Measurements of Slepton and Neutralino Masses in Slope B Models

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We present results of results of Slope B models. We discuss the measurement of slepton masses and propose a new method for measuring the stau mass. We also discuss the experimental precision of measuring the mass of two lightest neutralinos.

1. Introduction

This paper describes the work that was done during Snowmass-2001 on experimental aspects of Slope B models [1]. The goal was to estimate the precision that could be0 achieved at a 500 GeV Linear Collider (LC). This work focused on measurement of slepton and neutralino masses, and a separate study [2] was devoted to chargino masses.

This paper is organized as follows. Section 2 describes the points that were considered on the Slope, the event generation procedure, and resultant SUSY cross-sections. In Section 3 we examine smuon production and measurement of the smuon mass, and discuss what makes these measurements more difficult in Slope B models. Measurements of sneutrino production and mass are also discussed. We propose a new method for dealing with particles that decay into tau leptons, and apply it to stau mass measurement in Section 4. Finally, in Section 5 we estimate the precision achievable in measurements of neutralino masses.

2. Model Points and Their Generation

To get representative points we performed a "reversed" mass scan, i.e. we varied M_2 for e^+e^- center of mass energy fixed at 500 GeV. For $M_2 = 340$ GeV the only observable processes are $e^+e^- \to Z_1Z_2, W_1W_2$ and Z^0h. For 330 GeV, Z_2Z_2 becomes kinematically allowed, for 320 GeV τ_1 are produced, and for 300 GeV right-handed selectron and smuon production opens up. For $M_2 = 200$ GeV all charginos, neutralinos and sleptons are produced, as well as the lightest Higgs boson. Gluinos and squarks in Slope B models can not be observed at 500 GeV collider.

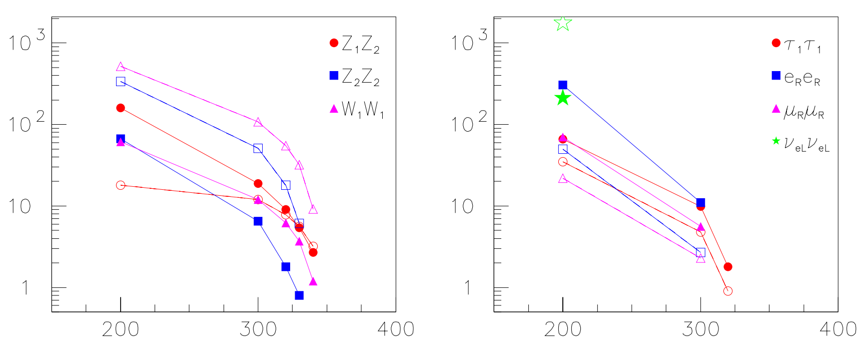

Figure 1: Cross-sections for SUSY production at 500 GeV LC v.s. M_2. Open points and dashed lines correspond to 90% left electron polarization, filled points and solid lines - 90% right electron polarization.

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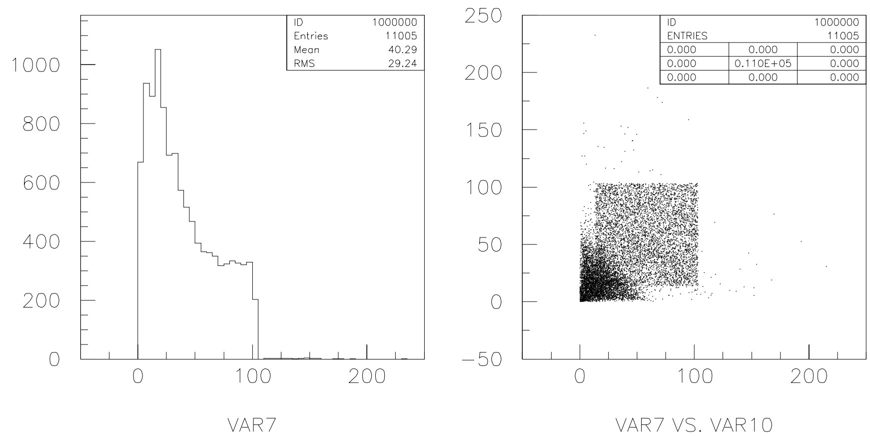

