Study of tau polarization in GMSB models at the linear collider[1]

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Abstract. We analyze the potential of the next generation linear collider (LC) to study the long-lived τ superpartner in the context of GMSB models. Depending on the parameter space of these models, the $\tilde{\tau}$ is the next lightest superparticle and may travel some visible distance before decaying to τ and gravitino. From the decay product of the τ, it is possible to measure its polarization, and consequently determine the stau mixing angle at the decay level.

In gauge mediated supersymmetry breaking (GMSB) models [1] the gravitino can be the lightest SUSY particle (LSP), provided that the SUSY breaking scale is low ($\sqrt{F} \sim 100$ TeV). Furthermore, due to the weak coupling of gravitino, the next to lightest (NLSP) superparticle can be long-lived, with the lifetime given by

$$c\tau = 16\pi \frac{F^2}{M^5_{\rm NLSP}} \sim \left(\frac{\sqrt{F}}{10^7\ \rm GeV}\right)^4 \left(\frac{100\ \rm GeV}{M_{\rm NLSP}}\right)^5 10\ \rm km. \tag{1}$$

In this study we consider the case where the NLSP is $\tilde{\tau}$ [2], the superpartner of tau lepton. Such long-lived charged particle can be identified in the clean environment of a LC [2]. Using only kinematics, a LC can probe stau masses up to 85% of the beam energy. Particle identification devices, namely time of flight (TOF) and dE/dX, the energy deposit by ionization, can extend the reach up to the beam energy with integrated luminosity of 50 fb^{-1} for $\sqrt{s} = 500$ GeV machine.

This conclusion is valid for a long lived $\tilde{\tau}$ that does not decay inside the detector. In the intermediate lifetime case, counting the decayed stau with respect with the distance from interaction point can give us information on $c\tau$, the decay length. For $m_{\tilde{\tau}} \sim 100$ GeV we are able to get $0.0013 < c\tau$ (m) < 50 ($0.13 < c\tau$ (m) < 25) with 10% precision if it is possible to analyze distances of 0.01m (1 m) away from the interaction point. The measurement of $c\tau$ is very interesting because it can give us information on the fundamental SUSY breaking scale, according to Eq. 1.

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[1] Talk given by J. K. Mizukoshi at LCWS 2000, Fermilab, October 24-28, 2000.
[2] We refer $\tilde{\tau}$ as the lightest mass eigenstate of $\tilde{\tau}_R$ and $\tilde{\tau}_R$ mixture, as discussed later in the text.

Another aspect of $\tilde{\tau} \to \tau \tilde{G}$, which is the topic of this talk, is to determine the τ polarization from the energy distribution of primary scalar or vector mesons. In the following, we describe in details the error on the polarization achievable at the LC with $\sqrt{s} = 500$ GeV.

In the minimal supersymmetric standard model (MSSM) the mass eingenstates for the superpartners of left and right handed fermions are mixed, due to Yukawa interactions. The mixing is usually negligible for the first two generations, however it has to be taken into account for the stau. Considering $\theta_{\tilde{\tau}}$ to be the mixing angle, the mass eigenstates are given by

$$\begin{pmatrix} \tilde{\tau}_1 \\ \tilde{\tau}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\tilde{\tau}} & \sin\theta_{\tilde{\tau}} \\ -\sin\theta_{\tilde{\tau}} & \cos\theta_{\tilde{\tau}} \end{pmatrix} \begin{pmatrix} \tilde{\tau}_L \\ \tilde{\tau}_R \end{pmatrix} , \tag{2}$$

and $\tilde{\tau}_1$ is assumed to be lighter than $\tilde{\tau}_2$.

For unpolarized beams, the total cross section for $\tilde{\tau}_i$ pair production is practically independent of $\theta_{\tilde{\tau}}$. However, the LC is expected to operate with both beams polarized, $P(e^-) = 0.8$ and $P(e^+) = 0.6$, left- or right-handed. In this case the mixing angle is expected to be determined at the production level.

