach was earlier exploited for the discrimination against Z' exchange [8].

²For the case of single beam polarization, A_{LR} is an analogue of A_{double} defined by Eq. (16).

Model	$\Delta_{\alpha\beta}$
composite fermions [1]	$\pm \frac{s}{\alpha_{\text{em}} \Lambda_{\alpha\beta}^2}$
extra gauge boson Z' [2-5]	$g_{\alpha}^{\prime e} g_{\beta}^{\prime f} \chi_{Z'}$
AGC ($f = \ell$) [10]	$\Delta_{\text{LL}} = s \left(\frac{\tilde{f}_{DW}}{2s_W^2} + \frac{2\tilde{f}_{DB}}{c_W^2} \right), \frac{\Delta_{\text{RR}}}{2} = \Delta_{\text{LR}} = \Delta_{\text{RL}} = s \frac{4\tilde{f}_{DB}}{c_W^2}$
TeV-scale extra dim. [15,16]	$-(Q_e Q_f + g_{\alpha}^e g_{\beta}^f) \frac{\pi^2 s}{3 M_C^2}$
ADD model [11,13]	$\Delta_{\text{LL}} = \Delta_{\text{RR}} = f_G (1 - 2z), \Delta_{\text{LR}} = \Delta_{\text{RL}} = -f_G (1 + 2z)$
R -parity violating SUSY [7,8] ($\tilde{\nu}$ exchange in t -channel)	$\Delta_{\text{LL}} = \Delta_{\text{RR}} = 0, \Delta_{\text{LR}} = \Delta_{\text{RL}} = \frac{1}{2} C_{\tilde{\nu}}^t \chi_{\tilde{\nu}}^t$

Table 1: Parametrization of the $\Delta_{\alpha\beta}$ functions in different NP models ($\alpha, \beta = \text{L, R}$). For the explanation of notation see text.

In terms of the helicity cross sections $\sigma_{\alpha\beta}^{\text{CI}}$ (with $\alpha, \beta = \text{L, R}$), directly related to the individual CI couplings $\Delta_{\alpha\beta}$ (see Eq. (10)):

$$\begin{aligned} \sigma_+^{\text{CI}} &= \frac{1}{4} [(1 - P^-)(1 + P^+) \sigma_{\text{LL}}^{\text{CI}} + (1 + P^-)(1 - P^+) \sigma_{\text{RR}}^{\text{CI}}] \\ &= \frac{D}{4} [(1 - P_{\text{eff}}) \sigma_{\text{LL}}^{\text{CI}} + (1 + P_{\text{eff}}) \sigma_{\text{RR}}^{\text{CI}}], \end{aligned} \quad (6)$$

$$\begin{aligned} \sigma_-^{\text{CI}} &= \frac{1}{4} [(1 - P^-)(1 + P^+) \sigma_{\text{LR}}^{\text{CI}} + (1 + P^-)(1 - P^+) \sigma_{\text{RL}}^{\text{CI}}] \\ &= \frac{D}{4} [(1 - P_{\text{eff}}) \sigma_{\text{LR}}^{\text{CI}} + (1 + P_{\text{eff}}) \sigma_{\text{RL}}^{\text{CI}}], \end{aligned} \quad (7)$$

where the first (second) subscript refers to the chirality of the electron (muon) current. Furthermore,

$$P_{\text{eff}} = \frac{P^- - P^+}{1 - P^- P^+} \quad (8)$$

is the effective polarization, $|P_{\text{eff}}| \leq 1$, and $D = 1 - P^- P^+$. For unpolarized positrons $P_{\text{eff}} \rightarrow P^-$ and $D \rightarrow 1$, but with $P^+ \neq 0$, $|P_{\text{eff}}|$ can be larger than $|P^-|$. Moreover, in Eqs. (6) and (7):

$$\sigma_{\alpha\beta}^{\text{CI}} = \sigma_{\text{pt}} |\mathcal{M}_{\alpha\beta}^{\text{CI}}|^2, \quad (9)$$

where $\sigma_{\text{pt}} \equiv \sigma(e^+ e^- \rightarrow \gamma^* \rightarrow \mu^+ \mu^-) = (4\pi\alpha_{\text{em}}^2)/(3s)$. The helicity amplitudes $\mathcal{M}_{\alpha\beta}^{\text{CI}}$ can be written as

$$\mathcal{M}_{\alpha\beta}^{\text{CI}} = \mathcal{M}_{\alpha\beta}^{\text{SM}} + \Delta_{\alpha\beta} = Q_e Q_{\mu} + g_{\alpha}^e g_{\beta}^{\mu} \chi_{Z} + \Delta_{\alpha\beta}, \quad (10)$$

where

$$\chi_Z = \frac{s}{s - M_Z^2 + iM_Z \Gamma_Z} \quad (11)$$

represents the Z propagator, $g_L^l = (I_{3L}^l - Q_l s_W^2)/s_W c_W$ and $g_R^l = -Q_l s_W^2/s_W c_W$ are the SM left- and right-handed lepton ($l = e, \mu$) couplings of the Z with $s_W^2 = 1 - c_W^2 \equiv \sin^2 \theta_W$ and Q_l the leptonic electric charge. The $\Delta_{\alpha\beta}$ functions represent the contact interaction contributions coming from TeV-scale physics.