Figure 2: Left: muon energy for inclusive SUSY signal in events with two muons and no other objects. Right: Energy of positive muon versus energy of negative muon for inclusive SUSY events

The production cross-sections depend very strongly on beam polarization, as is demonstrated in Fig. 1. In most of the cases considered below, we assumed that the electron beam is 90% right polarized. The center of mass energy was always fixed at 500 GeV and the integrated luminosity was 100 fb^{-1}.

We used ISAJET 7.51 to generate both signal and Standard Model (SM) background. Two-photon and other QED backgrounds were not taken into account. It was shown in [3] that these are not very important for leptons with $p_T > 10$ GeV.

3. Smuons and Sneutrinos

In Slope B models, the background from gaugino production to slepton production is much larger than in the model considered in [4]. The muon energy spectrum for a model with $M_2 = 300$ GeV is shown in the left frame of Fig. 2 (we selected events with two muons and no jets or extra leptons). As one can see, lower edge of the characteristic box shape distribution from smuon decay is completely obscured by low energy muons from gaugino decays. The right frame of Fig. 2 shows a scatter plot of energies of the two muons in these events. One can easily separate signal and background smuons in this case and measure both the smuon and LSP masses from a fit of the two-dimensional plot.

If sneutrino production is kinematically allowed, it becomes a dominant SUSY production process (see Fig. 1). The best and almost background free process to look for sneutrinos and measure their masses is

$$e^+e^- \to \nu_{eL}\bar{\nu}_{eL} \to W_1^+e^-W_1^-e^+ \to e^+e^- \ + \ 4\ jets \tag{1}$$

As was the case in [4], the dominant error on these measurements is systematic, and arises from uncertainties in beam energy and energy scale.

4. Staus

The problem with measuring staus, is that they decay into τ leptons, which in turn decay to final states with at least one neutrino. The familiar fits to a box shape distribution are therefore not possible. Moreover, the visible energy in τ decays is a strong function of τ polarization, especially for channels like $\tau \to \pi\nu$ and $\tau \to \rho\nu$.

There have been attempts to perform a simultaneous fit to both the energy spectrum and polarization of τ leptons [4, 5]. While yielding an impressively small statistical error, a measurement like this requires a complete understanding of backgrounds over a broad range of energies, as

