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Supersymmetric Lepton Flavor Violation at the NLC

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Abstract

Supersymmetric theories generally have new flavor violation sources in the squark and slepton mass matrices. If significant lepton flavor violation exists, selectron and smuon should be nearly degenerate. This leads to the phenomenon of slepton oscillations, which is analogous to neutrino oscillations, if sleptons are produced at the Next Linear Collider. The direct slepton production at the Next Linear Collider provides a much more powerful probe of lepton flavor violation than the current bounds from rare processes, such as $\mu \to e\gamma$.

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Weak scale supersymmetry (SUSY) may provide a solution to the gauge hierarchy problem and is one of the most attractive candidates beyond the standard model (SM). If SUSY is discovered, measuring the masses and couplings of the superpartners will become the focus of study. However, in most SUSY extensions of the SM, mass matrices of the fermions and their scalar superpartners are not diagonalized in the same basis. New flavor mixing matrices W, analogous to the CKM matrix, will appear at the gaugino vertices. These new mixing matrices may provide important clues to the flavor structure and therefore should also be an important subject of study. Rare flavor-changing processes, such as $\mu \to e\gamma$, and neutral meson mixing already provide important constraints on these mixing matrices through the virtual effects of superpartners. However, as will be seen below, if the superpartners are produced in the future colliders, it is possible to probe these mixings directly and much more powerfully at the colliders. The talk is based on work done with N. Arkani-Hamed, J.L. Feng, and L.J. Hall [1].

In this study we will concentrate on the mixing in the slepton sector. The choice is motivated by the theoretical prejudice that sleptons are probably lighter than squarks and hence more likely to be found first, and also by the absence of the lepton flavor violation in SM, which means that any lepton flavor violation should come from the supersymmetric origin. We also specialize to the case of two generation mixing, in particular $\tilde{e}_R - \tilde{\mu}_R$ mixing for simplicity.

The current experimental bound[2], $B(\mu \to e\gamma) < 4.9 \times 10^{-11}$, put strong constraints on the slepton masses and mixings. If the mixing angle $W_{12} = \sin\theta$ is not small, the first two generation slepton masses have to be quite degenerate for the flavor-changing process $\mu \to e\gamma$ to be super-GIM suppressed. The bound constrains the product $\sin 2\theta \Delta m^2$, where $\Delta m^2 = m^2_{\tilde{e}_R} - m^2_{\tilde{\mu}_R}$, and is plotted in Fig. 1 for some choices of the SUSY parameters.

If sleptons are produced at colliders, flavor mixing will lead to the interesting slepton oscillation phenomenon analogous to neutrino oscillation. The flavor-violating signal we hope to observe at the e^+e^- colliders is $e^+e^- \to$ slepton pairs $\to e^\pm \mu^\mp \tilde{\chi}^0 \tilde{\chi}^0$. For simplicity, we consider the case where the right-handed sleptons decay directly to the LSP. For large $\Delta m^2 (\gg m\Gamma$, where Γ is the slepton decay width), the $\tilde{e}$ and $\tilde{\mu}$ are already out of phase when they decay and there is no interference between them. The flavor-violating cross section is given simply by multiplying the flavor conserving cross sections by appropriate factors of the branching ratios $B(\tilde{e} \to \mu\tilde{\chi}^0) = B(\tilde{\mu} \to e\tilde{\chi}^0) = \frac{1}{2}\sin^2 2\theta$, When $\Delta m^2 < m\Gamma$, the interference effects become important. One finds for uncorrelated slepton production, the flavor-violating cross section will be suppressed by the factor $\epsilon = (\Delta m^2)^2/[(\Delta m^2)^2 + 4m^2\Gamma^2]$. For correlated production as in the case we study, the formulae are somewhat more complicated but contain the similar suppression factor. The detailed derivation for different cases can be found in Ref.[3]. We can see that $\epsilon \simeq 1$ for $\Delta m^2 \gg m\Gamma$ and $\epsilon \to 0$ as $\Delta m^2 \to 0$ as we expect. When sleptons are directly produced at high energy colliders, the super-GIM suppression of the flavor-violating processes only occurs when $\Delta m < \Gamma$, in constrast with the low energy flavor-violating processes which are suppressed by $\Delta m^2/m^2$. This makes the high energy colliders a more powerful probe of the flavor violation than the low energy processes.

Having discussed the flavor-violating cross sections, we consider the possibility of detecting such flavor-violating signals at future colliders. If sleptons are discovered at LEP II, their masses should be below 85-90 GeV. The constraint from $\mu \to e\gamma$ is strong for such light sleptons. We found that the probing power at LEP II can still be competitive with $\mu \to e\gamma$ for moderate $\tan\beta$, though the regions of parameter space that can be probed are quite limited [1]. We concentrate on the study of lepton flavor violation at the Next Linear Collider (NLC) here, with assumed design energy $\sqrt{s} = 500$GeV and luminosity 50 fb^{-1}/yr in the e^+e^- mode. We consider a case with the following SUSY parameters: $m_{\tilde{e}_R}, m_{\tilde{\mu}_R} \simeq 200$GeV, $M_1 = M_2/2 = 150$GeV, $\mu = -400$GeV. The LSP is almost pure bino and the cross section has little dependence on μ and M_2 if they are large. We calculate the cross section of the flavor-violating signal as a function of $\sin 2\theta$ and Δm^2 and the result is shown in Fig. 1.

