Supersymmetry and τ Decays

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Abstract

A brief review of the status of searches for supersymmetry involving the τ lepton is given.

Introduction

Low energy supersymmetry[1] is an attractive extension of the Standard Model[2][3] addressing the problems of divergencies encountered in the theory by introduction of the fermion-boson symmetry. It predicts the existence of partners of all known fundamental particles with the same quantum numbers but with spin different by $\frac{1}{2}$. Scalar supersymmetric charged leptons (sleptons) and supersymmetric neutrinos (sneutrinos) should exist and obey the flavor conservation laws. The symmetry of fermionic and bosonic degrees of freedom is broken at an unknown mass scale and thus, the masses of the predicted supersymmetric particles are also unknown.

All experimental searches for such new objects rely on the fact that the lightest supersymmetric particle must be stable. In the following, we will restrict the discussion to the aspects of such searches related to the τ lepton.

Searches for stau ($\tilde{\tau}$).

The production cross section of $\tilde{\tau}$-pairs in e^+e^- collisions is given by:

$$\sigma(e^+e^- \rightarrow \tilde{\tau}^+\tilde{\tau}^-) =$$

$$\frac{\pi\alpha^2}{3s}\beta^3\left[1 + 8r(\tfrac{1}{2} + \sin^2\theta_W)(1 - 4\sin^2\theta_W) + 16r^2(\tfrac{1}{2} + \sin^2\theta_W)(1 + (1 - 4\sin^2\theta_W)^2)\right]$$

where

$$r = \frac{s}{16(s - m_Z^2)\cos^2\theta_W \sin^2\theta_W}$$

and the velocity β depends on the mass of the $\tilde{\tau}$:

$$\beta = \sqrt{\frac{1 - 4m_{\tilde{\tau}}^2}{s}}$$

At low energies the effects of the weak interactions can be neglected and the differential cross section is:

$$\frac{d\sigma}{d\cos\theta}(e^+e^- \rightarrow \tilde{\tau}^+\tilde{\tau}^-) = \frac{2\pi\alpha^2}{8s}\beta^3\sin^2\theta$$

where θ is the angle with respect to the beam axis.

The signatures of the $\tilde{\tau}$-pair production process depend on its mass relatively to the mass of tau sneutrino, $\tilde{\nu}_\tau$, and the mass of the photino, $\tilde{\gamma}$.

For $m_{\tilde{\tau}} < m_{\tilde{\gamma}}$ and $m_{\tilde{\tau}} < m_{\tilde{\nu}_\tau}$ the stau will be a stable penetrating particle with experimental signatures similar to that of the muon. Searches for heavy stable new particles have been conducted at every new accelerator. The best limits to date can be derived from the UA1 experiment at the CERN Sp$\bar{p}$S collider.[5] New sequential lepton with massless neutrino has to have mass greater than 41 GeV/c^2. The formalism allowing extension of such experimental searches to the case of massive neutrinos and to the searches for supersymmetric particles has been given by Barnett and Haber.[6] Their formalism has not been, as yet, applied to the data.

For $m_{\tilde{\tau}} > m_{\tilde{\gamma}}$ the stau will decay via the electromagnetic interactions into tau and photino, and the photino will escape detection. The kinematic constraints here are identical to those used in searches for Higgs decays into τ and ν_τ. The events are required to have a characteristic topology of a τ-pairs with missing energy and large acoplanarity with respect to the beam axis, since the two undetected photinos carry away large fraction of the available momentum. Several experiments performed searches for this process assuming massless photino.[7] The best result to date, obtained by JADE experiment[8] excludes $m_{\tilde{\tau}} < 18.7$ GeV/c^2.

Finally, for $m_{\tilde{\tau}} < m_{\tilde{\gamma}}$ and $m_{\tilde{\tau}} > m_{\tilde{\nu}_\tau}$, the stau will decay via the weak interactions into the three body final state:

$$\tilde{\tau} \longrightarrow \tau \nu_\tau \tilde{\nu}_\tau$$

No experimental searches have been made for this decay mode.

One can summarize the status of the searches for $\tilde{\tau}$ as a little explored field of study. Stronger limits probably can be obtained with existing data. The theory does not give any indication as to the mass hierarchy of the supersymmetric particles and allowes for large range of possibilities thus making future systematic searches difficult.

Search for supersymmetry in τ decays.

The supersymmetric charged sleptons have not been detected so far indicating that they may have large masses. However, their neutral partners - the sneutrinos are not directly observable. Light sneutrinos will have consequences on the low energy phenomenology of the τ lepton by allowing for supersymmetric decays

$$\tau^- \longrightarrow \tilde{\nu}_\tau \tilde{\nu}_l l^-$$

where l^- may be either tau or a muon (see Fig. 1).