The structure of the differential cross section (5) is particularly interesting in that it is equally valid for a wide variety of NP models listed in Table 1. Note that only graviton and t -channel sneutrino exchanges induce a modified angular dependence to the differential cross section via the z -dependence of $\Delta_{\alpha\beta}$.

In Table 1 $\Lambda_{\alpha\beta}$ denote compositeness scales; $\chi_{Z'}$ and $\chi_{\tilde{\nu}}^t$ parametrize the Z' and sneutrino propagators defined analogously to Eq. (11), with superscript t referring to the t -channel, e.g., $\chi_{\tilde{\nu}}^t = s/(t - M_{\tilde{\nu}}^2)$, where $M_{\tilde{\nu}}$ is the sneutrino mass. For the t -channel $\tilde{\nu}$ sneutrino exchange $C_{\tilde{\nu}}^t = \lambda^2/4\pi\alpha_{\text{em}}$ with λ being the relevant

Yukawa coupling. $g'_\alpha f$ parametrizes the Z' couplings to the f current of chirality α . Furthermore, \tilde{f}_{DW} and \tilde{f}_{DB} are related to f_{DW} and f_{DB} of ref. [10] by $\tilde{f} = f/m_t^2$ (f_{DW} and f_{DB} parametrize new-physics effects associated with the SU(2) and hypercharge currents, respectively); M_C is the compactification scale; $f_G = \pm s^2/(4\pi\alpha_{\text{em}}M_H^4)$ parametrizes the strength associated with massive graviton exchange with M_H the cut-off scale in the KK graviton tower sum.

The doubly polarized total cross section can be obtained from Eq. (5) after integration over z within the interval $-1 \leq z \leq 1$. In the limit of s, t small compared to the CI mass scales, the result takes the form

$$\sigma^{\text{CI}} = \sigma_+^{\text{CI}} + \sigma_-^{\text{CI}} = \frac{1}{4} [(1 - P^-)(1 + P^+) (\sigma_{\text{LL}}^{\text{CI}} + \sigma_{\text{LR}}^{\text{CI}}) + (1 + P^-)(1 - P^+) (\sigma_{\text{RR}}^{\text{CI}} + \sigma_{\text{RL}}^{\text{CI}})]. \quad (12)$$

It is clear that the formula in the SM has the same form where one should replace the superscript CI \rightarrow SM in Eq. (12).

Since the $\tilde{\nu}$ exchanged in the s -channel does not interfere with the s -channel SM γ and Z exchanges, the differential cross section with both electron and positron beams polarized can be written as [8, 22]

$$\frac{d\sigma^{\tilde{\nu}}}{dz} = \frac{3}{8} \left[(1+z)^2 \sigma_+^{\text{SM}} + (1-z)^2 \sigma_-^{\text{SM}} + 2 \frac{1+P^-P^+}{2} (\sigma_{\text{RL}}^{\tilde{\nu}} + \sigma_{\text{LR}}^{\tilde{\nu}}) \right]. \quad (13)$$

Here, $\sigma_{\text{RL}}^{\tilde{\nu}} (= \sigma_{\text{LR}}^{\tilde{\nu}}) = \sigma_{\text{pt}} |\mathcal{M}_{\text{RL}}^{\tilde{\nu}}|^2$, $\mathcal{M}_{\text{RL}}^{\tilde{\nu}} = \mathcal{M}_{\text{LR}}^{\tilde{\nu}} = \frac{1}{2} C_{\tilde{\nu}}^s \chi_{\tilde{\nu}}^s$, and $C_{\tilde{\nu}}^s$ and $\chi_{\tilde{\nu}}^s$ denote the product of the R -parity violating couplings and the propagator of the exchanged sneutrino. For the s -channel $\tilde{\nu}_\tau$ sneutrino exchange they read

$$C_{\tilde{\nu}}^s \chi_{\tilde{\nu}}^s = \frac{\lambda_{131} \lambda_{232}}{4\pi\alpha_{\text{em}}} \frac{s}{s - M_{\tilde{\nu}_\tau}^2 + iM_{\tilde{\nu}_\tau} \Gamma_{\tilde{\nu}_\tau}} \quad (14)$$

Below we will use the abbreviation $\lambda^2 = \lambda_{131} \lambda_{232}$.

