Center-edge asymmetry as a discriminator of new physics indirect signatures at e^+e^- linear collider

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Abstract

We explore the potential of a e^+e^- linear collider to disentangle new physics scenarios on $\mu^+\mu^-$-pair production. R-parity violation and extensions of the Standard Model gauge structure offer two non-minimal realizations of supersymmetry at low energies that can lead to similar new physics signatures at e^+e^- linear collider. We discuss the center-edge asymmetry which is useful for discriminating amongst these two new physics scenarios.

In this note we consider the problem of how to distinguish two potential new physics scenarios from each other below the threshold for direct production of new particles at e^+e^- Linear Collider: R-parity violation SUSY and the extension of the Standard Model (SM) gauge group by an additional $U(1)$ factor [1]. 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. 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 tools that are useful in accomplishing our task: (i) the angular distribution of the final state fermion, and (ii) the center-edge asymmetry, $A_{\rm CE}$. The purpose of the present analysis is to study the center-edge asymmetry $A_{\rm CE}$ [2] that can be used to distinguish these scenarios at e^+e^- colliders which can be then applied to other more complex scenarios.

If R-parity is violated it is possible that the exchange of sparticles can contribute significantly to the SM processes. 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. He 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 e^+e^- linear collider. If just the R-parity violating λLLE^c terms of the superpotential are present it is clear that only the observables associated with leptonic processes ($l = \mu, \tau$)

$$e^+ + e^- \to l^+ + l^-, \tag{1}$$

will be affected by the exchange of $\tilde{\nu}$ in the t- or s- channels [1].

The differential cross section of the process (1) for unpolarized beams can be written as

$$\frac{\mathrm{d}\sigma}{\mathrm{d}z} = \frac{1}{4}\left(\frac{\mathrm{d}\sigma_{\mathrm{LL}}}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_{\mathrm{RR}}}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_{\mathrm{LR}}}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_{\mathrm{RL}}}{\mathrm{d}z}\right). \tag{2}$$

Here, $z \equiv \cos\theta$, with θ the angle between the incoming electron and the outgoing fermion in the c.m. frame, and $\mathrm{d}\sigma_{\alpha\beta}/\mathrm{d}\cos\theta$ ($\alpha, \beta = \mathrm{L}, \mathrm{R}$) are the helicity cross sections given by:

$$\frac{\mathrm{d}\sigma_{\alpha\beta}}{\mathrm{d}z} = \frac{\pi\alpha^2_{\mathrm{e.m.}}}{2s}\,|\mathcal{M}_{\alpha\beta}|^2\,(1 \pm z)^2, \tag{3}$$

where the two signs $\pm$ correspond to the LL, RR, and LR, RL, helicity configurations, respectively. The helicity amplitudes $\mathcal{M}_{\alpha\beta}$ can be written as

$$\mathcal{M}_{\alpha\beta} = \mathcal{M}^{\mathrm{SM}}_{\alpha\beta} + \Delta_{\alpha\beta} = Q_e Q_f + g^e_\alpha\, g^f_\beta\, \chi_Z + \Delta_{\alpha\beta}, \tag{4}$$

where: $\chi_Z = s/(s - M^2_Z + iM_Z\Gamma_Z) \approx s/(s - M^2_Z)$ represents the Z propagator; $g^f_{\mathrm{L}} = (I^f_{3L} - Q_f s^2_W)/s_W c_W$ and $g^f_{\mathrm{R}} = -Q_f s_W/c_W$ are the SM left- and right-handed fermion couplings of the Z with $s^2_W = 1 - c^2_W \equiv \sin^2\theta_W$; Q_e and Q_f are the fermion electric charges.

