LC-TH-2000-024

Width effects in slepton production $e^+e^- \to \tilde{\mu}_R^+ \tilde{\mu}_R^-$ [a]

Hans-Ulrich Martyn
I. Physikalisches Institut, RWTH Aachen, Germany

A case study will be presented to investigate width effects in the precise determination of slepton masses at the e^+e^- TESLA Linear Collider.

1 Introduction

If supersymmetry will be discovered in nature a precise measurement of the particle spectrum will be very important in order to determine the underlying theory. The potential of the proposed TESLA Linear Collider [1] with its high luminosity and polarisation of both $e^\pm$ beams will allow to obtain particle masses with an accuracy of 10^{-3} or better [2]. At such a precision width effects of primary and secondary particles may become non-negligible.

The present case study is based on a particular R-parity conserving mSUGRA scenario, also investigated in the ECFA/DESY Study [3], with parameters m_0 = 100 GeV, $m_{1/2}$ = 200 GeV, A_0 = 0 GeV, $\tan\beta$ = 3 and sgn(μ) > 0. The particle spectrum is shown in fig. 1. Typical decay widths of the scalar leptons are expected to be $\Gamma \sim 0.3 - 0.5$ GeV, while the widths of the light gauginos, decaying into 3-body final states, are (experimentally) negligible.

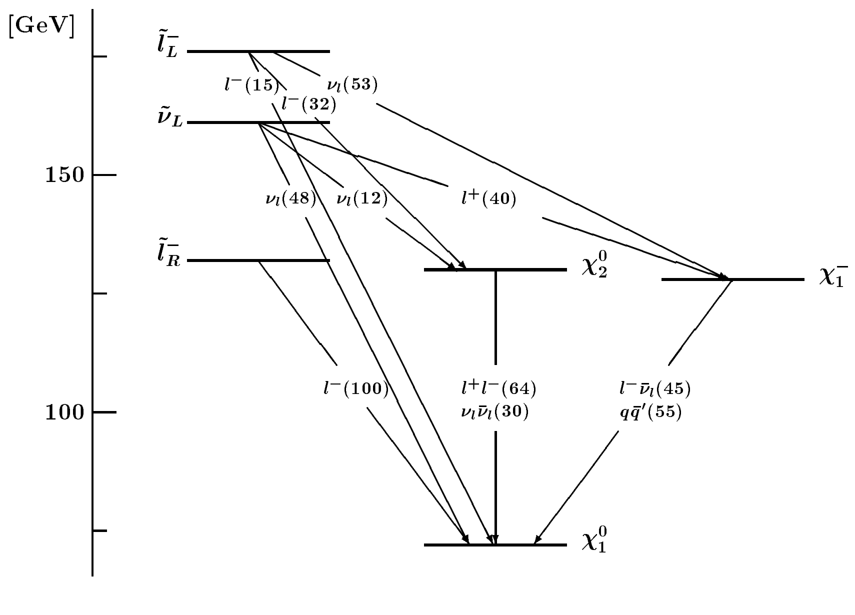

Figure 1: Mass spectrum and decay modes of sleptons and light gauginos

[a] Contribution to Workshop *'Physics at TeV Colliders'*, Les Houches, France, 8 - 18 June 1999

This note presents, as an example, a simulation of right scalar muon production

$$\begin{aligned} e^-_R e^+_L &\rightarrow \tilde{\mu}^-_R \tilde{\mu}^+_R \ , \\ &\rightarrow \mu^- \chi^0_1 \, \mu^+ \chi^0_1 \ . \end{aligned} \tag{1}$$

The analysis is based on the methods and techniques described in a comprehensive study of the same SUSY spectrum [4]. The detector concept, acceptances and resolutions are taken from the TESLA Conceptual Design Report [1]. Events are generated with the Monte Carlo program PYTHIA 6.115 [5], which includes QED radiation and beamstrahlung [6]. Particle widths are treated by smearing the nominal masses according to a Breit-Wigner distribution. Correlations between particles, *e.g.* in pair production, are not taken into account. It is assumed that both beams are polarised, right-handed electrons to a degree of $\mathcal{P}_{e^-_R} = 0.80$ and left-handed positrons by $\mathcal{P}_{e^+_L} = 0.60$. A proper choice of polarisations increases the cross section by a factor of ~ 3 and reduces the background substantially, e.g. by more than an order of magnitude for Standard Model processes.

2 Mass determinations

Scalar muons $\tilde{\mu}_R$ are produced in pairs via s channel γ and Z exchange and decay into an ordinary muon and a stable neutralino χ^0_1 (LSP), which escapes detection. The experimental signatures are two acoplanar muons in final state with large missing energy and nothing else in the detector. Simple selection criteria [1] (essentially cuts on acollinearity angle and missing energy) suppress background from W^+W^- pairs and cascade decays of higher mass SUSY particles and result in detection efficiencies around $\sim 70\%$.