As seen from Eq. (13) the polarized differential cross section picks up a z -independent term in addition to the SM part. The corresponding total cross section can be written as

$$\begin{aligned} \sigma^{\tilde{\nu}} &= \frac{1}{4} (1 - P^-)(1 + P^+) (\sigma_{\text{LL}}^{\text{SM}} + \sigma_{\text{LR}}^{\text{SM}}) + \frac{1}{4} (1 + P^-)(1 - P^+) (\sigma_{\text{RR}}^{\text{SM}} + \sigma_{\text{RL}}^{\text{SM}}) \\ &+ \frac{3}{2} \frac{1 + P^-P^+}{2} (\sigma_{\text{RL}}^{\tilde{\nu}} + \sigma_{\text{LR}}^{\tilde{\nu}}). \end{aligned} \quad (15)$$

It is possible to uniquely identify the effect of the s -channel sneutrino exchange exploiting the double beam polarization asymmetry defined as [8, 22]

$$A_{\text{double}} = \frac{\sigma(P_1, -P_2) + \sigma(-P_1, P_2) - \sigma(P_1, P_2) - \sigma(-P_1, -P_2)}{\sigma(P_1, -P_2) + \sigma(-P_1, P_2) + \sigma(P_1, P_2) + \sigma(-P_1, -P_2)}, \quad (16)$$

where $P_1 = |P^-|$, $P_2 = |P^+|$. It can easily be checked for the whole set of contact interactions listed in Table 1, with the exception of the s -channel sneutrino exchange, that from (12) and (16) one finds

$$A_{\text{double}}^{\text{SM}} = A_{\text{double}}^{\text{CI}} = P_1 P_2 = 0.48, \quad (17)$$

where the numerical value corresponds to electron and positron degrees of polarization: $P_1 = 0.8$, $P_2 = 0.6$. This is because these contact interactions contribute to the same amplitudes as shown in (10). Eq. (17) demonstrates that $A_{\text{double}}^{\text{SM}}$ and $A_{\text{double}}^{\text{CI}}$ are indistinguishable for any values of the contact interaction parameters, $\Delta_{\alpha\beta}$, i.e. $\Delta A_{\text{double}} = A_{\text{double}}^{\text{CI}} - A_{\text{double}}^{\text{SM}} = 0$.

On the contrary, the $\tilde{\nu}$ exchange in the s -channel will force this observable to a smaller value, $\Delta A_{\text{double}} = A_{\text{double}}^{\tilde{\nu}} - A_{\text{double}}^{\text{SM}} \propto -P_1 P_2 |C_{\tilde{\nu}}^s \chi_{\tilde{\nu}}^s|^2 < 0$. The value of A_{double} below $P_1 P_2$ can provide a signature of scalar exchange in the s -channel. All those features in the A_{double} behavior are shown in Fig. 1.

The non-zero value of the λ_{131} coupling implies that the Bhabha scattering process will receive $\tilde{\nu}_\tau$ contributions from both the s - and t -channel exchanges. The differential cross section can be written in this

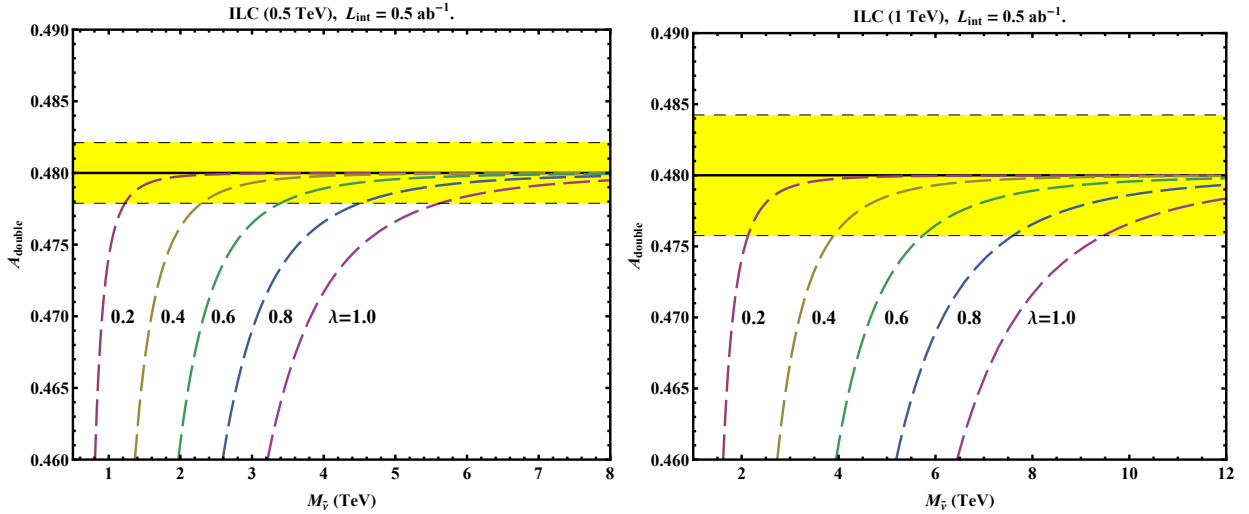


Figure 1: Double beam polarization asymmetry $A_{\text{double}}^{\bar{\nu}}$ as a function of sneutrino mass $M_{\bar{\nu}}$ for different choices of λ (dashed lines) at the ILC with $\sqrt{s} = 0.5$ TeV (left panel) and $\sqrt{s} = 1.0$ TeV (right panel), $\mathcal{L}_{\text{int}} = 0.5 \text{ ab}^{-1}$. From left to right, λ varies from 0.2 to 1.0 in steps of 0.2. The solid horizontal line corresponds to $A_{\text{double}}^{\text{SM}} = A_{\text{double}}^{\text{CI}}$. The yellow bands indicate the expected uncertainty in the SM case.