Additional contribution to the helicity amplitudes, $\Delta_{\alpha\beta}$, induced by Z' is given by

$$\Delta_{\alpha\beta} = g'^{\,e}_\alpha\, g'^{\,f}_\beta\, \chi_{Z'}, \tag{5}$$

where $\chi_{Z'}$ is the Z' propagator defined according to χ_Z. In case of the t-channel $\tilde{\nu}$ contribution the helicity amplitudes caused by $\tilde{\nu}$ exchange can be written as

$$\Delta_{\mathrm{LL}} = \Delta_{\mathrm{RR}} = 0, \qquad \Delta_{\mathrm{LR}} = \Delta_{\mathrm{RL}} = \frac{1}{2} C_{\tilde{\nu}} P^t_{\tilde{\nu}}, \tag{6}$$

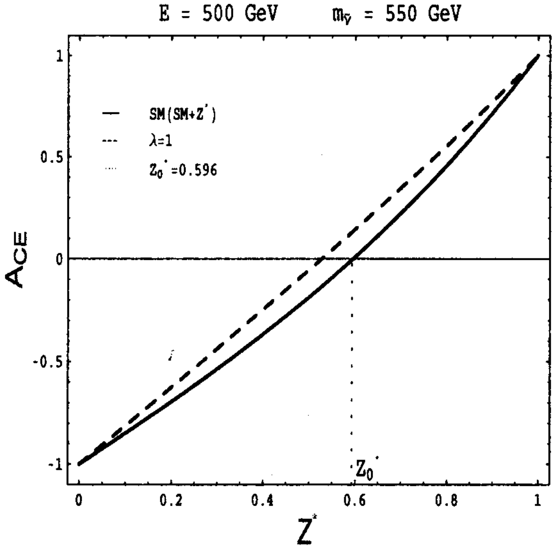

Figure 1: A_{CE} for the process $e^+e^- \to l^+l^-$ $(l = \mu, \tau)$ as a function of z^* in the SM, in a model with heavy Z', and in R-parity violation SUSY with sneutrino parameters: $m_{\tilde\nu} = 550$ GeV and $\lambda = 1$.

where $P^t_{\tilde\nu} = s/(t - m^2_{\tilde\nu})$ and $t = -s(1-z)/2$, $C_{\tilde\nu} = \lambda^2/4\pi\alpha_{\rm e.m.}$, with λ in this case the Yukawa coupling [1].

We define center–edge asymmetry $A_{\rm CE}$ as [2]:

$$A_{\rm CE} = \frac{\sigma_{\rm CE}}{\sigma}, \tag{7}$$

where

$$\sigma_{\rm CE} = \left[\int_{-z^*}^{z^*} - \left(\int_{-1}^{-z^*} + \int_{z^*}^{1}\right)\right] \frac{{\rm d}\sigma}{{\rm d}z}\,{\rm d}z, \tag{8}$$

and the total cross section

$$\sigma = \int_{-1}^{1} \frac{{\rm d}\sigma}{{\rm d}z}\,{\rm d}z, \tag{9}$$

and $0 < z^* < 1$. Note that, at $z^* = 0$ and 1, $\sigma_{\rm CE} = \mp\sigma$, respectively.

In the case of the SM the center–edge asymmetry $A^{\rm SM}_{\rm CE}$ can be written as:

$$A^{\rm SM}_{\rm CE} = \frac{\sigma^{\rm SM}_{\rm CE}}{\sigma^{\rm SM}} = \frac{1}{2}\,z^*\left(z^{*2} + 3\right) - 1. \tag{10}$$

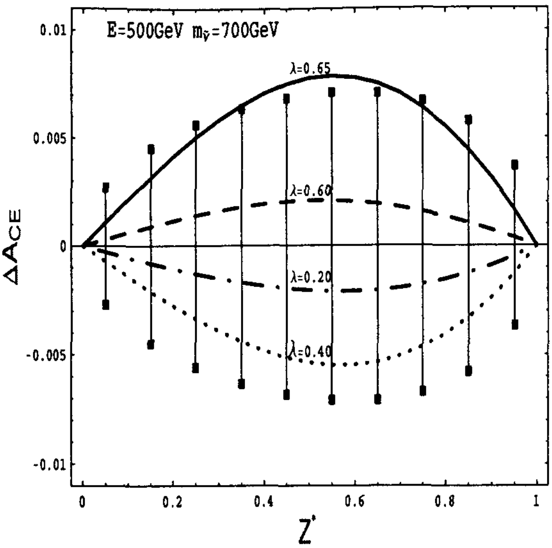

Figure 2: The deviation of A_{CE} from the SM (or SM+Z') expectations as a function of z^* for the process $e^+e^- \to l^+l^-$ for $m_{\tilde\nu} = 700$ GeV and $\lambda = 0.2 - 0.65$ at $\sqrt{s} = 0.5$ TeV. The expected statistical uncertainties at $\mathcal{L}_{\text{int}} = 50$ fb^{-1} are shown as error bars.

