Sparticle Masses and Widths via Threshold Scans at the Linear Collider

Grahame A. Blair*
Royal Holloway, University of London

The future linear collider will allow accurate determination of particle masses by scanning the centre of mass energy across the particle pair-production thresholds. Issues related to the determination of both the masses and the widths of smuons and squarks are explored in the context of a representative supersymmetric scenario.

I. INTRODUCTION

The precision determination of particle masses via threshold scans will be central to the physics programme at the future e^+e^- linear collider (LC). In particular, if supersymmetry (SUSY) is realised in nature, there will be a wealth of new states to explore and it will be the precision measurements of the properties of these states that will allow meaningful extrapolations to very high energy scales, where the underlying theory may be reconstructed [1]. Previous studies have addressed the precision of mass extraction from threshold scans [2] and have indicated the additional possibility of width measurement [3]. These studies are extended here to explore in more detail the threshold scanning strategy and potential.

Despite the success of recent experimental programmes in setting limits on SUSY parameter space, a wide set of possibilities remains, even if one decides to concentrate on the minimal supergravity (mSUGRA) scenario alone [4]. For the sake of definiteness this study concentrates on point SPS1, which is mSUGRA with m_0=100, $m_{\frac{1}{2}}$=250, A_0=0, $\tan\beta$=10, sign(μ)=+. This point, considered in detail in Ref. [5], is very similar to point B of Ref. [4] and covers the case where most of the SUSY particles (sparticles) are light enough to be pair-produced at an O(1 TeV) LC.

Only the e^+e^- mode of LC operation is considered. Other modes such as e^-e^- have been shown to be very useful for instance in precision measurements of the selectron mass [6], so the selectron is not considered further here. Instead, attention is restricted to the production of smuons and squarks, which are pair-produced in the *s*-channel by via standard model couplings only, and the charginos $\chi_1^+\chi_1^-$ and $\chi_2^+\chi_2^-$ (the threshold production of $\chi_1^+\chi_2^-$ is not studied here). The relevant masses and widths considered are shown in table I.

II. THRESHOLD SCANS

The exact procedure employed for a threshold scan will depend on the knowledge available at the time, with preliminary information on masses and branching ratios (BRs) both from the LHC and from early runs at the highest LC energy; in both cases the sparticle masses will be determined from end-point measurements of the daughter particle kinematics. A knowledge of the BRs can be central to the accuracy obtainable from threshold scans and the difficulty of determining them can limit the relevance of the scans to some channels [7].

The BRs are assumed here to be well known and all channels are included in the scans, *i.e.* the total cross-sections are used. The backgrounds have not yet been explored, although some conservatism is introduced by assuming a small, constant level of background in the fits as described below. The aim is to present the best possible results that could be obtained at various energy scales and in this spirit the initial e^+e^- helicities were chosen to maximise the relevant cross section. An electron polarisation P_- of $\pm$ 0.8 and a positron polarisation P_+ of $\pm$ 0.6 are assumed; so for right-handed sfermion production P_-=0.8, P_+=-0.6, whereas for left-handed sfermion and chargino production P_-=-0.8, P_+=0.6.

The sfermion cross-sections were obtained from analytic formulae [8] consisting of tree-level expressions folded with a Breit-Wigner (BW) form factor for each final state particle. The chargino cross-sections were obtained using SUSYGEN3 [9], folded with BWs. These expressions were then employed in a dedicated Monte Carlo program [10] that integrates over the BW form factors, including initial state radiation (ISR) and beamstrahlung. The beamstrahlung was calculated using CIRCE [11] with TESLA parameters for the O(1TeV) spectrum.