case as

$$\begin{aligned} \frac{d\sigma^{\bar{\nu}}}{dz} = \frac{\pi\alpha_{\text{em}}^2}{8s} & \left[(1+z)^2 \{ (1-P^-)(1+P^+) |f_{LL}^s + f_{LL}^t|^2 + (1+P^-)(1-P^+) |f_{RR}^s + f_{RR}^t|^2 \} \right. \\ & + (1-z)^2 \{ (1-P^-)(1+P^+) |f_{LR}^s|^2 + (1+P^-)(1-P^+) |f_{RL}^s|^2 \} \\ & \left. + 4(1+P^-P^+) \{ |f_{LR}^t|^2 + |f_{RL}^t|^2 \} \right] \end{aligned} \quad (18)$$

where³

$$\begin{aligned} f_{LL}^s &= 1 + (g_L^e)^2 \chi_Z, & f_{RR}^s &= 1 + (g_R^e)^2 \chi_Z, \\ f_{LR}^s &= 1 + g_L^e g_R^e \chi_Z + \frac{1}{2} C_{\bar{\nu}} \chi_{\bar{\nu}}^t, & f_{RL}^s &= 1 + g_R^e g_L^e \chi_Z + \frac{1}{2} C_{\bar{\nu}} \chi_{\bar{\nu}}^t, \\ f_{LL}^t &= \frac{s}{t} + (g_L^e)^2 \chi_Z^t, & f_{RR}^t &= \frac{s}{t} + (g_R^e)^2 \chi_Z^t, \\ f_{LR}^t &= \frac{s}{t} + g_L^e g_R^e \chi_Z^t + \frac{1}{2} C_{\bar{\nu}} \chi_{\bar{\nu}}^s, & f_{RL}^t &= \frac{s}{t} + g_R^e g_L^e \chi_Z^t + \frac{1}{2} C_{\bar{\nu}} \chi_{\bar{\nu}}^s, \end{aligned} \quad (19)$$

where $\chi_i^t = s/(t - M_i^2)$. Note that we use the same notation as in Eq. (14) for the reduced sneutrino coupling $C_{\bar{\nu}}$. However, since now the same lepton generation is present in the initial and final states, consequently in Eq. (19) we have

$$C_{\bar{\nu}} = \frac{\lambda_{131}^2}{4\pi\alpha_{\text{em}}} \quad (20)$$

for both s - and t -channel sneutrino exchanges.

3 Numerical analysis

In the numerical analysis, cross sections are evaluated including initial- and final-state radiation by means of the program ZFITTER [23], together with ZEFIT [24], with $m_{\text{top}} = 175$ GeV and $m_H = 125$ GeV. One-loop SM electroweak corrections are accounted for by improved Born amplitudes [25], such that the forms of the

³Note that Ref. [7], for example, uses a different convention for the chirality of the final state current.

previous formulae remain the same. Concerning initial-state radiation, a cut on the energy of the emitted photon $\Delta = E_\gamma/E_{\text{beam}} = 0.9$ is applied in order to avoid the radiative return to the Z peak and enhance the signal originating from the nonstandard physics contribution [21].

As numerical inputs, we shall assume the identification efficiencies of $\epsilon = 95\%$ for $\mu^+\mu^-$ final states, integrated luminosity of $\mathcal{L}_{\text{int}} = 0.5 \text{ ab}^{-1}$ with uncertainty $\delta\mathcal{L}_{\text{int}}/\mathcal{L}_{\text{int}} = 0.5\%$, and a fiducial experimental angular range $|\cos\theta| \leq 0.99$. Also, regarding electron and positron degrees of polarization, we shall consider the following values: $P^- = \pm 0.8$; $P^+ = \pm 0.6$, with $\delta P^-/P^- = \delta P^+/P^+ = 0.5\%$.

Discovery and identification reaches on the sneutrino mass $M_{\tilde{\nu}}$ (95% C.L.) plotted in Fig. 2 are obtained from conventional χ^2 analysis. The discovery limit (Disc) is obtained from a combined analysis of the polarized differential cross sections, $d\sigma/dz$, in 10 equal-size z -bins in the range $[-0.99, 0.99]$, with beam polarizations of the same sign, $(P^-, P^+) = (+0.8, +0.6); (-0.8, -0.6)$. This procedure provides the best sensitivity to sneutrino parameters, whereas the identification reach (ID) is derived from A_{double} . In the latter case the χ^2 function is constructed as follows: $\chi^2 = (\Delta A_{\text{double}}/\delta A_{\text{double}})^2$ where δA_{double} is the expected experimental uncertainty accounting for both statistical and systematic components.