The major backgrounds come from W^+W^-, $e^\pm\nu W^\mp$, $(e^+e^-)W^+W^-$, and $\tau^+\tau^-$ events. Efficient cuts[4] and a right-polarized e^- beam can effectively isolate the flavor-violating signal. Given a year's running at design luminosity, the required 5σ signal is 3.8(3.6) fb for 90%(95%) right-handed beam polarization. We can see that NLC is a powerful probe of the flavor-violating parameter space, extending to $\sin 2\theta \sim 0.1$ and much beyond the bounds from $\mu \to e\gamma$.

An intriguing feature of the NLC is its ability to run in e^-e^- mode. Although the luminosity may be degraded somewhat from the e^+e^- mode, the cross section is generally higher for most regions of the parameter space and many troublesome backgrounds, for example, W pair production, are completely eliminated. In addition, both beams may be polarized and there are essentially no backgrounds for RR beam polarization. The dominant background is $e^-\nu W^-$, arising from imperfect beam polarization. This can be the most powerful mode for probing flavor violation. Even without additional cuts, the mixing angle may be probed down to $\sin 2\theta \sim 0.04$[1], far beyond the current bounds. We find that , if sleptons are kinematically accessible at the NLC, the $e\mu$ signal will provide either stringent limits on slepton mixing or the exciting discovery of SUSY lepton flavor violation.

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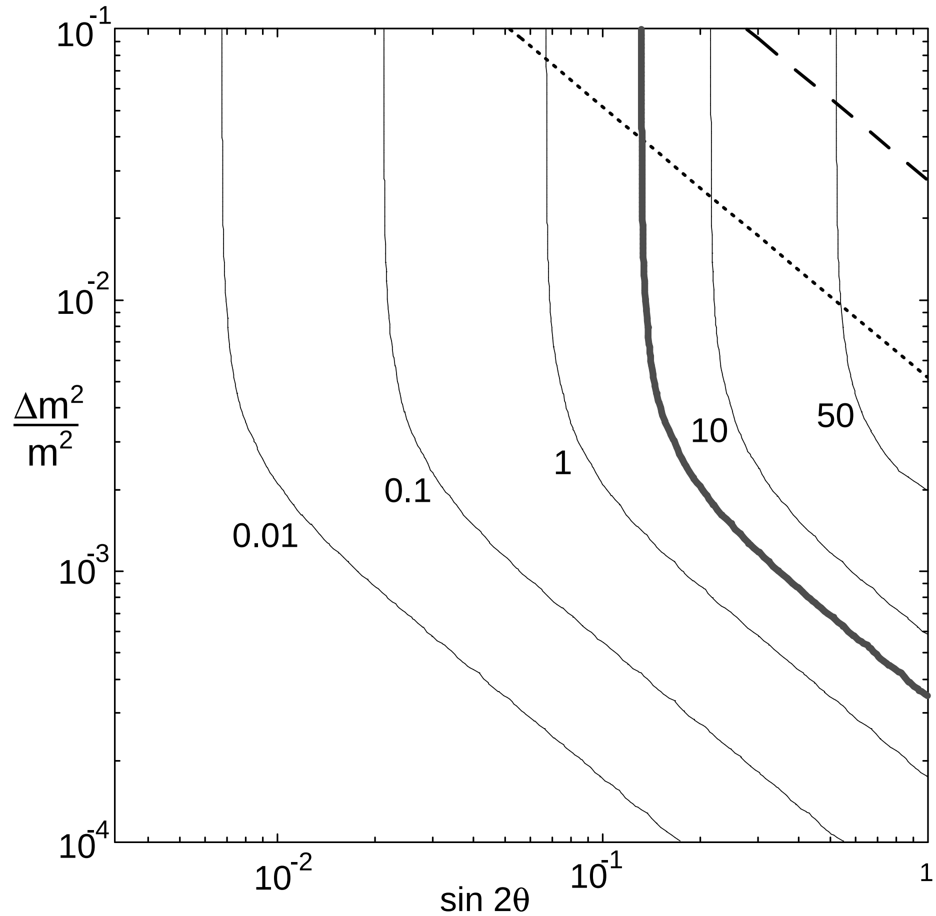

Figure 1: Contours of constant $\sigma(e^+e^-_R \to e^\pm\mu^\mp\tilde{\chi}^0\tilde{\chi}^0)$ (solid) in fb for NLC, with $m_{\tilde{e}_R}, m_{\tilde{\mu}_R} \simeq 200\mathrm{GeV}$, $M_1 = 150\mathrm{GeV}$, $\mu = -400\mathrm{GeV}$, $M_2 = 300\mathrm{GeV}$, and $\tan\beta = 2$. The thick gray contour represents the experimental reach for one year's integrated luminosity. The dashed (dotted) contour is the current experimental bound from $B(\mu \to e\gamma) = 4.9 \times 10^{-11}$ for the same parameters and $\tan\beta = 2(50)$, $m_{\tilde{e}_L}, m_{\tilde{\mu}_L} = 350\mathrm{GeV}$. (The cross section contours are basically unchanged for $\tan\beta = 50$.)