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Supersymmetric decay of the τ lepton

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The angular distribution of muons or electrons produced in the supersymmetric decay of tau leptons, $\tau^- \to \tilde{\nu}_\tau \bar{\tilde{\nu}}_l l^-$, is calculated. This decay mode has the same observable final state as the ordinary leptonic decay $\tau^- \to \nu_\tau \bar{\nu}_l l^-$ but may be distinguished from it by the differing energy and angular distribution of the final-state lepton.

Low-energy supersymmetry[1] is an attractive and feasible extension to the standard model.[2] It is a solution to the hierarchy problem in the sense that it provides a natural way of protecting a small Higgs-boson mass from large radiative corrections. Experimentally, supersymmetric particles (sparticles) have not been seen and hence the masses of detectable sparticles, with the possible exception of the gauginos and Higgsinos, are much greater than those of their corresponding partners. However, sneutrinos are not directly detectable but light sneutrinos will have consequences on low-energy phenomenology unless the sleptons and gauginos are very heavy. If the sneutrinos associated with the τ^- and either the μ^- or e^- are light, by which we mean less than 1 GeV, then the supersymmetric decay of the tau lepton $\tau^- \to \tilde{\nu}_\tau \bar{\tilde{\nu}}_l l^-$ will compete with the ordinary leptonic decay $\tau^- \to \nu_\tau \bar{\nu}_l l^-$ (which has the same observable final state) giving rise to deviations both in the energy distribution[3] and angular distribution of the final-state lepton. With a new generation of e^+e^- machines on line in the near future, a large event sample of τ decays will soon be available for analysis. Small deviations in the energy and angular distribution of the final-state lepton from that predicted by the standard model will be easily observable. In this Brief Report we calculate the angular distribution of the lepton produced in the supersymmetric decay of polarized τ leptons.

The matrix element for the process $\tau^- \to \bar{\tilde{\nu}}_l \tilde{\nu}_\tau l^-$ is found from evaluating the Feynman diagram shown in Fig. 1 (Ref. 3):

$$\mathcal{M} = \frac{-ig^2}{2M_{\tilde{W}}^2} q_{\tilde{W}}^\mu \bar{u}_l \gamma_\mu (1-\gamma_5) u_\tau ,$$

where $M_{\tilde{W}}$ is the mass of the supersymmetric partner of the W boson $\tilde{W}$, $q_{\tilde{W}}^\mu = p_l^\mu + p_{\tilde{\nu}_l}^\mu$ is the four-momentum carried by the $\tilde{W}$, and g is the $SU(2)_L$ weak coupling constant of the standard model. The variation of the $\tilde{W}$ propagator with $q_{\tilde{W}}^2$ has been neglected. Upon squaring this expression, we find that, for a polarized τ,

$$|\mathcal{M}|^2 = \left[\frac{g}{M_{\tilde{W}}} \right]^4 [2(p_l \cdot q_{\tilde{W}})(p_\tau \cdot q_{\tilde{W}}) - (p_l \cdot p_\tau) q_{\tilde{W}}^2 - 2M_\tau (p_l \cdot q_{\tilde{W}})(q_{\tilde{W}} \cdot s) + M_\tau (p_l \cdot s) q_{\tilde{W}}^2] ,$$

where p_τ and p_l are the four-momentum of the τ and final-state lepton. The four-vector s is the spin vector of the τ lepton, such that in its rest frame $p_\tau \cdot s = 0$ and $p_l \cdot s = -|\mathbf{p}_l| \cos\theta_{ls}$, where θ_{ls} is the angle between the direction of the final-state lepton and the polarization of the tau. The spin-averaged lepton energy distribution has been calculated before by Kane and Rolnick in Ref. 3; we will use their notation for simplicity.