Another way to determine the mixing angle is to study τ polarization, $P(\tau)$. The novel aspect of the GMSB models in case $\tilde{\tau}_1$ is the NLSP is that $\tilde{\tau}$ interaction with $\tilde{G}$ (strictly speaking the Goldstino, the longitudinal component of the gravitino) is chirality conserving. Therefore, the decay width of the $\tilde{\tau}_1$ decaying to right- (left-) handed τ is given by

$$\begin{pmatrix} \Gamma_R \\ \Gamma_L \end{pmatrix} = \Gamma_0 \begin{pmatrix} \sin^2\theta_{\tilde{\tau}} \\ \cos^2\theta_{\tilde{\tau}} \end{pmatrix} , \tag{3}$$

where $\Gamma_0 = (1/16\pi F^2)(m_{\tilde{\tau}}^2 - m_\tau^2)^4/m_{\tilde{\tau}}^3$.

The average τ polarization is therefore expressed as

$$P(\tau) = \frac{BR(\tilde{\tau} \to \tau_R \tilde{G}) - BR(\tilde{\tau} \to \tau_L \tilde{G})}{BR(\tilde{\tau} \to \tau_R \tilde{G}) + BR(\tilde{\tau} \to \tau_L \tilde{G})} = \sin^2\theta_{\tilde{\tau}} - \cos^2\theta_{\tilde{\tau}} , \tag{4}$$

which can be measured experimentally from the decay product of tau, $\tau_{R,L} \to \nu_\tau A, (A = \pi, \rho, ...)$, where the decay amplitude in the tau rest-frame is expressed as

$$|\mathcal{M}|^2(\tau_{R,L} \to \nu_\tau A) \propto [(1 \pm \cos\theta) + 2\frac{m_A^2}{m_\tau^2}(1 \mp \cos\theta)] , \tag{5}$$

where θ is the polar angle with respect to the tau helicity. It should be noticed that for $A = \pi$ and ρ the left- and right-handed tau decay patterns are quite distinct. However for the $A = a_1$, there is an accidental angular dependence cancellation due to the relation $2m_{a_1}^2/m_\tau^2 \sim 1$. Therefore, we restrict our analyses to tau decay to $\pi^\pm$ and $\rho^\pm$, where the latter further decays to neutral and charged pions. In our preliminary study, we assume $\rho^\pm$ can be identified with 100% efficiency.

In order to illustrate the angular dependence of Eq. 5, we simulate $\tilde{\tau}_1$ pair production by ISAJET [3], considering the decay chain $\tilde{\tau}_1 \to \tau\tilde{G}$, $\tau \to \nu_\tau A$. In Fig. 1a the solid (dashed) line shows the case $\tilde{\tau}_1 = \tilde{\tau}_R(\tilde{\tau}_L)$ in the lab. frame. Since there is a boost in the tau direction, the strong angular dependence is smeared out. We notice, however, that in case $\tilde{\tau}_1$ is reasonably long-lived we can reconstruct its momentum from the track, which will allow us to make a boost in the stau rest frame. In this frame, we can see from Fig. 1b that the distinction between left- and right-handed stau decays is noticeable.

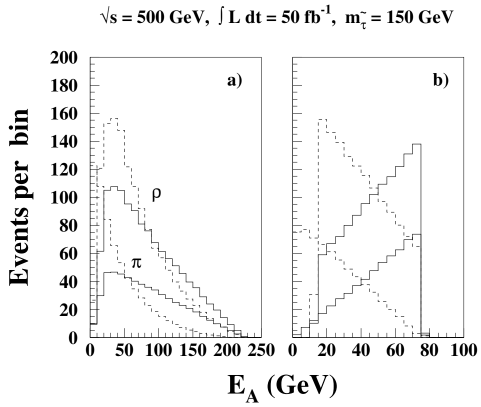

FIGURE 1. Energy distribution for the $\pi^\pm$ and $\rho^\pm$ decaying from right- (solid line) and left-handed (dashed line) $\tilde{\tau}$. In a) lab. frame and in b) $\tilde{\tau}$ rest frame.

In order to study the polarization sensitivity at the linear collider, we present a case study with the reference point at $P(\tau) = \sin^2\theta_{\tilde{\tau}} - \cos^2\theta_{\tilde{\tau}} = 0$, and, in this preliminary analysis, we assume an ideal case where stau, $\pi^\pm$, and $\rho^\pm$ momenta are fully reconstructed, without taking into account the smearing effects, as well as the ISR and beamstrahlung.