A multi-point scan is not necessarily the most efficient way to extract the mass and width, especially when the luminosity is limited as described in Ref. [5]. To investigate this further two sensitivity variables were explored:

*g.blair@rhul.ac.uk

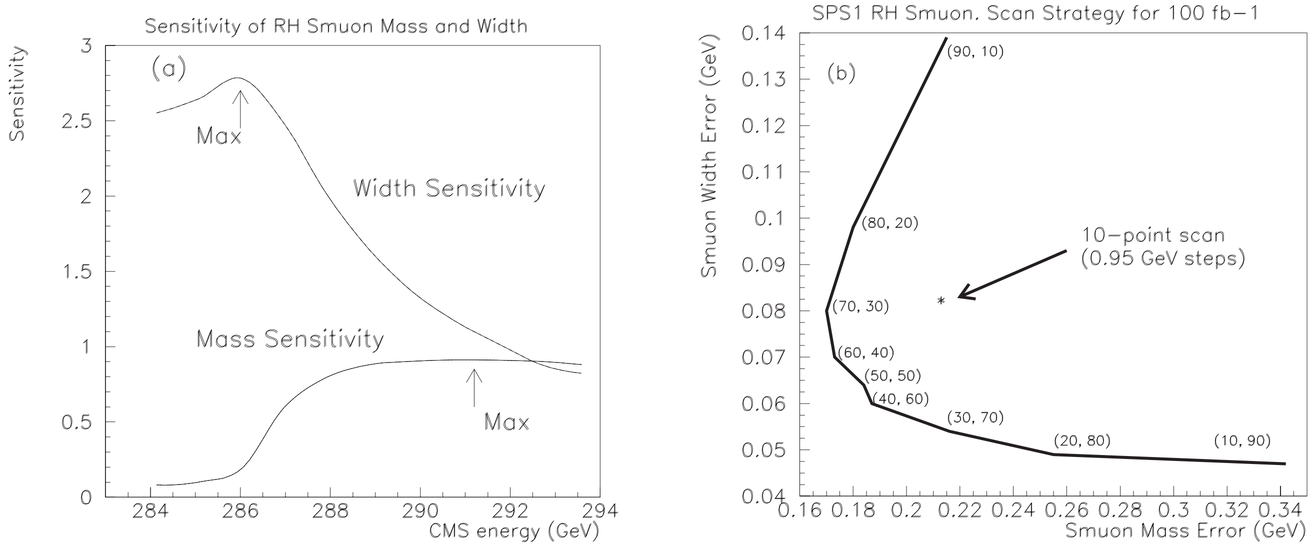

FIG. 1: (a) Sensitivity curves for the SPS1 $\tilde{\mu}_R$. (b) The effect of distributing the luminosity between $\sqrt{s}$=286 GeV and 291 GeV. The values in brackets indicate the percentages of luminosity at each point respectively.

Sparticle	True Mass	True Width	Fit Mass Error	Fit Width Error	Fit Mass Error (Width Fixed)
$\tilde{\mu}_R$	143	0.20	0.18	0.06	0.15
$\tilde{\mu}_L$	202	0.25	0.30	0.11	0.26
$\tilde{u}_R$	520	25	11	14	2.7
$\tilde{u}_L$	537	30	5.3	9.0	1.9
$\tilde{d}_R$	520	25	24	30	5.8
$\tilde{d}_L$	543	30	8.0	12	2.7
χ_1^+	175	0.002	0.17	0.003	0.09
χ_2^+	364	1.9	0.44	0.24	0.23

TABLE I: Masses and widths of the smuons and squarks in the mSUGRA point SPS1. The units are GeV/c^2. All the fit errors correspond to the (50:50) two-point scan, the details of which are included in Tab. II

$\left|\frac{1}{\sqrt{\sigma}}\frac{\partial\sigma}{\partial m}\right|$ and $\left|\frac{1}{\sqrt{\sigma}}\frac{\partial\sigma}{\partial\Gamma}\right|$ where m is the sfermion mass, Γ the sfermion width and σ the cross section. These mass and width sensitivity variables are plotted as a function of $\sqrt{s}$ for the SPS1 $\tilde{\mu}_R$ in Fig. 1(a). The appearance of maxima in the sensitivities implies that a two-point scan may be more efficient, as also suggested in Ref. [6]. The scan points used here are listed in Tab. II. These optimal $\sqrt{s}$ points should already be known to sufficient accuracy using masses determined from earlier end-point measurements. The effect of distributing 100 fb^{-1} between the two chosen $\sqrt{s}$ points is shown in Fig. 1(b). Clearly the optimal strategy is to run with $\sim$50 fb^{-1} at each energy.