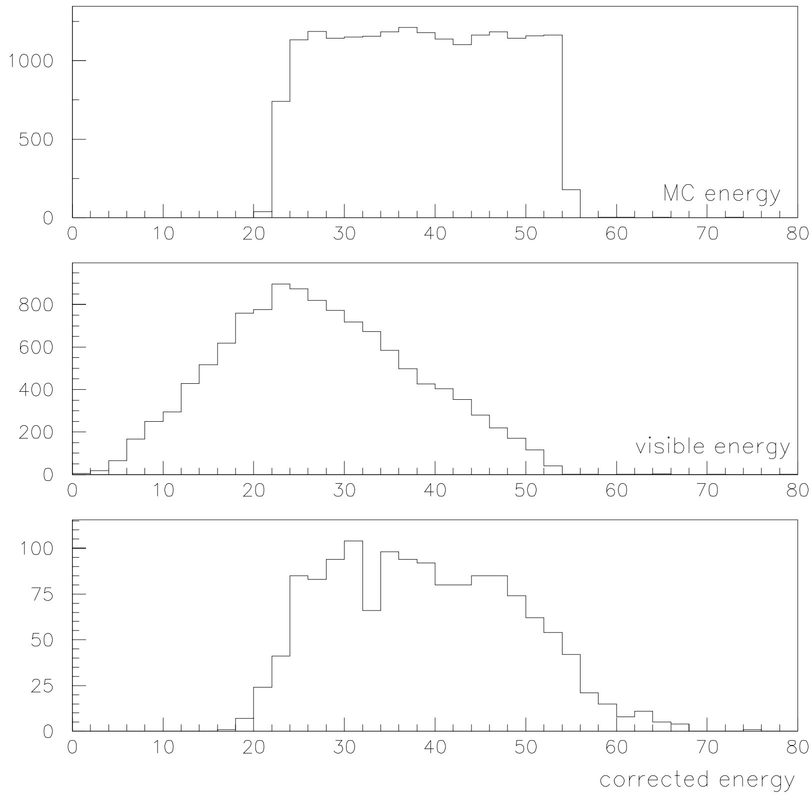

Figure 3: Illustration of performance of the method to reconstruct τ energy.

well as of calorimeter clustering. For Slope B in particular, this is quite a challenging problem since the background is large.

We propose a different approach. The idea is to select hadronic tau decays with large visible mass, i.e. $\tau \to n\pi\nu$, with $M_{n\pi}$ close to the τ mass. Then, as in all decays when energy release is small compared to the mass of decaying object, one can estimate

$$E_\tau = E_{n\pi} \cdot \frac{M_\tau}{M_{n\pi}} \tag{2}$$

The precision of this method increases for a tighter mass selection, but at the same time the statistics decrease. We chose $M_{n\pi} > 1.3$ GeV, which yields about 10% τ energy resolution with approximately 10% efficiency. The performance of this procedure is shown in Fig. 3.

We used the above method on stau pair production for several Slope B models. Figure 4 shows the $M_2 = 200$ GeV point. The upper left frame shows MC energies of τ leptons. Huge background from other SUSY processes is clearly visible at low energies. The upper right panel shows the energy of the τ^+ lepton corrected using (2) versus the uncorrected visible energy of the τ^-. A uniform spectrum with a relatively sharp endpoint is visible in the corrected spectrum at about 90 GeV, clearly separated from the gaugino background at low energies. The uncorrected distribution is sharply falling with no distinct separation between signal and background. The lower left plane shows the distribution of the corrected τ energy after requiring visible energy of the second τ to be more than 20 GeV, together with a fit to a convolution of a box shape with expected energy resolution. The stau mass from the fit is 152 ± 1 GeV, compared to the stau input mass of 151.3 GeV. Fig. 5 shows similar fits for M_2 of 250 and 300 GeV. Results are summarized in Table I. Note that for 300 GeV the lower edge of the tau energy spectrum is at high enough energy to perform a fit to both the high and the low edges.