After integrating over the phase space of both sneutrinos we find that the double differential cross section of a massless final-state lepton is given by

$$\frac{d\Gamma}{dx\, dc_{ls}} = \frac{G_F^2 M_\tau^5}{8\pi^3} \left[\frac{M_W}{M_{\tilde{W}}} \right]^4 \left(xJ(x)\{x(1-x)[1+\eta(x)]^2 + \tfrac{1}{3}x^2 J^2(x) - 2x x_{\nu_l}^2\} - c_{ls} J(x) x^2 \{\tfrac{1}{3}(1-x) J^2(x) + x[1+\eta(x)]^2 + 2x_{\nu_l}^2\} \right) ,$$

where $x_j = M_j / M_\tau$ and $x = E_l / M_\tau$. Phase space dictates that x lie within the range 0 to $\frac{1}{2}[1-(x_{\nu_\tau}+x_{\nu_l})^2]$. Also, we have

$$\eta(x) = \frac{x_{\nu_l}^2 - x_{\nu_\tau}^2}{1-2x} ,$$

$$J(x) \left[1 - 2\frac{x_{\nu_l}^2 + x_{\nu_\tau}^2}{1-2x} + \eta^2(x) \right]^{1/2} ,$$

and $c_{ls} = \cos\theta_{ls}$ as defined before. When we perform the angular integration over $\cos\theta_{ls}$ we recover the result of Ref. 3 for the energy distribution of the final-state lepton.

If we define the asymmetry $A(\theta_{ls})$ to be

$$A(\theta_{ls}) = \frac{\int_0^{x_{\max}} dx \left[\frac{d\Gamma}{dx\, dc_{ls}}(\uparrow) - \frac{d\Gamma}{dx\, dc_{ls}}(\downarrow) \right]}{\int_0^{x_{\max}} dx \left[\frac{d\Gamma}{dx\, dc_{ls}}(\uparrow) + \frac{d\Gamma}{dx\, dc_{ls}}(\downarrow) \right]} ,$$

where ↑ indicates a spin-up τ and ↓ a spin-down τ, then we find in the limit of massless sneutrinos that

$$A(\theta_{ls}) \rightarrow -\tfrac{7}{9}\cos\theta_{ls} \ ,$$

which is significantly greater than the asymmetry found in ordinary leptonic decay of $-\frac{1}{3}\cos\theta_{ls}$.

In conclusion, we have calculated the angular distribution of massless leptons produced in the supersymmetric decay of τ leptons. We find that the angular asymmetry is much stronger than for the ordinary leptonic decay mode. This feature along with the differing energy distribution of the final-state lepton, as indicated in Ref. 3, provides useful tools for observing the supersymmetric decay mode or setting limits on the masses of the superpartners. Unfortunately, since $M_{\tilde{W}}$ appears as an inverse fourth power in the expression for the rate, the lower limit that can be found for $M_{\tilde{W}}$ does not depend strongly on the precision of the experimental data. An example of which is, if we assume that an upper limit on the deviation of the angular distribution is of order $\sim 1\%$, then this translates into $M_{\tilde{W}} > 4M_W$ for massless sneutrinos. It is interesting to speculate that if a fourth generation of leptons exists in nature then it would have significant phase space available to its supersymmetric decay mode for sneutrinos considerably more massive than the ones considered in this work.

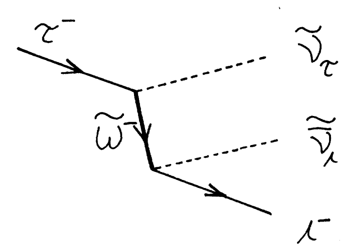

FIG. 1. The diagram responsible for the supersymmetric decay of the τ lepton.

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[1] For a review see H. P. Nilles, Phys. Rep. **110**, 1 (1985), and references therein; M. B. Wise, in *Proceedings of the Fourth Theoretical Advanced Study Institute on Elementary Particle Physics,* Sante Fe, New Mexico, 1987, edited by R. Slansky and G. West (World Scientific, Singapore, 1988).

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[3] G. L. Kane and W. R. Rolnick, Nucl. Phys. **B232**, 21 (1984).