Two methods to determine the mass of $\tilde{\mu}_R$ will be discussed: (i) a threshold scan of the pair production cross section, and (ii) a measurement of the energy spectrum of the decay muons, which simultaneously constrains the mass of the primary smuon and the secondary neutralino. The particle masses and width given by the chosen mSUGRA scenario are $m_{\tilde{\mu}_R} = 132.0$ GeV, $\Gamma_{\tilde{\mu}_R} = 0.310$ GeV and $m_{\chi^0_1} = 71.9$ GeV.

2.1 Threshold scan

Cross section measurements close to production threshold are relatively simple. One essentially counts additional events with a specific signature, here two oppositely charged, almost monoenergetic muons, over a smooth background. The cross section for slepton pair production rises as $\sigma \propto \beta^3$, where $\beta = \sqrt{1 - 4\, m^2_{\tilde{\mu}_R}/s}$ is the velocity related to the $\tilde{\mu}_R$ mass. The excitation curve as a function of the cms energy, including effects due to QED initial state radiation and beamstrahlung, is shown in figure 2. The sensitivity to the width $\Gamma_{\tilde{\mu}_R}$ is most pronounced close to the kinematic production limit and diminishes with inreasing energy. A larger width 'softens' the rise of the cross section with energy. Fits to various mass and/or width hypotheses are performed by simulating measurements with a total integrated luminosity of 100 fb^{-1} distributed over 10 equidistant points around $\sqrt{s} = 264 - 274$ GeV. The data may be collected within a few months of TESLA operation.

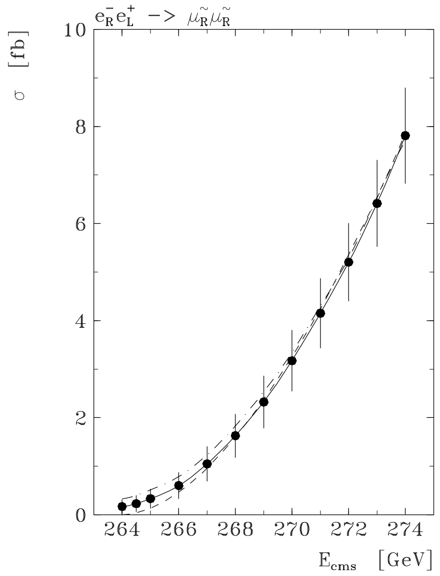

Figure 2: Observable cross section near threshold of the reaction $e^-_R e^+_L \to \tilde{\mu}_R \tilde{\mu}_R$ including QED radiation and beamstrahlung. Curves assume a mass $m_{\tilde{\mu}_R} = 132.0$ GeV and width $\Gamma_{\tilde{\mu}_R}$ of 310 MeV (full curve), 0 MeV (dashed curve) and 620 MeV (dashed-dotted curve). Measurements correspond to $\mathcal{L} = 10$ fb^{-1} per point.

Taking the width from the model prediction, $\Gamma_{\tilde{\mu}_R} = 310$ MeV, a fit to the threshold curve gives a statistical accuracy of $\delta m_{\tilde{\mu}_R} = 90$ MeV for the smuon mass. This error is considerably smaller than the expected width. A two-parameter fit yields $m_{\tilde{\mu}_R} = 132.002\ ^{+0.170}_{-0.130}$ GeV and $\Gamma_{\tilde{\mu}_R} = 311\ ^{+560}_{-225}$ MeV. However, both parameters are highly correlated with a correlation coefficient of 0.95. Finally, if one fixes the $\tilde{\mu}_R$ mass using other information, the width can be determined to $\delta\Gamma_{\tilde{\mu}_R} = 190$ MeV. It should be noted that the scan procedure and choice of energy measurement points is not optimised. Possibilities to reduce the correlations should be studied.

2.2 Energy spectrum of $\mu^\pm$

For energies far above threshold, the kinematics of the decay chain of reaction (1) allows to identify and to reconstruct the masses of the primary and secondary sparticles. The isotropic decay of the scalar muon leads to a flat energy spectrum of the observed final $\mu^\pm$ in the laboratory frame. The endpoints of the energy distribution are related to the masses of $\tilde{\mu}_R$ and χ^0_1 via

$$E_{max,min} \quad = \quad \frac{m_{\tilde{\mu}}}{2}\left(1 - \frac{m^2_{\chi^0}}{m^2_{\tilde{\mu}}}\right)\gamma\,(1 \pm \beta)\ . \tag{2}$$

In practice the sharp edges of the energy spectrum will be smeared by effects due to detector resolution, selection criteria and in particular initial state radiation and beamstrahlung. The results of a simulation at $\sqrt{s} = 320$ GeV assuming an integrated luminosity of 160 fb^{-1} are shown in figure 3. One observes a clear signal from $\tilde{\mu}_R$ pair production above a small background of cascade decays $\chi_2^0 \to \mu^+\mu^-\chi_1^0$ from the reaction $e_R^- e_L^+ \to \chi_2^0\chi_1^0$. Contamination from chargino or W pair production is completely negligible.