In Eq. (10) the helicity amplitudes in the numerator and denominator cancel and only a ratio of kinematical factors remains. Fig. 1 shows $A_{\text{CE}}^{\text{SM}}$ as a function of z^*. From Eq. (10) one can determine the value of z^* where $A_{\text{CE}}^{\text{SM}}$ vanishes,

$$z_0^* = (\sqrt{2}+1)^{1/3} - (\sqrt{2}-1)^{1/3} = 0.596, \tag{11}$$

corresponding to $\theta = 53.4°$.

Application of Eq. (7) to composite-like contact interactions is straightforward, the result can be written as:

$$A_{\text{CE}}^{\text{SM+Z}'} = \frac{\sigma_{\text{CE}}^{\text{SM+Z}'}}{\sigma^{\text{SM+Z}'}} = \frac{1}{2}\, z^* \left(z^{*2} + 3\right) - 1. \tag{12}$$

This result is *identical* to $A_{\text{CE}}^{\text{SM}}$ defined by Eq. (10). In other words, A_{CE} has the form (12) in the SM and will remain so even if Z' effects are present. Thus, Z' effects yield *the same* center–edge asymmetry as the Standard

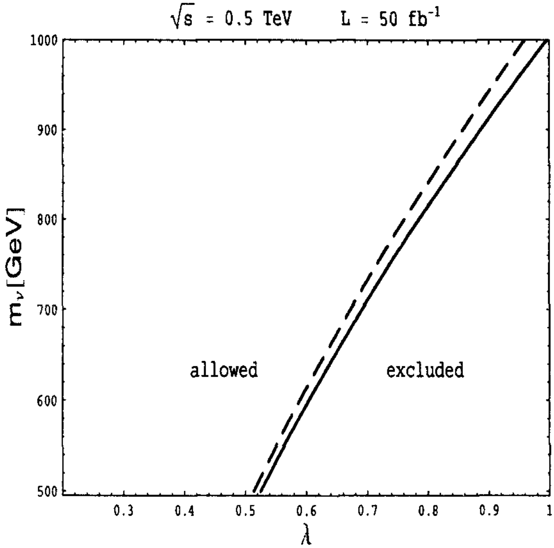

Figure 3: Allowed region (95% C.L.) on $m_{\tilde{\nu}}$ and λ from the process $e^+e^- \to l^+l^-$ for $\sqrt{s} = 0.5$ TeV and luminosity $\mathcal{L}_{\rm int} = 50$ fb^{-1}. Solid: unpolarized; dashed: both beams polarized, $P = 0.8$, $\bar{P} = -0.6$.

Model. The reason is simply that in case of Z' the angular distribution of leptons retains their SM form, (2).

The deviation of $A_{\rm CE}$ from the SM (and SM+Z') prediction is clearly a signal of the spin-0 particle exchange. Thus, it is clear that a non-zero value of $\Delta A_{\rm CE} = A_{\rm CE} - A_{\rm CE}^{\rm SM}$ (Fig. 1 and Fig. 2) can provide a clean signature for sneutrino, or more generally, spin-0 exchange in the process (1).

To assess a realistic reach on the sneutrino parameters, $m_{\tilde{\nu}}$ and λ, we can consider a χ^2-function made of the deviation of the asymmetry $A_{\rm CE}$ from its SM value. We assume the values $\delta\mathcal{L}_{\rm int}/\mathcal{L}_{\rm int} = \delta P/P = \delta\bar{P}/\bar{P} = 0.5\%$. We take the beam polarization to be 80% and 60% for electrons and positrons, respectively, and employ a 10° angular cut around the beam pipe, i.e., $z_{\rm cut} = 0.98$. The result of the χ^2 analysis is shown in Fig. 3 ($z^* = z_0^*$).

References

[1] T. G. Rizzo, Phys. Rev. D **59** (1999) 113004.

[2] P. Osland, A. A. Pankov and N. Paver, Phys. Rev. D **68**, 015007 (2003).