For comparison, current limits from low-energy data are also shown [26,27]. From Fig. 2 one can see that identification of sneutrino exchange effects in the s -channel with A_{double} is feasible in the region of parameter and mass space far beyond the current limits.

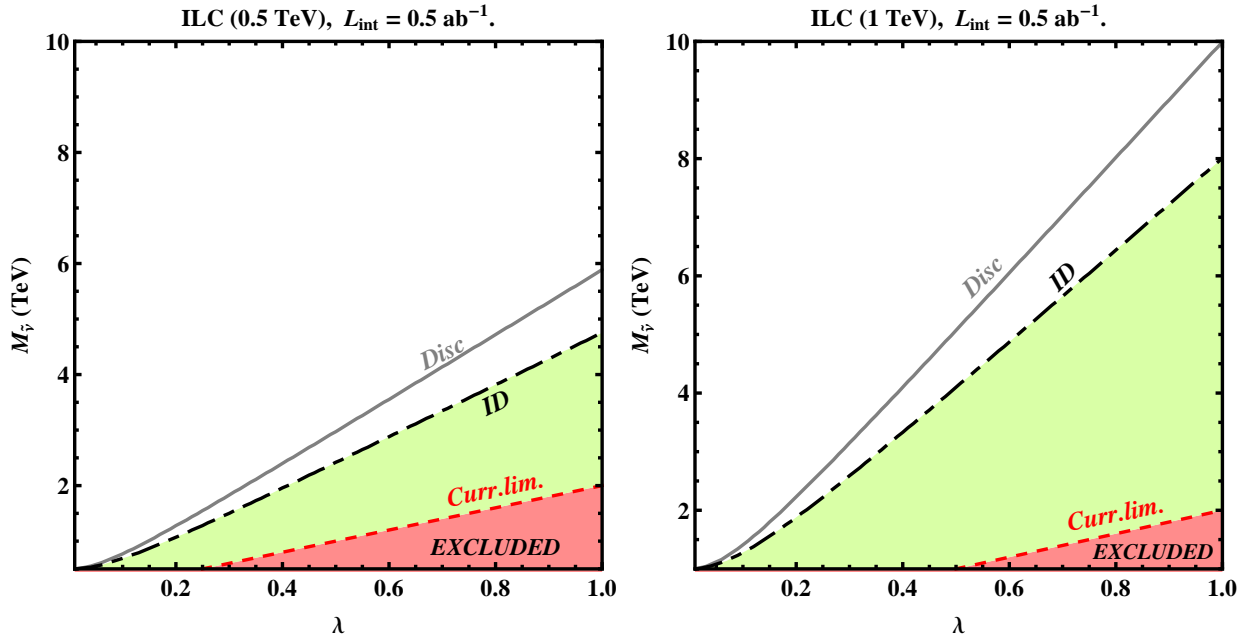


Figure 2: Discovery and identification reaches on sneutrino mass $M_{\tilde{\nu}}$ (95% C.L.) as a function of λ for the process $e^+e^- \rightarrow \mu^+\mu^-$ at the ILC with $\sqrt{s} = 0.5 \text{ TeV}$ (left panel) and $\sqrt{s} = 1.0 \text{ TeV}$ (right panel), $\mathcal{L}_{\text{int}} = 0.5 \text{ ab}^{-1}$. For comparison, current limits from low energy data are also displayed.

As was demonstrated in Ref. [19] the resonant s -channel production of sneutrino $\tilde{\nu}$ with their subsequent decay into purely leptonic final states via R -parity violating couplings can be observed over a wide range of parameters (couplings and masses) in hadronic collisions (4). This process provides a clean and powerful probe of R -parity violating supersymmetric parameter space and the corresponding LHC search reaches in the parameter plane spanned by the sneutrino mass and the R -parity-violating coupling were obtained there. Specifically, in the dilepton process (4) of interest here, a spin-0 sneutrino can be exchanged through the subprocess $d\bar{d} \rightarrow \tilde{\nu} \rightarrow l^+l^-$ and manifest itself as a peak in the dilepton invariant mass distribution and also with a flat angular distribution. The cross section is proportional to the R -parity violating product $X = (\lambda')^2 B_l$ where B_l is the sneutrino leptonic branching ratio and λ' the relevant sneutrino coupling to the $d\bar{d}$ quarks. The experimental 95% CL lower limits on $M_{\tilde{\nu}}$ range from 397 GeV (for $X = 10^{-4}$) to 866

GeV (for $X = 10^{-2}$) [28].