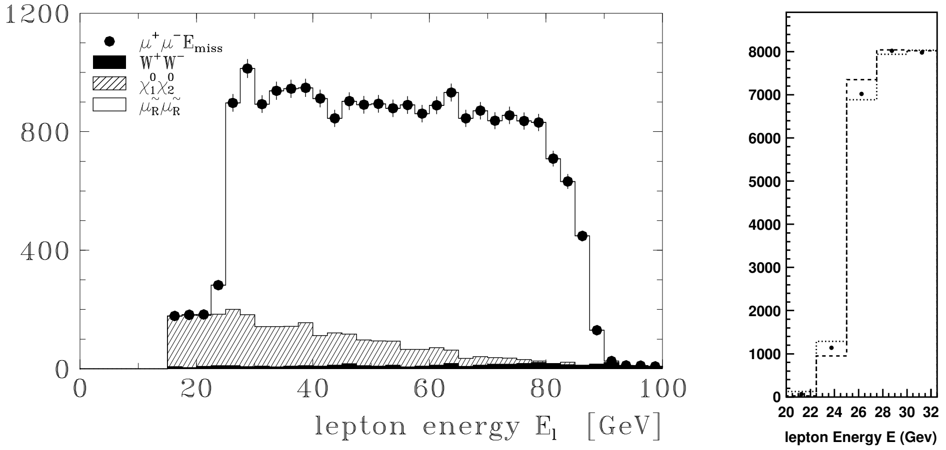

Figure 3: **Left:** Energy spectrum of di-muon events from the reaction $e_R^- e_L^+ \to \tilde{\mu}_R\tilde{\mu}_R$ and the background $e_R^- e_L^+ \to \chi_1^0\chi_2^0$ at $\sqrt{s} = 320$ GeV assuming $\mathcal{L} = 160$ fb^{-1}. **Right:** Lower endpoint region of the μ energy spectrum illustrating the effect of various widths $\Gamma_{\tilde{\mu}_R}$ of 310 MeV (dots), 0 MeV (dashed) and 620 MeV (dotted) using the tenfold luminosity.

A two-parameter fit to the μ energy spectrum yields masses of $m_{\tilde{\mu}_R} = 132.0 \pm 0.3$ GeV and $m_{\chi_1^0} = 71.9 \pm 0.2$ GeV. The statistical accuracy is of the same size as the expected width of the scalar muon. Choosing a different width $\Gamma_{\tilde{\mu}_R}$ in the simulation modifies essentially the μ energy spectrum at the low endpoint and has little impact at higher energies. This is illustrated in figure 3, right part, which compares the lower part of the spectrum with the predictions of width zero and twice the expected value. The sharp rise is getting smeared out with increasing width. With the anticipated luminosity of 160 fb^{-1} it may be feasible to distinguish these cases.

2.3 Production of other sparticles

It should be noted that estimates on the sensitivity of width effects in other slepton production channels can be obtained from the above results by scaling the cross section and taking the branching ratios into final states into account. Thus one expects e.g. a gain by a factor of $\sim$2 for selectron $\tilde{e}_R$ and sneutrino $\tilde{\nu}_e$ pair production. For the higher mass chargino $\chi_2^\pm$ and neutralinos $\chi_{3,4}^0$ mass resolutions of $\sim 0.25 - 0.50$ GeV may be obtained from threshold scans [4], where the cross sections rise as $\sigma \propto \beta$. The corresponding widths are expected to be $\sim 2 - 5$ GeV (two-body decays in a gauge boson and gaugino) and have certainly to be considered.

3 Conclusions

The high luminosity of TESLA allows to study the production and decays of the accessible SUSY particle spectrum. Polarisation of both e^- and e^+ beams is very important to optimise the signal and suppress backgrounds. A simulation of slepton production $e^+e^- \to \tilde{\mu}_R\tilde{\mu}_R$ shows that for precision mass measurements with an accuracy of $\mathcal{O}(100 \text{ MeV})$ the widths of the primary particles have to be taken into account. Finally, it is worth noting that the anticipated mass resolutions from threshold scans or lepton energy spectra can only be obtained if beamstrahlung effects are well under control.

References

1. *'Conceptual Design of a 500 GeV e^+e^- Linear Collider'*, eds. R. Brinkmann et al., DESY 1997-048 and ECFA 1997-182.
2. E. Accomando et al., Phys. Rep. 299 (1998) 1.
3. 2^{nd} ECFA/DESY Study on Physics and Detectors for a Linear e^+e^- Collider, http://www.desy.de/conferences/ecfa-desy-lc98.html
4. H.-U. Martyn and G.A. Blair, hep-ph/9910416, Proc. *'International Workshop on Linear Colliders'*, Sitges, Spain, 28 April - 5 Mai 1999.
5. T. Sjöstrand, Comp. Phys. Comm. 82 (1994) 74.
6. T. Ohl, Comp. Phys. Comm. 101 (1996) 269.