We generate events $e^+e^- \to \tilde{\tau}_1^+\tilde{\tau}_1^- \to \tau^+\tau^- + \not{E}_T$, requiring one $\tau^\pm \to \nu_\tau\pi^\pm, \nu_\tau\rho^\pm$, for $-0.3 \leq P(\tau) \leq 0.3$ with a fixed stau mass. For each stau mass, we calculate the χ^2 compared with the reference point $P(\tau) = 0$ fitting the $\pi^\pm$ and $\rho^\pm$ energy distributions at stau rest frame. Assuming in the stau pair production at least one of them will always decay inside the detector, we show in Fig. 2a the $\Delta\chi^2$ plot as a function of tau polarization.

From this figure, we can see that $\Delta P(\tau) \sim 0.05$ can be achieved with only 50 fb^{-1} of integrated luminosity. However, depending on the decay length, a long-lived stau may survive all the way through the detector. The number of decayed stau as a function of l, the distance traveled from the interaction point, is given by $N = N_0 \exp(-\alpha l)$, where $\alpha = 1/\beta\gamma c\tau$.

Since $c\tau$ is not a fixed quantity, as well as the stau mass, it is interesting to investigate the reach of these parameters for a given fixed error on the polarization, *e.g.* $\Delta P(\tau) = 0.1, 0.2$ and 0.3. Requiring $\Delta\chi^2 = 1$ (1-sigma level) for $P(\tau) \sim 0 \pm \Delta P(\tau)$, we obtain the contour plot shown in Fig. 2b. This result takes into

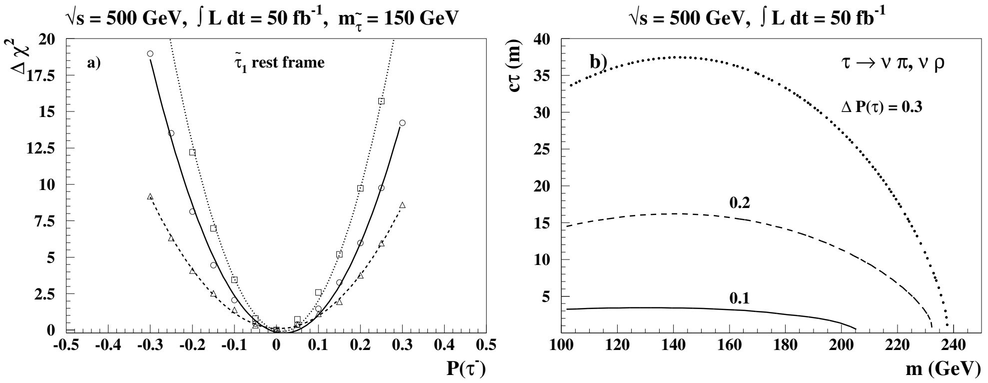

FIGURE 2. In a) $\Delta\chi^2$ compared to the reference point $P(\tau) = 0$ for $\pi^{\pm}$ (solid line) $\rho^{\pm}$ (dashed line) and combined (dotted line) energy distribution fit. In b) decay length for $\Delta P(\tau) = 0.1$ (solid line), 0.2 (dashed line) and 0.3 (dotted line) with $\Delta\chi^2 = 1$ as a function of stau mass.

account combination of the two tau decay products considered. For $\Delta P(\tau) \leq 0.3$ the maximum mass reach is around 240 GeV, which is only slightly below the beam energy. We expect that once detector efficiency and smearing effects are taken into account, much higher luminosity is needed in order to get some few percent level of precision.

In conclusion, we have studied the production and decay of a long-lived stau NLSP predicted in some parameter space of GMSB models. Besides precision mass and decay length measurements, the decay of this particle into tau and gravitino can give us information on the mixing angle at decay level. On the other hand, this quantity can be measured at production level with electron and positron beam polarizations. The compatibility of these two independent measurements of the mixing angle can confirm or not the predictions of GMSB models.

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