If this signature is observed, the leptonic center-edge integrated asymmetry [29] can be successfully used to distinguish slepton resonances from those associated with new spin-1 Z' gauge bosons and the Randall-Sundrum graviton resonance (spin-2). Once large integrated luminosities of order $\sim 100 \text{ fb}^{-1}$ are obtained at the LHC, these new scalar resonances should be visible for masses as large as $\sim 1.5 - 5.5 \text{ TeV}$ depending on the specific details of the model (couplings and leptonic branching ratios). Accordingly, the analysis performed in [19] indicates that the identification of the sneutrino against the RS graviton and Z' bosons by center-edge asymmetry is possible at the LHC for $M_{\tilde{\nu}} \leq 4.5 \text{ TeV}$ for X in the range of $10^{-5} < X < 10^{-1}$.

As mentioned above, future e^+e^- colliders operating in the TeV energy range can indirectly probe for new physics effects by exploring contact-interaction-like deviations from the cross sections and asymmetries predicted by the SM. For luminosity expected at ILC, $\sim 0.5 \text{ ab}^{-1}$, and with both electron and positron beams polarized, from Fig. 2 we see that this implies that the parameter space region $\lambda/M_{\tilde{\nu}} > 0.17$ (0.10) ($M_{\tilde{\nu}}$ in TeV unit) would certainly be probed at $\sqrt{s} = 0.5$ (1) TeV by such measurements while identification parameter space populates the region 0.21 (0.13) $< \lambda/M_{\tilde{\nu}} < 0.5$.

For Bhabha scattering, the angular range $|\cos\theta| < 0.90$ is divided into nine equal-size bins. We combine the cross sections with the following initial electron and positron longitudinal polarizations: $(P^-, P^+) = (|P^-|, -|P^+|)$; $(-|P^-|, |P^+|)$; $(|P^-|, |P^+|)$; $(-|P^-|, -|P^+|)$. The assumed reconstruction efficiencies, that determine the expected statistical uncertainties, are 100% for e^+e^- final pairs. Concerning the $\mathcal{O}(\alpha_{\text{em}})$ QED corrections, the (numerically dominant) effects from initial-state radiation for Bhabha scattering are again accounted for by a structure function approach including both hard and soft photon emission [30], and by a flux factor method [31], respectively.

One can parametrize the bounds depicted in Fig. 2 (in the plane $(M_{\tilde{\nu}}, \lambda)$) approximately as a straight line, $M_{\tilde{\nu}} = k_{\mu}\lambda$ ($M_{\tilde{\nu}}$ is taken in TeV units), $\lambda = \sqrt{\lambda_{131} \cdot \lambda_{232}}$ and k_{μ} is the slope of the these lines for the process $e^+e^- \rightarrow \mu^+\mu^-$. For instance, for the discovery reach we have $k_{\mu} \approx 5.9$ (10) for $\sqrt{s} = 0.5$ (1) TeV. In order to convert the bounds shown in Fig. 2 into limits on $M_{\tilde{\nu}}$ vs λ_{131} one should fix λ_{232} . For that purpose one can take the (mass dependent) current limit on that Yukawa coupling λ_{232} represented as $\lambda_{232}/M_{\tilde{\nu}} = 0.5$. From these formulae one finds: $M_{\tilde{\nu}} < (k_{\mu}^2/2) \lambda_{131}$. These areas which can be explored in the muon pair production process are shown in Fig. 3. In contrast to the limits shown in Fig. 2 as curves, limits on $M_{\tilde{\nu}}$ vs λ_{131} for both the discovery and the identification are represented in Fig. 3 as areas constrained by the line for the current limit, $M_{\tilde{\nu}} = 2\lambda_{131}$, and the lines for the upper bounds, $M_{\tilde{\nu}} = (k_{\mu}^2/2) \lambda_{131}$.

In contrast to muon pair production, identification of the sneutrino exchange effects by means of Bhabha scattering is impossible because CI and sneutrino give rise to the same helicity amplitudes as clearly seen from (18) and (19) [32]. Therefore only the discovery reach for the Bhaba process is shown in the figure.

4 Concluding remarks

In this note we have studied how uniquely identify the indirect (propagator) effects of spin-0 sneutrino predicted by supersymmetric theories with R -parity violation, against other new physics scenarios in high energy e^+e^- annihilation into lepton-pairs at the ILC. The competitive models are the interactions based on gravity in large and in TeV-scale extra dimensions, anomalous gauge couplings, extra Z' bosons, and the compositeness-inspired four-fermion contact interactions. All those kinds of new physics can lead to qualitatively similar modifications of SM cross sections, angular distributions and various asymmetries, but they differ in detail. To evaluate the identification reach on the sneutrino exchange signature, we develop a technique based on a double polarization asymmetry formed by polarizing both beams in the initial state, that is particularly suitable to directly test for such s -channel sneutrino exchange effects in the data analysis. We show that the availability of both beams being polarized, plays a crucial rôle in identifying that new physics scenario, as the commonly considered asymmetry, A_{LR} , formed when only a single beam is polarized, was shown not to be useful for the purpose of sneutrino identification.