The differential decay rate of τ is given for the Standard Model diagram as

$$\frac{d\Gamma}{dx} = \frac{G_F^2 m_\tau^5}{4\pi^3} x^2 (1 - \tfrac{4}{3})$$

where $x = E_{l^-}/m_\tau$ and masses of neutrino and electron have been neglected. The supersymmetric diagram (Fig. 1b) gives an additional term[9]

$$\frac{d\Gamma}{dx} = \frac{G_F^2 m_\tau^5}{4\pi^3} \left(\frac{m_W}{m_{\tilde{W}}}\right)^4 f(x,y,z)$$

where $\tilde{W}$ denotes the supersymmetric partner of the W boson and f(x,y,z) is a kinematic term dependent on the ratios of masses of the particles involved in the decay, $y = \frac{m_{\tilde{\nu}_\tau}}{m_\tau}$ and $z = \frac{m_{\tilde{\nu}_e}}{m_\tau}$.

For massless sneutrinos the above equation can provide a limit on the mass of the $\tilde{W}$.

$$m_{\tilde{W}} = \frac{m_W}{\left[\frac{2}{3}\left(\frac{192\pi^3 \hbar Br(\tau \rightarrow e\nu\nu)}{G_F^2 m_\tau^5 \tau_\tau} - 1\right)\right]^{\frac{1}{4}}}$$

For the presently measured values of the τ lifetime τ_τ and the branching ratio for the τ decay into electron, this limit is $m_{\tilde{W}} > 143$ GeV/c^2.

It should be noted that the diagrams in Fig. 1 also contribute to the muon decays. Therefore special care has to be taken in correcting the value of the G_F which is usually taken from high precision muon decay experiments. Another option is to use the value of G_F obtained in experiments with polarized beams, which exclude the possibility of supersymmetric winos mediating the decay.

In the case of decays of polarized τ's, the diagram shown in Fig. 1 also has a strong influence on the angular distribution of the final state lepton. The decay angular distribution has been calculated by Savage[10] and the resulting value of the spin asymmetry:

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

where θ_{ls} is the angle between the direction of the final state lepton and the polarization of the tau, is much greater than the asymmetry found in ordinary leptonic decays:

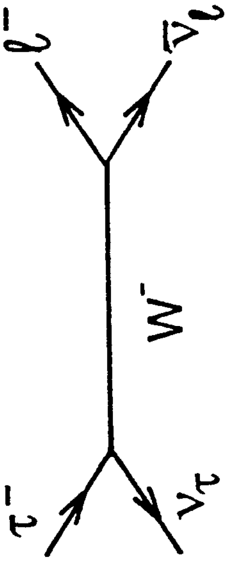
$$A(\theta_{ls}) = -\tfrac{1}{3}\cos\theta_{ls}$$

High precision experiments envisioned at the tau-charm and the B-$\bar{\mathrm{B}}$ factories will allow the extension of the searches for the effects of the supersymmetric partner of the W boson to the TeV mass range. Polarized beams may provide additional sensitivity in such searches.

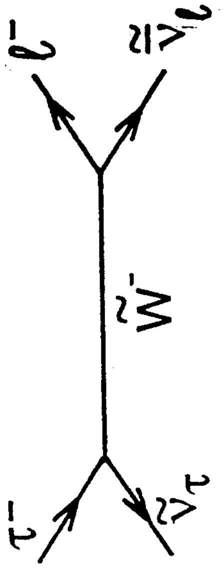
REFERENCES

1. For a review see H.E. Haber and G.L. Kane, Phys. Reports 117, 75(1985).
2. S. Glashow, Nucl. Physics 22, 579 (1961).
3. S. Weinberg, Phys. Rev. Letters 19, 1264 (1967).
4. T. Kobayashi and M. Kuroda, Phys. Letters B134, 271 (1984).
5. C. Albajar et al., Phys. Letters B185, 24 (1987).
6. R.M. Barnet and H.E. Haber, Phys. Rev. D36, 2042 (1987).
7. For a review see eg. S. Komamiya, Proceedings of the thirteenth SLAC Summer Institute on Particle Physics, SLAC Report 296 (1985).
8. W. Bartel at al., Z. Phys C31, 359 (1986).
9. G.L. Kane and W.R. Rolnik, Nucl. Phys. B232, 21 (1984).
10. M. Savage, Supersymmetric Decay of the τ Lepton, CALT-68-1561 (1989).

(a)


τ^-
ν_τ
W^-
ℓ^-
$\bar{\nu}_\ell$

(b)


τ^-
$\tilde{\nu}_\tau$
$\tilde{W}^-$
ℓ^-
$\tilde{\bar{\nu}}_\ell$