In order to extract the mass and width from the threshold curves, the cross section was approximated to a function locally linear in m and Γ with the linear coefficients (partial derivatives, also listed in Tab. II) at each point in the scan determined using the Monte Carlo integrator described above. These functions were then used to fit to the threshold curves using a binned least likelihood such as described in [6] [12]. To introduce some conservatism, an expected background level of one event per bin was assumed.

The errors obtained from a fit to the two-point threshold scans are also shown in Tab. I. The first point is at the nominal threshold and the second point is that most sensitive to the mass. In the table, two mass fits are performed for each sparticle; one where the width is also floating in the fit and one where it is constrained to its theoretical value. The errors on the widths and masses are highly correlated in the two-parameter fit. The squark results assume that the LC can eventually reach just above 1 TeV with similar beamstrahlung spectra to the lower energy running.

Sparticle	Lower Scan Point $\sqrt{s}$ (GeV)	σ(fb)	$\frac{\partial\sigma}{\partial m}$ (fb GeV^{-1})	$\frac{\partial\sigma}{\partial\Gamma}$(fb GeV^{-1})	Upper Scan Point $\sqrt{s}$ (GeV)	σ(fb)	$\frac{\partial\sigma}{\partial m}$ (fb GeV^{-1})	$\frac{\partial\sigma}{\partial\Gamma}$(fb GeV^{-1})
$\tilde{\mu}_R$	286	0.316	-0.107	1.56	291	2.19	-1.35	1.73
$\tilde{\mu}_L$	404	0.159	-0.038	0.63	413	2.02	-0.70	0.69
$\tilde{u}_R$	1040	0.860	-0.027	0.029	1061	1.18	-0.047	0.031
$\tilde{u}_L$	1074	1.72	-0.055	0.047	1128	3.54	-0.11	0.045
$\tilde{d}_R$	1040	0.215	-0.0067	0.0071	1061	0.294	-0.012	0.0077
$\tilde{d}_L$	1086	1.12	-0.032	0.031	1126	1.91	-0.064	0.031
χ_1^+	350	0.09	-0.428	30.9	416	222	-11.7	0.58
χ_2^+	728	11.2	-1.80	3.75	786	132	-3.40	-0.60

TABLE II: SPS1 Cross-sections and relevant derivatives used to define the fit functions described in the text.

III. CONCLUSION

This study has made many optimistic assumptions. Little backgrounds have been included, optimistic polarisations have been assumed and the total cross-sections have been used. No systematic errors have been addressed, in particular the errors on the measured luminosity spectrum may affect the precision of the widths, especially for the narrow fermionic states such as the charginos. All these effects will serve to degrade (possibly greatly) the precisions quoted here. First estimates of the resulting degradation could be made by simple statistical scaling, such as discussed in Ref. [5]. However it has been shown here that it may indeed be possible to extract useful information on both the masses and the widths of sparticles at the LC and so this motivates the need for future more realistic studies.

Acknowledgments

The monte-carlo package used in these studies is based on the FOAM software of S. Jadach and was modified by him to facilitate this work. The analytical formulae used for the differential cross-sections for the sfermion thresholds were supplied by A. Freitas. Support from CERN is gratefully acknowledged.

[1] G.A. Blair,W. Porod, P.M. Zerwas, Phys Rev D**63**, 017703 (2001) [hep/ph 0007107].
[2] H-U. Martyn, G.A. Blair, hep-ph/9910416.
[3] H-U. Martyn, "Physics at TeV Colliders", Les Houches 1999 [hep-ph/0005142].
[4] M. Battaglia, A. DeRoeck, J. Ellis, F. Gianotti, K.T. Matchev, K.A. Olive, L. Pape,G. Wilson, hep-ph/0106204.
[5] P.D. Grannis *et al.*, these proceedings.
[6] J.L. Feng, M.E. Peskin, hep-ph/0105100.
[7] J.K. Mizukoshi, H. Baer, A.S. Belyaev, X. Tata, hep-ph/0107216.
[8] A. Freitas private communication
[9] N.Ghodbane, S.Katsanevas, P.Morawitz, E.Perez, Susygen 3, hep-ph/9909499
[10] S. Jadach private communication
[11] T. Ohl Comput.Phys.Commun.101:269-288,1997 [hep-ph/9607454].
[12] R.N. Cahn, this workshop.