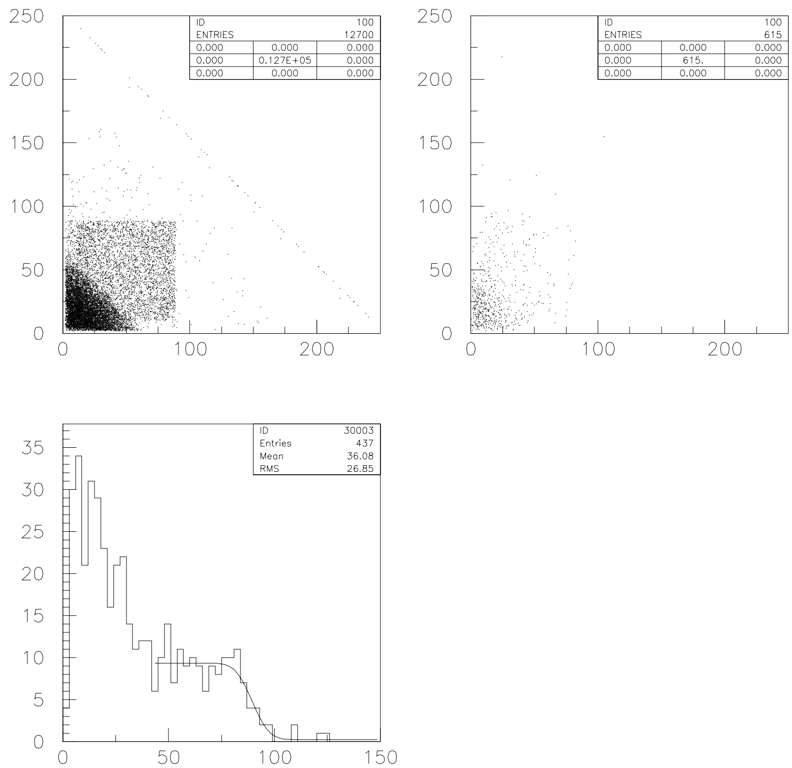

Figure 4: Stau signal for M_2 = 200 GeV. Upper left: MC energy of τ^+ v.s. MC energy of τ^-. Upper right: corrected τ^+ energy v.s. visible τ^- energy. Lower left: corrected τ energy.

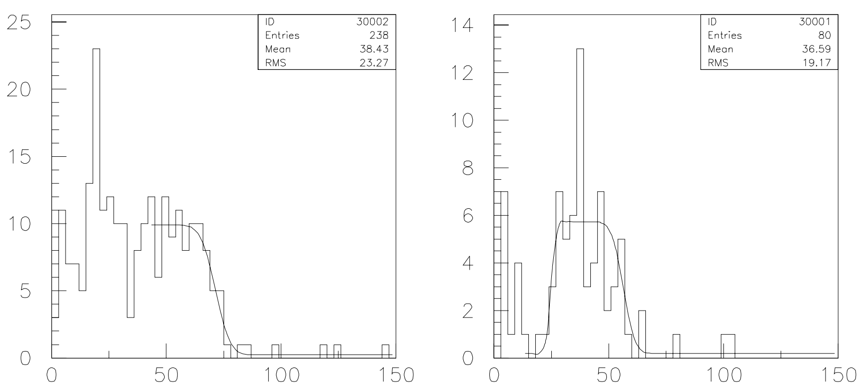

Figure 5: Stau signals for M_2 = 250 and 300 GeV

Table I Results for stau and LSP mass

M_2	$M_{\chi_1^0}$	M_{τ_1}	fitted $M_{\chi_1^0}$	fitted M_{τ_1}
200	117.7	151.3	fixed	152.0 ± 1.0
250	153.5	189.6	fixed	190.3 ± 1.3
300	189.6	227.8	fixed	232.0 ± 4.6
300	189.6	227.8	189.3 ± 4.8	230.3 ± 4.7