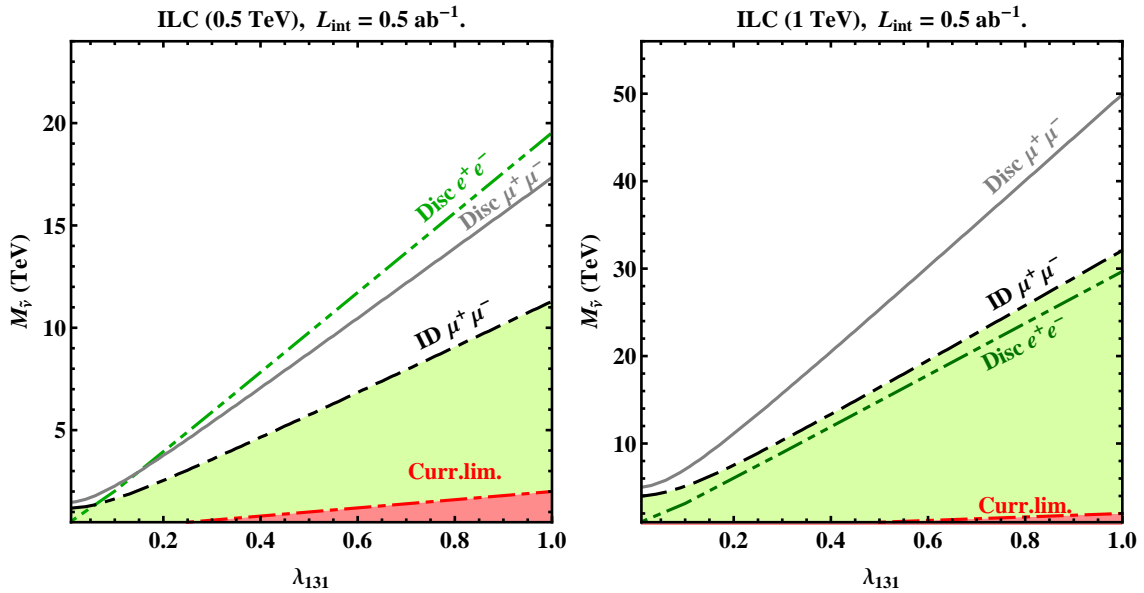


Figure 3: Discovery reach on sneutrino mass (95% C.L.) in Bhabha scattering as a function of λ_{131} at $\sqrt{s} = 0.5$ TeV (left panel) and 1 TeV (right panel), for $\mathcal{L}_{\text{int}} = 0.5 \text{ ab}^{-1}$. For comparison, discovery reach on $M_{\tilde{\nu}}$ in muon pair production is also depicted for $\lambda_{232} = 0.5 \times M_{\tilde{\nu}}/\text{TeV}$.

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References

- [1] E. Eichten, K. D. Lane and M. E. Peskin, Phys. Rev. Lett. **50**, 811 (1983); R. Rückl, Phys. Lett. B **129**, 363 (1983).
- [2] P. Langacker, Rev. Mod. Phys. **81**, 1199-1228 (2009). [arXiv:0801.1345 [hep-ph]].
- [3] T. G. Rizzo, [hep-ph/0610104].
- [4] A. Leike, Phys. Rept. **317**, 143-250 (1999). [hep-ph/9805494].
- [5] J. L. Hewett, T. G. Rizzo, Phys. Rept. **183**, 193 (1989).
- [6] W. Büchmüller, R. Rückl and D. Wyler, Phys. Lett. B **191**, 442 (1987) [Erratum-ibid. B **448**, 320 (1999)]; G. Altarelli, J. R. Ellis, G. F. Giudice, S. Lola and M. L. Mangano, Nucl. Phys. B **506**, 3 (1997) [hep-ph/9703276]; R. Casalbuoni, S. De Curtis, D. Dominici and R. Gatto, Phys. Lett. B **460**, 135 (1999) [hep-ph/9905568]; V. D. Barger and K. -m. Cheung, Phys. Lett. B **480**, 149 (2000) [hep-ph/0002259].
- [7] J. Kalinowski, R. Rückl, H. Spiesberger and P. M. Zerwas, Phys. Lett. B **406**, 314 (1997) [hep-ph/9703436]; Phys. Lett. B **414**, 297 (1997) [hep-ph/9708272].