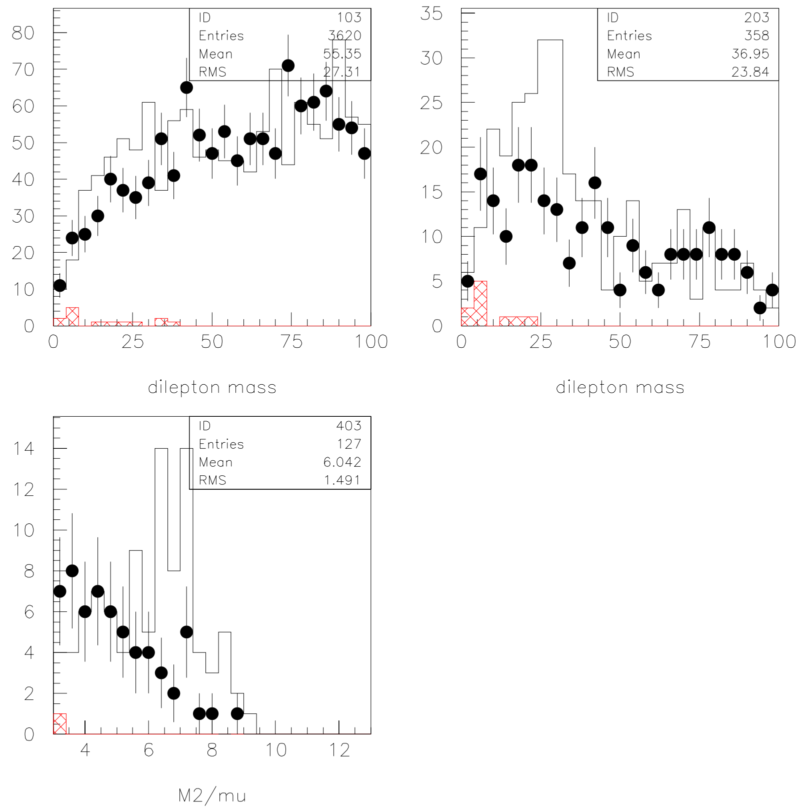

Figure 6: Second neutralino signal at $M_2 = 340$ GeV

5. Neutralinos

In Slope B models the mass difference between first and second neutralino is small, and is in fact smaller than M_Z for values of M_2 considered in this report. The dominant decay of the second neutralino is therefore $Z_2 \to l^+l^-Z_1$. The endpoint in the dilepton mass distribution is equal to the mass difference between the neutralinos (see, for example, [4] and references therein). In the spirit of the method described in the Section 4 for events with dilepton mass close to that endpoint, the following relation should hold true:

$$\frac{M_{Z_2}}{M_{Z_2} - M_{Z_1}} = \frac{E_{Z_2}}{E_{ll}} = \frac{E_{beam}}{E_{ll}} \tag{3}$$

This kind of measurement is especially important for high M_2, when SUSY production is limited to chargino and first and second neutralinos. For the case $M_2 = 340$ GeV, the signal consists of two oppositely charged leptons of same flavor and significant missing energy. The main Standard Model backgrounds are WW and $\tau\tau$ production (two photon backlgrounds, as was mentioned in Section 2, were neglected). Both yield leptons of uncorrelated flavor, so that one can use the $e\mu$ sample to determine SM content in ee and $\mu\mu$ samples.

We applied two cuts. One on the cosine of the opening angle between the leptons to be greater than -0.95 to reduce $\tau\tau$ contamination, and the second on the transverse energy of the system of two leptons to be less than 50 GeV. Figure 6 shows the dilepton mass before (upper left) and after (upper right) these selections. The solid histogram is the sum of ee and $\mu\mu$, and points with error bars correspond to $e\mu$ events. The hatched histogram shows small background from $Zh \to \nu\bar{\nu}\tau\tau$. The neutralino signal is clearly visible. The lower right panel in the same figure shows the distribution in the mass fraction, as defined in (3) for events with $25 < M_{ll} < 35$ GeV. Again, a peak is clearly visible. The fits to the dilepton mass and and the mass ratio were performed for several values of M_2. The results are summarized in Table II with their statistical errors. The systematic error from uncertainty in the shape of signal distributions has not been estimated.

Table II Fit results for first and second neutralino masses

M_2	$M_{\chi_2^0}$	$M_{\chi_2^0} - M_{\chi_1^0}$	fitted $M_{\chi_2^0}$	fitted $M_{\chi_2^0} - M_{\chi_1^0}$
340	250.2	32.7	239 ± 20	33.1 ± 2.2
330	242.0	31.5	227 ± 8	31.0 ± 0.6
320	234.3	30.62	230 ± 5	30.6 ± 0.3
300	218.2	28.62	212 ± 4	28.58 ± 0.08
200	139.6	21.96	138.5 ± 1.7	22.07 ± 0.07

6. Summary

We have studied capabilities of a 500 GeV Linear Collider to measure parameters of Slope B models. We find that with only 100 $\mathrm{fb}^{-}1$ it is possible to measure neutralino and slepton masses with good precision. The method we suggested for determination of the stau mass might be useful for other process with τ leptons in the final state.

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References

[1] *P3 summary report*, these proceedings.
[2] H. Neal, P3-26, these proceedings.
[3] E. Goodman, COLO HEP 398.
[4] H. Martyn and C. Blair, hep-ph/9910416.
[5] M. Nojiri, K. Fujii, and T. Tsukamoto, hep-ph/9606370.