- [8] T. G. Rizzo, Phys. Rev. D **59**, 113004 (1999) [hep-ph/9811440].
- [9] For a review, see F. Cuypers and S. Davidson, Eur. Phys. J. C **2**, 503 (1998) [hep-ph/9609487], and references therein.
- [10] G. J. Gounaris, D. T. Papadamou and F. M. Renard, Phys. Rev. D **56**, 3970 (1997) [hep-ph/9703281].
- [11] N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, Phys. Lett. B **429**, 263 (1998) [hep-ph/9803315]; Phys. Rev. D **59**, 086004 (1999) [hep-ph/9807344];
L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999) [hep-ph/9905221];
I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, Phys. Lett. B **436**, 257 (1998) [hep-ph/9804398].
- [12] G. F. Giudice, R. Rattazzi and J. D. Wells, Nucl. Phys. B **544**, 3 (1999) [hep-ph/9811291]; Nucl. Phys. B **630**, 293 (2002) [hep-ph/0112161].
- [13] J. L. Hewett, Phys. Rev. Lett. **82**, 4765 (1999) [hep-ph/9811356];
T. Han, J. D. Lykken and R. -J. Zhang, Phys. Rev. D **59**, 105006 (1999) [hep-ph/9811350];
T. G. Rizzo, Phys. Rev. D **64**, 095010 (2001) [hep-ph/0106336];
H. Davoudiasl, J. L. Hewett and T. G. Rizzo, Phys. Rev. Lett. **84**, 2080 (2000) [hep-ph/9909255]; Phys. Rev. D **63**, 075004 (2001) [hep-ph/0006041];
E. A. Mirabelli, M. Perelstein and M. E. Peskin, Phys. Rev. Lett. **82**, 2236 (1999) [hep-ph/9811337];
S. Cullen, M. Perelstein and M. E. Peskin, Phys. Rev. D **62**, 055012 (2000) [hep-ph/0001166].
- [14] I. Antoniadis and K. Benakli, Phys. Lett. B **326**, 69 (1994) [arXiv:hep-th/9310151]; I. Antoniadis, K. Benakli and M. Quiros, Phys. Lett. B **331**, 313 (1994) [arXiv:hep-ph/9403290].
- [15] G. Pasztor and M. Perelstein, in *Proc. of the APS/DPF/DPB Summer Study on the Future of Particle Physics (Snowmass 2001)* ed. N. Graf, arXiv:hep-ph/0111471.
- [16] K.-m. Cheung and G. L. Landsberg, Phys. Rev. D **65**, 076003 (2002) [hep-ph/0110346].
- [17] N.-E. Bomark, D. Choudhury, S. Lola and P. Osland, JHEP **1107**, 070 (2011) [arXiv:1105.4022 [hep-ph]].
- [18] G. Moortgat-Pick *et al.*, Phys. Rept. **460**, 131 (2008) [arXiv:hep-ph/0507011].
- [19] P. Osland, A. A. Pankov, N. Paver and A. V. Tsytrinov, Phys. Rev. D **82**, 115017 (2010) [arXiv:1008.1389 [hep-ph]].
- [20] B. Schrempp, F. Schrempp, N. Wermes and D. Zeppenfeld, Nucl. Phys. B **296**, 1 (1988).
- [21] A. Djouadi, A. Leike, T. Riemann, D. Schaile and C. Verzegnassi, Z. Phys. C **56**, 289 (1992).
- [22] P. Osland, A. A. Pankov and N. Paver, Phys. Rev. D **68**, 015007 (2003) [arXiv:hep-ph/0304123].
- [23] D. Y. Bardin, P. Christova, M. Jack, L. Kalinovskaya, A. Olchevski, S. Riemann and T. Riemann, Comput. Phys. Commun. **133**, 229 (2001) [hep-ph/9908433].
- [24] S. Riemann, FORTRAN program ZEFIT, Version 4.2.
- [25] M. Consoli, W. Hollik and F. Jegerlehner, CERN-TH-5527-89, presented at the *Workshop on Z Physics at LEP*;
G. Altarelli, R. Casalbuoni, D. Dominici, F. Feruglio and R. Gatto, Nucl. Phys. B **342**, 15 (1990).
- [26] Y. Kao and T. Takeuchi, arXiv:0910.4980 [hep-ph].
- [27] G. Bhattacharyya, H. Pas and D. Pidt, Phys. Rev. D **84**, 113009 (2011) [arXiv:1109.6183 [hep-ph]].
- [28] T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. Lett. **102**, 091805 (2009) [arXiv:0811.0053 [hep-ex]].

- [29] E. W. Dvergsnes, P. Osland, A. A. Pankov and N. Paver, Phys. Rev. D **69**, 115001 (2004) [hep-ph/0401199].
- [30] For reviews see, e.g., O. Nicrosini and L. Trentadue, in *Radiative Corrections for e^+e^- Collisions*, ed. J. H. Kühn 25 (Springer, Berlin, 1989), p. 25; in *QED Structure Functions, Ann Arbor, MI, 1989*, ed. G. Bonvicini, AIP Conf. Proc. No. 201 (AIP, New York, 1990), p. 12.
- [31] For a review see, e.g., W. Beenakker and F. A. Berends: *Proc. of the Workshop on Physics at LEP2*, CERN 96-01, vol. 1, p. 79 and references therein.
- [32] A. A. Pankov, N. Paver and A. V. Tsytin, Phys. Rev. D **73**, 115005 (2006) [hep-ph/0512131].